TEXAS TRANSPORTATION INSTITUTE

NCHRP REPORT 350 COMPLIANCE TESTS OF THE ADIEM

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Research Study No. 220517 and 220538

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And

Texas Transportation Institute
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COLLEGE STATION, TEXAS

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16. Abstract

ADIEM, the soft concrete end terminal and crash cushion, is in use in twenty states. The 9.1 m (30-ft) design, which is qualified by FHWA under NCHRP Report 230 for collisions up to 96.5 km/h (60 mph), has been subjected to a broad scope of environmental conditions and many different types of collisions during use across the United States over the past four (4) years.

This report presents additional testing necessary to qualify the ADIEM for NCHRP Report 350 *Recommended Procedures for the Safety Performance Evaluation of Highway Features,* Test Level 3 performance.

Tests conducted previously under NCHRP Report 230 and under the current test program show the acceptable performance of the ADIEM when impacted by errant vehicles. Smooth redirections and controlled stopping of the vehicles has been achieved under the various test configurations. All evaluation criteria outlined in NCHRP Report 350 for the tests conducted have been met.

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Form DOT F 1700.7 (8-69)

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)

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I. INTRODUCTION

ADIEM, the soft concrete end terminal and crash cushion, is in use in twenty states. The 9.1 m (30-ft) design, which is qualified by FHWA under NCHRP Report 230[1] for collisions up to 96.5 km/h (60 mph), has been subjected to a broad scope of environmental conditions and many different types of collisions during use across the United States over the past four (4) years.

This report presents additional testing necessary to qualify ADIEM for NCHRP Report 350 *Recommended Procedures for the Safety Performance Evaluation of Highway Features,* Test Level 3 performance.[2] The full test matrix for Gating Terminals and Redirective Crash Cushions from NCHRP Report 350 is shown below:

1. **Test Designation 3-30**. An 820 kg passenger car impacting the terminal end-on at a nominal speed and angle of 100 km/h and 0 degrees with the quarter-point of the vehicle aligned with the centerline of the nose of the terminal.

2. **Test Designation 3-31**. A 2000 kg pickup truck impacting the terminal end-on at a nominal speed and angle of 100 km/h and 0 degrees with the centerline of the vehicle aligned with the centerline of the nose of the terminal.

3 **Test Designation 3-32**. A 820 kg passenger car impacting the terminal end-on at a nominal speed and angle of 100 km/h and 15 degrees with the center of the front of the vehicle aligned with the center of the nose of the terminal.

4. **Test Designation 3-33**. A 2000 kg pickup truck impacting the terminal end-on at a nominal speed and angle of 100 km/h and 15 degrees with the center of the front of the vehicle aligned with the center of the nose of the terminal.

5. **Test Designation 3-34**. A 820 kg passenger car impacting the terminal at a nominal speed and angle of 100 km/h and 15 degrees mid-point between the end of the terminal and the beginning of the length-of-need.

6. **Test Designation 3-35**. A 2000 kg pickup truck impacting the terminal at a nominal speed and angle of 100 km/h and 20 degrees at the beginning of length-of-need.

7. **Test Designation 3-39**. A 2000 kg pickup truck impacting the terminal at a nominal speed and angle of 100 km/h and 20 degrees mid-point between the end of the terminal and the beginning of length-of-need in the reverse direction.

Tests 3-30 and 3-34 were both run under the previous NCHRP Report 230 testing. Tests 3-32 and 3-33 are judged to be less severe than tests 3-30 and 3-31 (page 18 of NCHRP Report 350) and are therefore not performed. The ADIEM will gate when impacted on the nose with the vehicle at 15 degrees. The remainder of the crash tests in the matrix have been conducted and the performance of the ADIEM under those test conditions is reported here.

II. STUDY APPROACH

TEST ARTICLE

An ADIEM carrier arm base 9.15 m (30.0 ft) was placed behind a standard concrete median barrier (CMB). The base was anchored by twelve 25.4 mm diameter (1.0 in) pins placed at 0.915 m (3.0 ft), 1.83 m (6.0 ft), 1.83 m (6.0 ft), 1.22 m (4.0 ft), 2.44 m (8.0 ft), and 0.305 m (1.0 ft), spacing respectively from the end of the CMB. The current carrier arm base is 0.305 m (1.0 ft) at the nose and tapers for 3.35 m (11.0 ft) back to the original shape as shown in figure 1. The connection brackets were attached to the base with two 28.575 mm (1.125 in) x 609.6 mm (24.0 in) threaded rods. The track is a cold rolled "C" shaped beam from a 4.8 mm (0.1875 in) plate attached to the base with 12.7 mm (0.5 in) Nelson Studs at 152.4 mm (6.0 in) spacing placed 12.7 mm (0.5 in) apart on a 133.35 mm (5.25 in) x 6.35 mm (0.25 in) plate. Two lifting recesses 304.8 mm (1.0 ft) in length were cast under the base at 2.796 m (9.167 ft), and 4.626 m (15.167 ft) spacing respectively. Two square pipe rails 102 mm (4.0 in) x 51 mm (2.0 in) x 4.27 m (14.0 ft) were cast into the sides of the base and attached with nineteen 12.7 mm (0.5 in) x 152.4 mm (6.0 in) Nelson Studs placed at 152.4 mm (6.0 in) or 304.8 mm (12.0 in) spacing.

The track was oiled and ten 901.7 mm (35.5 in) x 279.4 mm (11.0 in) x 609.6 mm (24.0 in) ADIEM lightweight crushable concrete modules were placed end to end. The ADIEM modules were fabricated and cast to meet the same specifications used in all previous NCHRP Report 230 testing. They were production run modules from Flexi-Core, Inc. of Houston, Texas. See figures 1 and 2 for details on the modules. Photographs of the completed installation are shown in figure 3.

NOTE: The only changes made in ADIEM for the NCHRP Report 350 testing are:

1. The 76 mm (3 in) end tapered steel pipe rails on both sides of the carrier arm have been replaced by 51x51x3 mm (2x2x1/8 in) steel tubing with tapered ends.

2. The two S3x7.5 beams forming the center channel into which the soft concrete modules slide have been replaced by a "C"-shaped 76x76x5 mm (3x3x3/16 in) cold rolled form.

3. The nose of the carrier arm has been tapered to a narrower section over the first 0.9 m (3 ft) of carrier arm length from an initial width under the NCHRP Report 230 testing of 610 mm (24 in) to the current width of 305 mm (12 in).

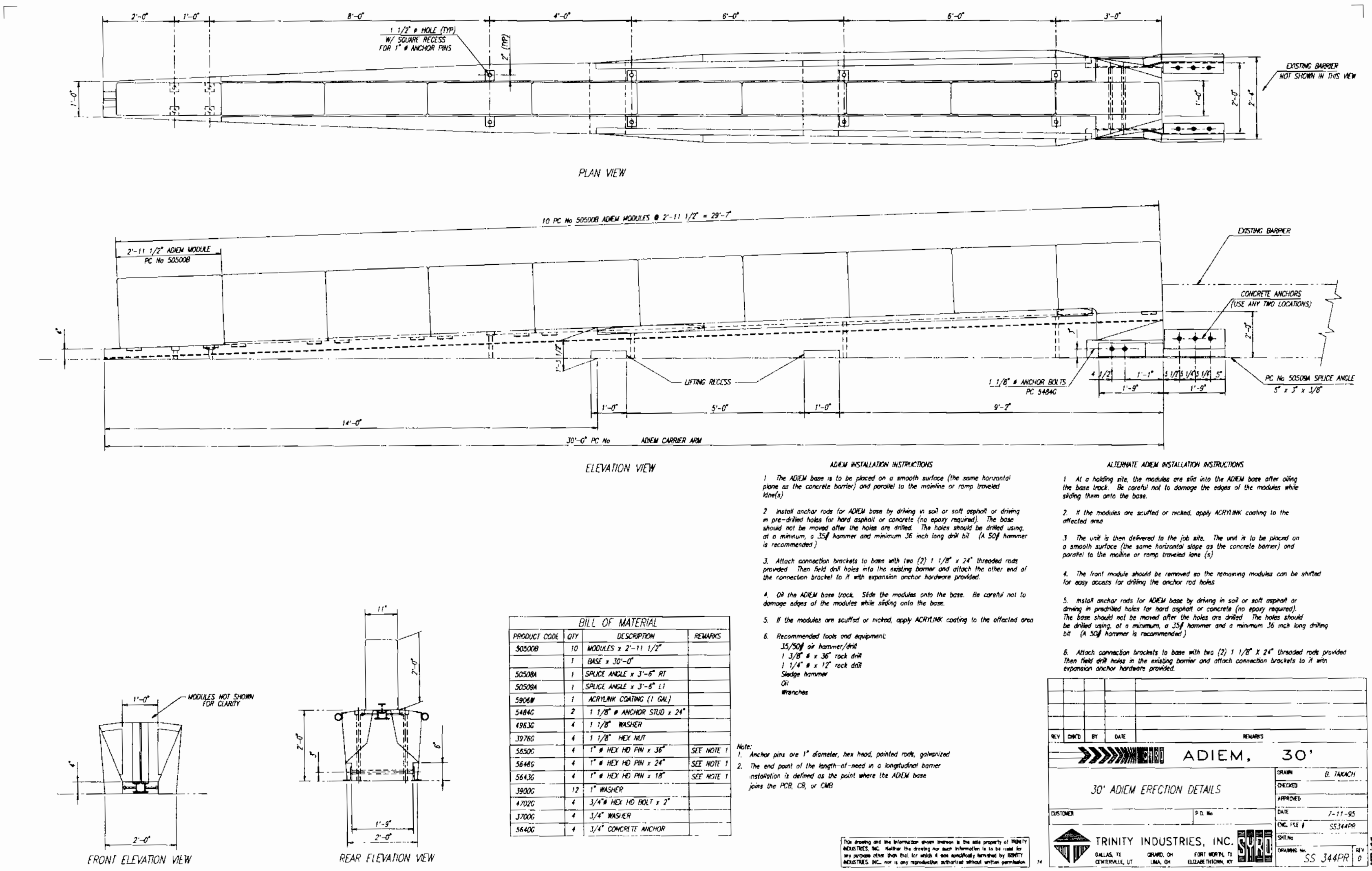

Figure 1. Details of the ADIEM installation.

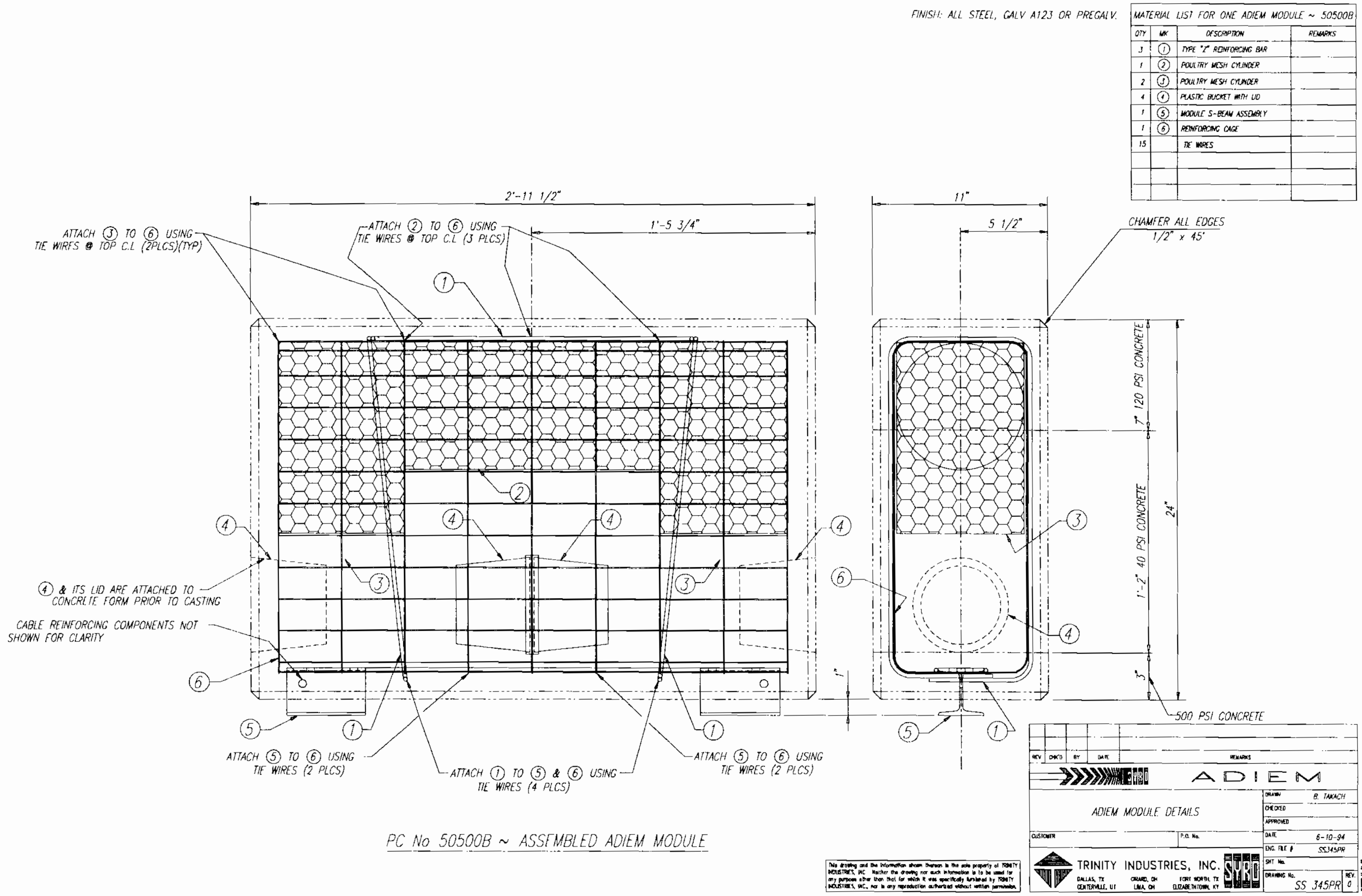

Figure 2. Details of the ADIEM module.

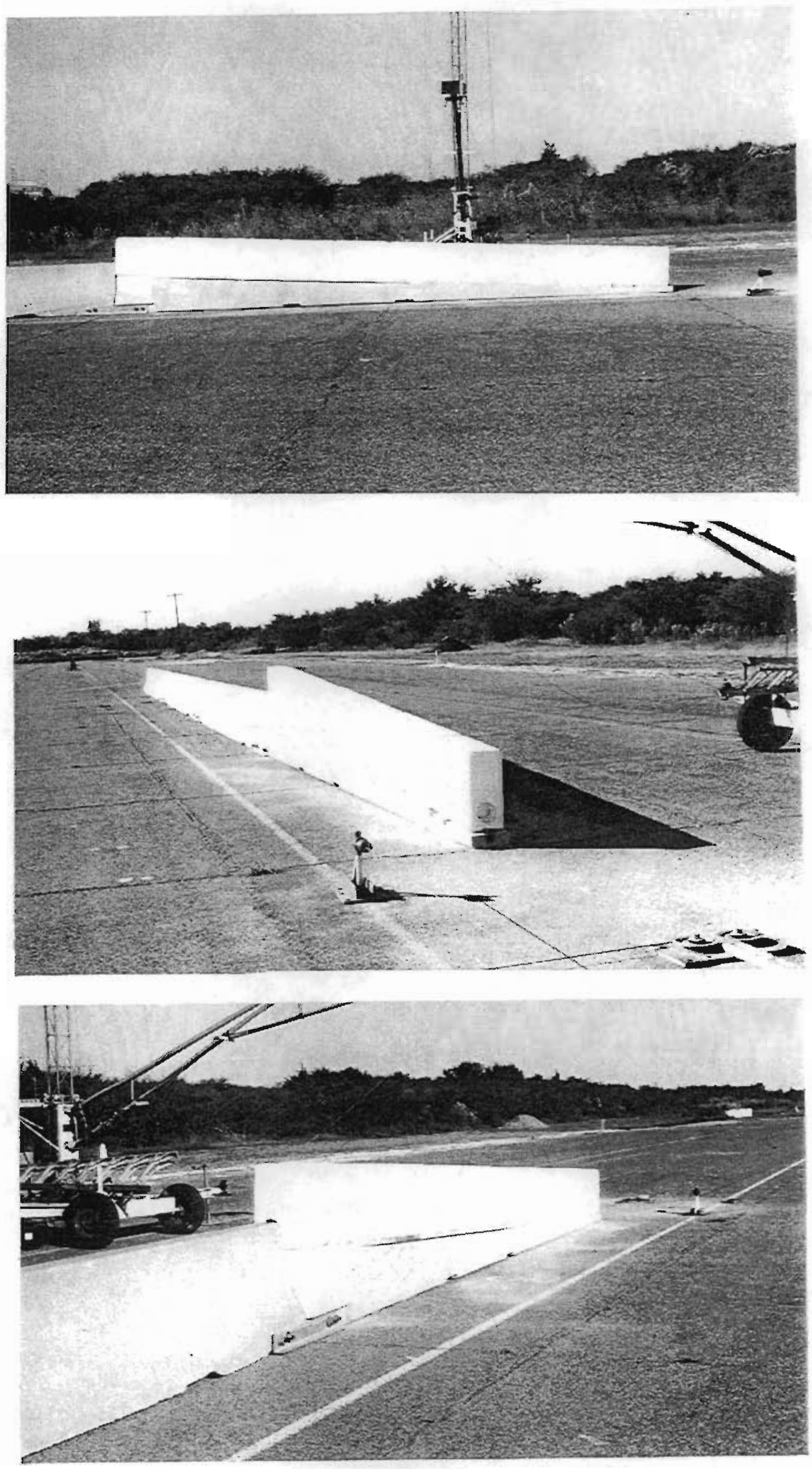

Figure 3. ADIEM installation before testing.

In the cases of changes to the side tubing (1) and locking track (2), computations were performed to satisfy the concern that the strength of the module attachment channel (locking track) would not be compromised. In addition, three NCHRP Report 350 compliance tests illustrate that point for the side tubes and also confirm the computations for the locking track. Test designations 3-35 and 3-39 with 2000P vehicles at 100km/h and 20 degrees on the side of the base (carrier arm), and test designation 3-31 with a 2000P vehicle at 100km/h headon confirmed the appropriate function of the box tube side rails and the holding strength of the locking track.

The final change (3), narrowing the nose of the barrier would make the possibility extremely remote that a "brush" contact on the nose of the barrier could allow a tire to ride up the top surface of the carrier arm. The end point of the length-of-need, as in the original ADIEM terminal, is defined as the connection point of the ADIEM terminal to a longitudinal barrier.

It is believed that these changes have no influence on any of the NCHRP Report 230 tests. As the original designers of this crash cushion, we believe these changes are appropriate from the standpoints of performance, aesthetics, and cost.

CRASH TEST CONDITIONS

According to guidelines presented in NCHRP Report 350, a total of up to seven (7) crash tests may be required for evaluation of a terminal under test level 3 conditions. These are as follows:

1. **Test Designation 3-30**. An 820 kg passenger car impacting the terminal end-on at a nominal speed and angle of 100 km/h and 0 degrees with the quarter-point of the vehicle aligned with the centerline of the nose of the terminal.

2. **Test Designation 3-31**. A 2000 kg pickup truck impacting the terminal end-on at a nominal speed and angle of 100 km/h and 0 degrees with the centerline of the vehicle aligned with the centerline of the nose of the terminal.

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It is the researchers' opinion, however, that only three of the seven crash tests, Test Designations 3-31, 3-35, and 3-39 are necessary to qualify the ADIEM under NCHRP Report 350 guidelines when coupled with four other crash tests which are either very similar to crash tests previously conducted under NCHRP Report 230 guidelines or are deemed unnecessary due to the fact that the ADIEM is being qualified as a gating terminal. Discussions of the rationale for the above opinions follow.

Tests 3-30 and 3-34 were both run with good results under the previous NCHRP Report 230 testing.[3] The ADIEM will gate when impacted on the nose with the vehicle at 15 degrees. This aspect of the ADIEM is similar to other gating devices discussed in NCHRP Report 350. Tests 3-32 and 3-33 are judged to be less severe than tests 3-30 and 3-31 because in test 3-30 the deceleration of the vehicle will be greater in a headon, quarter point hit than the nose hit at 15 degrees. In 3-30, the vehicle was in contact with ADIEM modules for a distance of 3.0 m (9.9 ft), while in 3-32 the contact distance is calculated to be 2.9 m (9.4 ft). The angle also reduces the resistance of each module to some degree. In test 3-33, again the reduction of the length of contact with modules as the 2000P vehicle gates through the nose of the barrier is much less than in 3-30. Tests 3-32 and 3-33 were primarily of interest in the case of so-called nongating cushions and/or terminals.

CRASH TEST AND DATA ANALYSIS PROCEDURES

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

Electronic Instrumentation and Data Processing

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

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

The multiplex of data channels, transmitted on one radio frequency, were received at the data acquisition station, and demultiplexed into separate tracks of Inter-Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with an SAE J211 filter, and digitized using a microcomputer, for analysis and evaluation of impact performance. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are provided as follows.

