NCHRP Report 350 Test 4-12 of the Modified Thrie Beam Guardrail

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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 those State and local highway officials who select, locate, and design traffic barriers. It documents the results of a crash test of a Modified Thrie Beam guardrail with an 8000-kg single unit truck impacting at a nominal speed and angle of 80 km/h and 15 degrees. This is the strength test for Test Level Four (TL-4) in NCHRP Report 350. It was found that the test results met all of the evaluation criteria. The single unit truck was smoothly redirected and remained upright.

Detailed drawings are presented for documentation and to facilitate implementation.

Michael F. Trentacoste

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Director, Office of Safety
Research and Development

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16. Abstract

The modified thrie beam guardrail has been successfully tested at Test Level 3 (TL-3) of NCHRP Report 350.[3] FHWA decided that the guardrail should be tested to TL-4, which involves a crash test with the 8000S (single-unit truck) traveling at a nominal speed and angle of 80 km/h and 15 degrees, impacting the critical impact point. This test is intended to evaluate the strength of the section in containing and redirecting the heavy vehicle.

This report presents the details and results of NCHRP Report 350 test designation 4-12 for evaluation of the modified thrie beam to TL-4. The modified thrie beam guardrail met all requirements for NCHRP Report 350 test designation 4-12.

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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		
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)

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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.

The modified thrie beam guardrail has been successfully tested at Test Level 3 (TL-3) of NCHRP Report 350.[(3)] FHWA decided that the guardrail should be tested to TL-4, which involves a crash test with the 8000S (single-unit truck) traveling at a nominal speed and angle of 80 km/h and 15 degrees, impacting the critical impact point. This test is intended to evaluate the strength of the section in containing and redirecting the heavy vehicle.

This report presents the details and results of NCHRP Report 350 test designation 4-12 for evaluation of the modified thrie beam to TL-4. The modified thrie beam guardrail met all requirements for NCHRP Report 350 test designation 4-12.

II. STUDY APPROACH

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 1. 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 1. Photographs of the completed test installation are shown in figure 2.

CRASH TEST CONDITIONS

According to NCHRP Report 350, three crash tests are required for evaluation of longitudinal barriers to Test Level four (TL-4):

NCHRP Report 350 test designation 4-10: An 820-kg passenger car impacting the critical impact point (CIP) in the length of need (LON) 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 LON section in general, and occupant risks in particular.

NCHRP Report 350 test designation 4-11: A 2000-kg pickup truck impacting the CIP in the LON 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 in containing and redirecting the pickup truck.

NCHRP Report 350 test designation 4-12: An 8000-kg single-unit truck impacting the CIP in the LON of the longitudinal barrier at a nominal speed and angle of 80 km/h and 15 degrees. The test is intended to evaluate the strength of the section in containing and redirecting the heavy truck.

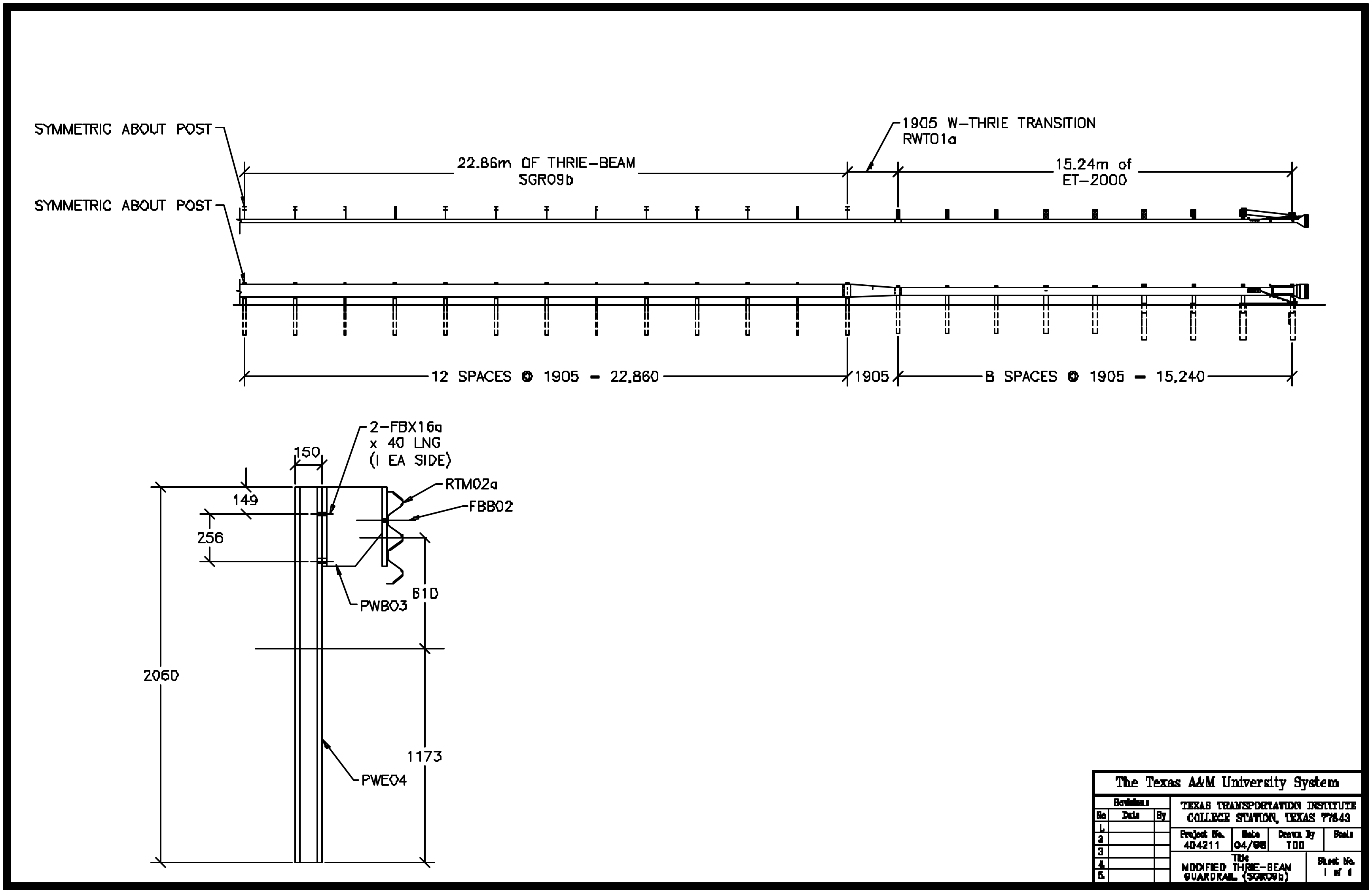


Figure 1. Details of the Modified Thrie Beam Guardrail installation.

Figure 2. Modified Thrie Beam Guardrail installation before test 404211-5a.

The test reported herein (test 404211-5a) 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.

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.

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

- **Vehicle Trajectory**

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

  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; a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels; and another back-up biaxial accelerometer in the front of the cab of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers were strain-gauge type with a linear millivolt output proportional to acceleration.

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

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

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

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. 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 97).

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

Anthropomorphic Dummy Instrumentation

Use of a dummy in the 8000S vehicle is optional according to NCHRP Report 350 and there was no dummy used in the test with the 8000S vehicle.

Photographic Instrumentation and Data Processing

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; 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 Betacam, a VHS-format video camera and recorder, and still cameras were used to record and document the condition of the test vehicle and installation before and after the test.

Test Vehicle Propulsion and Guidance

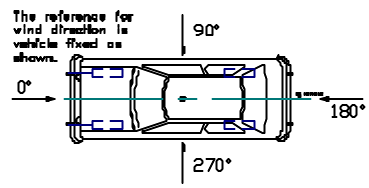
The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable 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 404211-5a (NCHRP Report 350 Test No. 4-12)

A 1988 GMC 7000 single-unit truck, shown in figures 3 and 4, 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 figure 5. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

The 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%, 4.0%, and 5.1%, 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 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 figures 6 and 7.

Figure 3. Vehicle/installation geometrics for test 404211-5a.

Figure 4. Vehicle before test 404211-5a.

