TEXAS TRANSPORTATION INSTITUTE

EVALUATION OF THE CRASHWORTHINESS OF THIN-WALLED ALUMINUM AND STEEL U-CHANNEL SIGN SUPPORTS

Prepared for

New Hampshire Department of Transportation
Bureau of Traffic
220 Sheep Davis Road (NH 106)
Concord, New Hampshire 03302-0483

Prepared by

D. Lance Bullard, Jr.
Engineering Research Associate

and

Wanda L. Menges
Assistant Research Scientist

TTI Project No. 405231-1F
Final Report

June 1995

Texas Transportation Institute
Texas A&M University System
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	ac
ha	hectares	2.47	acres	mi^2
km^2	square kilometers	0.386	square miles	
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised August 1992)

ABSTRACT

The New Hampshire Department of Transportation in cooperation with the Vermont Agency of Transportation (VTAOT) initiated a crash-test program at the Texas Transportation Institute (TTI) Proving Ground to evaluate the safety performance of small sign support installations currently being used in their states. The installations tested were (1) dual 76 mm (3.0 in) diameter thin-walled aluminum supports, (2) single and dual 102 mm (4.0 in) diameter thin-walled aluminum supports and (3) dual 3.7 kg/m (2.5 lb/ft) and 4.5 kg/m (3.0 lb/ft) steel u-channel small sign support installations. The crash tests were performed and evaluated in accordance with NCHRP Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features" for test level 3 (TL3) safety performance.

The dual 76 mm (3.0 in) diameter thin-walled aluminum supports, single 102 mm (4.0 in) diameter thin-walled aluminum support, and dual 3.7 kg/m (2.5 lb/ft) and 4.5 kg/m (3.0 lb/ft) steel u-channel small sign support installations were all found to comply satisfactorily with the safety performance evaluation criteria presented for TL3 in NCHRP Report 350.

The dual 102 mm (4.0 in) diameter thin-walled aluminum support sign installation was found to comply with the safety performance evaluation criteria presented for TL3 in NCHRP Report 350 when the cross-sections of the supports were modified by drilling holes as described in this report.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the New Hampshire Department of Transportation, the Vermont Agency of Transportation, the Federal Highway Administration or Texas Transportation Institute at the time of publication. This report does not constitute a standard, specification, or regulation. In addition, the above listed agencies assume no liability for its contents or use thereof. The names of specific products or manufacturers listed herein does not imply endorsement of those products or manufacturers.

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INTRODUCTION

The New Hampshire Department of Transportation in cooperation with the Vermont Agency of Transportation (VTAOT) initiated a crash-test program at the Texas Transportation Institute (TTI) Proving Ground to evaluate the safety performance of small sign supports currently being used in their states. Sign support installations constructed from thin-walled aluminum tubing and steel U-channel supports were erected and tested by means of full-scale vehicular crash tests.

This report covers the construction and performance of crash tests on the small sign support installations shown in Table 1 below, when erected in National Cooperative Highway Research Program (NCHRP) Report 350 "weak" and "standard" soils.

Table 1. Sequential Test Matrix

<u>Aluminum Tubing - 3.2 mm (0.125") - Direct Burial</u>

1. Dual 76 mm (3.0 in) diameter
2. Dual 102 mm (4.0 in) diameter
3. Dual 102 mm (4.0 in) diameter retrofitted
   (2 retrofit configurations)
4. Single 102 mm (4.0 in) diameter*

* The single 102 mm (4.0 in) diameter support was tested only after the dual 102 mm (4.0 in) support installation failed.

<u>Steel U-channel Supports-driven into soil</u>

1. Dual 2 1/2 lb/ft
2. Dual 3 lb/ft

The crash tests were performed and evaluated in accordance with the National Cooperative Highway Research Program (NCHRP) Report 350 "Recommended Procedures for the Safety Performance Evaluation of Highway Features"[(1)].

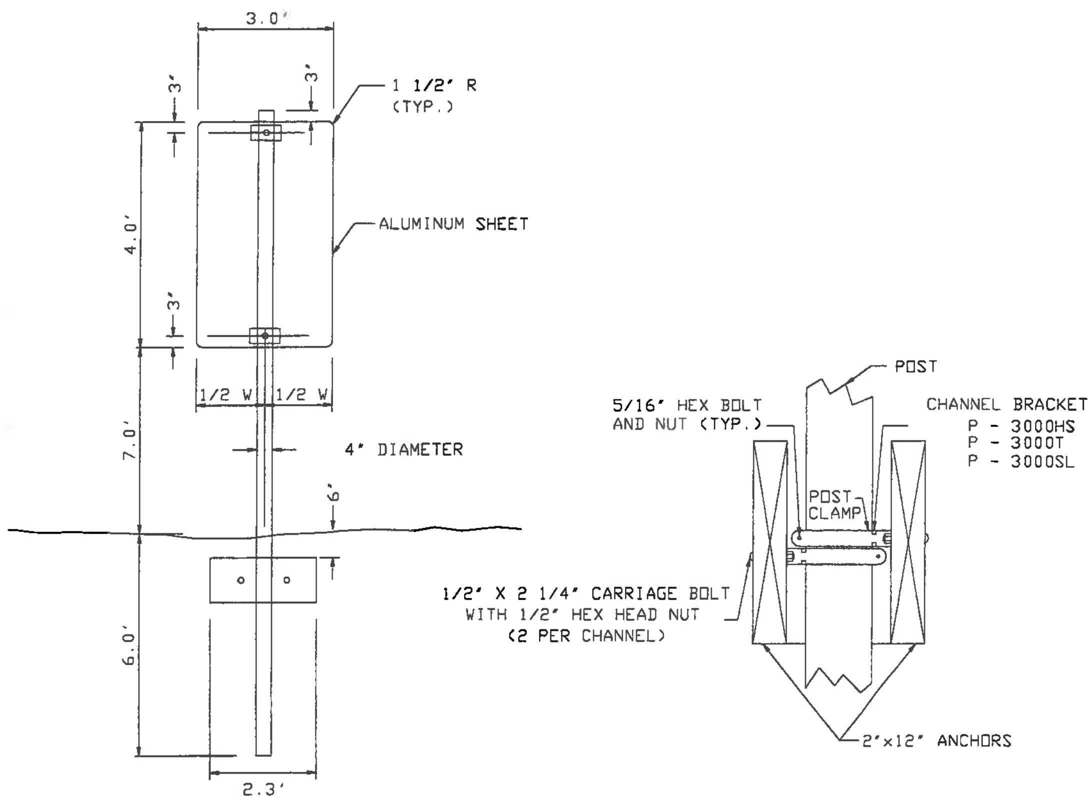
CONSTRUCTION OF THE TEST ARTICLES

Thin-Walled Aluminum Supports

Single and dual sign support installations were constructed from 6063-T6 schedule 10 seamless aluminum pipe. The wall thicknesses of the supports were 3.2 mm (0.125 in). Two support diameters were tested; 76 mm (3.0 in) and 102 mm (4.0 in). All aluminum sign support installations were erected at a minimum height of 2.1 m (7.0 ft) above the elevation of the near edge of the traveled way.

The single support sign installations were constructed using a 102 mm (4.0 in) diameter support. The overall lengths of the 102 mm (4.0 in) diameter supports were 5.3 m (17.3 ft). Embedment depths for the supports were 1.8 m (6.0 ft). Attached to the supports, 152.4 mm (6.0 in) below ground level, were two nominal 50.8 mm thick x 304.8 mm wide x 711.2 mm long (2.0 in x 12.0 x 28.0 in) pressure treated wood soil plates. The soil plates were attached on either side of the supports using 14 gauge channel brackets 203.2 mm (8.0 in) long and post clamps. The channel brackets were attached to the wood soil plates using two 12.7 mm diameter x 57.2 mm long (1/2 in x 2-1/4 in) carriage bolts with 12.7 mm (0.5 in) hex head nuts. The channel brackets and post clamps were also utilized for attaching the sign panels to the supports. All post clamps were anchored using 7.9 mm (5/16 in) diameter hex bolts and nuts. The aluminum sign panels attached to the supports, as tested, were 0.9 m (3.0 ft) wide and 1.2 m (4.0 ft) high. A thin-walled aluminum single sign support installation is shown in Figure 1.

The dual aluminum support sign installations were constructed using both 76 mm (3.0 in) and 102 mm (4.0 in) diameter supports. The embedment depths for the 76 mm (3.0 in) and 102 mm (4.0 in) diameter supports are 1.5 m (5.0 ft) and 1.8 m (6.0 ft), respectively. The dual support sign installations utilized the same hardware to attach the soil plates and sign panels as the single support sign installations discussed above. The lengths of the soil plates for the dual support sign installations tested were 1.8 m (6.0 ft). In addition, the length of the soil plates varied with post spacing, such that, a minimum of 304.8 mm (12.0 in) of plate extended past the outside edges of the supports. The aluminum sign panels attached to the supports, as tested, were 1.8 m (6.0 ft) wide and 1.5 m (5.0 ft) high. A typical aluminum sign support installation with



1 ft = 0.305 m
1 in = 25.4 mm

Figure 1. Elevation View of the Single Thin-Walled Aluminum Support Sign Installation.

the soil plates attached is shown in Figure 2. A thin-walled aluminum dual support sign installation is shown in Figure 3.

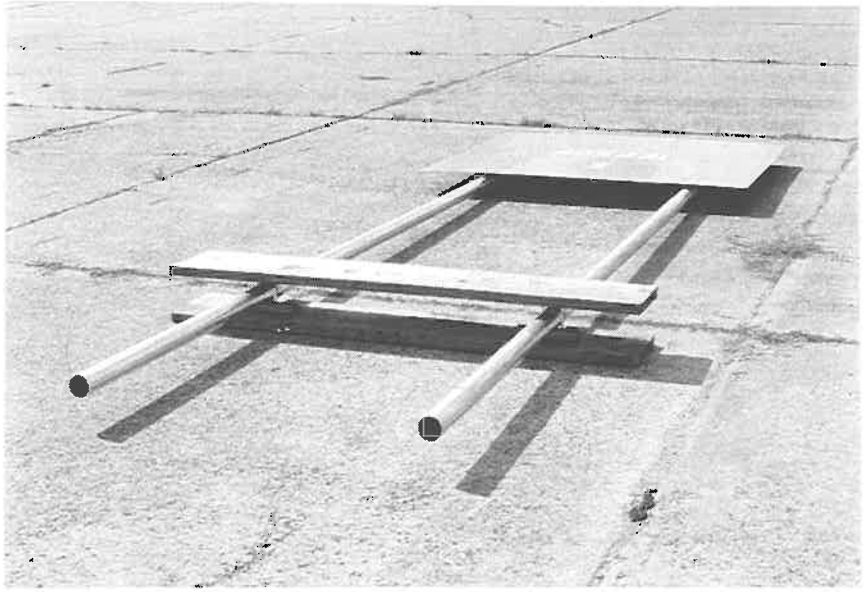
During the course of testing, a 102 mm (4.00 in) diameter thin-walled aluminum dual support sign installation failed to comply with the evaluation guidelines presented in NCHRP Report 350. A suitable retrofit was sought for use on installations currently in the field. Two retrofit configurations were considered. The first retrofit, shown in Figure 4, involved modifying the sign supports by drilling two 38 mm (1.5 in) holes in the supports at two different elevations along each support (4 holes total, per support). The holes were drilled at ground level and 457 mm (18.0 in) above ground level. The holes drilled at ground level were oriented 90 degrees to the plane of the sign panel or parallel to the direction of impact. The holes drilled 457 mm (18.0 in) above ground level were oriented parallel to the plane of the sign panel or transverse to the direction of impact. All holes drilled at the same elevation were oriented 180 degrees apart.

The second retrofit, shown in Figure 5, involved modifying the sign supports by drilling four - 25.4 mm (1.0 in) diameter holes in a cross pattern, 45 degrees relative to the sign panel face. Four holes were drilled at ground level and four additional holes were drilled at 457 mm (18.0 in) above the ground. The cross drilled pattern modification is shown in Figure 5. The holes drilled at the same elevation were oriented 90 degrees apart.

All other structural details of both retrofitted dual support sign installations (e.g. soil plate, sign panel attachment, etc.) remained unchanged.

Steel U-channel Supports

Dual sign support installations were constructed from Marion Steel, Rib-Bak, 3.7 kg/m (2.5 lb/ft) and 4.5 kg/m (3.0 lb/ft) steel U-channel. The steel U-channel sign support installations were erected at a minimum height of 1.5 m (5.0 ft) above the elevation of the near edge of the traveled way. All steel U-channel sign supports were driven 0.9 m (3.0 ft) below grade. The soil surrounding the support was then regraded and recompacted, as needed.



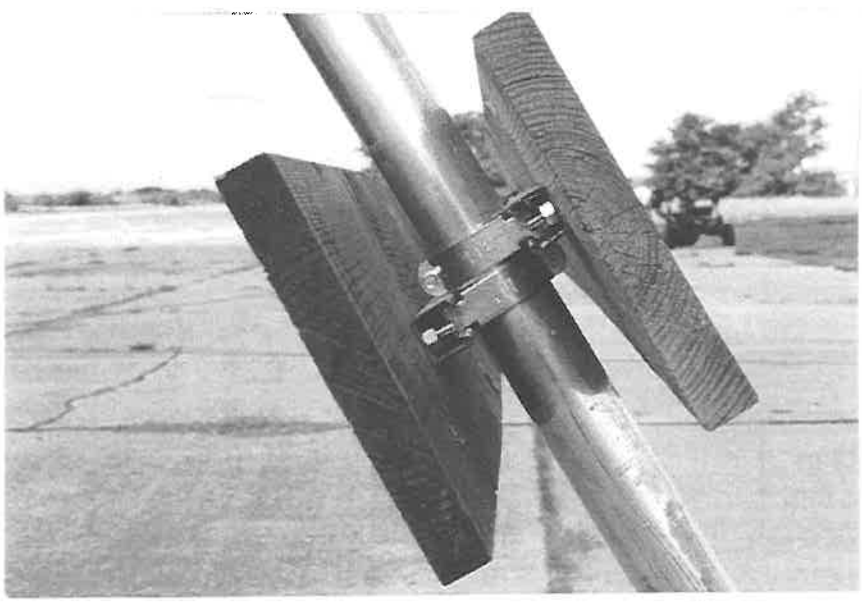
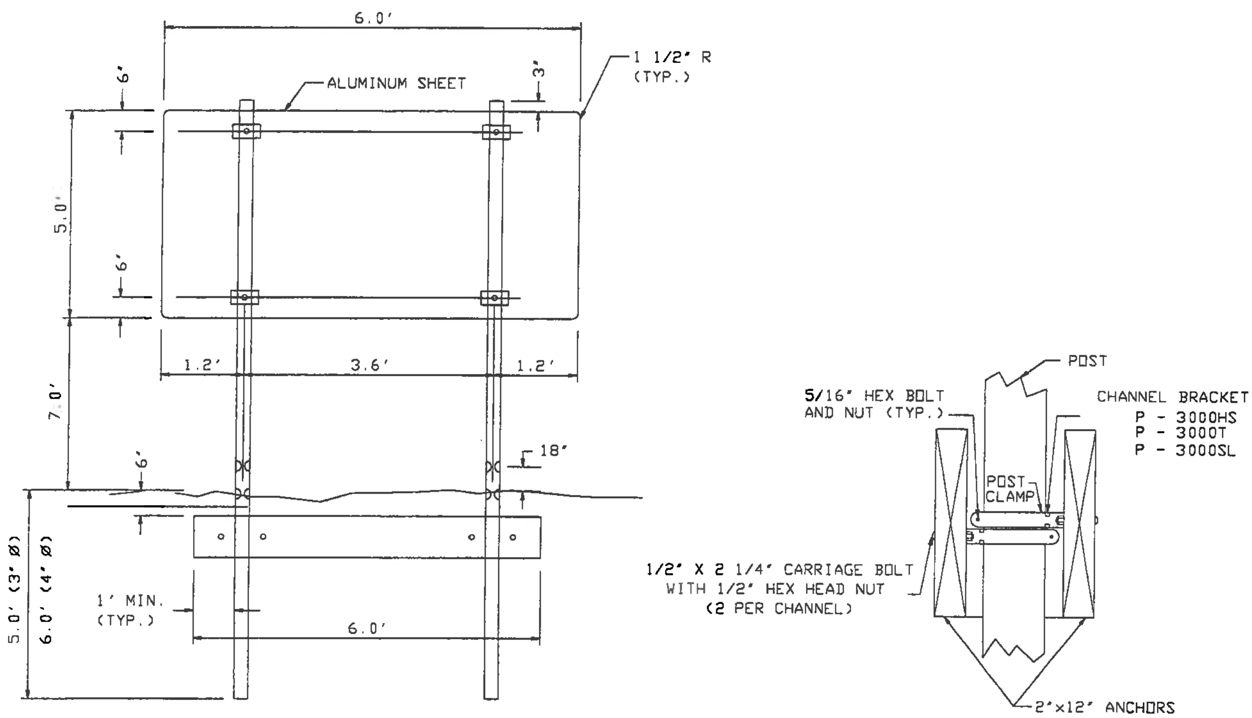
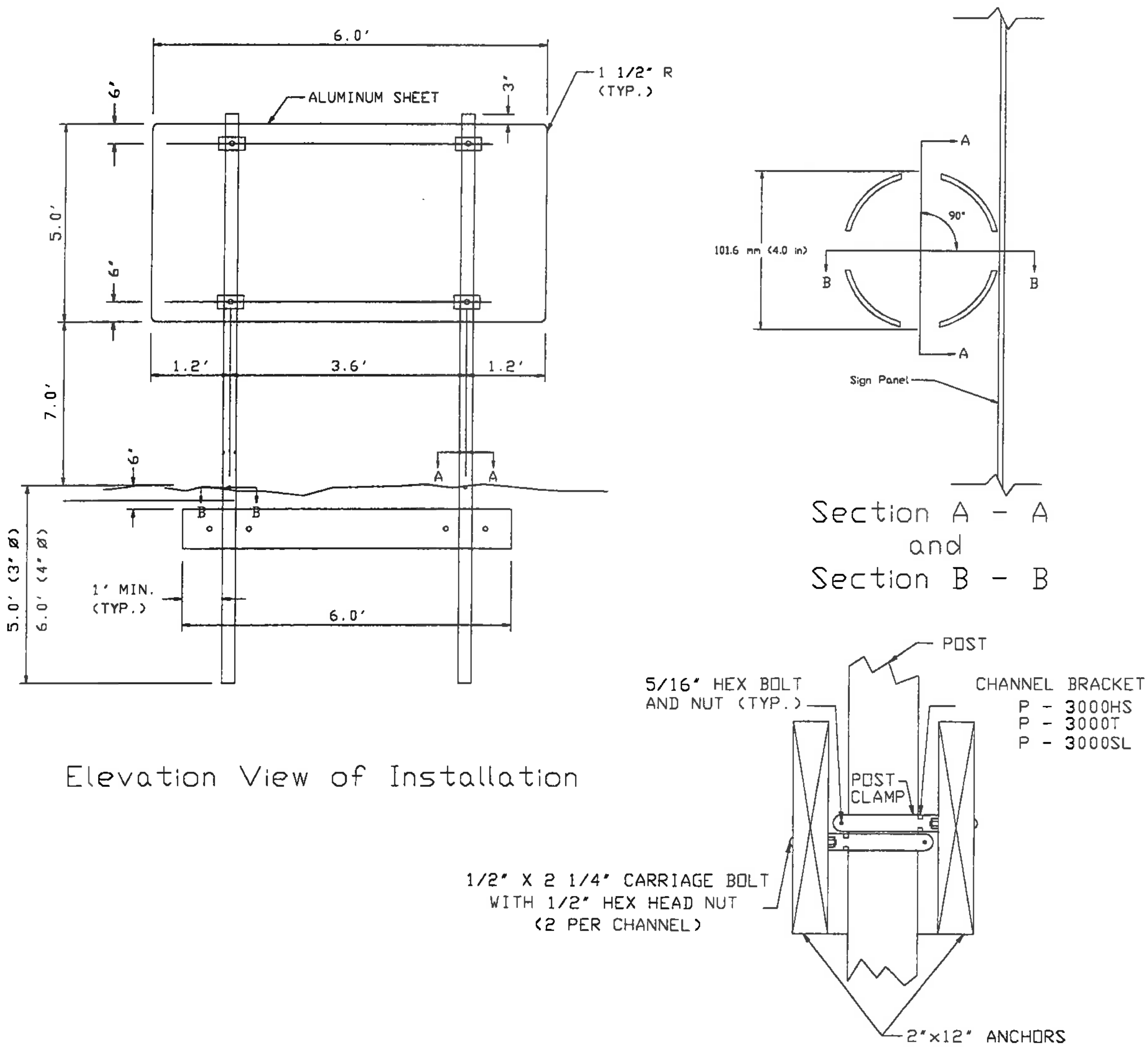


Figure 2. Typical aluminum sign support installation with attached soil plates prior to installation.



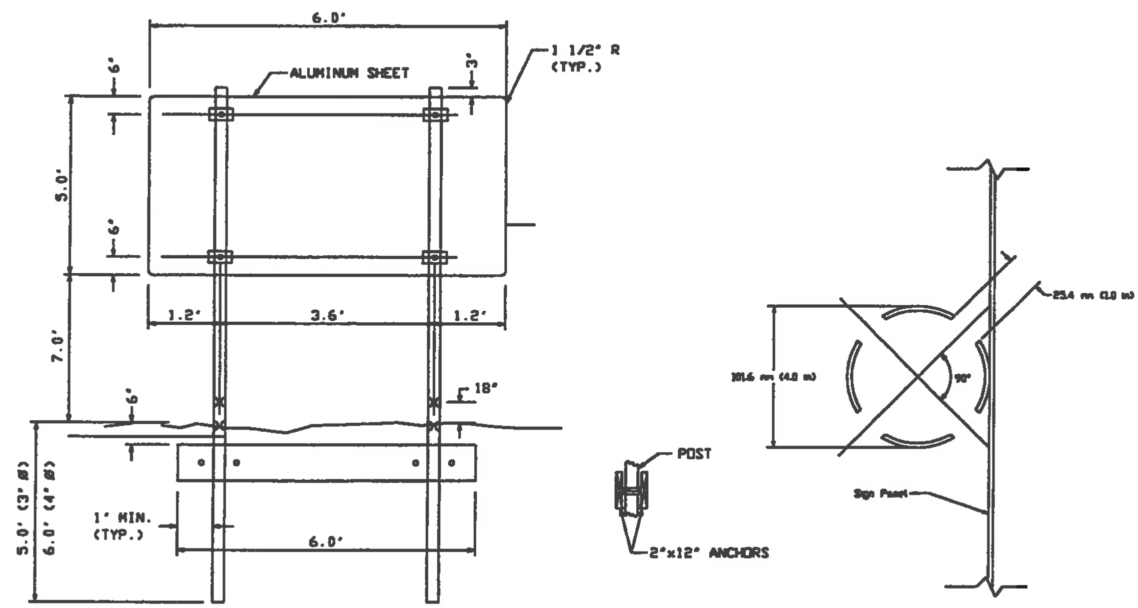
1 ft = 0.305 m
1 in = 25.4 mm

Figure 3. Elevation View of the Dual Thin-Walled Aluminum Support Sign Installation.



1 ft = 0.305 m
1 in = 25.4 mm

Figure 4. Elevation View of the Modified Dual Thin-Walled Aluminum Sign Support Installation.



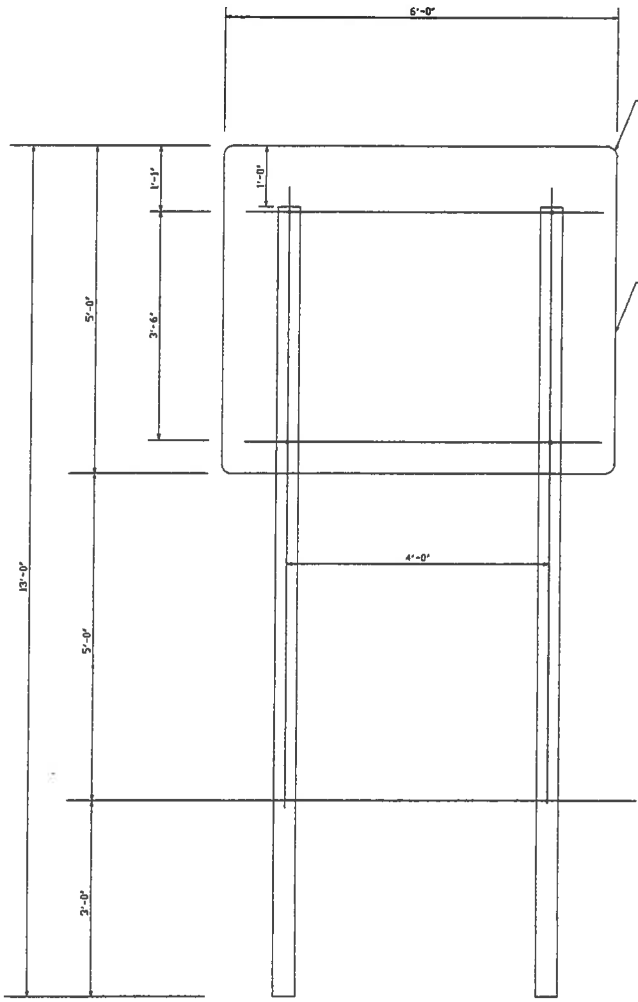
Elevation View of Installation

Plan View of Tube

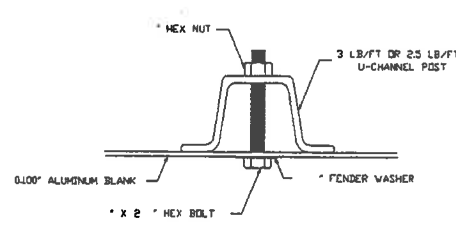
1 ft = 0.305 m 1 in = 25.4 mm

Figure 5. Elevation View of the Vermont Modified Dual Thin-Walled Aluminum Support Sign Installation.

The length of the U-channel supports were 3.7 m (12.0 ft) overall. Aluminum sign panels 1.8 m (6.0 ft) wide x 1.5 m (5.0 ft) high were attached to the supports using 7.9 mm (0.3 in) x 64 mm (2.5 in) hex bolt with fender washer and hex nuts. A steel U-channel sign support installation is shown in Figure 6.



DUAL STEEL U-CHANNEL POST INSTALLATION
(DRIVEN)



SIGN BLANK ATTACHMENT DETAIL

GENERAL NOTES

1. USE MARION STEEL, RIB-BAK, 3LB/FT AND 2.5 LB/FT U-CHANNEL POSTS.
2. DRIVE POSTS TO REQUIRED DEPTH IN PREVIOUSLY COMPACTED SOIL.
3. REGRADE AND COMPACT SURROUNDING SOIL AFTER DRIVING POSTS.

1 ft = 0.305 m 1 in = 25.4 mm

Figure 6. Elevation View of the Dual Steel U-channel Support Sign Installation.

FULL-SCALE CRASH TESTS

Description of Crash Test Procedures

According to NCHRP Report 350 guidelines, two crash tests are recommended for test level- 3 (TL3) evaluation of support structures:

> **NCHRP Test Designation 3-60:** 820C (1,808 lb) vehicle impacting the support structure at a speed of 35 km/h (21.8 mi/h) with the vehicle bumper at an impact angle between 0 and 20 degrees.
>
> **NCHRP Test Designation 3-61:** 820C (1,808 lb) vehicle impacting the support at a speed of 100 km/h (62.2 mi/h) with the vehicle bumper at an impact angle between 0 and 20 degrees.

The low-speed test is primarily performed for evaluating the breakaway or yielding characteristics of a test installation. The high-speed test is performed for the purpose of evaluating the post-test article and vehicle trajectory. Occupant risks are of foremost concern in the evaluation of both the low-speed and high-speed tests.

All crash tests conducted in the present study were in accordance with the procedures guidelines presented in NCHRP Report 350.

Evaluation Criteria

All crash tests were evaluated in accordance with the criteria presented in NCHRP Report 350 and the 1994 AASHTO Standards. As stated in NCHRP Report 230 and reiterated 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 in this study:

- Structural adequacy

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

(D) Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present 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.

- Occupant Risk

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

(H) Occupant impact velocity of hypothetical front seat passenger against vehicle interior, calculated from the vehicle accelerations and 0.6 m (23.6 in forward and 0.3 m (11.8 in) lateral displacement, shall be less than:

Longitudinal Occupant Impact Velocity - mps	
Preferred	Maximum
3	5

(I) Highest 10 ms average occupant ridedown accelerations subsequent to instant of hypothetical passenger impact should be less than:

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.

Electronic Instrumentation and Data Processing

Each 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.

Electronic signals from the accelerometers and transducers were transmitted to a base station by means of a constant bandwidth FM/FM telemetry link. Calibration signals were recorded before and after the tests, and accurate, time reference signals were recorded simultaneously with the data. Pressure sensitive switches on the bumpers of impacting vehicles were actuated just prior to impact by wooden dowels to indicate the elapsed time over known distances to provide measurement of impact velocities. The initial contacts also produced "event" marks on the data records to establish the exact instants of contact with the test installations.

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 (IRIG) 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. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions of 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. Maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are 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 (QUATTRO PRO).

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0067-second 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 un-instrumented Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belt, was placed in the driver's position of the vehicle. The anthropomorphic dummy used in the tests reported herein is shown in Figure 7.

Photographic Instrumentation and Data Processing

Photographic coverage of the tests included two high-speed cameras: one with a field of view perpendicular to and aligned with the test installation and one placed downstream of the test article at an angle of approximately 45 degrees. Flash bulbs visible from each camera were activated by pressure sensitive tape switches positioned on the impacting vehicles to indicate the instances of contact with the test installations. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collisions and to obtain time-events, displacements and angular data. A professional Betacam video camera and 35 mm still cameras were used to document the pre-test and post-test conditions of the vehicles and test installations.

Test Vehicle Propulsion and Guidance

The test vehicles were towed into the test installations using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicles was tensioned along the impact paths, anchored at both ends, and threaded through a guide plate attachment anchored to the front wheel of the test vehicles. An additional steel cable was connected to the test vehicles, passed around a pulley near the impact points and attached to a tow vehicle. A 2 to 1 speed ratio existed

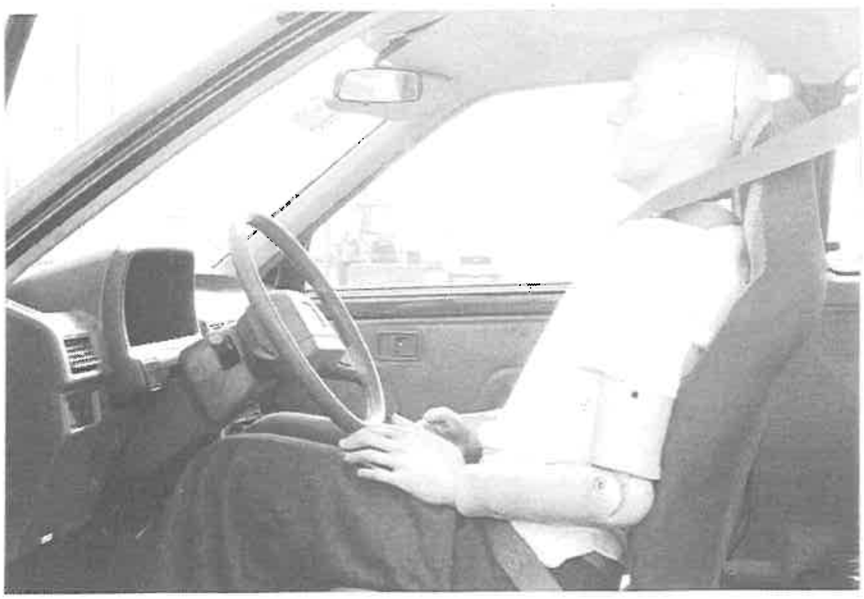


Figure 7. Anthropomorphic test dummy shown in restrained position prior to crash test.

between the test and tow vehicle for the high-speed test and a 1 to 1 speed ratio was used for the low-speed test. Just prior to impact with the test installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicles remained free-wheeling, i.e., no steering or braking inputs, until the vehicles cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring the vehicle to a safe and controlled stop.

CRASH TEST RESULTS

Dual 76 mm (3.0 in) diameter aluminum support anchored in strong soil - 35 km/h (21.8 mi/h)

- ***Test 405231-1***

A 1989 Ford Festiva, shown in Figures 8 and 9, was used for the crash test. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 897 kg (1,978 lb). The height to the lower edge of the vehicle bumper was 370 mm (14.6 in) and it was 550 mm (21.7 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A. The vehicle was directed into the dual 76 mm (3.0 in) diameter aluminum support sign installation anchored in strong soil, shown in Figure 10, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 35.7 km/h (22.2 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to bend at ground level and deform around the bumper. As the vehicle continued traveling forward, the supports yielded allowing the vehicle to continue moving. The supports pocketed around the front bumper, thus leading to the tensile failure of the left and right supports at 0.131 and 0.180 seconds, respectively. As the supports failed, the vehicle passed over the ground stubs with the upper portion of the sign installation remaining in contact with the front of the vehicle. The remaining intact portion of the sign installation rotated toward the ground allowing the vehicle to travel over the installation upon exiting the impact site. The sign panel began to contact the ground at approximately 0.853 seconds. At 1.051 seconds the front tires struck the panel, the vehicle traveled over the installation and exited the view of the high-speed camera. The vehicle came to rest upright 9.1 m (30.0 ft) downstream and 1.4 m (4.5 ft) right of the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 11. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 12, the supports were bent and fractured. The left support failed 381 mm (15.0 in) from ground level and the right support 457 mm (18.0 in) from ground level. The sign panel and all mounting and anchoring hardware received minimal damage and could be

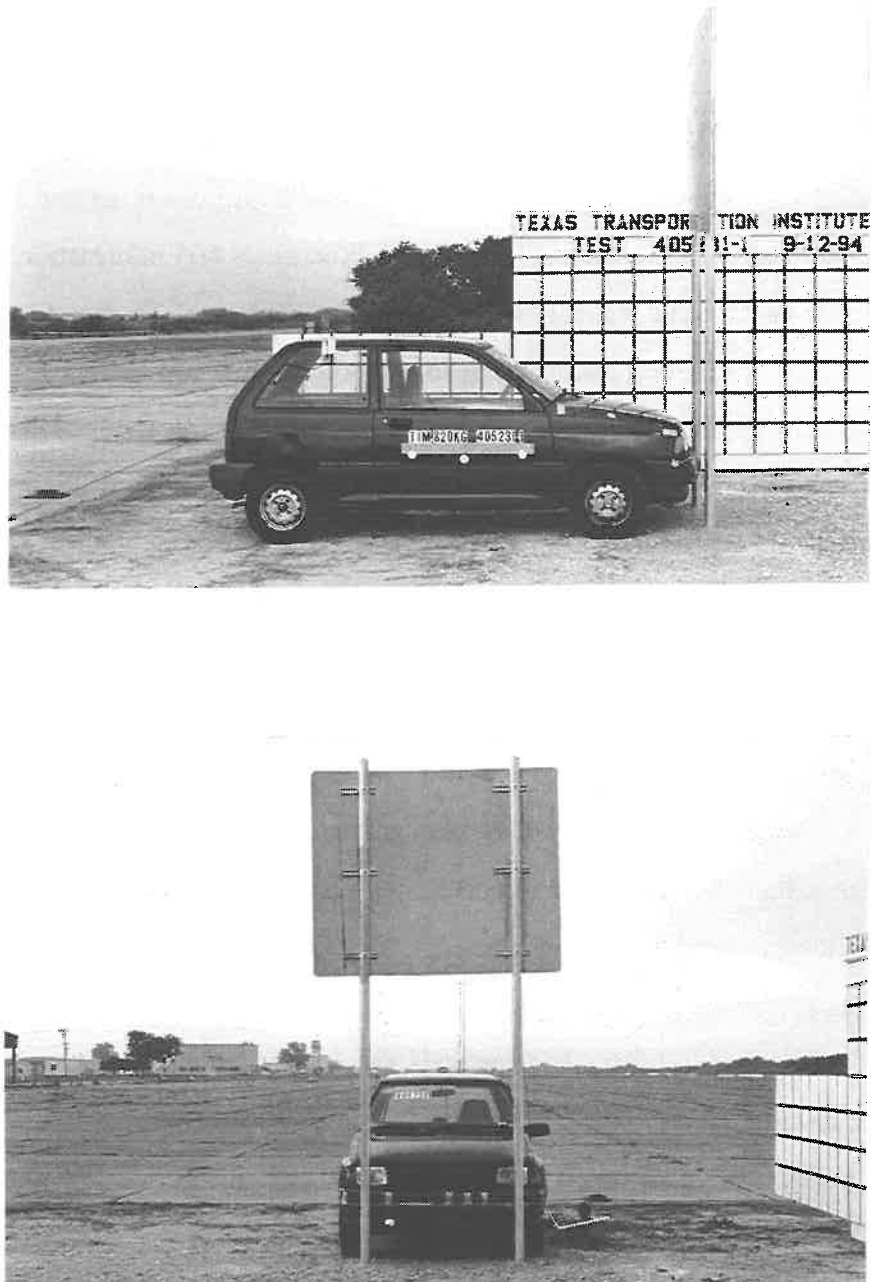


Figure 8 . Vehicle/sign installation geometrics for test 405231-1.

Figure 9 . Vehicle before test 405231-1.

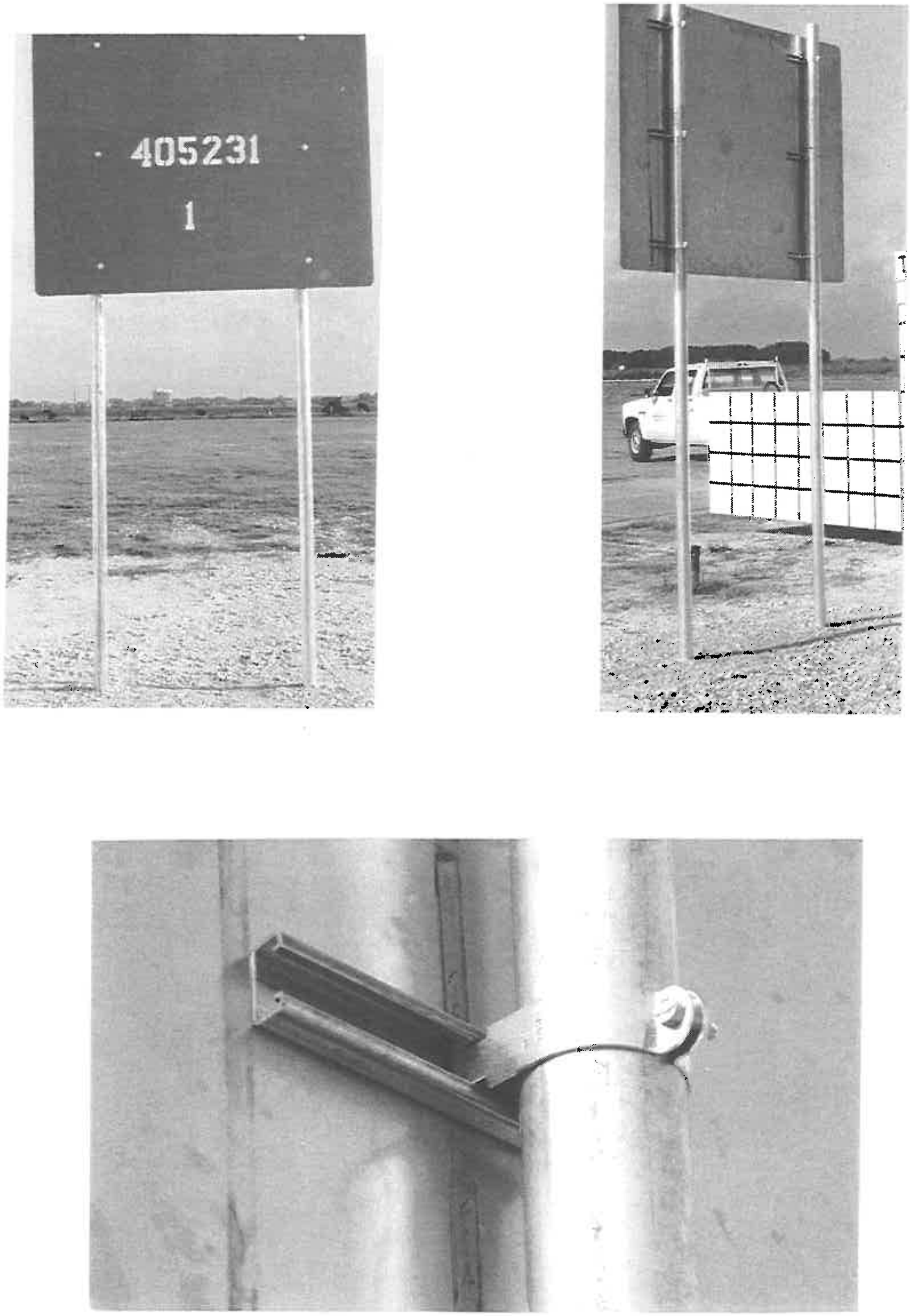


Figure 10 . Dual 3 in. aluminum sign support installation anchored in strong soil before test 405231-1.

Figure 11 . Final rest position of the sign installation and vehicle (test 405231-1).

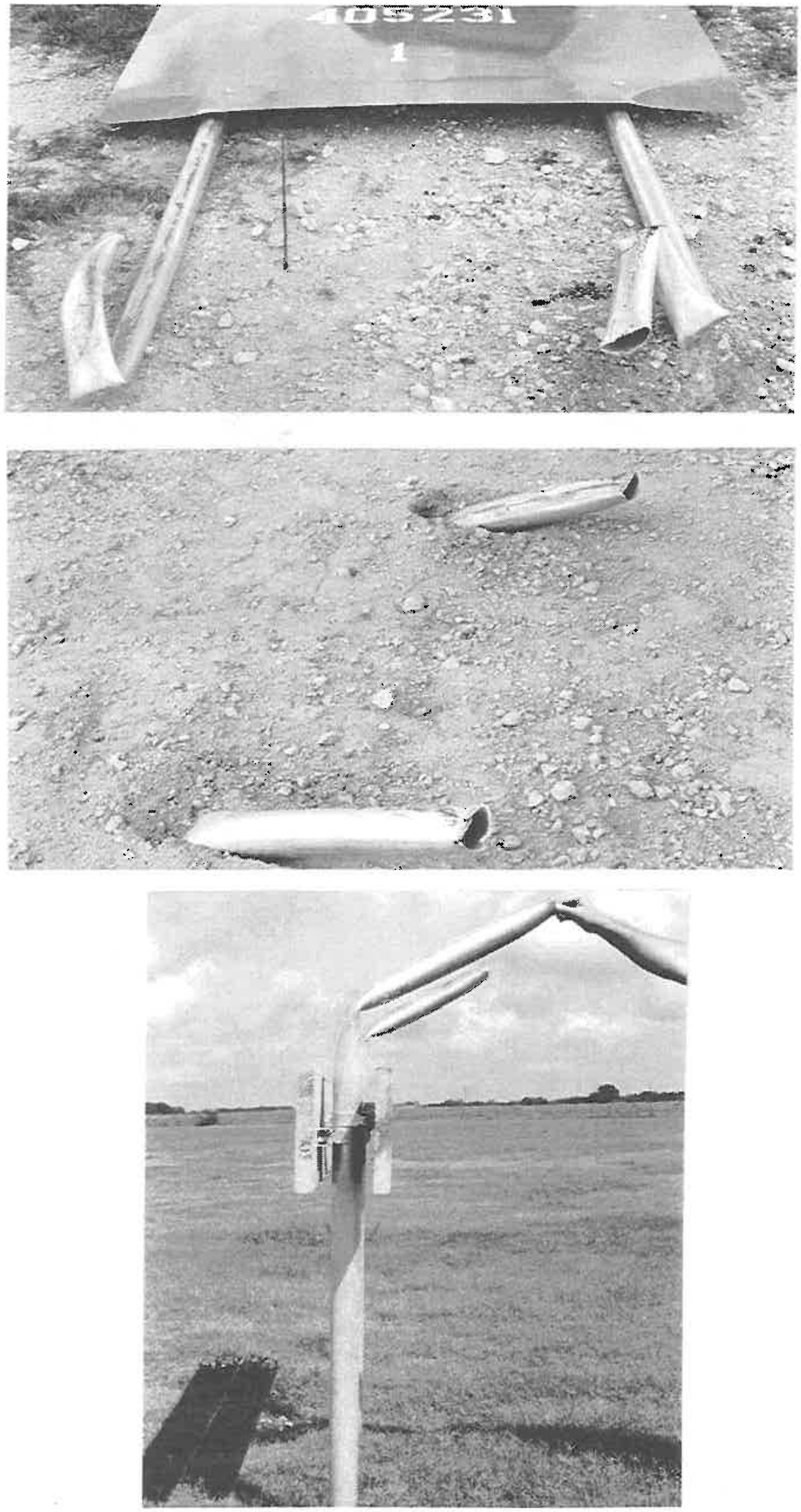
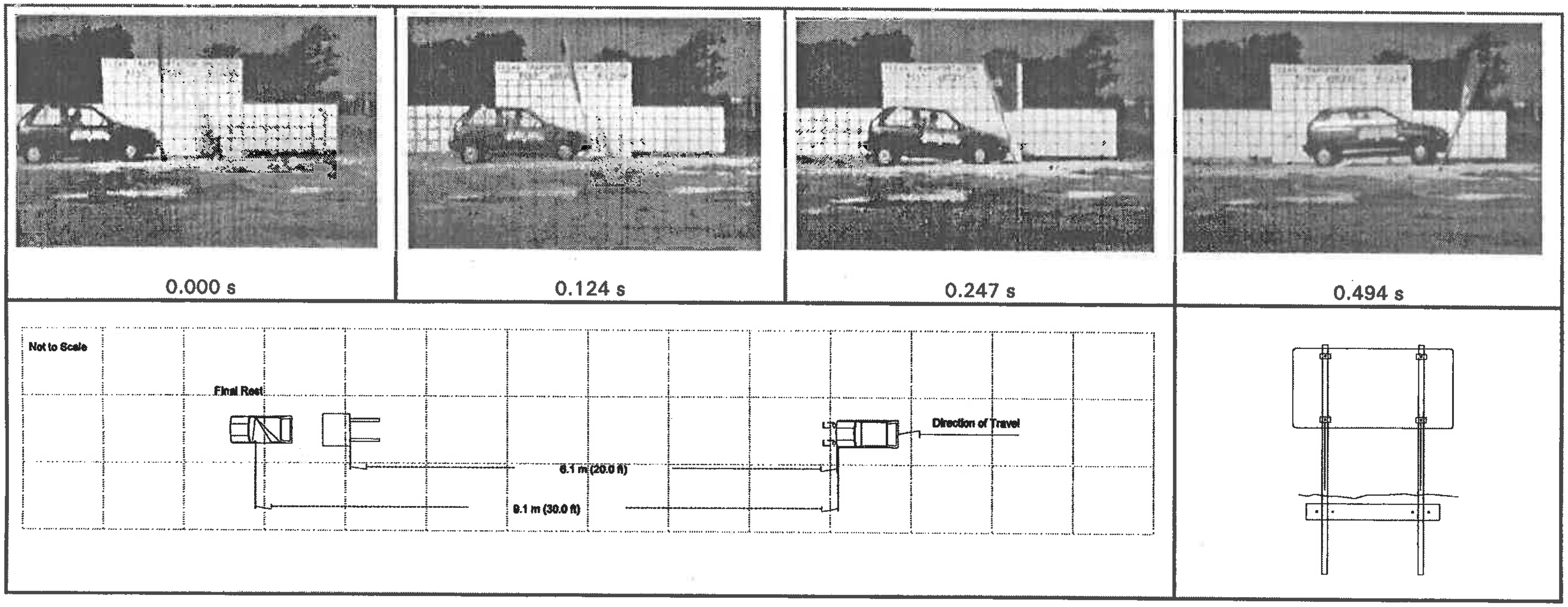


Figure 12 . Dual 3 in. aluminum sign support installation anchored in strong soil after test 405231-1.

reused in field renovation of this installation. Damage sustained by the vehicle during this test is shown in Figure 13. The vehicle sustained primarily cosmetic damage to the bumper and hood. The headlights were broken during the test, but the vehicle sustained no permanent deformation to the sheet metal. There was no deformation to the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 4.4 m/s (14.5 ft/s) at 0.221 s, the highest 0.010-s average ridedown acceleration was -1.2 g between 0.392 and 0.402 s, and the maximum 0.050-s average acceleration was -3.1 g between 0.047 and 0.095 s. Lateral occupant impact velocity was -0.8 m/s (-2.7 ft/s) at 0.786 s, the highest 0.010-s occupant ridedown acceleration was 0.7 g between 0.682 and 0.692 s and the maximum 0.050-s average acceleration was -0.3 g between 0.122 and 0.172 s. These data and other pertinent information from the test are summarized in Figure 14. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 2.

Figure 13 . Vehicle after test 405231-1.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-1
Date	09/11/94
Test Article	
Type	Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	76.2 (3.0 in)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	807 (1779 lb)
Test Inertial	820 (1808 lb)
Dummy	77 (170 lb)
Gross Static	897 (1978 lb)

Impact Conditions	
Speed (km/h)	35.7 (22.2 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	N.A.
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.4 (14.5 ft/s)
y-direction	-0.8 (-2.7 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.2
y-direction	0.7
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.1
y-direction	-0.3
z-direction	-1.0

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	-2.8
Max. Pitch Angle (deg)	4.7
Max. Yaw Angle (deg)	8.5

Figure 14. Summary of results for test 405231-1.

* N/A - not available from collected data.
* N/A - not applicable to this test.

Table 2. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-1

Test No.: 405231-1 | Test Date: 09/11/94 | Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports yielded by bending the aluminum tubes at ground level and fracturing in tension near bumper level.	Pass
<u>Occupant Risk</u> D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral — Preferred: 3 — Maximum: 5	Longitudinal occupant impact velocity: 4.4 m/s (14.5 ft/s) Lateral occupant impact velocity: -0.8 m/s (-2.7 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral — Preferred: 15 — Maximum: 20	Longitudinal Occupant Ridedown Acceleration: -1.2 g's Lateral Occupant Ridedown Acceleration: 0.7 g's	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Occupant Impact Velocity Limits (m/s)

Component	Preferred	Maximum
Longitudinal and Lateral	3	5

Occupant Ridedown Acceleration Limits (G's)

Component	Preferred	Maximum
Longitudinal and Lateral	15	20

Dual 76 mm (3.0 in) diameter aluminum support anchored in strong soil - 100 km/h (62.2 mi/h)

- **Test 405231-2**

The same 1989 Ford Festiva used in test 405231-1, shown in Figures 15 and 16, was reused for this crash test. The vehicle was directed into the dual 76 mm (3.0 in) diameter aluminum support sign installation anchored in strong soil, shown in Figure 17, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 99.9 km/h (62.1 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to bend at ground level and deform around the bumper. As the vehicle continued traveling forward, the supports yielded allowing the vehicle to continue moving. The supports pocketed around the front bumper, thus leading to the tensile failure of both sign supports at approximately 0.040 seconds. As the supports failed, the vehicle passed over the ground stubs as the upper portion of the sign installation continued to rotate over the front of the vehicle. The sign panel struck the roof of the vehicle at 0.087 seconds. The sign panel struck the roof with a force sufficient enough to deform the roof and A-pillars and cause the left passenger window to shatter. The brakes were applied and the vehicle exited traveling 83.7 km/h (52.0 mi/h) with the sign panel and supports still in contact with the front of the vehicle. The vehicle came to final rest upright 107.6 m (353.0 ft) downstream and 3.0 m (10.0 ft) right of the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 18. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 19, the supports were bent and fractured. The left support failed 572 mm (22.5 in) from ground level and the right support 406 mm (16.0 in) from ground level. The mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. However, the sign panel required replacement. Damage sustained by the vehicle during this test is shown in Figure 20. The vehicle sustained moderate roof and hood damage and minor damage to the front bumper, grill and windshield. Maximum vertical crush to the roof was 100 mm (3.9 in). Maximum deformation to the front of the vehicle at the impact points was 10 mm (0.4 in). There was deformation, but no intrusion into the vehicle occupant compartment.

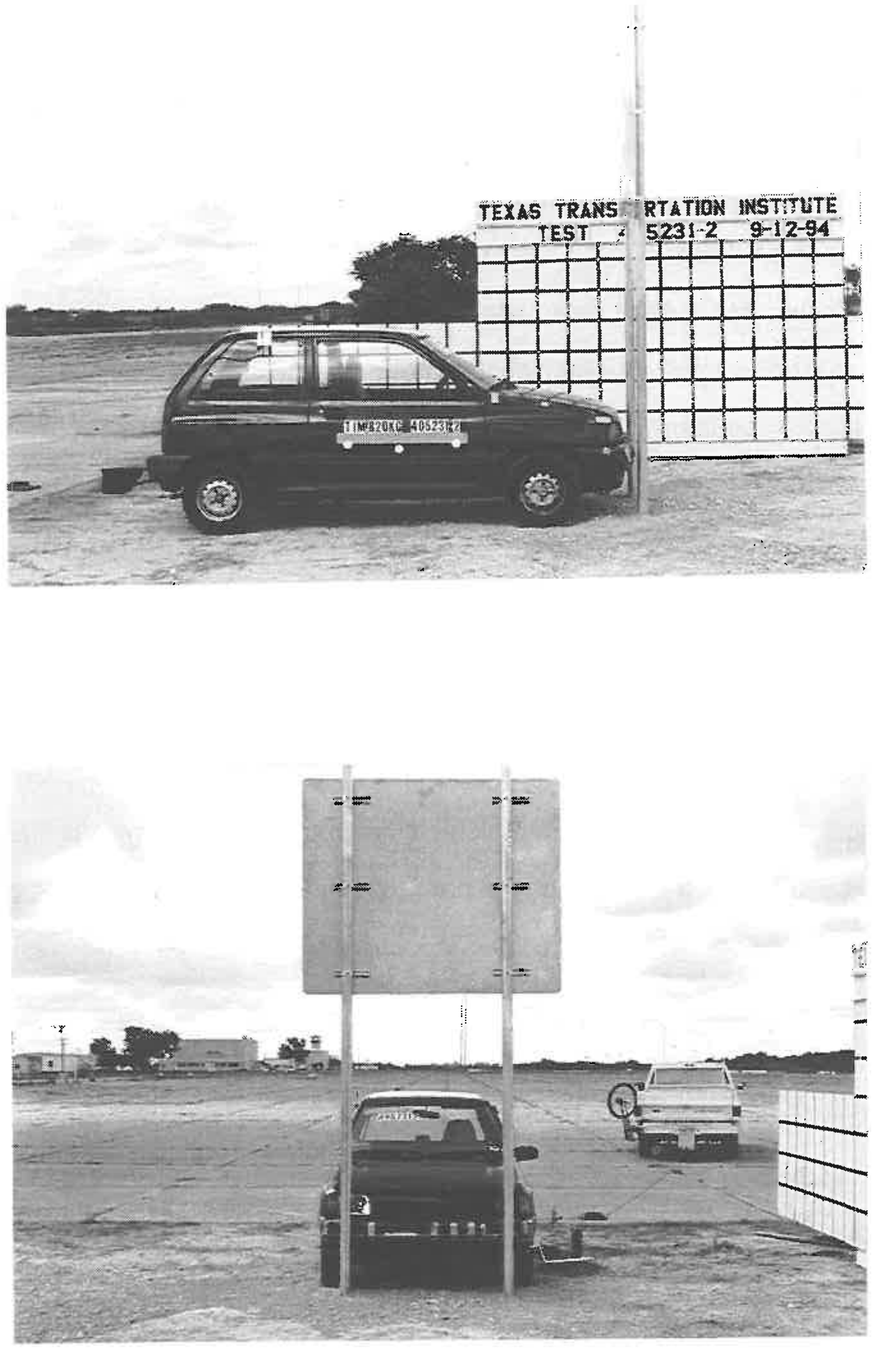
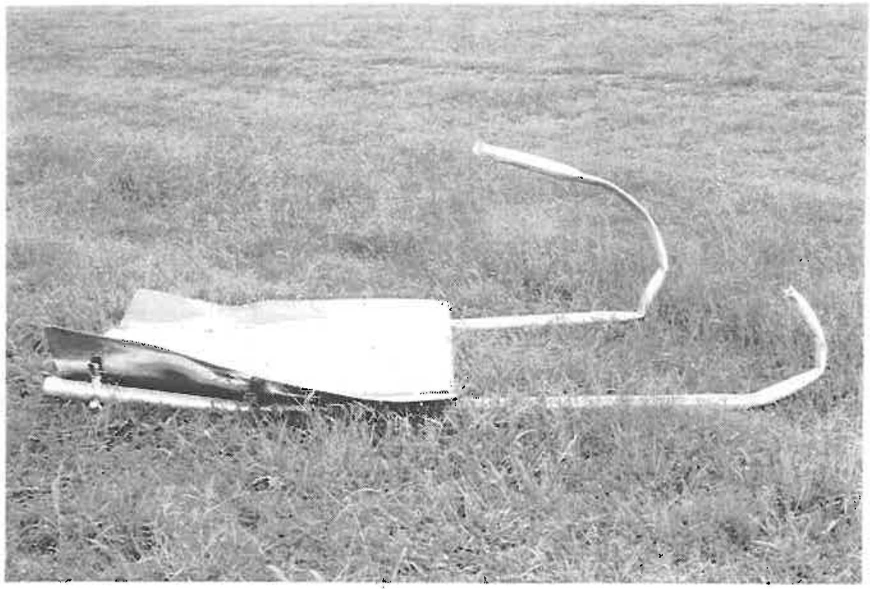


Figure 15 . Vehicle/sign installation geometrics for test 405231-2.

Figure 16 . Vehicle before test 405231-2.

Figure 17 . Dual 3 in. aluminum sign support installation anchored in strong soil before test 405231-2.

Figure 18 . Final rest position of the sign installation and vehicle (test 405231-2).



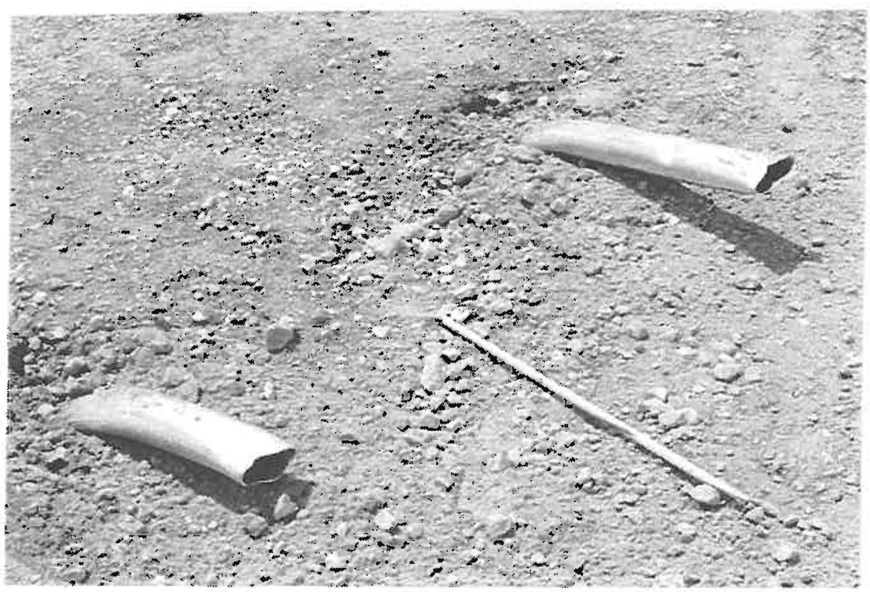
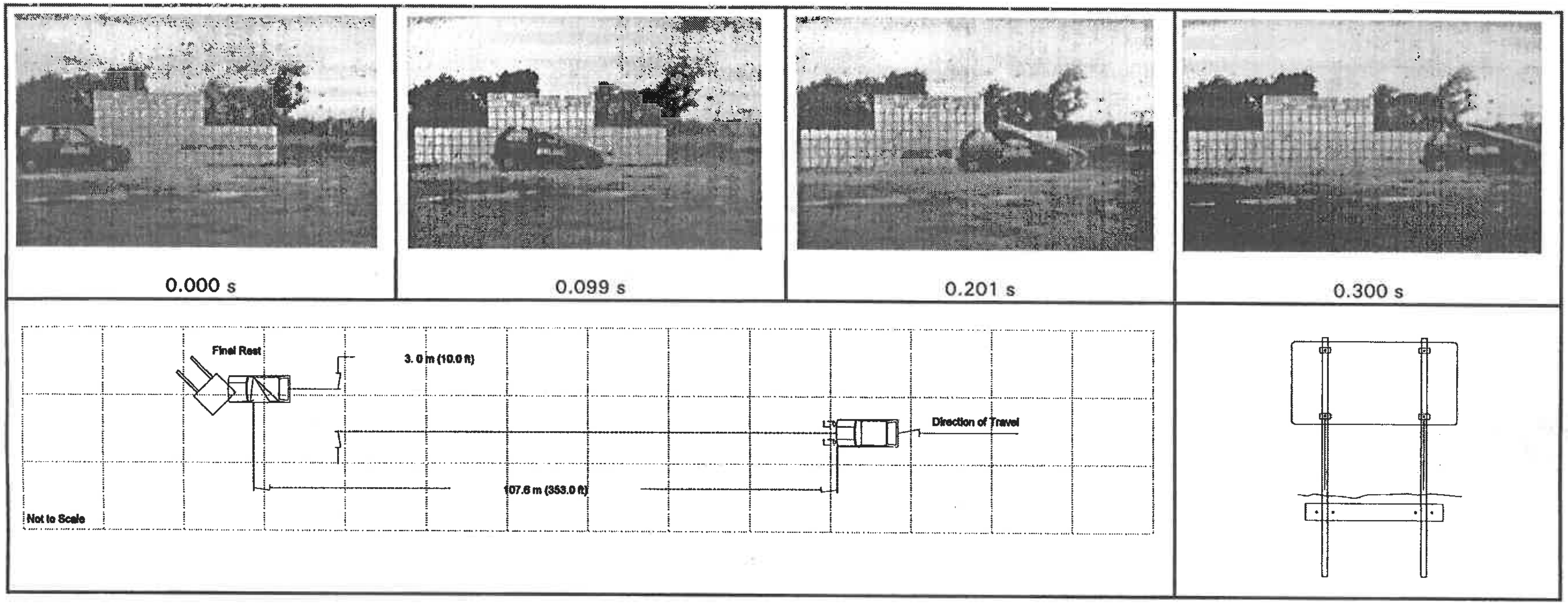


Figure 19 . Dual 3 in. aluminum sign support installation anchored in strong soil after test 405231-2.

Figure 20 . Vehicle after test 405231-2.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 4.2 m/s (13.8 ft/s) at 0.187 s, the highest 0.010-s average ridedown acceleration was -1.3 g between 0.207 and 0.217 s, and the maximum 0.050-s average acceleration was -6.6 g between 0.003 and 0.053 s. Lateral occupant impact velocity was -1.3 m/s (-4.4 ft/s) at 0.771 s, the highest 0.010-s occupant ridedown acceleration was 1.0 g between 0.266 and 0.276 s and the maximum 0.050-s average acceleration was 0.6 g between 0.598 and 0.648 s. These data and other pertinent information from the test are summarized in Figure 21. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 3.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-2
Date	09/11/94
Test Article	
Type	Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and Diameter of Tube (mm)	3.2 (0.125 in) 76.2 (3.0 in)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	807 (1779 lb)
Test Inertial	820 (1808 lb)
Dummy	77 (170 lb)
Gross Static	897 (1978 lb)

Impact Conditions	
Speed (km/h)	99.9 (62.1 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	83.7 (52.0 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.2 (13.8 ft/s)
y-direction	-1.3 (-4.4 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.3
y-direction	1.0
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-6.6
y-direction	-0.6
z-direction	-2.7

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1 & 12TDDW3
Interior	
OCDI	FS0200000
Maximum Exterior Vehicle Crush (mm)	10 (0.4 in)
Max. Occ. Compart. Deformation (mm)	100 (3.9 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-4.6
Max. Pitch Angle (deg)	14.9
Max. Yaw Angle (deg)	6.9

Figure 21. Summary of results for test 405231-2.

Table 3. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-2

Test No.: 405231-2 | Test Date: 09/11/94 | Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports yielded by bending the aluminum tubes at ground level and fracturing in tension near bumper level.	Pass
Occupant Risk		
D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was deformation of the front portion of the occupant compartment, but no actual intrusion into the compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral — Preferred: 3 — Maximum: 5	Longitudinal occupant impact velocity: 4.2 m/s (13.8 ft/s) Lateral occupant impact velocity: -1.3 m/s (-4.4 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral — Preferred: 15 — Maximum: 20	Longitudinal Occupant Ridedown Acceleration: -1.3 g's Lateral Occupant Ridedown Acceleration: 1.0 g's	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Dual 76. mm (3.0 in) diameter aluminum support anchored in weak soil - 35 km/h (21.8 mi/h)

- ***Test 405231-3***

A 1988 Ford Festiva, shown in Figures 22 and 23, was used for the crash test. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 896 kg (1,975 lb). The height to the lower edge of the vehicle bumper was 380 mm (15.0 in) and it was 540 mm (21.3 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A. The vehicle was directed into the dual 76 mm (3.0 in) diameter aluminum support sign installation anchored in weak soil, shown in Figure 24, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 34.5 km/h (21.4 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to bend at ground level and deform around the bumper. As the vehicle continued traveling forward, the supports yielded allowing the vehicle to continue moving. The supports pocketed around the front bumper, thus leading to the tensile failure of the left and right supports at 0.111 seconds. As the supports failed, the vehicle passed over the ground stubs with the upper portion of the sign installation remaining in contact with the front of the vehicle. The remaining intact portion of the sign installation was projected ahead of the vehicle. The vehicle again struck the supports at approximately 0.854 seconds. Shortly thereafter, the supports rotated away from the vehicle and toward the ground, allowing the vehicle to travel partially over the installation. The vehicle came to rest upright, over the sign installation, 8.6 m (28.1 ft) downstream and 0.3 m (1.0 ft) left of the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 25. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 26, the supports were bent and fractured. The left and right supports failed 406 mm (16.0 in) from ground level. The sign panel and all mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. Damage sustained by the vehicle during this test is shown in Figure 27. The vehicle sustained primarily cosmetic damage to the bumper and hood. The left headlight was broken during the test, but the vehicle sustained no permanent deformation to the sheet metal. There was no deformation into the vehicle occupant compartment.

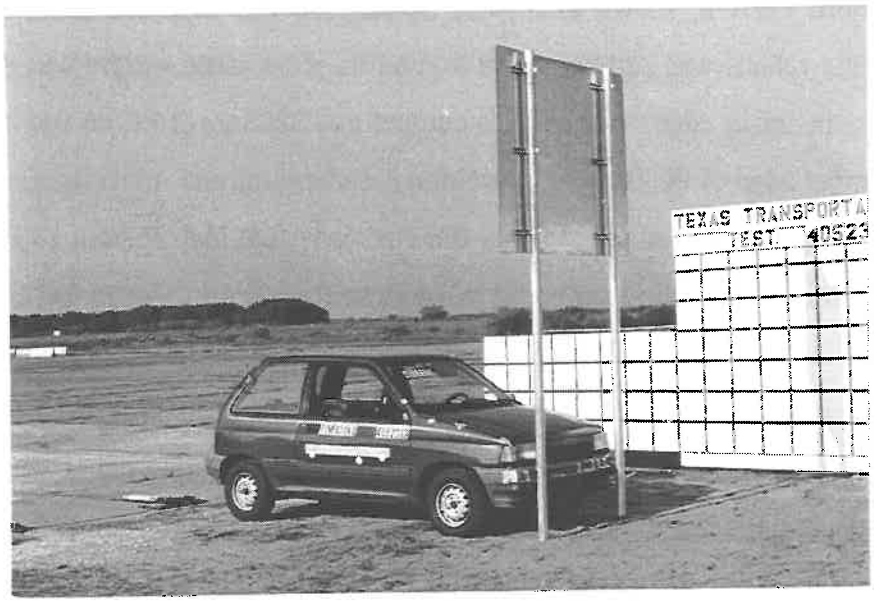


Figure 22 . Vehicle/sign installation geometrics for test 405231-3.

Figure 23 . Vehicle before test 405231-3.

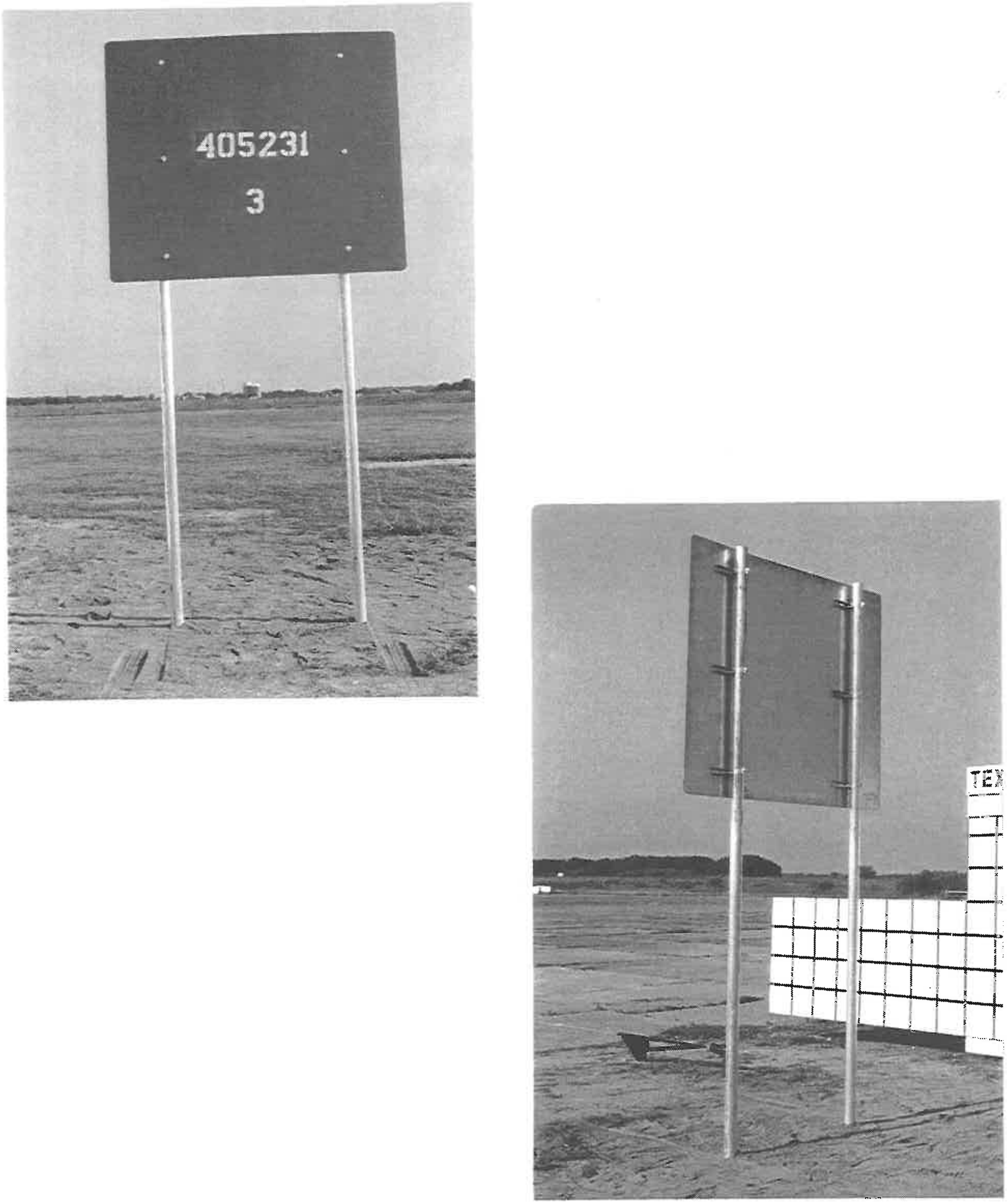


Figure 24 . Dual 3 in. aluminum sign support installation anchored in weak soil before test 405231-3.

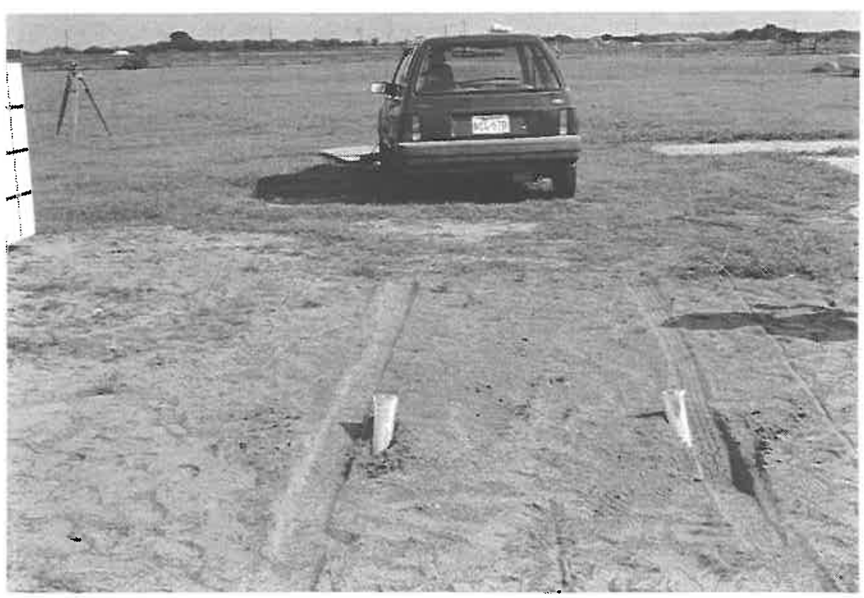
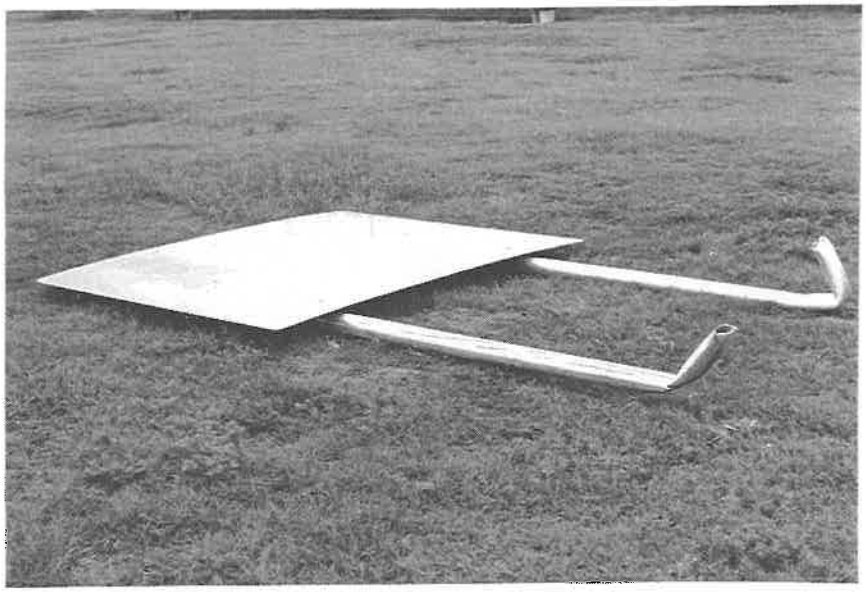


Figure 25 . Final rest position of the sign installation and vehicle (test 405231-3).



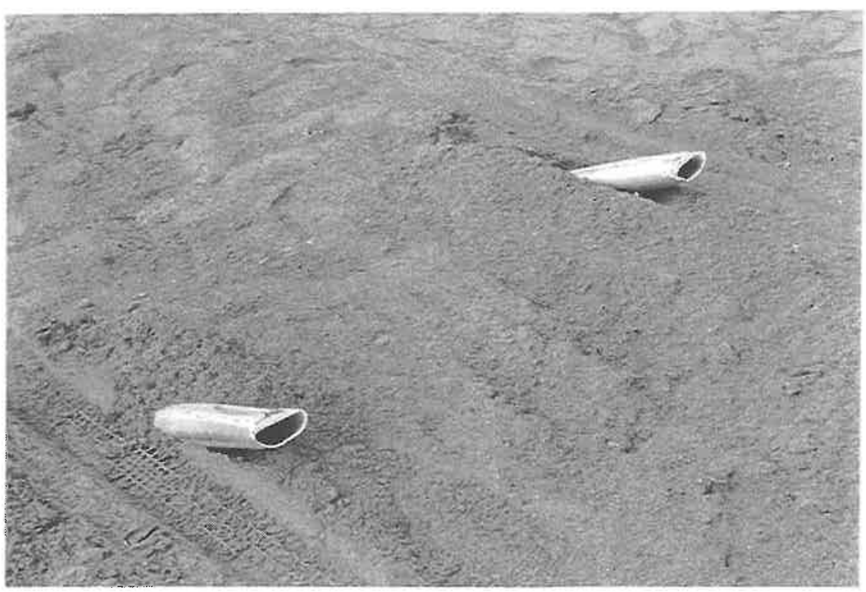
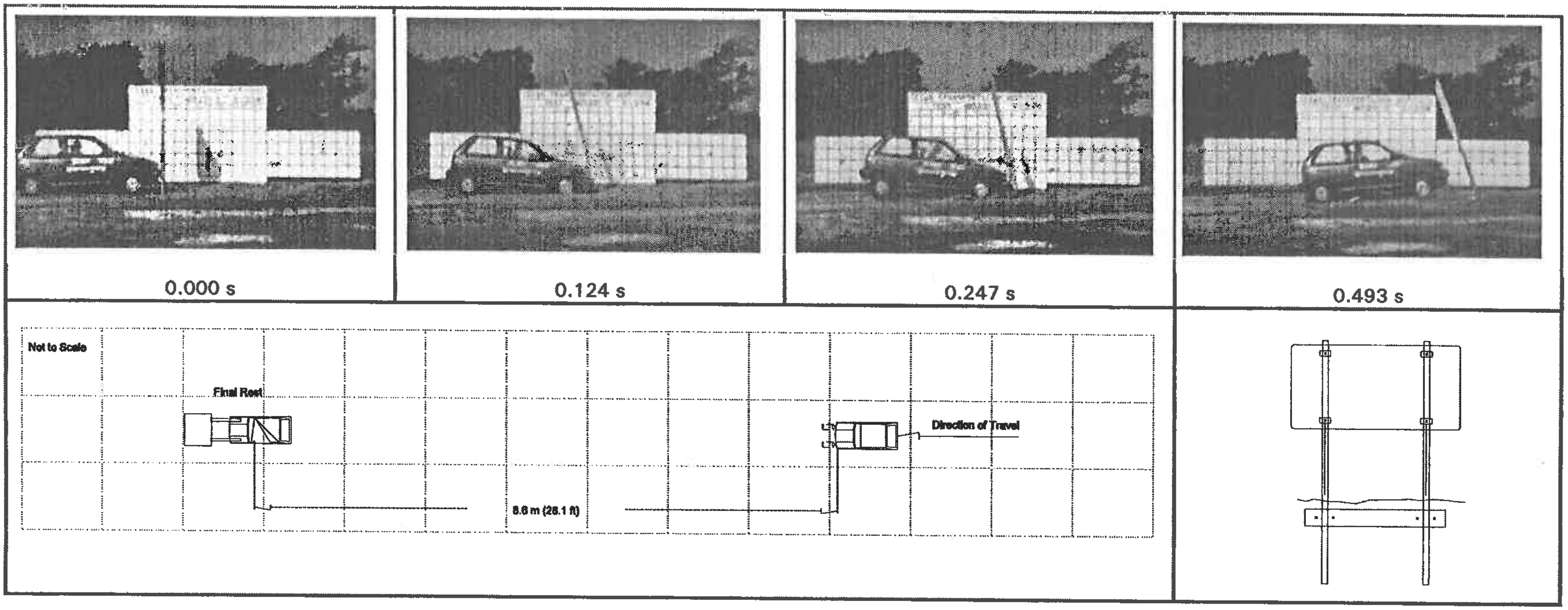


Figure 26 . Dual 3 in. aluminum sign support installation anchored in weak soil after test 405231-3.

Figure 27 . Vehicle after test 405231-3.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 4.7 m/s (15.6 ft/s) at 0.222 s, the highest 0.010-s average ridedown acceleration was -0.6 g between 0.610 and 0.620 s, and the maximum 0.050-s average acceleration was -3.5 g between 0.079 and 0.129 s. No contact occurred in the lateral direction. The maximum 0.050-s average lateral acceleration was -0.4 g between 0.134 and 0.184 s. These data and other pertinent information from the test are summarized in Figure 28. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 4.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-3
Date	09/13/94
Test Article	
Type	Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	76.2 (3.0 in)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	804 (1779 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	34.5 (21.4 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	18.0 (11.2 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.7 (15.6 ft/s)
y-direction	N/A
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.6
y-direction	No contact
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.5
y-direction	-0.4
z-direction	-3.0

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	2.2
Max. Pitch Angle (deg)	-10.7
Max. Yaw Angle (deg)	2.4

Figure 28. Summary of results for test 405231-3.

Table 4. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-3

Test No.: 405231-3 Test Date: 09/13/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports yielded by bending the aluminum tubes at ground level and fracturing in tension near bumper level.	Pass
<u>Occupant Risk</u> D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral; Preferred: 3; Maximum: 5	Longitudinal occupant impact velocity: 4.7 m/s (15.6 ft/s) Lateral occupant impact velocity: N/A	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral; Preferred: 15; Maximum: 20	Longitudinal Occupant Ridedown Acceleration: -0.6 g's Lateral Occupant Ridedown Acceleration: No Contact	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Dual 76 mm (3.0 in) diameter aluminum support anchored in weak soil - 100 km/h (62.2 mi/h)

- **Test 405231-4**

The same 1988 Ford Festiva used in test 405231-3, shown in Figures 29 and 30, was reused for this crash test. The vehicle was directed into the dual 76 mm (3.0 in) diameter aluminum support sign installation anchored in weak soil, shown in Figure 31, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 103.3 km/h (64.2 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to bend at ground level and deform around the bumper. As the vehicle continued traveling forward, the supports yielded allowing the vehicle to continue moving. The supports pocketed around the front bumper, thus leading to the tensile failure of both sign supports at approximately 0.042 seconds. As the supports failed, the vehicle passed over the ground stubs as the upper portion of the sign installation continued rotating over the front of the vehicle. The sign panel struck the roof of the vehicle at 0.087 seconds. The sign panel struck the roof with a force sufficient to deform the roof and A-pillars and cause the left passenger window to shatter. The sign panel bounced up and forward of the vehicle losing contact. Shortly thereafter, the sign panel struck the right A-pillar of the vehicle again and lost contact. The vehicle exited traveling 90.7 km/h (56.3 mi/h), the brakes were applied and the vehicle came to rest out of view of the high-speed camera with the sign panel and supports still in contact with the front of the vehicle. The vehicle came to final rest upright 96.2 m (315.5 ft) downstream and 40.0 m (131.1 ft) left of the point of impact. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 32, the supports were bent and fractured. The left support failed 610 mm (24.0 in) from ground level and the right support 584 mm (23.0 in) from ground level. The mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. However, the sign panel required replacement. Damage sustained by the vehicle during this test is shown in Figure 33. The vehicle sustained moderate roof, hood and top of doors damage. In addition, minor damage to the front bumper, grill, windshield and left front fender were sustained. Maximum vertical crush to the roof was 90 mm (3.5 in).

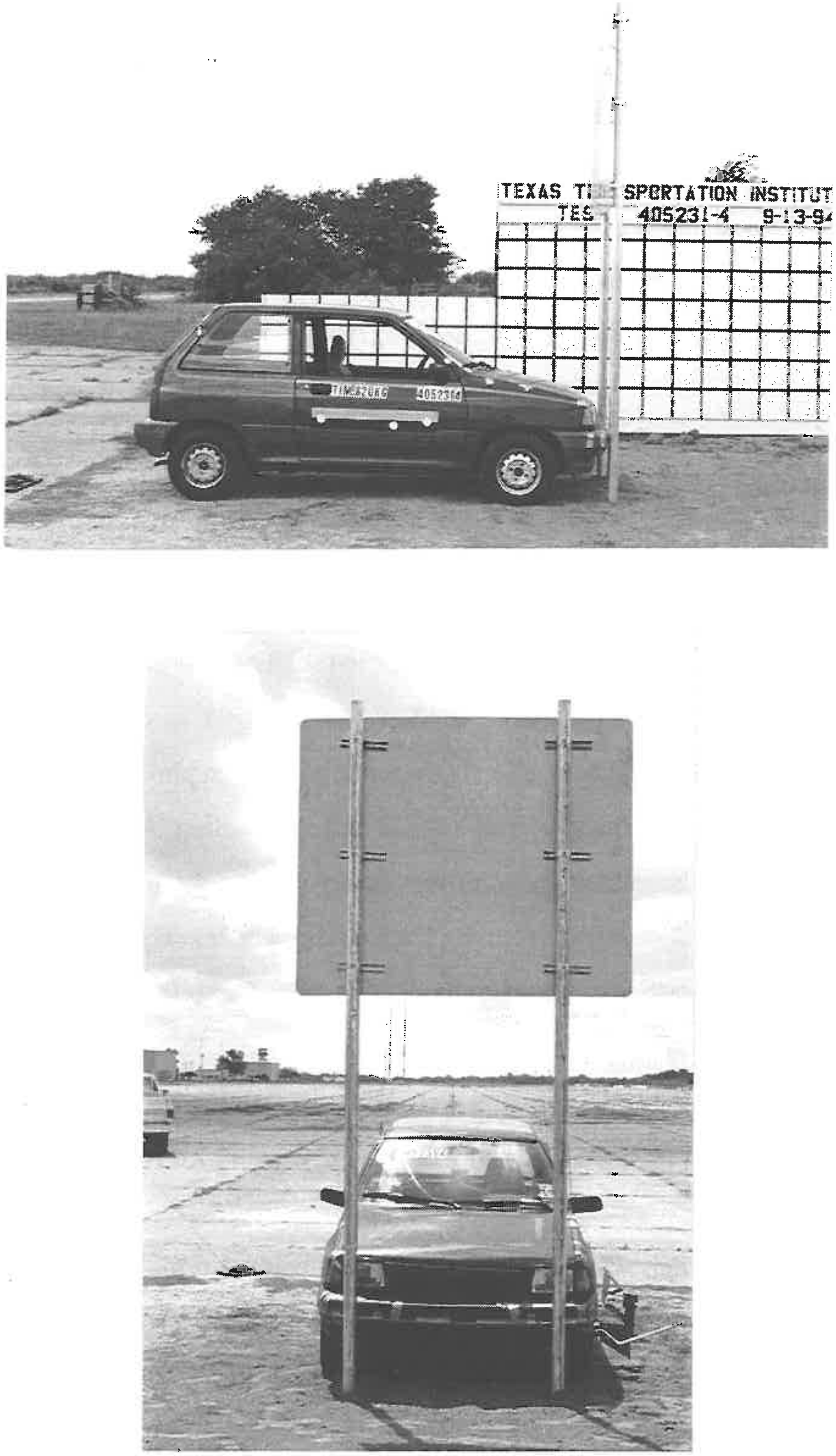


Figure 29 . Vehicle/sign installation geometrics for test 405231-4.

Figure 30 . Vehicle before test 405231-4.

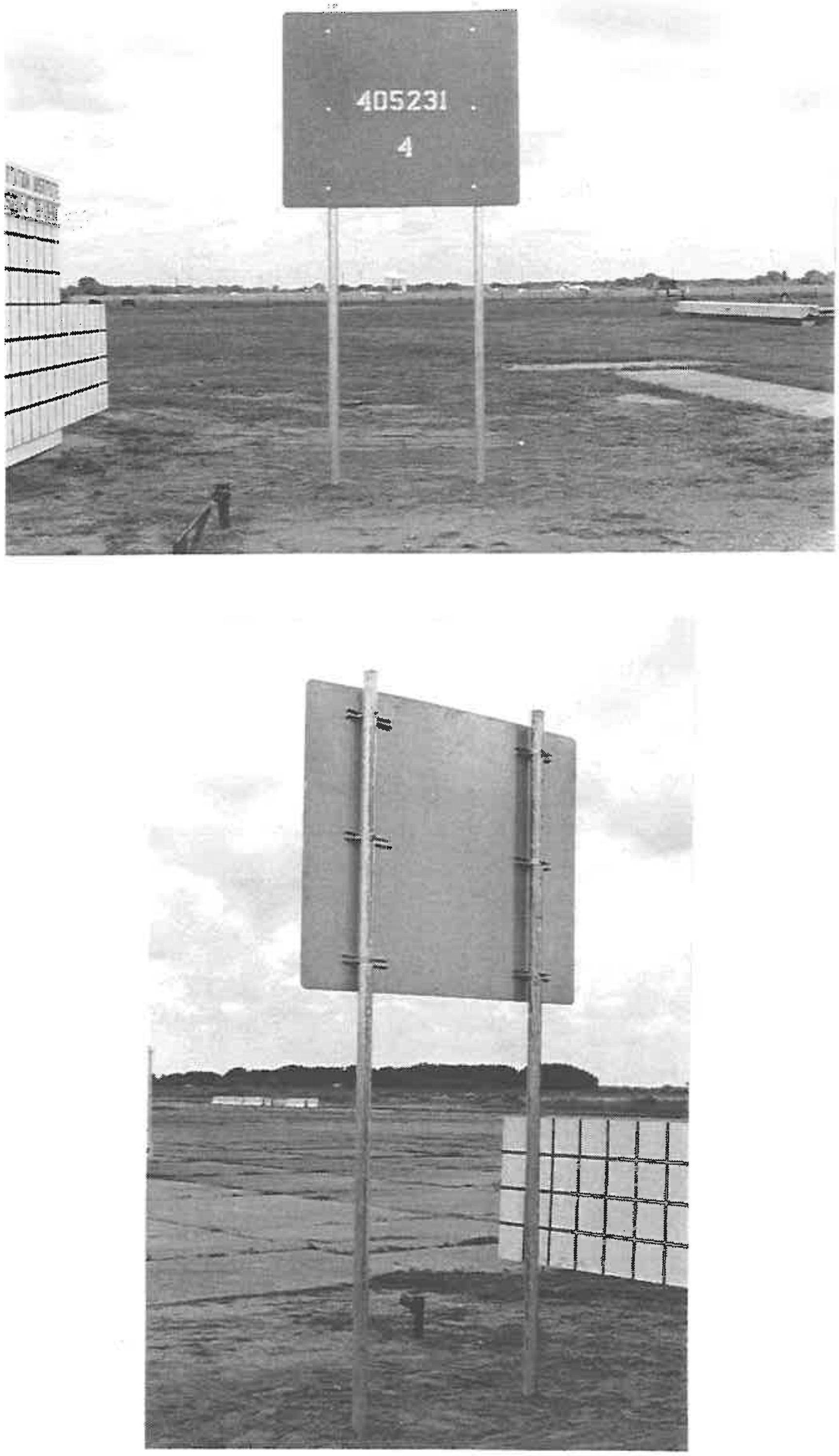


Figure 31 . Dual 3 in. aluminum sign support installation anchored in weak soil before test 405231-4.

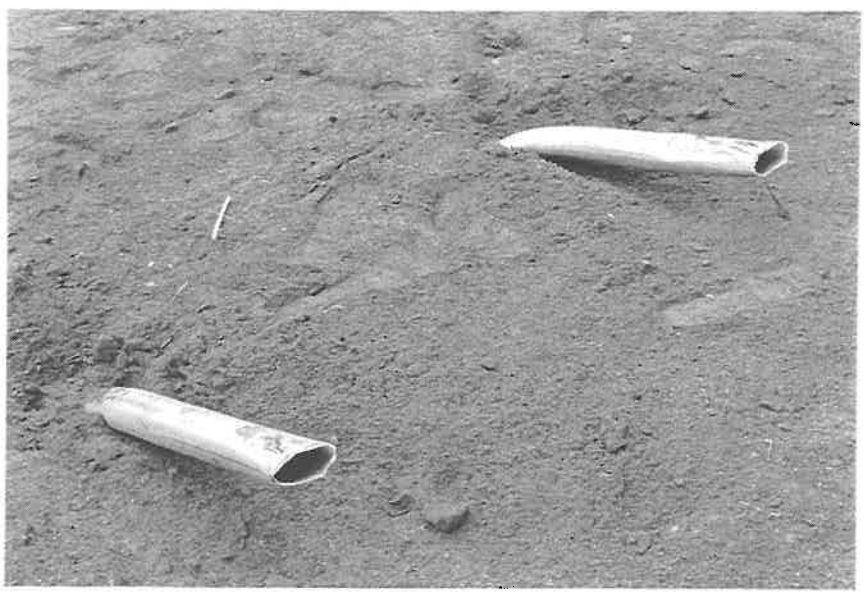


Figure 32 . Dual 3 in. aluminum sign support installation anchored in weak soil after test 405231-4.

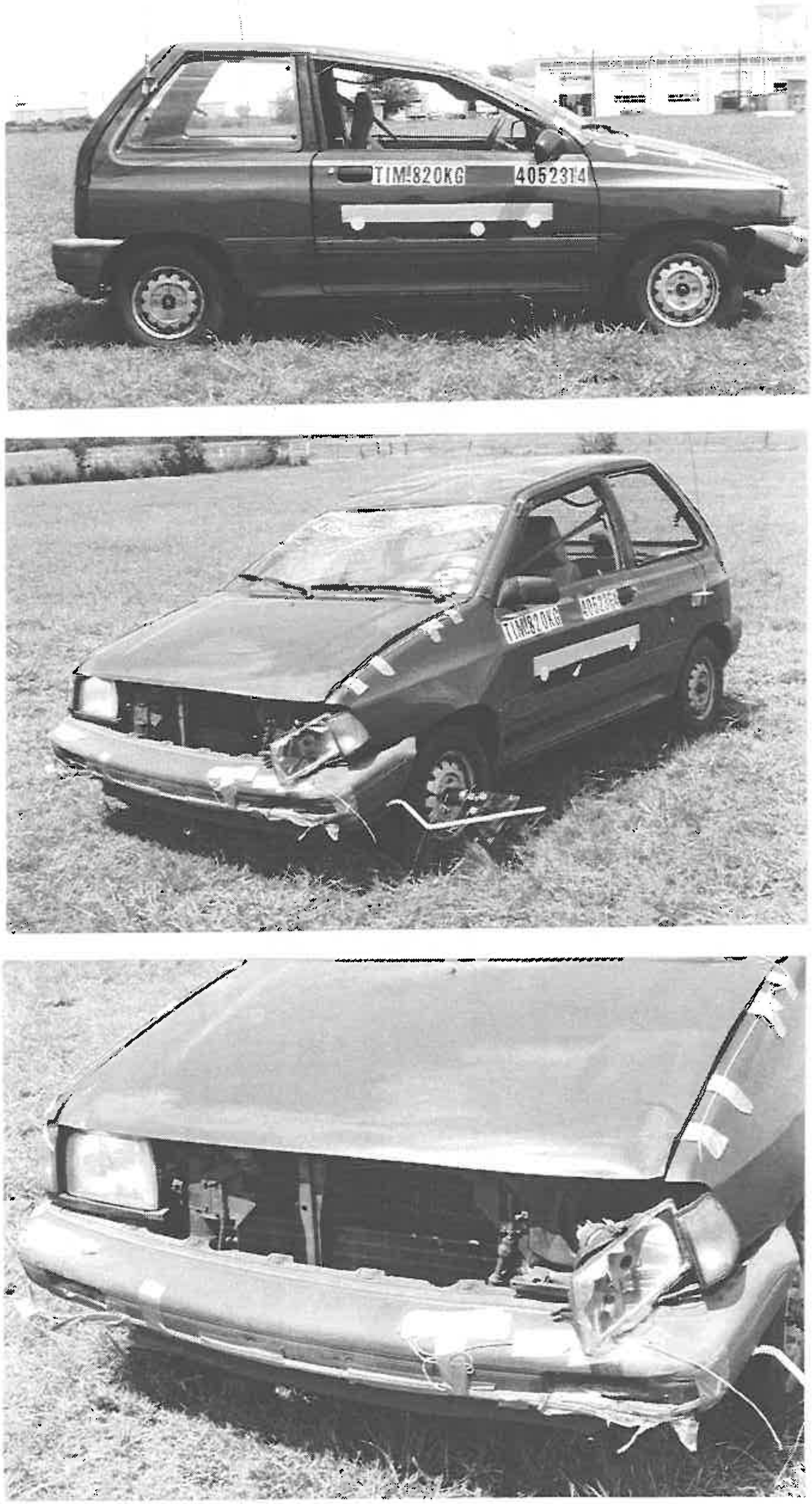
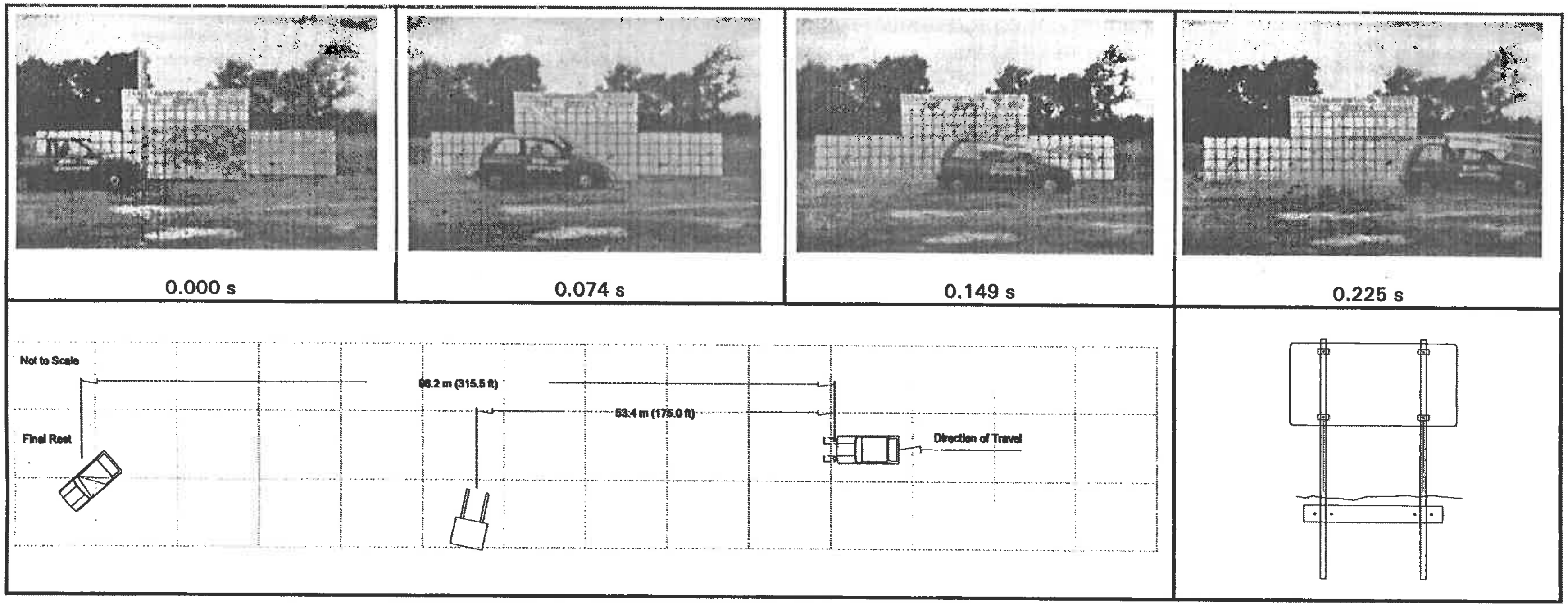


Figure 33 . Vehicle after test 405231-4.

Maximum deformation to the front of the vehicle at the impact point was 30 mm (1.2 in). There was deformation, but no intrusion into the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 3.7 m/s (12.3 ft/s) at 0.218 s, the highest 0.010-s average ridedown acceleration was -1.0 g between 0.280 and 0.290 s, and the maximum 0.050-s average acceleration was -5.8 g between 0.011 and 0.061 s. Lateral occupant impact velocity was -1.2 m/s (-3.9 ft/s) at 0.495 s, the highest 0.010-s occupant ridedown acceleration was -1.3 g between 0.830 and 0.840 s and the maximum 0.050-s average acceleration was -0.9 g between 0.004 and 0.054 s. These data and other pertinent information from the test are summarized in Figure 34. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 5.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-4
Date	09/13/94
Test Article	
Type	Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and Diameter of Tube (mm)	3.2 (0.125 in) 76.2 (3.0 in)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	804 (1773 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)
Impact Conditions	
Speed (km/h)	103.3 (64.2 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	90.7(56.3 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.7 (12.3 ft/s)
y-direction	1.2 (3.9 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.0
y-direction	-1.3
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-5.8
y-direction	-0.9
z-direction	3.1

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1 & 12TDDW3
Interior	
OCDI	FS0100000
Maximum Exterior Vehicle Crush (mm)	30 (1.2 in)
Max. Occ. Compart. Deformation (mm)	90 (3.5 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	5.1
Max. Pitch Angle (deg)	4.7
Max. Yaw Angle (deg)	-8.6

Figure 34. Summary of results for test 405231-4.

Table 5. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-4

Test No.: 405231-4 Test Date: 09/13/94 Test Agency: Texas Transportation Institute

<table>
<tr><th>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 sign supports yielded by bending the aluminum tubes at ground level and fracturing in tension near bumper level.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.</td><td>The sign supports fractured but did not present a hazard to other travel lanes. There was deformation of the front portion of the occupant compartment, but no actual intrusion into the 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 throughout the test period.</td><td>Pass</td></tr>
<tr><td>H. Occupant impact velocities should satisfy the following:<table><tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>3</td><td>5</td></tr></table></td><td>Longitudinal occupant impact velocity: 3.7 m/s (12.3 ft/s)
Lateral occupant impact velocity: 1.2 m/s (3.9 ft/s)</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits (G's)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15</td><td>20</td></tr></table></td><td>Longitudinal Occupant Ridedown Acceleration: -1.0 g's
Lateral Occupant Ridedown Acceleration: -1.3 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 trajectory was judged to be acceptable.</td><td>Pass</td></tr>
</table>

Dual 102 mm (4 in) diameter aluminum support anchored in strong soil - 35 km/h (21.8 mi/h)

- ***Test 405231-5***

A 1988 Ford Festiva, shown in Figures 35 and 36, was used for the crash test. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 896 kg (1,975 lb). The height to the lower edge of the vehicle bumper was 395 mm (15.6 in) and it was 550 mm (21.7 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A. The vehicle was directed into the dual 102 mm (4.0 in) diameter aluminum support sign installation anchored in strong soil, shown in Figure 37, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 36.1 km/h (22.4 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to bend at ground level and deform around the bumper. As the vehicle continued traveling forward, the supports yielded allowing the vehicle to continue moving. The supports pocketed around the front bumper, thus leading to the tensile failure of the left and right supports at 0.082 seconds. However, only the right support fractured across its entire cross section. As the front of the vehicle slowed and the left support resisted failing, the rear of the vehicle rotated upward and around counterclockwise, causing the right front tire and rear tires to lose contact with the roadway. The vehicle came to rest near the point of impact as the sign installation rotated counterclockwise around the remaining intact portion of the left sign support. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 38, the supports were bent and fractured. The right support failed 432 mm (17.0 in) from ground level and the left support partially fractured 533 mm (21.0 in) from ground level. The sign panel and all mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. Damage sustained by the vehicle during this test is shown in Figure 39. The vehicle sustained only minor damage to the bumper. There was no deformation to the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact

Figure 35 . Vehicle/sign geometrics for test 405231-5.

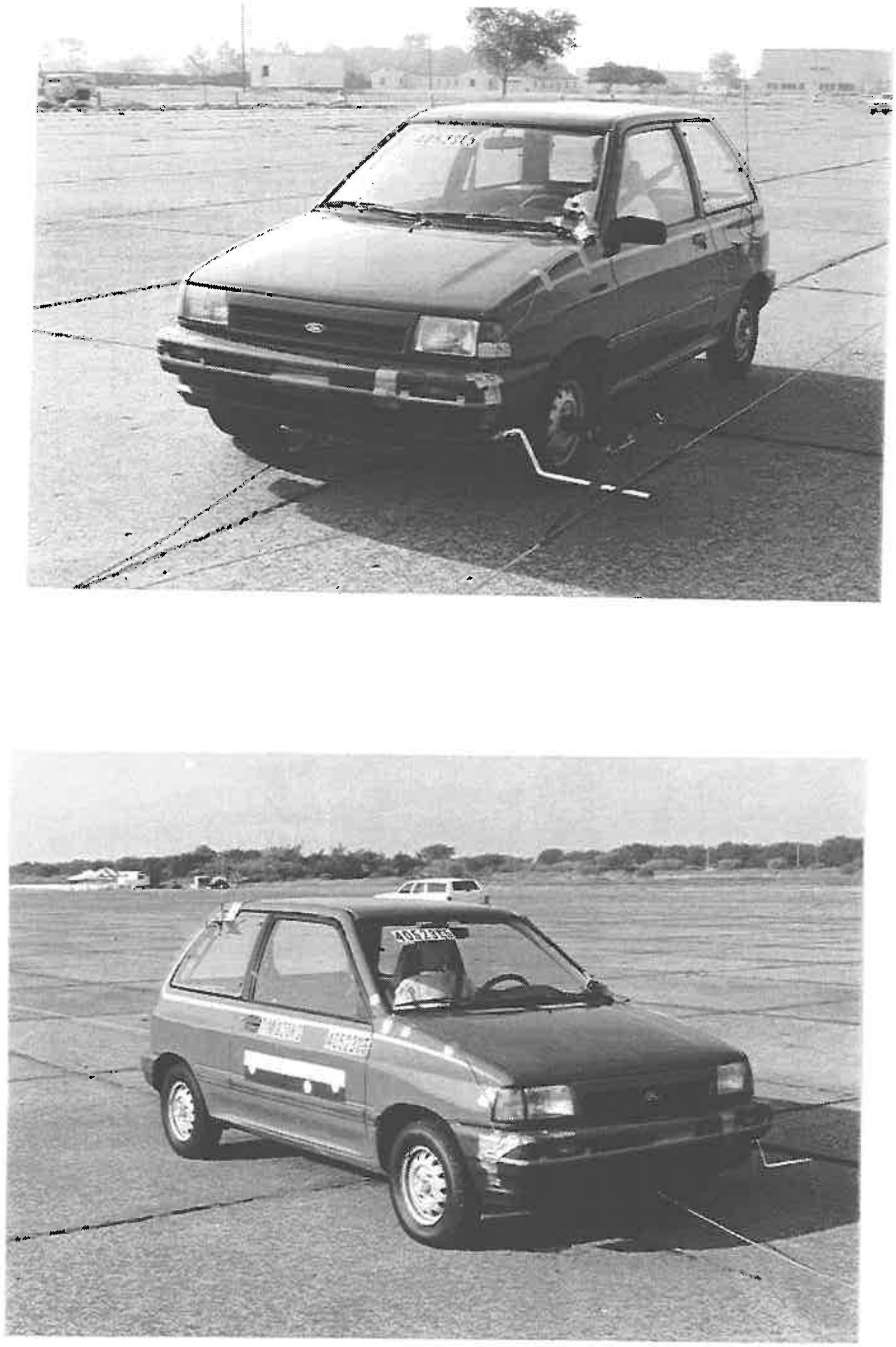


Figure 36 . Vehicle before test 405231-5.

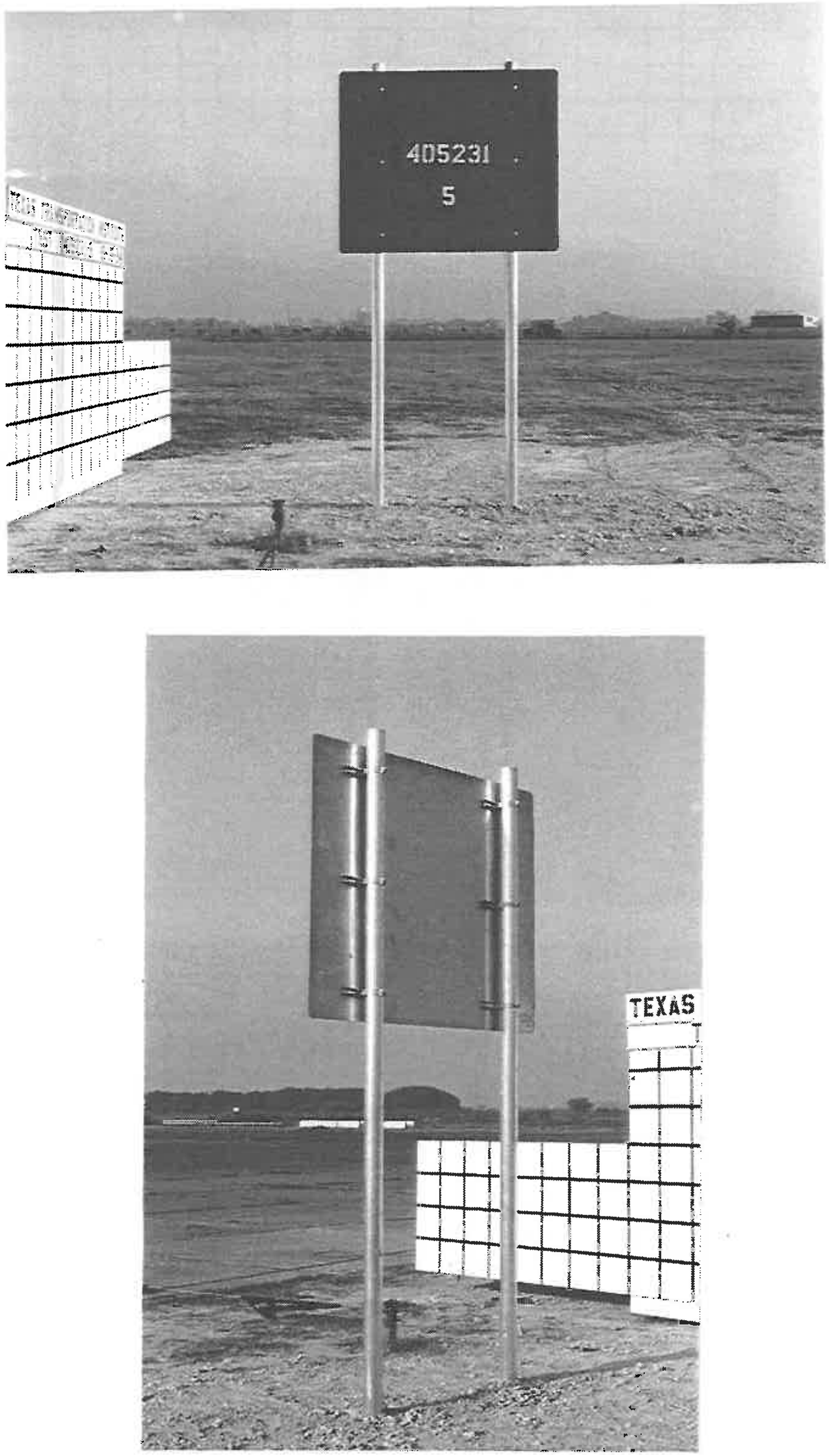


Figure 37 . Dual 4 in. aluminum sign support installation anchored in strong soil before test 405231-5.

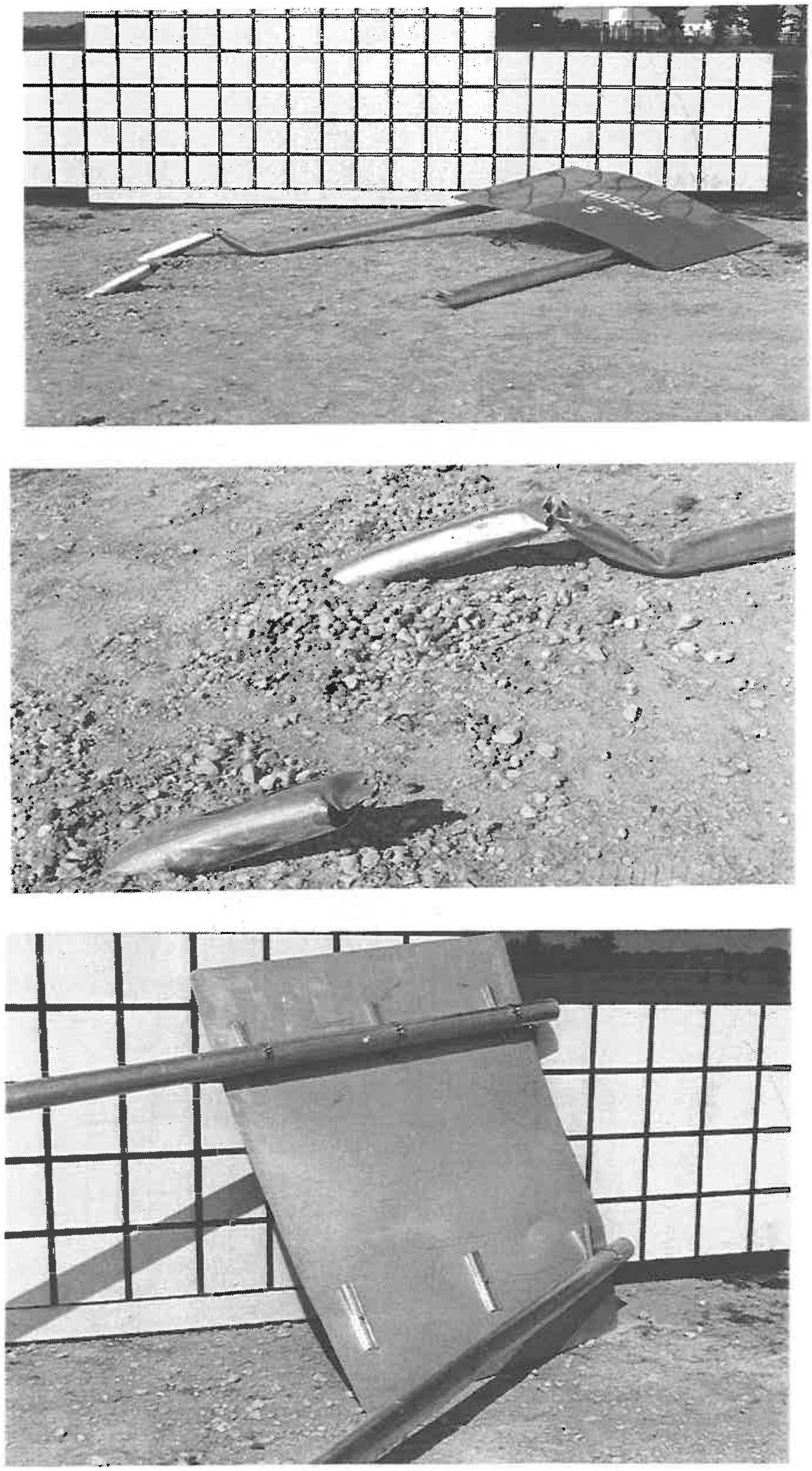
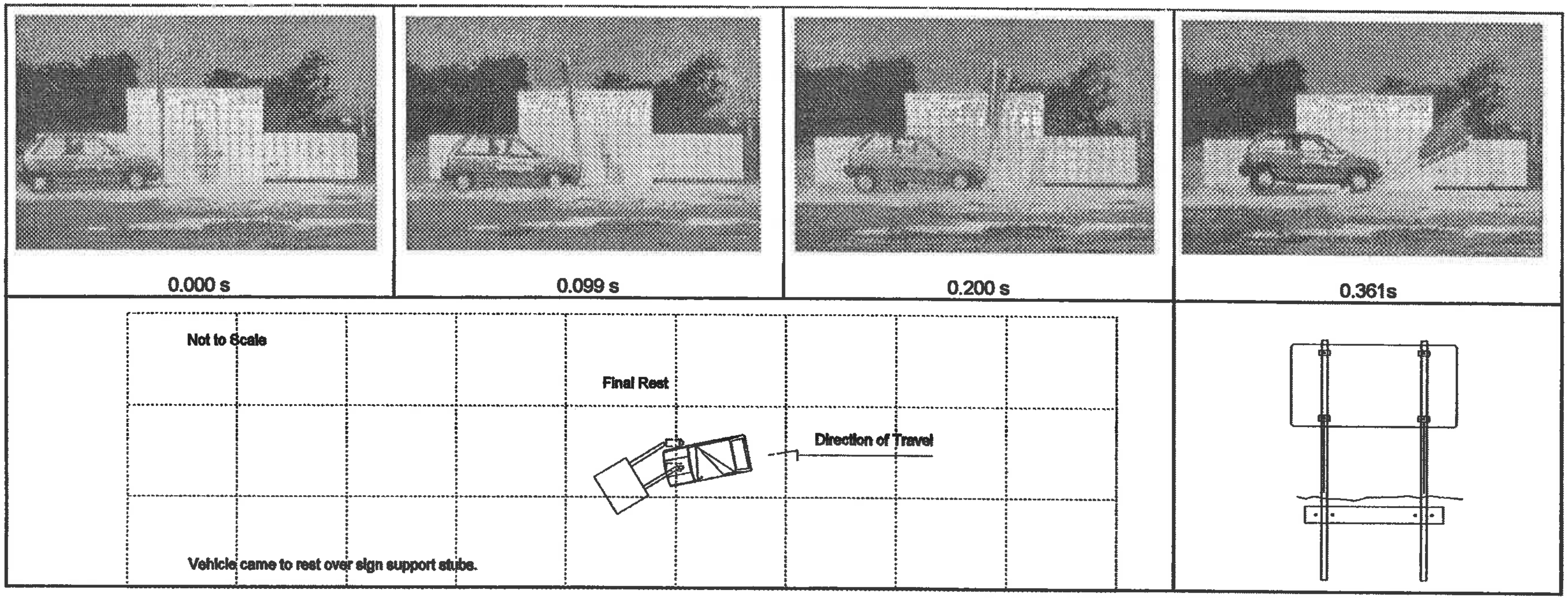


Figure 38 . Dual 4 in. aluminum sign support installation anchored in strong soil after test 405231-5.

Figure 39 . Vehicle after test 405231-5.

velocity was 7.1 m/s (23.2 ft/s) at 0.169 s, the highest 0.010-s average ridedown acceleration was -4.3 g between 0.184 and 0.194 s, and the maximum 0.050-s average acceleration was -5.2 g between 0.039 and 0.089 s. No contact occurred in the lateral direction. The maximum 0.050-s average lateral acceleration was +0.8 g between 0.091 and 0.141 s. These data and other pertinent information from the test are summarized in Figure 40. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 6.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-5
Date	09/15/94
Test Article	
Type	Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Ford Festiva
Mass (kg) Curb	782 (1724 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	36.1 (22.4 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	10.8 (6.7 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.1 (23.2 ft/s)
y-direction	N/A
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.3
y-direction	No Contact
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-5.2
y-direction	0.8
z-direction	-2.4

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	5.1
Max. Pitch Angle (deg)	-5.6
Max. Yaw Angle (deg)	-16.8

Figure 40. Summary of results for test 405231-5.

Table 6. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-5

Test No.: 405231-5 | Test Date: 09/13/94 | Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The right sign support yielded by bending the aluminum tube at ground level and fracturing in tension near bumper level. The left support bent at ground level, and only fractured part of the cross-section in tension.	Fail
Occupant Risk D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports yielded and **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral — Preferred: 3 — Maximum: 5	Longitudinal occupant impact velocity: 7.1 m/s (23.2 ft/s) Lateral occupant impact velocity: N/A	Fail
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral — Preferred: 15 — Maximum: 20	Longitudinal Occupant Ridedown Acceleration: -4.3 g's Lateral Occupant Ridedown Acceleration: No Contact	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Occupant Impact Velocity Limits (m/s)

Component	Preferred	Maximum
Longitudinal and Lateral	3	5

Occupant Ridedown Acceleration Limits (G's)

Component	Preferred	Maximum
Longitudinal and Lateral	15	20

Single 102 mm (4 in) diameter aluminum support anchored in strong soil - 35 km/h (21.8 mi/h)

- ***Test 405231-6***

The same 1988 Ford Festiva used in test 405231-5, shown in Figures 41 and 42, was reused for this crash test. The vehicle was directed into the single 102 mm (4.0 in) diameter aluminum support sign installation anchored in strong soil, shown in Figure 43, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign support with the left quarter point of the vehicle at a speed of 36.4 km/h (22.6 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the support began to bend at ground level and deform around the bumper. As the vehicle continued traveling forward, the support yielded allowing the vehicle to continue moving. The support pocketed around the front bumper, thus leading to the tensile failure of the support at 0.092 seconds. As the support failed, the vehicle passed over the ground stub with the upper portion of the sign installation remaining in contact with the front of the vehicle. The remaining intact portion of the sign installation was projected ahead of the vehicle. Shortly thereafter, the support rotated away from the vehicle and toward the ground, allowing the vehicle to travel over the installation. As the vehicle passed over the installation, the sign panel was pulled from the support by snagging on the vehicle. The vehicle came to rest upright 24.2 m (79.5 ft) downstream and 2.3 m (7.5 ft) left of the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 44. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 45, the support was bent and fractured. The support failed 521 mm (20.5 in) from ground level. The sign panel and all mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. Damage sustained by the vehicle during this test is shown in Figure 46. The vehicle sustained primarily cosmetic damage to the bumper and left front fender. There was no deformation to the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 2.6 m/s (8.5 ft/s) at 0.300 s, the highest 0.010-s average ridedown acceleration was

Figure 41. Vehicle/sign geometrics for test 405231-6.

Figure 42 . Vehicle before test 405231-6.

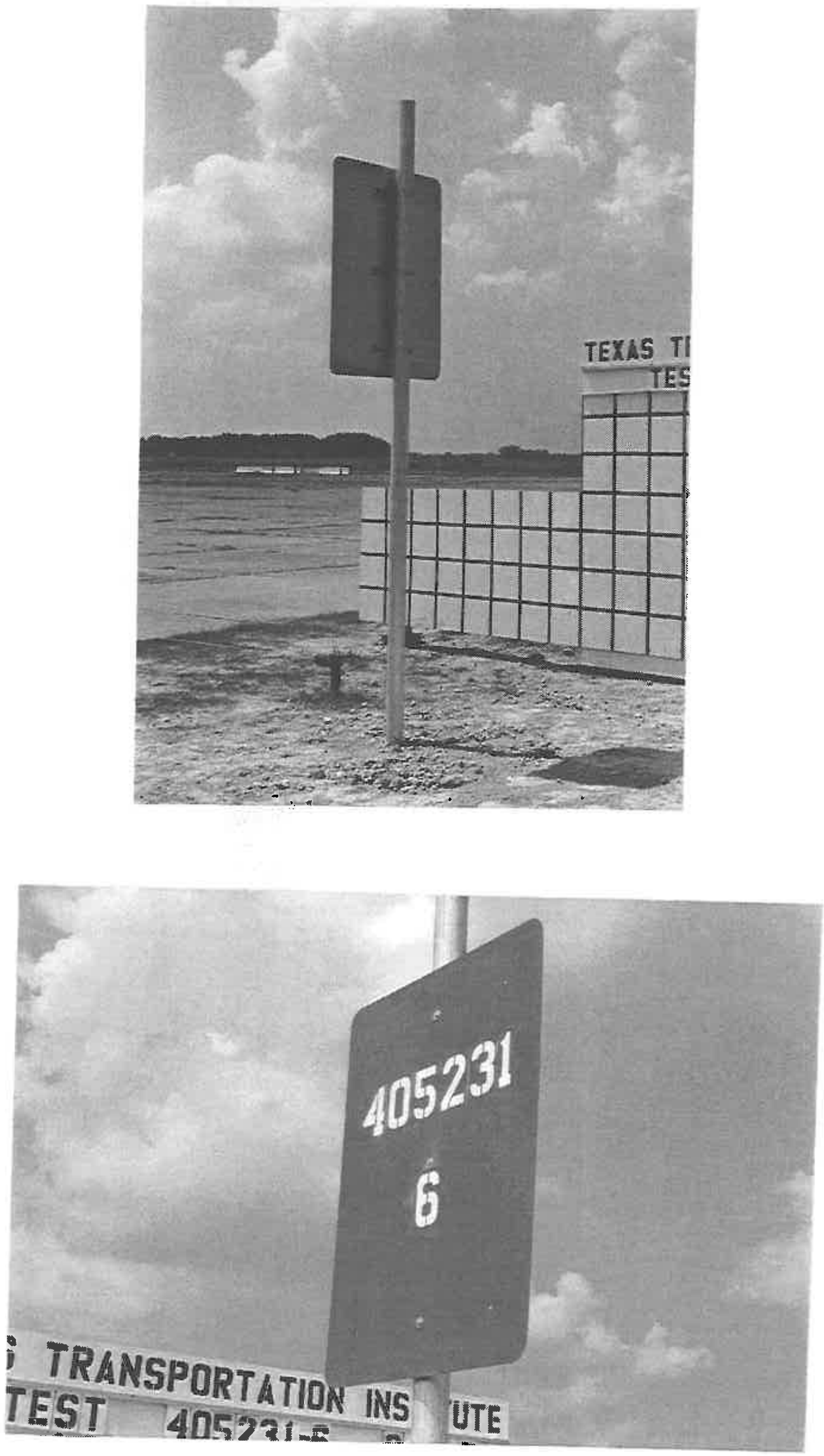


Figure 43 . Single 4 in. aluminum sign support installation anchored in strong soil before test 405231-6.

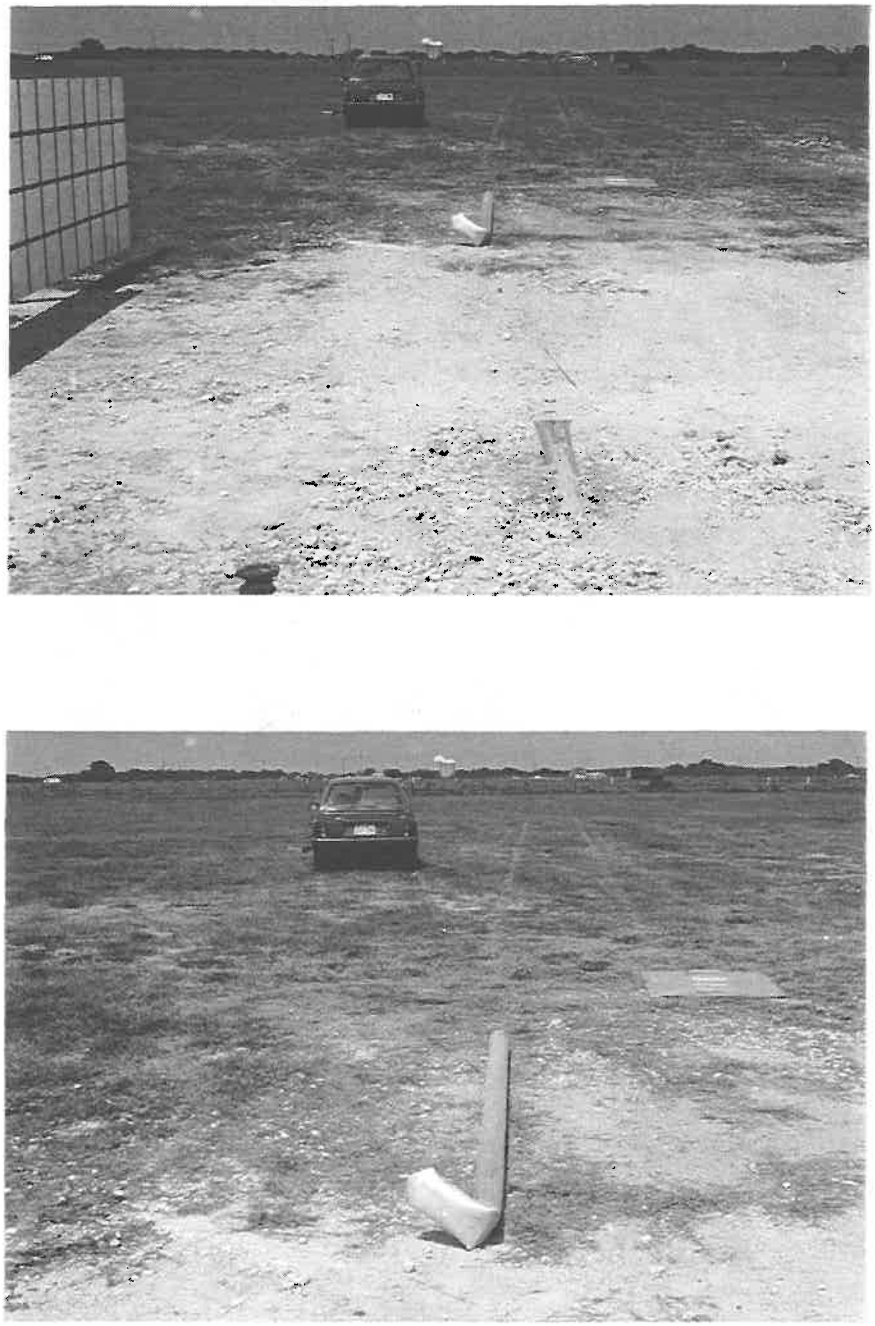


Figure 44 . Final rest position of the sign installation and vehicle (test 405231-6).

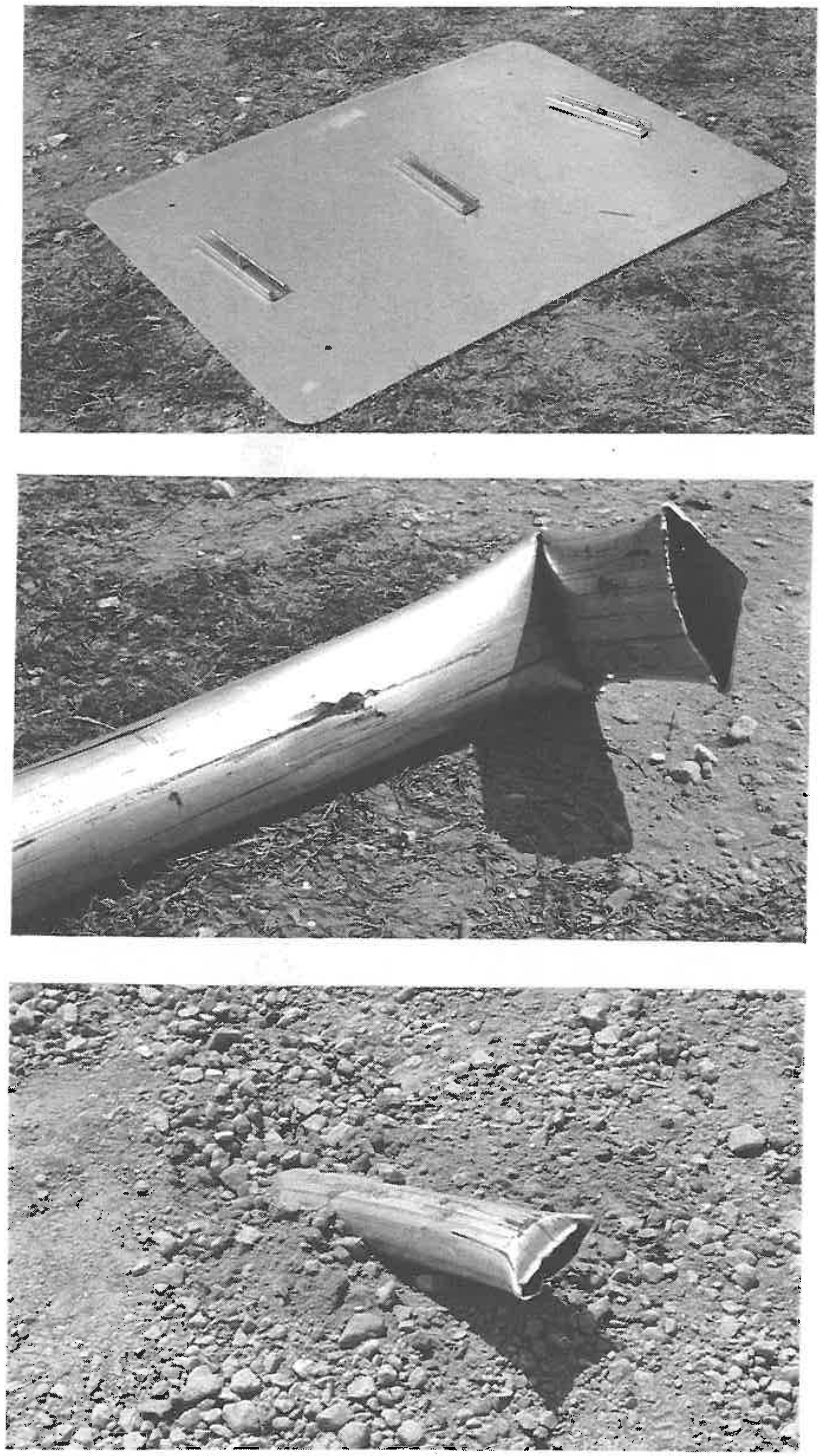
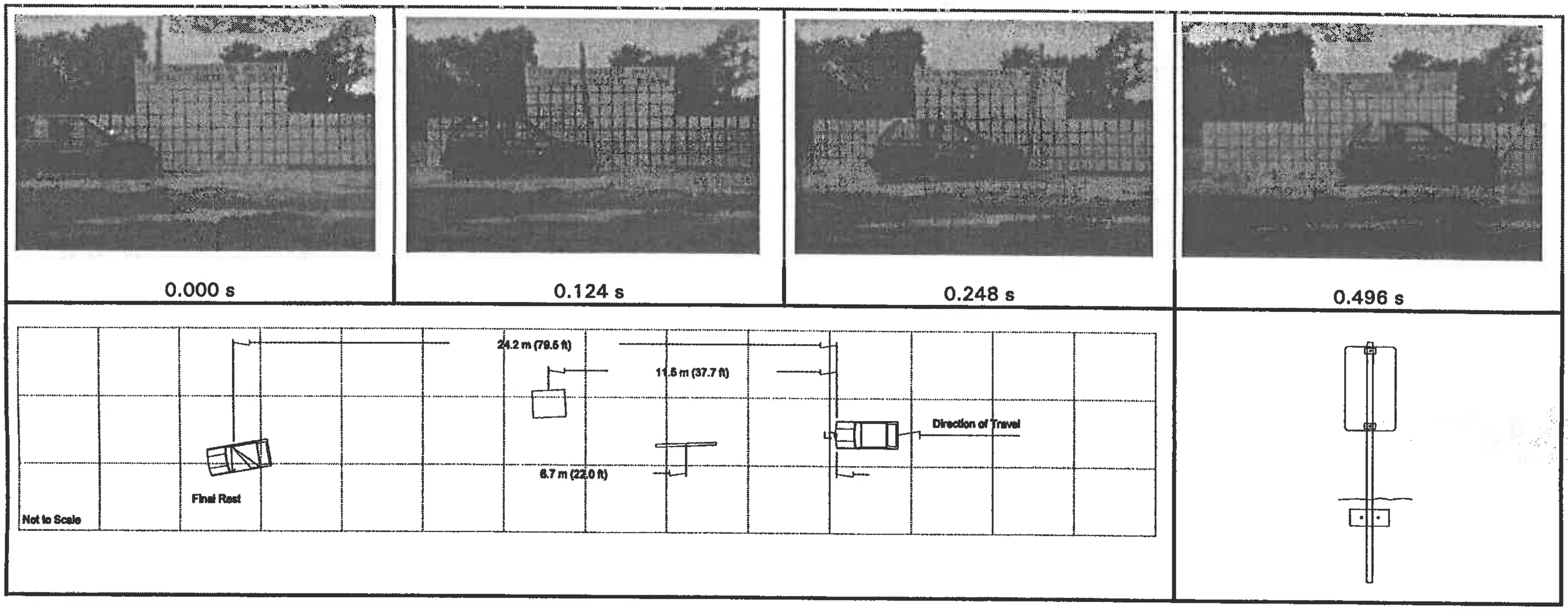


Figure 45. Single 4 in. aluminum sign support installation anchored in strong soil after test 405231-6.

Figure 46 . Vehicle after test 405231-6.

-0.6 g between 0.763 and 0.773 s, and the maximum 0.050-s average acceleration was -2.7 g between 0.065 and 0.115 s. Lateral occupant impact velocity was 1.1 m/s (3.7 ft/s) at 0.689 s, the highest 0.010-s occupant ridedown acceleration was -0.6 g between 0.580 and 0.590 s and the maximum 0.050-s average acceleration was -0.3 g between 0.085 and 0.134 s. These data and other pertinent information from the test are summarized in Figure 47. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 7.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-6
Date	09/15/94
Test Article	
Type	Single Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Ford Festiva
Mass (kg) Curb	782 (1724 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	36.4 (22.6 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	26.0 (16.2 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.6 (8.5 ft/s)
y-direction	1.1 (3.7 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.6
y-direction	-0.6
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-2.7
y-direction	-0.3
z-direction	-0.7

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	2.8
Max. Pitch Angle (deg)	4.6
Max. Yaw Angle (deg)	-7.9

Figure 47. Summary of results for test 405231-6.

