NCHRT report 350 Test 3-21 of the Vertical Flared Back Transition

PUBLICATION NO. FHWA-RD-99-062 DECEMBER 1999

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

This report will be of interest to researchers and those State and local highway officials who select, locate, and design traffic barriers. It documents the results of a crash test of a transition from a W-beam guardrail to a vertical flared back concrete end section. The test was conducted with a 2000-kg pickup truck impacting the critical impact point of the transition at a nominal speed and angle of 100 km/h and 25 degrees. Damage to the transition section was moderate. However, the pickup truck rolled over after impact. It was found that the test results did not meet all of the required criteria for test no. 3-21 in NCHRP Report 350.

Michael F. Trentacoste

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

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-99-062		

4. Title and Subtitle	5. Report Date
NCHRP REPORT 350 TEST 3-21 OF THE VERTICAL FLARED BACK TRANSITION	
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
C. Eugene Buth, Wanda L. Menges, and Barbara G. Butler	404211-4
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. DTFH61-97-C-00039
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Federal Highway Administration Office of Safety and Traffic Operations Research and Development 6300 Georgetown Pike McLean, VA 22101-2296	Test Report July 1997 - September 1998
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Federal Highway Administration.
Research Study Title: Assessment of Existing Roadside Safety Hardware - II
Contracting Officer’s Technical Representative (COTR): Charles F. McDevitt - HSR-20

16. Abstract

Few transitions have been tested to NCHRP Report 350 standards. Officials at FHWA decided that the W-Beam with W-Beam Rub Rail and Steel Posts Transition to the Vertical Flared Back Concrete Bridge Rail should be tested to test level three (TL-3). The test performed (test designation 3-21) involves the 2000P (pickup truck) traveling at a nominal speed and angle of 100 km/h and 25 degrees impacting the critical impact point. This test is intended to evaluate the strength of the section in containing and redirecting the pickup truck.

This report presents the details and results of NCHRP Report 350 test designation 3-21 for evaluation of the W-Beam with W-Beam Rub Rail and Steel Posts Transition to the Vertical Flared Back Concrete Bridge Rail to TL-3. The W-Beam with W-Beam Rub Rail and Steel Posts Transition to the Vertical Flared Back Concrete Bridge Rail did not meet required criteria K and F of NCHRP Report 350 test designation 3-21.

17. Key Words	18. Distribution Statement
Bridge rail, transition, crash testing, roadside safety.	No restrictions. This document is available to the public through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	51	

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

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		
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		
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)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

The Federal Highway Administration (FHWA) has recently adopted the new performance evaluation guidelines for roadside safety features set forth in National Cooperative Highway Research Program (NCHRP) Report 350.[1] In addition, FHWA has required that all new roadside safety features to be installed on the National Highway System (NHS) after September 1998 meet the NCHRP Report 350 performance evaluation guidelines. Most of the existing roadside safety features were tested according to the previous guidelines contained in NCHRP Report 230.[2] Testing existing roadside safety features to evaluate how they would perform under the new guidelines is, therefore, necessary.

Few transitions have been tested to NCHRP Report 350 standards. Officials at FHWA decided that the W-Beam with W-Beam Rub Rail and Steel Posts Transition to the Vertical Flared Back Concrete Bridge Rail should be tested to test level three (TL-3). The test performed (test designation 3-21) involves the 2000P (pickup truck) traveling at a nominal speed and angle of 100 km/h and 25 degrees impacting the critical impact point. This test is intended to evaluate the strength of the section in containing and redirecting the pickup truck.

This report presents the details and results of NCHRP Report 350 test designation 3-21 for evaluation of the W-Beam with W-Beam Rub Rail and Steel Posts Transition to the Vertical Flared Back Concrete Bridge Rail to TL-3. The W-Beam with W-Beam Rub Rail and Steel Posts Transition to the Vertical Flared Back Concrete Bridge Rail did not meet required criteria K and F of NCHRP Report 350 test designation 3-21.

II. STUDY APPROACH

TEST ARTICLE

This test was performed on the W-Beam with W-Beam Rub Rail and Steel Posts Transition to the Vertical Flared Back Concrete Bridge Rail. Drawings for this transition are presented in figures 1 through 4, and photographs of the test installation are shown in figures 5 and 6.

The test installation consisted of a portion of simulated bridge rail, a wingwall, a transition, a length of approach guardrail, and a guardrail terminal.

The concrete safety shape simulated bridge rail was 2440 mm long and had a foundation wall that extended 940 mm below grade. The wingwall extended from the simulated bridge rail a longitudinal distance of 3900 mm. The wingwall was embedded 2300 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 x 200 wood blockouts. Mounting height to the top of the rail element was 685 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 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 were W200x19x2290 long and were embedded 1605 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.

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. Additional details for the transition, including the rubrail, posts, and connections, are shown in figures 3 and 4.

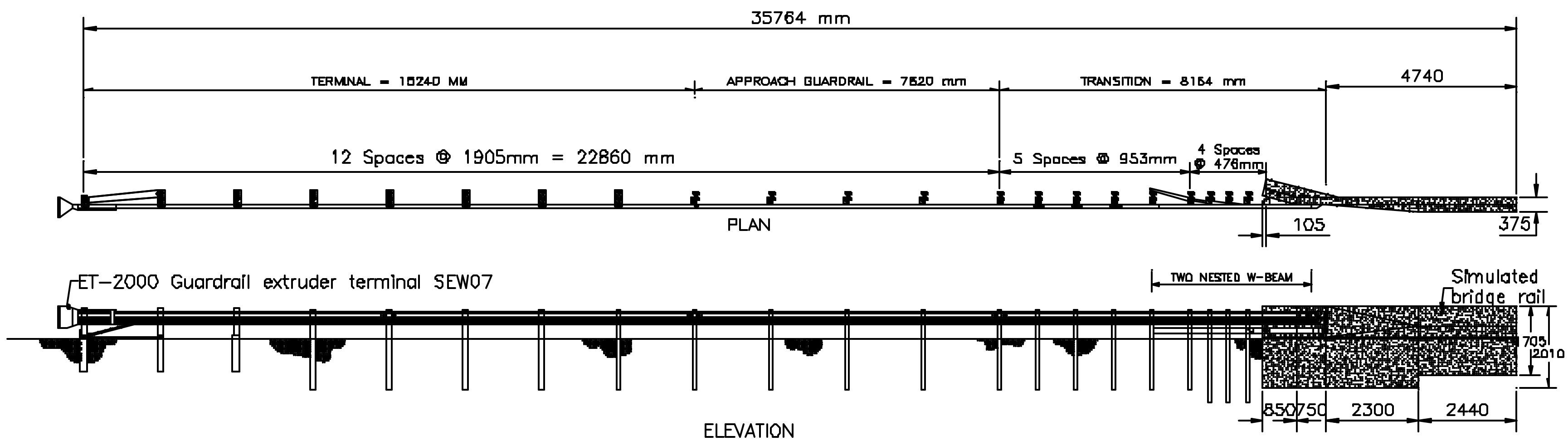


Figure 1. Layout of the vertical flared back transition.

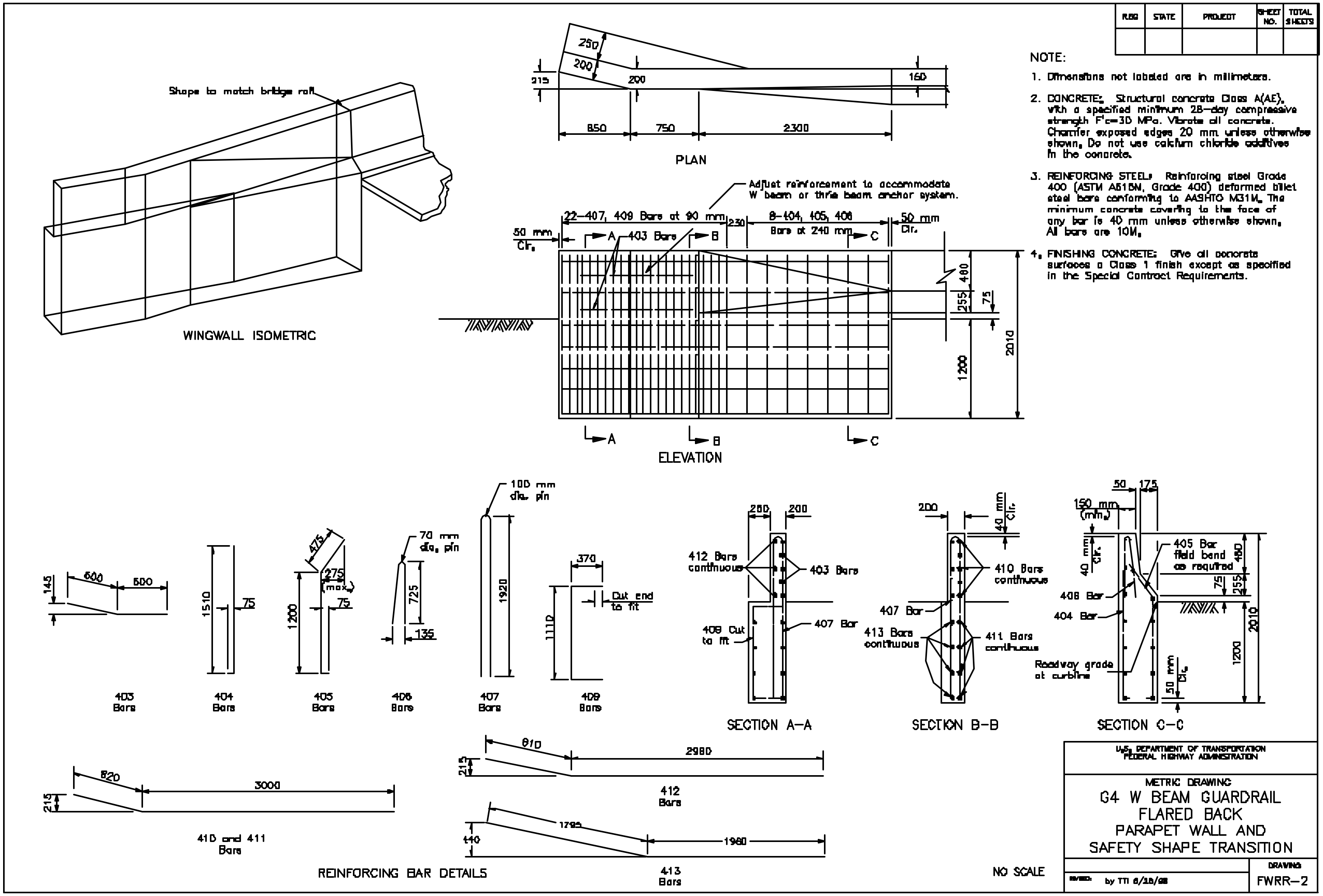


Figure 2. Details of the flared back parapet wall and safety shape transition.

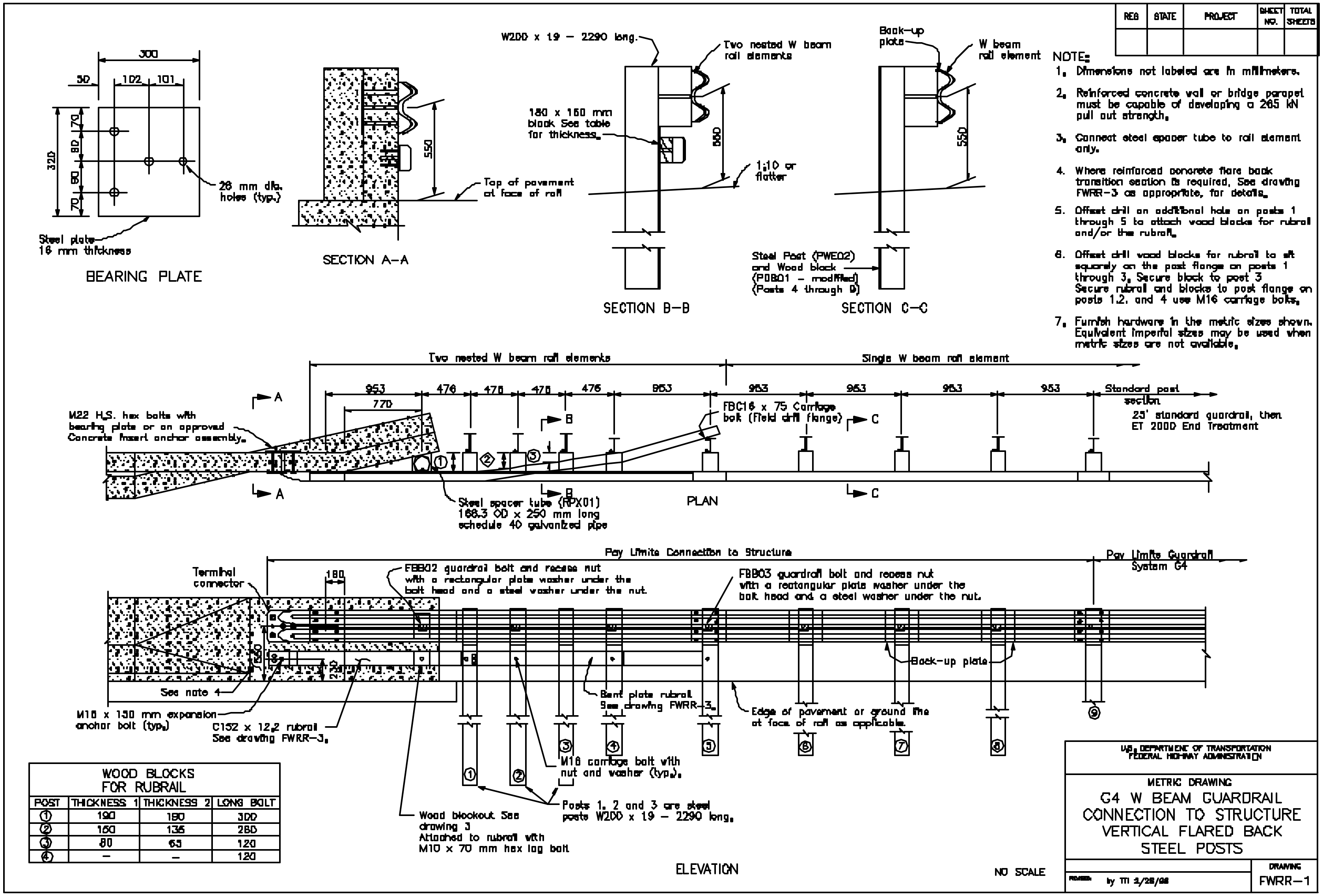


Figure 3. Details of the connection to structure, steel posts.