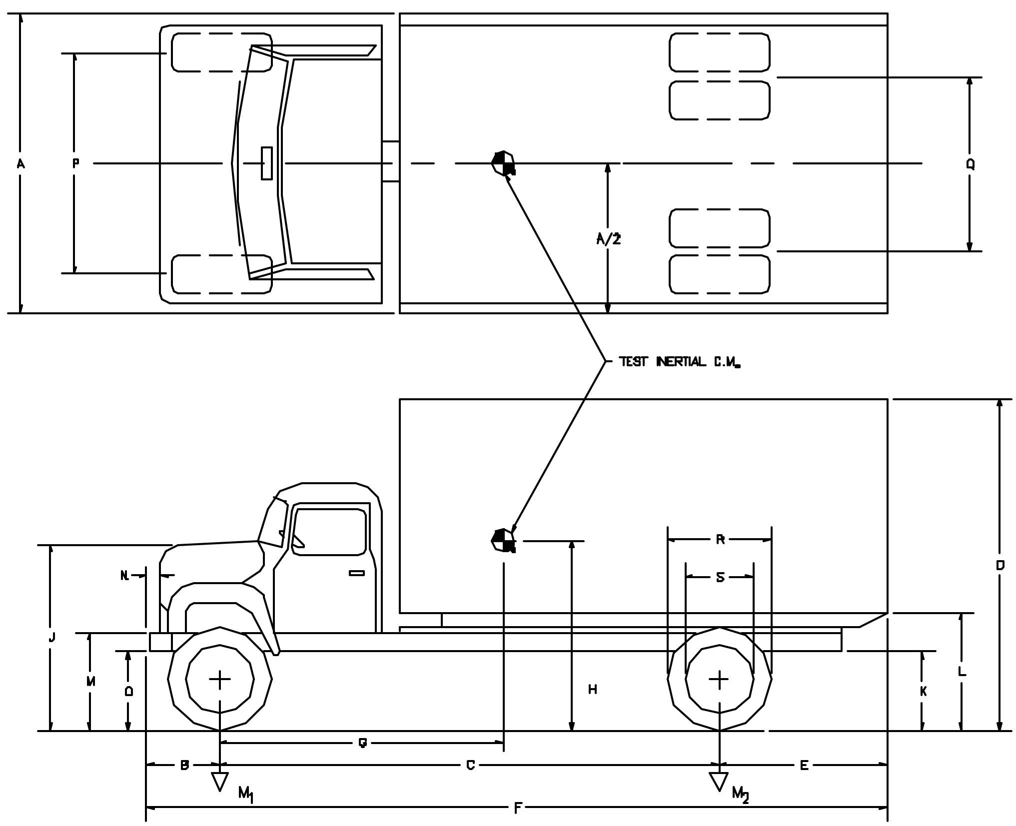
DATE: 6-12-98 TEST NO.: 404211-5a VIN NO.: 1GDJ7D1B5JV513347

MODEL: 7000 YEAR: 1988 ODOMETER: 67672 TIRE SIZE: 11R22.5

MAKE: Chevrolet

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 5. Vehicle properties for test 404211-5a.

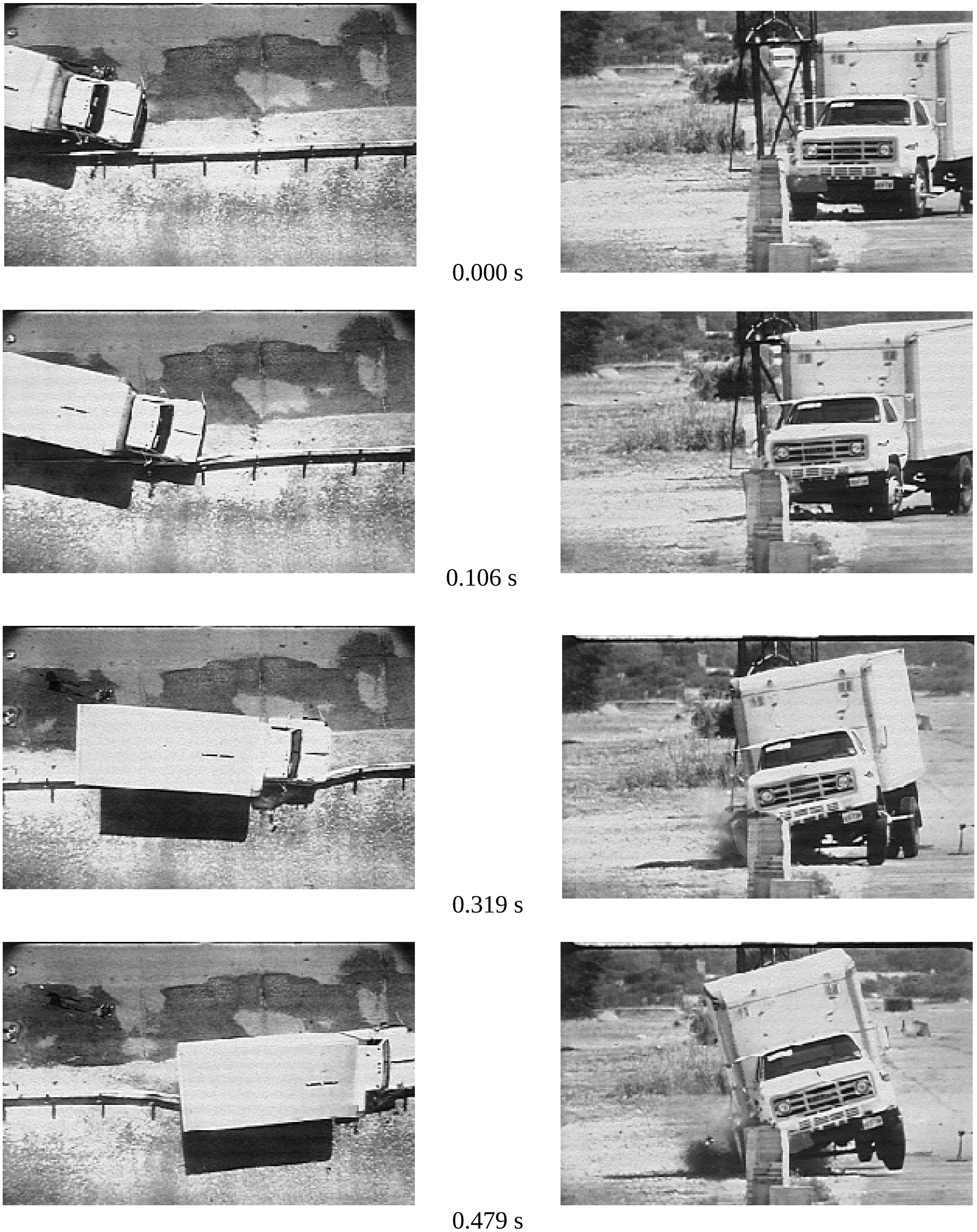
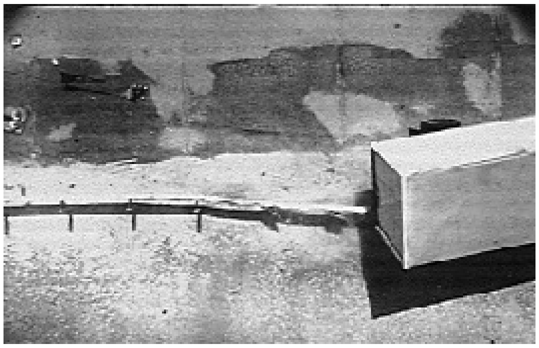
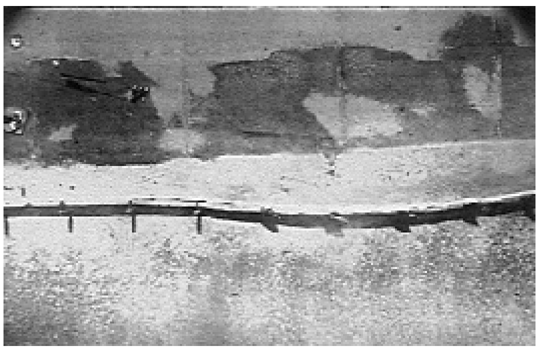


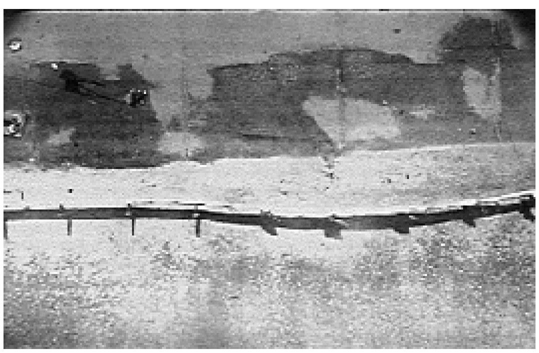
Figure 6. Sequential photographs for test 404211-5a (overhead and frontal views).



