TEXAS TRANSPORTATION INSTITUTE

WYOMING TEST LEVEL 4 BRIDGE RAILING

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Research Agreement No. 48251
TTI Project No. 472610
Bridge Railing Crash Test Program

Sponsored by

Wyoming Department of Transportation
Cheyenne, Wyoming 82003

January 1996

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A & M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
WYOMING TEST LEVEL 4 BRIDGE RAILING	5. Report Date: January 1996 6. Performing Organization Code:
7. Author(s) King K. Mak, Wanda L. Menges, and D. Lance Bullard, Jr.	8. Performing Organization Report No. Project 472610
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. NCP No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Wyoming Department of Transportation P. O. Box 1708 Cheyenne, Wyoming 82003-1708	13. Type of Report and Period Covered Final Report February 1995 through December 1995 14. Sponsoring Agency Code

15. Supplementary Notes

Contacting Representative from Wyoming DOT: David H. Pope, State Bridge Engineer

16. Abstract

The objective of this study is to crash test and evaluate a new Wyoming bridge railing design in accordance with guidelines set forth in NCHRP Report 350 for Test Level 4 (TL-4) conditions. The following three crash tests were conducted:

1. Test designation 4-10. A 820-kg passenger car impacting the length-of-need section of the bridge railing at a nominal speed and angle of 100 km/h and 20 degrees.
2. Test designation 4-11. A 2,000-kg pickup truck impacting the length-of-need section of the bridge railing at a nominal speed and angle of 100 km/h and 25 degrees.
3. Test designation 4-12. An 8,000-kg single unit truck impacting the length-of-need section of the bridge railing at a nominal speed and angle of 80 km/h and 15 degrees.

Results of the three crash tests are presented in this report. The bridge railing contained and smoothly redirected the impacting vehicles in all three tests. The occupant risk factors were all well within the preferred limits. The small car and pickup truck remained upright and stable during and after the impact sequence. The box of the single unit truck attained a maximum roll angle of 31 degrees during the impact sequence and the vehicle rolled on its left side after exiting from the test installation. The instability and subsequent rollover of the vehicle after exiting from the bridge rail was apparently caused by the front axle separating from the vehicle during the impact. The exit conditions of all three vehicles indicated minimal potential for the vehicles to intrude into adjacent traffic lanes. In summary, the proposed Wyoming TL-4 bridge railing design successfully met all evaluation criteria for a Test Level 4 (TL-4) bridge railing as outlined in NCHRP Report 350 or a Performance Level 2 (PL-2) bridge railing under guidelines set forth in the 1989 AASHTO *Guide Specifications for Bridge Railings*.

17. Key Words	18. Distribution Statement
Bridge rails, roadside safety, crash testing	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	76	

Form DOT F 1700.7 (8-69)

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	ac
ha	hectares	2.47	acres	mi^2
km^2	square kilometers	0.386	square miles	
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

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

(Revised August 1992)

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I. INTRODUCTION

The Federal Highway Administration (FHWA) has recently adopted National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, as the official guideline for evaluating the crashworthiness of roadside safety appurtenances and terrain features.[1] The guidelines in NCHRP Report 350 supersede those in NCHRP Report 230 and the 1989 American Association of State Highway and Transportation Officials (AASHTO) *Guide Specification for Bridge Railings*. [2,3] All new installations of traffic barriers and other roadside safety features on the National Highway System (NHS) will be required to meet the testing and evaluation criteria of NCHRP Report 350 after September of 1998.

The current bridge railing design (hereinafter referred to as 740WYBRAIL) used by the Wyoming Department of Transportation (WYDOT) was successfully crash tested according to guidelines set forth in NCHRP Report 230.[4] However, it is anticipated that the current bridge railing design will not be able to meet the new testing and evaluation criteria of NCHRP Report 350 for a Test Level 4 (TL-4) bridge railing. Thus, WYDOT has designed a new bridge railing (hereinafter referred to as 830WYBRAIL) that will satisfy the new testing and evaluation criteria of NCHRP Report 350.

The objective of this study is to crash test and evaluate the new 830WYBRAIL design in accordance with guidelines set forth in NCHRP Report 350 for Test Level 4 (TL-4) conditions. This report presents the results of the full-scale crash tests conducted on this new Wyoming bridge railing.

II. STUDY APPROACH

2.1 BRIDGE RAILING DESIGN DETAILS

The new Wyoming TL-4 bridge railing is of the post-and-rail design, details of which are shown in figures 1 and 2. The overall height of the bridge rail is 830 mm, including a 150-mm high, 500 mm wide concrete curb. The posts were fabricated from two 16-mm thick steel plates with nominal dimensions of 664 mm tall x 250 mm deep x 200 mm wide. The posts are attached to the concrete curb section by three cast-in-place 22-mm diameter high strength steel anchor bolts. The maximum allowable spacing between adjacent posts is 3 m. There are two horizontal rail elements. The top rail element is fabricated from TS 152 mm x 102 mm x 7.9 mm structural steel and the lower rail element is fabricated from TS 152 mm x 76 mm x 6.4 mm structural steel. The rail elements are attached to the posts with 16-mm diameter threaded U-bolts, 80 mm wide and 90 mm long. The face of the rail elements are flush with the face of the curb. A minimum yield stress of 250 MPa is specified for the steel posts and rail elements. Details of the steel reinforcement for the bridge deck and the curb section are shown in figure 2. Minimum yield strengths of 400 MPa is specified for the steel reinforcement and 26 MPa for the concrete.

2.2 TEST ARTICLE

A 23-m long test installation was constructed for crash testing of the Wyoming TL-4 bridge railing. The test installation consisted of a 1 m wide, 200 mm thick cantilevered concrete simulated bridge deck, with a 500 mm wide and 150 mm high concrete curb section. The maximum post spacing of 3 m was used since it represents the most critical condition. The bridge rail test installation included eight support posts spaced 3 m on-center and two 1-m long Type 3 terminal ends for a total length of 23 m. The top rail splices were located nominally 0.45 m and 0.47 m upstream of posts 3 and 6, respectively. The lower rail splices were located nominally 0.45 m and 0.47 m upstream of posts 4 and 7, respectively. Photographs of the completed proposed Wyoming bridge railing installation are presented in figure 3.

2.3 CRASH TEST MATRIX

According to guidelines set forth in NCHRP Report 350, the following three crash tests are required for evaluating the length-of-need (LON) section of a bridge railing design under the TL-4 test conditions:

1. Test designation 4-10. A 820-kg passenger car impacting the LON section of the bridge railing at a nominal speed and angle of 100 km/h and 20 degrees. The purpose of this small car test is to evaluate the overall performance of the LON section in general, and occupant risks in particular.

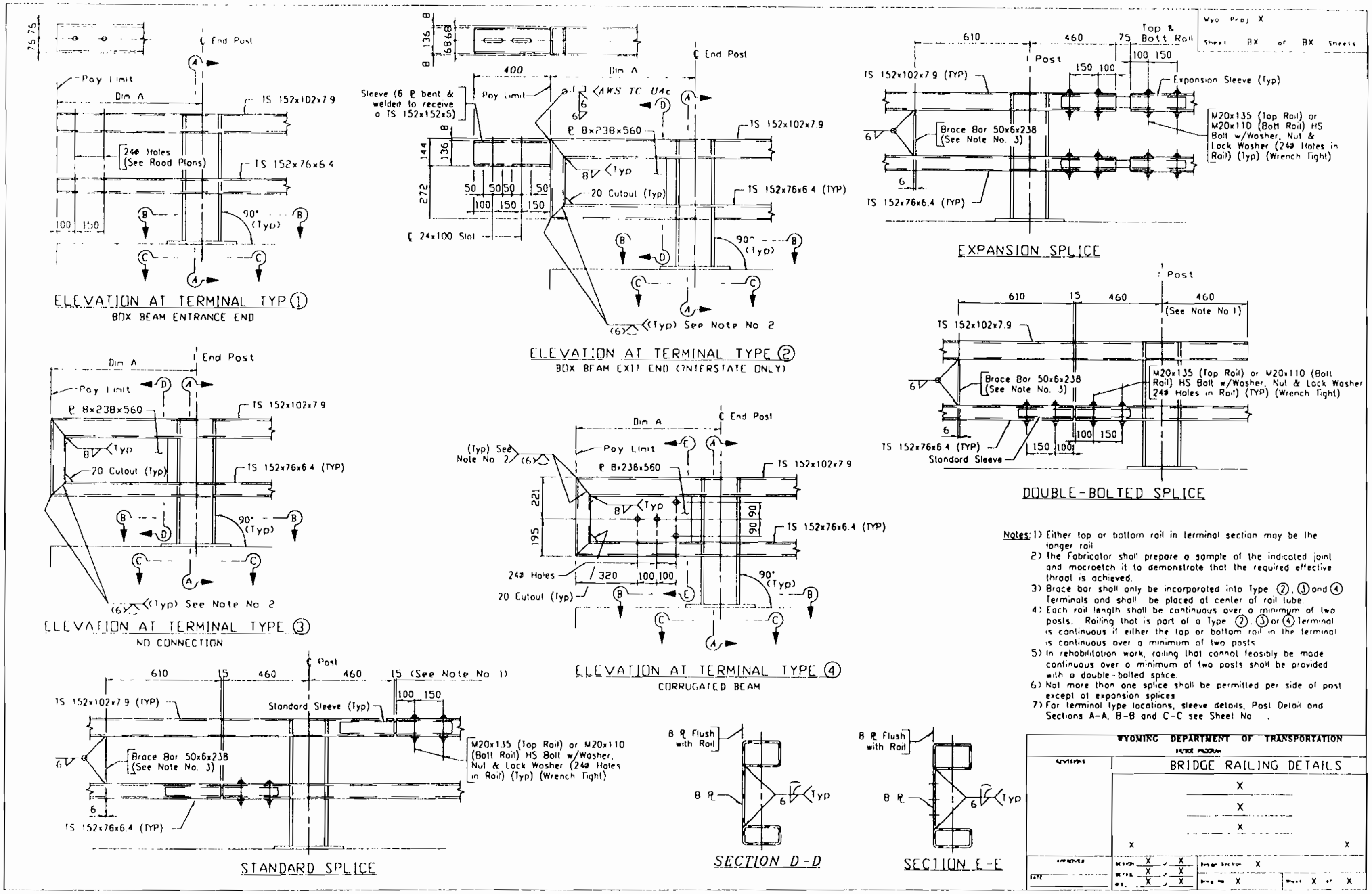


Figure 1. Details of Wyoming TL-4 bridge railing design.

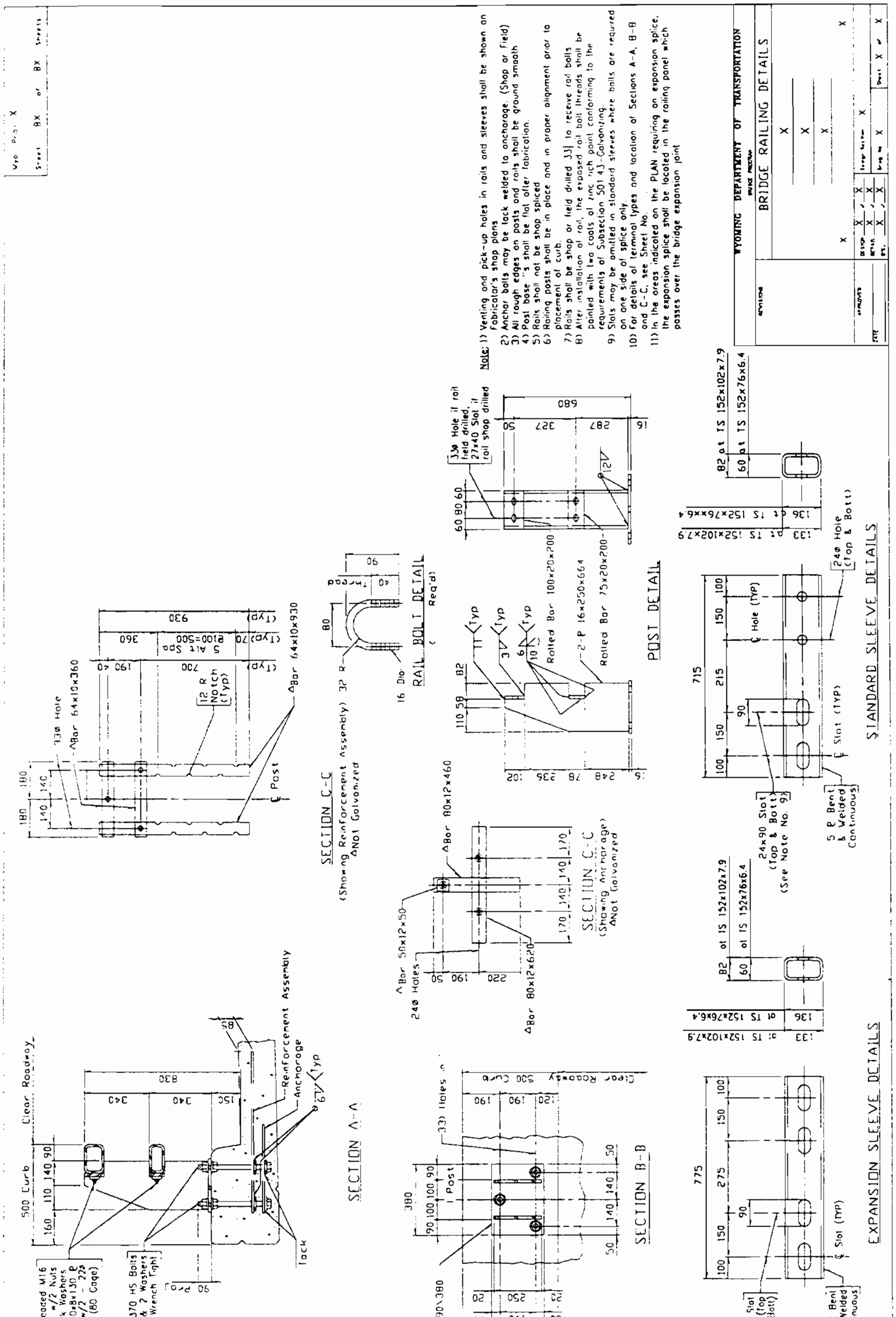
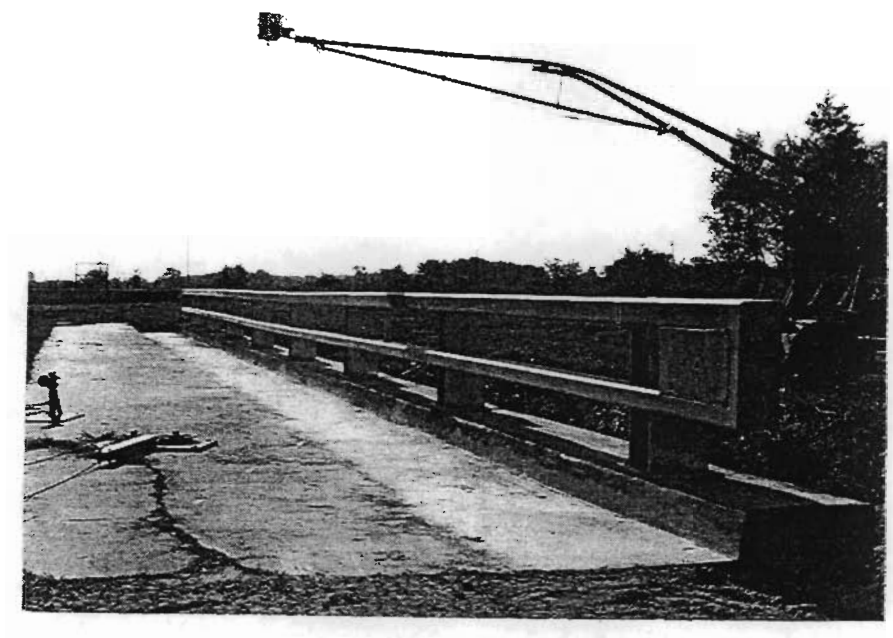


Figure 2. Details of Wyoming bridge deck and curb section.



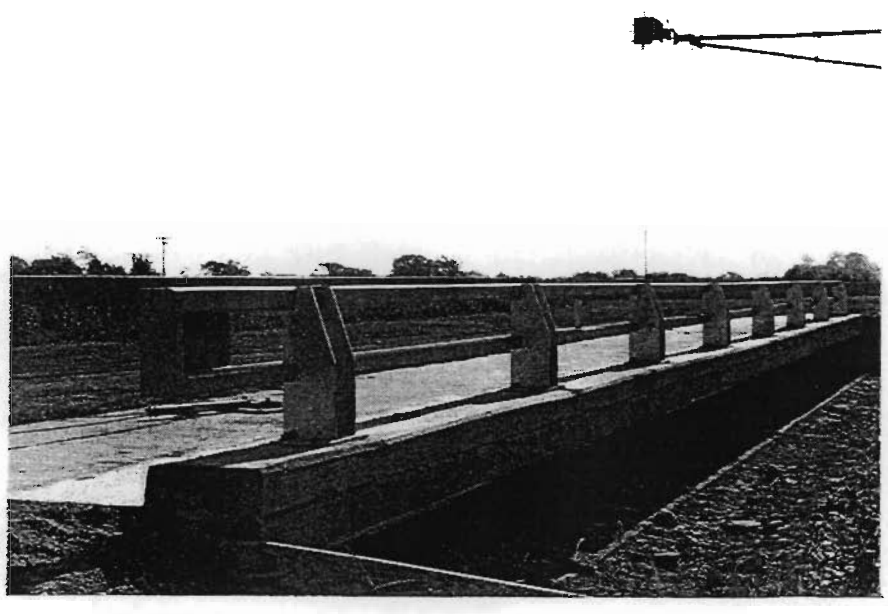


Figure 3. Wyoming TL-4 bridge railing test installation before testing.

2. Test designation 4-11. A 2,000-kg pickup truck impacting the LON section of the bridge railing at a nominal speed and angle of 100 km/h and 25 degrees. The purpose of this test is to evaluate the strength of the LON section in containing and redirecting the 2000P vehicle.

3. Test designation 4-12. An 8,000-kg single unit truck impacting the LON section of the bridge railing at a nominal speed and angle of 80 km/h and 15 degrees. The purpose of this test is to evaluate the strength of the LON section in containing and redirecting the 8000S vehicle.

2.4 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.

2.4.1 Electronic Instrumentation and Data Processing

The 820C and 2000P test vehicles were 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 8000S test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates and a triaxial accelerometer to measure longitudinal, lateral, and vertical levels in the cab of the truck. A triaxial accelerometer was also installed at the center-of-gravity of the vehicle in the cargo area to measure longitudinal, lateral, and vertical 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 bridge railing.

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 on the functions of these two computer programs are provided as follows.

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

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

2.4.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the 820C vehicle. The dummy was un-instrumented. Use of a dummy in the 2000P and 8000S vehicle is optional according to NCHRP Report 350 and there was no dummy used in the tests with these two vehicles.

2.4.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; and one placed behind the bridge railing at an angle; a third placed to have a field of view parallel to and aligned with the bridge railing at the downstream end. A flash bulb activated by pressure sensitive tapeswitches was positioned on the impacting vehicle to indicate the instant of contact with the bridge railing 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 conditions of the test vehicle and bridge railing before and after the test.

2.4.4 Test Vehicle Propulsion and Guidance

The test vehicles were 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 the vehicle to a safe and controlled stop.

III. CRASH TEST RESULTS

As mentioned previously, the following three crash tests were conducted to evaluate the performance of the Wyoming TL-4 bridge railing design:

1. Small car redirection test (test no. 472610-1). This test corresponded to test designation 4-10, which involved a 820-kg passenger car impacting the LON section of the bridge railing at a nominal speed and angle of 100 km/h and 20 degrees.

2. Pickup truck redirection test (test no. 472610-2). This test corresponded to test designation 4-11, which involved a 2,000-kg pickup truck impacting the LON section of the bridge railing at a nominal speed and angle of 100 km/h and 25 degrees.

3. Single unit truck redirection test (test no. 472610-3). This test corresponded to test designation 4-12, which involved an 8,000-kg single unit truck impacting the LON section of the bridge railing at a nominal speed and angle of 80 km/h and 15 degrees.

Detailed descriptions on the results of these three crash tests are presented in the following sections.

3.1 SMALL CAR REDIRECTION TEST (TEST NO. 472610-1)

A 1988 Ford Festiva, shown in figures 4 and 5, 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 410 mm and it was 565 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A, figure 22. 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.

3.1.1 Test Description

The vehicle impacted the bridge railing 1.6 m upstream of post 3, which was determined to be the critical impact point in accordance with the procedure outlined in NCHRP Report 350. The vehicle was traveling at a speed of 97.8 km/h and an angle of 20.8 degrees. At 0.032 second after impact, the right front tire aired out and, at 0.047 second, the vehicle began to redirect. The right front tire contacted the side plane of post 3 at 0.063 second, and the rear of the vehicle contacted the rail elements at 0.135 second. The vehicle was traveling parallel with the bridge railing at 0.137 second at a speed of 81.4 km/h. At 0.254 second, the vehicle lost contact with the bridge railing traveling at a speed of 78.5 km/h and an exit angle of 7.0 degrees. As the vehicle exited the

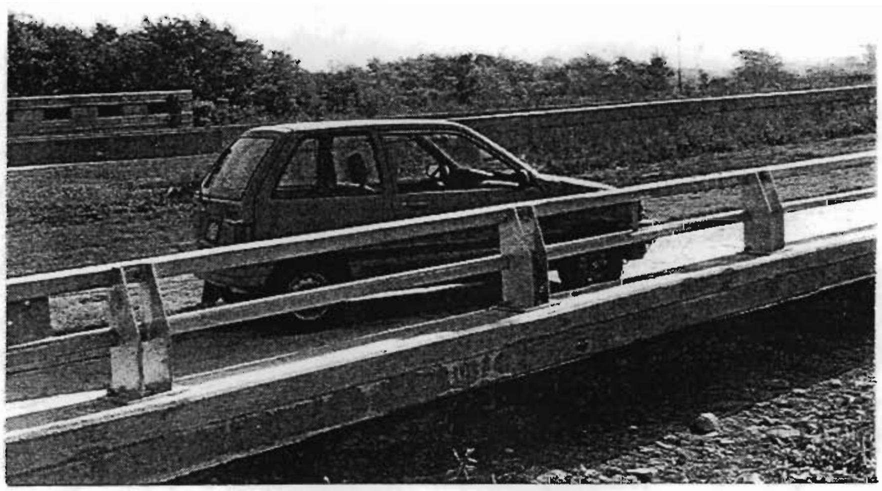


Figure 4. Vehicle/installation geometrics for test 472610-1.

Figure 5. Vehicle before test 472610-1.

test installation, it yawed clockwise and subsequently came to rest 46 m down and 7 m the impact point. Sequential photographs of the test are shown in Appendix B, figures 25 and 26.

3.1.2 Damage to Test Installation

The bridge railing received minimal damage as shown in figure 6. There were tire marks on the lower rail element (2.5 m in length) and the curb (2.2 m in length). The upper rail element was scraped by the body of the vehicle (2.5 m in length). Bumper marks were found on the impact side of post 3 between the upper and lower metal rail elements and the plate was bowed. Tire overlap on the lower part of post 3 measured 76 mm (or 114 mm from the curb).

3.1.3 Vehicle Damage

Most of the damage sustained by the vehicle was to the right front corner as shown in figure 7. The right side lower A-arm, tie rod, strut, axle, and stabilizer bar were bent and the bumper, hood, right front quarter panel, right front tire and rim, right door, and right rear quarter panel were damaged. The windshield received stress cracks in the lower corner on the right side and the right side B-pillar was buckled. Maximum exterior crush at the right front corner of the vehicle at bumper height was 120 mm. Maximum deformation into the occupant compartment was 19 mm at the beltline interior width near the front passenger area.

3.1.4 Occupant Risk Values

Data from the accelerometers located at the vehicle center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. Longitudinal occupant impact velocity was 5.5 m/s at 0.169 second, maximum longitudinal occupant ridedown acceleration was -4.0 g from 0.298 to 0.308 second, and the maximum longitudinal 0.050 second average was -8.5 g between 0.035 and 0.085 second. In the lateral direction, occupant impact velocity was 5.8 m/s at 0.097 second, maximum occupant ridedown acceleration was -3.4 g from 0.138 to 0.148 second, and the maximum 0.050 second average was -10.9 g between 0.018 and 0.068 second. These data and other information pertinent to the test are summarized in figure 8. Vehicle angular displacements during the test period are displayed in Appendix C, figure 31. Vehicle acceleration versus time traces are presented in Appendix D, figures 34 through 36.

