Texas Transportation Institute

NCHRP REPORT 350 ASSESSMENT OF EXISTING ROADSIDE SAFETY HARDWARE

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TEXAS TRANSPORTATION INSTITUTE
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FOREWORD

This report presents the results of a pooled-fund study to assess existing roadside hardware to the specifications of *NCHRP Report 350.* Under this study three terminals, five transitions, and four longitudinal barriers were tested and evaluated.

Two buried-in-backslope terminals were evaluated: the G4 on steel posts and wood blockouts with a rub rail and a 6 to 1 vee ditch, and the G4 with steel posts and wood blockouts with a 4 to 1 slope. Both met specifications for *NCHRP Report 350* test 3-35. The 3-strand New York cable terminal was evaluated and met requirements for *NCHRP Report 350* test 3-34.

The transitions evaluated under this contract included the vertical wall transition (W-beam with W-beam rub rail and steel posts), the vertical flared back transition (W-beam with channel rub rail, steel posts, and routed wood blockouts), the Pennsylvania Department of Transportation transition (vertical flared back concrete parapet with W-beam, rub rail, steel posts, and routed wood blockouts), the Nebraska thrie beam transition (vertical wall parapet with thrie beam), and the Connecticut W-beam transition (NJ-shape wall with W-beam and channel rub rail). All the transitions met the required criteria for *NCHRP Report 350* test 3-21, except for the vertical flared back transition.

The MB1 median cable barrier (the Washington State Department of Transportation (WSDOT) cable barrier) with a New York cable rail terminal, thrie beam guardrail with steel posts and routed wood blockouts, and the strong wood post thrie beam guardrail were also evaluated. The cable barrier and both thrie beam guardrails met the required specifications for *NCHRP Report 350 test 3-11.* The modified thrie beam guardrail with 2.1-m-long W150x14 steel posts and W360x33 blockouts (Design No. SGR09b) was evaluated and met specifications for *NCHRP Report 350 test 4-12.*

Construction details for all the terminals, transitions, and longitudinal barriers evaluated are reported herein for documentation and to facilitate implementation.

Michael F. Trentacoste
Director, Office of Safety
Research and Development

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16. Abstract

The Federal Highway Administration initiated this contract with the objective to crash test and evaluate several terminals, transitions, and longitudinal barriers to *NCHRP Report 350*. *NCHRP Report 350* specifies crash tests and evaluation criteria for three performance levels for terminals and six performance levels for transitions and longitudinal barriers.

The buried-in-backslope terminals evaluated were the G4 on steel posts and wood blockouts with a rub rail and a 6 to 1 vee ditch and the G4 with steel posts and wood blockouts with a 4 to 1 slope. Both met specifications for *NCHRP Report 350* test 3-35. The 3-strand New York cable terminal was evaluated and met requirements for *NCHRP Report 350* test 3-34.

The transitions evaluated under this contract included the vertical wall transition (W-beam with W-beam rub rail and steel posts), the vertical flared back transition (W-beam with channel rub rail, steel posts, and routed wood blockouts), the Pennsylvania Department of Transportation (DOT) transition (vertical flared back concrete parapet with W-beam, rub rail, steel posts, and routed wood blockouts), the Nebraska thrie beam transition (vertical wall parapet with thrie beam), and the Connecticut W-beam transition (NJ-shape wall with W-beam and channel rub rail). All the transitions met the required criteria for *NCHRP Report 350* test 3-21, except for the vertical flared back transition.

The MB1 median cable barrier chosen for evaluation was the Washington State DOT (WSDOT) cable barrier with a New York cable rail terminal. The thrie beam guardrail with steel posts and routed wood blockouts and the strong wood post thrie beam guardrail were also evaluated. The cable barrier and both thrie beam guardrails met the required specifications for *NCHRP Report 350* test 3-11. The modified thrie beam guardrail with 2.1-m-long W150x14 steel posts and W360x33 blockouts (Design No. SGR09b) was evaluated and met specifications for *NCHRP Report 350* test 4-12.

Construction details for all the terminals, transitions, and longitudinal barriers evaluated are reported herein. Also included are details of the crash tests performed and the assessment of each test.

17. Key Words
Terminals, transitions, longitudinal barriers, cable barriers, guardrails, crash testing, roadside safety

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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.			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
EF	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	EC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	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	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		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 (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
EC	Celcius temperature	1.8C+32	Fahrenheit temperature	EF
		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	lbf/in^2

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

(Revised September 1993)

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TECHNICAL SUMMARY

NCHRP REPORT 350 ASSESSMENT OF EXISTING ROADSIDE SAFETY HARDWARE

Publication No. FHWA-RD-01-042

Highway Safety

This technical summary announces the completion of an FHWA study that is fully documented in a final report (FHWA-RD-01-042. (See report-ordering information on the last page of this summary.)

Introduction

The Federal Highway Administration (FHWA) has adopted the National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, as the official guidelines for performance evaluation of roadside safety hardware. *NCHRP Report 350* specifies required crash tests for three performance levels for terminals and six performance levels for transitions and longitudinal barriers, as well as evaluation criteria for structural adequacy, occupant risk, and post-test vehicle trajectory.

Most existing roadside safety features have been tested according to the previous guidelines contained in *NCHRP Report 230*. FHWA has required that all roadside safety features to be installed under new construction on the National Highway System (NHS) meet the *NCHRP Report 350* performance evaluation guidelines. Implementation of this requirement for breakaway devices, longitudinal barriers (except weak-post W-beam guardrail), crash cushions, and W-beam guardrail terminals on new construction went into effect on October 1, 1998. Guardrail to bridge rail transitions will be required to meet the *NCHRP Report 350* requirements by October 1, 2002.

Purpose

Although numerous crash tests have been performed, and some longitudinal barriers and terminals have been approved that meet *NCHRP Report 350*, there is still a need to evaluate many existing roadside safety features to determine if they will perform acceptably according to the new specifications. In the case of guardrail to bridge rail transitions, very few (at the time of initiation of this study) performed acceptably according to the specifications of *NCHRP Report 350*. FHWA initiated this contract with the objective to crash test and evaluate several terminals, transitions, and longitudinal barriers.

Methodology

FHWA chose three terminals, five transitions, and four longitudinal barriers for evaluation. Two buried-in-backslope terminals were evaluated: the G4 on steel posts and wood blockouts with a rub rail and a 6 to 1 vee ditch, and the G4 with steel posts and wood blockouts with a 4 to 1 slope. The 3-strand New York cable terminal was also evaluated.

The transitions evaluated under this contract included the vertical wall transition (W-beam with W-beam, rub rail and steel posts), the vertical flared back transition (W-beam with channel rub rail, steel posts, and routed wood blockouts), the Pennsylvania DOT transition (vertical flared back concrete parapet with W-beam rub rail, steel posts, and routed wood blockouts), the Nebraska thrie beam transition (vertical wall parapet with thrie beam), and the Connecticut W-beam transition (vertical wall with W-beam and channel rub rail).

The MB1 median cable barrier (the Washington State Department of Transportation (WSDOT) cable barrier) with a New York cable rail terminal, the thrie beam guardrail with steel posts and routed wood blockouts, and the strong wood post thrie beam guardrail were evaluated according to *NCHRP Report 350* test 3-11. The modified thrie beam guardrail with 2.1-m-long W150x14 steel posts and W360x33 blockouts (Design No. SGR09b) was evaluated according to specifications for *NCHRP Report 350* test 4-12.

Results

The buried-in-backslope terminals (one with 6 to 1 vee ditch and one with 4 to 1 slope) met the required criteria for *NCHRP Report 350* test 3-35. The New York terminal for 3-cable barrier met the requirements for *NCHRP Report 350* test 3-34.

The vertical wall transition, the Pennsylvania transition, the Nebraska transition, and the Connecticut transition all met the required criteria for *NCHRP Report 350* test 3-21. The vertical flared back transition did not perform acceptably due to rollover.

The WSDOT cable barrier with New York terminal, the thrie beam with steel posts and routed wood blockouts, and the strong wood post thrie beam guardrail met specifications for *NCHRP Report 350* test 3-11. The modified thrie beam guardrail met specifications for *NCHRP Report 350* test 4-12.

Researcher - This study was performed by Texas Transportation Institute, The Texas A&M University System, College Station, Texas 77843-3135, telephone no. 979-845-6375, Contract No. DTFH61-97-C-00039.

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Key Words - Terminals, transitions, longitudinal barriers, guardrails, bridge rails, crash testing, roadside safety.

Publication No. FHWA-RD-01-042

INTRODUCTION

PROBLEM

In July of 1993, the Federal Highway Administration (FHWA) adopted National Cooperative Highway Research Program (NCHRP) Report 350 (*NCHRP Report 350*), *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, as the official guidelines for performance evaluation of roadside safety hardware.[1] *NCHRP Report 350* specifies the required crash tests for longitudinal barriers, terminals and transitions, as well as evaluation criteria for structural adequacy, occupant risk, and post-test vehicle trajectory for each test. FHWA has further mandated that all roadside safety features installed under new construction on the National Highway System (NHS) meet *NCHRP Report 350* performance evaluation guidelines. Implementation of this requirement for breakaway devices, longitudinal barriers (except weak-post W-beam guardrail), crash cushions, and W-beam guardrail terminals on new construction went into effect on October 1, 1998. Guardrail to bridge rail transitions will be required to meet the *NCHRP Report 350* requirements by October 1, 2002. Therefore, it is necessary to test new and/or some existing roadside safety features to evaluate their performance under these guidelines.

BACKGROUND

Since the adoption of *NCHRP Report 350*, FHWA has used pooled funds to help various States crash test and evaluate various roadside safety devices. Although numerous tests have been performed, and some longitudinal barriers and terminals approved meet *NCHRP Report 350* specifications, there is still a need to evaluate many of the existing roadside safety features to determine if they will perform acceptably according to the new specifications. In the case of guardrail to bridge rail transitions, there were very few (at the time of initiation of this contract) that performed acceptably to *NCHRP Report 350* specifications.

OBJECTIVES/SCOPE OF RESEARCH

FHWA initiated this contract with the objective to crash test and evaluate several terminals, transitions, and longitudinal barriers to *NCHRP Report 350*. *NCHRP Report 350* specifies crash tests and evaluation criteria for three performance levels for terminals and six performance levels for transitions and longitudinal barriers.

Two buried-in-backslope terminals and one cable terminal were evaluated under this contract. The first buried-in-backslope terminal evaluated was the G4 on steel posts and wood blockouts with a rub rail and a 6:1 vee ditch and the other was a G4 with steel posts and wood blockouts with a 4 to 1 slope. *NCHRP Report 350* test 3-35 with the pickup truck at 100 km/h and 20 degrees was performed on these buried-in-backslope terminals. The cable terminal evaluated was the 3-strand New York cable rail terminal. *NCHRP Report 350* test 3-34, with the small car at 100 km/h and 15 degrees (impacting the critical impact point of the terminal) was performed on the New York cable rail terminal.

The transitions evaluated under this contract included the vertical wall transition (W-beam with W-beam rub rail and steel posts), the vertical flared back transition (W-beam with channel rub rail, steel posts, and routed wood blockouts), the Pennsylvania Department of Transportation (DOT) transition (vertical flared back concrete parapet with W-beam rub rail, steel posts, and routed wood blockouts), the Nebraska thrie beam transition (vertical wall parapet with thrie beam), and the Connecticut W-beam transition (vertical wall with W-beam and channel rub rail). *NCHRP Report 350* test 3-21 with the pickup truck at 100 km/h and 25 degrees was performed on each to evaluate these transitions.

The longitudinal barriers evaluated under this contract were the MB1 median cable barrier and three thrie beam guardrails. The MB1 median cable barrier chosen for testing was the Washington State DOT (WSDOT) cable barrier with a New York cable rail terminal. This median barrier was previously tested with the small car at 100 km/h and 20 degrees, *NCHRP Report 350* test 3-10; however, it had never been subjected to the pickup truck test at 100 km/h and 25 degrees, *NCHRP Report 350* test 3-11. The thrie beam guardrail with steel posts and routed wood blockouts and the strong wood post thrie beam guardrail were tested with the pickup, *NCHRP Report 350* test 3-11, for TL-3 evaluation. The modified thrie beam guardrail with 2.1-m-long W150x14 steel posts and W360x33 blockouts (Design No. SGR09b) was evaluated to TL-4 with the single-unit truck at 80 km/h and 15 degrees, *NCHRP Report 350* test 4-12.

Construction details of all the terminals, transitions, and longitudinal barriers evaluated are given in the following sections of this report. Also included are details of the crash tests performed and the assessment of each test.

TEST PARAMETERS

TEST FACILITY

All testing performed under this contract was performed by Texas Transportation Institute (TTI). The test facilities at the TTI's Proving Ground consist of an 809-hectare complex of research and training facilities situated 16 km northwest of the main campus of Texas A&M University. The site, formerly an Air Force Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The sites selected for placing of each of the test articles is along a wide expanse of out-of-service aprons and runways. The aprons/runways consist of an unreinforced jointed concrete pavement in 3.8 m by 4.6 m blocks nominally 203 to 305 mm deep. The aprons and runways are about 50 years old and the joints have some displacement, but are otherwise flat and level.

TEST ARTICLES

All test articles evaluated were constructed according to details and drawings provided by FHWA and/or the States. Drawings of each installation are included with the description of each device in the following chapters.

TEST CONDITIONS

FHWA determined which *NCHRP Report 350* tests were to be performed on each of the test articles evaluated. Accordingly, the conditions specified in *NCHRP Report 350* for the specific tests chosen were used as target test conditions. The target and actual test conditions for each test article are reported herein. The vehicles in each test were directed into the installation using the cable reverse tow and guidance system (detailed in appendix A), and were released to be free-wheeling and unrestrained just prior to impact.

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

EVALUATION CRITERIA

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

5.1 of *NCHRP Report 350* were used to evaluate the crash tests reported herein. An assessment of the criteria related to each particular test is included at the end of each test.

Also included at the end of each test are supplemental evaluation factors and terminology used for visual assessment of test results as suggested by FHWA in a memo entitled: *Action: Identifying Acceptable Highway Safety Features* dated July 25, 1997.

TERMINALS

BURIED-IN-BACKSLOPE TERMINAL (WITH 6 to 1 VEE DITCH) (*NCHRP REPORT 350* TEST NO. 3-35)

Test Conditions

According to *NCHRP Report 350*, a total of up to seven tests is required for evaluation of guardrail terminals under test level 3 (TL3) conditions. However, under this contract only one of the seven required was performed on the buried-in-backslope terminal (with 6 to 1 vee ditch). The test performed was *NCHRP Report 350* test designation 3-35: A 2000P vehicle impacting the beginning of the length of need of the terminal at a nominal speed and impact angle of 100 km/h and 20 degrees.

This test is intended primarily to evaluate the ability of the device to contain and redirect (structural adequacy criteria) the 2000-kg pickup truck. The beginning of the length of need for this terminal was determined to be at post 8.

Test Article

The buried-in-backslope terminal with 6 to 1 vee ditch is an end treatment for a W-beam guardrail. The guardrail is flared across a vee ditch with its end anchored to a 1830-mm-long steel post buried in the backslope. The guardrail installation is the standard SGRO4a W-beam guardrail with wood blockouts. The guardrail between posts A, B, 1 and 2 (numbered sequentially from the end anchor) is flared back in a 4 to 1 ratio. The guardrail between posts 2 and 4 is flared back in a 6 to 1 ratio; between posts 4 and 8 in an 8 to 1 ratio; and between posts 8 and 22 in a 13 to 1 ratio. In addition, the top of the guardrail posts between post 8 and post A is tapered from 675 mm measured from the shoulder grade at post 8 to 140.5 mm below the shoulder grade at post A. The guardrail beginning at post 22 is parallel to the travel way and extends for 30.5 m (length of need). The top of the posts for the length of need is 675 mm measured from the shoulder grade. The top of the rail is 25 mm below the top of the post. A LET terminal was installed on the downstream end of the installation.

The buried-in-backslope end treatment consists of a W-beam guardrail attached to steel posts (PWE01) using wood blockouts (PDB01 - modified) with one 16-mm button-head bolt at every post. The 150-mm x 200-mm wood blockout is routed to fit over the flange of the steel post and is 360 mm long. The W-beam is connected to the end post using a special connection bracket as shown in page 1 of figure 1.

A W-beam rub rail extends from post 2 to post 22. The rubrail is mounted to the steel posts with one 16-mm bolt with a 75-mm vertical gap between the W-beam guardrail and the rub rail. The upstream end of the rub rail is connected to post 2 with the special connection bracket and the downstream end of the rub rail is connected to the back of post 22 with a 16-mm bolt.

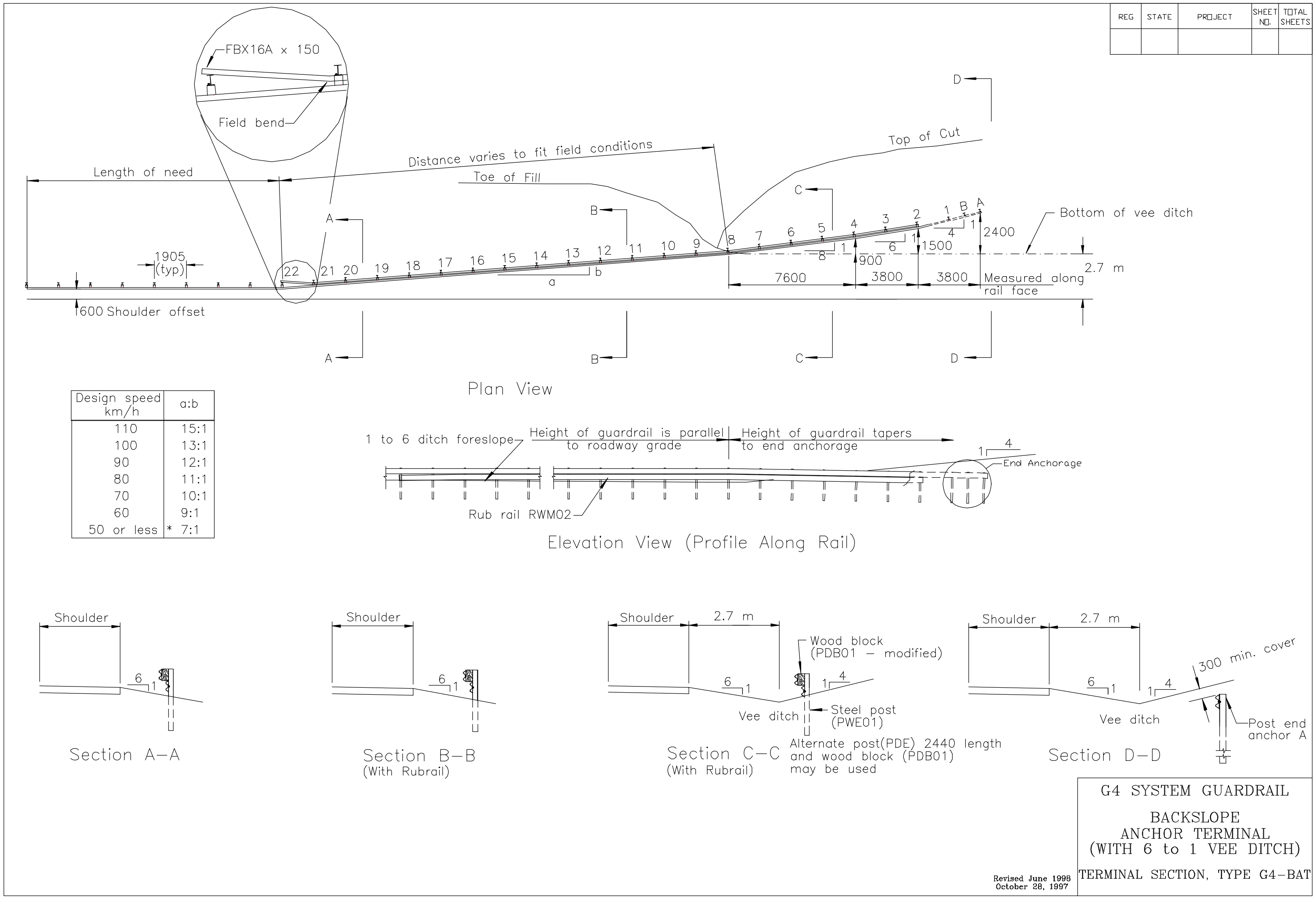


Figure 1. Details of the G4 W-beam guardrail buried-in-backslope terminal installation for test 404211-1.

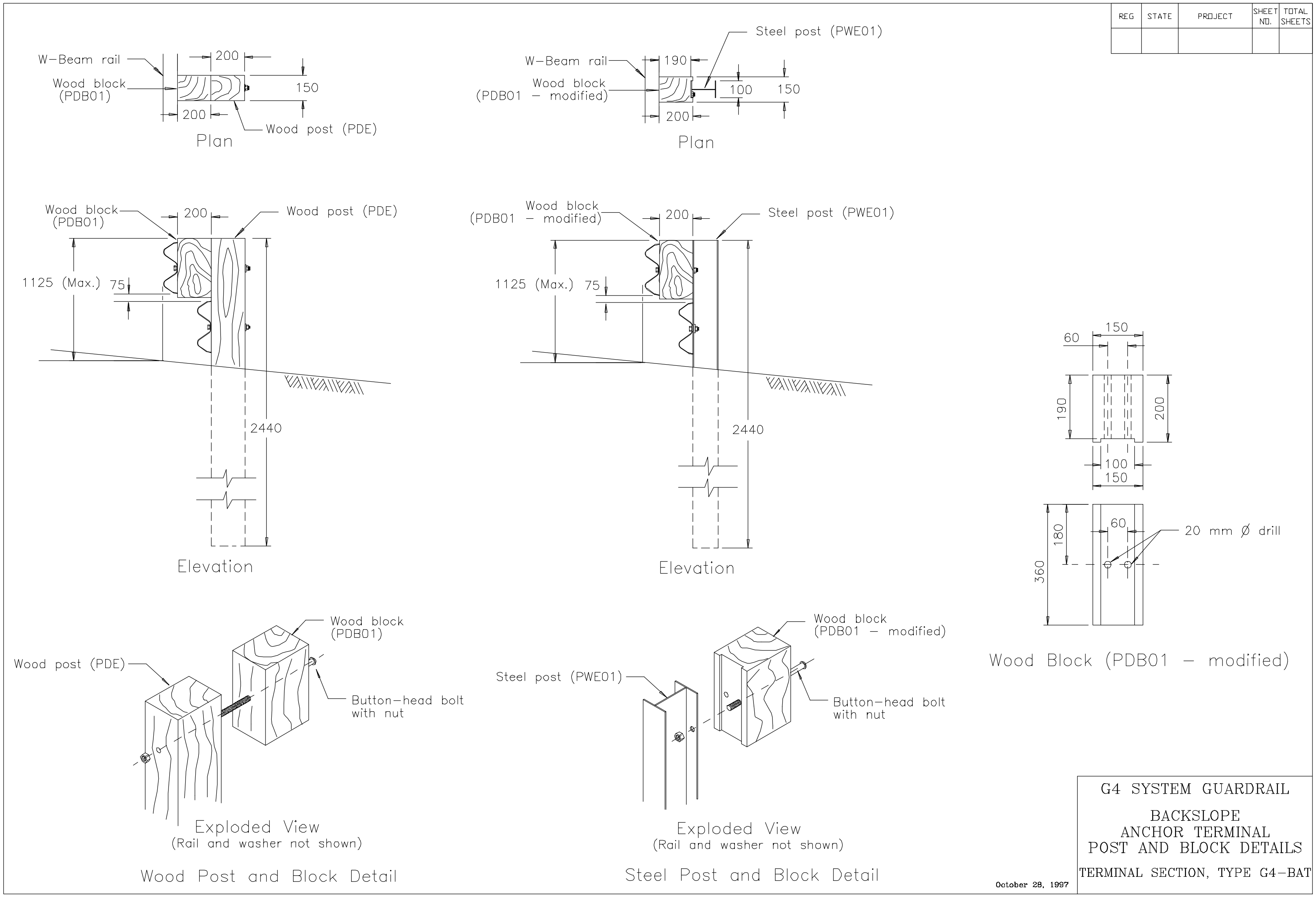


Figure 1. Details of the G4 W-beam guardrail buried-in-backslope terminal installation for test 404211-1 (continued).

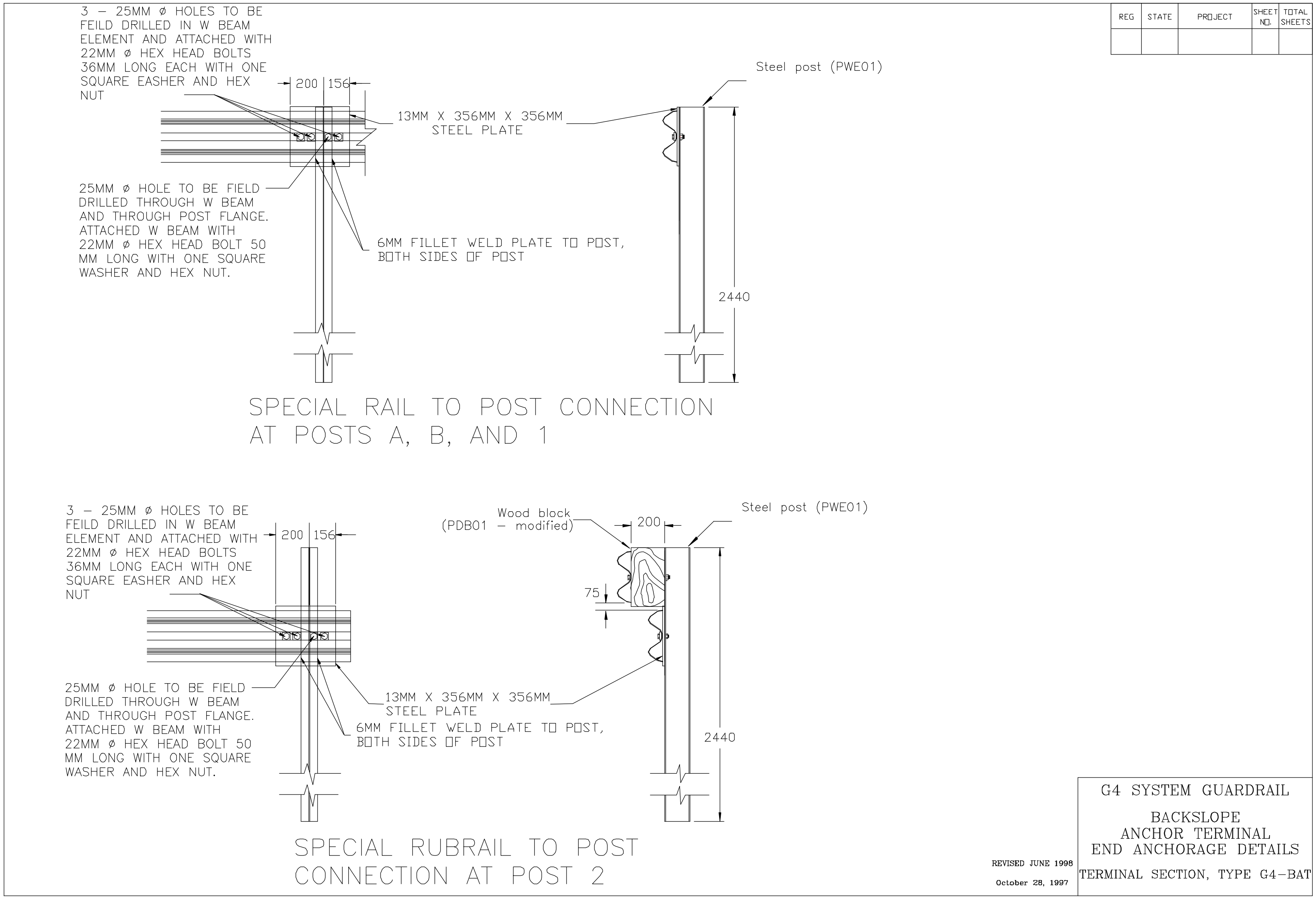


Figure 1. Details of the G4 W-beam guardrail buried-in-backslope terminal installation for 404211-1 (continued).

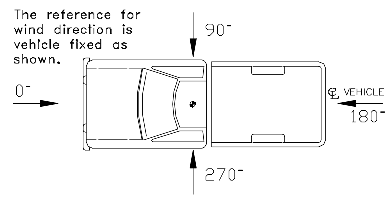
Posts 2 through 22 are 2440 mm long. Posts 1, A, B and the length of need posts are 1830 mm long.

A vee ditch runs through the installation. It consists of a 6 to 1 slope from the pavement for 2700 mm and then a 4 to 1 backslope continuing behind the rail. The vee ditch crosses the terminal 711 mm upstream of post 8.

Drawings for the buried-in-backslope end treatment are shown on page 1 of figure 1. Miscellaneous end treatment details for the installation are shown on pages 2 and 3 of figure 1. Photographs of the completed installation as tested are shown in figure 2.

Soil and Weather Conditions

The test was performed on the morning of January 29, 1998. A total of 18 mm of rainfall occurred eight days prior to the day of the test. No other rainfall occurred during the remaining 10 recording days prior to the test. Moisture content of the *NCHRP Report 350* standard soil in which the terminal was installed was 8.3 percent at post 8, 8.6 percent at post 9, and 8.6 percent at post 10. Weather conditions the day of the test were as follows: wind speed: 9 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle traveling northeasterly); temperature: 16EC; relative humidity: 84 percent.



Test Vehicle

A 1995 GMC 2500 pickup truck, shown in figure 3, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2076 kg. The height to the lower edge of the vehicle bumper was 395 mm and it was 600 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in appendix B, figure 79.

Impact Description

The vehicle, traveling at 97.2 km/h, impacted the G4 W-beam guardrail backslope anchor terminal 90 mm beyond post 8, at an angle of 25.2 degrees. At 0.010 s, post 8 moved and at 0.030 s, post 9 moved. The vehicle began to redirect at 0.052 s. At 0.070 s, posts 7 and 10 moved, at 0.084 s, the left front tire of the vehicle contacted post 9, and at 0.106 s, post 11 moved. The dummy’s head impacted the driver-side window, breaking the window at 0.159 s. The rear of the vehicle contacted the rail element at 0.211 s. At 0.239 s, the vehicle was at post 11, traveling parallel with the guardrail at a speed of 70.7 km/h. The vehicle lost contact with the guardrail at 0.496 s, traveling at a speed of 70.6 km/h and an angle of 8.1 degrees. Brakes on the vehicle were applied at 2.5 s after impact and the vehicle subsequently came to rest 66.8 m down from the point of impact and adjacent to the rail. Sequential photographs of the test period are shown in appendix C, figures 92 and 93.

Figure 2. G4 W-beam guardrail backslope anchor terminal installation prior to test 404211-1.

Figure 3. Vehicle before test 404211-1.

Damage to Test Article

Deformation to the upper and lower W-beams extended from between post 8 and 9 to past post 11, as shown in figure 4. The flange on the top of post 8 was deformed. Tire marks on the W-beam could be seen at a point 558 mm down from post 8. On post 9, the lower W-beam was deformed, the bolt on the upper W-beam was pulled completely through, the lower part of the flange was deformed and the wood on the lower section of the block was gouged out. Maximum dynamic deflection of the W-beam during the test was 0.67 m and the maximum residual deformation after the test was 0.41 m near post 11.

Vehicle Damage

The vehicle sustained structural damages on the front left and left side. The left stabilizer bar, upper and lower A-arms, spindle and assembly, tire and wheel were all severely damaged. The front left portion of the bumper, hood, grill and frame were crushed as shown in figure 5. The windshield was cracked in the lower left corner and the left door was deformed to the point that it separated from the frame 90 mm at the top. The left rear quarter panel was dented and the bed shifted 20 mm to the right. The right door was jammed and the front right quarter panel was jammed into the door. The maximum crush to the front bumper was 430 mm on the front and 520 mm on the left side. The floor pan and the firewall were deformed. Maximum deformation of the occupant compartment was 45 mm in the center floor pan area. Exterior vehicle crush and occupant compartment deformation measurements are shown in appendix B, tables 25 and 26.

Occupant Risk Factors

Longitudinal occupant impact velocity was 7.2 m/s at 0.204 s, the highest 0.010-s longitudinal occupant ridedown acceleration was -9.4 g's from 0.259 to 0.269 s, and the maximum 0.050-s average longitudinal acceleration was -6.0 g's between 0.084 and 0.134 s. In the lateral direction, the occupant impact velocity was 7.2 m/s at 0.227 s, the highest 0.010-s occupant ridedown acceleration was 8.6 g's from 0.209 to 0.219 s, and the maximum 0.050-s average was 8.8 g's between 0.242 and 0.292 s. These data and other pertinent information from the test are summarized in figure 6. Vehicle angular displacements are displayed in appendix D, figure 118. Vehicular accelerations versus time traces are presented in appendix E, figures 131 through 141.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

- **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.*

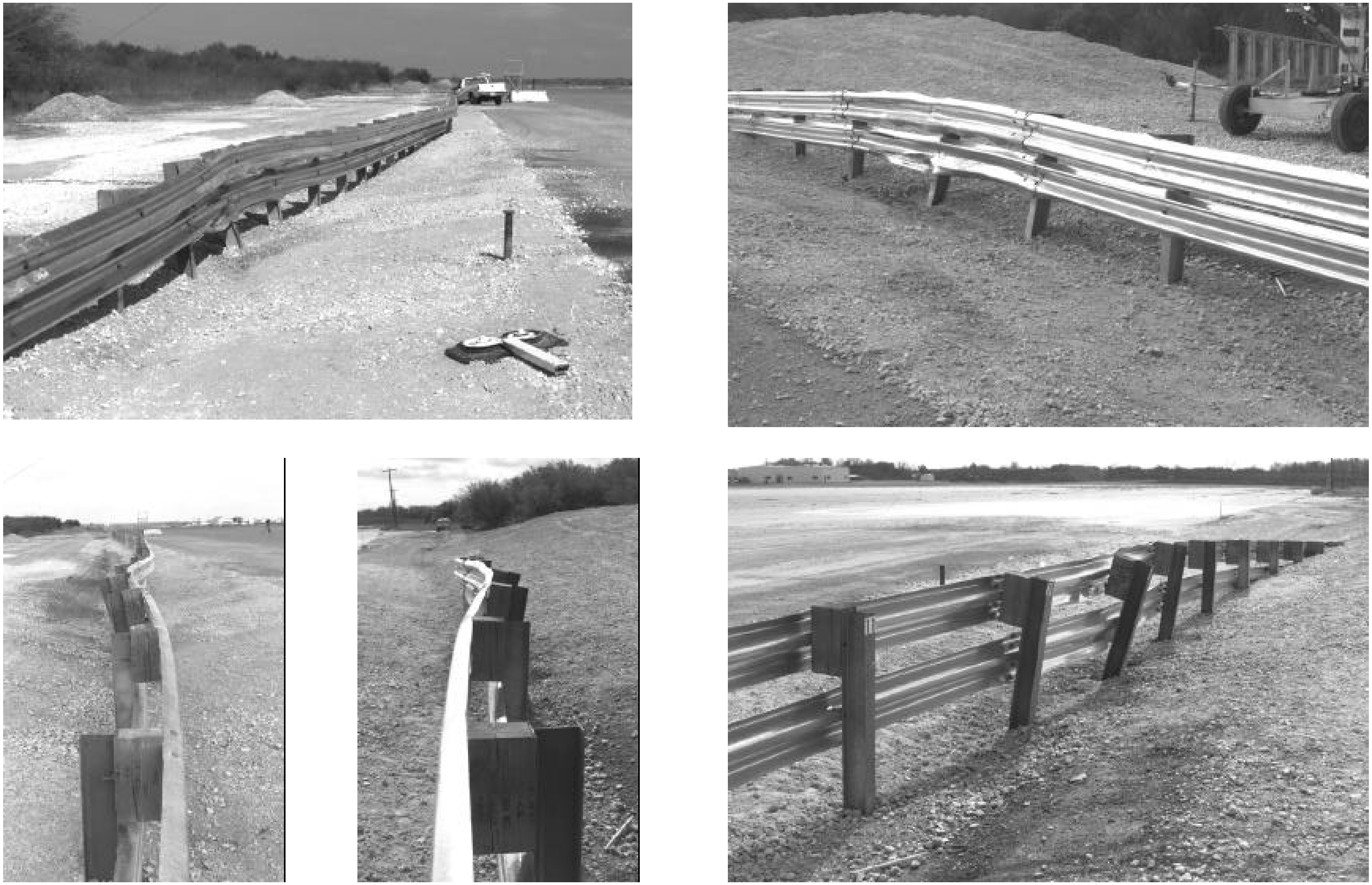


Figure 4. G4 W-beam guardrail buried-in-backslope terminal after test 404211-1.

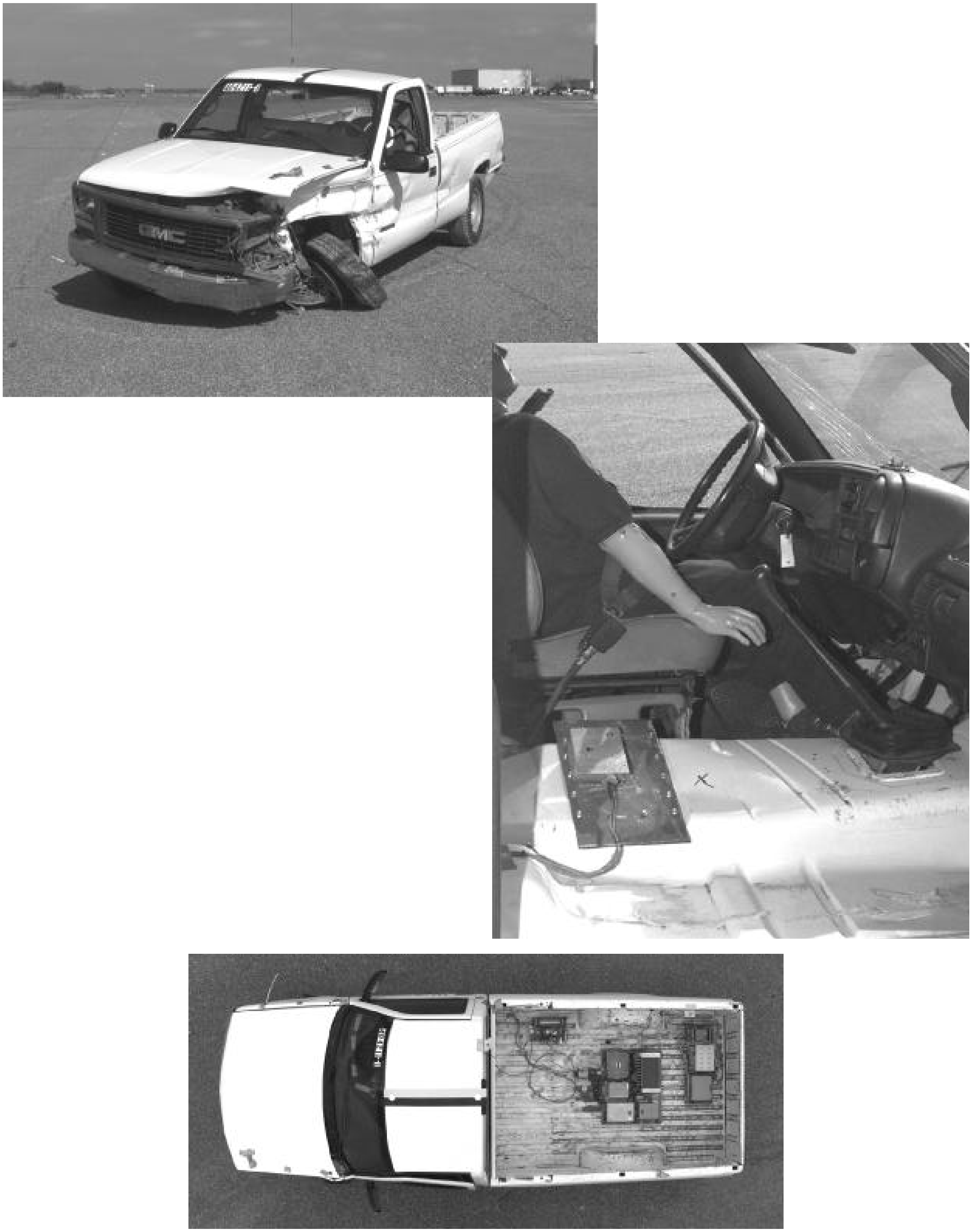
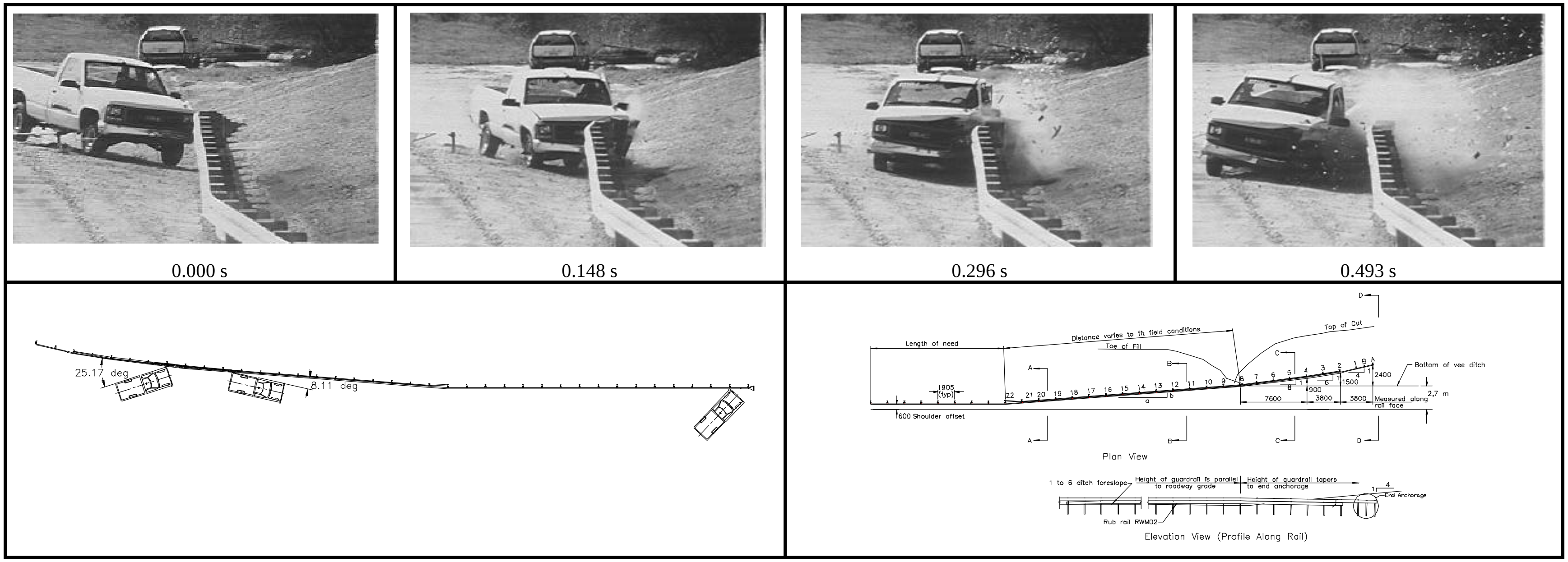


Figure 5. Vehicle after test 404211-1.



General Information

Test Agency	Texas Transportation Institute
Test No.	404211-1
Date	01/29/98

Test Article

Type	Terminal
Name	W-beam Buried in Backslope
Installation Length (m)	76.2
Material or Key Elements	W-beam Guardrail on Steel Posts w/WoodBlockouts, Rub rail, 6:1 Ditch

Soil Type and Condition . . . . . . Standard Soil, Damp

Test Vehicle

Type	Production
Designation	2000P
Model	1995 GMC 2500 Pickup Truck
Mass (kg) Curb	1933
Test Inertial	2000
Dummy	76
Gross Static	2076

Impact Conditions

Speed (km/h)	97.2
Angle (deg)	25.2

Exit Conditions

Speed (km/h)	70.6
Angle (deg)	8.1

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	7.2
y-direction	7.2
THIV	25.0
Ridedown Accelerations (g's)	
x-direction	-9.4
y-direction	8.6
PHD (g's)	9.3
ASI	1.15
Max. 0.050-s Average (g's)	
x-direction	-6.0
y-direction	8.8
z-direction	-9.3

Test Article Deflections (m)

Dynamic	0.67
Permanent	0.41

Vehicle Damage

Exterior	
VDS	11LFQ4
CDC	11FLEK2 &11LYEW3
Maximum Exterior Vehicle Crush (mm)	520
Interior	
OCDI	FS0100002
Max. Occ. Compart. Deformation (mm)	45

Post-Impact Behavior
(during 1.0 s after impact)

Max. Yaw Angle (deg)	32
Max. Pitch Angle (deg)	11
Max. Roll Angle (deg)	38

Figure 6. Summary of results for the Buried-in-Backslope Terminal (with 6 to 1 vee ditch) test, *NCHRP Report 350* test 3-35.

Result: The buried-in-backslope terminal with 6 to 1 vee ditch contained and redirected the vehicle. Maximum deflection of the guardrail was 0.67 m.

! **Occupant Risk**

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

Result: No detached elements or debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 45 mm.

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

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

! **Vehicle Trajectory**

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

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

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.*

Result: Longitudinal occupant impact velocity was 7.2 m/s and the longitudinal occupant ridedown acceleration was -9.4 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: Exit angle at loss of contact was 8.1 degrees, which was 32 percent of the impact angle.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— **PASSENGER COMPARTMENT INTRUSION**

1. Windshield Intrusion

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

2. Body Panel Intrusion yes or no

— **LOSS OF VEHICLE CONTROL**

1. Physical loss of control

2. Loss of windshield visibility

3. Perceived threat to other vehicles

4. Debris on pavement

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

1. Harmful debris that could injure workers or others in the area

2. Harmful debris that could injure occupants in other vehicles

No debris was present.

— **VEHICLE AND DEVICE CONDITION**

1. Vehicle Damage

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

2. Windshield Damage

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

3. Device Damage

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

BURIED-IN-BACKSLOPE TERMINAL (WITH 4 to 1 SLOPE) (*NCHRP REPORT 350* TEST NO. 3-35)

Test Conditions

The test performed on this buried-in-backslope terminal (with 4 to 1 slope) was *NCHRP Report 350* test designation 3-35: a 2000P vehicle impacting the beginning of the length of need of the terminal at a nominal speed and impact angle of 100 km/h and 20 degrees. The beginning of the length of need for this terminal was determined to be at post 8.

Test Article

A W-beam guardrail can be terminated by burying the end of the rail element into a soil berm. This type of guardrail termination installation will herein be referred to as a "buried-in-backslope end treatment." The guardrail is flared across a vee ditch with its end anchored to a 1830-mm-long steel post buried in the backslope. The guardrail installation is the standard SGRO4a W-beam guardrail with wood blockouts. The guardrail between posts A, B, 1 and 2 (numbered sequentially from the end anchor) is flared back in a 4 to 1 ratio. The guardrail between posts 2 and 4 is flared back in a 6 to 1 ratio; between posts 4 and 8 in an 8 to 1 ratio; and between posts 8 and 20 in a 13 to 1 ratio. In addition, the guardrail between post 8 and post A is tapered from 705 mm to 504 mm, measured from the top of the rail to the shoulder grade. The guardrail, beginning at post 8, is parallel to the travel way and extends for 30.5 m beyond post 20 (length of need). The top of the rail for the length of need is 705 mm, measured from the shoulder grade. A LET terminal was installed on the downstream end of the installation.

The buried-in-backslope end treatment consists of a W-beam guardrail attached to steel posts (PWE01) using wood blockouts (PDB01 - modified) with one 16-mm button-head bolt at every post. The 150-mm x 200-mm wood blockout is routed to fit the steel post and is 360 mm long. The W-beam is connected to the end post using a special connection bracket as shown in figure 7.

A W-beam rubrail extends from post 2 to post 20. The rubrail is mounted to the steel posts with one 16-mm bolt. A 75-mm gap between the W-beam guardrail and the rubrail is maintained. The upstream end of the rubrail is connected to post 2 with the special connection bracket and the downstream end of the rubrail is connected to the back of post 20 with a 16-mm bolt. Posts 2 through 20 are 2440 mm long. Posts 1, A, B and the length-of-need posts are 1830 mm long.

A vee ditch runs through the installation. It consists of a 4 to 1 slope from the pavement edge for 1830 mm and then a 2 to 1 backslope continuing behind the rail. The vee ditch crosses the rail terminal at post 8.

Drawings for the buried-in-backslope end treatment are shown in figure 7. Photographs of the completed installation as tested are shown in figure 8.

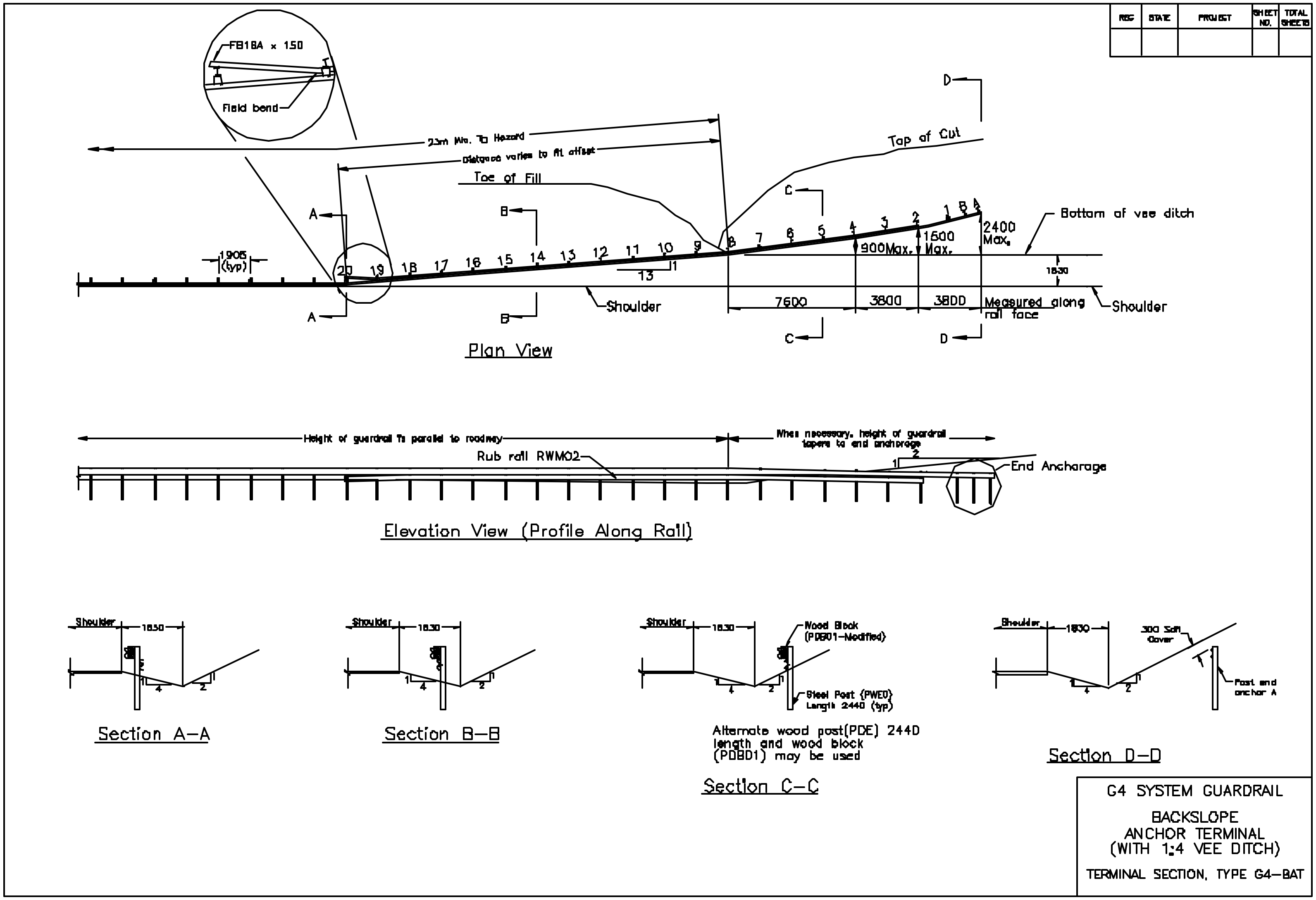


Figure 7. Details of the G4 W-beam guardrail buried-in-backslope installation for test 404211-13.

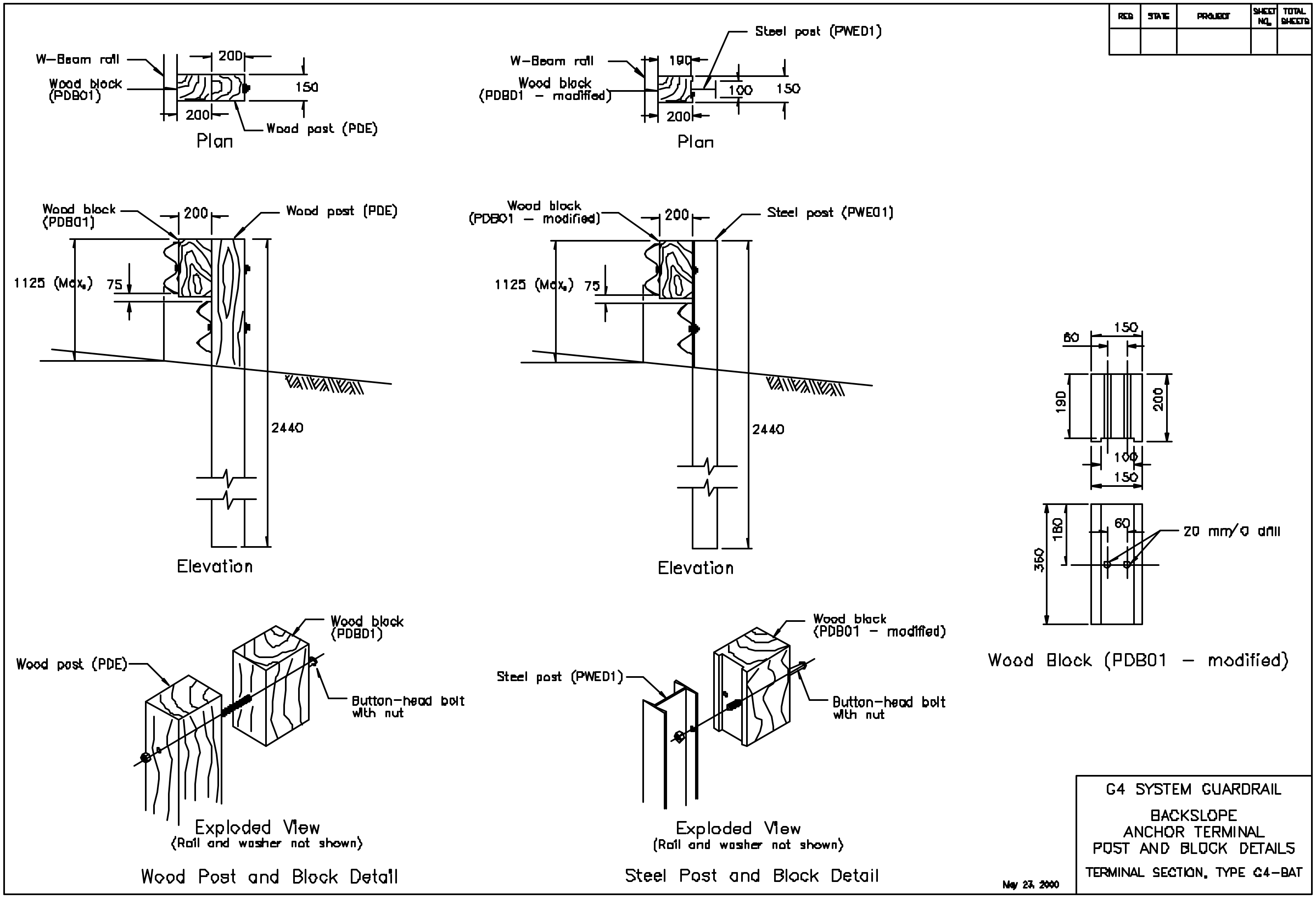


Figure 7. Details of the G4 W-beam guardrail buried-in-backslope installation for test 404211-13 (continued).

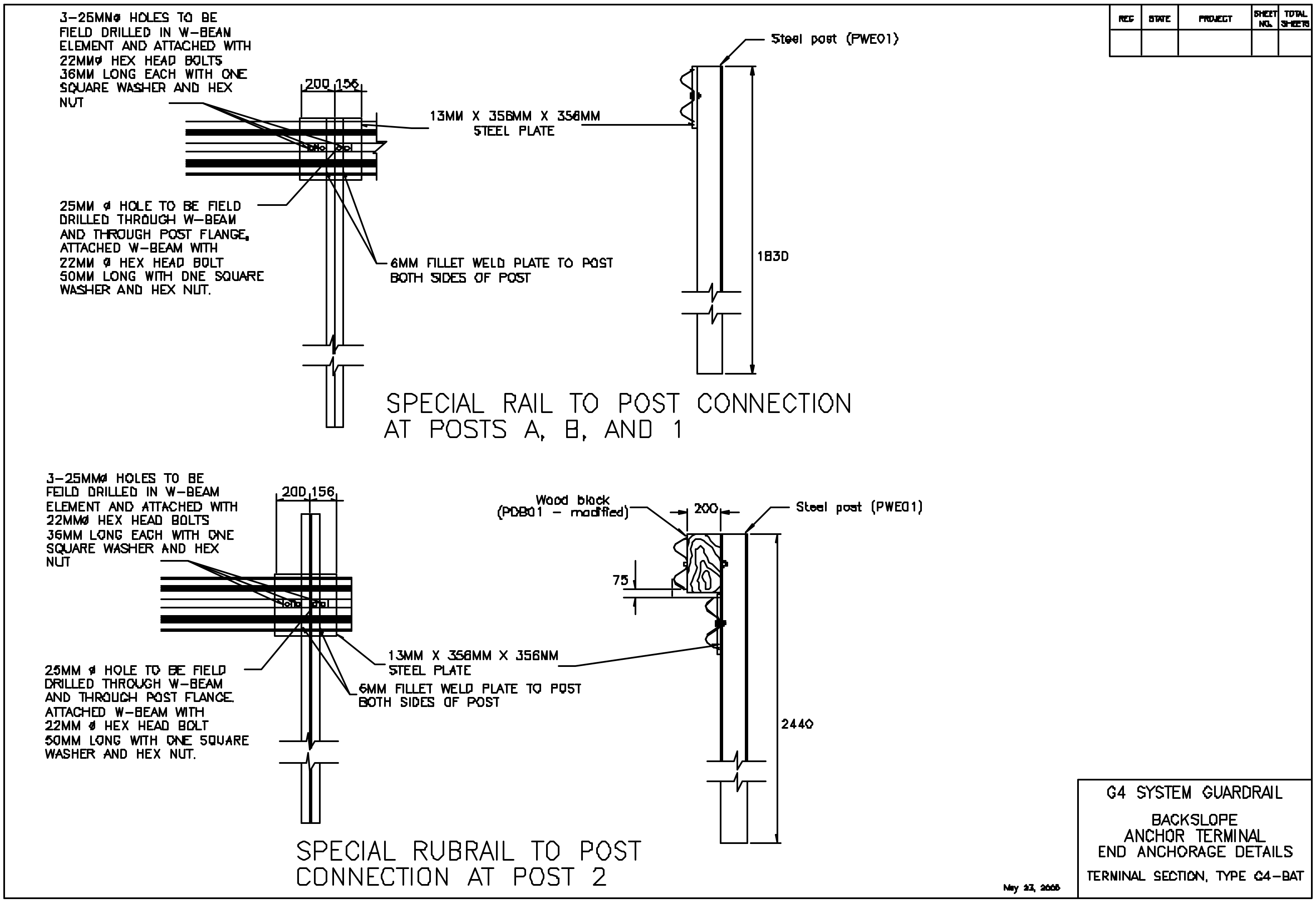


Figure 7. Details of the G4 W-beam guardrail buried-in-backslope installation for test 404211-13 (continued).

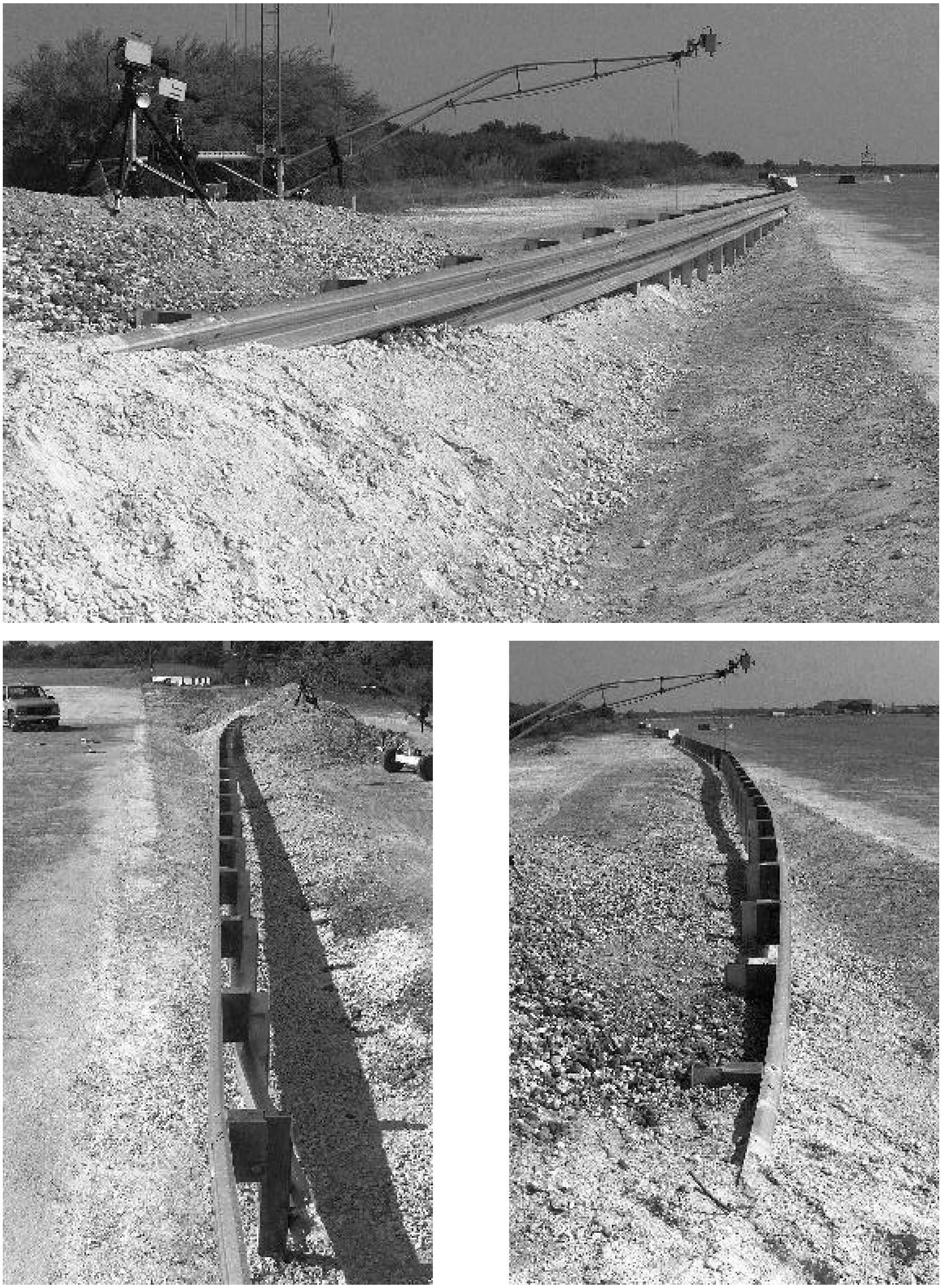
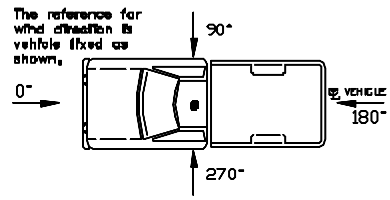


Figure 8. G4 W-beam guardrail buried-in-backslope installation prior to test 404211-13.

Soil and Weather Conditions

The crash test was performed the morning of July 27, 2000. No rainfall was recorded for the 10 recording days prior to the test. Moisture content of the *NCHRP Report 350* standard soil in which the terminal was installed was 4.2 percent, 2.4 percent, and 4.8 percent at posts 8, 10, and 12, respectively. Weather conditions at the time of testing were as follows: wind speed: 5 km/h; wind direction:180 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 32EC; relative humidity: 50 percent.



Test Vehicle

A 1995 GMC 2500 pickup truck, shown in figure 9, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2075 kg. The height to the lower edge of the vehicle front bumper was 430 mm and to the upper edge of the front bumper was 650 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 80.

Impact Description

The 2000P pickup truck impacted at post 8 of the buried-in-backslope terminal at a speed of 101.1 km/h and impact angle of 25.9 degrees. As the vehicle contacted the installation, the left side of the vehicle was pitched downward and the left front tire was airborne. Shortly after contact, post 8 moved. Posts 9 and 10 moved at 0.012 s and 0.045 s, respectively. At 0.062 s the vehicle began to redirect and at 0.077 s the right front wheel steered toward the rail. Post 11 moved at 0.088 s and post 12 moved at 0.126 s. The window glass on the driver side shattered at 0.157 s and the rear of the vehicle contacted the rail element at 0.237 s. The vehicle became parallel with the rail element at 0.267 s and was traveling at a speed of 67.6 km/h. At 0.556 s the vehicle lost contact with the installation and was traveling at a speed of 65.0 km/h and an exit angle of 17.5 degrees. As the vehicle lost contact with the rail element, it yawed back toward the rail and subsequently came to rest against the length of need at post 39. The brakes on the vehicle were not applied. Sequential photographs of the test period are shown in appendix C, figures 94 and 95.

Damage to Test Article

The buried-in-backslope terminal sustained minimal damage as shown in figure 10. Two sections of W-beam rail element and rub rail were deformed and tire marks were on the front face of posts 9 and 10. The blockout at post 9 was detached and resting behind the installation. The tops of the blockouts at posts 10 and 11 were scarred. Length of contact of the vehicle with the installation was 6.7 m. Maximum dynamic deflection during the test was 861 mm and maximum permanent deformation was 445 mm on the rub rail and 695 mm on the upper W-beam rail element.

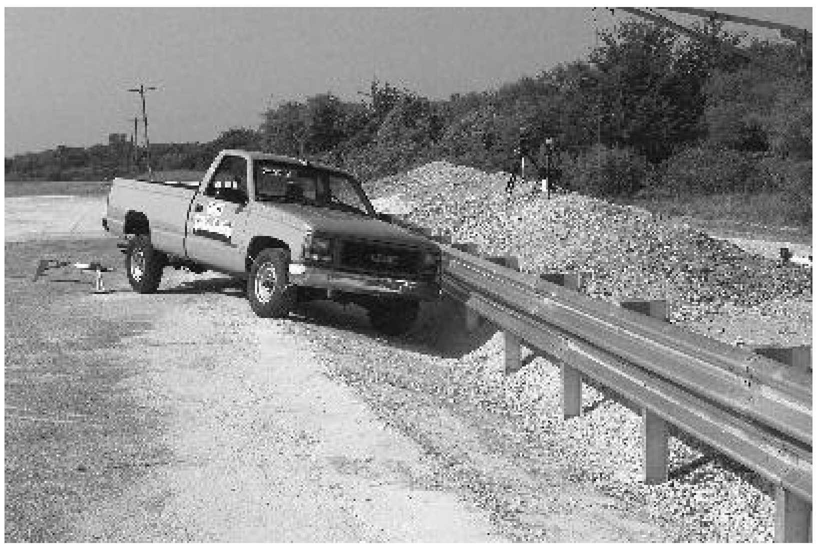
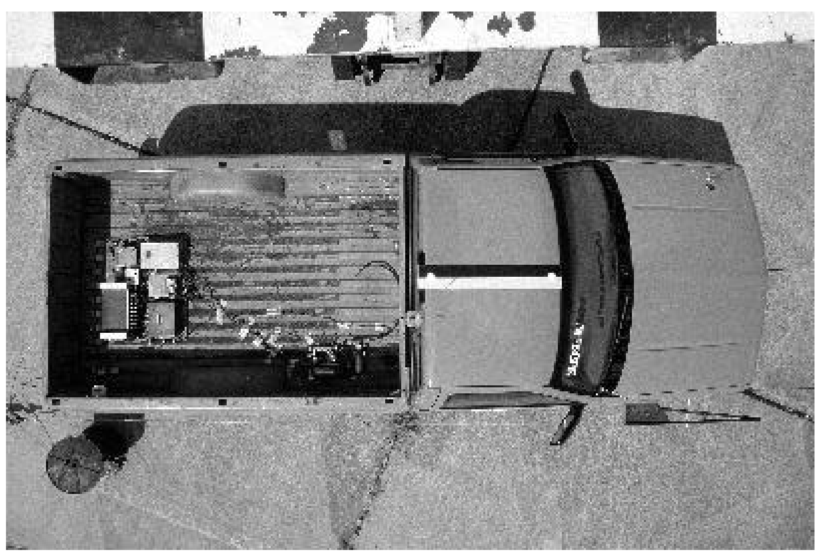




Figure 9. Vehicle before test 404211-13.

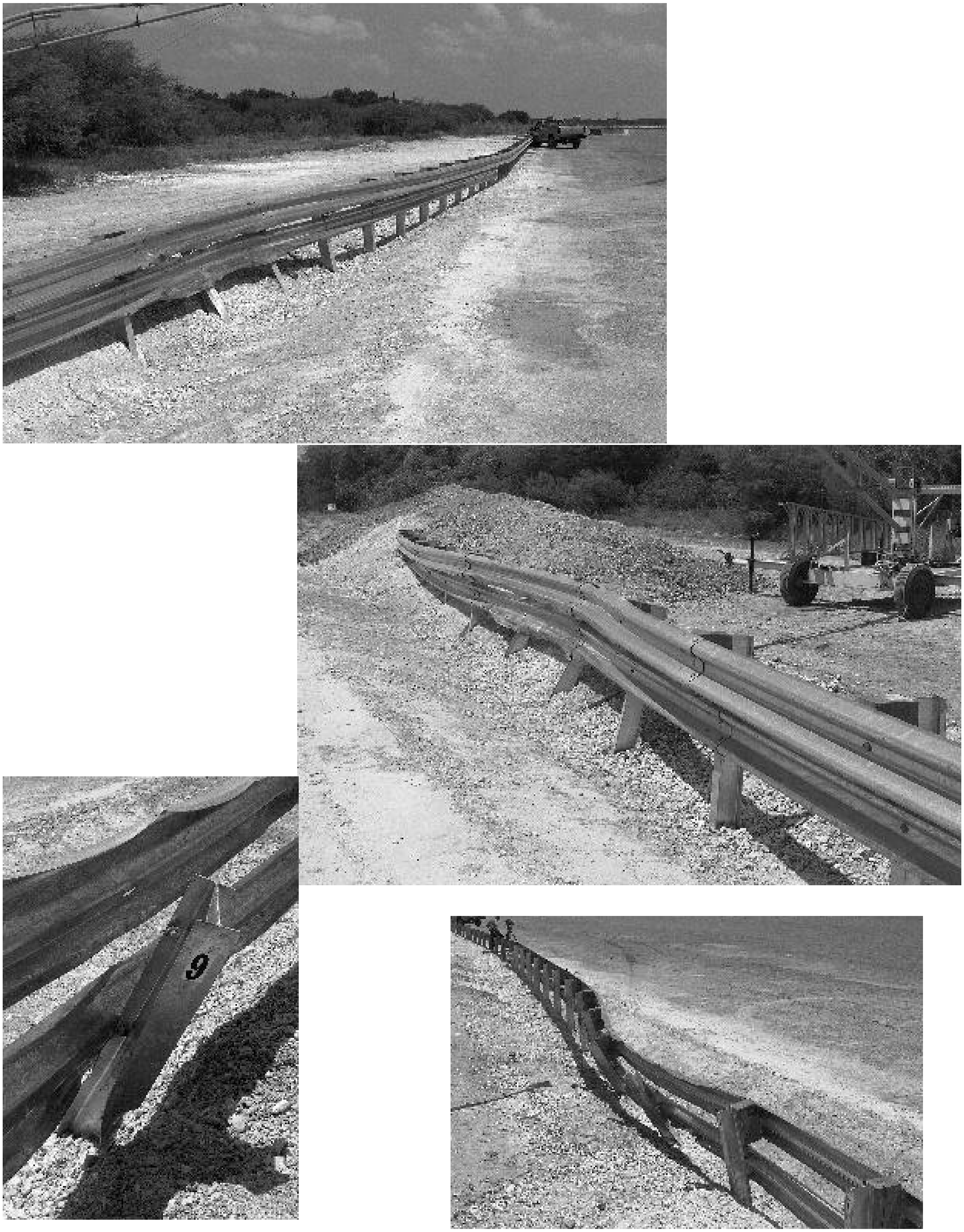


Figure 10. Installation after test 404211-13.

Vehicle Damage

The pickup sustained moderate damage as shown in figure 11. Structural damage included deformed left front frame and left outer tie rod. Also damaged were the front bumper, hood, radiator, fan, left front tire and wheel, left front quarter panel, left door, and left rear of the bed. The windshield received stress cracks and the left door window glass was broken. Maximum exterior crush was 550 mm to the left front corner at bumper height. Maximum occupant compartment deformation was 125 mm in the center floor pan area. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 27 and 28.

Occupant Risk Factors

Data from the triaxial accelerometer, located at the vehicle center of gravity (c.g.), were digitized to compute occupant impact velocity and ridedown accelerations. The occupant impact velocity and ridedown accelerations in the longitudinal axis only are required from these data for evaluation of criterion L of *NCHRP Report 350*. In the longitudinal direction, occupant impact velocity was 5.4 m/s at 0.137 s, maximum 0.010-s ridedown acceleration was -8.3 g's from 0.153 to 0.163 s, and the maximum 0.050-s average was -6.5 g's between 0.118 and 0.168 s. In the lateral direction, the occupant impact velocity was 6.5 m/s at 0.137 s, the highest 0.010-s occupant ridedown acceleration was 7.9 g's from 0.157 to 0.167 s, and the maximum 0.050-s average was 7.7 g's between 0.109 and 0.159 s. These data and other information pertinent to the test are presented in figure 12. Vehicle angular displacements are displayed in appendix D, figure 119. Vehicular accelerations versus time traces are presented in appendix E, figures 142 through 147.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

- **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.*

<u>Result:</u> The terminal contained and redirected the 2000-kg pickup truck. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 0.861 m.

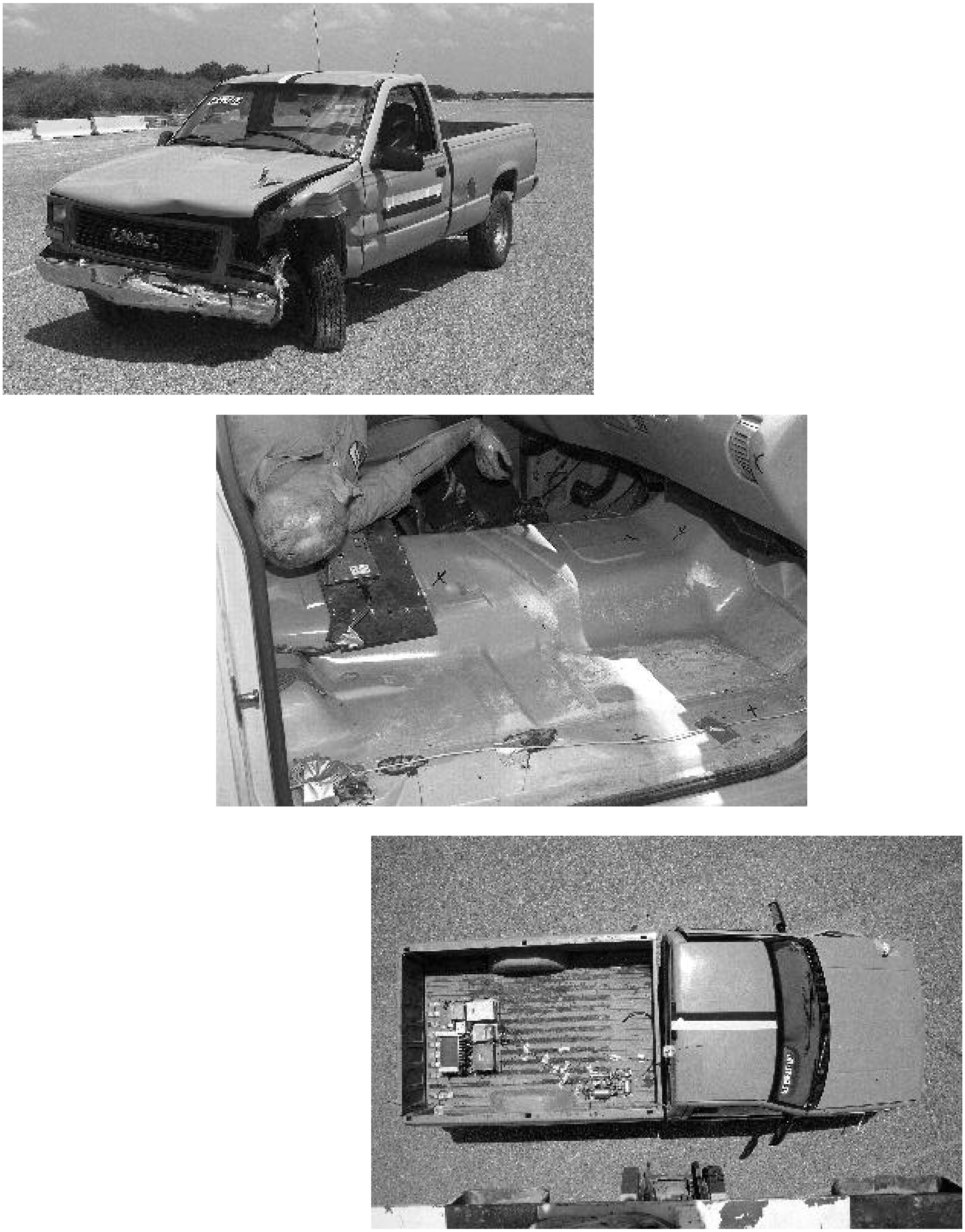
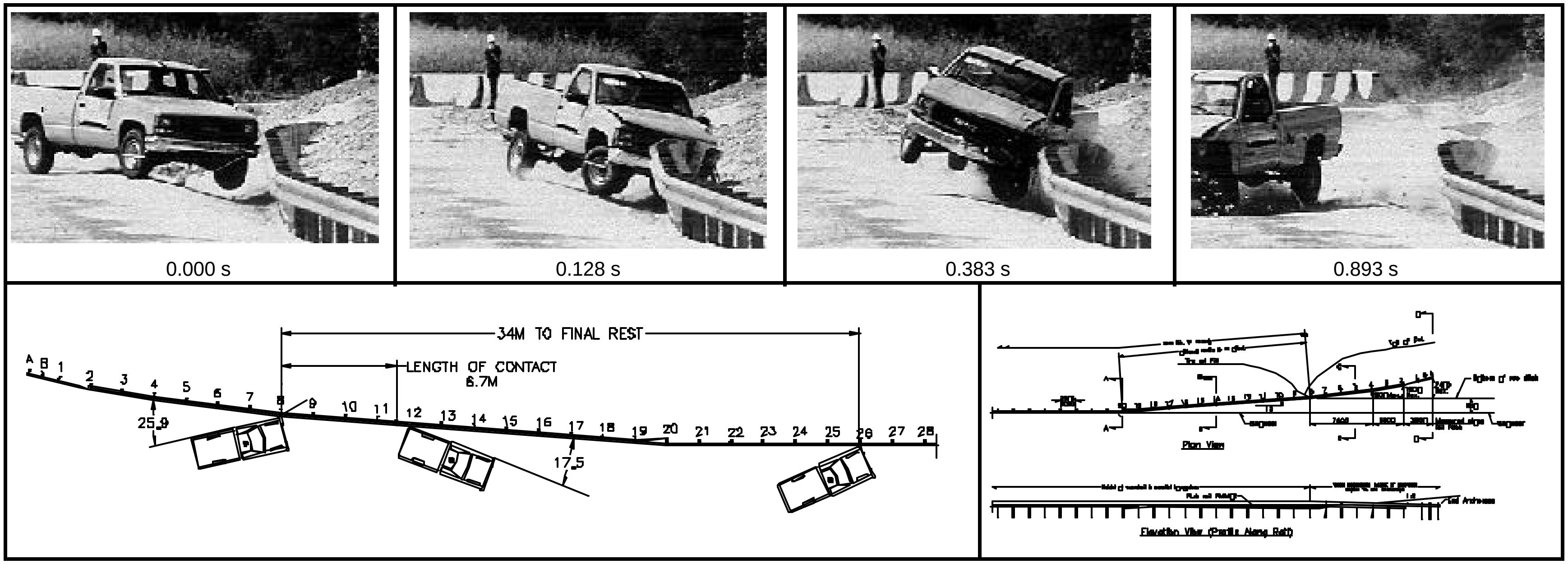


Figure 11. Vehicle after test 404211-13.



General Information
- Test Agency .... Texas Transportation Institute
- Test No. 404211-13
- Date 07/27/00

Test Article
- Type .... Terminal
- Name .... Buried-in-Backslope w/4 to 1 slope
- Installation Length (m) 38.2
- Material or Key Elements . W-beam Guardrail on Steel posts w/wood blockouts, Rubrail, 4 to 1 Slope

Soil Type and Condition . Standard Soil, Dry

Test Vehicle
- Type .... Production
- Designation 2000P
- Model .... 1995 GMC 2500 Pickup Truck
- Mass (kg)
  - Curb 2107
  - Test Inertial 2000
  - Dummy 75
  - Gross Static 2075

Impact Conditions
- Speed (km/h) 101.1
- Angle (deg) 25.9

Exit Conditions
- Speed (km/h) 65.0
- Angle (deg) 17.5

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 5.4
  - y-direction 6.5
- THIV (km/h) 28.5
- Ridedown Accelerations (g's)
  - x-direction .... -8.3
  - y-direction 7.9
- PHD (g's) 10.9
- ASI 0.99
- Max. 0.050-s Average (g's)
  - x-direction .... -6.5
  - y-direction 7.7
  - z-direction .... -4.7

Test Article Deflections (m)
- Dynamic 0.861
- Permanent 0.695
- Working Width 1.087

Vehicle Damage
- Exterior
  - VDS 11LFQ4
  - CDC .... 11FLEK2 &11LYEW3
- Maximum Exterior
  - Vehicle Crush (mm) 550
- Interior
  - OCDI LF0102000
- Max. Occ. Compart.
  - Deformation (mm) 125

Post-Impact Behavior
(during 1.0 s after impact)
- Max. Yaw Angle (deg) 43
- Max. Pitch Angle (deg) 7
- Max. Roll Angle (deg) ...... -18

Figure 12. Summary of results for the buried-in-backslope terminal (with 4 to 1 vee ditch) test, *NCHRP Report 350* test 3-35.

! **Occupant Risk**

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

Result: The blockout at post 9 detached but did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to others in the area. Maximum occupant compartment deformation was 125 mm and was judged not to cause serious injury.

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

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

! **Vehicle Trajectory**

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

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

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.*

Result: Longitudinal occupant impact velocity was 5.4 m/s and longitudinal ridedown acceleration was -8.3 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: Exit angle at loss of contact was 17.5 degrees, which was 68 percent of the impact angle; however, the vehicle yawed toward the installation and came to rest adjacent to the length of need.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— PASSENGER COMPARTMENT INTRUSION

1. Windshield Intrusion

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

2. Body Panel Intrusion yes or (no)

— LOSS OF VEHICLE CONTROL

(1.) Physical loss of control

2. Loss of windshield visibility

3. Perceived threat to other vehicles

4. Debris on pavement

— PHYSICAL THREAT TO WORKERS OR OTHER VEHICLES

1. Harmful debris that could injure workers or others in the area

2. Harmful debris that could injure occupants in other vehicles

The blockout at post 9 detached and came to rest behind the installation.

— VEHICLE AND DEVICE CONDITION

1. Vehicle Damage

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

2. Windshield Damage

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

3. Device Damage

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

NEW YORK TERMINAL FOR 3-CABLE BARRIER
(*NCHRP REPORT 350* TEST NO. 3-34)

Test Conditions

The test performed on the New York terminal for 3-cable barrier was *NCHRP Report 350* test designation 3-34: an 820-kg passenger car impacting the terminal at a nominal impact speed and angle of 100 km/h and 15 degrees midpoint between the end of the terminal and the beginning of the length of need. The target impact point was determined to be the point at which the right front corner of the bumper of the vehicle impacted the cables in the downward-sloping portion of the anchor.

Test Article

A 119.8-m-long New York 3-strand cable rail system was constructed for full scale crash testing of the terminal. The installation was constructed on a 6 to 1 slope as shown on page 1 of figure 13. Installation height of the system was 685 mm from the ground line to the center of the top cable. The posts were Type S75×8 steel posts spaced 5000 mm on-center. The posts were installed in *NCHRP Report 350* standard soil. The three cables were each 19-mm diameter 3-strand/7-wire rope cable, spaced 76 mm apart with a minimum tensile strength of 110 kN. The cables were connected to the posts using 8-mm hooked bolts. All cable ends were fitted with open end wedge type cable socket fittings. Each cable end was attached to a standard turnbuckle assembly, bolted to a breakaway anchor angle, and anchored rigidly to a concrete footing. Additionally, the last post on each end of the installation was anchored in the concrete footing and made frangible by a slip base connection. The concrete footing for the last post and the cable anchor terminal were constructed in two units that mated together with a tongue and groove as shown on page 2 of figure 13. The last post flared back from the tangent a total distance of 1220 mm over a total distance of 7410 mm. On one end of each of the cables, adjacent to the standard turnbuckle, a spring cable end assembly was attached. The spring cable assembly consisted of the standard turnbuckle with 305 mm of take-up, a 20-mm diameter threaded steel rod on each end, and a spring compensating device on one end. The spring compensating device had a spring rate of 80 + 8 N/mm and a total minimum throw of 150 mm. For the temperature conditions present just prior to the time the crash test was performed (29EC), the spring compensator was compressed 54 mm. Construction details are shown on pages 2 and 3 of figure 13. Photographs of the completed test installation are shown in figure 14.

The concrete footing for the cable anchor terminal and the last post (each integral unit) were constructed in two units that mated together with a tongue and groove. Each unit measured 660 mm by 1005 mm at the top and tapered to 725 mm by 1150 mm at the bottom. The height of the footing along the centerline of the post and terminal was 990 mm. The tops of the terminal units were constructed on a 6 to 1 slope. The units were connected together by an integral key way measuring 50 mm by 100 mm at the bottom and 50 mm by 150 mm at the top.

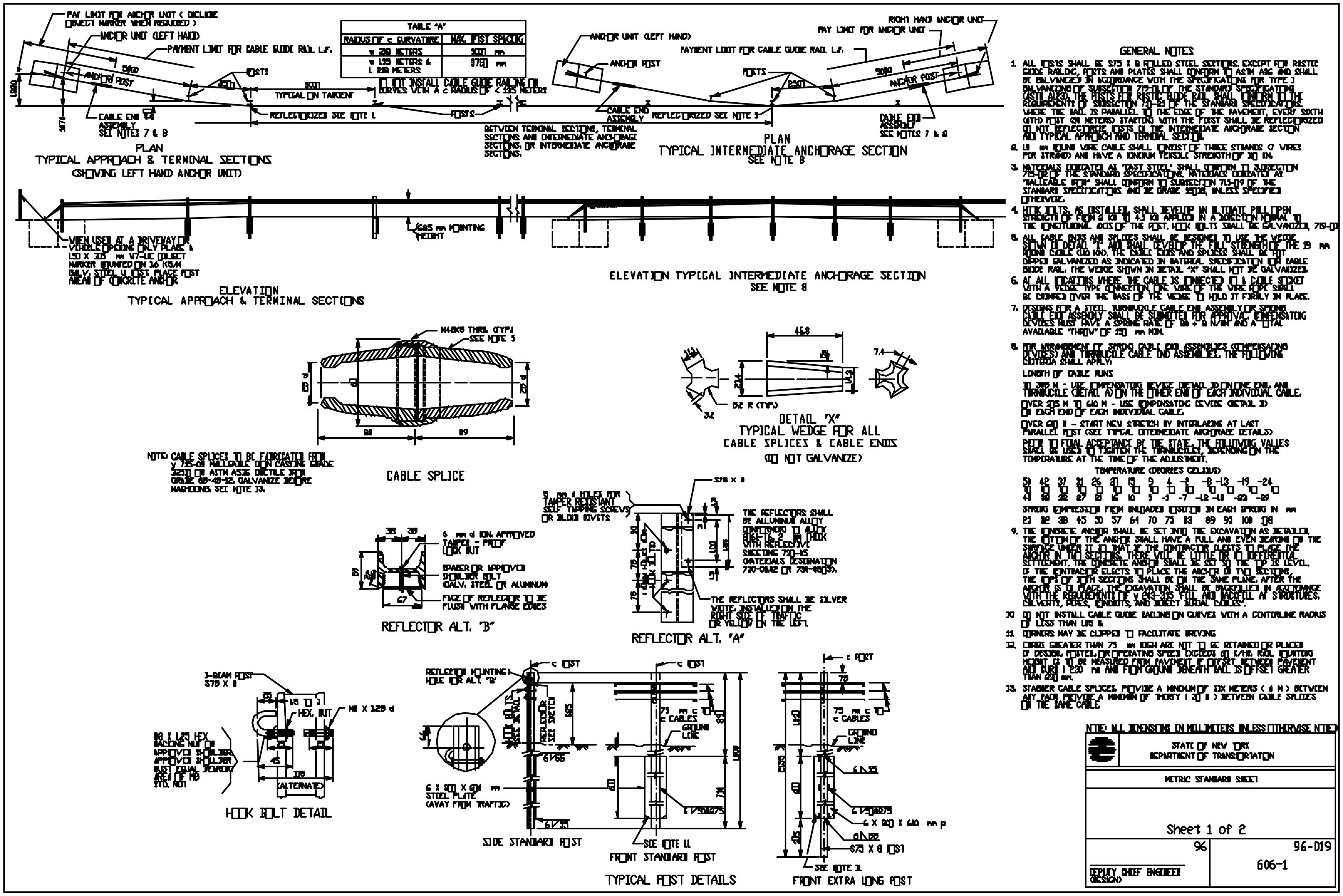


Figure 13. Details of the New York cable rail terminal installation for test 404211-6.

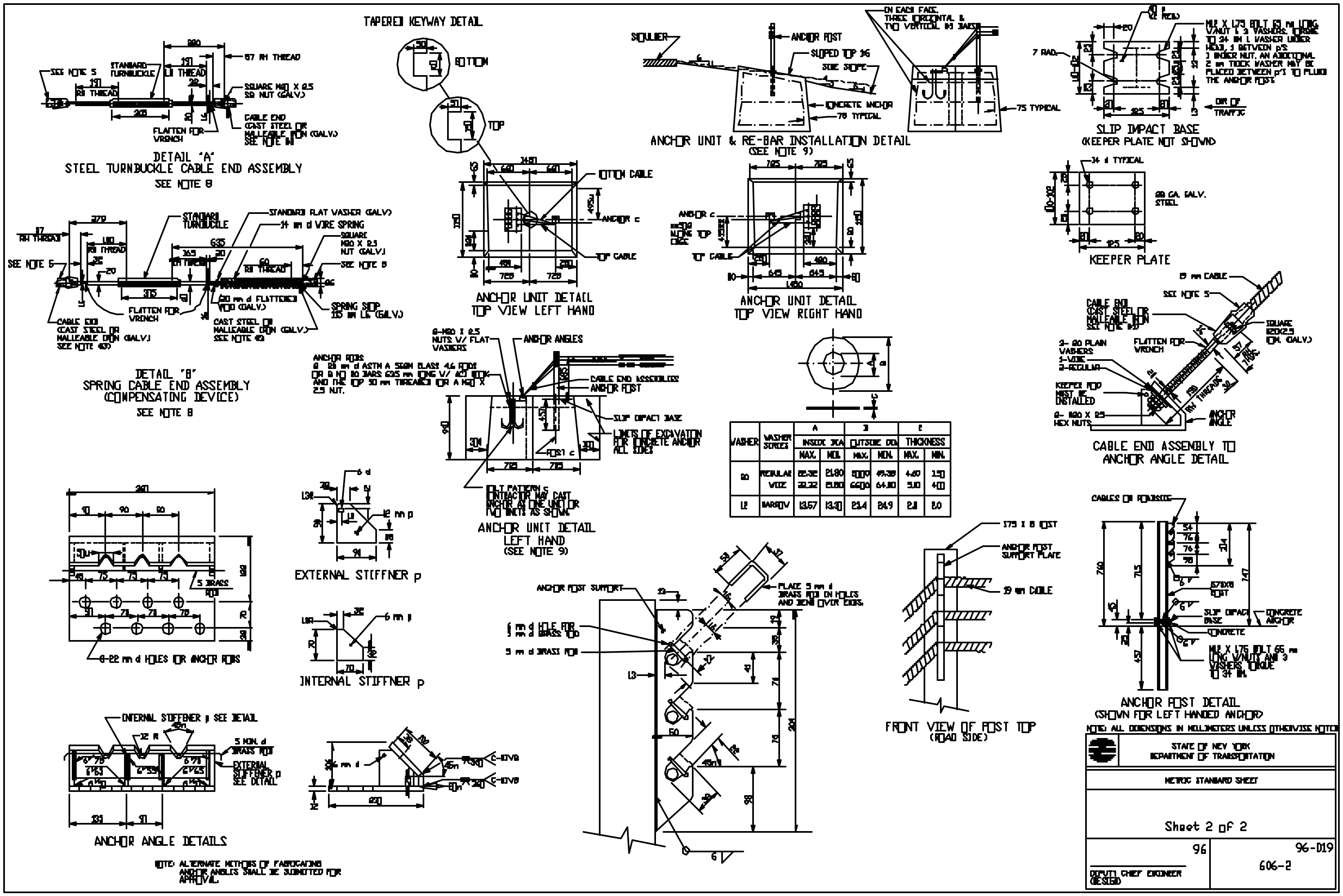


Figure 13. Details of the New York cable rail terminal installation for test 404211-6 (continued).

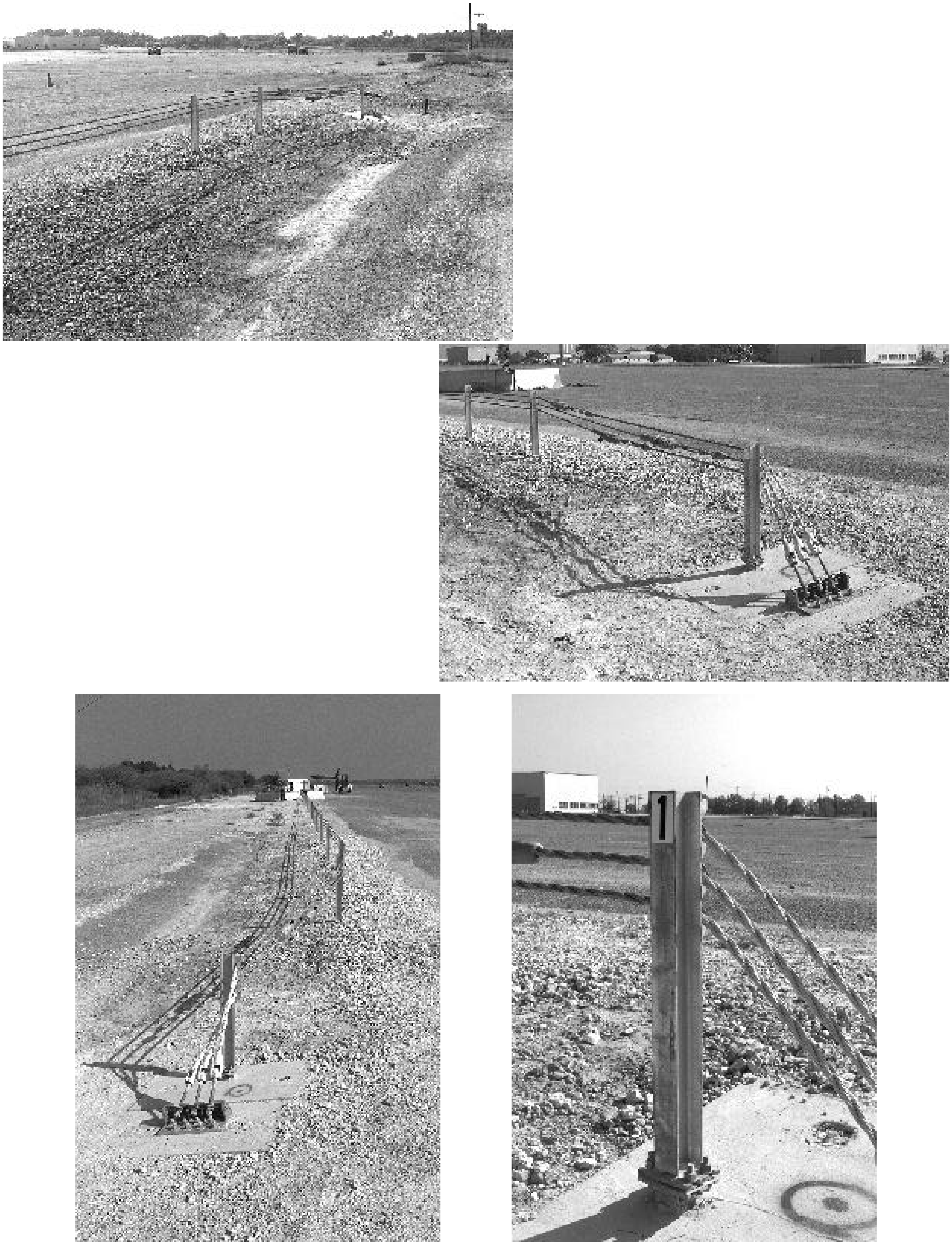
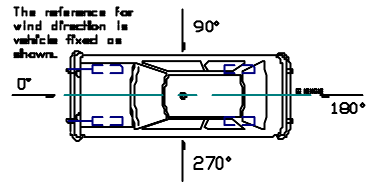


Figure 14. New York cable rail terminal installation prior to test 404211-6.

Soil and Weather Conditions

The test was performed the morning of October 1, 1998. No rainfall occurred during the 10 recording days prior to the test. Moisture content of the *NCHRP Report 350* soil in which the terminal was installed was between 6.9 and 7.5 percent. Weather conditions during the time of the test were as follows: wind speed: 8 km/h; wind direction: 190 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 31EC; relative humidity: 64 percent.



Test Vehicle

A 1992 Ford Festiva, shown in figure 15, was used for the crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. The height to the lower edge of the vehicle bumper was 355 mm and it was 530 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in appendix B, figure 81.

Impact Description

The vehicle, traveling at 99.3 km/h, impacted the New York terminal at 14.7 degrees. Initial contact with the terminal was such that the right front corner of the bumper of the vehicle impacted the cables in the downward-sloping portion of the anchor. Approximately 0.013 s after impact, the vehicle bumper contacted the end post (post 1), which activated at the slip base. The front right tire contacted the post at 0.036 s and knocked the post to the ground. The right rear wheel lost contact with the ground at 0.059 s and the right front at 0.085 s. The vehicle lost contact with the terminal at 0.115 s while traveling at a speed of 94.4 km/h and an exit angle behind the terminal of 15.7 degrees. The vehicle continued to travel down the slope of the ditch and the right side wheels touched ground again at 0.236 s and 0.305 s as the vehicle reached the field side of the ditch. The vehicle then traversed up the slope and traveled out of what would be the right of way and into private property. Brakes on the vehicle were not applied. As the vehicle entered the brushy area beyond the right of way, it yawed clockwise and rolled onto its left side for reasons not related to the performance of the guardrail (the vehicle impacted a large bush). The vehicle came to rest 42.5 m down from impact and 25.0 m behind the installation. Sequential photographs of the test period are shown in appendix C, figures 96 and 97.

Damage to Test Article

Damage to the 3-cable New York cable rail terminal was minimal as shown in figure 16. The end post broke away at the slip base and was found 480 mm from the base. The rear bolt on the right side remained on the base and the rear bolt from the left side was lying near the base. The two bolts on the front remained with the end post. The turnbuckles near the anchor plate and the cables received scuff marks from the vehicle tires. The cables were slack throughout the length of the installation, but neither anchor moved.

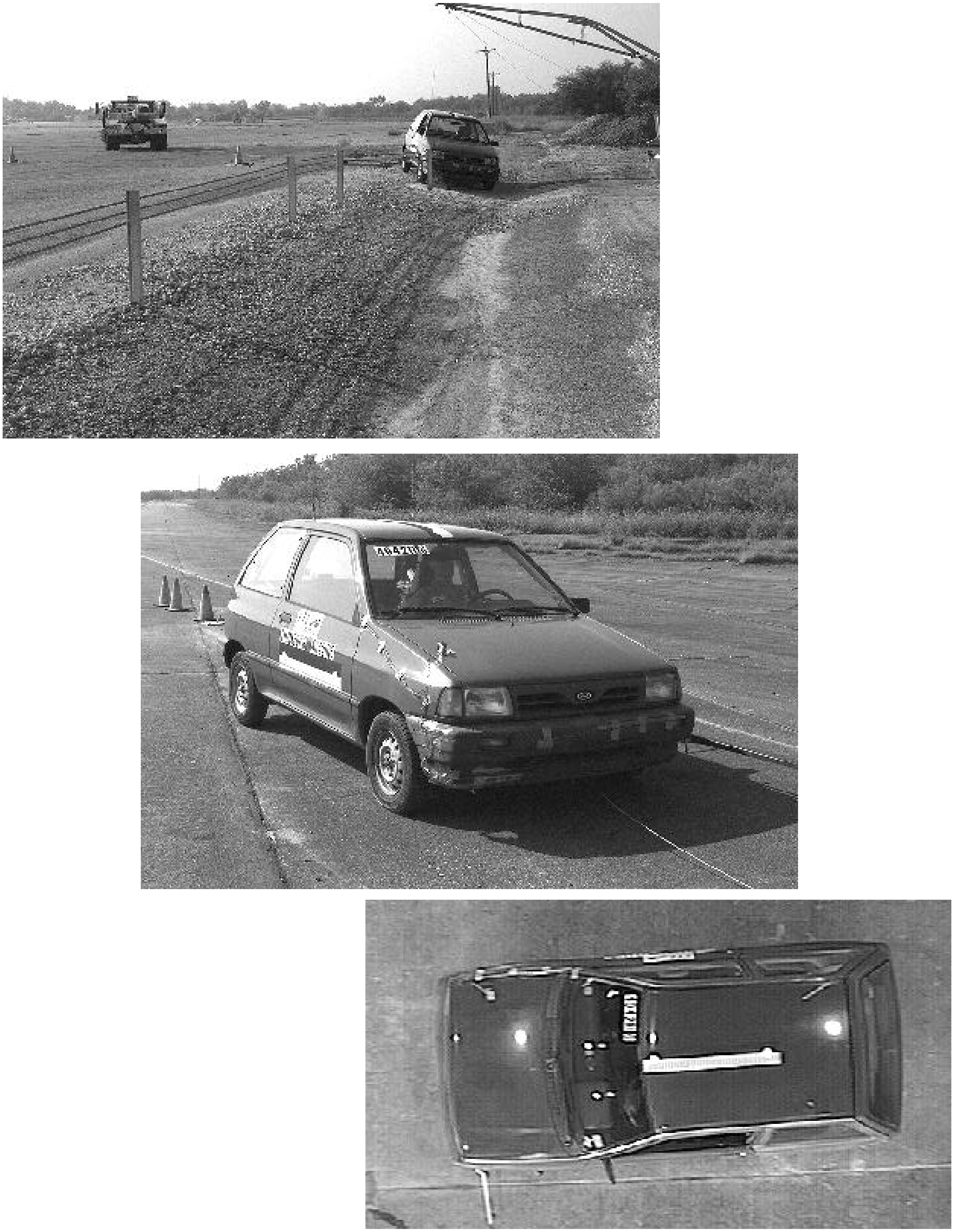


Figure 15. Vehicle before test 404211-6.

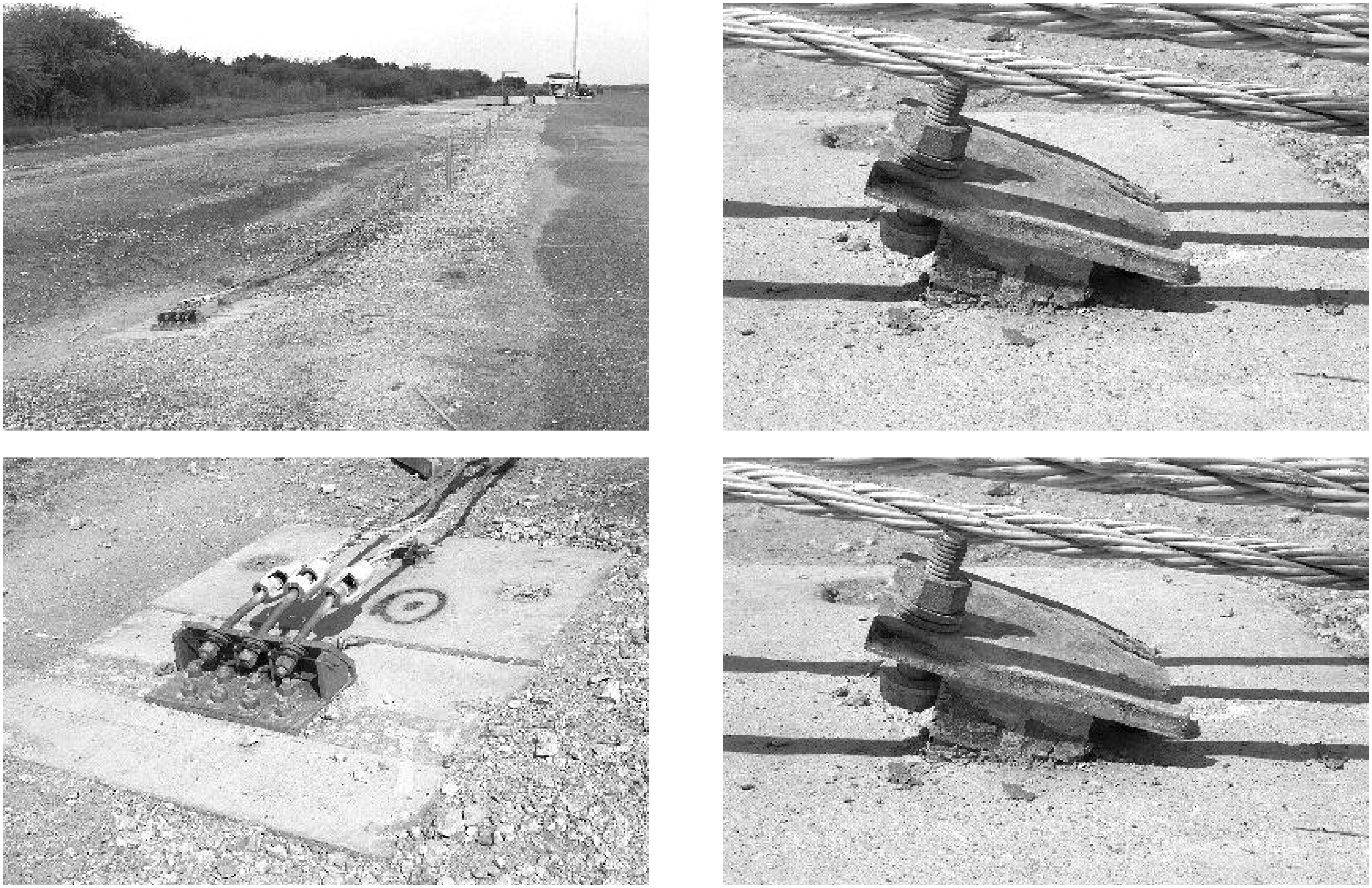


Figure 16. New York cable rail terminal after test 404211-6.

Vehicle Damage

The vehicle sustained little damage from impact with the terminal. Structural damage included a deformed lower control arm and strut tower and a torn upper right strut mount. Minor damage occurred to the front bumper. The front right rim was bent and the tire deflated. After the vehicle exited the test site (traversed the sloped ditch and traveled beyond the right of way) the vehicle yawed clockwise and rolled onto its left side. Photographs of the vehicle after the test are shown in figure 17; however, most of the damage occurred during the rollover. No measurable deformation occurred to the front of the vehicle from impact with the terminal. No deformation or intrusion of the occupant compartment occurred prior to the rollover. Exterior crush and occupant compartment measurements are shown in appendix B, tables 29 and 30.

Occupant Risk Factors

In the longitudinal direction, the occupant impact velocity was 1.8 m/s at 0.441 s, the highest 0.010-s occupant ridedown acceleration was -3.1 g's from 0.469 to 0.479 s, and the maximum 0.050-s average acceleration was -2.3 g's between 0.001 and 0.051 s. In the lateral direction, the occupant impact velocity was 0.9 m/s at 0.521 s, the highest 0.010-s occupant ridedown acceleration was -3.0 g's from 0.474 to 0.484 s, and the maximum 0.050-s average was -1.4 g's between 0.803 and 0.853 s. These data and other pertinent information from the test are summarized in figure 18. Vehicle angular displacements are displayed in appendix D, figure 120. Vehicular accelerations versus time traces are presented in appendix E, figures 148 through 157.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

! **Structural Adequacy**

C. *Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.*

Result: The New York Terminal for 3-cable barrier allowed the vehicle to gate through the end.

! **Occupant Risk**

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

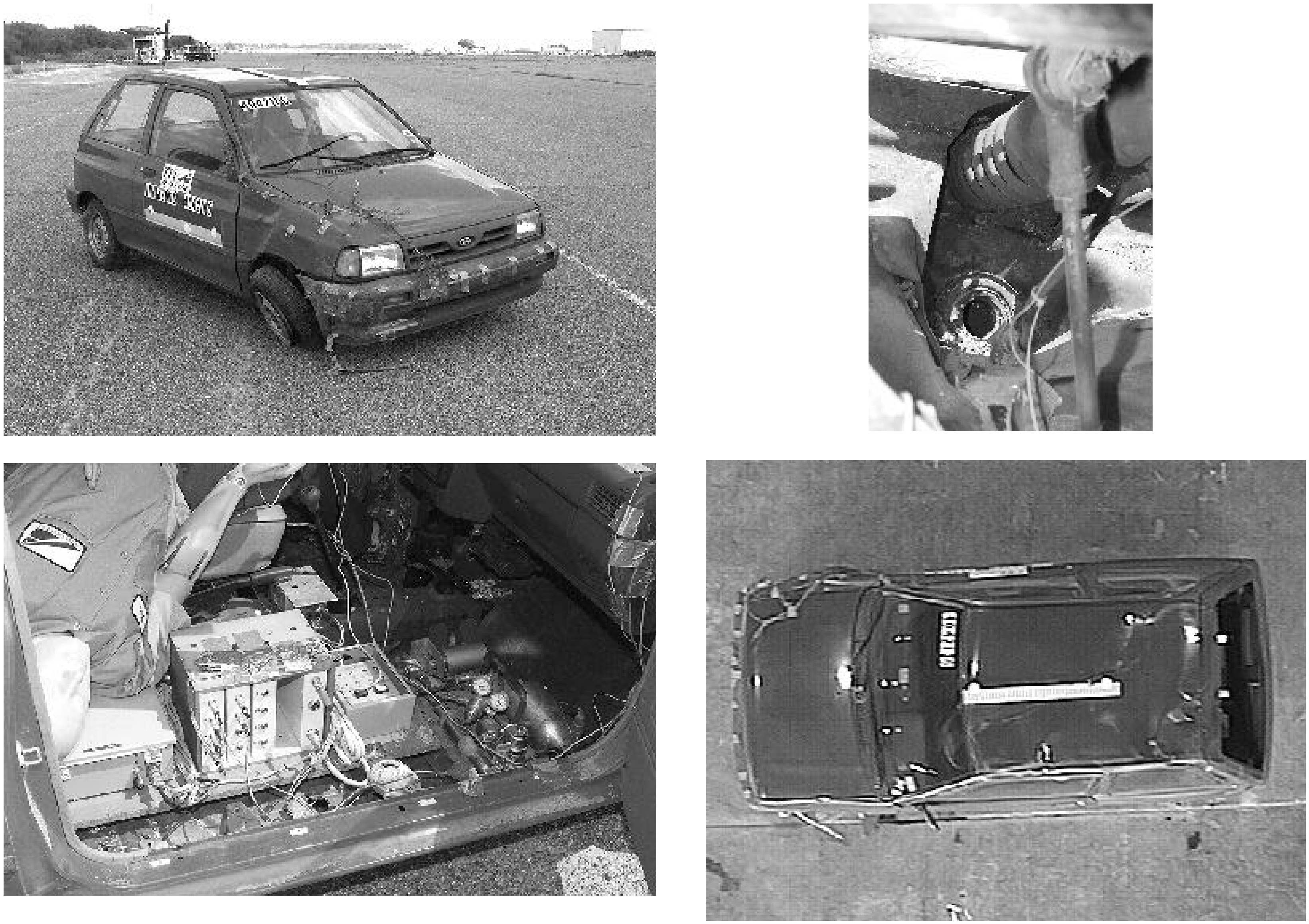
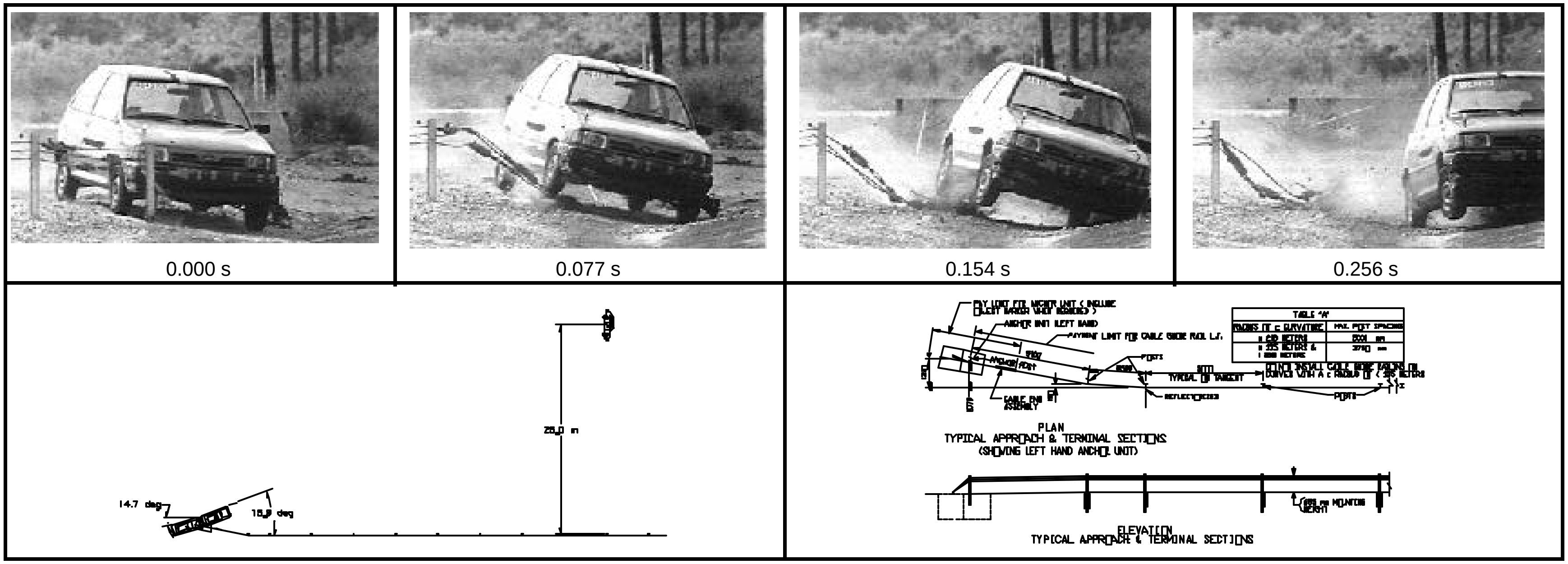


Figure 17. Vehicle after test 404211-6.



General Information
- Test Agency .... Texas Transportation Institute
- Test No. 404211-6
- Date 10/01/98

Test Article
- Type .... Terminal
- Name .... New York 3-Cable Guardrail Terminal
- Installation Length (m) 119.8
- Material or Key Elements . 3 @ 19-mm Diameter Wire Rope Cables With Embedded Concrete Anchor Block

Soil Type and Condition . Standard Soil, Dry

Test Vehicle
- Type .... Production
- Designation 820C
- Model .... 1992 Ford Festiva
- Mass (kg)
  - Curb 810
  - Test Inertial 820
  - Dummy 76
  - Gross Static 896

Impact Conditions
- Speed (km/h) 99.3
- Angle (deg) 14.7

Exit Conditions
- Speed (km/h) 94.4
- Angle (deg) 15.7

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 1.8
  - y-direction 0.9
- THIV (km/h) 7.8
- Ridedown Accelerations (g's)
  - x-direction .... -3.1
  - y-direction .... -3.0
- PHD (g's) 3.9
- ASI 0.22
- Max. 0.050-s Average (g's)
  - x-direction .... -2.3
  - y-direction .... -1.4
  - z-direction .... -2.0

Test Article Deflections (m)
- Dynamic .... nil
- Permanent .... nil

Vehicle Damage
- Exterior
  - VDS 12FR1
  - CDC 12FRLN1
- Maximum Exterior
  - Vehicle Crush (mm) ..... nil
- Interior
  - OCDI RF0000000
- Max. Occ. Compart.
  - Deformation (mm) 0

Post-Impact Behavior
(during 1.0 s after impact)
- Max. Yaw Angle (deg) ...... -25
- Max. Pitch Angle (deg) 11
- Max. Roll Angle (deg) 20

Figure 18. Summary of results for the New York terminal test, *NCHRP Report 350* test 3-34.

Result: No detached elements, fragments or debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.

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

Result: The vehicle remained upright during and immediately after the collision period, but rolled onto its side after exiting the test site for reasons not related to the performance of the guardrail.

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

Longitudinal and Lateral Occupant Impact Velocity - m/s	
Preferred	*Maximum*
9	*12*

Result: Longitudinal occupant impact velocity was 1.8 m/s and lateral occupant impact velocity was 0.9 m/s

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

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

Result: Longitudinal ridedown acceleration was -3.1 g’s and lateral ridedown acceleration was -3.0 g’s

! **Vehicle Trajectory**

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

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

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

Result: The vehicle came to rest behind the test article.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— **PASSENGER COMPARTMENT INTRUSION**

1. Windshield Intrusion

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

2. Body Panel Intrusion yes or (no)

— **LOSS OF VEHICLE CONTROL**

(**1.**) **Physical loss of control**

2. Loss of windshield visibility

3. Perceived threat to other vehicles

4. Debris on pavement

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

1. Harmful debris that could injure workers or others in the area

2. Harmful debris that could injure occupants in other vehicles

No debris was present.

— **VEHICLE AND DEVICE CONDITION**

1. Vehicle Damage

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

2. Windshield Damage

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

3. Device Damage

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

TRANSITIONS

According to *NCHRP Report 350,* two tests are required to evaluate transitions to test level three (TL-3), as described below.

> ***NCHRP Report 350* test designation 3-20**: An 820-kg passenger car impacting the transition at the critical impact point (CIP) of the transition at a nominal speed and angle of 100 km/h and 20 degrees. The test is intended to evaluate occupant risk and post-impact trajectory.

> ***NCHRP Report 350* test designation 3-21**: A 2000-kg pickup truck impacting the transition at the CIP of the transition at a nominal speed and angle of 100 km/h and 25 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 2000-kg vehicle.

NCHRP Report 350 test 3-21 was the only test performed on all the transition tests reported herein. As suggested in *NCHRP Report 350*, the BARRIER VII computer simulation program was used to determine the CIP in each of these tests.

VERTICAL WALL TRANSITION—TEST 2 (*NCHRP REPORT 350* TEST NO. 3-21)

Test Conditions

The test performed on the vertical wall transition was *NCHRP Report 350* test 3-21. The BARRIER VII program indicated the CIP to be 1.5 m from the end of the vertical wall concrete parapet.

Test Article

This test was performed on the W-beam with W-beam rub rail and steel posts transition to the vertical concrete bridge rail. This is a modification to the standard detailed in Figure 1B of FHWA Technical Advisory No. T5040.26 dated January 28, 1988.

A reinforced concrete parapet wall with a spread footing was constructed according to the drawings on page 1 of figure 19. The wall was 810 mm high from the roadway surface. It tapered from a vertical face at the rail transition to a NJ-shape bridge rail over 3.2 m. The spread footing was 3.2 m by 2.18 m in area. The top of the spread footing was 450 mm below the roadway surface and was 900 mm deep. A 2.4-m-long by 810-mm-high F-shape simulated bridge rail was constructed adjacent to the parapet wall.

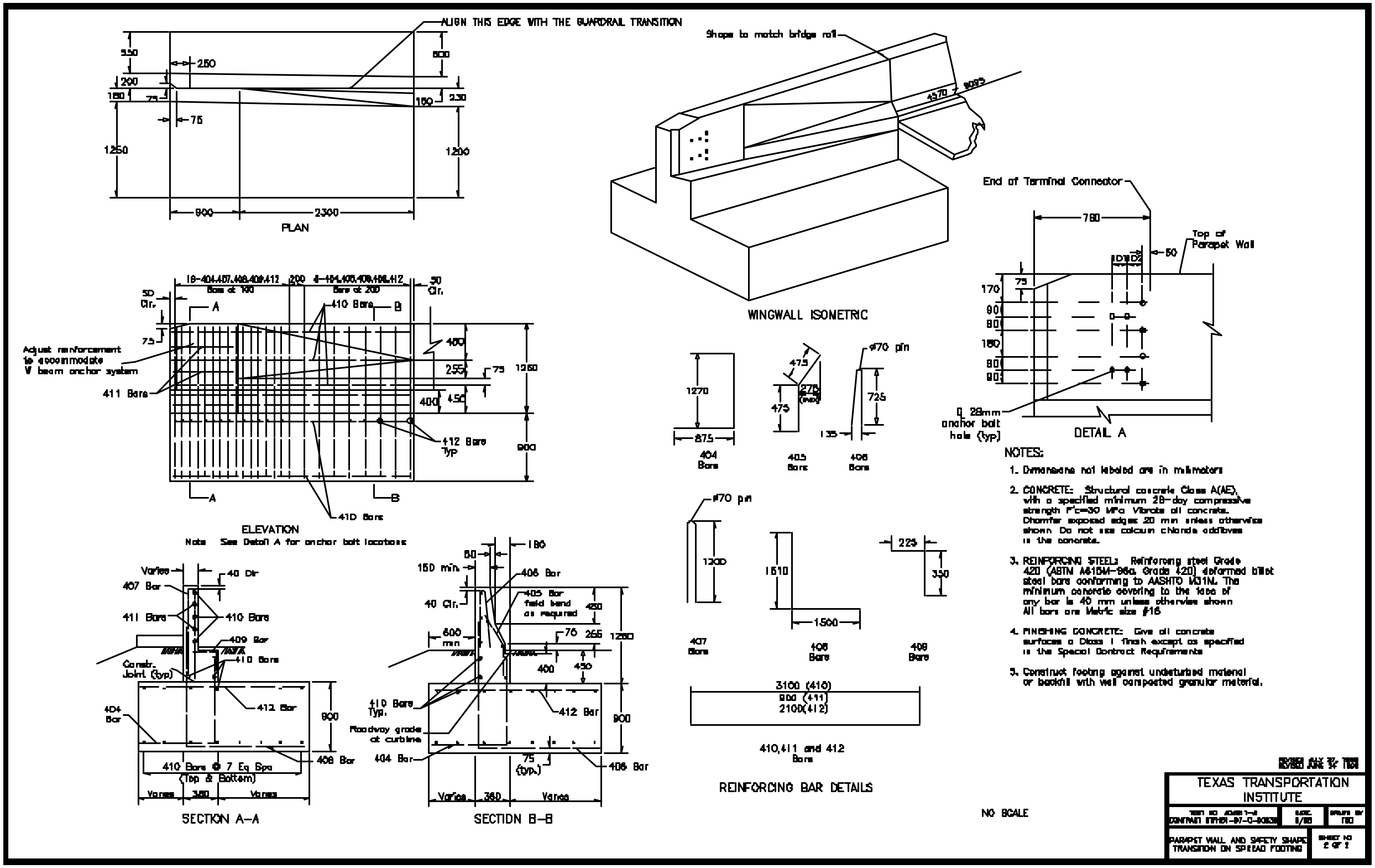


Figure 19. Details of the vertical wall transition installation for test 404211-2.

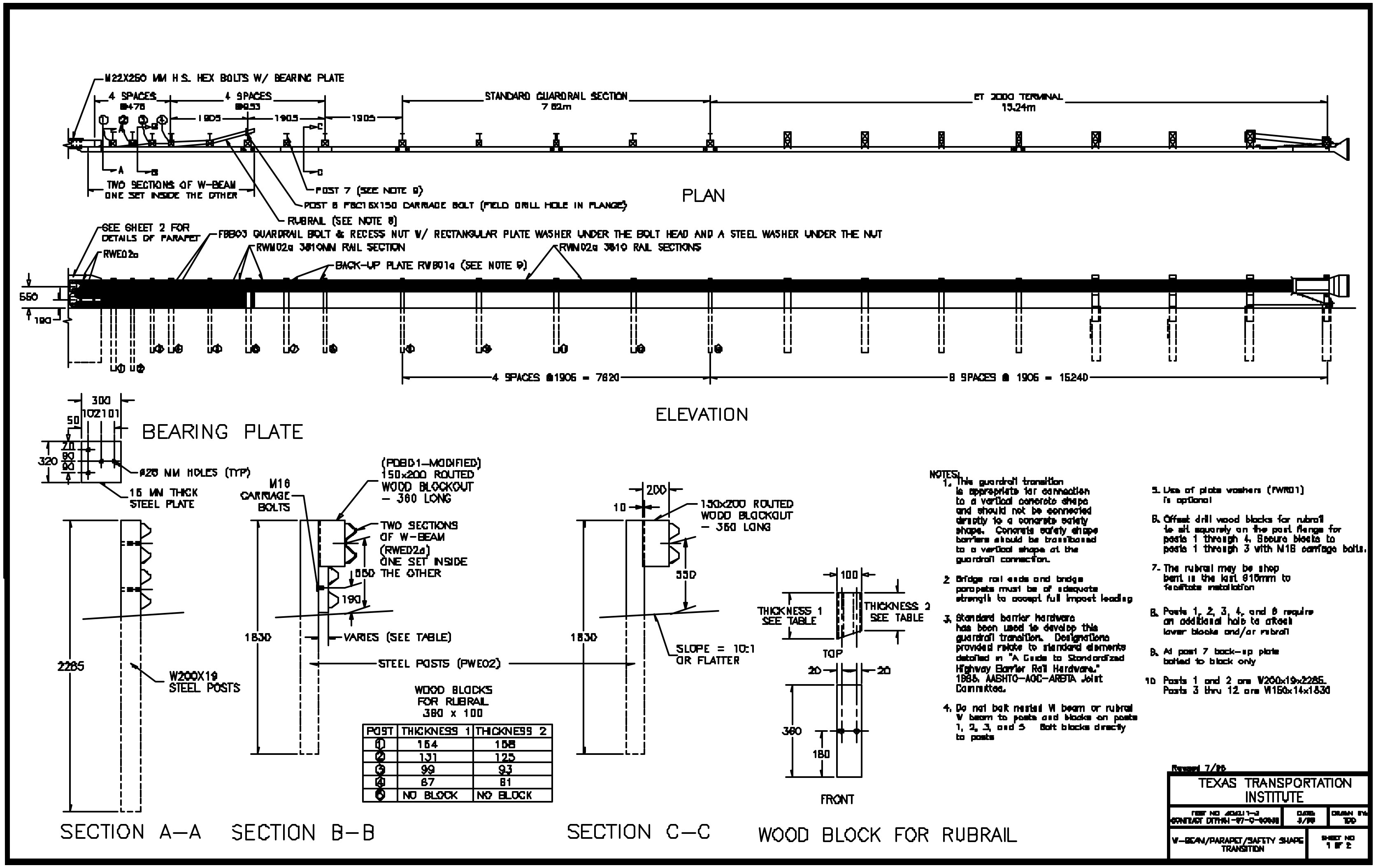


Figure 19. Details of the vertical wall transition installation for test 404211-2 (continued).

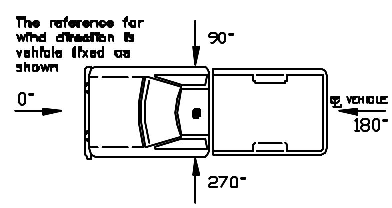
A standard W-beam guardrail with steel posts and wood blockouts is transitioned over a length of 3.8 m to the concrete parapet wall, as shown on page 2 of figure 19. The center of the guardrail is mounted 550 mm above the ground at the rail. The two nested W-beam guardrail elements are attached to a RWE02a terminal connector with eight standard guardrail connector bolts. The terminal connector is bolted through formed holes in the parapet wall with four M22x250 mm H.S. (high strength) hex bolts with a standard FPB02 terminal connector bearing plate on the back of the parapet wall. Posts 1, 2, 3, 5, and 7 are not connected to the rail. Post 4 is connected to the rail with an FBB03 guardrail bolt and recess nut with a rectangular plate washer under the bolt head and a steel washer under the nut. Posts 7 and 8 have backup plates. The standard guardrail section begins at post 9. The 150-mm x 200-mm routed wood blockout was used behind the guardrail at all posts.

The center of the rub rail is mounted 190 mm above the ground at the rail. The W-beam rub rail is attached to a RWE02a terminal connector with eight standard guardrail connector bolts. The terminal connector is bolted through formed holes in the parapet wall with four M22x250 mm H.S. hex bolts with a standard FPB02 terminal connector bearing plate on the back of the parapet wall. Posts 1, 2, 3, and 5 are not connected to the rub rail. Post 4 is connected to the rub rail with an FBB03 guardrail bolt and recess nut with a rectangular plate washer under the bolt head and a steel washer under the nut. The 100-mm-wide x 360-mm-long wood blockout used behind the rub rail at posts 1, 2, 3, and 4 was tapered to allow the rub rail to be flush at the parapet wall and connect behind post 6.

Posts 1 and 2 are W200x19 by 2285-mm-long steel posts. Posts 3 thru 13 are standard PWE02 steel posts. The post spacing between the parapet wall, posts 1, 2, 3, and 4 is 476 mm. The post spacing between posts 4, 5, 6, 7, and 8 is 953 mm. The post spacing for the standard guardrail section is 1905 mm. The guardrail is anchored at the upstream end with a standard ET-2000. The completed installation is shown in figure 20.

Soil and Weather Conditions

The test was performed the morning of July 27, 1998. No rainfall occurred during the 10 recording days prior to the test. Moisture content of the *NCHRP Report 350* standard soil in which the installation was constructed was 4.7 percent, 6.1 percent, and 5.5 percent at posts 1, 3 and 5, respectively. Weather conditions during the time of the test were as follows: wind speed: 10 km/h; wind direction: 15 degrees with respect to the vehicle (vehicle was traveling in a south/southwesterly direction); temperature: 33EC; relative humidity: 58 percent.



Test Vehicle

A 1995 Chevrolet 2500 pickup truck, shown in figure 21, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2074 kg. The height to

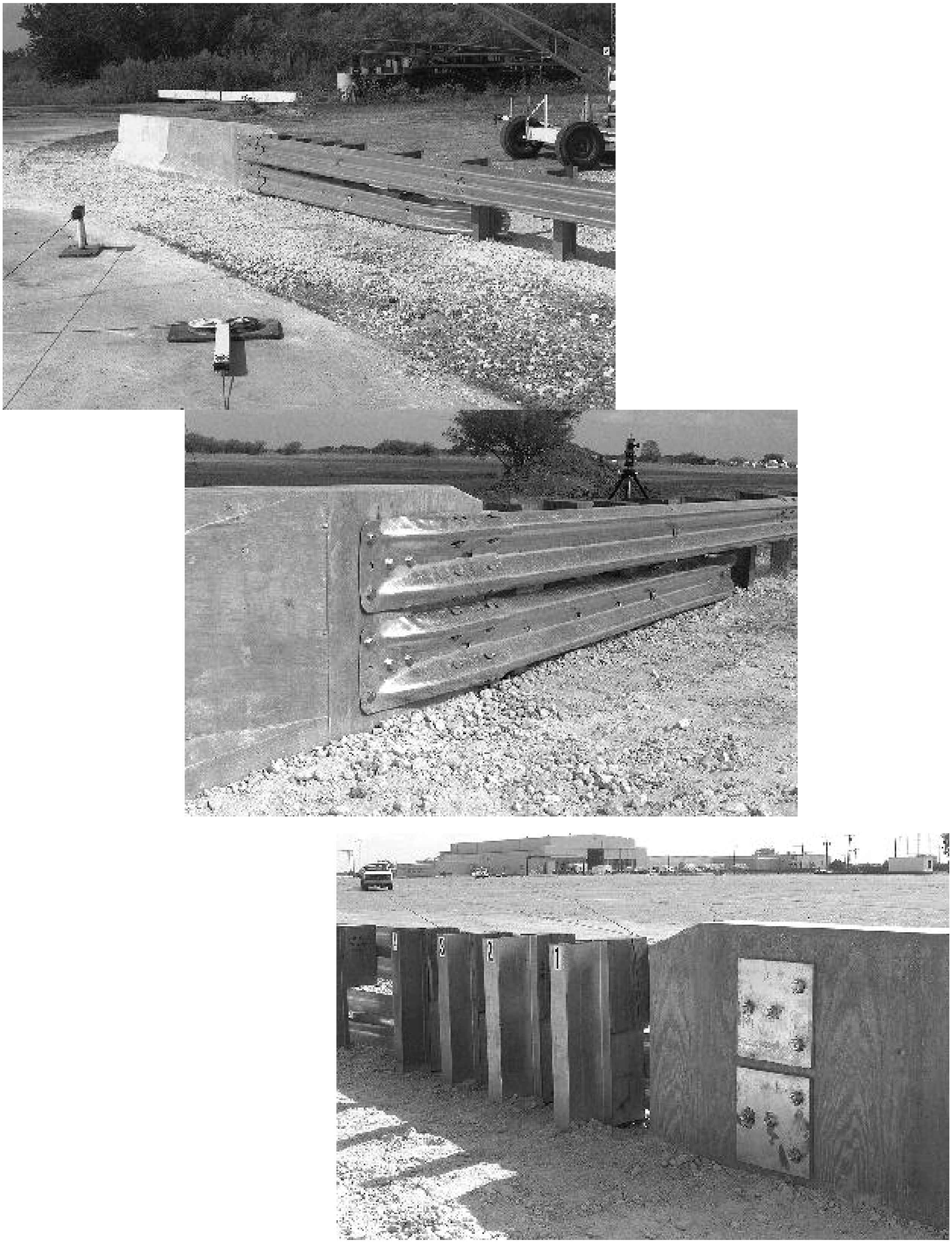


Figure 20. Vertical wall transition prior to test 404211-2.

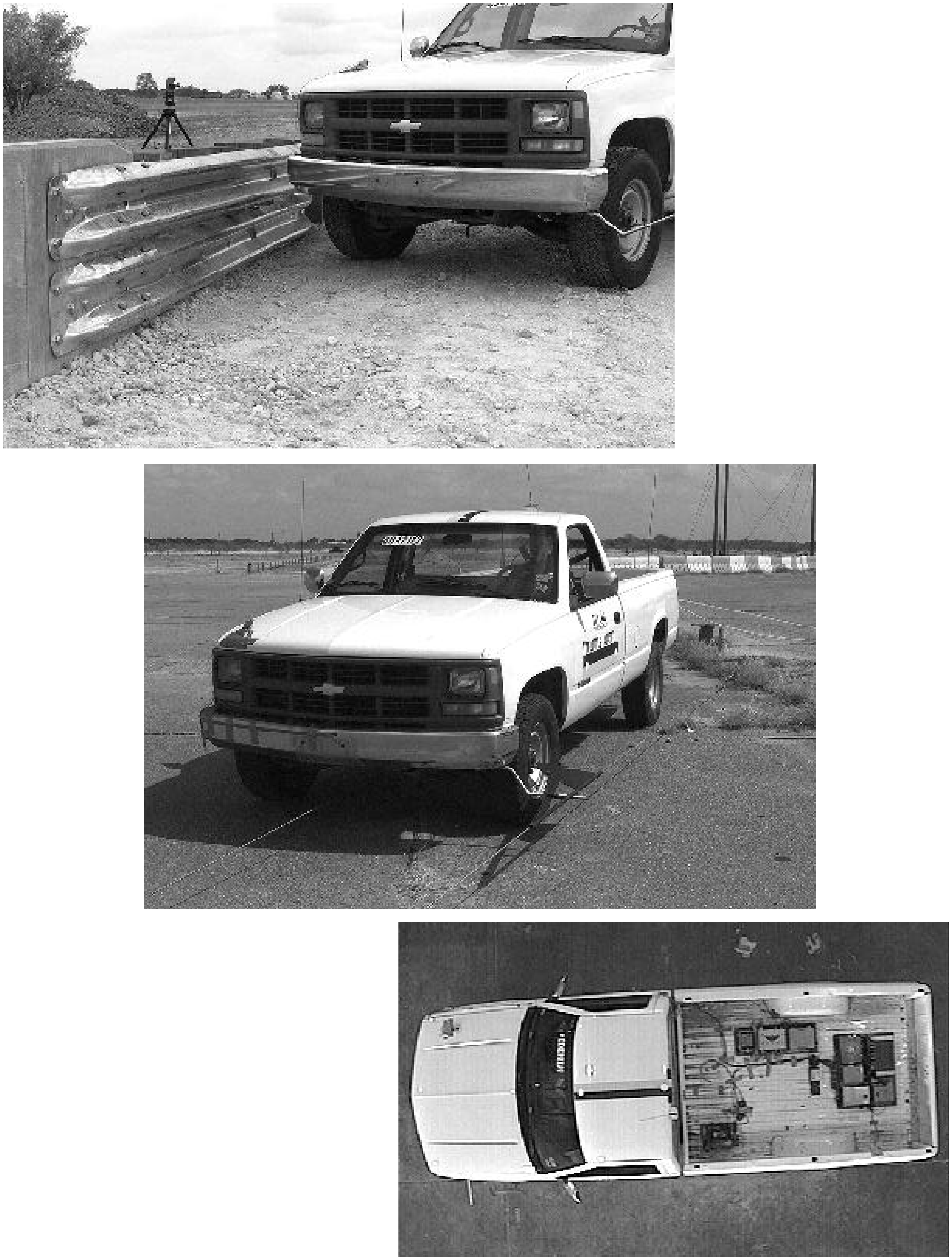


Figure 21. Vehicle before test 404211-2.

the lower edge of the vehicle bumper was 440 mm and it was 660 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in appendix B, figure 82.

Impact Description

The vehicle, traveling at 97.5 km/h, impacted the vertical wall transition 1.5 m from the end of the bridge parapet at a 25.5-degree angle. Shortly after impact, posts 3 and 4 moved followed by movement at post 2 and then 1. At 0.047 s redirection of the vehicle occurred. The concrete wall moved at 0.051 s. The top of the passenger's side door separated from the cab of the vehicle at 0.073 s, and the windshield cracked at 0.076 s. At 0.110 s the left front tire lost contact with the ground. The rear right and left tires lost contact with the ground at 0.163 and 0.187 s, respectively. The right rear tire contacted the rail at 0.207 s, and the right front tire lost contact with the ground. At 0.240 s the right rear tire snagged on the rail and at 0.261 s the tire blew out. At 0.272 s the vehicle began to roll clockwise. The vehicle, traveling at 66.5 km/h, was parallel to the installation at 0.289 s. The right front tire contacted the ground at 0.467 s. The vehicle lost contact with the transition at 0.625 s, and was traveling at 52.5 km/h and an exit angle of 7.3 degrees. As the vehicle exited the transition, the vehicle continued to roll clockwise and touched down on its right front corner. Brakes on the vehicle were not applied. The truck slid to a stop on its right side 44.2 m down from impact point and 3.0 m toward traffic lanes. Sequential photographs of the test period are shown in appendix C, figures 98 and 99.

Damage to Test Article

The vertical wall transition received moderate damage as shown in figure 22. The rail was deformed from post 5 through post 1. The blockout on the upper rail element at post 1 was split and separated from the post. The blockout on the rub rail at post 1 was split but remained attached. The blockout on the upper rail element at post 2 was gouged. A piece of metal from the vehicle was caught on the edge of the connection at the end shoe. The top of the CMB was scraped from contact with the vehicle. Total length of contact of the vehicle with the transition and CMB was 4.24 m. Maximum permanent deformation of the rail was 90 mm at post 2.

Vehicle Damage

The vehicle sustained substantial damage as shown in figure 23. Structural damage included the right front spindle, rod ends, stabilizer bar, front cross member, upper and lower A-arms, right side floor pan, firewall, and frame. The right rear axle springs, U-bolts, and right A-pillar sustained damage. The right front and rear tire and wheel were crushed. Both right side quarter panels were damaged and the right door had a 355-mm gap at the top. The fan, radiator, grill, hood, and bumper were deformed. The left front quarter panel was damaged and the left door was jammed. The windshield was shattered. A 20-mm buckle was noted on the passenger's side of the cab and the cab shifted out 70 mm on the driver's side. Maximum exterior crush to the vehicle was 540 mm at the top of the front bumper and 530 mm at the wheel well. Occupant compartment deformation was 40 mm in the floor to instrument panel area and 97 mm in the firewall area. Details can be found in appendix B, tables 31 and 32.

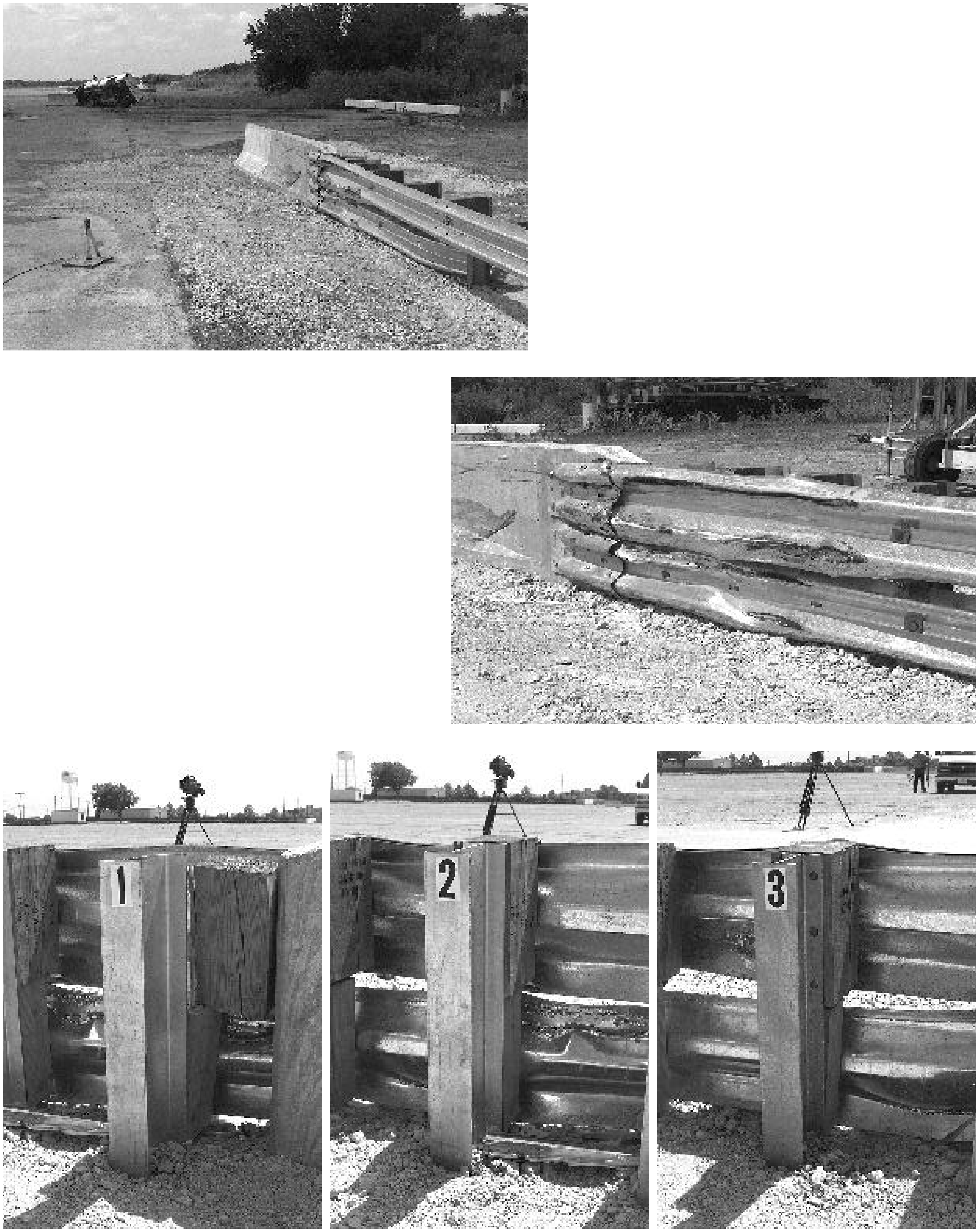
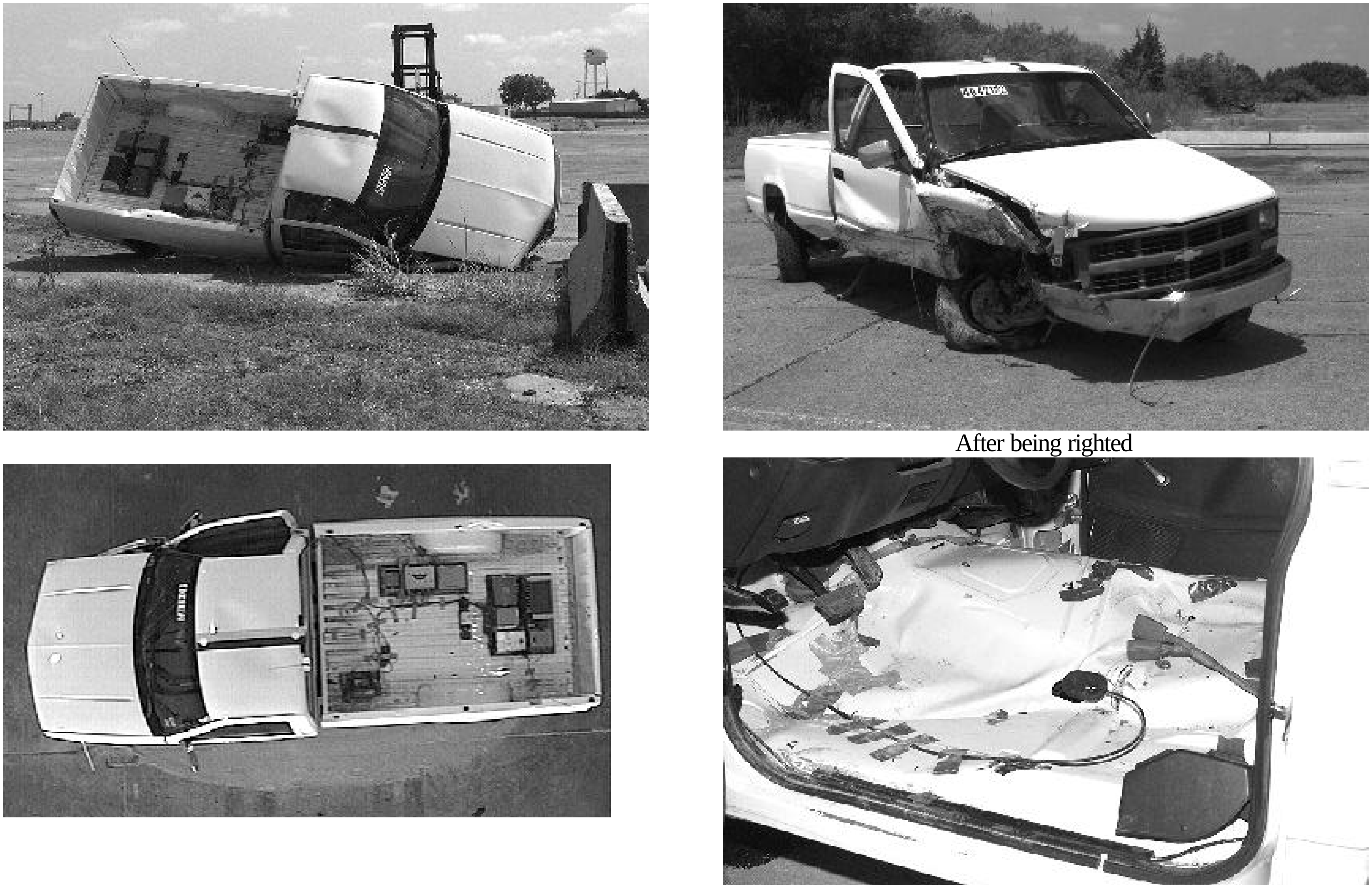


Figure 22. Installation after test 404211-2.



After being righted

Figure 23. Vehicle after test 404211-2.

Occupant Risk Factors

In the longitudinal direction, the occupant impact velocity was 9.1 m/s at 0.149 s, the highest 0.010-s occupant ridedown acceleration was -15.1 g's from 0.122 to 0.132 s, and the maximum 0.050-s average acceleration was -12.1 g's between 0.056 and 0.106 s. In the lateral direction, the occupant impact velocity was 7.8 m/s at 0.109 s, the highest 0.010-s occupant ridedown acceleration was 12.5 g's from 0.129 to 0.139 s, and the maximum 0.050-s average was -13.3 g's between 0.049 and 0.099 s. These data and other pertinent information from the test are summarized in figure 24. Vehicle angular displacements are displayed in appendix D, figure 121. Vehicular accelerations versus time traces are presented in appendix E, figures 158 through 168.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

! **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.*

Result: The vertical wall transition contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum permanent deformation was 0.01 m.

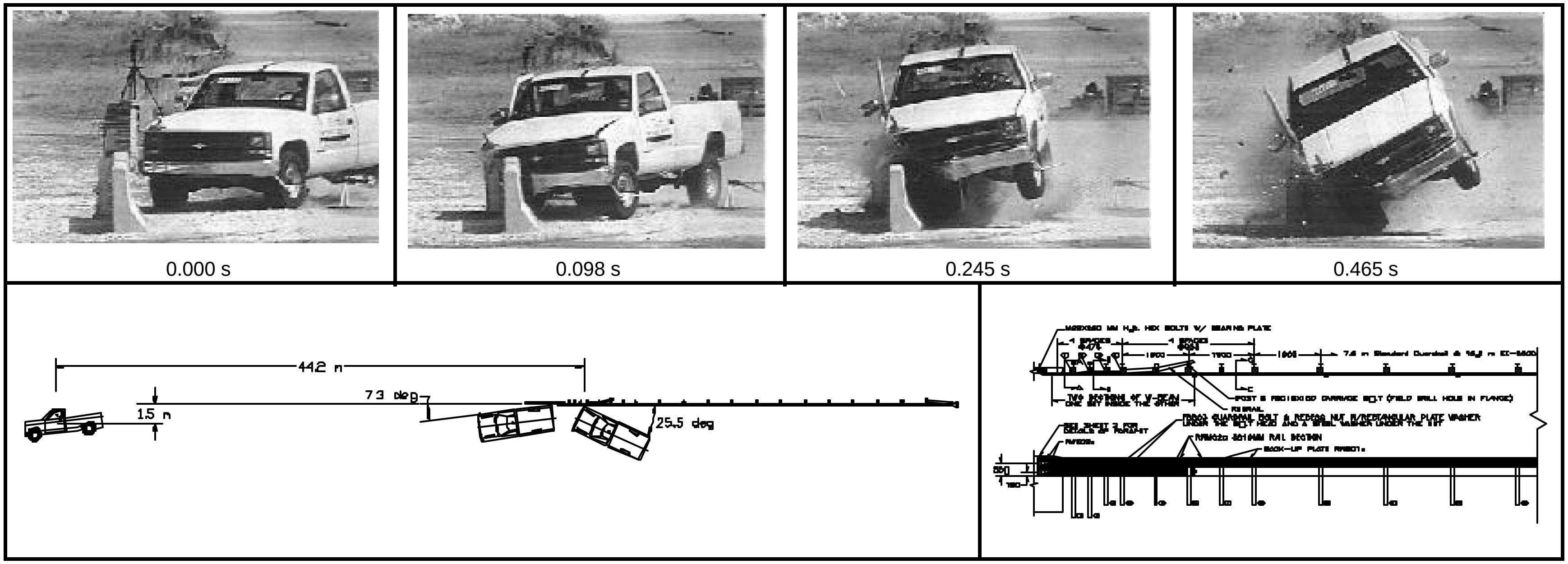
! **Occupant Risk**

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

Result: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum reduction of space was 27 percent in the center floor pan area, which may cause serious injury.