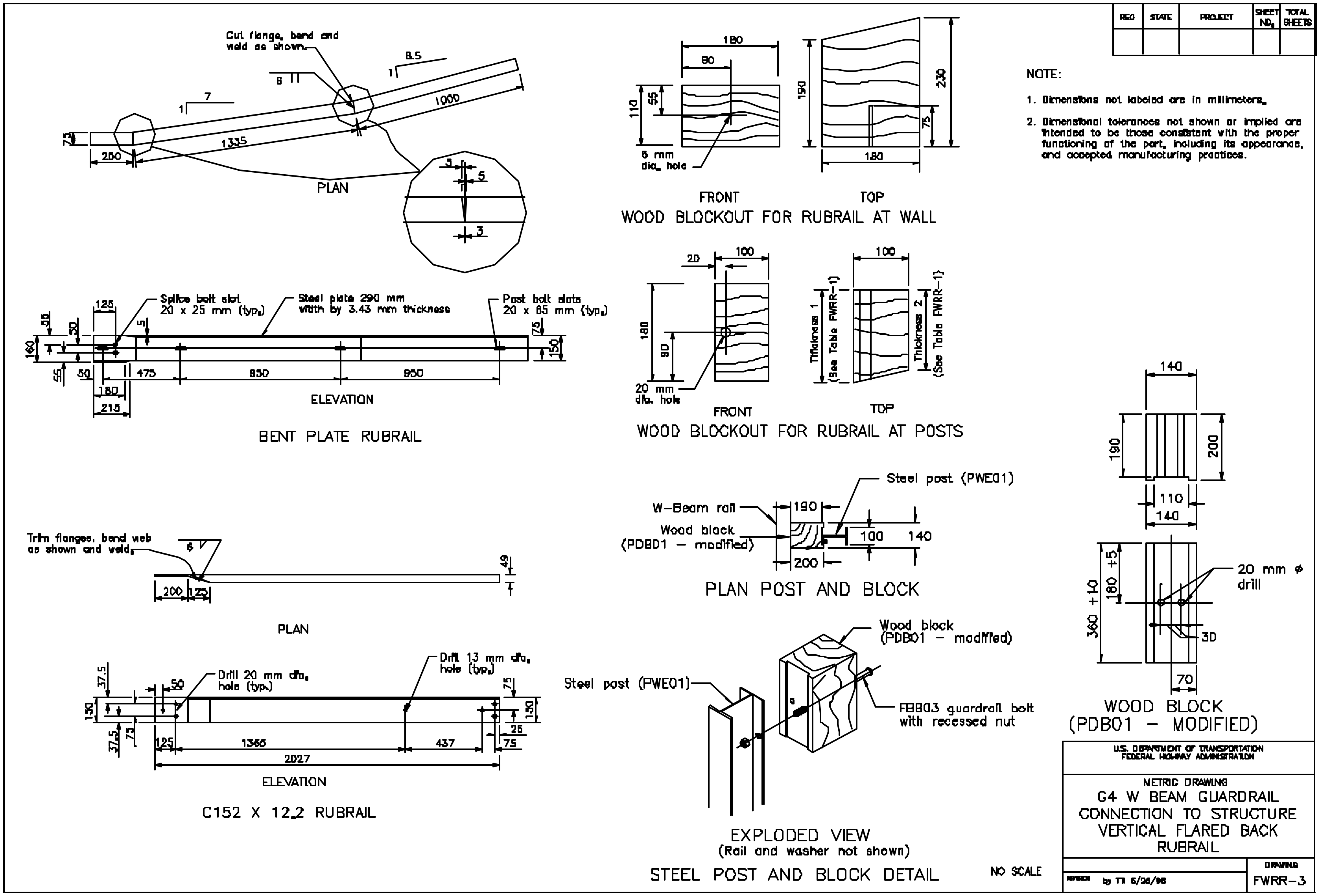


Figure 4. Details of the connection to structure, rub rail.

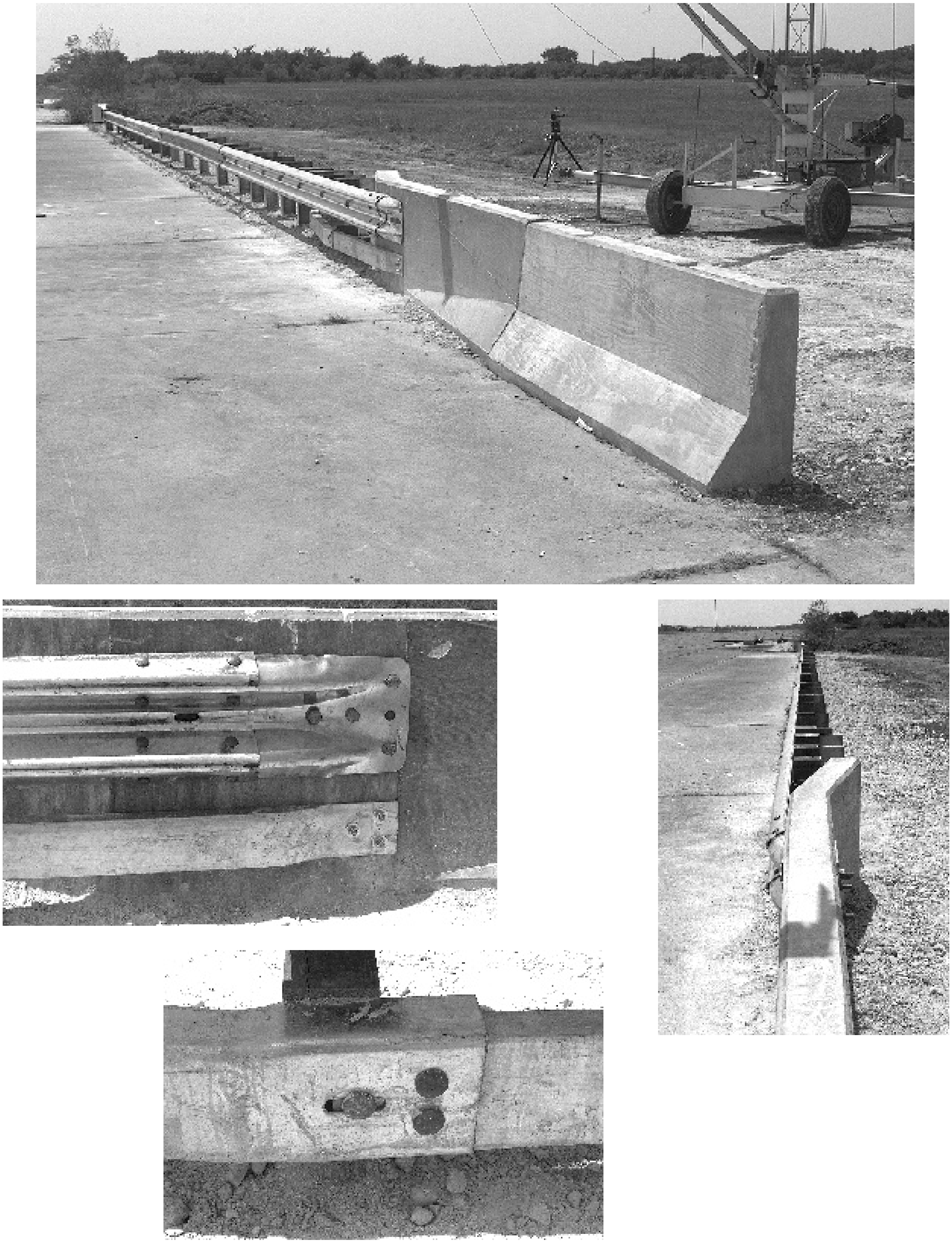


Figure 5. Vertical flared back transition before test 404211-4.

Figure 6. Details on field side of installation.

CRASH TEST CONDITIONS

The following test conditions are required to evaluate a transition to test level three (TL-3) of NCHRP Report 350.

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

As recommended in NCHRP Report 350, the BARRIER VII simulation program was used to select the CIP for this test. The program indicated the CIP to be 1.5 m from the end of the vertical wall concrete parapet.

EVALUATION CRITERIA

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

- **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.

- **Occupant Risk**

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

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

- **Vehicle Trajectory**

  K. After collision, it is preferable that the vehicle's trajectory 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.

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.

CRASH TEST AND DATA ANALYSIS PROCEDURES

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

Electronic Instrumentation and Data Processing

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

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

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

The 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 exact location of each accelerometer was measured and is reported in table 1. These accelerometers were ENDEVCO Model 7264A low-mass piezoresistive accelerometers with a ±2000-g range.

The data from these uniaxial accelerometers were captured using a Prosig P4000 data acquisition system. The P4000 is a modular, distributed data acquisition system based on independent data collection elements called PODs. Each POD has four high-speed analog, three digital, and time-zero inputs. The PODs sample synchronously at up to 10,000 samples per second, per channel, with 12-bit resolution. Non-volatile memory holds up to 13 s at the maximum data rate. Analog inputs have integral, strain gauge accelerometer signal conditioning and anti-aliasing filters. Each channel has a fully programmable amplifier and input offset adjustment. After extracting the data from the POD units to the host computer, fourth order, Bessel, digital filtering is used to produce SAE J211 data for processing. Data capture is started by a trigger pulse from a bumper switch or a predefined g level. Twenty-five percent of the captured data is prior to the trigger signal.

Table 1. 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

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

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

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0002-s intervals and then instructed a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

Anthropomorphic Dummy Instrumentation

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

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 was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A 16-mm movie cine, a Betacam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

Test Vehicle Propulsion and Guidance

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

III. CRASH TEST RESULTS

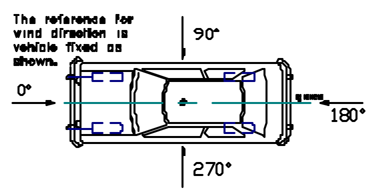
TEST 404211-4 (NCHRP REPORT 350 TEST NO. 3-21)

Test Vehicle

A 1994 Chevrolet 2500 pickup truck, shown in figures 7 and 8, 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 figure 9. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Weather and Soil Conditions

The test was performed the morning of September 3, 1998. Only a trace of rain was recorded during the 10 days prior to the test. Moisture content at posts 1, 3, and 5 was 9.1 percent, 8.9 percent, and 7.3 percent, 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 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 rear left side of the vehicle contacted the rail element between posts 3 and 4. At 0.304 s, the rear left 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 figures 10 and 11. Brakes on the vehicle were applied 8.3 s after impact.

Figure 7. Vehicle/installation geometrics for test 404211-4.

