Testing of State Roadside Safety Systems Volume XI: Appendix J–Crash Testing and Evaluation of Existing Guardrail Systems

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FOREWORD

Because of specific needs or constraints of individual States, new or modified roadside safety hardware are being designed and developed on a continuing basis. To ensure that these new or modified designs perform according to established guidelines, full-scale crash testing and evaluation were deemed necessary. The objective of this study is to crash test and evaluate these roadside safety hardware and where necessary redesign the devices to improve their impact performance. The three major areas addressed in this study are the impact performance of bridge railings, transitions from guardrails to bridge railings, and end treatments for guardrails and median barriers.

Detailed drawings are presented for documentation as well as a summary of findings and conclusions for each of the devices tested, and where necessary recommendations for improvement.

It should be noted that this research did not produce a version of the MELT—Modified Eccentric Loader Terminal—that was acceptable to FHWA for use on the National Highway System.

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

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16. Abstract

The purpose of this study is to crash test and evaluate new or modified roadside safety hardware and, where necessary, redesign the devices to improve their impact performance. The three major areas addressed in this study are the impact performance of bridge railings, transitions from guardrails to bridge railings, and end treatments for guardrails and median barriers.

This report presents the results of a series of crash tests conducted on existing guardrail systems with the 2000P test vehicle (i.e., a 2000-kg (4409-lb) pickup truck) in accordance with guidelines set forth in NCHRP Report 350. Results of the crash tests indicated that the cable (G1), box-beam (G3), W-beam, strong-wood-post (G4(2W)), and the modified thrie-beam guardrail systems performed satisfactorily under test level 3 conditions (i.e., at a nominal impact speed and angle of 100 km/h (62.2 mi/h) and 25 degrees). The W-beam, strong-steel-post (G4(1S)), and the thrie-beam (G9) guardrail systems failed to perform satisfactorily under test level 3 conditions. The W-beam, weak-post (G2) guardrail system failed to perform satisfactorily under test level 3 conditions, but performed satisfactorily under test level 2 conditions (i.e., at a nominal impact speed and angle of 70 km/h (43.5 mi/h) and 25 degrees).

This volume is the eleventh in a series of 13 volumes for the final report. The other volumes in the series are: Volume I - Technical Report; Volume II, Appendix A - Crash Testing and Evaluation of a Michigan Thrie-Beam Transition Design; Volume III, Appendix B - Crash Testing and Evaluation of a Guardrail System for Low-Fill Culvert; Volume IV, Appendix C - Crash Testing and Evaluation of a Pennsylvania Transition Design; Volume V, Appendix D - Crash Testing and Evaluation of a Washington, DC, PL-1 Bridge Rail; Volume VI, Appendix E - Crash Testing and Evaluation of a Modified Breakaway Cable Terminal (BCT) Design; Volume VII, Appendix F - Crash Testing and Evaluation of the Minnesota Swing-Away Mailbox Support; Volume VIII, Appendix G - Crash Testing and Evaluation of the Single Slope Bridge Rail; Volume IX, Appendix H - Crash Testing and Evaluation of the NETC PL-2 Bridge Rail Design; Volume X, Appendix I - Crash Testing and Evaluation of a Mini-MELT for a W-Beam, Weak-Post (G2) Guardrail System; Volume XII, Appendix K - Crash Testing and Evaluation of the MELT; and Volume XIII, Appendix L - Laboratory and Pendulum Testing of the Modified Breakaway Wooden Posts.

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PREFACE

Because of specific needs or constraints of individual states, new or modified roadside safety hardware are being designed and developed on a continuing basis. To ensure that these new or modified designs perform according to established guidelines, full-scale crash testing and evaluation were deemed necessary. The objective of this study is to crash test and evaluate these roadside safety hardware and, where necessary, redesign the devices to improve their impact performance. The three major areas addressed in this study are the impact performance of bridge railings, transitions from guardrails to bridge railings, and end treatments for guardrails and median barriers.

This is Volume XI of a 14-volume series of final reports for this study. The 14 volumes are as follows:

Volume	Appendix	Title
I		Technical Report.
II	A	Crash Testing and Evaluation of a Michigan Thrie-Beam Transition Design.
III	B	Crash Testing and Evaluation of a Guardrail System for Low-Fill Culvert.
IV	C	Crash Testing and Evaluation of a Pennsylvania Transition Design.
V	D	Crash Testing and Evaluation of a Washington, DC, PL-1 Bridge Rail.
VI	E	Crash Testing and Evaluation of a Modified Breakaway Cable Terminal (BCT) Design.
VII	F	Crash Testing and Evaluation of the Minnesota Swing-Away Mailbox Support.
VIII	G	Crash Testing and Evaluation of the Single Slope Bridge Rail.
IX	H	Crash Testing and Evaluation of the NETC PL-2 Bridge Rail Design.
X	I	Crash Testing and Evaluation of a Mini-MELT for a W-Beam, Weak-Post (G2) Guardrail System.
XI	J	Crash Testing and Evaluation of Existing Guardrail Systems.
XII	K	Crash Testing and Evaluation of the MELT.
XIII	L	Crash Testing and Evaluation of the Modified MELT.
XIV	M	Laboratory and Pendulum Testing of Modified Breakaway Wooden Posts.

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/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

(Revised August 1992)

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I. INTRODUCTION

The Federal Highway Administration (FHWA) has formally adopted the new performance evaluation guidelines for highway features set forth in National Cooperative Highway Research Program (NCHRP) Report 350[1] as a "Guide or Reference" document in *Federal Register*, Volume 58, Number 135, dated July 16, 1993, which added paragraph (a)(13) to 23 CFR, Part 625.5. FHWA has also mandated that, starting in September of 1998, only highway safety appurtenances that have successfully met the performance evaluation guidelines set forth in NCHRP Report 350 may be used on the National Highway System (NHS) for new installations. Most of the existing highway features were tested according to the previous guidelines contained in NCHRP Report 230.[2] It is, therefore, necessary to crash test and evaluate the performance of existing highway features under the newer guidelines.

One of the key revisions in the guidelines set forth in NCHRP Report 350 from those in NCHRP Report 230 is the replacement of the 2041-kg (4500-lb) passenger car by a 2000-kg (4409-lb) pickup truck as one of the design test vehicles. Very little information was available on the performance of existing highway features with the new 2000P test vehicle (i.e., 2000-kg (4409-lb) pickup truck). As part of an effort by FHWA to evaluate the performance of existing highway features with the new 2000P test vehicle, a series of crash tests with the new 2000P test vehicle was conducted on various existing guardrail systems, the results of which are presented in this appendix.

The following existing guardrail systems were crash tested and evaluated in this study:

- Cable (G1) guardrail system,
- W-beam, weak-post (G2) guardrail system,
- Box-beam (G3) guardrail system,
- W-beam, strong-post (G4) guardrail system,
- Thrie-beam (G9) guardrail system, and
- Modified thrie-beam guardrail system.

More descriptions of these crash tests and the results are presented in the following chapters.

II. STUDY APPROACH

2.1 GUARDRAIL SYSTEMS TESTED

As mentioned previously, the following existing guardrail systems were crash tested and evaluated in this study:

- Cable (G1) guardrail system,
- W-beam, weak-post (G2) guardrail system,
- Box-beam (G3) guardrail system,
- W-beam, strong-post (G4) guardrail system,
- Thrie-beam (G9) guardrail system, and
- Modified thrie-beam guardrail system.

Descriptions of these guardrail systems are presented in this section.

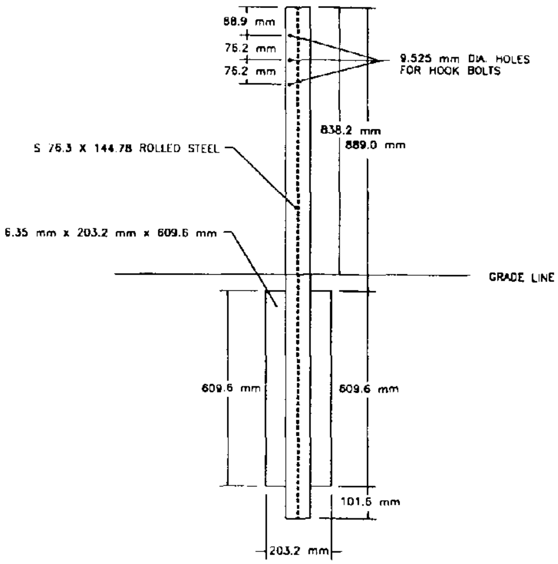
2.1.1 Cable (G1) Guardrail System

The cable (G1) guardrail system consisted of three 191-mm- (3/4-in-) diameter round wire cable mounted on S3x5.7 steel posts, spaced 4.9 m (16 ft) on center, a cross-section of which is shown in figure 1. The 19.1-mm- (3/4-in-) diameter round wire cable consisted of three strands (seven wires per strand) with a minimum tensile strength of 115.7 kN (26 000 lb). The mounting heights for the center of the three cables were 597, 673, and 749 mm (23.5, 26.5, and 29.5 in), respectively. The cables were attached to the posts with 7.9-mm- (5/16-in-) diameter hook bolts. The S3x5.7 steel posts were 1.6 m (63 in) long with an embedment depth of 762 mm (30 in). A 203-mm x 610-mm x 6.4-mm (8-in x 24-in x 1/4-in) soil plate was used with the steel posts.

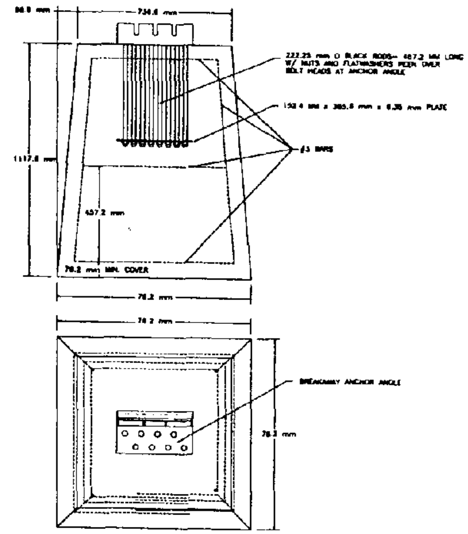
The 12.8-m- (42-ft-) long terminal section consisted of a 7.3-m (24-ft) section with four S3x5.7 posts spaced at 1.83 m (6.0 ft); the last 5.5 m (18 ft) was unsupported (i.e., the first or end post was located 5.5 m (18 ft) from the concrete anchor). The full guardrail height of 762 mm (30 in) was maintained until the second post where the cables began to slope down to ground level at the concrete anchor. The first two posts had end caps with shelf angles for the cables instead of the hook bolts. The first or end post was also mounted at a reduced height to accommodate the sloping of the cables. The cables were anchored to a concrete block with a breakaway anchor angle, details of which are shown in figure 1.

2.1.2 W-Beam, Weak-Post (G2) Guardrail System

The W-beam, weak-post (G2) guardrail system consisted of 1.6-m- (5-ft, 3-in-) long S3x5.7 posts with 203-mm x 610-mm x 6.4-mm (8-in x 24-in x 1/4-in) soil plates, spaced 3.8 m (12 ft, 6-in) center to center, and 3.8-m- (12-ft, 6-in-) long 12-gauge W-beam rail elements. A cross-section of the W-beam, weak-post (G2) guardrail system is shown in figure 2. The height



STANDARD POST DETAIL



CONCRETE ANCHOR DETAIL

Figure 1. Cross-section of the cable (G1) guardrail system.

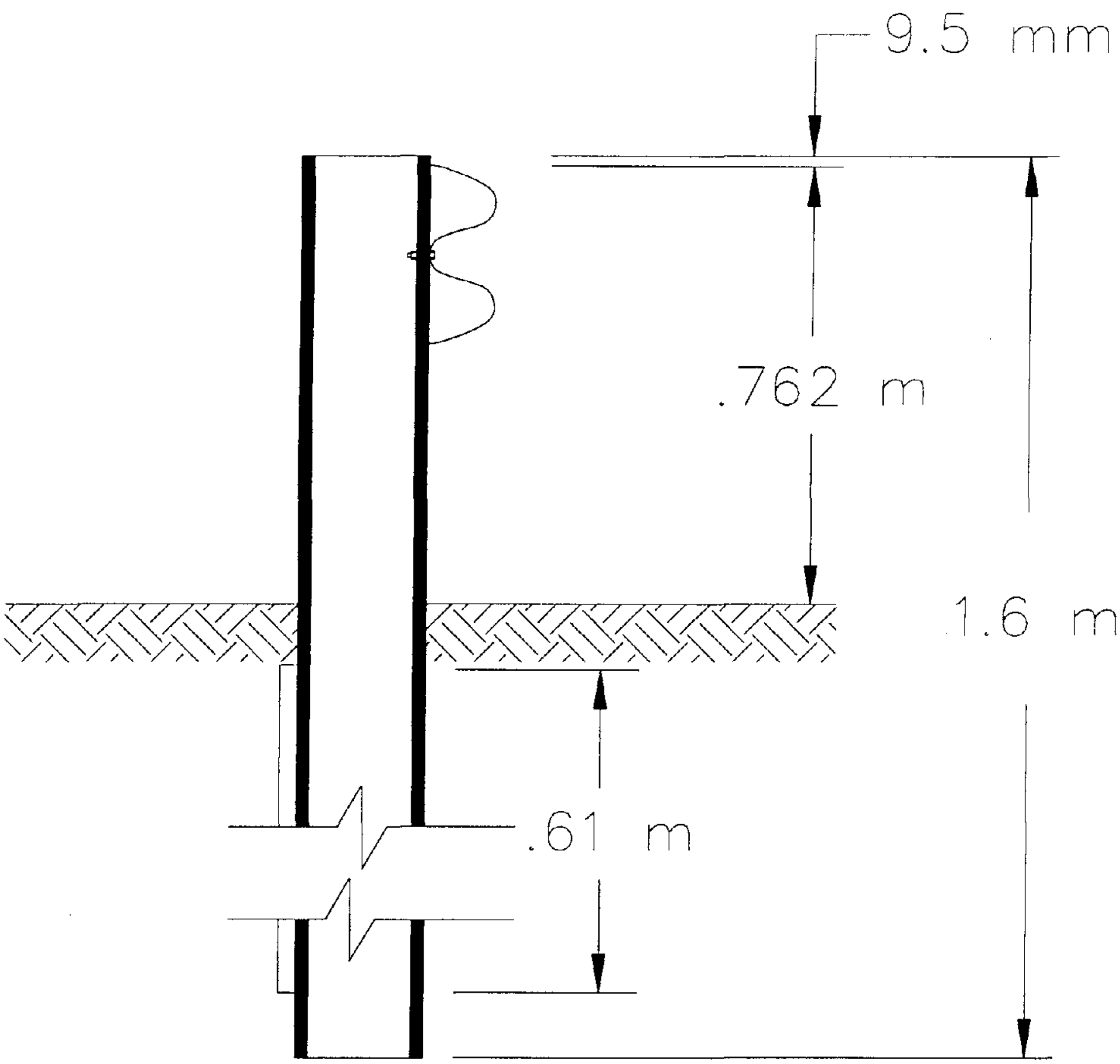


Figure 2. Cross-section of the W-beam, weak post (G2) guardrail system.

of the guardrail to the top of the W-beam rail element was 0.76 m (30 in). The W-beam rail elements were attached to the posts with 7.94-mm- (5/16-in-) diameter bolts and square plate washers. Also, 12.7-mm- (1/2-in-) diameter and 38.1-mm- (1-1/2 in-) long shelf bolts were attached to the posts with two or more nuts for the W-beam rail elements to rest on. The purpose of the shelf bolts is to reduce the loading on the 7.94-mm- (5/16-in-) diameter post bolts from the weight of the W-beam rail elements and other dead loads such as snow and ice on the rail elements.

2.1.3 Box-Beam (G3) Guardrail System

The box-beam (G3) guardrail system consisted of 1.6-m- (5-ft, 4-in-) long S3x5.7 steel posts spaced 1.8 m (6 ft) apart, a cross-section of which is shown in figure 3. A L127- x 89- x 10- x 114-mm-long (L5- x 3-1/2- x 3/8- x 4-1/2-in- long) shelf angle was attached to the post with a 13-mm- (½-in-) diameter, 38-mm- (1-1/2 in-) long hex bolt with washer and nut. A TS152- x 152- x 4.8- mm tubular steel (TS6- x 6- x 3/16-in) box-beam rail element was attached to the support angle with a 10-mm- (3/8-in-) diameter, 191-mm- (7-1/2-in-) long hex bolt with washer and nut. The mounting height of the box beam rail was 686 mm (27 in) to the top of the box-beam rail element.

2.1.4 W-Beam, Strong-Post (G4) Guardrail Systems

Both W-beam, strong-post guardrail systems, one with wooden posts and blockouts, G4(2W), and the other with steel posts and blockouts, G4(1S), were crash tested.

As shown in figure 4, the G4(2W) guardrail system consisted of 1.6-m- (5-ft, 4-in-) long, 152-mm x 203-mm (6-in x 8-in) wood posts with 356-mm- (14-in-) long, 152-mm x 203-mm (6-in x 8-in) wooden blockouts, spaced 1.9 m (6 ft, 3 in) on center, and 3.8-m- (12-ft, 6-in-) long 12-gauge W-beam rail elements. The height of the guardrail to the center of the W-beam rail element was 550 mm (21.7 in). The W-beam rail elements were attached to the posts with 15.9-mm- (5/8-in-) diameter carriage bolts without any washers.

The G4(1S) guardrail system consisted of 1.8-m- (6-ft, 0-in-) long, W6 x 9 steel posts with 356-mm- (14-in-) long W6 x 9 steel blockouts, spaced 1.9 m (6 ft, 3 in) on center and 3.8-m (12-ft, 6-in-) long 12-gauge W-beam rail elements. A cross-section of the G4(1S) guardrail system is shown in figure 5. The height of the guardrail to the center of the W-beam rail element was 550 mm (21.7 in). The W-beam rail elements were attached to the posts with 15.9-mm- (5/8-in-) diameter carriage bolts without any washers. Backup plates, similar in cross section to the W-beam rail element and 305 mm (12 in) in length, were used at non-splice posts.

2.1.5 Thrie-Beam (G9) Guardrail System

As shown in figure 6, the thrie-beam (G9) guardrail system consisted of 2.0-m- (6-ft, 6-in-) long W6 x 9 steel posts spaced 1.9 m (6 ft, 3 in) apart with 546-mm- (21.5-in-) long

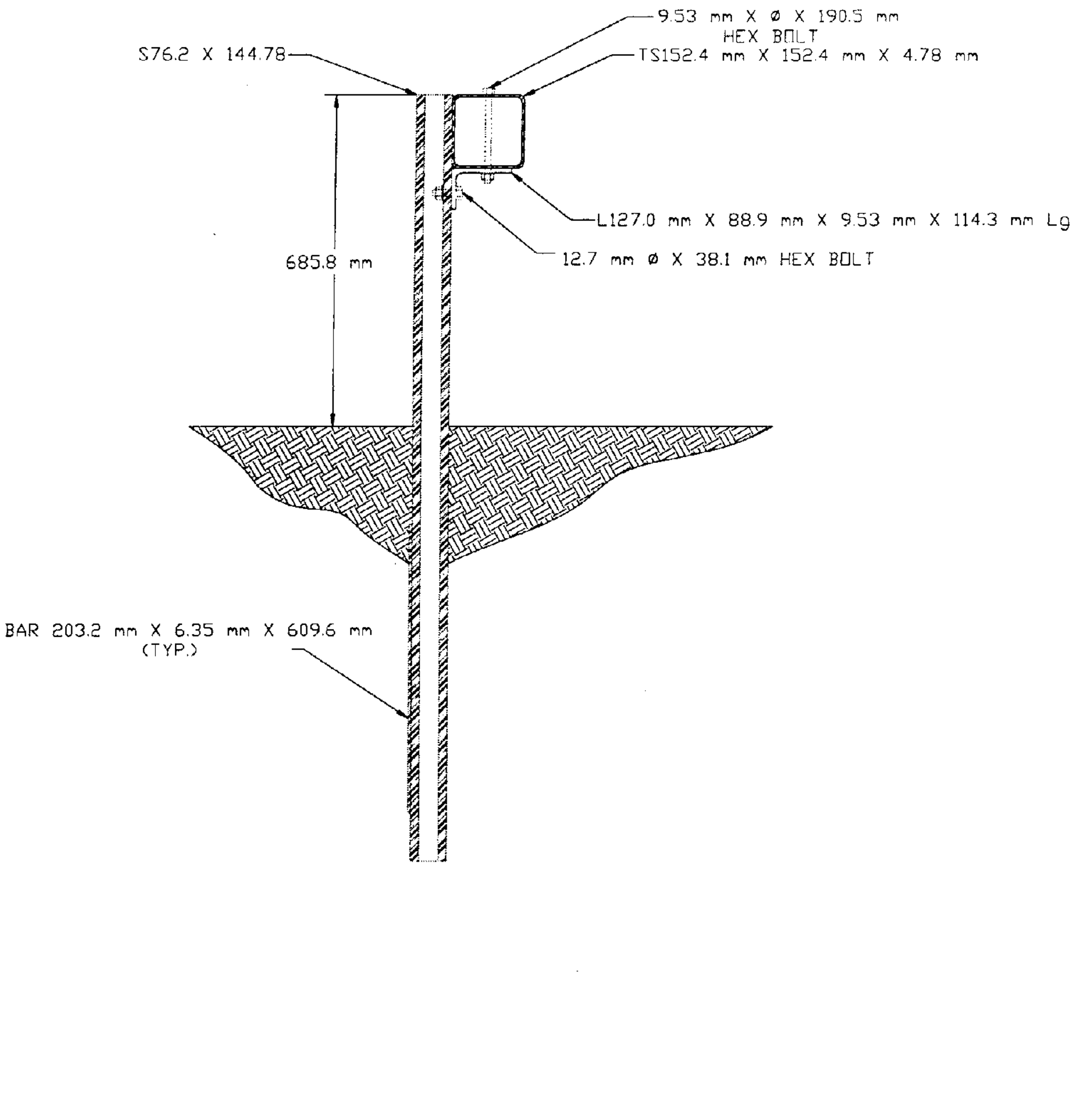
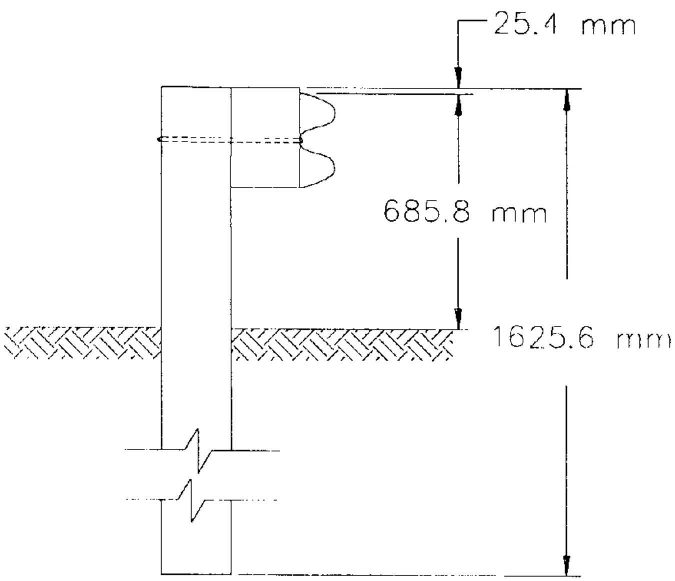


Figure 3. Cross-section of the box-beam (G3) guardrail system.



G4(2W)	
Post Type:	152x203 Wood
Post Spacing:	1.9 m
Beam Type:	12-gauge W-beam
Blockout:	152x203x356 Wood
Mountings:	16 mm dia. carriage bolts

Figure 4. Cross-Section of the W-beam, wood-post (G4(2W)) guardrail system.

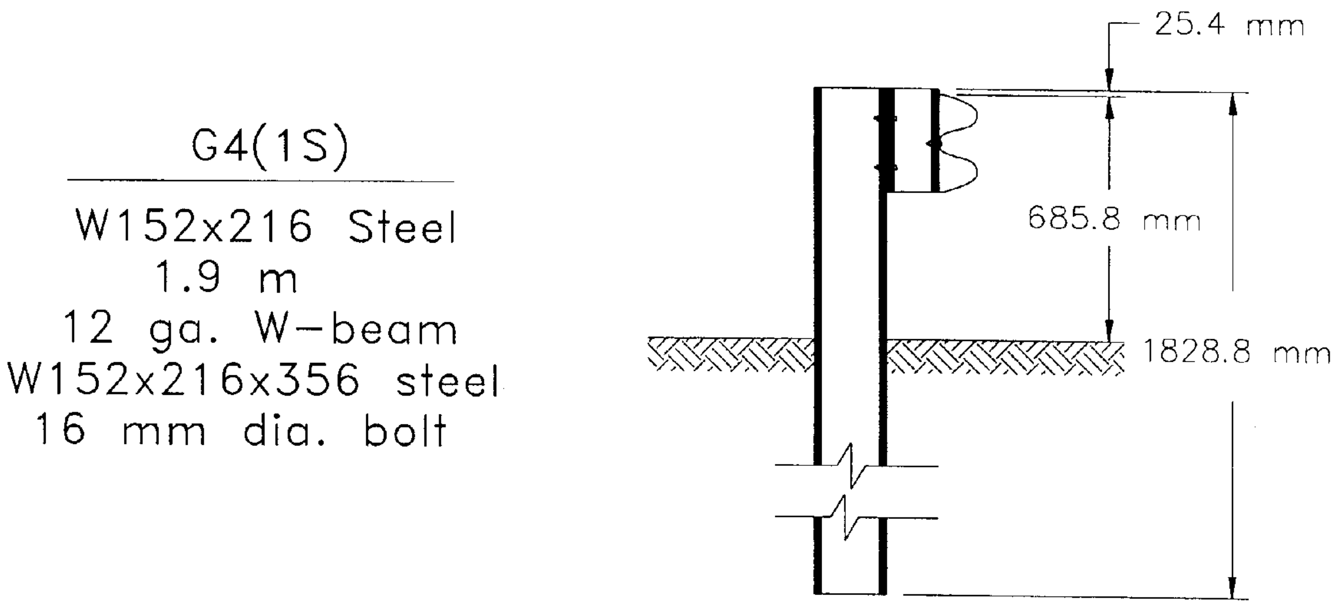


Figure 5. Cross-section of the W-beam, steel-post (G4(1S)) guardrail system.

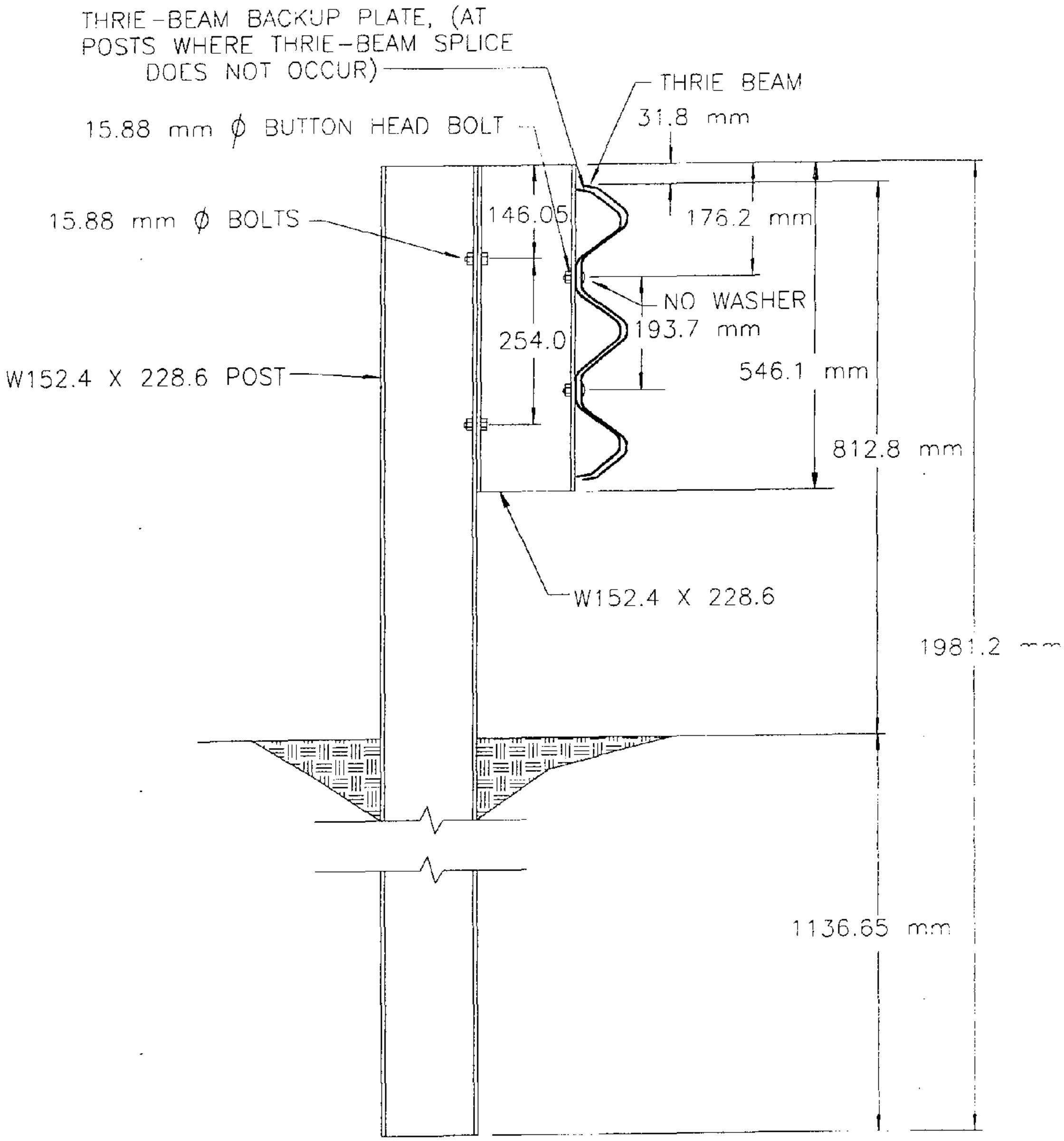


Figure 6. Cross-section of the thrie-beam (G9) guardrail system.

W6 x 9 steel blockouts. The blockout was attached to the post with two 15.9-mm- (5/8-in-) diameter bolts and the thrie-beam rail element was attached to the blockout with two 15.9-mm (5/8-in) diameter button head bolts without washers. The mounting height of the thrie-beam rail was 559 mm (22 in) to the center and 813 mm (32 in) to the top of the thrie-beam rail element.

2.1.6 Modified Thrie-Beam Guardrail System

The modified thrie-beam guardrail system consisted of 2.1-m- (6-ft, 9-1/4-in-) long W6x9 steel posts spaced 1.9 m (6 ft, 3 in) apart with M14x18 blockouts. A cross-section of the modified thrie-beam guardrail system is shown in figure 7. The blockouts were 432-mm (17-in) long, 457-mm (18-in) deep, and 152-mm (6-in) wide at the flanges. The webbing of the blockout had a cutout measuring 152 mm (6 in) 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 15.9-mm- (5/8-in-) diameter bolts and the thrie-beam rail element was attached to the blockout with a single 15.9-mm- (5/8-in-) diameter button head bolt without a washer. The mounting height of the thrie-beam rail was 610 mm (24 in) to the center and 864 mm (34 in) to the top of the thrie-beam rail element.

2.2 CRASH TEST CONDITIONS

All the crash tests, except for one test (test no. 471470-22) on the W-beam, weak-post (G2) guardrail system, were conducted at the test level 3 (TL-3) conditions. The test corresponded to test designation 3-11 of the NCHRP Report 350 crash test matrix for longitudinal barrier length-of-need section. The test involved a 2000P vehicle (i.e., a 2000-kg (4409-lb) pickup truck) impacting the length-of-need section at a nominal speed and angle of 100 km/h (62.2 mi/h) and 25 degrees. The purpose of the test is to evaluate the strength of the length-of-need section of the guardrail system in containing and redirecting the 2000P test vehicle under the TL-3 test conditions.

One test on the W-beam, weak-post (G2) guardrail system (test no. 471470-22) was conducted at the test level 2 (TL-2) conditions. The test corresponded to test designation 2-11 of the NCHRP Report 350 crash test matrix for longitudinal barrier length-of-need section. The test involved a 2000P test vehicle impacting the length-of-need section of the G2 guardrail system at the nominal speed and angle of 70 km/h (43.5 mi/h) and 25 degrees. The purpose of the test was to evaluate the strength of the length-of-need section of the guardrail system in containing and redirecting the 2000P test vehicle under the TL-2 test conditions. Note that the G2 guardrail system failed to meet the evaluation criteria under the TL-3 test conditions and this test was intended to evaluate if the G2 guardrail system would perform satisfactorily at a lower test level (i.e., TL-2 test conditions).

The critical impact points (CIPs) for the various guardrail systems were determined using the procedure outlined in NCHRP Report 350 and are summarized in table 1.

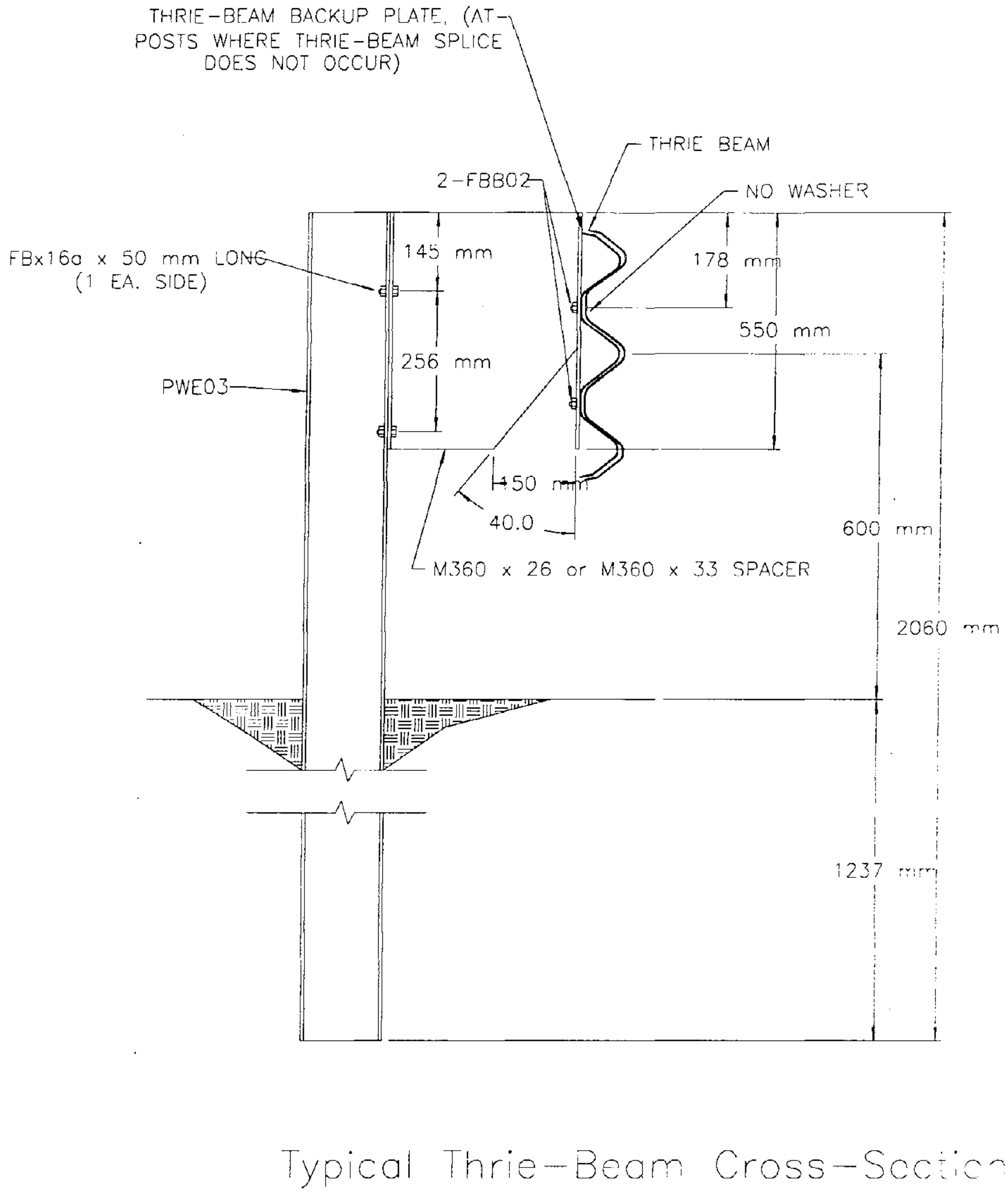


Figure 7. Cross-section of the modified thrie-beam guardrail system.

Table 1. List of crash tests conducted and critical impact points.

Guardrail Type	Test No.	Test Level	Critical Impact Point
Cable (G1)	471470-28	TL-3	Mid-span between two posts at roughly the one-third point of the test installation.
W-Beam, Weak-Post (G2)	471470-21	TL-3	Mid-span between posts 5 and 6 or 24.8 m (81 ft, 3 in) from the upstream end of the test installation.
W-Beam, Weak-Post (G2)	471470-22	TL-2	Mid-span between posts 4 and 5 or 21.0 m (68 ft, 9 in) from the upstream end of the test installation.
Box-Beam (G3)	471470-33	TL-3	Splice near the one-third point of the test installation.
W-Beam, Wood-Post G4(2W)	471470-26	TL-3	4.5 m (14.5 ft) upstream of splice at post 16.
W-Beam, Steel-Post G4(1S)	471470-27	TL-3	4.5 m (14.5 ft) upstream of splice at post 16.
Thrie-Beam (G9)	471470-31	TL-3	4.5 m (14.5 ft) upstream of splice near the one-third point of the test installation.
Modified Thrie-Beam	471470-30	TL-3	4.5 m (14.5 ft) upstream of splice near the one-third point of the test installation.

2.3 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.

2.3.1 Electronic Instrumentation and Data Processing

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

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

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 (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-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.

2.3.2 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 vehicle. The dummy was uninstrumented; however, a high-speed onboard camera recorded the motions of the dummy during the test.

2.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included four high-speed cameras: one placed behind the guardrail at an angle; one overhead with a field of view perpendicular to the ground and directly over the impact point; a third placed to have a field of view parallel to and aligned with the guardrail installation at the downstream end; and a fourth placed onboard the vehicle to record the motions of the dummy placed in the driver seat during the test sequence. A flash bulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the rail and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A 16-mm movie cine, a Betacam, VHS-format video cameras and recorders, and still cameras were used for documentary purposes to record the conditions of the test vehicle and guardrail system before and after the test.

2.3.4 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 the vehicle to a safe and controlled stop.

III. CRASH TEST RESULTS

As shown in table 1, a total of eight crash tests were conducted to evaluate the performance of various existing guardrail systems, including one test on the cable (G1) guardrail system, two tests on the W-beam, weak-post (G2) guardrail system, one test on the box-beam (G3) guardrail system, one test on the W-beam, wood-post (G4(2W)) guardrail system, one test on the W-beam, steel-post (G4(1S)) guardrail system, one test on the thrie-beam (G9) guardrail system, and one test on the modified thrie-beam guardrail system. Detailed descriptions of the results of these crash tests are presented in this chapter.

3.1 CABLE (G1) GUARDRAIL SYSTEM (TEST NO. 471470-28)

The test installation consisted of a 92.7-m- (304-ft-) long section of the cable (G1) guardrail system with a 12.8-m- (42-ft-) long terminal at each end, for a total installation length of 118.3 m (388 ft). The layout of the test installation is shown in figure 8, and photographs of the test installation are shown in figures 9 and 10.

A 1989 Chevrolet 2500 pickup (shown in figures 11 and 12) with a test inertia weight of 2000 kg (4409 lb) was used for the crash test. The gross static weight of the vehicle was 2075 kg (4570 lb) which included a restrained 50th-percentile male anthropomorphic dummy placed in the driver's position of the vehicle. The heights to the upper and lower edges of the vehicle bumper were 650 mm (25.6 in) and 410 mm (16.1 in), respectively. Additional dimensions and information on the vehicle are given in figure 13. 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 length-of-need section midway between posts 10 and 11, traveling at a speed of 95.1 km/h (59.1 mi/h) and at an angle of 26.7 degrees. As the vehicle impacted the installation, the cables began to deflect and the posts on either side of the impact point began to move inward and back. Redirection of the vehicle began at 0.078 s and vehicle contact with post 11 occurred at 0.083 s. At 0.104 s, post 12 began to move rearward and began to pull out of the ground at 0.218 s. The front of the vehicle contacted post 12 at 0.290 s. The cables made contact with the entire side of the vehicle at 0.329 s. Post 13 began to pull out of the ground at 0.395 s. The vehicle became parallel with the installation at 0.498 s, traveling at a speed of 77.3 km/h (48.0 mi/h). Maximum deflection of the cables was 2.4 m (7.8 ft) at 0.586 s. The vehicle contacted posts 13 and 14 at 0.838 s and 1.128 s, respectively. The vehicle lost contact with the installation at 1.599 s, traveling at a speed of 60.3 km/h (37.5 mi/h) and at an exit angle of approximately 2.0 degrees. The vehicle brakes were applied after the vehicle exited

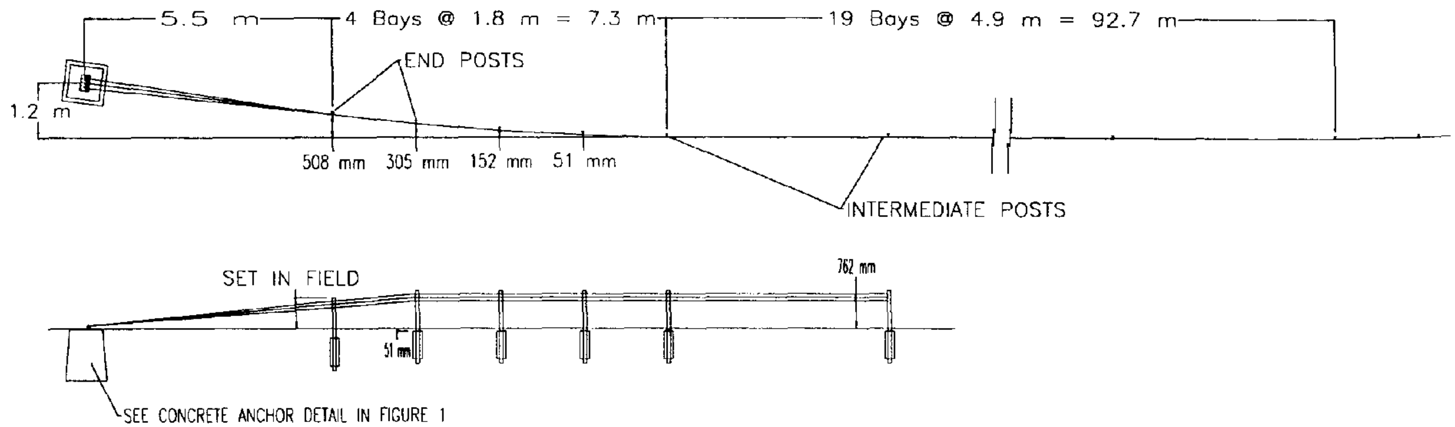


Figure 8. Layout of the cable (G1) guardrail system.

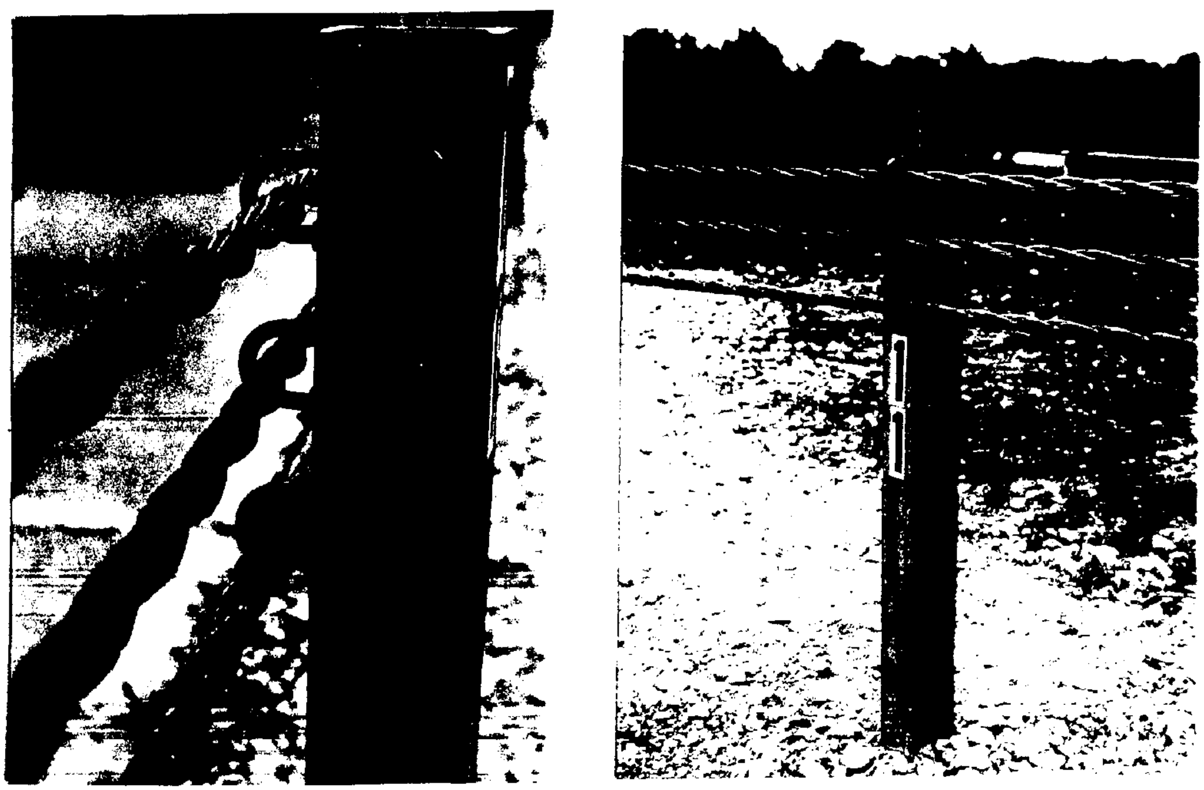


Figure 9. Cable (G1) guardrail installation before test 471470-28.

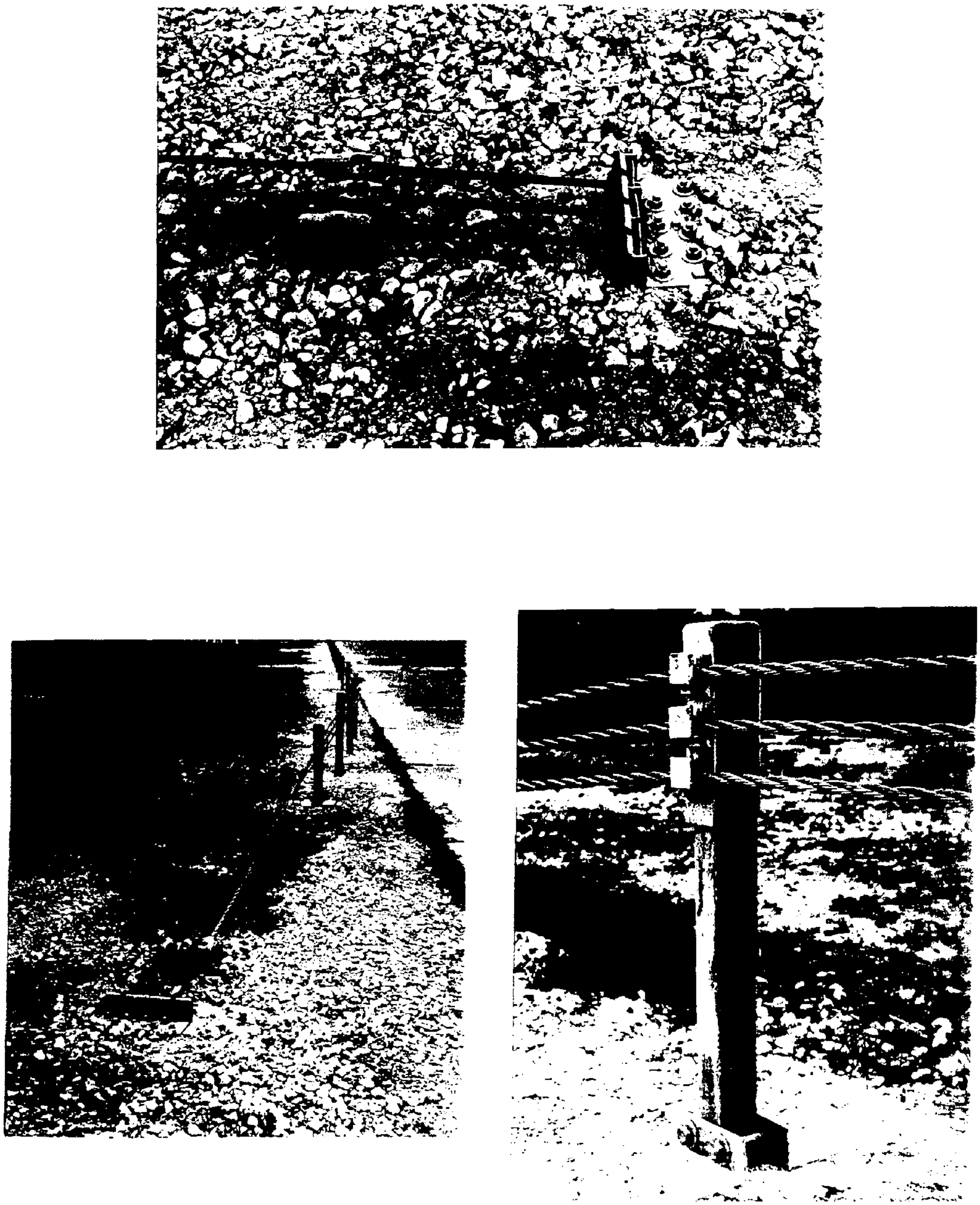


Figure 10. Anchor for the cable (G1) guardrail before test 471470-28.

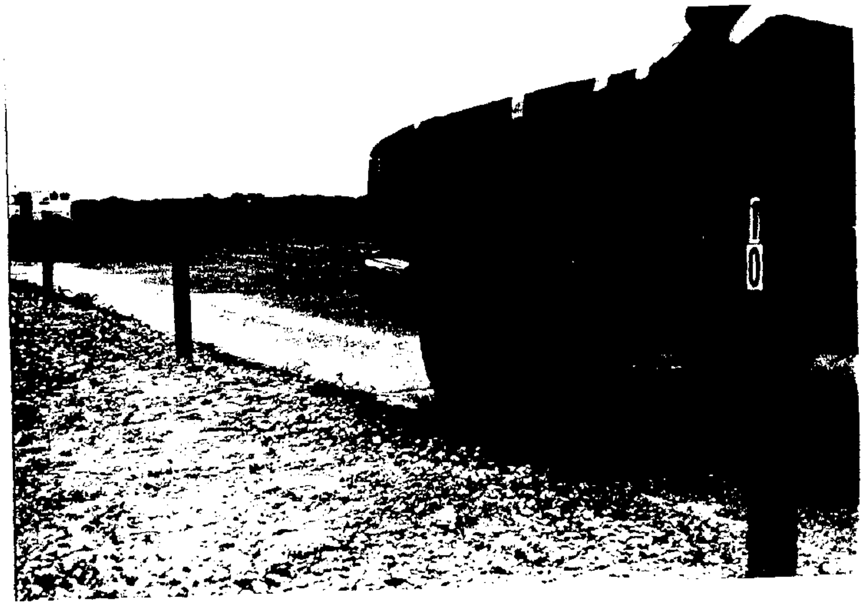


Figure 11. Vehicle/guardrail geometrics for test 471470-28.

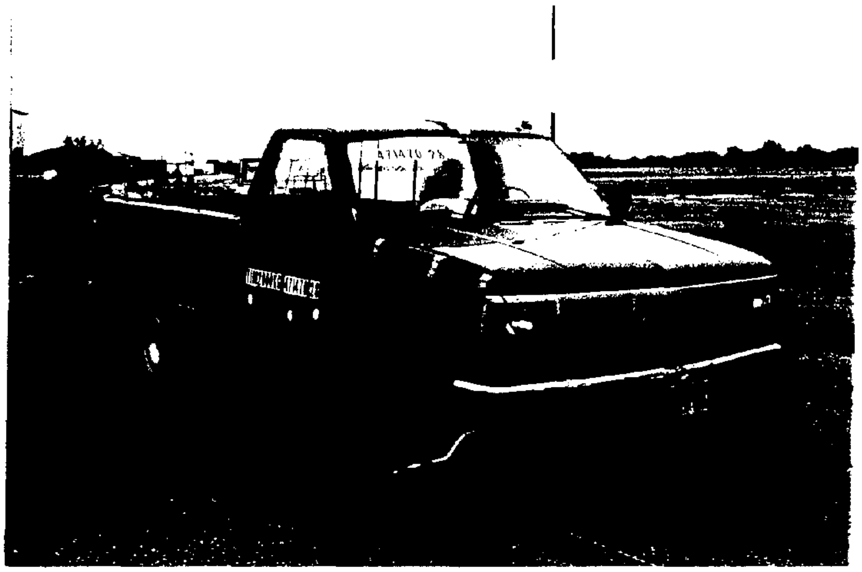


Figure 12. Vehicle before test 471470-28.