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

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.00067-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 Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the 820C vehicle. The dummy was un-instrumented. Use of a dummy in the 2000P vehicle is optional according to NCHRP Report 350 and there was no dummy used in the tests with the 2000P vehicle.

Photographic Instrumentation and Data Processing

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

Test Vehicle Propulsion and Guidance

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2 to 1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be freewheeling and unrestrained. The vehicle remained freewheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring the vehicle to a safe and controlled stop.

III. CRASH TEST RESULTS

TEST 220517-8 (NCHRP REPORT 360 TEST 3-39)

A 1989 Ford F-250 pickup truck, shown in figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2000 kg. The height to the lower edge of the vehicle bumper was 450 mm and it was 690 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A, figure 24. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Test Description

The vehicle impacted the ADIEM on the carrier rail midspan of module 5 at a speed and angle of 99.4 km/h and 20.2 degrees in the reverse direction. At 0.016 second, the left front tire contacted the end of the rubrail and base. The vehicle bumper rode up the carrier and contacted module 5 at 0.024 second. At 0.046 second the vehicle contacted module 6 and at 0.048 second the hood rode on top of the module. The vehicle began to redirect at 0.059 second and then made contact with module 7 at 0.075 second. At 0.107 the vehicle contacted module 8 and at 0.146 second contacted module 9. The right side of the vehicle became airborne at 0.173 second and the vehicle contacted module 10 at 0.177 second. At 0.320 second the vehicle wheels lost contact and at 0.455 second the vehicle recontacted the ground. The vehicle lost contact with the ADIEM at 0.456 second, traveling at an exit speed and angle of 83.1 km/h and 6.8 degrees. As the vehicle exited the test site it rotated counterclockwise and subsequently came to rest facing the installation 64 m down and 37 m behind the impact point. Sequential photographs of the test period are shown in Appendix B, figures 27 and 28.

Damage to Test Installation

Modules 1 thru 6 were damaged in the reverse direction hit. Additionally, there was some concrete spalling adjacent to the square tubular member in the impact area. Structural integrity of the carrier arm base was not compromised. As can be seen in figures 6 and 7, there was contact to the base starting next to module 6 and continuing to the nose of the device.

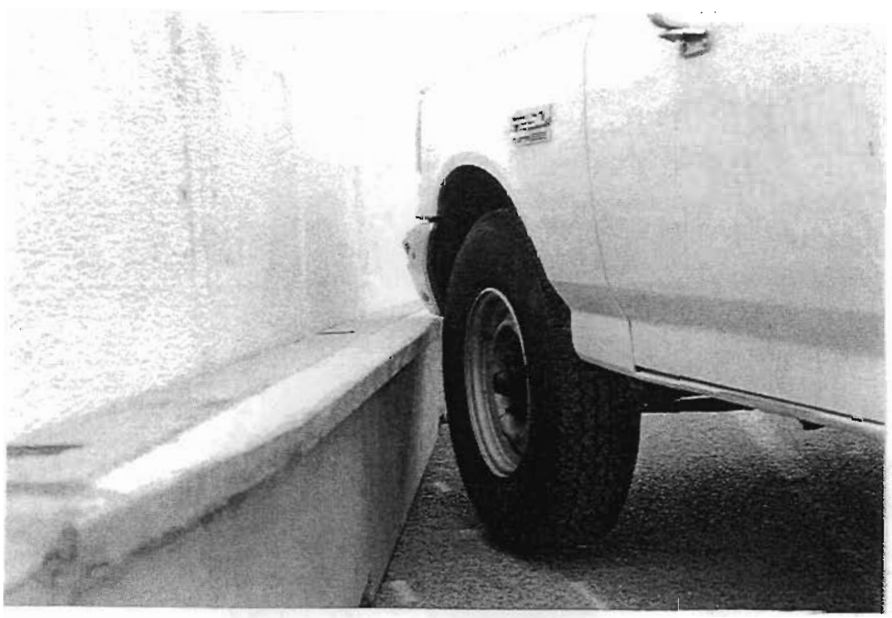


Figure 4. Vehicle/installation geometrics for test 220517-8.

Figure 5. Vehicle before test 220517-8.

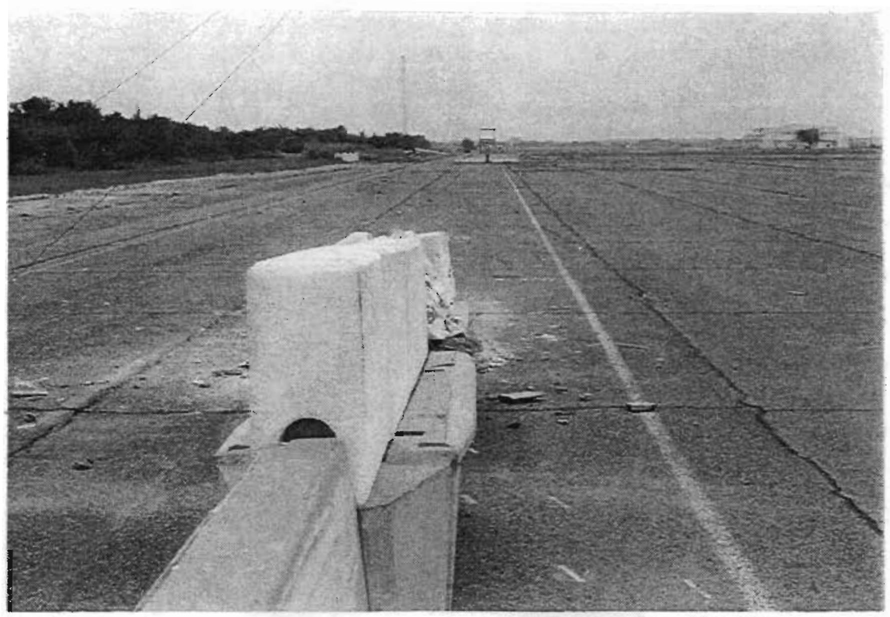
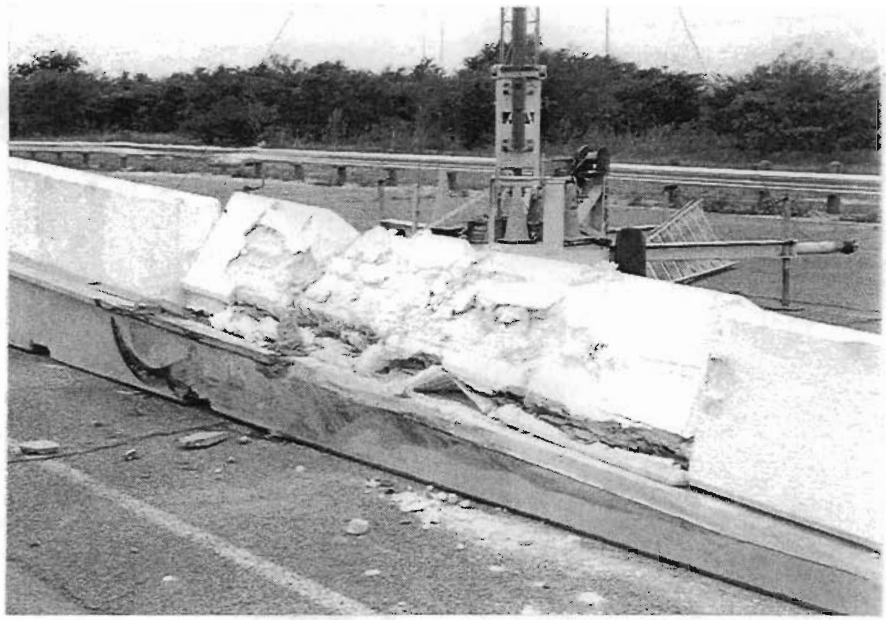


Figure 6. After impact trajectory for test 220517-8.



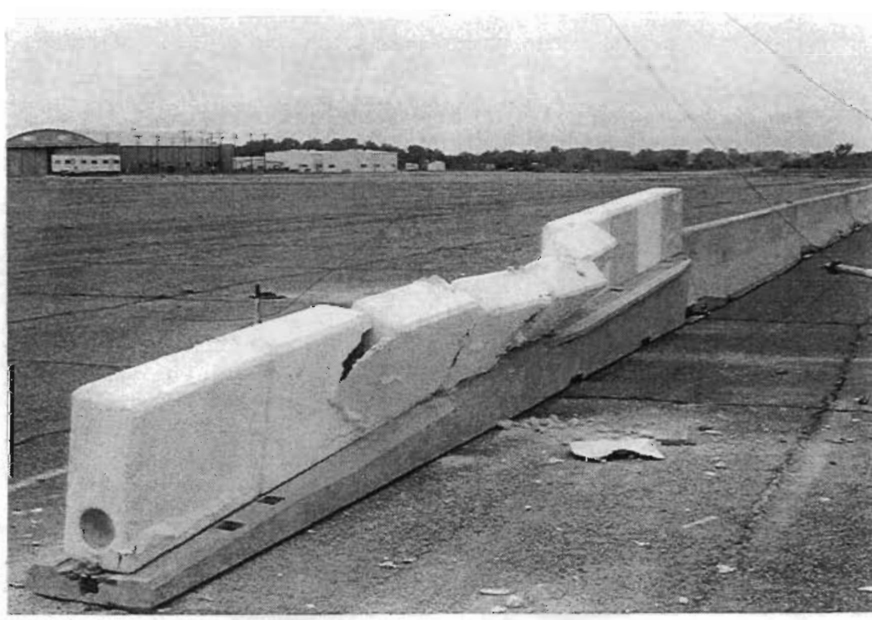


Figure 7. Installation after test 220517-8.

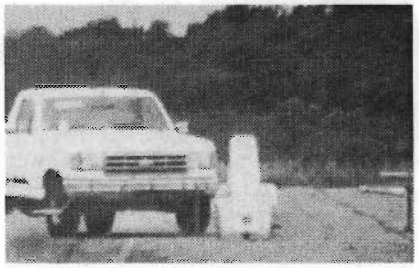
Vehicle Damage

The vehicle received minimal damage as shown in figure 8. The left side twin I-beam and tie rods were bent and the floorpan was buckled. The bumper, grill, fan, radiator, left front quarter panel, left door, and left front wheel were damaged and the windshield was stress cracked. Maximum exterior crush was 180 mm at the left front corner at bumper height. Maximum deformation into the occupant compartment was 21 mm at the left side floorpan.

Occupant Risk Values

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 5.0 m/s at 0.214 second, the highest 0.010-second average ridedown acceleration was -8.6 g from 0.252 to 0.262 second, and the maximum 0.050-second average acceleration was -6.8 g between 0.068 and 0.118 second. In the lateral direction, occupant impact velocity was 5.6 m/s at 0.127 second, the highest 0.010-second average ridedown acceleration was 9.9 g from 0.214 to 0.224 second, and the maximum 0.050-second average acceleration was 9.3 g between 0.068 and 0.118 second. These data and other information pertinent to the test are summarized in figure 9. Vehicle angular displacements during the test period are displayed in Appendix C, figure 33. Vehicle accelerations versus time traces are presented in Appendix D, figures 36 through 38.

Figure 8. Vehicle after test 220517-8.

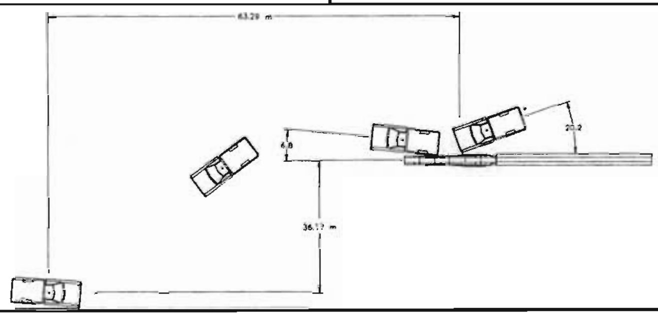


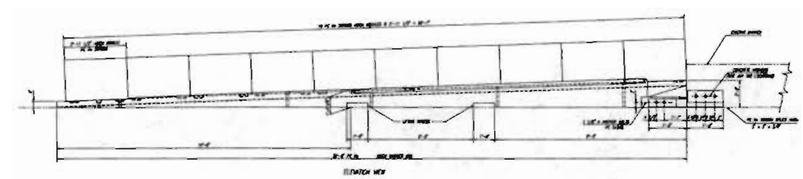
0.000 s

0.131 s

0.262 s

0.393 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	220517-8
Date	05/16/95
Test Article	
Type	Terminal
Name	ADIEM
Installation Length (m)	9.1
Size and/or dimension and material of key elements	10 each 902 mm long x 279 mm wide x 610 mm high Perlite concrete modules on carrier
Soil Type and Condition	Concrete pavement, dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Ford F250 Pickup
Mass (kg) Curb	2049
Test Inertial	2000
Dummy	No Dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	99.4
Angle (deg)	20.2
Exit Conditions	
Speed (km/h)	83.1
Angle (deg)	6.8
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.0
y-direction	-5.6
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-8.6
y-direction	9.9
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-6.8
y-direction	9.3
z-direction	-3.9

Test Article Deflections (m)	
Dynamic	N/A
Permanent	0.12
Vehicle Damage	
Exterior	
VDS	11LFQ3
CDC	11FLEW3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	180
Max. Occ. Compart. Deformation (mm)	21
Post-Impact Behavior	
Max. Roll Angle (deg)	-32.3
Max. Pitch Angle (deg)	4.1
Max. Yaw Angle (deg)	14.7

Figure 9. Summary of results for test 220517-8.

TEST 220538-9 (NCHRP REPORT 350 TEST 3-31)

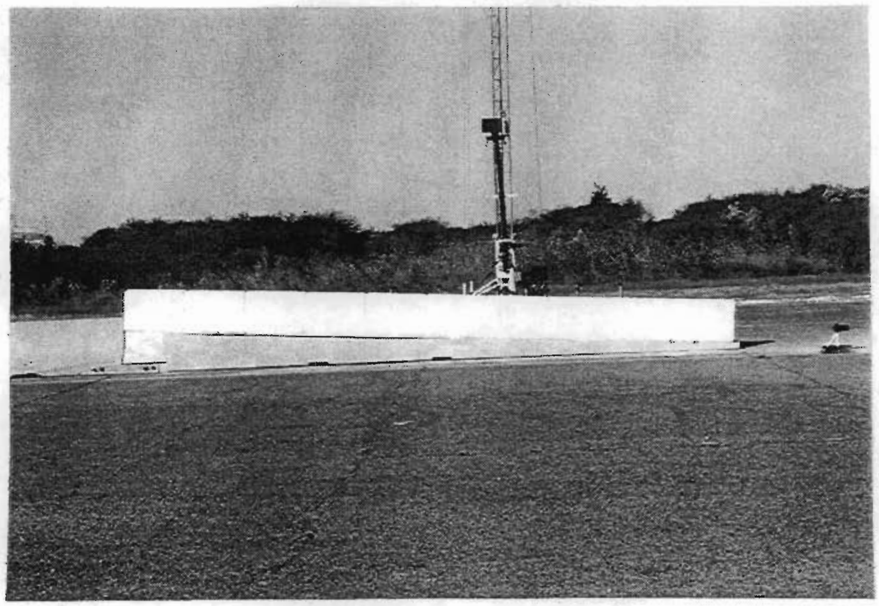
The ADIEM installation was repaired as shown in figure 10 and used for the second test. A 1989 Ford F-250 pickup truck, shown in figures 11 and 12, was used for this crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2000 kg. The height to the lower edge of the vehicle bumper was 425 mm and it was 690 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A, figure 25. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Test Description

The vehicle, traveling at a speed and angle of 100.3 km/h and 0.4 degrees, impacted the ADIEM end-on, centerline of the vehicle aligned with the centerline of the installation. At 0.017 second the movement of the first module was detected, and at 0.024 second movement at the second module was noted. The first two modules began deforming at 0.027 second as movement was noted at modules 3 through 8. At 0.041 second, modules 9 and 10 were moving, and at 0.049 second module 9 began deforming at the rear. Module 10 began deforming at the rear at 0.056 second, and module 8 at the front at 0.061 second. At 0.066 second, the vehicle had traveled into the ADIEM 1.8 m and had slowed to a speed of 82.2 km/h. As the vehicle continued forward, modules 3 through 7 crushed. The modules slowed the vehicle gradually to 70.5 km/h at 2.7 m (0.107 second), 66.5 km/h at 3.7 m (0.151 second), 60.3 km/h at 4.6 m (0.202 second), 53.1 km/h at 5.5 m (0.261 second), 46.0 km/h at 6.4 m (0.322 second), 37.0 km/h at 7.3 m (0.398 second), and 13.8 km/h at 8.2 m. The vehicle stopped astradle to the carrier at 0.598 second. Sequential photographs of the test period are shown in Appendix B, figures 29 and 30.

Damage to Test Installation

Damage to the ADIEM installation is shown in figures 13 and 14. All ten modules were consumed in absorbing the kinetic energy. There was minor contact from the undercarriage of the pickup to the top face of the carrier arm base. The base was used on the subsequent test. One module was wedged free of the carrier arm and moved 3.5 m to the rear of the base and adjacent to the median barrier.



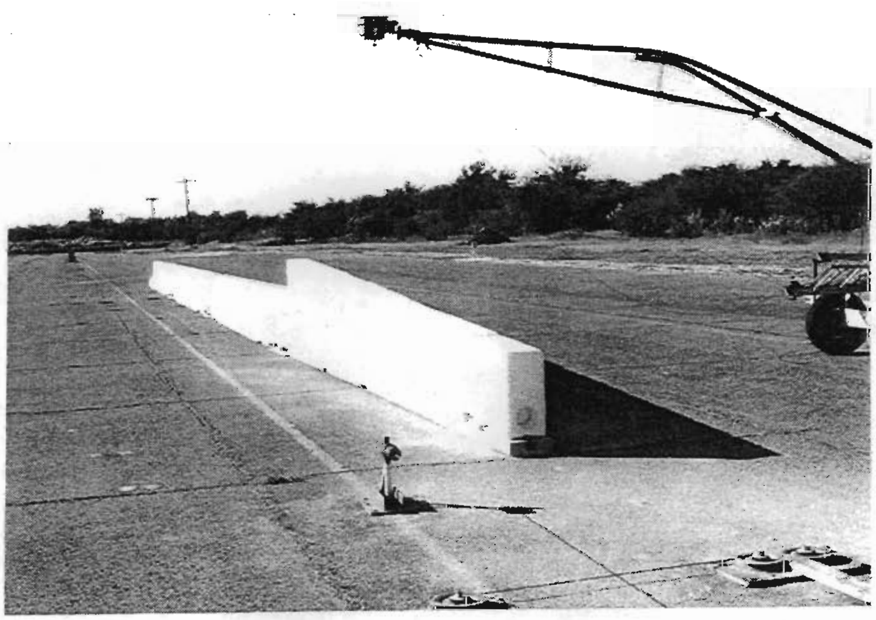


Figure 10. ADIEM installation before test 220538-9.

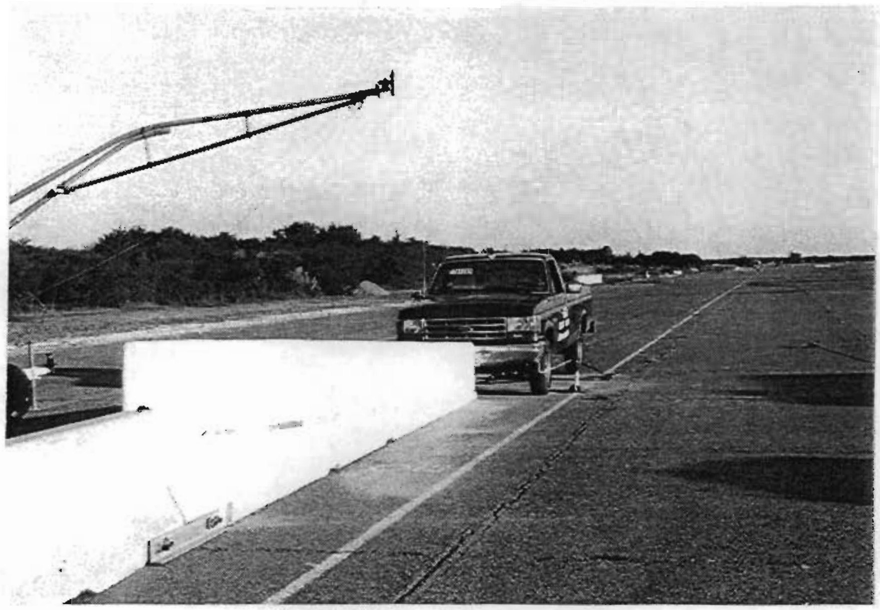


Figure 11. Vehicle/installation geometrics for test 220538-9.