Table 7. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-6

Test No.: 405231-6 Test Date: 09/15/94 Test Agency: Texas Transportation Institute

<table>
<tr><th>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 sign support yielded by bending the aluminum tube at ground level and fracturing in tension near bumper level.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.</td><td>The sign support fractured but did not present a hazard to other travel lanes. There was no deformation of 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 throughout the test period.</td><td>Pass</td></tr>
<tr><td>H. Occupant impact velocities should satisfy the following:<table><tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>3</td><td>5</td></tr></table></td><td>Longitudinal occupant impact velocity: 2.6 m/s (8.5 ft/s)
Lateral occupant impact velocity: 1.1 m/s (3.7 ft/s)</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits (G's)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15</td><td>20</td></tr></table></td><td>Longitudinal Occupant Ridedown Acceleration: -0.6 g's
Lateral Occupant Ridedown Acceleration: -0.6 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 trajectory was judged to be acceptable.</td><td>Pass</td></tr>
</table>

Single 102 mm (4 in) diameter aluminum support anchored in strong soil - 100 km/h (62.2 mi/h)

- **Test 405231-7**

The same 1988 Ford Festiva used in test 405231-6, shown in Figures 48 and 49, was reused for this crash test. The vehicle was directed into the single 102 mm (4.0 in) diameter aluminum support sign installation anchored in strong soil, shown in Figure 50, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign support with the aright quarter point of the vehicle at a speed of 100.3 km/h (62.3 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the support began to bend at ground level and deform around the bumper. As the vehicle continued traveling forward and it began to yaw clockwise, the support yielded allowing the vehicle to continue moving. The support pocketed around the front bumper, thus leading to the tensile failure of the sign support at approximately 0.042 seconds. As the support failed, the vehicle passed over the ground stub as the upper portion of the sign installation continued to rotate over the front of the vehicle. The sign panel struck the roof of the vehicle at 0.087 seconds. The sign installation then rotated up and away from the vehicle. The vehicle exited traveling at 89.2 km/h (55.4 mi/h), the brakes were applied and the vehicle came to rest out of view of the high-speed cameras. The vehicle came to final rest upright 93.6 m (307.0 ft) downstream and 7.7 m (25.3 ft) right of the point of impact. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 51, the support was bent and fractured. The support failed 699 mm (27.5 in) from ground level. The sign support and sign panel came to rest 63.4 m (208.0 ft) down and 3.0 (10.0 ft) to the right of impact sight. The mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. However, the sign panel required replacement. Damage sustained by the vehicle during this test is shown in Figure 52. The vehicle sustained moderate roof, hood, windshield and bumper damage. Maximum vertical crush to the roof was 60 mm (2.4 in). Maximum deformation to the front of the vehicle at the impact point was 65 mm (2.6 in). There were deformation and minor intrusion into the vehicle occupant compartment. The occupant compartment was punctured by two of the bolts anchoring the sign panel to the support.

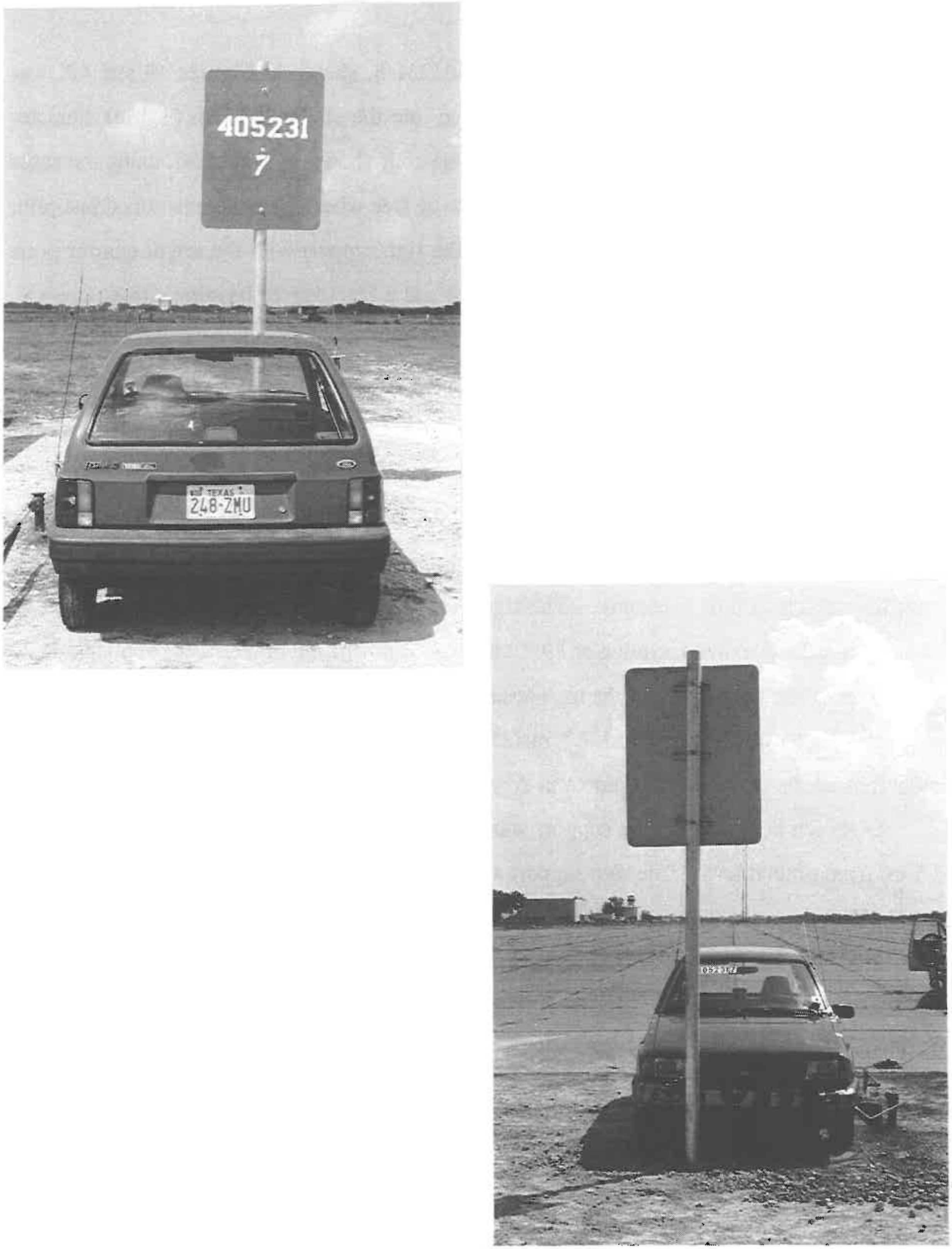


Figure 48 . Vehicle/sign geometrics for test 405231-7.

Figure 49. Vehicle before test 405231-7.

Figure 50 . Single 4 in. aluminum sign support installation anchored in strong soil before test 405231-7.

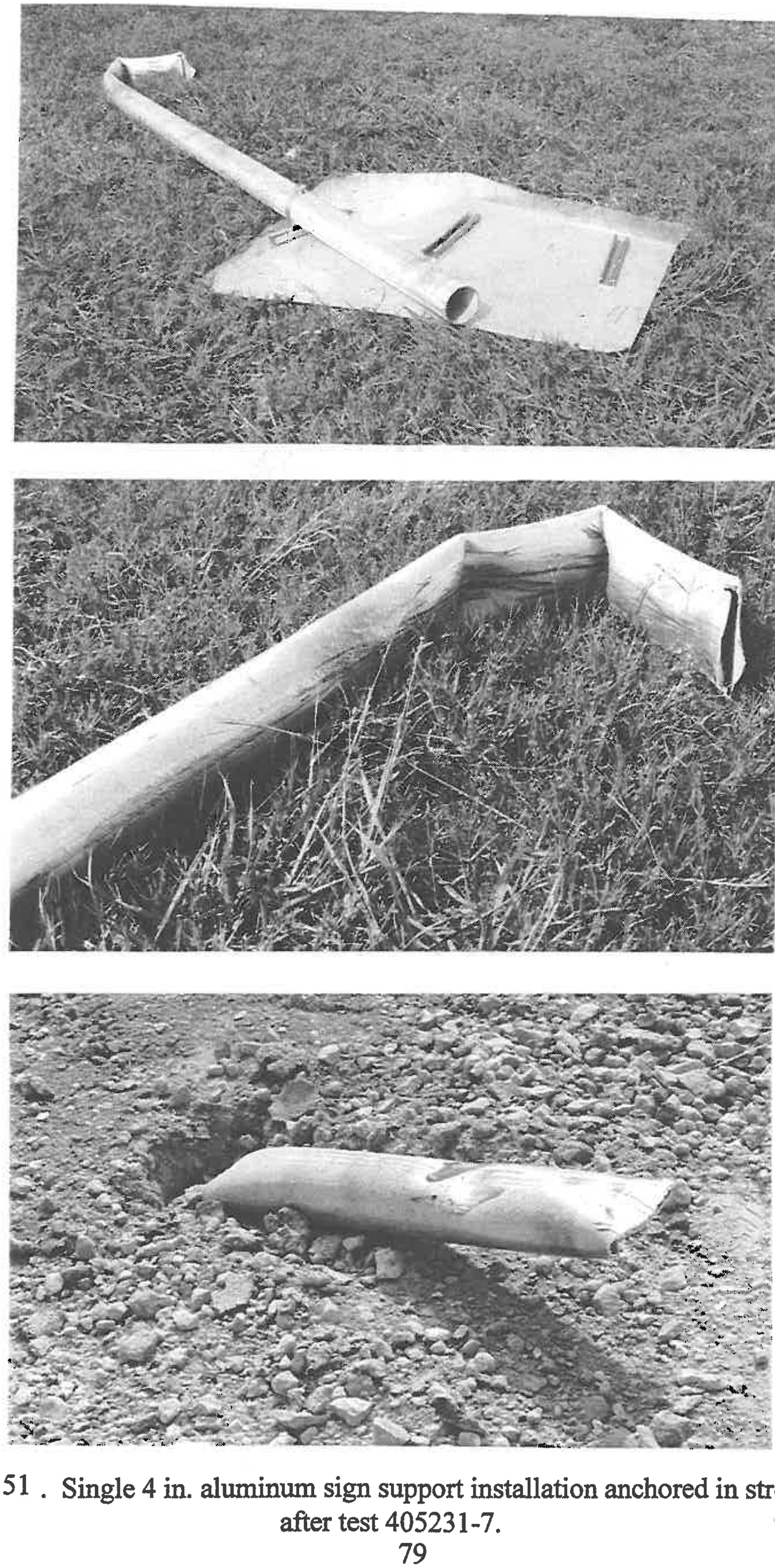


Figure 51 . Single 4 in. aluminum sign support installation anchored in strong soil after test 405231-7.

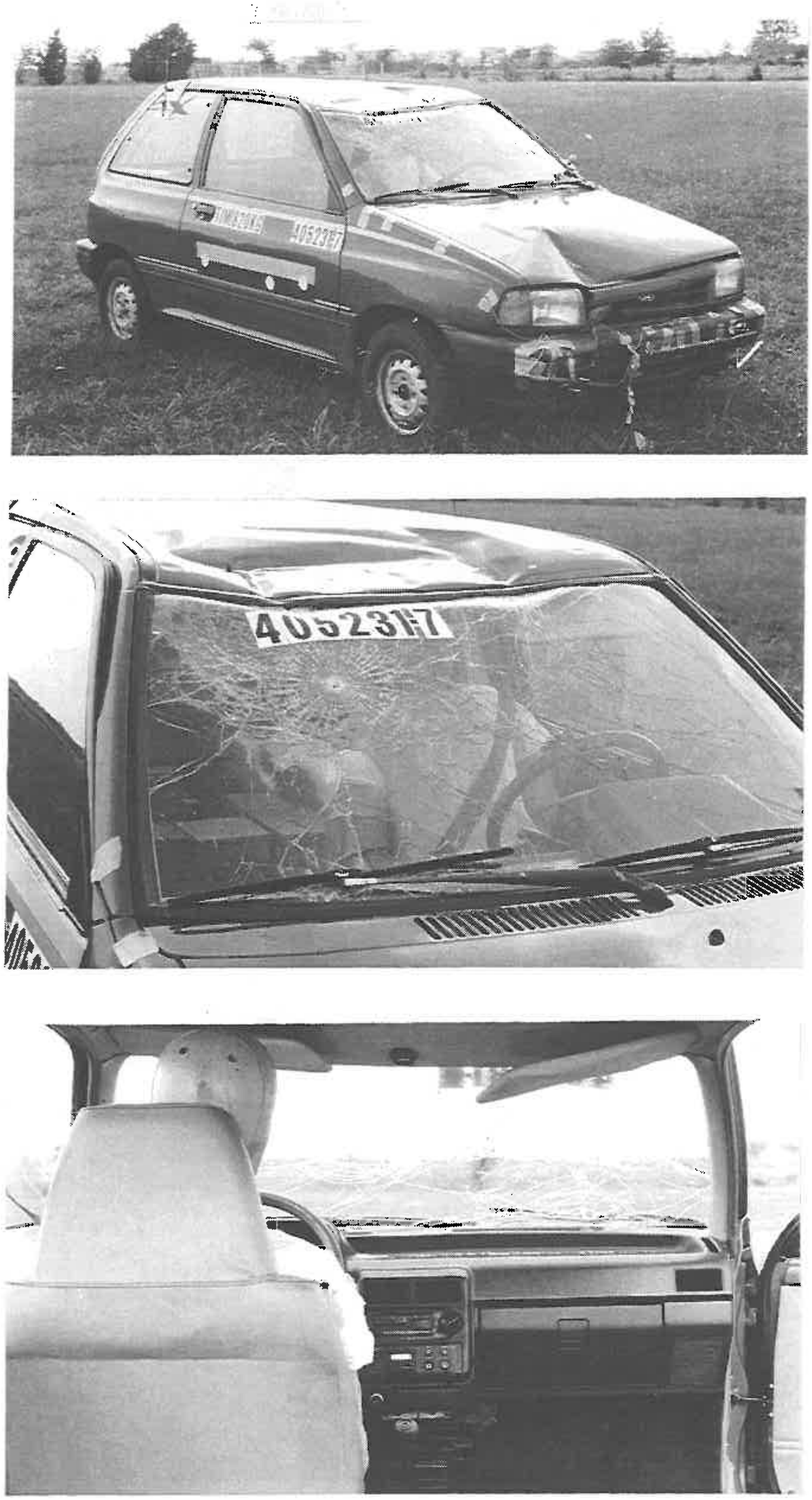
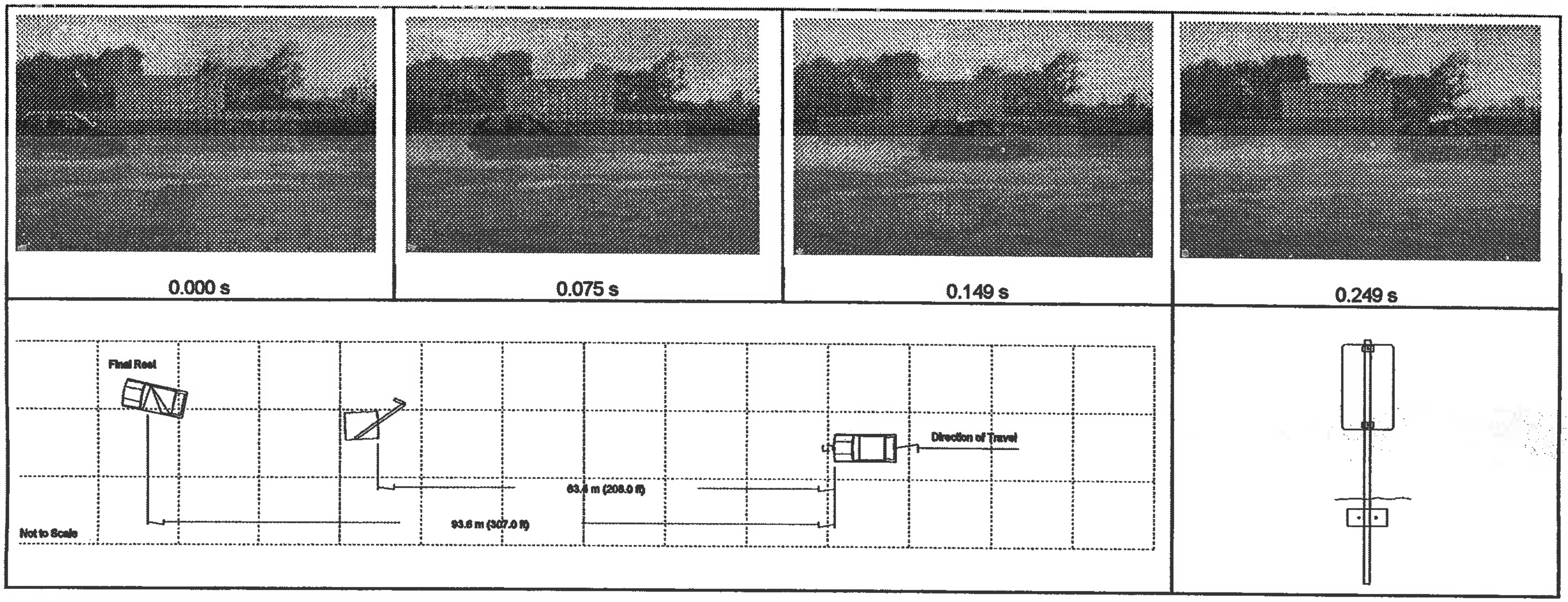


Figure 52 . Vehicle after test 405231-7.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 1.9 m/s (6.1 ft/s) at 0.364 s, the highest 0.010-s average ridedown acceleration was -0.5 g between 0.590 and 0.600 s, and the maximum 0.050-s average acceleration was -3.2 g between 0.000 and 0.050 s. Lateral occupant impact velocity was -4.3 m/s (-1.3 ft/s) at 0.530 s, the highest 0.010-s occupant ridedown acceleration was 0.9 g between 0.677 and 0.687 s and the maximum 0.050-s average acceleration was 0.6 g between 0.187 and 0.237 s. These data and other pertinent information from the test are summarized in Figure 53. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 8.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-7
Date	09/15/94
Test Article	
Type	Single Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Ford Festiva
Mass (kg) Curb	782 (1724 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	100.3 (62.3 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	89.2 (55.4 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.9 (6.1 ft/s)
y-direction	-1.3 (-4.3 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.5
y-direction	-0.9
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.2
y-direction	0.6
z-direction	-1.6

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1 & 12TDDW2
Interior	
OCDI	AS0100000
Maximum Exterior Vehicle Crush (mm)	65 (2.6 in)
Max. Occ. Compart. Deformation (mm)	60 (2.4 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-4.0
Max. Pitch Angle (deg)	8.4
Max. Yaw Angle (deg)	10.4

Figure 53. Summary of results for test 405231-7.

Table 8. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-7

Test No.: 405231-7 Test Date: 09/11/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign support yielded by bending the aluminum tube at ground level and fracturing in tension near bumper level.	Pass
Occupant Risk		
D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign support fractured but **did not** present a hazard to other travel lanes. There was deformation of the front portion of the occupant compartment, but no actual intrusion into the compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 3 / 5	Longitudinal occupant impact velocity: 1.9 m/s (6.1 ft/s) Lateral occupant impact velocity: -1.3 m/s (-4.3 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: -0.5 g's Lateral Occupant Ridedown Acceleration: -0.9 g's	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Single 102 mm (4 in) diameter aluminum support anchored in weak soil - 35 km/h (21.8 mi/h)

- ***Test 405231-8***

A 1989 Ford Festiva, shown in Figures 54 and 55, was used for the crash test. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 897 kg (1,978 lb). The height to the lower edge of the vehicle bumper was 350 mm (13.8 in) and it was 525 mm (20.7 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A. The vehicle was directed into the single 102 mm (4.0 in) diameter aluminum support sign installation anchored in weak soil, shown in Figure 56, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign support with the left quarter point of the vehicle at a speed of 34.5 km/h (21.4 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the support began to bend at ground level and collapse in and around the bumper. As the vehicle continued traveling forward it began to yaw counter-clockwise, the support yielded allowing the vehicle to continue moving. The support collapsed and pocketed around the front bumper, thus leading to the tensile failure of the support at 0.141 seconds. As the support failed, the remaining intact portion of the sign installation was projected ahead of the vehicle. The support rotated away from the vehicle and toward the ground, allowing the vehicle to travel partially over the installation and come to rest atop the installation. The vehicle and sign installation both came to rest approximately 7.0 m (23.0 ft) downstream and 0.6 m (2.0 ft) left of the point of impact. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 57, the support was bent and fractured. The support failed 457 mm (18.0 in) from ground level. The sign panel and all mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. Damage sustained by the vehicle during this test is shown in Figure 58. The vehicle sustained only cosmetic damage to the bumper. The vehicle occupant compartment was not deformed.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 3.8 m/s (12.4 ft/s) at 0.245 s, the highest 0.010-s average ridedown acceleration was -0.8 g between 0.870 and 0.880 s, and the maximum 0.050-s average acceleration was -3.3 g

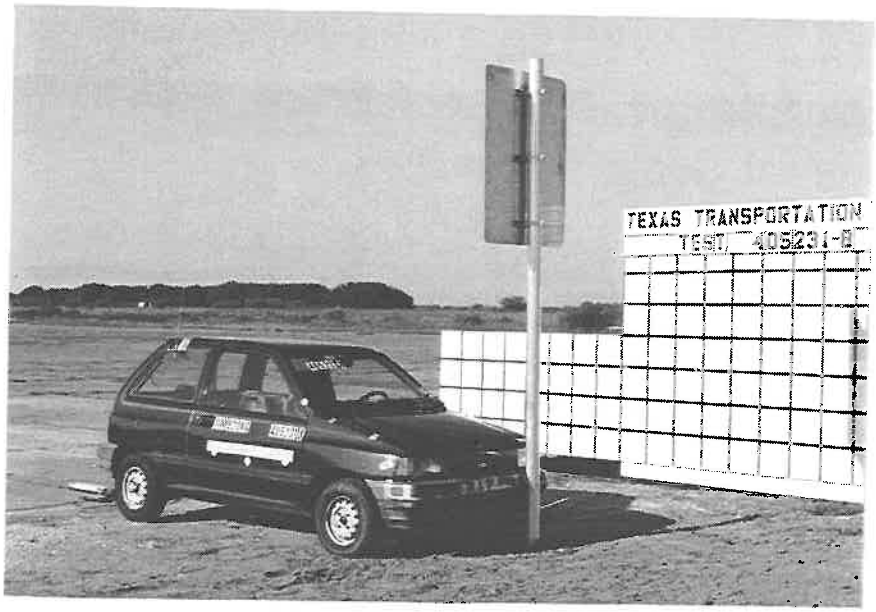


Figure 54 . Vehicle/sign geometrics for test 405231-8.

Figure 55 . Vehicle before test 405231-8.

Figure 56 . Single 4 in. aluminum sign support installation anchored in weak soil before test 405231-8.

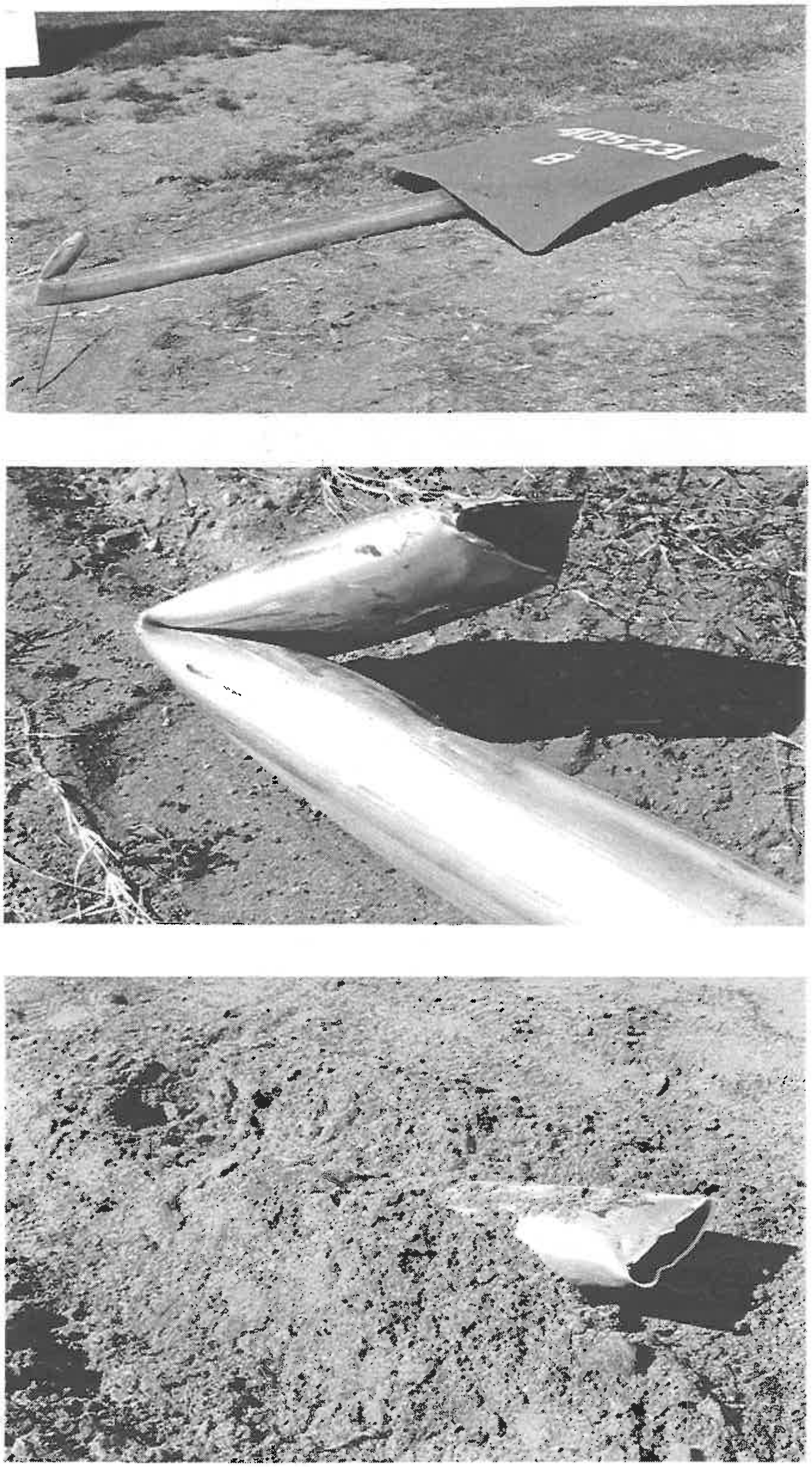
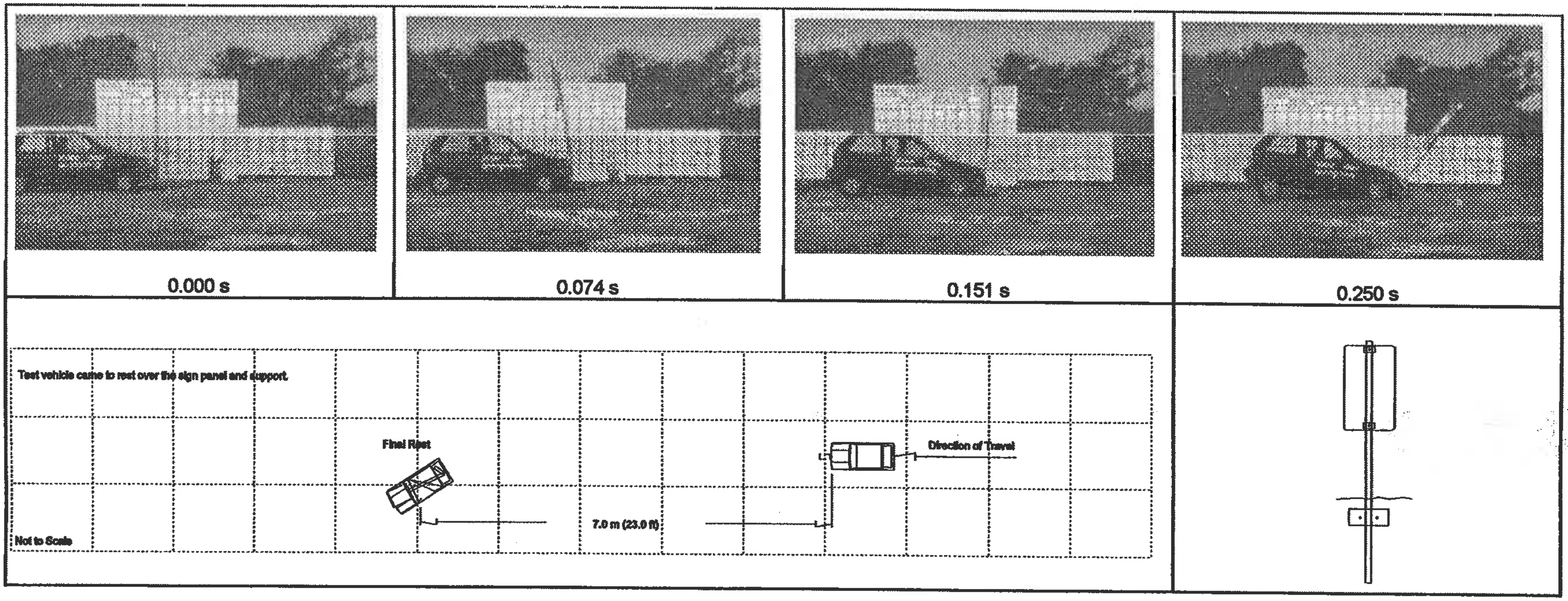


Figure 57 . Single 4 in. aluminum sign support installation anchored in weak soil after test 405231-8.

Figure 58 . Vehicle after test 405231-8.

between 0.057 and 0.107 s. Lateral occupant impact velocity was 1.7 m/s (5.4 ft/s) at 0.966 s, the highest 0.010-s occupant ridedown acceleration was -0.7 g between 0.844 and 0.854 s and the maximum 0.050-s average acceleration was -0.5 g between 0.756 and 0.806 s. These data and other pertinent information from the test are summarized in Figure 59. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 9.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-8
Date	09/19/94
Test Article	
Type	Single Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Ford Festiva
Mass (kg) Curb	810 (1786 lb)
Test Inertial	820 (1808 lb)
Dummy	77 (170 lb)
Gross Static	897 (1978 lb)

Impact Conditions	
Speed (km/h)	34.5 (21.4 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	22.5 (14.0 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.8 (12.4 ft/s)
y-direction	1.7 (5.4 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.8
y-direction	-0.7
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.3
y-direction	-0.5
z-direction	-1.6

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	6.9
Max. Pitch Angle (deg)	-8.4
Max. Yaw Angle (deg)	-22.4

Figure 59. Summary of results for test 405231-8.

Table 9. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-8

Test No.: 405231-8 Test Date: 09/19/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign support yielded by bending the aluminum tube at ground level and fracturing in tension near bumper level.	Pass
<u>Occupant Risk</u> D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign support fractured but **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral; Preferred: 3; Maximum: 5	Longitudinal occupant impact velocity: 3.8 m/s (12.4 ft/s) Lateral occupant impact velocity: 1.7 m/s (5.4 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral; Preferred: 15; Maximum: 20	Longitudinal Occupant Ridedown Acceleration: -0.8 g's Lateral Occupant Ridedown Acceleration: -0.7 g's	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Single 102 mm (4 in) diameter aluminum support anchored in weak soil - 100 km/h (62.2 mi/h)

- **Test 405231-9**

The same 1989 Ford Festiva used in test 405231-8, shown in Figures 60 and 61, was reused for this crash test. The vehicle was directed into the single 102 mm (4.0 in) diameter aluminum support sign installation anchored in weak soil, shown in Figure 62, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign support with the right quarter point of the vehicle at a speed of 101.4 km/h (63.0 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the support began to bend at ground level and collapse in and around the bumper. As the vehicle continued traveling forward it began to yaw clockwise, the support yielded allowing the vehicle to continue moving. The support pocketed around the front bumper, thus leading to the tensile failure of the sign support at approximately 0.045 seconds. As the support failed, the vehicle passed over the ground stub as the upper portion of the sign installation continued to rotate over the front of the vehicle. The sign panel struck the roof of the vehicle at 0.074 seconds. The sign panel struck the roof with a force sufficient enough to deform the roof and right A-pillar and cause the right passenger window to shatter. The sign installation then rotated up and away from the vehicle, exiting to the right. The vehicle exited traveling 88.4 km/h (54.9 mi/h), the brakes were applied and the vehicle came to rest out of view of the high-speed. The vehicle came to final rest upright 50.0 m (164.0 ft) downstream and 12.2 m (40.0 ft) right of the point of impact. The sign support and sign panel came to rest 44.5 m (146.0 ft) down and 2.1 m (7.0 ft) to the right of impact sight. Final rest positions of the vehicle and sign installation are shown in Figure 63. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 64, the support was bent and fractured. The support failed 609.6 mm (24.0 in) from ground level. The mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. However, the sign panel required replacement. Damage sustained by the vehicle during this test is shown in Figure 65. The vehicle sustained moderate roof, hood, windshield, top of right door and bumper damage. Maximum vertical crush to the roof was 110 mm (4.3 in). Maximum deformation to the front of the vehicle at the impact point was 40 mm (1.6 in). There were deformation and minor intrusion into the

Figure 60 . Vehicle/sign geometrics for test 405231-9.

Figure 61 . Vehicle before test 405231-9.

Figure 62 . Single 4 in. aluminum sign support installation anchored in weak soil before test 405231-9.

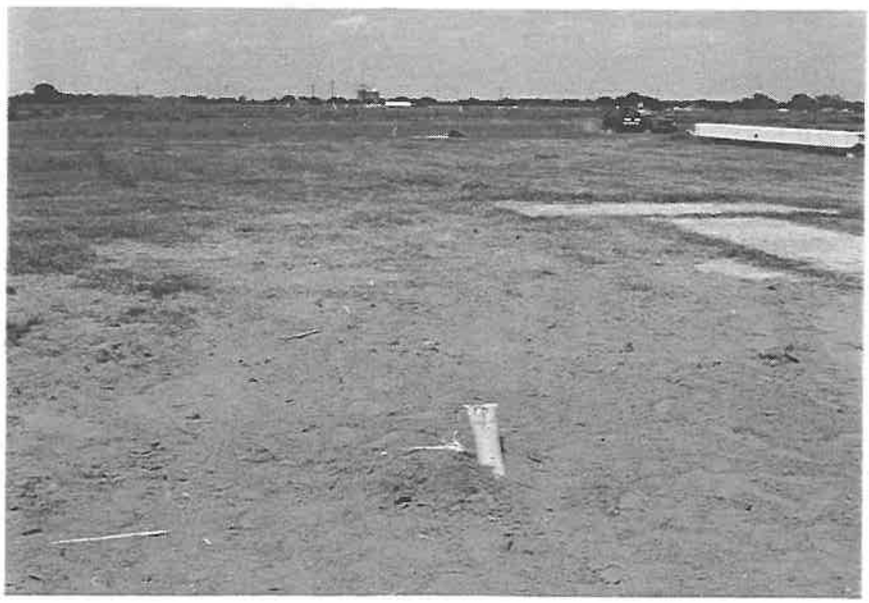


Figure 63 . Final rest position of the sign installation and vehicle (test 405231-9).

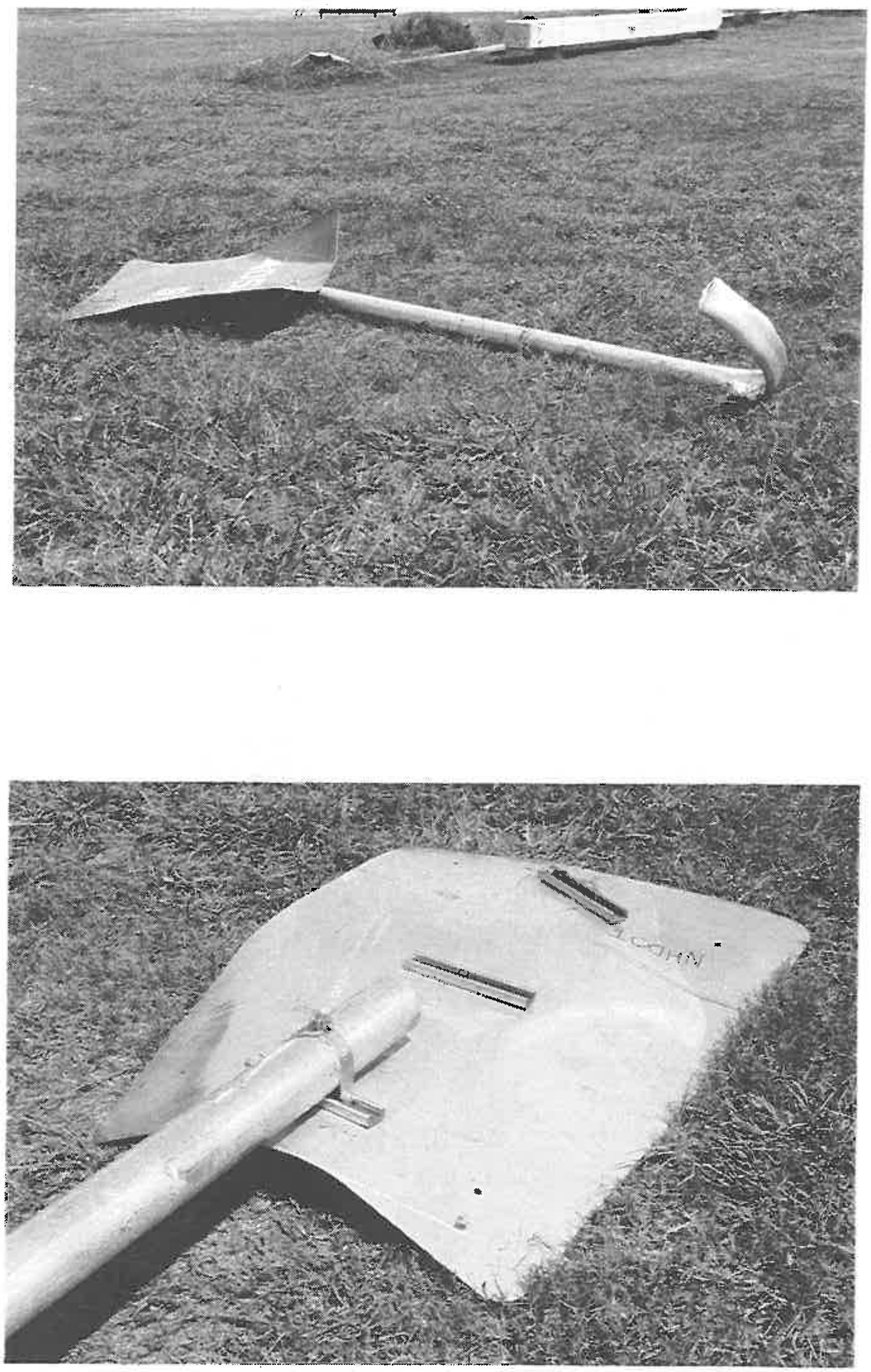


Figure 64 . Single 4 in. aluminum sign support installation anchored in weak soil after test 405231-9.

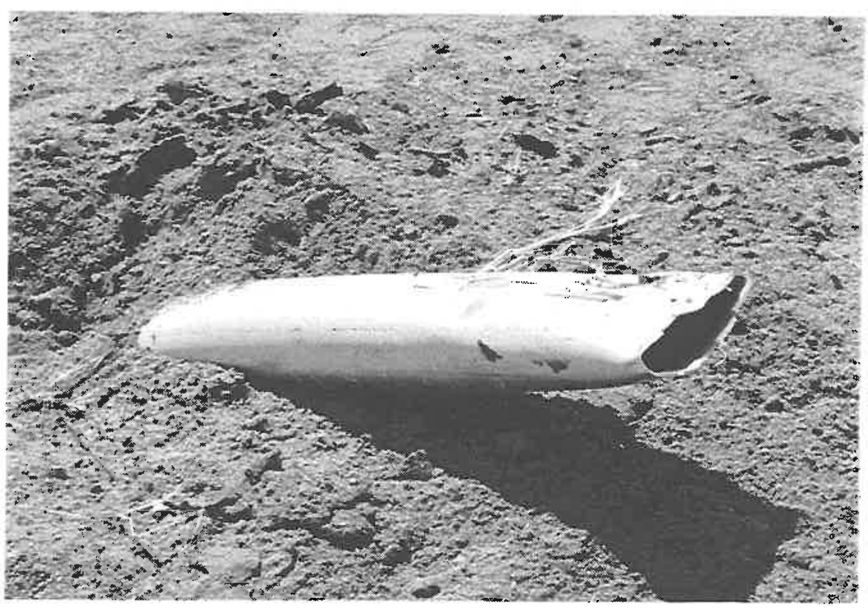
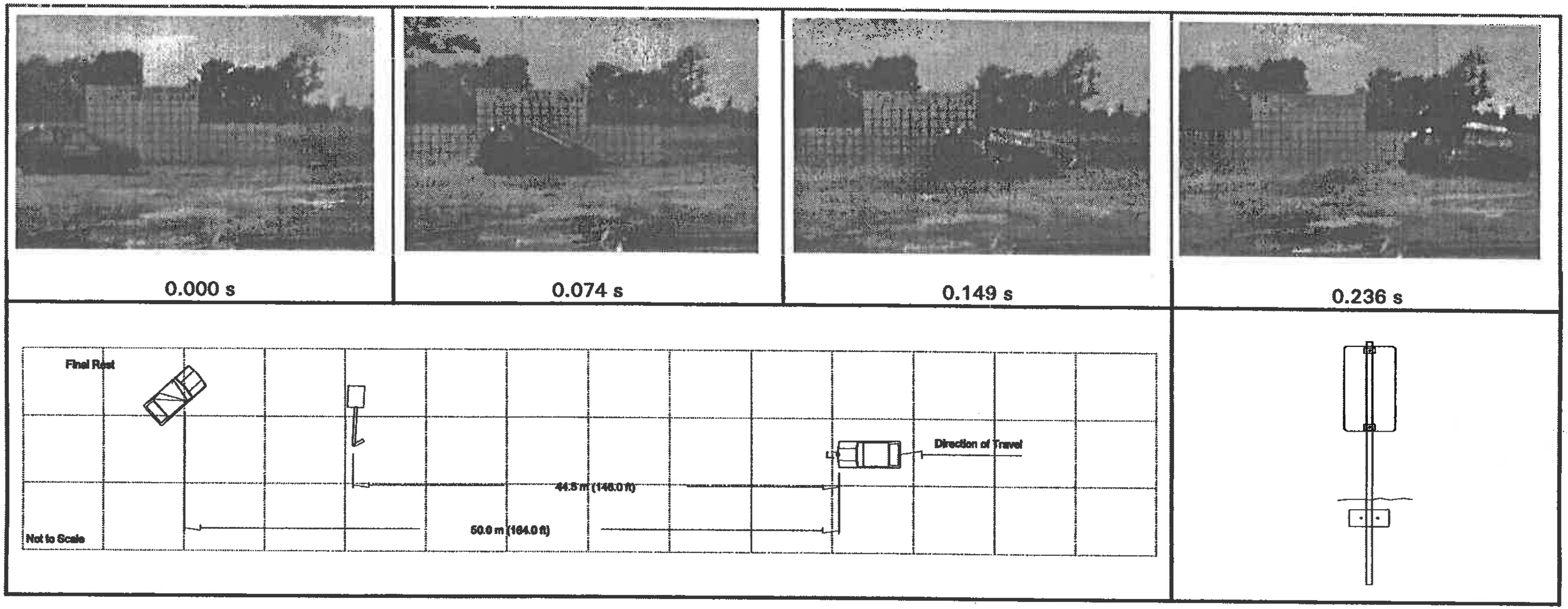


Figure 64 . Single 4 in. aluminum sign support installation anchored in weak soil after test 405231-9 (continued).

Figure 65 . Vehicle after test 405231-9.

vehicle occupant compartment. The occupant compartment was punctured by one of the bolts anchoring the sign panel to the support.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 2.3 m/s (7.7 ft/s) at 0.304 s, the highest 0.010-s average ridedown acceleration was 1.7 g between 0.798 and 0.808 s, and the maximum 0.050-s average acceleration was -4.1 g between 0.001 and 0.051 s. Lateral occupant impact velocity was -1.2 m/s (-4.0 ft/s) at 0.720 s, the highest 0.010-s occupant ridedown acceleration was 3.5 g between 0.796 and 0.806 s and the maximum 0.050-s average acceleration was 1.9 g between 0.780 and 0.830 s. These data and other pertinent information from the test are summarized in Figure 66. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 10.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-9
Date	09/19/94
Test Article	
Type	Single Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Ford Festiva
Mass (kg) Curb	810 (1786 lb)
Test Inertial	820 (1808 lb)
Dummy	77 (170 lb)
Gross Static	897 (1978 lb)

Impact Conditions	
Speed (km/h)	101.4 (63.0 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	88.4 (54.9 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.3 (7.7 ft/s)
y-direction	-1.2 (-4.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	1.7
y-direction	3.5
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-4.1
y-direction	1.9
z-direction	1.4

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1 & 12TDDW3
Interior	
OCDI	FS0100000
Maximum Exterior Vehicle Crush (mm)	40 (1.6 in)
Max. Occ. Compart. Deformation (mm)	110 (4.3 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-7.1
Max. Pitch Angle (deg)	-4.8
Max. Yaw Angle (deg)	45.2

Figure 66. Summary of results for test 405231-9.

Table 10. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-9

Test No.: 405231-9 Test Date: 09/19/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign support yielded by bending the aluminum tube at ground level and fracturing in tension near bumper level.	Pass
<u>Occupant Risk</u> D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign support fractured but **did not** present a hazard to other travel lanes. There was deformation of the front portion of the occupant compartment, but no actual intrusion into the compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral — Preferred: 3 — Maximum: 5	Longitudinal occupant impact velocity: 2.3 m/s (7.7 ft/s) Lateral occupant impact velocity: -1.2 m/s (-4.0 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral — Preferred: 15 — Maximum: 20	Longitudinal Occupant Ridedown Acceleration: 1.7 g's Lateral Occupant Ridedown Acceleration: 3.5 g's	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Occupant Impact Velocity Limits (m/s)

Component	Preferred	Maximum
Longitudinal and Lateral	3	5

Occupant Ridedown Acceleration Limits (G's)

Component	Preferred	Maximum
Longitudinal and Lateral	15	20

Dual 3.7 kg/m (2.5 lb/ft) steel U-channel supports anchored in strong soil - 35 km/h (21.8 mi/h)

- ***Test 405231-10***

A 1989 Ford Festiva, shown in Figures 67 and 68, was used for the crash test. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 897 kg (1,978 lb). The height to the lower edge of the vehicle bumper was 245 mm (9.6 in) and it was 540 mm (21.3 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A. The vehicle was directed into the dual 3.7 kg/m (2.5 lb/ft) steel U-channel sign installation anchored in strong soil, shown in Figure 69, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign installation with the centerline of the vehicle at a speed of 34.6 km/h (21.5 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to deflect rearward, allowing the vehicle to begin to climb upward. As the vehicle continued traveling forward, the left support fractured at 0.076 seconds. The front wheels of the vehicle lost contact with the ground at approximately 0.153 seconds. As the vehicle climbed the right support and left support stub, the connection between the support and upper right sign panel failed at 0.201 seconds and the lower connection failed very shortly thereafter. The vehicle traveled up and over the remaining left ground stub and the intact right sign support. The fronts wheel came back into contact with the ground at 0.574 seconds. As the vehicle continued moving over the supports, the rear of the vehicle began to climb the left support and shortly thereafter lost contact with the ground at 0.818 seconds. The vehicle was clear of the left support stub by 1.082 seconds and the right support by 3.082 seconds. The rear wheels were back in contact with the ground by 1.149 seconds. The vehicle came to rest approximately 6.1 m (20.0 ft) downstream from the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 70. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 71, the supports were bent and fractured. The left support failed 533 mm (21.0 in) from ground level and the right support remained intact. Damage sustained by the vehicle during this test is shown in Figure 72. The vehicle sustained only cosmetic damage to the bumper. The vehicle occupant compartment was not deformed.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation

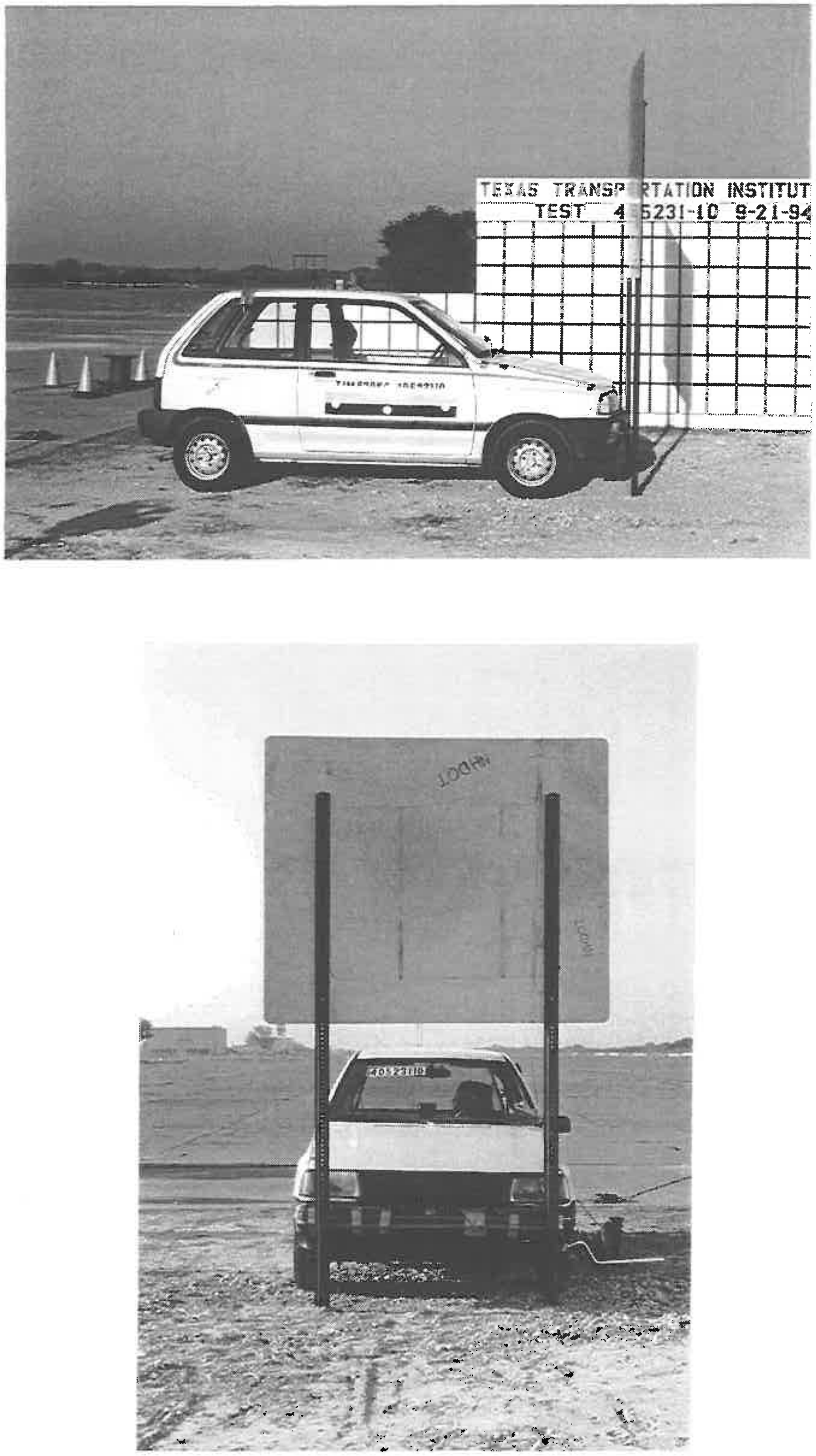


Figure 67 . Vehicle/sign geometrics for test 405231-10.

Figure 68 . Vehicle before test 405231-10.

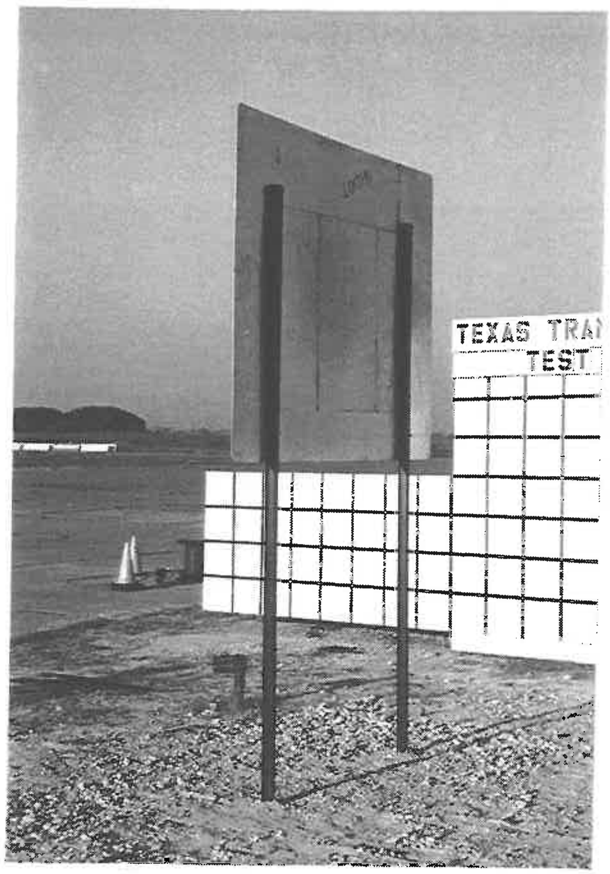


Figure 69. Dual 2-1/2 lb steel U-channel support installation anchored in strong soil before test 405231-10.

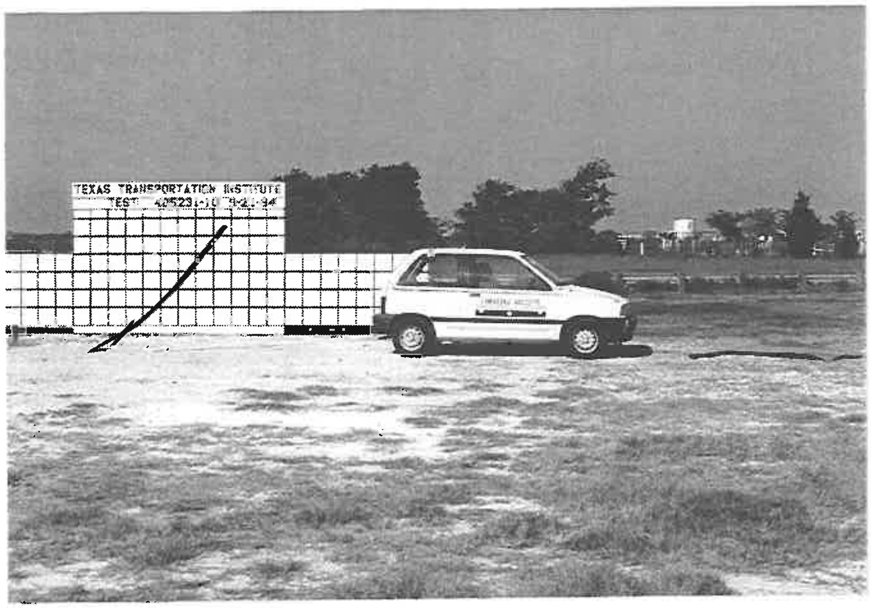


Figure 70 . Final rest position of the sign installation and vehicle (test 405231-10).

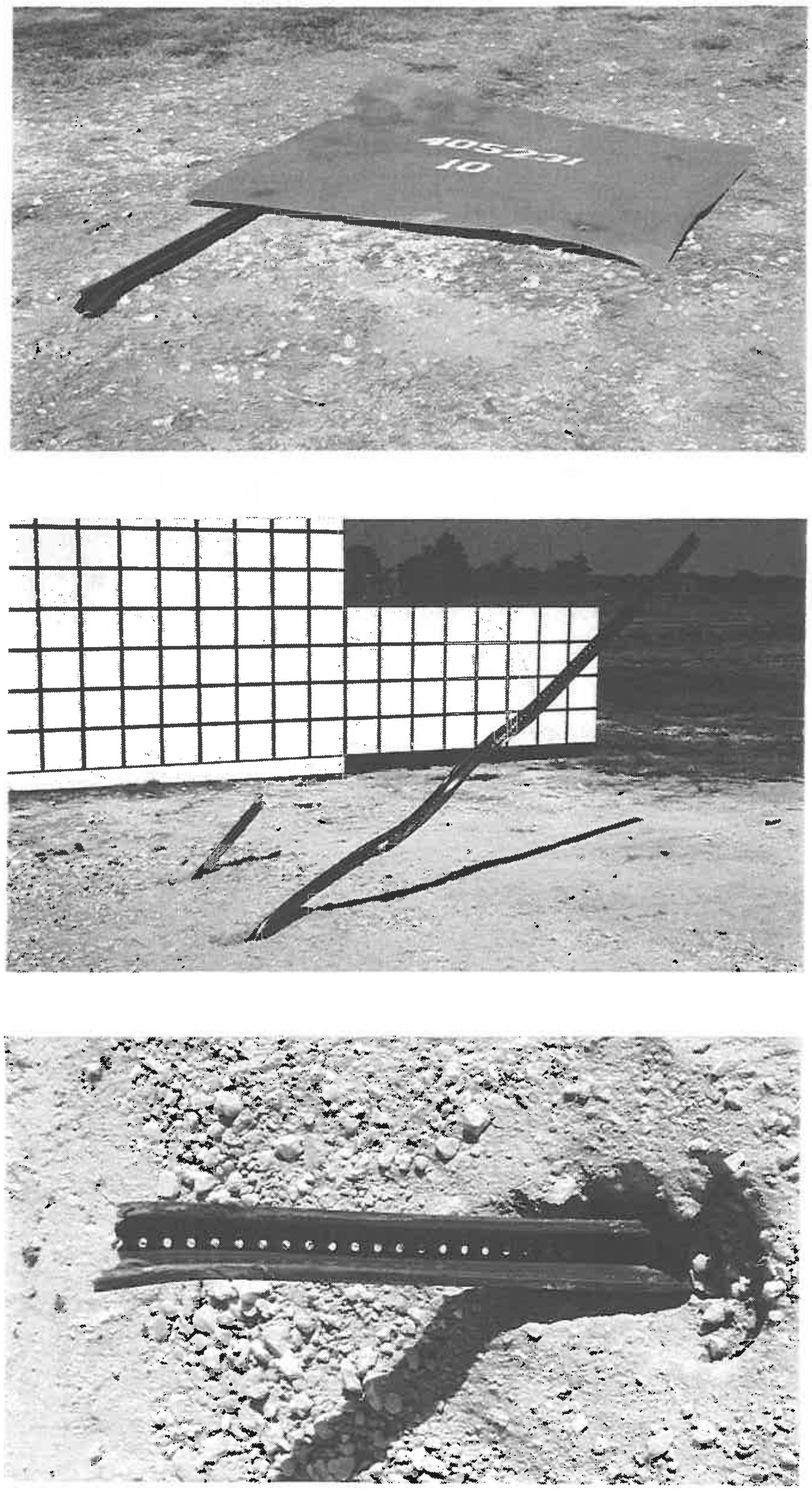
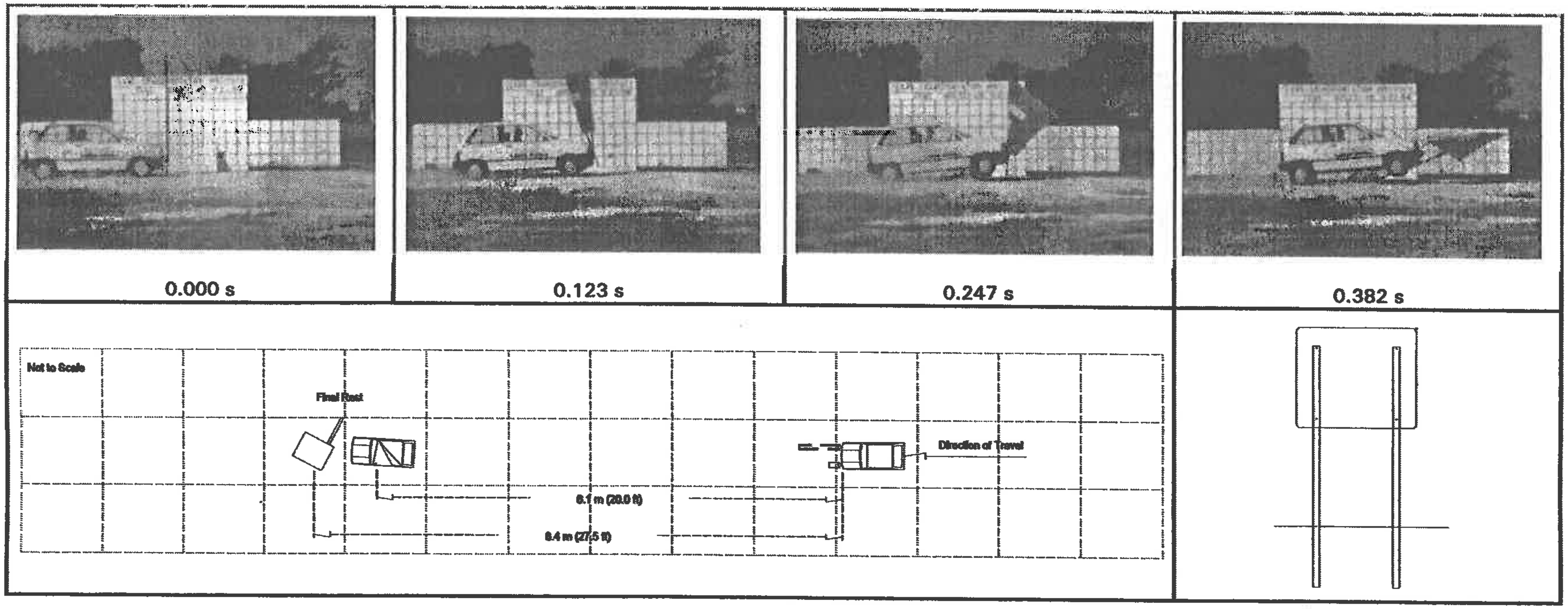


Figure 71. dual 2-1/2 lb steel U-channel support installation anchored in strong soil after test 405231-10.

Figure 72 . Vehicle after test 405231-10.

of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 4.2 m/s (13.8 ft/s) at 0.231 s, the highest 0.010-s average ridedown acceleration was -3.1 g between 0.232 and 0.242 s, and the maximum 0.050-s average acceleration was -3.1 g between 0.007 and 0.057 s. Lateral occupant impact velocity was -0.4 m/s (-1.4 ft/s) at 1.228 s, the highest 0.010-s occupant ridedown acceleration was -1.6 g between 0.251 and 0.261 s and the maximum 0.050-s average acceleration was 0.6 g between 0.142 and 0.192 s. These data and other pertinent information from the test are summarized in Figure 73. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 11.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-10
Date	09/21/94
Test Article	
Type	Dual Steel U-channel
Key Element	2.5 lb/ft U-channel
Height to Bottom of Sign Panel (m)	1.5 (5.0 ft)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	832 (1834 lb)
Test Inertial	820 (1808 lb)
Dummy	77 (170 lb)
Gross Static	897 (1978 lb)

Impact Conditions	
Speed (km/h)	34.6 (21.5 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	4.0 (2.5 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.2 (13.8 ft/s)
y-direction	-0.4 (-1.4 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-3.1
y-direction	-1.6
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.1
y-direction	0.6
z-direction	-1.4

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	5.3
Max. Pitch Angle (deg)	6.3
Max. Yaw Angle (deg)	6.0

Figure 73 . Summary of results for test 405231-10.

Table 11. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-10

Test No.: 405231-10 | Test Date: 09/21/94 | Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The left sign support yielded by bending the steel U-channel at ground level and fracturing near bumper level. The right support was bent at ground level, but did not fracture.	Pass
<u>Occupant Risk</u> D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports yielded and **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 3 / 5	Longitudinal occupant impact velocity: 4.2 m/s (13.8 ft/s) Lateral occupant impact velocity: -0.4 m/s (-1.4 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: -3.1 g's Lateral Occupant Ridedown Acceleration: -1.6 g's	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Dual 3.7 kg/m (2.5 lb/ft) steel U-channel supports anchored in strong soil - 100 km/h (62.2 mi/h)

- **Test 405231-11**

The same 1989 Ford Festiva used in test 405231-10, shown in Figures 74 and 75, was reused for this crash test. The vehicle was directed into the dual 3.7 kg/m (2.5 lb/ft) steel U-channel sign installation anchored in strong soil, shown in Figure 76, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign installation with the centerline of the vehicle at a speed of 97.2 km/h (60.4 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to bend at ground level and pocket around the front of the vehicle. The sign panel struck the roof of the vehicle at 0.072 seconds. The sign panel struck the roof with a force sufficient to deform the roof and A-pillars and break the windshield. At some indeterminable time, the supports were completely pulled from the ground. The sign installation remained wrapped around the front of the vehicle as it exited. The brakes were applied and the vehicle came to rest out of view of the high-speed camera. The vehicle came to final rest upright 61.3 m (201.0 ft) downstream and 16.6 m (54.5 ft) right of the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 77. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 78, the supports were bent and twisted. The supports pulled completely from the ground without fracturing. The sign support and sign panel came to rest just ahead of the vehicle. Damage sustained by the vehicle during this test is shown in Figure 79. The vehicle sustained moderate roof, hood, windshield and bumper damage. Maximum vertical crush to the roof was 180 mm (7.1 in). Maximum deformation to the front of the vehicle at the impact point was 105 mm (4.1 in). There was deformation, but no intrusion into the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 4.4 m/s (14.5 ft/s) at 0.186 s, the highest 0.010-s average ridedown acceleration was -1.1 g between 0.556 and 0.566 s, and the maximum 0.050-s average acceleration was -6.6 g between 0.005 and 0.055 s. Lateral occupant impact velocity was -1.5 m/s (-4.9 ft/s) at 0.691

Figure 74 . Vehicle/sign geometrics for test 405231-11.

Figure 75 . Vehicle before test 405231-11.

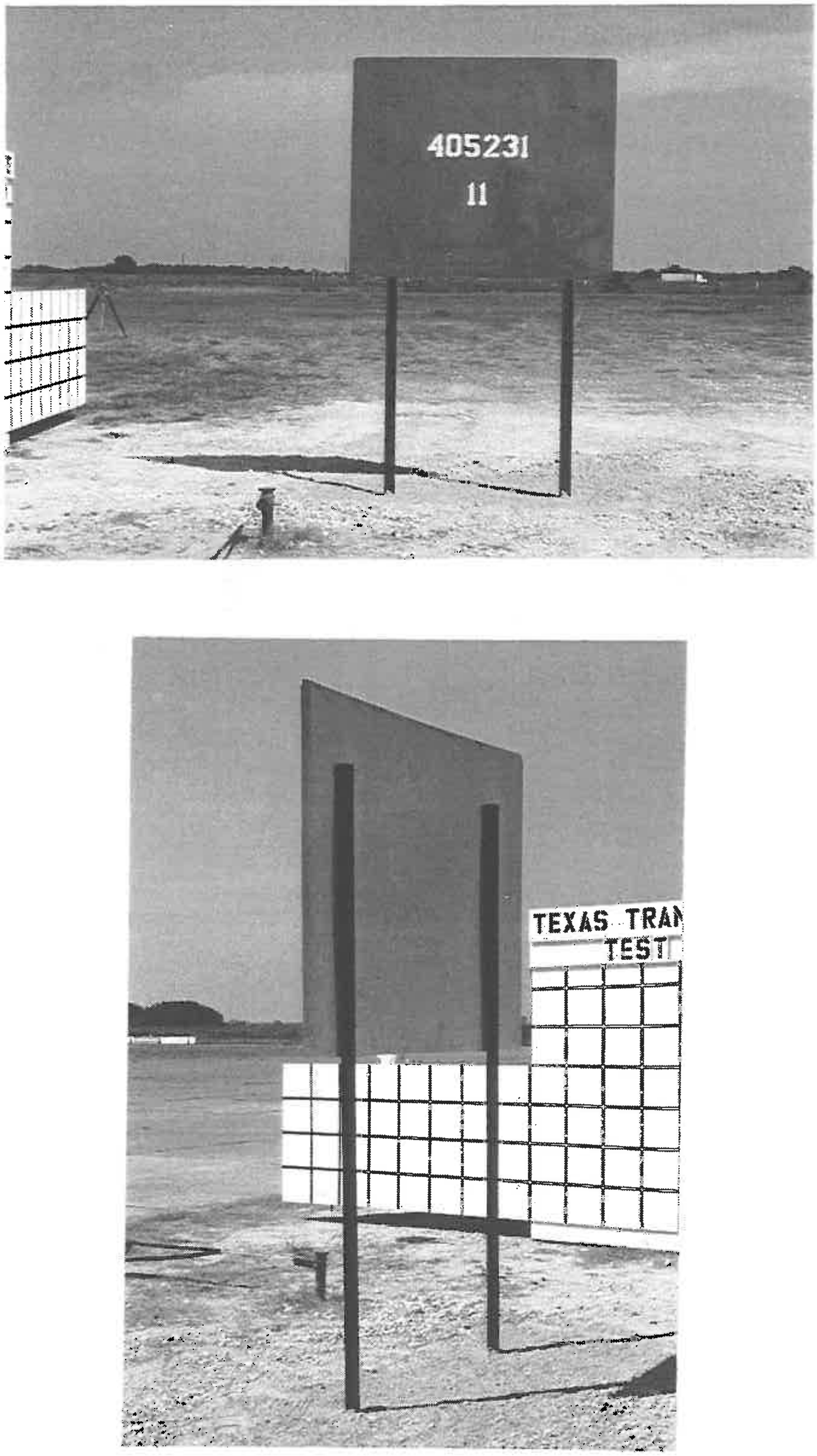


Figure 76. Dual 2-1/2 lb steel U-channel support installation anchored in strong soil before test 405231-11.

Figure 77. Final rest position of the sign installation and vehicle (test 405231-11).

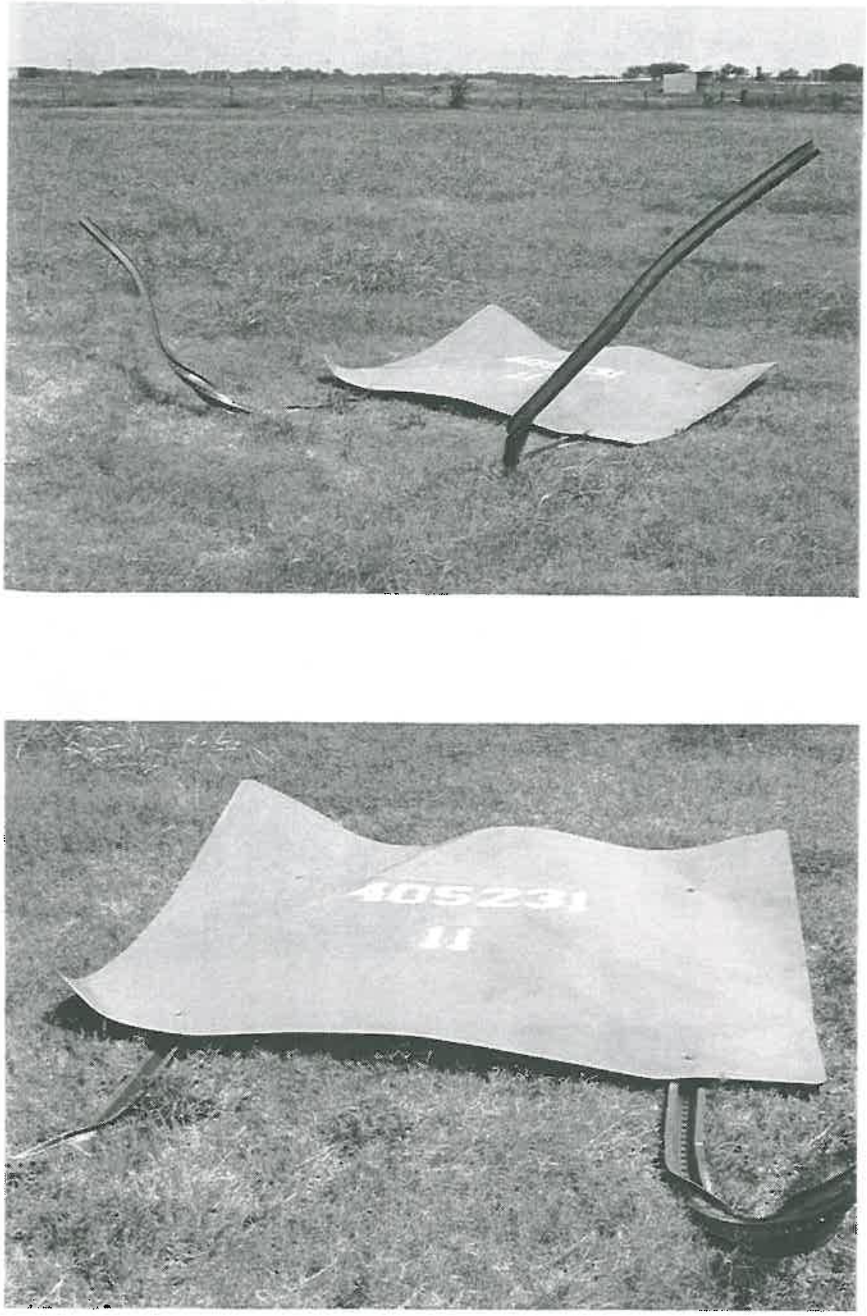
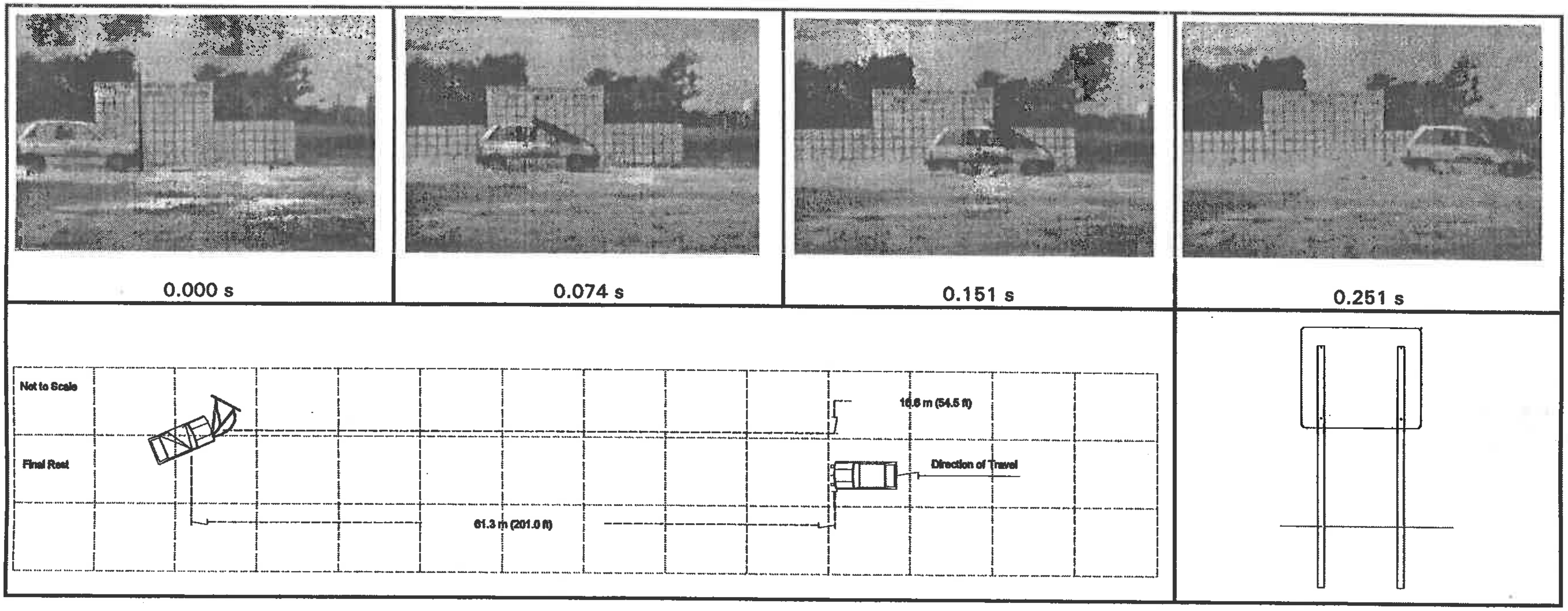


Figure 78. Dual 2-1/2 lb steel U-channel support installation anchored in strong soil after test 405231-11.

Figure 79 . Vehicle after test 405231-11.

s, the highest 0.010-s occupant ridedown acceleration was 1.5 g between 0.735 and 0.745 s and the maximum 0.050-s average acceleration was 0.8 g between 0.819 and 0.869 s. These data and other pertinent information from the test are summarized in Figure 80. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 12.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-11
Date	09/21/94
Test Article	
Type	Dual Steel U-channel
Key Element	2.5 lb/ft U-channel
Height to Bottom of Sign Panel (m)	1.5 (5.0 ft)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	832 (1834 lb)
Test Inertial	820 (1808 lb)
Dummy	77 (170 lb)
Gross Static	897 (1978 lb)

Impact Conditions	
Speed (km/h)	97.2 (60.4 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	83.6 (51.9 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.4 (14.5 ft/s)
y-direction	-1.5 (-4.9 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.1
y-direction	1.5
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-6.6
y-direction	0.8
z-direction	-1.9

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1 & 12TDDN3
Interior	
OCDI	FS0100000
Maximum Exterior Vehicle Crush (mm)	105.0 (4.1 in)
Max. Occ. Compart. Deformation (mm)	180.0 (7.1 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	3.9
Max. Pitch Angle (deg)	3.9
Max. Yaw Angle (deg)	17.7

Figure 80. Summary of results for test 405231-11.

Table 12. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-11

Test No.: 405231-11 | Test Date: 09/21/94 | Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports yielded by bending the steel U-channel at ground level and fracturing near the bumper level.	Pass
Occupant Risk		
D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was deformation of the front portion of the occupant compartment, but no actual intrusion into the compartment	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral; Preferred: 3; Maximum: 5	Longitudinal occupant impact velocity: 4.4 m/s (14.5 ft/s) Lateral occupant impact velocity: -1.5 m/s (-4.9 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral; Preferred: 15; Maximum: 20	Longitudinal Occupant Ridedown Acceleration: -1.1 g's Lateral Occupant Ridedown Acceleration: 1.5 g's	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Dual 3.7 kg/m (2.5 lb/ft) steel U-channel supports anchored in weak soil - 35 km/h (21.8 mi/h)

- ***Test 405231-12***

A 1989 Yugo GVL, shown in Figures 81 and 82, was used for the crash test. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 896 kg (1,975 lb). The height to the lower edge of the vehicle bumper was 370 mm (14.6 in) and it was 510 mm (20.1 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A. The vehicle was directed into the dual 3.7 kg/m (2.5 lb/ft) steel U-channel sign installation anchored in weak soil, shown in Figure 83, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign installation with the centerline of the vehicle at a speed of 34.6 km/h (21.5 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the right support began to deflect outward, losing contact with the bumper. Thereafter, the right support scraped along the right front fender. The left support deformed and was pulled downward until the sign panel came into contact with the hood of the vehicle. As the left support was pulled down, the right support was pulled firmly into the right fender. The lower edge of the sign panel struck the hood at approximately 0.276 seconds. As the vehicle became snared under the sign panel at approximately 0.330 seconds, the right and left support began pulling from the ground. The vehicle, while still in contact with the supports, lost contact with the sign panel at 0.608 seconds. Contact with the supports was lost very shortly thereafter and the vehicle came to rest atop the installation near the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 84. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 85, the supports were bent and pulled up from the ground. The left support was completely pulled from the ground while 18 mm (0.7 in) of the right support remained in the ground. Damage sustained by the vehicle during this test is shown in Figure 86. The vehicle sustained 100.0 mm (3.9 in) of crush to the bumper. In addition, the right front fender and hood were dented and scraped. There was no deformation to the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation

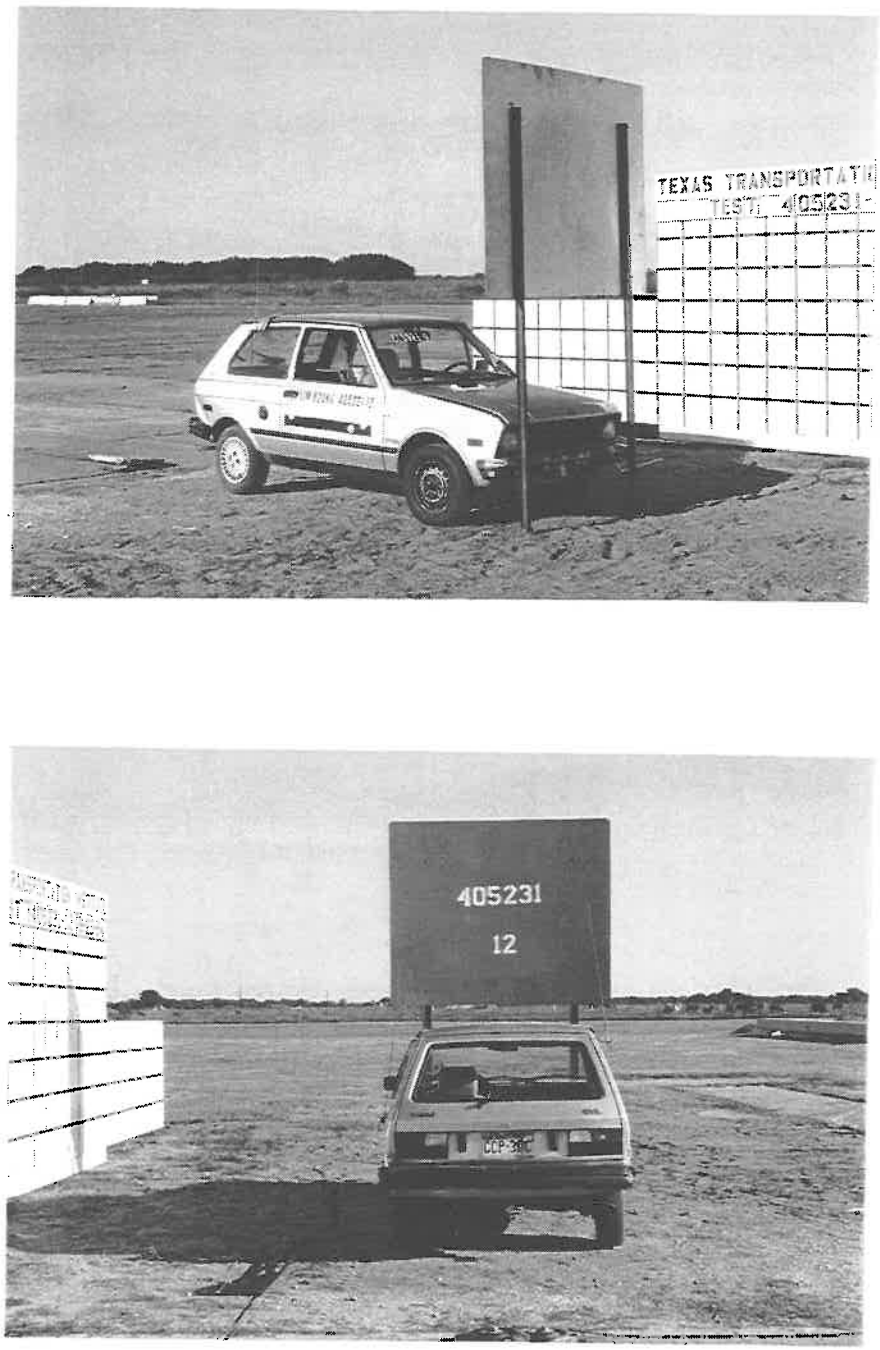


Figure 81 . Vehicle/sign geometrics for test 405231-12.

Figure 82 . Vehicle before test 405231-12.

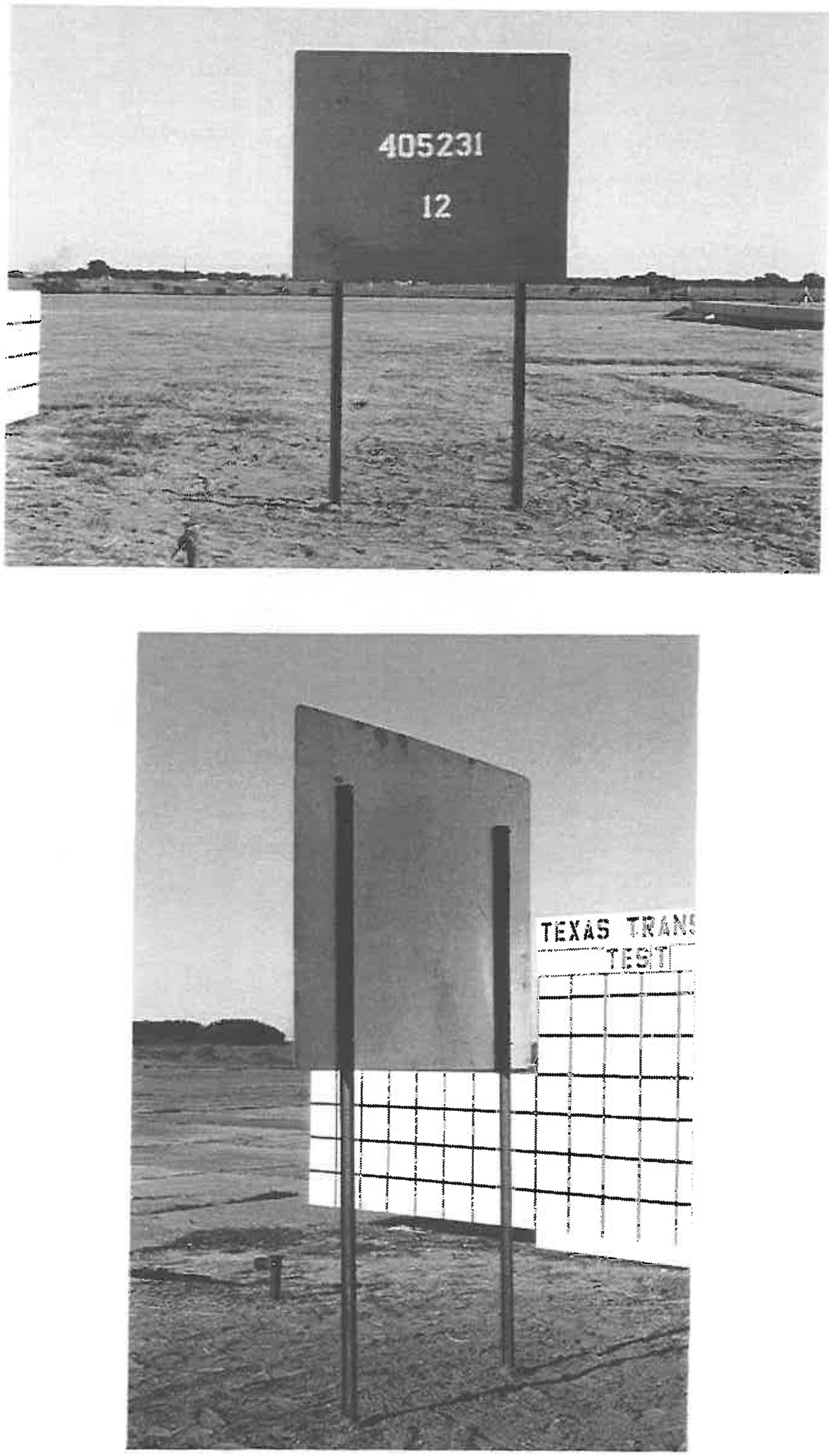


Figure 83. Dual 2-1/2 lb steel U-channel support installation anchored in weak soil before test 405231-12.

Figure 84 . Final rest position of the sign installation and vehicle (test 405231-12).

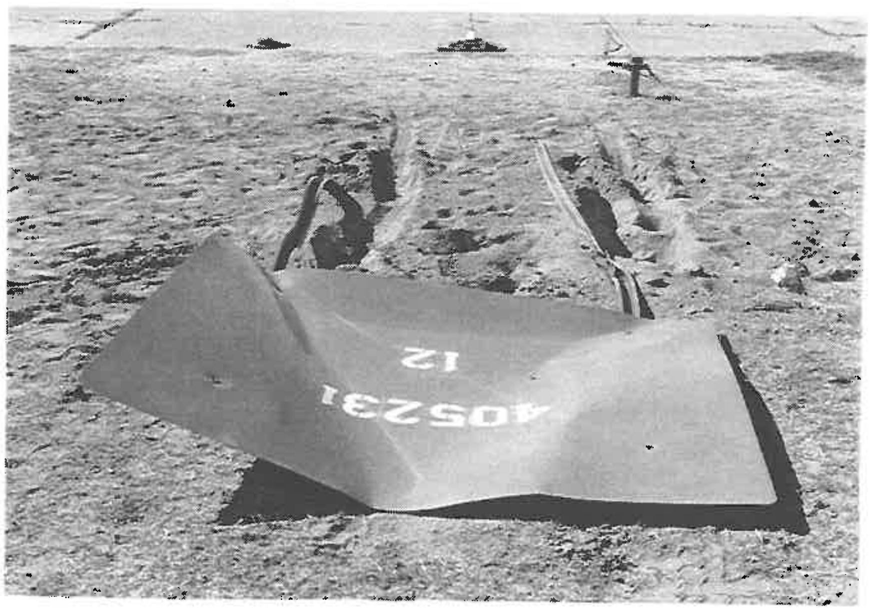


Figure 85. Dual 2-1/2 lb steel U-channel support installation anchored in weak soil after test 405231-12.

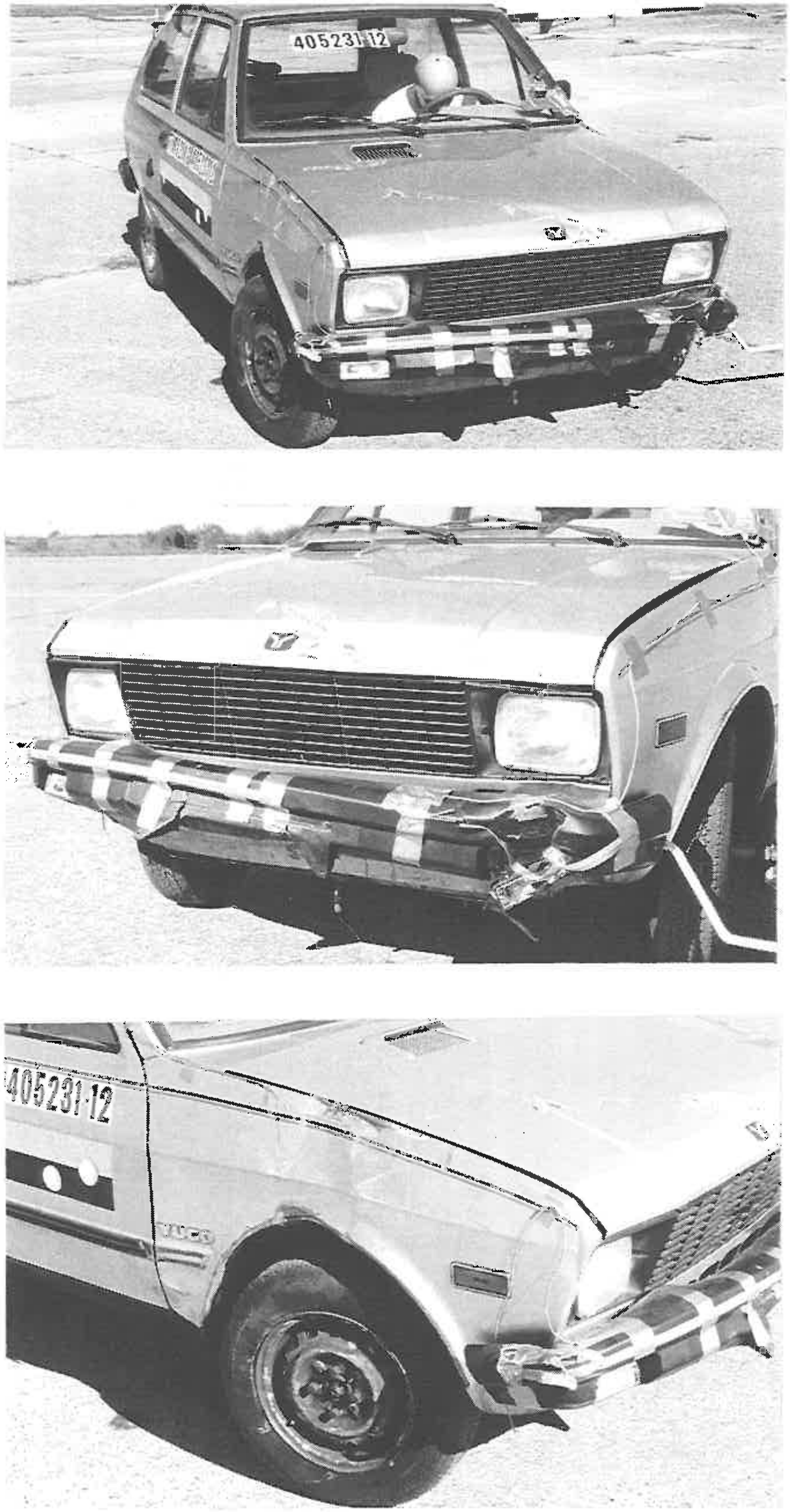
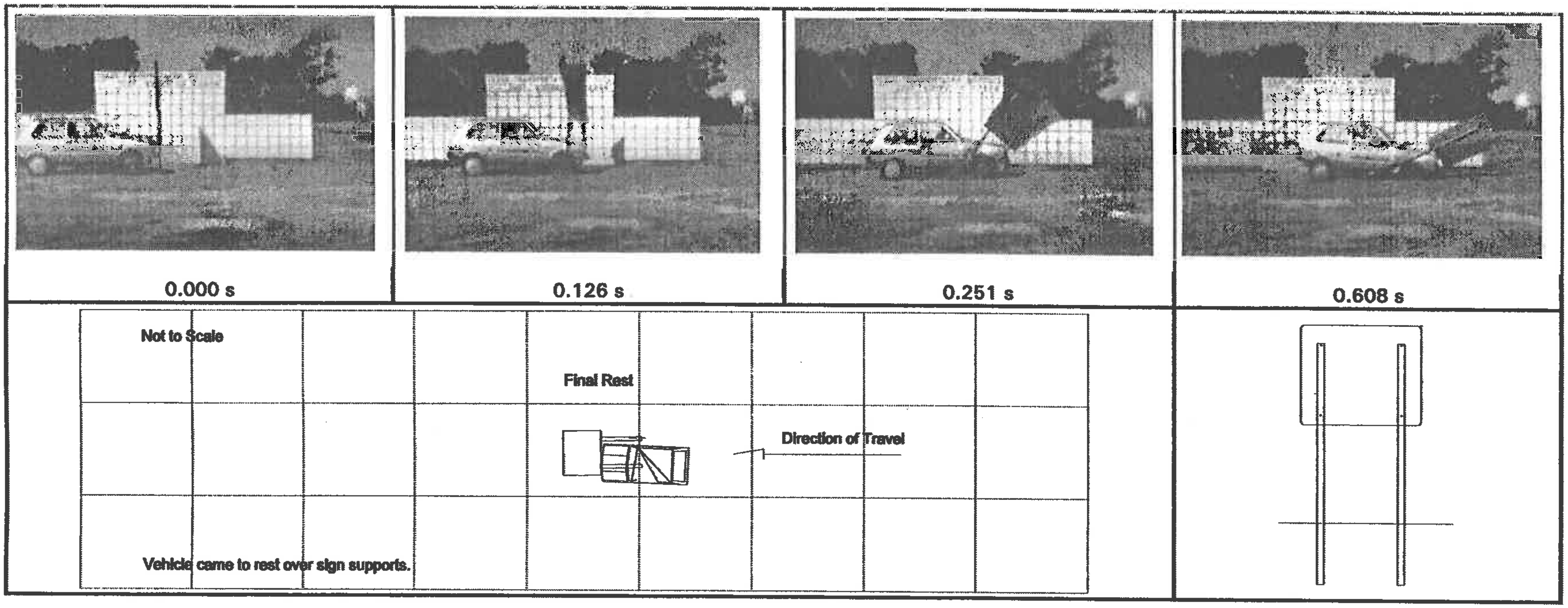


Figure 86 . Vehicle after test 405231-12.

of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 4.4 m/s (14.5 ft/s) at 0.244 s, the highest 0.010-s average ridedown acceleration was -1.8 g between 0.278 and 0.288 s, and the maximum 0.050-s average acceleration was -2.8 g between 0.060 and 0.110 s. There was no occupant contact in the lateral direction. The maximum 0.050-s average acceleration in the lateral direction was -1.1 g between 0.122 and 0.172 s. These data and other pertinent information from the test are summarized in Figure 87. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 13.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-12
Date	09/23/94
Test Article	
Type	Dual Steel U-channel
Key Element	2.5 lb/ft U-channel
Height to Bottom of Sign Panel (m)	1.5 (5.0 ft)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Yugo GVL
Mass (kg) Curb	798 (1759 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	34.6 (21.5 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	N.A.
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.4 (14.5 ft/s)
y-direction	N/A
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.8
y-direction	No Contact
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-2.8
y-direction	-1.1
z-direction	1.1

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	100 (3.9 in)
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	4.5
Max. Pitch Angle (deg)	-11.0
Max. Yaw Angle (deg)	5.9

Figure 87. Summary of results for test 405231-12.

Table 13. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-12

Test No.: 405231-12 Test Date: 09/23/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports yielded by bending the steel U-channel at ground level.	Pass
Occupant Risk D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports yielded and **did not** present a hazard to other travel lanes. There was **no** deformation or intrusion into the compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 3 / 5	Longitudinal occupant impact velocity: 4.4 m/s (14.5 ft/s) Lateral occupant impact velocity: N/A	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: -1.8 g's Lateral Occupant Ridedown Acceleration: No Contact	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Dual 3.7 kg/m (2.5 lb/ft) steel U-channel supports anchored in weak soil - 100 km/h (62.2 mi/h)

- **Test 405231-13**

The same 1989 Yugo GVL used in test 405231-12 shown in Figures 88 and 89, was reused for this crash test. The vehicle was directed into the dual 3.7 kg/m (2.5 lb/ft) steel U-channel sign installation anchored in weak soil, shown in Figure 90, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign installation with the centerline of the vehicle at a speed of 99.8 km/h (62.0 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to bend at ground level and at the vehicle's hood. The right support fractured at 0.029 seconds and the left support at 0.034 seconds. The sign panel rotated over the hood striking the roof of the vehicle at 0.076 seconds. The sign panel and attached support fragments remained atop the roof/windshield area of the vehicle as the vehicle cleared the ground stubs at 0.143 seconds. The vehicle was traveling 91.1 km/h (56.6 mi/h) after the supports fractured. The vehicle exited, the brakes were applied and the vehicle came to rest out of view of the high-speed camera. The vehicle came to final rest upright 80.8 m (265.0 ft) downstream and 1.5 m (5.0 ft) right of the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 91. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 92, the supports were fractured and bent. The right support fractured 977 mm (38.5 in) from ground level and the left support 840 mm (33.1 in) from ground level. The right sign support and the sign panel came to rest 75.6 m (248.0 ft) down and 2.7 m (9.0 ft) to the right of the point of impact. The upper portion of the left support, detached from the sign panel, came to rest 72.6 m (238.0 ft) from the point of impact and inline with the sign panel. Damage sustained by the vehicle during this test is shown in Figure 93. The vehicle sustained minor damage to the roof and hood. The windshield was broken and the bumper required replacement. Maximum vertical crush to the roof was 20 mm (0.8 in). Maximum deformation to the front of the vehicle at the impact point was 90 mm (3.5 in). There was deformation, but no intrusion into the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation

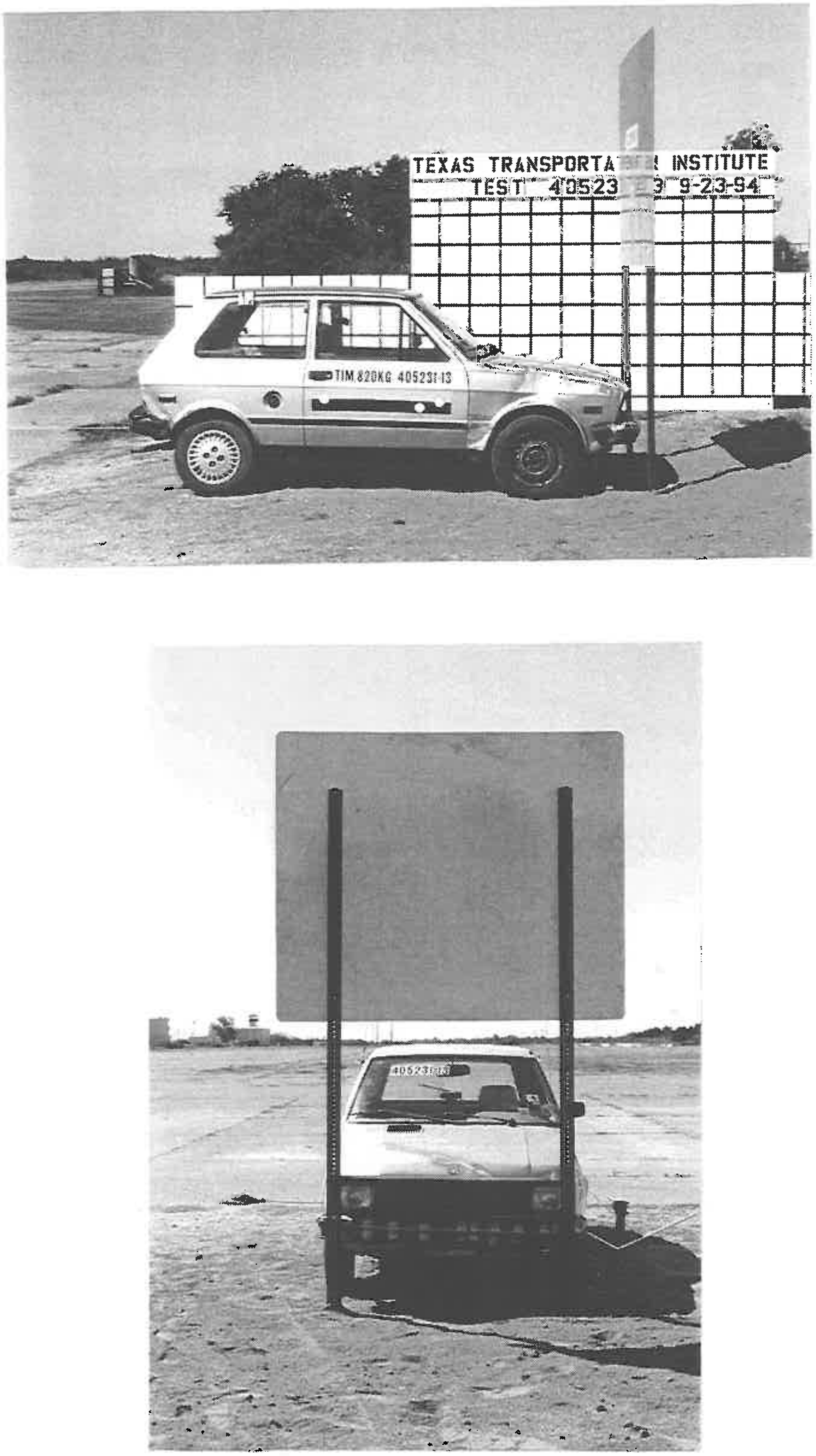
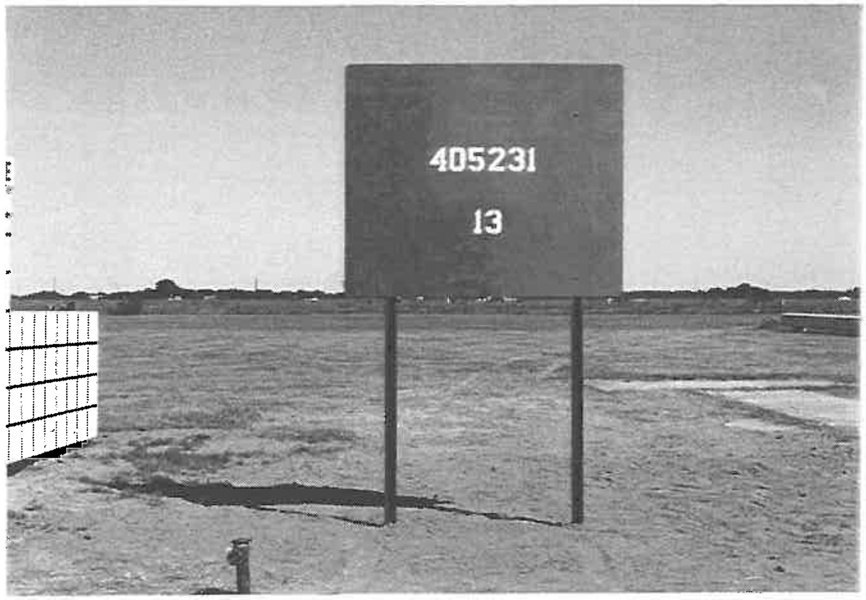


Figure 88 . Vehicle/sign geometrics for test 405231-13.

Figure 89 . Vehicle before test 405231-13.



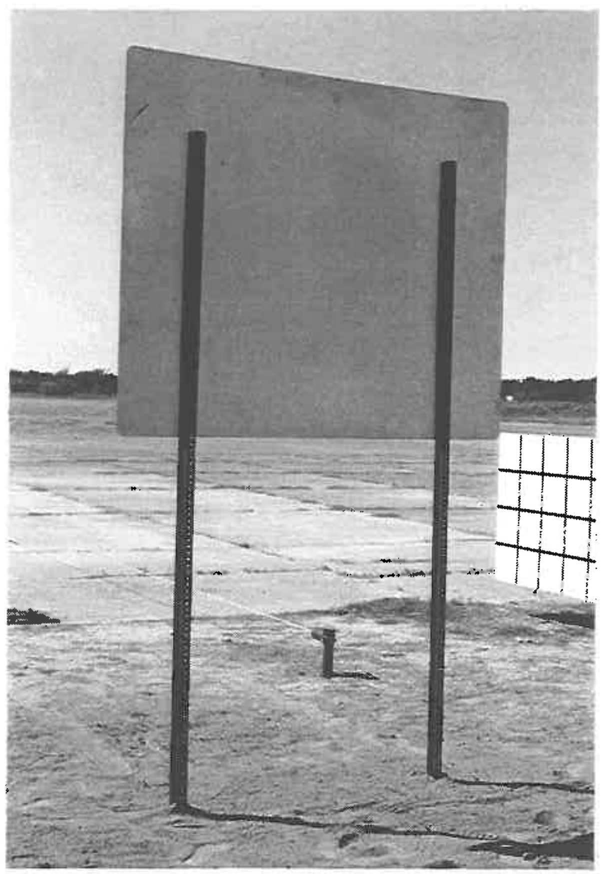


Figure 90. Dual 2-1/2 lb steel U-channel support installation anchored in weak soil before test 405231-13.

Figure 91 . Final rest position of the sign installation and vehicle (test 405231-13).

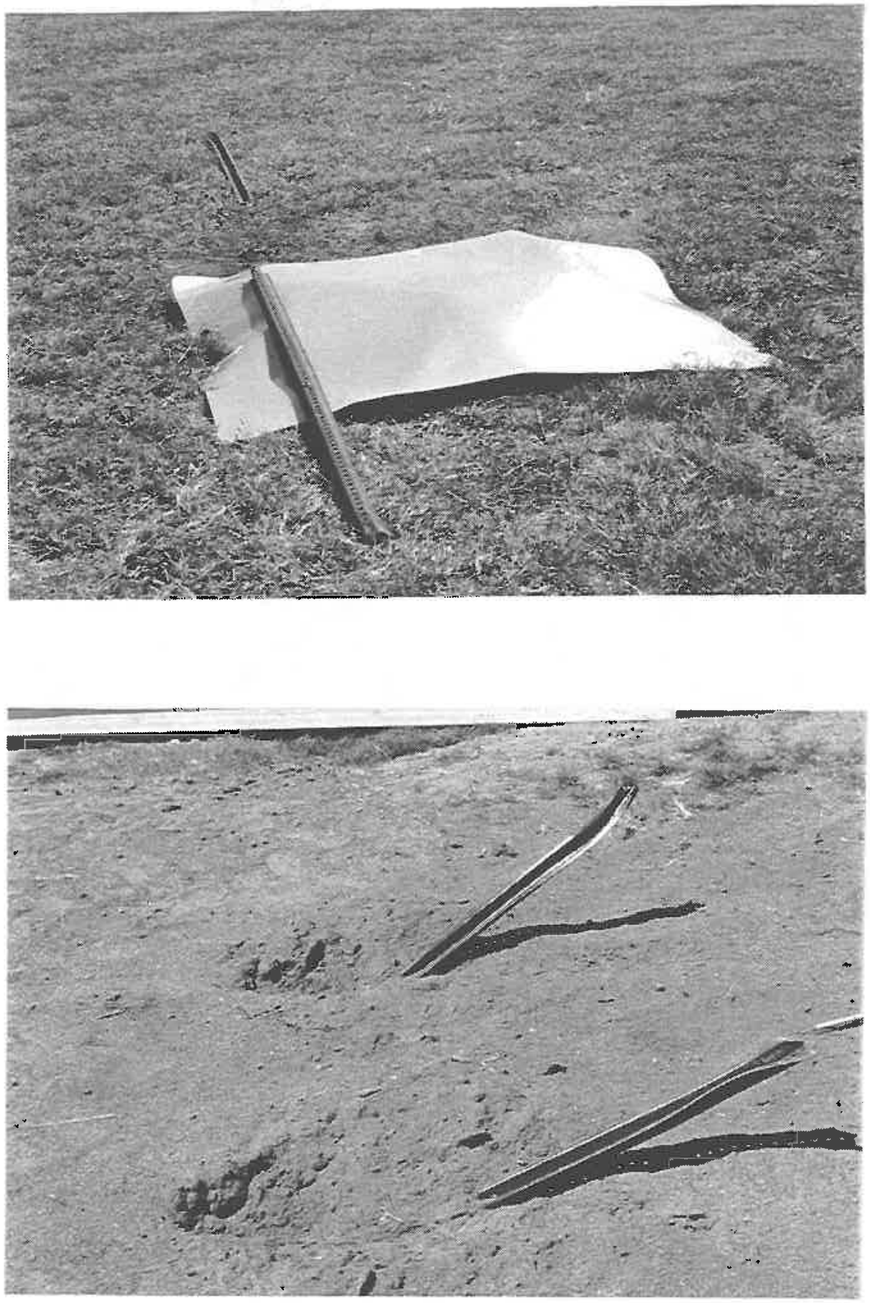
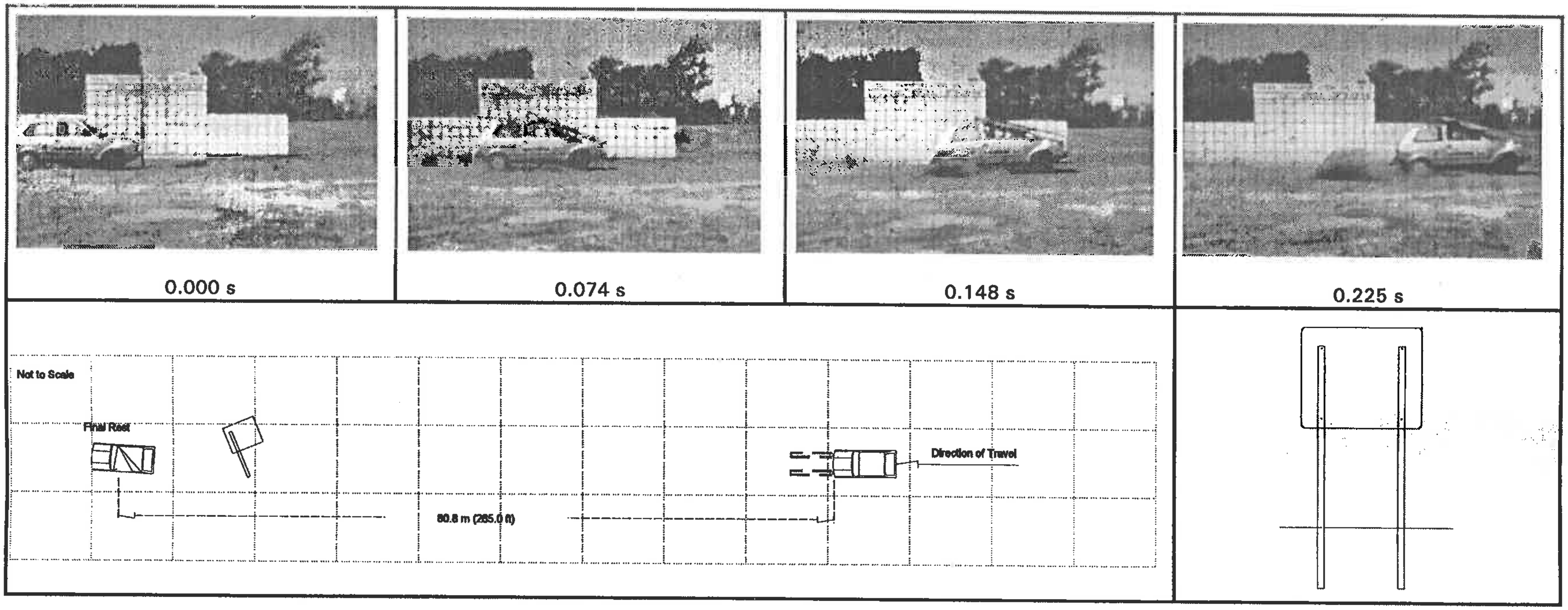


Figure 92. Dual 2-1/2 lb steel U-channel support installation anchored in weak soil after test 405231-13.

Figure 93 . Vehicle after test 405231-13.

of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 3.0 m/s (9.7 ft/s) at 0.265 s, the highest 0.010-s average ridedown acceleration was -0.5 g between 0.302 and 0.312 s, and the maximum 0.050-s average acceleration was -3.9 g between 0.005 and 0.055 s. Lateral occupant impact velocity was 0.8 m/s (2.7 ft/s) at 0.925 s, the highest 0.010-s occupant ridedown acceleration was 1.8 g between 1.796 and 1.806 s and the maximum 0.050-s average acceleration was -0.8 g between 0.122 and 0.172 s. These data and other pertinent information from the test are summarized in Figure 94. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 14.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-13
Date	09/23/94
Test Article	
Type	Dual Steel U-channel
Key Element	2.5 lb/ft U-channel
Height to Bottom of Sign Panel (m)	1.5 (5.0 ft)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Yugo GVL
Mass (kg) Curb	798 (1759 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	99.8 (62.0 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	91.1 (56.6 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.0 (9.7 ft/s)
y-direction	0.8 (2.7 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.5
y-direction	1.8
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.9
y-direction	-0.8
z-direction	2.7

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1 & 12TDDN1
Interior	
OCDI	FS0100000
Maximum Exterior Vehicle Crush (mm)	90.0 (3.5 in)
Max. Occ. Compart. Deformation (mm)	20.0 (0.7 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	3.5
Max. Pitch Angle (deg)	6.3
Max. Yaw Angle (deg)	-4.0

Figure 94. Summary of results for test 405231-13.

Table 14. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-13

Test No.: 405231-13 | Test Date: 09/23/94 | Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports yielded by bending the steel U-channel at ground level and fracturing near the bumper level.	Pass
Occupant Risk		
D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was deformation of the front portion of the occupant compartment, but no actual intrusion into the compartment	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 3 / 5	Longitudinal occupant impact velocity: 3.0 m/s (9.7 ft/s) Lateral occupant impact velocity: 0.8 m/s (2.7 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: -0.5 g's Lateral Occupant Ridedown Acceleration: 1.8 g's	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Modified Dual 102 mm (4 in) diameter aluminum supports anchored in strong soil - 35 km/h (21.8 mi/h)

- ***Test 405231-14 & 15***

Following the failure of the 35 km/h (21.8 mi/h) test involving the dual 102 mm (4.0 in) diameter dual aluminum sign support installation anchored in strong soil (test no. 405231-5), the Department acknowledged the need for a suitable retrofit for supports of this type already installed in the field. Two developmental tests (405231-14 & 15) were performed to evaluate the impact performance of the 102 mm (4.0 in) diameter supports when modified by reducing the cross-sectional area by placing four (4) holes through the supports. These modifications are illustrated in Figures 95 and 96.

Both the 25 mm (1.0 in) and 32 mm (1.25 in) diameter holes, test 405231-14 and 15 respectively, proved unsuccessful in full-scale crash testing. The results of these two tests are given in Table 26 and warrant no further discussion. However, a successful retrofit was found utilizing a 38 mm (1.5 in) diameter hole. This test is discussed in the section that follows.

Modified Dual 102 mm (4 in) diameter aluminum supports anchored in strong soil - 35 km/h (21.8 mi/h)

- ***Test 405231-16***

The same 1988 Subaru Justy, shown in Figures 95 and 96, was used for the crash test (Figures 97 and 98). The vehicle was directed into the dual 102 mm (4.0 in) diameter aluminum support sign installation anchored in strong soil, shown in Figure 99, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The sign supports were modified by drilling two 38 mm (1.5 in) holes in each support (in the vehicle travel direction) at ground level and two additional 38 mm (1.5 in) holes 457 mm (18.0 in) up from ground level in each support (perpendicular to the vehicle travel direction). The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 36.9 km/h (22.9 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to bend at bumper height and ground level. The supports began to fracture at bumper height at approximately 0.032

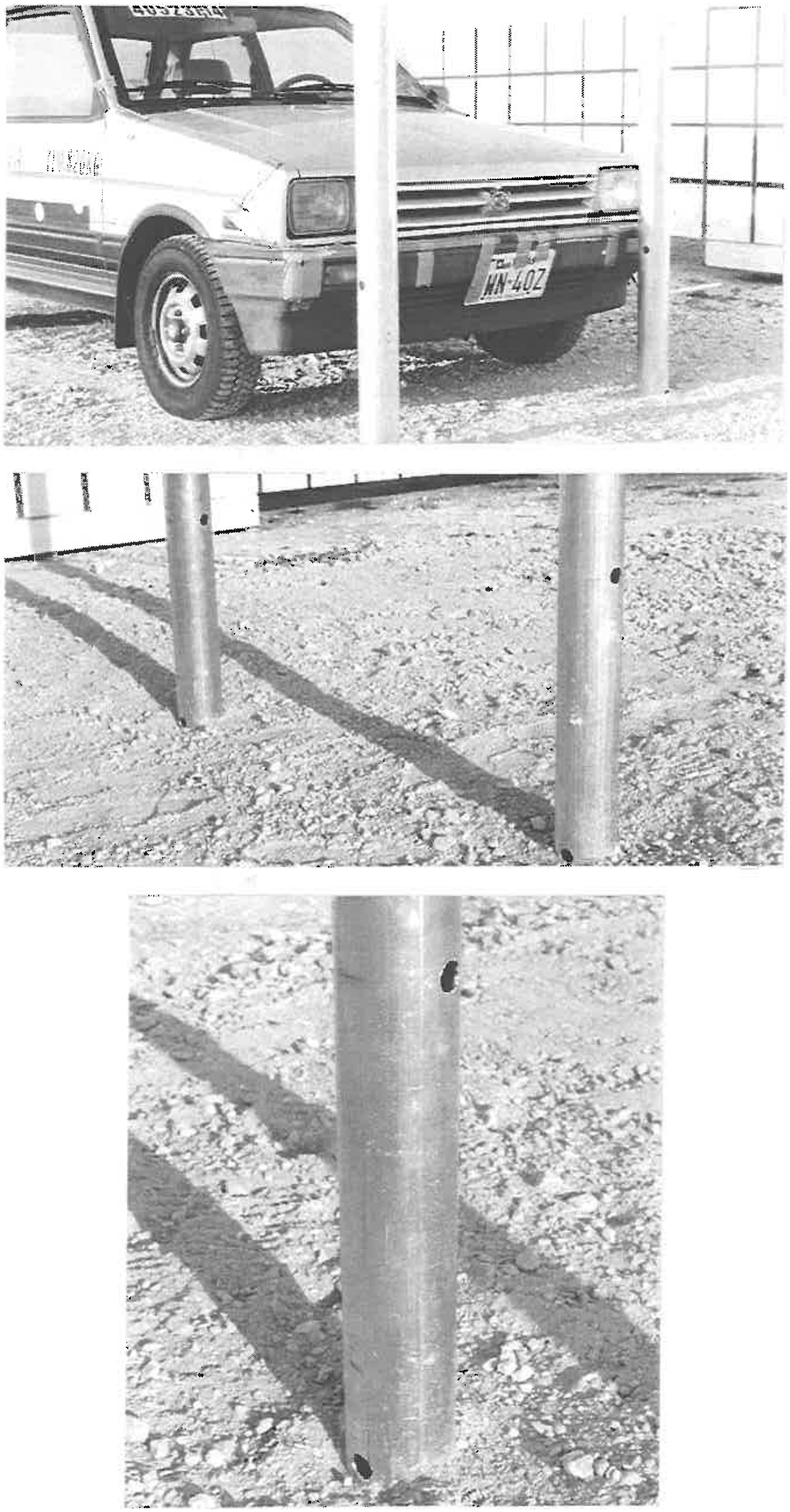


Figure 95 . Dual 4 in. aluminum sign support installation modified with four - 1.0 in. holes and anchored in strong soil (test 405231-14).

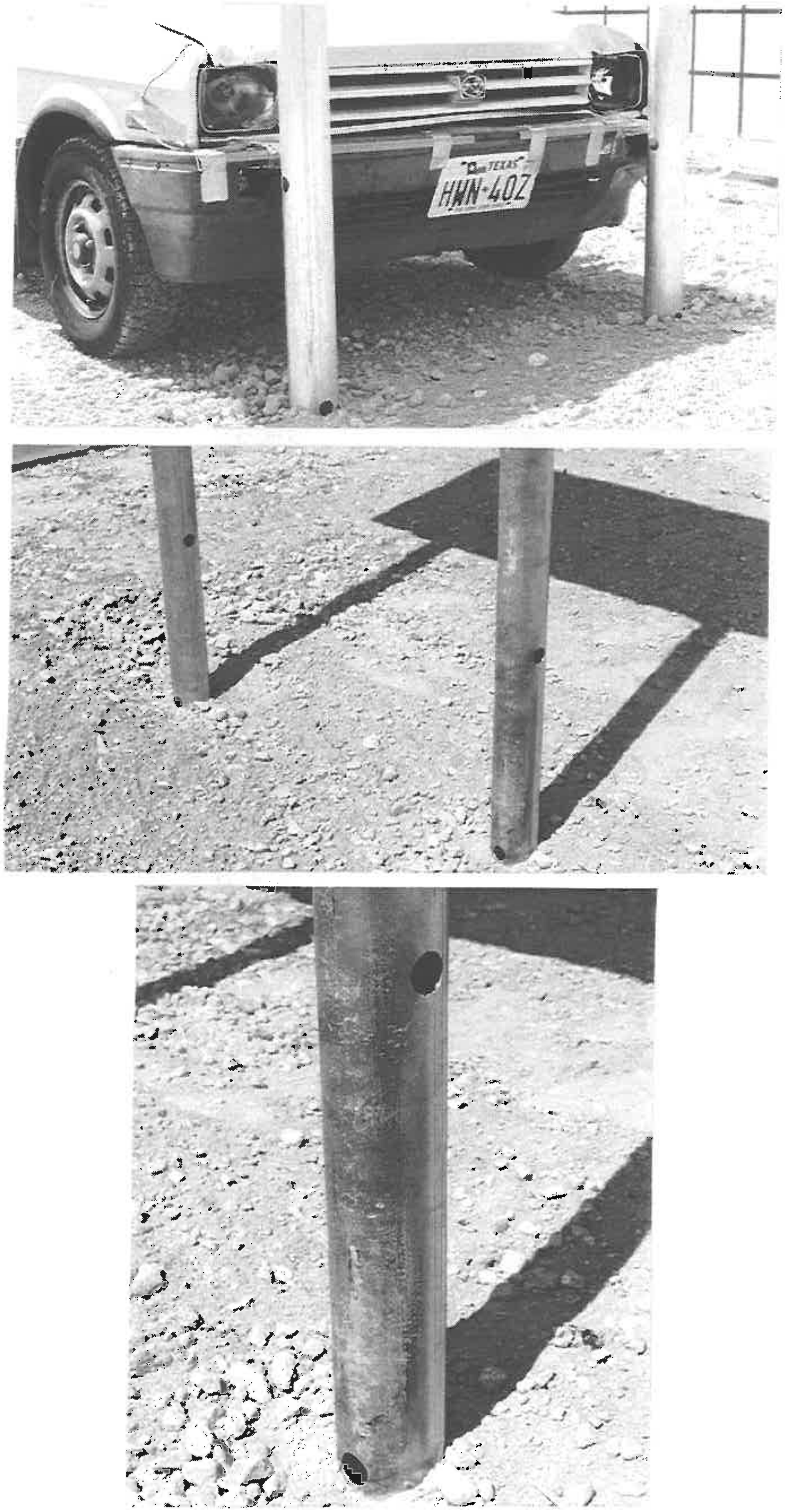
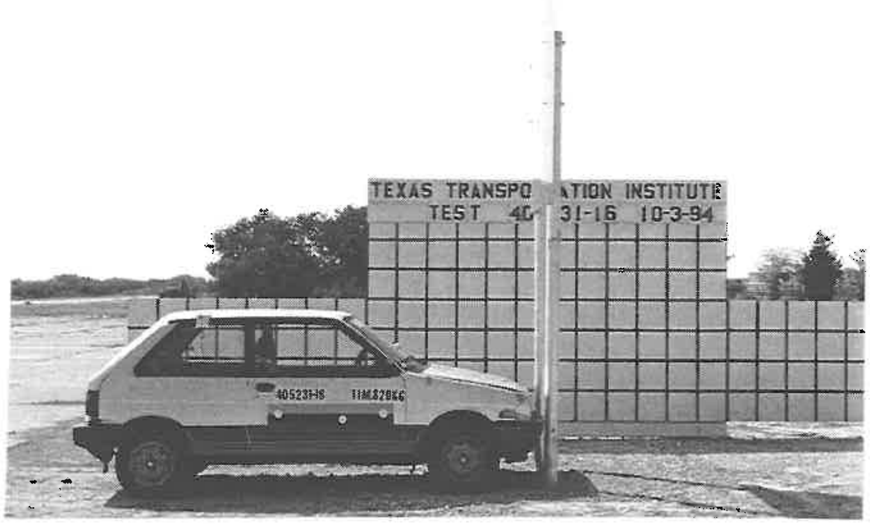


Figure 96 . Dual 4 in. aluminum sign support installation modified with four - 1.25 in. holes and anchored in strong soil (test 405231-15).



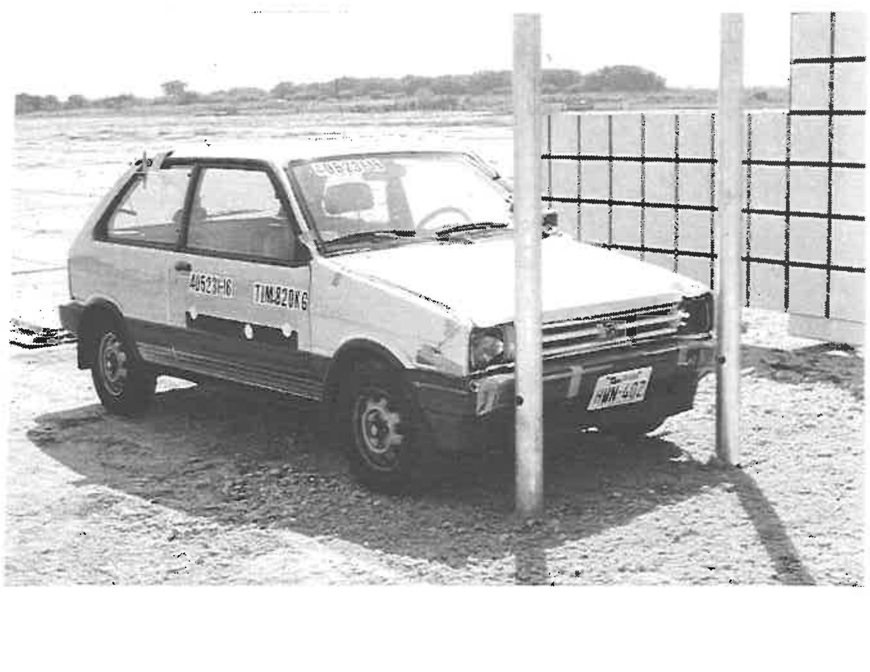


Figure 97 . Vehicle/sign installation geometrics for test 405231-16.

Figure 98 . Vehicle before test 405231-16.

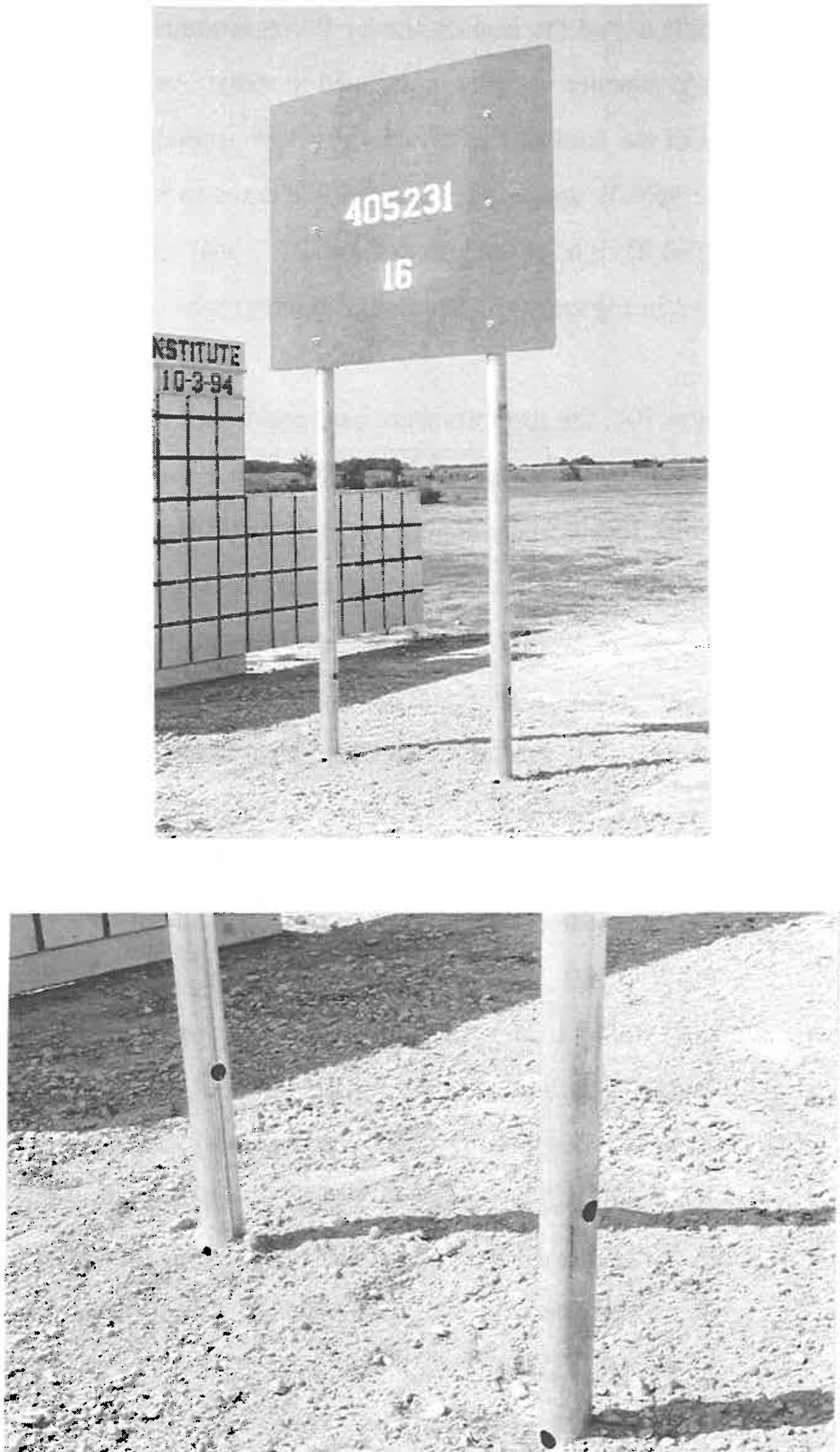


Figure 99 . Dual 4 in. aluminum sign support installation modified with four - 1.5 in. holes and anchored in strong soil (test 405231-16).

seconds. As the vehicle continued traveling forward, the supports fractured at ground level at 0.060 second. The vehicle exited the impact site by 0.409 seconds traveling 30.4 km/h (18.9 mi/h). The sign panel and attached supports continued to rotate over the vehicle. The sign panel struck the front portion of the roof of the vehicle at 0.925 seconds. The sign installation was displaced away from the vehicle upon exit. The vehicle came to rest upright 33.5 m (110.0 ft) downstream and 1.8 m (6.0 ft) right of the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 100. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 101, the supports were bent and fractured. The left and right supports failed their entire cross-sections at the holes located at ground level. In addition, both supports were collapsed at the holes located near bumper height. The sign panel and all mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. Damage sustained by the vehicle during this test is shown in Figure 102. The vehicle sustained minor damage to the bumper, hood and windshield. Maximum deformation to the vehicle was 60 mm (2.4 in), located at the leading edge of the hood directly above the headlights. There was no deformation to the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 2.1 m/s (6.8 ft/s) at 0.347 s, the highest 0.010-s average ridedown acceleration was -0.6 g between 0.936 and 0.946 s, and the maximum 0.050-s average acceleration was -2.8 g between 0.011 and 0.061 s. Lateral occupant impact velocity was -0.7 m/s (-2.2 ft/s) at 0.900 s, the highest 0.010-s occupant ridedown acceleration was 0.3 g between 0.792 and 0.802 s and the maximum 0.050-s average acceleration was 0.3 g between 0.015 and 0.065 s. These data and other pertinent information from the test are summarized in Figure 103. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 15.

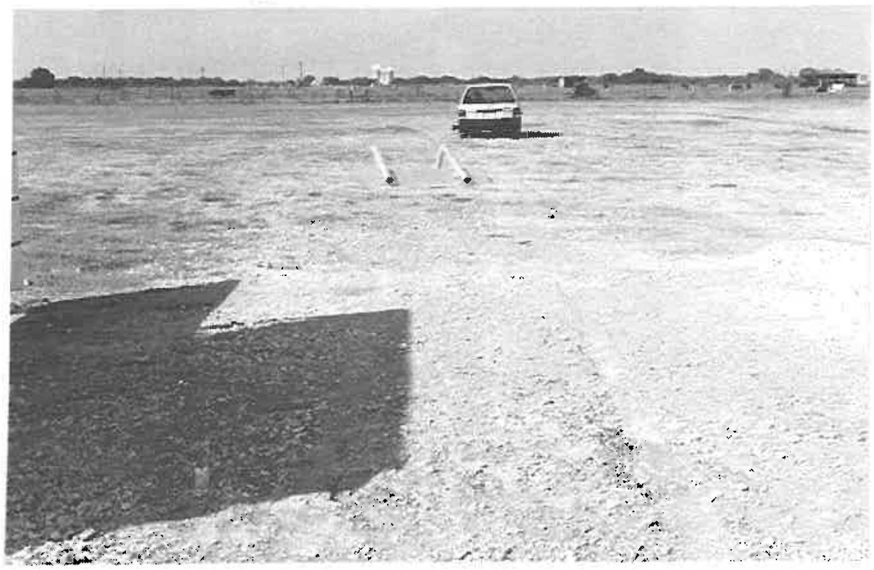


Figure 100. Final rest position of the sign installation and vehicle (test 405231-16).