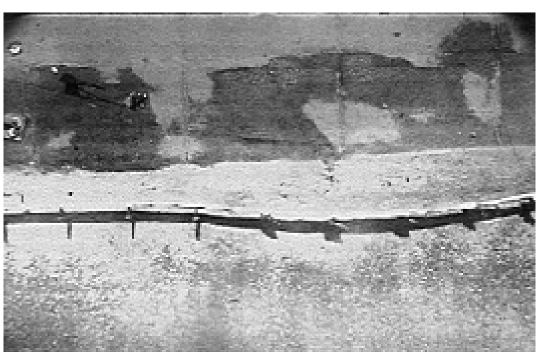

0.692 s




1.064 s

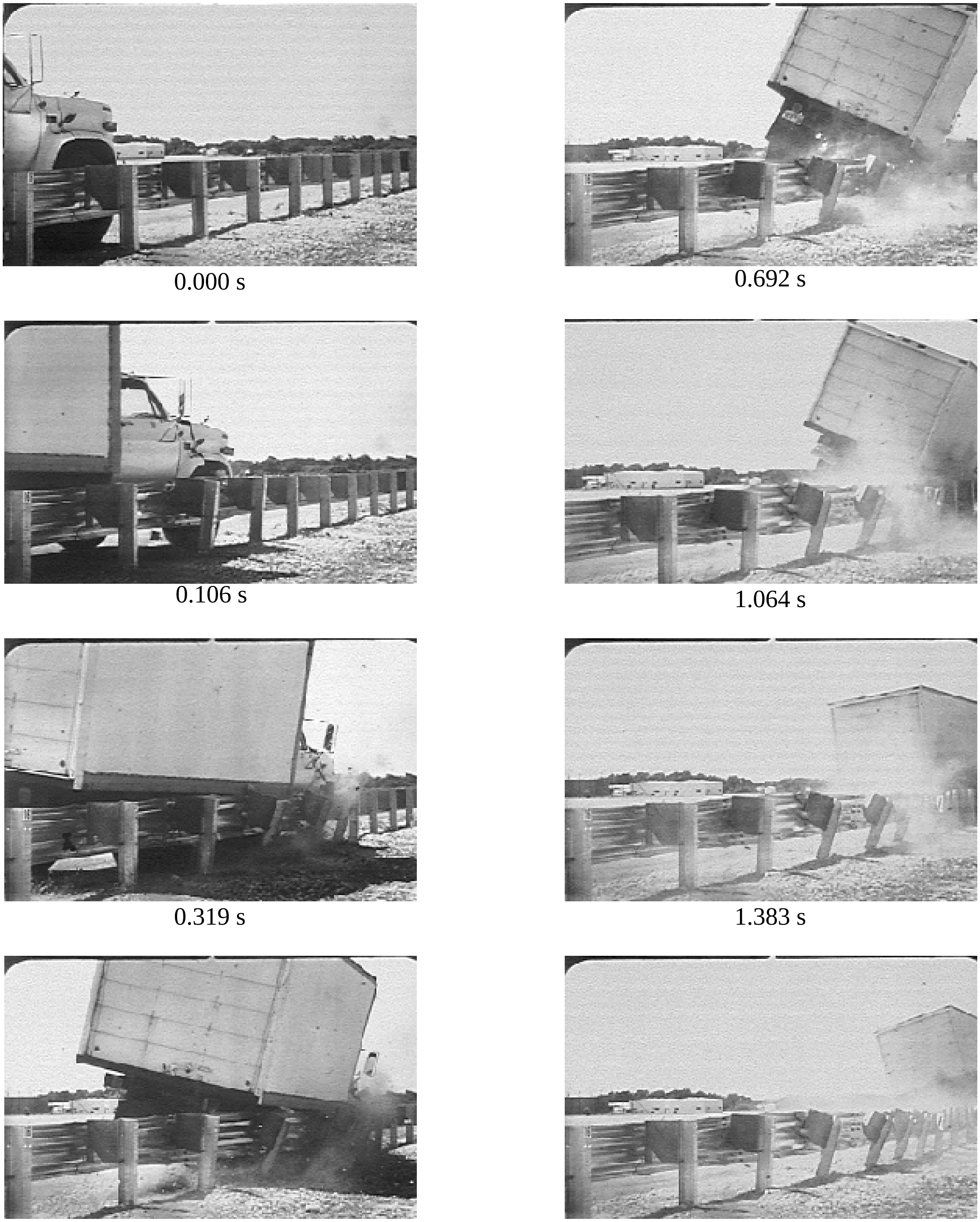



1.383 s




1.862 s

Figure 6. Sequential photographs for test 404211-5a
(overhead and frontal views) (continued).



0.000 s

0.692 s

0.106 s

1.064 s

0.319 s

1.383 s

0.479 s

1.862 s

Figure 7. Sequential photographs for test 404211-5a
(rear view).

Damage to Test Installation

Damage to the modified thrie beam guardrail is shown in figures 8 and 9. 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 of which the truck rode on top of the thrie beam for 2.8 m. 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 10. 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. The interior of the vehicle is shown in figure 11.

Occupant Risk Values

Occupant risk values are not required for this test, but were computed and are reported for information only. Data from the accelerometer located at the vehicle center of gravity were digitized and values are as follows: 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 12. Vehicle angular displacements are displayed in figure 13. Vehicular accelerations versus time traces are presented in figures 14 through 20.