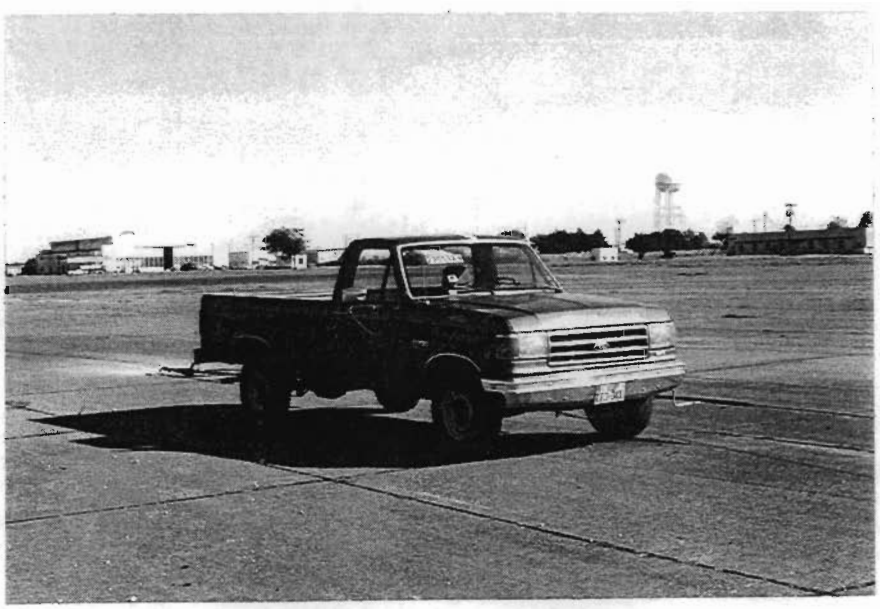


Figure 12. Vehicle before test 220538-9.

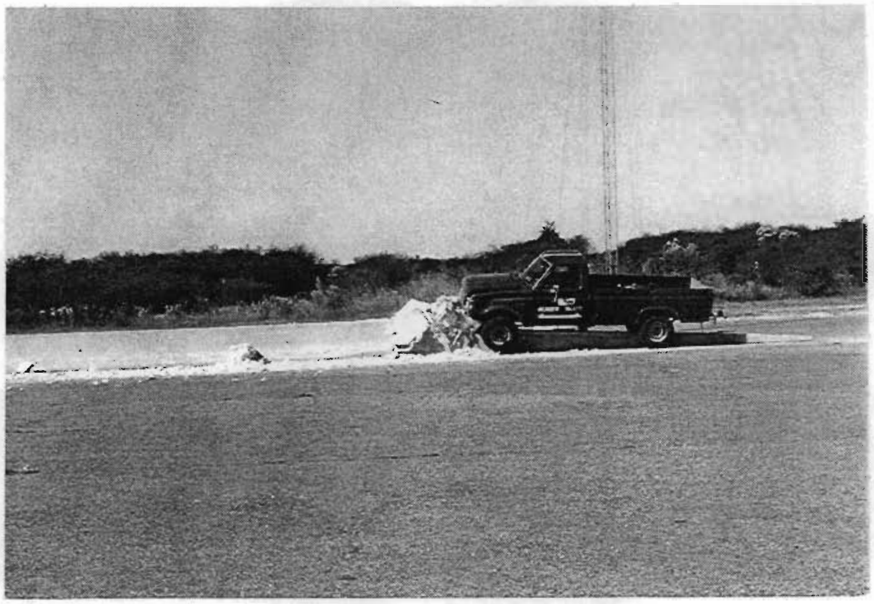


Figure 13. After impact trajectory for test 220538-9.

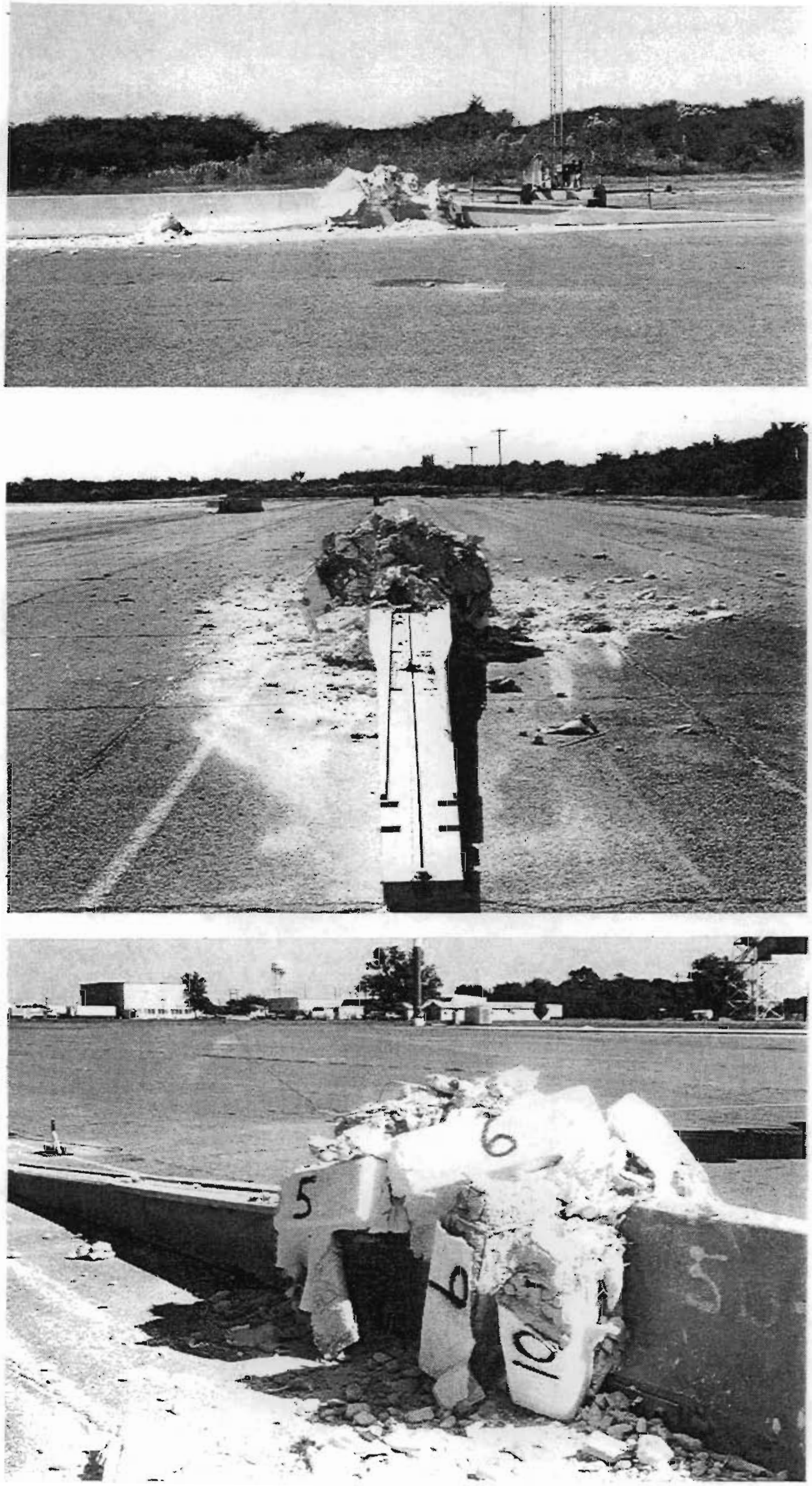


Figure 14. Installation after test 220538-9.

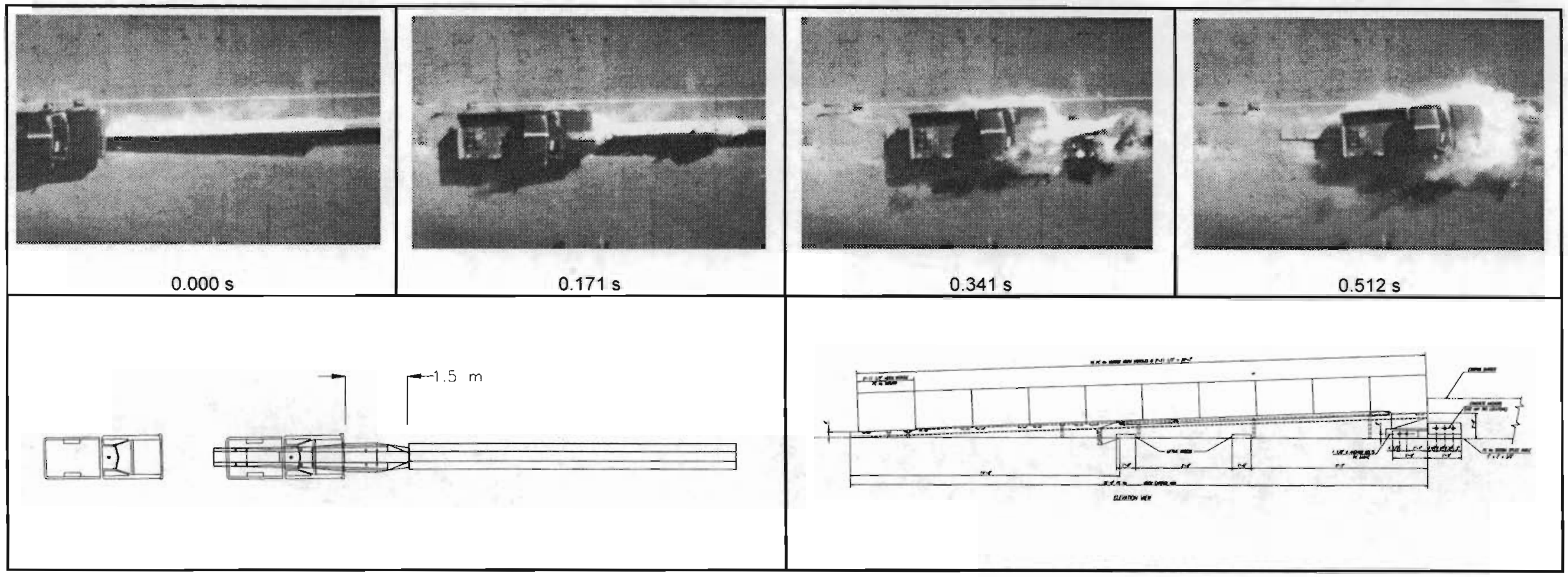
Vehicle Damage

The vehicle received moderate damage as shown in figure 15. The twin I-beam and right side frame were bent and the rode ends and center link were damaged. Also damaged were the bumper and supports, grill, fan, radiator, hood, and left and right doors. Maximum crush to the center front of the vehicle was 550 mm. Maximum deformation into the occupant compartment was 25 mm at the center of the instrument panel.

Occupant Risk Values

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 8.9 m/s at 0.140 second, the highest 0.010-second average ridedown acceleration was -9.6 g from 0.489 to 0.499 second, and the maximum 0.050-second average acceleration was -10.7 g between 0.044 and 0.094 second. In the lateral direction, occupant impact velocity was 0.7 m/s at 0.403 second, the highest 0.010-second average ridedown acceleration was -6.1 g from 0.460 to 0.470 second, and the maximum 0.050-second average acceleration was -6.1 g between 0.057 and 0.107 second. These data and other information pertinent to the test are summarized in figure 16. Vehicle angular displacements during the test period are displayed in Appendix C, figure 34. Vehicle accelerations versus time traces are presented in Appendix D, figures 39 through 41.

Figure 15. Vehicle after test 220538-9.



General Information	
Test Agency	Texas Transportation Institute
Test No.	220538-9
Date	10/24/95
Test Article	
Type	Terminal
Name	ADIEM
Installation Length (m)	9.1
Size and/or dimension and material of key elements	10 each 902 mm long x 279 mm wide x 610 mm high Perlite concrete modules on carrier
Soil Type and Condition	Concrete pavement, dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Ford F250 Pickup
Mass (kg) Curb	1960
Test Inertial	2000
Dummy	No dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	100.3
Angle (deg)	0.4
Exit Conditions	
Speed (km/h)	Stopped
Angle (deg)	1.0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	8.9
y-direction	0.7
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-9.6
y-direction	-6.1
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-10.7
y-direction	-6.1
z-direction	0.8

Test Article Deflections (m)	
Dynamic	6.4
Permanent	6.4
Vehicle Damage	
Exterior	
VDS	12FC4
CDC	12FCEN3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	550
Max. Occ. Compart. Deformation (mm)	25
Post-Impact Behavior	
Max. Roll Angle (deg)	-23.8
Max. Pitch Angle (deg)	9.5
Max. Yaw Angle (deg)	-1.5

Figure 16. Summary of results for test 220538-9.

TEST 220538-10 (NCHRP REPORT 350 TEST 3-35)

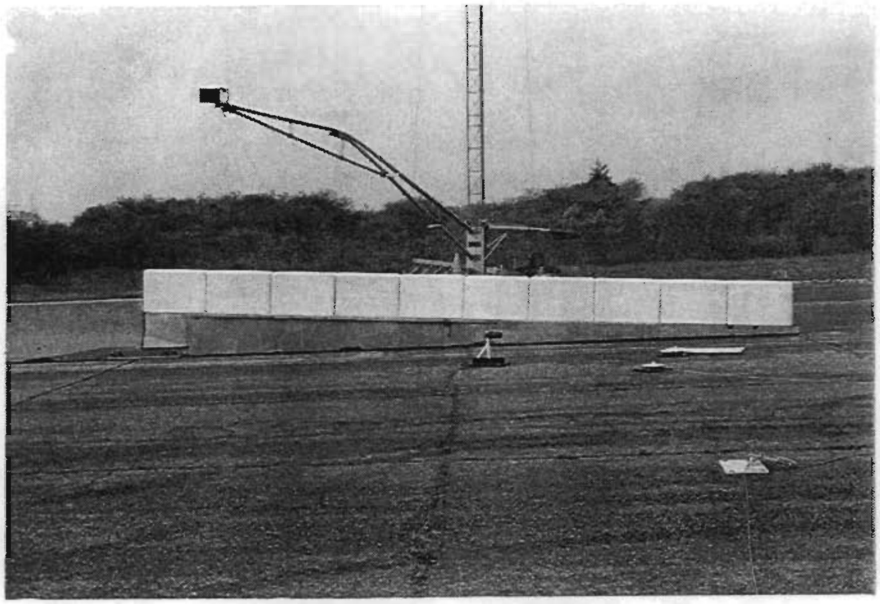
The ADIEM installation was repaired as shown in figure 17 and used for the third test. A 1990 Ford F-250 pickup truck, shown in figures 18 and 19, was used for this crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2000 kg. The height to the lower edge of the vehicle bumper was 460 mm and it was 720 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A, figure 26. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Test Description

The vehicle, traveling at a speed and angle of 100.5 km/h and 20.5 degrees, impacted module 6 of the ADIEM at the joint between modules 5 and 6. At 0.007 the bumper contacted module 7 and at 0.038 second module 8. Vehicle redirection began at 0.072 second, contact with module 9 occurred at 0.074 second as the vehicle began to rise up. At 0.111 second, the vehicle contacted module 10 and at 0.140 second the vehicle wheels lost contact. The vehicle became parallel with the ADIEM at 0.183 second traveling at a speed of 86.2 km/h. As the vehicle continued to rise, the left front reached a maximum height of 823 mm above the ground at 0.293 second. Loss of contact with the ADIEM occurred at 0.327 second with the vehicle traveling at 85.6 km/h and an exit angle of 1.1 degrees. Brakes on the vehicle were applied at 2.1 second after impact and the vehicle yawed clockwise subsequently coming to rest 89 m downstream and 17 m laterally from the point of impact. Sequential photographs during the test period are shown in Appendix B, figures 31 and 32.

Damage to Test Installation

As can be seen in figures 20 and 21, modules 6 through 10 were damaged during the impact. Concrete adjacent to the base of several anchor pins was chipped when the installation rotated slightly due to impact. Structural integrity was not compromised. Additionally, some cosmetic damage was sustained on the concrete impact face of the base.



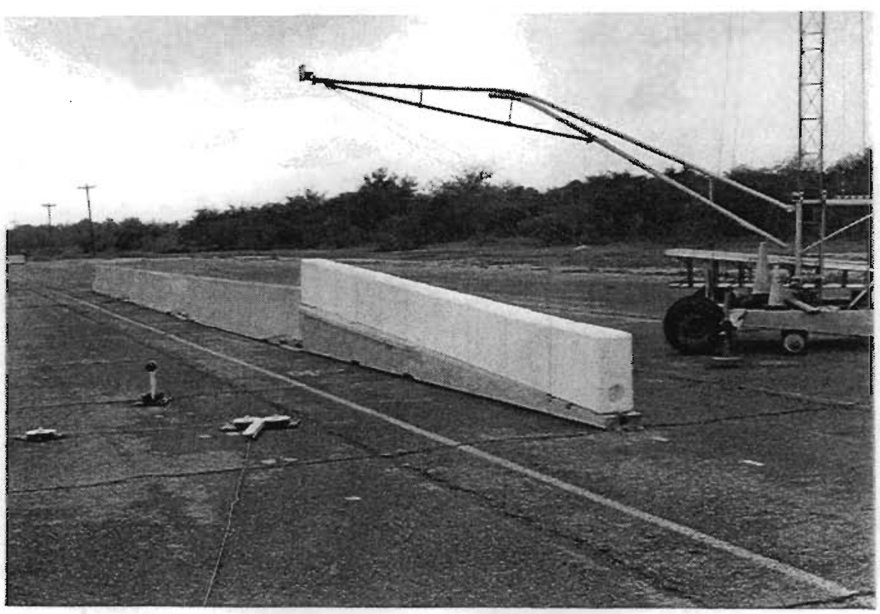


Figure 17. ADIEM installation before test 220538-10.

Figure 18. Vehicle/installation geometrics for test 220538-10.

Figure 19. Vehicle before test 220538-10.

Figure 20. After impact trajectory for test 220538-10.

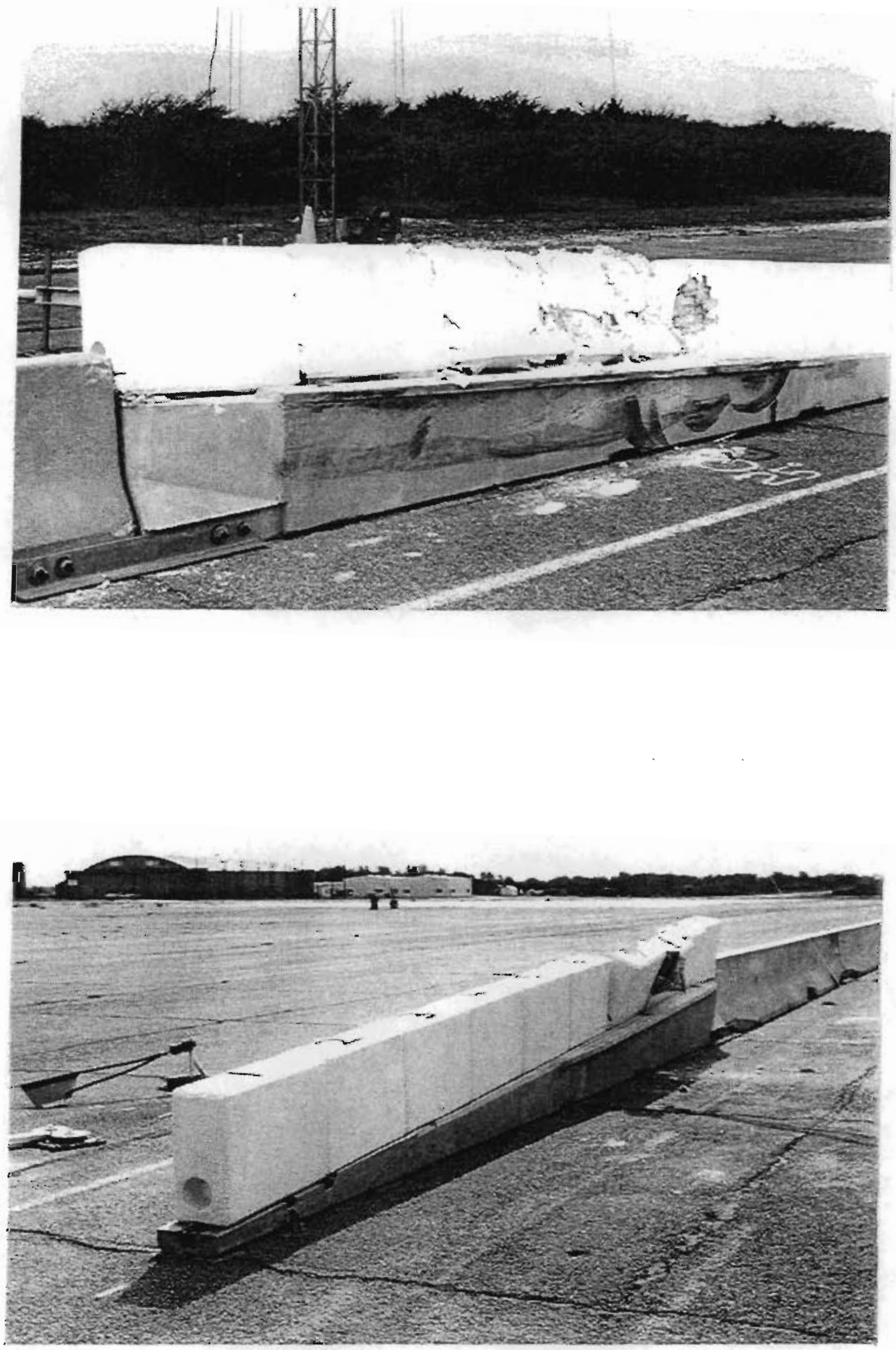


Figure 21. Installation after test 220538-10.