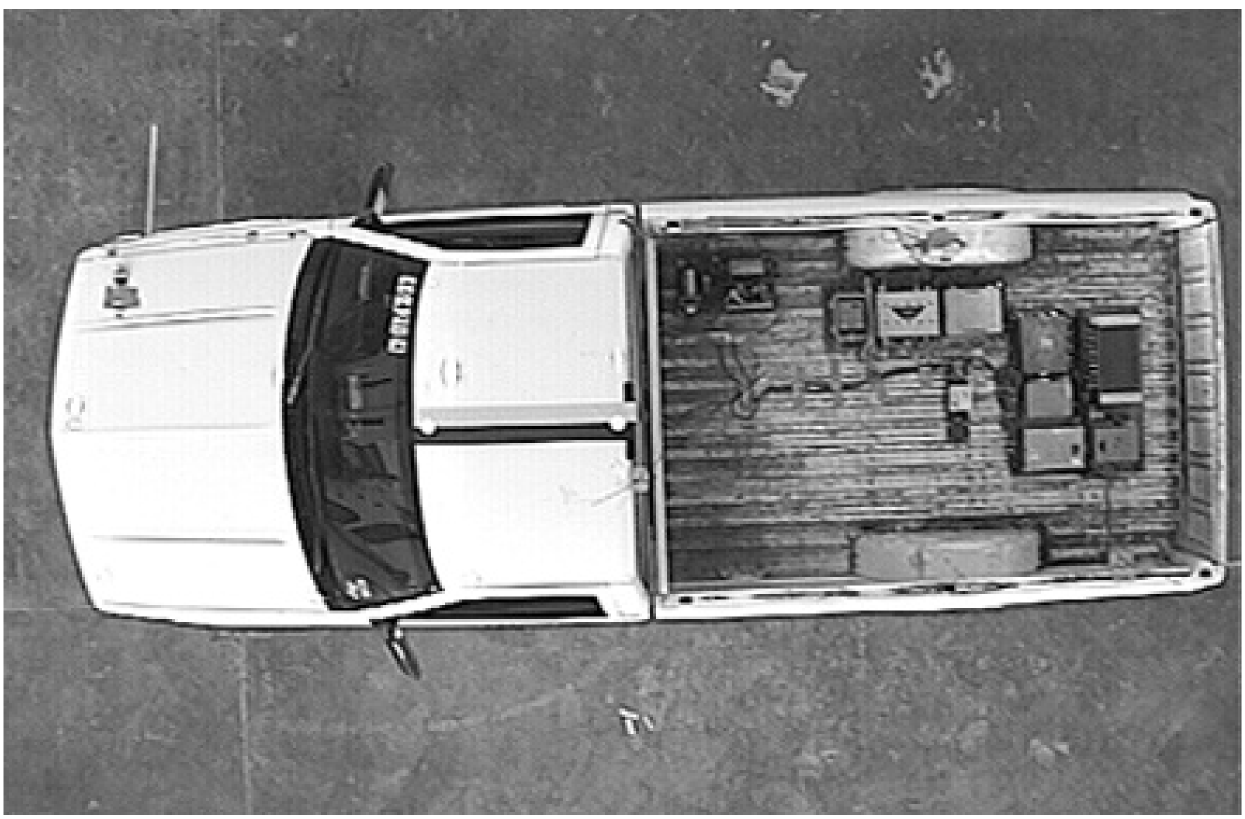


Figure 8. Vehicle before test 404211-4.

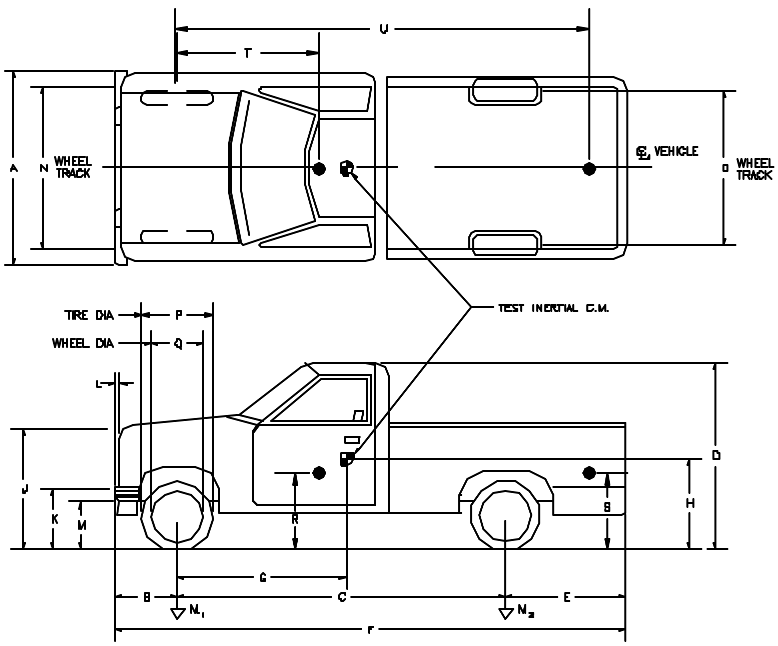
DATE: 9-3-98 | TEST NO.: 404211-4 | VIN NO.: 1GCFC24K7RE189349

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

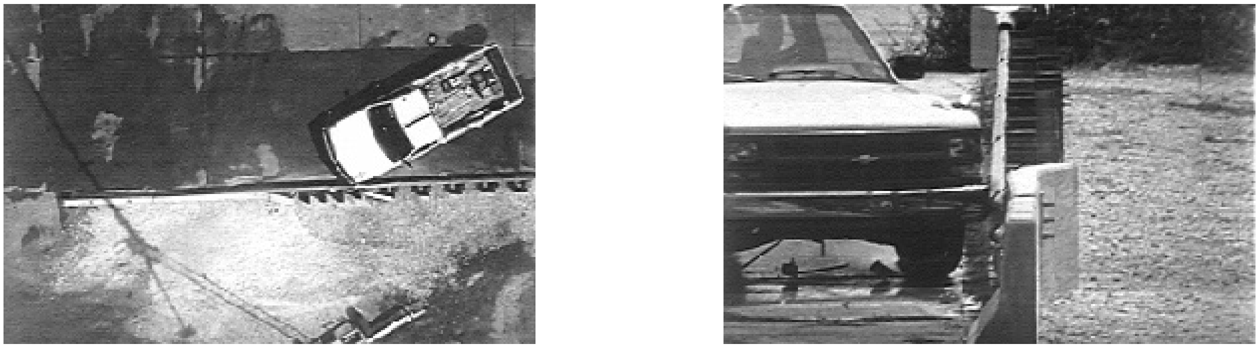
SEAT POSITION: Driver

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

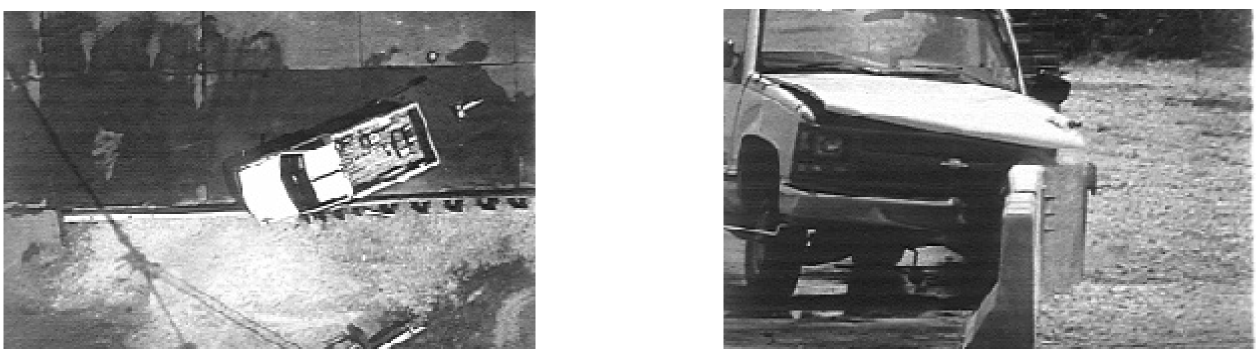
MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1092	1071	1114
M_2	773	929	960
M_T	1865	2000	2074

Figure 9. Vehicle properties for test 404211-4.

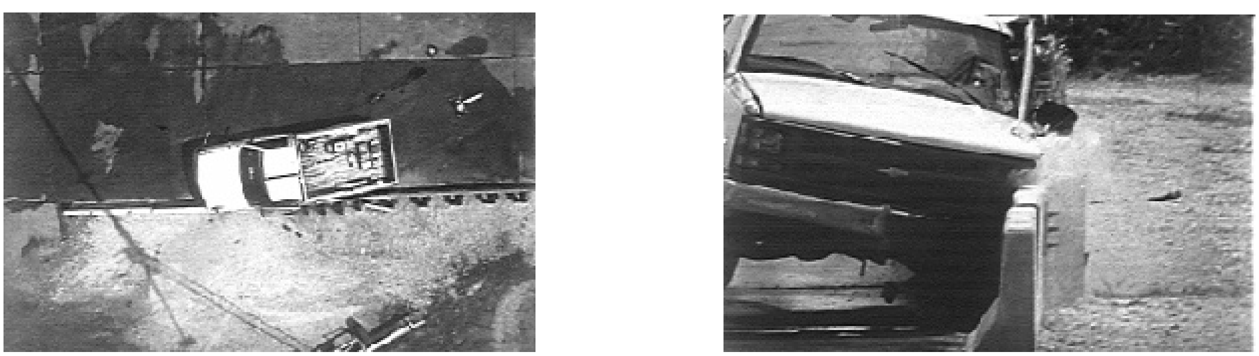


0.000 s

0.050 s

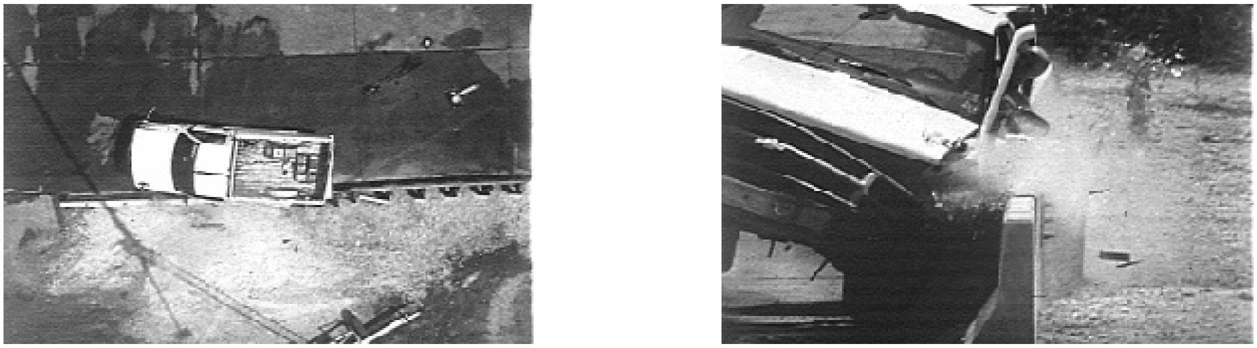


0.099 s



0.149 s

Figure 10. Sequential photographs for test 404211-4
(overhead and frontal views).



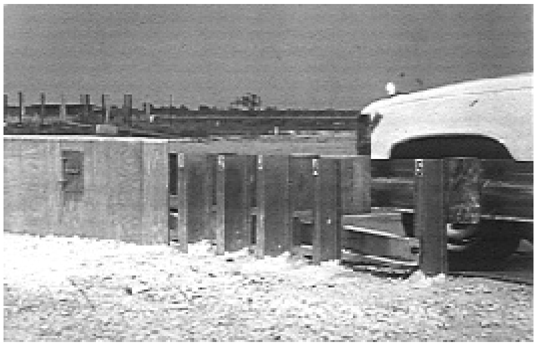
0.223 s

0.297 s

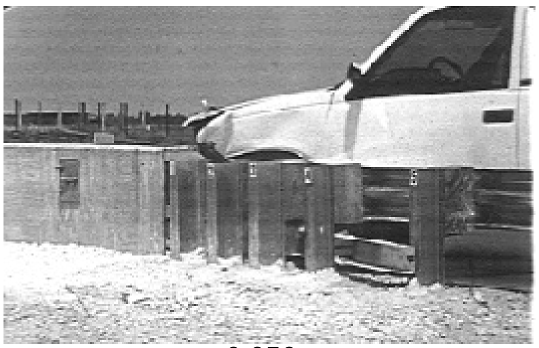
0.396 s

0.545 s

Figure 10. 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 11. Sequential photographs for test 404211-4
(rear view).

Damage to Test Installation

The vertical flared back transition received moderate damage as shown in figures 12 and 13. 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 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 14. 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 tail gate. The front bumper, grill, hood, radiator, fan, and cab were deformed. The windshield and the right, left, and rear glasses were shattered. As shown in table 2, 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 (7-percent reduction in space) in the center floor pan area and 27 mm (2-percent reduction in space) in the firewall area. Details can be found in table 3. The interior of the vehicle is shown in figure 15.

Occupant Risk Values

Data from the tri-axial accelerometer, located at the vehicle center of gravity, 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, the occupant impact velocity was 6.6 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 16. Vehicle angular displacements are displayed in figure 17. Vehicular accelerations versus time traces are presented in figures 18 through 28.