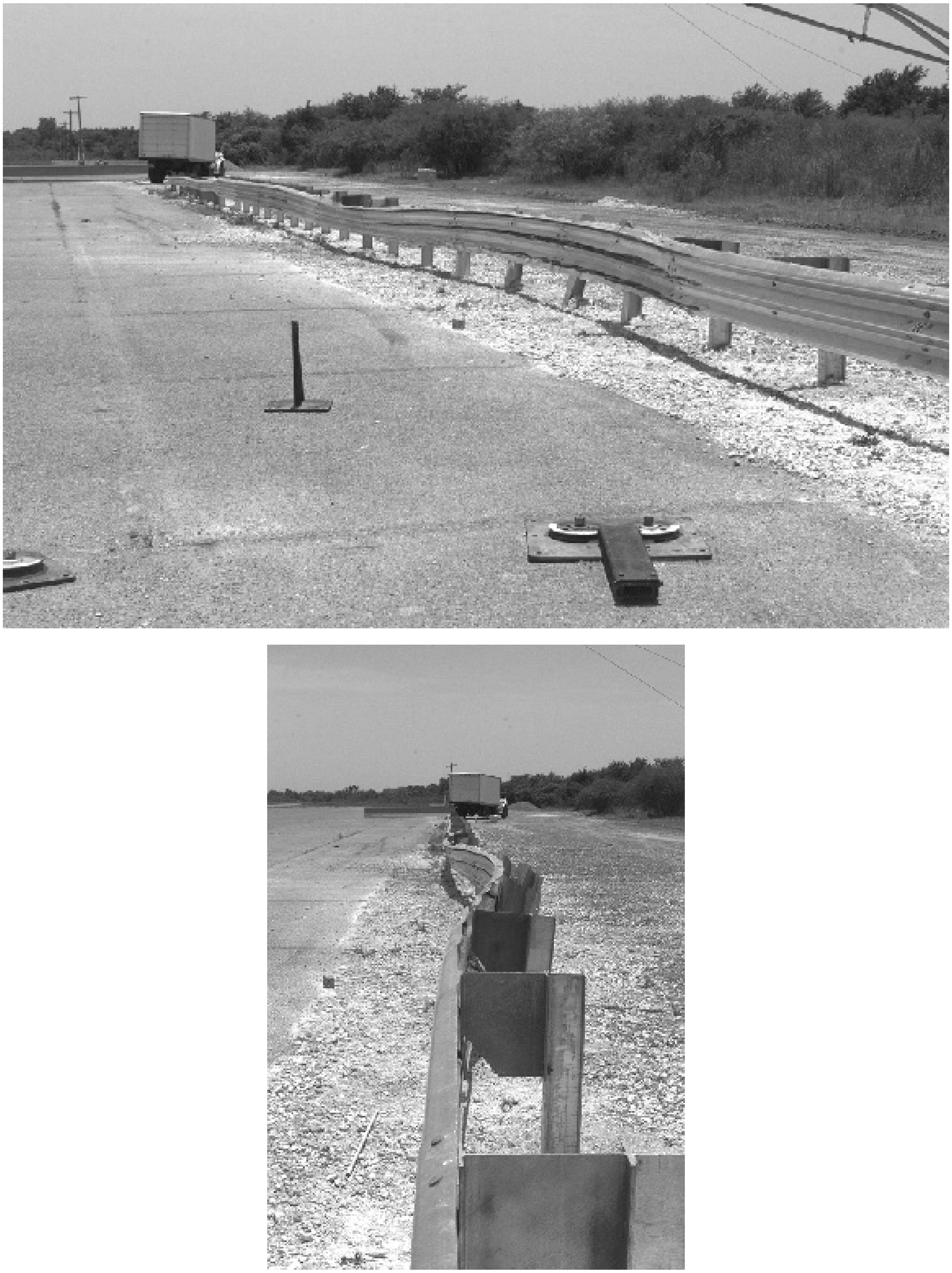
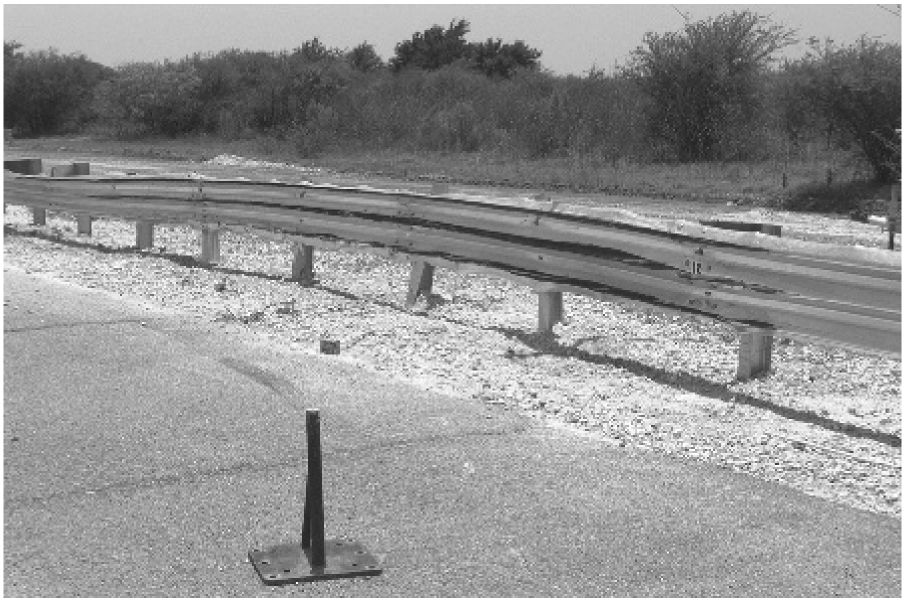


Figure 8. After-impact trajectory for test 404211-5a.



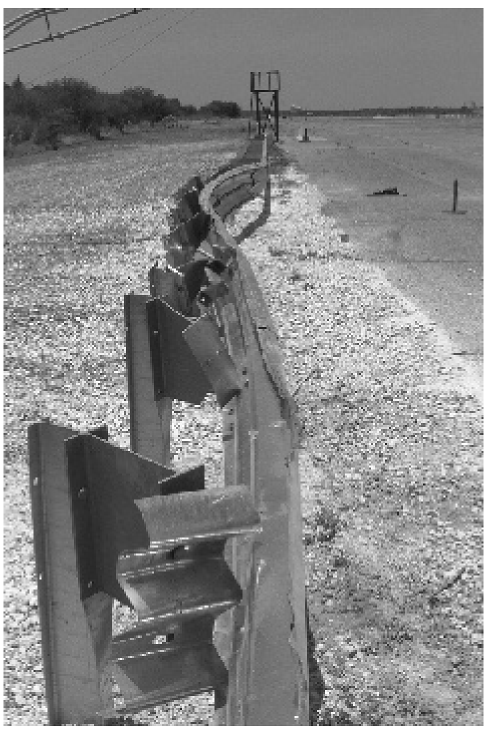


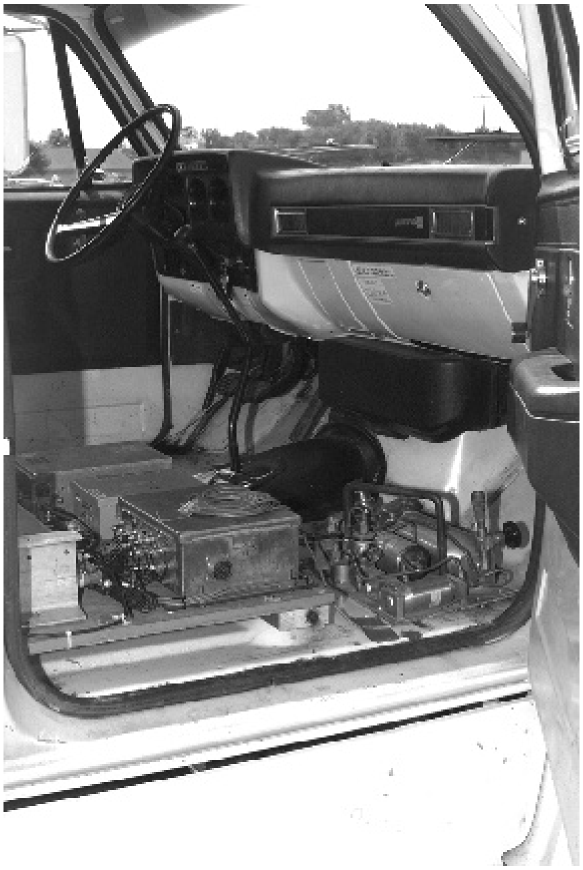
Figure 9. Installation near initial impact after test 404211-5a.

Second impact

Third impact

Figure 10. Installation near second and third impact after test 404211-5a.

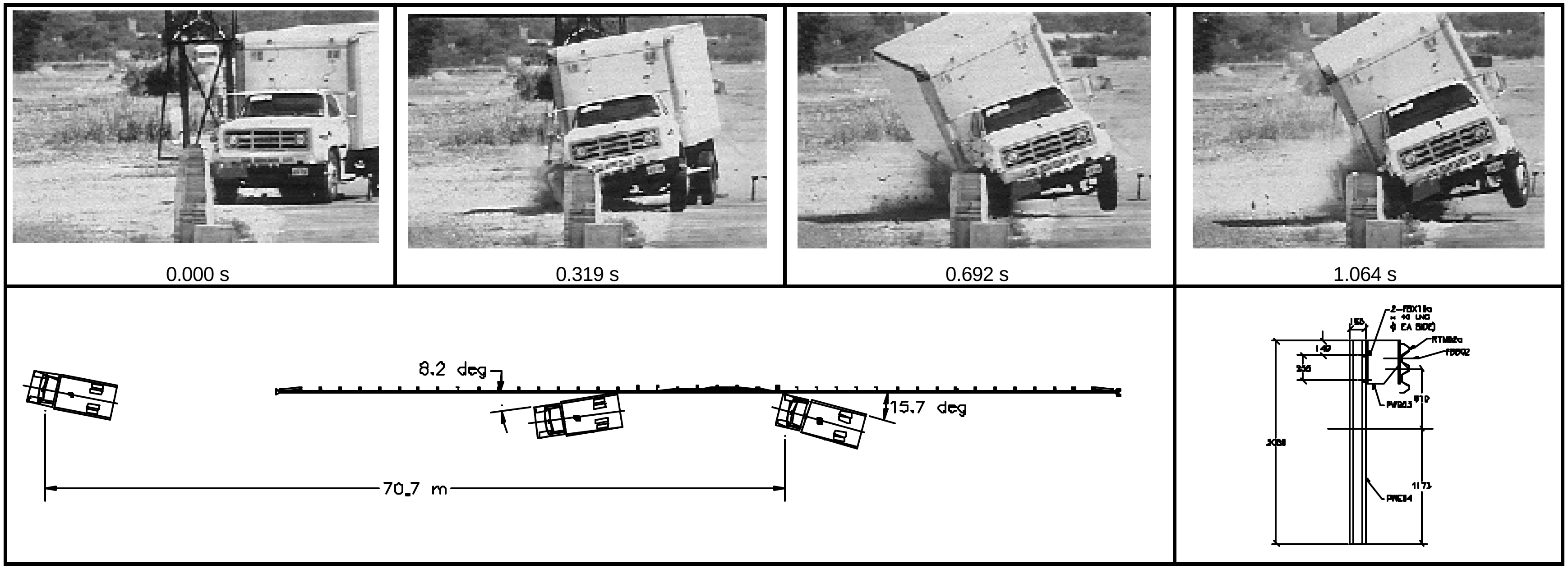
Figure 11. Vehicle after test 404211-5a.