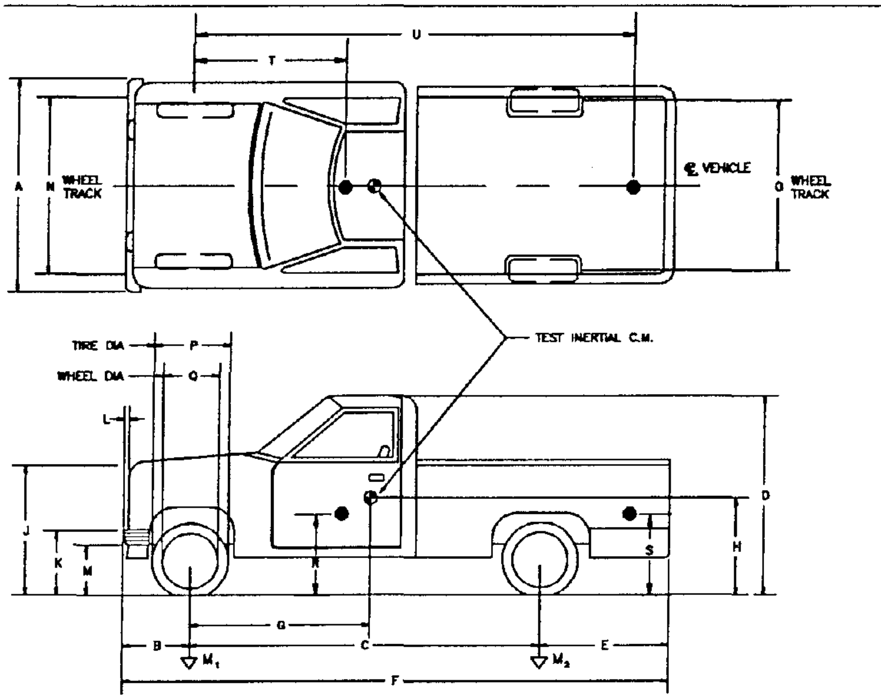
DATE: 11-15-94 TEST NO.: 471470-28 VIN NO. 1GTFC24K6KE552066 MAKE: Chevrolet

MODEL: 2500 YEAR: 1989 ODOMETER: 141646 GVW: ____

TIRE SIZE: LT 225 75R16 TIRE INFLATION PRESSURE: ____ TREAD TYPE: ____

MASS DISTRIBUTION (kg) LF 522 RF 560 LR 470 RR 448

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ____

ENGINE TYPE: 8 cyl gas

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

— MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ____

MASS: ____

SEAT POSITION: ____

GEOMETRY – (mm)

A 1890	E 1300	J 980	N 1590	R 700
B 720	F 5375	K 650	O 1630	S 1040
C 3355	G 1540	L 80	P 780	T 1490
D 1790	H	M 410	Q 440	U 4215

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1051	1082	1120
M_2	723	918	955
M_T	1774	2000	2075

Figure 13. Vehicle properties for test 471470-28.

the test area, and it subsequently came to rest 97 m (318 ft) down and 7 m (24 ft) forward of the impact point. Sequential photographs are shown in figures 14 and 15.

3.1.2 Damage to Test Installation

As seen in figures 16 and 17, the test installation received moderate damage. The cables were separated from the posts between posts 10 through 16. The lateral deflections recorded at posts 8 through 16 are noted in table 2.

Table 2. Lateral post deflections for test 471470-28.

Post 8	13 mm (0.5 in)	Post 13	pulled out
Post 9	102 mm (4.0 in)	Post 14	260 mm (10.3 in)
Post 10	76 mm (3.0 in)	Post 15	70 mm (2.8 in)
Post 11	152 mm (6.0 in)	Post 16	38 mm (1.5 in)
Post 12	pulled out		

Maximum dynamic deflection of the cables during the test was 2.4 m (7.8 ft). Maximum permanent deformation of the installation was 0.3 m (0.9 ft). The upstream concrete anchor was pulled up 89 mm (3.5 in) and inward 95 mm (3.8 in). The downstream anchor was pulled up and inward 57 mm (2.3 in).

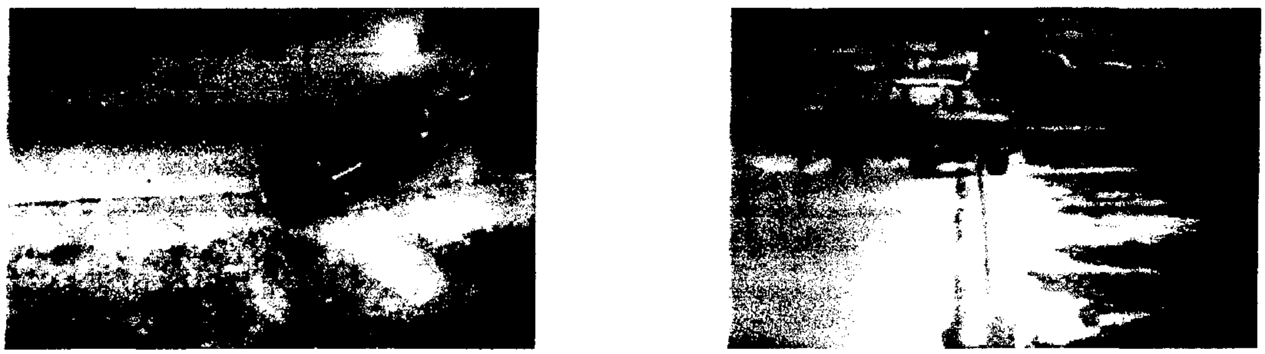
3.1.3 Vehicle Damage

The vehicle sustained minimal damage, as shown in figure 18. The front bumper and grill were damaged, and the entire left side of the vehicle was scraped by the wire rope. Maximum exterior crush at the left front corner of the vehicle was 360 mm (14.2 in), and there was no deformation or intrusion into the occupant compartment.

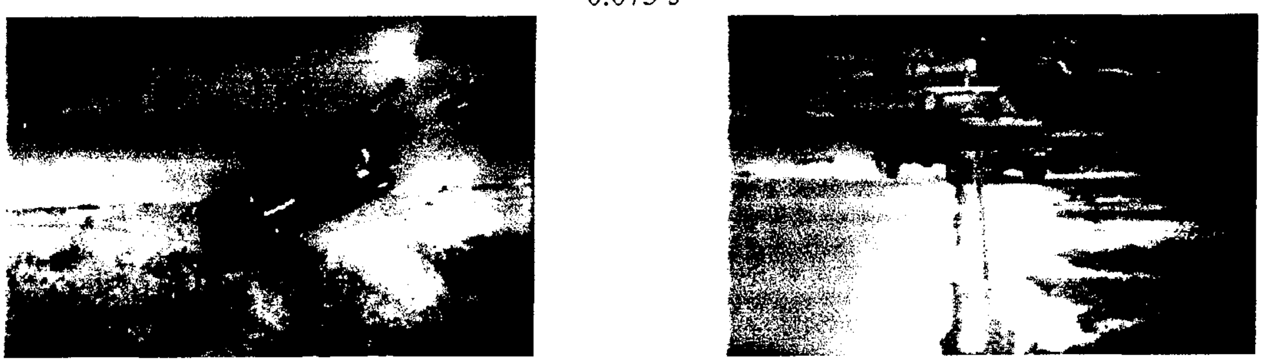
3.1.4 Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. Occupant contact first occurred in the lateral direction. Lateral occupant impact velocity was 3.5 m/s (11.6 ft/s) at 0.243 s; the highest 0.010-s lateral occupant ridedown acceleration was 5.6 g's between 0.333 and 0.343 s, and the maximum 0.050-s average acceleration was 2.9 g's between 0.194 and 0.244 s. In the longitudinal direction, the occupant impact velocity was 4.3 m/s (14.2 ft/s); the highest 0.010-s occupant ridedown acceleration was -4.0 g's between 0.526 and 0.536 s, and the maximum 0.050-s average was -1.9 g's between 0.073 and 0.123 s. These data and other information

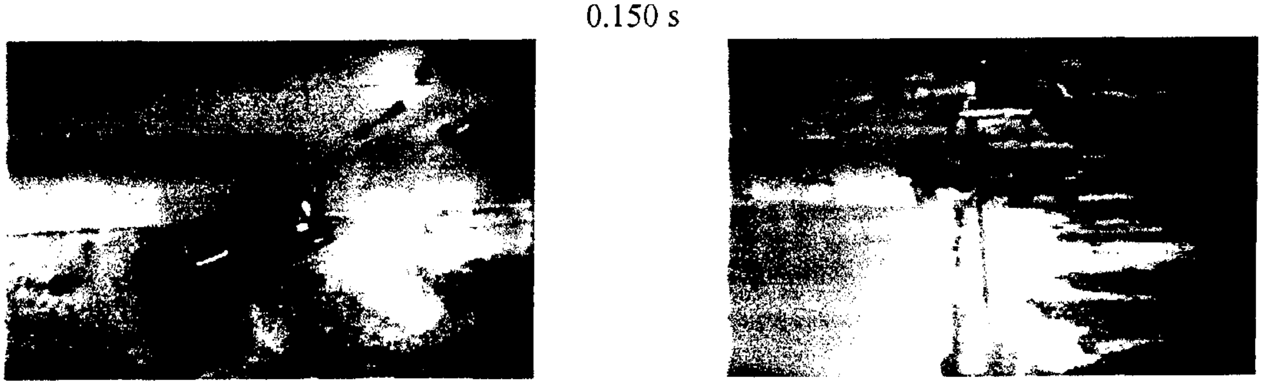
0.000 s



0.075 s

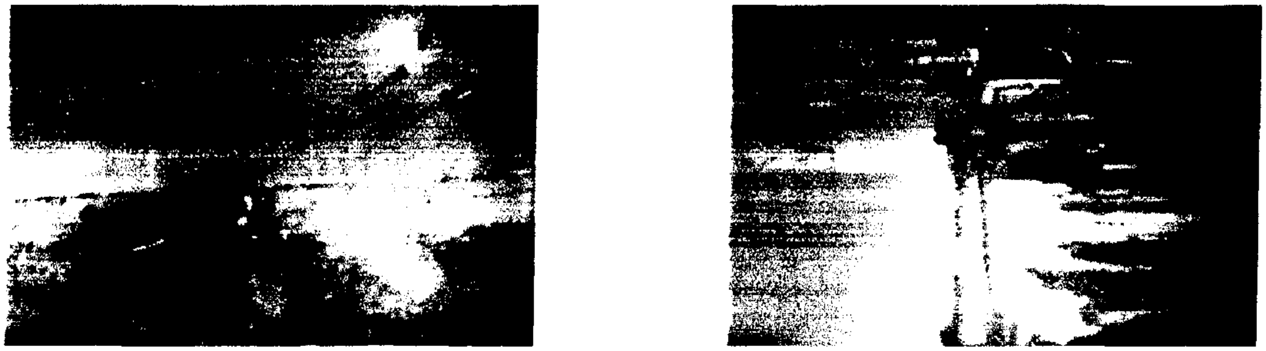


0.150 s

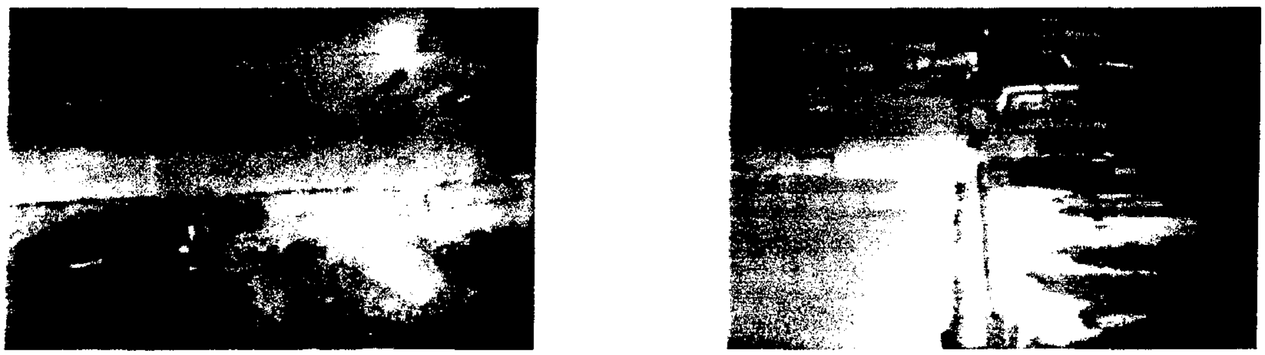


0.226 s

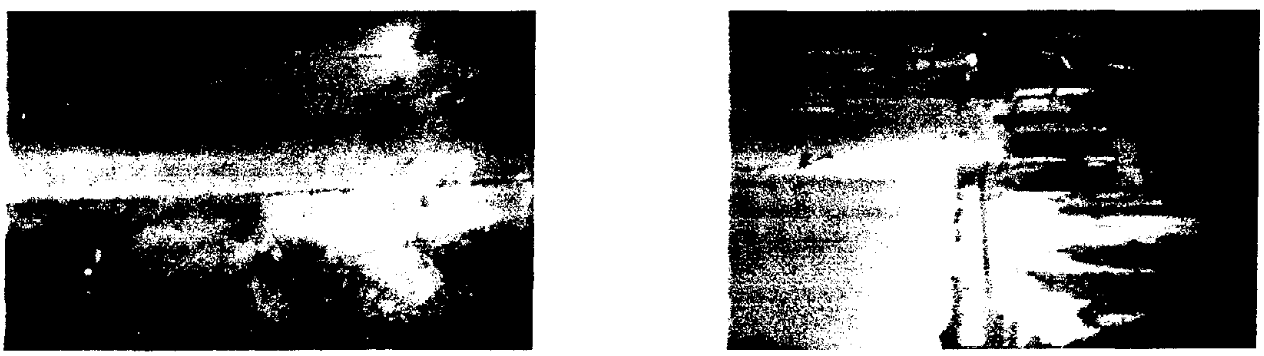
Figure 14. Sequential photographs for test 471470-28
(overhead and frontal views).



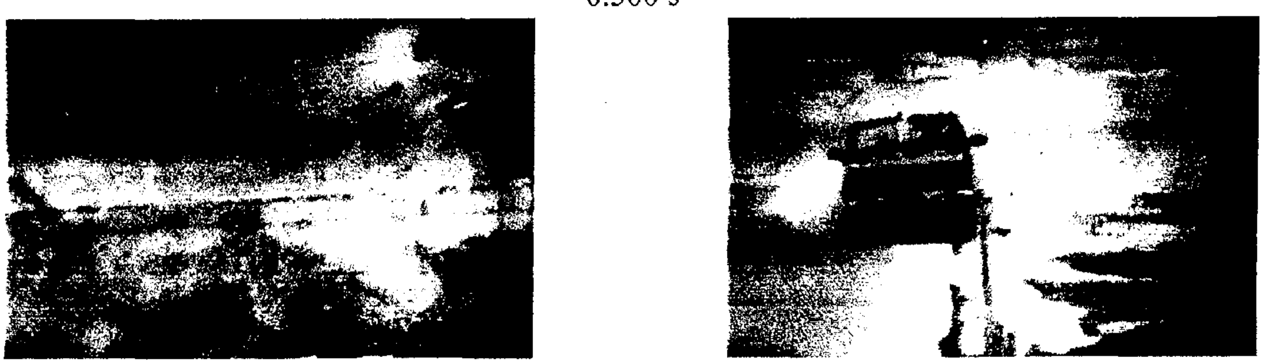
0.301 s



0.376 s



0.500 s



1.597 s

Figure 14. Sequential photographs for test 471470-28 (overhead and frontal views) (continued).

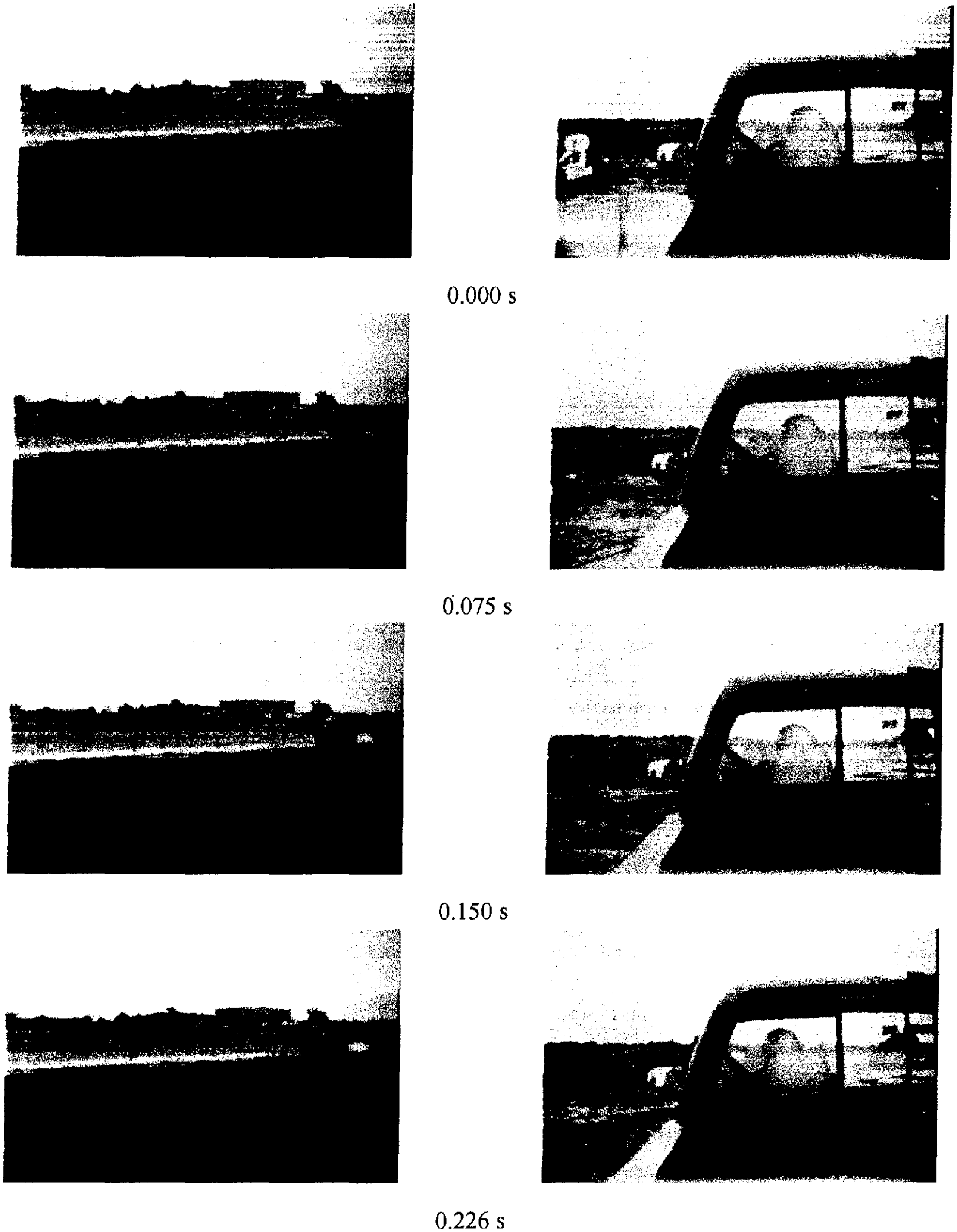
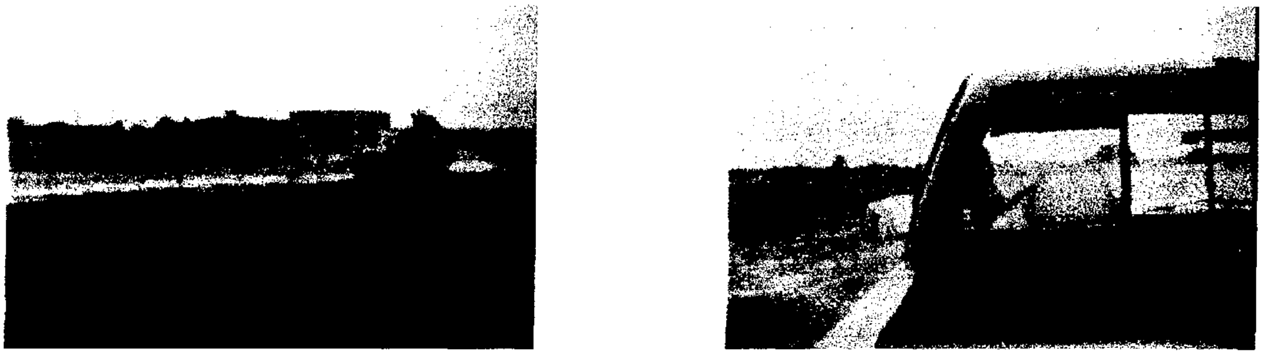


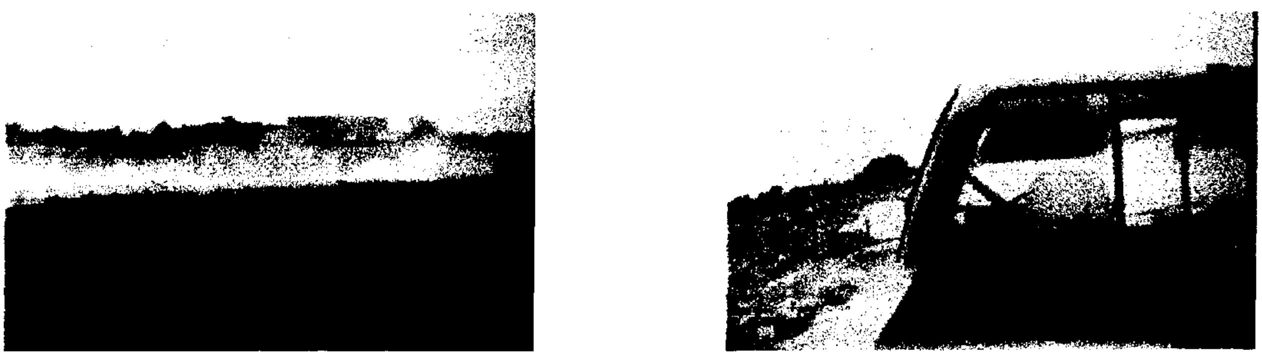
Figure 15. Sequential photographs for test 471470-28 (rear and interior views).

0.301 s



0.376 s

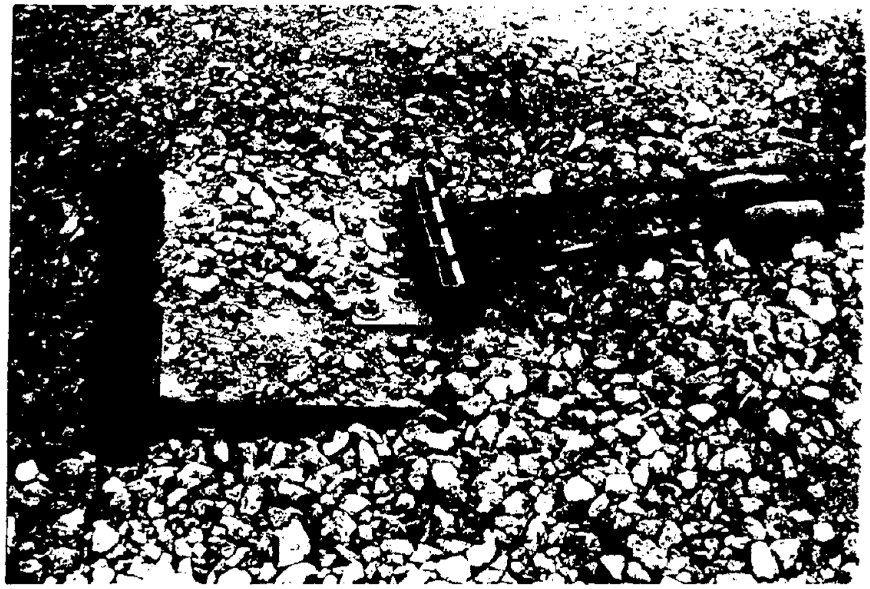
0.500 s



1.597 s

Figure 15. Sequential photographs for test 471470-28 (rear and interior views) (continued).

Figure 16. Cable (G1) guardrail installation after test 471470-28.



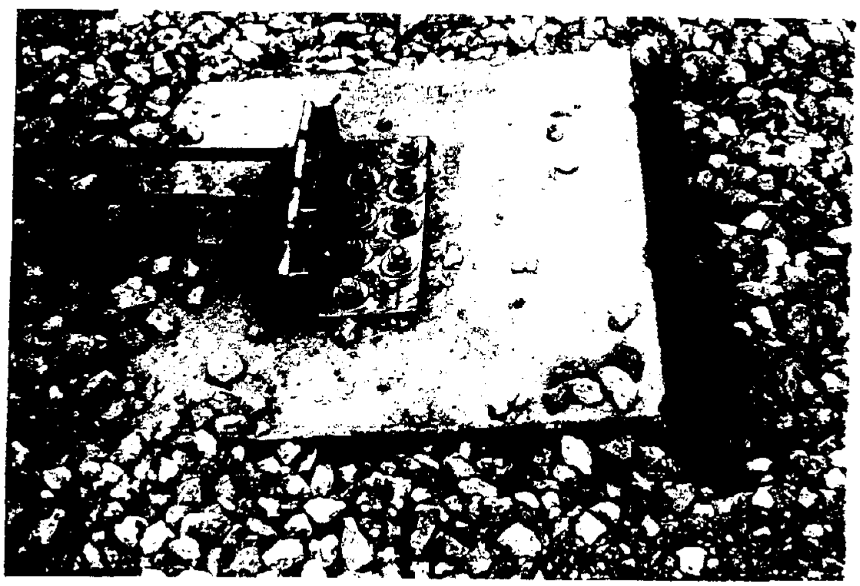
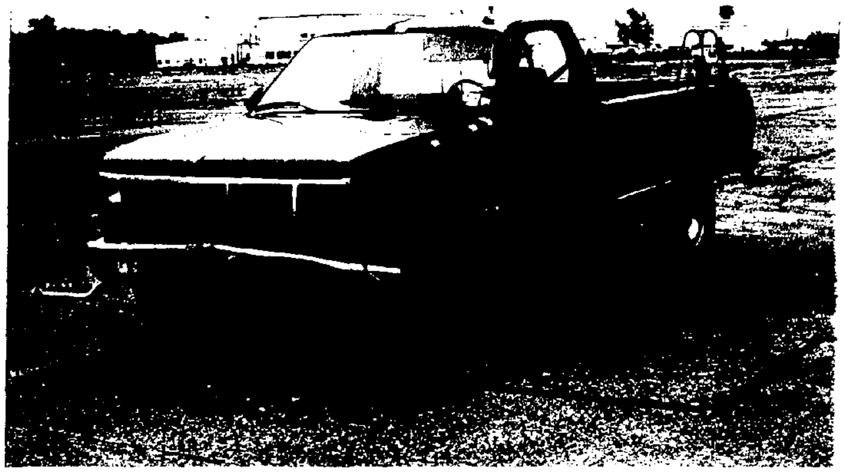


Figure 17. Anchor for the cable (G1) guardrail after test 471470-28.



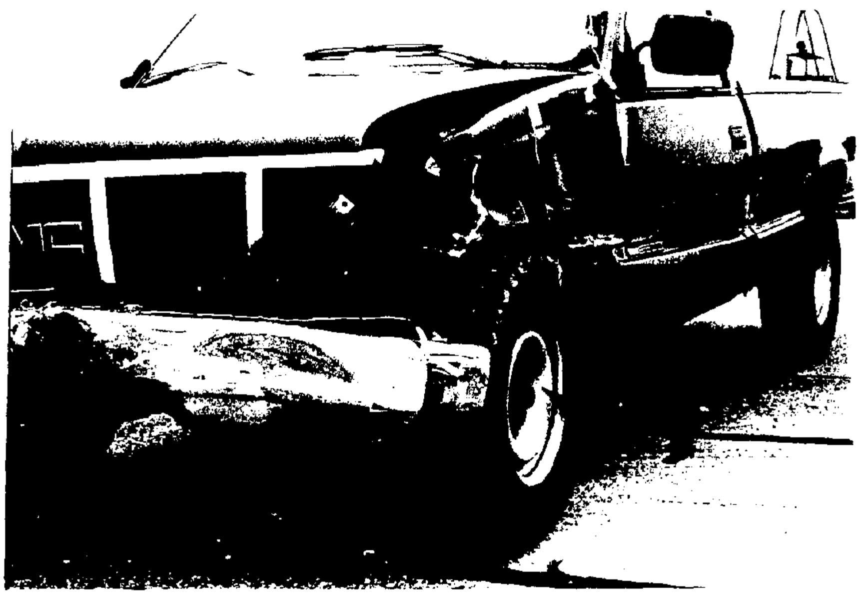
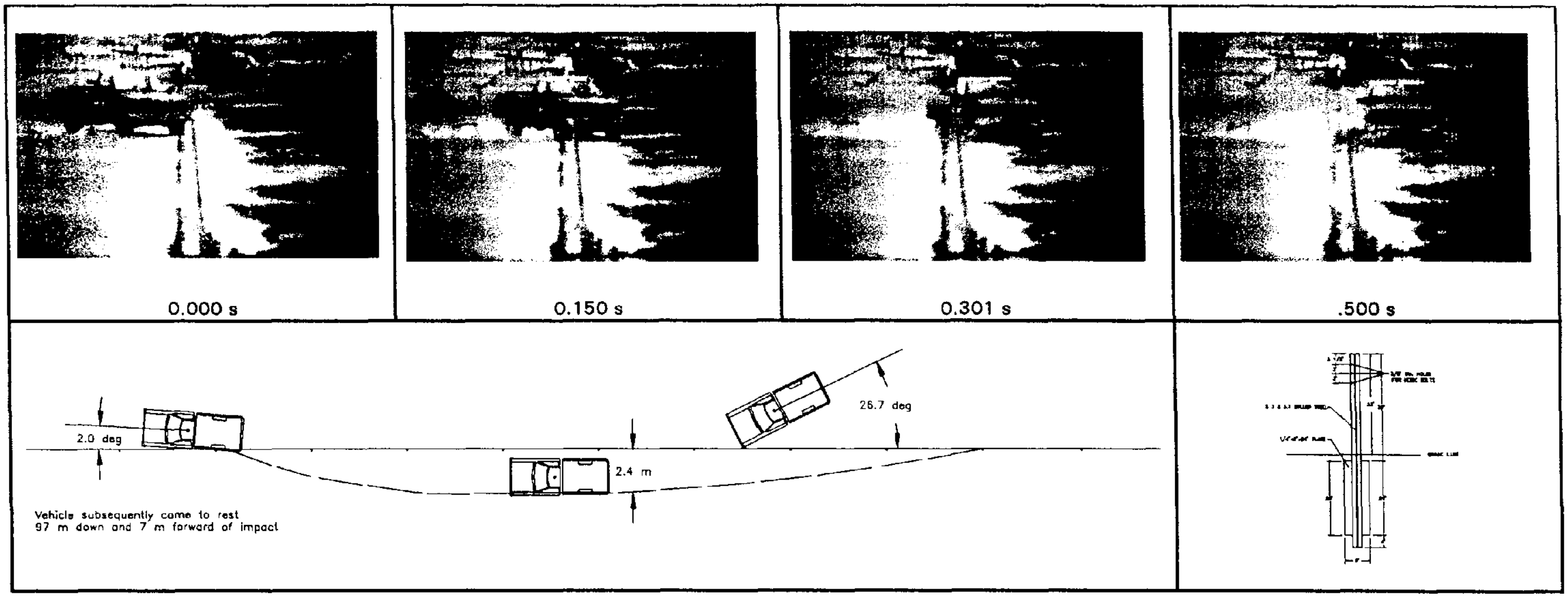


Figure 18. Vehicle after test 471470-28.



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-28
Date	11/15/94
Test Article	
Type	Guardrail
Name or Manufacturer	G1 Wire Rope
Installation Length (m)	122 m (400 ft)
Size and/or Dimension and Material of Key Elements	3/4-in Round Wire Cable on S3x5.7 Steel Posts
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500
Mass (kg) Curb	1774 (3907 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2075 (4570 lb)

Impact Conditions	
Speed (km/h)	95.1 (59.1 mi/h)
Angle (deg)	26.7
Exit Conditions	
Speed (km/h)	60.3 (37.5 mi/h)
Angle (deg)	2.0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.3 (14.2 ft/s)
y-direction	3.5 (11.6 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.0
y-direction	5.6
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-2.0
y-direction	2.9
z-direction	1.9

Test Article Deflections (m)	
Dynamic	2.4 (7.8 ft)
Permanent	0.3 (0.9 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ3
CDC	11FYEK1 & 11LDEW2
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	360 (14.2 in)
Max. Occ. Compart. Deformation (mm)	0 (0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	10
Max. Pitch Angle (deg)	-3
Max. Yaw Angle (deg)	27

Figure 19. Summary of results for test 417470-28.

pertinent to the test are summarized in figure 19. Vehicle angular displacements during the test are displayed in figure 20. Vehicular accelerations versus time traces filtered at 60 Hz are presented in figures 21 through 23.

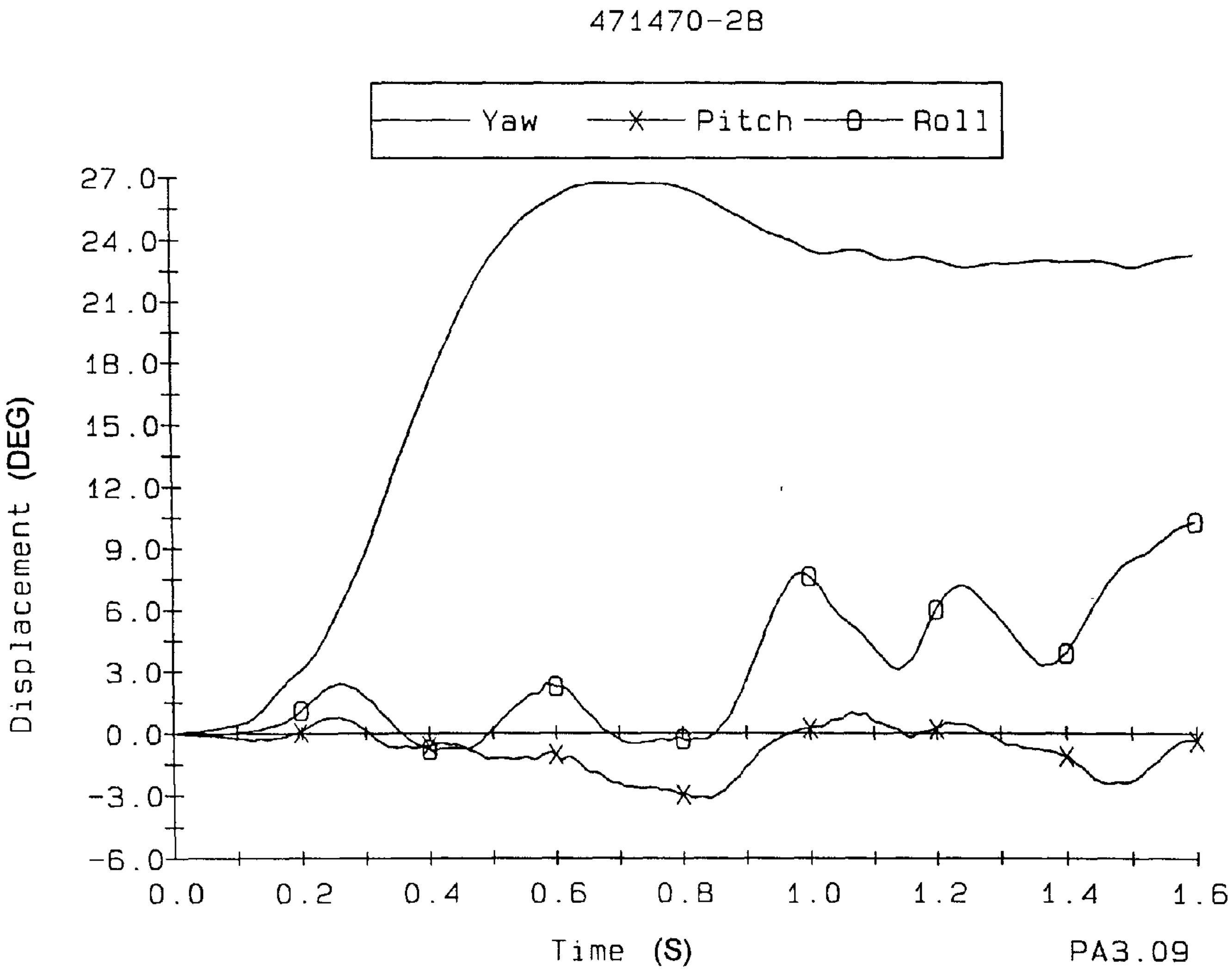
3.2 W-BEAM, WEAK POST (G2) GUARDRAIL SYSTEM (TEST NO. 471470-21)

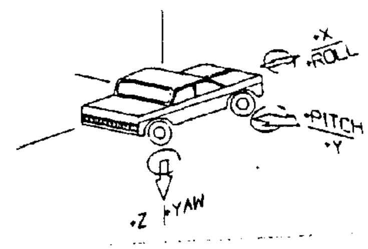
The test installation consisted of 45.7 m (150 ft) of length-of-need section with a 7.62-m- (25-ft-) long turned-down terminal at each of the two ends, for a total installation length of 61.0 m (200 ft). The layout of the test installation is shown in figure 24, and photographs of the test installation are shown in figure 25.

A 1985 Chevrolet Custom 20 pickup, shown in figures 26 and 27, was used for the crash test. Test inertia weight of the vehicle was 2000 kg (4409 lb) and its gross static weight was 2076 kg (4573 lb). The height to the lower edge of the vehicle bumper was 445 mm (17.5 in) and it was 686 mm (27.0 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in figure 28. The vehicle was directed into the G2 guardrail system 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 terminal system at midspan between posts 5 and 6 at a speed of 99.8 km/h (62.0 mi/h) and an angle of 24.4 degrees. As the vehicle impacted the guardrail installation, the W-beam rail element began to deform. Post 6 began to deflect at 0.017 s and post 5 began to deflect at 0.026 s. Post 7 (second post downstream from impact) began to deflect at 0.060 s and the vehicle began to redirect at 0.120 s after impact. As the vehicle continued forward, the W-beam rail element rode over the top of posts as the W-beam deformed along the path of the vehicle. The rear of the vehicle contacted the guardrail at 0.310 s and at 0.356 s, the vehicle was traveling parallel to the installation at 80.2 km/h (49.9 mi/h). Maximum dynamic deflection of the guardrail of 2.4 m (7.9 ft) occurred at 0.640 s after impact. As the vehicle was being redirected, the W-beam rail element dropped and began to dig into the ground at 0.732 s. At 0.768 s, the left front tire began to mount the guardrail and was on top of the rail by 0.895 s. The right front wheel came into contact with the guardrail at 1.003 s. The left rear tire came into contact with and eventually mounted the rail at 1.101 s and 1.162 s, respectively. At 1.260 s, the right front wheel was on top of the rail and air out occurred at 1.391 s. The W-beam rail element separated from the last post at 1.601 s. At 1.948 s, the right front tire contacted the ground and the vehicle separated from the guardrail at approximately 2 s after initial impact. The vehicle remained upright and came to rest 28.8 m (94.6 ft) downstream and 2.4 m (8.0 ft) behind the point of impact. Sequential photographs are shown in figures 29 and 30. The left front, left rear, and right front tires of the vehicle overrode the guardrail and exited only when the end of the guardrail installation was reached. It is evident from reviewing the high-speed film that, had there been a longer run of guardrail, the vehicle would likely have vaulted over the guardrail completely, which is not acceptable.





Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

Figure 20. Vehicle angular displacements during test 471470-28.

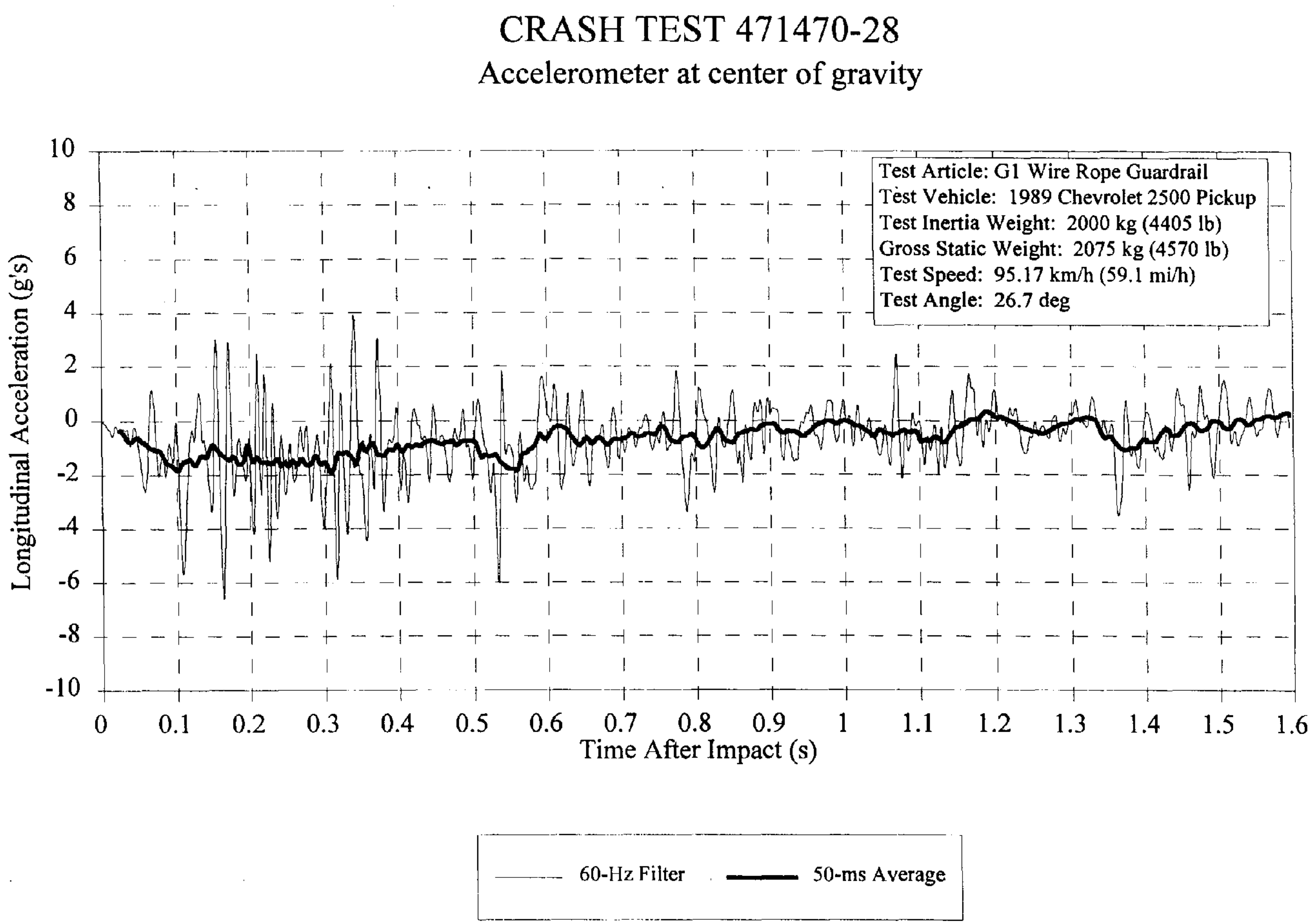


Figure 21. Vehicle longitudinal accelerometer trace for test 471470-28.

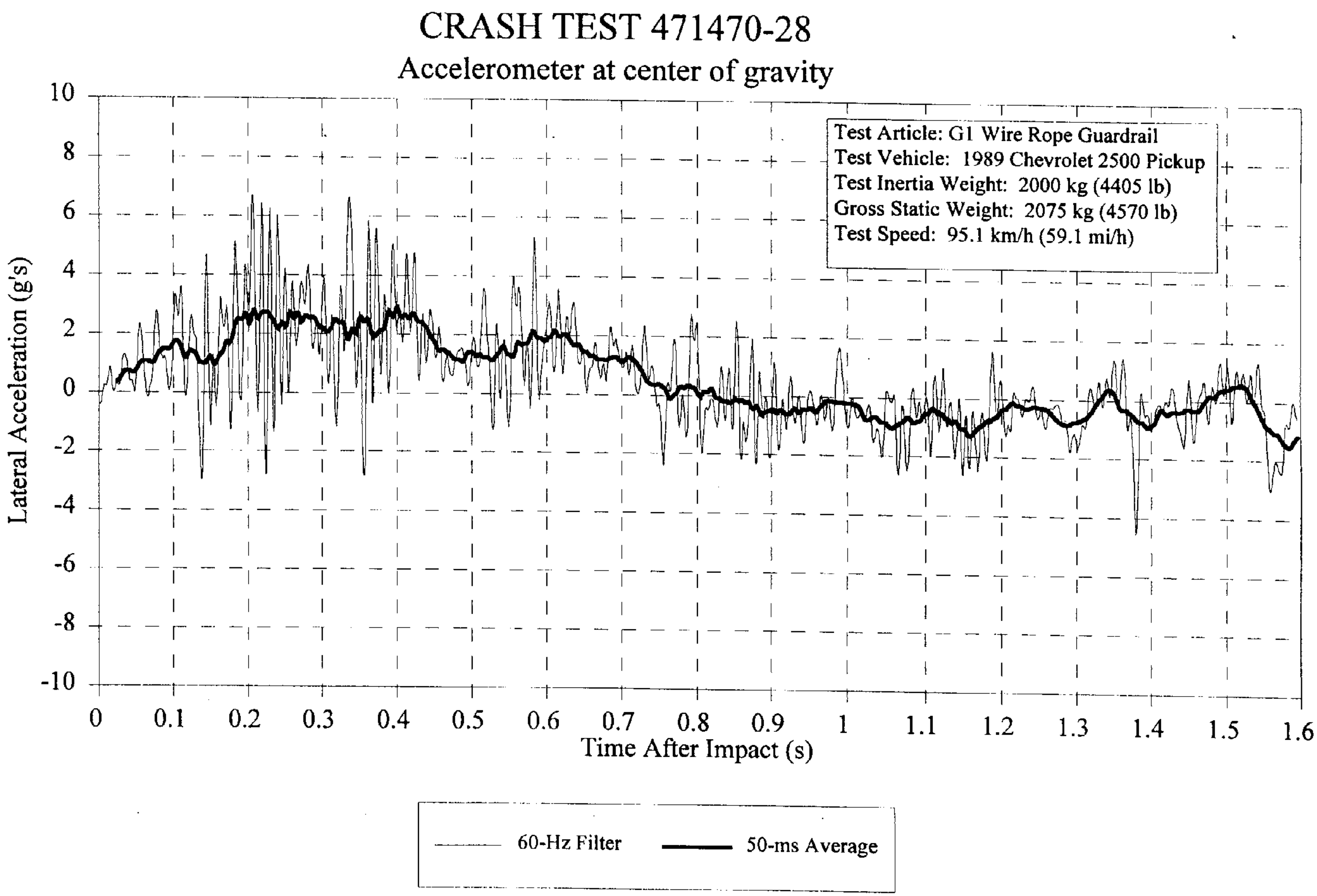


Figure 22. Vehicle lateral accelerometer trace for test 471470-28.

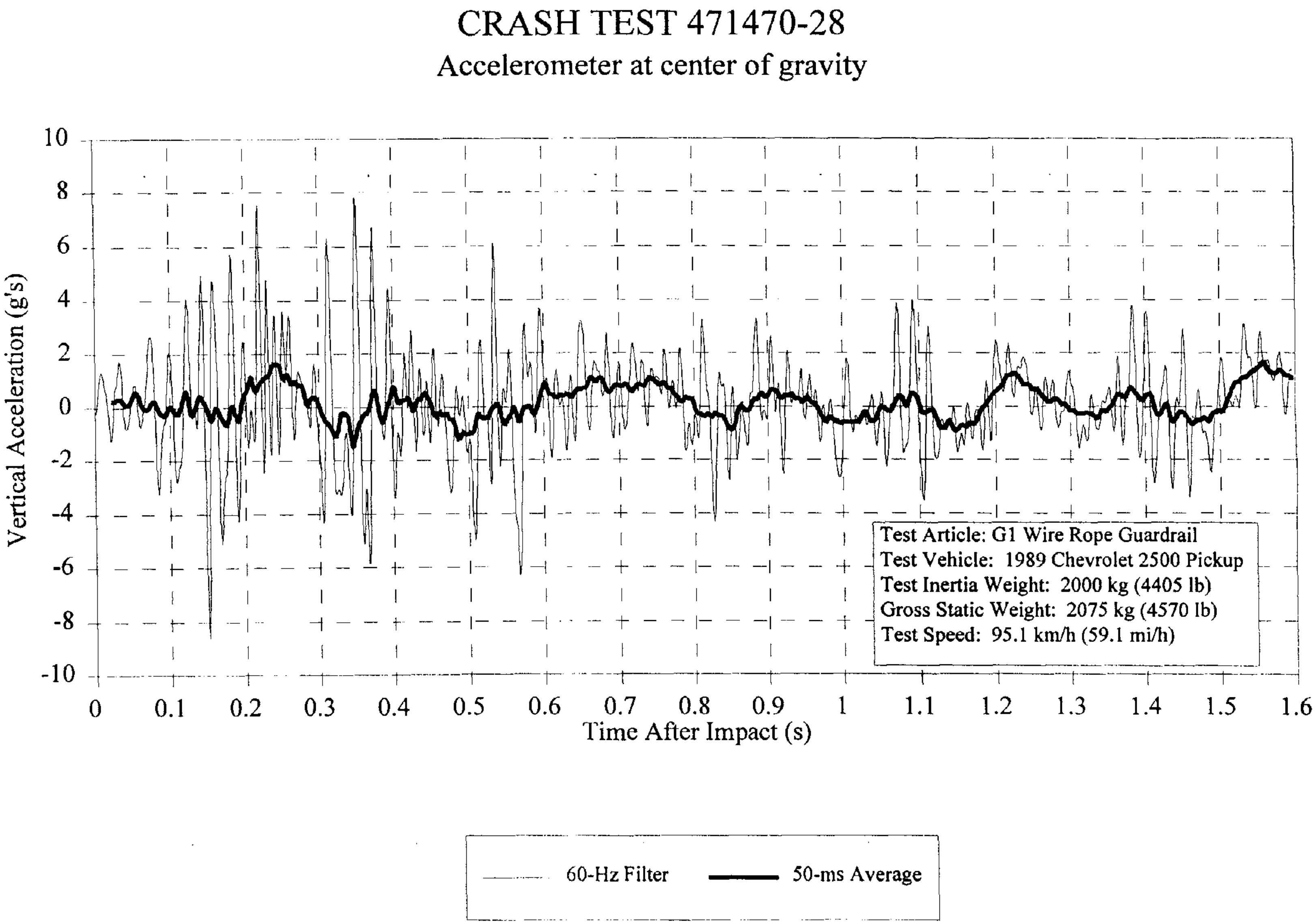


Figure 23. Vehicle vertical accelerometer trace for test 471470-28.

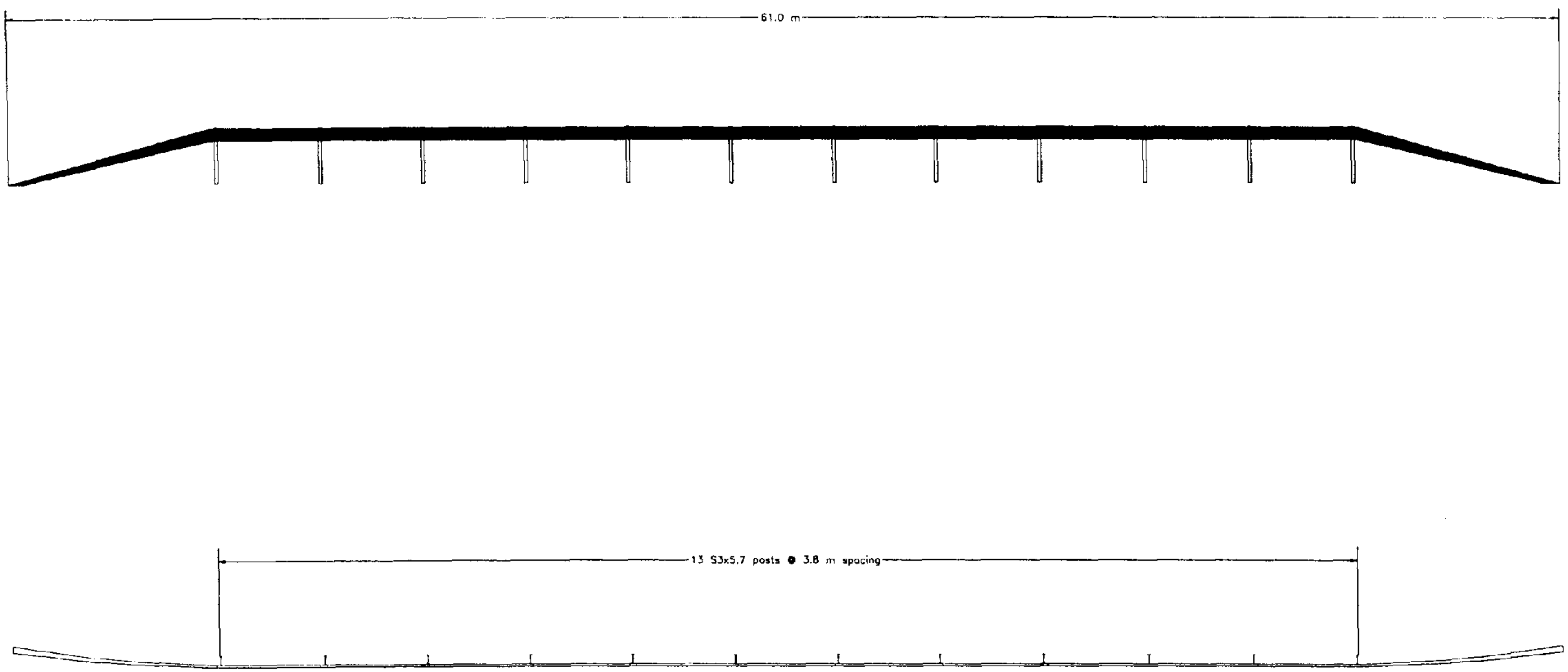


Figure 24. Layout of the W-beam, weak-post (G2) guardrail installation.