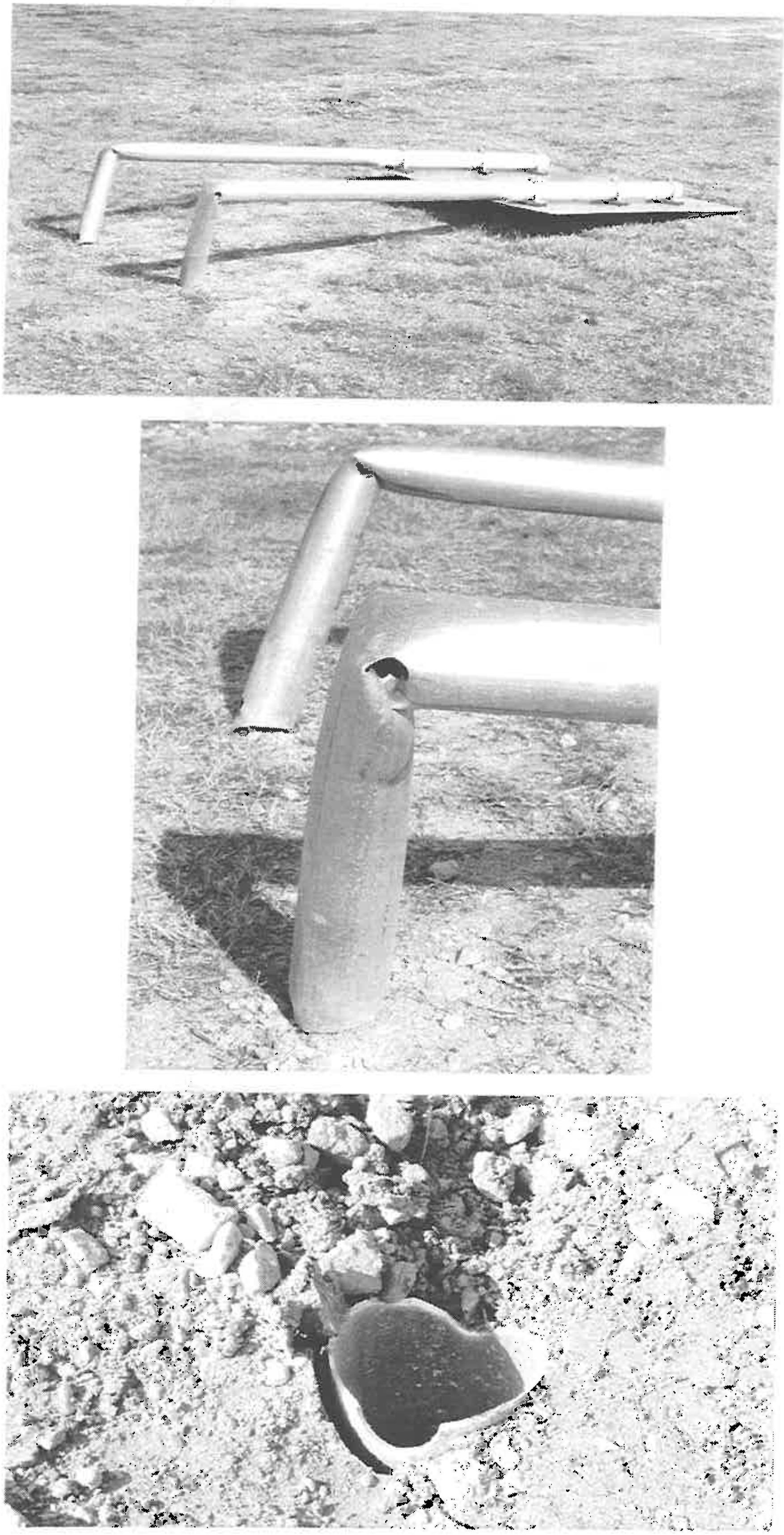
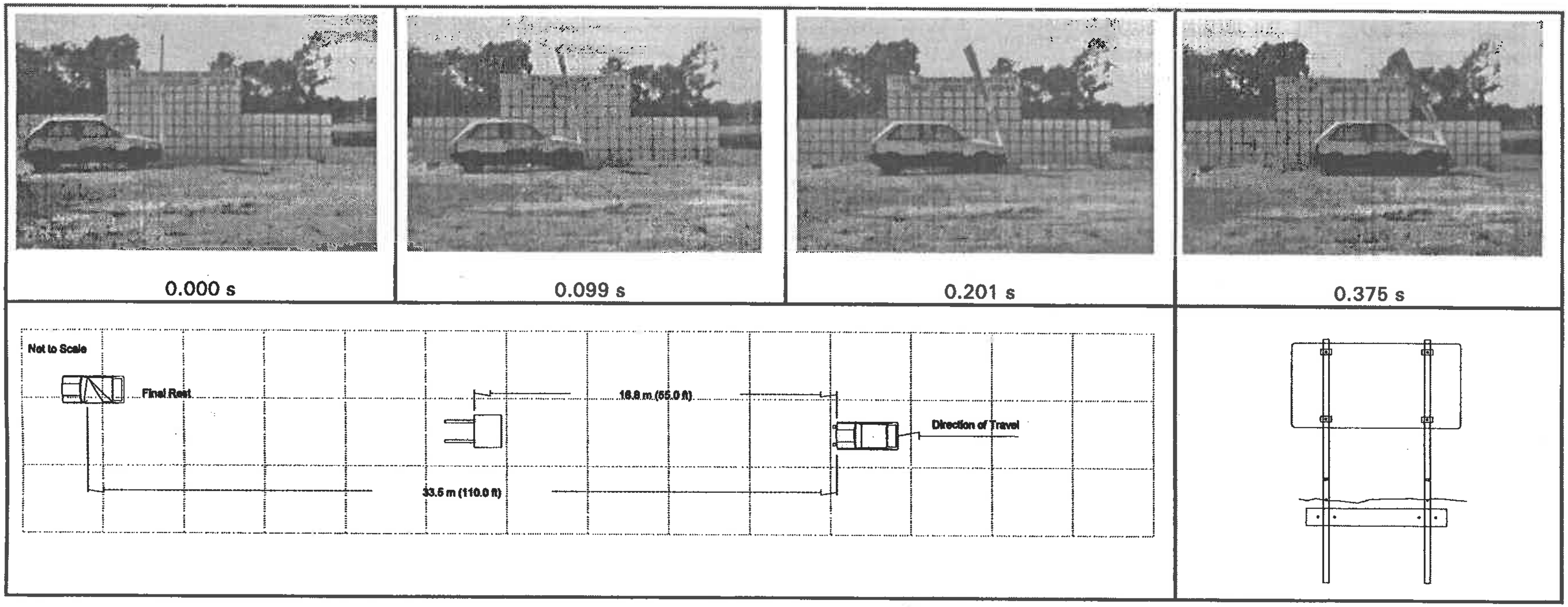


Figure 101. Dual 4 in. aluminum sign support installation modified with four - 1.5 in. holes and anchored in strong soil after test 405231-16.

Figure 102. Vehicle after test 405231-16.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-16
Date	10/03/94
Test Article	
Type	Modified Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Subaru Justy GL
Mass (kg) Curb	760 (1676 lb)
Test Inertial	820 (1808 lb)
Dummy	77 (170 lb)
Gross Static	897 (1978 lb)

Impact Conditions	
Speed (km/h)	36.9 (22.9 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	30.4 (18.9 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.1 (6.8 ft/s)
y-direction	-0.7 (-2.2 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.6
y-direction	0.3
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-2.8
y-direction	0.3
z-direction	1.0

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	60.0 (2.4 in)
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	3.0
Max. Pitch Angle (deg)	-10.3
Max. Yaw Angle (deg)	1.7

Figure 103. Summary of results for test 405231-16.

Table 15. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-16

Test No.: 405231-16 Test Date: 10/03/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	Both the right and left sign supports yielded by fracturing the aluminum tubes at the holes located at ground level and also by bending at the holes located near bumper level.	Pass
Occupant Risk		
D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports yielded and **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 3 / 5	Longitudinal occupant impact velocity: 2.1 m/s (6.8 ft/s) Lateral occupant impact velocity: -0.7 m/s (-2.2 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: - 0.6 g's Lateral Occupant Ridedown Acceleration: 0.3 g's	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Modified Dual 102 mm (4 in) diameter aluminum supports anchored in strong soil - 100 km/h (62.2 mi/h)

- **Test 405231-17**

The same 1988 Subaru Justy used in test 405231-16, shown in Figures 104 and 105, was reused for this crash test. The vehicle was directed into the dual 102 mm (4.0 in) diameter aluminum support sign installation anchored in strong soil, shown in Figure 106, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The sign supports were modified by drilling two 38 mm (1.5 in) holes in each support (in the vehicle travel direction) at ground level and two additional 38 mm (1.5 in) holes 457 mm (18.0 in) up from ground level in each support (perdendicular to the vehicle travel direction). The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 99.2 km/h (61.7 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to bend at ground level and deform at bumper height. As the vehicle continued traveling forward, the right support fractured at ground level at 0.015 seconds and the left support fractured at 0.017 seconds. The vehicle lost contact with the supports at 0.064 seconds as the sign installation rotated up and over the vehicle. As the sign supports struck the ground at approximately 0.493 seconds, the splice weld made to construct the left support failed. The vehicle exited the impact site traveling 93.8 km/h (58.3 mi/h), the brakes were applied and the vehicle came to final rest upright 117.4 m (385.0 ft) downstream and 5.5 m (18.0 ft) left of the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 107. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 108, the supports were bent and fractured. Both supports failed at the holes located at ground level. The supports however bent 88.9 mm (3.5 in) below the upper holes. The sign panel and mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. It should be noted, the left support was fabricated from two pieces of tubing by welding the sections together. In addition, the fabricated support failed at the weld when the support impacted the ground after the test and not due to the initial vehicle impact. The sign installation came to rest 7.6 m (25.0 ft) from the point of impact. Damage sustained by the vehicle during this test is shown in Figure 109. The vehicle sustained

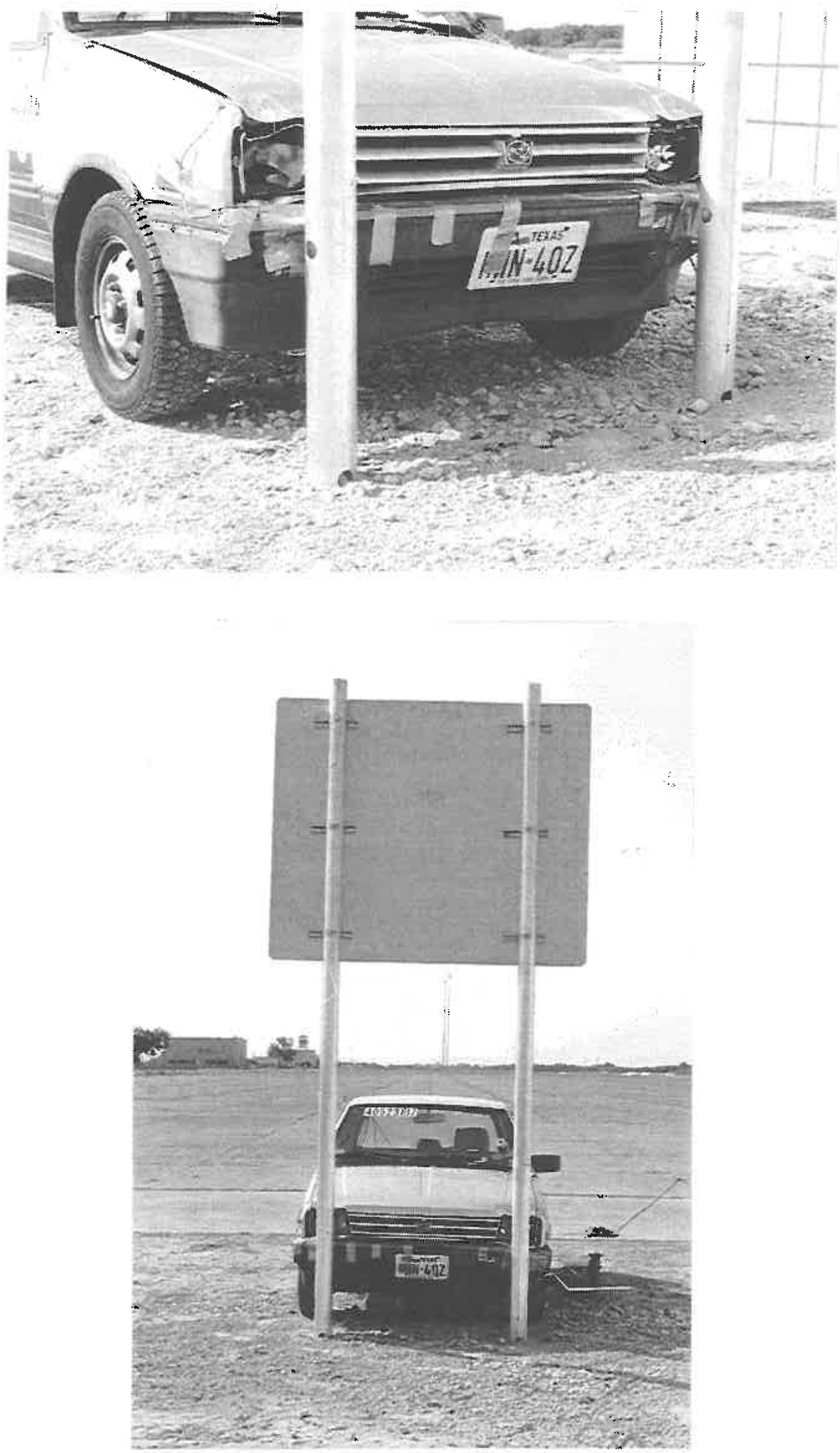


Figure104 . Vehicle/sign installation geometrics for test 405231-17.

Figure 105. Vehicle before test 405231-17.

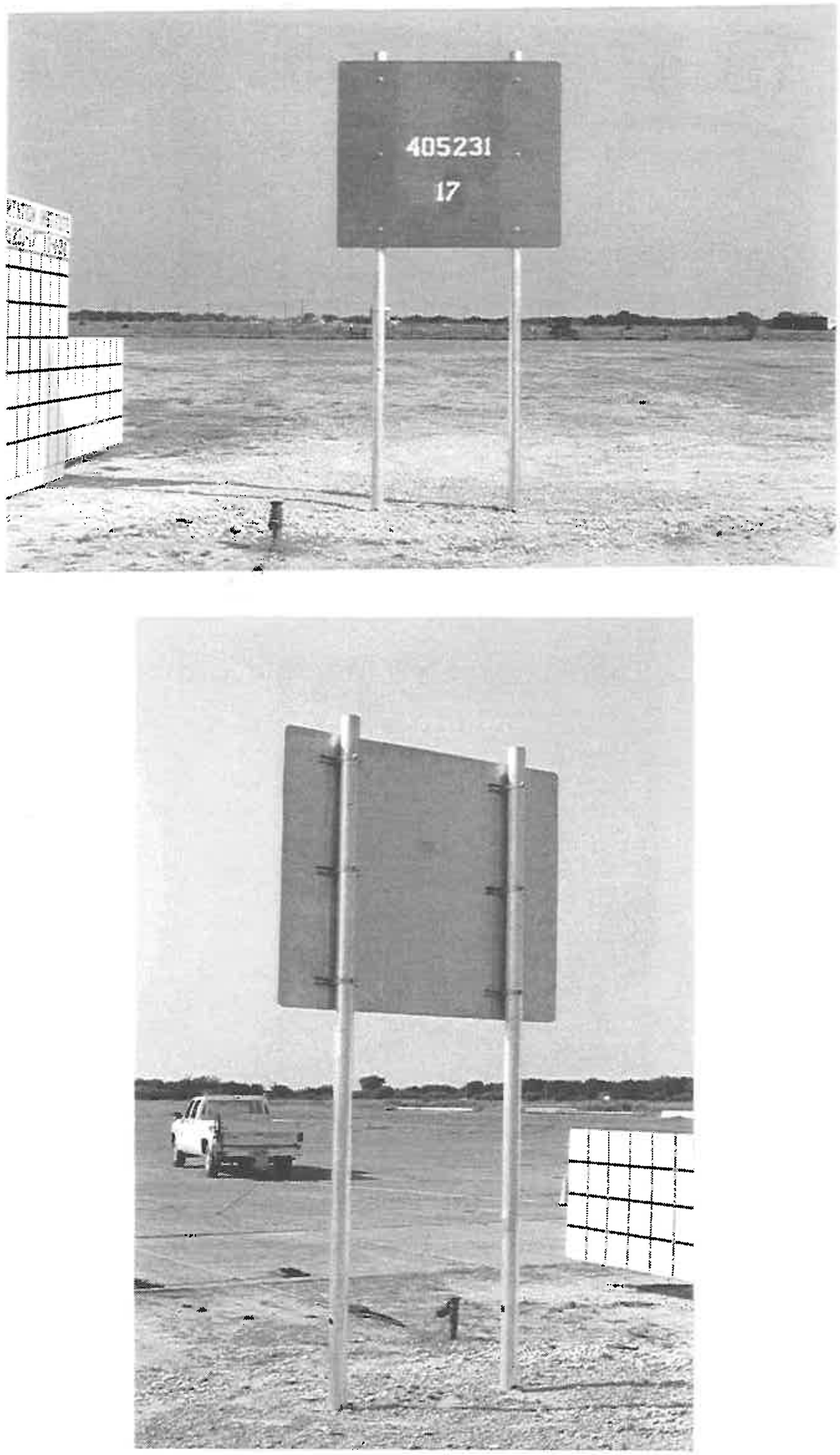
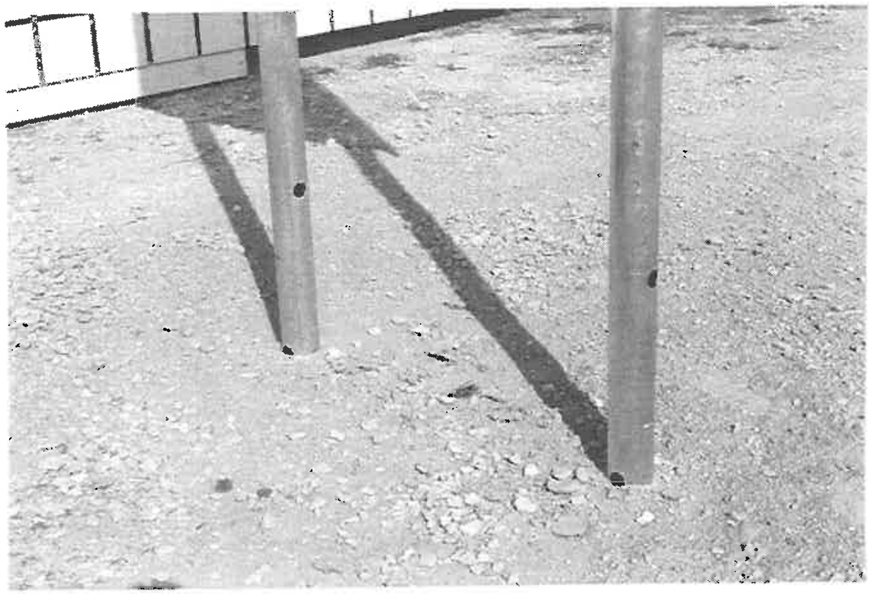


Figure 106. Dual 4 in. aluminum sign support installation modified with four - 1.5 in holes and anchored in strong soil before test 405231-17.



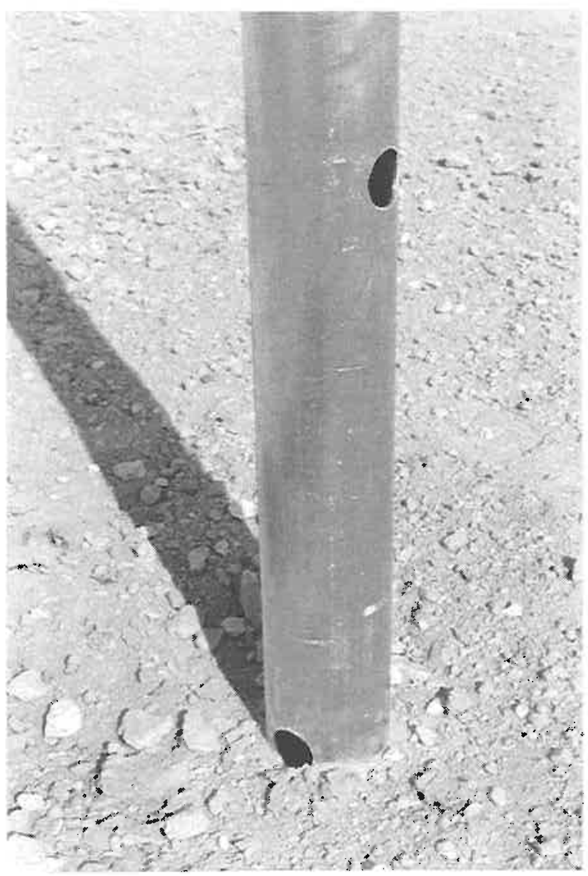


Figure 106. Dual 4 in. aluminum sign support installation modified with four - 1.5 in holes and anchored in strong soil before test 405231-17 (continued).

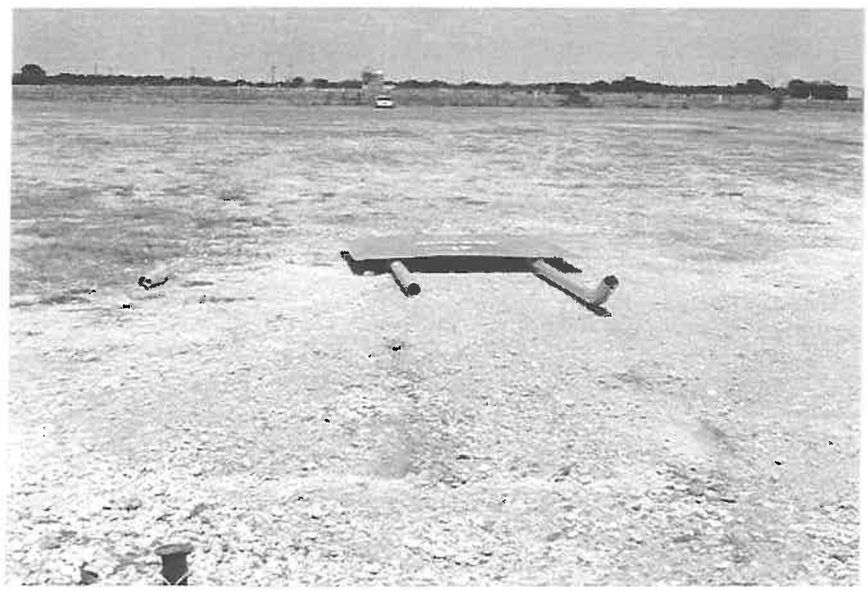


Figure 107. Final rest position of the sign installation and vehicle (test 405231-17).

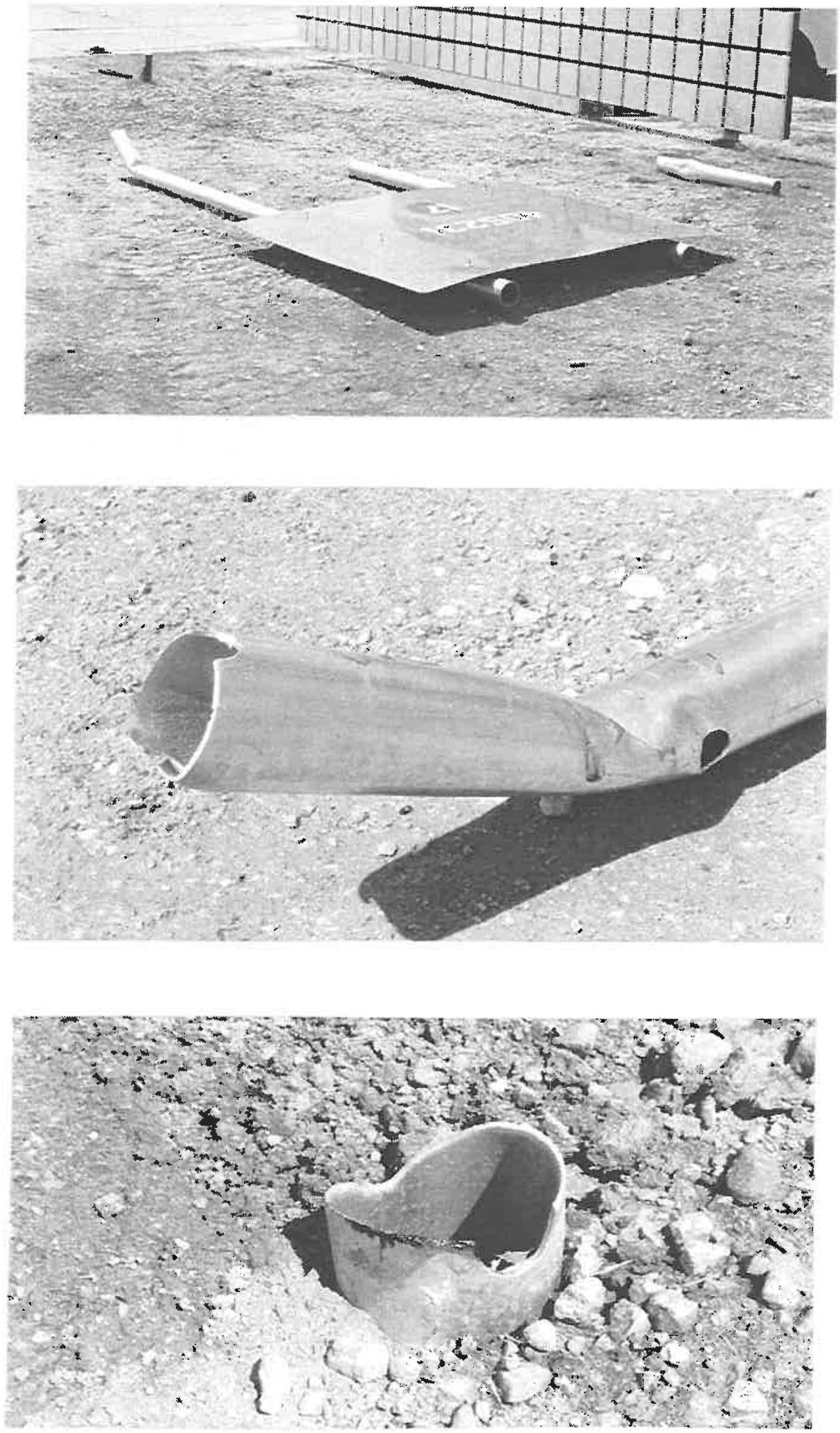
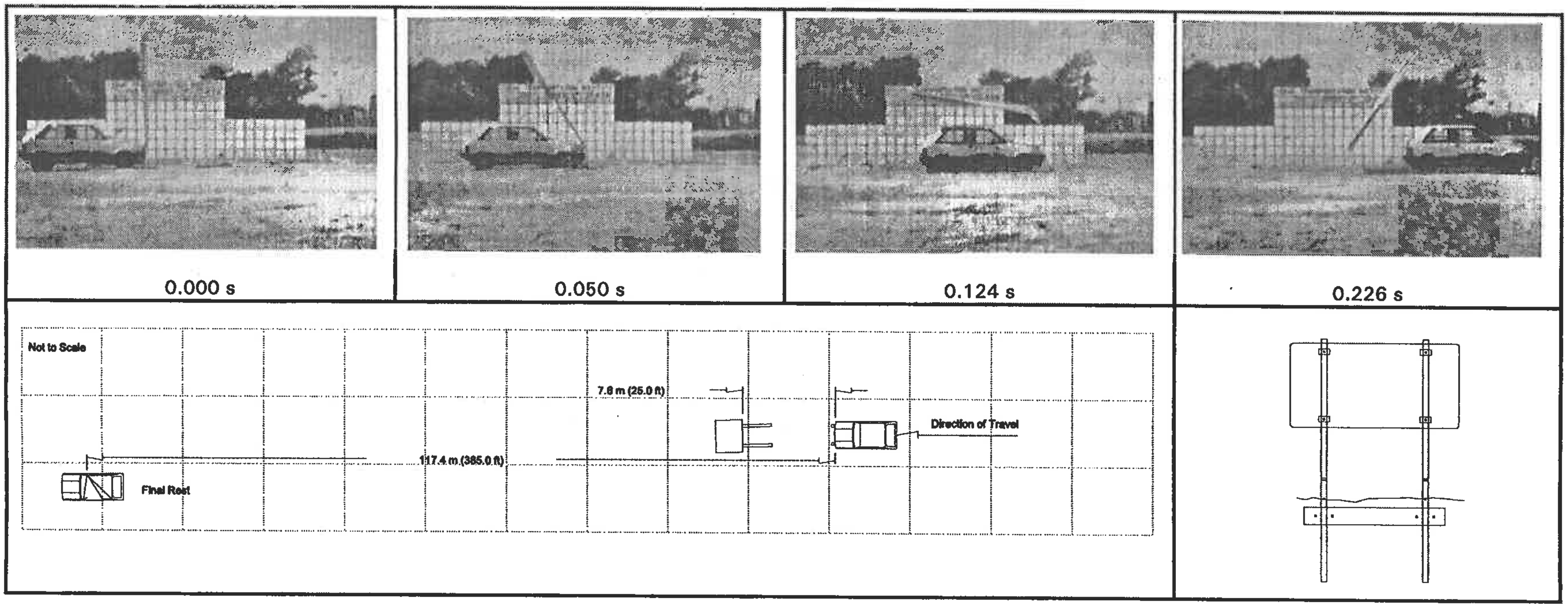


Figure 108. Dual 4 in. aluminum sign support installation modified with four - 1.5 in. holes and anchored in strong soil after test 405231-17.

Figure 109. Vehicle after test 405231-17.

minor damage to the bumper and hood. Maximum deformation to the vehicle was 90 mm (3.5 in), located at the leading edge of the hood directly above the headlights. There was no deformation to the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 1.0 m/s (3.2 ft/s) at 0.626 s, the highest 0.010-s average ridedown acceleration was -0.2 g between 0.798 and 0.808 s, and the maximum 0.050-s average acceleration was -1.7 g between 0.003 and 0.053 s. Lateral occupant impact velocity was 0.3 m/s (1.0 ft/s) at 1.742 s, the highest 0.010-s occupant ridedown acceleration was -0.9 g between 2.278 and 2.288 s and the maximum 0.050-s average acceleration was -0.3 g between 0.008 and 0.058 s. These data and other pertinent information from the test are summarized in Figure 110. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 16.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-17
Date	10/04/94
Test Article	
Type	Modified Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Subaru Justy GL
Mass (kg) Curb	760 (1676 lb)
Test Inertial	820 (1808 lb)
Dummy	77 (170 lb)
Gross Static	897 (1978 lb)

Impact Conditions	
Speed (km/h)	99.2 (61.7 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	93.8 (58.3 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.0 (3.2 ft/s)
y-direction	0.3 (1.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.2
y-direction	-0.9
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-1.7
y-direction	-0.3
z-direction	-1.8

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	90.0 (3.5 in)
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	4.9
Max. Pitch Angle (deg)	2.0
Max. Yaw Angle (deg)	-1.2

Figure 110. Summary of results for test 405231-17.

Table 16. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-17

Test No.: 405231-17 | Test Date: 10/04/94 | Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	Both the right and left sign supports yielded by fracturing the aluminum tubes at the front of the holes located at ground level.	Pass
<u>Occupant Risk</u>		
D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports yielded and **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 3 / 5	Longitudinal occupant impact velocity: 1.0 m/s (3.2 ft/s) Lateral occupant impact velocity: 0.3 m/s (1.0 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: - 0.2 g's Lateral Occupant Ridedown Acceleration: -0.9 g's	Pass
<u>Vehicle Trajectory</u>		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Occupant Impact Velocity Limits (m/s):

Component	Preferred	Maximum
Longitudinal and Lateral	3	5

Occupant Ridedown Acceleration Limits (G's):

Component	Preferred	Maximum
Longitudinal and Lateral	15	20

Dual 4.5 kg/m (3.0 lb/ft) steel U-channel supports anchored in strong soil - 35 km/h (21.8 mi/h)

- ***Test 405231-18***

A 1989 Ford Festiva, shown in Figures 111 and 112, was used for the crash test. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 896 kg (1,975 lb). The height to the lower edge of the vehicle bumper was 365 mm (14.4 in) and it was 545 mm (21.5 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A. The vehicle was directed into the dual 4.5 kg/m (3.0 lb/ft) steel U-channel sign installation anchored in strong soil, shown in Figure 113, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign installation with the centerline of the vehicle at a speed of 35.7 km/h (22.2 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to deflect rearward, then subsequently fracture at bumper level . The right support fractured at 0.010 seconds and the left support at 0.034 seconds. As the vehicle continued traveling forward, the vehicle momentarily lost contact with the upper portion of the supports that were still attached to the sign panel and now rotating over the front of the vehicle. The front of the vehicle at this point was beginning to climb the ground stubs and the front wheels of the vehicle lost contact with the ground at 0.136 seconds. The detached portion of the sign support struck the roof of the vehicle at 0.286 seconds. As the vehicle traveled up and over the ground stubs, the rear axle struck the stubs next causing the rear wheels to lose contact with the ground. As the rear of the vehicle went airborne at 0.504 seconds, the front of the vehicle came back down with the front wheels contacting the ground at 0.607 seconds. The rear of the vehicle was back in contact with the ground at 1.128 seconds. The sign panel bounced off the roof of the vehicle, recontacted the hood and front of the vehicle several times, then eventually slid off the front of the vehicle. The vehicle traveled clear of the support stubs at 16.1 km/h (10.0 mi/h), the brakes were applied and the vehicle came to rest 7.6 m (25.0 ft) downstream and 1.2 m (4.0 ft) from the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 114. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 115, the supports were bent and fractured. The right support failed 432 mm (17.0 in) from ground level and the left support 508 mm (20.0 in). Damage sustained

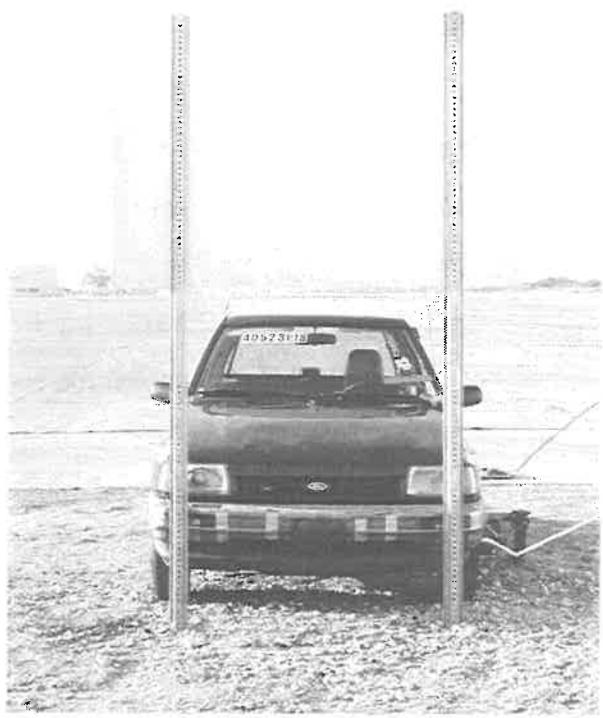
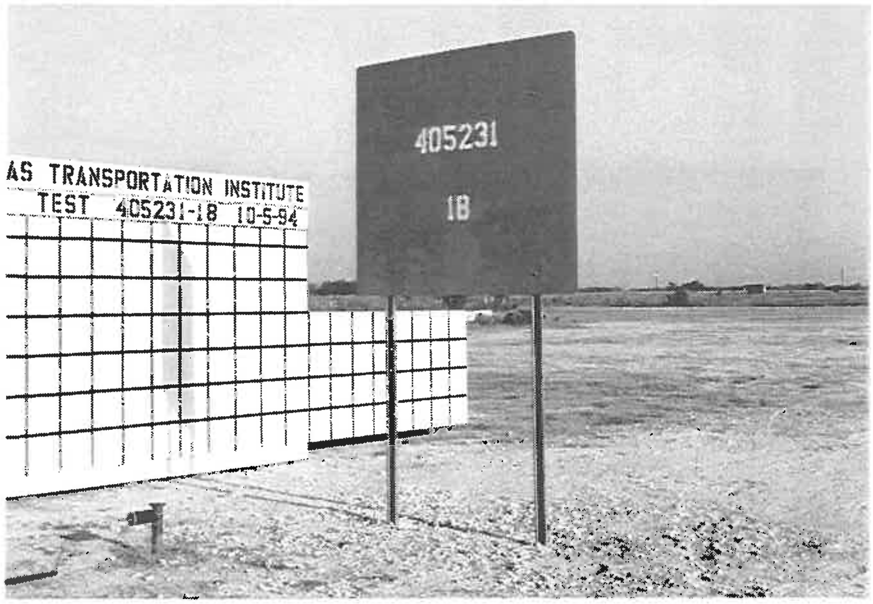


Figure 111. Vehicle/sign installation geometrics for test 405231-18.

Figure 112. Vehicle before test 405231-18.



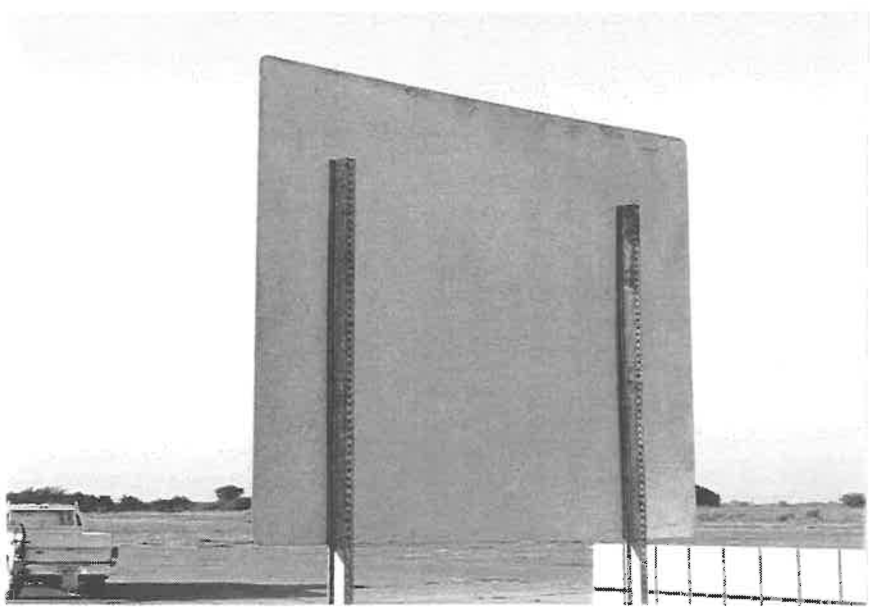


Figure 113. Dual 3-lb sign support installation anchored in strong soil before test 405231-18.

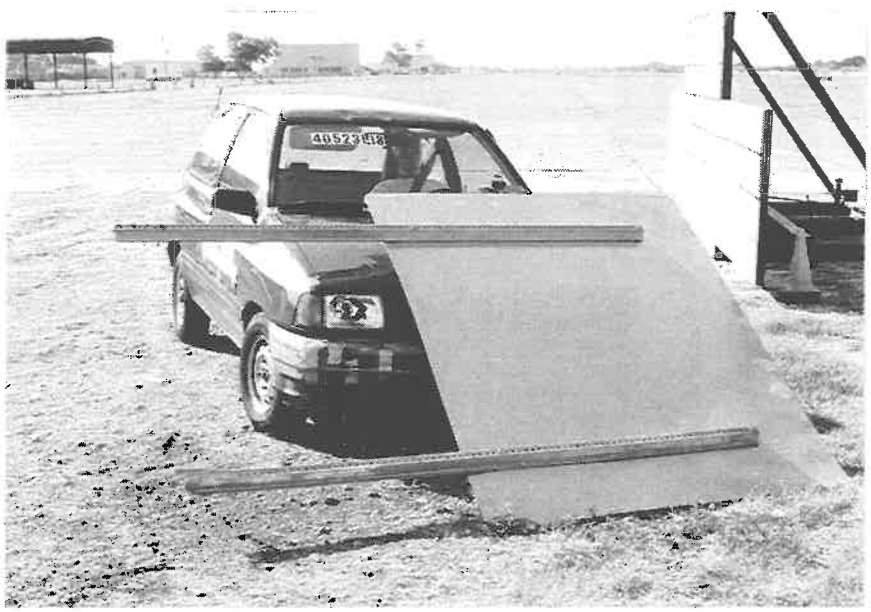


Figure 114. Final rest position of the sign installation and vehicle (test 405231-18).

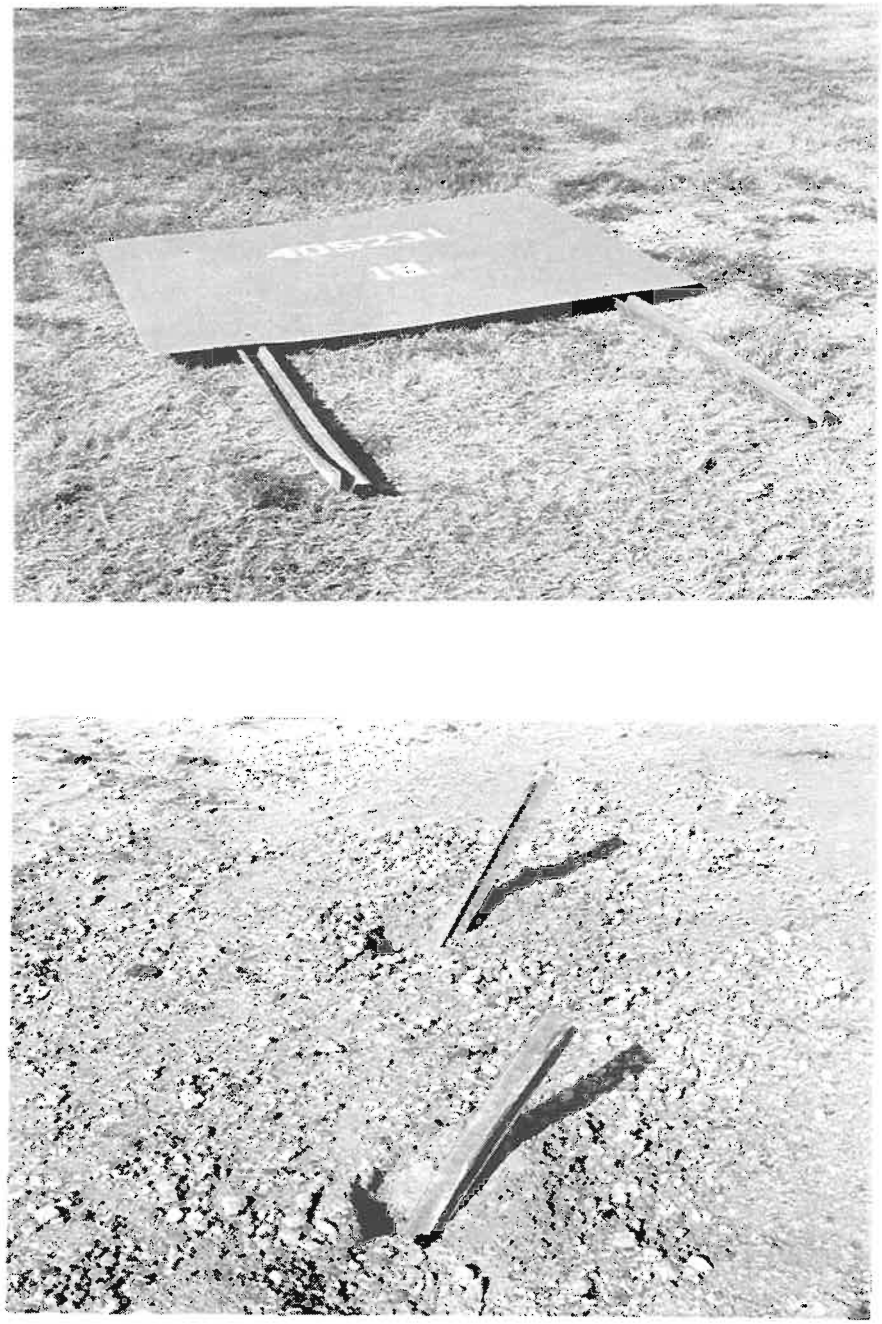
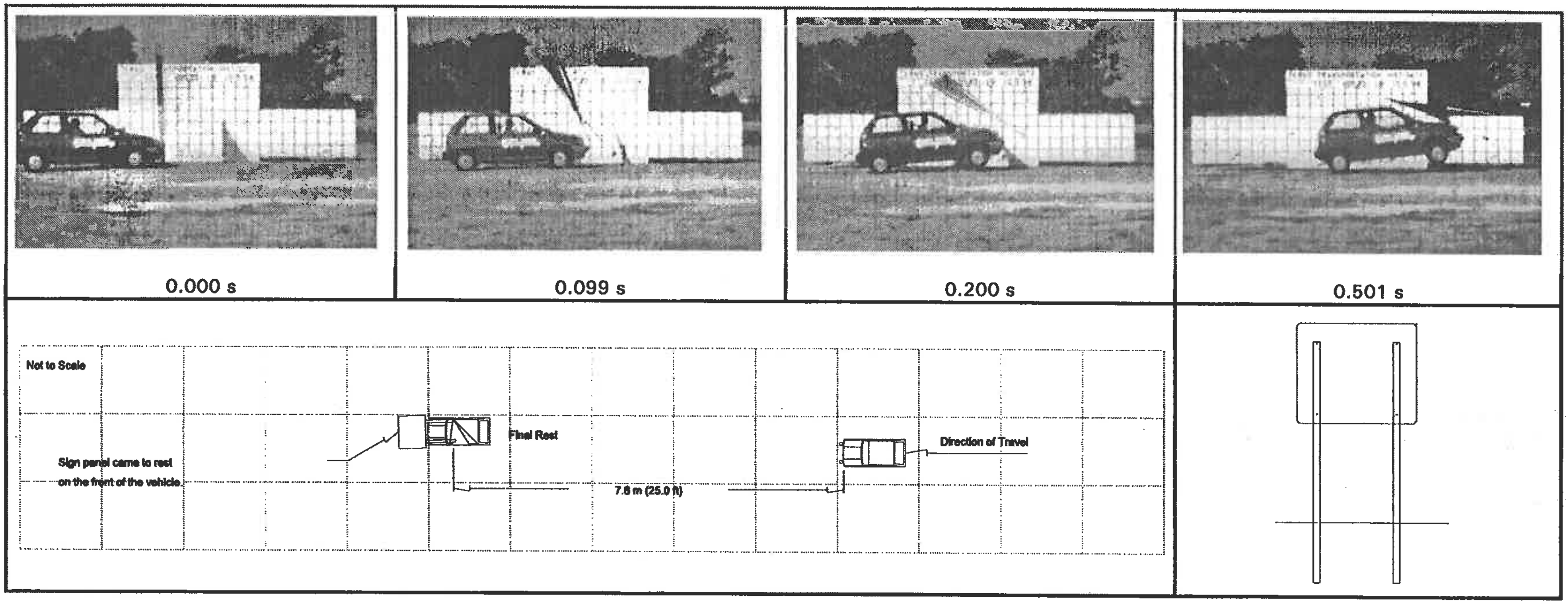


Figure 115. Dual 3-lb sign support installation anchored in strong soil after test 405231-18.

by the vehicle during this test is shown in Figure 116. The vehicle sustained only cosmetic damage to the bumper, hood, roof and undercarriage. There was no deformation to the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 3.9 m/s (12.8 ft/s) at 0.235 s, the highest 0.010-s average ridedown acceleration was -4.7 g between 0.726 and 0.736 s, and the maximum 0.050-s average acceleration was -3.3 g between 0.009 and 0.059 s. Lateral occupant impact velocity was 0.7 m/s (2.3 ft/s) at 1.503 s, the highest 0.010-s occupant ridedown acceleration was -1.7 g between 0.725 and 0.735 s and the maximum 0.050-s average acceleration was -0.5 g between 1.265 and 1.315 s. These data and other pertinent information from the test are summarized in Figure 117. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 17.

Figure 116. Vehicle after test 405231-18.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-18
Date	10/05/94
Test Article	
Type	Dual Steel U-channel
Key Element	3.0 lb/ft U-channel
Height to Bottom of Sign Panel (m)	1.5 (5.0 ft)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	820 (1808 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	35.7 (22.2 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	16.1 (10.0 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.9 (12.8 ft/s)
y-direction	0.7 (2.3 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.7
y-direction	-1.7
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.3
y-direction	-0.5
z-direction	-2.7

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	7.7
Max. Pitch Angle (deg)	-19.1
Max. Yaw Angle (deg)	- 2.8

Figure 117. Summary of results for test 405231-18.

Table 17. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-18

Test No.: 405231-18 Test Date: 10/05/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports fractured 584 mm (23 in) and 737 mm (29 in) from ground level (right and left support, respectively).	Pass
Occupant Risk D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was **no** deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 3 / 5	Longitudinal occupant impact velocity: 3.9 m/s (12.8 ft/s) Lateral occupant impact velocity: 0.7 m/s (2.3 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: -3.3 g's Lateral Occupant Ridedown Acceleration: -0.5 g's	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Dual 4.5 kg/m (3.0 lb/ft) ssteel U-channel supports anchored in strong soil - 100 km/h (62.2 mi/h)

- **Test 405231-19**

The same 1989 Ford Festiva used in test 405231-18, shown in Figures 118 and 119, was reused for this crash test. The vehicle was directed into the dual 4.5 kg/m (3.0 lb/ft) steel U-channel sign installation anchored in strong soil, shown in Figure 120, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign installation with the centerline of the vehicle at a speed of 98.9. km/h (61.5 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to deflect rearward, then subsequently fractured at bumper level . The left support fractured at 0.010 seconds and the right support at 0.017 seconds. As the vehicle continued traveling forward, the vehicle momentarily lost contact (at 0.035 seconds) with the upper portion of the supports that were still attached to the sign panel and were rotating over the front of the vehicle. The sign panel struck the top, rear portion of the roof of the vehicle at 0.104 seconds. The vehicle passed beneath and the sign panel lost contact at 0.161 seconds. The vehicle traveled clear of the support stubs at 89.8 km/h (55.8 mi/h), the brakes were applied and the vehicle came to rest 96.0 m (315.0 ft) downstream and 4.6 m (15.0 ft) from the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 121. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 122, the supports were bent and fractured. The right support failed 584 mm (23.0 in) from ground level and the left support 737 mm (29.0 in). Damage to the vehicle during this test is shown in Figure 123. The vehicle sustained minor damage to the bumper, hood, roof and left front fender. Maximum crush to the bumper was 100 mm (3.9 in). There was no deformation to the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 2.9 m/s (9.7 ft/s) at 0.266 s, the highest 0.010-s average ridedown acceleration was -0.9 g between 0.384 and 0.394 s, and the maximum 0.050-s average acceleration was -3.6 g between 0.003 and 0.053 s. Lateral occupant impact velocity was 0.7 m/s (2.3 ft/s) at 0.654 s, the highest 0.010-s occupant ridedown acceleration was 1.1 g between 0.341 and 0.351 s and the maximum 0.050-s average acceleration was -1.4 g between 0.090 and 0.140 s. These data and

Figure 118. Vehicle/sign installation geometrics for test 405231-19.

Figure 119. Vehicle before test 405231-19.

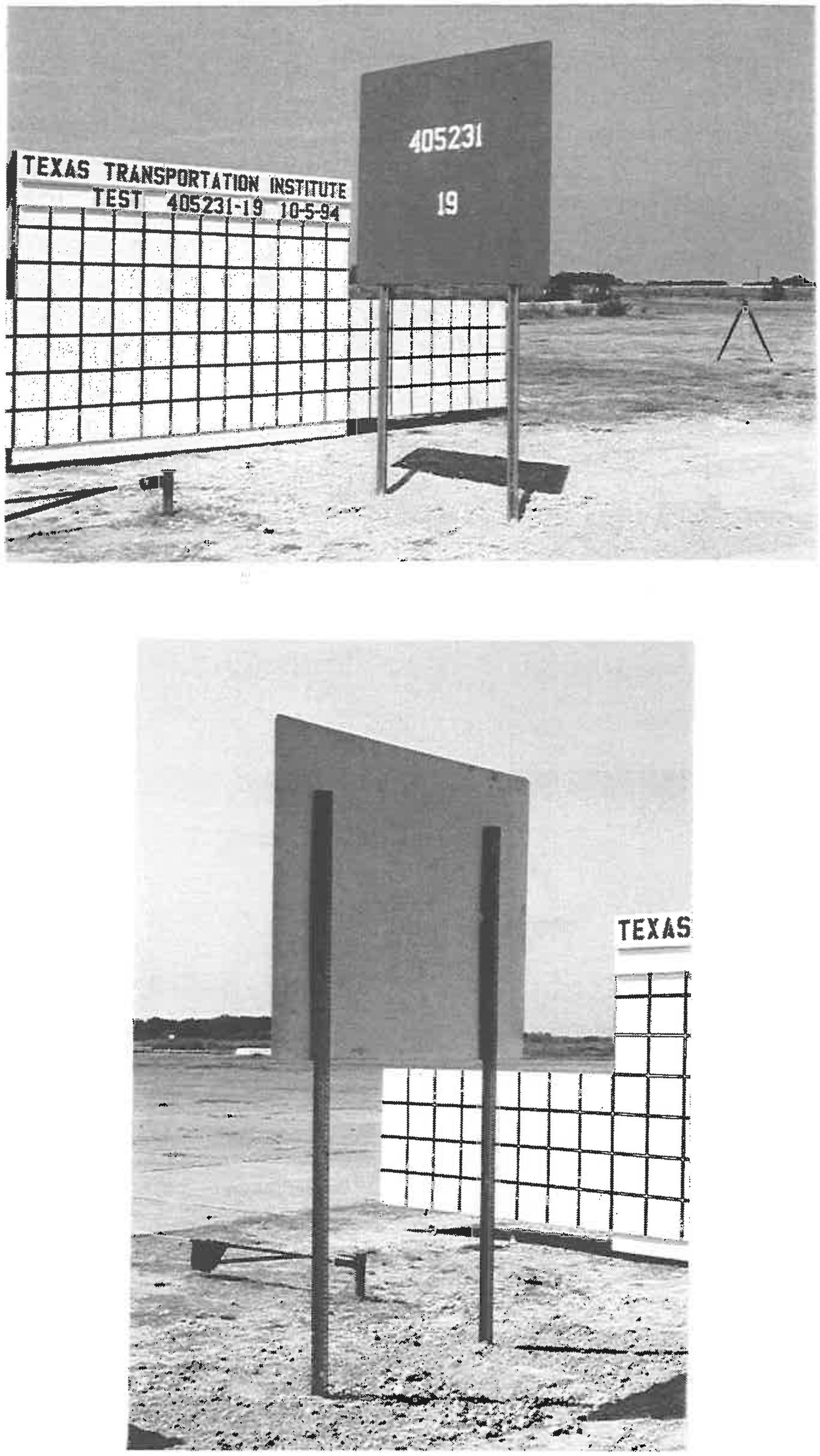


Figure 120. Dual 3-lb sign support installation anchored in strong soil before test 405231-19.

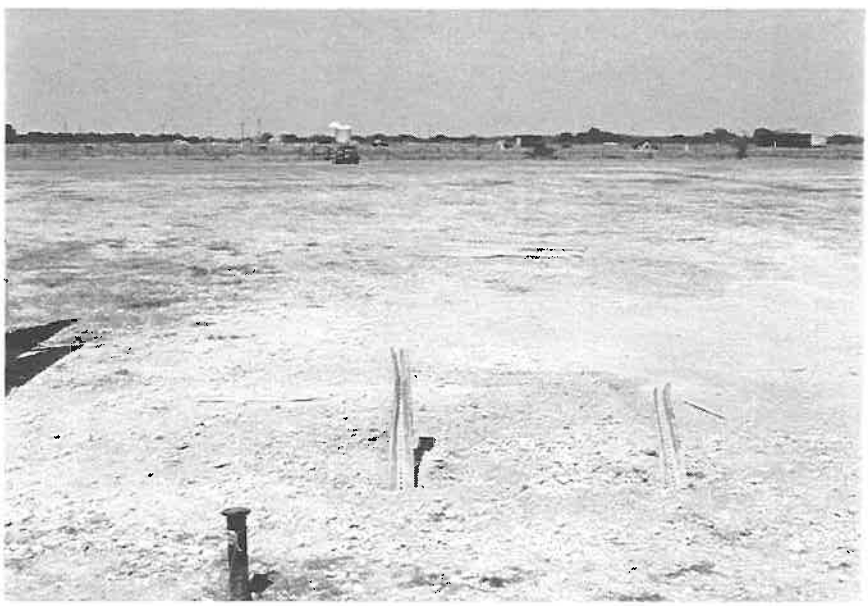
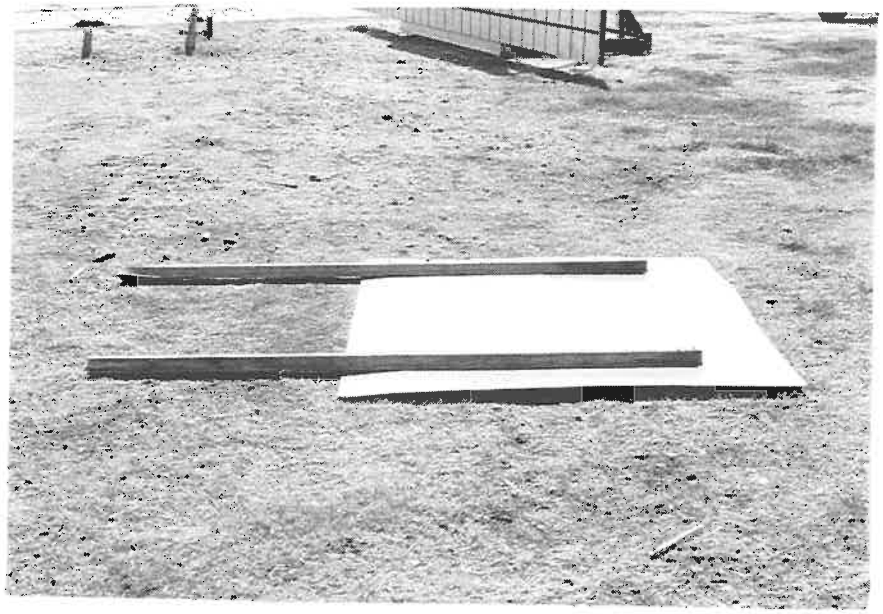


Figure 121. Final rest position of the sign installation and vehicle (test 405231-19).



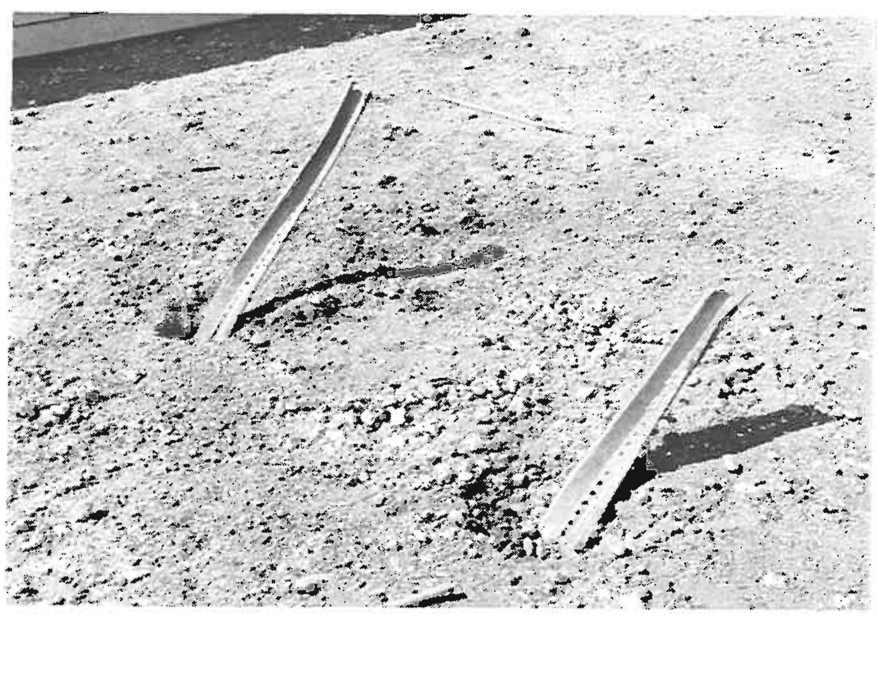


Figure 122. Dual 3-lb sign support installation anchored in strong soil after test 405231-19.

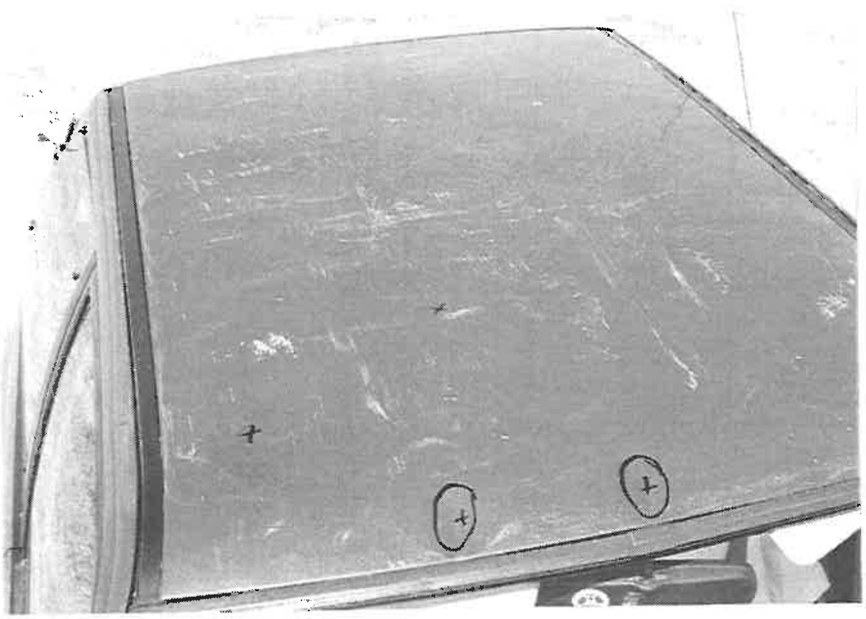
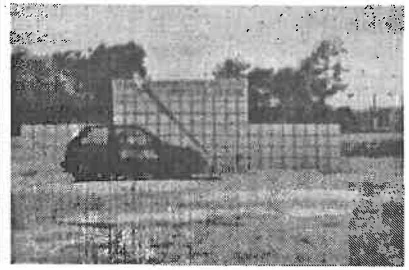
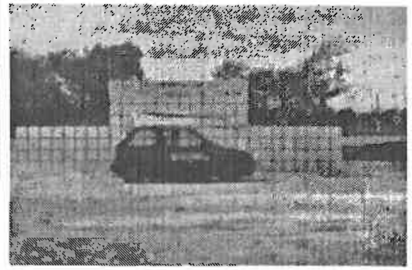


Figure 123. Vehicle after test 405231-19.

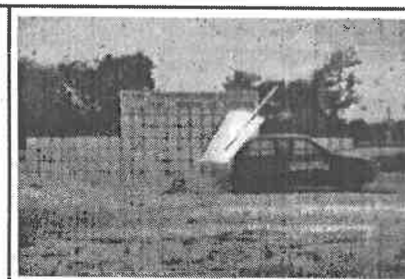
0.000 s



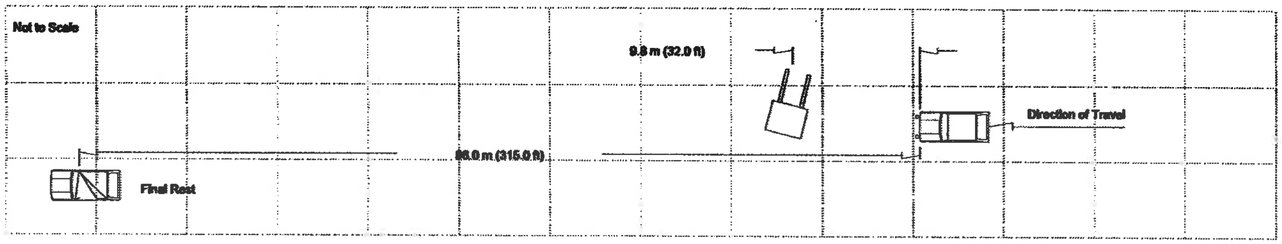
0.050 s

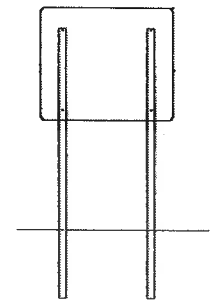


0.099 s



0.200 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-19
Date	10/05/94
Test Article	
Type	Dual Steel U-channel
Key Element	3.0 lb/ft U-channel
Height to Bottom of Sign Panel (m)	1.5 (5.0 ft)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	820 (1808 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	98.9 (61.5 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	89.8 (55.8 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.9 (9.7 ft/s)
y-direction	0.7 (2.3 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.9
y-direction	1.1
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.6
y-direction	-1.4
z-direction	-2.2

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	- 1.9
Max. Pitch Angle (deg)	23.6
Max. Yaw Angle (deg)	- 2.3

Figure 124. Summary of results for test 405231-19.

other pertinent information from the test are summzrized in Figure 124. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 18.

Table 18. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-19

Test No.: 405231-19 Test Date: 10/05/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports fractured 584 mm (23 in) and 737 mm (29 in) from ground level (right and left support, respectively).	Pass
<u>Occupant Risk</u> D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was **no** deformation or intrusion into the occupant compartment	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral; Preferred: 3; Maximum: 5	Longitudinal occupant impact velocity: 2.9 m/s (9.7 ft/s) Lateral occupant impact velocity: 0.7 m/s (2.3 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral; Preferred: 15; Maximum: 20	Longitudinal Occupant Ridedown Acceleration: -0.9 g's Lateral Occupant Ridedown Acceleration: 1.1 g's	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Dual 4.5 kg/m (3.0 lb/ft) steel U-channel supports anchored in weak soil - 35 km/h (21.8 mi/h)

- ***Test 405231-20***

A 1989 Ford Festiva, shown in Figures 125 and 126, was used for the crash test. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 896 kg (1,975 lb). The height to the lower edge of the vehicle bumper was 360 mm (14.2 in) and it was 535 mm (21.1 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A. The vehicle was directed into the dual 4.5 kg/m (3.0 lb/ft) steel U-channel sign installation anchored in weak soil, shown in Figure 127, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign installation with the centerline of the vehicle at a speed of 34.2 km/h (21.3 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the right support began to deflect and twist outward. The left support fractured at bumper level at 0.034 seconds. Shortly thereafter, at 0.074 seconds, the right support slipped off the end of the bumper The right support scraped along the right front fender and the sign panel and left support rotated clockwise into the front upper corner of the fender and over the vehicle. The sign panel struck the right side of the windshield at 0.419 seconds. Shortly thereafter, the vehicle snared the bottom of the sign panel on the right A-pillar and acted as a momentum arm, pulling the right support out the ground. The right support was pulled from the ground between 0.480 and 0.687 seconds. The vehicle exited traveling 19.3 km/h (12.0 mi/h) while still in contact with the sign installation and came to rest 27.4 m (90.0 ft) down and 1.5 m (5.0 ft) to the right of the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 128. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 129, the left support fractured and the right support was pulled up from the ground. The left support was pushed rearward 648 mm (25.5 in) and fractured 406 mm (16.0 in) from ground level. The sign installation stayed on the front of the vehicle during the crash. Damage sustained by the vehicle during this test is shown in Figure 130. The vehicle sustained a 100 mm (3.9 in) cut in the right front fender. Damage sustained by the vehicle was primarily cosmetic, with the notable exception of a dent in the right A-pillar. There was no deformation to the vehicle occupant compartment.

Figure 125. Vehicle/sign installation geometrics for test 405231-20.

Figure 126. Vehicle before test 405231-20.

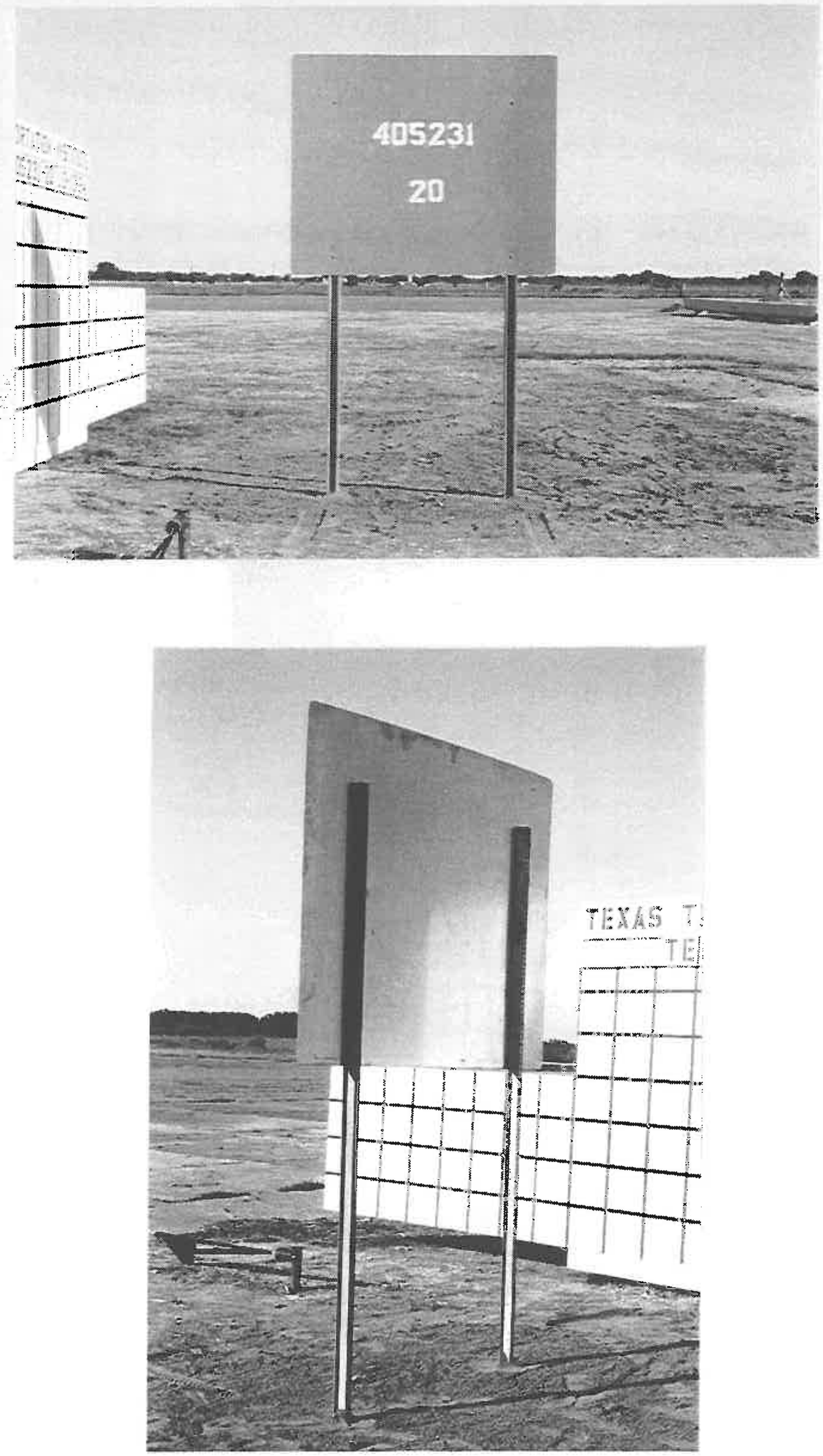


Figure 127. Dual 3-lb sign support installation anchored in weak soil before test 405231-20.

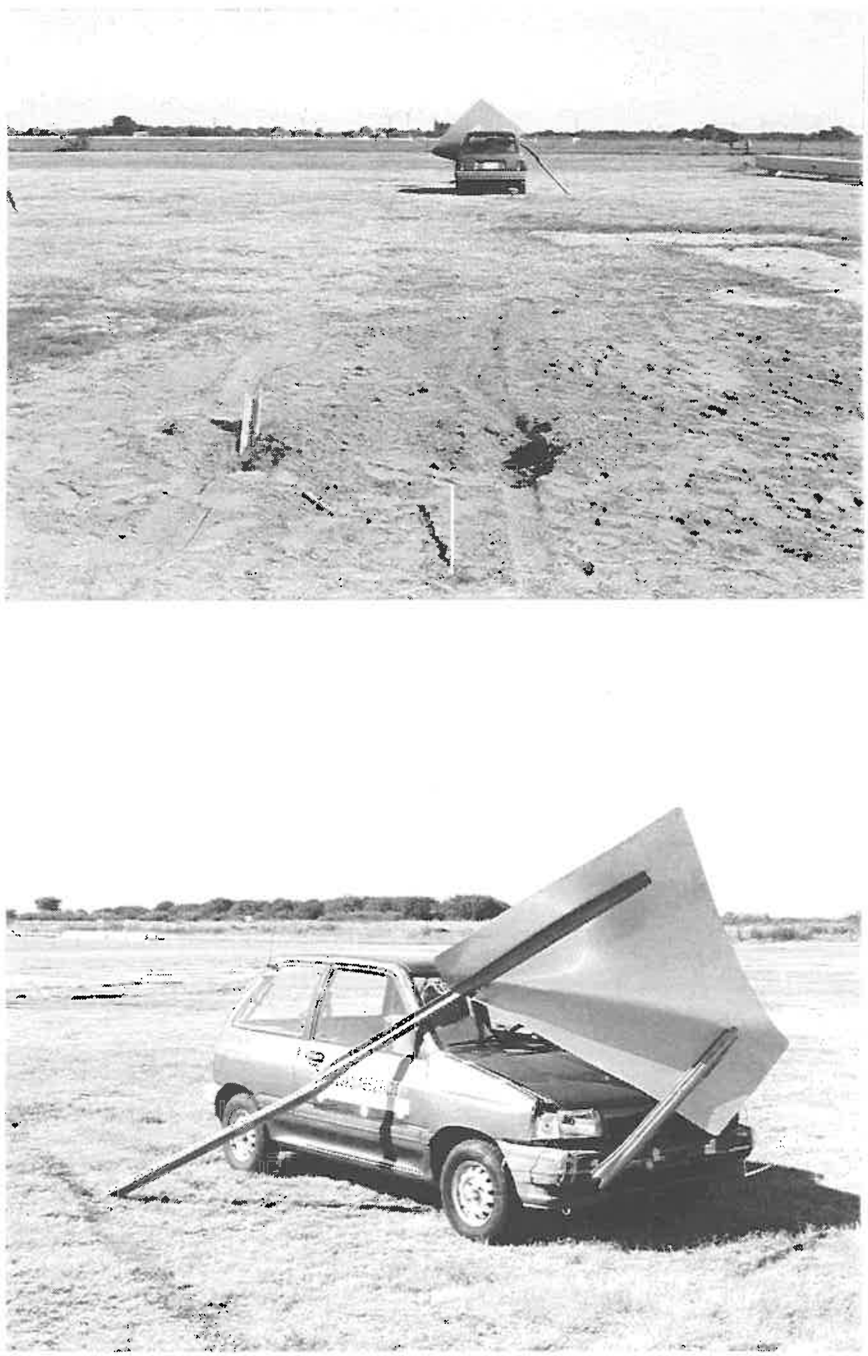


Figure 128. Final rest position of the sign installation and vehicle (test 405231-20).

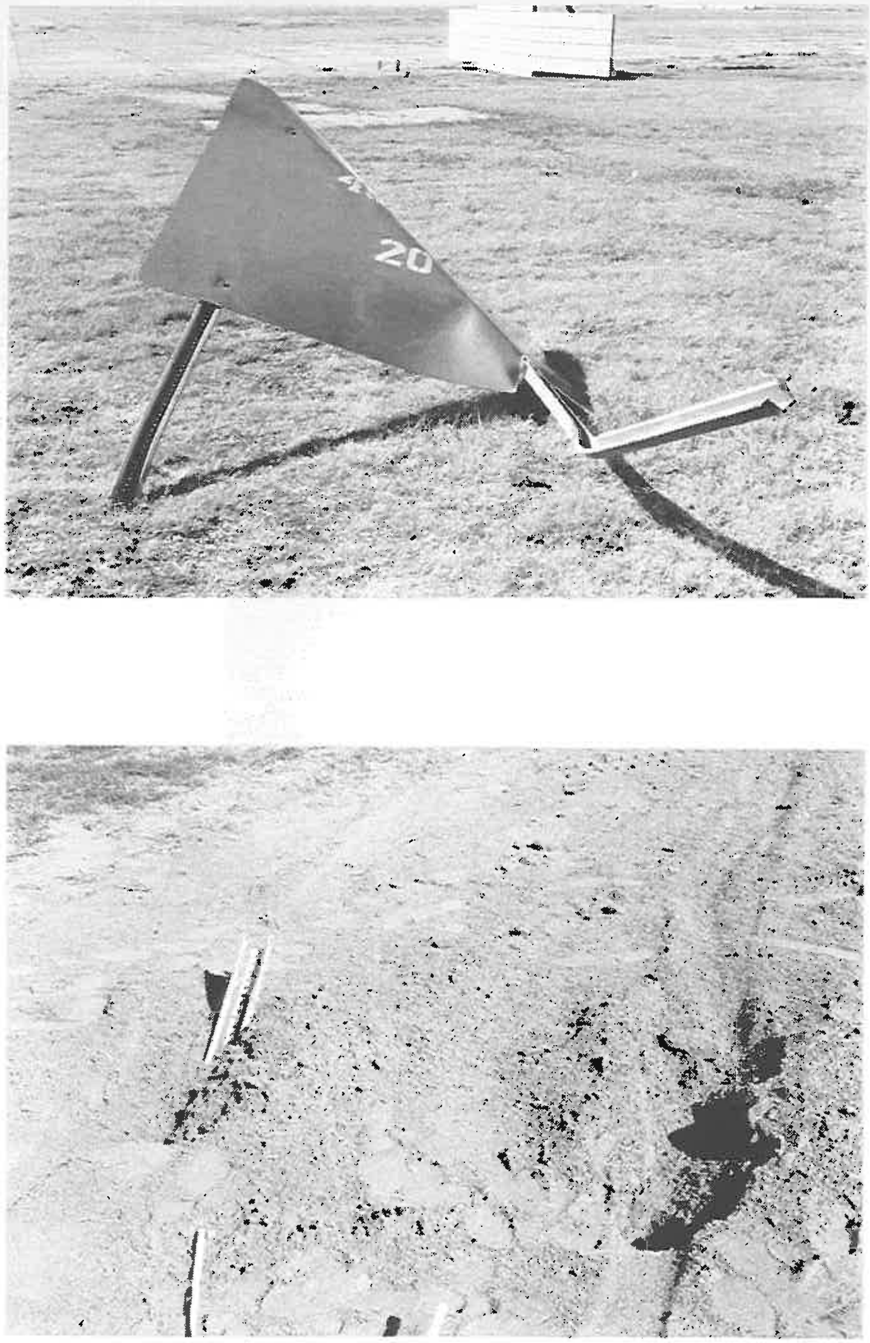
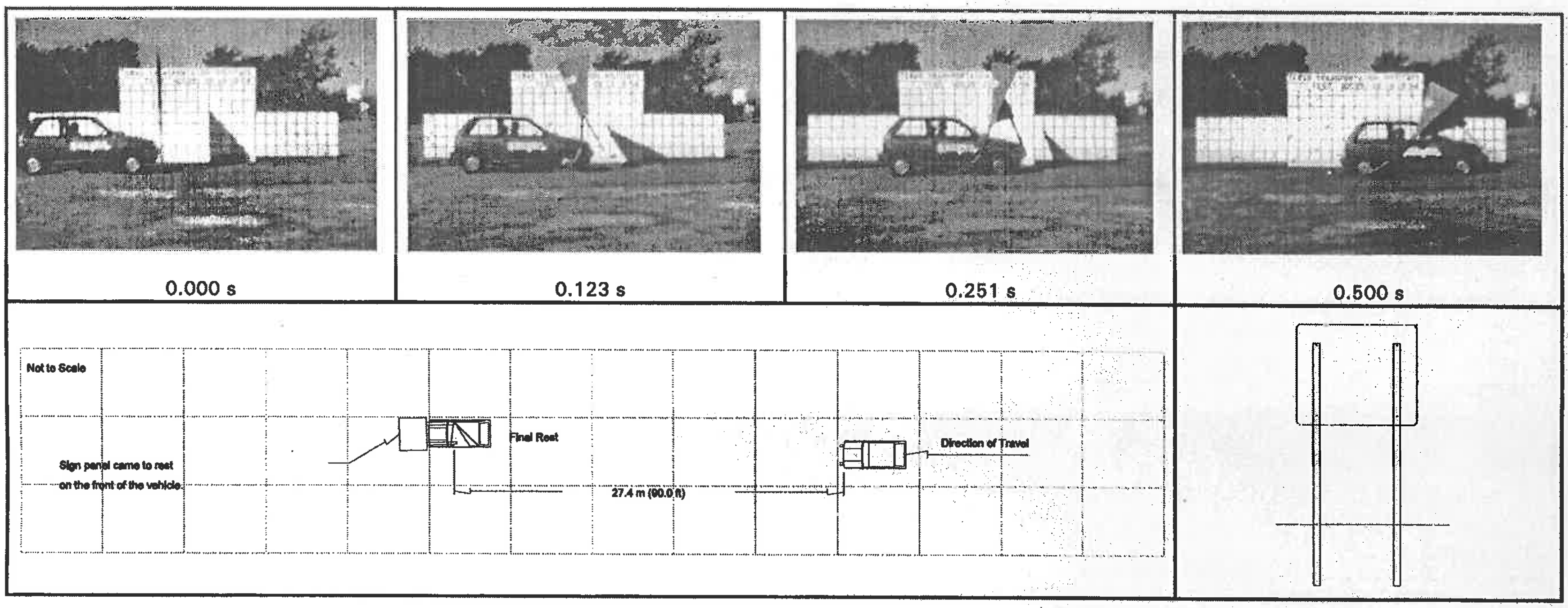


Figure 129. Dual 3-lb sign support installation anchored in weak soil after test 405231-20.

Figure 130. Vehicle after test 405231-20.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 2.1 m/s (6.9 ft/s) at 0.389 s, the highest 0.010-s average ridedown acceleration was -1.6 g between 0.429 and 0.439 s, and the maximum 0.050-s average acceleration was -1.9 g between 0.000 and 0.050 s. Lateral occupant impact velocity was -0.5 m/s (-1.5 ft/s) at 1.743 s, the highest 0.010-s occupant ridedown acceleration was 1.0 g between 0.418 and 0.428 s and the maximum 0.050-s average acceleration was -0.4 g between 0.368 and 0.418 s. These data and other pertinent information from the test are summarized in Figure 131. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 19.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-20
Date	10/10/94
Test Article	
Type	Dual Steel U-channel
Key Element	3.0 lb/ft U-channel
Height to Bottom of Sign Panel (m)	1.5 (5.0 ft)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	789 (1739 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	34.2 (21.3 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	19.3 (12.0 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.1 (6.9 ft/s)
y-direction	-0.5 (-1.5 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.6
y-direction	1.0
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-1.9
y-direction	-0.4
z-direction	-0.7

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS000000
Maximum Exterior Vehicle Crush (mm)	100 (3.9 in)
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	3.0
Max. Pitch Angle (deg)	-1.8
Max. Yaw Angle (deg)	4.9

Figure 131. Summary of results for test 405231-20

Table 19. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-20

Test No.: 405231-20 Test Date: 10/10/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The left sign support fractured 406 mm (16 in) from ground level and the right support was pulled from the soil.	Pass
Occupant Risk D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured or yielded in some manner but **did not** present a hazard to other travel lanes. There was **no** deformation or intrusion into the occupant compartment	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 3 / 5	Longitudinal occupant impact velocity: 2.1 m/s (6.9 ft/s) Lateral occupant impact velocity: - 0.5 m/s (-1.5 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: -1.6 g's Lateral Occupant Ridedown Acceleration: 1.0 g's	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Dual 4.5 kg/m (3.0 lb/ft) steel U-channel supports anchored in weak soil - 100 km/h (62.2 mi/h)

- **Test 405231-21**

The same 1989 Ford Festiva used in test 405231-20, shown in Figures 132 and 133, was reused for this crash test. The vehicle was directed into the dual 4.5 kg/m (3.0 lb/ft) steel U-channel sign installation anchored in weak soil, shown in Figure 134, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the centerline of the sign installation with the centerline of the vehicle at a speed of 100.5 km/h (62.5 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to bend at ground and bumper. The right support fractured at bumper level at 0.010 seconds and the left support at 0.015 seconds. The sign panel, rotating up and over the vehicle, lost contact temporarily at 0.047 seconds. The sign panel struck the roof of the vehicle at 0.091 seconds. The vehicle lost contact with the sign panel traveling 93.5 km/h (58.1 mi/h), the brakes were applied and the vehicle came to rest out of view of the high-speed camera. The vehicle came to final rest upright 95.9 m (314.5 ft) downstream from the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 135. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 136, the right support fractured 533 mm (21.0 in) from ground level and the left support 483 mm (19.0 in) from ground level. The right support not only fractured, but was pulled from the ground as well. The left ground stub was displaced 660 mm (26.0 in) rearward. The upper portions of the right and left sign supports and sign panel came to rest 8.4 m (27.5 ft) down and 4.6 m (15.0 ft) to the right of the point of impact. The lower portion of the right support, came to rest 15.9 m (52.0 ft) from the point of impact and in line with the left ground stub. Damage sustained by the vehicle during this test is shown in Figure 137. The vehicle sustained minor damage to the roof and bumper. Maximum deformation to the front of the vehicle at the impact point was 72 mm (2.8 in). There was deformation, but no intrusion into the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 1.9 m/s (6.3 ft/s) at 0.369 s, the highest 0.010-s average ridedown acceleration was

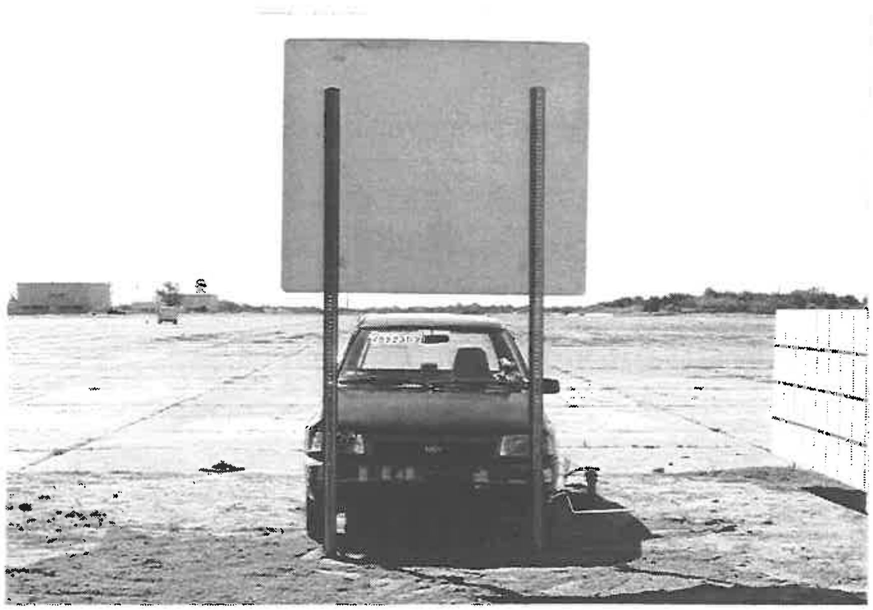


Figure 132. Vehicle/sign installation geometrics for test 405231-21.

Figure 133. Vehicle before test 405231-21.

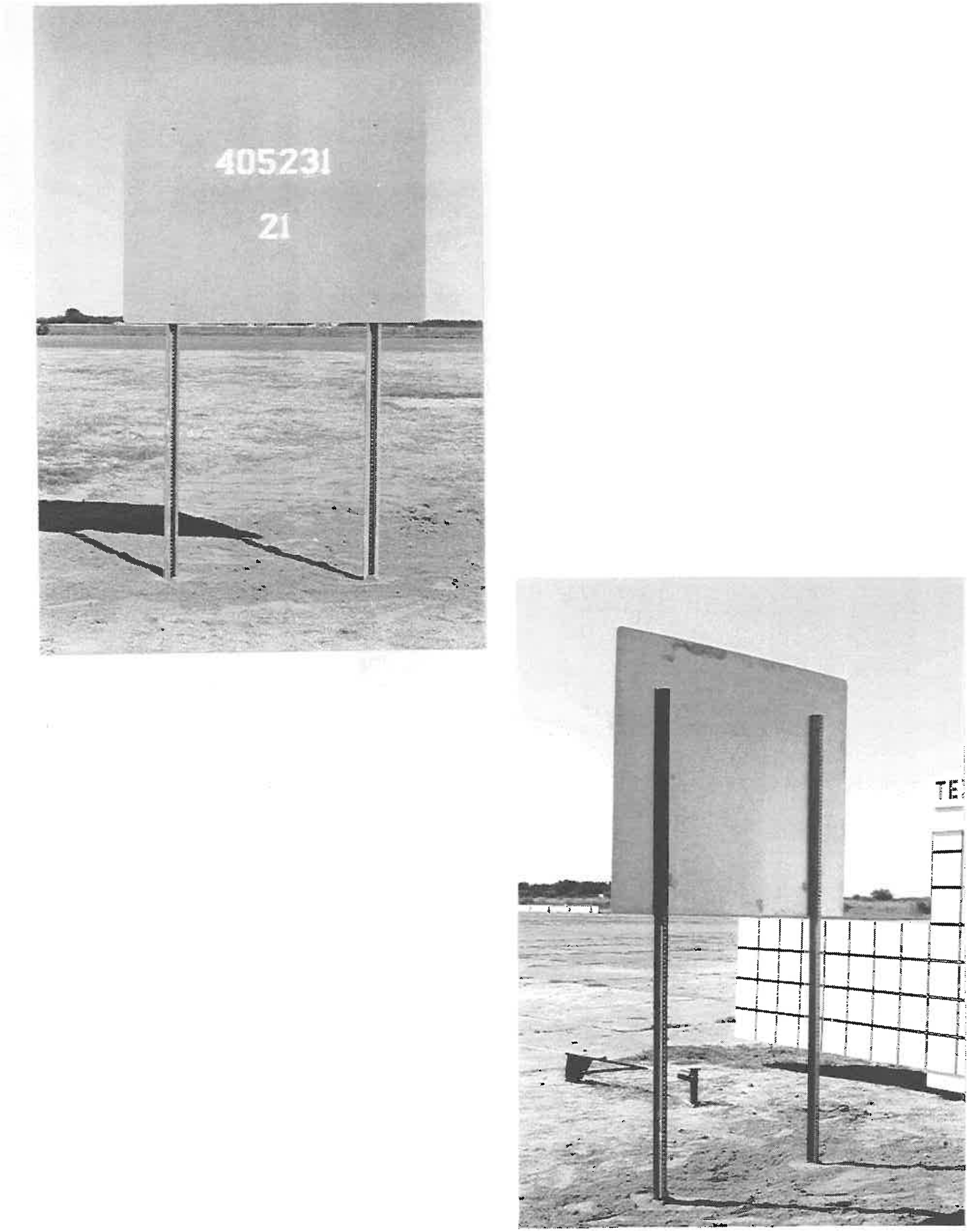


Figure 134. Dual 3-lb sign support installation anchored in weak soil before test 405231-21.

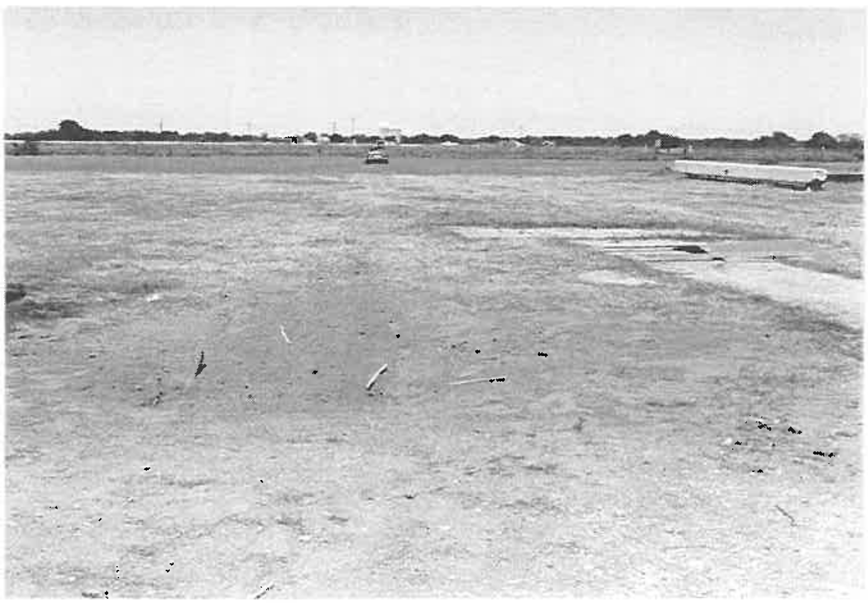


Figure 135. Final rest position of the sign installation and vehicle (test 405231-21).

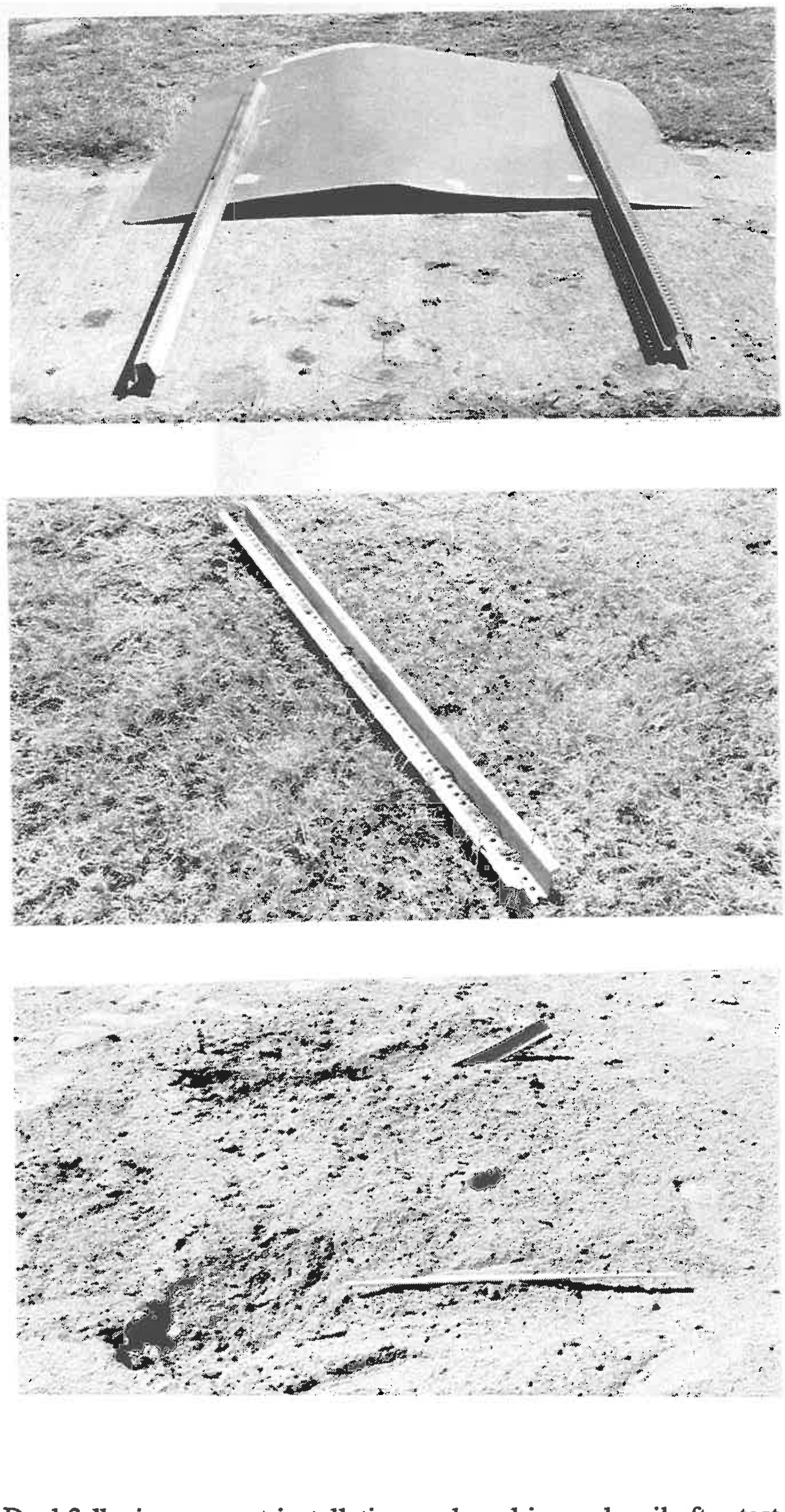


Figure 136. Dual 3-lb sign support installation anchored in weak soil after test 405231-21.

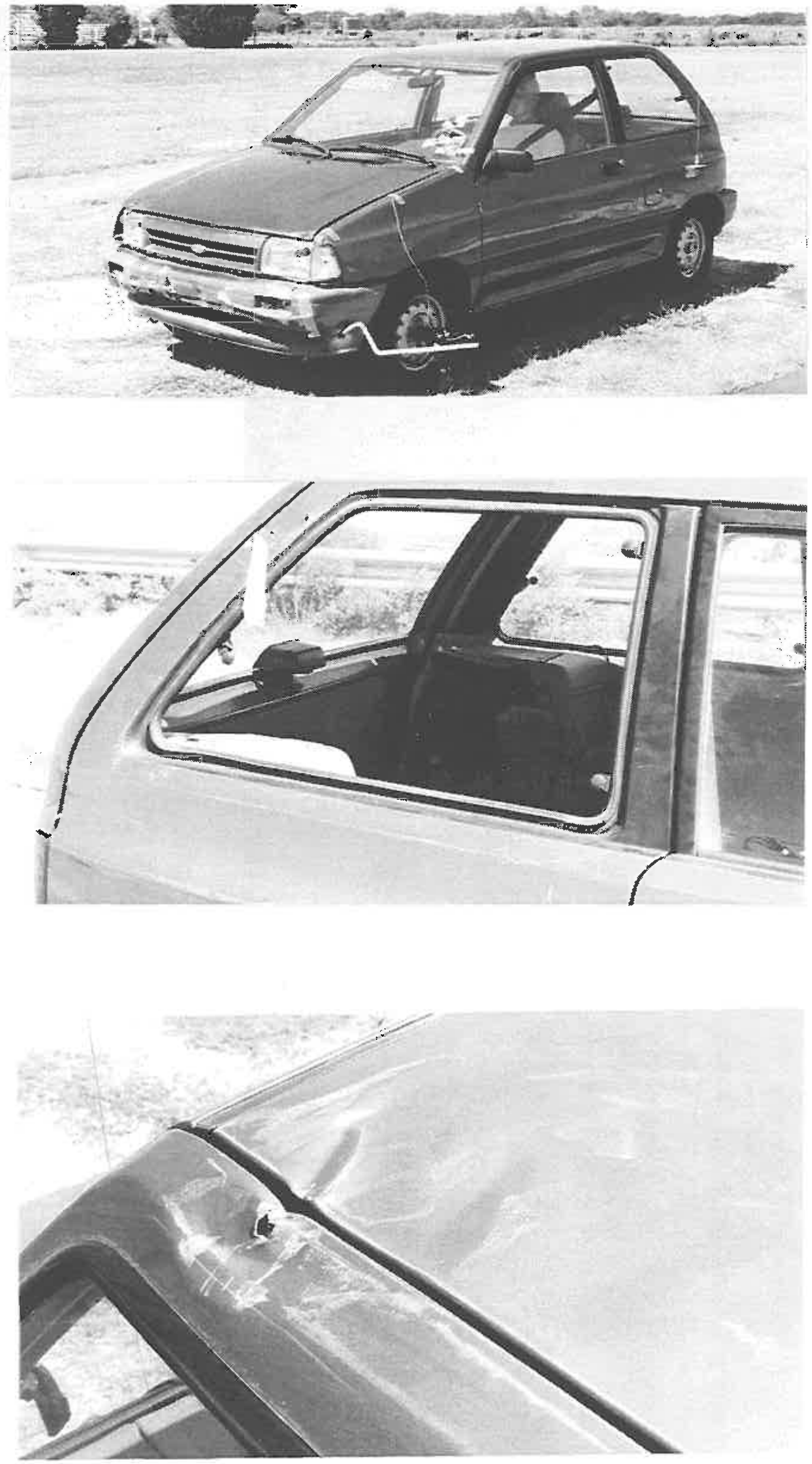
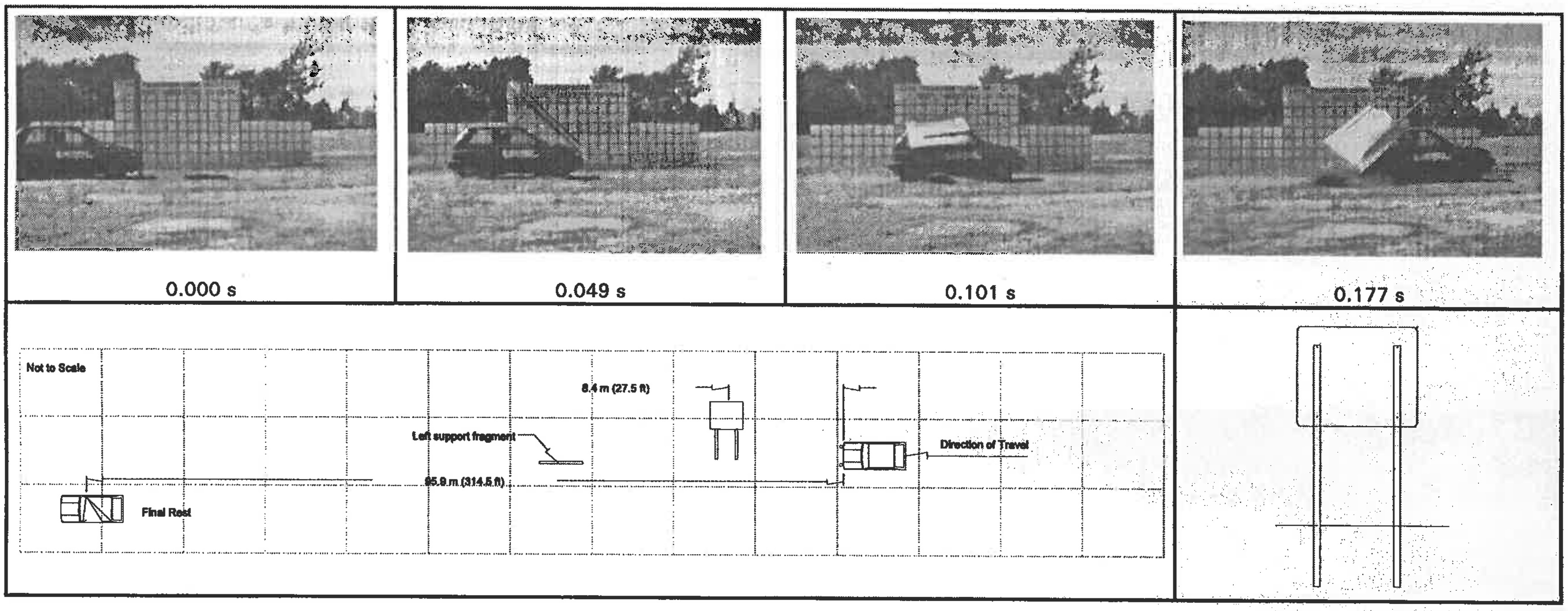


Figure 137. Vehicle after test 405231-21.

-0.5 g between 0.898 and 0.908 s, and the maximum 0.050-s average acceleration was -2.7 g between 0.000 and 0.050 s. No occupant contact occurred in the lateral direction. The maximum 0.050-s average acceleration in the lateral direction was -0.9 g between 0.032 and 0.082 s. These data and other pertinent information from the test are summarized in Figure 138. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 20.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-21
Date	10/10/94
Test Article	
Type	Dual Steel U-channel
Key Element	3.0 lb/ft U-channel
Height to Bottom of Sign Panel (m)	1.5 (5.0 ft)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	789 (1739 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	100.5 (62.5 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	93.5 (58.1 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.9 (6.3 ft/s)
y-direction	N/A
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.5
y-direction	No Contact
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-2.7
y-direction	-0.9
z-direction	2.6

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS000000
Maximum Exterior Vehicle Crush (mm)	72 (2.8 in)
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	5.2
Max. Pitch Angle (deg)	-12.4
Max. Yaw Angle (deg)	-0.8

Figure 138. Summary of results for test 405231-21

Table 20. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-21

Test No.: 405231-21 | Test Date: 10/10/94 | Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports fractured 483 mm (19 in) and 533 mm (21 in) from ground level (right and left support, respectively).	Pass
Occupant Risk		
D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was **no** deformation or intrusion into the occupant compartment	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 3 / 5	Longitudinal occupant impact velocity: 1.9 m/s (6.3 ft/s) Lateral occupant impact velocity: N/A	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: -0.5 g's Lateral Occupant Ridedown Acceleration: No Contact	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Modified Dual 102 mm (4 in) diameter aluminum supports anchored in weak soil - 35 km/h (21.8 mi/h)

- ***Test 405231-22***

The same 1989 Ford Festiva used in test 405231-21, shown in Figures 139 and 140, was reused for this crash test. The vehicle was directed into the dual 102 mm (4.0 in) diameter aluminum support sign installation anchored in weak soil, shown in Figure 141, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The sign supports were modified by drilling two 38 mm (1.5 in) holes in each support (in the vehicle travel direction) at ground level and two additional 38 mm (1.5 in) holes 457 mm (18.0 in) up from ground level in each support (perpendicular to the vehicle travel direction). The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 34.5 km/h (21.4 mi/h) and a zero degree heading angle.

As the vehicle impacted the sign installation, the supports began to deform at bumper height and ground level. The vehicle pocketed in the supports at bumper level and forward travel terminated as the supports were bent over. As forward motion terminated, the rear wheels lost contact with the ground at 0.187 seconds. The rear of the vehicle rotated upward and the sign supports yielded losing contact with the vehicle at 0.320 seconds. As the rear of the vehicle was airborne, the sign panel, still attached to the supports, contacted the ground at 0.506 seconds. Shortly thereafter, the rear wheels of the vehicle came back into contact with the ground at 0.669 seconds and the vehicle came to final rest over the sign supports and 1.2 m (4.0 ft) from the point of impact as shown in Figure 142. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 143, the supports were bent and fractured. The left and right supports failed at the holes located at bumper level. All, but a 64 mm (2.5 in) wide strip across the rearward cross-section of each support, failed in tension. In addition, the soil plates were pulled upward and displaced rearward approximately 38 mm (1.5 in). The sign panel and all mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. Damage sustained by the vehicle during this test is shown in Figure 144. The vehicle sustained minor damage to the bumper only. No measurable deformation to the vehicle was recorded. There was no deformation or intrusion into the vehicle occupant compartment.

Figure139.Vehicle/sign installation geometrics for test 405231-22.

Figure140.Vehicle before test 405231-22.

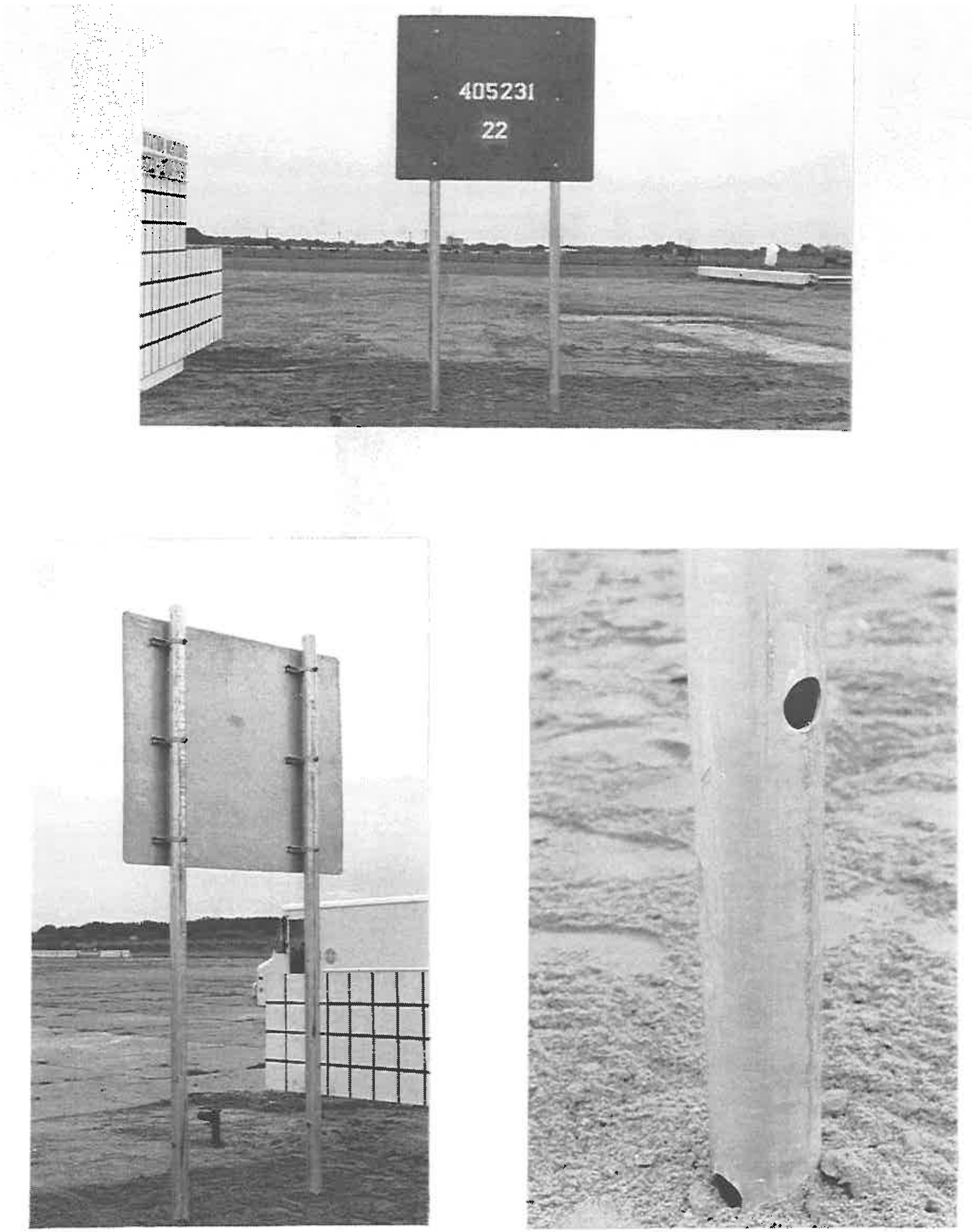


Figure 141 . Dual 4-in with 1-1/2 in holes aluminum sign support installation anchored in weak soil before test 405231-22.

Figure142.Final rest position of the sign installation and vehicle (test 405231-22).

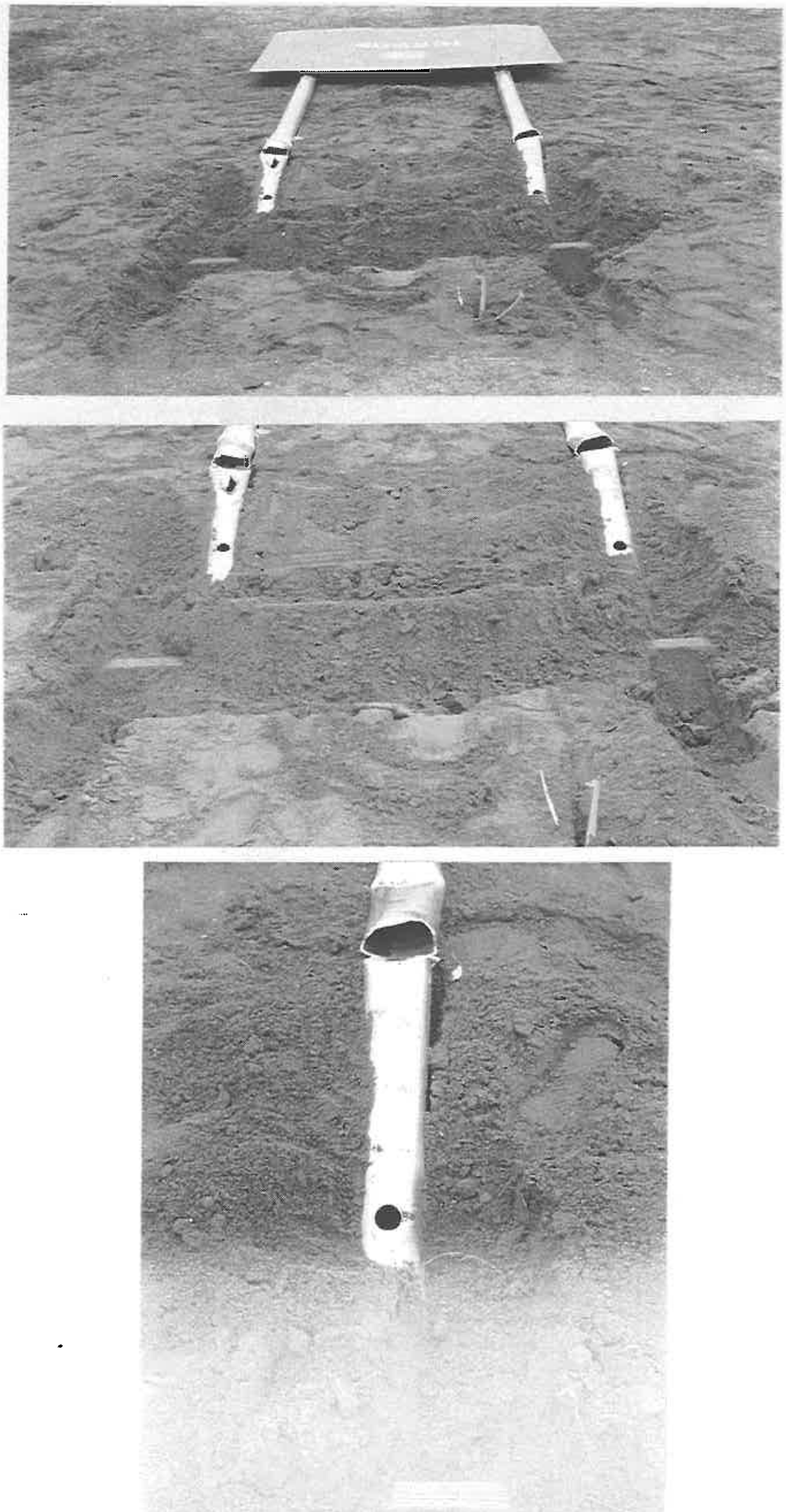


Figure 143 . Dual 4-in with 1-1/2 in holes aluminum sign support installation anchored in weak soil after test 405231-22.

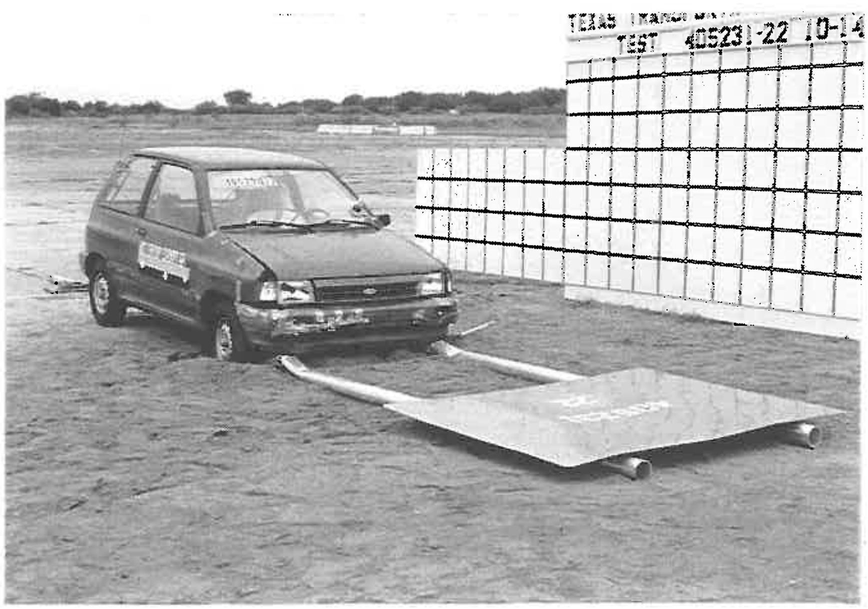
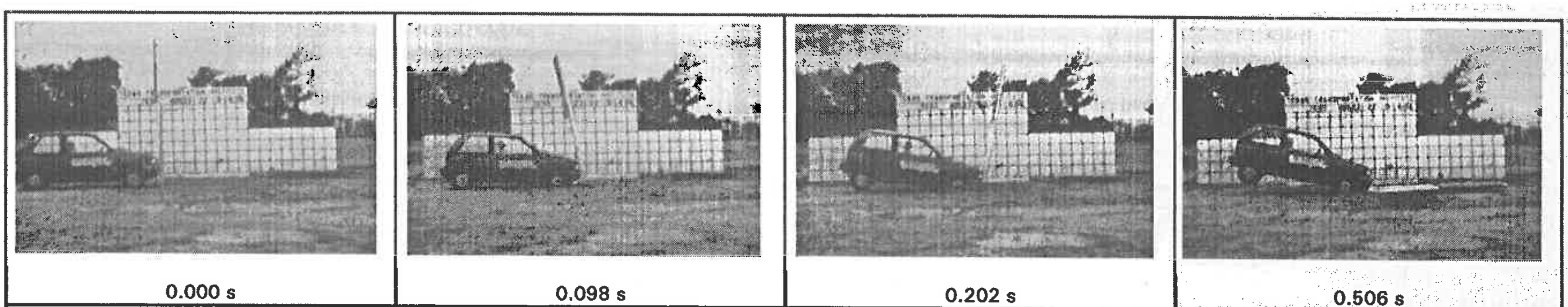
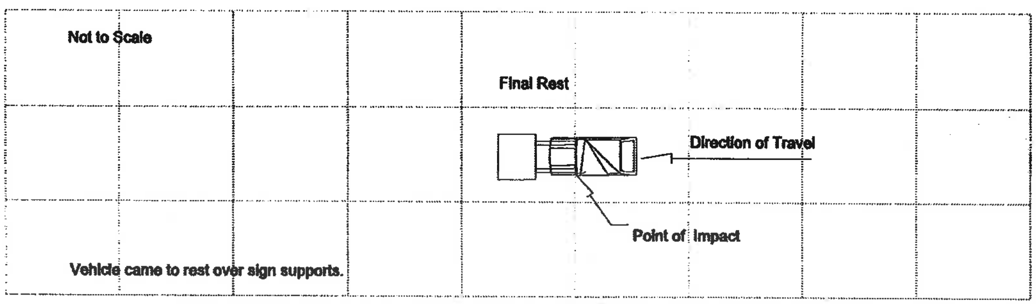
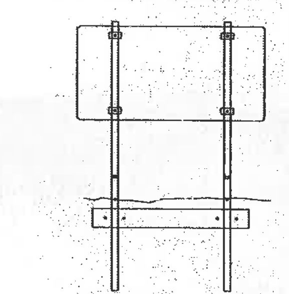


Figure144. Vehicle after test 405231-22.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 8.1 m/s (26.5 ft/s) at 0.179 s, the highest 0.010-s average ridedown acceleration was -3.8 g between 0.179 and 0.189 s, and the maximum 0.050-s average acceleration was -6.4 g between 0.120 and 0.170 s. Lateral occupant impact velocity was -0.4 m/s (-1.4 ft/s) at 1.508 s, the highest 0.010-s occupant ridedown acceleration was -0.9 g between 0.186 and 0.196 s and the maximum 0.050-s average acceleration was 0.3 g between 0.507 and 0.557 s. These data and other pertinent information from the test are summarized in Figure 145. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 21.







General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-22
Date	10/14/94
Test Article	
Type	Modified Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	789 (1739 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	34.5 (21.4 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	13.4 (8.3 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	8.1 (26.5 ft/s)
y-direction	-0.4 (-1.4 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-3.8
y-direction	-0.9
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-6.4
y-direction	0.3
z-direction	-3.2

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	2.7
Max. Pitch Angle (deg)	-15.5
Max. Yaw Angle (deg)	1.6

Figure 145. Summary of results for test 405231-22.

Table 21. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-22

Test No.: 405231-22 Test Date: 10/14/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports partially fractured at the holes located near bumper level.	Fail
<u>Occupant Risk</u> D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports did not fracture entirely and therefore **did not** present a hazard to other travel lanes. There was **no** deformation or intrusion into the occupant compartment	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral; Preferred: 3; Maximum: 5	Longitudinal occupant impact velocity: 8.1 m/s (26.5 ft/s) Lateral occupant impact velocity: -0.4 (-1.4 ft/s)	Fail
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral; Preferred: 15; Maximum: 20	Longitudinal Occupant Ridedown Acceleration: -3.8 g's Lateral Occupant Ridedown Acceleration: -0.9 g's	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Modified Dual 102 mm (4-inch) diameter aluminum support anchored in strong soil - 35 km/h (21.8 mi/h)

- ***Test 405231-23***

The same 1989 Ford Festiva was used in test 405231-22, shown in Figures 146 and 147, was used for this crash test. The vehicle was directed into the dual 102 mm (4.0 in) diameter aluminum support sign installation anchored in strong soil, shown in Figure 148 using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The sign supports were modified by drilling four 25 mm (1.0 in) holes in the supports at two different elevations along each support. The two elevations of four holes each were drilled at ground level and 457 mm (18.0 in) above ground level. The holes were oriented 90 degrees with respect to each other and 45 degrees with respect to the plane of the sign panel. The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 33.2 km/h (20.6 mi/h) and a zero degree heading angle.

Upon the vehicle impacting the sign installation, the supports began to deflect at bumper height. As the vehicle continued traveling forward, the supports began to fracture at 0.017 seconds and subsequently fail across their entire cross-section at bumper height. At 0.022 seconds, the supports began to partially fracture at ground level. As the vehicle traveled over the stubs, the supports and attached sign panel slid downward, contacting the ground and rotating over and toward the vehicle. The vehicle pushed the supports and attached sign panel upward and over the hood of the vehicle. The vehicle lost contact with the supports at 0.167 seconds. As the vehicle passed under the installation, the sign panel struck the roof at 0.352 seconds. Thereafter, the sign panel lost contact with the roof of the vehicle at 0.906 seconds. The vehicle came to rest upright 25.6 m (84.0 ft) downstream from the point of impact and the sign installation came to rest 8.2 m (27.0 ft) down and 0.9 m (3.0 ft) over from the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 149. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 150, the supports were bent and fractured. The left and right supports failed in tension across their entire cross-section at the holes located near bumper height. In addition, both supports failed in tension across all but the most rearward part of their cross\sections at the holes located at ground level. The sign panel and all mounting and anchoring

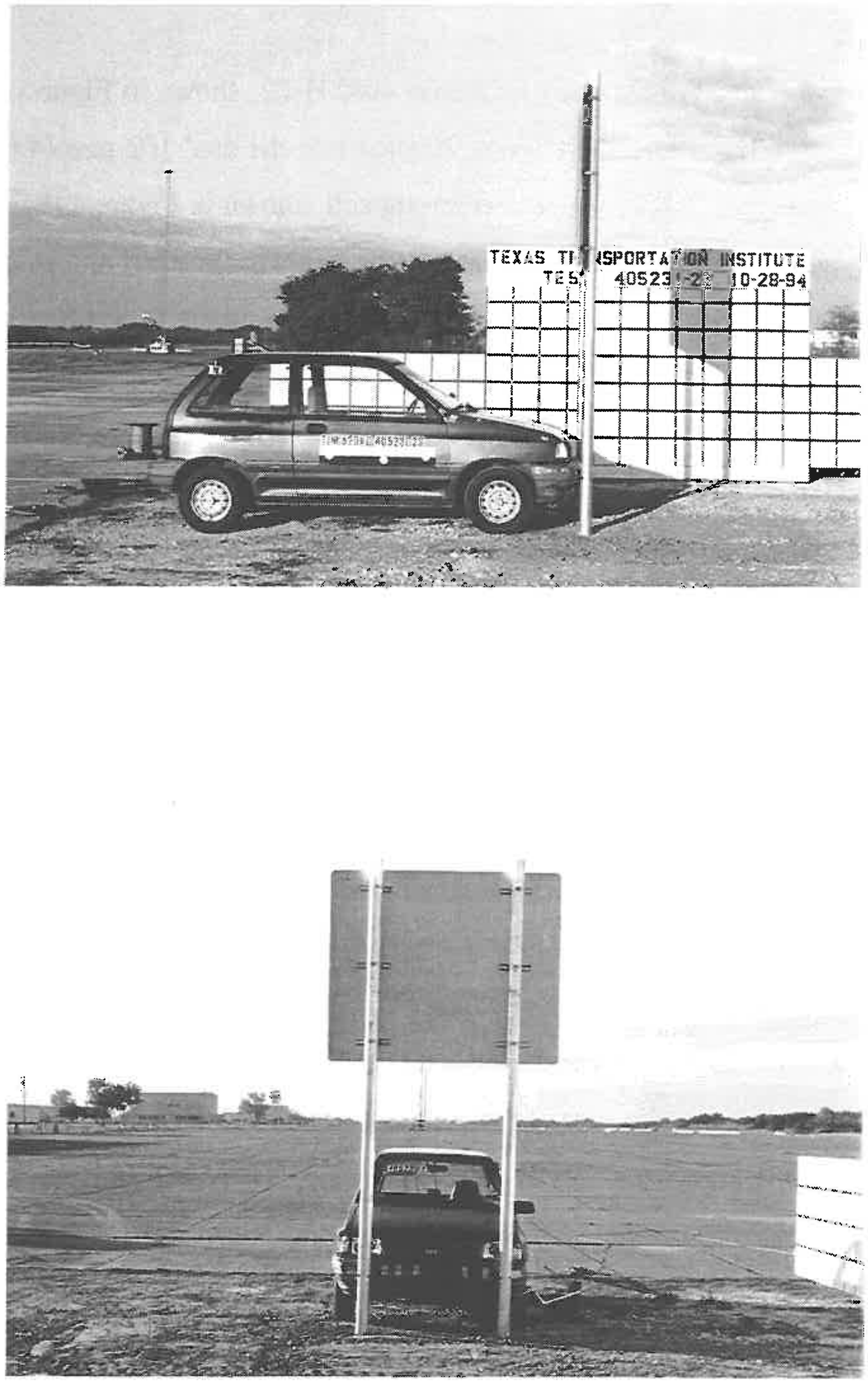


Figure146. Vehicle/sign installation geometrics for test 405231-23.

Figure 147.Vehicle before test 405231-23.

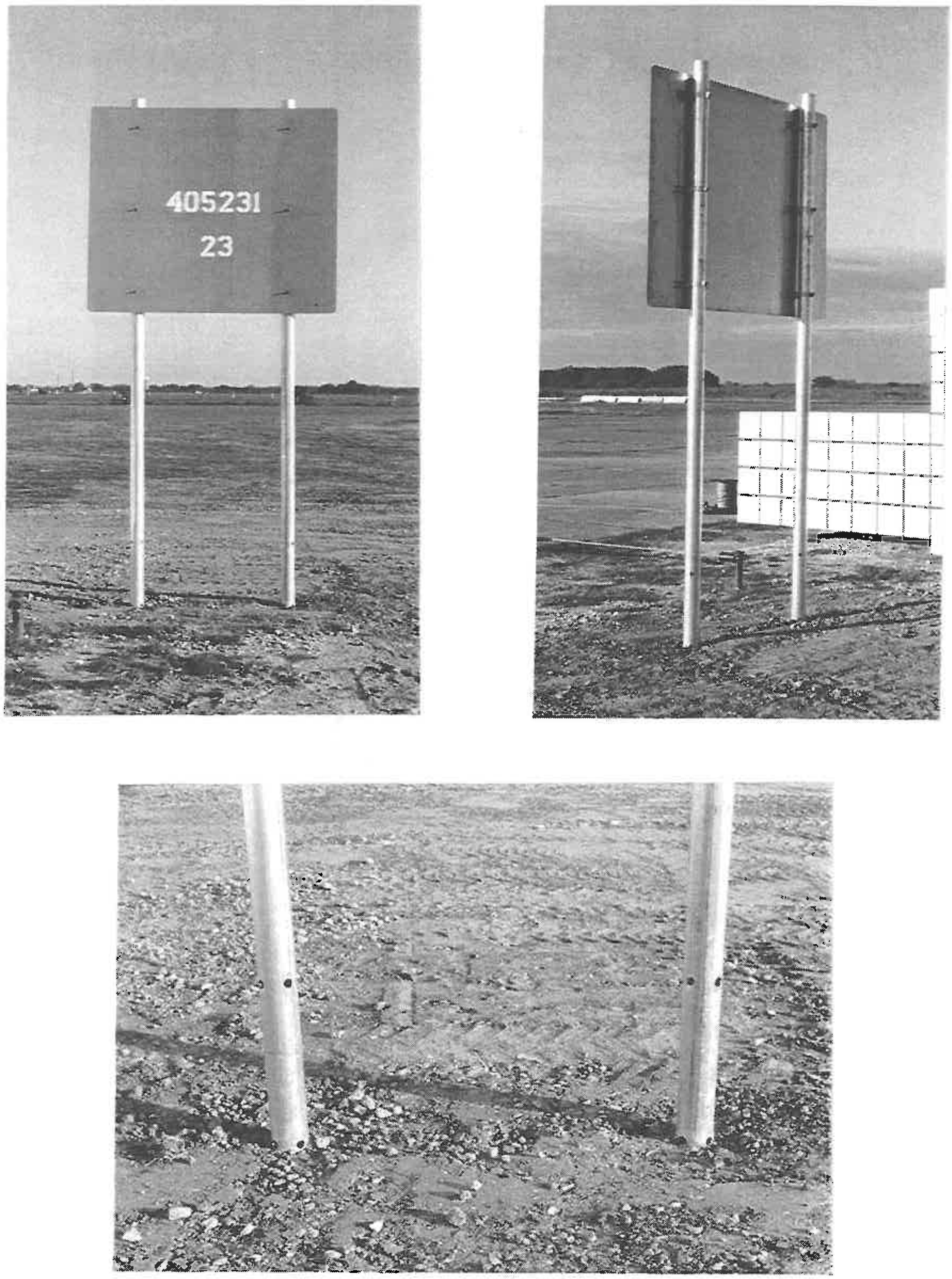


Figure 148 . Dual 4-in with 1-in holes aluminum sign support installation anchored in strong soil before test 405231-23.

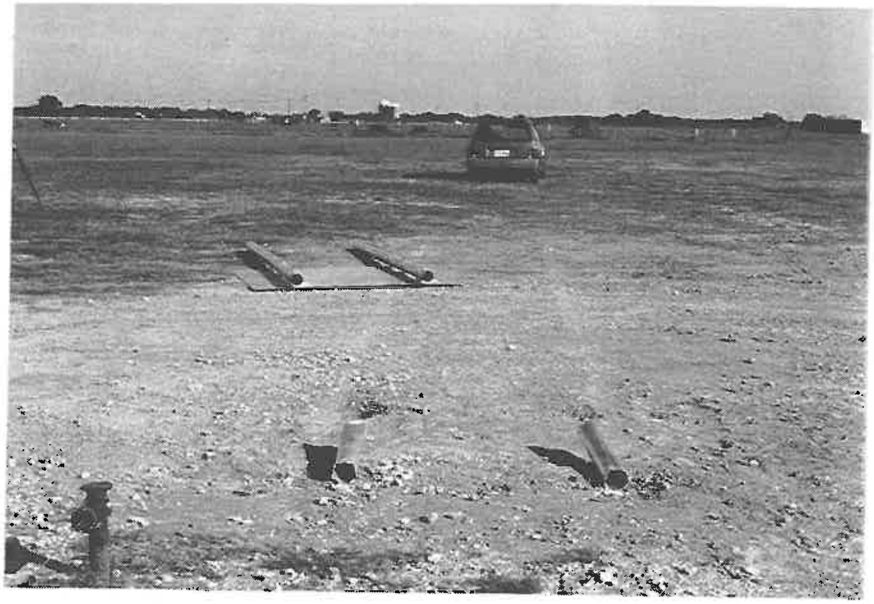


Figure149.Final rest position of the sign installation and vehicle (test 405231-23).

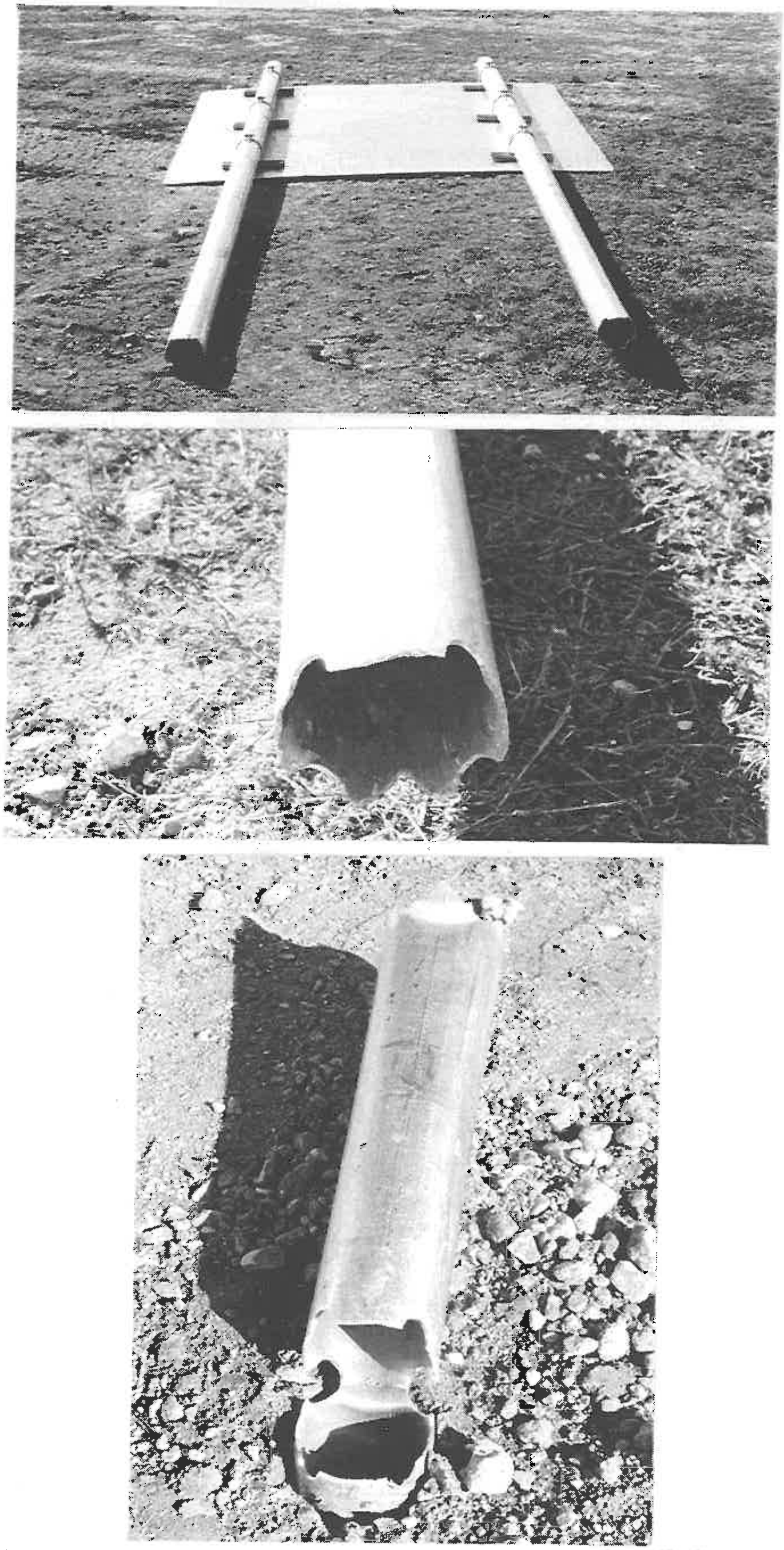


Figure 150 . Dual 4-in with 1-in holes aluminum sign support installation anchored in strong soil after test 405231-23.

hardware received minimal damage and could be reused in field renovation of this installation. Damage sustained by the vehicle during this test is shown in Figure 151. The vehicle sustained minor damage to the bumper and roof. No measurable deformation to the vehicle was recorded. There was no deformation to the vehicle occupant compartment and no intrusion into the compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 1.1 m/s (3.6 ft/s) at 0.564 s, the highest 0.010-s average ridedown acceleration was 0.4 g between 0.685 and 0.695 s, and the maximum 0.050-s average acceleration was -1.6 g between 0.000 and 0.050 s. Lateral occupant impact velocity was -0.5 m/s (-1.6 ft/s) at 0.930 s, the highest 0.010-s occupant ridedown acceleration was 0.3 g between 0.618 and 0.628 s and the maximum 0.050-s average acceleration was 0.6 g between 0.055 and 0.105 s. These data and other pertinent information from the test are summarized in Figure 152. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 22 .