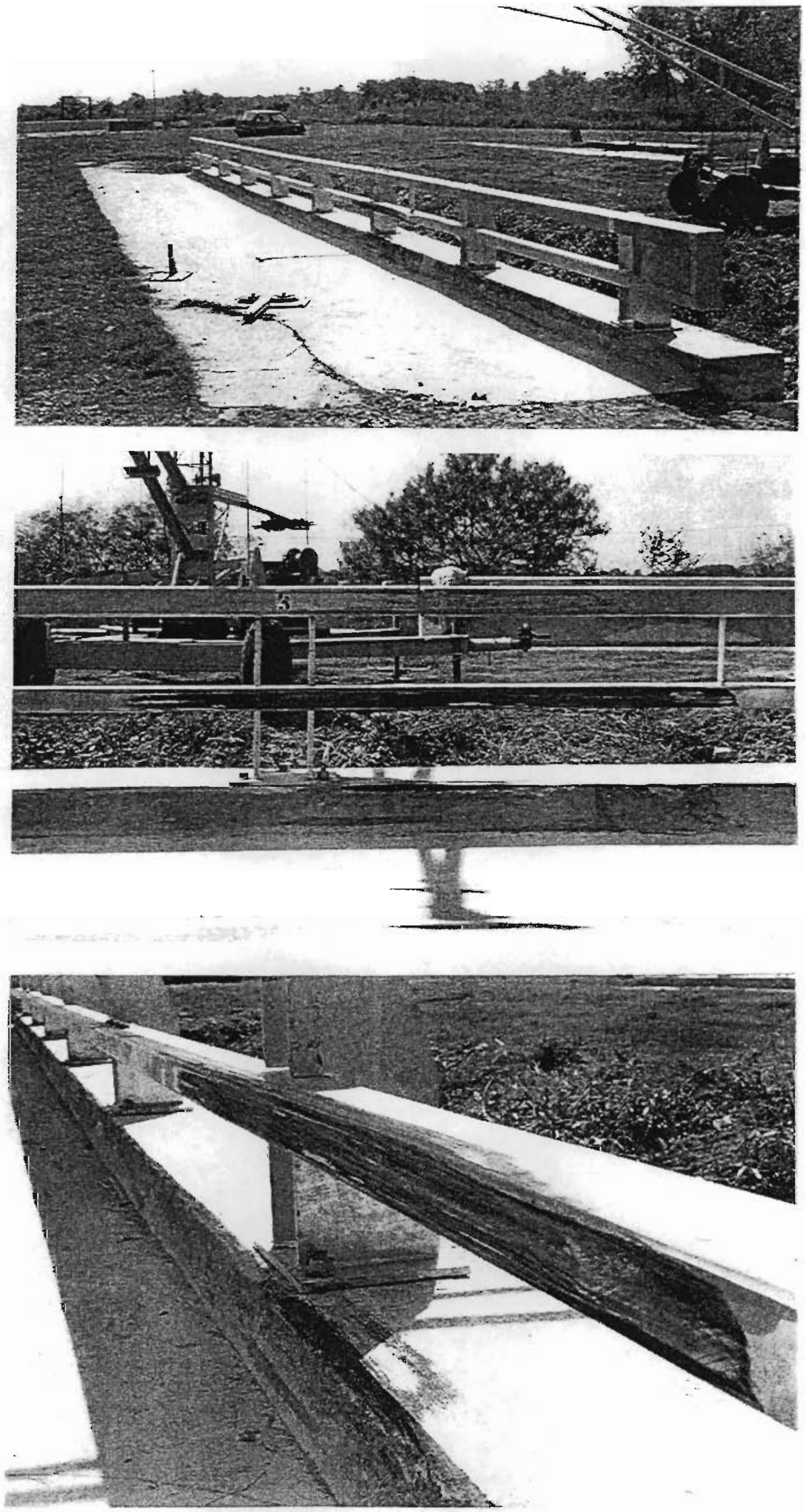


Figure 6. Installation after test 472610-1.

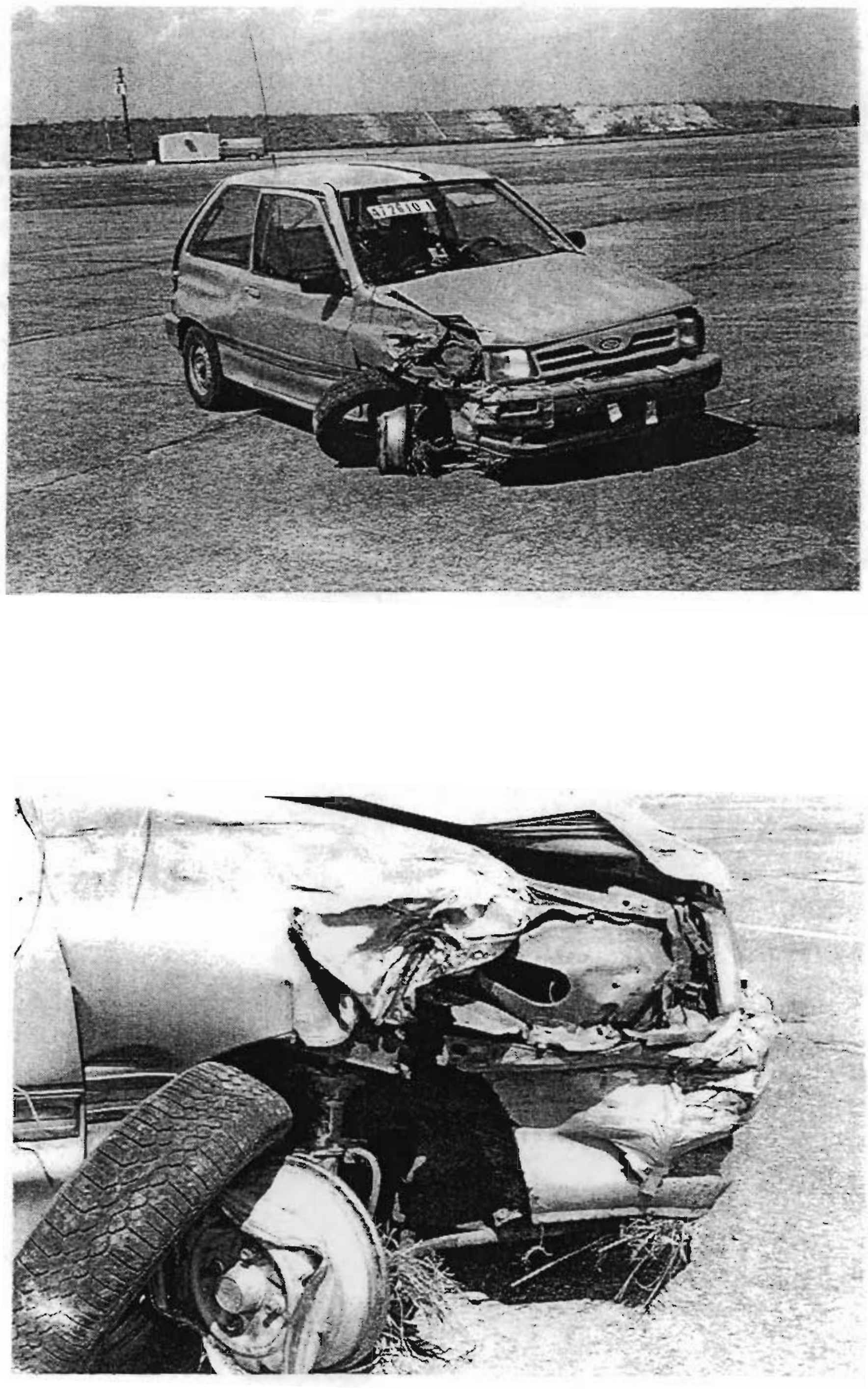
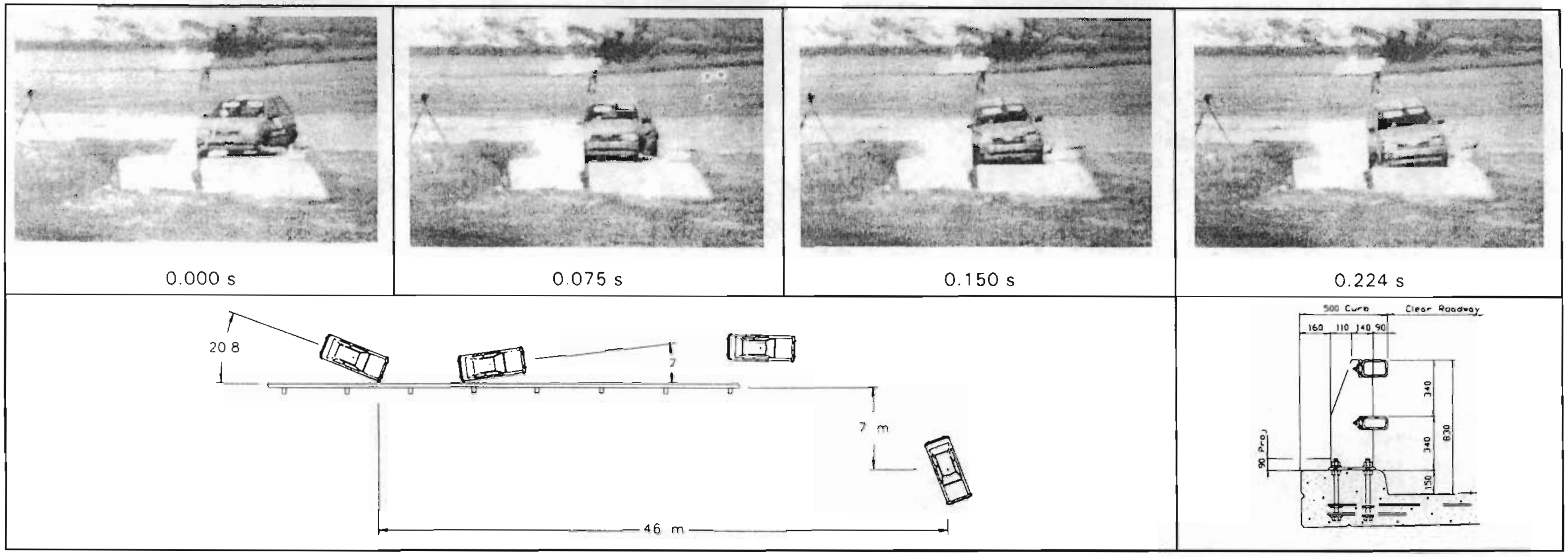


Figure 7. Vehicle after test 472610-1.



General Information	
Test Agency	Texas Transportation Institute
Test No.	472610-1
Date	10/02/95
Test Article	
Type	Bridge Railing
Name	Wyoming TL4 Bridge Railing
Installation Length (m)	23
Size and/or dimension and material of key elements	Tubular steel railing on concrete bridge deck and curb
Soil Type and Condition	Concrete bridge deck, dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Ford Festiva
Mass (kg) Curb	785
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	97.8
Angle (deg)	20.8
Exit Conditions	
Speed (km/h)	48.8
Angle (deg)	7.0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.5
y-direction	5.8
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.0
y-direction	-3.4
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-8.5
y-direction	-10.9
z-direction	3.3

Test Article Deflections (m)	
Dynamic	nil
Permanent	nil
Vehicle Damage	
Exterior	
VDS	01RFQ5
CDC	01FREK2 & 01RDES3
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	120
Max. Occ. Compart. Deformation (mm)	19
Post-Impact Behavior	
Max. Roll Angle (deg)	5.2
Max. Pitch Angle (deg)	3.9
Max. Yaw Angle (deg)	-20.5

Figure 8. Summary of results for test 472610-1.

3.2 PICKUP TRUCK REDIRECTION TEST (TEST NO. 472610-2)

The bridge railing test installation was repaired (which consisted of painting over the tire and contact marked) and used for the second test. Photographs of the test installation are shown in figure 9. A 1989 Chevrolet 2500 pickup truck, shown in figures 10 and 11, was used for the crash test. Test inertia weight of the vehicle was 2,000 kg, and its gross static weight was 2,000 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 A, figure 23. 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.

3.2.1 Test Description

The vehicle impacted the bridge railing 2.0 m upstream of post 3, which was determined to be the critical impact point in accordance with the procedure outlined in NCHRP Report 350, at a speed of 101.0 km/h and an angle of 24.9 degrees. At 0.007 second after impact, the bumper of the vehicle moved between the two rail elements and at 0.022 second the right front tire aired out as it contacted the curb. The vehicle began to redirect at 0.042 second and the right front tire contacted post 3 at 0.066 second. The rear of the vehicle contacted the rail as it became parallel with the bridge railing at 0.172 second, traveling at a speed of 87.1 km/h. At 0.178 second, the right front tire of the vehicle rode past the front face of post 4. The vehicle lost contact with the bridge railing at 0.291 second, traveling at a speed of 85.3 km/h and an exit angle of 6.1 degrees. As the vehicle exited the test installation, it yawed clockwise and subsequently came to rest 63 m down and 4 m forward of the impact point. Sequential photographs of the test are shown in Appendix B, figures 27 and 28.

3.2.2 Damage to Test Installation

The bridge railing received minimal damage as shown in figure 12. The lower rail element received a maximum deformation of 3 mm near the impact area. There were tire marks on the lower rail element (3.5 m in length) and the curb (3.5 m in length). The upper rail element was scraped by the body of the vehicle (3.5 m in length). Bumper marks were found on the impact side of post 3 between the upper and lower rail elements. Tire overlap on the base plate of post 3 measured 51 mm (or 102 mm from the face of the curb) and on the side of post 3 it was 19 mm. There was also a surface crack in the curb radiating out from the left front bolt behind post 3.

3.2.3 Vehicle Damage

Most of the damage sustained by the vehicle was to the right front corner as shown in figure 13. The right side A-arm, tie rod, stabilizer bar, and frame were deformed and the drive shaft, transmission tunnel, and floorpan were twisted. The front bumper, hood, grill, right front

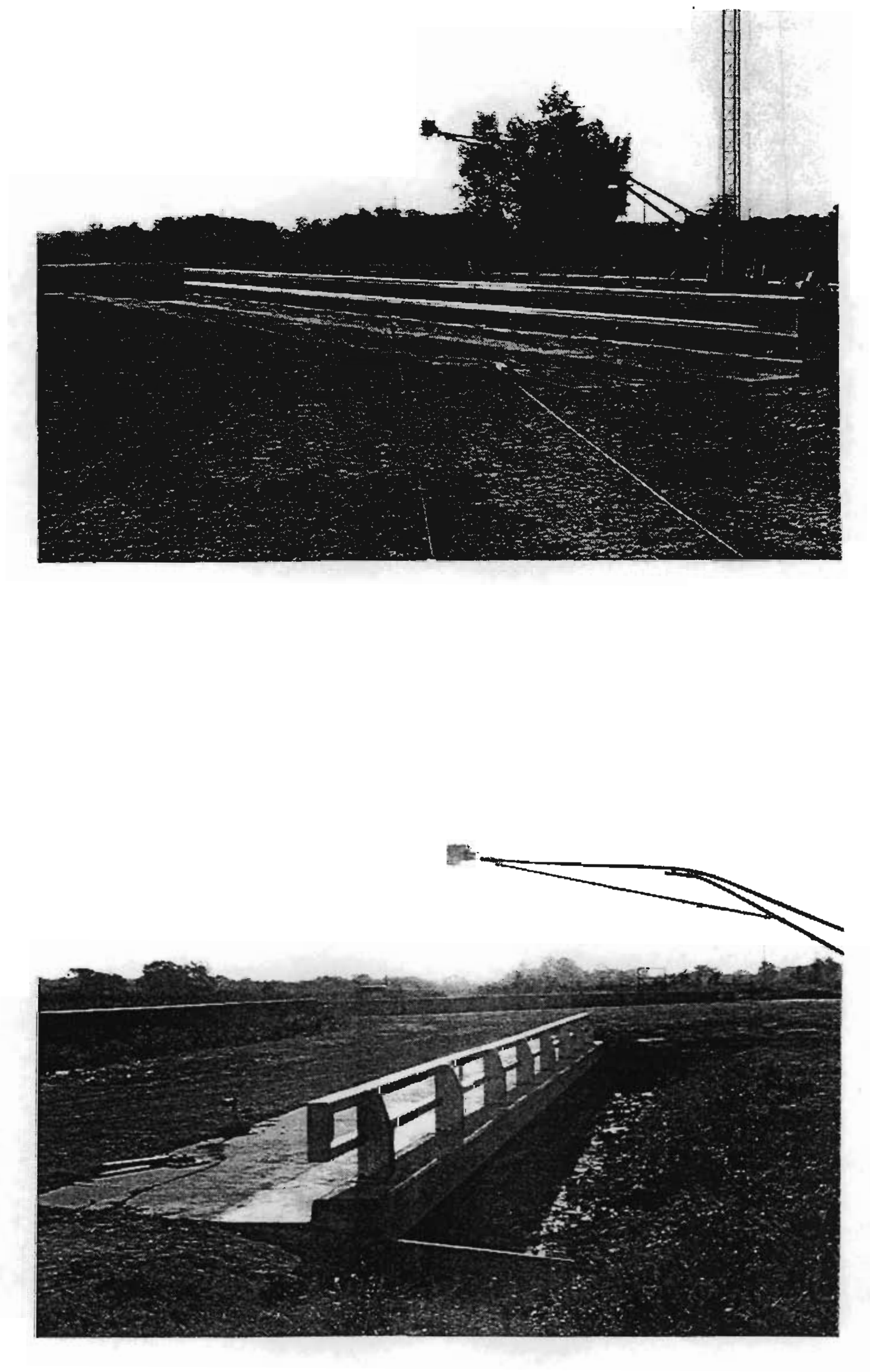


Figure 9. Wyoming TL-4 bridge railing test installation before test 472610-2.

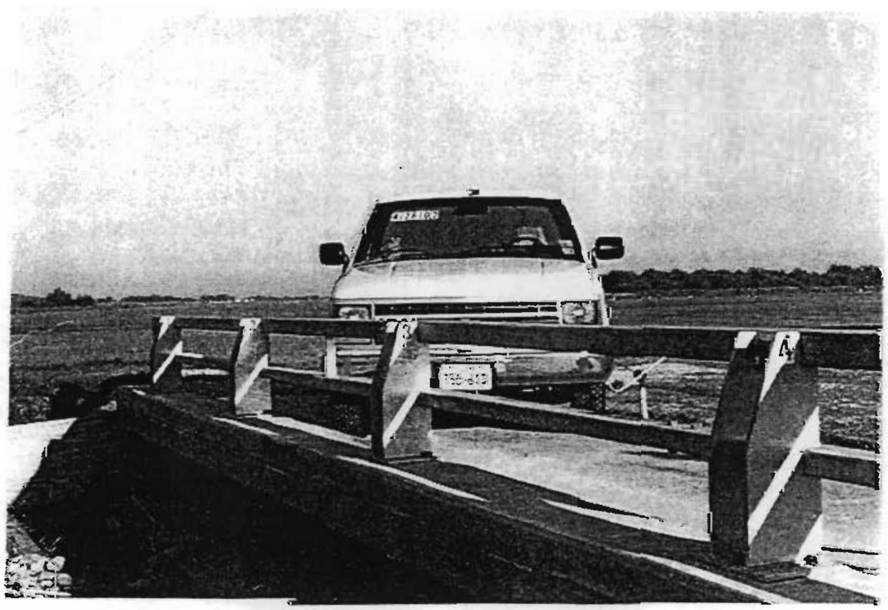


Figure 10. Vehicle/installation geometrics for test 472610-2.

Figure 11. Vehicle before test 472610-2.

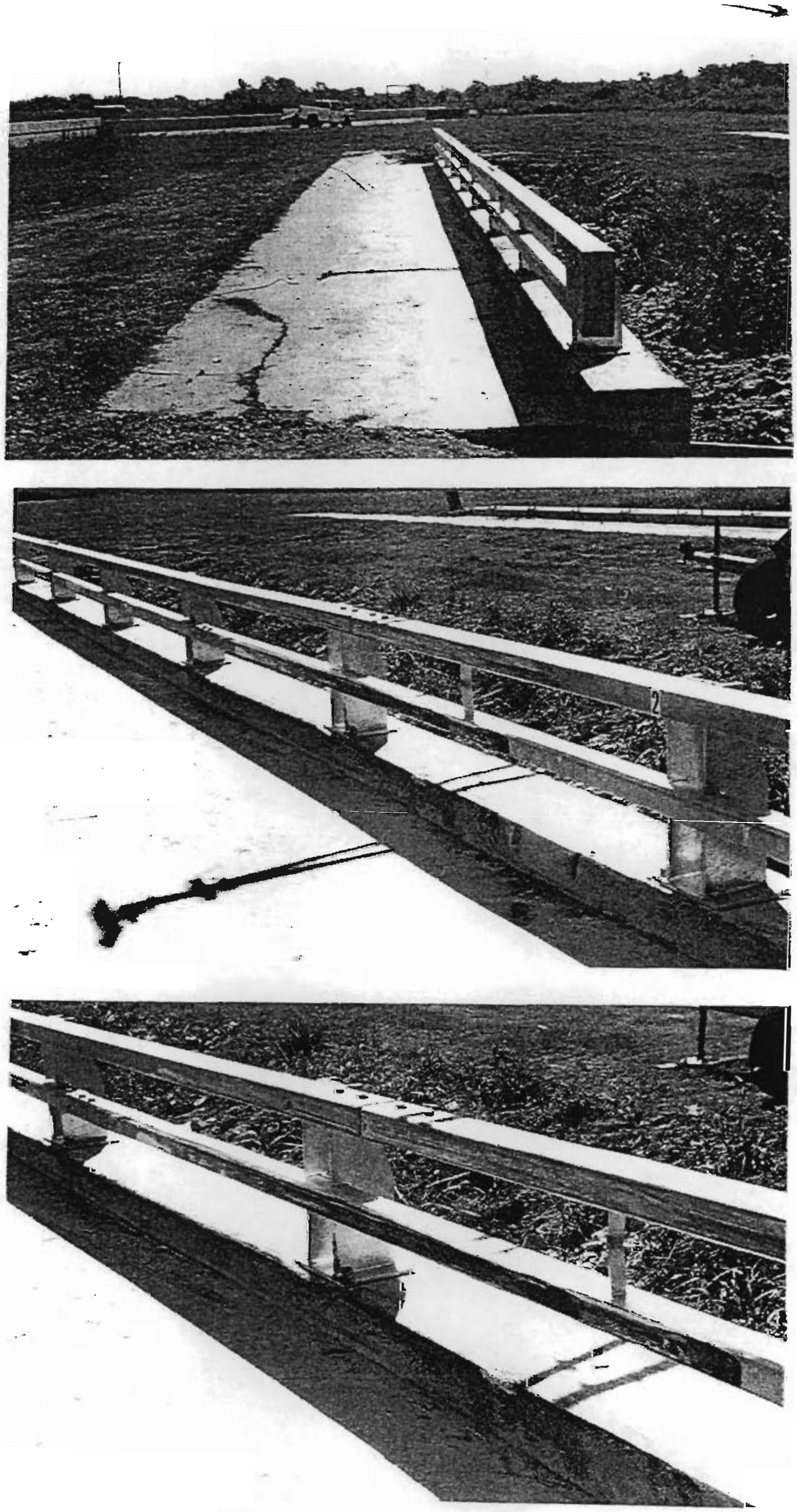


Figure 12. Installation after test 472610-2.

Figure 13. Vehicle after test 472610-2.

quarter panel, right front tire and rim, right door, right rear quarter panel, right rear rim, rear bumper, and tailgate were damaged. The windshield received stress cracks in the lower corner on the right side. Maximum exterior crush at the right front corner of the vehicle at bumper height was 330 mm. Maximum deformation into the occupant compartment was 79 mm in the floorpan area of the right passenger area.

3.2.4 Occupant Risk Values

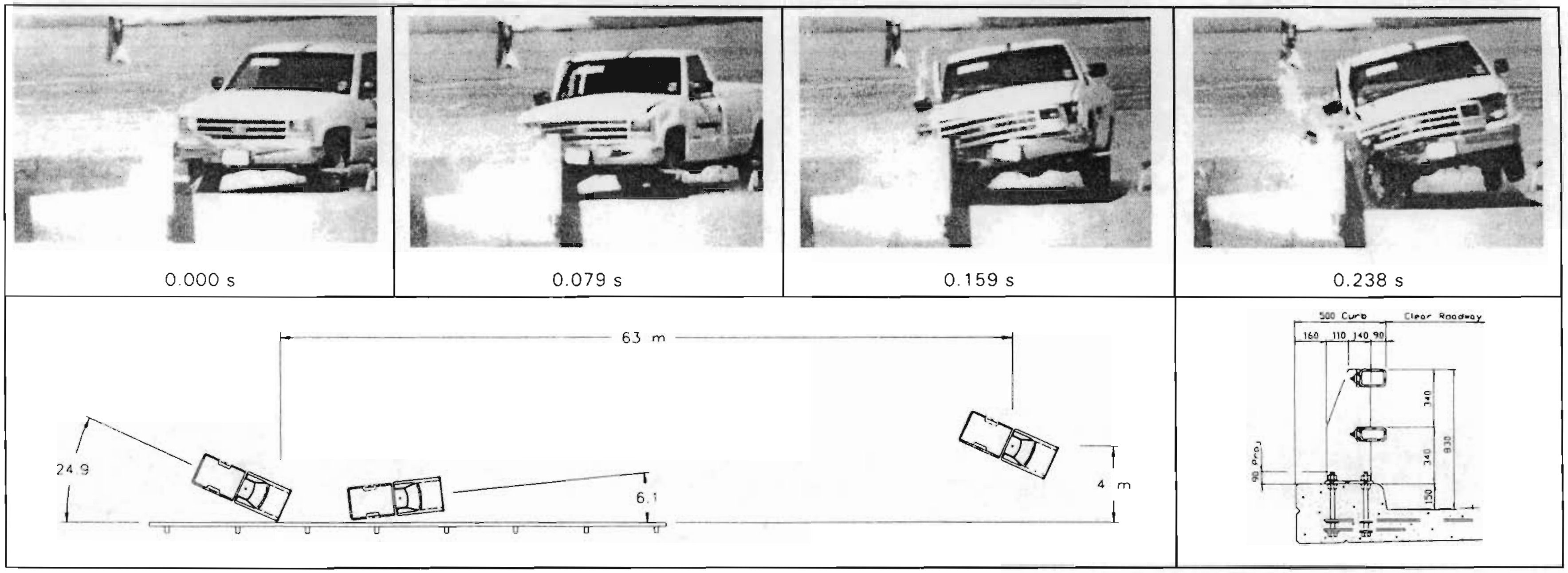
Data from the accelerometers located at the vehicle center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. Longitudinal occupant impact velocity was 6.0 m/s at 0.173 second, maximum longitudinal occupant ridedown acceleration was -9.2 g from 0.106 to 0.116 second, and the maximum longitudinal 0.050 second average was -10.4 g between 0.038 and 0.088 second. In the lateral direction, occupant impact velocity was 6.7 m/s at 0.106 second, maximum occupant ridedown acceleration was -12.0 g from 0.200 to 0.210 second, and the maximum 0.050 second average was -10.4 g between 0.040 and 0.090 second. These data and other information pertinent to the test are summarized in figure 14. Vehicle angular displacements during the test period are displayed in Appendix C, figure 32. Vehicle acceleration versus time traces are presented in Appendix D, figures 37 through 39.