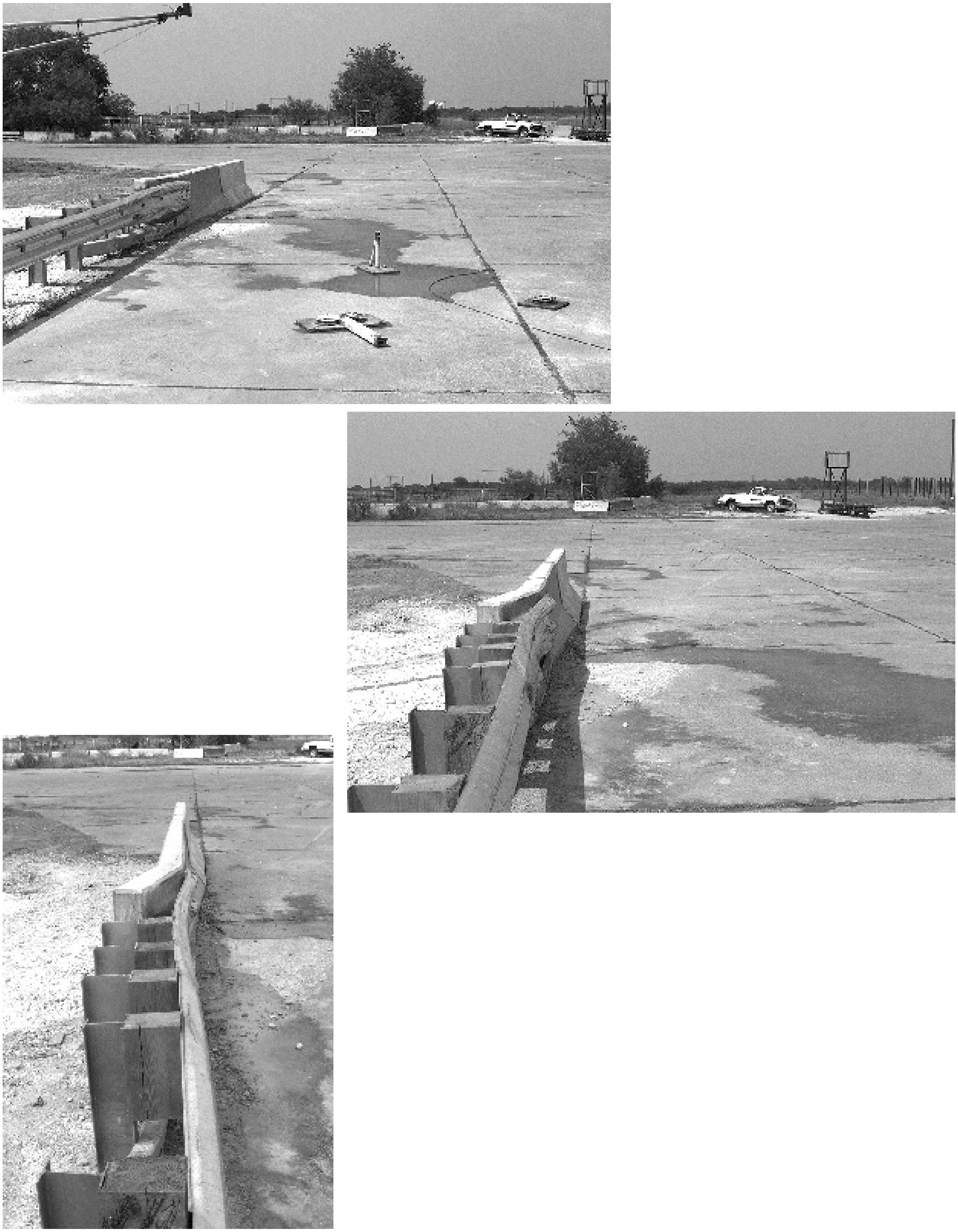


Figure 12. After-impact trajectory for test 404211-4.

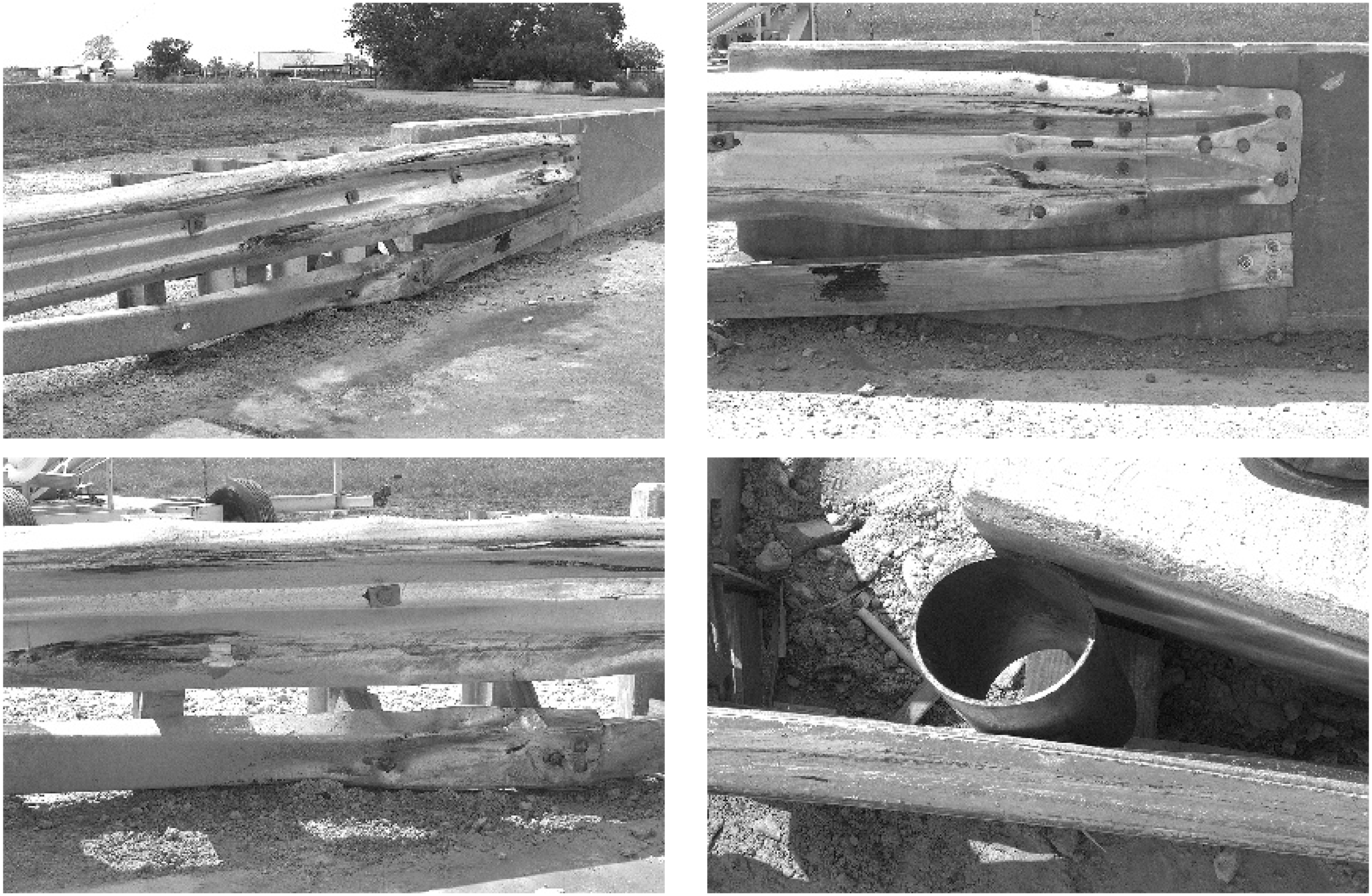


Figure 13. Installation after test 404211-4.

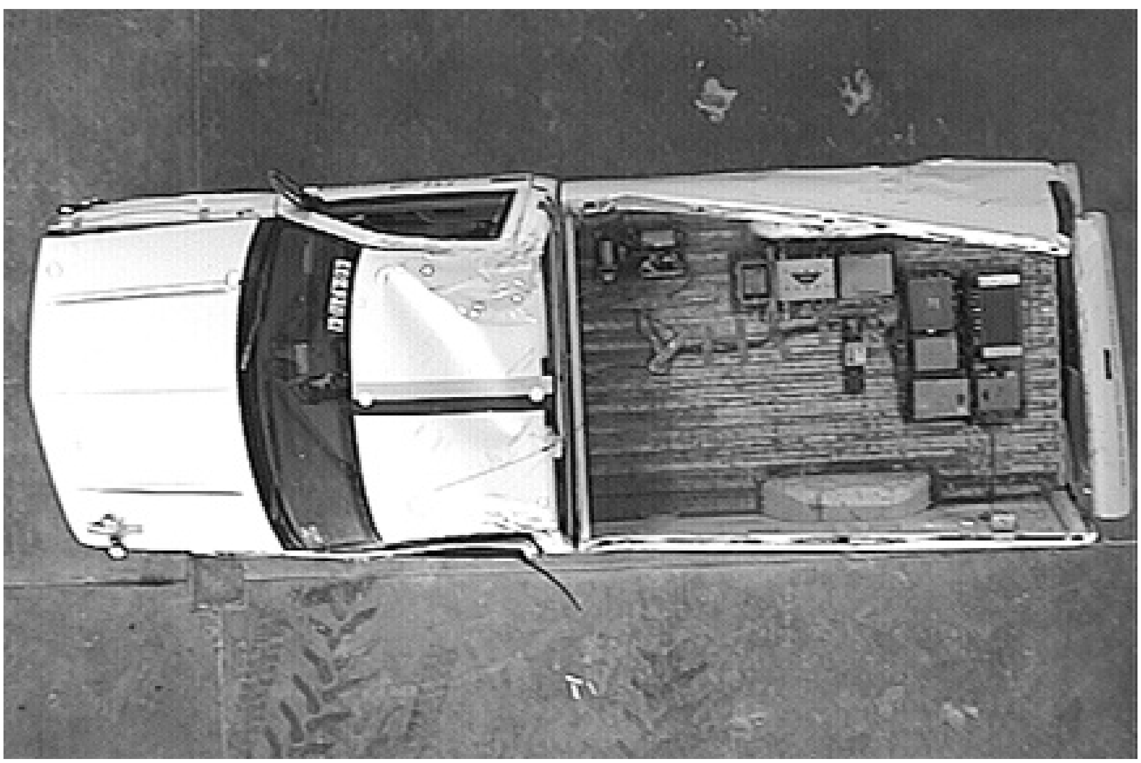


Figure 14. Vehicle after test 404211-4.

Table 2. Exterior crush measurements for test 404211-4.

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 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).

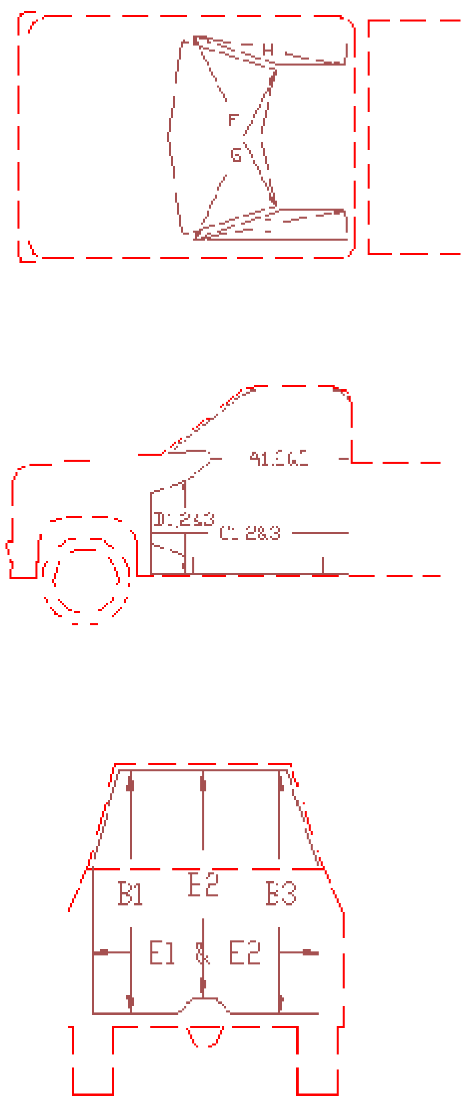
***Measure and document on the vehicle diagram the location of the maximum crush.

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

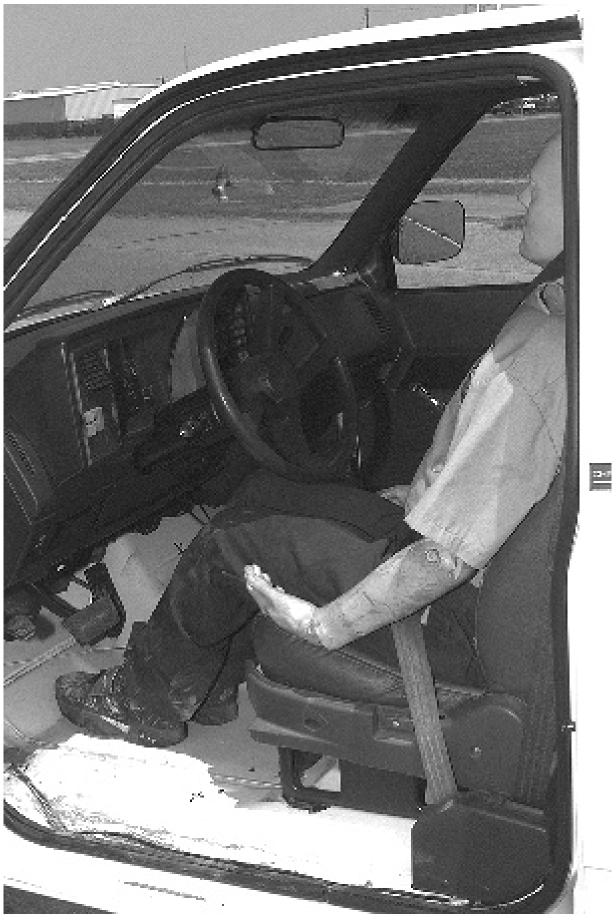
Table 3. Occupant compartment measurements for test 404211-4.