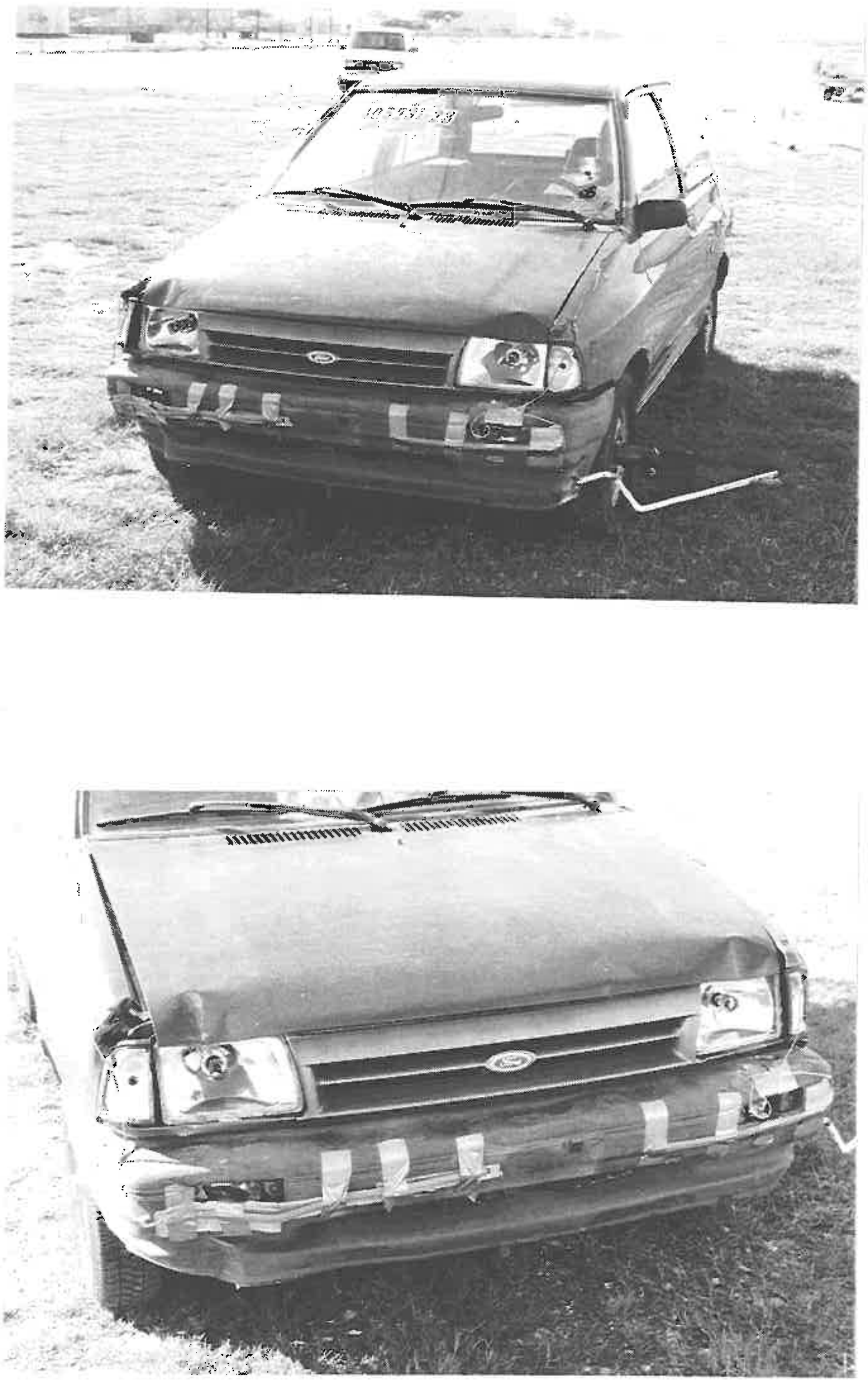
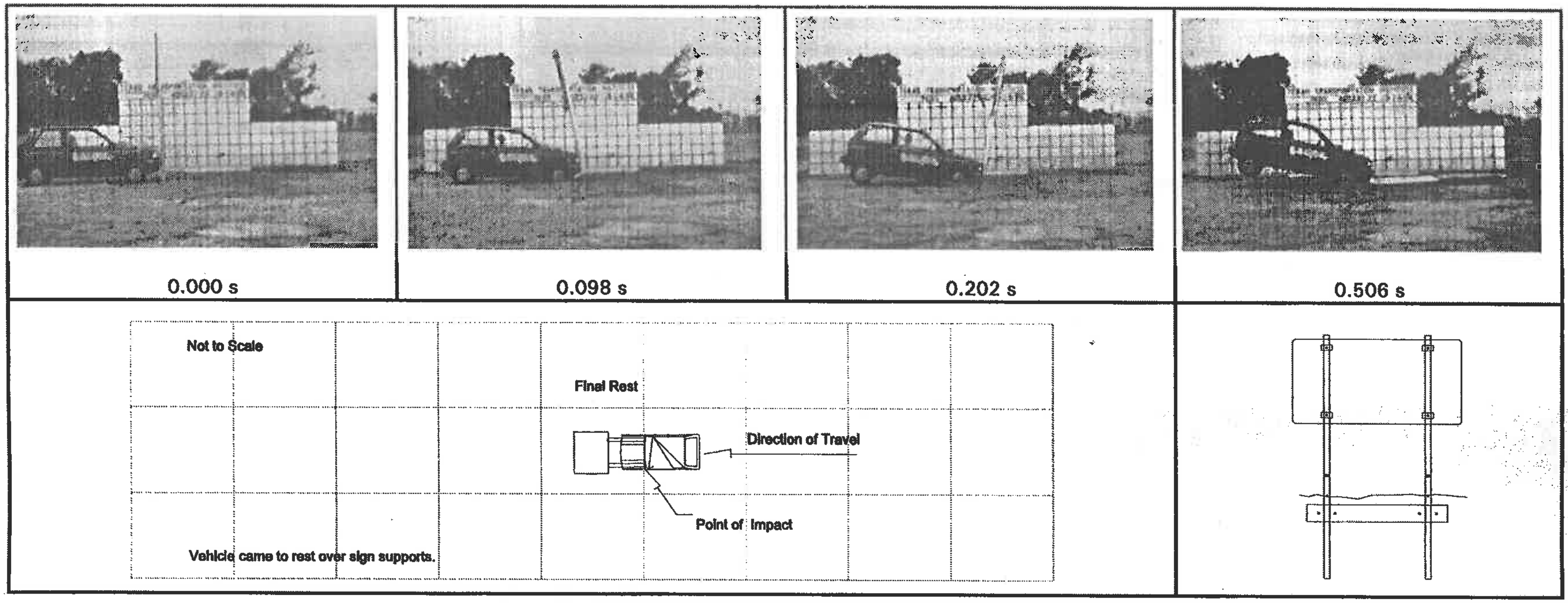


Figure151. Vehicle after test 405231-23.



General Information		**Impact Conditions**		**Test Article Deflections (m)**	
Test Agency	Texas Transportation Institute	Speed (km/h)	33.2 (20.6 mi/h)	Dynamic	N/A
Test No.	405231-23	Angle (deg)	0	Permanent	N/A
Date	10/28/94	**Exit Conditions**			
Test Article		Speed (km/h)	26.8 (16.7 mi/h)	**Vehicle Damage**	
Type	Modified Dual Sign Support	Angle (deg)	0	Exterior	
Key Element	6063-T6 Aluminum Tube	**Occupant Risk Values**		VDS	12FC-1
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)	Impact Velocity (m/s)		CDC	12FDEN1
		x-direction	1.1 (3.6 ft/s)		
Wall Thickness and Diameter of Tube (mm)	3.2 (0.125 in) 101.6 (4.0 in)	y-direction	-0.5 (-1.6 ft/s)	Interior	
		THIV (optional)		OCDI	AS0000000
Soil Type and Condition	Strong, Dry	Ridedown Accelerations (g's)		Maximum Exterior Vehicle Crush (mm)	Nil
Test Vehicle		x-direction	0.4		
Type	Production	y-direction	0.3	Max. Occ. Compart. Deformation (mm)	Nil
Designation	820C	PHD (optional)			
Model	1989 Ford Festiva	ASI (optional)			
Mass (kg) Curb	789 (1739 lb)	Max. 0.050-sec Average (g's)		**Post-Impact Behavior**	
Test Inertial	820 (1808 lb)	x-direction	-1.6	Max. Roll Angle (deg)	2.0
Dummy	76 (168 lb)	y-direction	0.6	Max. Pitch Angle (deg)	-5.8
Gross Static	896 (1975 lb)	z-direction	0.8	Max. Yaw Angle (deg)	3.2

Figure 152. Summary of results for test 405231-23.

Table 22. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-23

Test No.: 405231-23 Test Date: 10/28/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports yielded by fracturing the aluminum tubes at bumper level and partially fracturing and bending at ground level.	Pass
<u>Occupant Risk</u> D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral; Preferred: 3; Maximum: 5	Longitudinal occupant impact velocity: 1.1 m/s (3.6 ft/s) Lateral occupant impact velocity: -0.5 m/s (-1.6 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral; Preferred: 15; Maximum: 20	Longitudinal Occupant Ridedown Acceleration: 0.4 g's Lateral Occupant Ridedown Acceleration: 0.3 g's	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

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Modified Dual 102 mm (4-inch) diameter aluminum support anchored in strong soil - 100 km/h (62.2 mi/h)

- **Test 405231-24**

The same 1989 Ford Festiva used in test 405231-23, shown in Figures 153 and 154, was reused for this crash test. The vehicle was directed into the dual 102 mm (4.0 in) diameter aluminum support sign installation anchored in strong soil, shown in Figure 155, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The sign supports were modified by drilling four 25 mm (1.0 in) holes in the supports at two different elevations along each support. The two elevations of four holes each were drilled at ground level and 457 mm (18.0 in) above ground level. The holes were oriented 90 degrees with respect to each other and 45 degrees with respect to the plane of the sign panel. The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 98.3 km/h (61.1 mi/h) and a zero degree heading angle.

Upon impact the support began to deflect toward the ground. As the vehicle continued traveling forward, the right support began to fracture at bumper height at 0.005 seconds. Subsequently, the left support fractured at bumper height at 0.007 seconds. As the vehicle traveled over the stubs, the vehicle pushed the supports and attached sign panel up and over the hood and roof of the vehicle. The vehicle lost contact with the supports at 0.040 seconds. The sign installation rotated 270 degrees over the vehicle and came to rest 3.0 m (10.0 ft) from the point of impact. The vehicle lost contact with the installation traveling 94.7 km/h (58.9 mi/h), the brakes were applied, and the vehicle came to rest upright 109.5 m (359.0 ft) downstream and 4.6 m (15.0 ft) from the point of impact Final rest positions of the vehicle and sign installation are shown in Figure 156. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 157, the supports were bent and fractured. The left and right supports failed in tension across their entire cross-sections at the holes located near bumper height. In addition, the right support failed in tension across all but the most rearward part of its cross-section at the holes located at ground level. The left support failed the entire cross-section at the holes located at ground level. The sign panel and all mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. Damage sustained to the vehicle during this test is shown in Figure 158. The vehicle sustained minor damage to the

Figure153.Vehicle/sign installation geometrics for test 405231-24.

Figure154.Vehicle before test 405231-24.

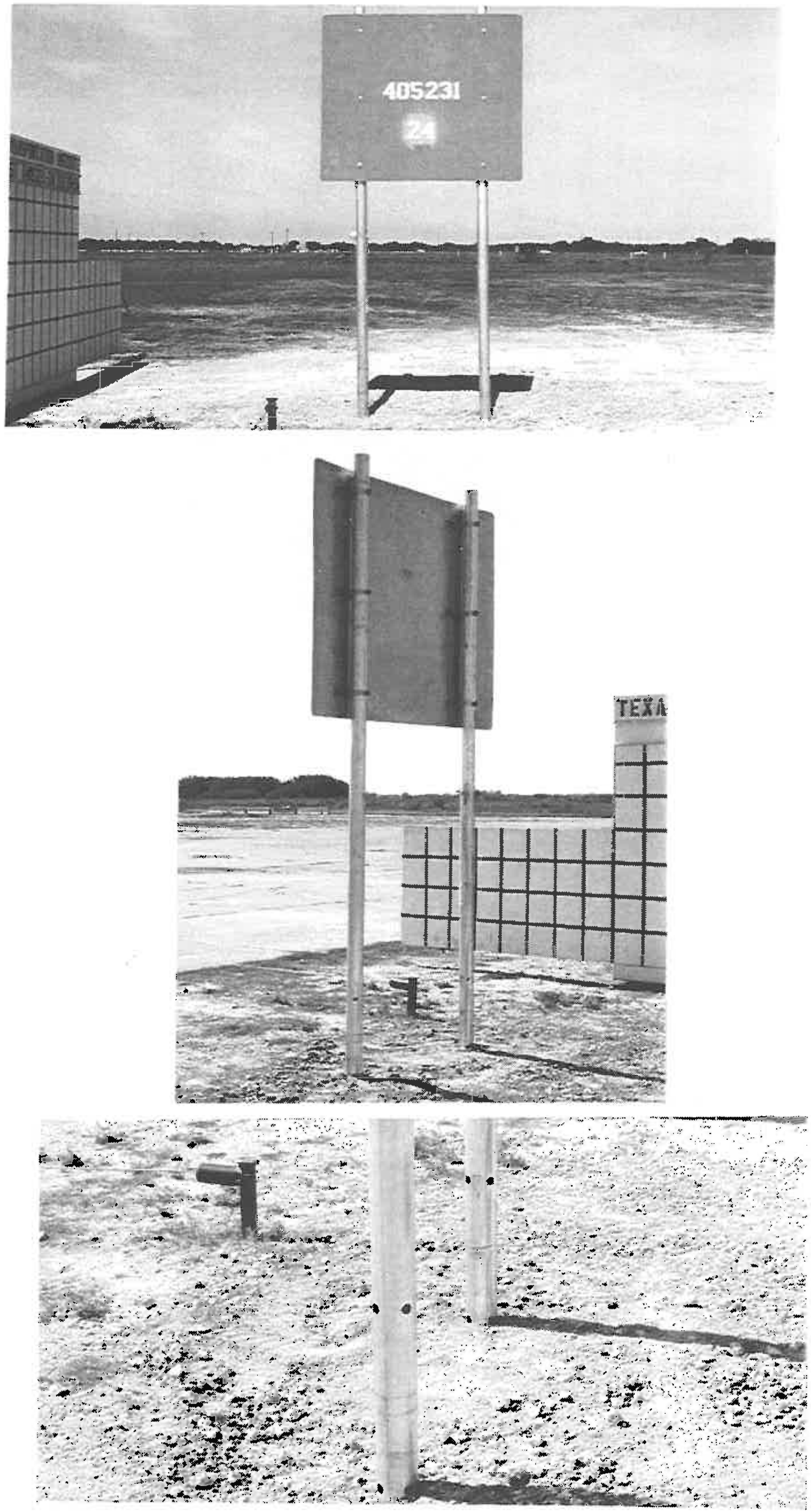


Figure 155 . Dual 4-in with 1-in holes aluminum sign support installation anchored in strong soil before test 405231-24.

Figure156.Final rest position of the sign installation and vehicle (test 405231-24).

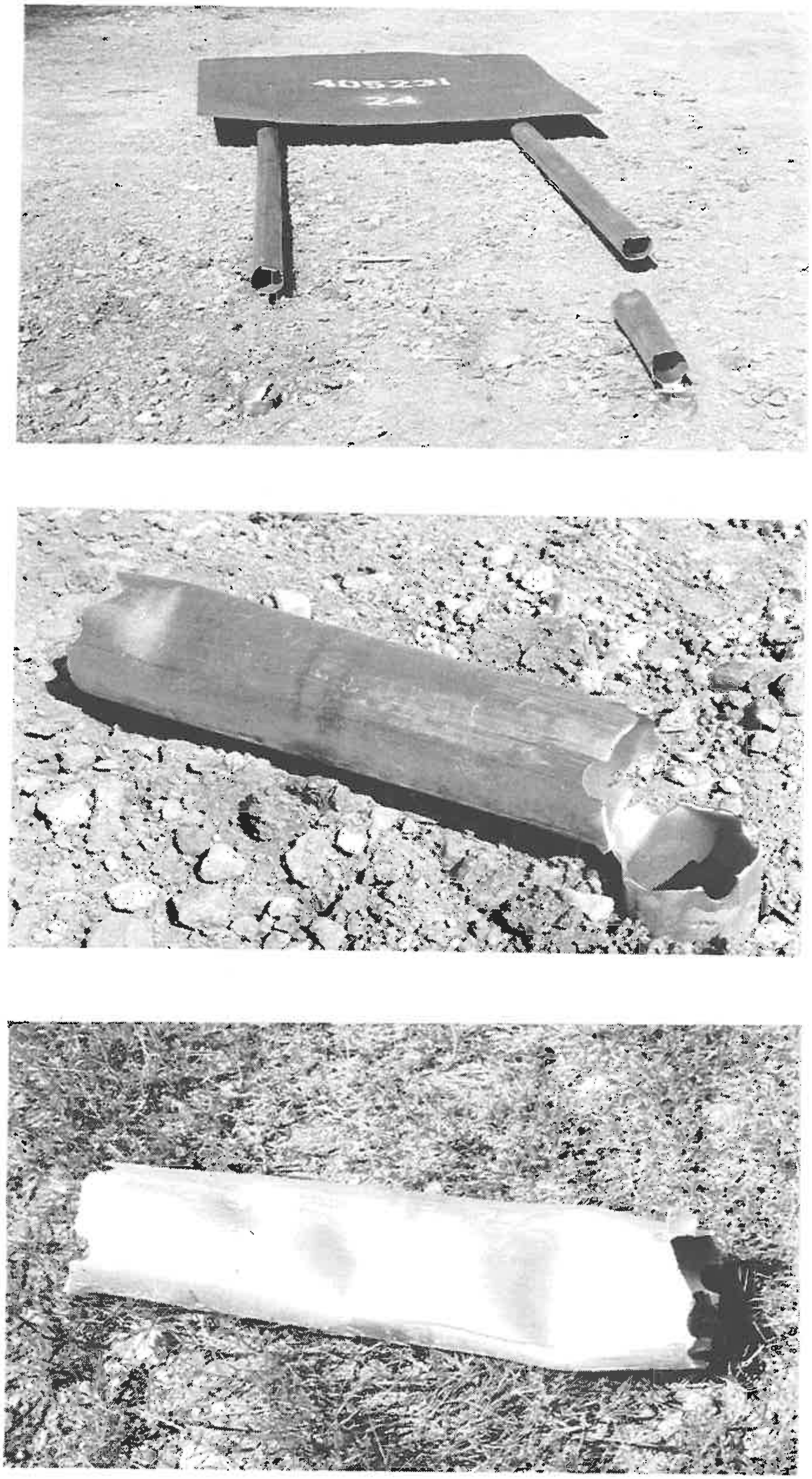


Figure 157 . Dual 4-in with 1-in holes aluminum sign support installation anchored in strong soil after test 405231-24.

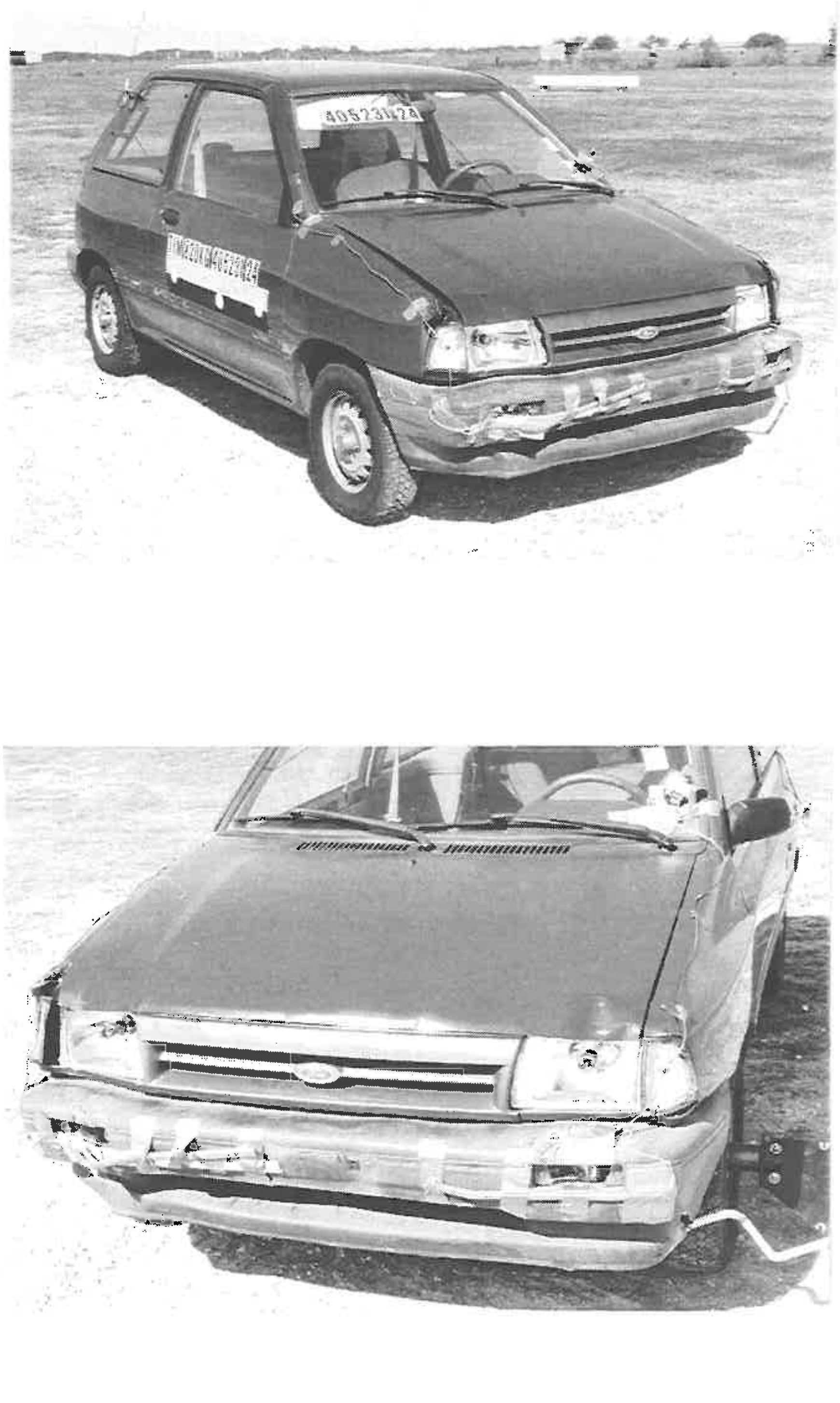
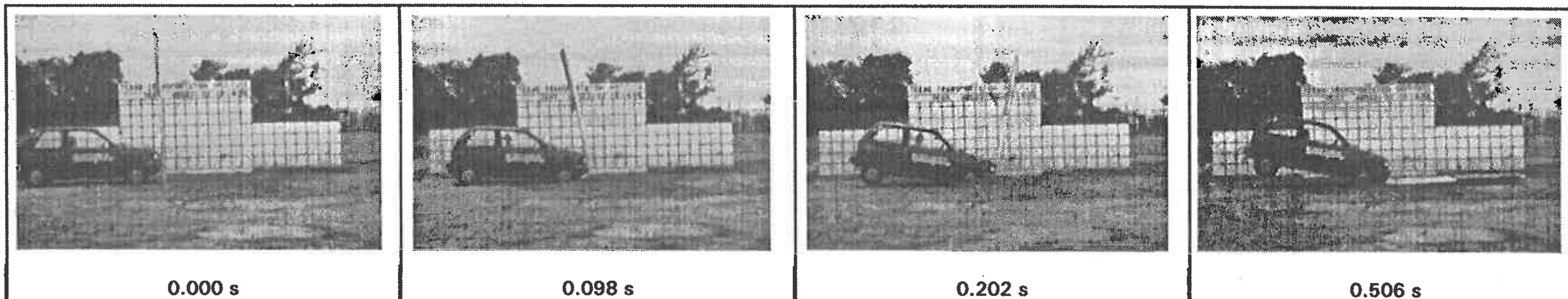
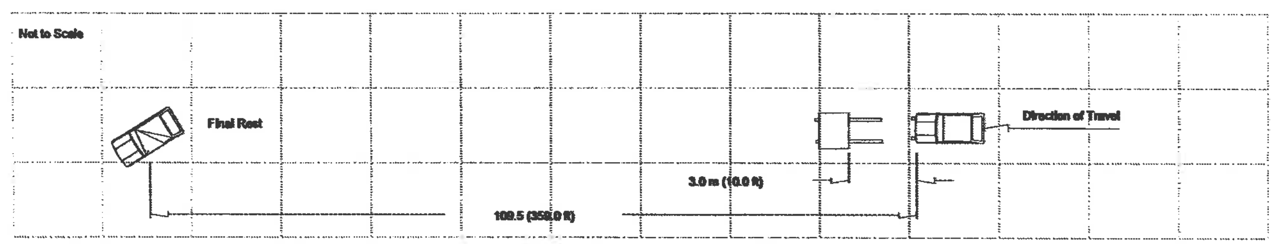


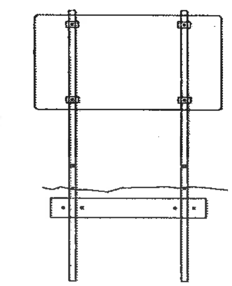
Figure158.Vehicle after test 405231-24.

bumper only. No measurable deformation to the vehicle was recorded. There was no deformation to, or intrusion into, the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 0.6 m/s (2.0 ft/s) at 0.861 s, the highest 0.010-s average ridedown acceleration was 0.4 g between 1.286 s and 1.296 s, and the maximum 0.050-s average acceleration was -1.2 g between 0.004 and 0.054 s. Lateral occupant impact velocity was 0.7 m/s (2.2 ft/s) at 0.865 s, the highest 0.010-s occupant ridedown acceleration was 0.5 g between 1.193 and 1.203 s and the maximum 0.050-s average acceleration was -0.4 g between 0.051 and 0.101 s. These data and other pertinent information from the test are summarized in Figure 159. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 23.







General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-24
Date	10/28/94
Test Article	
Type	Modified Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Strong, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	789 (1739 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	98.3 (61.1 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	94.7 (58.9 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	0.6 (2.0 ft/s)
y-direction	0.7 (2.2 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	0.4
y-direction	0.5
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-1.2
y-direction	-0.4
z-direction	-1.2

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	3.1
Max. Pitch Angle (deg)	6.4
Max. Yaw Angle (deg)	1.6

Figure 159. Summary of results for test 405231-24.

Table 23. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-24

Test No.: 405231-24 | Test Date: 10/28/94 | Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports yielded by fracturing the aluminum tubes at bumper level. The left support was fractured and the right support only partially fractured at ground level.	Pass
Occupant Risk D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral — Preferred: 3 — Maximum: 5	Longitudinal occupant impact velocity: 0.6 m/s (2.0 ft/s) Lateral occupant impact velocity: 0.7 m/s (2.2 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral — Preferred: 15 — Maximum: 20	Longitudinal Occupant Ridedown Acceleration: -0.9 g's Lateral Occupant Ridedown Acceleration: -0.5 g's	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Modified Dual 102 mm (4 in) diameter aluminum support anchored in weak soil - 35 km/h (21.8 mi/h)

- ***Test 405231-25***

The same 1989 Ford Festiva used in test 405231-24, shown in Figures 160 and 161, was reused for this crash test. The vehicle was directed into the dual 102 mm (4.0 in) diameter aluminum support sign installation anchored in weak soil, shown in Figure 162, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The sign supports were modified by drilling four 25 mm (1.0 in) holes in the supports at two different elevations along each support. The two elevations of four holes each were drilled at ground level and 457 mm (18.0 in) above ground level. The holes were oriented 90 degrees with respect to each other and 45 degrees with respect to the plane of the sign panel. The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 32.9 km/h (20.4 mi/h) and a zero degree heading angle.

Upon impact the supports began to deflect at ground level and at bumper height. As the vehicle continued traveling forward, the right and left supports began to fracture near the upper holes at 0.027 and 0.029 seconds, respectively. The sign installation rotated over the front of the vehicle and lost contact with the vehicle at 0.142 seconds. The vehicle came back into contact with the supports at 0.216 seconds. The sign installation continued to rotate over the front of the vehicle and shortly thereafter, the sign panel struck the roof of the vehicle at 0.022 seconds. The vehicle lost contact with the sign panel temporarily at 0.468 seconds. The vehicle exited the installation with the sign panel and supports still in contact with the front of the vehicle. The final rest position of the sign installation was 15.5 m (51.0 ft) from the point of impact. The vehicle came to rest upright 20.1 m (66.0 ft) downstream and 0.6 m (2.0 ft) left of the point of impact. Final rest positions of the vehicle and sign installation are shown in Figure 163. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 164, the supports were bent and fractured. The left and right supports failed in tension across their entire cross-section at the upper holes. At ground level, the supports were displaced rearward 279 mm (11.0 in). The sign panel and all mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. Damage sustained by the vehicle during this test is shown in Figure 165. The vehicle sustained

Figure 160. Vehicle/sign geometrics for test 405231-25.

Figure 161. Vehicle before test 405231-25.

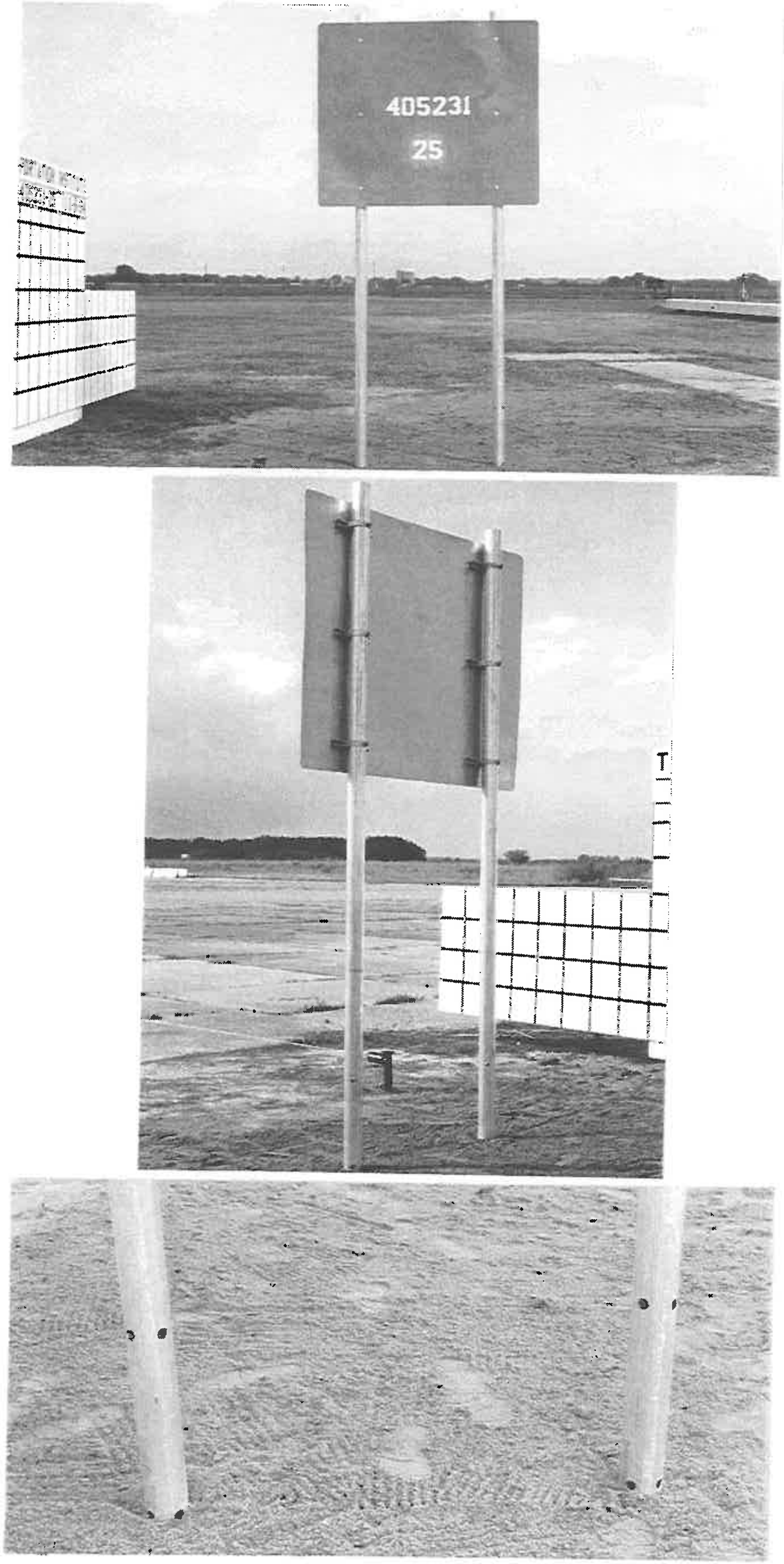


Figure 162. Dual 4-in with 1-in holes aluminum sign support anchored in weak soil before test 405231-25.

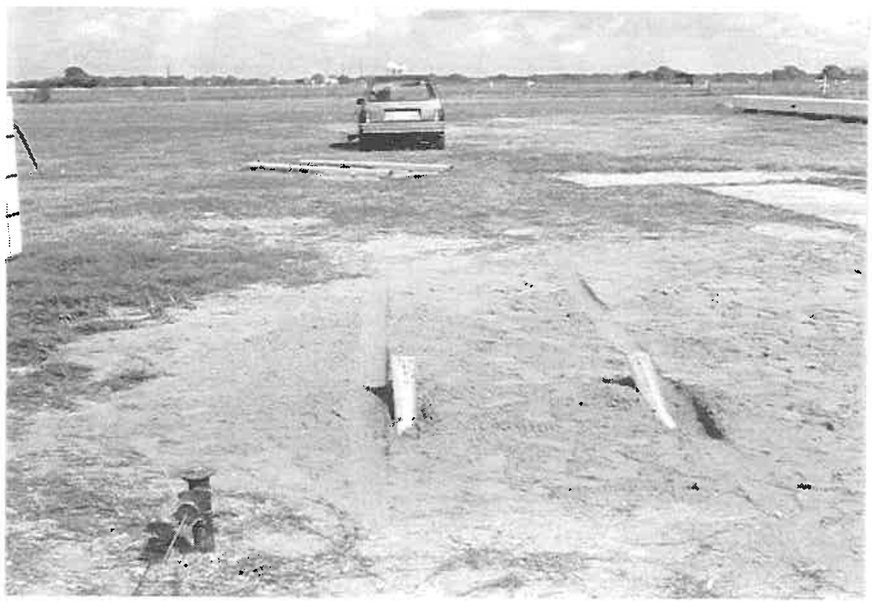
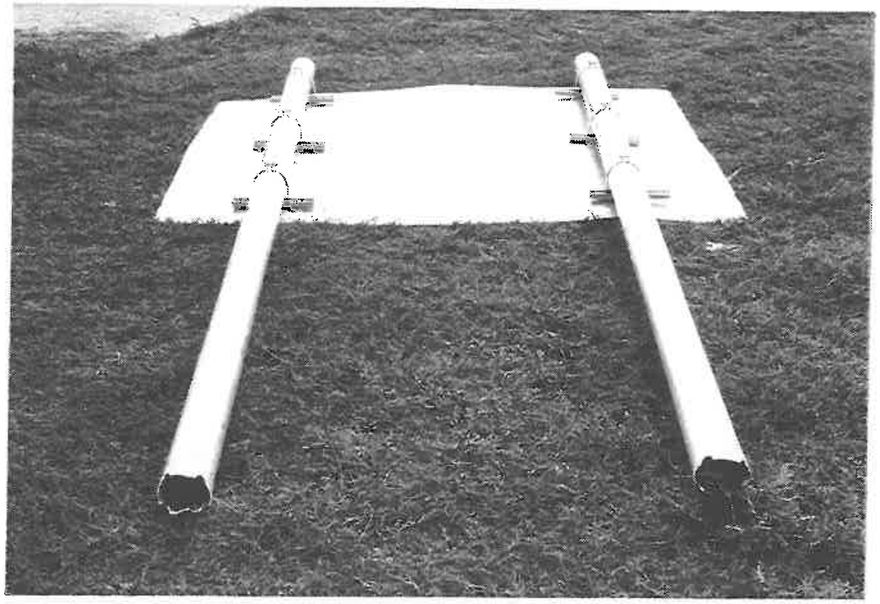


Figure 163 . Final rest position of sign installation and vehicle (test 405231-25).



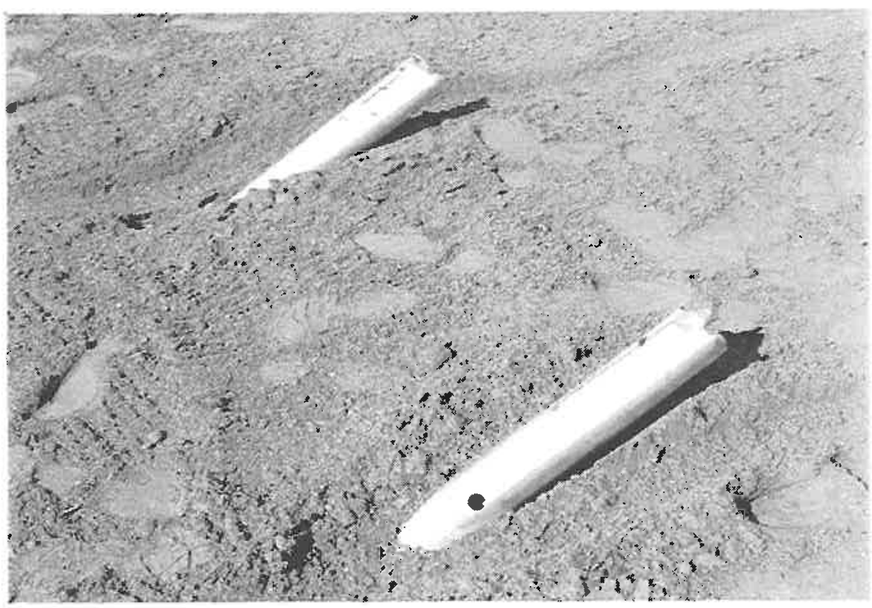
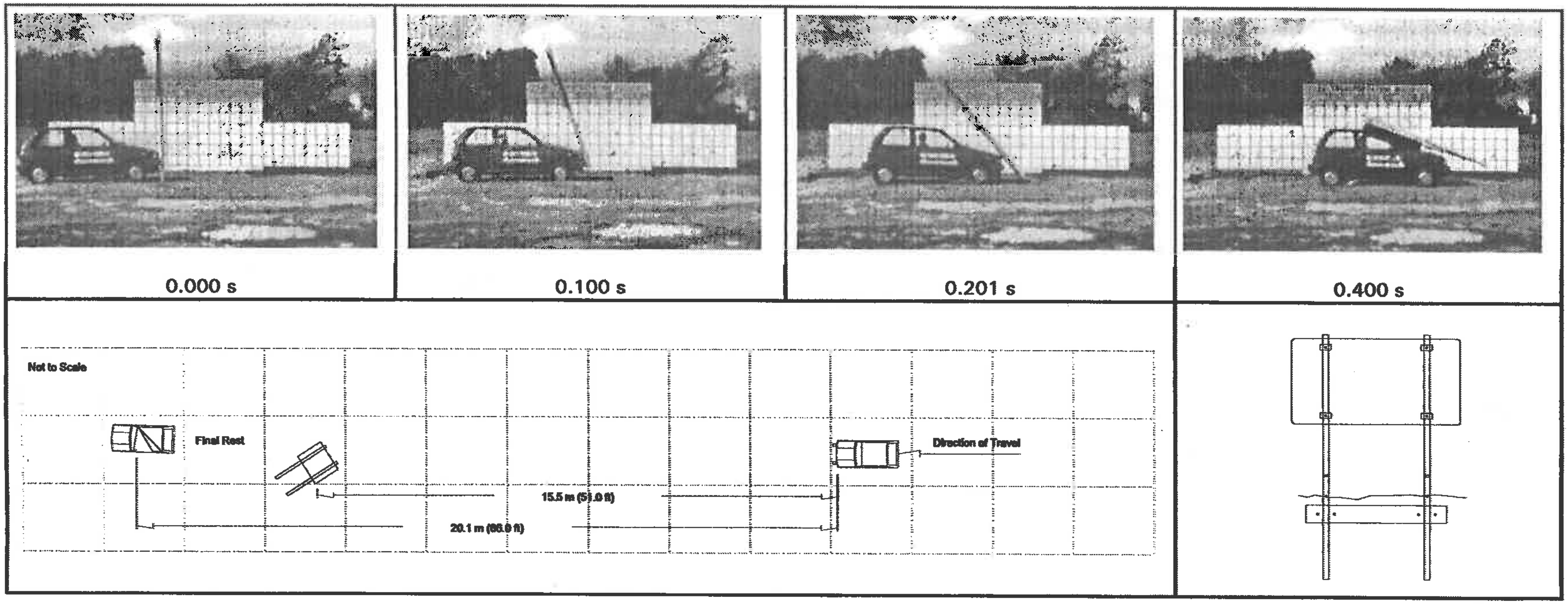


Figure 164 . Dual 4-in with 1-in holes aluminum sign support anchored in weak soil after test 405231-25.

Figure 165 . Vehicle after test 405231-25.

minor damage to the bumper, hood and roof. The upper right side of the windshield was struck and broken. The roof was deformed 7 mm (0.3 in). There was no deformation to, or intrusion into, the vehicle occupant compartment.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 2.3 m/s (7.6 ft/s) at 0.342 s, the highest 0.010-s average ridedown acceleration was -0.9 g between 0.446 and 0.456 s, and the maximum 0.050-s average acceleration was -2.3 g between 0.003 and 0.053 s. Lateral occupant impact velocity was -0.5 m/s (-1.5 ft/s) at 1.029 s, the highest 0.010-s occupant ridedown acceleration was 0.7 g between 0.392 and 0.402 s and the maximum 0.050-s average acceleration was 0.3 g between 0.065 and 0.115 s. These data and other pertinent information from the test are summarized in Figure 166. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 24.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-25
Date	11/08/94
Test Article	
Type	Modified Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	789 (1739 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	32.9 (20.4 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	24.1 (15.0 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.3 (7.6 ft/s)
y-direction	- 0.5 (-1.5 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.9
y-direction	0.7
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-2.3
y-direction	0.3
z-direction	0.9

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	2.2
Max. Pitch Angle (deg)	-8.8
Max. Yaw Angle (deg)	1.6

Figure166. Summary of results for test 405231-25.

Table 24. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-25

Test No.: 405231-25 Test Date: 11/08/94 Test Agency: Texas Transportation Institute

<table>
<tr><th>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 sign supports yielded by fracturing the aluminum tubes at bumper level. In addition, the supports were bent and pushed rearward at ground level.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.</td><td>The sign supports fractured but did not present a hazard to other travel lanes. There was no deformation of 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 throughout the test period.</td><td>Pass</td></tr>
<tr><td>H. Occupant impact velocities should satisfy the following:
<table><tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>3</td><td>5</td></tr></table></td><td>Longitudinal occupant impact velocity: 2.3 m/s (7.6 ft/s)
Lateral occupant impact velocity: -0.5 m/s (-1.5 ft/s)</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following
<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits (G's)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15</td><td>20</td></tr></table></td><td>Longitudinal Occupant Ridedown Acceleration: -0.9 g's
Lateral Occupant Ridedown Acceleration: 0.7 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 trajectory was judged to be acceptable.</td><td>Pass</td></tr>
</table>

Modified Dual 102 mm (4 in) diameter support anchored in weak soil - 100 km/h (62.2 mi/h)

- **Test 405231-26**

The same 1989 Ford Festiva used in test 405231-25, shown in Figures 167 and 168. was reused for this crash test. The vehicle was directed into the dual 102 mm (4.0 in) diameter aluminum support sign installation anchored in weak soil, shown in Figure 169, using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The sign supports were modified by drilling four 25 mm (1.0 in) holes in the support at two different elevations along each support. The two elevations of four holes each were drilled at ground level and 457 mm (18.0 in) above ground level. The holes were oriented 90 degrees with respect to each other and 45 degrees with respect to the plane of the sign panel. The vehicle impacted the centerline of the sign supports with the centerline of the vehicle at a speed of 101.7 km/h (63.2 mi/h) and a zero degree heading angle.

Upon impact the supports began to deflect at the ground and bumper height. As the vehicle continued traveling forward, the right support began to fracture near the upper holes at 0.005 seconds ; the left support began to fracture near the upper holes at 0.010 seconds. As the vehicle traveled over the stubs, the vehicle pushed the supports and attached sign panel upward and over the hood and roof of the vehicle. The vehicle lost contact with the supports at 0.039 seconds. The sign installation rotated 270 degrees over the vehicle and came to rest 3.3 m (10.7 ft) from the point of impact. The vehicle lost contact with the installation traveling 98.6 km/h (61.3 mi/h). The brakes were applied, and the vehicle came to rest upright 102.3 m (335.5 ft) downstream from the point of impact Final rest positions of the vehicle and sign installation are shown in Figure 170. Sequential photographs of the crash test are shown in Appendix B.

As shown in Figure 171, the supports were bent and fractured. The left and right supports failed in tension across their entire cross-section at the upper holes. The sign panel and all mounting and anchoring hardware received minimal damage and could be reused in field renovation of this installation. Damage sustained by the vehicle during this test is shown in Figure 172. The vehicle sustained minor damage to the bumper and hood. No measurable deformation to the vehicle was recorded. There was no deformation to, or intrusion into, the vehicle occupant compartment.

Figure 167 . Vehicle/sign geometrics for test 405231-26.

Figure 168 . Vehicle before test 405231-26.

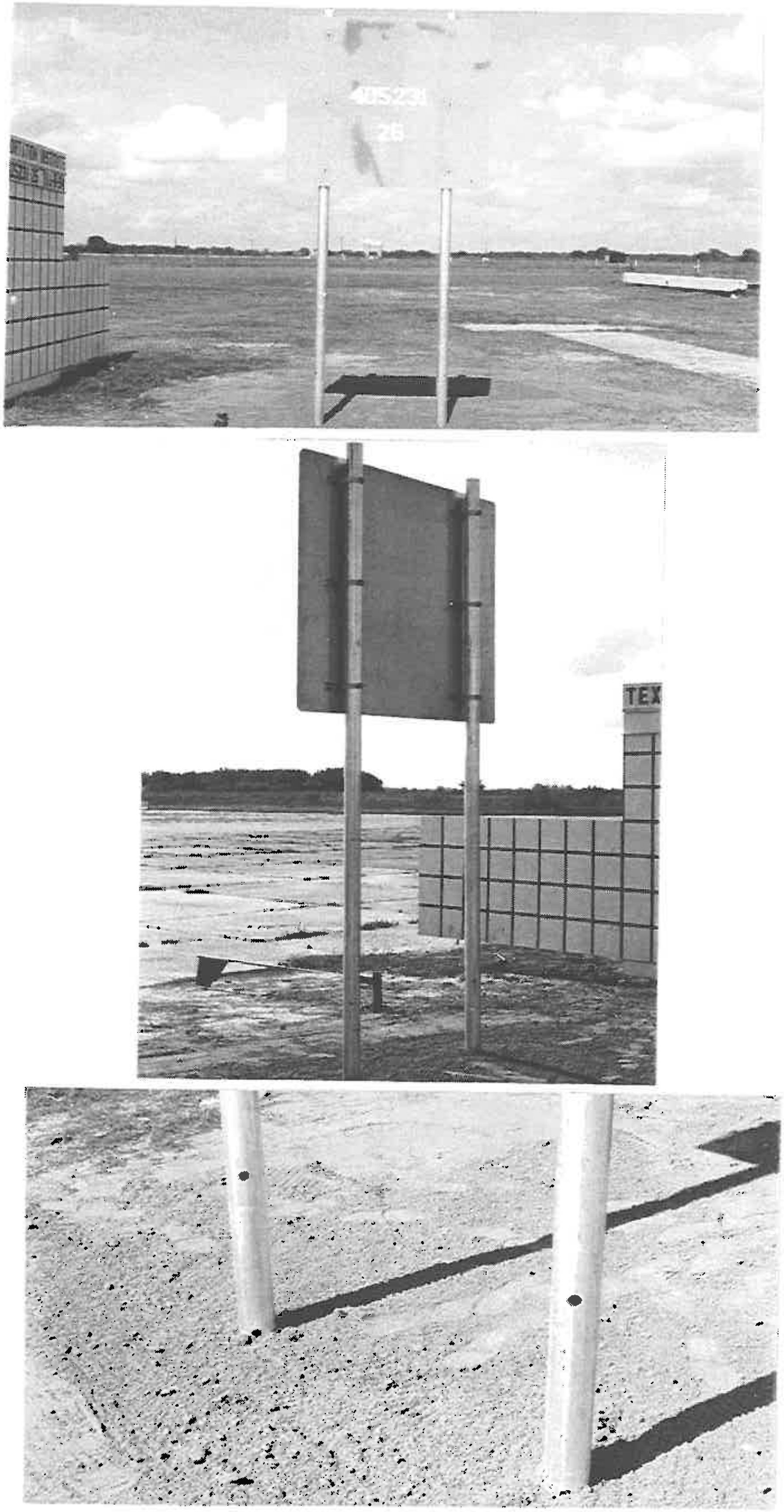


Figure 169 . Dual 4-in with 1-in holes aluminum sign support anchored in weak soil before test 405231-26.

Figure 170. Final rest position of sign installation and vehicle (test 405231-26).

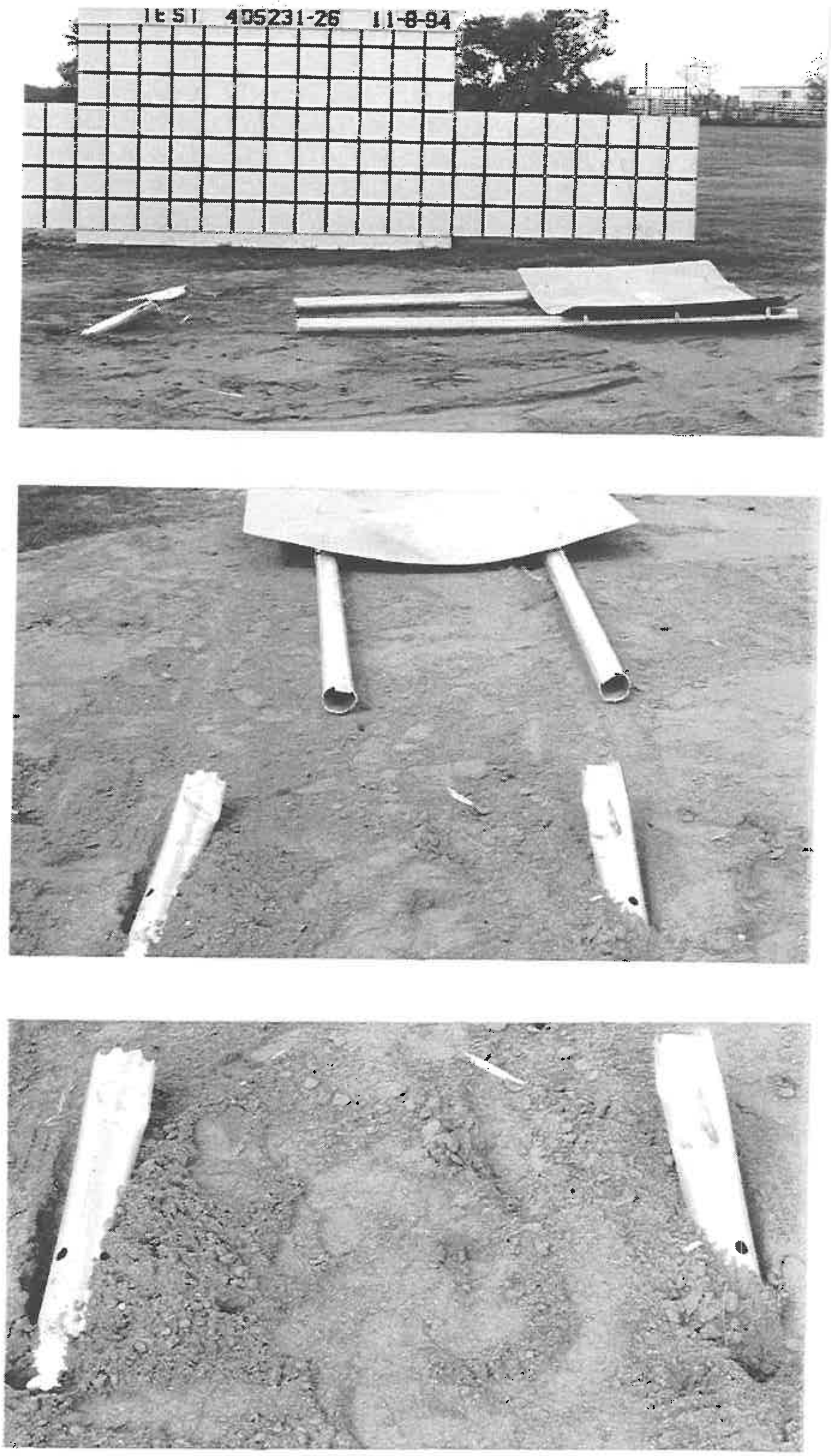
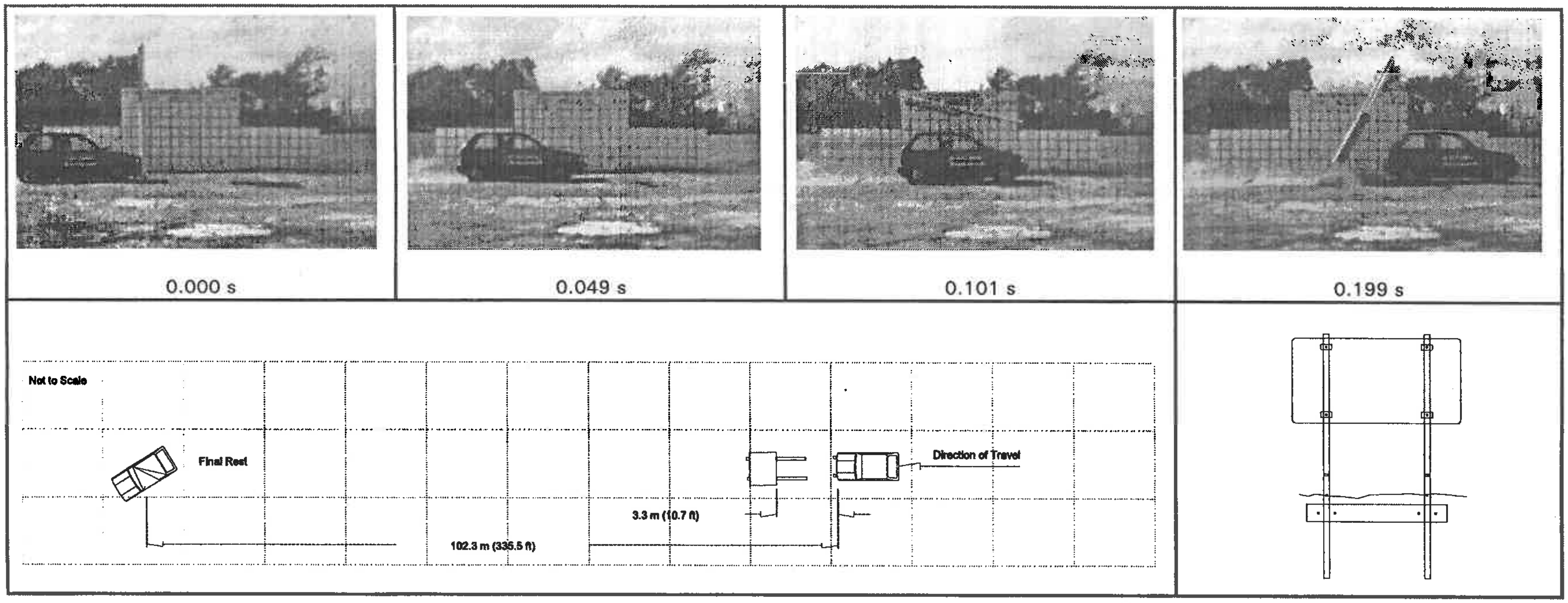


Figure 171. Dual 4-in with 1-in holes aluminum sign support anchored in weak soil after test 405231-26.

Figure 172 . Vehicle after test 405231-26.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 0.8 m/s (2.5 ft/s) at 0.701 s, the highest 0.010-s average ridedown acceleration was 0.4 g between 0.786 s and 0.796 s, and the maximum 0.050-s average acceleration was -1.9 g between 0.001 and 0.051 s. Lateral occupant impact velocity was -0.8 m/s (-2.6 ft/s) at 1.115 s, the highest 0.010-s occupant ridedown acceleration was 0.7 g between 0.745 and 0.755 s and the maximum 0.050-s average acceleration was -0.7 g between 0.008 and 0.058 s. These data and other pertinent information from the test are summarized in Figure 173. Vehicular angular displacements are displayed in Appendix C. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Appendix D. The NCHRP Report 350 evaluation criteria and the assessment of the performance of this installation with respect to those criteria are presented in Table 25.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405231-26
Date	11/08/94
Test Article	
Type	Modified Dual Sign Support
Key Element	6063-T6 Aluminum Tube
Height to Bottom of Sign Panel (m)	2.1 (7.0 ft)
Wall Thickness and	3.2 (0.125 in)
Diameter of Tube (mm)	101.6 (4.0 in)
Soil Type and Condition	Weak, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	789 (1739 lb)
Test Inertial	820 (1808 lb)
Dummy	76 (168 lb)
Gross Static	896 (1975 lb)

Impact Conditions	
Speed (km/h)	101.7 (63.2 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	98.6 (61.3 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	0.8 (2.5 ft/s)
y-direction	-0.8 (-2.6 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	0.4
y-direction	0.7
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-1.9
y-direction	-0.7
z-direction	-1.2

Test Article Deflections (m)	
Dynamic	N/A
Permanent	N/A
Vehicle Damage	
Exterior	
VDS	12FC-1
CDC	12FDEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	Nil
Max. Occ. Compart. Deformation (mm)	Nil
Post-Impact Behavior	
Max. Roll Angle (deg)	3.9
Max. Pitch Angle (deg)	-6.9
Max. Yaw Angle (deg)	3.2

Figure 173. Summary of results for test 405231-26.

Table 25. Assessment of compliance with NCHRP Report 350 evaluation criteria for test 405231-26

Test No.: 405231-26 Test Date: 11/08/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The sign supports yielded by fracturing the aluminum tubes at bumper level. In addition, the supports were bent and pushed rearward at ground level.	Pass
<u>Occupant Risk</u> D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The sign supports fractured but **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral; Preferred: 3; Maximum: 5	Longitudinal occupant impact velocity: 0.8 m/s (2.5 ft/s) Lateral occupant impact velocity: -0.8 m/s (-2.6 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and Lateral; Preferred: 15; Maximum: 20	Longitudinal Occupant Ridedown Acceleration: 0.4 g's Lateral Occupant Ridedown Acceleration: 0.7 g's	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

CONCLUSIONS AND RECOMMENDATIONS

Dual aluminum support sign installations (3.2 mm x 76 mm and 3.2 mm x 102 mm) and Marion 3.7 kg/m and 4.5 kg/m steel U-channel dual support sign installations were crash tested and evaluated in this study. A 102 mm (4.0 in) single aluminum support sign installation was also tested and evaluated. Performance evaluation summaries of all the crash tests performed are presented in Tables 26 and 27.

Aluminum Support Sign Installations

- *Dual 76 mm (3.0 in) diameter aluminum support sign installation - test nos. 1-4*

The dual 76 mm (3.0 in) diameter aluminum supports with 3.2 mm (0.125 in) wall thicknesses performed satisfactorily in the crash tests conducted in both weak and strong soil. In summary, the 76 mm (3.0 in) diameter aluminum sign support installation yielded to the impacting vehicle through failure of the supports near bumper height. The detached elements of the sign installation were safely displaced away and did not present a secondary hazard to other motorists. The vehicles sustained minor damages in the low-speed tests and moderate to severe roof damage in the high-speed tests. Although damage sustained by vehicle roofs in the high-speed tests did deform the occupant compartments, the extent of the damage was not considered to be life threatening. Additionally, the vehicle remained stable throughout the collision sequences without exhibiting any instability or tendency to roll. The occupant impact velocities and ridedown accelerations were well within the current recommended limits of 5.0 m/s (16.4 ft/s) and 20 g's, respectively. This sign installation is considered acceptable according to the criteria presented in NCHRP Report 350.

- *Dual 102 mm (4.0 in) diameter aluminum support sign installation - test no. 5*

The dual 102 mm (4.0 in) diameter aluminum supports with 3.2 mm (0.125 in) wall thicknesses performed unsatisfactorily in this low-speed crash test conducted in strong soil. No additional tests were performed on this installation. In this test, the 102 mm (4.0 in) diameter aluminum support sign installation yielded to the impacting vehicle through failure of the right support and partial failure of the left support near bumper height. The detached elements of the sign installation were safely displaced away and did not present a secondary hazard to other motorists. The vehicles sustained very minor damage in the test. Additionally, the vehicle remained stable throughout the collision sequence without exhibiting any instability or tendency to roll over. However, the occupant impact velocity (7.1 m/s) in the longitudinal direction was above the recommended 5.0 m/s. Occupant impact velocity in the lateral direction and the ridedown accelerations were well below the current recommended limits of 5.0 m/s (16.4 ft/s) and 20 g's, respectively. Because of excessive longitudinal occupant impact velocity, this sign installation is considered unacceptable according to the criteria presented in NCHRP Report 350.

- *Modified Dual 102 mm (4.0 in) diameter aluminum support sign installation - test nos. 16, 17, & 22*

The dual 102 mm (4.0 in) diameter aluminum supports with 3.2 mm (0.125 in) wall thicknesses were modified as shown in Figure 95. The sign supports were modified by drilling two 38 mm (1.5 in) holes in the support cross-section at two different elevations along each support (4 holes total). The two elevations of four holes each were drilled at ground level and 457 mm (18.0 in) up from ground level. The holes drilled at ground level were oriented 90 degrees to the plane of the sign panel or parallel to the direction of impact. The holes drilled 457 mm (18.0 in) above ground level were oriented parallel to the plane of the sign panel or transverse to the direction of impact. The 102 mm (4.0 in) diameter aluminum support sign installation, when modified as described above, performed satisfactorily in both the low-speed and high-speed crash tests (16 and 17) conducted in strong soil. A low-speed test (22) performed in weak soil produced unsatisfactory results.

In summary, the dual 102 mm (4.0 in) diameter aluminum support sign installation in strong soil yielded to the impacting vehicle through failure of the supports at ground level. The detached elements of the sign installation were safely displaced away and did not present a secondary hazard to other motorists. The vehicles sustained minor damage in both the low-speed and high-speed test. Additionally, the vehicle remained stable throughout the collision sequence without exhibiting any instability or tendency to roll over in either test. The occupant impact velocities and ridedown accelerations were well within the current recommended limits of 5.0 m/s (16.4 ft/s) and 20 g's, respectively. This sign installation, when installed in strong soil, is considered acceptable according to the criteria presented in NCHRP Report 350.

The dual 102 mm (4.0 in) diameter aluminum supports with 3.2 mm (0.125 in) wall thicknesses performed unsatisfactorily in the low-speed test conducted in weak soil. A high-speed test in weak soil was not performed on this installation. In summary, the dual 102 mm (4.0 in) diameter aluminum support sign installation in weak soil yielded to the impacting vehicle through partial failure of the right and left supports near bumper height and rearward displacement of the supports at ground level. The installation was safely bent over during impact and did not present a secondary hazard to other motorists. The vehicle sustained very minor damage in the test. Additionally, the vehicle remained stable throughout the collision sequence without exhibiting any instability or tendency to roll over. However, the occupant impact velocity (8.1 m/s) in the longitudinal direction was above the recommended 5.0 m/s. Occupant impact velocity in the lateral direction and the ridedown accelerations (longitudinal and lateral) were well below the current recommended limits of 5.0 m/s (16.4 ft/s) and 20 g's, respectively. Because of excessive longitudinal occupant impact velocity, this sign installation is considered unacceptable according to the criteria presented in NCHRP Report 350.

- *Modified Dual 102 mm (4.0 in) diameter aluminum support sign installation - test nos. 23-26*

The dual 102 mm (4.0 in) diameter aluminum supports with a 3.2 mm (0.125 in) wall thicknesses were modified as shown in Figure 148. The sign supports were modified by drilling four 25 mm (1.0 in) holes in the support cross-section at two different elevations along each support (8 holes total). The two elevations of four holes each were drilled at ground level and 457 mm (18.0 in) above ground level. The holes were oriented 90 degrees with respect to each other and 45 degrees with respect to the plane of the sign panel. The 102 mm (4.0 in) diameter aluminum support sign installations, when modified as described above, performed satisfactorily in the crash tests conducted in both weak and strong soil.

In summary, the 102 mm (4.0 in) diameter aluminum support sign installations yielded to the impacting vehicle through failure of the supports. The detached elements of the sign installations were safely displaced away and did not present a secondary hazard to other motorists. The vehicle sustained minor damage in both the low-speed and high-speed tests. Additionally, the vehicle remained stable throughout the collision sequence without exhibiting any instability or tendency to roll in any of the tests performed on this installation configuration. The occupant impact velocities and ridedown accelerations were well within the current recommended limits of 5.0 m/s (16.4 ft/s) and 20 g's, respectively. This installation is considered acceptable according to the criteria presented in NCHRP Report 350.

- *Single 102 mm (4.0 in) diameter aluminum support sign installation - test nos. 6-9*

The single 102 mm (4.0 in) diameter aluminum supports with 3.2 mm (0.125 in) wall thicknesses performed satisfactorily in the crash tests conducted in both weak and strong soil. In summary, the 102 mm (4.0 in) diameter aluminum support sign installations yielded to the impacting vehicles through failure of the support near bumper height. The detached elements of the sign installations were safely displaced away and did not present a secondary hazard to other motorists. The vehicles sustained minor damage in the low-speed tests and moderate roof damage in the high-speed tests. Although damage sustained to vehicle roofs in the high-speed tests did deform the occupant compartments, the extent of the damage was not considered to be life threatening. Additionally, the vehicle remained stable throughout the collision sequence without exhibiting instability or any tendency to rollover in any of the tests performed on this installation configuration. The occupant impact velocities and ridedown accelerations were well below the current recommended limits of 5.0 m/s (16.4 ft/s) and 20 g's, respectively. This installation is considered acceptable according to the criteria presented in NCHRP Report 350.

Recommendations for the Aluminum Support Sign Installations

The current practice of the New Hampshire Department of Transportation when installing the channel bracket to the sign panel is to face the threaded portion of the bolt outward to the sign panel face. However, the 8 mm (5/16 in) diameter x 38 mm (1.5 in) long bolt presents a potential secondary hazard as the sign panel strikes the roof of the vehicle at high-speeds and punctures the occupant compartment. This practice has been used to minimize the number of bolt sizes stocked. It is recommended, however, that the bolts attaching the channel bracket to the sign panel be turned around and installed with the head of the bolt installed flat against the sign panel.

Steel U-channel Sign Supports

- *Dual 3.7 kg/m (2.5 lb/ft) steel U-channel sign installation - test nos. 10-13*

The 3.7 kg/m (2.5 lb/ft) steel U-channel dual support sign installations performed satisfactorily in the crash tests conducted in both weak and strong soil. In summary, the 3.7 kg/m (2.5 lb/ft) steel U-channel support installation yielded to the impacting vehicle by a variety of different failure mechanisms. In the low-speed, strong soil test (10), the left support fractured near bumper height and the right support displaced rearward without fracturing. In the high-speed, strong soil test (11) and the low-speed, weak soil test (12), the supports were pulled completely from the soil without fracturing. In the high-speed, weak soil test (13) both supports were fractured. The detached elements of the sign installations in all of the above tests were safely displaced away and did not present secondary hazards to other motorists. The vehicles sustained minor damage in the low-speed tests and moderate roof damage in the high-speed test, strong soil test and less severe roof damage in the high-speed, weak soil test. Although the damage sustained by the vehicle roofs in both high-speed tests did deform the occupant compartments, the extent of the damage was not considered to be life threatening. Additionally, the vehicle remained stable throughout the collision sequence without exhibiting any instability or tendency to roll over in any of the tests performed on this installation configuration. The occupant impact velocities and ridedown accelerations were well within the current recommended limits of 5.0 m/s (16.4 ft/s) and 20 g's, respectively. This sign installation is considered acceptable according to the criteria presented in NCHRP Report 350.

- *Dual 4.5 kg/m (3.0 lb/ft) steel U-channel sign installation - test nos. 18-21*

The 4.5 kg/m (2.5 lb/ft) steel U-channel dual support sign installations performed satisfactorily in the crash tests conducted in both weak and strong soil. In summary, the 4.5 kg/m (3.0 lb/ft) steel U-channel support installations yielded to the impacting vehicle through failure of the support near bumper height. In addition to being fractured, in the weak soil tests, the right supports in both tests (20 and 21) were pulled from the soil. The detached elements of the sign installations were safely displaced away and did not present secondary hazards to other motorists. The vehicles sustained minor damage in both the low-speed and high-speed tests. Additionally, the vehicle remained stable throughout the collision sequence without exhibiting any instability or tendency to roll over in any of the tests performed on this installation configuration. The occupant impact velocities and ridedown accelerations were well within the current recommended limits of 5.0 m/s (16.4 ft/s) and 20 g's, respectively. This sign installation is considered acceptable according to the criteria presented in NCHRP Report 350.

Table 26. Performance Evaluation Summary of Crash Tests Performed on Aluminum Support Sign Installations

TEST NO.	SUPPORT TYPE	SOIL TYPE	SPEED (km/h)	VEHICLE ACCEL. (Max 50 msec. avg.)		OCCUPANT IMPACT VELOCITY		OCCUPANT RIDEDOWN ACCELERATION		ΔV km/h	PASS/ FAIL
				X	Y	X	Y	X	Y		
1	3.2 mm x 76 mm (0.125 in x 3.0 in) Dual Aluminum Supports	Strong	35.7	-3.1 g	-0.3 g	4.4 m/s	-0.8 m/s	-1.2 g	0.7 g	N.A.	Pass
2			99.9	-6.6 g	-0.6 g	4.2 m/s	-1.3 m/s	-1.3 g	1.0 g	16.2	Pass
3		Weak	34.5	-3.5 g	-0.4 g	4.7 m/s	N/A	-0.6 g	No Contact	16.5	Pass
4			103.3	-5.8 g	-0.9 g	3.7 m/s	1.2 m/s	-1.0 g	-1.3 g	12.6	Pass
5	3.2 mm x 102 mm (0.125 in x 4.0 in) Dual Aluminum Supports	Strong	36.1	-5.2 g	0.8 g	7.1 m/s	N/A	-4.3 g	No Contact	25.3	Fail
6	3.2 mm x 102 mm (0.125 in x 4.0 in) Single Aluminum Support	Strong	36.4	-2.7 g	-0.3g	2.6 m/s	1.1 m/s	-0.6 g	-0.6 g	10.4	Pass
7			100.3	-3.2 g	0.6 g	1.9 m/s	-1.3 m/s	-0.5 g	-0.9 g	11.1	Pass
8		Weak	34.5	-3.3 g	-0.5 g	3.8 m/s	1.7 m/s	-0.8 g	-0.7 g	12.0	Pass
9			101.4	-4.1 g	1.9 g	2.3 m/s	-1.2 m/s	1.7 g	3.5 g	13.0	Pass
14	* Modified 3.2 mm x 102 mm (0.125 in x 4.0 in) Dual Aluminum Supports	Strong	34.2	-3.8 g	0.8 g	6.5 m/s	-0.6 m/s	-3.7 g	0.9 g	28.3	Fail
15			36.0	-5.0 g	0.4 g	7.3 m/s	-0.4 m/s	-4.8 g	-0.4 g	34.1	Fail
16	* Modified 3.2 mm x 102 mm (0.125 in x 4.0 in) Dual Aluminum Supports	Strong	36.9	-2.8 g	0.3 g	2.1 m/s	-0.7 m/s	-0.6 g	0.3 g	6.5	Pass
17			99.2	-1.7 g	-0.3 g	1.0 m/s	0.3 m/s	-0.2 g	-0.9 g	5.4	Pass
22	* Modified 3.2 mm x 102 mm (0.125 in x 4.0 in) Dual Aluminum Supports	Weak	34.5	-6.4 g	0.3 g	8.1 m/s	-0.4 m/s	-3.8 g	-0.9 g	21.1	Fail
23	** Modified 3.2 mm x 102 mm (0.125 in x 4.0 in) Dual Aluminum Supports	Strong	33.2	-1.6 g	0.6 g	1.1 m/s	-0.5 m/s	0.4 g	0.3 g	6.4	Pass
24			98.3	-1.2 g	-0.4 g	0.6 m/s	0.7 m/s	0.4 g	0.5 g	3.6	Pass
25		Weak	32.9	-2.3 g	0.3 g	2.3 m/s	-0.5 m/s	-0.9 g	0.7 g	8.8	Pass
26			101.7	-1.9 g	-0.7 g	0.8 m/s	-0.8 g	0.4 g	0.7 g	3.1	Pass

* See Figure 4 for details of Modification.
** See Figure 5 for details of Modification.
*** N/A - not applicable, occupant impact did not occur.

Table 27. Performance Evaluation Summary of Crash Tests Performed on Steel U-channel Sign Installations

TEST NO.	SUPPORT TYPE	SOIL TYPE	SPEED (km/h)	VEHICLE ACCEL. (Max 50 msec. avg.)		OCCUPANT IMPACT VELOCITY		OCCUPANT RIDEDOWN ACCELERATION		ΔV km/h	PASS/ FAIL
				X	Y	X	Y	X	Y		
10	3.7 kg/m (2.5 lb/ft) Dual Steel U-channels	Strong	34.6	-3.1 g	0.6 g	4.2 m/s	-0.4 m/s	-3.1 g	-1.6 g	30.6	Pass
11			97.2	-6.6 g	0.8 g	4.4 m/s	-1.5 m/s	-1.1 g	1.5 g	13.6	Pass
12		Weak	34.6	-2.8 g	-1.1 g	4.4 m/s	N/A	-1.8 g	No Contact	N.A.	Pass
13			99.8	-3.9 g	-0.8 g	3.0 m/s	0.8 m/s	-0.5 g	1.8 g	8.7	Pass
18	4.5 kg/m (3.0 lb/ft) Dual Steel U-channels	Strong	35.7	-3.3 g	-0.5 g	3.9 m/s	0.7 m/s	-4.7 g	-1.7 g	19.6	Pass
19			98.9	-3.6 g	-1.4 g	2.9 m/s	0.7 m/s	-0.9 g	1.1 g	9.1	Pass
20		Weak	34.2	-1.9 g	-0.4 g	2.1 m/s	-0.5 m/s	-1.6 g	1.0 g	14.9	Pass
21			100.5	-2.7 g	-0.9 g	1.9 m/s	N/A	-0.5 g	No Contact	7.0	Pass

REFERENCES

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

APPENDIX A

Vehicle Property Data Sheets

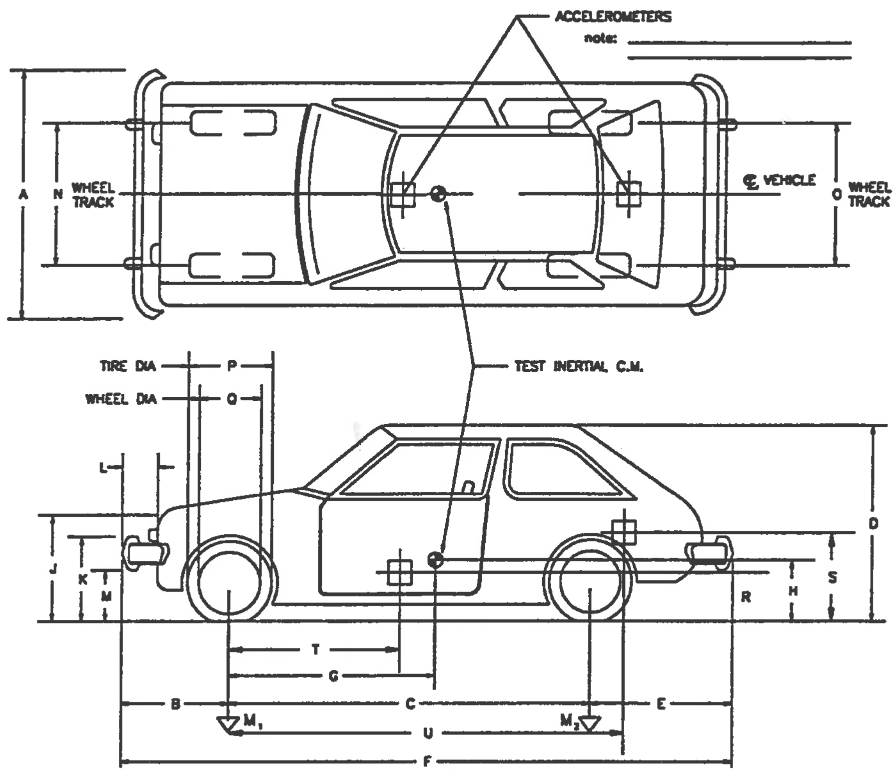
DATE: 09-12-94 TEST NO.: 405231-1 & 2 VIN NO.: KNJBT06K1K6106432

YEAR: 1989 MAKE: Ford MODEL: Festiva L

TIRE INFLATION PRESSURE: ______ ODOMETER: 113900 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 269 RF 254 LR 150 RR 147

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cyl

ENGINE CID: 80.8

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A 1490	E 560	J 715	N 1395	R 430
B 610	F 3460	K 550	O 1380	S 620
C 2290	G 829.4	L 115	P 550	T 880
D 1450	H	M 370	Q 335	U 2510

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	528	523	562
M_2	279	297	335
M_T	807	820	897

Figure A-1. Vehicle properties for test 404231-1 & 2.

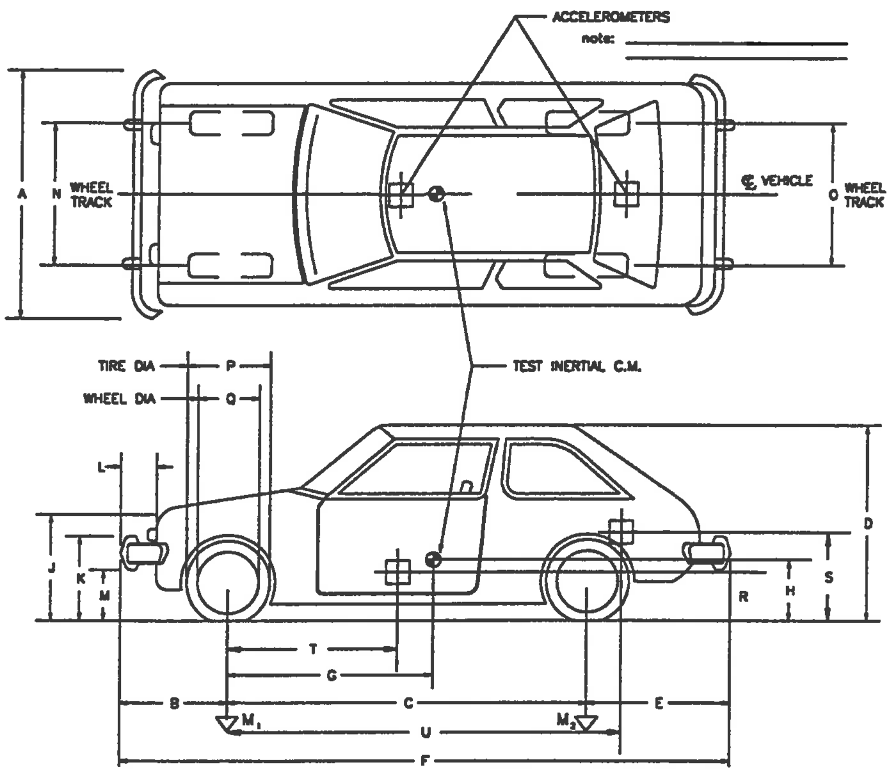
DATE: 09-13-94 TEST NO.: 405231-3 & 4 VIN NO.: KNLBTo6K8J6159708

YEAR: 1988 MAKE: Ford MODEL: Festiva

TIRE INFLATION PRESSURE: ______ ODOMETER: 81053.2 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 268 RF 254 LR 151 RR 147

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cyl

ENGINE CID: 80.8

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A 1470	E 545	J 760	N 1395	R 400
B 590	F 3430	K 540	O 1385	S 635
C 2295	G 834	L 130	P 535	T 885
D 1450	H	M 380	Q 331	U 2480

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	522	522	562
M_2	282	298	334
M_T	804	820	896

Figure A-2. Vehicle properties for test 405231-3 & 4.

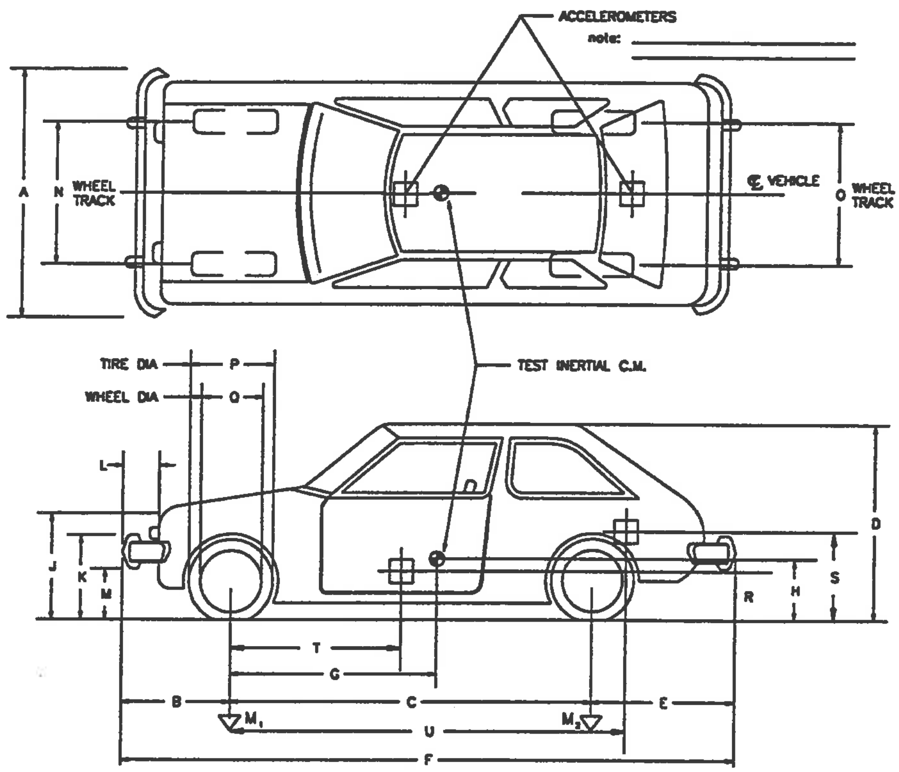
DATE: 09-15-94 TEST NO.: 405231-5,6, & 7 VIN NO.: KNJBT06K4J6183990

YEAR: 1988 MAKE: Ford MODEL: Festiva L

TIRE INFLATION PRESSURE: ______ ODOMETER: 070106 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 256 RF 245 LR 168 RR 151

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cyl

ENGINE CID: 80.8

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	1520	E	525	J	730	N	1385	R	410
B	640	F	3465	K	550	O	1390	S	600
C	2300	G	894.8	L	130	P	550	T	890
D	1450	H		M	395	Q	335	U	2530

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	497	501	539
M_2	285	319	357
M_T	782	820	896

Figure A-3. Vehicle properties for test 405231-5, 6 & 7.

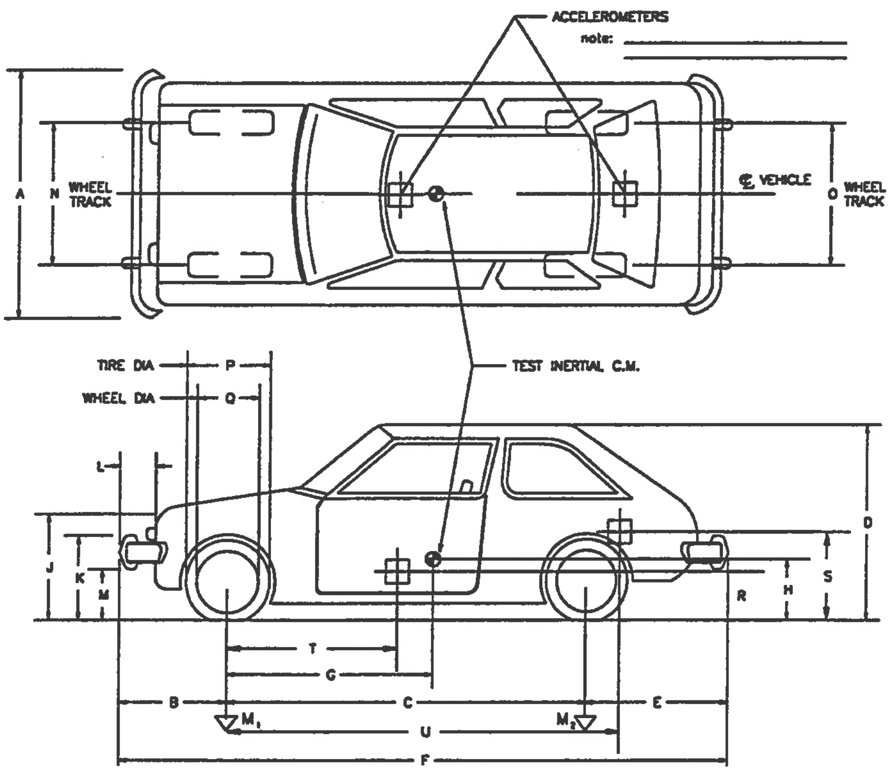
DATE: 09-19-94 TEST NO.: 405231-8 & 9 VIN NO.: KNJBT06H2K6130291

YEAR: 1989 MAKE: Ford MODEL: Festiva

TIRE INFLATION PRESSURE: ______ ODOMETER: 132189 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 274 RF 265 LR 153 RR 128

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cyl

ENGINE CID: 80.8

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A	1490	E	510	J	715	N	1395	R	390
B	620	F	3435	K	525	O	1390	S	625
C	2305	G	791.6	L	85	P	330	T	880
D	1450	H		M	350	Q	550	U	2495

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	525	539	576
M_2	285	281	321
M_T	810	820	897

Figure A-4. Vehicle properties for test 405231-8 & 9.

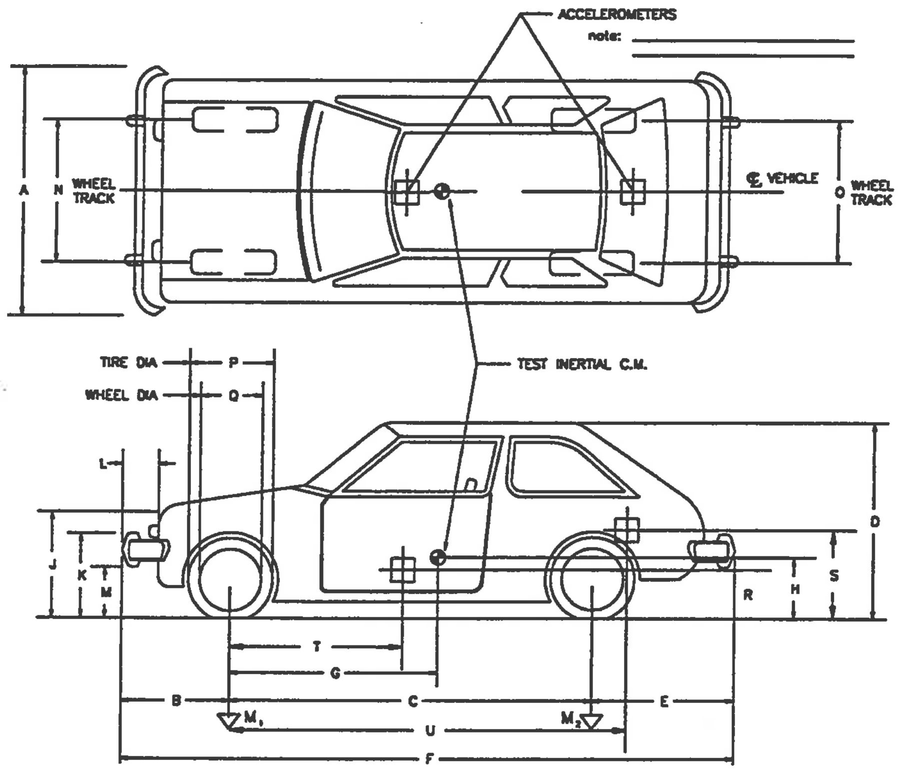
DATE: 9-21-94 TEST NO.: 405231-10 & 11 VIN NO.: KNJBT06H9K6133611

YEAR: 1989 MAKE: Ford MODEL: Festiva

TIRE INFLATION PRESSURE: ______ ODOMETER: 112588 TIRE SIZE: 145SR12

MASS DISTRIBUTION (kg) LF 263 RF 255 LR 168 RR 134

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cyl

ENGINE CID: 80.8

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	1495	E	525	J	750	N	1385	R	405
B	635	F	3460	K	540	O	1390	S	600
C	2300	G	847.1	L	122	P	520	T	890
D	1445	H		M	245	Q	331	U	2495

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	555	518	556
M_2	277	302	341
M_T	832	820	897

Figure A-5. Vehicle properties for test 405231-10 & 11.

DATE: 9-23-94 TEST NO.: 405231-12 & 13 VIN NO.: VX1BB1227KK439339

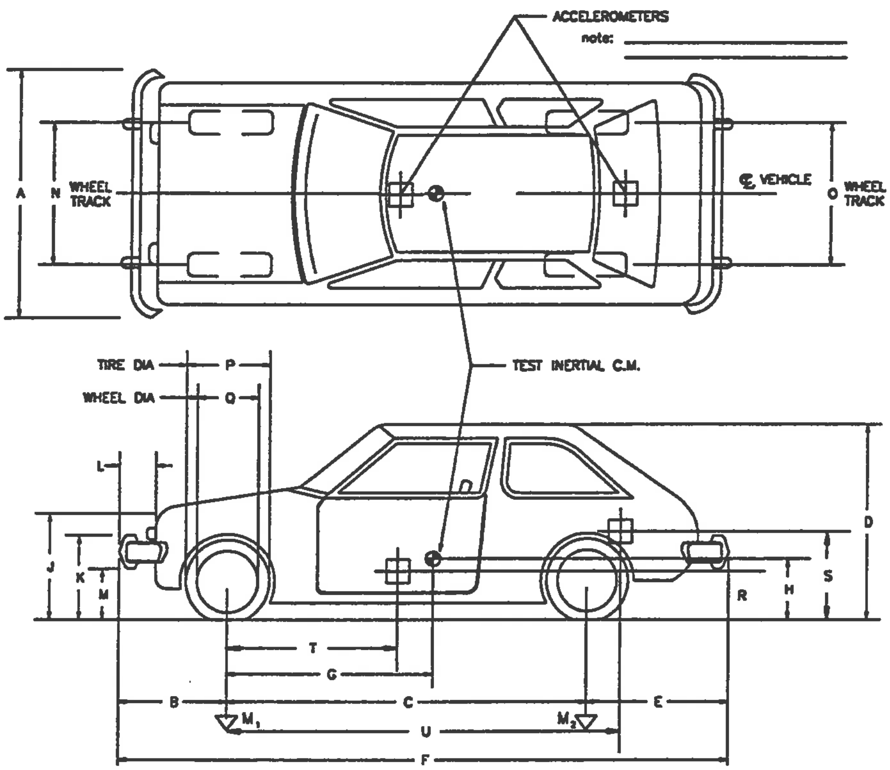
YEAR: 1989 MAKE: Yugo MODEL: GVL

TIRE INFLATION PRESSURE: ______ ODOMETER: 32090 TIRE SIZE: 155R13

MASS DISTRIBUTION (kg) LF 264 RF 255 LR 156 RR 145

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Dent in right rear bumper and quarter panel



ENGINE TYPE: 4 cyl

ENGINE CID: 1100 cc

TRANSMISSION TYPE:

__ AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A	1420	E	610	J	810	N	1295	R	390
B	660	F	3430	K	510	O	1240	S	740
C	2160	G	792.8	L	70	P	565	T	820
D	1430	H		M	370	Q		U	2405

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	518	519	555
M_2	280	301	341
M_T	798	820	896

Figure A-6. Vehicle properties for test 405231-12 & 13.

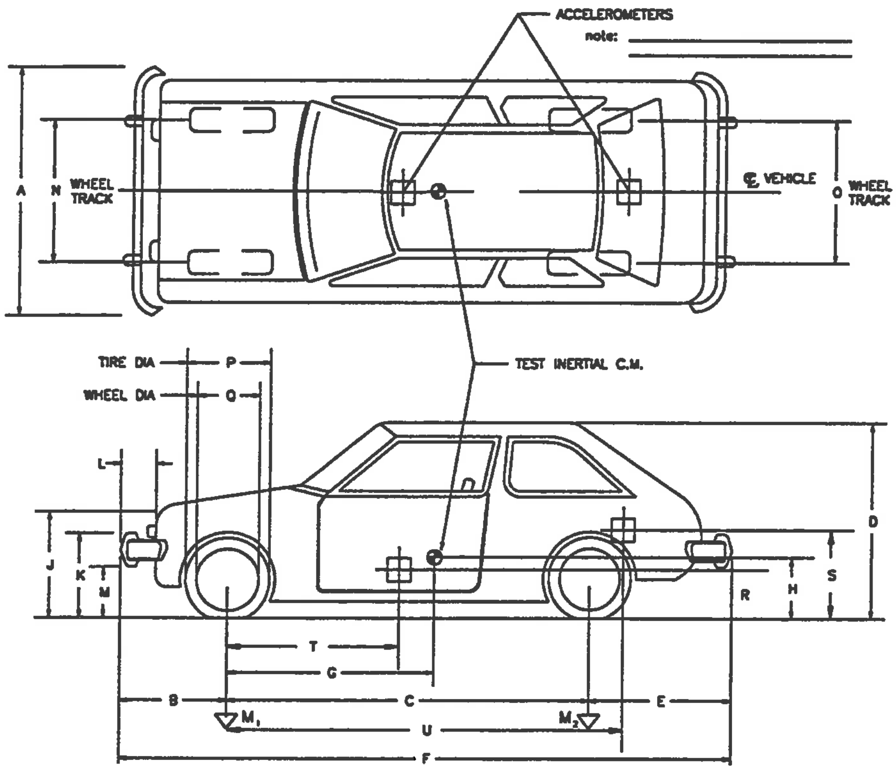
DATE: 10-3-94 & 10-4-94 TEST NO.: 405231-14,15,16 & 17 VIN NO.: JF1KA73A8JB709936

YEAR: 1988 MAKE: Subaru MODEL: Justy GL

TIRE INFLATION PRESSURE: ________ ODOMETER: 13407 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 251 RF 241 LR 165 RR 163

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 cyl

ENGINE CID: 73 CID

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A	1515	E	604	J	745	N	1330	R	400
B	620	F	3514	K	535	O	1305	S	736
C	2290	G	916	L	90	P	535	T	900
D	1365	H		M	410	Q	330	U	2600

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	482	492	531
M_2	278	328	366
M_T	760	820	897

Figure A-7. Vehicle properties for test 405231-14, 15, 16 & 17.

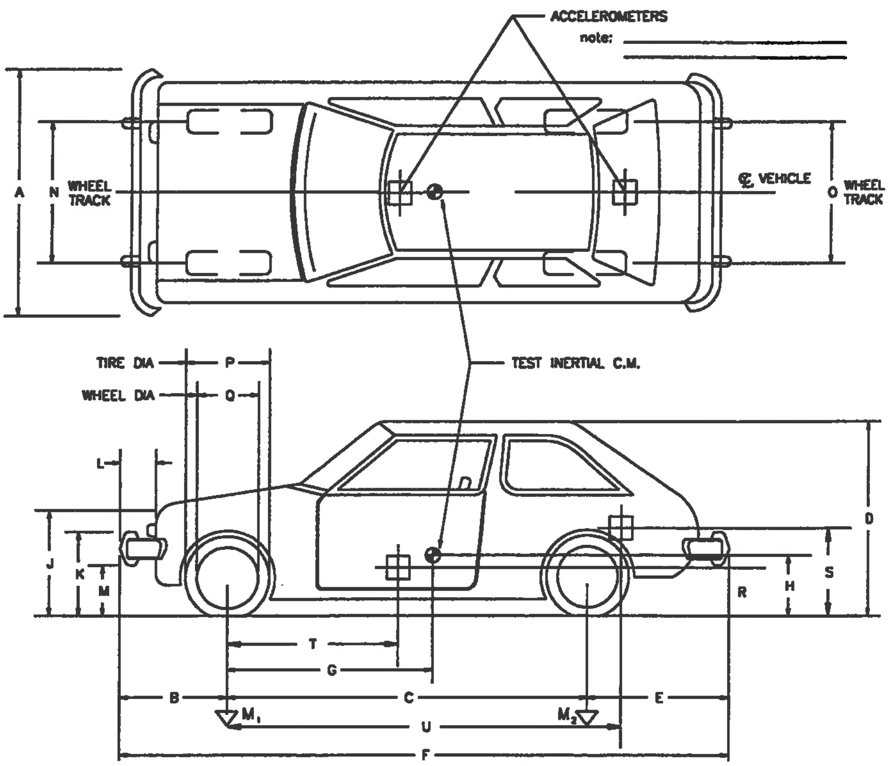
DATE: 10-5-94 TEST NO.: 405231-18 & 19 VIN NO.: KNJBT07K2K6176925

YEAR: 1989 MAKE: Ford MODEL: Festiva LX

TIRE INFLATION PRESSURE: ____ ODOMETER: 158499 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 263 RF 263 LR 157 RR 137

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cyl

ENGINE CID: 80.8

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A	1510	E	530	J	720	N	1400	R	410
B	640	F	3480	K	545	O	1390	S	600
C	2310	G	828.2	L	100	P	550	T	890
D	1440	H		M	365	Q	335	U	2520

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	531	526	562
M_2	289	294	334
M_T	820	820	896

Figure A-8. Vehicle properties for test 405231-18 & 19.

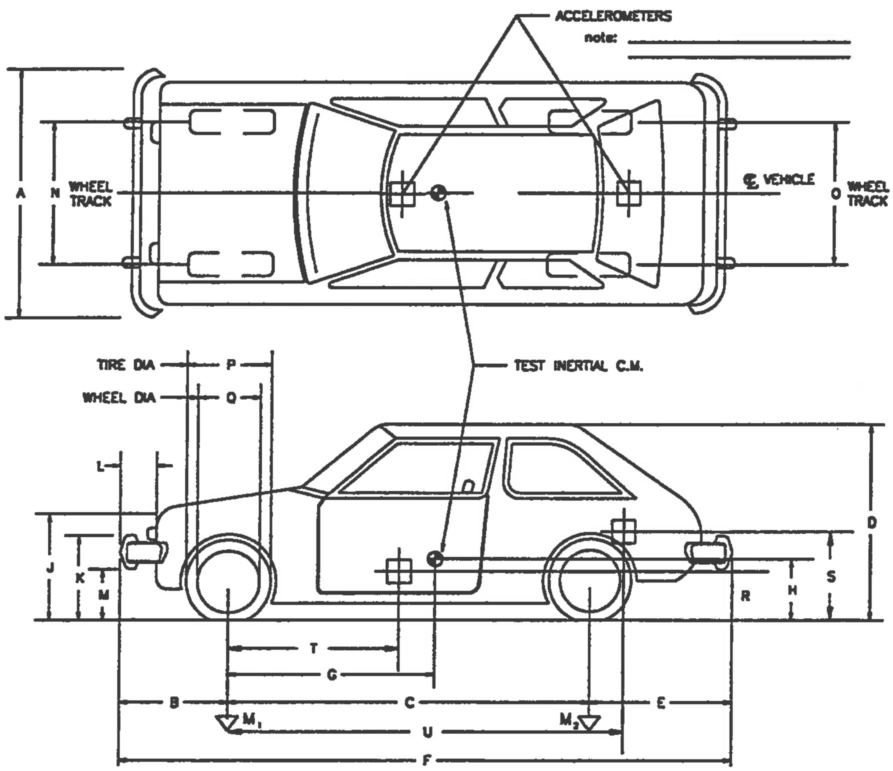
DATE: 10-10-94 TEST NO.: 405231-20 thru 26 VIN NO.: KNJBT06K7K6122330

YEAR: 1989 MAKE: Ford MODEL: Festiva L

TIRE INFLATION PRESSURE: ______ ODOMETER: 88037 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 261 RF 244 LR 161 RR 154

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cyl

ENGINE CID: 1.3 L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

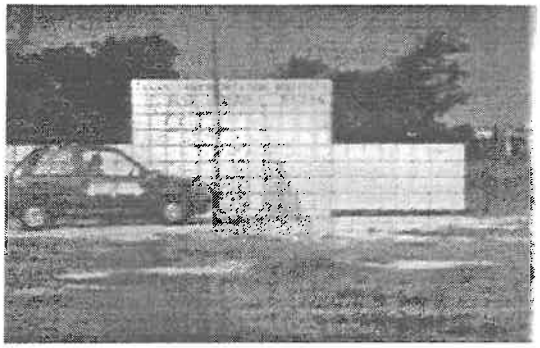
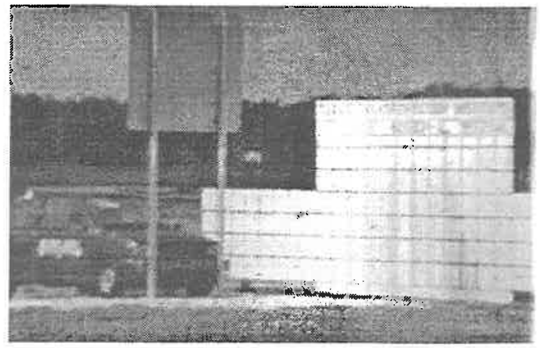
A	1500	E	540	J	760	N	1405	R	405
B	660	F	3505	K	535	O	1390	S	605
C	2305	G	885.5	L	60	P	550	T	890
D	1440	H		M	360	Q	335	U	2585

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	519	505	542
M_2	270	315	354
M_T	789	820	896

Figure A-9. Vehicle properties for test 405231-20 thru 26.

APPENDIX B

Sequential Photographs

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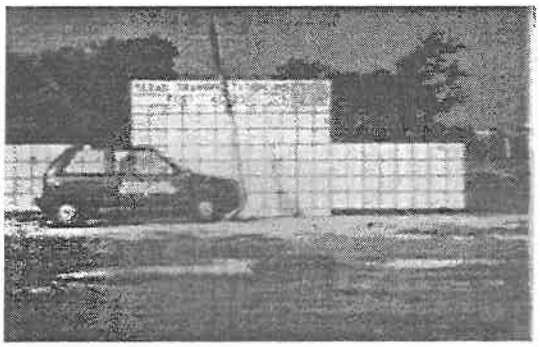
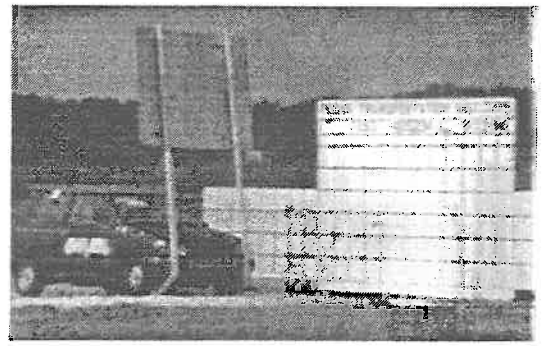

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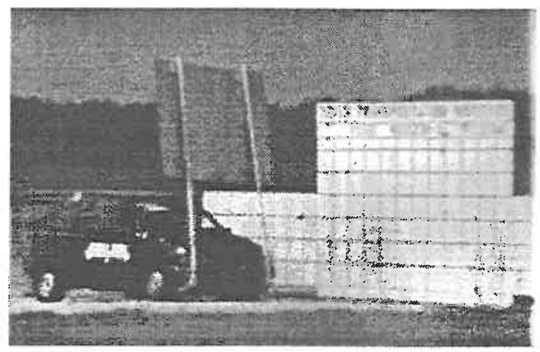

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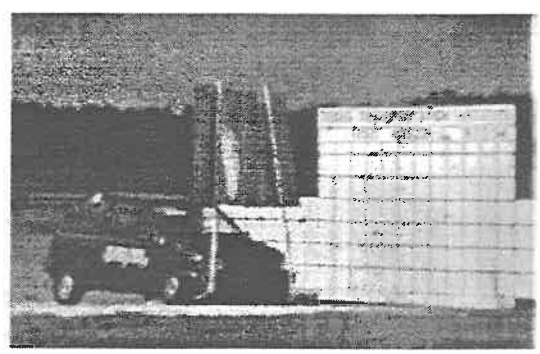

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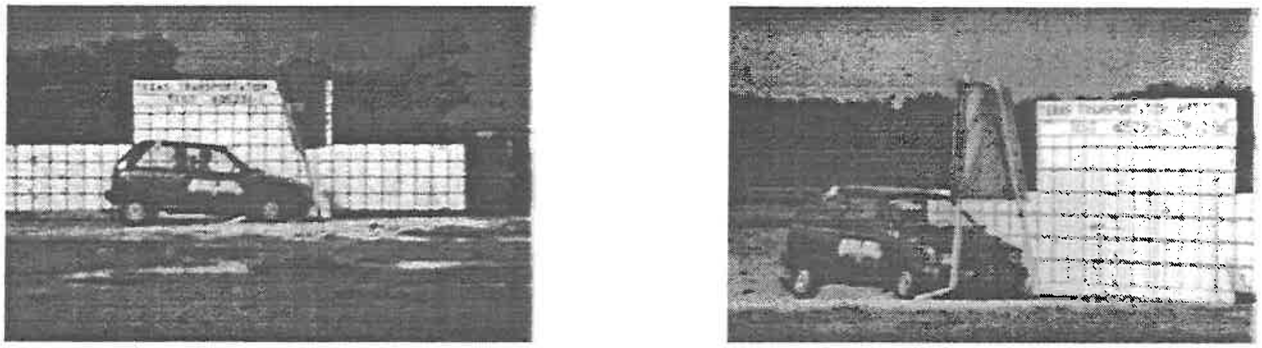
Figure B-1. Sequential photographs for test 405231-1.
(perpendicular and angular views)



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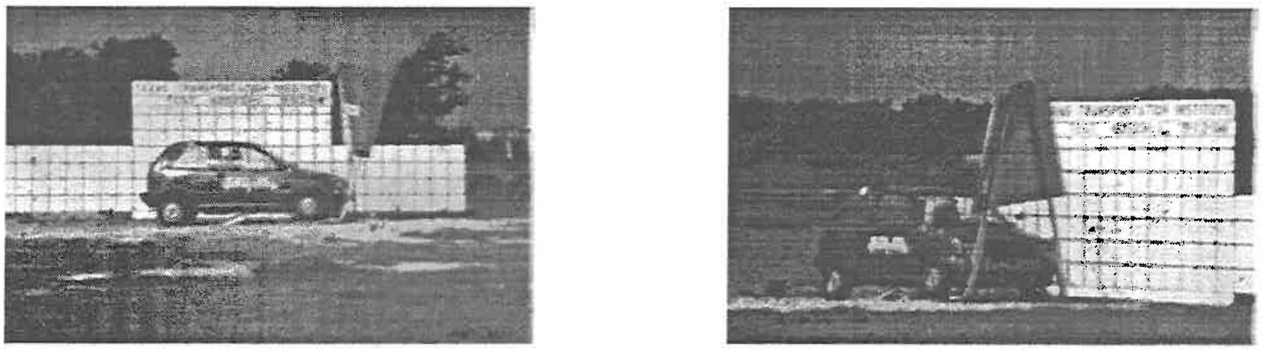

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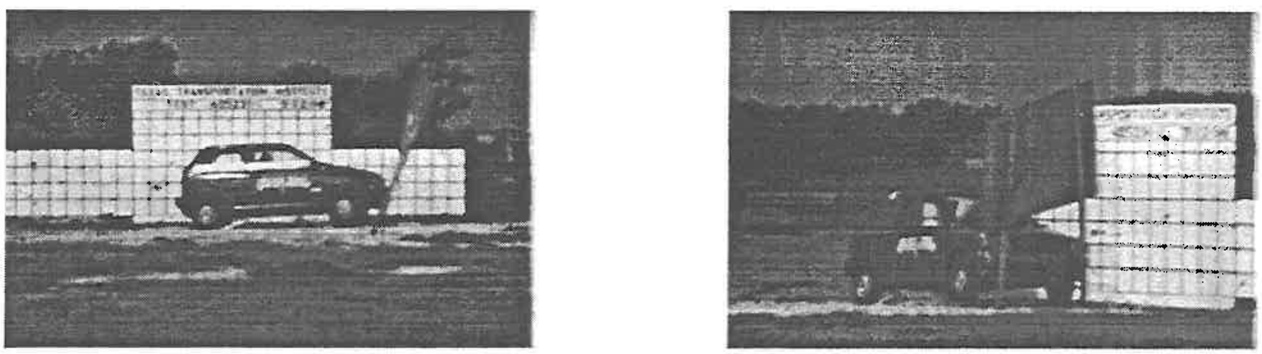

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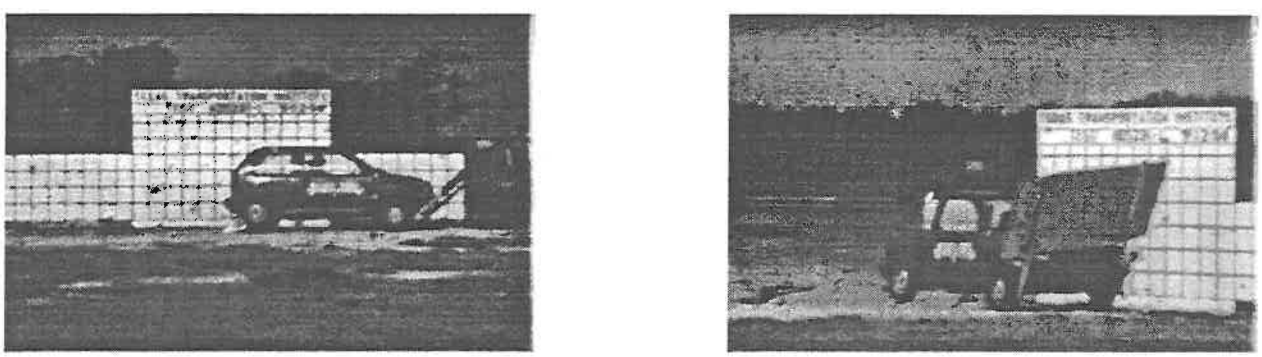

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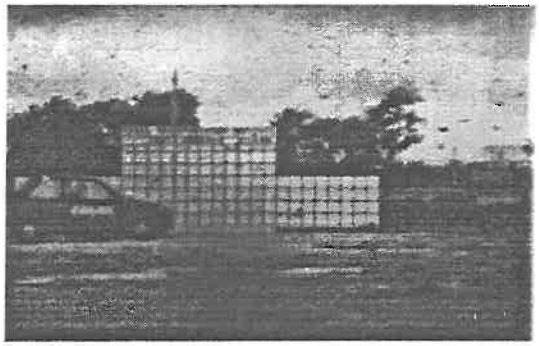
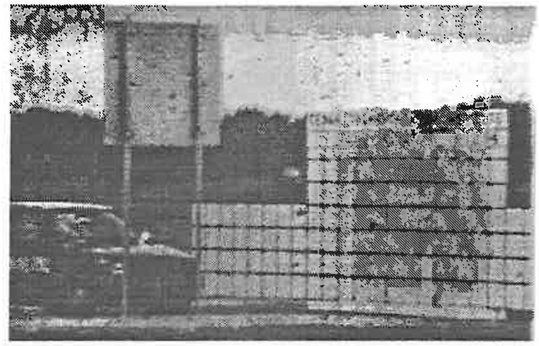
Figure B-1. Sequential photographs for test 405231-1 (continued).
(perpendicular and angular views)





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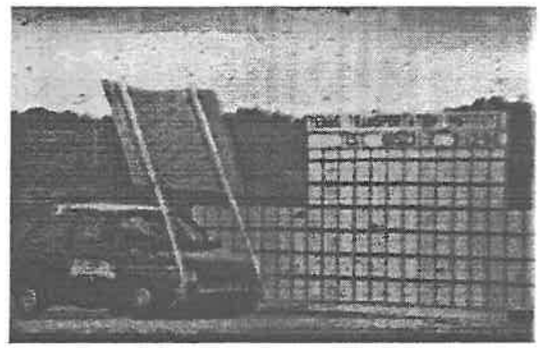

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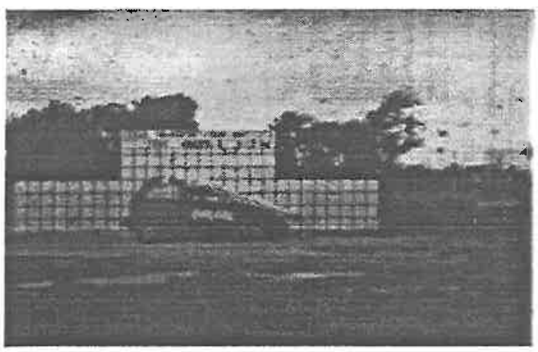

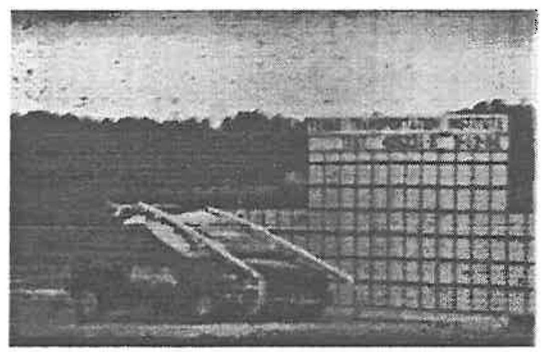

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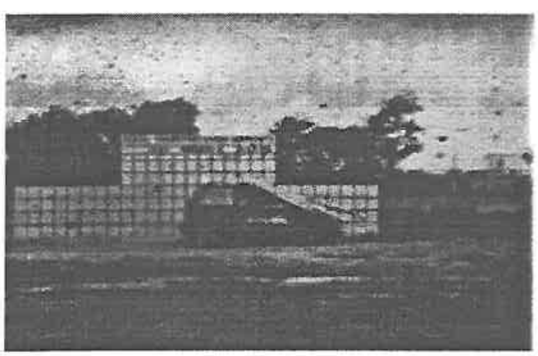

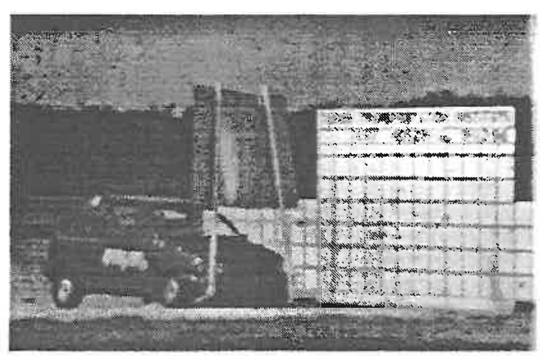

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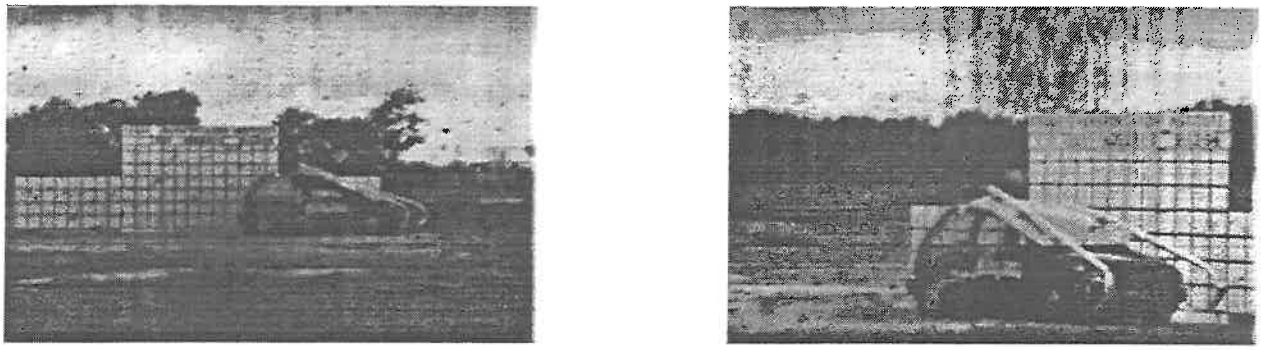
Figure B-2. Sequential photographs for test 405231-2.
(perpendicular and angular views)



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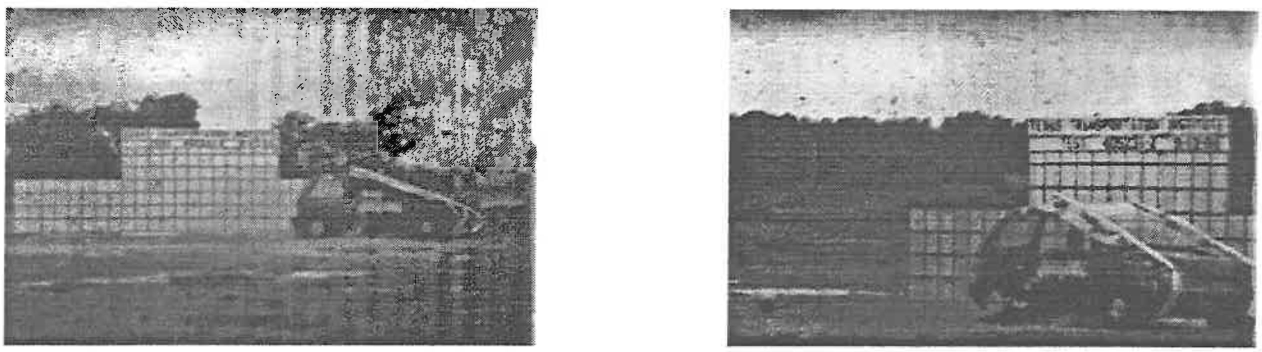

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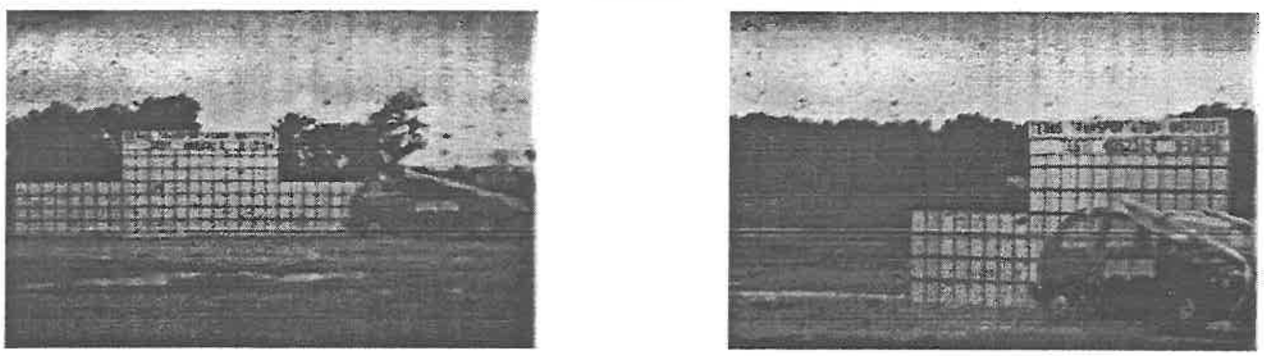

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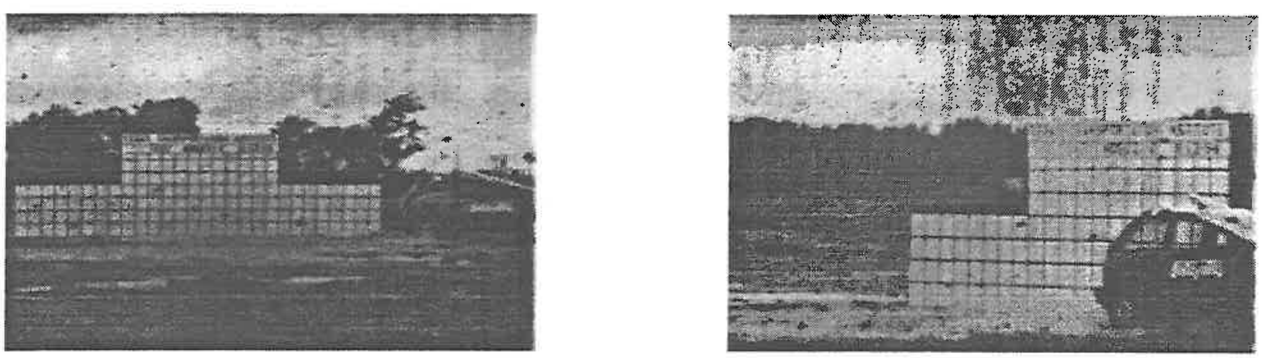

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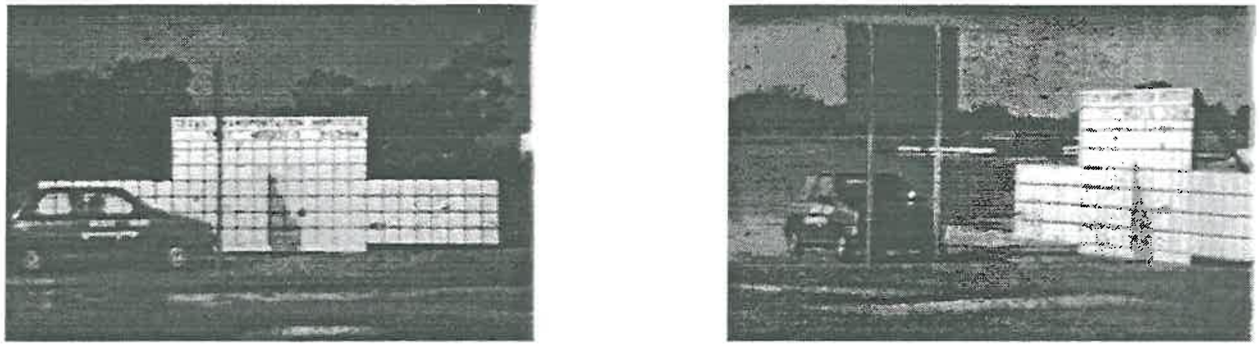
Figure B-2. Sequential photographs for test 405231-2 (continued).
(perpendicular and angular views)



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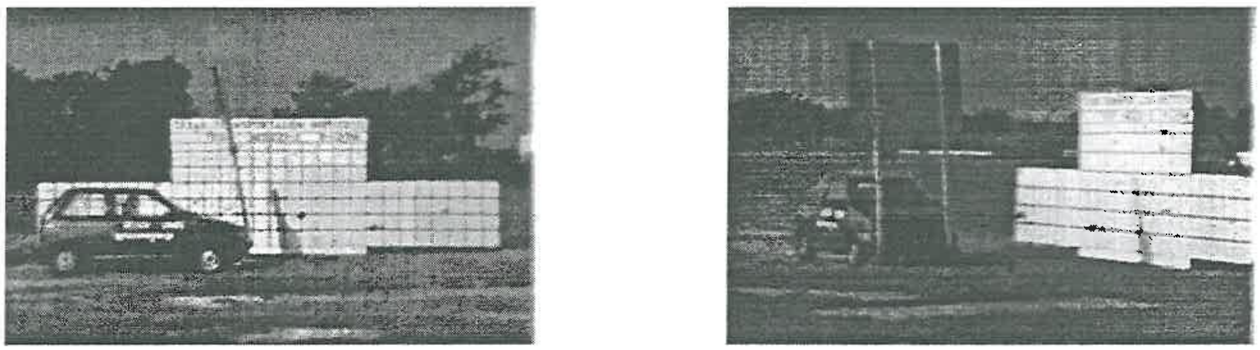

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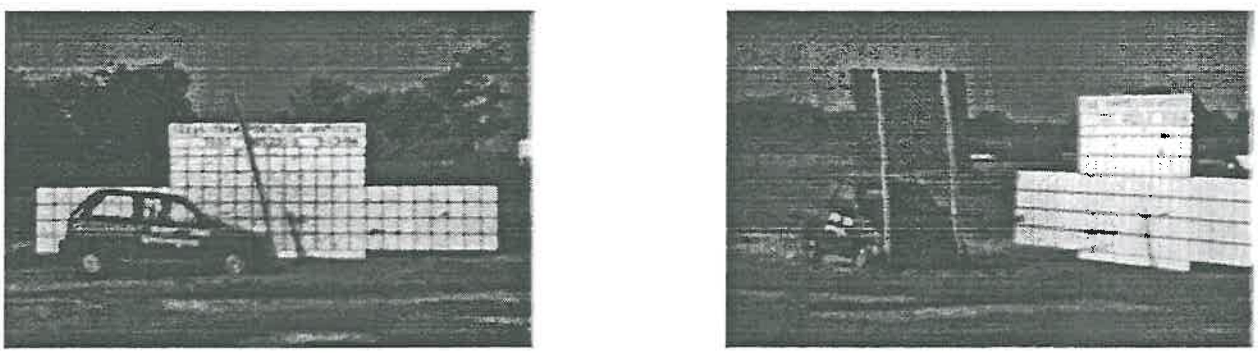

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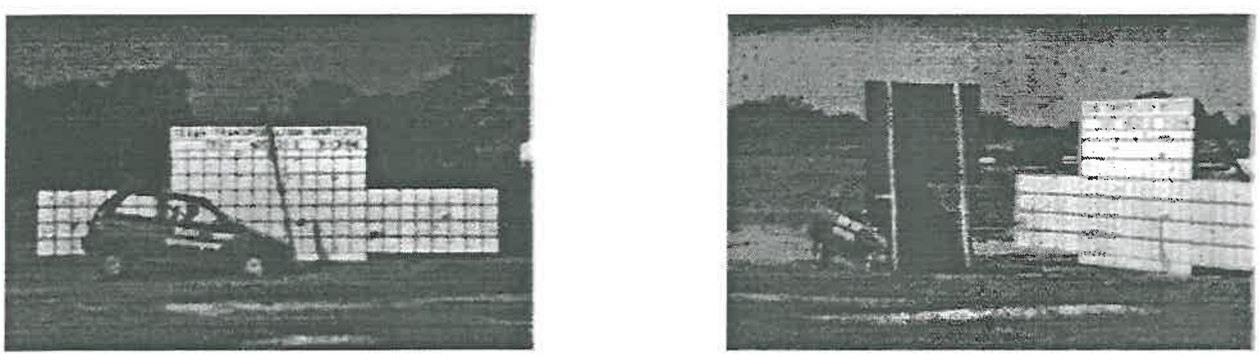
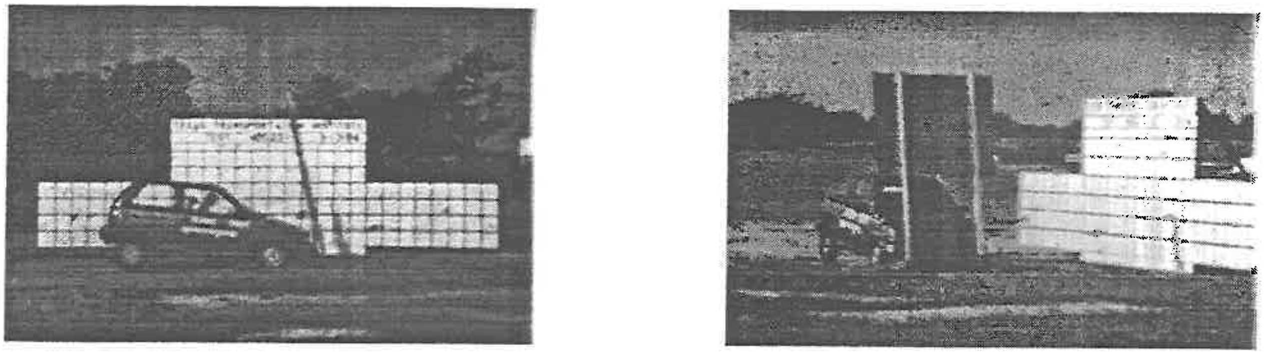
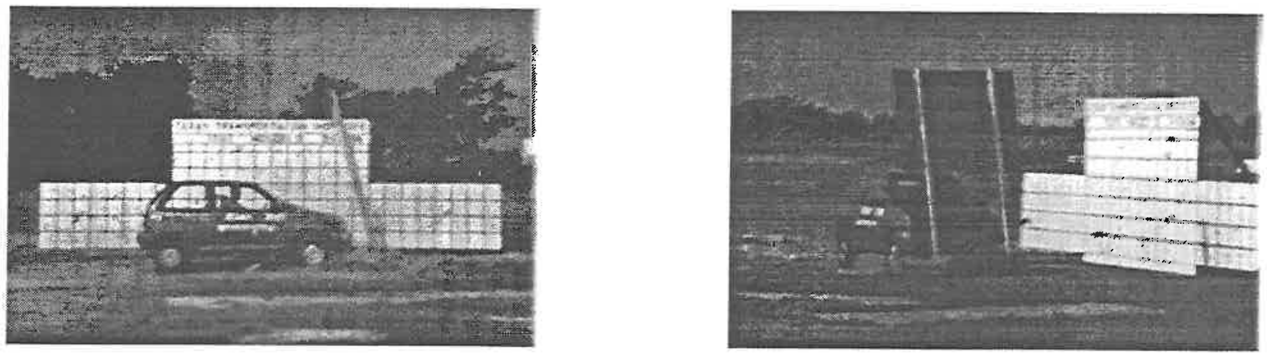


0.185 s

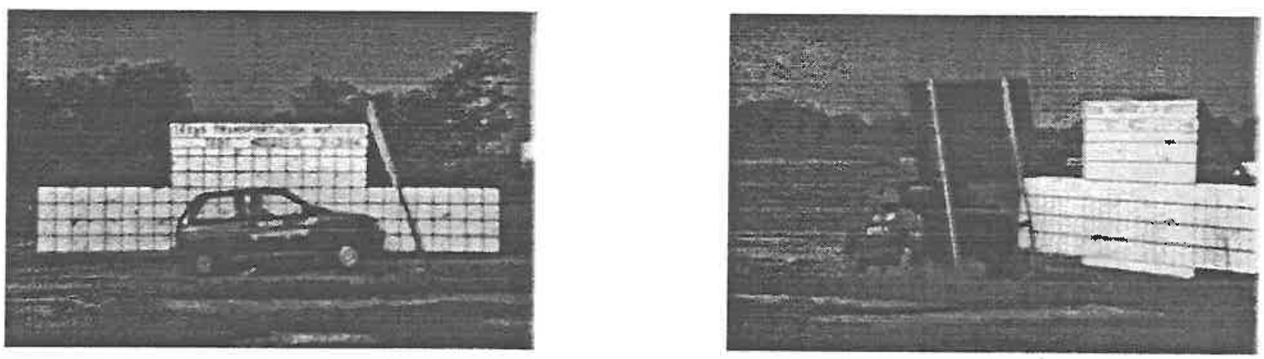
Figure B-3. Sequential photographs for test 405231-3.
(perpendicular and angular views)



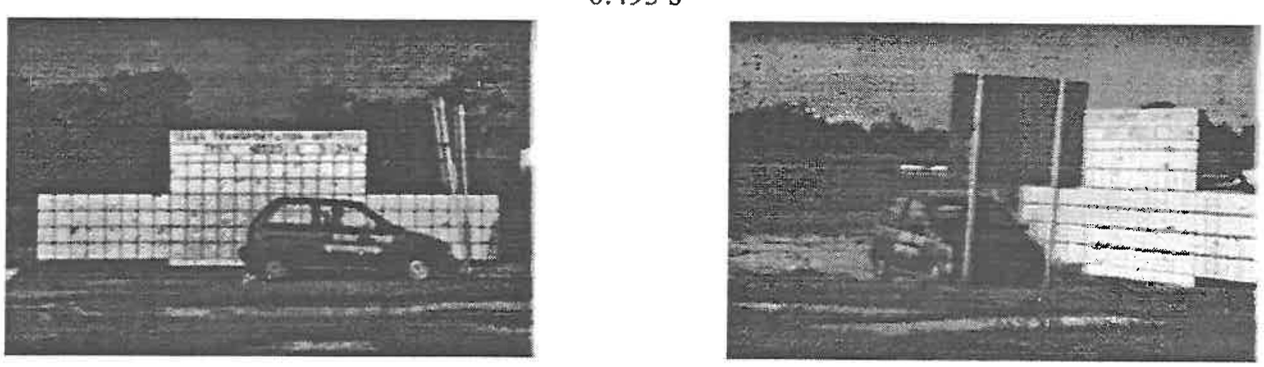
0.247 s



0.370 s



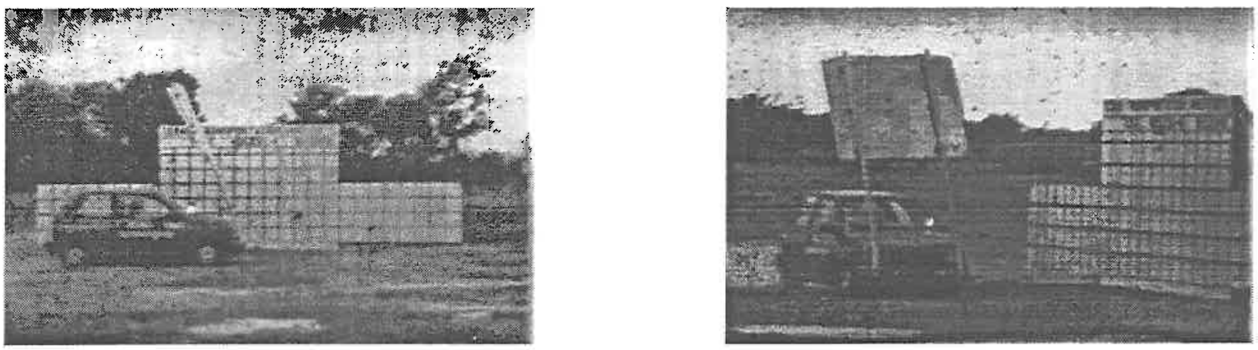
0.493 s



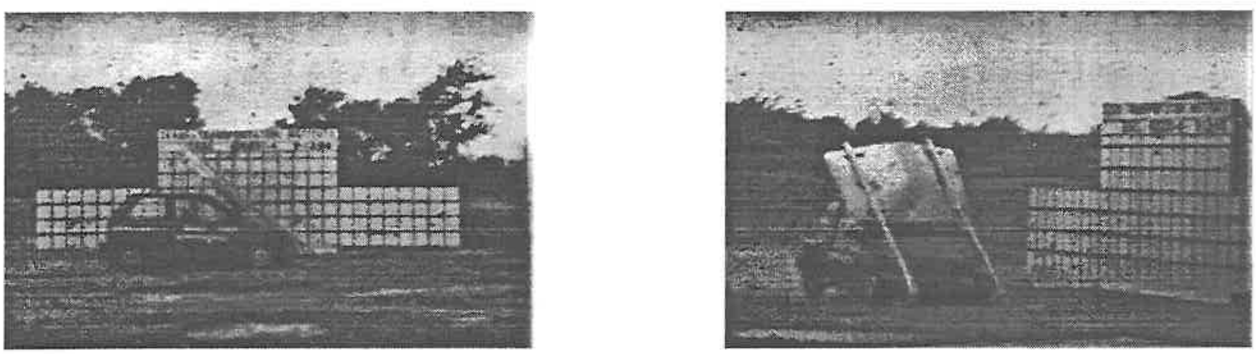
0.766 s

Figure B-3. Sequential photographs for test 405231-3 (continued).
(perpendicular and angular views)