Before test

After test

Figure 12. Interior of vehicle for test 404211-5a.



General Information	
Test Agency	Texas Transportation Institute
Test No.	404211-5a
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)	6.8
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 13. Summary of results for test 404211-5a, NCHRP Report 350 test 4-12.

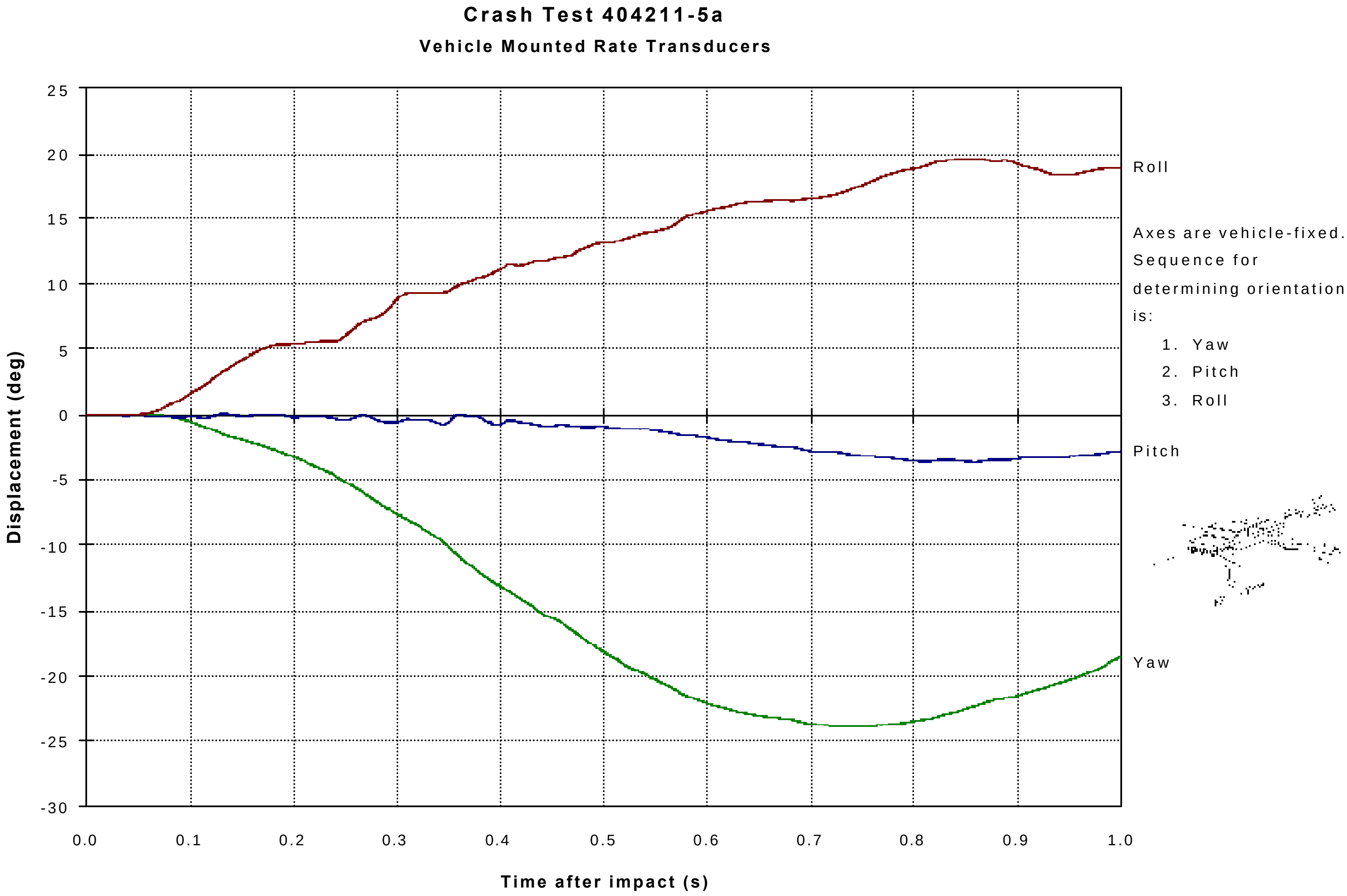


Figure 14. Vehicle angular displacements for test 404211-5a.

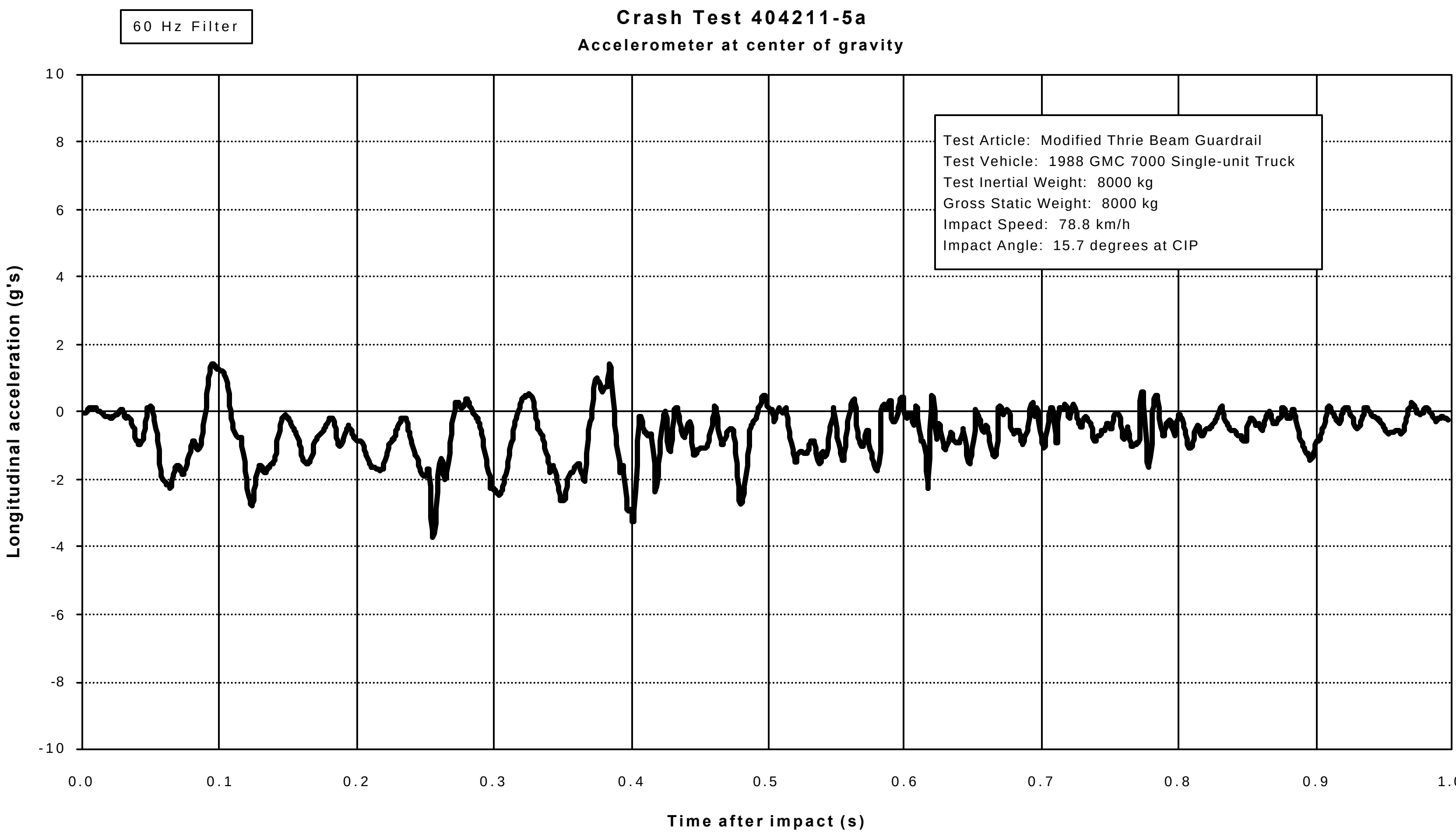


Figure 15. Vehicle longitudinal accelerometer trace for test 404211-5a (accelerometer located at center of gravity).