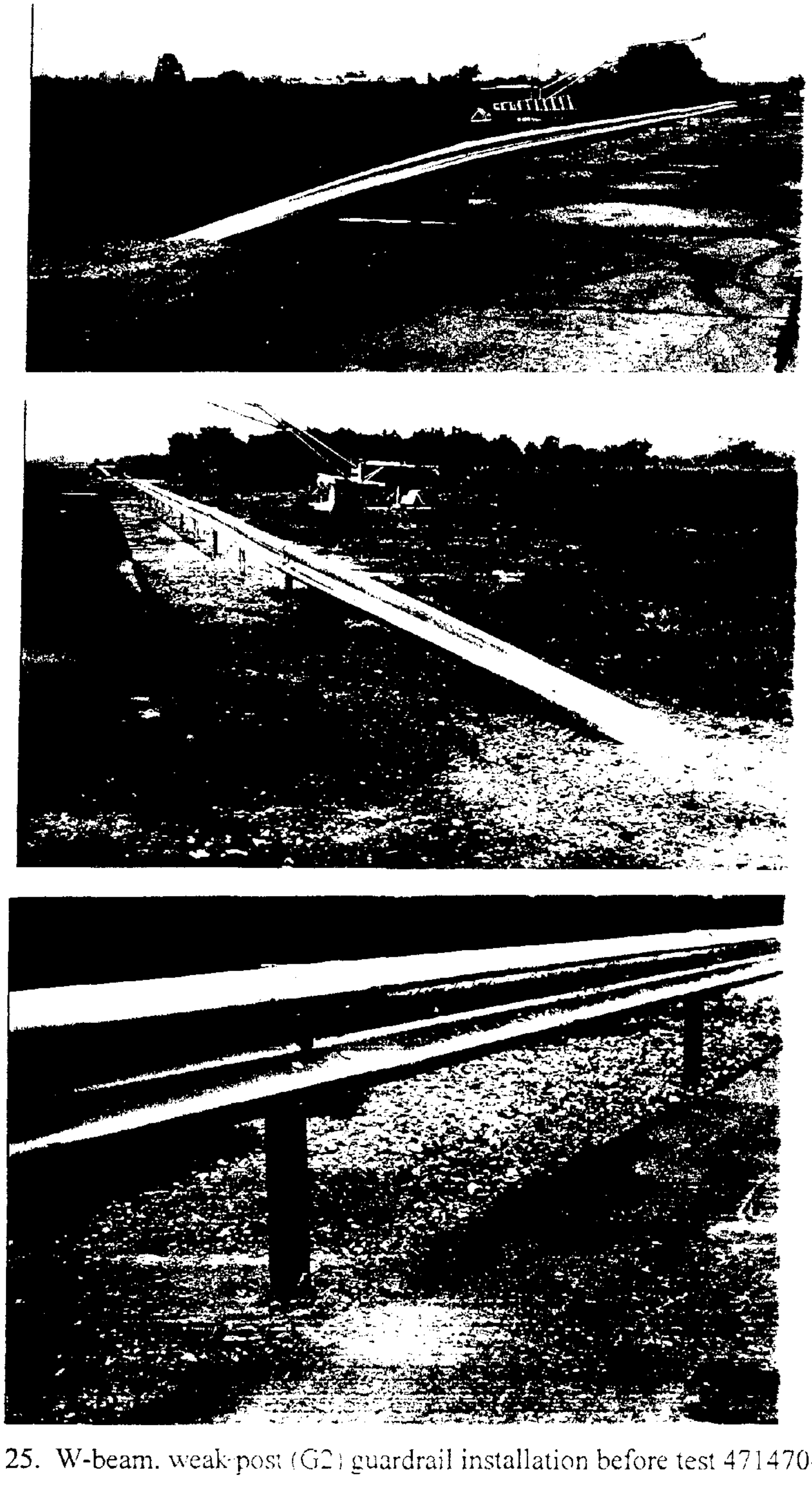


Figure 25. W-beam, weak-post (G2) guardrail installation before test 471470-21.

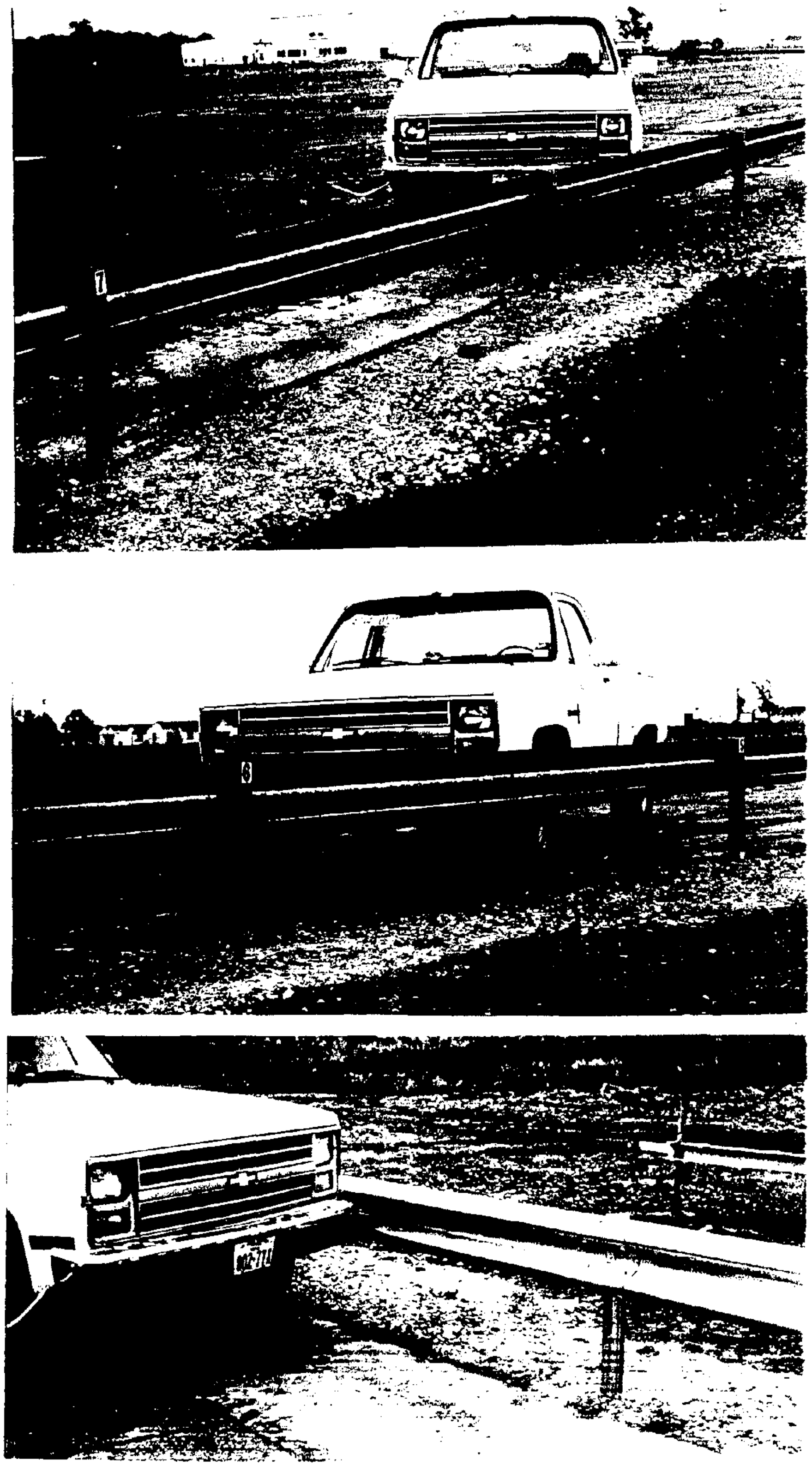


Figure 26. Vehicle/guardrail geometrics for test 471470-21.

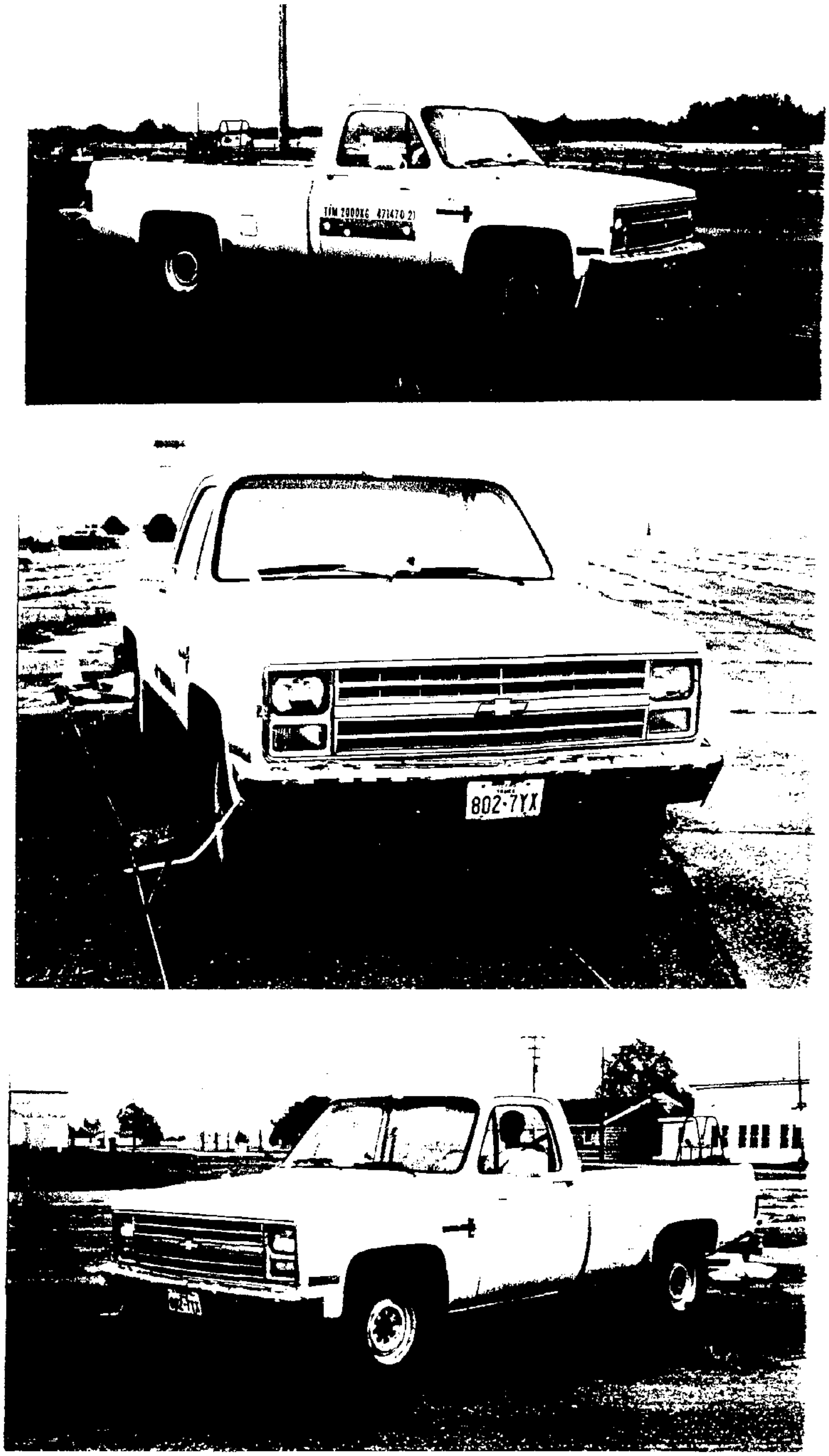


Figure 27. Vehicle before test 471470-21.

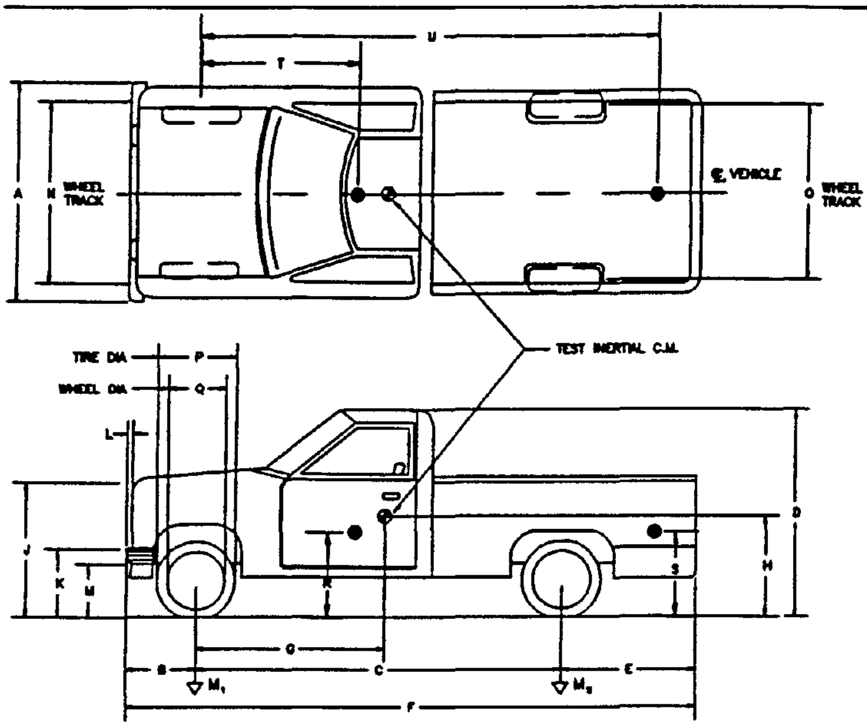
DATE: 11-09-93 TEST NO.: 471470-21 VIN NO.: 1GCGC24M8FS109690 MAKE: Chevy

MODEL: Custom 20 YEAR: 1985 ODOMETER: 60799 GVW: 3265 kg

TIRE SIZE: LT235/85RIL TIRE INFLATION PRESSURE: ____ TREAD TYPE: Hwy

MASS DISTRIBUTION (kg) LF 541 RF 529 LR 467 RR 463

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ____

ENGINE TYPE: V-8

ENGINE CID: 5.7 Liter

TRANSMISSION TYPE:

X AUTO

— MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ____

MASS: ____

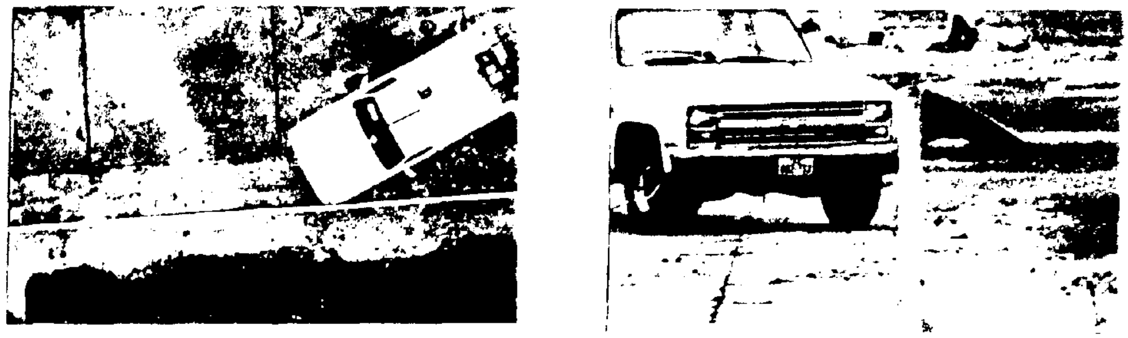
SEAT POSITION: ____

GEOMETRY – (cm)

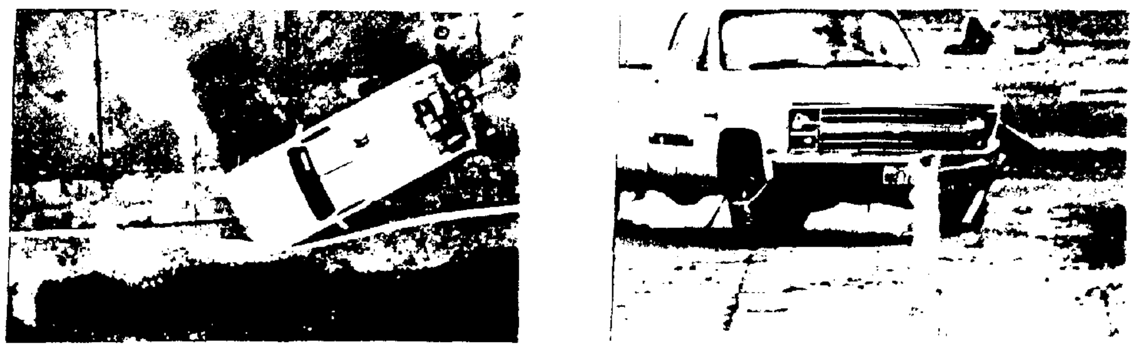
A 197	E 133	J 116.5	N 167.5	R 65.5
B 82	F 548	K 68.6	O 167	S 102
C 333	G 154.8	L 7.5	P 77.5	T 154
D 184.4	H	M 44.5	Q 45	U 428.5

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1126	1070	1113
M_2	874	930	963
M_T	2000	2000	2076

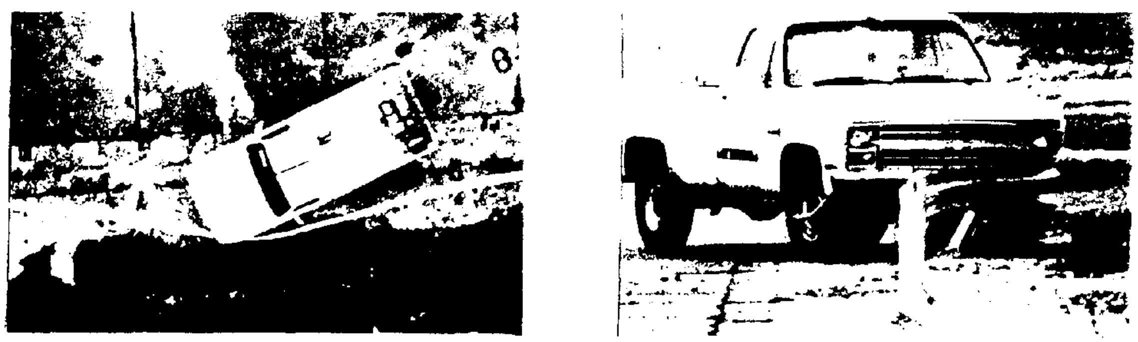
Figure 28. Vehicle properties for test 471470-21.



0.000 s



0.072 s

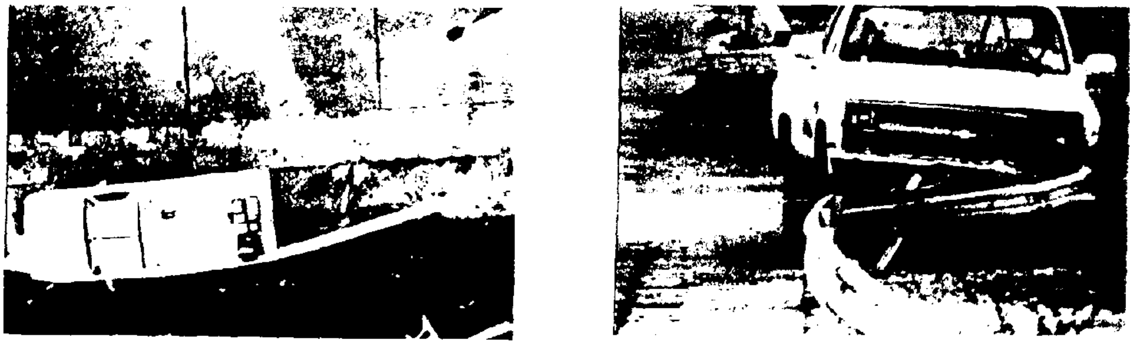


0.144 s

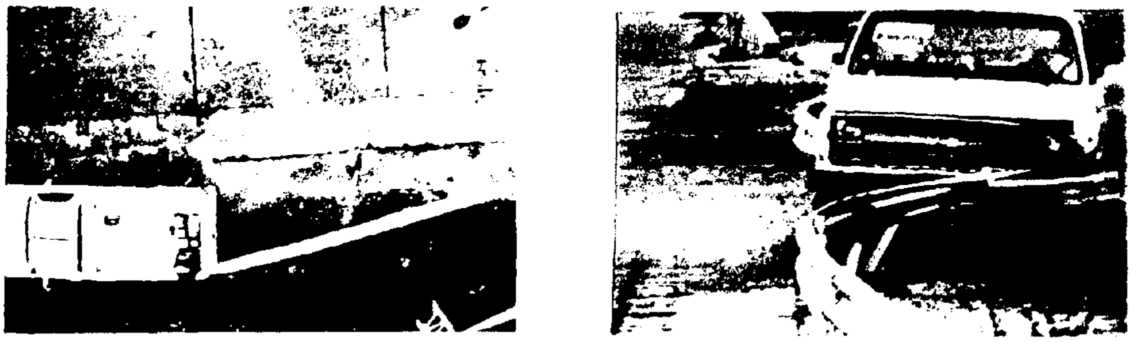
0.216 s

Figure 29. Sequential photographs for test 471470-21 (overhead and frontal views).

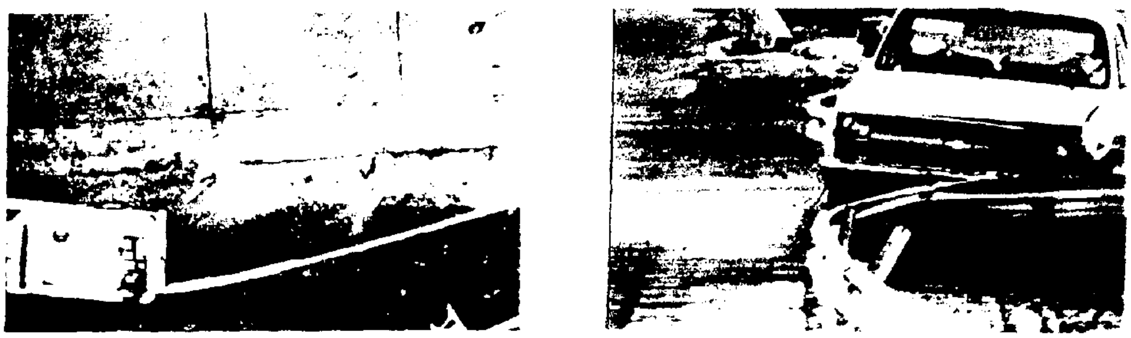
0.289 s



0.361 s

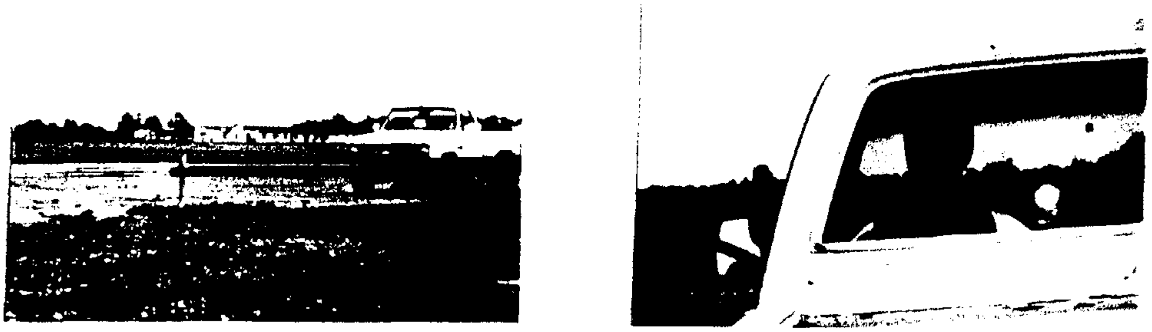


0.433 s

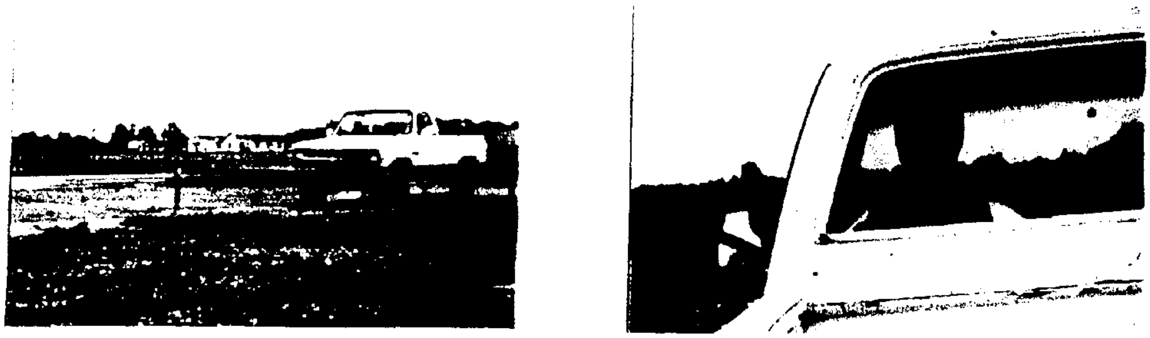


0.505 s

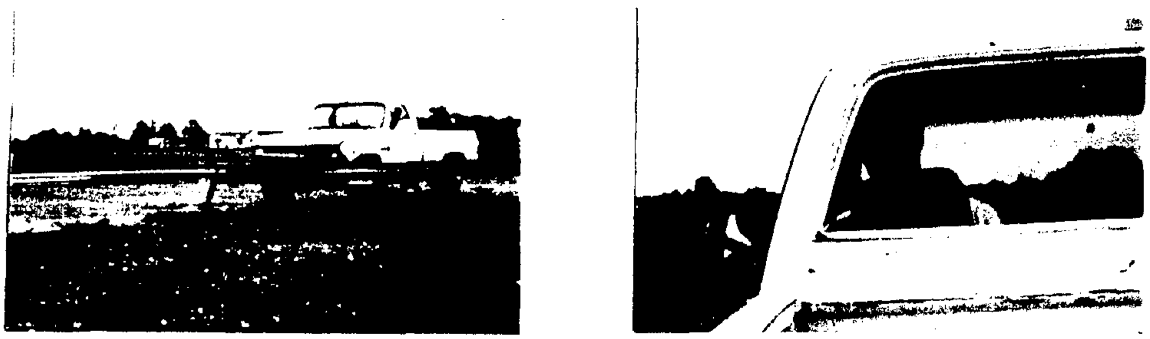
Figure 29. Sequential photographs for test 471470-21
(overhead and frontal views) (continued).



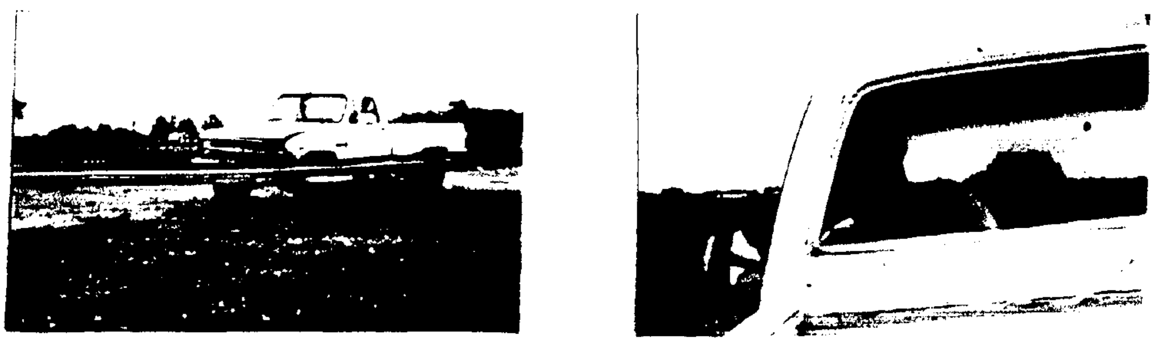
0.000 s



0.072 s

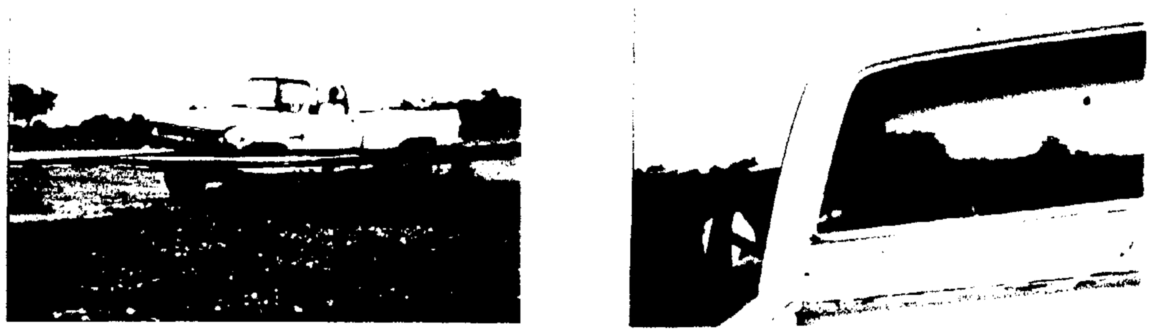


0.144 s



0.216 s

Figure 30. Sequential photographs for test 471470-21 (rear and interior views).



0.289 s

0.361 s

0.433 s

0.505 s

Figure 30. Sequential photographs for test 471470-21 (rear and interior views) (continued).

3.2.2 Damage to Test Installation

As can be seen in figure 31, the test installation received considerable damage. There was evidence of movement on all of the posts and the W-beam slipped over the tops of post 5 through 13 and the maximum permanent deformation of the W-beam was 1.8 m (5.9 ft). The vehicle was in contact with the installation from impact to the end of the guardrail.

3.2.3 Vehicle Damage

The vehicle sustained moderate damage to the left side as shown in figure 32. Maximum exterior crush at the left front corner at bumper height of the vehicle was 259 mm (10.2 in), and there was no intrusion into or deformation of the occupant compartment. Damage was sustained to the front bumper, grill, hood, and along the entire left side the body panels were dented and scraped. There was slight damage to the right front corner where the vehicle came to rest against the next installation downstream.

3.2.4 Occupant Risk Values

Data from the accelerometer located at the center of gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 5.0 m/s (16.4 ft/s) at 0.276 s, the highest 0.010-s average ridedown acceleration was -4.2 g's between 0.392 and 0.402 s; and the maximum 0.050-s average acceleration was -3.0 g's between 0.221 and 0.271 s. Lateral occupant impact velocity was 3.0 m/s (10.0 ft/s) at 0.218 s, the highest 0.010-s occupant ridedown acceleration was 4.5 g's between 0.374 and 0.384 s, and the maximum 0.050-s average acceleration was 3.2 g's between 0.343 and 0.393 s. These data and other pertinent information from the test are summarized in figure 33. Vehicular angular displacements are displayed in figure 34. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in figures 35 through 37.

3.3 W-BEAM, WEAK-POST (G2) GUARDRAIL SYSTEM (TEST NO. 471470-22)

The test installation consisted of 61.0 m (200 ft) of length-of-need section with a 7.62-m (25-ft) turned-down terminal at each of the two ends, for a total test installation length of 76.2 m (250 ft). All other details of the installation were the same as in the previous test (test no. 471470-21). Photographs of the test installations are shown in figure 38.

A 1985 Chevrolet Custom 20 pickup truck, shown in figures 39 and 40, was used for the crash test. Test inertia weight of the vehicle was 2000 kg (4409 lb) and its gross static weight was 2076 kg (4573 lb). The height to the lower edge of the vehicle bumper was 390 mm (15.4 in) and it was 680 mm (26.8 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in figure 41. The vehicle was directed into the G2 guardrail

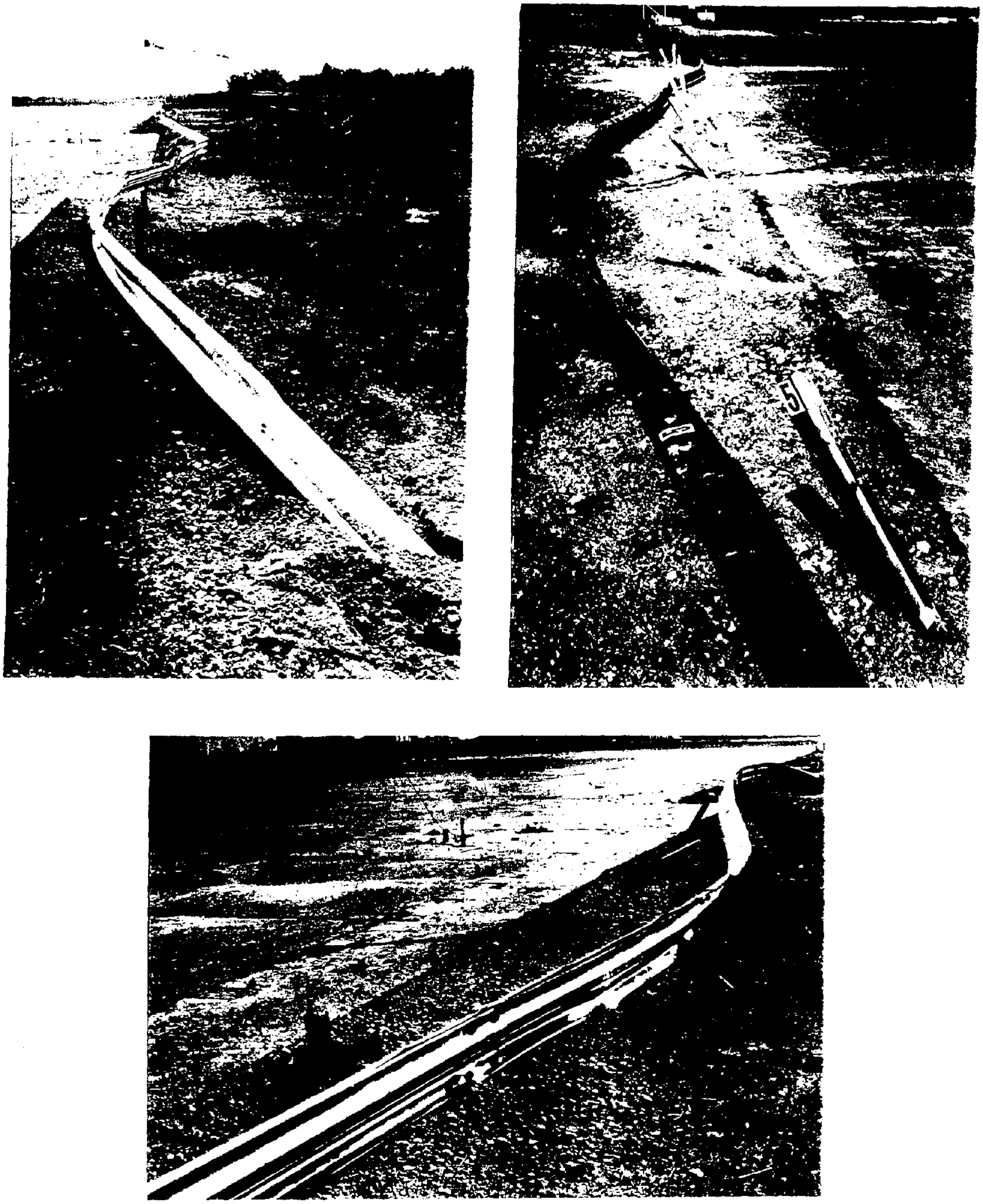


Figure 31. W-beam, weak-post (G2) guardrail after test 471470-21.

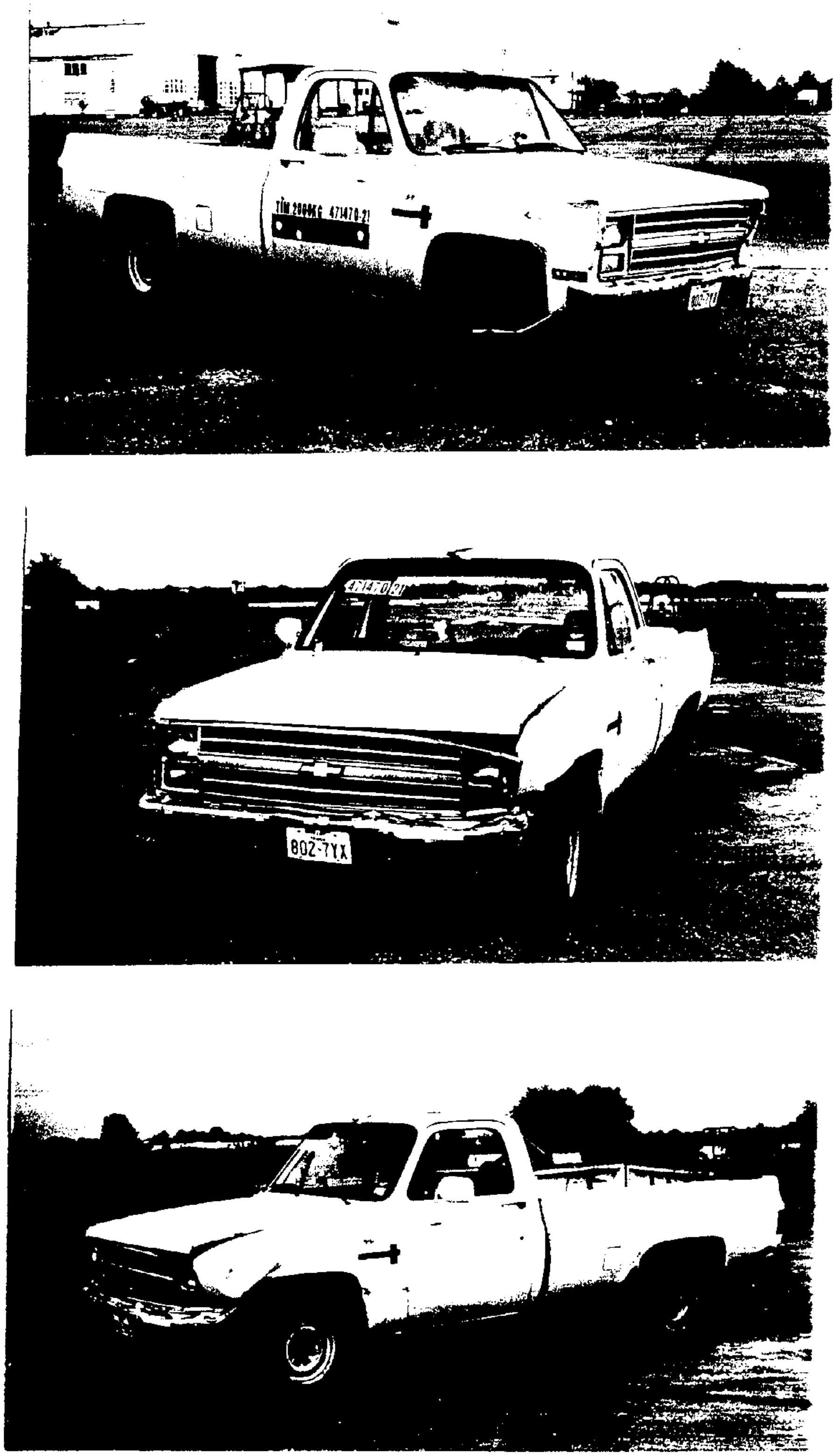
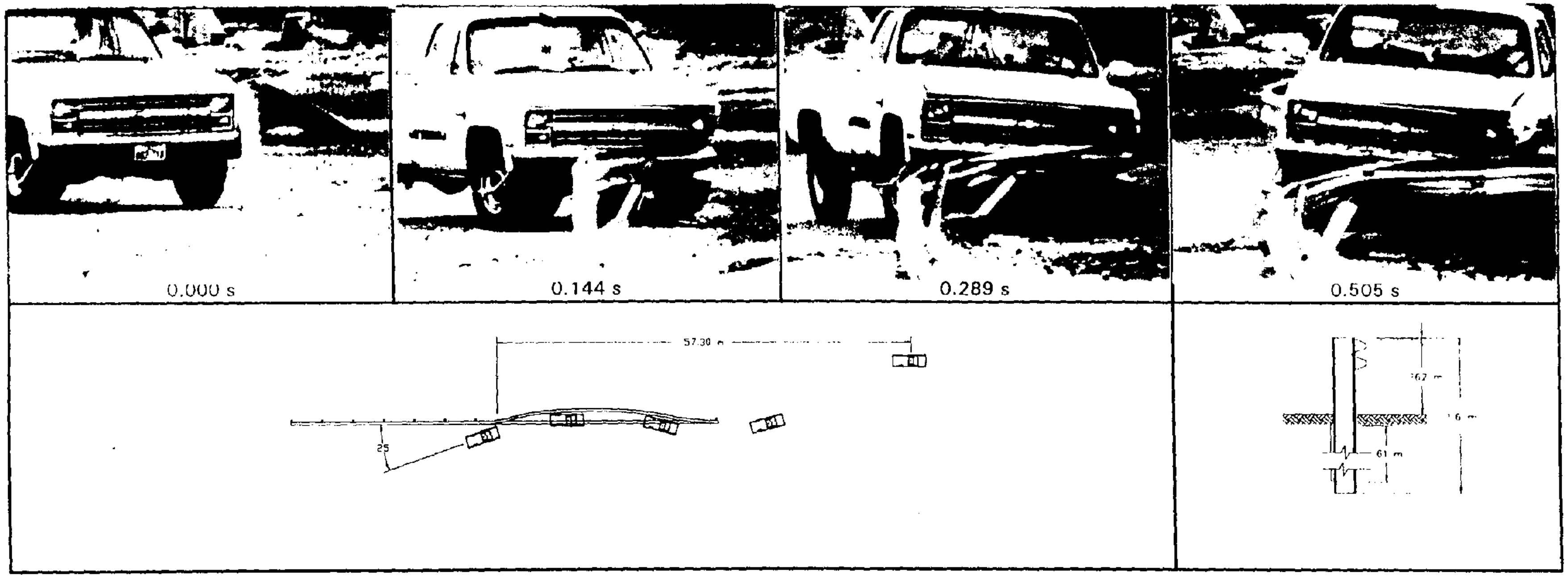


Figure 32. Vehicle after test 471470-21.



General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-21
Date	11/17/93
Test Article	
Type	Guardrail w/Turned-Down
Name or Manufacturer	Weak-Post W-Beam (G2)
Installation Length (m)	61 (200 ft)
Size and/or Dimension and Material of Key Elements	76 cm (30 in) mount height W-Beam (ARTBA RE-3-73) S3x5.7 Post
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1985 Chevrolet Custom 20
Mass (kg) Curb	2000 (4405 lb)
Test Inertial	2000 (4405 lb)
Dummy	76 (167 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	99.8 (62.0mi/h)
Angle (deg)	24.4
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.0 (16.4 ft/s)
y-direction	3.0 (10.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.2
y-direction	4.5
PHD (optional)	
ASI (optional)	
Max. 0.050-s average (g's)	
x-direction	-3.0
y-direction	3.2
z-direction	-3.0

Test Article Deflections (m)	
Dynamic	2.4 (7.9 ft)
Permanent	1.8 (5.9 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ4 & 11LD2
CDC	11FLEK3 & 11LDEW2
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	259 (10.2 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	-29
Max. Pitch Angle (deg)	7
Max. Yaw Angle (deg)	34

Figure 33. Summary of results for test 471470-21.

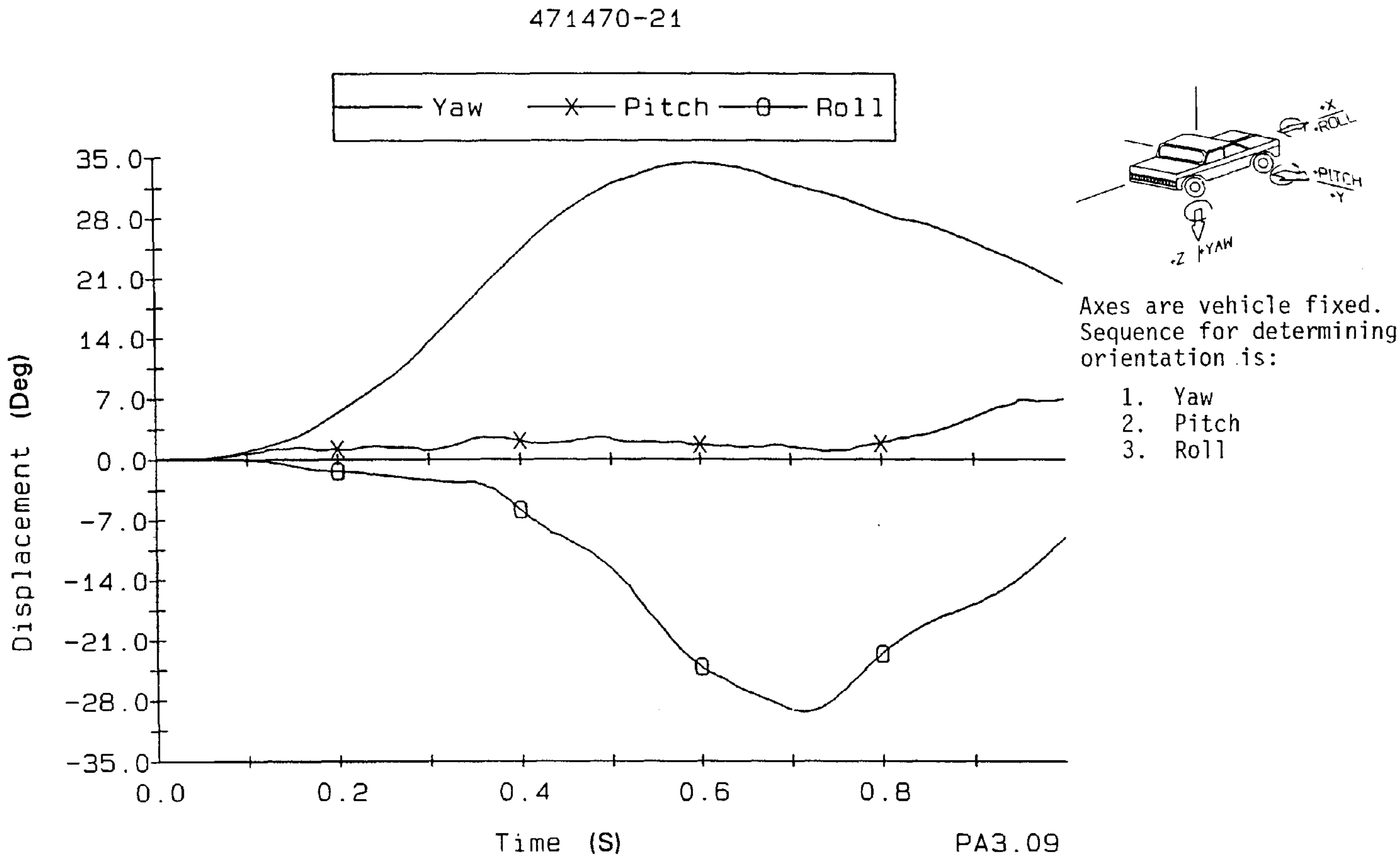


Figure 34. Vehicle angular displacements for test 471470-21.

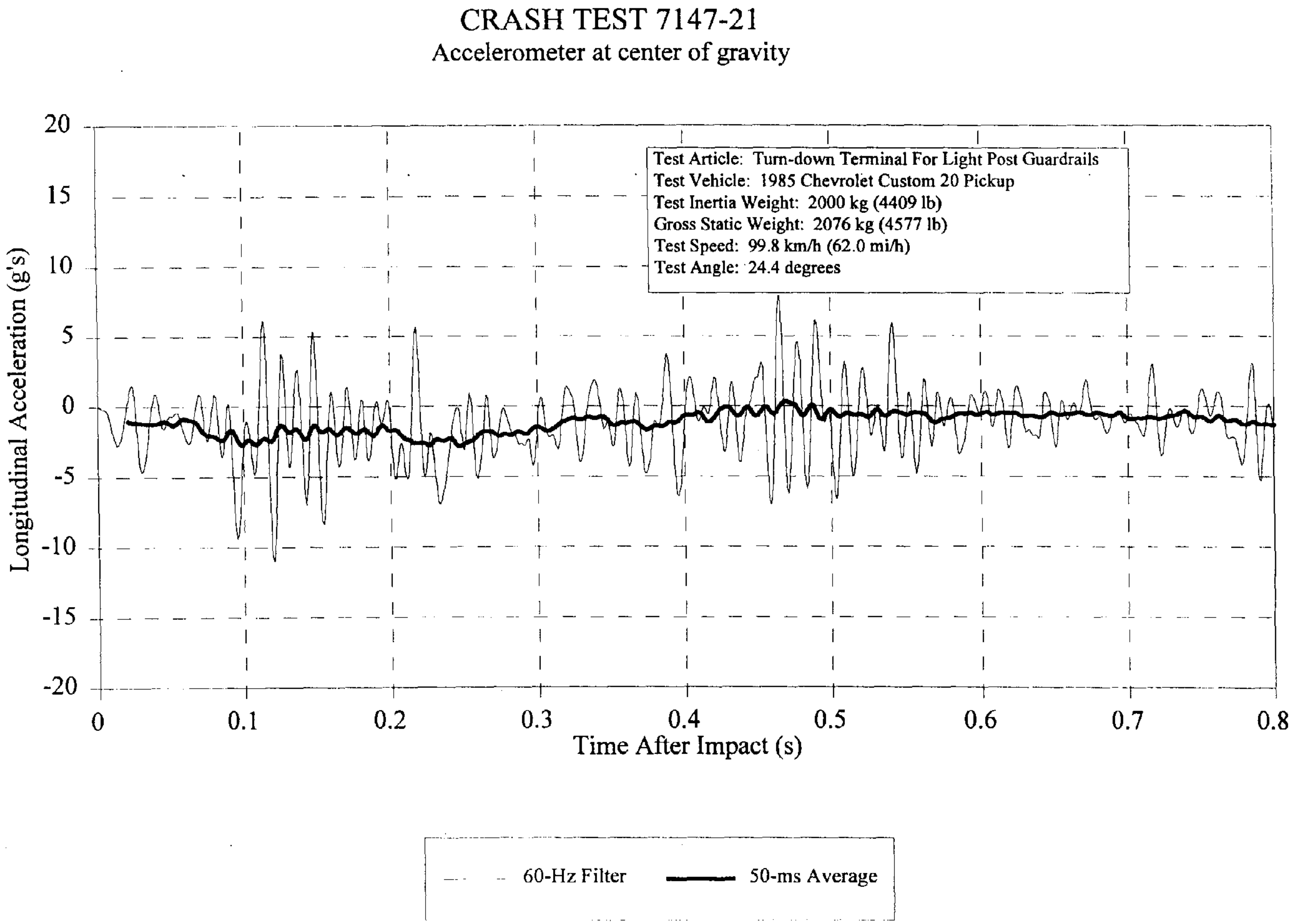


Figure 35. Vehicle longitudinal accelerometer trace for test 7147-21.

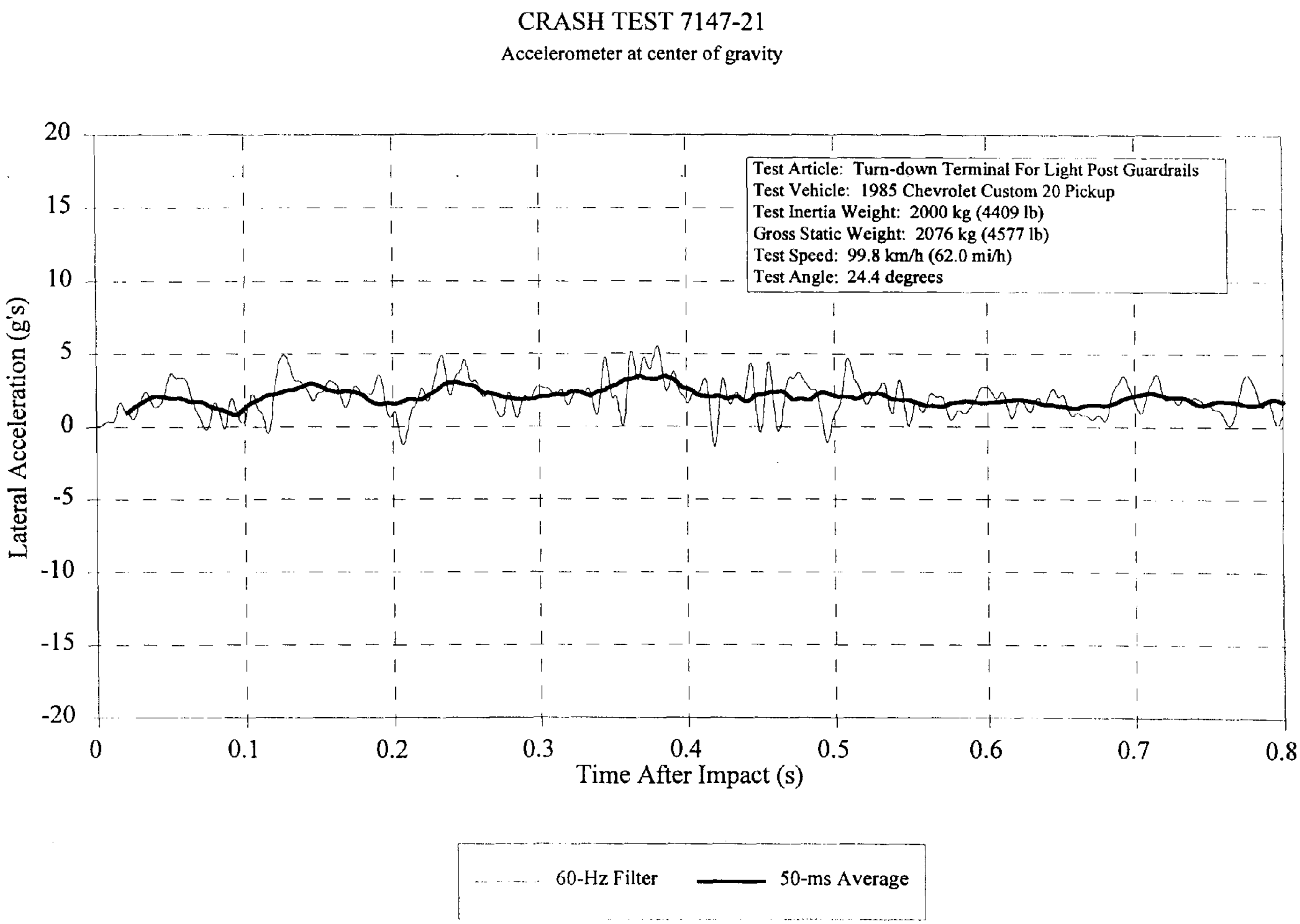


Figure 36. Vehicle lateral accelerometer trace for test 7147-21.