0.000 s



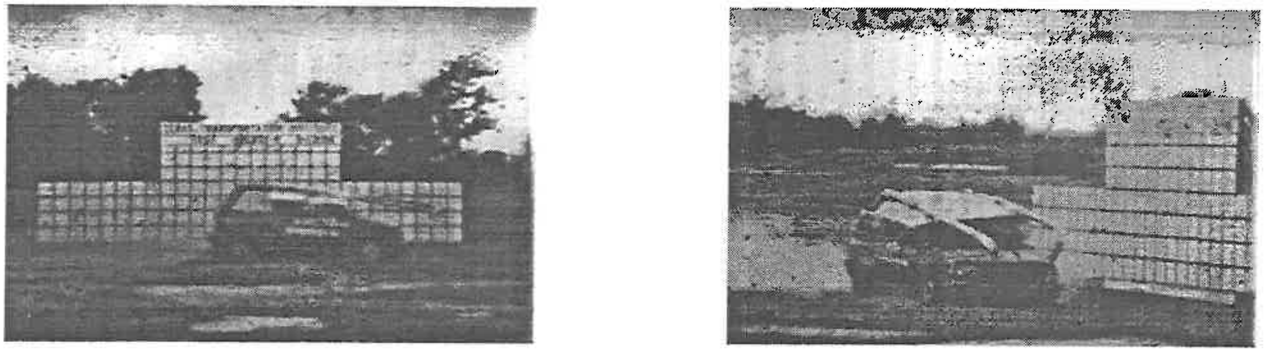
0.037 s



0.074 s

0.112 s

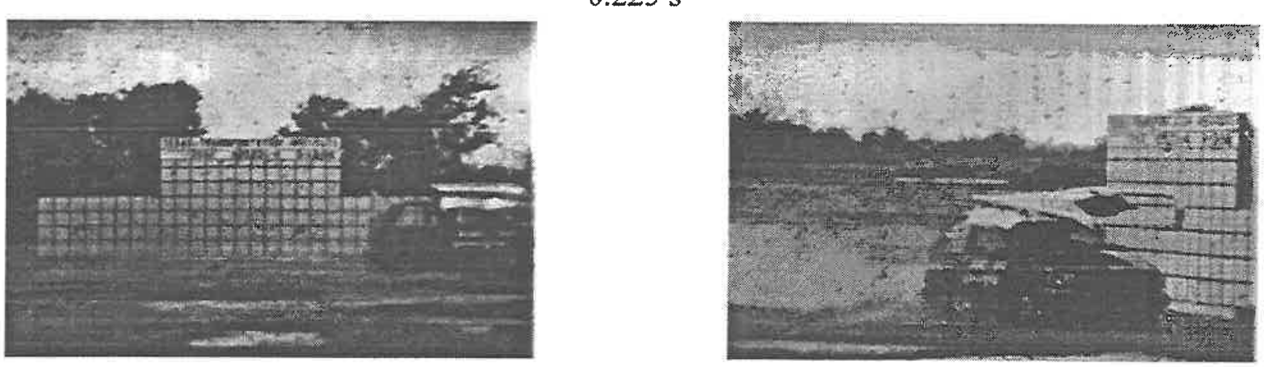
Figure B-4. Sequential photographs for test 405231-4.
(perpendicular and angular views)



0.149 s

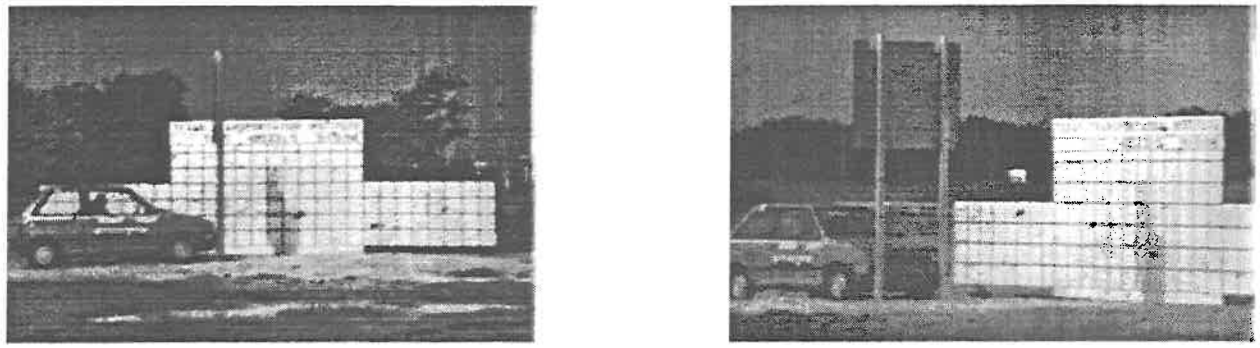
0.186 s

0.225 s

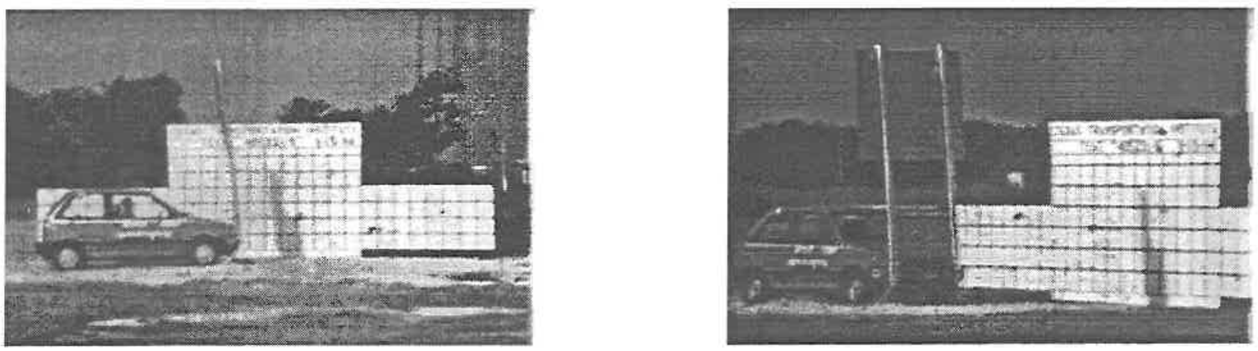


0.263 s

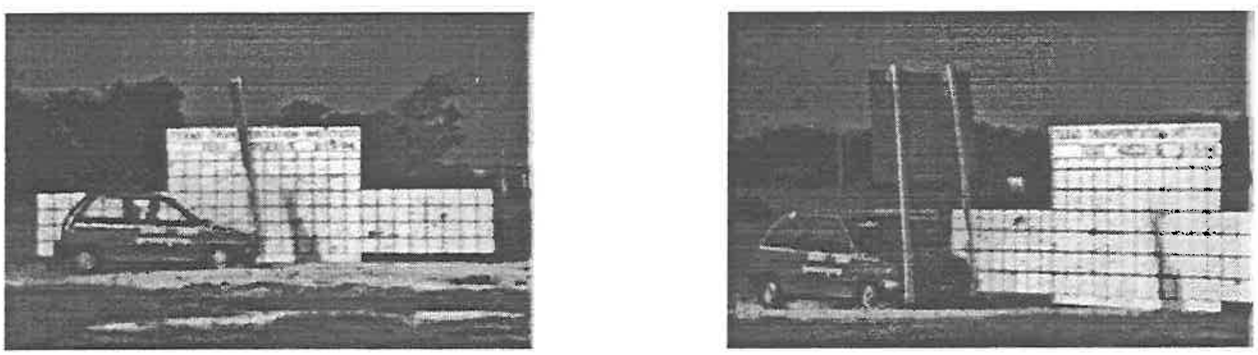
Figure B-4. Sequential photographs for test 405231-4 (continued).
(perpendicular and angular views)



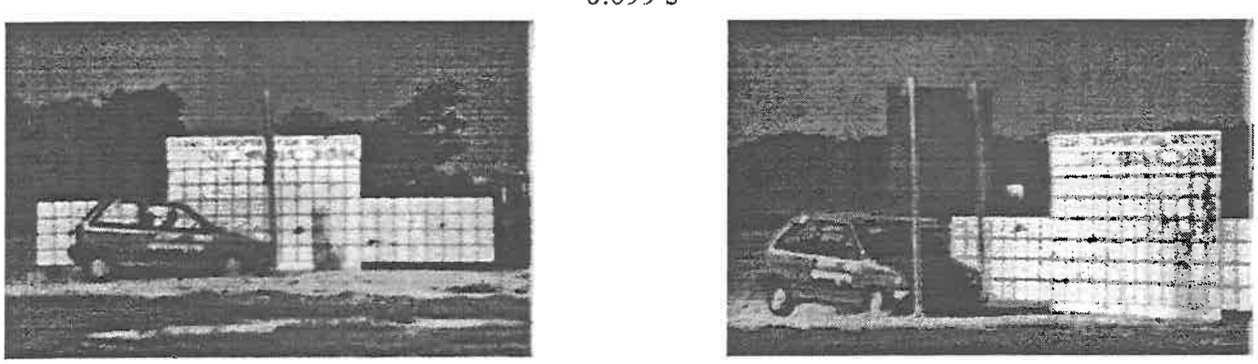
0.000 s



0.049 s

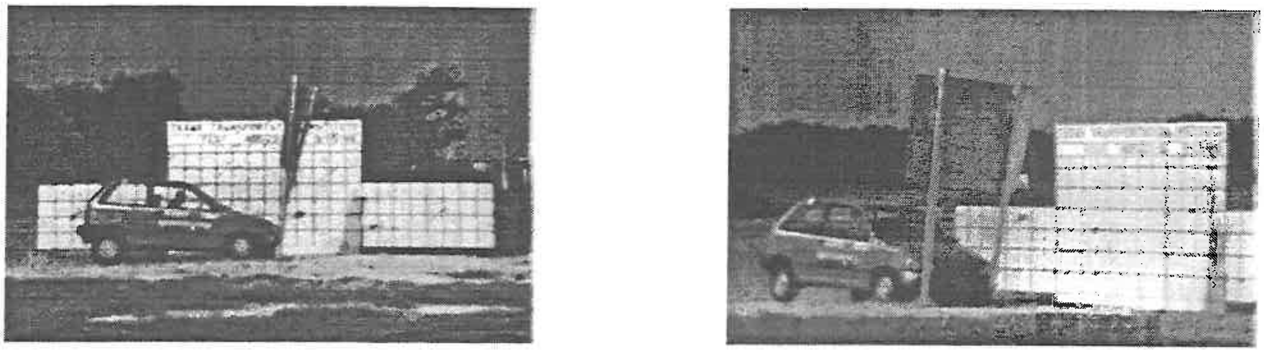


0.099 s

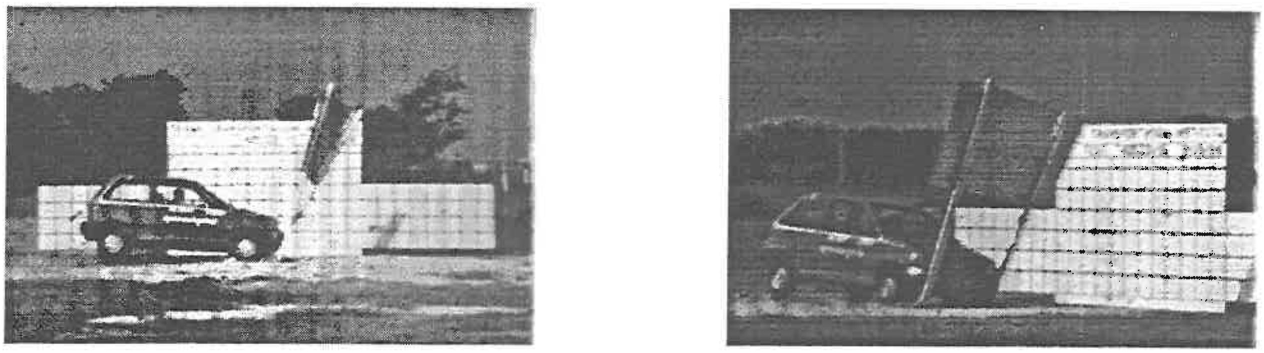


0.151 s

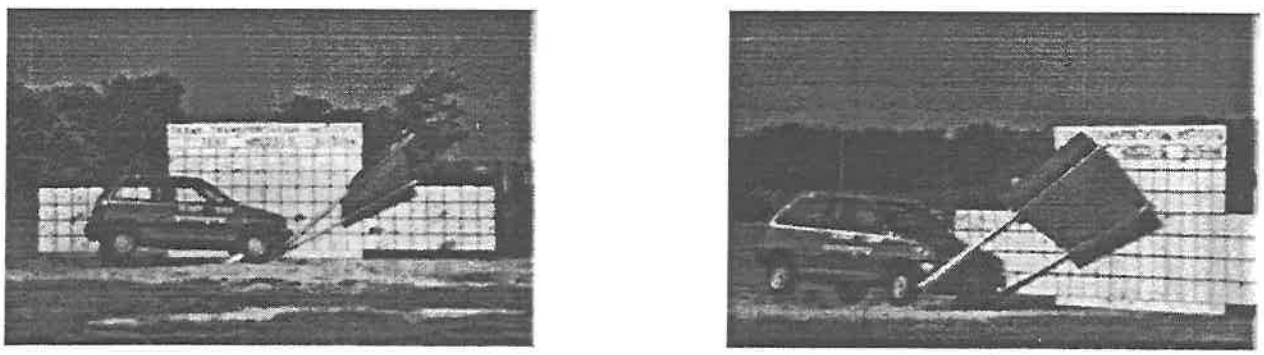
Figure B-5. Sequential photographs for test 405231-5.
(perpendicular and angular views)



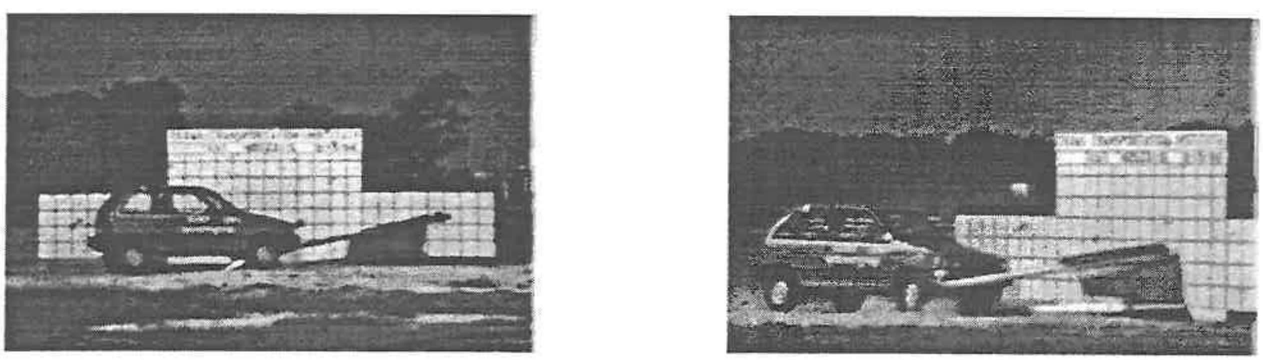
0.200 s



0.250 s

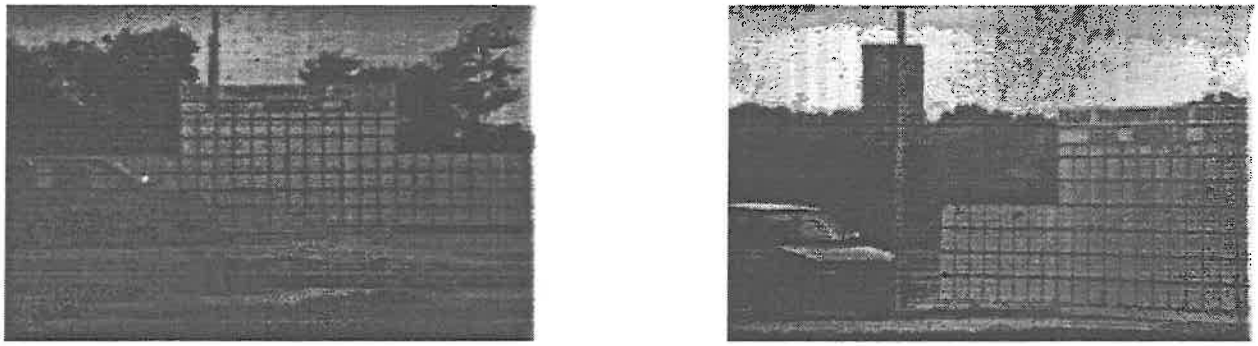


0.361 s

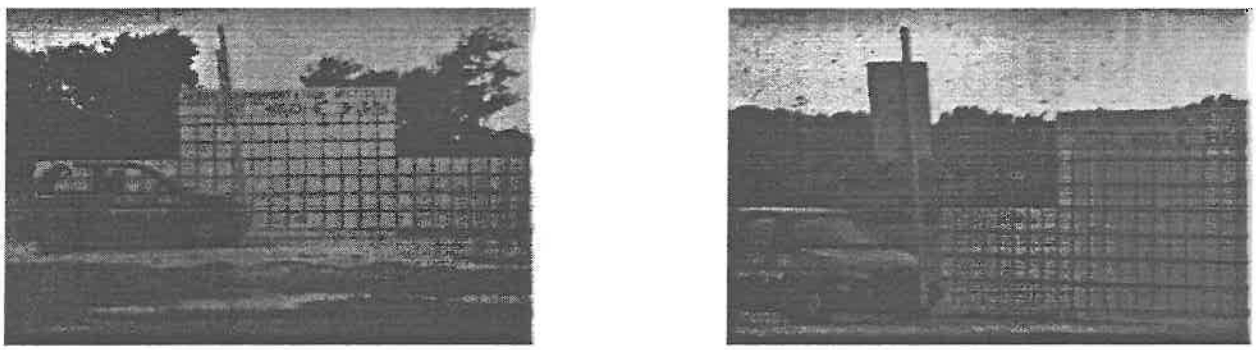


0.469 s

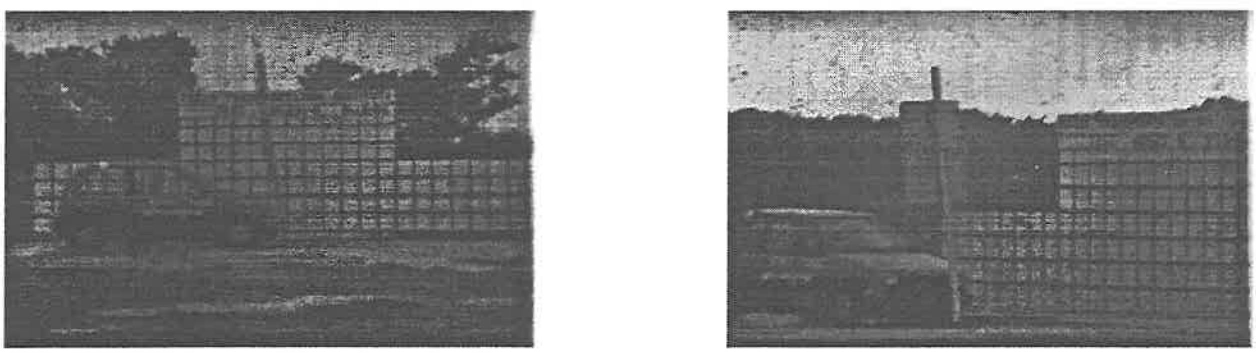
Figure B-5. Sequential photographs for test 405231-5 (continued).
(perpendicular and angular views)



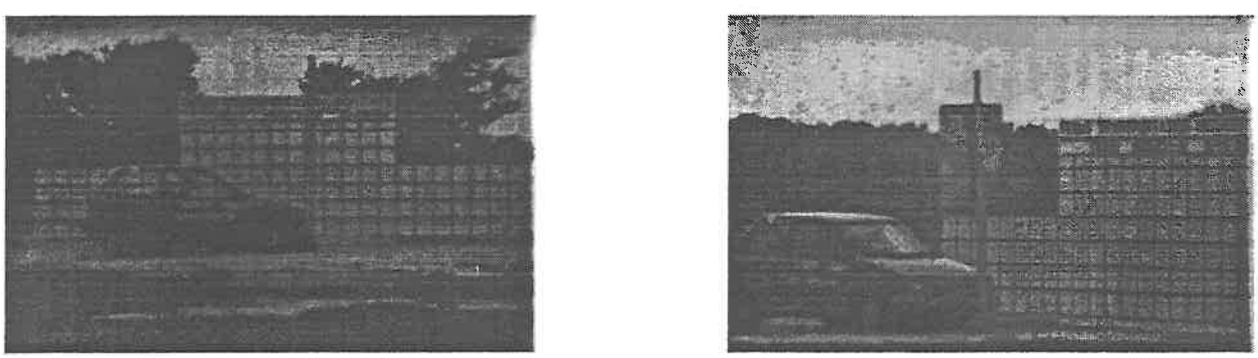
0.000 s



0.062 s

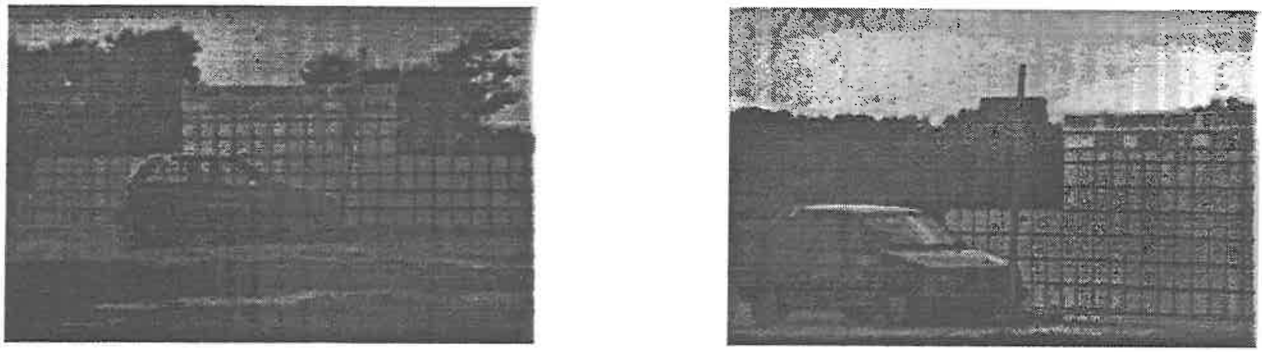


0.124 s

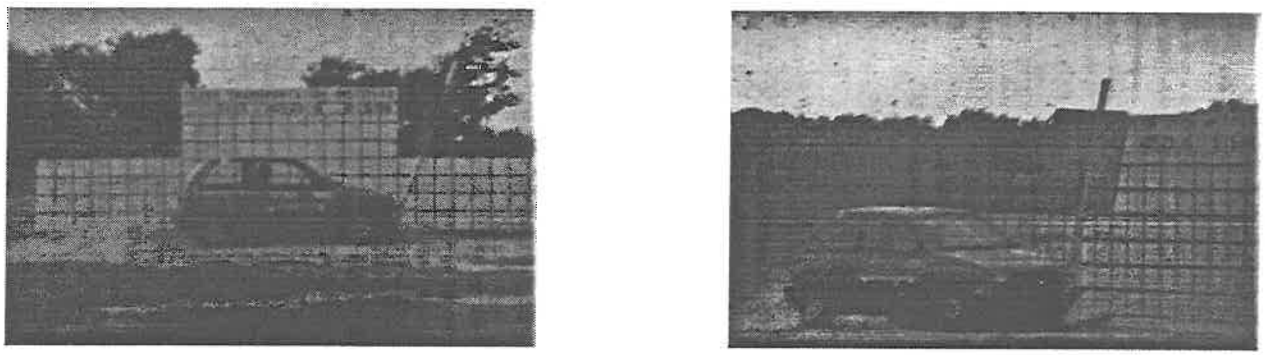


0.186 s

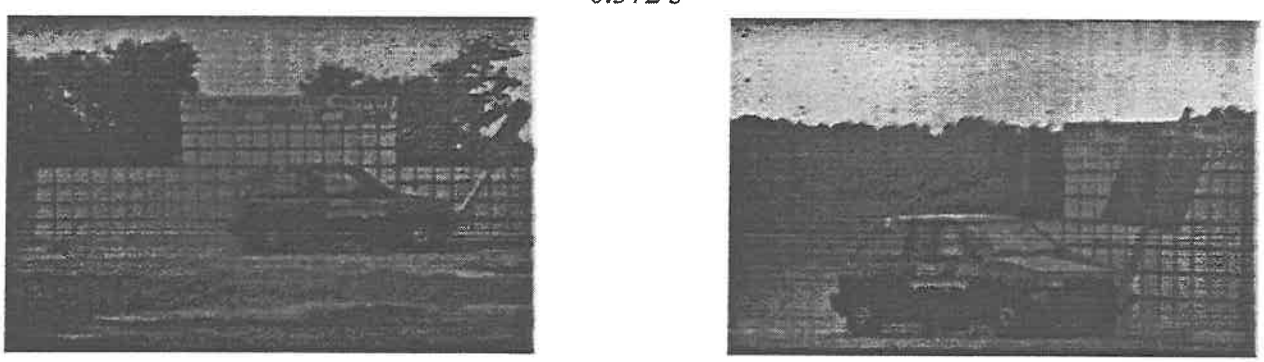
Figure B-6. Sequential photographs for test 405231-6.
(perpendicular and angular views)



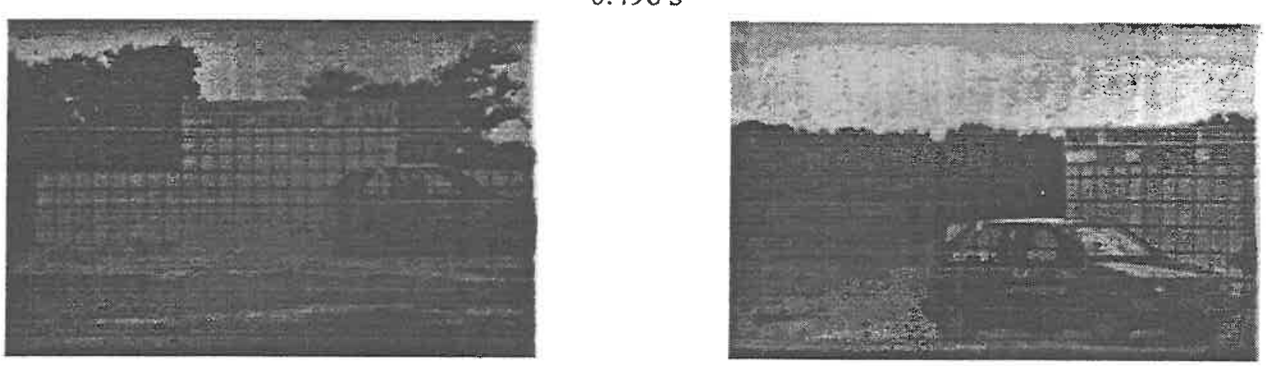
0.248 s



0.372 s



0.496 s

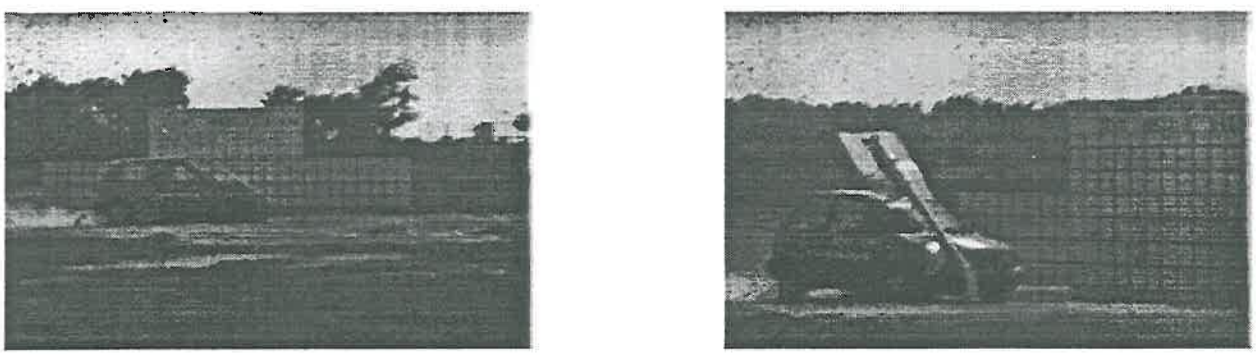


0.714 s

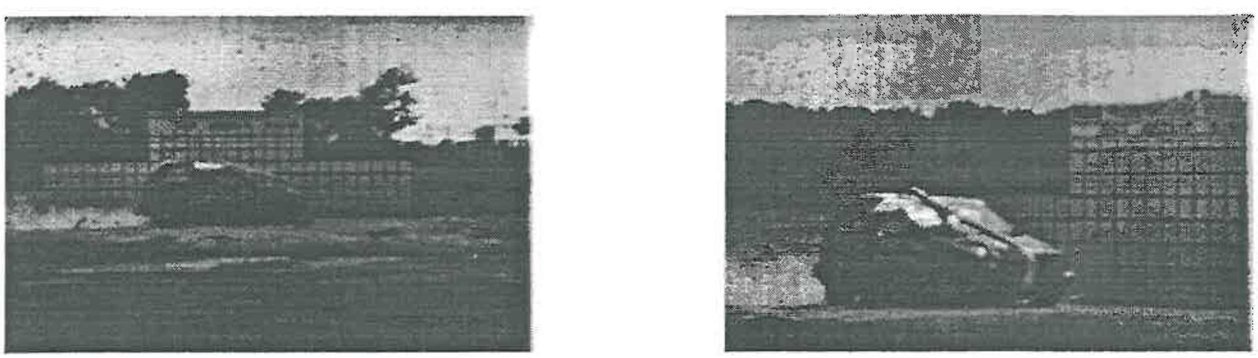
Figure B-6. Sequential photographs for test 405231-6 (continued).
(perpendicular and angular views)

0.000 s

0.037 s

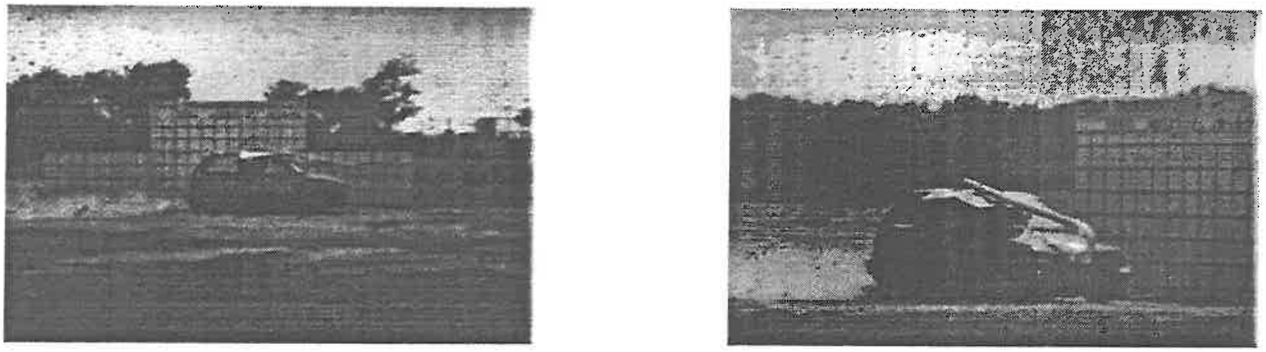


0.075 s

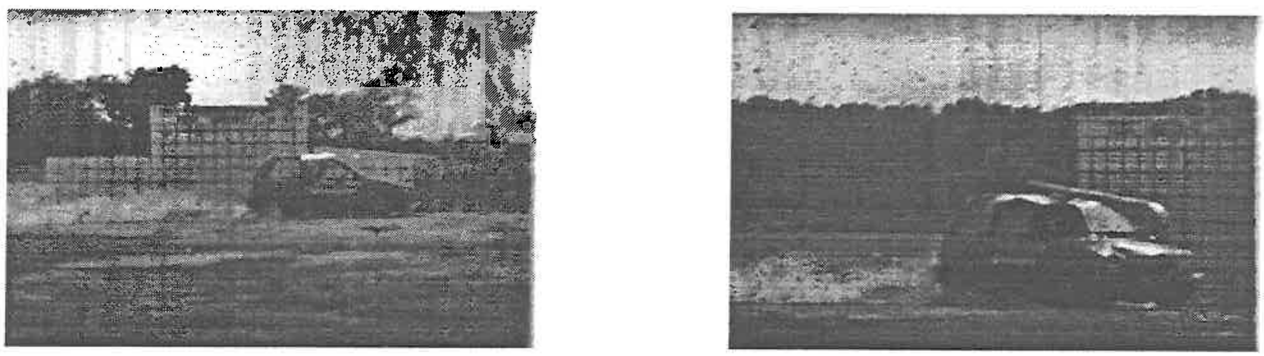


0.112 s

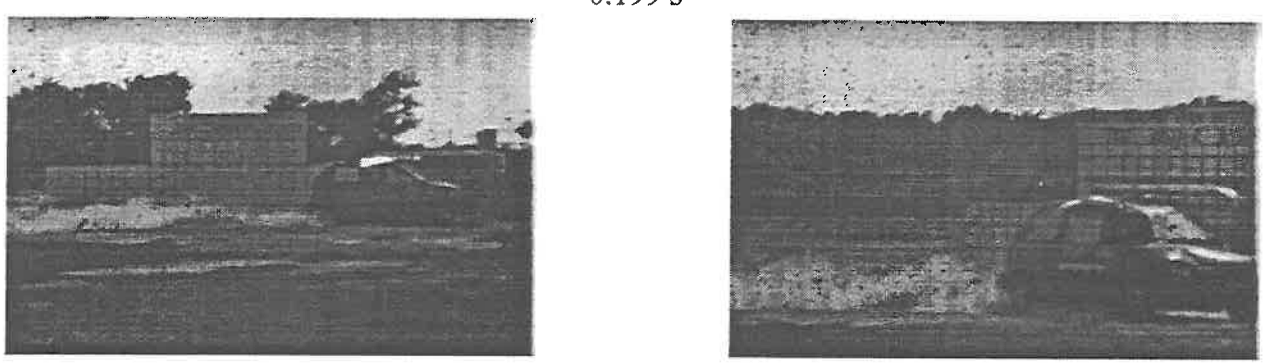
Figure B-7. Sequential photographs for test 405231-7.
(perpendicular and angular views)



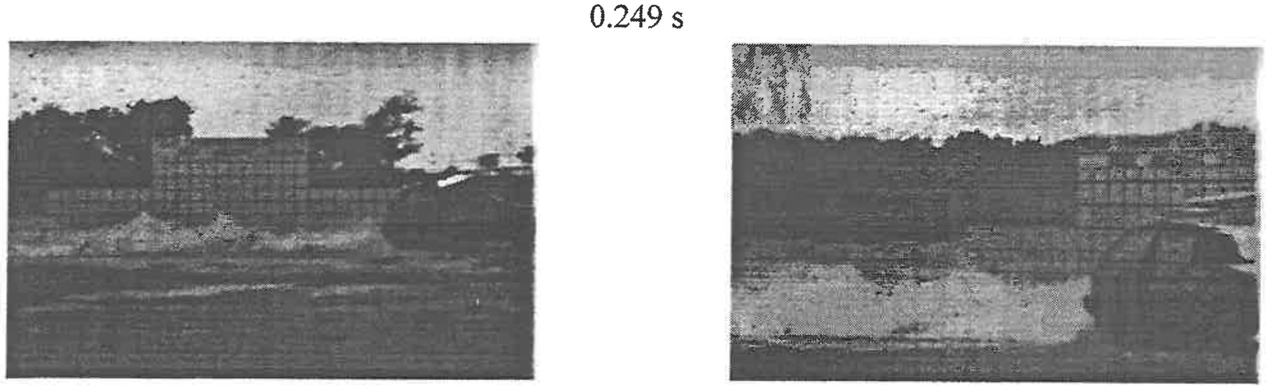
0.149 s



0.199 s

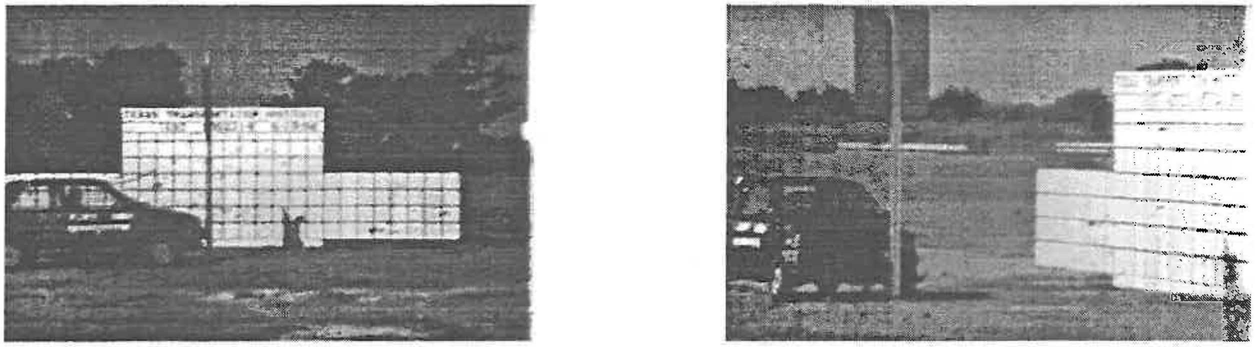


0.249 s

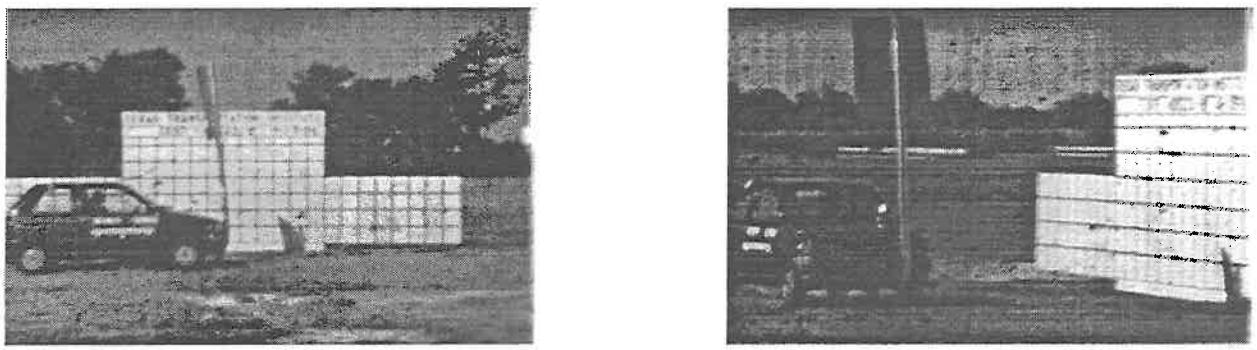


0.311 s

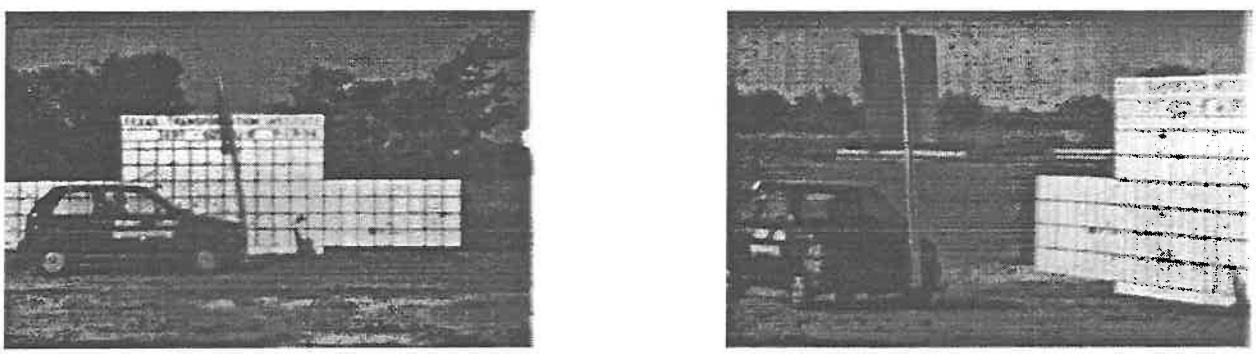
Figure B-7. Sequential photographs for test 405231-7 (continued).
(perpendicular and angular views)



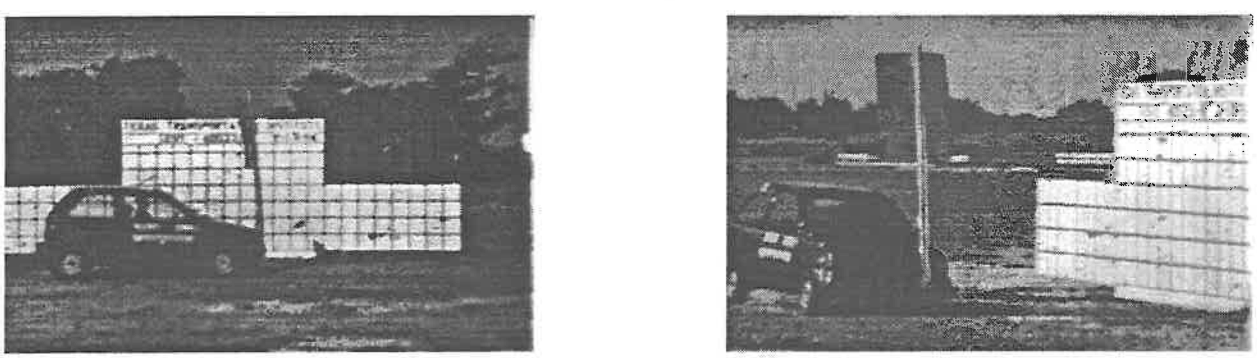
0.000 s



0.037 s

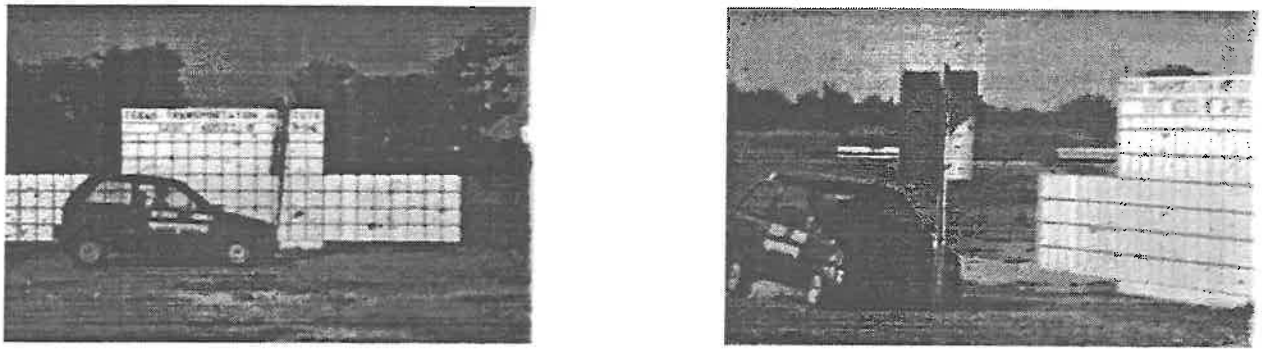


0.074 s

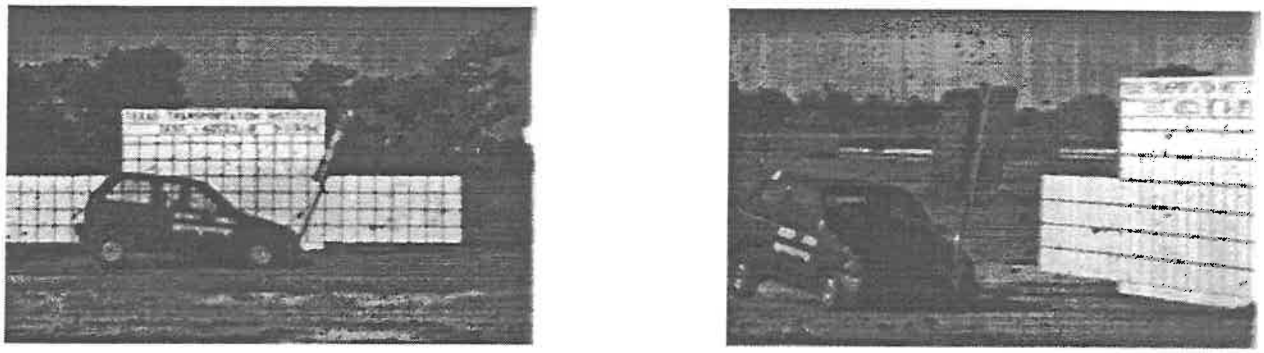


0.111 s

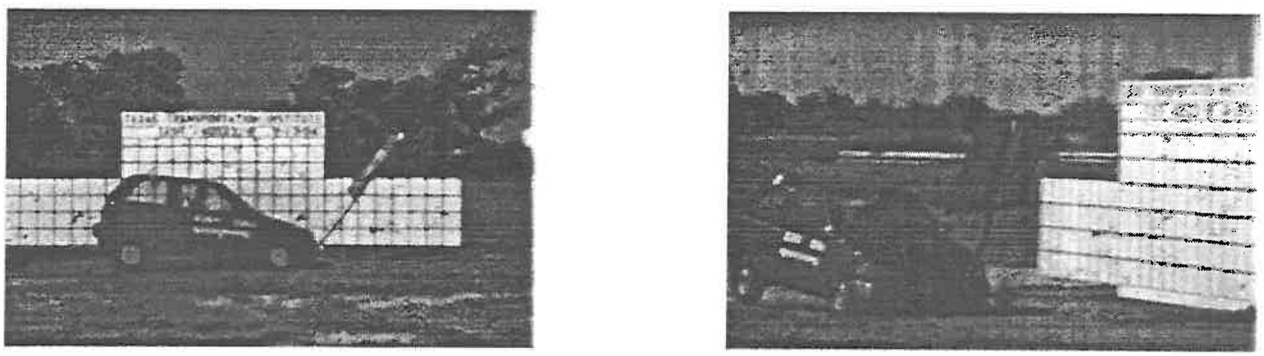
Figure B-8. Sequential photographs for test 405231-8.
(perpendicular and angular views)



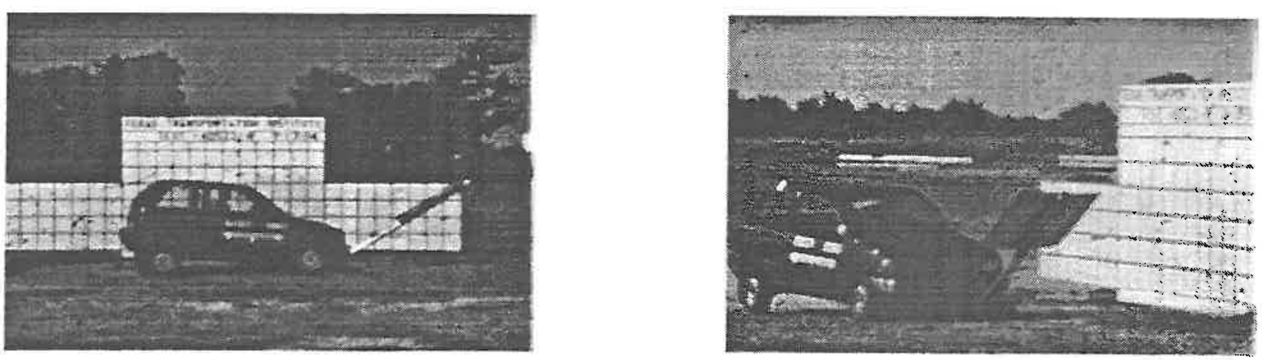
0.151 s



0.200 s

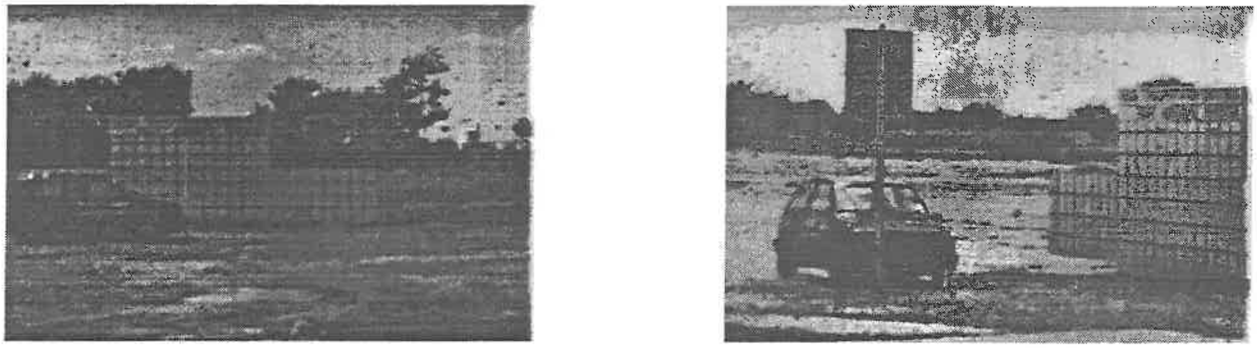


0.250 s

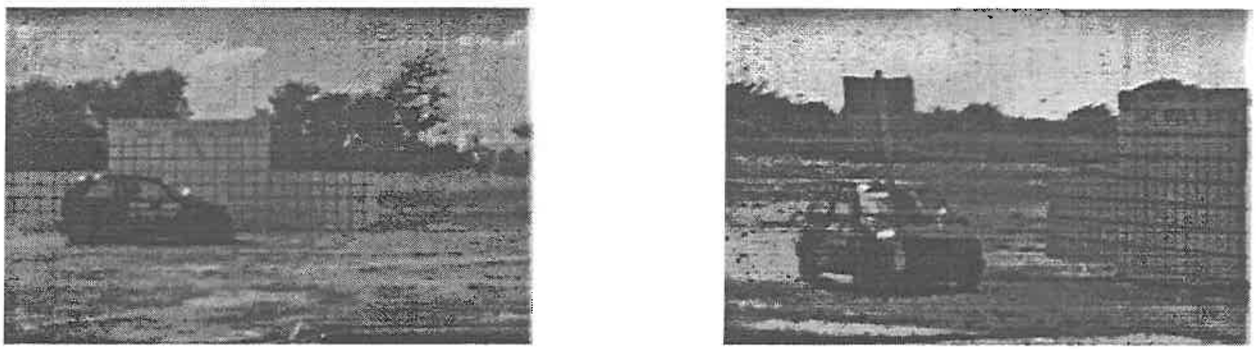


0.329 s

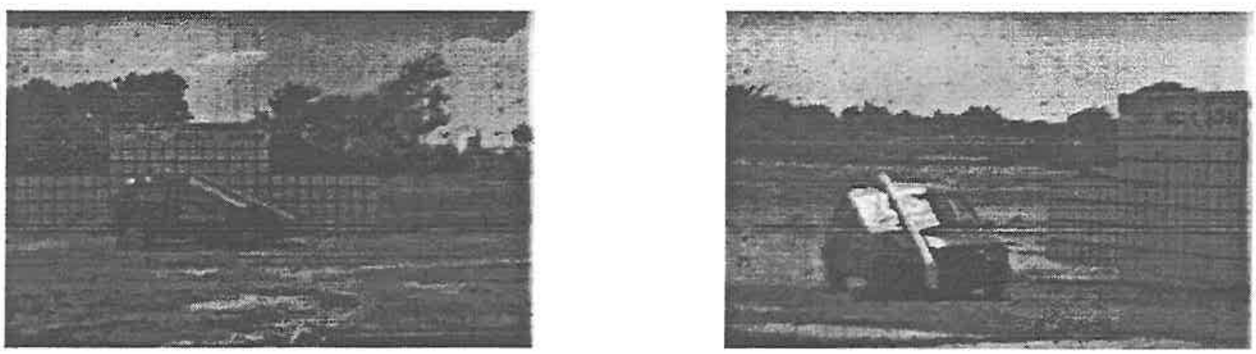
Figure B-8. Sequential photographs for test 405231-8 (continued).
(perpendicular and angular views)



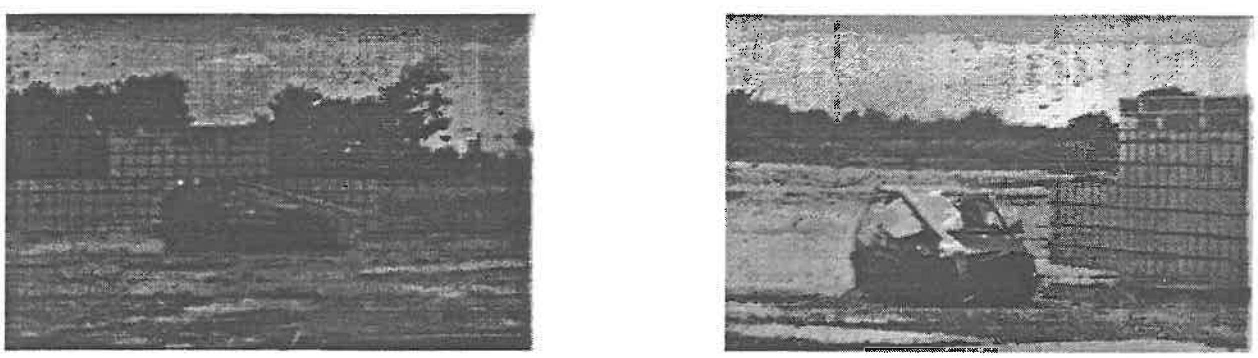
0.000 s



0.037 s

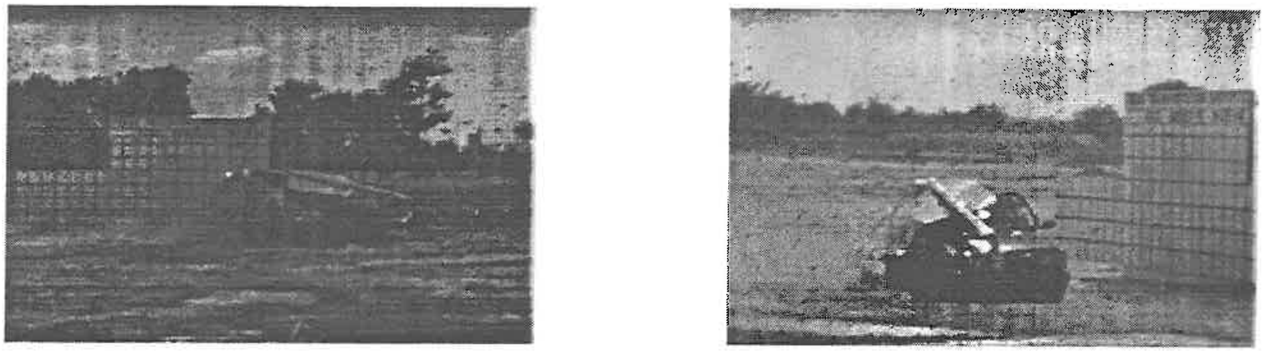


0.074 s

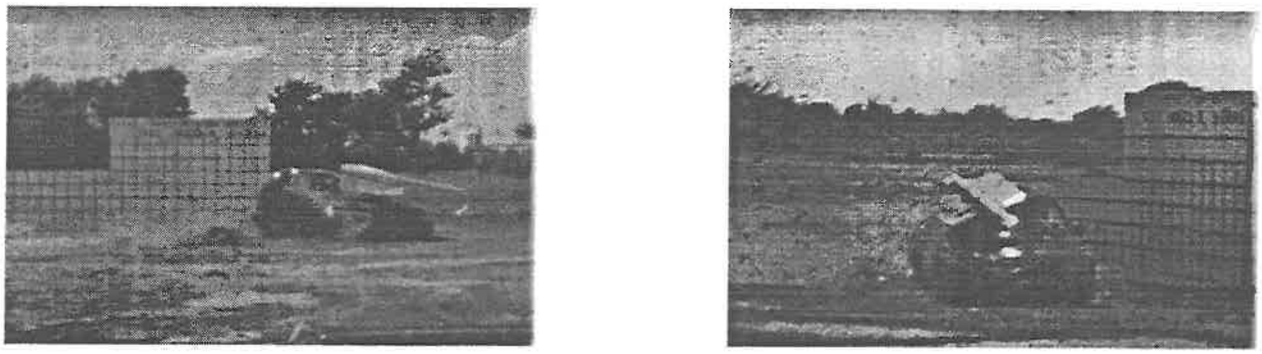


0.112 s

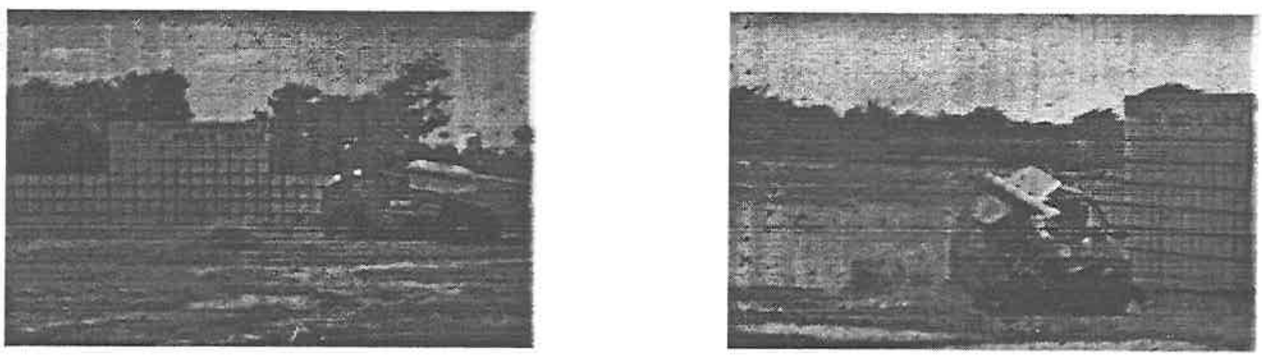
Figure B-9. Sequential photographs for test 405231-9.
(perpendicular and angular views)



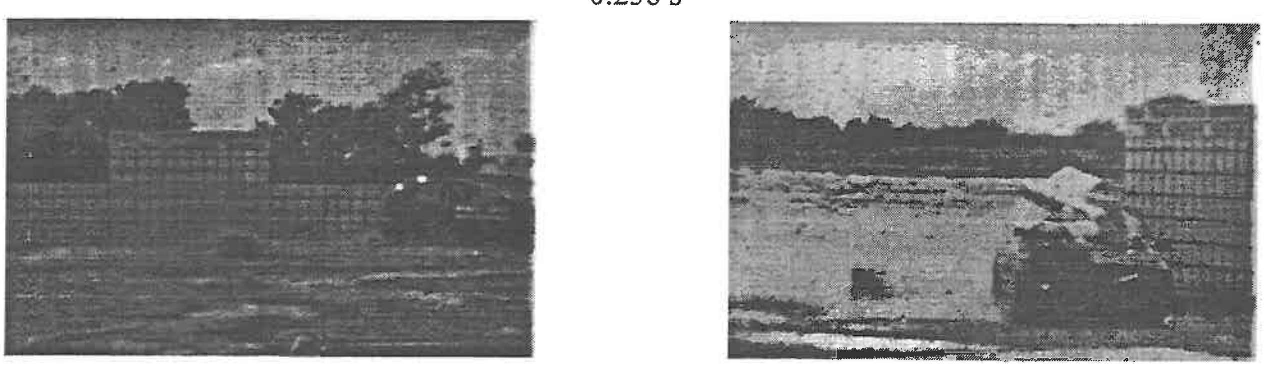
0.149 s



0.186 s

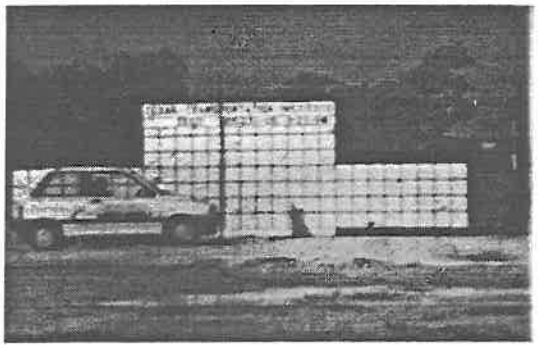
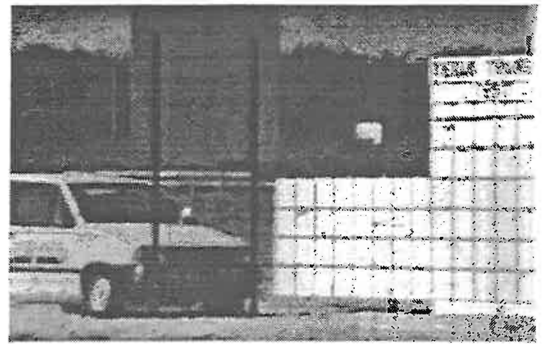


0.236 s

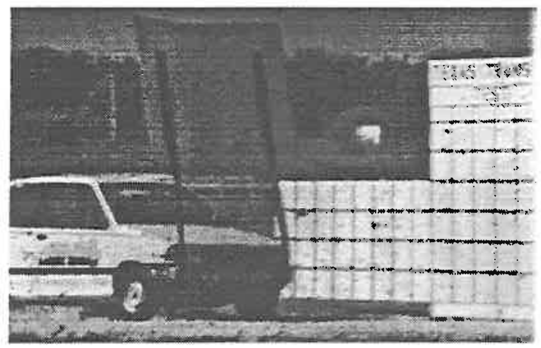


0.286 s

Figure B-9. Sequential photographs for test 405231-9 (continued).
(perpendicular and angular views)

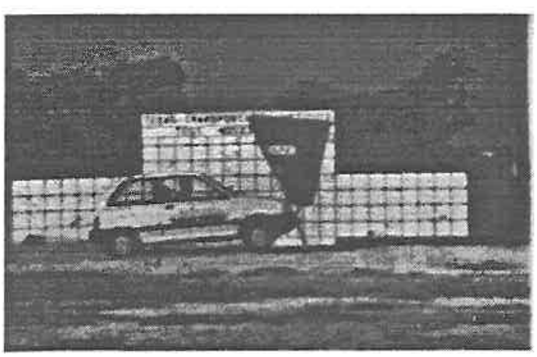
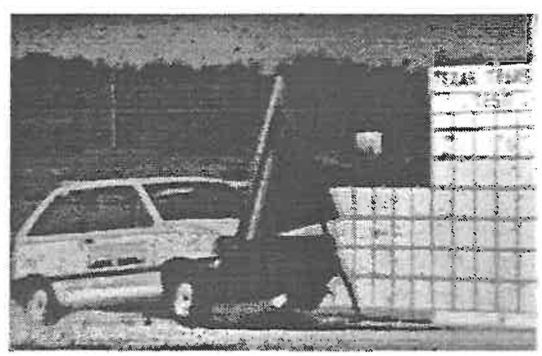



0.000 s

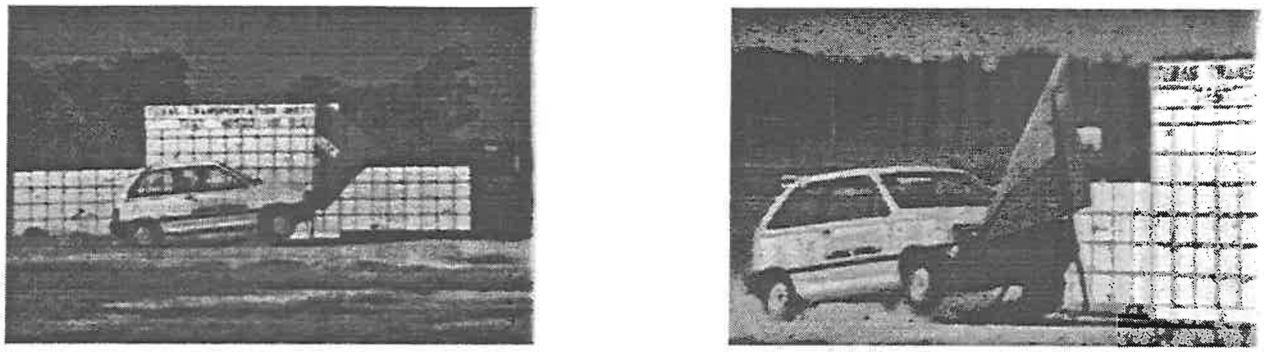
0.062 s


0.123 s

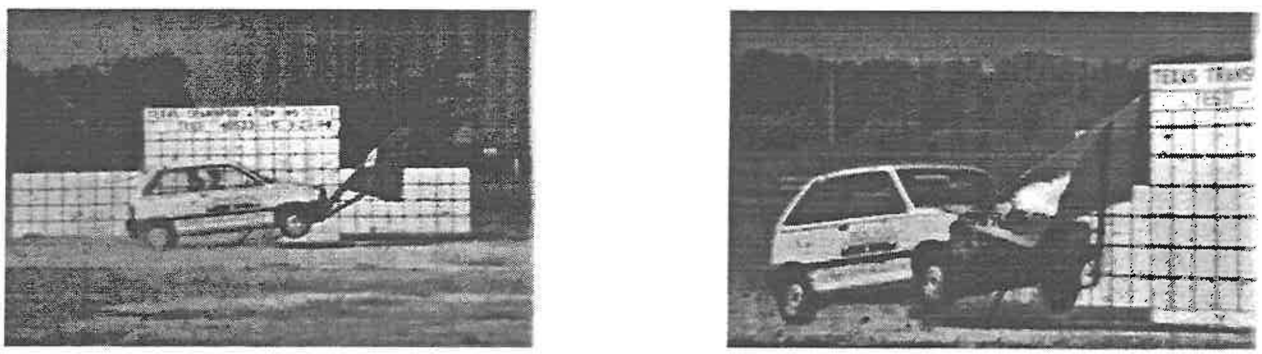



0.185 s

FigureB-10. Sequential photographs for test 405231-10.
(perpendicular and angular views)

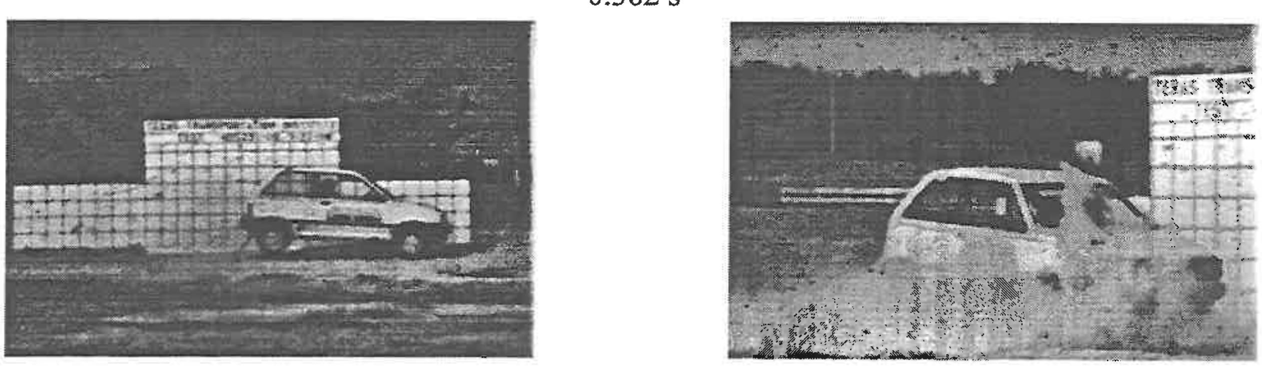


0.247 s



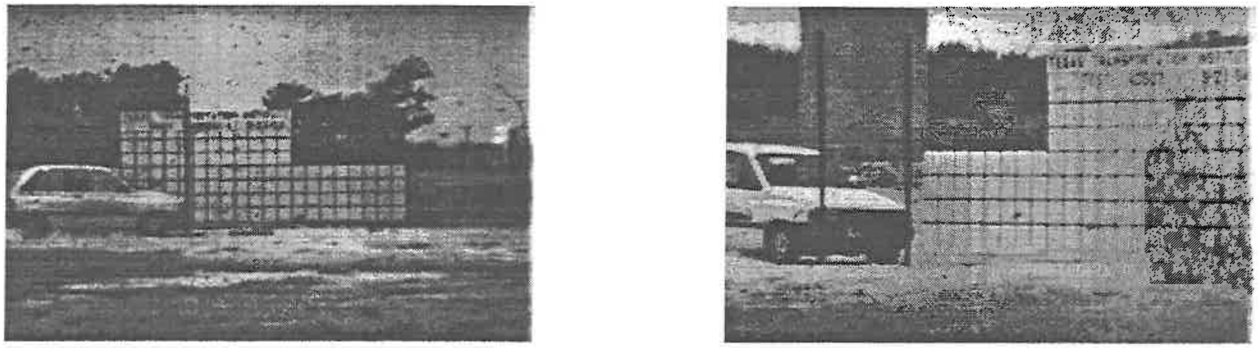
0.313 s

0.382 s

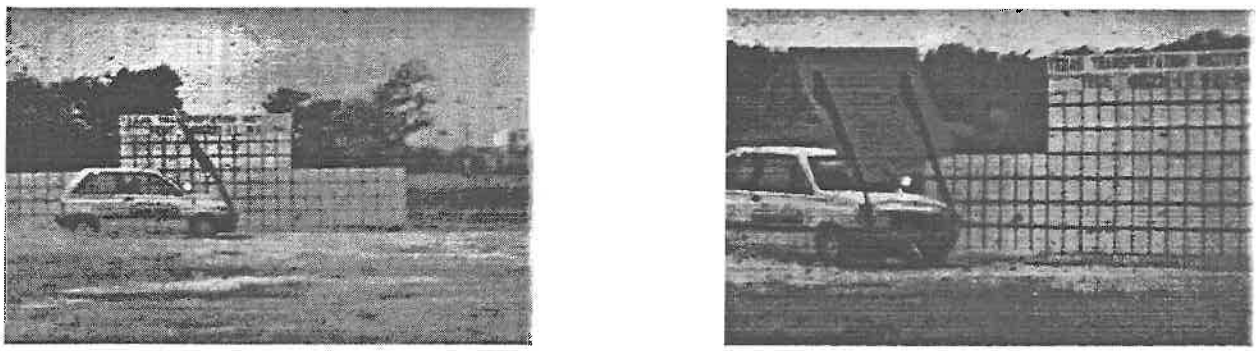


1.082 s

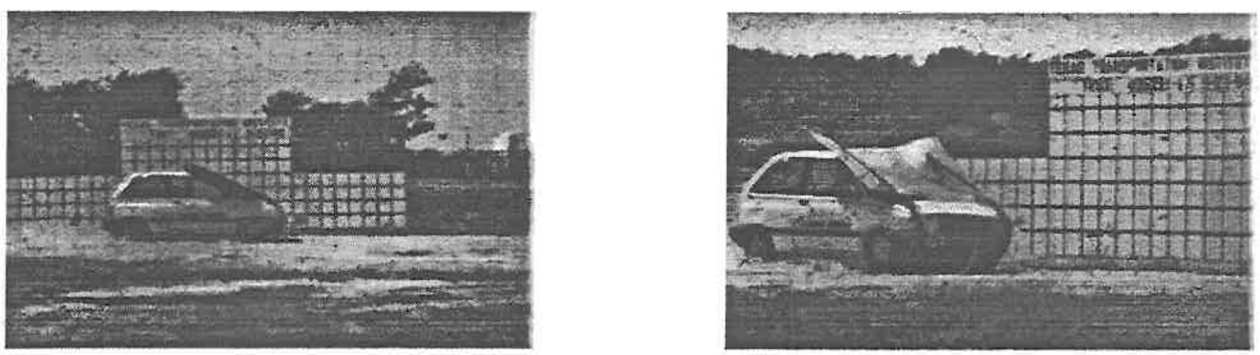
FigureB-10.Sequential photographs for test 405231-10 (continued).
(perpendicular and angular views)



0.000 s



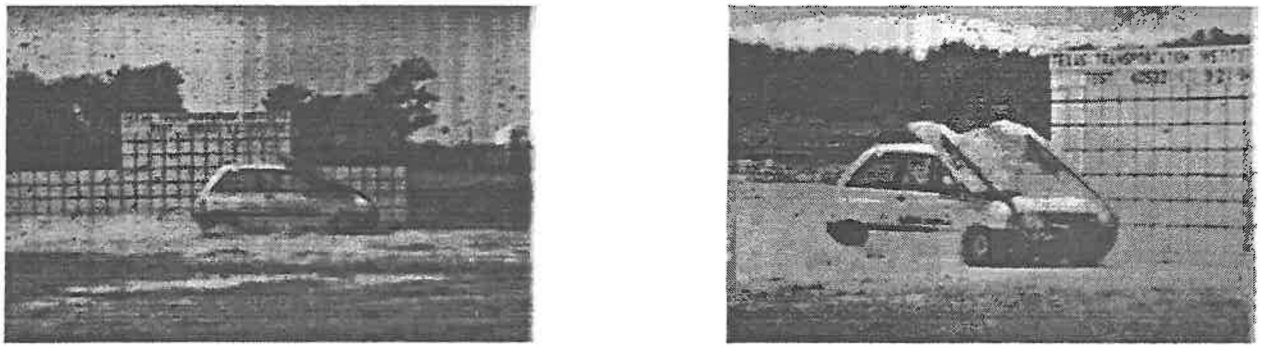
0.037 s



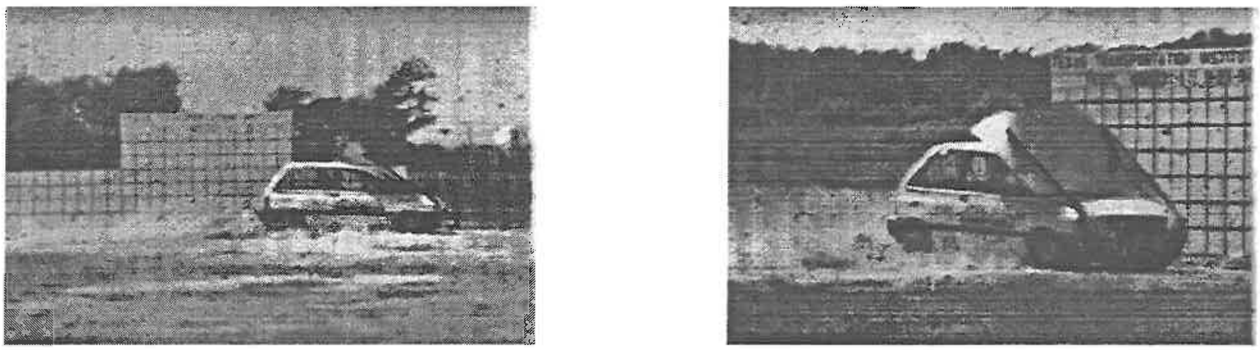
0.074 s

0.112 s

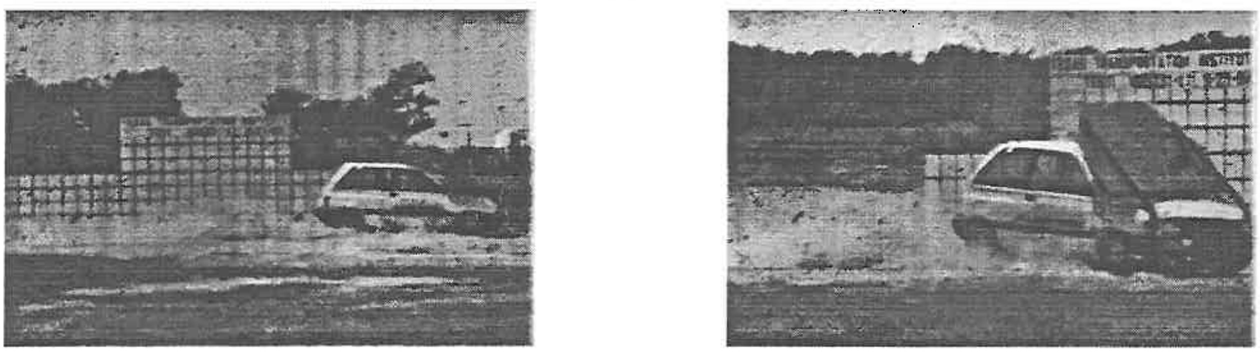
FigureB-11.Sequential photographs for test 405231-11.
(perpendicular and angular views)



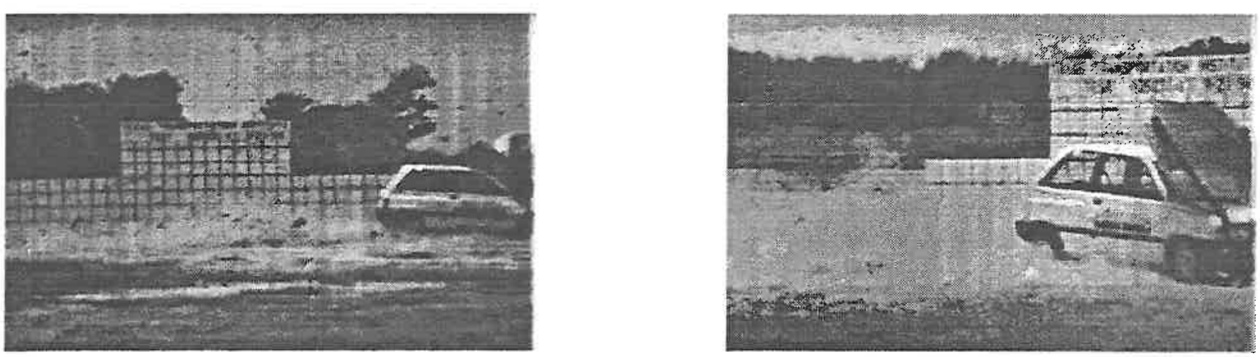
0.151 s



0.201 s

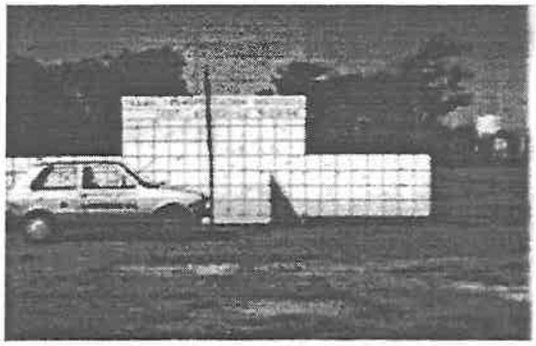
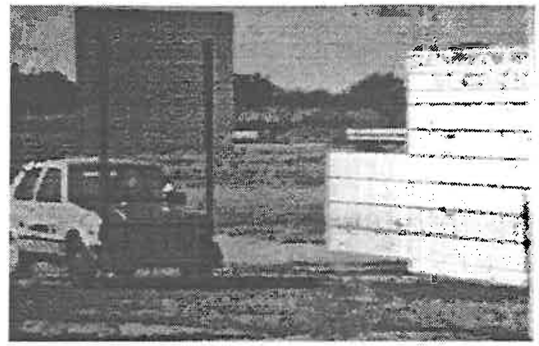


0.251 s

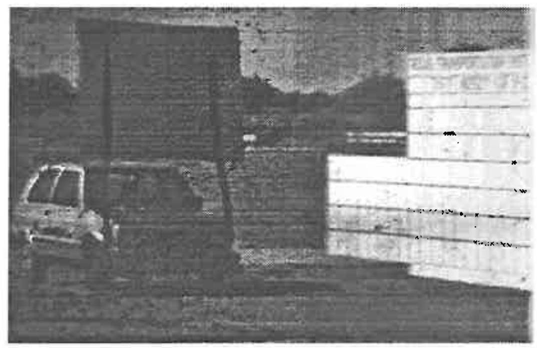


0.300 s

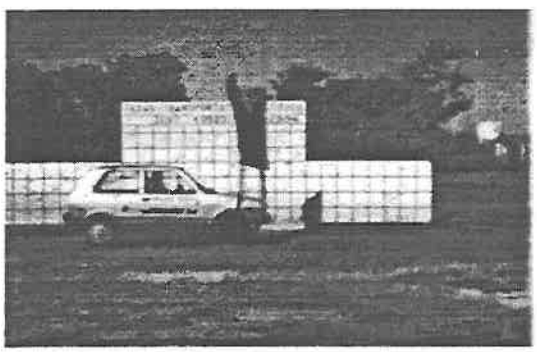
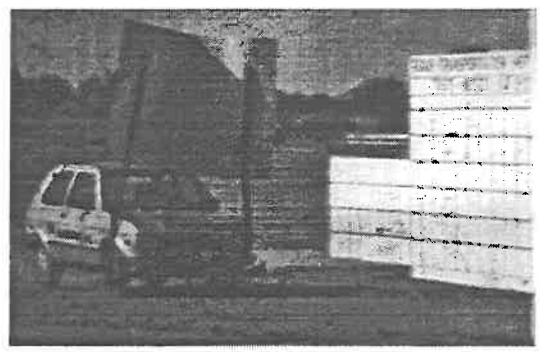
FigureB-11.Sequential photographs for test 405231-11 (continued).
(perpendicular and angular views)

0.000 s

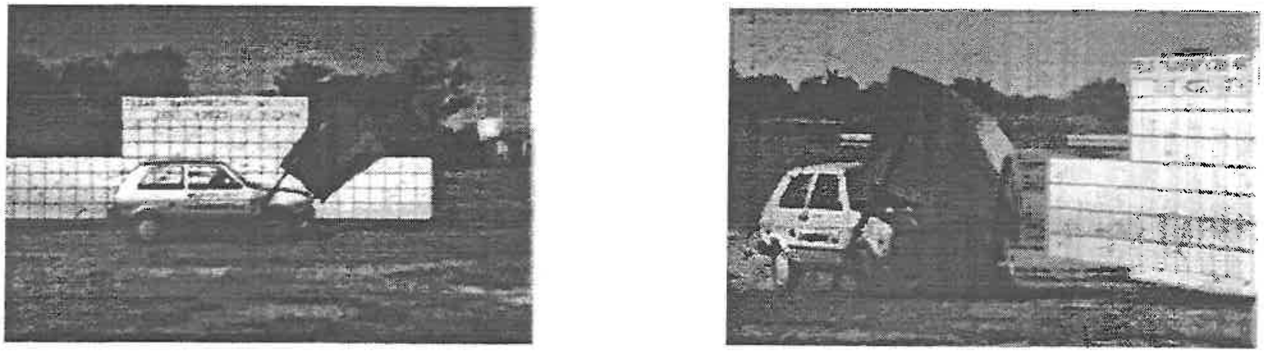
0.062 s

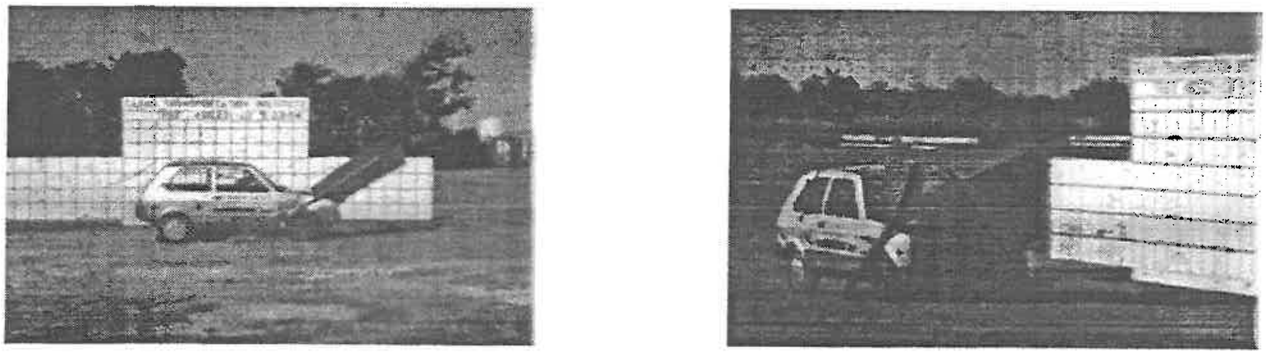
0.126 s


0.187 s

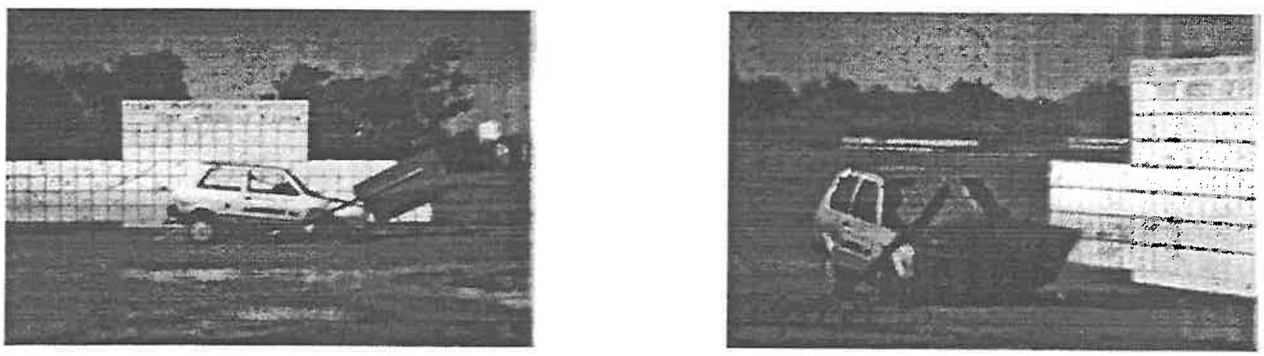
FigureB-12. Sequential photographs for test 405231-12.
(perpendicular and angular views)



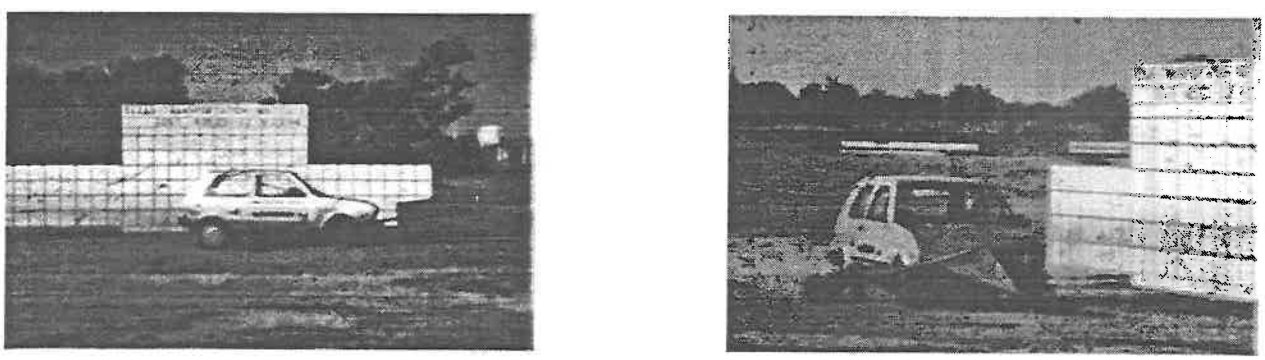
0.251 s



0.355 s

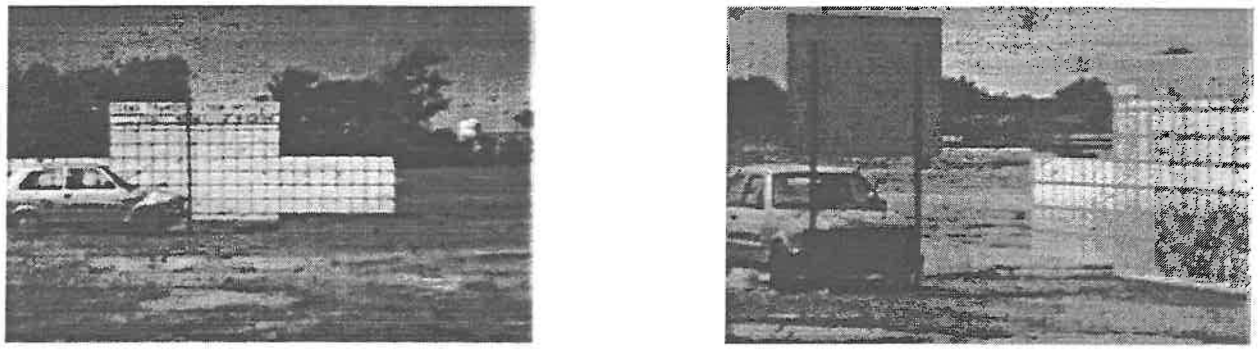


0.608 s



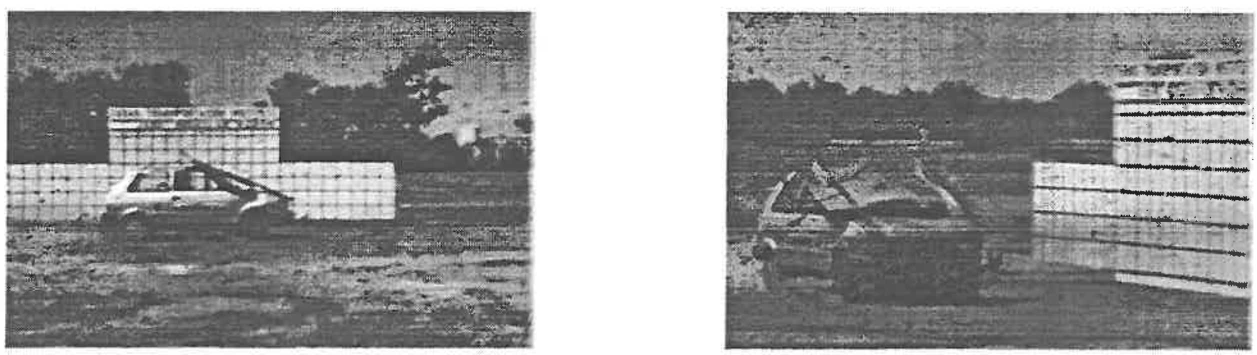
0.886 s

Figure B-12. Sequential photographs for test 405231-12 (continued).
(perpendicular and angular views)



0.000 s

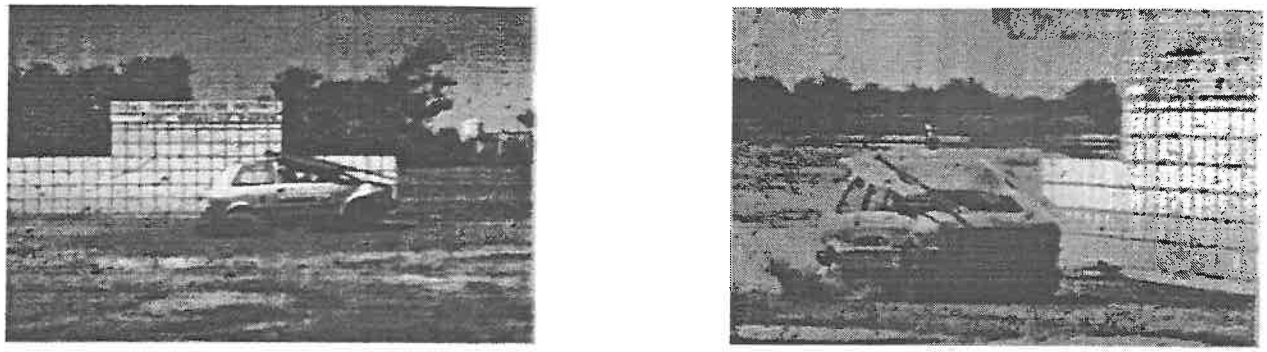
0.037 s



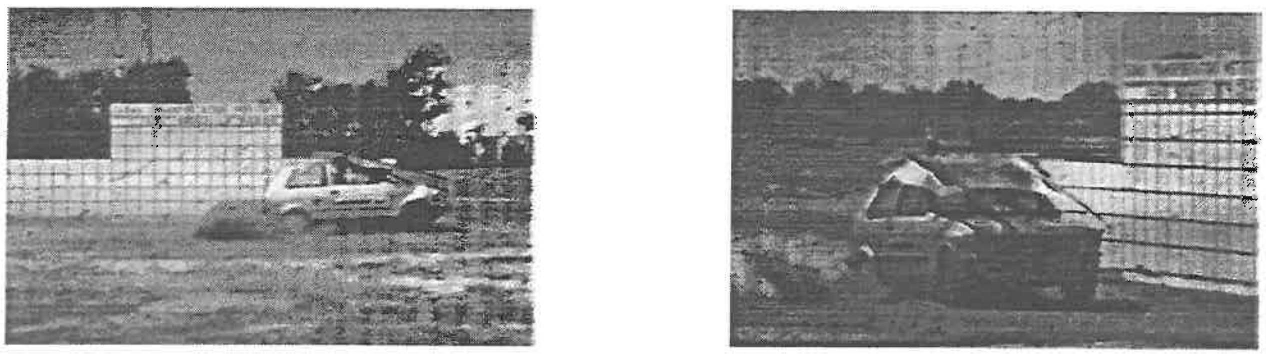
0.074 s

0.111 s

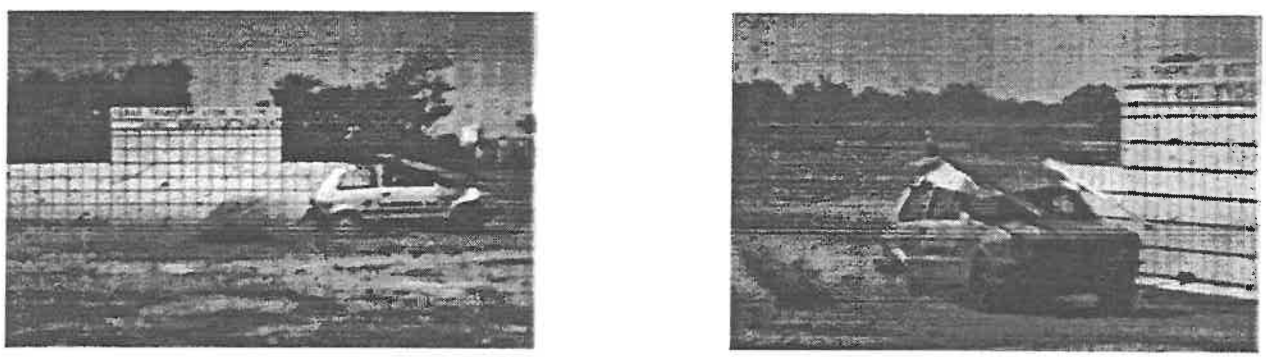
FigureB-13. Sequential photographs for test 405231-13.
(perpendicular and angular views)



0.148 s



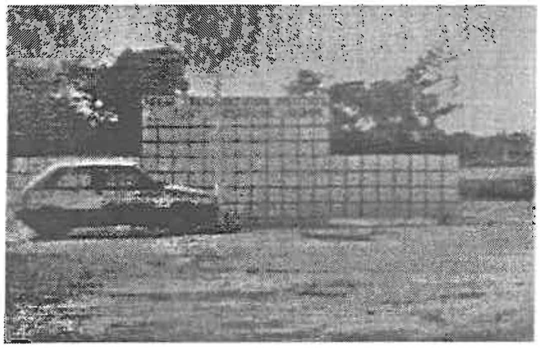
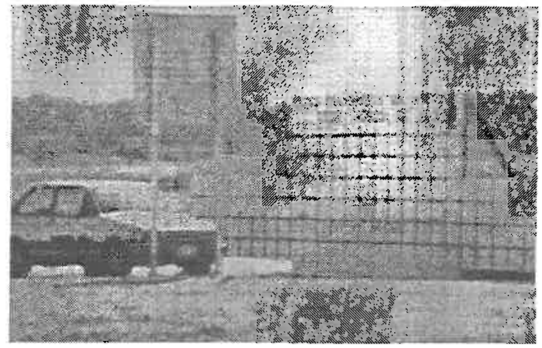
0.188 s



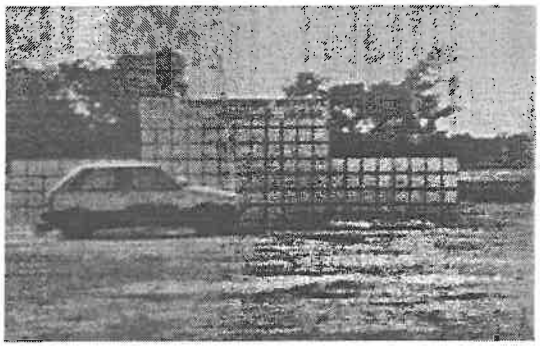
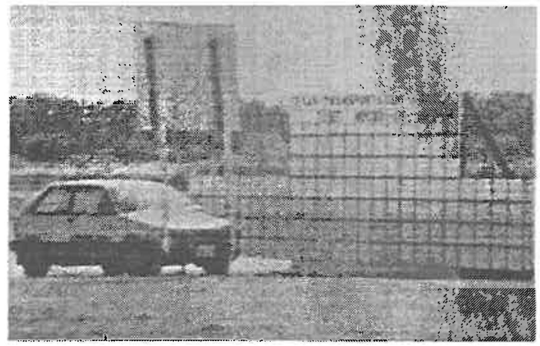
0.225 s

0.262 s

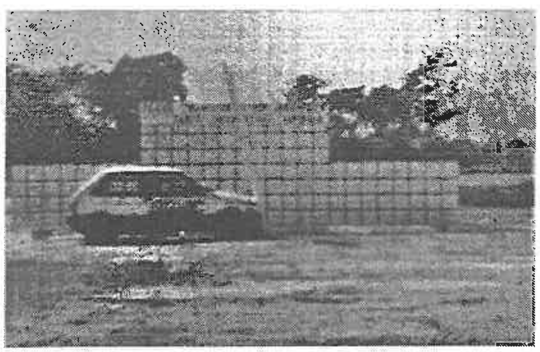
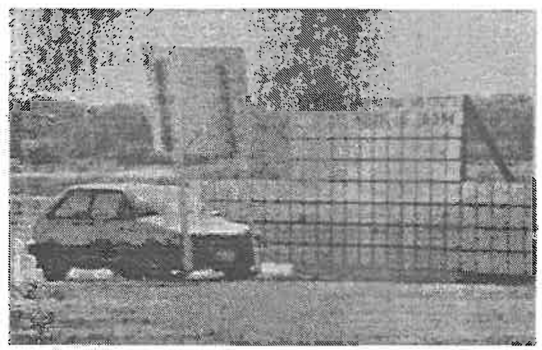
Figure B-13. Sequential photographs for test 405231-13 (continued).
(perpendicular and angular views)

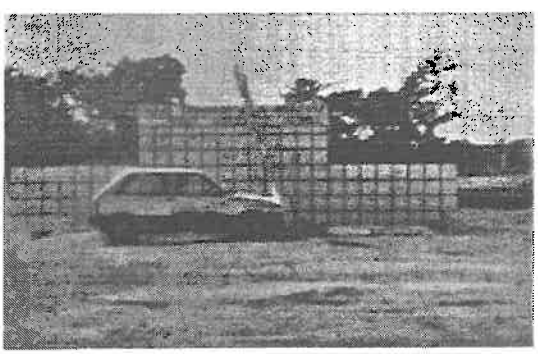
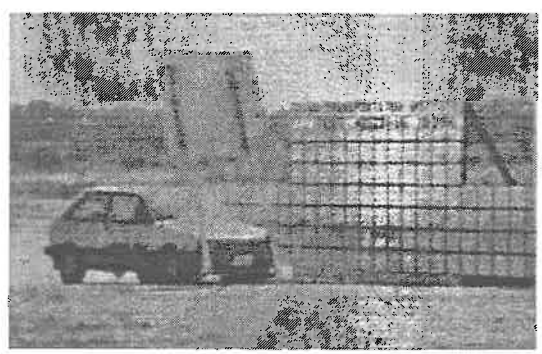
0.000 s

0.049 s

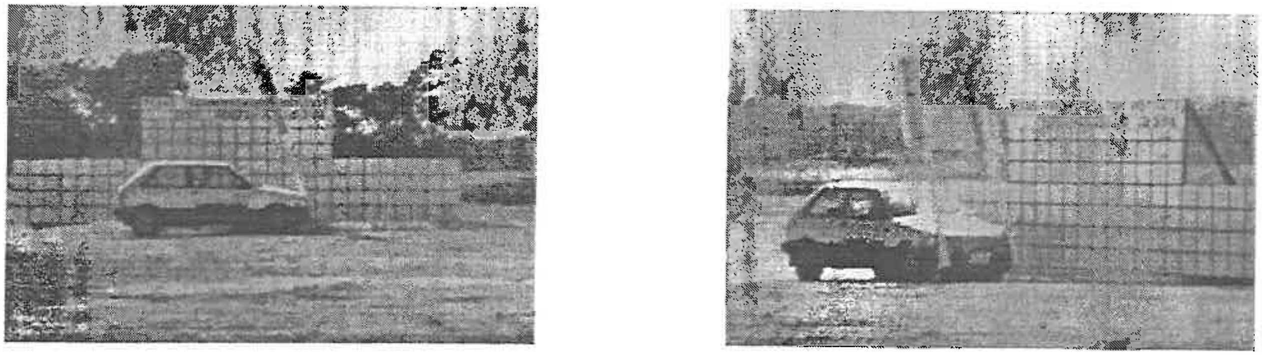



0.099 s

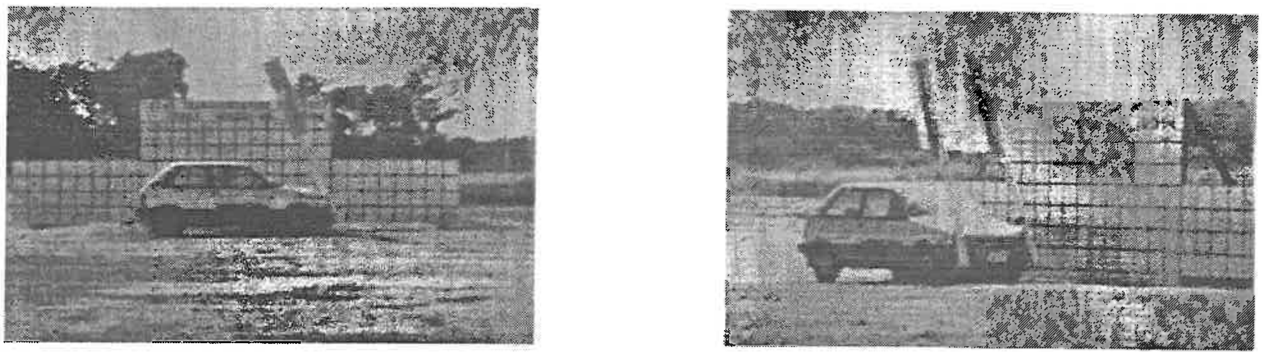



0.149 s

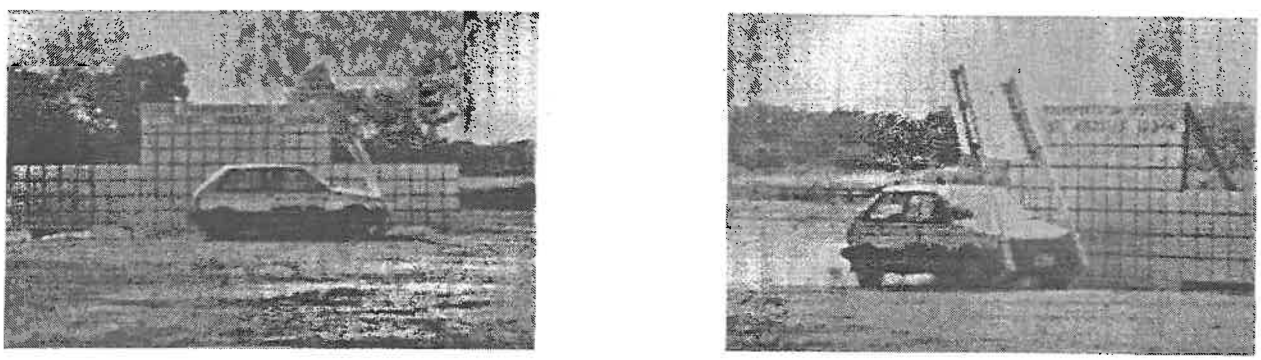
FigureB-14.Sequential photographs for test 405231-16.
(perpendicular and angular views)



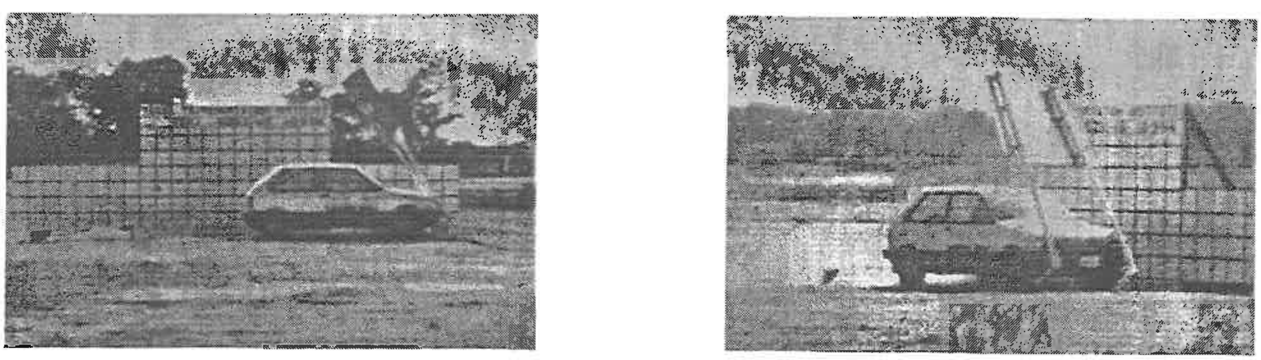
0.201 s



0.251 s



0.375 s



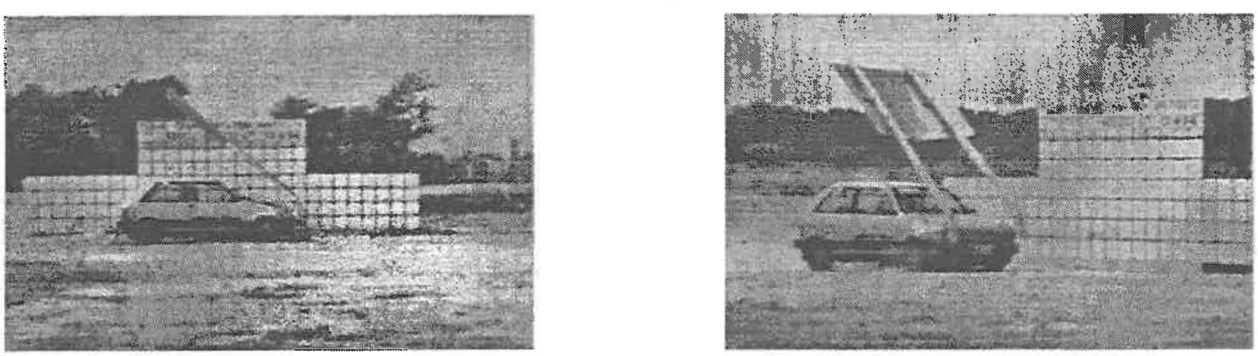
0.499 s

Figure B-14. Sequential photographs for test 405231-16 (continued).
(perpendicular and angular views)

0.000 s

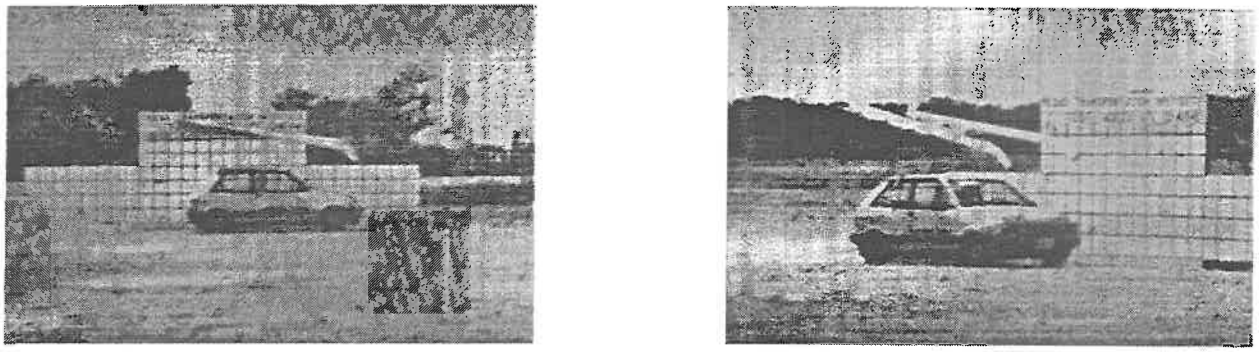
0.025 s

0.050 s

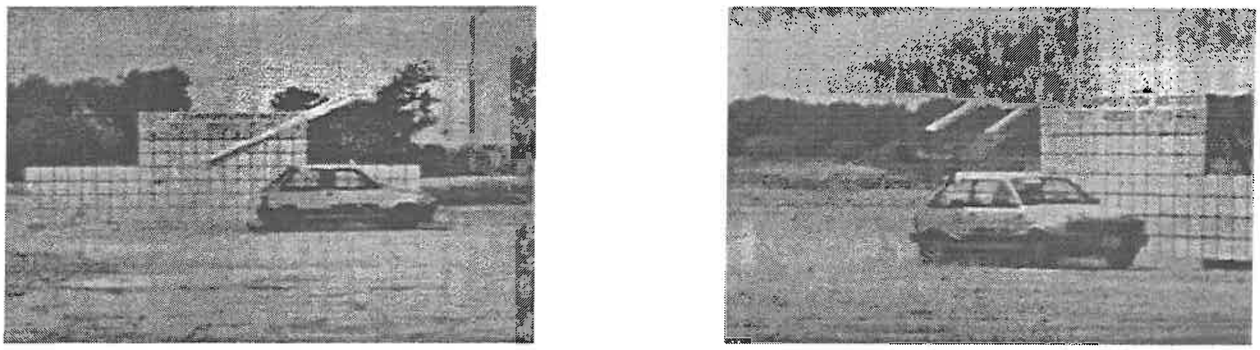


0.075 s

Figure B-15. Sequential photographs for test 405231-17.
(perpendicular and angular views)

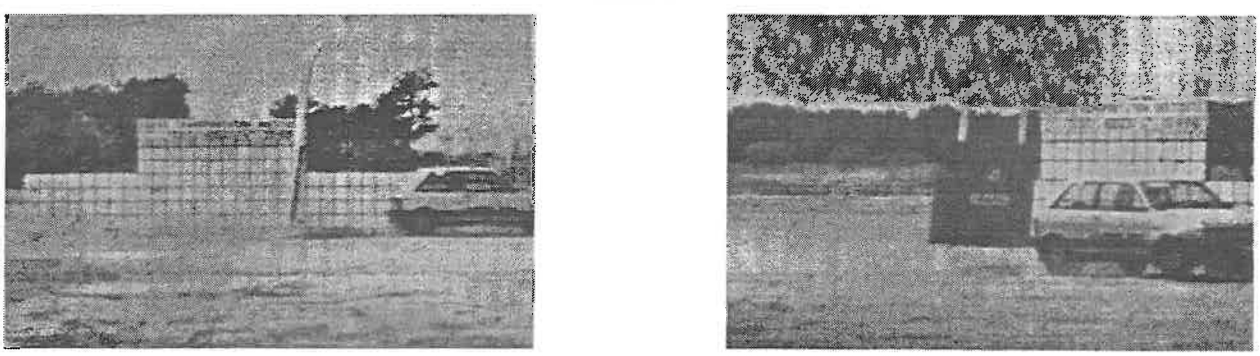


0.124 s



0.176 s

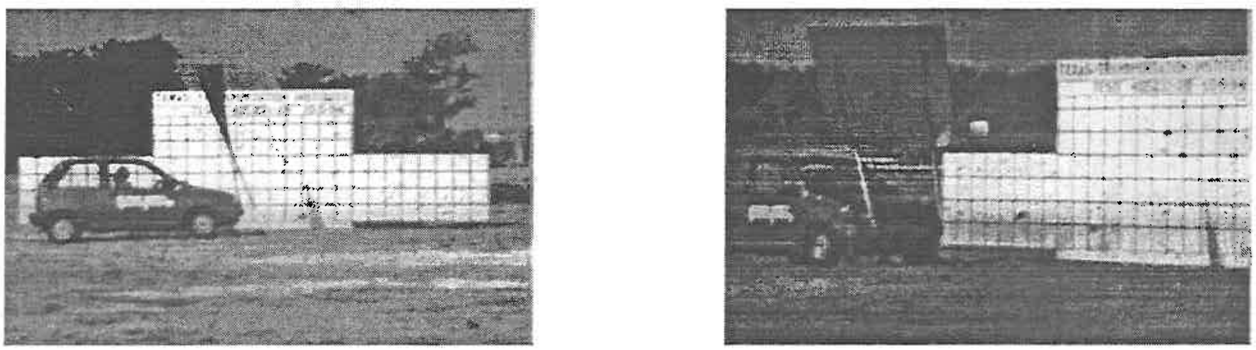
0.226 s



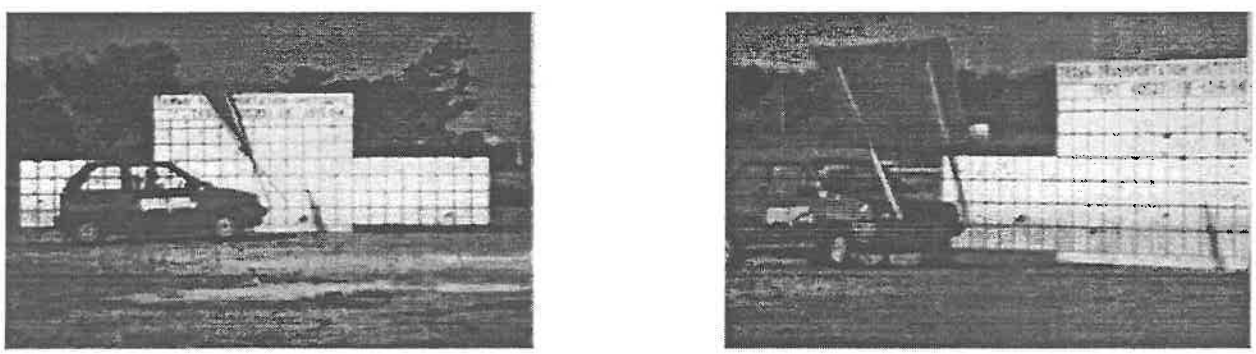
0.275 s

Figure B-15. Sequential photographs for test 405231-17 (continued).
(perpendicular and angular views)

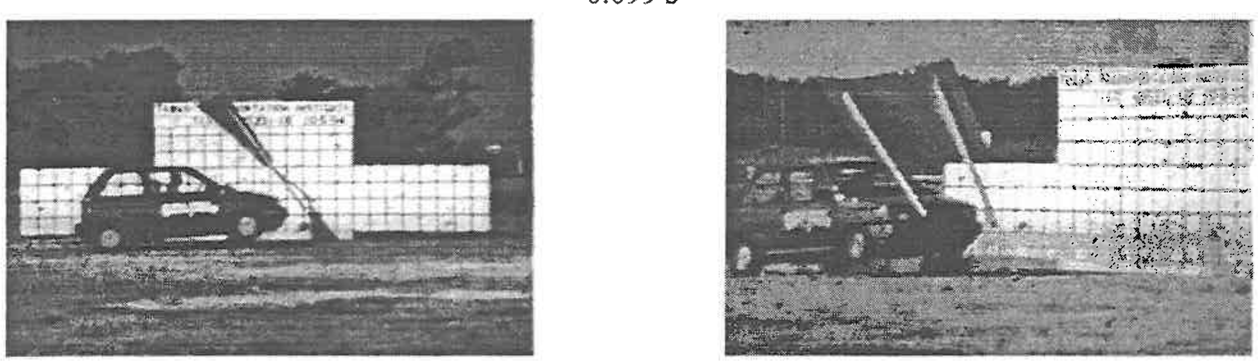
0.000 s



0.049 s

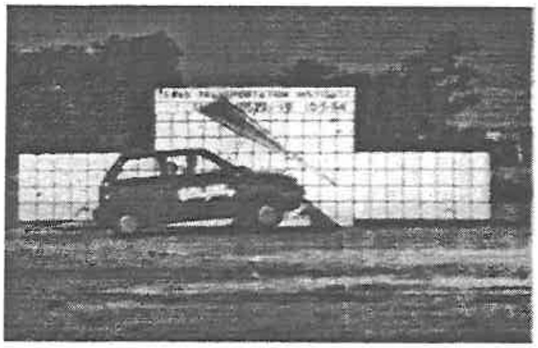
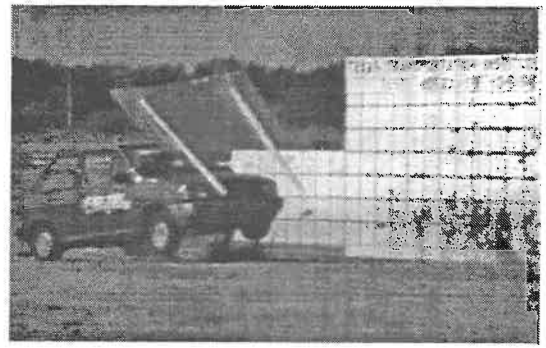


0.099 s

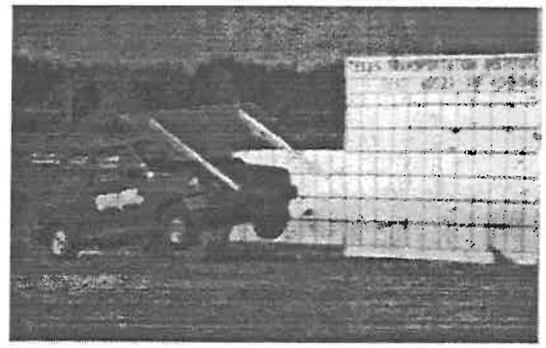


0.151 s

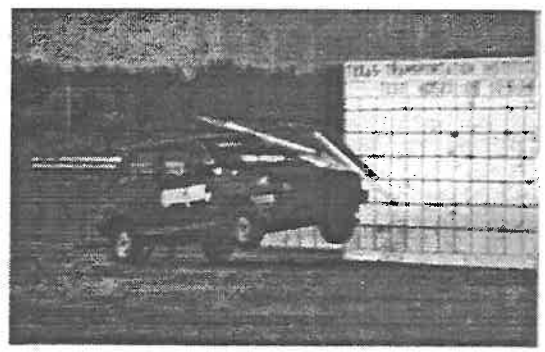
FigureB-16.Sequential photographs for test 405231-18.
(perpendicular and angular views)

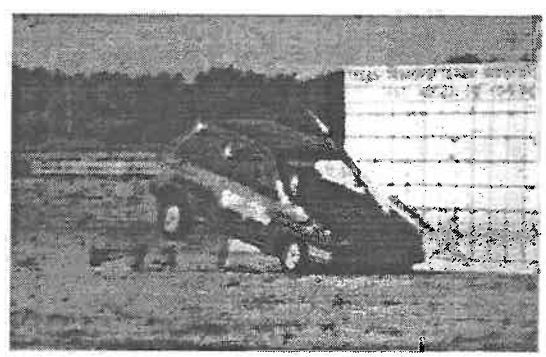
0.200 s

0.249 s

0.501 s

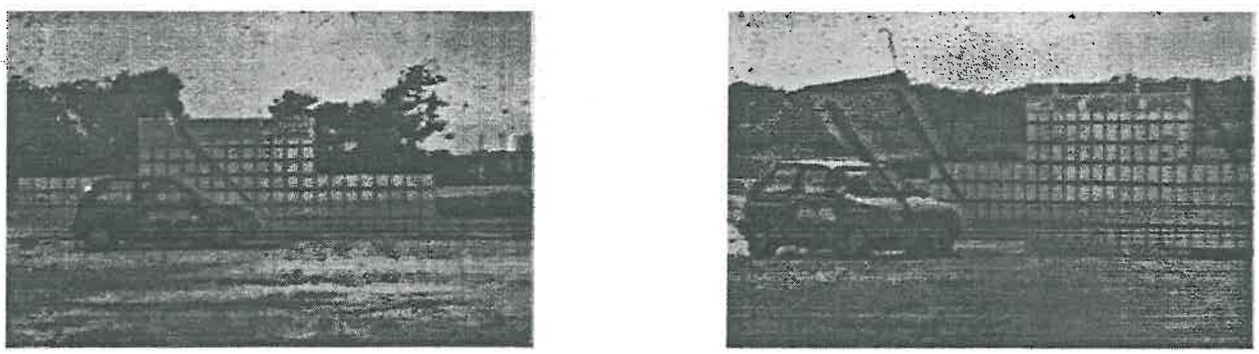



0.750 s

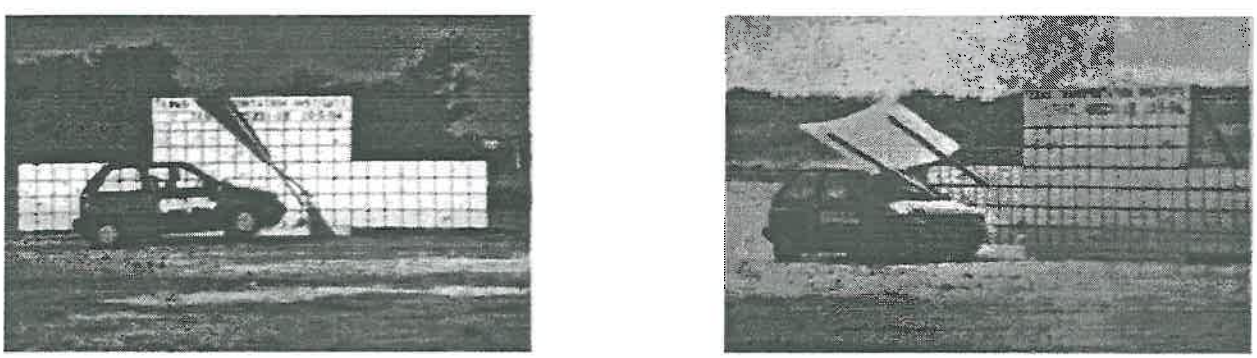
Figure B-16. Sequential photographs for test 405231-18 (continued).
(perpendicular and angular views)

0.000 s

0.025 s

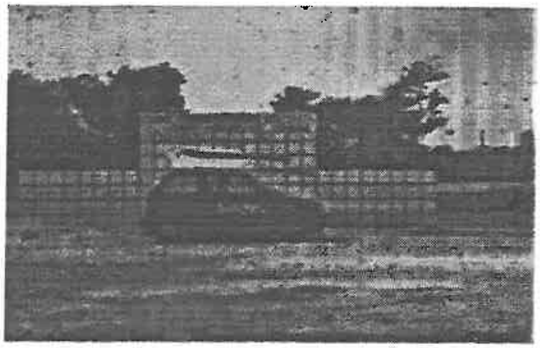
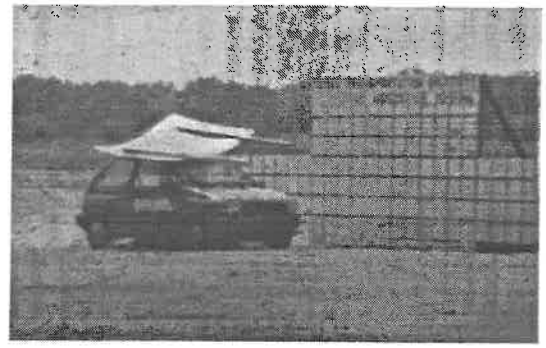


0.050 s

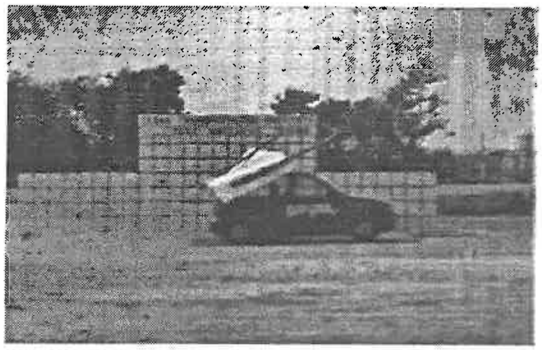
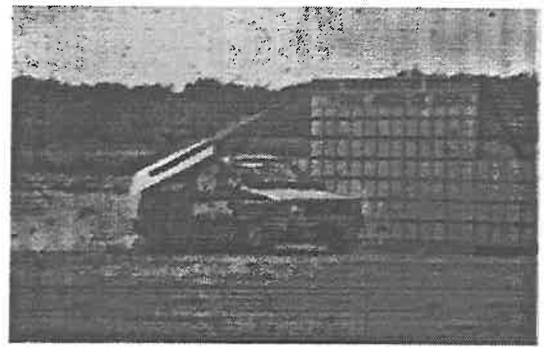


0.074 s

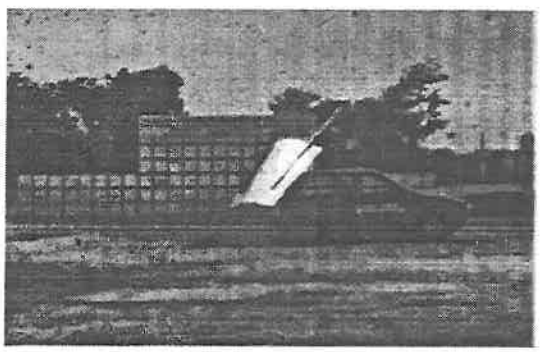
FigureB-17. Sequential photographs for test 405231-19.
(perpendicular and angular views)

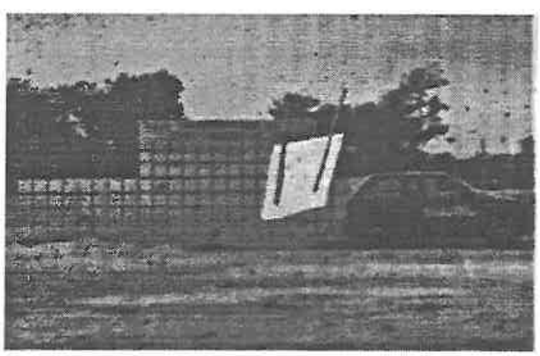
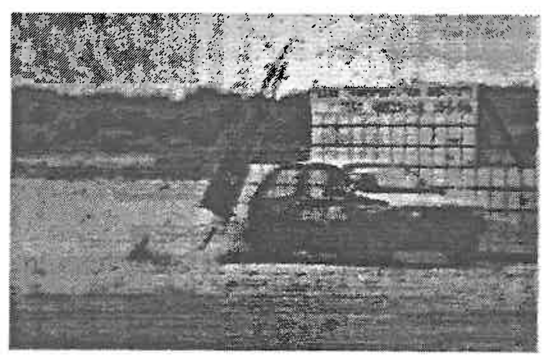
0.099 s

0.151 s




0.200 s

0.250 s

FigureB-17.Sequential photographs for test 405231-19 (continued).
(perpendicular and angular views)

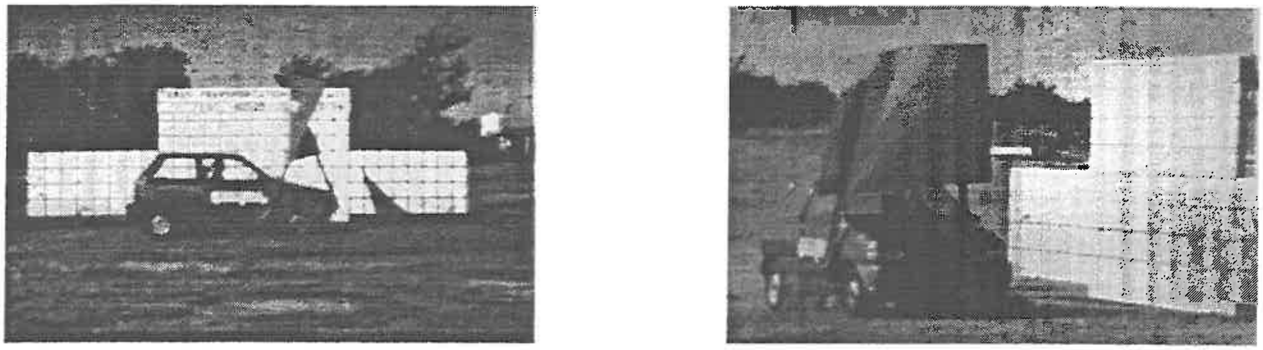
0.000 s

0.062 s

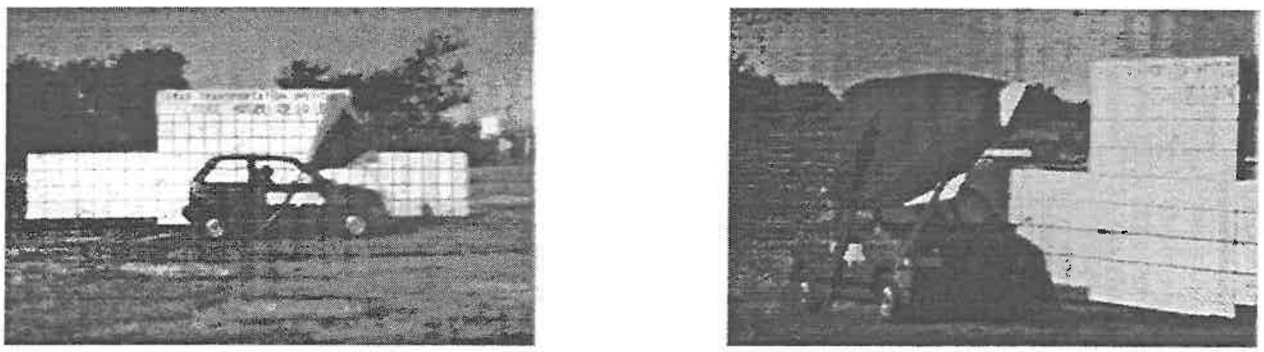
0.123 s

0.185 s

FigureB-18.Sequential photographs for test 405231-20.
(perpendicular and angular views)



0.251 s



0.374 s

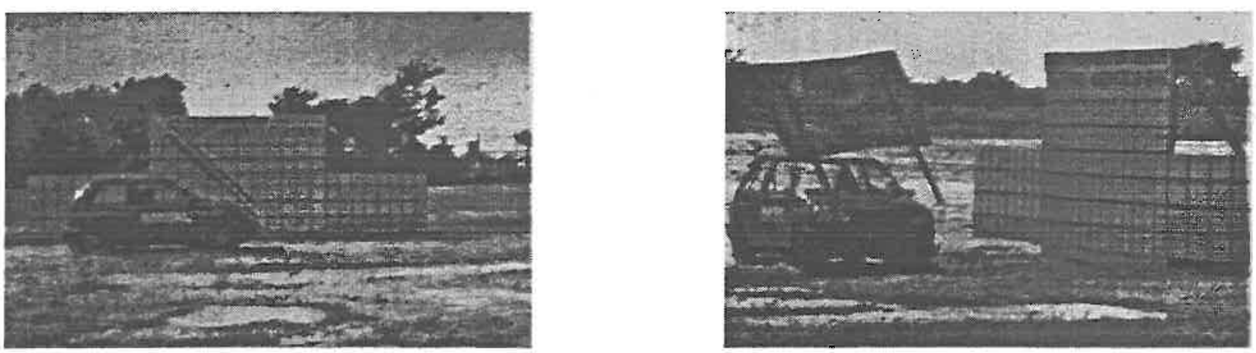
0.500 s

0.687 s

FigureB-18. Sequential photographs for test 405231-20 (continued).
(perpendicular and angular views)

0.000 s

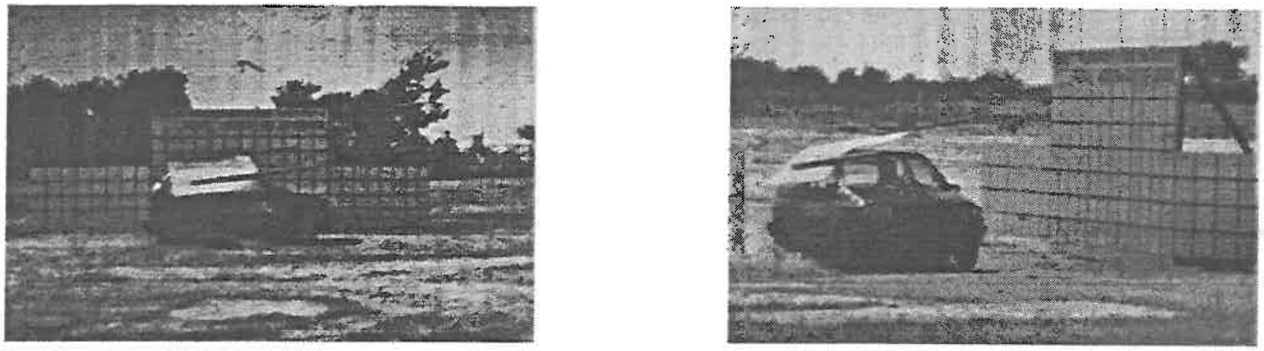
0.025 s



0.049 s

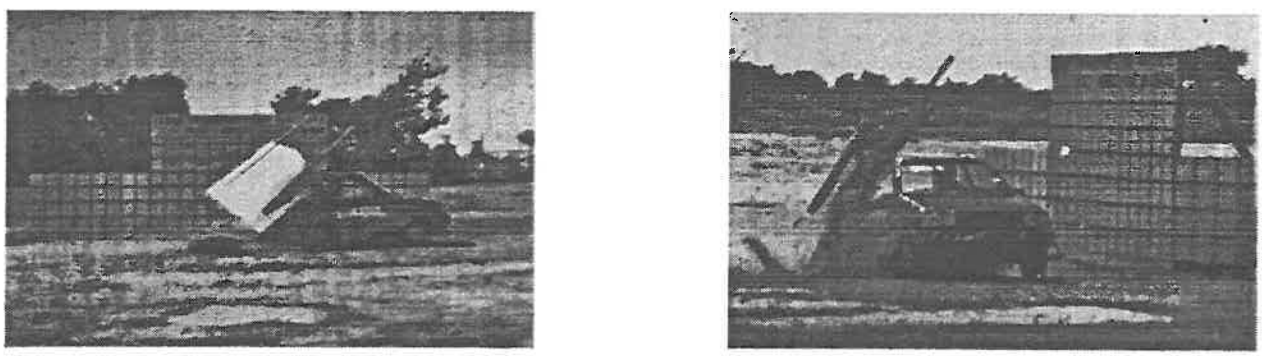
0.076 s

FigureB-19. Sequential photographs for test 405231-21.
(perpendicular and angular views)



0.101 s

0.126 s



0.177 s

0.249 s

Figure B-19. Sequential photographs for test 405231-21 (continued).
(perpendicular and angular views)