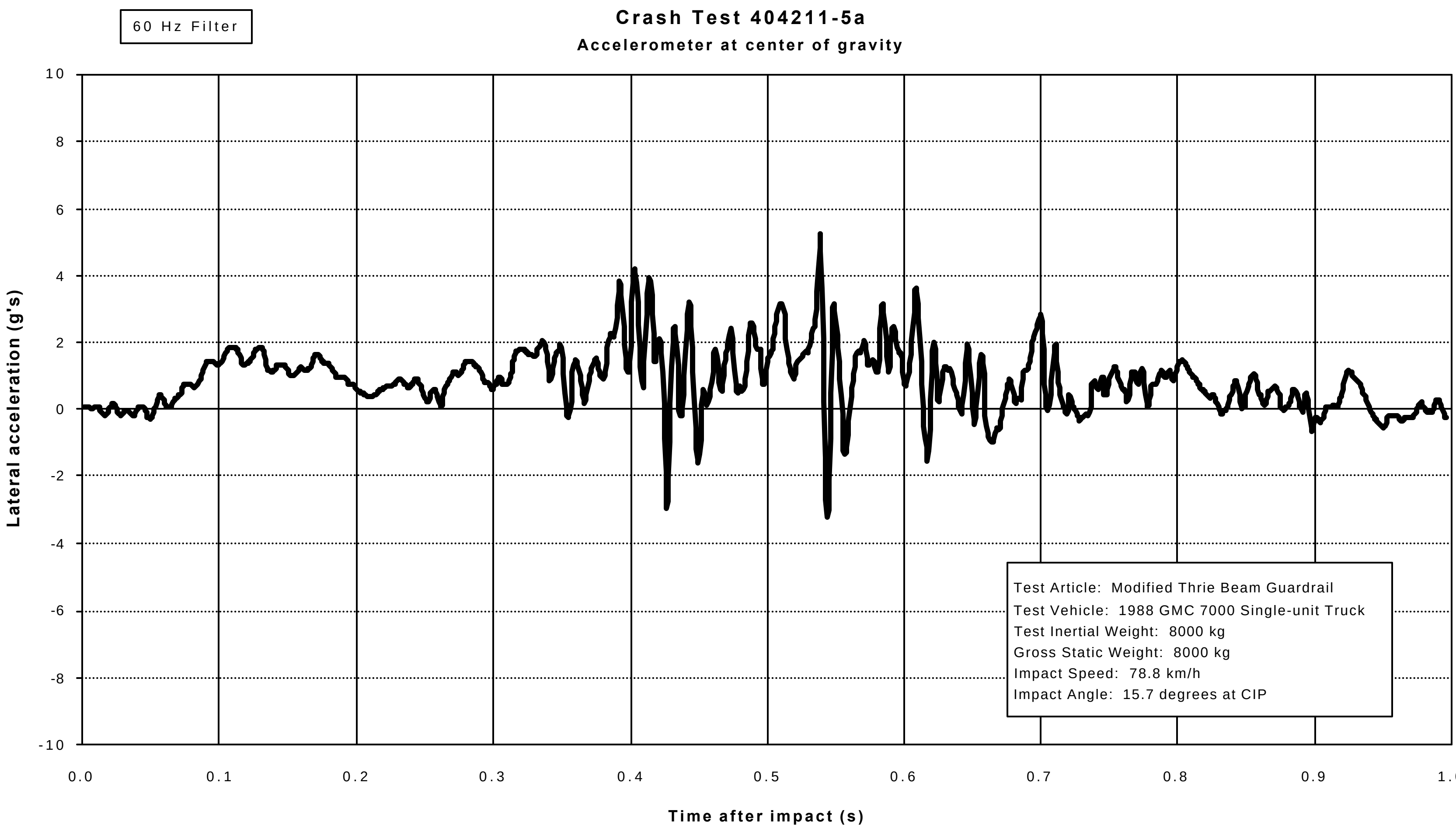


Figure 16. Vehicle lateral accelerometer traces for test 404211-5a
(accelerometer located at center of gravity).

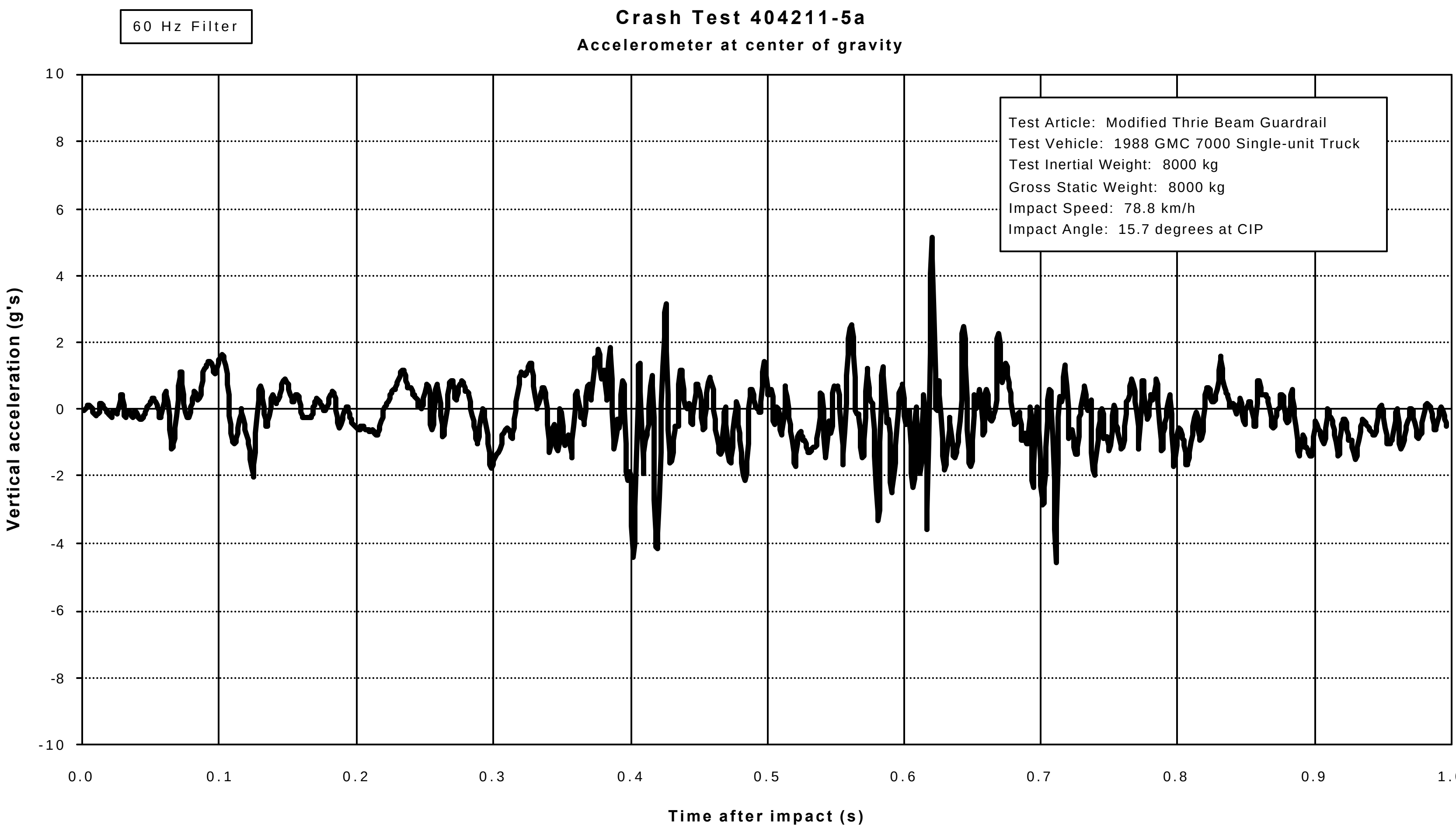


Figure 17. Vehicle vertical accelerometer trace for test 404211-5a (accelerometer located at center of gravity).