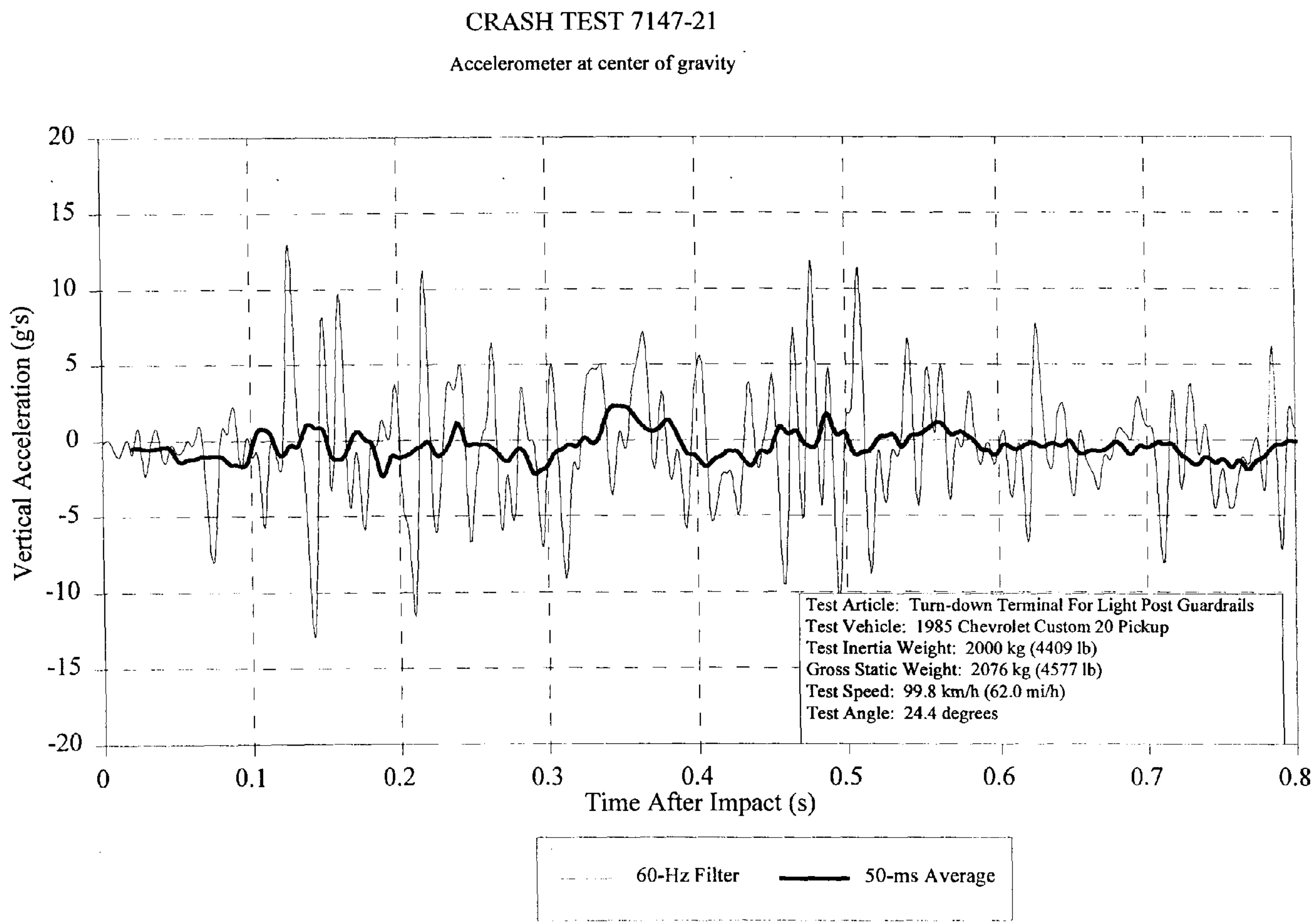


Figure 37. Vehicle vertical accelerometer trace for test 7147-21.

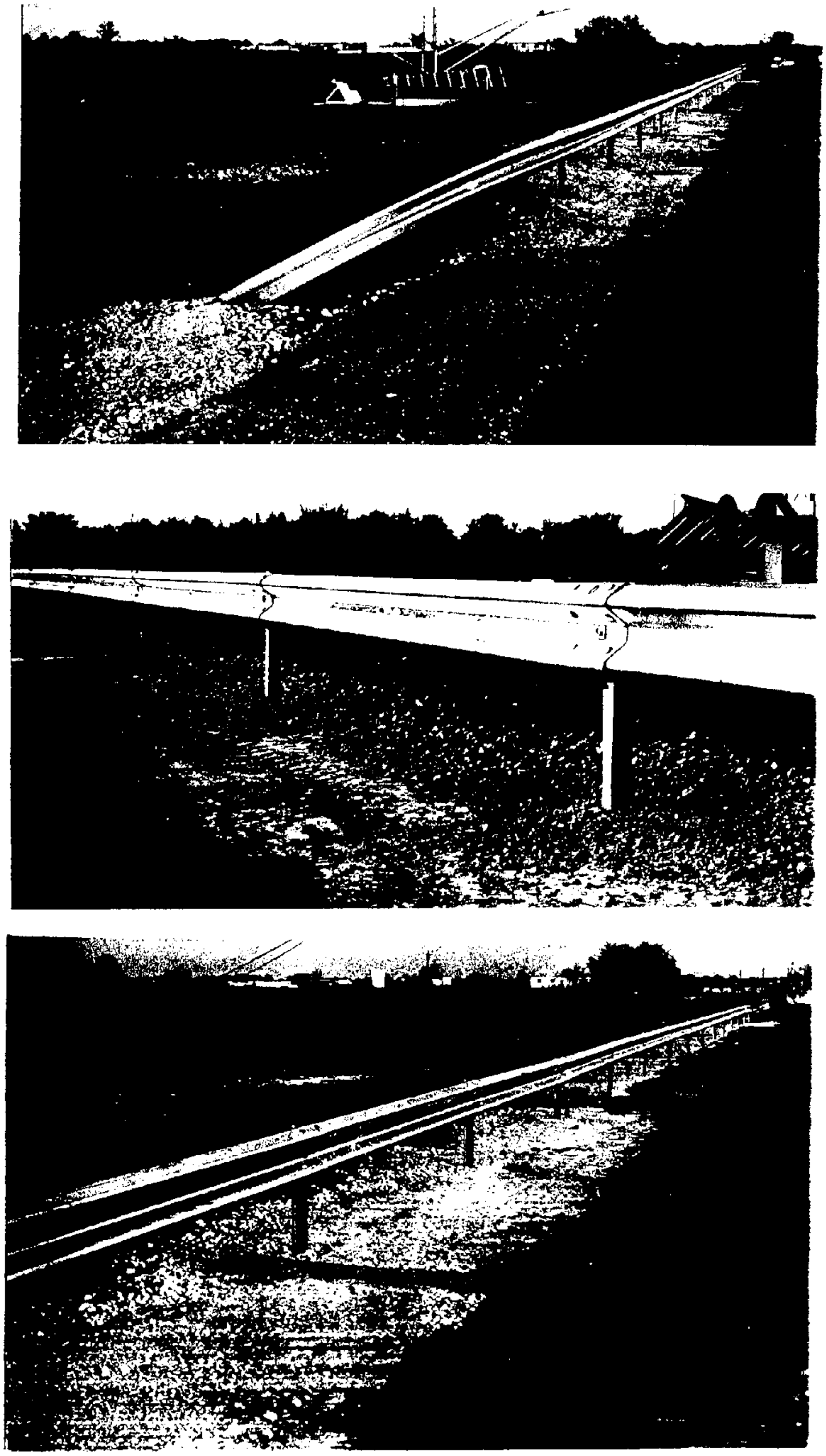


Figure 38. W-beam, weak-post (G2) guardrail before test 471470-22.

Figure 39. Vehicle/guardrail geometrics for test 471470-22.

Figure 40. Vehicle before test 471470-22.

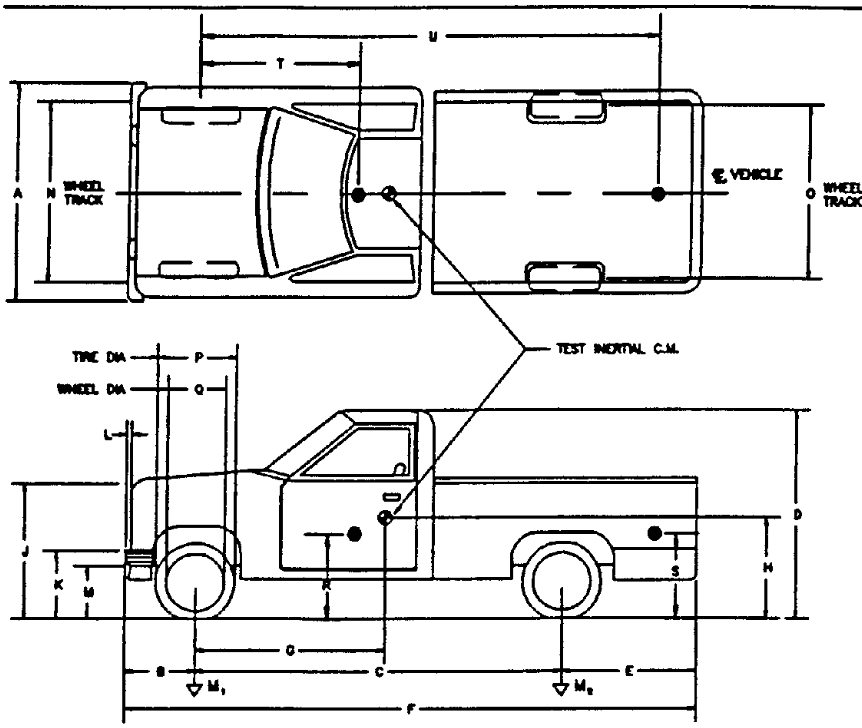
DATE: 1-6-94 TEST NO.: 471470-22 VIN NO.: 1GCGC24M3f5105997 MAKE: Chevy

MODEL: Scottsdale C/20 YEAR: 1985 ODOMETER: 87103 GVW: 3901

TIRE SIZE: LT235 85R16 TIRE INFLATION PRESSURE: 303/502 TREAD TYPE: HWY

MASS DISTRIBUTION (kg) LF 554 RF 520 LR 462 RR 464

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES:

ENGINE TYPE: V8 Gasoline

ENGINE CID: 350

TRANSMISSION TYPE:

X AUTO

MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (cm)

A	196	E	135	J	114	N	165.5	R	64.5
B	82	F	552	K	68	O	166	S	100
C	335	G	155	L	9	P	80	T	150
D	189	H		M	39	Q	44	U	421

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1153	1074	1117
M_2	888	926	959
M_T	2041	2000	2076

Figure 41. Vehicle properties for test 471470-22.

system using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

3.3.1 Test Description

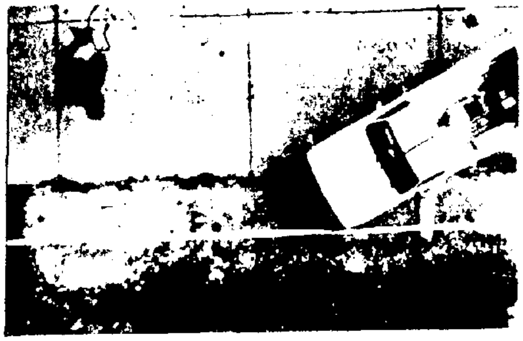
The vehicle impacted the guardrail system at midspan between posts 4 and 5 at a speed of 71.0 km/h (44.1 mi/h) and an angle of 26.1 degrees. As the vehicle impacted the guardrail installation, the W-beam rail element began to deform. Post 5 (first post downstream from impact) began to deflect at 0.017 s, post 4 (first post upstream from impact) began to deflect at 0.043 s, and post 6 (second post downstream from impact) began to deflect at 0.072 s. The left front tire of the vehicle contacted post 5 at 0.093 s after impact, resulting in the front tires being turned toward the guardrail. The vehicle began to redirect at 0.167 s after impact. The W-beam rail element went over the top of post 6 at 0.201 s after impact and the front of the vehicle impacted post 6 at 0.306 s. Maximum dynamic deflection of the guardrail of 1.4 m (4.5 ft) occurred at 0.372 s after impact. At 0.533 s, the vehicle was traveling parallel to the installation at 38.0 km/h (23.6 mi/h). The front of the vehicle impacted post 7 at 0.646 s after impact. As the vehicle continued to be redirected, the vehicle began to turn counterclockwise toward the rail because of the orientation of the front tires. The vehicle separated from the guardrail at approximately 1.08 s after impact, traveling at an estimated exit speed and angle of 25.7 km/h (16.0 mi/h) and 9.5 degrees. The separation conditions were estimates since the vehicle was partially out of the view of the overhead camera and the camera placed behind the rail. The camera placed at the downstream end of the test installation would have provided the information, but that camera was jammed and did not provide any coverage. The vehicle came to rest 17.3 m (56.7 ft) downstream from the initial point of impact adjacent to the face of the rail element. Sequential photographs are shown in figures 42 and 43.

3.3.2 Damage to Test Installation

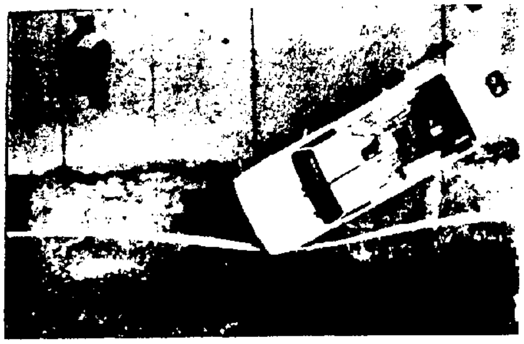
As can be seen in figures 44 and 45, the guardrail installation received considerable damage in the area of contact. There was evidence of movement on the first 9 posts. The W-beam slipped over the tops of posts 5 through 7 and the maximum permanent deformation of the W-beam was 1.3 m (4.2 ft). The vehicle was in contact with the installation for a total length of 15.7 m (51.7 ft).

3.3.3 Vehicle Damage

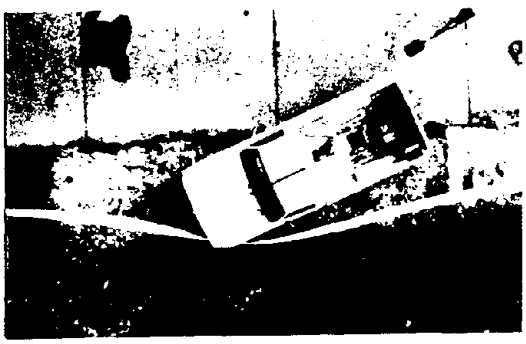
The vehicle sustained moderate damage to the left side, as shown in figure 46. Maximum exterior crush at the left front corner at bumper height of the vehicle was 231mm (9.1 in), and there was no intrusion into or deformation of the occupant compartment. Damage was sustained to the front bumper, grill, hood, left front lower A-arm assembly, and along the left side the body panels were dented and scraped through the driver's door.



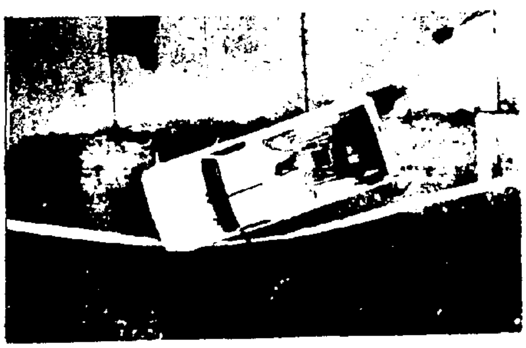
0.000 s



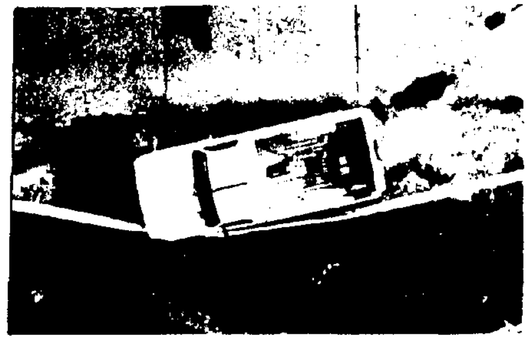
0.100 s



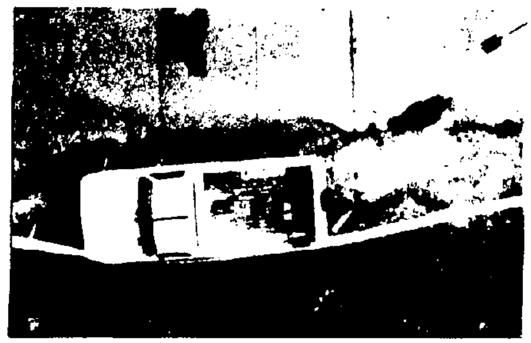
0.201 s



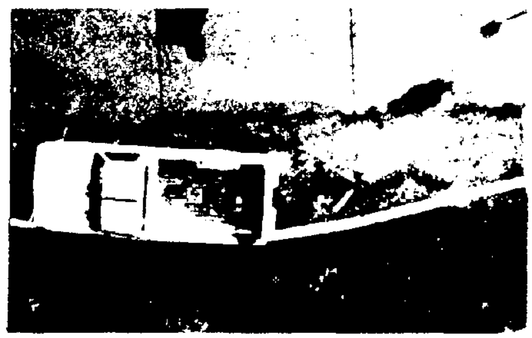
0.301 s



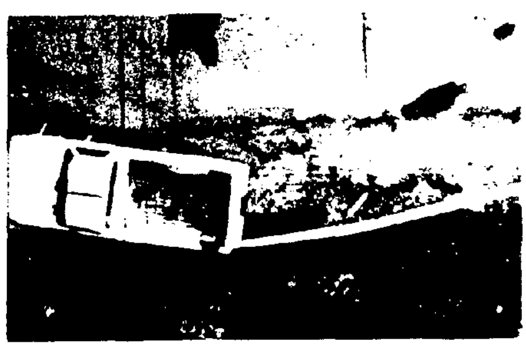
0.401 s



0.502 s

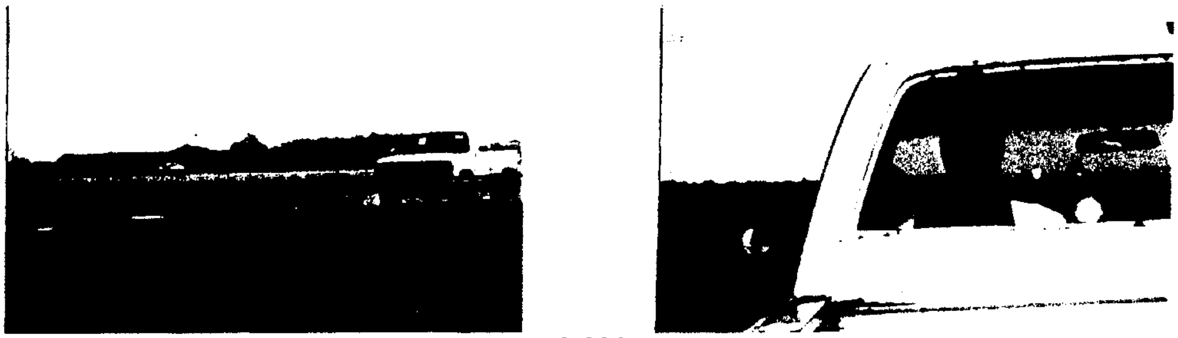


0.602 s

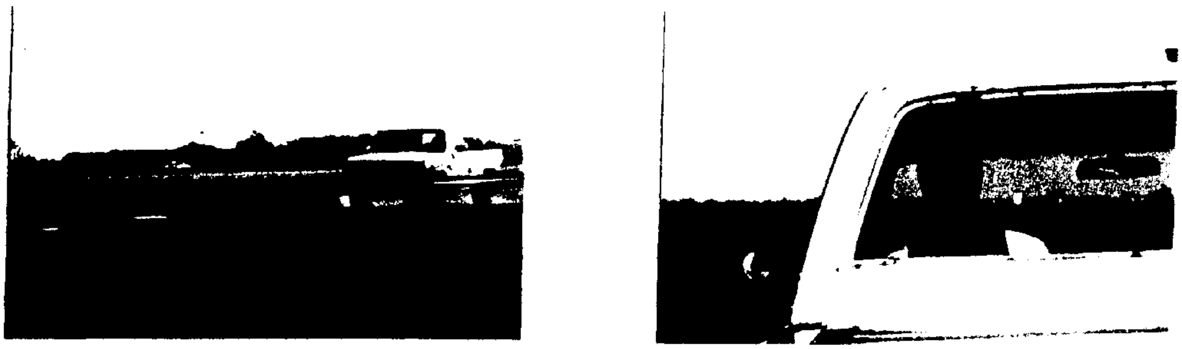


0.702 s

Figure 42. Sequential photographs for test 471470-22 (overhead view).

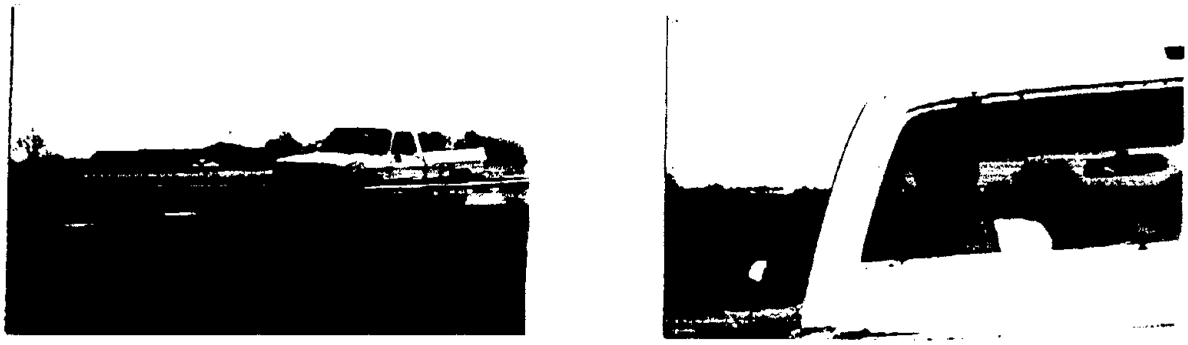


0.000 s



0.100 s

0.201 s



0.301 s

Figure 43. Sequential photographs for test 471470-22
(rear and interior views).

0.401 s

0.502 s

0.602 s

0.702 s

Figure 43. Sequential photographs for test 471470-22 (rear and interior views) (continued).

Figure 44. W-beam, weak-post (G2) guardrail after test 471470-22.

Figure 45. Vehicle after test 471470-22.

3.3.4 Occupant Risk Values

Data from the accelerometer located at the center of gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 4.6 m/s (14.9 ft/s) at 0.300 s; the highest 0.010-s average ridedown acceleration was -4.8 g's between 0.384 and 0.394 s; and the maximum 0.050-s average acceleration was -3.1 g's between 0.110 and 0.160 s. Lateral occupant impact velocity was 3.3 m/s (10.7 ft/s) at 0.228 s; the highest 0.010-s occupant ridedown acceleration was 3.1 g's between 0.386 and 0.396 s; and the maximum 0.050-s average acceleration was 2.6 g's between 0.144 and 0.194 s. These data and other pertinent information from the test are summarized in figure 46. Vehicular angular displacements are displayed in figure 47. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in figures 48 through 50.

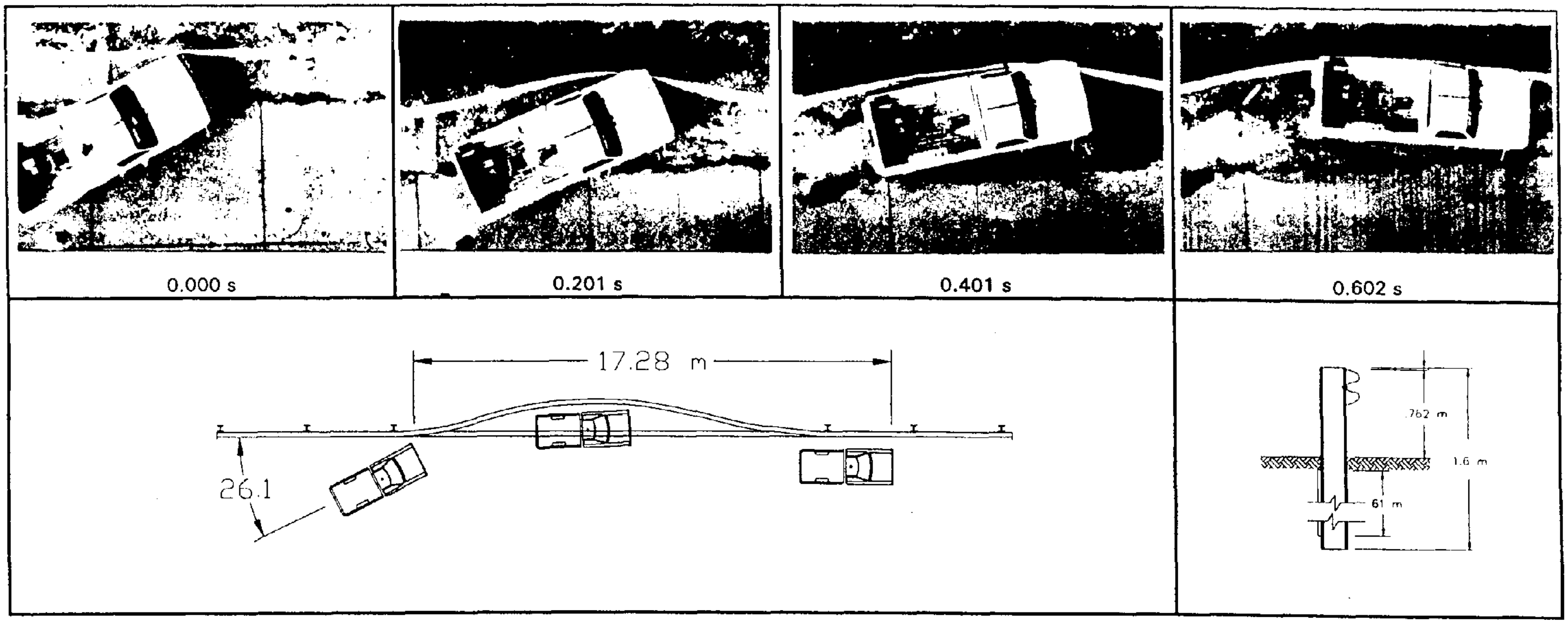
3.4 BOX-BEAM (G3) GUARDRAIL SYSTEM (TEST NO. 471470-33)

The test installation consisted of a 45.7-m- (150-ft-) long section of the box-beam (G3) guardrail with a 15-m- (49.2-ft-) long telescoping tube terminal (WYBET) on the impact end and a turned-down terminal on the downstream end. The layout of the test installation is shown in figure 51. Photographs of the test installation are shown in figures 52 and 53.

A 1989 Chevrolet 2500 pickup (shown in figures 54 and 55) with a test inertia weight of 2000 kg (4409 lb) was used for the crash test. The gross static weight of the vehicle was 2076 kg (4573 lb) which included a restrained 50th-percentile male anthropomorphic dummy placed in the driver's position of the vehicle. The heights to the upper and lower edges of the vehicle bumper were 640 mm (25.2 in) and 415 mm (16.3 in), respectively. Additional dimensions and information on the vehicle are given in figure 56. 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.

3.4.1 Test Description

The vehicle impacted the length-of-need section 0.9 m (2.9 ft) upstream of post 15, traveling at a speed of 95.2 km/h (59.1 mi/h) and at an angle of 25.5 degrees. As the vehicle impacted the installation, the box-beam rail element began to deflect and redirection of the vehicle began at 0.048 s. The right front tire contacted post 15 at 0.056 s. At 0.118 s after impact, the right front tire contacted post 16 and the wheels began to steer sharply toward the guardrail. The left front tire caught post 17 at 0.188 s and post 18 at 0.265 s. The vehicle became parallel with the installation at 0.287 s, traveling at 73.0 km/h (45.4 mi/h). Maximum dynamic deflection of the box-beam rail element of 1.15 m (3.8 ft) occurred at 0.364 s as the vehicle contacted post 19. The vehicle lost contact with the installation at 0.798 s, traveling at a speed of 44.8 km/h (27.8 mi/h) and an exit angle of approximately 0.7 degree toward the guardrail. As the vehicle exited the installation, it continued to yaw counterclockwise toward the guardrail.



General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-22
Date	1/6/94
Test Article	
Type	Guardrail w/Turned-Down
Name or Manufacturer	Weak-Post W-Beam (G2)
Installation Length (m)	76.2 (250 ft)
Size and/or Dimension and Material of Key Elements	76 cm (30 in) mount ht W-Beam (ARTBA RE-3-73) S3x5.7 Post
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1985 Chevrolet Custom 20
Mass (kg) Curb	2000 (4405 lb)
Test Inertial	2000 (4405 lb)
Dummy	76 (167 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	71.0 (44.1 mi/h)
Angle (deg)	26.1
Exit Conditions	
Speed (km/h)	25.7 (16.0 mi/h)
Angle (deg)	9.5
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.6 (14.9 ft/s)
y-direction	3.3 (10.7 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.8
y-direction	3.1
PHD (optional)	
ASI (optional)	
Max. 0.050-s average (g's)	
x-direction	-3.1
y-direction	2.6
z-directon	-1.6

Test Article Deflections (m)	
Dynamic	1.4 (4.5 ft)
Permanent	1.3 (4.2 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ3 & 11LD2
CDC	11FLEK2 & 11LDEW2
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	231 (9.1 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	9
Max. Pitch Angle (deg)	-3
Max. Yaw Angle (deg)	37

Figure 46. Summary of results for test 471470-22.

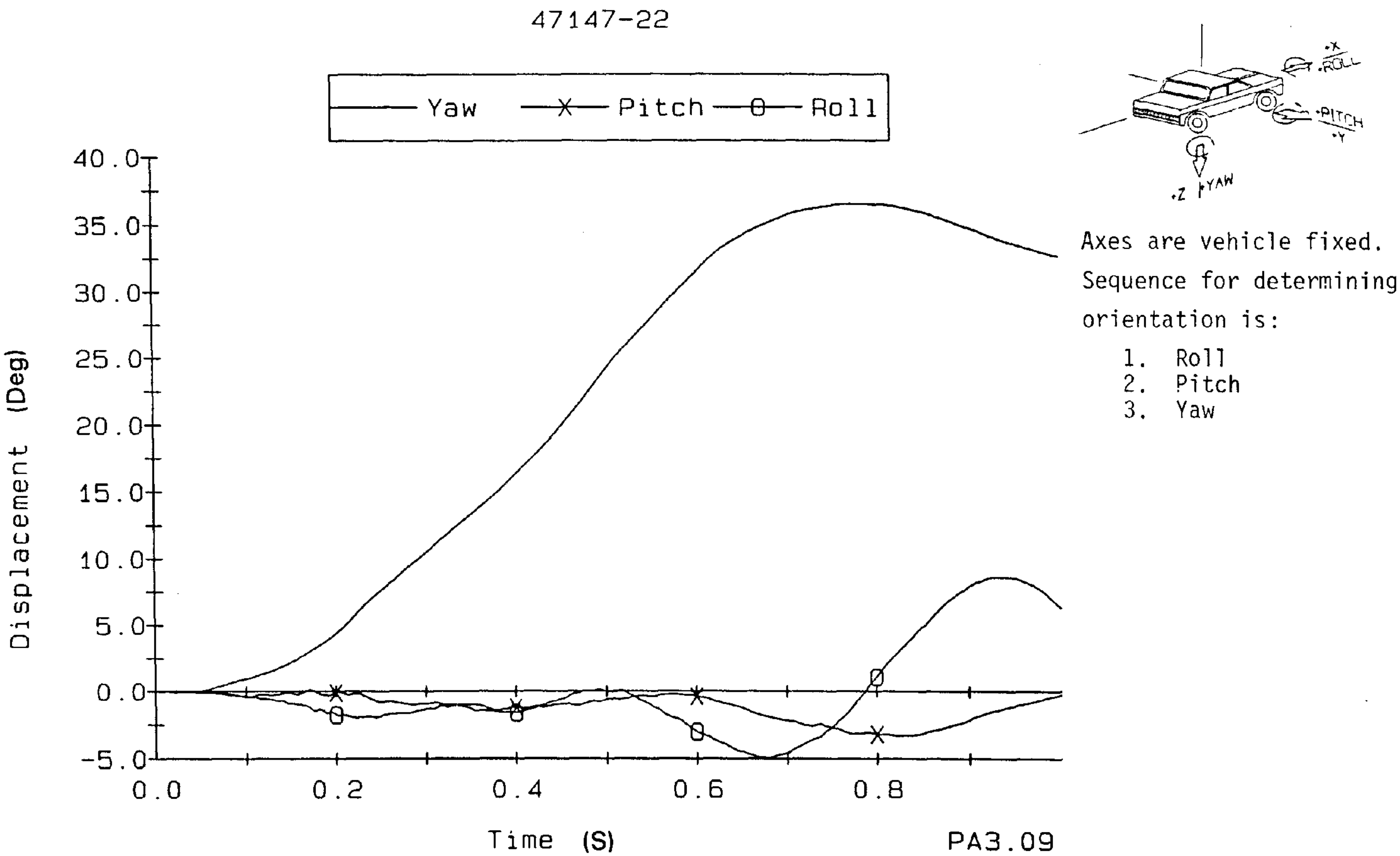


Figure 47. Vehicle angular displacements during test 471470-22.

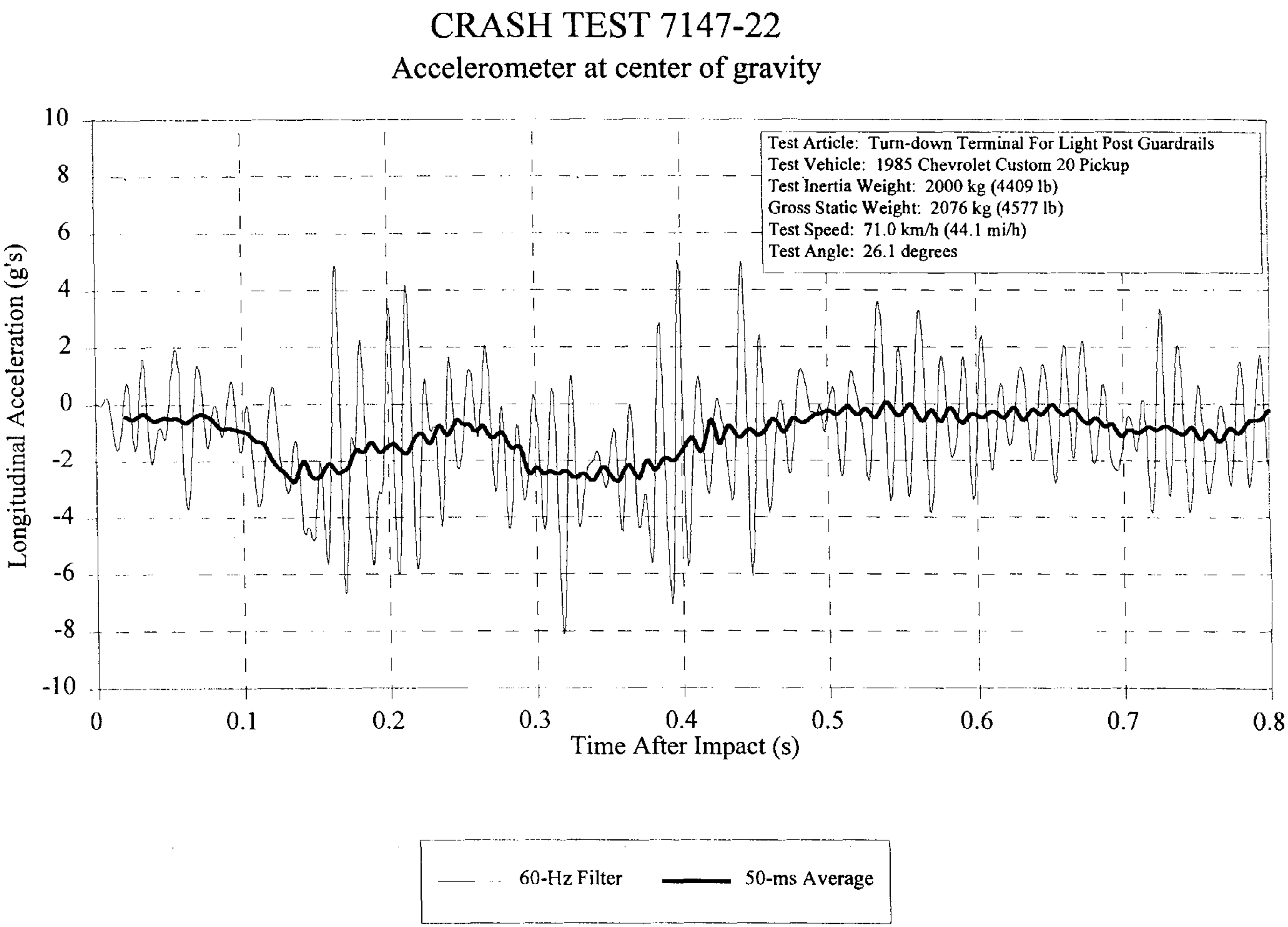


Figure 48. Vehicle longitudinal accelerometer trace for test 7147-22.

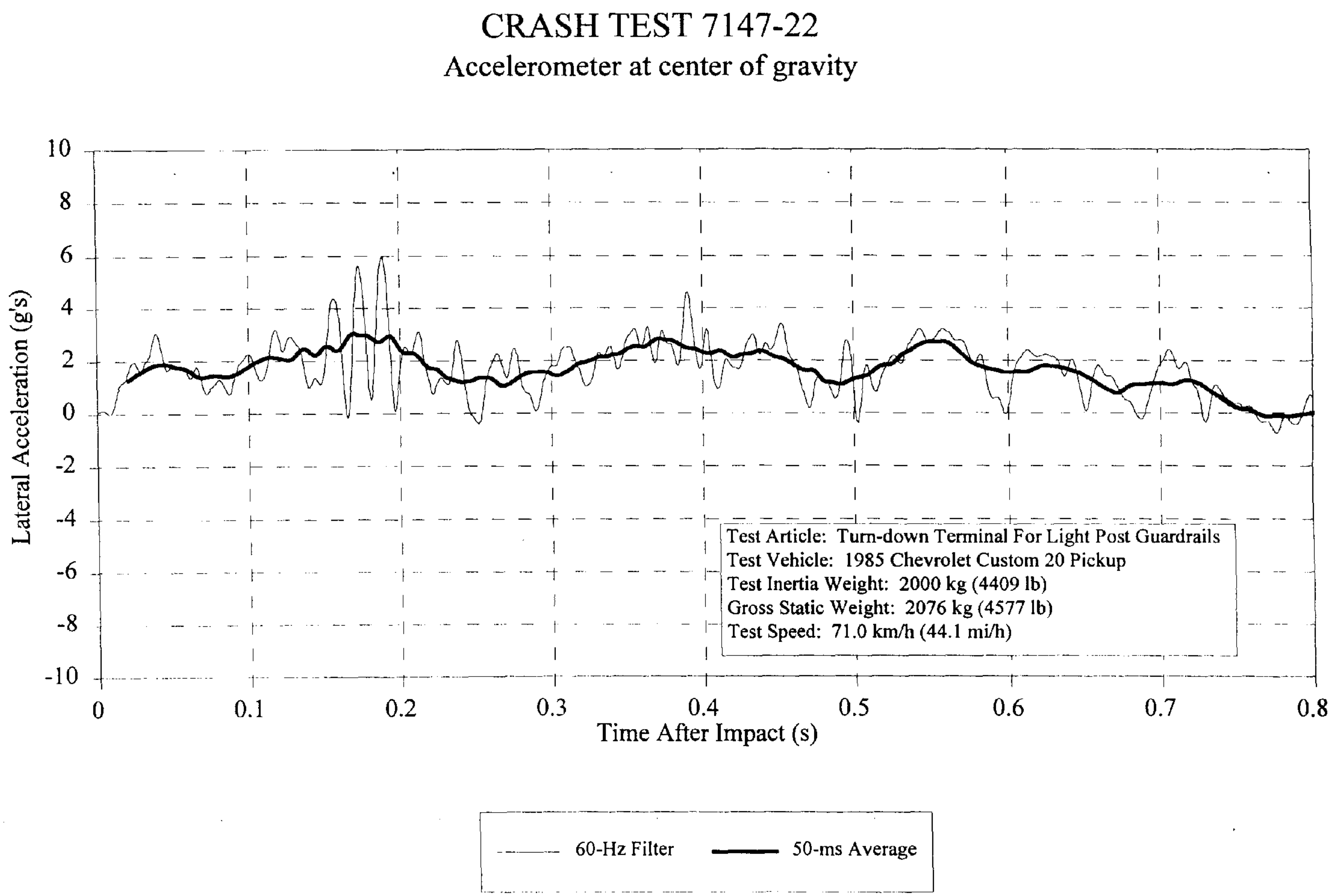


Figure 49. Vehicle lateral accelerometer trace for test 7147-22.

CRASH TEST 7147-22

Accelerometer at center of gravity

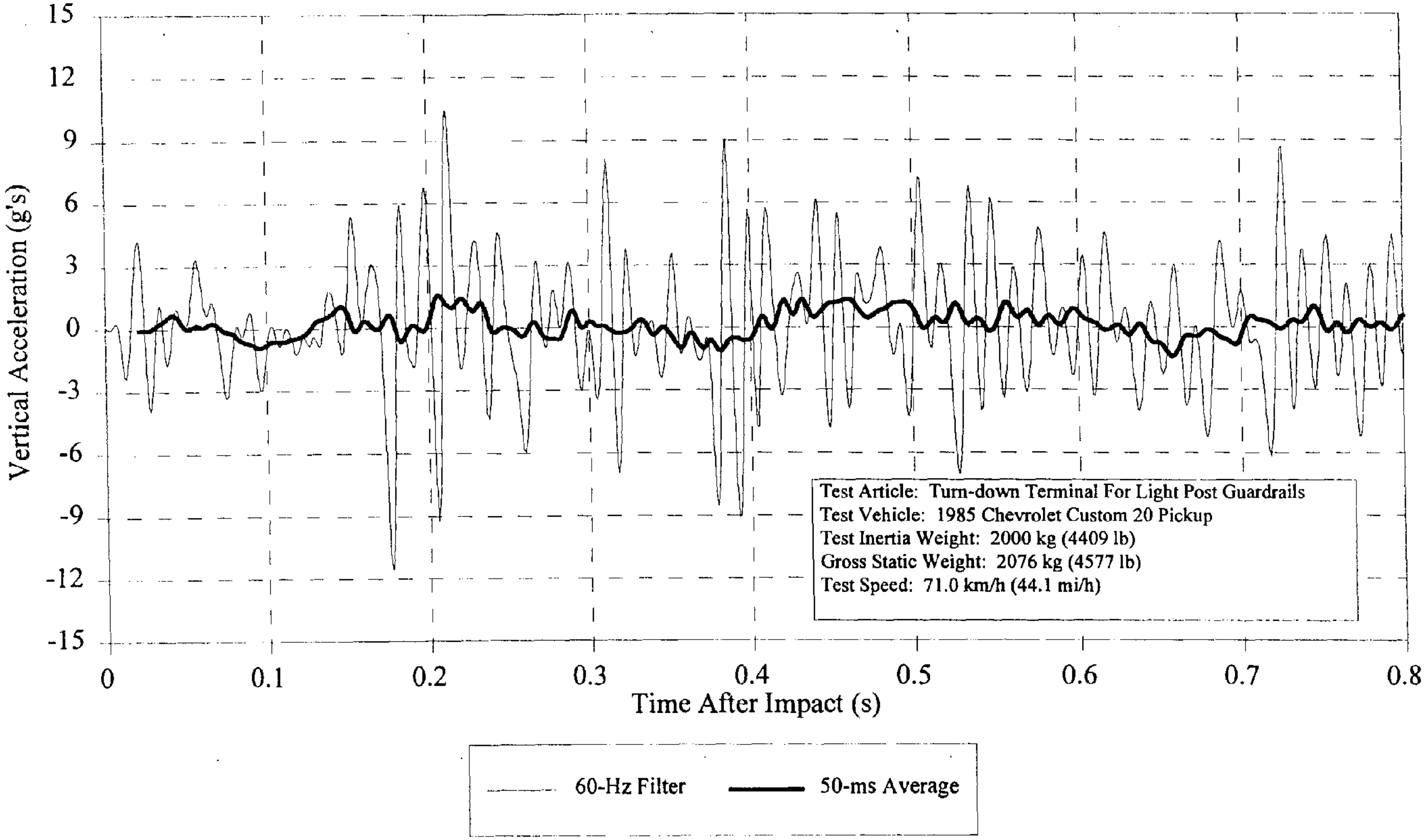


Figure 50. Vehicle vertical accelerometer trace for test 7147-22.

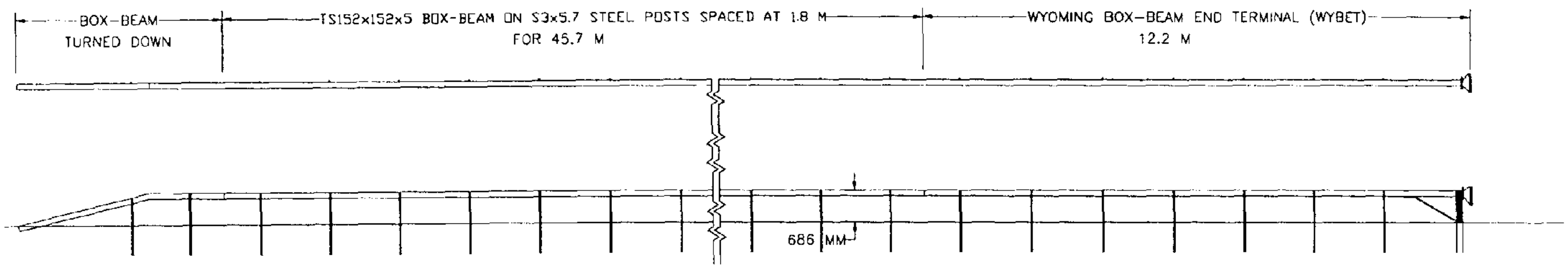
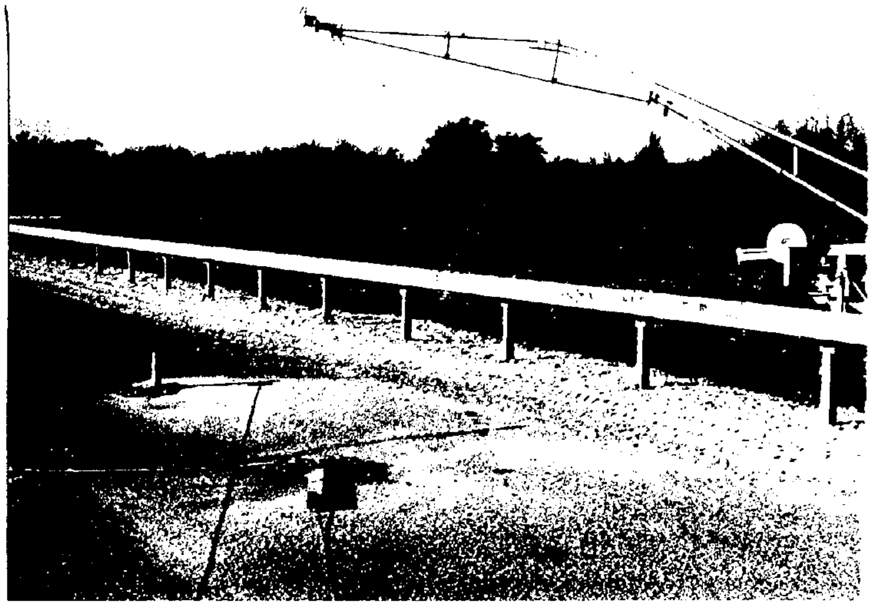


Figure 51. Layout of box-beam (G3) guardrail installation.



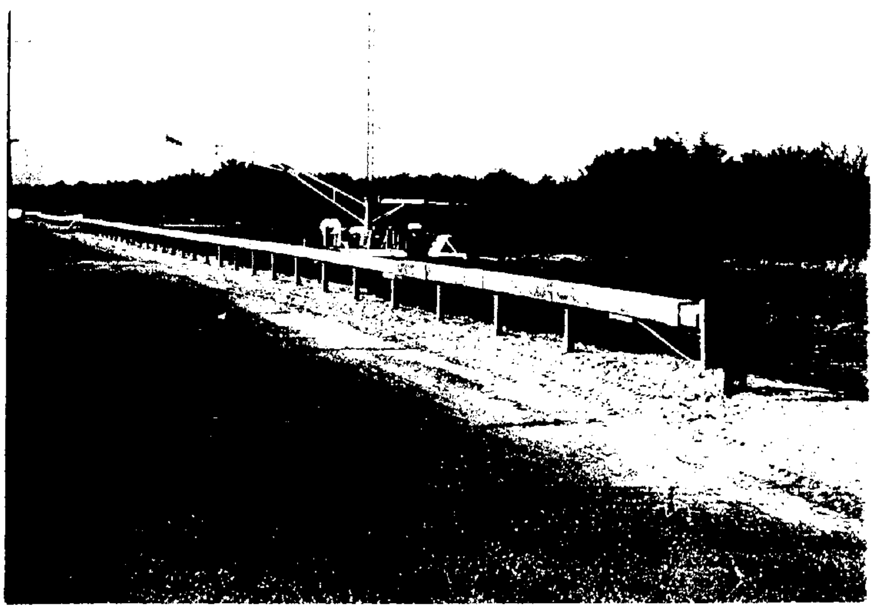


Figure 52. Box-beam (G3) guardrail installation used for test 471470-33.

Figure 53. Box-beam (G3) guardrail section before test 471470-33.

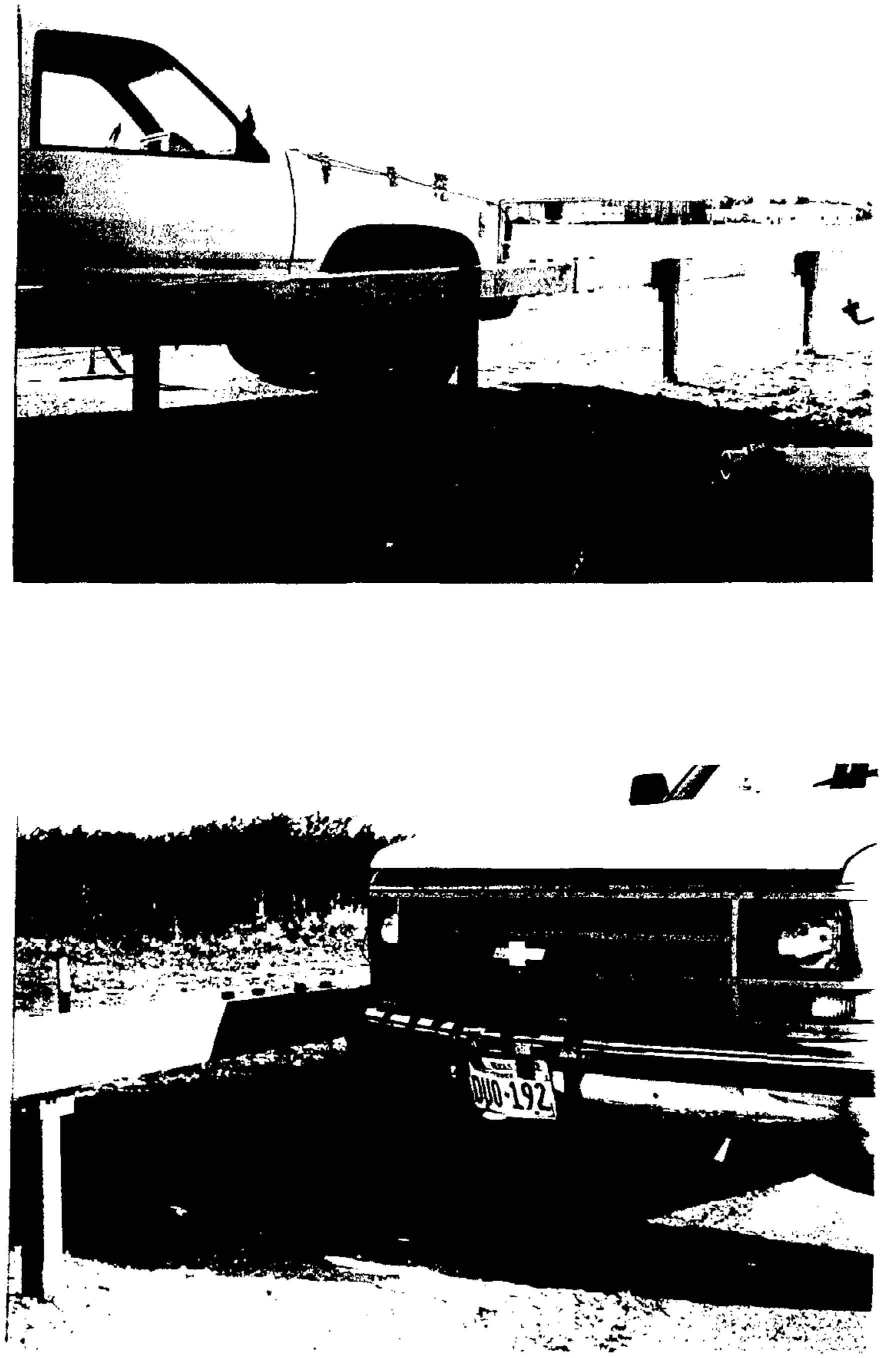


Figure 54. Vehicle/guardrail geometrics for test 471470-33.