Truck

Occupant Compartment Deformation



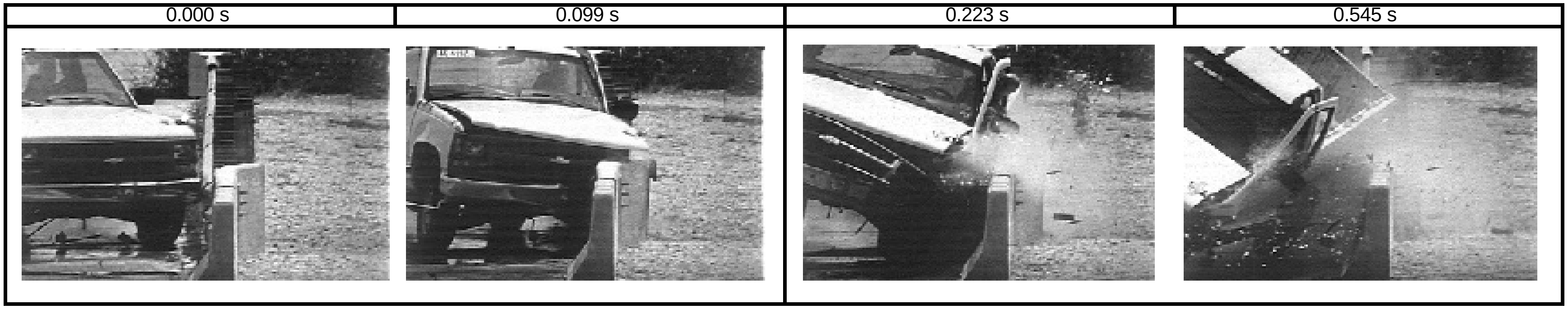
	BEFORE	AFTER
A1	1055	1040
A2	1090	1100
A3	1050	1067
B1	1076	1070
B2	1060	985
B3	1074	1093
C1	1372	1345
C2	1262	1255
C3	1372	1372
D1	310	315
D2	95	75
D3	312	320
E1	1593	1606
E2	1595	1630
F	1475	1460
G	1475	1465
H	900	890
I	900	880

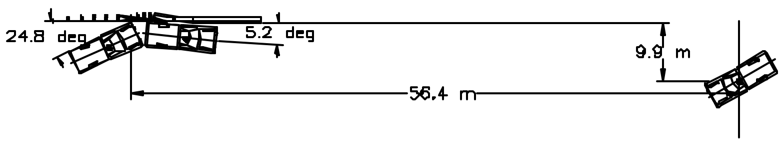


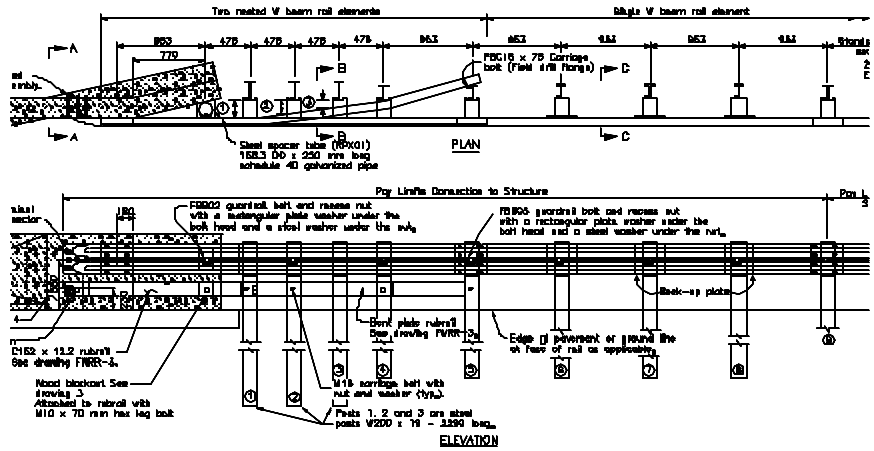
Before test

After test

Figure 15. Interior of vehicle for 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)	9.9
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 16. Summary of results for test 404211-4, NCHRP Report 350 test 3-21.

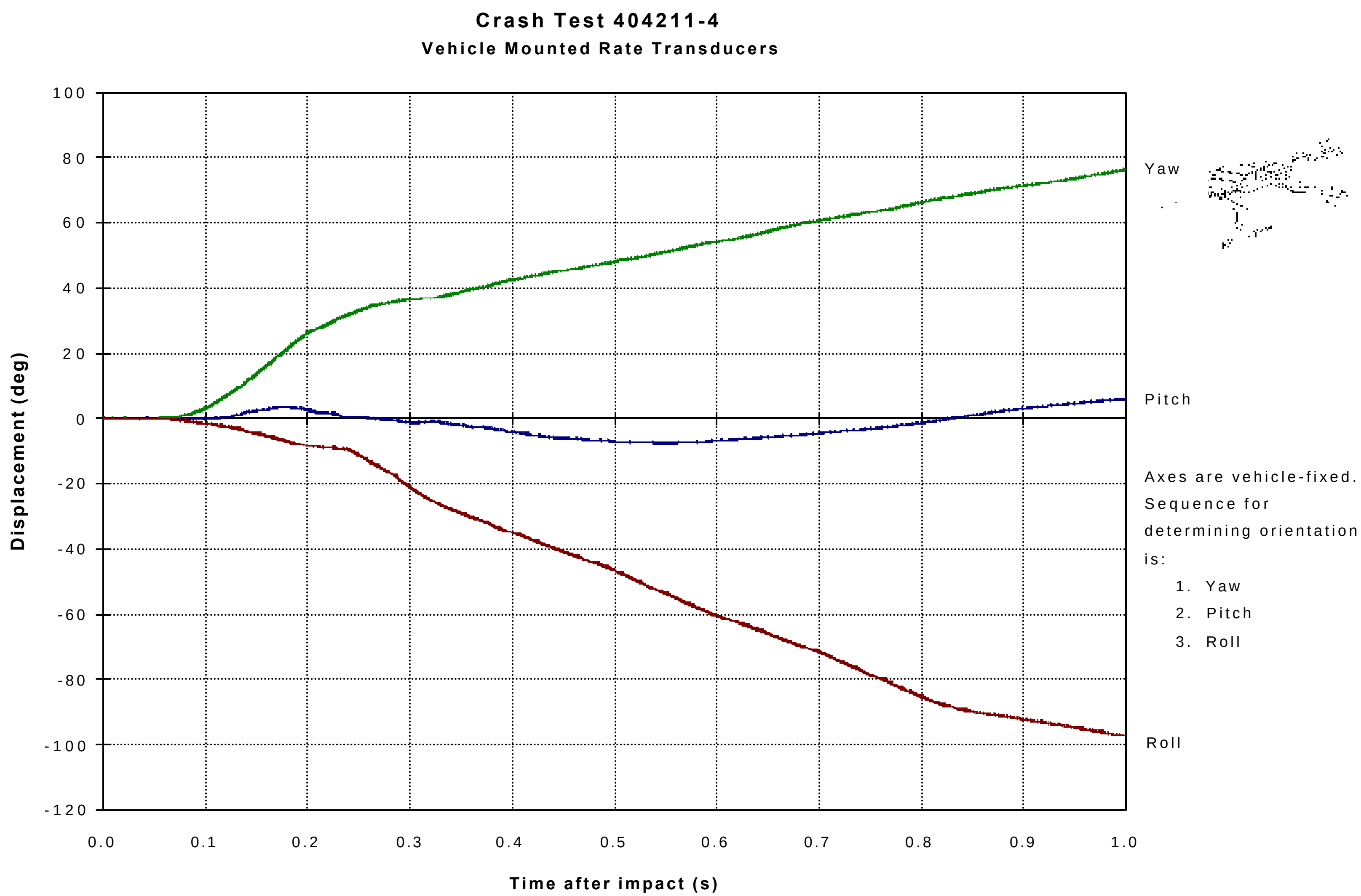


Figure 17. Vehicle angular displacements for test 404211-4.

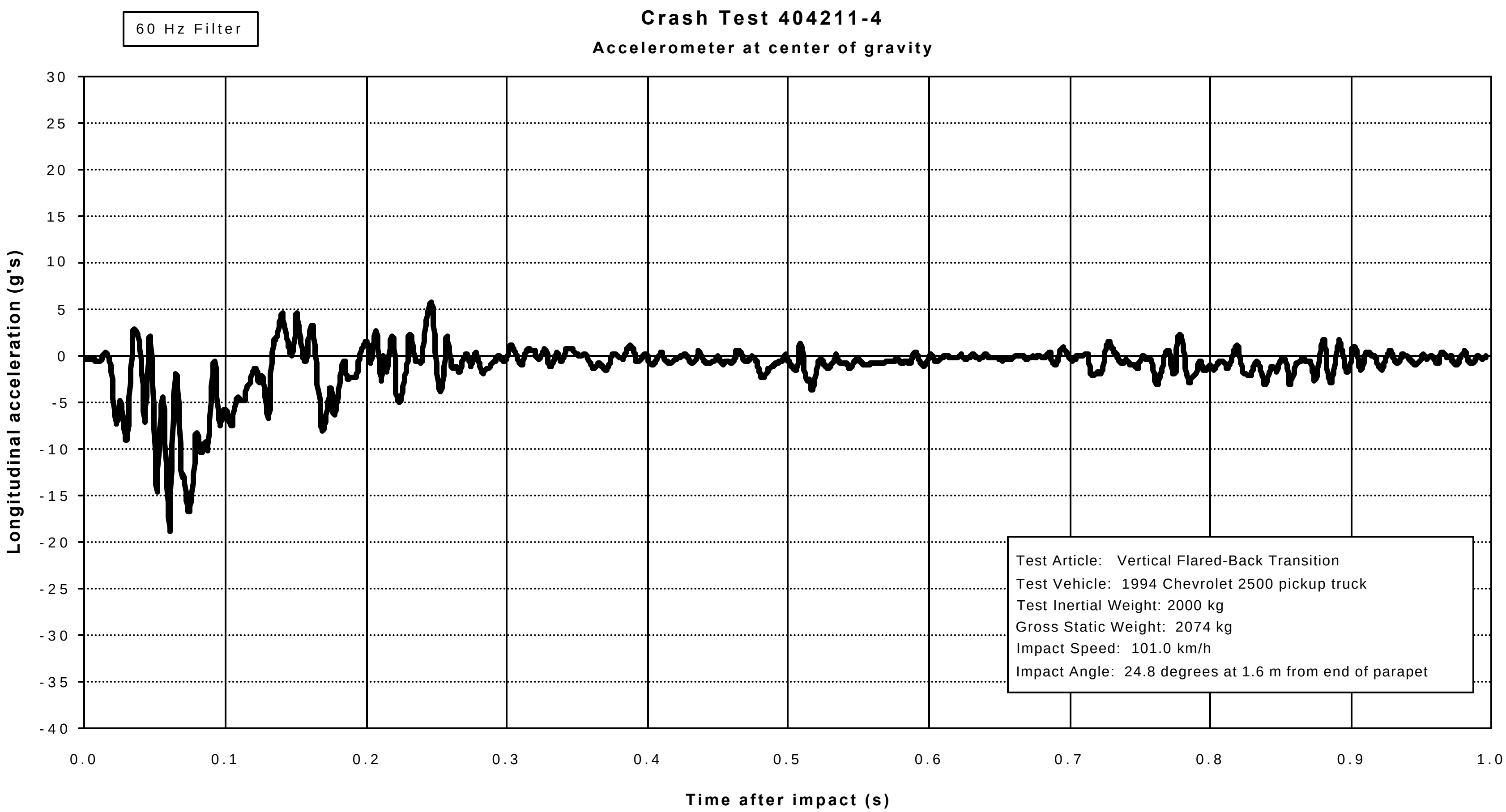


Figure 18. Vehicle longitudinal accelerometer trace for test 404211-4
(accelerometer located at center of gravity).