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

Result: The vehicle rolled onto its right side after exiting the installation.



General Information
- Test Agency .... Texas Transportation Institute
- Test No. 404211-2
- Date 07/27/98

Test Article
- Type .... Transition
- Name .... Vertical Wall Transition
- Installation Length (m) 35.3
- Material or Key Elements . W-beam with W-beam Rub Rail & Steel Posts to Vertical Concrete Bridge Rail

Soil Type and Condition . Standard Soil, Dry

Test Vehicle
- Type .... Production
- Designation 2000
- Model .... 1995 Chevrolet Pickup Truck
- Mass (kg)
  - Curb 2056
  - Test Inertial 2000
  - Dummy 74
  - Gross Static 2074

Impact Conditions
- Speed (km/h) 97.5
- Angle (deg) 25.5

Exit Conditions
- Speed (km/h) 52.5
- Angle (deg) 7.3

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 9.1
  - y-direction 7.8
- THIV (km/h) 38.6
- Ridedown Accelerations (g's)
  - x-direction .... -15.1
  - y-direction 12.5
- PHD (g's) 14.8
- ASI 1.70
- Max. 0.050-s Average (g's)
  - x-direction .... -12.1
  - y-direction .... -13.3
  - z-direction 6.7

Test Article Deflections (m)
- Dynamic .... N/A
- Permanent 0.09

Vehicle Damage
- Exterior
  - VDS 01RFQ5
  - CDC .... 01FREK4 & 01RDEW4
- Maximum Exterior
  - Vehicle Crush (mm) 540
- Interior
  - OCDI FS0113000
- Max. Occ. Compart.
  - Deformation (mm) 97

Post-Impact Behavior
- (during 1.0 s after impact)
- Max. Yaw Angle (deg) ...... -34
- Max. Pitch Angle (deg) ..... -9
- Max. Roll Angle (deg) 45

Figure 24. Summary of results for the first test on the vertical wall transition, *NCHRP Report 350* test 3-21.

! **Vehicle Trajectory**

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

Result: The vehicle did intrude into adjacent traffic lanes.

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.*

Result: Longitudinal occupant impact velocity was 9.1 m/s and longitudinal ridedown acceleration was -15.1 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: Exit angle at loss of contact was 7.3 degrees, which was less than 60 percent of the impact angle.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— PASSENGER COMPARTMENT INTRUSION

1. Windshield Intrusion

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

2. Body Panel Intrusion yes or no (circled: no)

— LOSS OF VEHICLE CONTROL

1. Physical loss of control (circled)

2. Loss of windshield visibility

3. Perceived threat to other vehicles (circled)

4. Debris on pavement

— PHYSICAL THREAT TO WORKERS OR OTHER VEHICLES

1. Harmful debris that could injure workers or others in the area

2. Harmful debris that could injure occupants in other vehicles

No debris was present.

— VEHICLE AND DEVICE CONDITION

1. Vehicle Damage

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

2. Windshield Damage

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

3. Device Damage

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

VERTICAL WALL TRANSITION—TEST 12 (*NCHRP REPORT 350* TEST NO. 3-21)

Test Conditions

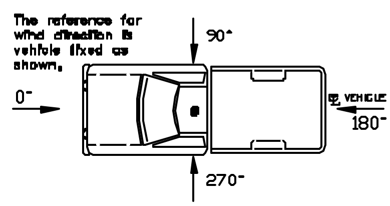
This test was a repeat of *NCHRP Report 350* test 3-21. The BARRIER VII program indicated the CIP to be 1.5 m from the end of the vertical wall concrete parapet.

Test Article

This test was performed on this transition previously (Test 2). When constructing the installation for the previous test, the end shoe would fit properly only if lapped over the W-beams. During the test the vehicle snagged on the exposed end of the end shoe and the vehicle rolled onto its side after exiting the transition. The installation used for the last test was repaired for use in the repeat test. The end shoe was modified to fit while lapped under the W-beams when installed on the W-beam with W-beam rub rail and steel posts transition. The holes in the terminal connector were enlarged with a drift pin (punch) so that the splice bolts could be installed with the terminal connector lapped under the W-beams. The terminal connector was then bolted through formed holes in the parapet wall with four M22x250 mm high strength (H.S.) hex bolts with a standard FPB02 terminal connector bearing plate on the back of the parapet wall. Drawings of the installation were shown previously in figure 19. Photographs of the completed installation as tested are shown in figure 25.

Soil and Weather Conditions

The crash test was performed the morning of November 5, 1998. A total of 41 mm of rain was recorded four days before the test. No other rainfall was recorded for the 10 days prior to the test. Moisture content was 8.1 percent, 8.2 percent, and 8.4 percent at posts 1, 3, and 5, respectively. Weather conditions at the time of testing were as follows: wind speed: 13 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a southerly direction); temperature: 12EC; relative humidity: 57 percent.



Test Vehicle

A 1994 Chevrolet 2500 pickup truck, shown in figure 26, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2077 kg. The height to the lower edge of the vehicle front bumper was 385 mm and to the upper edge of the front bumper was 615 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 83.

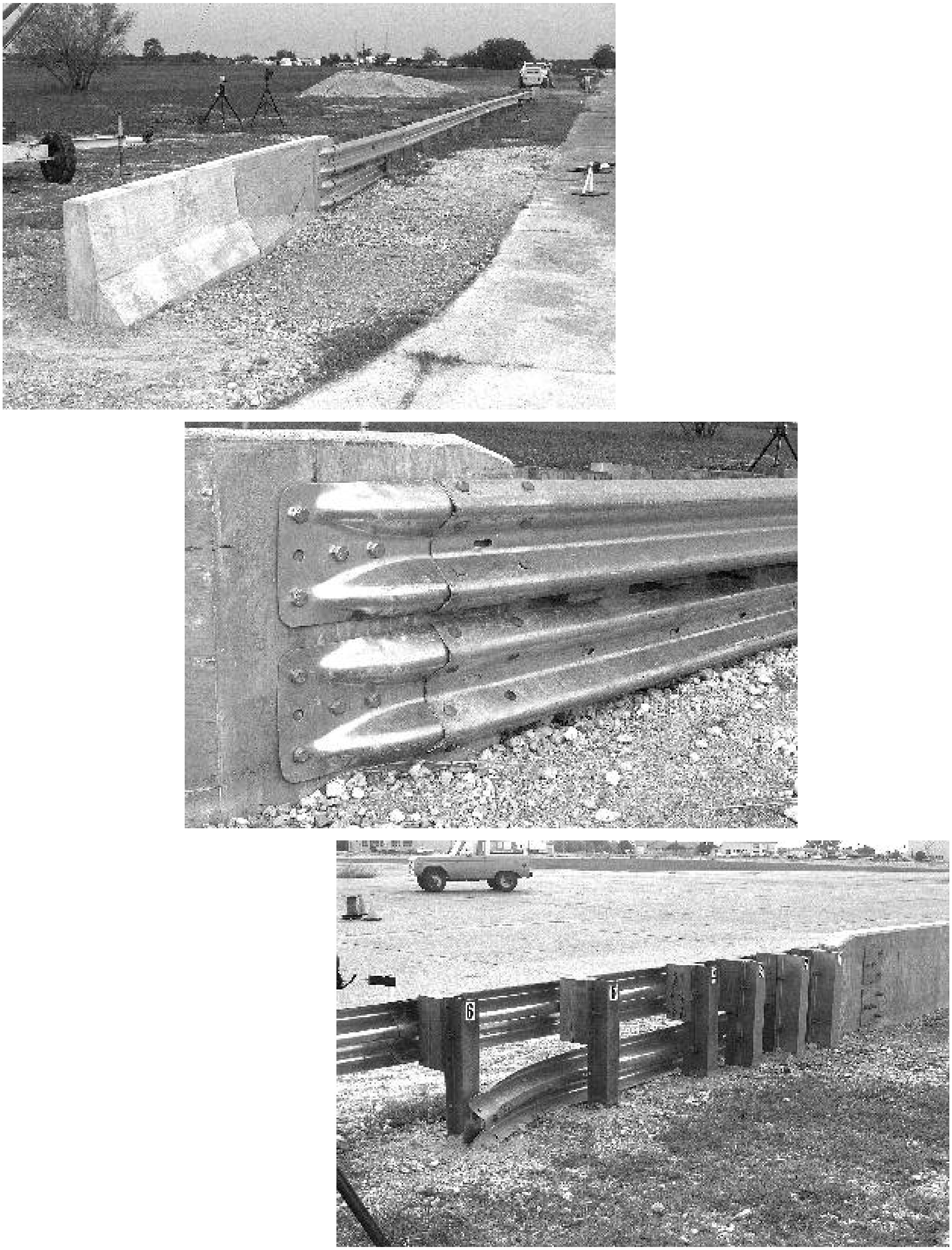


Figure 25. Vertical wall transition prior to test 404211-12.

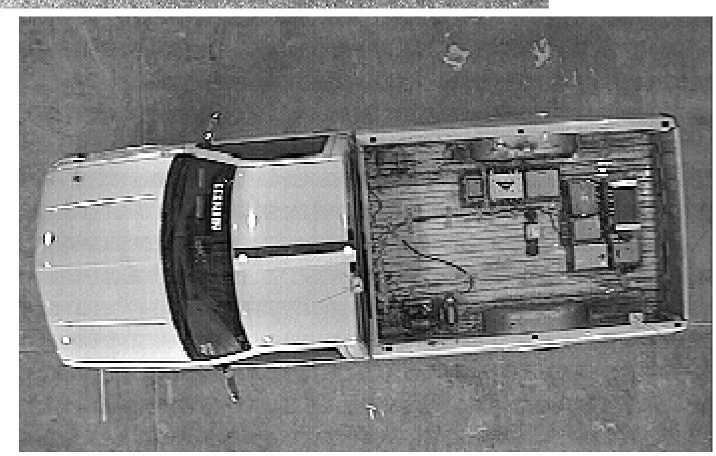


Figure 26. Vehicle before test 404211-12.

Impact Description

The vehicle, traveling at 101.3 km/h, impacted the transition 1.6 m from the end of the concrete parapet at an angle of 24.2 degrees. Shortly after impact posts 4, 3, and 2 moved. At 0.015 s the right front tire contacted the W-beam and then steered left. By 0.017 s post 4 moved and at 0.034 s the concrete parapet moved. The right front wheel was traveling parallel with the rail and the tire impacted the rub rail at 0.037 s. Redirection of the vehicle began at 0.040 s and at 0.191 s the vehicle was traveling parallel with the rail at a speed of 79.6 km/h. The rear of the vehicle contacted the W-beam at 0.196 s. The vehicle lost contact with the transition and parapet at 0.414 s, and was traveling at a speed of 73.3 km/h and an exit angle of 13.9 degrees. Maximum roll during the 1.0 s after impact was 25 degrees. Brakes on the vehicle were applied at 1.75 s after impact and the vehicle subsequently came to rest 54.1 m beyond impact and 8.4 m toward traffic lanes. Sequential photographs of the test period are shown in appendix C, figures 100 and 101.

Damage to Test Article

Minimal damage was sustained by the transition as shown in figure 27. The top blockout at post 1 was split and the W-beam and rub rail were deformed. Maximum deformation of the W-beam rail element was 25 mm and the rub rail sustained a maximum deformation of 15 mm. The edge of the parapet wall was chipped. Total length of contact of the vehicle with the transition was 3.84 m.

Vehicle Damage

The vehicle sustained structural damage to the right side frame rail, right front upper and lower A-arms, and floor pan. The drive shaft was separated, the right rear U-bolts broke at the axle and the shock pulled out. As shown in figure 28, the front bumper, grill, radiator, fan, right front tire and rim, right front quarter panel, right door, right rear quarter panel, rear bumper, and right rear tire and rim were damaged. The windshield was shattered and the cab was pushed rearward into the bed. The front end of the vehicle was shifted to the left 140 mm. Maximum exterior crush to the vehicle was 500 mm at the right corner at bumper height. Maximum occupant compartment deformation was 80 mm in the lateral direction near the occupant's feet. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 33 and 34.

Occupant Risk Factors

Longitudinal occupant impact velocity was 7.3 m/s at 0.156 s, maximum 0.010-s ridedown acceleration was -6.7 g's from 0.209 to 0.219 s, and the maximum 0.050-s average was -10.9 g's between 0.051 and 0.101 s. These data and other information pertinent to the test are presented in figure 29. Vehicle angular displacements are displayed in appendix D, figure 122. Vehicular accelerations versus time traces are presented in appendix E, figures 169 through 179.

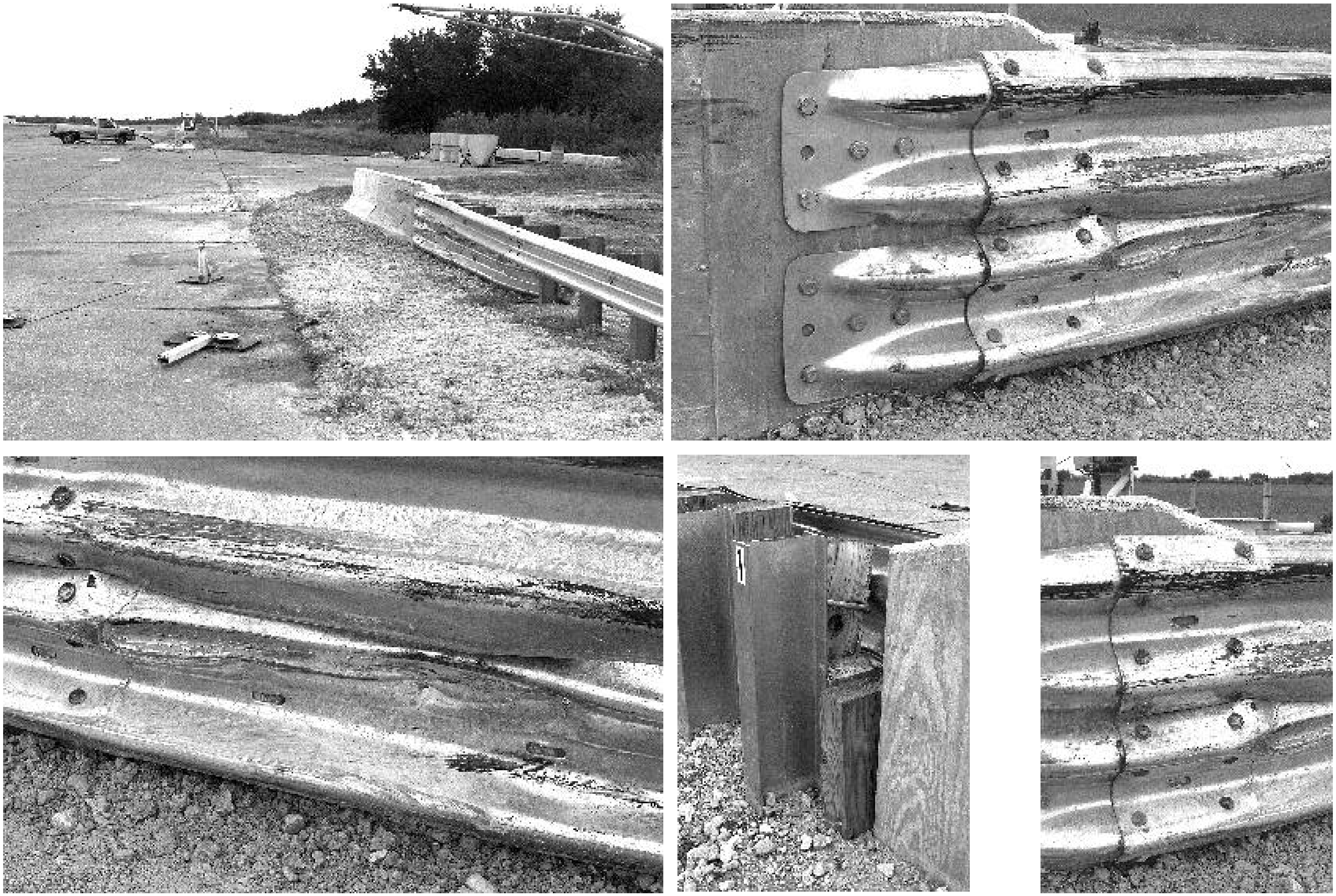
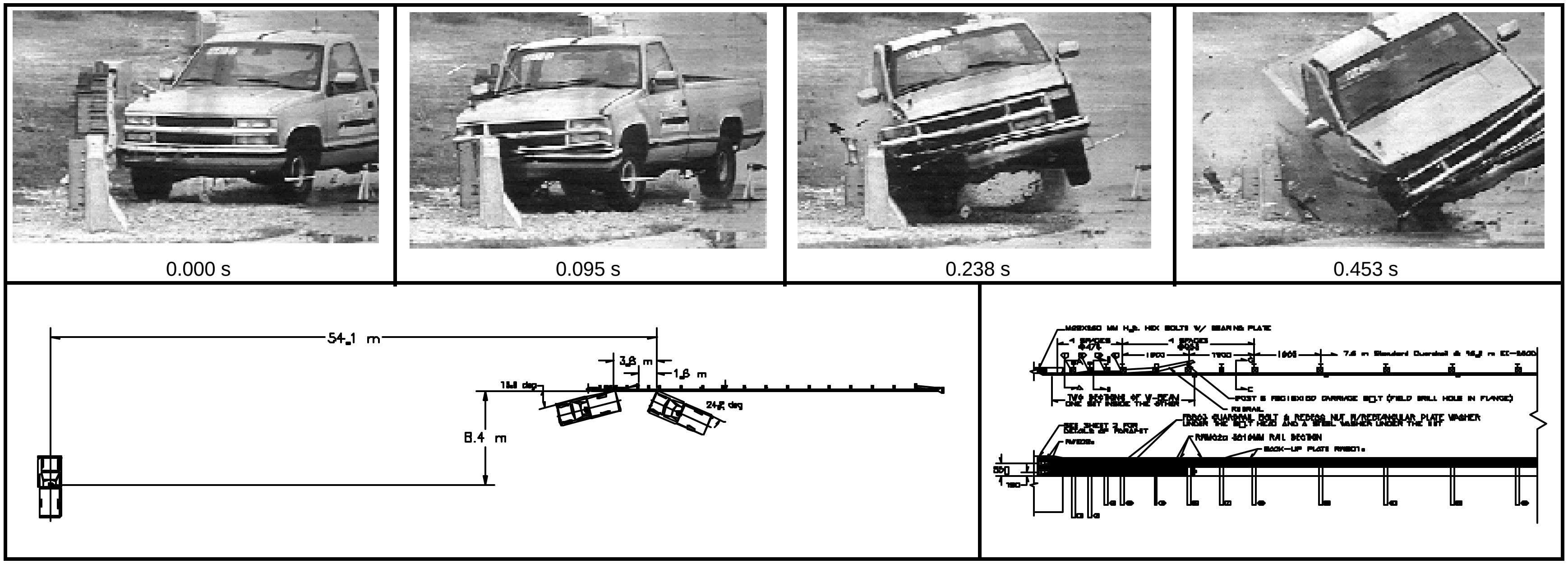


Figure 27. Installation after test 404211-12.

Figure 28. Vehicle after test 404211-12.



General Information

Test Agency	Texas Transportation Institute
Test No.	404211-12
Date	11/05/98

Test Article

Type	Transition
Name	Vertical Wall Transition
Installation Length (m)	35.3
Material or Key Elements	W-Beam With W-Beam Rub Rail & Steel Posts to Vertical Concrete Bridge Rail

Soil Type and Condition	Standard Soil, Damp

Test Vehicle

Type	Production
Designation	2000P
Model	1994 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1925
Test Inertial	2000
Dummy	77
Gross Static	2077

Impact Conditions

Speed (km/h)	101.3
Angle (deg)	24.2

Exit Conditions

Speed (km/h)	73.3
Angle (deg)	13.9

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	7.3
y-direction	7.8
THIV (km/h)	35.6
Ridedown Accelerations (g's)	
x-direction	-6.7
y-direction	-10.1
PHD (g's)	10.6
ASI	1.85
Max. 0.050-s Average (g's)	
x-direction	-10.9
y-direction	-13.9
z-direction	-9.5

Test Article Deflections (m)

Dynamic	0.07
Permanent	0.03

Vehicle Damage

Exterior	
VDS	01RFQ4
CDC	01FYEK2 & 01RDEW3
Maximum Exterior Vehicle Crush (mm)	500
Interior	
OCDI	RF0104000
Max. Occ. Compart. Deformation (mm)	90

Post-Impact Behavior

(during 1.0 s after impact)	
Max. Yaw Angle (deg)	-50
Max. Pitch Angle (deg)	8
Max. Roll Angle (deg)	25

Figure 29. Summary of results for the repeat test on the vertical wall transition, *NCHRP Report 350* test 3-21.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

- **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.*

Result: The W-beam with W-beam rub rail on steel posts transition to the vertical concrete bridge railing contained and redirected the vehicle. The vehicle did not penetrate, override, or underride the installation.

- **Occupant Risk**

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

Result: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 80 mm in the lateral direction near the occupant's feet.

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

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

- **Vehicle Trajectory**

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

Result: The vehicle came to rest 8.4 m toward traffic lanes and may intrude into adjacent traffic lanes.

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.*

Result: Longitudinal occupant impact velocity was 7.3 m/s and ridedown acceleration was -6.7 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Results: Exit angle at loss of contact was 13.9 degrees, which was 57 percent of the impact angle.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— **PASSENGER COMPARTMENT INTRUSION**

1. **Windshield Intrusion**

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

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

— **LOSS OF VEHICLE CONTROL**

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

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

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

No debris was present.

— **VEHICLE AND DEVICE CONDITION**

1. Vehicle Damage

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

2. Windshield Damage

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

3. Device Damage

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

VERTICAL FLARED BACK TRANSITION
(*NCHRP REPORT 350* TEST NO. 3-21)

Test Conditions

NCHRP Report 350 test designation 3-21 was performed on the vertical flared back transition. The BARRIER VII program indicated the CIP to be 1.5 m from the end of the vertical wall concrete parapet.

Test Article

The W-beam with W-beam rub rail and steel posts transition to the vertical flared back concrete bridge rail consisted of a portion of simulated bridge rail, a wingwall, a transition, a length of approach guardrail, and a guardrail terminal. Drawings for this transition are presented in figure 30. Photographs of the completed test installation are shown in figure 31.

The concrete safety shape simulated bridge rail was 2440 mm long and had a foundation wall that extended 1200 mm below grade. The wingwall extended from the simulated bridge rail a longitudinal distance of 3900 mm. The wingwall was embedded 1200 mm below grade. The traffic face of the wingwall transitioned from a safety shape to a vertical face over a distance of 2300 mm. The vertical face extended another 750 mm and then flared back a distance of 215 mm over a longitudinal distance of 850 mm.

The approach guardrail (7620 mm long) was a 2.67-mm-thick (12-ga) W-beam mounted on W150X14 steel posts spaced at 1905 mm with 150 mm x 200 mm routed wood blockouts. Mounting height to the top of the rail element was 706 mm. An ET-2000 terminal (15.24 mm long) was installed on the end of the guardrail.

The transition, starting from the guardrail end, consisted of a 3810-mm length of 2.67-mm-thick (12-ga) W-beam mounted on W150x14 steel posts and 150 x 200 routed wood blockouts. Mounting height of the rail element was 685 mm to the top. Proceeding toward the transition, two nested, 2.67-mm-thick (12-ga) W-beam sections were used and connected to the concrete parapet with a 2.67-mm-thick (12-ga) standard terminal connector. A 168.3-mm-diameter by 250-mm-long steel spacer tube was installed as a blockout between the W-beam and flared back parapet. The first four posts adjacent to the parapet were spaced at 476 mm. The first three posts adjacent to the parapet were W200x19x2290 long and were embedded 1605 mm into the ground. The remaining posts in the transition (posts 4–8) were W150x15x1980 steel posts and were embedded 1250 mm into the ground.

The rub rail consisted of a length of C152x12.2 and a length of channel made from bent plate. Tapered wood blockouts were used at the first three posts, no blockout at post 4, and the rub rail was bent back and terminated on the field side of post 5. The centerline height of the rub rail was 230 mm.

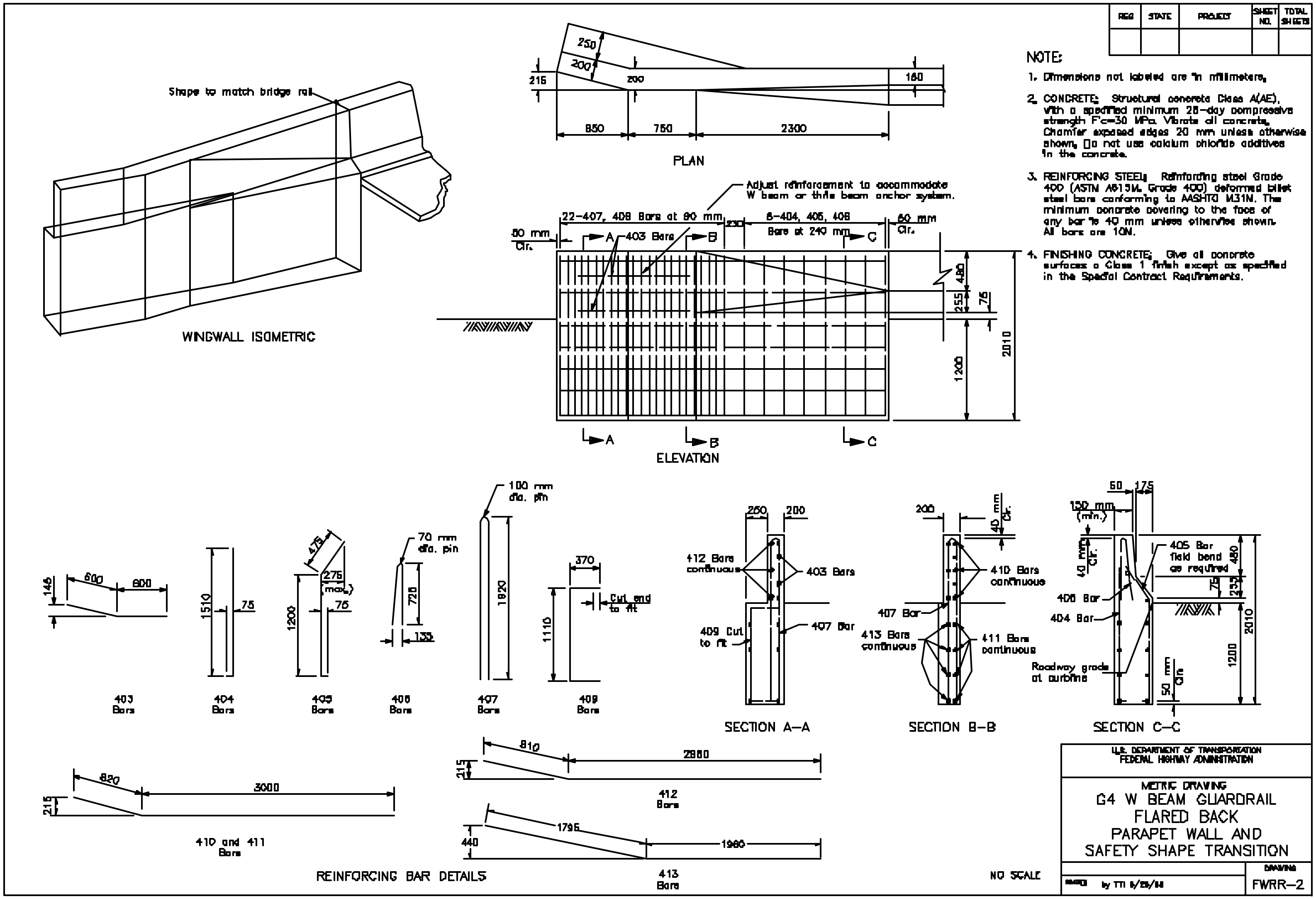


Figure 30. Details of the vertical flared back transition installation for test 404211-4.

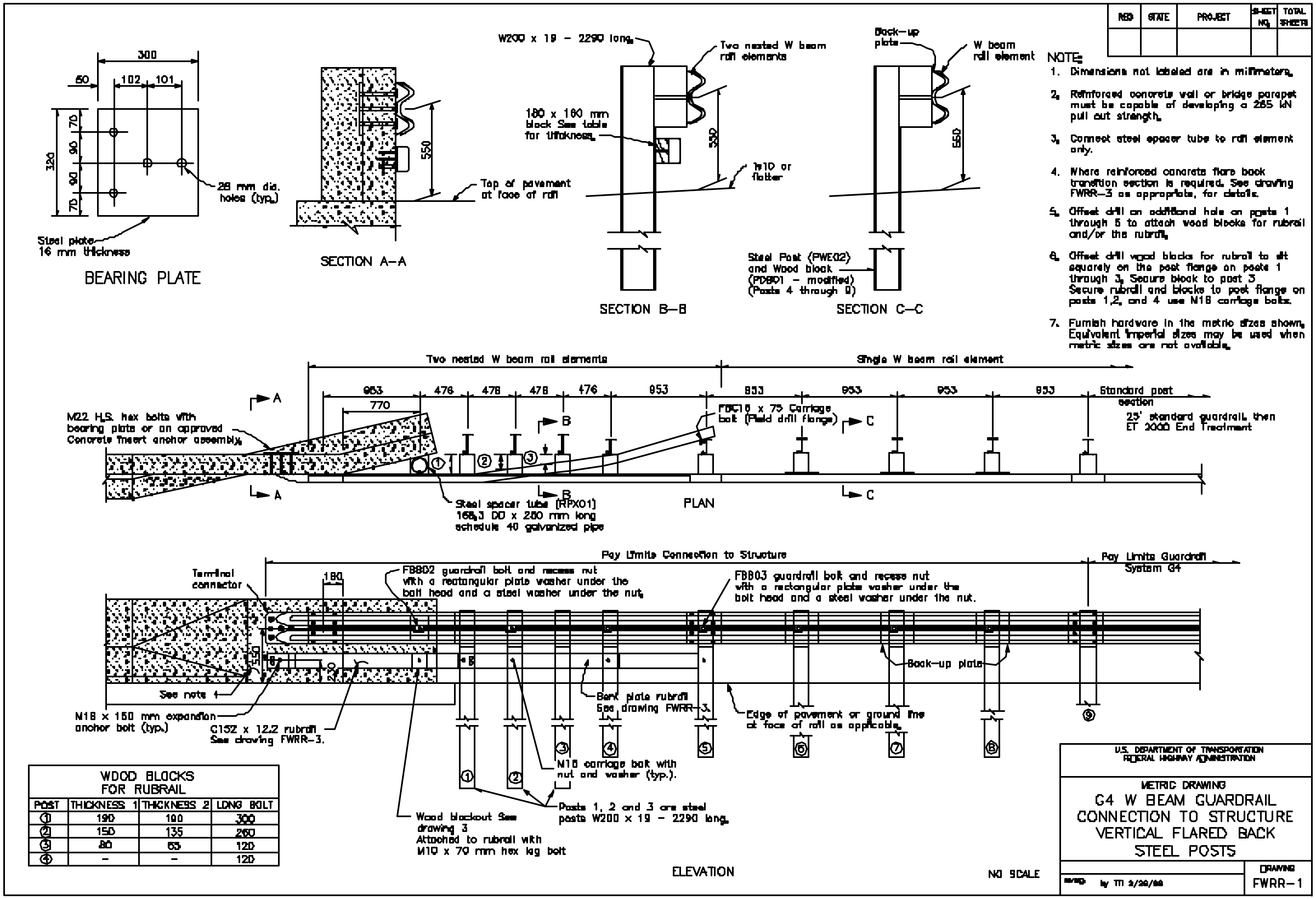


Figure 30. Details of the vertical flared back transition installation for test 404211-4 (continued).

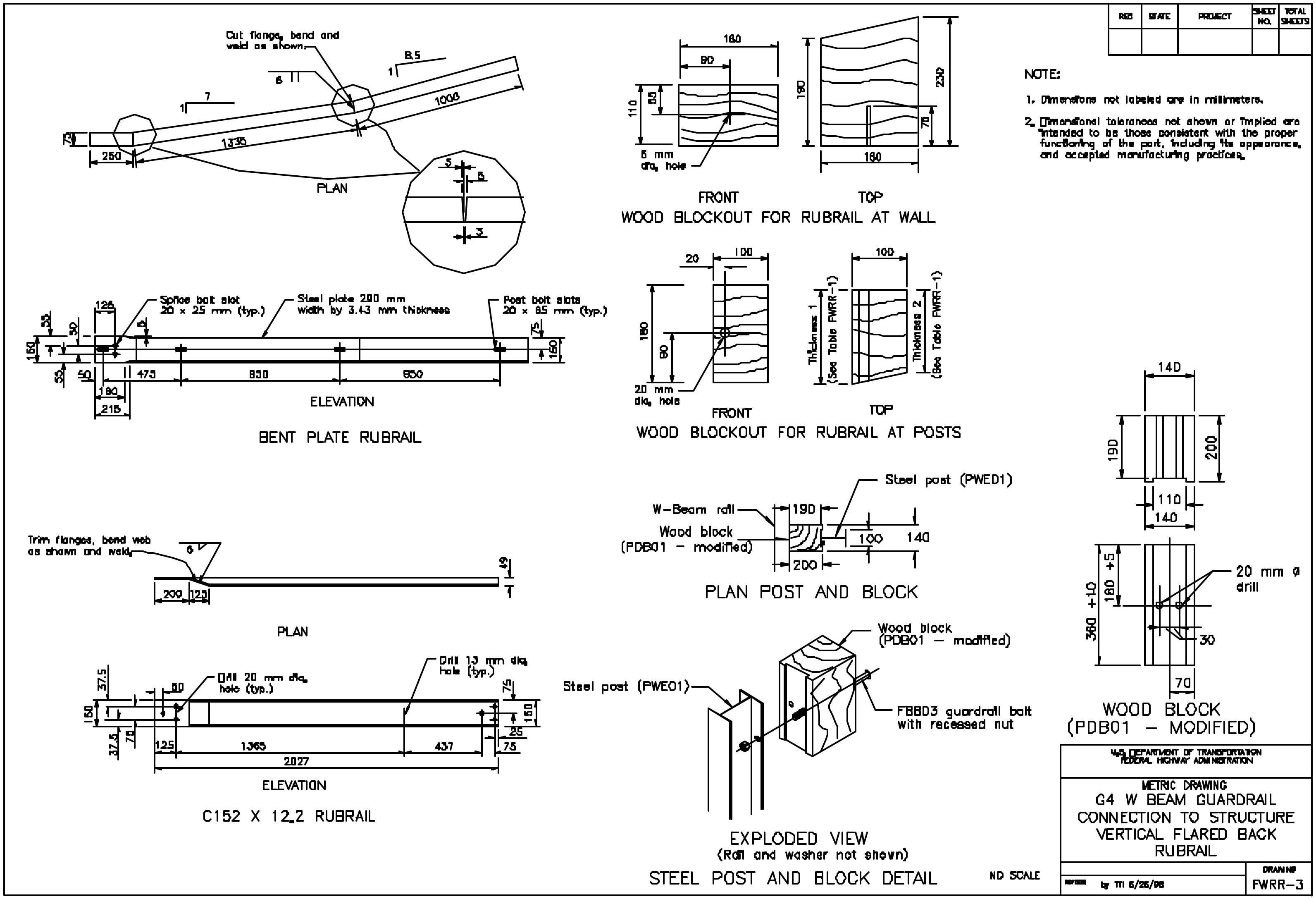


Figure 30. Details of the vertical flared back transition installation for test 404211-4(continued).

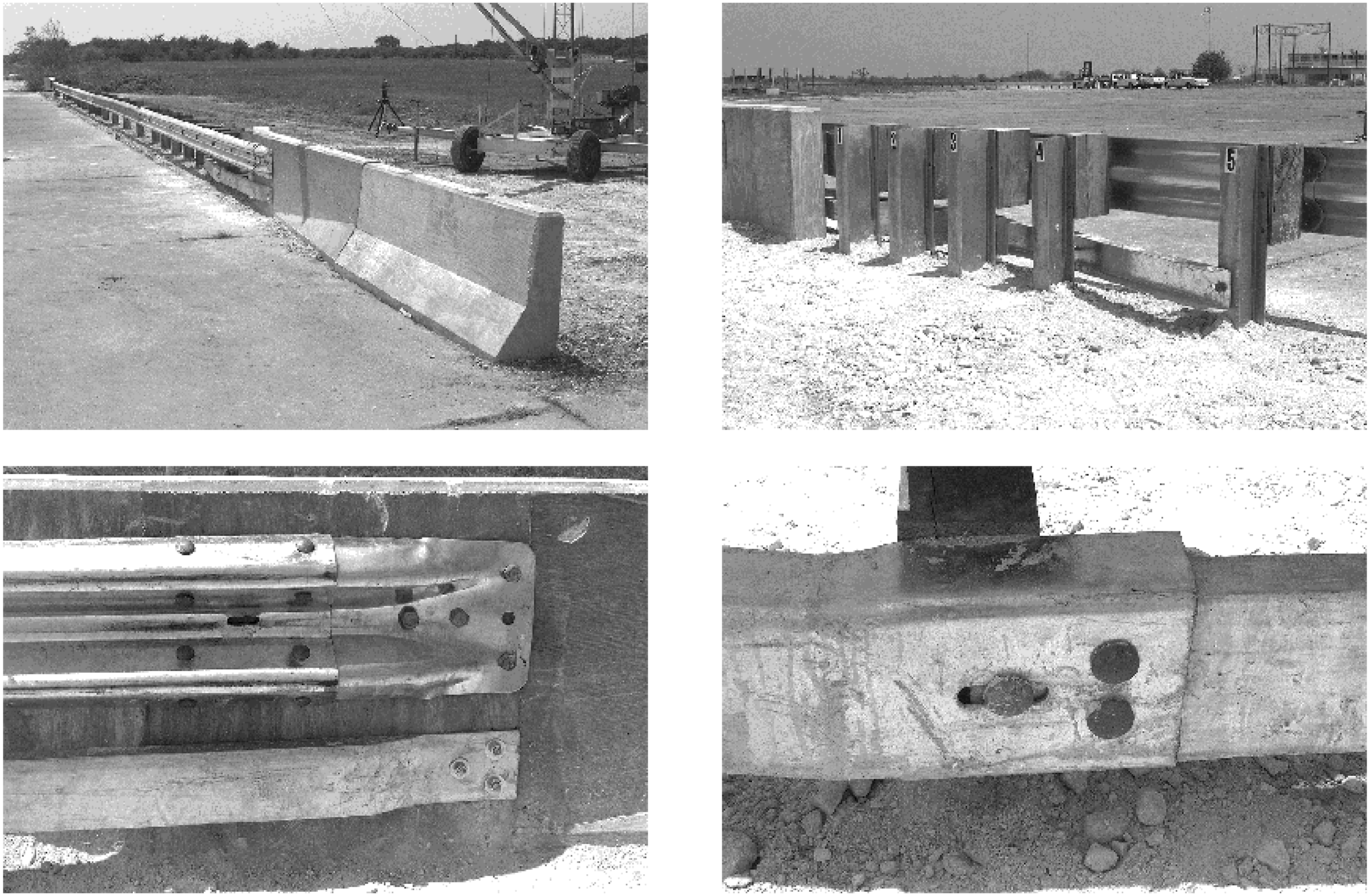
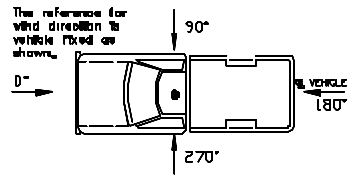


Figure 31. Vertical flared back transition prior to test 404211-4.

Holes, 610 mm in diameter, were drilled for each post. The post was installed and the hole backfilled with *NCHRP Report 350* standard soil (Georgetown crushed limestone). Similar backfill was used around the wingwall and the foundation for the simulated bridge rail.

Soil and Weather Conditions

The test was performed the morning of September 3, 1998. Only a trace of rain was recorded during the 10 recording days prior to the test. Moisture content of the *NCHRP Report 350* soil in which the transition was installed was 9.1 percent, 8.9 percent, and 7.3 percent at posts 1, 3, and 5, respectively. Weather conditions during the time of the test were as follows: wind speed: 6 km/h; wind direction: 0 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 41EC; relative humidity: 24 percent.



Test Vehicle

A 1994 Chevrolet 2500 pickup truck, shown in figure 32, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2074 kg. The height to the lower edge of the vehicle bumper was 380 mm and it was 600 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in appendix B, figure 84.

Impact Description

The vehicle, traveling at 101.2 km/h, impacted the vertical flared back transition 0.69 m from the end of the bridge parapet at a 24.7-degree angle. Shortly after impact, posts 4, 3, and 2 moved, followed by movement at posts 1 and 5. At 0.052 s, redirection of the vehicle began. The concrete parapet moved at 0.058 s and the driver's side window shattered at 0.108 s. The right front and left rear tires lost contact with the ground at 0.102 and 0.183 s, respectively. At 0.170 s, the right rear tire lost contact with the ground. The vehicle, traveling at 80.2 km/h, was parallel to the installation at 0.173 s. At 0.174 s, the left rear side of the vehicle contacted the rail element between posts 3 and 4. At 0.304 s, the left rear tire lost contact with the concrete parapet and the left rear tire lost contact with the ground. The vehicle lost contact with the concrete parapet at 0.399 s, and was traveling at 75.7 km/h and an exit angle of 5.2 degrees. After exiting the transition, the vehicle yawed clockwise and rolled counterclockwise. The vehicle subsequently rolled one revolution and came to rest upright 56.4 m down from the point of impact and 9.9 m toward traffic lanes. Sequential photographs of the test period are shown in appendix C, figures 102 and 103. Brakes on the vehicle were applied 8.3 s after impact.

Damage to Test Article

The vertical flared back transition received moderate damage as shown in figure 33. Deformation to the upper and lower W-beams extended from post 5 through post 1. The bolt was out of posts 1 and 2 at the bottom blockout. Also at post 2, the rub rail was deformed outward. At

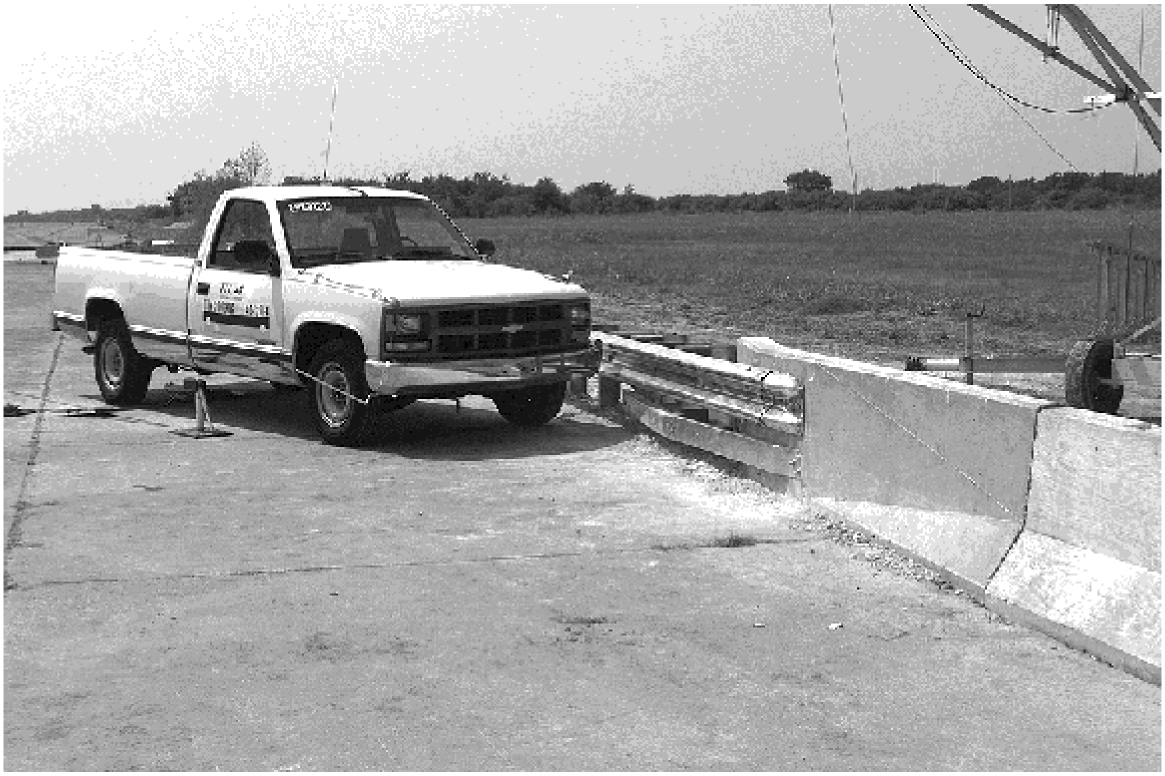


Figure 32. Vehicle before test 404211-4.

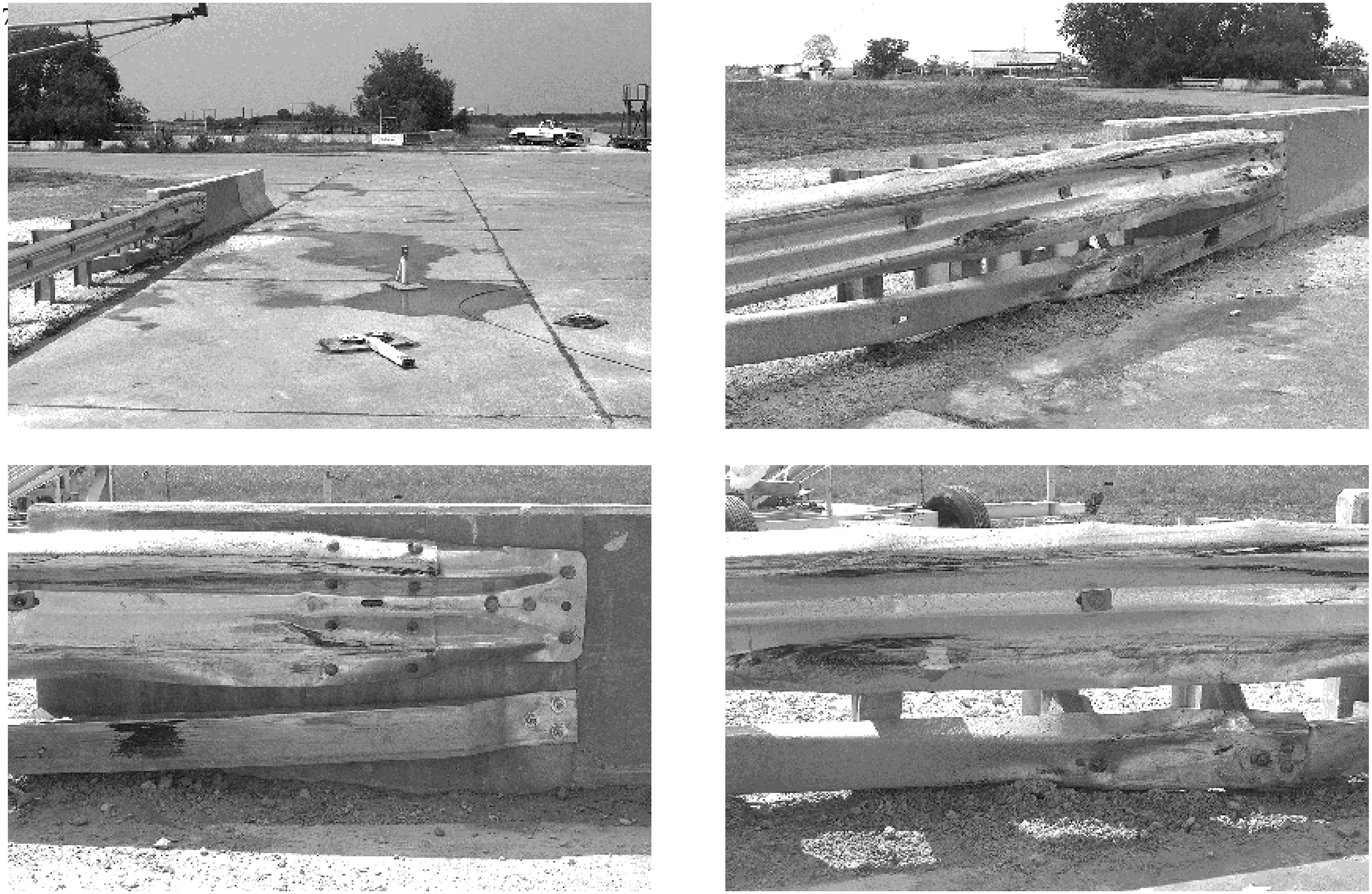


Figure 33. Installation after test 404211-4.

post 3, the rub rail was twisted. The spacing between the metal pipe and blockout and the concrete parapet was 45 mm before the test and after the test the pipe was leaning against the parapet and the spacing was 15 mm. The concrete parapet was pushed back 25 mm. Total length of contact of the vehicle with the transition and concrete parapet was 3.91 m.

Vehicle Damage

The vehicle sustained substantial damage as shown in figure 34. The upper and lower A-arms and frame rail were all severely damaged. Both left-side quarter panels were damaged and the left door had a gap (not measurable). The right door, front and rear rims, and the rear quarter panel sustained damage. Also damaged were the rear bumper and tailgate. The front bumper, grill, hood, radiator, fan, and cab were deformed. The windshield and the right, left, and rear glasses were shattered. Maximum exterior crush to the vehicle was 530 mm at the front bumper and 410 mm above the front bumper. Maximum deformation of the occupant compartment was 75 mm in the center floor pan area and 27 mm in the firewall area. Details can be found in appendix B, tables 35 and 36.

Occupant Risk Factors

In the longitudinal direction, the occupant impact velocity was 6.1 m/s at 0.161 s, the highest 0.010-s occupant ridedown acceleration was -6.1 g's from 0.101 to 0.111 s, and the maximum 0.050-s average acceleration was -9.7 g's between 0.049 and 0.099 s. In the lateral direction, the occupant impact velocity was 7.7 m/s at 0.101 s, the highest 0.010-s occupant ridedown acceleration was 9.2 g's from 0.126 to 0.136 s, and the maximum 0.050-s average was 11.9 g's between 0.048 and 0.098 s. These data and other pertinent information from the test are summarized in figure 35. Vehicle angular displacements are displayed in appendix D, figure 123. Vehicular accelerations versus time traces are presented in appendix E, figures 180 through 190.

Assessment of Test Results

As stated previously, the following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

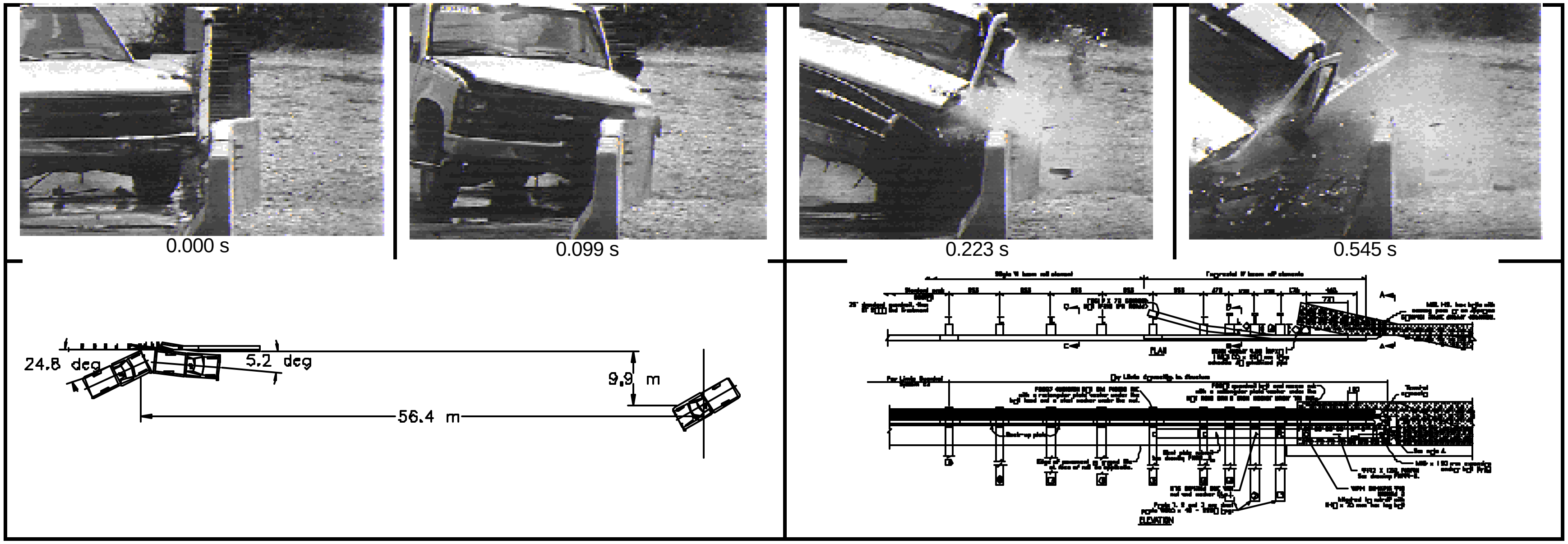
! **Structural Adequacy**

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.*

Result: The vertical flared back transition contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection was 0.17 m.

After being righted

Figure 34. Vehicle after test 404211-4.



General Information

Test Agency	Texas Transportation Institute
Test No.	404211-4
Date	09/03/98
Test Article	
Type	Transition
Name or Manufacturer	Vertical Flared Back Transition
Installation Length (m)	38.3
Material or Key Elements	W-beam with W-beam Rub Rail & Steel Posts to Vertical Flared Back Parapet
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1994 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1865
Test Inertial	2000
Dummy	74
Gross Static	2074

Impact Conditions

Speed (km/h)	101.0
Angle (deg)	24.8
Exit Conditions	
Speed (km/h)	75.7
Angle (deg)	5.2
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.1
y-direction	-7.7
THIV (km/h)	33.6
Ridedown Accelerations (g's)	
x-direction	-6.1
y-direction	9.2
PHD (g's)	9.4
ASI	1.58
Max. 0.050-s Average (g's)	
x-direction	-9.7
y-direction	11.9
z-direction	-7.5

Test Article Deflections (m)

Dynamic	0.17
Permanent	0.09
Vehicle Damage	
Exterior	
VDS	11LFQ4
CDC	11FLEK3 & 11LDEW3
Maximum Exterior Vehicle Crush (mm)	530
Interior	
OCDI	LF0100000
Max. Occ. Compart. Deformation (mm)	75
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	76
Max. Pitch Angle (deg)	-7
Max. Roll Angle (deg)	-97

Figure 35. Summary of results for the vertical flared back transition test, *NCHRP Report 350* test 3-21.

! **Occupant Risk**

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

Result: No detached elements or debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 75 mm in the center floor pan area.

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

Result: After exiting the transition, the vehicle rolled one revolution and came to rest upright, 9.9 m toward traffic lanes.

! **Vehicle Trajectory**

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

Result: The vehicle did intrude into adjacent traffic lanes.

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.*

Result: Longitudinal occupant impact velocity was 6.1 m/s and longitudinal ridedown acceleration was -6.1 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: Exit angle at loss of contact was 5.2 degrees, which was less than 60 percent of the impact angle.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— **PASSENGER COMPARTMENT INTRUSION**

1. **Windshield Intrusion**

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

2. **Body Panel Intrusion** yes or no (circled)

— **LOSS OF VEHICLE CONTROL**

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

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

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

No debris was present.

— **VEHICLE AND DEVICE CONDITION**

1. **Vehicle Damage**

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

2. **Windshield Damage**

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

3. **Device Damage**

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

PENNSYLVANIA TRANSITION
(*NCHRP REPORT 350* TEST NO. 3-21)

Test Conditions

The test performed on the Pennsylvania transition corresponds to *NCHRP Report 350* test designation 3-21. The BARRIER VII simulation program was used to select the CIP for this test. The program indicated the CIP to be 2.0 m from the end of the concrete parapet.

Test Article

The Pennsylvania Guide Rail Transition (without drainage inlet) consists of 3810 mm of two nested 12-gauge W-beam guardrails blocked out from the end of the parapet using a 150-mm-diameter spacer tube followed by 3810 mm of single W-beam guardrail. In addition, the transition incorporates a "flared-back" C150 rub rail. The height of the W-beam guardrail used in this transition was approximately 790 mm from the pavement surface. The centerline height of the rub rail from the pavement surface was approximately 330 mm. TTI received numerous drawings from Pennsylvania DOT entitled "Standard Bridge Parapet to Guide Rail Transition, BC-739M, Sheet 1 of 2," dated December 24, 1999, and "Type 2 Strong Post Guide Rail, RC52M," dated September 30, 1998. Details for the moment slab constructed to support the concrete parapet were also received. TTI incorporated the details provided from these drawings to construct the field test installation for this project. TTI received all the hardware to construct this transition from Trinity Industries, Fort Worth, Texas.

TTI constructed 5 m of Pennsylvania Standard Bridge Parapet from details provided to TTI by Pennsylvania DOT. The standard parapet constructed for this project was approximately 1070 mm in height and 440 mm in width at the base on the downstream end. At approximately 1802 mm from the end of the parapet, the parapet flared 10 degrees back away from the traffic side and transitioned to a height and width of approximately 810 mm, and 315 mm respectively, at the end of the parapet. The parapet was supported by a 330-mm-thick concrete moment slab. Vertical reinforcement in the parapet consisted of #16 enclosed stirrup bars located approximately 150 mm on centers. Longitudinal reinforcement in the parapet consisted of six #16 bars located in the lower portion of the parapet with four #19 bars located in the upper portion of the parapet. All reinforcement in the parapet was epoxy coated. A Type "B" Insert was purchased from Brocker Rebar Company, York, Pennsylvania, and was installed in the parapet approximately 1280 mm from the end of the parapet and at a centerline height of approximately 634 mm for anchoring the terminal connector to the parapet. Three 25-mm pipe sleeves were cast in the parapet approximately 1287 mm from the end of the parapet (centerline distance) and at a centerline height of approximately 330 mm. These pipe sleeves were used for anchoring the rub rail to the parapet with three 22-mm diameter A325 bolts. The rub rail bolts fastened completely through the parapet and a 175-mm x 175-mm x 12-mm thick plate on the field side of the parapet.

The moment slab constructed for the project was approximately 4.7 m by 6.6 m in plan and 330 mm thick. The slab was connected to an existing concrete runway slab located at our testing facility with 762-mm-long dowels located approximately 456 mm on centers. The parapet and slab were constructed so that the parapet was oriented approximately 10 degrees with the existing edge of runway. Top transverse reinforcement in the slab consisted of #19 hooked bars located approximately 152 mm on centers. Bottom transverse reinforcement in the slab consisted of #16 straight bars located approximately 305 mm on centers. Longitudinal reinforcement in the slab consisted of #13 straight bars located approximately 305 mm on centers in both the top and bottom layers in the slab with the exception of the distance between the second and third bars located from the field side edge of the slab. These bars were located approximately 152 mm apart. The parapet was anchored to the slab by #16 "V-shaped" bars that were cast in the slab and extended from the bottom layer of reinforcement in the slab upwards into the parapet. These bars were located approximately 150 mm on centers from the end of the parapet to a distance of approximately 4.3 m from the end. Beyond this distance these bars were located 300 mm on centers.

The transition was attached to the concrete parapet with a 10-gauge W-beam terminal connector welded to a steel plate. The connector attached to the parapet using four 22-mm-diameter ASTM A307 bolts in the Type B Insert. The rub rails were attached to the parapet with three A325 bolts. All posts used in the transitions and length of need W-beam guardrail were W150x13.5 steel posts. The first four posts (posts 1 through 4) used in the transition were 2135 mm in length and embedded approximately 1355 mm below grade. The remaining posts (posts 5 through 15) were 1830 mm in length and embedded approximately 1030 mm below grade. The centerline of post 1 was located approximately 263 mm from the end of the concrete parapet. A 150-mm-diameter by 305-mm-long steel spacer tube attached to the nested W-beam guardrail and was located approximately 475 mm toward the terminal connector from post 1. From post 1 to post 7, the post spacing was approximately 475 mm. Posts were spaced approximately 952 mm apart from post 7 to 11. From post 11 to 15 (W-beam guardrail length of need), the post spacing was 1905 mm apart. A LET end treatment was used beyond the length of need to anchor the W-beam guardrail.

The rub rail used for this project consisted of a two-piece rub rail mounted 330 mm from the pavement surface to its centerline. Both pieces of the rub rail were fabricated from C150x12 steel channel. Both pieces of the rub rail were spliced together at post 1 with a 10-mm-thick steel splice plate. From post 1, the rub rail was connected on each post and flared back at post 7 to the web of post 8 and was not attached.

The nested W-beam guardrail and the rub rail (at post 1 through 7) were blocked out from the posts approximately 190 mm. Routed wood blockouts (150 mm x 200 mm x 565 mm) were used at posts 1 through 7. Standard routed wood blockouts (150 mm x 200 mm x 360 mm) were used at posts 8 through 15. The rub rail and the nested W-beam guardrail were attached to each post using 16-mm-diameter A307 "button head" bolts. Detailed drawings are provided in figure 36. Photographs of the completed installation as tested are shown in figure 37.

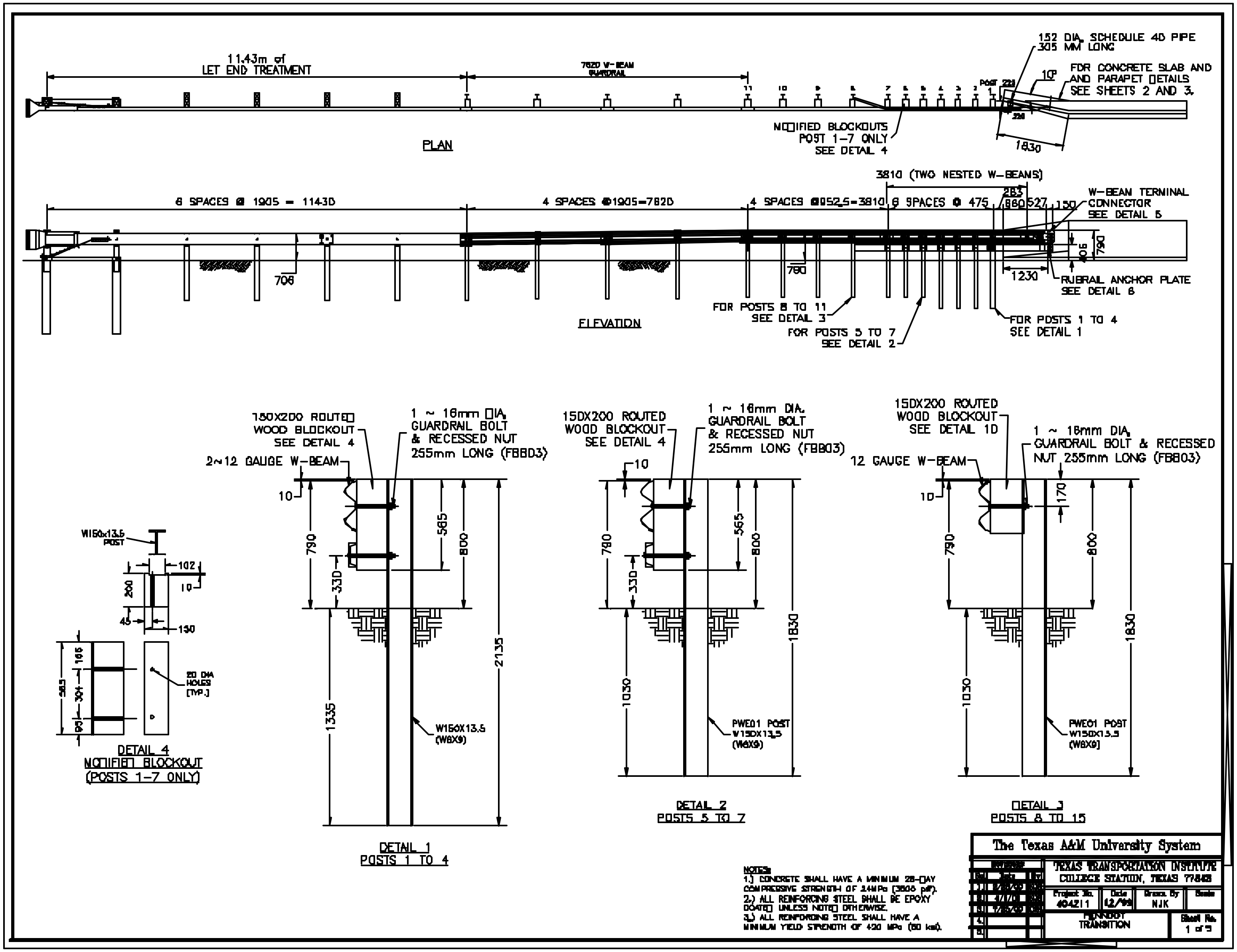


Figure 36. Details of the Pennsylvania transition installation for test 404211-3.

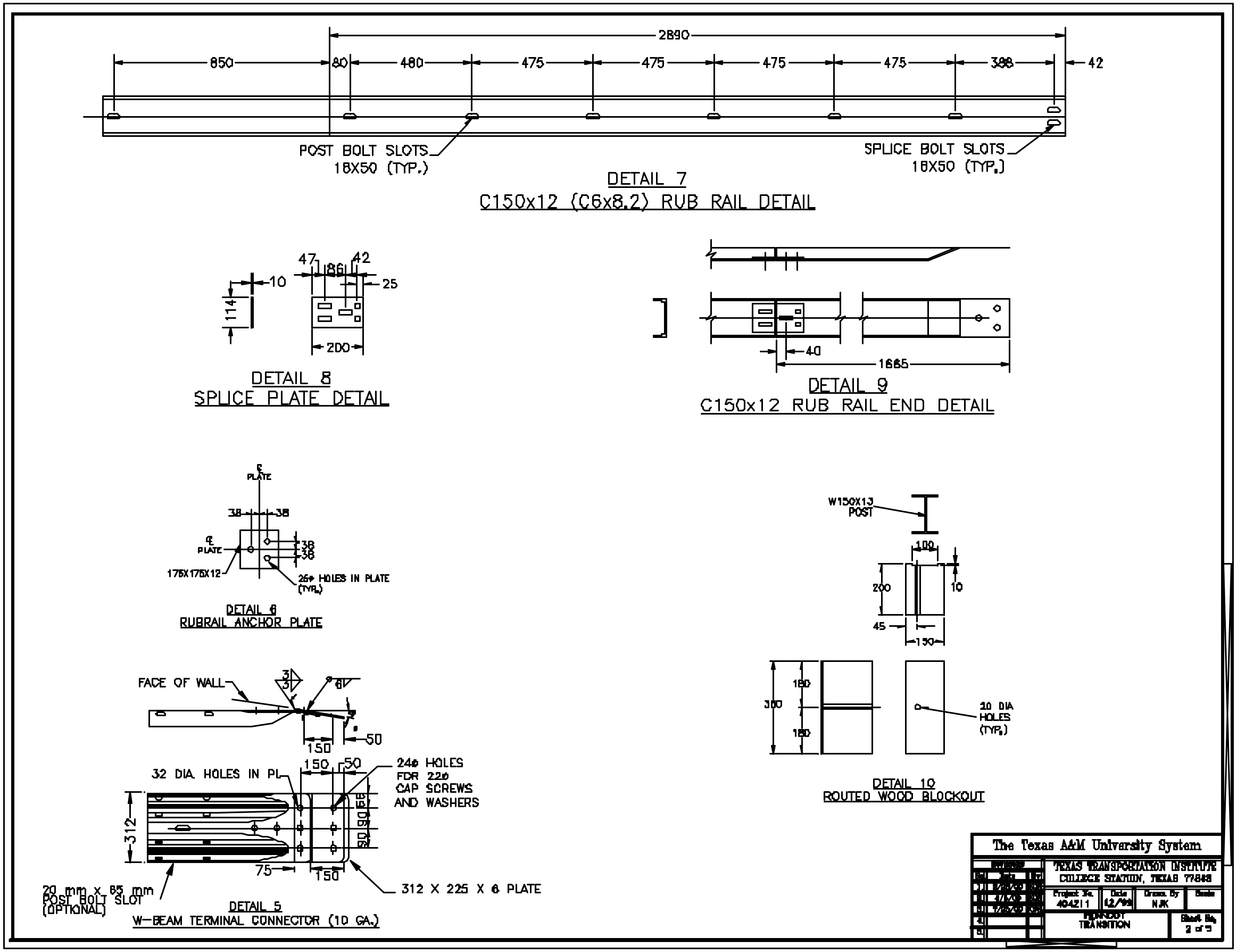


Figure 36. Details of the Pennsylvania transition installation for test 404211-3 (continued).

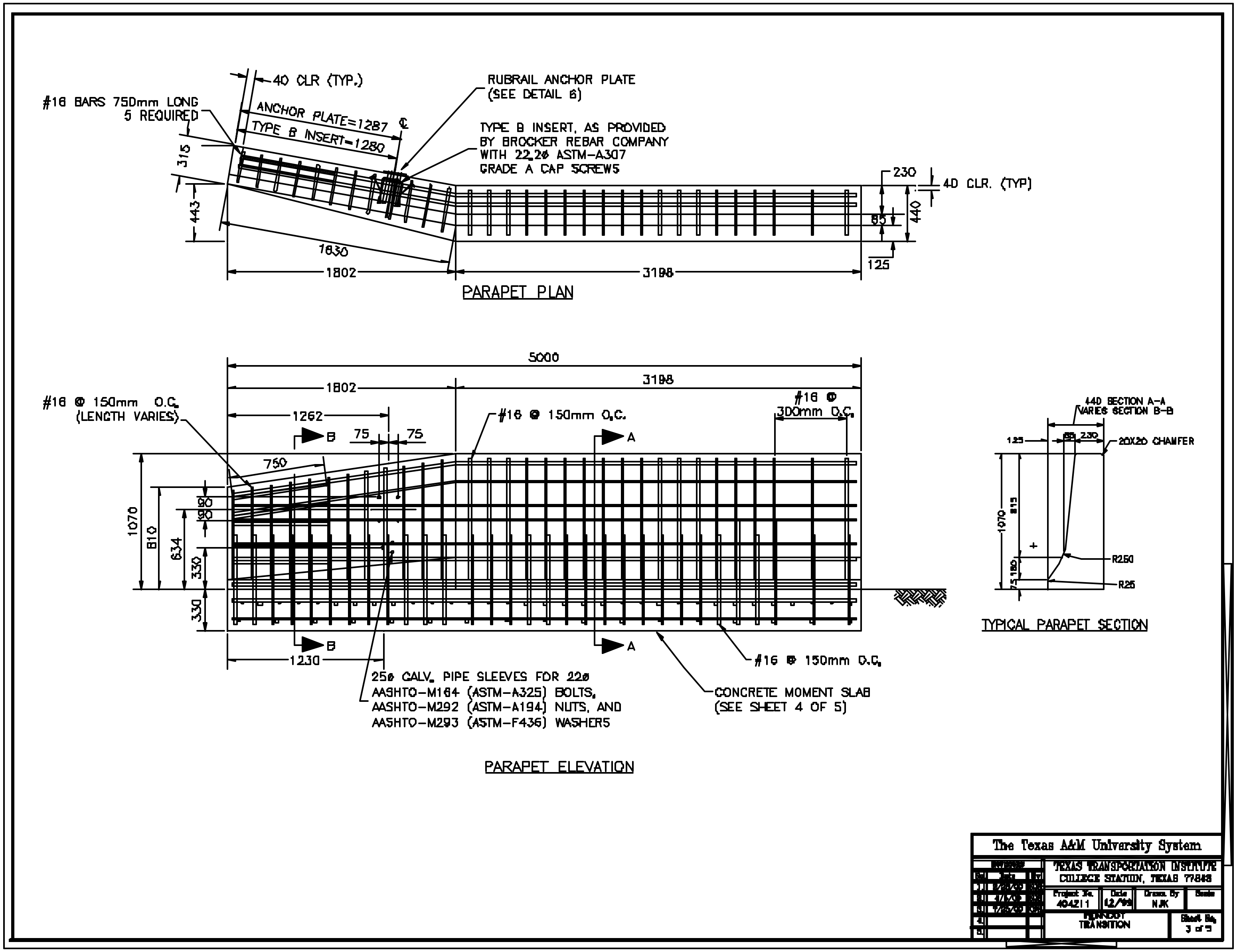


Figure 36. Details of the Pennsylvania transition installation for test 404211-3 (continued).

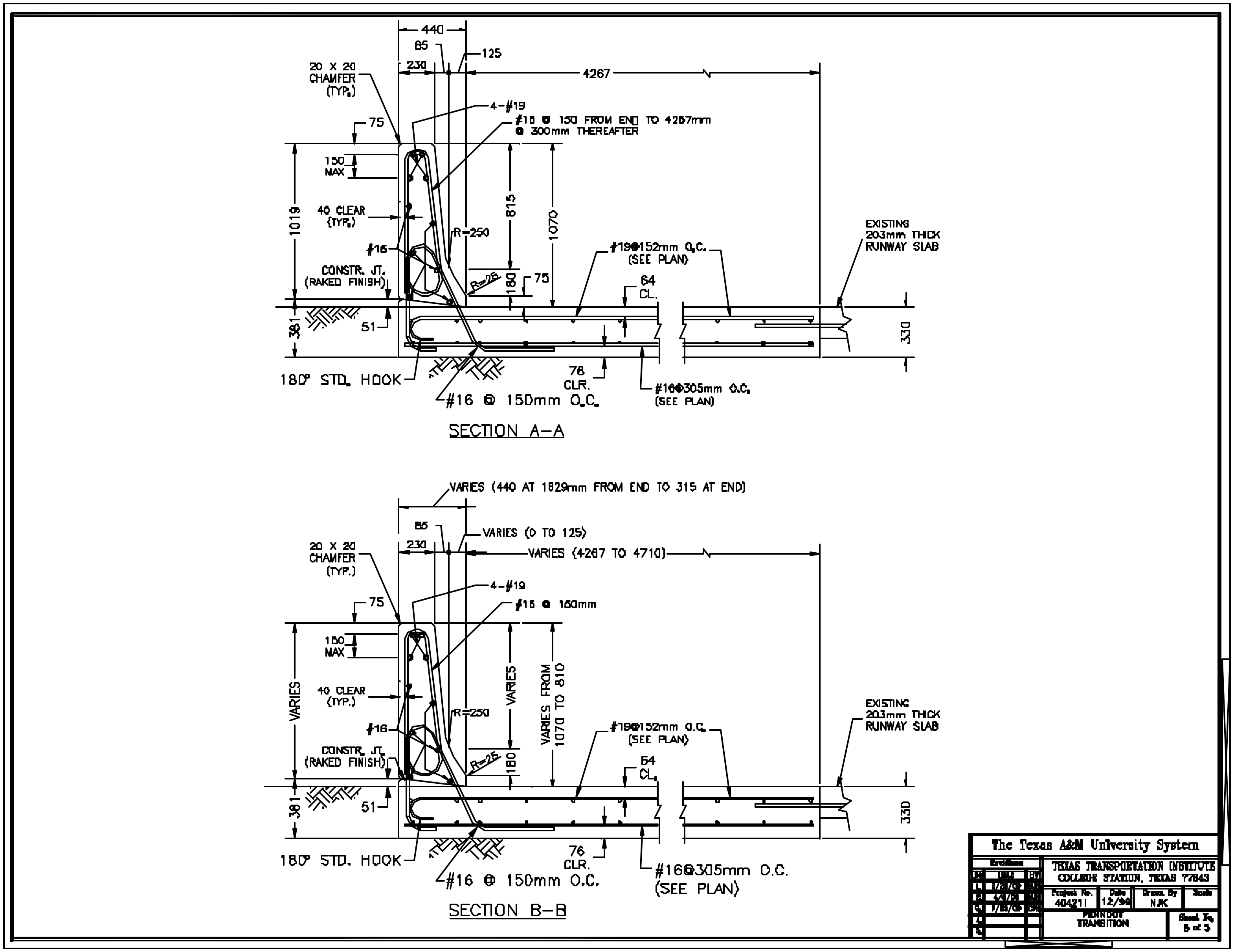


Figure 36. Details of the Pennsylvania transition installation for test 404211-3 (continued).

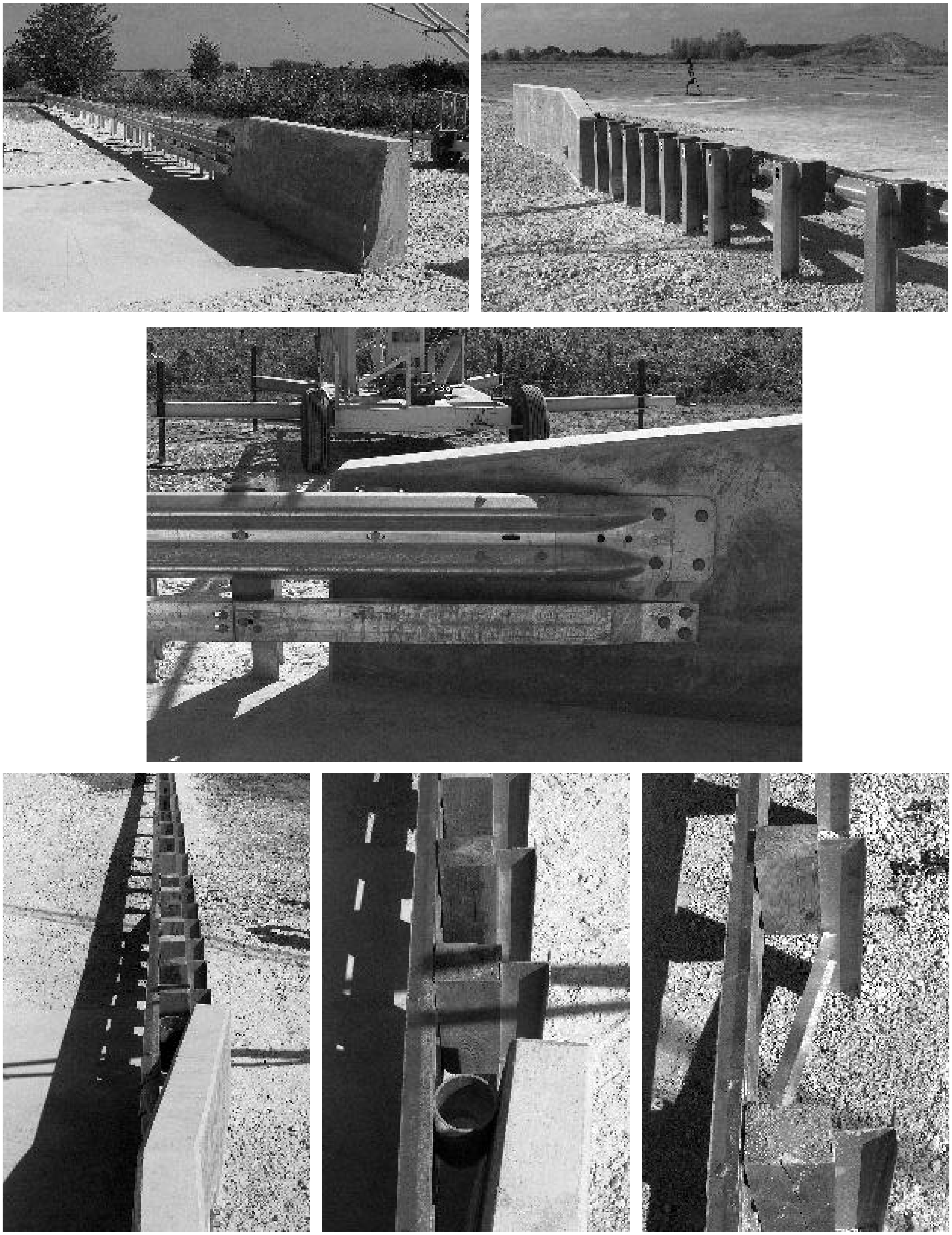
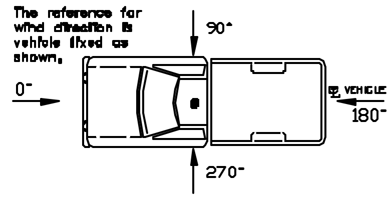


Figure 37. Pennsylvania transition prior to test 404211-3.

Soil and Weather Conditions

The crash test was performed the morning of July 7, 2000. No rainfall was recorded for the 10 days prior to the test. Moisture content of the *NCHRP Report 350* standard soil in which the transition was installed was 5.8 percent, 6.7 percent, and 7.6 percent at posts 1, 3, and 5, respectively. Weather conditions at the time of testing were as follows: temperature: 33EC; wind speed: 0 km/h; wind direction: 0 (vehicle was traveling in a westerly direction); relative humidity: 51 percent.



Test Vehicle

A 1996 Chevrolet 2500 pickup truck, shown in figure 38, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2075 kg. The height to the lower edge of the vehicle front bumper was 390 mm and to the upper edge of the front bumper was 600 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 85.

Impact Description

The left front corner of the bumper of the 2000-kg pickup truck impacted the transition 2.1 m from the end of the concrete parapet. The vehicle was traveling at a speed of 100.9 km/h and an impact angle of 24.3 degrees. Shortly after impact, posts 4 and 5 moved. Post 3 moved at 0.010 s, and at 0.012 s post 6 moved. At 0.013 s the left front tire contacted the rail element, and at 0.014 s post 2 moved. Posts 1 and 7 moved at 0.019 s and 0.31 s, respectively. The vehicle began to redirect at 0.052 s. The right front wheel lost contact with the pavement surface at 0.100 s, and by 0.141 s the rear of the pickup truck contacted the rail element. The pickup truck became parallel with the transition at 0.171 s and was traveling at a speed of 78.4 km/h. The right rear wheel lost contact with the pavement surface at 0.194 s. At 0.220 s the left front wheel lost contact with the concrete parapet. The left rear wheel lost contact with the concrete parapet at 0.332 s. The vehicle lost contact with the transition at 0.378 s and was traveling at a speed of 78.0 km/h and an exit angle of 13.7 degrees. The left rear wheel touched the pavement surface at 0.552 s, and the left front at 0.619 s. The vehicle remained upright and stable during the collision period and after loss of contact. Brakes on the vehicle were not applied and the vehicle yawed clockwise, subsequently coming to rest 64.0 m beyond impact and 25.9 m toward traffic lanes. Sequential photographs of the test period are shown in appendix C, figures 104 and 105.

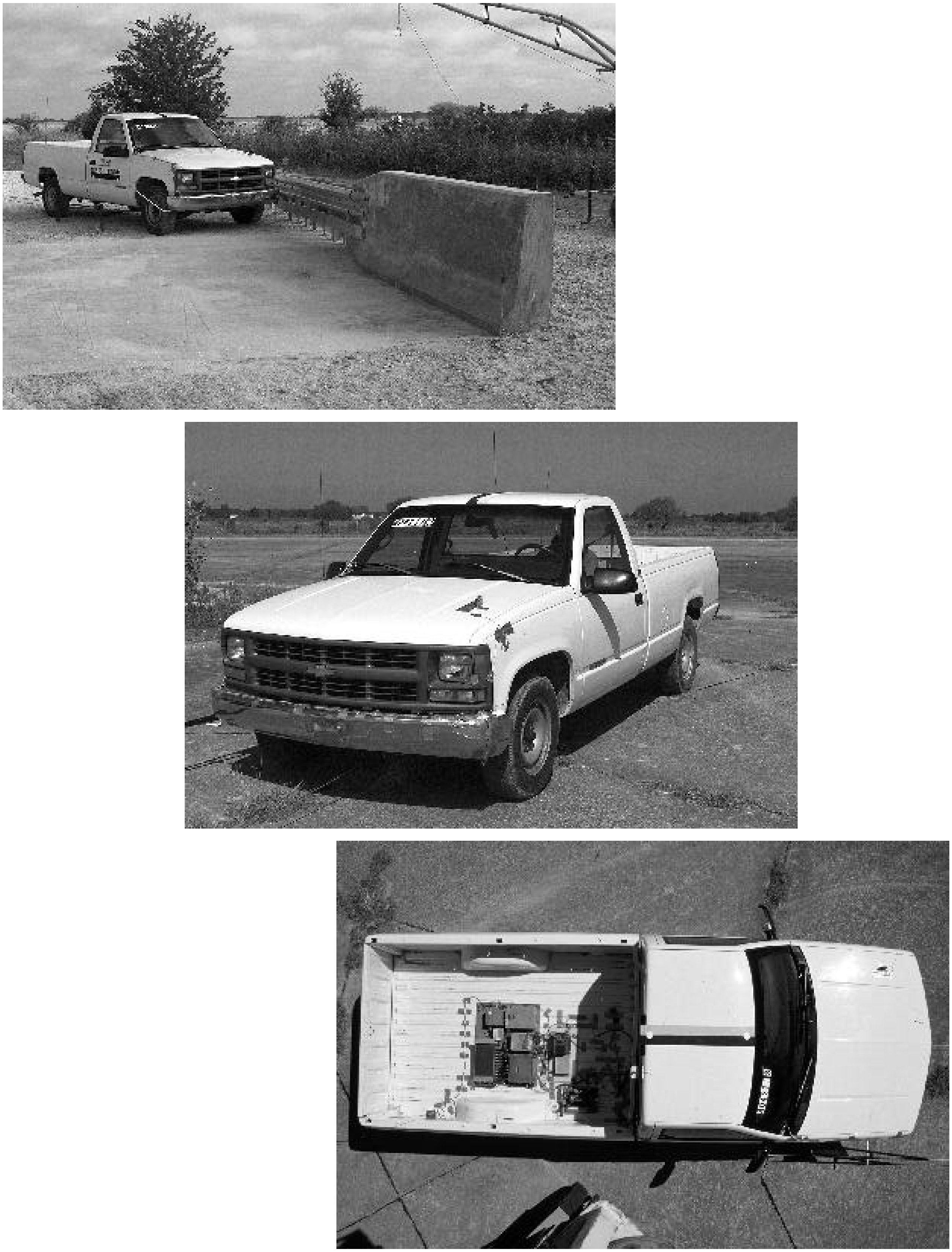


Figure 38. Vehicle before test 404211-3.

Damage to Test Article

The Pennsylvania transition sustained minimal damage as shown in figure 39. Tire marks were on the face of the W-beam rail element and rub rail and both were deformed. The bolt on the rub rail at post 2 was bent and the bolt was pulled out of the rub rail at post 4. The spacer tube was crushed 28 mm. The space between the spacer tube and the concrete parapet was reduced 5 mm. No movement was noted in the end terminal. Maximum dynamic deflection of the W-beam rail element was 177 mm. Maximum permanent rail deformation of the W-beam rail element was 110 mm at post 1 and the rub rail was deformed 98 mm at post 2. The length of contact of the vehicle with the transition was 3.9 m. No apparent cracking was observed in the concrete parapet or slab.

Vehicle Damage

The vehicle sustained damage to the left front as shown in figure 40. Structural damage included the left front of the frame, left upper and lower A-arms, left tie rod end, stabilizer bar, floor pan and firewall. Also damaged were the front bumper, grill, fan, radiator, left front and rear quarter panels, left door and window, left front and rear tires and wheel rims. The windshield sustained stress cracks. Maximum exterior crush of the vehicle was 440 mm at the left front corner at bumper height. The maximum deformation of the occupant compartment was 117 mm in the center of the floor pan area. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 37 and 38.

Occupant Risk Factors

In the longitudinal direction, occupant impact velocity was 5.5 m/s at 0.100 s, maximum 0.010-s ridedown acceleration was -8.5 g's from 0.111 to 0.121 s, and the maximum 0.050-s average was -8.8 g's between 0.053 and 0.103 s. In the lateral direction, the occupant impact velocity was 7.4 m/s at 0.100 s, the highest 0.010-s occupant ridedown acceleration was 7.8 g's from 0.112 to 0.122 s, and the maximum 0.050-s average was 12.8 g's between 0.043 and 0.093 s. These data and other information pertinent to the test are presented in figure 41. Vehicle angular displacements are presented in appendix D, figure 124, and accelerations versus time traces are shown in appendix E, figures 191 through 201.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

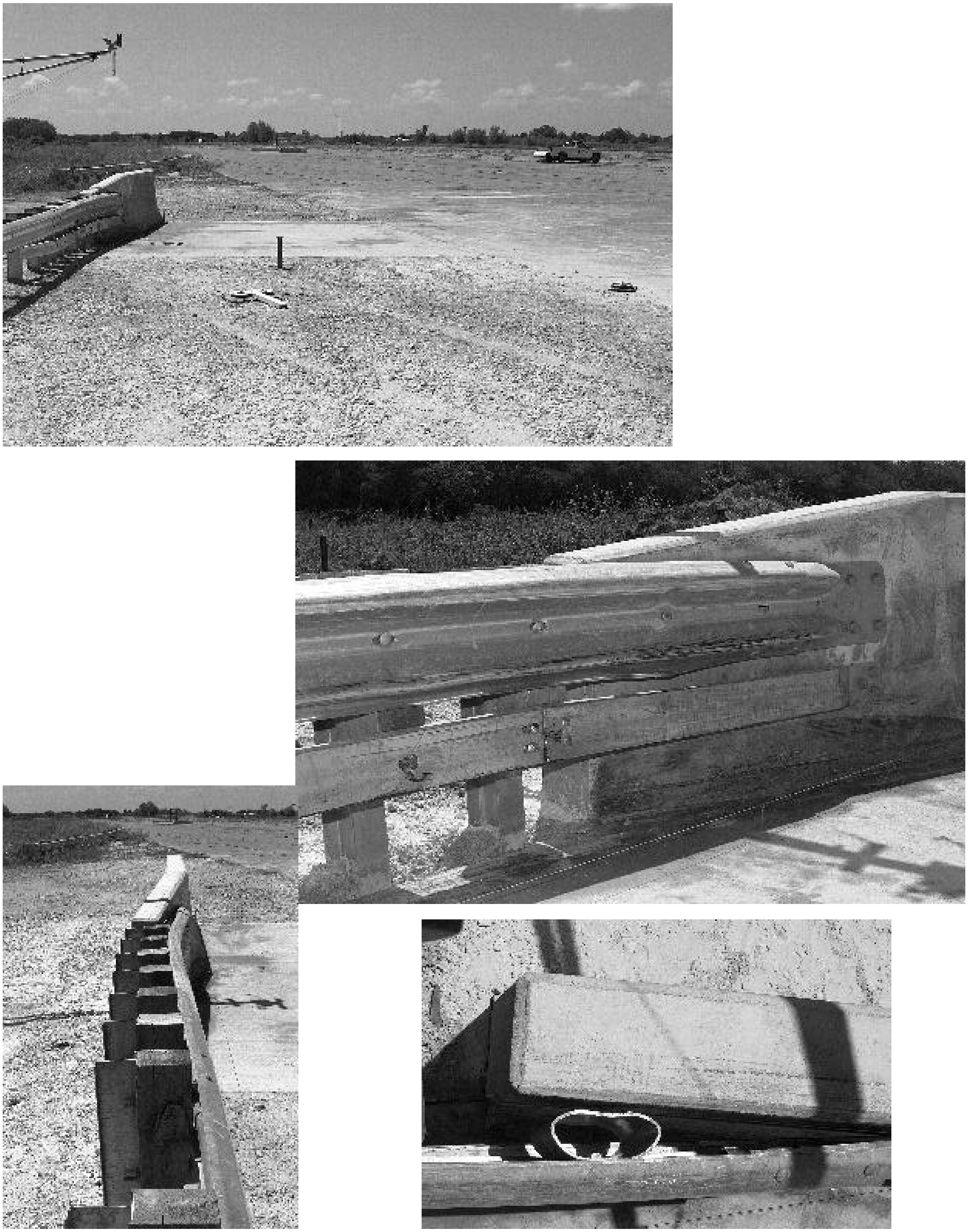


Figure 39. Installation after test 404211-3.

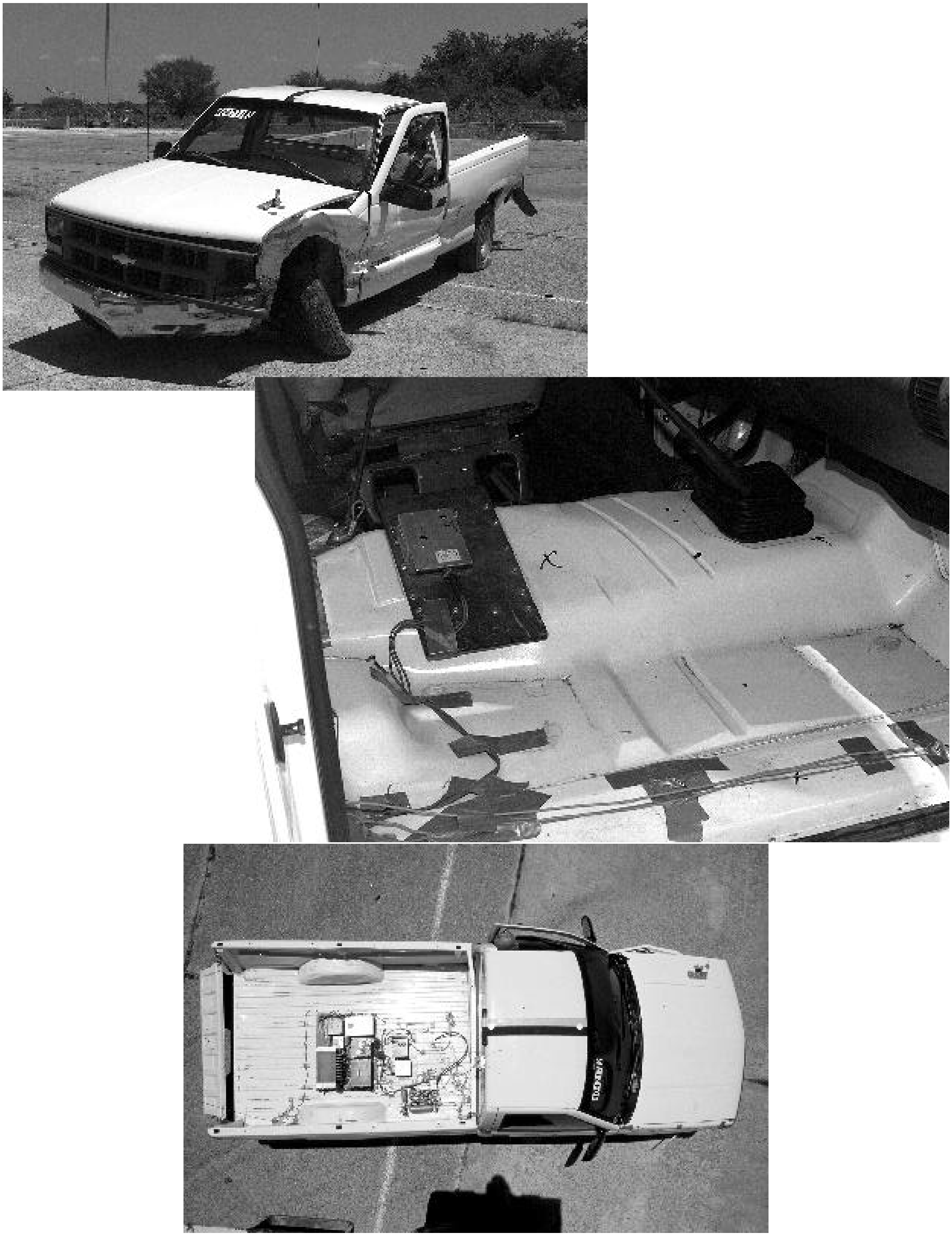
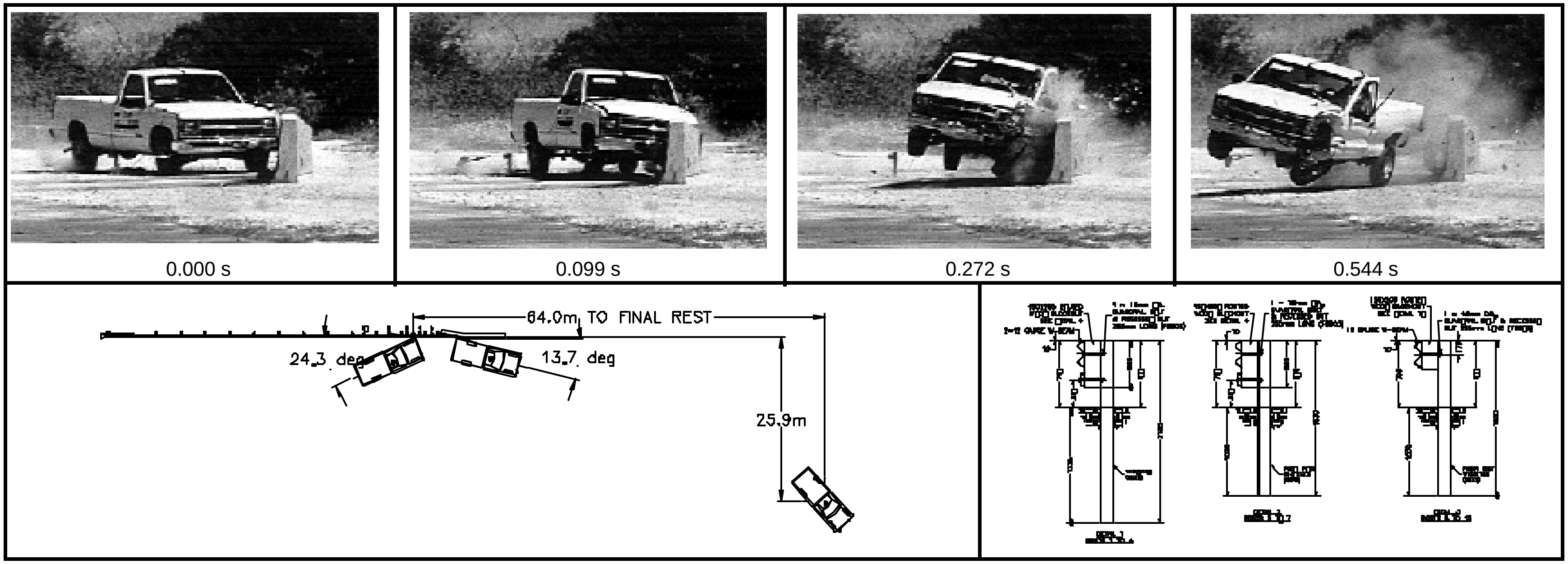


Figure 40. Vehicle after test 404211-3.



General Information

Test Agency	Texas Transportation Institute
Test No.	404211-3
Date	07/07/00

Test Article

Type	Transition
Name	Pennsylvania Transition
Installation Length (m)	31.0
Material or Key Elements	W-beam Rail with Rub Rail Attached to Concrete Parapet

Soil Type and Condition . Standard Soil, Dry

Test Vehicle

Type	Production
Designation	2000P
Model	1996 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1903
Test Inertial	2000
Dummy	75
Gross Static	2075

Impact Conditions

Speed (km/h)	100.9
Angle (deg)	24.3

Exit Conditions

Speed (km/h)	78.0
Angle (deg)	13.7

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	5.5
y-direction	7.4
THIV (km/h)	32.1
Ridedown Accelerations (g's)	
x-direction	-8.5
y-direction	7.8
PHD (g's)	11.5
ASI	1.71
Max. 0.050-s Average (g's)	
x-direction	-8.8
y-direction	12.8
z-direction	-7.7

Test Article Deflections (m)

Dynamic	0.177
Permanent	0.110

Vehicle Damage

Exterior	
VDS	11LFQ4
CDC	11FLEK3 & 11LDEW3
Maximum Exterior Vehicle Crush (mm)	440
Interior	
OCDI	LF0200100
Max. Occ. Compart. Deformation (mm)	117

Post-Impact Behavior

(during 1.0 s after impact)

Max. Yaw Angle (deg)	46
Max. Pitch Angle (deg)	-6
Max. Roll Angle (deg)	-15

Figure 41. Summary of results for the Pennsylvania Transition test, *NCHRP Report 350* test 3-21.

! **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.*

Result: The Pennsylvania transition contained and redirected the 2000P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum lateral deflection was 177 mm.

! **Occupant Risk**

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

Result: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 117 mm in the center floor pan area and was judged to not cause serious injury.

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

Result: The 2000P vehicle remained upright during and after the collision period.

! **Vehicle Trajectory**

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

Result: The 2000P vehicle came to rest 25.9 m toward traffic lanes, which indicated intrusion into adjacent traffic lanes.

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.*

Result: Longitudinal occupant impact velocity was 5.5 m/s and occupant ridedown acceleration was -8.5 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: Exit angle at loss of contact with the transition was 13.7 degrees, which was 56 percent of the impact angle.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— **PASSENGER COMPARTMENT INTRUSION**

1. **Windshield Intrusion**

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

2. **Body Panel Intrusion** yes or no (circled)

— **LOSS OF VEHICLE CONTROL**

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

After loss of contact with the transition, the vehicle came to rest 25.9 m laterally from the traffic face of the rail, which indicated intrusion into adjacent traffic lanes and a perceived threat to other vehicles in those lanes.

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

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

No debris was present to threaten workers or other vehicles.

— **VEHICLE AND DEVICE CONDITION**

1. **Vehicle Damage**

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

2. Windshield Damage

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

3. Device Damage

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

NEBRASKA TRANSITION (*NCHRP REPORT 350* TEST NO. 3-21)

Test Conditions

The test performed on the Nebraska transition corresponds to *NCHRP Report 350* test designation 3-21. The BARRIER VII simulation program was used to select the CIP for this test. The program indicated the CIP to be 1.8 m from the end of the concrete parapet.

Test Article

The Nebraska thrie beam transition consists of 3810 mm of two nested 12-gauge thrie beam guardrails followed by a 12-gauge W-beam to 12-gauge thrie beam transition piece. This transition piece connected to 7.62 m of W-beam guardrail that was anchored with a LET End Treatment. The height of the thrie beam transition was approximately 804 mm. The height of the W-beam guardrail was approximately 706 mm. TTI received AutoCAD drawing details for this transition from Dr. Ron Faller with Midwest Roadside Safety Facility in September 1999. TTI received additional drawings from FHWA Eastern Federal Lands Highway Division (EFLHD) for the concrete parapet supported by two drilled shafts in February 2000.

TTI constructed 2.23 m of concrete parapet from details provided to TTI by EFLHD. This parapet was 835 mm in height and 350 mm wide. At the guardrail transition end, the parapet tapered from 350 mm wide to 150 mm over a distance of 630 mm. The parapet was supported by a 600-mm × 650-mm footing that was supported by two 450-mm-diameter drilled shafts spaced approximately 1.35 m apart. These drilled shafts extended 3.0 m below the footing, which was constructed flush with grade. Reinforcement in the parapet consisted of #19 "U" shaped and straight vertical bars at 150 mm on centers on each face of the parapet. Horizontal reinforcement in the parapet consisted of eight sets of overlapping #13 "U" and "V" shaped bars equally spaced. Reinforcement in the concrete footing consisted of #13 closed stirrups at 150 mm on centers. These stirrups were not closed in the areas of the vertical reinforcement for the drilled shafts extending into the footing. Longitudinal reinforcement in the footing consisted of 10 #16 bars inside the stirrups. Reinforcement for the drilled shafts consisted of 12 #19 bars equally spaced inside #13 spiral reinforcement. The outside diameter of the spiral reinforcement was approximately 300 mm. The #13 spiral reinforcement was constructed with a 45-mm pitch. The average compressive strength of the parapet and footing concrete measured 31 MPa (4500 psi) and 32 MPa (4636 psi), respectively. All reinforcement used in the parapet was bare steel (not epoxy coated) and had an approximate yield strength of 420 MPa (60 ksi). Details of the parapet are shown on page 1 of figure 42.

The nested thrie beam transition was attached to the concrete parapet with a 10-gauge thrie beam terminal connector attached to the parapet using five 22-mm diameter ASTM A325 bolts. The centerline of post 1 was located approximately 1220 mm from the end of the parapet. The Nebraska thrie beam transition design incorporates a special "hidden post" design using a TS 102 × 102 × 7.9 steel tube that attaches to the end of the parapet and is supported by post 1. This steel tube supports a

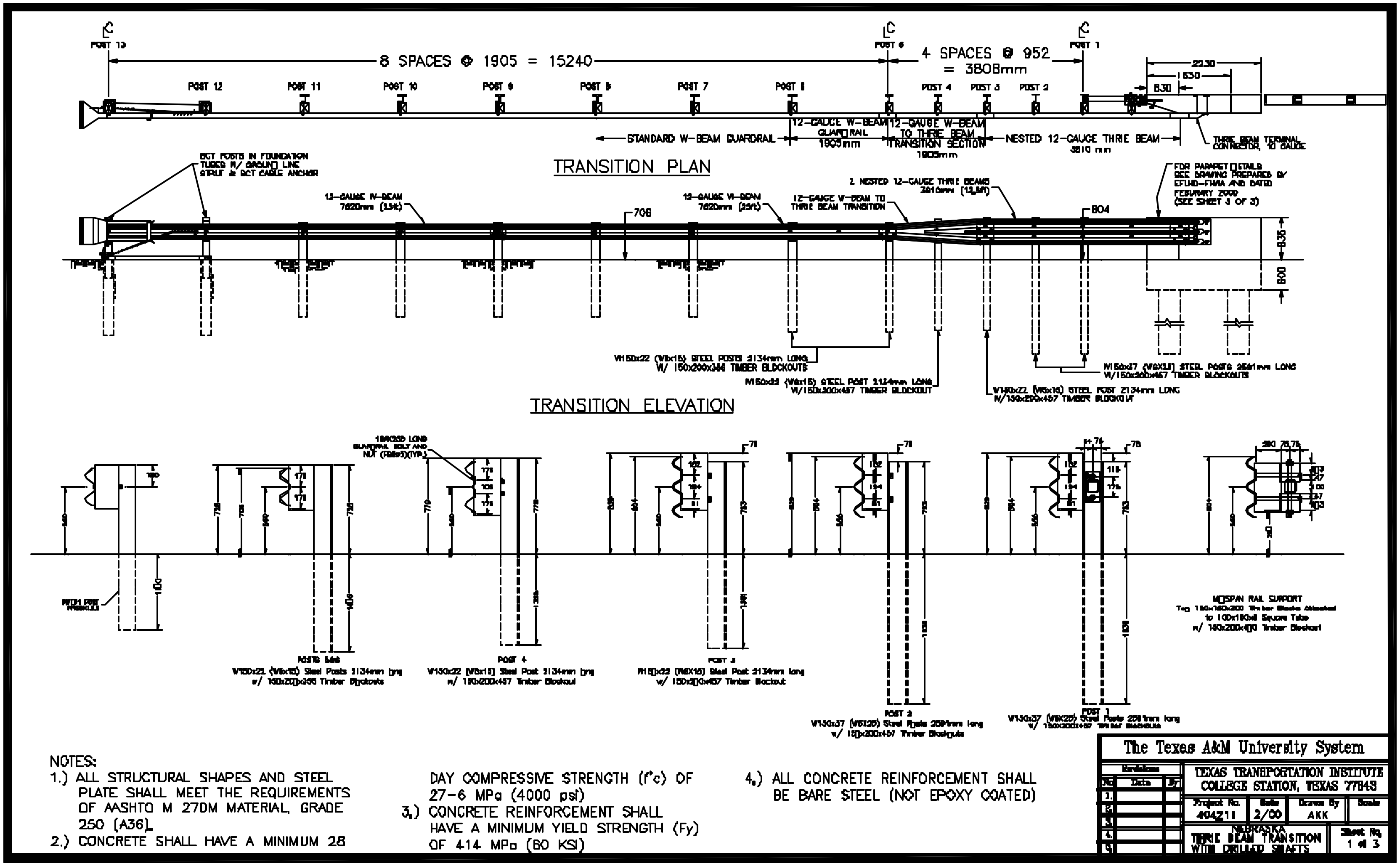


Figure 42. Details of the Nebraska thrie beam transition installation for test 404211-7.

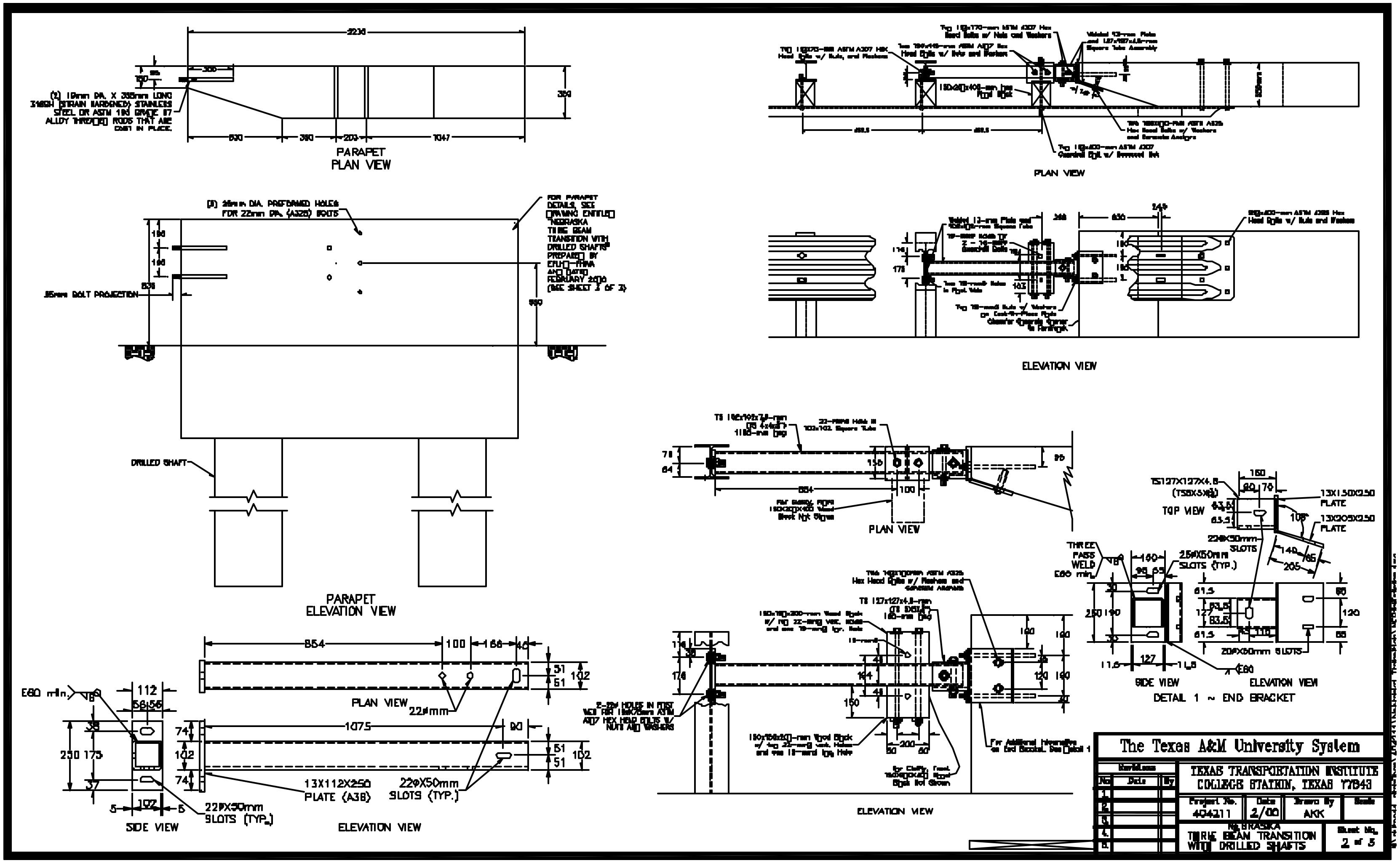


Figure 42. Details of the Nebraska thrie beam transition installation for test 404211-7 (continued).

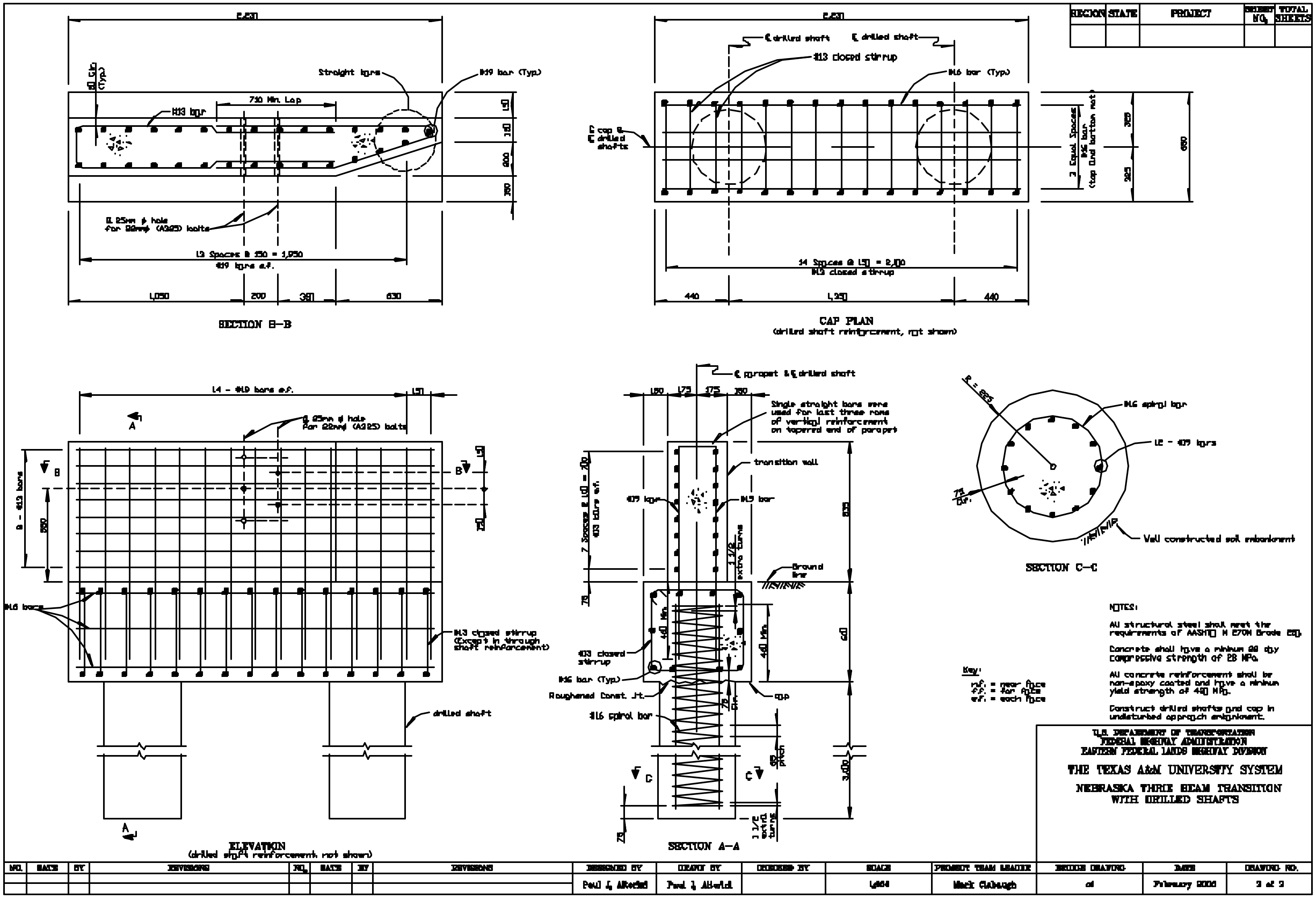


Figure 42. Details of the Nebraska thrie beam transition installation for test 404211-7 (continued).

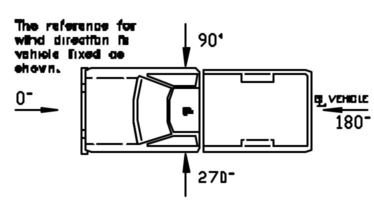
150-mm × 200-mm × 400-mm wood block that is located 298 mm from the end of the parapet, which, in turn, supports the nested thrie beam guardrail without the use of an embedded post at this location. A 112-mm × 250-mm × 13-mm thick A36 steel plate was welded to the end of the tube and was used to attach the steel tube to post 1 using two 22-mm-diameter A307 bolts that bolted through the plate and web of post 1. The steel tube is supported at the parapet by a steel plate bracket fabricated from 13-mm-thick plate with a 160-mm-long piece of TS 127 × 127 × 4.8 steel tube welded to the plate bracket. The TS 102 × 102 × 7.9 steel tube supporting the “hidden post” blockout fits inside the TS 127 × 127 × 4.8 tube welded to the bracket and is bolted with two 19-mm-diameter A307 bolts, 170 mm in length. The steel bracket was attached to the parapet with two 16-mm-diameter A325 mechanical anchors located on the sloped surface of the parapet. In addition, the bracket was secured with two chemically anchored ASTM 193 Grade B7 fully threaded rods embedded 300 mm at the end of the parapet. These bolts projected out from the end of the parapet approximately 55 mm.

Posts 1 through 5 were spaced approximately 952 mm apart. Between posts 5 and 9 the post spacing was approximately 1905 mm. The posts were spaced approximately 1905 mm apart in the LET end anchorage system. Posts 1 and 2 were W150 × 37 steel posts, approximately 2591 mm in length, and embedded approximately 1838 mm below grade. Posts 3 through 6 were W150 × 22 steel posts, and 2134 mm in length. Posts 3, 4, 5, and 6 were embedded below grade approximately 1381 mm, 1355 mm, 1406 mm, and 1406 mm, respectively. Posts 7 through 9 were W150 × 13.5 steel posts, approximately 1830 mm in length, and embedded approximately 1100 mm below grade.

Wood blockouts were used at posts 1 through 13. Wood blockouts were not required for posts 14 and 15. For posts 1 through 4, 150-mm × 200-mm × 457-mm long wood blocks were used between the guardrail and posts. At posts 5 and 6, 150-mm × 200-mm × 356-mm long wood blockouts were used between the guardrail and posts. For posts 7 through 9, 150-mm × 200-mm × 356-mm routed wood blockouts were used between the guardrail and posts. Posts 1–4 used two 16-mm-diameter by 255-mm-long guardrail bolts and nuts to secure the guardrail and blockout to each post. In addition, posts 5–9 used one 16-mm-diameter by 255-mm-long guardrail bolt and nut to secure the guardrail and blockout to each post. Longer 16-mm-diameter bolts (460 mm) were used for the wood posts in the LET end anchorage system. All posts were embedded in compacted *NCHRP Report 350* standard soil with the moisture content within 4% +/- of optimum moisture content of the material. Additional detail drawings are shown on pages 2 and 3 of figure 42. Photographs of the completed test installation are shown in figure 43.

Soil and Weather Conditions

The crash test was performed the morning of May 16, 2000. Seven days prior to the test 38 mm of rainfall was recorded, and four days prior to the test 10 mm of rainfall was recorded. Soil moisture content was 5.6 percent, 7.0 percent, and 8.6 percent at posts 1, 3, and 5, respectively. Weather conditions at the time of testing were as follows: wind speed: 24 km/h; wind direction: 15 degrees with respect to the vehicle (vehicle was traveling in a southeasterly direction); temperature: 32EC; relative humidity: 55 percent.



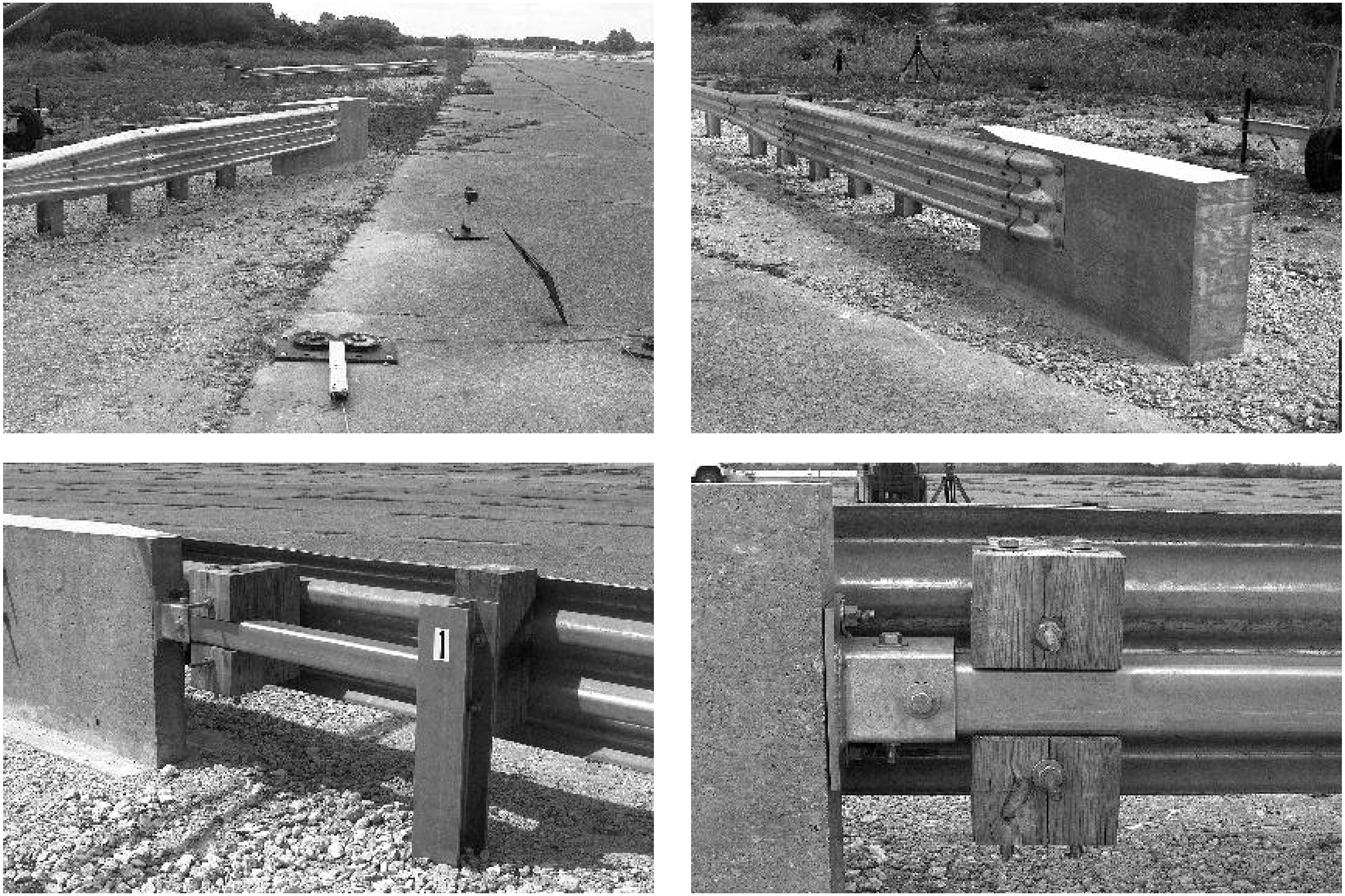


Figure 43. Nebraska thrie beam transition prior to test 404211-7.

Test Vehicle

A 1995 Chevrolet 2500 pickup truck, shown in figure 44, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2075 kg. The height to the lower edge of the vehicle front bumper was 370 mm and to the upper edge of the front bumper was 590 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 86.

Impact Description

The 2000P vehicle traveling at 99.6 km/h impacted the transition 1.93 m from the end of the parapet at an impact angle of 24.6 degrees. Shortly after impact, posts 1 and 2 moved. At 0.022 s the left front wheel steered away from the rail and the vehicle began to redirect. At 0.027 s post 3 moved. The left front tire was traveling parallel with the rail at 0.037 s and began to angle under the rail element at 0.039 s. At 0.066 s movement was noted in the concrete parapet and at 0.095 s the left front tire contacted the end of the parapet. The dummy’s head contacted the door glass at 0.120 s, but the glass did not break. The vehicle became parallel with the rail at 0.174 s and was traveling at a speed of 8l.6 km/h. The left rear of the vehicle impacted the rail at 0.186 s. At 0.298 s the vehicle lost contact with the transition and was traveling 78.3 km/h and an exit angle of 6.8 degrees. As the vehicle exited the transition both rear wheels were airborne. The left rear tire touched ground at 0.657 s. Brakes on the vehicle were applied at 1.75 s after impact, the vehicle yawed counterclockwise, and subsequently came to rest 75 m downstream from impact and 6 m forward of the front face of the transition. Sequential photographs of the test period are shown in appendix C, figures 106 and 107.

Damage to Test Article

The Nebraska thrie beam transition sustained minimal damage as shown in figure 45. No movement was noted in the end terminal. Posts 4 and 5 were disturbed, post 3 moved rearward 4 mm, and post 2 was pushed rearward 20 mm. The corner of the blockout at post 1 was missing and the post was pushed back 15 mm. The pipe spacer between the parapet and rail element was crushed 25 mm and the parapet base was disturbed 2 mm. Tire marks were on the flare of the parapet and cracks in the end of the parapet radiated from the bolts connecting the thrie beam. Length of contact of the vehicle with the transition was 3.07 m. Maximum dynamic deflection of the rail element during the test was 82 mm and maximum permanent deformation was 24 mm, both occurring at post 2.

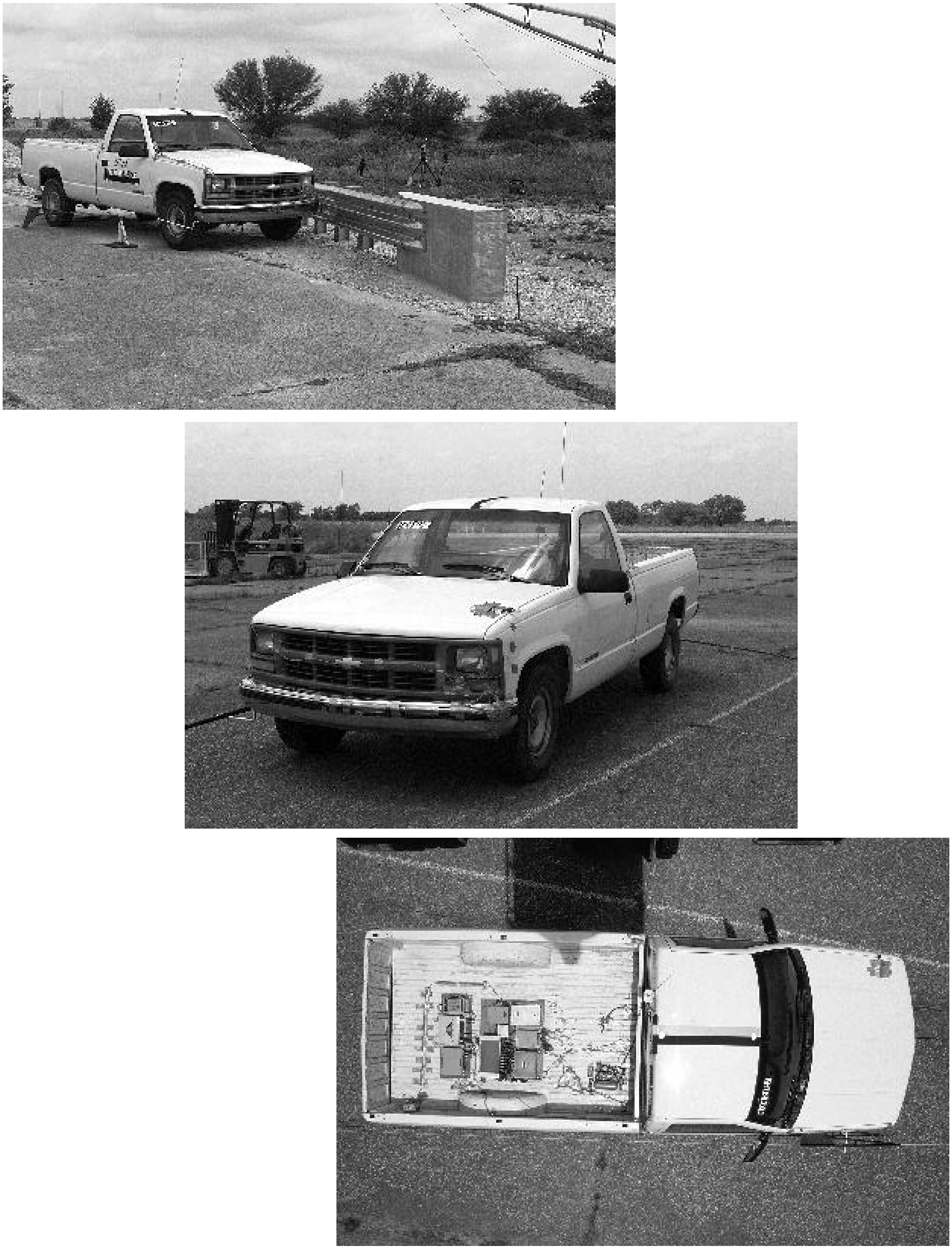


Figure 44. Vehicle before test 404211-7.

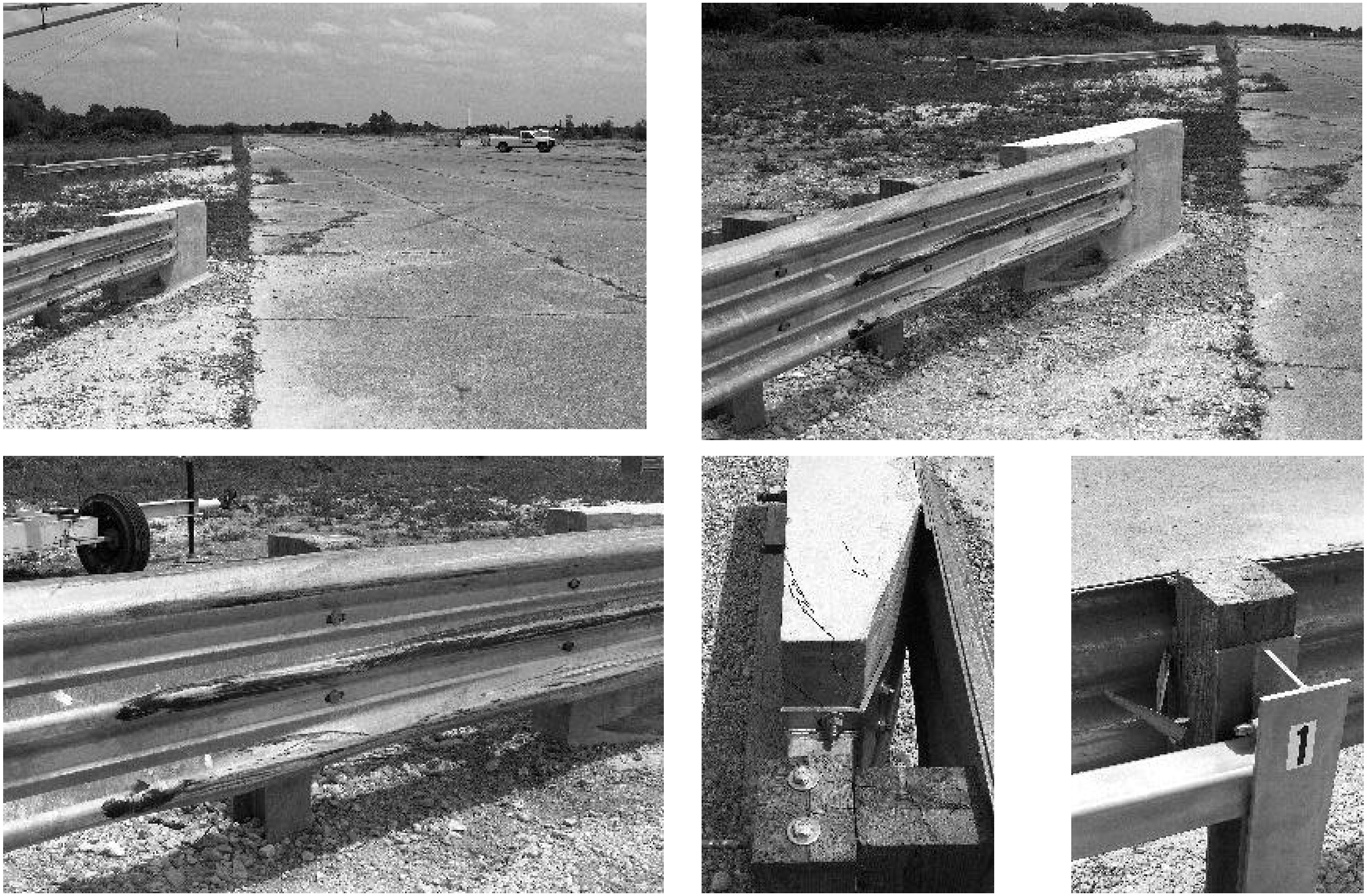


Figure 45. Installation after test 404211-7.

Vehicle Damage

Moderate damage was imparted to the 2000P vehicle as shown in figure 46. The following vehicle components received structural damage: the frame at the left front, steering arm, stabilizer bar, left side rod ends, left upper and lower A-arms, and left front spindle, rotor and tire. Also damaged were the front bumper, fan, radiator, left front quarter-panel, left door, left side of the bed, and the left rear rim. The floor pan and firewall were deformed and the seam where the floor pan and firewall connect were separated. Maximum exterior crush to the left front corner was 400 mm. Maximum interior deformation was 129 mm at the left side floor pan area. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 39 and 40.

Occupant Risk Factors

In the longitudinal direction, occupant impact velocity was 5.0 m/s at 0.100 s, maximum 0.010-s ridedown acceleration was -13.9 g's from 0.114 to 0.124 s, and the maximum 0.050-s average was -8.2 g's between 0.050 and 0.100 s. In the lateral direction, the occupant impact velocity was 8.1 m/s at 0.100 s, the highest 0.010-s occupant ridedown acceleration was 11.9 g's from 0.114 to 0.124 s, and the maximum 0.050-s average was 12.5 g's between 0.050 and 0.100 s. These data and other information pertinent to the test are presented in figure 47. Vehicle angular displacements are presented in appendix D, figure 125, and accelerations versus time traces are shown in appendix E, figures 202 through 212.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

- **Structural Adequacy**

  i. *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.*

  Result: The Nebraska thrie beam transition contained and redirected the vehicle with minimal deformation of the rail element. The 2000P vehicle did not penetrate, underride, or override the installation.

- **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*

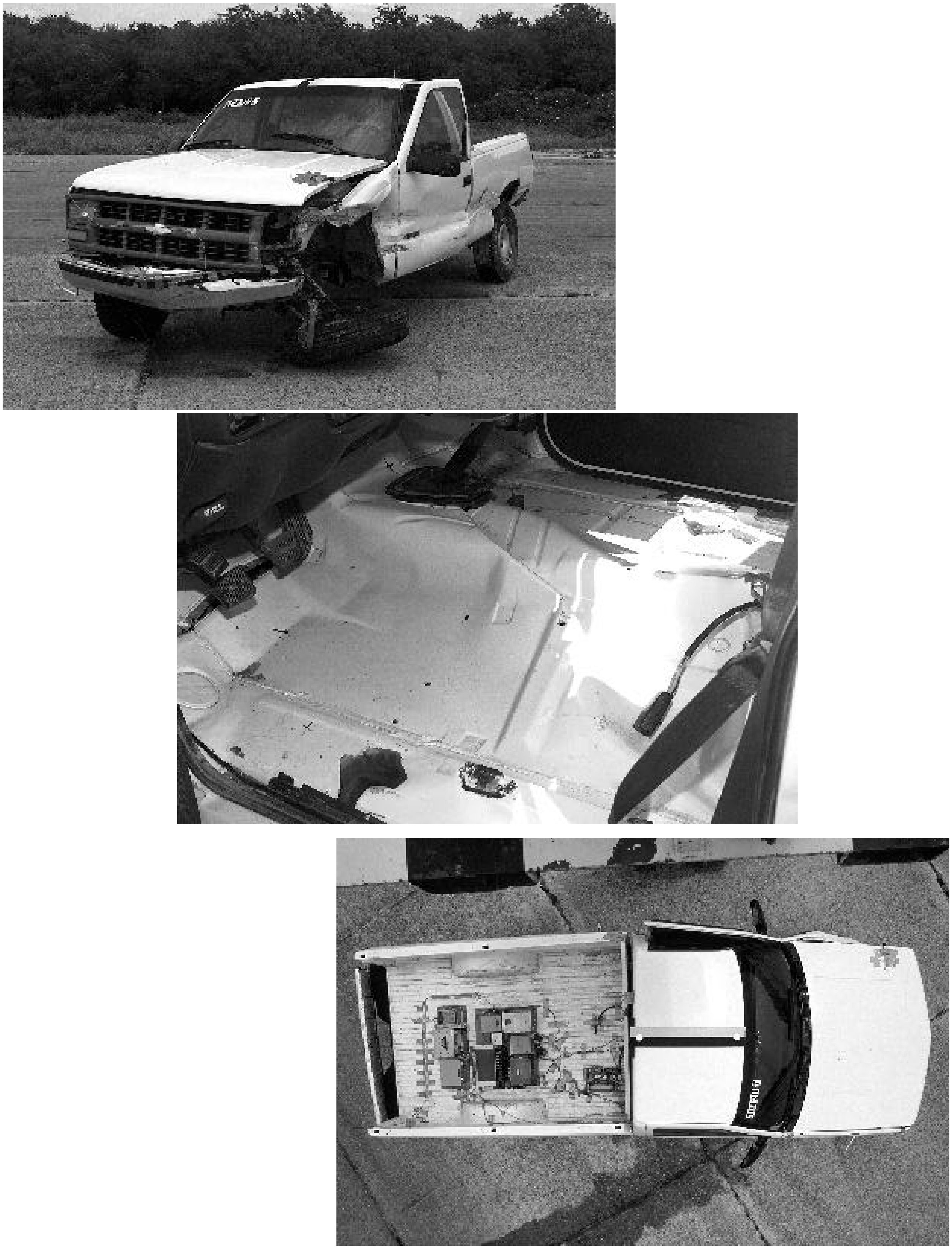
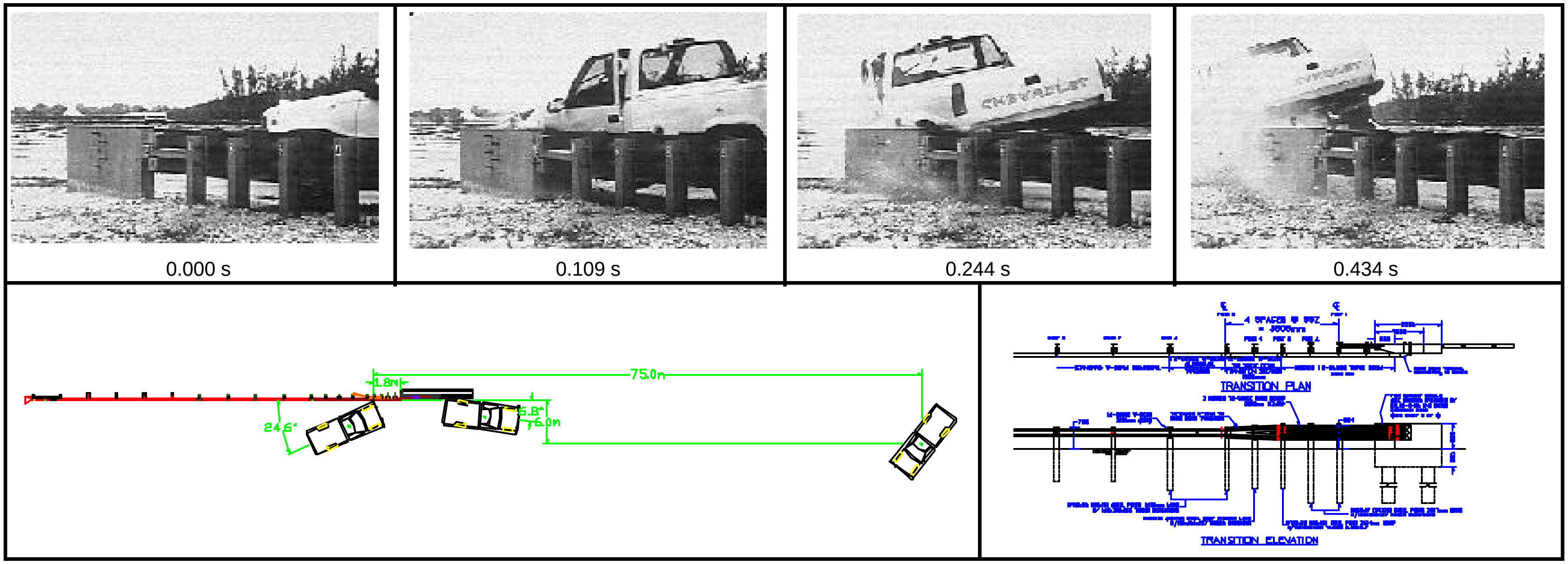


Figure 46. Vehicle after test 404211-7.



General Information

Test Agency	Texas Transportation Institute
Test No.	404211-7
Date	05/17/00

Test Article

Type	Transition
Name	Nebraska Thrie Beam Transition
Installation Length (m)	22.2
Material or Key Elements	Nested Thrie Beam on Steel Posts with Wood Blockouts

Soil Type and Condition . Standard Soil, Dry

Test Vehicle

Type	Production
Designation	2000P
Model	1995 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1932
Test Inertial	2000
Dummy	75
Gross Static	2075

Impact Conditions

Speed (km/h)	99.6
Angle (deg)	24.6

Exit Conditions

Speed (km/h)	78.3
Angle (deg)	6.8

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	5.0
y-direction	8.1
THIV (km/h)	33.0
Ridedown Accelerations (g's)	
x-direction	-13.9
y-direction	11.9
PHD (g's)	18.8
ASI	1.82
Max. 0.050-s Average (g's)	
x-direction	-8.2
y-direction	12.5
z-direction	-11.2

Test Article Deflections (m)

Dynamic	0.08
Permanent	0.02

Vehicle Damage

Exterior	
VDS	11LFQ4
CDC	11FLEK3 & 11LDEW3
Maximum Exterior Vehicle Crush (mm)	400
Interior	
OCDI	FS02000000
Max. Occ. Compart. Deformation (mm)	129

Post-Impact Behavior

(during 1.0 s after impact)	
Max. Yaw Angle (deg)	41
Max. Pitch Angle (deg)	-5
Max. Roll Angle (deg)	-23

Figure 47. Summary of results for Nebraska Transition test, *NCHRP Report 350* test 3-21.

present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

Result: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. The floor pan and firewall were deformed and the seam where the floor pan meets the firewall was separated. Maximum occupant compartment deformation was 129 mm and damage to the interior was judged to not cause serious injury.

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

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

! **Vehicle Trajectory**

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

Result: Intrusion into adjacent traffic lanes was minimal, i.e., the vehicle came to rest 6 m forward from the face of the transition.

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.*

Result: Longitudinal occupant impact velocity was 5.0 m/s and longitudinal ridedown acceleration was -13.9 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: Exit angle at loss of contact was 6.8 degrees, which was 28 percent of the impact angle.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— **PASSENGER COMPARTMENT INTRUSION**

1. Windshield Intrusion

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

2. Body Panel Intrusion yes or (no)

— **LOSS OF VEHICLE CONTROL**

(1.) Physical loss of control

2. Loss of windshield visibility

3. Perceived threat to other vehicles

4. Debris on pavement

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

1. Harmful debris that could injure workers or others in the area

2. Harmful debris that could injure occupants in other vehicles

No debris present.

— **VEHICLE AND DEVICE CONDITION**

1. Vehicle Damage

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

2. Windshield Damage

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

3. Device Damage

- a. None
- (b.) Superficial (rail element)
- c. Substantial, but can be straightened
- (d.) Substantial, replacement parts needed for repair (parapet)
- e. Cannot be repaired

CONNECTICUT TRANSITION
(*NCHRP REPORT 350* TEST NO. 3-21)

Test Conditions

NCHRP Report 350 test designation 3-21 was performed on the Connecticut transition. The BARRIER VII program indicated the CIP to be 2.0 m from the end of the concrete parapet.

Test Article

The Connecticut R-B 350 guiderail transition consists of 3810 mm of two nested W-beam guardrails blocked out from the end of the parapet using a 150-mm-diameter spacer pipe followed by 3810 mm of single W-beam guardrail. In addition, the transition incorporates a “flared-back” C150 rubrail and a 100-mm-high asphalt curb. The height of the W-beam guardrail used in this transition was approximately 706 mm from the pavement surface. The height of the rubrail from the pavement surface was approximately 305 mm. TTI received a drawing from Connecticut DOT entitled “Standard R-B 350 Bridge Attachment, Drawing Number M910.04.” TTI incorporated the details provided from this drawing to construct the field test installation for this project. TTI received all the hardware to construct this transition from Trinity Industries, Fort Worth, Texas.

TTI constructed 5 m of Connecticut Jersey shape barrier from details provided to TTI by ConnDOT. This barrier was 815 mm in height and 580 mm in width at the base and transitioned to 300 mm in width at the top of the parapet. The parapet was anchored below grade by a 580-mm-wide footing embedded 1895 mm below grade and extended the full length of the parapet. Vertical reinforcement for the parapet consisted of #16 “U-Shaped” Bars spaced at 300 mm on centers. Longitudinal reinforcement in the parapet consisted of eight #16 longitudinal reinforcing bars. The end of the parapet was constructed with a 2.5(H) to 1.0(V) taper at the top. The concrete used to construct the concrete parapet had an average concrete compressive strength of 4483 psi 30 days after construction.

The transition was attached to the concrete parapet with a 10-gauge W-beam terminal connector attached to the parapet using five 22-mm-diameter ASTM A449 fully threaded rods. These threaded rods were 300 mm long and were chemically anchored inside 25-mm-diameter holes drilled into the parapet. The end of the terminal connector was located approximately 2150 mm from the end of the parapet. The rubrail was attached to the parapet using three 16-mm-diameter ASTM A449 fully threaded rods. These threaded rods used for the rubrail were 150 mm long and were chemically anchored inside 19-mm-diameter holes drilled into the parapet. The end of the rubrail was located approximately 1291 mm from the end of the parapet.

The first two posts (posts 1 and 2) used in the transition were two W200x19 steel posts. These posts were each 2290 mm in length. Posts 1 and 2 were embedded approximately 1560 mm below grade. The remaining posts used in the transition (posts 3 through 9) and the posts used for the guardrail length of need were W150x13 steel posts, 1830 mm in length. These posts were embedded approximately 1100 mm below grade. Post 1 was located approximately 300 mm from the end of the concrete parapet. Between posts 1 and 5, the posts were spaced approximately 476 mm apart. Between posts 5 and 9, the posts were spaced approximately 952 mm apart. Between posts 9 and 13 (W-beam guardrail length of need), the posts were spaced 1905 mm apart. A LET guardrail end treatment was used beyond the length of need to anchor and protect the end of the W-beam guardrail.

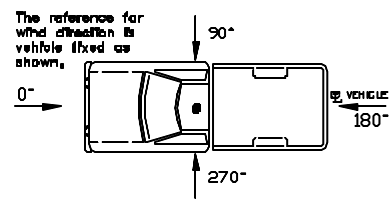
The W-beam guardrail was blocked out from the concrete parapet at approximately 145 mm from the end of the parapet with a 150 mm diameter, schedule 40 steel spacer tube, 230 mm in length. The W-beam guardrail was blocked out from the steel posts with 150 mm x 200 mm routed wood blocks, 360 mm in length.

The rubrail used consisted of a two-piece rubrail mounted 230 mm from the pavement surface to the rubrail centerline. The smaller rubrail piece, which connected to the concrete parapet, was fabricated from C150x12 steel channel approximately 1595 mm in length. This portion of the rubrail extended from the connection of the concrete parapet to post 1. At post 1, the rubrail was spliced using a bent plate rubrail that extended from post 1 to the field side face of post 6. The rubrail was blocked out from the concrete parapet at approximately 134 mm from the end of the parapet with a sloped 114-mm-long by 90-mm-wide wood block. This block was sloped to match the shape of the concrete parapet. At posts 1 through 4, 180-mm-long by 100-mm-wide wood blocks were used to block out the rubrail from the steel posts. The thickness of these blockouts varied from 108 mm to 25 mm between posts 1 through 4 due to the flaring back of the rubrail. No blockout was required at post 5. The rubrail flared behind post 6 and was not attached.

An asphalt curb was constructed as part of this transition installation. The curb was 100 mm in height, 180 mm wide at the base, and 75 mm at the top. The curb was constructed with an 80-mm sloped face. The base of the curb was constructed flush with the base of the parapet and sloped toward the roadway on a 20(H) to 1(V) slope until the face of the curb was even with the face of the W-beam guardrail. The face of the curb remained even with the guardrail for the remainder of the curb installation. Detailed drawings are provided in figure 48. Photographs of the completed installation as tested are shown in figure 49.

Soil and Weather Conditions

The crash test was performed the morning of April 6, 2000. Eight days before the test 10 mm of rainfall was recorded and a total of 33 mm of rainfall was recorded four days prior to the test. Moisture content of the *NCHRP Report 350* standard soil in which the transition was installed was 5.5 percent, 9.0 percent, and 9.8 percent at posts 1, 3, and 5, respectively. Weather conditions at the time of testing were as follows: wind speed: 11 km/h; wind direction: 85 degrees with respect to the vehicle (vehicle was traveling in an easterly direction); temperature: 22EC; relative humidity: 55 percent.