Figure 55. Vehicle before test 471470-33.

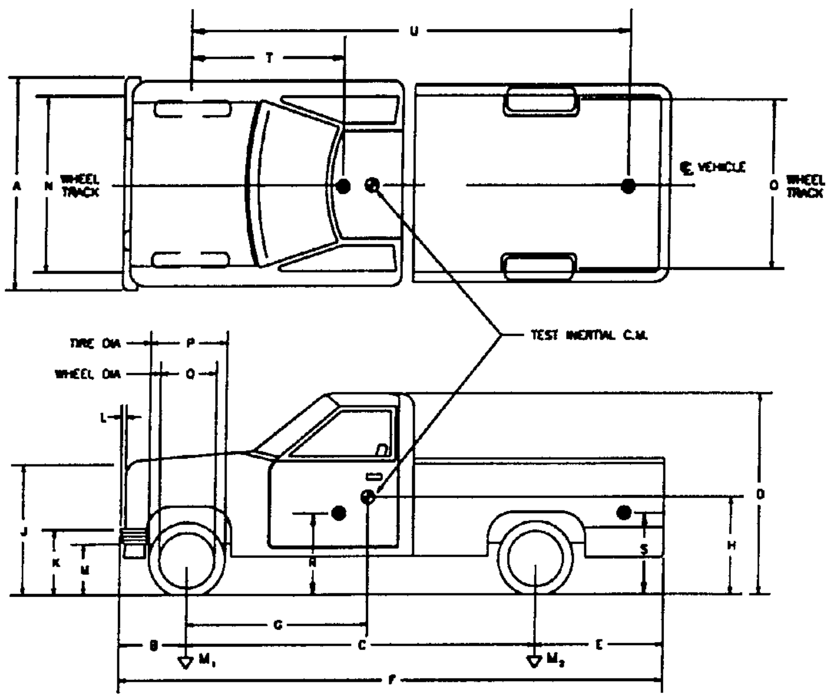
DATE: 04/13/95 TEST NO.: 471470-33 VIN NO.: 1GCGC24K1KE129139

YEAR: 1989 MAKE: Chevrolet MODEL: 2500

TIRE INFLATION PRESSURE: ______ ODOMETER: 175119 TIRE SIZE: 245/75R16

MASS DISTRIBUTION (kg) LF 538 RF 541 LR 454 RR 467

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 cyl EFI

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY - (mm)

A	1880	E	1310	J	1050	N	1605	R	730
B	740	F	5400	K	640	O	1625	S	1070
C	3350	G	1543.7	L	70	P	775	T	1449
D	1840	H		M	415	Q	445	U	4180

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1120	1079	1124
M_2	860	921	952
M_T	1980	2000	2076

Figure 56. Vehicle properties for test 471470-33.

The vehicle contacted the guardrail a second time at 1.566 s and subsequently came to rest with the nose of the vehicle against the guardrail 26 m (85 ft) down from the initial point of impact. Sequential photographs are shown in figures 57 and 58.

3.4.2 Damage to Test Installation

As seen in figures 59 through 61, the guardrail installation received moderate damage. There were tire marks on the face of the box-beam rail element from posts 15 through 21, and on posts 15 through 20. The box-beam rail element was separated from posts 16 through 20, and these posts were bent at ground level. The lateral deflections recorded at posts 12 through 22 are noted in table 3.

Maximum dynamic deflection of the box-beam rail element was 1.15 m (3.8 ft). Maximum permanent deformation of the installation was 0.74 m (2.4 ft) near post 16. Total length of contact of the vehicle with the installation was 12.6 m (41.3 ft).

Table 3. Lateral post deflections for test 471470-33.

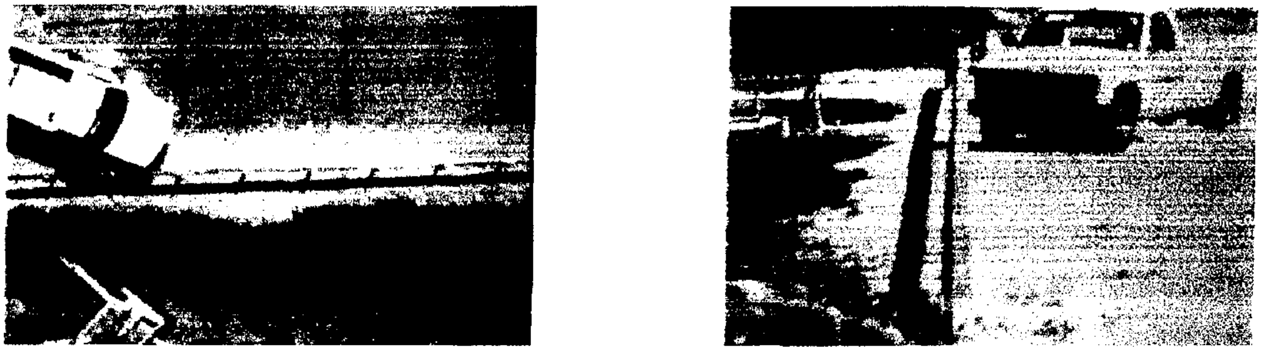
Post 12	25 mm (1.0 in)	Post 18	191 mm (7.5 in)
Post 13	71 mm (2.8 in)	Post 19	152 mm (6.0 in)
Post 14	127 mm (5.0 in)	Post 20	229 mm (9.0 in)
Post 15	191 mm (7.5 in)	Post 21	25 mm (1.0 in)
Post 16	178 mm (7.0 in)	Post 22	25 mm (1.0 in)
Post 17	191 mm (7.5 in)		

3.4.3 Vehicle Damage

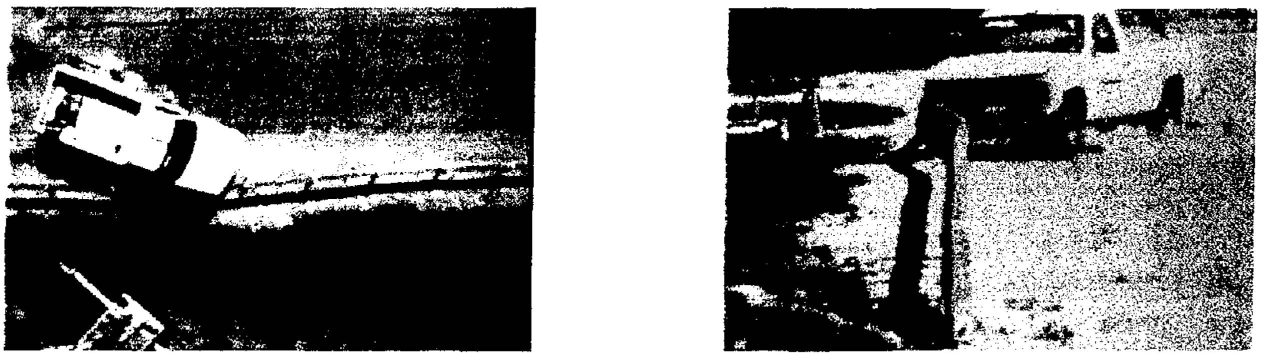
The vehicle sustained moderate damage as shown in figure 62. The right lower A-arm, stabilizer bar, and tie rod ends on the right side were damaged. The front bumper, grill, right front quarter panel, right door, right rear quarter panel, and the right front wheel also were damaged. Maximum exterior crush at the right front corner of the vehicle was 530 mm (20.9 in), and maximum deformation of the occupant compartment was 9 mm (0.4 in) at the instrument panel area on the passenger side.

3.4.4 Occupant Risk Values

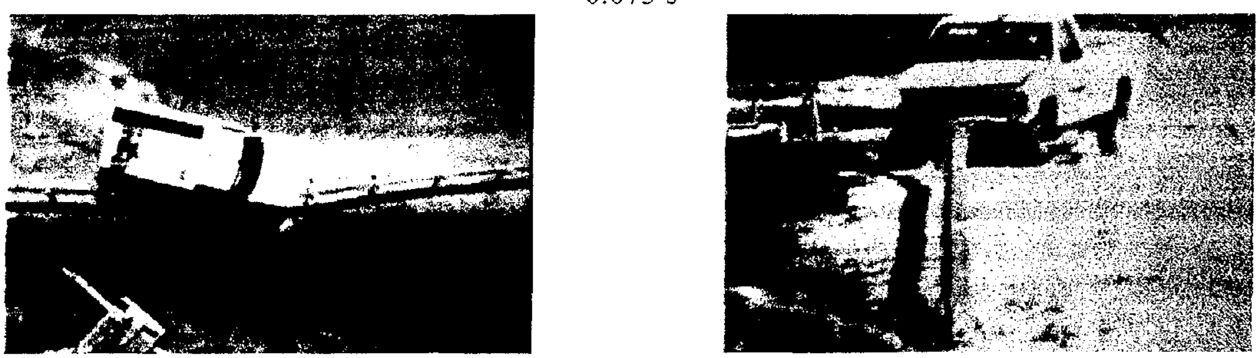
Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. Occupant contact first occurred in the longitudinal direction at 0.222 s. The longitudinal occupant impact velocity was 6.3 m/s (20.7 ft/s), the highest 0.010-s occupant ridedown acceleration was -5.8 g's between 0.296 and 0.306 s, and the maximum 0.050-second average was -4.8 g's between 0.125 and 0.175 s.



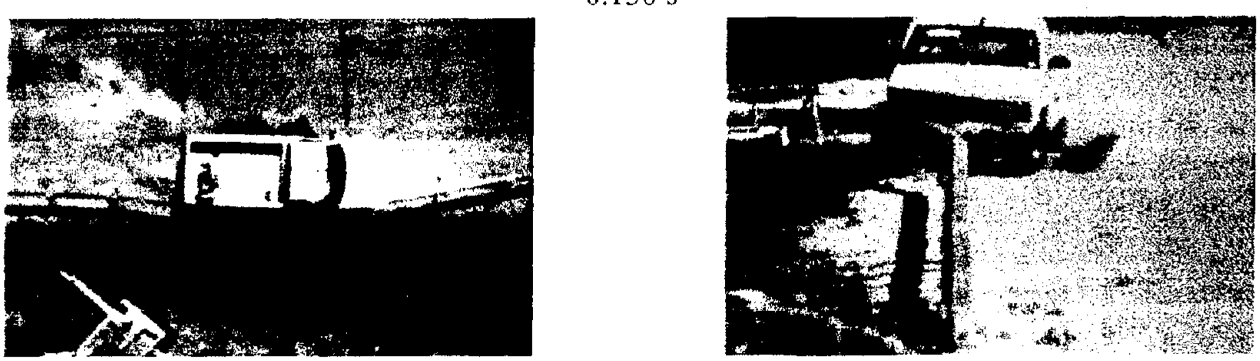
0.000 s



0.075 s



0.150 s



0.251

Figure 57. Sequential photographs for test 471470-33 (overhead and frontal views).

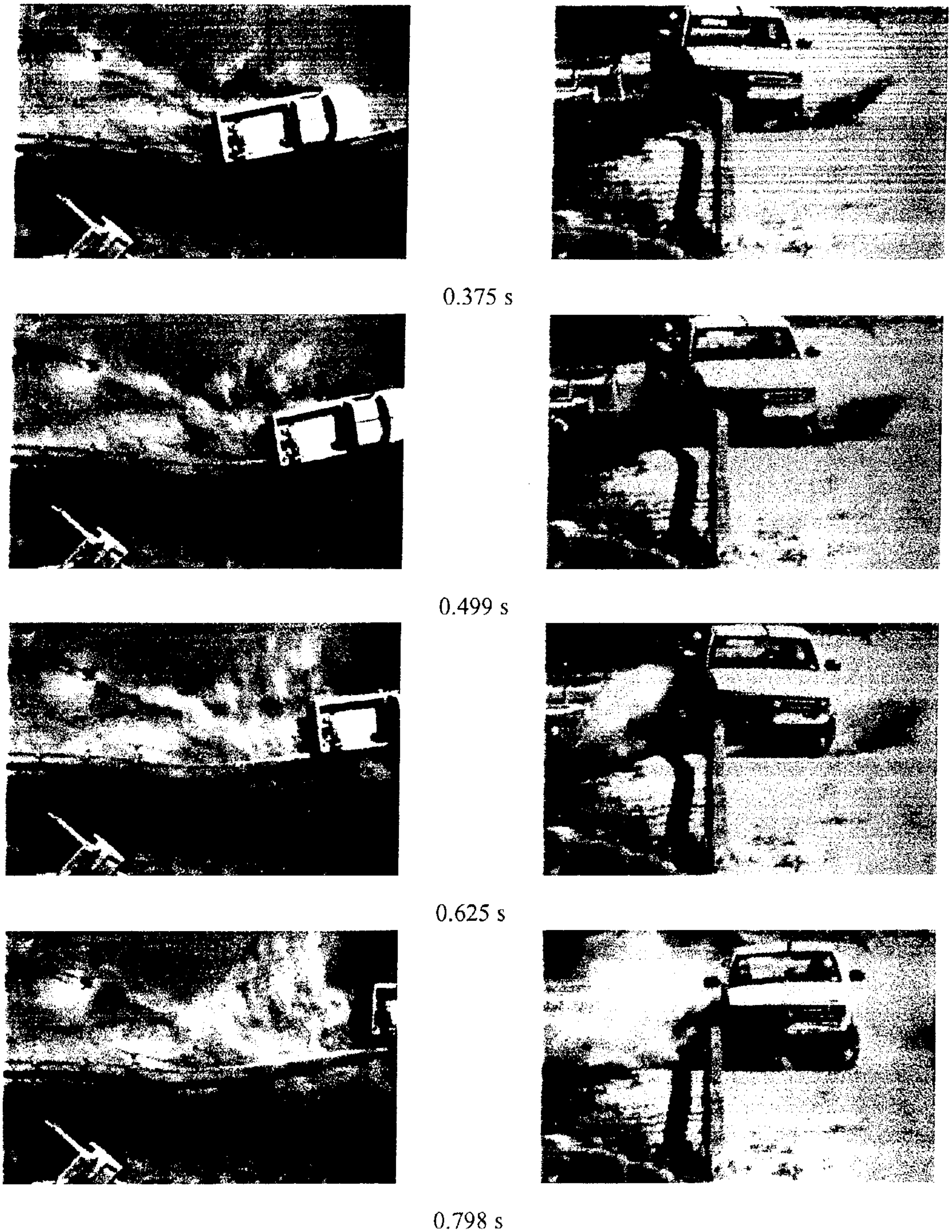
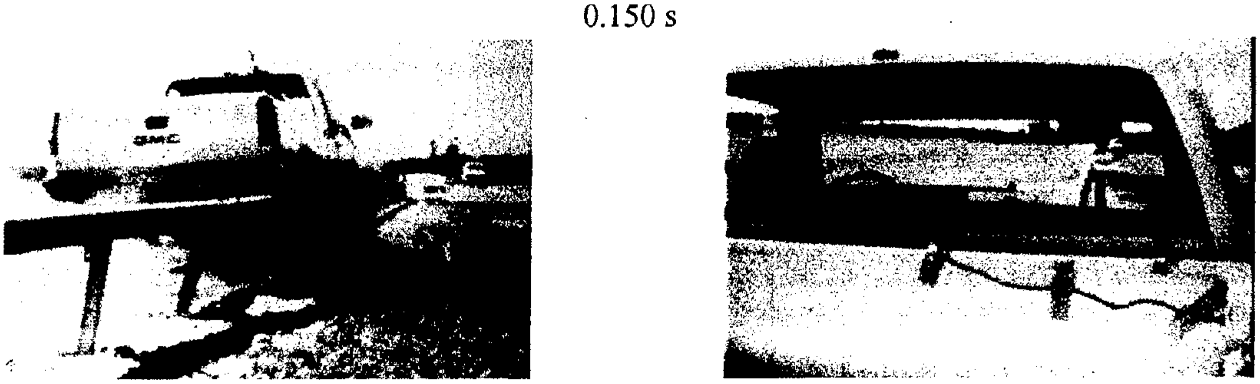


Figure 57. Sequential photographs for test 471470-33 (overhead and frontal views) (continued).

0.000 s

0.075 s

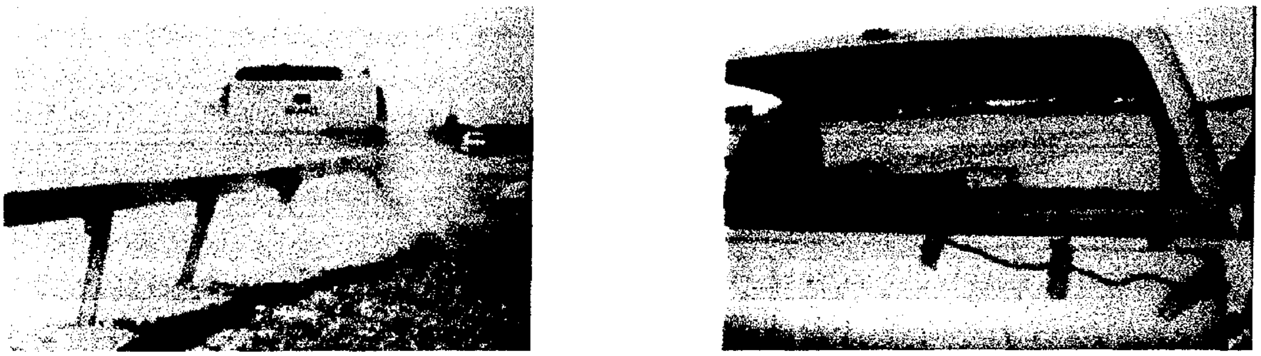
0.150 s



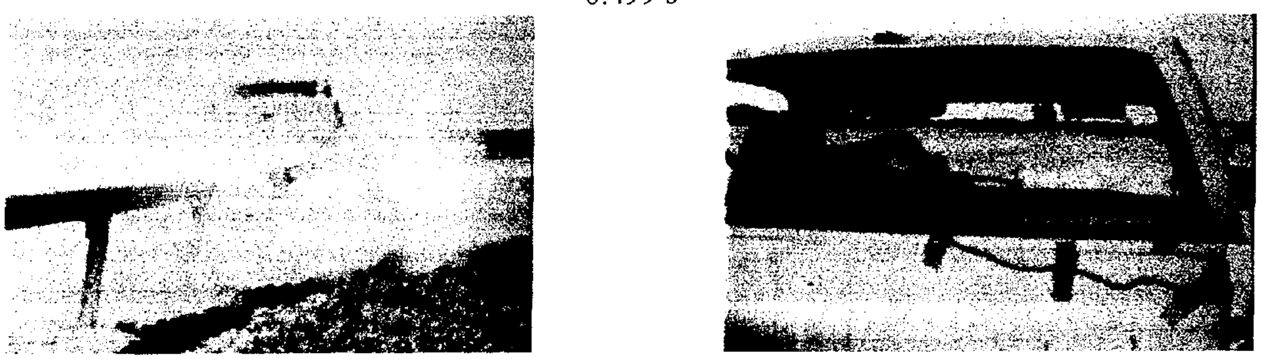
0.251 s

Figure 58. Sequential photographs for test 471470-33
(rear and interior views).

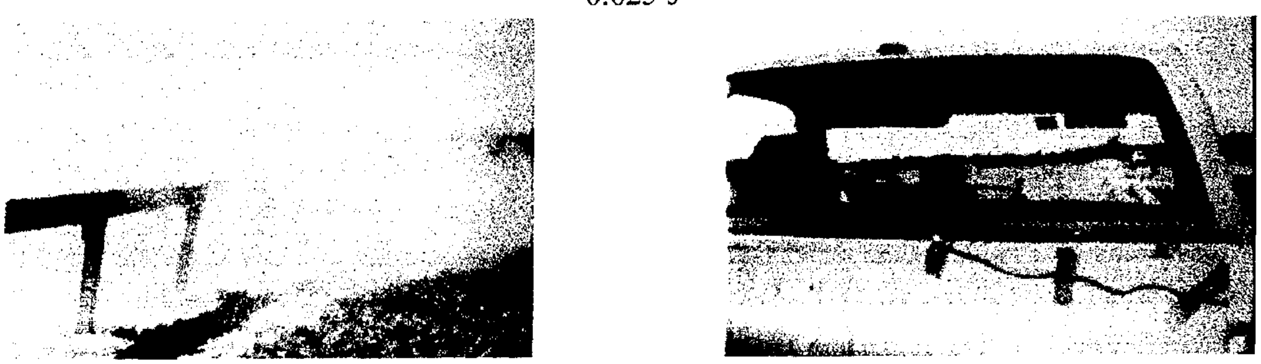
0.375 s



0.499 s



0.625 s



0.798 s

Figure 58. Sequential photographs for test 471470-33
(rear and interior views) (continued).

Figure 59. Box-beam (G3) guardrail after test 471470-33.

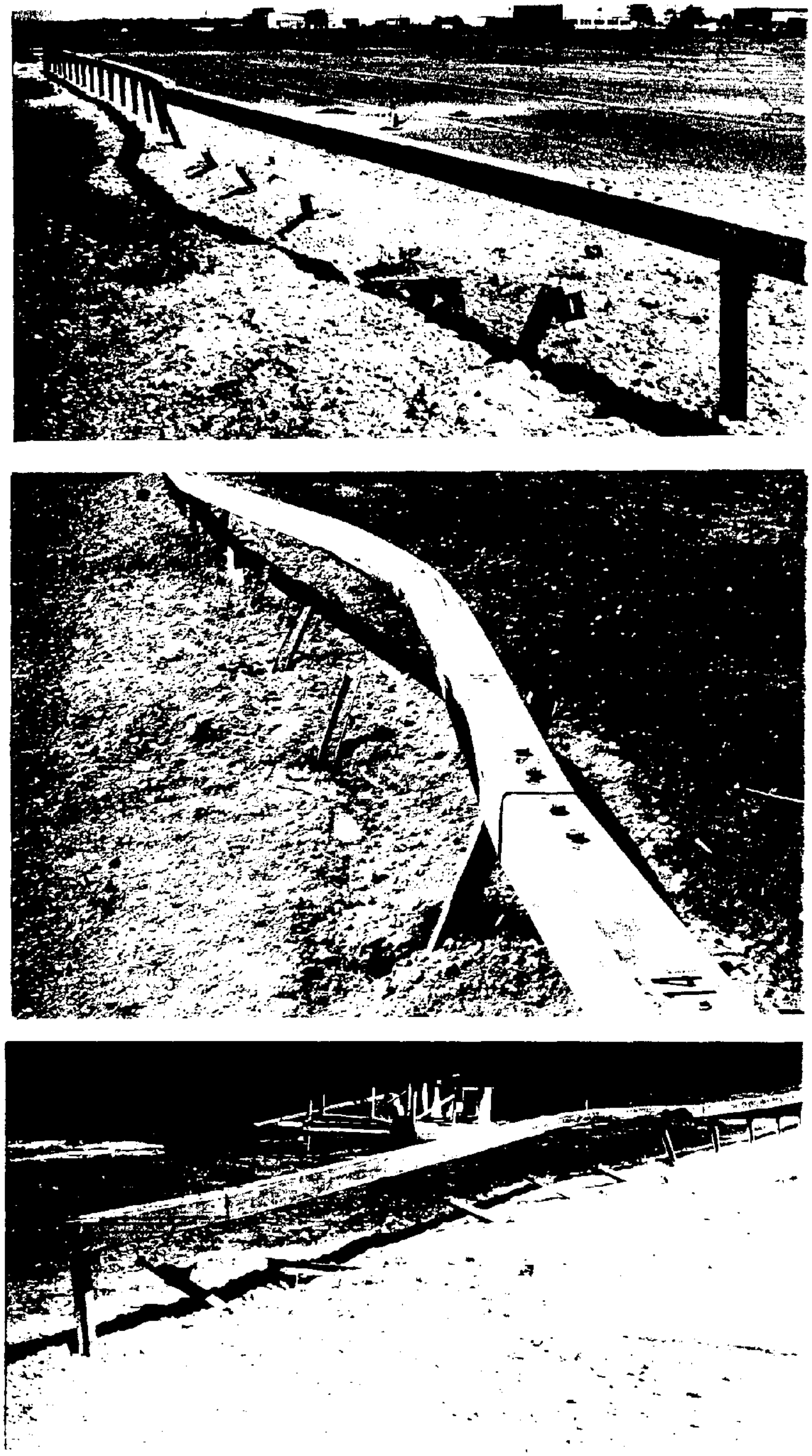


Figure 60. Damage at posts 14 through 21, test 471470-33.

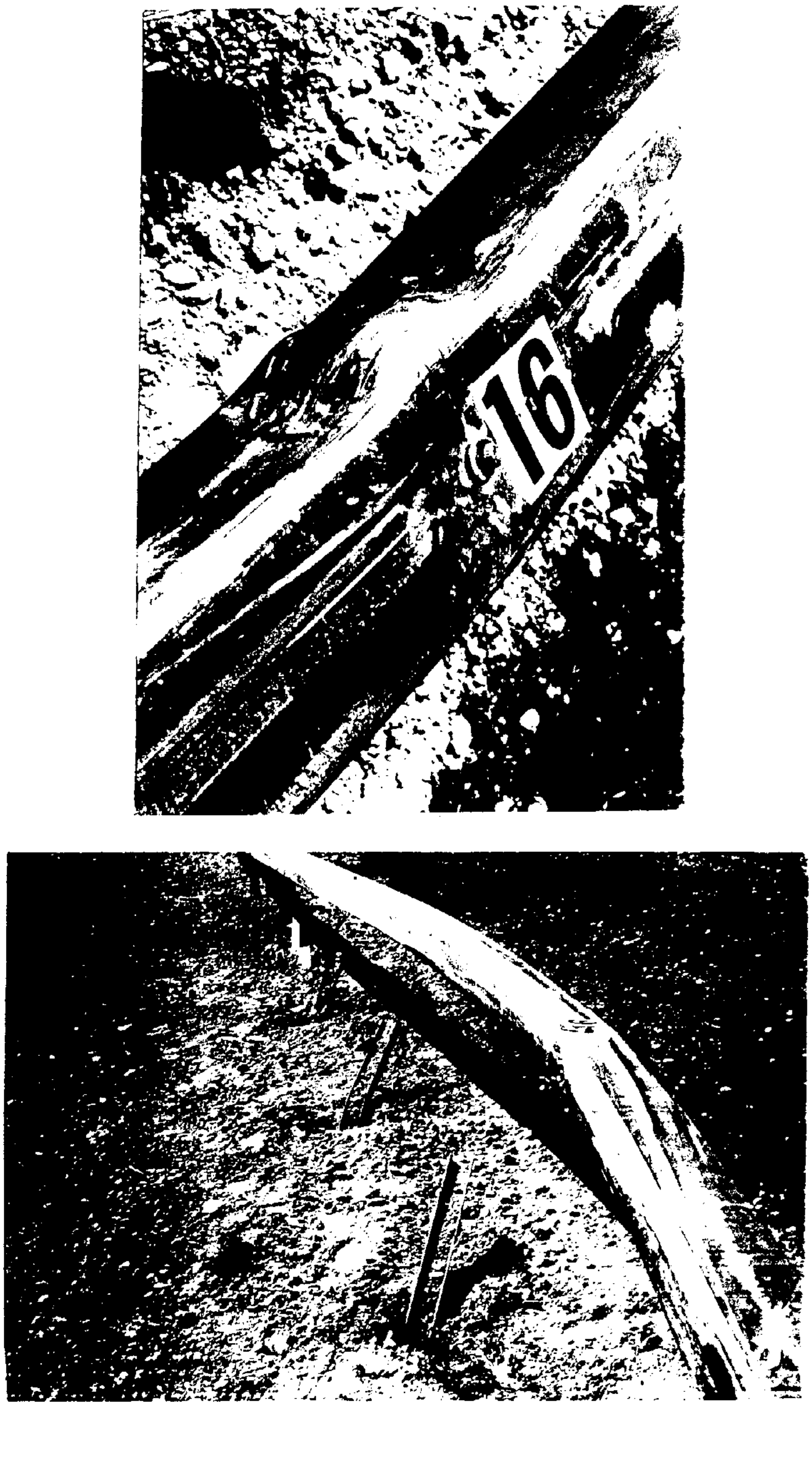


Figure 61. Damage at post 16, test 471470-33.

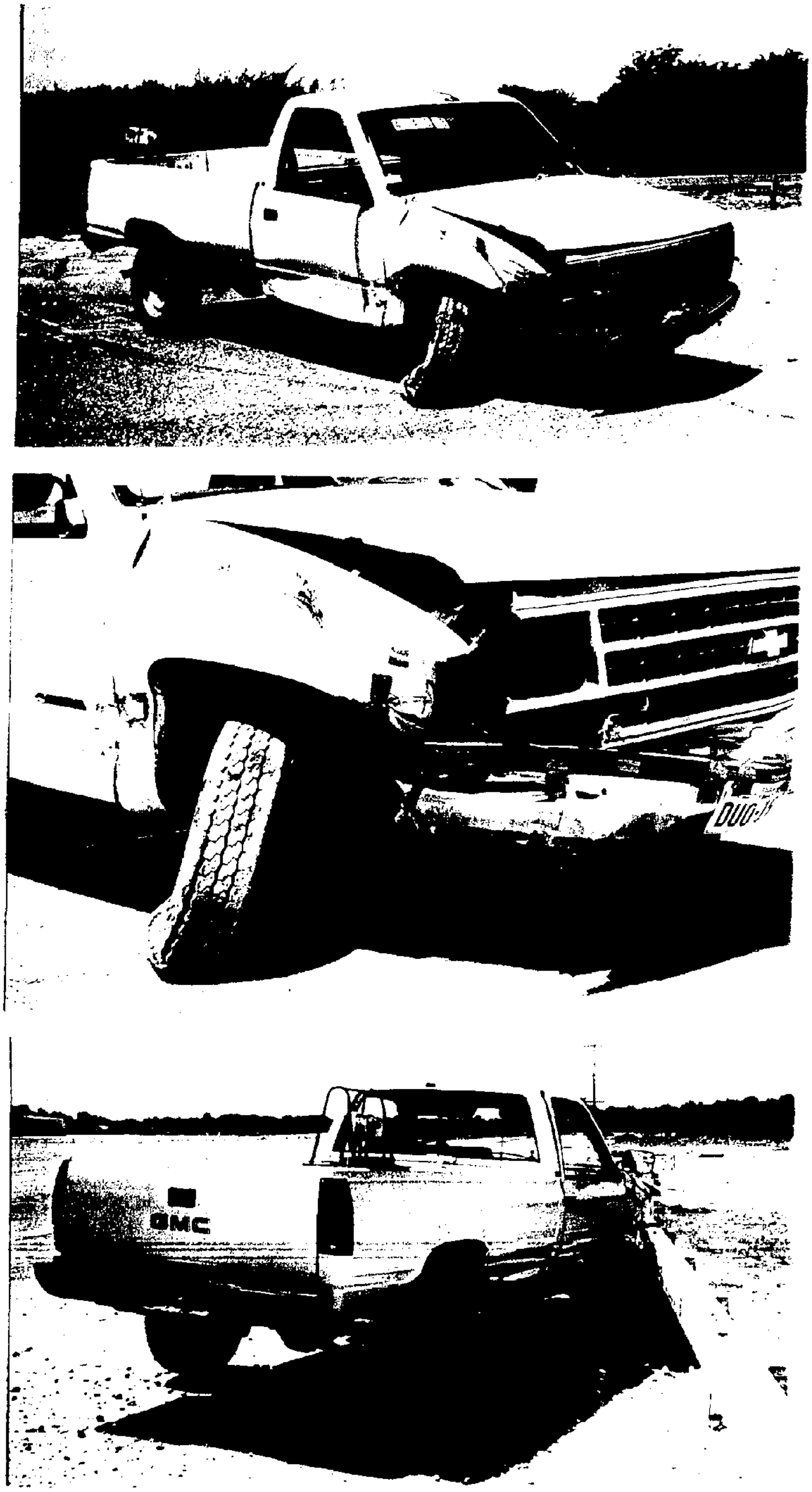


Figure 62. Vehicle after test 471470-33.

Lateral occupant impact velocity was 0.9 m/s (3.0 ft/s) at 0.559 s, the highest 0.010-s lateral occupant ridedown acceleration was -10.7 g's between 0.388 and 0.398 s, and the maximum 0.050-s average acceleration was 2.6 g's between 0.447 and 0.497 s. These data and other information pertinent to the test are summarized in figure 63. Vehicle angular displacements during the test are displayed in figure 64. Vehicular accelerations versus time traces filtered at 60 Hz are presented in figures 65 through 67.

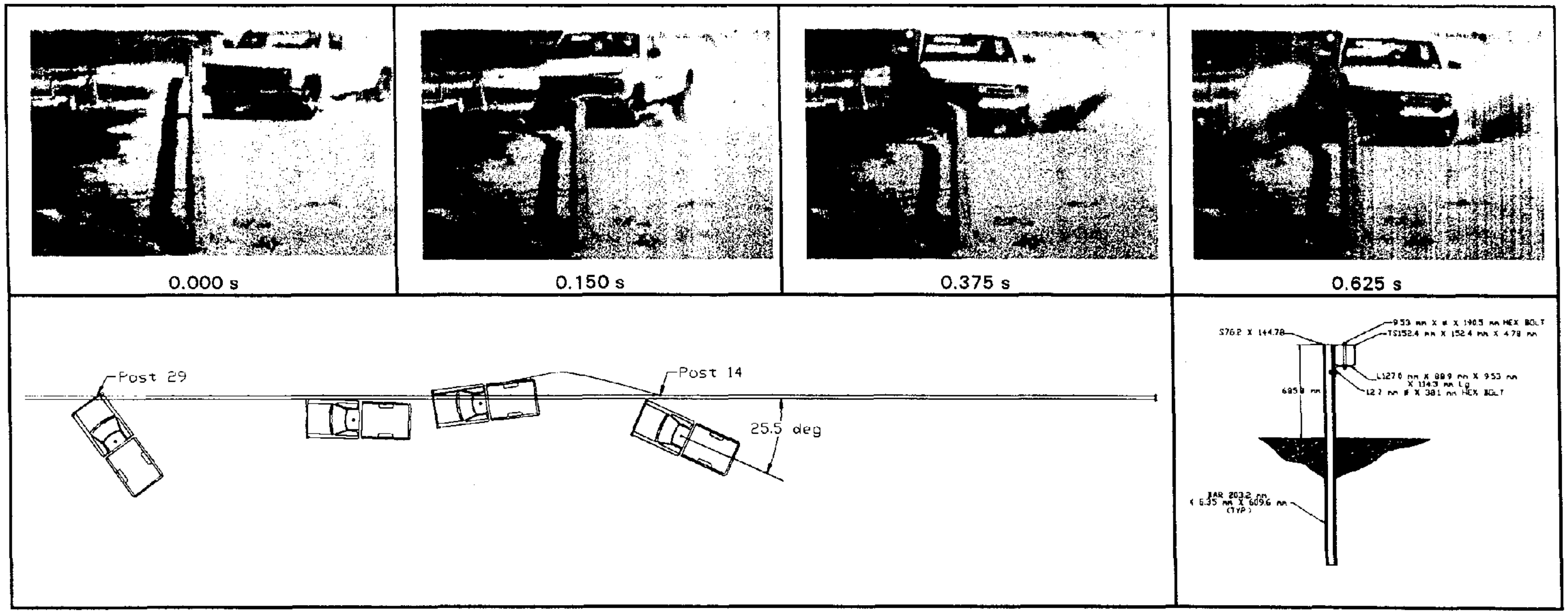
3.5 W-BEAM, WOOD-POST (G4(2W)) GUARDRAIL SYSTEM (TEST 471470-26)

The test installation consisted of a 45.7-m- (150-ft-) long section of the standard G4(2W) length-of-need section, with a modified eccentric loader terminal (MELT) at the upstream end and a standard breakaway cable terminal (BCT) at the downstream end for a total installation length of 68.6 m (225 ft). A layout of the test installation is shown in figure 68, and photographs of the test installation is shown in figure 69.

A 1989 Chevrolet 2500 pickup truck, shown in figures 70 and 71, was used for the crash test. Test inertia mass or empty weight of the vehicle was 2000 kg (4409 lb) and its gross static mass or test weight was 2074 kg (4568 lb), including a restrained 50th-percentile male anthropomorphic dummy placed in the driver's position of the vehicle. The heights to the upper and lower edges of the vehicle bumper were 650 mm (25.6 in) and 430 mm (16.9 in), respectively. Additional dimensions and information on the vehicle are given in figure 72. 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.

3.5.1 Test Description

The vehicle impacted the length-of-need section 0.61 m (2 ft) upstream of post 14, or 4.5 m (14.5 ft) upstream of the splice at post 16, traveling at a speed of 100.8 km/h (62.6 mi/h) and at an angle of 24.3 degrees. As the vehicle impacted the guardrail, the W-beam rail element began to deform and post 14 began to displace laterally. The vehicle impacted post 14 shortly thereafter, and movement began at post 15. Redirection of the vehicle began at 0.056 s, and movement at post 16 began at 0.063 s. The vehicle contacted post 15 at 0.086 s and tire contact with post 15 occurred at 0.104 s. Post 17 began to move at 0.108 s. The vehicle contacted post 16 at 0.157 s and movement began at post 18 at 0.165 s. Tire contact with post 16 occurred at 0.193 s, and shortly thereafter, the left front wheel assembly separated from the vehicle and the blockout on post 16 split. The rear of the vehicle made contact with the guardrail at 0.203 s. The vehicle contacted post 17 at 0.236 s. The vehicle was parallel with the installation at 0.249 s, traveling at 74.3 km/h (46.3 mi/h). Vehicle contact with post 18 occurred at 0.356 s. Maximum deflection of the W-beam rail of 0.82 m (2.7 ft) occurred near post 16 at 0.371 s. The vehicle lost contact with the installation at 0.513 s, traveling at a speed of 70.8 km/h (44.0 mi/h) and at an exit angle of 8.1 degrees. As the vehicle exited the rail, it had rolled 25 degrees counterclockwise and was yawing clockwise. Maximum roll angle was 39 degrees at 0.709 s.

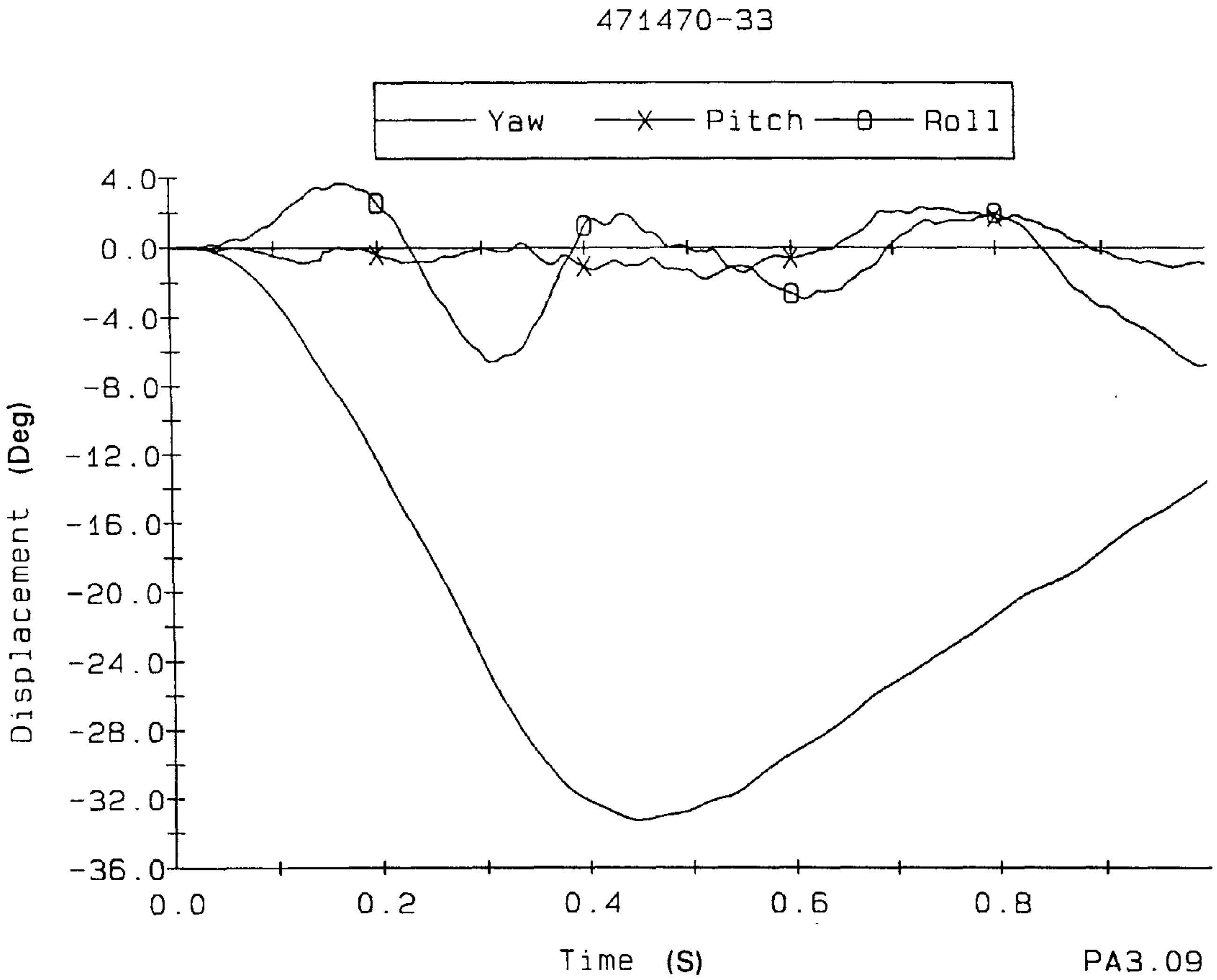


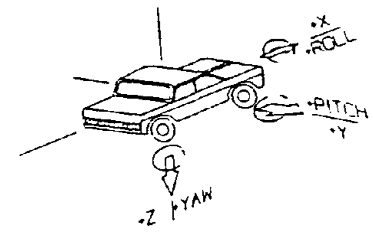
General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-33
Date	04/13/95
Test Article	
Type	Guardrail
Name or Manufacturer	G3 Box Beam
Installation Length (m)	68 m (223 ft)
Size and/or Dimension and Material of Key Elements	TS6x6x.188 Box Beam on S3x5.7 Steel Posts
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500
Mass (kg) Curb	1980 (4361 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	95.2 (59.1 mi/h)
Angle (deg)	25.5
Exit Conditions	
Speed (km/h)	44.8 (27.8 mi/h)
Angle (deg)	0.7 toward rail
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.3 (20.7 ft/s)
y-direction	0.9 (3.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-5.8
y-direction	-10.7
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.8
y-direction	2.6
z-direction	-4.1

Test Article Deflections (m)	
Dynamic	1.15 (3.8 ft)
Permanent	0.74 (2.4 ft)
Vehicle Damage	
Exterior	
VDS	01RFQ4
CDC	01FREK2 & 01RYES3
Interior	
OCDI	RF0000000
Maximum Exterior Vehicle Crush (mm)	530 (20.9 in)
Max. Occ. Compart. Deformation (mm)	9 (0.4 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-7
Max. Pitch Angle (deg)	2
Max. Yaw Angle (deg)	-33

Figure 63. Summary of results for test 471470-33.





Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

Figure 64. Vehicle angular displacements during test 471470-33.

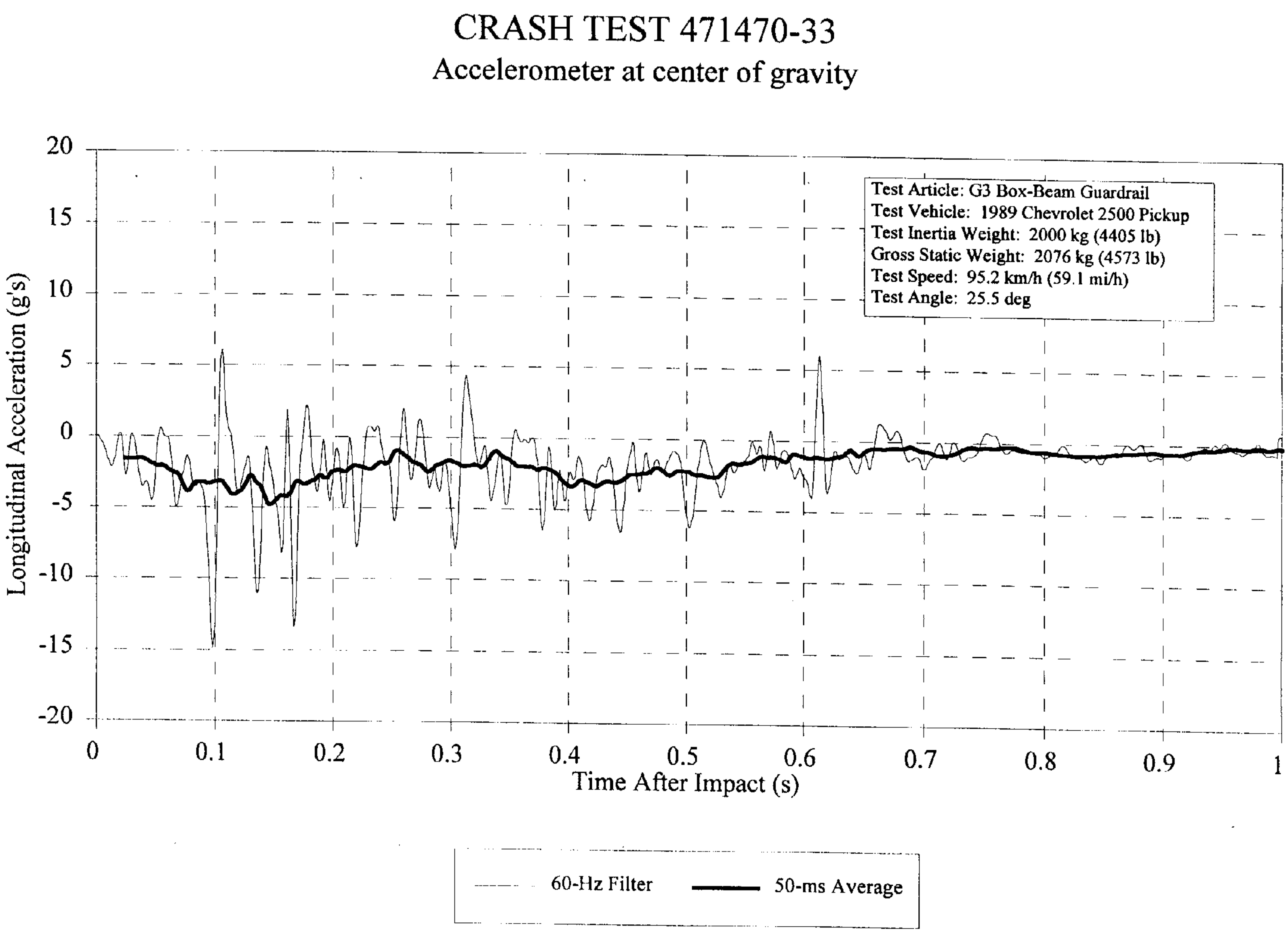


Figure 65. Vehicle longitudinal accelerometer trace for test 471470-33.

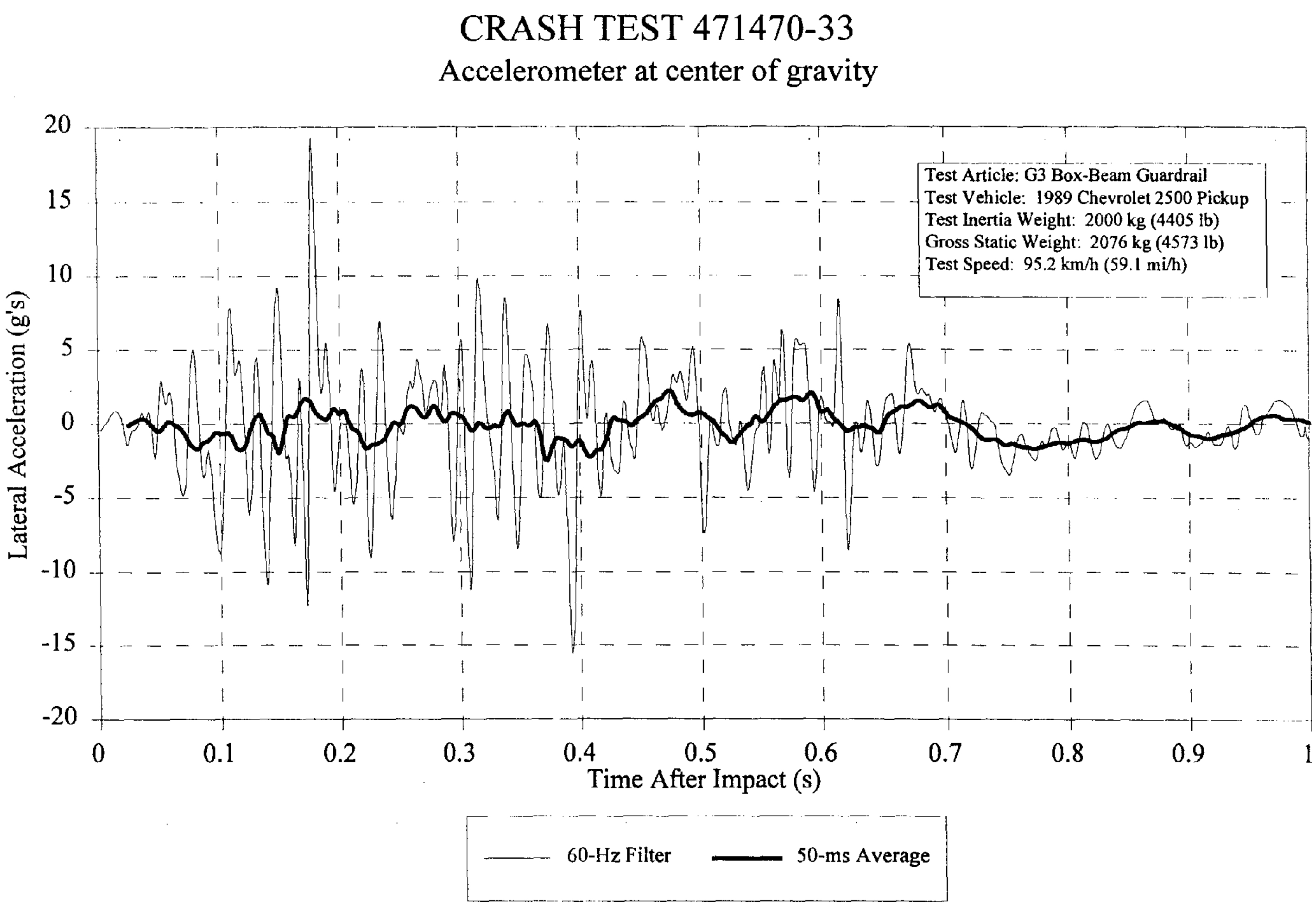


Figure 66. Vehicle lateral accelerometer trace for test 471470-33.