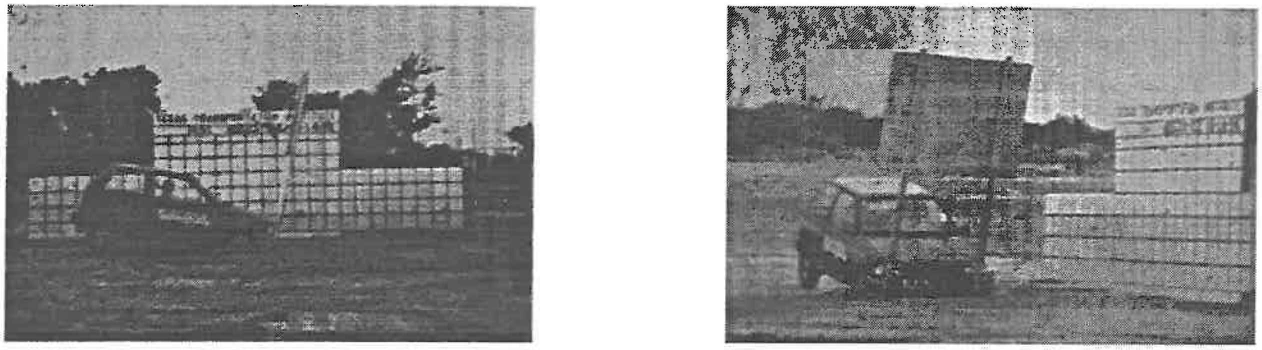
0.000 s

0.049 s

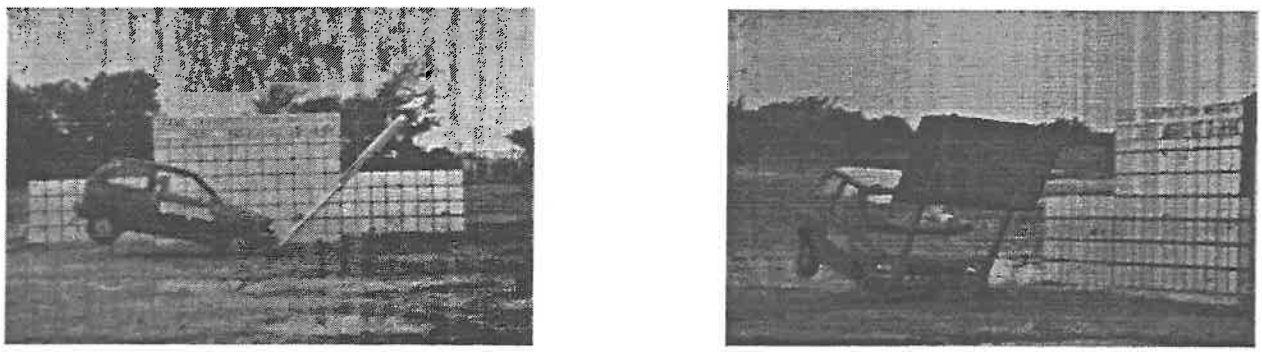
0.098 s

0.152 s

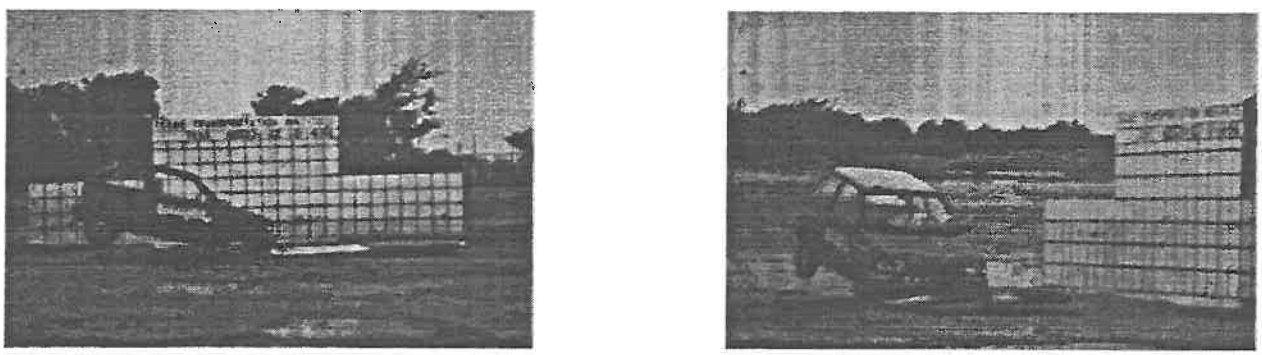
FigureB-20. Sequential photographs for test 405231-22.
(perpendicular and angular views)



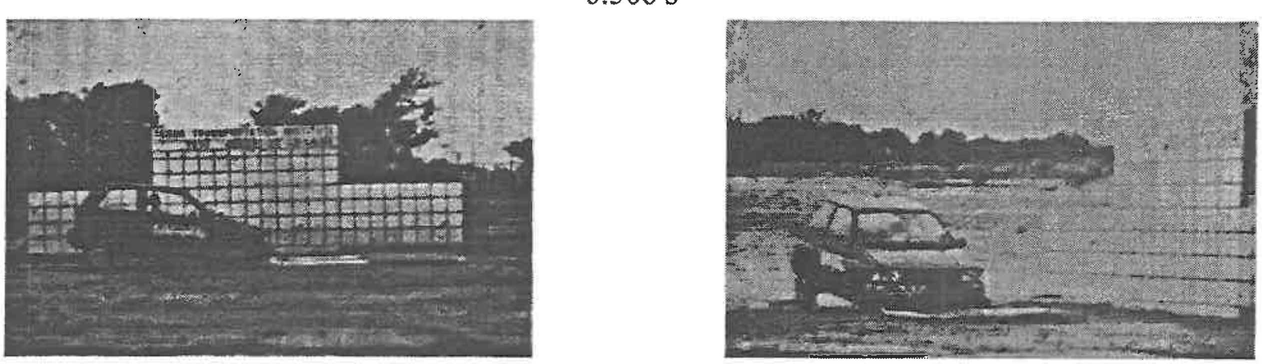
0.202 s



0.320 s

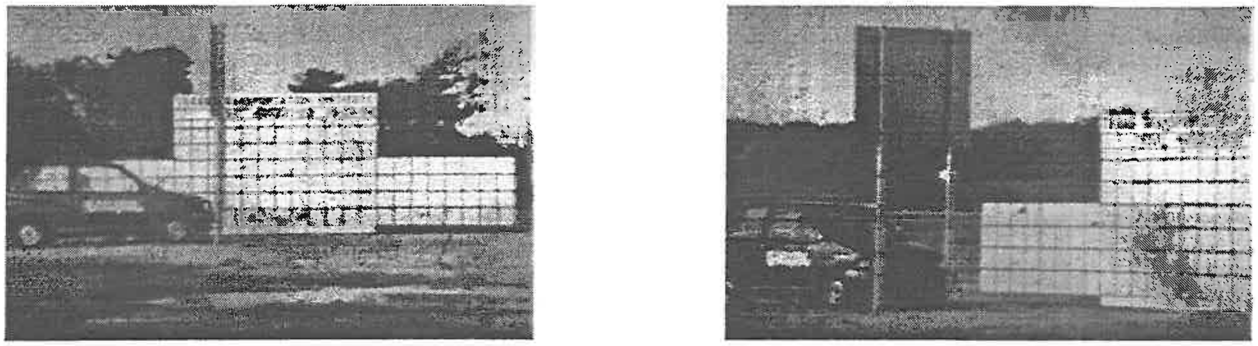


0.506 s

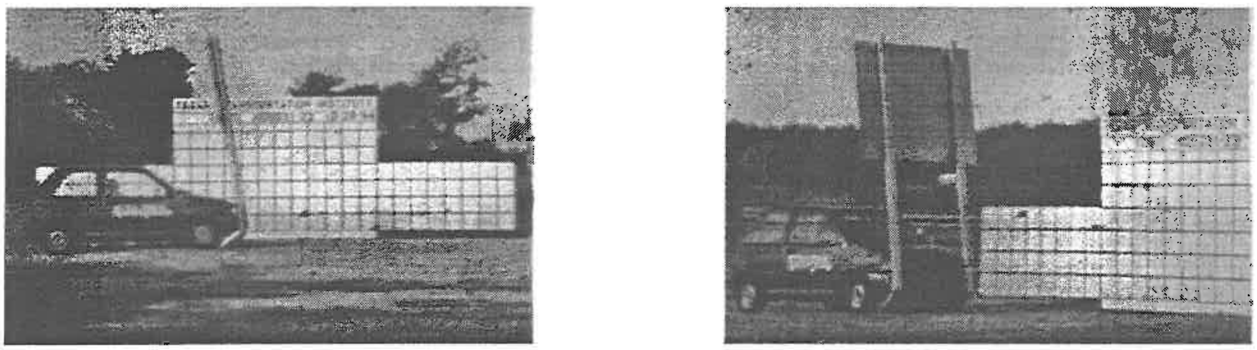


0.669 s

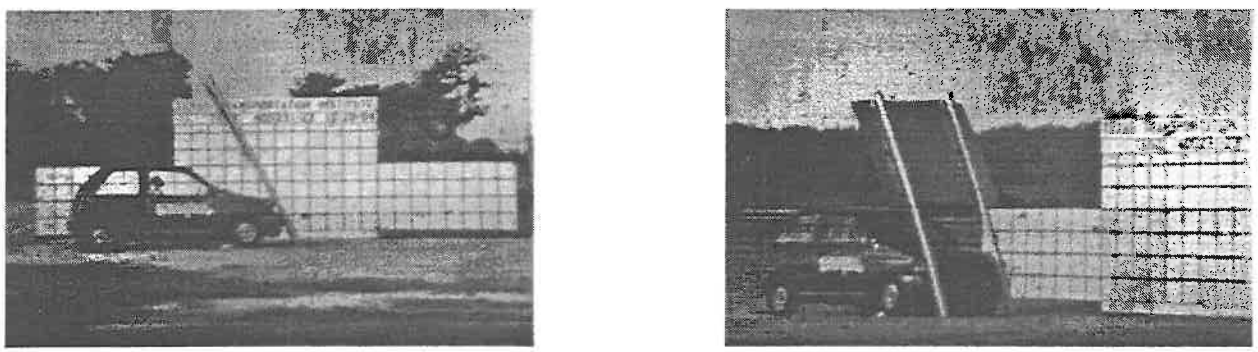
FigureB-20.Sequential photographs for test 405231-22 (continued).
(perpendicular and angular views)



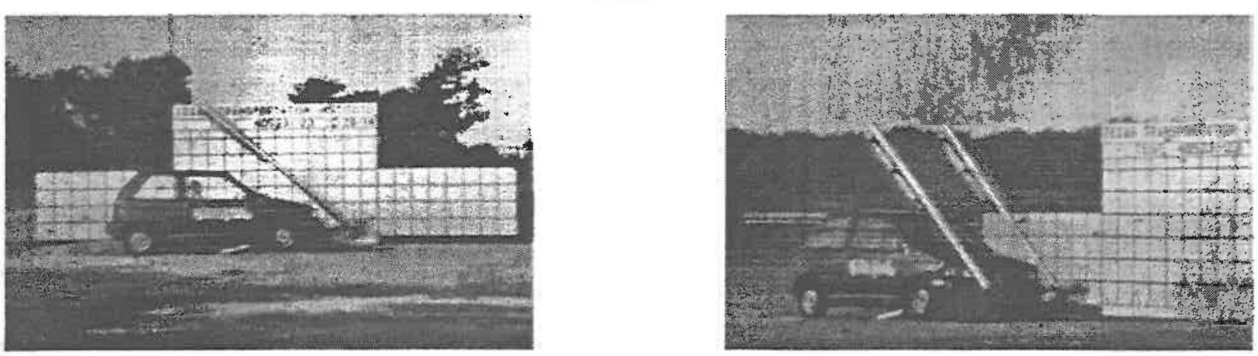
0.000 s



0.049 s

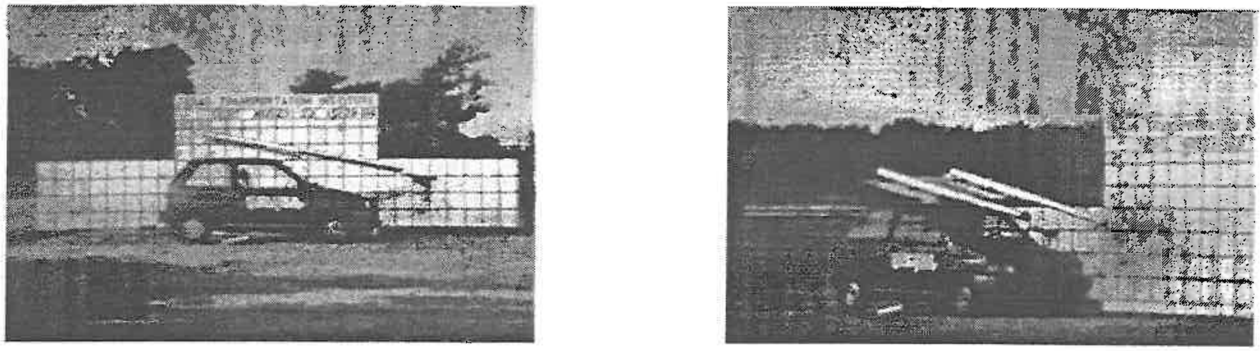


0.126 s

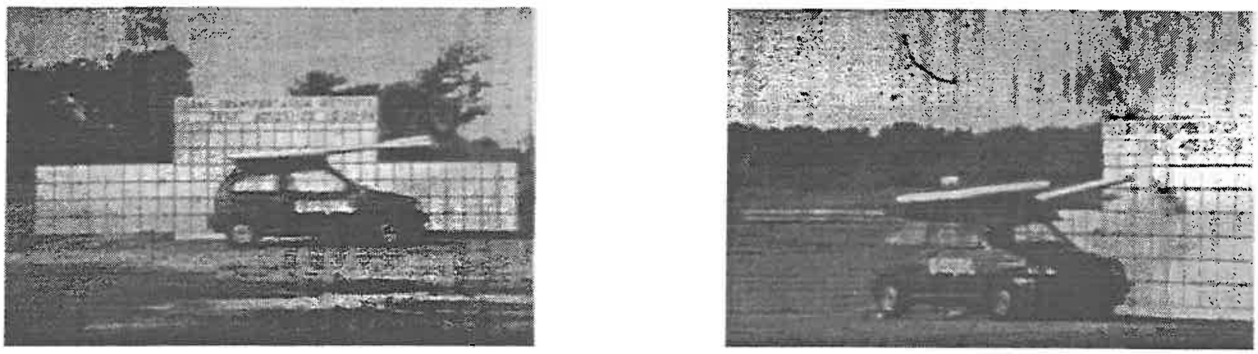


0.200 s

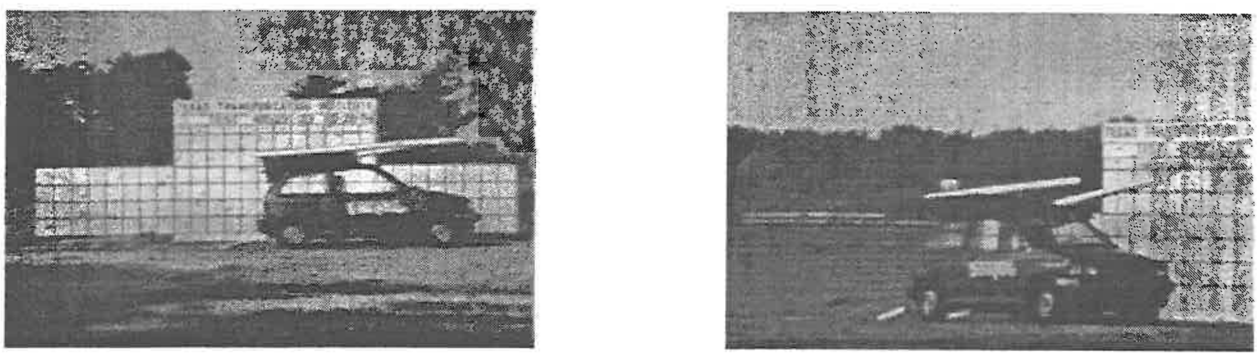
Figure B-21. Sequential photographs for test 405231-23.
(perpendicular and angular views)



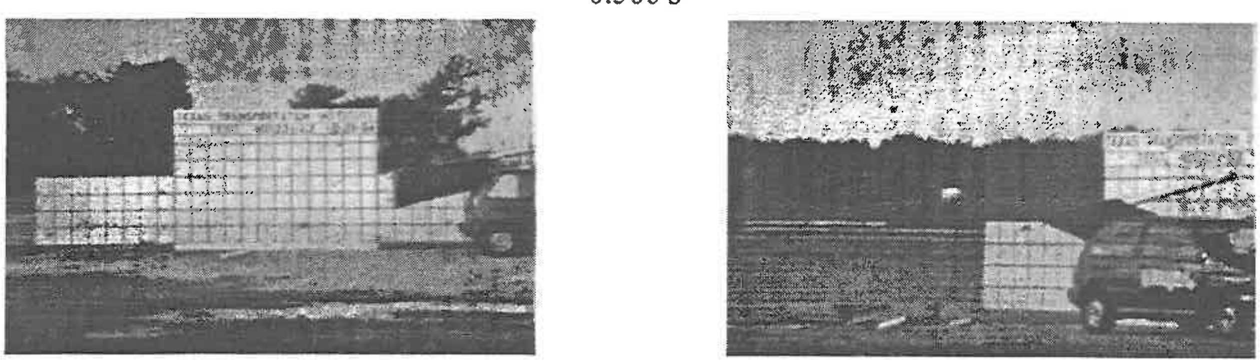
0.300 s



0.400 s

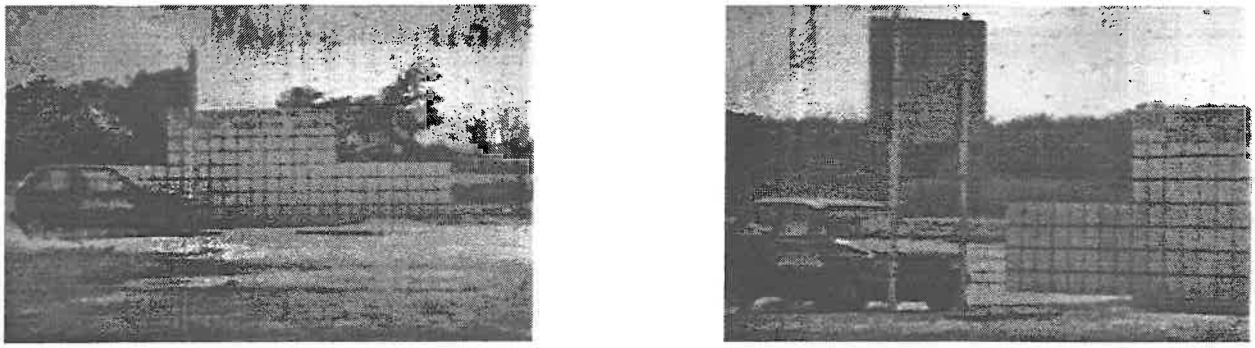


0.500 s

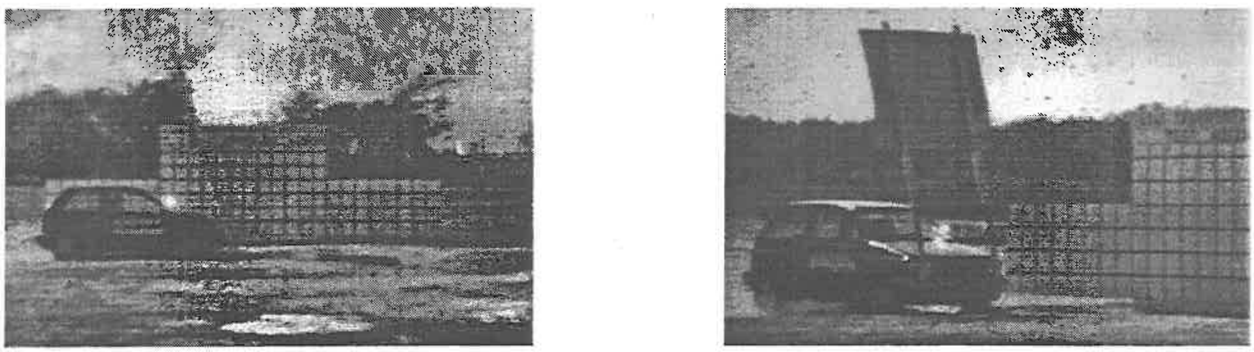


0.906 s

Figure B-21. Sequential photographs for test 405231-23 (continued).
(perpendicular and angular views)



0.000 s

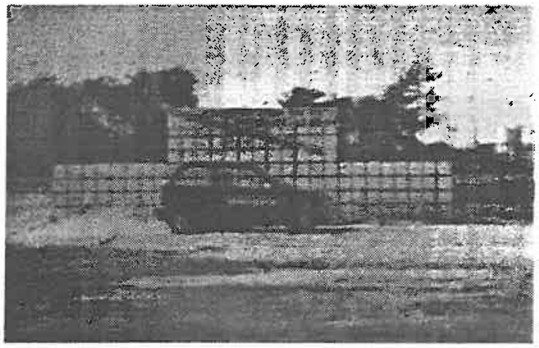
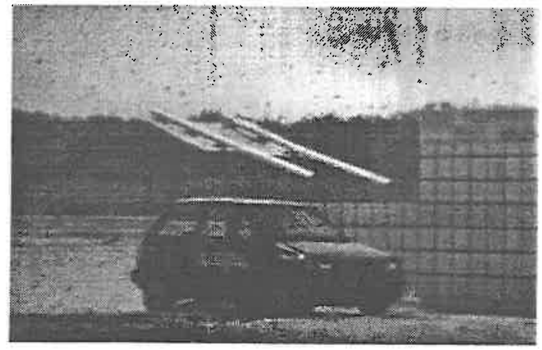


0.025 s

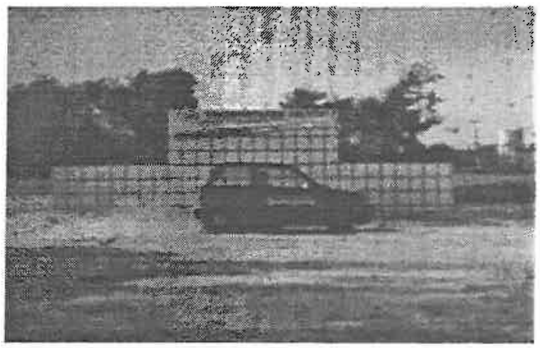
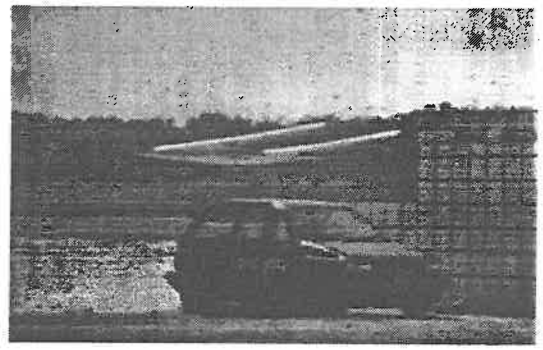
0.050 s

0.074 s

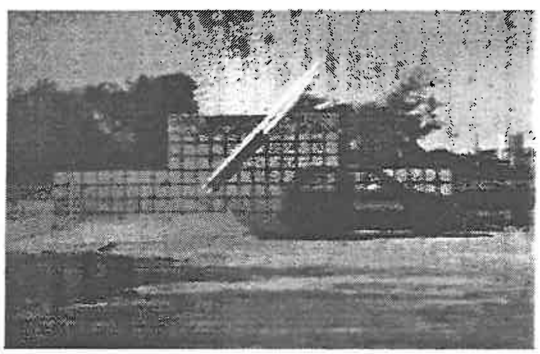
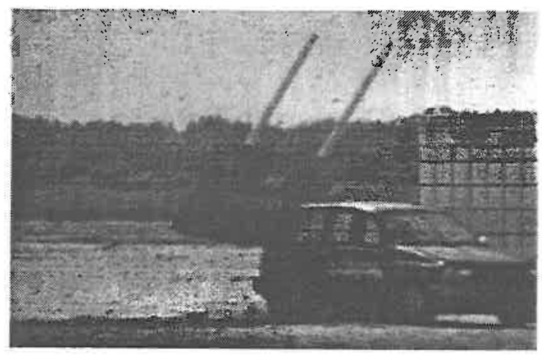
Figure B-22. Sequential photographs for test 405231-24.
(perpendicular and angular views)

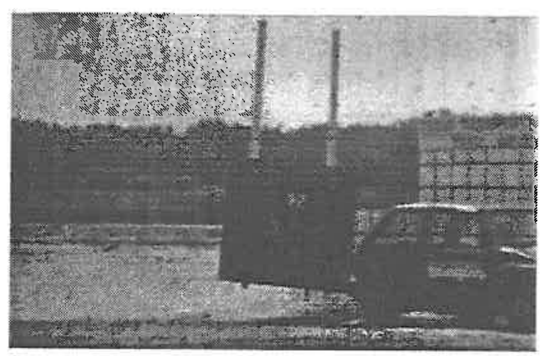
0.099 s

0.126 s

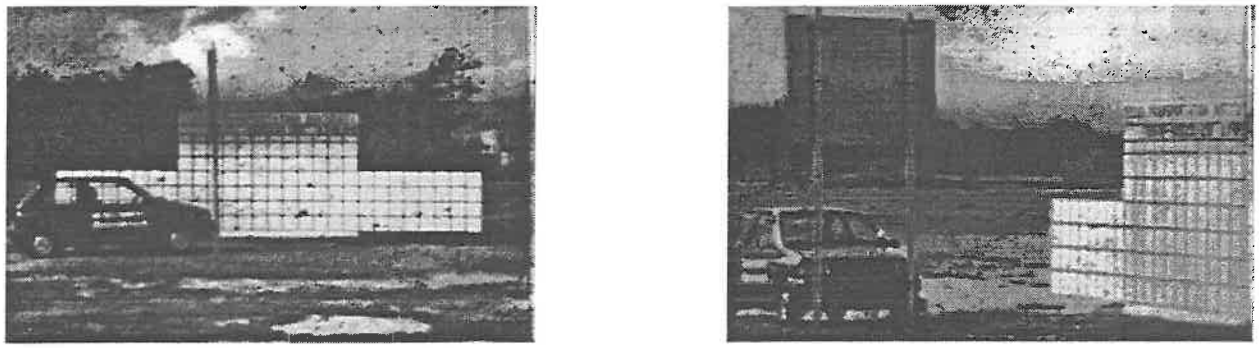



0.188 s

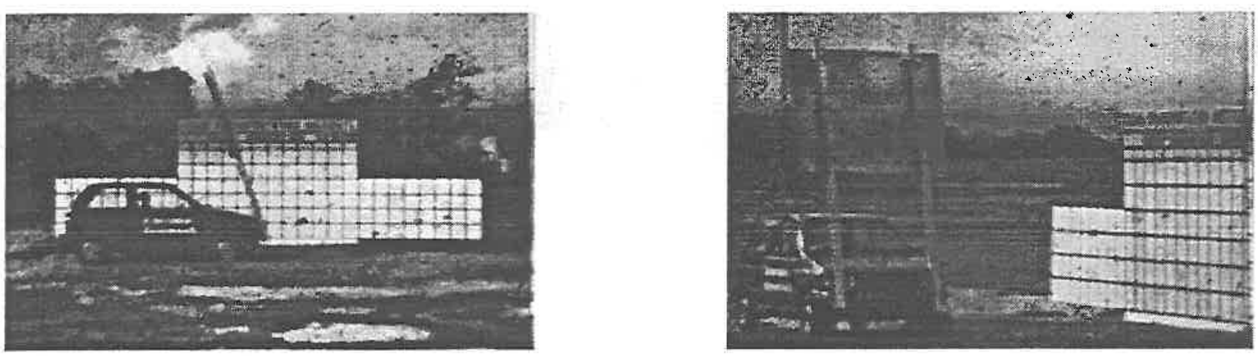
0.250 s

Figure B-22. Sequential photographs for test 405231-24 (continued).
(perpendicular and angular views)

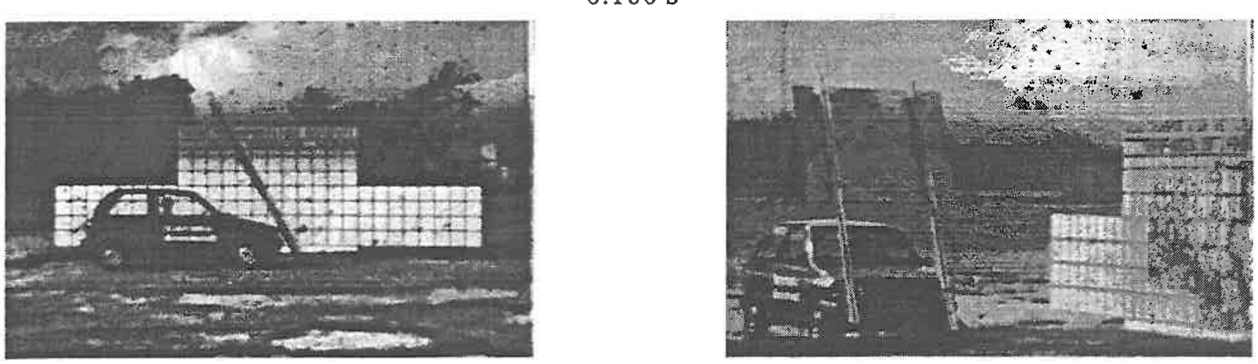


0.000 s

0.049 s

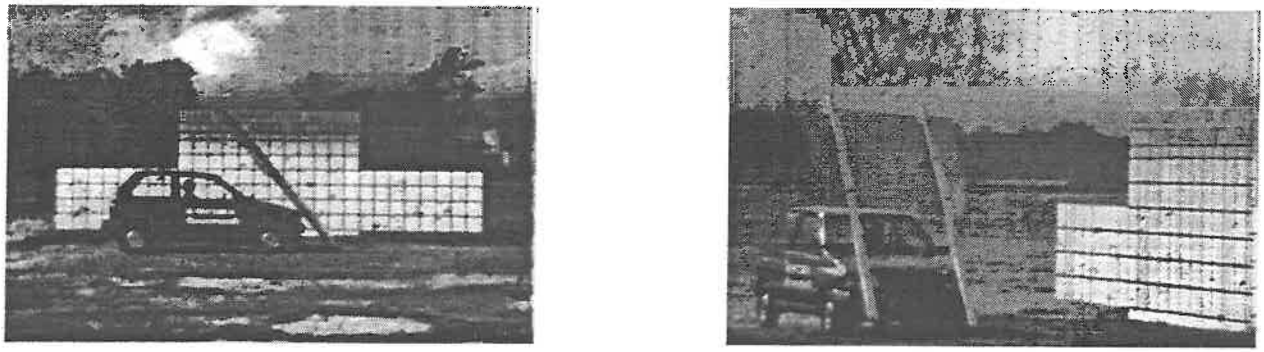


0.100 s

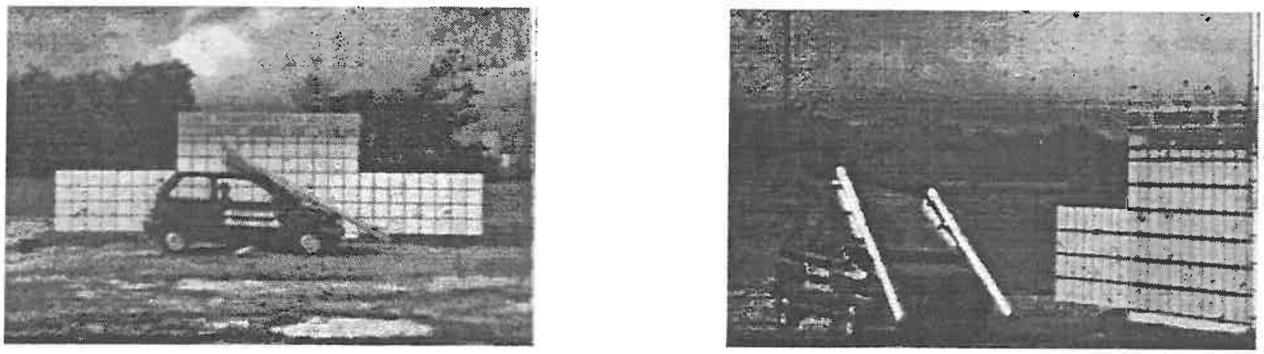


0.150 s

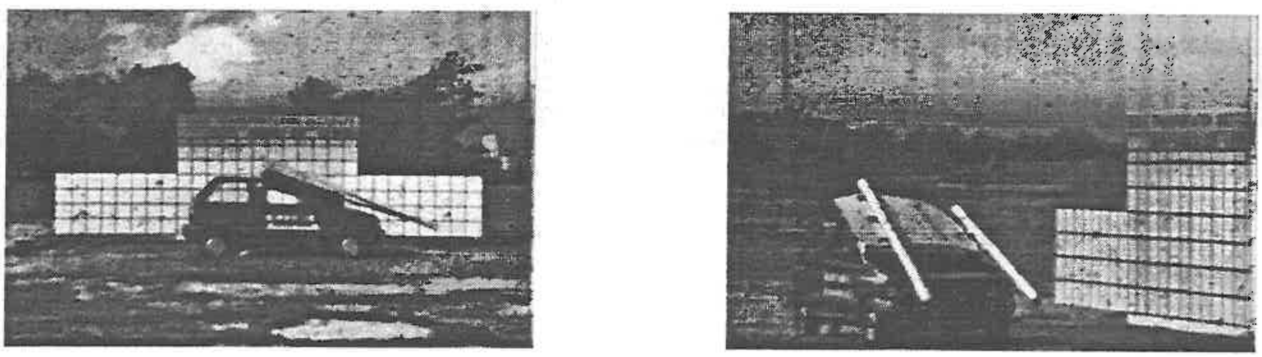
Figure B-23. Sequential photographs for test 405231-25.
(perpendicular and angular views)



0.201 s



0.299 s

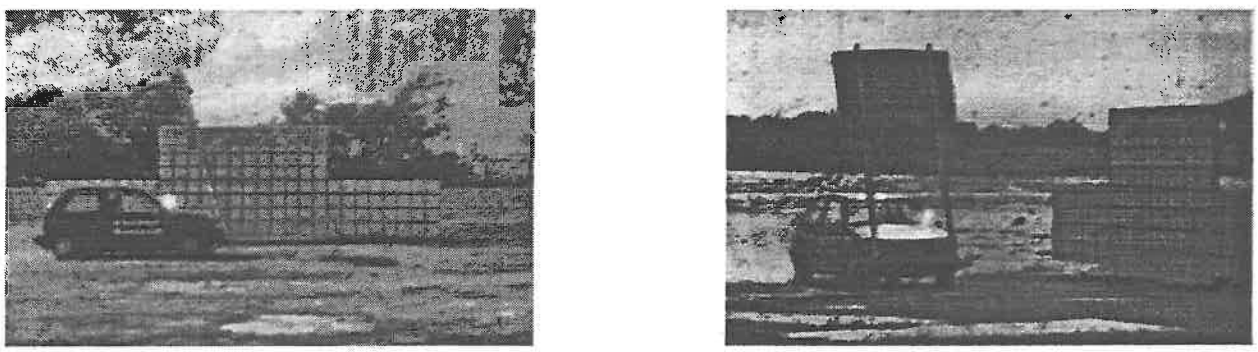


0.400 s

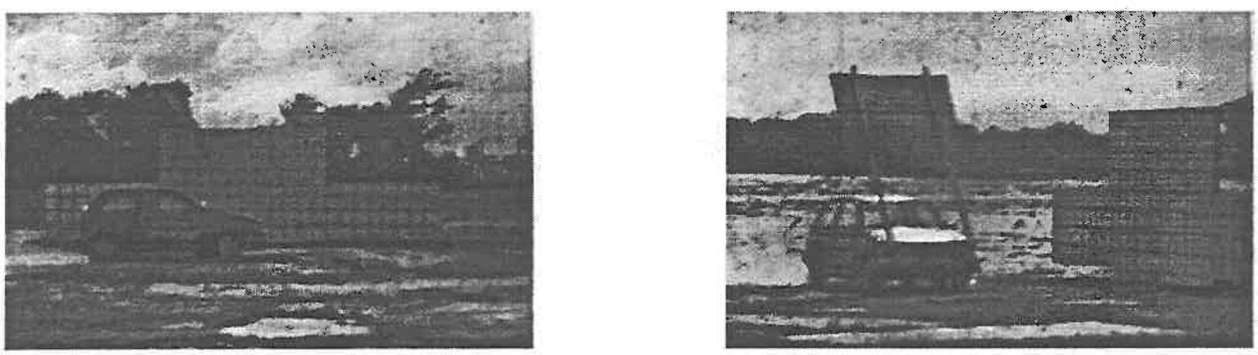
0.549 s

Figure B-23. Sequential photographs for test 405231-25 (continued).
(perpendicular and angular views)

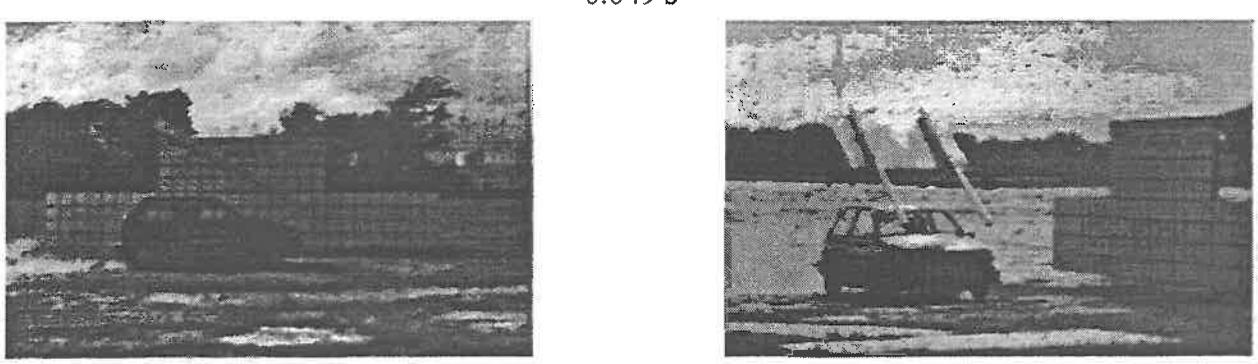
0.000 s



0.025 s

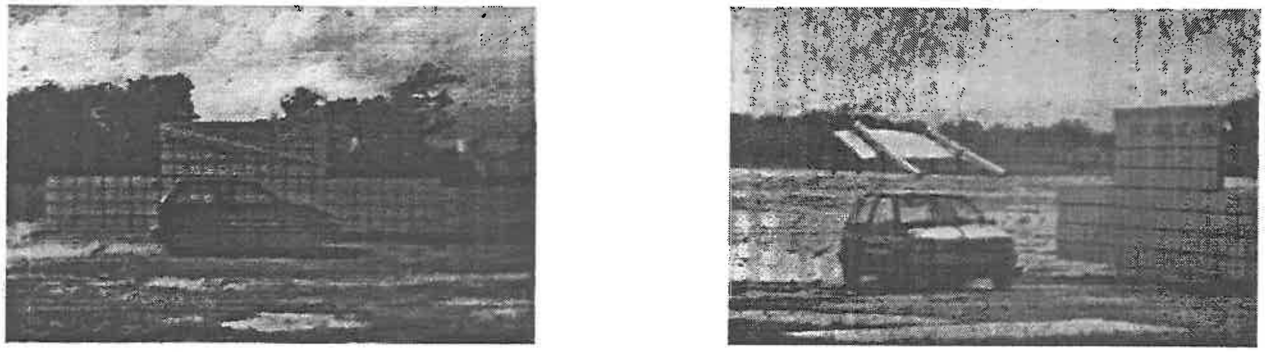


0.049 s

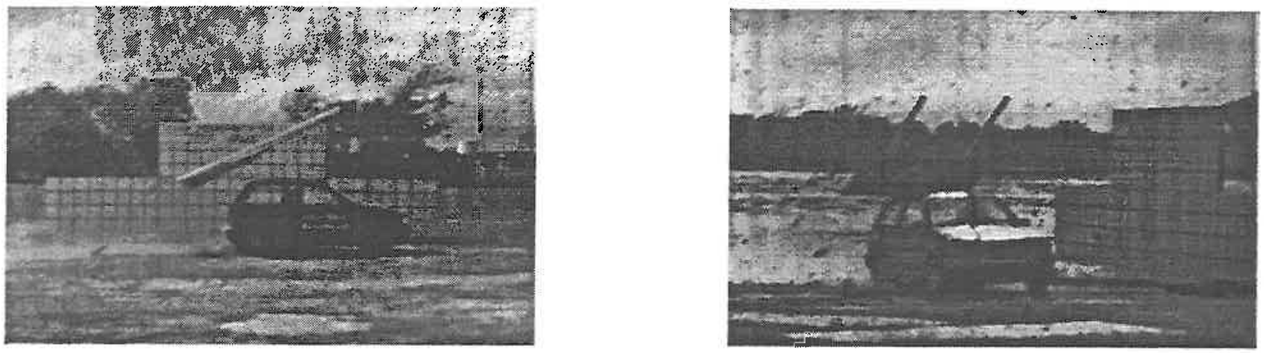


0.076 s

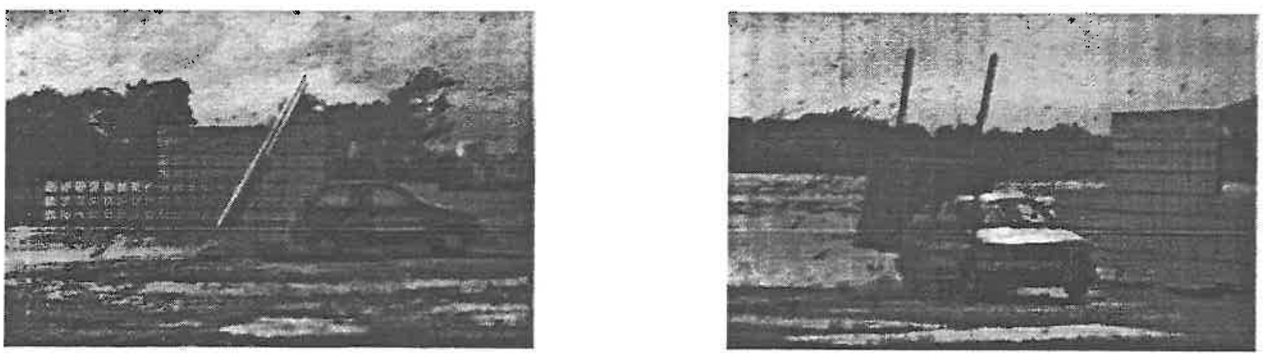
Figure B-24. Sequential photographs for test 405231-26.
(perpendicular and angular views)



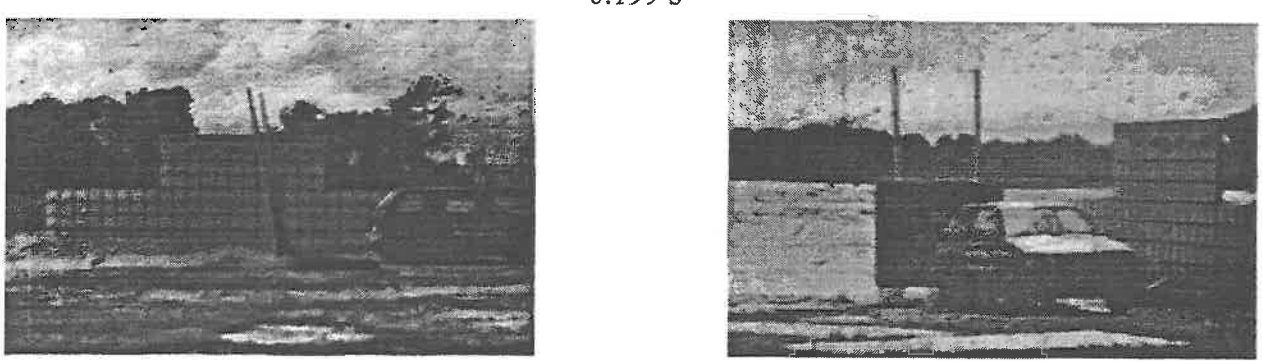
0.101 s



0.150 s



0.199 s



0.251 s

Figure B-24. Sequential photographs for test 405231-26 (continued).
(perpendicular and angular views)

APPENDIX C

Vehicle Angular Displacements

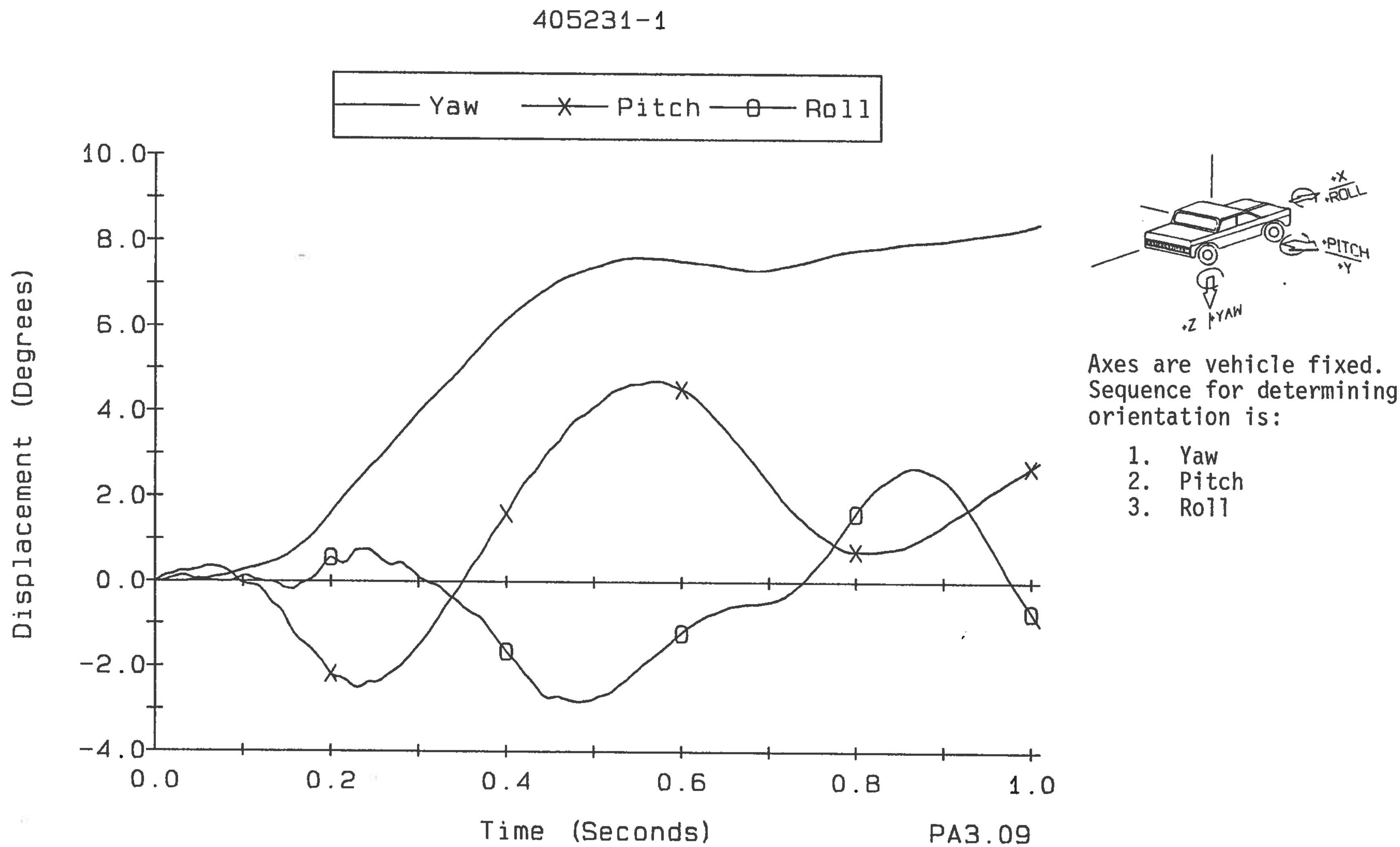


Figure C-1. Vehicle angular displacements during test 405231-1.

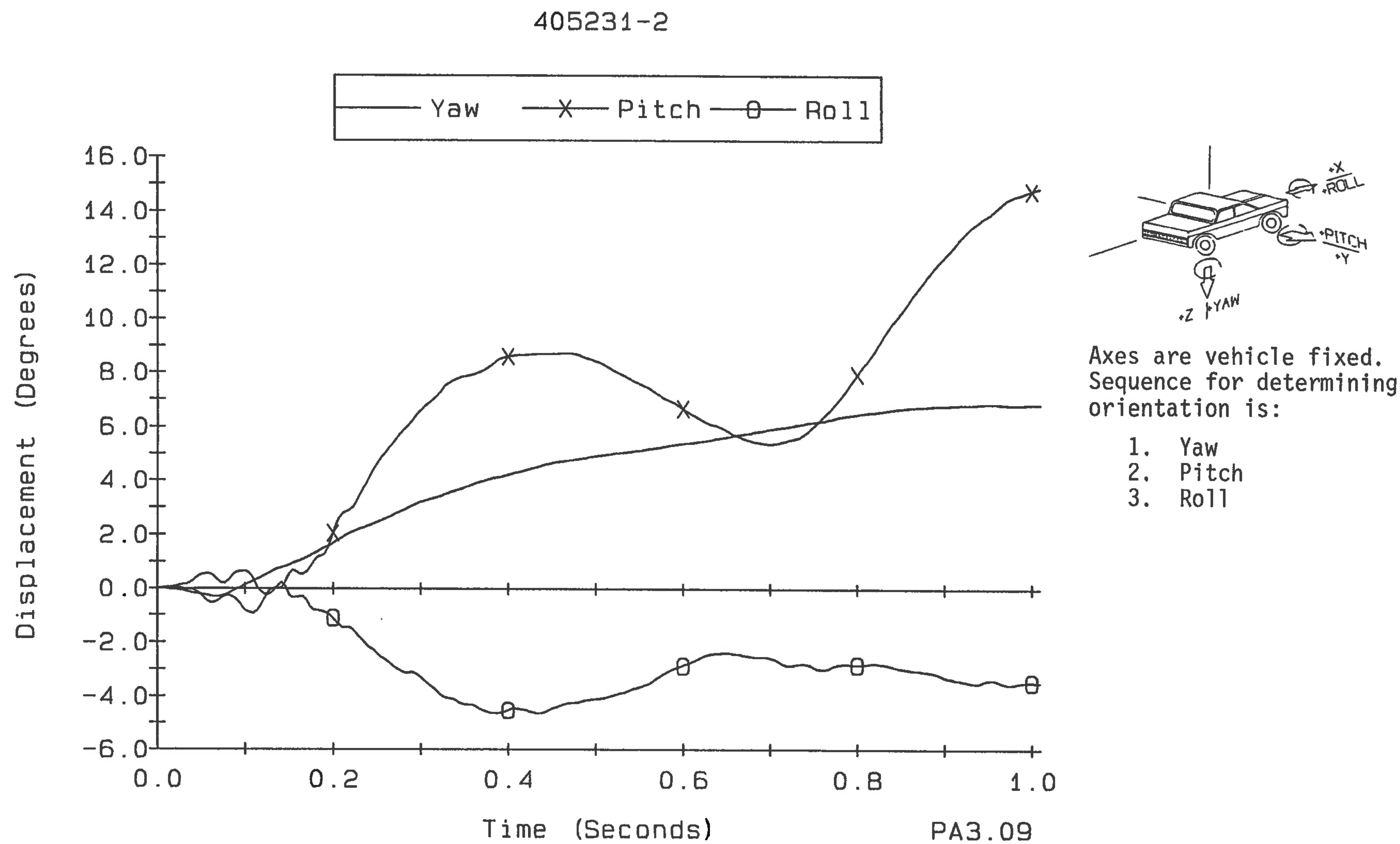


Figure C-2. Vehicle angular displacements during test 405231-2.

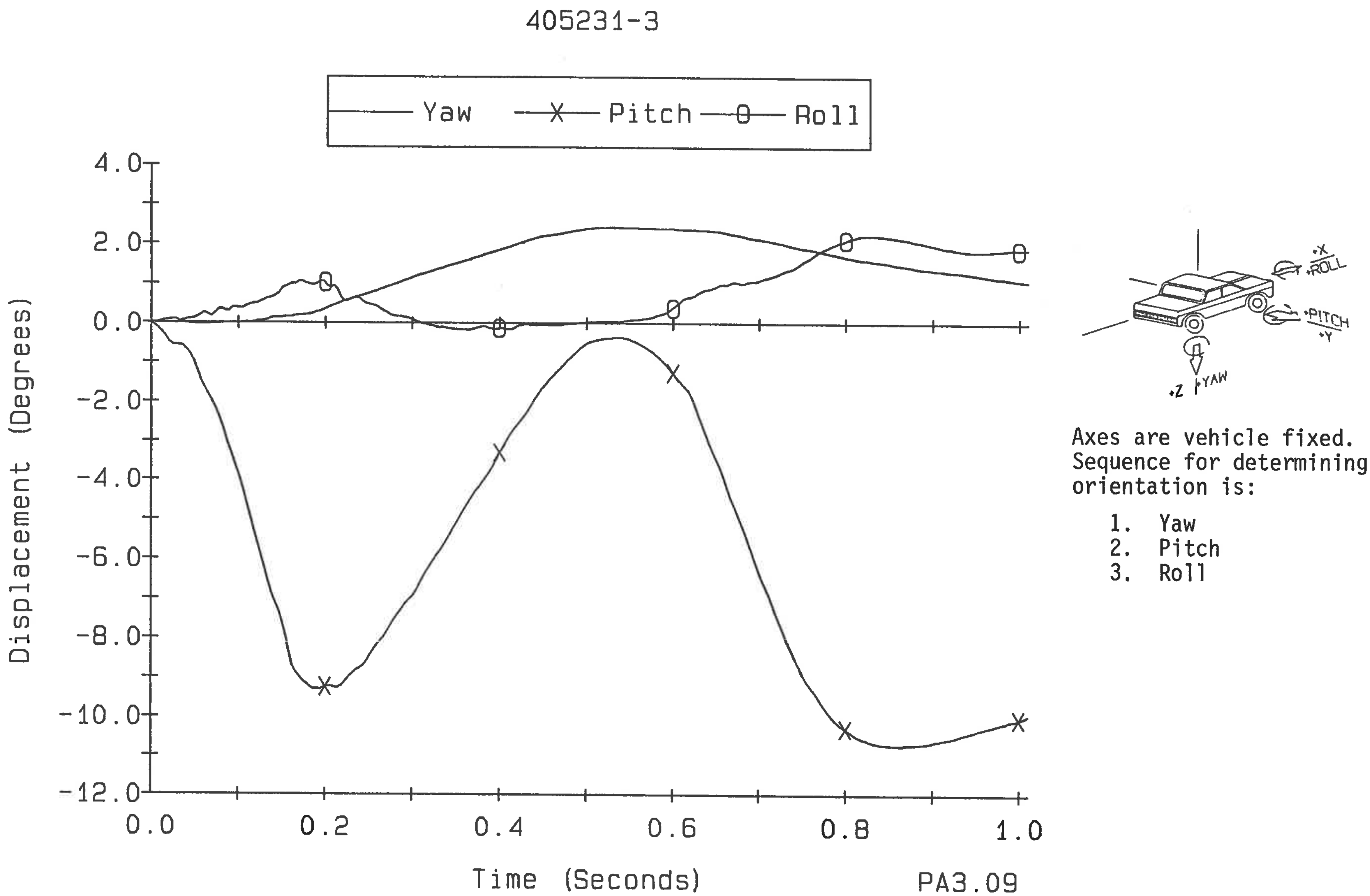


Figure C-3. Vehicle angular displacements during test 405231-3.

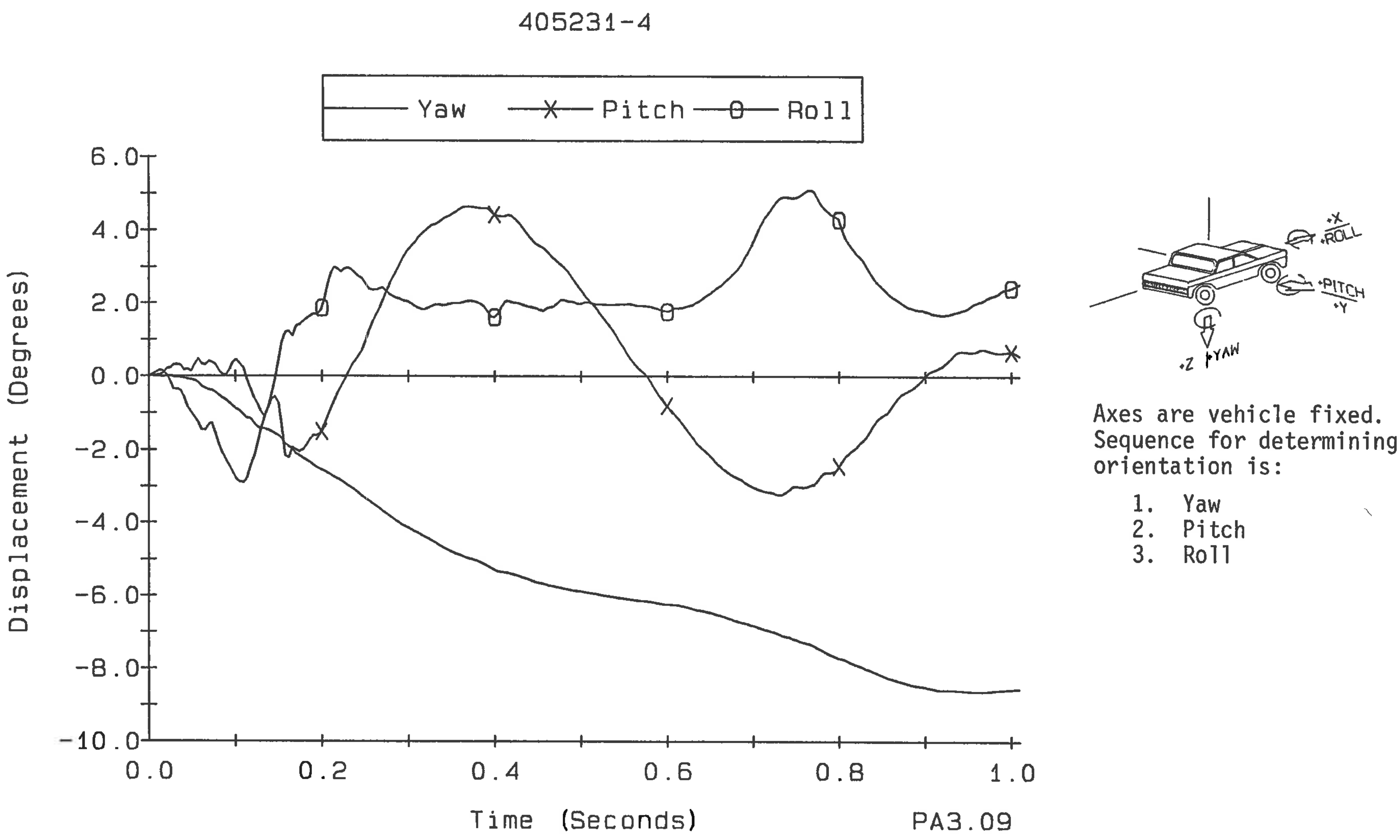


Figure C-4. Vehicle angular displacements during test 405231-4.

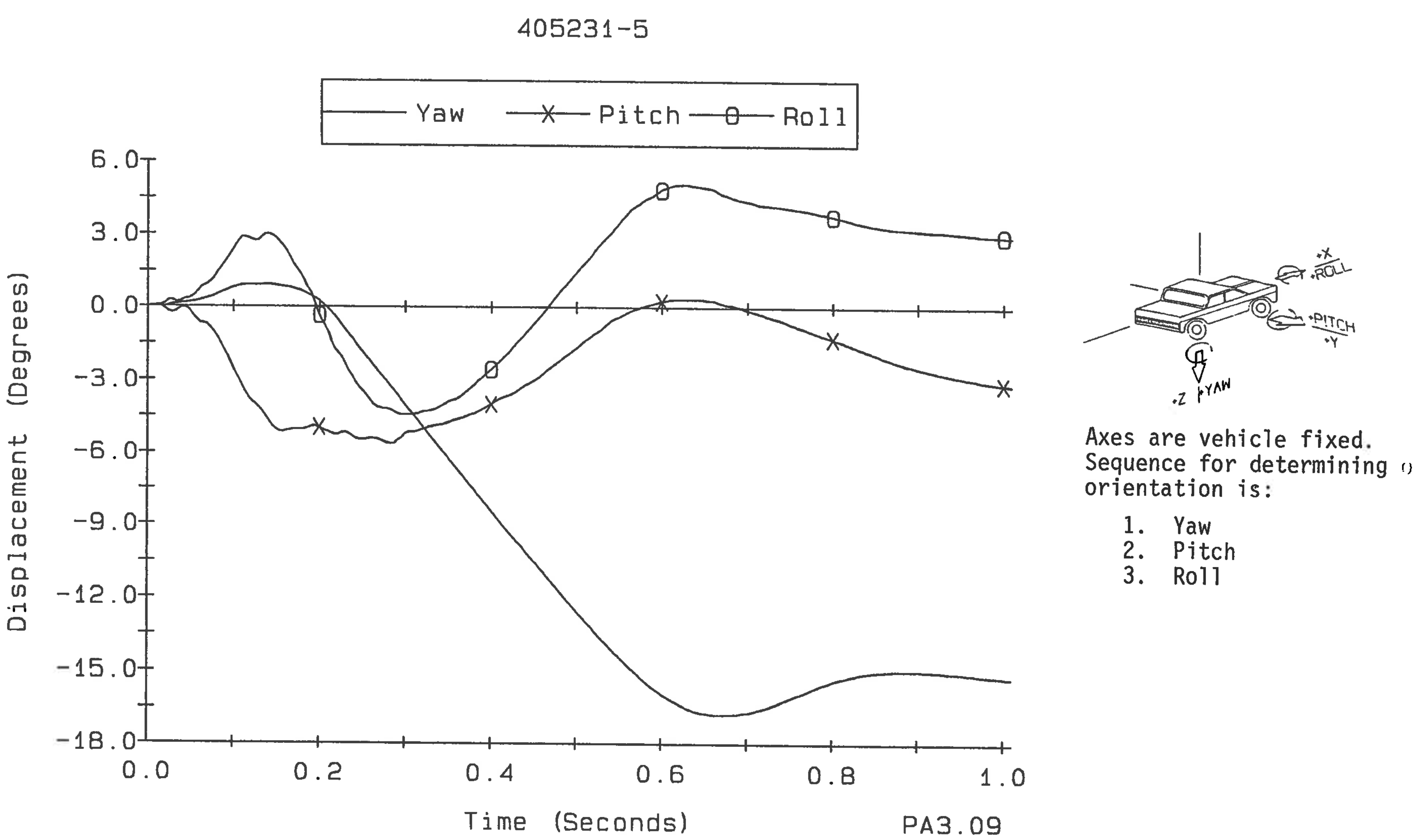


Figure C-5. Vehicle angular displacements during test 405231-5.

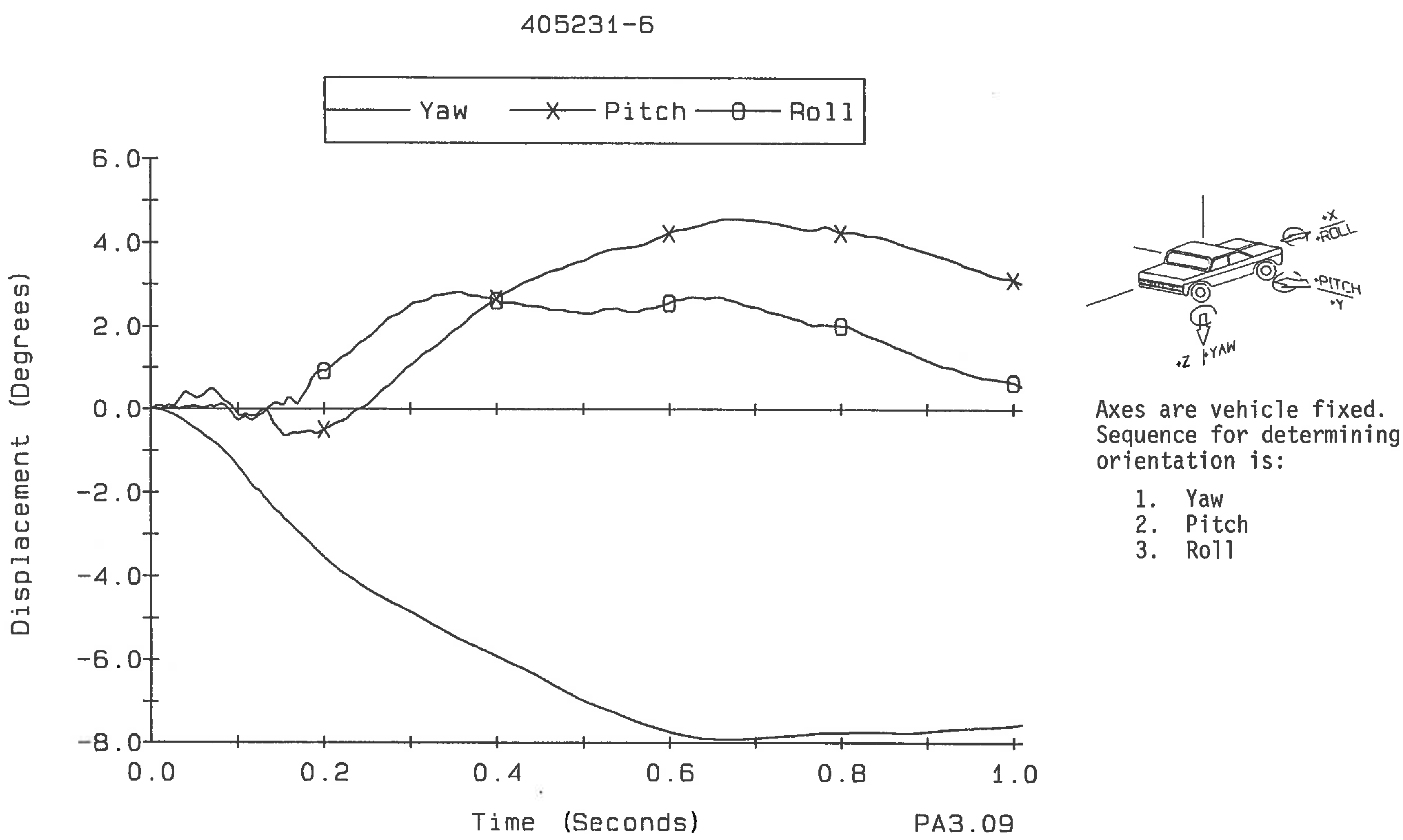
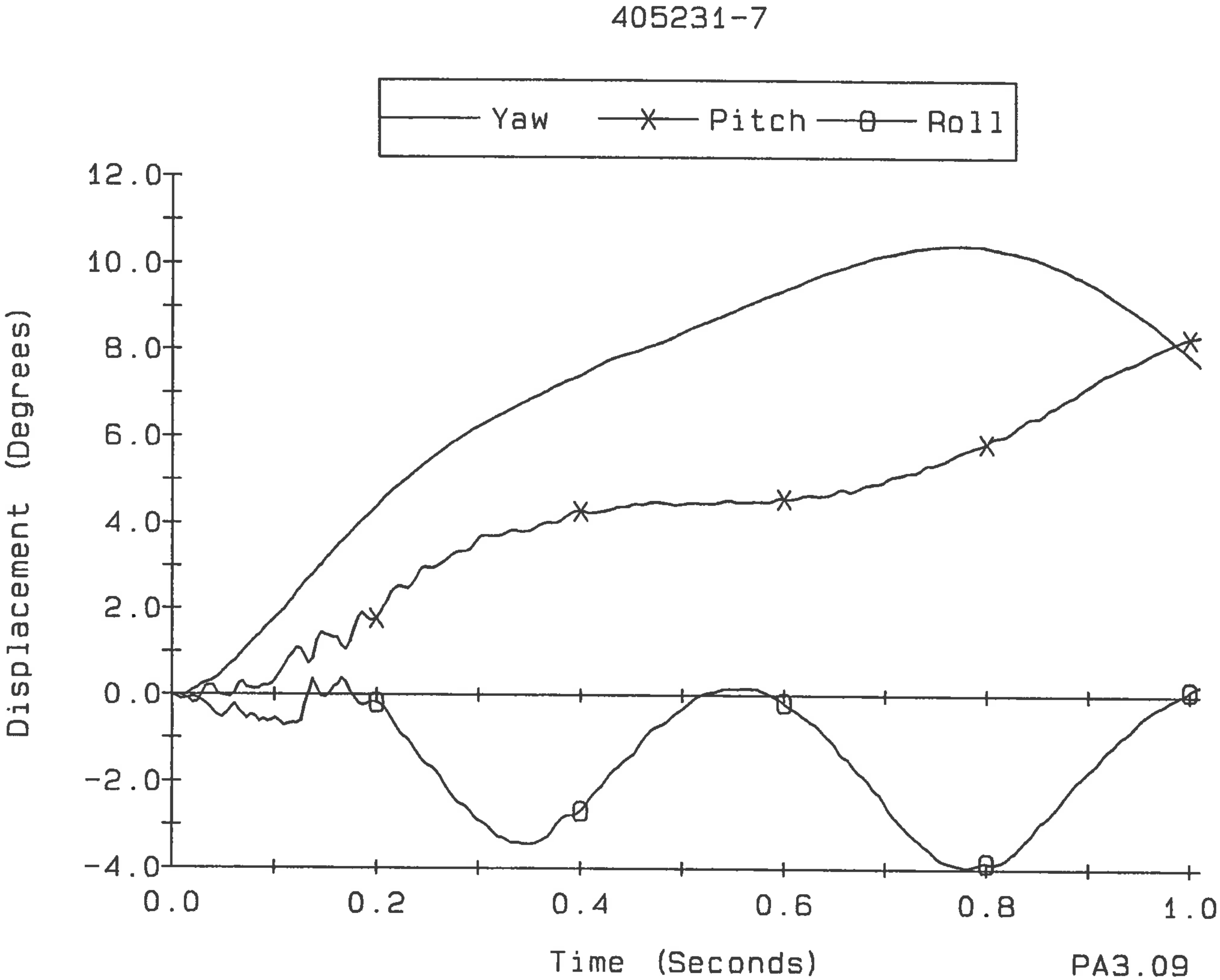
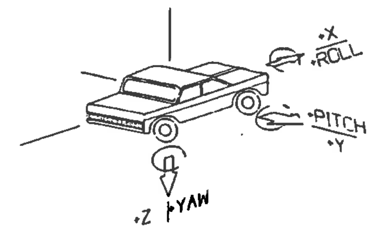


Figure C-6. Vehicle angular displacements during test 405231-6.





Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

Figure C-7. Vehicle angular displacements during test 405231-7.

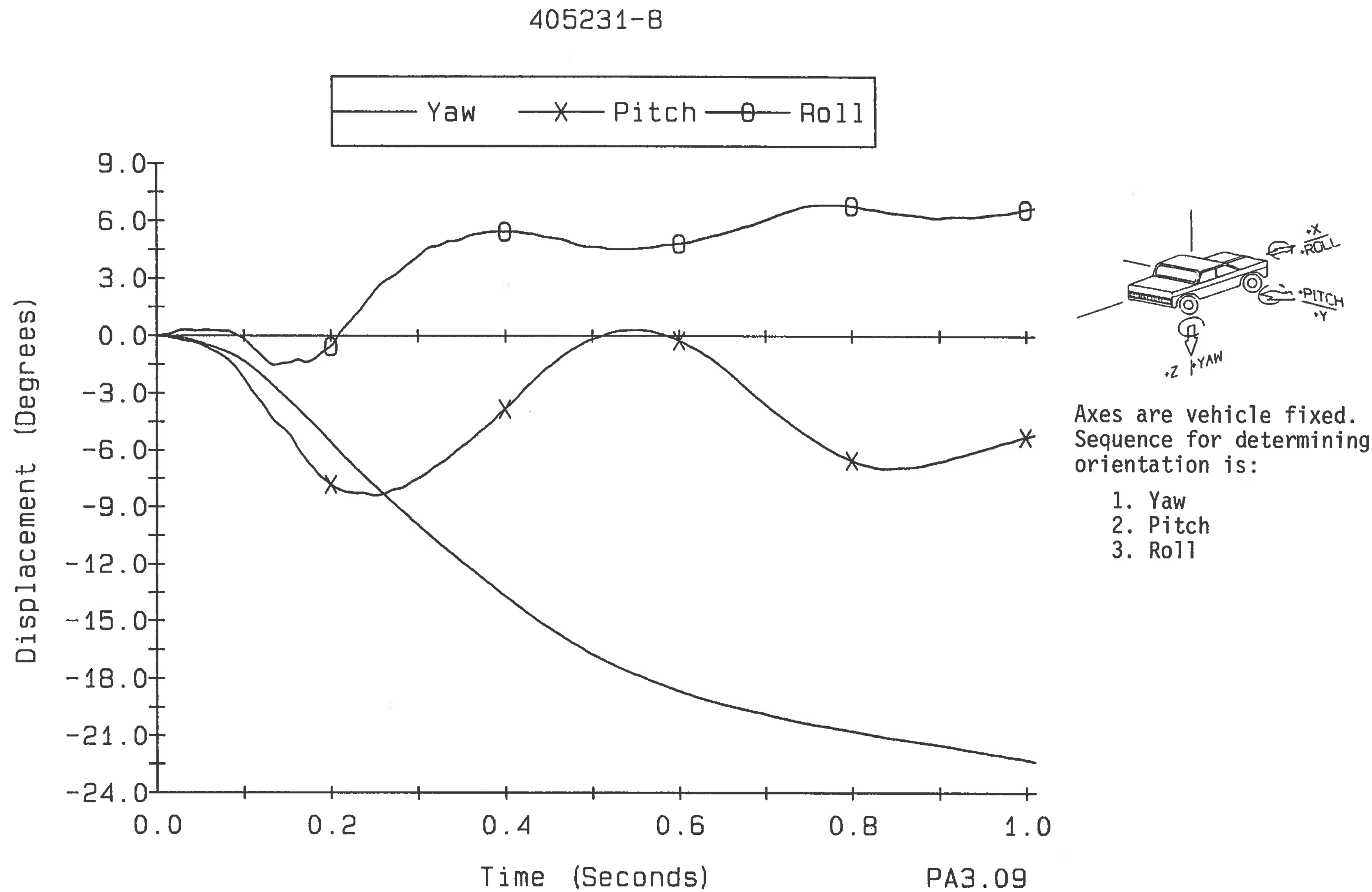
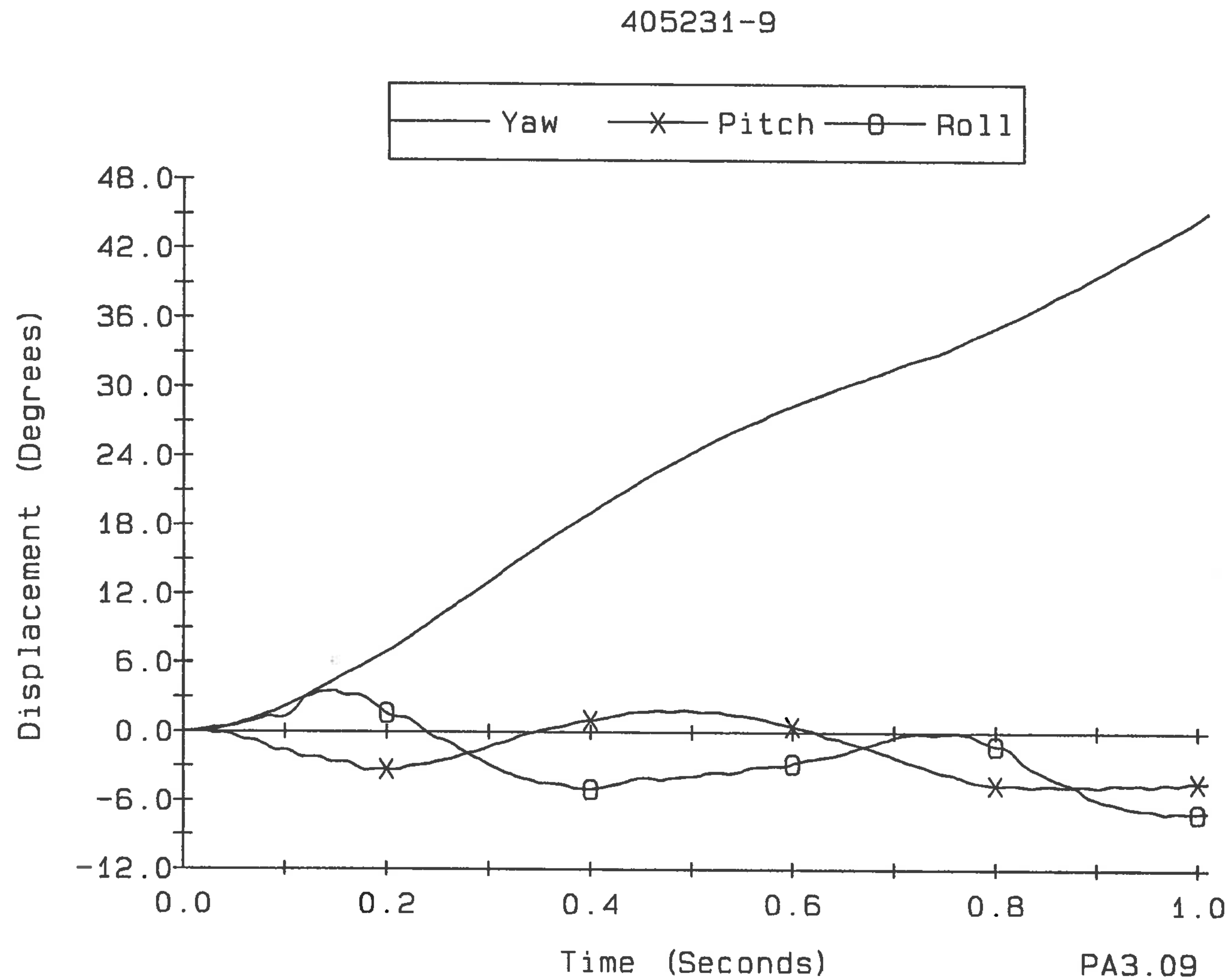
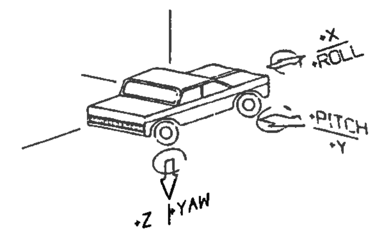


Figure C-8. Vehicle angular displacements during test 405231-8.





Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

Figure C-9. Vehicle angular displacements during test 405231-9.

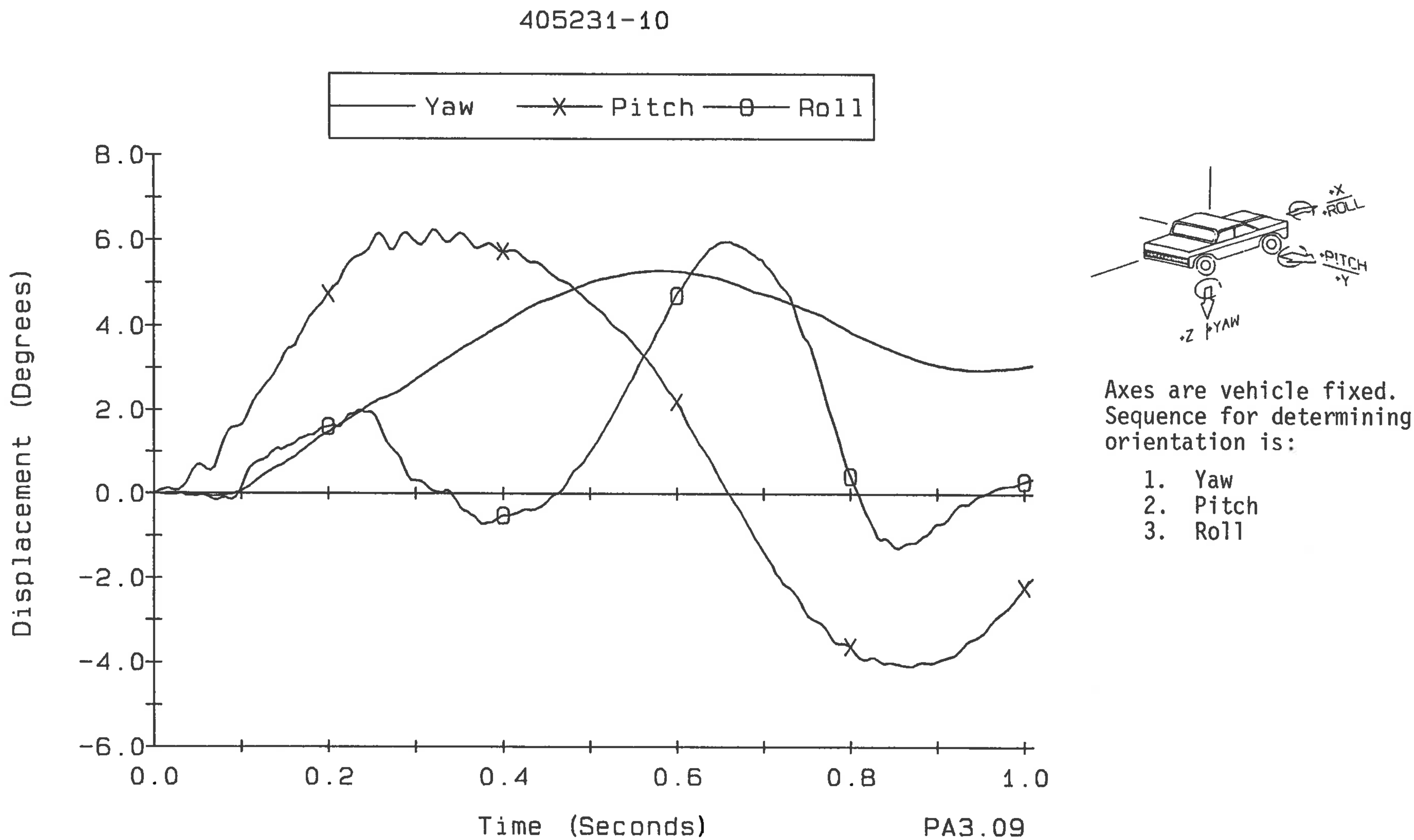


Figure C-10. Vehicle angular displacements during test 405231-10.

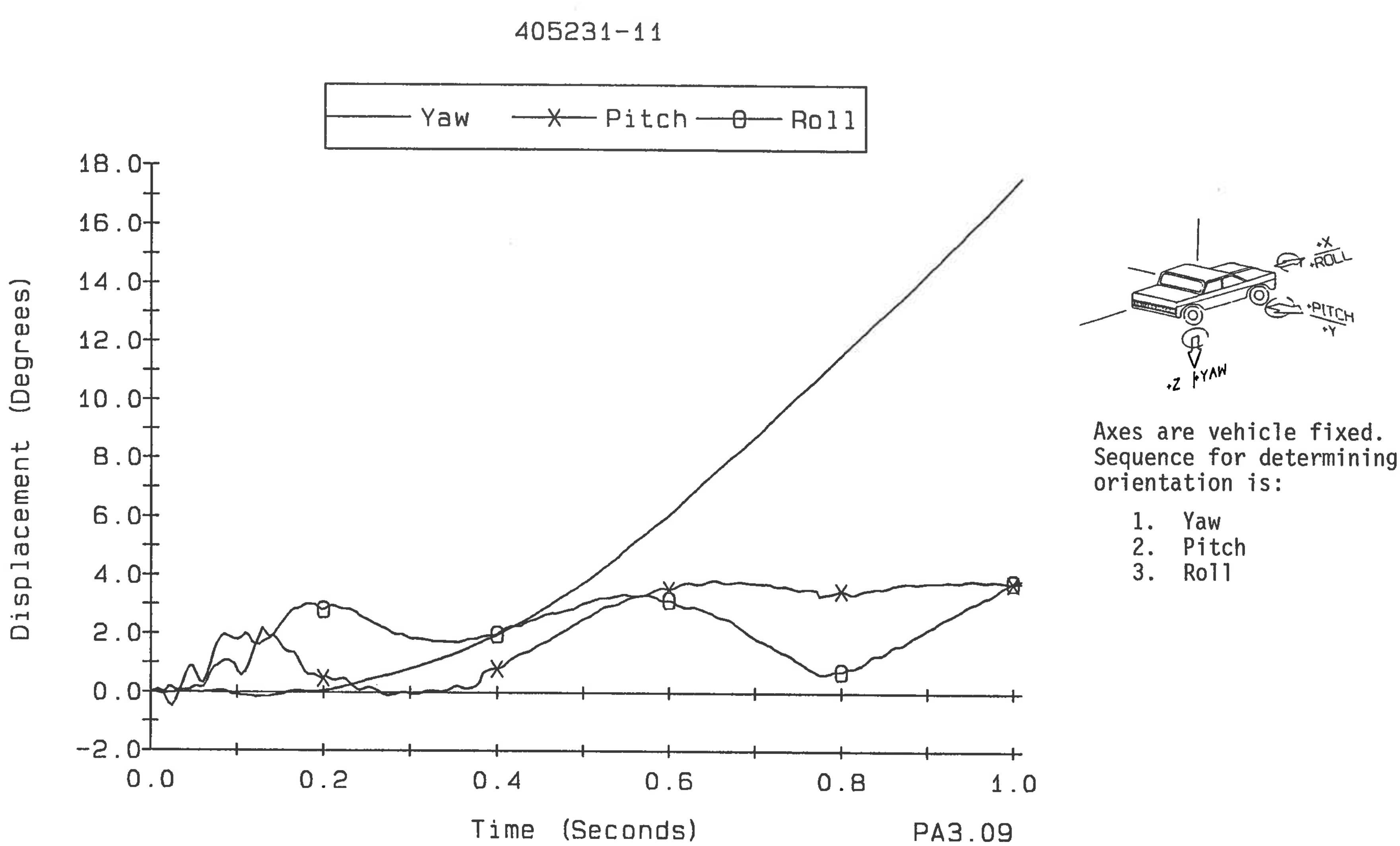
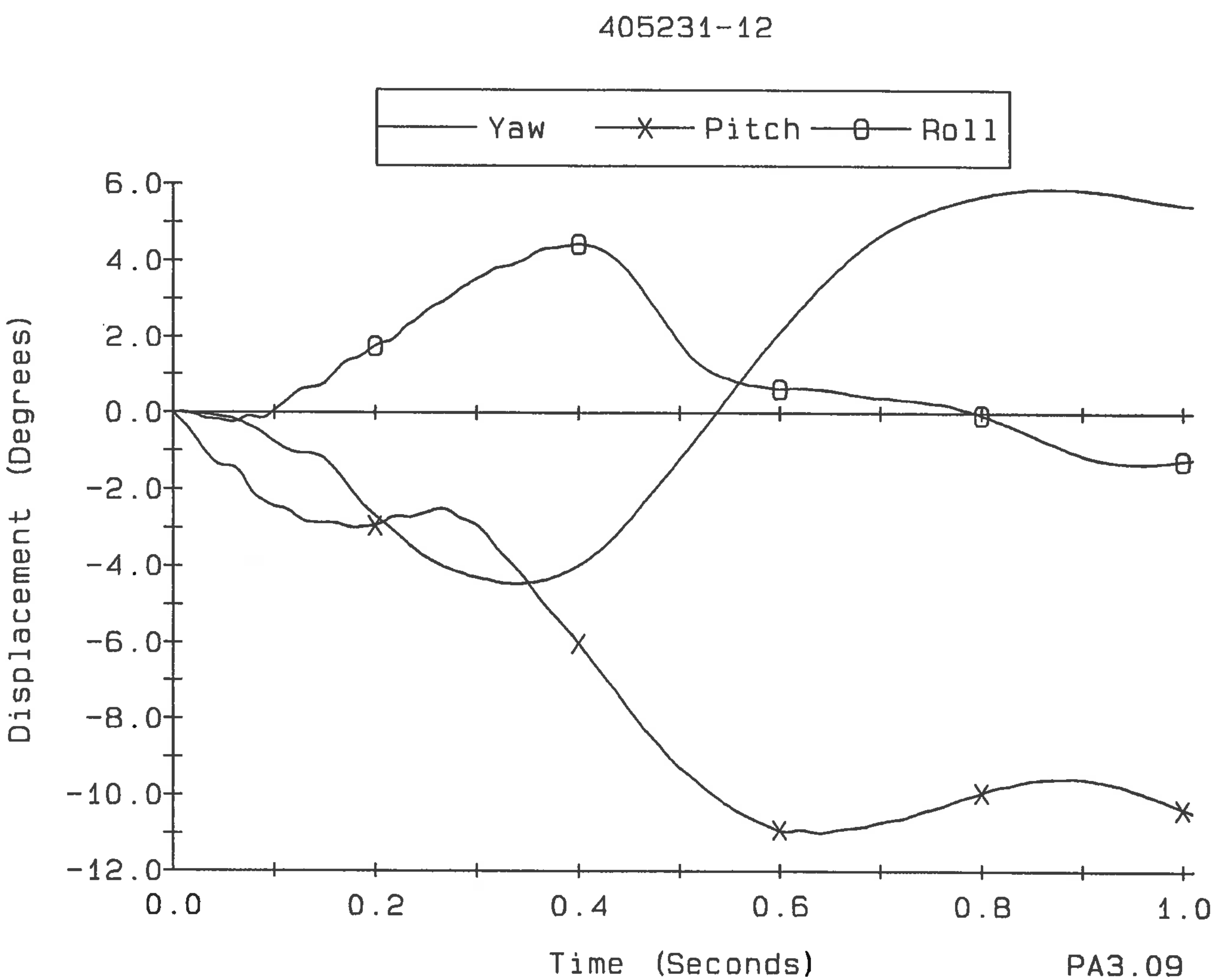
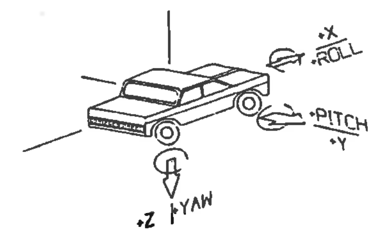


Figure C-11. Vehicle angular displacements during test 405231-11.





Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

Figure C-12. Vehicle angular displacements during test 405231-12.

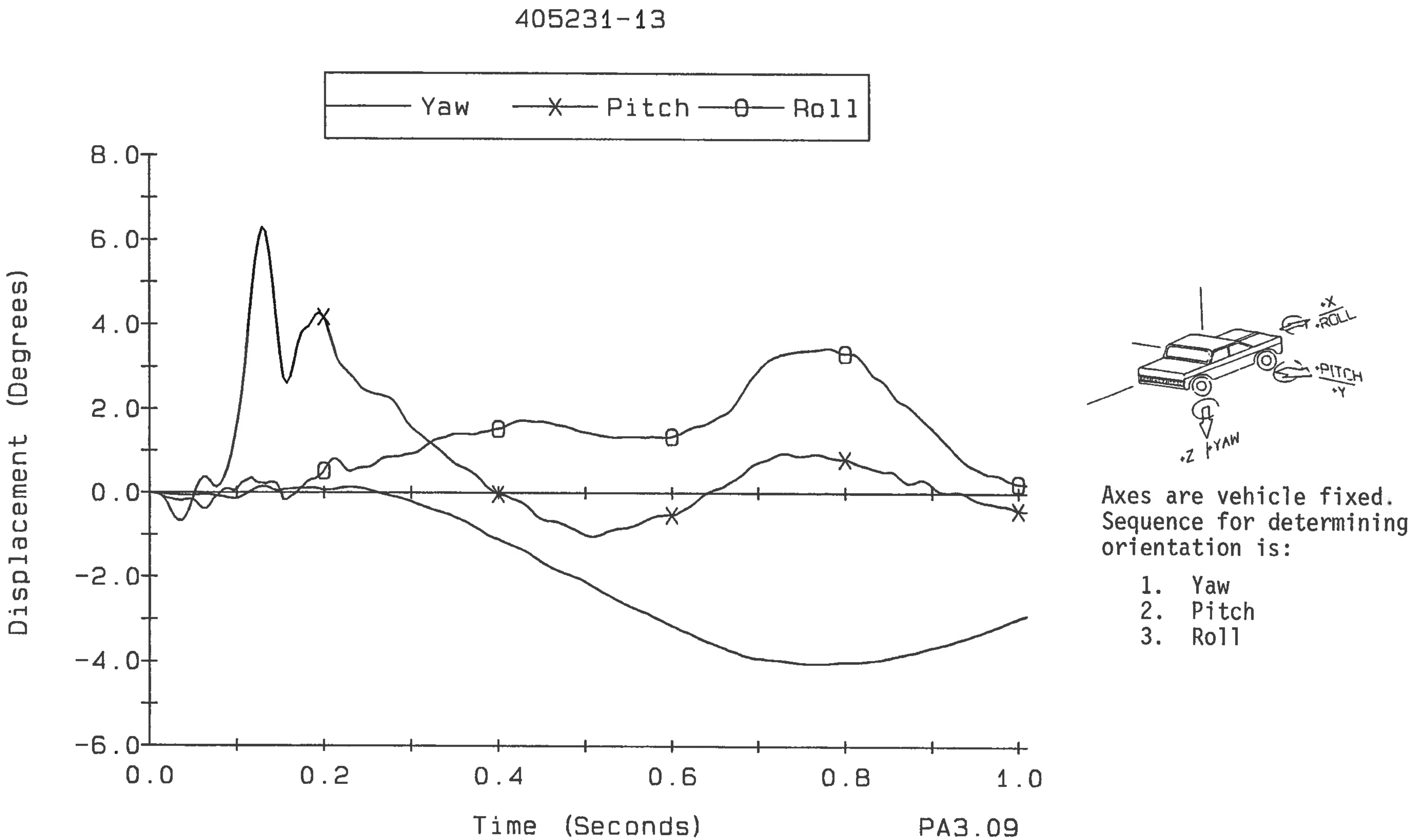


Figure C-13. Vehicle angular displacements during test 405231-13.

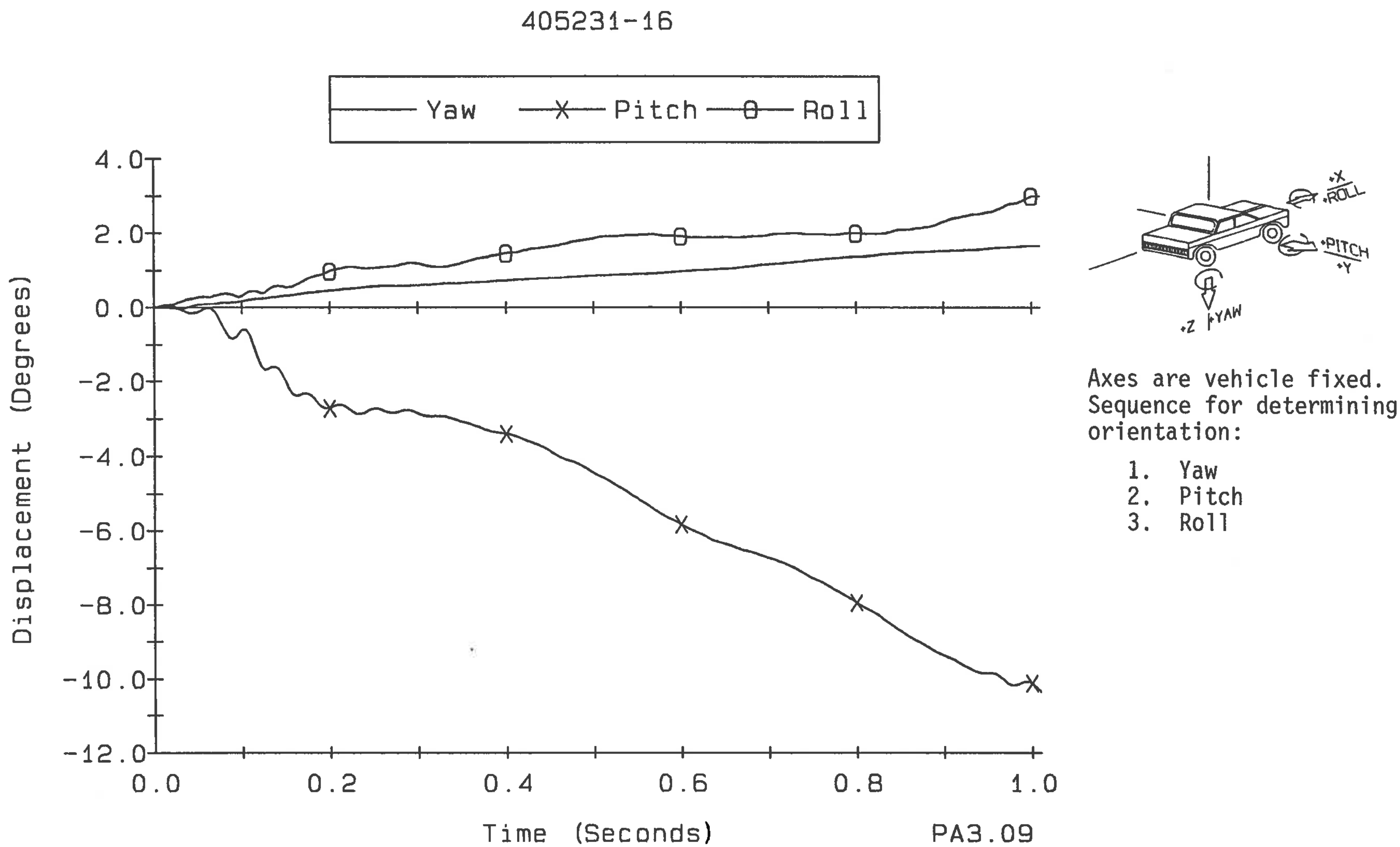


Figure C-14. Vehicle angular displacements during test 405231-16.

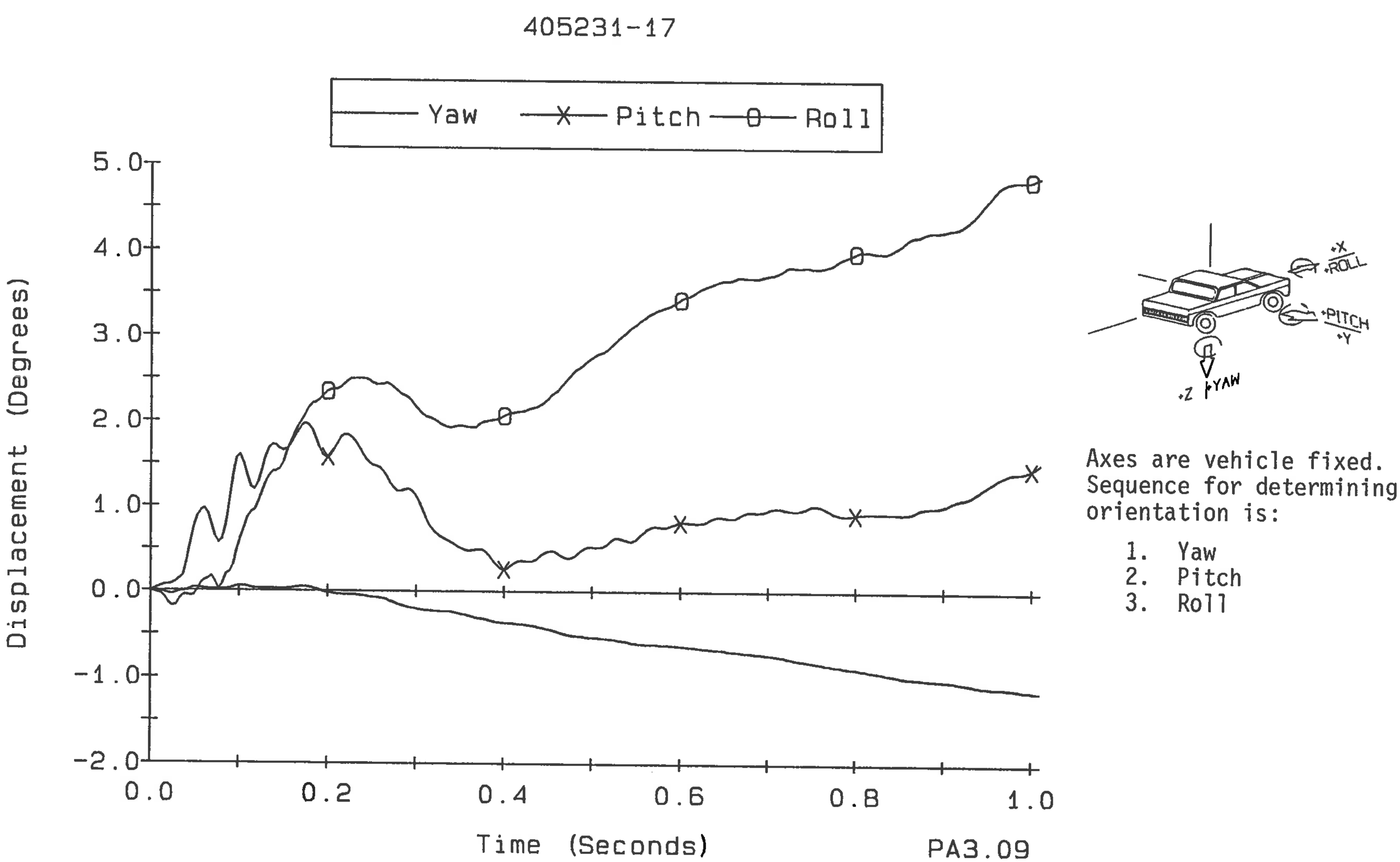


Figure C-15. Vehicle angular displacements during test 405231-17.

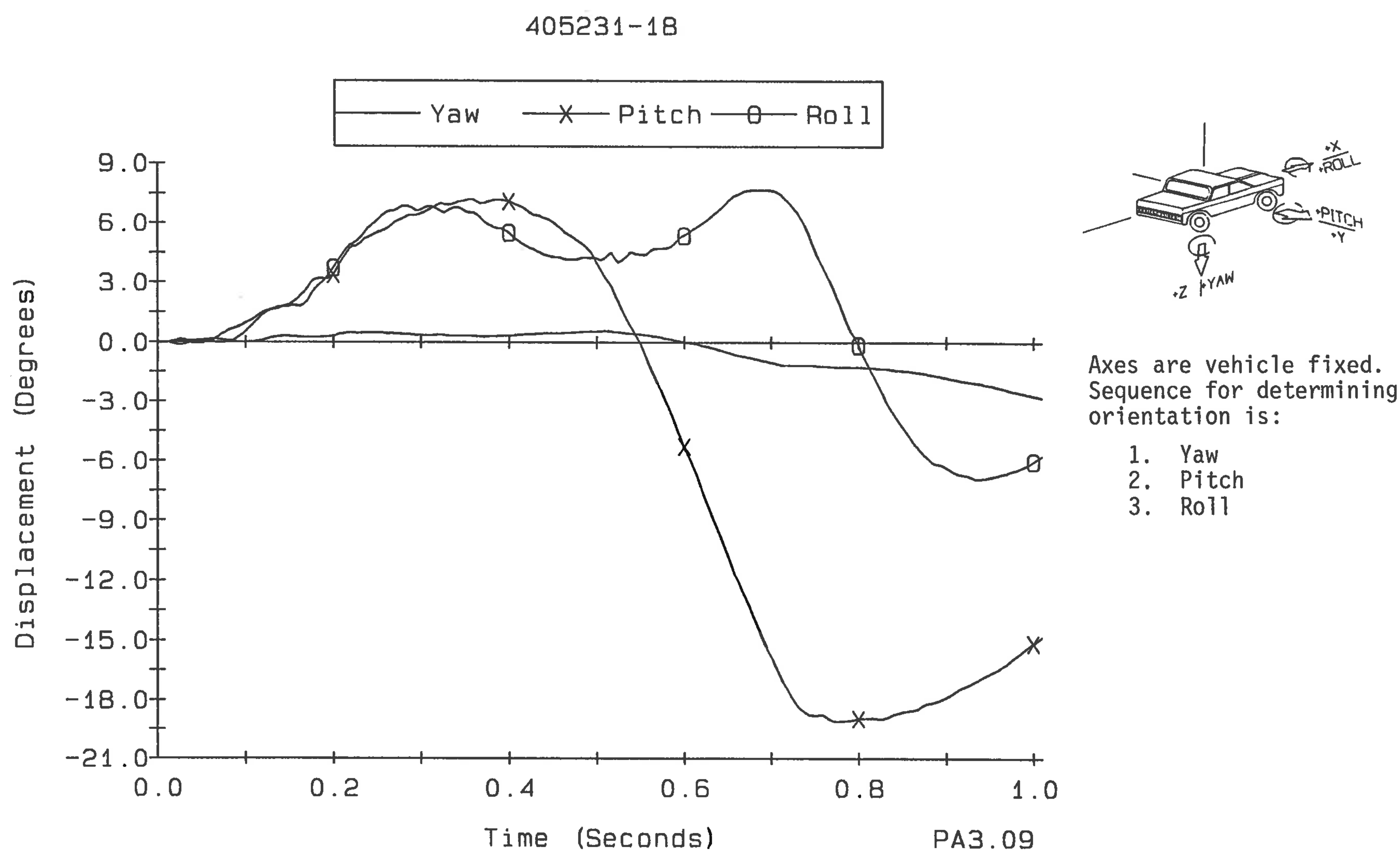


Figure C-16. Vehicle angular displacements during test 405231-18.

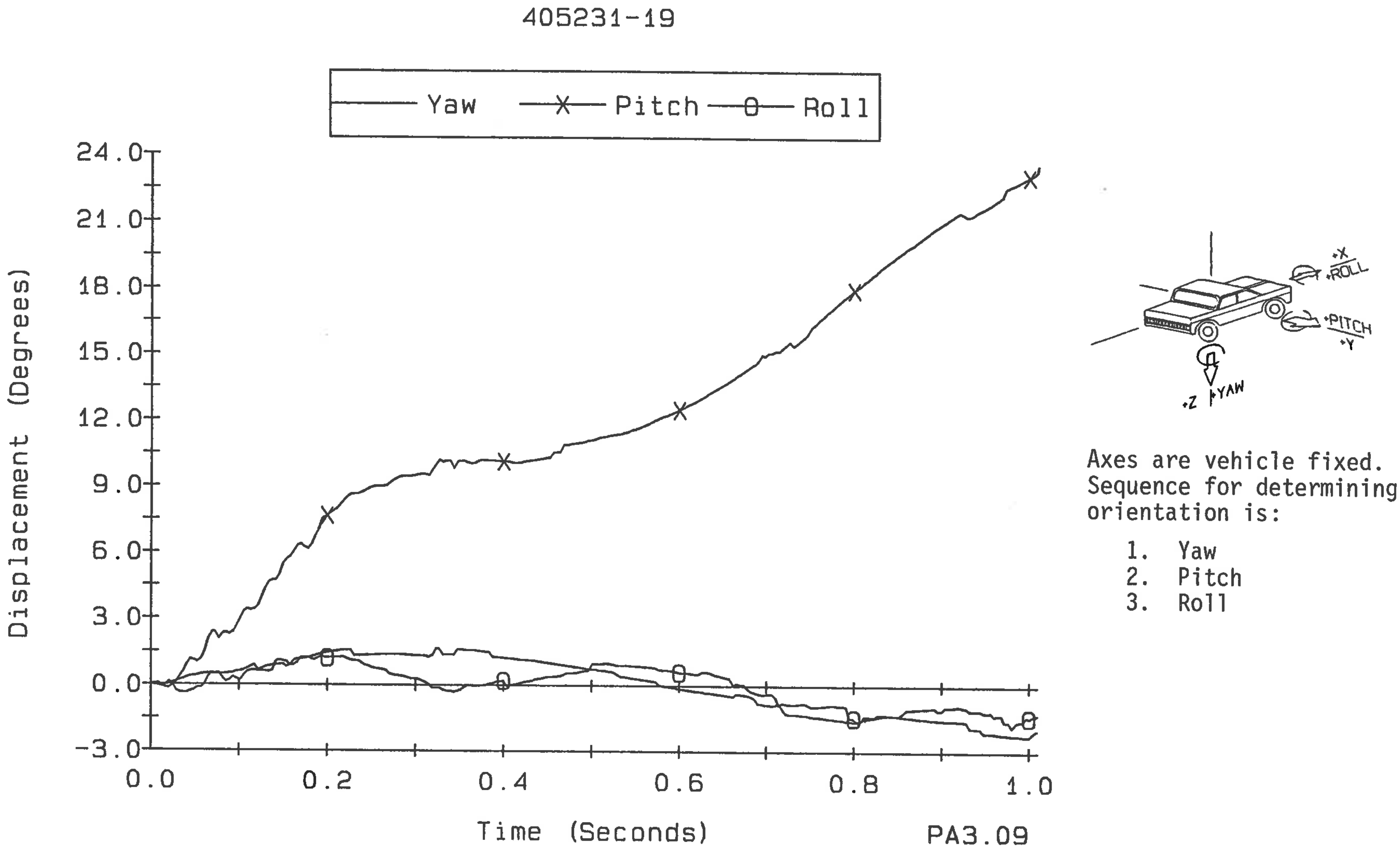


Figure C-17. Vehicle angular displacements during test 405231-19.

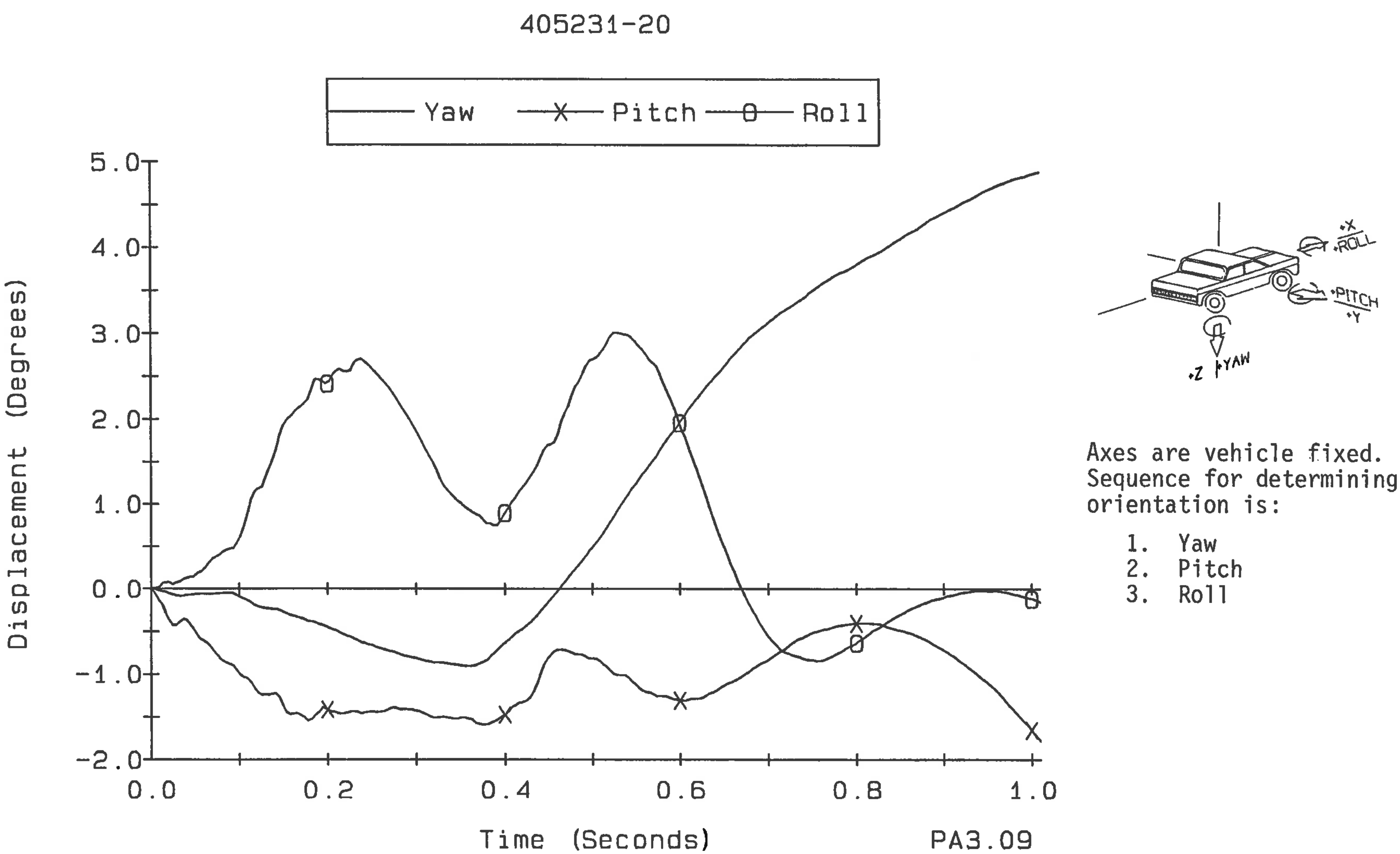


Figure C-18. Vehicle angular displacements during test 405231-20.

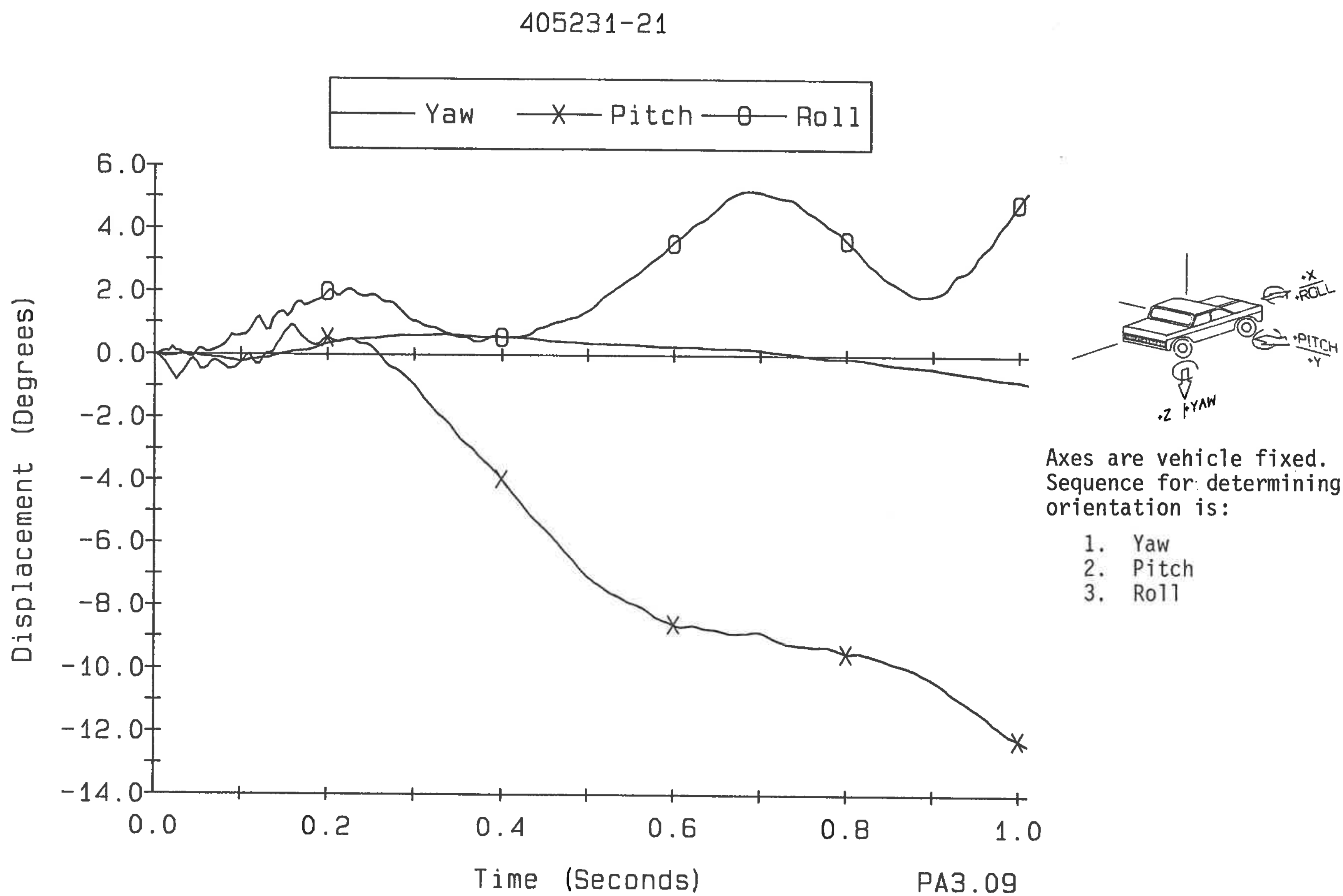


Figure C-19. Vehicle angular displacements during test 405231-21.

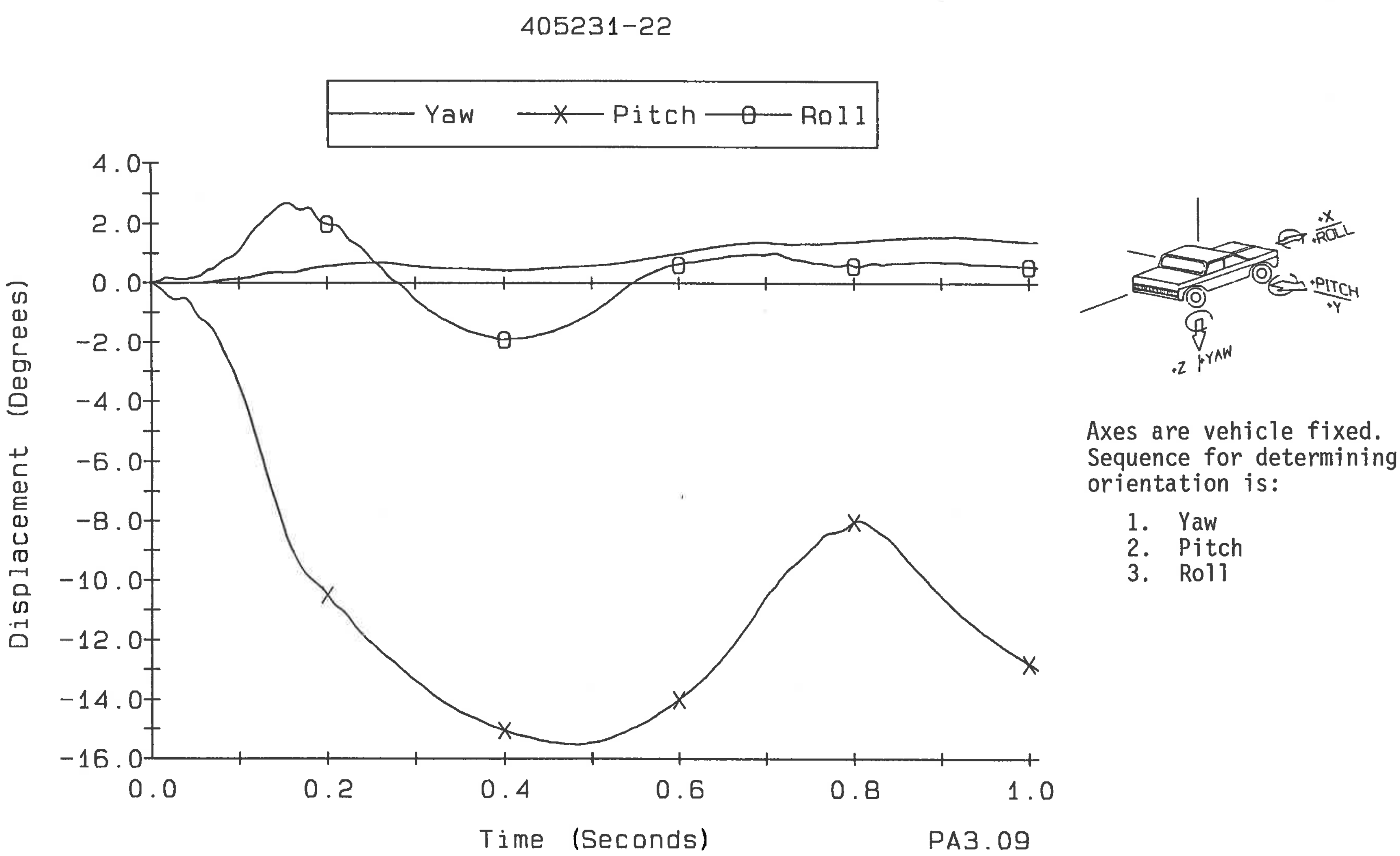


Figure C-20. Vehicle angular displacements during test 405231-22.

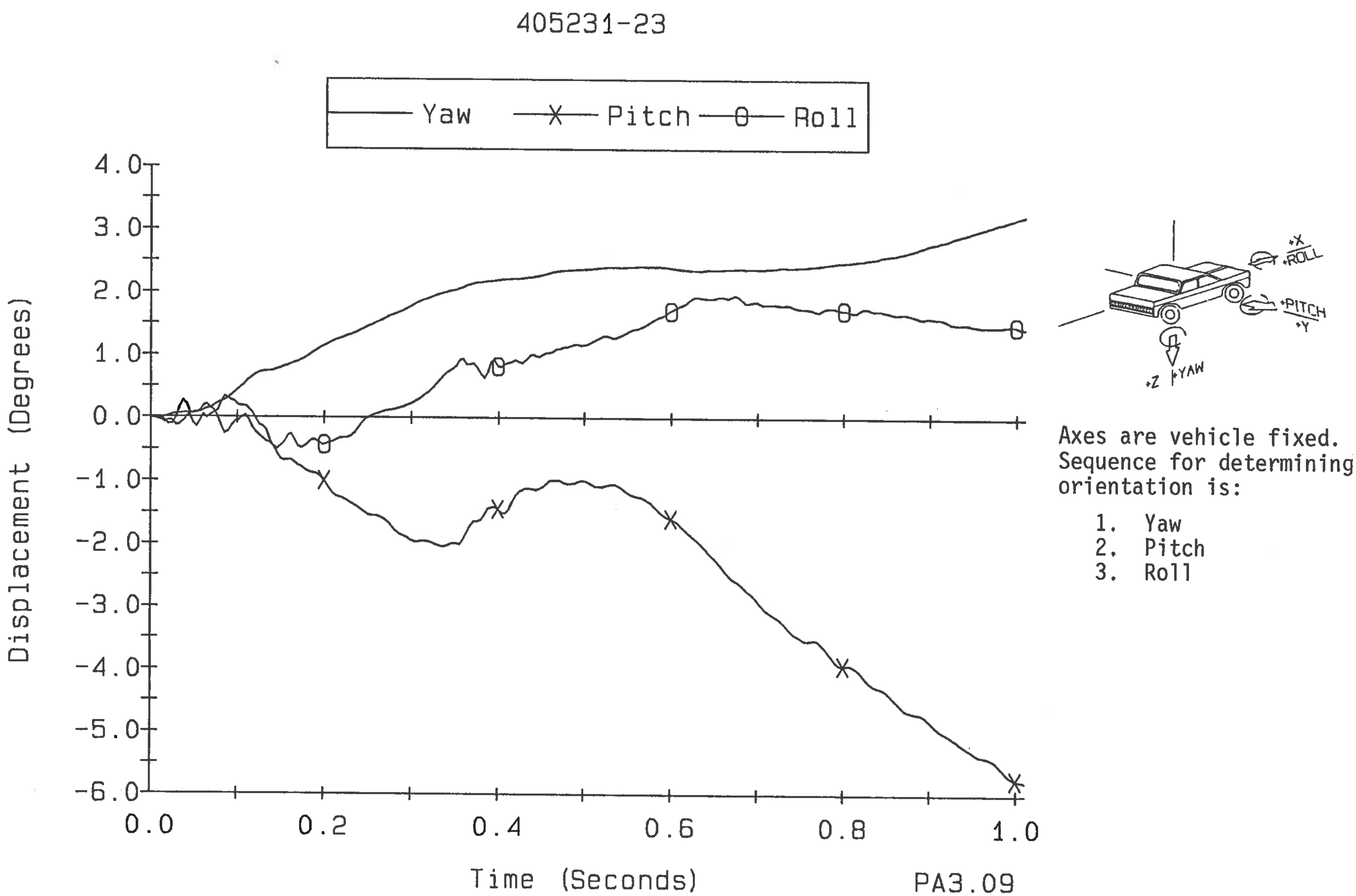


Figure C-21. Vehicle angular displacements for test 405231-23.

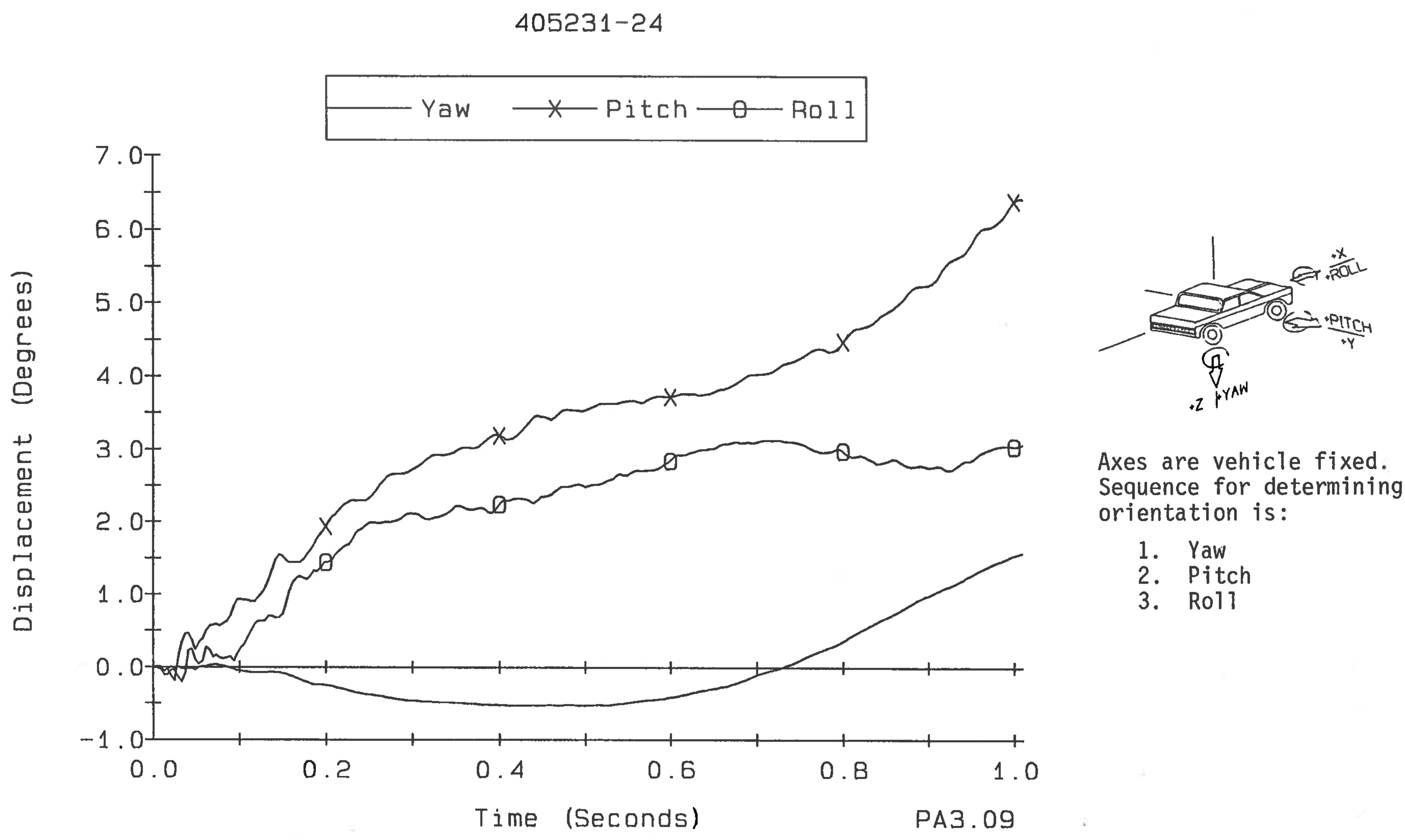


Figure C-22. Vehicle angular displacements during test 405231-24.

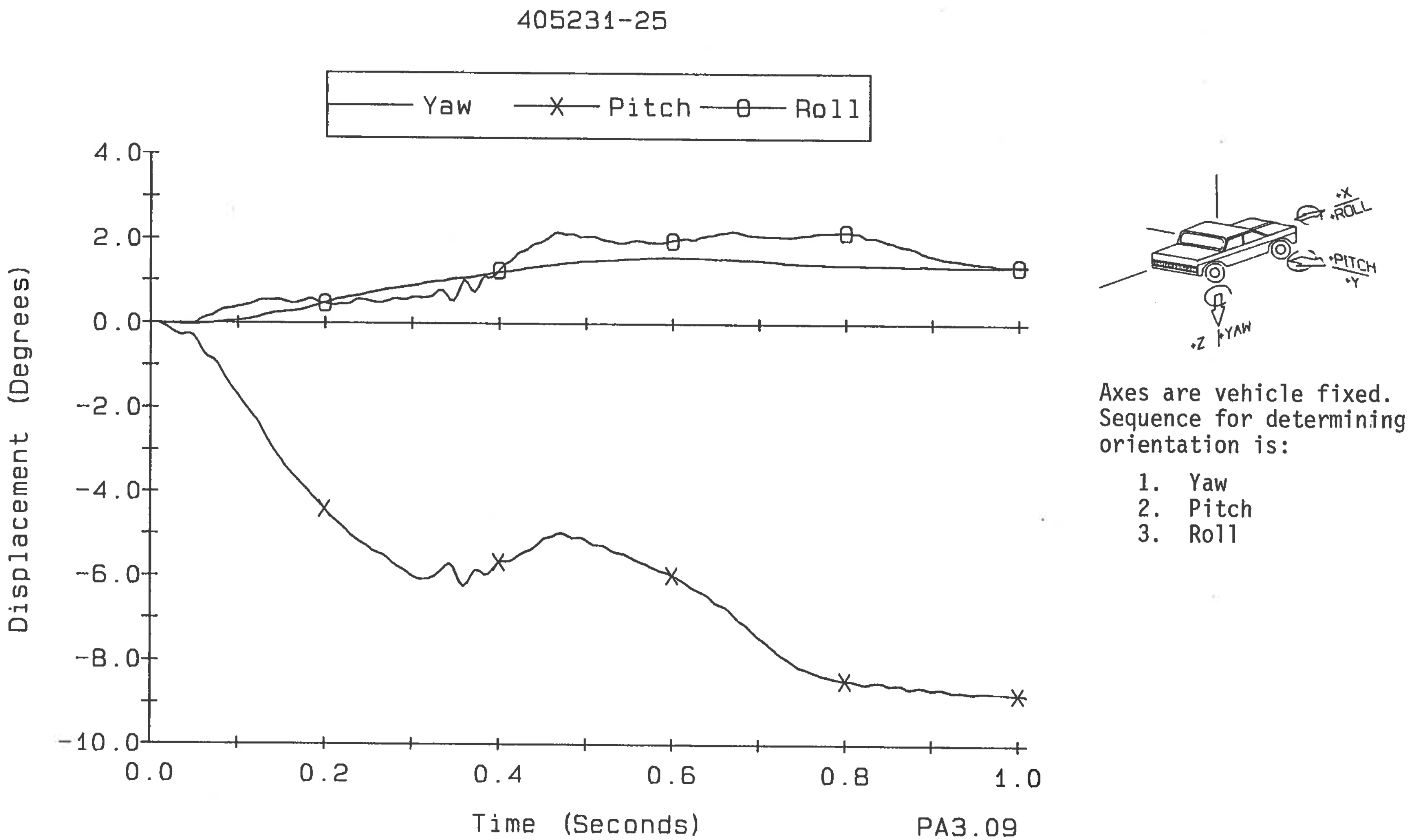


Figure C-23. Vehicle angular displacements during test 405231-25.

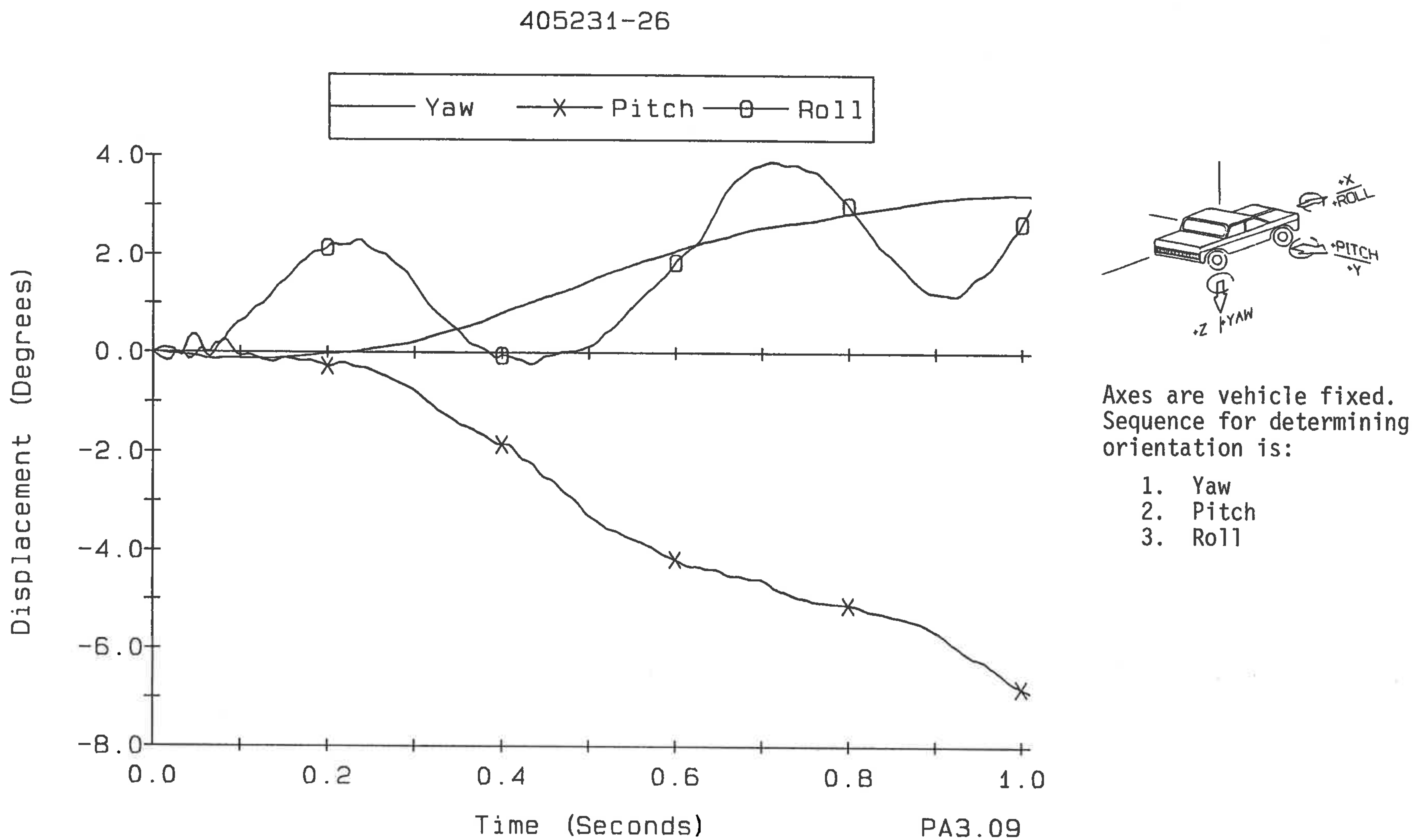


Figure C-26. Vehicle angular displacements during test 405231-26.

APPENDIX D

Vehicle Accelerometer Traces

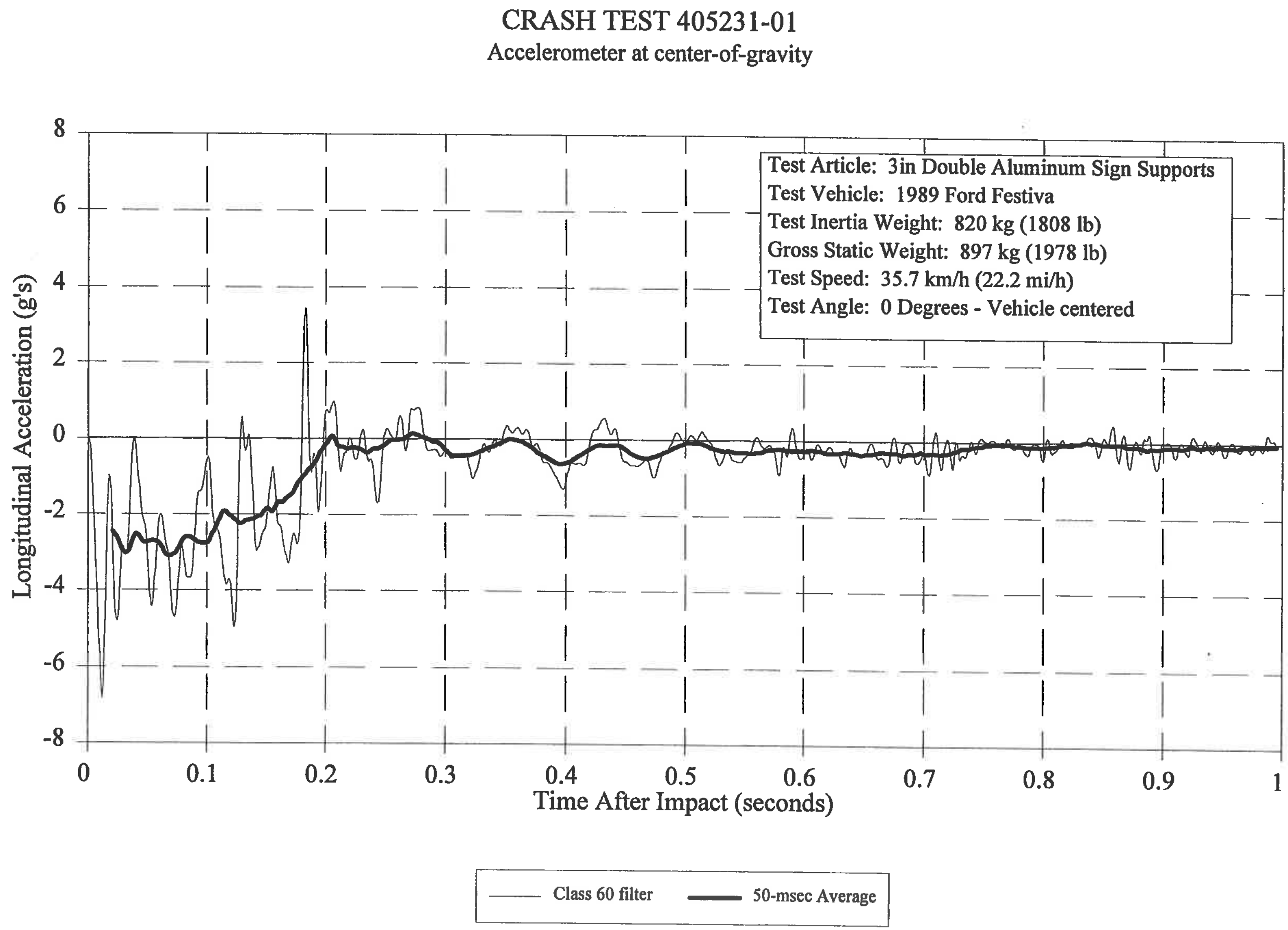


Figure D-1. Vehicle longitudinal accelerometer trace for test 405231-01.