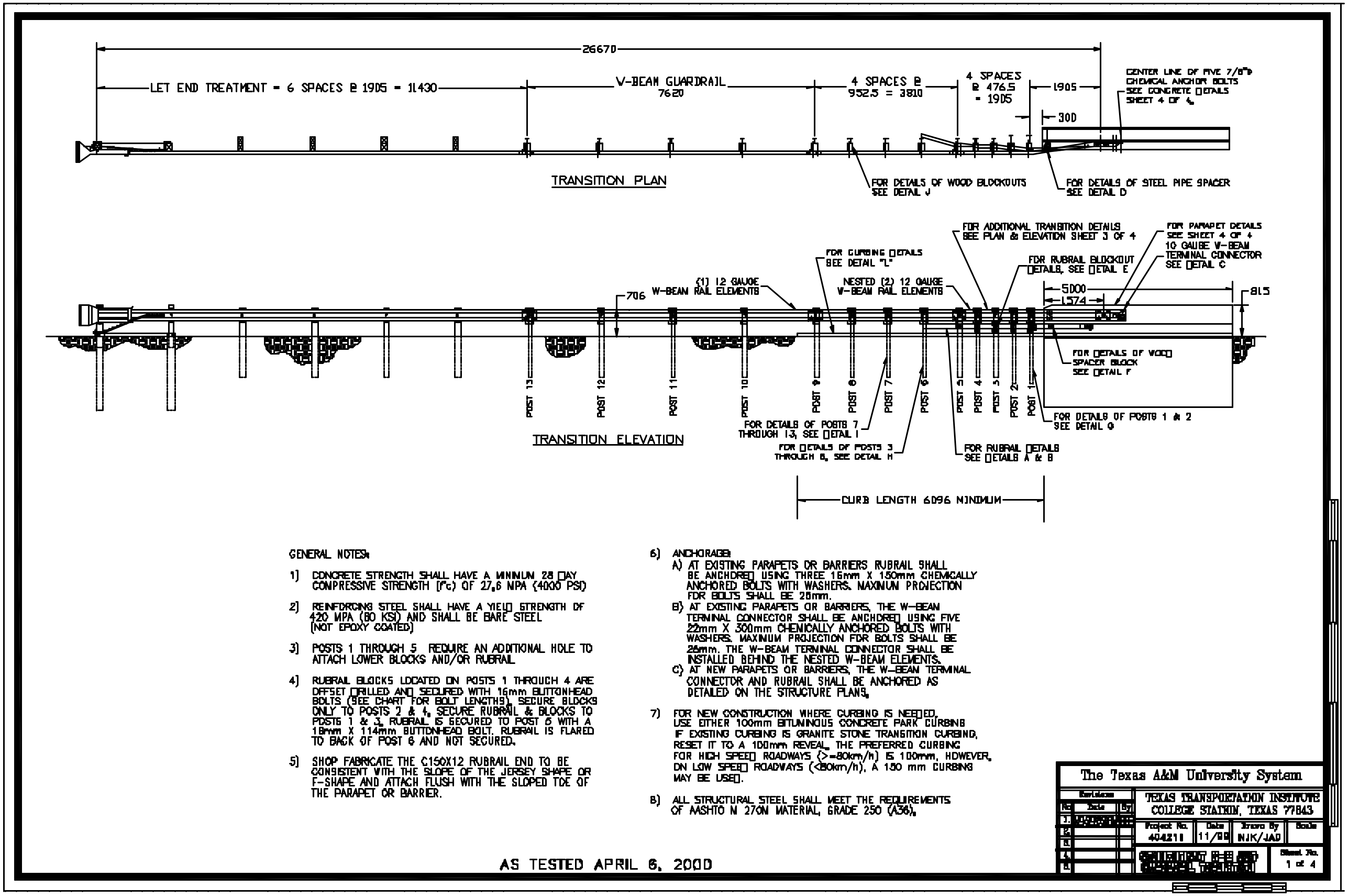


Figure 48. Details of the Connecticut transition installation for test 404211-9.

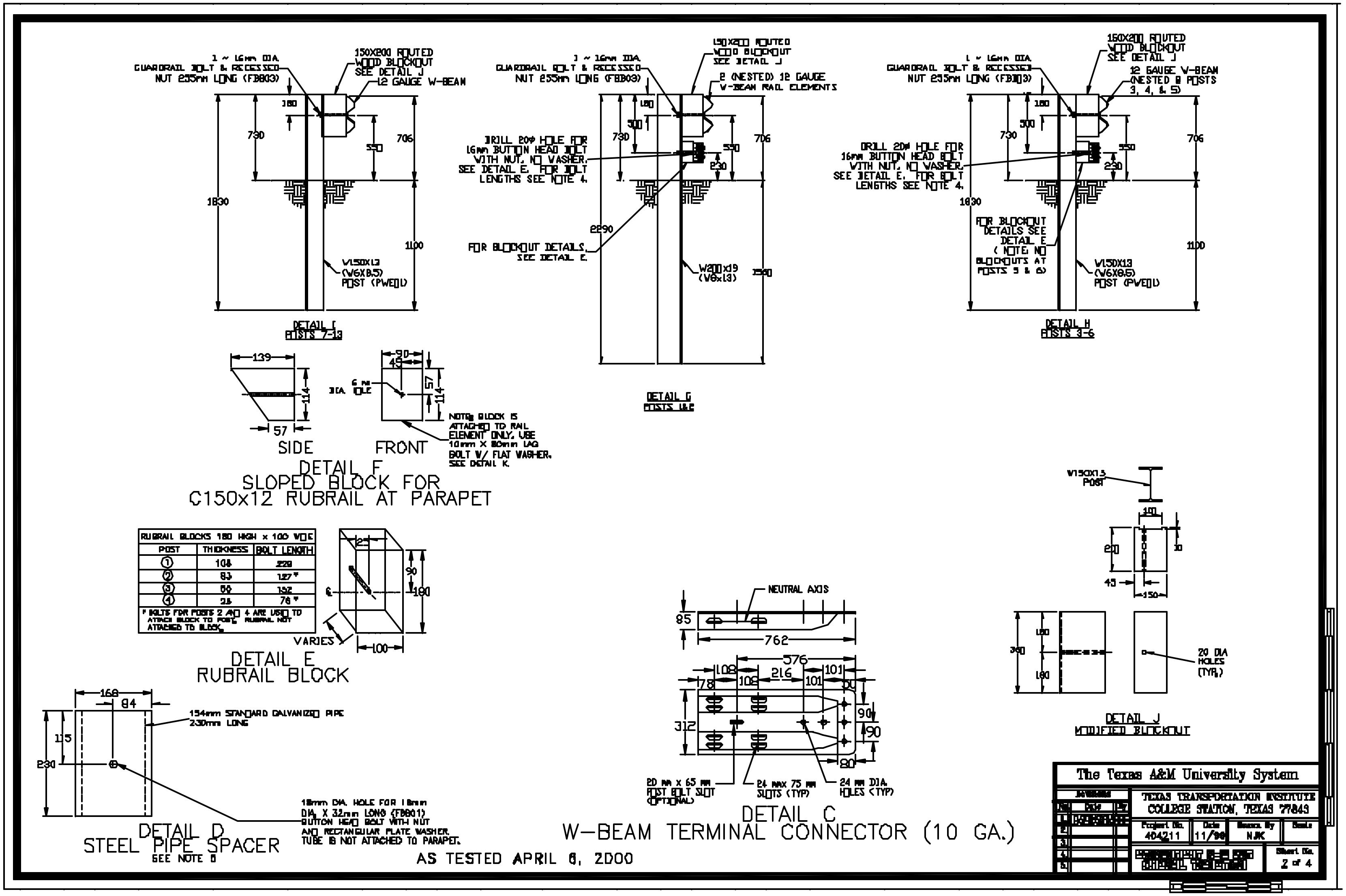


Figure 48. Details of the Connecticut transition installation for test 404211-9 (continued).

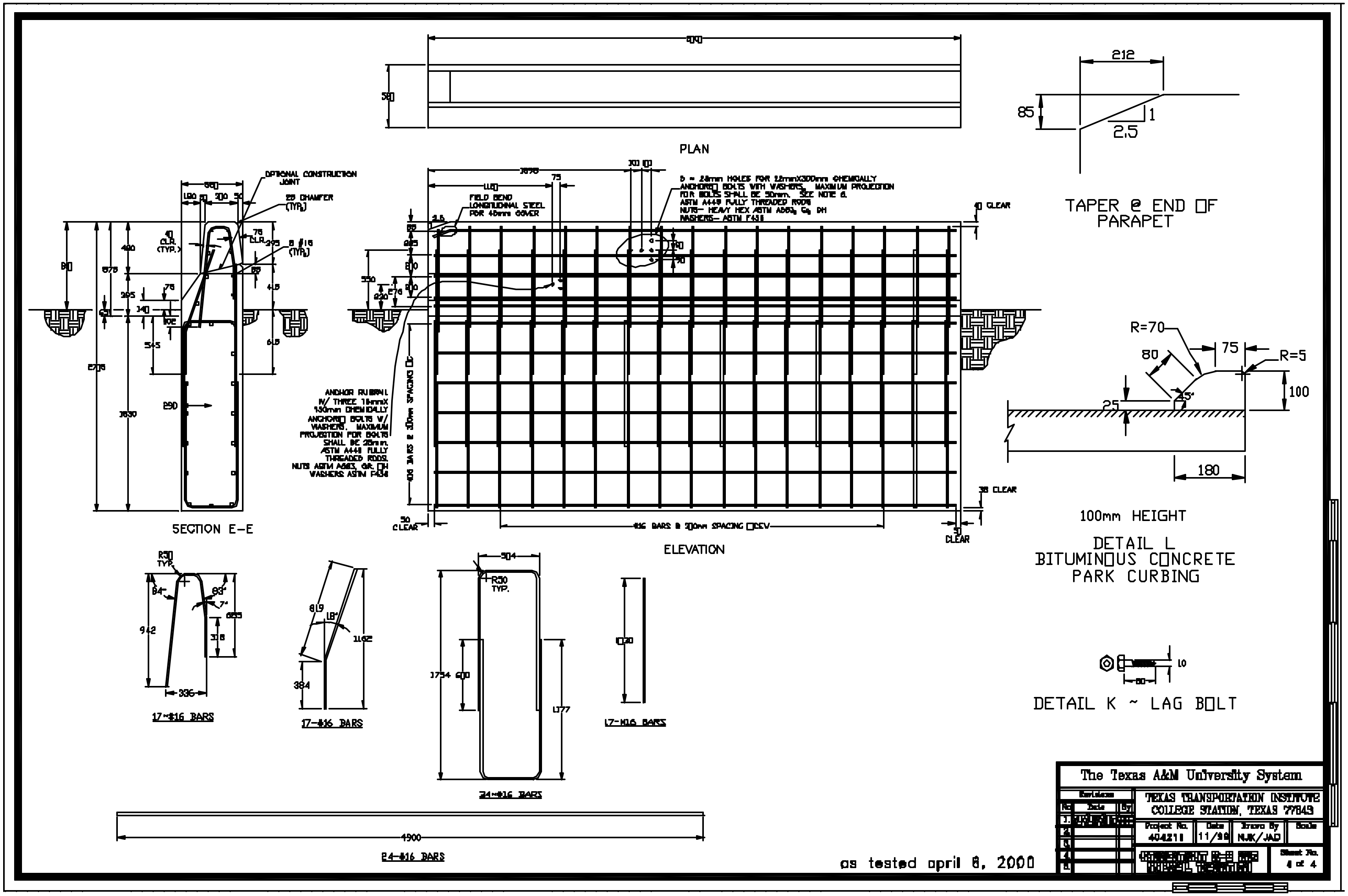


Figure 48. Details of the Connecticut transition installation for test 404211-9 (continued).

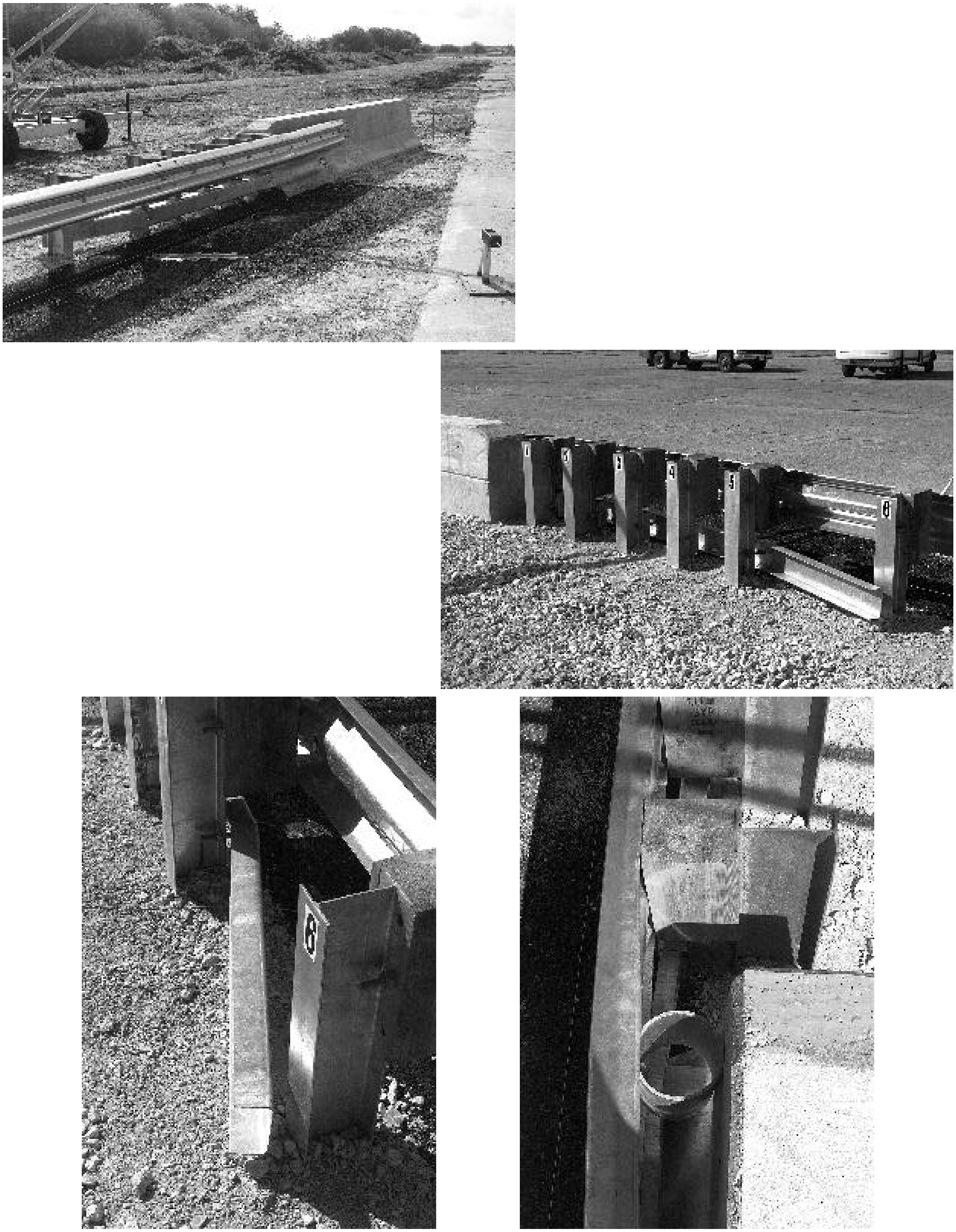


Figure 49. Connecticut transition prior to test 404211-9.

Test Vehicle

A 1995 Chevrolet 2500 pickup truck, shown in figure 50, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2075 kg. The height to the lower edge of the vehicle front bumper was 370 mm and to the upper edge of the front bumper was 590 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 87.

Impact Description

The 2000P pickup truck, traveling at 100.8 km/h, impacted the Connecticut transition 1.96 m from the end of the concrete parapet at a 25.6-degree angle. Shortly after impact, the left front tire contacted the rubrail. The left and right front wheels steered away from the rail element at 0.029 s and the vehicle began to redirect at 0.051 s. The dummy contacted the driver's side window, and the window glass shattered at 0.099 s. By 0.106 s, the right front tire lost contact with the ground, and by 0.175 s, the rear left side of the vehicle contacted the rail element. At 0.186 s, the vehicle was traveling parallel with the transition at a speed of 80.3 km/h, and at 0.187 s, the right rear tire lost contact with the ground. The left rear tire lost contact with the ground at 0.285 s. The vehicle lost contact with the transition at 0.299 s, and was traveling at a speed of 77.0 km/h and an exit angle of 3.7 degrees. The left rear, right front, and right rear tires returned to the ground surface at 0.858 s, 0.920 s, and 0.933 s, respectively. Brakes on the vehicle were applied at 1.55 s, the vehicle yawed clockwise and subsequently came to rest 61.7 m down from impact and 27.4 m laterally from the traffic face of the rail. Sequential photographs of the test period are shown in appendix C, figures 108 and 109.

Damage to Test Article

Moderate damage was imparted to the transition as shown in figure 51. Tire marks were on the face of the W-beam rail element and rub rail and both were deformed. The blockouts at posts 2 and 3 were rotated and the blockout at post 4 was fractured on one corner. The pipe insert was crushed 10 mm. The lower bolt on the connection to the parapet was partially pulled out. No movement was noted in the end terminal. Maximum dynamic deflection of the W-beam rail element was 77 mm. Maximum permanent rail deformation of the W-beam rail element was 68 mm at post 2 and the rubrail was deformed 45 mm at post 2. The length of contact with the transition was 2.9 m.

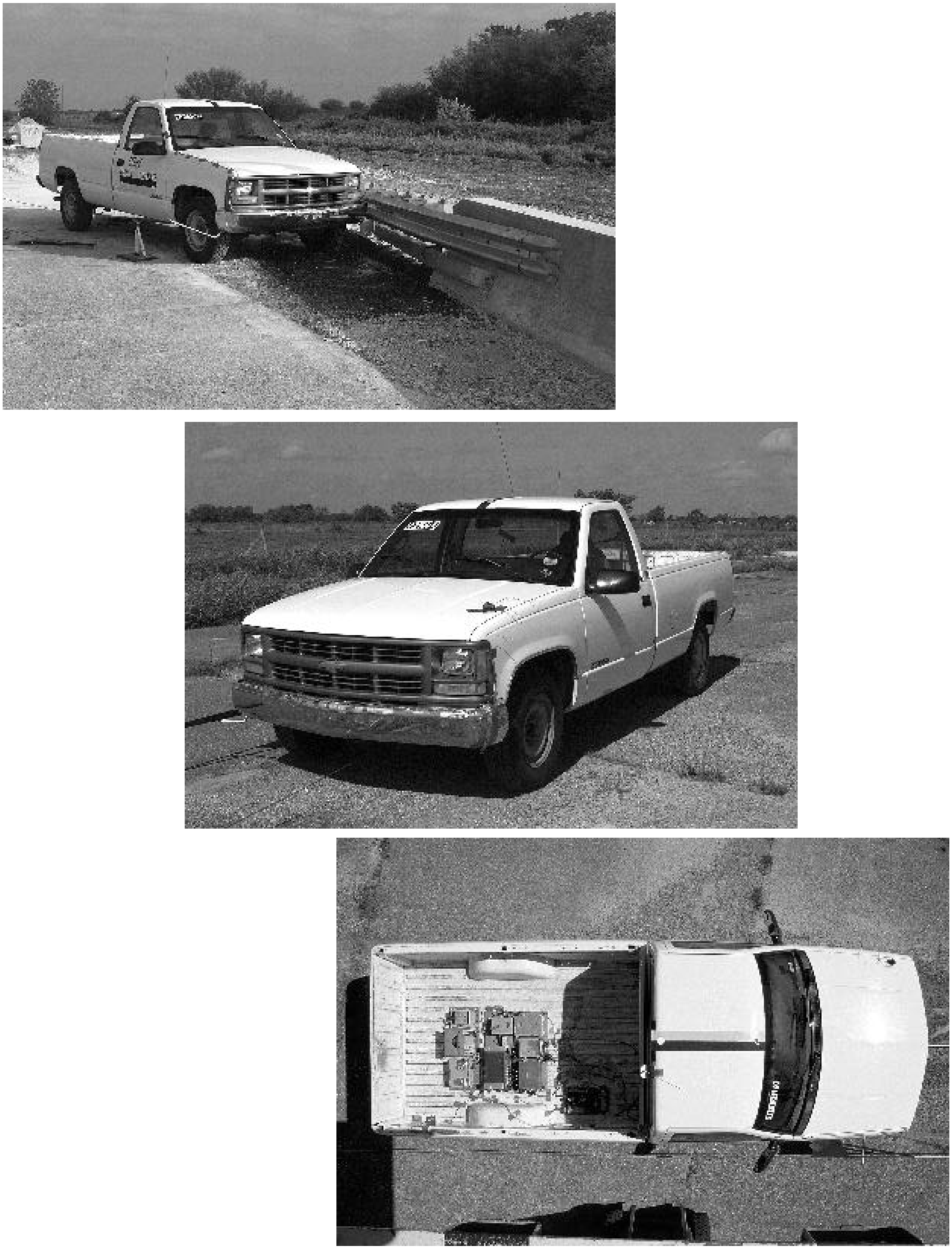


Figure 50. Vehicle before test 404211-9.

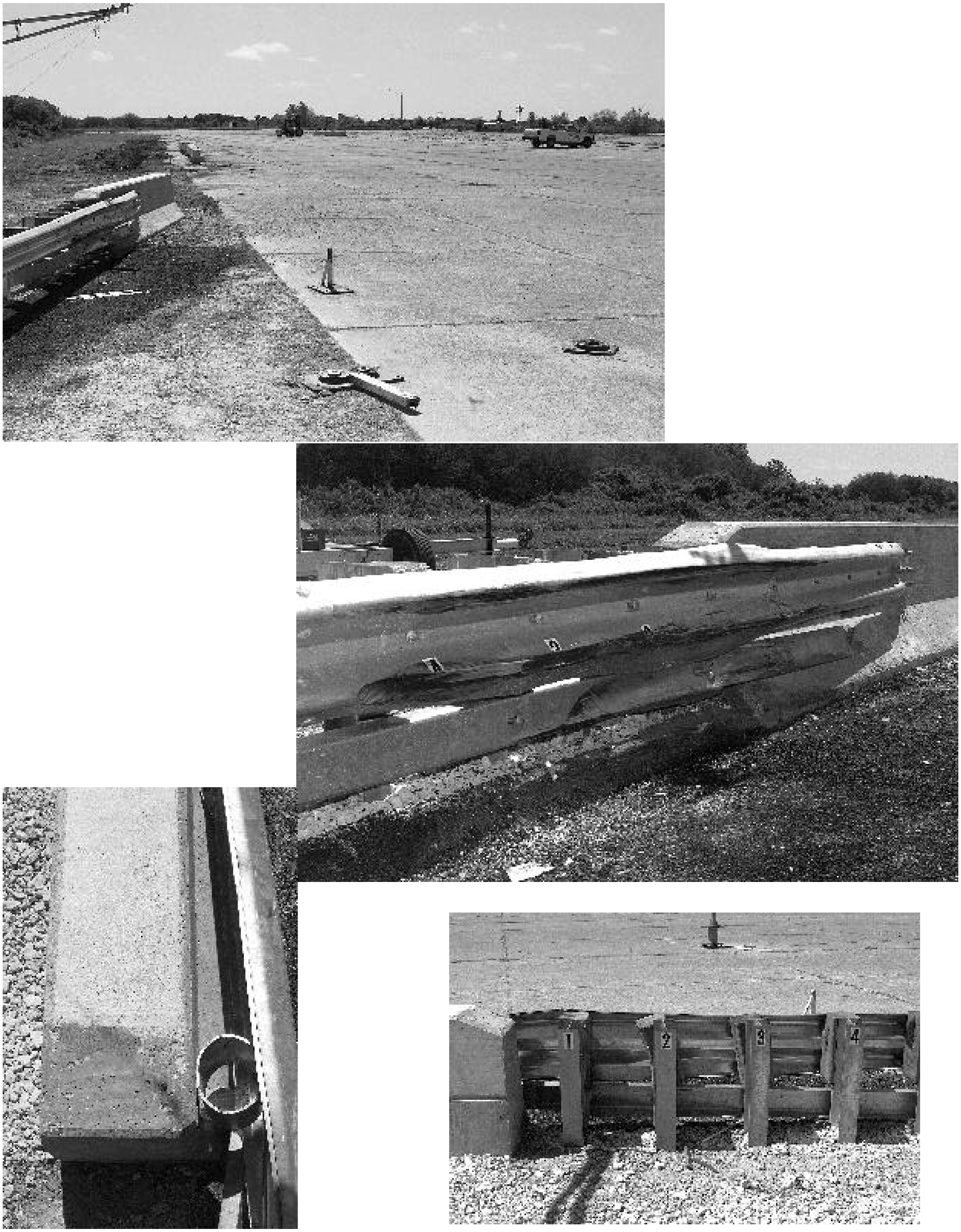


Figure 51. Installation after test 404211-9.

Vehicle Damage

The vehicle sustained structural damage to the left front as shown in figure 52. Structural damage included the left front of the frame, left upper and lower A-arms, left inner and outer tie rods, steering arm, stabilizer bar, floor pan, and firewall. Also damaged were the front bumper, hood, grill, fan, radiator, left front quarter panel, left door, left rear quarter panel, and the left front tire and wheel rim. The windshield sustained stress cracks. Maximum exterior crush of the vehicle was 430 mm at the left front corner at bumper height. The maximum deformation of the occupant compartment was 130 mm in the center floor pan area and 124 mm in the center firewall area. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 41 and 42.

Occupant Risk Factors

In the longitudinal direction, occupant impact velocity was 4.9 m/s at 0.099 s, maximum 0.010-s ridedown acceleration was -11.4 g's from 0.103 to 0.113 s, and the maximum 0.050-s average was -10.1 g's between 0.040 and 0.090 s. In the lateral direction, the occupant impact velocity was 7.0 m/s at 0.099 s, the highest 0.010-s occupant ridedown acceleration was 17.2 g's from 0.212 to 0.222 s, and the maximum 0.050-s average was 12.6 g's between 0.026 and 0.076 s. These data and other information pertinent to the test are presented in figure 53. Vehicle angular displacements are presented in appendix D, figure 126, and accelerations versus time traces are shown in appendix E, figures 213 through 223.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

- **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.*

  Result: The Connecticut transition contained and redirected the 2000P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum lateral deflection was 77 mm.

- **Occupant Risk**

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

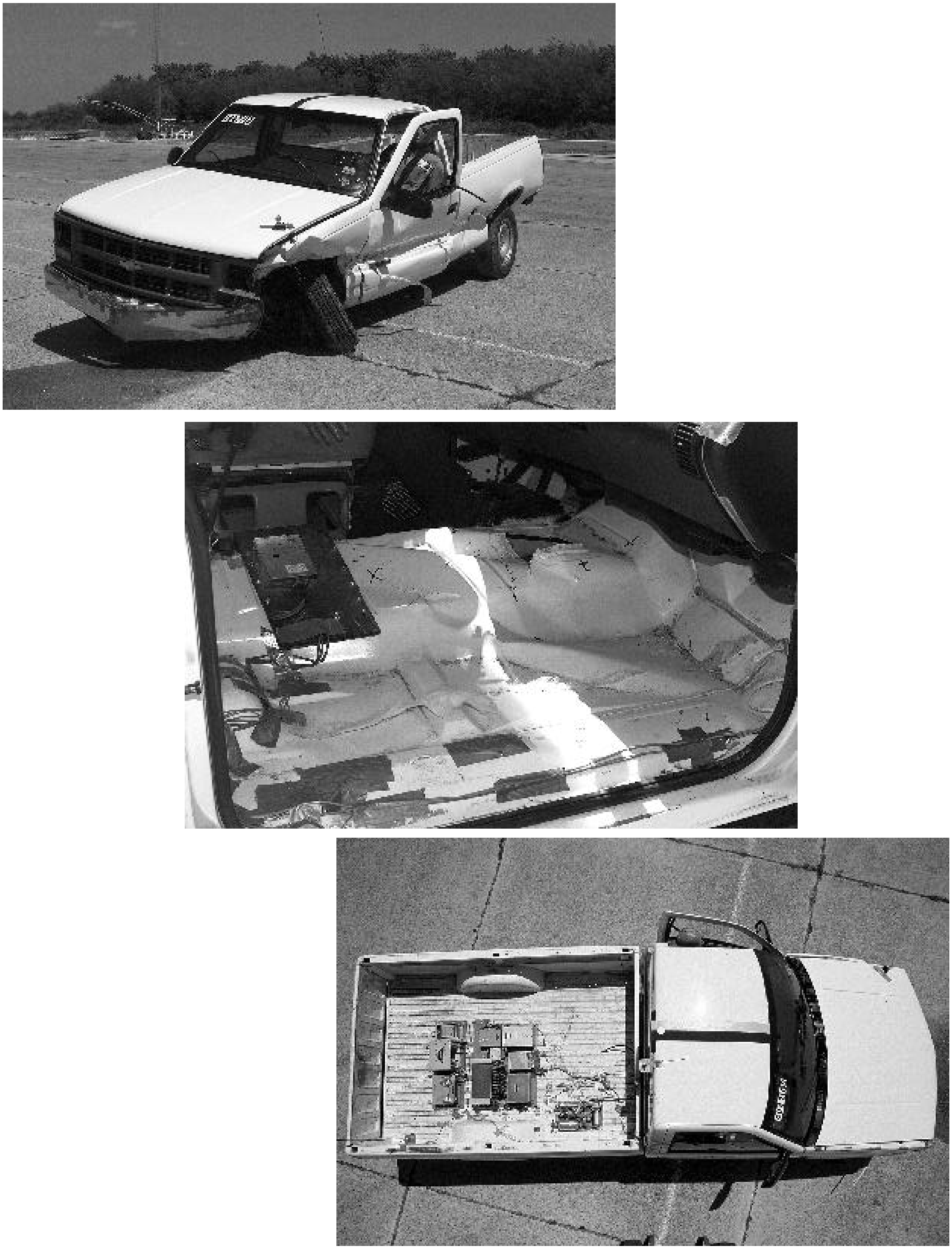
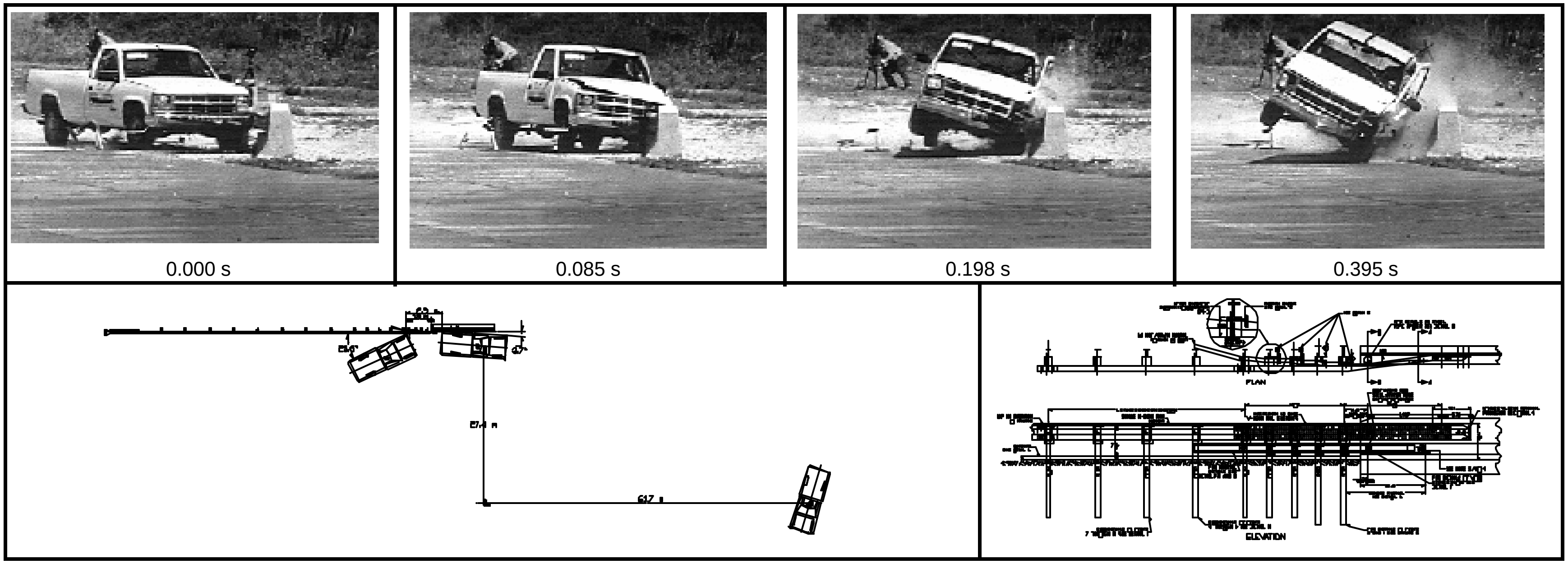


Figure 52. Vehicle after test 404211-9.



General Information

Test Agency	Texas Transportation Institute
Test No.	404211-9
Date	04/06/00

Test Article

Type	Transition
Name	Connecticut Transition
Installation Length (m)	26.7
Material or Key Elements	W-beam Rail with Rubrail Attached to Connecticut Jersey Shape Parapet

Soil Type and Condition . Standard Soil, Dry

Test Vehicle

Type	Production
Designation	2000P
Model	1995 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1940
Test Inertial	2000
Dummy	75
Gross Static	2075

Impact Conditions

Speed (km/h)	100.8
Angle (deg)	25.6

Exit Conditions

Speed (km/h)	77.0
Angle (deg)	3.7

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	4.9
y-direction	7.0
THIV (km/h)	31.0
Ridedown Accelerations (g's)	
x-direction	-11.4
y-direction	17.2
PHD (g's)	18.6
ASI	1.68
Max. 0.050-s Average (g's)	
x-direction	-10.1
y-direction	12.6
z-direction	-7.0

Test Article Deflections (m)

Dynamic	0.077
Permanent	0.068

Vehicle Damage

Exterior	
VDS	11LFQ4
CDC	11FLEK3 & 11LDEW3
Maximum Exterior Vehicle Crush (mm)	430
Interior	
OCDI	LF0212100
Max. Occ. Compart. Deformation (mm)	130

Post-Impact Behavior

(during 1.0 s after impact)

Max. Yaw Angle (deg)	35
Max. Pitch Angle (deg)	-7
Max. Roll Angle (deg)	-28

Figure 53. Summary of results for the Connecticut Transition test, *NCHRP Report 350* test 3-21.

Result: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 130 mm in the center floor pan area and was judged to not cause serious injury.

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

Result: The 2000P vehicle remained upright during and after the collision period.

! **Vehicle Trajectory**

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

Result: The 2000P vehicle came to rest 27.4 m toward traffic lanes, which indicated intrusion into adjacent traffic lanes.

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.*

Result: Longitudinal occupant impact velocity was 4.9 m/s and occupant ridedown acceleration was -11.4 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: Exit angle at loss of contact with the transition was 3.7 degrees, which was 14 percent of the impact angle.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

– **PASSENGER COMPARTMENT INTRUSION**

1. **Windshield Intrusion**

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

2. **Body Panel Intrusion** yes or (no) (circled)

— **LOSS OF VEHICLE CONTROL**

1. Physical loss of control

2. Loss of windshield visibility

3. Perceived threat to other vehicles (circled)

4. Debris on pavement

After loss of contact with the transition, the vehicle came to rest 27.4 m laterally from the traffic face of the rail, which indicated intrusion into adjacent traffic lanes and perceived threat to other vehicles in those lanes.

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

1. Harmful debris that could injure workers or others in the area

2. Harmful debris that could injure occupants in other vehicles

No debris was present to threaten workers or other vehicles.

— **VEHICLE AND DEVICE CONDITION**

1. Vehicle Damage

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

2. Windshield Damage

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

3. Device Damage

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

LONGITUDINAL BARRIERS

According to *NCHRP Report 350*, two crash tests are required for evaluation of longitudinal barriers to test level three (TL-3): 1) *NCHRP Report 350* test designation 3-10: an 820-kg passenger car impacting the CIP in the length of need of the longitudinal barrier at a nominal speed and angle of 100 km/h and 20 degrees. The purpose of this test is to evaluate the overall performance of the length of need section in general, and occupant risks in particular and 2) *NCHRP Report 350* test designation 3-11: a 2000-kg pickup truck impacting the CIP in the length of need of the longitudinal barrier at a nominal speed and angle of 100 km/h and 25 degrees. The test is intended to evaluate the strength of the section for containing and redirecting the pickup truck.

NCHRP Report 350 test 3-11 was performed on all but one of the longitudinal barriers. The modified thrie beam guardrail was tested to test level four (4-12), which included the 8000-kg single-unit truck impacting the length of need at a nominal speed and angle of 80 km/h and 15 degrees.

MB1 (WSDOT) MEDIAN CABLE BARRIER (*NCHRP REPORT 350* TEST NO. 3-11)

Test Conditions

The test performed on the Washington State DOT (WSDOT) median cable barrier corresponds to *NCHRP Report 350* test designation 3-11. The CIP for this test was determined using information contained in *NCHRP Report 350* and accordingly was determined to be at post 11.

Test Article

A 145-m-long 3-strand cable barrier was constructed for full-scale crash testing. The length of need was constructed using details of the Washington 3-strand cable barrier (figure 54) and the terminals used details of the New York Cable Terminal (figure 55). The installation was constructed on level terrain and the posts were installed in *NCHRP Report 350* standard soil. Installation height of the top cable was 770 mm from the ground surface to the top of the upper cable. The posts were S75 x 8.5 x 1.6 m and spaced 5.0 m on-center. The three cables were each 19 mm in diameter, spaced 120 mm apart and manufactured in accordance with American Association of State Highway Transportation Officials (AASHTO) M-30, Type I, Class A coating. All cable ends were fitted with open end wedge type cable socket fittings. Each cable end was attached to a standard turnbuckle assembly and bolted to a breakaway anchor angle and anchored rigidly to a concrete footing. Additionally, the last post on each end of the installation was anchored in a concrete footing and made frangible by a slip base connection. The concrete footing for the cable anchor terminal, shown on page 2 of figure 55, and the last post (each integral unit) were constructed in two units that mated together with a tongue and groove. Each unit measured 660 mm by 1005 mm at the top and tapered to 725 mm by 1150 mm at the bottom. The height of the footing along the centerline of the post and terminal was 990 mm. The tops of the terminal units were constructed on a 6:1 slope. The units were connected together by an

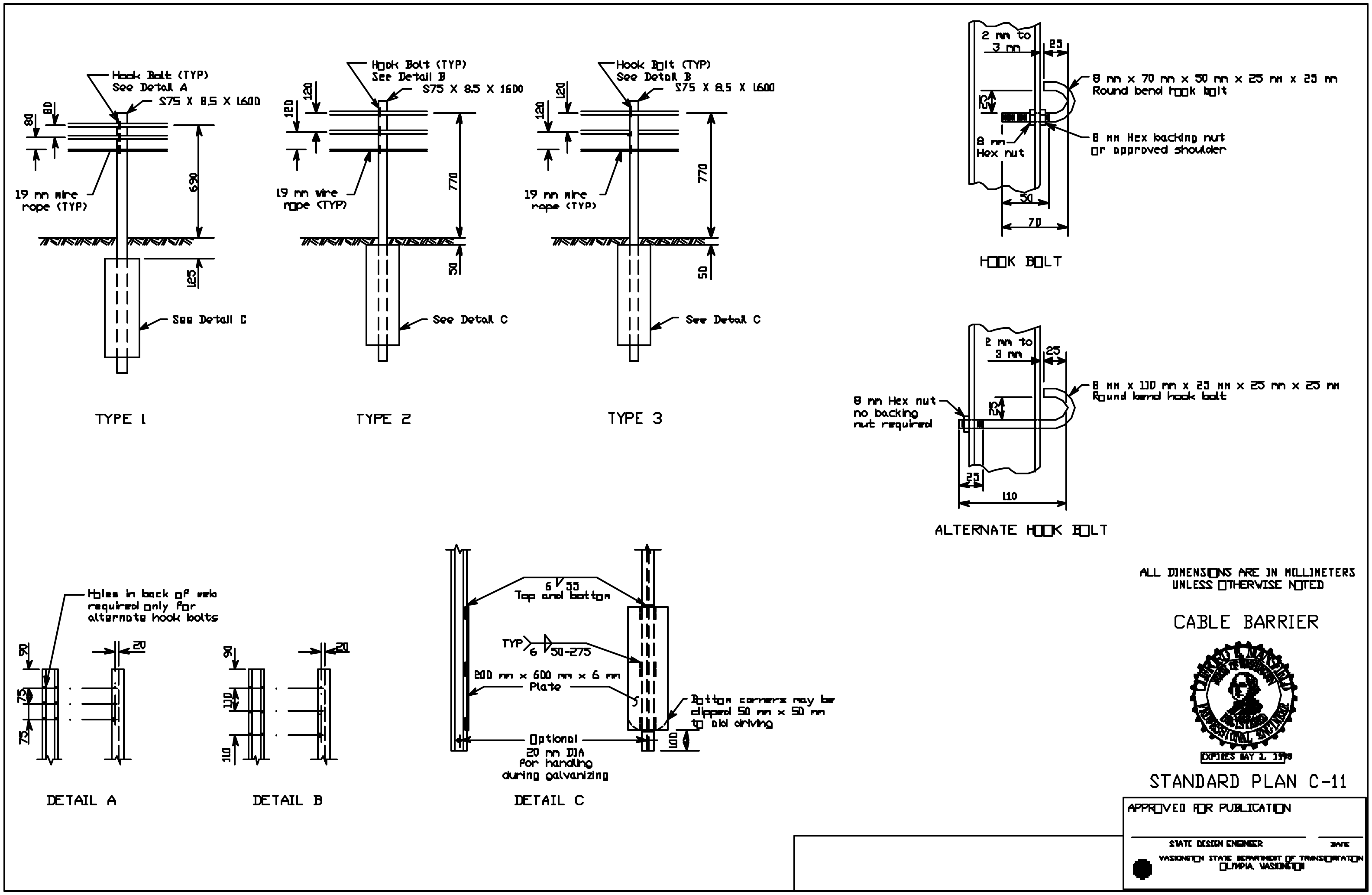


Figure 54. Details of the Washington 3-strand cable barrier for test 404211-8.

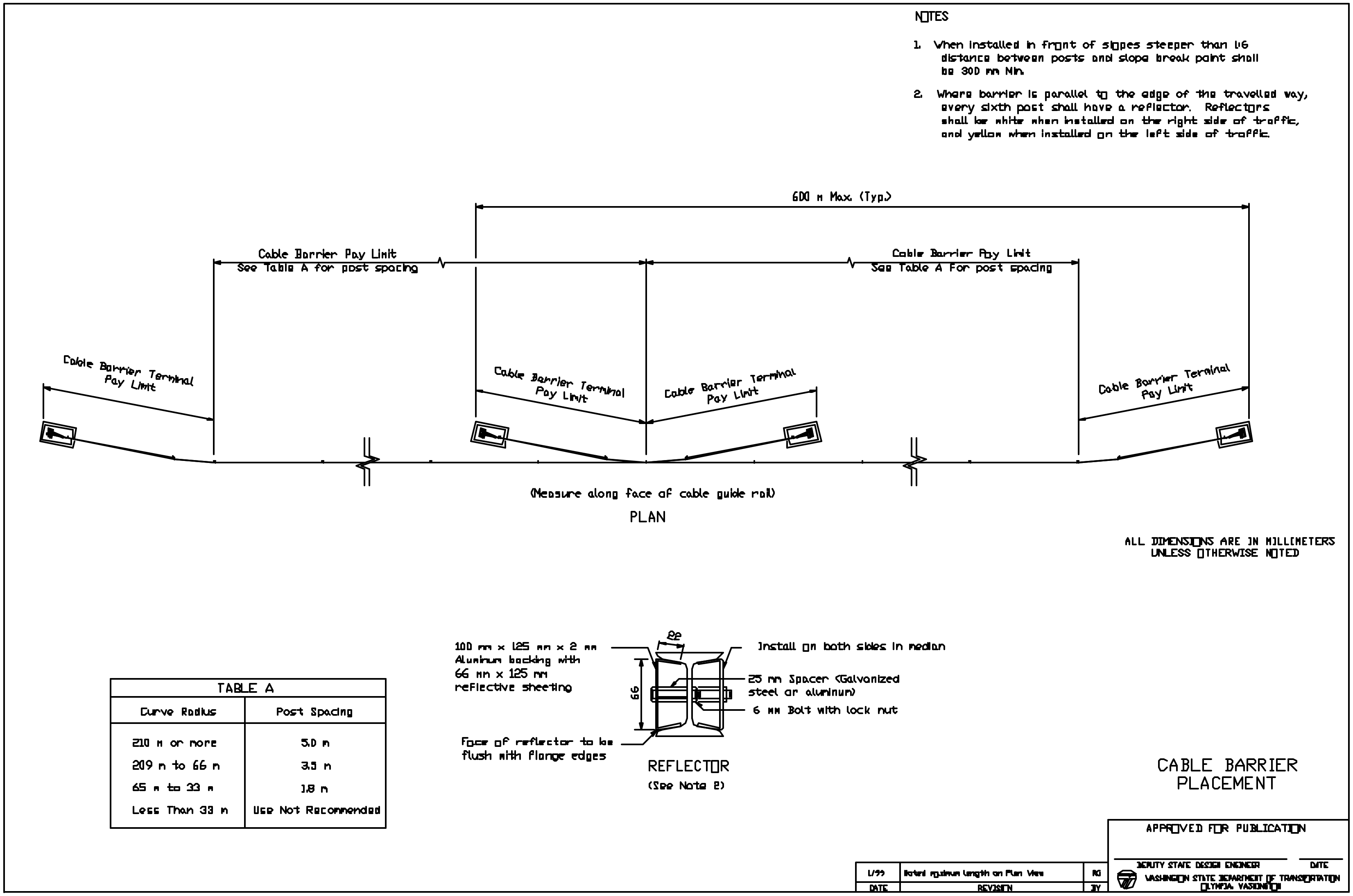


Figure 54. Details of the Washington 3-strand cable barrier for test 404211-8 (continued).

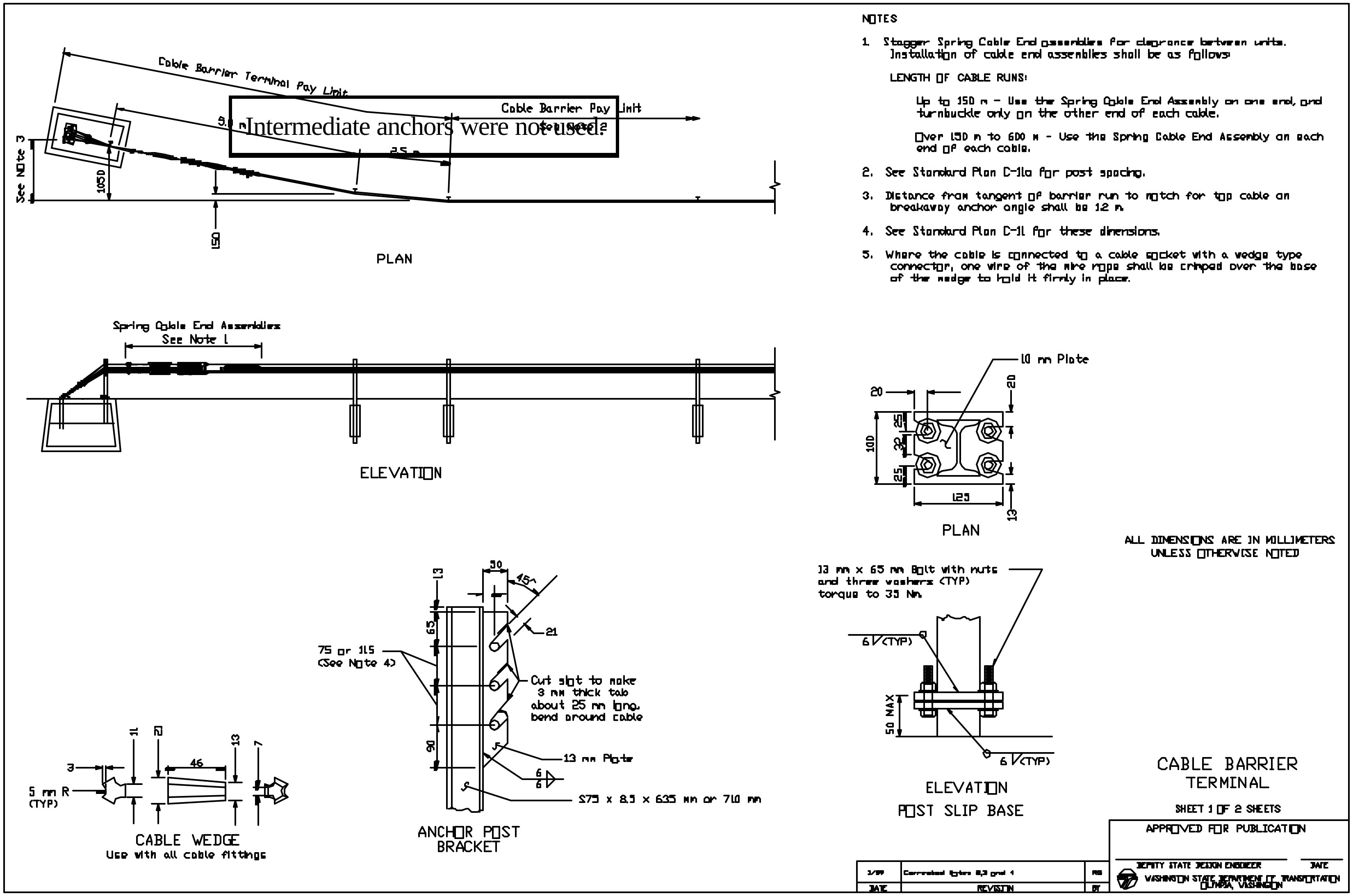


Figure 54. Details of the Washington 3-strand cable barrier for test 404211-8 (continued).

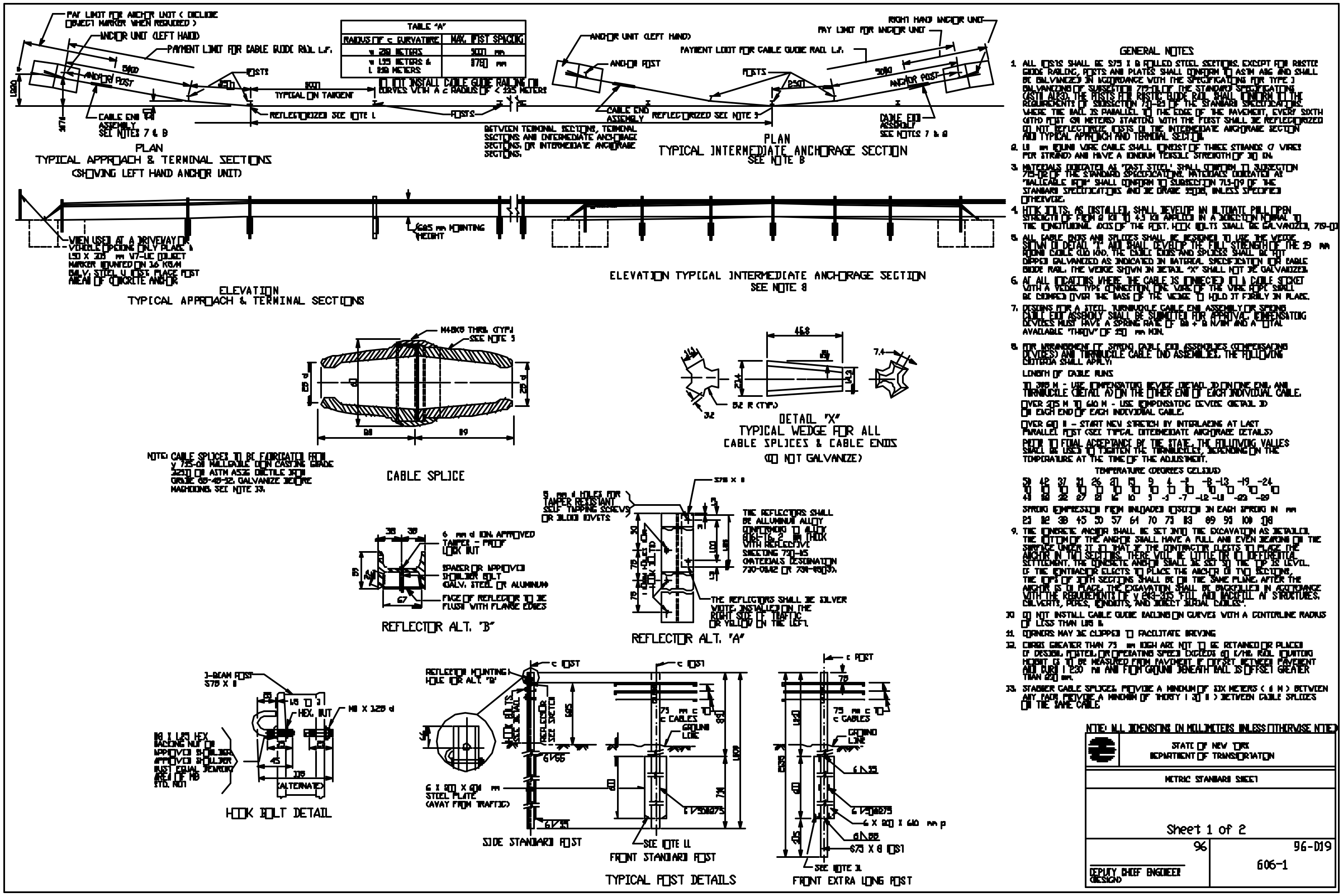


Figure 55. Details of the New York cable terminal used for test 404211-8.

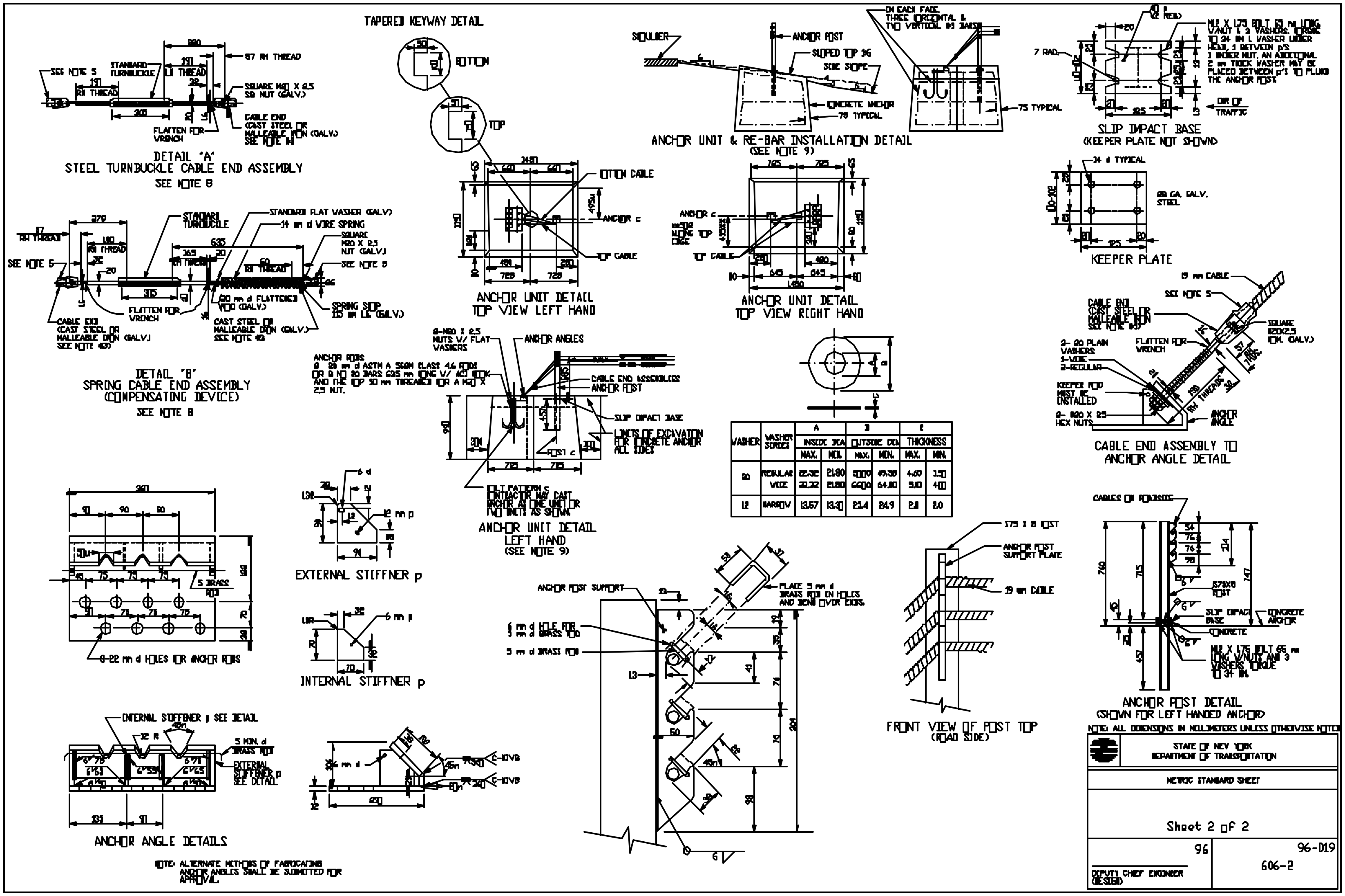
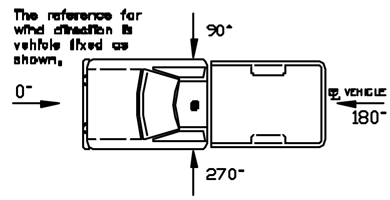


Figure 55. Details of the New York cable terminal used for test 404211-8 (continued).

integral key way measuring 50 mm by 100 mm at the bottom and 50 mm by 150 mm at the top. The last post flared back from the tangent a total distance of 1200 mm over a total distance of 7500 mm to the first post. On one end of each of the cables, adjacent to the standard turnbuckle, a spring cable end assembly was attached. The spring cable assembly consisted of the standard turnbuckle with 305 mm of take-up, a 20-mm diameter threaded steel rod on each end, and a spring compensating device on one end. The spring compensating device had a spring rate of 80 + 8 N/mm and a total minimum throw of 150 mm minimum. For the temperature conditions present just prior to the time of the crash test, the spring compensator was compressed 54 mm. Intermediate anchors were not used. Construction details are shown in figures 54 and 55. Photographs of the completed installation as tested are shown in figure 56.

Soil and Weather Conditions

The crash test was performed the morning of February 16, 2000. No rainfall was recorded for the 10 days prior to the test. Soil moisture content was 7.4 percent, 10.6 percent, and 7.9 percent at posts 11, 12, and 13, respectively. Weather conditions at the time of testing were as follows: wind speed: 10 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling northerly direction); temperature: 25EC; relative humidity: 60 percent.



Test Vehicle

A 1995 Chevrolet 2500 pickup truck, shown in figure 57, 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 front bumper was 400 mm and to the upper edge of the front bumper was 620 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 88.

Impact Description

The 2000P vehicle, traveling at a speed of 101.4 km/h, impacted the Washington 3-strand cable barrier at post 11 at an angle of 24.8 degrees. At 0.039 s, the left front corner of the vehicle lightly contacted post 11, and at 0.041 s, post 11 moved. The lower cable detached from post 11 at 0.068 s and at 0.071 s, post 12 moved. At 0.073 s, the upper cable detached from post 11, and at 0.096 s, the vehicle began to redirect. By 0.114 s, the lower cable detached from post 12, and by 0.122 s, the upper cable detached from post 12. The lower and upper cables detached from post 10 at 0.124 s and 0.146 s, respectively. At 0.164 s, the lower cable detached from post 3, and at 0.166 s, the middle cable rode over the top of post 12. The left front bumper contacted at post 12 at 0.188 s, and at 0.190 s, post 13 moved. The right front tire contacted post 12 and the upper cable detached from post 13 at 0.193 s. By 0.217 s, the lower cable detached from post 14, and by 0.222 s, post 12 rotated in the ground. At 0.239 s, the middle cable detached from all posts downstream, and at 0.243 s, the upper cable detached from post 14. The left front tire rode over the lower cable on the ground, and the lower cable detached from post 15 at 0.251 s. The middle cable rode over the top of post 13 and the upper cable detached from post 15 at 0.283 s.

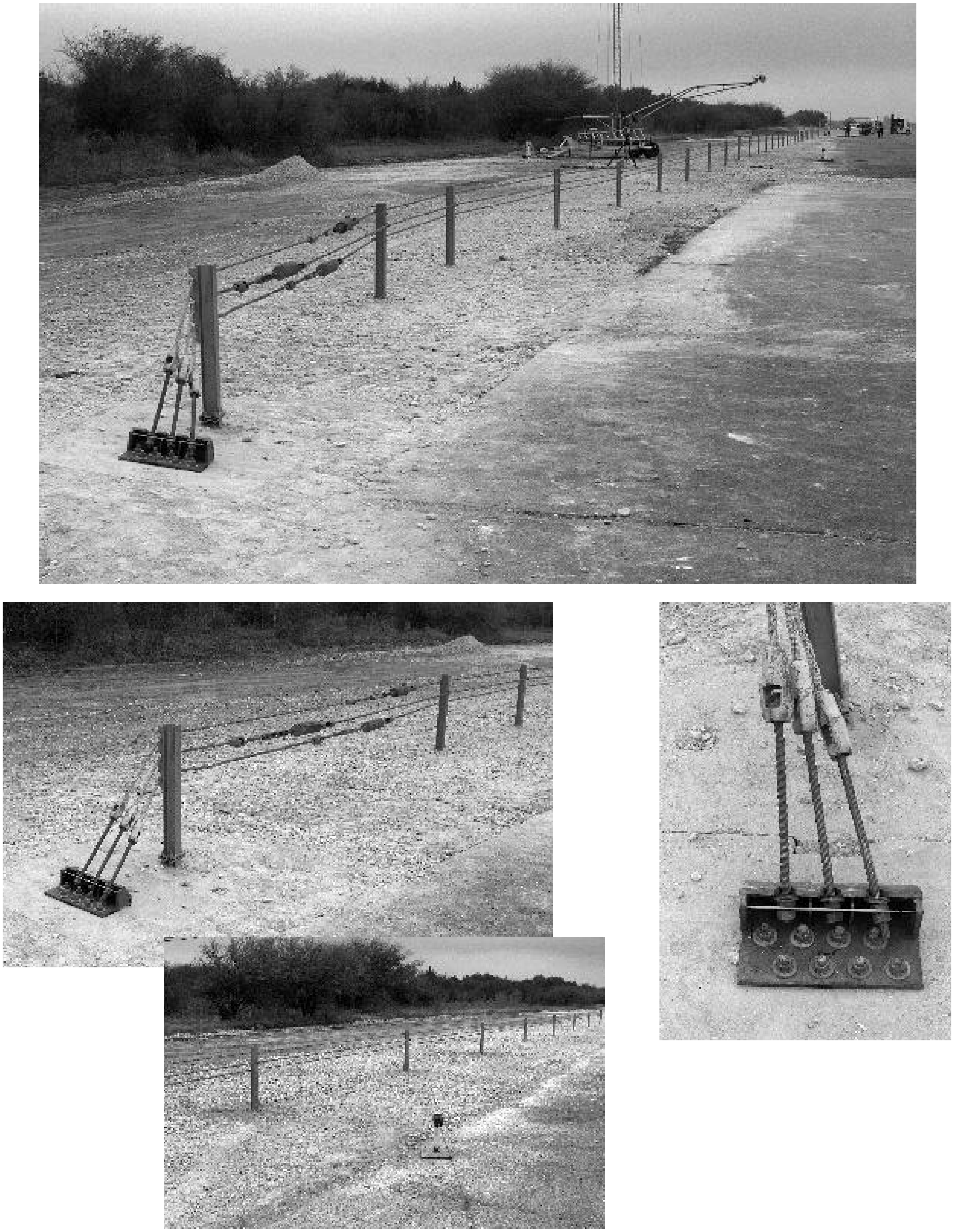


Figure 56. Washington 3-strand cable barrier with New York terminal prior to test 404211-8.

Figure 57. Vehicle before test 404211-8.

By 0.299 s, the lower cable detached from post 16, and by 0.314 s, the middle cable detached at post 14 and post 14 moved. The upper cable detached from post 16 at 0.365 s, and at 0.370 s, the lower cable broke away from post 17. The middle cable rode over the top of posts 11 and 14 at 0.382 s and 0.391 s, respectively. The middle cable detached at post 15 at 0.412 s, and at 0.417 s, post 15 moved. By 0.425 s, the upper cable detached from post 17, and by 0.449 s, post 16 moved. The vehicle began to travel parallel with the test installation at 0.464 s and was traveling at a speed of 83.6 km/h. The middle cable rode over the top of post 15 at 0.465 s. At 0.536 s, the middle cable detached from post 16, and at 0.561 s, the front wheels began to steer toward the cable barrier. The middle cable rode over the top of post 16 and post 17 began to deform toward the field side of the installation at 0.653 s. By 0.665 s, the vehicle began to yaw toward the cable barrier, and by 0.819 s, the middle cable rode over the top of post 17. At 0.970 s, the vehicle began to be pulled sideways toward the posts, and at 1.613 s, the vehicle was again parallel with the installation. The side of the vehicle contacted post 18 at 1.705 s, and at 1.895 s, the front bumper made contact with the post. The vehicle, traveling parallel with the installation, then yawed toward the rail. At this point, 65 percent of the vehicle was estimated to be on the back side of the posts at 2.550 s. The vehicle stopped moving forward at 3.915 s, and at 4.035 s, the front wheels of the vehicle straighten as the vehicle began moving backwards. The vehicle stopped moving at 5.547 s. Brakes on the vehicle were not applied and the vehicle subsequently came to rest on top of post 22. Sequential photographs of the test period are shown in appendix C, figures 110 and 111.

Damage to Test Article

Other than damage to the posts, damage to the Washington 3-strand cable barrier was minimal as shown in figure 58. The upstream anchor had minor stress cracks radiating from the anchor bolts in the concrete footing. Post 1 moved 670 mm longitudinally downstream. Posts 2 through 9 were disturbed and posts 10 through 15 were displaced 25 mm, 13 mm, 40 mm, 45 mm, 15 mm, and 40 mm, respectively. Posts 11 through 17 were rotated and post 12 was torn on the flange above the soil plate. The downstream anchor moved 5 mm longitudinally upstream. The cables were slack throughout the length of the installation. Maximum dynamic deflection during the test was 3.4 m.

Vehicle Damage

The vehicle sustained minor damage as shown in figure 59. There were scuff marks on the left front and rear quarter panels and left door. In addition, the left front and rear tires were cosmetically damaged. Maximum exterior crush to the vehicle was 320 mm above the front bumper at the left front corner. No deformation or intrusion into the occupant compartment occurred from the impact with the cable barrier. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 43 and 44.

Upstream anchor Downstream anchor

Figure 58. Installation after test 404211-8.

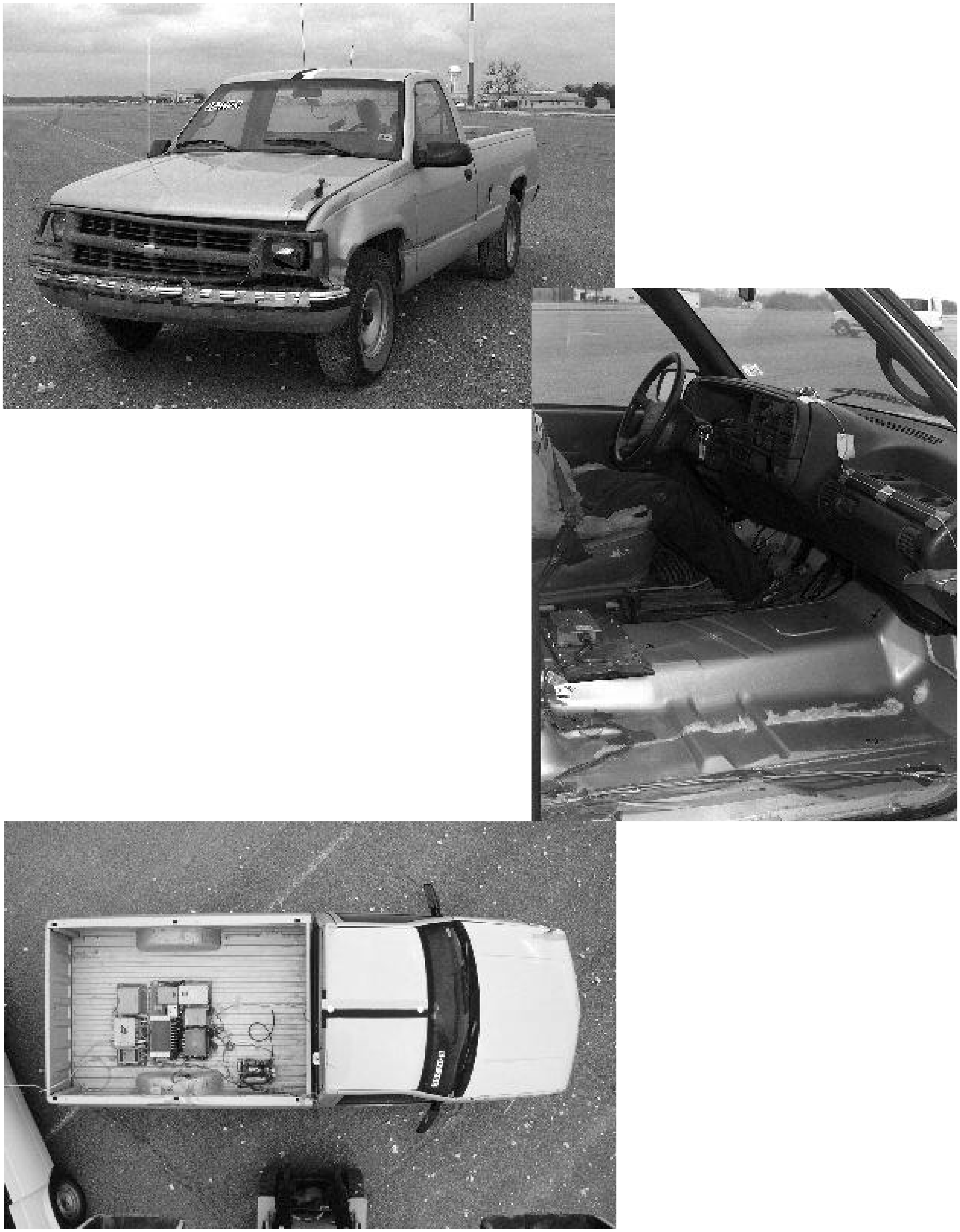


Figure 59. Vehicle after test 404211-8.

Occupant Risk Factors

In the longitudinal direction, occupant impact velocity was 2.2 m/s at 0.240 s, maximum 0.010-s ridedown acceleration was -2.7 g's from 0.546 to 0.556 s, and the maximum 0.050-s average was -1.6 g's between 0.137 and 0.187 s. In the lateral direction, the occupant impact velocity was 2.9 m/s at 0.240 s, the highest 0.010-s occupant ridedown acceleration was 4.9 g's from 0.360 to 0.370 s, and the maximum 0.050-s average was 2.1 g's between 0.348 and 0.398 s. These data and other information pertinent to the test are presented in figure 60. Vehicle angular displacements are presented in appendix D, figure 127, and accelerations versus time traces are shown in appendix E, figures 224 through 234.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

- **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.*

Result: The Washington 3-strand cable barrier contained and redirected the 2000P vehicle. Maximum dynamic deflection of the barrier was 3.4 m.

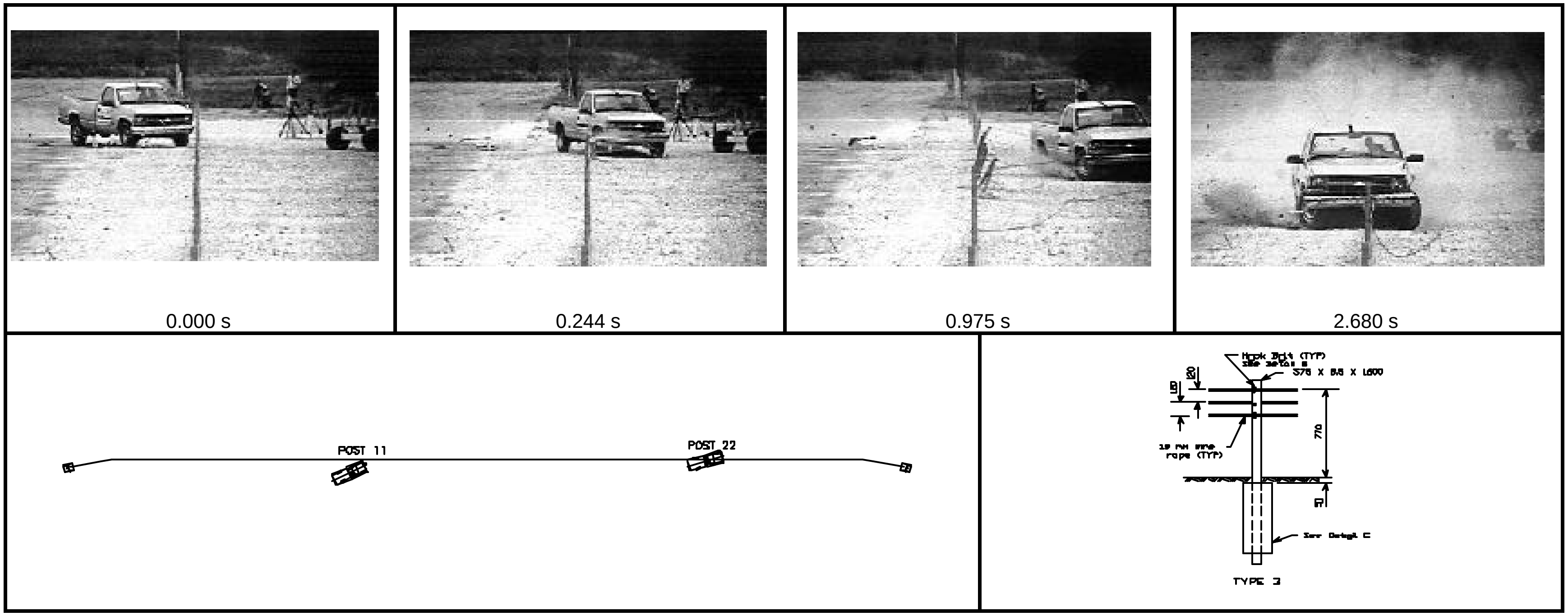
- **Occupant Risk**

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

Result: No detached elements, fragments, or debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.

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

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



General Information

Test Agency	Texas Transportation Institute
Test No.	404211-8
Date	02/16/00

Test Article

Type	Cable Barrier
Name	WSDOT Cable Rail with NY terminal
Installation Length (m)	145.0
Material or Key Elements	3 Strand Wire Cable, Top at 770 mm, with New York Cable Terminal

Soil Type and Condition . Standard Soil, Dry

Test Vehicle

Type	Production
Designation	2000P
Model	1994 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1932
Test Inertial	2000
Dummy	No dummy
Gross Static	2000

Impact Conditions

Speed (km/h)	101.4
Angle (deg)	24.8

Exit Conditions

Speed (km/h)	Stopped
Angle (deg)	N/A

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	2.2
y-direction	2.9
THIV (km/h)	12.0
Ridedown Accelerations (g's)	
x-direction	-2.7
y-direction	4.9
PHD (g's)	5.2
ASI	0.26
Max. 0.050-s Average (g's)	
x-direction	-1.6
y-direction	2.1
z-direction	-1.2

Test Article Deflections (m)

Dynamic	3.4
Permanent	0.7

Vehicle Damage

Exterior	
VDS	11LFQ2
CDC	11FLEK2 & 11LDEW2
Maximum Exterior Vehicle Crush (mm)	320
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	0

Post-Impact Behavior
(during 1.0 s after impact)

Max. Yaw Angle (deg)	18
Max. Pitch Angle (deg)	3
Max. Roll Angle (deg)	-3

Figure 60. Summary of results for WSDOT Cable Barrier test, *NCHRP Report 350* test 3-11.

! **Vehicle Trajectory**

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

Result: The vehicle did not intrude into adjacent traffic lanes. Final rest of the vehicle was over post 22.

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.*

Result: The longitudinal occupant impact velocity was 2.2 m/s and ridedown acceleration was -2.7 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: The vehicle did not exit the test installation.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— PASSENGER COMPARTMENT INTRUSION

1. Windshield Intrusion

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

2. Body Panel Intrusion yes or (no)

— LOSS OF VEHICLE CONTROL

1. Physical loss of control

2. Loss of windshield visibility

3. Perceived threat to other vehicles

4. Debris on pavement

The vehicle could have been kept under control, there was no loss of visibility, no perceived threat to other vehicles, and no debris on pavement.

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

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

No debris of significance that would harm others in the area was present.

— **VEHICLE AND DEVICE CONDITION**

1. **Vehicle Damage**

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

2. **Windshield Damage**

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

3. **Device Damage**

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

THRIE BEAM GUARDRAIL (STEEL POSTS AND ROUTED WOOD BLOCKOUTS) (*NCHRP REPORT 350* TEST NO. 3-11)

Test Conditions

The test performed on the thrie beam guardrail (test 404211-10) corresponds to *NCHRP Report 350* test designation 3-11. The CIP for this test was determined, using information contained in *NCHRP Report 350*, to be 4.5 m upstream of the splice at the one-third point, or 805 mm upstream of post 14 of the thrie beam guardrail system.

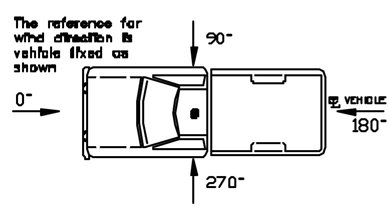
Test Article

The thrie beam guardrail system consisted of 2.1-m-long W150x14 steel posts, spaced 1.9 m apart, with routed wood blockouts, and 3.8-m-long 12-gauge thrie beam rail elements. A cross section of the modified thrie beam guardrail system is shown in figure 1. The routed wood blockouts were 554 mm long, 200 mm deep, and 150 mm wide. A 100-mm-wide, 10-mm-deep channel was routed out and centered on the post side of the blockout to fit over the face of the post. The blockouts and thrie beam rail elements were attached to the flange of the posts with two 16-mm-diameter through bolts. No backup plates or washers were used. The mounting height of the thrie beam rail was 550 mm to the center.

The test installation consisted of a 45.7-m-long length-of-need section of thrie beam guardrail with a 1.9-m-long transition section from the thrie beam to the W-beam rail element, and a 11.4-m-long LET at each end, for a total installation length of 68.5 m. The details and layout of the test installation are shown in figure 61. Photographs of the completed installation as tested are shown in figure 62.

Soil and Weather Conditions

The crash test was performed on the morning of April 9, 1999. Ten days before the test 49 mm of rainfall was recorded. No other rainfall was recorded for the remaining 10 recording days prior to the test. Moisture content of the *NCHRP Report 350* standard soil in which the guardrail was installed was 6.6 percent, 7.5 percent, and 7.1 percent at posts 13, 15, and 17, respectively. Weather conditions at the time of testing were as follows: wind speed: 6 km/h; wind direction: 45 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 28EC; relative humidity: 60 percent.



Test Vehicle

A 1993 Chevrolet Cheyenne 2500 pickup truck, shown in figure 63, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2076 kg. The height to the lower edge of the vehicle front bumper was 390 mm and to the upper edge of the front bumper was 605 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 89.

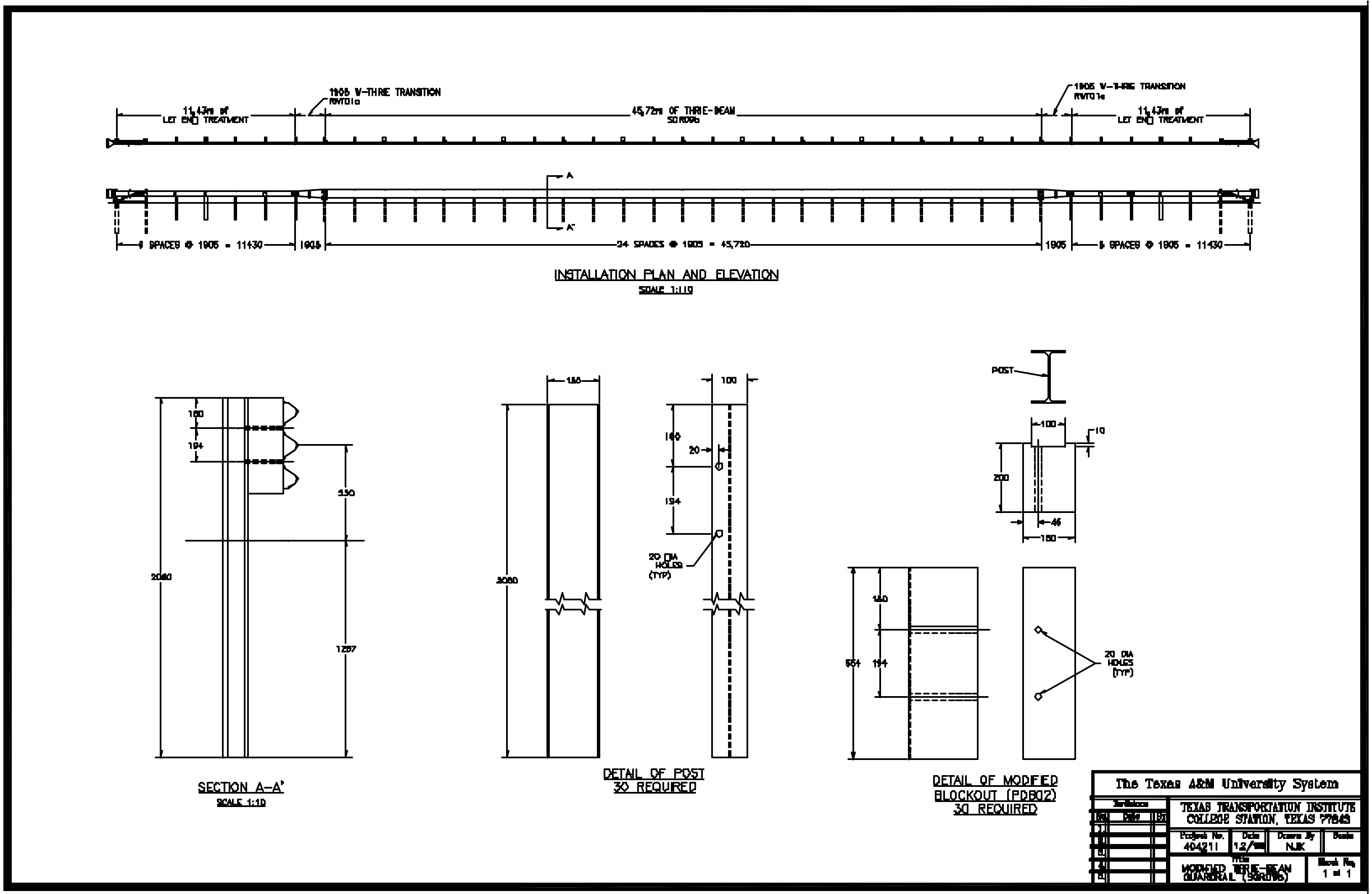


Figure 61. Details of the thrie beam guardrail with 2.1-m steel posts and wood blockouts installation for test 404211-10.

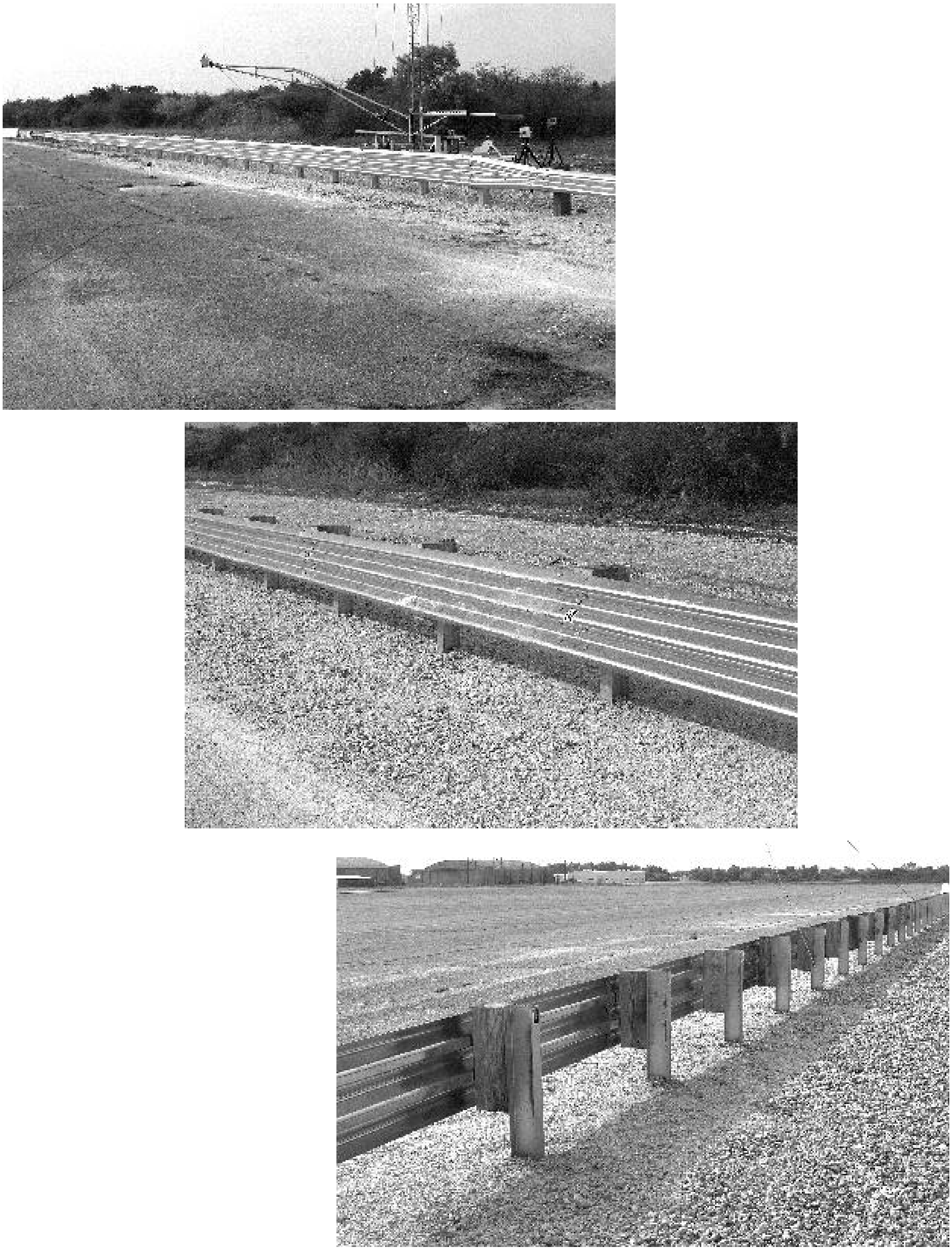


Figure 62. Thrie beam guardrail installation prior to test 404211-10.

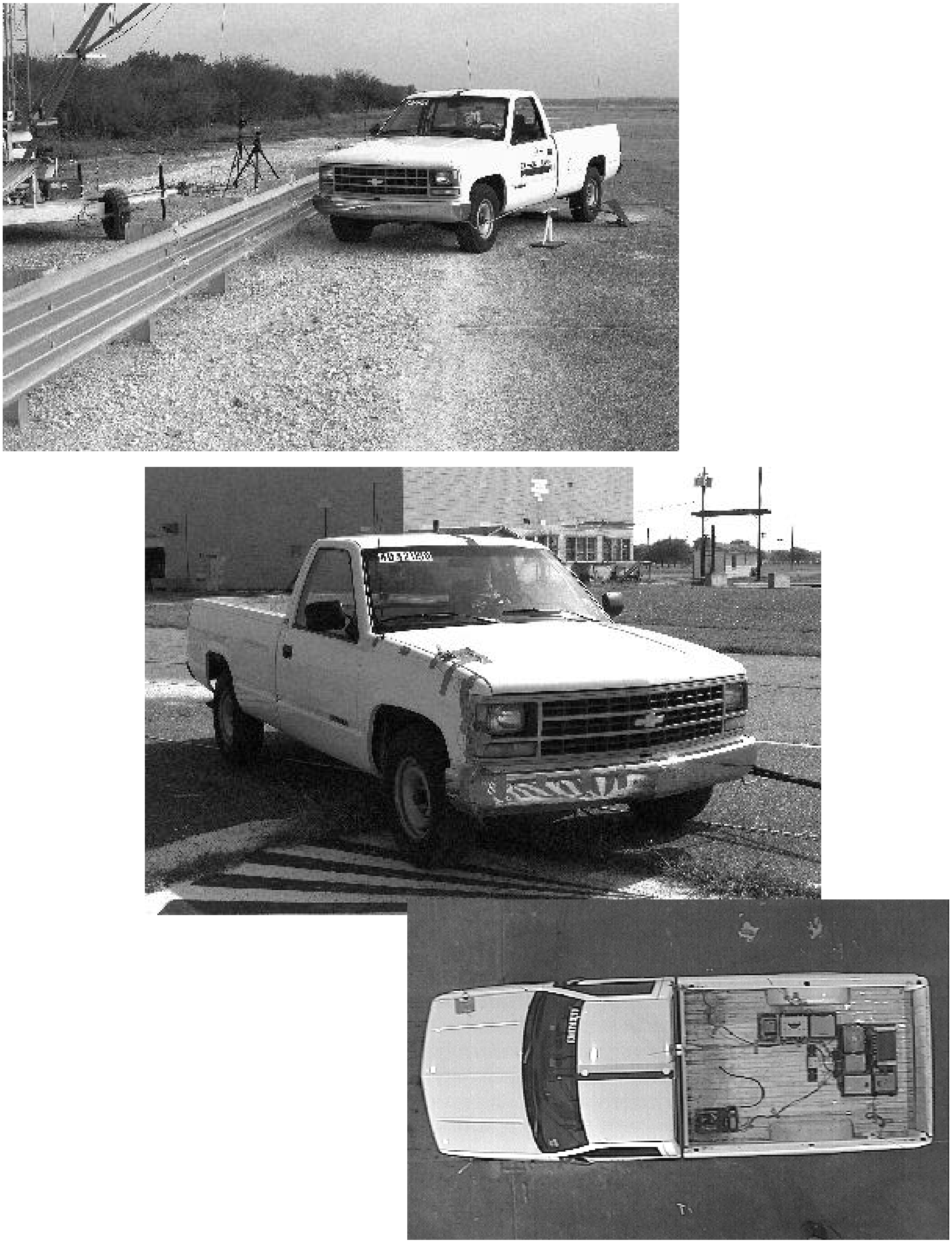


Figure 63. Vehicle before test 404211-10.

Impact Description

The 2000P vehicle, traveling at a speed of 98.2 km/h, impacted the thrie beam guardrail installation 805 mm upstream of post 14 at an impact angle of 24.4 degrees. Shortly after impact posts 13 and 14 moved. At 0.027 s, the front of the vehicle contacted post 14, and at 0.029 s, post 15 moved. By 0.037 s, post 12 moved, and at 0.047 s, the vehicle began to redirect. The left front wheel steered left at 0.049 s, and by 0.076 s, post 16 moved. At 0.101 s, the vehicle contacted post 15, and at 0.142 s, post 17 moved. By 0.177 s, the vehicle contacted post 16, and by 0.204 s, the right rear of the vehicle contacted the rail element. Post 18 moved at 0.205 s, and at 0.225 s, the front left tire lost contact with the ground. The vehicle, traveling at 75.9 km/h, was parallel with the test installation at 0.234 s. At 0.263 s, the vehicle contacted post 17, and at 0.294 s, the left rear tire lost contact with the ground. By 0.517 s, the vehicle lost contact with the test installation and was traveling at a speed of 72.5 km/h and an exit angle of 11.3 degrees. The left front and rear tires of the vehicle returned to the ground surface at 0.519 s and 0.602 s, respectively. Brakes on the vehicle were applied at 3.2 s. The vehicle came to rest 67.0 m down from impact and 30.5 m toward traffic lanes. Sequential photographs of the collision are shown in appendix C, figures 112 and 113.

Damage to Test Article

The thrie beam installation sustained minimal damage as shown in figure 64. The upstream end anchor moved 10 mm and posts 2 through 11 were disturbed. Post 12 moved back 13 mm, post 13 moved back 50 mm, and post 14 was pushed back 155 mm. Both post bolts at post 15 pulled through the rail element and the post was rotated. The blockout remained attached to the post 15 and the post was pushed back 235 mm. Post 16 was pushed back 145 mm and post 17 was back 57 mm. Posts 19 through 29 were disturbed. Maximum dynamic deflection during the test was 0.58 m and maximum permanent deformation was 0.42 m. The vehicle was in contact with the rail element for 6.1 m.

Vehicle Damage

Damage to the 2000P vehicle was also minimal, as shown in figure 65. Structural damage was imparted to the right side rod ends, right upper and lower A-arms, the stabilizer bar and the right front frame. Also damaged were the front bumper, grill, fan, radiator, right front quarter panel, right front tire and rim, and the right door was jammed. Maximum exterior crush to the vehicle was 280 mm at the front right corner at bumper height. Maximum occupant compartment deformation was 75 mm in the center floor pan area. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 45 and 46.

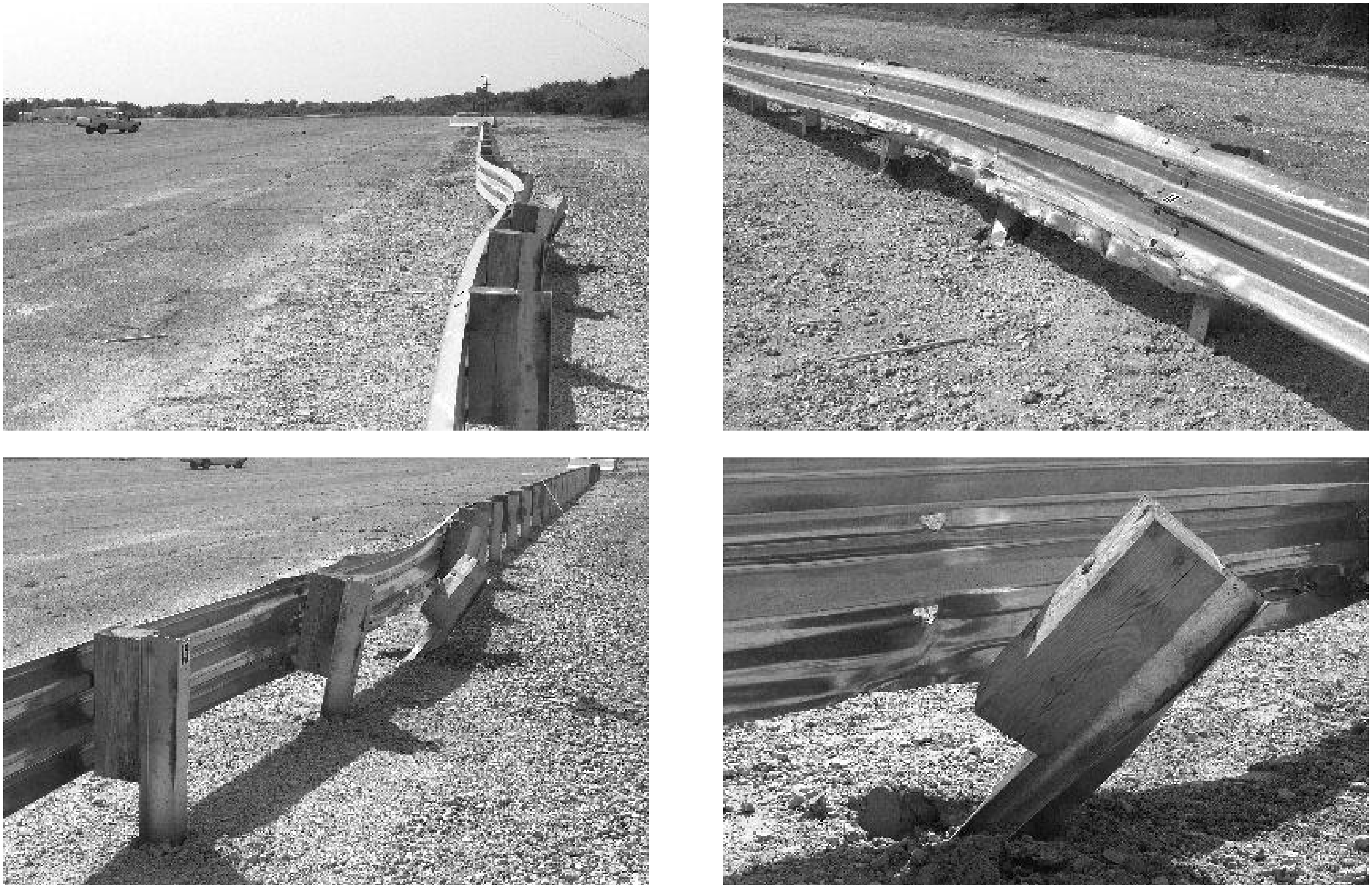


Figure 64. Installation after test 404211-10.

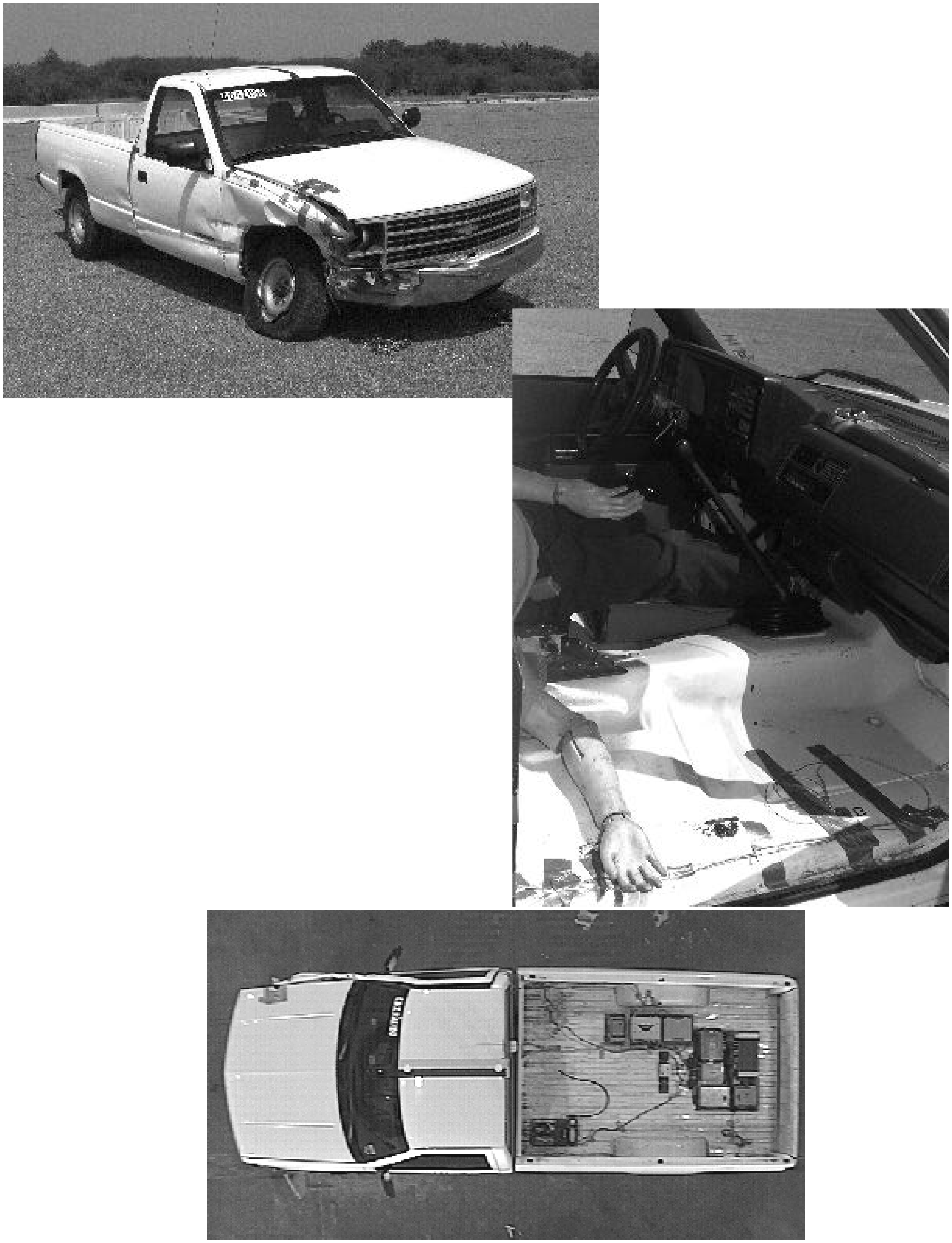


Figure 65. Vehicle after test 404211-10.

Occupant Risk Factors

In the longitudinal direction, occupant impact velocity was 7.0 m/s at 0.204 s, maximum 0.010-s ridedown acceleration was -7.6 g's from 0.242 to 0.252 s, and the maximum 0.050-s average was -5.6 g's between 0.087 and 0.137 s. For informational purposes, in the lateral direction, the occupant impact velocity was 6.4 m/s at 0.137 s, the highest 0.010-s occupant ridedown acceleration was -9.3 g's from 0.217 to 0.227 s, and the maximum 0.050-s average was -7.2 g's between 0.089 and 0.139 s. These data and other information pertinent to the test are presented in figure 66. Vehicle angular displacements are presented in appendix D, figure 128, and accelerations versus time traces are shown in appendix E, figures 235 through 245.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

- **Structural Adequacy**

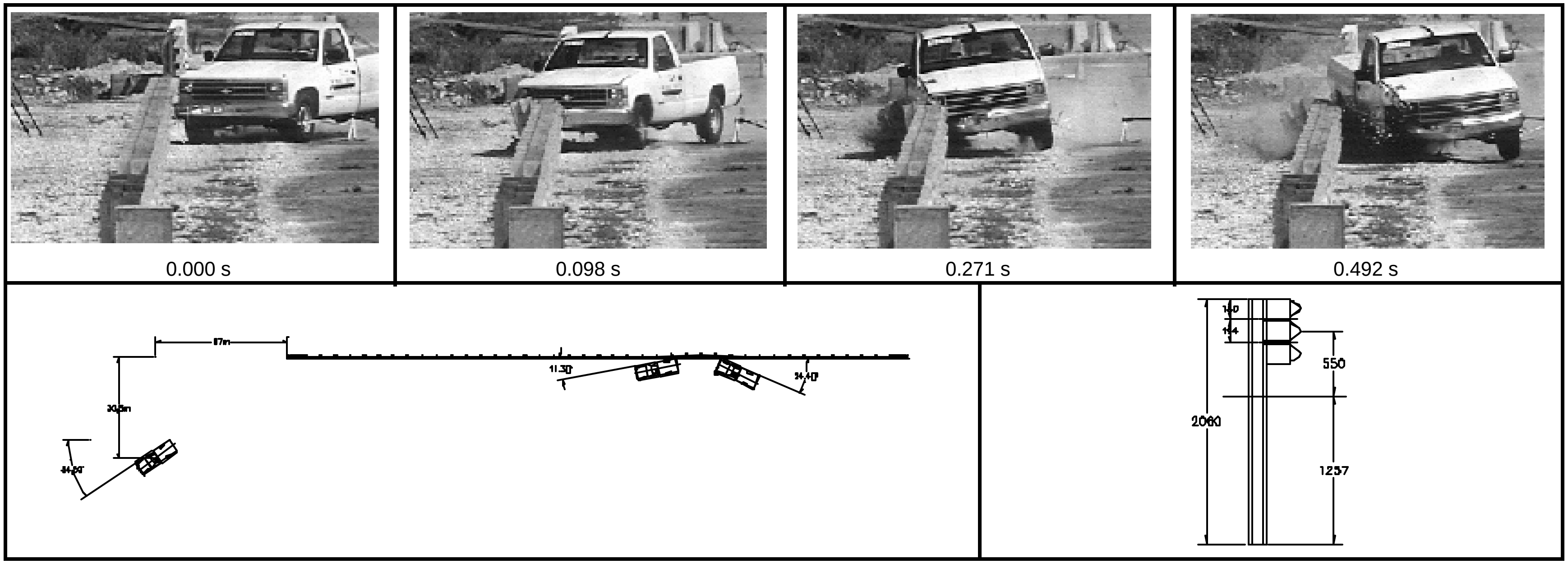
A. *Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*

Result: The thrie beam guardrail with 2.1-m-long steel posts and wood blockouts contained and redirected the 2000P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum lateral deflection of the installation was 0.58 m.

- **Occupant Risk**

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

Result: The rail element separated from post 15. No other detached elements, fragments, or other debris were present. Neither the separated rail element nor the post penetrated or showed potential for penetrating the occupant compartment or presented undue hazard to others in the area. Maximum occupant compartment deformation was 75 mm in the center floor pan area. Due to the location, this deformation was judged to not cause serious injury.



General Information

Test Agency	Texas Transportation Institute
Test No.	404211-10
Date	04/09/99

Test Article

Type	Guardrail
Name	Thrie Beam Guardrail
Installation Length (m)	68.5
Material or Key Elements	Thrie Beam Guardrail with 2.1 m Steel Posts and Routed Wood Blockouts

Soil Type and Condition Standard Soil, Dry

Test Vehicle

Type	Production
Designation	2000P
Model	1993 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1905
Test Inertial	2000
Dummy	76
Gross Static	2076

Impact Conditions

Speed (km/h)	98.2
Angle (deg)	24.4

Exit Conditions

Speed (km/h)	72.5
Angle (deg)	11.3

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	7.0
y-direction	6.4
THIV (km/h)	26.4
Ridedown Accelerations (g's)	
x-direction	-7.6
y-direction	-9.3
PHD (g's)	9.9
ASI	0.93
Max. 0.050-s Average (g's)	
x-direction	-5.6
y-direction	-7.2
z-direction	-3.0

Test Article Deflections (m)

Dynamic	0.58
Permanent	0.42

Vehicle Damage

Exterior	
VDS	01RFQ3
CDC	01RFEK2 &01RYEW2
Maximum Exterior Vehicle Crush (mm)	280
Interior	
OCDI	RF01040000
Max. Occ. Compart. Deformation (mm)	75

Post-Impact Behavior

(during 1.0 s after impact)	
Max. Yaw Angle (deg)	-34
Max. Pitch Angle (deg)	4
Max. Roll Angle (deg)	12

Figure 66. Summary of results for the Thrie Beam Guardrail (steel posts/wood blockouts) test, *NCHRP Report 350* test 3-11.

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

Result: The 2000P vehicle remained upright and relatively stable during and after the collision event.

! **Vehicle Trajectory**

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

Result: The vehicle did intrude into adjacent traffic lanes as it came to rest 67.0 m down from impact and 30.5 m toward traffic lanes.

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.*

Result: Longitudinal occupant impact velocity was 7.0 m/s and longitudinal ridedown acceleration was -7.6 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: The exit angle at loss of contact with the installation was 11.3 degrees, which was 46 percent of the impact angle.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— **PASSENGER COMPARTMENT INTRUSION**

1. **Windshield Intrusion**

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

2. **Body Panel Intrusion** yes or no (circled)

— **LOSS OF VEHICLE CONTROL**

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

The vehicle could have been kept under control, there was no loss of visibility, no perceived threat to other vehicles, and no debris on pavement.

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

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

No debris of significance that would harm others in the area was present.

— **VEHICLE AND DEVICE CONDITION**

1. **Vehicle Damage**
   - a. None
   - b. Minor scrapes, scratches or dents
   - c. Significant cosmetic dents
   - d. Major dents to grill and body panels
   - (e.) Major structural damage

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

3. **Device Damage**
   - a. None
   - b. Superficial
   - c. Substantial, but can be straightened
   - (d.) Substantial, replacement parts needed for repair
   - e. Cannot be repaired

THRIE BEAM ON STRONG WOOD POSTS (*NCHRP REPORT 350* TEST NO. 3-11)

Test Conditions

The test performed on the thrie beam on strong wood posts (404211-11) corresponds to *NCHRP Report 350* test designation 3-11. The CIP for this test was determined using information contained in *NCHRP Report 350* and accordingly was determined to be the midpoint of the span between posts 15 and 16 of the strong wood post thrie beam guardrail.

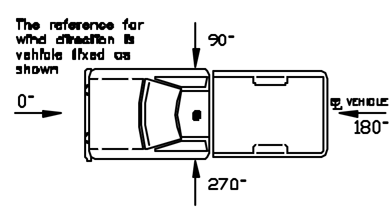
Test Article

The strong wood post thrie beam guardrail system consisted of 2050-mm-long, 150-mm by 200-mm wood posts spaced 1.9 m apart with 150-mm by 200-mm by 554-mm blockouts. A cross section of the strong wood post thrie beam guardrail system is shown in figure 1. The blockout and rail element were attached to each post with two 16-mm-diameter button head bolts without a washer under the head. One flat washer was used under the nut. The mounting height of the thrie beam rail was 550 mm to the center and 804 mm to the top of the thrie beam rail element.

The test installation consisted of a 45.7-m-long length-of-need section of strong wood post thrie beam guardrail with a 1.9-m-long transition section from the thrie beam to the W-beam rail element, and a 15.2-m-long ET-2000 at each end, for a total installation length of 80.0 m. The details and layout of the test installation are shown in figure 67. Photographs of the completed installation as tested are shown in figure 68.

Soil and Weather Conditions

The test was performed on the morning of July 3, 1998. A total of 10 mm of rain occurred four days before the test. No other rain occurred during the remaining 10 recording days prior to the test. Moisture content of the *NCHRP Report 350* standard soil in which the guardrail was installed was 7.7 percent, 9.7 percent, and 9.6 percent at posts 16, 18, and 20, respectively. Weather conditions during the time of the test were as follows: wind speed: 0 km/h; wind direction: N/A (vehicle was traveling in a southwesterly direction); temperature: 33EC; relative humidity: 82 percent.



Test Vehicle

A 1993 Chevrolet 2500 pickup truck, shown in figure 69, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2075 kg. The height to the lower edge of the vehicle bumper was 370 mm and it was 600 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in appendix B, figure 90.

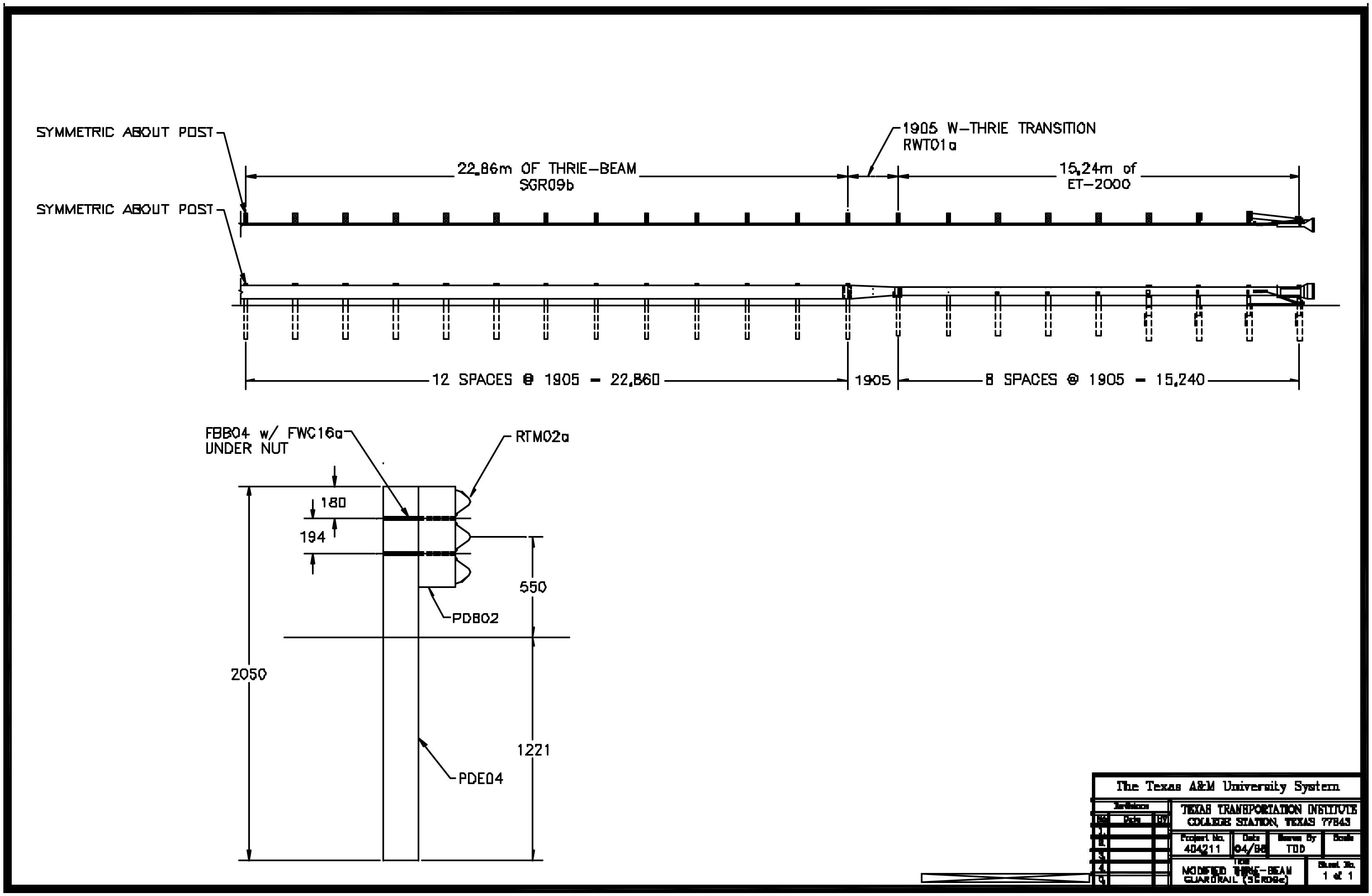


Figure 67. Details of the Strong wood post thrie beam guardrail installation for test 404211-11.

Figure 68. Strong wood post thrie beam guardrail installation prior to test 404211-11.

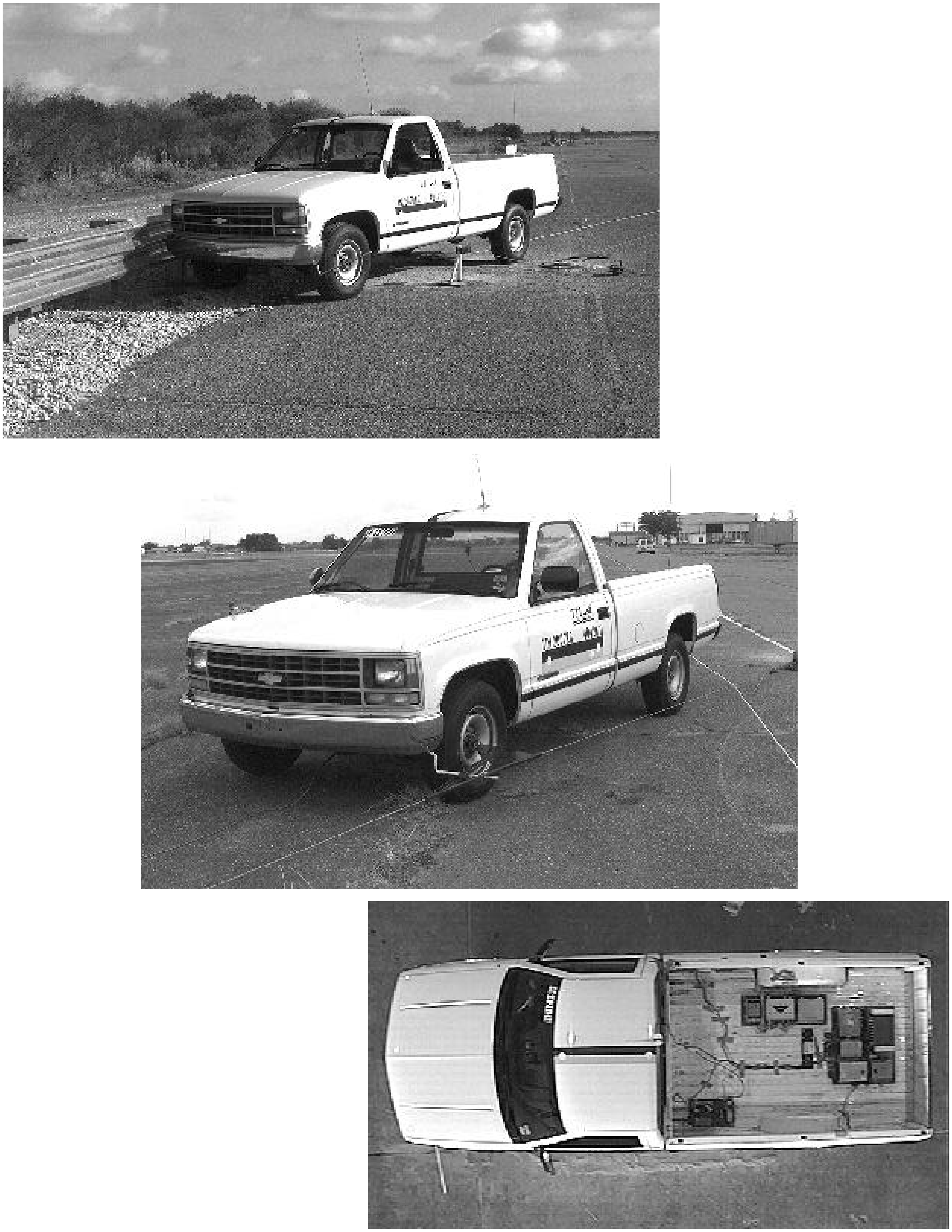


Figure 69. Vehicle before test 404211-11.

Impact Description

The vehicle, traveling at 99.6 km/h, impacted the strong wood post thrie beam guardrail 609 mm before post 16 at an impact angle of 23.6 degrees. Shortly after impact, posts 16 and 15 moved, followed by movement in the thrie beam element, and then movement at post 17 at 0.017 s. The vehicle contacted post 16 at 0.030 s and the vehicle redirected at 0.048 s. Post 18 moved at 0.083 s, and post 19 moved shortly after. The front of the vehicle contacted post 17 at 0.094 s and the right front tire impacted post 17 at 0.115 s, which caused the post to fracture just below ground level. At 0.144 s, post 20 moved and at 0.165 s, the vehicle contacted post 18. The right front tire impacted post 18 at 0.205 s, which caused the post to split along the longitudinal axis. The rear of the vehicle contacted the thrie beam rail element at 0.197 s. At 0.238 s, the vehicle was traveling parallel with the guardrail at a speed of 75.8 km/h. The front of the vehicle contacted post 19 at 0.257 s and the front of the vehicle lost contact with the rail element at 0.314 s. The vehicle lost contact with the rail at 0.511 s and was traveling at an exit speed of 73.6 km/h and an exit angle of 14.7 degrees. The vehicle immediately steered back into the rail and contacted the guardrail again at post 41 at 2.802 s. The vehicle rode off the end of the terminal and rotated counterclockwise. Brakes on the vehicle were not applied. The vehicle subsequently came to rest 68.6 m down and 1.8 m behind the installation. Sequential photographs of the test period are shown in appendix C, figures 114 and 115.

Damage to Test Article

Damage to the strong wood post thrie beam guardrail is shown in figure 70. Post 17 fractured just below ground level and post 18 split along the longitudinal axis. The bolts pulled out of the rail element at posts 17 and 18. The ET-2000 end terminal on the downstream end was disturbed as were posts 6 through 14. Posts 15 through 20 were pushed back with a maximum displacement of 110 mm at post 16. Maximum dynamic deflection of the guardrail was 676 mm and the maximum permanent deformation was 390 mm between posts 16 and 17. Total length of contact during the initial impact was 6.3 m. The vehicle contacted the installation again at post 40 and rode off the end (post 43).

Vehicle Damage

The bumper, hood, grill, fan, radiator, right front tire and wheel, right door, right front and rear quarter panels, and left door were damaged and the windshield was shattered as shown in figure 71. Structural damage included the right upper and lower A-arms, right spindle and rod ends, stabilizer bar, right front frame, firewall, and floor pan. Maximum exterior crush to the vehicle was 470 mm at the right front corner of the bumper. Maximum occupant compartment deformation was 30 mm in the center floor pan area under the instrument panel. Exterior crush measurements and occupant compartment measurements are shown in appendix B, tables 47 and 48.

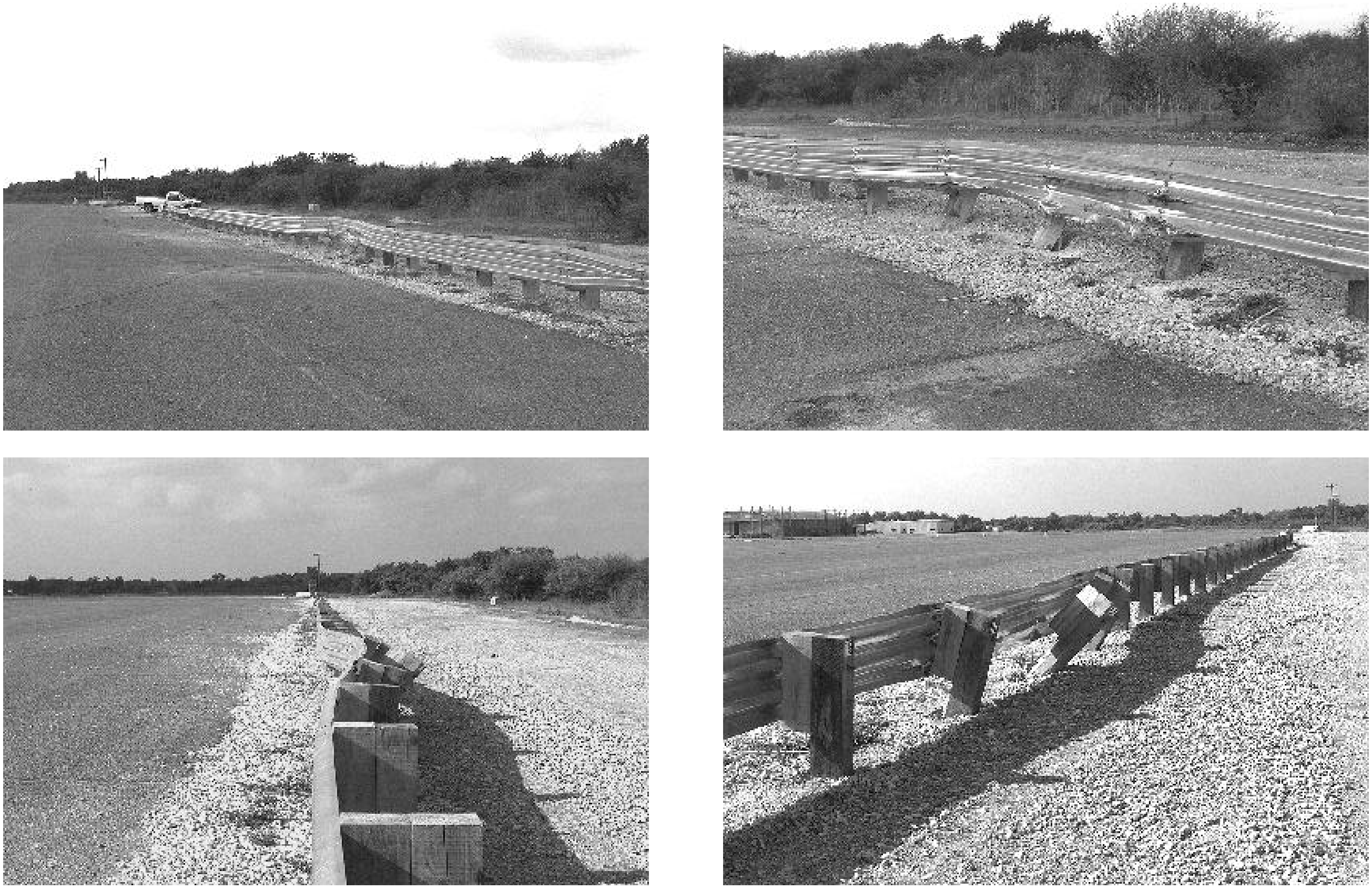


Figure 70. Installation after test 404211-11.

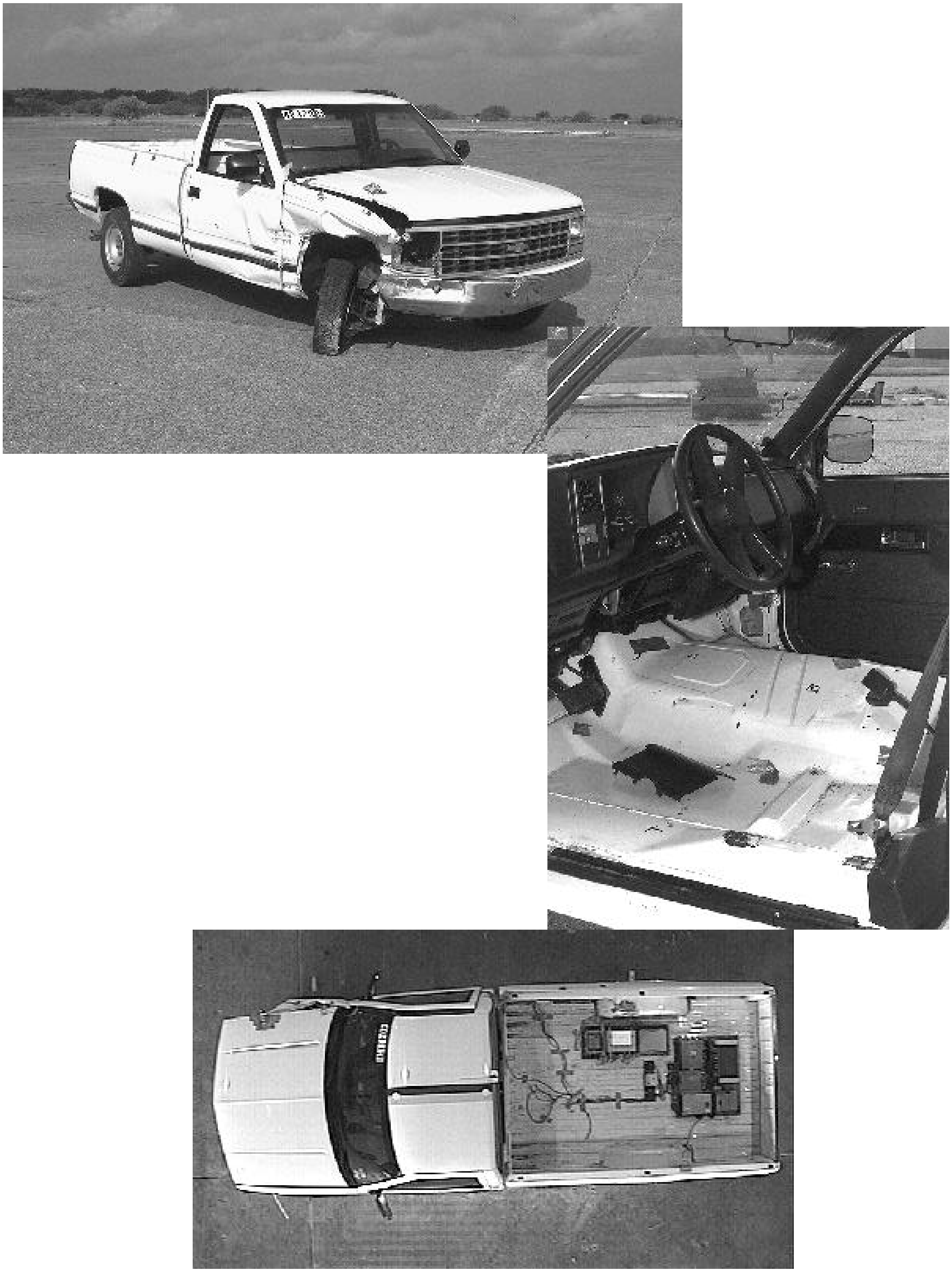


Figure 71. Vehicle after test 404211-11.

Occupant Risk Factors

In the longitudinal direction, the occupant impact velocity was 6.3 m/s at 0.198 s, the highest 0.010-s occupant ridedown acceleration was -8.4 g's from 0.223 to 0.233 s, and the maximum 0.050-s average acceleration was -5.5 g's between 0.082 and 0.132 s. In the lateral direction, the occupant impact velocity was 5.6 m/s at 0.130 s, the highest 0.010-s occupant ridedown acceleration was -9.0 g's from 0.202 to 0.212 s, and the maximum 0.050-s average was -5.8 g's between 0.068 and 0.118 s. These data and other pertinent information from the test are summarized in figure 72. Vehicle angular displacements are displayed in appendix D, figure 129. Vehicular accelerations versus time traces are presented in appendix E, figures 246 through 256.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

! **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.*

Result: The strong wood post thrie beam guardrail contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the installation was 676 mm.

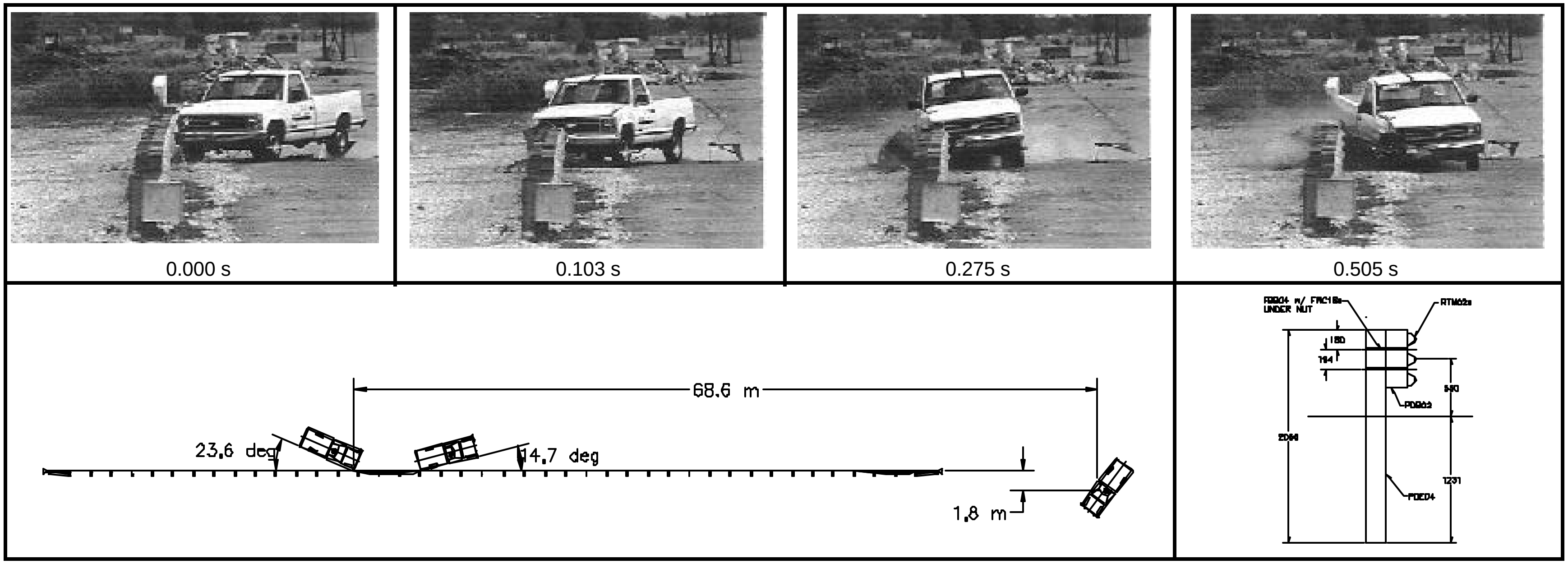
! **Occupant Risk**

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

Result: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 30 mm in the center front floor pan area under the instrument panel and should not cause serious injury.

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

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



General Information

Test Agency	Texas Transportation Institute
Test No.	404211-11
Date	06/03/98
Test Article	
Type	Guardrail
Name	Strong Wood Post Thrie Beam Guardrail
Installation Length (m)	80.0
Material or Key Elements	12-ga Thrie Beam on Strong Wood Posts With Wood Blockouts
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1993 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1861
Test Inertial	2000
Dummy	75
Gross Static	2075

Impact Conditions

Speed (km/h)	99.6
Angle (deg)	23.6
Exit Conditions	
Speed (km/h)	73.6
Angle (deg)	14.7
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.3
y-direction	5.6
THIV (km/h)	20.5
Ridedown Accelerations (g's)	
x-direction	-8.4
y-direction	-9.0
PHD (g's)	11.1
ASI	0.99
Max. 0.050-s Average (g's)	
x-direction	-5.5
y-direction	-5.8
z-direction	2.1

Test Article Deflections (m)

Dynamic	0.68
Permanent	0.39
Vehicle Damage	
Exterior	
VDS	01RFQ4
CDC	01FREK3 & 01RYEW3
Maximum Exterior Vehicle Crush (mm)	470
Interior	
OCDI	FS0104000
Max. Occ. Compart. Deformation (mm)	30
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	-31
Max. Pitch Angle (deg)	3
Max. Roll Angle (deg)	6

Figure 72. Summary of results for the thrie beam guardrail on strong wood posts, *NCHRP Report 350* test 3-11.

! **Vehicle Trajectory**

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

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

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.*

Result: Longitudinal occupant impact velocity was 6.3 m/s and longitudinal ridedown acceleration was -8.4 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: The exit angle at loss of contact was 14.7 degrees, which was 62 percent of the impact angle; however, the vehicle steered back toward the installation.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— **PASSENGER COMPARTMENT INTRUSION**

1. **Windshield Intrusion**

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

2. **Body Panel Intrusion** yes or no (circled)

— **LOSS OF VEHICLE CONTROL**

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

The vehicle could have been kept under control, there was no loss of visibility, no perceived threat to other vehicles, and no debris on pavement.

— PHYSICAL THREAT TO WORKERS OR OTHER VEHICLES

1. Harmful debris that could injure workers or others in the area

2. Harmful debris that could injure occupants in other vehicles

No debris of significance that would harm others in the area was present.

— VEHICLE AND DEVICE CONDITION

1. Vehicle Damage

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

2. Windshield Damage

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

3. Device Damage

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

MODIFIED THRIE BEAM GUARDRAIL (*NCHRP REPORT 350* TEST NO. 4-12)

Test Conditions

The test performed on the modified thrie beam guardrail (test 404211-5) corresponds to *NCHRP Report 350* test designation 4-12. The CIP for this test was determined using information contained in *NCHRP Report 350* and accordingly was determined to be the midpoint of the span between posts 17 and 18 of the modified thrie beam guardrail.

Test Article

The modified thrie beam guardrail system consisted of 2.1-m-long W150x14 steel posts spaced 1.9 m apart with W360x33 blockouts. A cross section of the modified thrie beam guardrail system is shown in figure 73. The blockouts were 432 mm long, 457 mm deep, and 152 mm wide at the flanges. The web of the blockout had a cutout measuring 152 mm at the bottom and angled upward at 40 degrees to the flange upon which the thrie beam was attached. The blockout was attached to the post with four 16-mm-diameter bolts and the thrie beam rail element was attached to the blockout with a single 16-mm-diameter button head bolt without a washer. The mounting height of the thrie beam rail was 610 mm to the center and 864 mm to the top of the thrie beam rail element.

The test installation consisted of a 45.7-m-long length-of-need section of modified thrie beam guardrail with a 1.9-m-long transition section from the thrie beam to the W-beam rail element, and a 15.2-m-long ET-2000 at each end, for a total installation length of 80.0 m. The details and layout of the test installation are shown in figure 73. Photographs of the completed installation are shown in figure 74.

Soil and Weather Conditions

The test was performed the morning of June 12, 1998. No rain had occurred for the 10 days prior to the test. Moisture content at posts 18, 20, and 22 was 6.7 percent, 4.0 percent, and 5.1 percent, respectively. Weather conditions during the time of the test were as follows: wind speed: 16 km/h; wind direction: 345 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 34EC; relative humidity: 51 percent.

Test Vehicle

A 1988 GMC 7000 single-unit truck, shown in figure 75, was used for the crash test. Test inertia weight of the vehicle was 8000 kg, and its gross static weight was 8000 kg. The height to the lower edge of the vehicle bumper was 520 mm and it was 815 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in appendix B, figure 91.

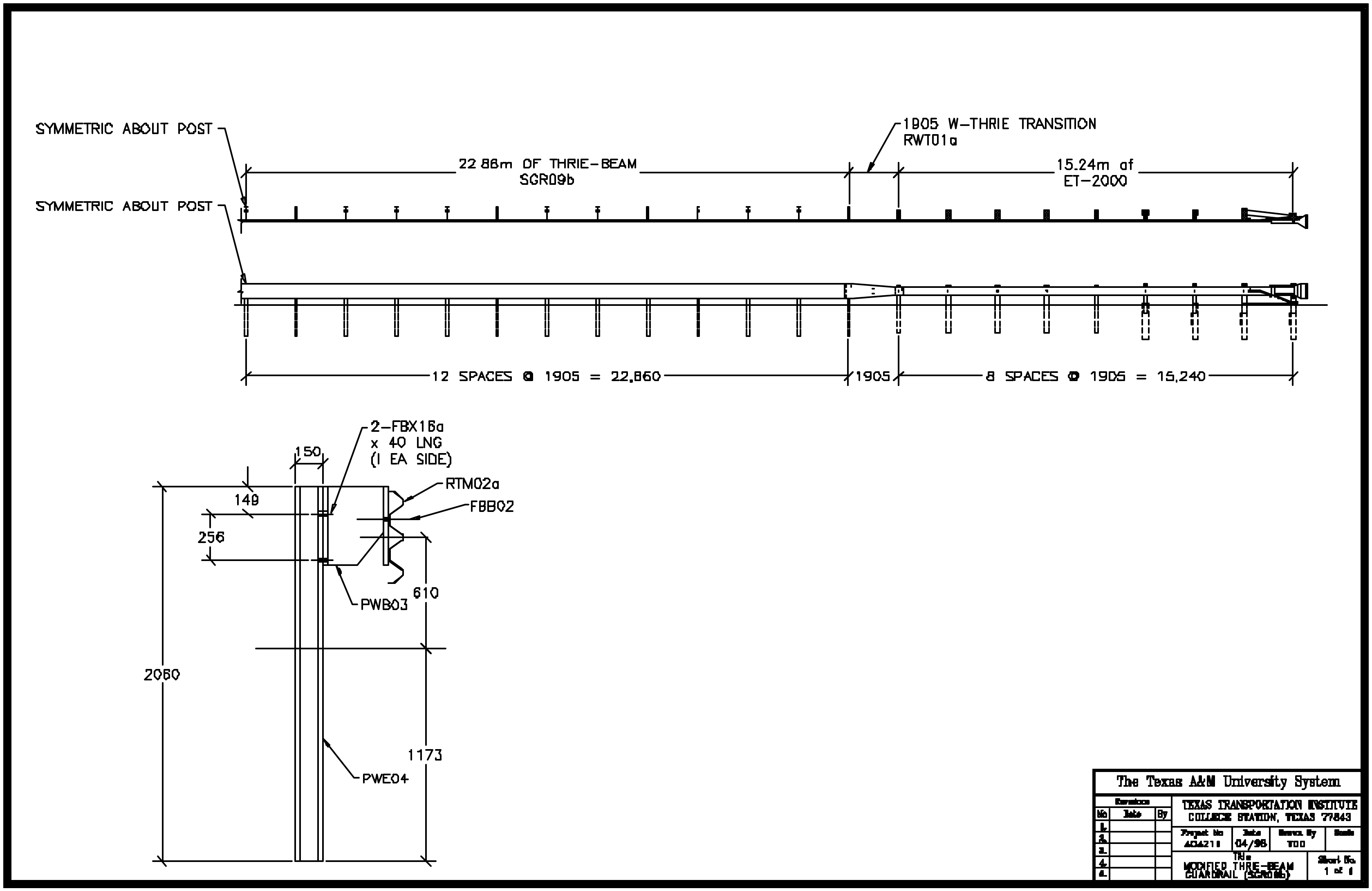


Figure 73. Details of the modified thrie beam guardrail installation for test 404211-5.

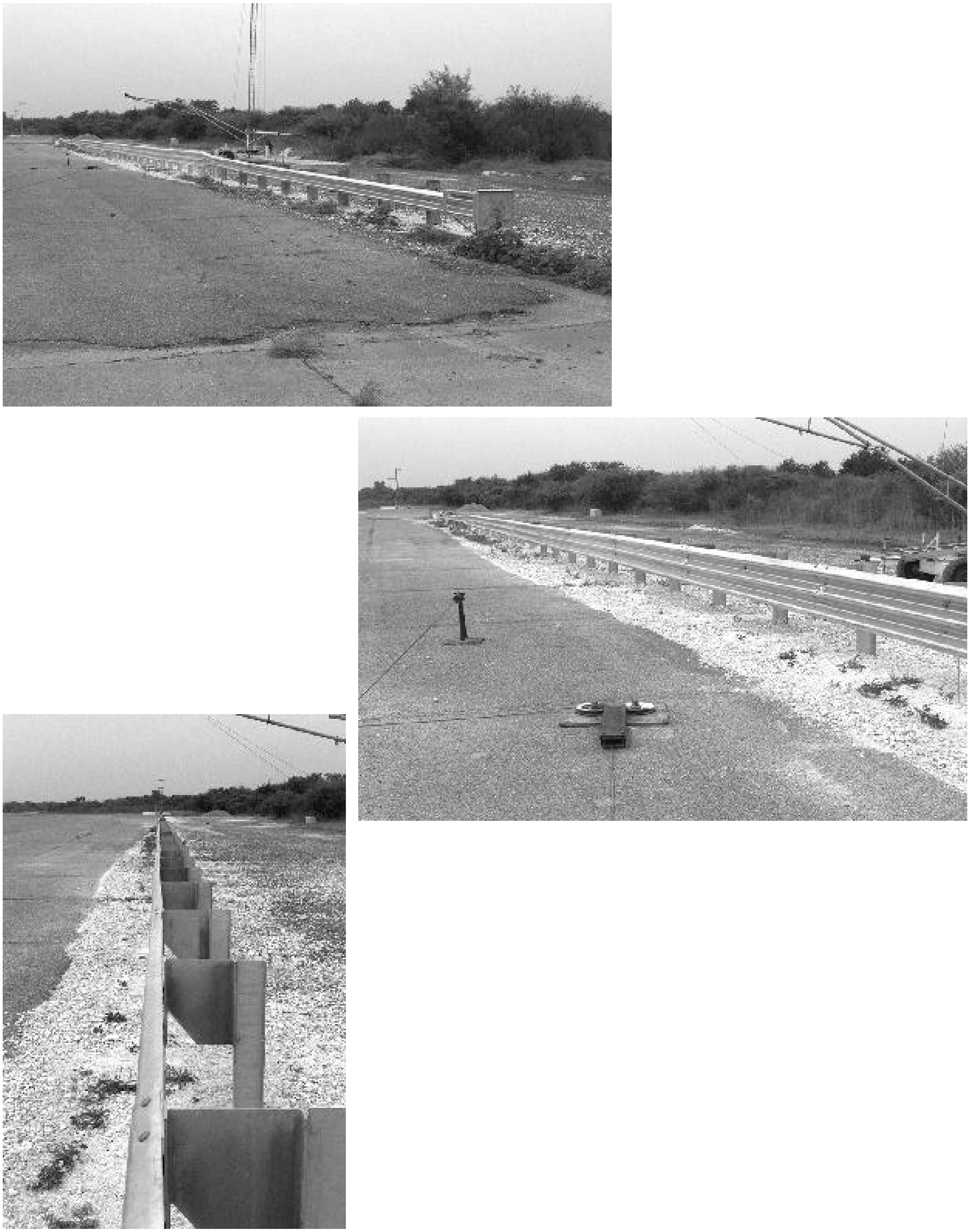


Figure 74. Modified thrie beam guardrail installation prior to test 404211-5.

Figure 75. Vehicle before test 404211-5.

Impact Description

The vehicle, traveling at 78.8 km/h, impacted the modified thrie beam guardrail 750 mm before post 18 at an impact angle of 15.7 degrees. Shortly after impact, post 18 and then post 17 moved. By 0.036 s after impact, the vehicle contacted post 18 and at 0.039 s, post 19 moved. The vehicle began to redirect at 0.061 s and post 20 moved at 0.098 s. At 0.130 s, the vehicle contacted post 19 and at 0.137 s, post 21 moved. Post 22 moved at 0.225 s and the vehicle contacted post 21 at 0.301 s. Post 23 moved at 0.322 s, the right rear tire contacted the guardrail at 0.361 s, and the front of the vehicle contacted post 22 at 0.397 s. The vehicle was traveling parallel with the guardrail at 0.416 s at a speed of 64.6 km/h. At 0.505 s, the front wheels turned to the right and the front of the vehicle lost contact with the rail at 0.521 s. The rear of the vehicle lost contact with the guardrail near post 26 at 0.612 s and was traveling at 64.0 km/h and an exit angle of 8.2 degrees. The vehicle rotated clockwise at 0.851 s and contacted the guardrail between posts 27 and 28 at 1.138 s. At 1.160 s, the front wheels turned to the left and at 1.673 s, the vehicle lost contact with the guardrail just past post 30. The vehicle continued forward and then contacted the ET-2000 between posts 37 and 38 at 3.551 s. As the vehicle continued forward, the vehicle pulled the ET-2000 head off the end. The vehicle rode off the end of the terminal and brakes on the vehicle were applied at 4.9 s. The vehicle subsequently came to rest 70.7 m down from impact and in line with the installation. Sequential photographs of the test period are shown in appendix C, figures 116 and 117.

Damage to Test Article

Damage to the modified thrie beam guardrail is shown in figure 76. Posts 19 through 26 were deformed and the blockouts on those posts were significantly deformed. The blockouts on posts 17, 18, and 27 were slightly deformed. The guardrail bolts pulled through the thrie beam at posts 20, 23, 24, and 25. Tire marks were on the face of posts 20 and 21. Length of contact during the initial collision was 16.0 m. For 2.8 m of that distance, the truck rode on top of the thrie beam. The second contact occurred between posts 27 and 28 and continued to just past post 30. The third contact occurred between posts 37 and 38 and the vehicle rode off the end, taking the ET-2000 head off the end. Maximum dynamic deflection during the test was 0.71 m and maximum permanent deformation was 0.51 m, both occurring near post 21.

Vehicle Damage

Minimal damage was sustained by the vehicle as shown in figure 77. Structural damage was received by the front axle and right front wheel. The lower right front corner of the cargo box received a dent as well as the right side fuel tank. The bumper and supports, hood, right front quarter panel, grill, and right door step were damaged. The right door was jammed and the right outside tire received gouges. Maximum exterior vehicle crush was 140 mm at the right front corner of the bumper.

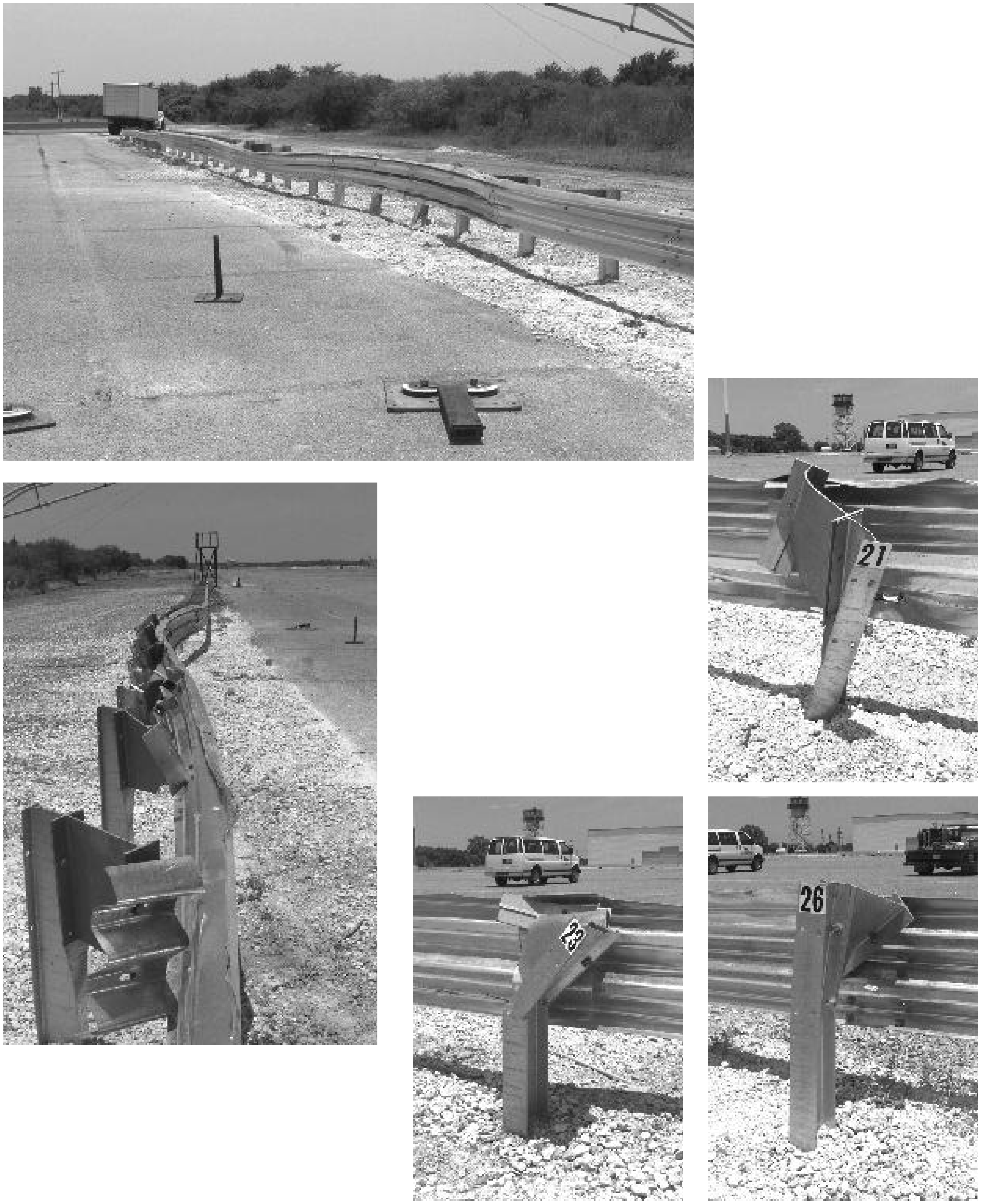


Figure 76. Installation after test 404211-5.

Figure 77. Vehicle after test 404211-5.

Occupant Risk Factors

In the longitudinal direction, the occupant impact velocity was 3.5 m/s at 0.405 s, the highest 0.010-s occupant ridedown acceleration was -2.9 g's from 0.394 to 0.404 s, and the maximum 0.050-s average acceleration was -1.4 g's between 0.215 and 0.265 s. In the lateral direction, the occupant impact velocity was 2.4 m/s at 0.301 s, the highest 0.010-s occupant ridedown acceleration was 3.8 g's from 0.531 to 0.541 s, and the maximum 0.050-s average was 2.3 g's between 0.699 and 0.749 s. These data and other pertinent information from the test are summarized in figure 78. Vehicle angular displacements are displayed in appendix D, figure 130. Vehicular accelerations versus time traces are presented in appendix E, figures 257 through 263.

Assessment of Test Results

The following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

! **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.*

Result: The modified thrie beam guardrail was contained and smoothly redirected. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 0.71 m.

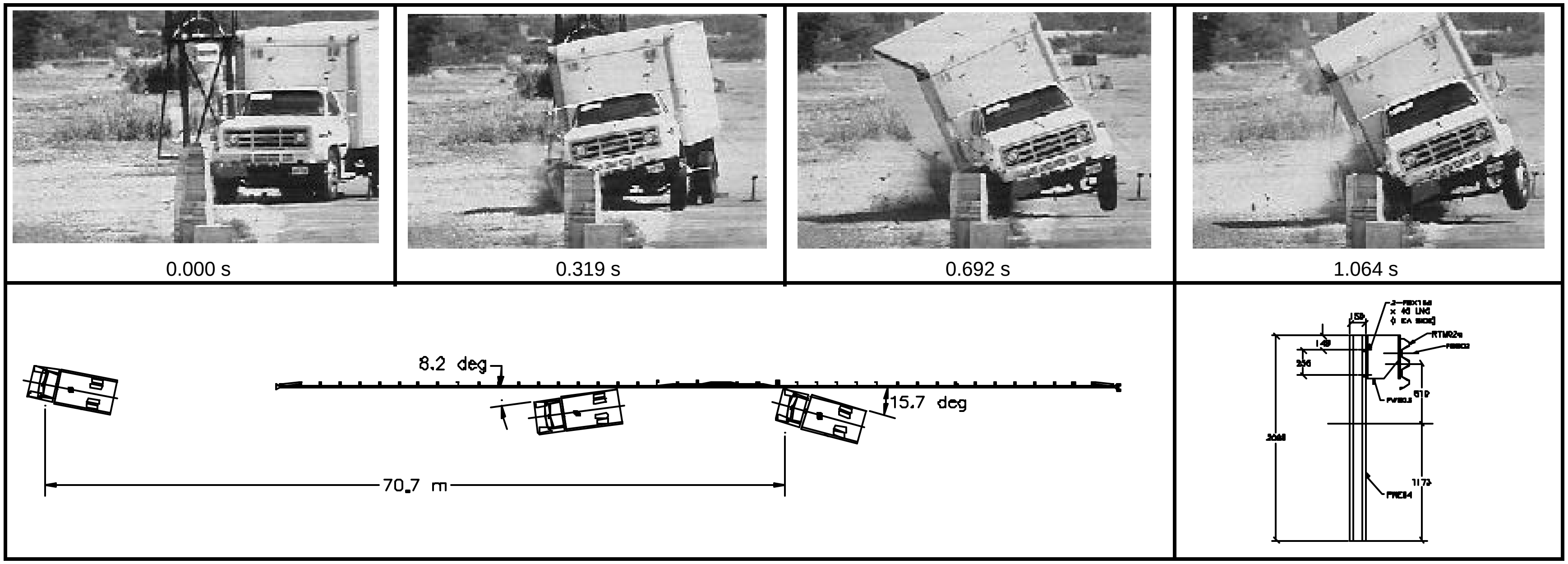
! **Occupant Risk**

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

Result: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No deformation or intrusion into the occupant compartment occurred.