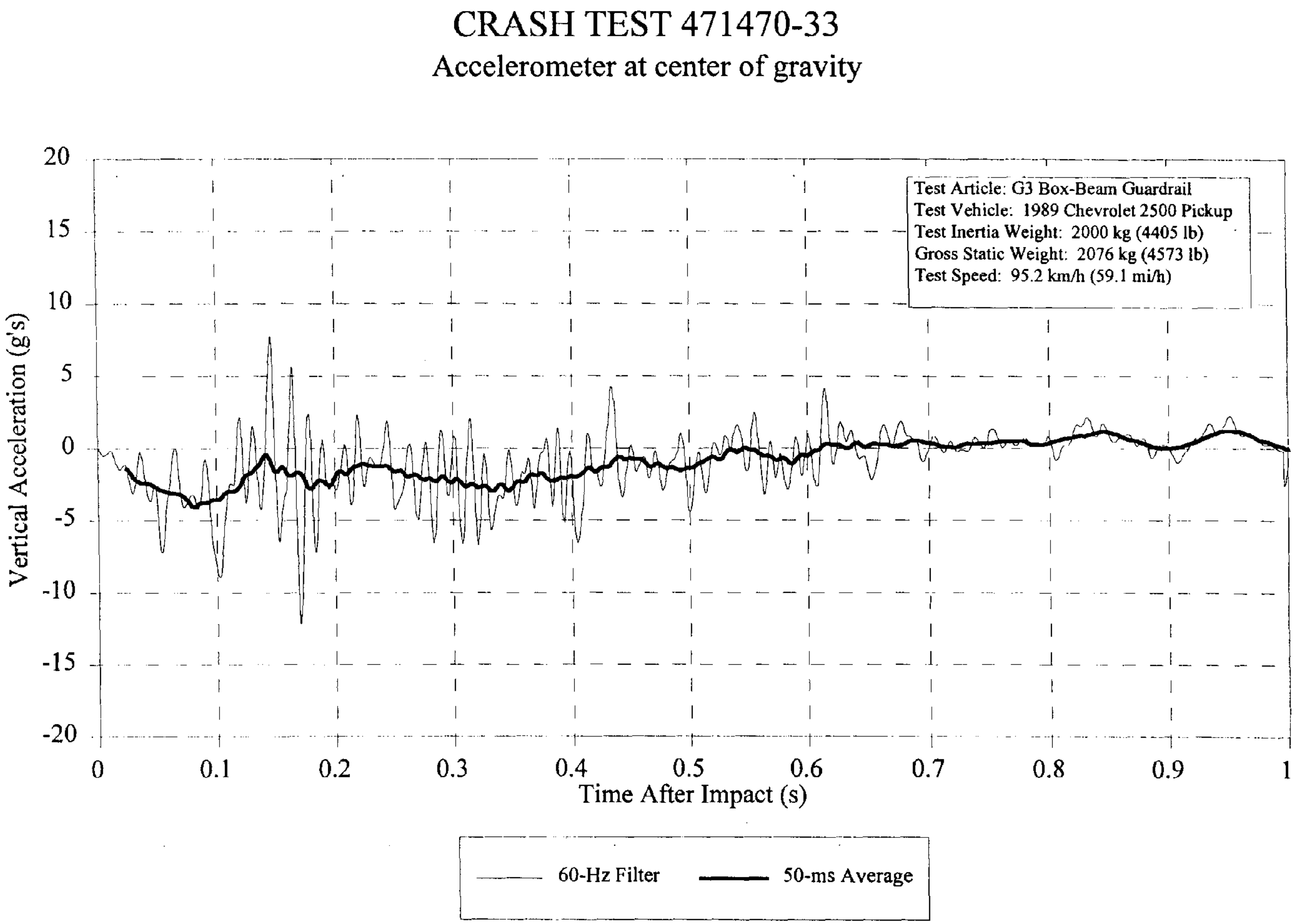
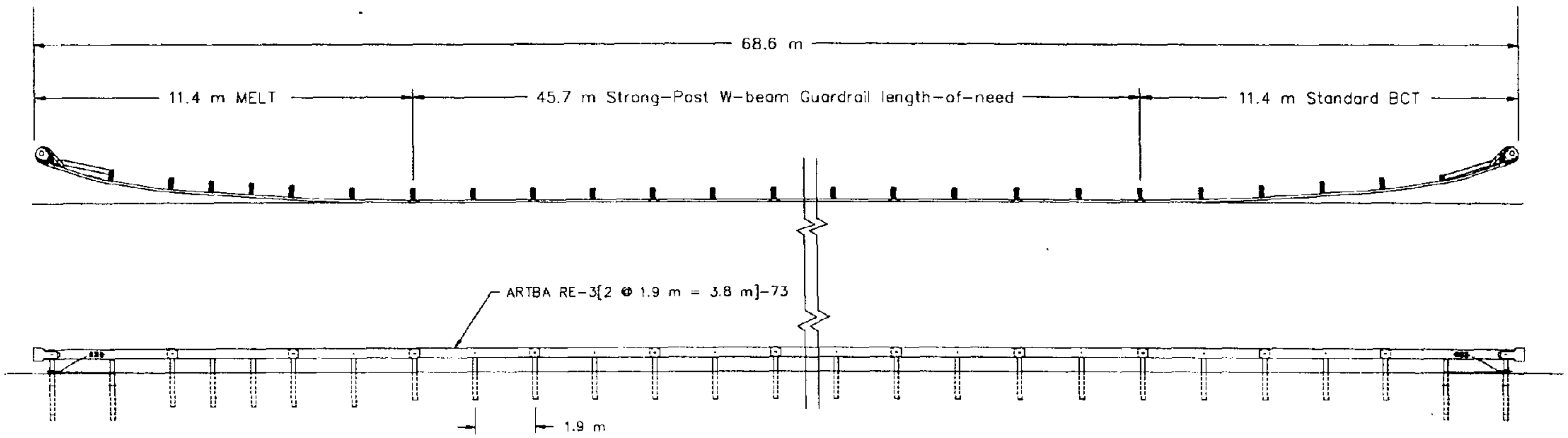
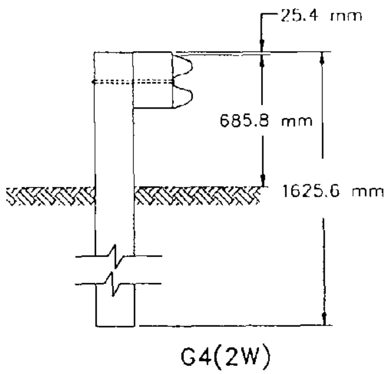


Figure 67. Vehicle vertical accelerometer trace for test 471470-33.





	G4(2W)	G4(1S)
Post Type:	152x203 Wood	W152x216 Steel
Post Spacing	1.9 m	1.9 m
Beam Type:	12 ga. W-beam	12 ga. W-beam
Blockout:	152x203x356 Wood	W152x216x356 steel
Mountings:	16 mm dia. carriage bolts	16 mm dia. bolt

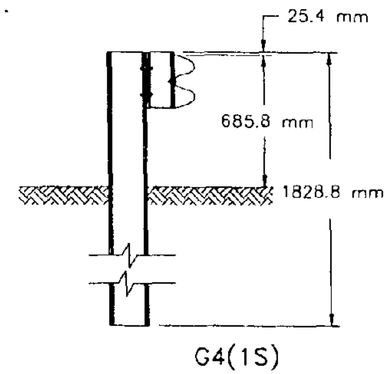


Figure 68. Layout of the W-beam, wood-post (G4(2W)) guardrail installation.

Figure 69. W-beam, wood-post (G4(2W)) guardrail before test 471470-26.

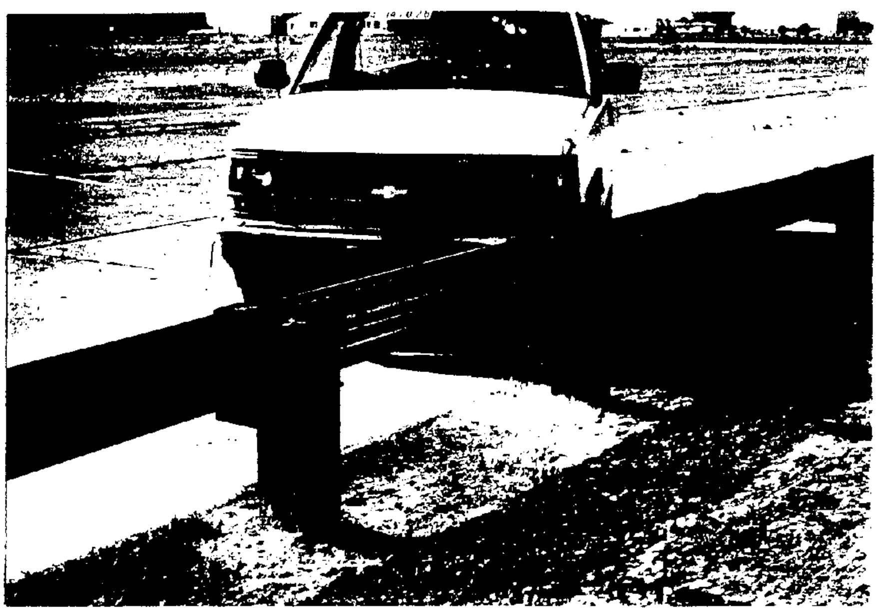


Figure 70. Vehicle/guardrail geometrics for test 471470-26.

Figure 71. Vehicle before test 471470-26.

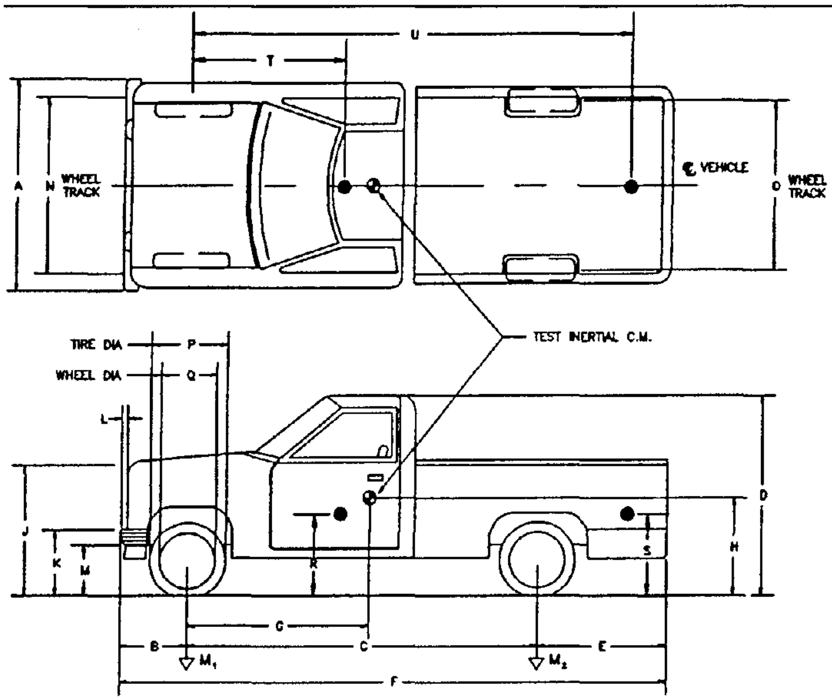
DATE: 05-25-94 TEST NO.: 471470-26 VIN NO: 1GCFC24K7KZ120532 MAKE: Chevrolet

MODEL: 2500 YEAR: 1989 ODOMETER: 246673 GVW: 03266

TIRE SIZE: LT 225 75R16 TIRE INFLATION PRESSURE: ______ TREAD TYPE: ______

MASS DISTRIBUTION (kg) LF 554 RF 526 LR 461 RR 459

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 cyl gas

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

— MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	1860	E	1340	J	1045	N	1570	R	710
B	800	F	5490	K	650	O	1620	S	1030
C	3350	G	1541	L	90	P	790	T	1500
D	1800	H		M	430	Q	440	U	4160

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1086	1080	1124
M_2	763	920	950
M_T	1849	2000	2074

Figure 72. Vehicle properties for test 471470-26.

As the damaged front end of the vehicle contacted the ground, the vehicle righted itself and began to yaw counterclockwise, subsequently coming to rest 80 m (263 ft) downstream and 10.7 m (35 ft) forward of the point of impact. The vehicle had yawed approximately 150 degrees. Sequential photographs are shown in figures 73 and 74.

3.5.2 Damage to Test Installation

As can be seen in figures 75 and 76, the installation received moderate damage. The bolts were pulled out of the W-beam rail element at posts 15 and 16, and the blockout on post 16 was split. None of the posts broke off, but some posts were pushed back. The displacements of the posts are shown in table 4.

The W-beam rail element was deformed from posts 13 through 18 and there was evidence of tire contract with posts 14 through 17. Maximum dynamic deflection of the guardrail during the test was 0.82 m (2.7 ft) near post 16. Maximum permanent deformation of the guardrail was 0.69 m (2.25 ft) between posts 15 and 16. The vehicle was in contact with the guardrail system for a total length of 6.9 m (22.7 ft).

Table 4. Lateral post deflections for test 471470-26.

Post 10	nil	Post 15	330 mm (13.0 in)
Post 11	19 mm (0.75 in)	Post 16	343 mm (13.5 in)
Post 12	6 mm (0.25 in)	Post 17	121 mm (4.75 in)
Post 13	51 mm (2.00 in)	Post 18	38 mm (1.50 in)
Post 14	127 mm (5.00 in)	Post 19	6 mm (0.25 in)

3.5.3 Vehicle Damage

The vehicle sustained moderate damage, as shown in figure 77. The stabilizer bar, upper and lower A-arms, and tie rods on the left side were damaged, and the frame at the left front was bent. The left front spindle, wheel, and tire were separated from the vehicle. The front bumper, grill, and entire left side were also damaged. Maximum exterior crush at the left front corner of the vehicle was 370 mm (14.6 in) at bumper height. There was 44-mm (1.7-in) deformation of the occupant compartment in the floor pan area near the transmission tunnel.

3.5.4 Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. Occupant contact first occurred in the lateral direction. Lateral occupant impact velocity was 5.9 m/s (19.3 ft/s) at 0.144 s, the highest 0.010-second occupant ridedown acceleration was 11.4 g's between 0.239 and 0.249 s

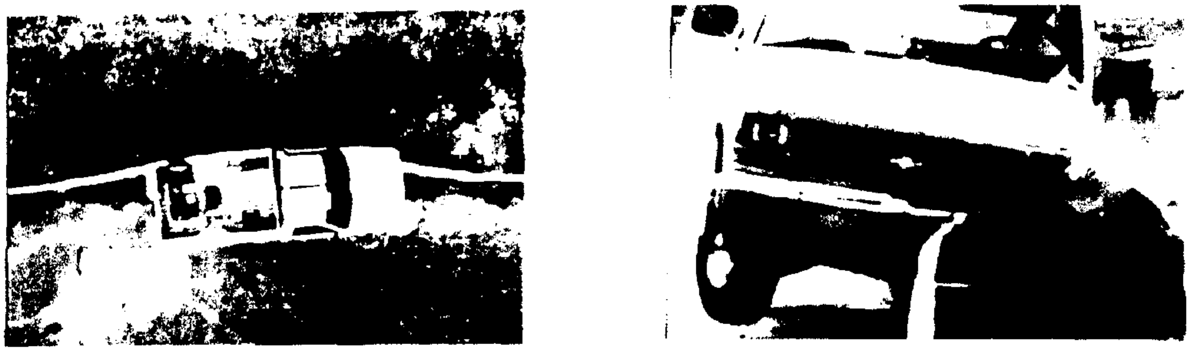
0.000 s

0.061 s

0.119 s

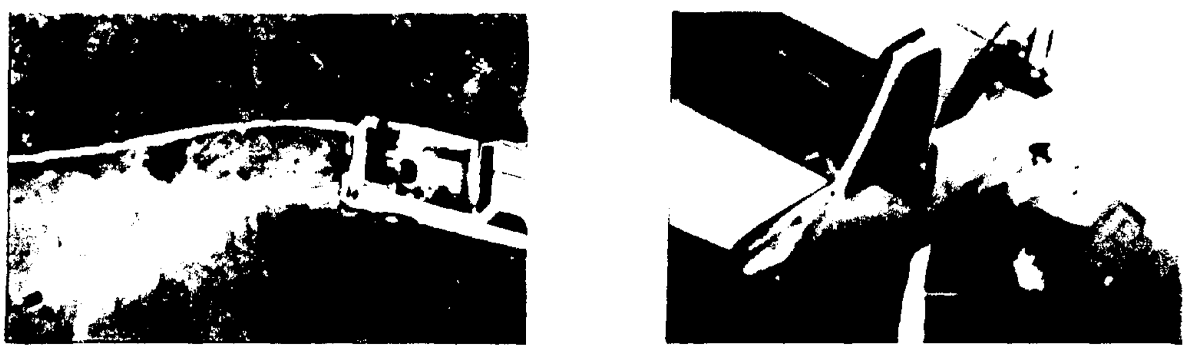
0.180 s

Figure 73. Sequential photographs for test 471470-26
(overhead and frontal views).



0.241 s

0.361 s



0.480 s

0.599 s

Figure 73. Sequential photographs for test 471470-26
(overhead and frontal views) (continued).

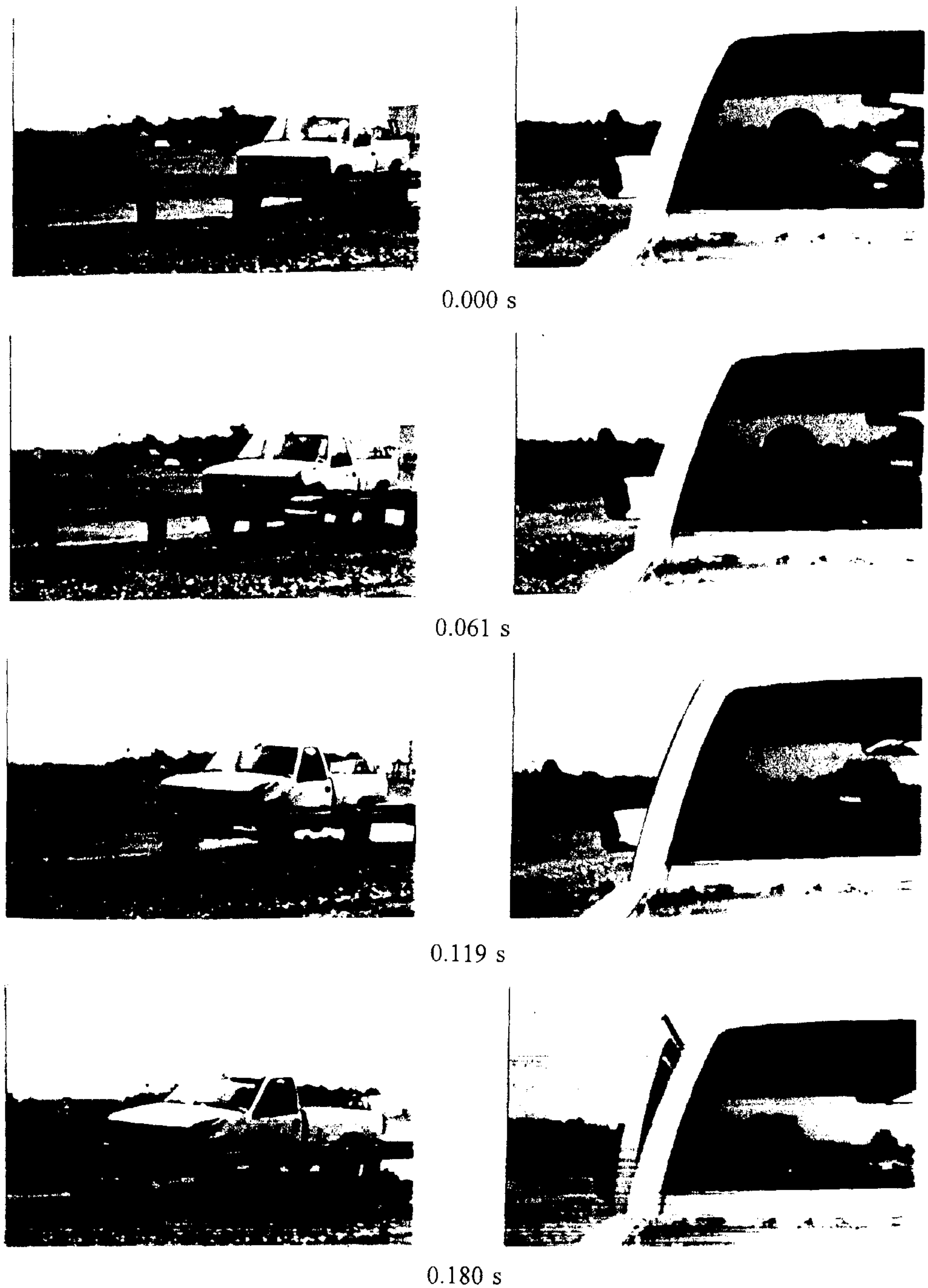
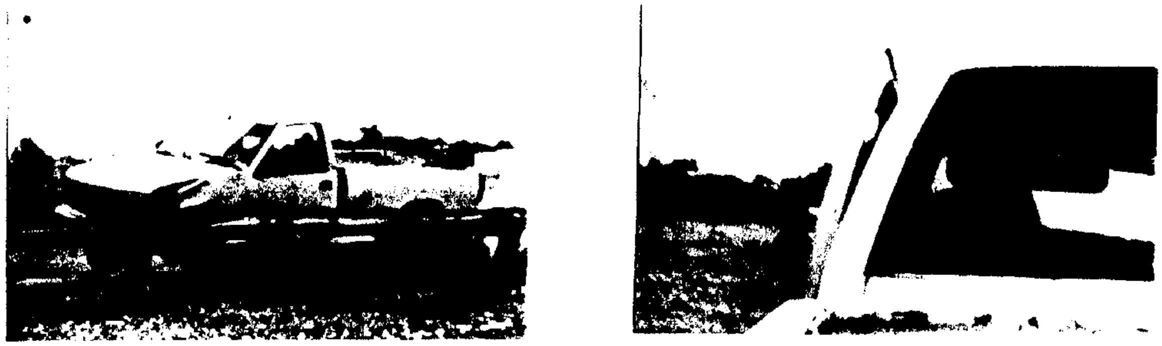
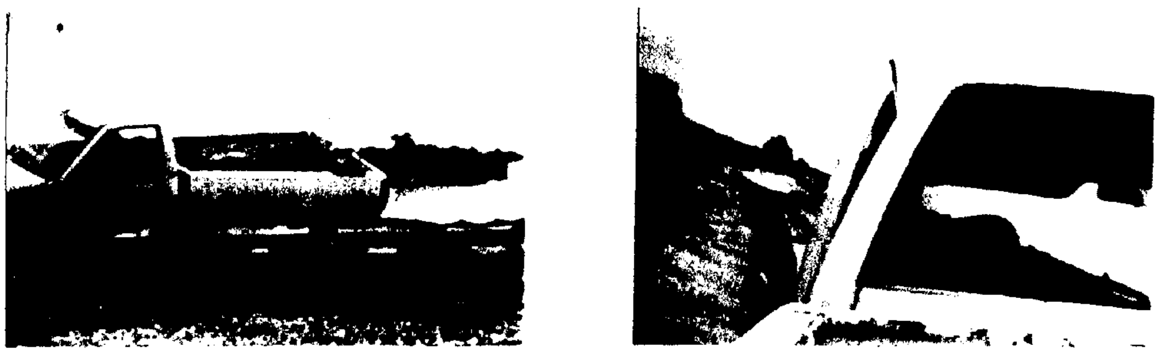


Figure 74. Sequential photographs for test 471470-26
(rear and interior views).



0.241 s



0.361 s

0.480 s

0.599 s

Figure 74. Sequential photographs for test 471470-26
(rear and interior views) (continued).

Figure 75. W-beam, wood-post (G4(2W)) guardrail installation after test 471470-26.

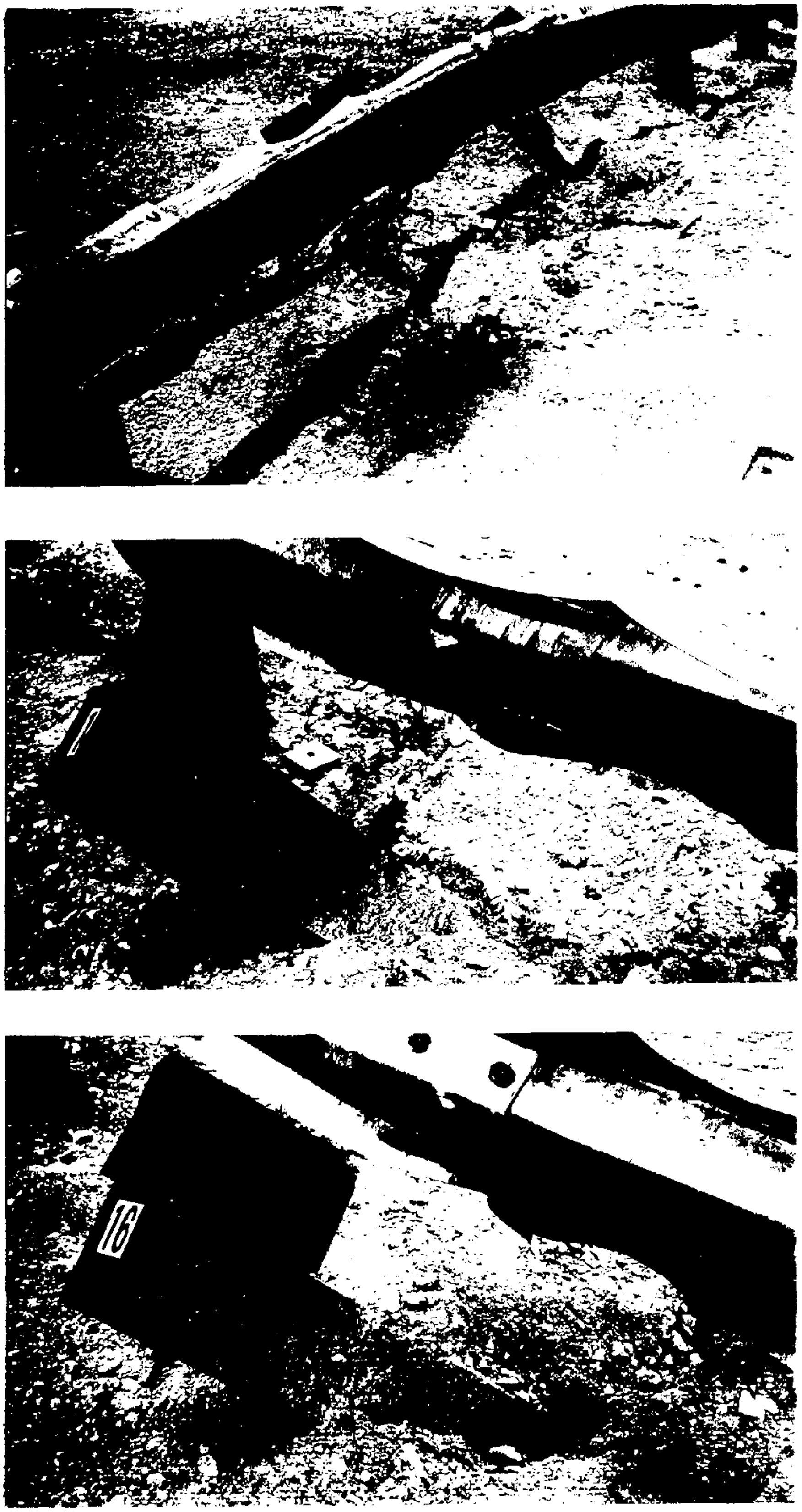


Figure 76. Damage at posts 15 and 16, test 471470-26.

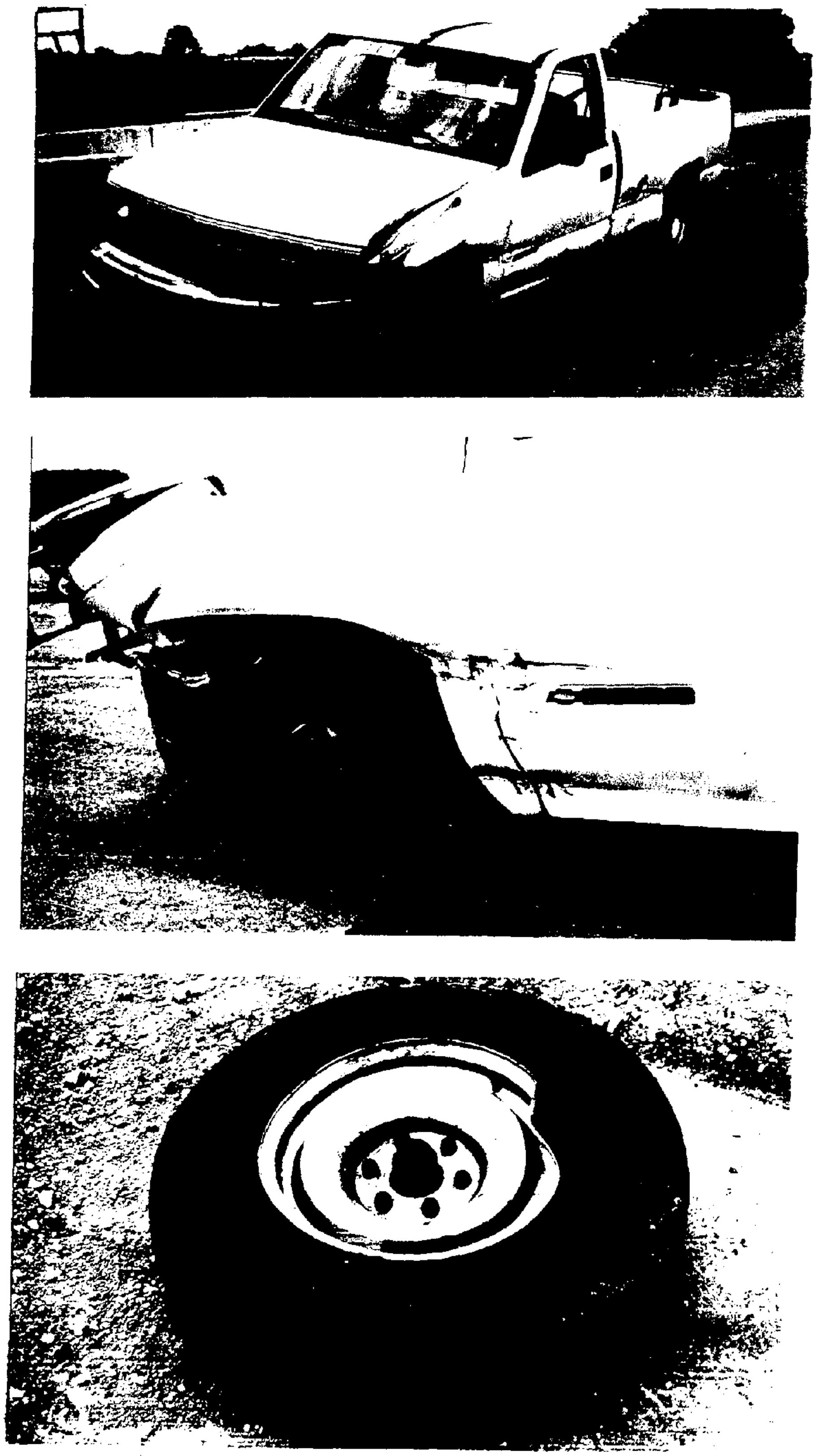


Figure 77. Vehicle after test 471470-26.

and the maximum 0.050-second average acceleration was 6.8 g's between 0.095 and 0.145 s. In the longitudinal direction, occupant impact velocity was 7.5 m/s (24.5 ft/s); the highest 0.010-s average ridedown acceleration was -11.4 g's between 0.203 and 0.213 s, and the maximum 0.050-s average acceleration was -6.1 g's between 0.139 and 0.189 s. These data and other pertinent information from the test are summarized in figure 78. Vehicular angular displacements are displayed in figure 79. Vehicular accelerations versus time traces filtered at 60 Hz are presented in figures 80 through 82.

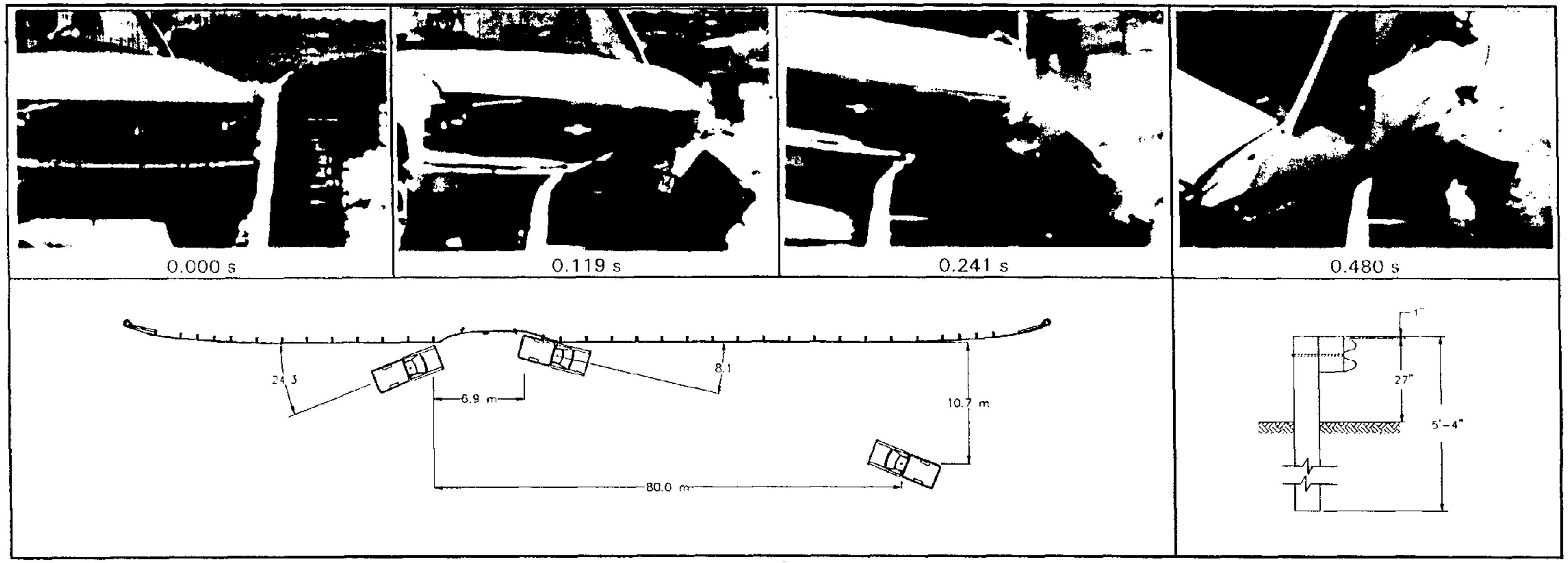
3.6 W-BEAM, STEEL-POST (G4(1S)) GUARDRAIL SYSTEM (TEST NO. 471470-27)

The test installation consisted of a 45.7-m- (150-ft-) long section of the standard G4(1S) length-of-need section, with a MELT at the upstream end and a standard BCT at the downstream end, for a total installation length of 68.6 m (225 ft). The layout of the test installation is shown in figure 83 and photographs of the test installation is shown in figure 84.

A 1988 Chevrolet 2500 pickup truck, shown in figures 85 and 86, was used for the crash test. Test inertia mass or empty weight of the vehicle was 2000 kg (4409 lb) and its gross static mass or test weight was 2075 kg (4570 lb), including a restrained 50th-percentile male anthropomorphic dummy placed in the driver's position of the vehicle. The heights to the upper and lower edges of the vehicle bumper were 650 mm (25.6 in) and 420 mm (16.5 in), respectively. Additional dimensions and information on the vehicle are given in figure 87. 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.

3.6.1 Test Description

The vehicle impacted the length-of-need section 0.61 m (2 ft) upstream of post 14, or 4.5 m (14.5 ft) upstream of the splice at post 16, traveling at a speed of 101.4 km/h (63.0 mi/h) and at an angle of 26.1 degrees. As the vehicle impacted the guardrail, the W-beam rail element began to deform, and posts 13 and 14 began to displace laterally. The vehicle impacted post 14 shortly thereafter, and movement began at post 15. At 0.035 s after impact, the left front tire of the vehicle contacted post 15 and, as the vehicle continued forward, the tire aired out and began to fold under. Redirection of the vehicle began at 0.045 s. Movement began at post 16 at 0.063 s and at post 17 at 0.120 s. The body of the vehicle began to bow upward in the center (between the cab and bed) at 0.164 s. At 0.213 s, the left front tire snagged on post 16 and the body of the vehicle began to bow substantially. The rear of the vehicle made contact with the W-beam rail at 0.229 s. The vehicle was parallel with the installation at 0.274 s, traveling at 66.0 km/h (41.0 mi/h). As the vehicle traveled past post 17 at 0.300 s, the left front tire made slight contact with the post. Maximum deflection of the W-beam rail of 1.01 m (3.3 ft) occurred at 0.365 s. The vehicle lost contact with the installation at 0.530 s, traveling at a speed of 58.7 km/h (36.5 mi/h) and at an exit trajectory of 5.2 degrees. As the vehicle exited the rail, it had rolled 28 degrees



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-26
Date	05/25/94
Test Article	
Type	Guardrail
Name or Manufacturer	G4(2W)
Installation Length (m)	69 m (225 ft)
Size and/or Dimension and Material of Key Elements	G4(2W) Guardrail System with MELT End Terminals
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500
Mass (kg) Curb	1849 (4073 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2074 (4568 lb)

Impact Conditions	
Speed (km/h)	100.8 (62.6 mi/h)
Angle (deg)	24.3
Exit Conditions	
Speed (km/h)	70.8 (44.0 mi/h)
Angle (deg)	8.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.5 (24.5 ft/s)
y-direction	5.9 (19.3 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-11.6
y-direction	11.4
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.1
y-direction	6.8
z-direction	9.1

Test Article Deflections (m)	
Dynamic	0.82 (2.7 ft)
Permanent	0.69 (2.25 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ5
CDC	11FLEK2 & 11LDLW4
Interior	
OCDI	FS0100000
Maximum Exterior Vehicle Crush (mm)	370 (14.6 in)
Max. Occ. Compart. Deformation (mm)	44 (1.7 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-40
Max. Pitch Angle (deg)	-12
Max. Yaw Angle (deg)	47

Figure 78. Summary of results for test 471470-26.

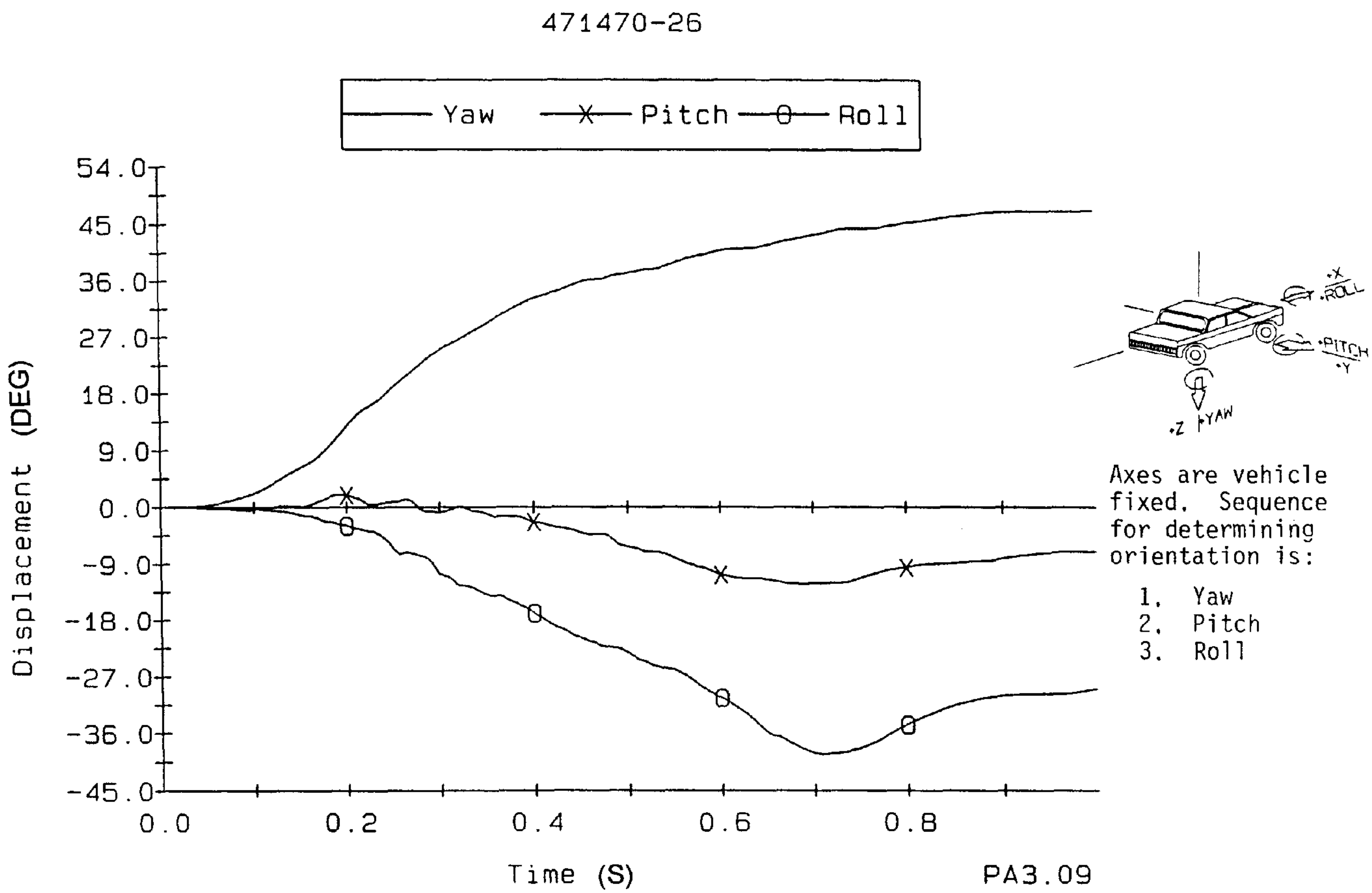


Figure 79. Vehicle angular displacements during test 471470-26.

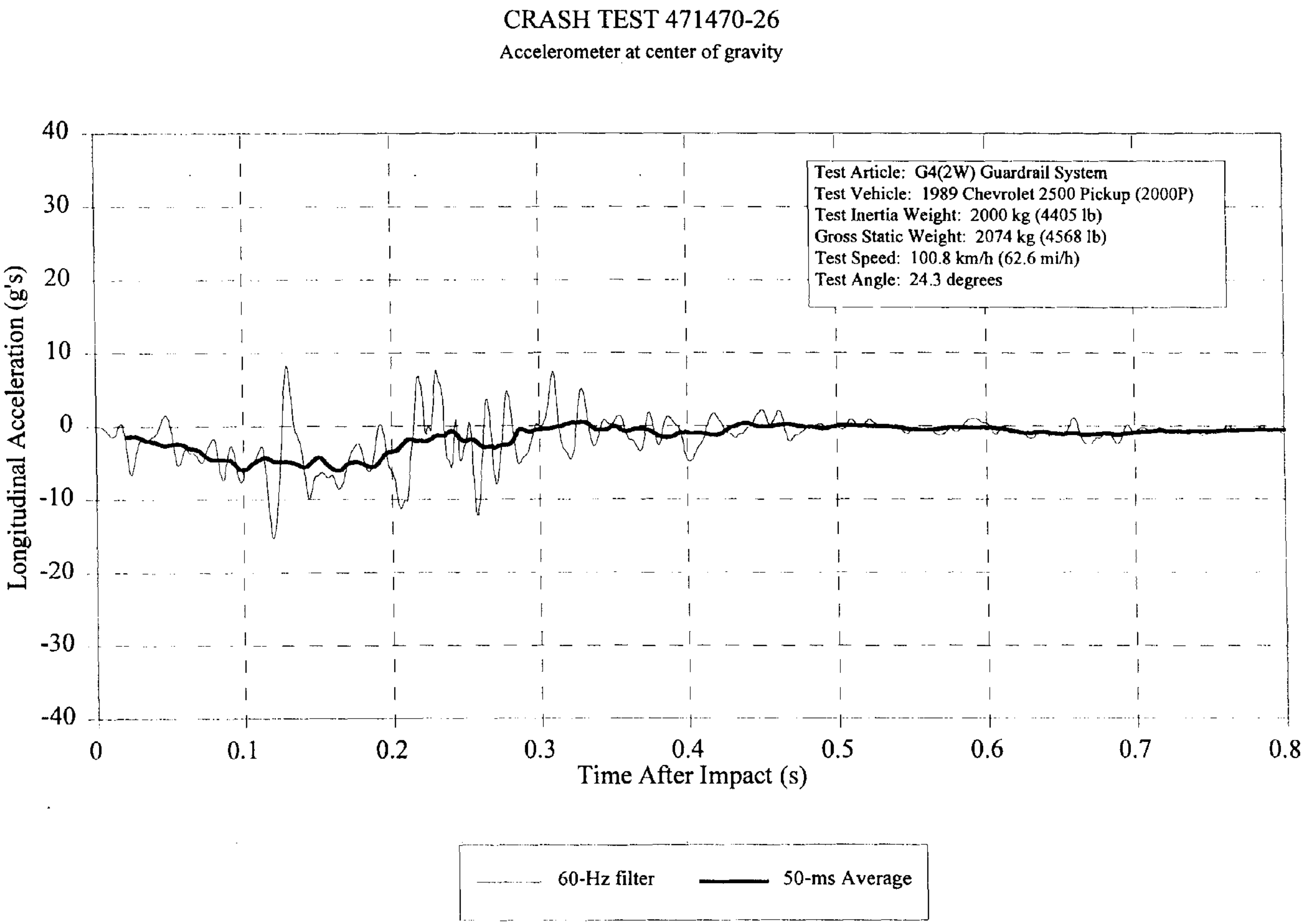


Figure 80. Vehicle longitudinal accelerometer trace for test 471470-26.

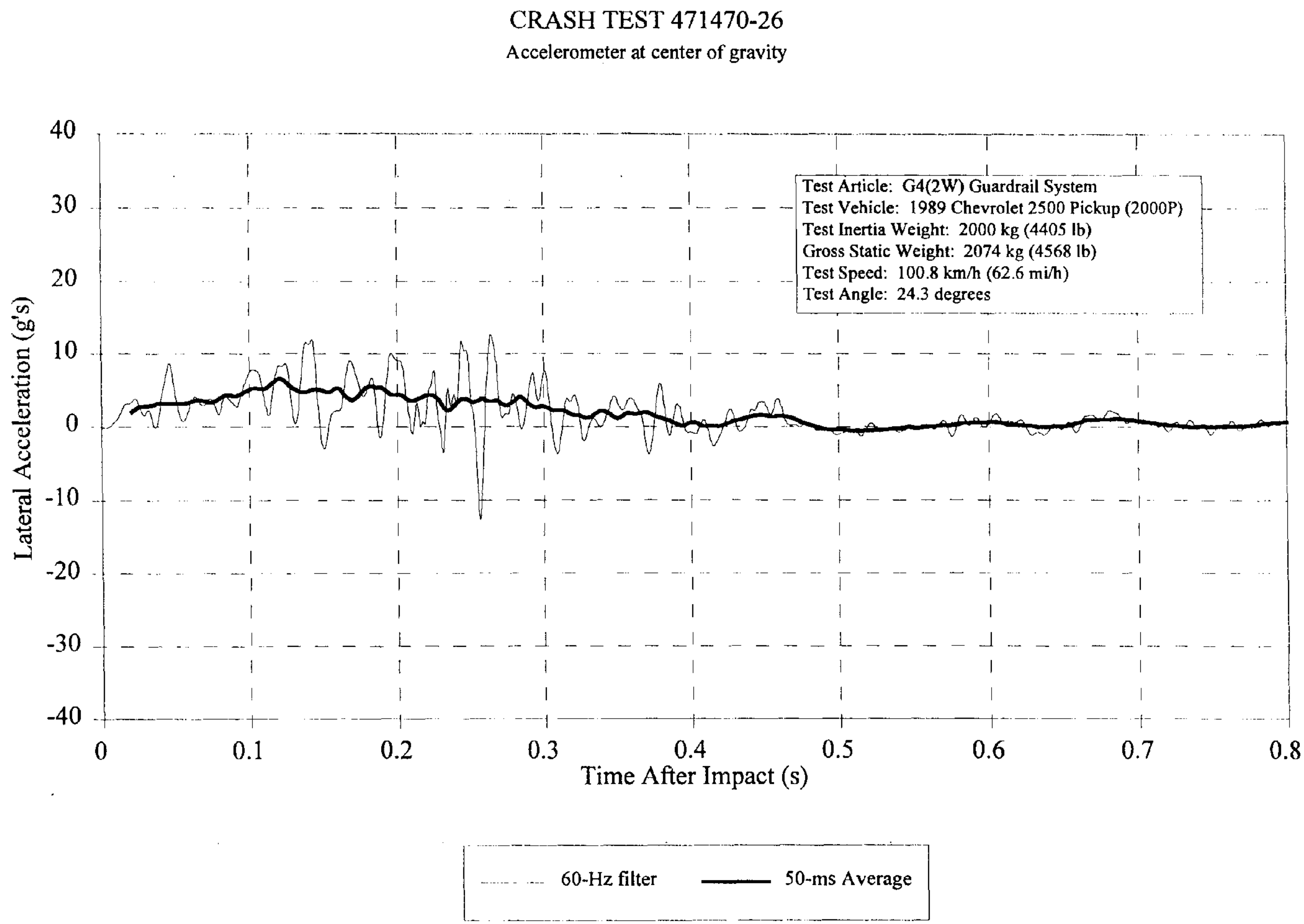


Figure 81. Vehicle lateral accelerometer trace for test 471470-26.

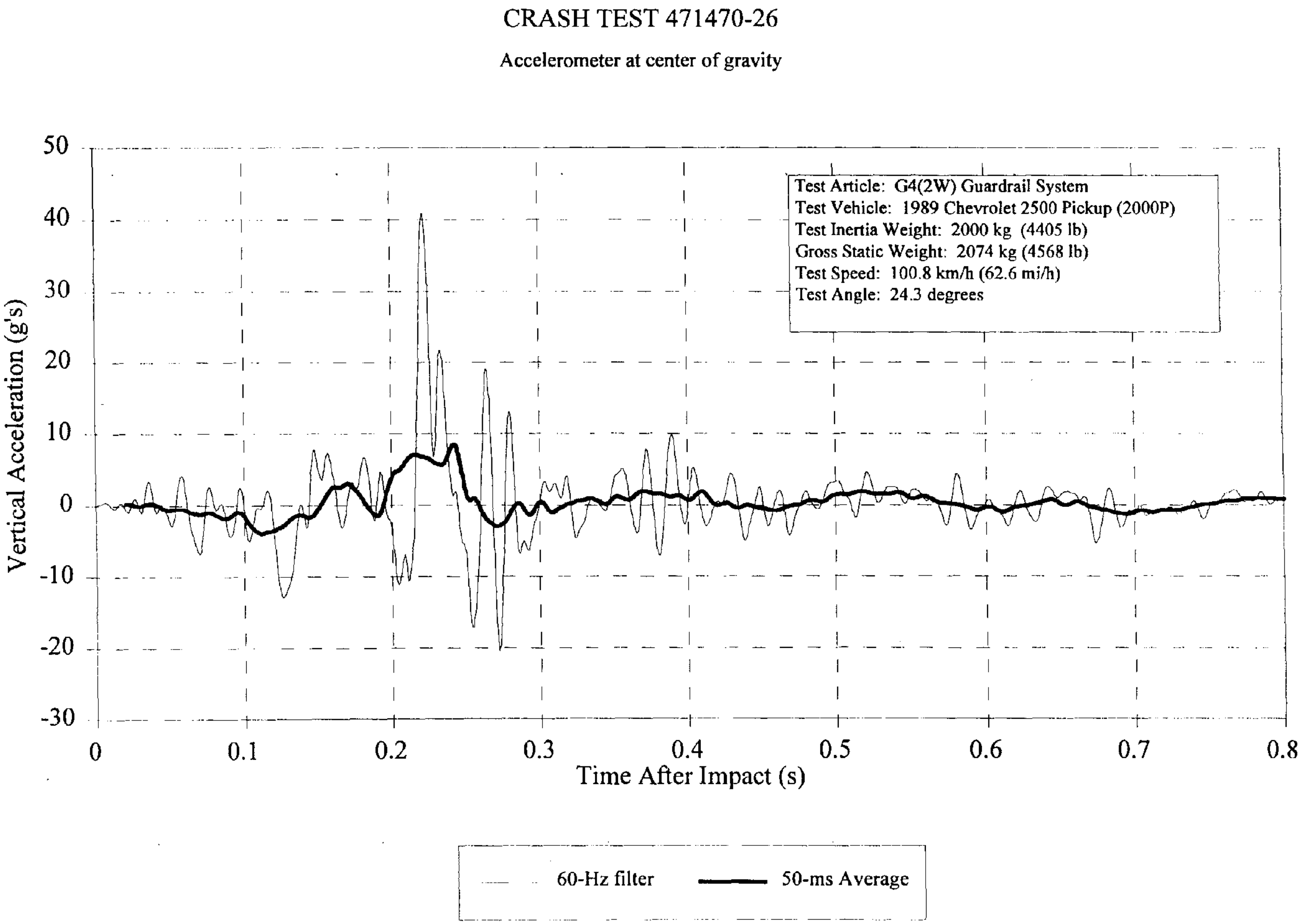
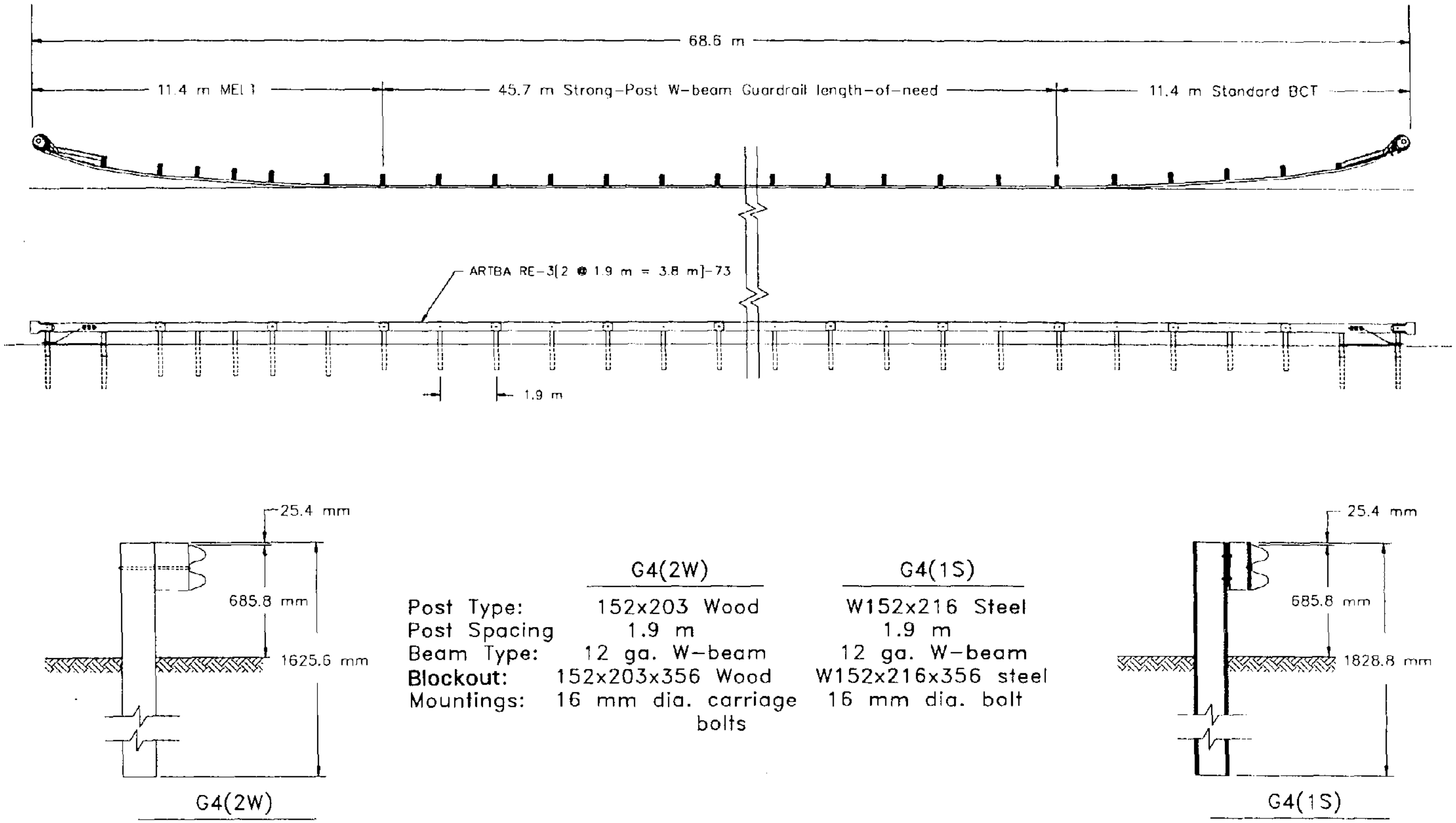


Figure 82. Vehicle vertical accelerometer trace for test 471470-26.