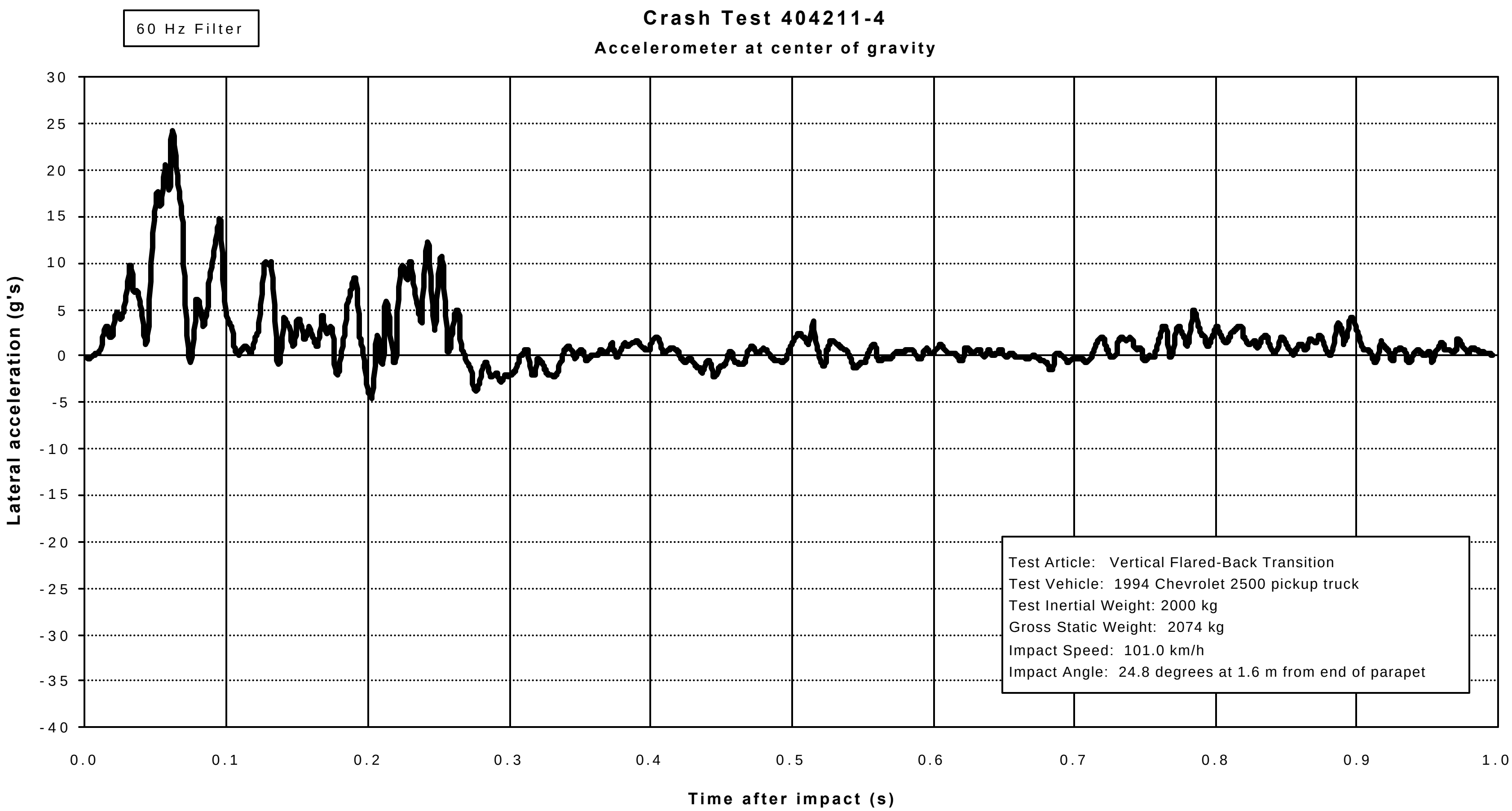


Figure 19. Vehicle lateral accelerometer traces for test 404211-4
(accelerometer located at center of gravity).

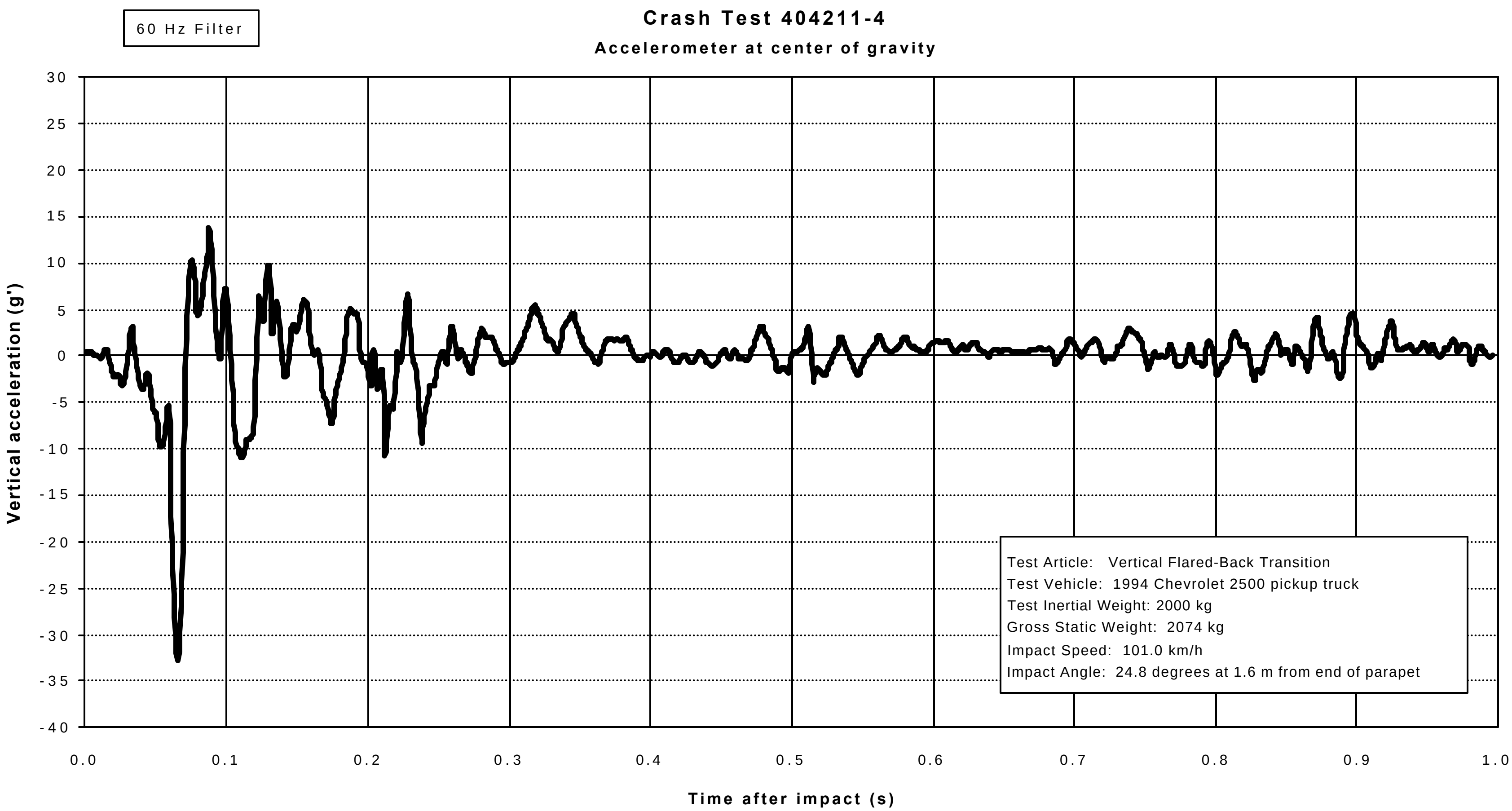


Figure 20. Vehicle vertical accelerometer trace for test 404211-4
(accelerometer located at center of gravity).

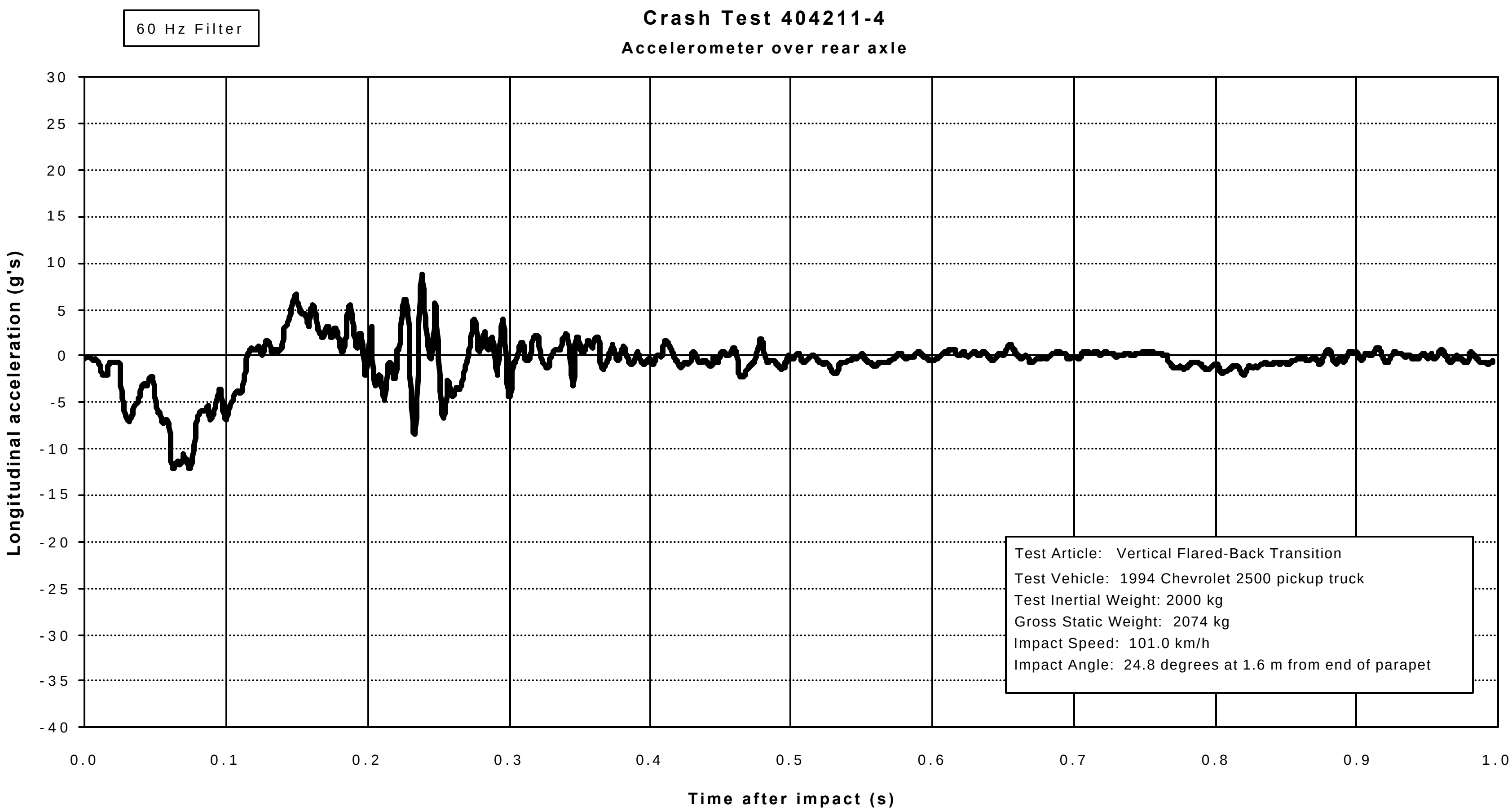


Figure 21. Vehicle longitudinal accelerometer trace for test 404211-4
(accelerometer located over rear axle).

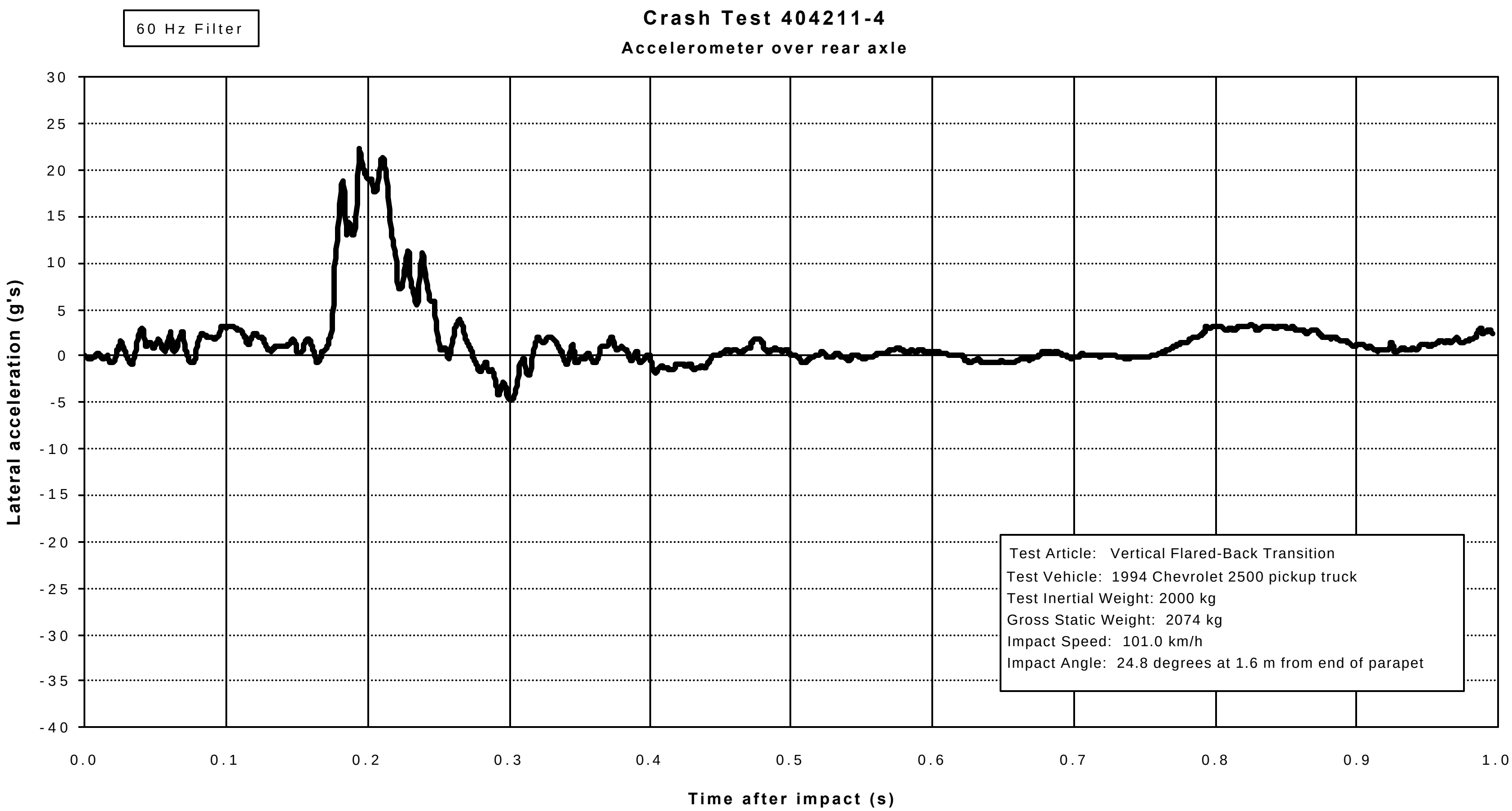


Figure 22. Vehicle lateral accelerometer traces for test 404211-4
(accelerometer located over rear axle).