G. *It is preferable, although not essential, that the vehicle remain upright during and after the collision.*

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



General Information

Test Agency	Texas Transportation Institute
Test No.	404211-5
Date	06/12/98

Test Article

Type	Guardrail
Name	Modified Thrie Beam Guardrail
Installation Length (m)	83.8
Material or Key Elements	12-gauge thrie beam on W150x14 steel posts and steel blockouts

Soil Type and Condition Standard Soil, Dry

Test Vehicle

Type	Production
Designation	8000S
Model	1988 GMC 7000 Single-Unit Truck
Mass (kg)	
Curb	5049
Test Inertial	8000
Dummy	No dummy
Gross Static	8000

Impact Conditions

Speed (km/h)	78.8
Angle (deg)	15.7

Exit Conditions

Speed (km/h)	64.0
Angle (deg)	8.2

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	3.5
y-direction	2.4
THIV (km/h)	14.1
Ridedown Accelerations (g's)	
x-direction	-2.9
y-direction	3.8
PHD (g's)	4.0
ASI	0.2
Max. 0.050-s Average (g's)	
x-direction	-1.4
y-direction	2.3
z-direction	-1.3

Test Article Deflections (m)

Dynamic	0.71
Permanent	0.51

Vehicle Damage

Exterior	
VDS	N/A
CDC	N/A
Maximum Exterior Vehicle Crush (mm)	140
Interior	
OCDI	RS0000000
Max. Occ. Compart. Deformation (mm)	0

Post-Impact Behavior

(during 1.0 s after impact)

Max. Yaw Angle (deg)	-24
Max. Pitch Angle (deg)	-4
Max. Roll Angle (deg)	20

Figure 78. Summary of results for test 404211-5, *NCHRP Report 350* test 4-12.

! **Vehicle Trajectory**

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

Result: The vehicle did not intrude into adjacent traffic lanes as it remained adjacent to the guardrail.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Result: Exit angle at loss of contact was 8.2 degrees, which was 52 percent of the impact angle.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

— **PASSENGER COMPARTMENT INTRUSION**

1. Windshield Intrusion

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

2. Body Panel Intrusion yes or (no)

— **LOSS OF VEHICLE CONTROL**

(1.) Physical loss of control

2. Loss of windshield visibility

3. Perceived threat to other vehicles

4. Debris on pavement

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

1. Harmful debris that could injure workers or others in the area

2. Harmful debris that could injure occupants in other vehicles

No debris of significance that would harm others in the area was present.

— **VEHICLE AND DEVICE CONDITION**

1. Vehicle Damage

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

2. Windshield Damage

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

3. Device Damage

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

SUMMARY AND CONCLUSIONS

TERMINALS

Buried-in-Backslope Terminal (with 6 to 1 vee ditch)

The buried-in-backslope terminal with 6 to 1 vee ditch contained and redirected the vehicle. Maximum deformation of the occupant compartment was 45 mm and was judged to not cause serious injury. The vehicle remained upright and stable during and after the collision. As shown in table 1, the buried-in-backslope terminal with 6 to 1 vee ditch performed acceptably for *NCHRP Report 350* test designation 3-35.

Buried-in-Backslope Terminal (with 4 to 1 slope)

The buried-in-backslope terminal with 4 to 1 slope contained and redirected the vehicle. Maximum deformation of the occupant compartment was 125 mm but was judged to not cause serious injury. The vehicle remained upright and stable during and after the collision. As shown in table 2, the buried-in- backslope terminal with 4 to 1 slope performed acceptably according to the required criteria for *NCHRP Report 350* test designation 3-35.

New York Terminal for 3-Cable Barrier

The New York terminal for 3-cable barrier allowed the vehicle to gate through the end. The vehicle remained upright during and immediately after the collision period, but rolled onto its side after exiting the test site for reasons not related to the performance of the guardrail. The 3-cable New York cable rail terminal met all criteria specified for test designation 3-34 of *NCHRP Report 350*, as shown in table 3.

TRANSITIONS

Vertical Wall Transition

It was found that the nested W-beam rail elements and the terminal connector could not be bolted together with the rail elements lapped on top of the connector in the direction of traffic. Therefore, in the first test, the terminal connector was lapped on top of the nested W-beams. The vertical wall transition contained and redirected the vehicle; however, the vehicle rolled onto its right side after exiting the installation. Snagging was observed on the end of the connector. The transition did not perform acceptably, due to rollover (see table 4).

For the repeat of the test, the holes in the terminal connector were enlarged for the splice bolts to be installed with the connector lapped under the nested W-beams. The W-beam with W-beam rub rail on steel posts transition contained and redirected the vehicle. The vehicle remained upright during and after the collision event. The W-beam with W-beam rub rail on steel posts transition to the vertical concrete bridge railing with the terminal connector correctly lapped under the W-beam met the required criteria for the repeat of *NCHRP Report 350* test designation 3-21, as shown in table 5.

Vertical Flared Back Transition

The vertical flared back transition contained and redirected the vehicle. After exiting the transition, the vehicle rolled one revolution and came to rest upright, 9.9 m forward of the front face of the rail element. The vertical flared back transition did not perform satisfactorily, due to rollover (see table 6).

Pennsylvania Transition

The Pennsylvania transition met the required criteria as specified for *NCHRP Report 350* test 3-21 and shown in table 7.

Nebraska Transition

The maximum occupant compartment deformation was 129 mm; however, the seam in the floor pan/firewall area opened. No sharp edges were noted in the opening and the opening was judged to not cause serious injury. Also, the vehicle did intrude into adjacent traffic lanes; however, this criterion is preferable not required. The Nebraska thrie beam transition met required criteria for *NCHRP Report 350* test 3-21, as shown in table 8.

Connecticut Transition

The Connecticut transition contained and redirected the 2000P vehicle with minimal deflection of the rail element, thereby meeting the criteria for structural adequacy. The transition also met all criteria for occupant risk, as shown in table 9. The 2000P vehicle came to rest 27.4 m laterally from the traffic face of the rail. This indicates that the vehicle would have intruded into adjacent traffic lanes; however, meeting this criterion is preferred, not required. The Connecticut transition met the required criteria specified for *NCHRP Report 350* test designation 3-21.

LONGITUDINAL BARRIERS

MB1 (WSDOT) Median Cable Barrier

As shown in table 10, the Washington 3-strand cable barrier met all criteria specified for *NCHRP Report 350* test designation 3-11. The installation permitted 3.4 m of lateral deflection, redirected the vehicle, and brought it to a safe, controlled stop within the installation. The Washington 3-strand cable barrier performs well where space permits relatively large lateral deflections.

Thrie Beam Guardrail (with steel posts and routed wood blockouts)

As shown in table 11, the thrie beam guardrail with 2.1 m long steel posts and wood blockouts met the required criteria specified for *NCHRP Report 350* test designation 3-11.

Thrie Beam on Strong Wood Posts

As can be seen in table 12, the strong wood post thrie beam guardrail met all required criteria for *NCHRP Report 350* test designation 3-11.

Modified Thrie Beam Guardrail

As can be seen in table 13, the modified thrie beam guardrail met all requirements for *NCHRP Report 350* test designation 4-12.

Table 1. Performance evaluation summary for the buried-in-backslope terminal (with 6 to 1 vee ditch), *NCHRP Report 350* test 3-35.

Test Agency: Texas Transportation Institute | Test No.: 404211-1 | Test Date: 01/29/98

NCHRP Report 350 **Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> 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 buried-in-backslope terminal with 6 to 1 vee ditch contained and redirected the vehicle. Maximum deflection of the guardrail was 0.7 m.	Pass
<u>Occupant Risk</u> D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 45 mm in the center floor pan area.	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.	Pass
<u>Vehicle Trajectory</u> 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 was 7.2 m/s and the longitudinal occupant ridedown acceleration was -9.4 g's.	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.	Exit angle at loss of contact was 8.1 degrees, which was 32 percent of the impact angle.	Pass

*Criterion K and M are preferable, not required.

Table 2. Performance evaluation summary for the buried-in-backslope terminal (4 to 1 slope), *NCHRP Report 350* test 3-35.

Test Agency: Texas Transportation Institute | Test No.: 404211-13 | Test Date: 07/27/2000

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 terminal contained and redirected the 2000-kg pickup truck. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 0.861 m.	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.	The blockout at post 9 detached but did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to others in the area. Maximum occupant compartment deformation was 125 mm and was judged to not cause serious injury.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
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 was 5.4 m/s and longitudinal ridedown acceleration was -8.3 g's.	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.	Exit angle at loss of contact was 17.5 degrees which was 68 percent of the impact angle; however, the vehicle yawed toward the installation and came to rest adjacent to the length of need.	Fail*

*Criterion K and M are preferable, not required.

Table 3. Performance evaluation summary for the New York terminal, *NCHRP Report 350* test 3-34.

Test Agency: Texas Transportation Institute | Test No.: 404211-6 | Test Date: 10/01/98

<table>
<tr><th colspan="3">NCHRP Report 350 Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td colspan="3"><u>Structural Adequacy</u>
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.</td><td>The New York terminal for 3-cable barrier allowed the vehicle to gate through the end.</td><td>Pass</td></tr>
<tr><td colspan="3"><u>Occupant Risk</u>
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>No detached elements, fragments, or debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.</td><td>Pass</td></tr>
<tr><td colspan="3">F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.</td><td>The vehicle remained upright during and immediately after the collision period.</td><td>Pass</td></tr>
<tr><td colspan="3">H. Occupant impact velocities should satisfy the following:</td><td rowspan="4">Longitudinal occupant impact velocity = 1.8 m/s
Lateral occupant impact velocity = 0.9 m/s</td><td rowspan="4">Pass</td></tr>
<tr><td colspan="3">Occupant Velocity Limits (m/s)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and lateral</td><td>9</td><td>12</td></tr>
<tr><td colspan="3">I. Occupant ridedown accelerations should satisfy the following:</td><td rowspan="4">Longitudinal ridedown acceleration = -3.1 g’s
Lateral ridedown acceleration = -3.0 g’s</td><td rowspan="4">Pass</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits (g's)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
<tr><td colspan="3"><u>Vehicle Trajectory</u>
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td colspan="3">N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest behind the installation.</td><td>Pass</td></tr>
</table>

*Criterion K is preferable, not required.

Table 4. Performance evaluation summary for the first test on the vertical wall transition, *NCHRP Report 350* test 3-21.

Test Agency: Texas Transportation Institute | Test No.: 404211-2 | Test Date: 07/27/98

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 vertical wall transition contained and redirected the vehicle. The vehicle did not penetrate, underride, or override 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.	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum reduction of space was 27 percent in the center floor pan area, which may cause serious injury.	Fail
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle rolled onto its right side after exiting the installation.	Fail
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 was 9.1 m/s and longitudinal ridedown acceleration was -15.1 g's.	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.	Exit angle at loss of contact was 7.3 degrees, which was less than 60 percent of the impact angle.	Pass

*Criterion K and M are preferable, not required.

Table 5. Performance evaluation summary for the repeat test on the vertical wall transition, *NCHRP Report 350* test 3-21.

Test Agency: Texas Transportation Institute | Test No.: 404211-12 | Test Date: 11/05/98

***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 W-beam with W-beam rub rail on steel posts transition contained and redirected the vehicle. The vehicle did not penetrate, underride, or override 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.	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 80 mm in the lateral direction near the occupant's feet.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision event.	Pass
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle came to rest 8.4 m toward traffic lanes.	Fail*
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 was 7.3 m/s and longitudinal ridedown acceleration was -6.7 g's.	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.	Exit angle at loss of contact was 13.9 degrees, which was 57 percent of the impact angle.	Pass*

*Criterion K and M are preferable, not required.

Table 6. Performance evaluation summary for the vertical flared back transition, *NCHRP Report 350* test 3-21.

Test Agency: Texas Transportation Institute | Test No.: 404211-4 | Test Date: 07/27/98

NCHRP Report 350 **Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u>		
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 vertical flared back transition contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection was 0.17 m.	Pass
<u>Occupant Risk</u>		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 75 mm in the center floor pan area.	Pass
F. The vehicle should remain upright during and after collision, although moderate roll, pitching, and yawing are acceptable.	After exiting the transition, the vehicle rolled one revolution and came to rest upright.	Fail
<u>Vehicle Trajectory</u>		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle rolled and came to rest 9.9 m toward traffic lanes.	Fail*
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 was 6.1 m/s and longitudinal ridedown acceleration was -6.1 g's.	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.	Exit angle at loss of contact was 5.2 degrees, which was less than 60 percent of the impact angle.	Pass*

* Criterion K and M are preferred, not required.

Table 7. Performance evaluation summary for Pennsylvania transition, *NCHRP Report 350* test 3-21.

Test Agency: Texas Transportation Institute | Test No.: 404211-3 | Test Date: 07/07/2000

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 Pennsylvania transition contained and redirected the 2000P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum lateral deflection was 177 mm.	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.	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 117 mm in the center floor pan area and was judged to not cause serious injury.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The 2000P vehicle remained upright 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 2000P vehicle came to rest 25.9 m toward traffic lanes, which indicated intrusion into adjacent traffic lanes.	Fail*
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 was 5.5 m/s and occupant ridedown acceleration was -8.5 g's.	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.	Exit angle at loss of contact with the transition was 13.7 degrees, which was 56 percent of the impact angle.	Pass*

*Criterion K and M are preferable, not required.

Table 8. Performance evaluation summary for the Nebraska transition, *NCHRP Report 350* test 3-21.

Test Agency: Texas Transportation Institute | Test No.: 404211-7 | Test Date: 05/16/2000

***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 Nebraska thrie beam transition contained and redirected the vehicle with minimal deformation of the rail element. The 2000P vehicle did not penetrate, underride, or override 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.	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. The floor pan and firewall were deformed and the seam where the floor pan meets the firewall was separated. Maximum occupant compartment deformation was 129 mm and damage to the interior was judged to not cause serious injury.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
Vehicle Trajectory K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	Intrusion into adjacent traffic lanes was minimal, i.e., the vehicle came to rest 6 m forward from the face for the transition.	Fail*
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 was 5.0 m/s and longitudinal ridedown acceleration was -13.9 g's.	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.	Exit angle at loss of contact was 6.8 degrees, which was 28 percent of the impact angle.	Pass*

*Criterion K and M are preferable, not required.

Table 9. Performance evaluation summary for the Connecticut transition, *NCHRP Report 350* test 3-21.

Test Agency: Texas Transportation Institute | Test No.: 404211-9 | Test Date: 04/06/2000

***NCHRP Report 350* Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u>		
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 Connecticut transition contained and redirected the 2000P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum lateral deflection was 77 mm.	Pass
<u>Occupant Risk</u>		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 130 mm in the center floor pan area and was judged to not cause serious injury.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The 2000P vehicle remained upright during and after the collision period.	Pass
<u>Vehicle Trajectory</u>		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The 2000P vehicle came to rest 27.4 m laterally from the traffic face of the rail, which indicated intrusion into adjacent traffic lanes.	Fail*
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 was 4.9 m/s and occupant ridedown acceleration was -11.4 g's.	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.	Exit angle at loss of contact with the transition was 3.7 degrees, which was 14 percent of the impact angle.	Pass*

*Criterion K and M are preferable, not required.

Table 10. Performance evaluation summary for WSDOT cable barrier, *NCHRP Report 350* test 3-11.

Test Agency: Texas Transportation Institute | Test No.: 404211-8 | Test Date: 02/16/2000

***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 Washington 3-strand cable barrier contained and redirected the 2000P vehicle. Maximum lateral deflection of the barrier was 3.4 m.	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.	No detached elements, fragments, or debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
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 as the vehicle came to rest over post 22.	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.	The longitudinal occupant impact velocity was 2.2 m/s and ridedown acceleration was -2.7 g's.	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 vehicle did not exit the test installation.	N/A*

*Criterion K and M are preferable, not required.

Table 11. Performance evaluation summary for the thrie beam guardrail (with steel posts/routed wood blockouts), *NCHRP Report 350* test 3-11.

Test Agency: Texas Transportation Institute | Test No.: 404211-10 | Test Date: 04/09/99

***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 thrie beam guardrail with 2.1-m steel posts and routed wood blockouts contained and redirected the 2000P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum lateral deflection of the installation was 0.58 m.	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.	The rail element separated from post 15. No other detached elements, fragments, or other debris were present. Neither the separated rail element nor the post penetrated nor showed potential for penetrating the occupant compartment nor to present undue hazard to others in the area. Maximum occupant compartment deformation was 75 mm in the center floor pan area.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The 2000P vehicle remained upright and relatively stable during and after the collision event.	Pass
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did intrude into adjacent traffic lanes as it came to rest 67.0 m down from impact and 30.5 m toward traffic lanes.	Fail*
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 was 7.0 m/s and longitudinal ridedown acceleration was -7.6 g’s.	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.	Exit angle at loss of contact with the installation was 11.3 degrees, which was 46 percent of the impact angle.	Pass*

*Criterion K and M are preferable, not required.

Table 12. Performance evaluation summary for the thrie beam guardrail on strong wood posts, *NCHRP Report 350* test 3-11.

Test Agency: Texas Transportation Institute | Test No.: 404211-11 | Test Date: 07/03/98

NCHRP Report 350 **Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u>		
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 strong wood post thrie beam guardrail contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the installation was 0.68 m.	Pass
<u>Occupant Risk</u>		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 30 mm in the center front floor pan area under the instrument panel and should not cause serious injury.	Pass
F. The vehicle should remain upright during and after collision, although moderate rolling, pitching, and yawing are acceptable.	The vehicle remained upright during and after the collision.	Pass
<u>Vehicle Trajectory</u>		
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 was 6.3 m/s and longitudinal ridedown acceleration was -8.4 g's.	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 was 14.7 degrees, which was 62 percent of the impact angle; however, the vehicle steered back toward the installation.	Fail*

*Criterion preferable, not required.

Table 13. Performance evaluation summary for the modified thrie beam guardrail, *NCHRP Report 350* test 4-12.

Test Agency: Texas Transportation Institute | Test No.: 404211-5 | Test Date: 06/12/98

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
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 modified thrie beam guardrail was contained and smoothly redirected. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection was 0.71 m.	Pass
<u>Occupant Risk</u>		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No deformation or intrusion into the occupant compartment occurred.	Pass
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The vehicle remained upright and stable during and after the collision.	Pass
<u>Vehicle Trajectory</u>		
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 as it remained adjacent to the guardrail.	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.	Exit angle at loss of contact was 8.2 degrees, which was 52 percent of the impact angle.	Pass

REFERENCE

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

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

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 five uniaxial accelerometers mounted in the following locations: (1) center top surface of the instrument panel; (2) inside end of right front wheel spindle; (3) inside end of left front wheel spindle; (4) top of engine block; and (5) bottom of engine block. The location of each accelerometer is reported in tables 14 through 24. These accelerometers were ENDEVCO Model 7264A low mass piezoresistive accelerometers with a ±2000 g range.

Onboard data acquisition is provided by a 16-channel, Prosig P4010 system. Each analog channel has integral signal conditioning, fixed frequency anti-alias filtering, and a programmable transducer bridge power supply. Each P4010, four-channel POD contains one megabyte of battery backed memory allowing for more than 13 seconds of storage at a maximum of 10,000 samples per second per channel. All channels are synchronized by a common external clock. The accuracy of this system is ±0.1 percent.

In addition, 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 (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO Model 2262CA, piezoresistive accelerometers with a ±100 g range.

The accelerometers are strain gauge type with a linear millivolt output proportional to acceleration. Angular rate transducers are solid state, gas flow units designed for high-“g” service. Signal conditioners and amplifiers in the test vehicle increase the low level signals to a ±2.5 volt maximum level. The signal conditioners also provide the capability of an R-Cal or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15-channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals, from the test vehicle, are recorded before the test and immediately afterwards. A crystal controlled time reference signal is simultaneously recorded with the data. Pressure-sensitive switches on the bumper of the impacting vehicle are actuated prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an “event” mark on the data record to establish the instant of contact with the installation.

Table 14. Locations of vehicle accelerometers for test 404211-1.

Location	X (mm)* (distance from front axle)	Y (mm)* (distance from centerline)	Z (mm)* (distance from ground)	Data Axis
Instrument panel	-845	0	-1305	+X
Right front wheel spindle	0	+720	-360	+X
Left front wheel spindle	0	-720	-360	-Y
Top of engine block	+60	0	-890	+X
Bottom of engine block	-230	-40	-315	+X
Vehicle c.g.	-1480	-90	-660	+X,+Y,+Z
Vehicle rear axle	-3225	-90	-865	+X,+Y,+Z

*Reference point: X=0 at front axle Y=0 at centerline Z=0 at ground
Sign convention: +X=forward +Y=right +Z=down

Table 15. Locations of vehicle accelerometers for test 404211-6.

Location	X (mm) (distance from front axle)	Y (mm) (distance from centerline)	Z (mm) (distance from ground)	Data Axis
Instrument panel	-485	0	-970	+X
Right front wheel spindle	50	+655	-225	+X
Left front wheel spindle	50	-655	-225	+X
Top of engine block	+160	0	-760	+X
Bottom of engine block	+130	0	-275	+X
Vehicle c.g.	-900	0	-385	+X,+Y,+Z
Vehicle rear axle	-2310	-160	-490	+X,+Y

*Reference point: X=0 at front axle Y=0 at centerline Z=0 at ground
Sign convention: +X=forward +Y=right +Z=down

Table 16. Locations of vehicle accelerometers for test 404211-2.

Location	X (mm) (distance from front axle)	Y (mm) (distance from centerline)	Z (mm) (distance from ground)	Data Axis
Instrument panel	-860	0	-1390	+X
Right front brake caliper	0	+720	-350	-Y
Left front brake caliper	0	-720	-350	+X
Top of engine block	+90	0	-865	+X
Bottom of engine block	-240	0	-320	+X
Vehicle c.g.	-1480	0	-730	+X,+Y,+Z
Vehicle rear axle	-3375	0	-915	+X,+Y,+Z

*Reference point:	X=0 at front axle	Y=0 at centerline	Z=0 at ground
Sign convention:	+X=forward	+Y=right	+Z=down

Table 17. Locations of vehicle accelerometers for test 404211-12.

Location	X (mm) (distance from front axle)	Y (mm) (distance from centerline)	Z (mm) (distance from ground)	Data Axis
Instrument panel	-670	0	-1220	+X
Right front wheel spindle	0	+690	-350	-Y
Left front wheel spindle	0	-690	-350	+X
Top of engine block	+90	0	-900	+X
Bottom of engine block	-330	0	-320	+X
Vehicle c.g.	-1480	0	-660	+X,+Y,+Z
Vehicle rear axle	-3350	0	-860	+X,+Y,+Z

*Reference point:	X=0 at front axle	Y=0 at centerline	Z=0 at ground
Sign convention:	+X=forward	+Y=right	+Z=down

Table 18. Locations of vehicle accelerometers for test 404211-4.

Location	X (mm) (distance from front axle)	Y (mm) (distance from centerline)	Z (mm) (distance from ground)	Data Axis
Instrument panel	-850	0	-1400	+X
Right front brake caliper	0	+710	-350	+Y
Left front brake caliper	0	-710	-350	+X
Top of engine block	+100	0	-880	+X
Bottom of engine block	-295	0	-340	+X
Vehicle c.g.	-1500	0	-670	+X,+Y,+Z
Vehicle rear axle	-3350	0	-830	+X,+Y,+Z

*Reference point: X=0 at front axle Y=0 at centerline Z=0 at ground
Sign convention: +X=forward +Y=right +Z=down

Table 19. Locations of vehicle accelerometers for test 404211-3.

Location	X (mm) (distance from front axle)	Y (mm) (distance from centerline)	Z (mm) (distance from ground)	Data Axis
Instrument panel	-805	0	-1310	+X
Right front wheel spindle	0	+720	-360	+X
Left front wheel spindle	0	-720	-360	+Y
Top of engine block	+120	-60	-1010	+X
Bottom of engine block	+350	-220	-435	+X
Vehicle c.g.	-1480	0	-670	+X,+Y,+Z
Vehicle rear axle	-3350	0	-840	+X,+Y,+Z

*Reference point: X=0 at front axle Y=0 at centerline Z=0 at ground
Sign convention: +X=forward +Y=right +Z=down

Table 20. Locations of vehicle accelerometers for test 404211-7.

Location	X (mm) (distance from front axle)	Y (mm) (distance from centerline)	Z (mm) (distance from ground)	Data Axis
Instrument panel	-830	0	-1345	+X
Right front wheel spindle	0	+725	-376	+X
Left front wheel spindle	0	-725	-376	+Y
Top of engine block	+100	-50	-885	+X
Bottom of engine block	-390	0	-320	+X
Vehicle c.g.	-1480	0	-700	+X,+Y,+Z
Vehicle rear axle	-3350	0	-820	+X,+Y,+Z

*Reference point: X=0 at front axle Y=0 at centerline Z=0 at ground
Sign convention: +X=forward +Y=right +Z=down

Table 21. Locations of vehicle accelerometers for test 404211-9.

Location	X (mm) (distance from front axle)*	Y (mm) (distance from centerline)*	Z (mm) (distance from ground)*	Data Axis
Instrument panel	-860	0	-1270	+X
Right front wheel spindle	0	+710	-350	+X
Left front wheel spindle	0	-710	-350	+Y
Top of engine block	+80	-70	-890	+X
Bottom of engine block	-340	-100	-310	+X
Vehicle c.g.	-1490	0	-660	+X,+Y,+Z
Vehicle rear axle	-3380	0	-820	+X,+Y,+Z

*Reference point: X=0 at front axle Y=0 at centerline Z=0 at ground
Sign convention: +X=forward +Y=right +Z=down

Table 22. Locations of vehicle accelerometers for test 404211-8.

Location	X (mm)* (distance from front axle)	Y (mm)* (distance from centerline)	Z (mm)* (distance from ground)	Data Axis
Instrument panel	-850	0	-1360	+X
Right front wheel spindle	0	+720	-370	+X
Left front wheel spindle	0	-720	-370	+Y
Top of engine block	+80	+60	-880	+X
Bottom of engine block	-370	0	-360	+X
Vehicle c.g.	-1480	0	-720	+X,+Y,+Z
Vehicle rear axle	-3395	0	-870	+X,+Y,+Z

*Reference point: X=0 at front axle Y=0 at centerline Z=0 at ground
Sign convention: +X=forward +Y=right +Z=down

Table 23. Locations of vehicle accelerometers for test 404211-10.

Location	X (mm) (distance from front axle)	Y (mm) (distance from centerline)	Z (mm) (distance from ground)	Data Axis
Instrument panel	-600	0	-1250	+X
Right front wheel spindle	0	+720	-360	-Y
Left front wheel spindle	0	-720	-360	+X
Top of engine block	+15	+50	-1100	+X
Bottom of engine block	-360	-65	-320	+X
Vehicle c.g.	-1470	0	-660	+X,+Y,+Z
Vehicle rear axle	-3350	0	-900	+X,+Y,+Z

*Reference point: X=0 at front axle Y=0 at centerline Z=0 at ground
Sign convention: +X=forward +Y=right +Z=down

Table 24. Locations of vehicle accelerometers for test 404211-11.

Location	**X (mm) (distance from front axle)**	**Y (mm) (distance from centerline)**	**Z (mm) (distance from ground)**	**Data Axis**
Instrument panel	-690	0	-1270	+X
Right front brake caliper	0	+720	-350	-Y
Left front brake caliper	0	-720	-350	+X
Top of engine block	+90	0	-865	+X
Bottom of engine block	-270	-50	-320	+X
Vehicle c.g.	-1380	0	-670	+X,+Y,+Z
Vehicle rear axle	-3320	0	-855	+X,+Y,+Z

*Reference point: X=0 at front axle Y=0 at centerline Z=0 at ground
Sign convention: +X=forward +Y=right +Z=down

The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto separate tracks of a 28-track, (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine, digitized and filtered with Society of Automotive Engineers (SAE J211) filters, using a microcomputer, at 10,000 samples per second per channel, for analysis and evaluation of impact performance.

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

The Test Risk Assessment Program (TRAP) uses the 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. TRAP 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 are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0005-s intervals and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

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

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; one placed behind the installation at an angle; and 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 tape switches is positioned on the impacting vehicle to indicate the instant of contact with the installation and is visible from each camera. The films from these high-speed cameras are analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain event time, displacement, and angular data. A 16-mm movie cine, a BetaCam, a VHS-format video camera, and still cameras are used to document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

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

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

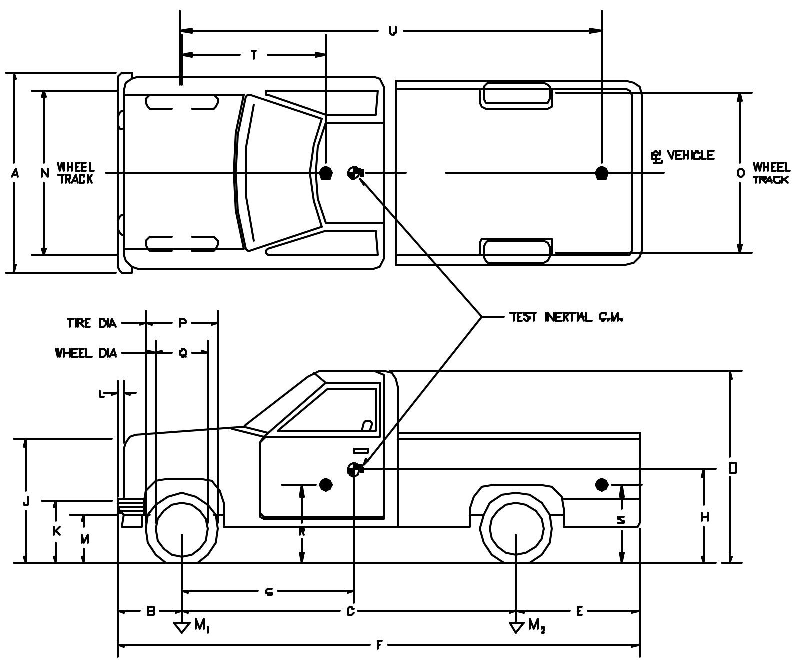
DATE: 1/29/98 TEST NO.: 404211-1 VIN NO.: 1GTFC24K45Z510455

YEAR: 1995 MAKE: GMC MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 114516 TIRE SIZE: LT 225 75R16

MASS DISTRIBUTION (kg) LF 554 RF 534 LR 468 RR 444

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: R-80mm TO LT

ENGINE TYPE: V-8

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1850	E	1300	J	1045	N	1585	R	660
B	740	F	5395	K	600	O	1610	S	855
C	3355	G	1529.9	L	80	P	740	T	1480
D	1740	H		M	395	Q	440	U	3455

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1130	1088	1131
M_2	803	912	945
M_T	1933	2000	2076

Figure 79. Vehicle properties for test 404211-1.

Table 25. Exterior crush measurements for test 404211-1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant X1 % X2 , 2 _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	Top front bumper	800	430	760	-430	-270	-130	-40	-15	0	-380
2	950 mm above ground	1100	520	4950	-70	-10	-35	-75	-320	-520	0

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

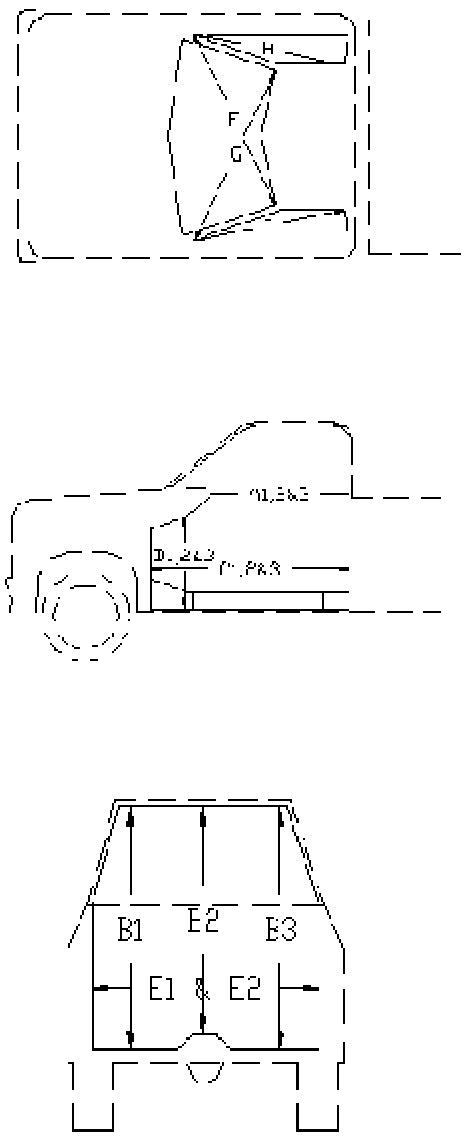
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 26. Occupant compartment deformations for test 404211-1.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	920	908
A2	946	950
A3	941	946
B1	1070	1070
B2	1064	1019
B3	1075	1075
C1	1379	1375
C2	1262	1251
C3	1377	1377
D1	321	325
D2	151	151
D3	311	311
E1	1595	1600
E2	1582	1625
F	1465	1465
G	1465	1460
H	800	800
I	800	790

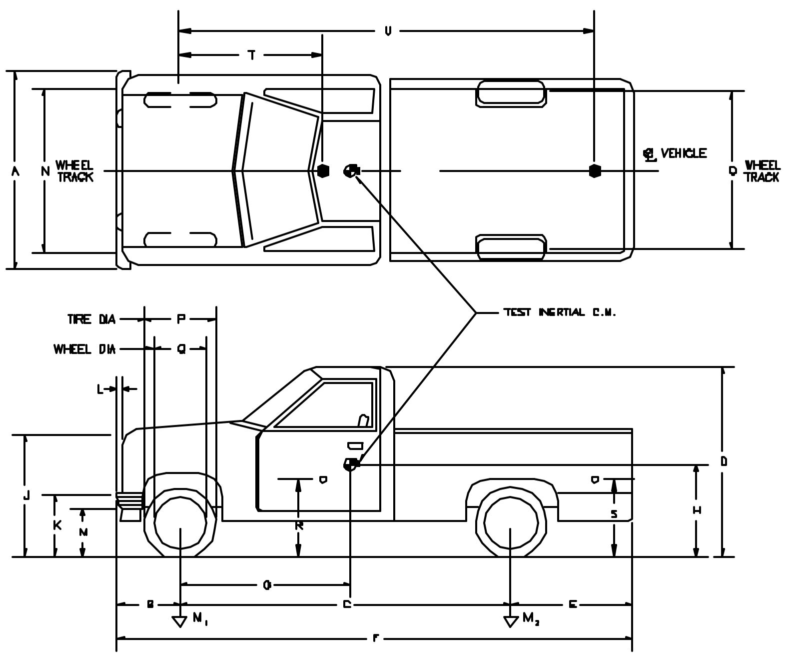
DATE: 07/27/00 TEST NO.: 404211-13 VIN NO.: 1GTGC24K7SE535801

YEAR: 1995 MAKE: GMC MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 107154 TIRE SIZE: LT 245 75R16

MASS DISTRIBUTION (kg) LF 562 RF 554 LR 429 RR 455

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES R-70 mm ToLT

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1840	E	1310	J	1080	N	1600	R	730
B	820	F	5480	K	650	O	1620	S	900
C	3350	G	1480.7	L	80	P	770	T	1470
D	1840	H		N	430	Q	440	U	4050

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1175	1116	1160
M_2	932	884	915
M_T	2107	2000	2075

Figure 80. Vehicle properties for test 404211-13.

Table 27. Exterior crush measurements for test 404211-13.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	**Side Damage**
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant X1 % X2 / 2 , _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	Front bumper	1170	430	1600	-430	-360	-210	-80	+5	+70	0
2	800 mm above ground	1170	550	1800	0	-40	-65	-130	N/A	-550	890
									Wheel Well		

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

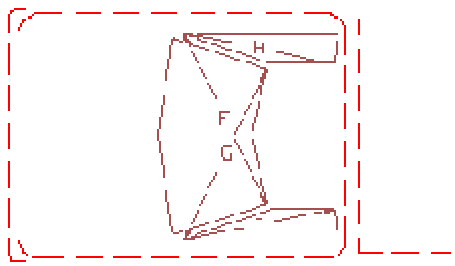
***Measure and document on the vehicle diagram the location of the maximum crush.

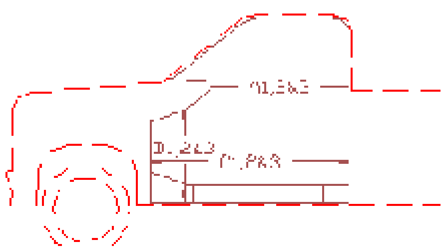
Note: Use as many lines/columns as necessary to describe each damage profile.

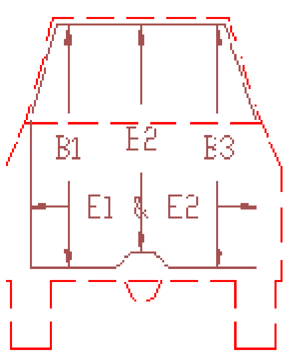
Table 28. Occupant compartment measurements for test 404211-13.

Truck

Occupant Compartment Deformation







	BEFORE	AFTER
A1	870	864
A2	882	882
A3	910	913
B1	1076	1068
B2	1065	970
B3	1075	1075
B4	1100	975
C1	1377	1377
C2	1265	1255
C3	1369	1369
D1	316	313
D2	155	125
D3	314	314
E1	1585	1600
E2	1596	1637
F	1470	1470
G	1470	1460
H	900	900
I	900	900
J	1525	1482

DATE: 10-1-98 TEST NO.: 404211-6 VIN NO.: KNJPT05H8P6128916

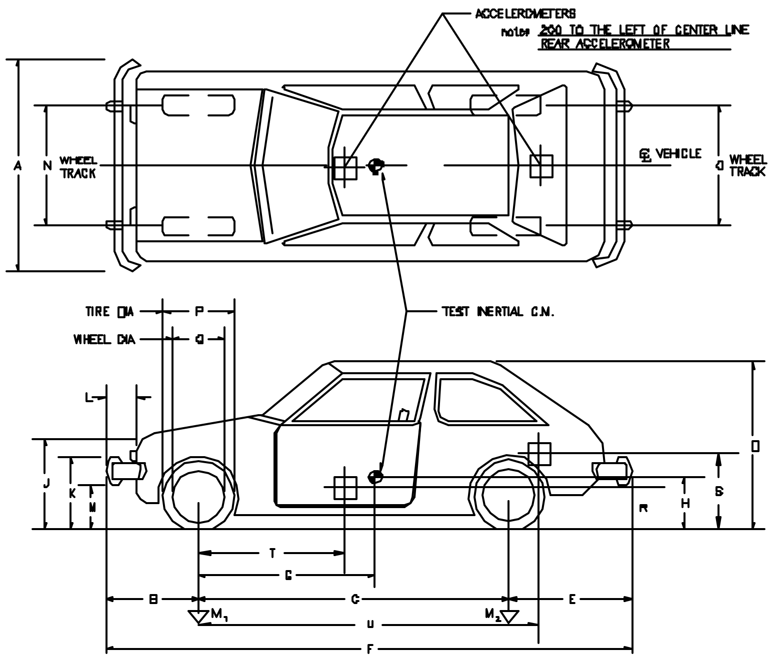
YEAR: 1992 MAKE: FORD MODEL: FESTIVA

TIRE INFLATION PRESSURE: ____ ODOMETER: 48100 TIRE SIZE: 155R12

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

MASS DISTRIBUTION (kg) LF 253 RF 249 LR 163 RR 155

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 CYL.

ENGINE CID: 1.3L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 78 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1500	E	550	J	770	N	1400	R	385
B	630	F	3465	K	530	O	1405	S	470
C	2285	G	886.1	L	116	P	515	T	920
D	1430	H		M	355	Q	330	U	2430

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	527	502	542
M_2	283	318	354
M_T	810	820	896

Figure 81. Vehicle properties for test 404211-6.

Table 29. Exterior crush measurements for test 404211-6.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing: B1 ____ X1 ____ B2 ____ X2 ____ Bowing constant X1 % X2 , 2 ____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
No measurable damage											

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

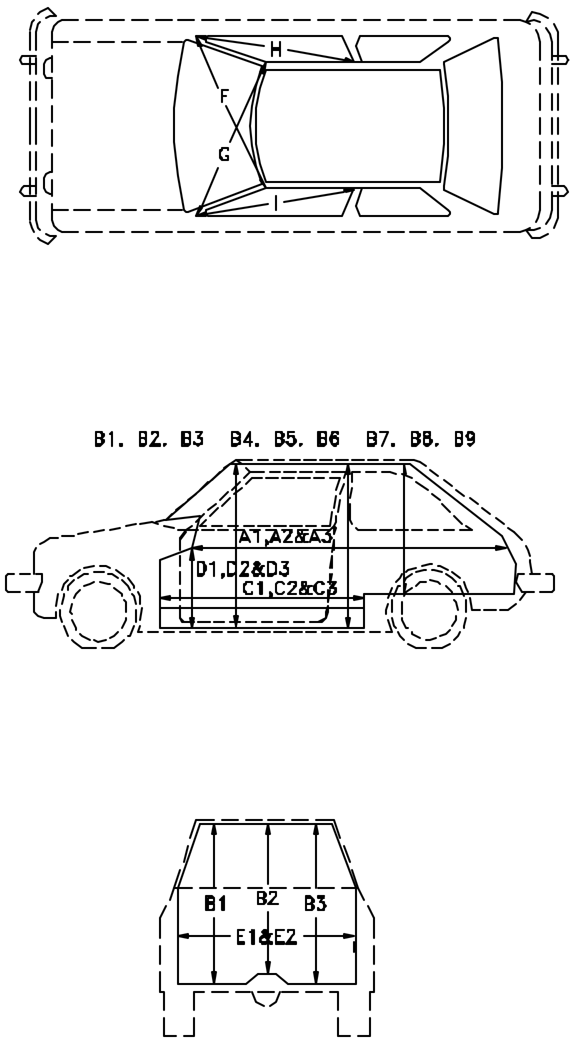
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 30. Occupant compartment measurements for test 404211-6.

Small Car

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1545	1545
A2	2030	2030
A3	1555	1555
B1	1047	1047
B2	932	932
B3	1056	1056
B4	960	910
B5	970	920
B6	965	950
B7	---	---
B8	---	---
B9	---	---
C1	635	635
C2	640	640
C3	630	630
D1	350	350
D2	217	217
D3	335	335
E1	1255	1255
E2	1255	1255
F	1200	1200
G	1200	1200
H	1100	1000
I	1100	1100

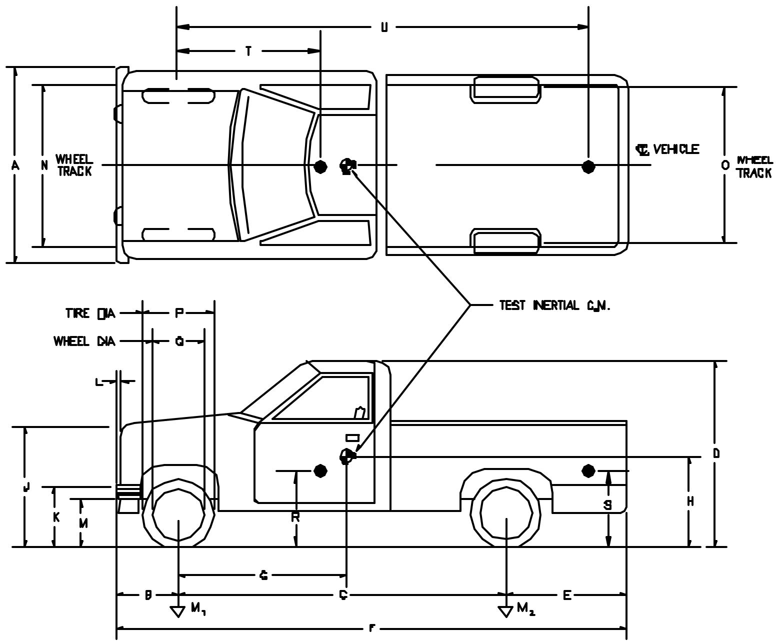
DATE: 7-27-98 TEST NO.: 404211-2 VIN NO.: 1GCGC24K5SE128169

YEAR: 1995 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 161856 TIRE SIZE: 245 75R16

MASS DISTRIBUTION (kg) LF 543 RF 554 LR 449 RR 454

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 74 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1840	E	1290	J	1075	N	1595	R	730
B	760	F	5400	K	660	O	1620	S	820
C	3350	G	1215.5	L	75	P	755	T	1480
D	1850	H		M	440	Q	445	U	3350

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1164	1097	1143
M_2	892	903	931
M_T	2056	2000	2074

Figure 82. Vehicle properties for test 404211-2.

Table 31. Exterior crush measurements for test 404211-2.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC) (check one) < 4 inches T________ $ 4 inches ________	Bowing constant $\frac{X1 \% X2}{2}$ ' _____

Note: Measure C_1 to C_6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width ** (CDC)	Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Top front bumper	880	540	500	0	130	150	340	480	540	+250
1	Top front wheel well 930 mm above ground	880	530	2070	0	90	110	200	240	530	+770

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

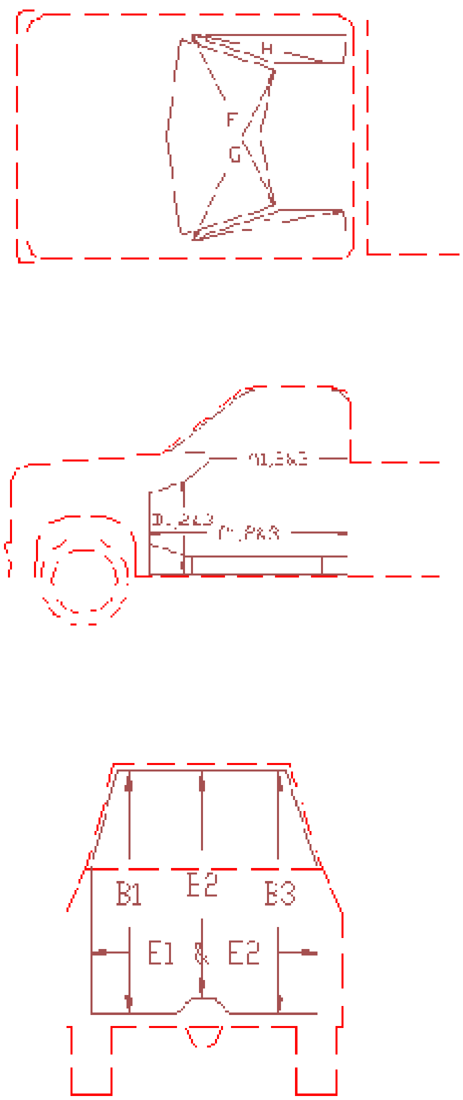
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 32. Occupant compartment measurements for test 404211-2.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	955	990
A2	971	1002
A3	952	940
B1	1084	1074
B2	972	904
B3	1085	1015
C1	1370	1380
C2	1245	1148
C3	1372	1270
D1	331	329
D2	150	110
D3	315	310
E1	1585	1640
E2	1600	1700
F	1470	1460
G	1470	1465
H	1100	1095
I	1100	1095

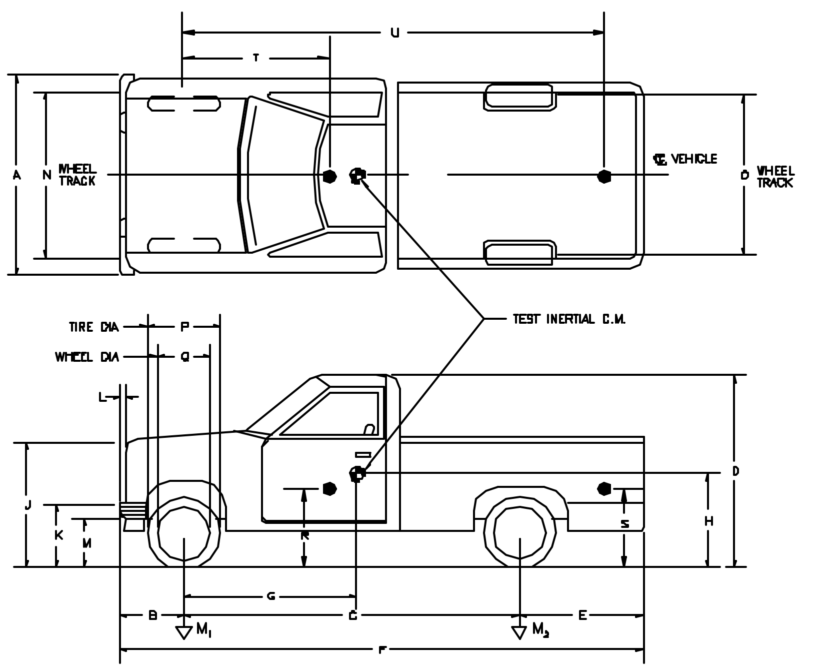
DATE: 11-5-98 TEST NO.: 404211-12 VIN NO.: 1GCFC24K7RZ264298

YEAR: 1994 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 185621 TIRE SIZE: 245 75R16

MASS DISTRIBUTION (kg) LF 545 RF 523 LR 490 RR 442

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

6 LUGS

DUMMY DATA:

TYPE: 50th percentile male

MASS: 77 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1860	E	1350	J	1020	N	1590	R	660
B	760	F	5460	K	615	O	1620	S	860
C	3350	G	156.1	L	80	P	730	T	1480
D	1760	H		M	385	Q	445	U	3350

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1095	1068	1114
M_2	830	932	963
M_T	1925	2000	2077

Figure 83. Vehicle properties for test 404211-12.

Table 33. Exterior crush measurements for test 404211-12.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant $\frac{X1 \% X2}{2}$, _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	At front bumper	700	410	670	0	40	60	120	240	410	+260
2	Bumper height	700	500	1640	20	130	n/a	n/a	410	500	+1540

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

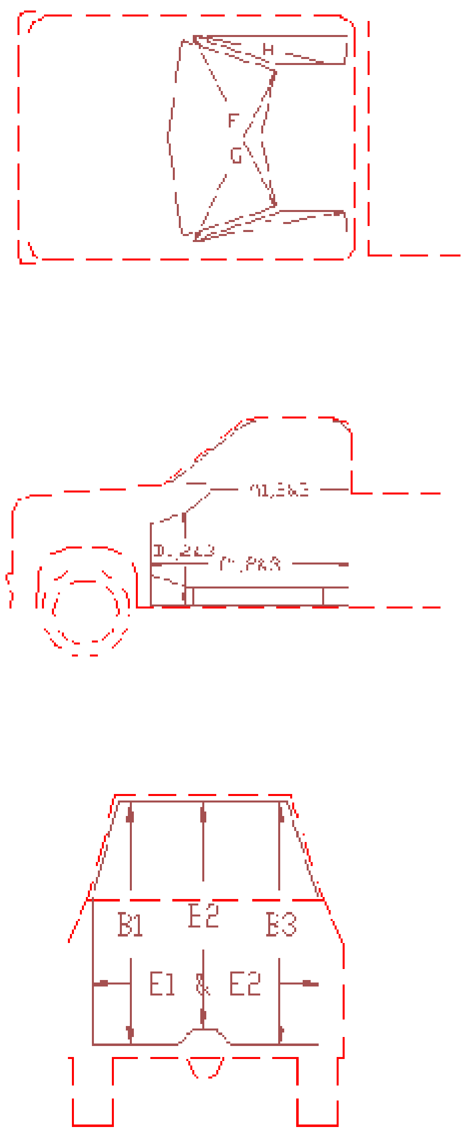
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 34. Occupant compartment measurements for test 404211-12.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1040	1045
A2	1082	1080
A3	1040	1030
B1	1070	1070
B2	1055	985
B3	1086	1075
C1	1370	1370
C2	1247	1190
C3	1367	1340
D1	310	315
D2	73	50
D3	309	295
E1	1590	1570
E2	1595	1585
F	1470	1465
G	1470	1470
H	900	885
I	900	900
J	1525	1445

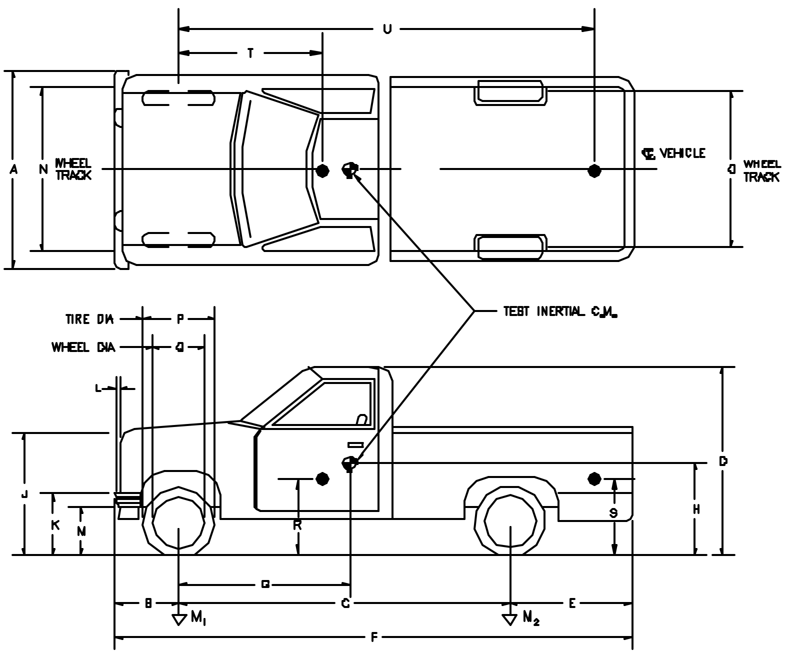
DATE: 8-11-98 TEST NO.: 404211-4 VIN NO.: 1GCFC24K7RE189349

YEAR: 1994 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 101856 TIRE SIZE: 245 75R16

MASS DISTRIBUTION (kg) LF 541 RF 530 LR 475 RR 454

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES:

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

6 LUGS

DUMMY DATA:

TYPE: 50th percentile male

MASS: 74 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1860	E	1290	J	1020	N	1585	R	670
B	730	F	5370	K	600	O	1625	S	830
C	3350	G		L	65	P	740	T	1500
D	1780	H		M	380	Q	445	U	3350

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1092	1071	1114
M_2	773	929	960
M_T	1865	2000	2074

Figure 84. Vehicle properties for test 404211-4.

Table 35. Exterior crush measurements for test 404211-4.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches T________ $ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant X1 % X2 / 2 , _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	At front bumper	700	530	600	530	250	130	80	30	0	-320
2	Above front bumper	700	410	1100	0	10	40	200	460	410	+1630

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

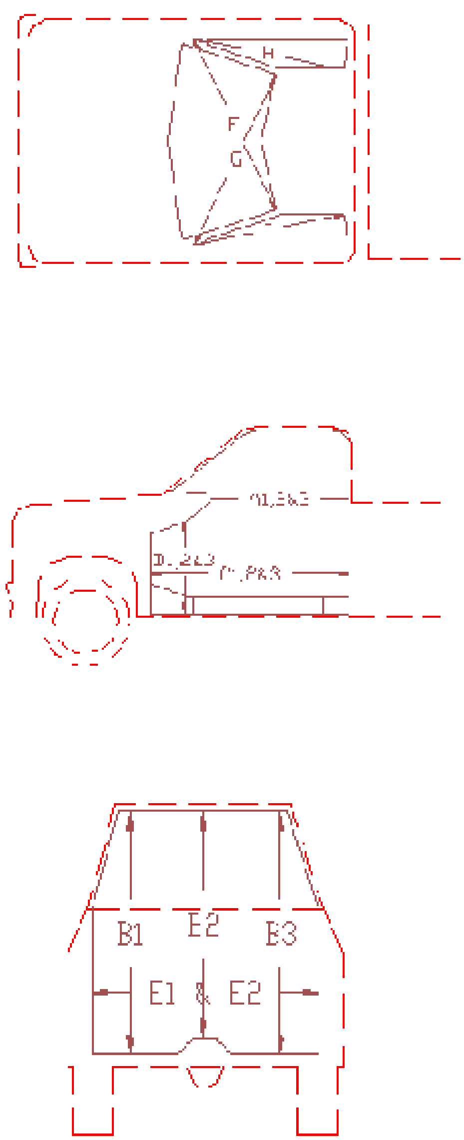
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 36. Occupant compartment measurements for test 404211-4.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1055	1040
A2	1090	1100
A3	1050	1067
B1	1076	1070
B2	1060	985
B3	1074	1093
C1	1372	1345
C2	1262	1255
C3	1372	1372
D1	310	315
D2	95	75
D3	312	320
E1	1593	1606
E2	1595	1630
F	1475	1460
G	1475	1465
H	900	890
I	900	880

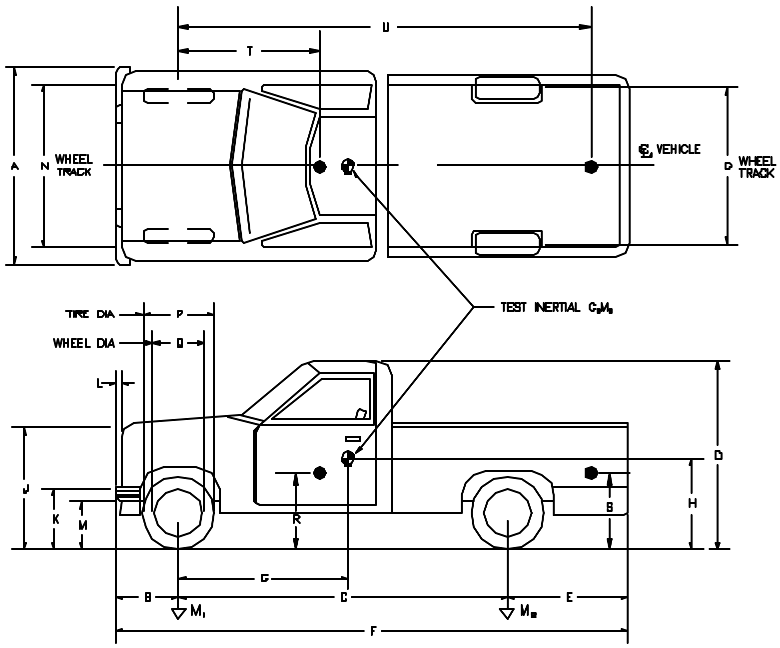
DATE: 07/07/00 TEST NO.: 404211-3 VIN NO.: 1GCFC24MSTZ178965

YEAR: 1996 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 117574 TIRE SIZE: LT 225 75R16

MASS DISTRIBUTION (kg) LF 587 RF 542 LR 447 RR 424

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

6 LUGS

DUMMY DATA:

TYPE: 50th percentile male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1895	E	1300	J	1025	N	1590	R	670
B	840	F	5490	K	600	O	1610	S	840
C	3350	G	1459	L	75	P	730	T	1480
D	1800	H		M	390	Q	445	U	3350

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1131	1129	1175
M_2	772	871	900
M_T	1903	2000	2075

Figure 85. Vehicle properties for test 404211-3.

Table 37. Exterior crush measurements for test 404211-3.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing constant $\frac{X1 + X2}{2} =$ _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	Front bumper	800	-440	700	-440	-350	-220	-100	-20	+60	-350
2	800 mm above ground	800	330	1300	15	50	100	N/A	N/A	330	+1330
								Wheel Well			

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

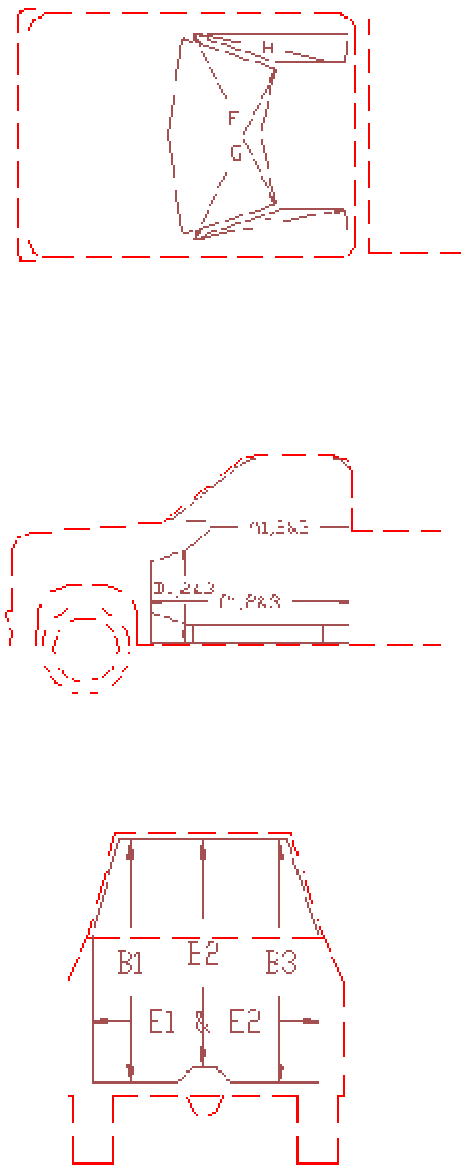
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 38. Occupant compartment measurements for test 404211-3.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	868	842
A2	880	880
A3	910	910
B1	1075	1100
B2	1067	950
B3	1076	1076
C1	1377	1360
C2	1377	1377
C3	1375	1375
D1	320	348
D2	163	163
D3	317	317
E1	1587	1645
E2	1595	1670
F	1470	1465
G	1470	1455
H	900	900
I	900	895
J	1520	1460

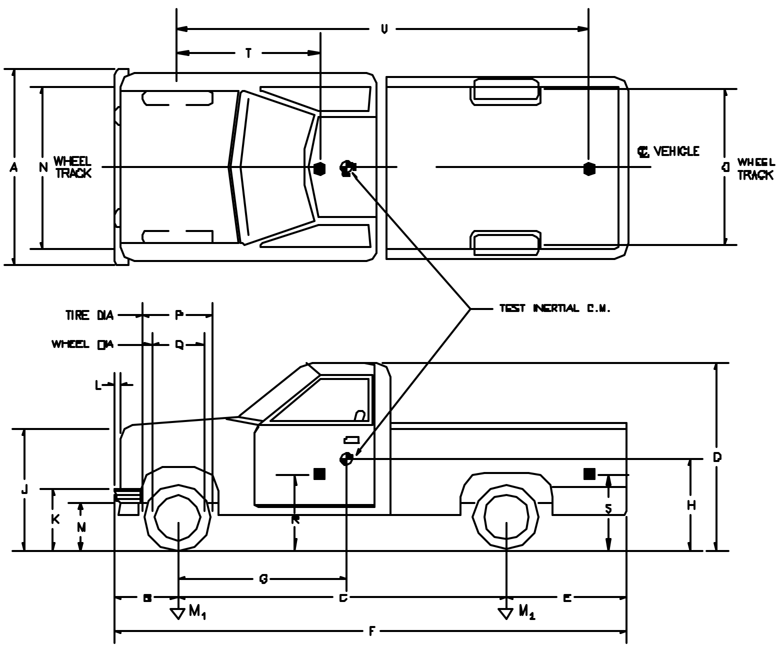
DATE: 05/16/00 TEST NO.: 404211-7 VIN NO.: 1GCFC24K0SZ145367

YEAR: 1995 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 153919 TIRE SIZE: LT 245 75R16

MASS DISTRIBUTION (kg) LF 556 RF 571 LR 445 RR 428

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

6 LUGS

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	1840	E	1310	J	1020	N	1595	R	700
B	820	F	5480	K	590	O	1610	S	820
C	3350	G	1462.3	L	65	P	720	T	1480
D	1760	H		M	370	Q	445	U	3350

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1158	1127	1170
M_2	774	873	905
M_T	1932	2000	2075

Figure 86. Vehicle properties for test 404211-7.

Table 39. Exterior crush measurements for test 404211-7.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing: B1 ____ X1 ____ B2 ____ X2 ____ Bowing constant X1 % X2 ' 2 ____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	Front bumper	900	400	700	400	320	260	90	-40	+25	-350
2	830 mm above ground	900	380	2060	25	60	110	210	N/A	380	+930
									Wheel Well		

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

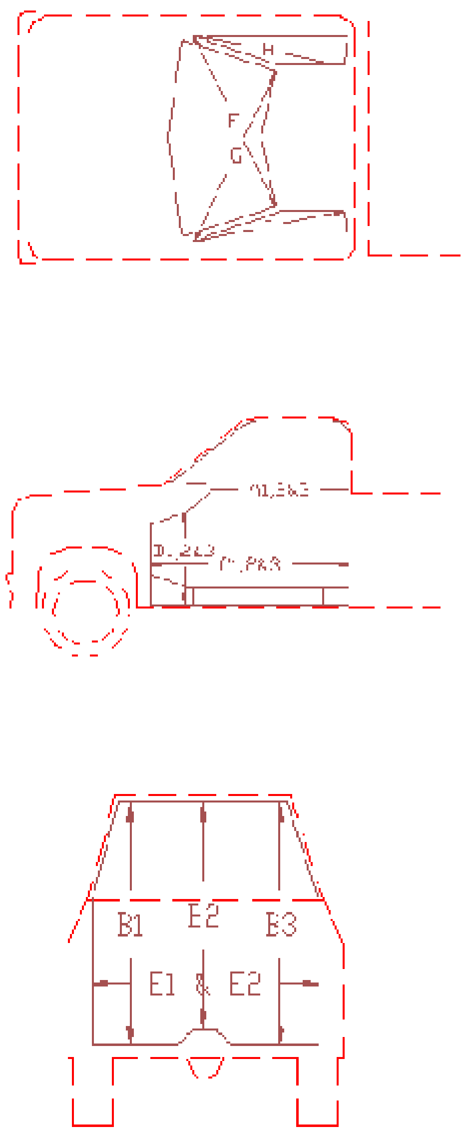
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 40. Occupant compartment measurements for test 404211-7.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	870	855
A2	878	860
A3	911	911
B1	1105	976
B2	1066	990
B3	1069	1069
C1	1348	1370
C2	1260	1255
C3	1347	1347
D1	322	360
D2	160	170
D3	311	311
E1	1588	1618
E2	1590	1690
F	1465	1465
G	1465	1455
H	900	900
I	900	890
J	1522	1522

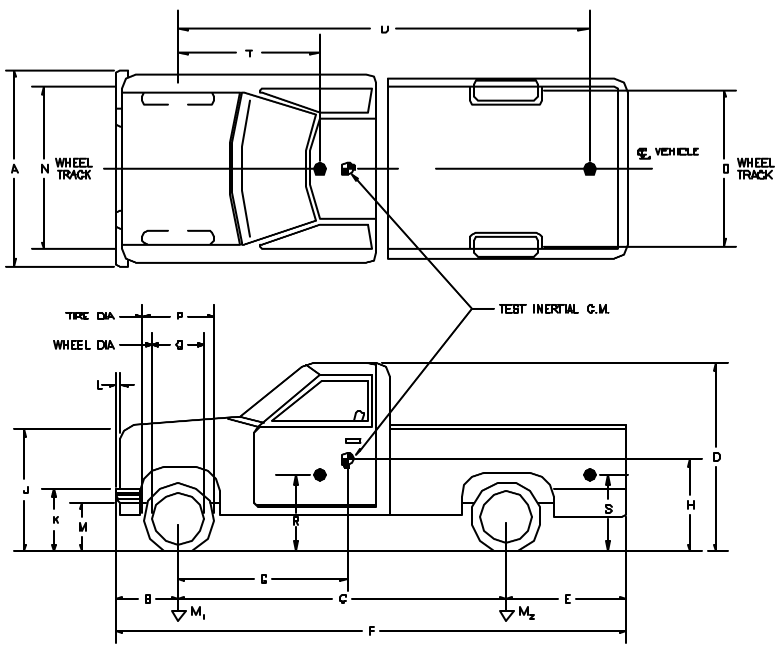
DATE: 04/06/00 TEST NO.: 404211-9 VIN NO.: 1GCFC24K7SZ162652

YEAR: 1995 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ________ ODOMETER: 100180 TIRE SIZE: LT 225 75R16

MASS DISTRIBUTION (kg) LF 562 RF 521 LR 460 RR 457

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ________

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7L

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ________

MASS: ________

SEAT POSITION: ________

GEOMETRY – (mm)

A	1835	E	1315	J	1020	N	1590	R	660
B	820	F	5485	K	590	O	1610	S	810
C	3350	G	1536	L	65	P	720	T	1475
D	1760	H		M	370	Q	445	U	3350

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1130	1083	1126
M_2	810	917	949
M_T	1940	2000	2075

Figure 87. Vehicle properties for test 404211-9.

Table 41. Exterior crush measurements for test 404211-9.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant X1 % X2 , 2 _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	Front bumper	900	430	-650	-430	-320	-200	-80	-10	+30	-325
2	680 mm above ground	900	400	2150	50	75	75	140	N/A	400	+800
									Wheel Well		

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

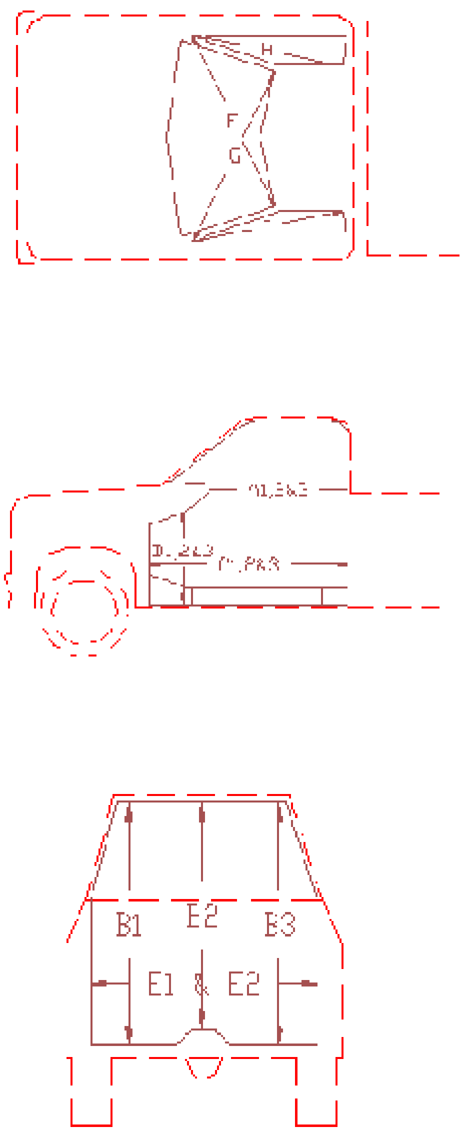
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 42. Occupant compartment measurements for test 404211-9.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	868	860
A2	890	890
A3	911	911
B1	1078	1111
B2	1115	985
B3	1072	1072
C1	1381	1345
C2	1261	1247
C3	1373	1373
D1	315	360
D2	160	120
D3	312	312
E1	1588	1643
E2	1595	1700
F	1460	1460
G	1460	1465
H	900	900
I	900	905
J	1625	1450

DATE: 02-16-00 TEST NO.: 404211-8 VIN NO.: 1GCFC24K1SZ110515

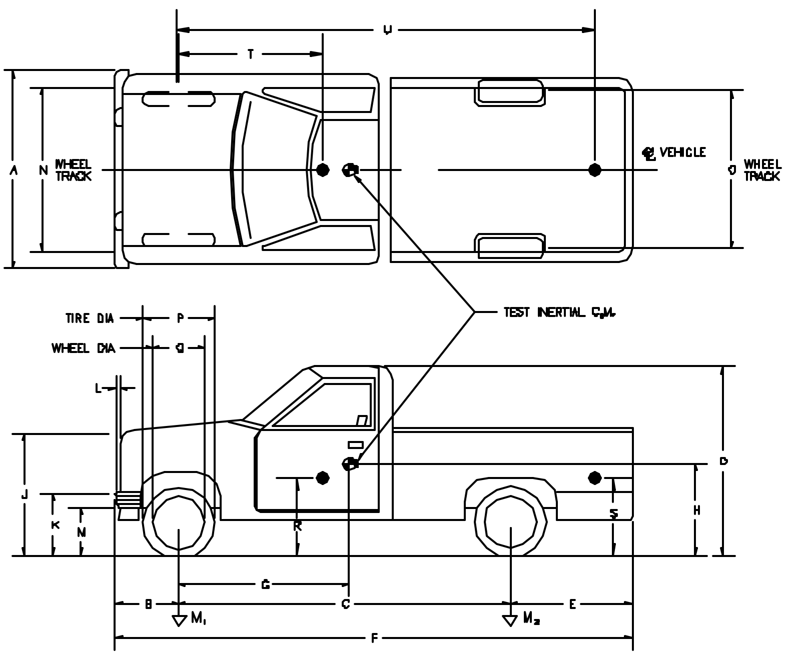
YEAR: 1995 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 143611 TIRE SIZE: LT 245 75R16

MASS DISTRIBUTION (kg) LF 560 RF 540 LR 455 RR 445

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Dent In Rt Rear Quarter Panel (Marked)



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

6 LUGS

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	860	E	1320	J	1050	N	1600	R	700
B	810	F	5480	K	620	O	1620	S	875
C	3350	G	1507.5	L	75	P	750	T	1500
D	1780	H		M	400	Q	445	U	3350

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1110	1100	
M_2	822	900	
M_T	1932	2000	

Figure 88. Vehicle properties for test 404211-8.

Table 43. Exterior crush measurements for test 404211-8.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width __________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant $\frac{X1 \% X2}{2}$, _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width ** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Above front bumper	250	320	340	320	220	100	0			-640
2	650 mm above ground	470	240	1200	0	50	N/A	N/A	210	280	5480

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

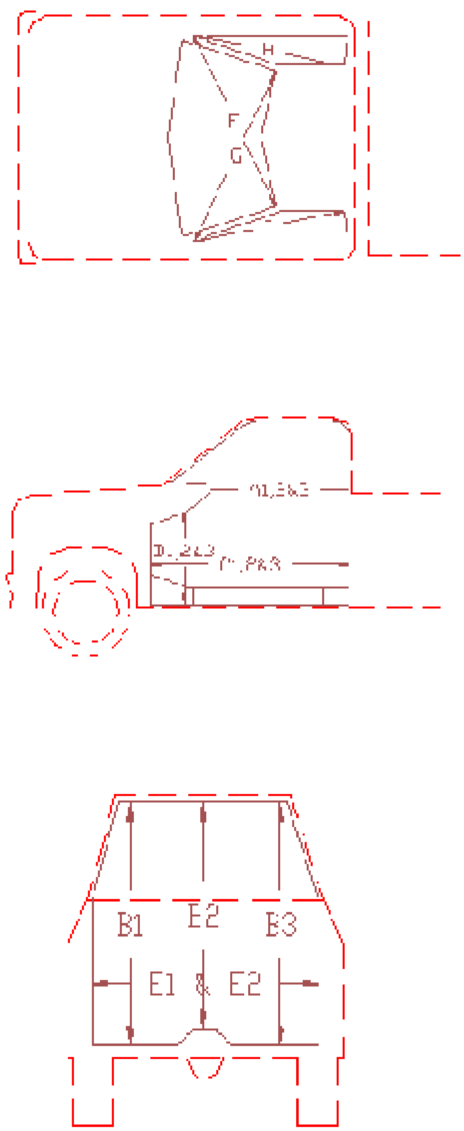
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 44. Occupant compartment measurements for test 404211-8.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	867	867
A2	920	920
A3	910	910
B1	1070	1070
B2	1059	1059
B3	1067	1067
C1	1376	1376
C2	1266	1266
C3	1372	1372
D1	311	311
D2	152	152
D3	308	308
E1	1579	1579
E2	1597	1597
F	1475	1475
G	1475	1475
H	800	800
I	800	800

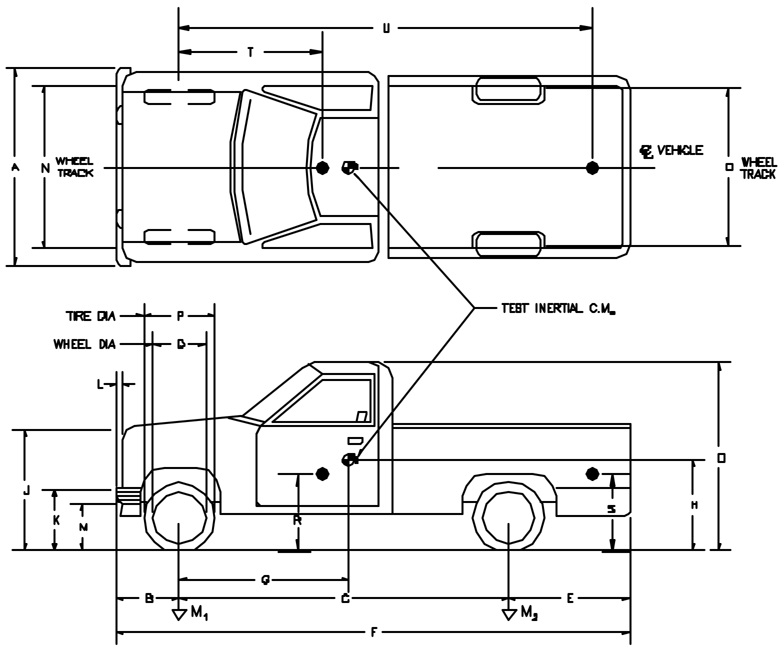
DATE: 04/09/99 TEST NO.: 404211-10 VIN NO.: 1GCFC24K7PZ191771

YEAR: 1993 MAKE: CHEVROLET MODEL: CHEYENNE 2500 P/U

TIRE INFLATION PRESSURE: ________ ODOMETER: 255695 TIRE SIZE: 245 75R16

MASS DISTRIBUTION (kg) LF 564 RF 518 LR 463 RR 455

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: R-100 TO LT

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

6 LUGS

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A 1830	E 1280	J 1030	N 1585	R 665
B 845	F 5475	K 605	O 1620	S 885
C 3350	G 1537.7	L 65	P 750	T 1480
D 1815	H	M 390	Q 445	U 4020

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1102	1082	1126
M_2	803	918	950
M_T	1905	2000	2076

Figure 89. Vehicle properties for test 404211-10.

Table 45. Exterior crush measurements for test 404211-10.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing constant X1 % X2 / 2 , _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width ** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front bumper	790	280	680	0	40	120	210	240	280	+340
2	Top front wheel well	790	200	1200	0	30	60	20	140	200	+1525

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

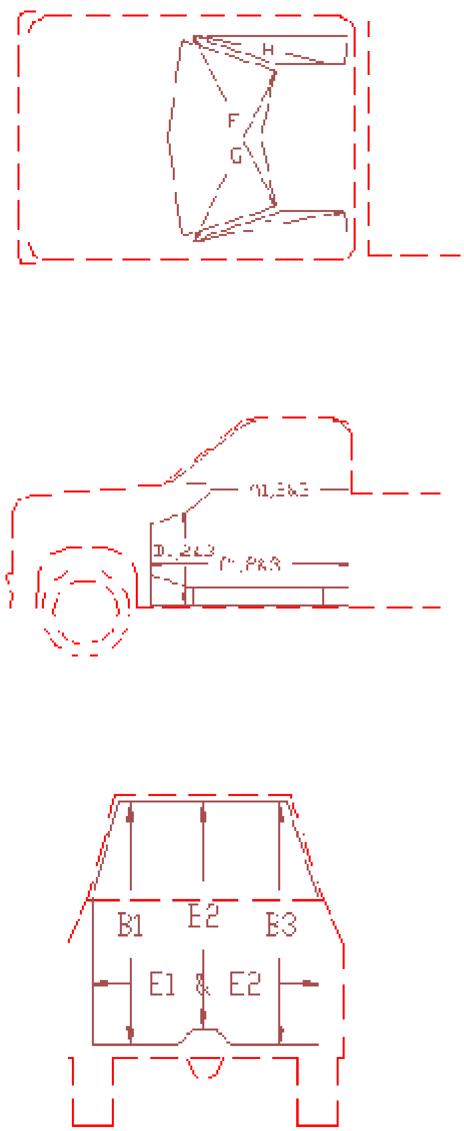
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 46. Occupant compartment measurements for test 404211-10.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1035	1035
A2	928	928
A3	1044	1044
B1	1076	1076
B2	1055	980
B3	1087	1076
C1	1370	1370
C2	1342	1342
C3	1370	1370
D1	301	301
D2	100	62
D3	309	301
E1	1604	1604
E2	1605	1614
F	1470	1470
G	1470	1470
H	990	990
I	990	990
J	1518	1498

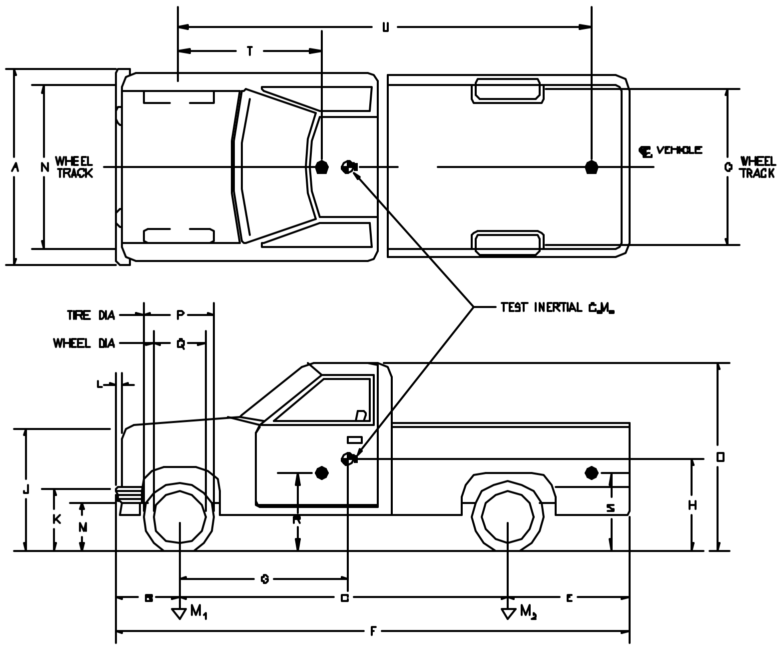
DATE: 07/03/98 TEST NO.: 404211-11 VIN NO.: 1GCFC24KET2169844

YEAR: 1993 MAKE: CHEVROLET MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 162202 TIRE SIZE: LT 245 75R16

MASS DISTRIBUTION (kg) LF 551 RF 519 LR 468 RR 462

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES:

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1900	E	1330	J	1040	N	1575	R	650
B	785	F	5465	K	600	O	1615	S	860
C	3350	G	1557.8	L	70	P	730	T	1500
D	1790	H		M	370	Q	440	U	3350

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1092	1070	1118
M_2	769	930	957
M_T	1861	2000	2075

Figure 90. Vehicle properties for test 404211-11.

Table 47. Exterior crush measurements for test 404211-11.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	**Side Damage**
Undeformed end width ______	Bowing: B1 _____ X1 _____
Corner shift: A1 ______	B2 _____ X2 _____
A2 ______	
End shift at frame (CDC) (check one) < 4 inches ______ $ 4 inches ______	Bowing constant $\frac{X1 \% X2}{2}$ ' _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	Top front bumper	800	470	660	0	70	120	180	290	470	+330
2	Top front wheel well	800	300	2150	0	15	30	85	60	300	+1130

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

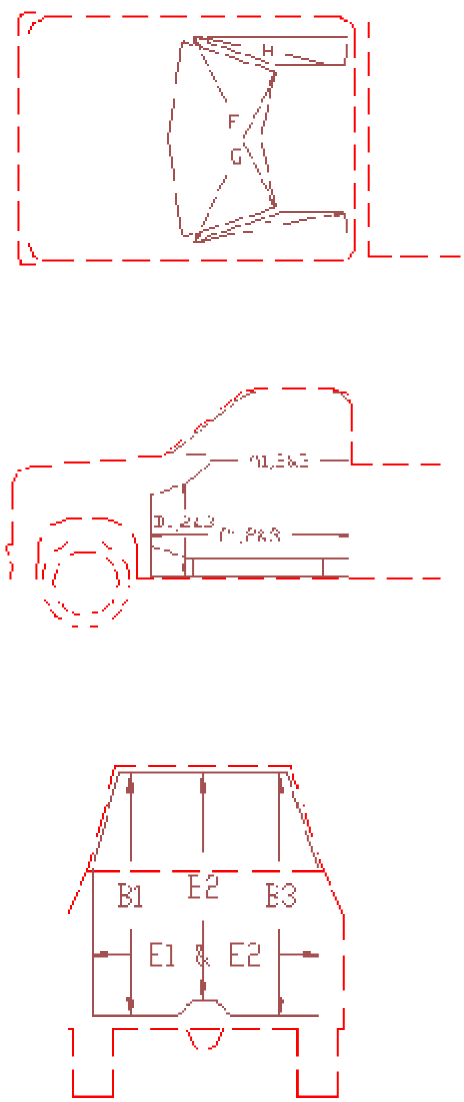
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 48. Occupant compartment measurements for test 404211-11.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1040	1040
A2	1077	1077
A3	1040	1040
B1	1075	1075
B2	1020	980
B3	1086	1077
C1	1380	1380
C2	1240	1240
C3	1370	1370
D1	306	306
D2	95	65
D3	310	302
E1	1600	1588
E2	1595	1598
F	1075	1465
G	1075	1075
H	1100	1100
I	1100	1100

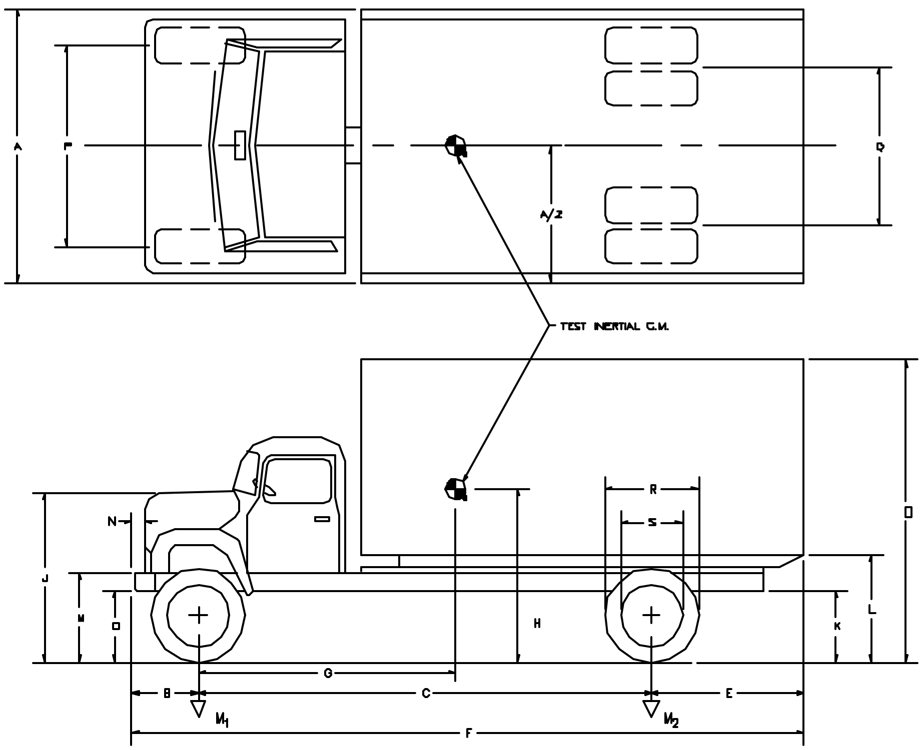
DATE: 6-12-98 TEST NO.: 404211-5 VIN NO.: 1GDJ7D1B5JV513347

YEAR: 1988 MAKE: Chevrolet ODOMETER: 67672 TIRE SIZE: 11R22.5

MODEL: 7000

MASS DISTRIBUTION (kg) LF 1565 RF 1614 LR 2399 RR 2422

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



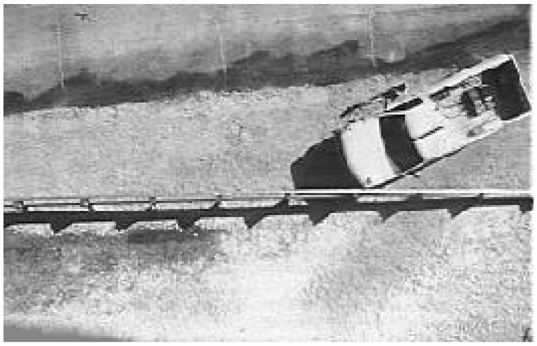
GEOMETRY—(mm)

A 2290	D 3440	G 3121.6	K 850	N 85	Q 1850
B 760	E 2150	H 1247.1	L 1270	O 520	R 1060
C 5180	F 8090	J 1560	M 815	P 1920	S 610

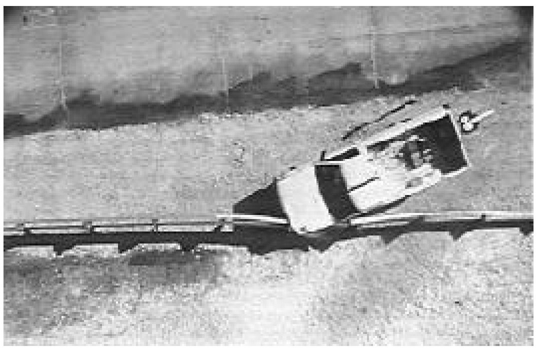
MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	2300	3179	
M_2	2749	4821	
M_T	5049	8000	

Figure 91. Vehicle properties for test 404211-5.

APPENDIX C. SEQUENTIAL PHOTOGRAPHS




0.000 s

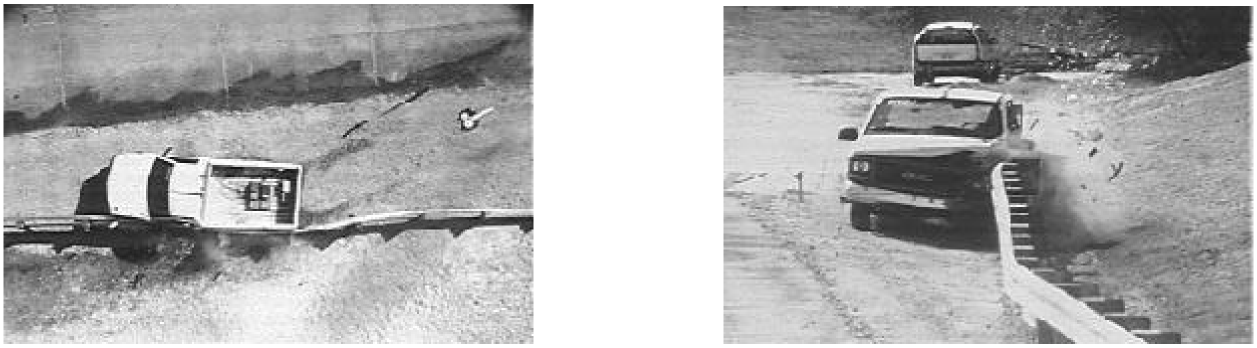



0.074 s

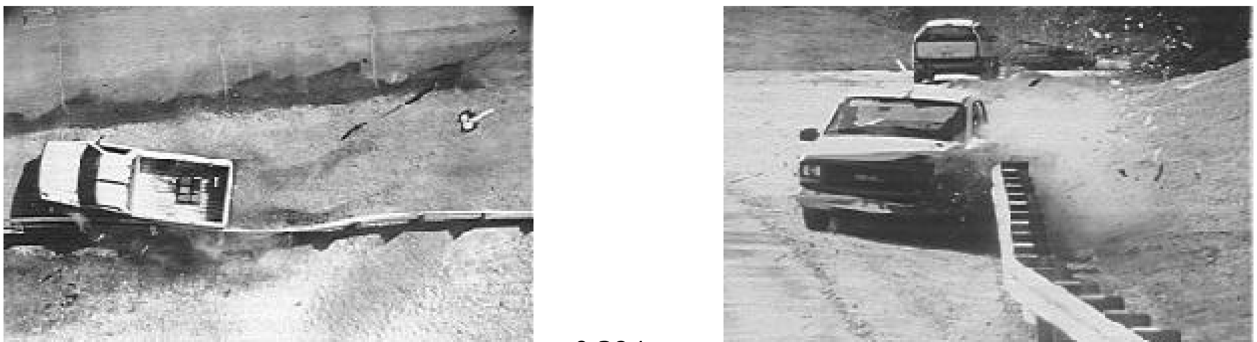

0.148 s


0.222 s

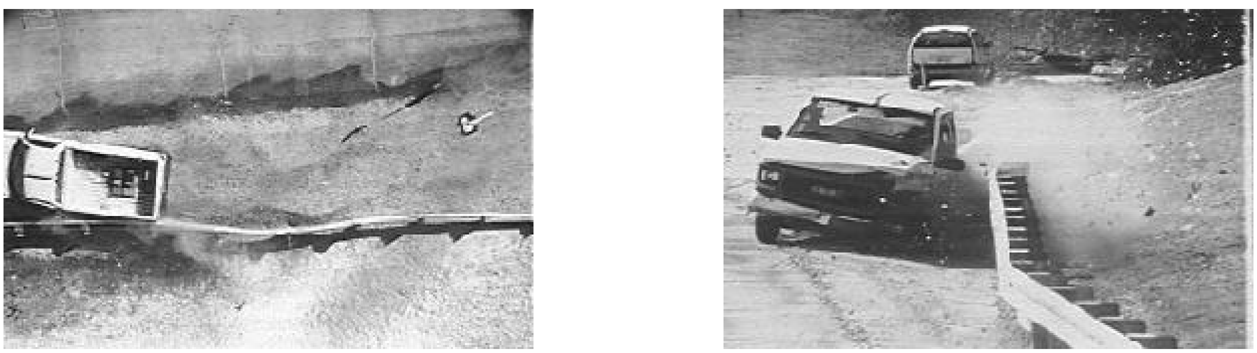
Figure 92. Sequential photographs for test 404211-1
(overhead and frontal views).



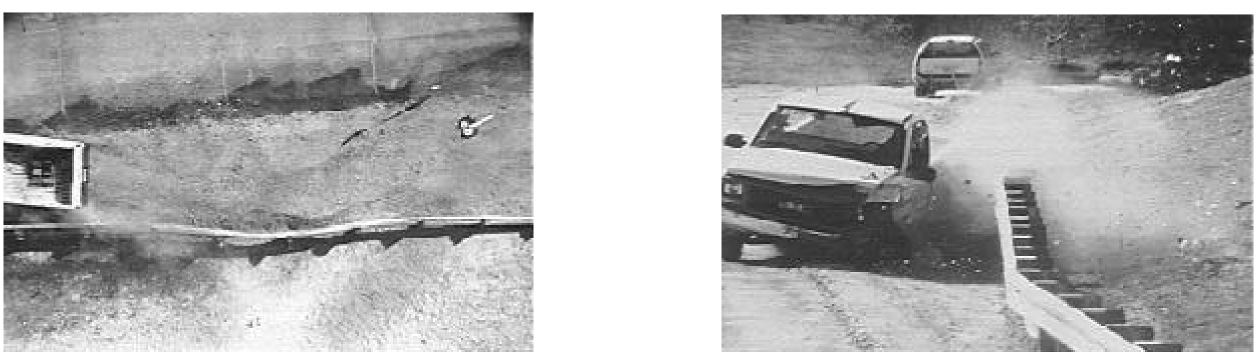
0.296 s



0.394 s

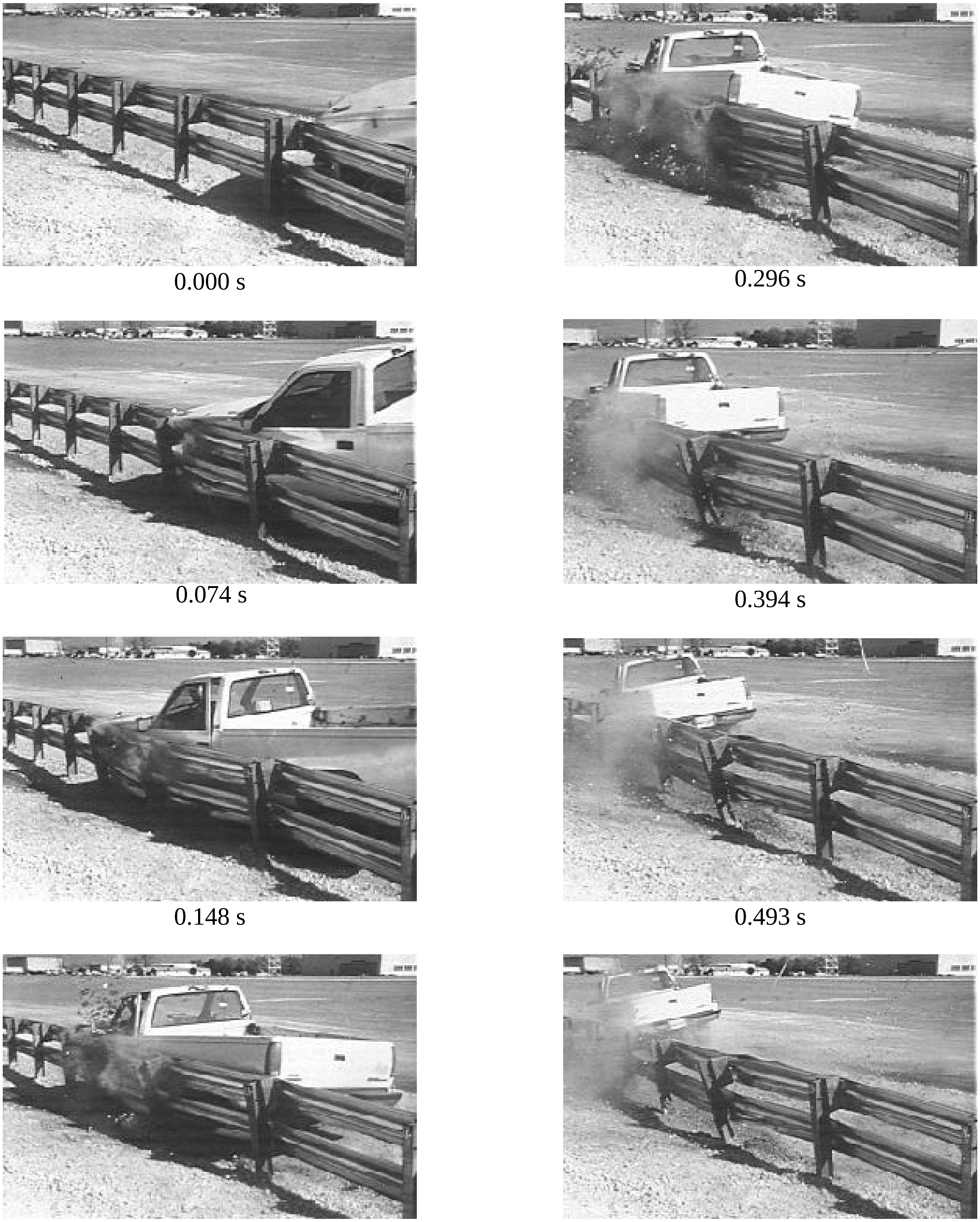


0.493 s



0.616 s

Figure 92. Sequential photographs for test 404211-1
(overhead and frontal views) (continued).



0.000 s

0.074 s

0.148 s

0.222 s

0.296 s

0.394 s

0.493 s

0.616 s

Figure 93. Sequential photographs for test 404211-1 (rear view).

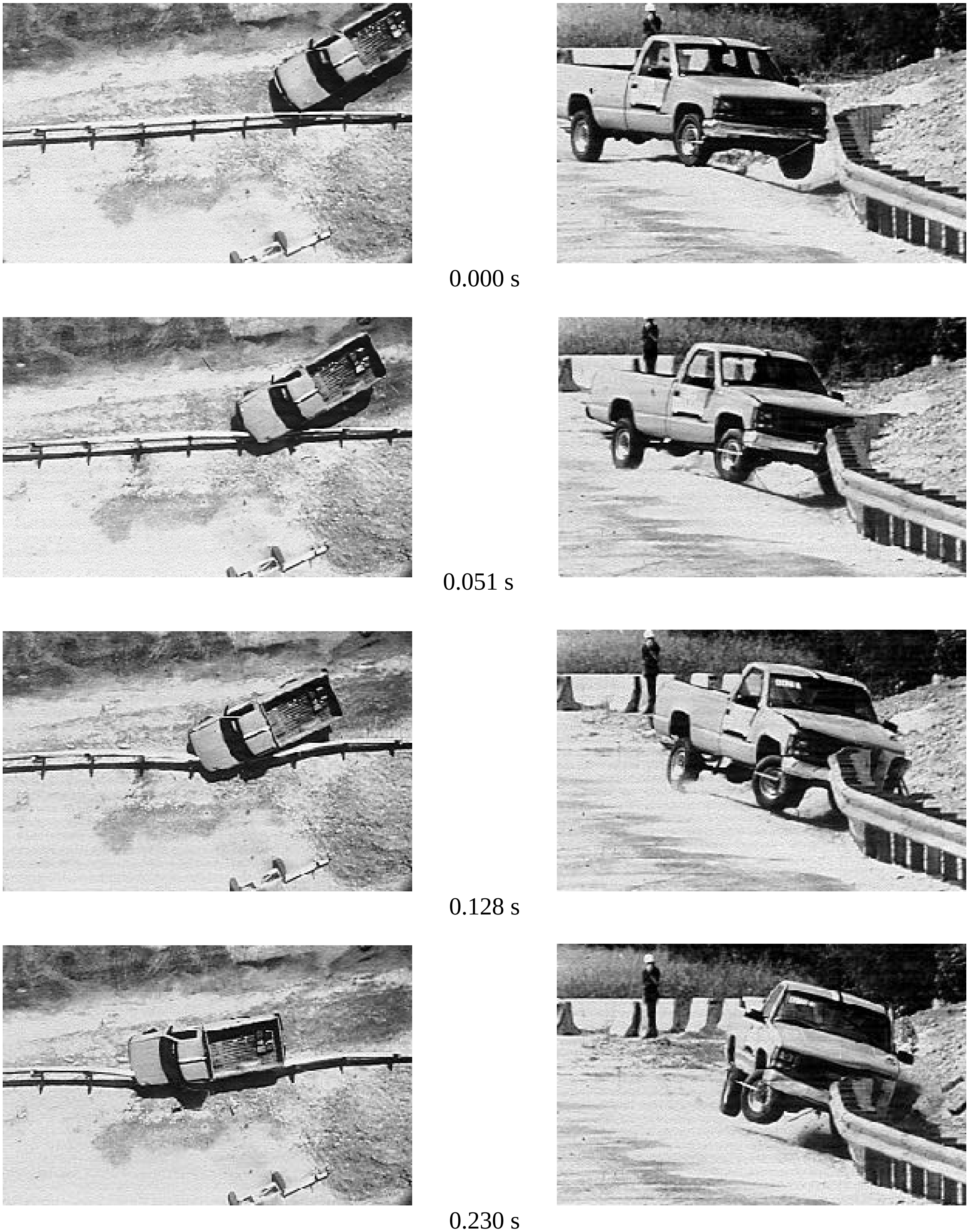
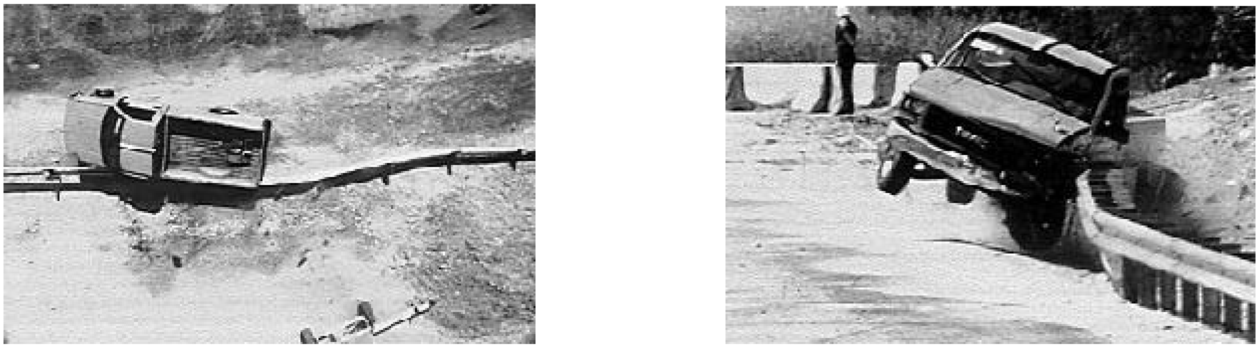


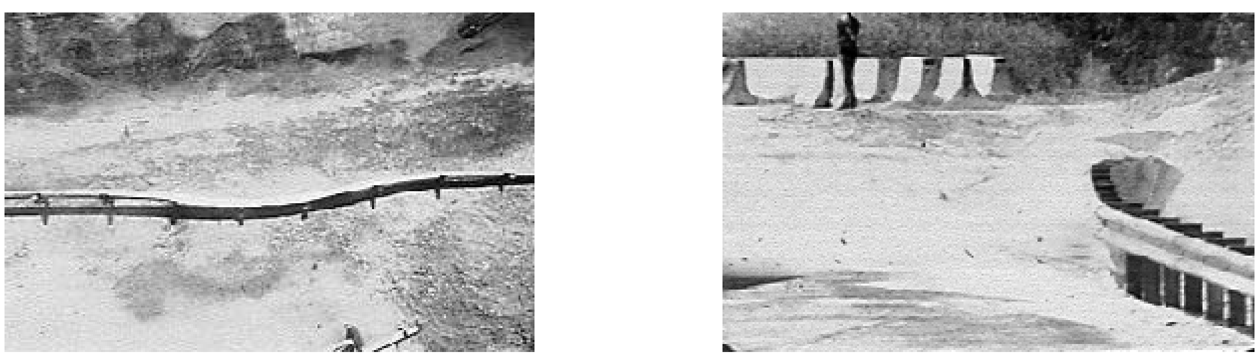
Figure 94. Sequential photographs for test 404211-13
(overhead and frontal views).



0.383 s

0.587 s

0.893 s



1.276 s

Figure 94. Sequential photographs for test 404211-13
(overhead and frontal views) (continued).

0.000 s

0.051 s

0.128 s

0.230 s

0.383 s

0.587 s

0.893 s

1.276 s

Figure 95. Sequential photographs for test 404211-13 (rear view).

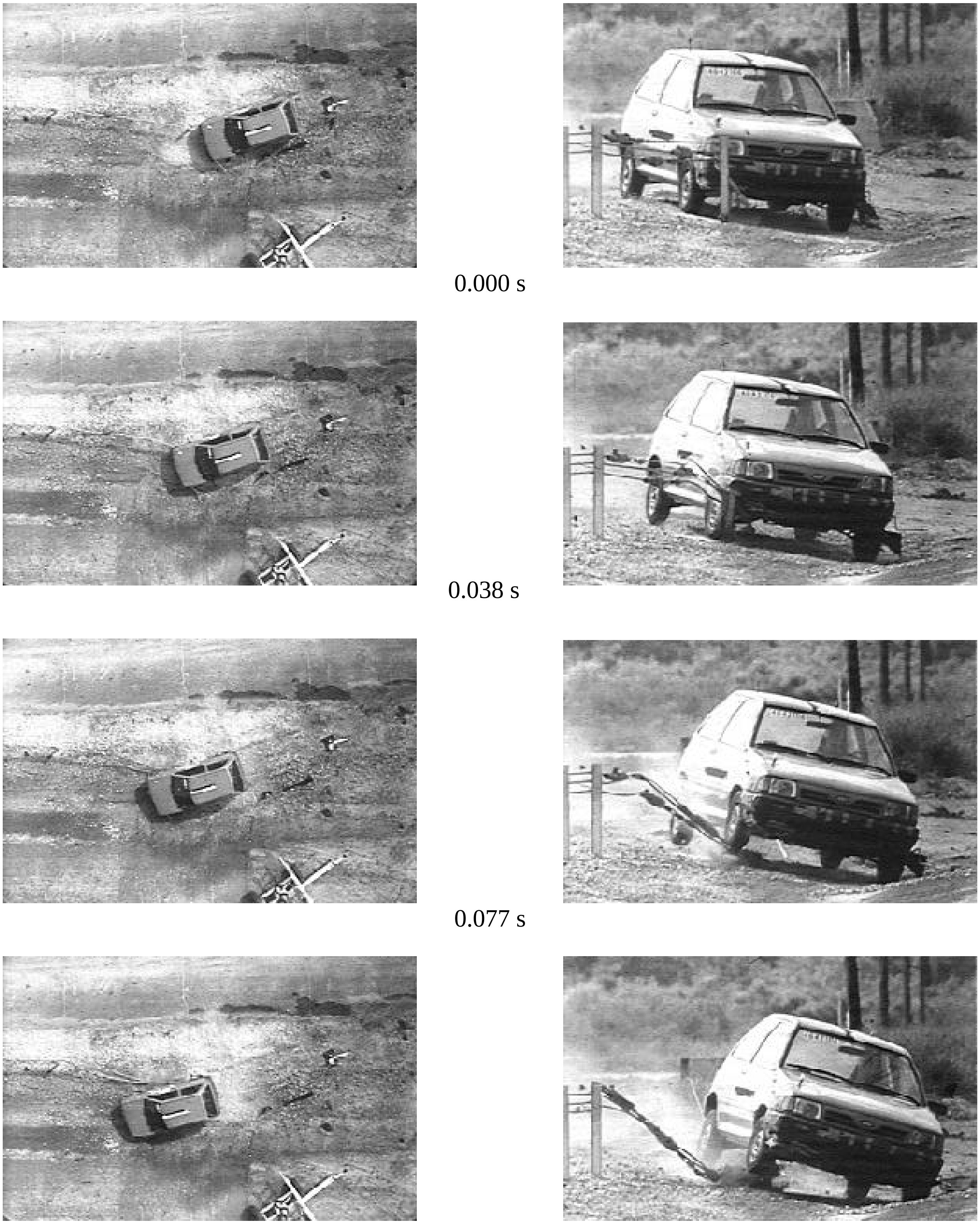


Figure 96. Sequential photographs for test 404211-6 (overhead and frontal views).

0.154 s

0.205 s

0.256 s

0.333 s

Figure 96. Sequential photographs for test 404211-6
(overhead and frontal views) (continued).

0.000 s

0.038 s

0.077 s

0.115 s

0.154 s

0.205 s

0.256 s

0.333 s

Figure 97. Sequential photographs for test 404211-6
(oblique view).

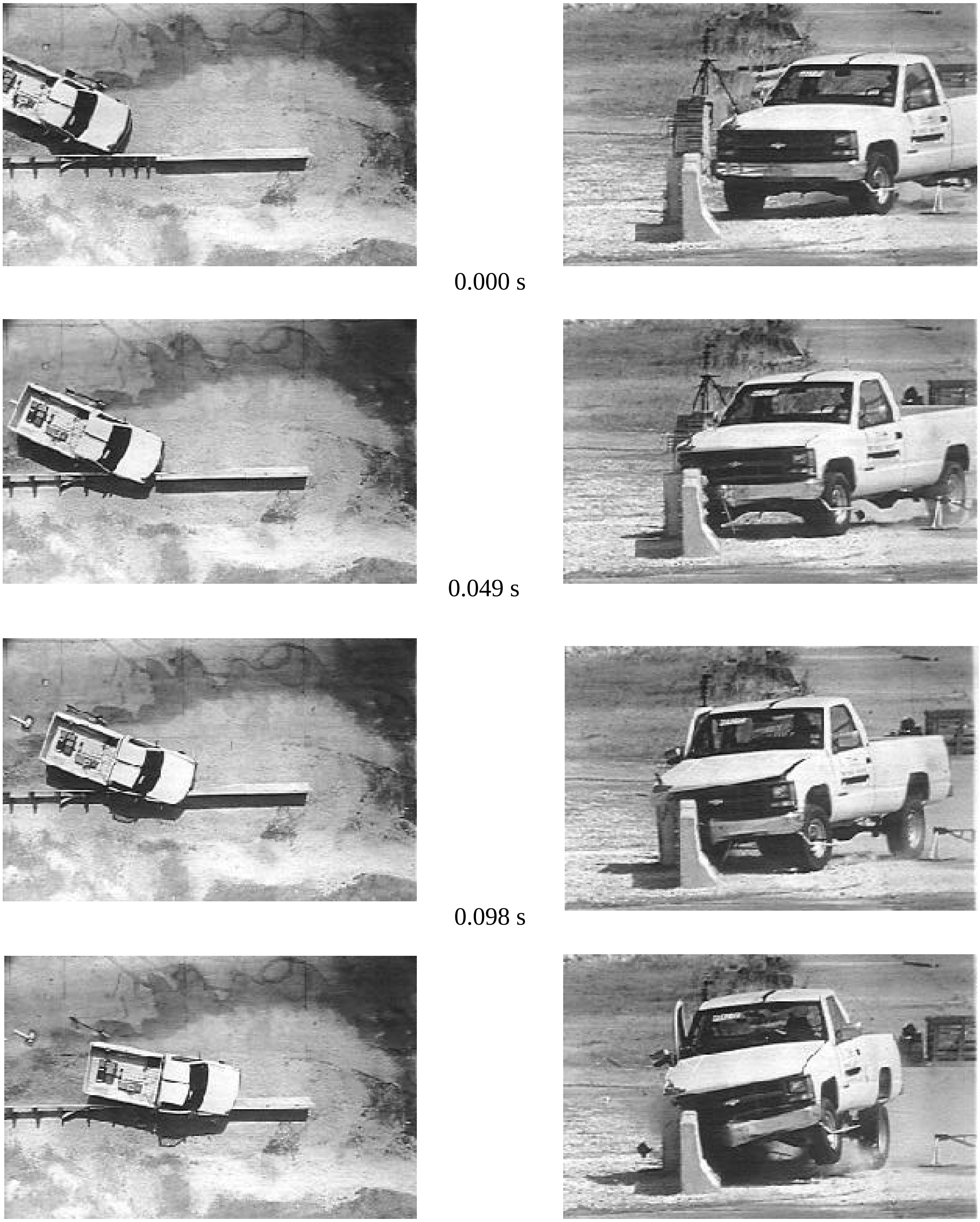
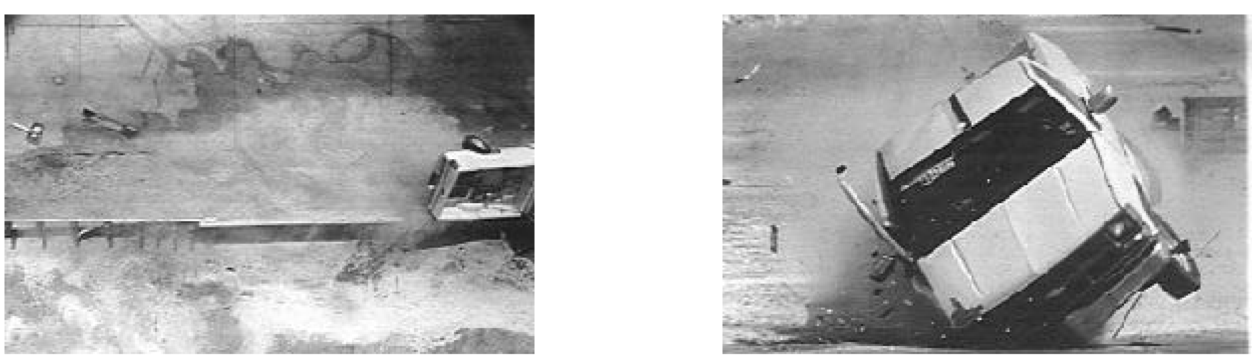


Figure 98. Sequential photographs for test 404211-2
(overhead and frontal views).

0.245 s

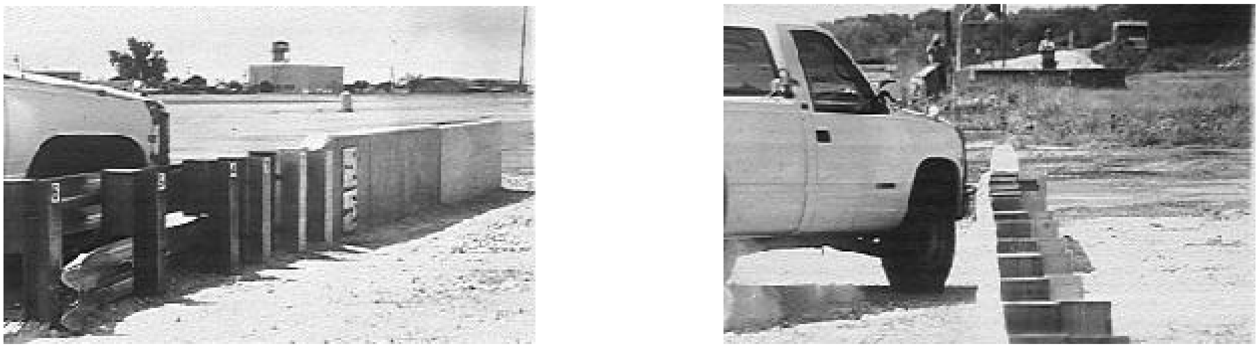
0.343 s

0.465 s

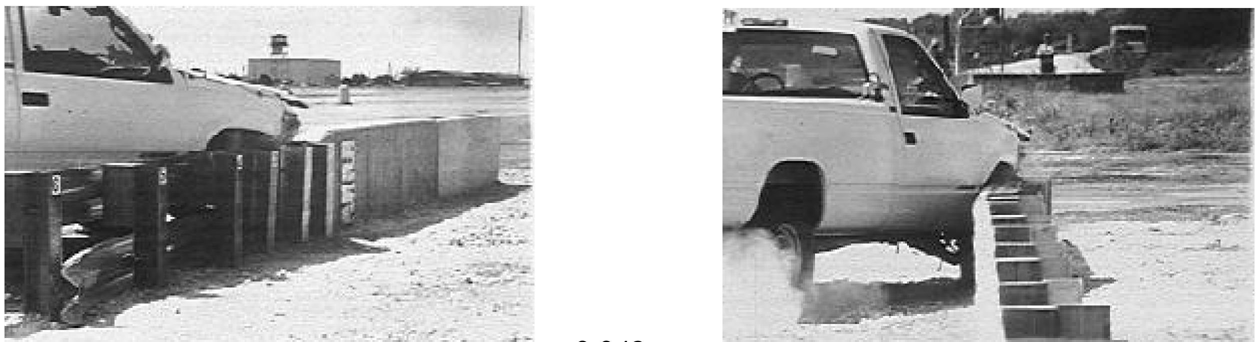


0.661 s

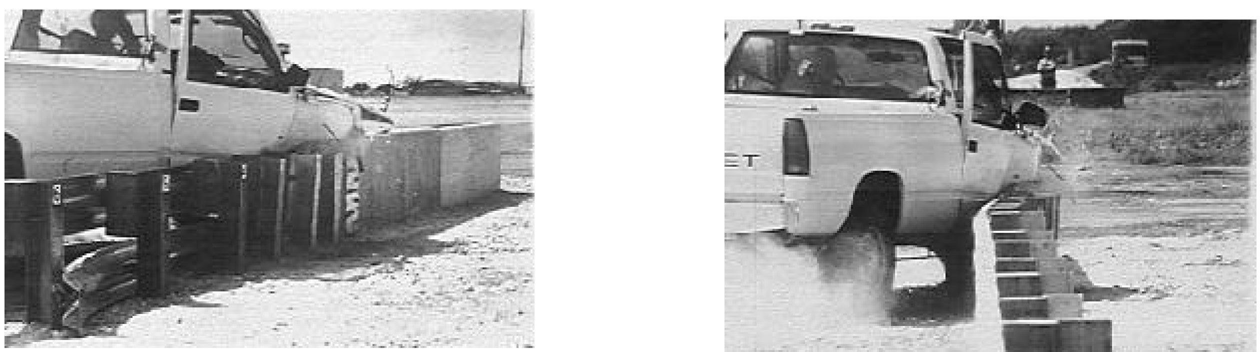
Figure 98. Sequential photographs for test 404211-2
(overhead and frontal views) (continued).



0.000 s



0.049 s



0.098 s

0.171 s

Figure 99. Sequential photographs for test 404211-2
(rear views).

0.245 s

0.343 s

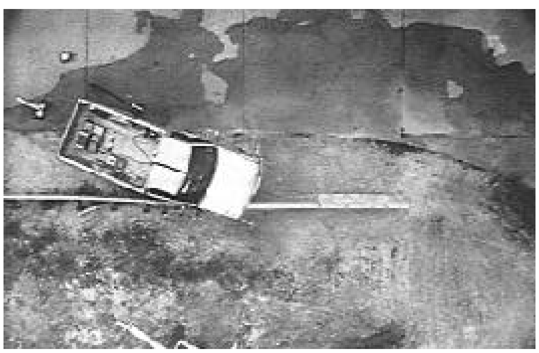
0.465 s

0.661 s

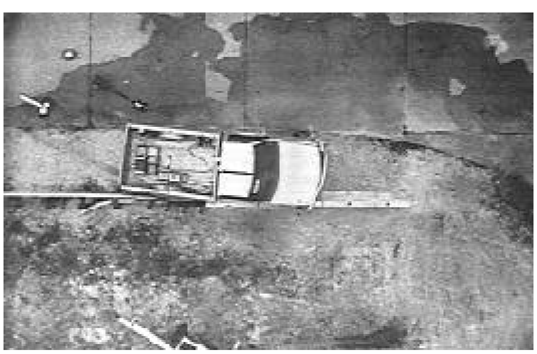
Figure 99. Sequential photographs for test 404211-2
(rear views) (continued).


0.000 s


0.047 s

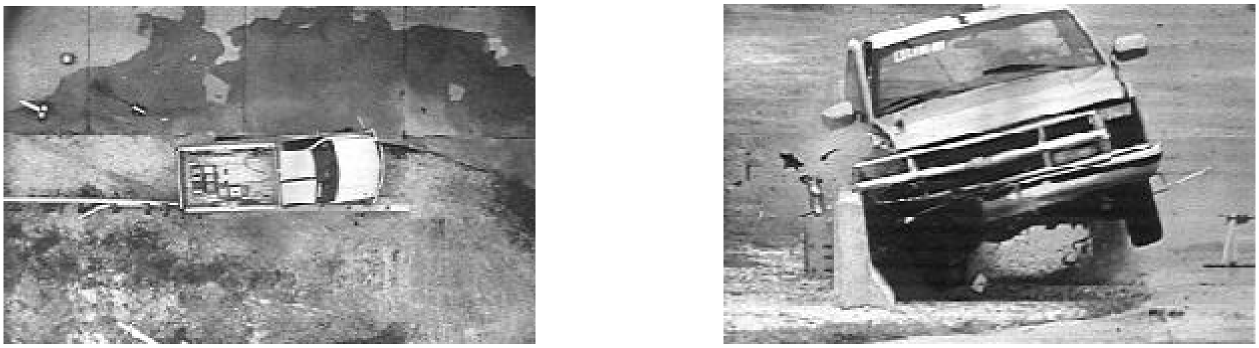



0.095 s



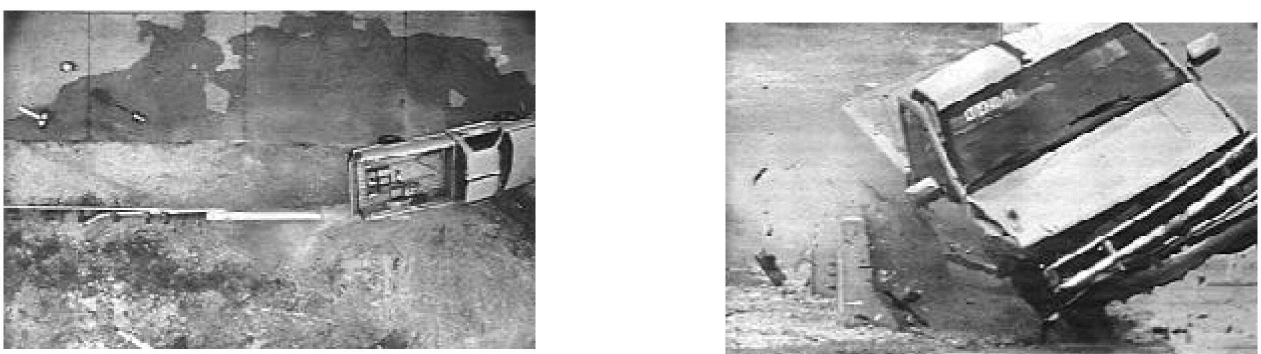

0.167 s

Figure 100. Sequential photographs for test 404211-12
(overhead and frontal views).



0.238 s

0.333 s



0.453 s

0.596 s

Figure 100. Sequential photographs for test 404211-12
(overhead and frontal views) (continued).

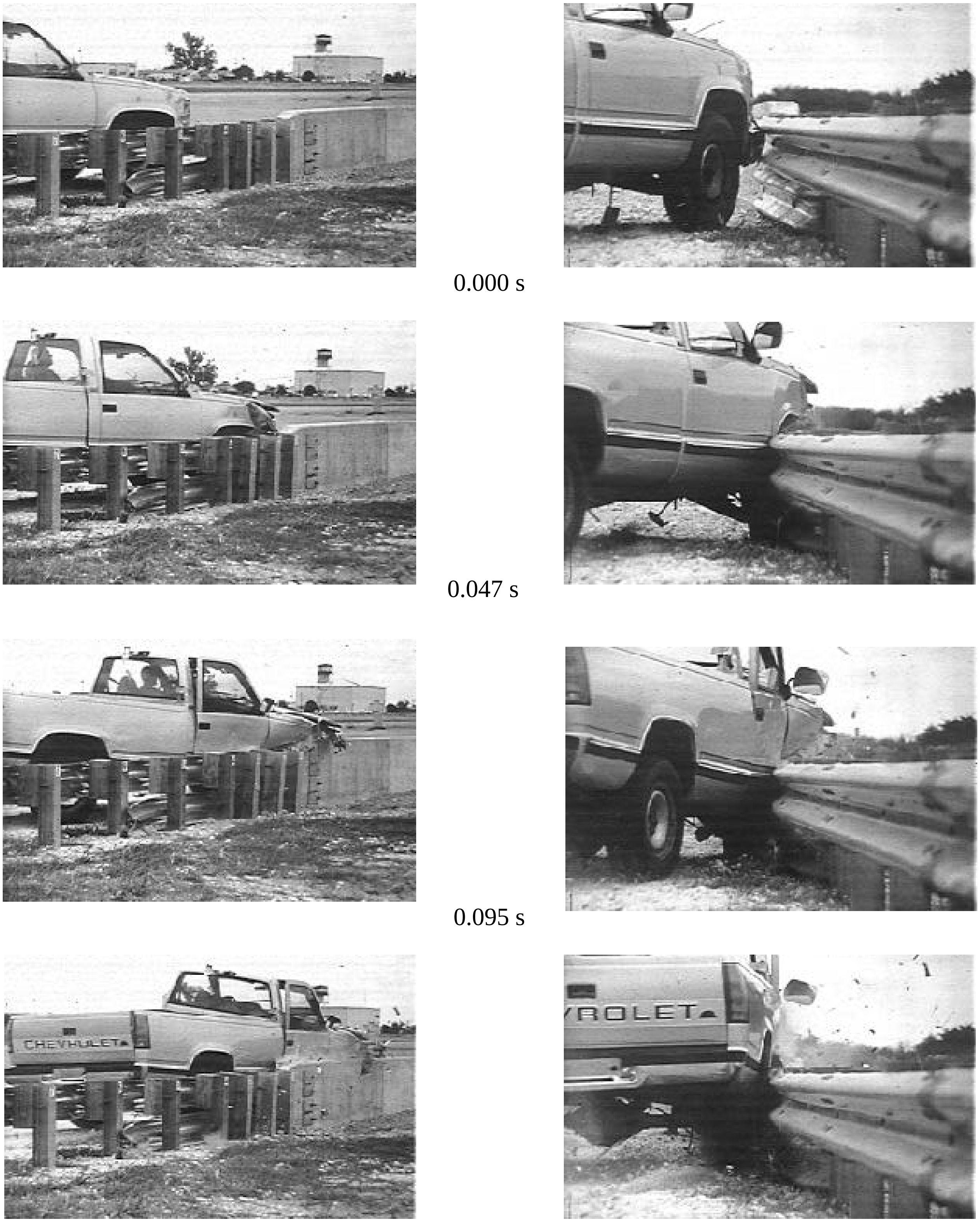
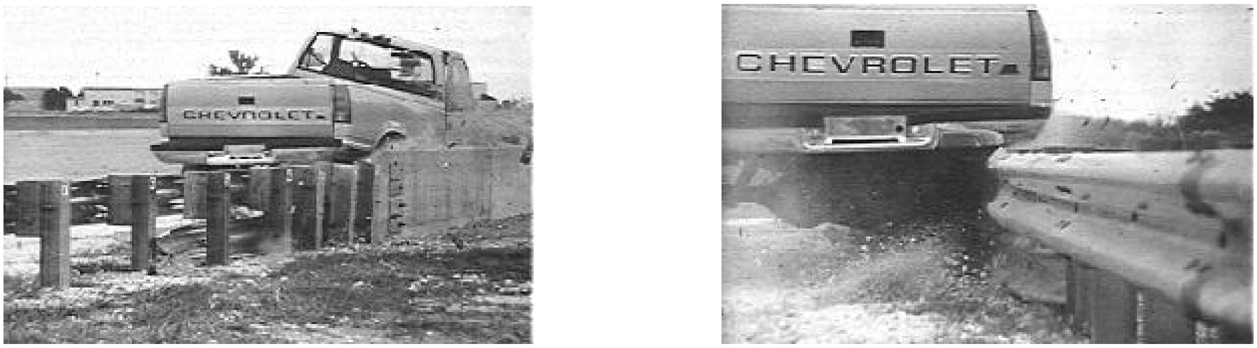
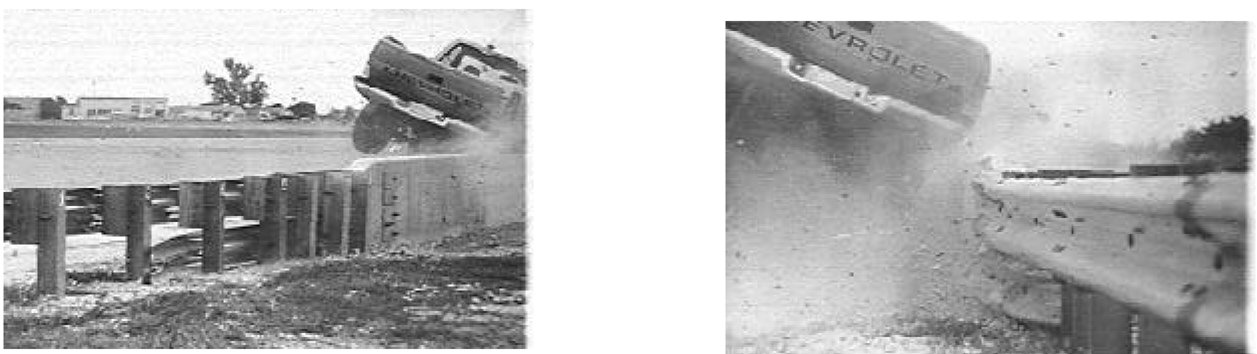


Figure 101. Sequential photographs for test 404211-12 (rear views).

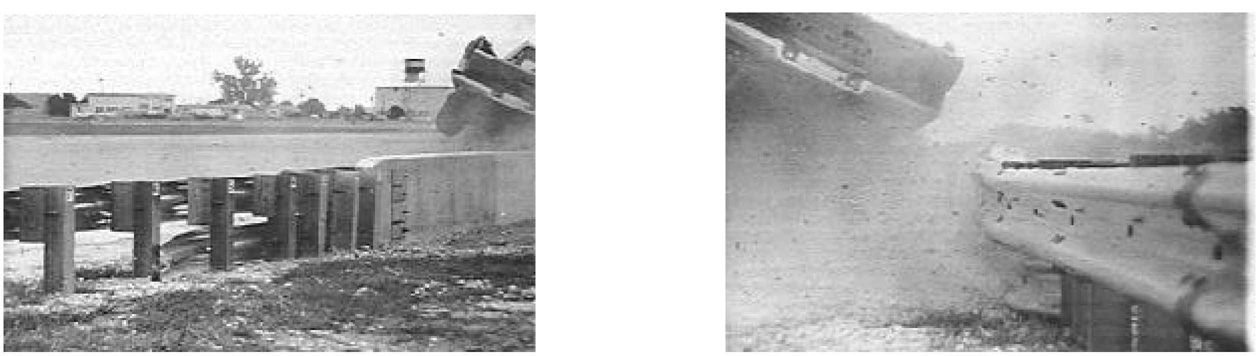


0.238 s

0.333 s

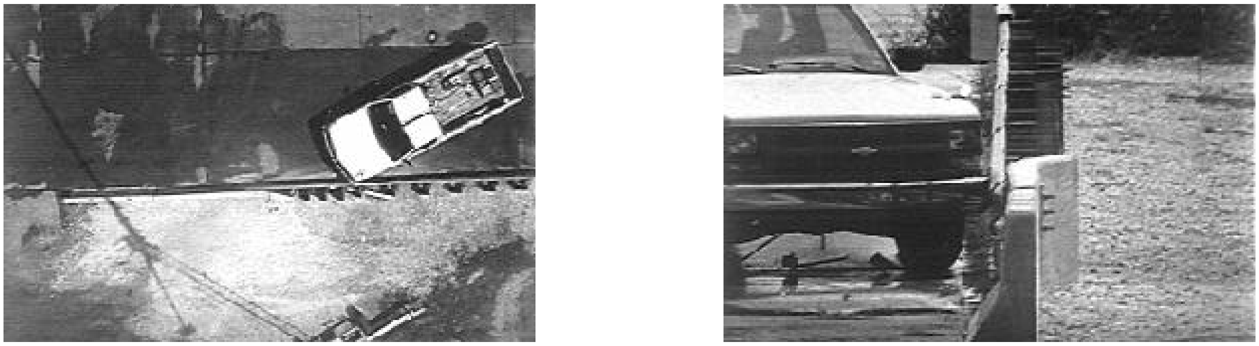


0.453 s



0.596 s

Figure 101. Sequential photographs for test 404211-12
(rear views) (continued).



0.000 s

0.050 s

0.099 s

0.149 s

Figure 102. Sequential photographs for test 404211-4
(overhead and frontal views).

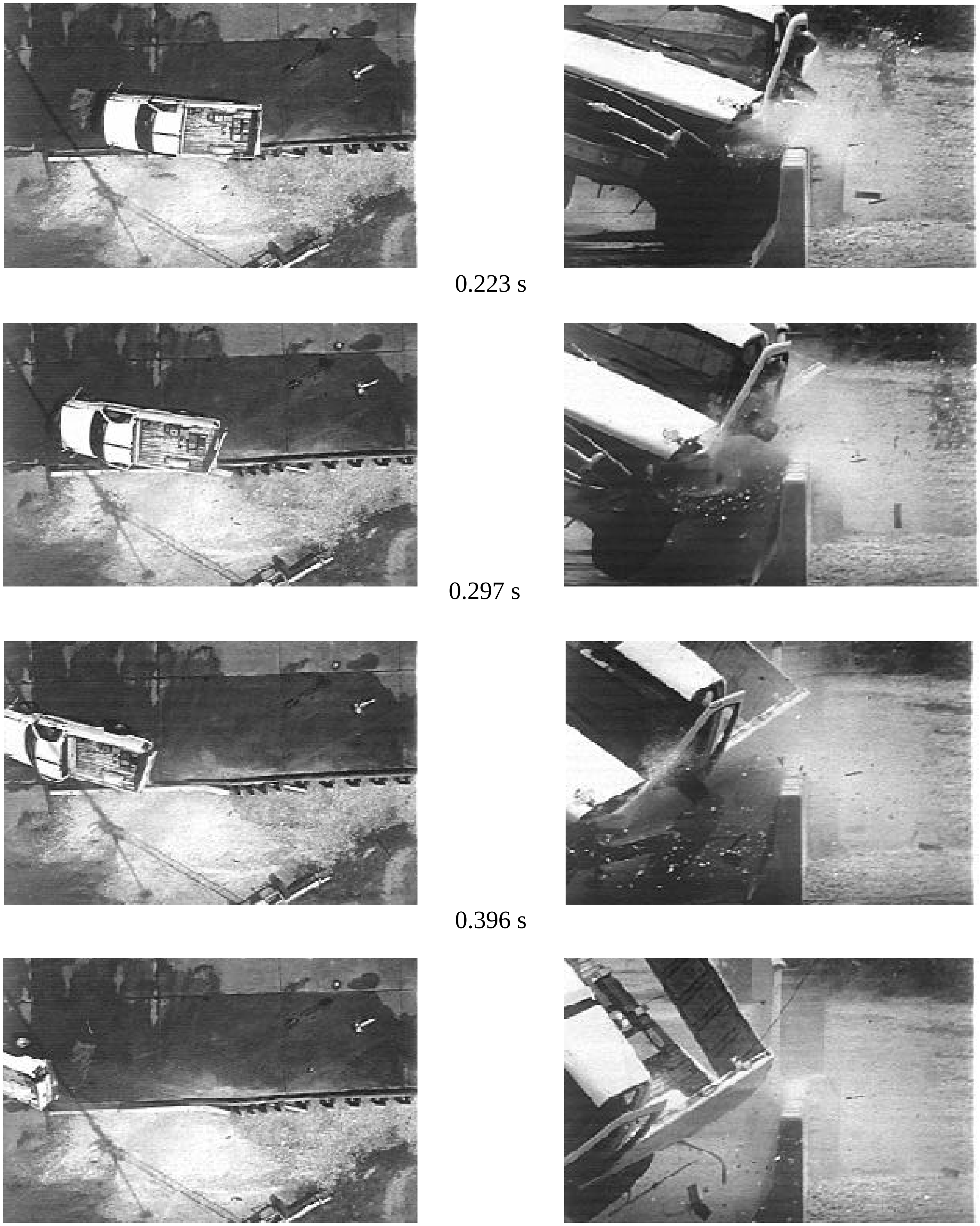


Figure 102. Sequential photographs for test 404211-4 (overhead and frontal views) (continued).

0.000 s

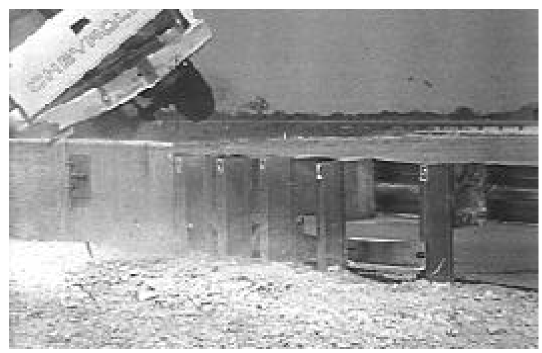
0.050 s

0.099 s

0.149 s

0.223 s

0.297 s



0.396 s

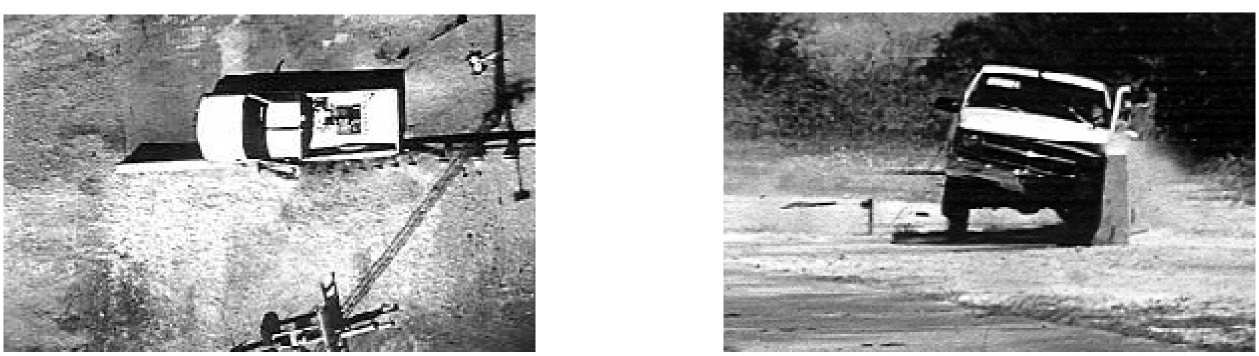
0.545 s

Figure 103. Sequential photographs for test 404211-4
(rear view).

0.000 s

0.049 s

0.099 s



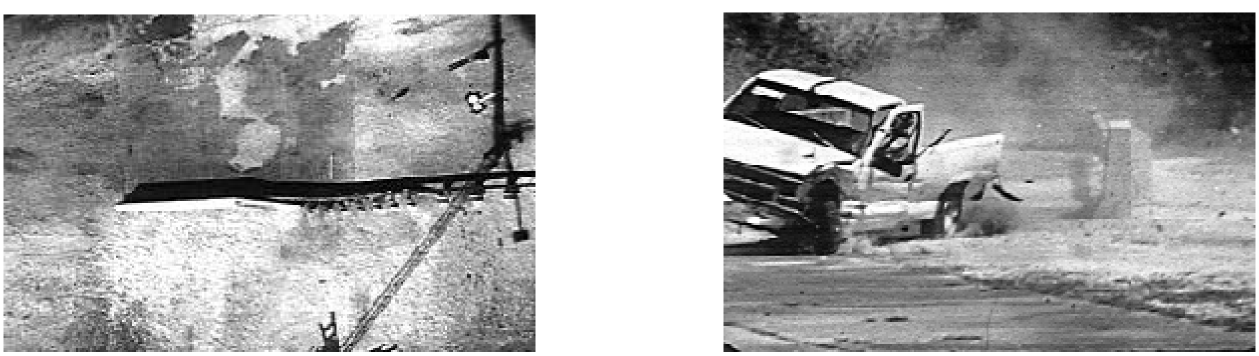
0.173 s

Figure 104. Sequential photographs for test 404211-3
(overhead and frontal views).

0.272 s

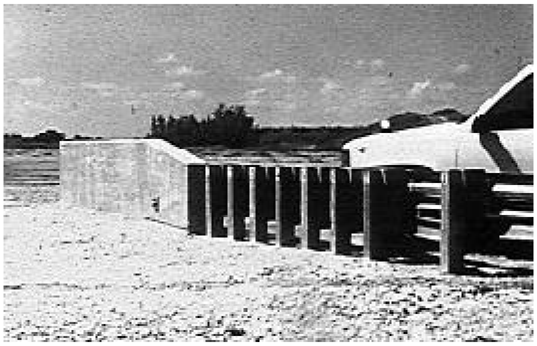
0.396 s

0.544 s

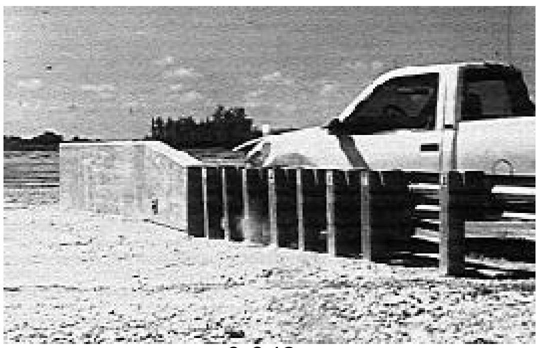


0.742 s

Figure 104. Sequential photographs for test 404211-3
(overhead and frontal views) (continued).



0.000 s

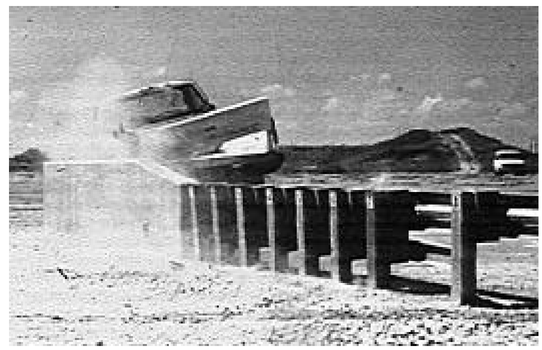


0.049 s

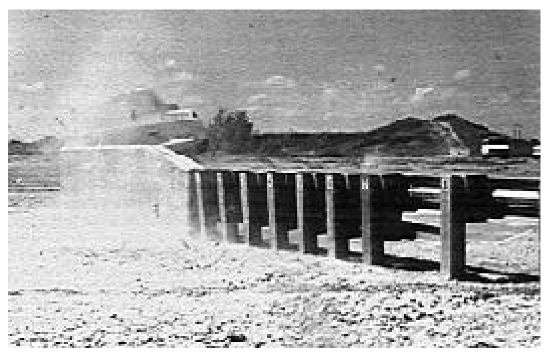
0.099 s

0.173 s

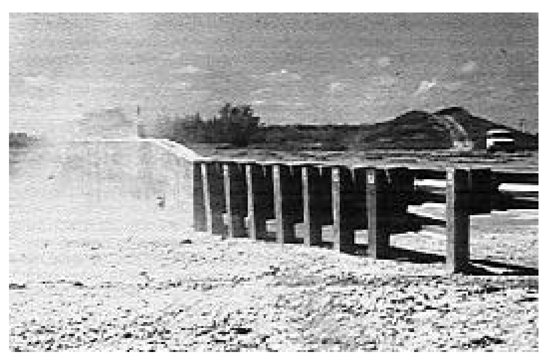
0.272 s



0.396 s



0.544 s



0.742 s

Figure 105. Sequential photographs for test 404211-3
(rear view).

0.000 s

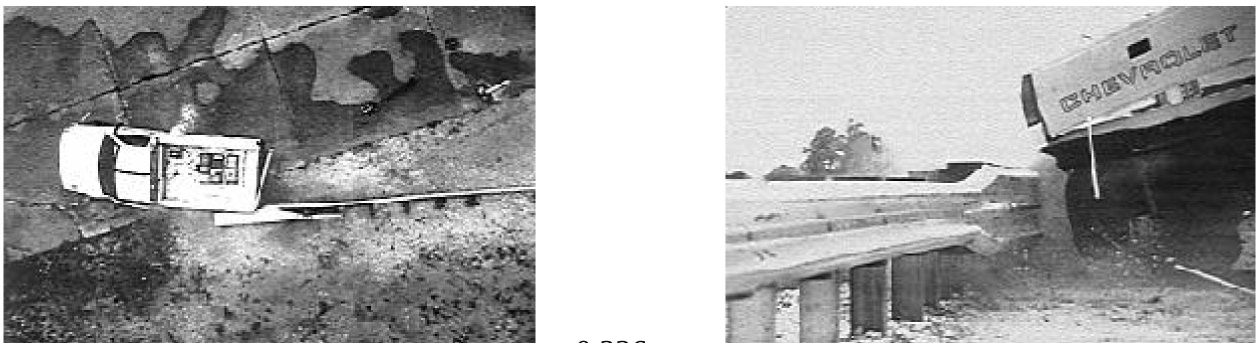
0.054 s

0.109 s

0.163 s

Figure 106. Sequential photographs for test 404211-7
(overhead and frontal views).

0.244 s



0.326 s

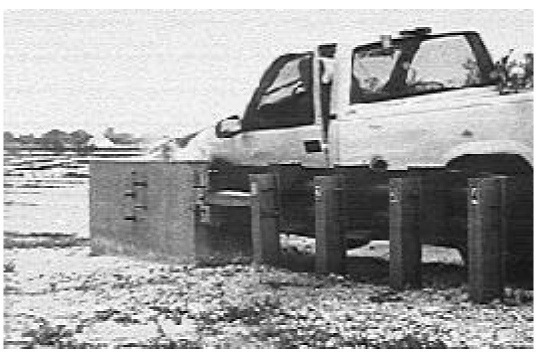
0.434 s

0.597 s

Figure 106. Sequential photographs for test 404211-7
(overhead and frontal views) (continued).

0.000 s

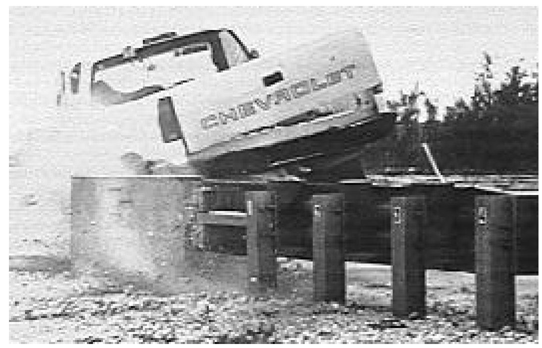
0.054 s



0.109 s

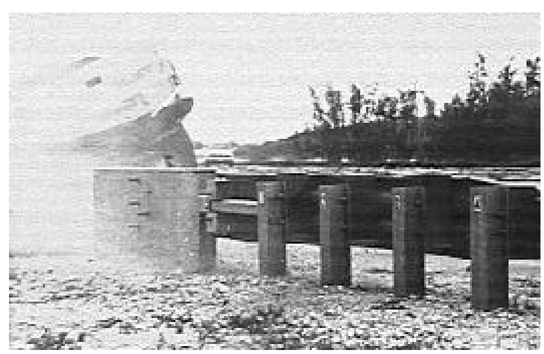
0.163 s

0.244 s



0.326 s

0.434 s



0.597 s

Figure 107. Sequential photographs for test 404211-7
(rear view).