	G4(2W)	G4(1S)
Post Type:	152x203 Wood	W152x216 Steel
Post Spacing	1.9 m	1.9 m
Beam Type:	12 ga. W-beam	12 ga. W-beam
Blockout:	152x203x356 Wood	W152x216x356 steel
Mountings:	16 mm dia. carriage bolts	16 mm dia. bolt

Figure 83. Layout of the W-beam, steel-post (G4(1S) guardrail installation.

Figure 84. W-beam, steel-post (G4(1S)) guardrail installation before test 471470-27.

Figure 85. Vehicle/guardrail geometrics for test 471470-27.

Figure 86. Vehicle before test 471470-27.

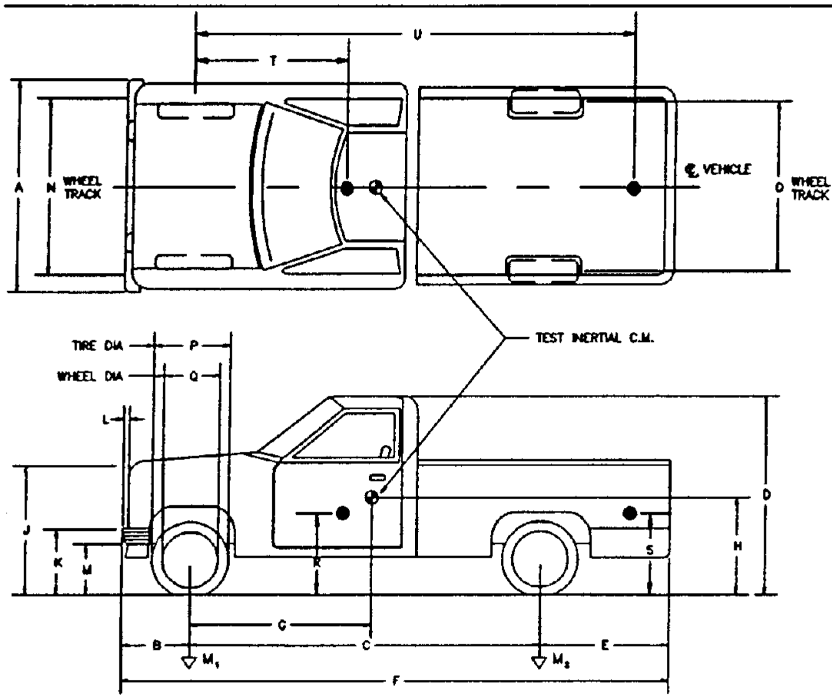
DATE: 06-09-94 TEST NO.: 471470-27 VIN NO.: 2GCFC24K8J1142885 MAKE: Chevrolet

MODEL: 2500 YEAR: 1988 ODOMETER: 143072 GVW: ______

TIRE SIZE: LT 235/85R16 TIRE INFLATION PRESSURE: ______ TREAD TYPE: ______

MASS DISTRIBUTION (kg) LF 541 RF 539 LR 473 RR 447

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 cyl gas

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

— MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	1900	E	1280	J	1010	N	1580	R	1070
B	770	F	5400	K	650	O	1640	S	720
C	3350	G	1541	L	80	P	780	T	1420
D	1830	H		M	420	Q	440	U	4140

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1106	1080	1121
M_2	838	920	954
M_T	1944	2000	2075

Figure 87. Vehicle properties for test 471470-27.

counterclockwise and was yawing clockwise. As the damaged front end of the vehicle contacted the ground, the vehicle continued to roll onto its left side and subsequently slid to rest on its left side 34 m (112 ft) downstream and 6.7 m (22 ft) forward of the point of impact. Sequential photographs are shown in figures 88 and 89.

3.6.2 Damage to Test Installation

As can be seen in figures 90 and 91, the installation received moderate damage. The MELT anchor on the upstream end had pulled up slightly and moved laterally 44.5 mm (1.75 in). The buffered end nose was pulled off the end post (post 1). The bolts were pulled out of the W-beam rail element at posts 15, 16, and 17, and the posts and blockouts were bent. All the steel posts upstream of impact were disturbed, with measurable displacements as shown in table 5.

Table 5. Lateral post deflections for test 471470-27.

Post 12	13 mm (0.50 in)	Post 16	279 mm (11.0 in)
Post 13	63 mm (2.50 in)	Post 17	165 mm (6.50 in)
Post 14	146 mm (5.75 in)	Post 18	13 mm (0.50 in)
Post 15	330 mm (13.0 in)	Post 19	13 mm (0.50 in)

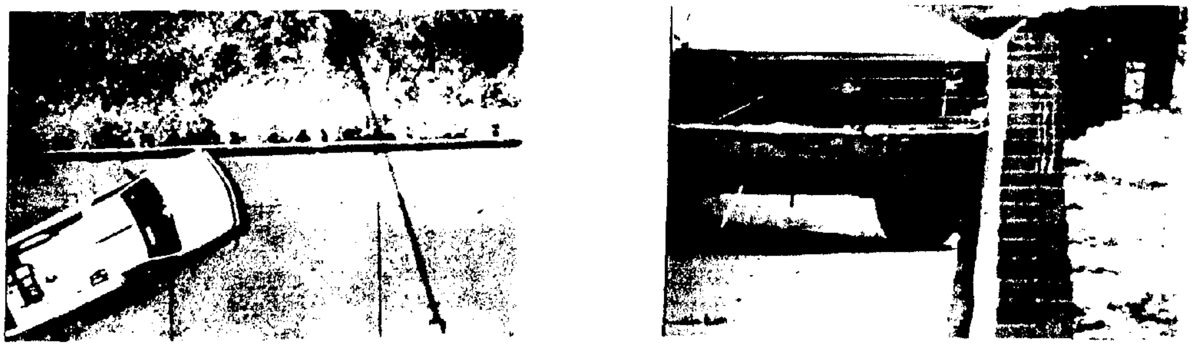
The W-beam rail element was deformed between posts 14 through 18 and there was evidence of tire contract with posts 15 through 17. Maximum dynamic deflection of the guardrail during the test was 1.01 m (3.3 ft). Maximum permanent deformation of the guardrail was 0.73 m (2.4 ft) between posts 15 and 16. The vehicle was in contact with the guardrail system for a total length of 8.1 m (26.5 ft).

3.6.3 Vehicle Damage

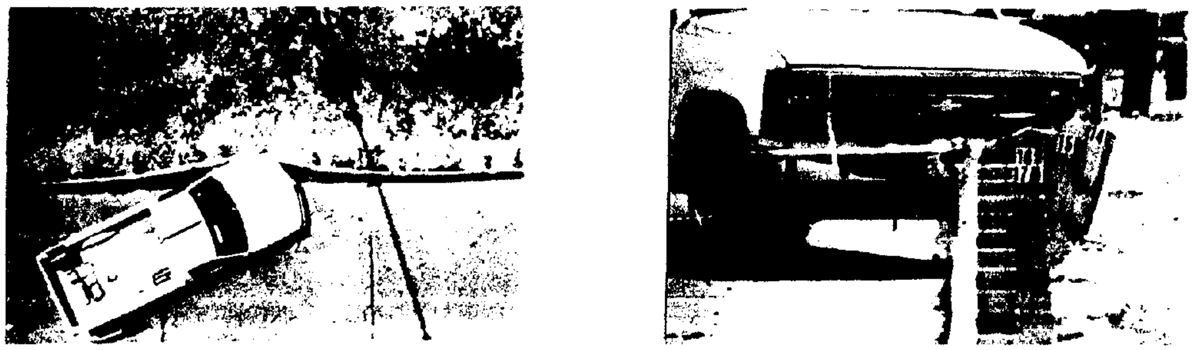
The vehicle sustained moderate damage, as shown in figures 92 and 93. The stabilizer bar, upper and lower A-arms, and tie rods on the left side were damaged, and the frame at the left front was bent. The left front spindle, wheel, and tire were damaged. The front bumper, grill, hood, radiator, windshield, and entire left side also were damaged. Maximum exterior crush at the left front corner of the vehicle was 570 mm (22.4 in) at bumper height. There was 53-mm (2.1-in) deformation of the occupant compartment in the floor pan area on the driver's side.

3.6.4 Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. Occupant contact first occurred in the lateral direction. Lateral occupant impact velocity was 4.9 m/s (16.0 ft/s) at 0.158 s, the highest 0.010-s occupant ridedown acceleration was 6.2 g's between 0.334 and 0.344 s; and the maximum 0.050-s average acceleration was 4.7 g's between 0.105 and 0.155 s. In the

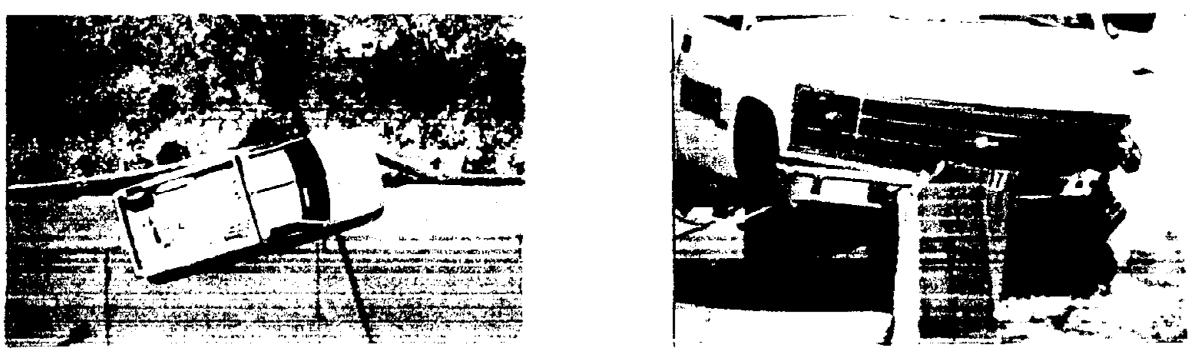


0.000 s



0.060 s

0.121 s



0.181 s

Figure 88. Sequential photographs for test 471470-27
(overhead and frontal views).

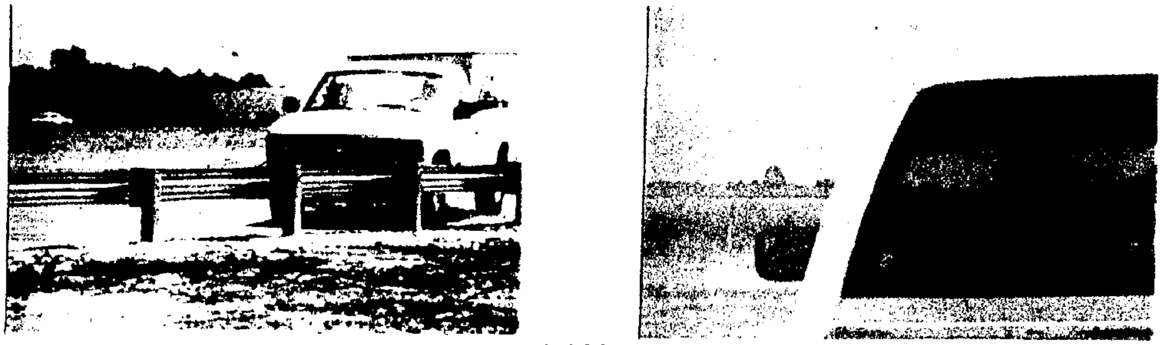
0.239 s

0.335 s

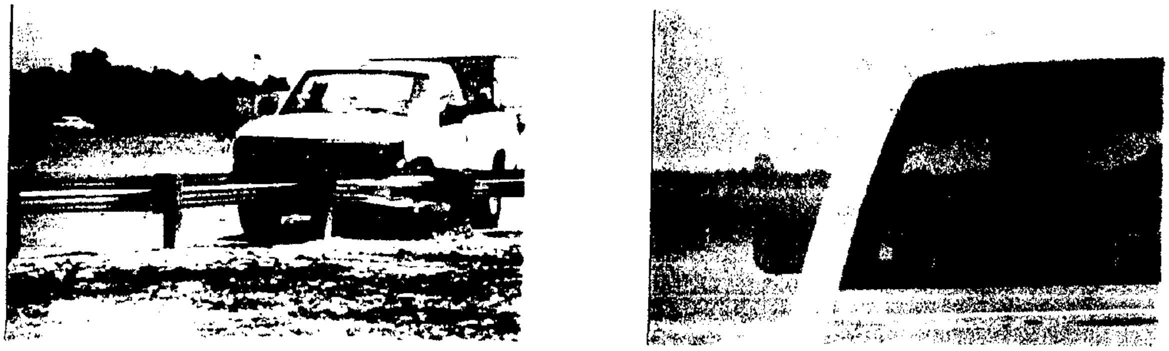
0.430 s

0.525 s

Figure 88. Sequential photographs for test 471470-27
(overhead and frontal views) (continued).

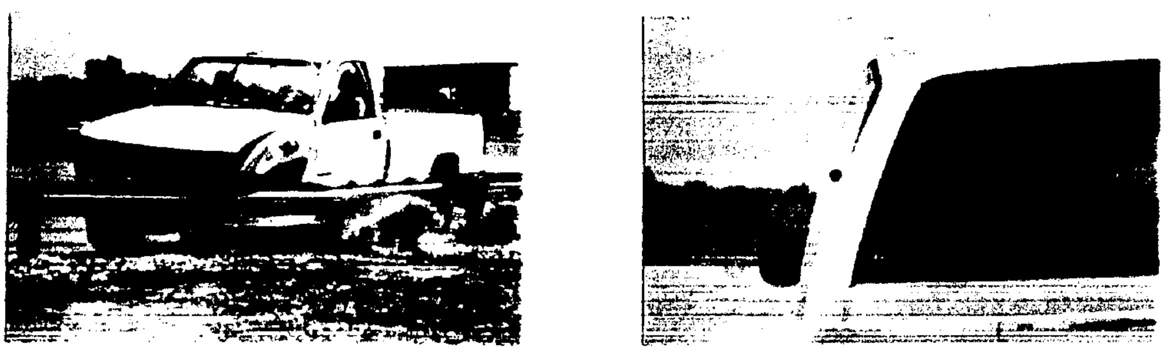


0.000 s



0.060 s

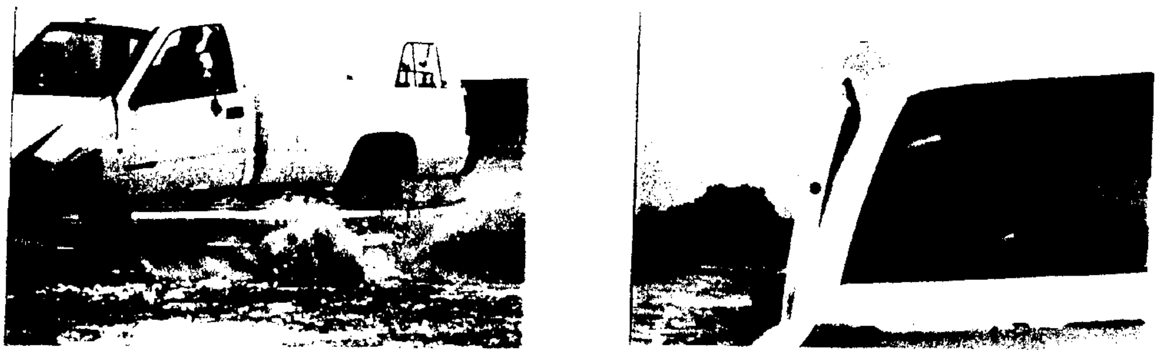
0.121 s



0.181 s

Figure 89. Sequential photographs for test 471470-27
(rear and interior views).

0.239 s



0.335 s

0.430 s

0.525 s

Figure 89. Sequential photographs for test 471470-27
(rear and interior views) (continued).

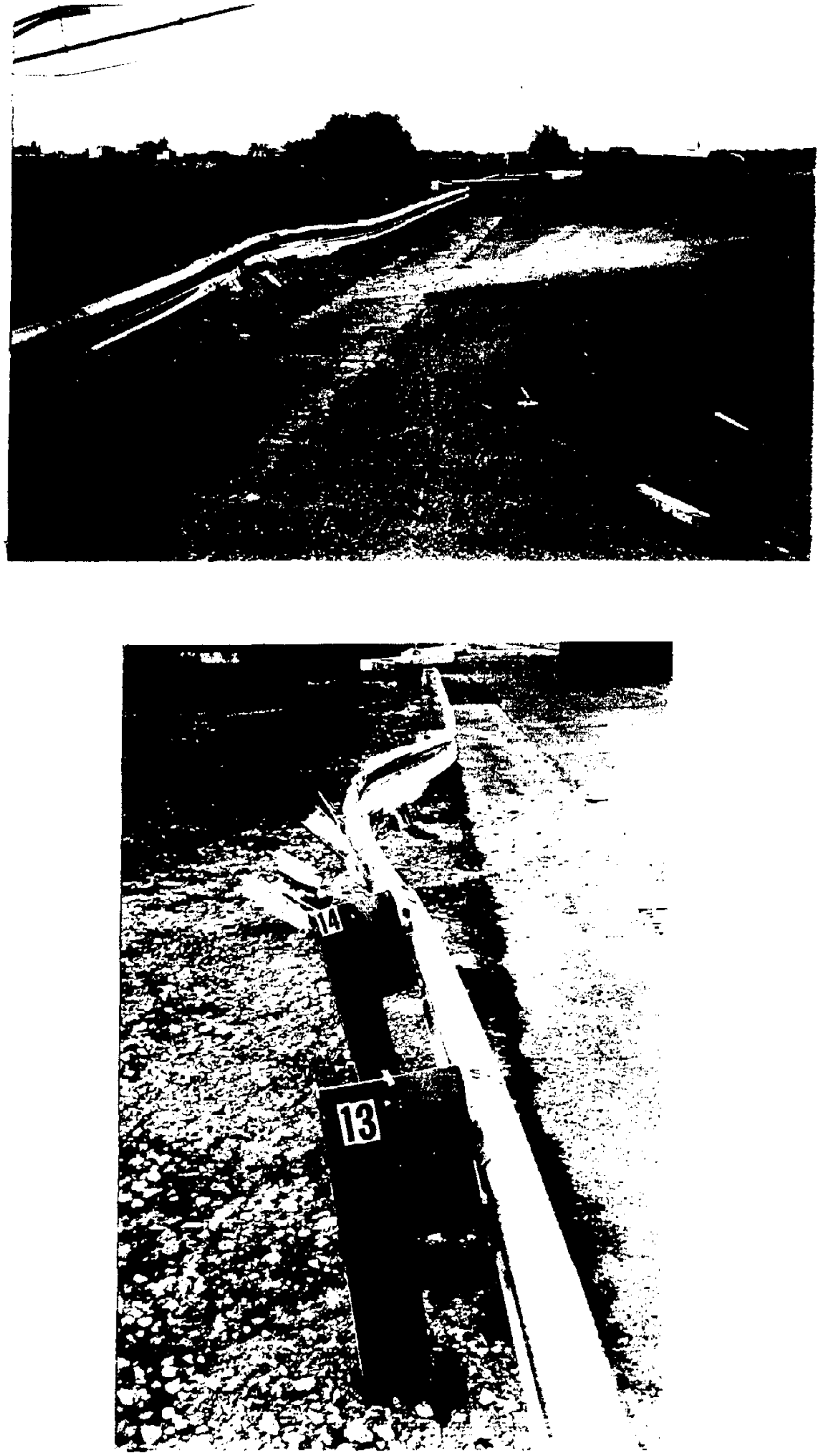
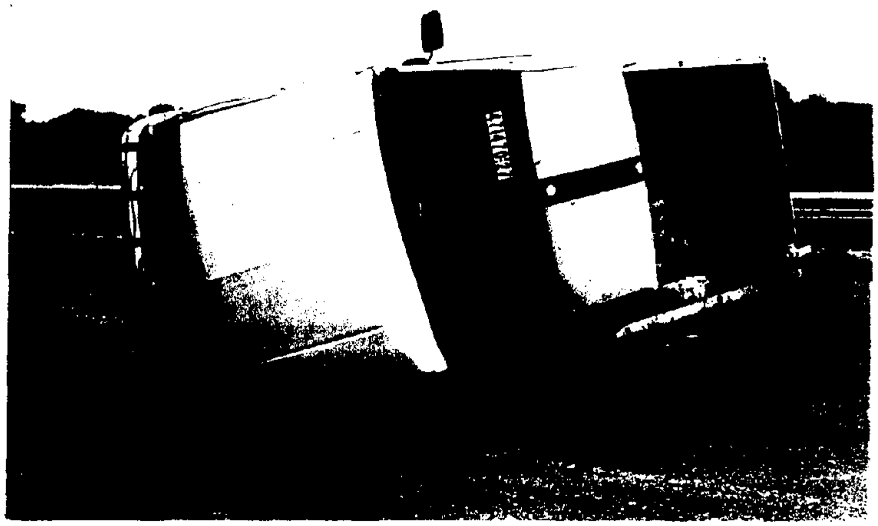


Figure 90. W-beam, steel-post (G4(1S)) guardrail installation after test 471470-27.

Figure 91. Damage at posts 14 through 17, test 471470-27.



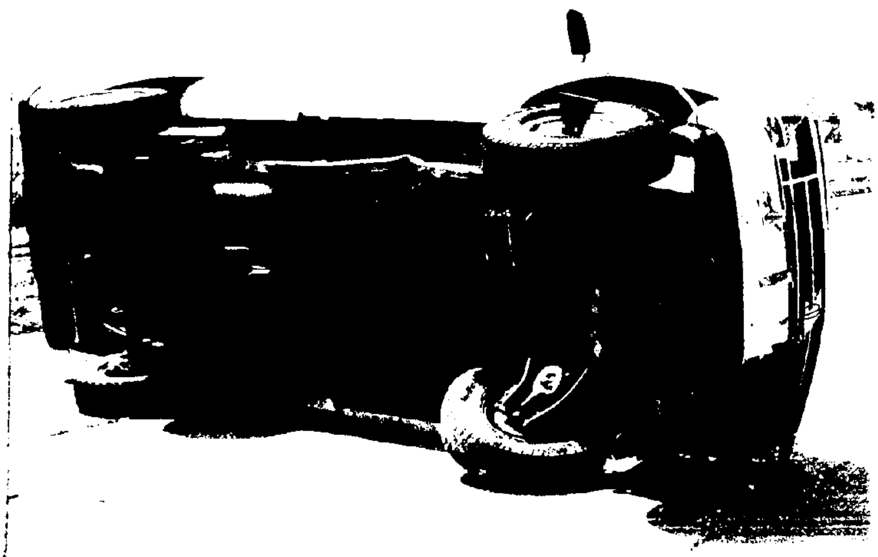


Figure 92. Vehicle after test 471470-27.

Figure 93. Vehicle after being uprighted, test 471470-27.

longitudinal direction, occupant impact velocity was 7.5 m/s (24.8 ft/s); the highest 0.010-s average ridedown acceleration was -7.8 g's between 0.229 and 0.239 s, and the maximum 0.050-s average acceleration was -6.0 g between 0.111 and 0.161 s. These data and other pertinent information from the test are summarized in figure 94. Vehicular angular displacements are displayed in figure 95. Vehicular accelerations versus time traces filtered at 60 Hz are presented in figures 96 through 98.

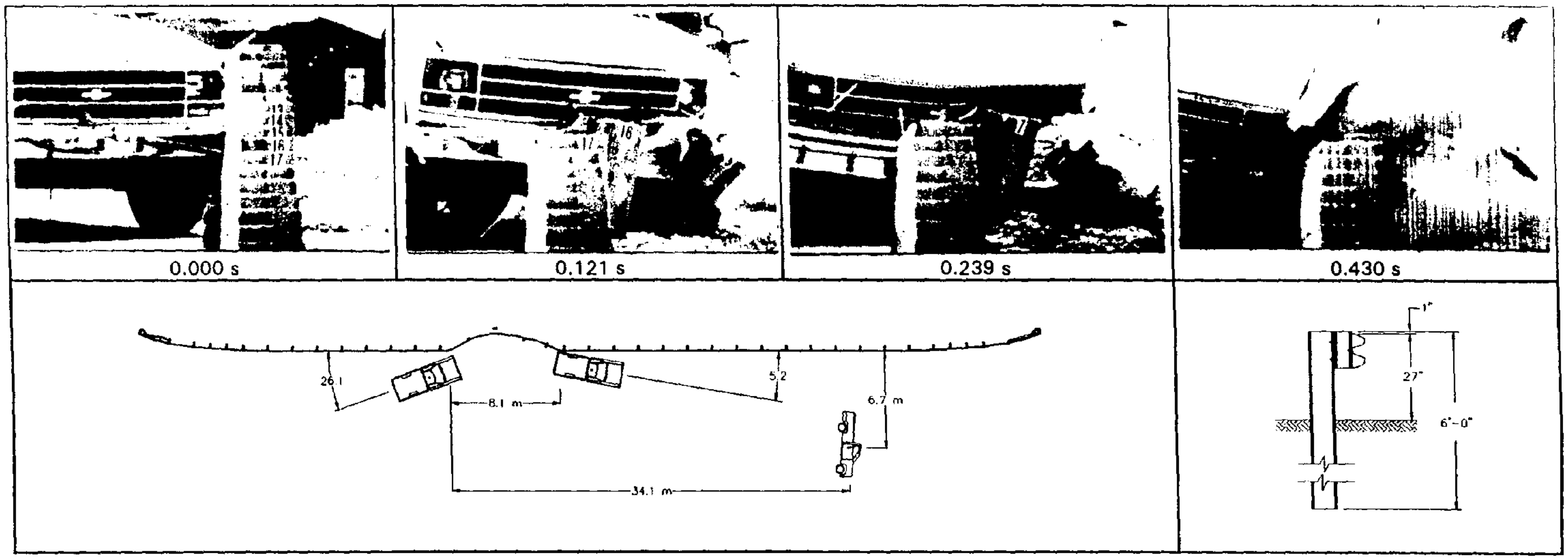
3.7 THRIE-BEAM (G9) GUARDRAIL SYSTEM (TEST NO. 471470-31)

The test installation consisted of a 30.5-m- (100-ft-) long length-of-need section of thrie-beam (G9) guardrail with a 1.9-m- (6-ft, 3-in-) long transition section from the thrie beam to the W-beam rail element, a 3.8-m- (12-ft, 6-in-) long section of standard steel-post, W-beam G4(1S) guardrail, and a 11.4-m- (37-ft, 6-in-) long MELT at each end, for a total installation length of 64.8 m (212 ft, 6 in). The layout of the test installation is shown in figure 99. Photographs of the test installation are shown in figures 100 and 101.

A 1990 GMC 2500 pickup (shown in figures 102 and 103) with a test inertia weight of 2000 kg (4409 lb) was used for the crash test. The gross static weight of the vehicle was 2076 kg (4573 lb), which included a restrained 50th-percentile male anthropomorphic dummy placed in the driver's position of the vehicle. The heights to the upper and lower edges of the vehicle bumper were 660 mm (26.0 in) and 440 mm (17.3 in), respectively. Additional dimensions and information on the vehicle are given in figure 104. 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.

3.7.1 Test Description

The vehicle impacted the length-of-need section 102 mm (4.0 in) upstream of post 15, traveling at a speed of 102.5 km/h (63.5 mi/h) and at an angle of 26.1 degrees. As the vehicle impacted the installation, the thrie-beam rail element began to deflect and redirection of the vehicle began at 0.054 s. At 0.073 s after impact, the left front wheel began to steer sharply toward the guardrail, and posts 16 and 17 began to rotate about their vertical axes. The left front tire caught the flanges of post 16 at 0.094 s and post 17 at 0.170 s. Maximum dynamic deflection of the thrie-beam rail element of 1.07 m (3.5 ft) occurred at 0.216 s between posts 17 and 18. At 0.260 s, the tire passed in front of post 18. The vehicle became parallel with the installation at 0.282 s, traveling at 67.5 km/h (41.9 mi/h). At 0.316 s, the rear of the vehicle contacted the thrie-beam rail element. The vehicle lost contact with the installation at 0.645 s, traveling at a speed of 54.5 km/h (33.9 mi/h), an exit angle of approximately 35 degrees, and a roll angle of roughly -45 degrees. As the vehicle exited the installation, it continued to roll counterclockwise and yaw clockwise. The vehicle rolled two and a quarter revolutions and came to rest on its left side 42 m (138 ft) down and 13 m (44 ft) forward of the initial point of impact with the front of the vehicle facing the direction of impact. Sequential photographs are shown in figures 105 and 106.



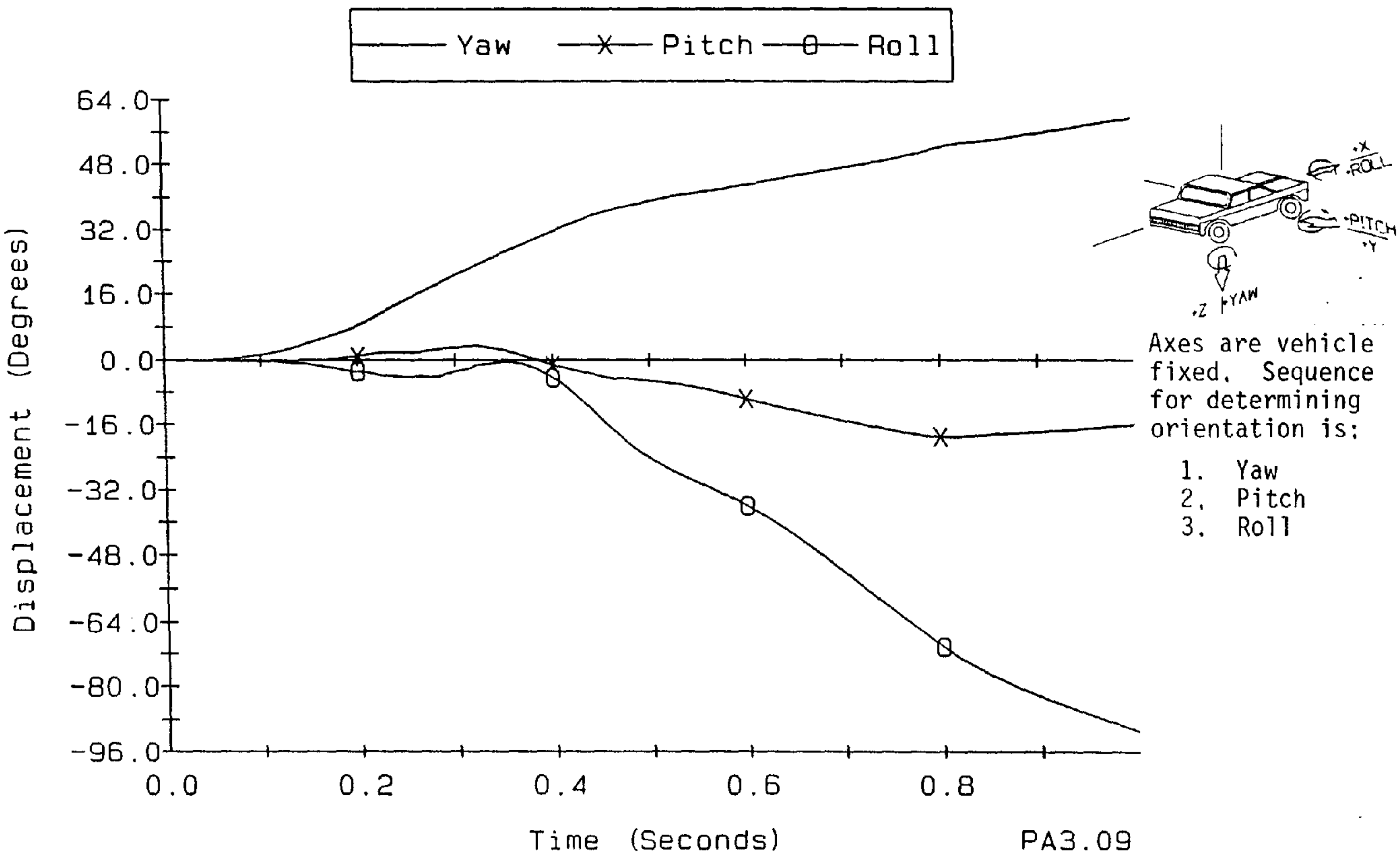
General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-27
Date	06/09/94
Test Article	
Type	Guardrail
Name or Manufacturer	G4(1S)
Installation Length (m)	69 m (225 ft)
Size and/or Dimension and Material of Key Elements	G4(1S) Guardrail System with MELT End Terminals
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1988 Chevrolet 2500
Mass (kg) Curb	1944 (4282 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2075 (4570 lb)

Impact Conditions	
Speed (km/h)	101.4 (63.0 mi/h)
Angle (deg)	26.1
Exit Conditions	
Speed (km/h)	58.7 (36.5 mi/h)
Angle (deg)	5.2
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.5 (24.8 ft/s)
y-direction	4.9 (16.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-7.8
y-direction	6.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.0
y-direction	4.7
z-direction	3.9

Test Article Deflections (m)	
Dynamic	0.91 (3.0 ft)
Permanent	0.64 (2.1 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ6 9L&T3
CDC	11FLEK3 & 00LDA03
Interior	
OCDI	LF0100000
Maximum Exterior Vehicle Crush (mm)	570 (22.4 in)
Max. Occ. Compart. Deformation (mm)	53 (2.1 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-119
Max. Pitch Angle (deg)	-19
Max. Yaw Angle (deg)	79

Figure 94. Summary of results for test 471470-27.

471470-27



PA3.09

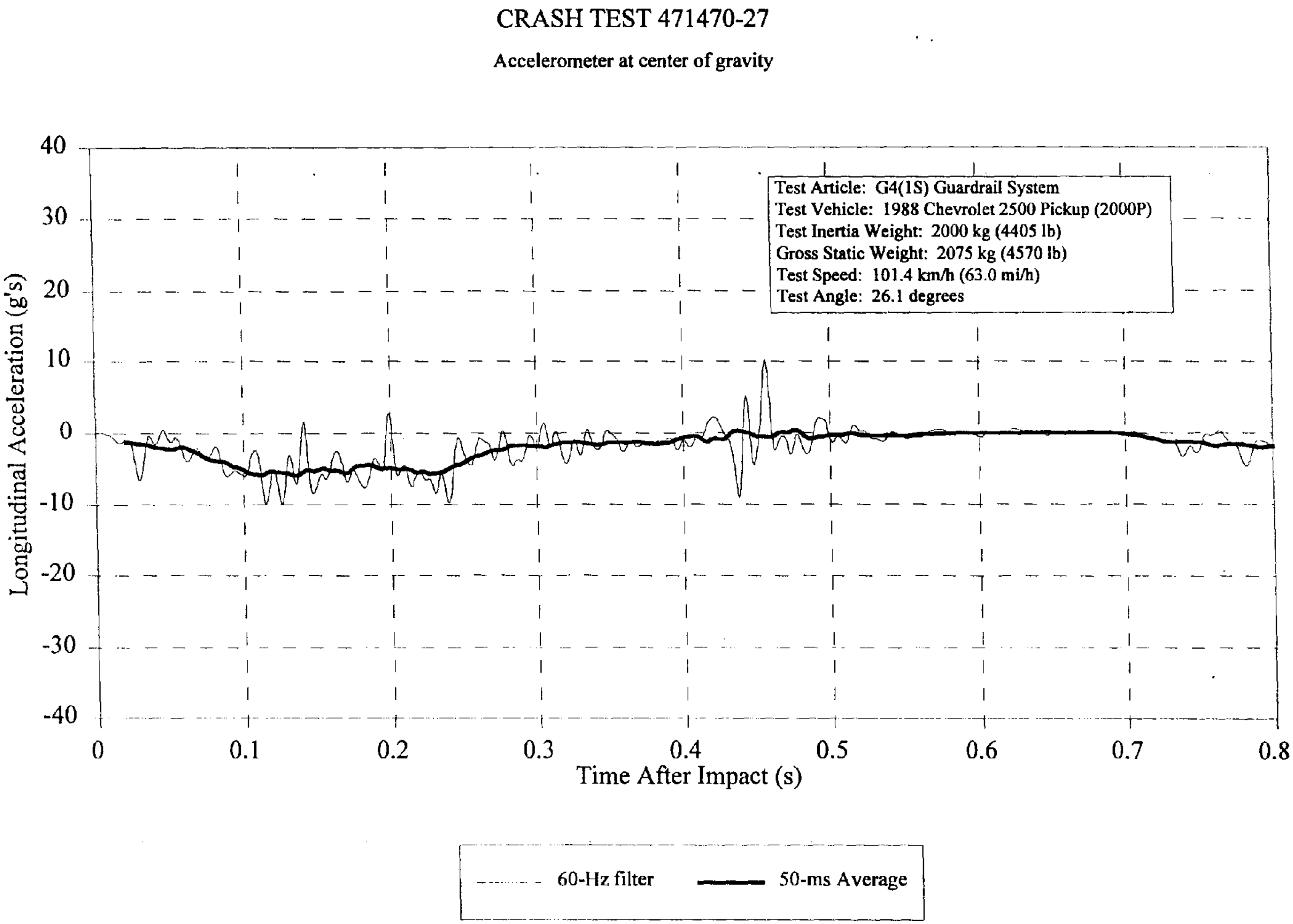


Figure 96. Vehicle longitudinal accelerometer trace for test 471470-27.

CRASH TEST 471470-27

Accelerometer at center of gravity

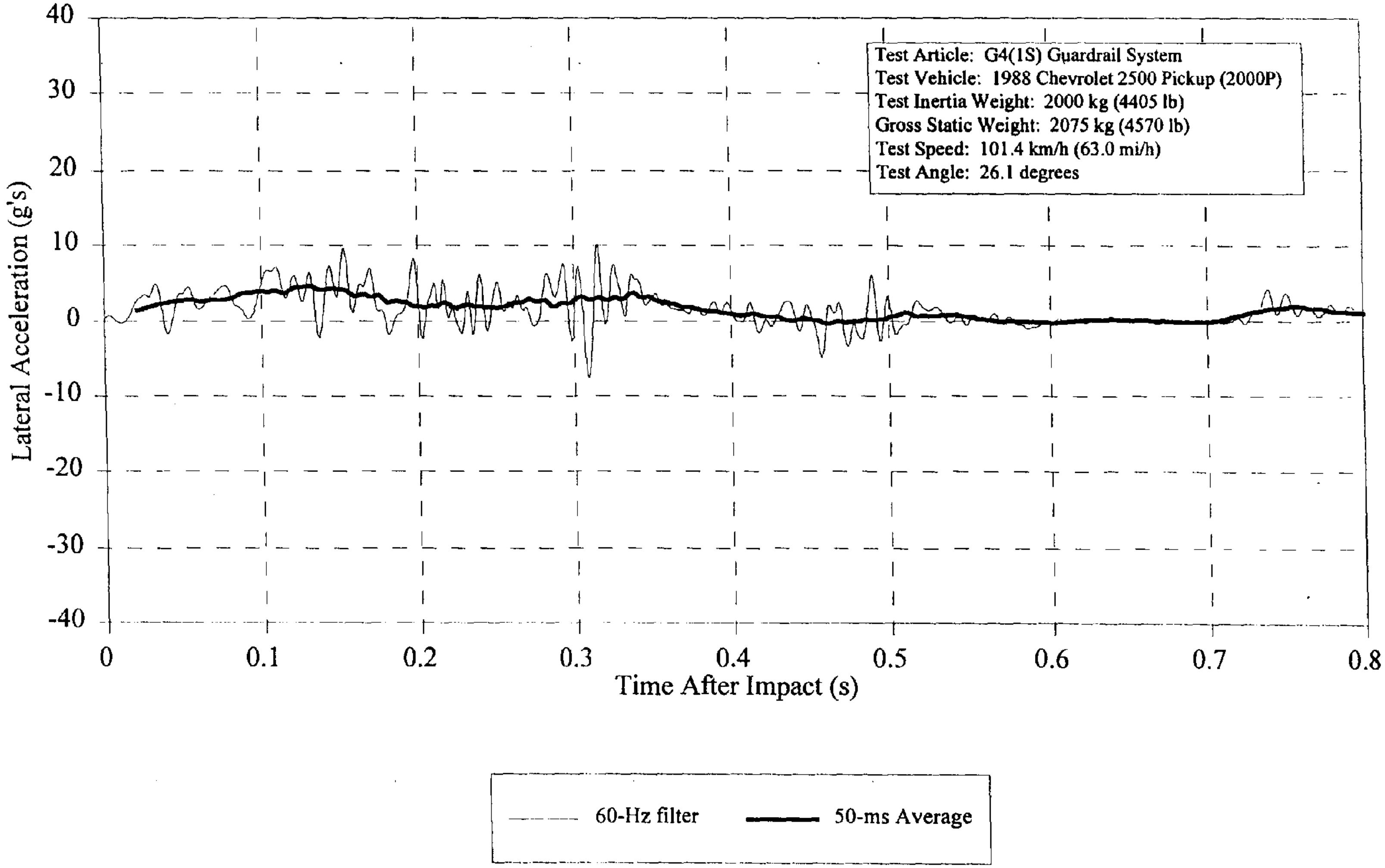


Figure 97. Vehicle lateral accelerometer trace for test 471470-27.

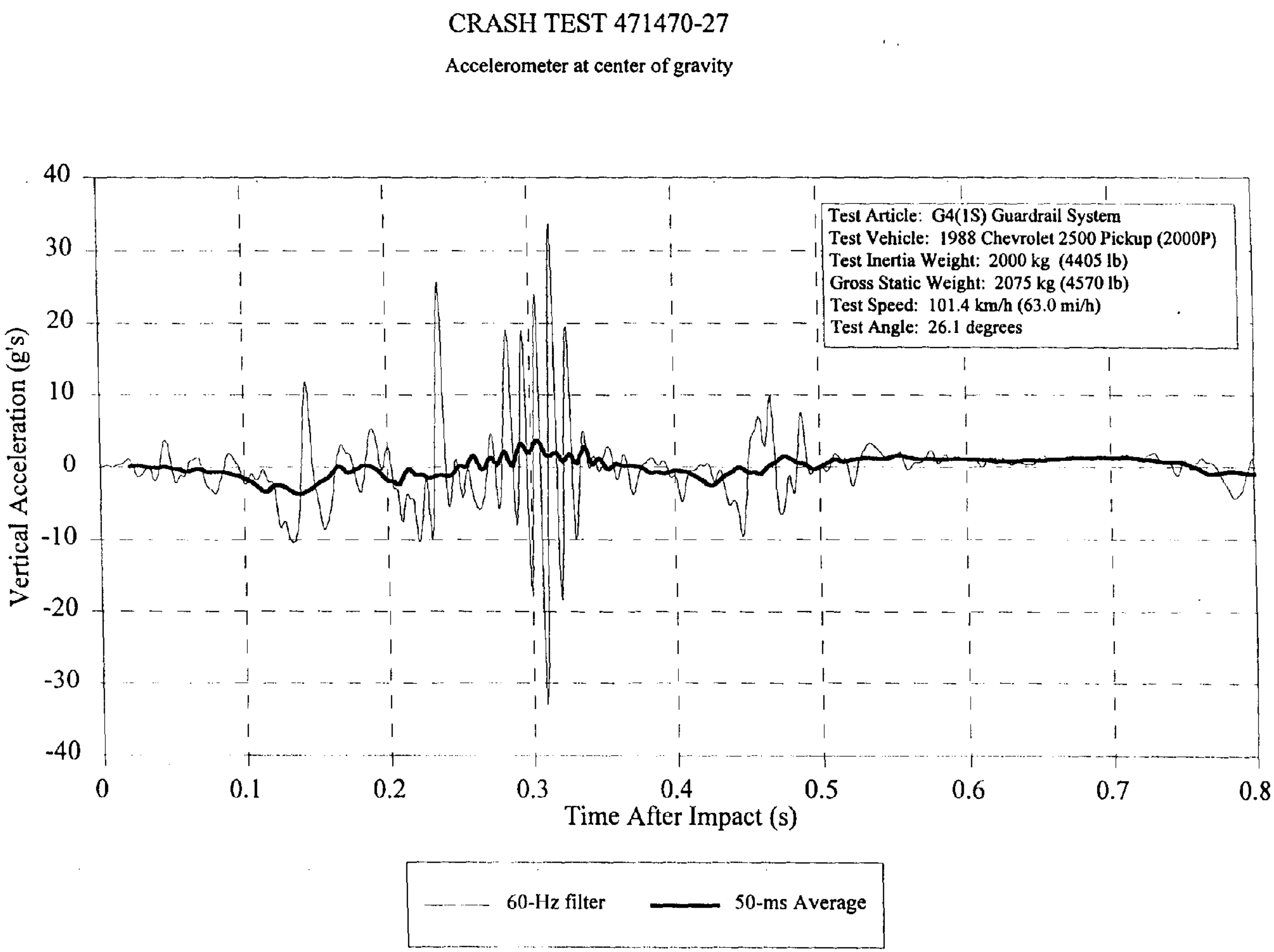


Figure 98. Vehicle vertical accelerometer trace for test 471470-27.

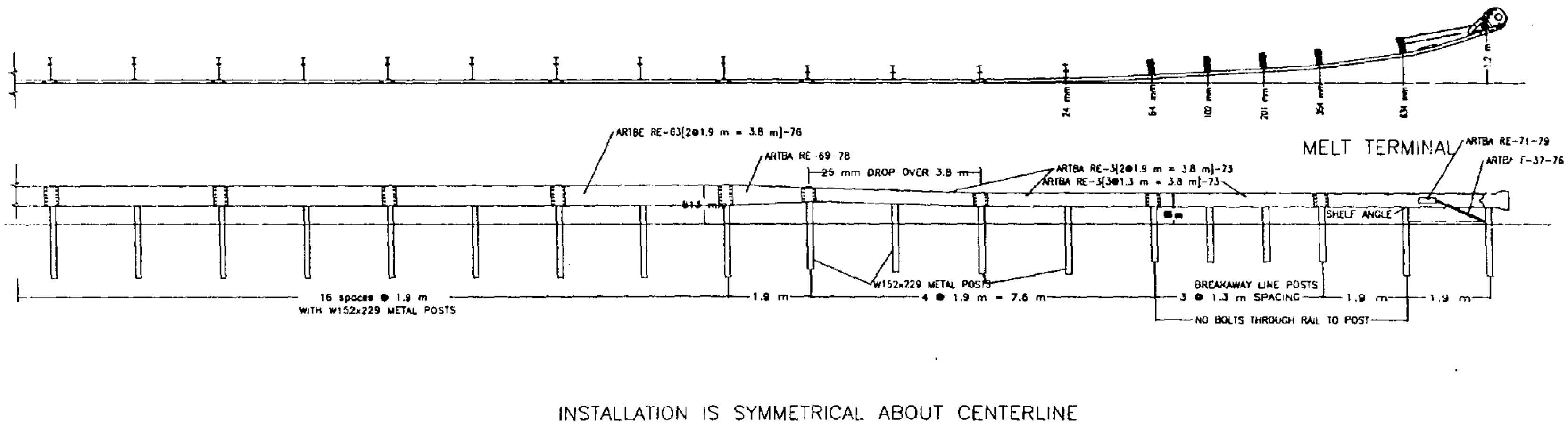
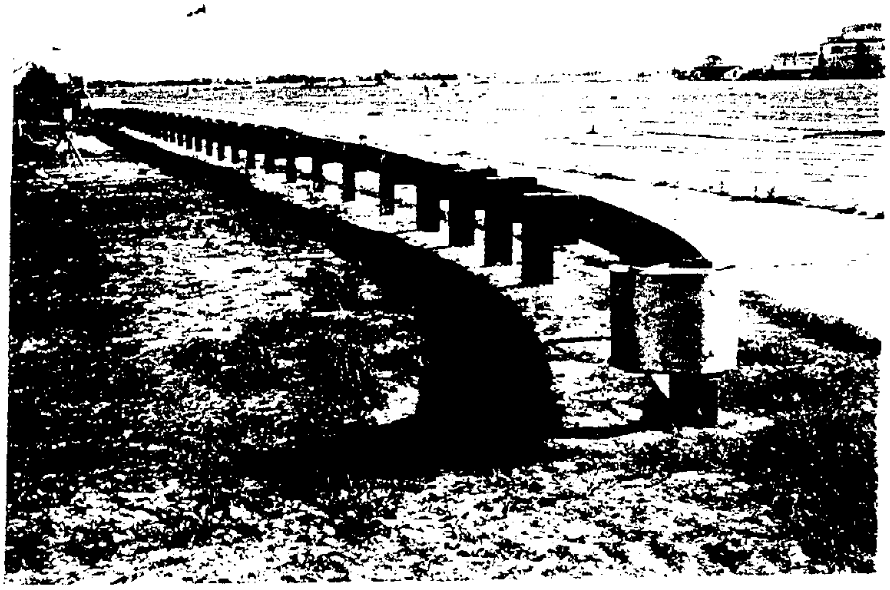


Figure 99. Layout of the thrie-beam (G9) guardrail installation.



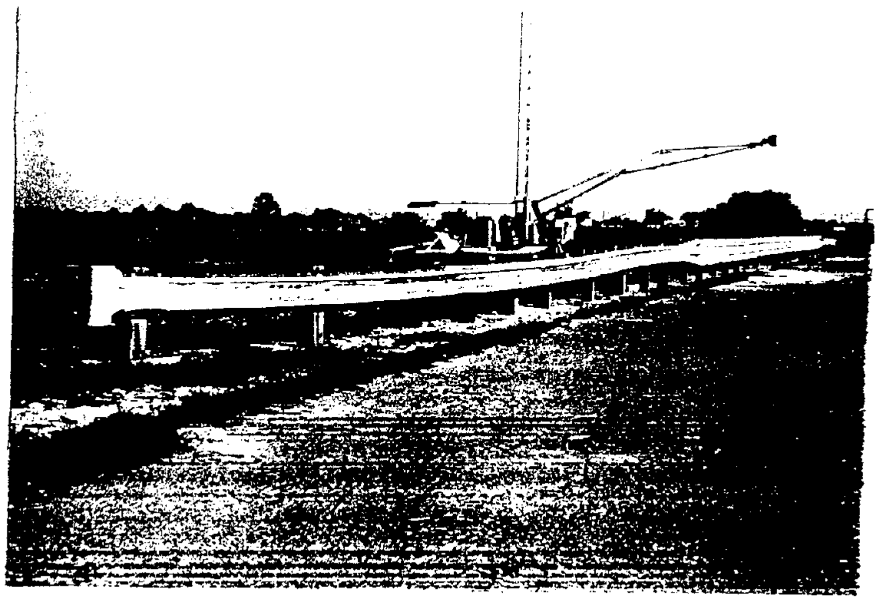


Figure 100. Thrie-beam (G9) guardrail installation used in test 471470-31.

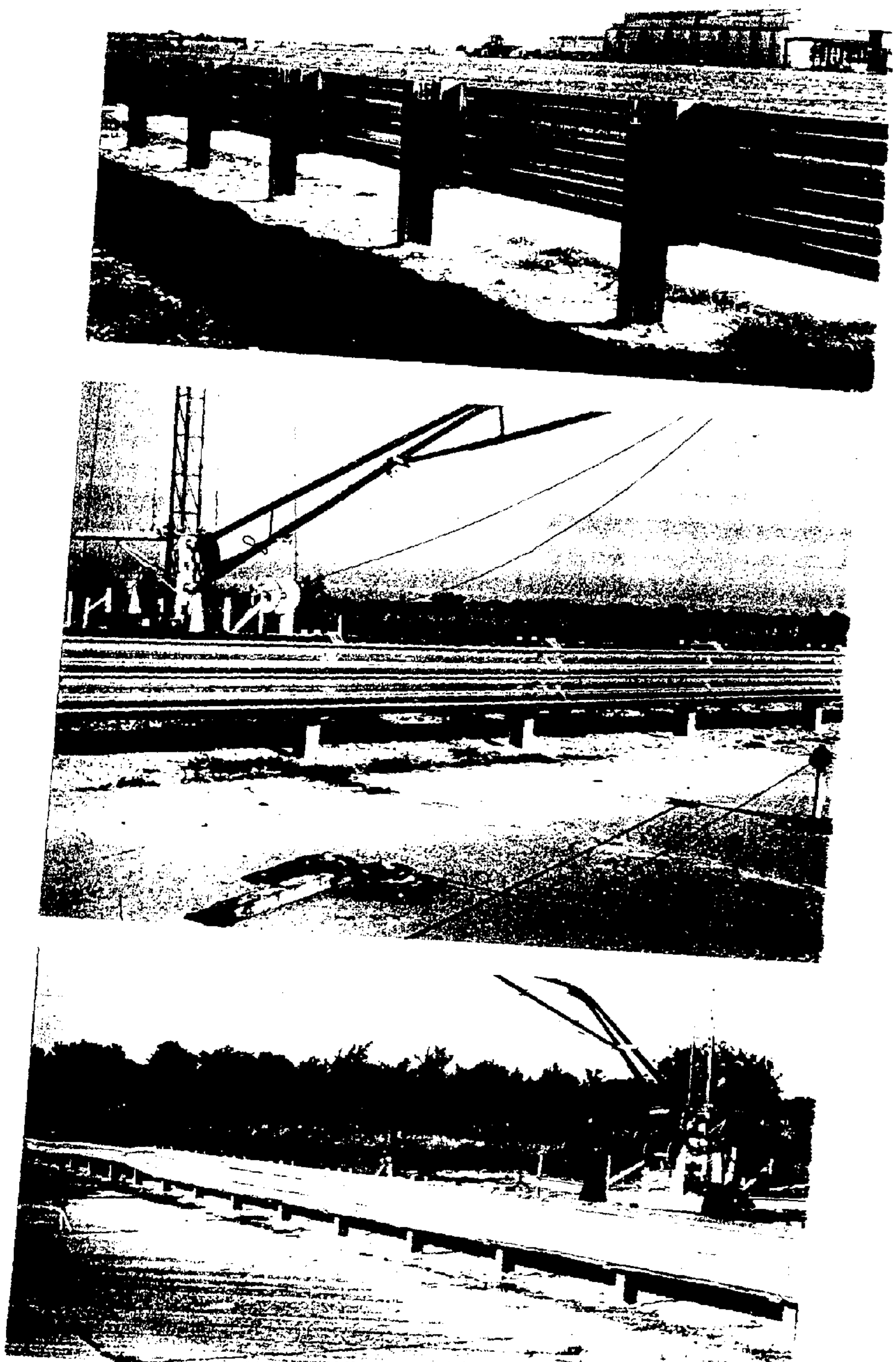


Figure 101. Thrie-beam (G9) guardrail section before test 471470-31.