Vehicle Damage

The right front corner of the vehicle received moderate damage as shown in figure 22. The right twin I-beam and frame rail were bent. The front bumper, hood, grill, right front quarter panel, right front and rear rims, and right door were damaged and the windshield was stress cracked. Maximum exterior crush to the right front corner at bumper height was 260 mm. Maximum deformation into the occupant compartment was 18 mm on the right side firewall area.

Occupant Risk Values

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 5.3 m/s at 0.187 second, the highest 0.010-second average ridedown acceleration was -7.6 g from 0.202 to 0.212 second, and the maximum 0.050-second average acceleration was -5.7 g between 0.044 and 0.094 second. In the lateral direction, occupant impact velocity was 1.9 m/s at 0.228 second, the highest 0.010-second average ridedown acceleration was -15.2 g from 0.202 to 0.212 second, and the maximum 0.050-second average acceleration was -6.9 g between 0.052 and 0.102 second. These data and other information pertinent to the test are summarized in figure 23. Vehicle angular displacements during the test period are displayed in Appendix C, figure 35. Vehicle accelerations versus time traces are presented in Appendix D, figures 42 through 44.

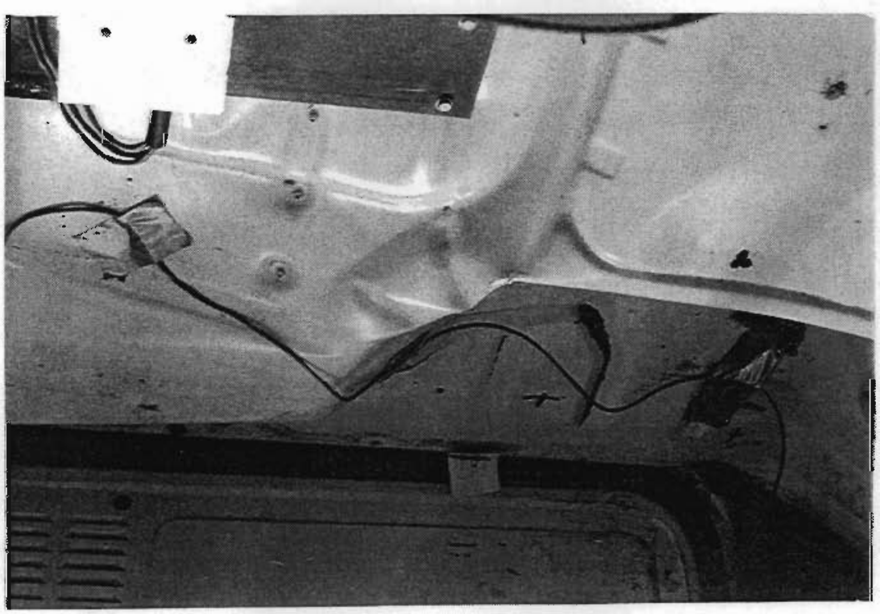
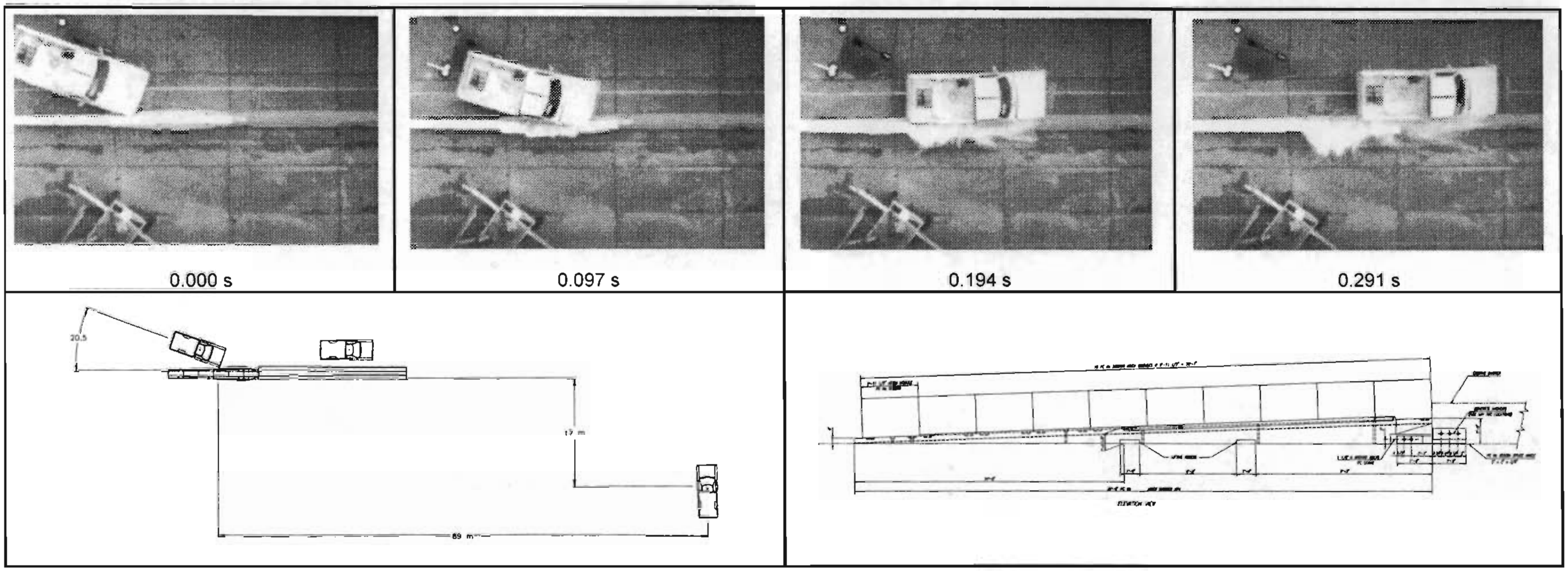


Figure 22. Vehicle after test 220538-10.



General Information	
Test Agency	Texas Transportation Institute
Test No.	220538-10
Date	11/02/95
Test Article	
Type	Terminal
Name	ADIEM
Installation Length (m)	9.1
Size and/or dimension and material of key elements	10 each 902 mm long x 279 mm wide x 610 mm high Perlite concrete modules on carrier
Soil Type and Condition	Concrete pavement, dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1990 Ford F250 Pickup
Mass (kg) Curb	2000
Test Inertial	2000
Dummy	No dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	100.5
Angle (deg)	20.5
Exit Conditions	
Speed (km/h)	85.6
Angle (deg)	1.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.3
y-direction	1.9
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-7.6
y-direction	-15.2
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-5.7
y-direction	-6.9
z-direction	-8.9

Test Article Deflections (m)	
Dynamic	0.5
Permanent	0.3
Vehicle Damage	
Exterior	
VDS	01RFQ2
CDC	01FREW3
Interior	
OCDI	FS0001000
Maximum Exterior Vehicle Crush (mm)	260
Max. Occ. Compart. Deformation (mm)	18
Post-Impact Behavior	
Max. Roll Angle (deg)	25.9
Max. Pitch Angle (deg)	6.8
Max. Yaw Angle (deg)	-23.4

Figure 23. Summary of results for test 220538-10.

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

SUMMARY OF FINDINGS

The ADIEM performed as designed during all crash tests. The vehicles remained upright and trajectories were acceptable. The impact on the nose of the device resulted in a controlled complete stop. Occupant compartment deformations were minimal. Occupant risk values for both contact velocity and ridedown accelerations were all within limits set forth in NCHRP Report 350. Evaluation of the test results are presented in tables 1 though 3.

CONCLUSIONS

Tests conducted previously under NCHRP Report 230 and under the current test program show the acceptable performance of the ADIEM when impacted by errant vehicles.[(3)] Smooth redirections and controlled stopping of the vehicles has been achieved under the various test configurations. All evaluation criteria outlined in NCHRP Report 350 for the tests conducted have been met.

Table 1. Performance evaluation summary for test 220517-8, NCHRP Report 350 Test 3-39.

Test Agency: Texas Transportation Institute | Test No.: 220517-8 | Test Date: 05/12/95

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The ADIEM performed satisfactorily by redirecting the vehicle.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to show potential for penetrating the occupant compartment or to cause undue hazard to others in the area. Deformation of the occupant compartment was minimal (21 mm).	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 during and after the collision period.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.	Longitudinal occupant impact velocity = 5.0 m/s Longitudinal occupant ridedown acceleration = -8.6 G	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact with the ADIEM was 6.8 degrees which was less than 60 percent of the impact angle.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest behind the installation.	Pass

Table 2. Performance evaluation summary for test 220538-9, NCHRP Report 350 Test 3-31.

Test Agency: Texas Transportation Institute | Test No.: 220538-9 | Test Date: 10/24/95

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The ADIEM performed satisfactorily by controlled stopping of the vehicle.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	All debris from the ADIEM was soft and crushed exhibiting no potential for penetrating the occupant compartment nor causing undue hazard to others in the area. Deformation of the occupant compartment was minimal (25 mm).	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 collision period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and lateral / 9 / 12	Longitudinal occupant impact velocity = 8.9 m/s Lateral occupant impact velocity = 0.7 m/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 = -9.6 G Lateral occupant ridedown acceleration = -6.1 G	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle remained in contact with the ADIEM.	N/A

Table 3. Performance evaluation summary for test 220538-10, NCHRP Report 350 Test 3-35.

Test Agency: Texas Transportation Institute | Test No.: 220538-10 | Test Date: 11/02/95

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The ADIEM contained and redirected the vehicle. The vehicle did not penetrate, nor go over or under the installation.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to show potential for penetrating the occupant compartment or to cause undue hazard to others in the area. Deformation into the occupant compartment was minimal (18 mm).	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 during and after the collision period.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.	Longitudinal occupant impact velocity = 5.3 m/s Longitudinal occupant ridedown acceleration = -7.6 G	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact with the ADIEM was 1.1 degrees which was less than 60 percent of the impact angle.	Pass

REFERENCES

1. J. D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, Transportation Research Board, Washington, D.C., 1980.

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

3. Don L. Ivey and Mark A. Marek, "ADIEM: Low-Cost Terminal for Concrete Barriers," Transportation Research Record 1367, Transportation Research Board, Washington, D.C., December 1993.

APPENDIX A. VEHICLE PROPERTIES

This section provides additional dimensions and information on vehicles used for the crash tests performed under this study.

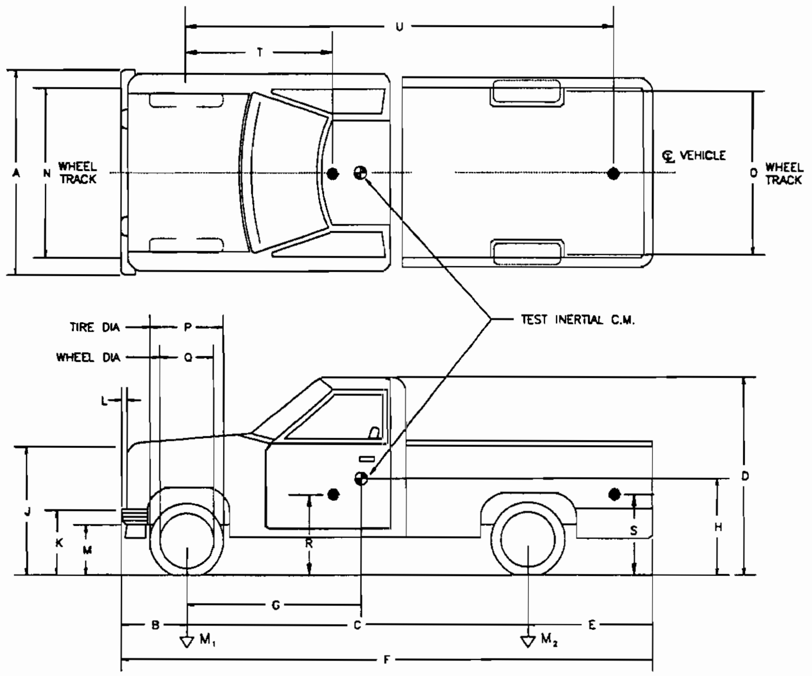
DATE: 05/12/95 TEST NO.: 220517-8 VIN NO.: 1FTHF25H8KNB48298

YEAR: 1989 MAKE: FORD MODEL: F250

TIRE INFLATION PRESSURE: ______ ODOMETER: 02104 TIRE SIZE: LT23585R16

MASS DISTRIBUTION (kg) LF 551 RF 580 LR 427 RR 442

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES:

ENGINE TYPE: 8 CYL EFI

ENGINE CID: 5.8 L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY - (mm)

A 1910	E 1280	J 1210	N 1670	R 770
B 760	F 5420	K 690	O 1635	S 1070
C 3380	G 1468.6	L 75	P 820	T 1480
D 1870	H	M 450	Q 450	U 4160

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1183	1131	
M_2	866	869	
M_T	2049	2000	

Figure 24. Vehicle properties for test 220517-8.

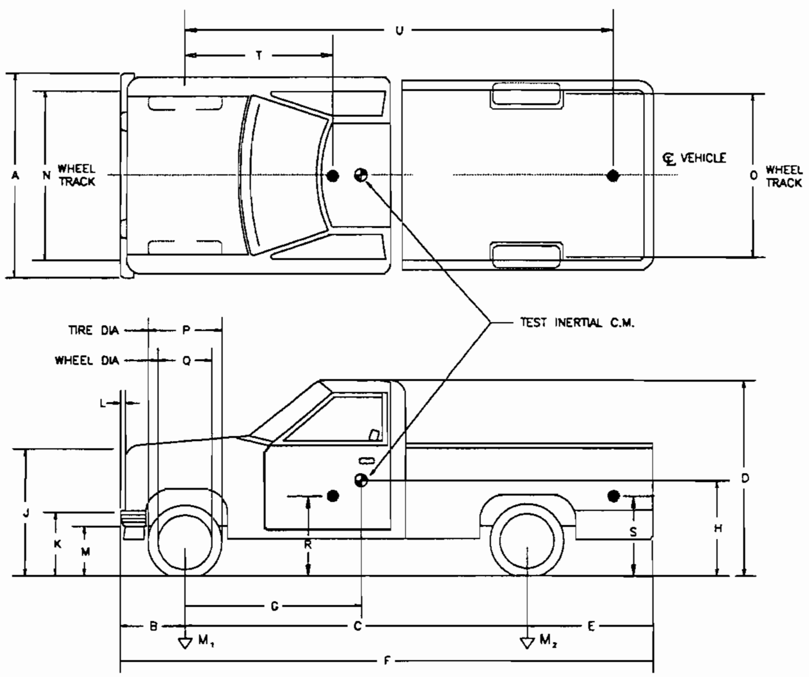
DATE: 10-24-95 TEST NO.: 220538-9 VIN NO.: 1FTEF25Y1KNA24425

YEAR: 1989 MAKE: FORD MODEL: F250 P/U

TIRE INFLATION PRESSURE: ______ ODOMETER: 22508 TIRE SIZE: LT 215 85R16

MASS DISTRIBUTION (kg) LF 549 RF 556 LR 457 RR 438

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 6 CYL

ENGINE CID: 4.9 L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY - (mm)

A 1900	E 1250	J 4485	N 1690	R 1500
B 770	F 5400	K 690	O 1640	S 920
C 3380	G 1512.6	L 85	P 770	T 1500
D 1860	H	M 425	Q 445	U 4020

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1125	1105	
M_2	835	895	
M_T	1960	2000	

Figure 25. Vehicle properties for test 220538-9.

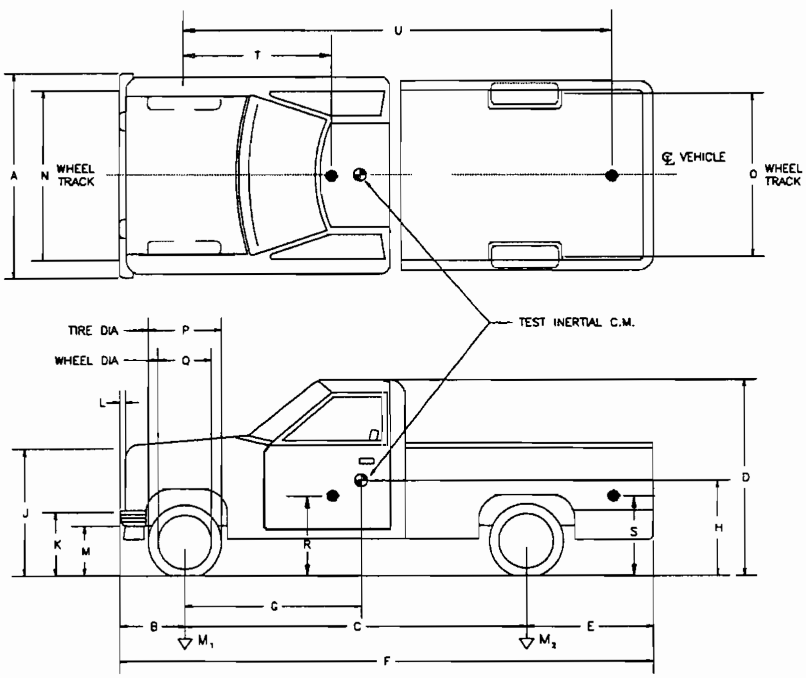
DATE: 11-02-95 TEST NO.: 220538-10 VIN NO.: 1FTHF25H8KKB01662

YEAR: 1990 MAKE: FORD MODEL: F250 P/U

TIRE INFLATION PRESSURE: ______ ODOMETER: 58673 TIRE SIZE: LT 235 85R16

MASS DISTRIBUTION (kg) LF 556 RF 566 LR 435 RR 443

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL

ENGINE CID: 5.8 L

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY - (mm)

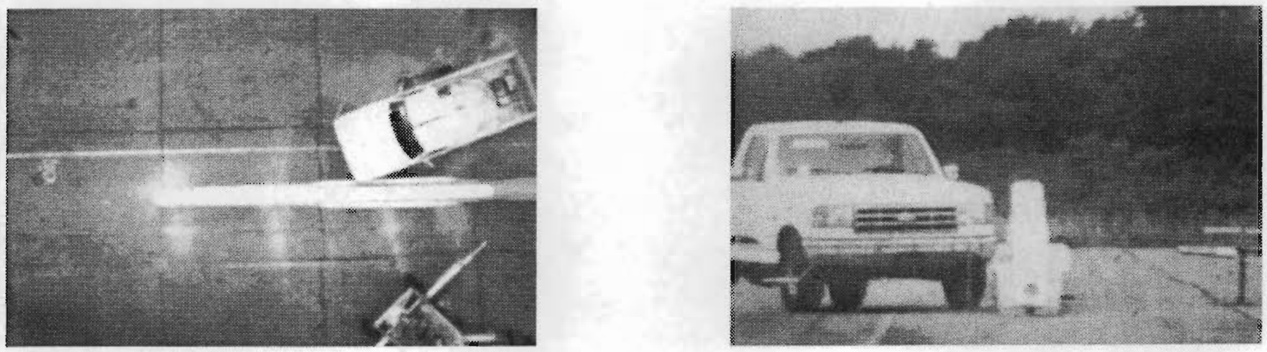
A	1900	E	1360	J	1220	N	1660	R	780
B	760	F	5490	K	720	O	1640	S	930
C	3370	G	1479.4	L	80	P	810	T	1490
D	1870	H		M	460	Q	445	U	3930

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1130	1122	
M_2	868	878	
M_T	2000	2000	

Figure 26. Vehicle properties for test 220538-10.

APPENDIX B. SEQUENTIAL PHOTOGRAPHS

This section contains photographs taken from high speed film during the test sequence of the crash tests performed under this study.