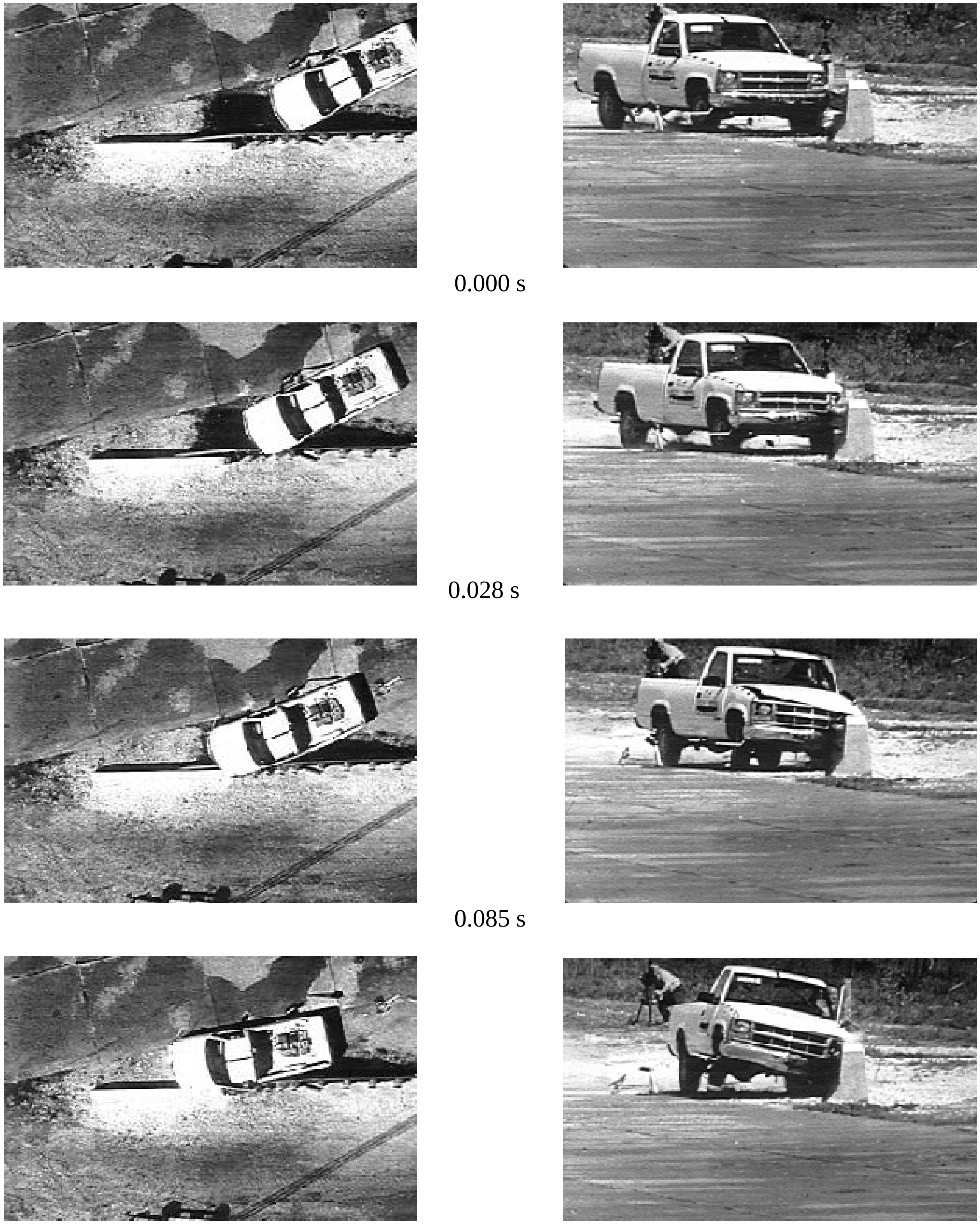
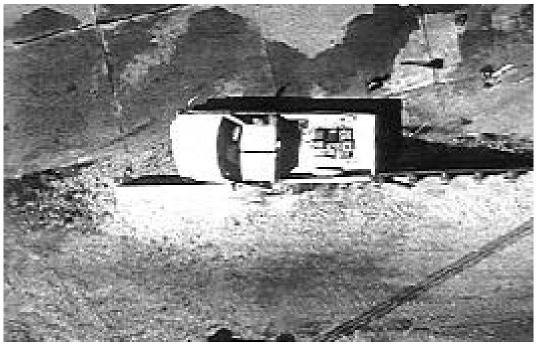


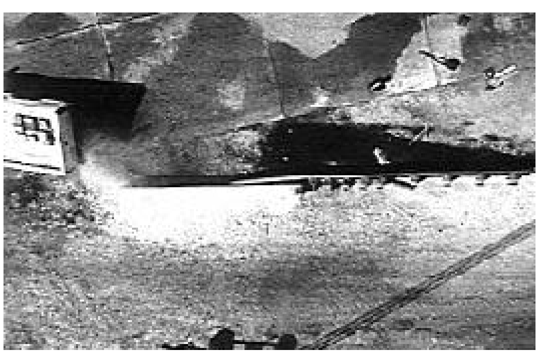
Figure 108. Sequential photographs for test 404211-9
(overhead and frontal views).




0.198 s

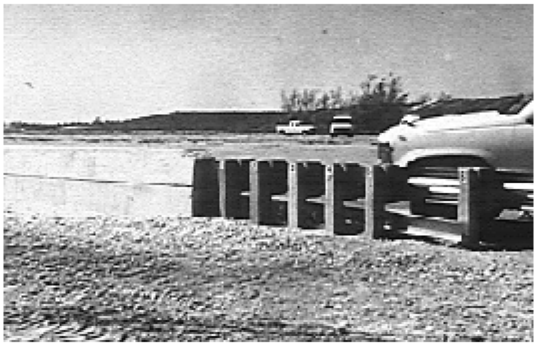

0.282 s


0.395 s

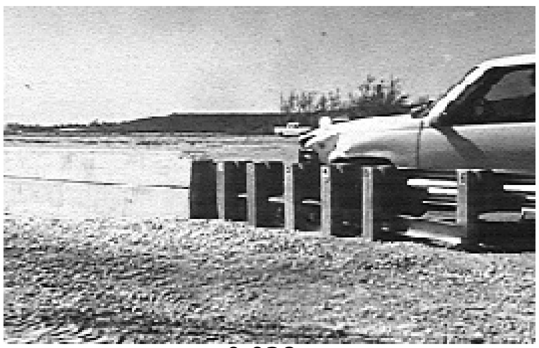



0.564 s

Figure 108. Sequential photographs for test 404211-9
(overhead and frontal views) (continued).



0.000 s



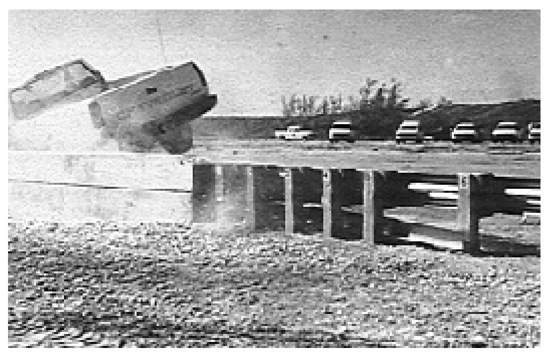
0.028 s

0.085 s

0.141 s

0.198 s

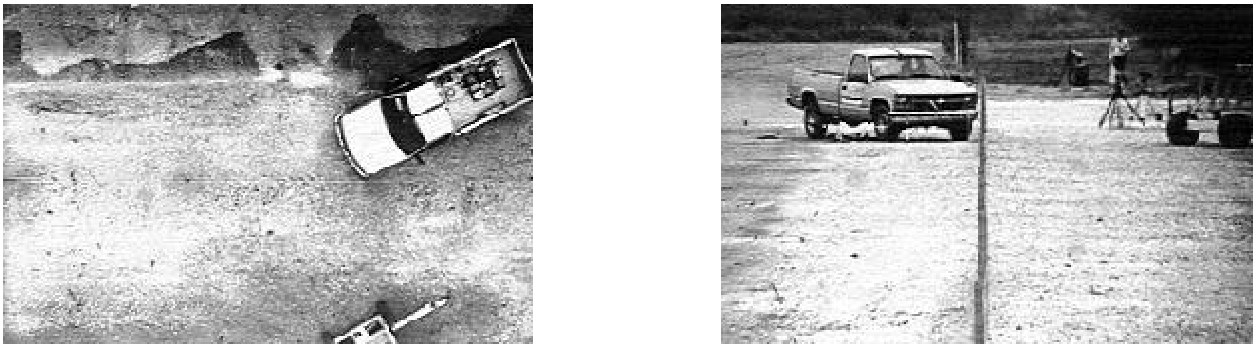
0.282 s



0.395 s

0.564 s

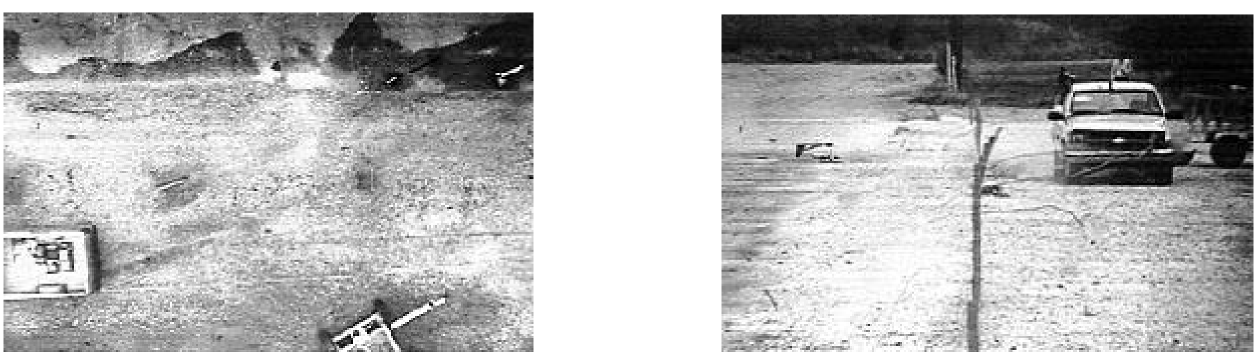
Figure 109. Sequential photographs for test 404211-9
(rear view).



0.000 s

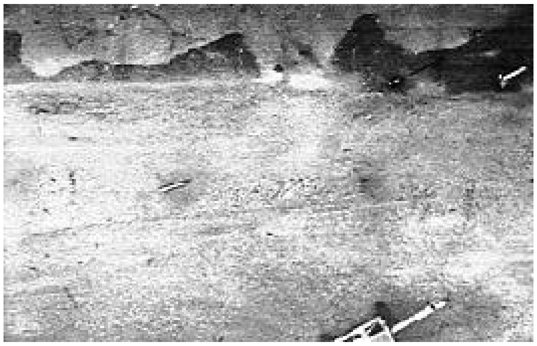
0.097 s

0.244 s



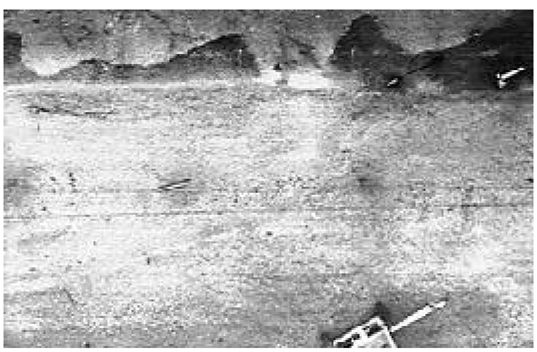
0.487 s

Figure 110. Sequential photographs for test 404211-8
(overhead and frontal views).




0.975 s

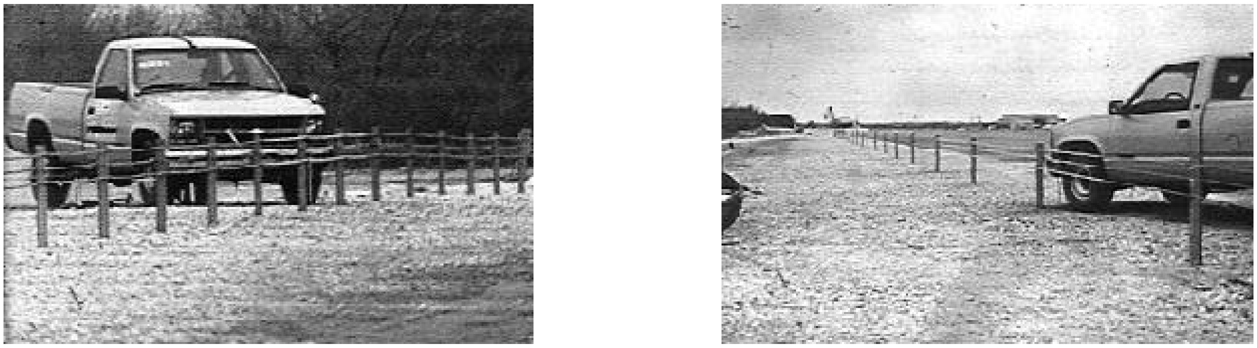

1.705 s




2.680 s

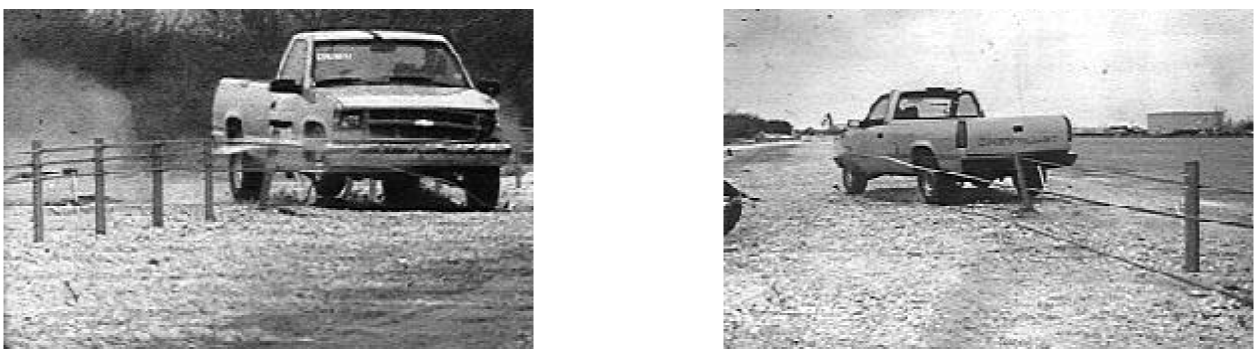

5.603 s

Figure 110. Sequential photographs for test 404211-8
(overhead and frontal views) (continued).

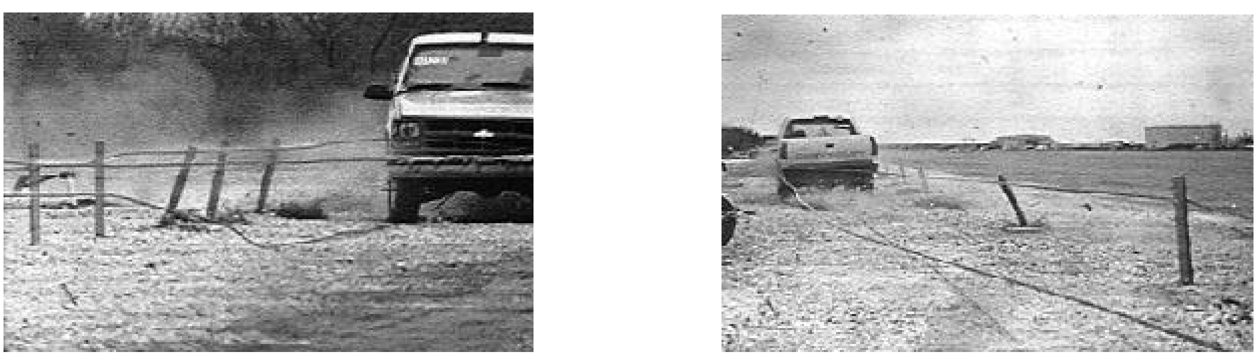


0.000 s

0.097 s



0.244 s

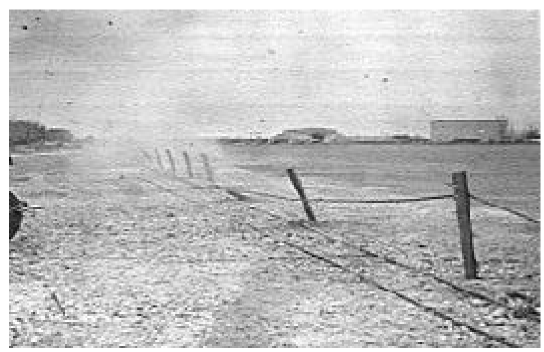


0.487 s

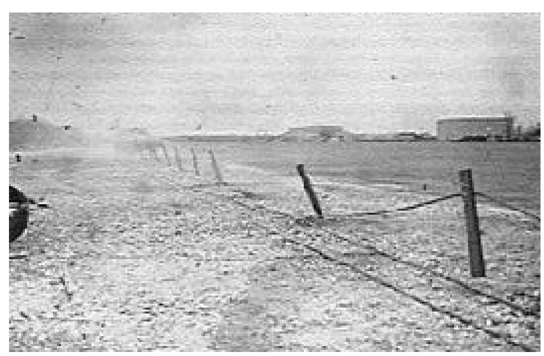
Figure 111. Sequential photographs for test 404211-8
(rear views).


0.975 s


1.705 s

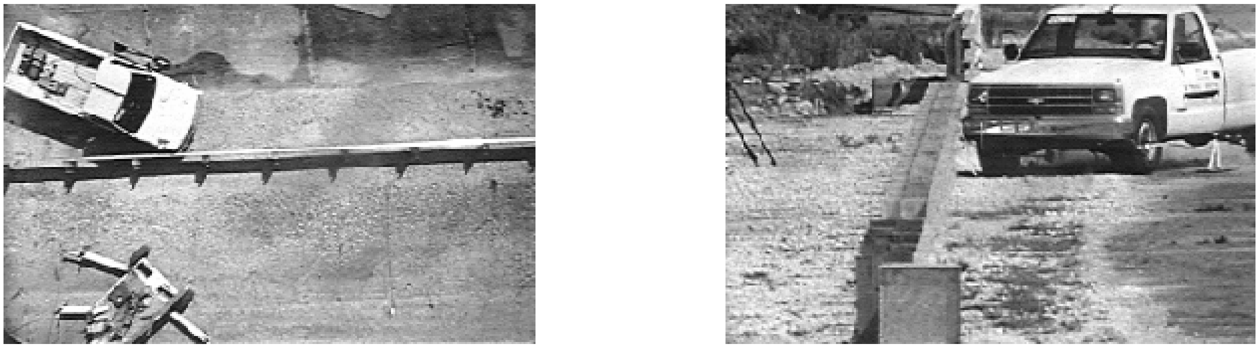



2.680 s

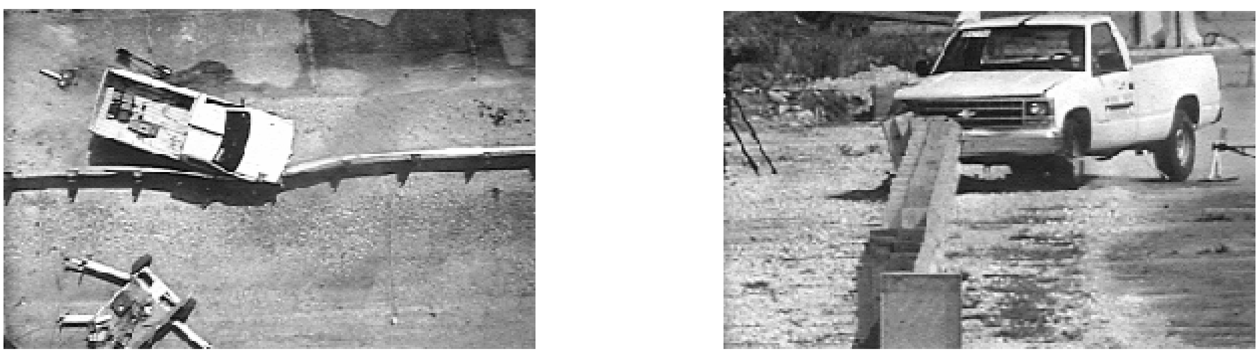
5.603 s

Figure 111. Sequential photographs for test 404211-8
(rear views) (continued).

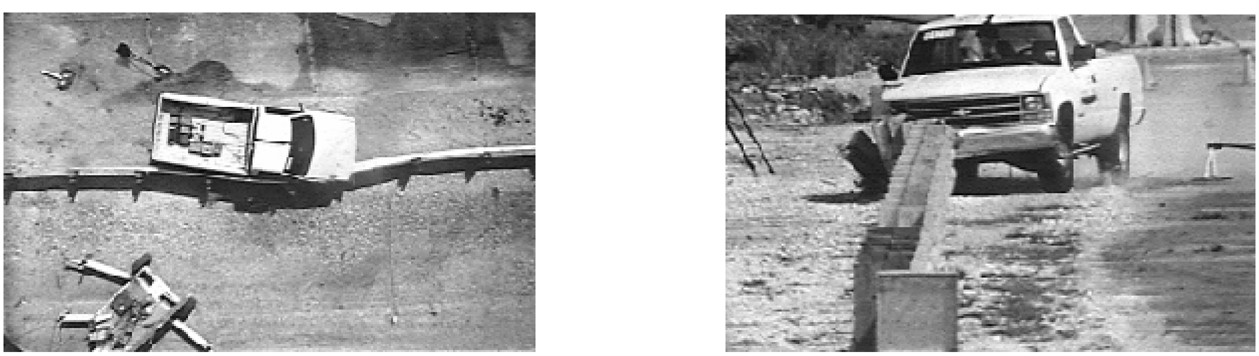


0.000 s

0.049 s

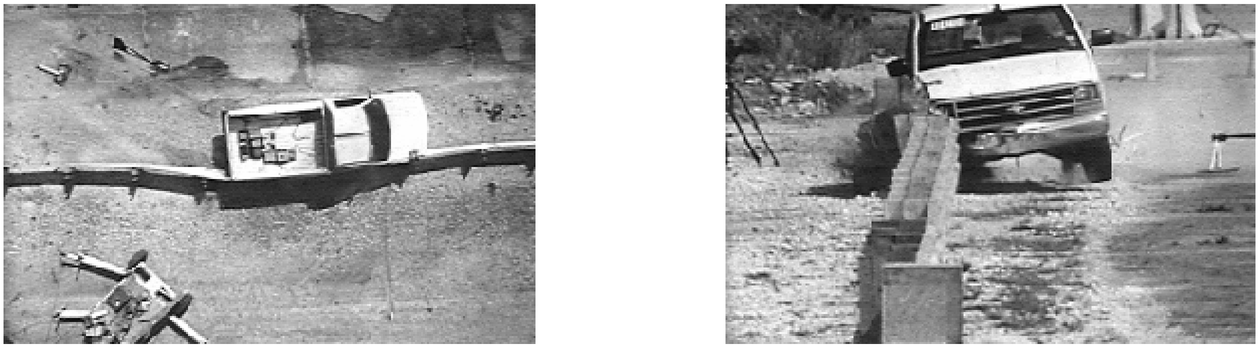


0.098 s

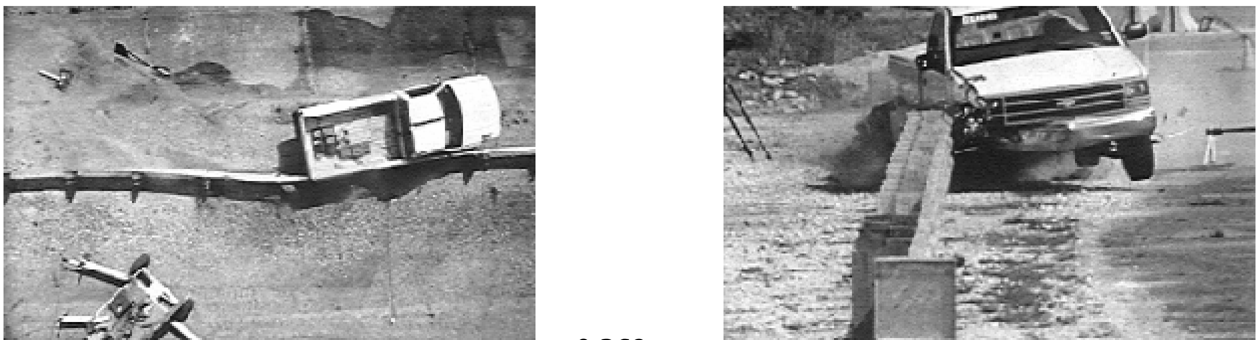


0.172 s

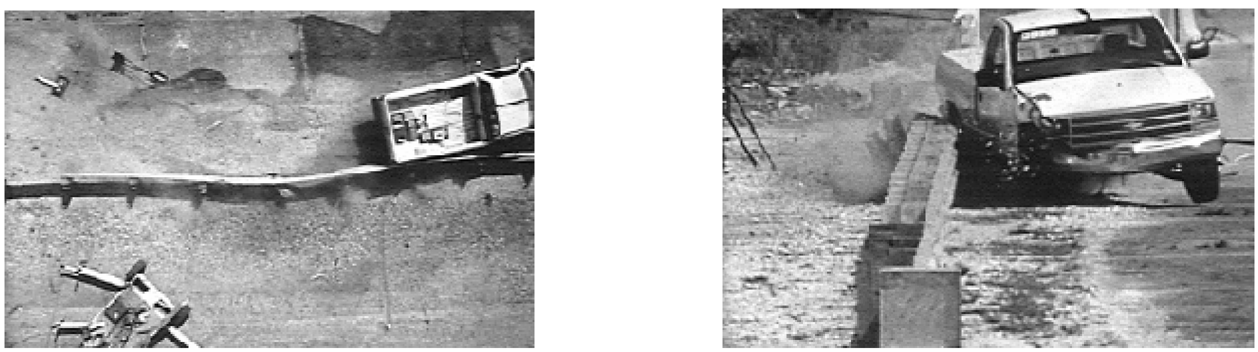
Figure 112. Sequential photographs for test 404211-10 (overhead and frontal views).



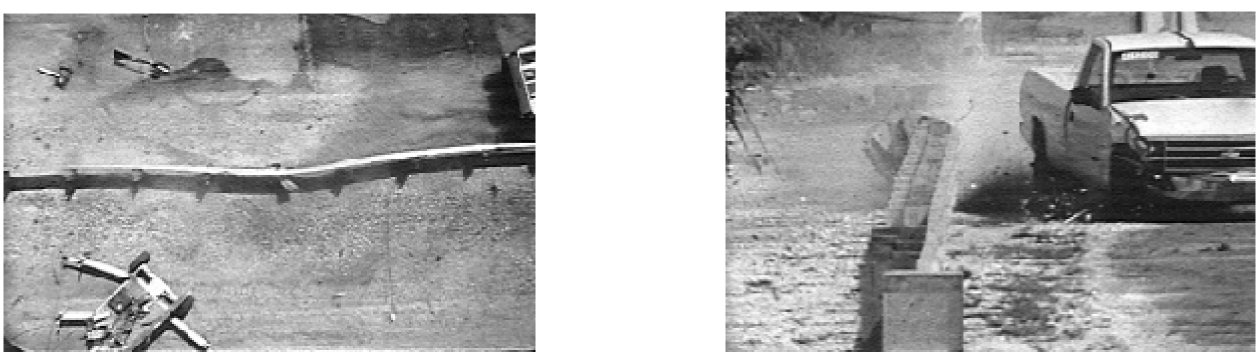
0.271 s



0.369 s



0.492 s



0.689 s

Figure 112. Sequential photographs for test 404211-10
(overhead and frontal views) (continued).

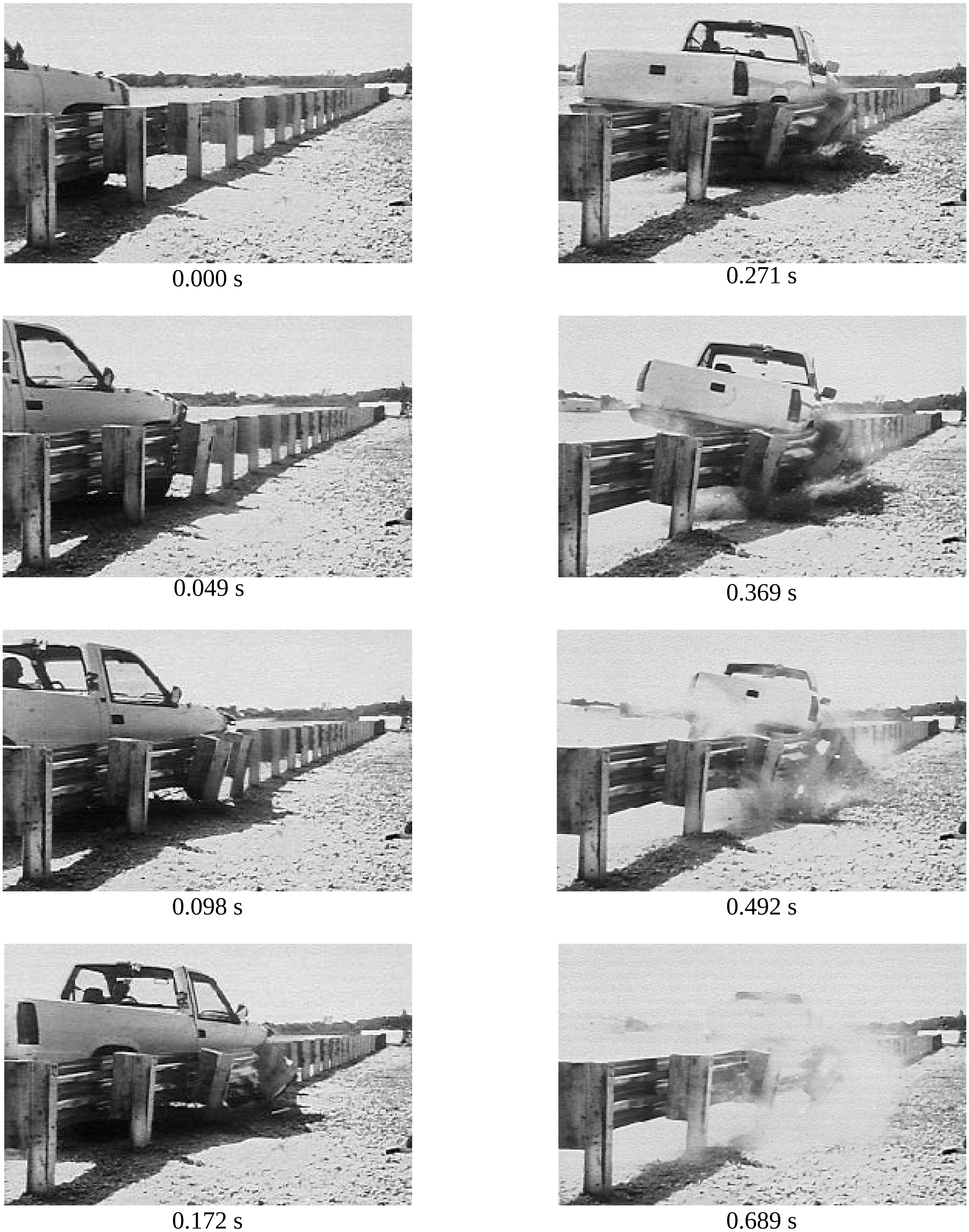


Figure 113. Sequential photographs for test 404211-10
(rear view).

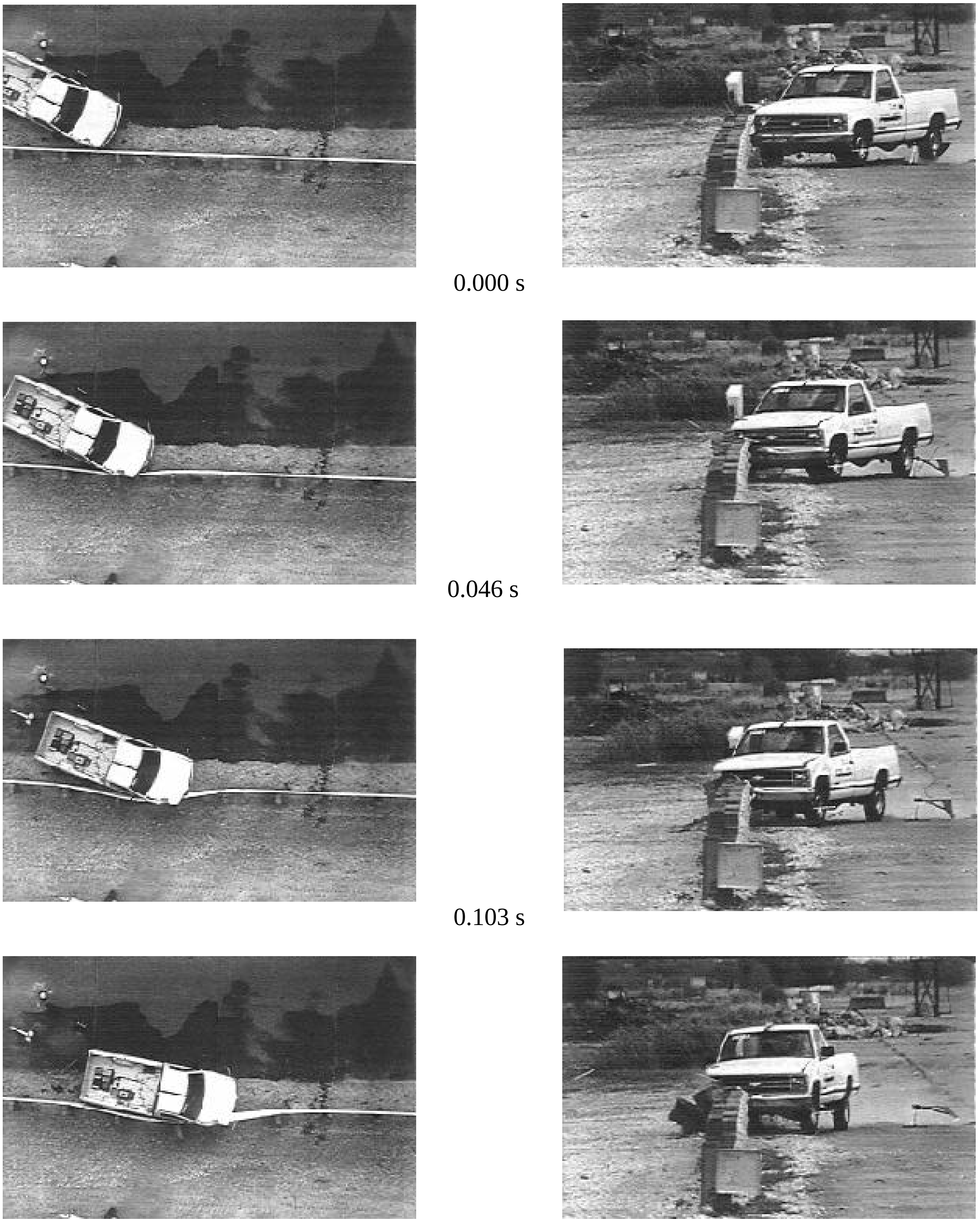
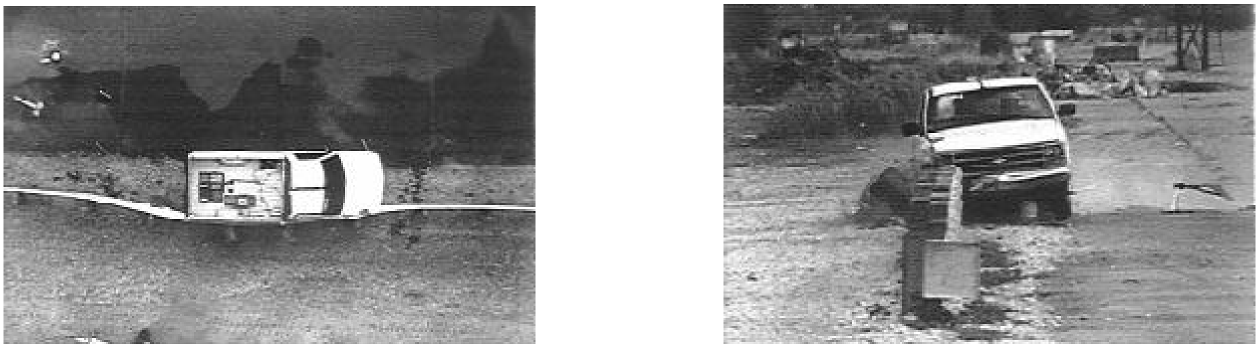


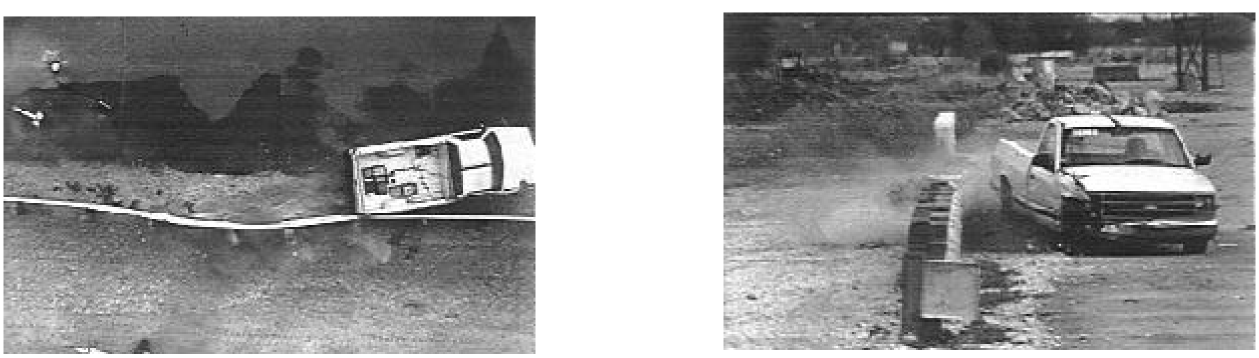
Figure 114. Sequential photographs for test 404211-11
(overhead and frontal views).



0.275 s

0.390 s

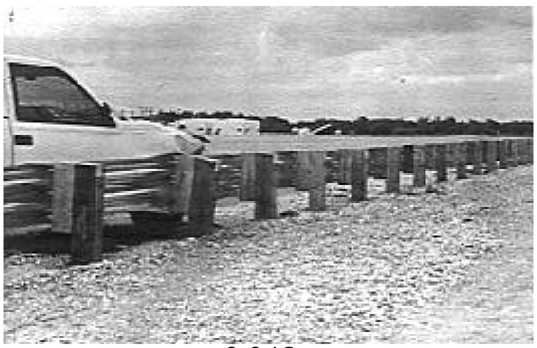
0.505 s



0.642 s

Figure 114. Sequential photographs for test 404211-11
(overhead and frontal views) (continued).

0.000 s



0.046 s

0.103 s

0.172 s

0.275 s

0.390 s

0.505 s

0.642 s

Figure 115. Sequential photographs for test 404211-11
(rear view).

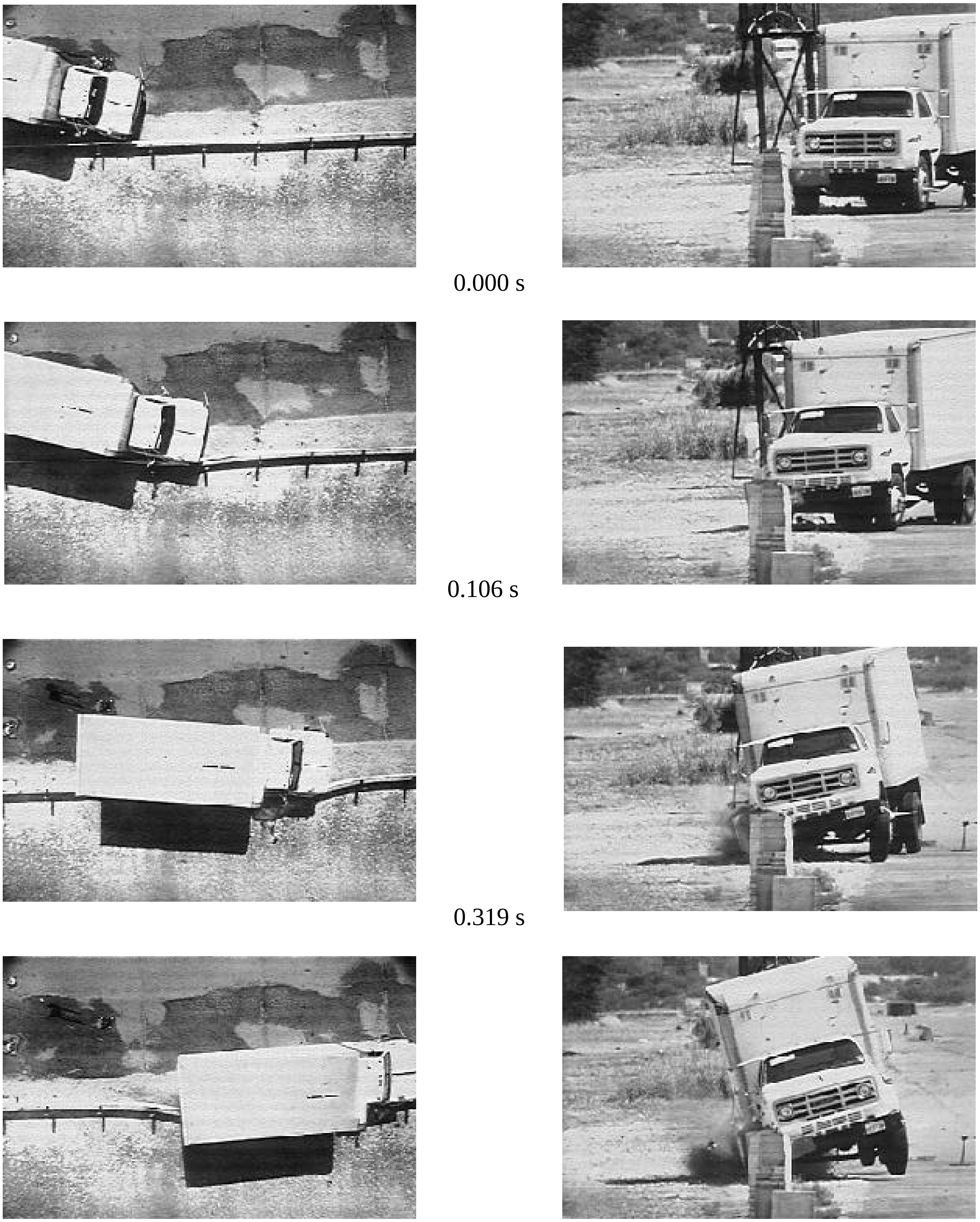
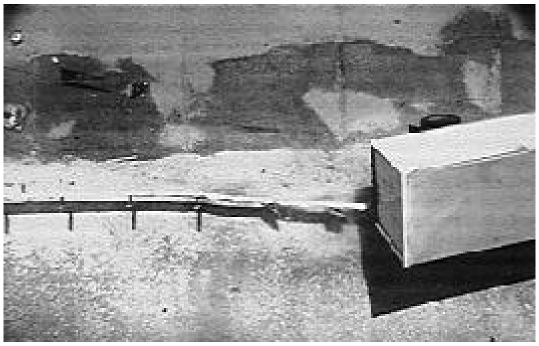
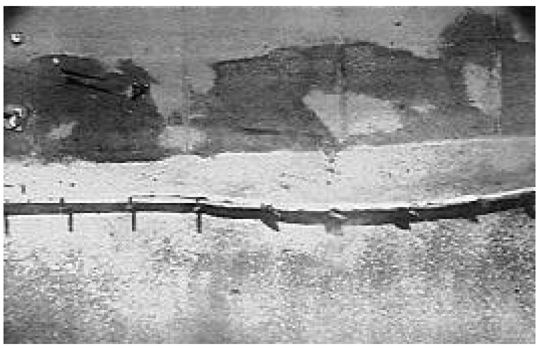


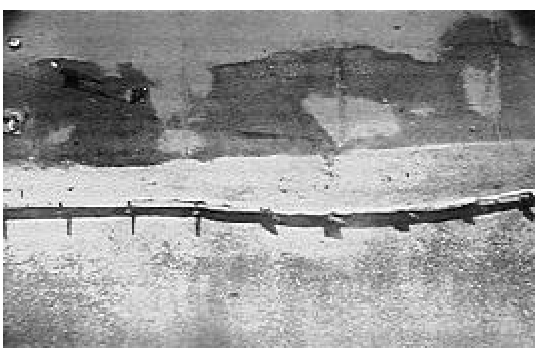
Figure 116. Sequential photographs for test 404211-5
(overhead and frontal views).



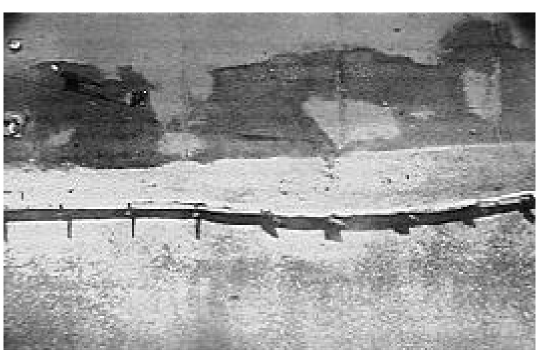

0.692 s




1.064 s

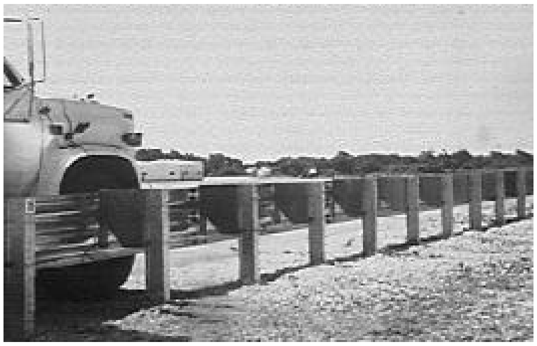



1.383 s

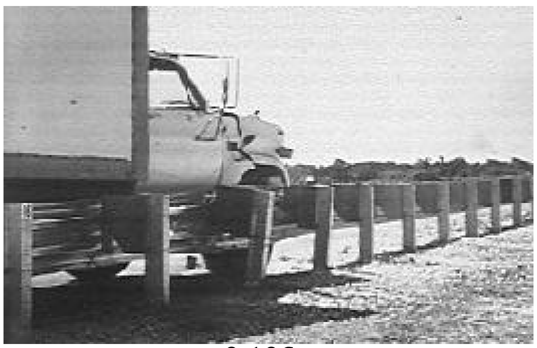



1.862 s

Figure 116. Sequential photographs for test 404211-5
(overhead and frontal views) (continued).



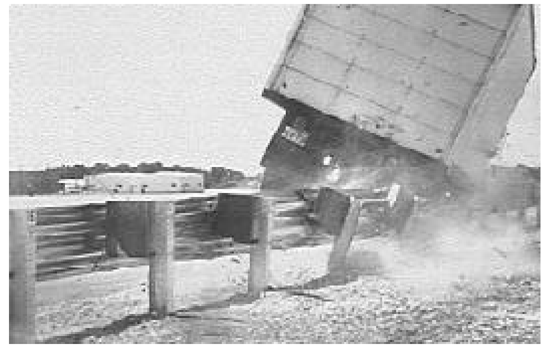
0.000 s



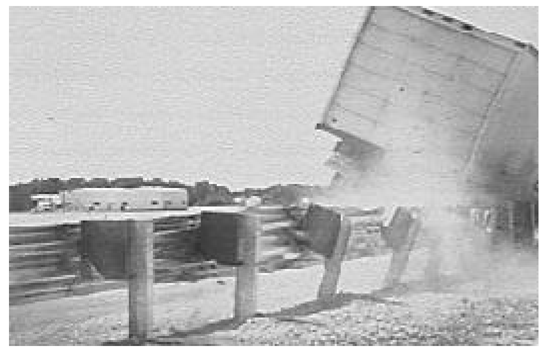
0.106 s

0.319 s

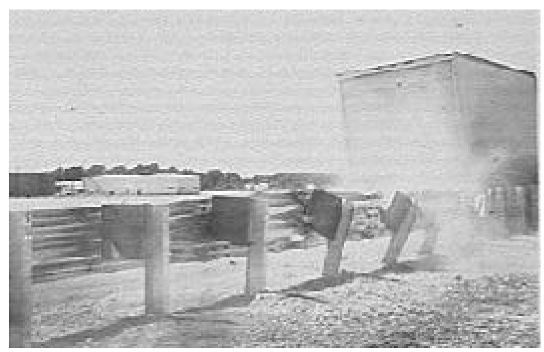
0.479 s



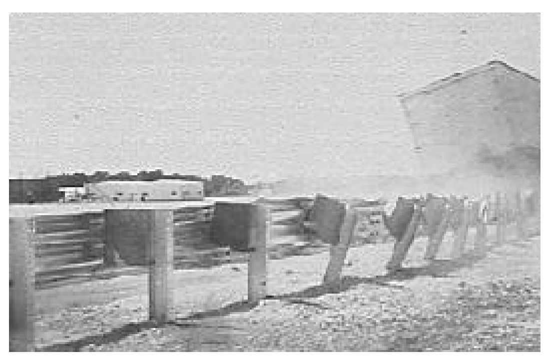
0.692 s



1.064 s



1.383 s



1.862 s

Figure 117. Sequential photographs for test 404211-5
(rear view).

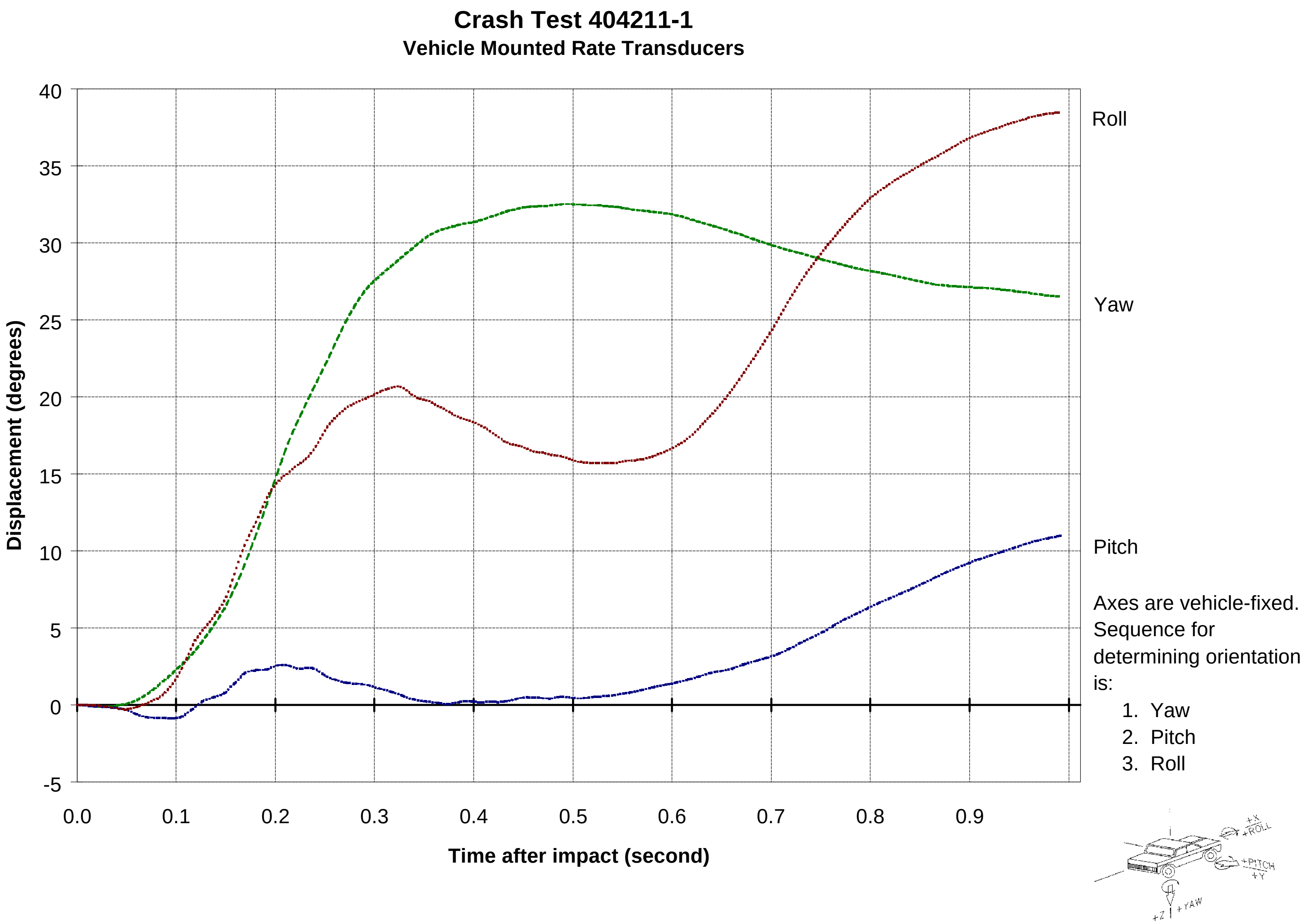
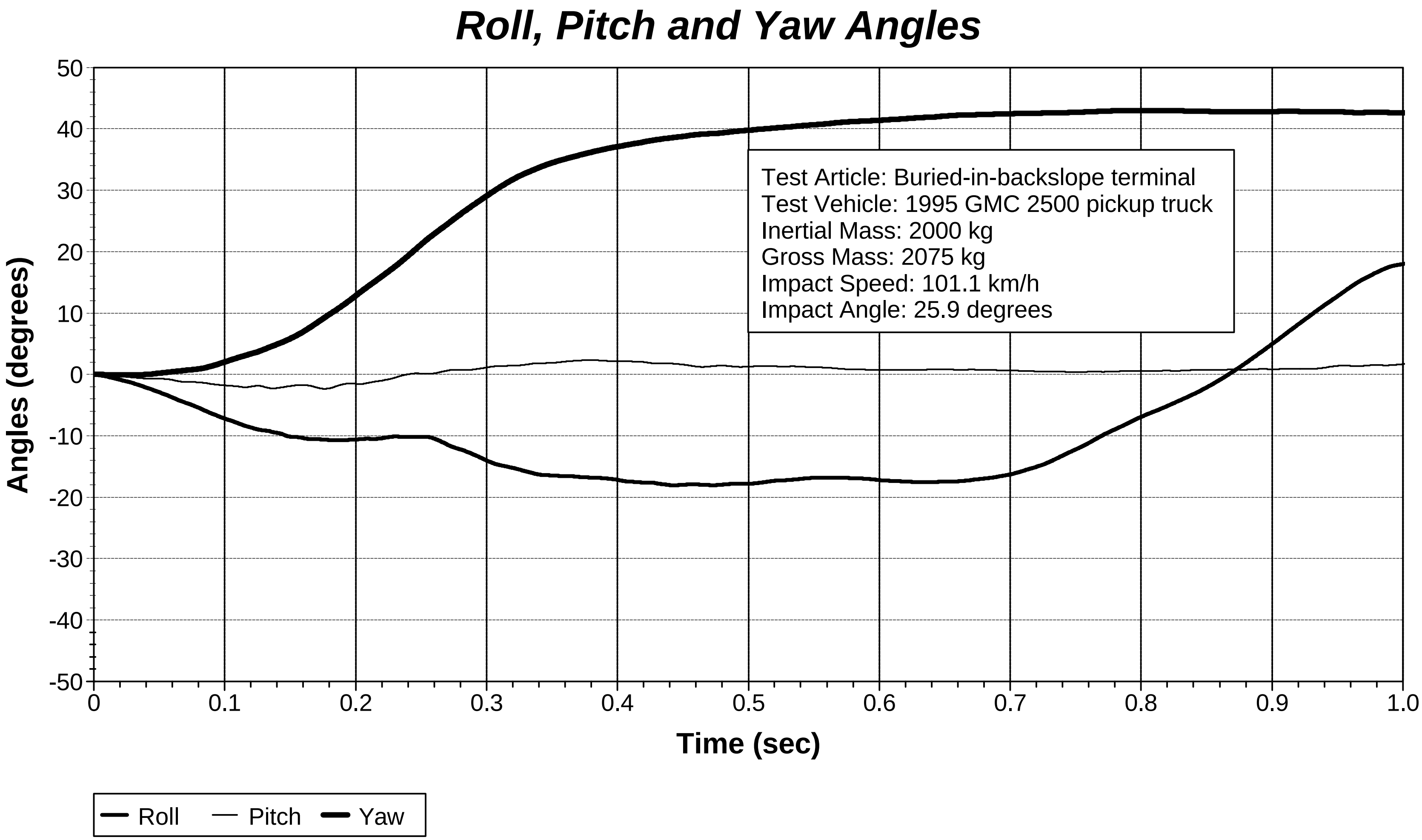


Figure 118. Vehicular angular displacements for test 404211-1.



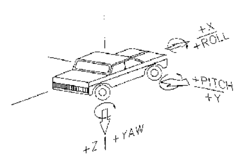


Figure 119. Vehicular angular displacements for test 404211-13.

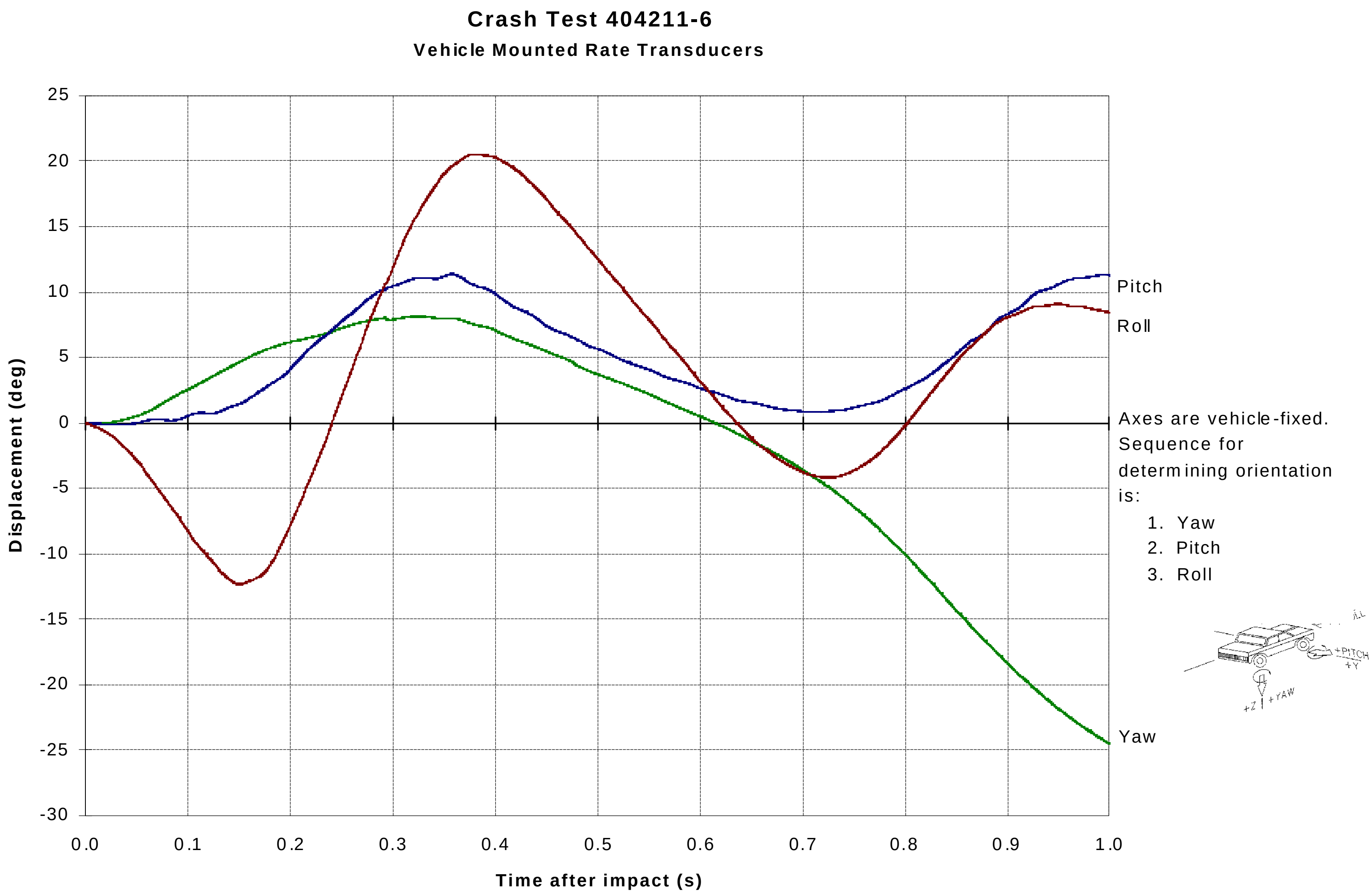


Figure 120. Vehicular angular displacements for test 404211-6.

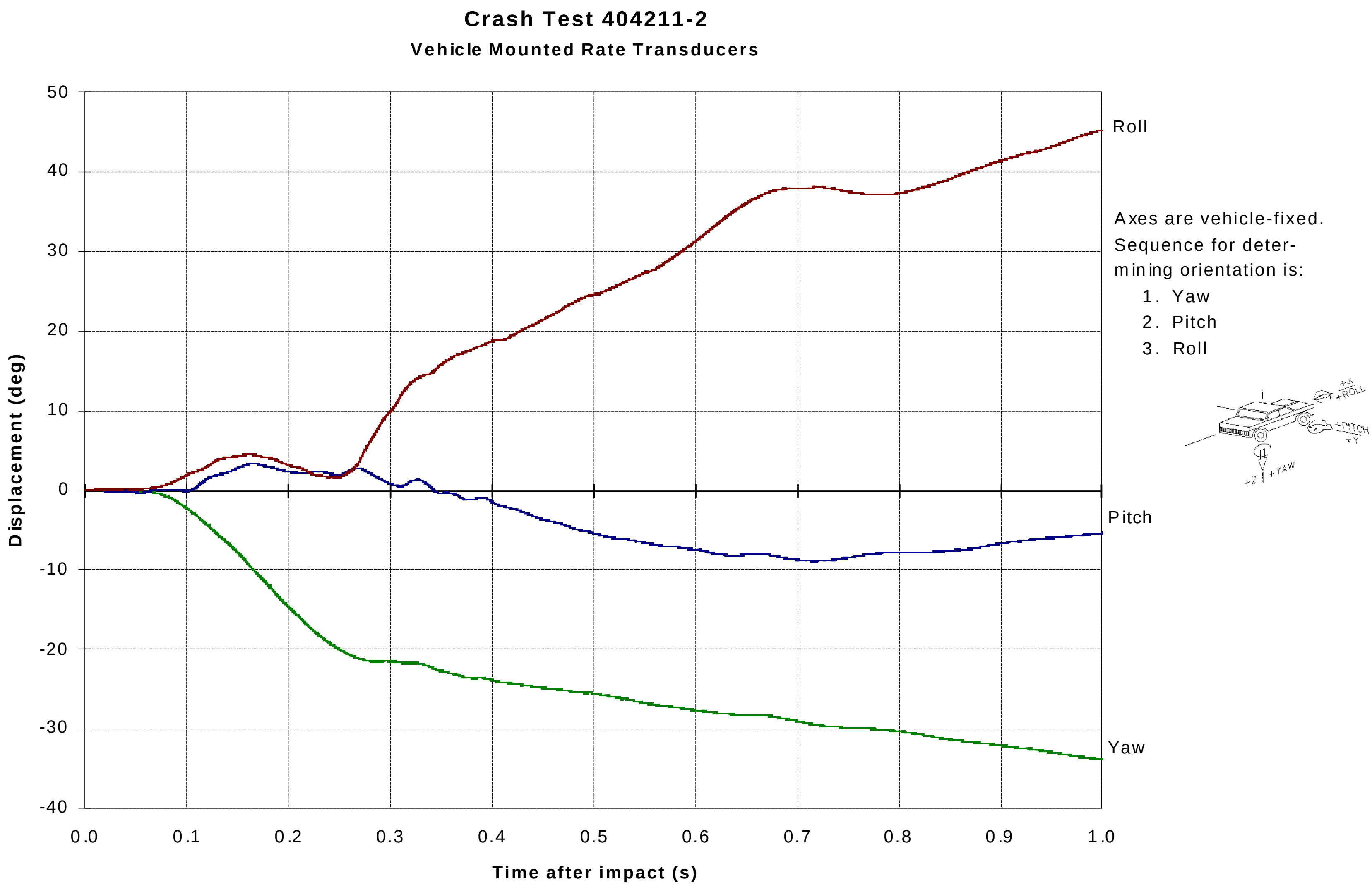


Figure 121. Vehicular angular displacements for test 404211-2.

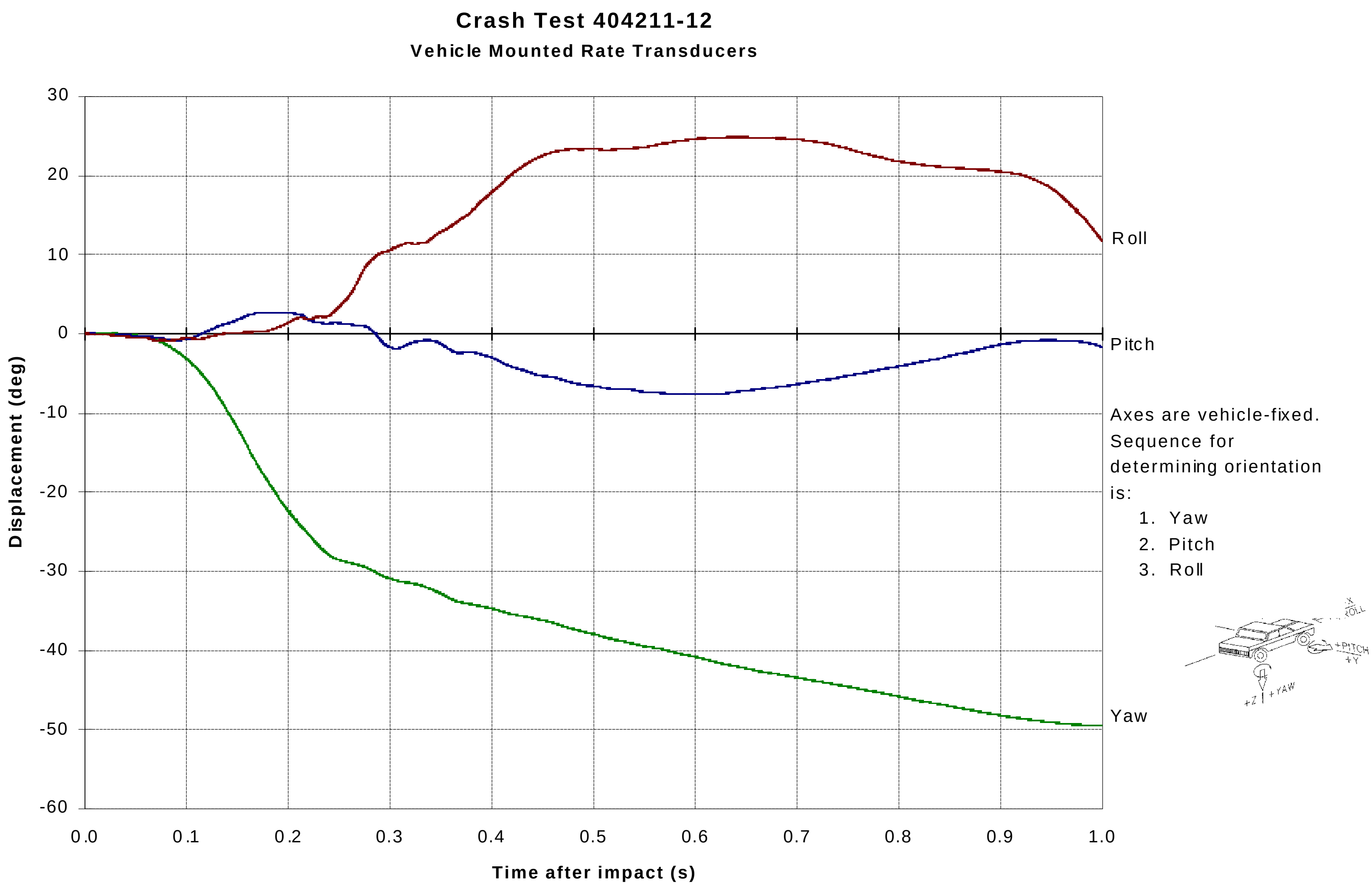


Figure 122. Vehicular angular displacements for test 404211-12.

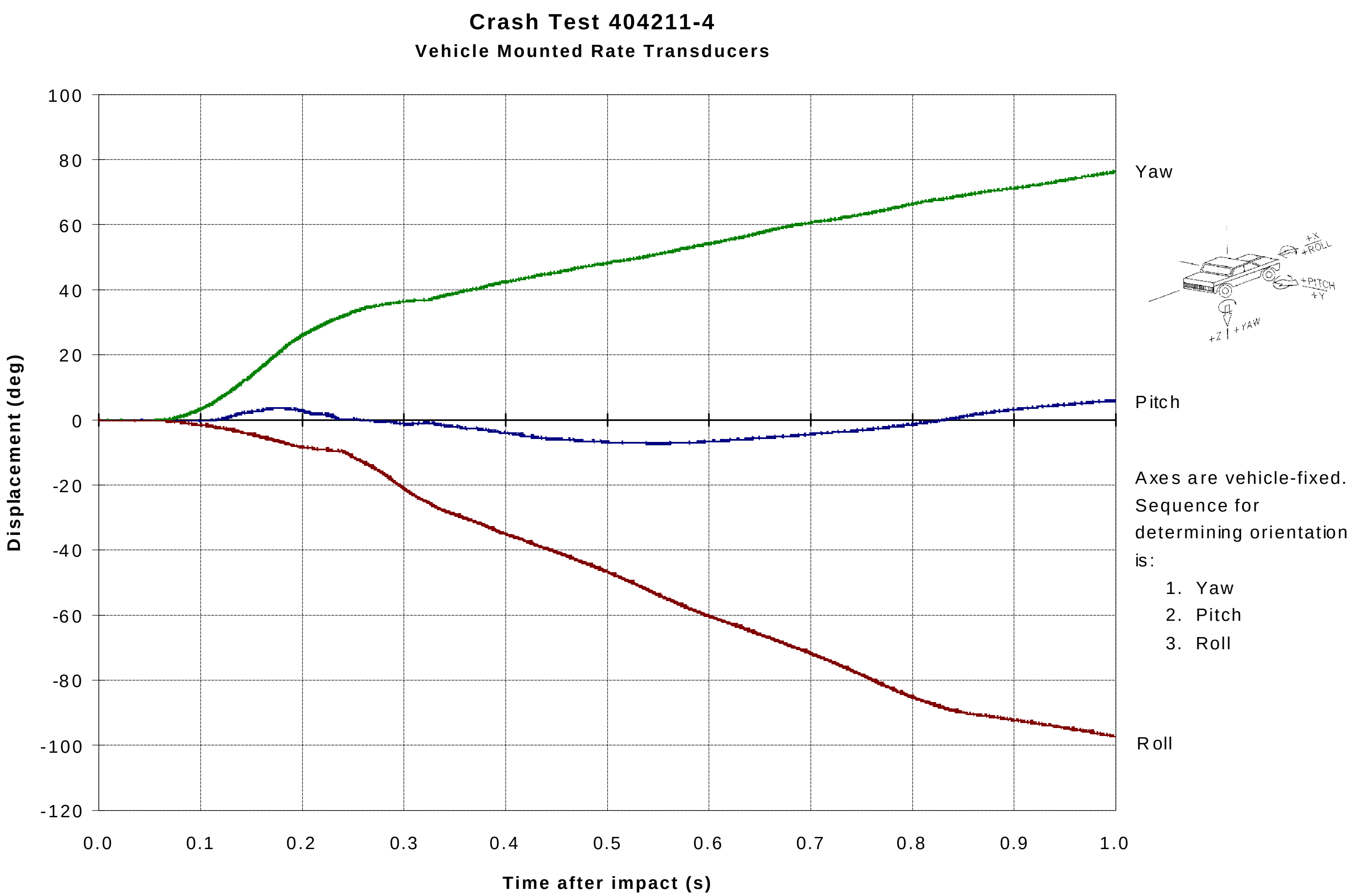


Figure 123. Vehicular angular displacements for test 404211-4.

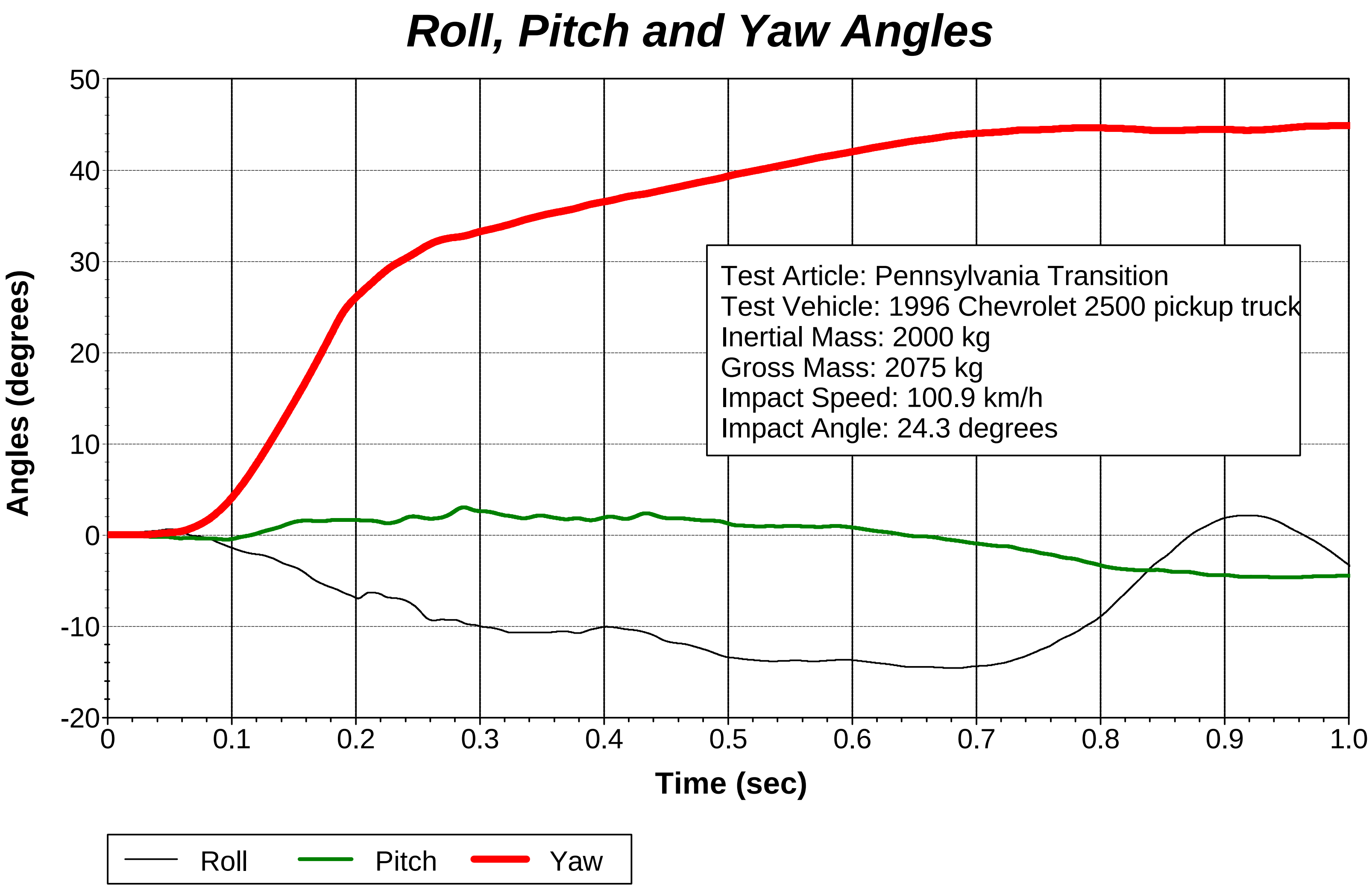
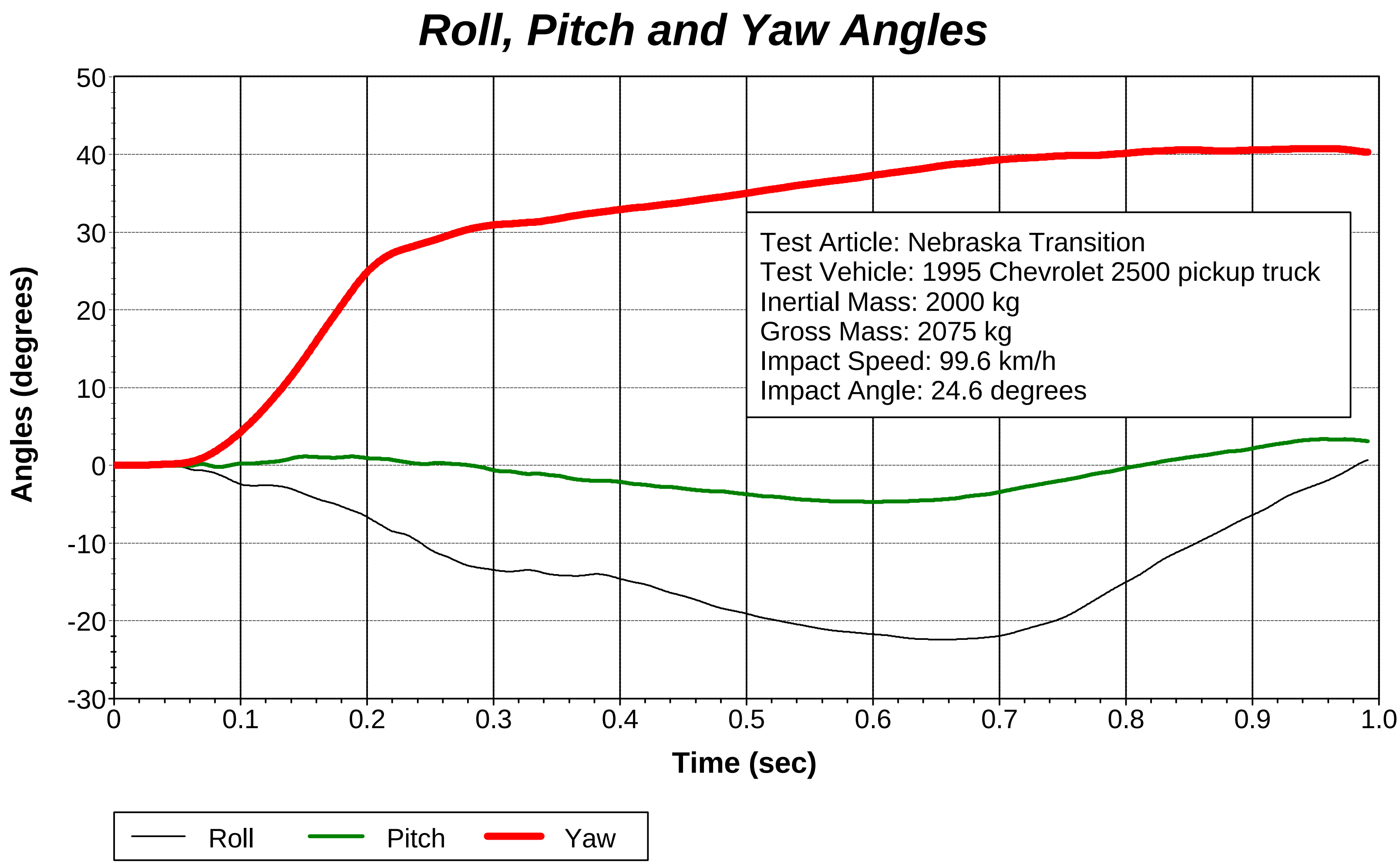


Figure 124. Vehicular angular displacements for test 404211-3.



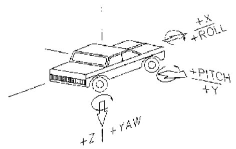


Figure 125. Vehicular angular displacements for test 404211-7.

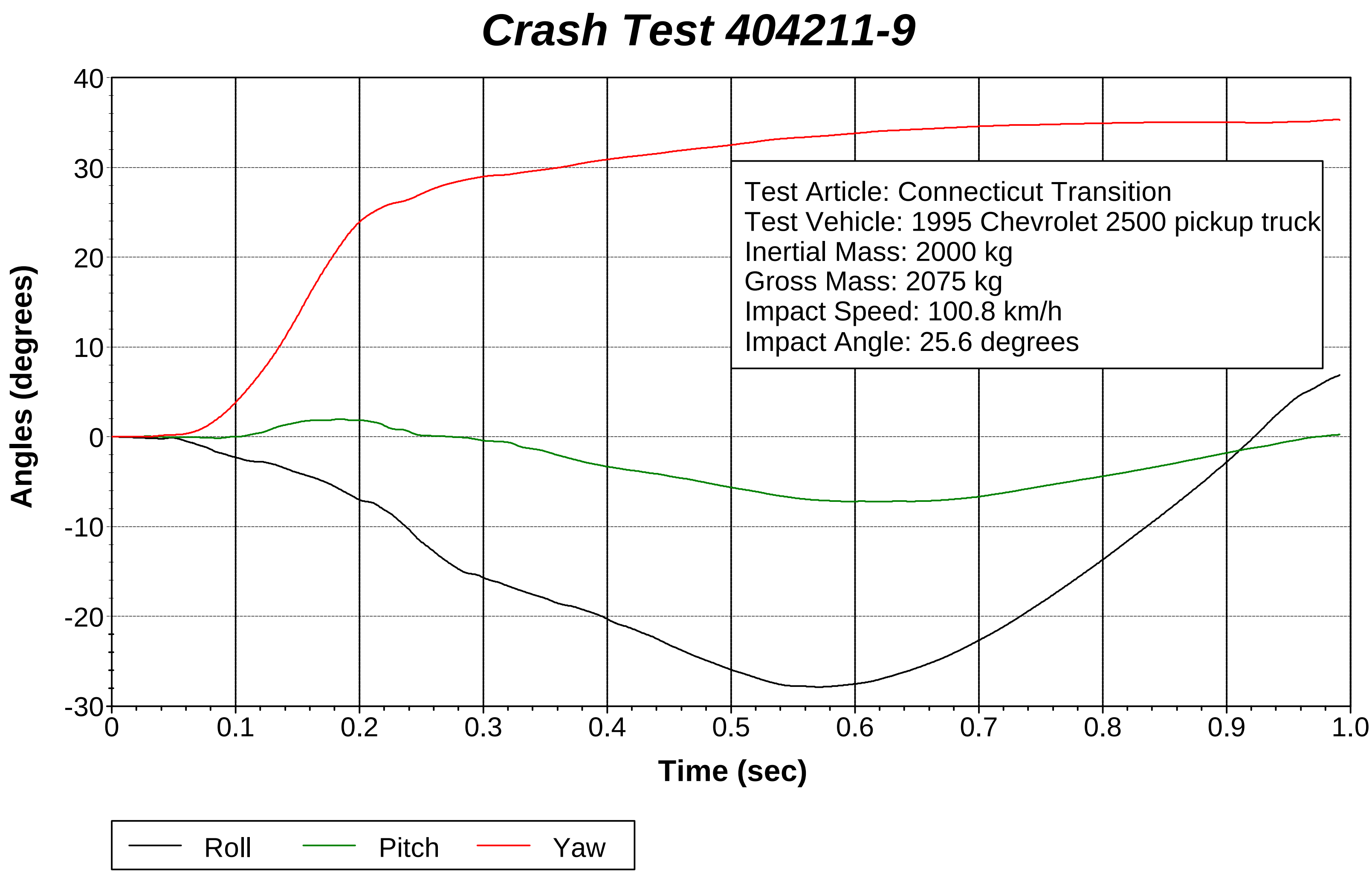


Figure 126. Vehicular angular displacements for test 404211-9.

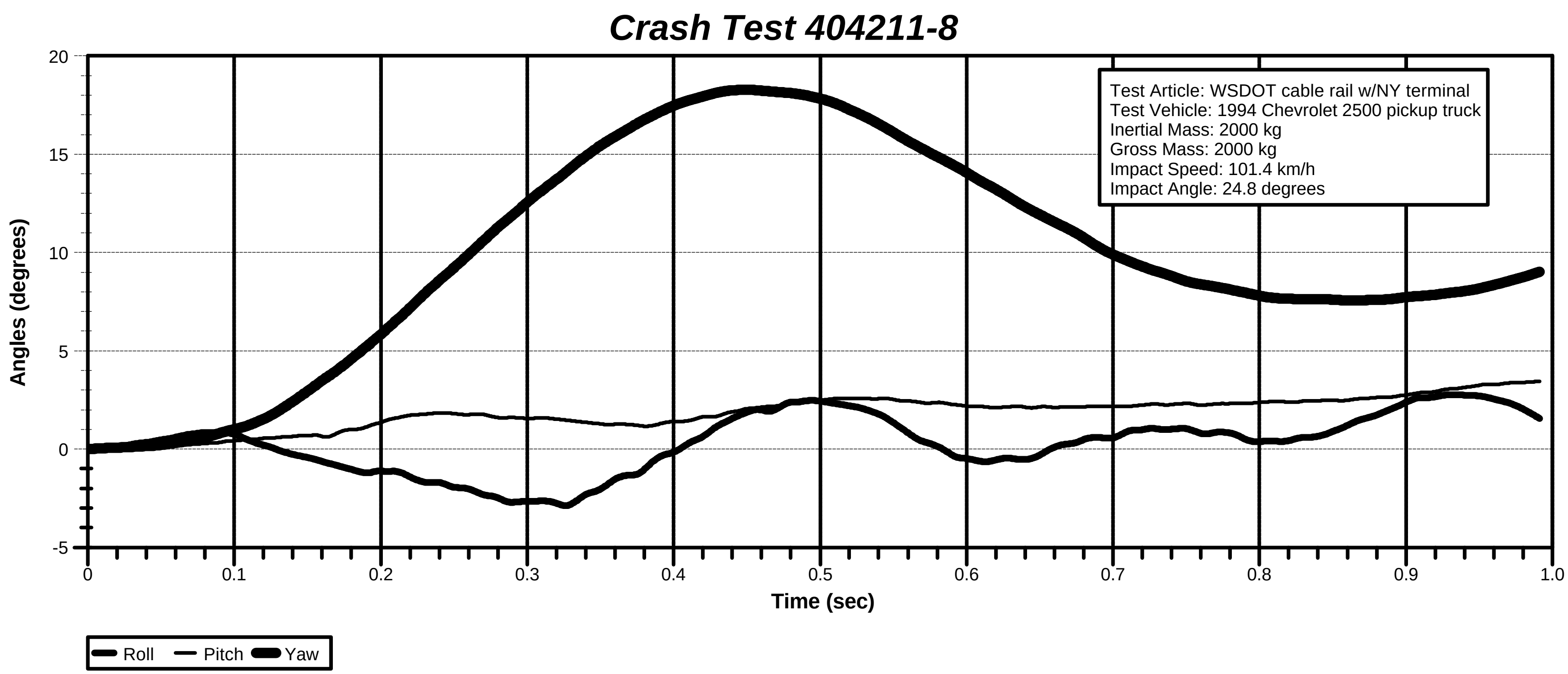
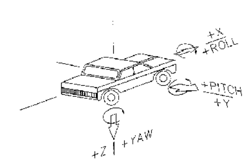


Figure 127. Vehicular angular displacements for test 404211-8.



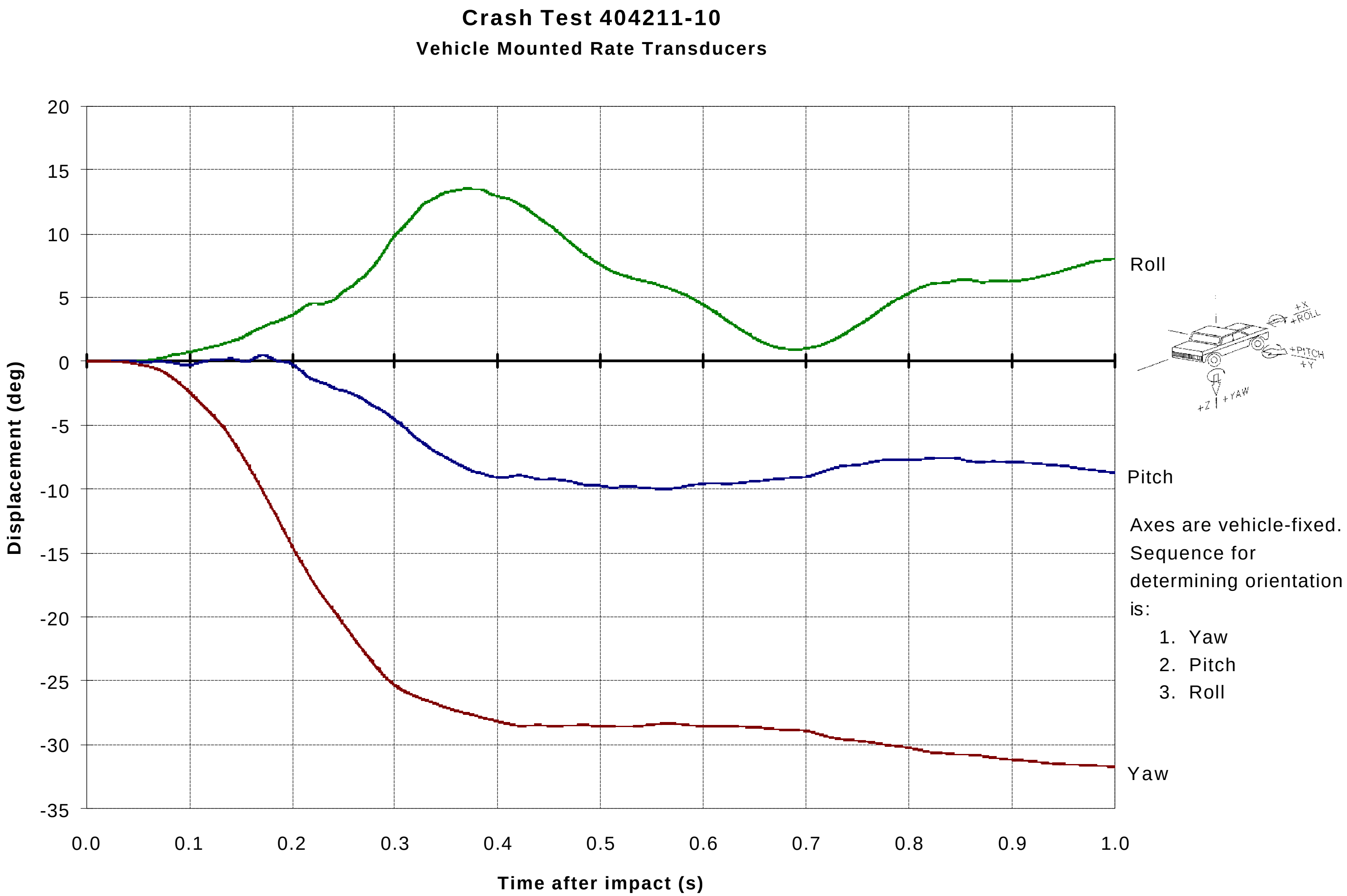


Figure 128. Vehicular angular displacements for test 404211-10.

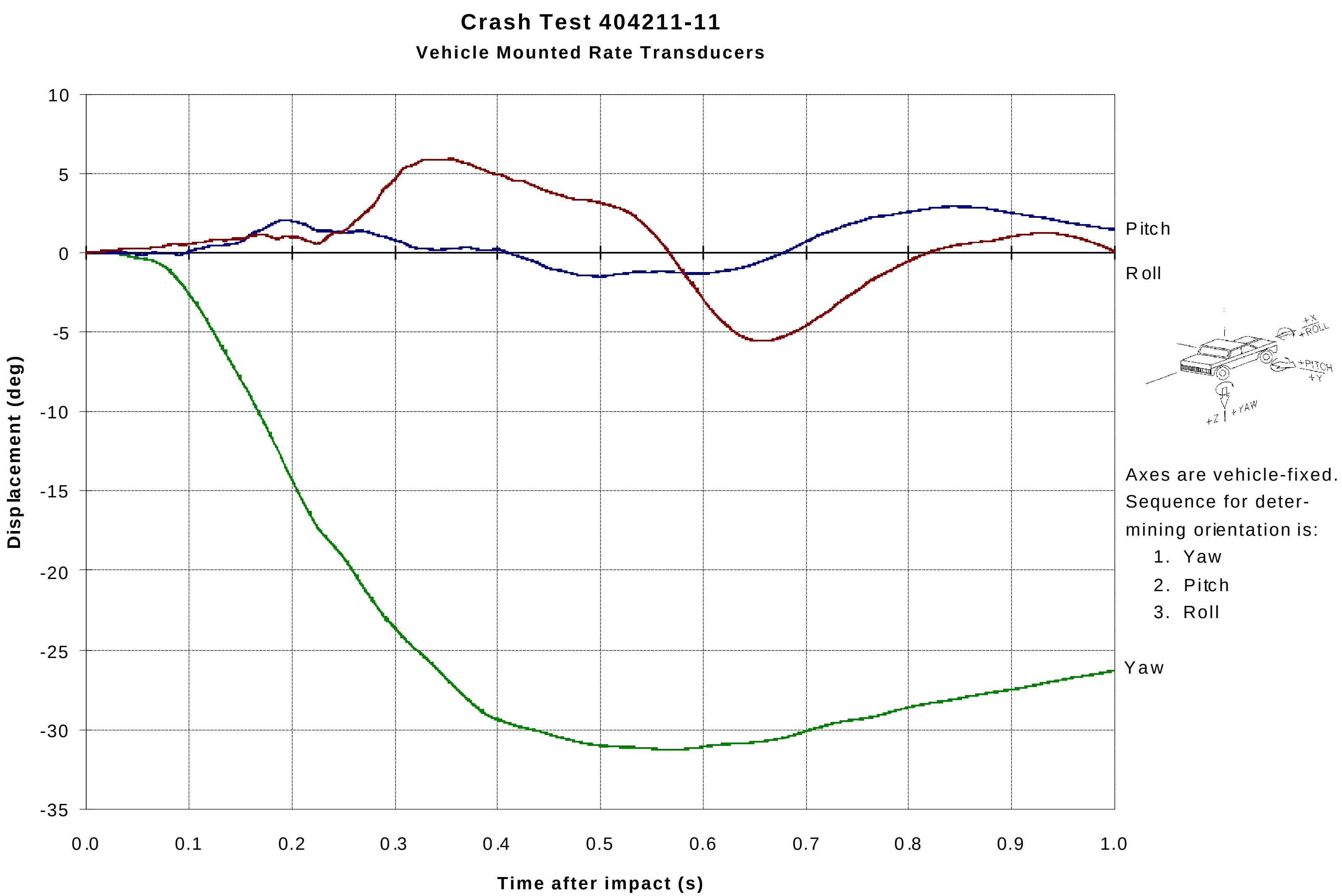


Figure 129. Vehicular angular displacements for test 404211-11.

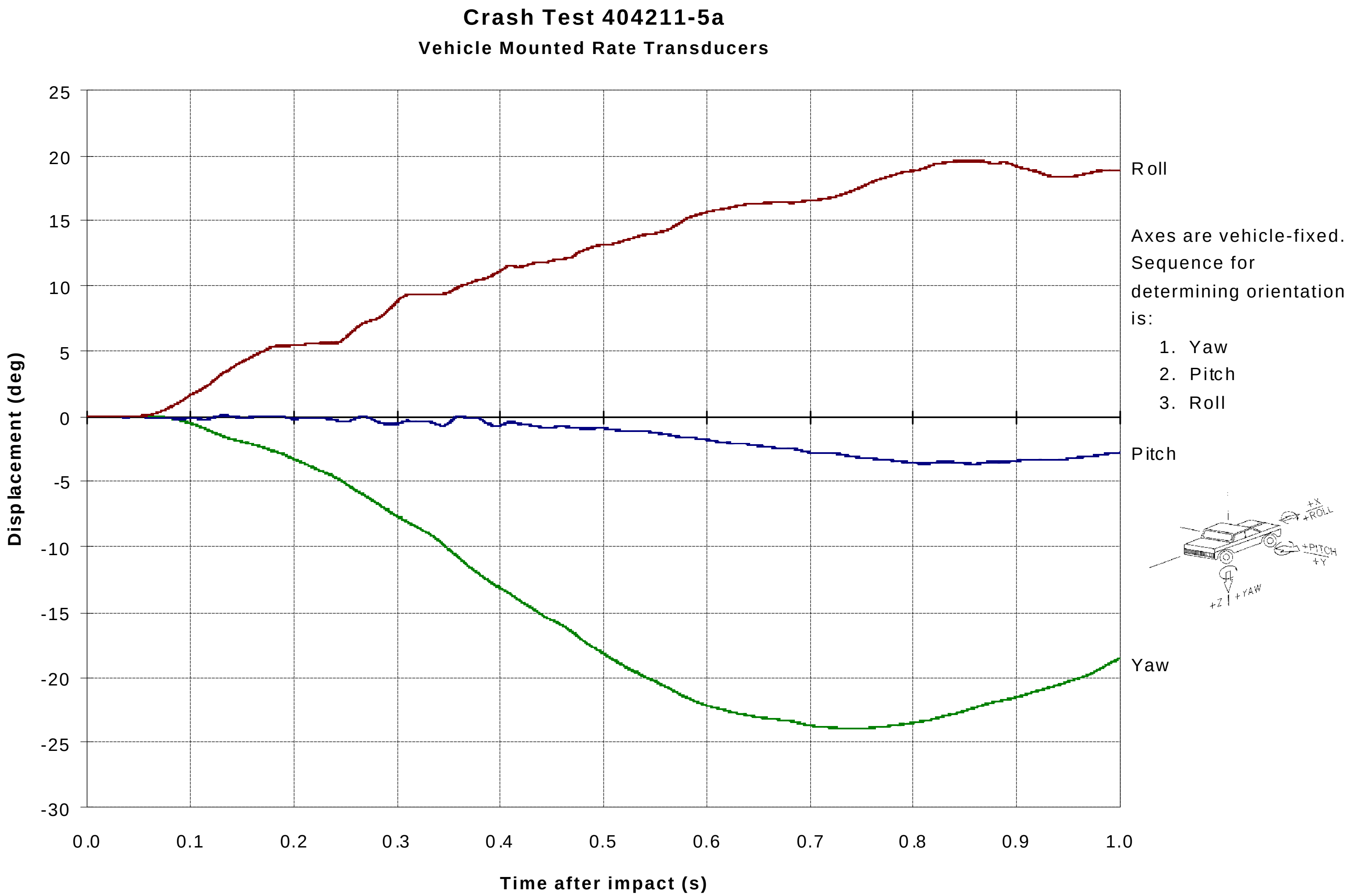


Figure 130. Vehicular angular displacements for test 404211-5.

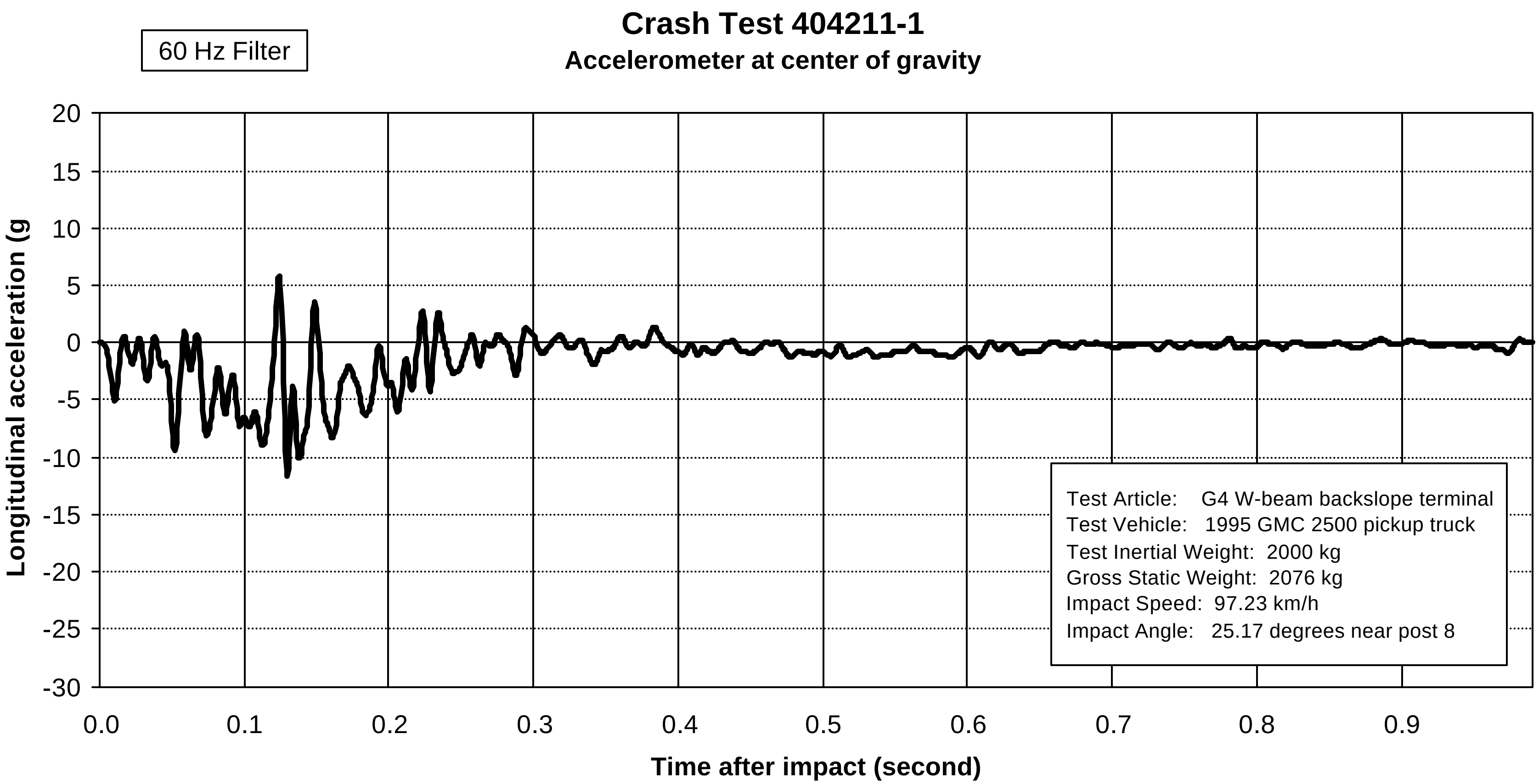


Figure 131. Vehicle longitudinal accelerometer trace for test 404211-1 (accelerometer located at center of gravity).

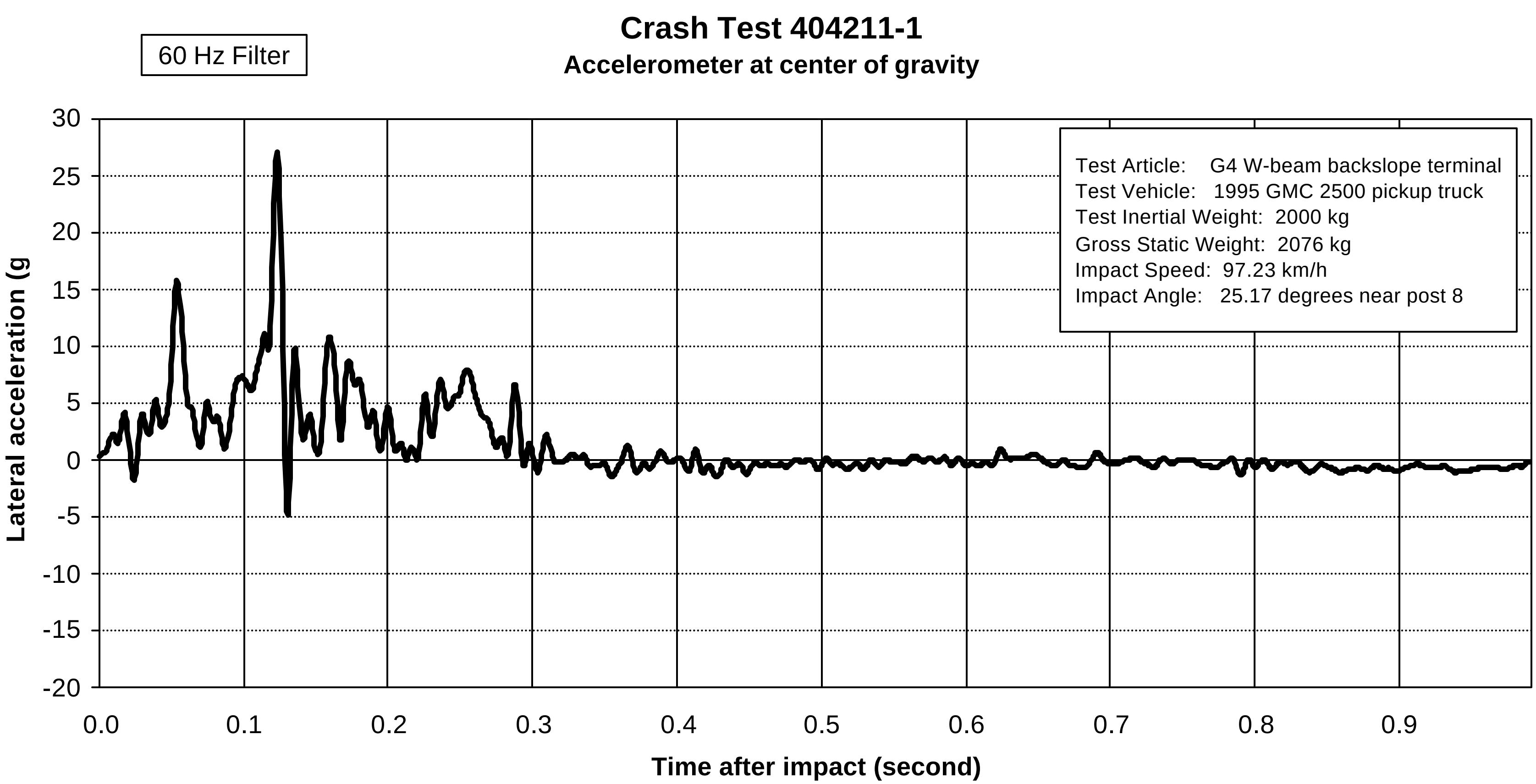


Figure 132. Vehicle lateral accelerometer traces for test 404211-1
(accelerometer located at center of gravity).

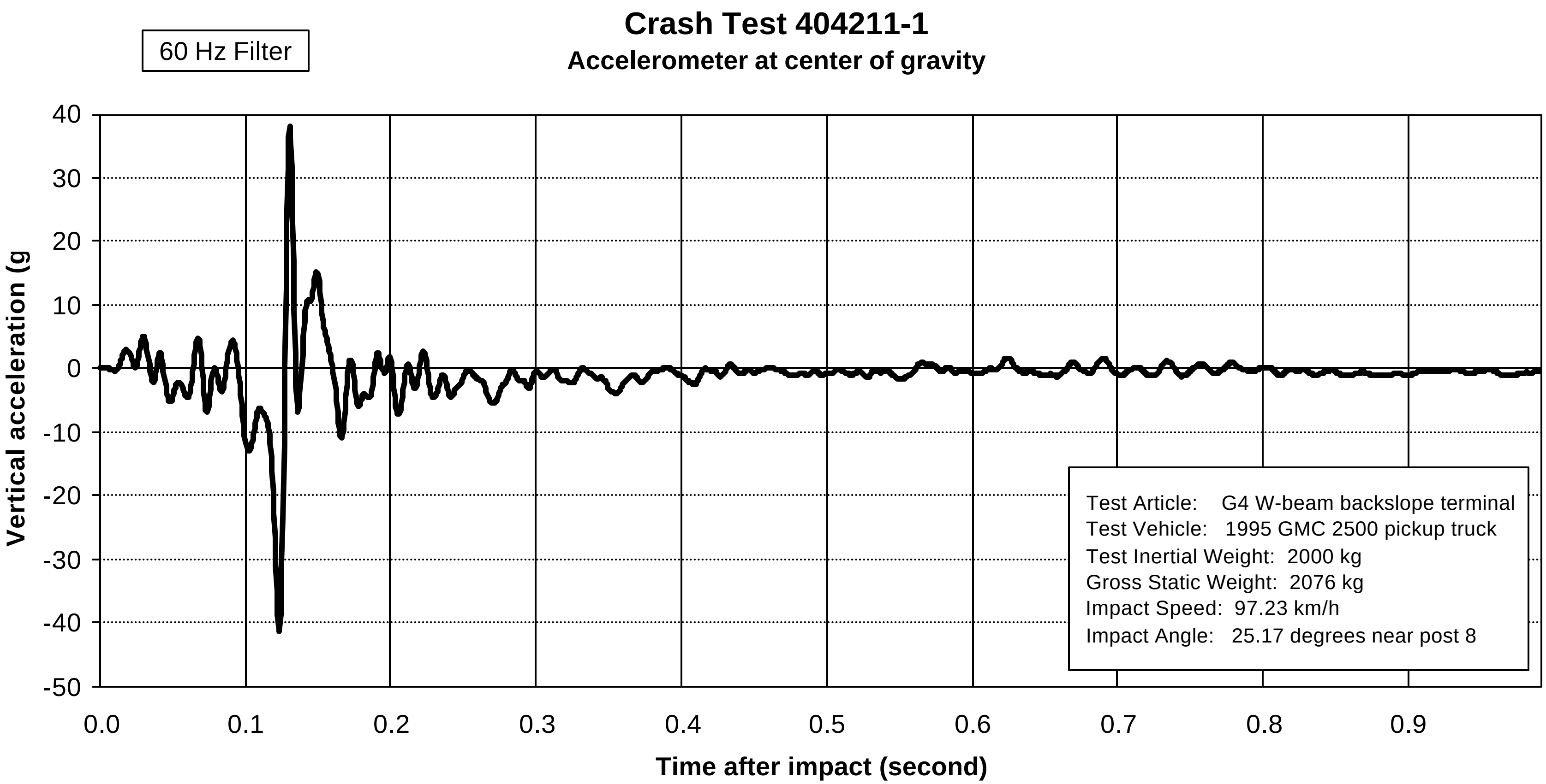


Figure 133. Vehicle vertical accelerometer trace for test 404211-1 (accelerometer located at center of gravity).

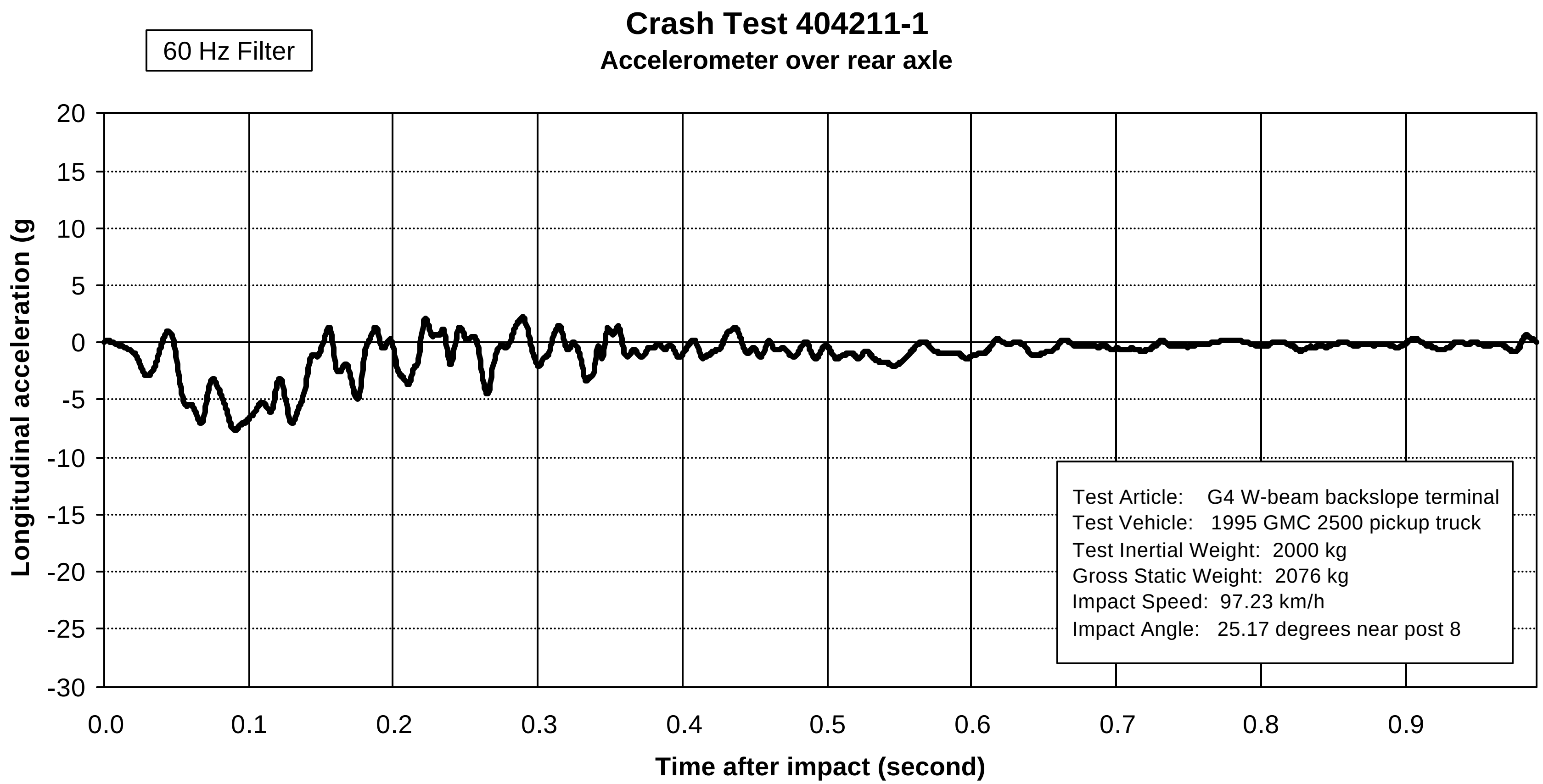


Figure 134. Vehicle longitudinal accelerometer trace for test 404211-1 (accelerometer located over rear axle).

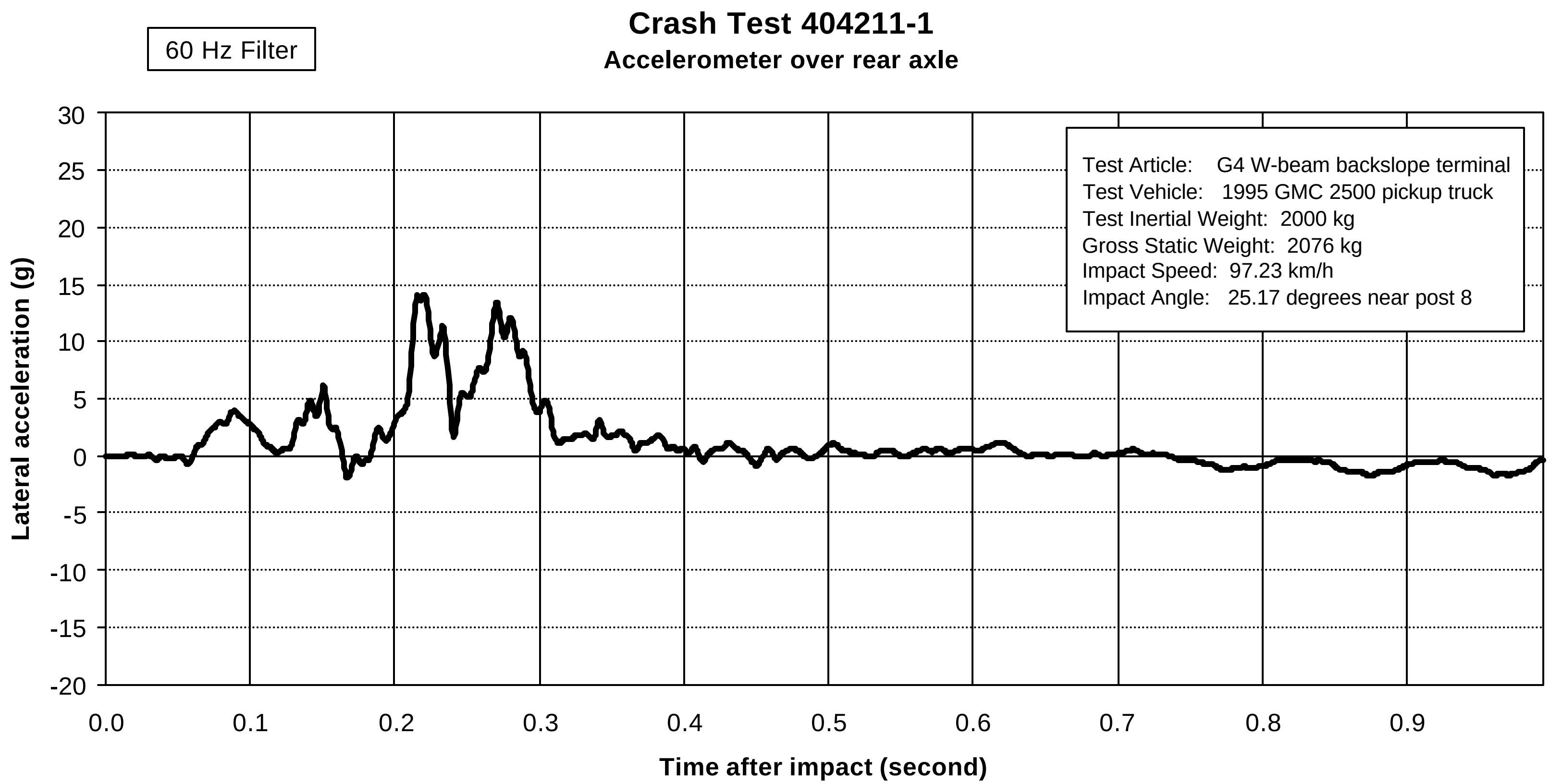


Figure 135. Vehicle lateral accelerometer traces for test 404211-1 (accelerometer located over rear axle).

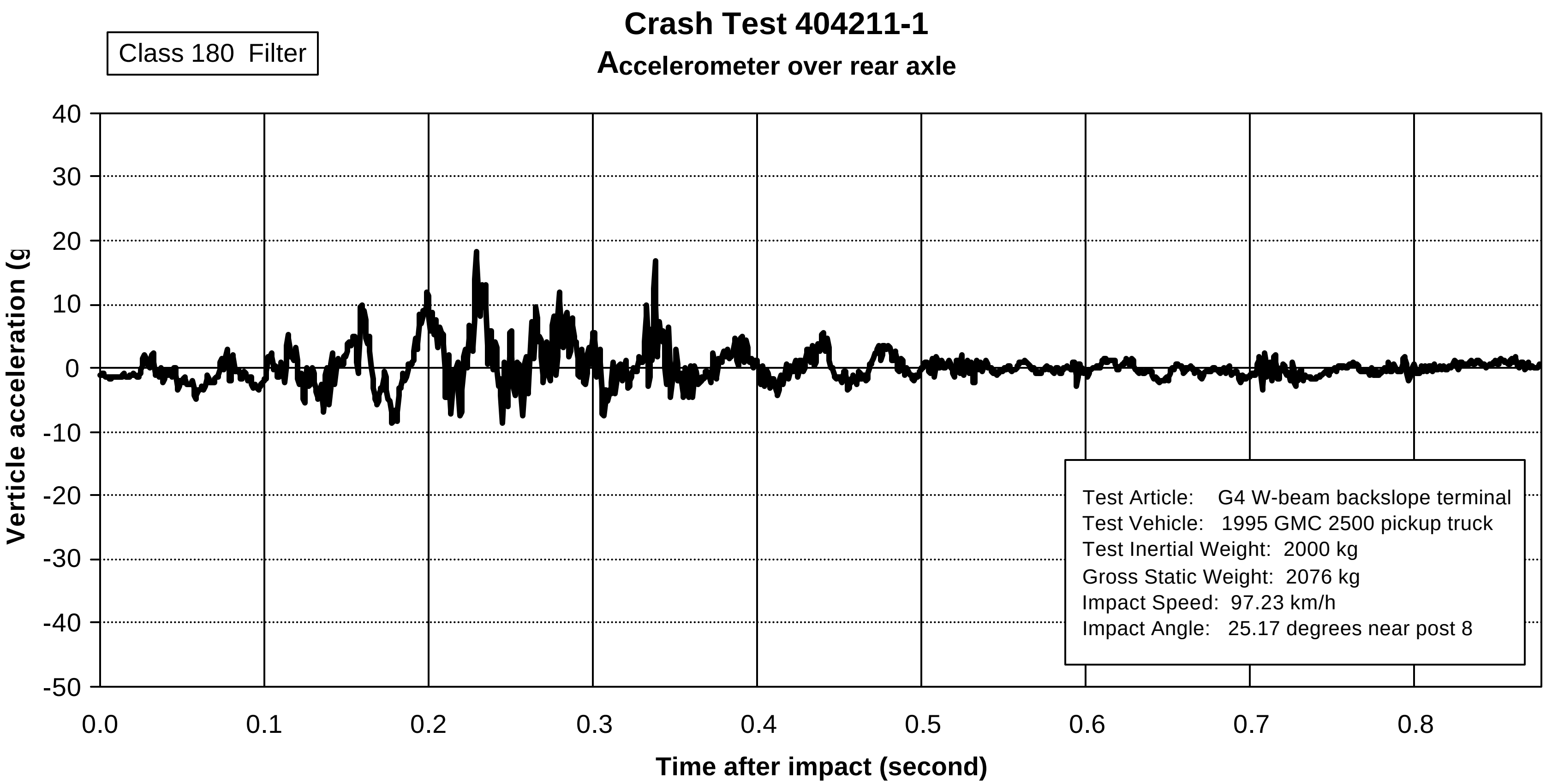


Figure 136. Vehicle vertical accelerometer trace for test 404211-1 (accelerometer located over rear axle).

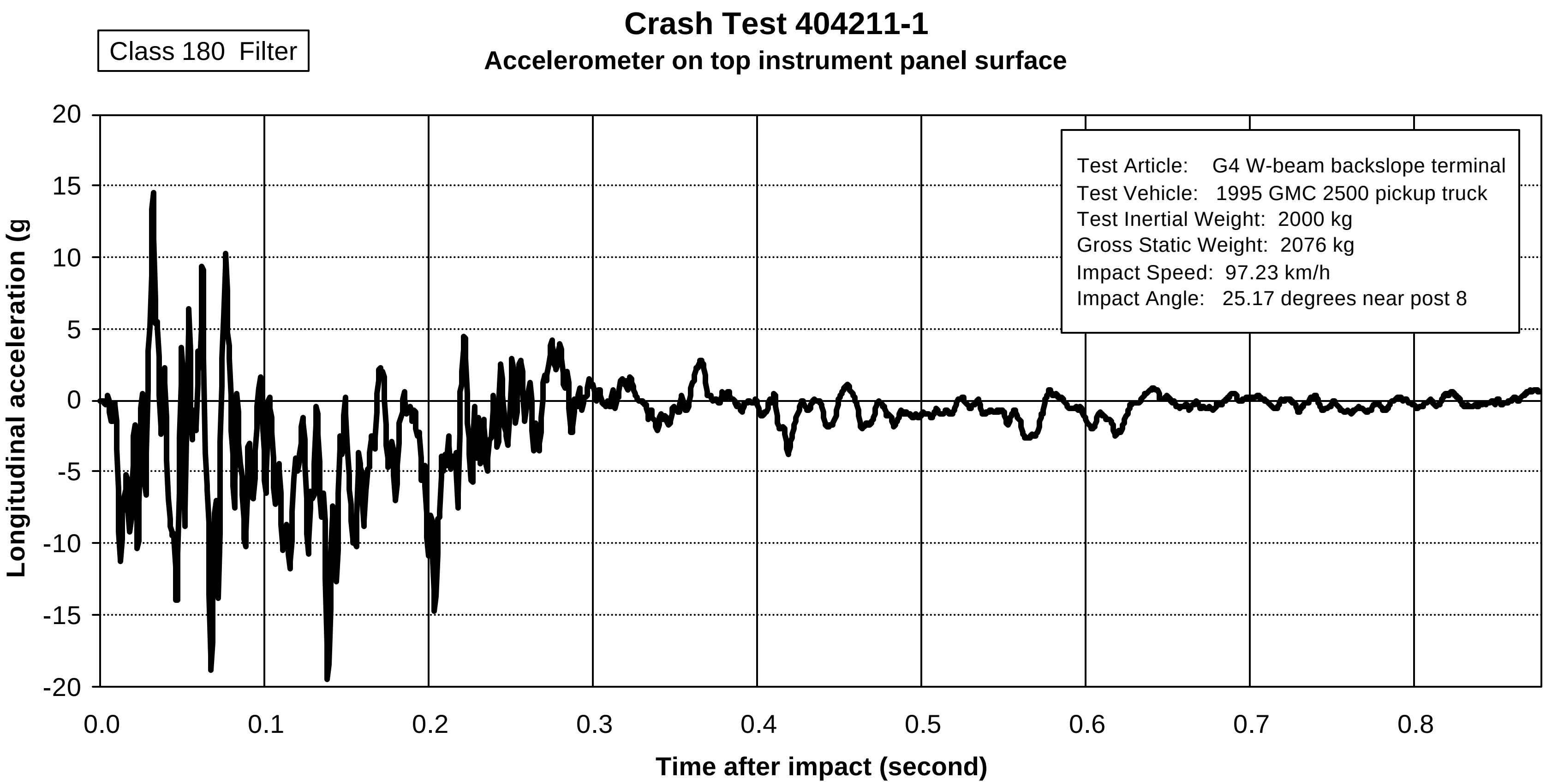


Figure 137. Vehicle longitudinal accelerometer trace for test 404211-1
(accelerometer located on top surface of instrument panel).

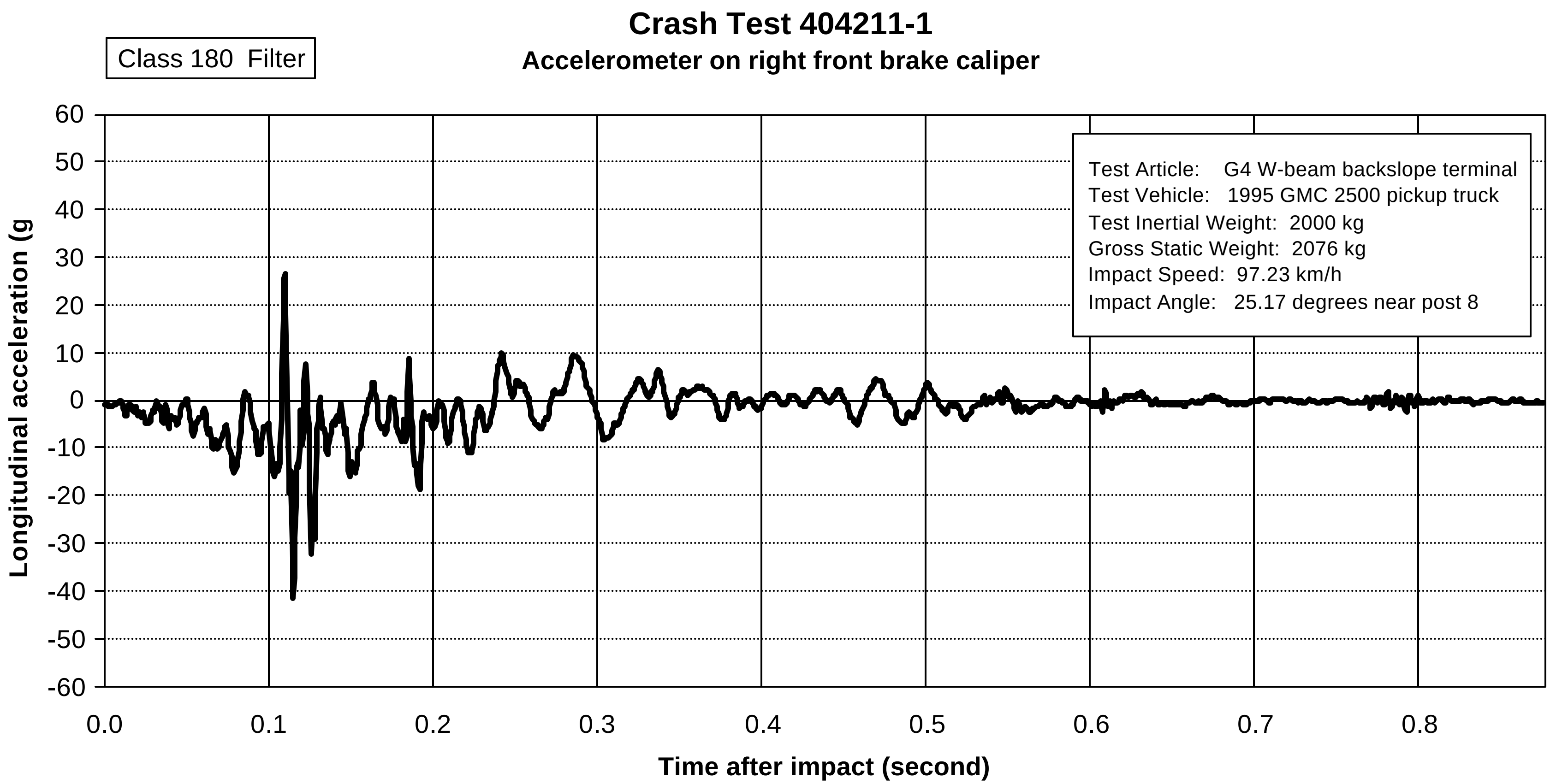


Figure 138. Vehicle longitudinal accelerometer trace for test 404211-1
(accelerometer located on right front brake caliper).

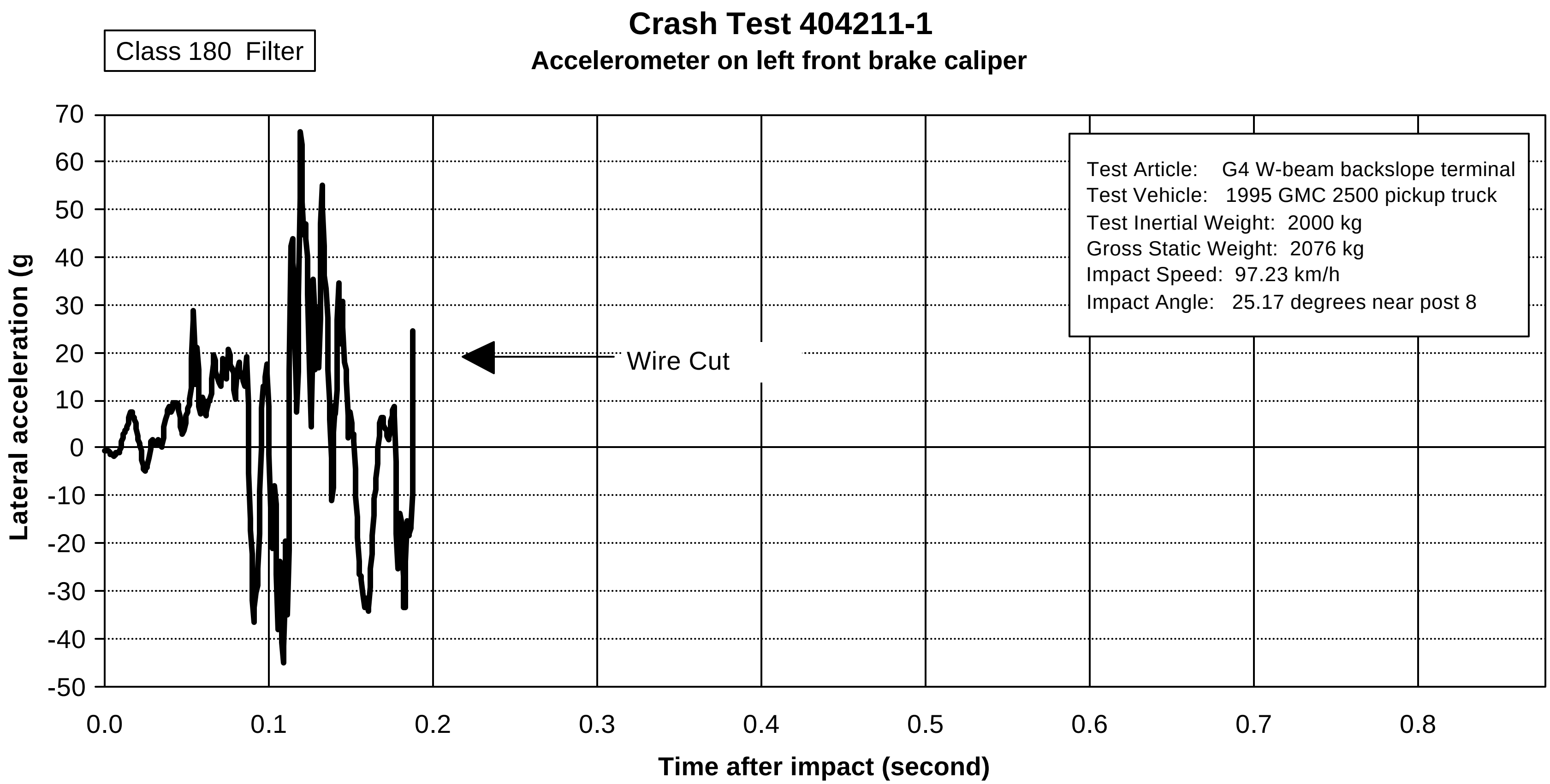


Figure 139. Vehicle lateral accelerometer trace for test 404211-1
(accelerometer located on left front brake caliper).

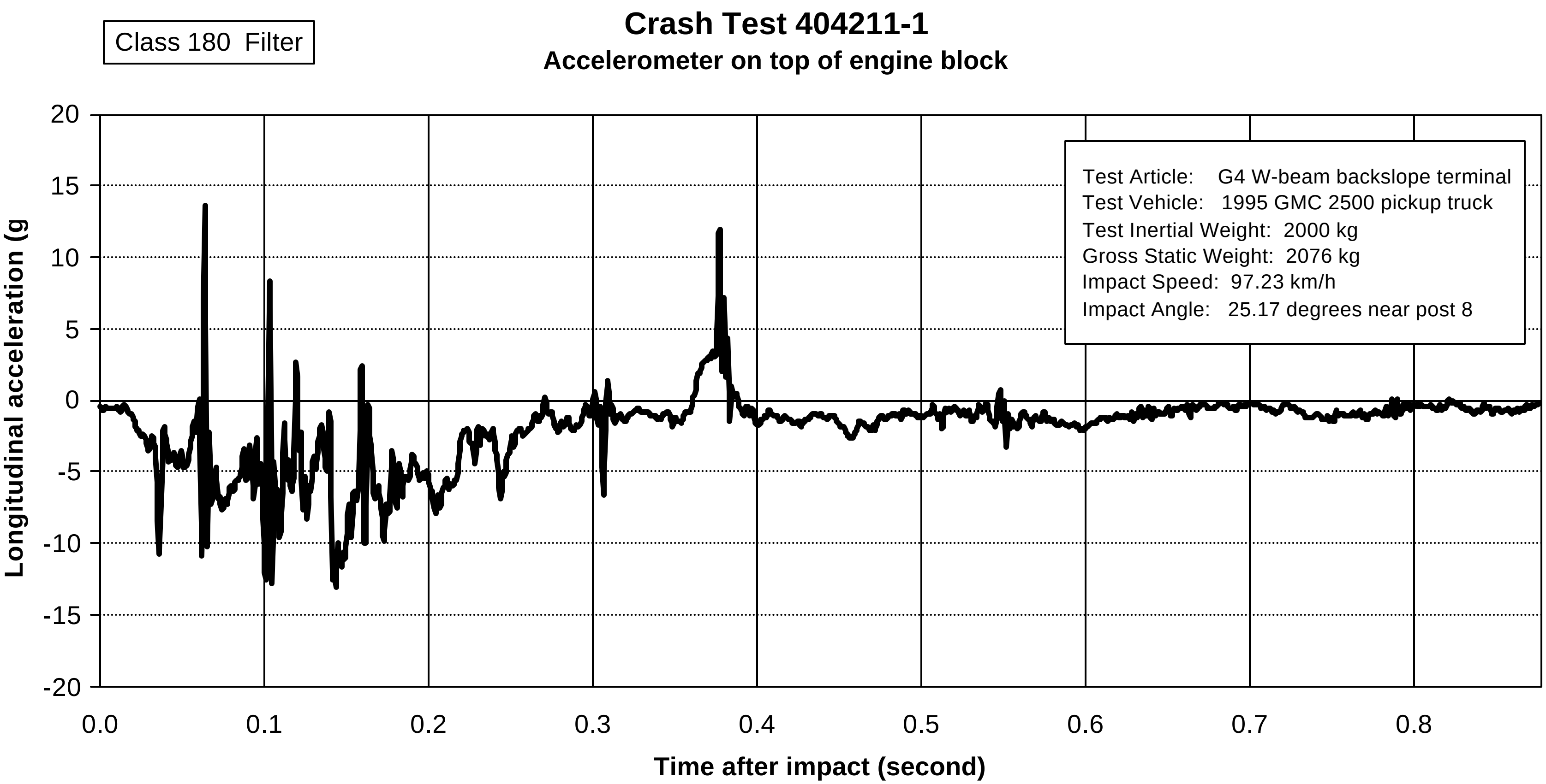


Figure 140. Vehicle longitudinal accelerometer trace for test 404211-1 (accelerometer located on top of engine block).

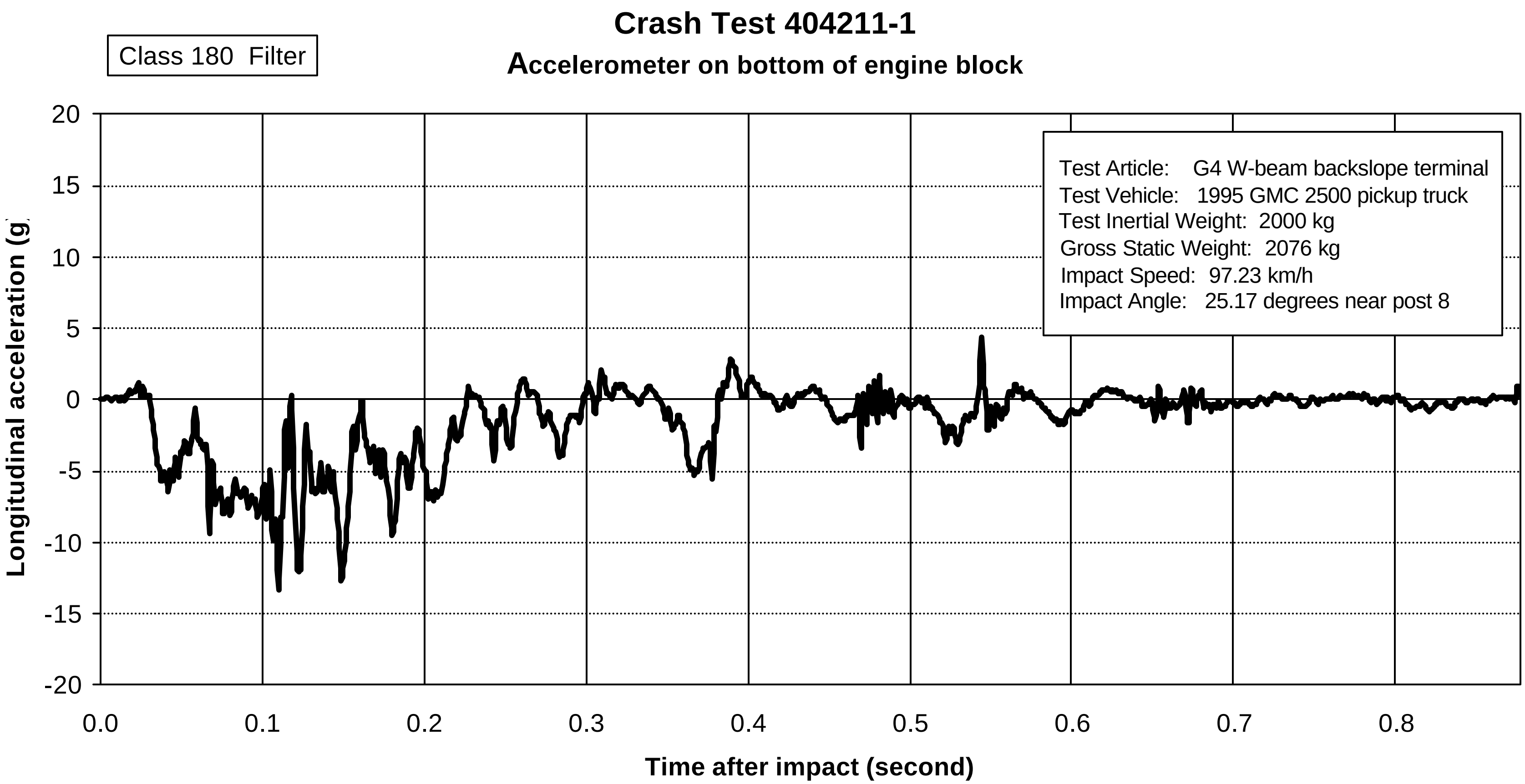


Figure 141. Vehicle longitudinal accelerometer trace for test 404211-1 (accelerometer located on bottom of engine block).

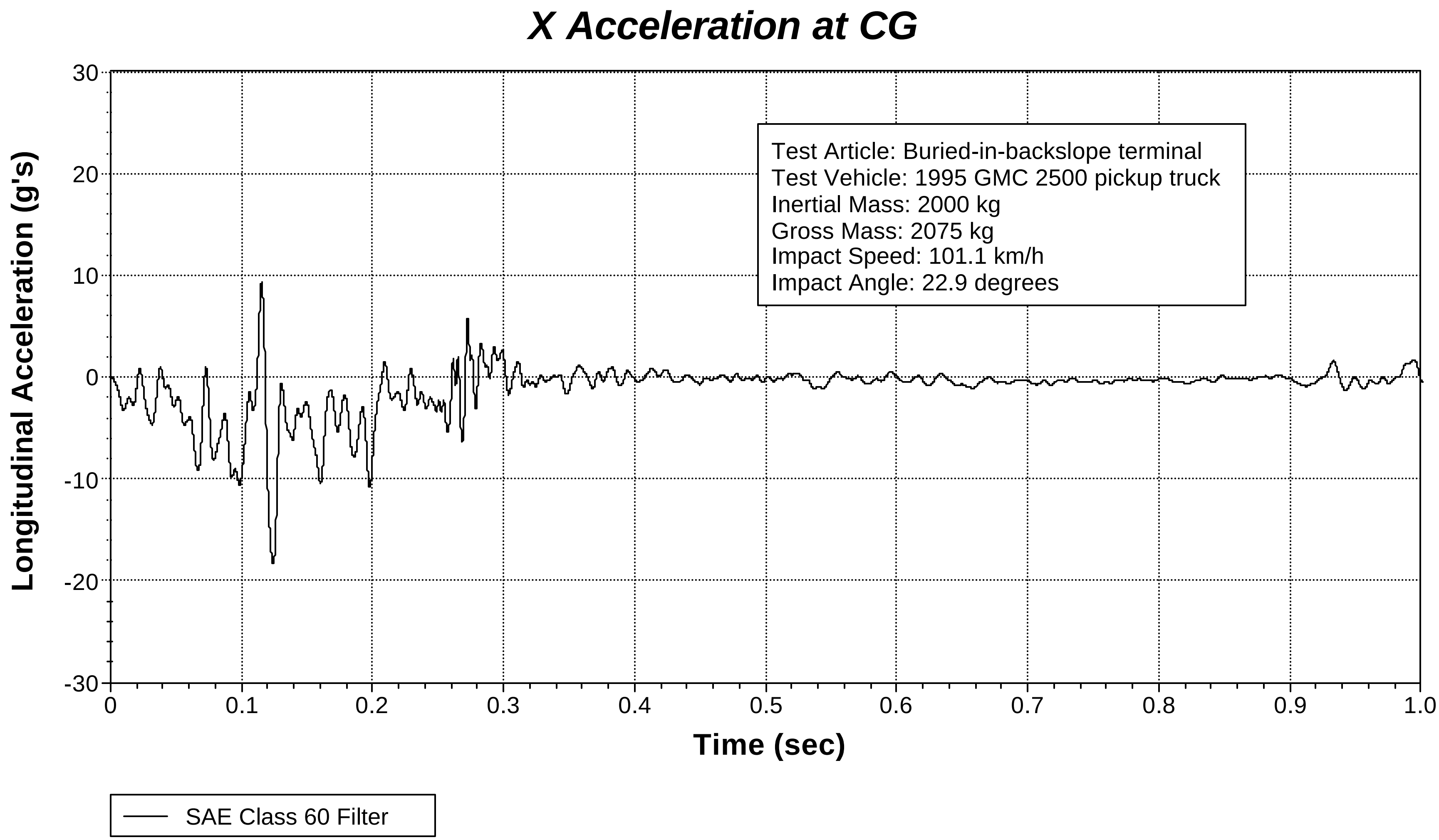


Figure 142. Vehicle longitudinal accelerometer trace for test 404211-13 (accelerometer located at center of gravity).

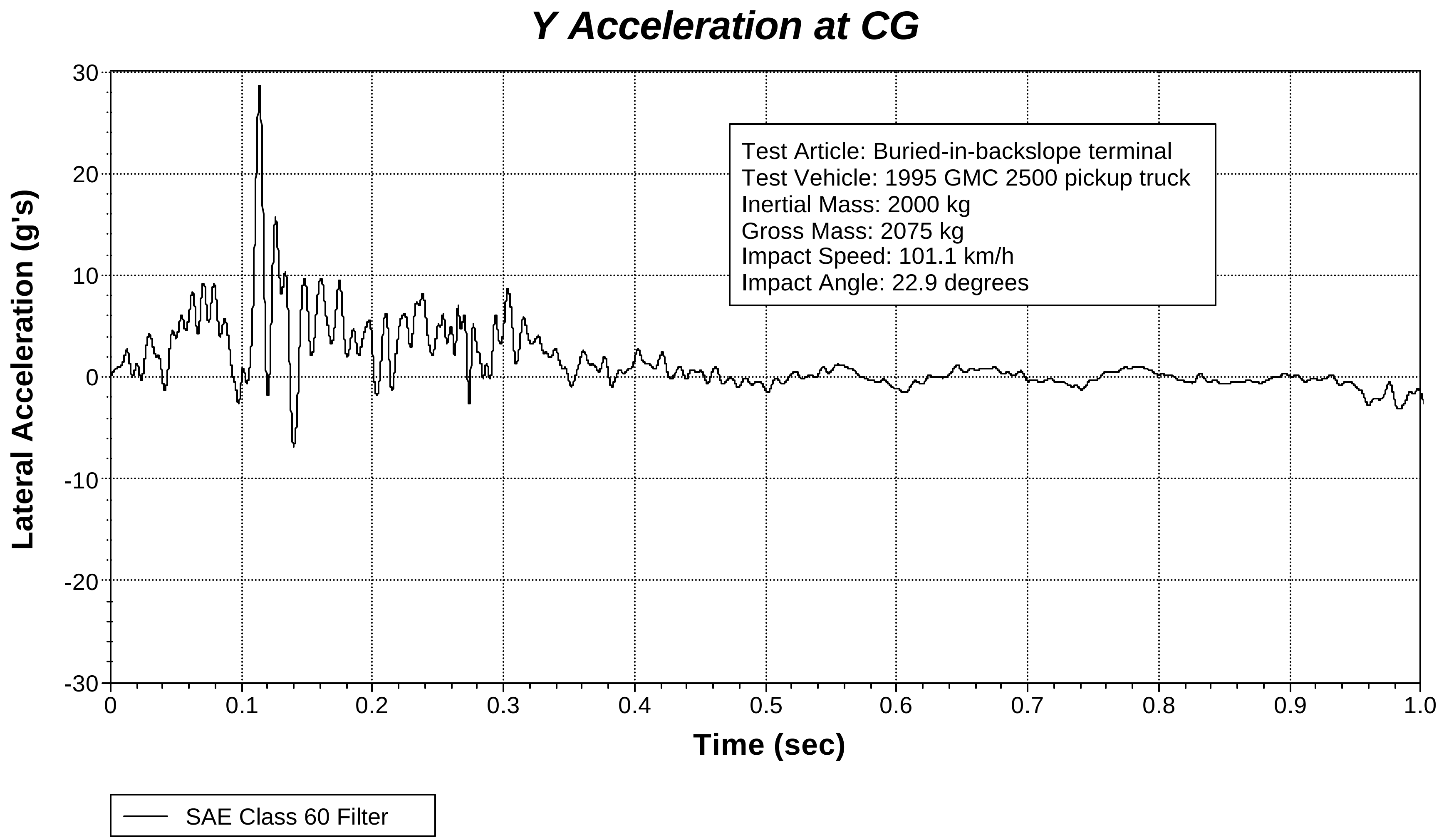


Figure 143. Vehicle lateral accelerometer trace for test 404211-13
(accelerometer located at center of gravity).

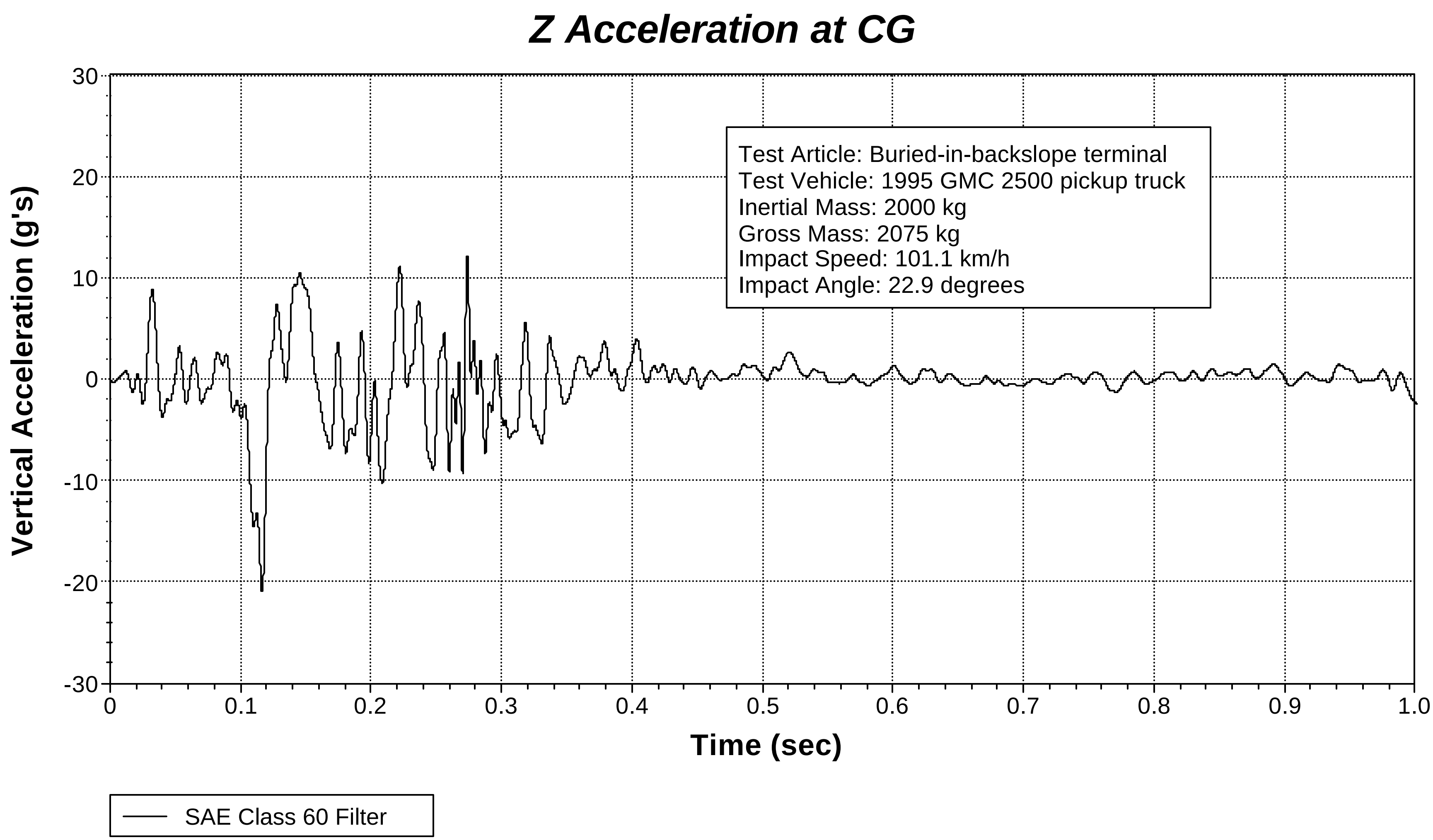


Figure 144. Vehicle vertical accelerometer trace for test 404211-13 (accelerometer located at center of gravity).