3.3 SINGLE UNIT TRUCK REDIRECTION TEST (TEST NO. 472610-3)

The bridge railing test installation was again repaired (which consisted of painting over the tire and contact marks) for the third test, photographs of which are shown in figure 15. A 1980 Ford F700 single unit truck, shown in figures 16 and 17, was used for the crash test. The empty weight of the vehicle was 4,653 kg and the test inertia weight of the vehicle was 8,000 kg. The height to the lower edge of the vehicle bumper was 475 mm and it was 795 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix A, figure 24. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

3.3.1 Test Description

The vehicle impacted the bridge railing 279 mm downstream of post 2, or 2.0 m upstream of the splice upstream of post 3, which was determined to be the critical impact point in accordance with the procedure outlined in NCHRP Report 350, traveling at a speed of 79.7 km/h and an angle of 15.9 degrees. At 0.019 second after impact, the right front tire contacted the curb and, at 0.027 second, the bumper of the vehicle moved up between the metal rail elements. The front axle partially separated from the vehicle at 0.138 second, and the vehicle began to redirect at 0.152 second. At 0.342 second, the cab of the vehicle was traveling parallel to the bridge railing at a speed of 76.9 km/h. As the vehicle continued to move down the rail, the right bottom edge of the box of the truck set down on top of the rail at 0.388 second and continued down the top of the upper rail element to the end of the test installation. The box attained a maximum clockwise roll of 31 degrees



General Information	
Test Agency	Texas Transportation Institute
Test No.	472610-2
Date	10/10/95
Test Article	
Type	Bridge Railing
Name	Wyoming TL4 Bridge Railing
Installation Length (m)	23
Size and/or dimension and material of key elements	Tubular steel railing on concrete deck and curb
Soil Type and Condition	Concrete bridge deck, dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500 Pickup
Mass (kg) Curb	1919
Test Inertial	2000
Dummy	No dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	101.0
Angle (deg)	24.9
Exit Conditions	
Speed (km/h)	85.3
Angle (deg)	6.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.0
y-direction	6.7
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	9.2
y-direction	-12.0
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-10.4
y-direction	-10.4
z direction	-9.4

Test Article Deflections (mm)	
Dynamic	N/A
Permanent	3.2
Vehicle Damage	
Exterior	
VDS	01RFQ4
CDC	01FREK3 &01RDES3
Interior	
OCDI	FS0103000
Maximum Exterior Vehicle Crush (mm)	330
Max. Occ. Compart. Deformation (mm)	79
Post-Impact Behavior	
Max. Roll Angle (deg)	12.6
Max. Pitch Angle (deg)	3.5
Max. Yaw Angle (deg)	-36.9

Figure 14. Summary of results for test 472610-2.

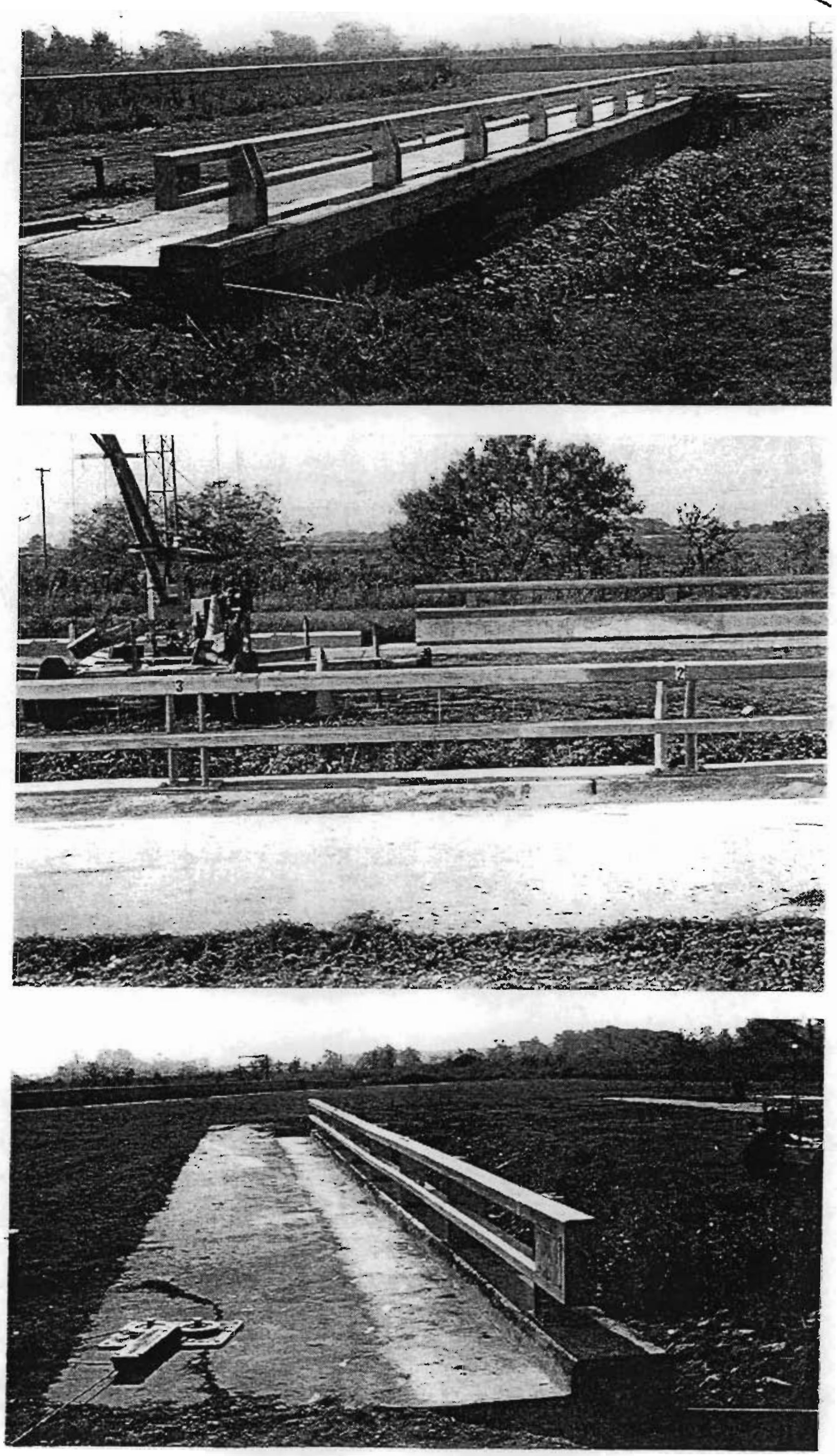


Figure 15. Wyoming TL-4 bridge railing test installation before test 472610-3.

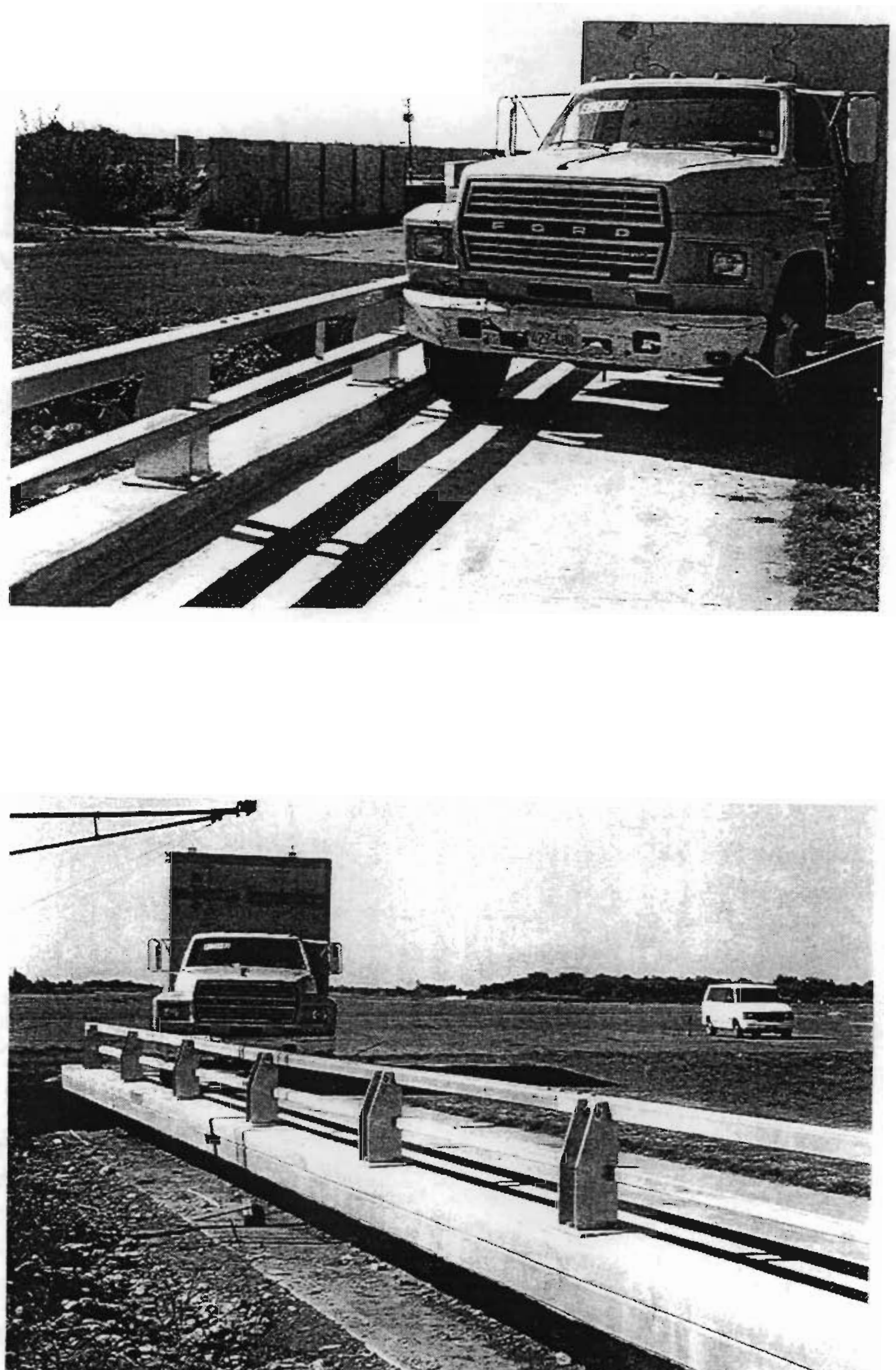


Figure 16. Vehicle/installation geometrics for test 472610-3.

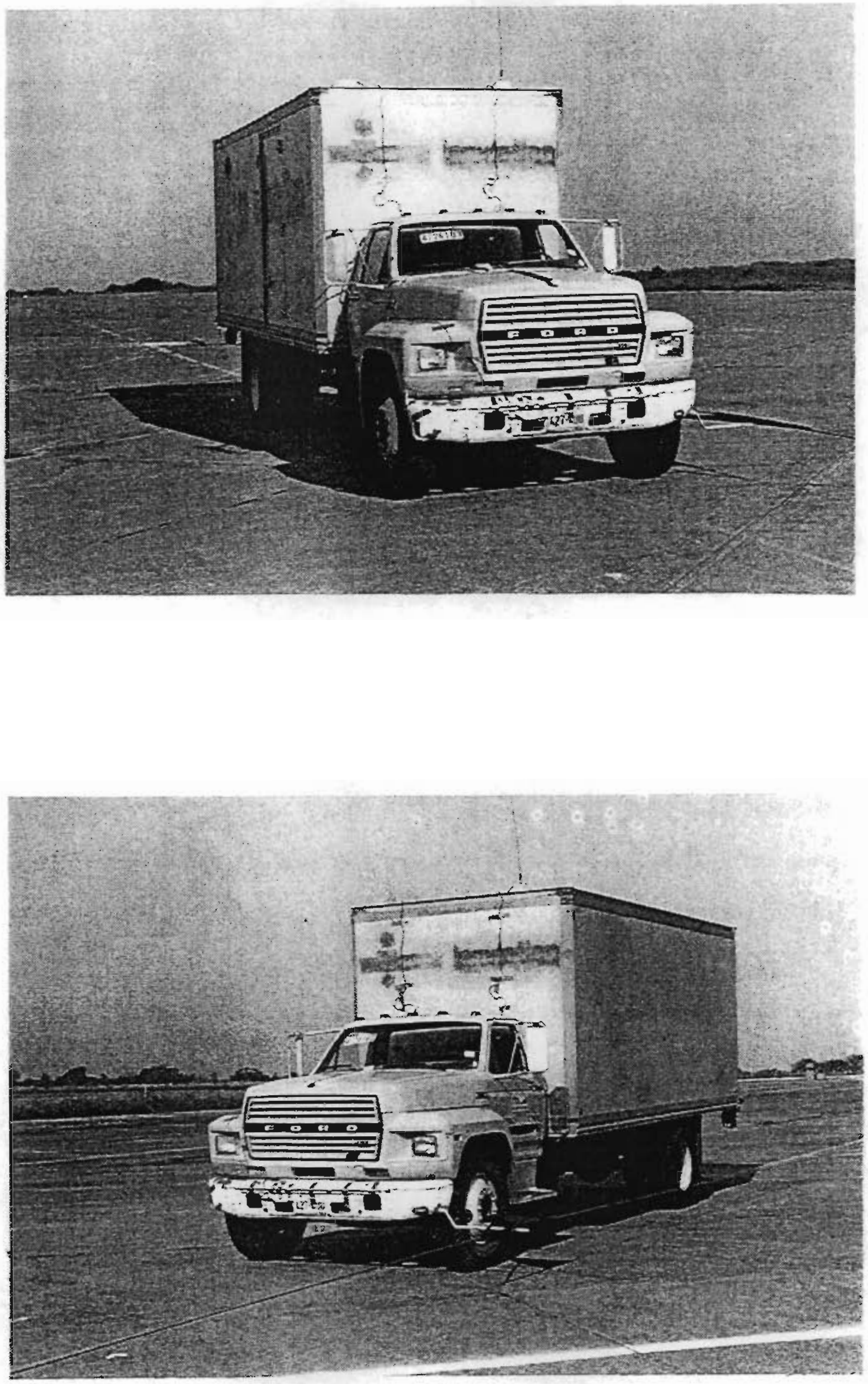


Figure 17. Vehicle before test 472610-3.

at 0.725 second and the vehicle was traveling at a speed of 66.5 km/h. As the vehicle rode off the end of the bridge railing, the box rotated counterclockwise and the vehicle yawed clockwise. The vehicle subsequently rolled onto its left side 46 m down from impact and in-line with the bridge railing. Sequential photographs of the test are shown in Appendix B, figures 29 and 30.

3.3.2 Damage to Test Installation

The bridge railing received minimal damage as shown in figures 18 and 19. There were tire marks on the upper and lower rail elements and the curb (1.2 m). The vehicle remained in contact with the rail from 279 mm downstream of post 2 until the end of the bridge railing. Maximum deformation of the upper rail element was 16 mm and the lower rail element was 22 mm. There was a gouge in the lower metal rail element near the point of initial impact and the spacer between post 2 and 3 was pulled up. A surface crack radiated from the right front bolt at post 2 and also from the center rear bolt at post 3.

3.3.3 Vehicle Damage

Most of the damage sustained by the vehicle during the collision was to the right side as shown in figure 20. The springs, shackles, shocks, suspension, and steering were damaged and the front axle was separated from the vehicle. The bumper, hood, front quarter panels and fuel tank were also damaged. Maximum exterior crush at the right front corner of the vehicle at bumper height was 590 mm.

3.3.4 Occupant Risk Values

Data from the accelerometers located at the vehicle center-of-gravity were digitized for information purposes only and were computed as follows. Longitudinal occupant impact velocity was -2.4 m/s at 0.500 second, maximum longitudinal occupant ridedown acceleration was -3.5 g from 0.335 to 0.345 second, and the maximum longitudinal 0.050 second average was 1.5 g between 0.282 and 0.332 second. In the lateral direction, occupant impact velocity was -2.7 m/s at 0.300 second, maximum occupant ridedown acceleration was 8.7 g from 0.341 to 0.351 second, and the maximum 0.050 second average was 3.9 g between 0.306 and 0.356 second. These data and other information pertinent to the test are summarized in figure 21. Vehicle angular displacements during the test period are displayed in Appendix C, figure 33. Vehicle acceleration versus time traces are presented in Appendix D, figures 40 through 47.

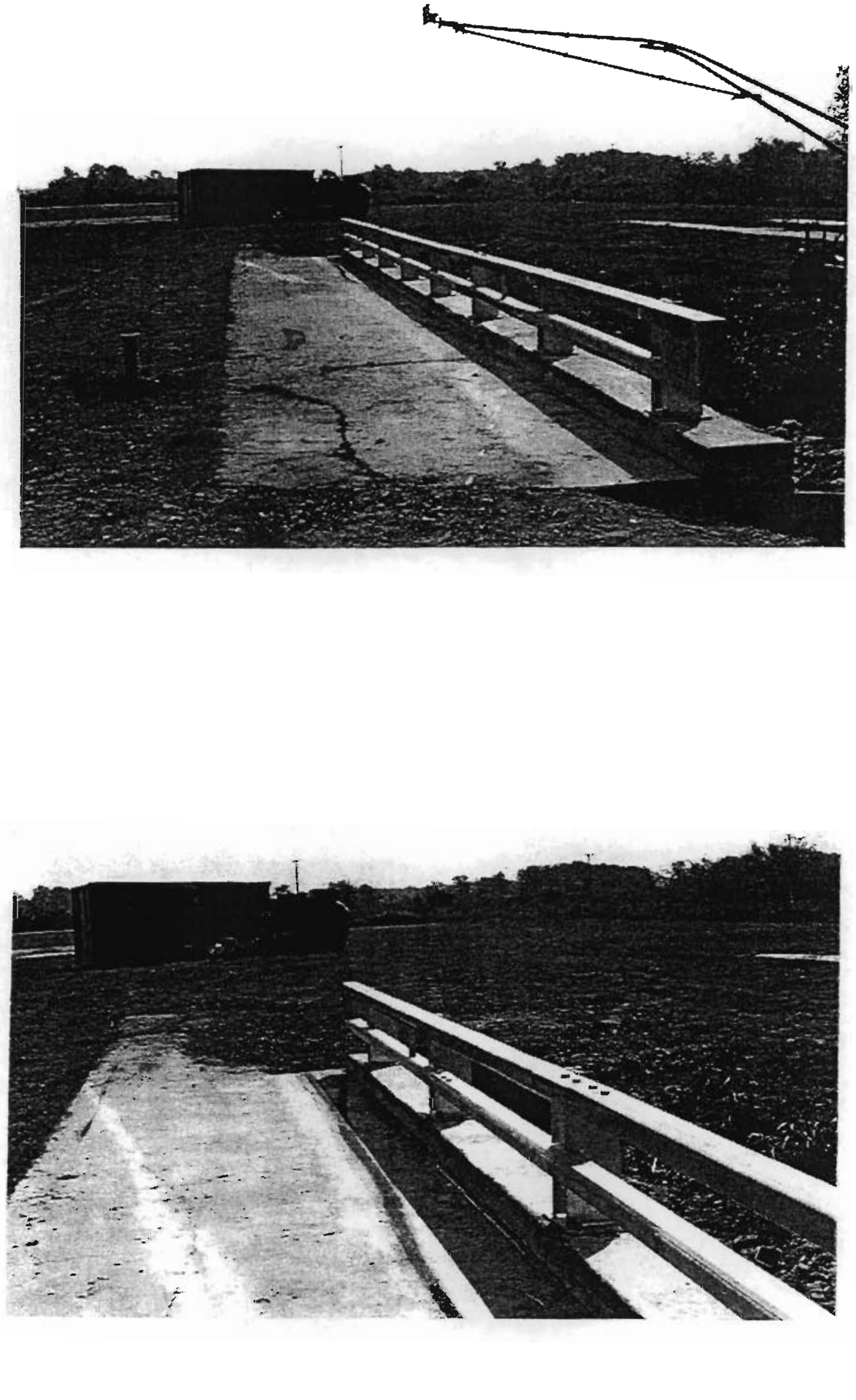


Figure 18. After impact trajectory for test 472610-3.

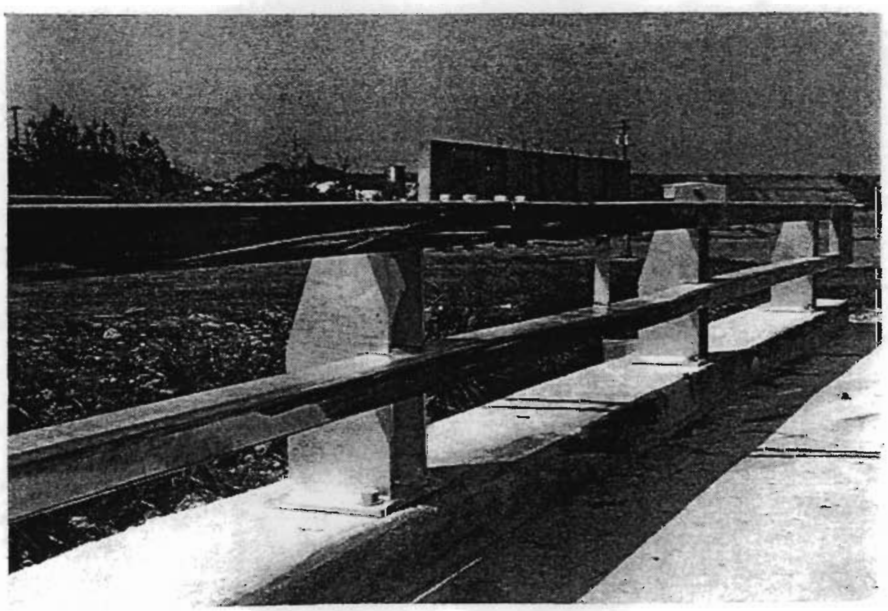


Figure 19. Installation after test 472610-3.