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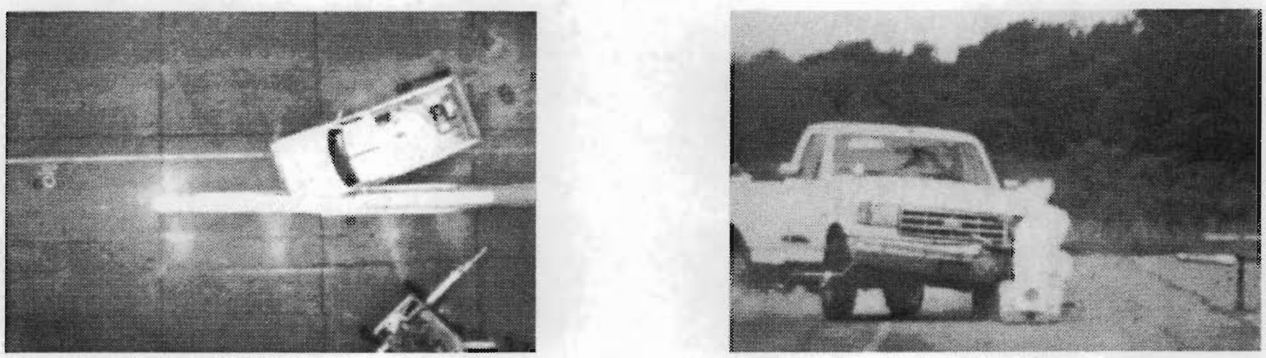

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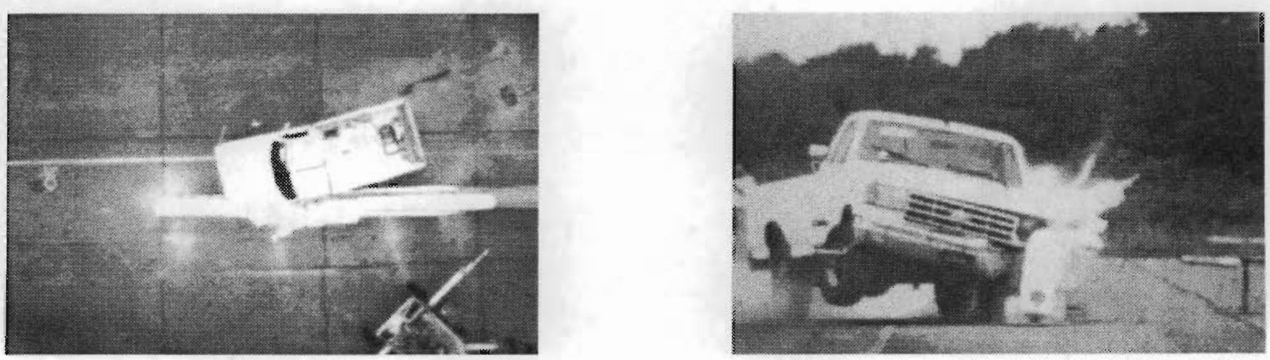

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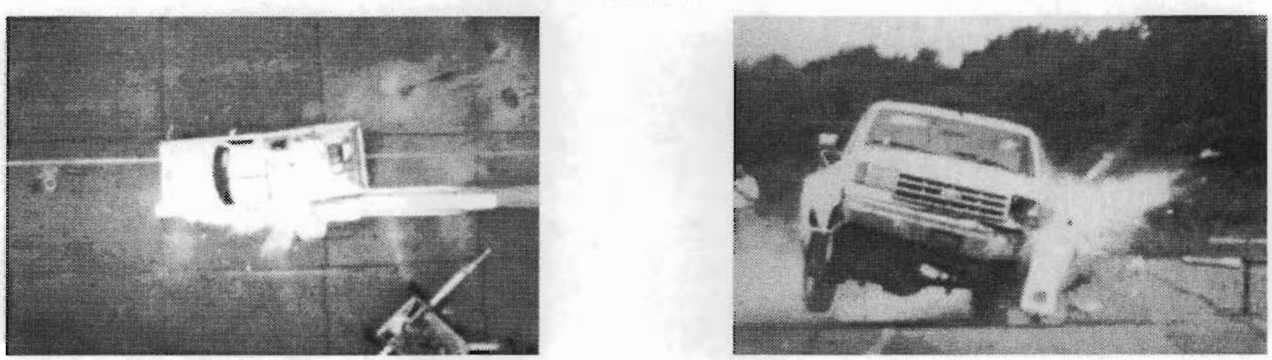
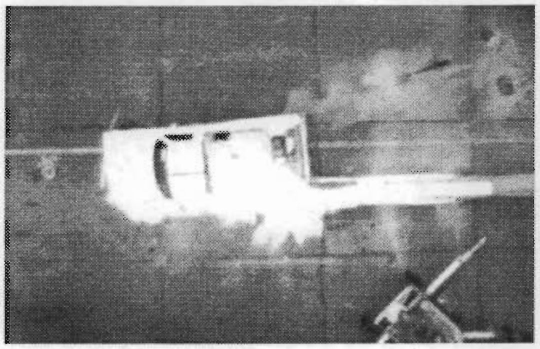
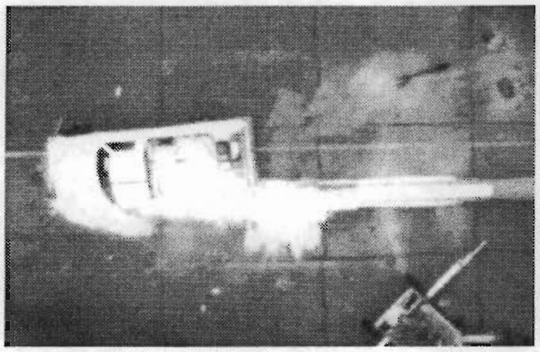


0.197 s

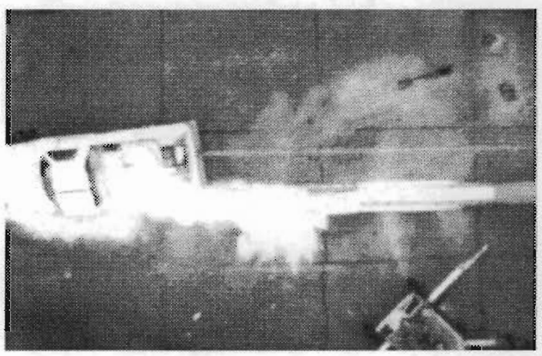
Figure 27. Sequential photographs for test 220517-8.
(overhead and frontal view)



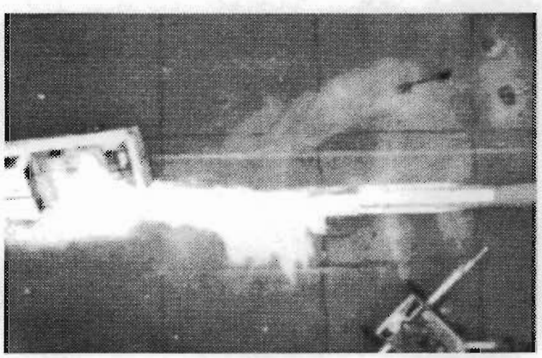

0262 s




0.328 s

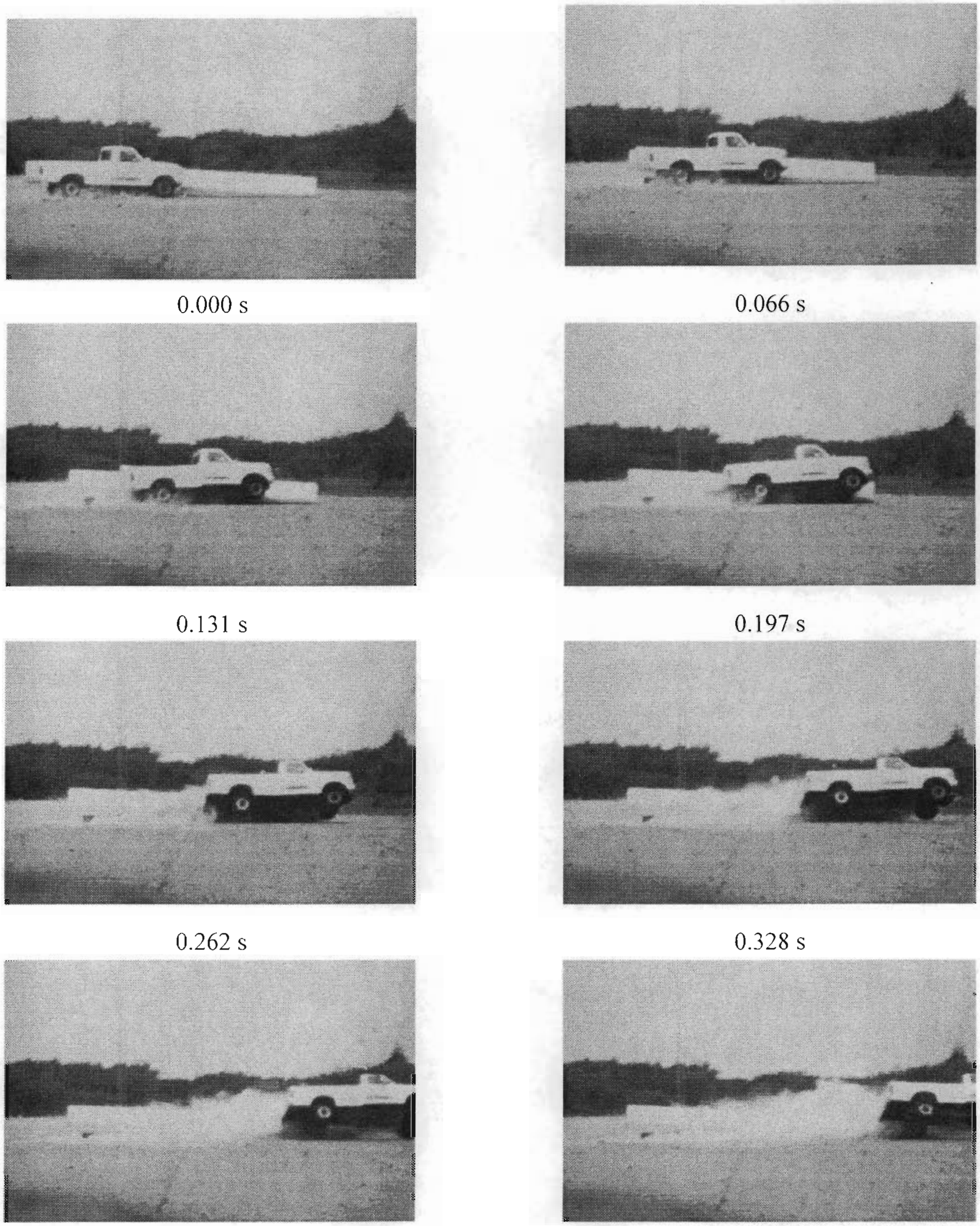



0.393 s




0.459 s

Figure 27. Sequential photographs for test 220517-8 (continued).
(overhead and frontal view)



0.000 s

0.066 s

0.131 s

0.197 s

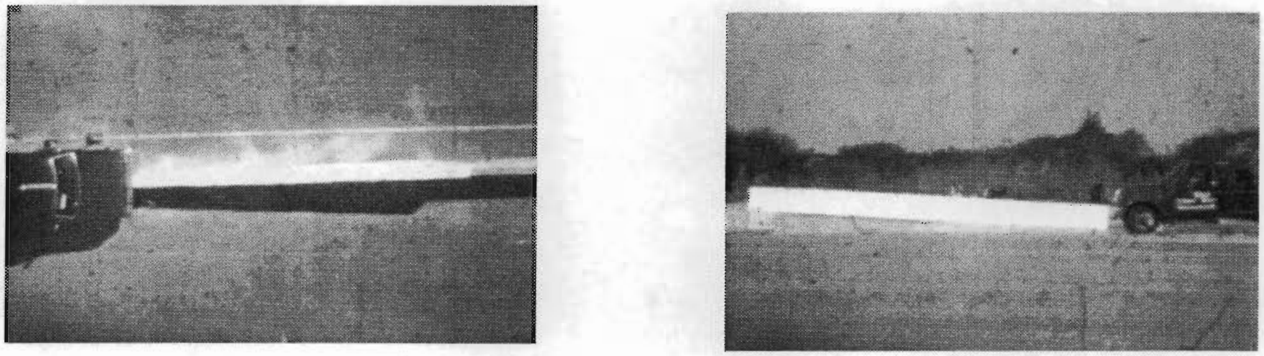
0.262 s

0.328 s

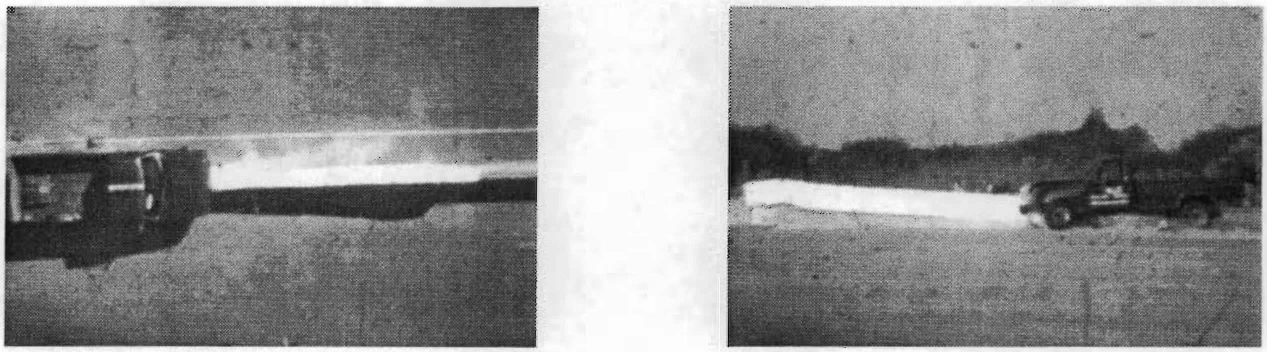
0.393 s

0.459 s

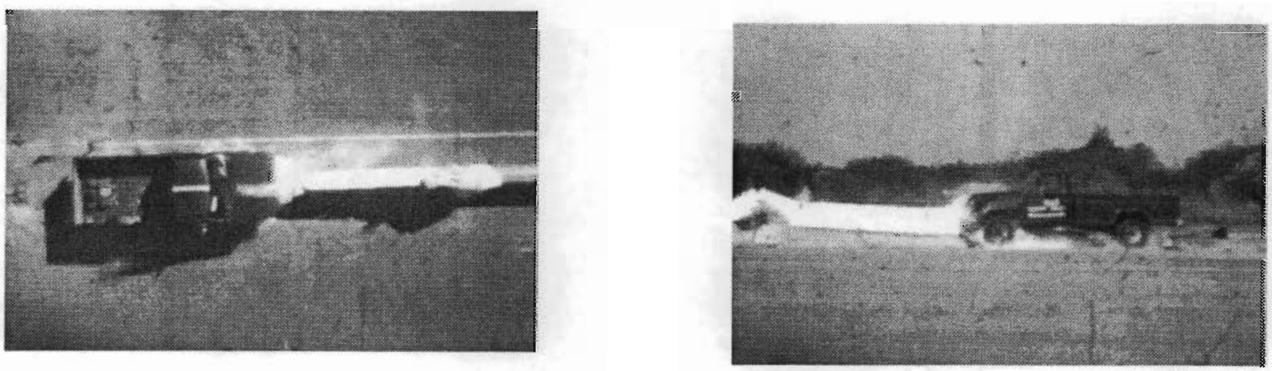
Figure 28. Sequential photographs for test 220517-8.
(perpendicular view)



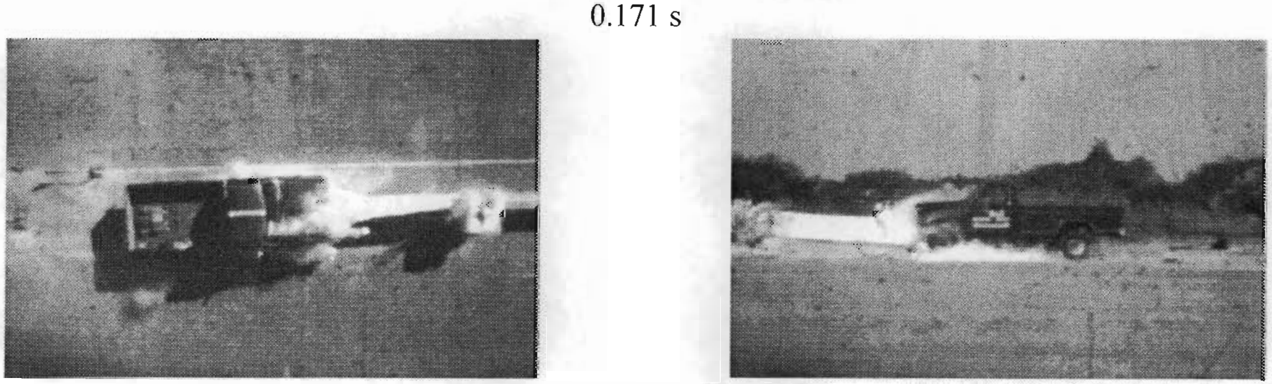
0.000 s



0.088 s

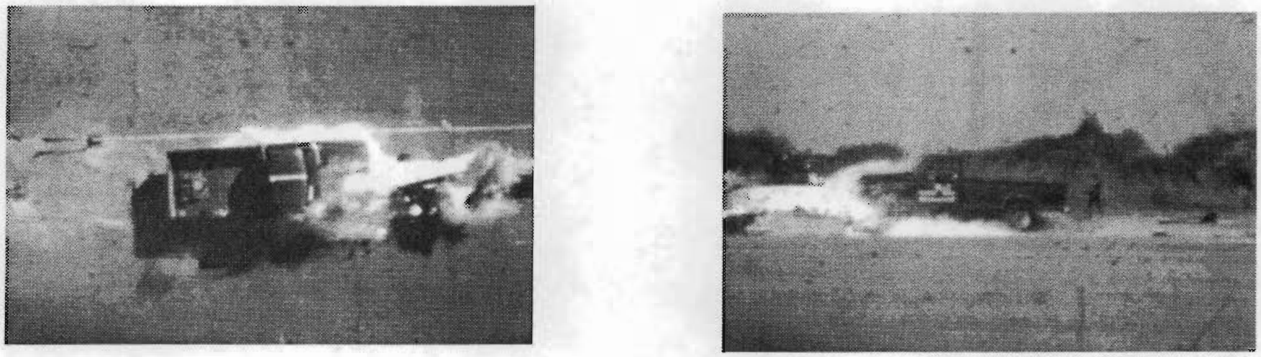


0.171 s

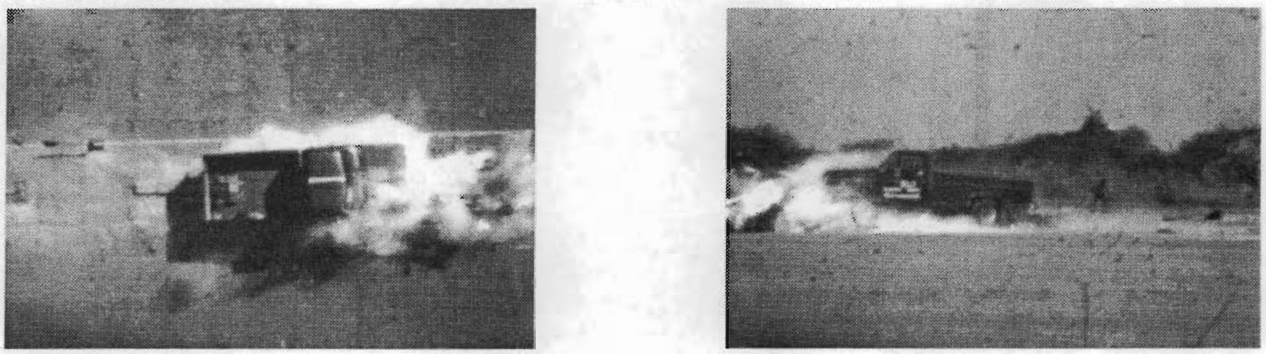


0.256 s

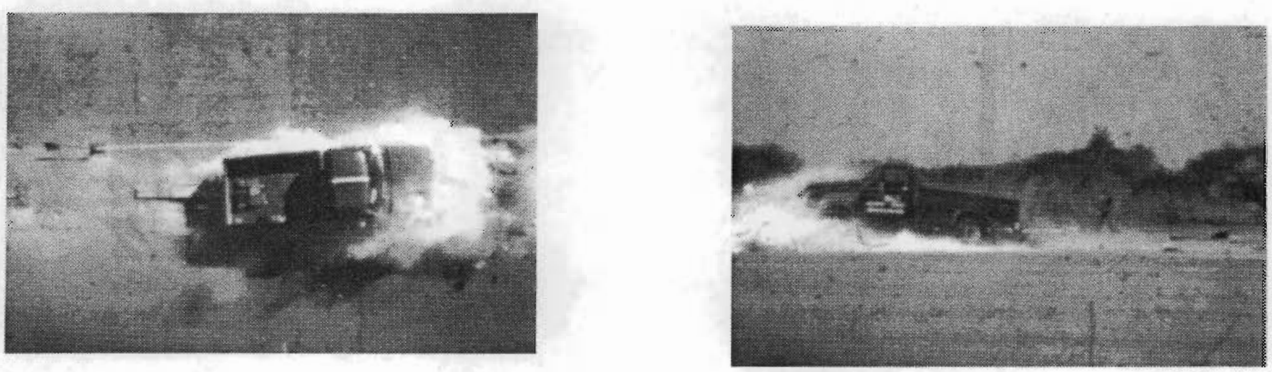
Figure 29. Sequential photographs for test 220538-9.
(overhead and perpendicular views)