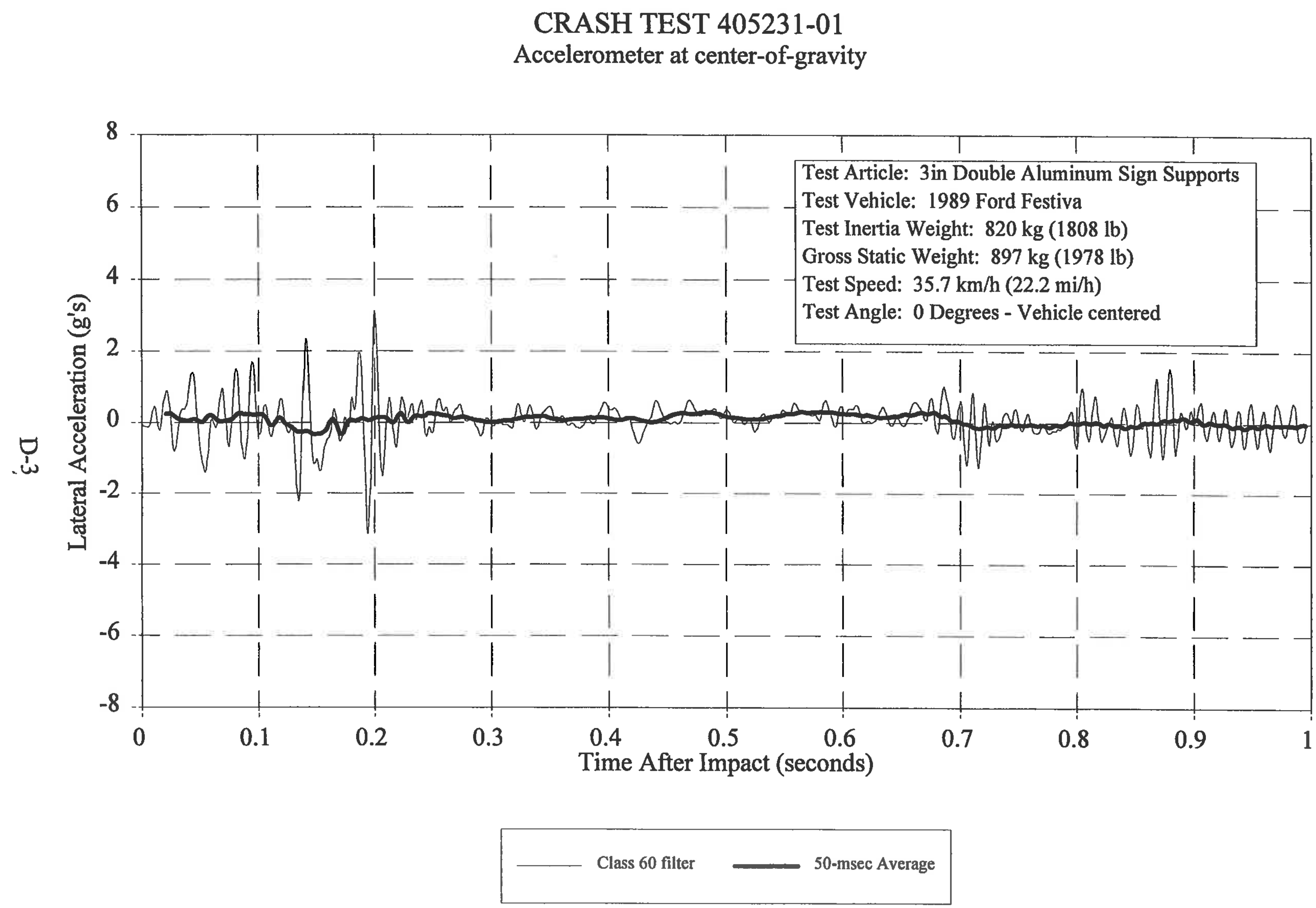


Figure D-2. Vehicle lateral accelerometer trace for test 405231-01.

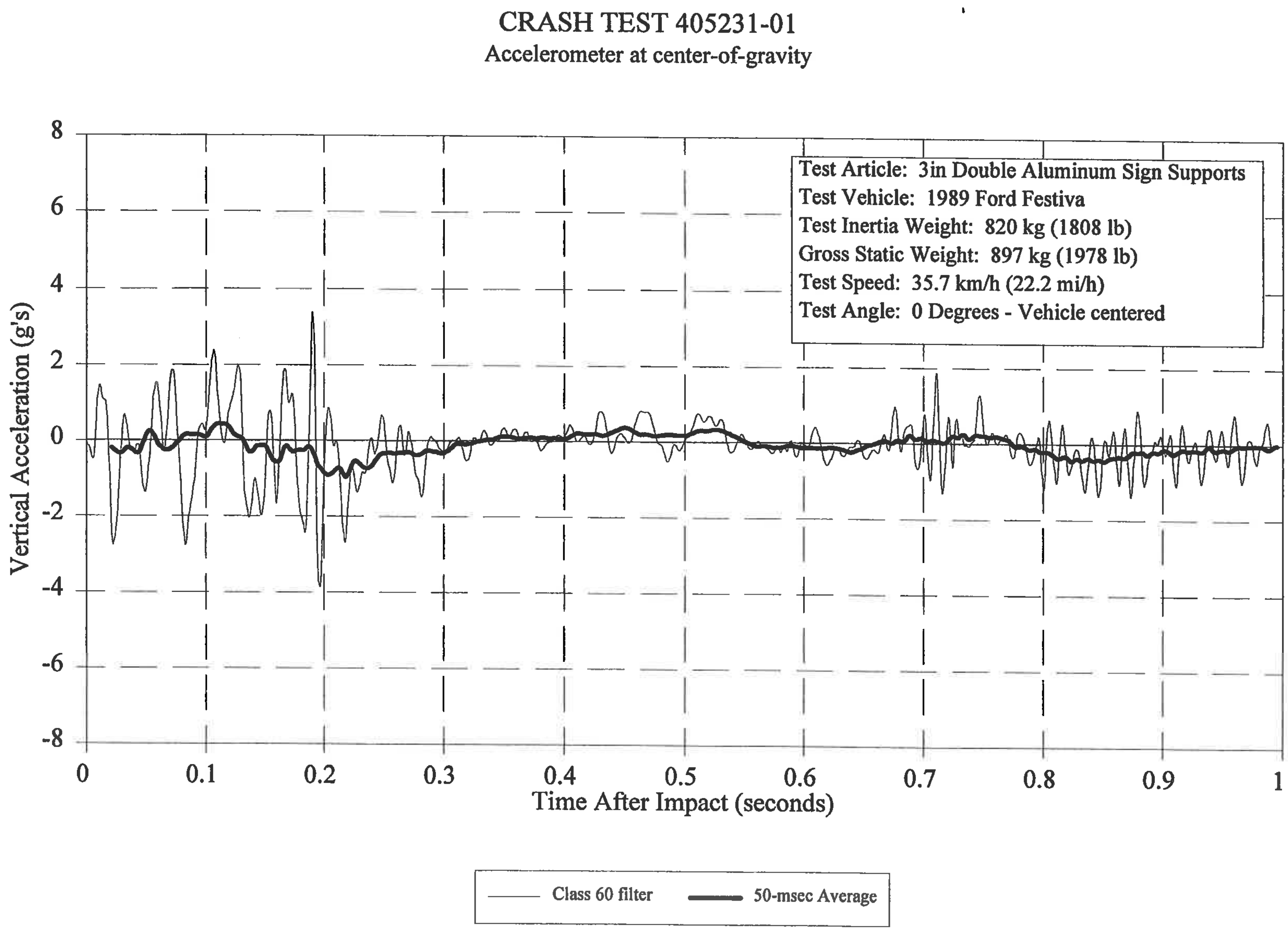


Figure D-3. Vehicle vertical accelerometer trace for test 405231-01.

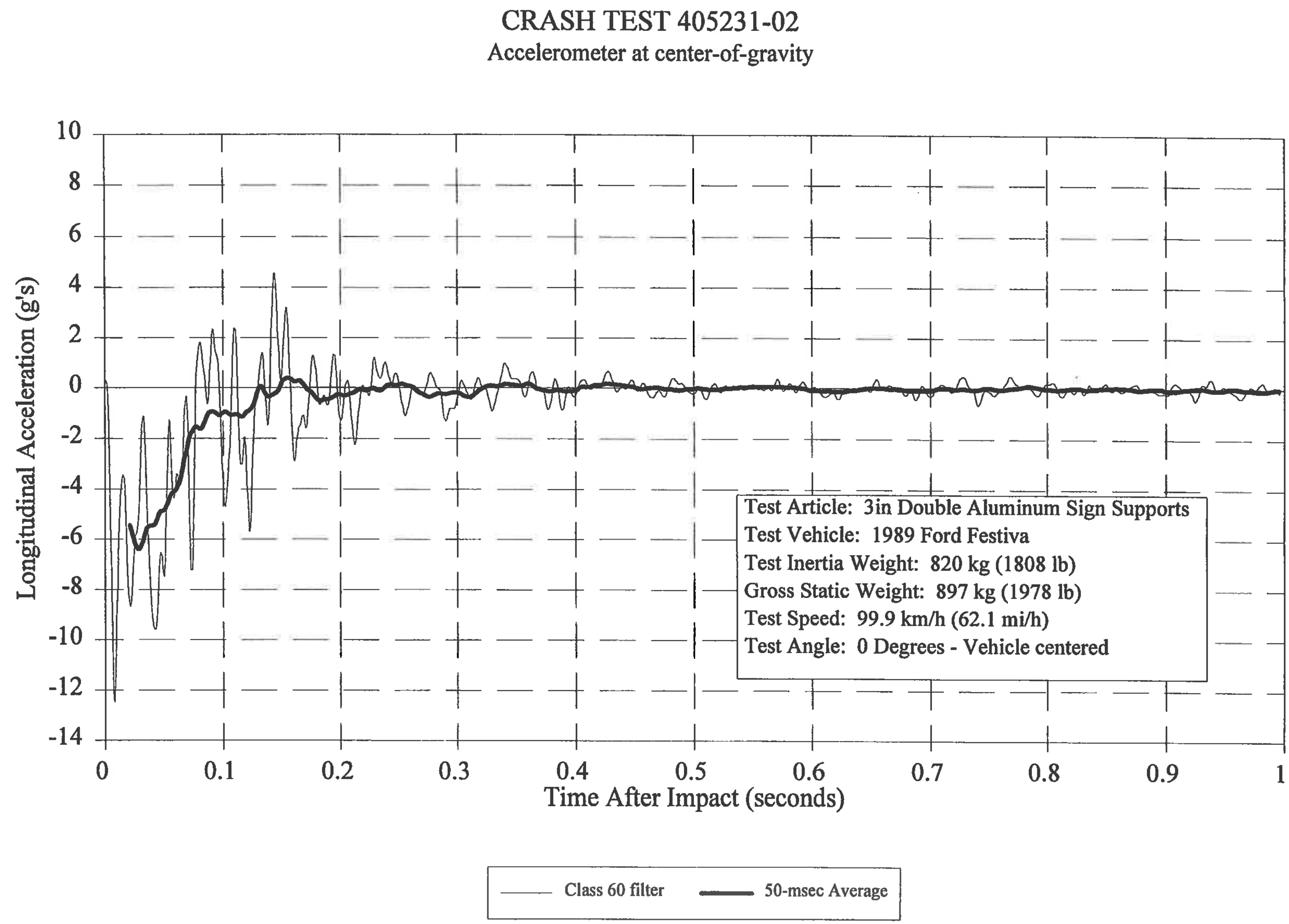


Figure D-4. Vehicle longitudinal accelerometer trace for test 405231-02.

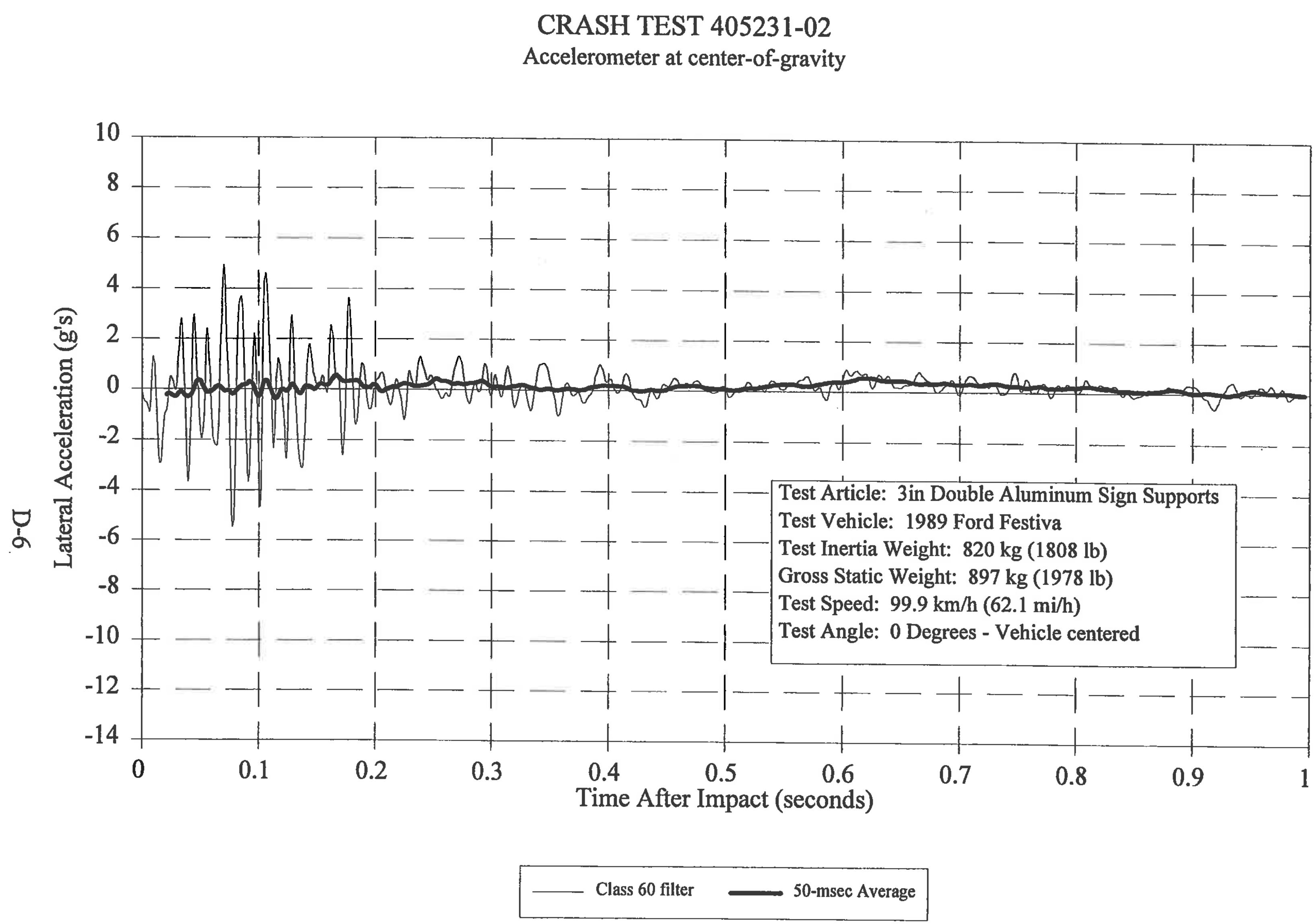


Figure D-5. Vehicle lateral accelerometer trace for test 405231-02.

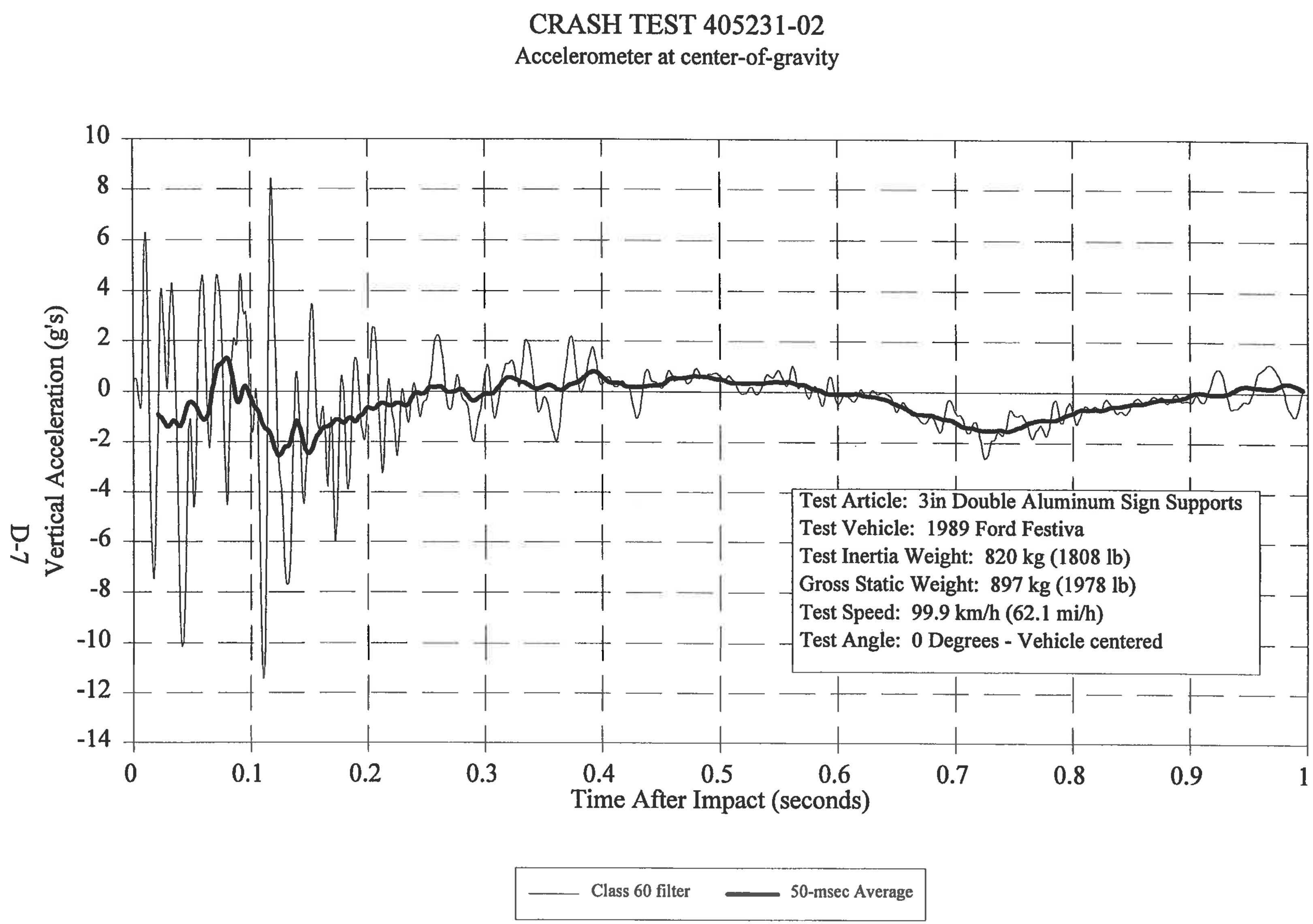


Figure D-6. Vehicle vertical accelerometer trace for test 405231-02.

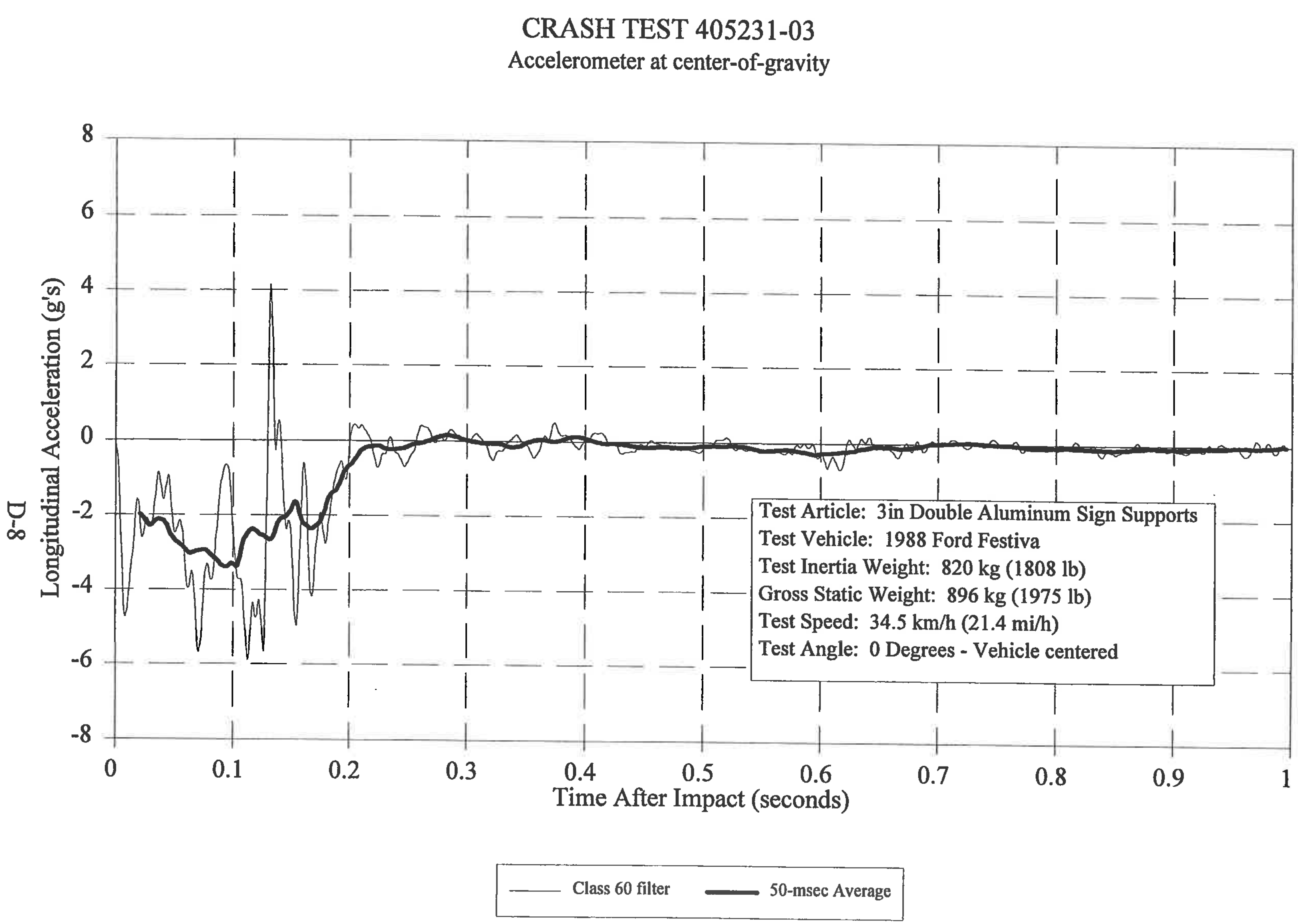


Figure D-7. Vehicle longitudinal accelerometer trace for test 405231-03.

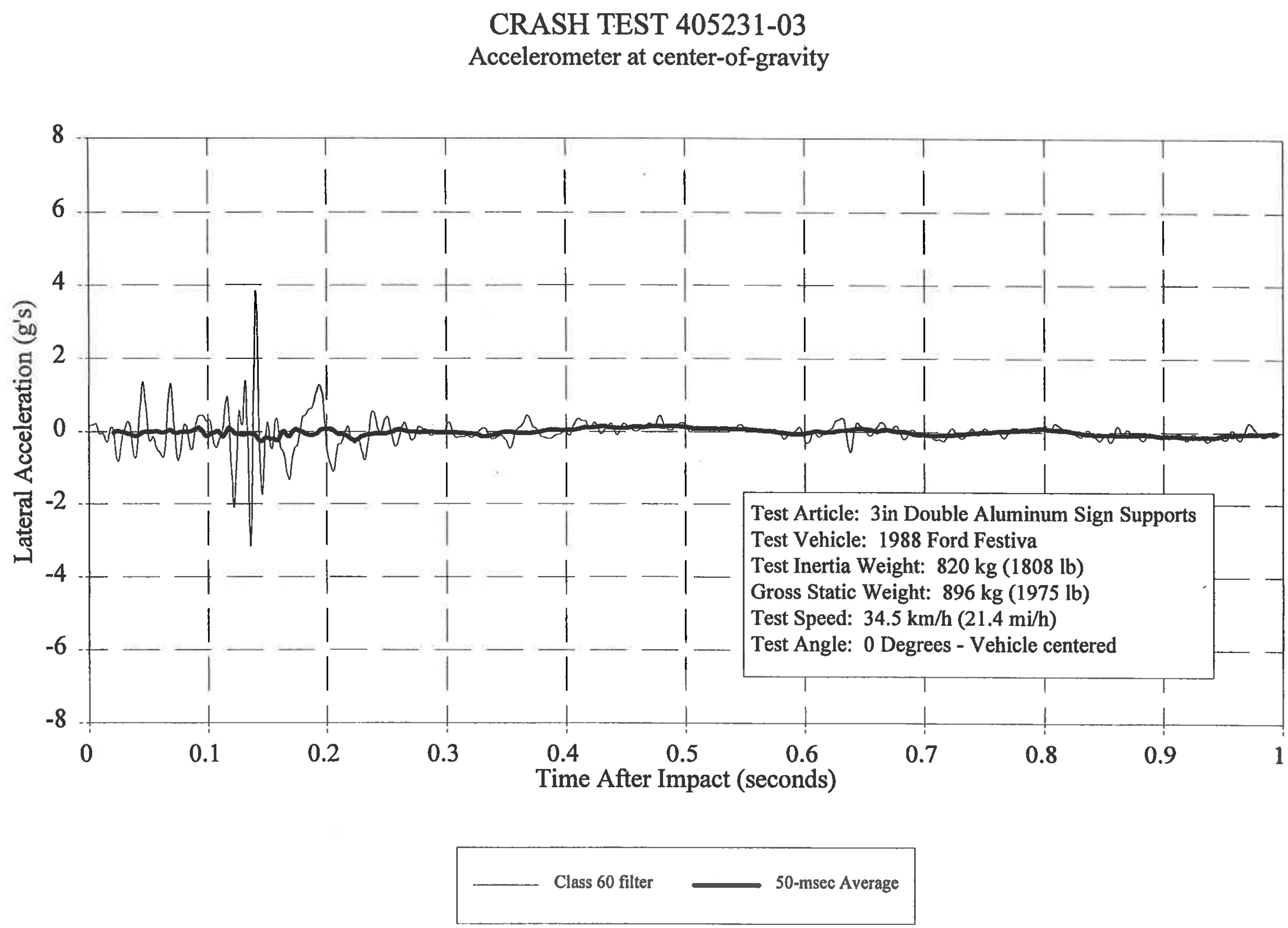


Figure D-8. Vehicle lateral accelerometer trace for test 405231-03.

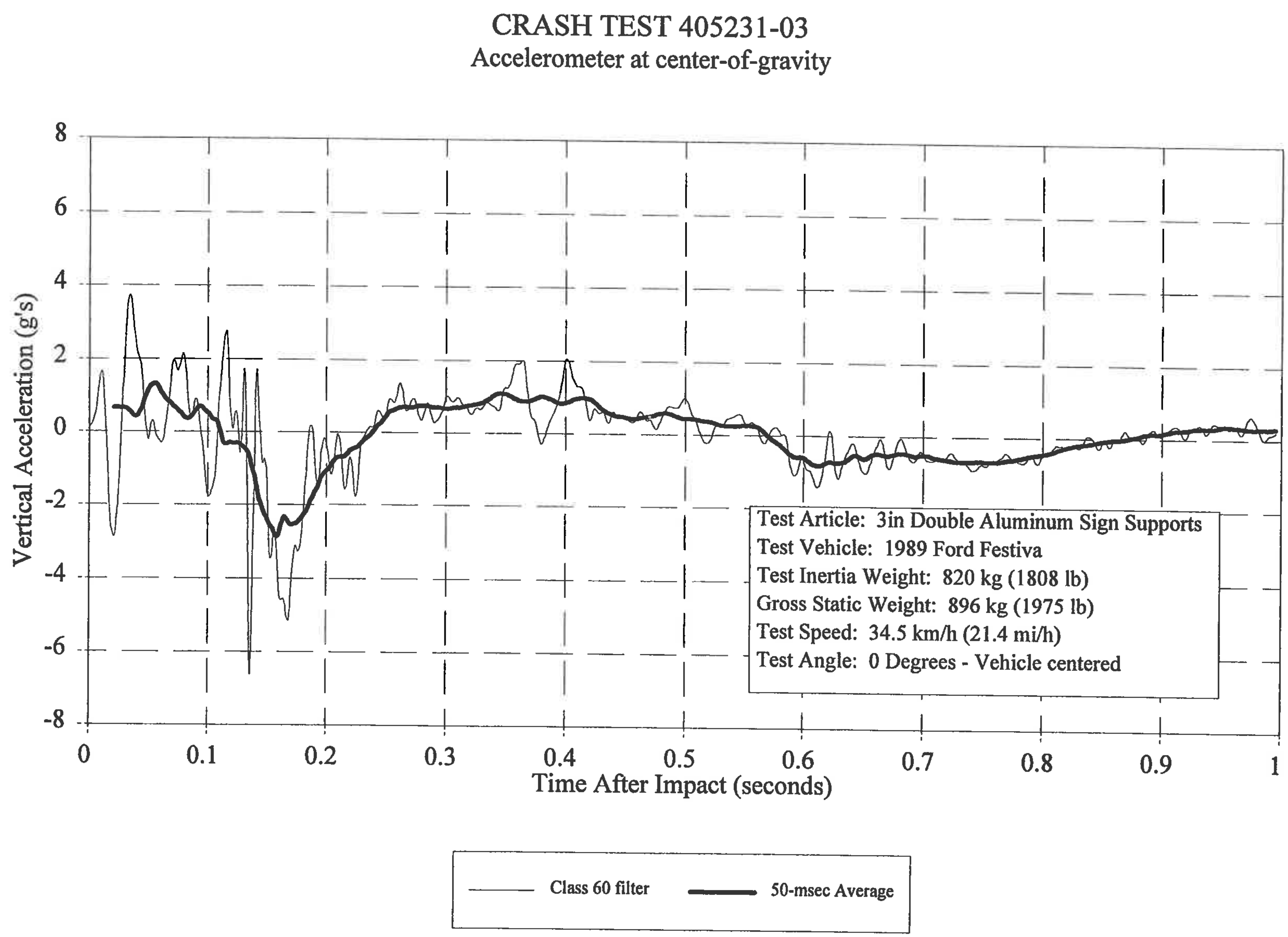


Figure D-9. Vehicle vertical accelerometer trace for test 405231-03.

CRASH TEST 405231-04
Accelerometer at center-of-gravity

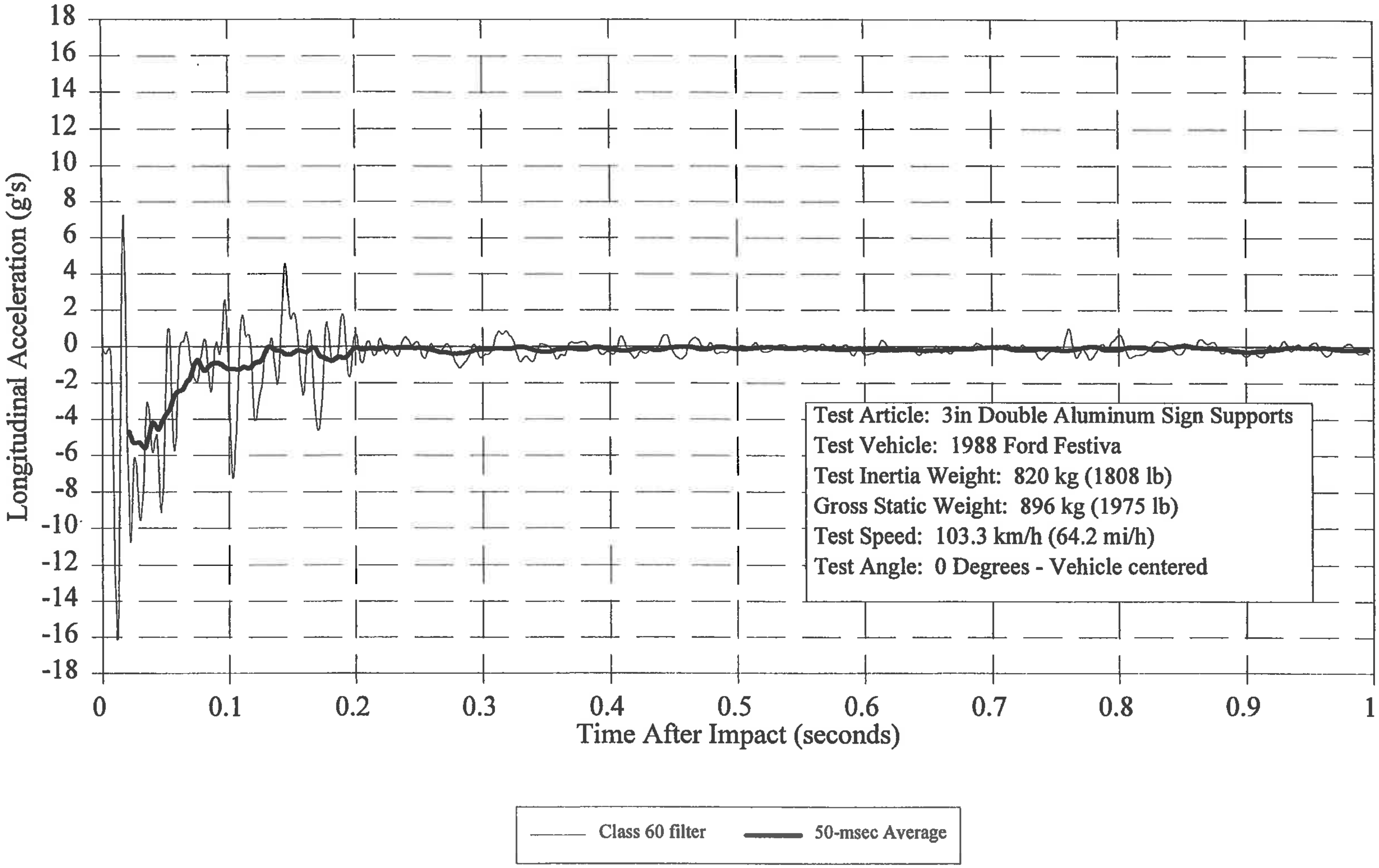


Figure D-10. Vehicle longitudinal accelerometer trace for test 405231-04.

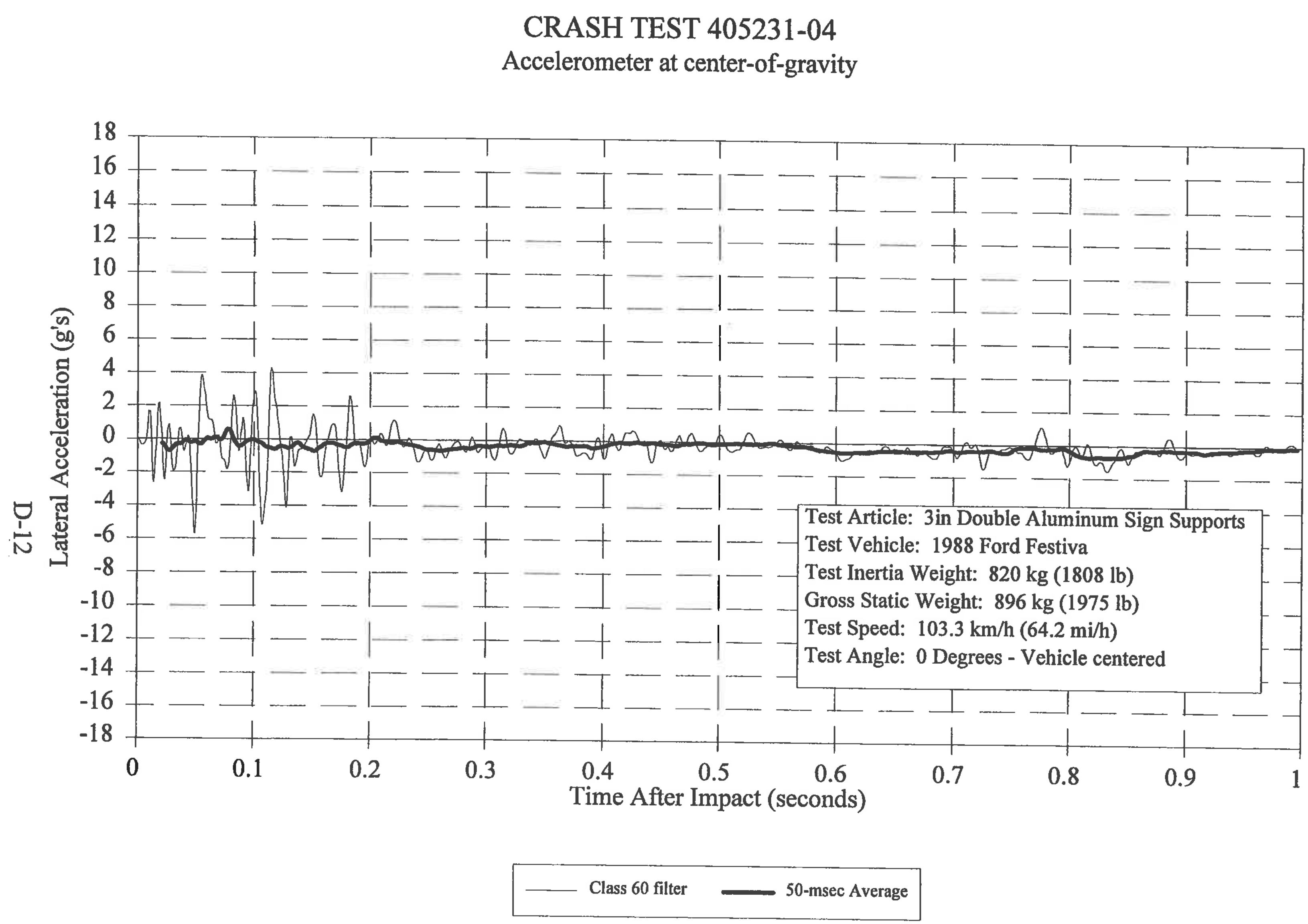


Figure D-11. Vehicle lateral accelerometer trace for test 405231-04.

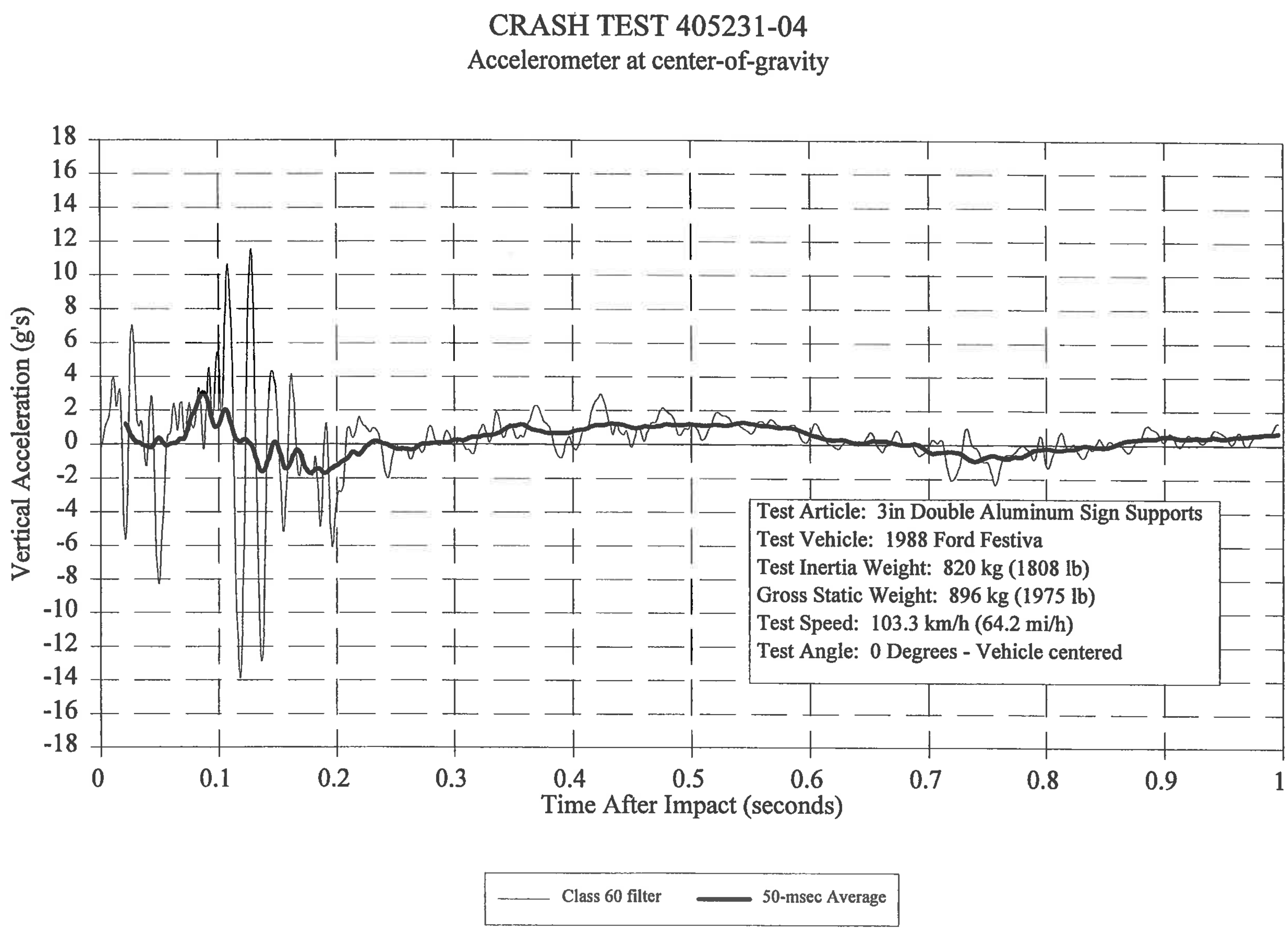


Figure D-12. Vehicle vertical accelerometer trace for test 405231-04.

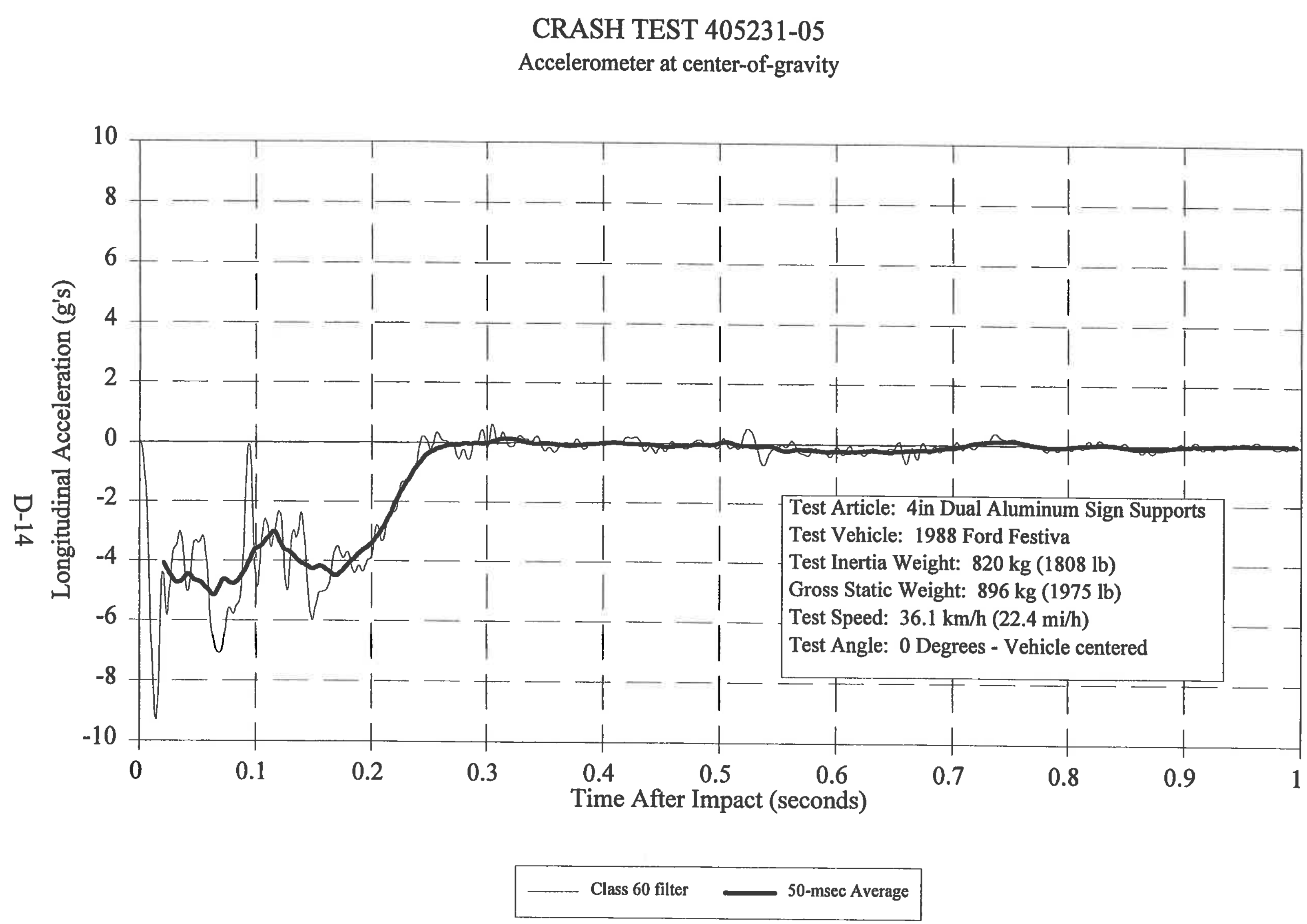


Figure D-13. Vehicle longitudinal accelerometer trace for test 405231-05.

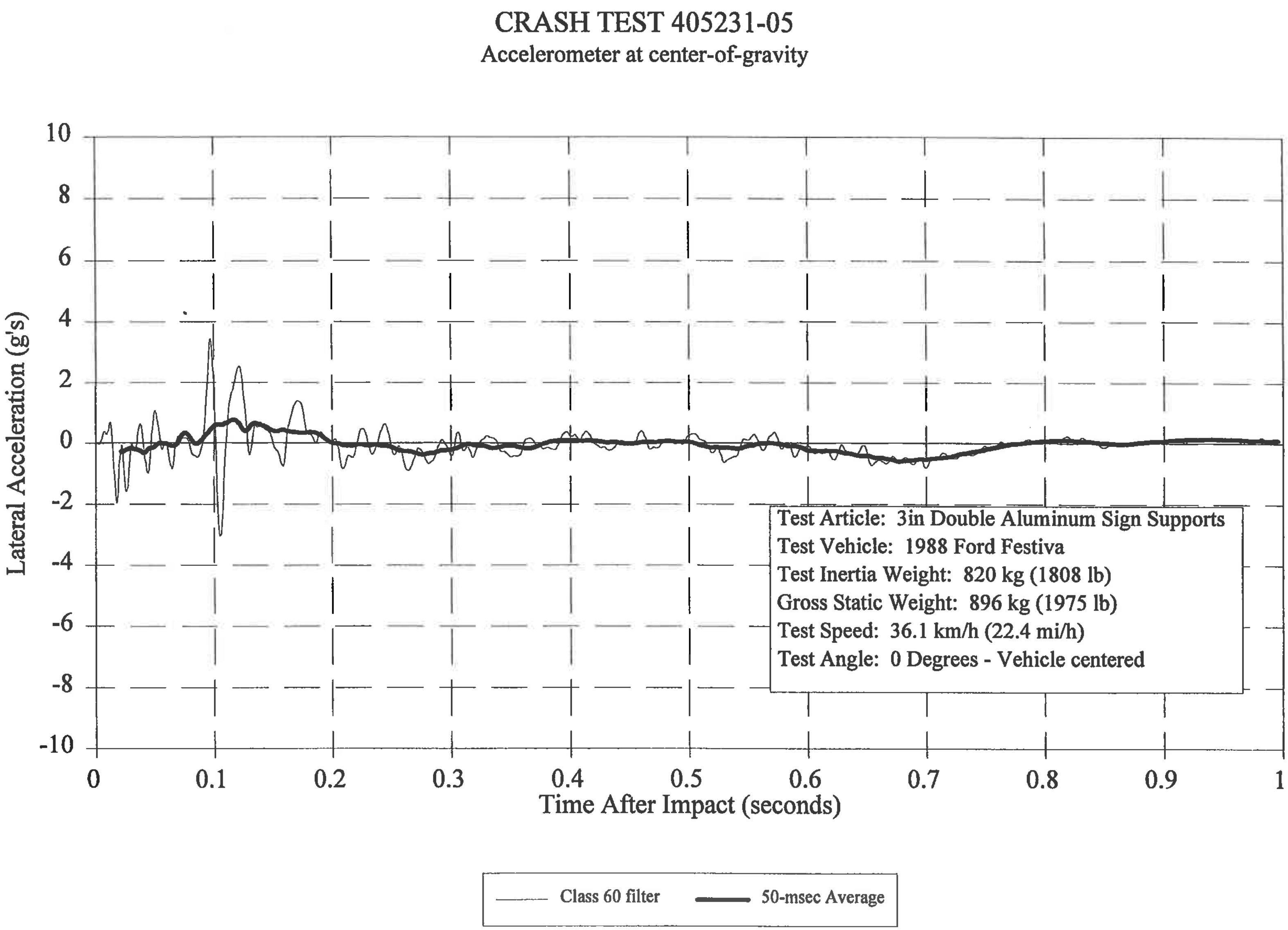


Figure D-14. Vehicle lateral accelerometer trace for test 405231-05.

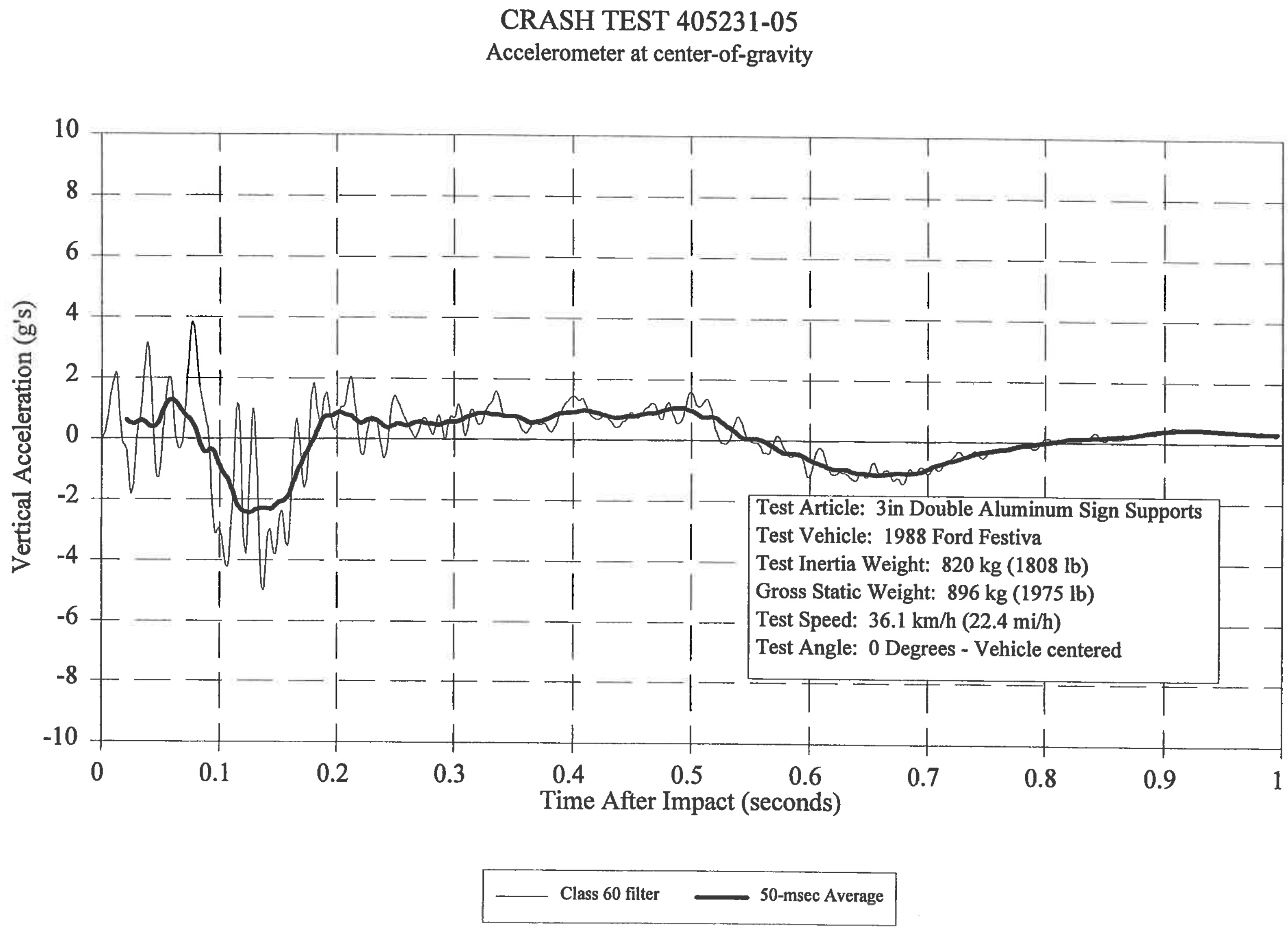


Figure D-15. Vehicle vertical accelerometer trace for test 405231-05.

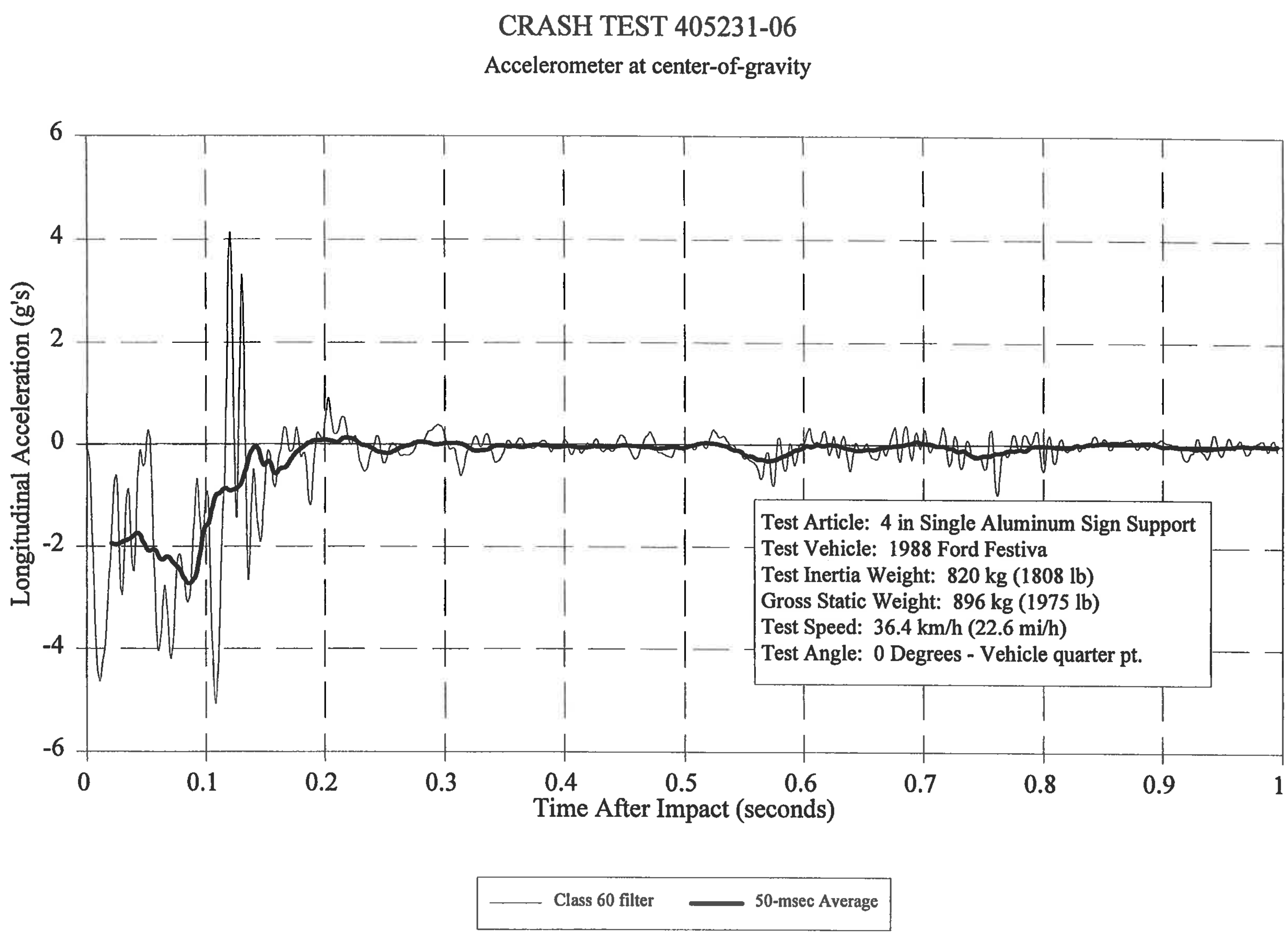


Figure D-16. Vehicle longitudinal accelerometer trace for test 405231-06.

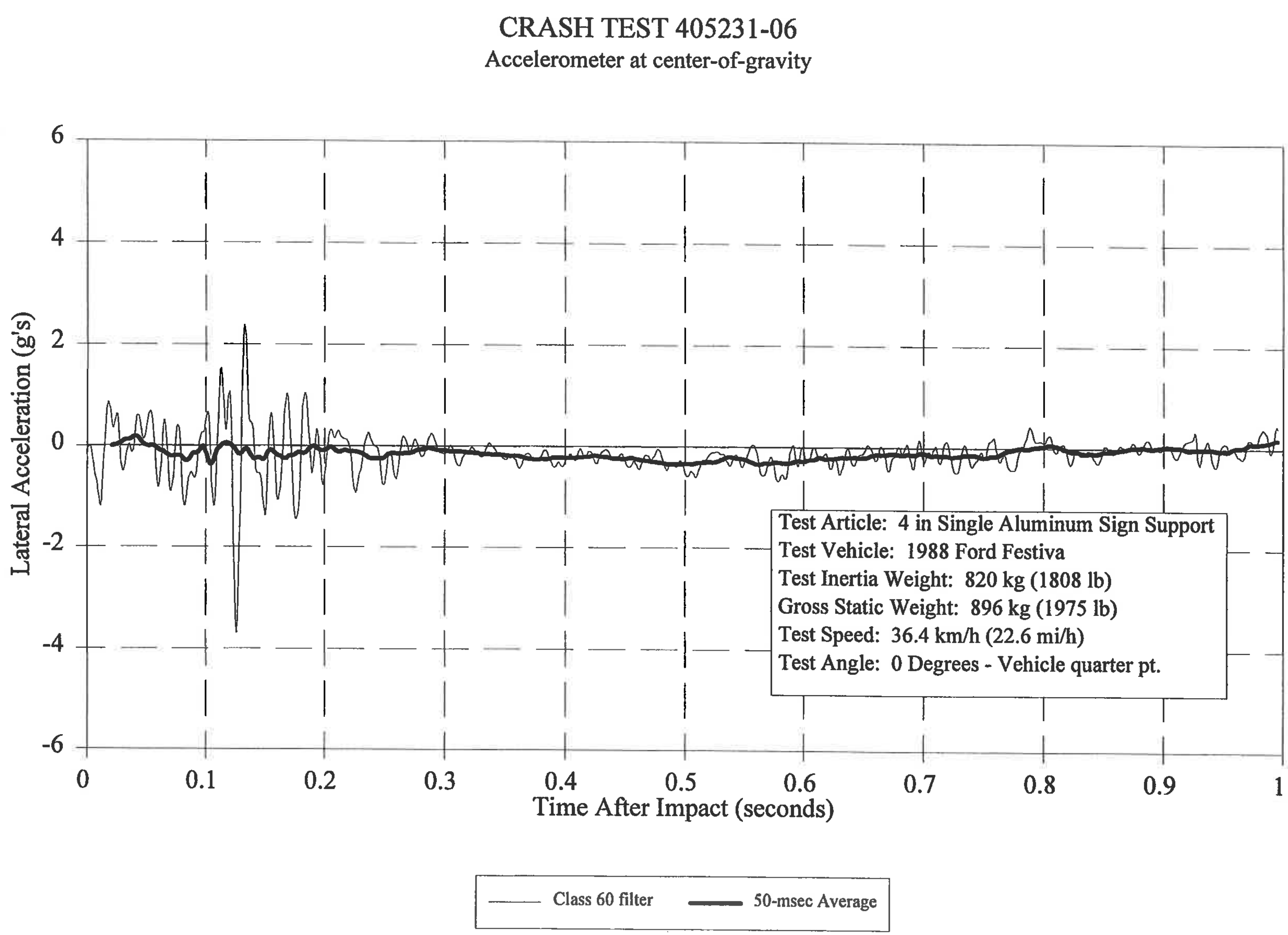


Figure D-17. Vehicle lateral accelerometer trace for test 405231-06.

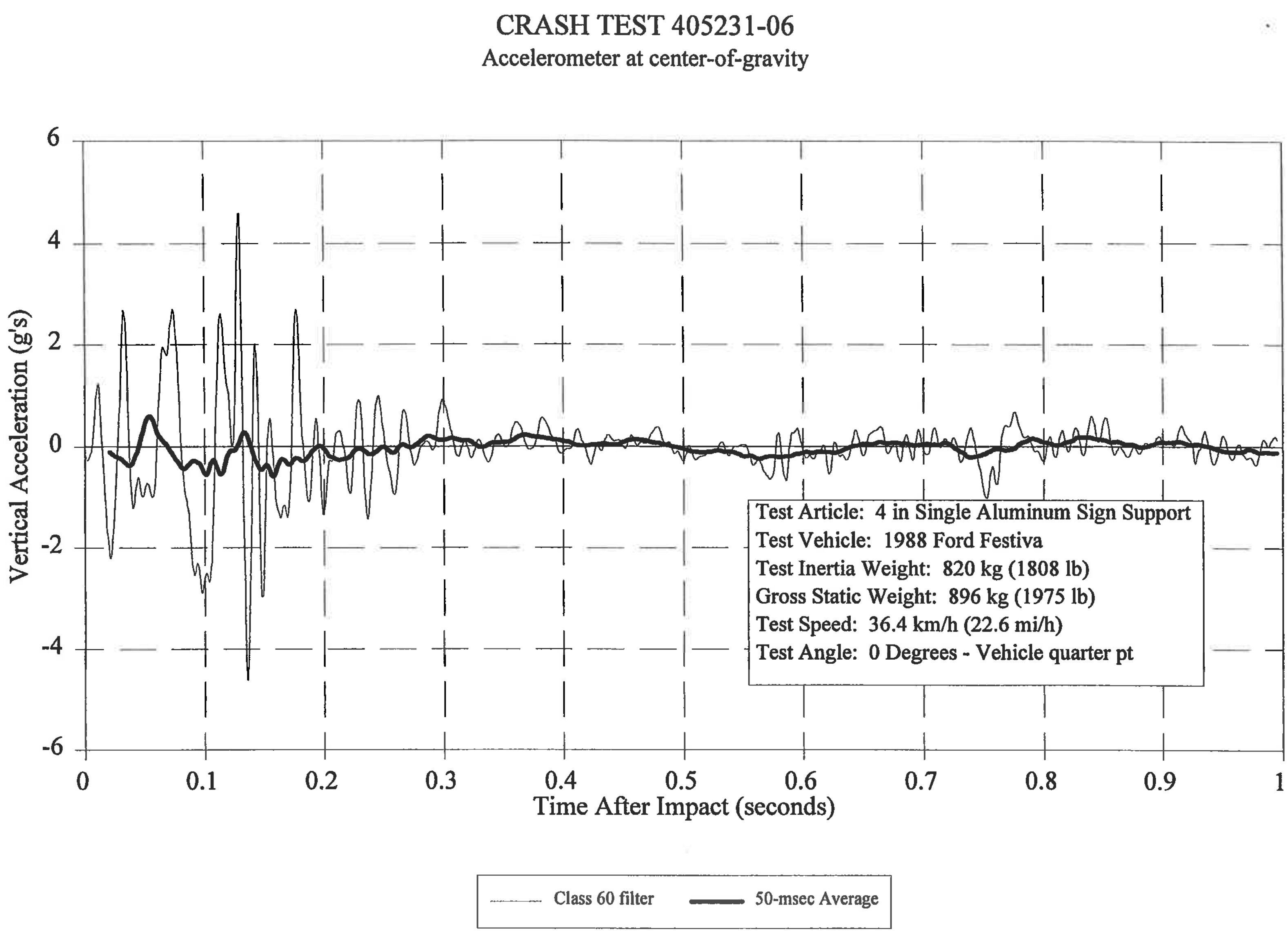


Figure D-18. Vehicle vertical accelerometer trace for test 405231-06.

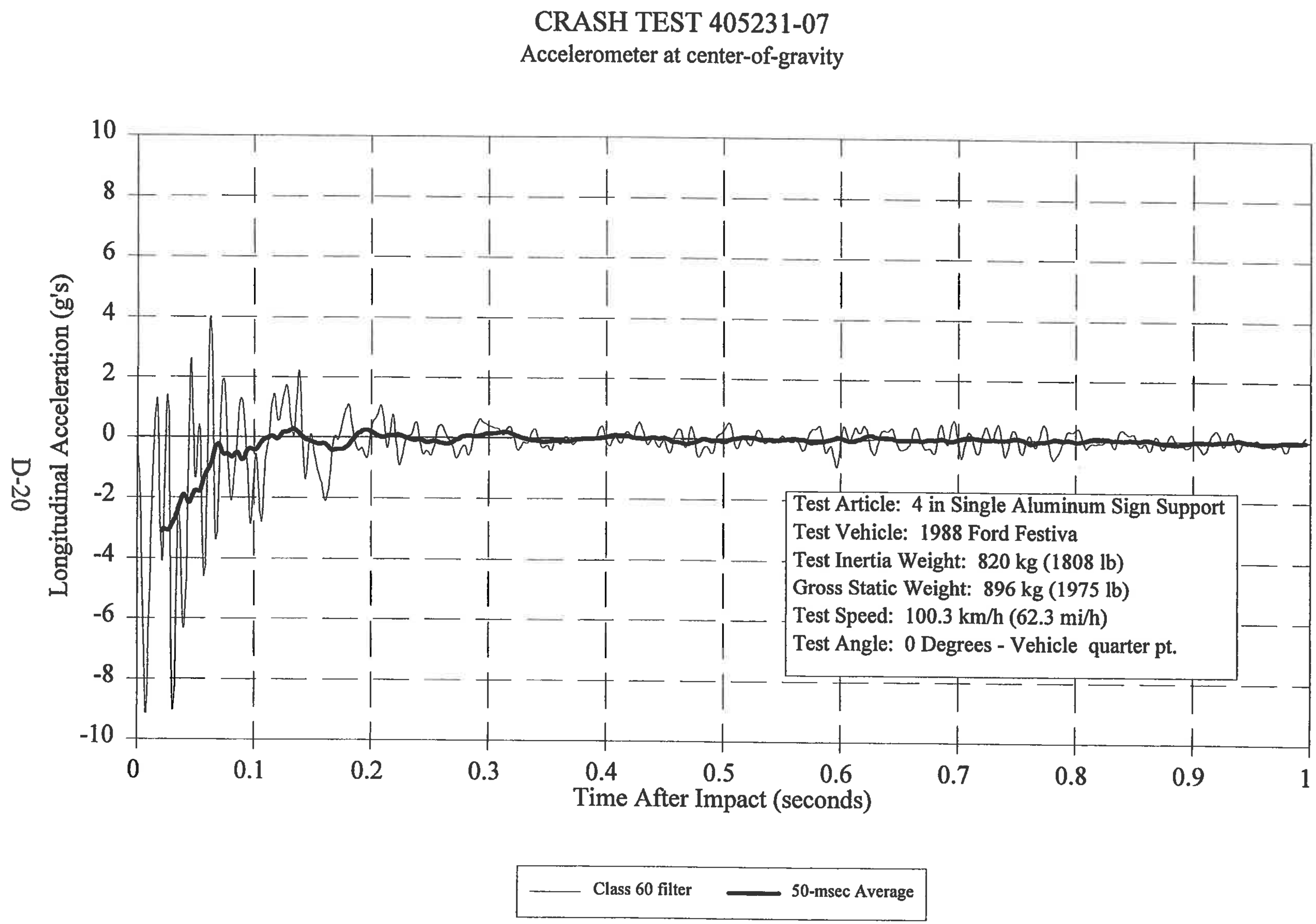


Figure D-19. Vehicle longitudinal accelerometer trace for test 405231-07.

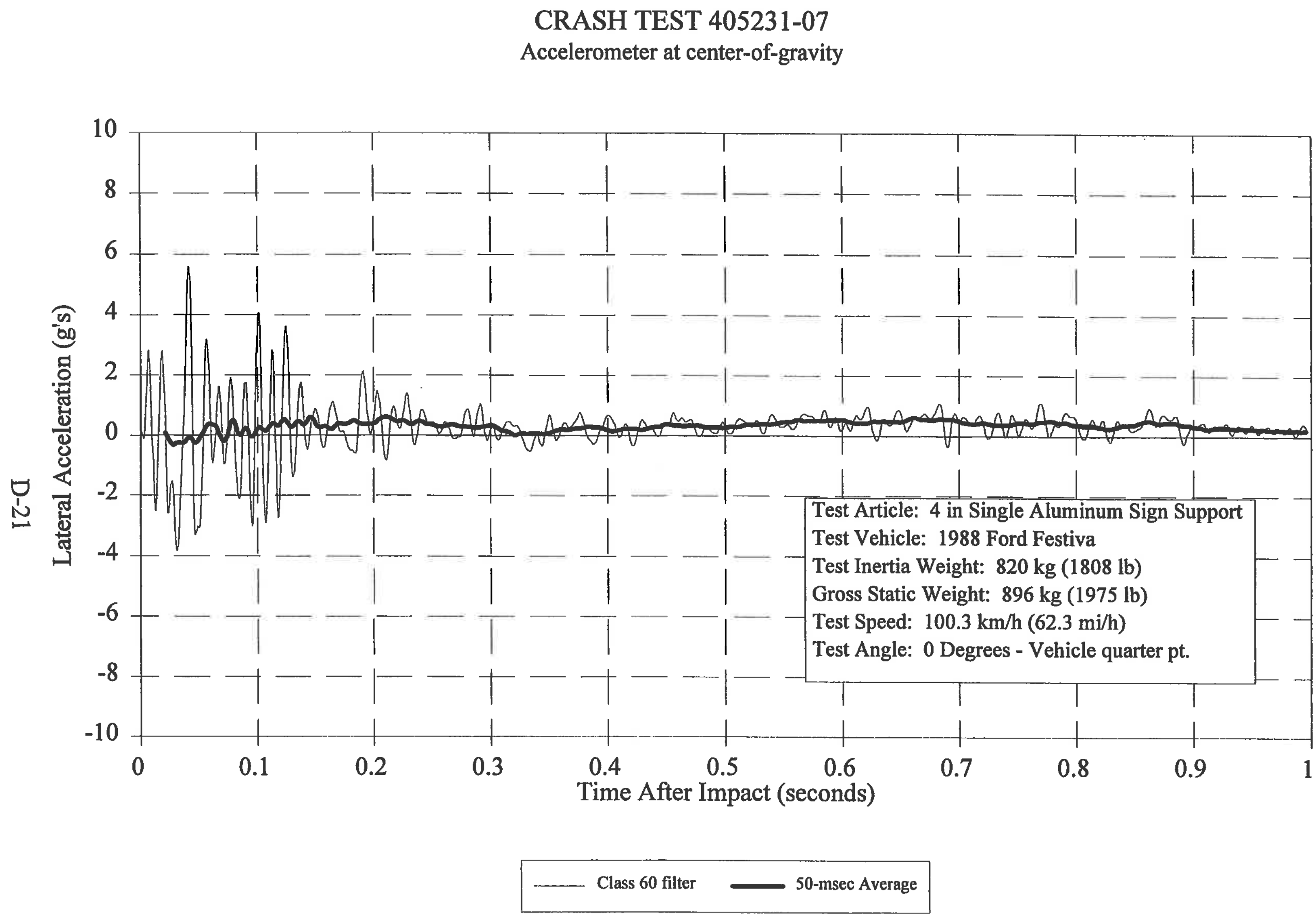


Figure D-20. Vehicle lateral accelerometer trace for test 405231-07.

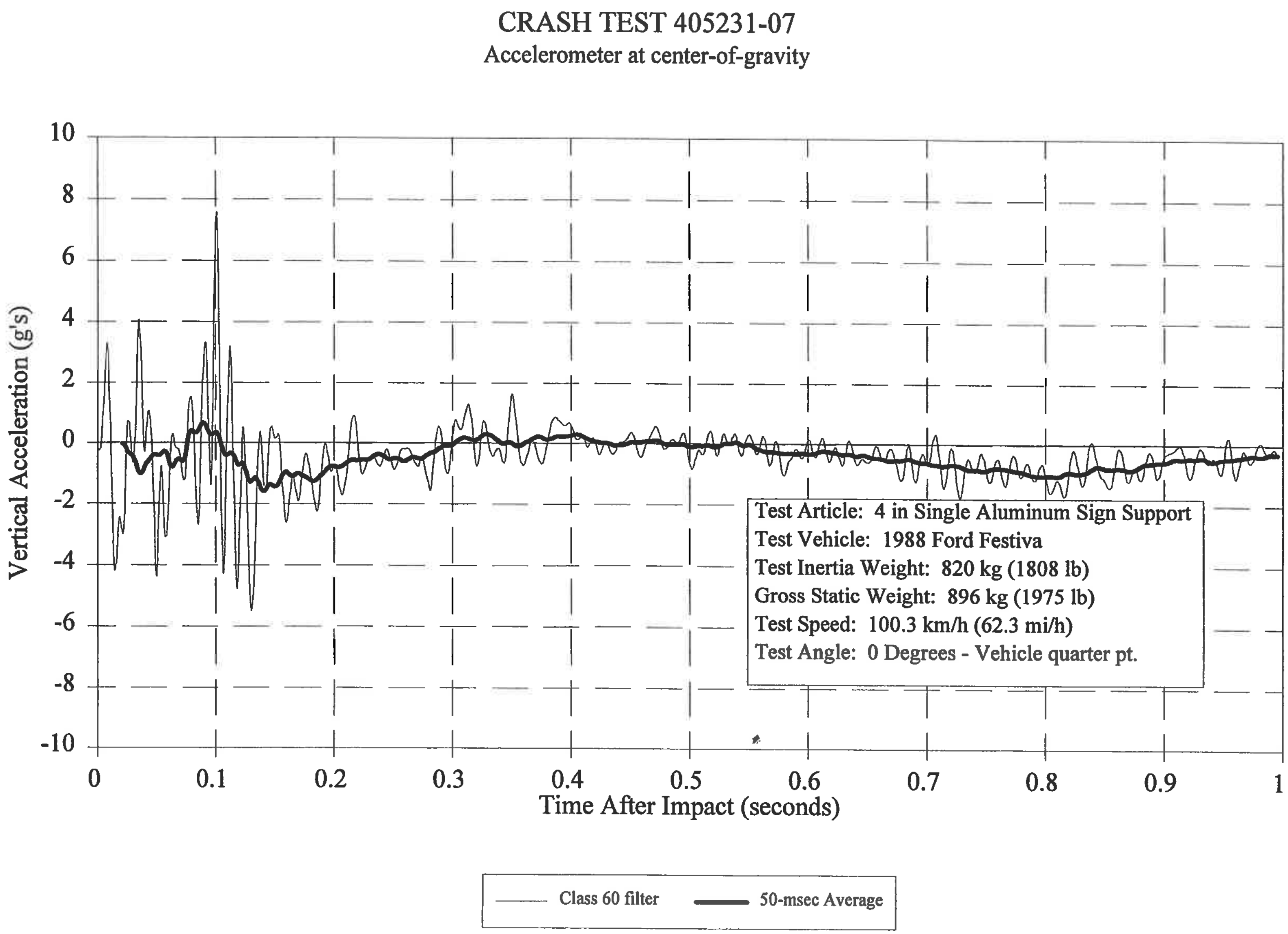


Figure D-21. Vehicle vertical accelerometer trace for test 405231-07.

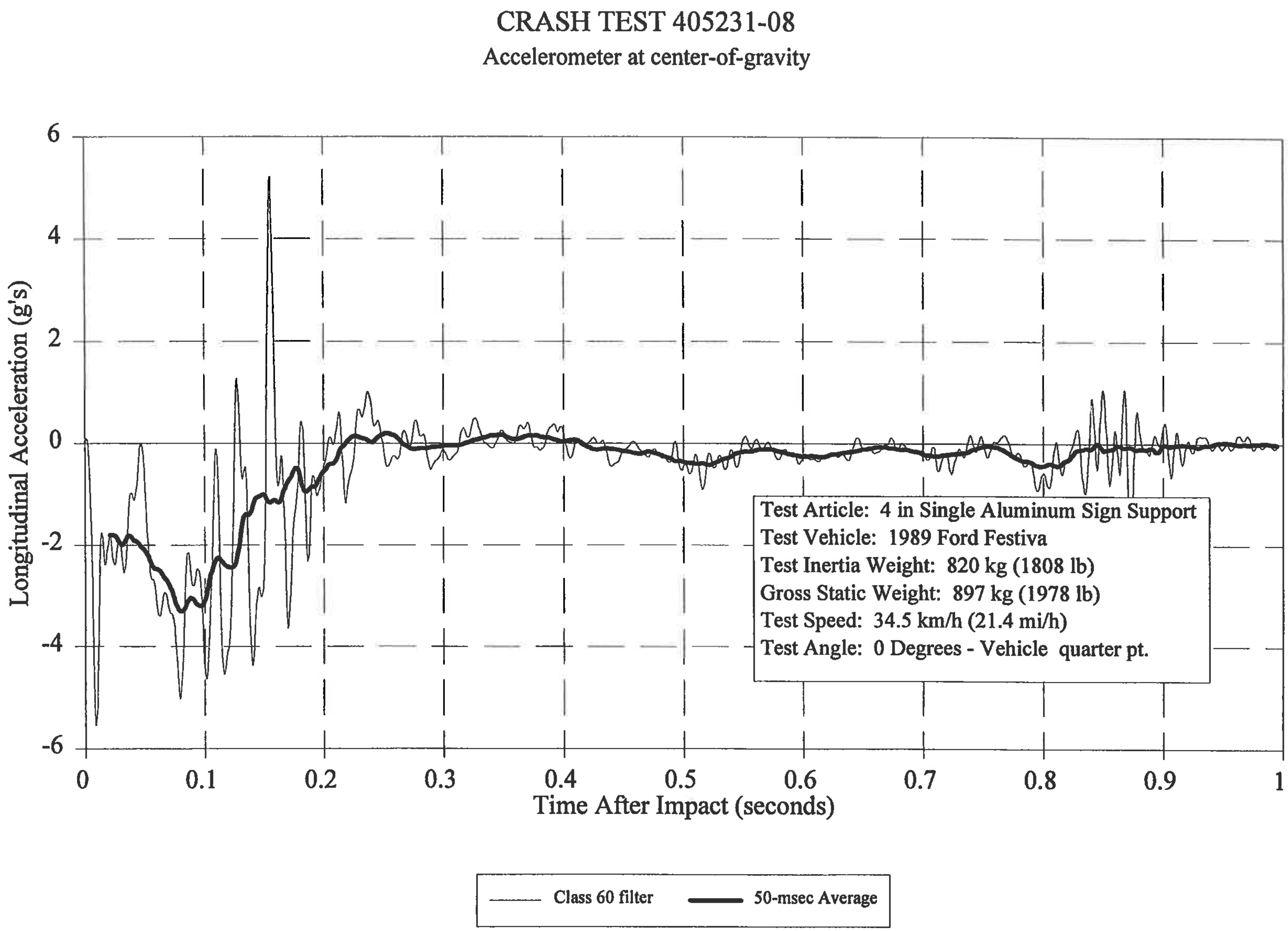


Figure D-22. Vehicle longitudinal accelerometer trace for test 405231-08.

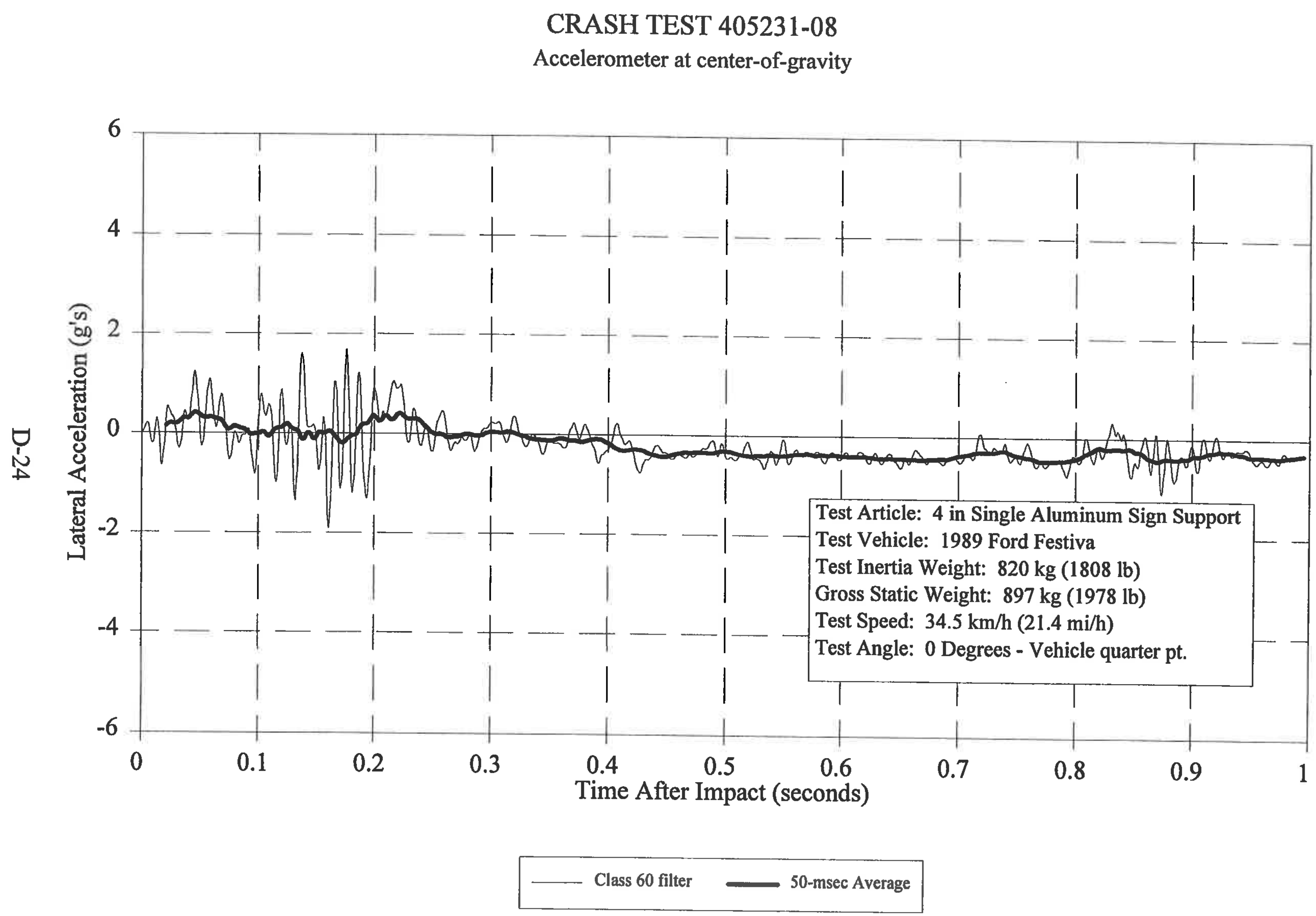


Figure D-23. Vehicle lateral accelerometer trace for test 405231-08.

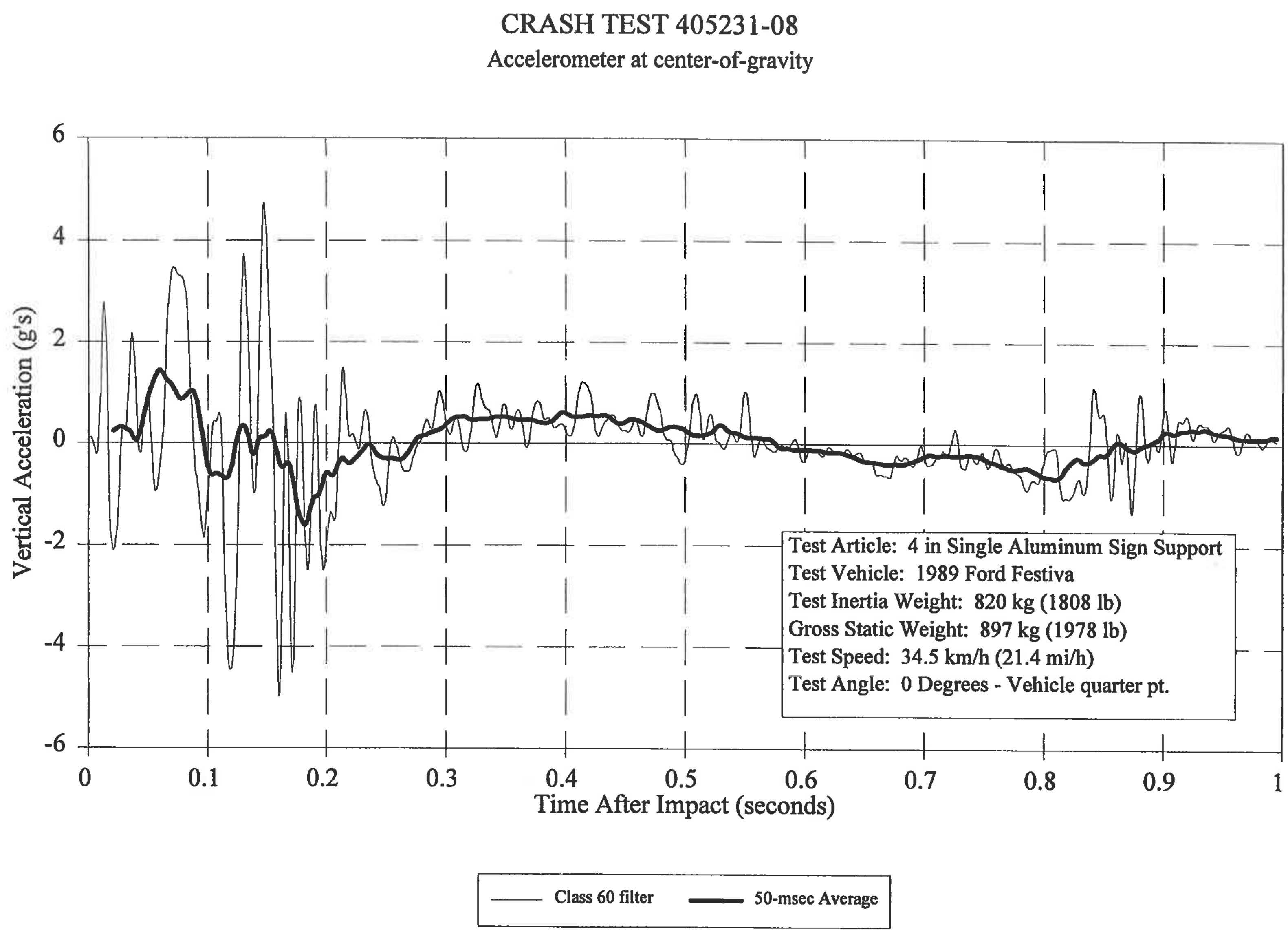


Figure D-24. Vehicle vertical accelerometer trace for test 405231-08.

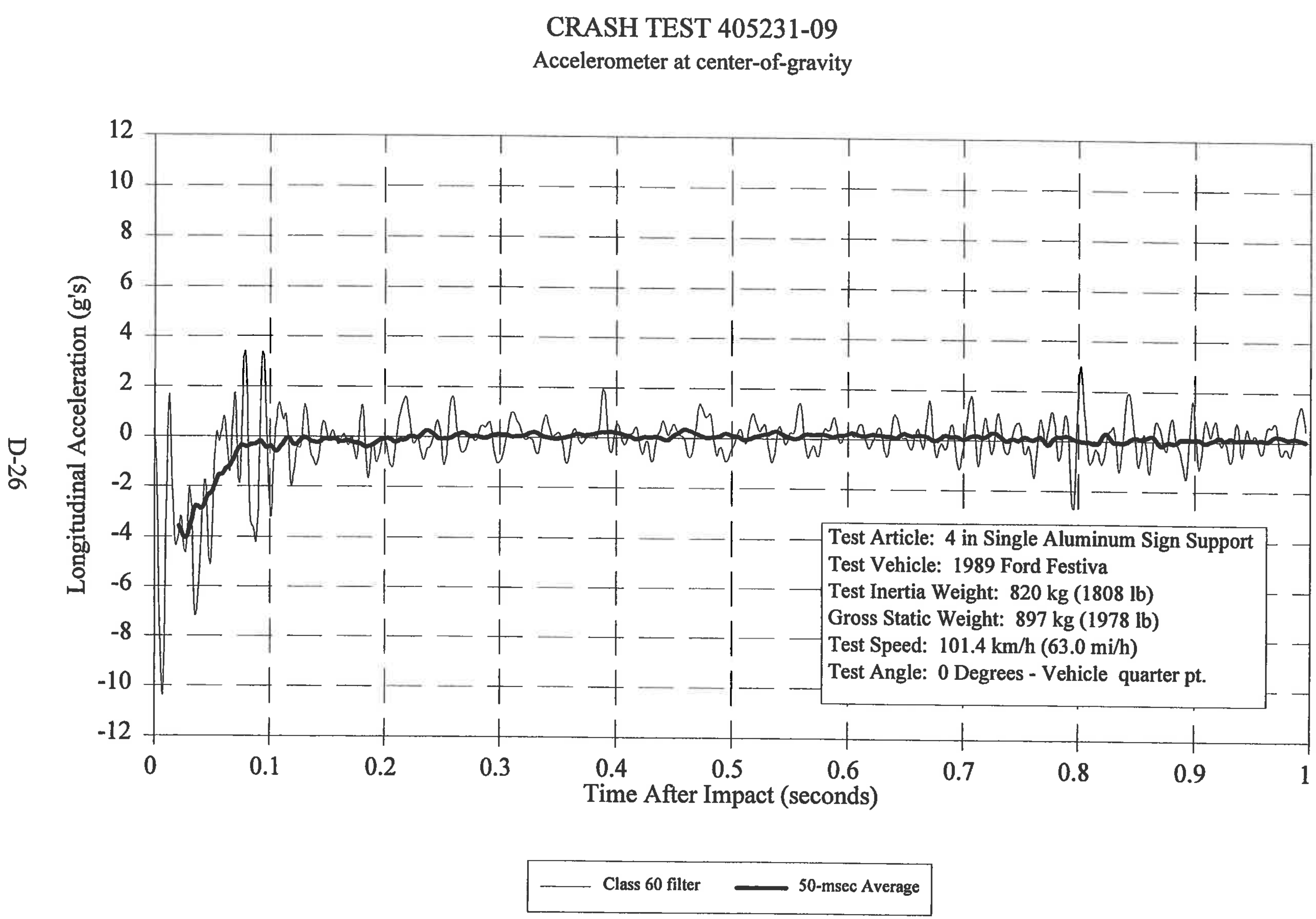


Figure D-25. Vehicle longitudinal accelerometer trace for test 405231-09.

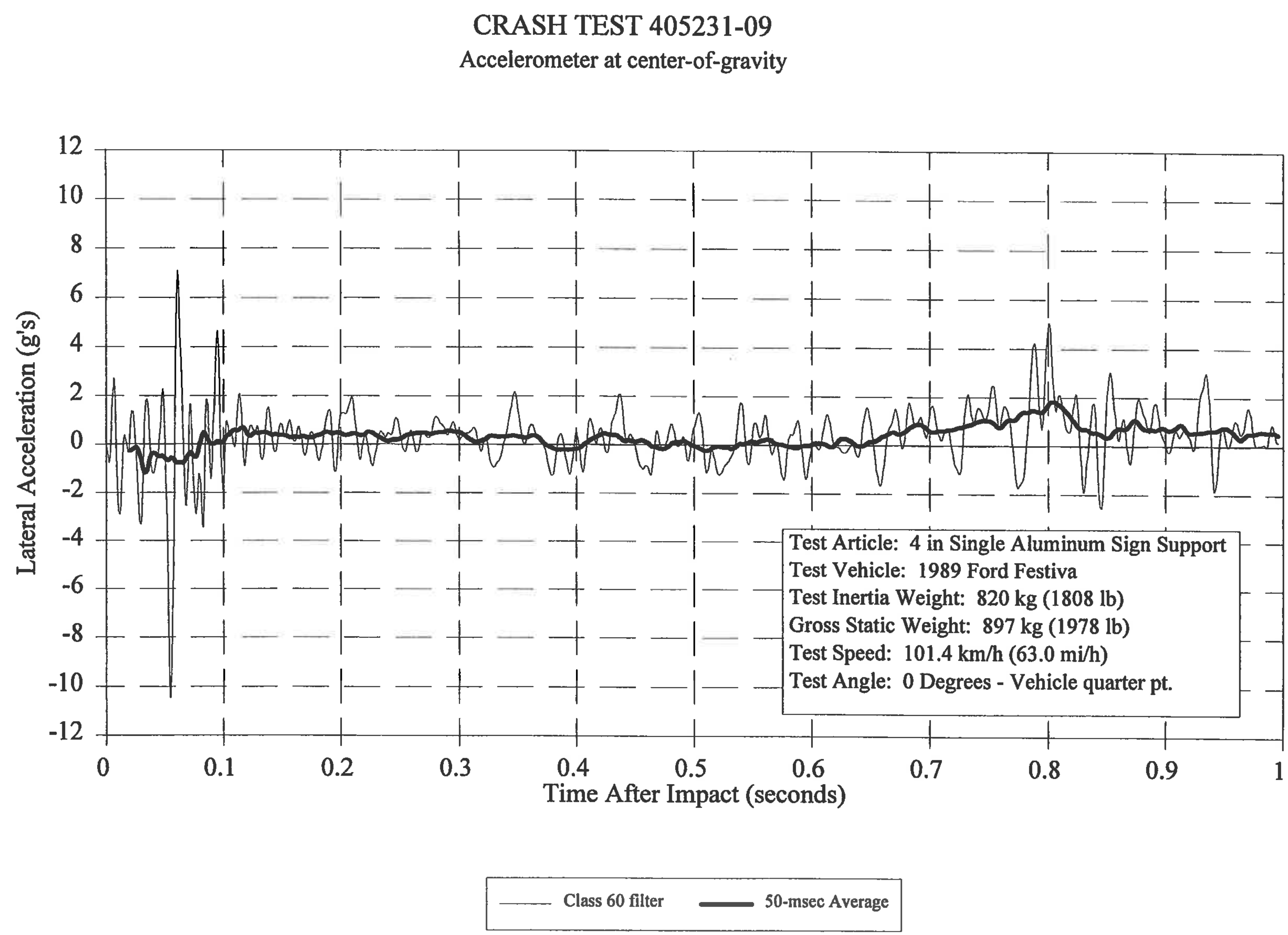


Figure D-26. Vehicle lateral accelerometer trace for test 405231-09.

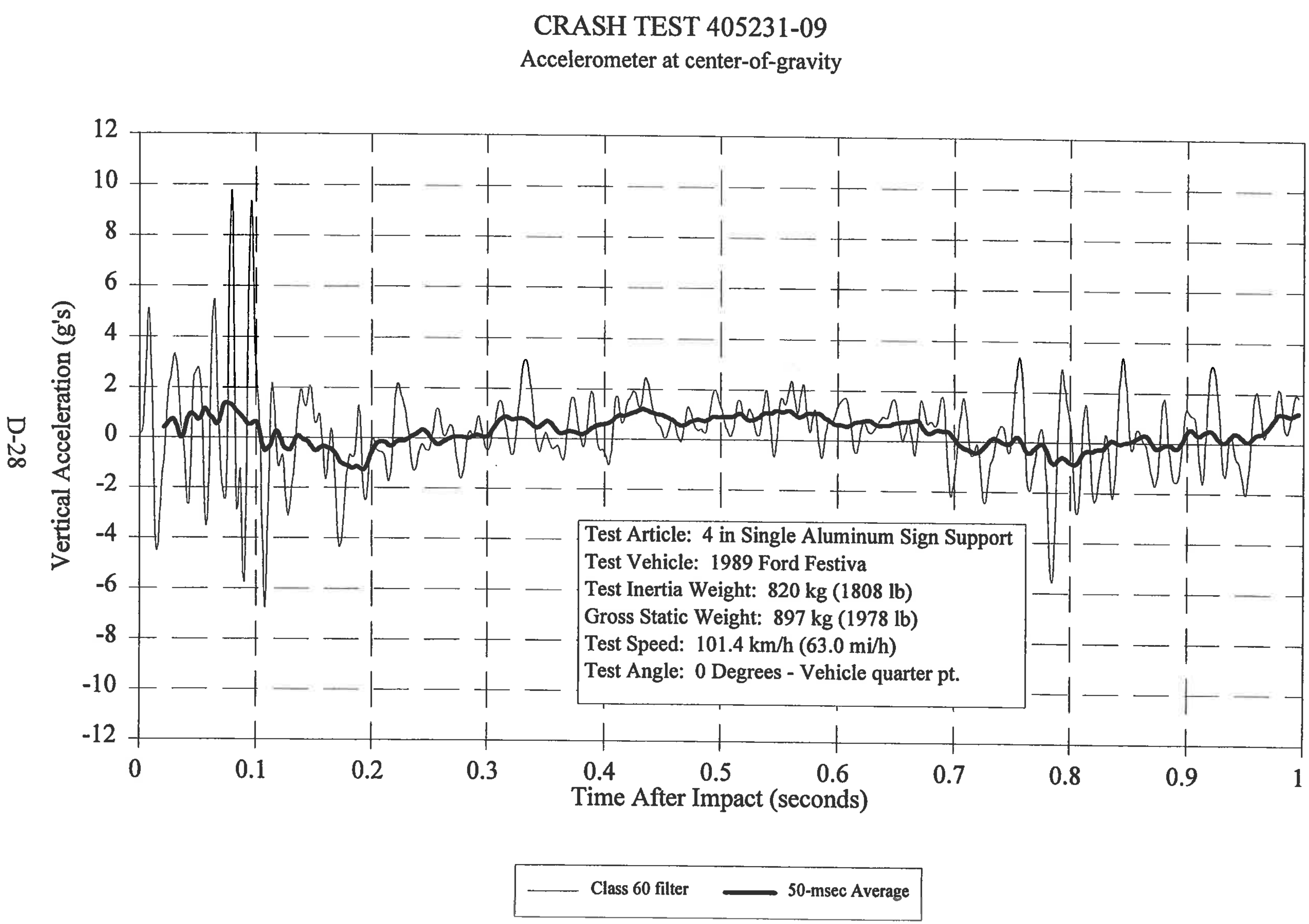


Figure D-27. Vehicle vertical accelerometer trace for test 405231-09.

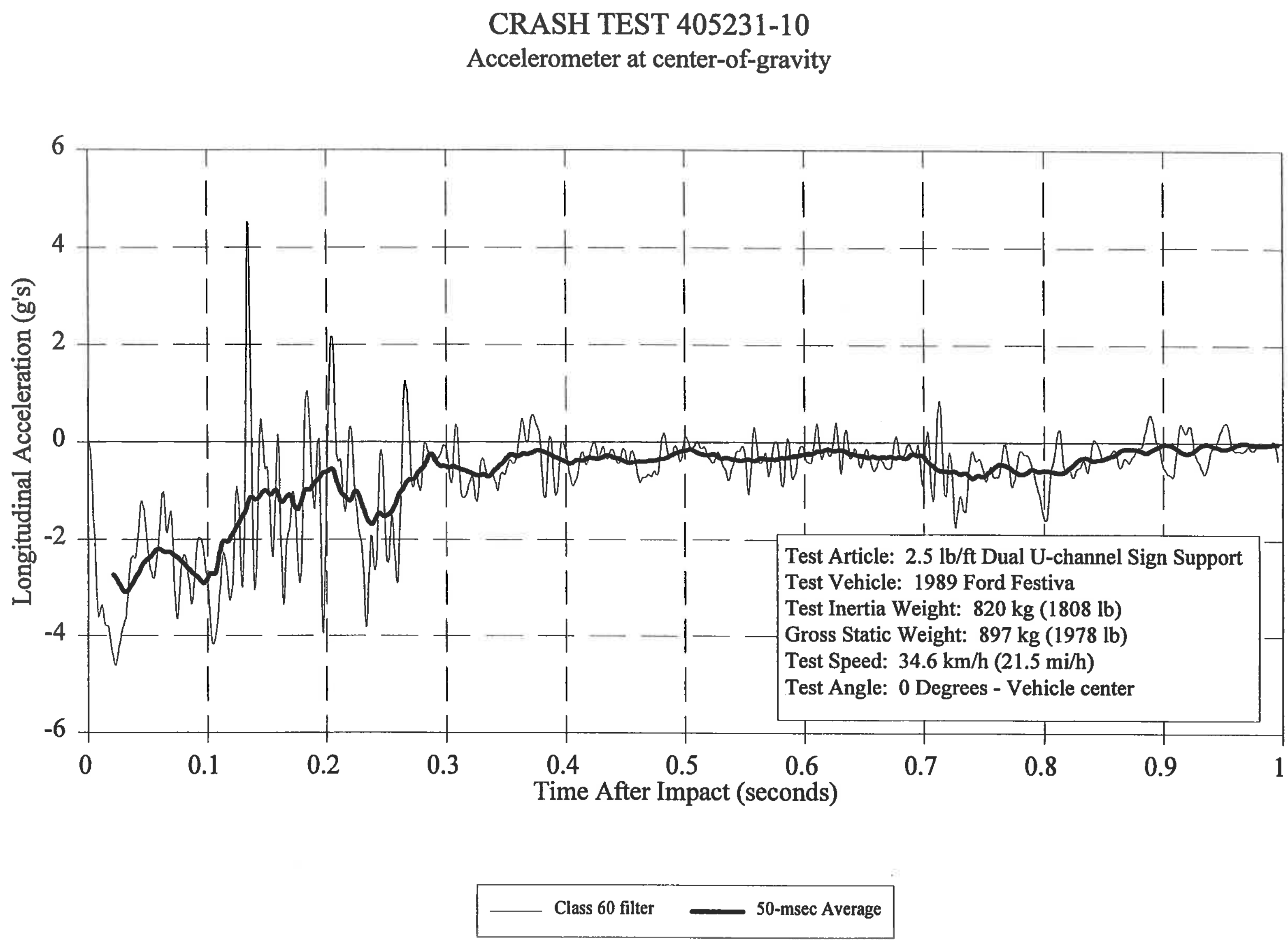


Figure D-28. Vehicle longitudinal accelerometer trace for test 405231-10.

CRASH TEST 405231-10

Accelerometer at center-of-gravity

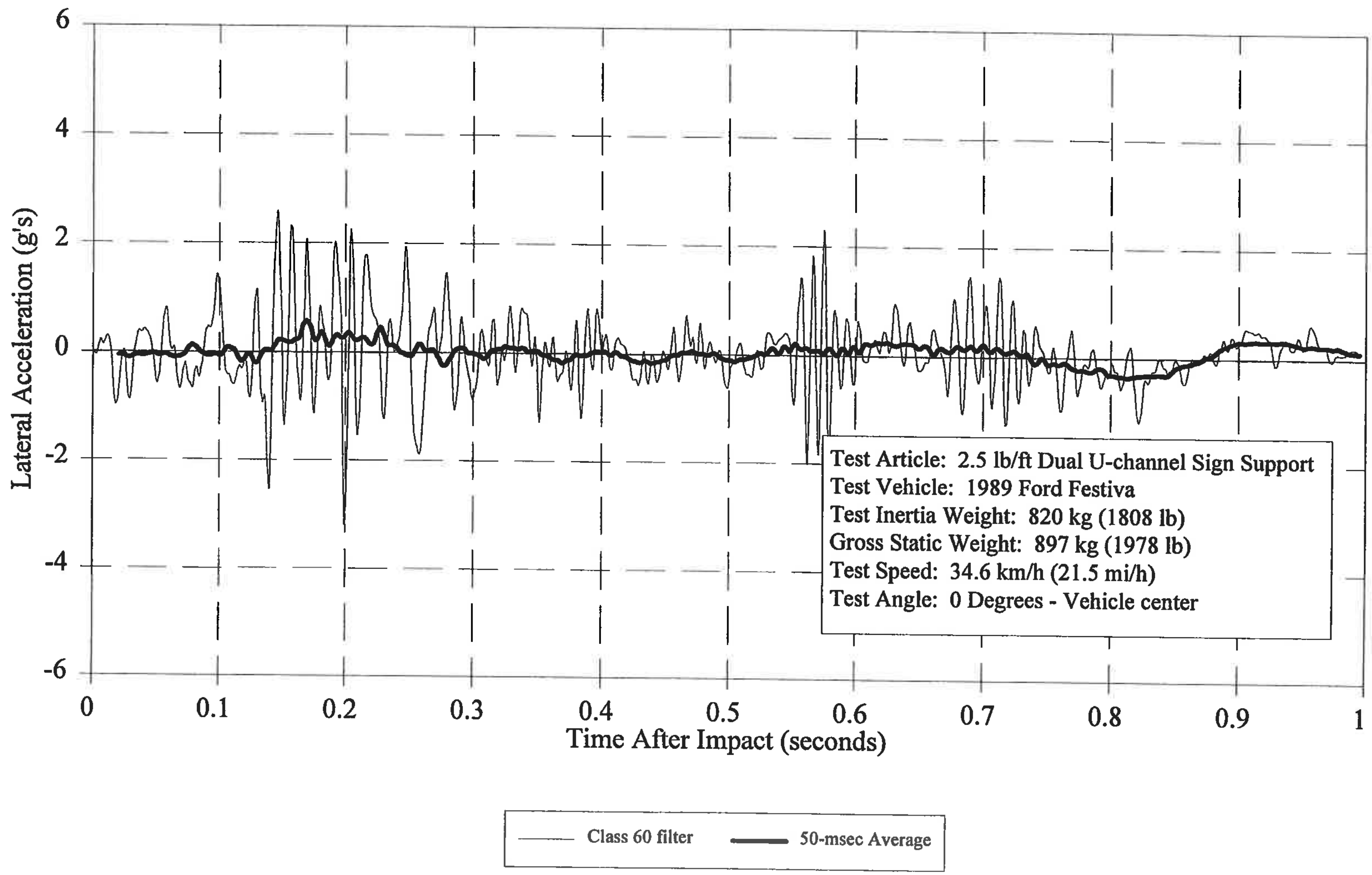


Figure D-29. Vehicle lateral accelerometer trace for test 405231-10.

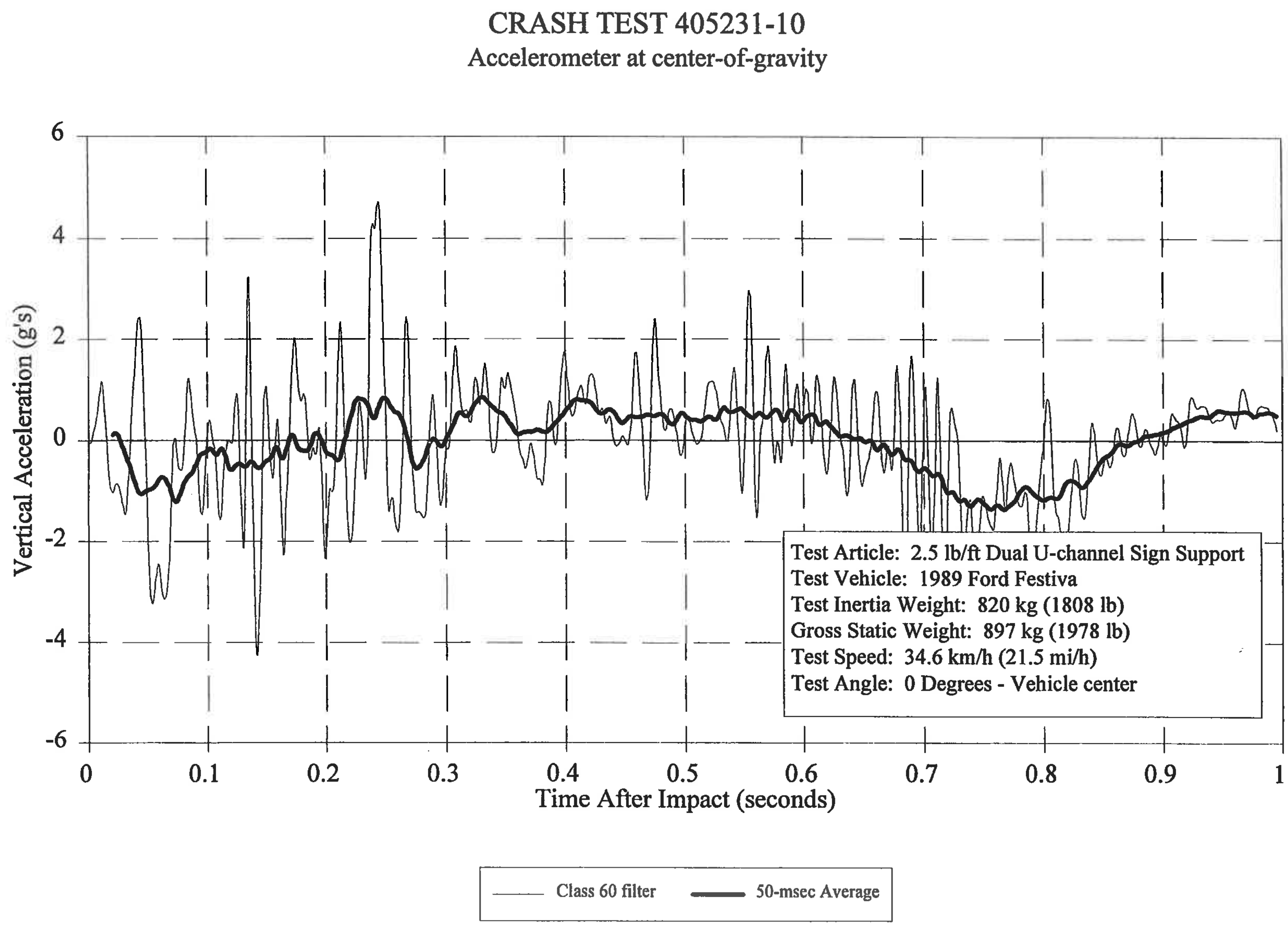


Figure D-30. Vehicle vertical accelerometer trace for test 405231-10.

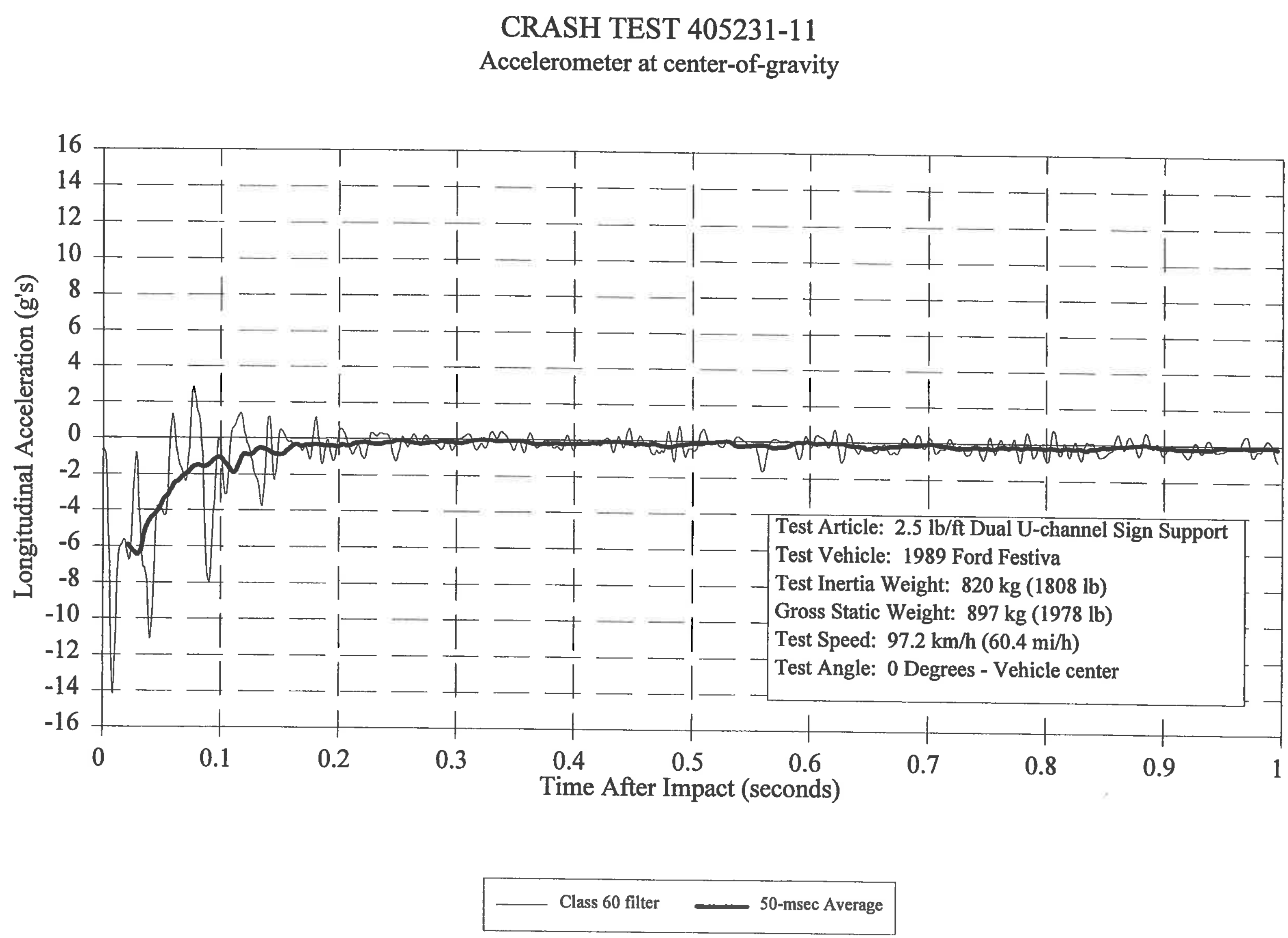


Figure D-31. Vehicle longitudinal accelerometer trace for test 405231-11.

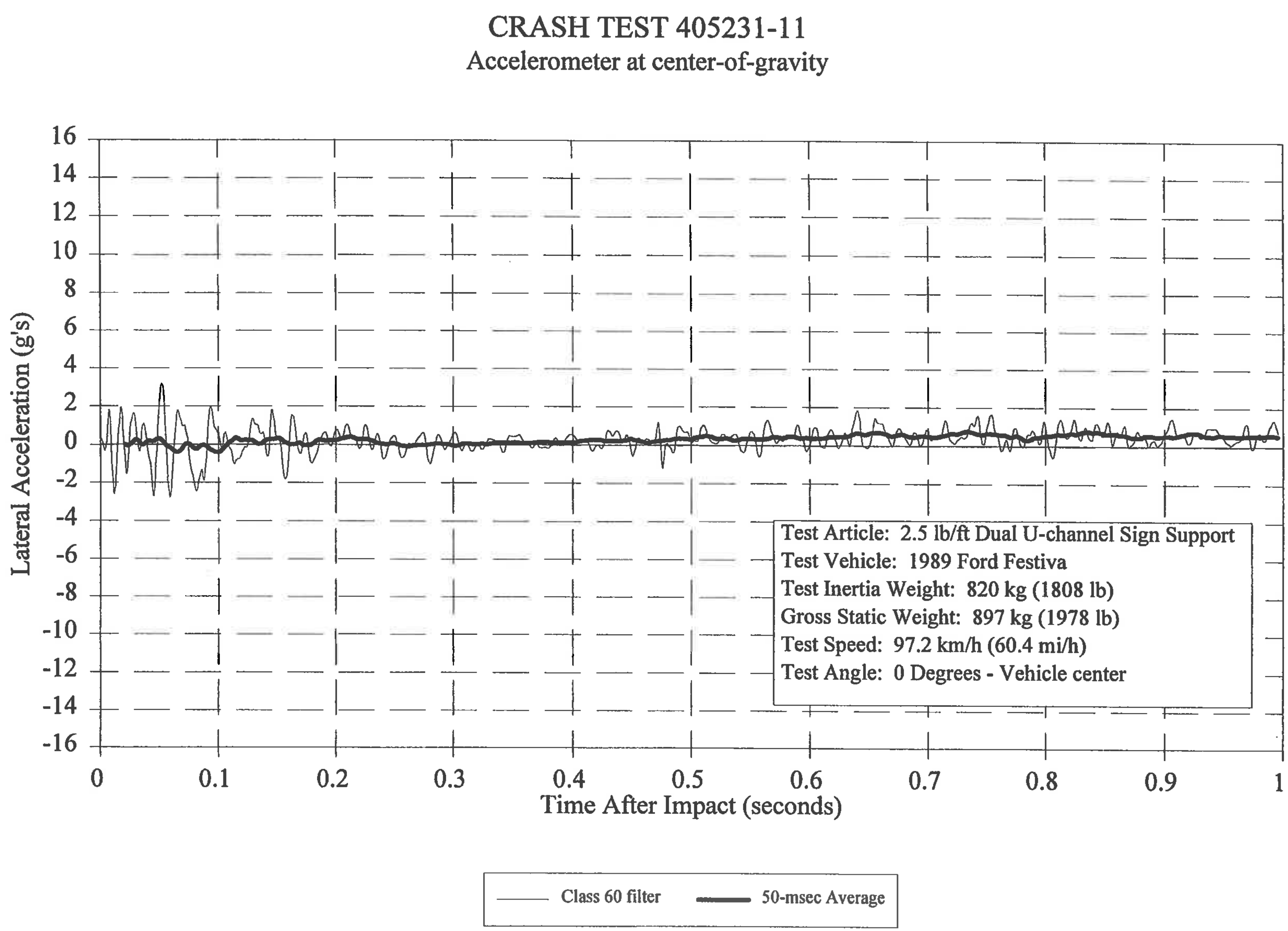


Figure D-32. Vehicle lateral accelerometer trace for test 405231-11.

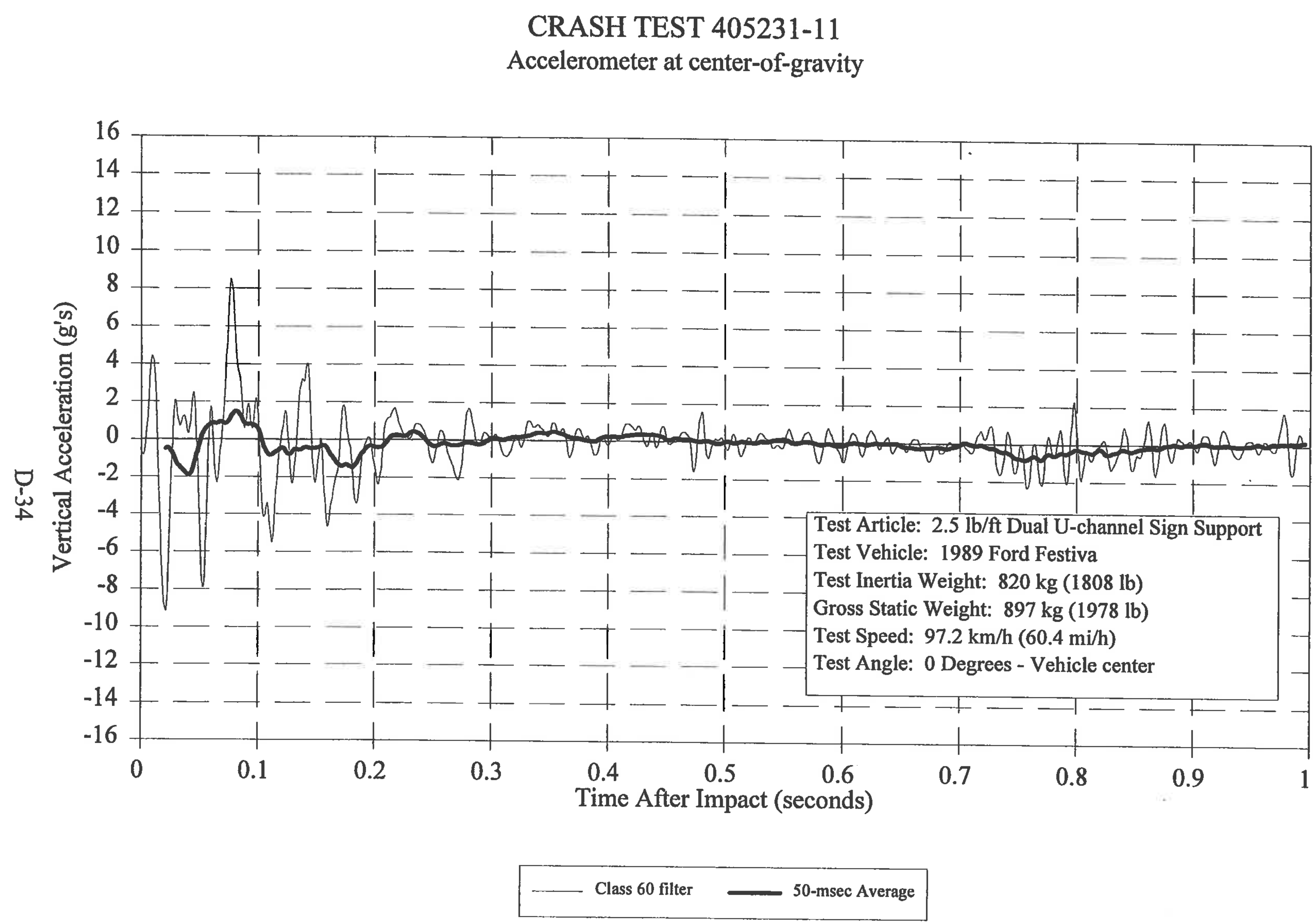


Figure D-33. Vehicle vertical accelerometer trace for test 405231-11.

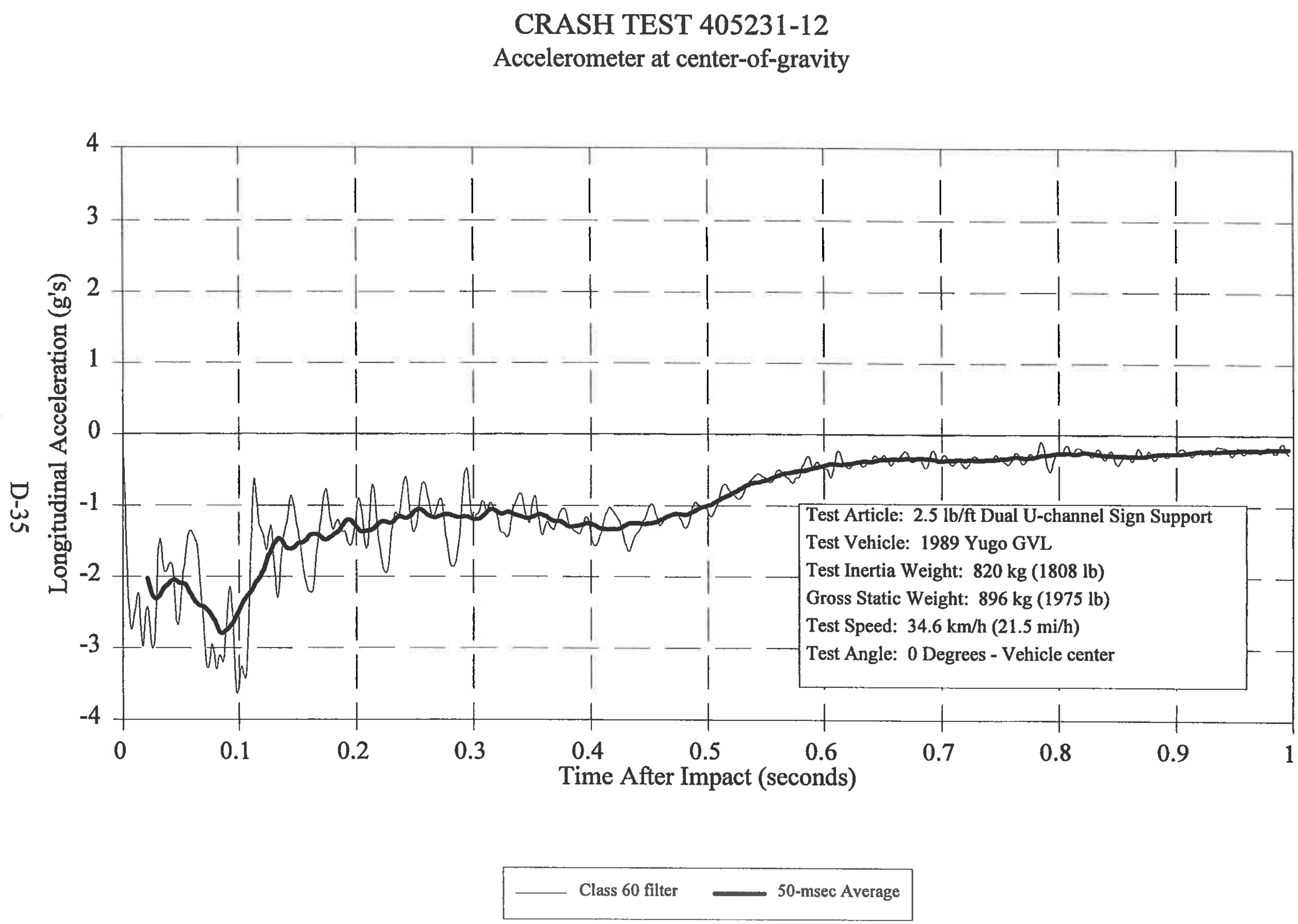


Figure D-34. Vehicle longitudinal accelerometer trace for test 405231-12.

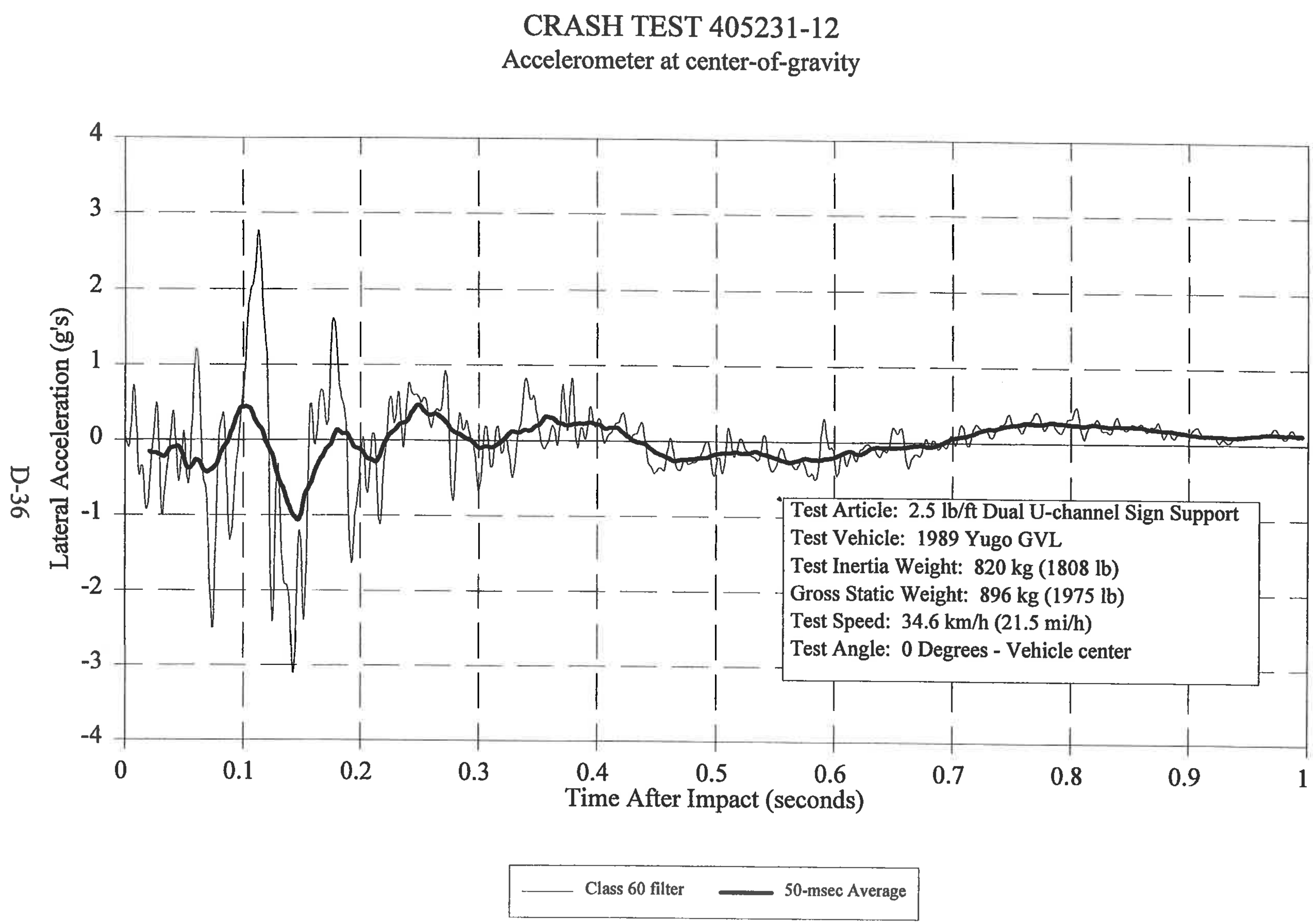


Figure D-35. Vehicle lateral accelerometer trace for test 405231-12.

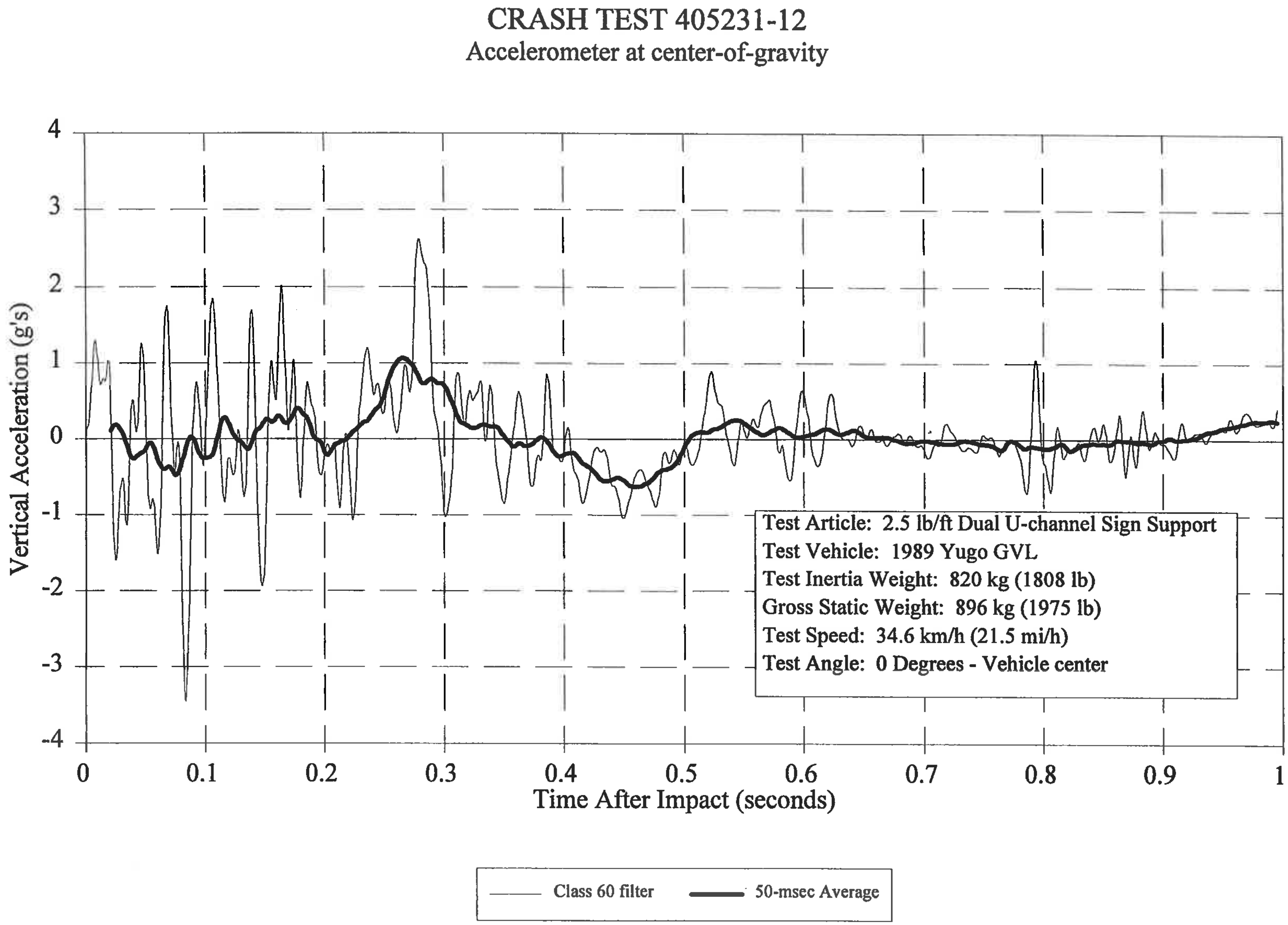


Figure D-36. Vehicle vertical accelerometer trace for test 405231-12.