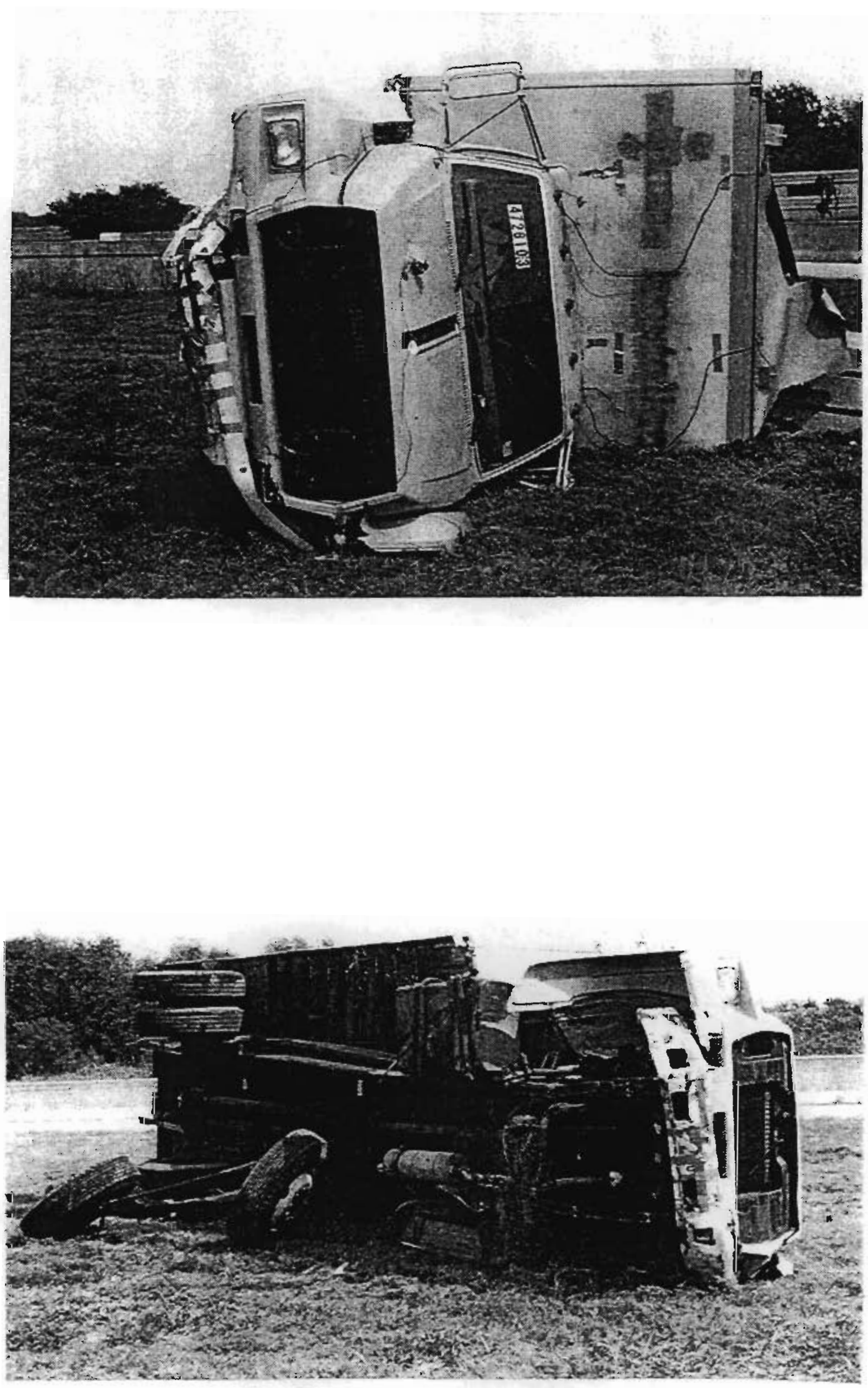
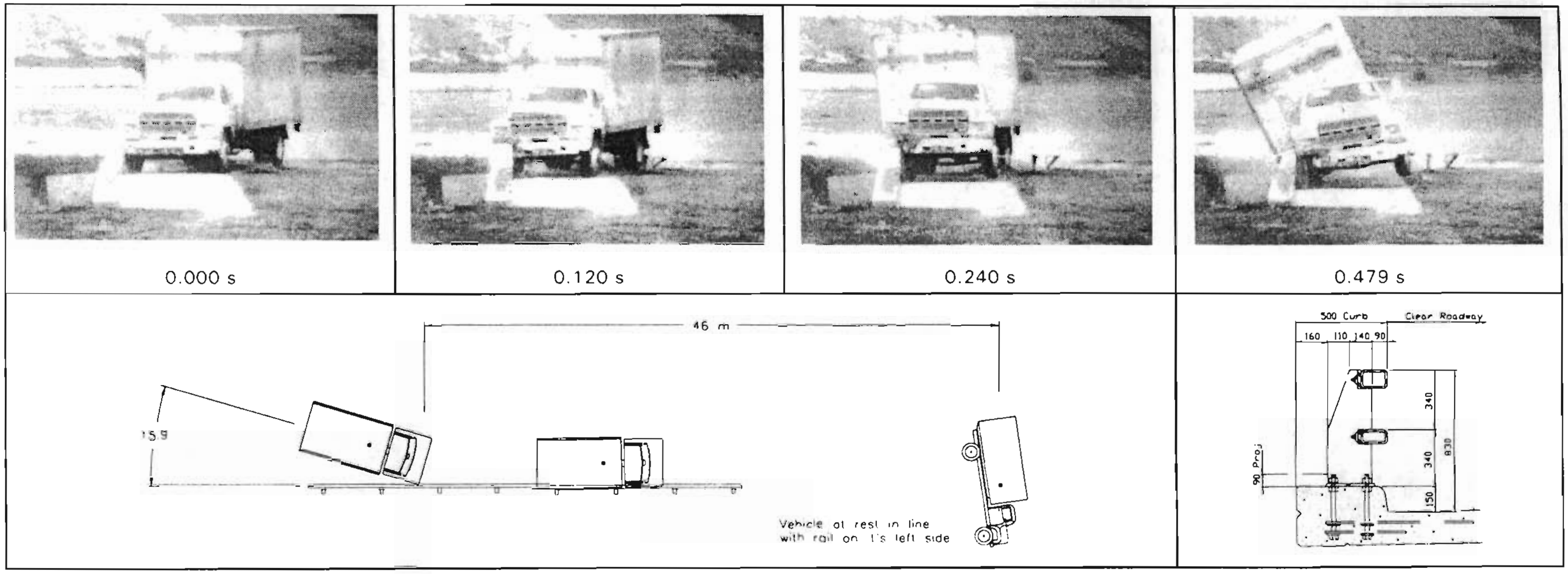


Figure 20. Vehicle after test 472610-3.



General Information	
Test Agency	Texas Transportation Institute
Test No.	472610-3
Date	10/12/95
Test Article	
Type	Bridge Railing
Name	Wyoming TL4 Bridge Railing
Installation Length (m)	23
Size and/or dimension and material of key elements	Tubular steel railing on concrete deck and curb
Soil Type and Condition	Concrete bridge deck, dry
Test Vehicle	
Type	Production
Designation	8000S
Model	1980 Ford F700 single-unit truck
Mass (kg) Curb	4653
Test Inertial	8000
Dummy	No dummy
Gross Static	8000

Impact Conditions	
Speed (km/h)	79.7
Angle (deg)	15.9
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.4
y-direction	2.7
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-3.5
y-direction	8.7
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	1.5
y-direction	3.9
z-direction	-4.3

Test Article Deflections (mm)	
Dynamic	N/A
Permanent	22
Vehicle Damage	
Exterior	
VDS	N/A
CDC	N/A
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	590
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	7.9
Max. Pitch Angle (deg)	-6.8
Max. Yaw Angle (deg)	-17.3

Figure 21. Summary of results for test 472610-3.

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

4.1 SUMMARY OF FINDINGS

The proposed Wyoming TL-4 bridge rail design was evaluated through a series of three crash tests in accordance with guidelines set forth in NCHRP Report 350. Summaries of the performance evaluation on these three tests are shown in tables 1 through 3. The bridge railing contained and smoothly redirected the impacting vehicles in all three tests. There were no detached elements or debris to penetrate the occupant compartment or cause undue hazard to others in the area. Damages to the impacting vehicles were considered moderate given the severe nature of the impact conditions. There were minor deformations of the occupant compartments for both the small car and the pickup truck, which were judged not to cause serious injuries. The occupant risk factors were all well within the preferred limits specified in NCHRP Report 350.

The small car and pickup truck remained upright and stable during and after the impact sequence. The box of the single unit truck attained a maximum roll angle of 31 degrees during the impact sequence and the vehicle rolled on its left side after exiting from the test installation. The instability and subsequent rollover of the vehicle after exiting from the bridge rail was apparently caused by the front axle separating from the vehicle during the impact. The exit conditions of all three vehicles indicated minimal potential for the vehicles to intrude into adjacent traffic lanes.

4.2 CONCLUSIONS

In summary, the proposed Wyoming TL-4 bridge railing design successfully met all evaluation criteria for a Test Level 4 bridge railing set forth in NCHRP Report 350. Since NCHRP Report 350 supersedes the 1989 AASHTO *Guide Specifications for Bridge Railings*, the proposed Wyoming TL-4 bridge railing design is also considered to have successfully met all evaluation criteria for a Performance Level 2 (PL-2) bridge railing under guidelines set forth in the 1989 AASHTO *Guide Specifications for Bridge Railings*.

Table 1. Performance evaluation summary for test 472610-1, NCHRP Report 350 test designation 4-10.

Test Agency: Texas Transportation Institute — Test No.: 472610-1 — Test Date: 10/02/95

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Wyoming TL-4 bridge railing contained and redirected the vehicle. The vehicle did not penetrate, go under or over the installation.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached fragments or elements to penetrate the occupant compartment or cause undue hazard to others in the area. There was minimal deformation of the occupant compartment (19 mm) that was judged not to 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 sequence.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and lateral / 9 / 12	Longitudinal occupant impact velocity = 5.5 m/s Lateral occupant impact velocity =5.8 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and lateral / 15 / 20	Longitudinal occupant ridedown acceleration = -4.1 G Lateral occupant ridedown acceleration = -3.4 G	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
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 bridge railing was 7.0 degrees which was less than 60 percent of the impact angle.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest 7 m behind the installation.	Pass

Table 2. Performance evaluation summary for test 472610-2, NCHRP Report 350 test designation 4-11.

Test Agency: Texas Transportation Institute | Test No.: 472610-2 | Test Date: 10/10/95

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Wyoming TL-4 bridge railing contained and redirected the vehicle. The vehicle did not penetrate or go over or under the installation.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate the occupant compartment or cause undue hazard to others in the area. Maximum deformation of the occupant compartment was 79 mm in the floorpan area on the right side and was judged not to 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.	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 = 6.0 m/s Longitudinal occupant ridedown acceleration = -9.2 G	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact with the bridge railings was 6.1 degrees which was less than 60 percent of the impact angle.	Pass

Table 3. Performance evaluation summary for test 472610-3, NCHRP Report 350 test designation 4-12.

Test Agency: Texas Transportation Institute | Test No.: 472610-3 | Test Date: 10/12/95

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Wyoming TL-4 bridge railing contained and redirected the vehicle. The vehicle did not penetrate or go over or under the installation.	Pass
Occupant Risk D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate the occupant compartment or cause undue hazard to others in the area. There was no deformation of the occupant compartment.	Pass
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The vehicle remained upright during the collision; however, after exiting the rail the vehicle rolled onto its left side.	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
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 was not attainable; however, judging from tire marks the exit angle was between 3 and 5 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, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 1993.

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

3. *Guide Specification for Bridge Railings,* American Association of State Highway and Transportation Officials, Washington, D. C., 1989.

4. K. K. Mak and D. L. Bullard, "Testing and Evaluation of Wyoming Tube-Type Bridge Rail," Report No. 0368-1, Texas Transportation Institute, Texas A&M University System, College Station, Texas, March 1988.

APPENDIX A. TEST VEHICLE PROPERTIES

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

DATE 10/02/95 TEST NO.: 472610-1 VIN NO.: KNJBT07K6J6154537

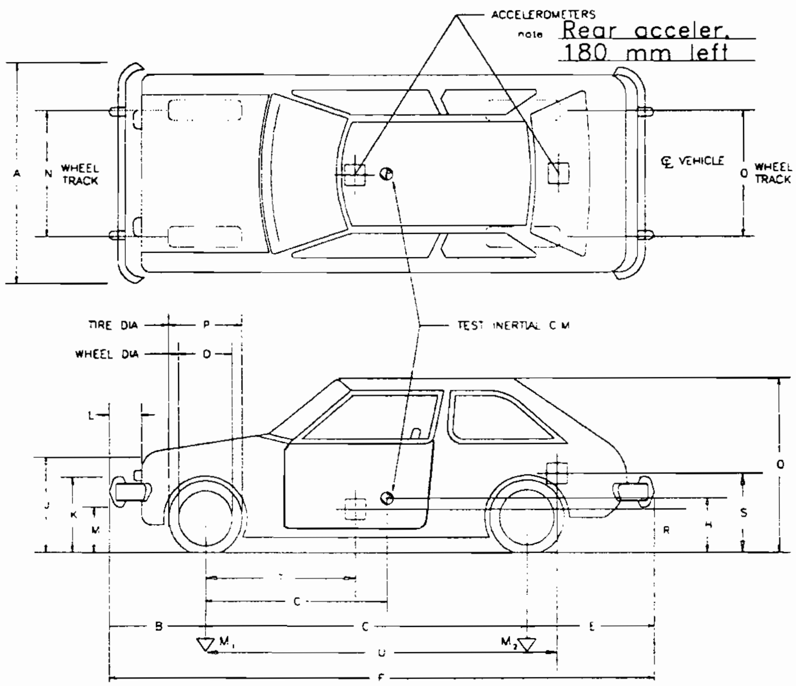
YEAR: 1988 MAKE: Ford MODEL: Festiva

TIRE INFLATION PRESSURE: ______ ODOMETER: 151773 TIRE SIZE: 155R12

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

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Windshield cracked (marked)



ENGINE TYPE: 4 cylinder

ENGINE CID: 1.3 liter

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1500	E	360	J	765	N	1375	R	400
B	640	F	3280	K	565	O	1400	S	470
C	2280	G	825.8	L	110	P	550	T	870
D	1440	H		M	410	Q	335	U	2410

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	520	523	563
M_2	265	297	333
M_T	785	820	896

Figure 22. Vehicle properties for test 472610-1.

DATE: 10/10/95 TEST NO.: 472610-2 VIN NO.: 1GCFC24H5KE223153

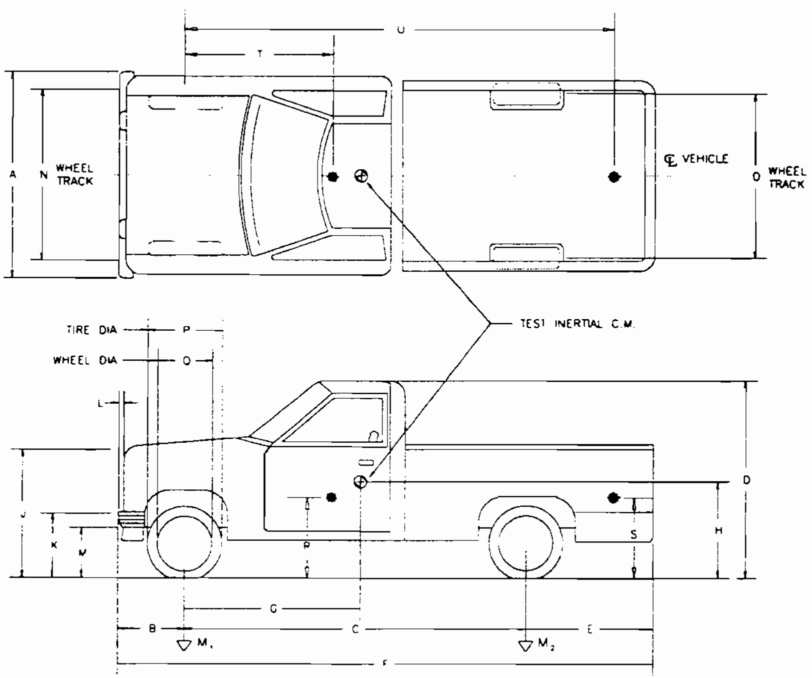
YEAR: 1989 MAKE: Chevrolet MODEL: 2500 Pickup

TIRE INFLATION PRESSURE: ______ ODOMETER: 102946 TIRE SIZE: LT225 75R16

MASS DISTRIBUTION (kg) LF 564 RF 537 LR 462 RR 437

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST

Crack in windshield (marked)



● Denotes accelerometer location.

NOTES: Rear accel 60 mm right

ENGINE TYPE: 8 cylinder

ENGINE CID: 5.7 Litre

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY - (mm)

A	1870	E	1290	J	990	N	1585	R	670
B	780	F	5400	K	600	O	1620	S	890
C	3330	G	1496.8	L	75	P	740	T	1500
D	1780	H		M	370	Q	445	U	4010

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1060	1101	
M_2	759	899	
M_T	1919	2000	

Figure 23. Vehicle properties for test 472610-2.

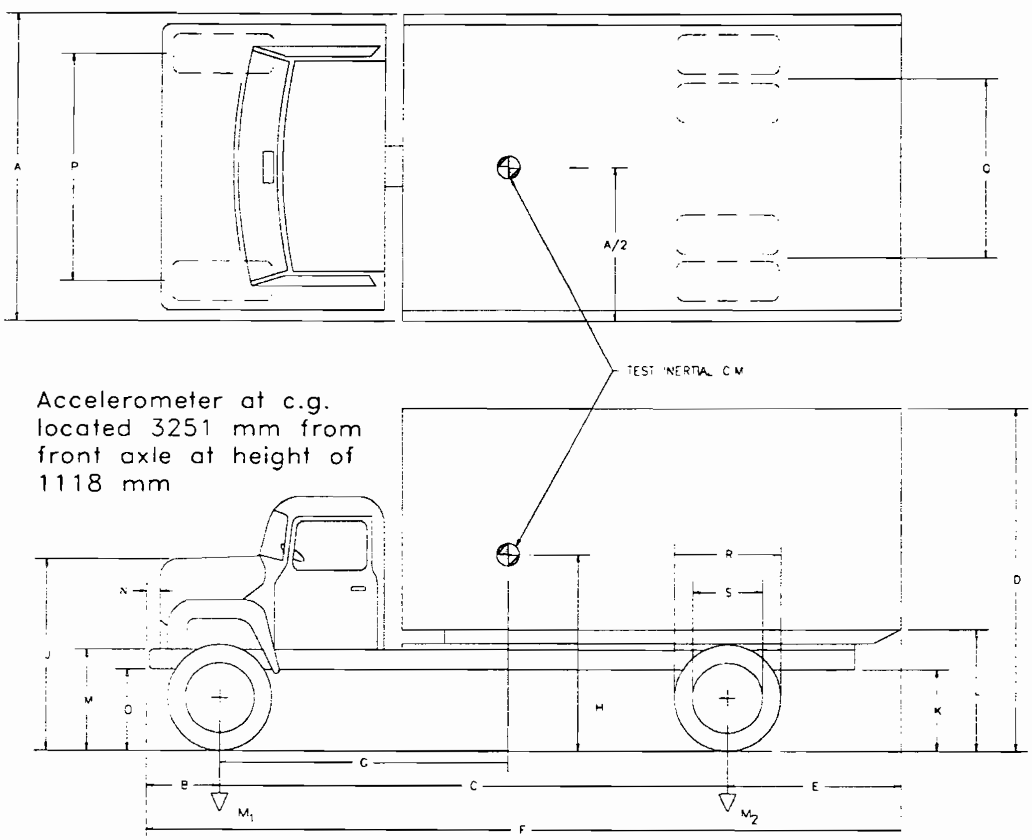
DATE: 10/12/95 TEST NO.: 472610-3 VIN NO.: F70HVHD7492

YEAR: 1980 MAKE: Ford ODOMETER: 87730 TIRE SIZE: 11R22.5

MODEL: F700

MASS DISTRIBUTION (kg) LF 1606 RF 1694 LR 2355 RR 2345

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



GEOMETRY–(mm)

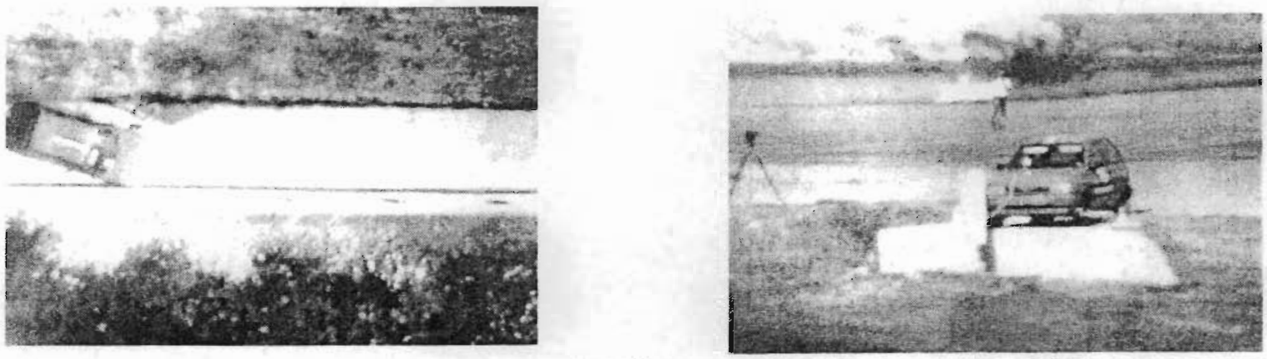
A	2420	D	3350	G	3102	K	720	N	80	Q	1790
B	810	E	2180	H	1245	L	1240	O	475	R	4030
C	5280	F	8270	J	1570	M	795	P	2020	S	590

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	2136	3330	
M_2	2517	4700	
M_T	4653	8000	

Figure 24. Vehicle properties for test 472610-3.

APPENDIX B. SEQUENTIAL PHOTOGRAPHS OF TESTS

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



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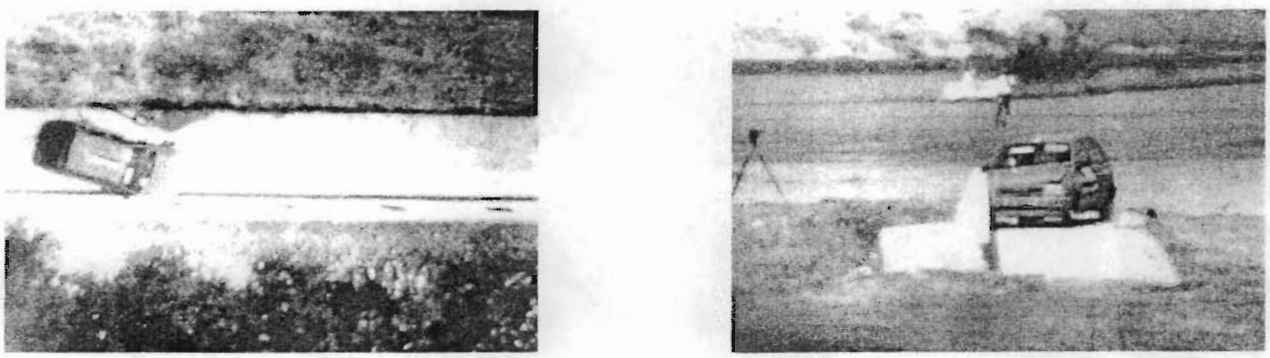

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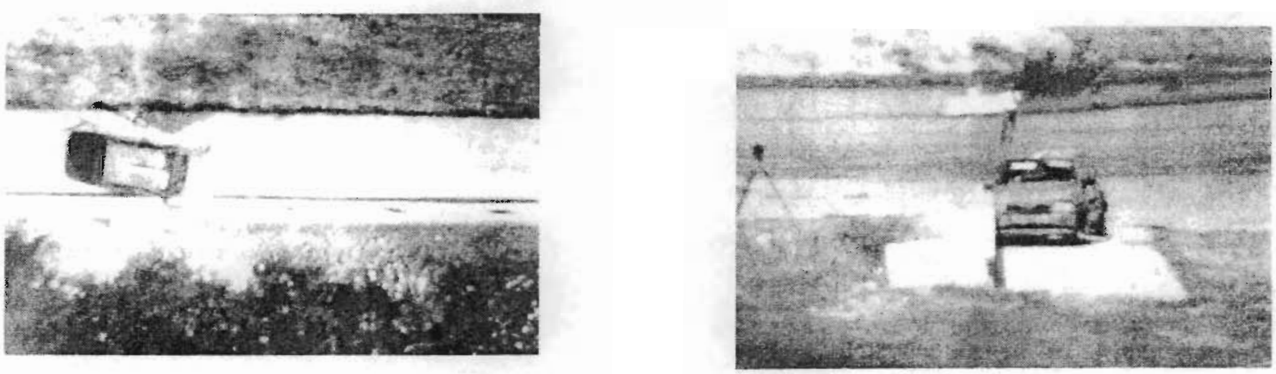
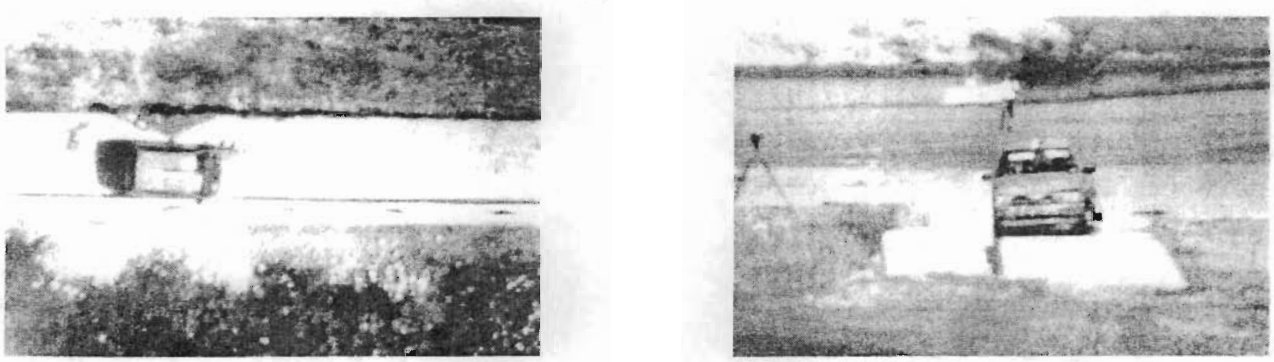
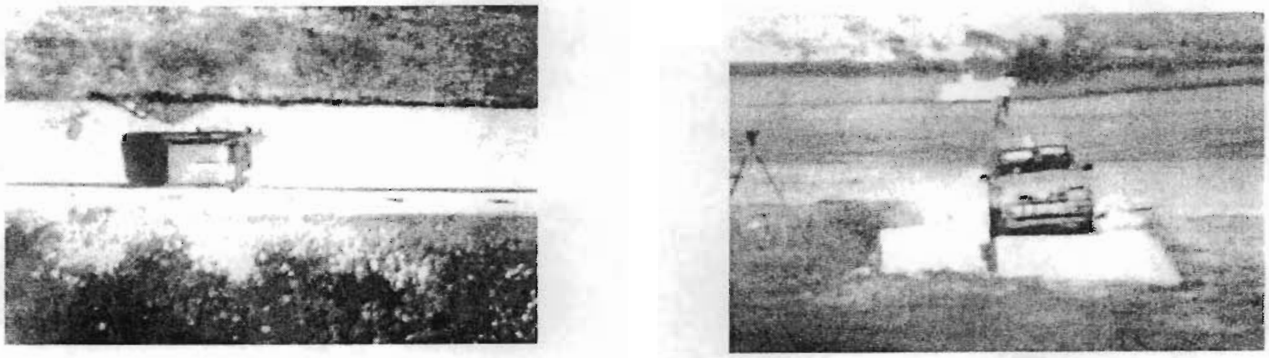