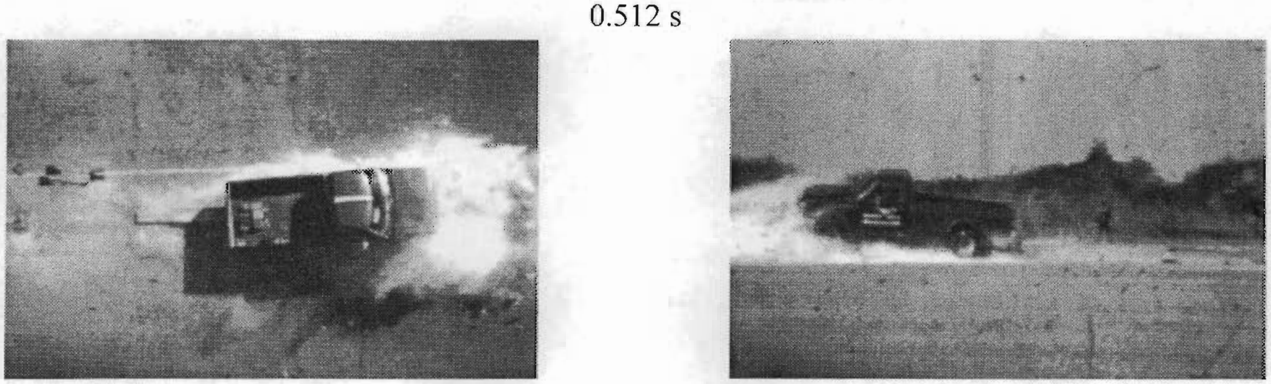
0.341 s



0.427 s



0.512 s



0.598 s

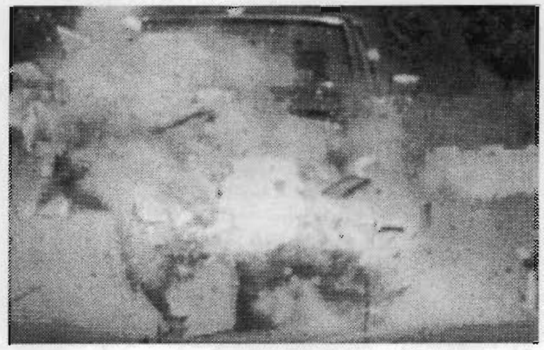
Figure 29. Sequential photographs for test 220538-9 (continued).
(overhead and perpendicular views)

0.000 s

0.088 s

0.171 s

0.256 s



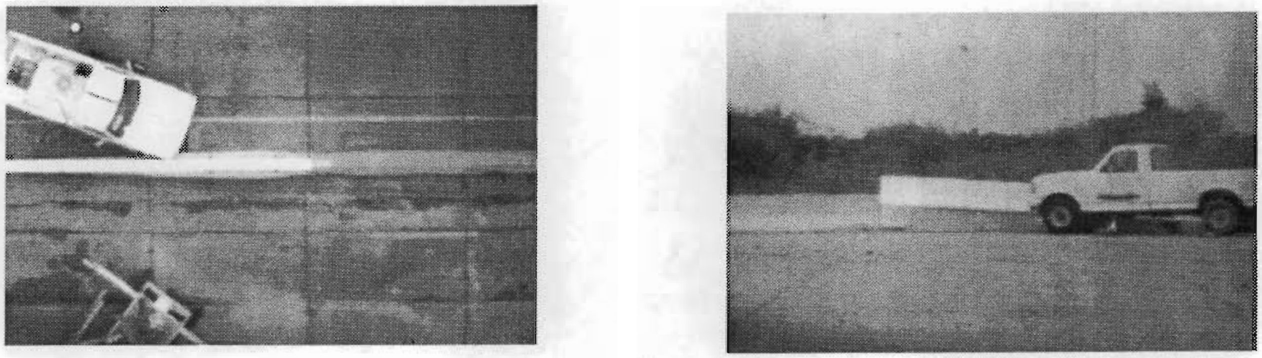
0.341 s

1.427 s

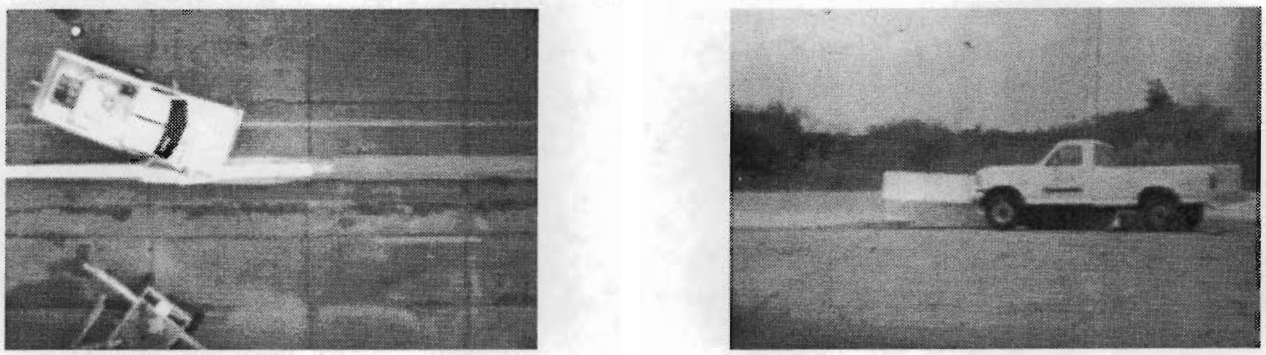
1.512 s

1.598 s

Figure 30. Sequential photographs for test 220538-9.
(frontal view)

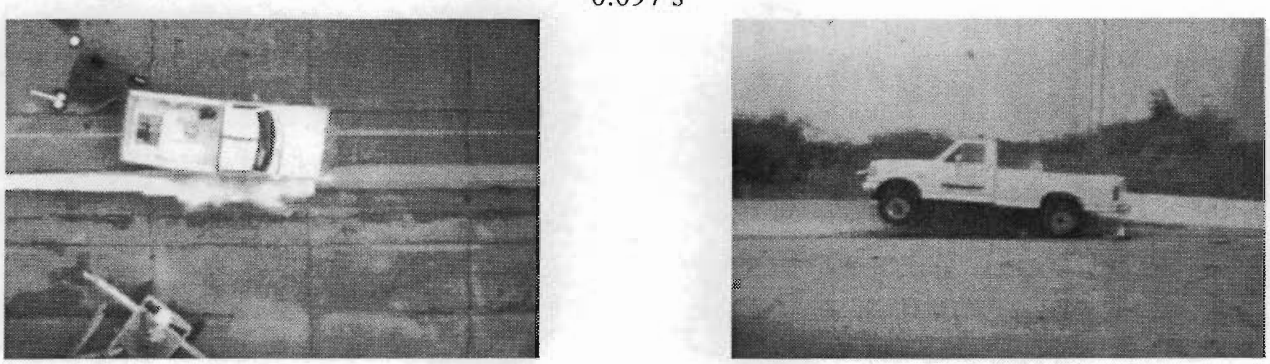


0.000 s



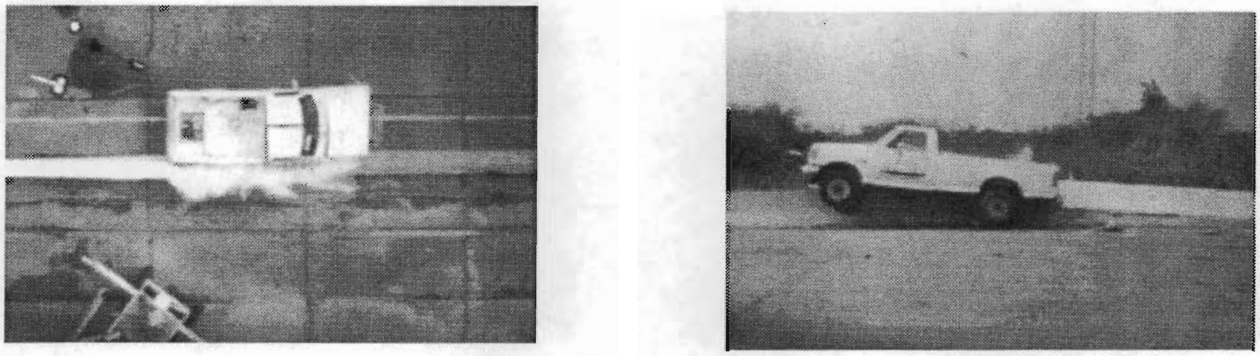
0.048 s

0.097 s

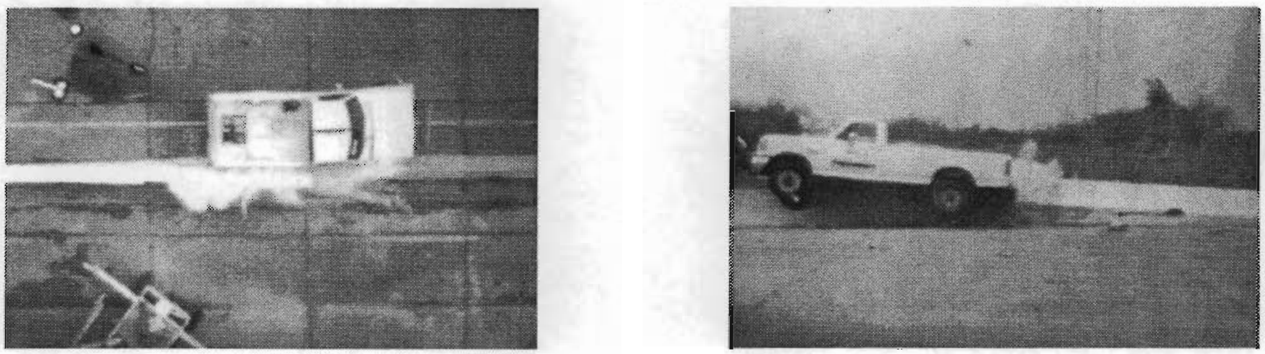


0.145 s

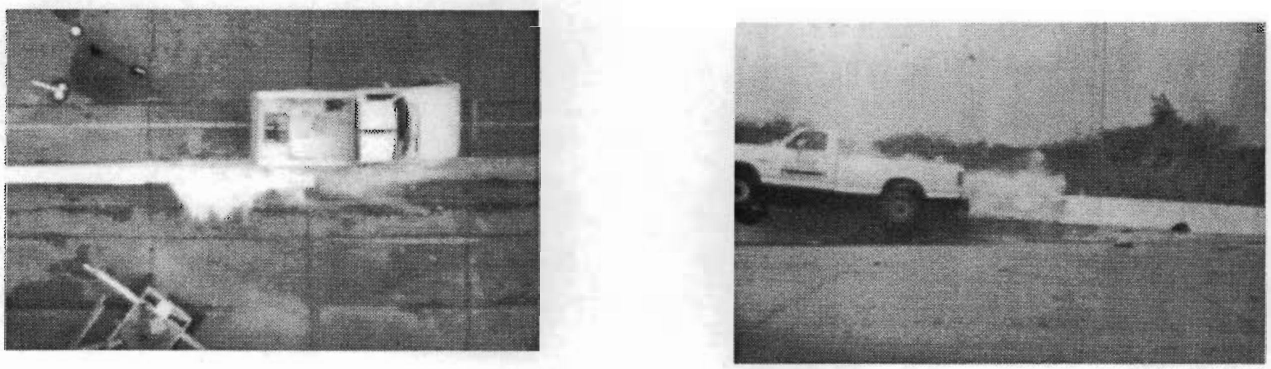
Figure 31. Sequential photographs for test 220538-10.
(overhead and perpendicular views)



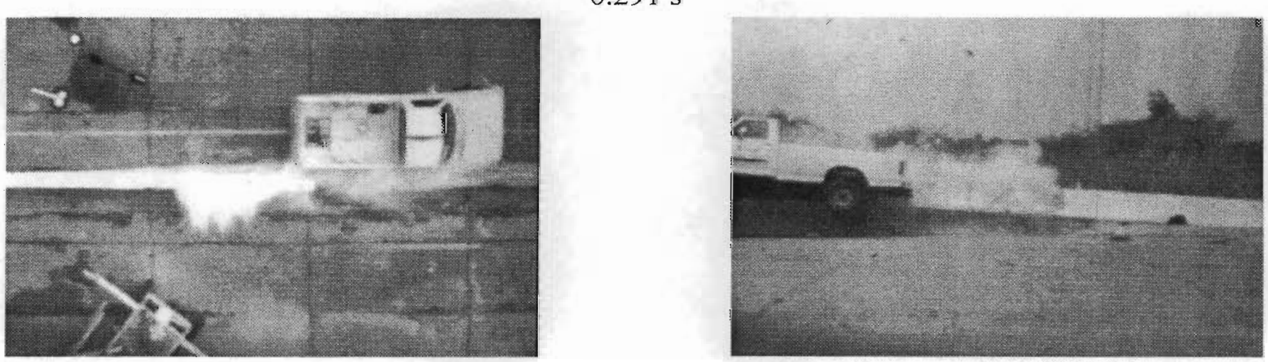
0.194 s



0.242 s

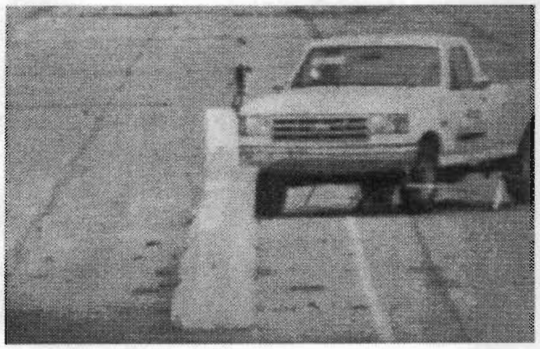


0.291 s

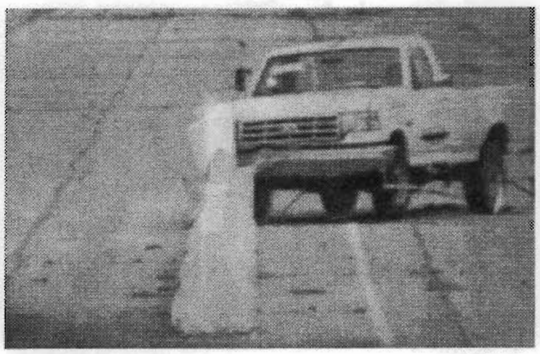


0.339 s

Figure 31. Sequential photographs for test 220538-10 (continued).
(overhead and perpendicular views)

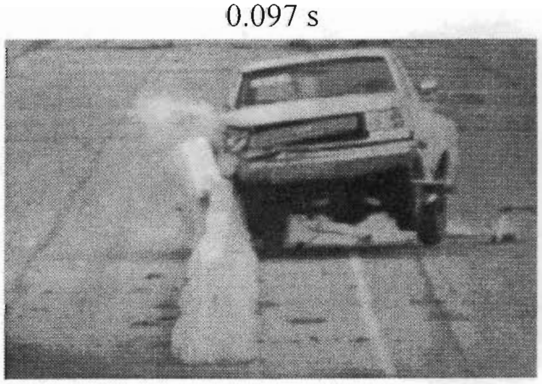


0.000 s



0.048 s

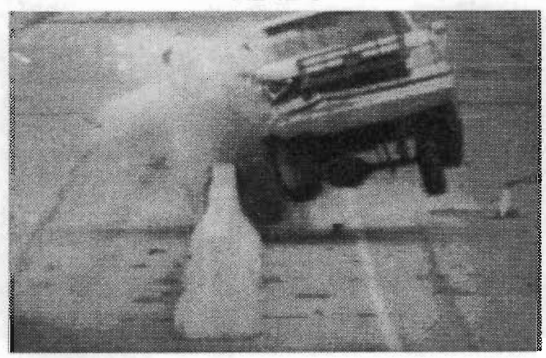
0.097 s



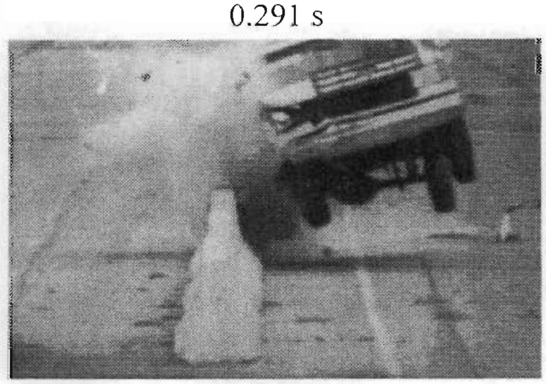
0.145 s

0.194 s

0.242 s



0.291 s



0.339 s

Figure 32. Sequential photographs for test 220538-10.
(frontal view)

APPENDIX C. VEHICLE ANGULAR DISPLACEMENTS

This section contains plots of the vehicular angular displacements exhibited by the vehicle in the crash tests performed under this study.

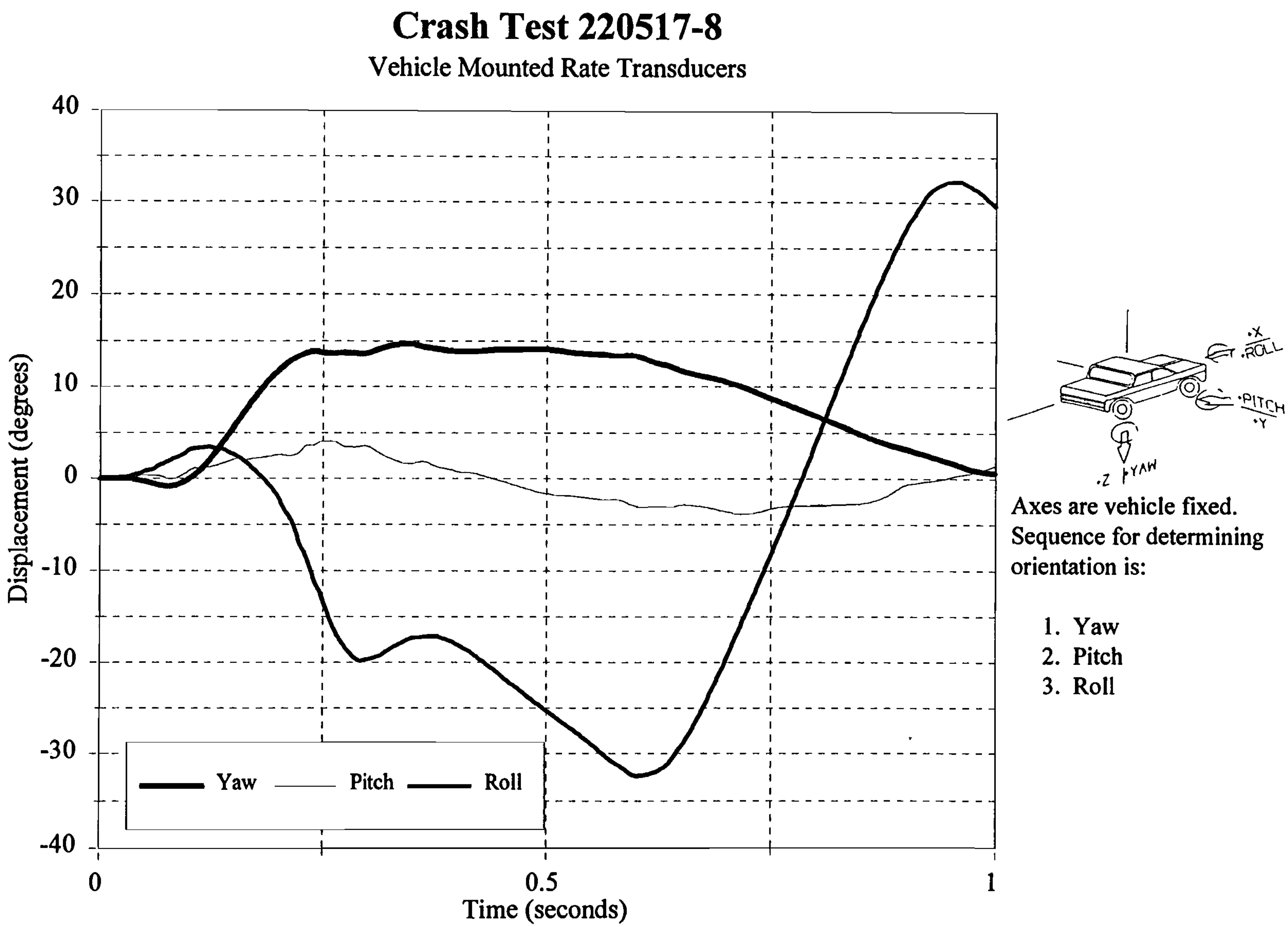


Figure 33. Vehicle angular displacements for test 220517-8.