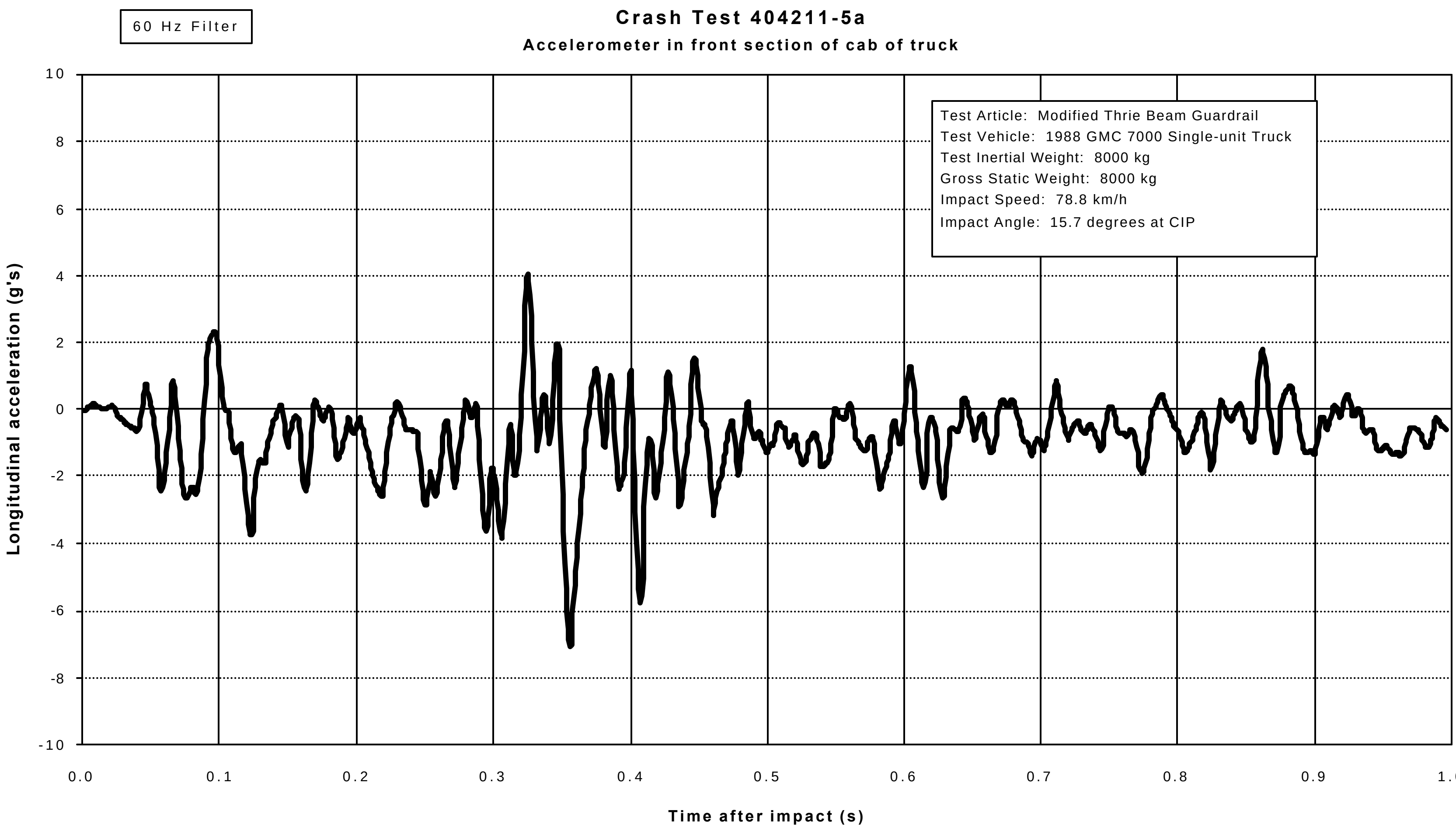


Figure 18. Vehicle longitudinal accelerometer trace for test 404211-5a (accelerometer located in front section of the cab of the vehicle).

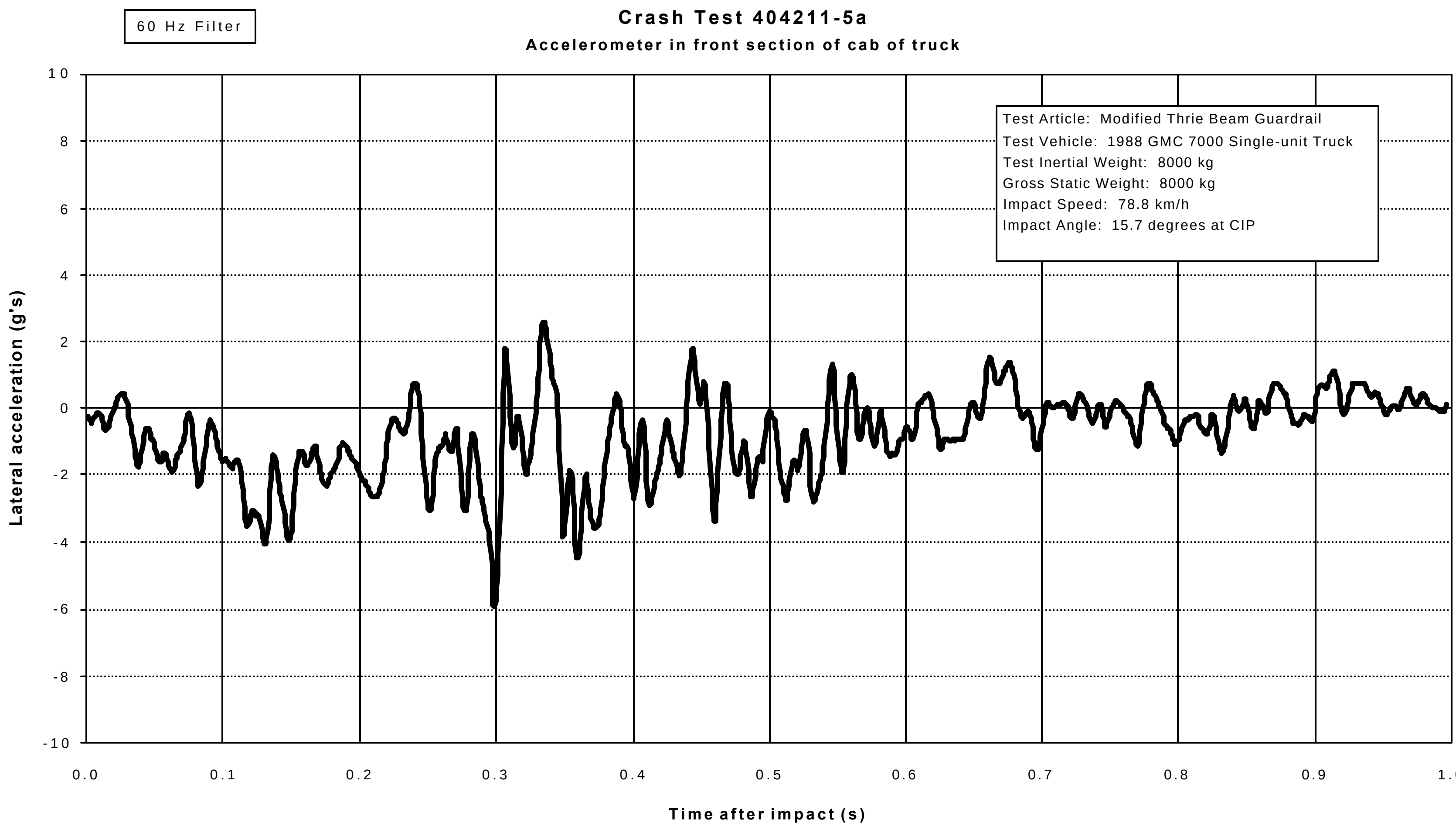


Figure 19. Vehicle lateral accelerometer traces for test 404211-5a (accelerometer located in front section of the cab of the vehicle).