0.075 s



0.112 s

Figure 25. Sequential photographs for test 472610-1.
(overhead and frontal views)



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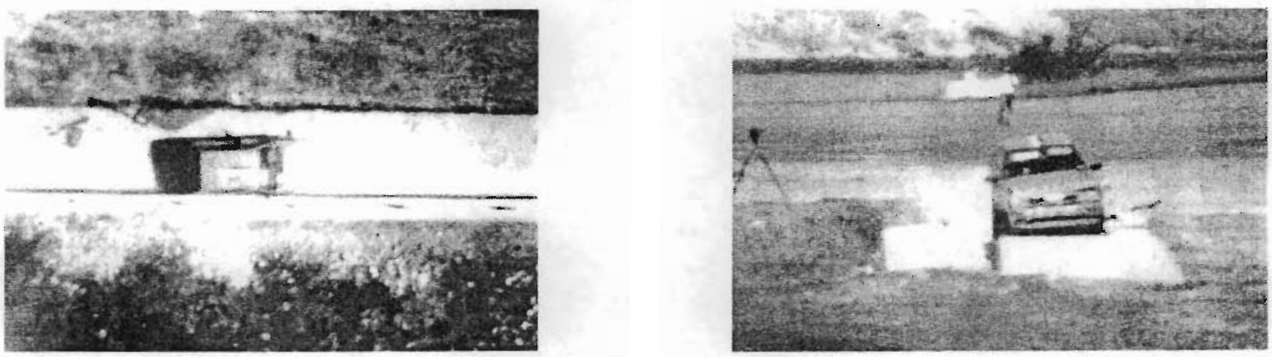

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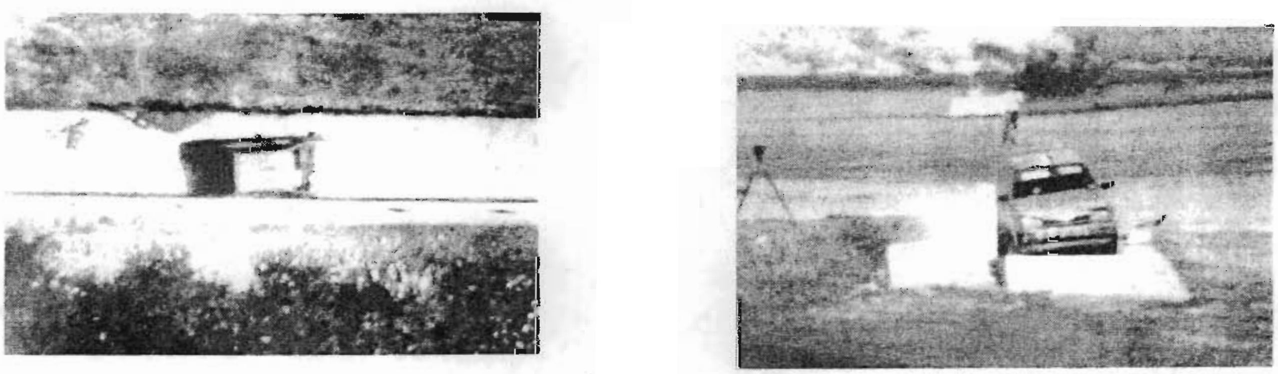

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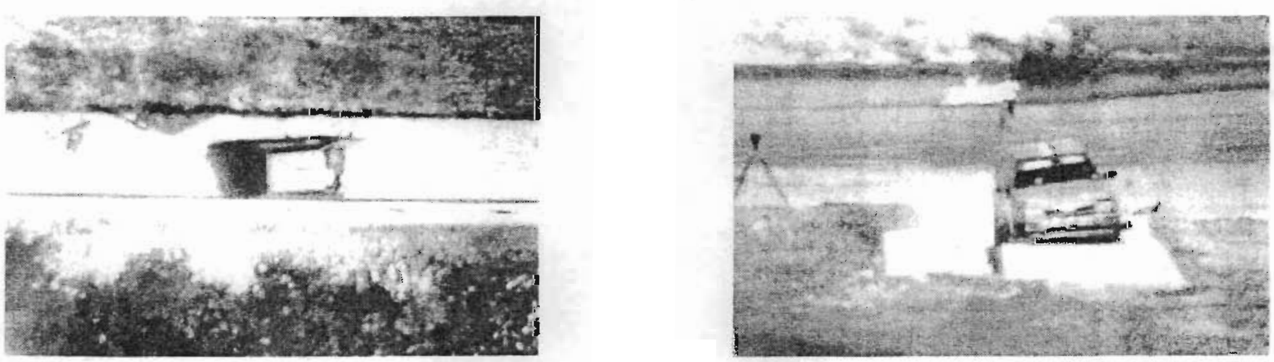


0.262 s

Figure 25. Sequential photographs for test 472610-1 (continued).
(overhead and frontal views)

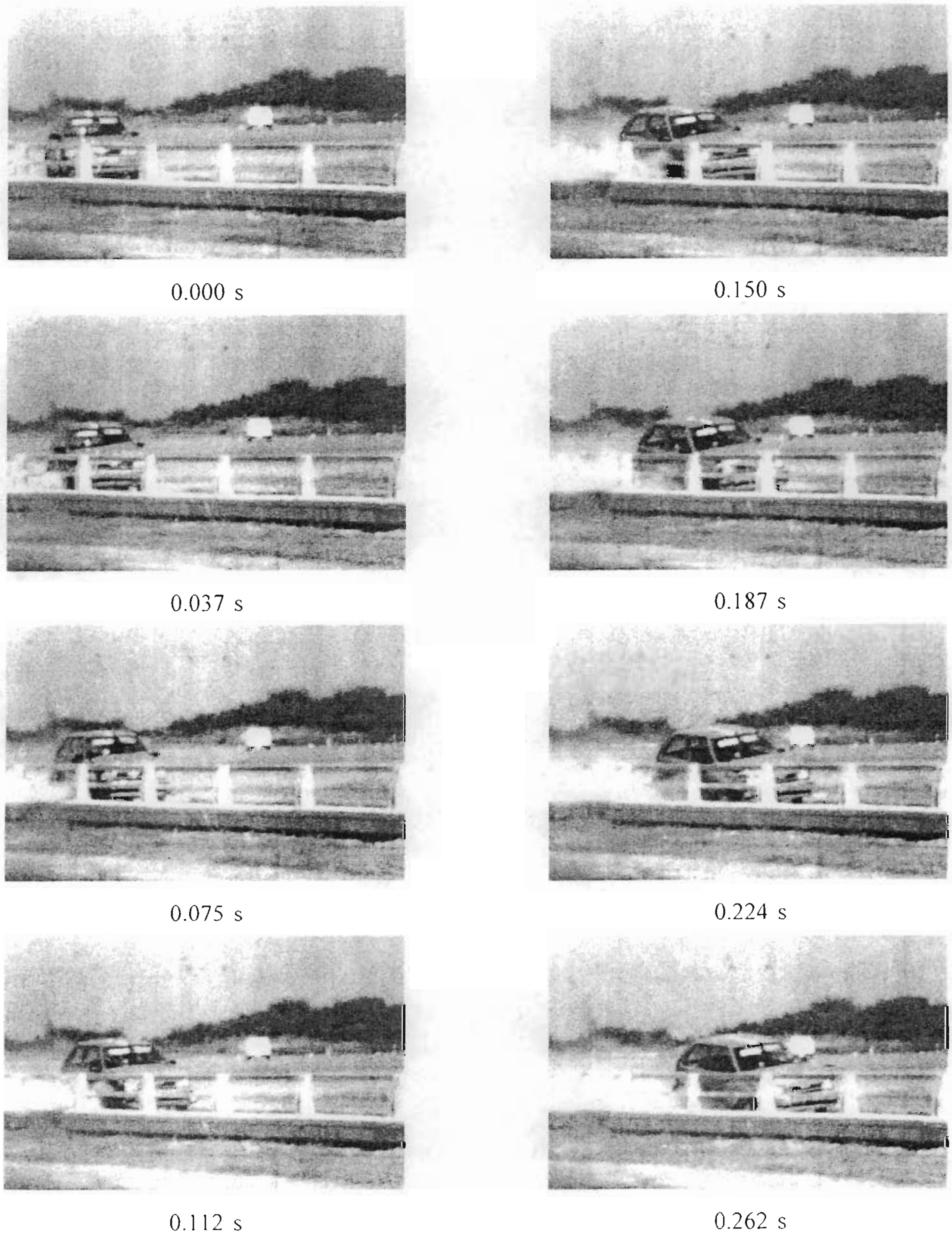


Figure 26. Sequential photographs for test 472610-1.
(rear view)

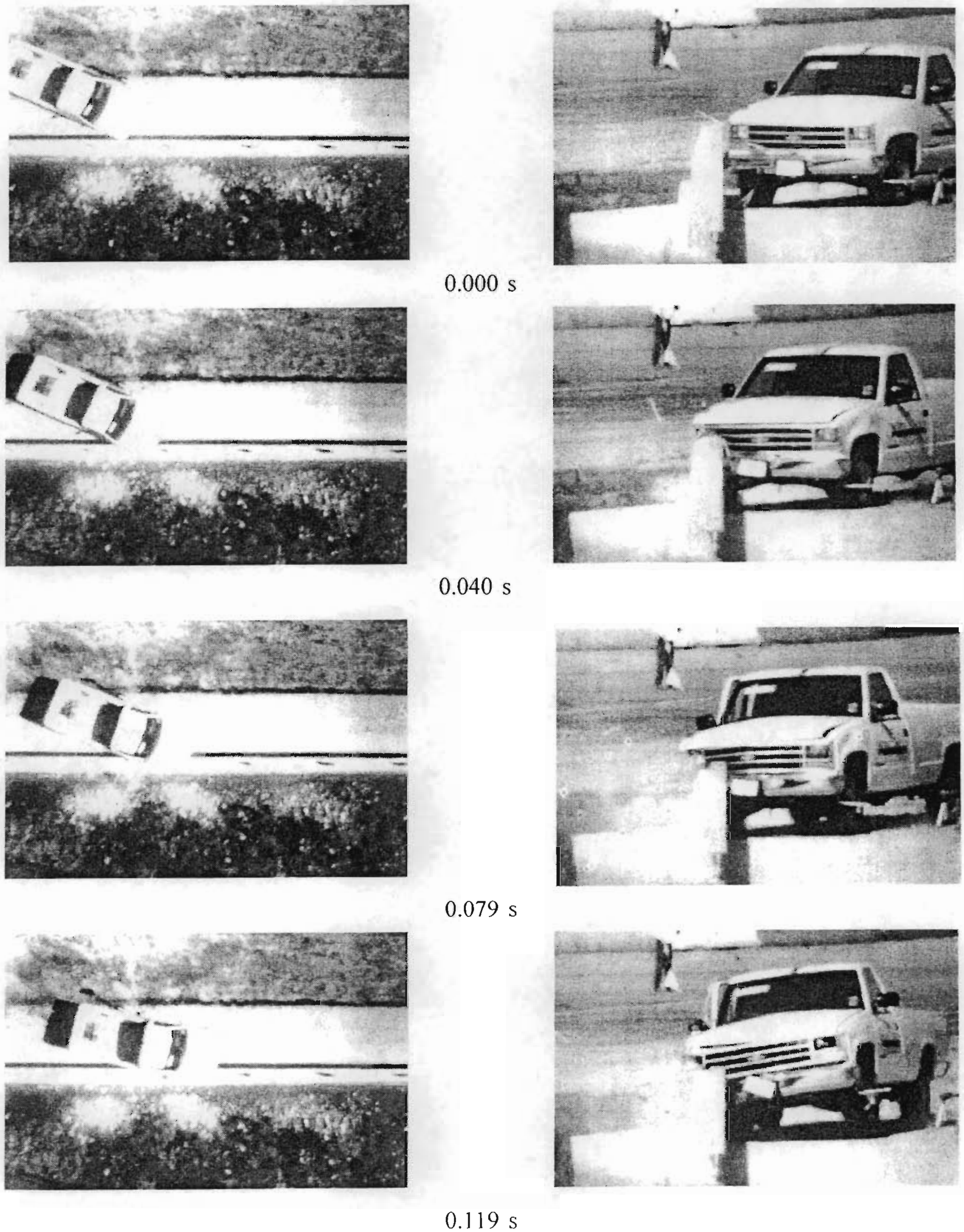
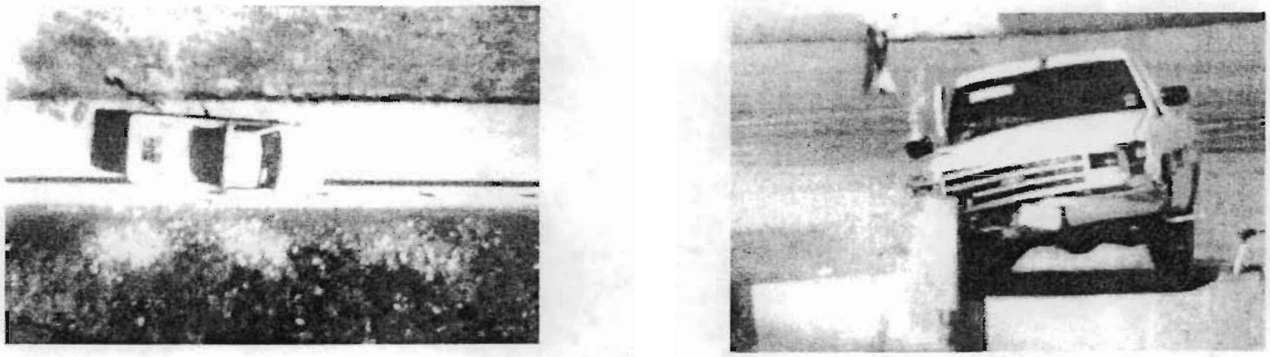


Figure 27. Sequential photographs for test 472610-2.
(overhead and frontal views)



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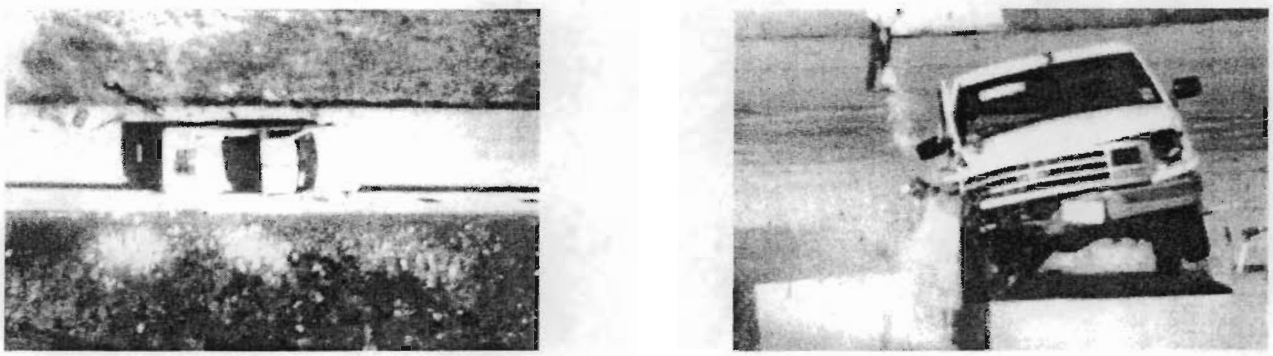
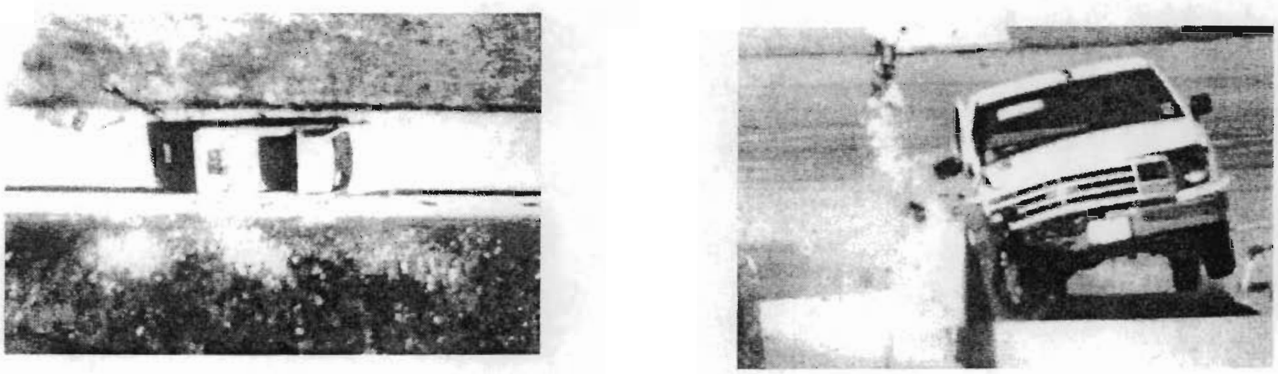
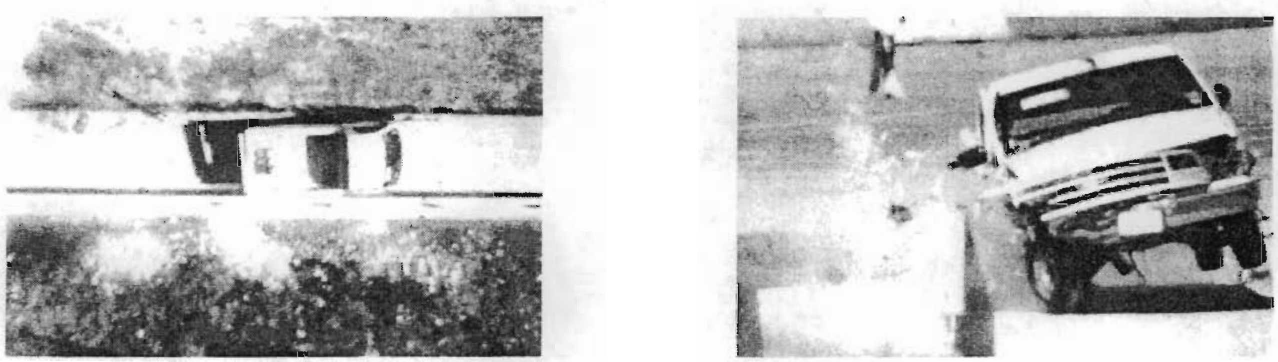


0.199 s



0.238 s



0.291 s

Figure 27. Sequential photographs for test 472610-2 (continued).
(overhead and frontal views)

0.000 s

0.040 s

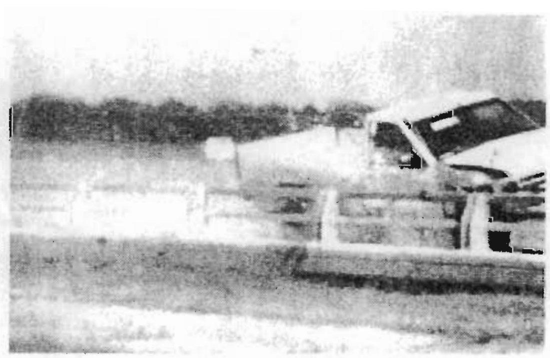
0.079 s

0.119 s

0.159 s

0.199 s

0.238 s



0.291 s

Figure 28. Sequential photographs for test 472610-2.
(rear view)

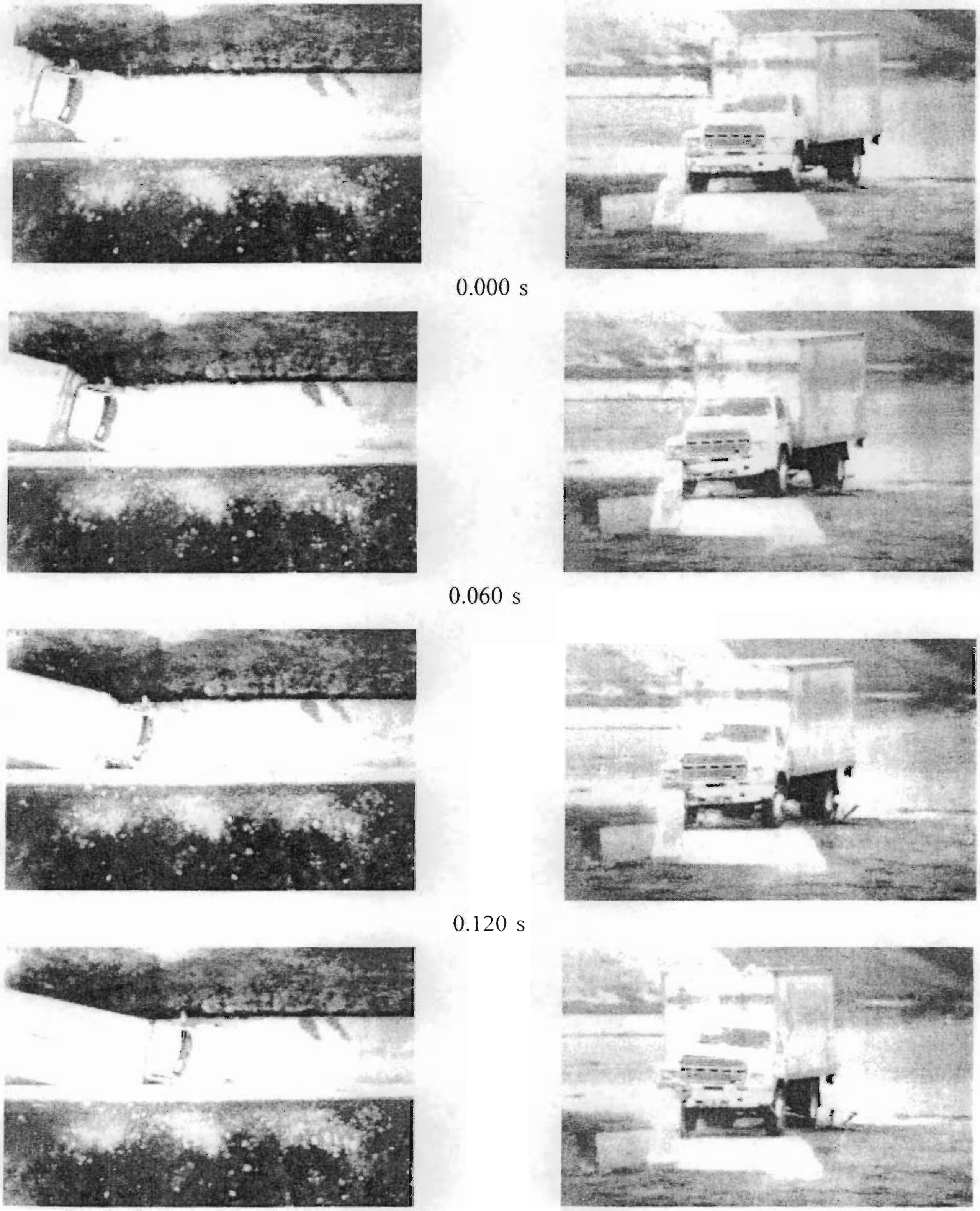
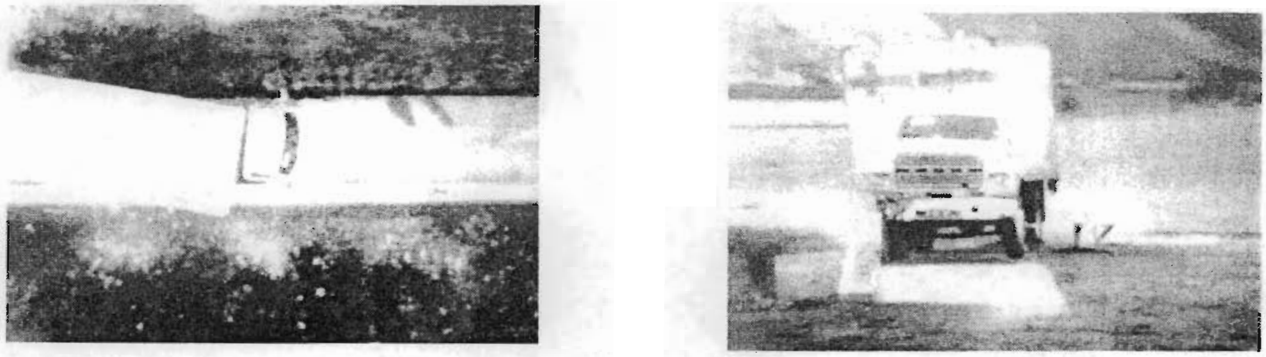
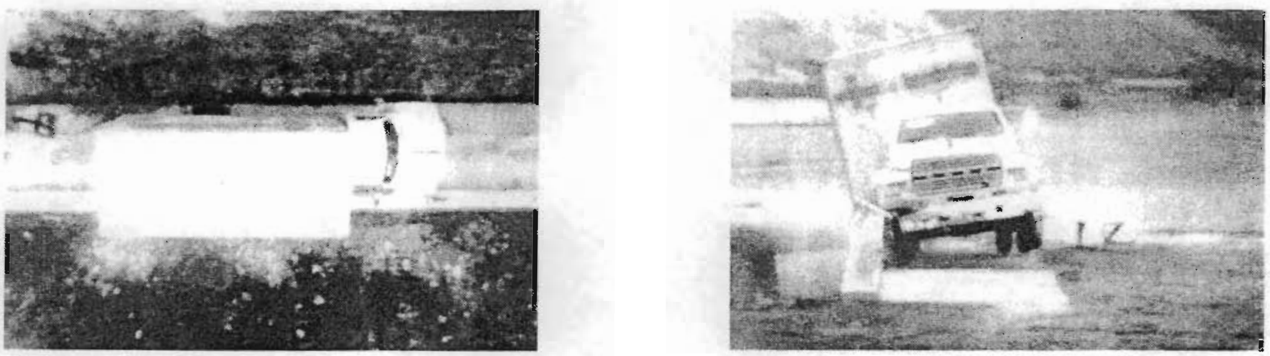