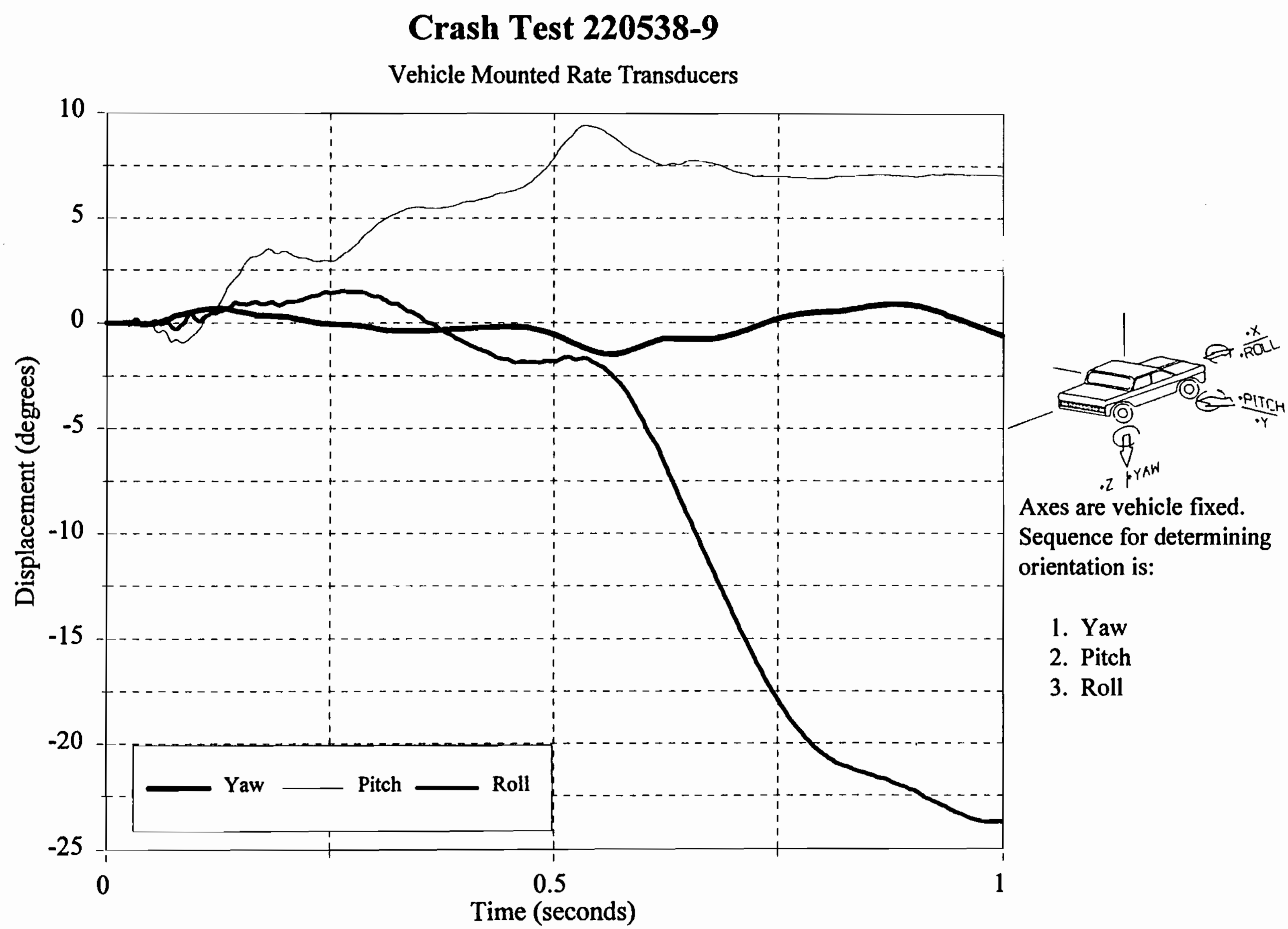


Figure 34. Vehicle angular displacements for test 220538-9.

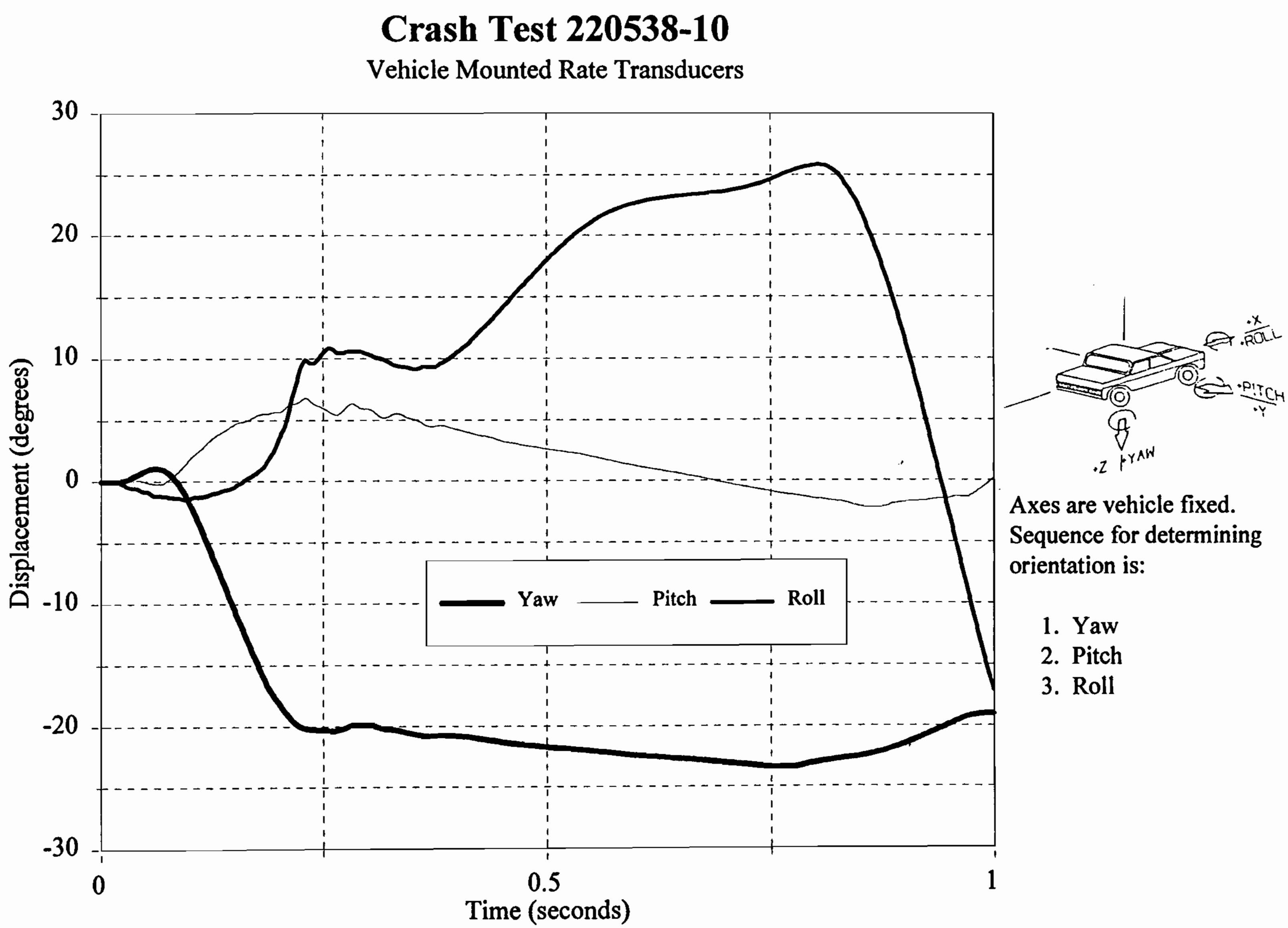


Figure 35. Vehicle angular displacements for test 220538-10.

APPENDIX D. VEHICLE ACCELEROMETER TRACES

This section contains graphs of the vehicle accelerations experienced by the vehicles during the crash tests performed under this study.

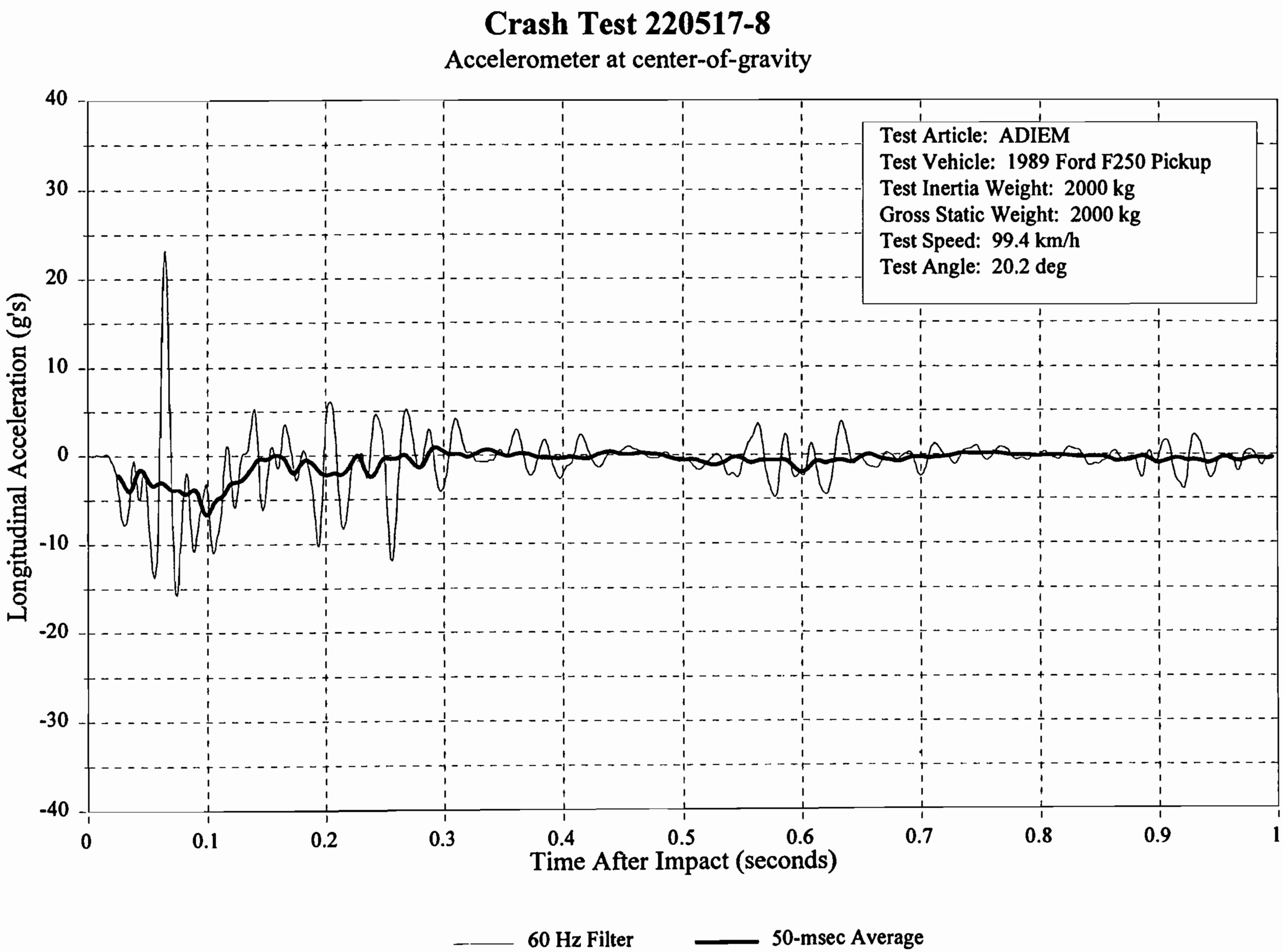


Figure 36. Vehicle longitudinal accelerometer trace for test 220517-8.

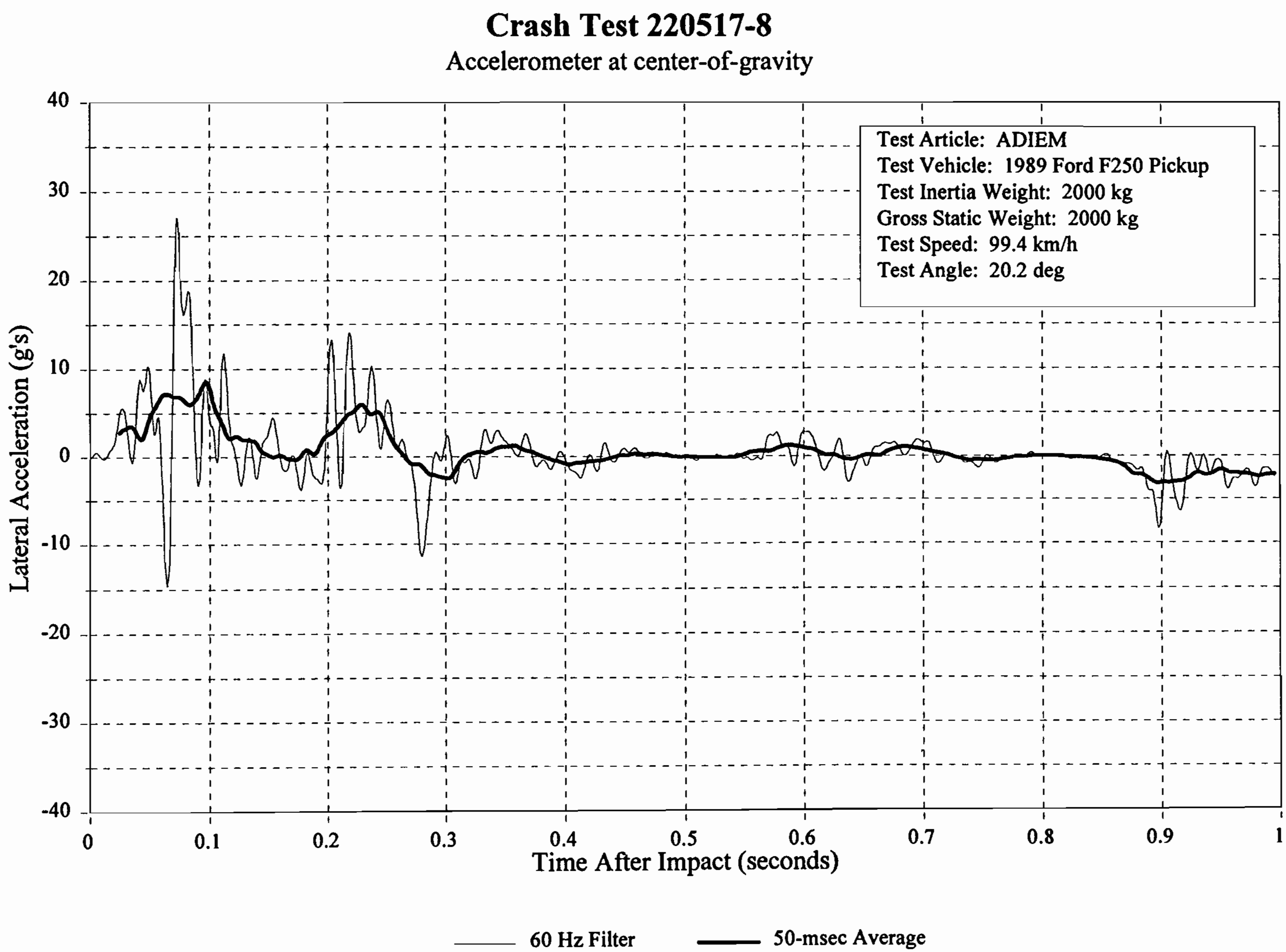


Figure 37. Vehicle lateral accelerometer trace for test 220517-8.

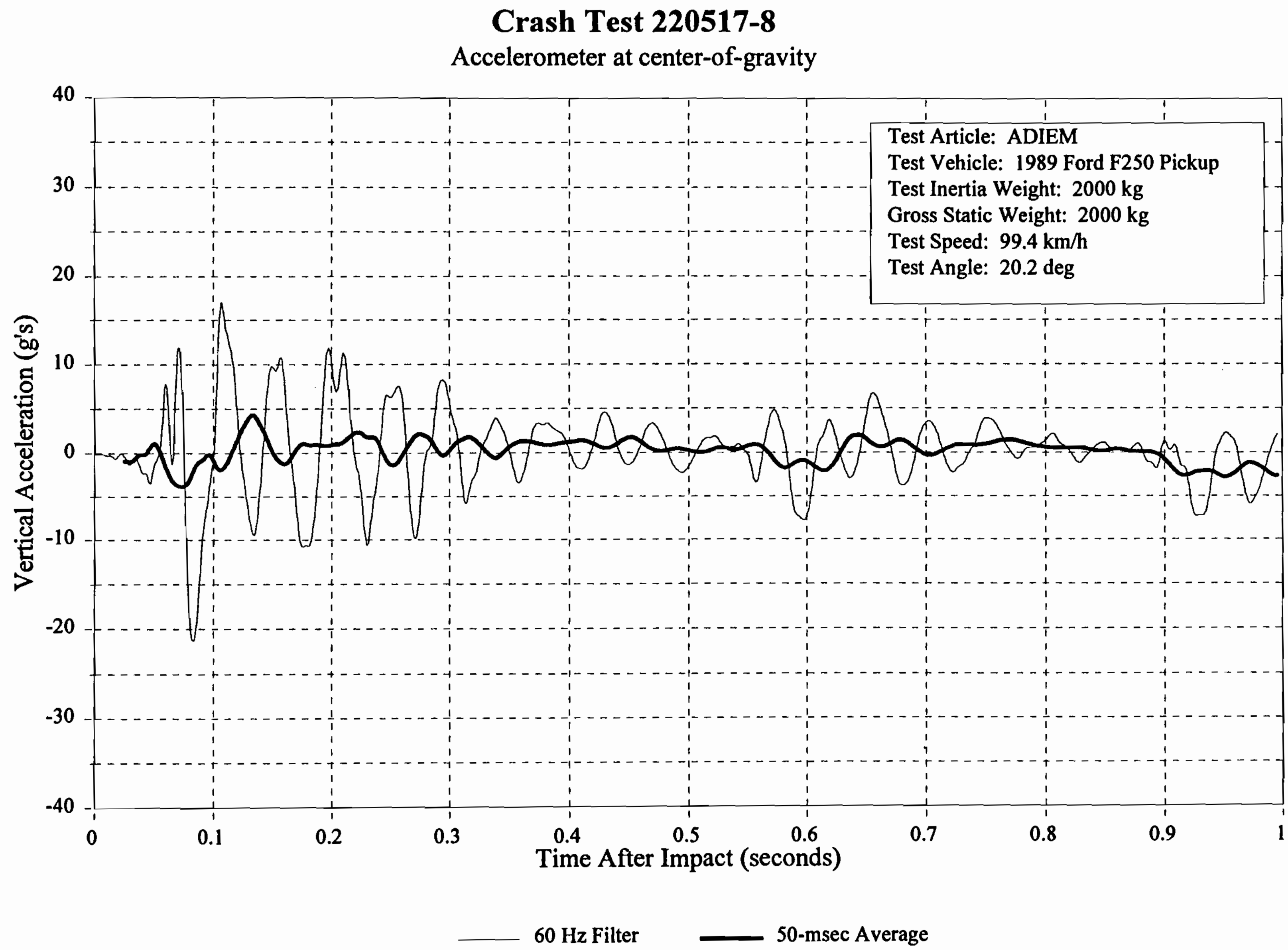


Figure 38. Vehicle vertical accelerometer trace for test 220517-8.

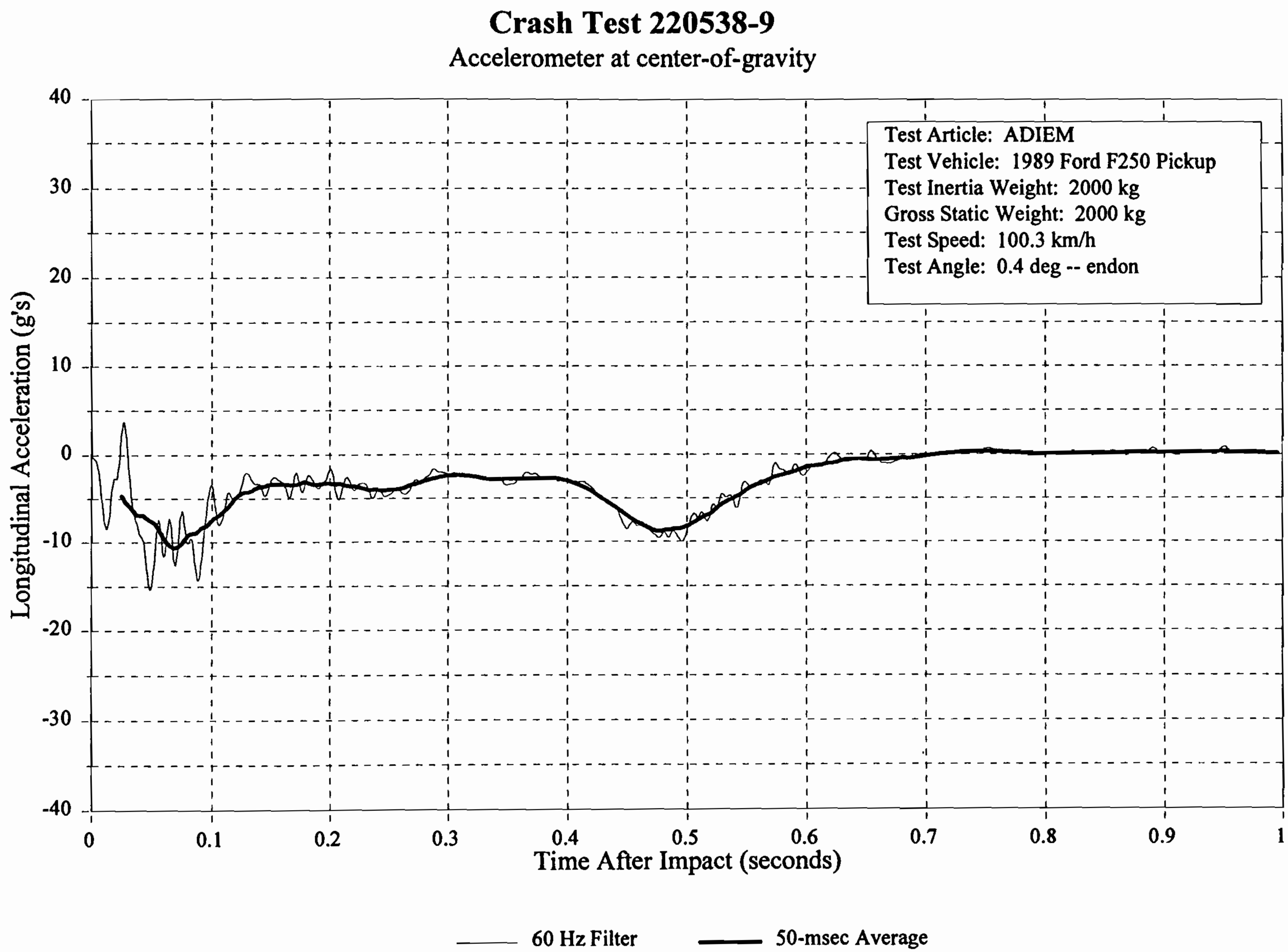


Figure 39. Vehicle longitudinal accelerometer trace for test 220538-9.