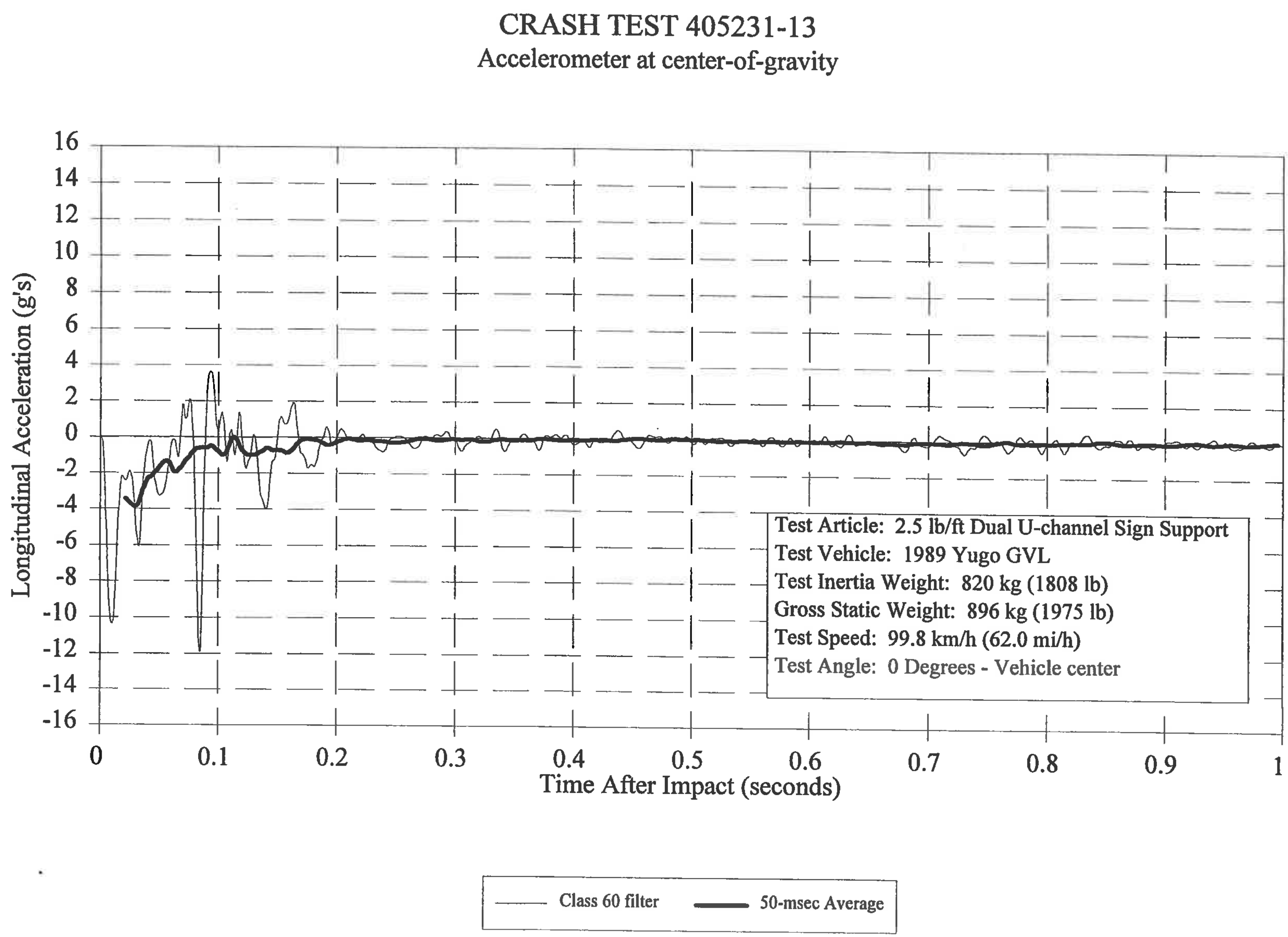


Figure D-37. Vehicle longitudinal accelerometer trace for test 405231-13.

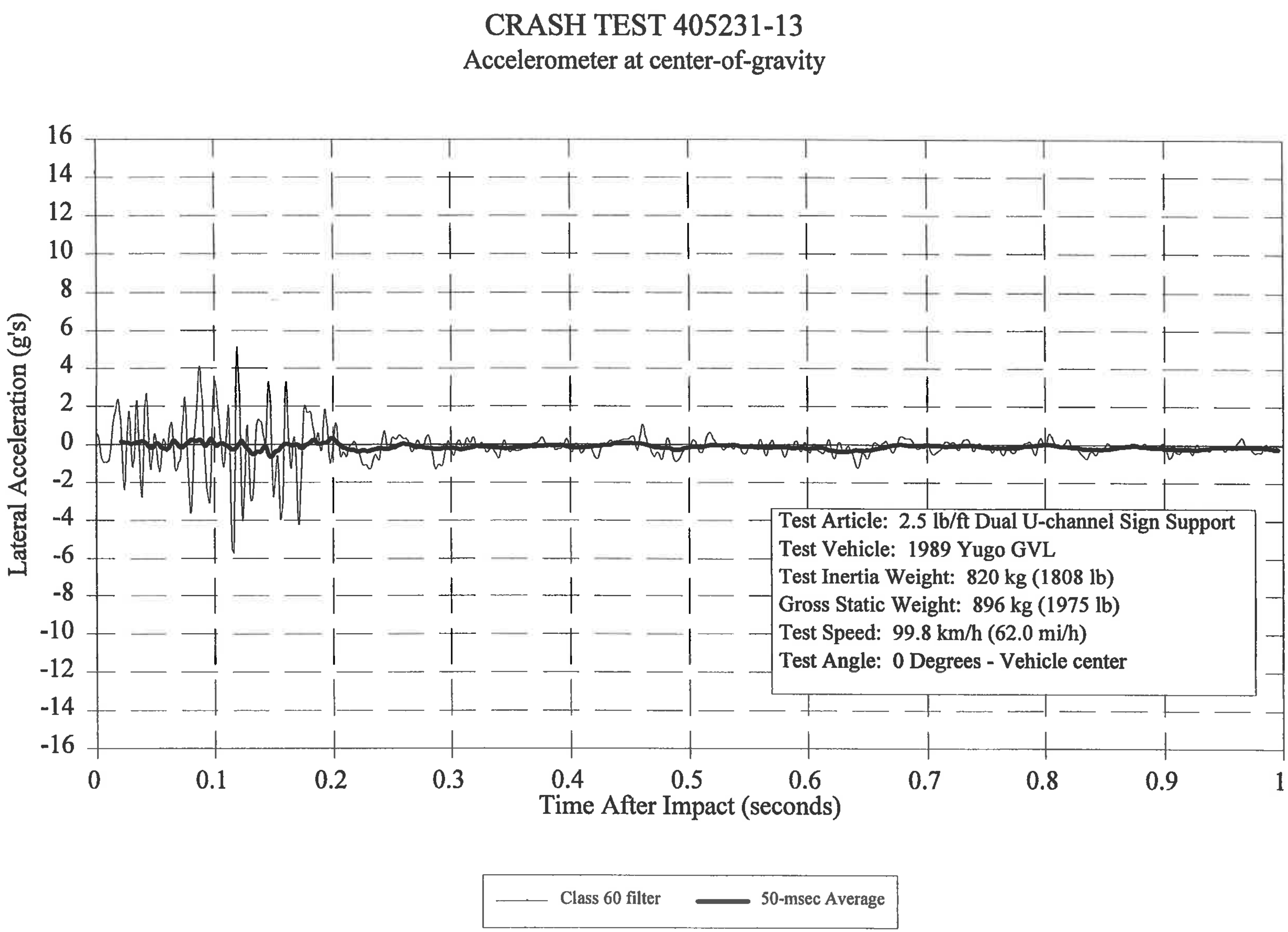


Figure D-38. Vehicle lateral accelerometer trace for test 405231-13.

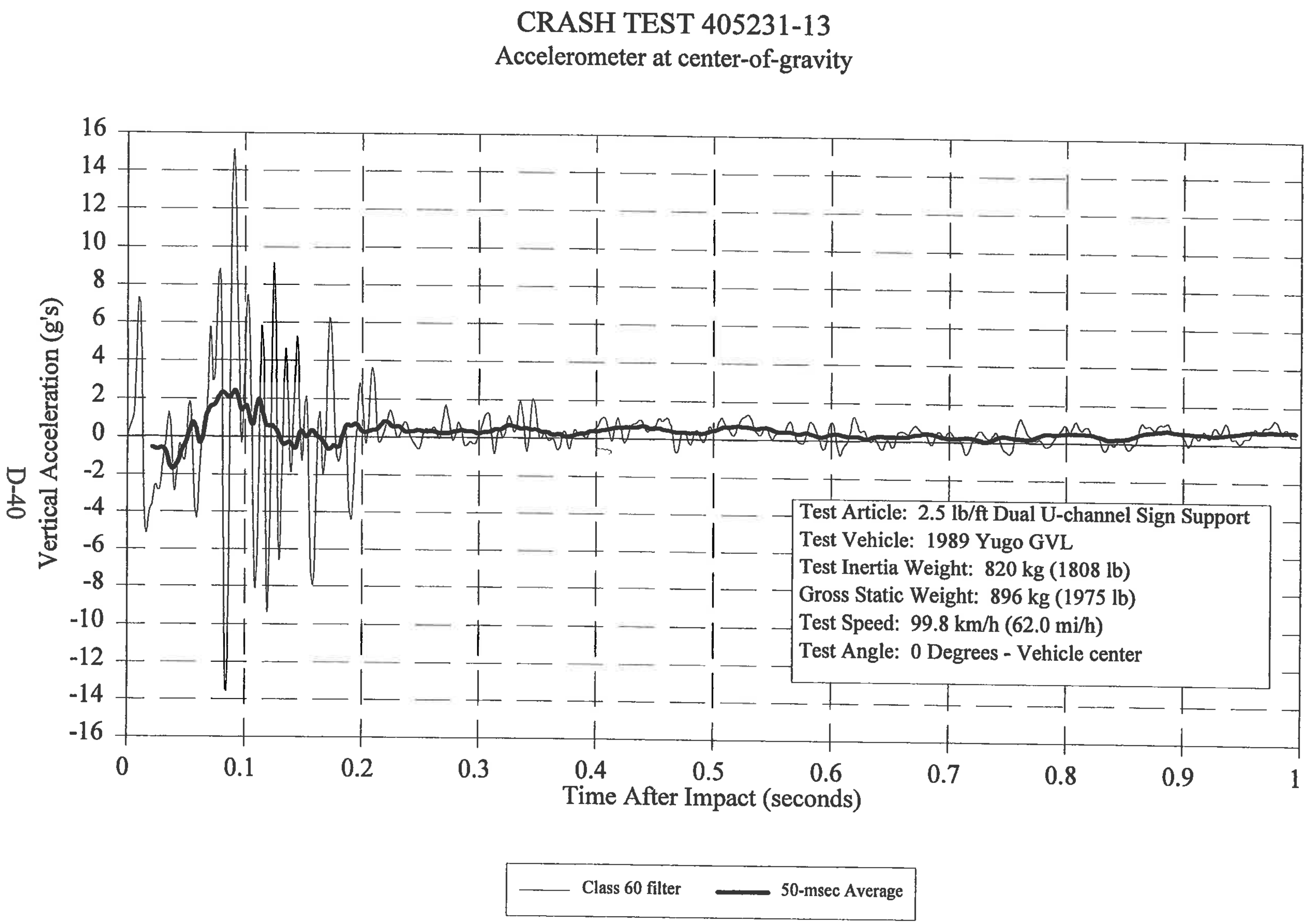


Figure D-39. Vehicle vertical accelerometer trace for test 405231-13.

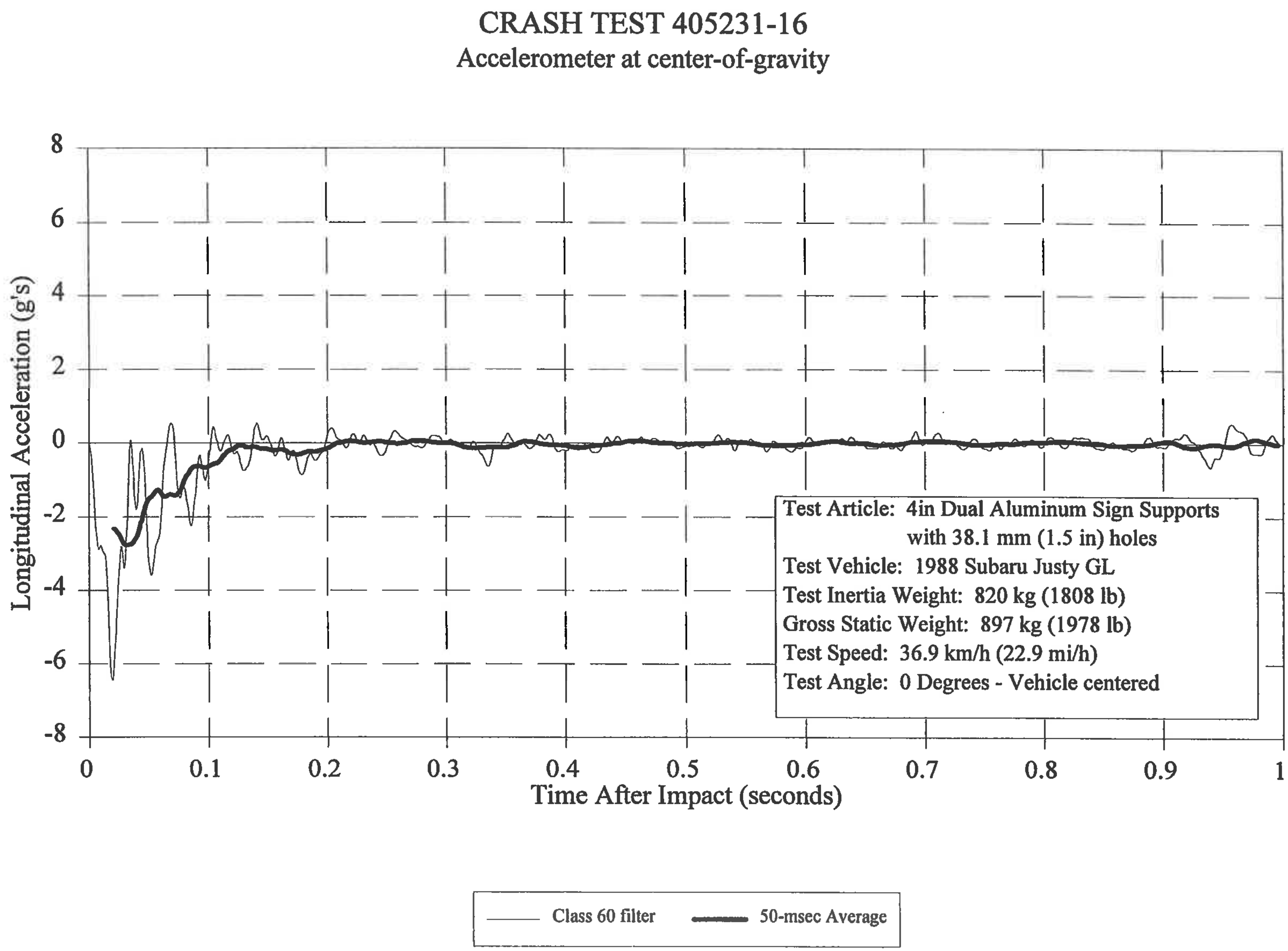


Figure D-40. Vehicle longitudinal accelerometer trace for test 405231-16.

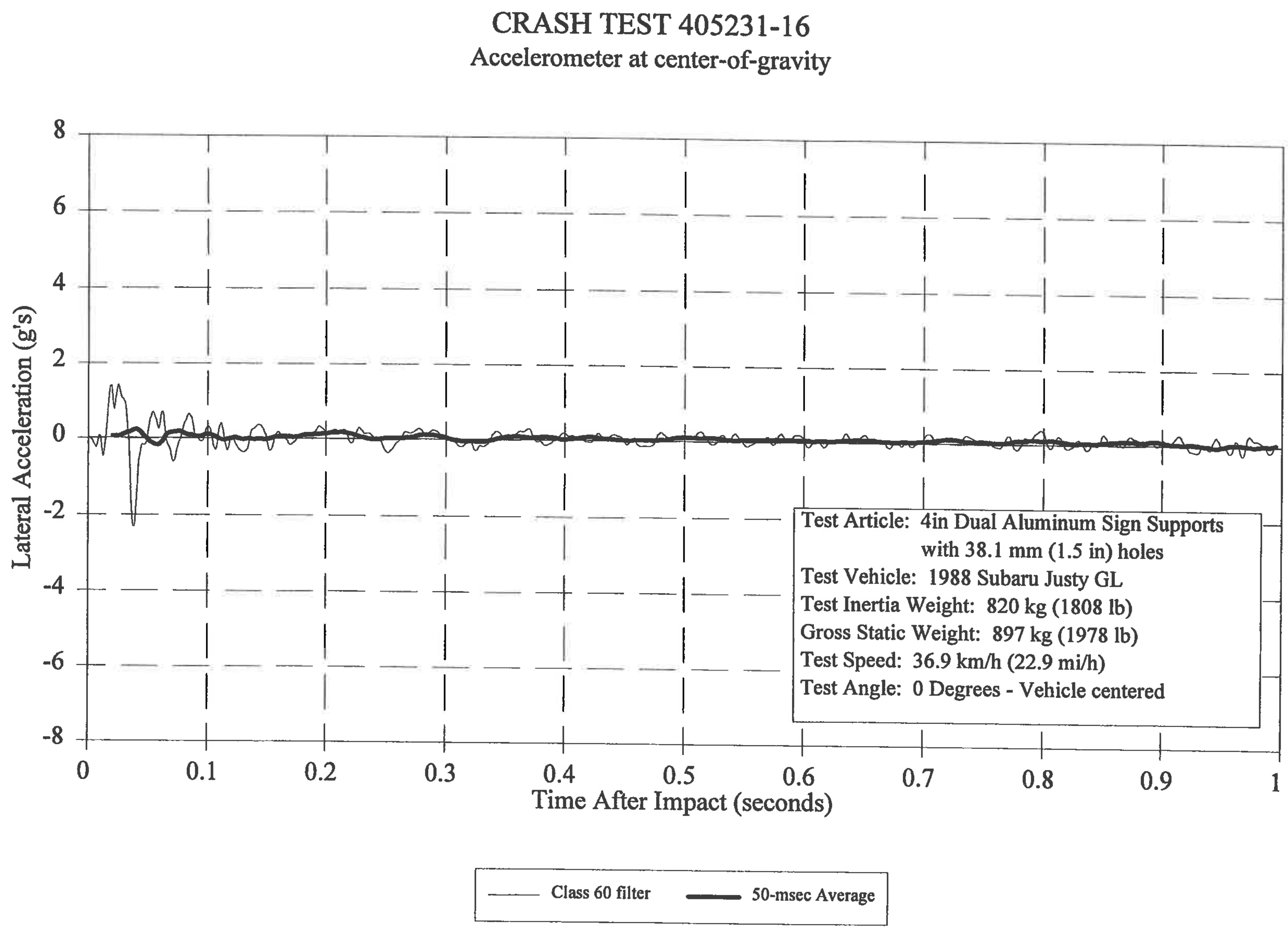


Figure D-41. Vehicle lateral accelerometer trace for test 405231-16.

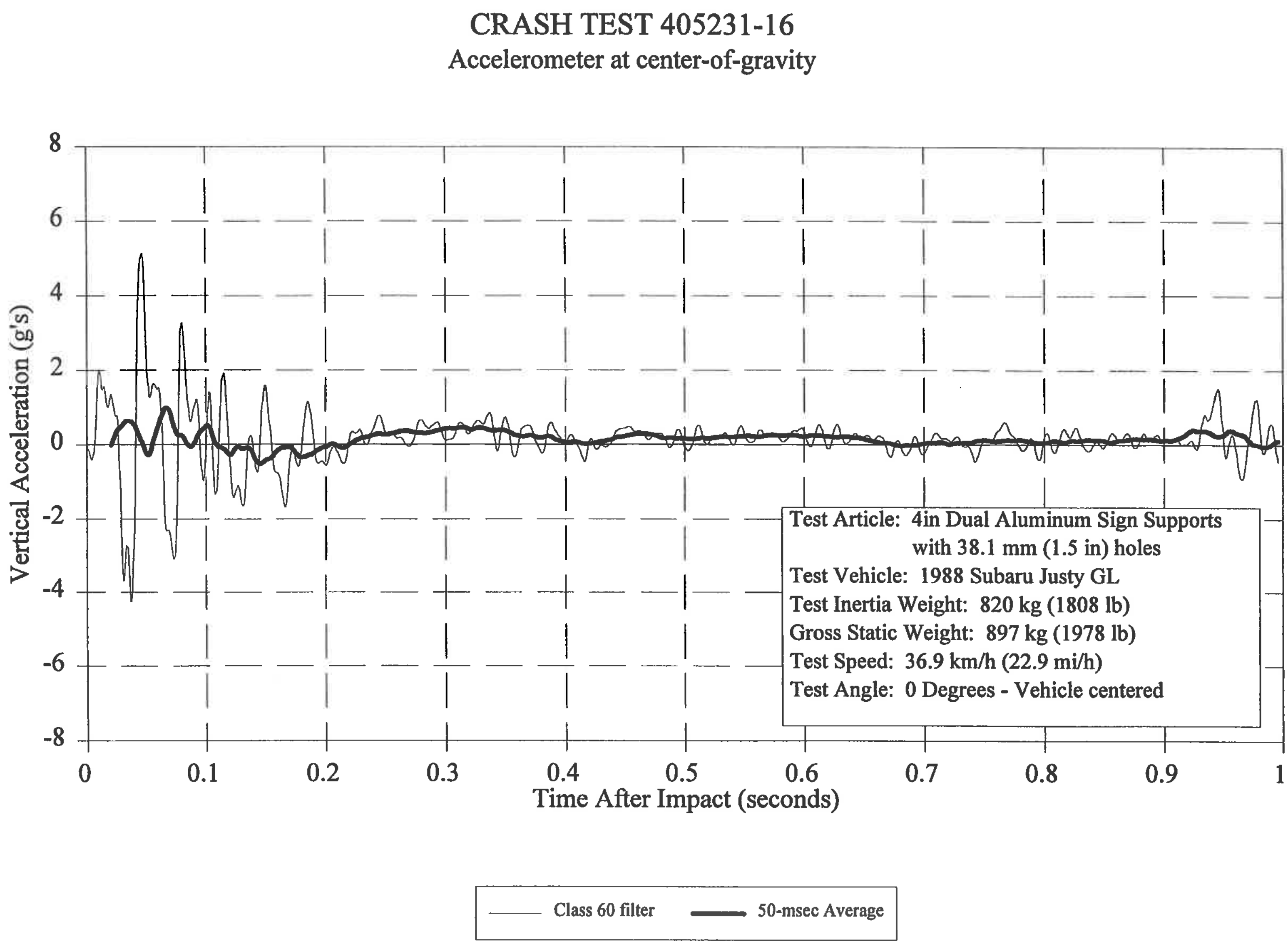


Figure D-42. Vehicle vertical accelerometer trace for test 405231-16.

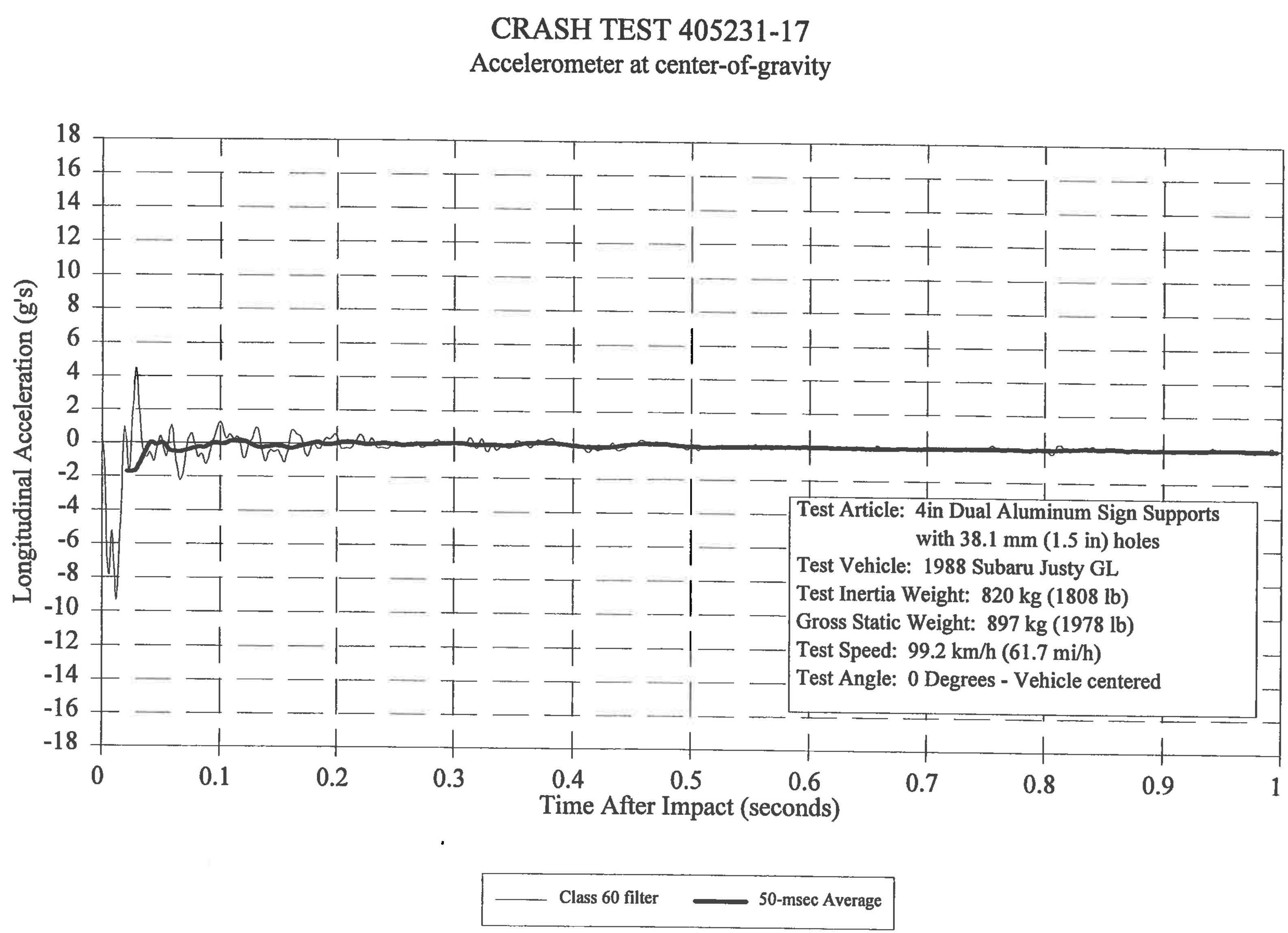


Figure D-43. Vehicle longitudinal accelerometer trace for test 405231-17.

CRASH TEST 405231-17
Accelerometer at center-of-gravity

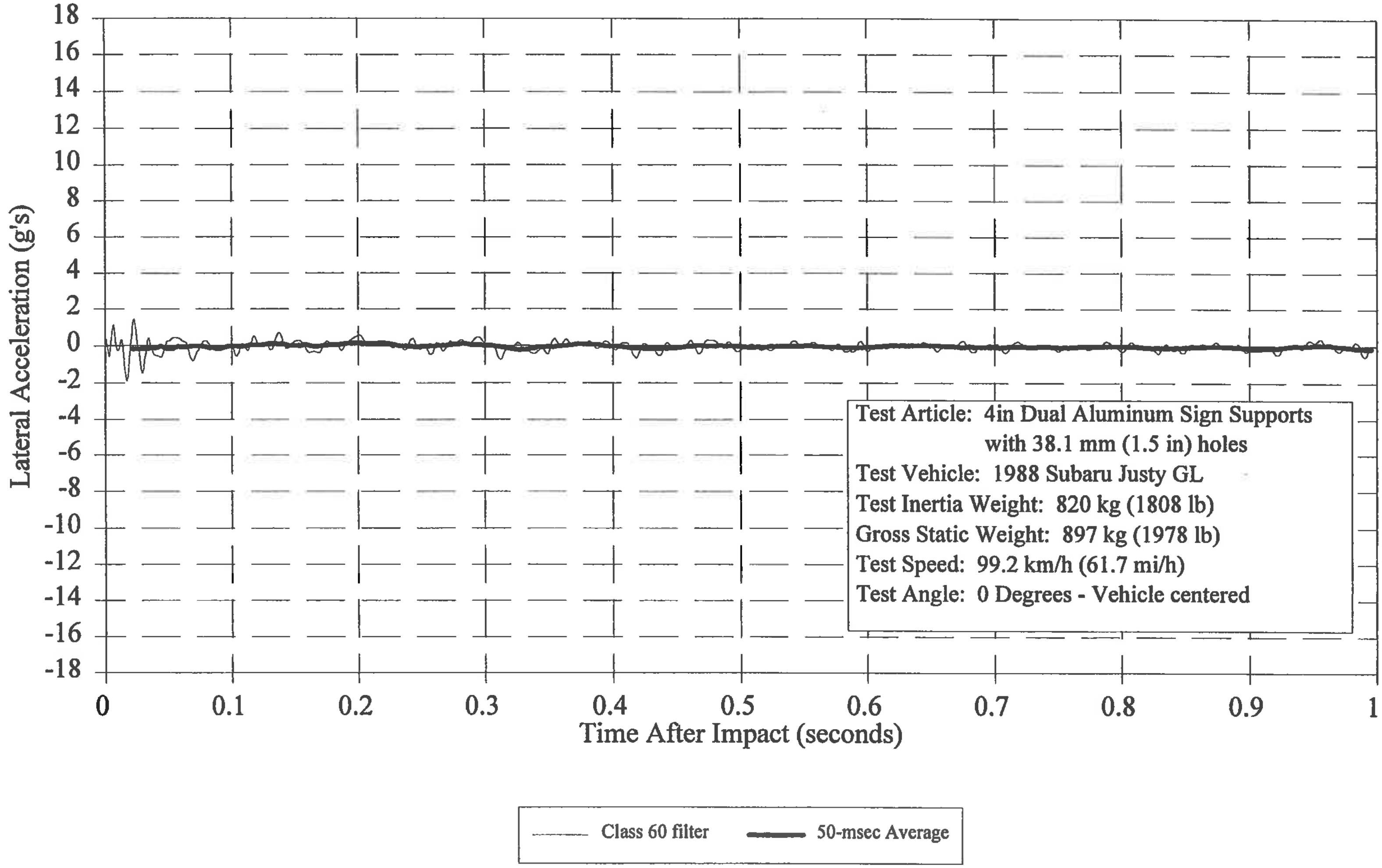


Figure D-44. Vehicle lateral accelerometer trace for test 405231-17.

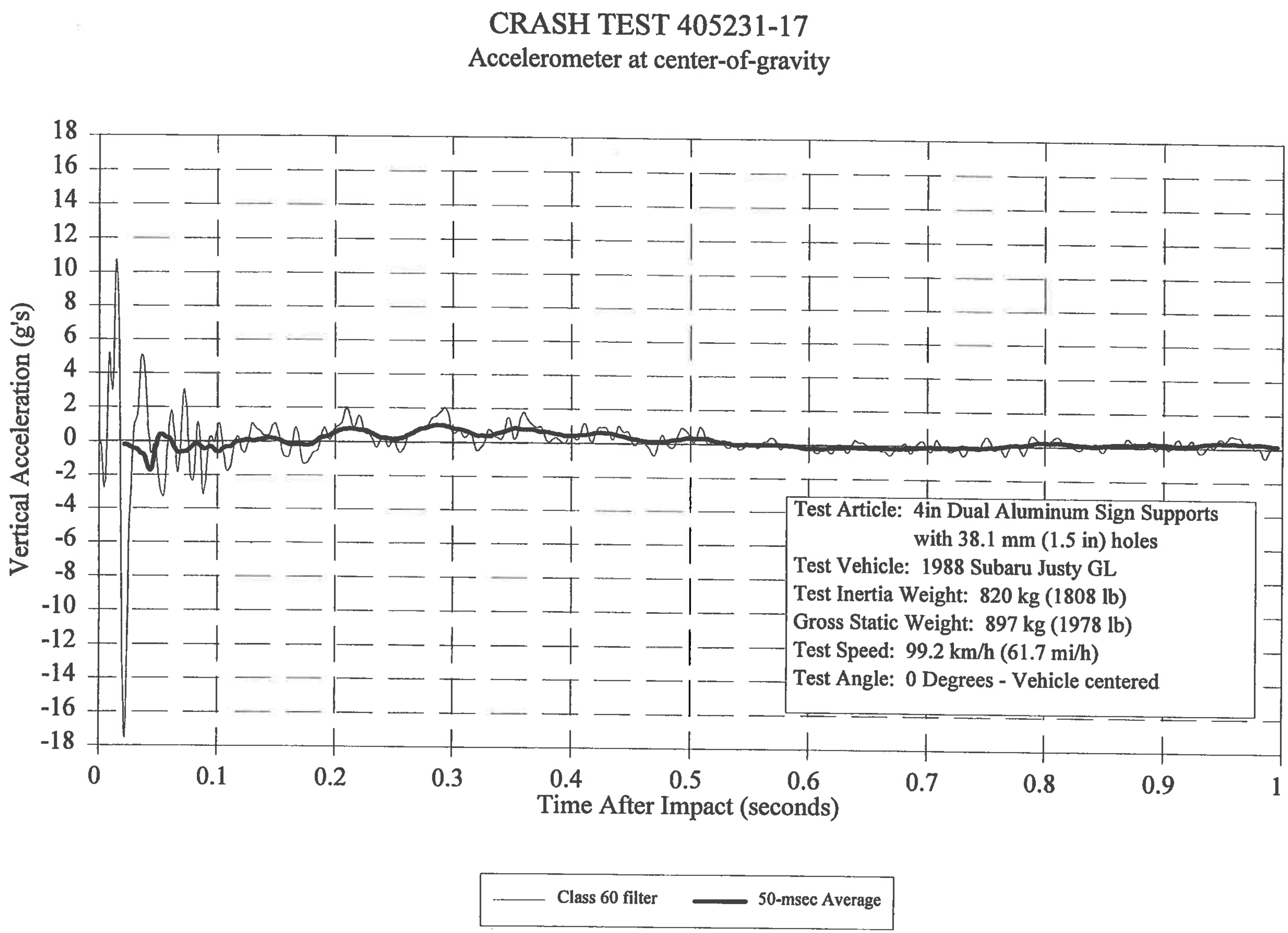


Figure D-45. Vehicle vertical accelerometer trace for test 405231-17.

CRASH TEST 405231-18

Accelerometer at center-of-gravity

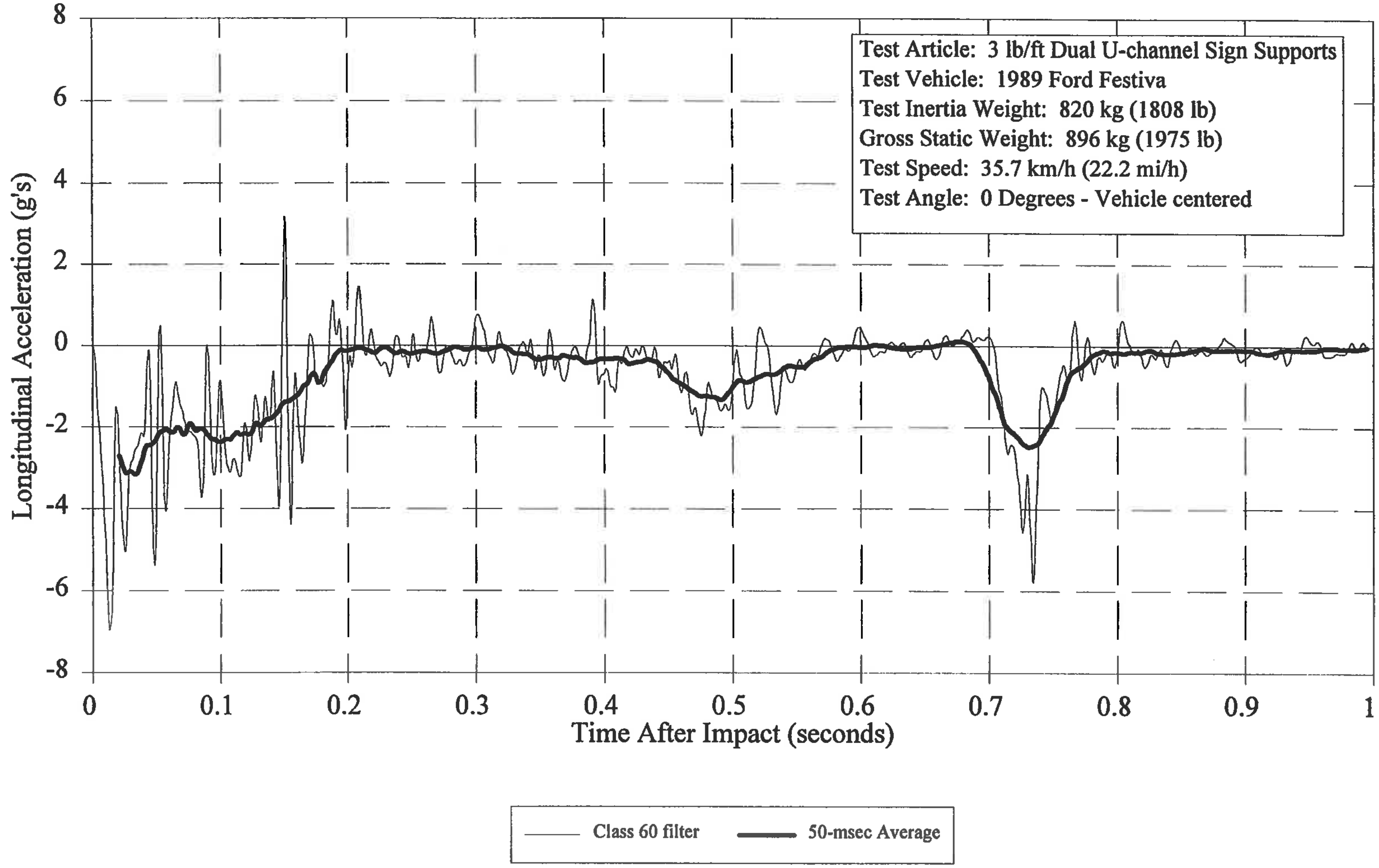


Figure D-46. Vehicle longitudinal accelerometer trace for test 405231-18.

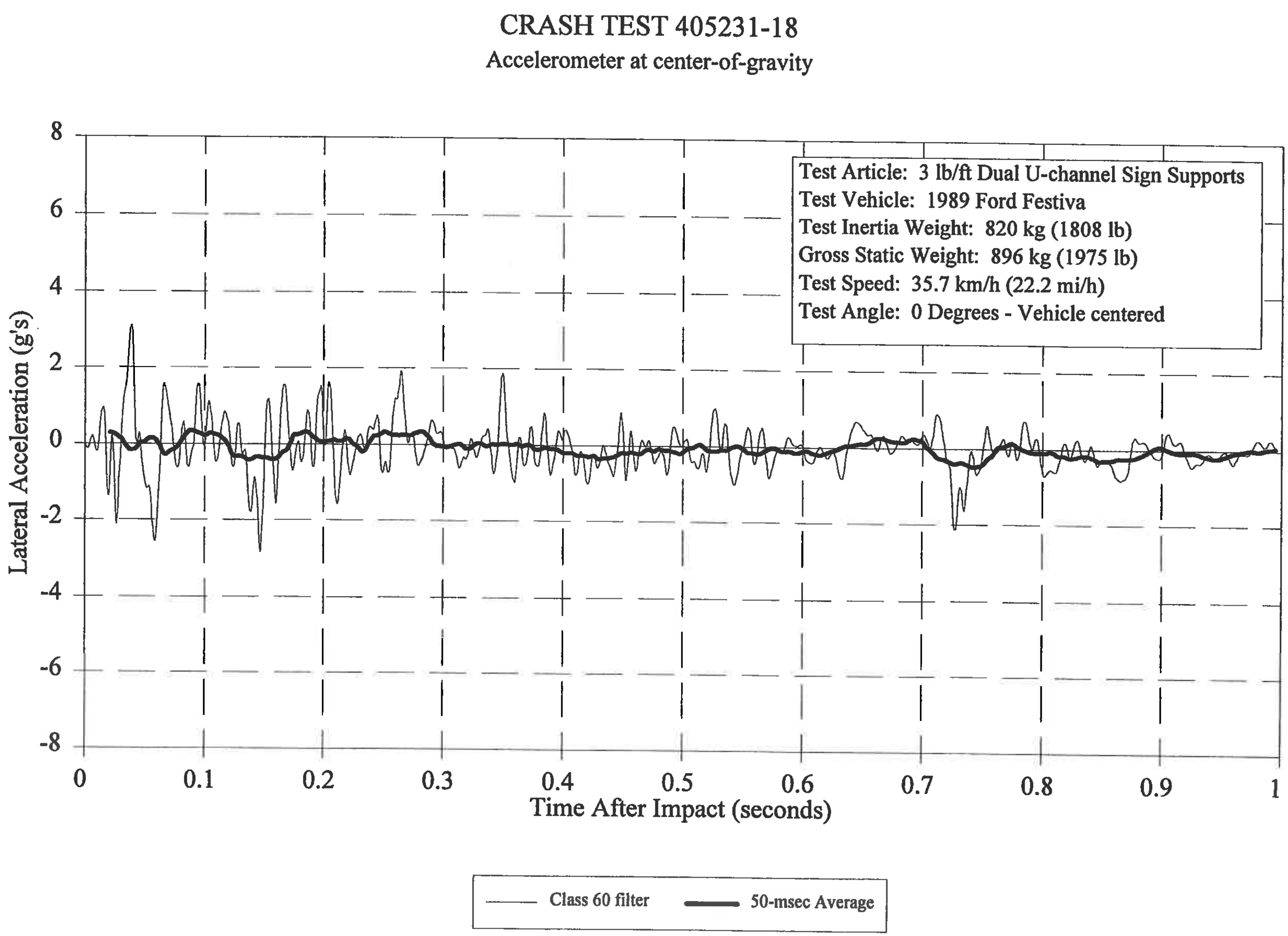


Figure D-47. Vehicle lateral accelerometer trace for test 405231-18.

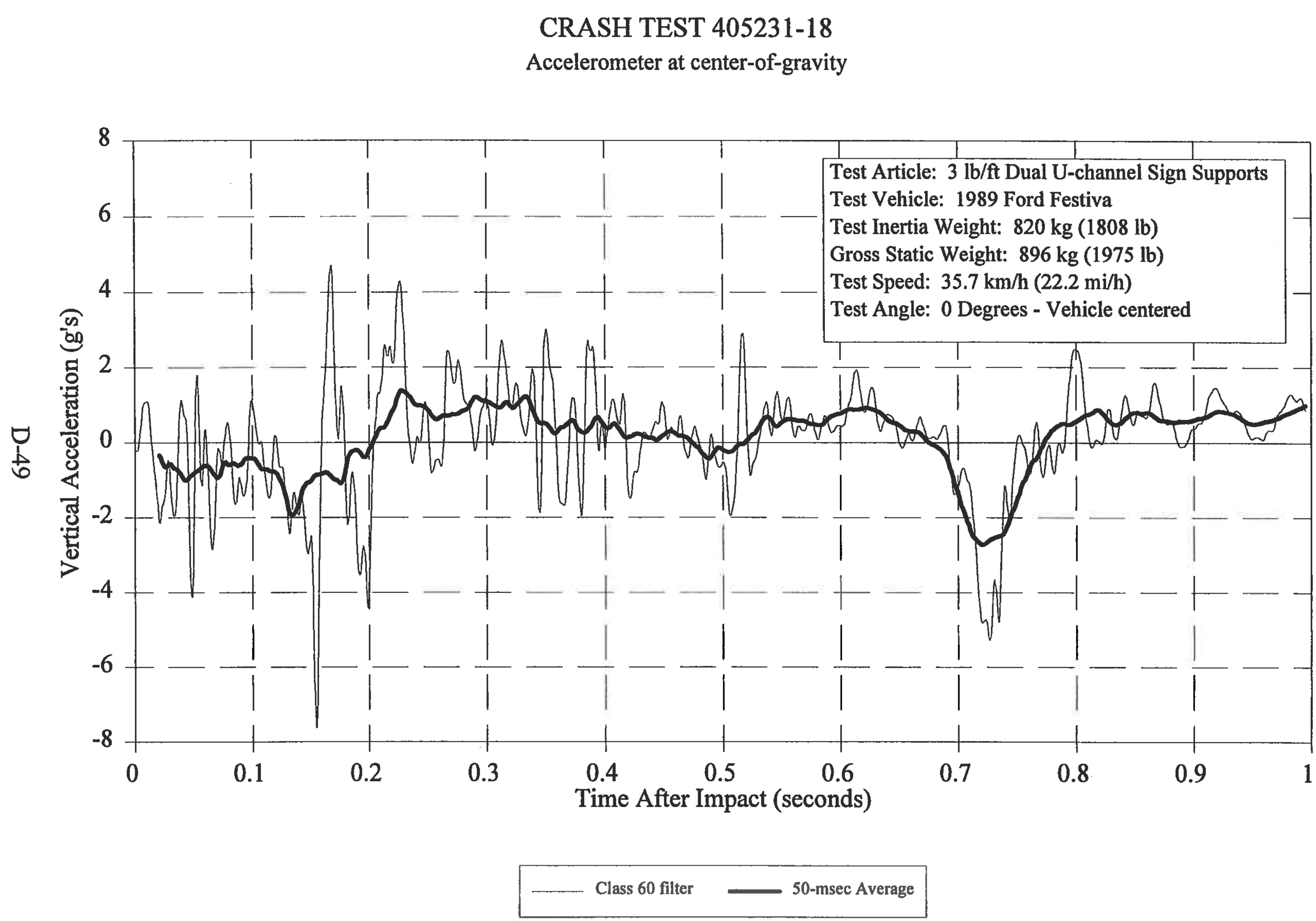


Figure D-48. Vehicle vertical accelerometer trace for test 405231-18.

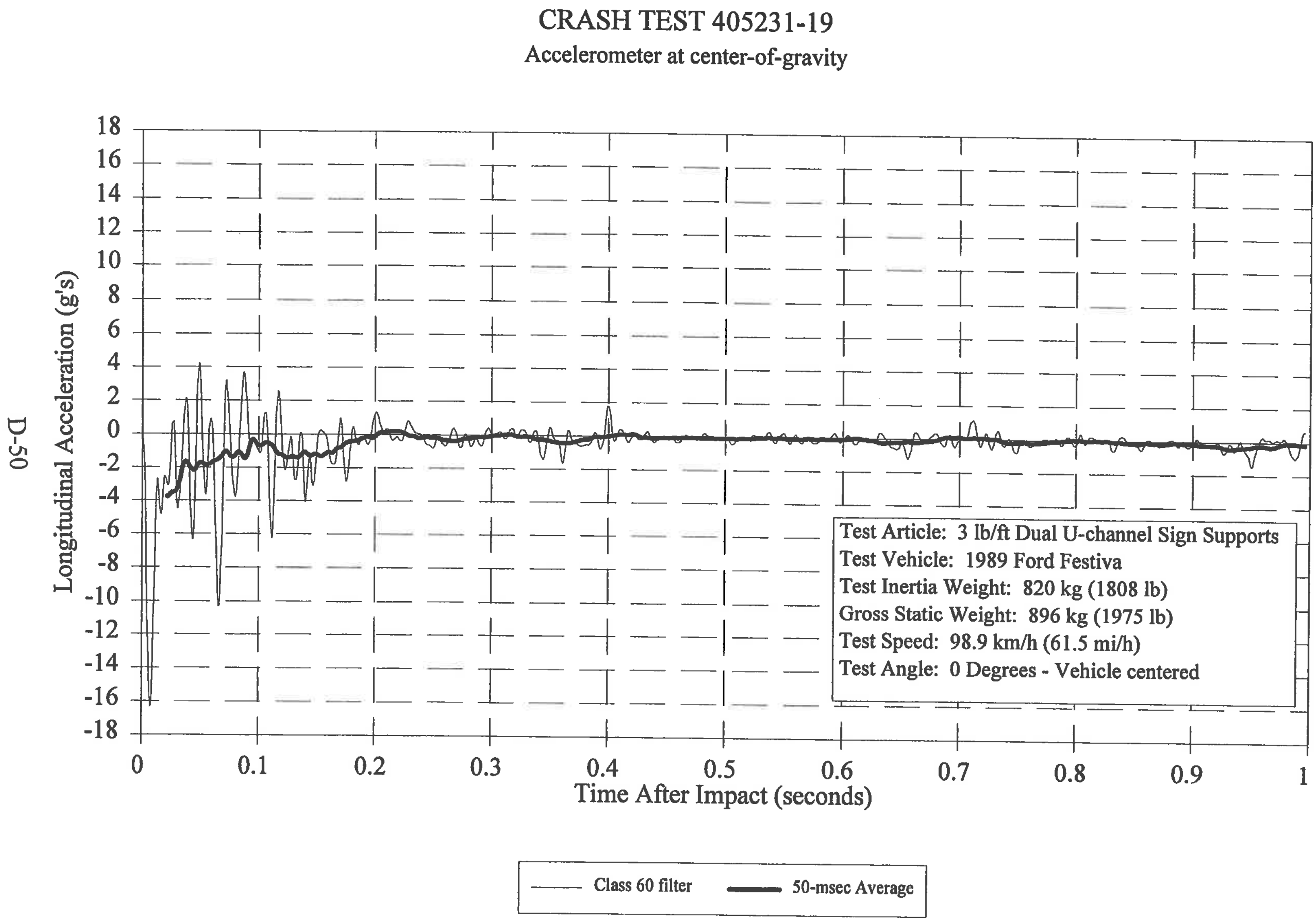


Figure D-49. Vehicle longitudinal accelerometer trace for test 405231-19.

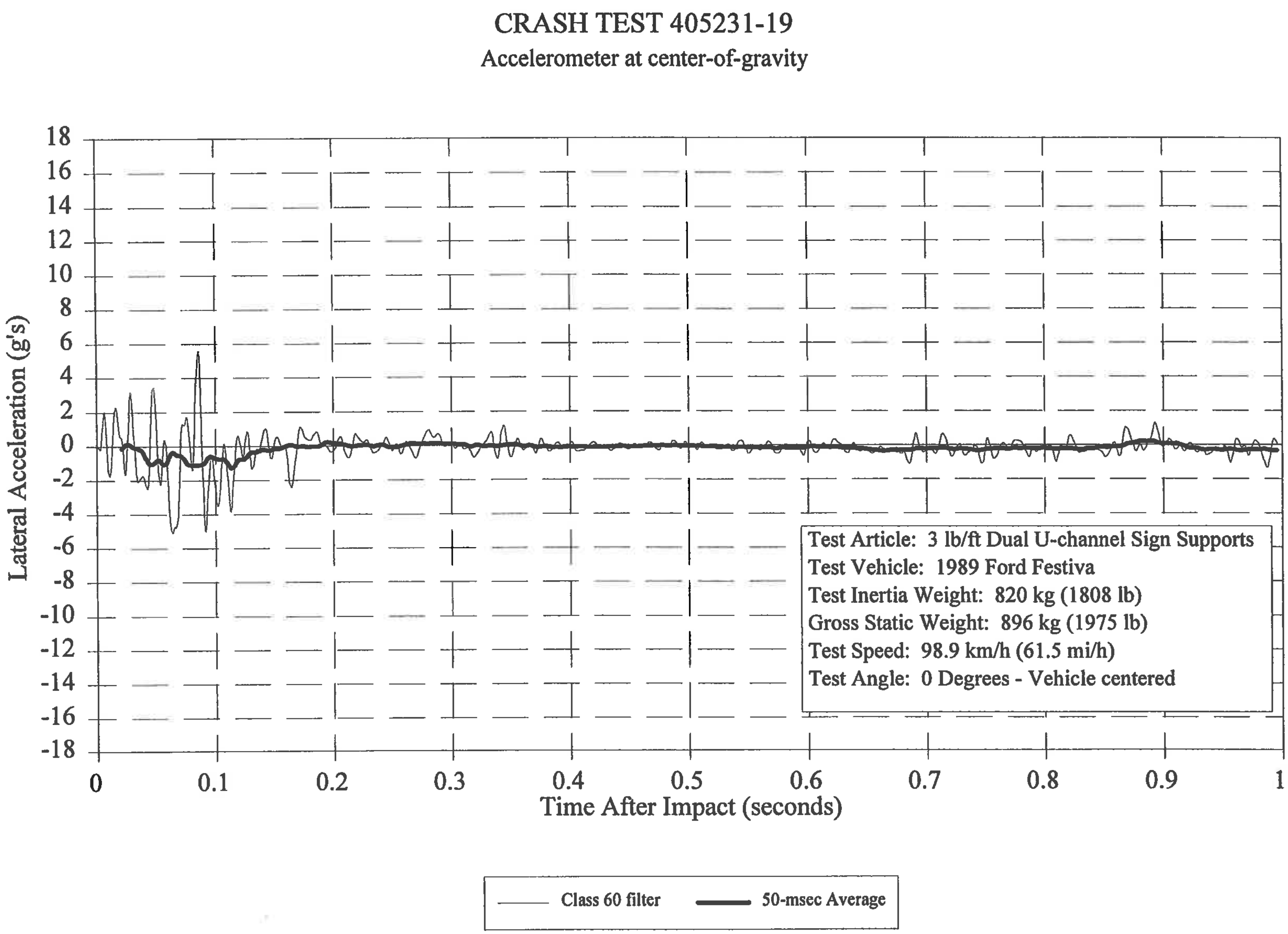


Figure D-50. Vehicle lateral accelerometer trace for test 405231-19.

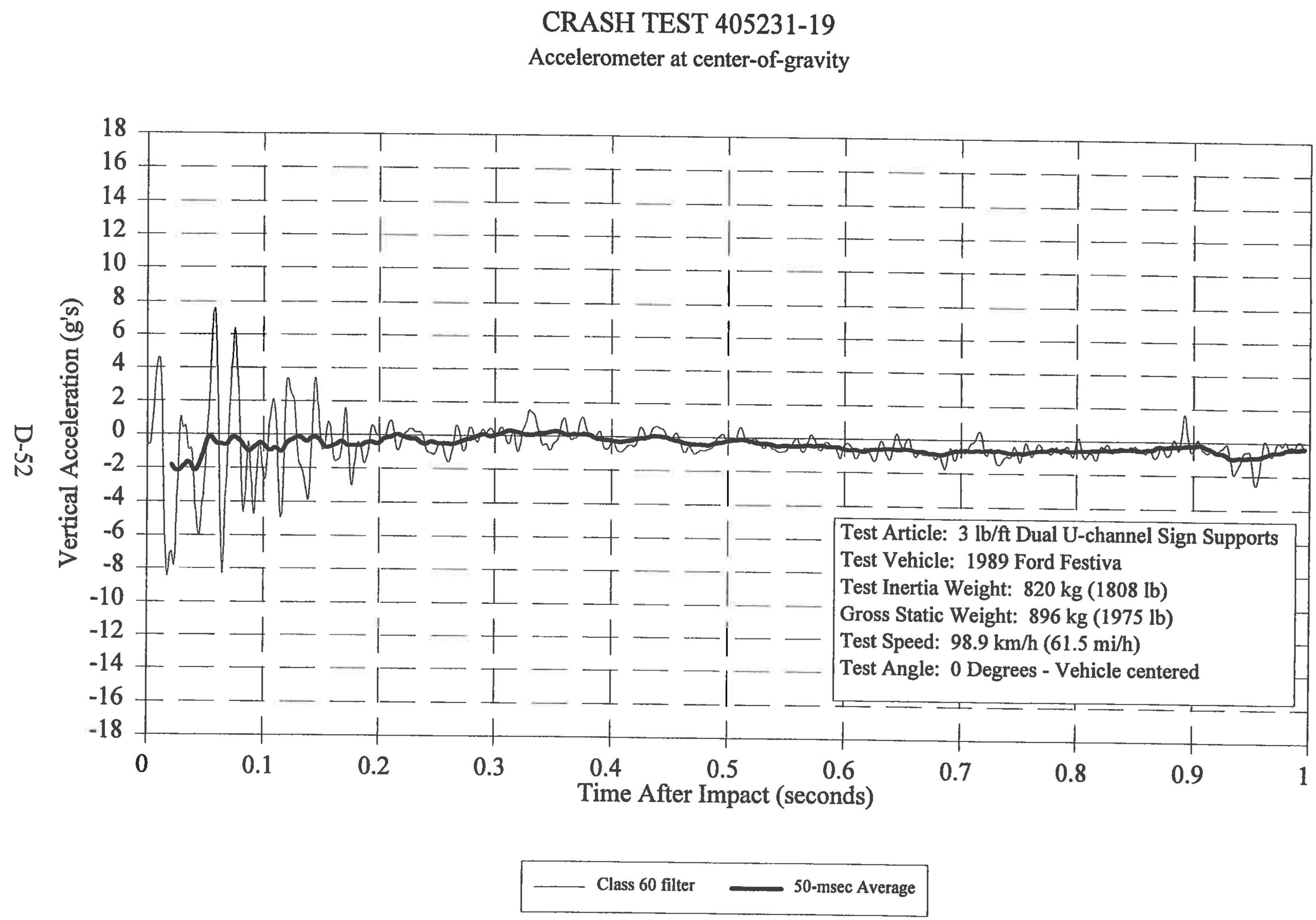


Figure D-51. Vehicle vertical accelerometer trace for test 405231-19.

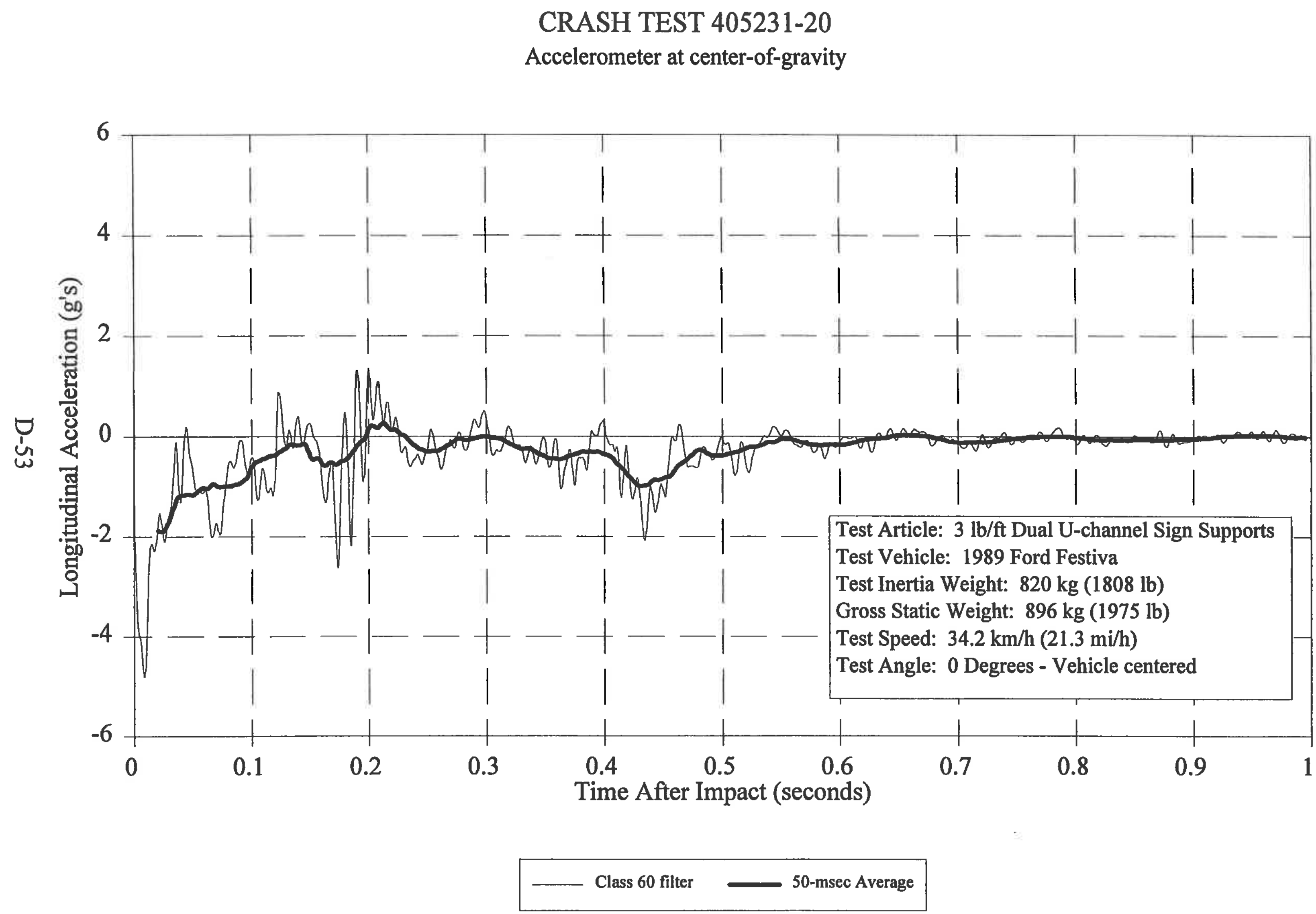


Figure D-52. Vehicle longitudinal accelerometer trace for test 405231-20.

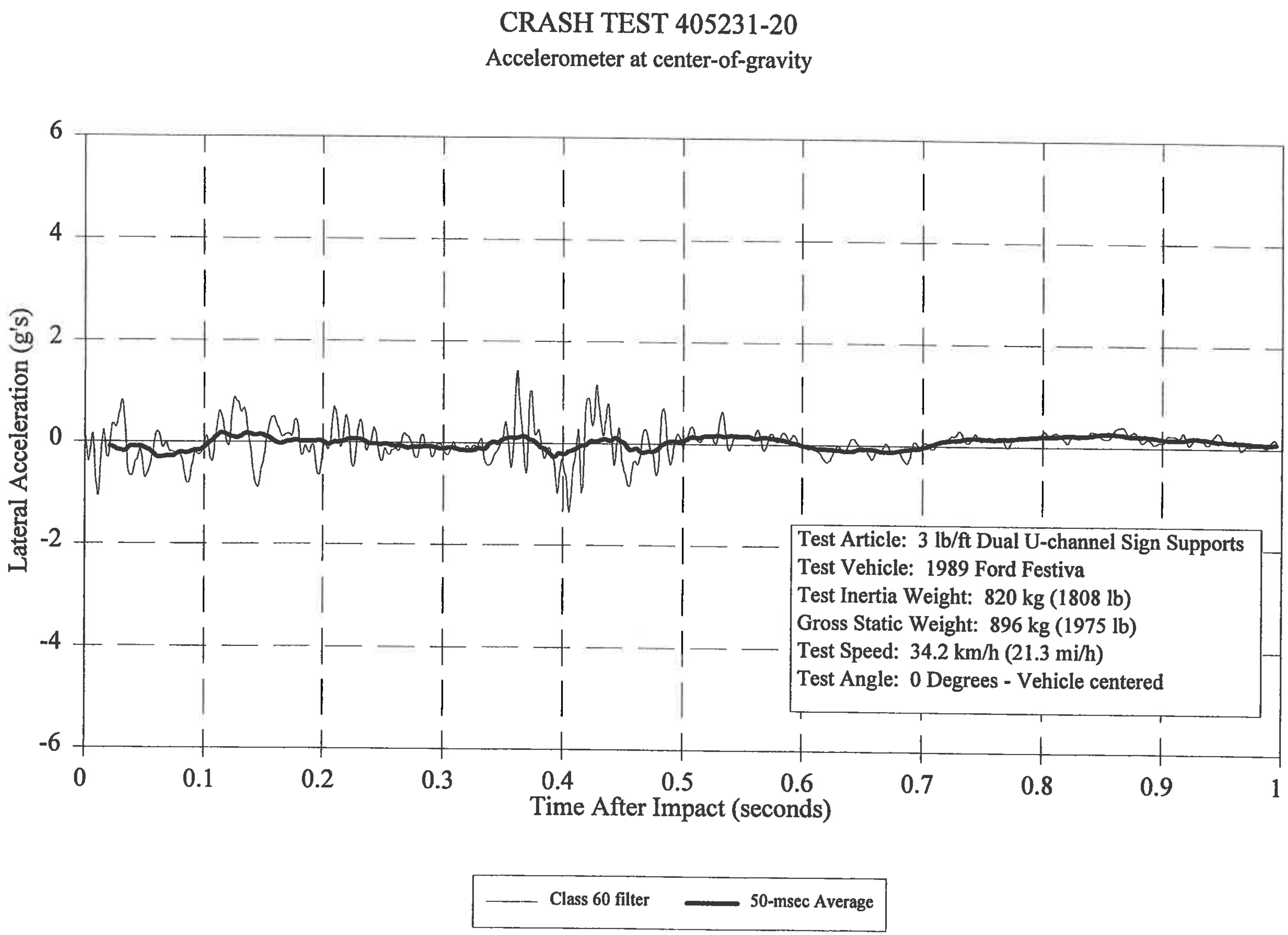


Figure D-53. Vehicle lateral accelerometer trace for test 405231-20.

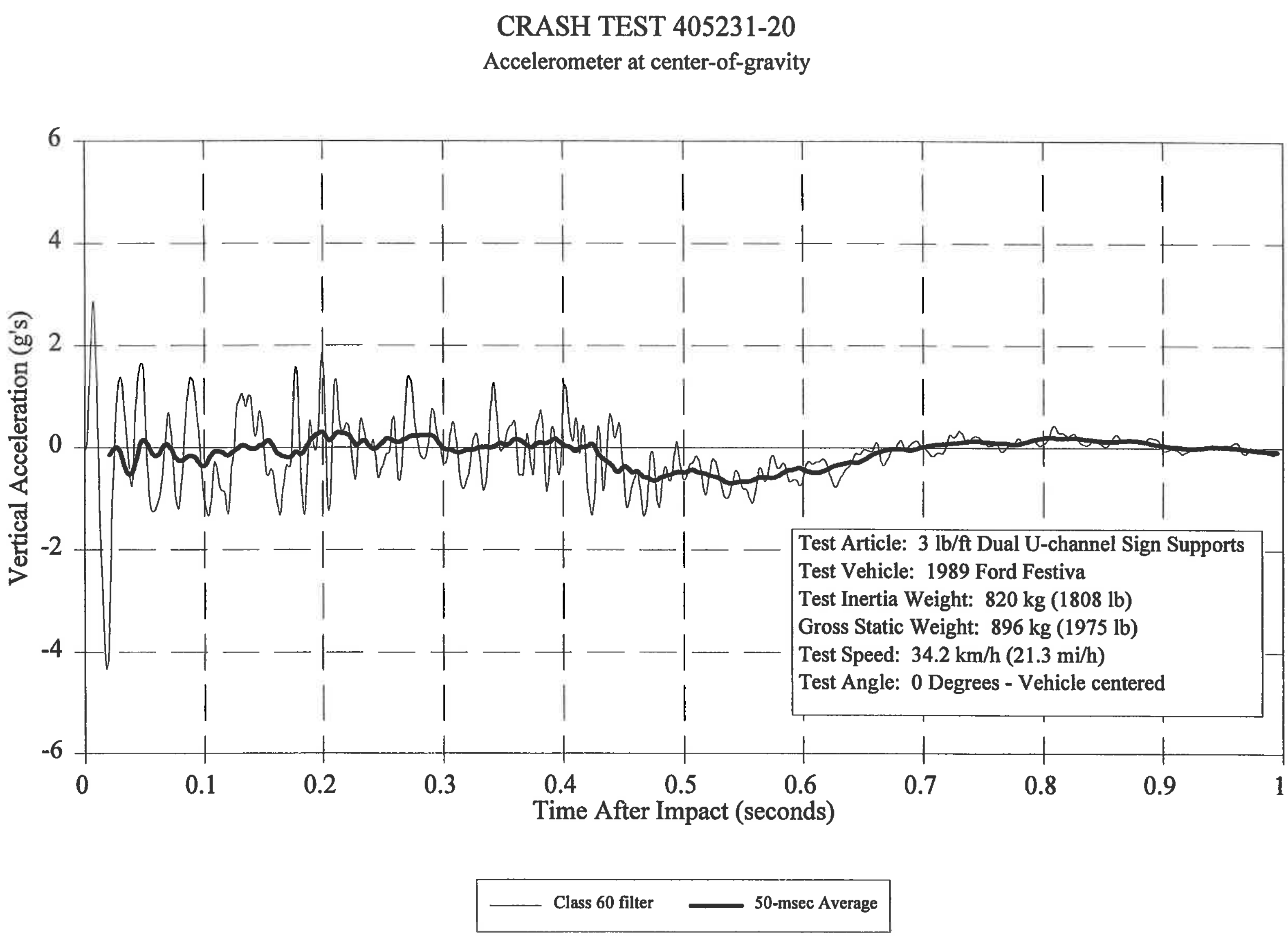


Figure D-54. Vehicle vertical accelerometer trace for test 405231-20.

CRASH TEST 405231-21

Accelerometer at center-of-gravity

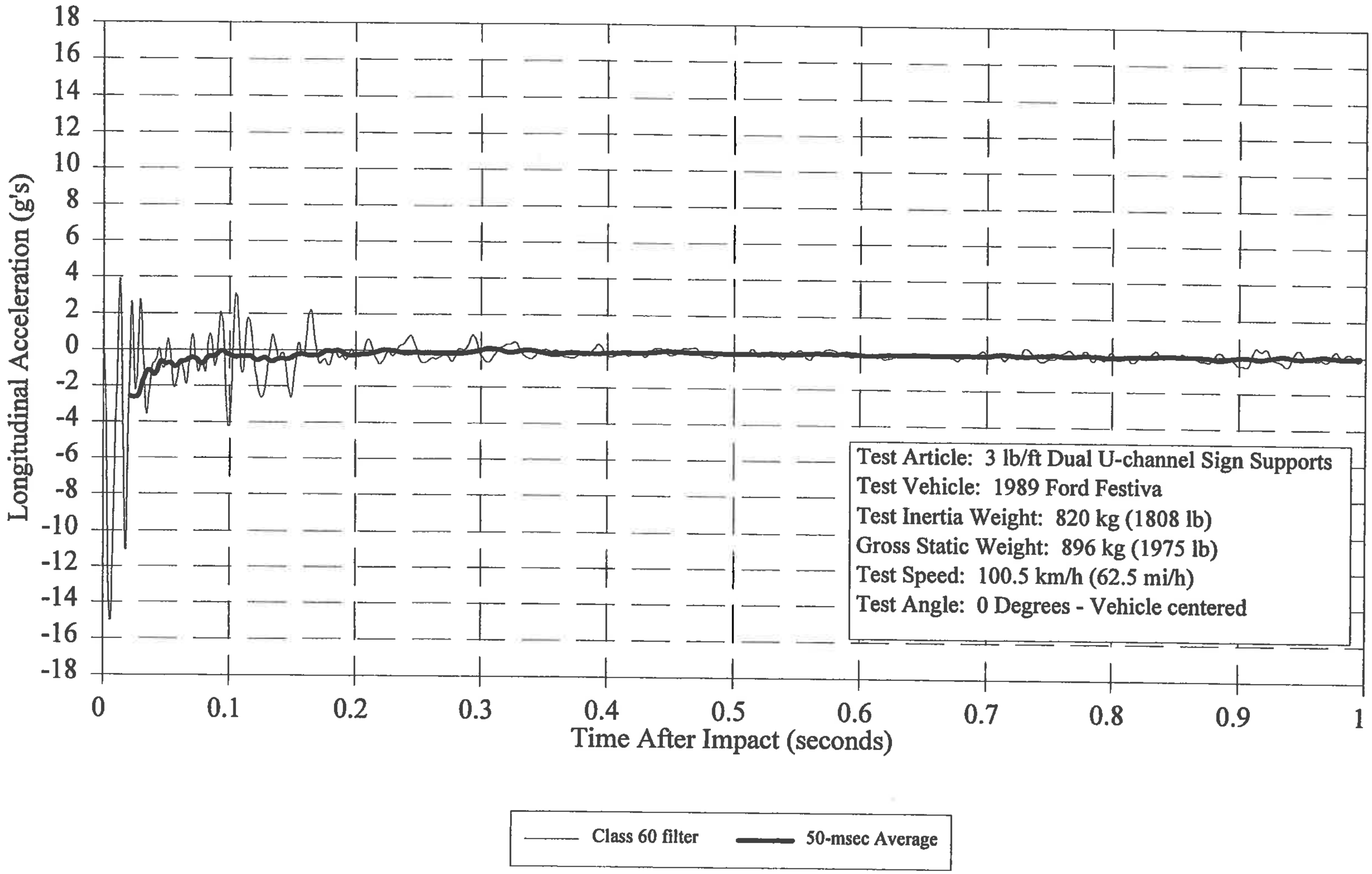


Figure D-55. Vehicle longitudinal accelerometer trace for test 405231-21.

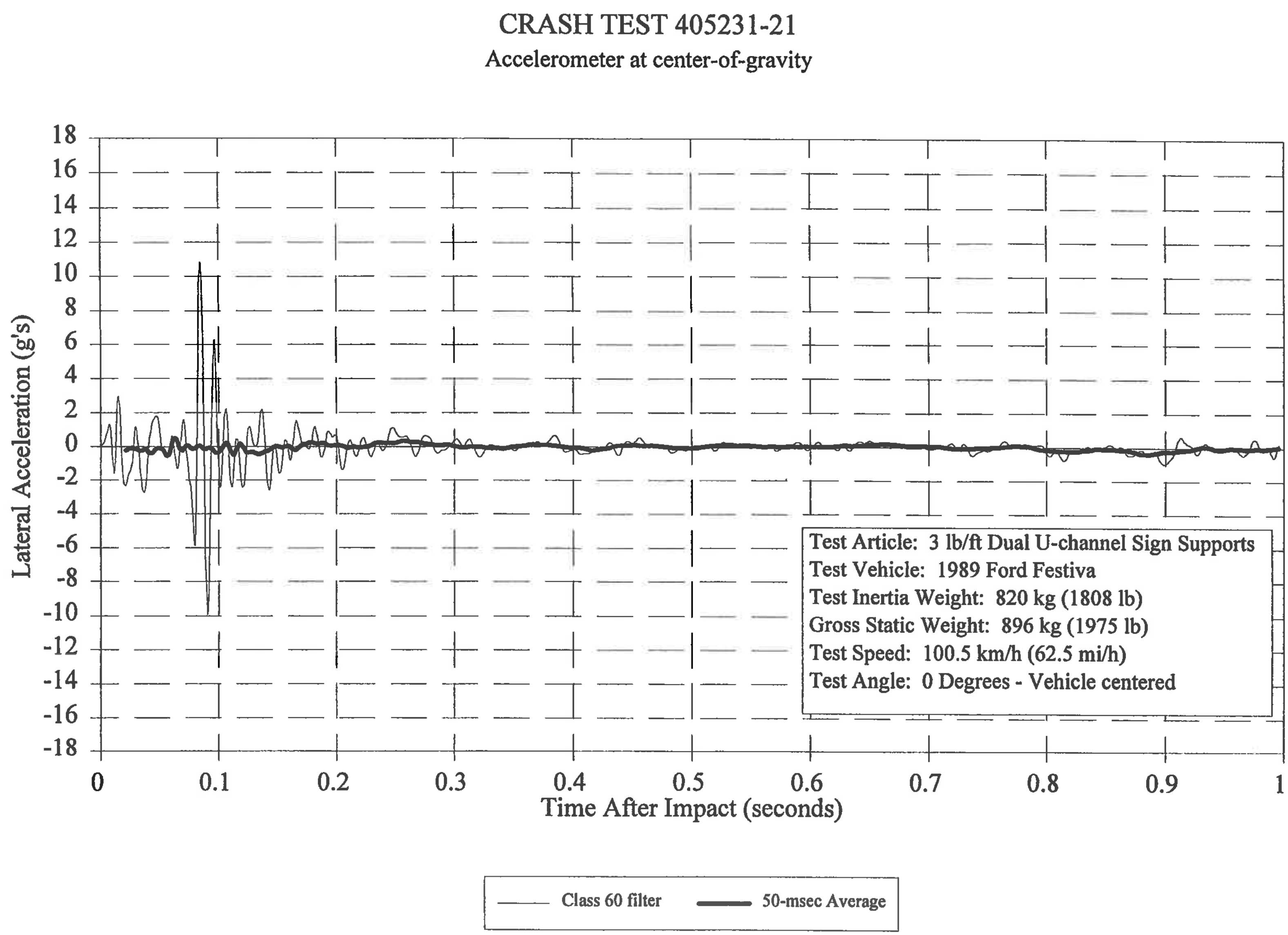


Figure D-56. Vehicle lateral accelerometer trace for test 405231-21.

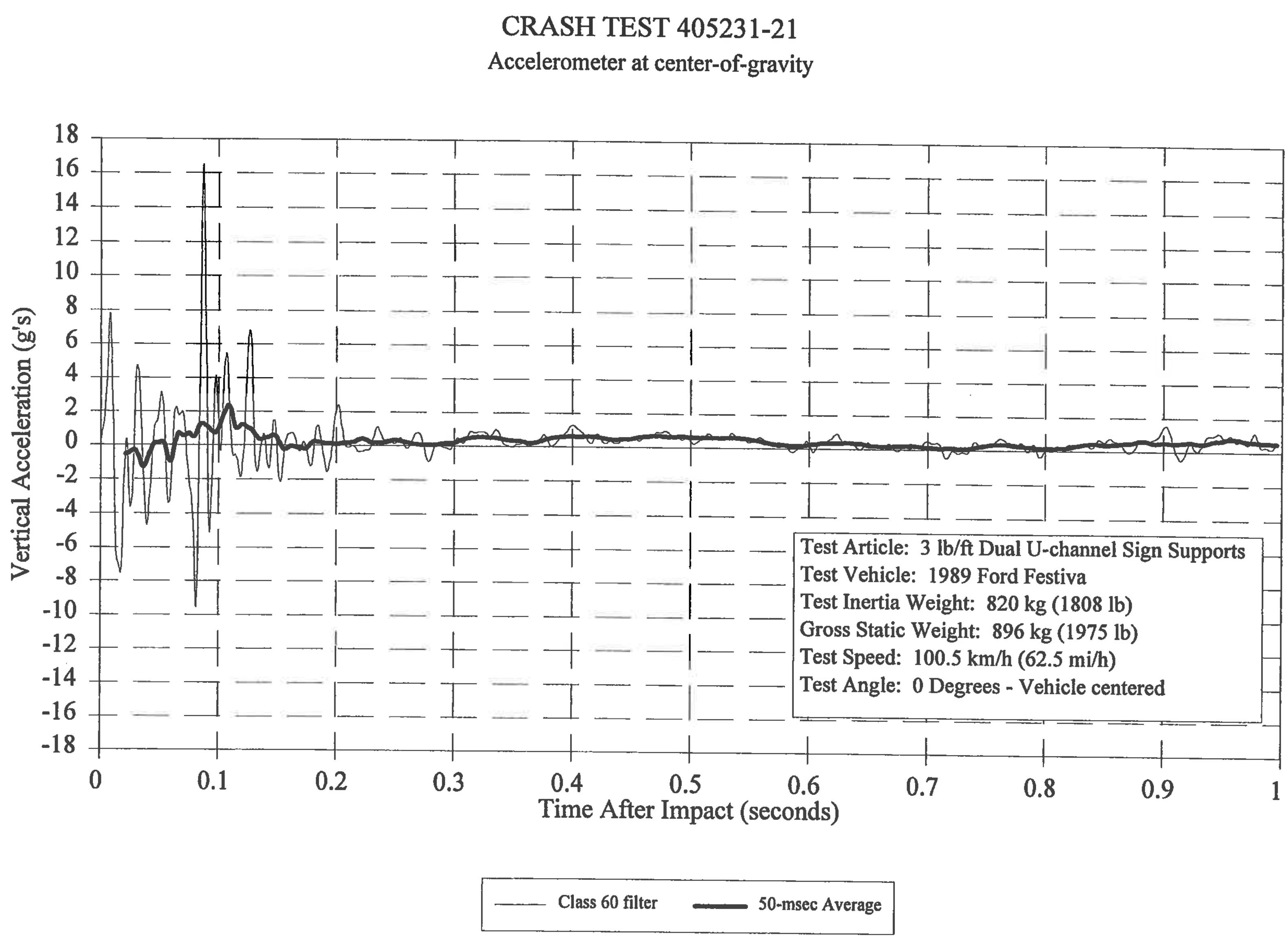


Figure D-57. Vehicle vertical accelerometer trace for test 405231-21.

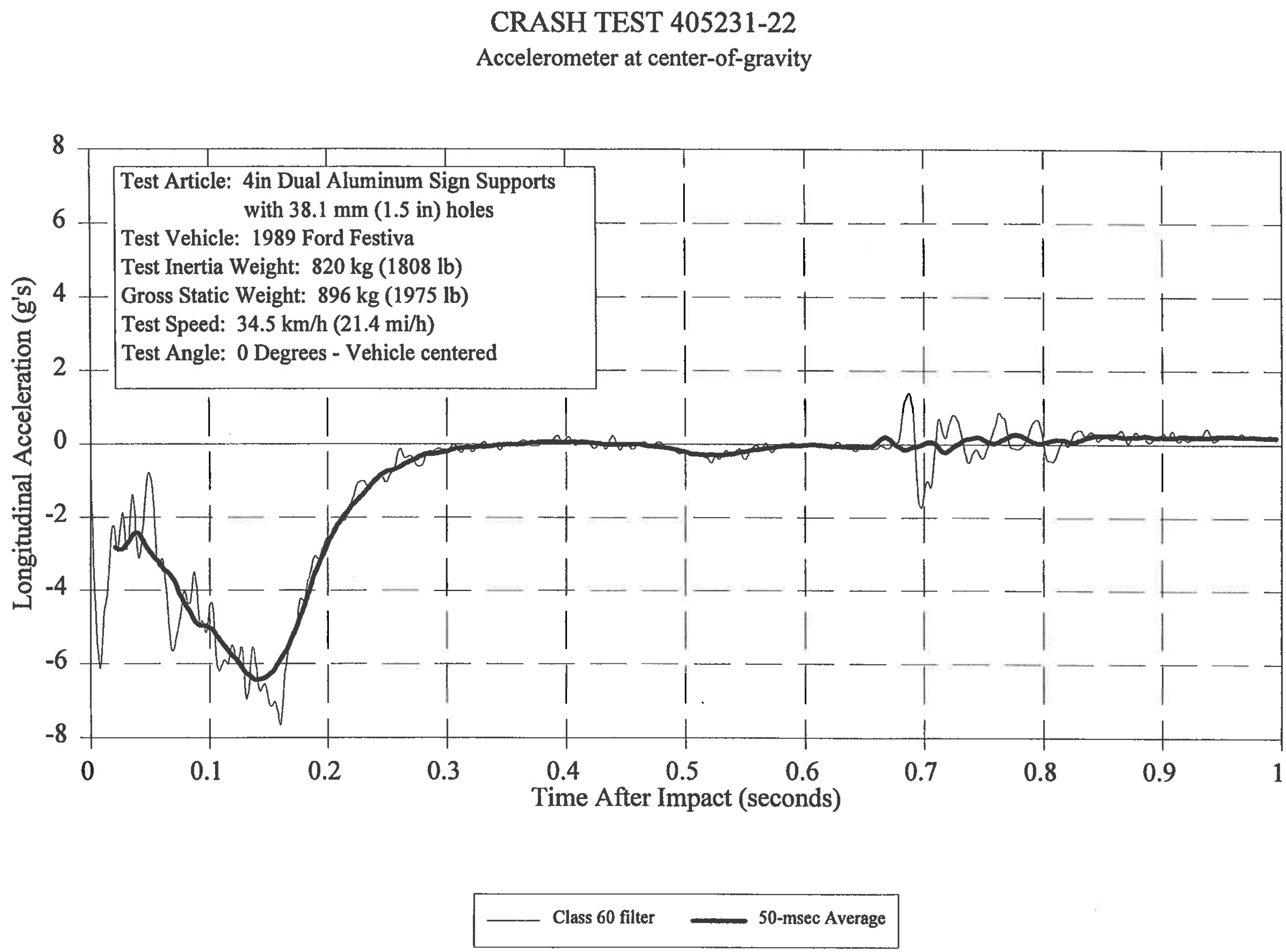


Figure D-58. Vehicle longitudinal accelerometer trace for test 405231-22.

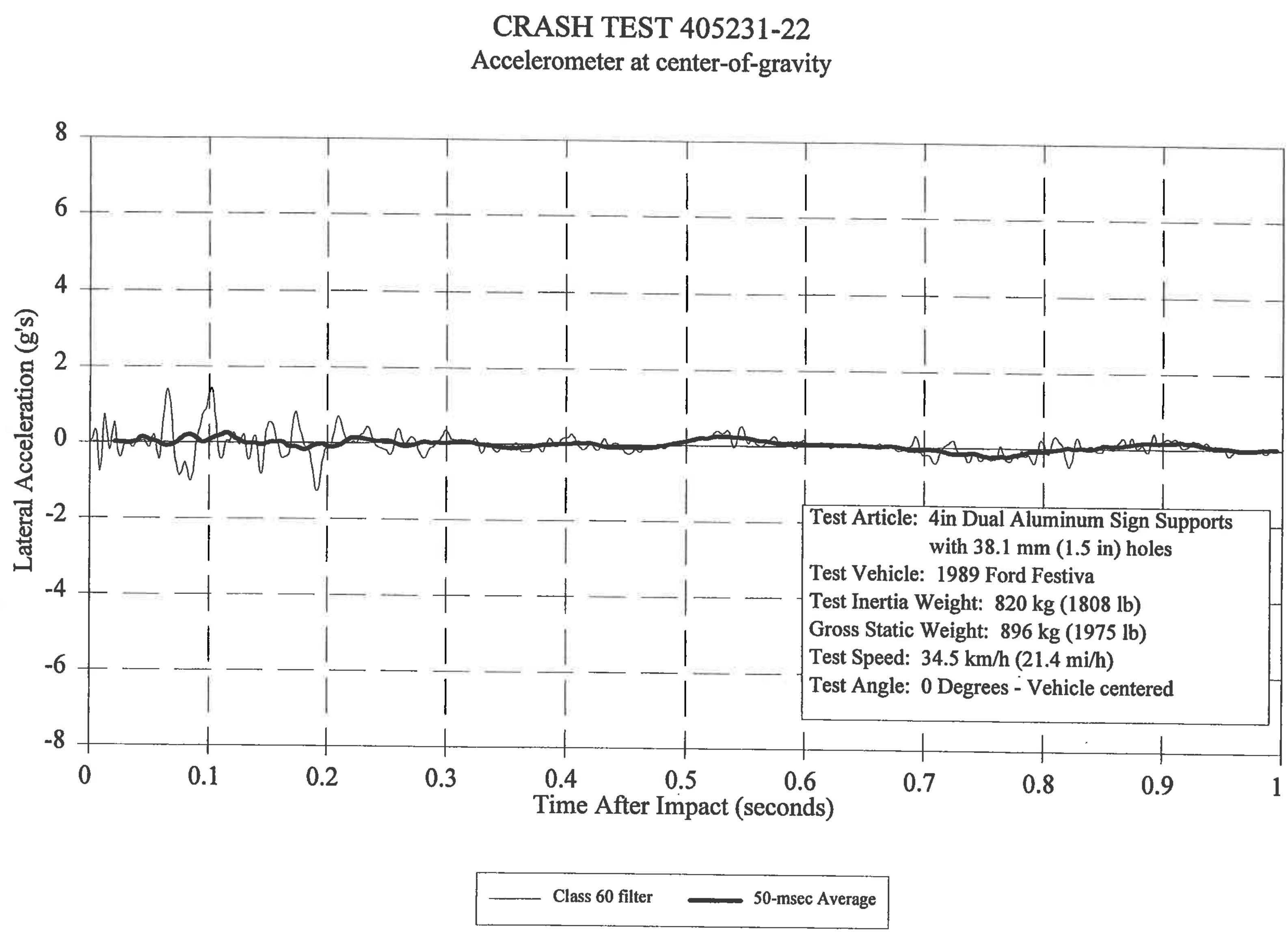


Figure D-59. Vehicle lateral accelerometer trace for test 405231-22.

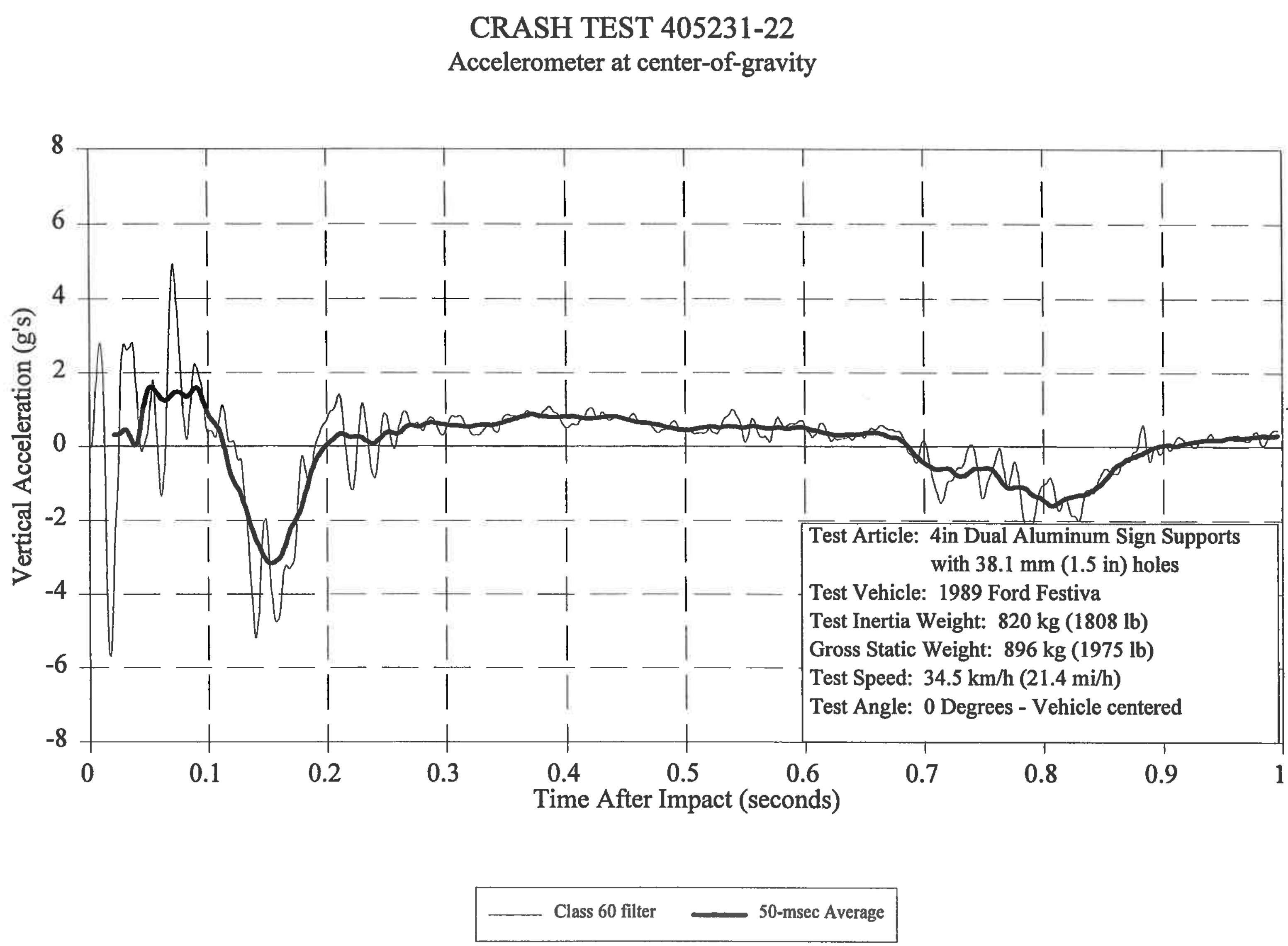


Figure D-60. Vehicle vertical accelerometer trace for test 405231-22.

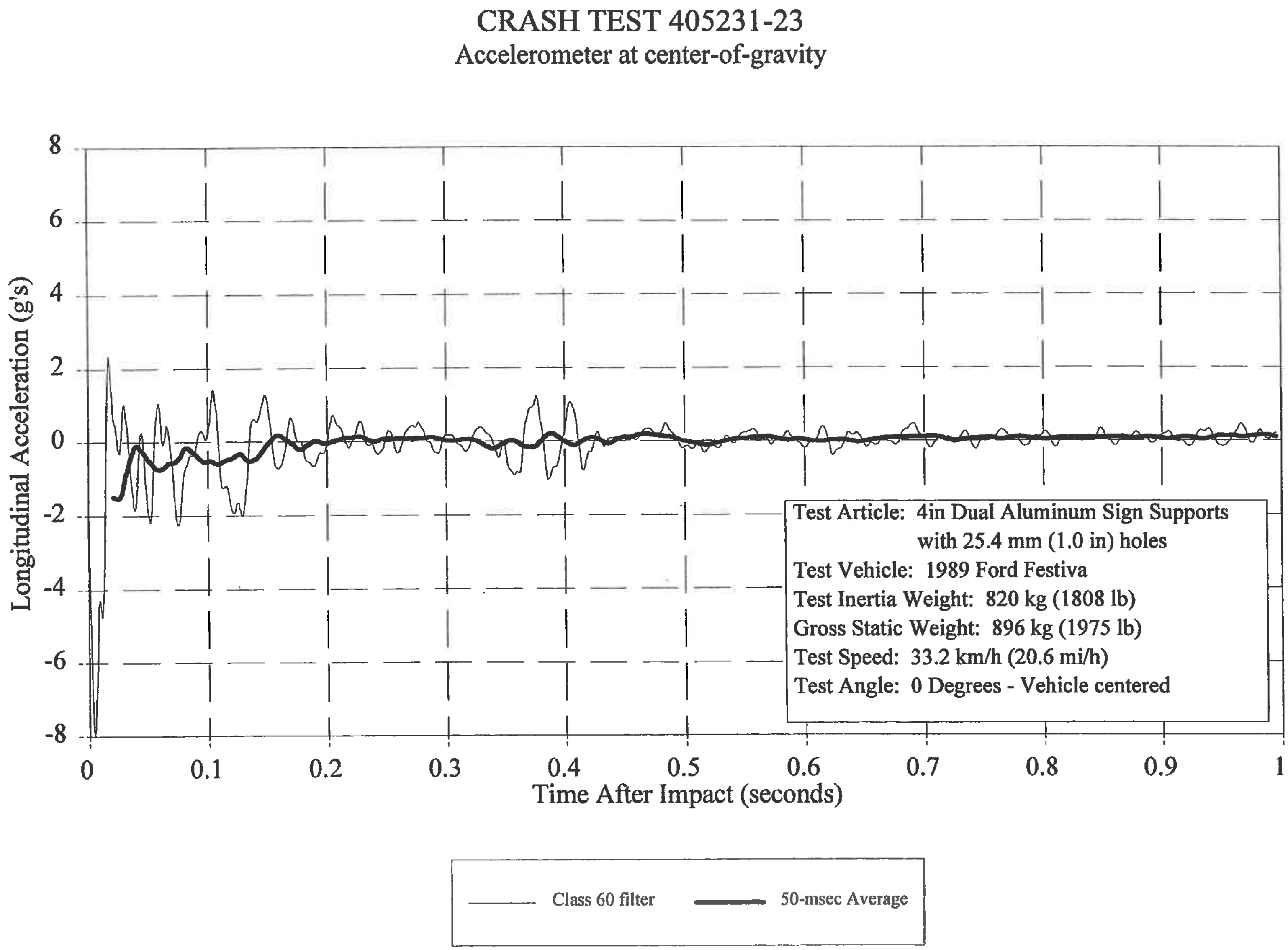


Figure 61. Vehicle longitudinal accelerometer trace for test 405231-23.

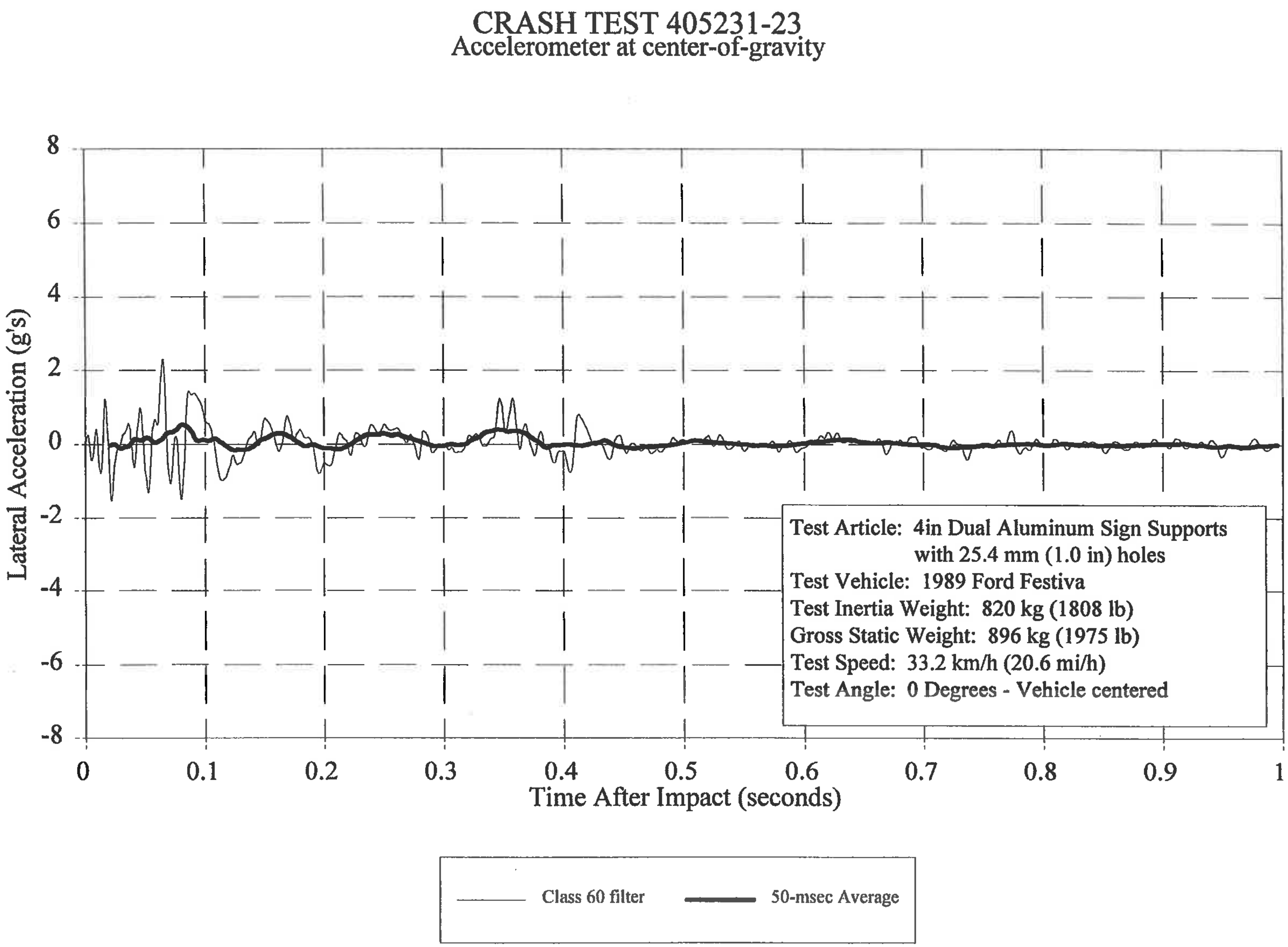


Figure 62. Vehicle lateral accelerometer trace for test 405231-23.

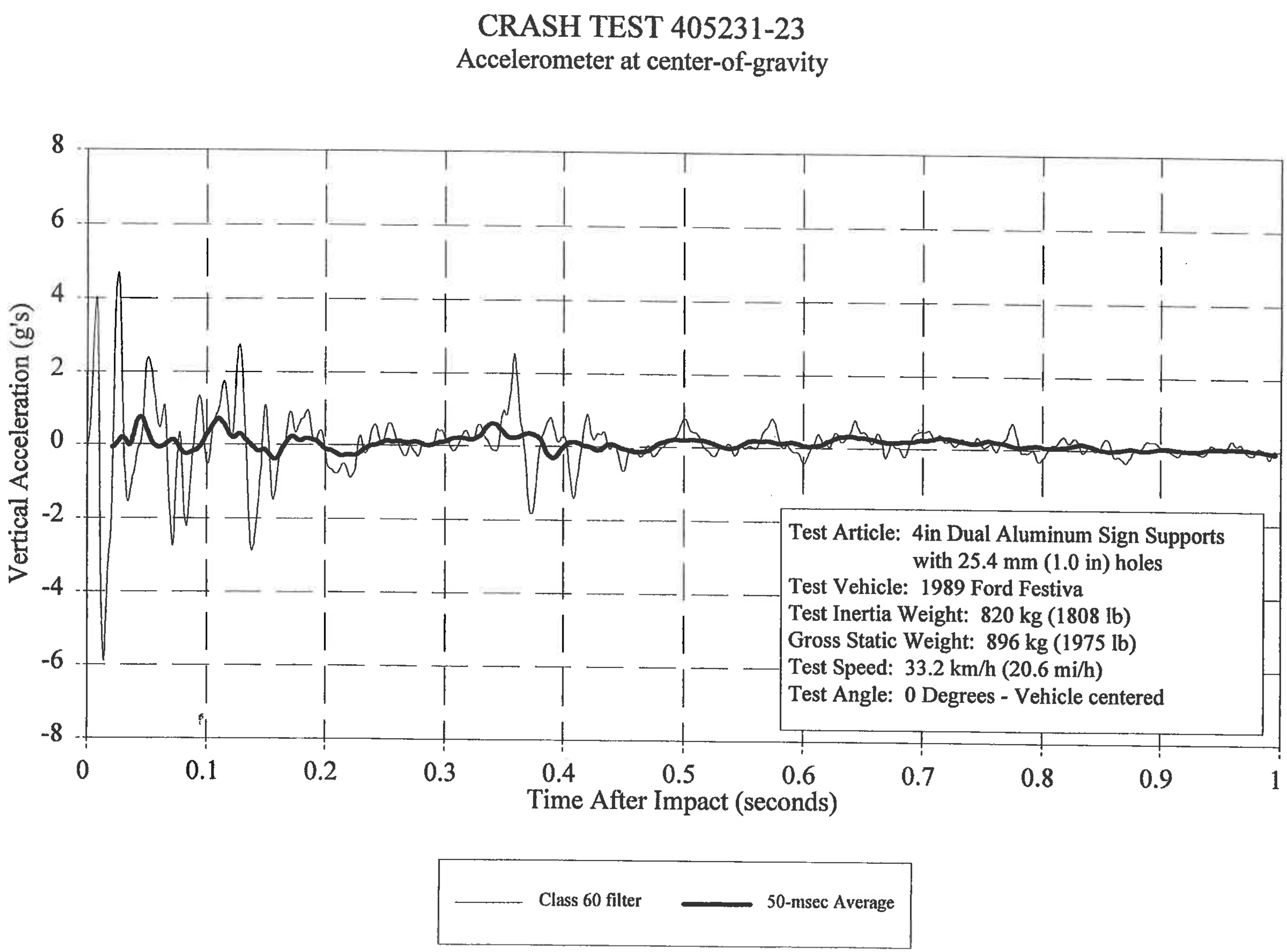


Figure 63. Vehicle vertical accelerometer trace for test 405231-23.

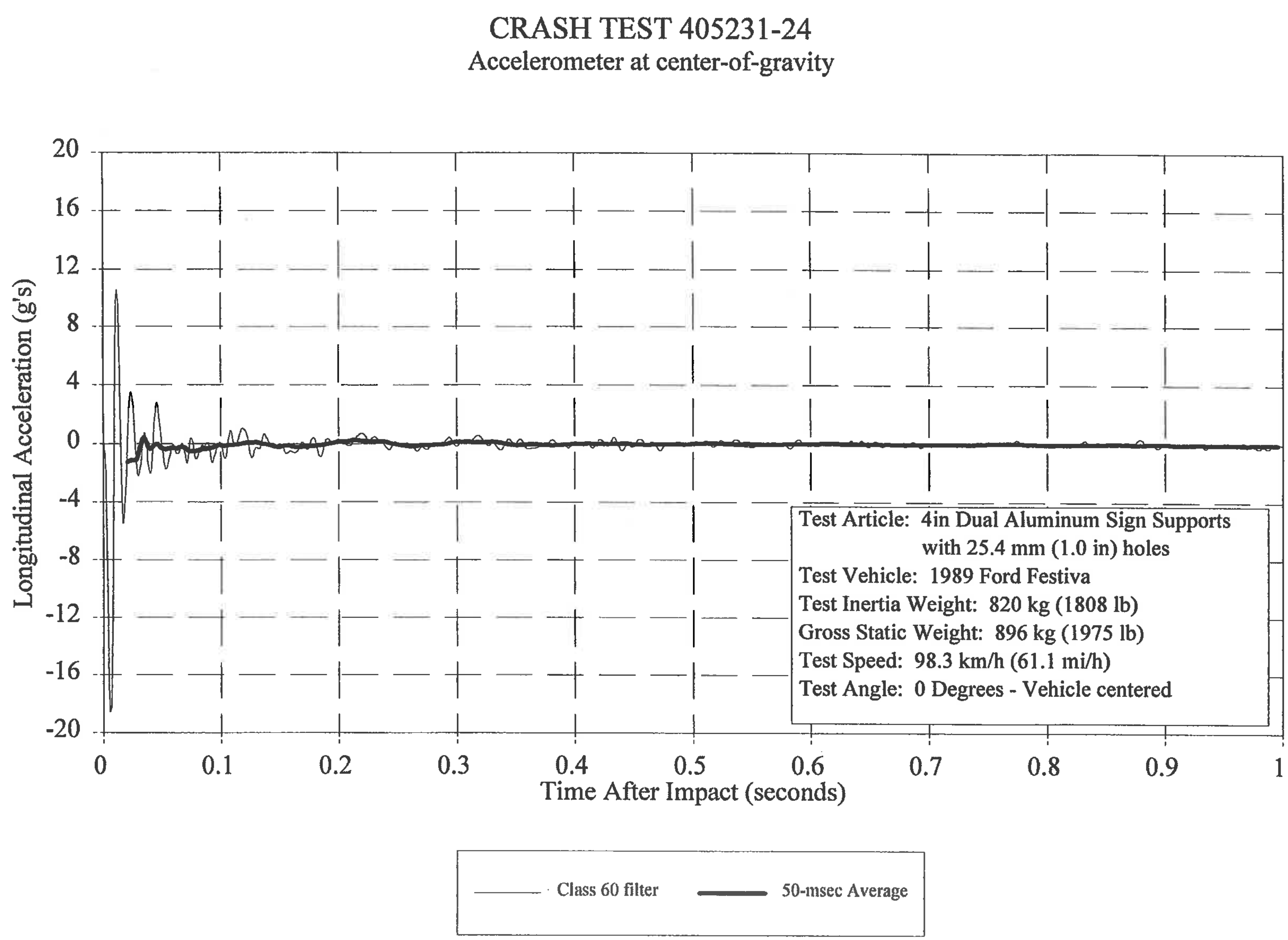


Figure 64. Vehicle longitudinal accelerometer trace for test 405231-24.

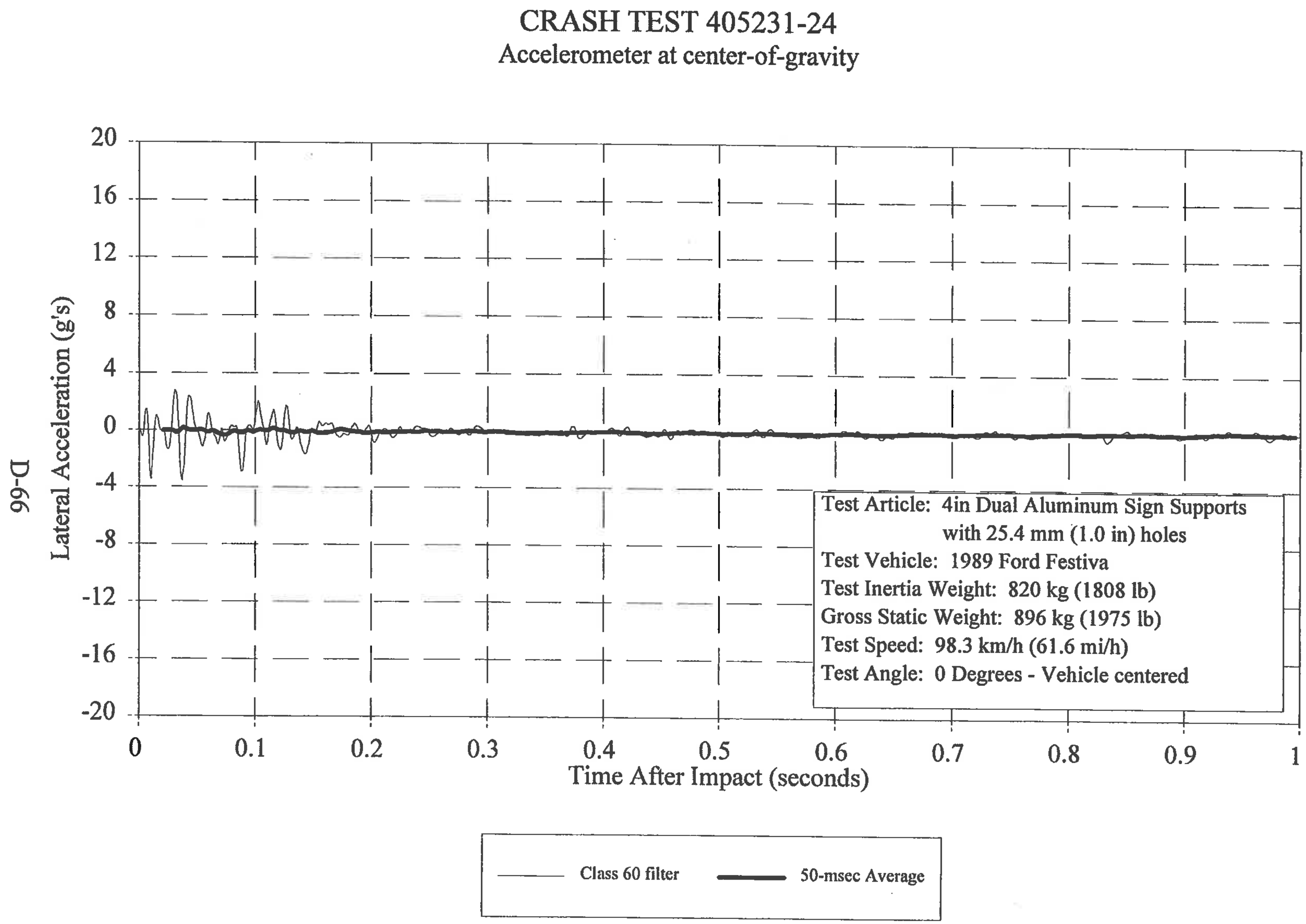


Figure 65. Vehicle lateral accelerometer trace for test 405231-24.

CRASH TEST 405231-24

Accelerometer at center-of-gravity

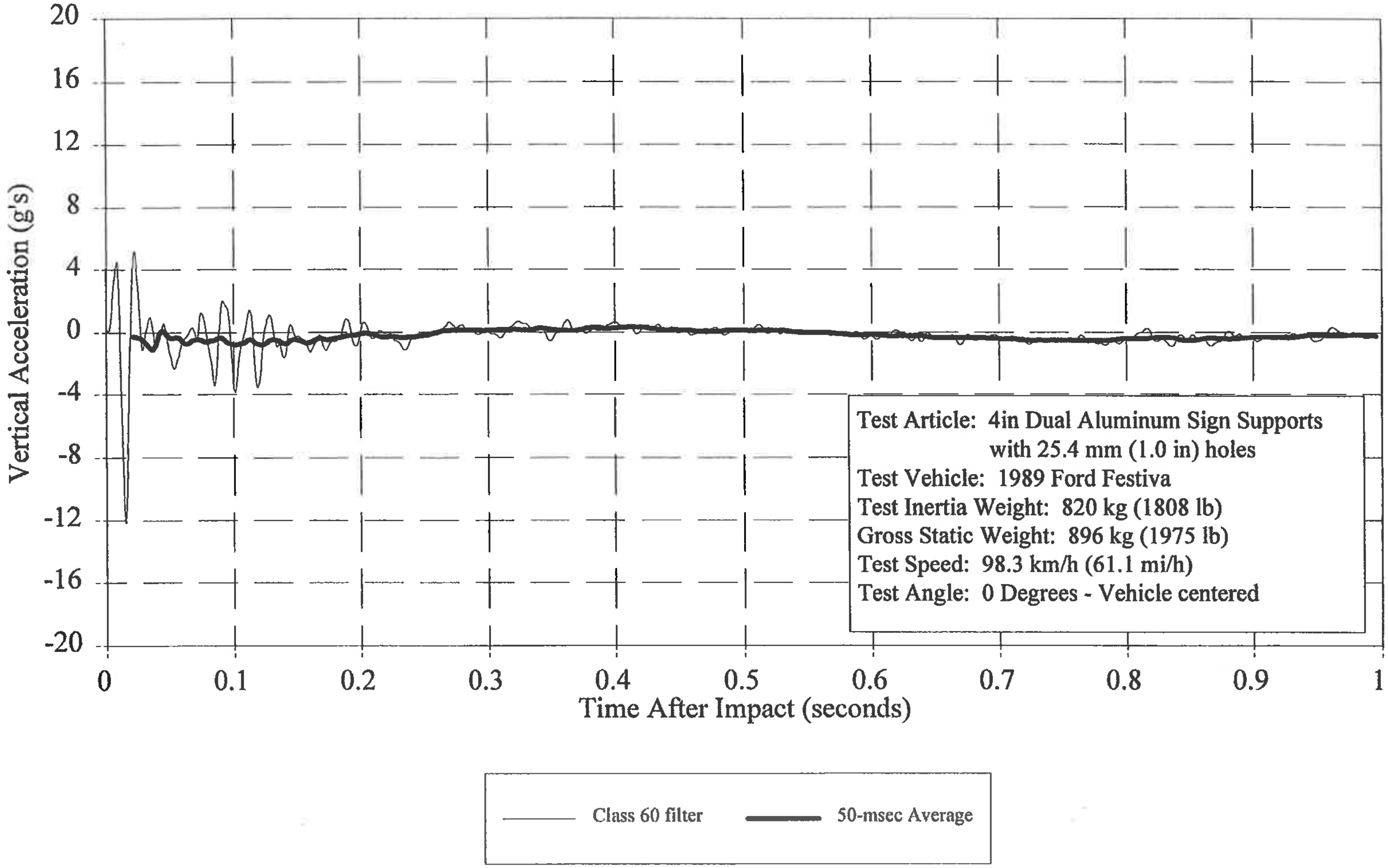


Figure 66. Vehicle vertical accelerometer trace for test 405231-24.

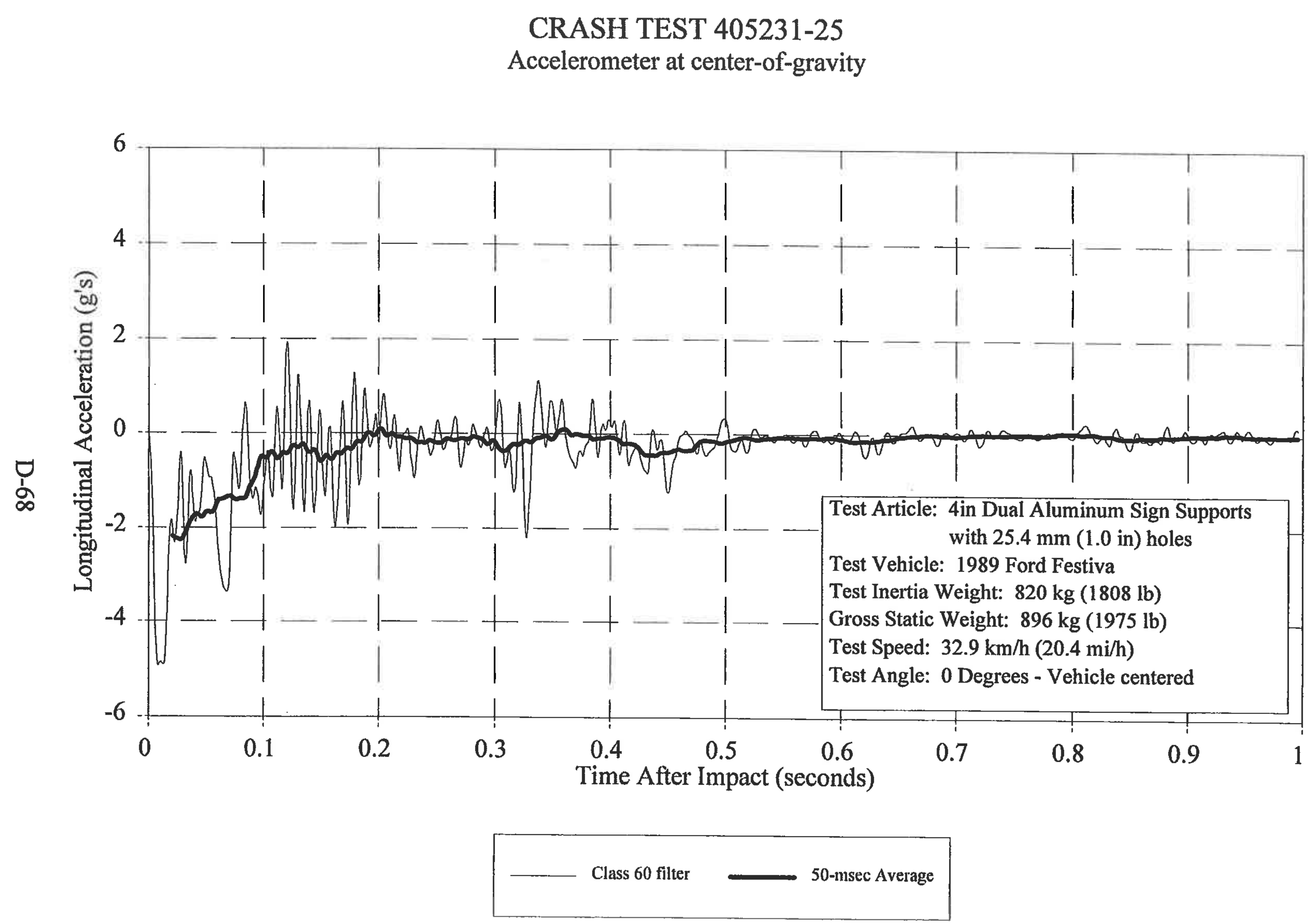


Figure 67. Vehicle longitudinal accelerometer trace for test 405231-25.

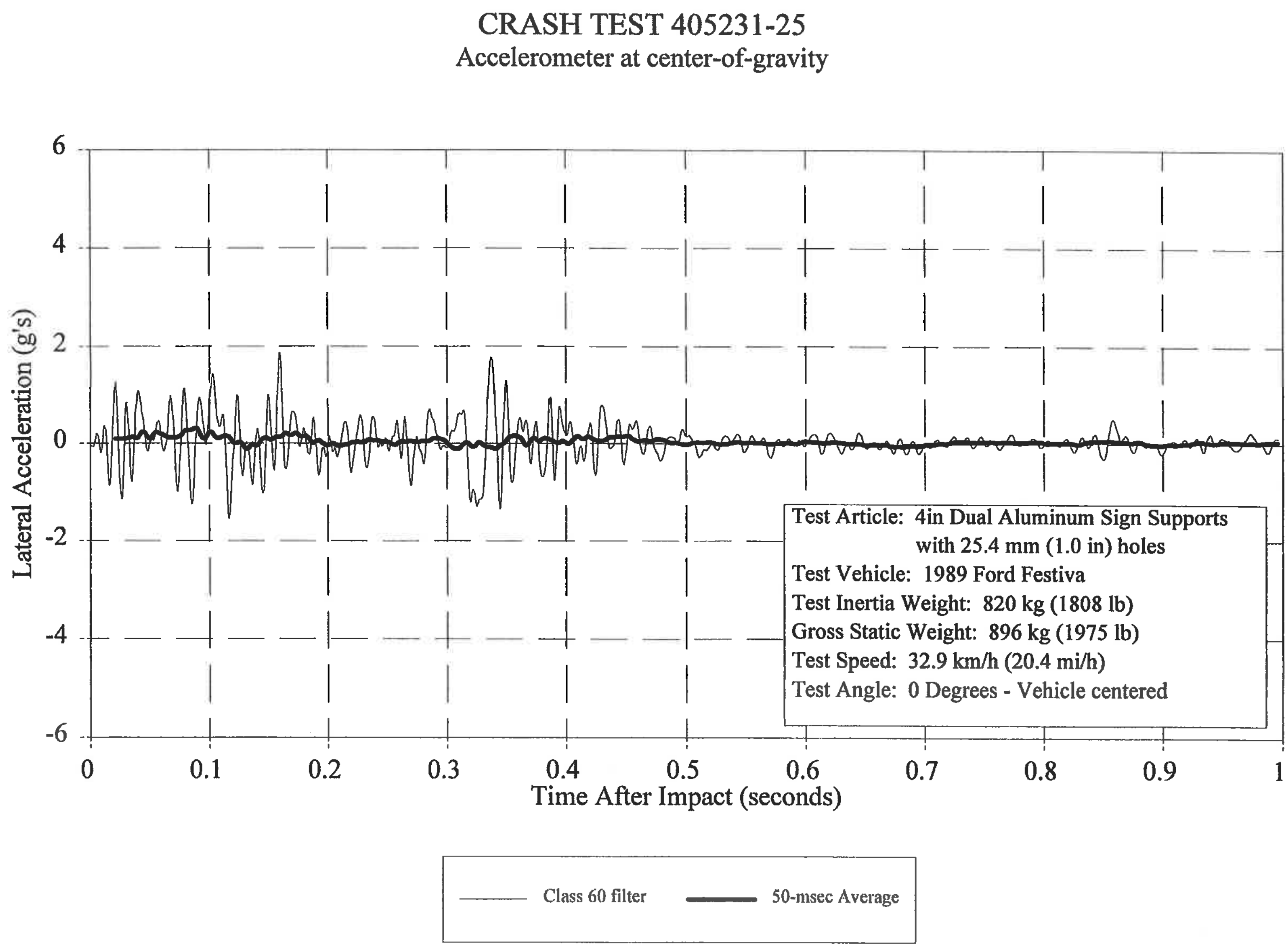


Figure 68. Vehicle lateral accelerometer trace for test 405231-25.

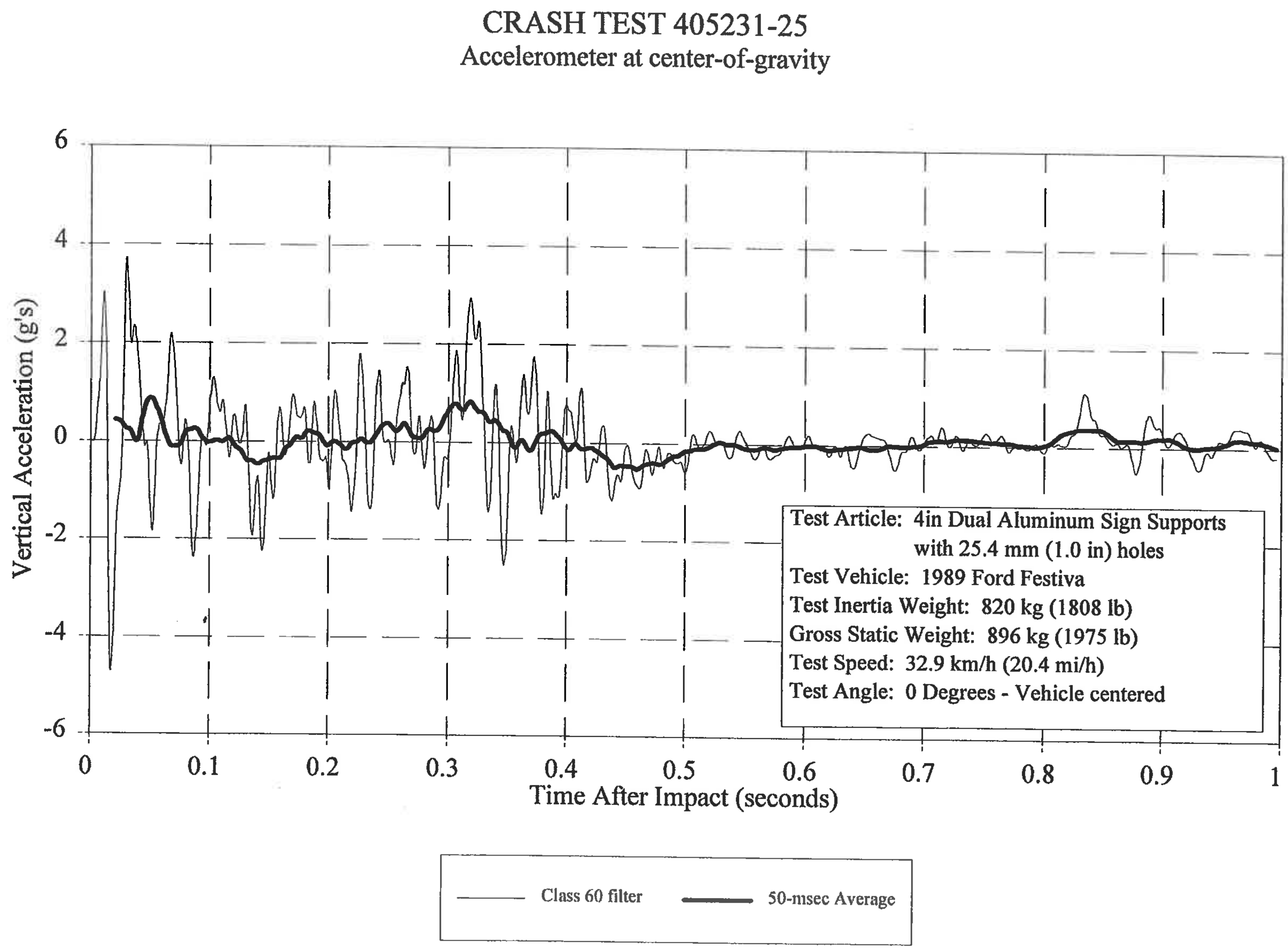


Figure 69. Vehicle vertical accelerometer trace for test 405231-25.

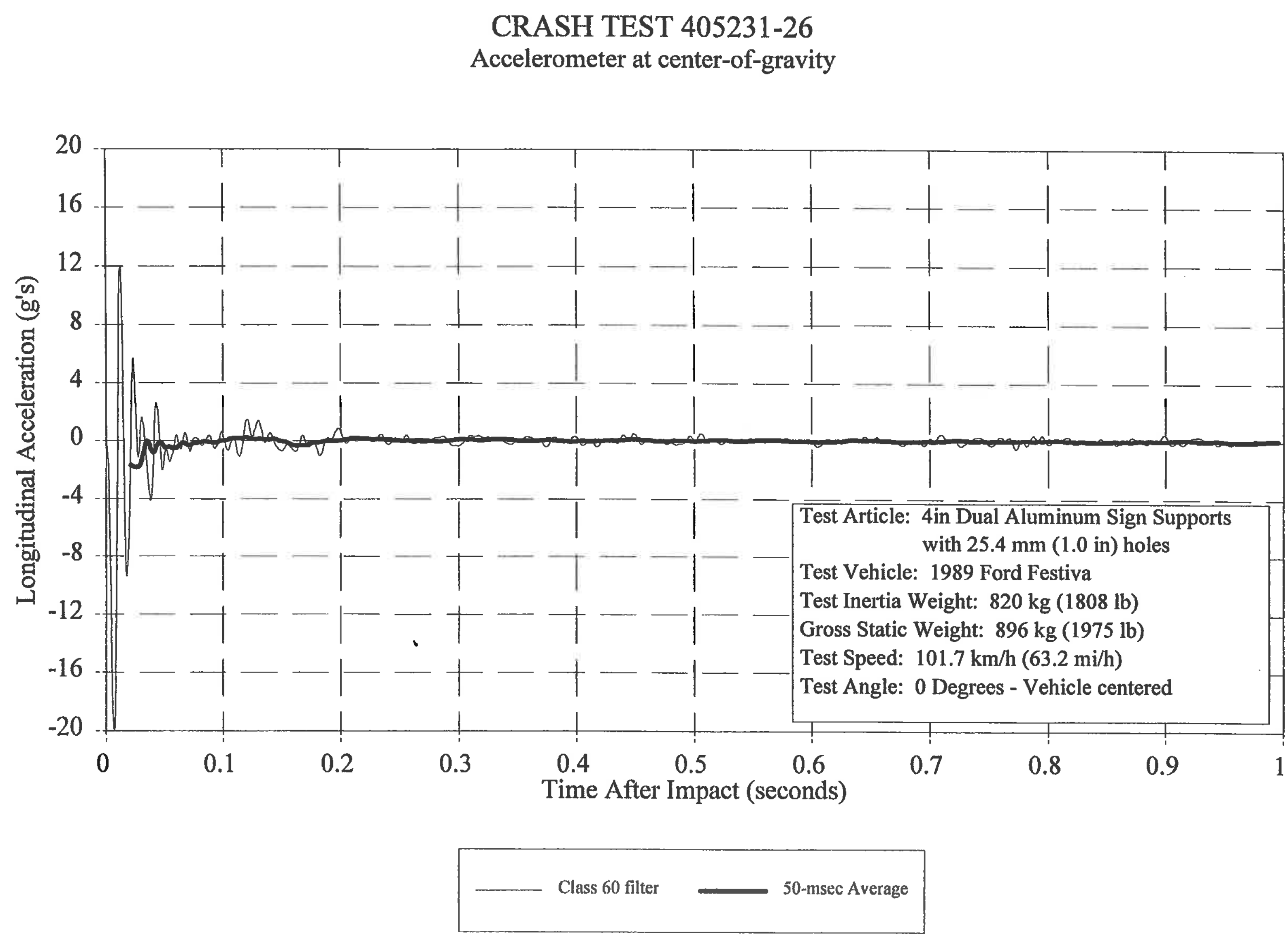


Figure 70. Vehicle longitudinal accelerometer trace for test 405231-26.

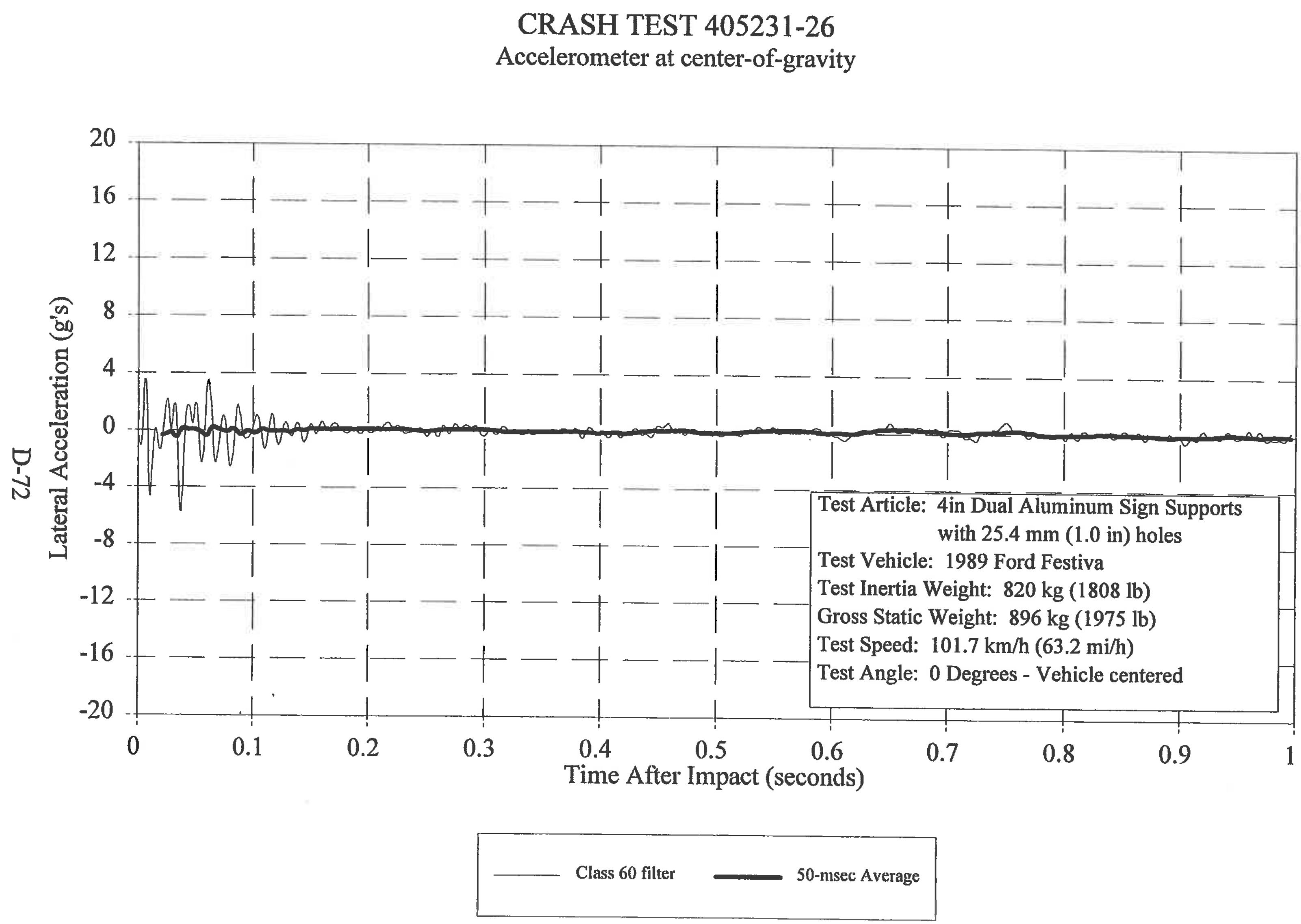


Figure 71. Vehicle lateral accelerometer trace for test 405231-26.

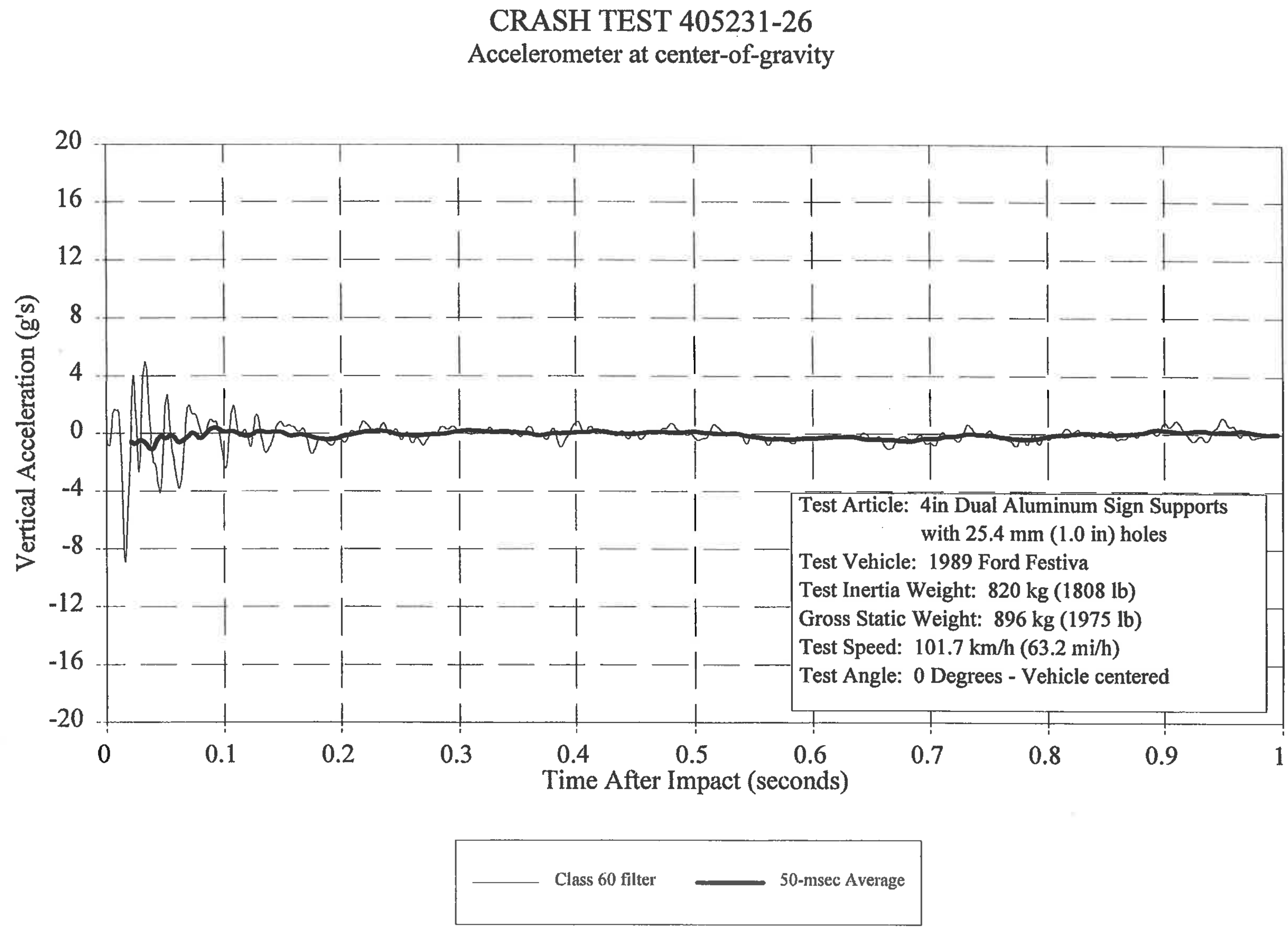


Figure 72. Vehicle vertical accelerometer trace for test 405231-26.