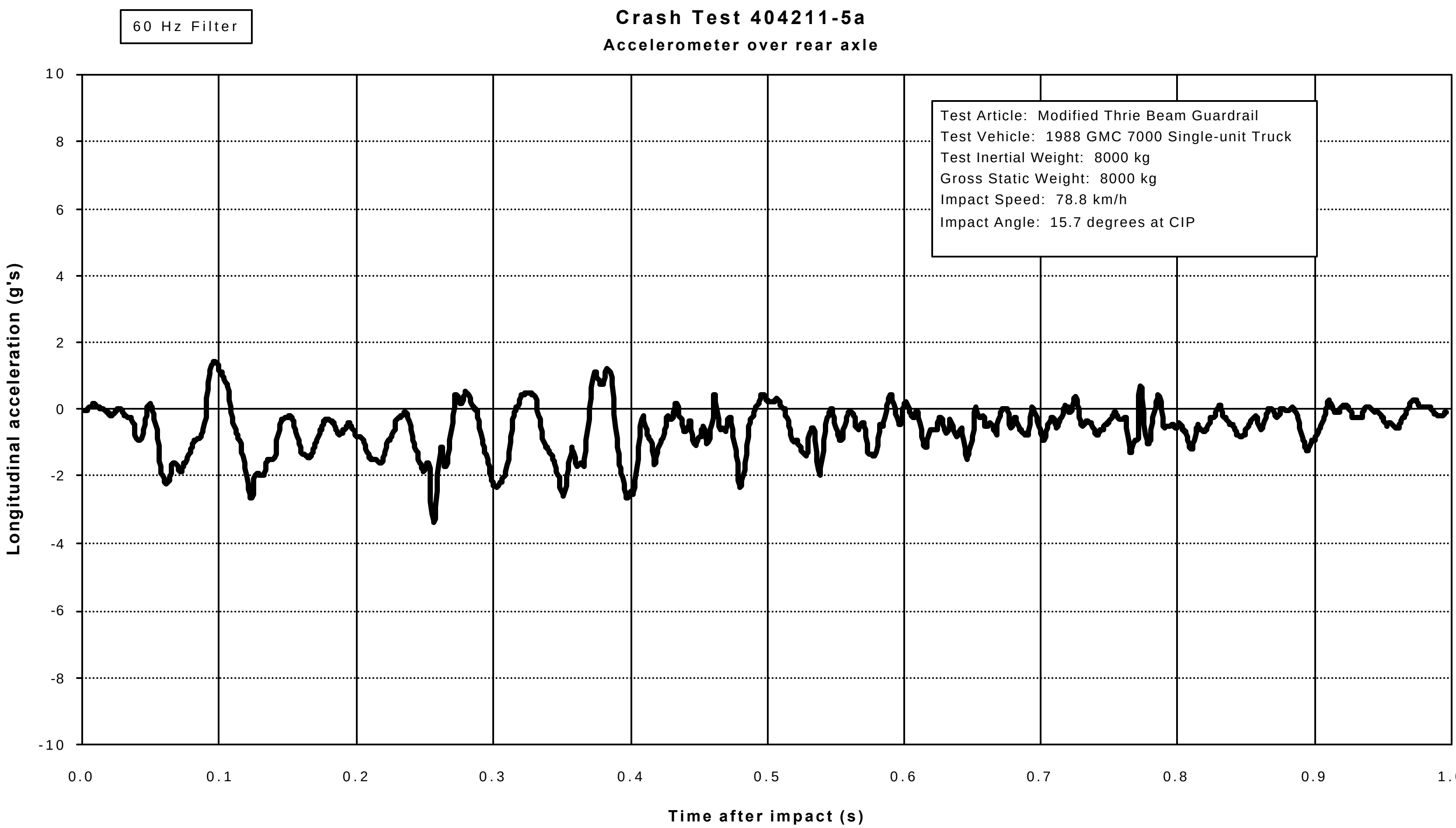


Figure 20. Vehicle longitudinal accelerometer trace for test 404211-5a (accelerometer located over rear axles).

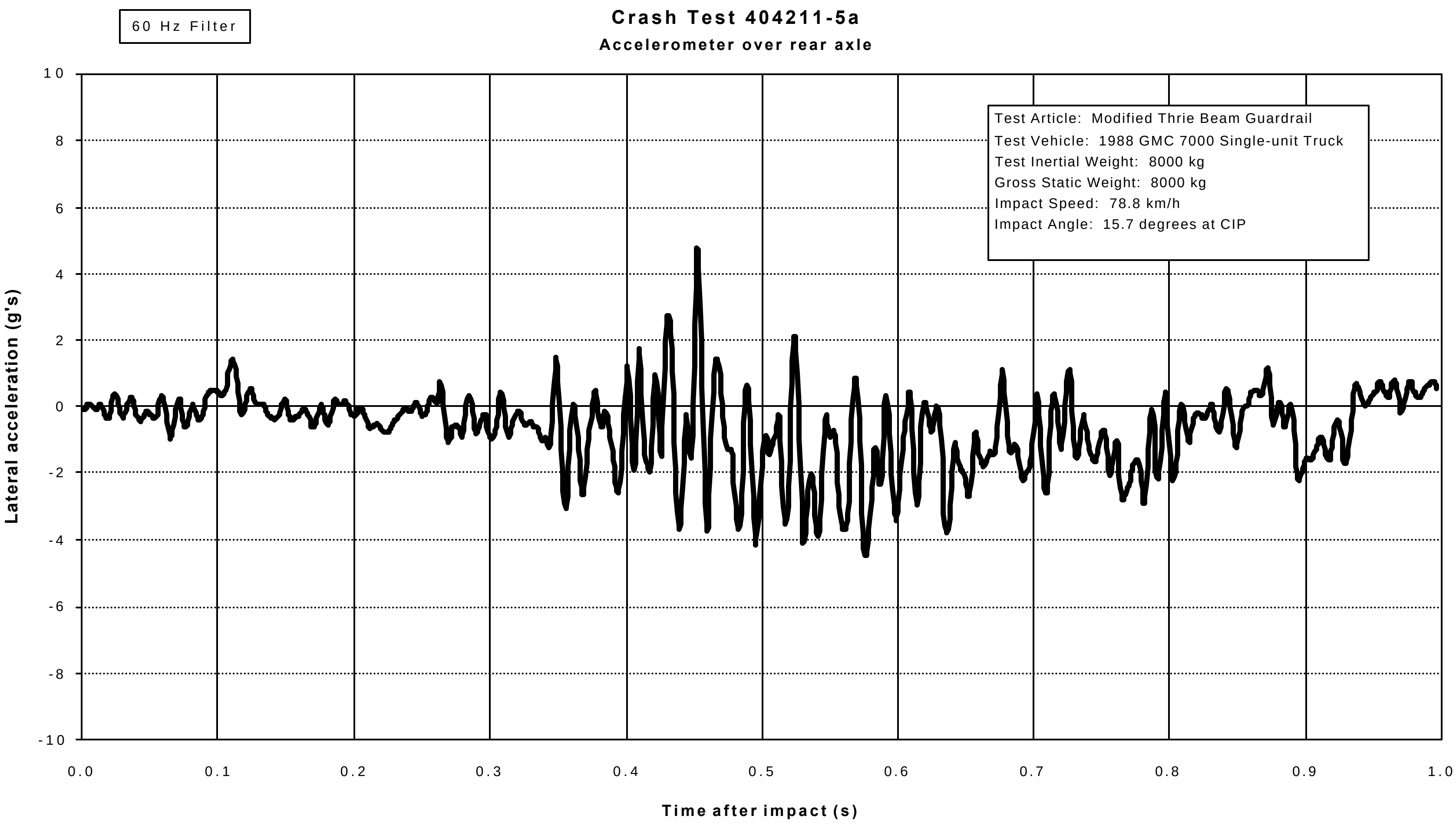


Figure 21. Vehicle lateral accelerometer traces for test 404211-5a (accelerometer located over rear axles).

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

SUMMARY OF FINDINGS

The modified thrie beam guardrail was contained and smoothly redirected. The vehicle did not penetrate, underride, or override the installation. 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. No deformation or intrusion into the occupant compartment occurred. The vehicle remained upright and stable during and after the collision. The vehicle did not intrude into adjacent traffic lanes as it remained adjacent to the guardrail. Exit angle at loss of contact was 8.2 degrees, which was 52 percent of the impact angle.

CONCLUSIONS

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

Table 1. Performance evaluation summary for test 404211-5a, NCHRP Report 350 test 4-12.

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

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 modified thrie beam guardrail was contained and smoothly redirected. 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, nor 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
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 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

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.

3. King K. Mak, Roger P. Bligh, and Wanda L. Menges, *Testing of State Roadside Safety Systems, Volume I: Technical Report*, Report FHWA-RD-98-036, prepared by Texas Transportation Institute, The Texas A&M University, College Station, Texas, for Federal Highway Administration, Washington, D.C., February 1998.