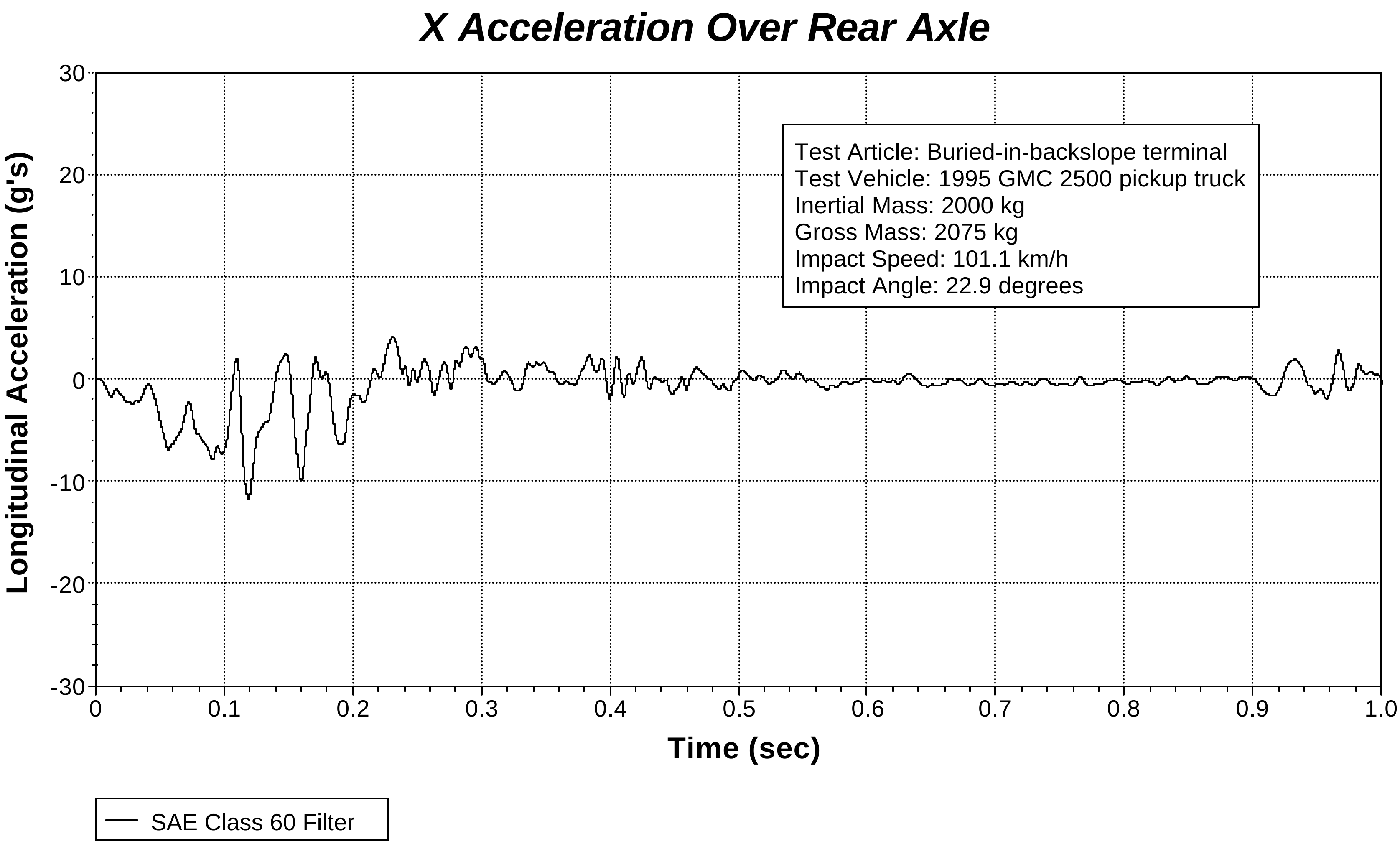


Figure 145. Vehicle longitudinal accelerometer trace for test 404211-13 (accelerometer located over rear axle).

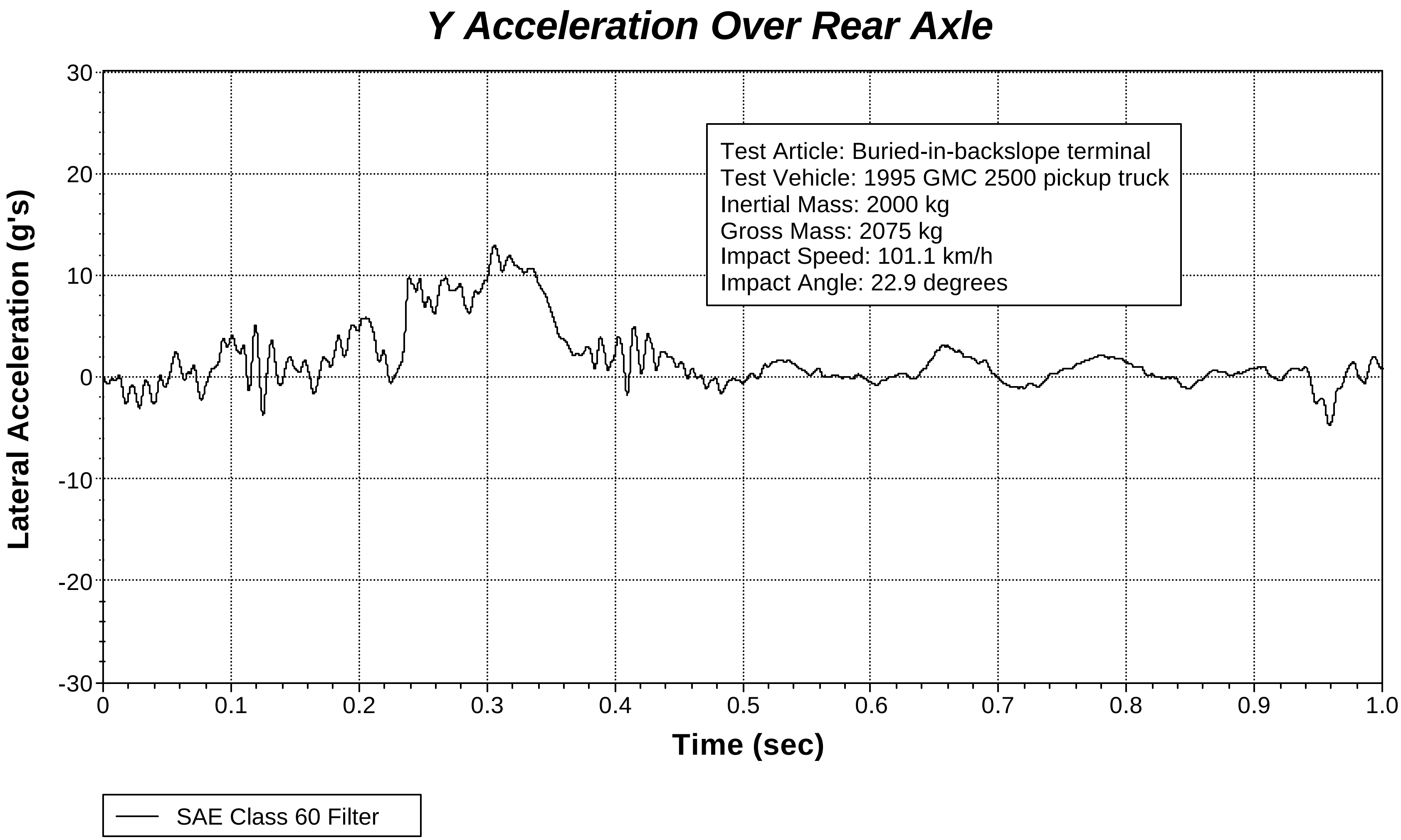


Figure 146. Vehicle lateral accelerometer trace for test 404211-13 (accelerometer located over rear axle).

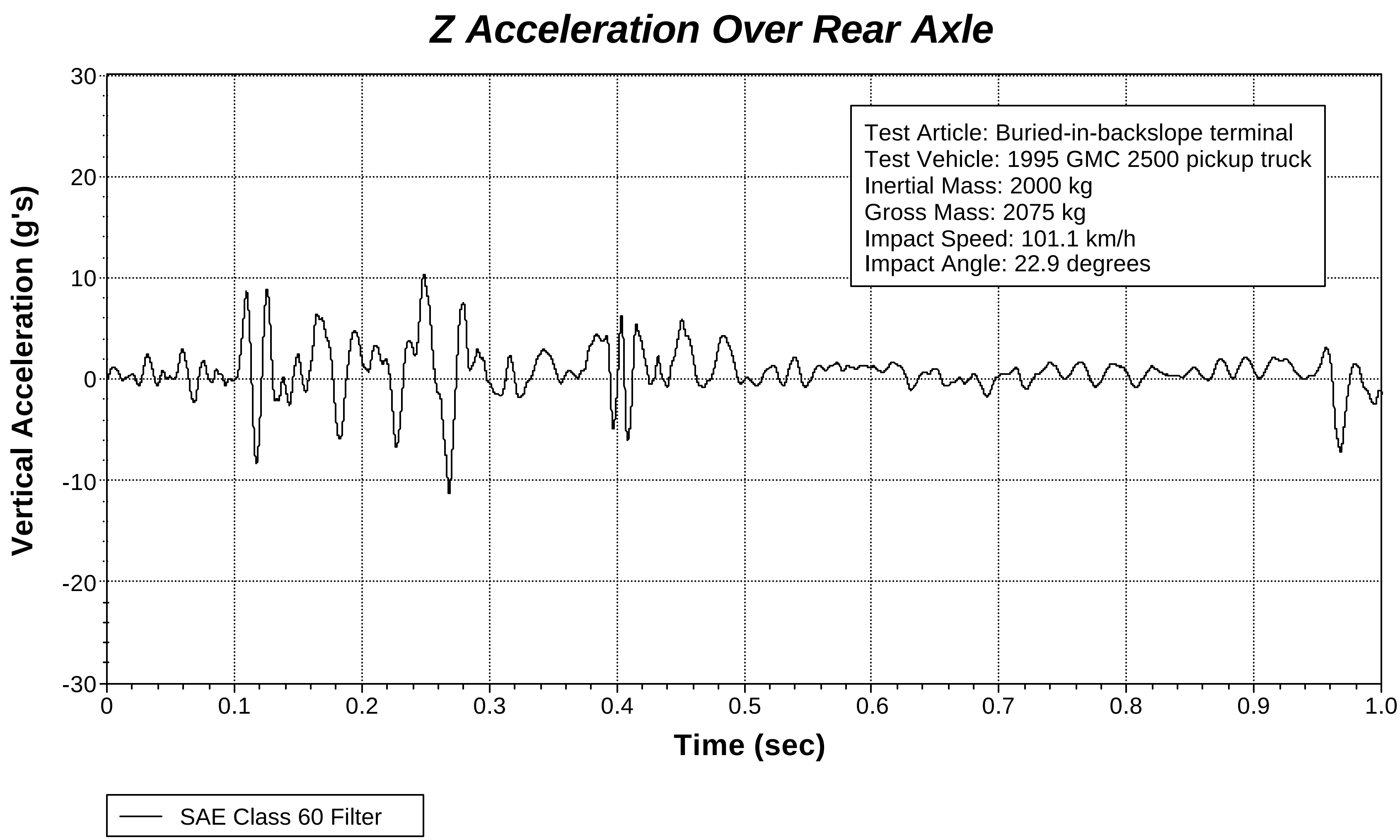


Figure 147. Vehicle vertical accelerometer trace for test 404211-13 (accelerometer located over rear axle).

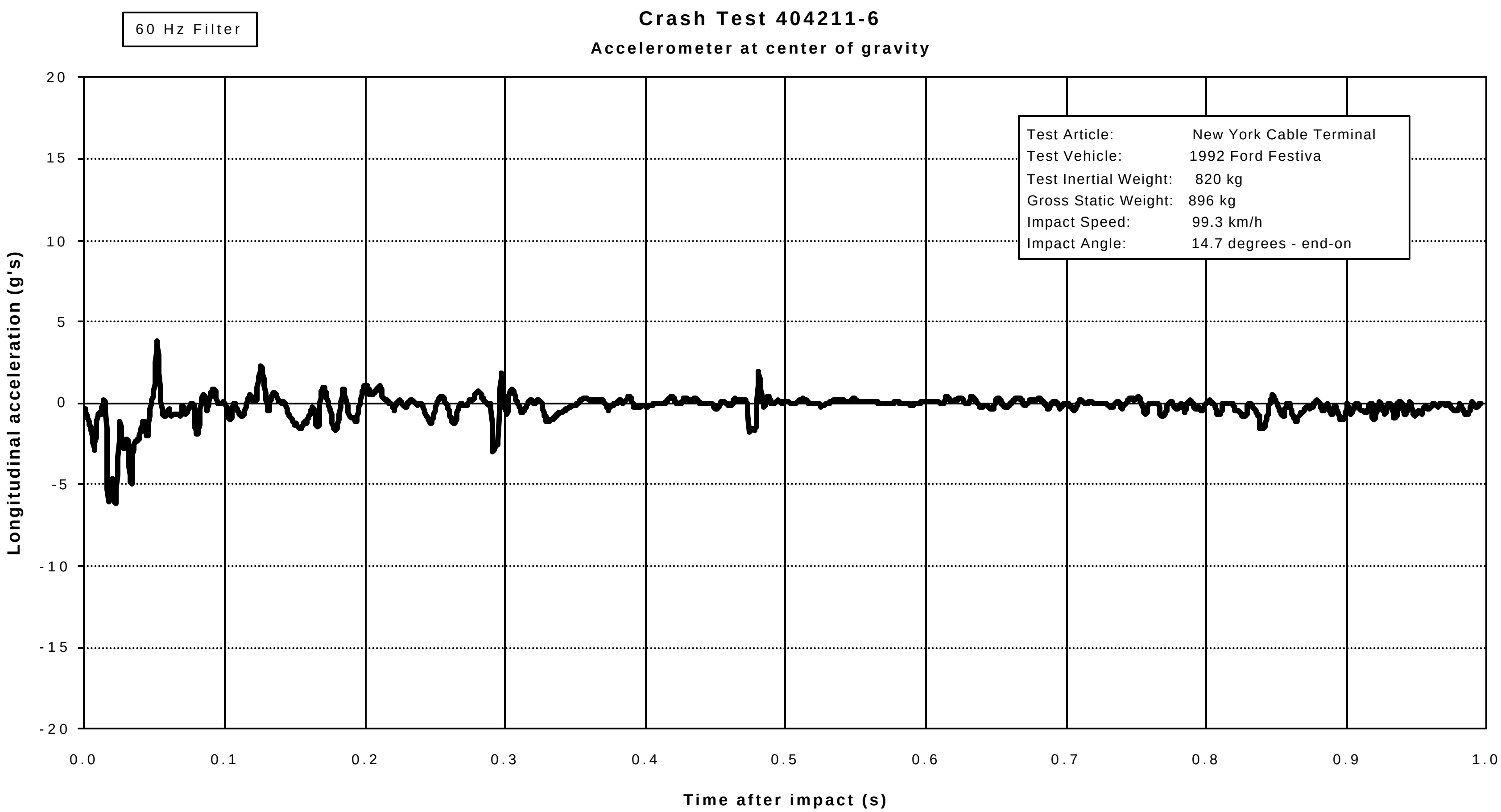


Figure 148. Vehicle longitudinal accelerometer trace for test 404211-6
(accelerometer located at center of gravity).

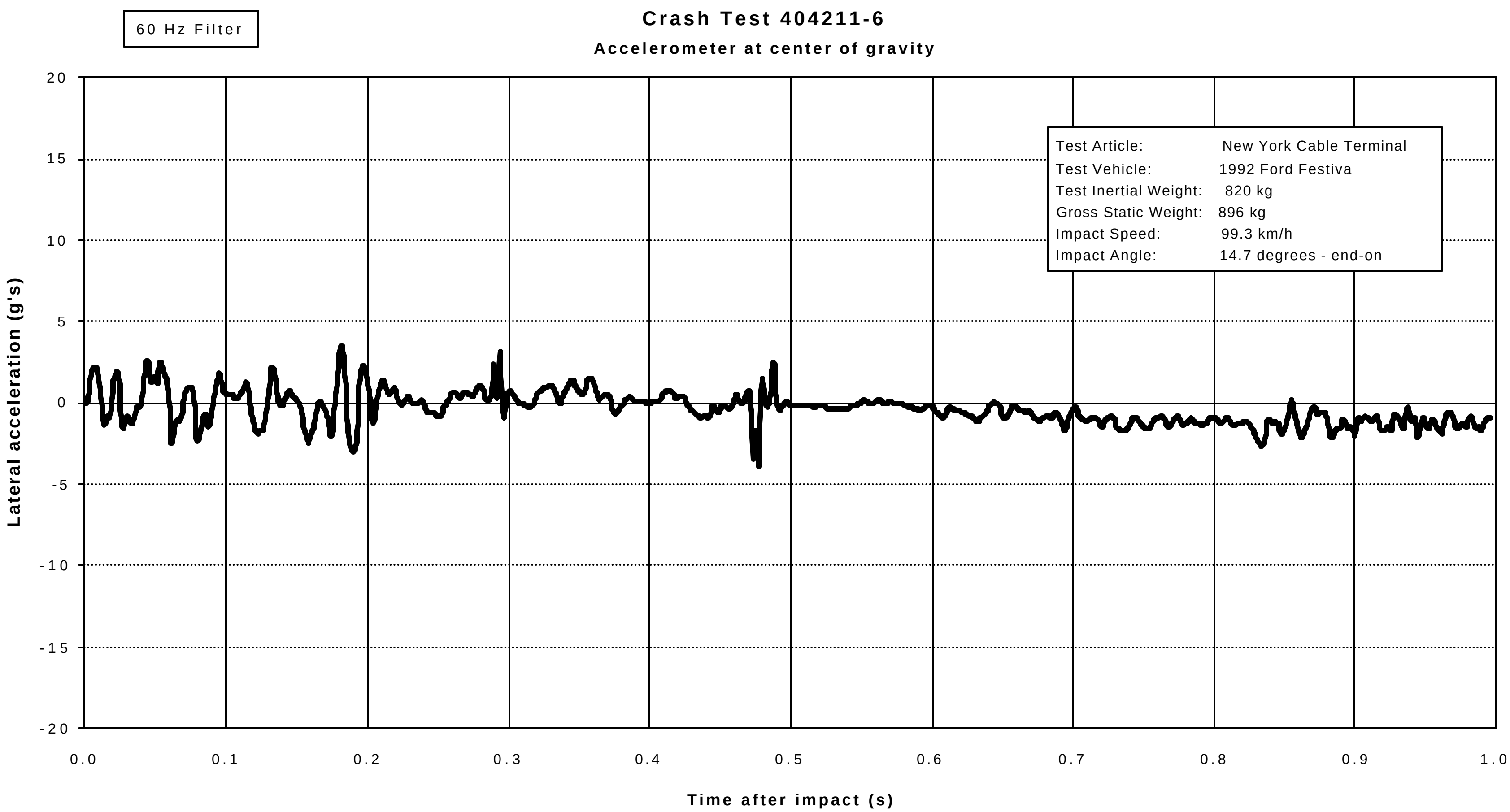


Figure 149. Vehicle lateral accelerometer trace for test 404211-6
(accelerometer located at center of gravity).

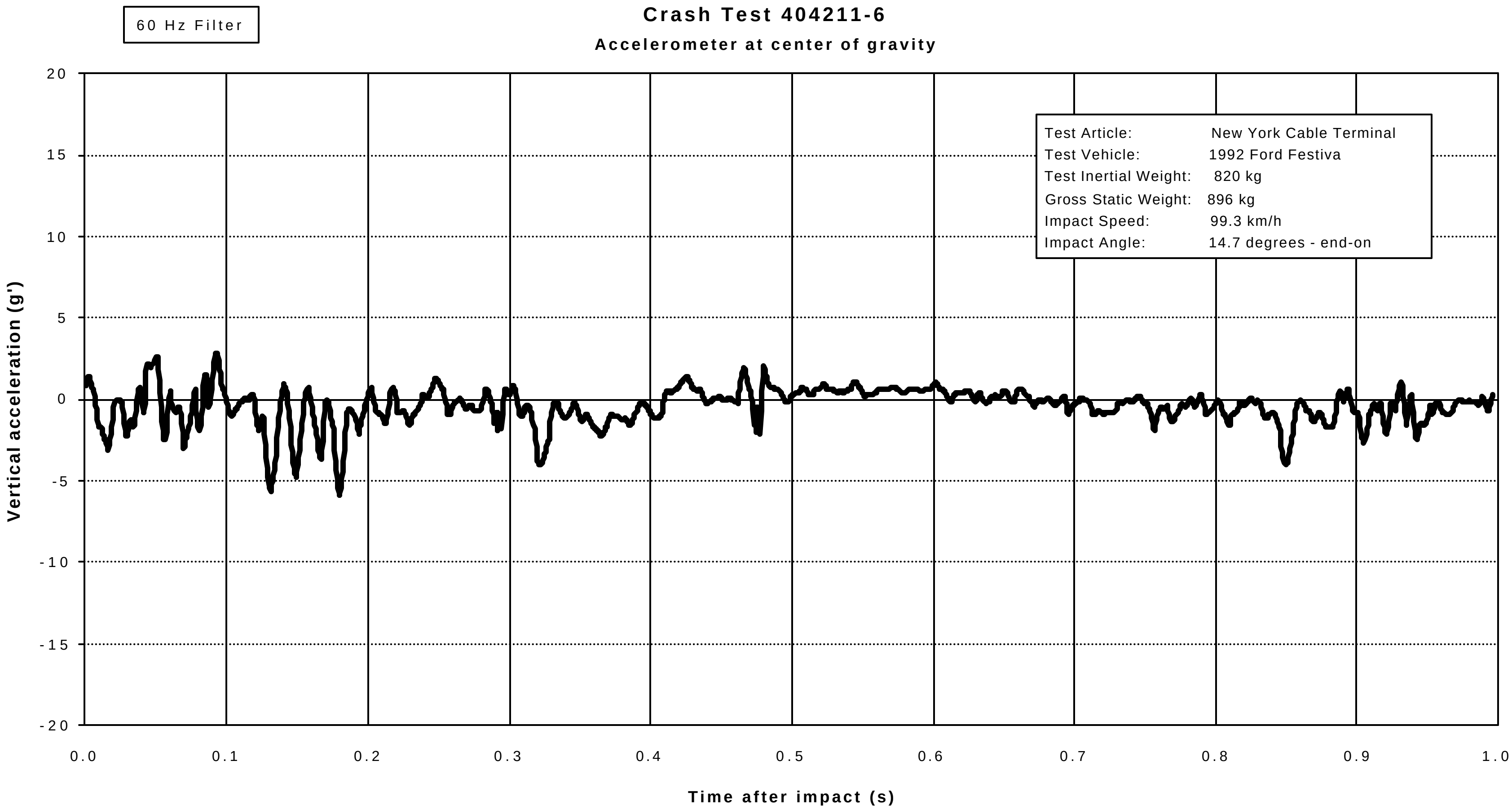


Figure 150. Vehicle vertical accelerometer trace for test 404211-6
(accelerometer located at center of gravity).

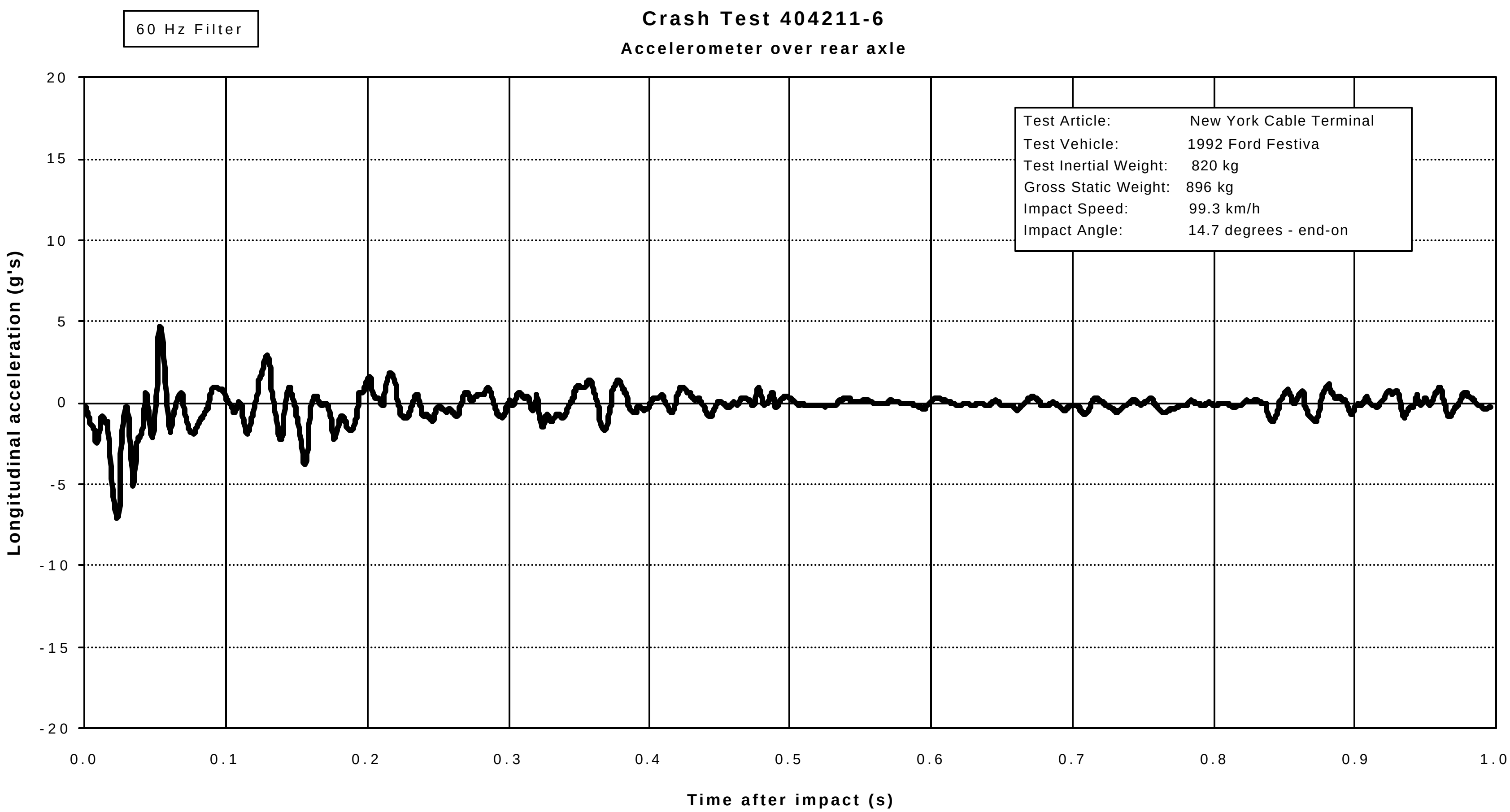


Figure 151. Vehicle longitudinal accelerometer trace for test 404211-6 (accelerometer located over rear axle).

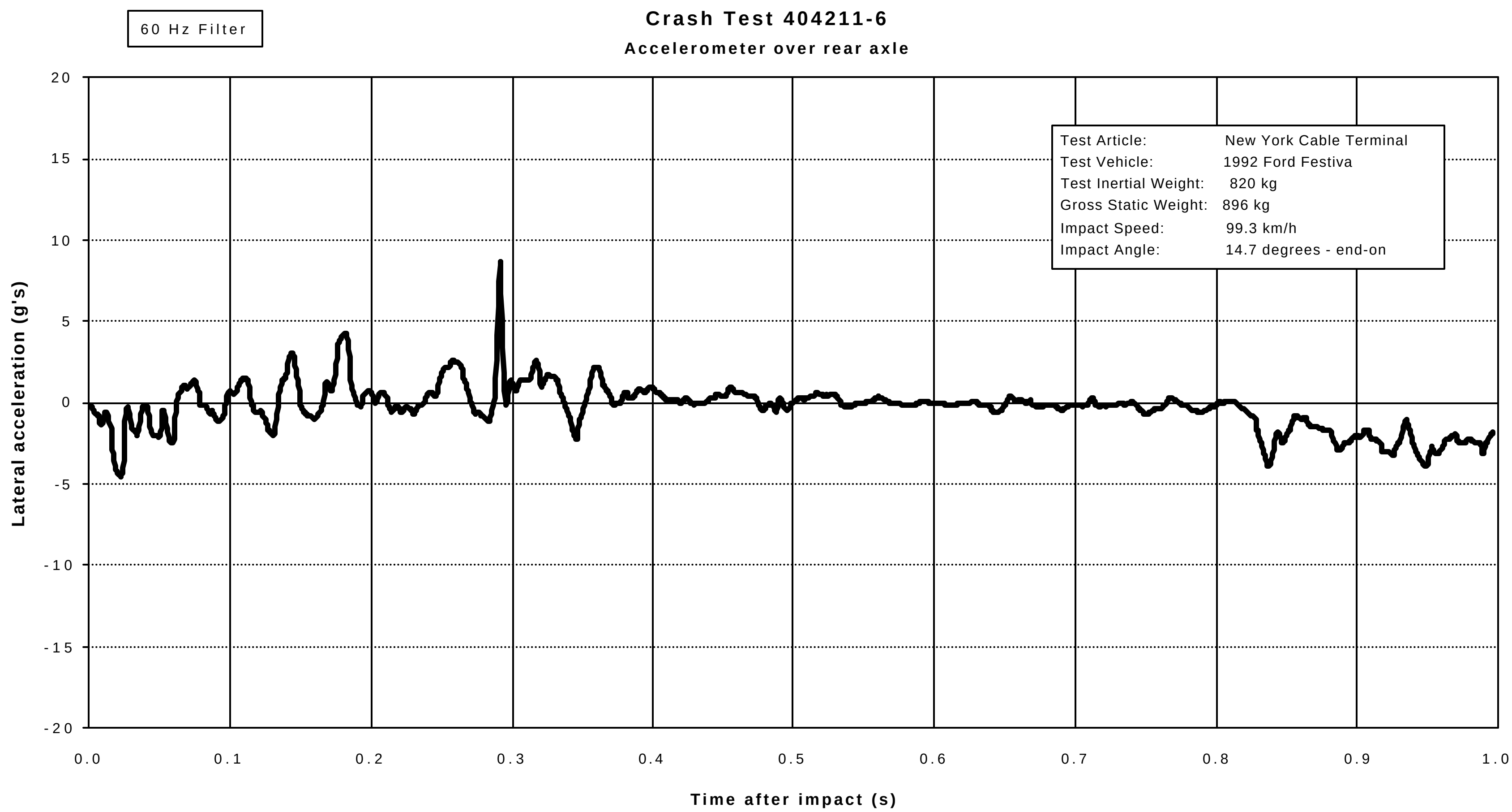


Figure 152. Vehicle lateral accelerometer trace for test 404211-6 (accelerometer located over rear axle).

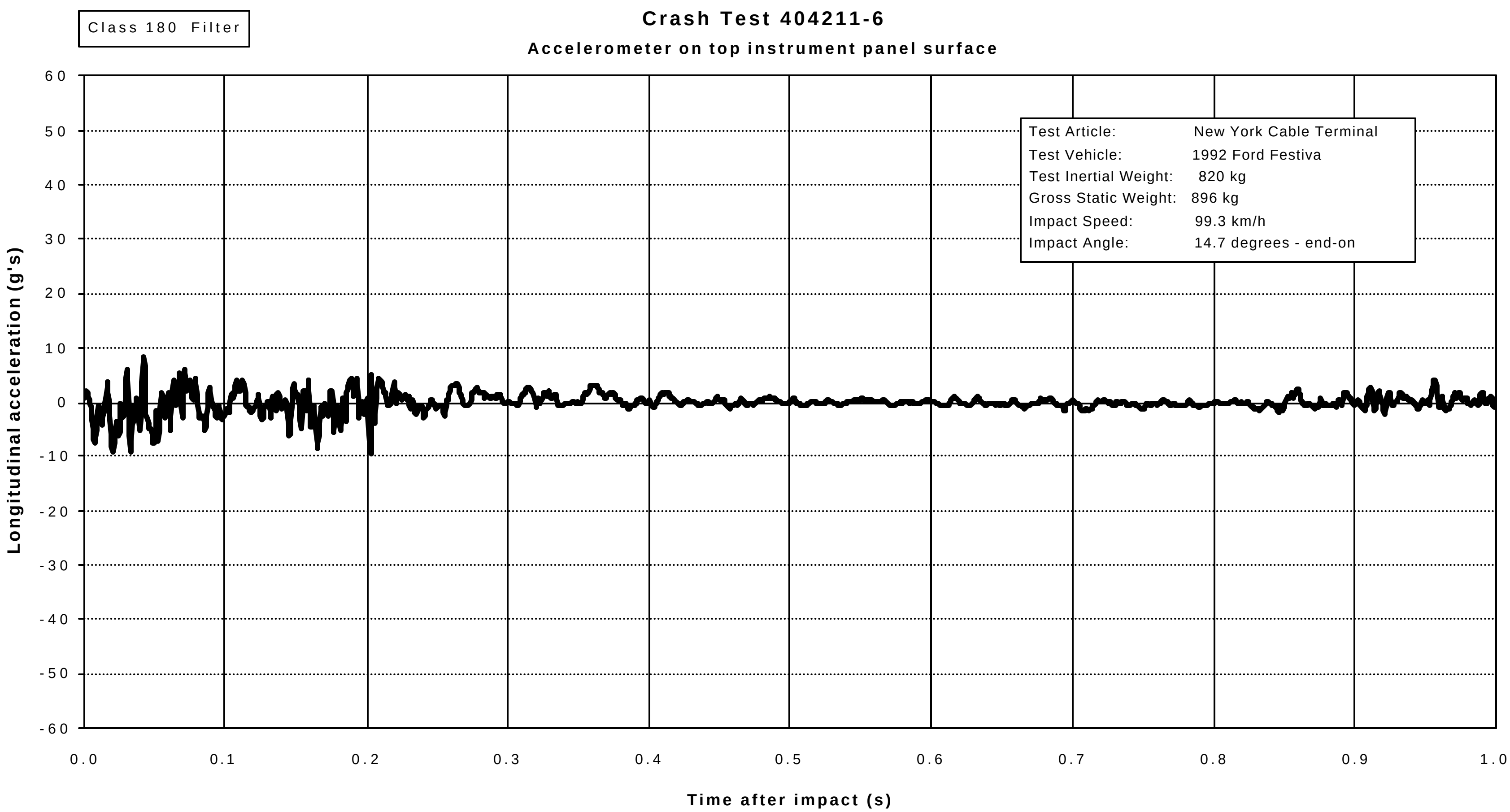


Figure 153. Vehicle longitudinal accelerometer trace for test 404211-6 (accelerometer located on top surface of instrument panel).

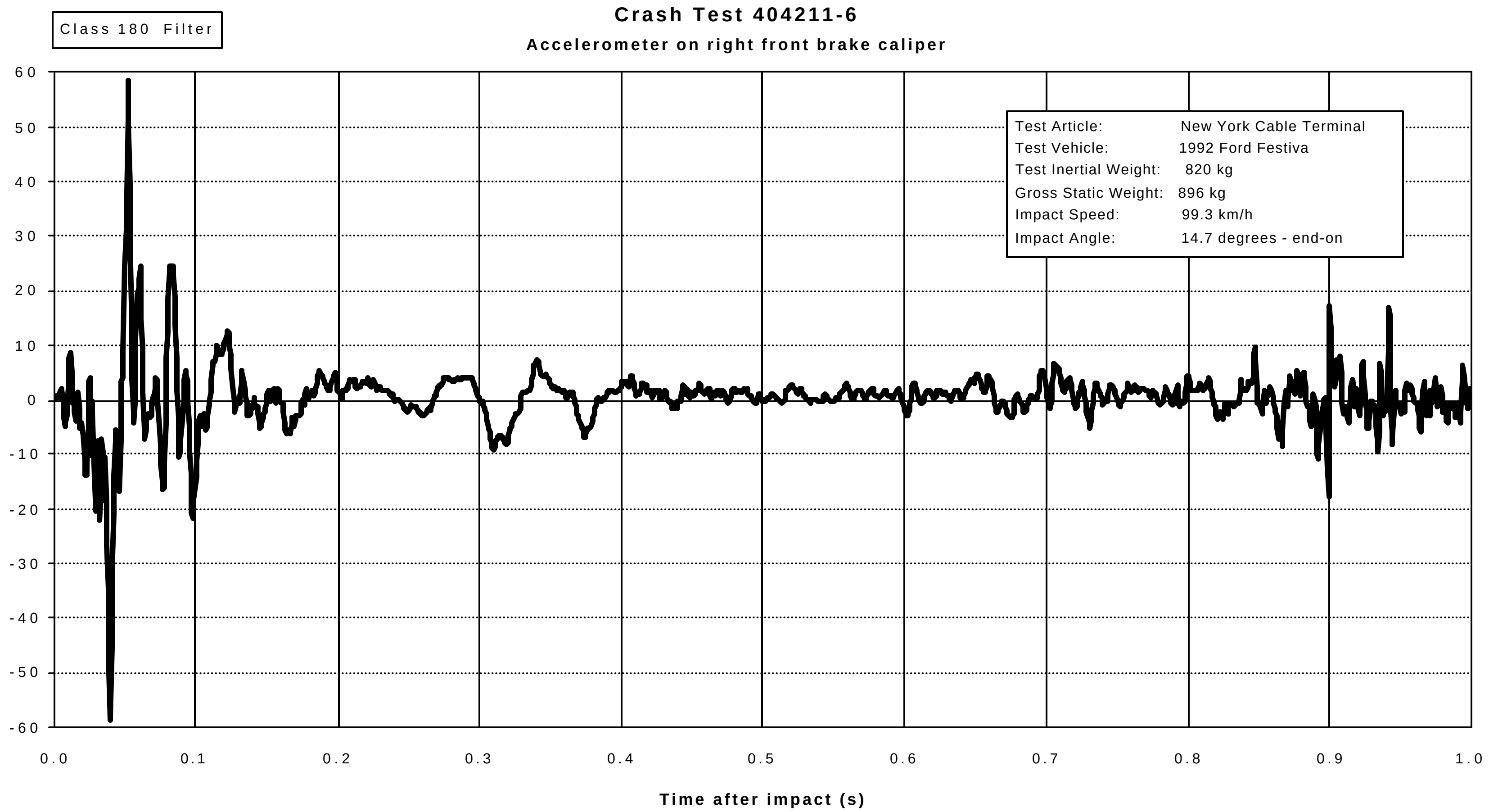


Figure 154. Vehicle longitudinal accelerometer trace for test 404211-6 (accelerometer located on right front brake caliper).

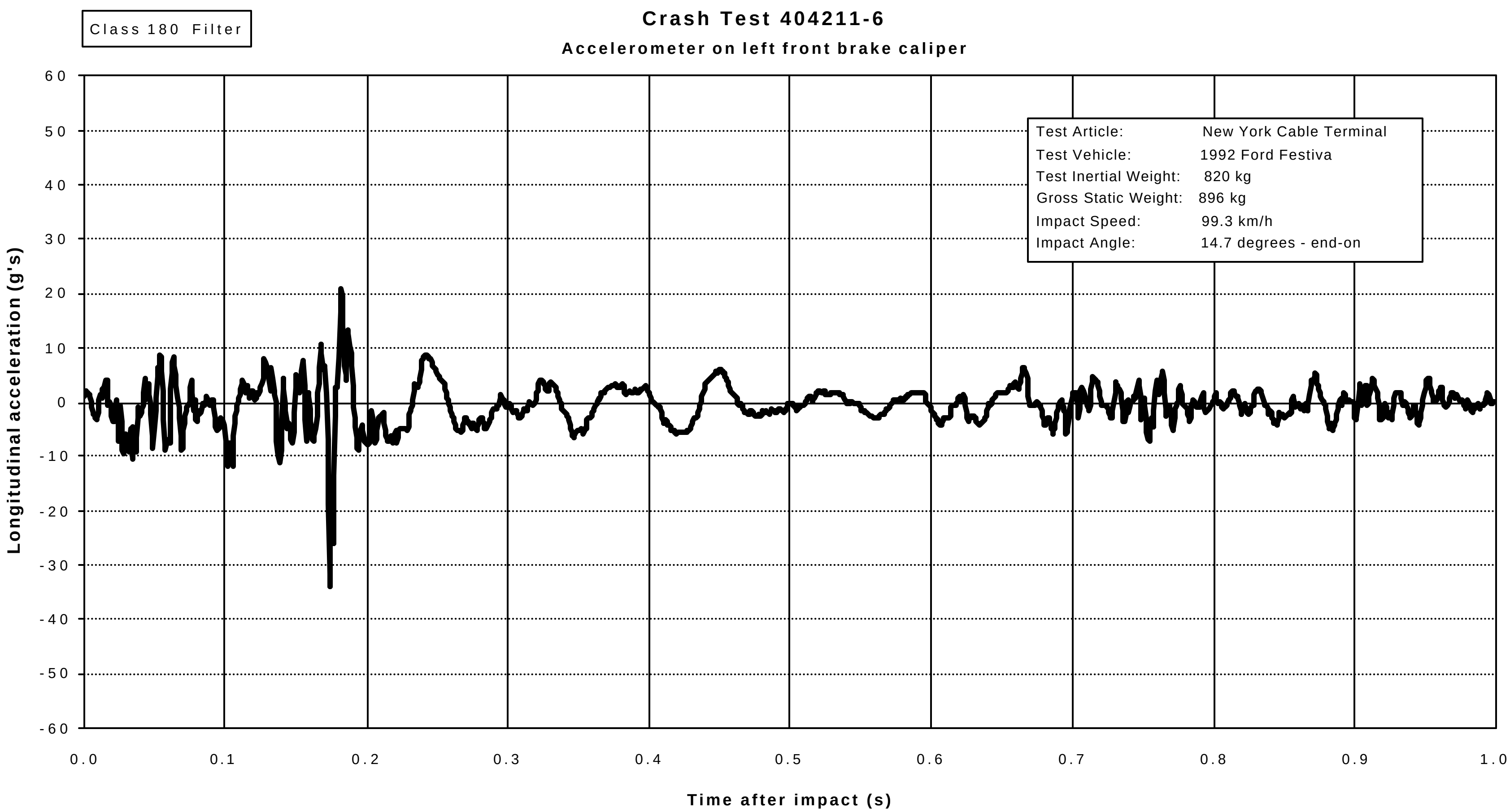


Figure 155. Vehicle longitudinal accelerometer trace for test 404211-6 (accelerometer located on left front brake caliper).

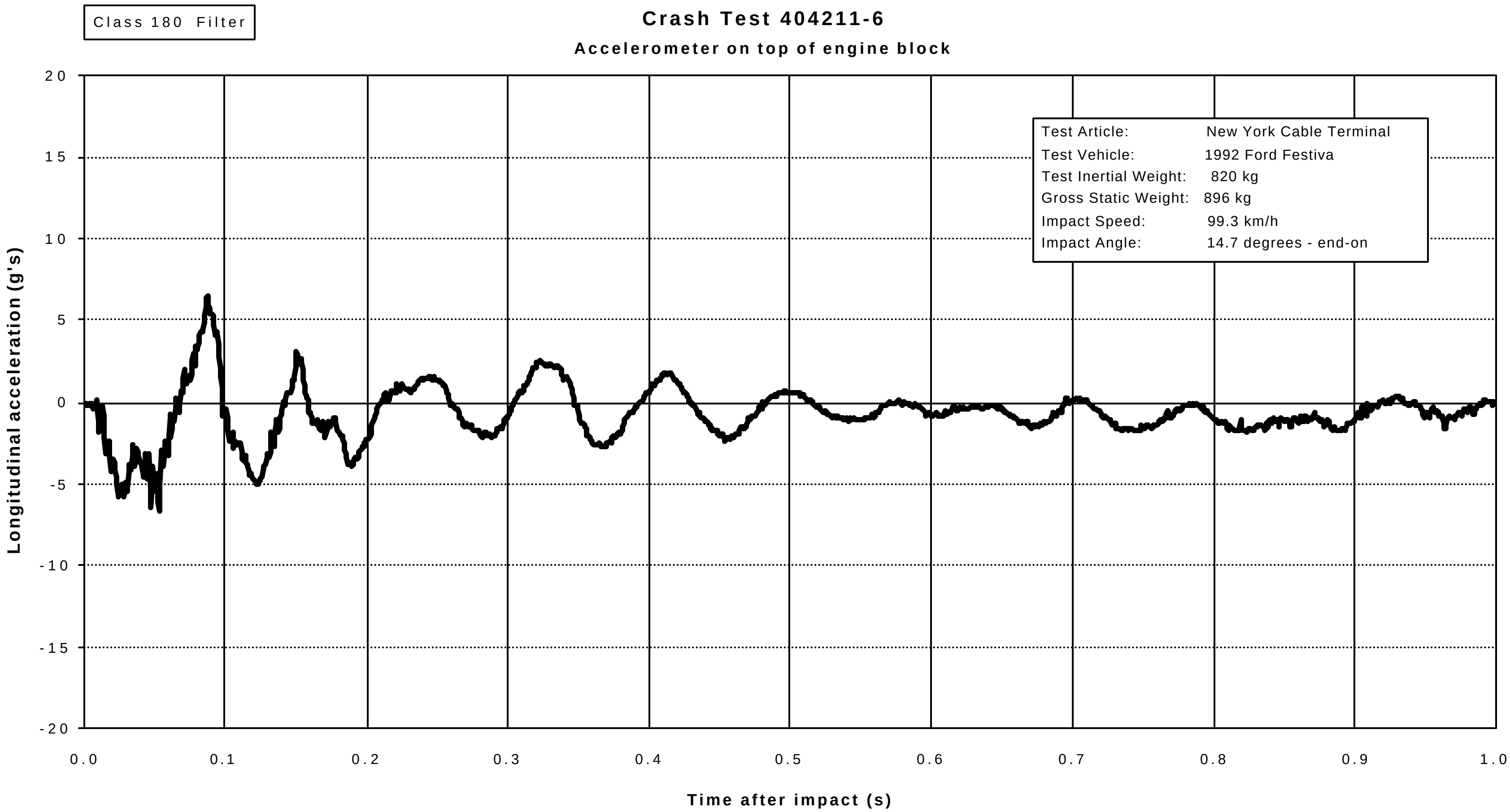


Figure 156. Vehicle longitudinal accelerometer trace for test 404211-6
(accelerometer located on top of engine block).

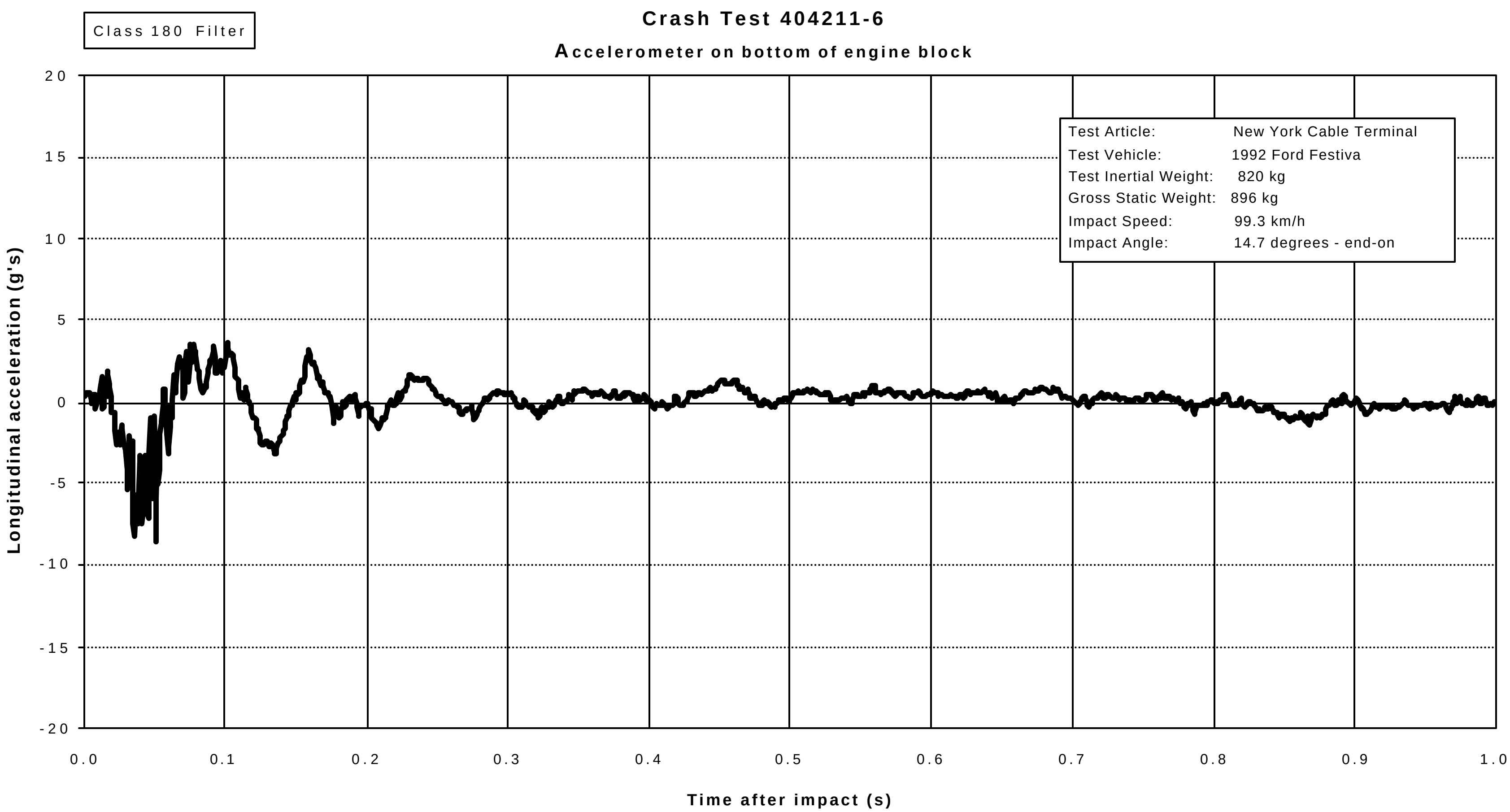


Figure 157. Vehicle longitudinal accelerometer trace for test 404211-6 (accelerometer located on bottom of engine block).

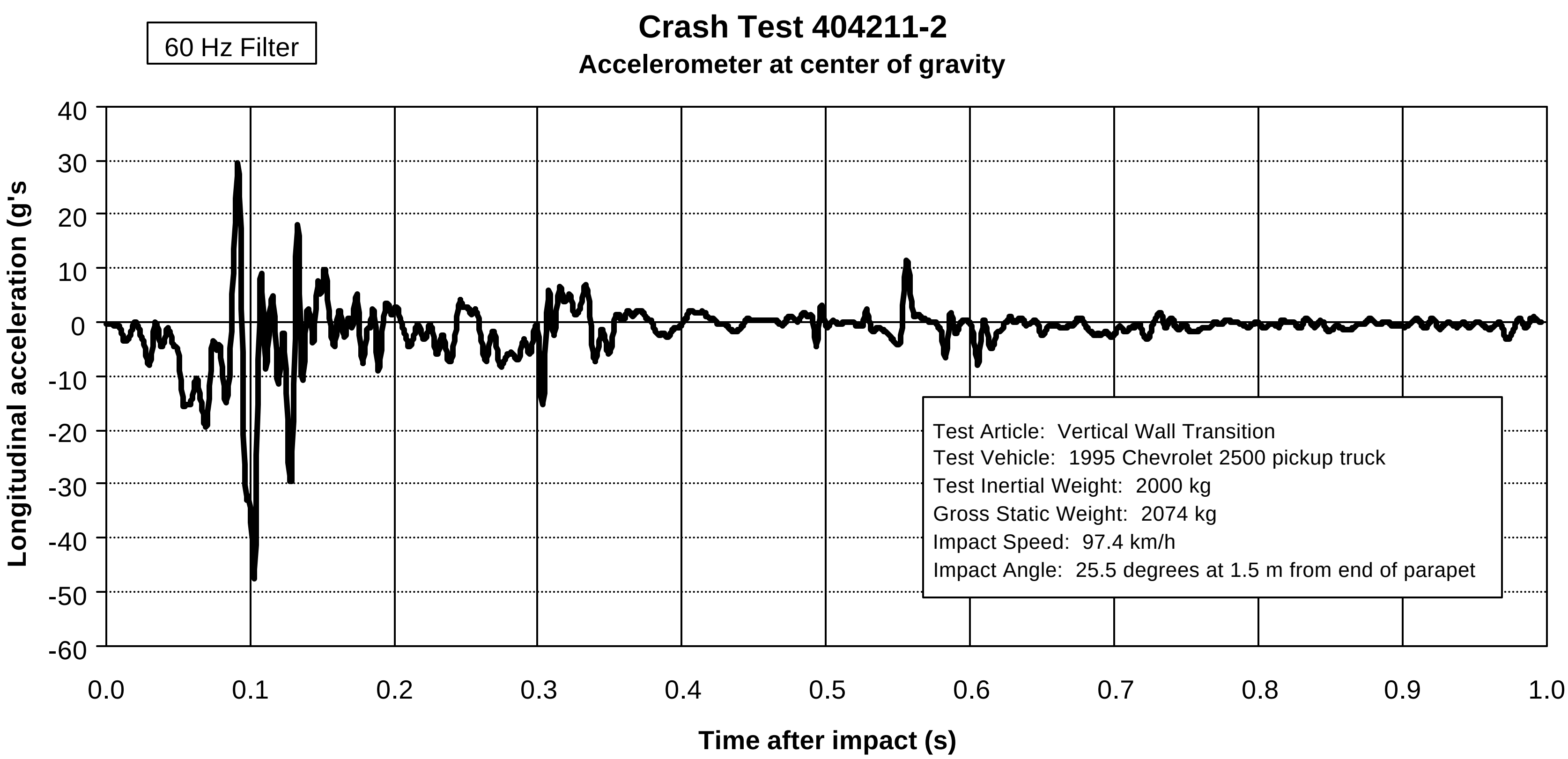


Figure 158. Vehicle longitudinal accelerometer trace for test 404211-2 (accelerometer located at center of gravity).

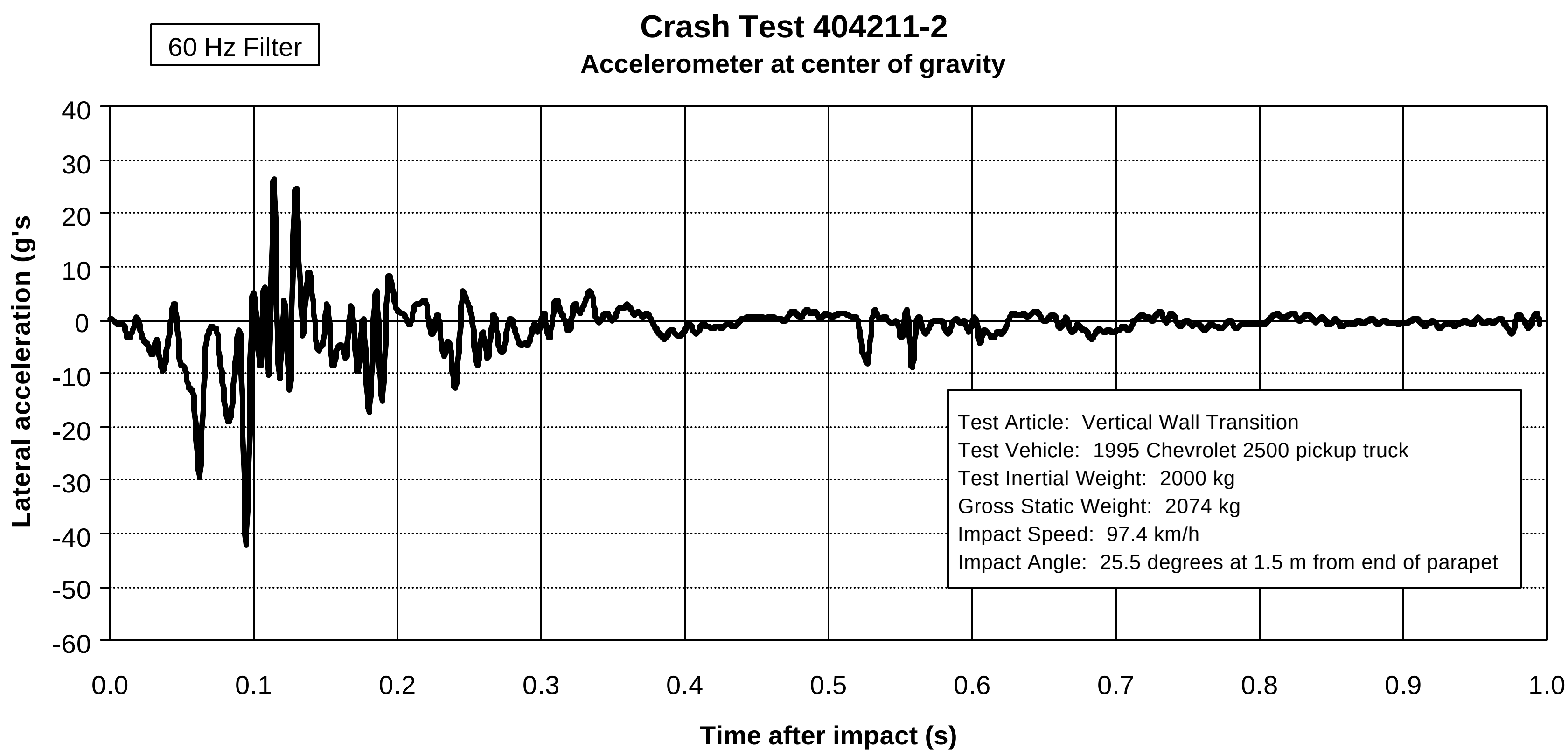


Figure 159. Vehicle lateral accelerometer traces for test 404211-2
(accelerometer located at center of gravity).

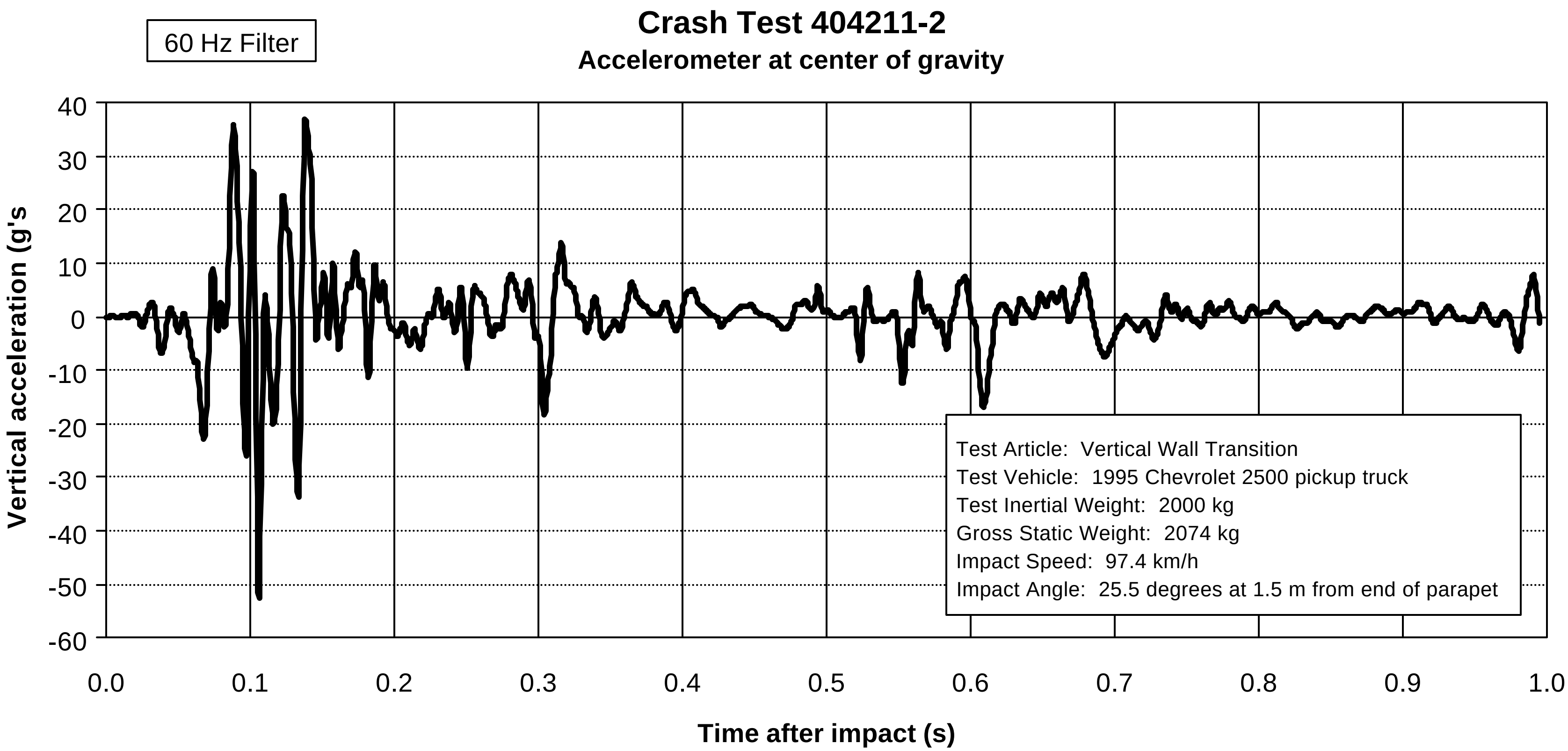


Figure 160. Vehicle vertical accelerometer trace for test 404211-2 (accelerometer located at center of gravity).

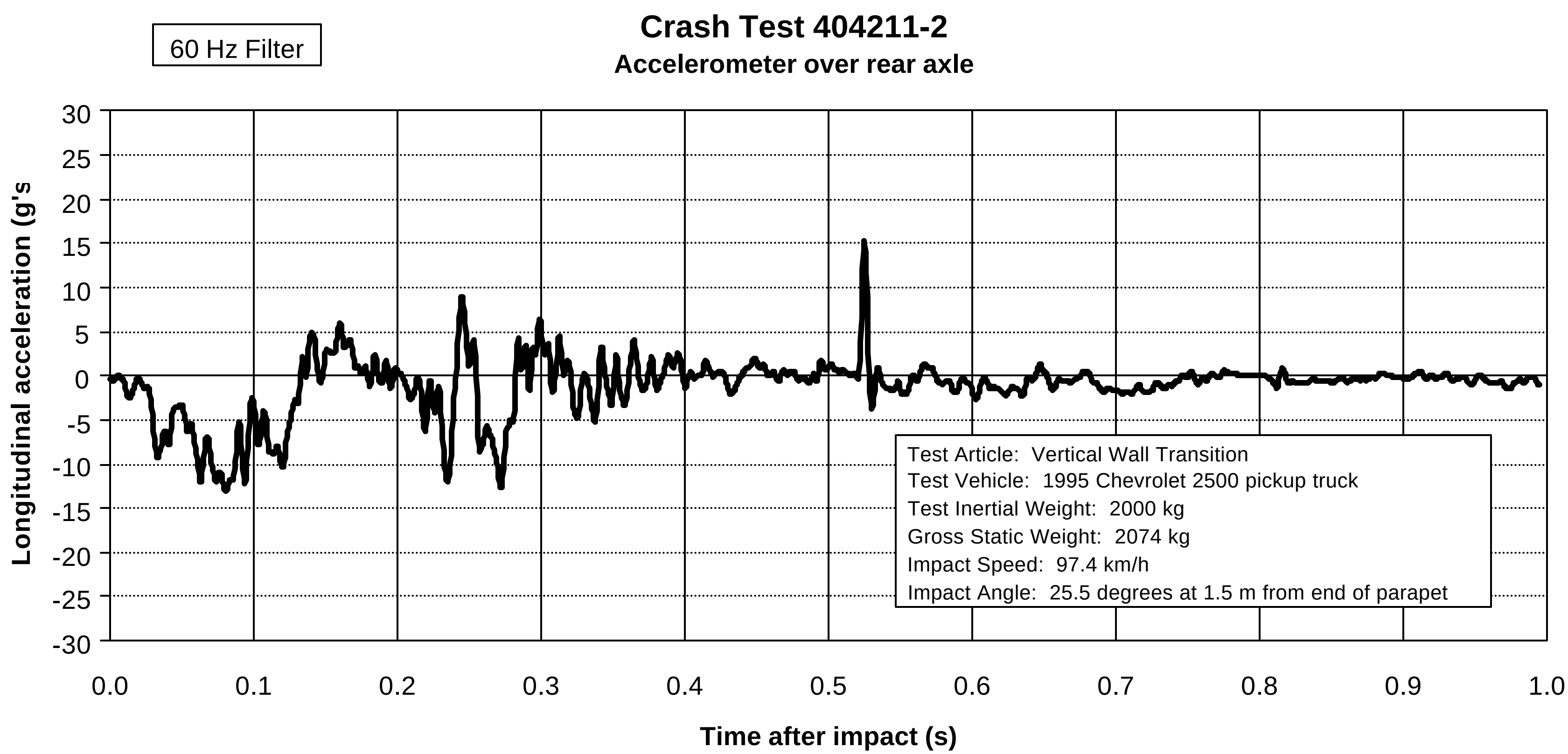


Figure 161. Vehicle longitudinal accelerometer trace for test 404211-2 (accelerometer located over rear axle).

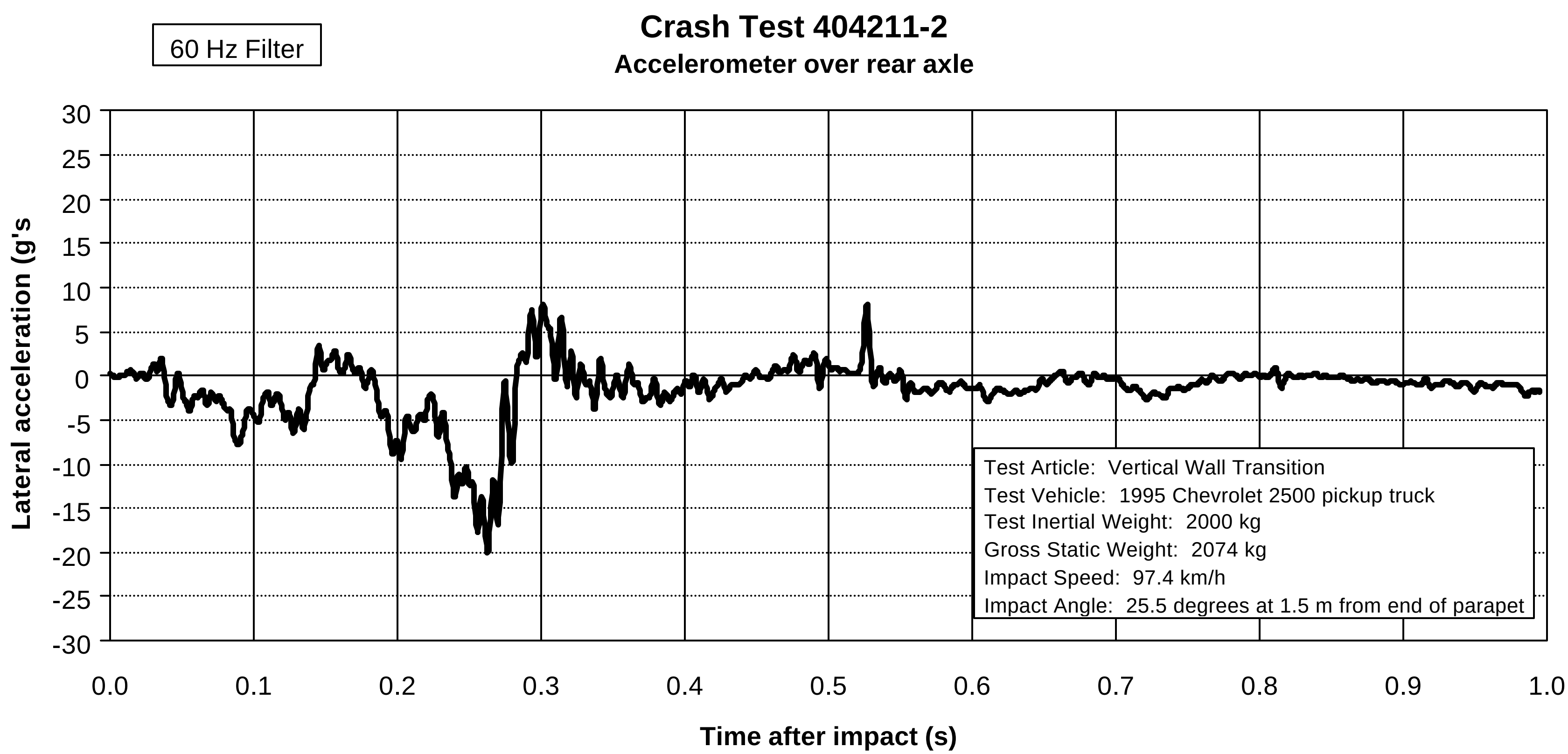


Figure 162. Vehicle lateral accelerometer traces for test 404211-2
(accelerometer located over rear axle).

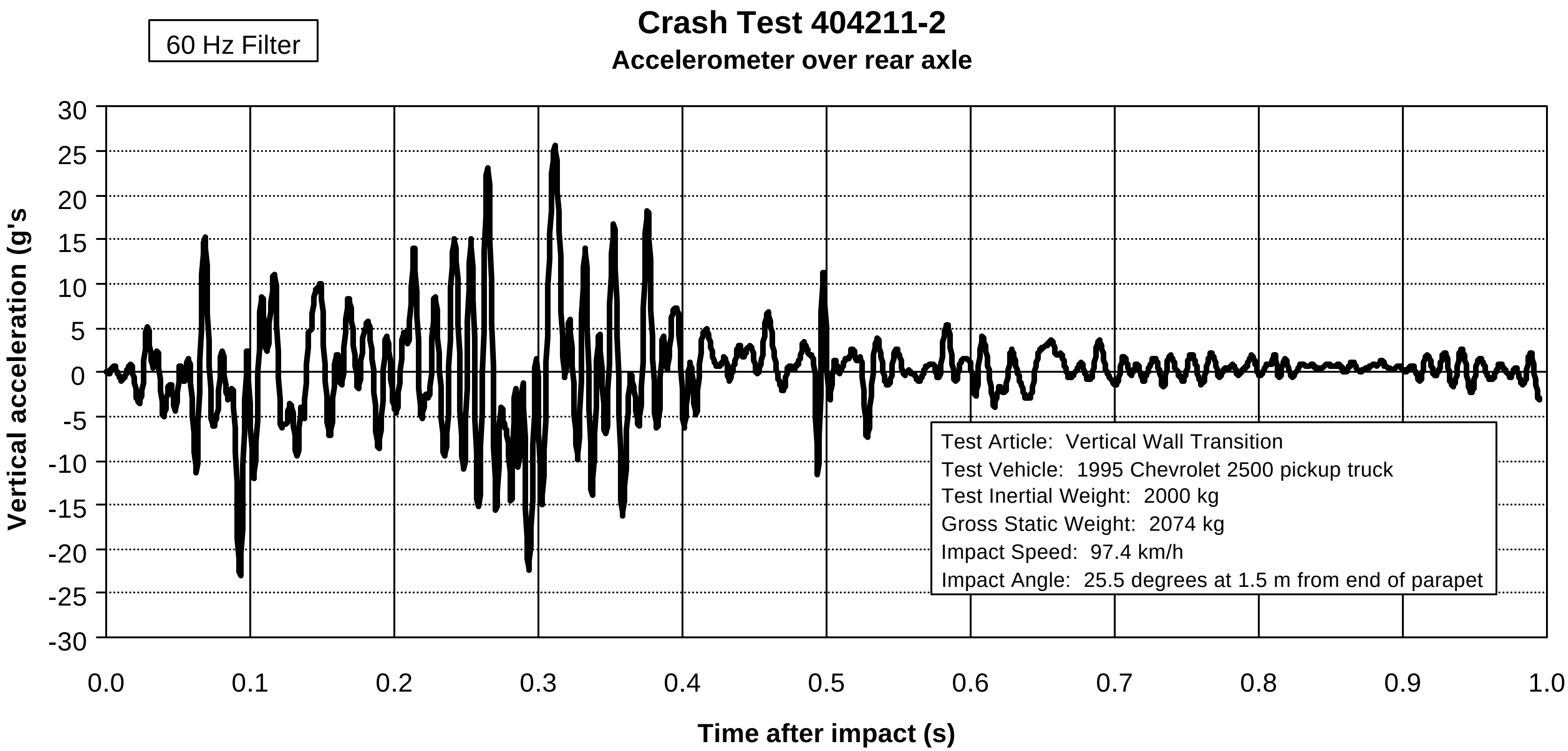


Figure 163. Vehicle vertical accelerometer trace for test 404211-2
(accelerometer located over rear axle).

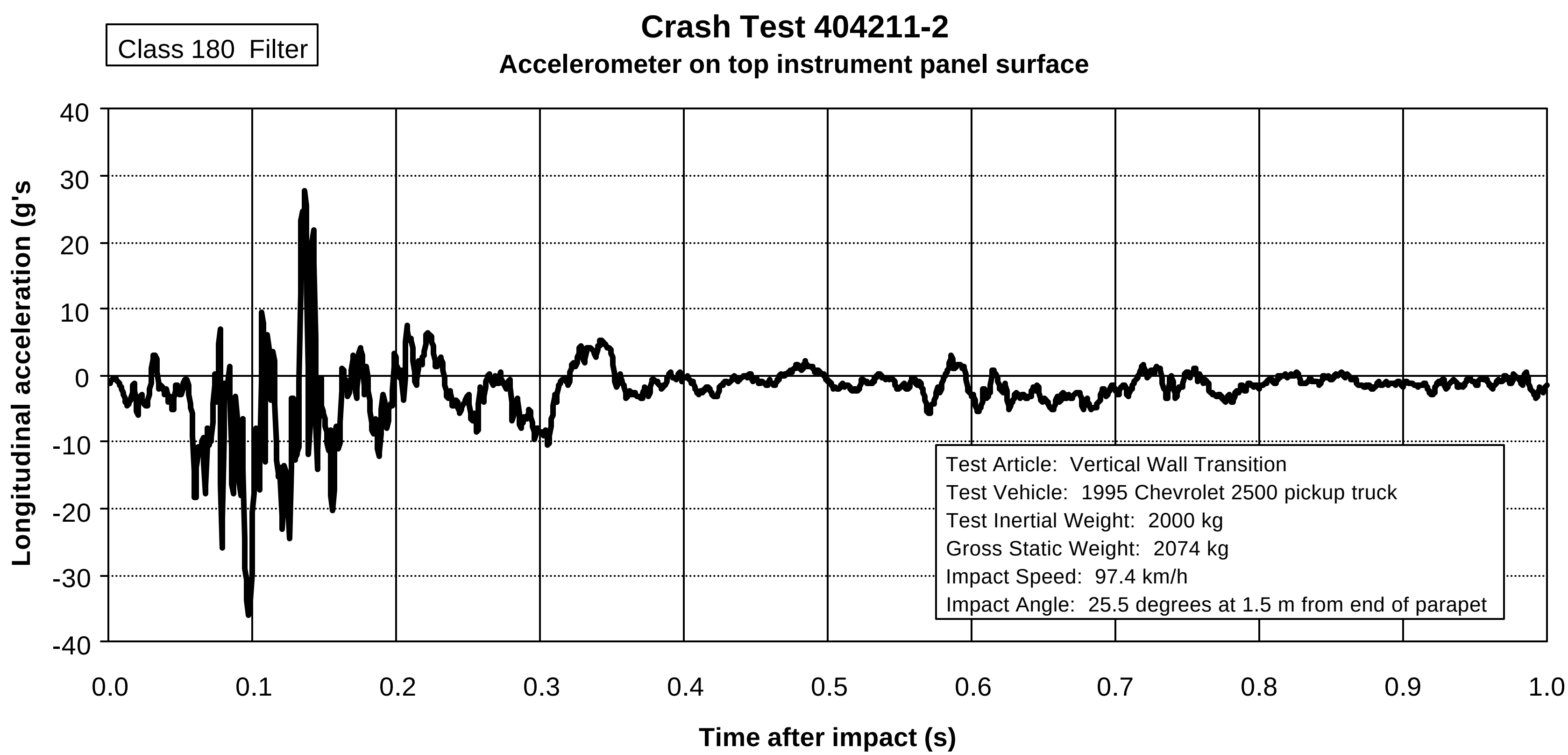


Figure 164. Vehicle longitudinal accelerometer trace for test 404211-2
(accelerometer located on top surface of instrument panel).

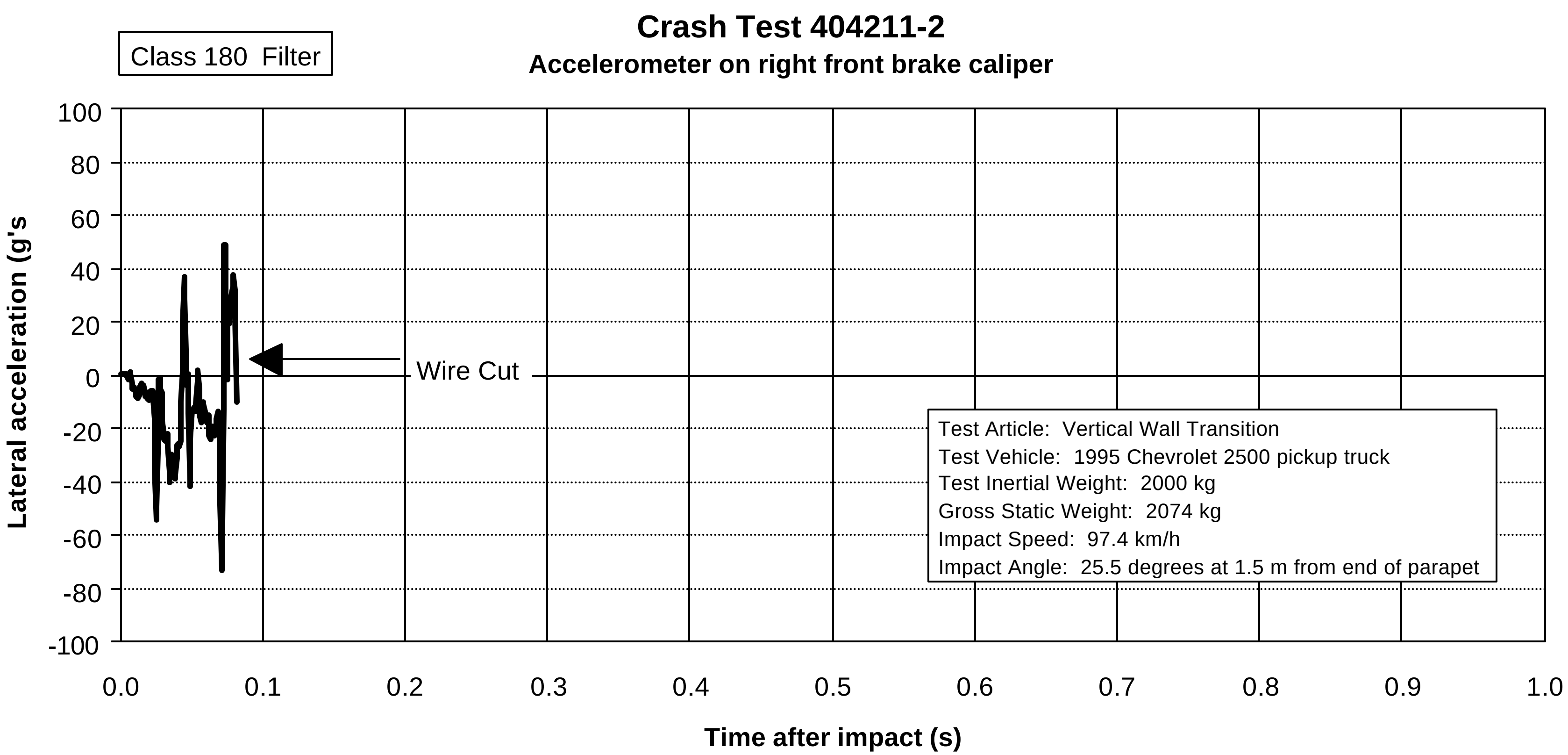


Figure 165. Vehicle lateral accelerometer traces for test 404211-2
(accelerometer located on right front brake caliper).

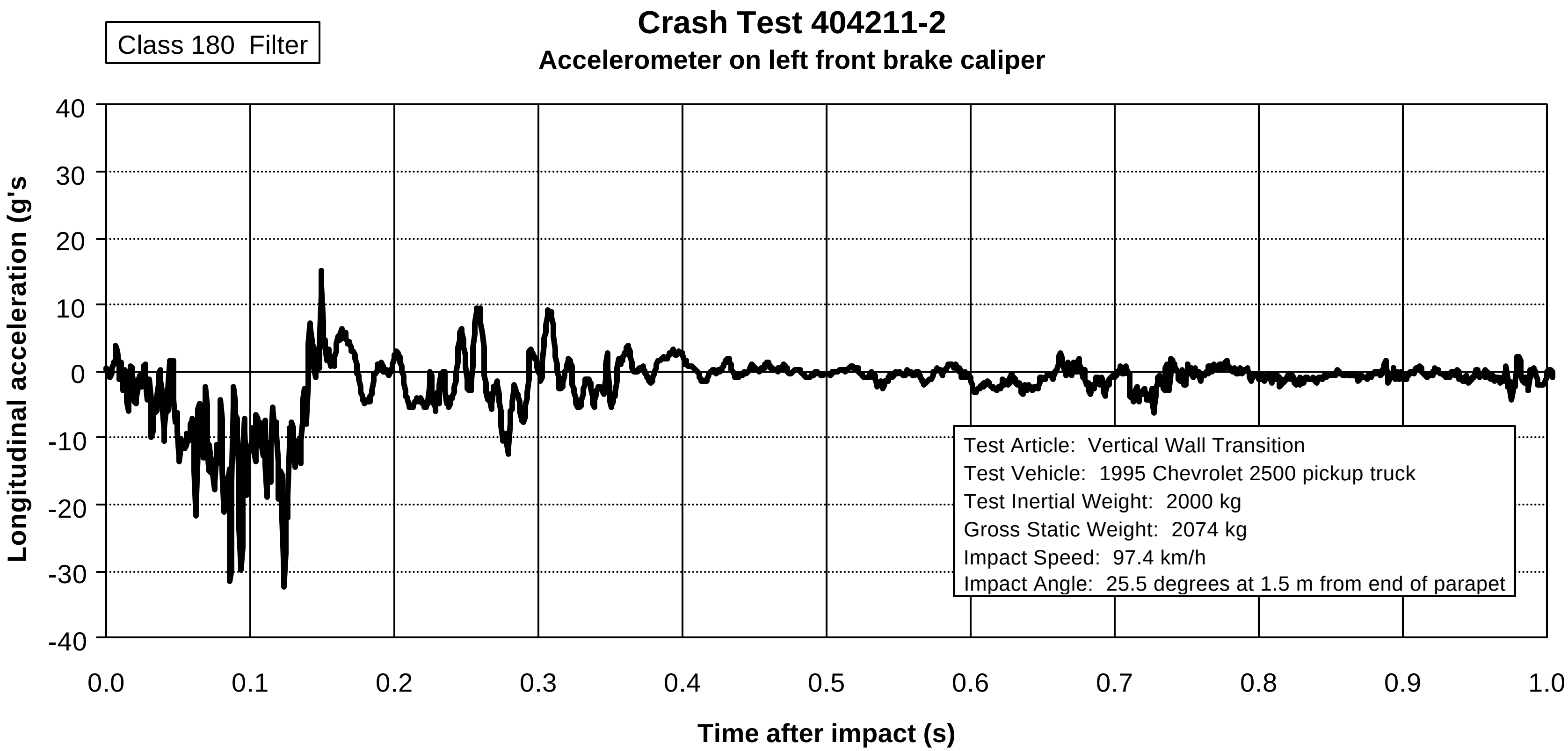


Figure 166. Vehicle longitudinal accelerometer trace for test 404211-2 (accelerometer located on left front brake caliper).

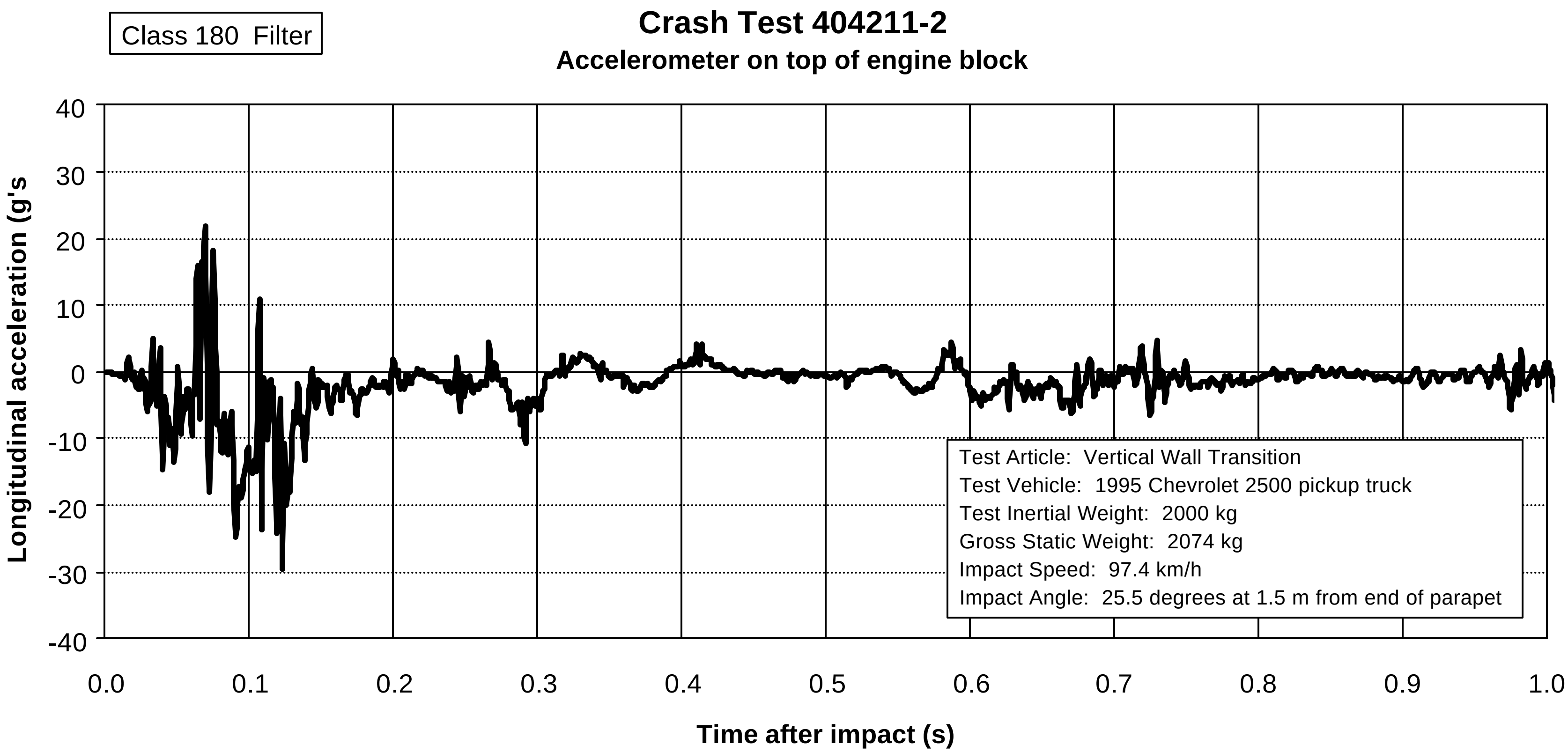


Figure 167. Vehicle longitudinal accelerometer trace for test 404211-2 (accelerometer located on top of engine block).

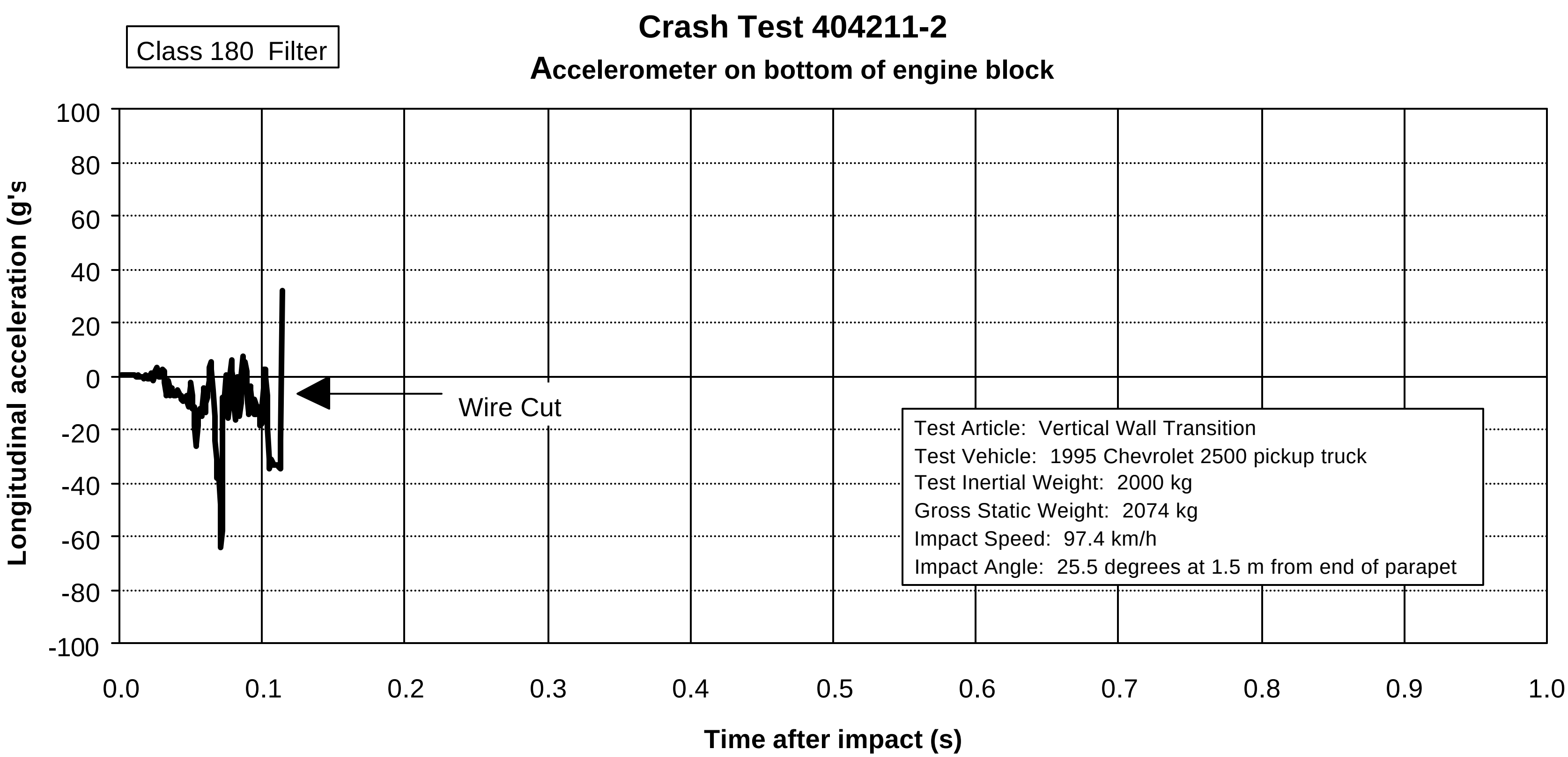


Figure 168. Vehicle longitudinal accelerometer trace for test 404211-2
(accelerometer located on bottom of engine block).

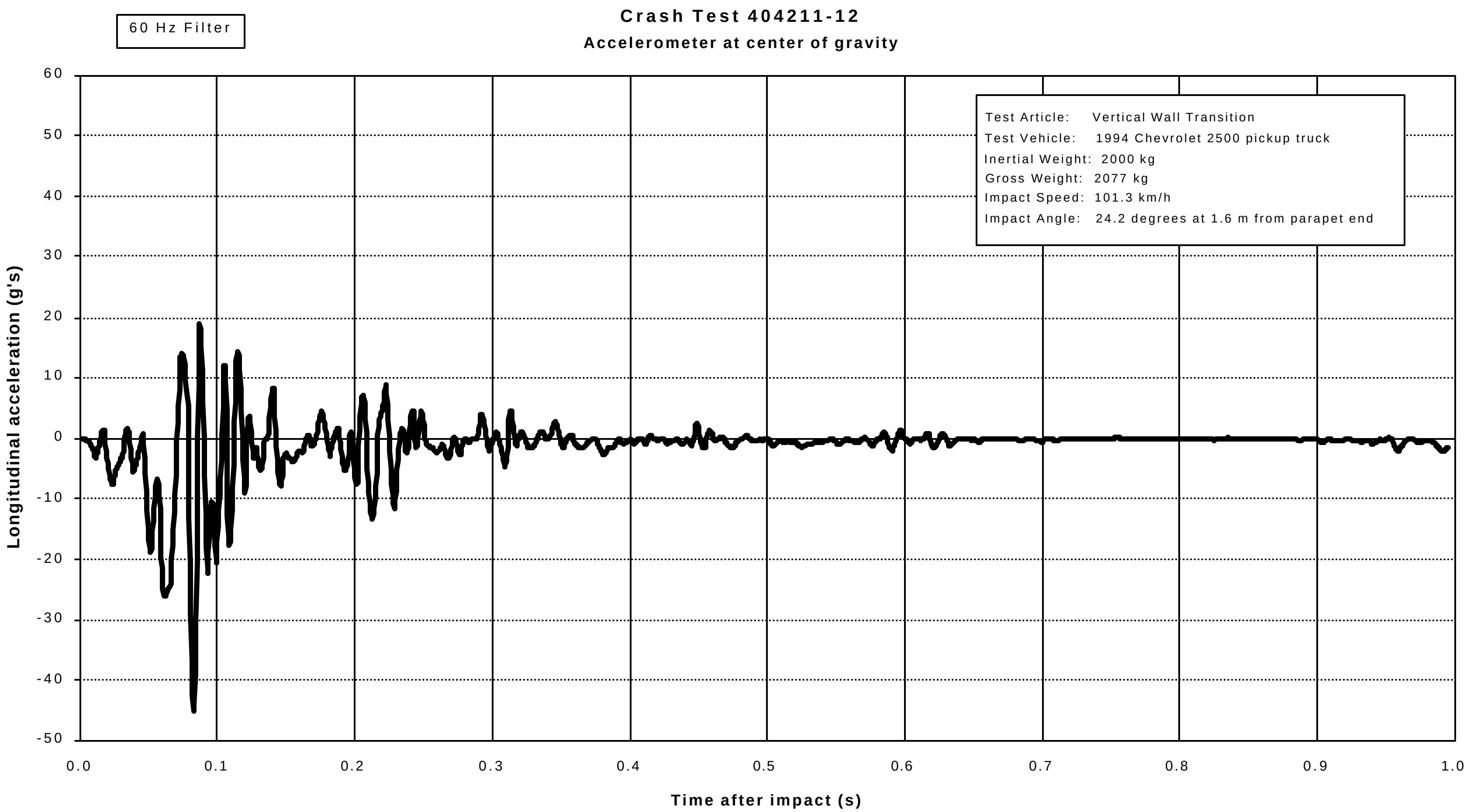


Figure 169. Vehicle longitudinal accelerometer trace for test 404211-12 (accelerometer located at center of gravity).

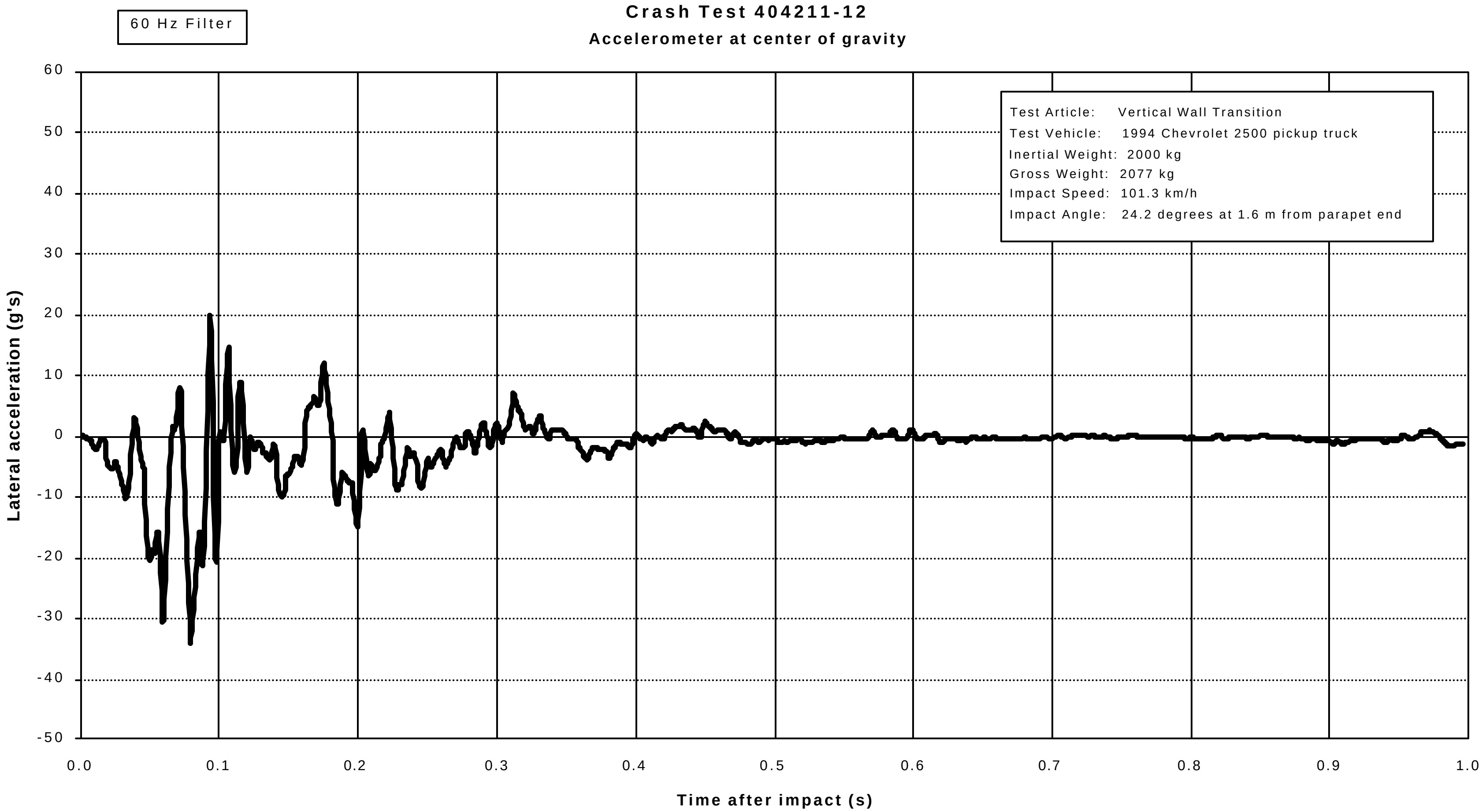


Figure 170. Vehicle lateral accelerometer trace for test 404211-12 (accelerometer located at center of gravity).

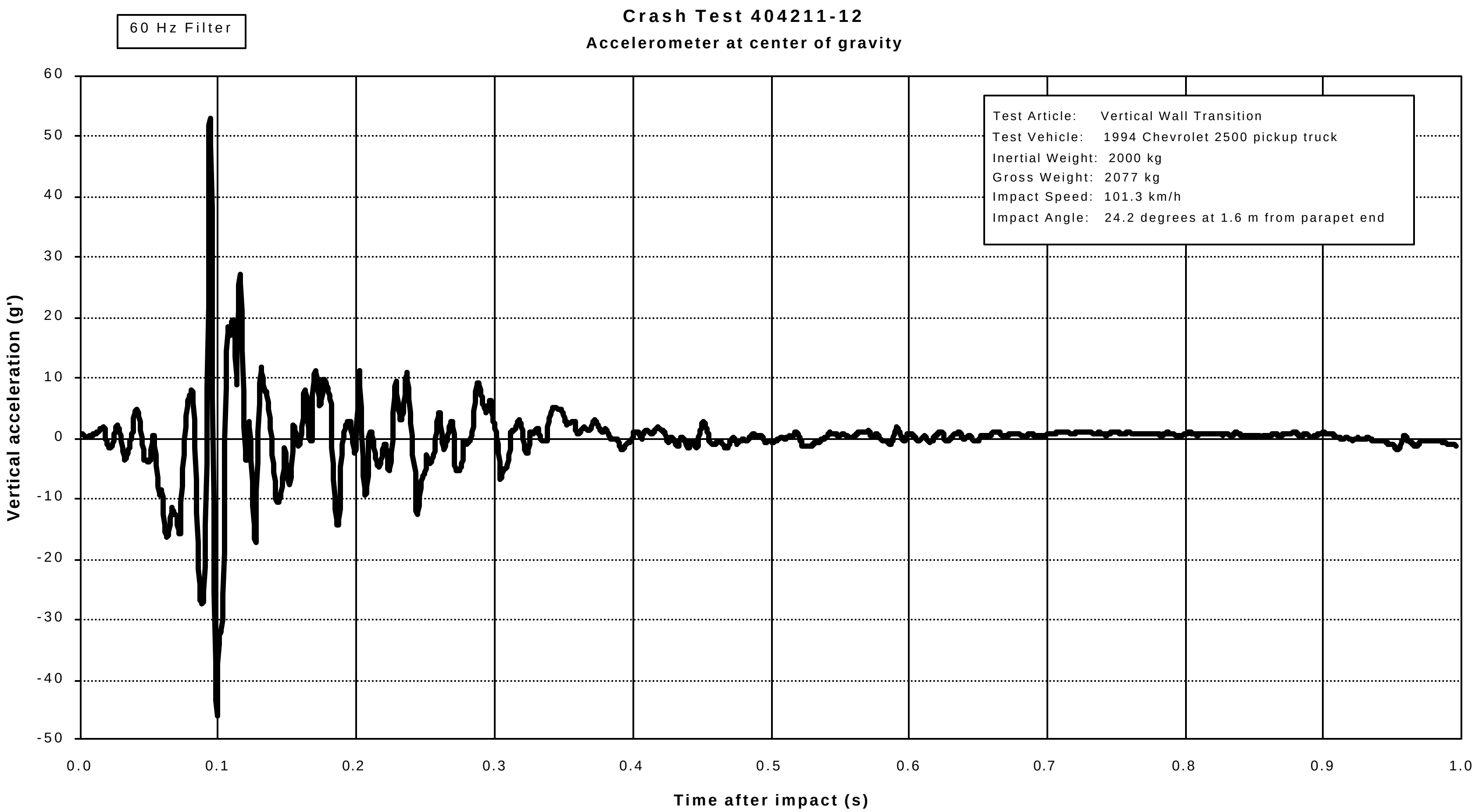


Figure 171. Vehicle vertical accelerometer trace for test 404211-12 (accelerometer located at center of gravity).

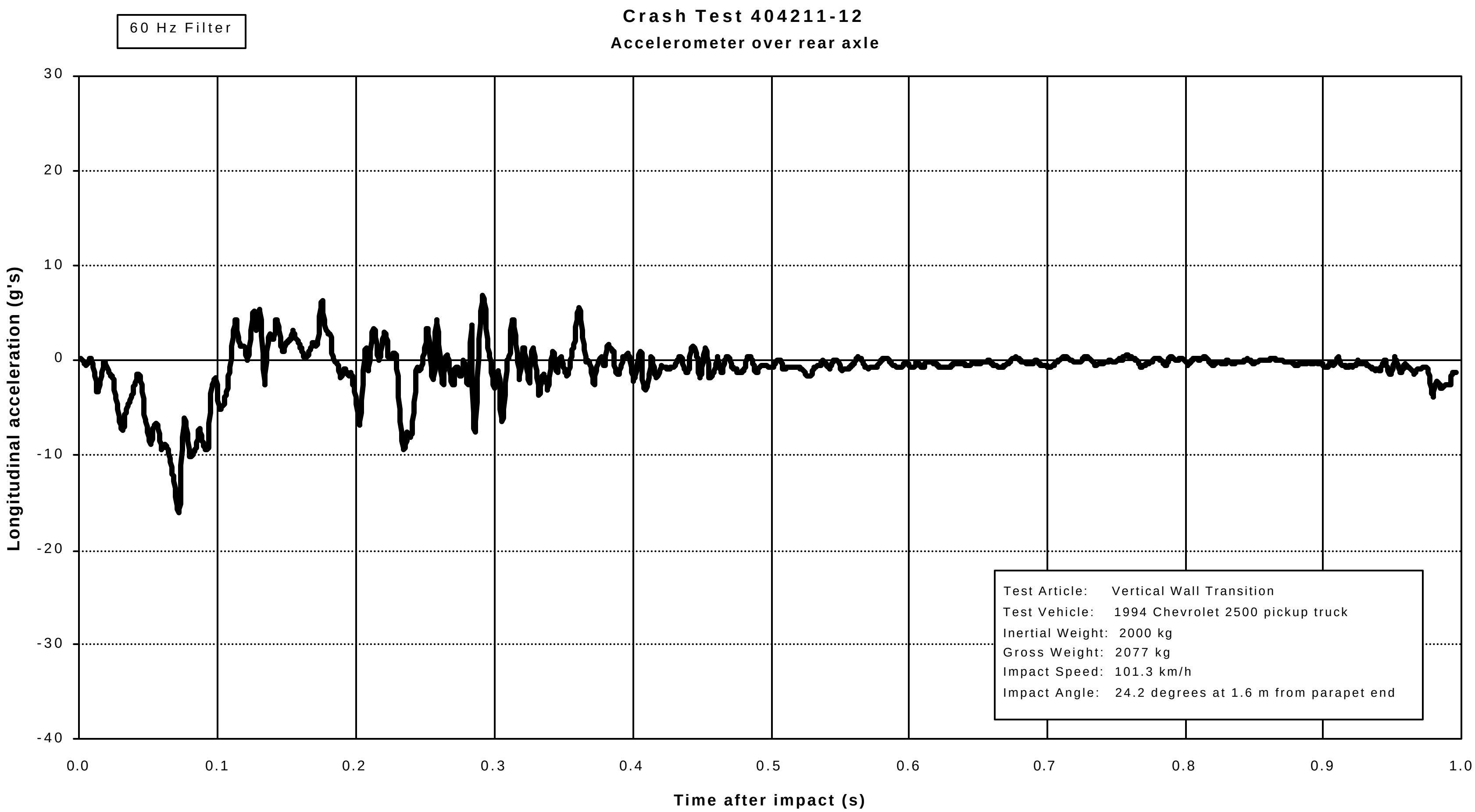


Figure 172. Vehicle longitudinal accelerometer trace for test 404211-12 (accelerometer located over rear axle).

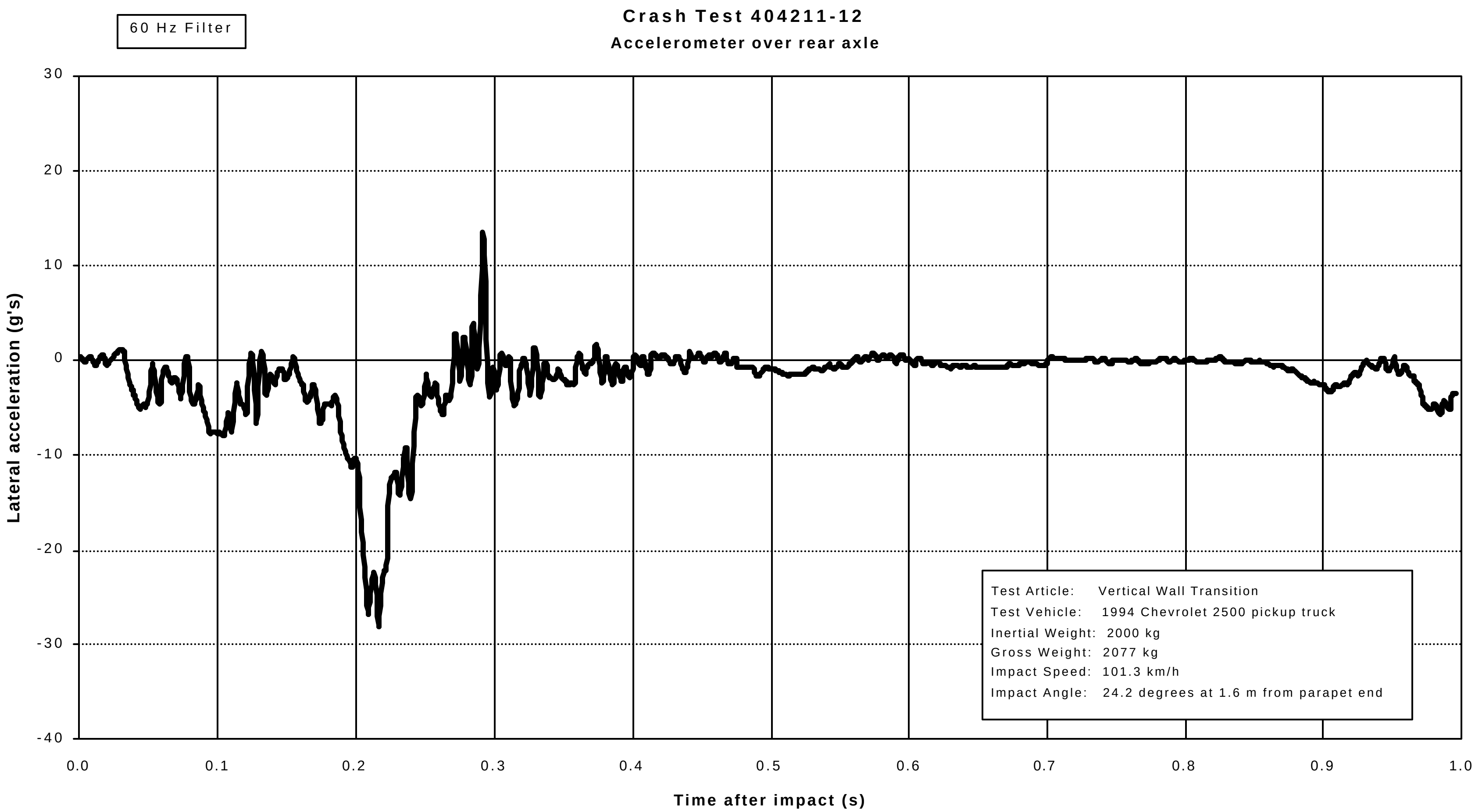


Figure 173. Vehicle lateral accelerometer trace for test 404211-12 (accelerometer located over rear axle).

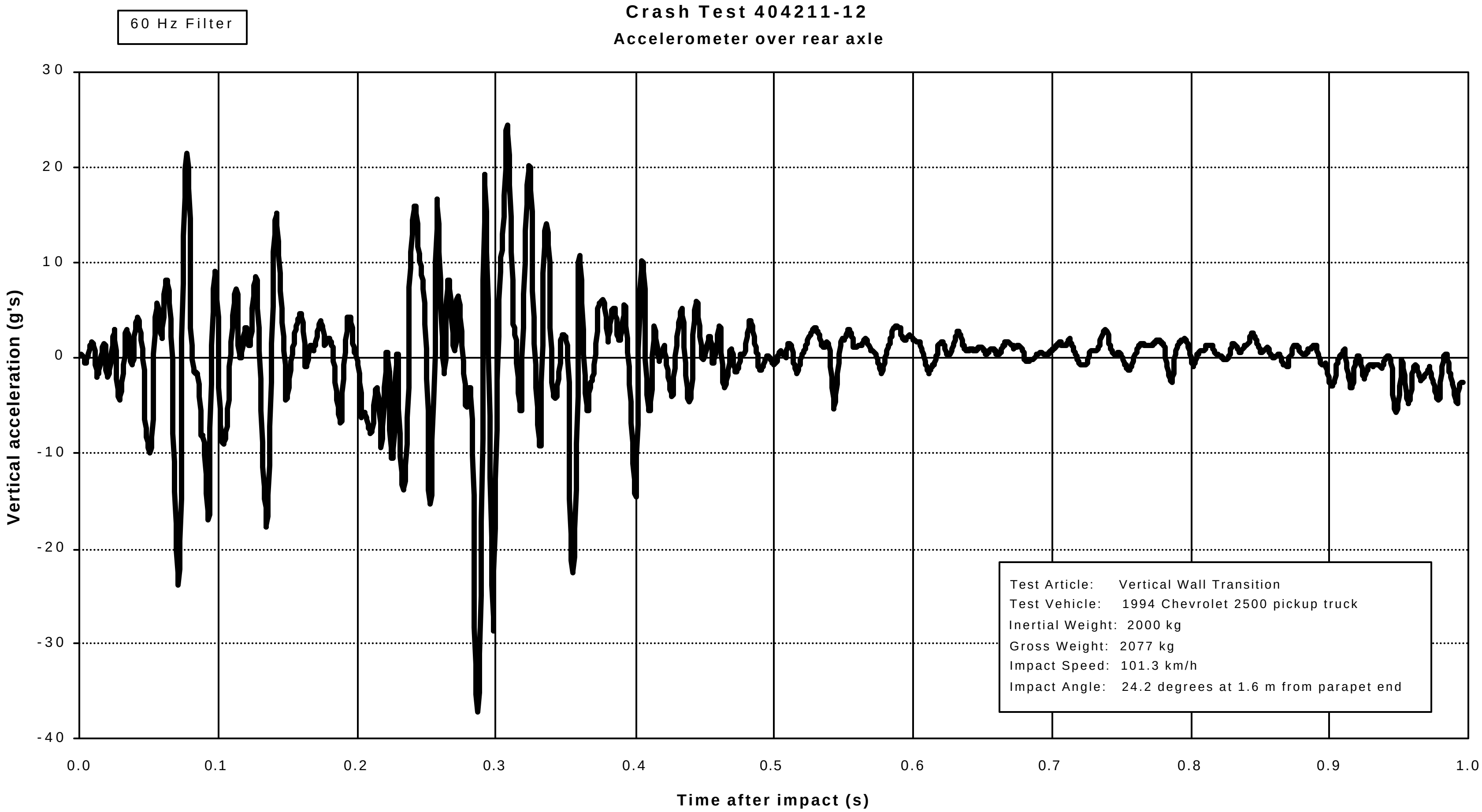


Figure 174. Vehicle vertical accelerometer trace for test 404211-12 (accelerometer located over rear axle).

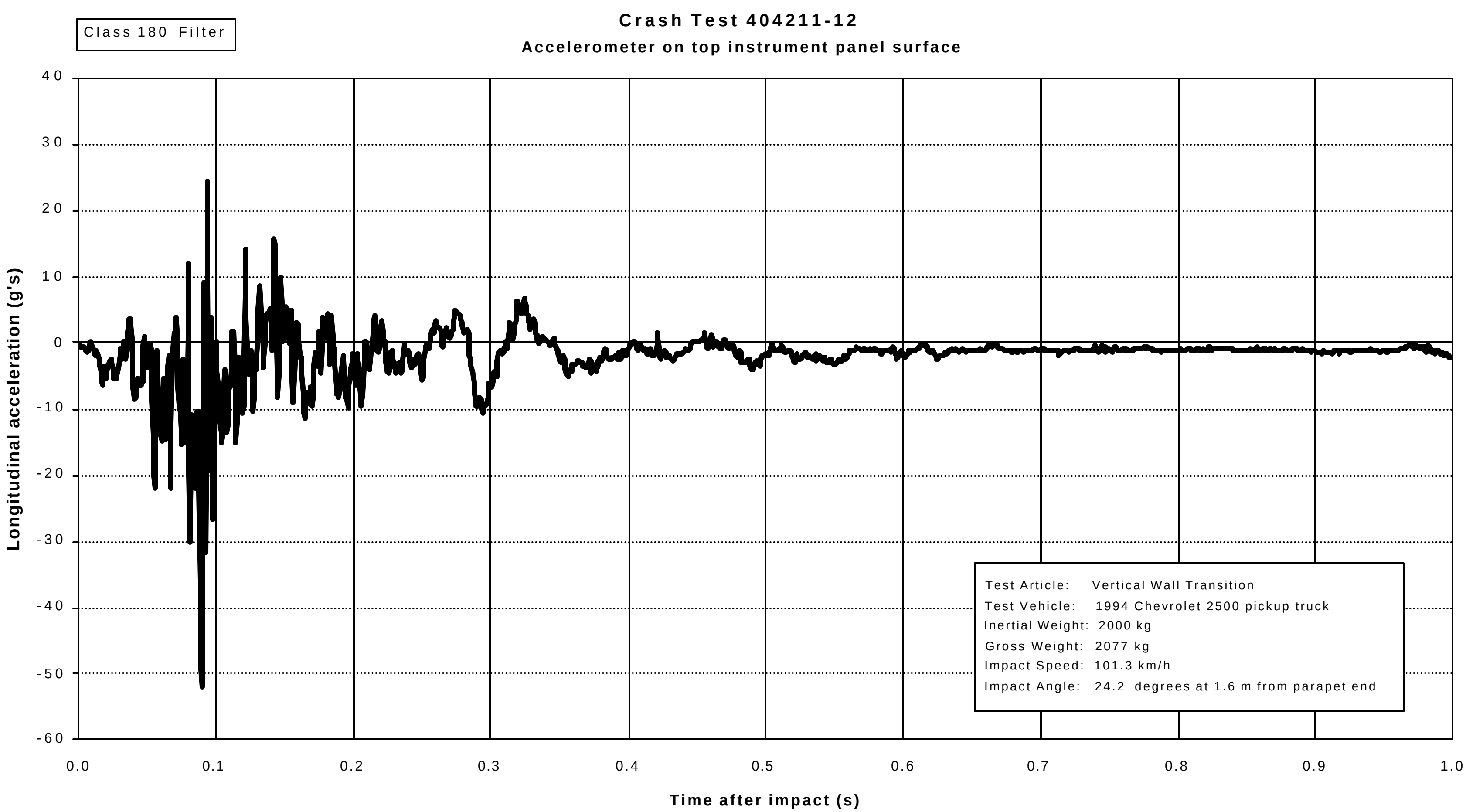


Figure 175. Vehicle longitudinal accelerometer trace for test 404211-12 (accelerometer located on top surface of instrument panel).

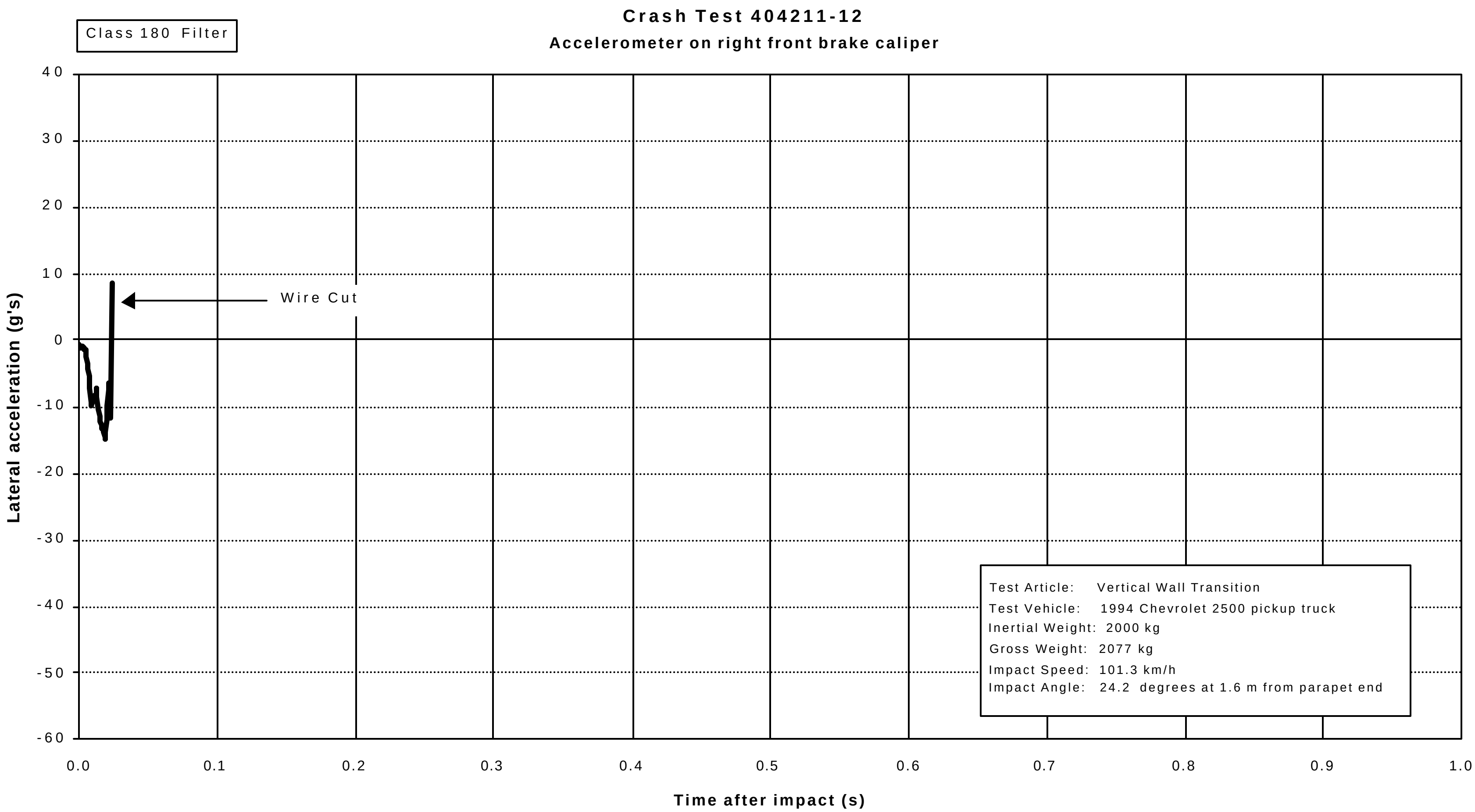


Figure 176. Vehicle lateral accelerometer trace for test 404211-12
(accelerometer located on right front brake caliper).

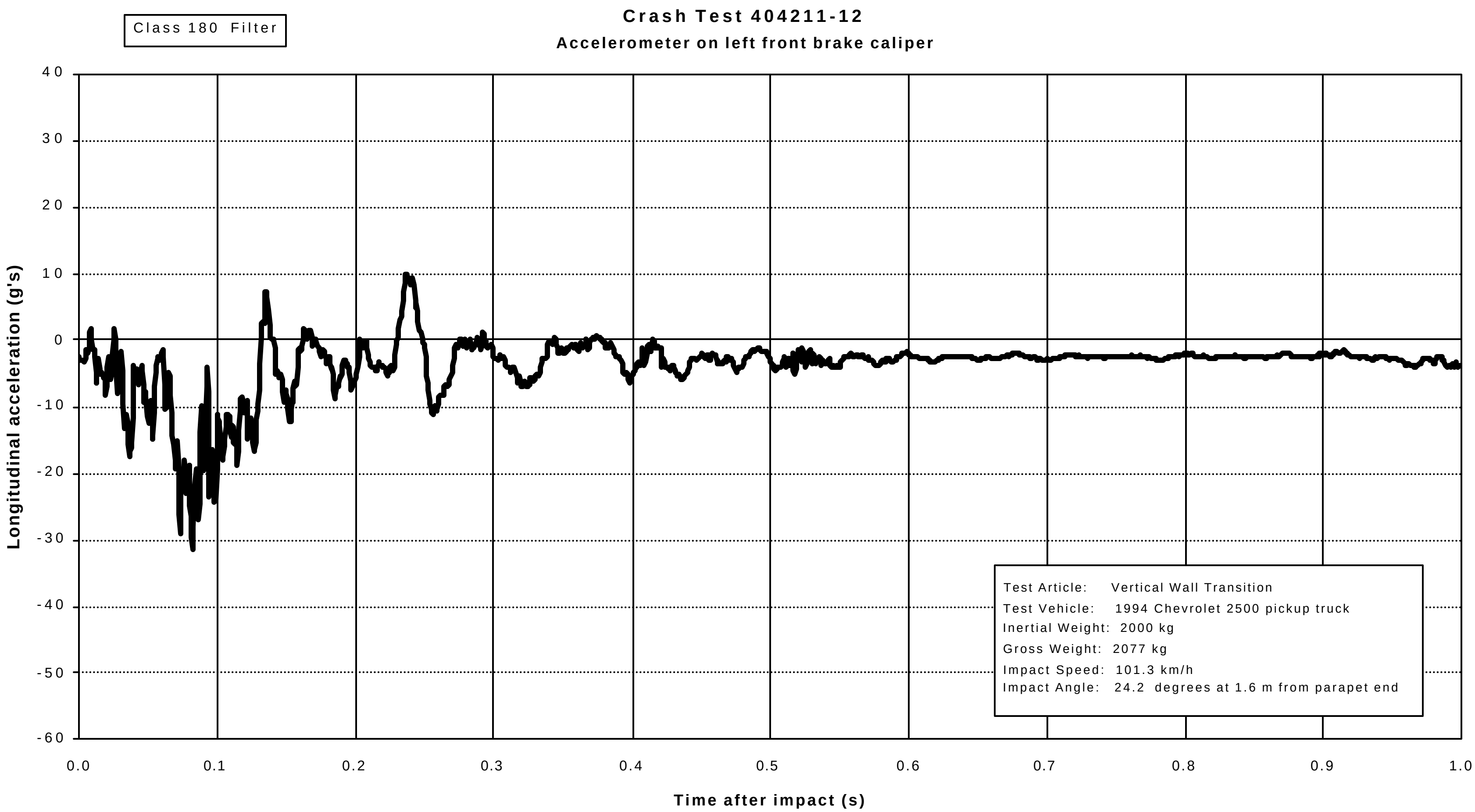


Figure 177. Vehicle longitudinal accelerometer trace for test 404211-12 (accelerometer located on left front brake caliper).

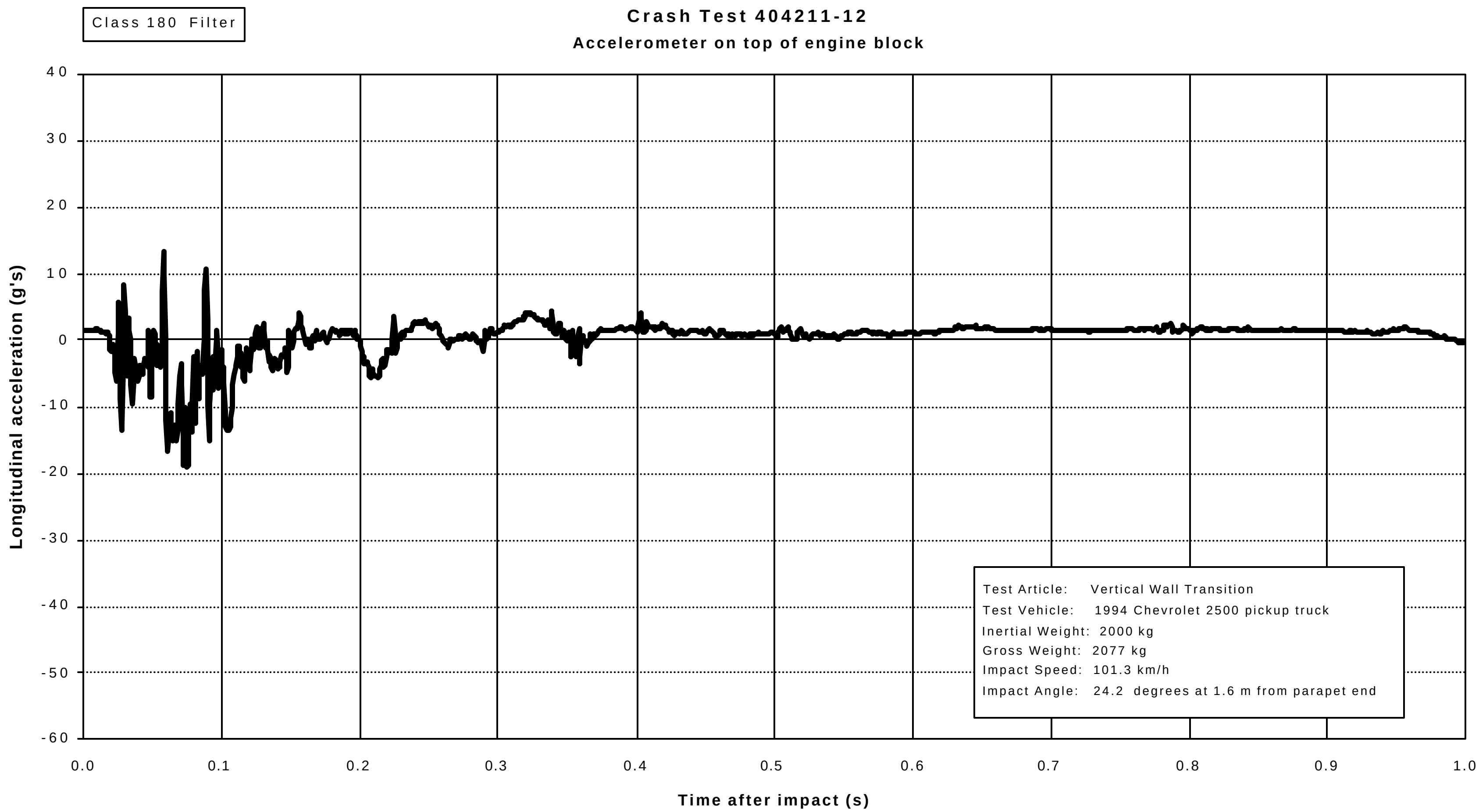


Figure 178. Vehicle longitudinal accelerometer trace for test 404211-12
(accelerometer located on top of engine block).

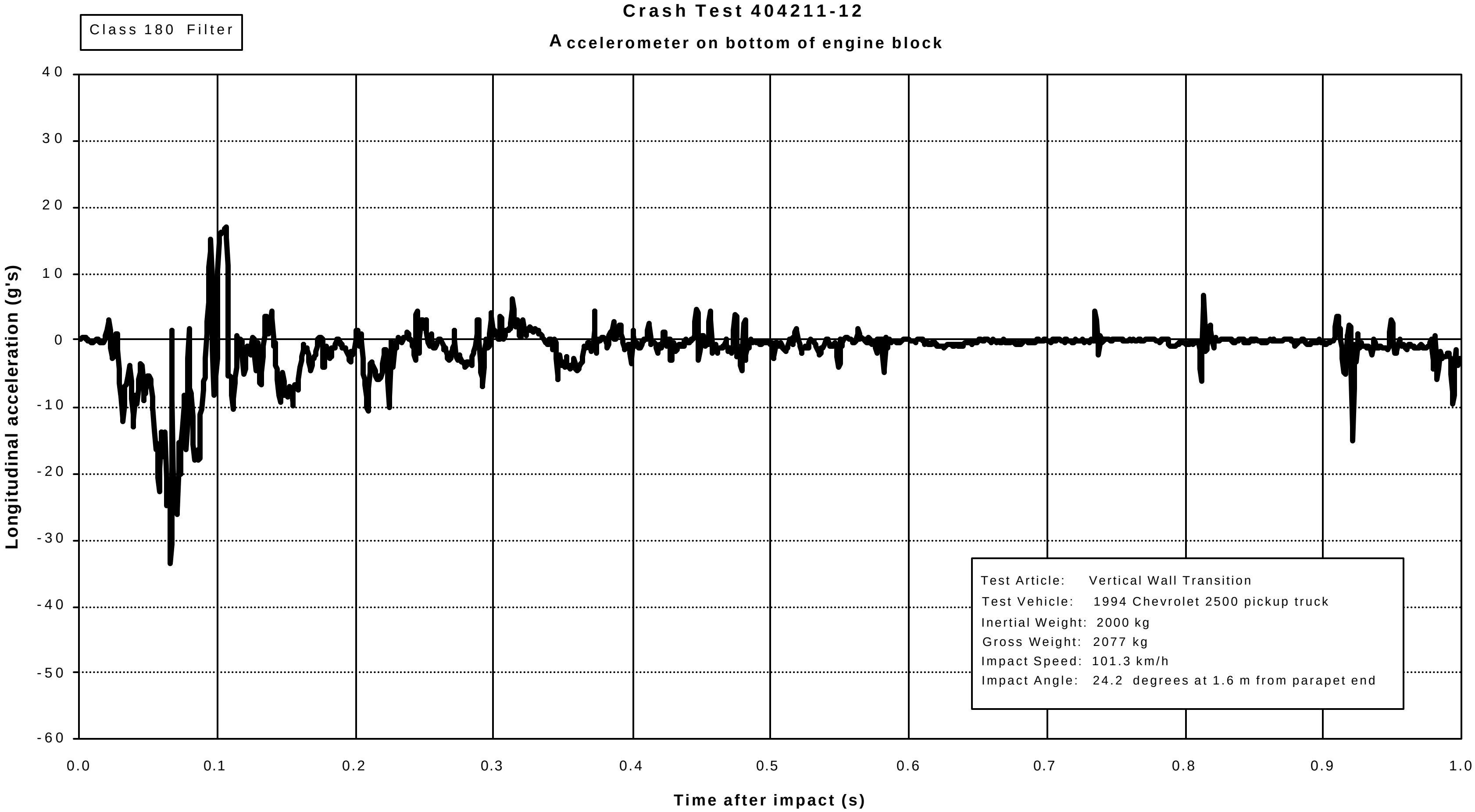


Figure 179. Vehicle longitudinal accelerometer trace for test 404211-12 (accelerometer located on bottom of engine block).

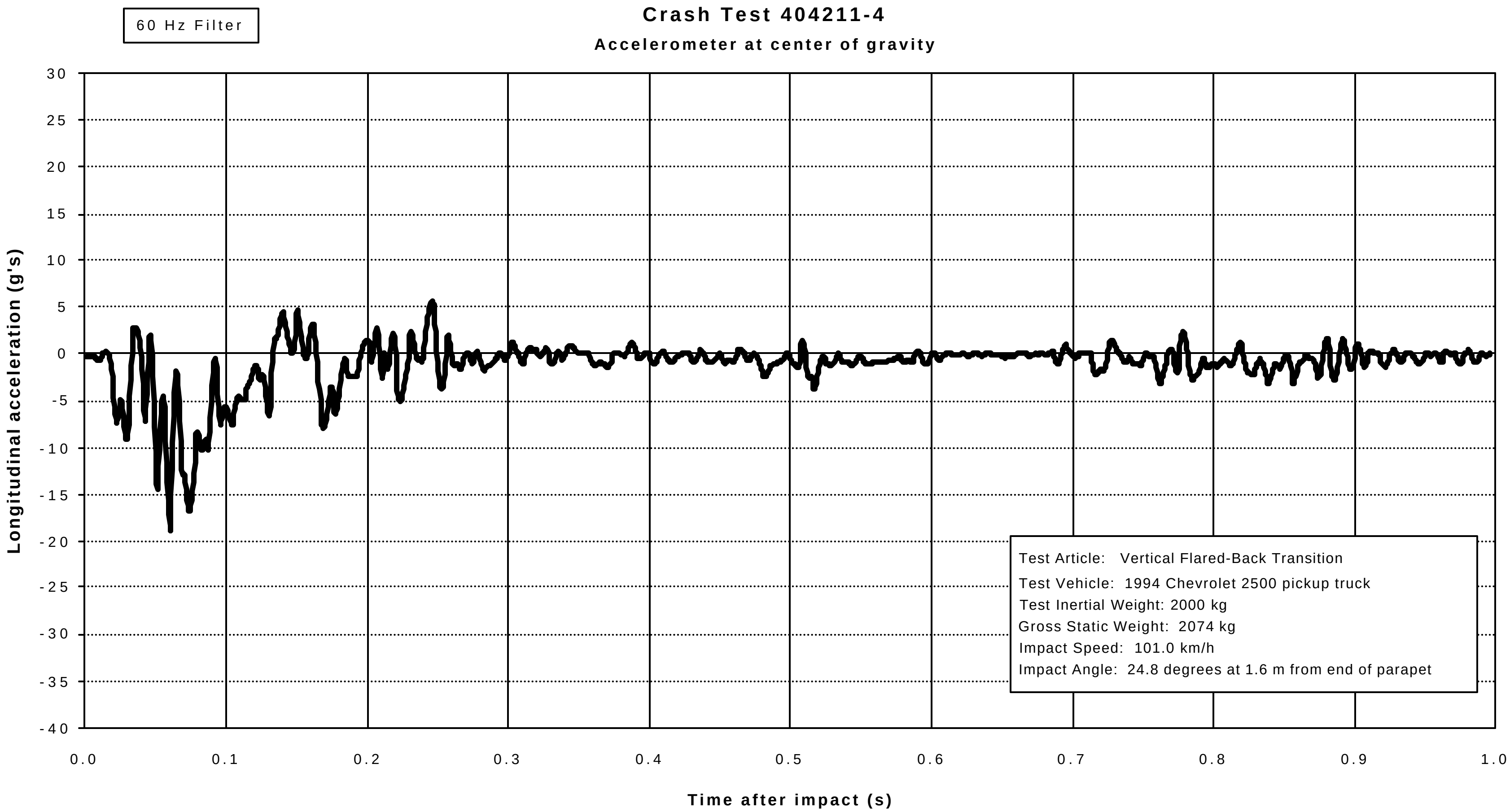


Figure 180. Vehicle longitudinal accelerometer trace for test 404211-4 (accelerometer located at center of gravity).

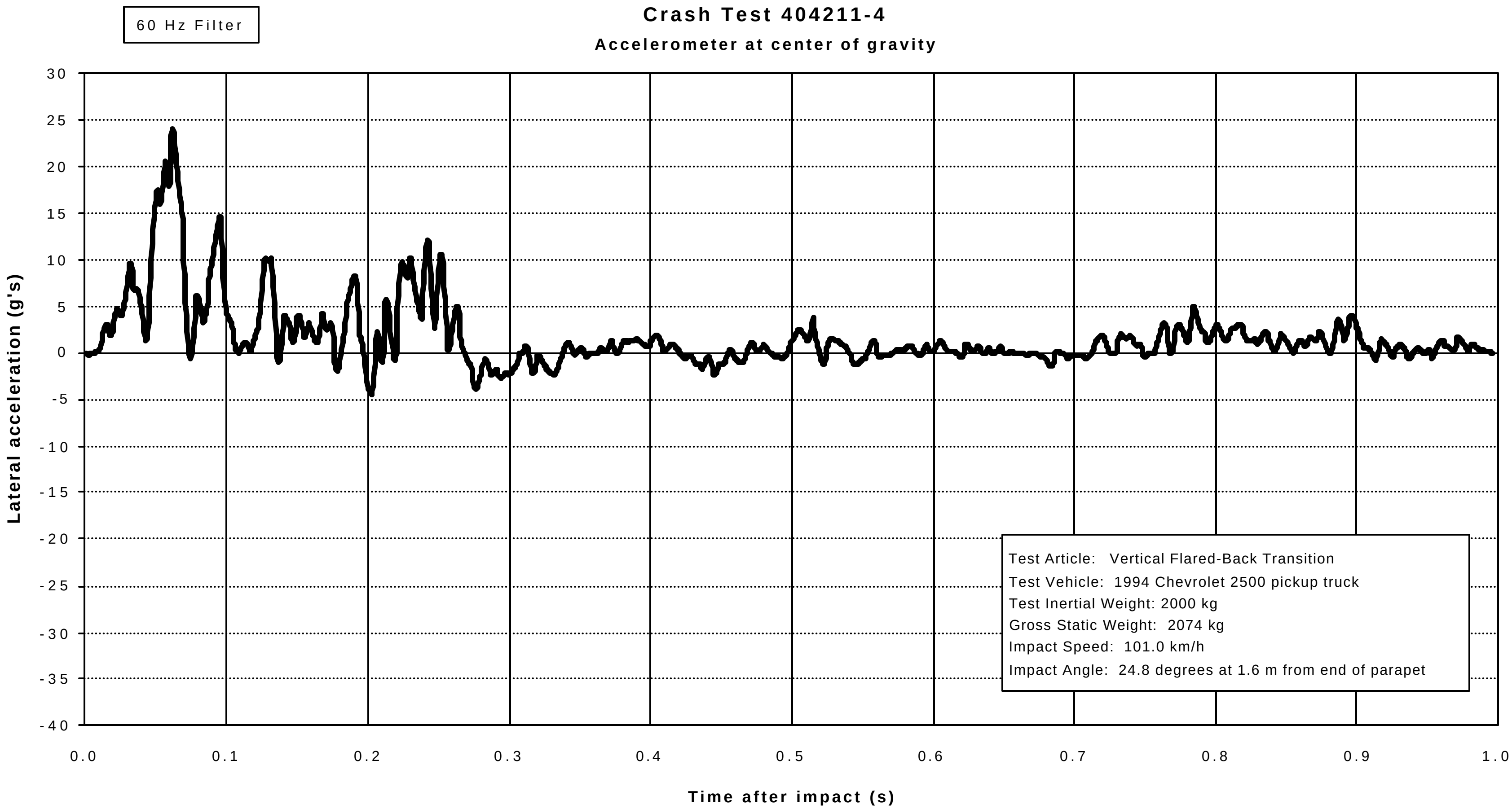


Figure 181. Vehicle lateral accelerometer traces for test 404211-4
(accelerometer located at center of gravity).

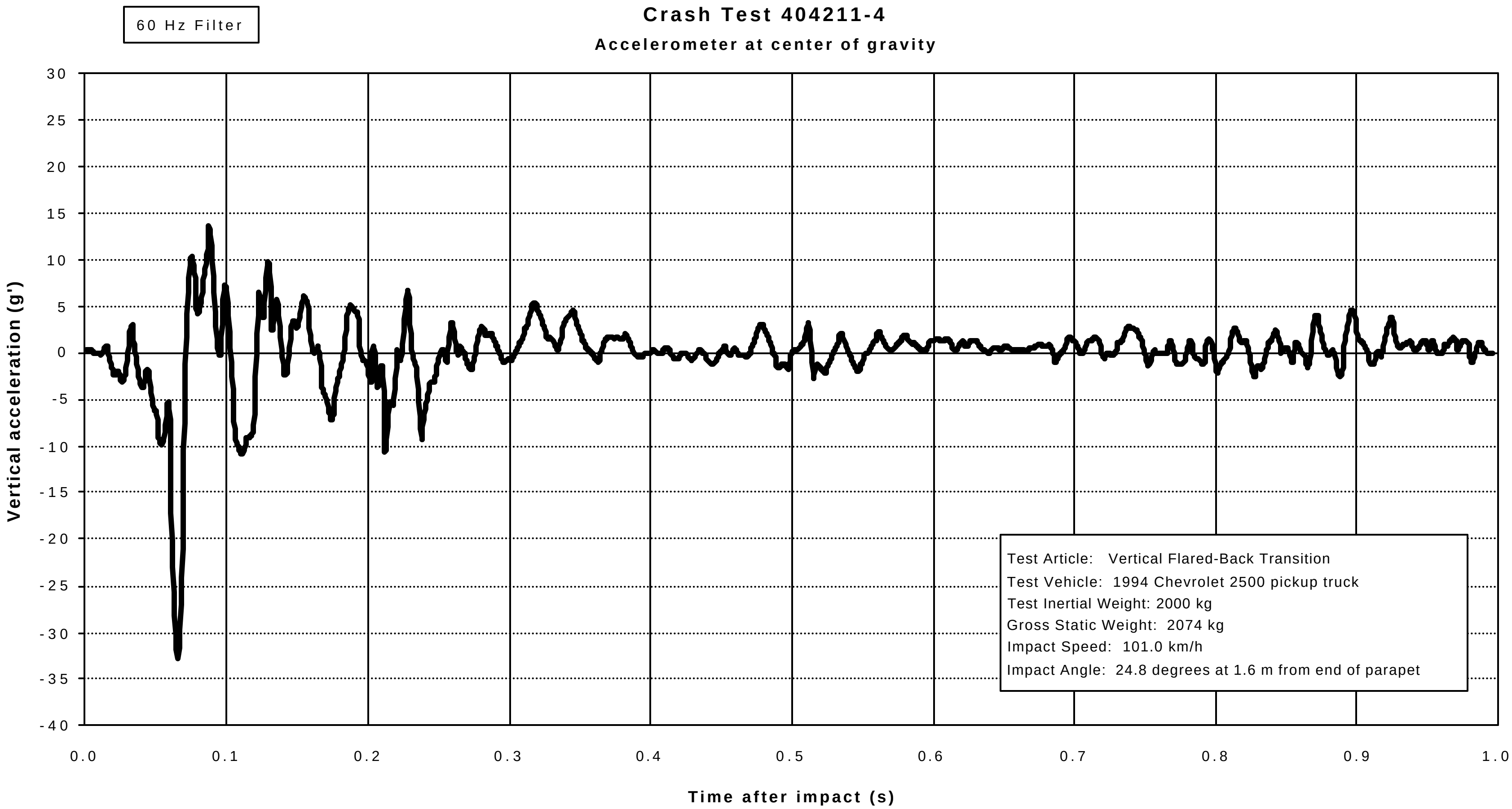


Figure 182. Vehicle vertical accelerometer trace for test 404211-4
(accelerometer located at center of gravity).

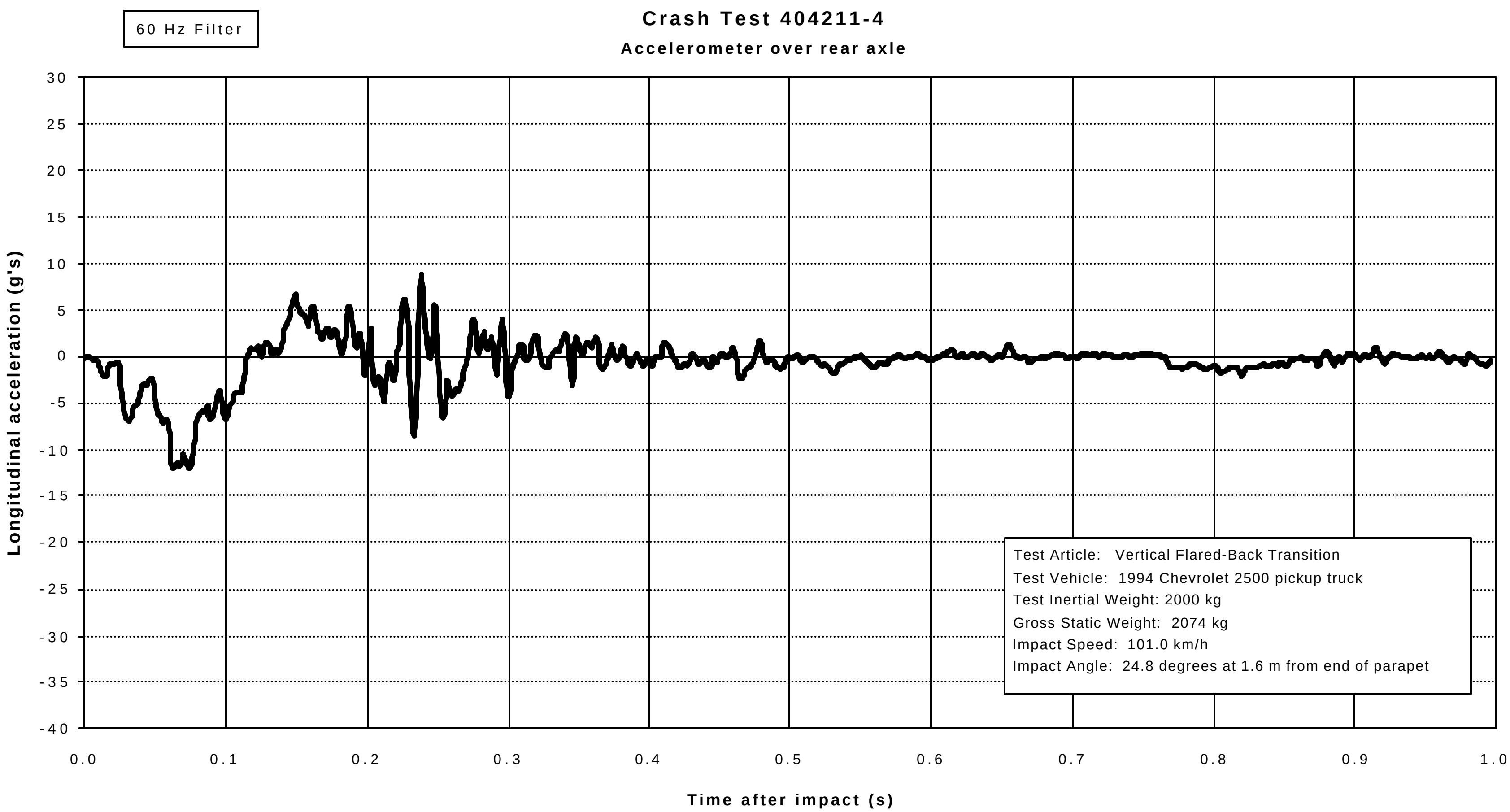


Figure 183. Vehicle longitudinal accelerometer trace for test 404211-4 (accelerometer located over rear axle).

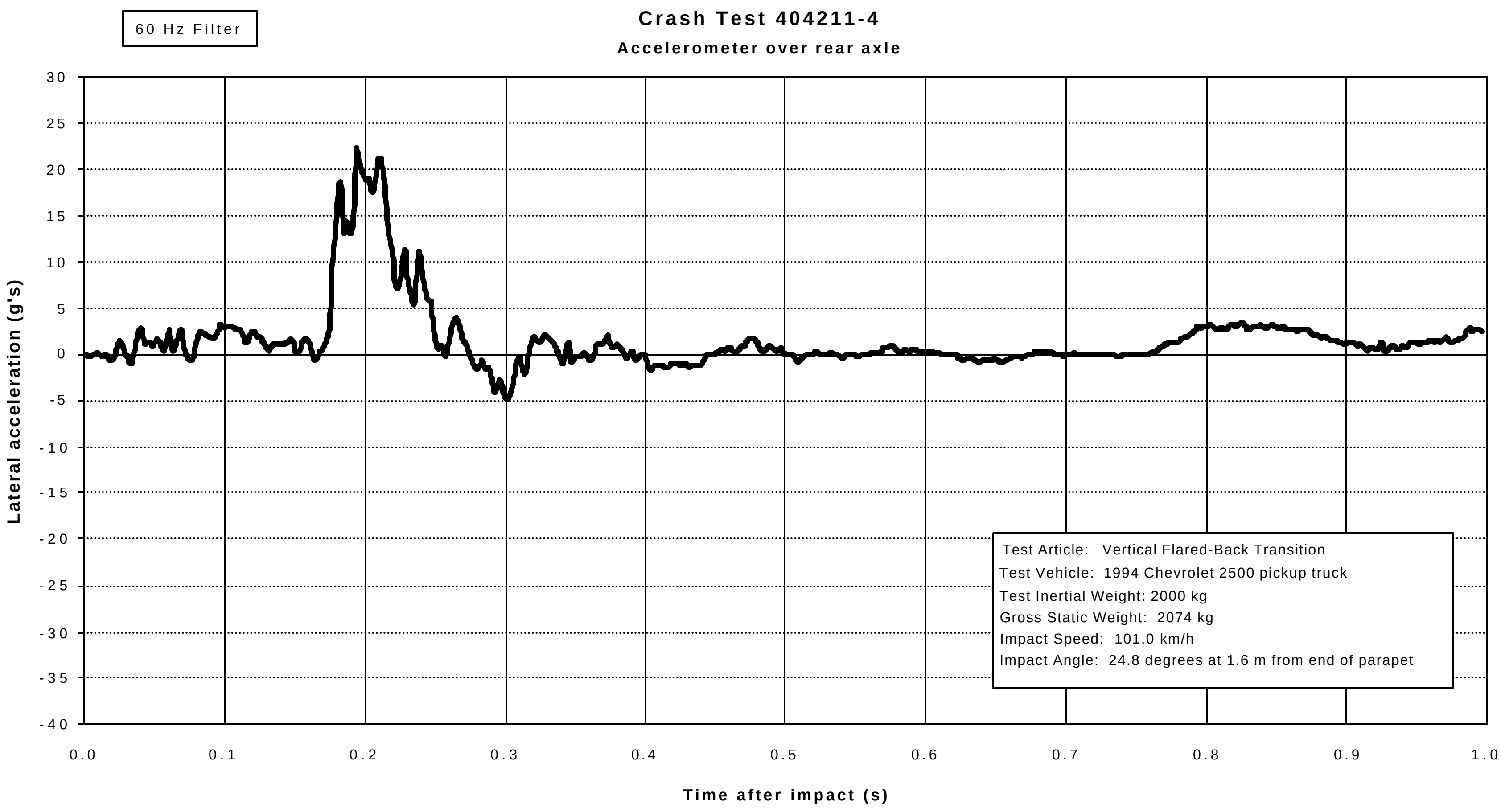


Figure 184. Vehicle lateral accelerometer traces for test 404211-4 (accelerometer located over rear axle).