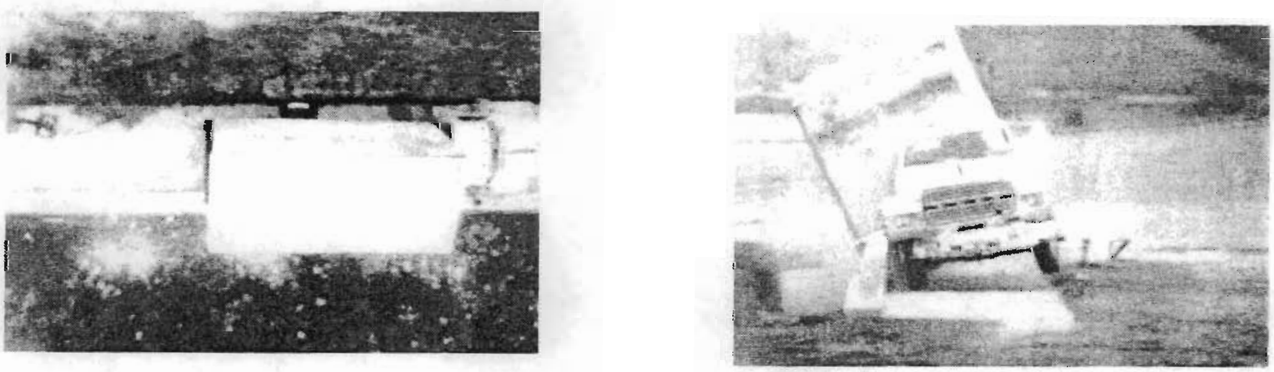
Figure 29. Sequential photographs for test 472610-3.
(overhead and frontal views)



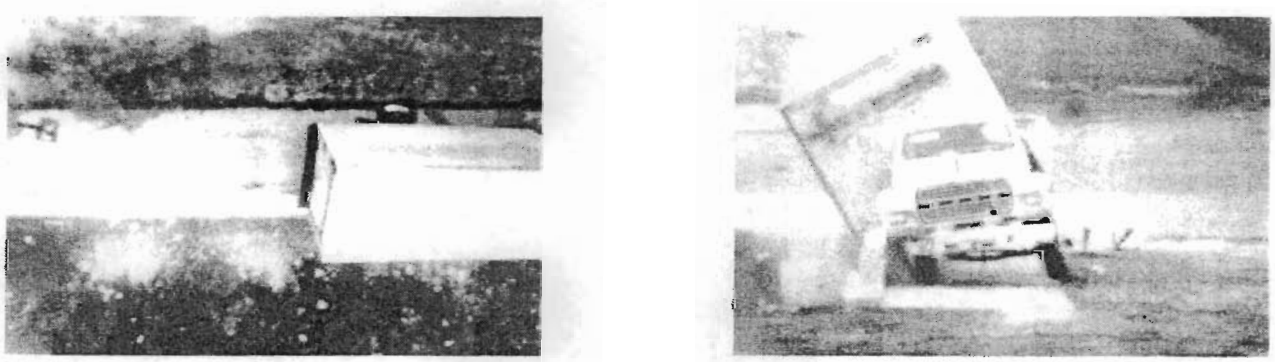
0.241 s



0.361 s

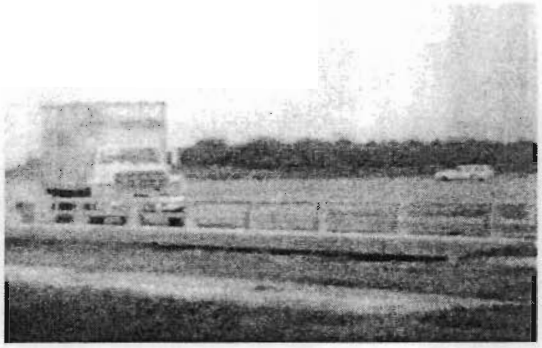


0.479 s

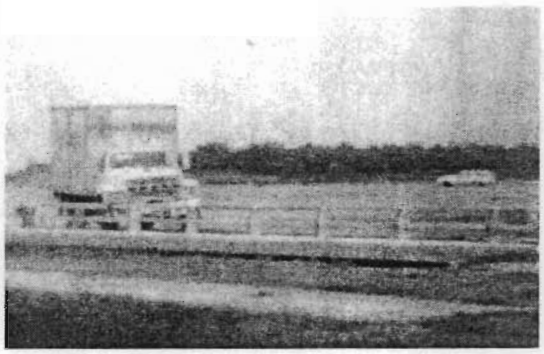


0.600 s

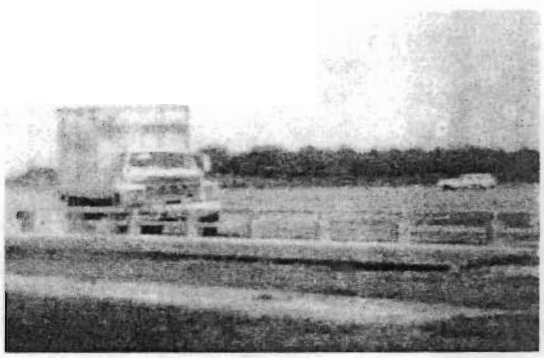
Figure 29. Sequential photographs for test 472610-3 (continued).
(overhead and frontal views)



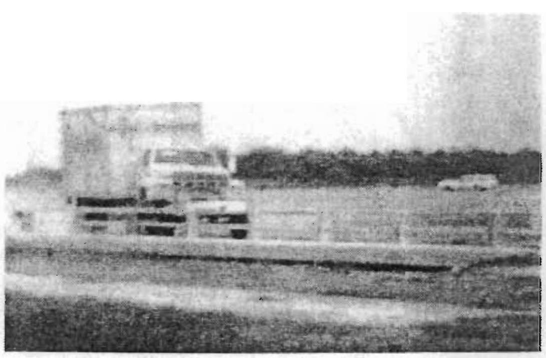
0.000 s



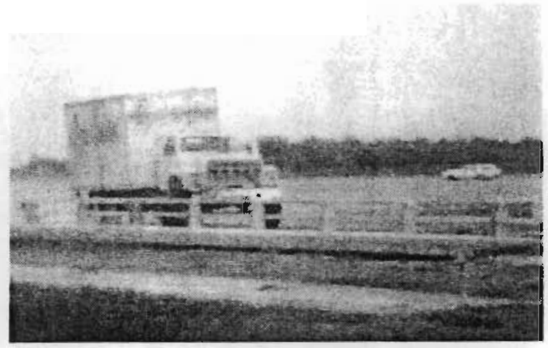
0.060 s



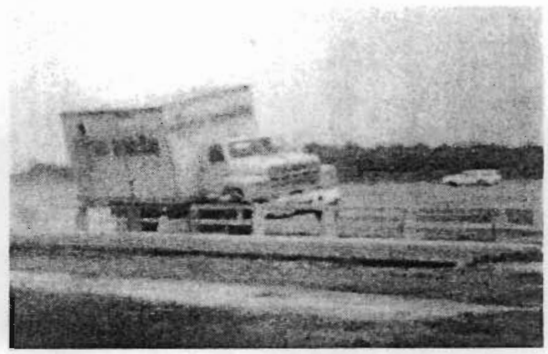
0.120 s



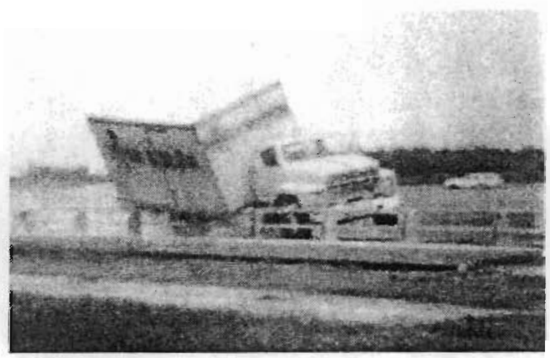
0.181 s



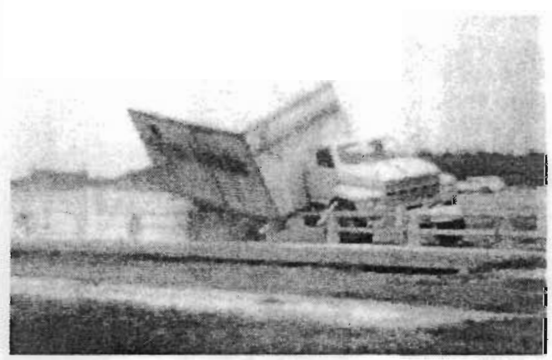
0.241 s



0.361 s



0.479 s



0.600 s

Figure 30. Sequential photographs for test 472610-3.
(rear view)

APPENDIX C. VEHICLE ANGULAR DISPLACEMENTS

This section contains plots of the vehicular angular displacements exhibited by the vehicles used in the crash tests performed under this contract.

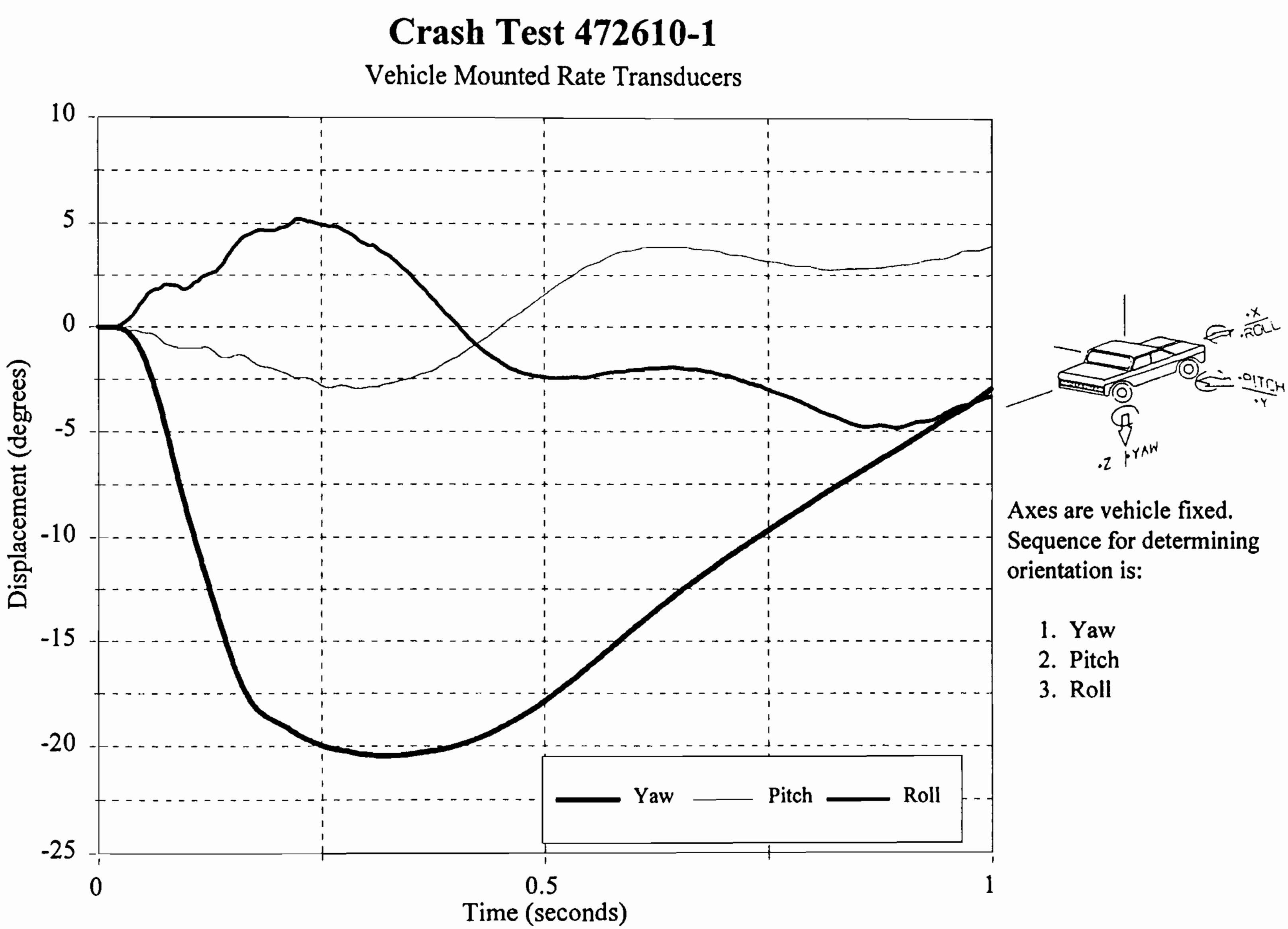


Figure 31. Vehicle angular displacements for test 472610-1.

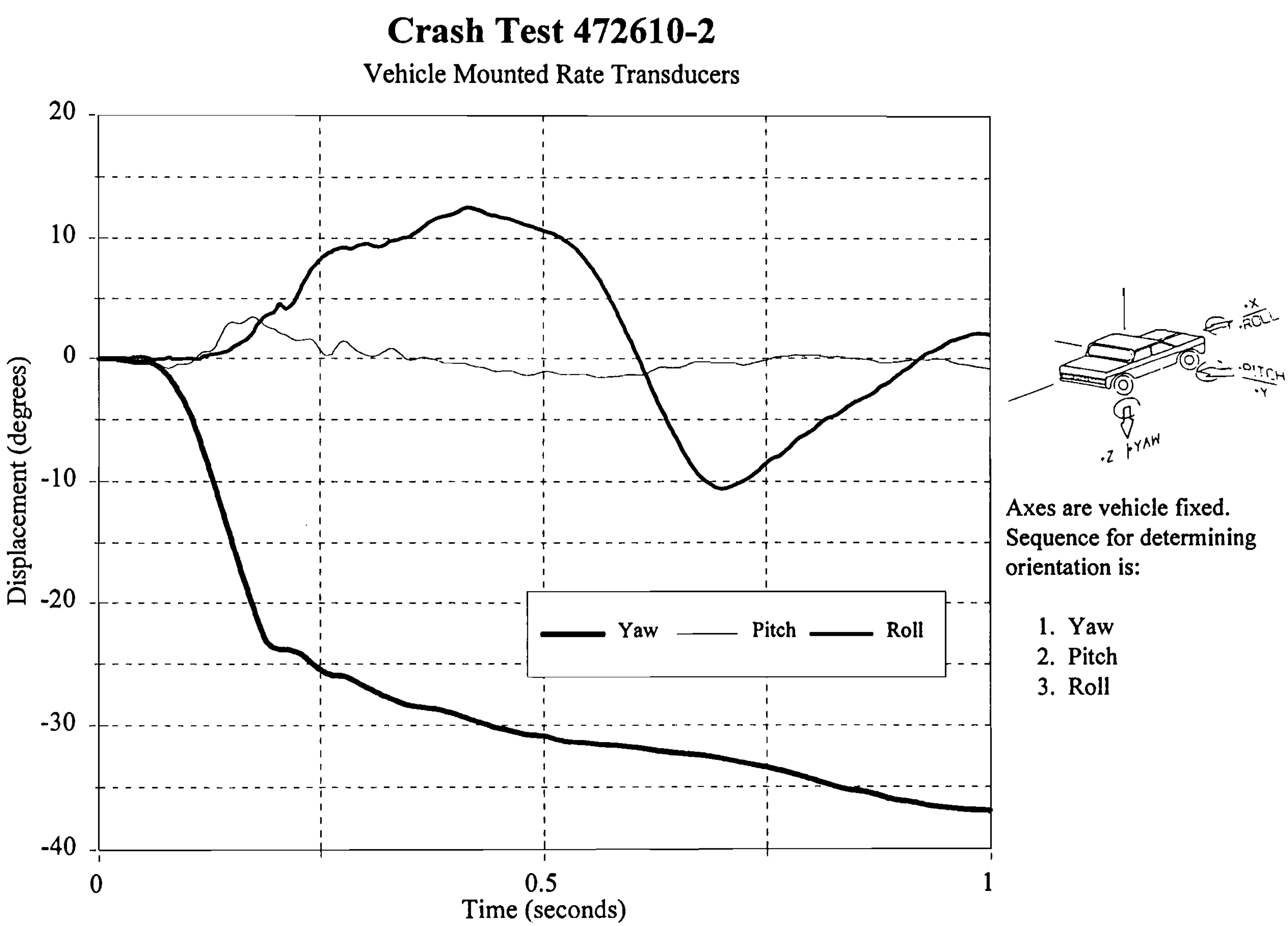


Figure 32. Vehicle angular displacements for test 472610-2.

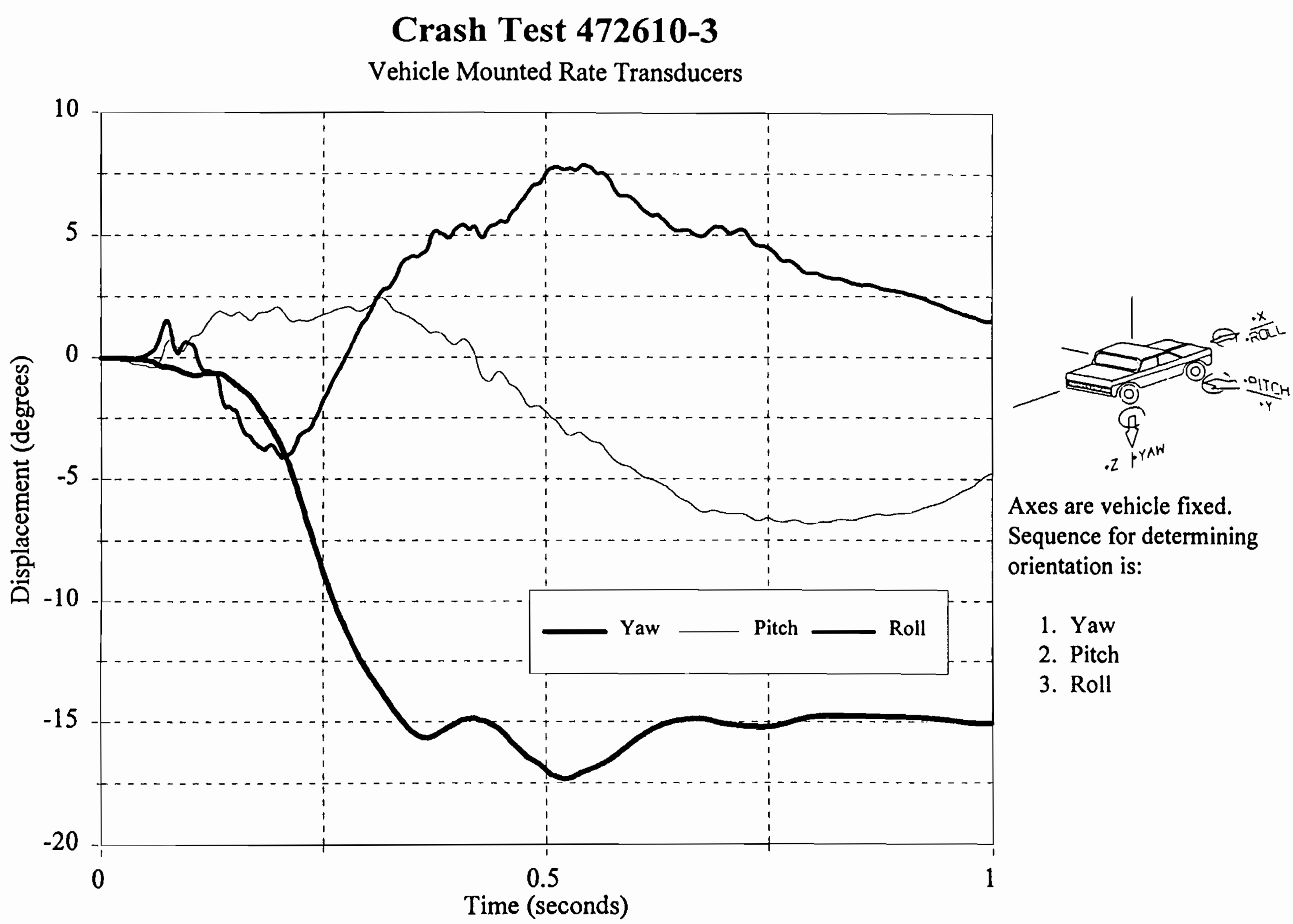


Figure 33. Vehicle angular displacements for test 472610-3.

APPENDIX D. VEHICLE ACCELEROMETER TRACES

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

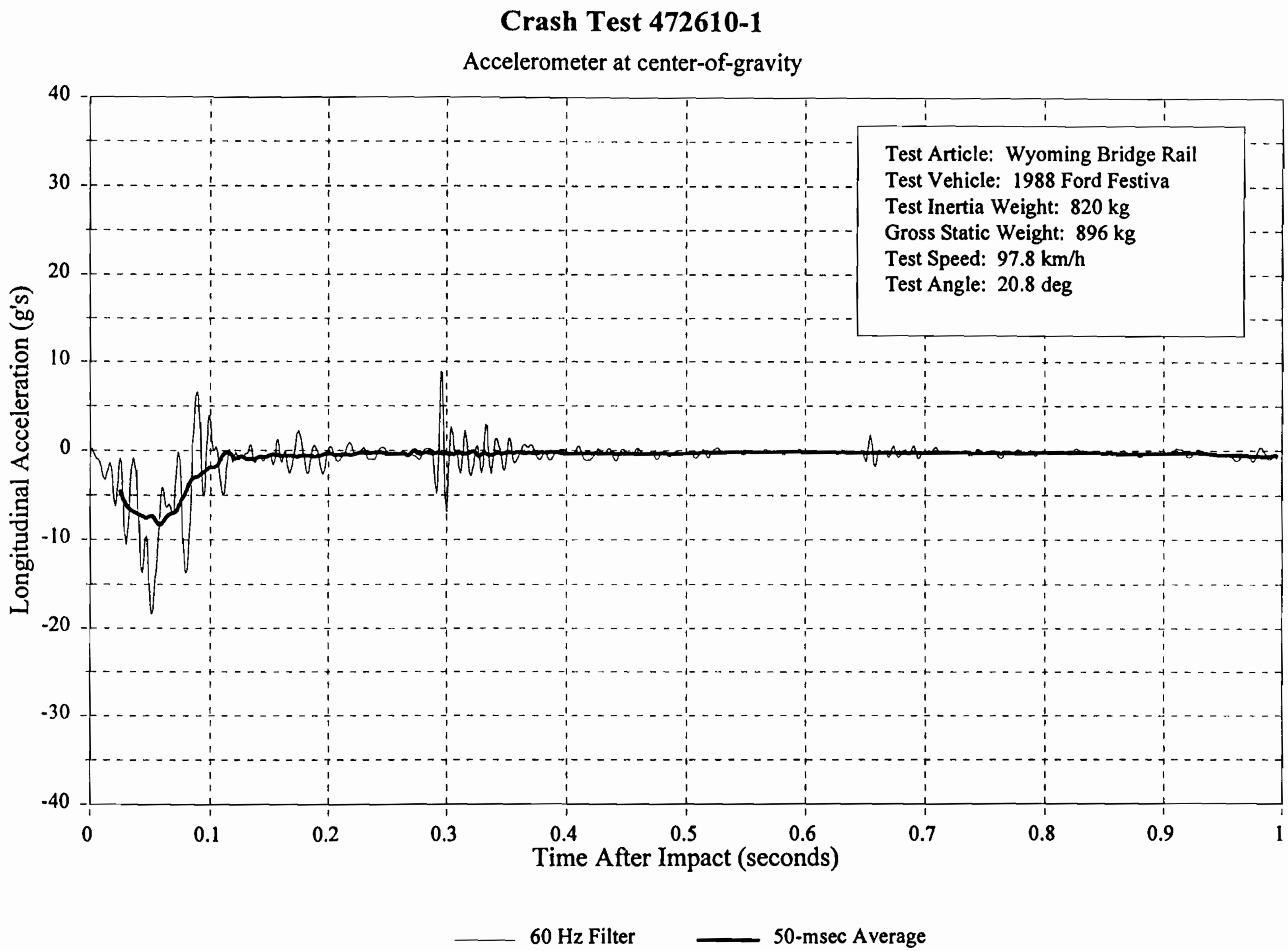


Figure 34. Vehicle longitudinal accelerometer trace for test 472610-1.