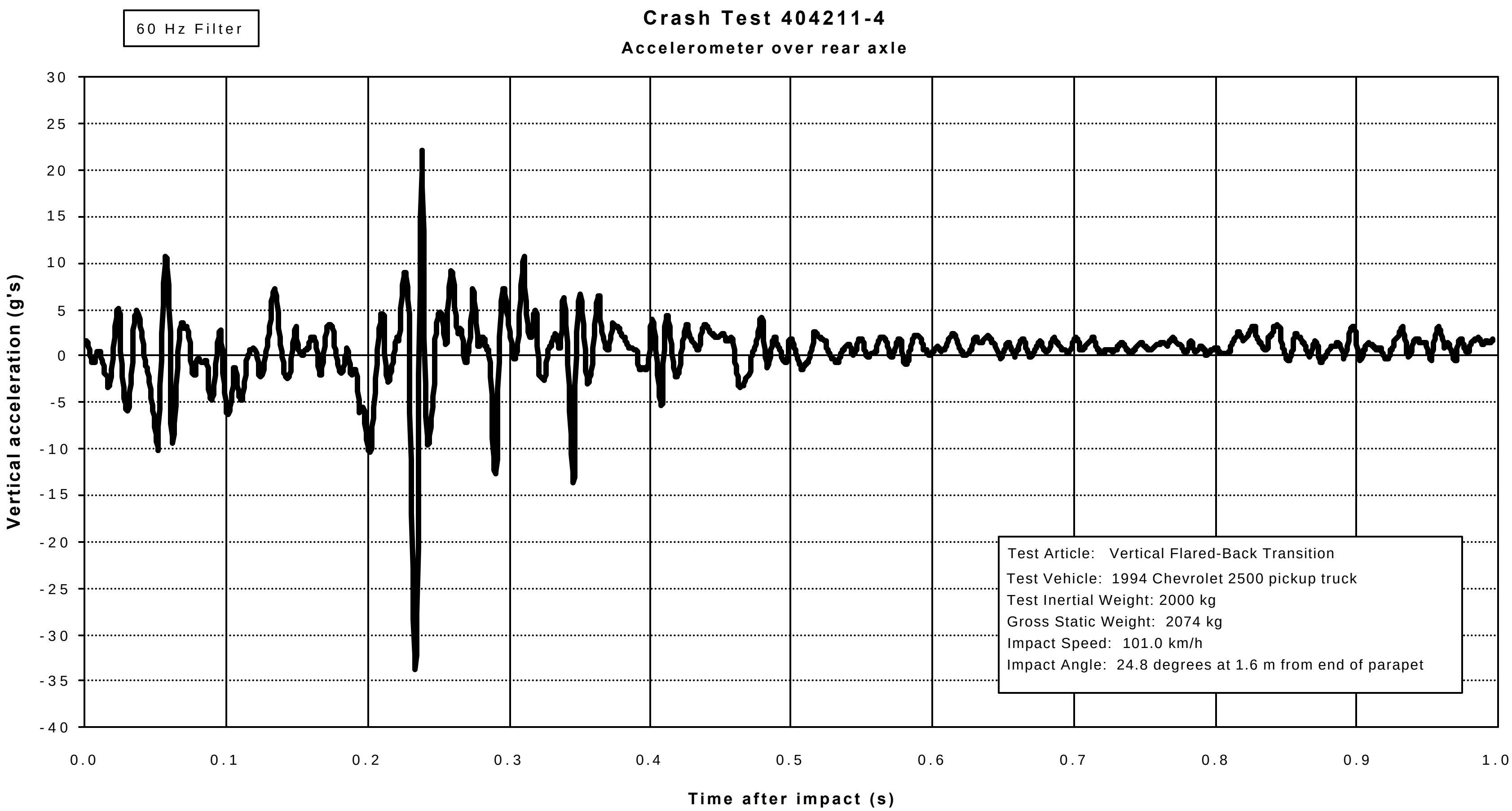


Figure 23. Vehicle vertical accelerometer trace for test 404211-4
(accelerometer located over rear axle).

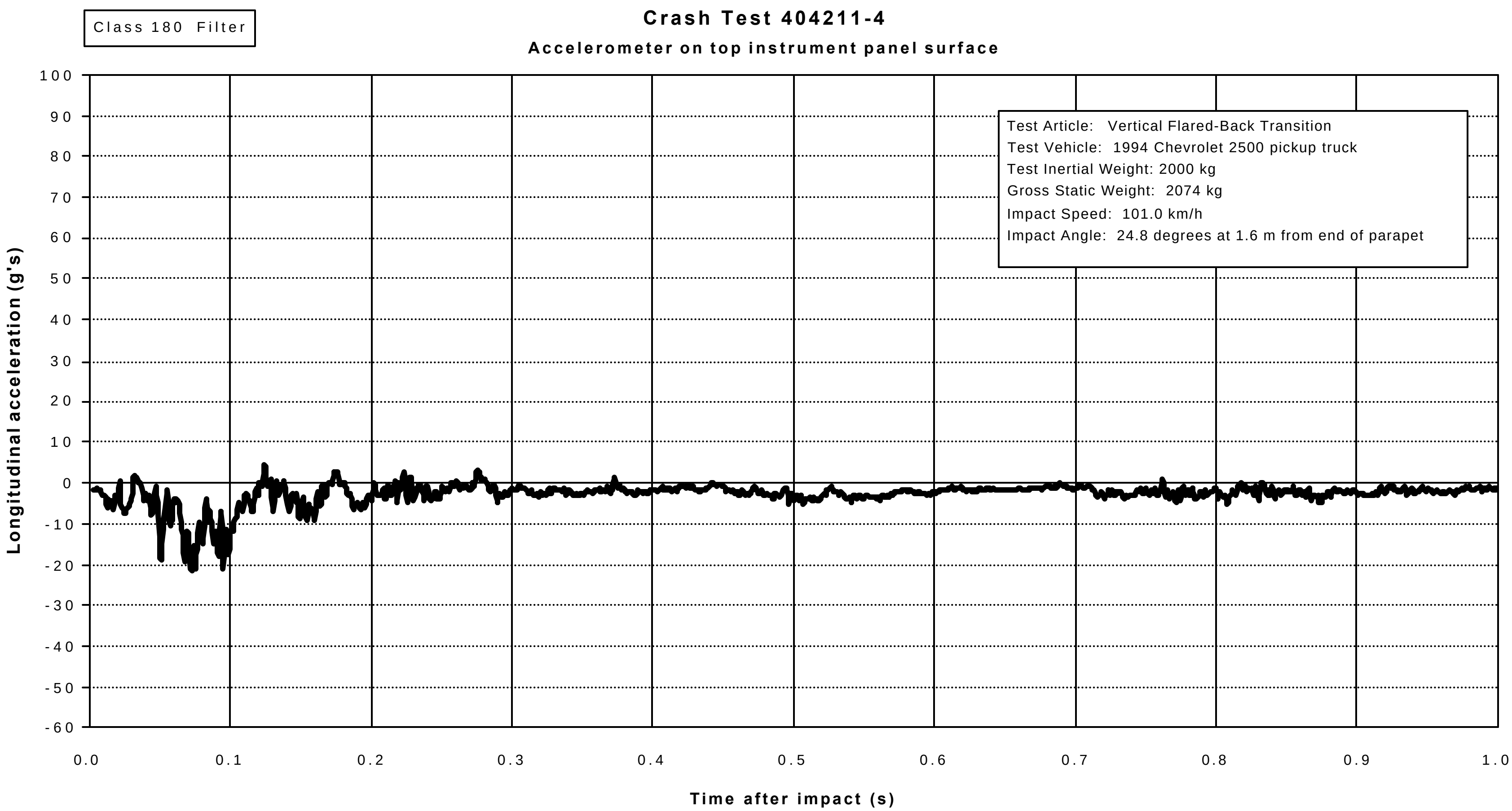


Figure 24. Vehicle longitudinal accelerometer trace for test 404211-4
(accelerometer located on top surface of instrument panel).

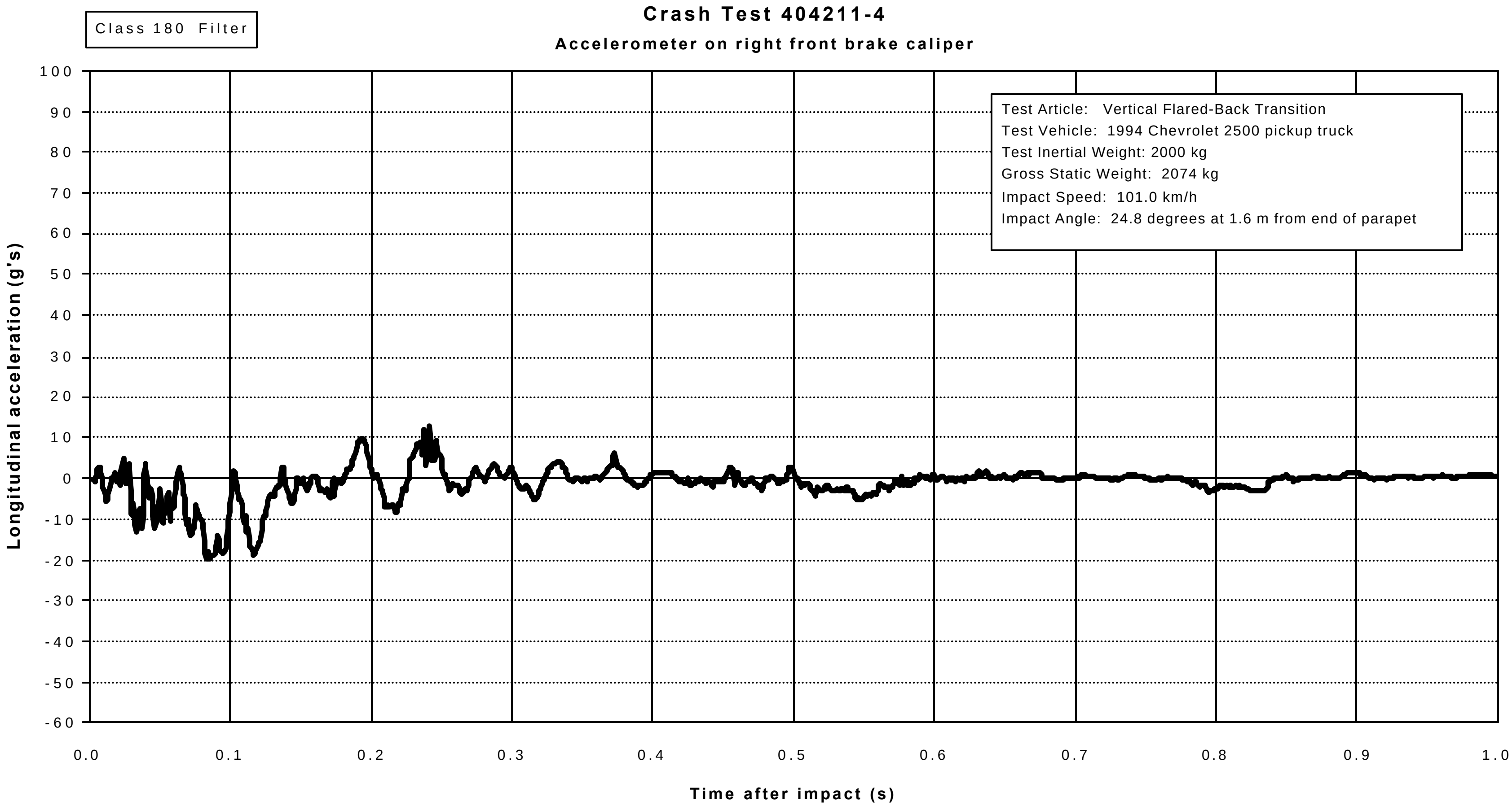


Figure 25. Vehicle longitudinal accelerometer traces for test 404211-4
(accelerometer located on right front brake caliper).