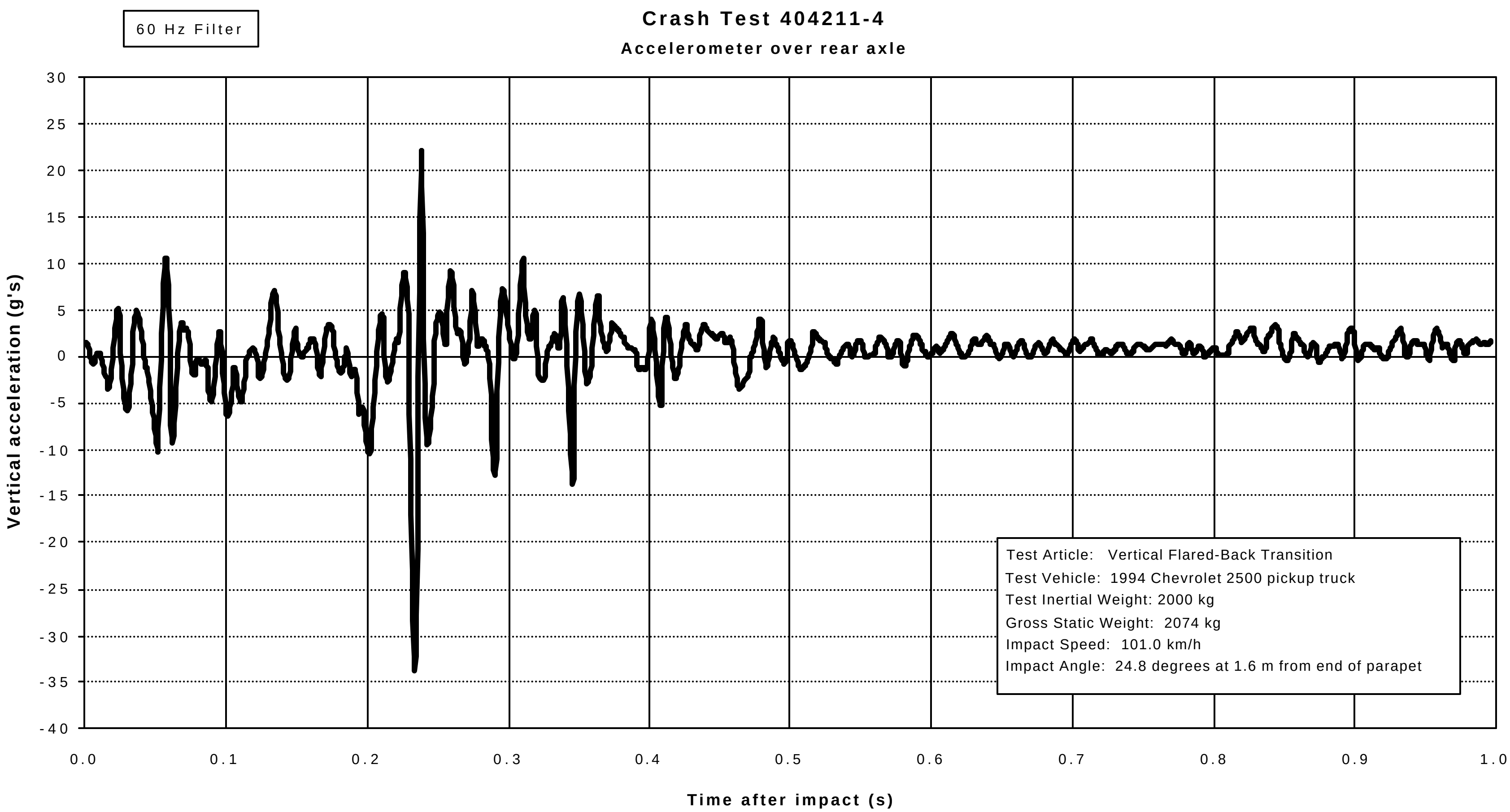


Figure 185. Vehicle vertical accelerometer trace for test 404211-4 (accelerometer located over rear axle).

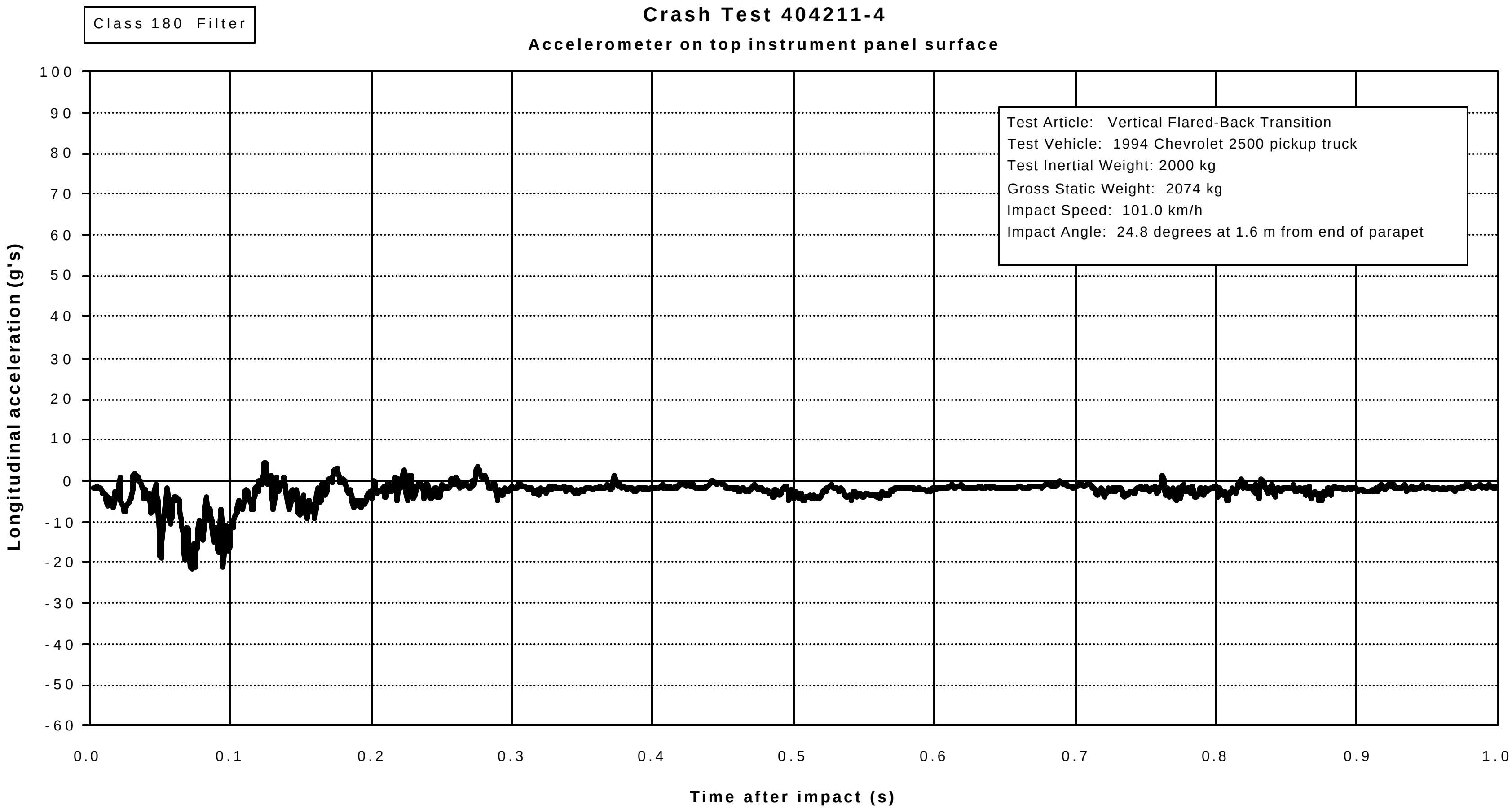


Figure 186. Vehicle longitudinal accelerometer trace for test 404211-4
(accelerometer located on top surface of instrument panel).

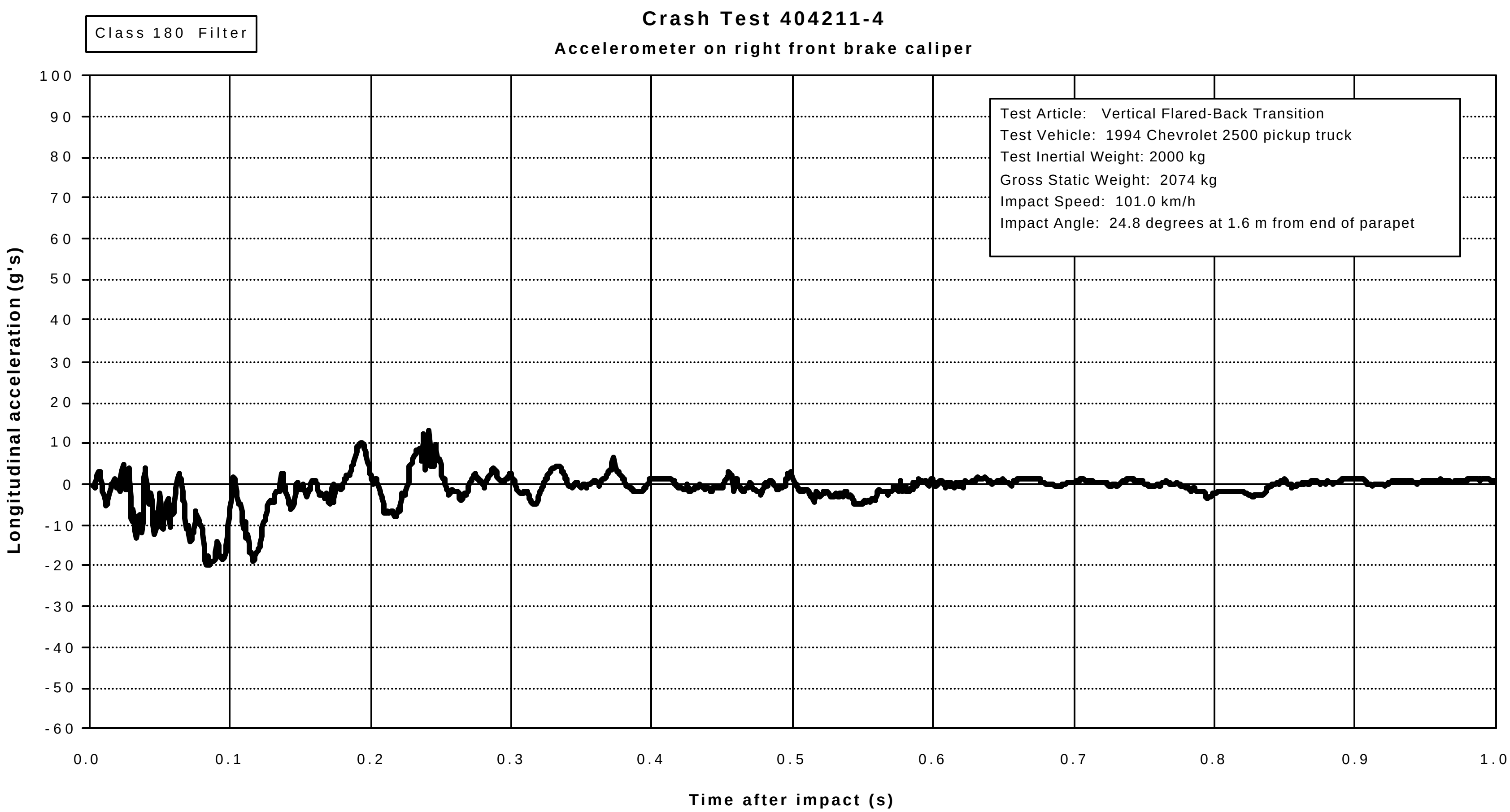


Figure 187. Vehicle longitudinal accelerometer traces for test 404211-4
(accelerometer located on right front brake caliper).

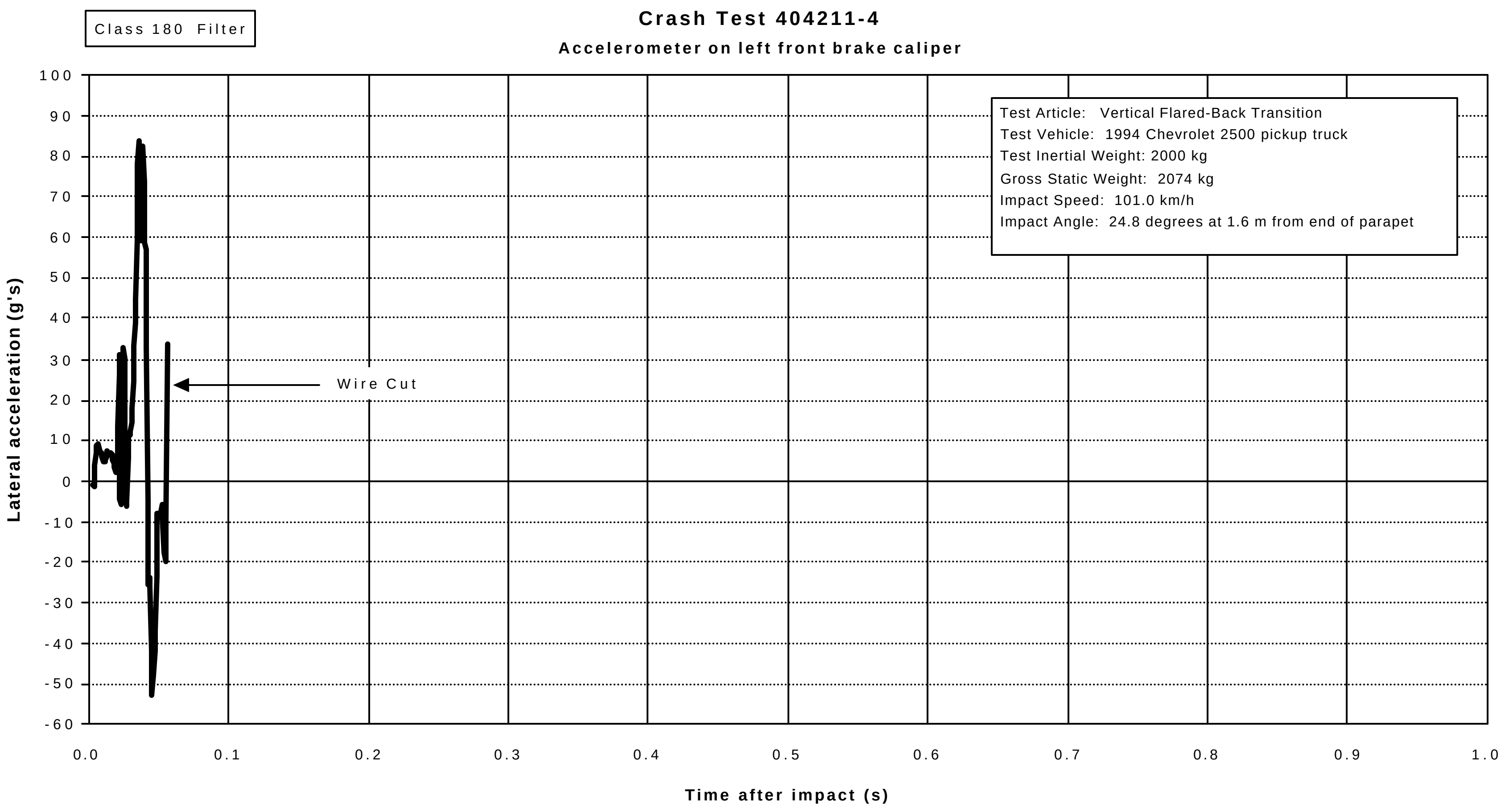


Figure 188. Vehicle lateral accelerometer trace for test 404211-4 (accelerometer located on left front brake caliper).

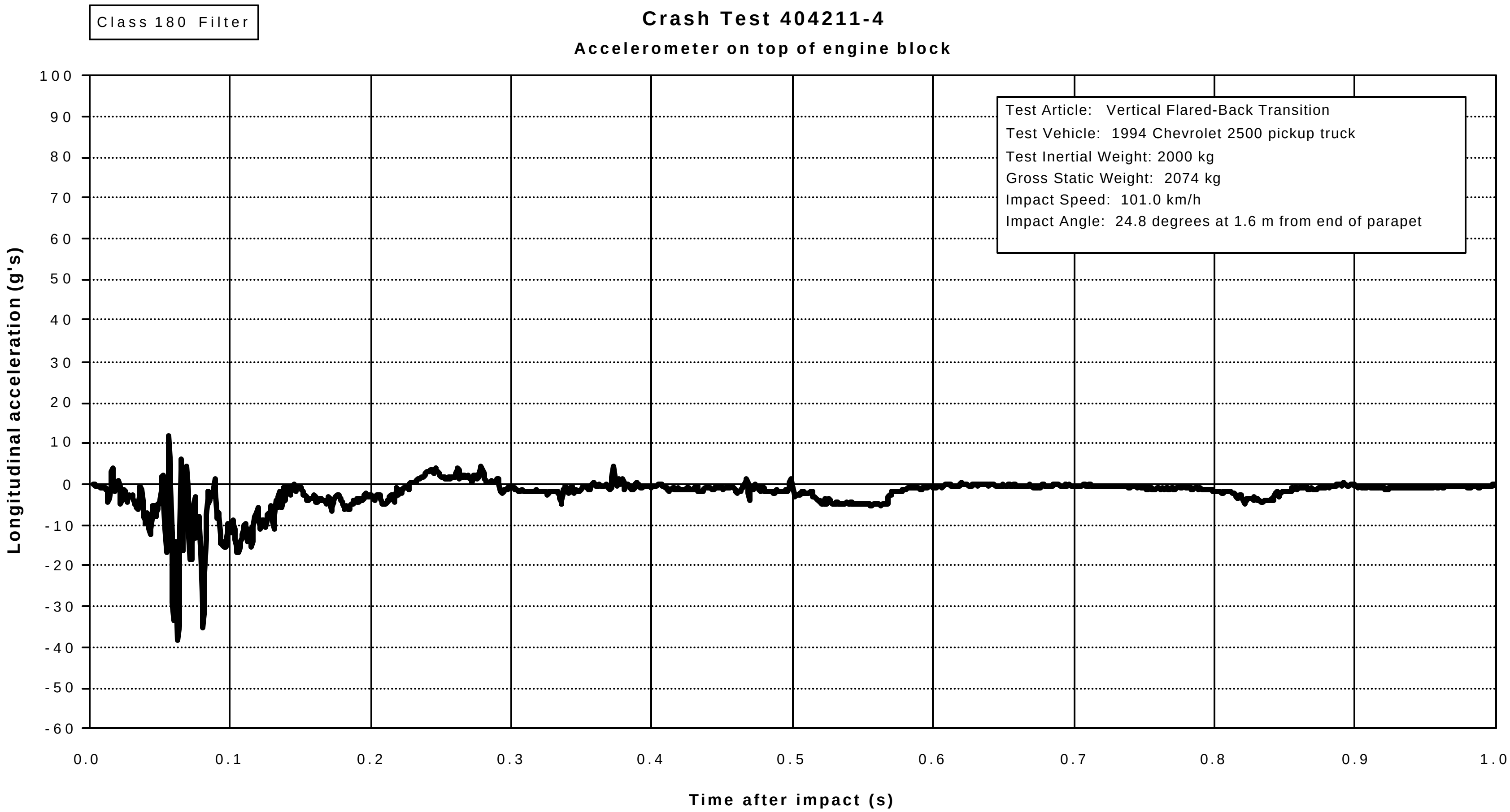


Figure 189. Vehicle longitudinal accelerometer trace for test 404211-4 (accelerometer located on top of engine block).

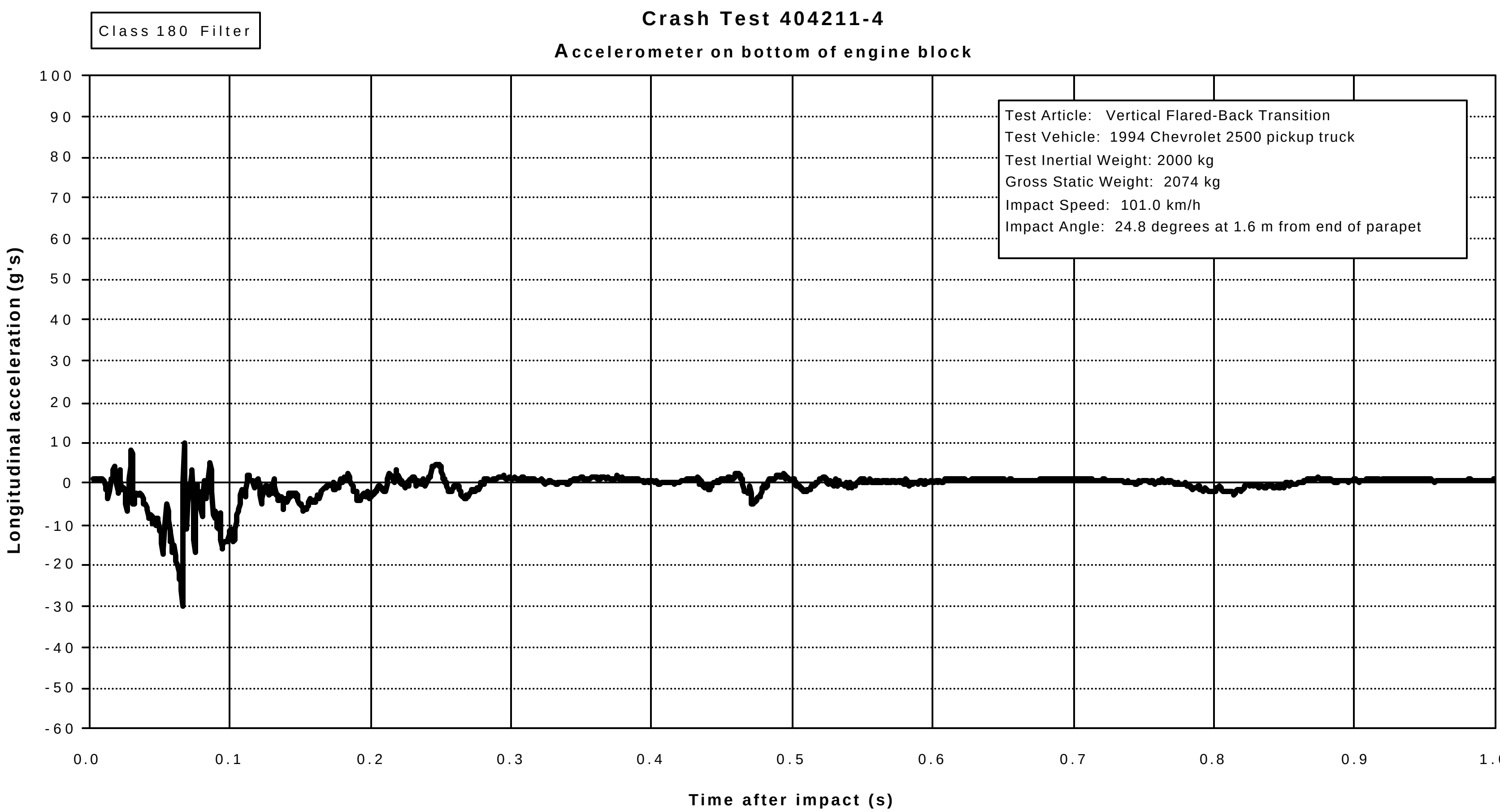


Figure 60. Vehicle longitudinal accelerometer trace for test 404211-4 (accelerometer located on bottom of engine block).

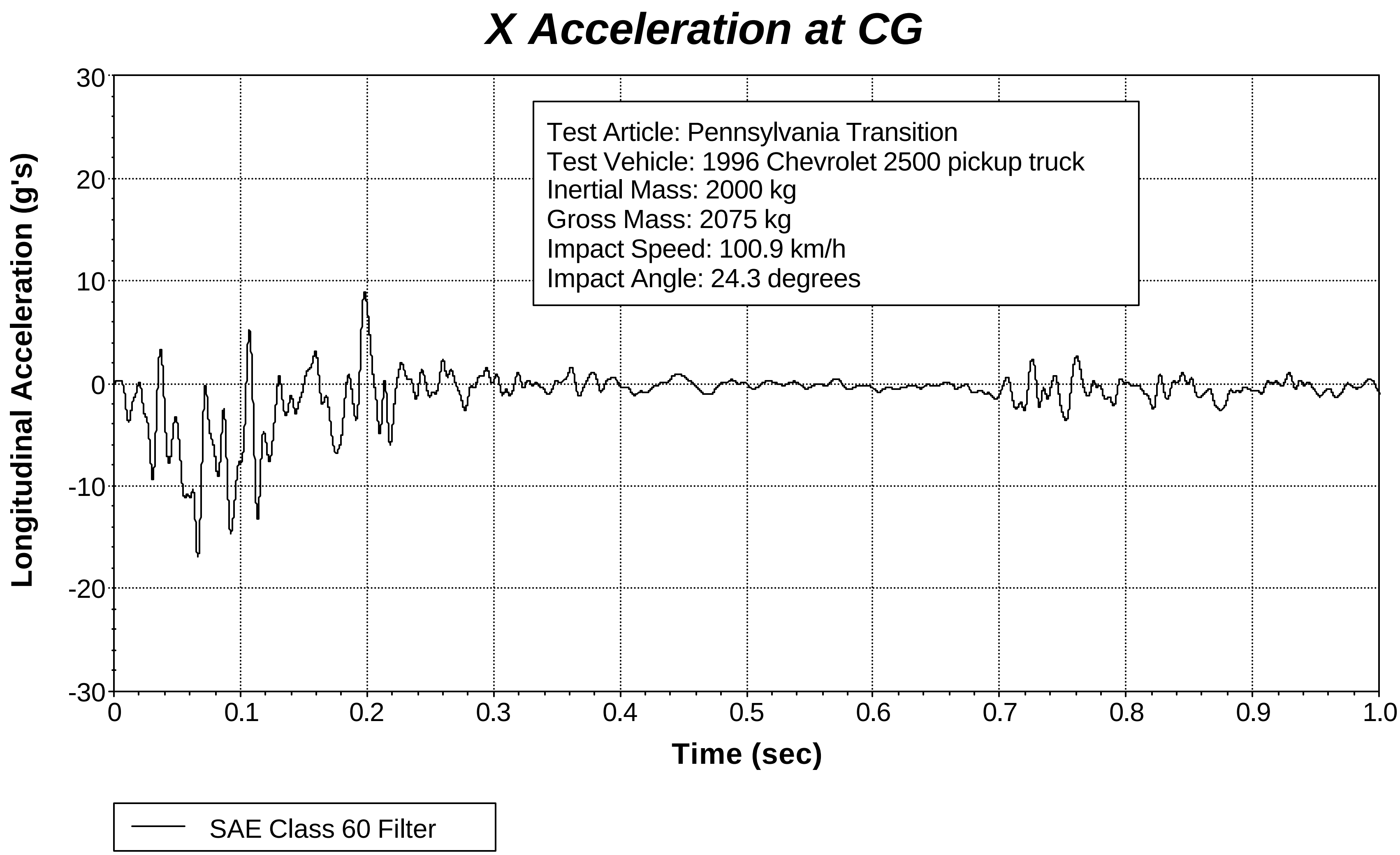


Figure 61. Vehicle longitudinal accelerometer trace for test 404211-3 (accelerometer located at center of gravity).

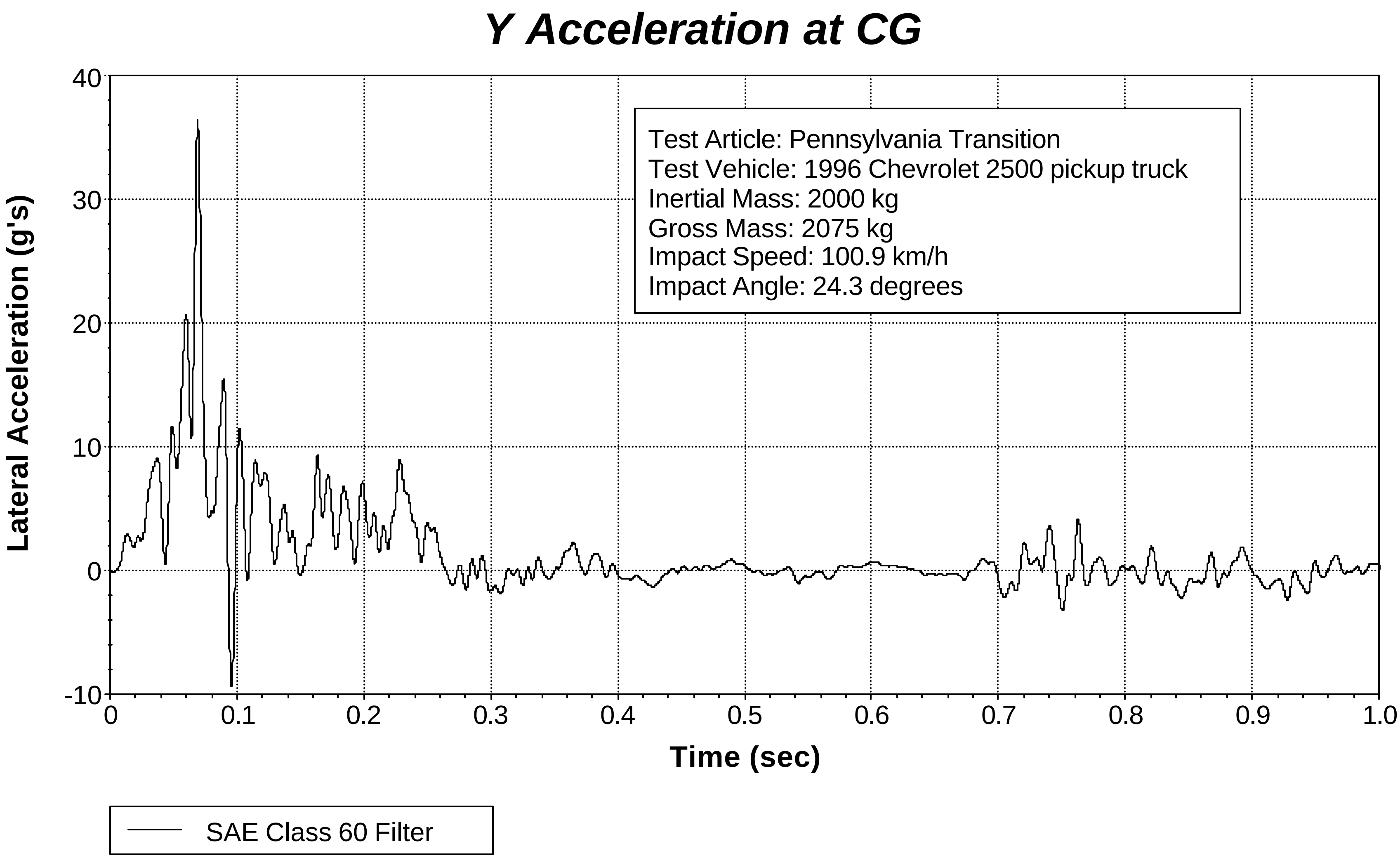


Figure 62. Vehicle lateral accelerometer trace for test 404211-3 (accelerometer located at center of gravity).

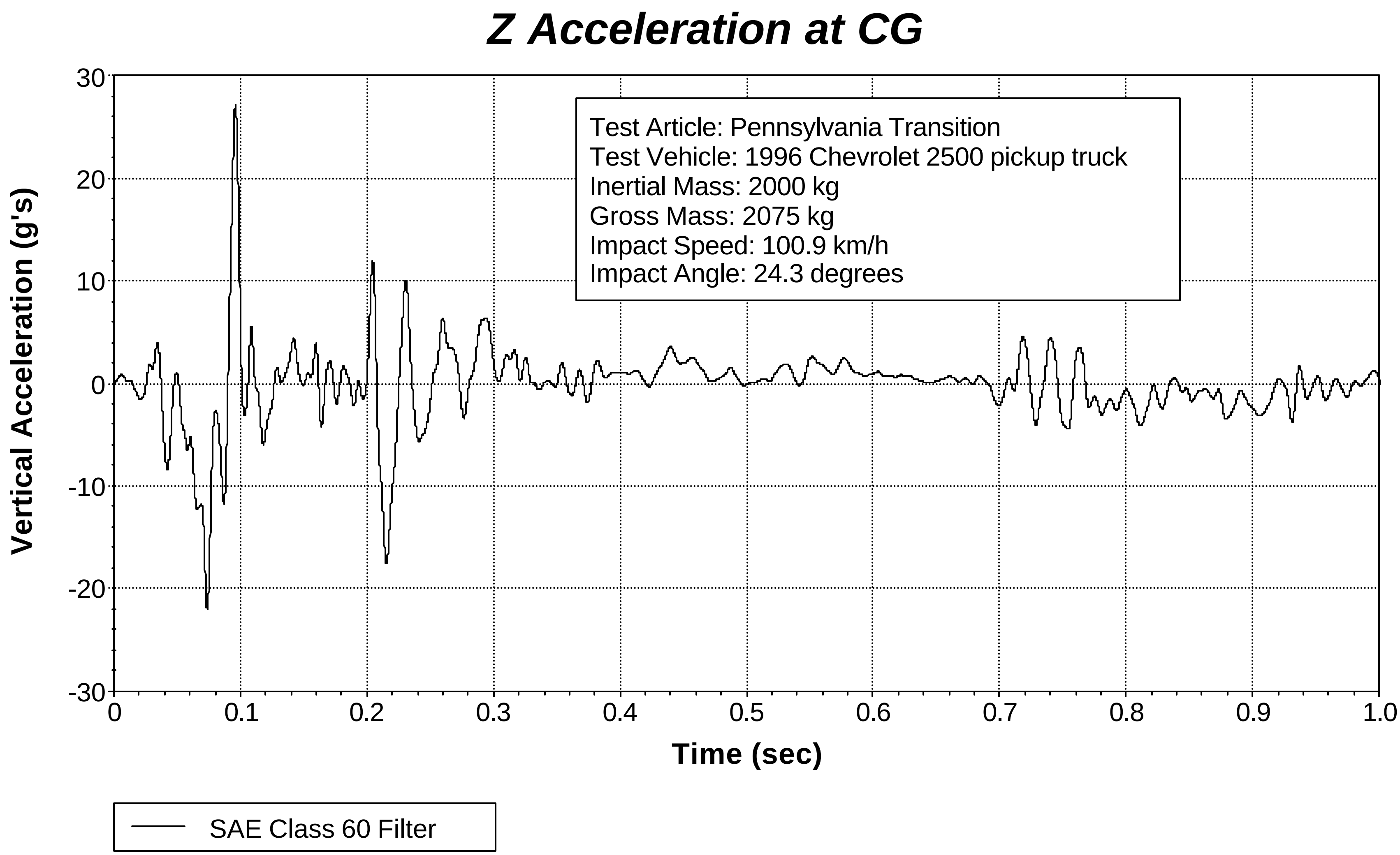


Figure 63. Vehicle vertical accelerometer trace for test 404211-3
(accelerometer located at center of gravity).

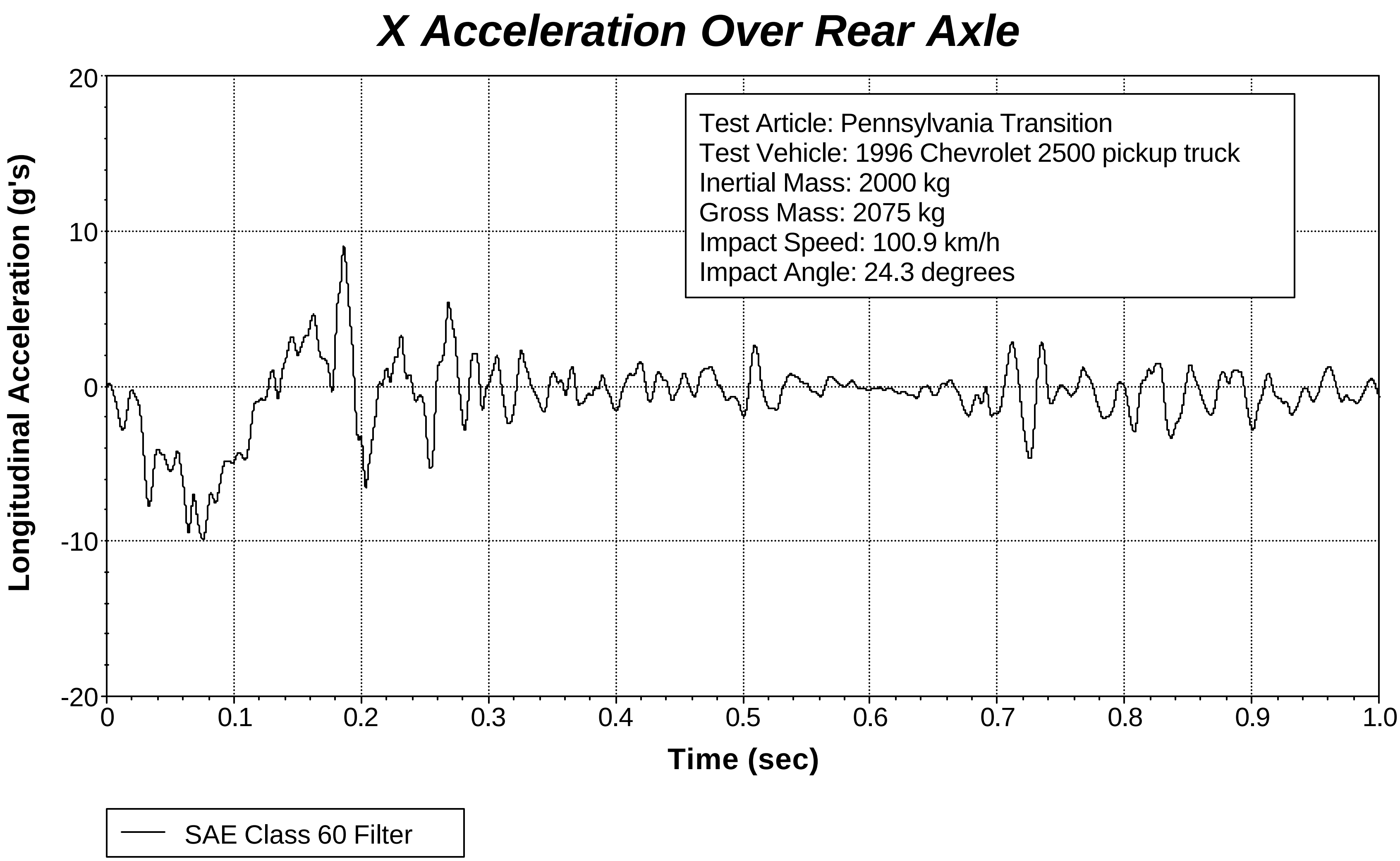


Figure 64. Vehicle longitudinal accelerometer trace for test 404211-3
(accelerometer located over rear axle).

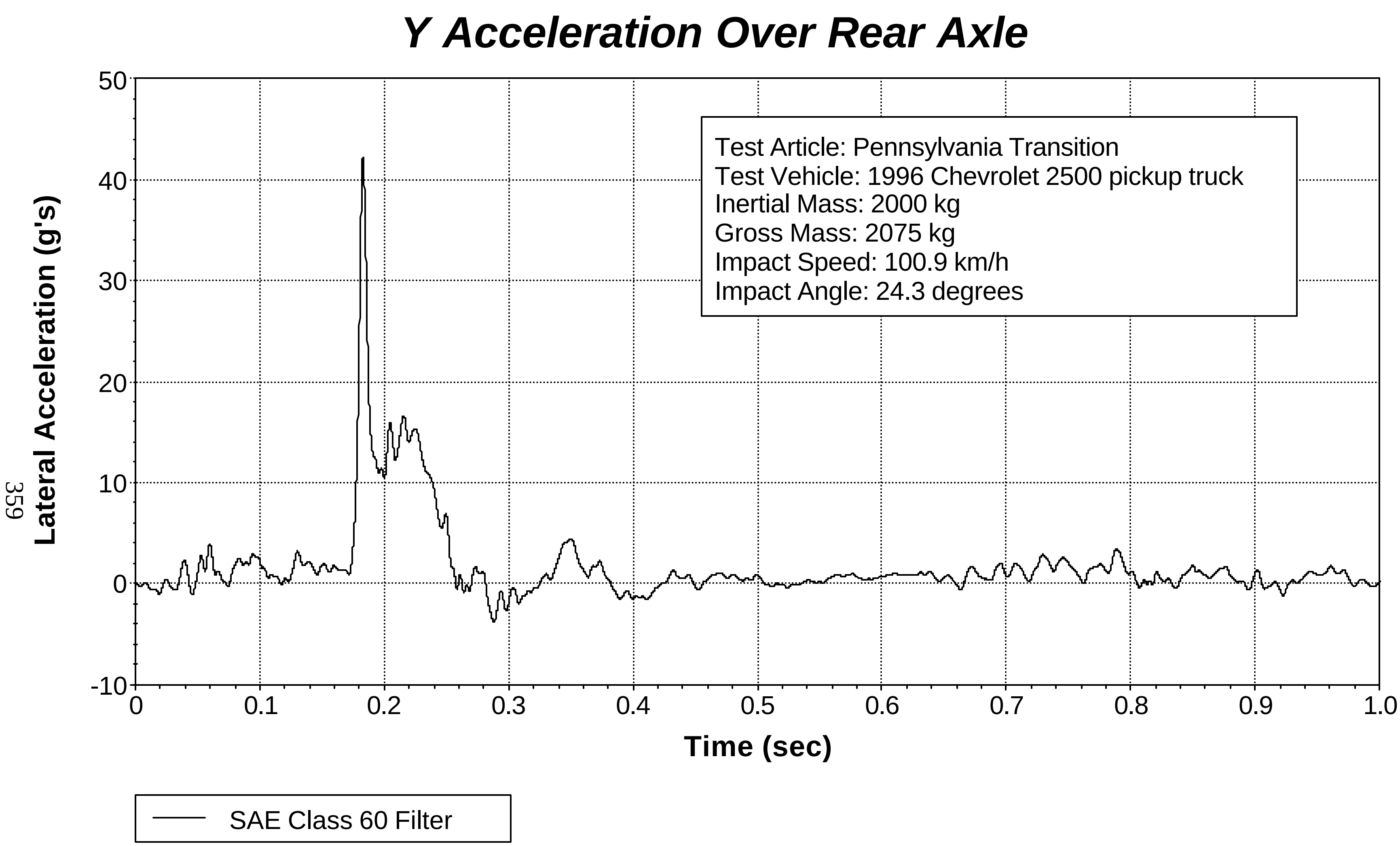


Figure 65. Vehicle lateral accelerometer trace for test 404211-3 (accelerometer located over rear axle).

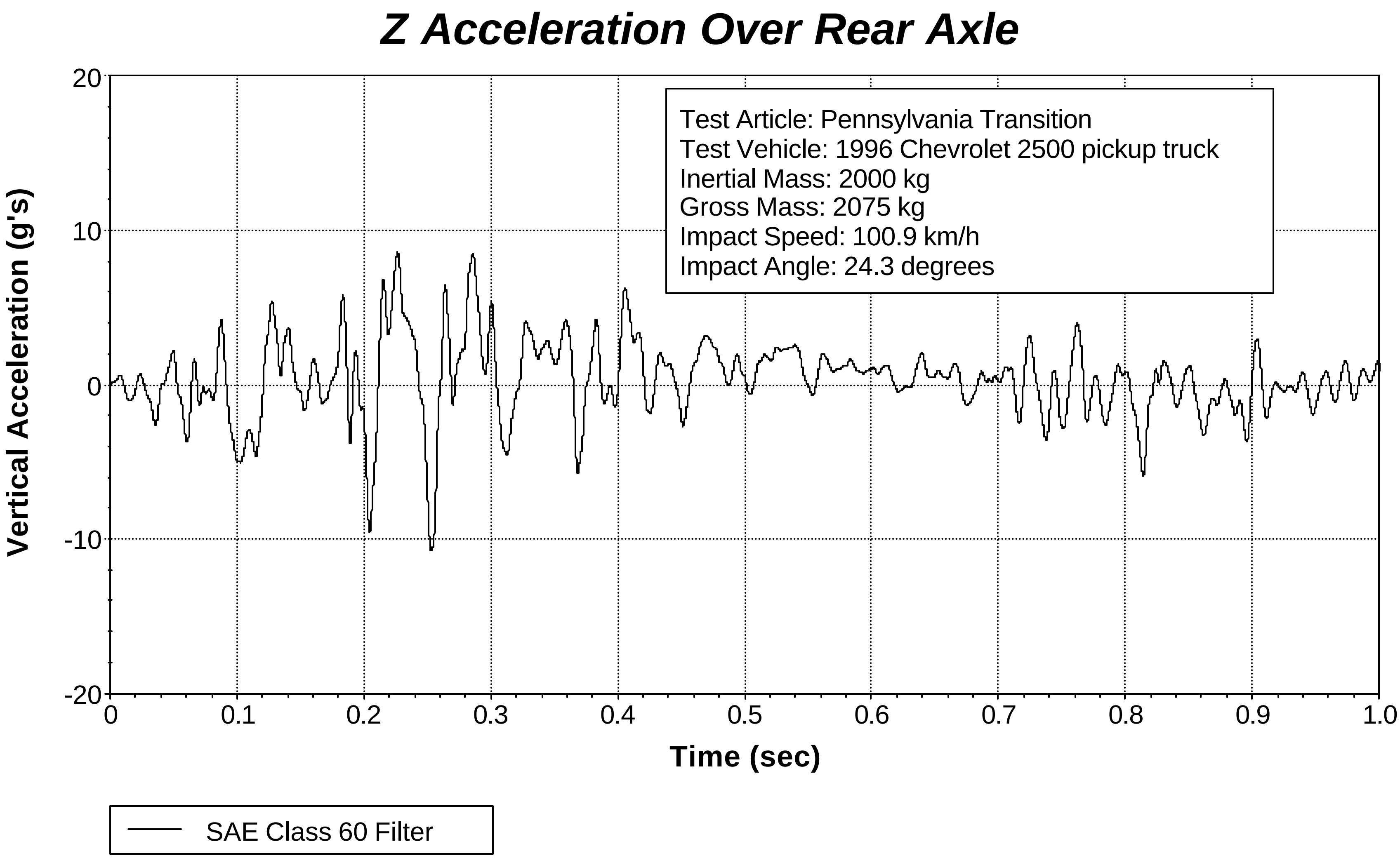


Figure 66. Vehicle vertical accelerometer trace for test 404211-3
(accelerometer located over rear axle).

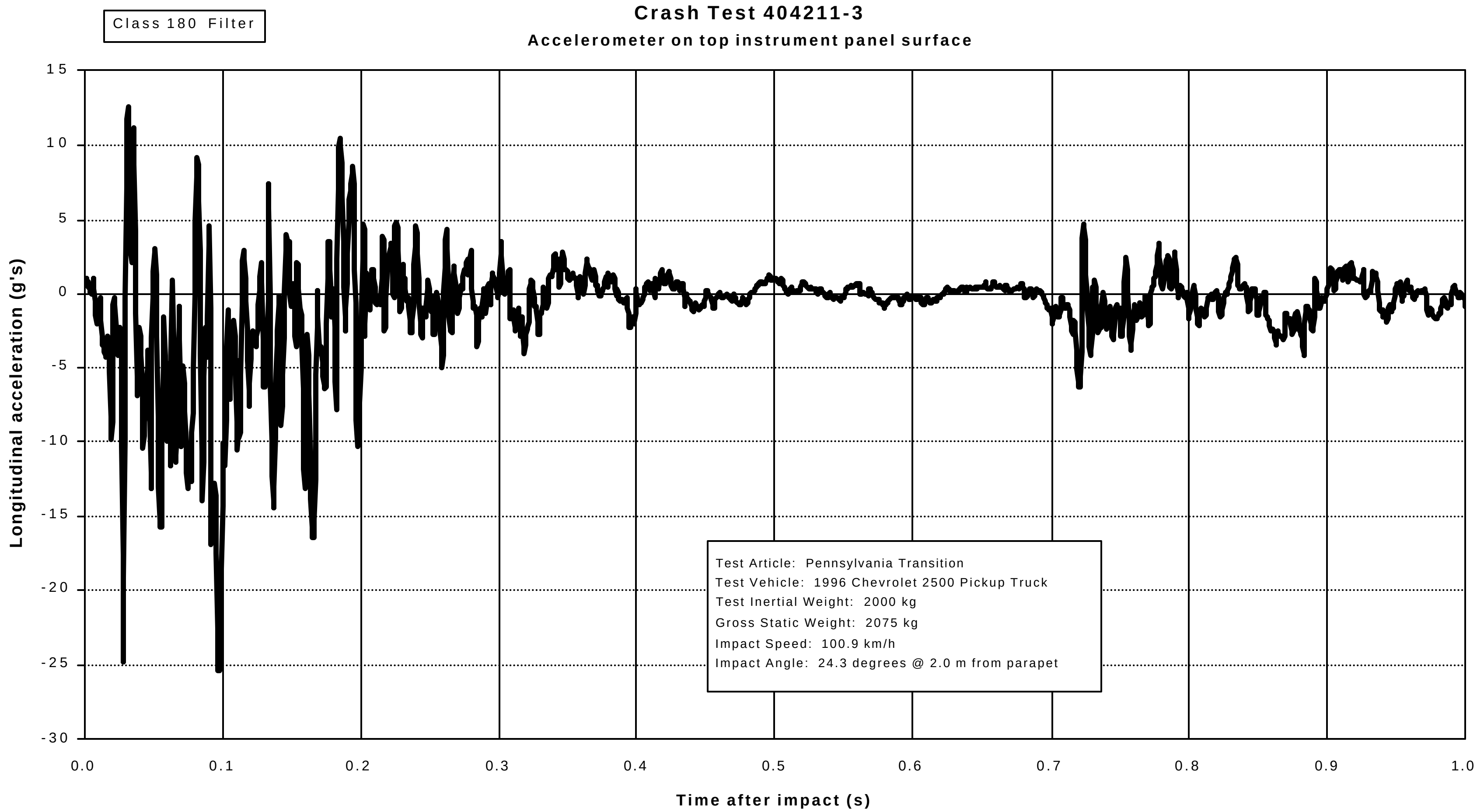


Figure 67. Vehicle longitudinal accelerometer trace for test 404211-3 (accelerometer located on top surface of instrument panel).

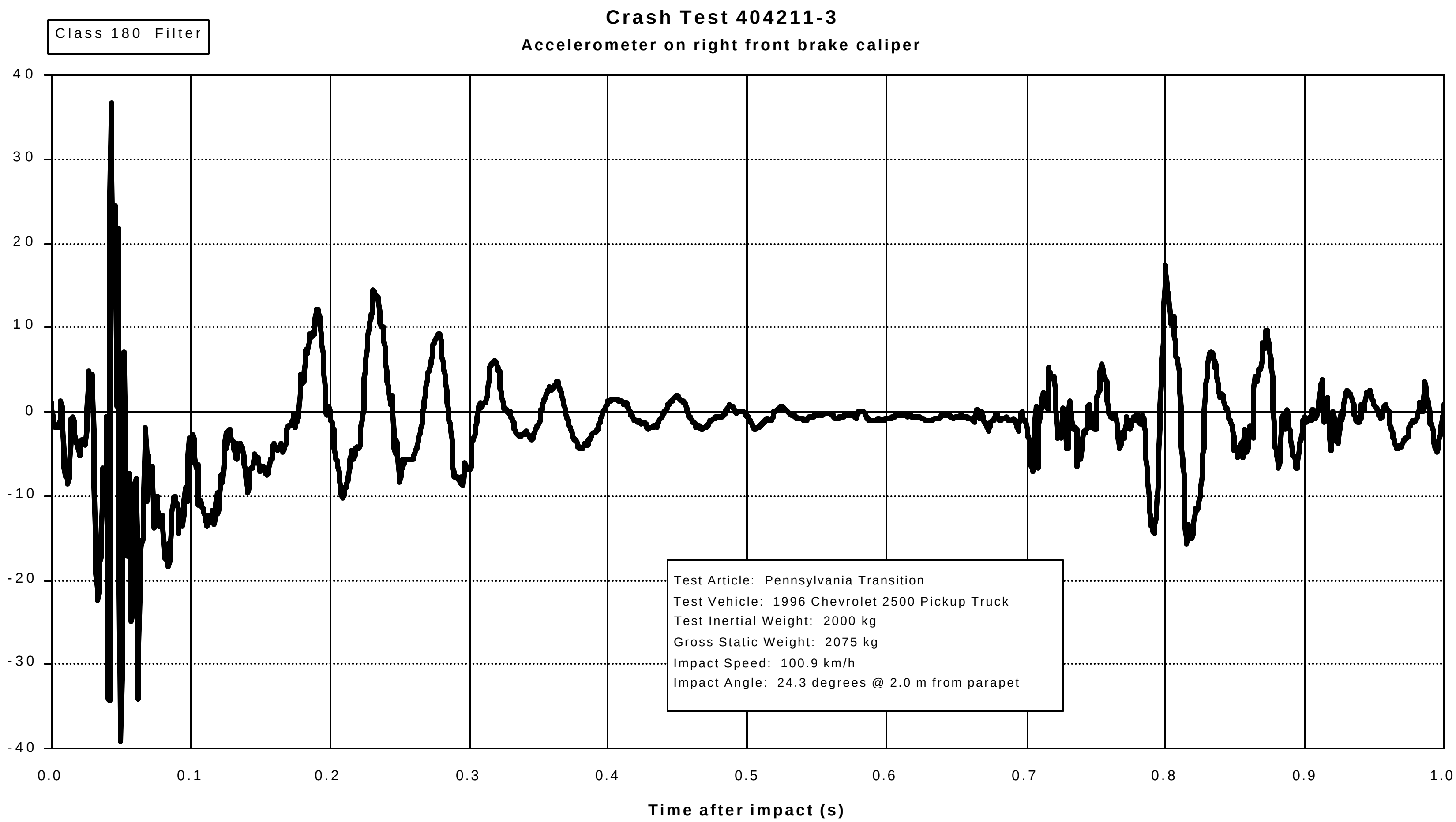


Figure 68. Vehicle lateral accelerometer trace for test 404211-3
(accelerometer located on right front brake caliper).

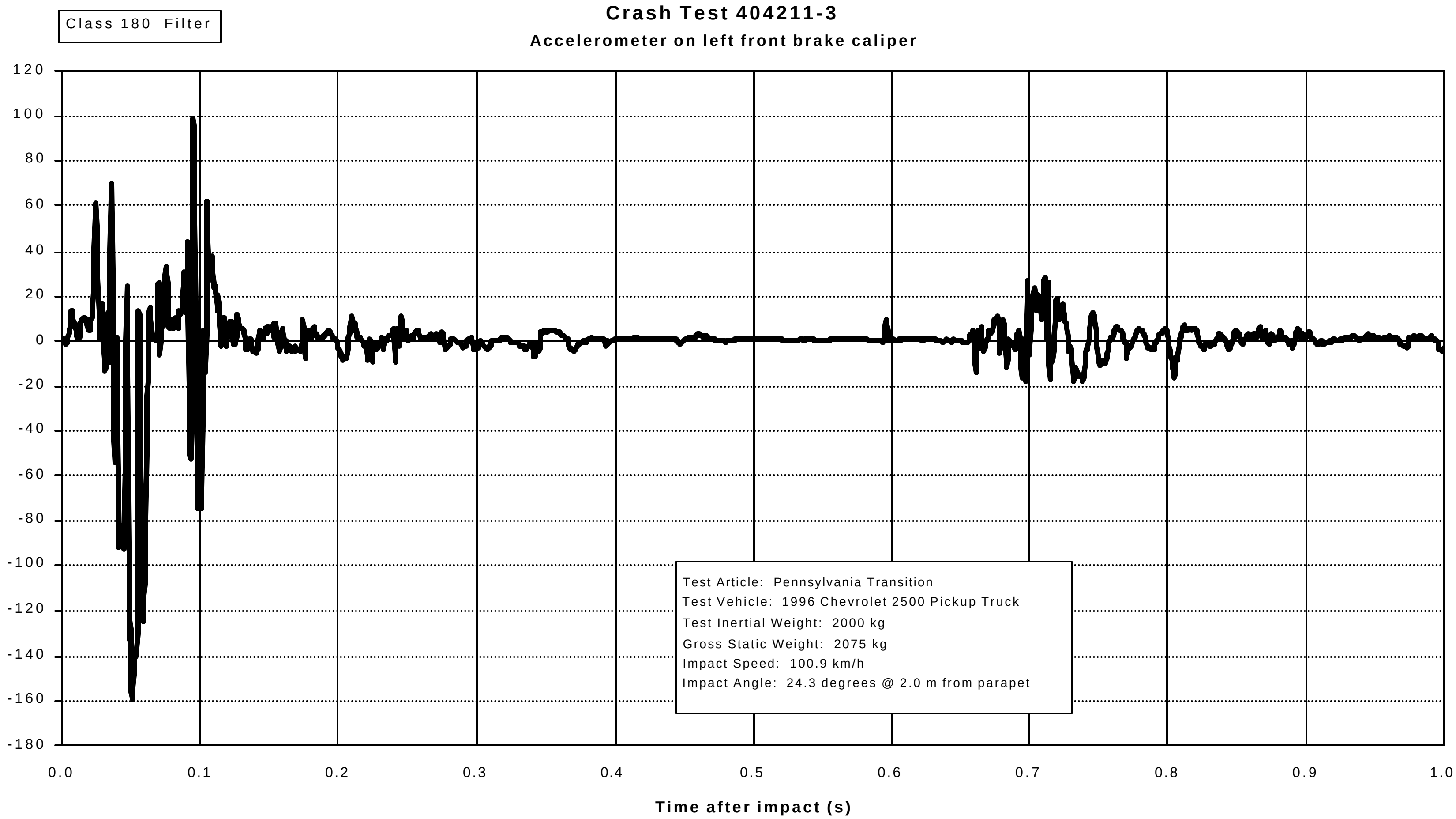


Figure 69. Vehicle longitudinal accelerometer trace for test 404211-3 (accelerometer located on left front brake caliper).

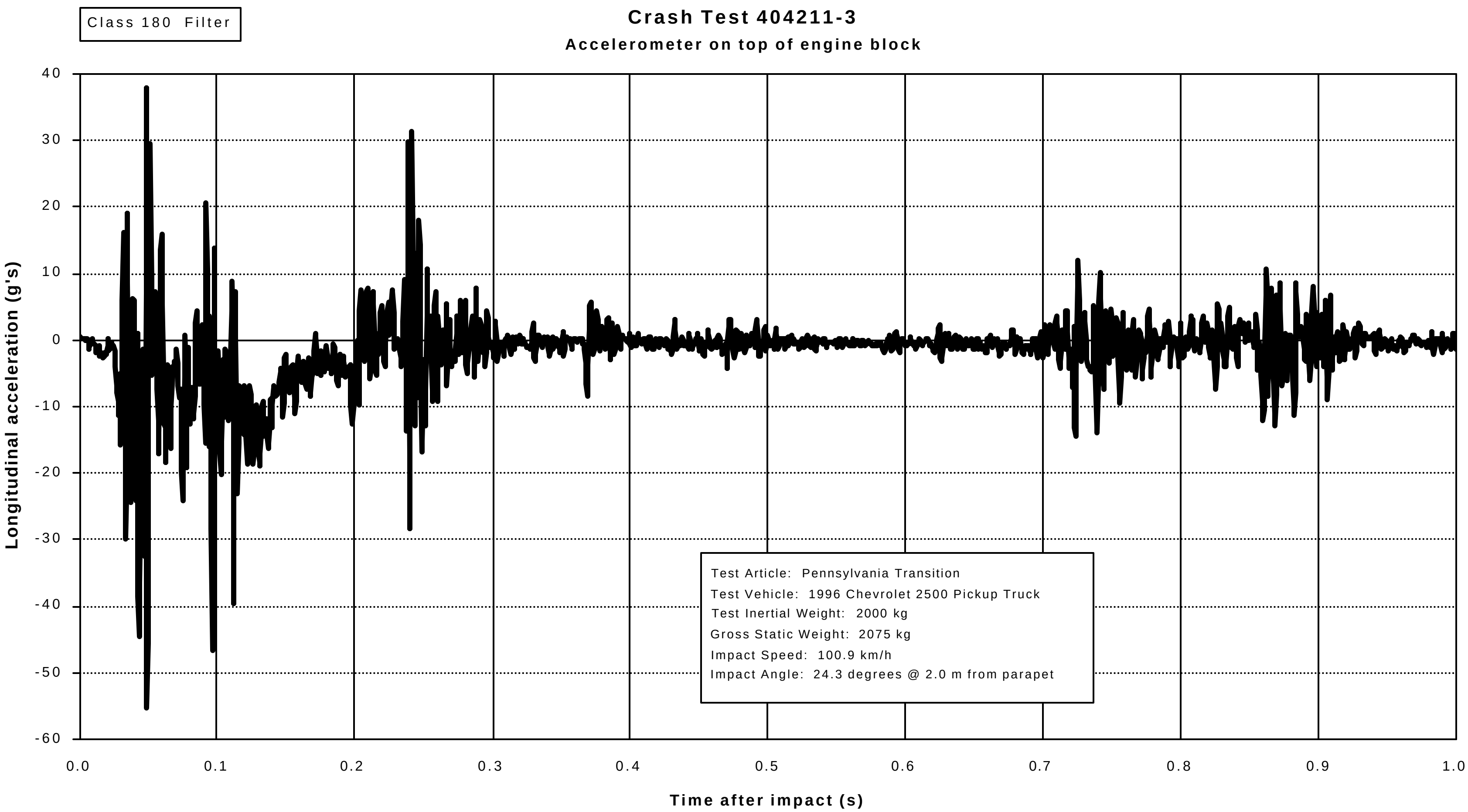


Figure 70. Vehicle longitudinal accelerometer trace for test 404211-3 (accelerometer located on top of engine block).

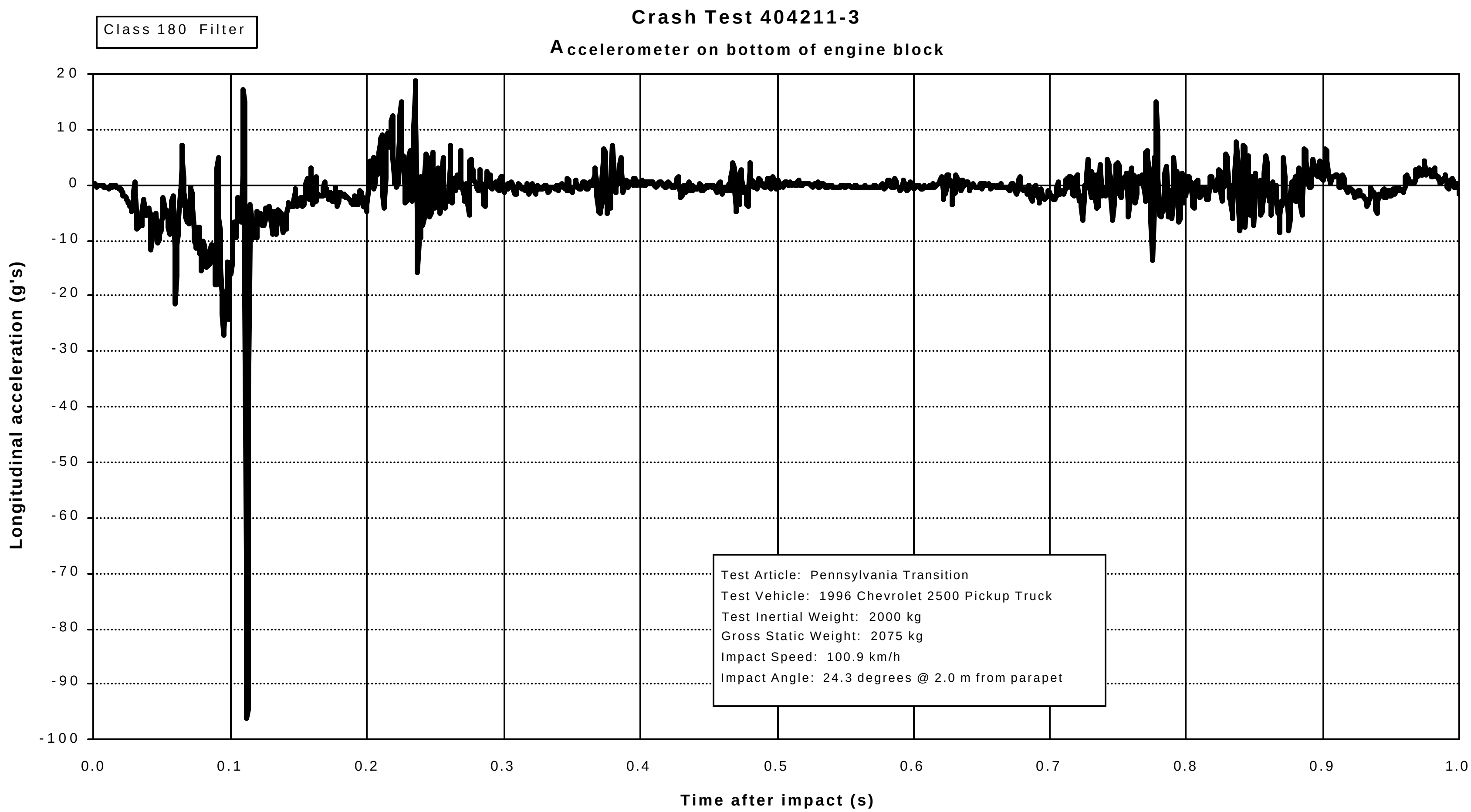


Figure 71. Vehicle longitudinal accelerometer trace for test 404211-3 (accelerometer located on bottom of engine block).

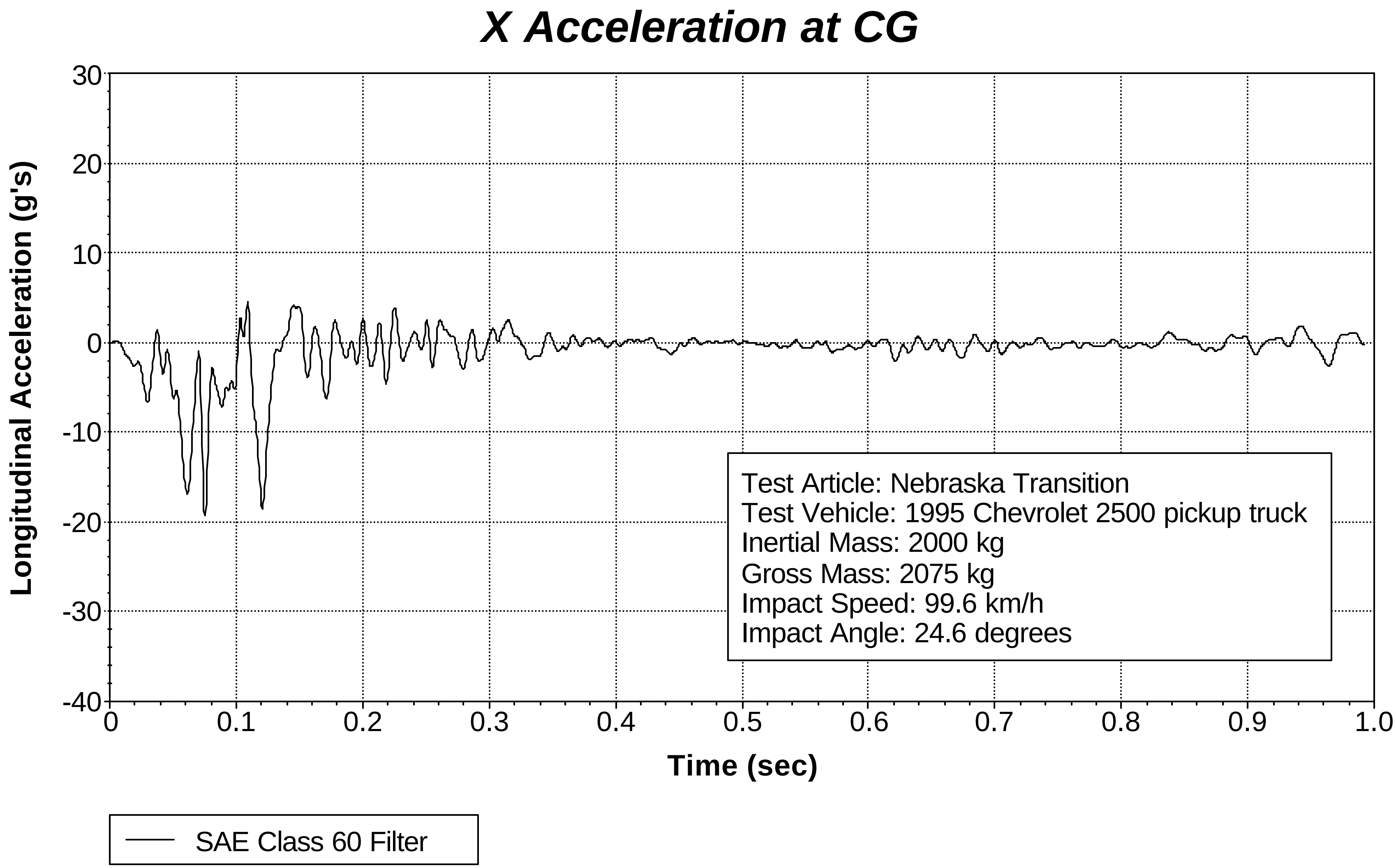


Figure 72. Vehicle longitudinal accelerometer trace for test 404211-7 (accelerometer located at center of gravity).

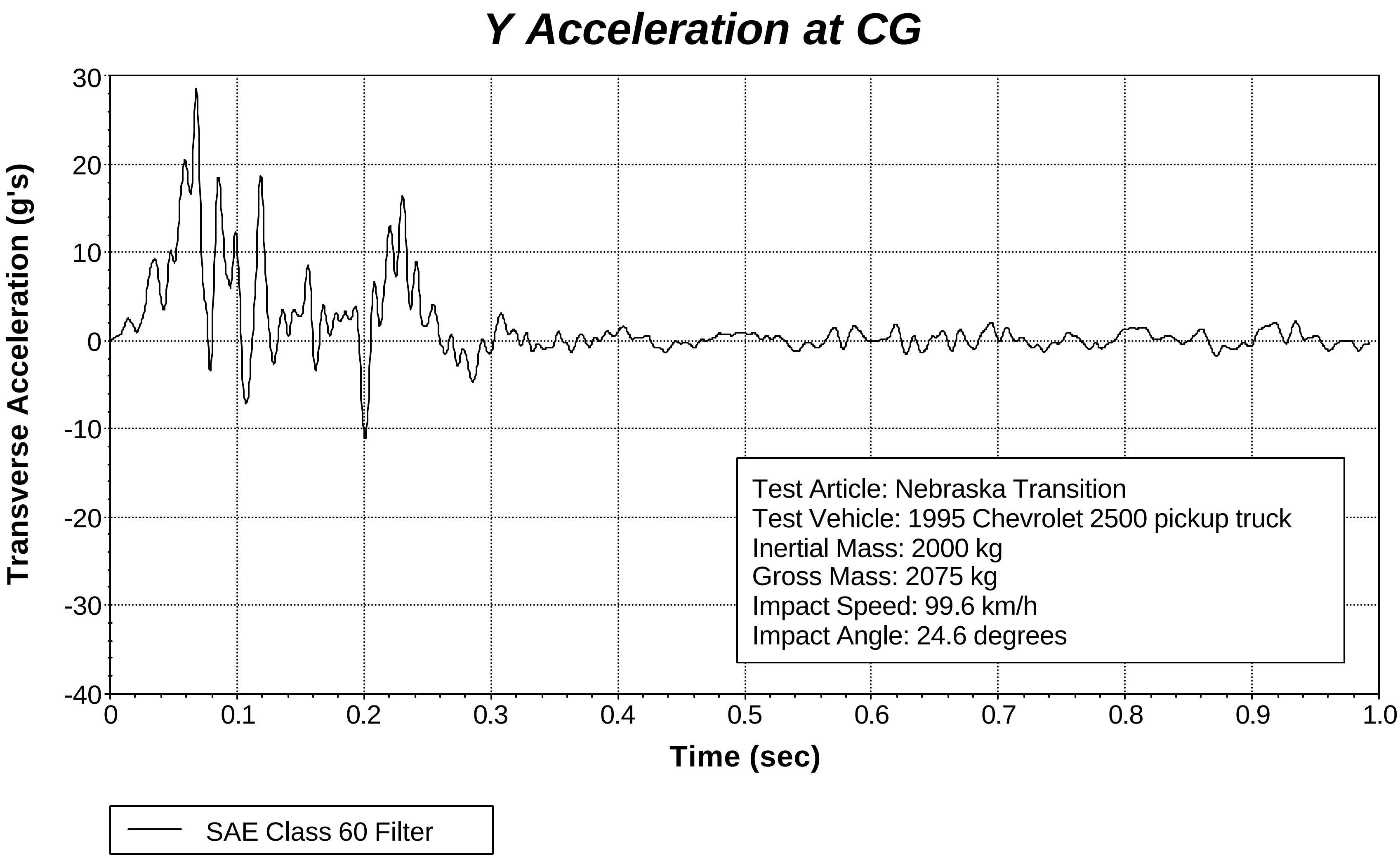


Figure 73. Vehicle lateral accelerometer trace for test 404211-7
(accelerometer located at center of gravity).

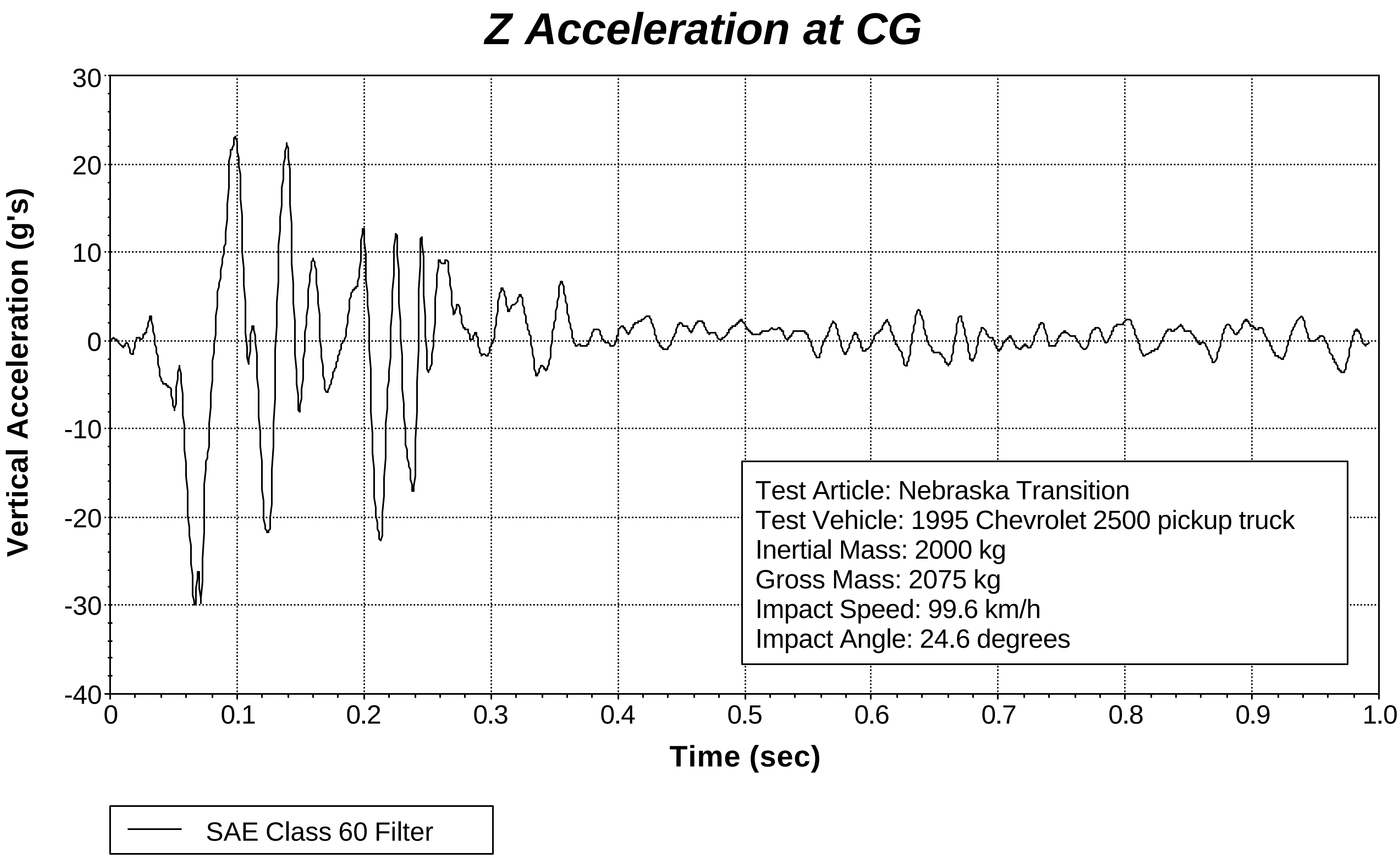


Figure 74. Vehicle vertical accelerometer trace for test 404211-7
(accelerometer located at center of gravity).

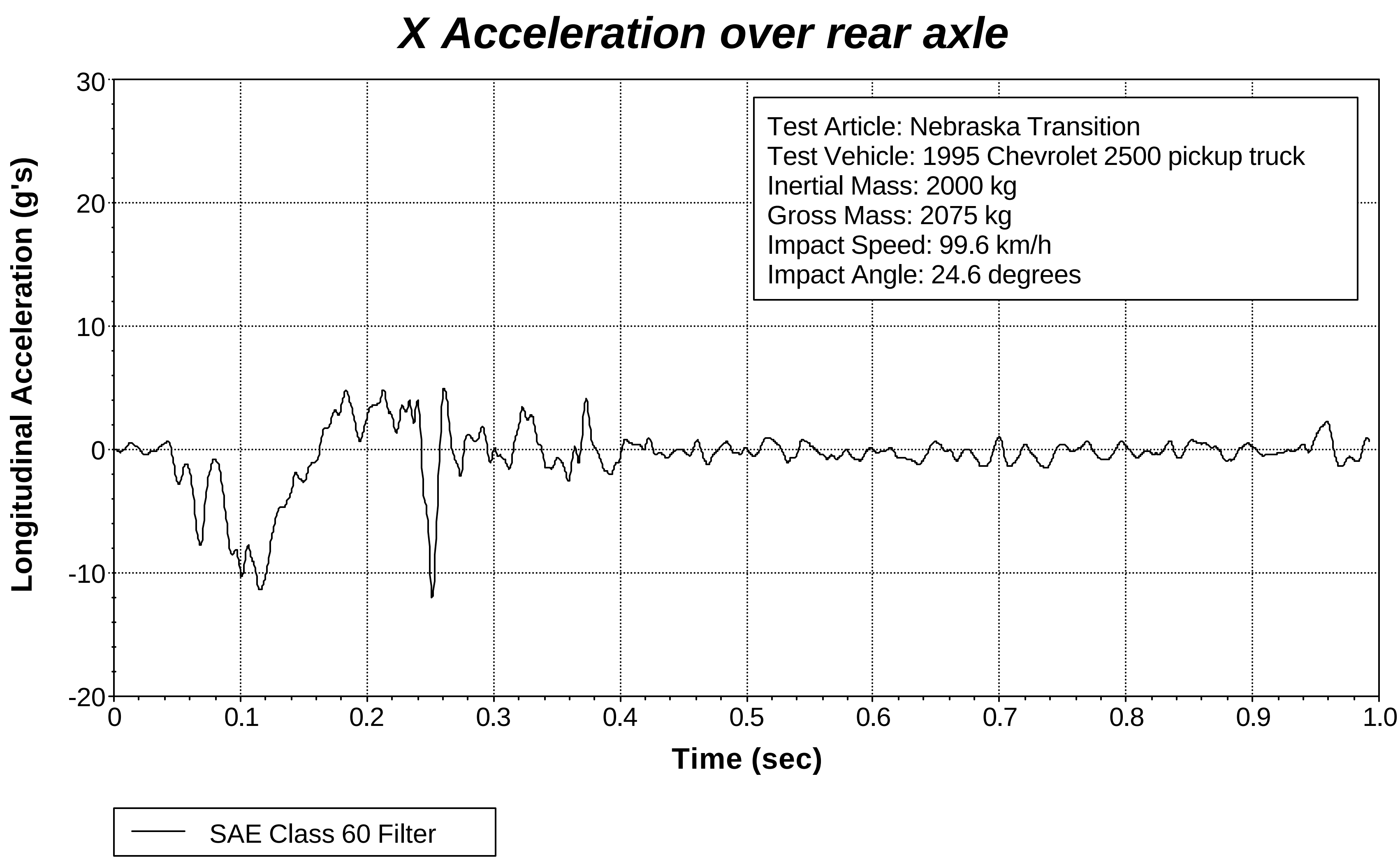


Figure 75. Vehicle longitudinal accelerometer trace for test 404211-7 (accelerometer located over rear axle).

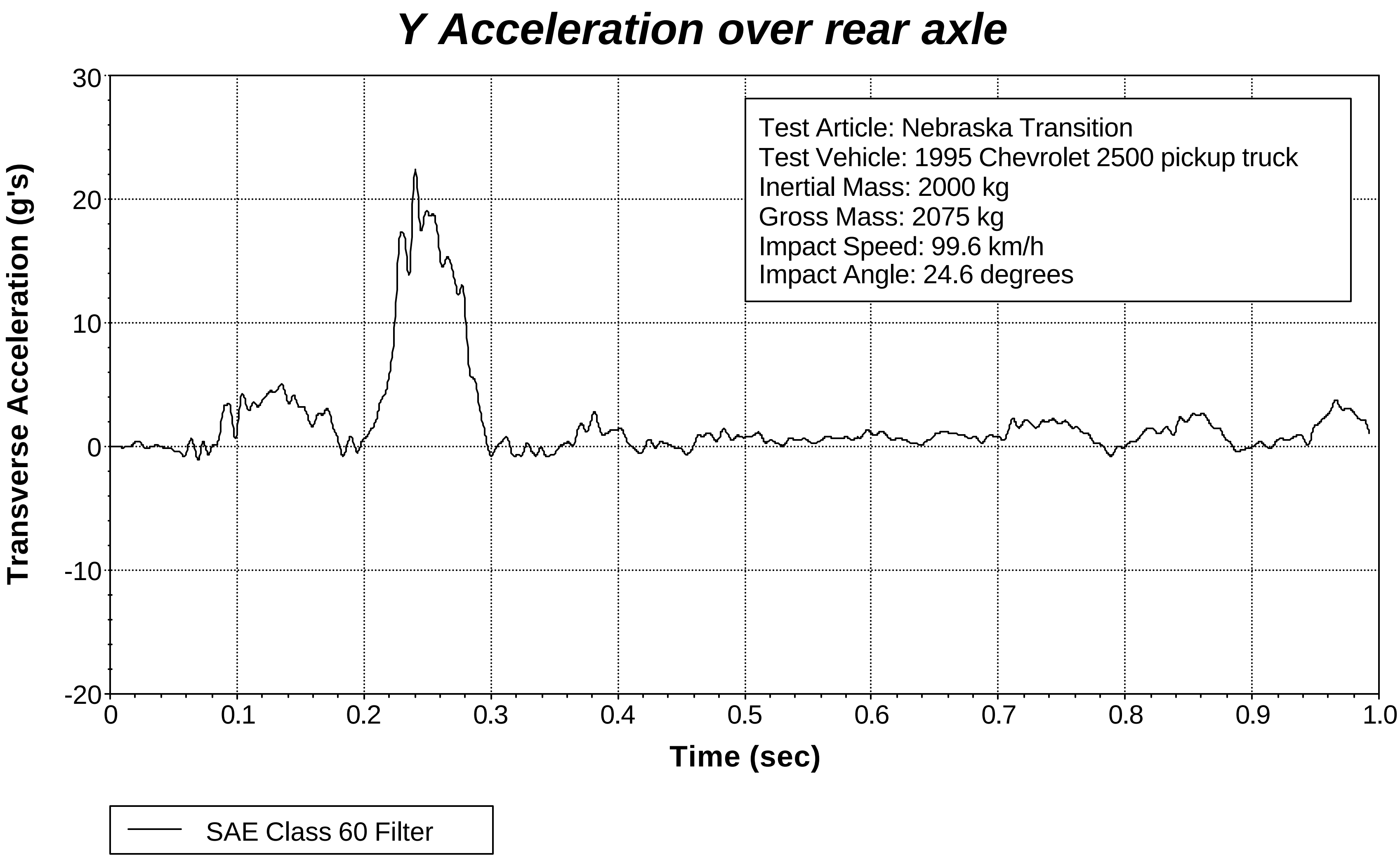


Figure 76. Vehicle lateral accelerometer trace for test 404211-7
(accelerometer located over rear axle).

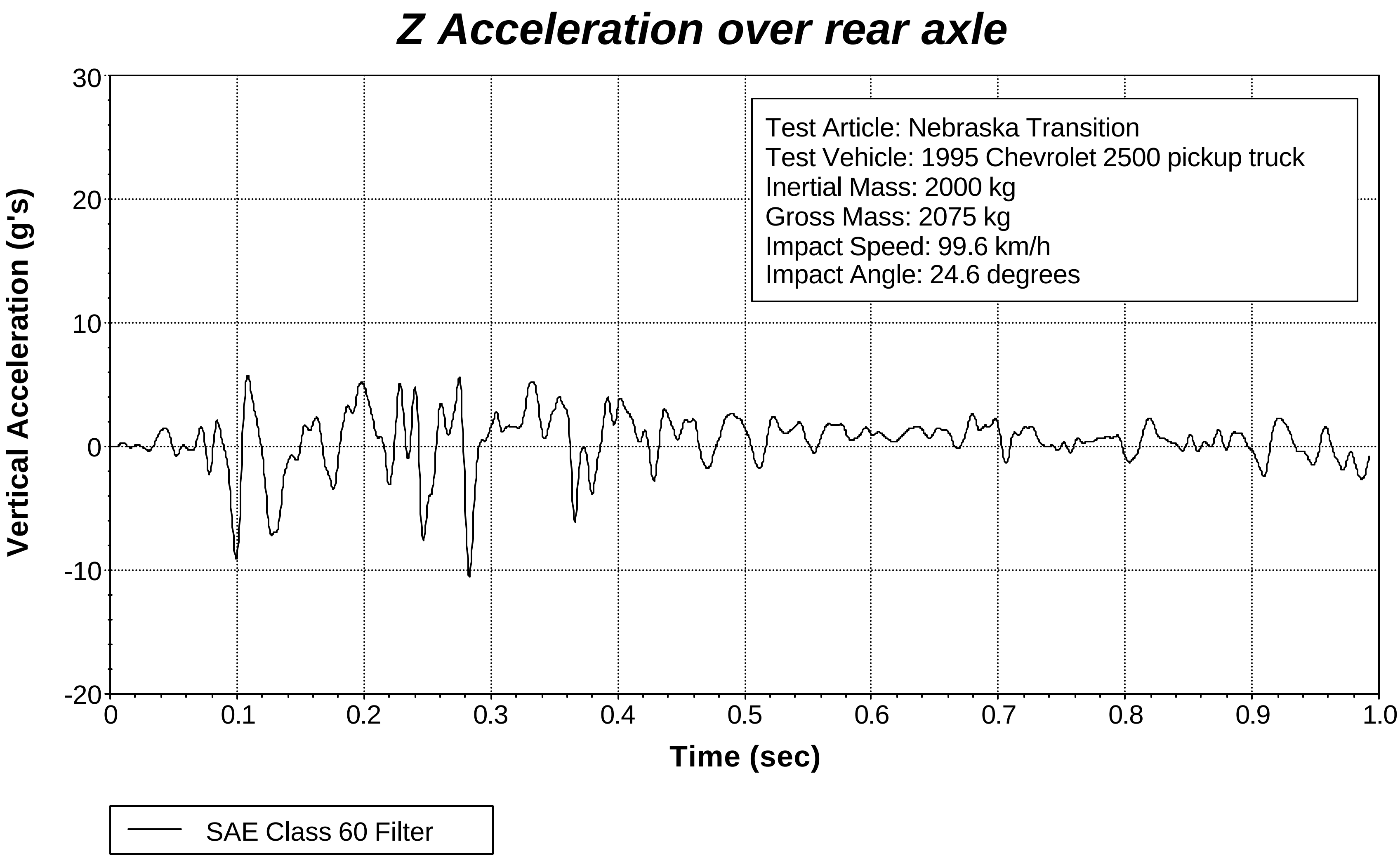


Figure 77. Vehicle vertical accelerometer trace for test 404211-7 (accelerometer located over rear axle).

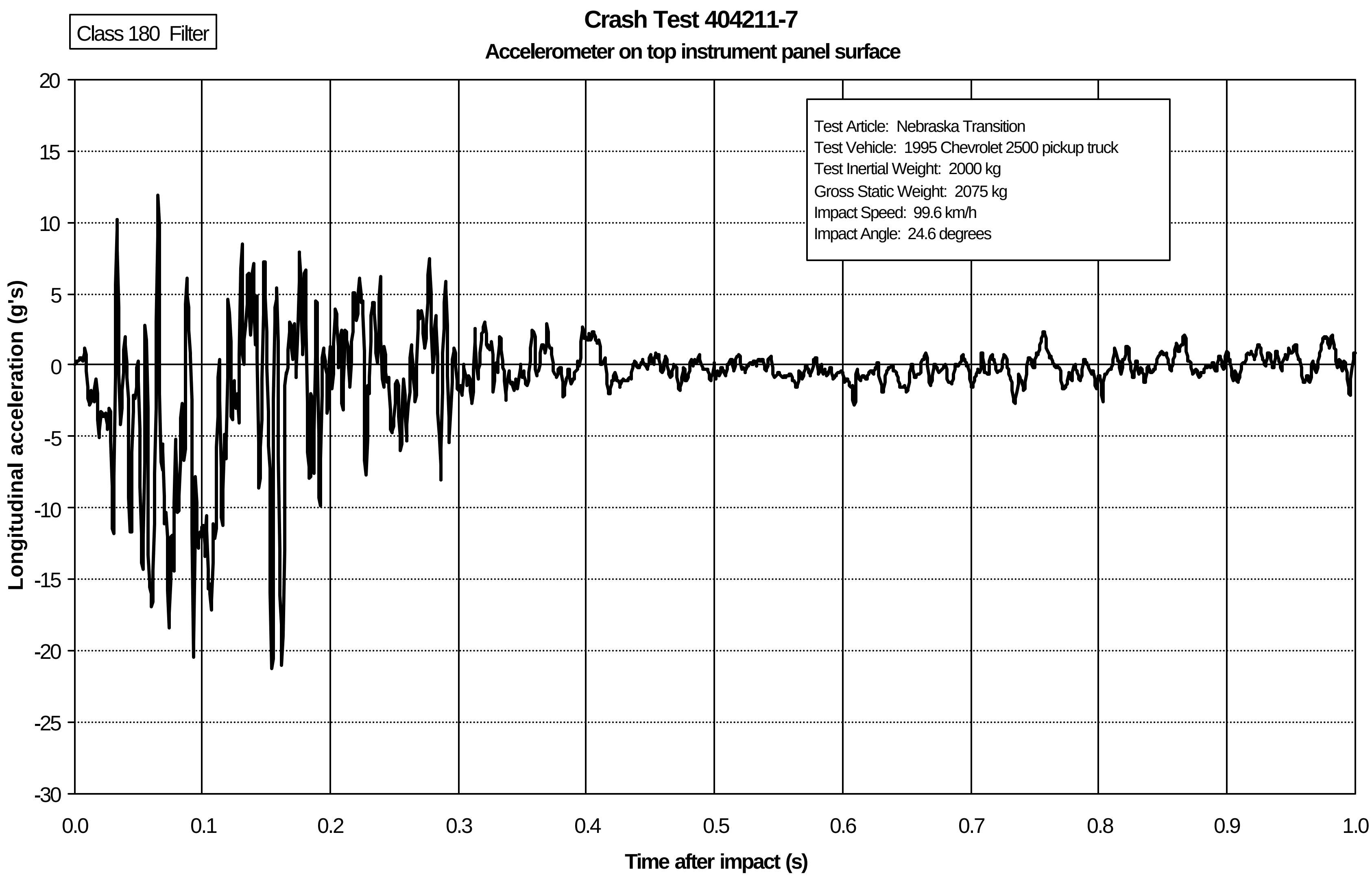


Figure 78. Vehicle longitudinal accelerometer trace for test 404211-7 (accelerometer located on top surface of instrument panel).

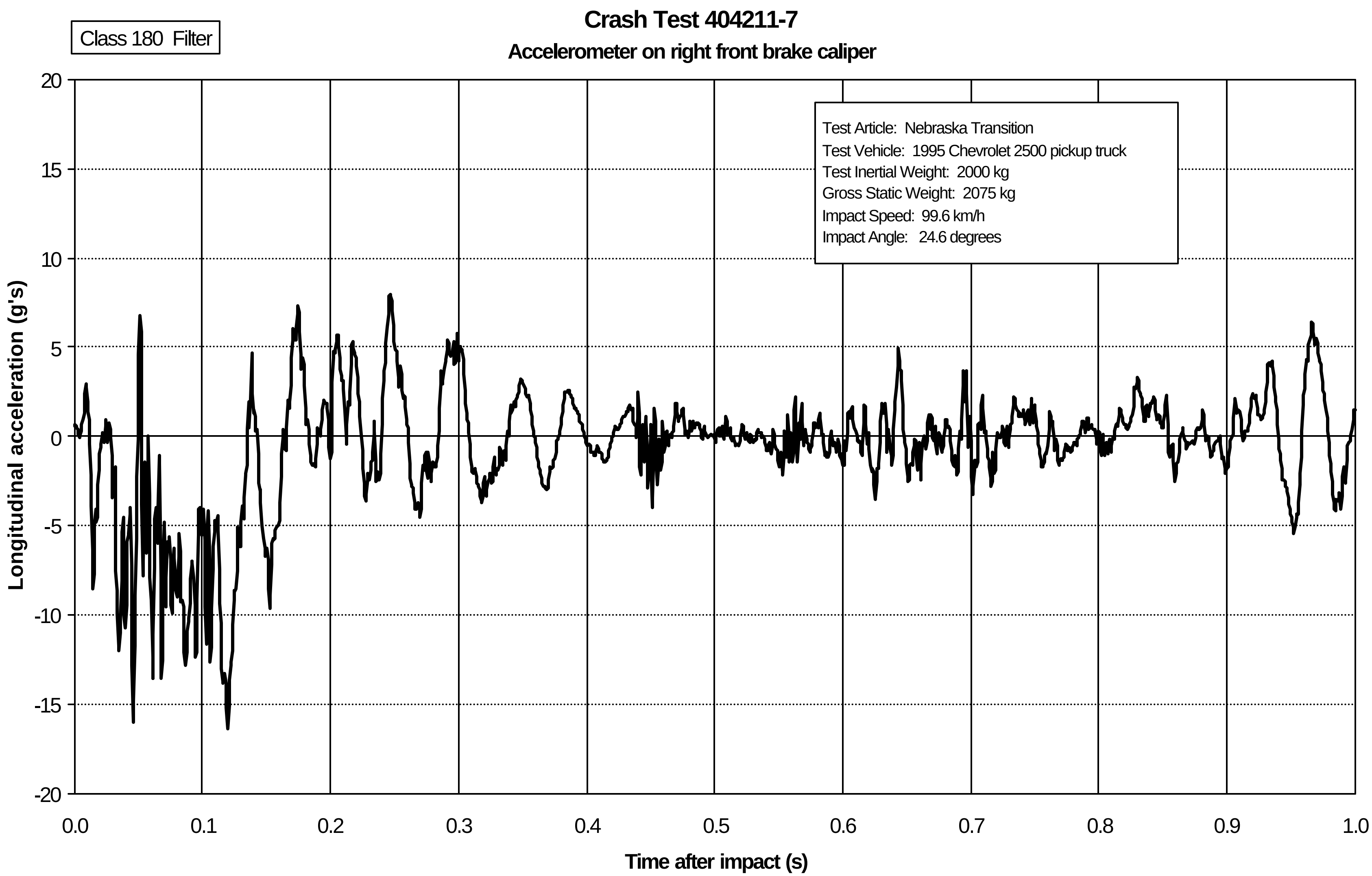


Figure 79. Vehicle lateral accelerometer trace for test 404211-7 (accelerometer located on right front brake caliper).

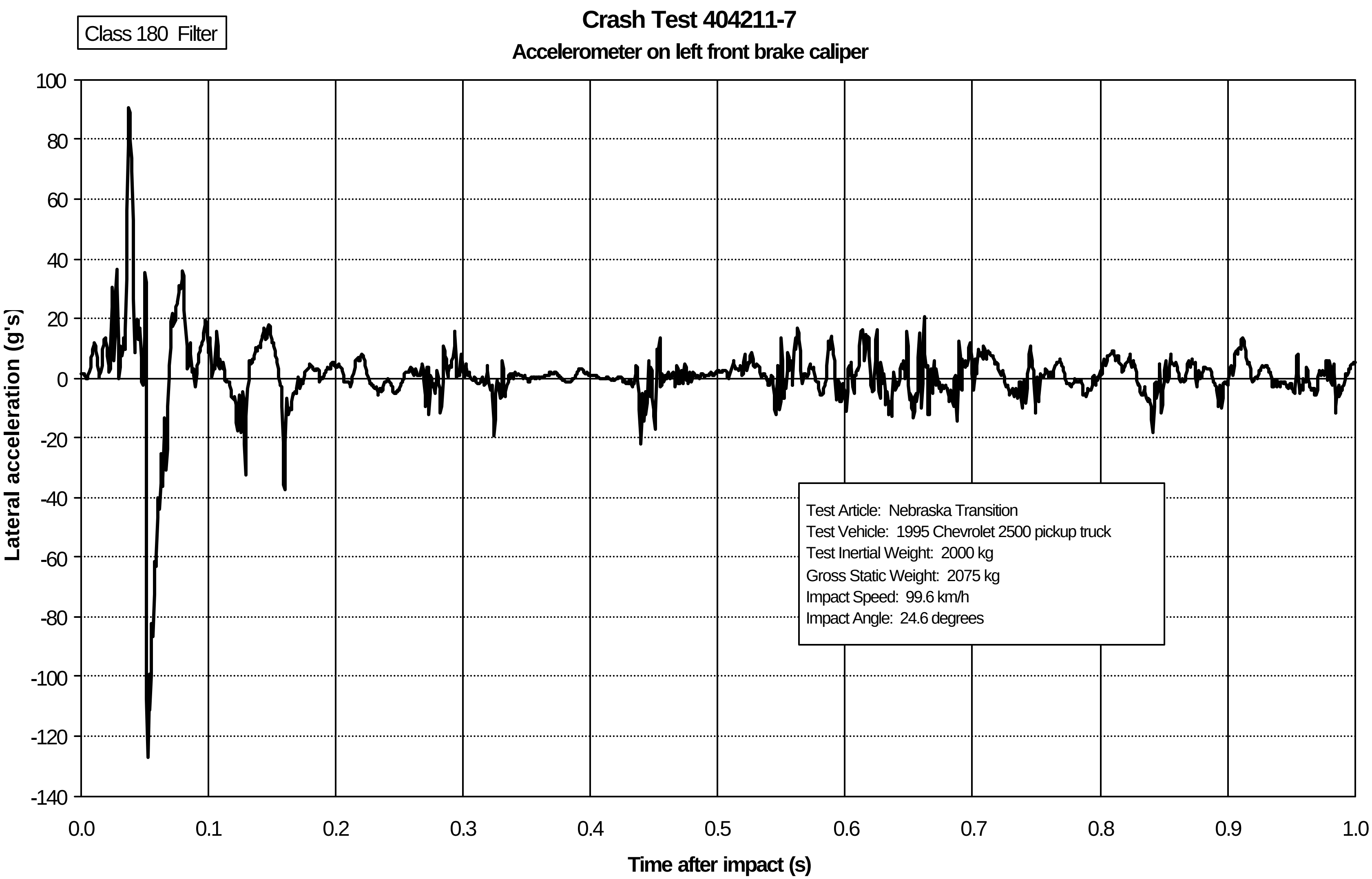


Figure 80. Vehicle longitudinal accelerometer trace for test 404211-7 (accelerometer located on left front brake caliper).

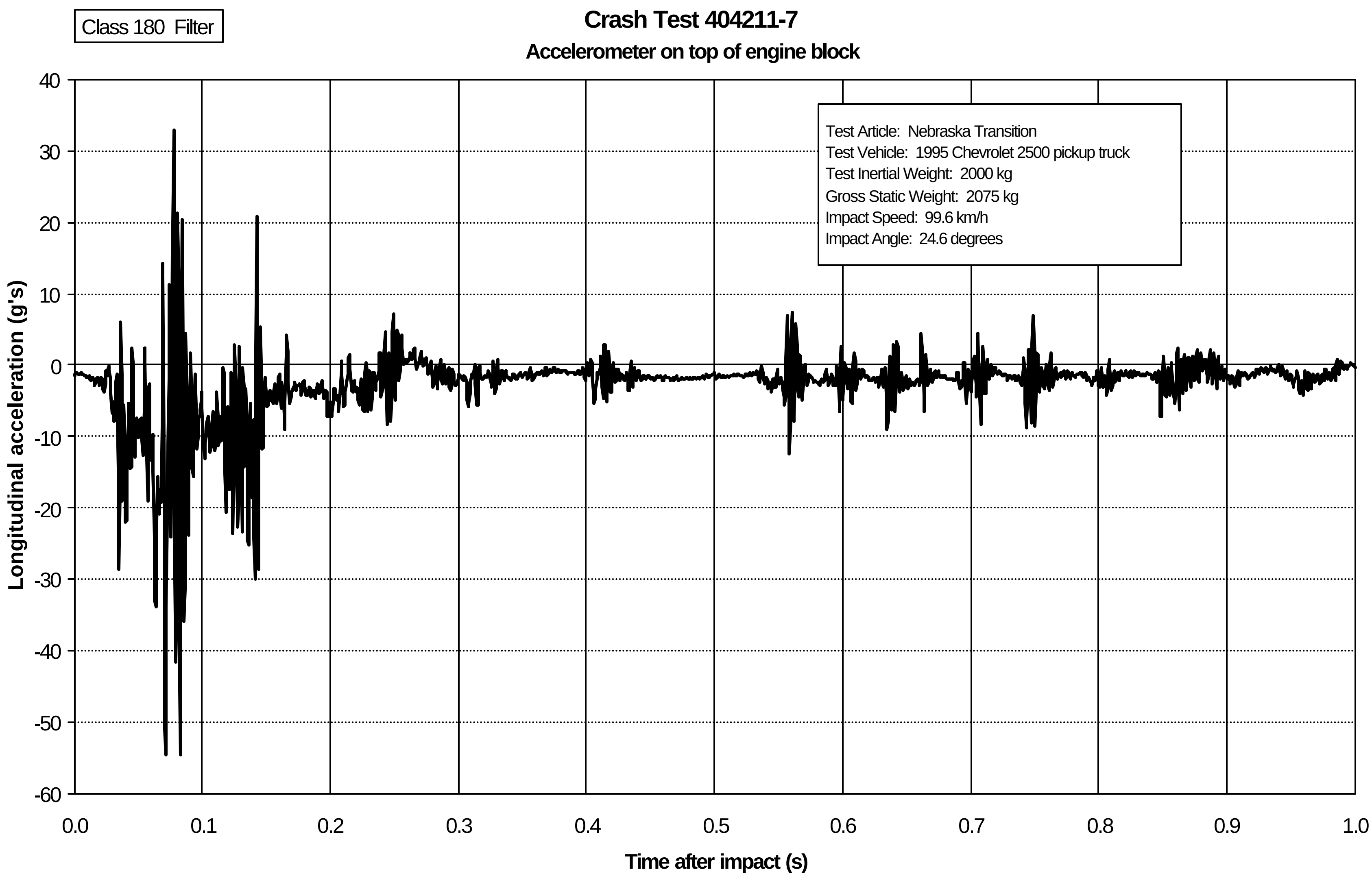


Figure 81. Vehicle longitudinal accelerometer trace for test 404211-7
(accelerometer located on top of engine block).

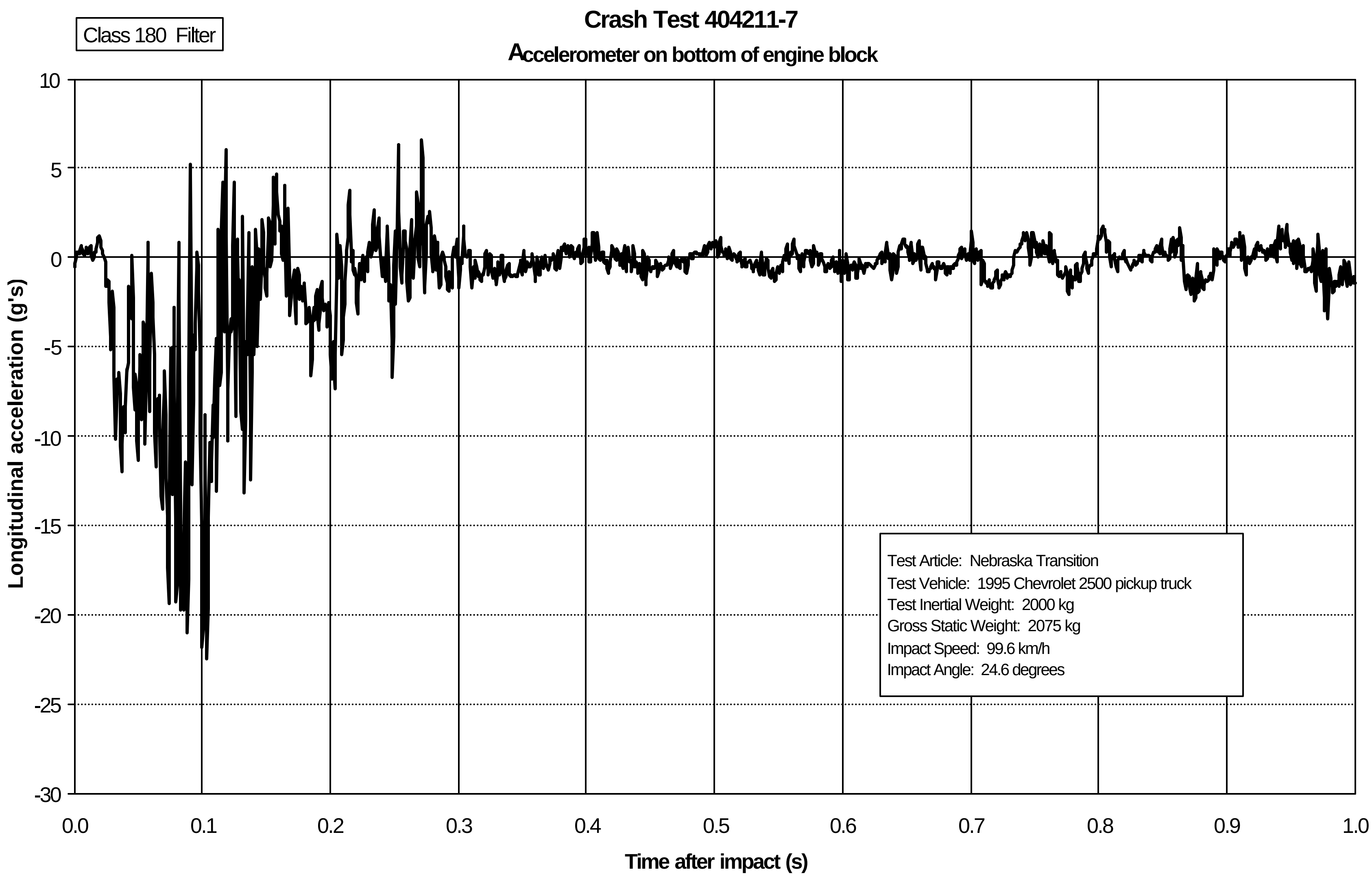


Figure 82. Vehicle longitudinal accelerometer trace for test 404211-7 (accelerometer located on bottom of engine block).

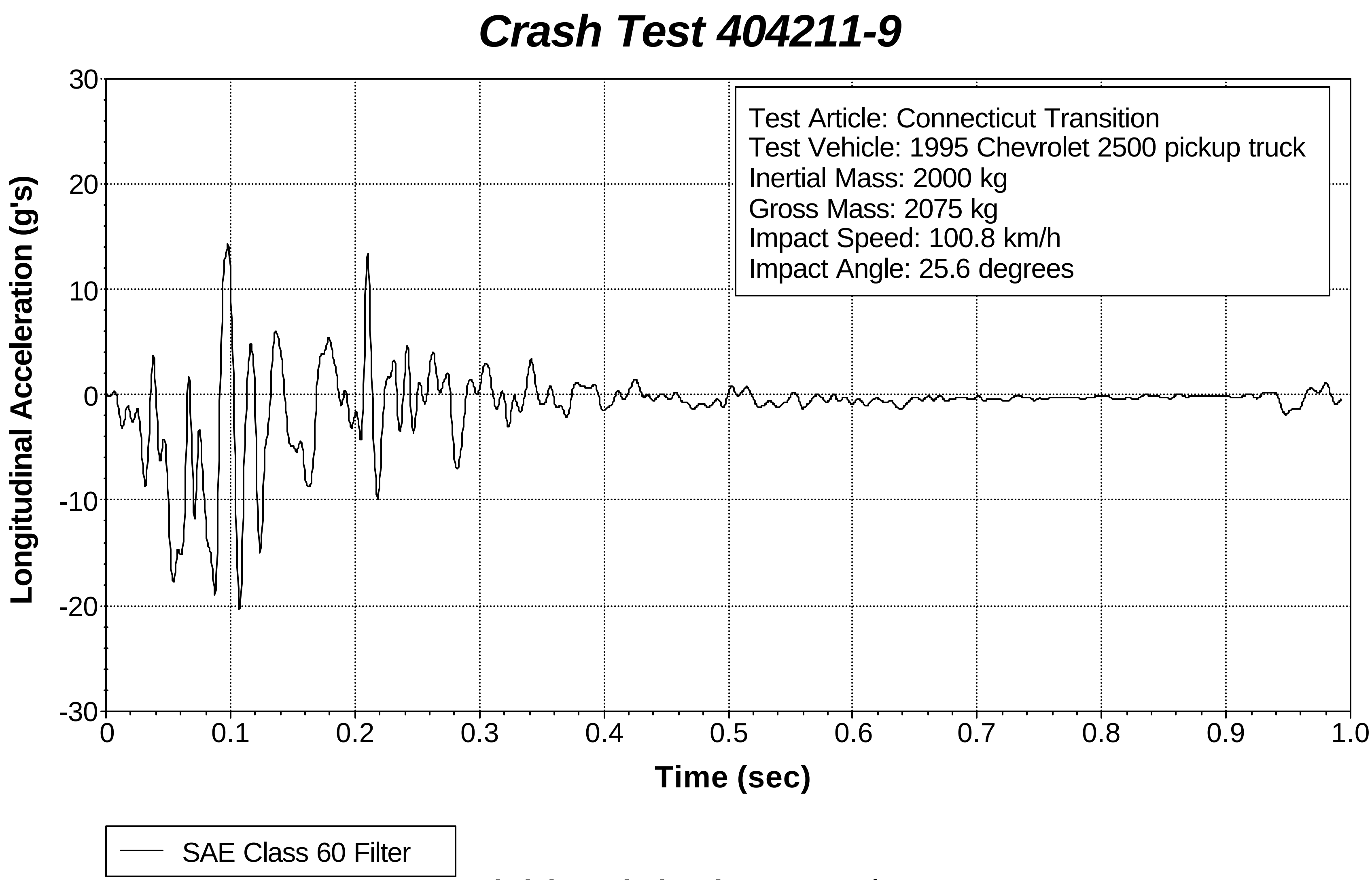


Figure 83. Vehicle longitudinal accelerometer trace for test 404211-9
(accelerometer located at center of gravity).

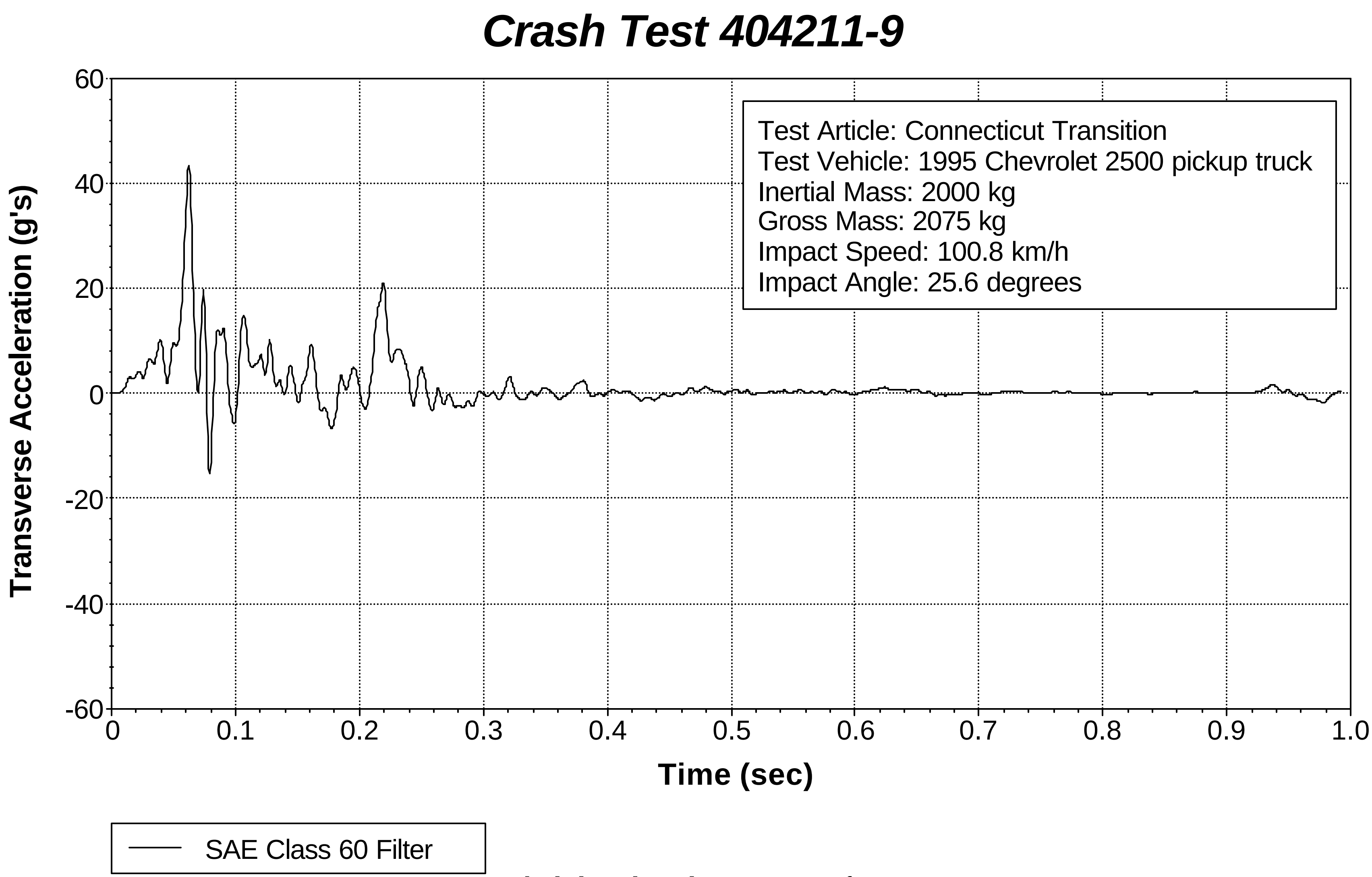


Figure 84. Vehicle lateral accelerometer trace for test 404211-9
(accelerometer located at center of gravity).

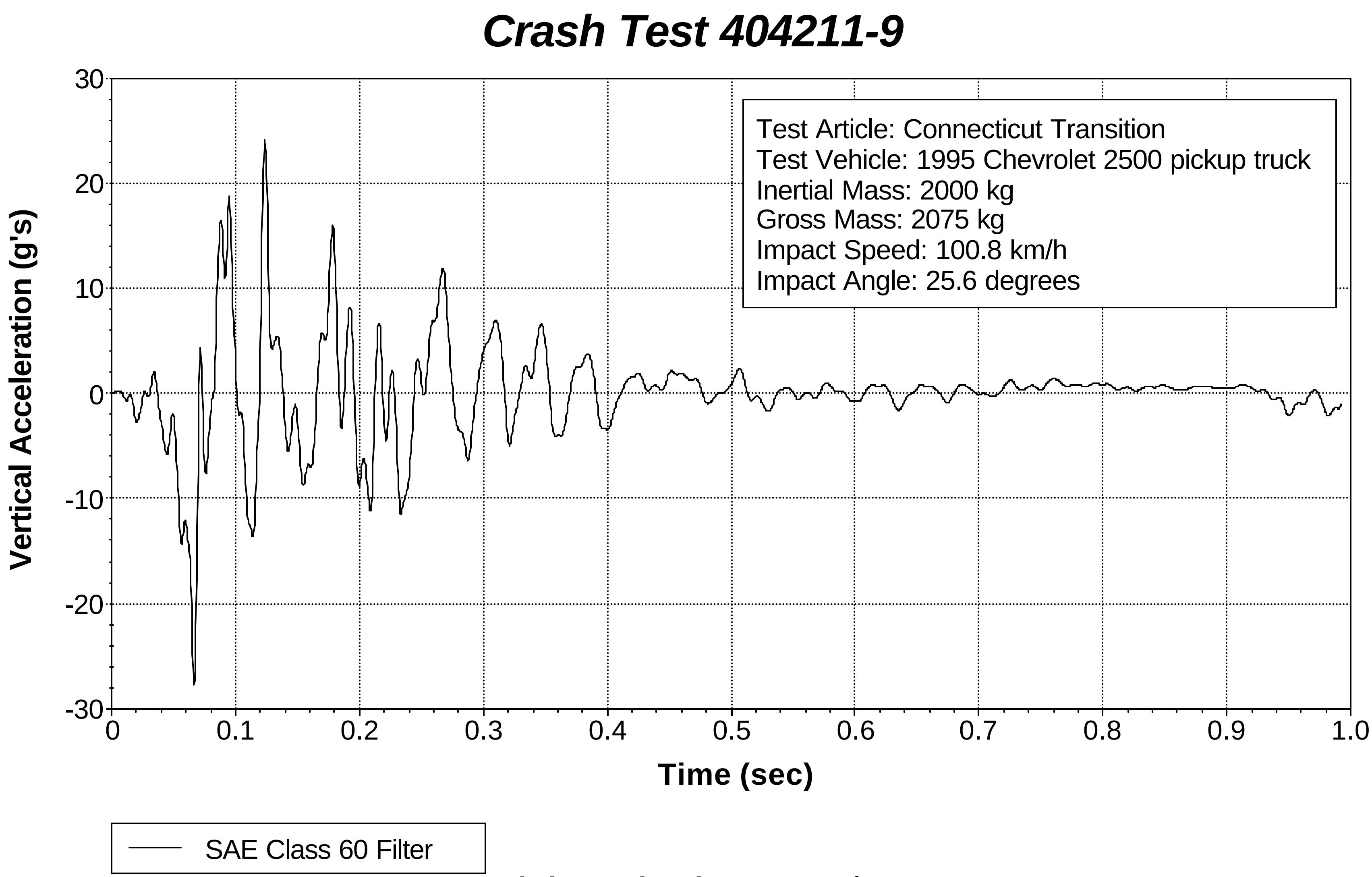


Figure 85. Vehicle vertical accelerometer trace for test 404211-9 (accelerometer located at center of gravity).

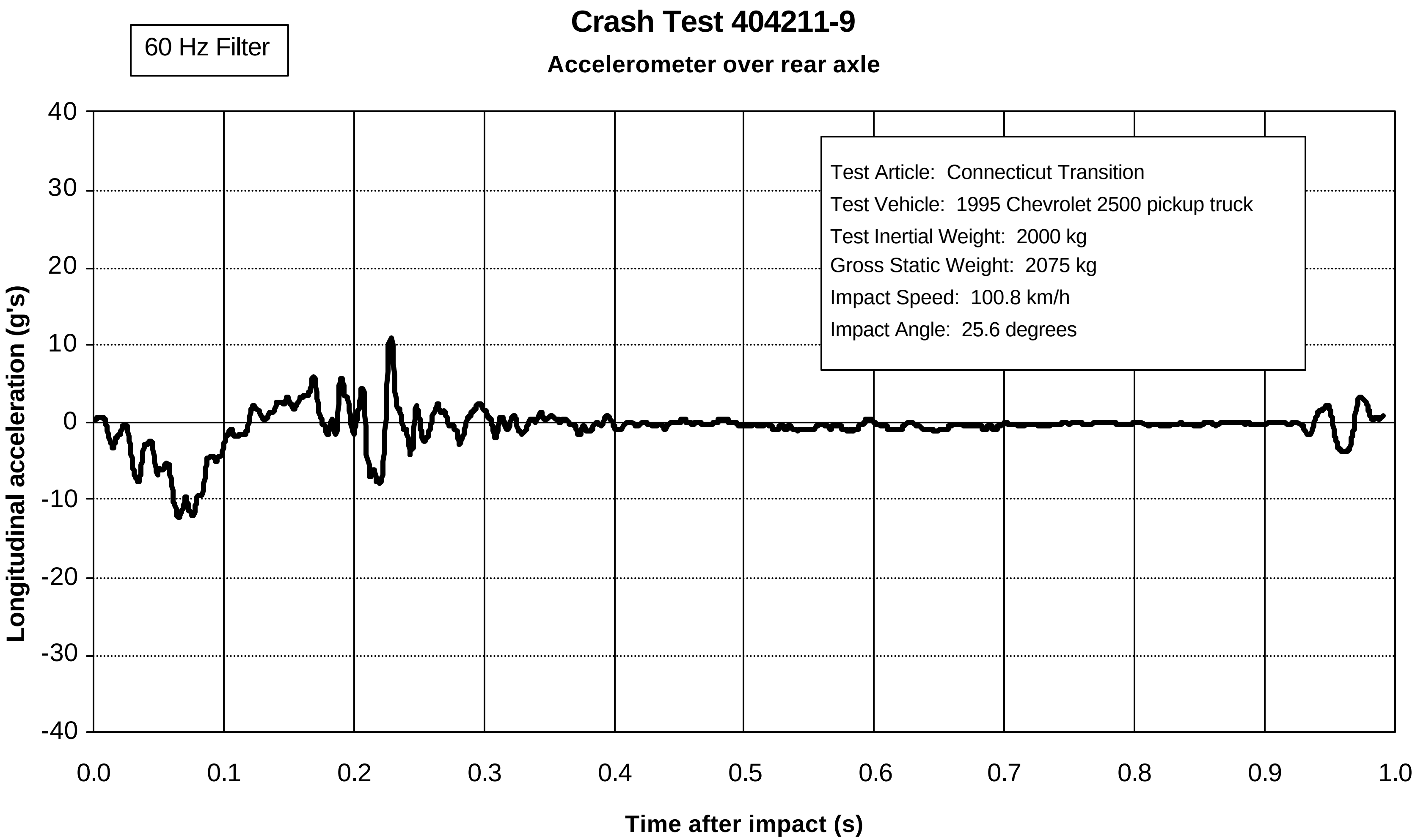


Figure 86. Vehicle longitudinal accelerometer trace for test 404211-9
(accelerometer located over rear axle).

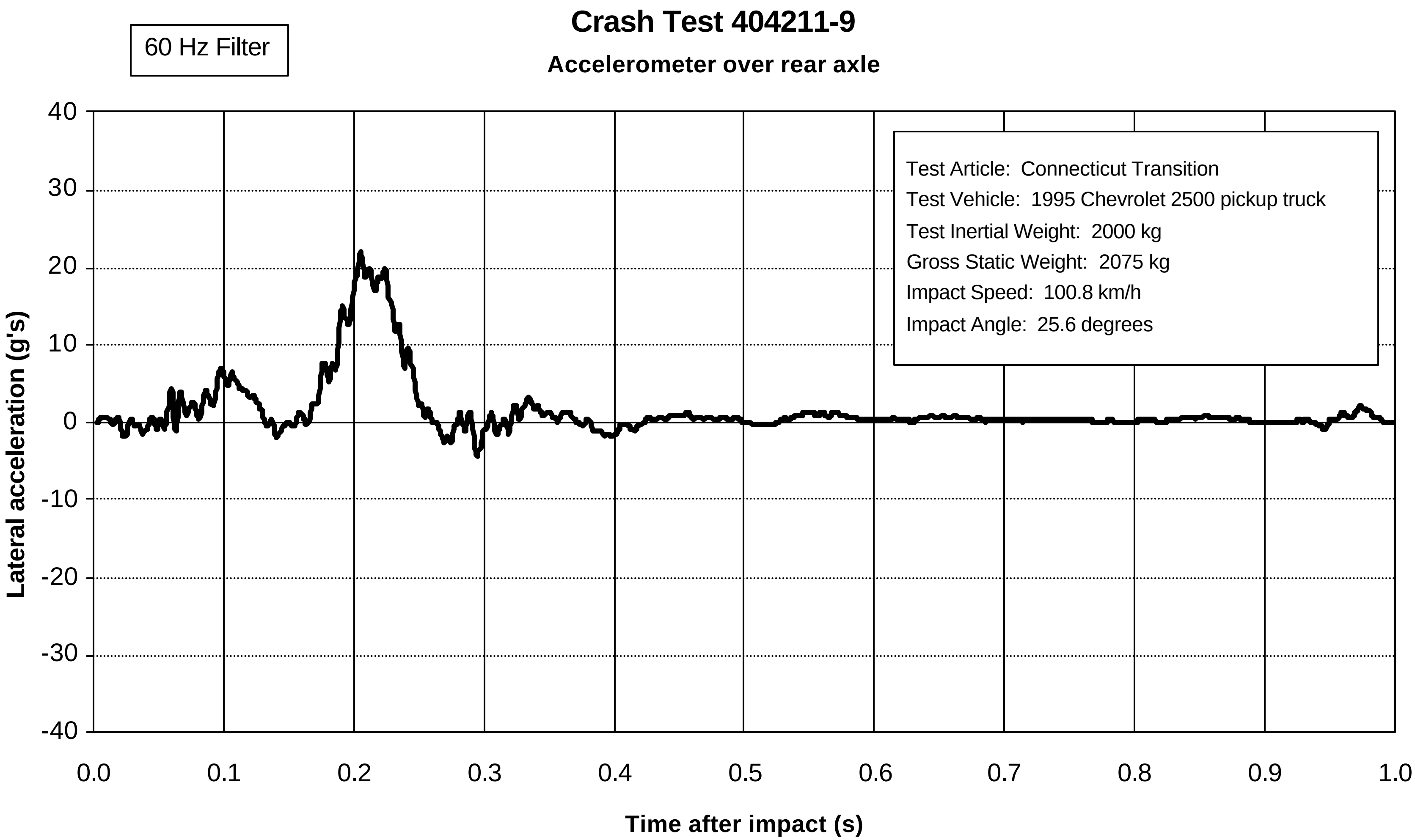


Figure 87. Vehicle lateral accelerometer trace for test 404211-9
(accelerometer located over rear axle).

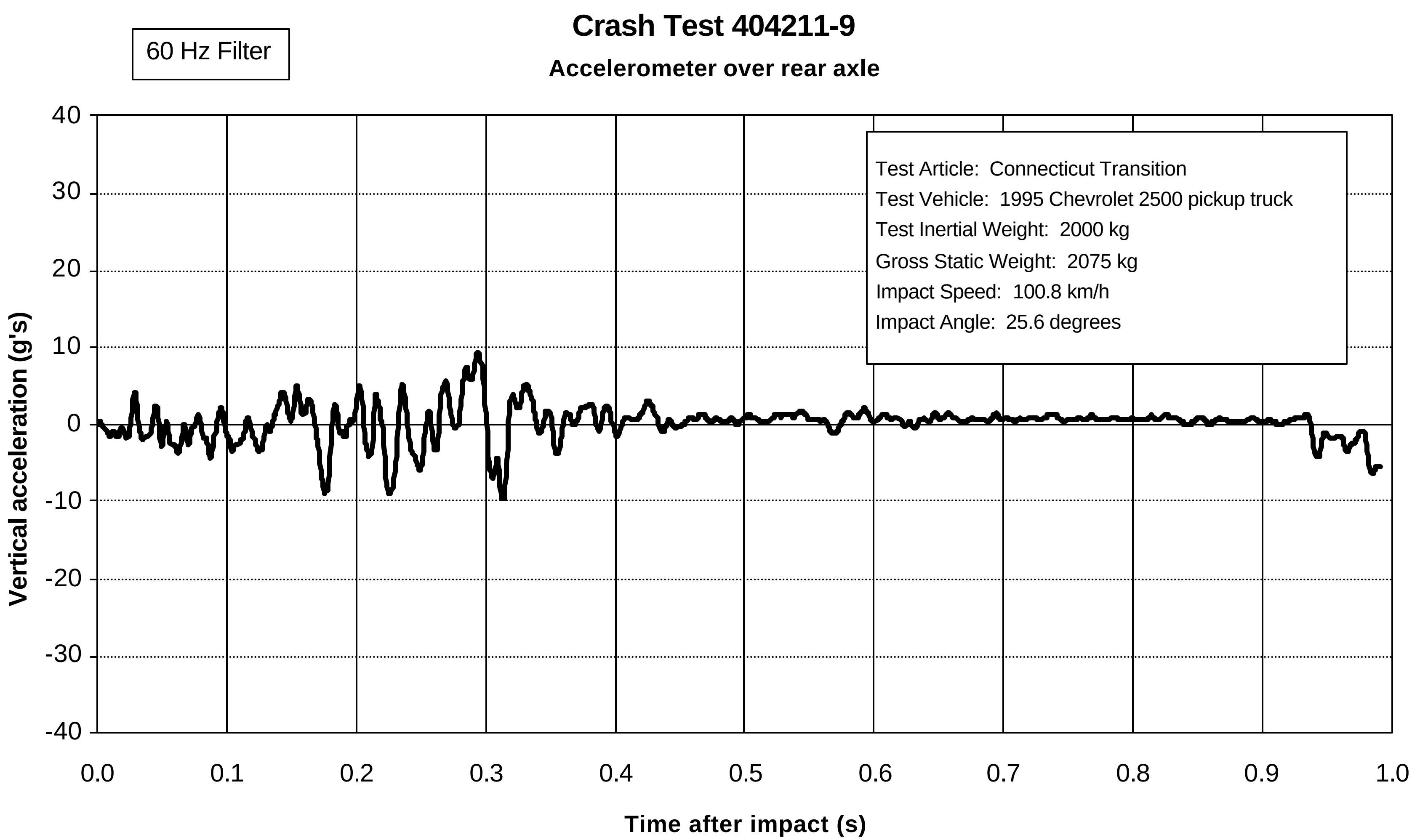


Figure 88. Vehicle vertical accelerometer trace for test 404211-9
(accelerometer located over rear axle).

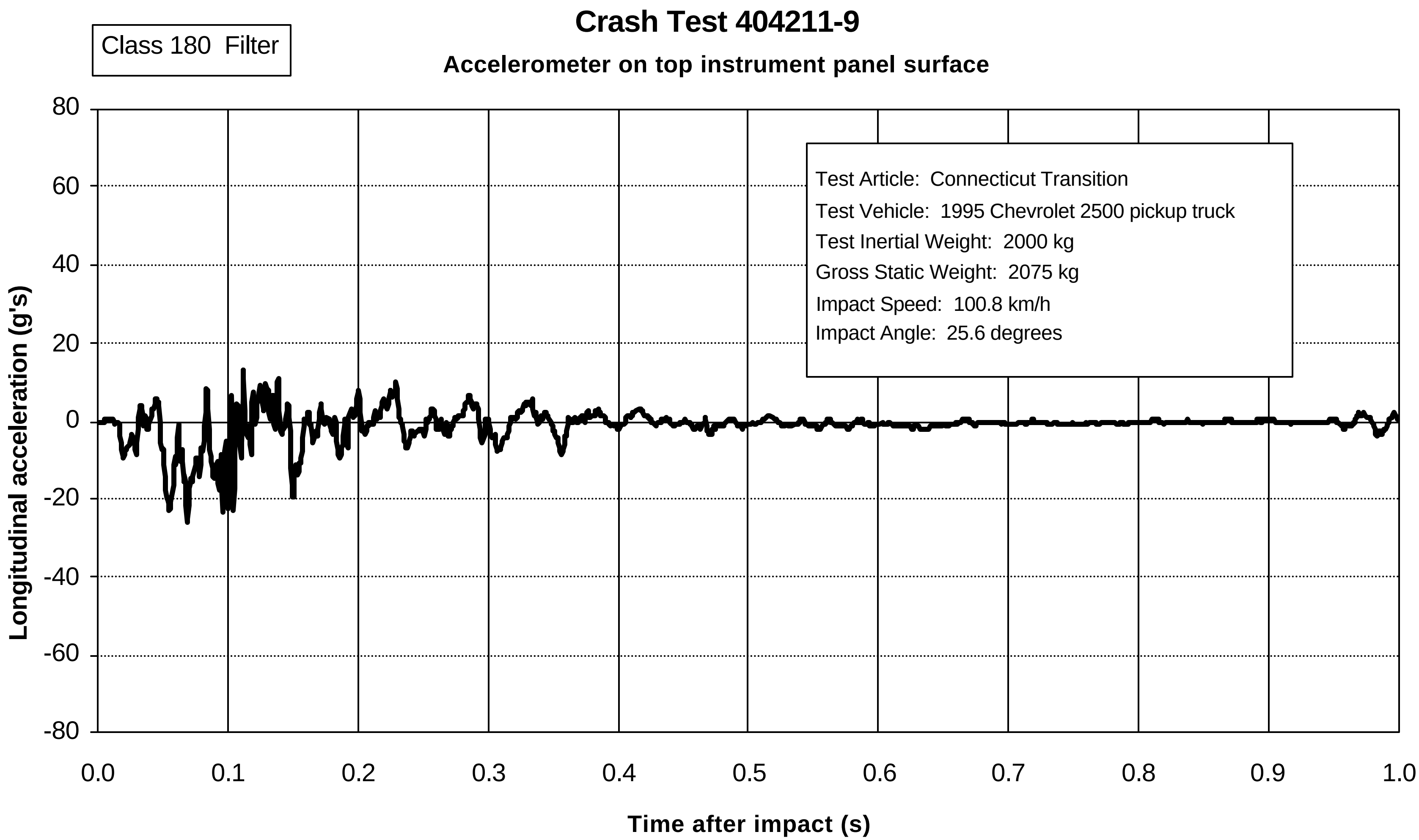


Figure 89. Vehicle longitudinal accelerometer trace for test 404211-9
(accelerometer located on top surface of instrument panel).

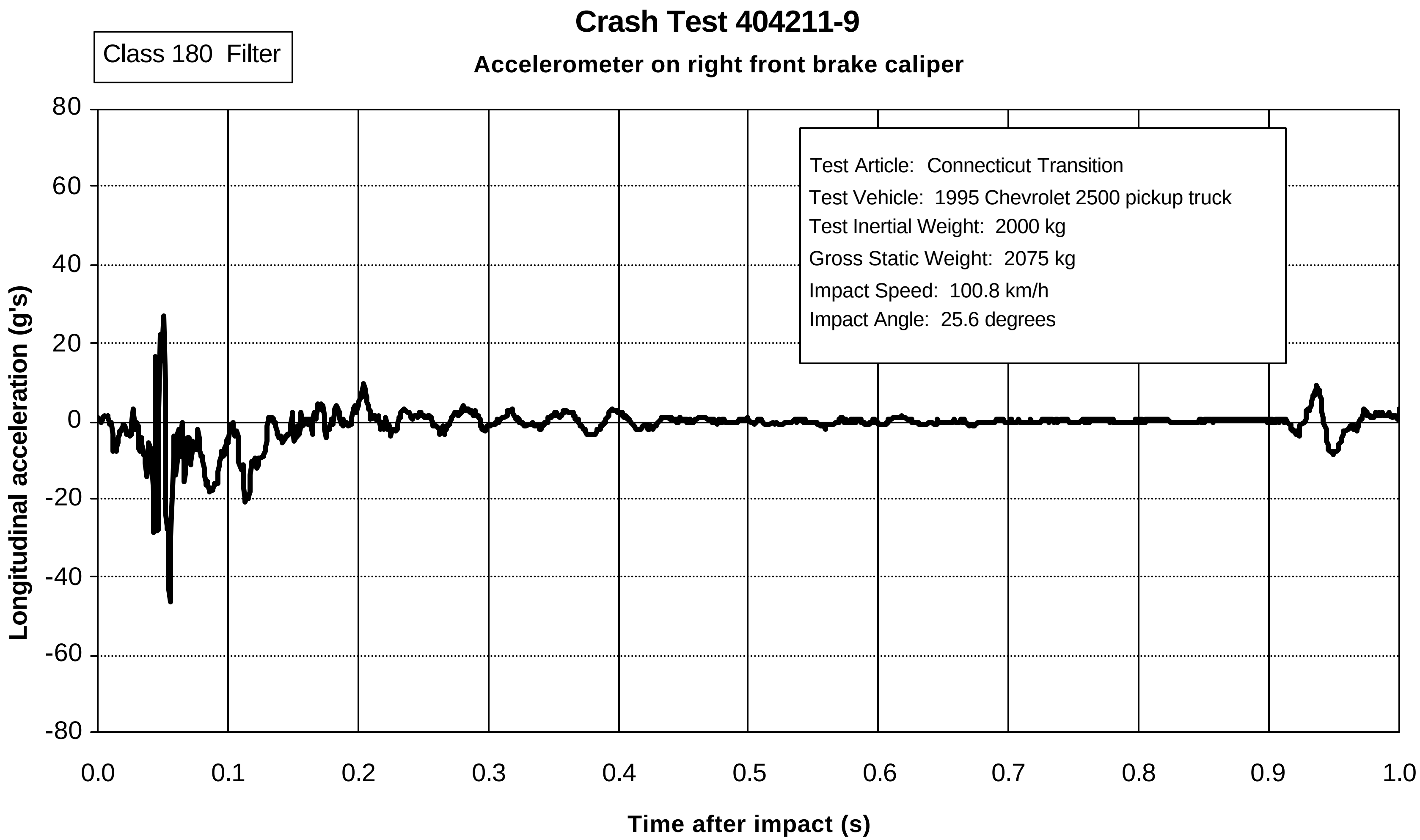


Figure 90. Vehicle longitudinal accelerometer trace for test 404211-9
(accelerometer located on right front brake caliper).

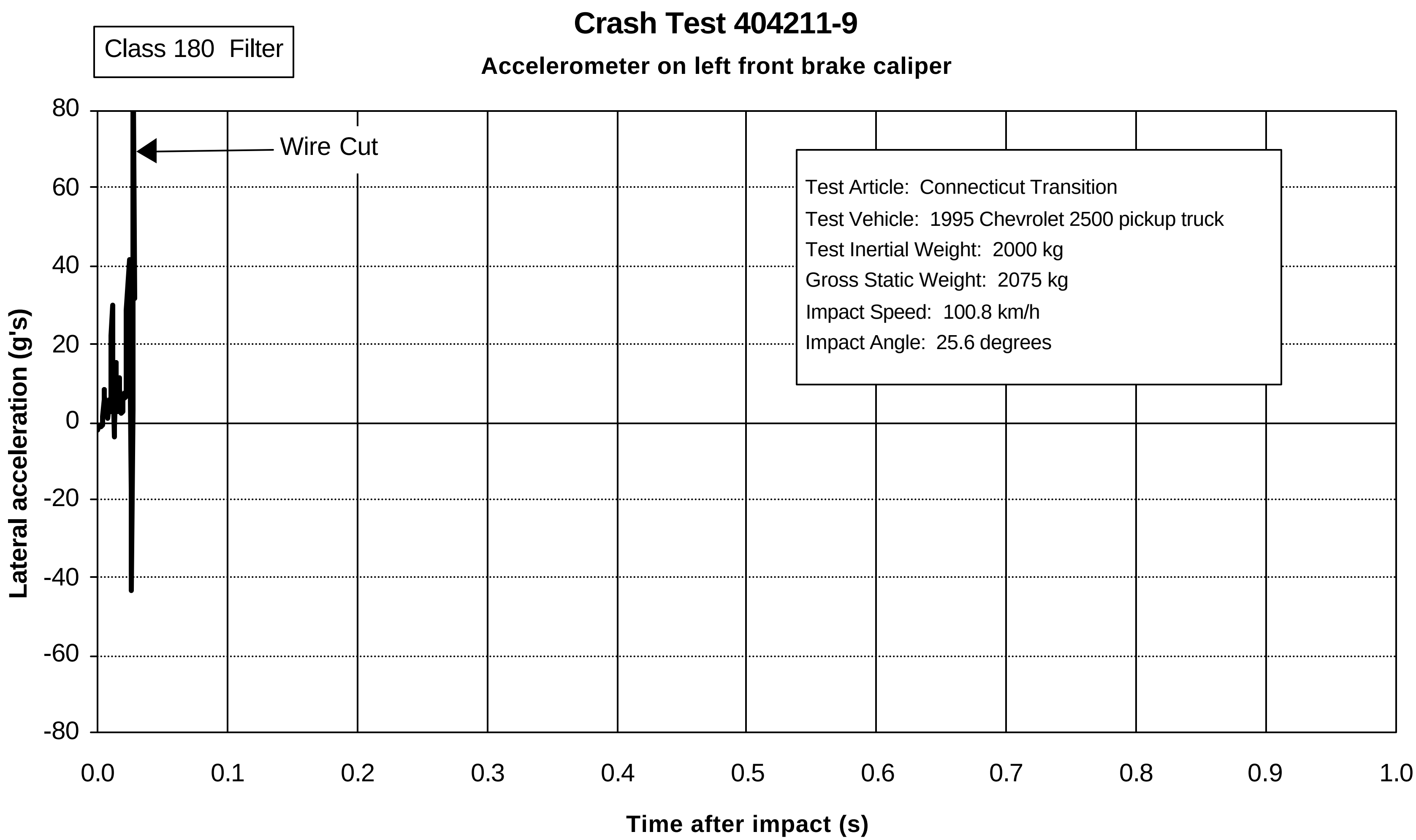


Figure 91. Vehicle lateral accelerometer trace for test 404211-9 (accelerometer located on left front brake caliper).

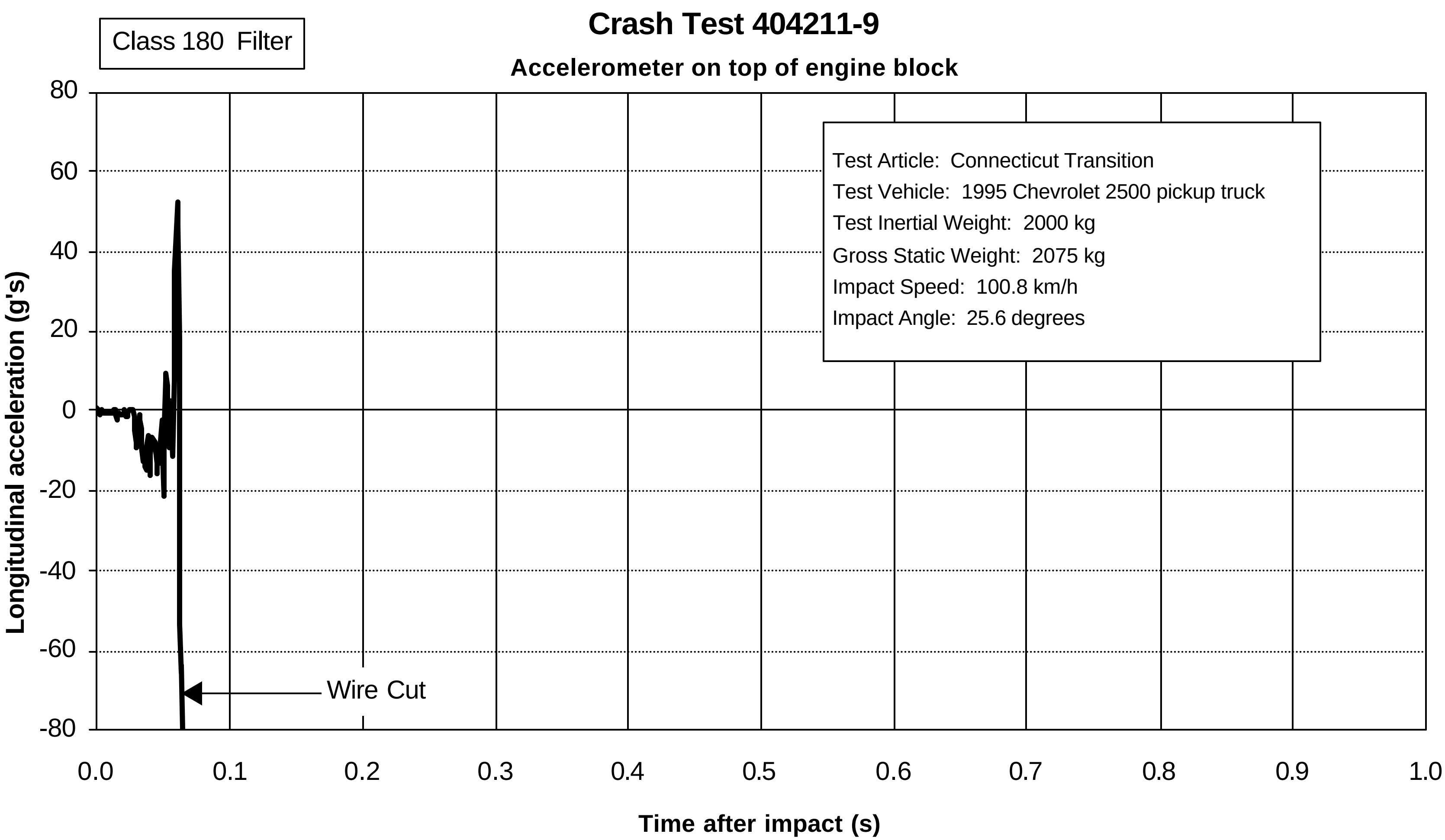


Figure 92. Vehicle longitudinal accelerometer trace for test 404211-9 (accelerometer located on top of engine block).

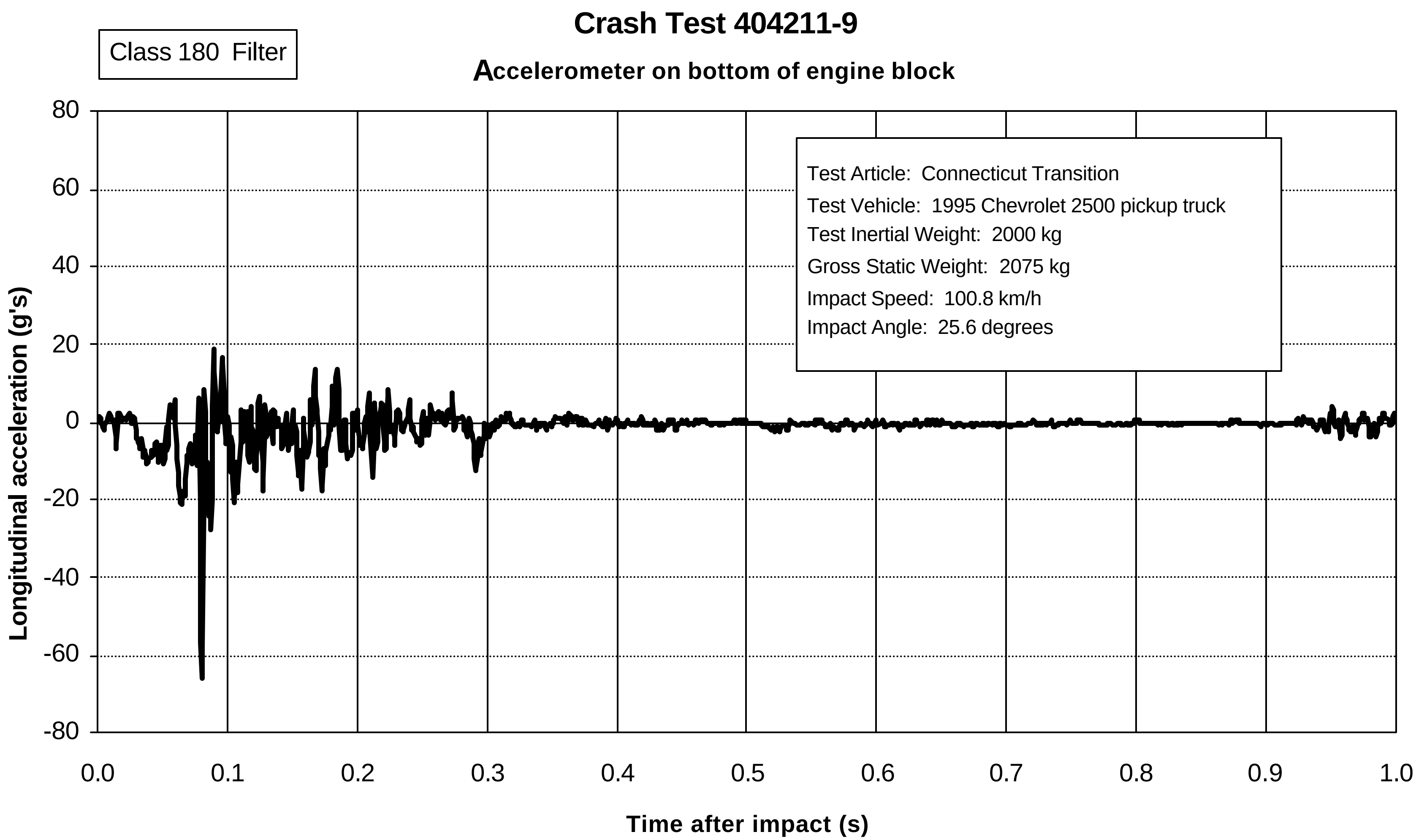


Figure 93. Vehicle longitudinal accelerometer trace for test 404211-9
(accelerometer located on bottom of engine block).