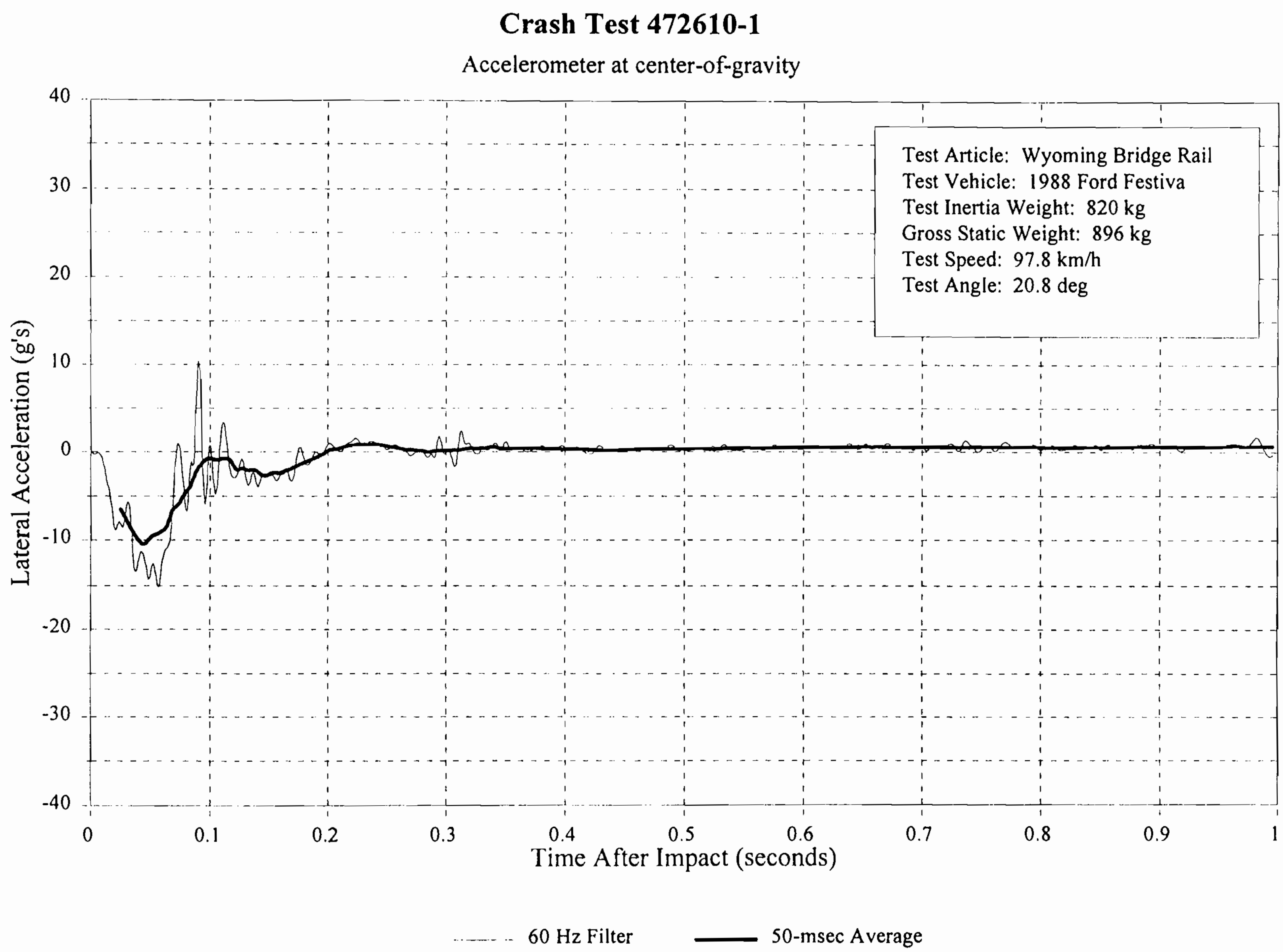


Figure 35. Vehicle lateral accelerometer trace for test 472610-1.

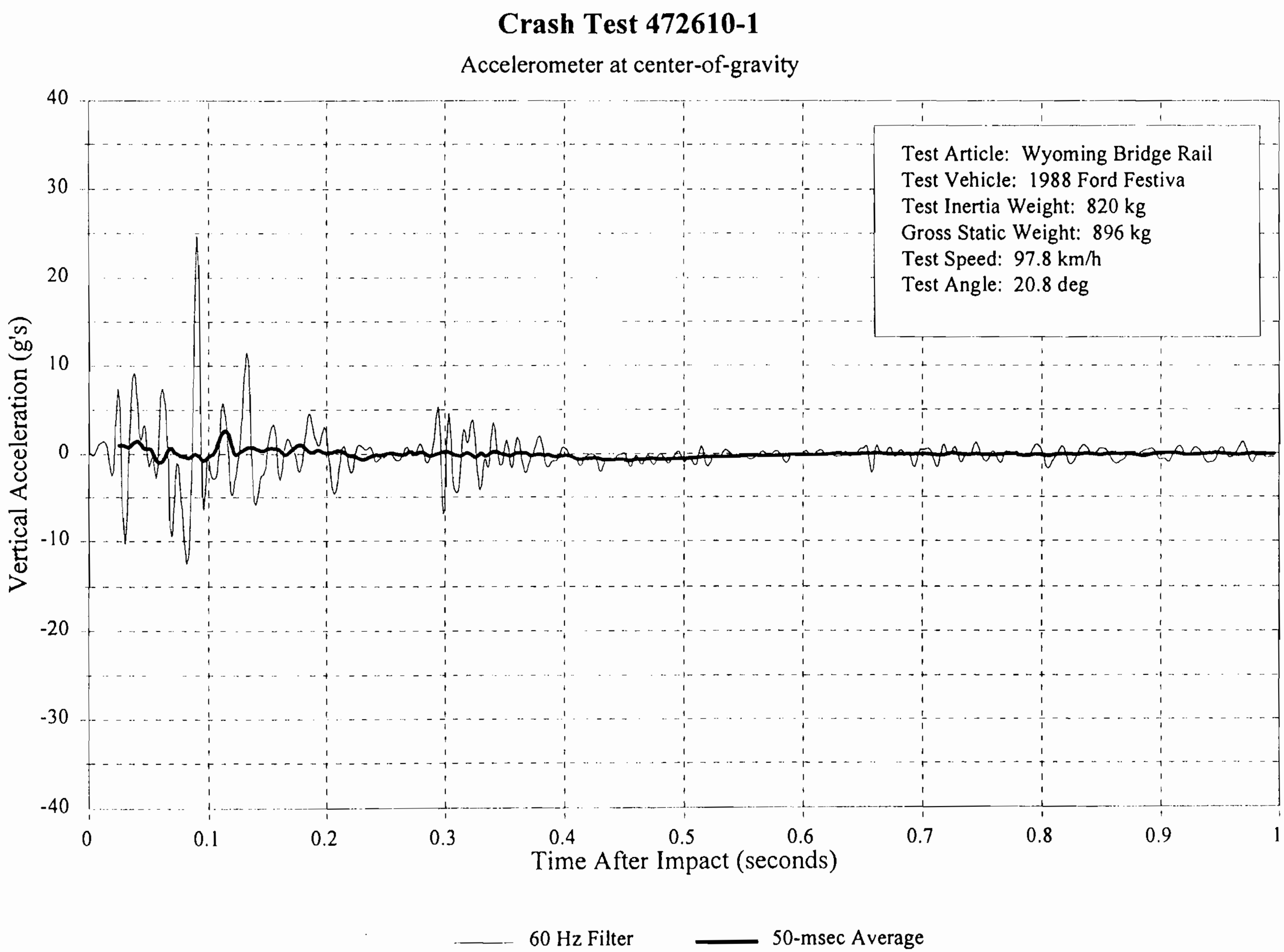


Figure 36. Vehicle vertical accelerometer trace for test 472610-1.

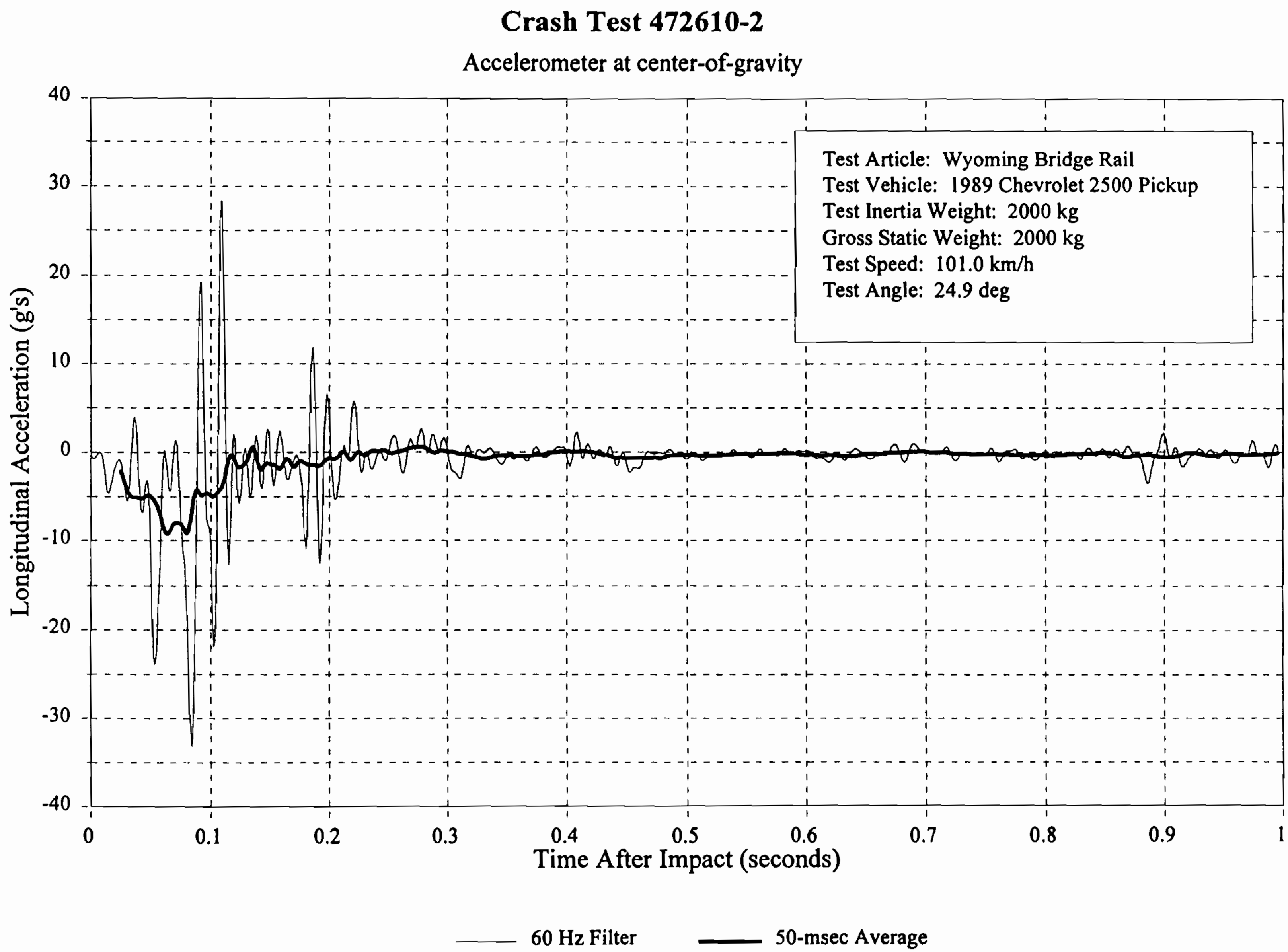


Figure 37. Vehicle longitudinal accelerometer trace for test 472610-2.

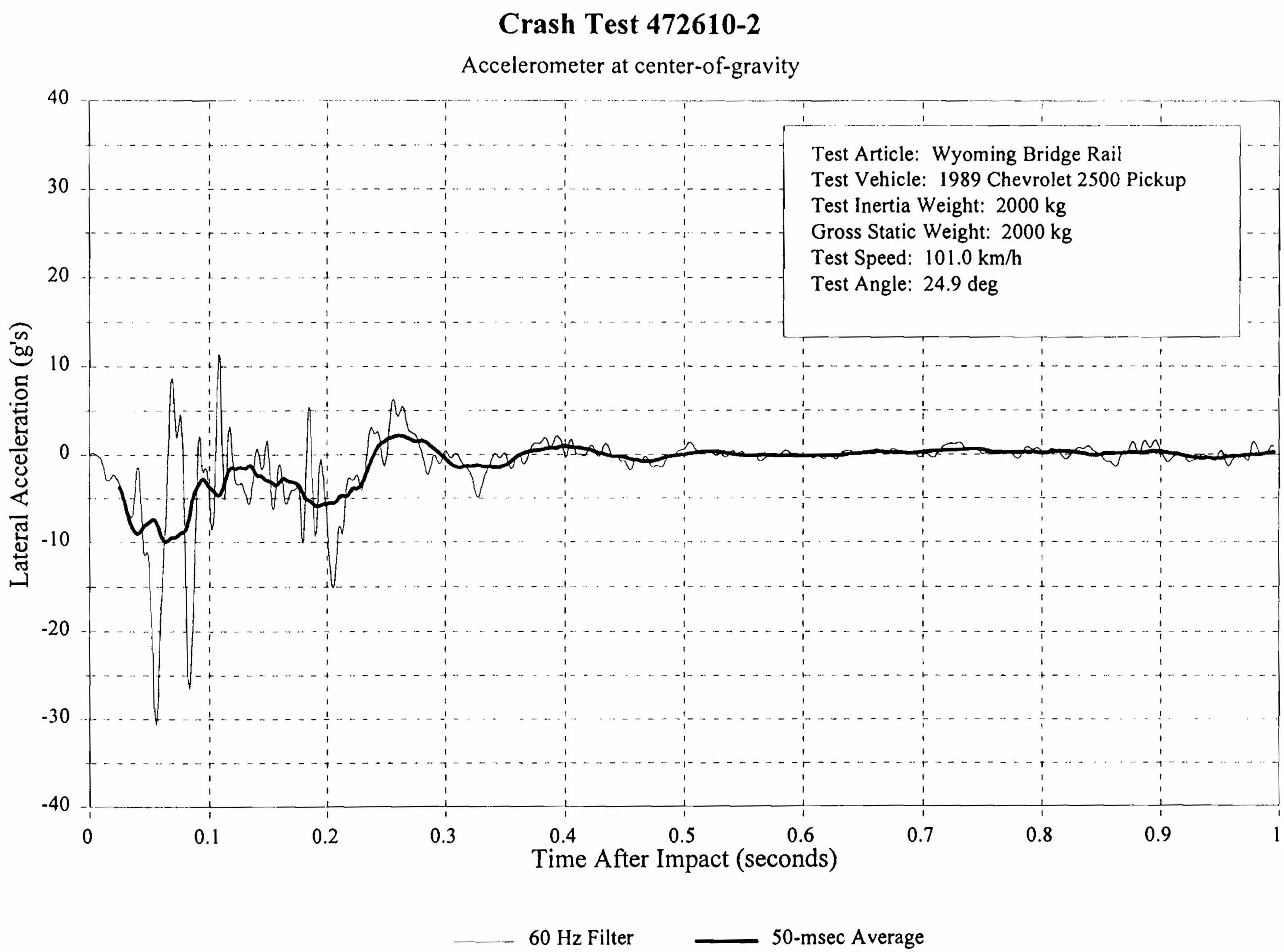


Figure 38. Vehicle lateral accelerometer trace for test 472610-2.

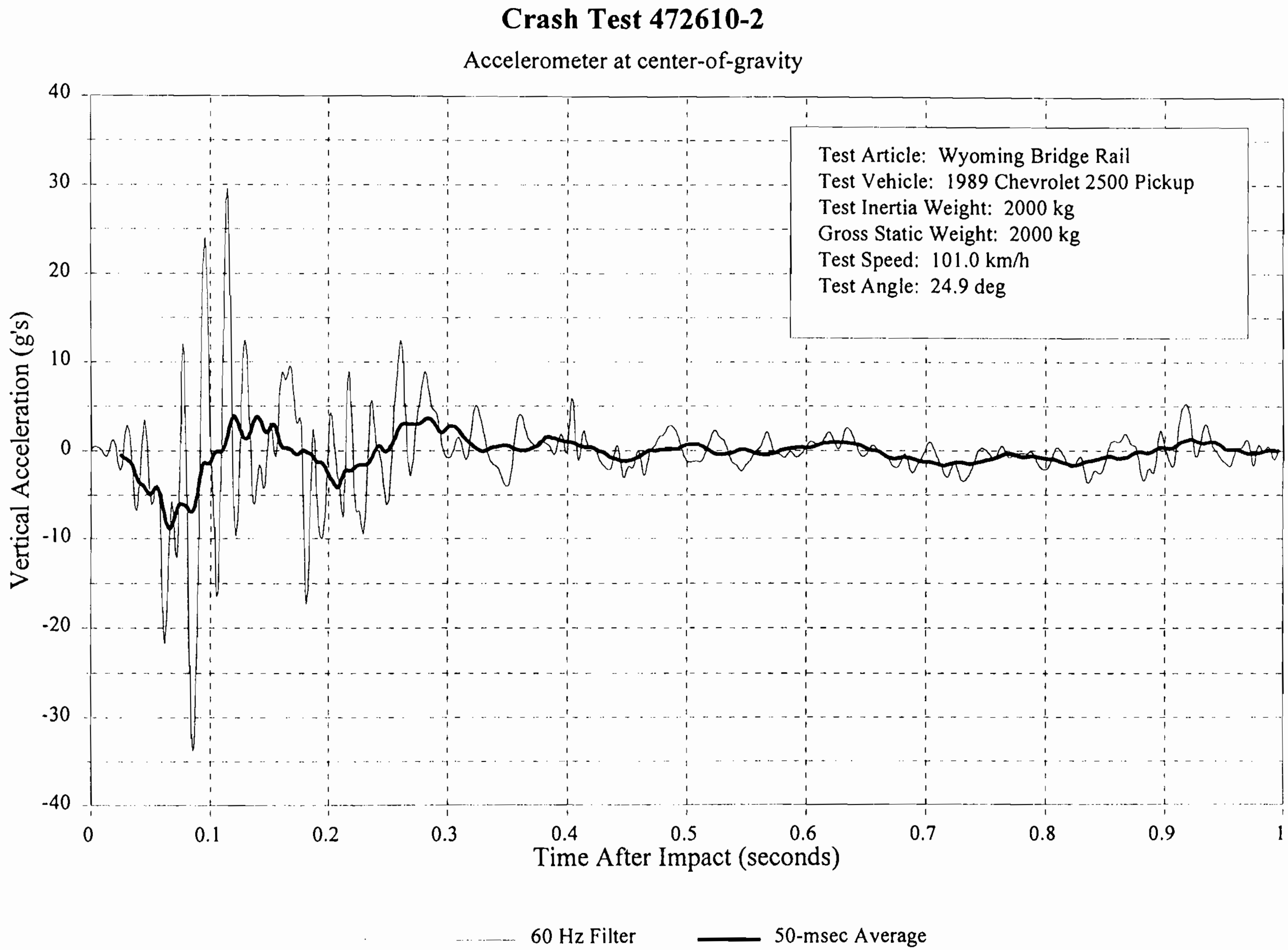


Figure 39. Vehicle vertical accelerometer trace for test 472610-2.

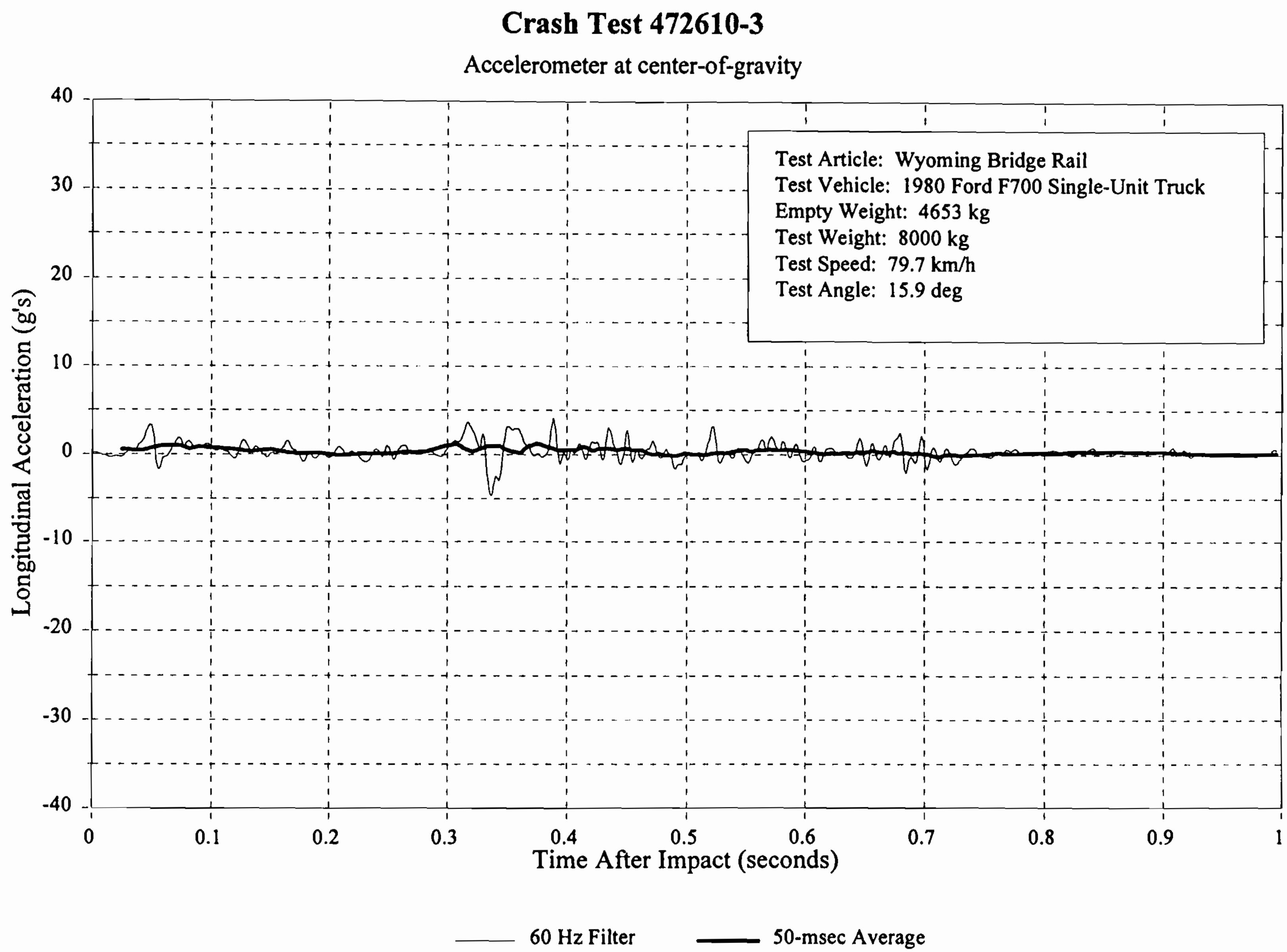


Figure 40. Vehicle longitudinal accelerometer trace for test 472610-3. (accelerometer located at center-of-gravity)

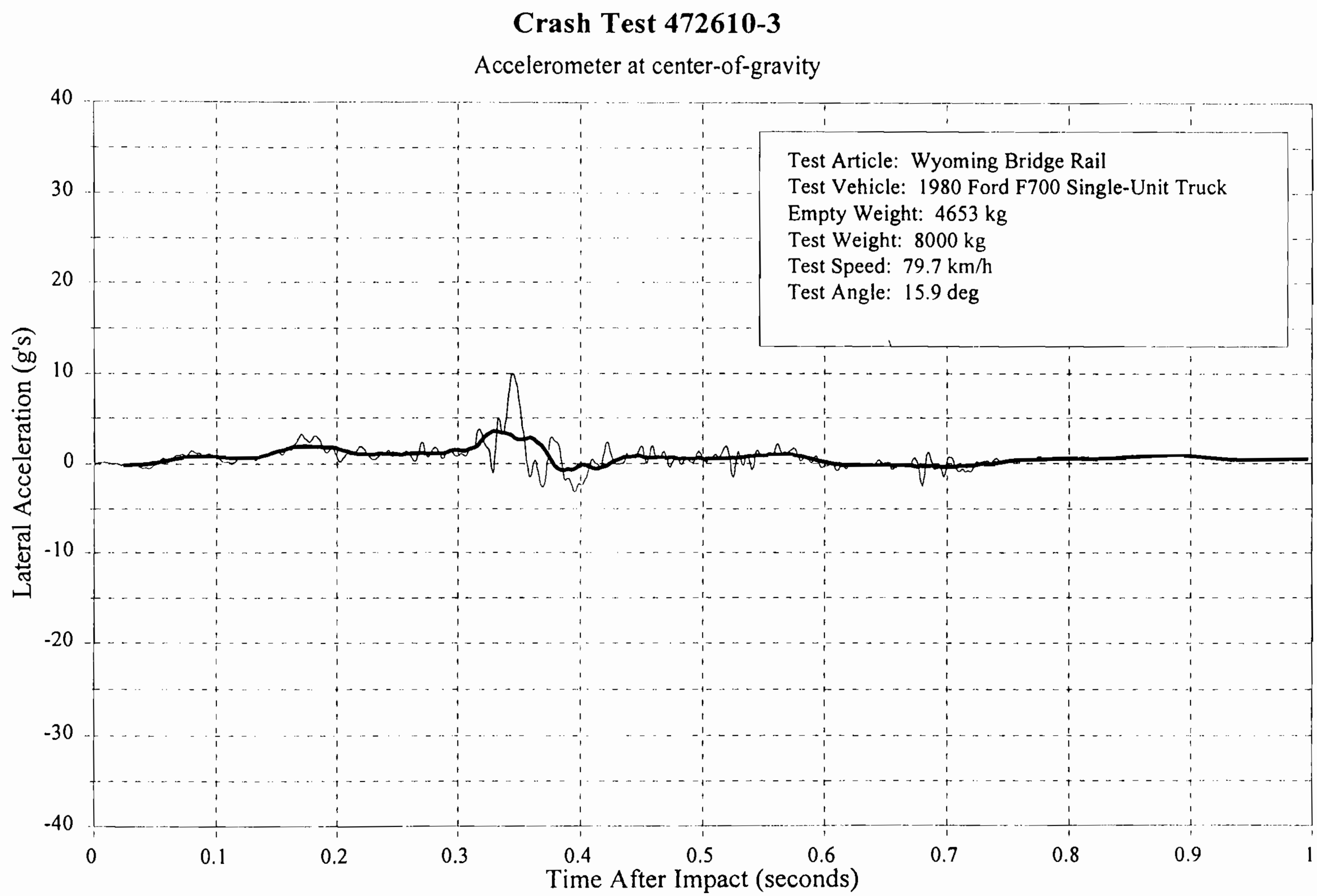


Figure 41. Vehicle lateral accelerometer trace for test 472610-3.
(accelerometer located at center-of-gravity)