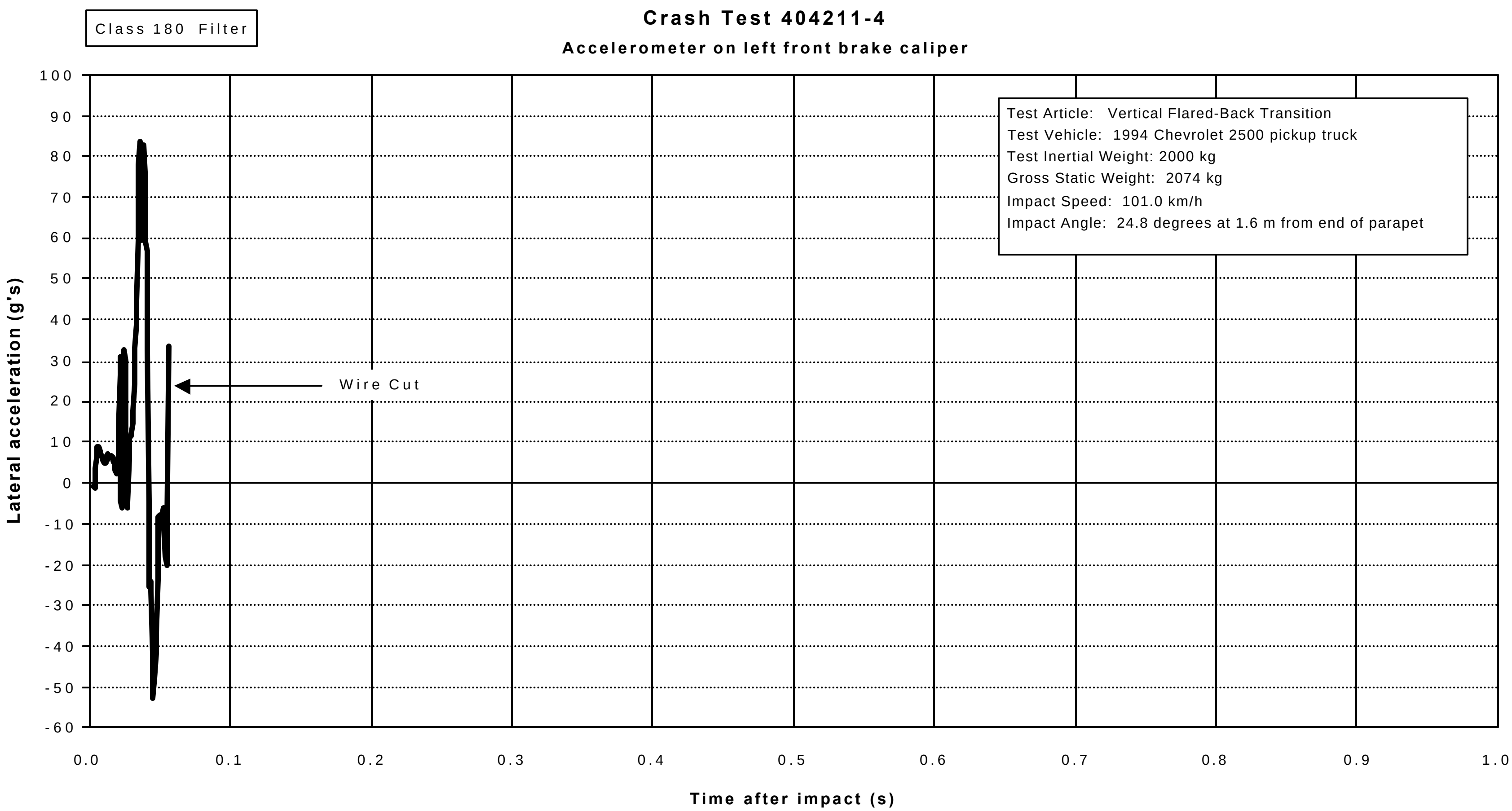


Figure 26. Vehicle lateral accelerometer trace for test 404211-4
(accelerometer located on left front brake caliper).

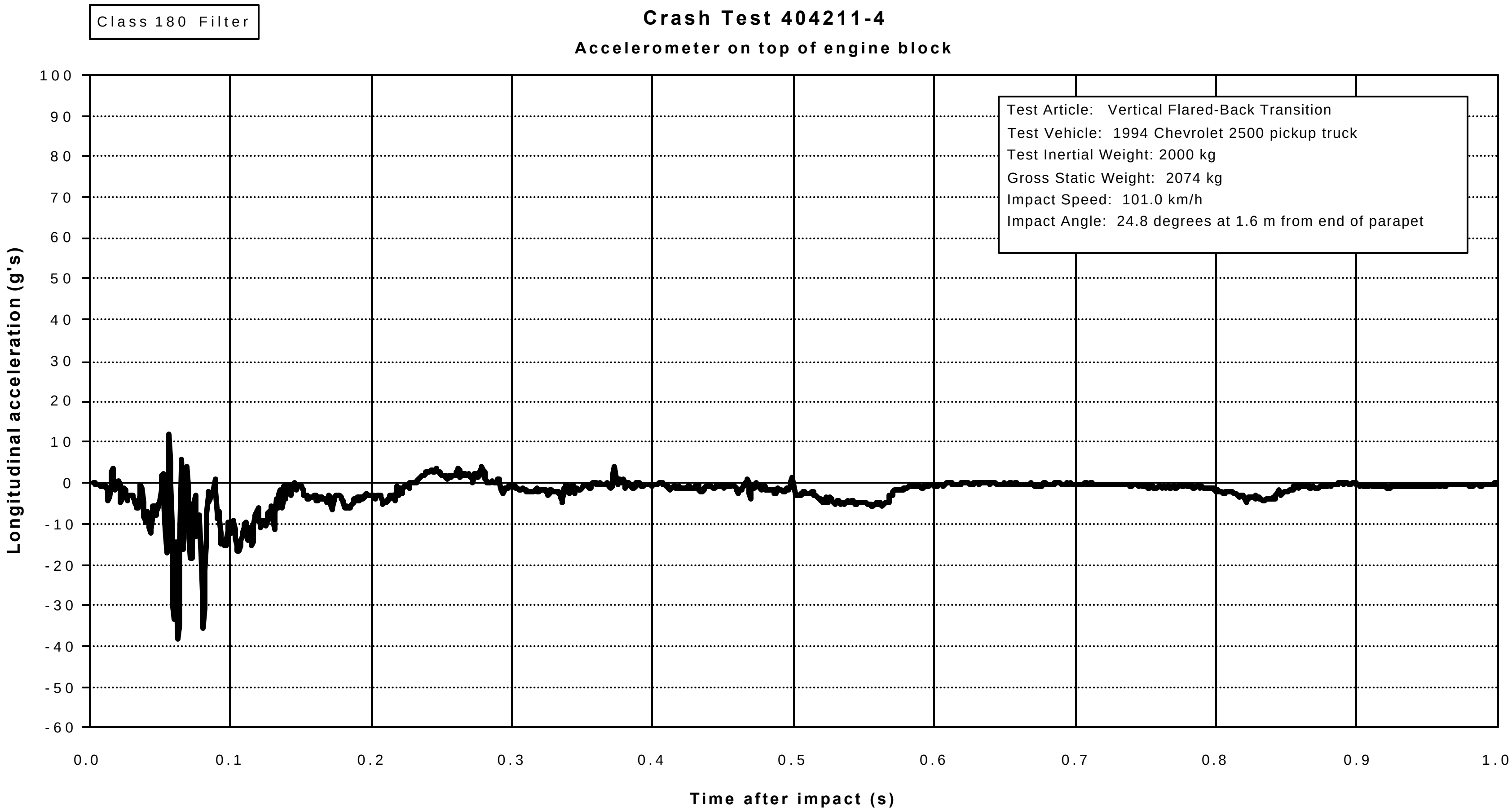


Figure 27. Vehicle longitudinal accelerometer trace for test 404211-4 (accelerometer located on top of engine block).

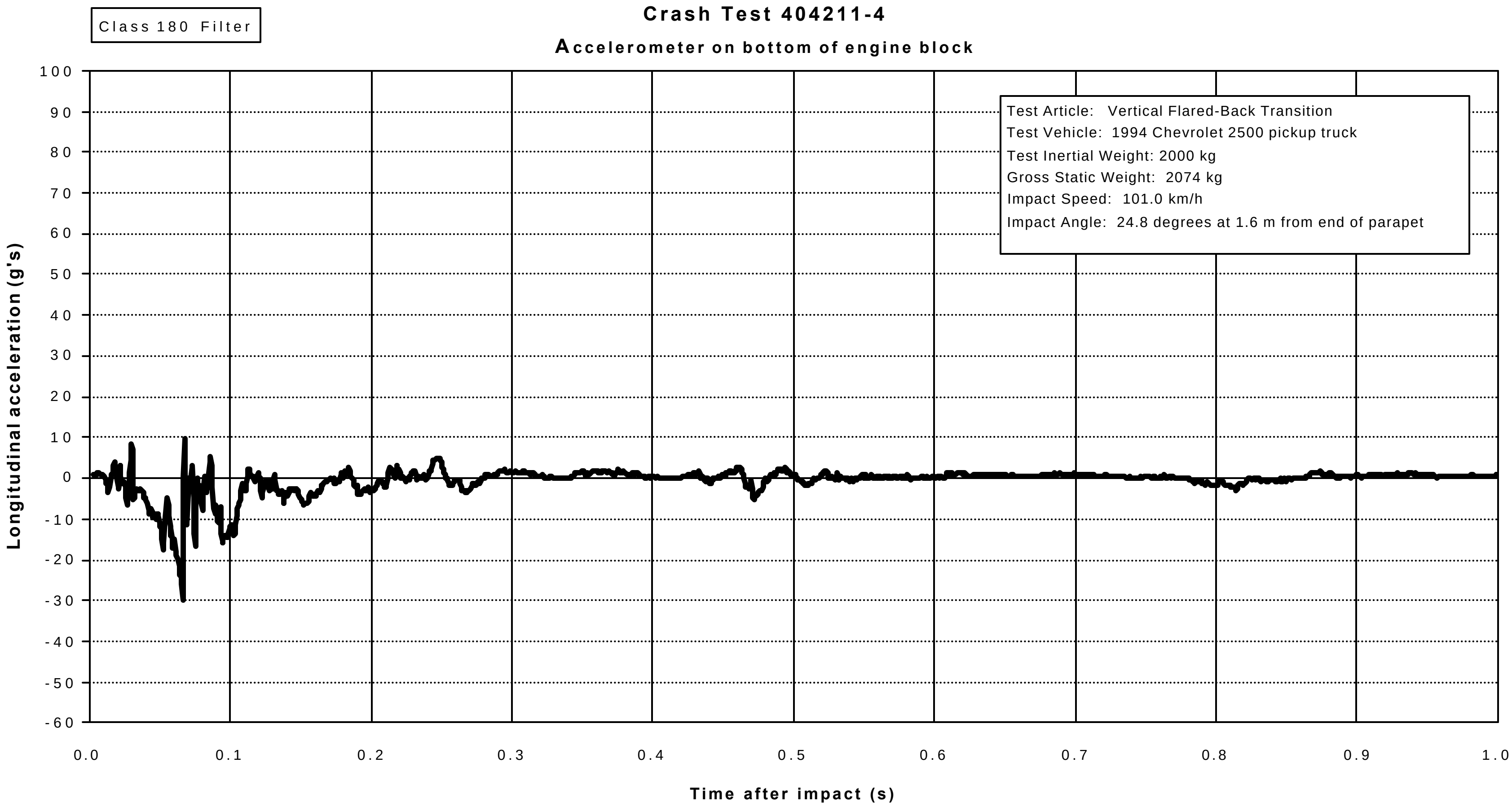


Figure 28. Vehicle longitudinal accelerometer trace for test 404211-4 (accelerometer located on bottom of engine block).

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

SUMMARY OF FINDINGS

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. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 75 mm (7-percent reduction in space) in the center floor pan area. After exiting the transition, the vehicle rolled one revolution and came to rest upright, 9.9 m toward traffic lanes. Longitudinal occupant impact velocity was 6.6 m/s and longitudinal ridedown acceleration was -6.1 g’s. Exit angle at loss of contact was 5.2 degrees, which was less than 60 percent of the impact angle.

CONCLUSIONS

As shown in table 4, the Vertical Flared Back Transition failed to meet the requirements for NCHRP Report 350 test designation 3-21.

Table 4. Performance evaluation summary for test 404211-4, 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 (7-percent reduction in space) 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 6.6 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

REFERENCES

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*, NCHRP Report 350, Transportation Research Board, Washington, D.C., 1993.

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