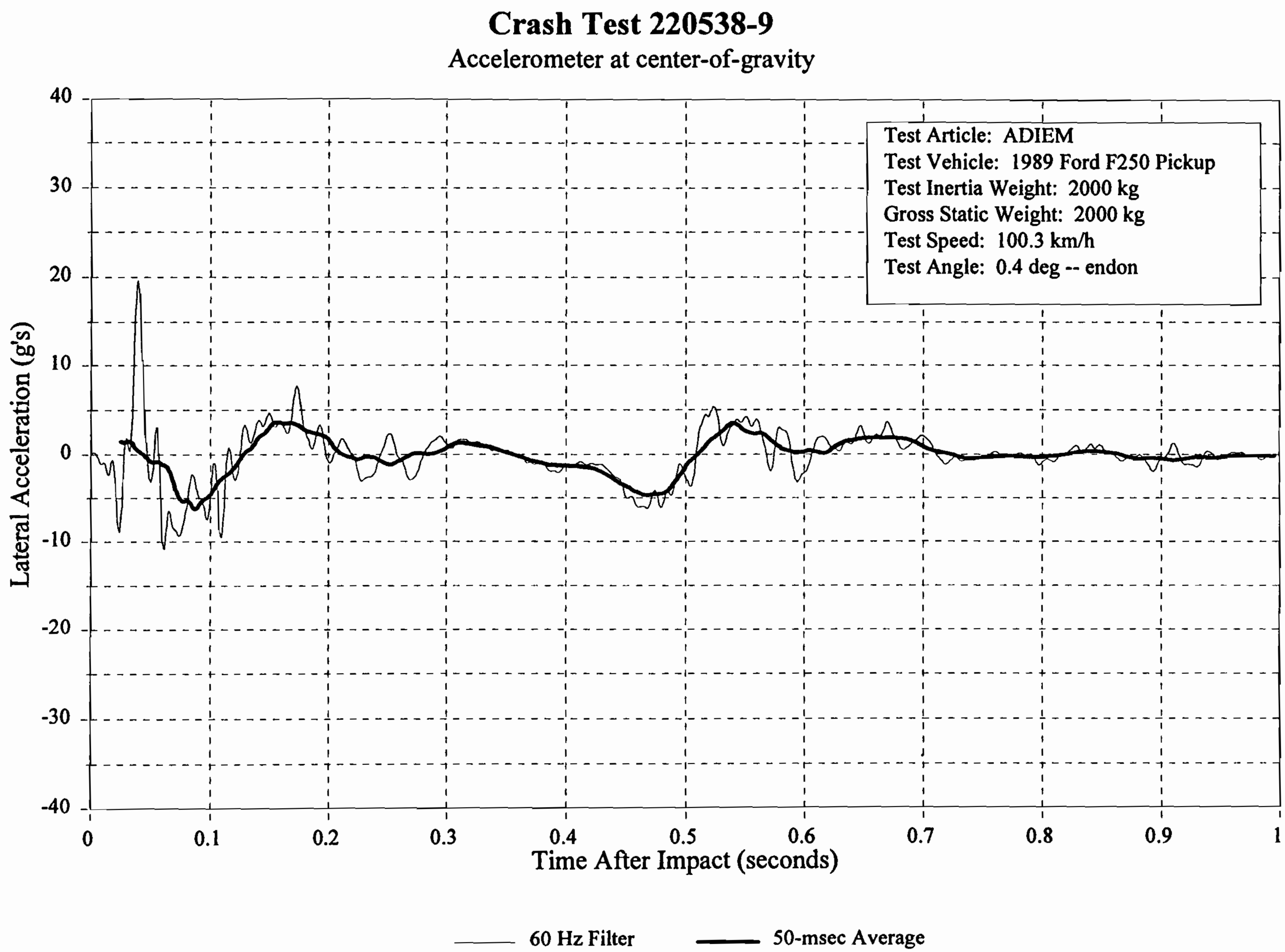


Figure 40. Vehicle lateral accelerometer trace for test 220538-9.

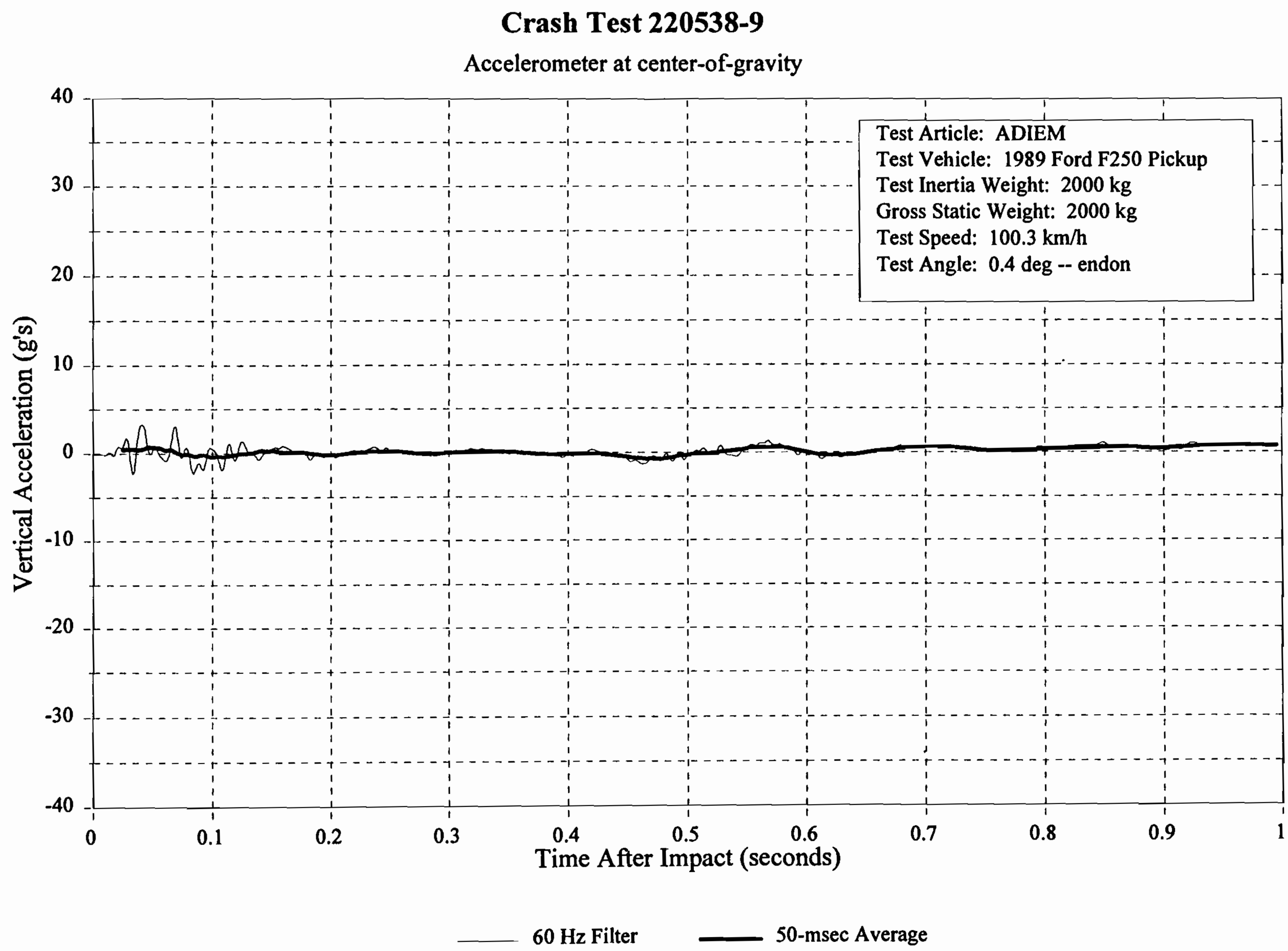


Figure 41. Vehicle vertical accelerometer trace for test 220538-9.

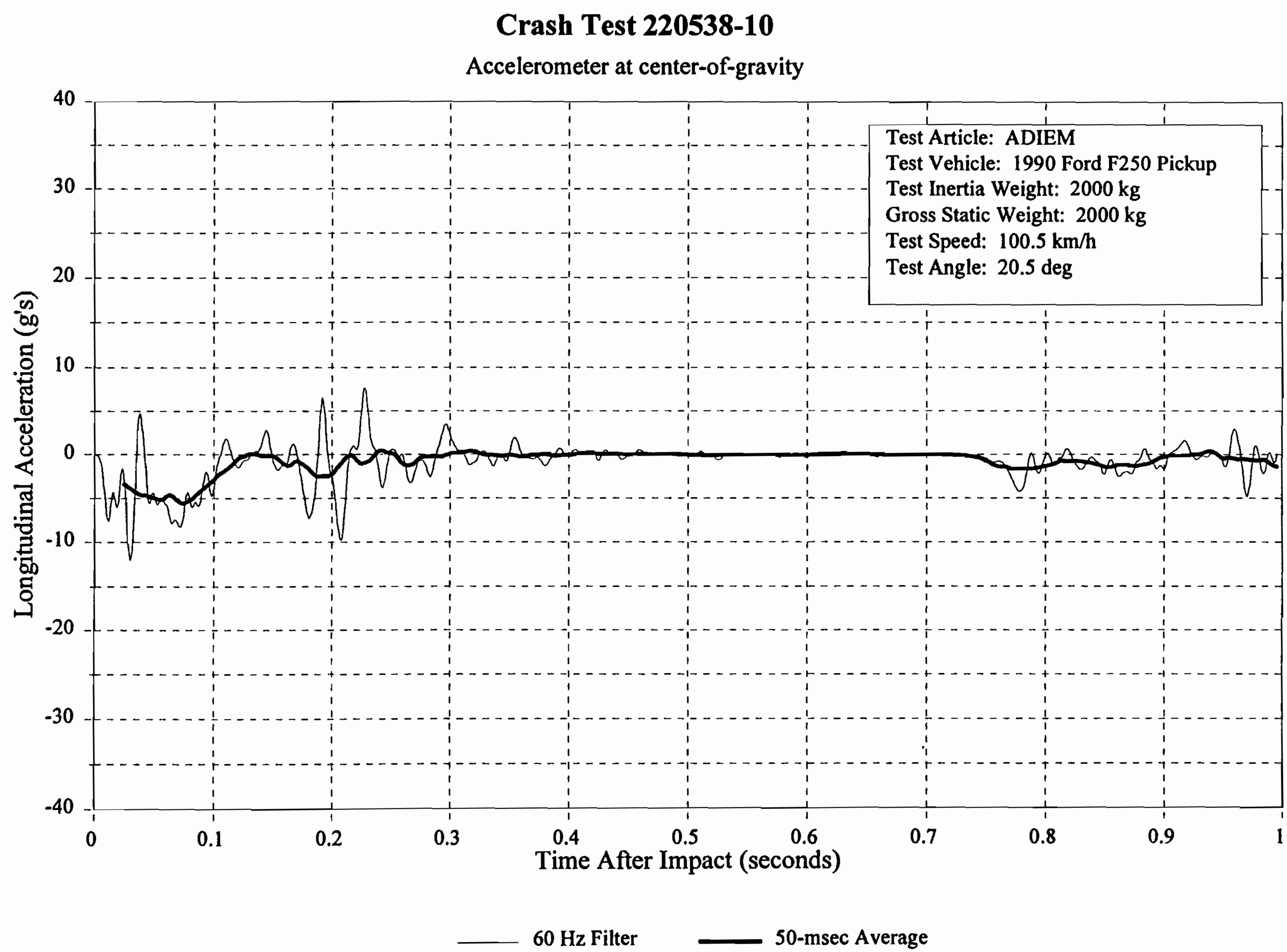


Figure 42. Vehicle longitudinal accelerometer trace for test 220538-10.

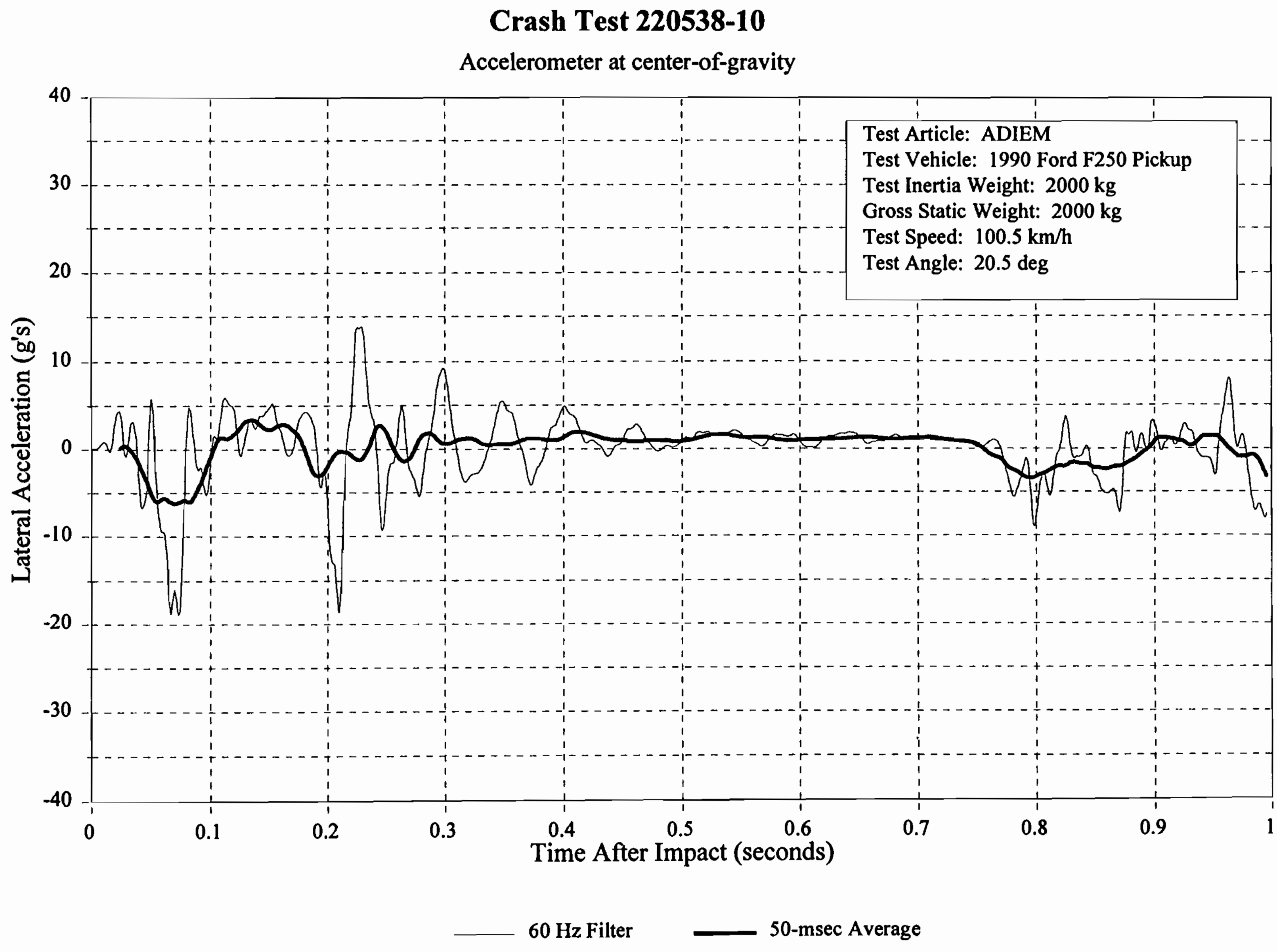


Figure 43. Vehicle lateral accelerometer trace for test 220538-10.

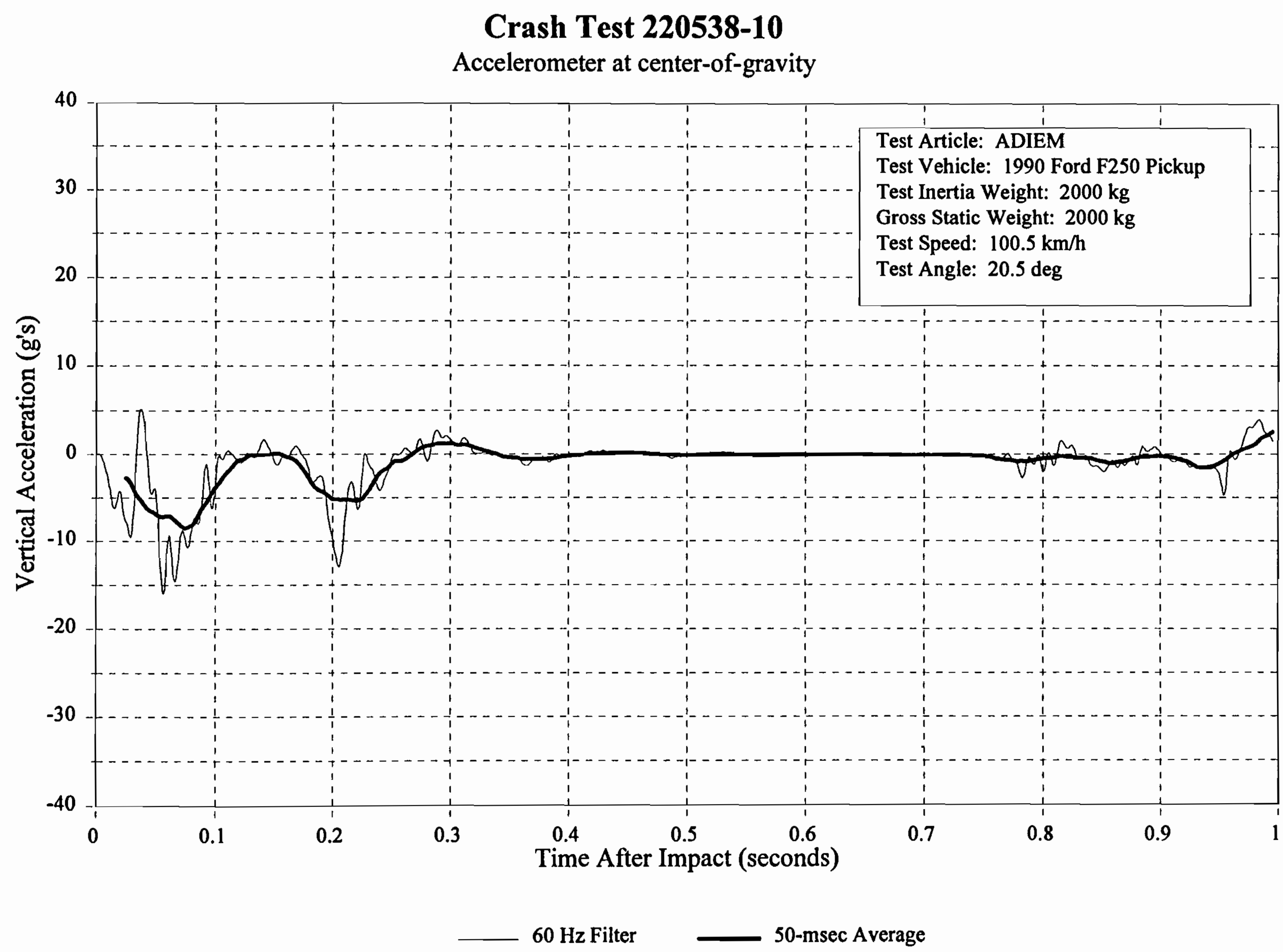


Figure 44. Vehicle vertical accelerometer trace for test 220538-10.