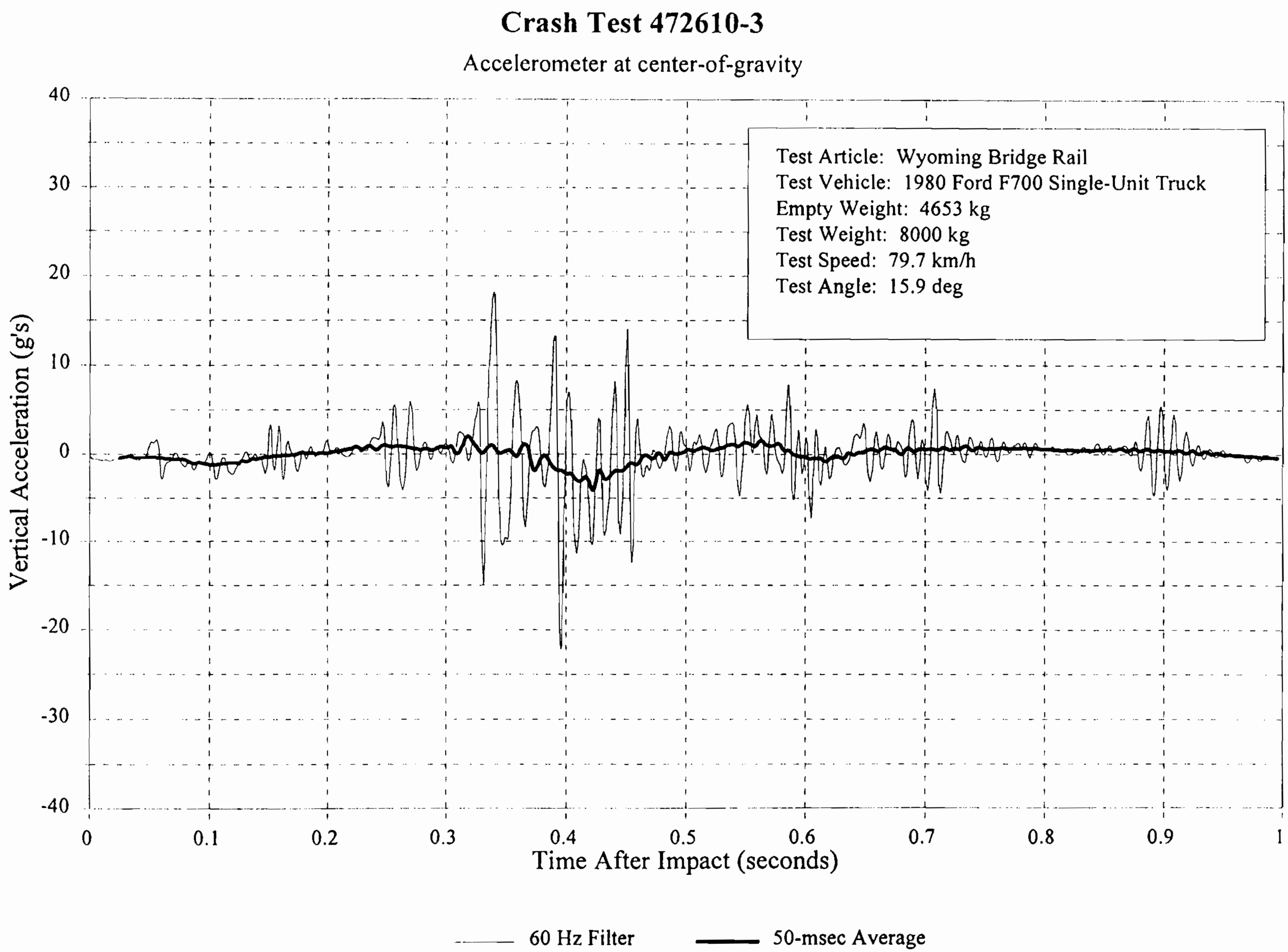


Figure 42. Vehicle vertical accelerometer trace for test 472610-3. (accelerometer located at center-of-gravity)

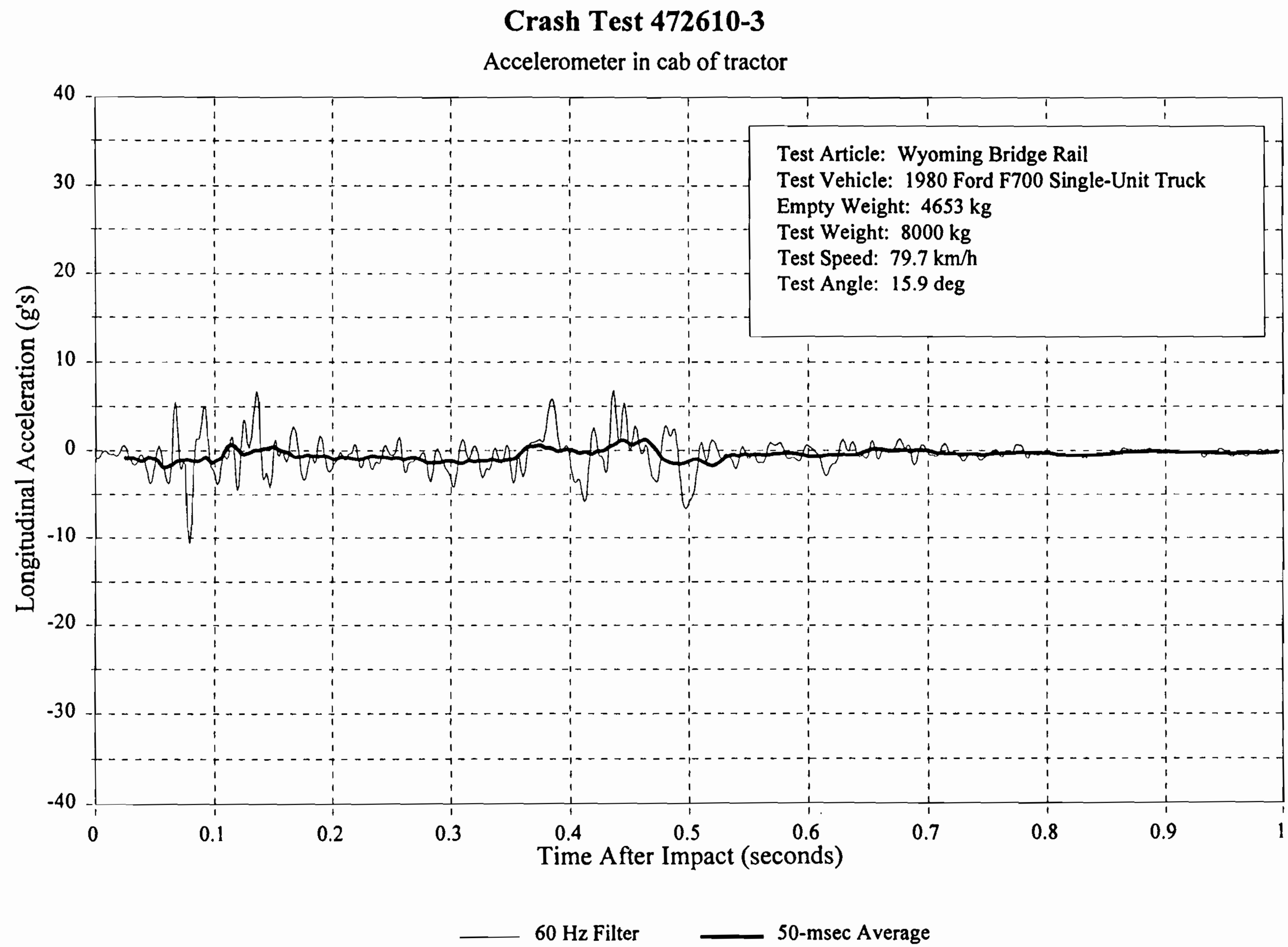


Figure 43. Vehicle longitudinal accelerometer trace for test 472610-3. (accelerometer located in cab of truck)

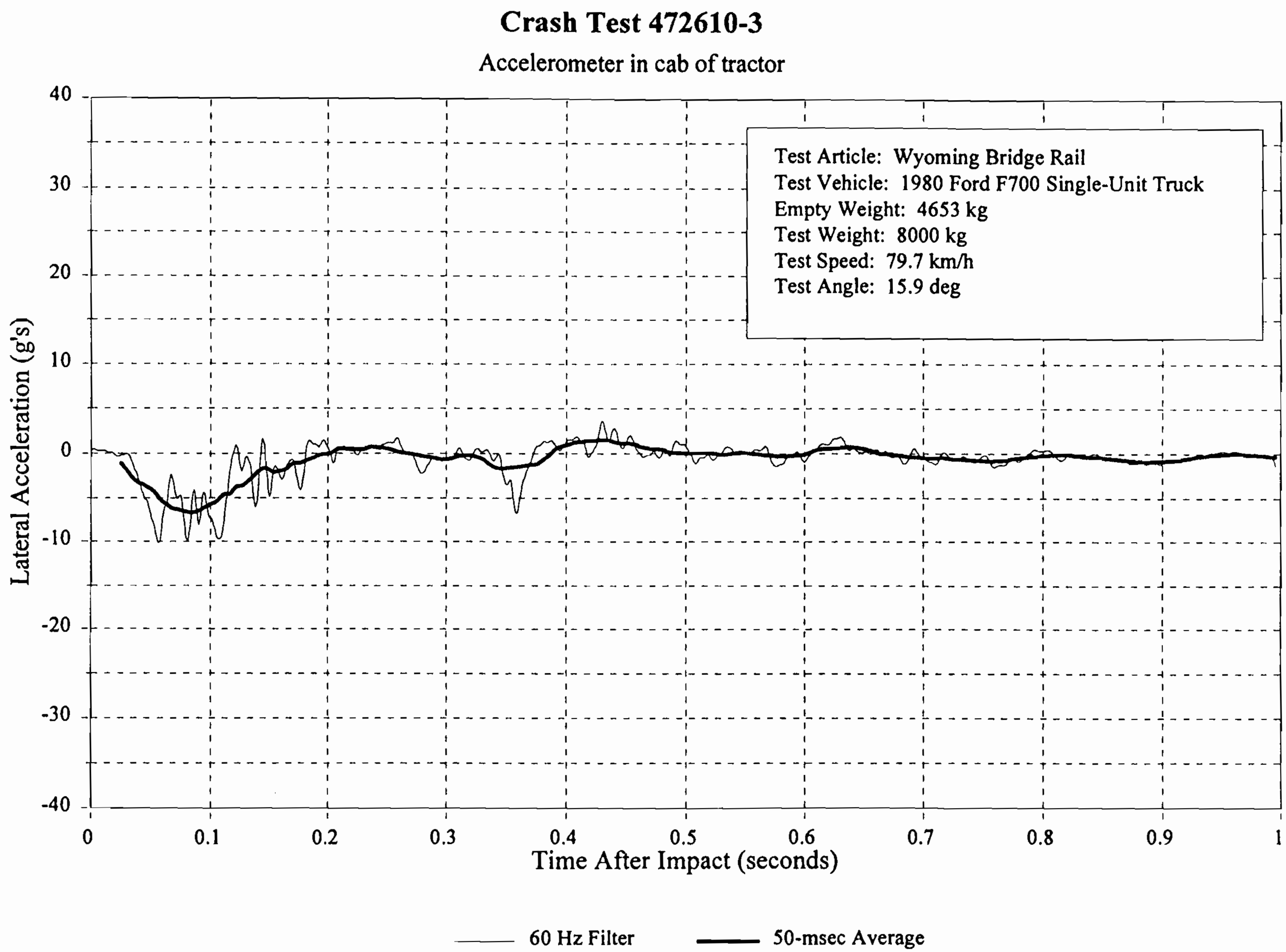


Figure 44. Vehicle lateral accelerometer trace for test 472610-3.
(accelerometer located in cab of truck)

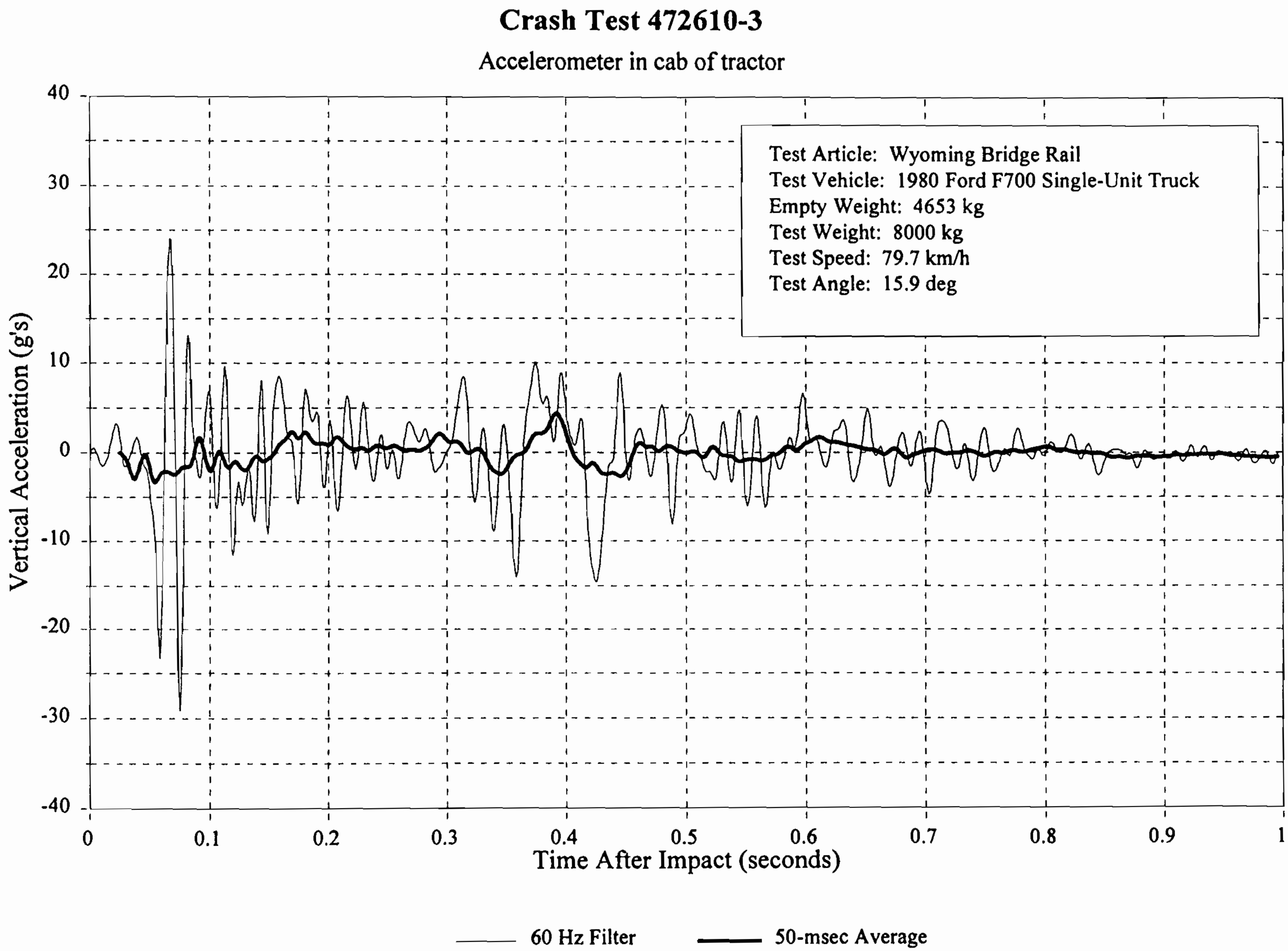


Figure 45. Vehicle vertical accelerometer trace for test 472610-3. (accelerometer located in cab of truck)

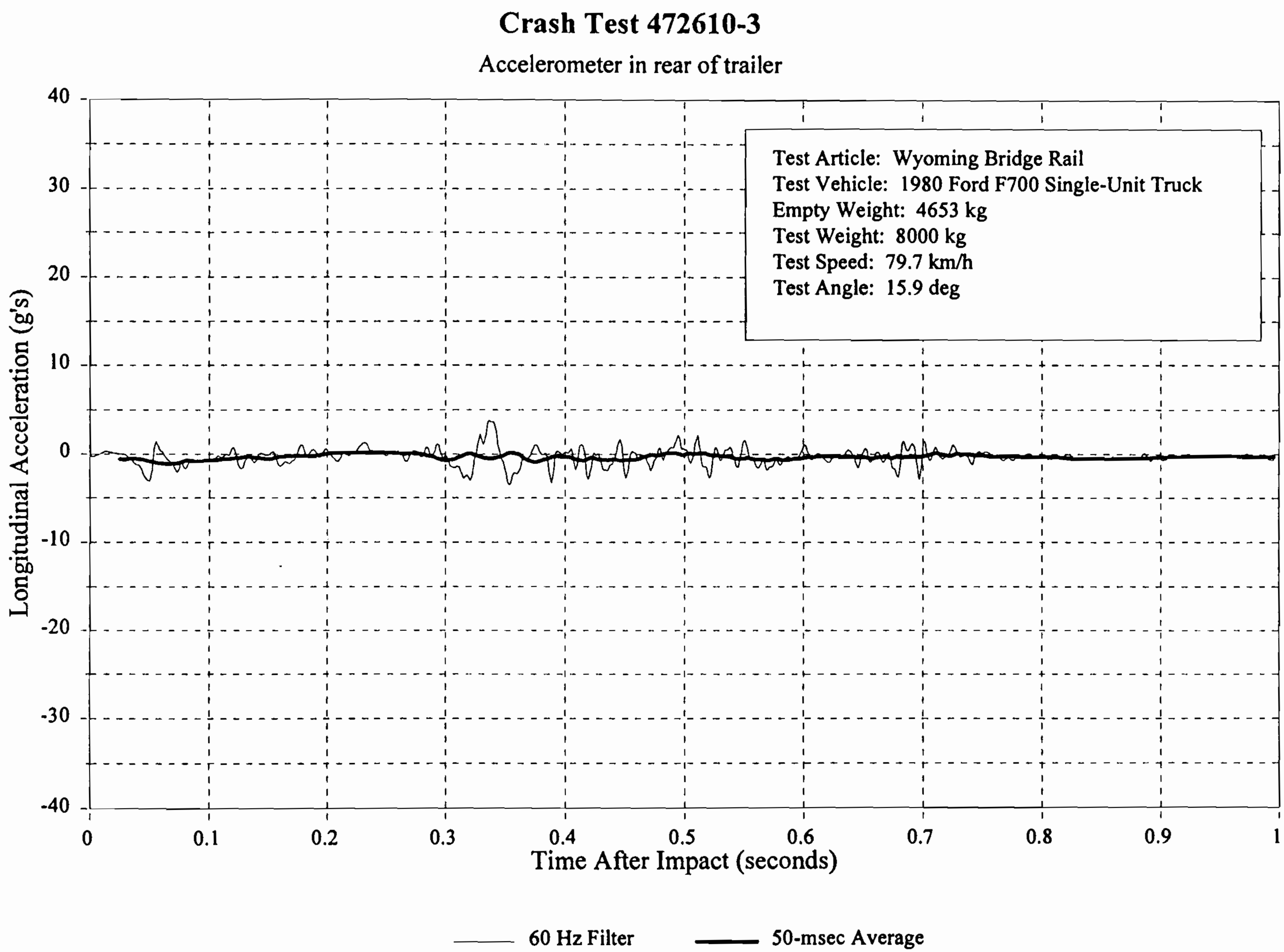


Figure 46. Vehicle longitudinal accelerometer trace for test 472610-3.
(accelerometer located in rear of trailer)

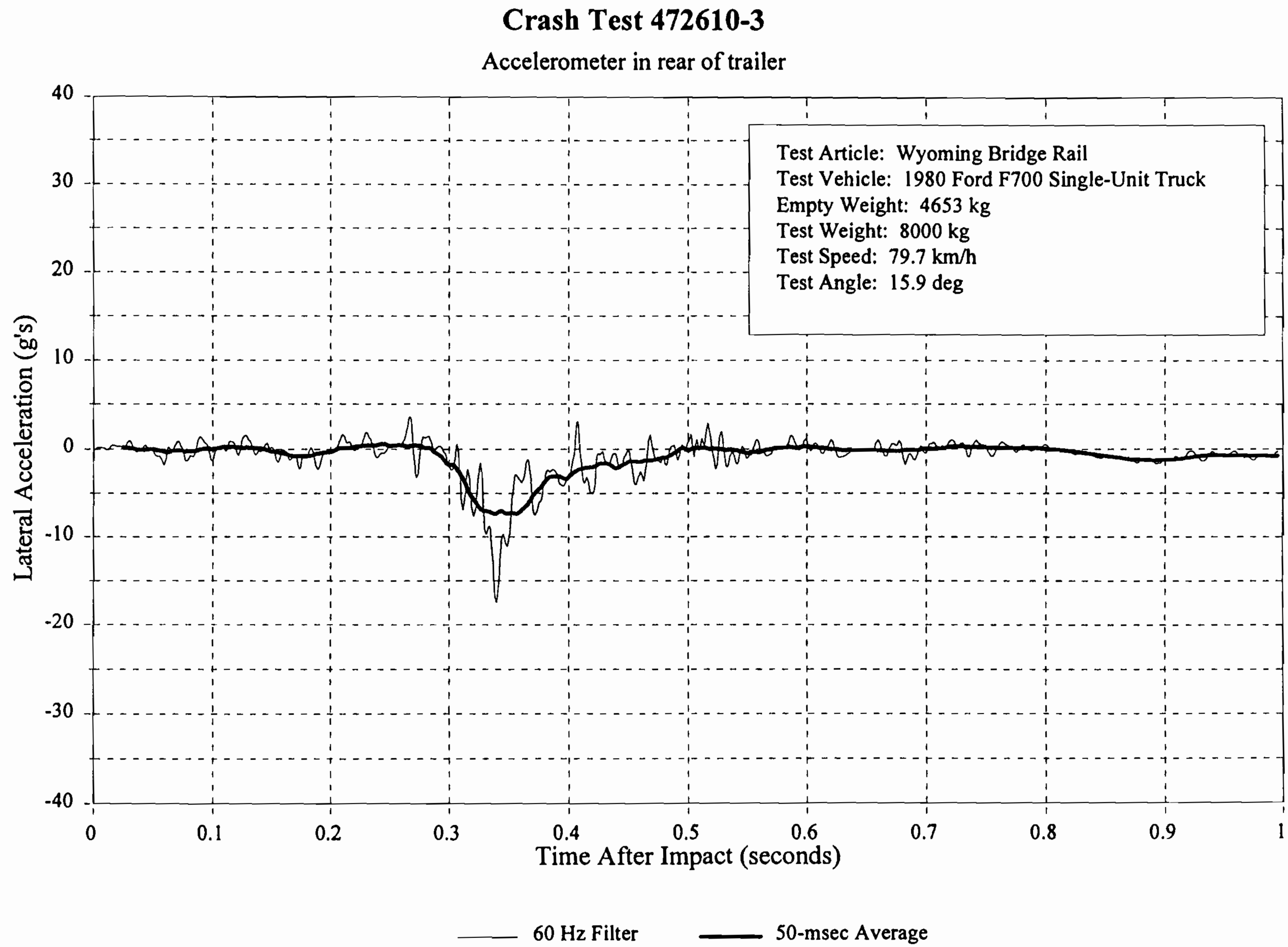


Figure 47. Vehicle lateral accelerometer trace for test 472610-3.
(accelerometer located in rear of trailer)