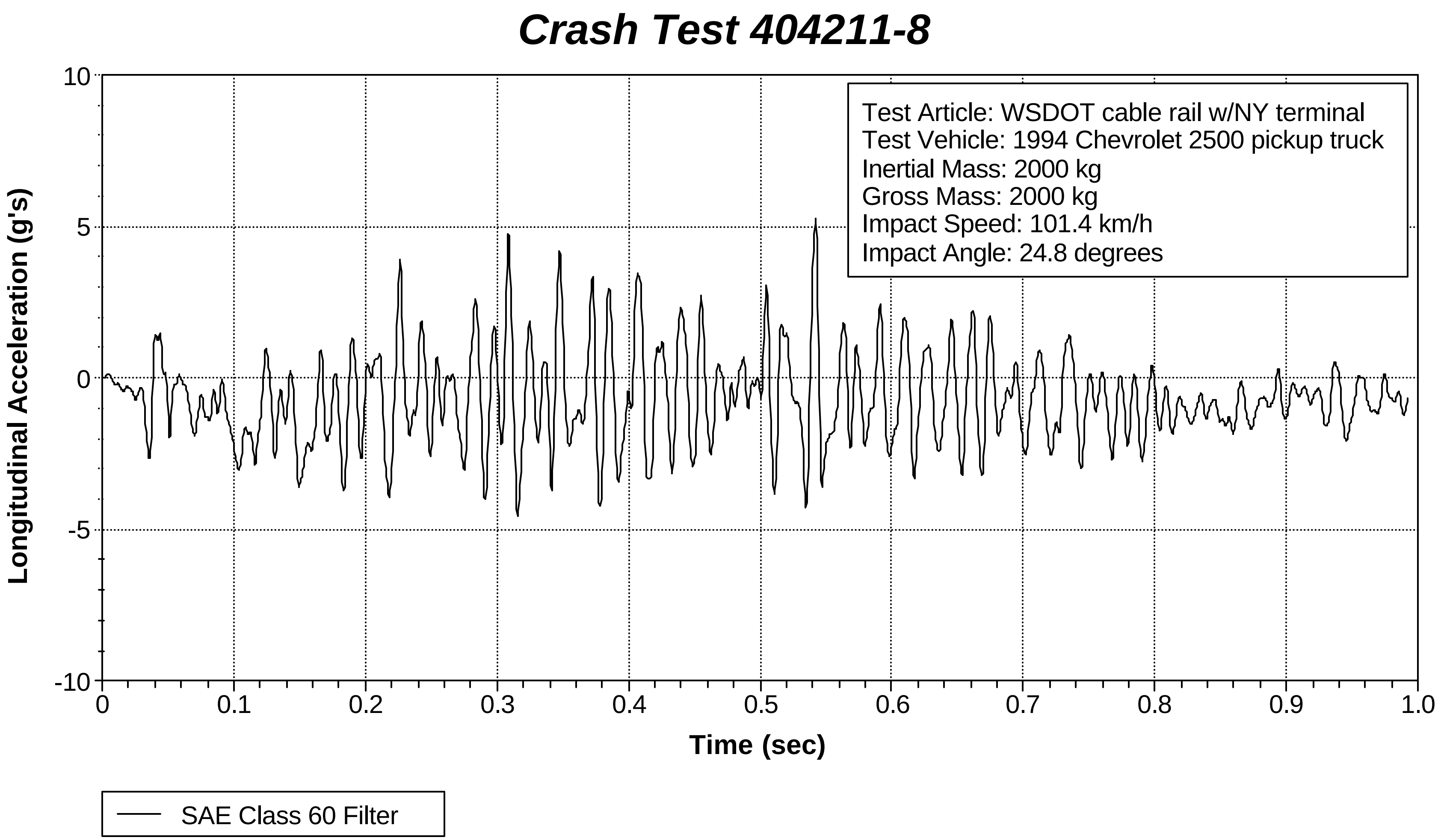


Figure 94. Vehicle longitudinal accelerometer trace for test 404211-8
(accelerometer located at center of gravity).

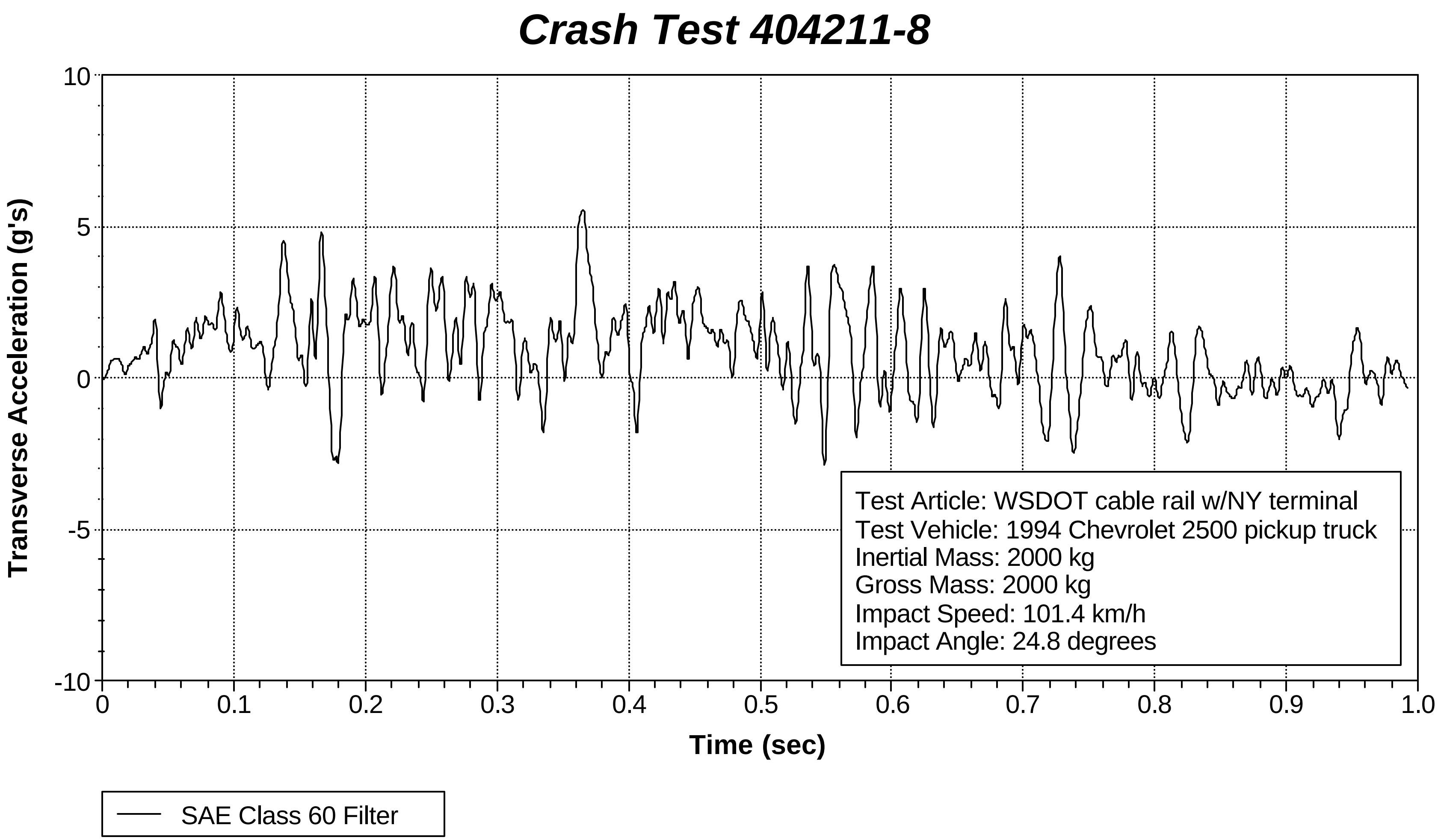


Figure 95. Vehicle lateral accelerometer trace for test 404211-8
(accelerometer located at center of gravity).

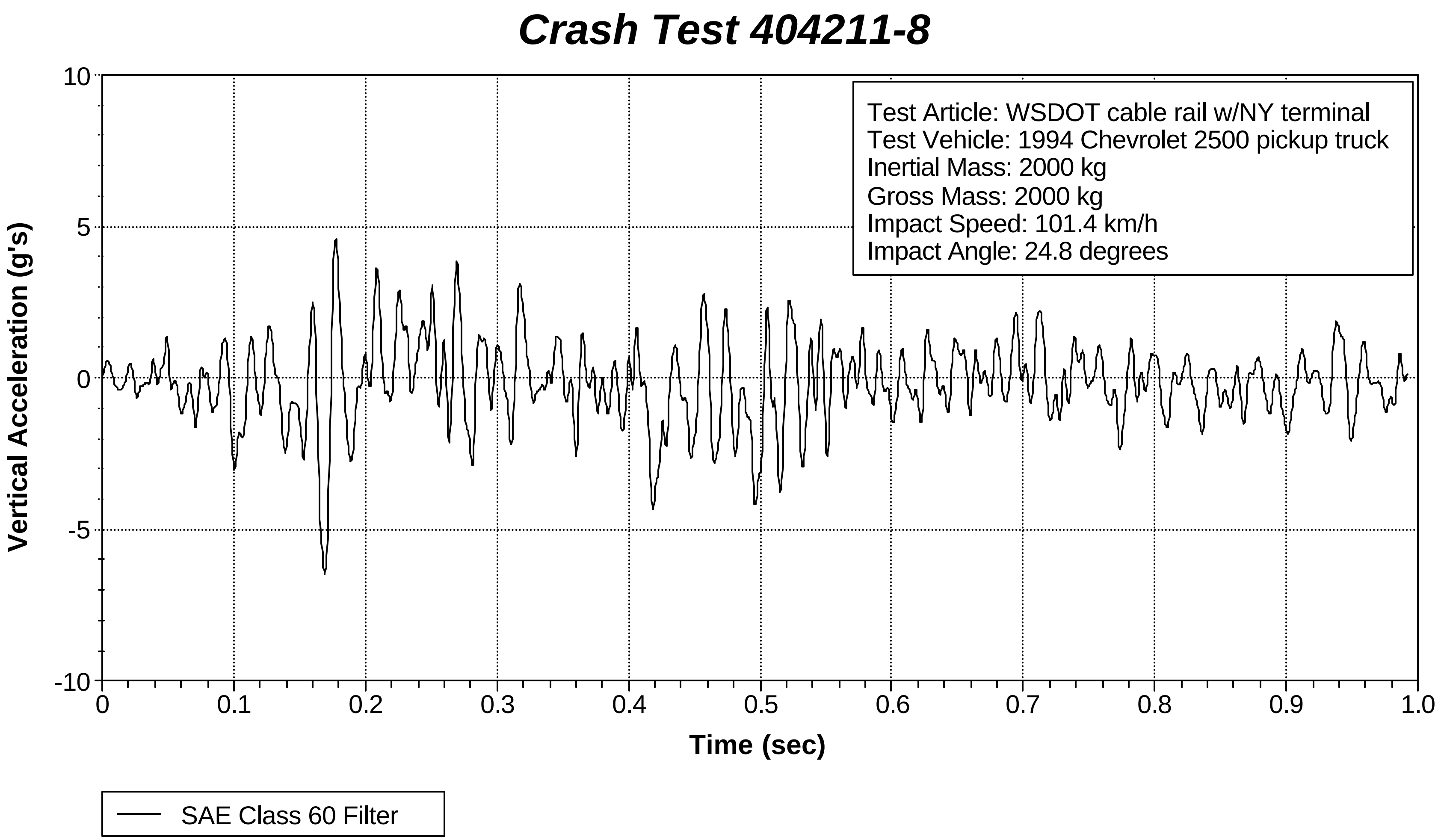


Figure 96. Vehicle vertical accelerometer trace for test 404211-8
(accelerometer located at center of gravity).

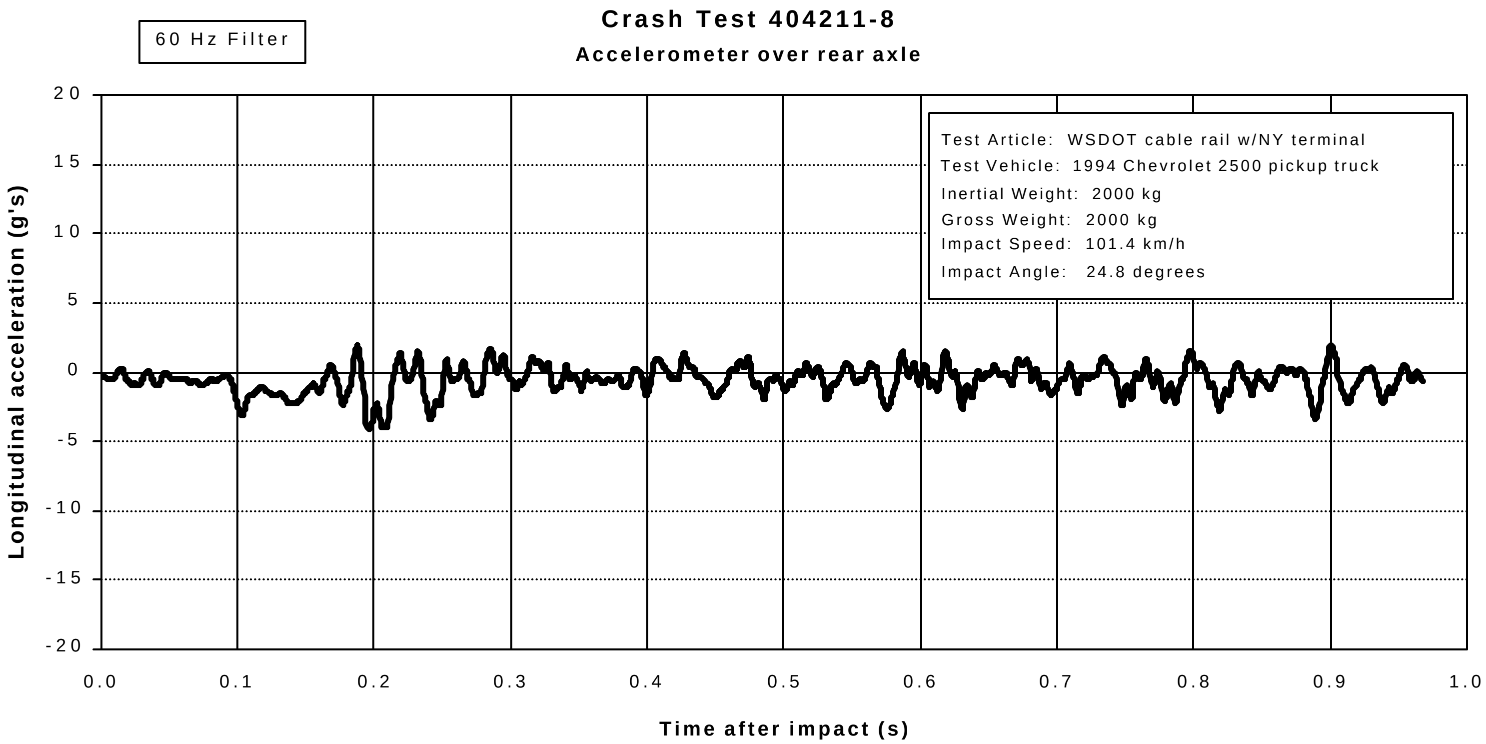


Figure 97. Vehicle longitudinal accelerometer trace for test 404211-8 (accelerometer located over rear axle).

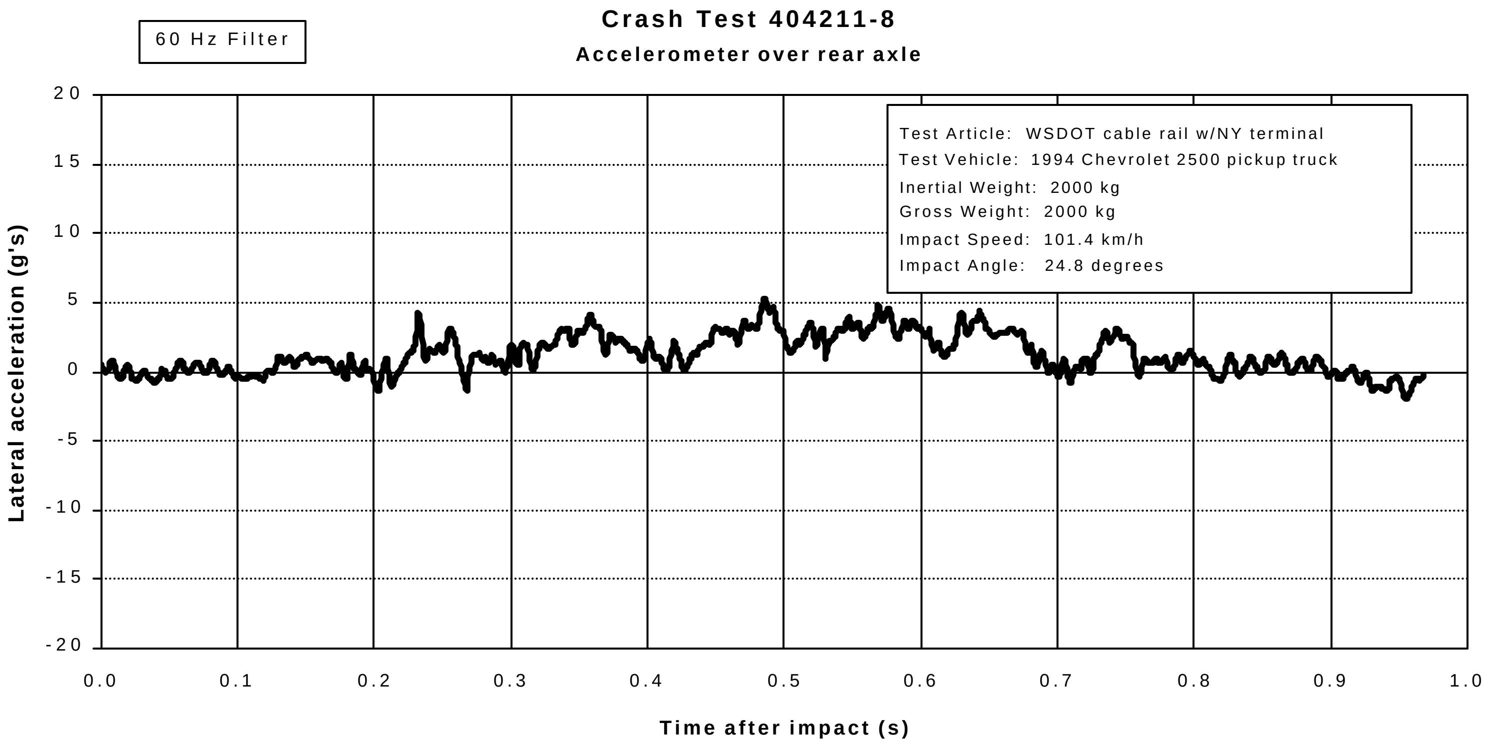


Figure 98. Vehicle lateral accelerometer trace for test 404211-8
(accelerometer located over rear axle).

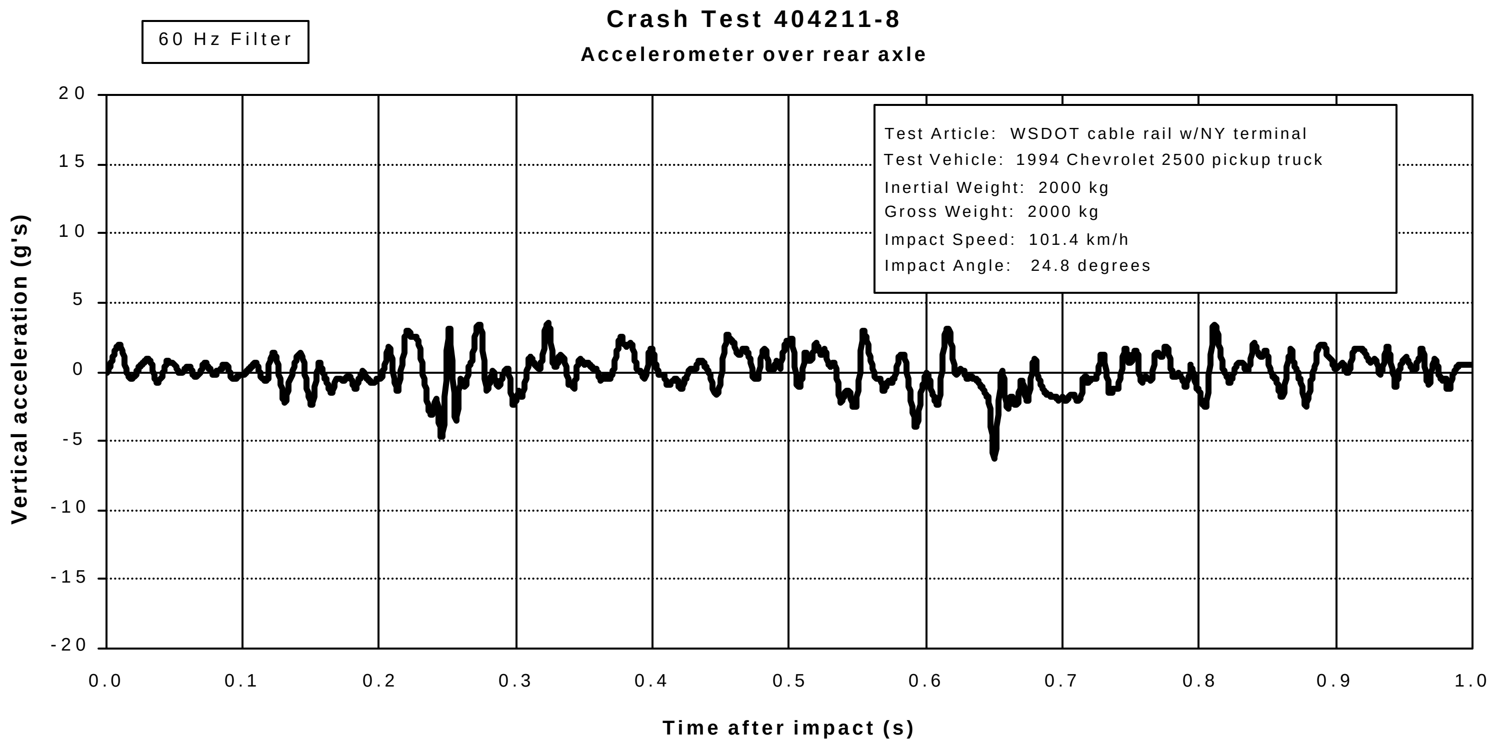


Figure 99. Vehicle vertical accelerometer trace for test 404211-8 (accelerometer located over rear axle).

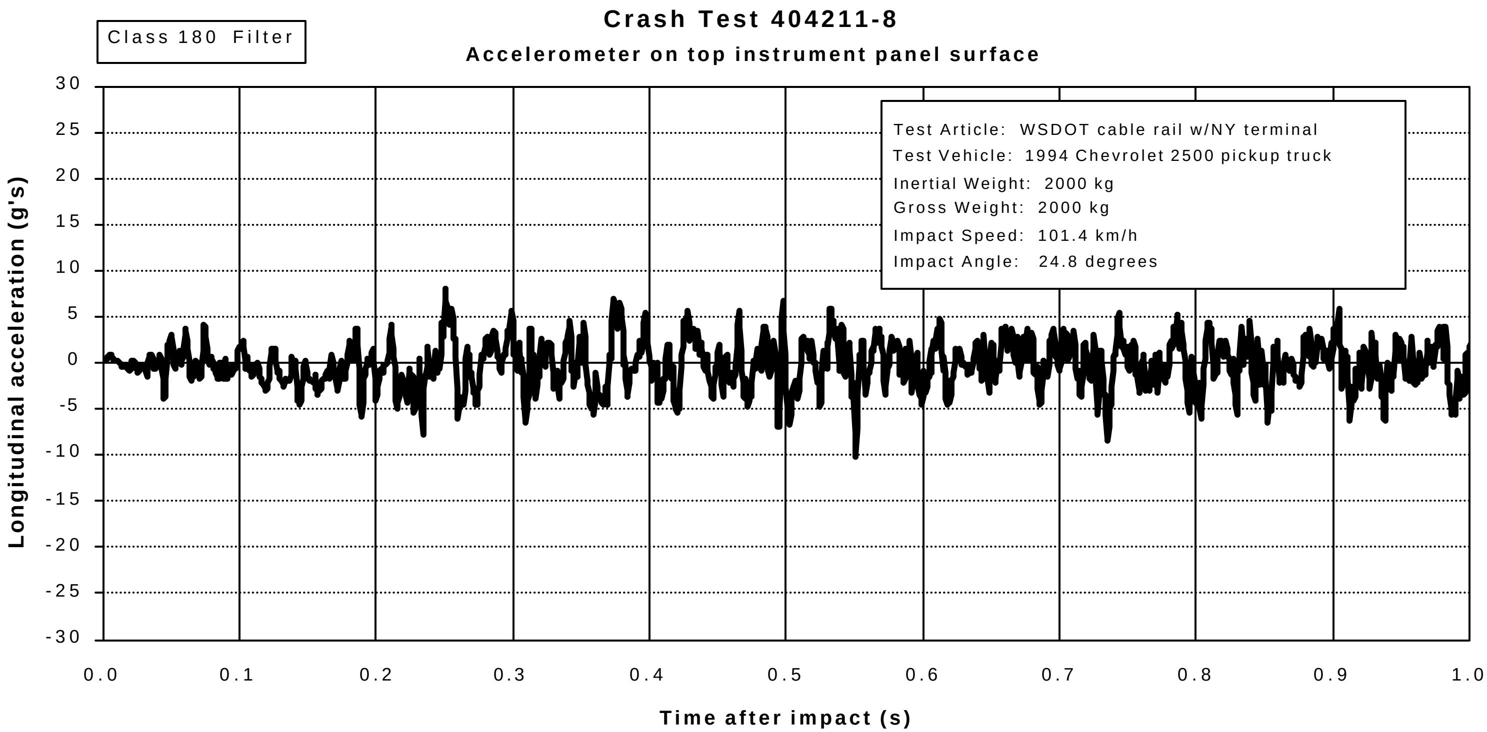


Figure 100. Vehicle longitudinal accelerometer trace for test 404211-8
(accelerometer located on top surface of instrument panel).

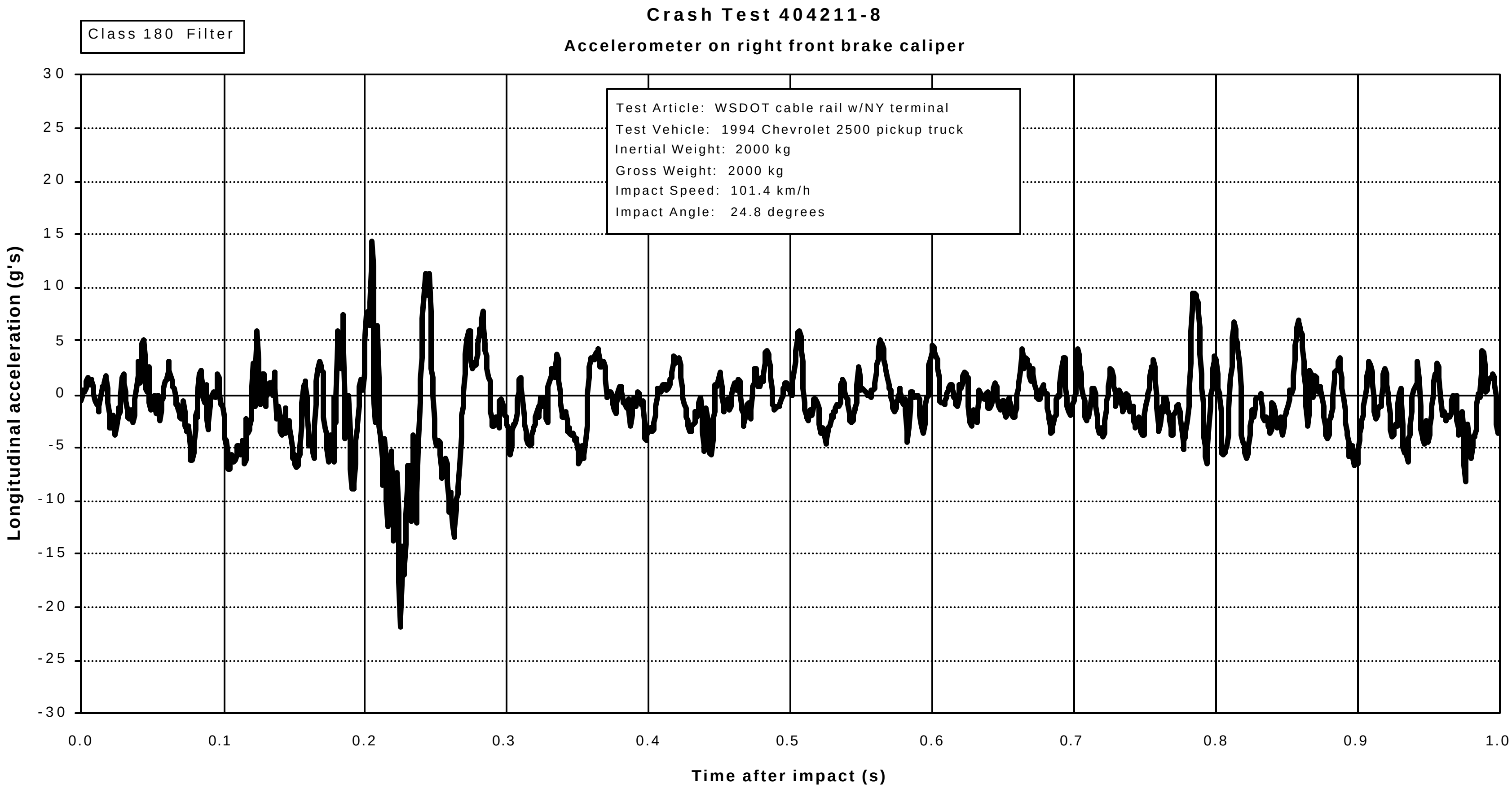


Figure 101. Vehicle longitudinal accelerometer trace for test 404211-8
(accelerometer located on right front brake caliper).

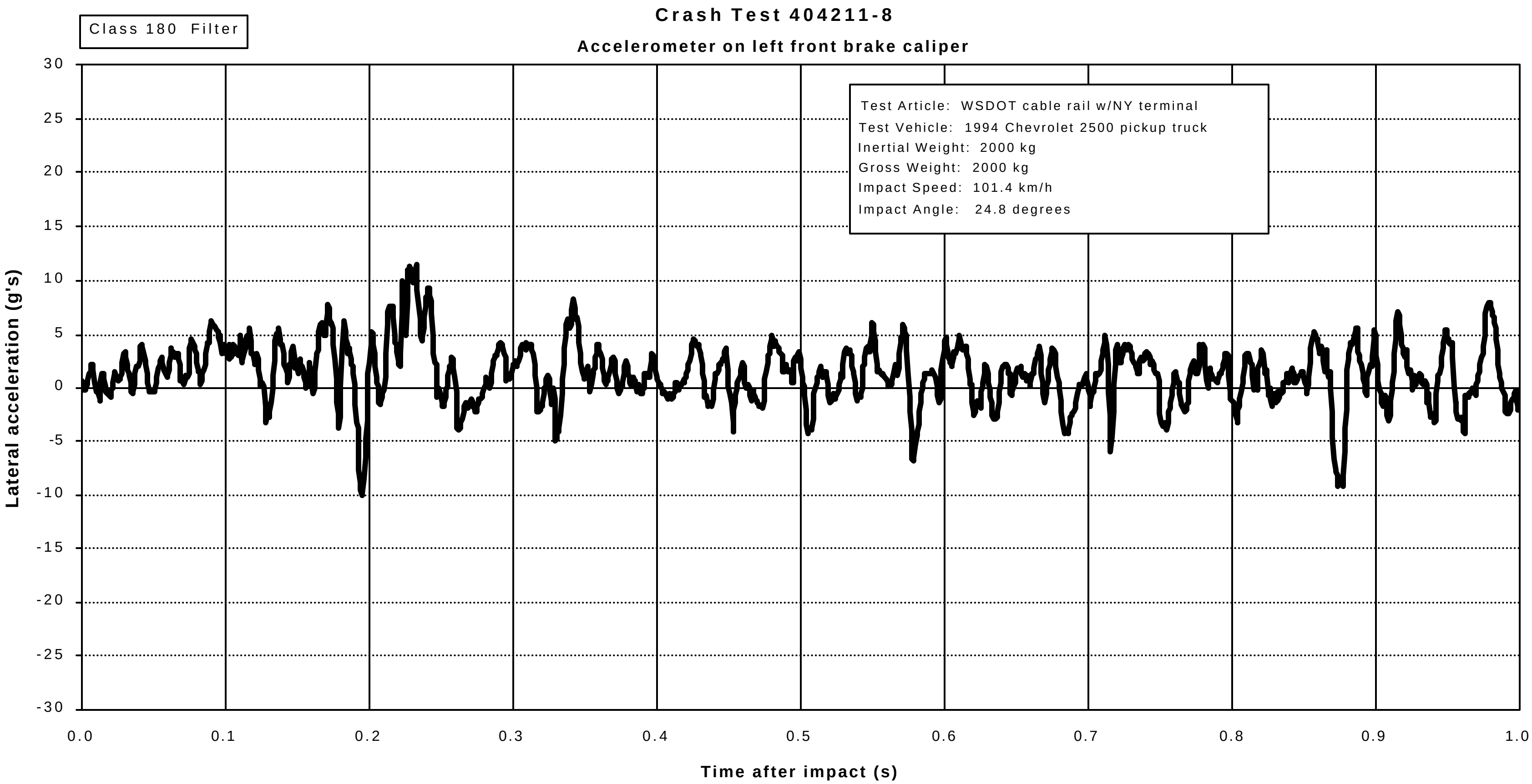


Figure 102. Vehicle longitudinal accelerometer trace for test 404211-8 (accelerometer located on left front brake caliper).

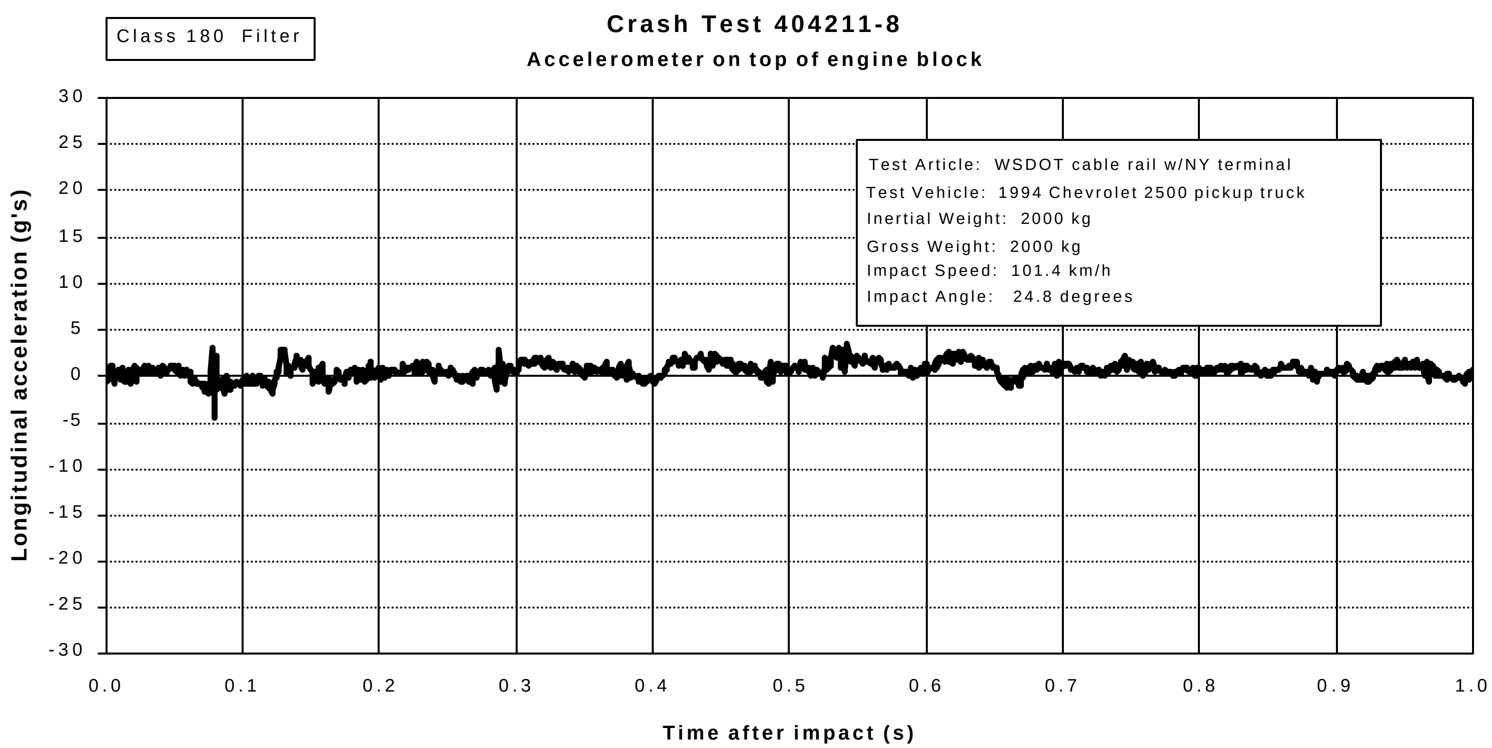


Figure 103. Vehicle longitudinal accelerometer trace for test 404211-8
(accelerometer located on top of engine block).

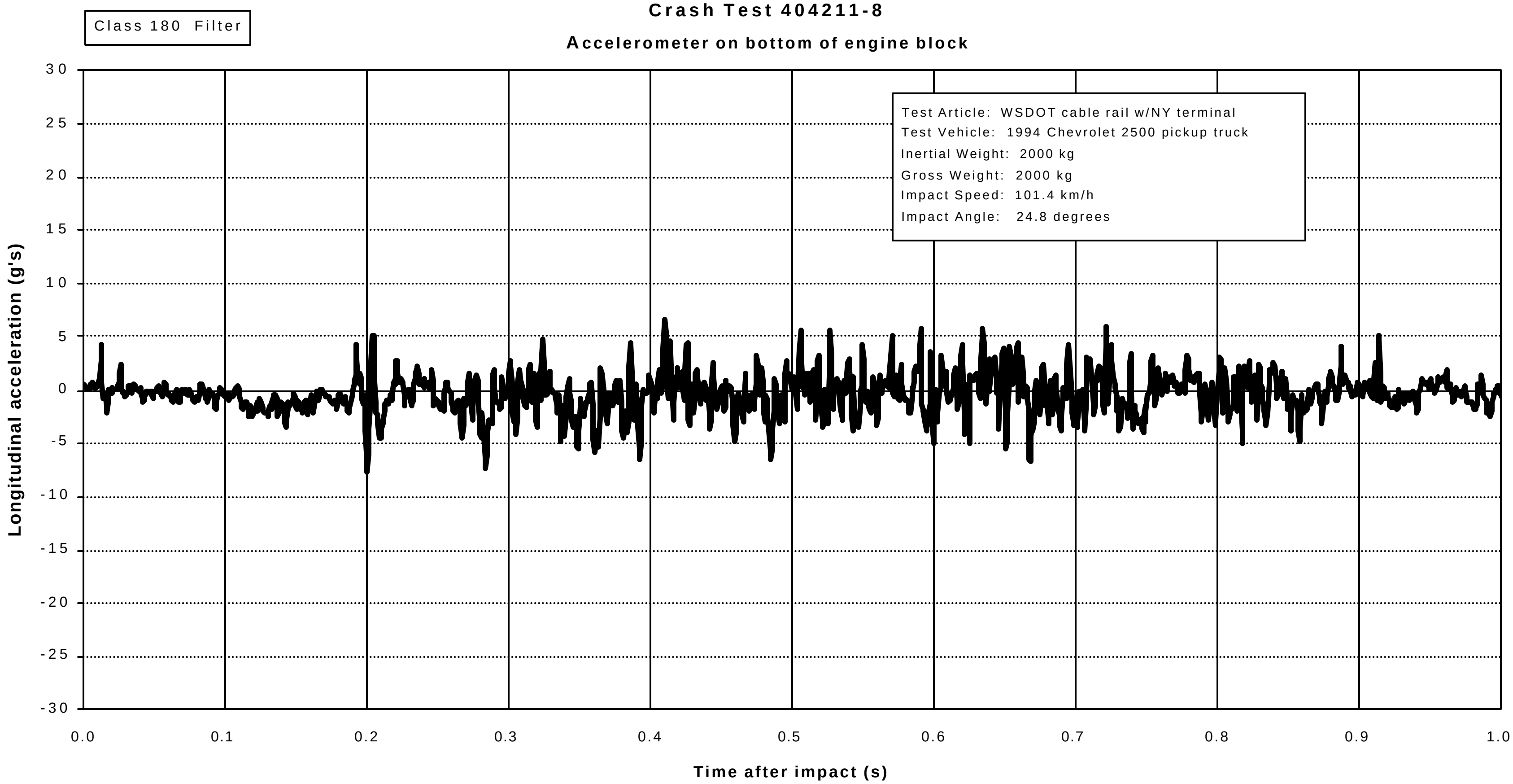


Figure 104. Vehicle longitudinal accelerometer trace for test 404211-8
(accelerometer located on bottom of engine block).

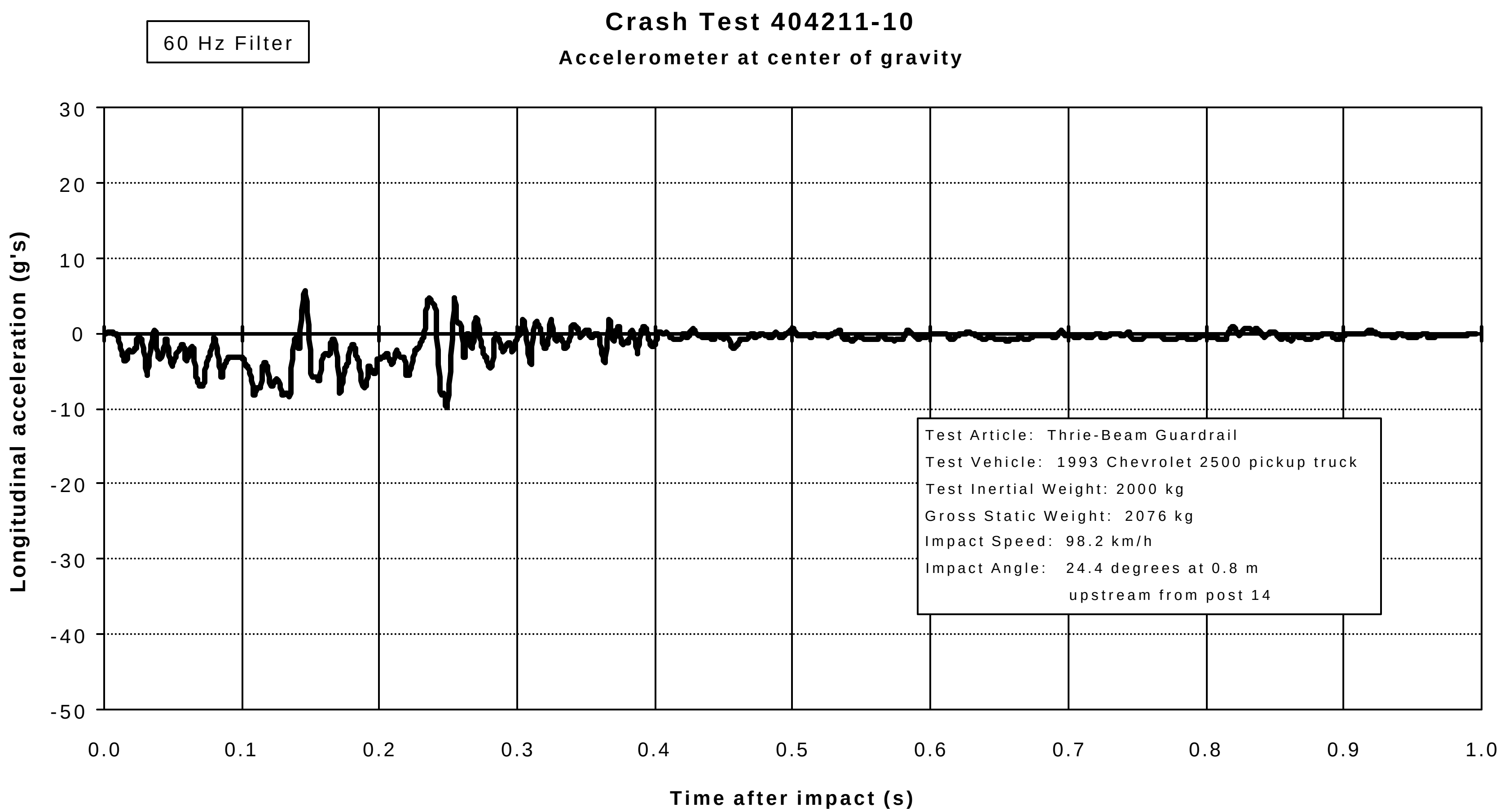


Figure 105. Vehicle longitudinal accelerometer trace for test 404211-10
(accelerometer located at center of gravity).

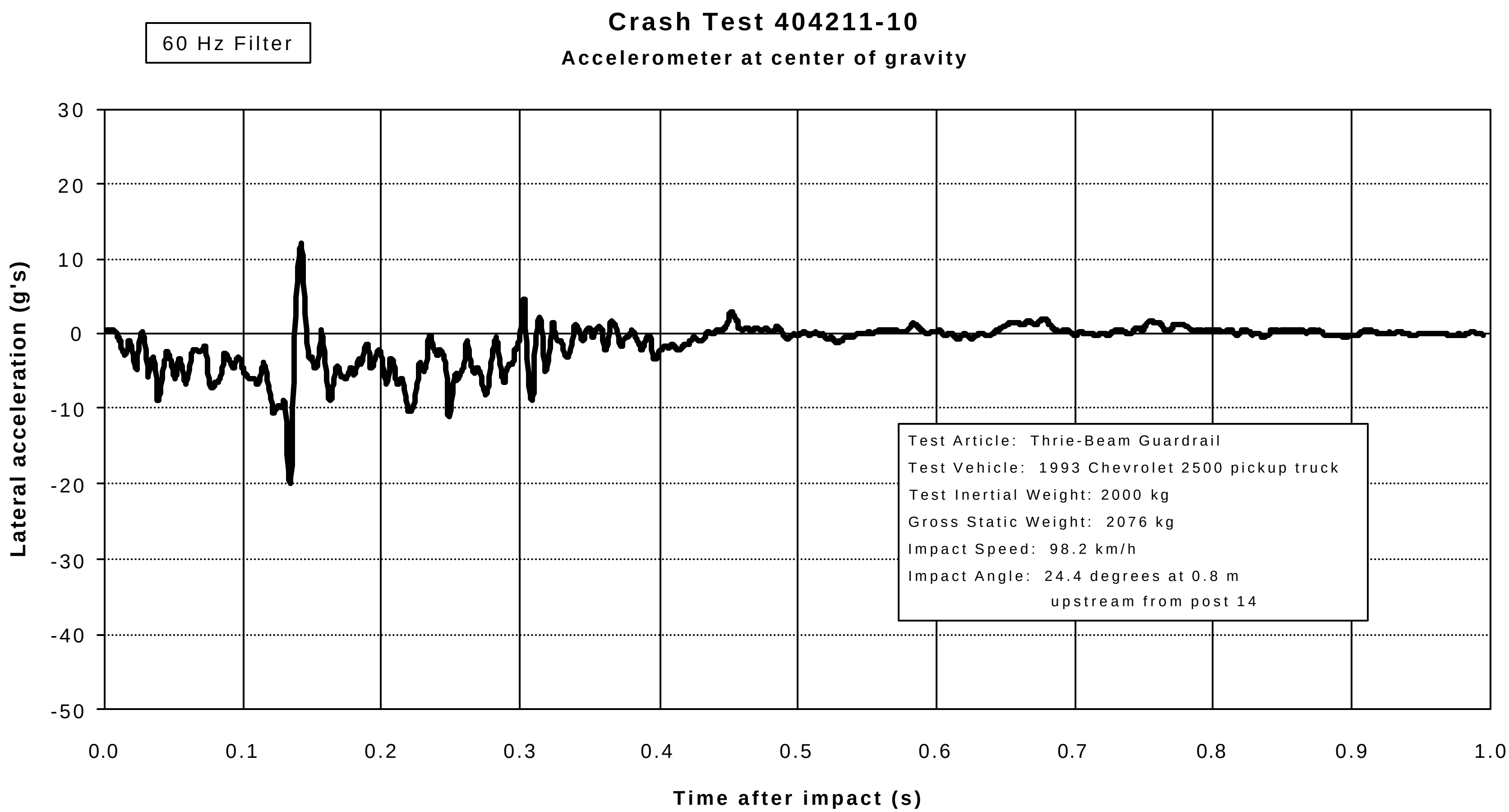


Figure 106. Vehicle lateral accelerometer trace for test 404211-10 (accelerometer located at center of gravity).

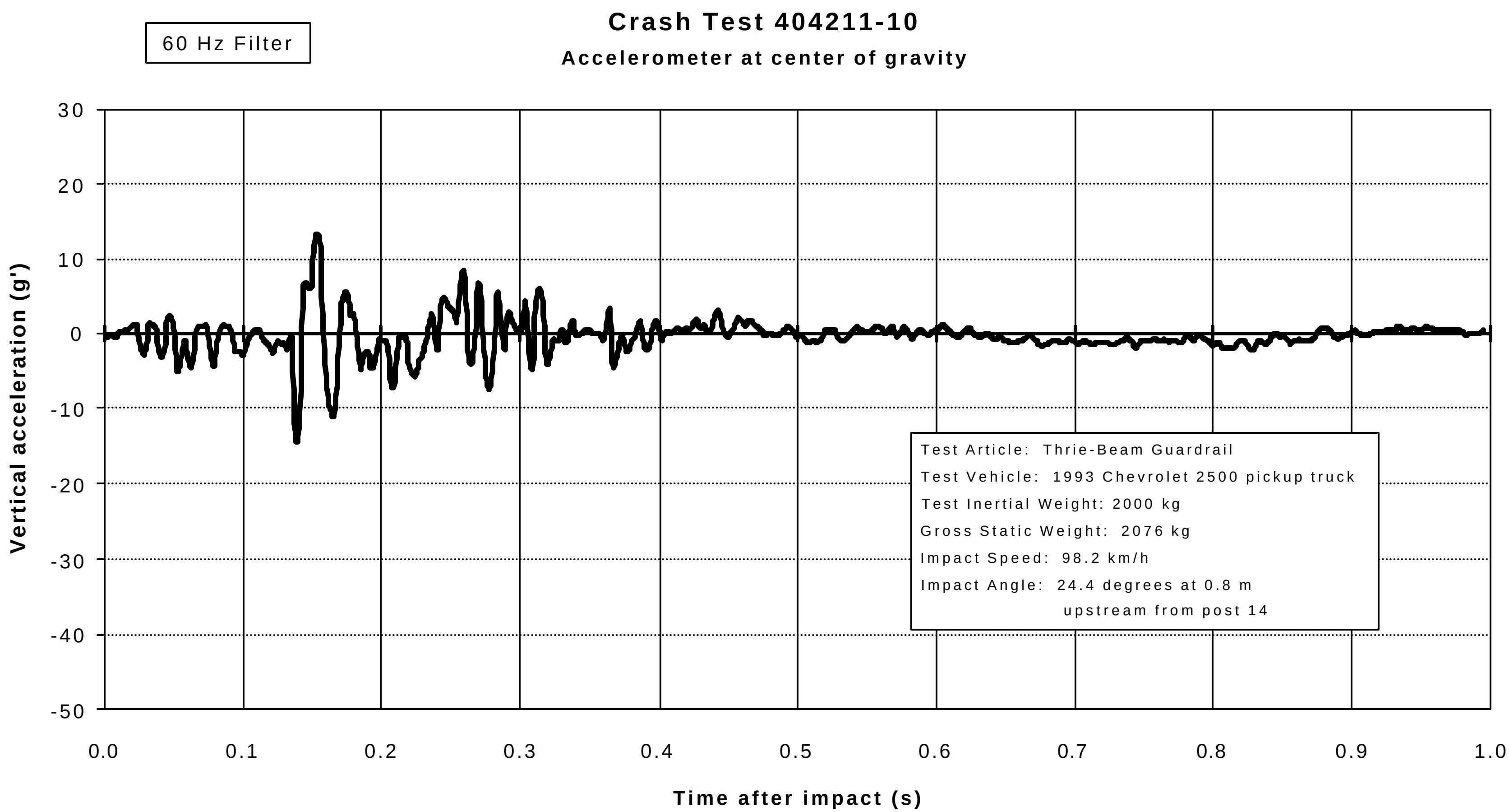


Figure 107. Vehicle vertical accelerometer trace for test 404211-10 (accelerometer located at center of gravity).

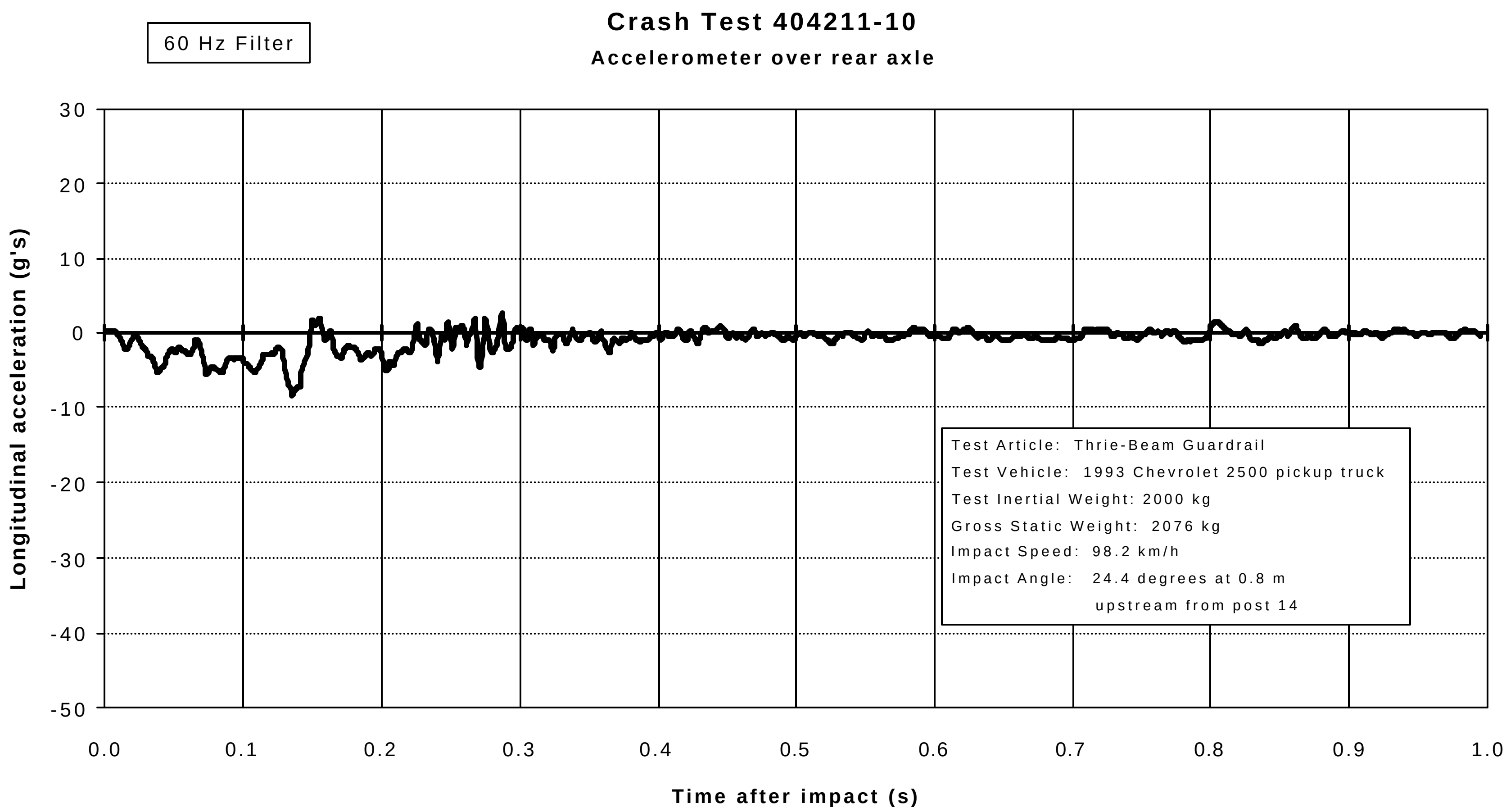


Figure 108. Vehicle longitudinal accelerometer trace for test 404211-10
(accelerometer located over rear axle).

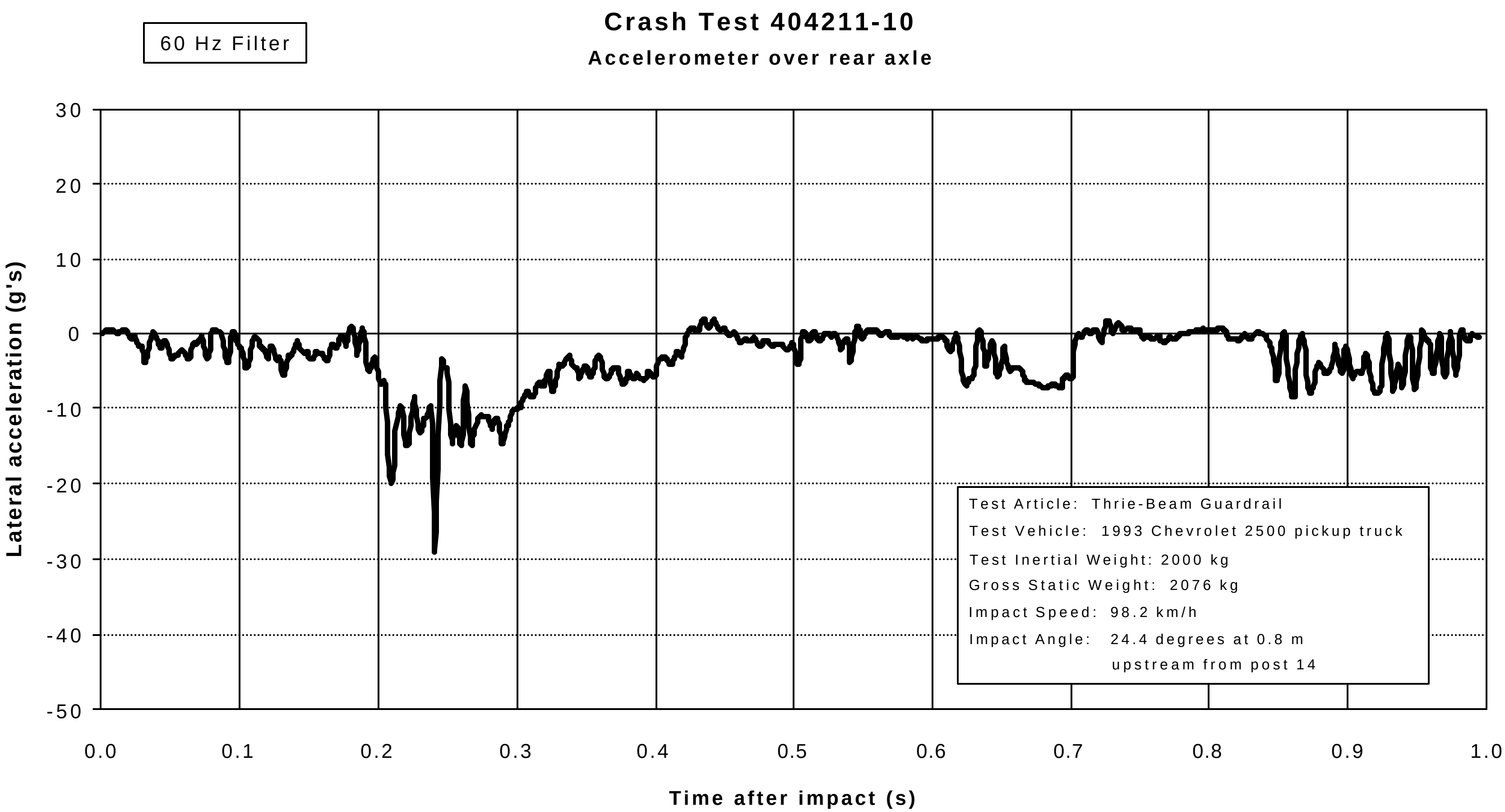


Figure 109. Vehicle lateral accelerometer trace for test 404211-10 (accelerometer located over rear axle).

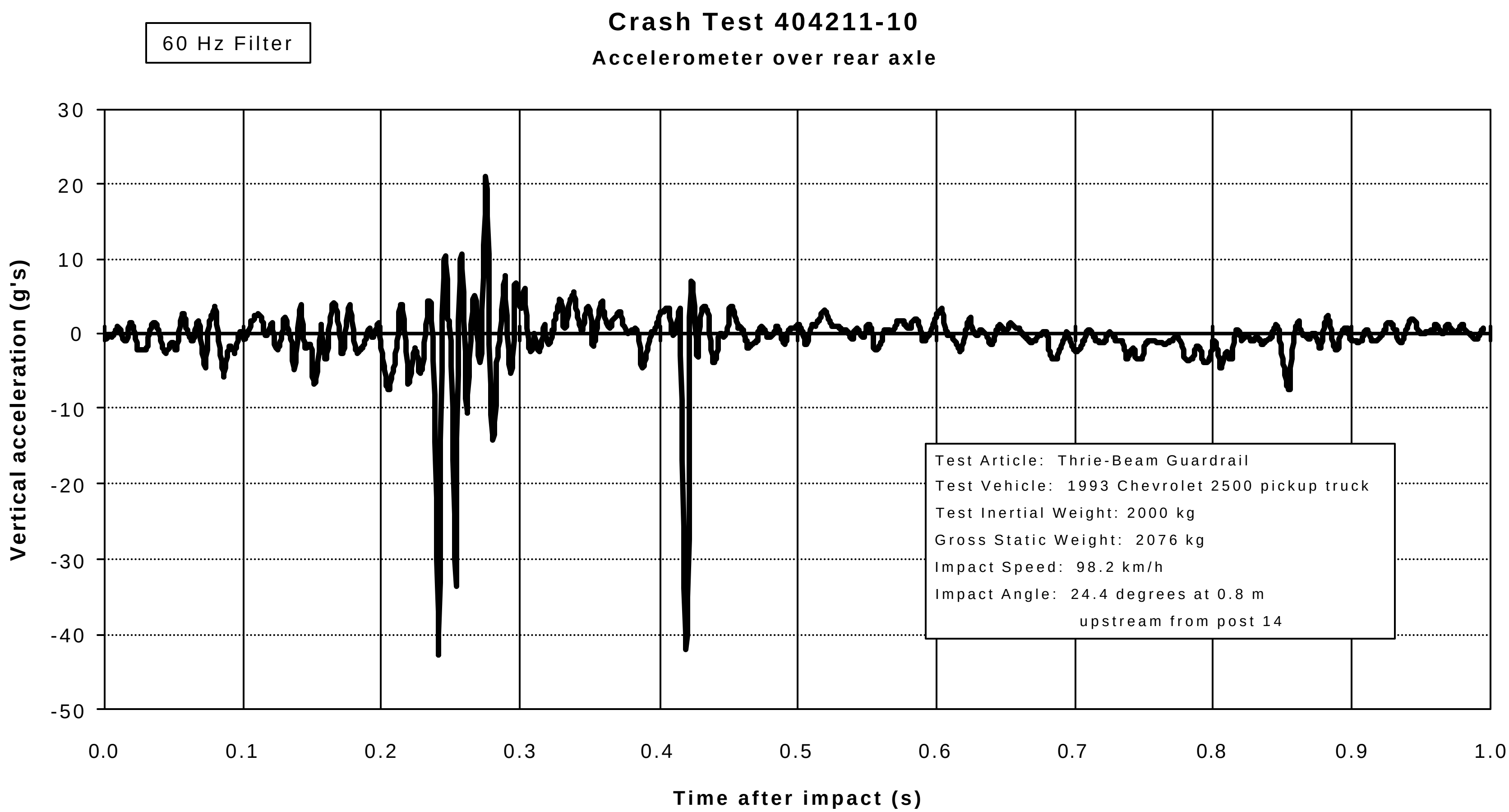


Figure 110. Vehicle vertical accelerometer trace for test 404211-10
(accelerometer located over rear axle).

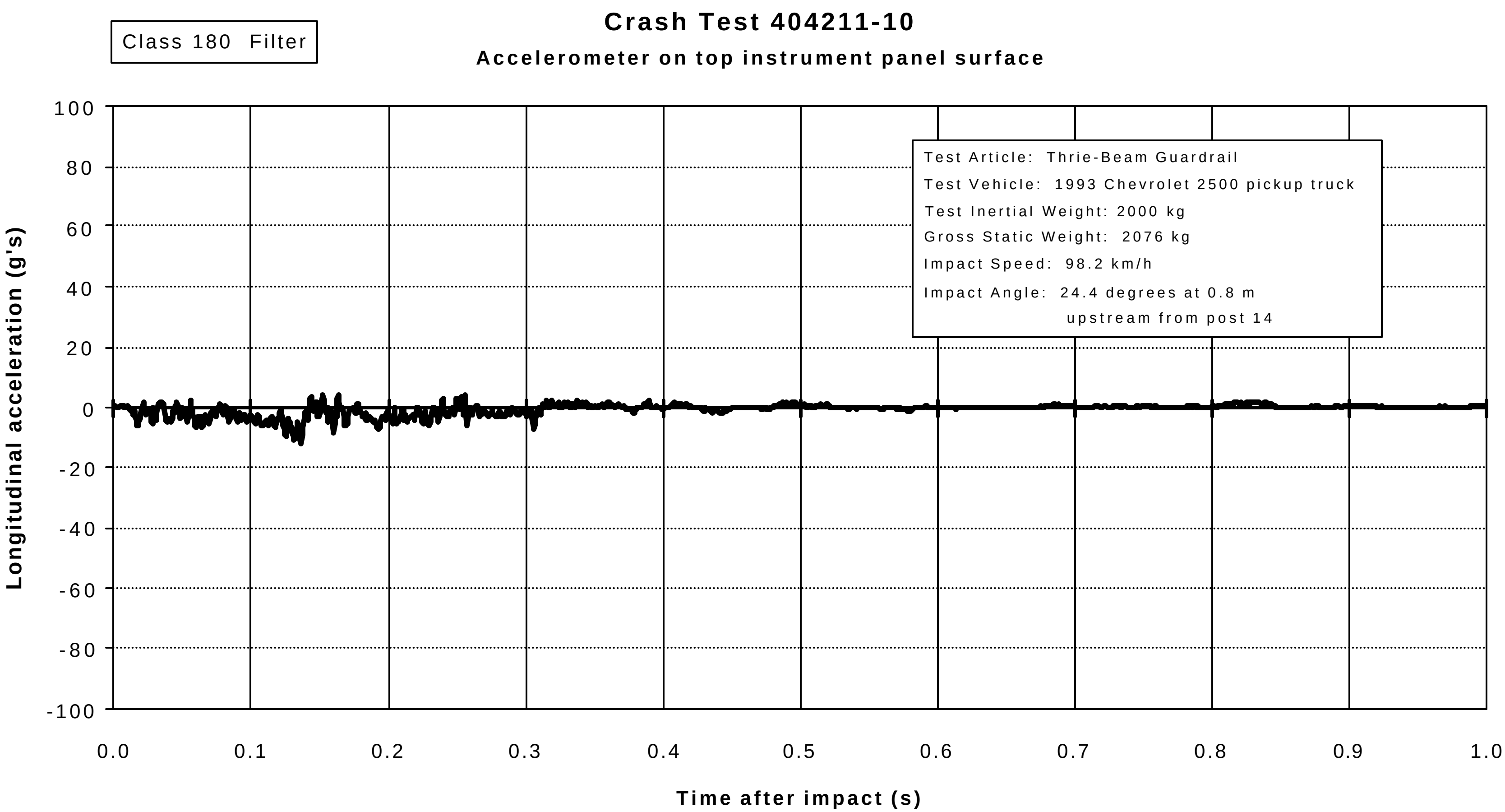


Figure 111. Vehicle longitudinal accelerometer trace for test 404211-10 (accelerometer located on top surface of instrument panel).

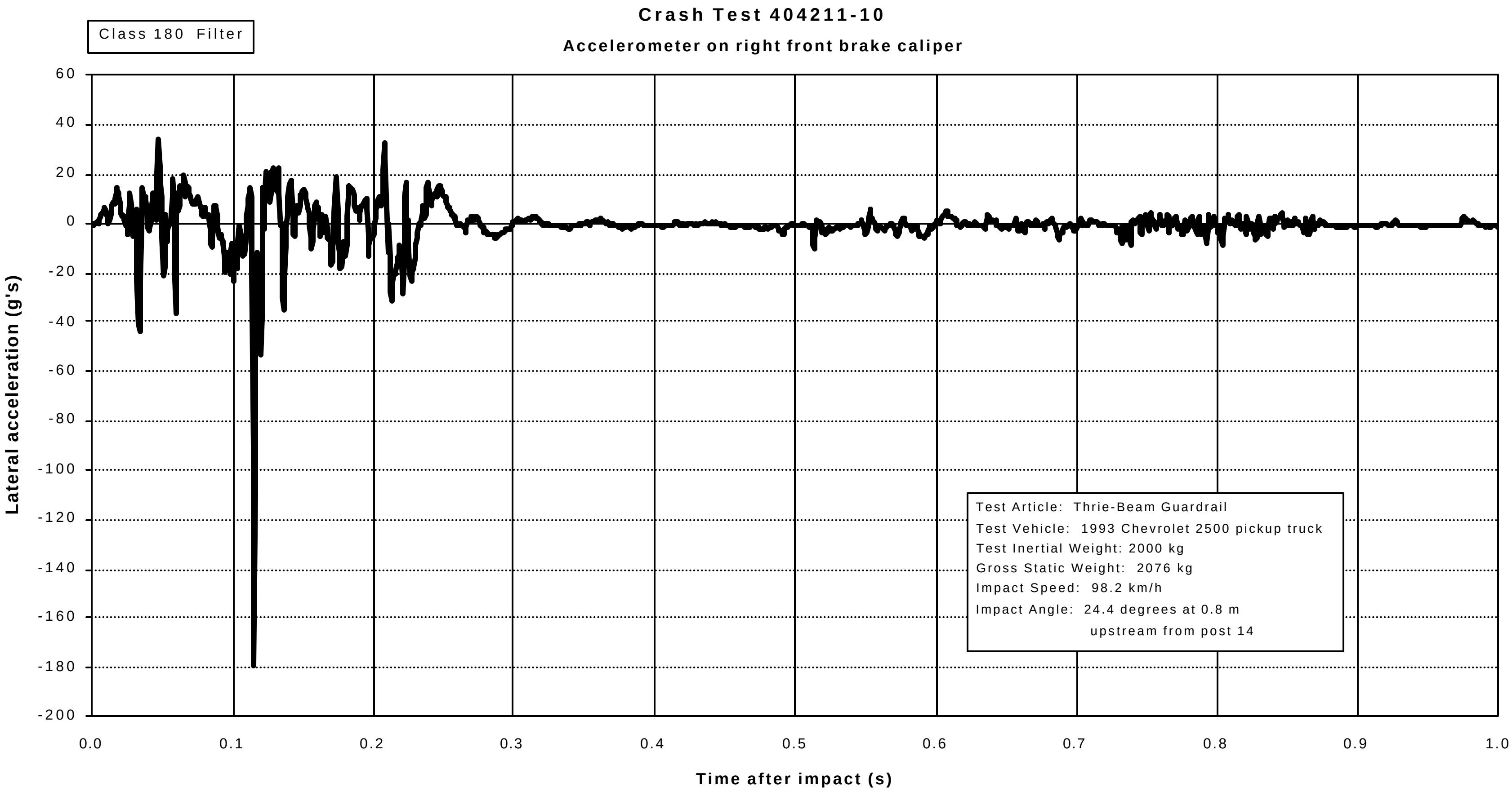


Figure 112. Vehicle lateral accelerometer trace for test 404211-10 (accelerometer located on right front brake caliper).

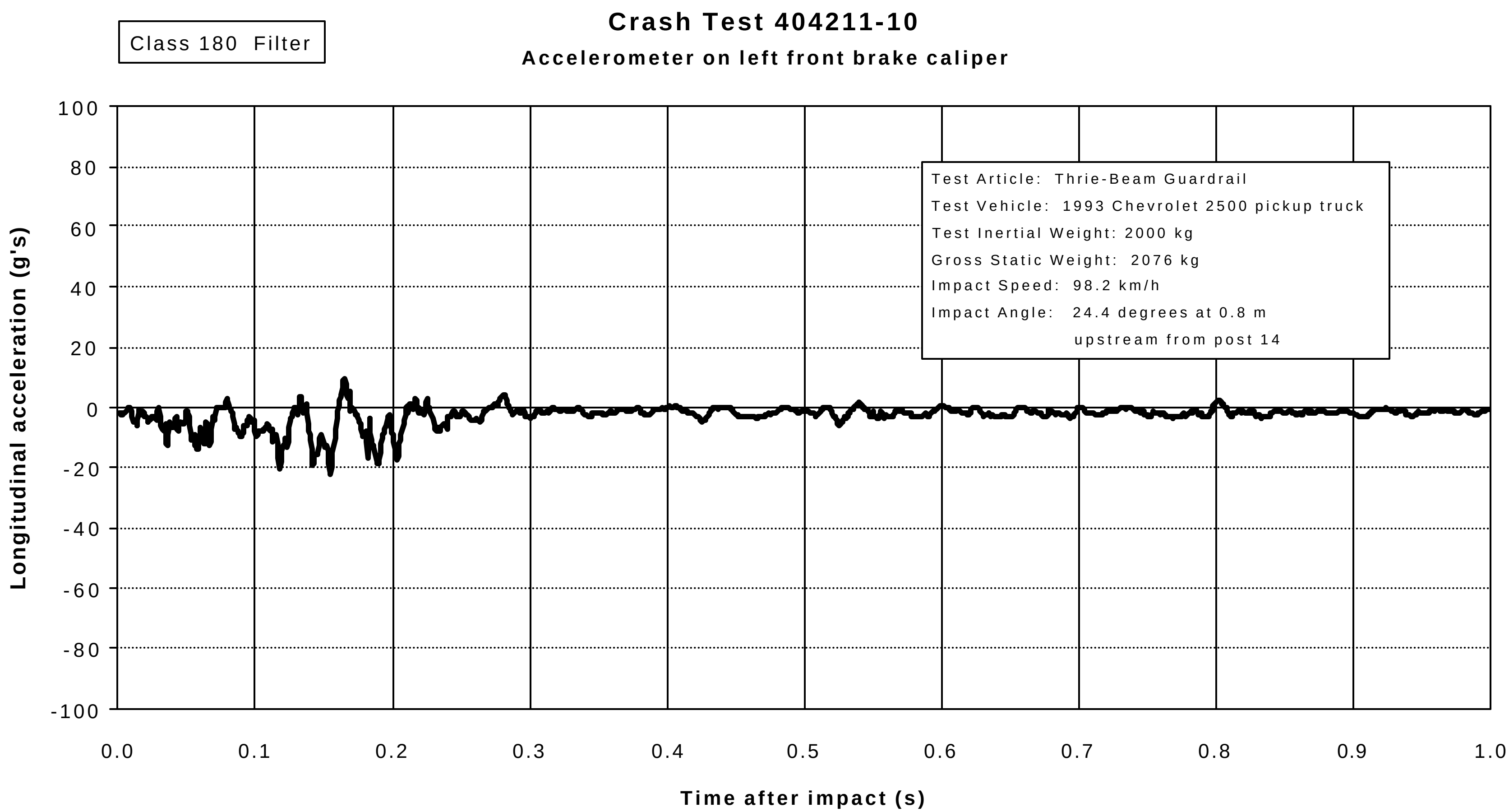


Figure 113. Vehicle longitudinal accelerometer trace for test 404211-10 (accelerometer located on left front brake caliper).

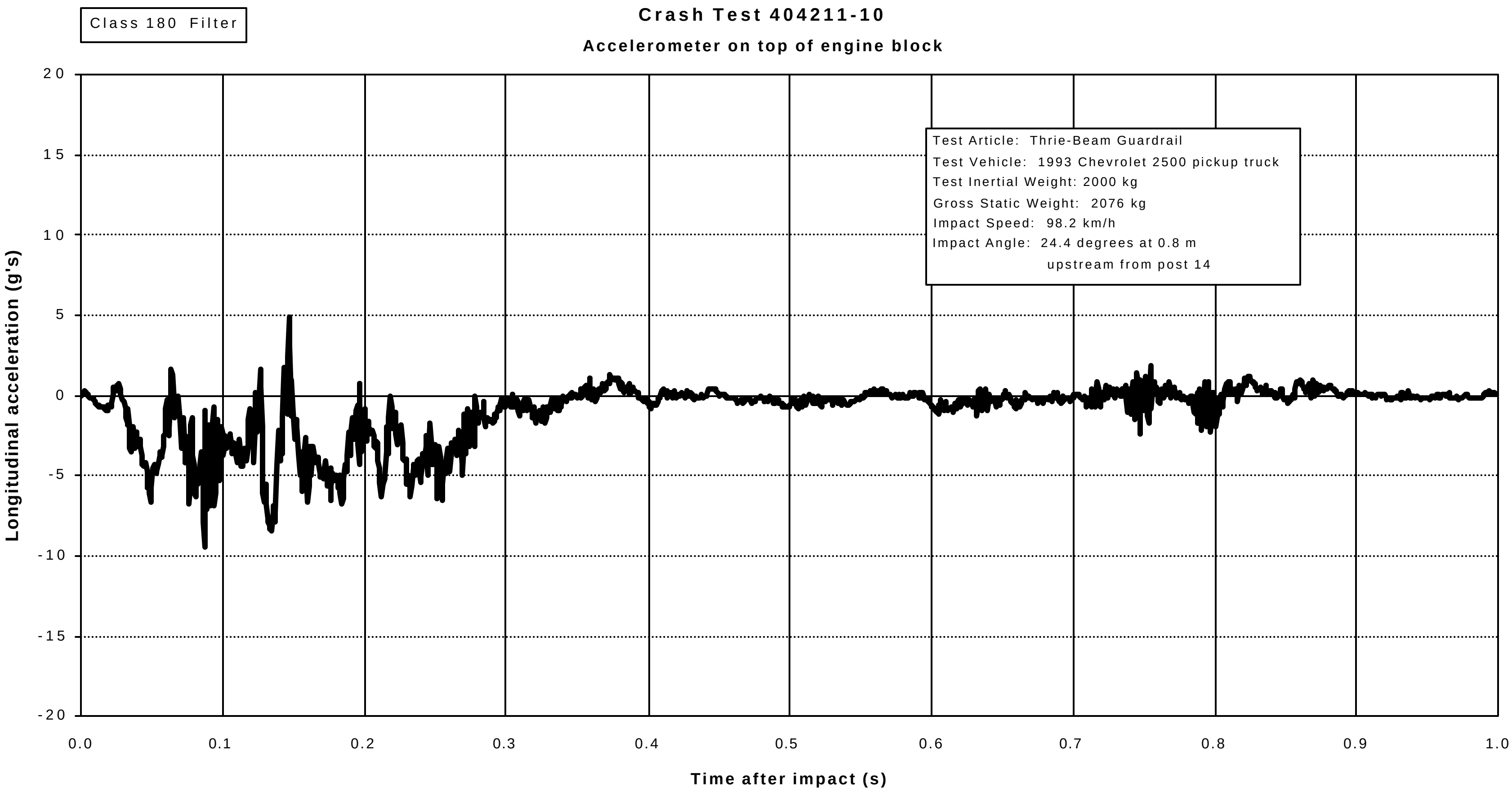


Figure 114. Vehicle longitudinal accelerometer trace for test 404211-10
(accelerometer located on top of engine block).

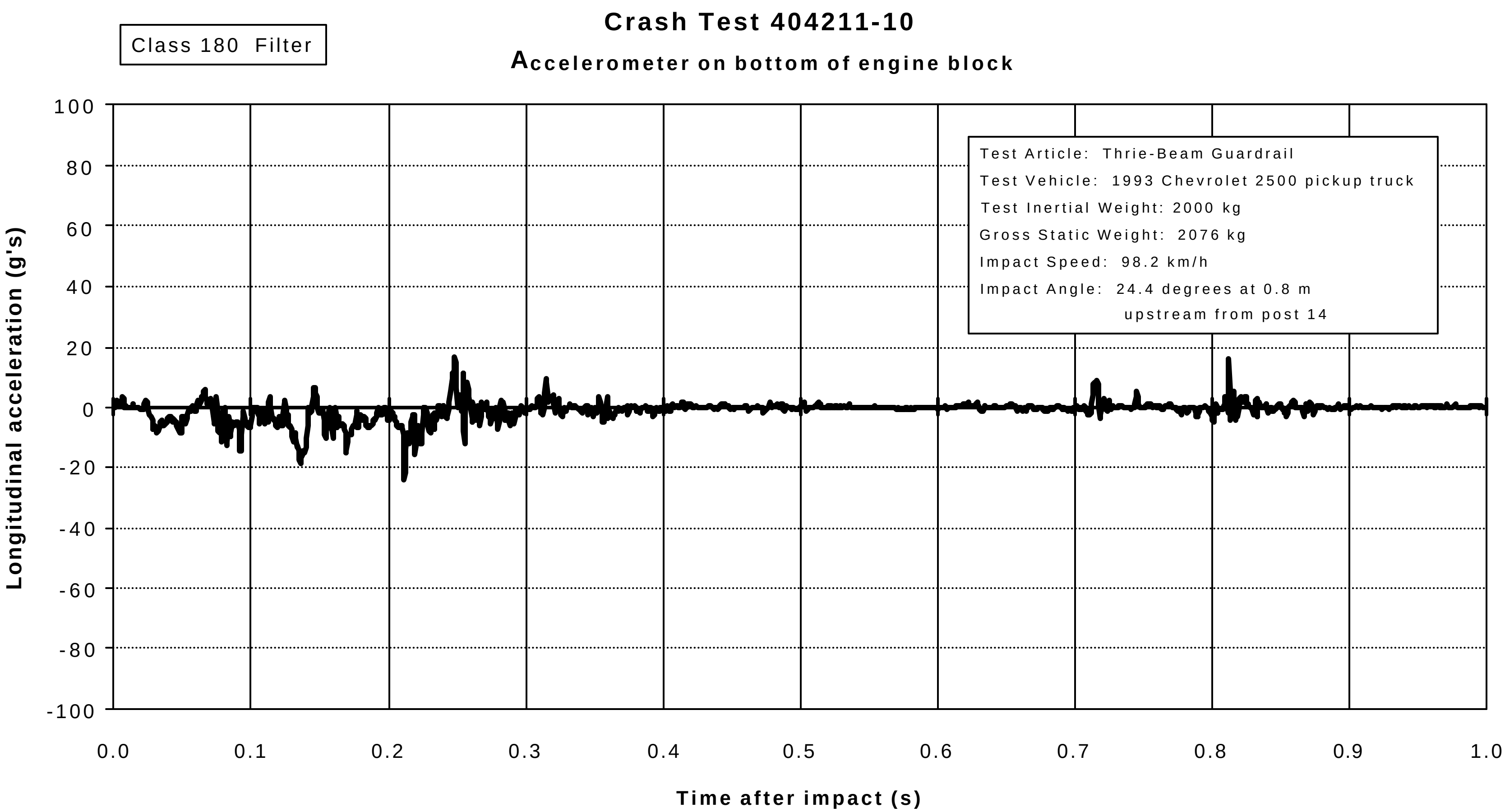


Figure 115. Vehicle longitudinal accelerometer trace for test 404211-10 (accelerometer located on bottom of engine block).

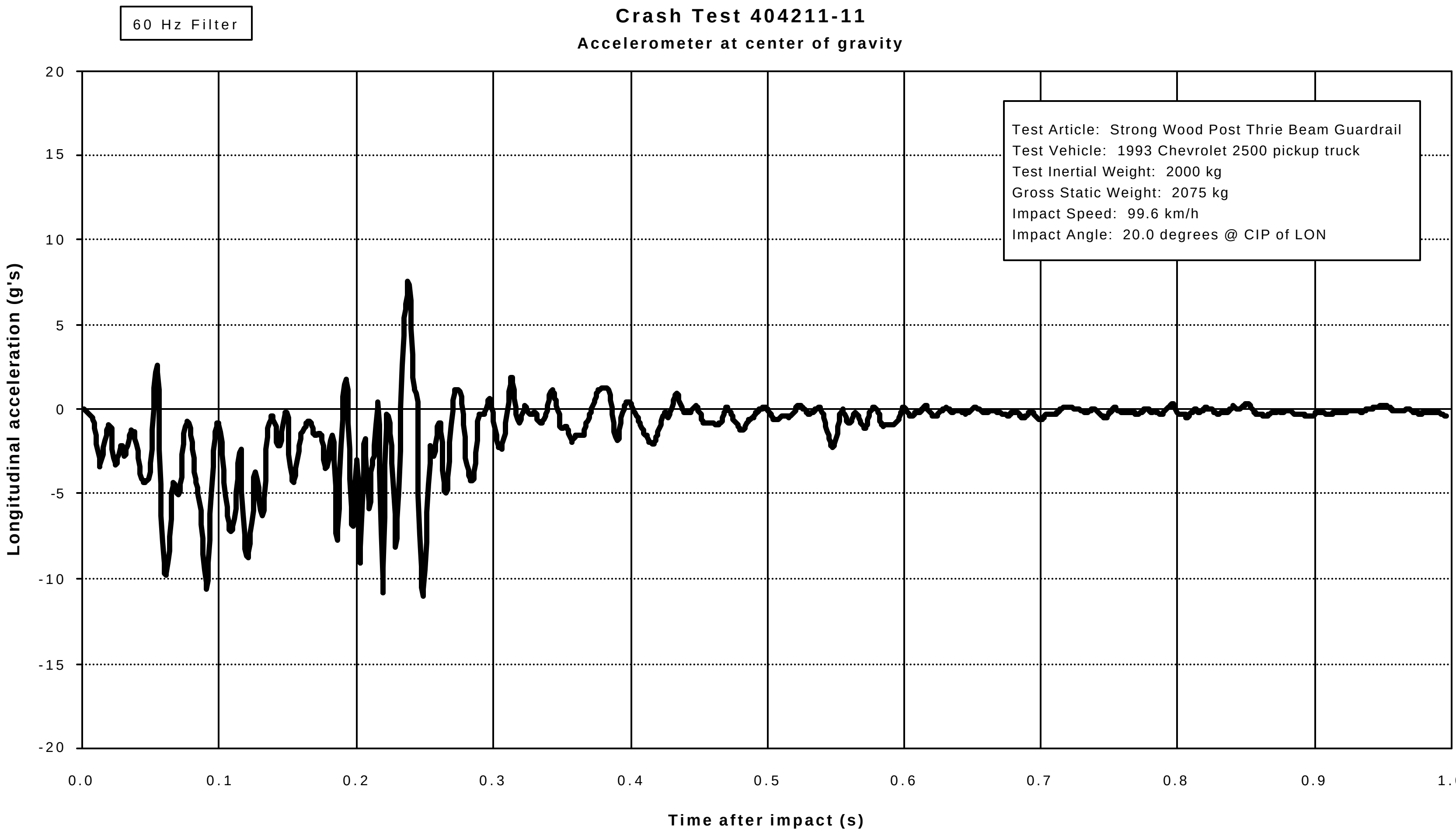


Figure 116. Vehicle longitudinal accelerometer trace for test 404211-11 (accelerometer located at center of gravity).

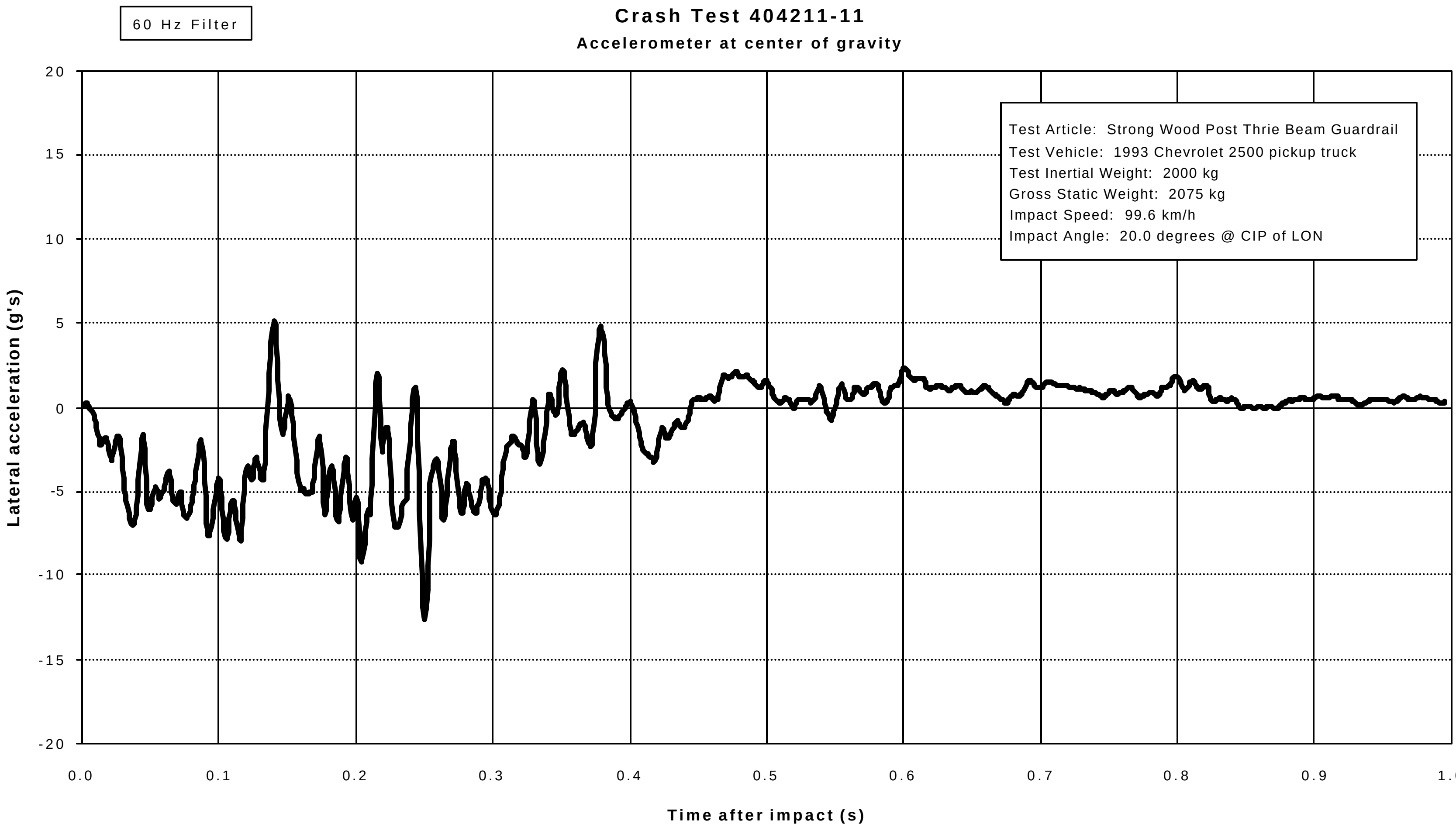


Figure 117. Vehicle lateral accelerometer traces for test 404211-11 (accelerometer located at center of gravity).

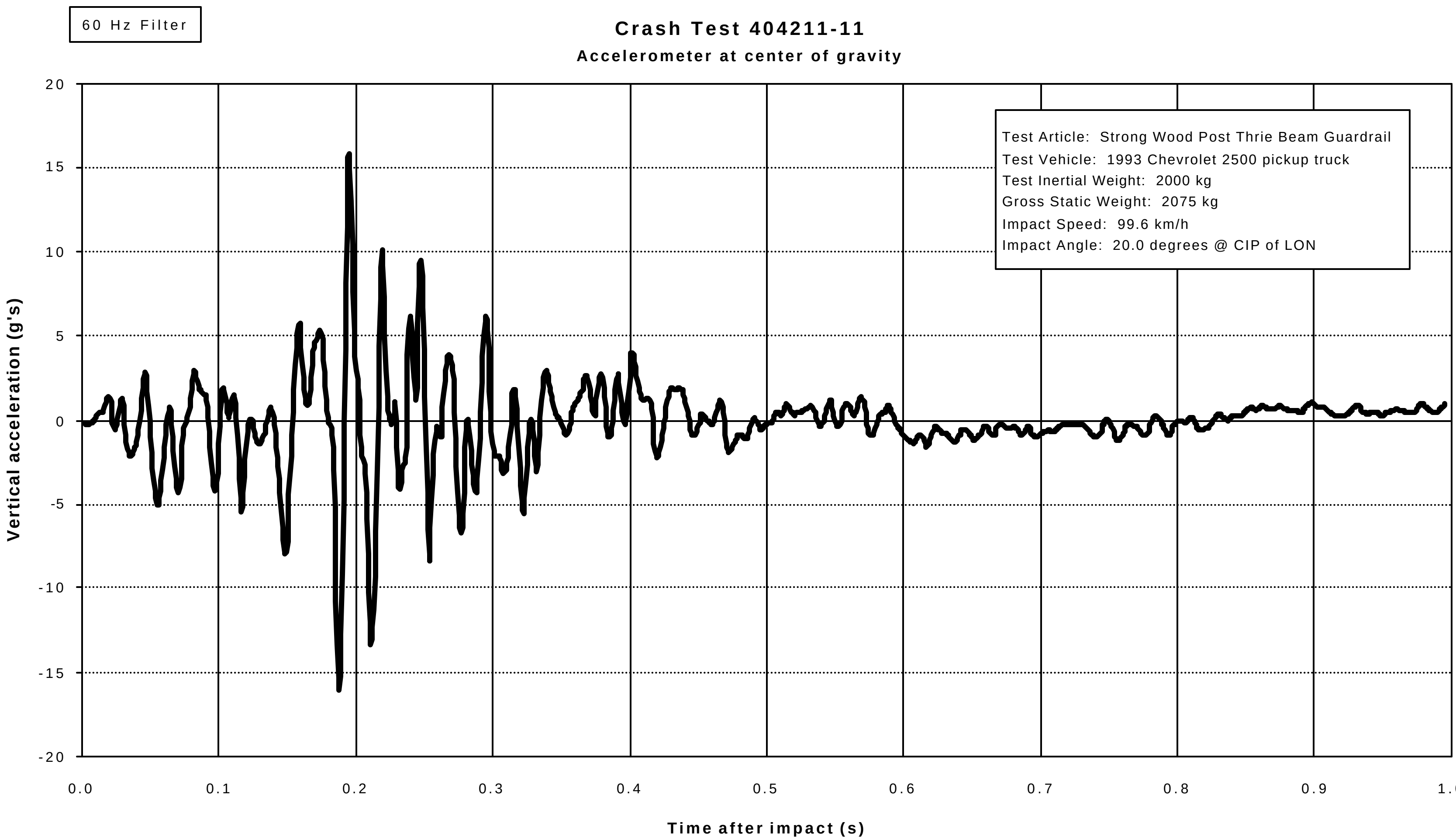


Figure 118. Vehicle vertical accelerometer trace for test 404211-11 (accelerometer located at center of gravity).

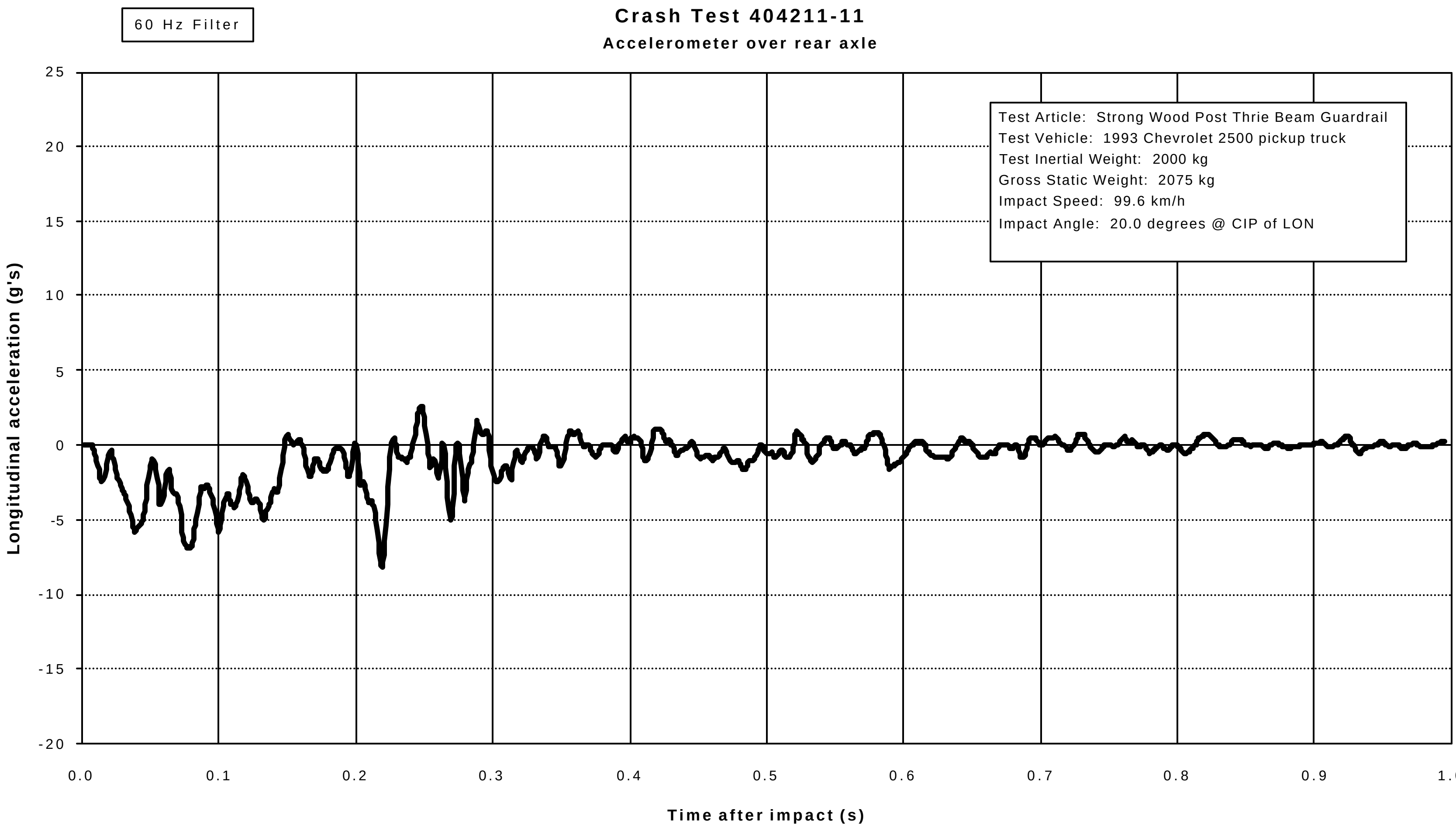


Figure 119. Vehicle longitudinal accelerometer trace for test 404211-11 (accelerometer located over rear axle).

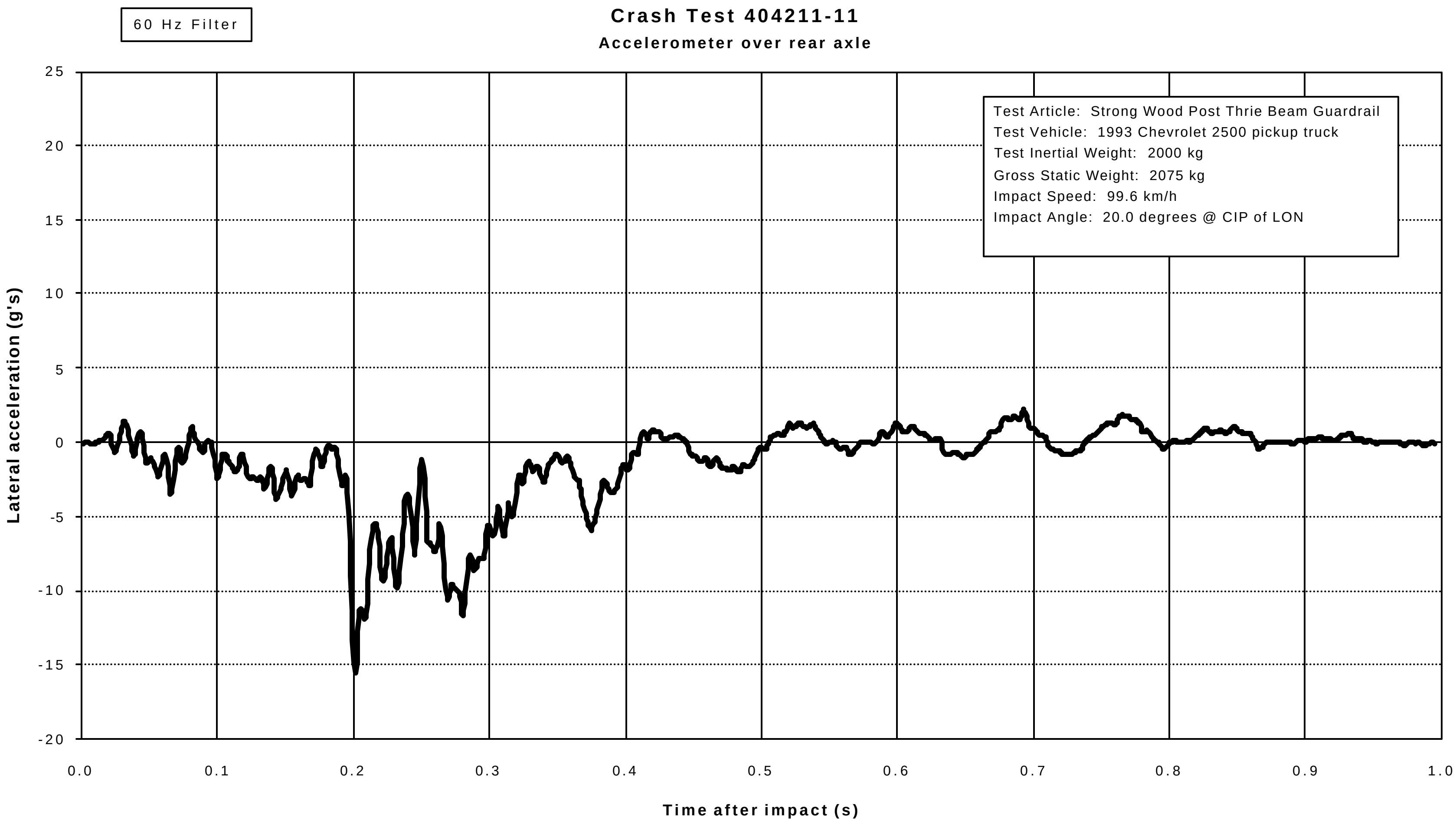


Figure 120. Vehicle lateral accelerometer traces for test 404211-11 (accelerometer located over rear axle).

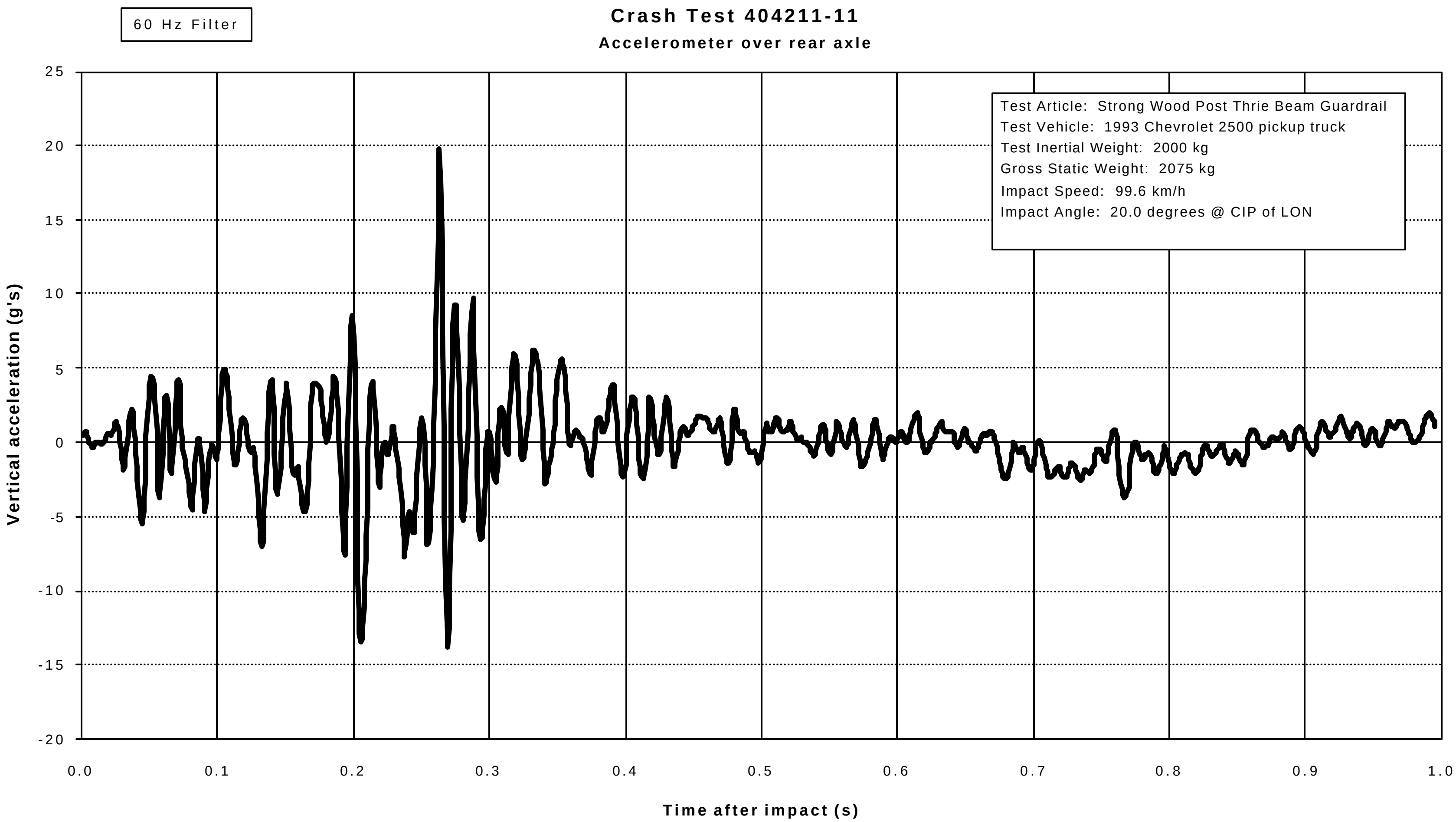


Figure 121. Vehicle vertical accelerometer traces for test 404211-11 (accelerometer located over rear axle).

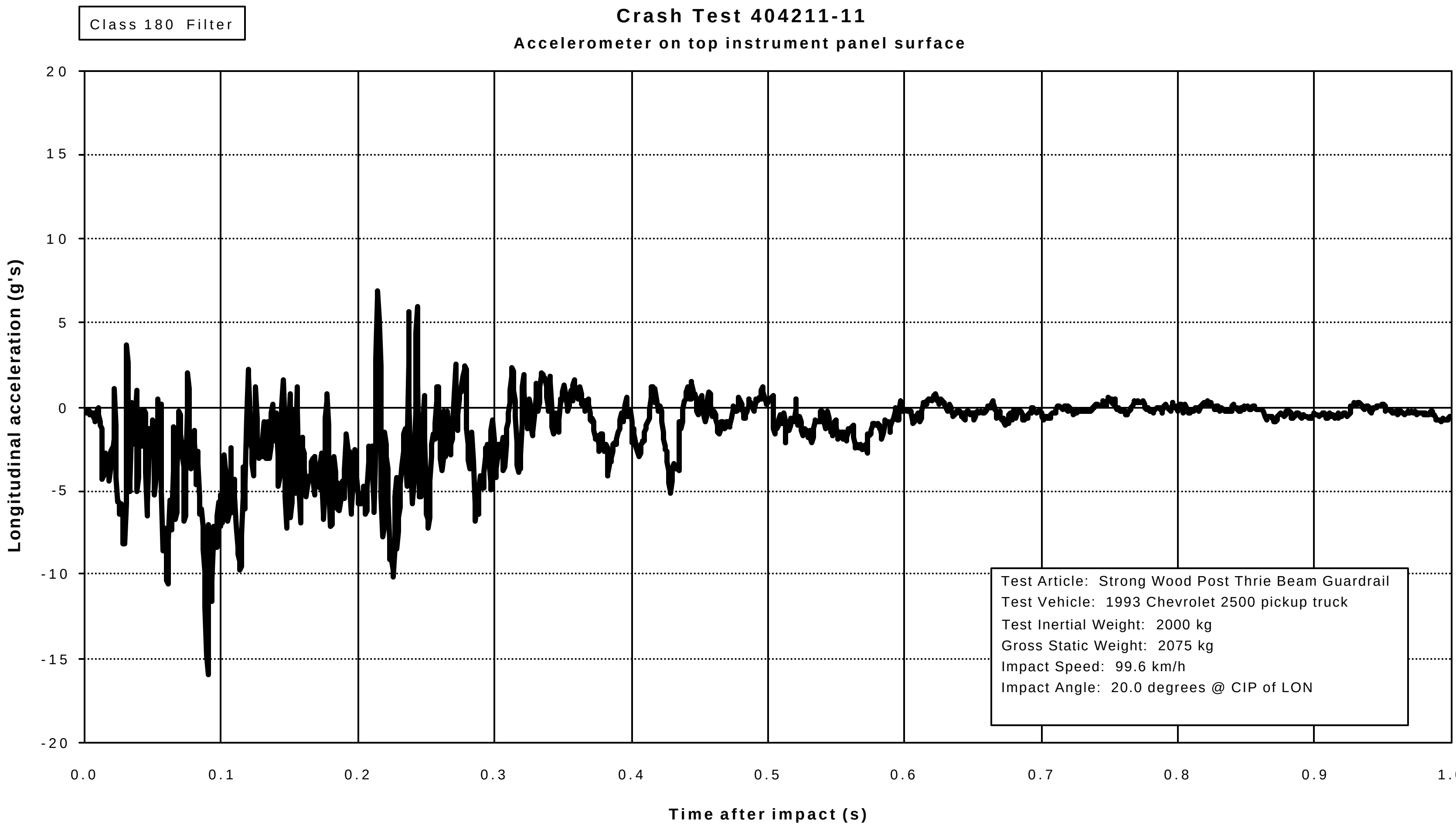


Figure 122. Vehicle longitudinal accelerometer trace for test 404211-11 (accelerometer located on top surface of instrument panel).

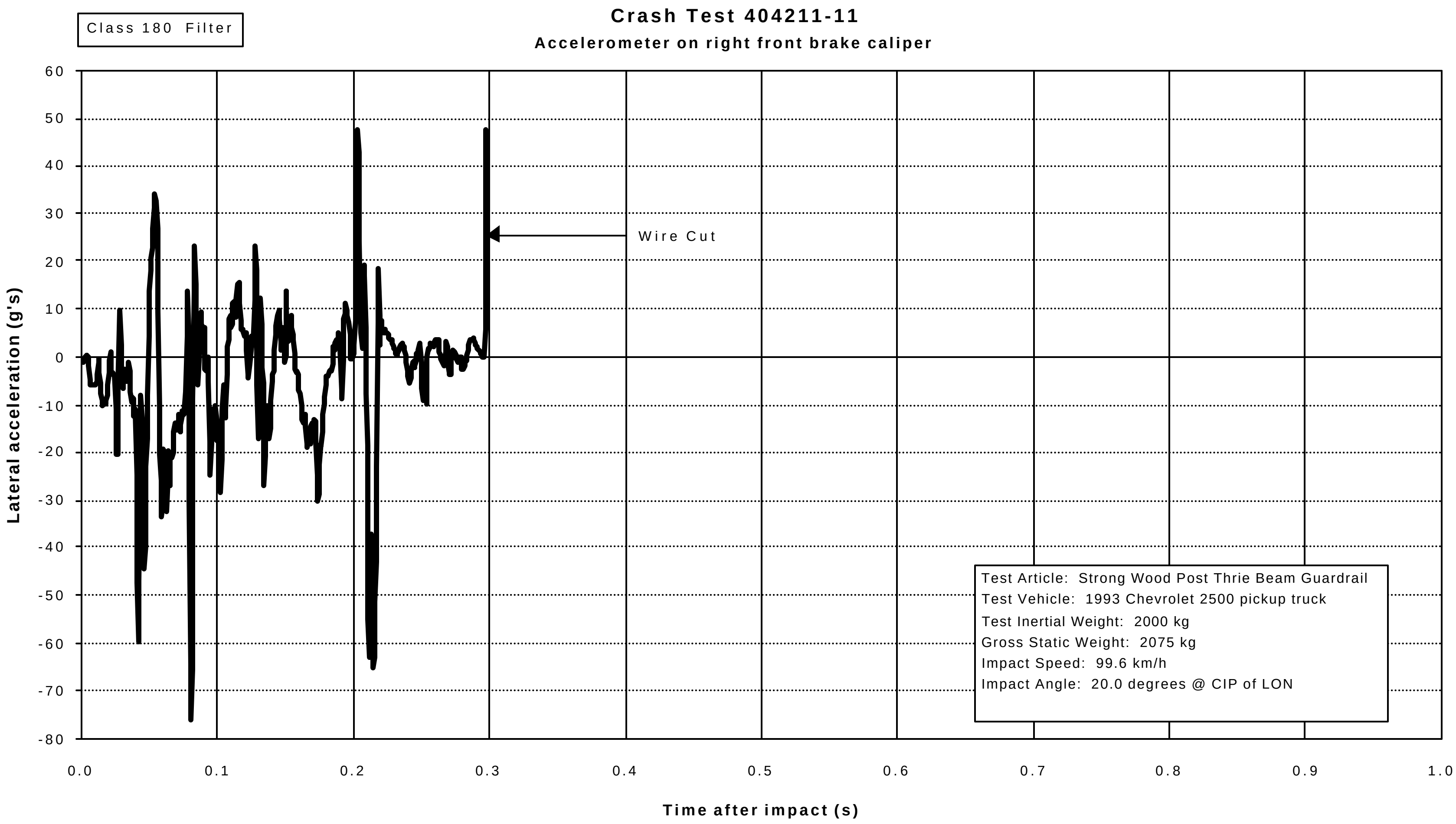


Figure 123. Vehicle lateral accelerometer trace for test 404211-11
(accelerometer located on right front brake caliper).

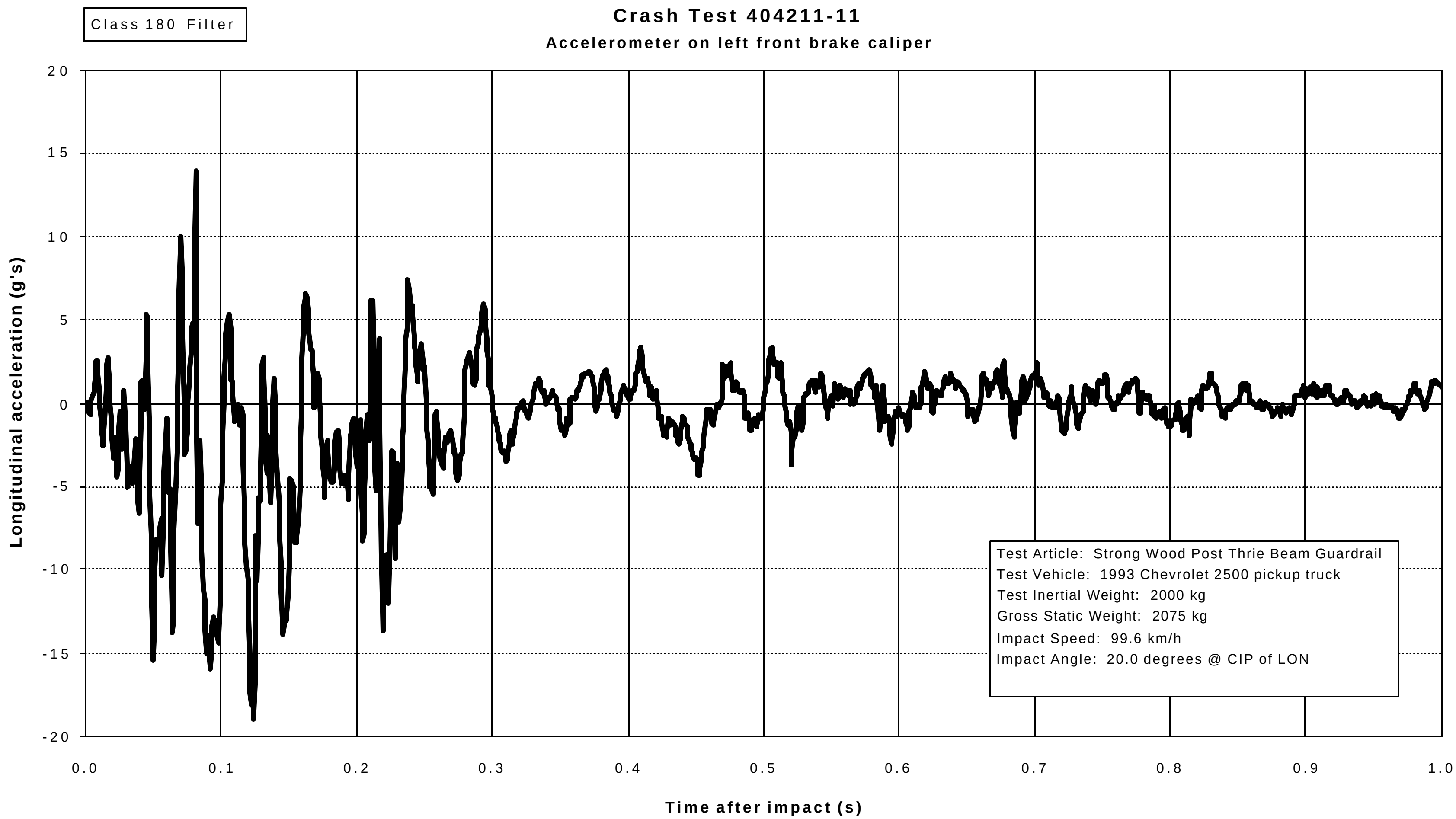


Figure 124. Vehicle longitudinal accelerometer traces for test 404211-11 (accelerometer located on left front brake caliper).

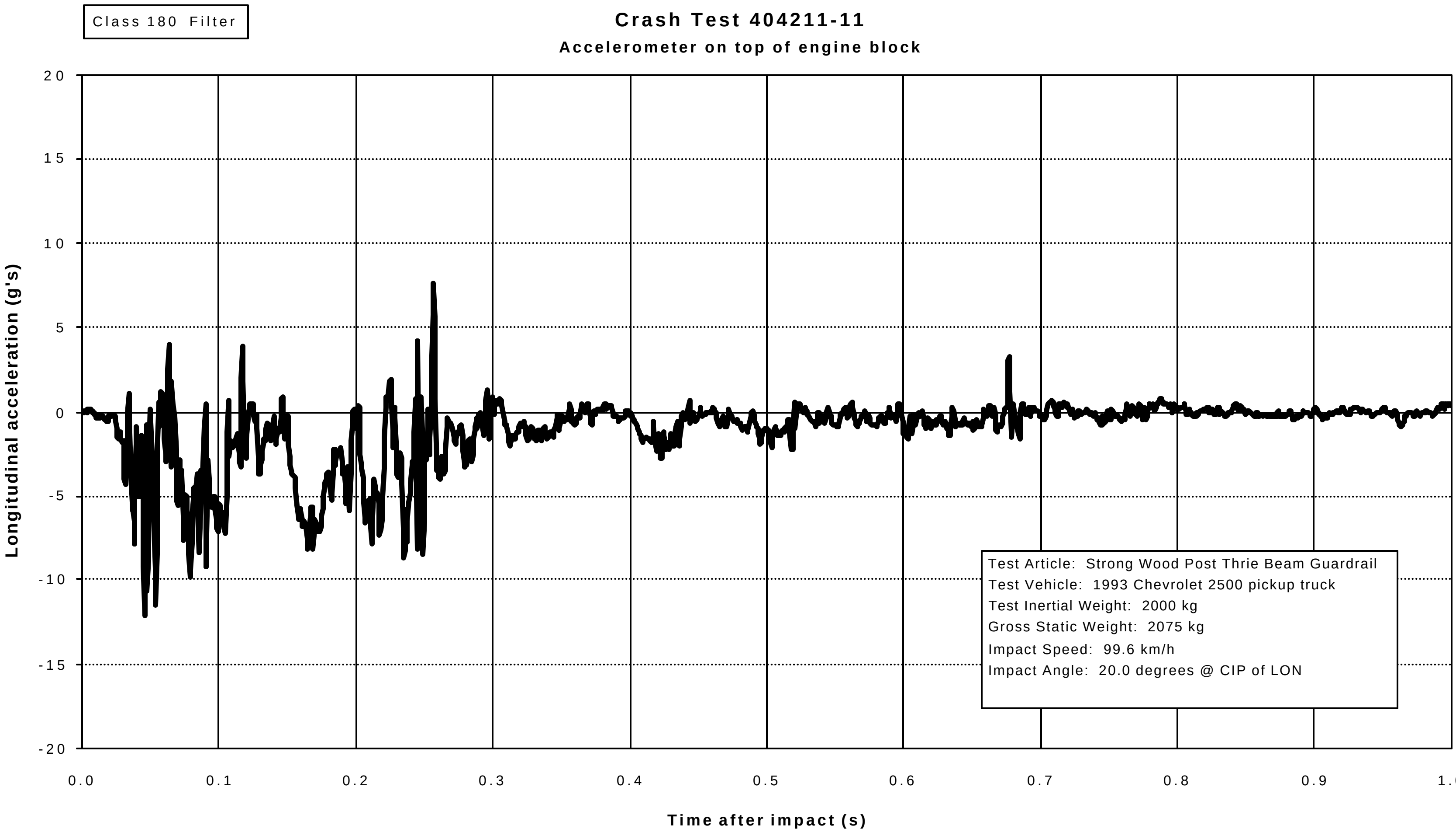


Figure 125. Vehicle longitudinal accelerometer trace for test 404211-11
(accelerometer located on top of engine block).

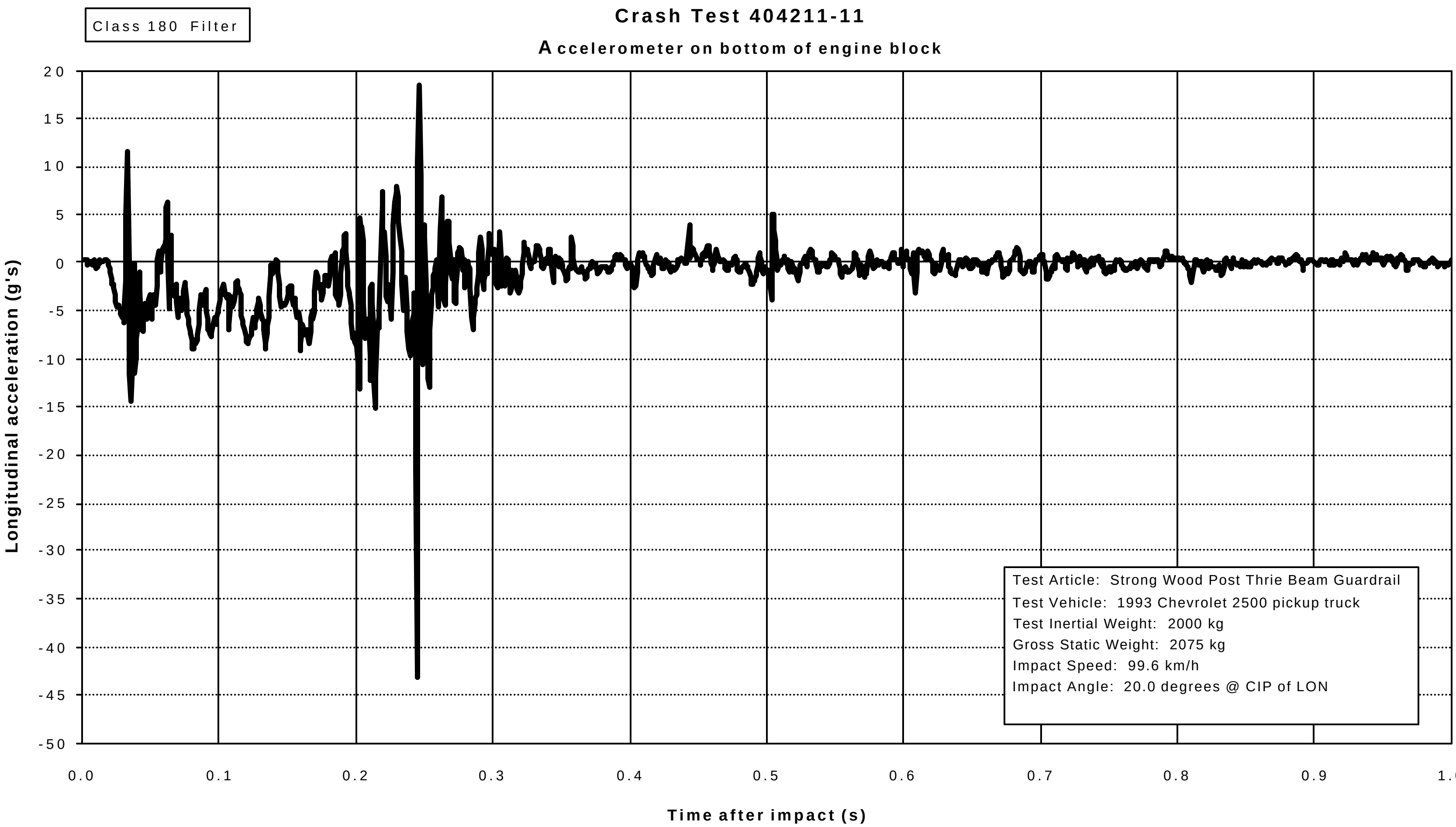


Figure 126. Vehicle longitudinal accelerometer trace for test 404211-11
(accelerometer located on bottom of engine block).

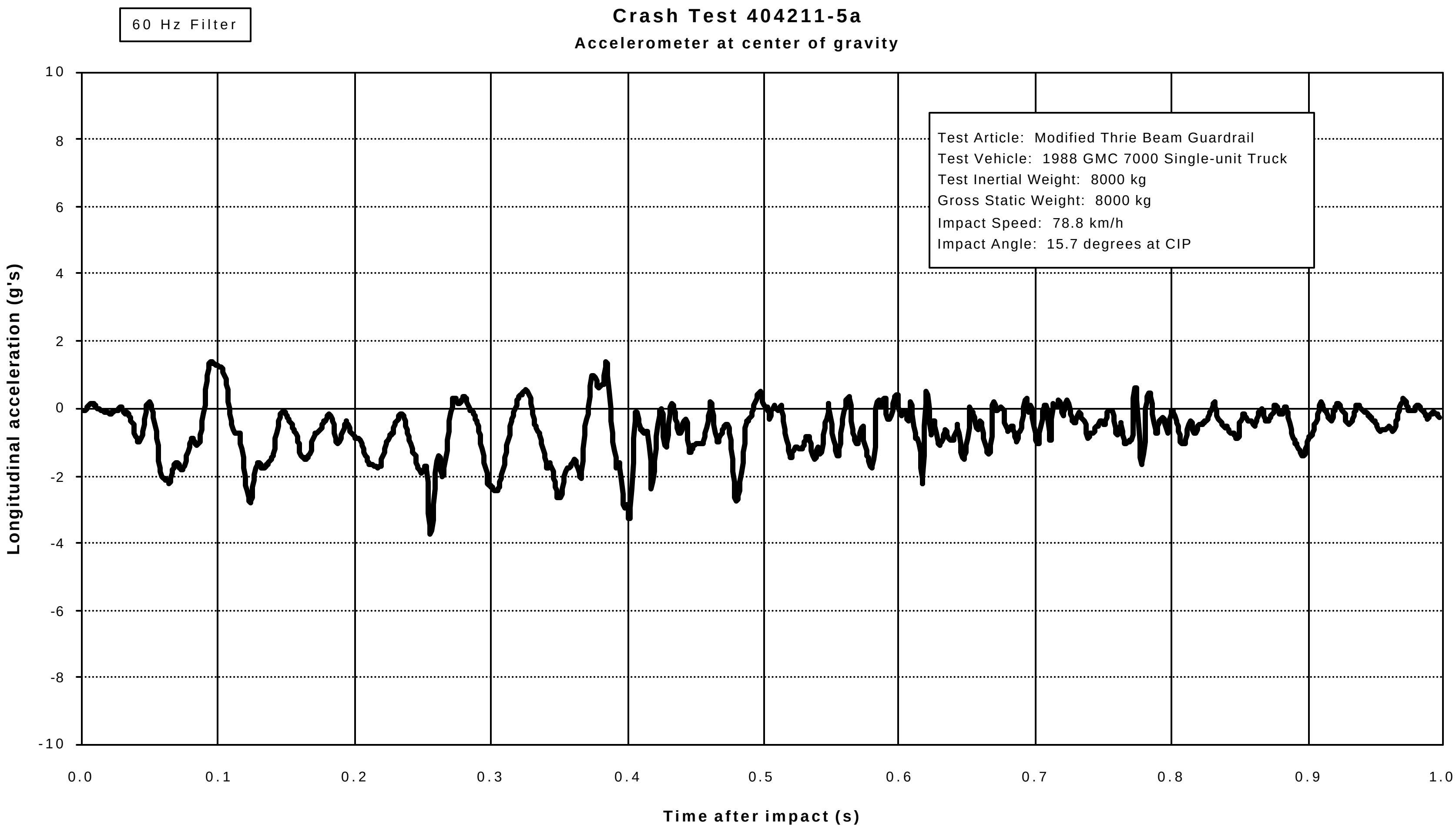


Figure 127. Vehicle longitudinal accelerometer trace for test 404211-5
(accelerometer located at center of gravity).

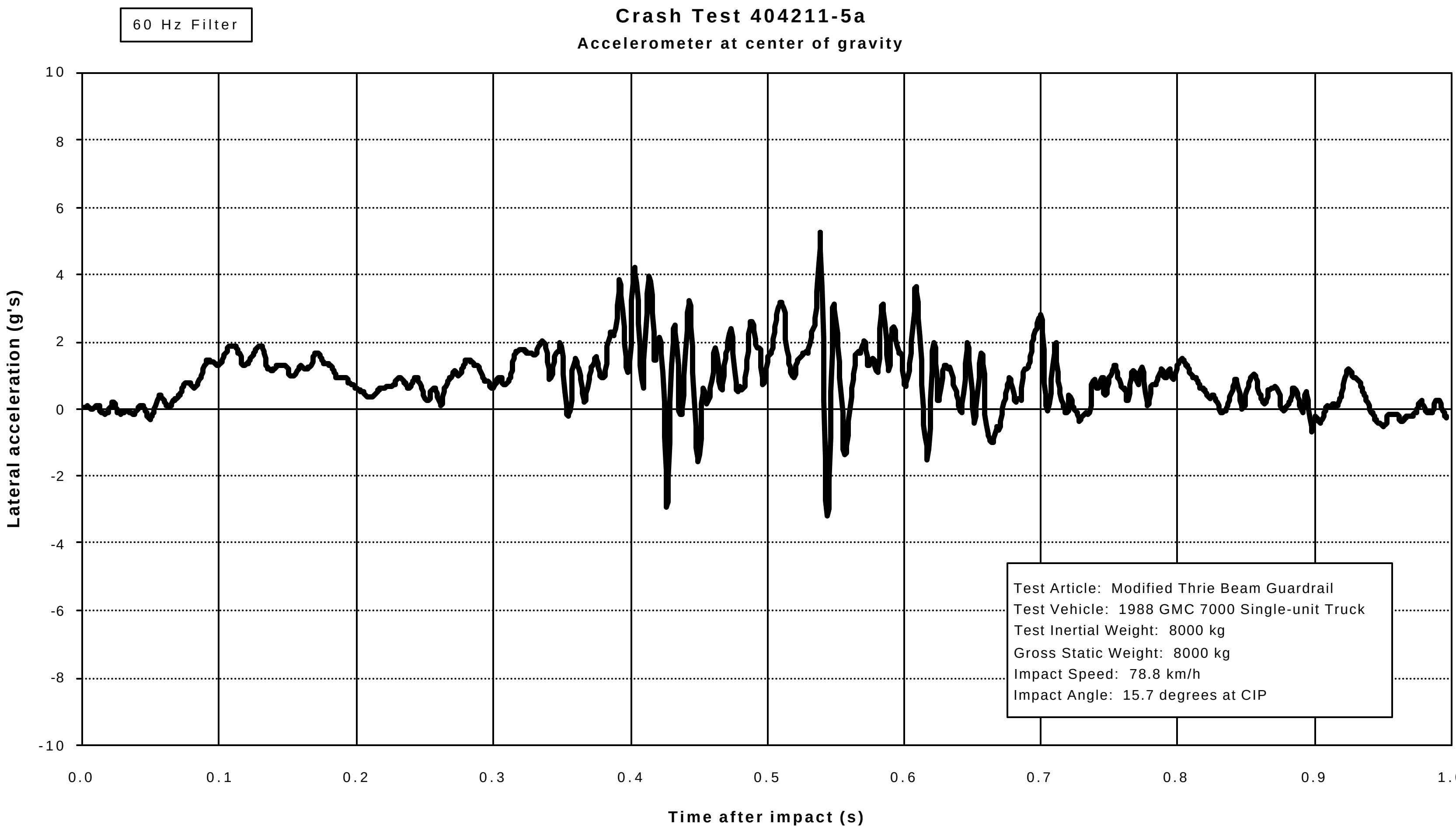


Figure 128. Vehicle lateral accelerometer traces for test 404211-5 (accelerometer located at center of gravity).

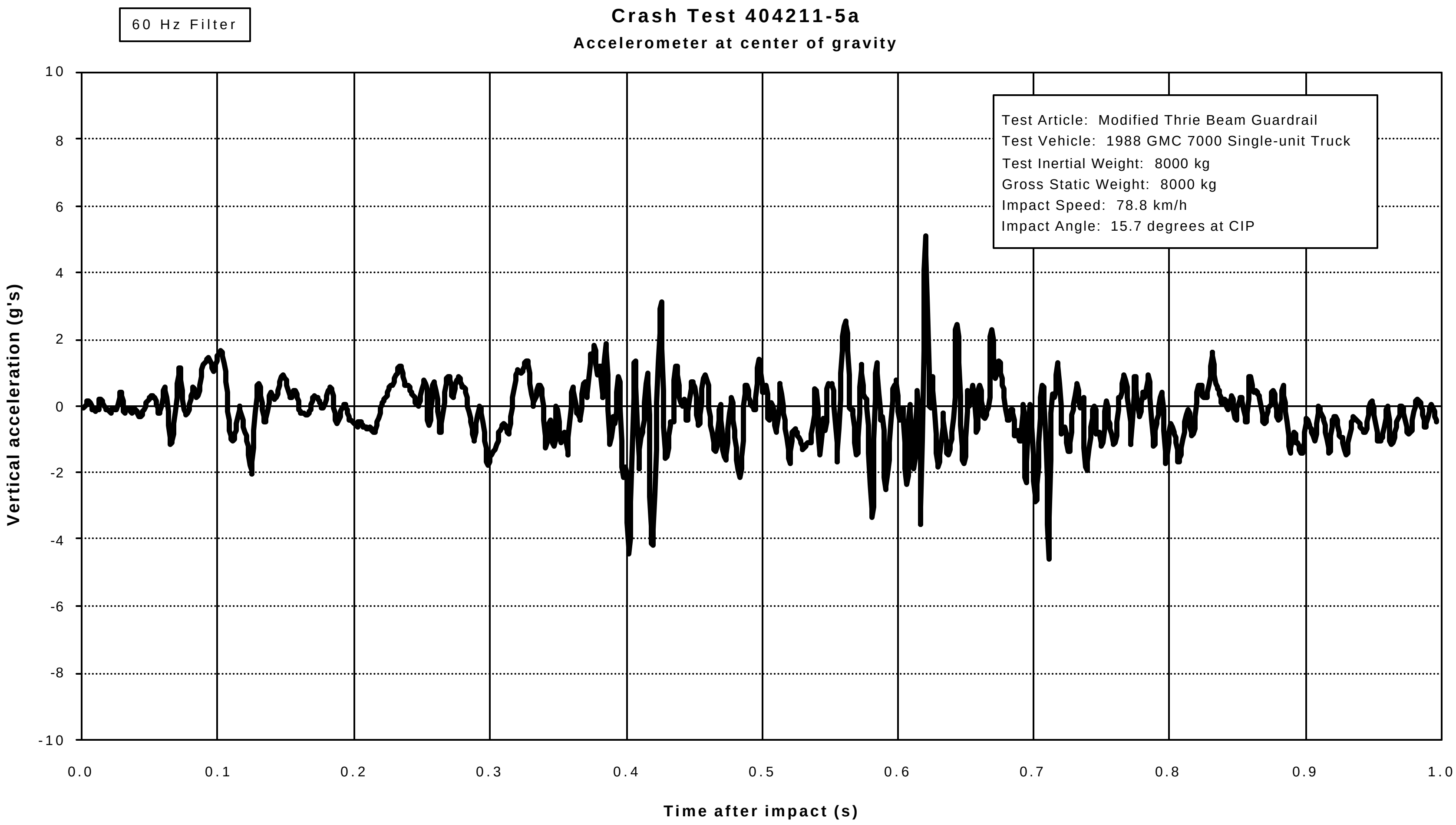


Figure 129. Vehicle vertical accelerometer trace for test 404211-5 (accelerometer located at center of gravity).

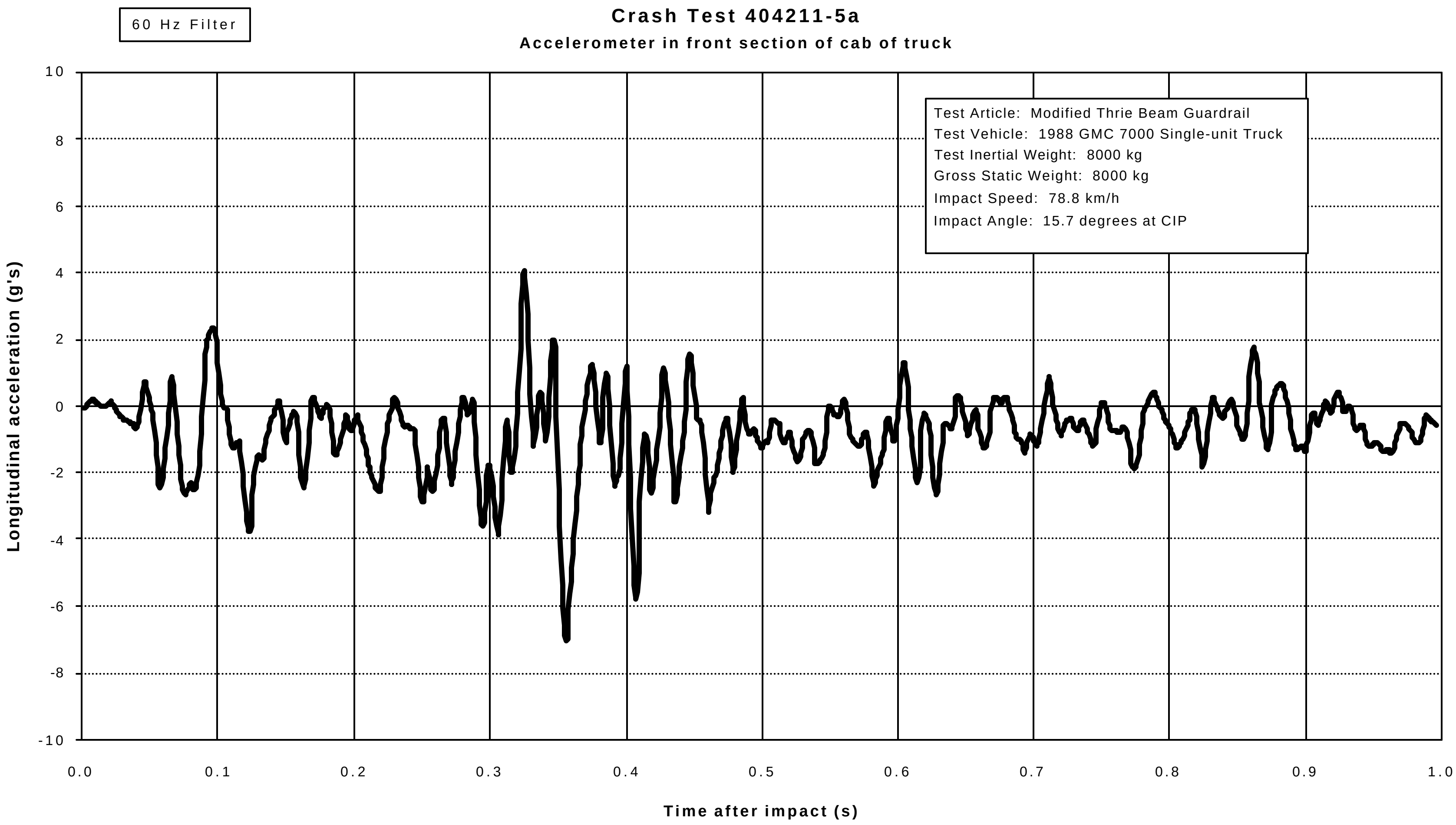


Figure 130. Vehicle longitudinal accelerometer trace for test 404211-5 (accelerometer located in front section of the cab of the vehicle).

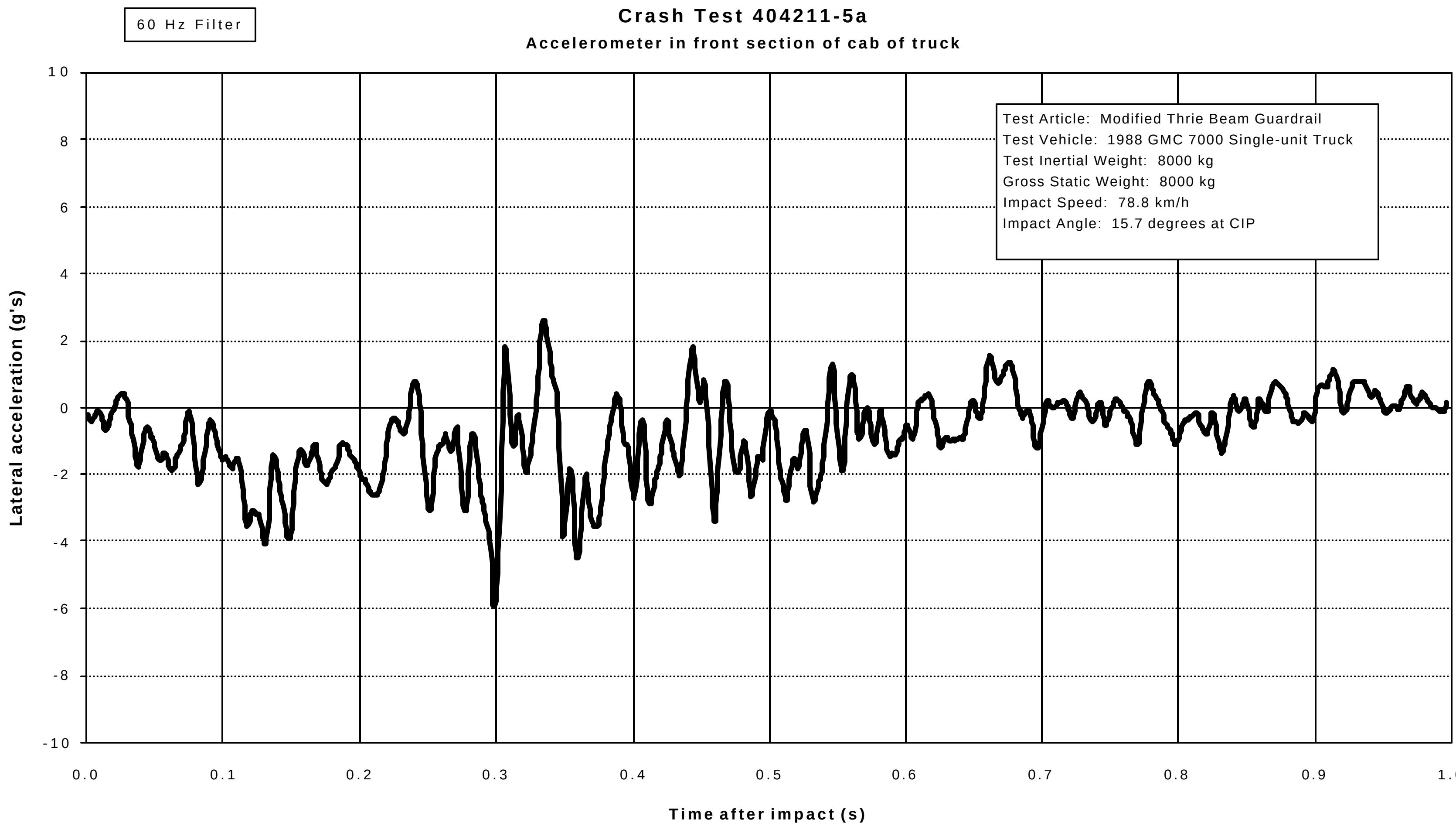


Figure 131. Vehicle lateral accelerometer traces for test 404211-5 (accelerometer located in front section of the cab of the vehicle).

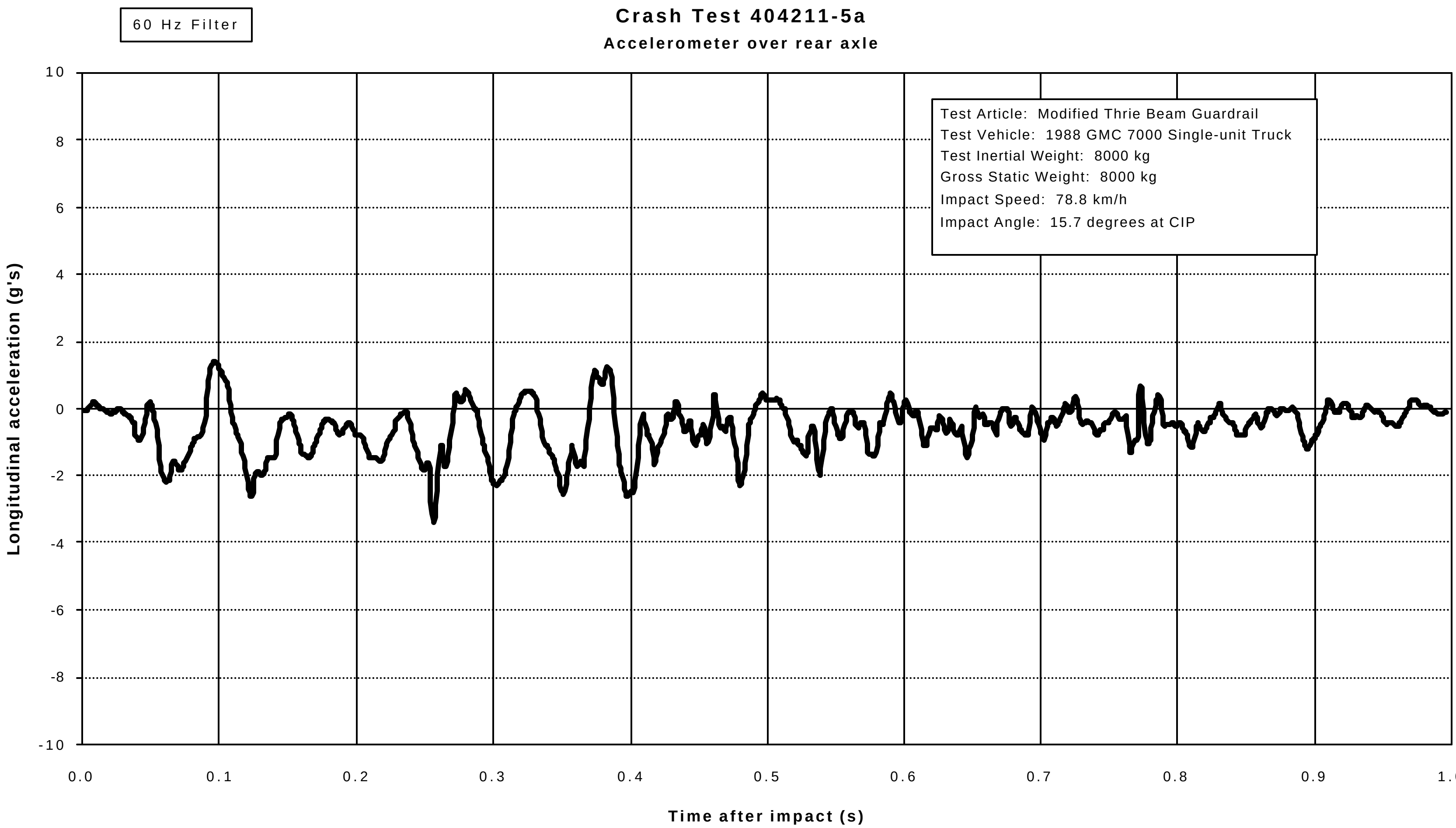


Figure 132. Vehicle longitudinal accelerometer trace for test 404211-5 (accelerometer located over rear axles).

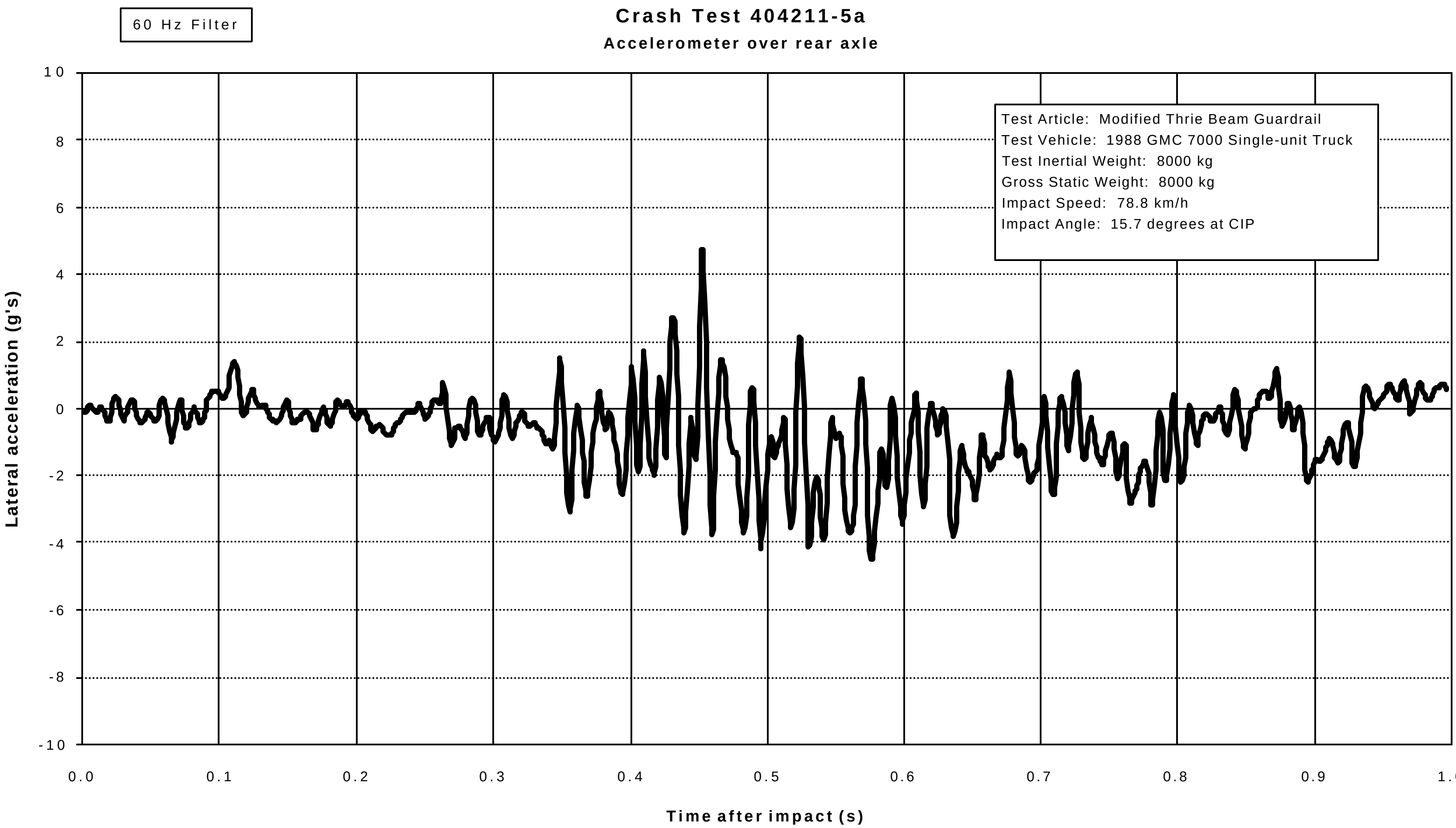


Figure 133. Vehicle lateral accelerometer traces for test 404211-5
(accelerometer located over rear axles).