Figure 102. Vehicle/guardrail geometrics for test 471470-31.

Figure 103. Vehicle prior to test 471470-31.

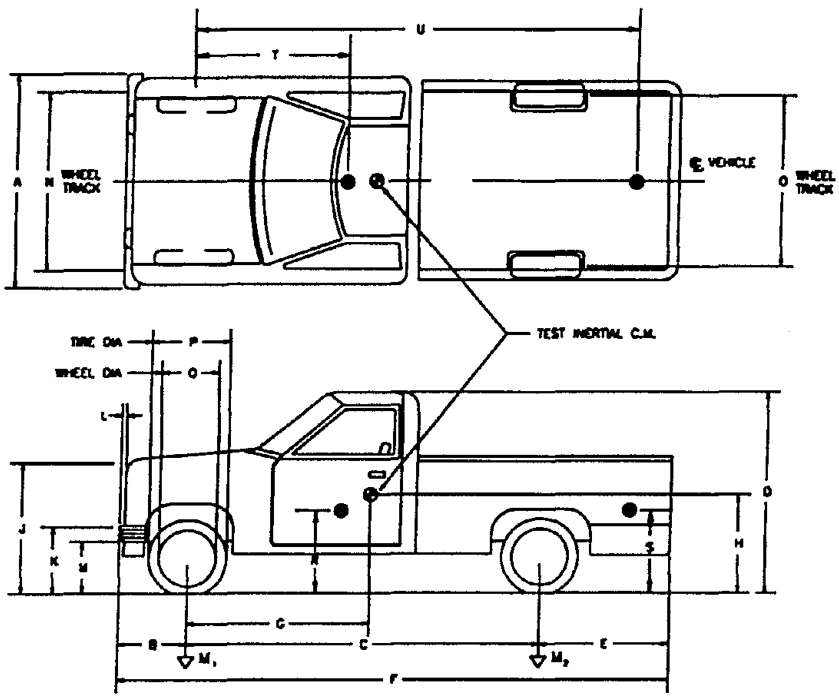
DATE: 04/14/95 | TEST NO.: 471470-31 | VIN NO.: 1GTGC24K5LE520473

YEAR: 1990 | MAKE: GMC | MODEL: 2500

TIRE INFLATION PRESSURE: ______ | ODOMETER: 197102 | TIRE SIZE: LT235/85R16

MASS DISTRIBUTION (kg) LF 544 RF 544 LR 458 RR 454

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 cyl EFI

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th male

MASS: 75 kg

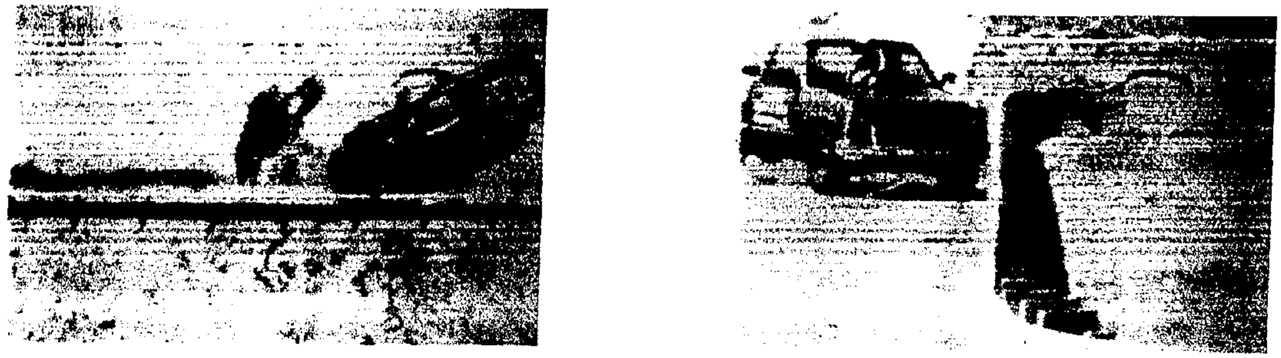
SEAT POSITION: Driver's

GEOMETRY - (mm)

A	1880	E	1340	J	1060	N	1600	R	740
B	750	F	5450	K	660	O	1660	S	1090
C	3360	G	1532.2	L	65	P	800	T	1490
D	1850	H		M	440	Q	445	U	4200

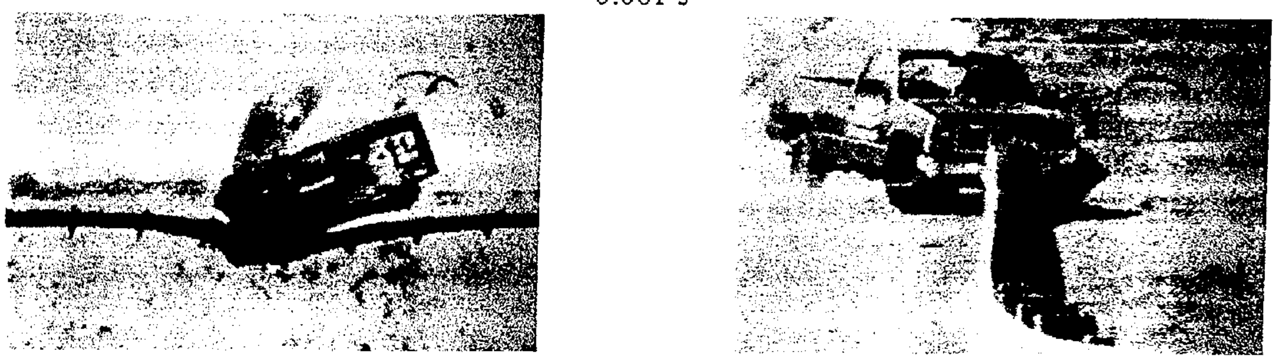
MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1182	1088	1134
M_2	912	912	942
M_T	2094	2000	2076

Figure 104. Vehicle properties for test 471470-31.

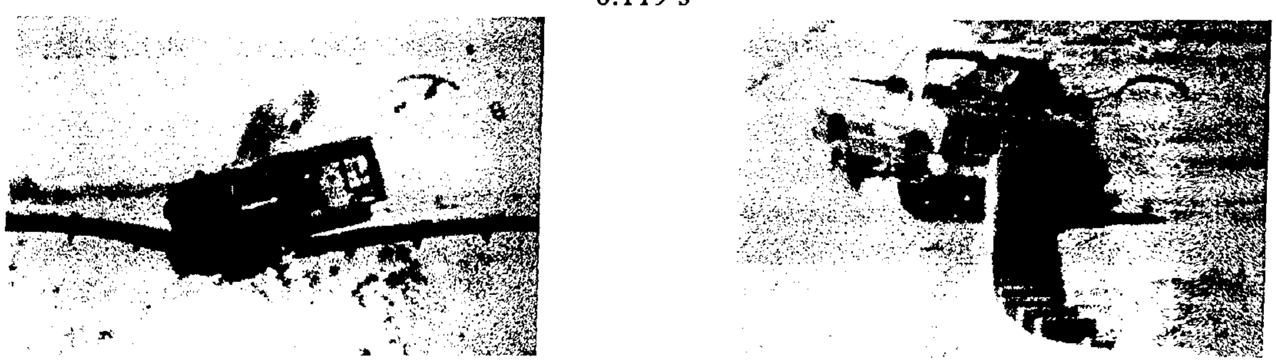


0.000 s

0.061 s

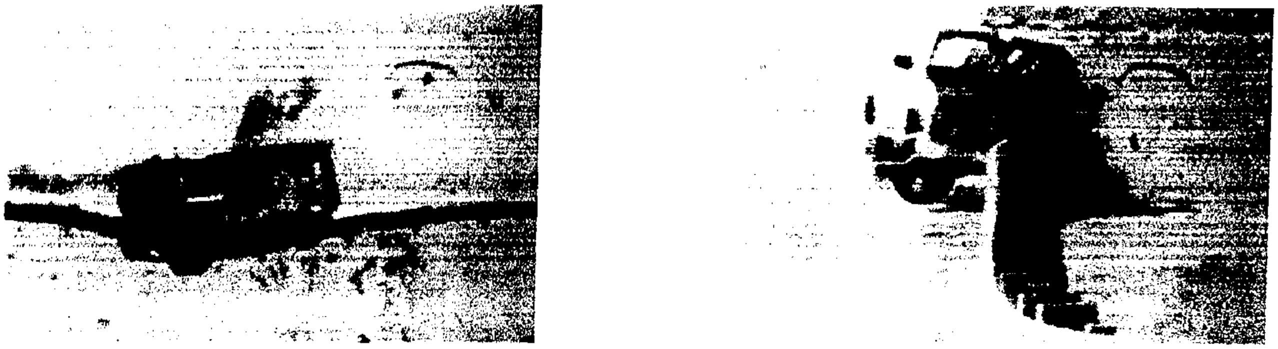


0.119 s

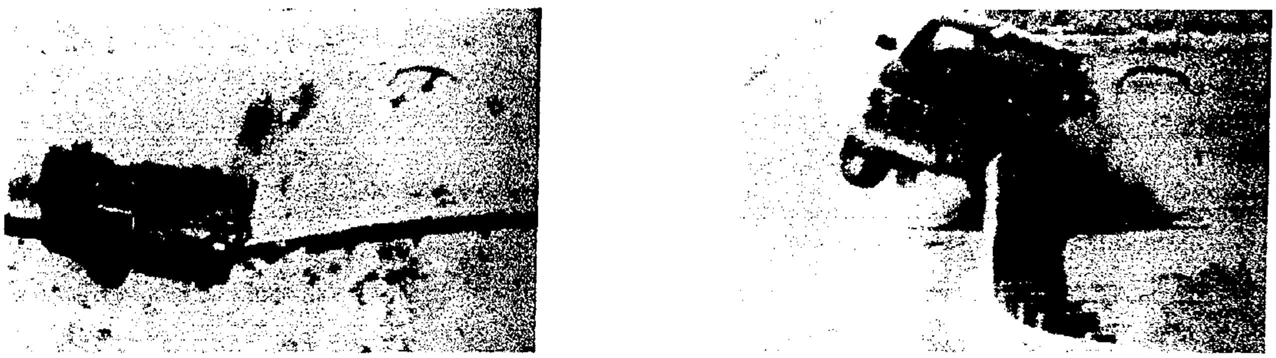


0.180 s

Figure 105. Sequential photographs for test 471470-31 (overhead and frontal views).

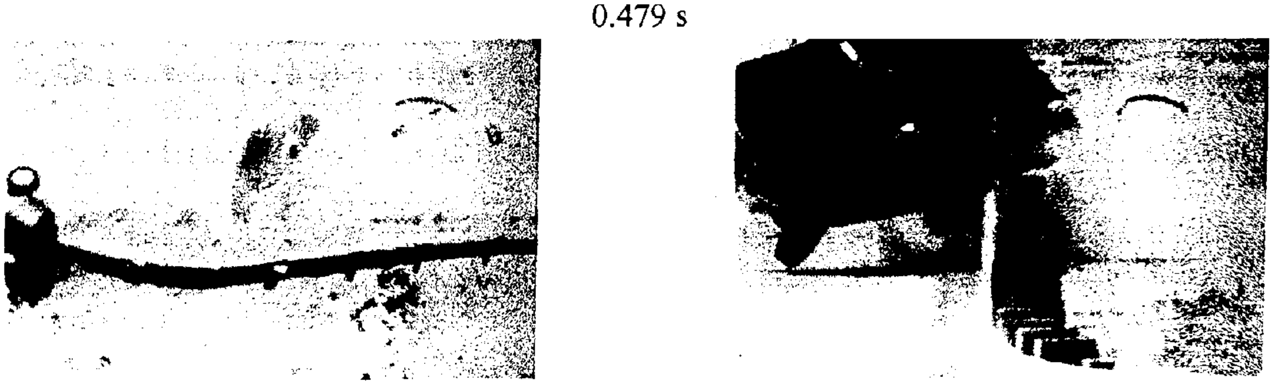


0.241 s



0.360 s

0.479 s

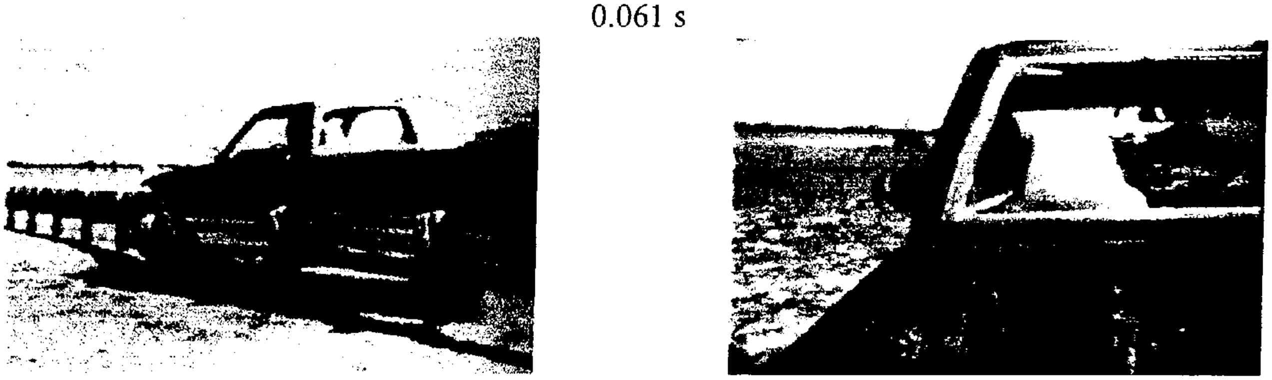


0.644 s

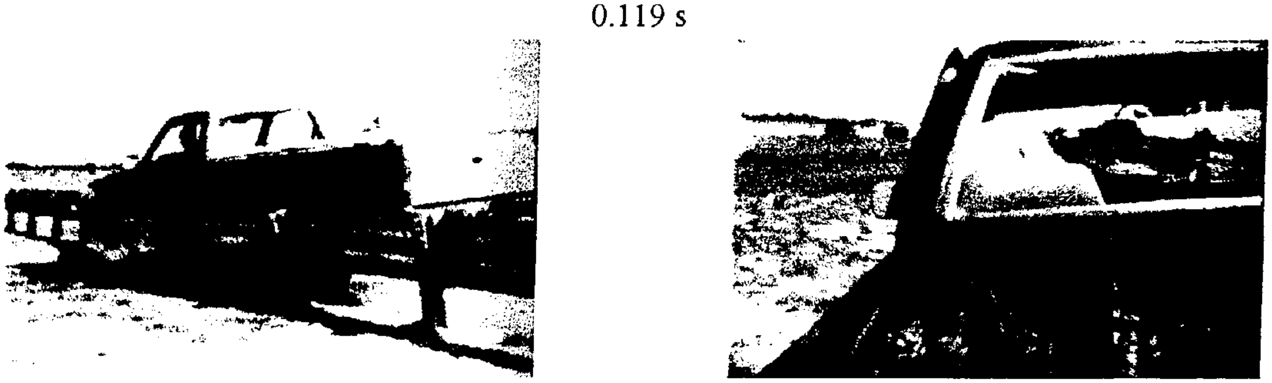
Figure 105. Sequential photographs for test 471470-31 (overhead and frontal views) (continued).

0.000 s

0.061 s



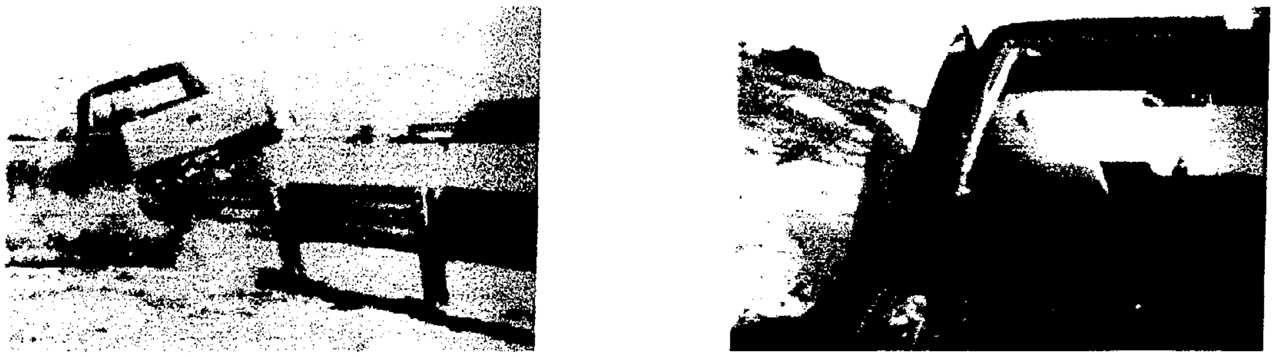
0.119 s



0.180 s

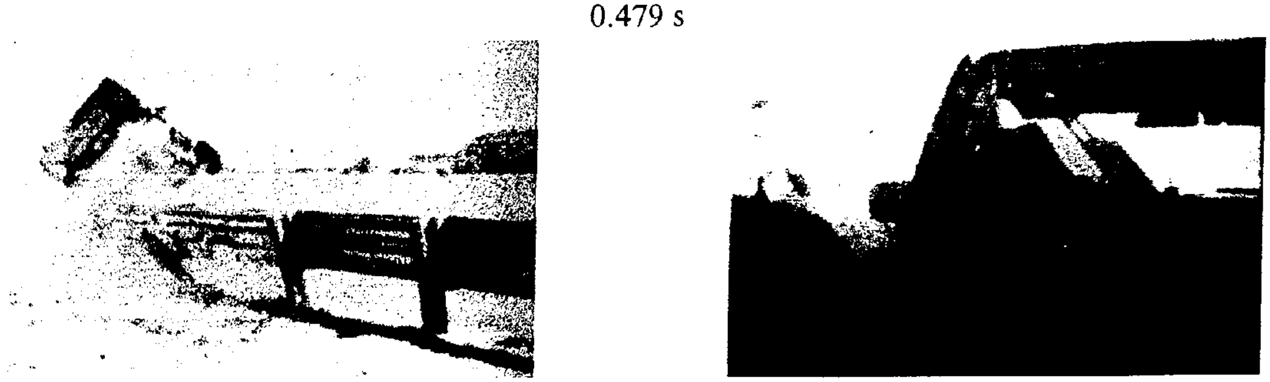
Figure 10b. Sequential photographs for test 471470-31
(rear and interior views).

0.241 s



0.360 s

0.479 s



0.644 s

Figure 106. Sequential photographs for test 471470-31
(rear and interior views) (continued).

3.7.2 Damage to Test Installation

As seen in figures 107 through 109, the test installation received moderate damage. There were tire marks on the face of the thrie-beam rail element from post 15 through post 19, and on the face of posts 16 and 17. The thrie-beam rail element was separated from post 16, and the flanges on post 17 showed evidence of wheel contact. Posts 15 through 19 were twisted severely. The lateral deflections recorded at posts 13 through 20 are noted in table 6.

Table 6. Lateral post deflections for test 471470-31.

Post 13 .... 25 mm (1.0 in)	Post 17 .... 159 mm (6.3 in)
Post 14 .... 76 mm (3.0 in)	Post 18 .... 210 mm (8.3 in)
Post 15 .... 191 mm (7.5 in)	Post 19 .... 102 mm (4.0 in)
Post 16 .... 343 mm (13.5 in)	Post 20 .... 32 mm (1.3 in)

Maximum dynamic deflection of the thrie-beam rail element was 1.07 m (3.5 ft). Maximum permanent deformation of the installation was 0.64 m (2.1 ft) just upstream of post 17. Total length of contact of the vehicle with the installation was 8.2 m (26.8 ft).

3.7.3 Vehicle Damage

The vehicle sustained extensive damage, as shown in figure 110. The upper and lower A-arms, stabilizer bar, frame, and tie rod ends on the left side were damaged. The front bumper, grill, hood, left front quarter panel, both doors, and the left front and rear wheels also were damaged. The windshield and windows were broken and the roof was damaged due to the rollover. Maximum exterior crush at the left front corner of the vehicle was 420 mm (16.5 in), and maximum deformation of the occupant compartment was 144 mm (4.5 in) downward from the roof area on the passenger side.

3.7.4 Occupant Risk Values

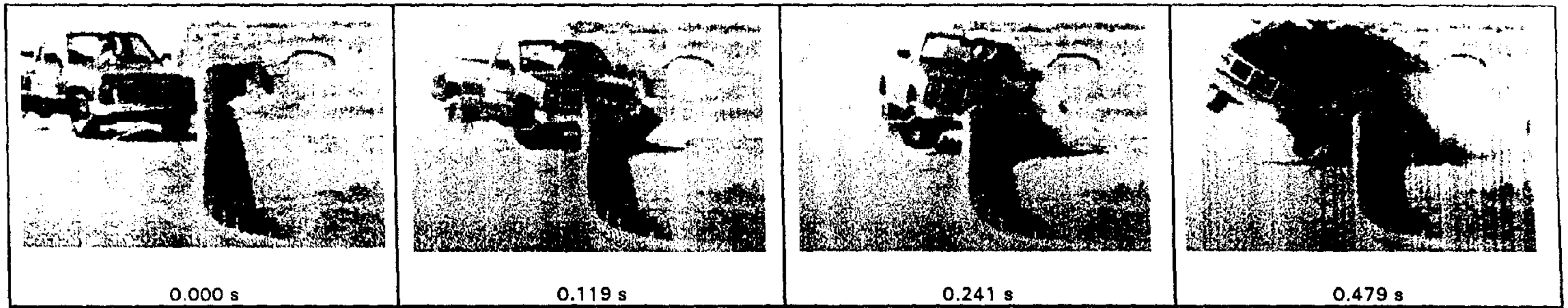
Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. Occupant contact first occurred in the lateral direction. Lateral occupant impact velocity was 4.9 m/s (16.2 ft/s) at 0.145 s, the highest 0.010-s lateral occupant ridedown acceleration was 6.3 g between 0.185 and 0.195 s, and the maximum 0.050-s average acceleration was 4.5 g between 0.161 and 0.201 s. In the longitudinal direction, the occupant impact velocity was 8.0 m/s (26.4 ft/s), the highest 0.010-s occupant ridedown acceleration was -7.0 g between 0.179 and 0.189 s, and the maximum 0.050-s average was -6.4 g between 0.142 and 0.192 s. These data and other information pertinent to the test are summarized in figure 111. Vehicle angular displacements during the test are displayed

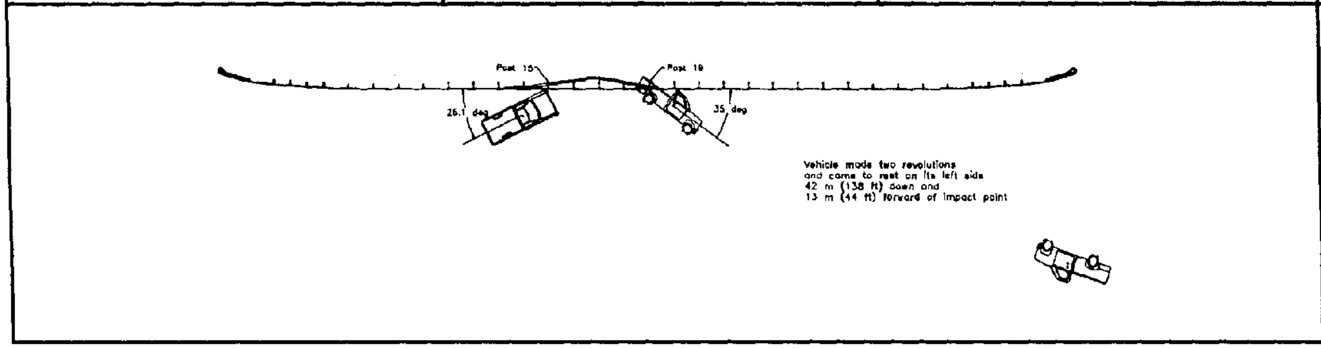
Figure 107. Thrie-beam [illegible] guardrail after test 471470-31.

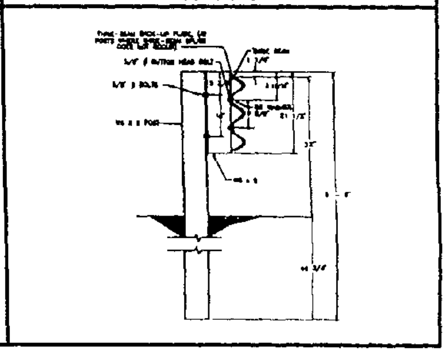
Figure 108. Damage at posts 15 and 16, test 471470-31.

Figure 109. Damage at posts 17 through 19, test 471470-31.

Figure 110. Vehicle after test 471470-31.







General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-31
Date	04/14/95
Test Article	
Type	Guardrail
Name or Manufacturer	G9 Thrie Beam
Installation Length (m)	53 m (175 ft)
Size and/or Dimension and Material of Key Elements	Thrie Beam on W6x9 Posts with M14x17.2 Blockouts
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1990 GMC 2500
Mass (kg) Curb	2094 (4612 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	102.2 (63.5 mi/h)
Angle (deg)	26.1
Exit Conditions	
Speed (km/h)	54.5 (33.9 mi/h)
Angle (deg)	approx. 35
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	8.0 (26.4 ft/s)
y-direction	4.9 (16.2 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-7.0
y-direction	6.3
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.4
y-direction	4.5
z-direction	-3.3

Test Article Deflections (m)	
Dynamic	1.07 (3.5 ft)
Permanent	0.64 (2.1 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ4 & 9L&T5
CDC	11FLEK2 & 80TZDO5
Interior	
OCDI	RF0200000
Maximum Exterior Vehicle Crush (mm)	420 (16.5 in)
Max. Occ. Compart. Deformation (mm)	114 (4.5 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-810
Max. Pitch Angle (deg)	-7
Max. Yaw Angle (deg)	221

Figure 111. Summary of results for test 471470-31.

in figure 112. Vehicular accelerations versus time traces filtered at 60 Hz are presented in figures 113 through 115.

3.8 MODIFIED THRIE-BEAM GUARDRAIL (TEST NO. 471470-30)

The test installation consisted of a 30.5-m- (100-ft-) long length-of-need section of modified thrie-beam guardrail with a 1.9-m- (6-ft, 3-in-) long transition section from the thrie beam to the W-beam rail element, a 3.8-m- (12-ft, 6-in-) long section of standard steel-post, W-beam G4(1S) guardrail, and a 11.4-m- (37-ft, 6-in-) long MELT at each end, for a total installation length of 64.8 m (212 ft, 6 in). The layout of the test installation is shown in figure 116. Photographs of the test installation are shown in figures 117 and 118.

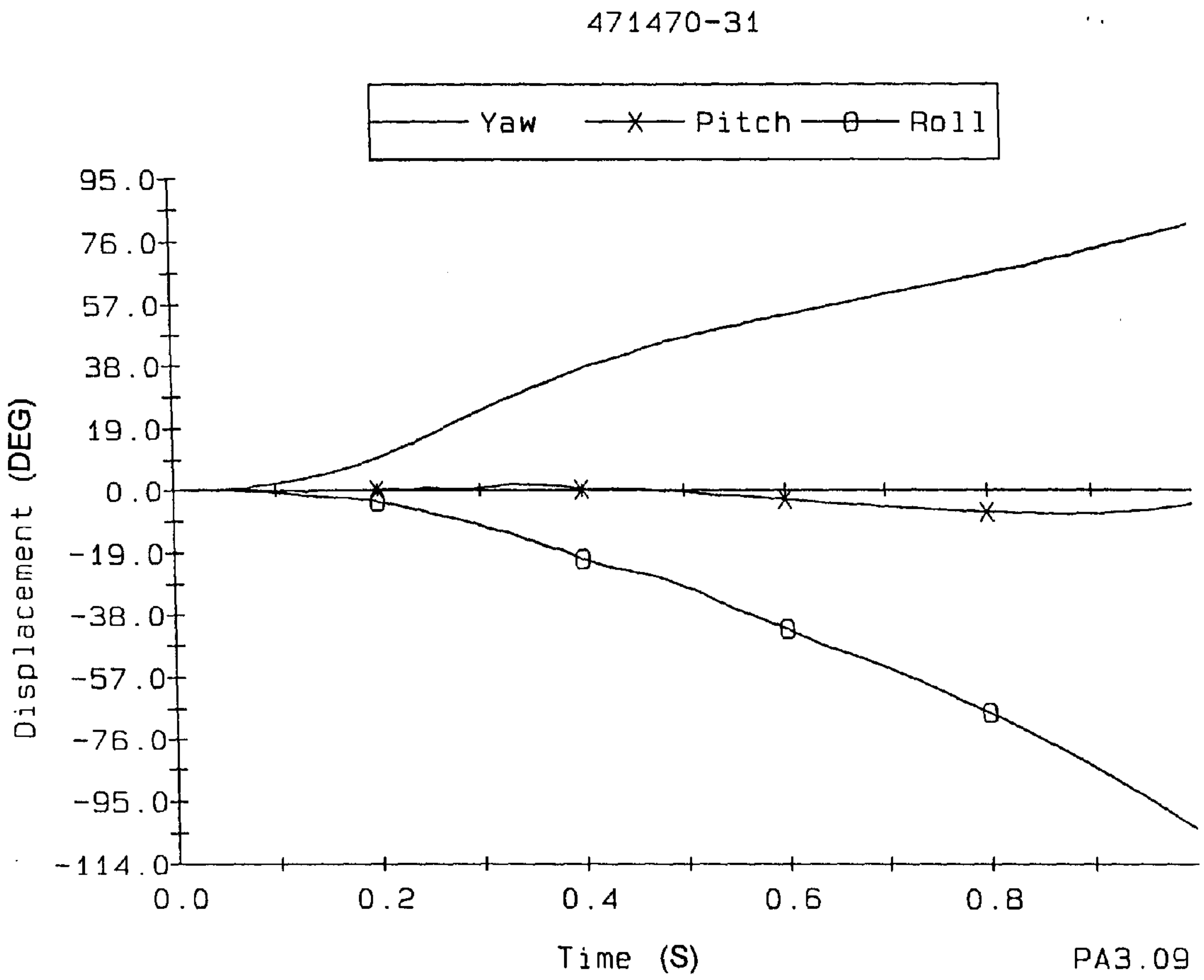
A 1989 GMC 2500 pickup (shown in figures 119 and 120) with a test inertia weight of 2000 kg (4409 lb) was used for the crash test. The gross static weight of the vehicle was 2076 kg (4573 lb) which included a restrained 50th-percentile male anthropomorphic dummy placed in the driver's position of the vehicle. The heights to the upper and lower edges of the vehicle bumper were 670 mm (26.4 in) and 450 mm (17.7 in), respectively. Additional dimensions and information on the vehicle are given in figure 121. 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.

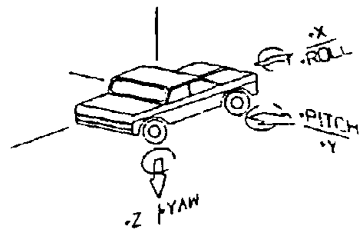
3.8.1 Test Description

The vehicle impacted the length-of-need section at post 15, traveling at a speed of 100.2 km/h (62.3 mi/h) and at an angle of 25.1 degrees. As the vehicle impacted the installation, the thrie-beam guardrail began to deflect and redirection of the vehicle began at 0.044 s. At 0.077 s after impact, the left front tire made contact with the flange and face of post 16, which caused the wheel to turn outward (or counterclockwise). The vehicle continued forward as post 17 and 18 began to rotate about their vertical axis at 0.125 s and 0.161 s, respectively. At 0.189 s, the left front wheel assembly caught the flange at post 17 and the entire wheel assembly was torn from the axle. The front of the vehicle reached post 18 and the rear of the vehicle made contact with the thrie-beam rail element at 0.232 s. The vehicle became parallel with the installation at 0.264 s, traveling at 74.3 km/h (46.2 mi/h). The vehicle lost contact with the installation at 0.560 s, traveling at a speed of 67.4 km/h (41.9 mi/h) and an exit angle of approximately 11.1 degrees. The vehicle brakes were applied as the vehicle exited the test area, and subsequently came to rest 49 m (160 ft) down and 6 m (19 ft) behind the initial point of impact. Sequential photographs are shown in figures 122 and 123.

3.8.2 Damage to Test Installation

As seen in figures 124 through 128, the installation received moderate damage. There were tire marks on the face of the thrie-beam rail element from post 15 through post 19, and on





Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

Figure 112. Vehicle angular displacements during test 471470-31.

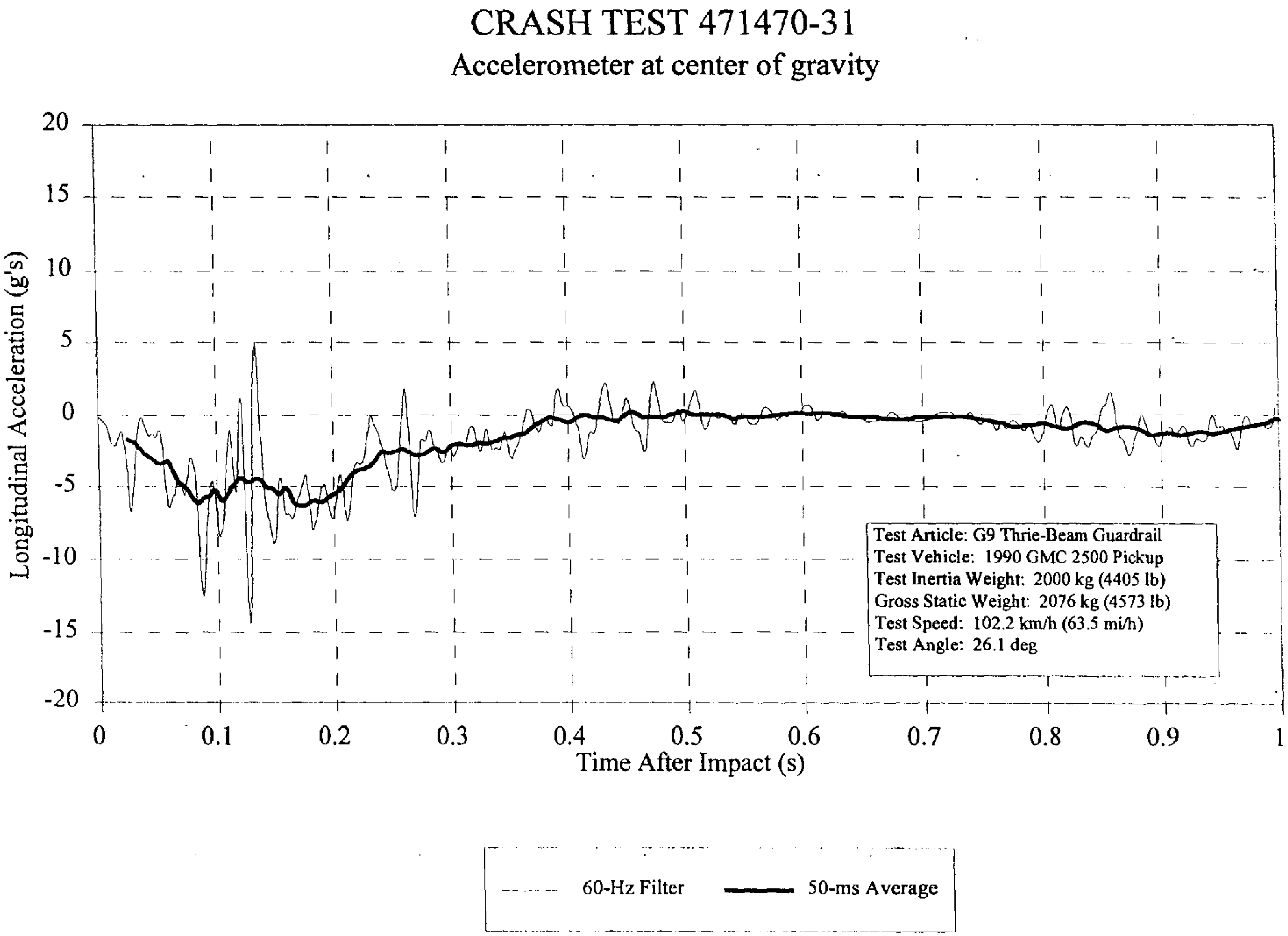


Figure 113. Vehicle longitudinal accelerometer trace for test 471470-31.

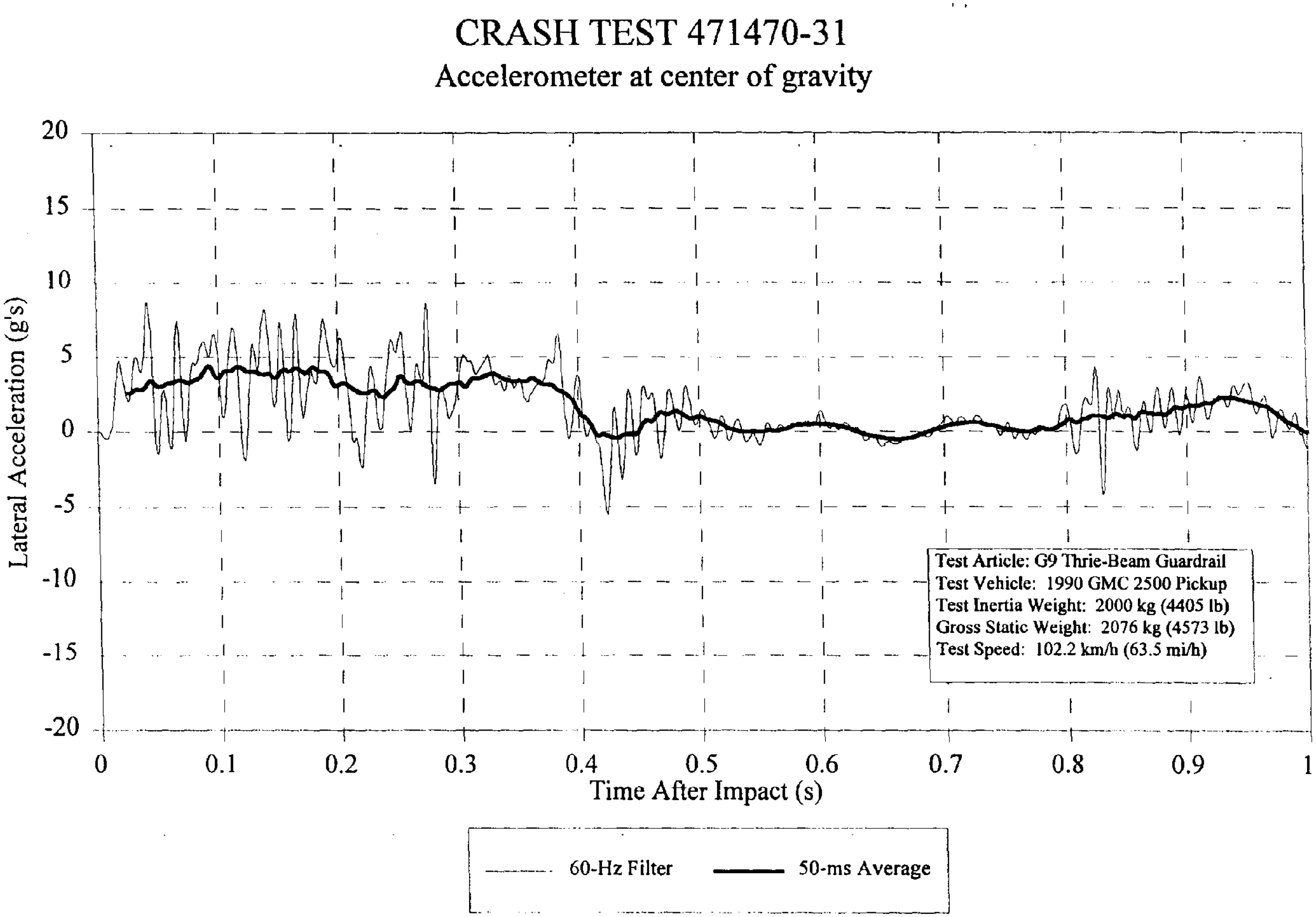


Figure 114. Vehicle lateral accelerometer trace for test 471470-31.

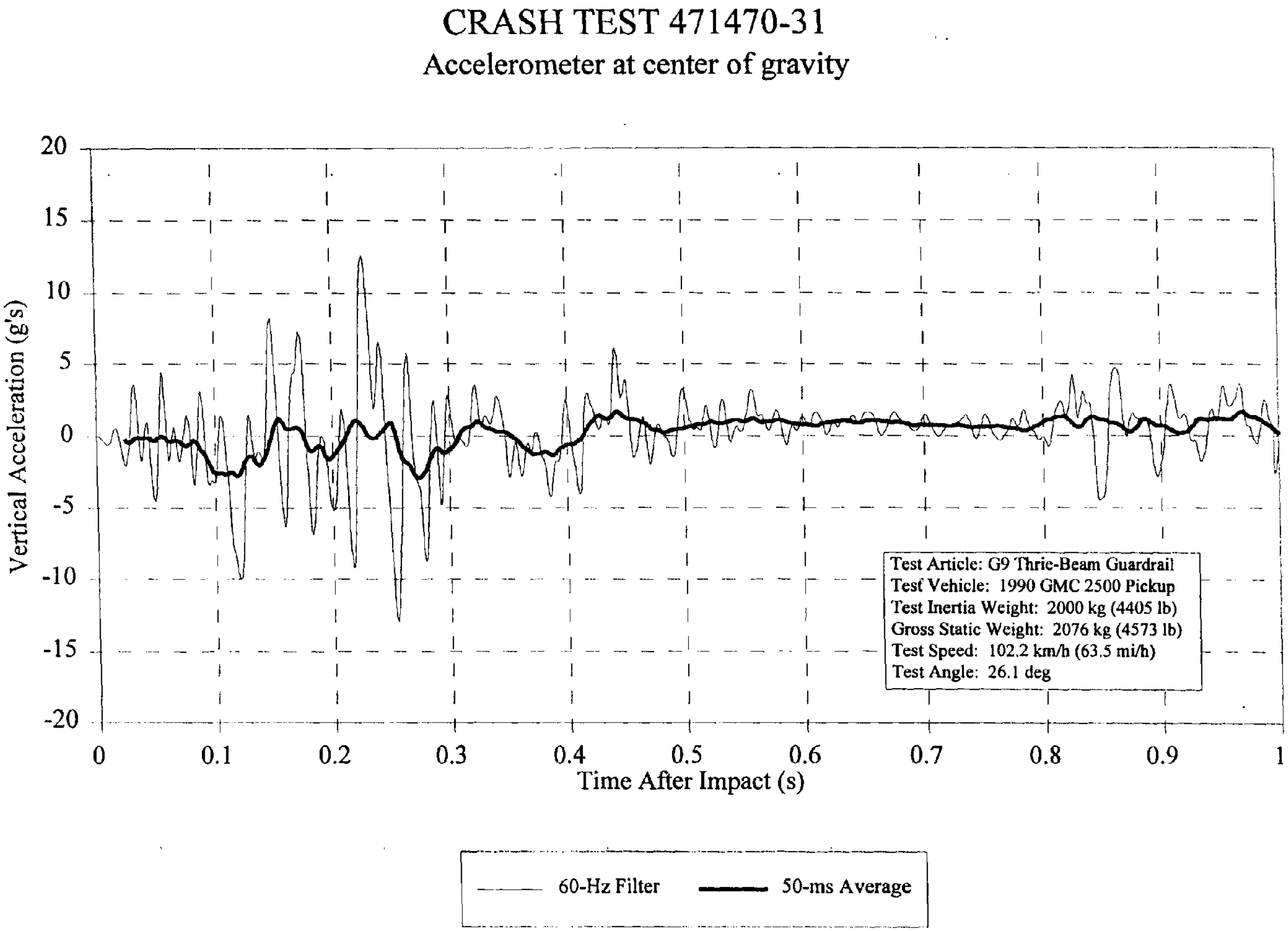
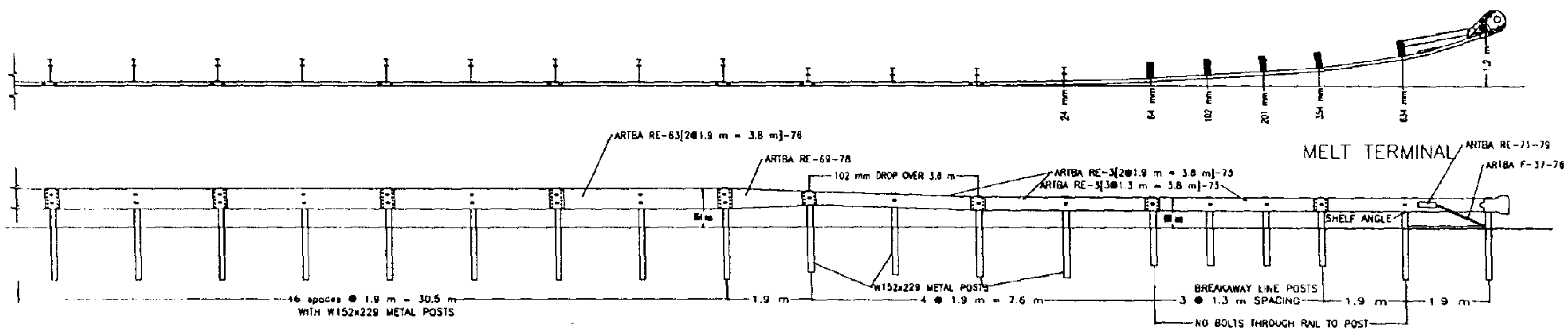


Figure 115. Vehicle vertical accelerometer trace for test 471470-31.



INSTALLATION IS SYMMETRICAL ABOUT CENTERLINE

Figure 116. Layout of the modified thrie-beam guardrail installation.

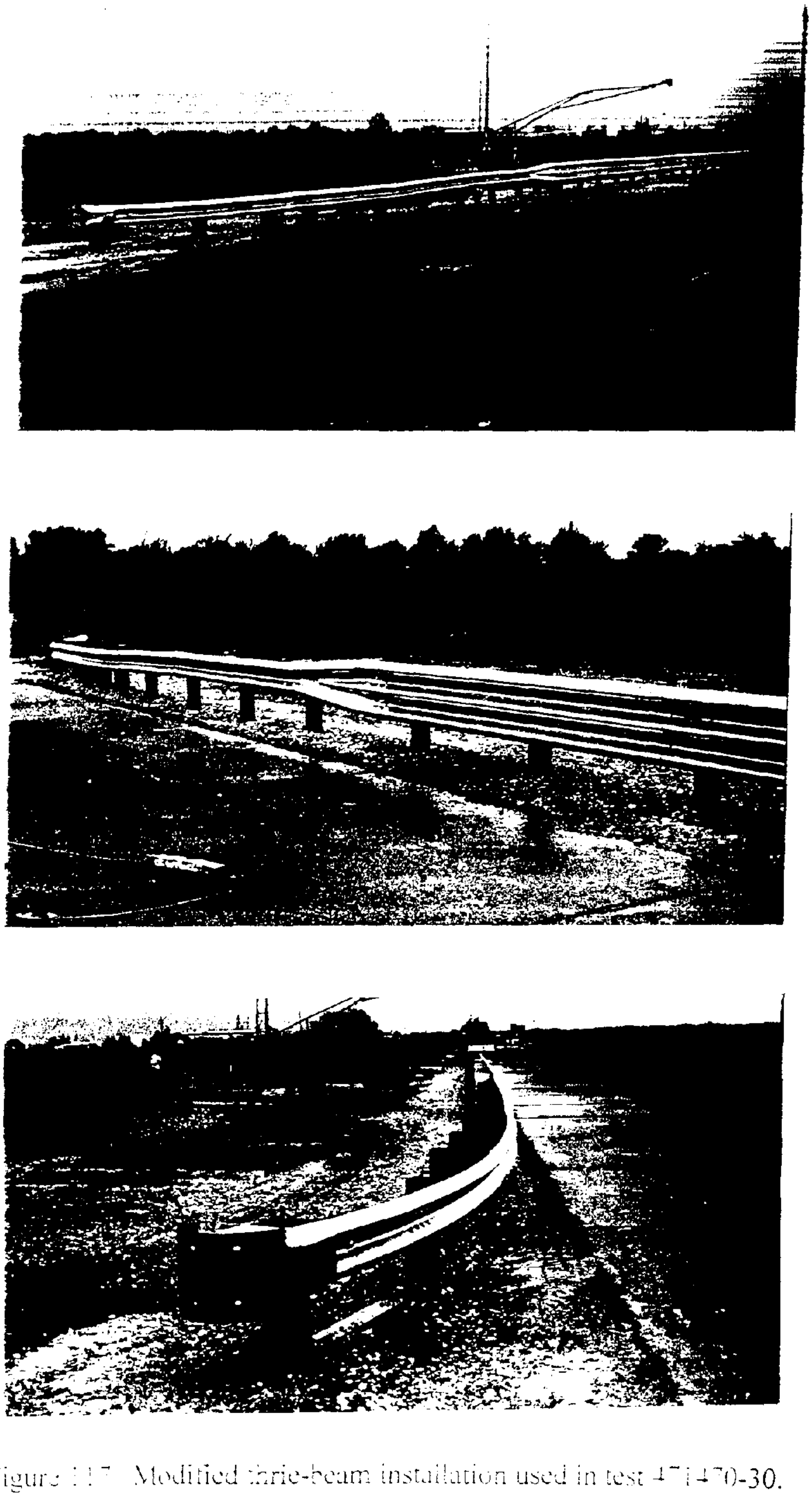


Figure 117. Modified thrie-beam installation used in test 471470-30.

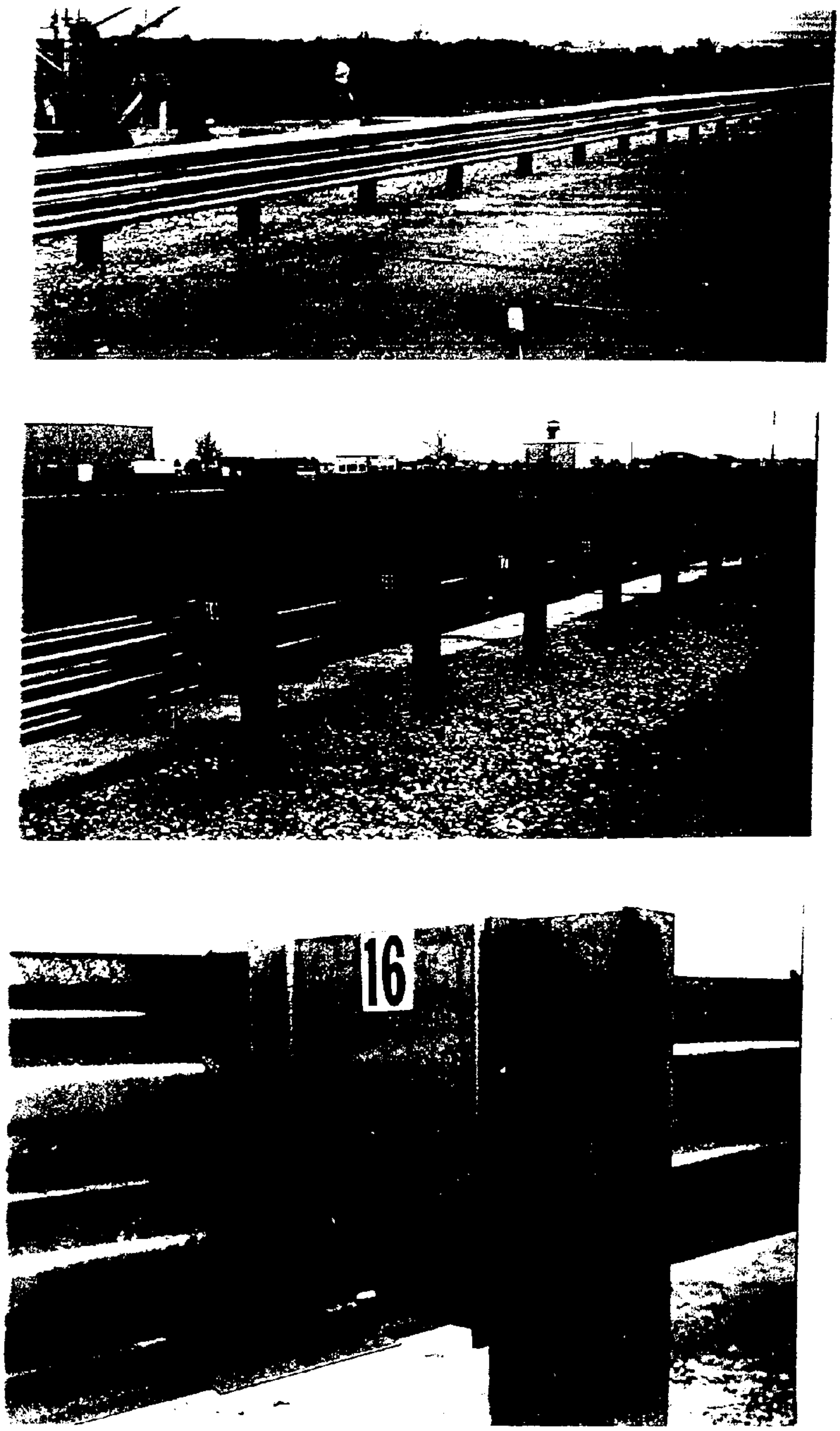


Figure 118. Modified thrie-beam guardrail section before test 471470-30.

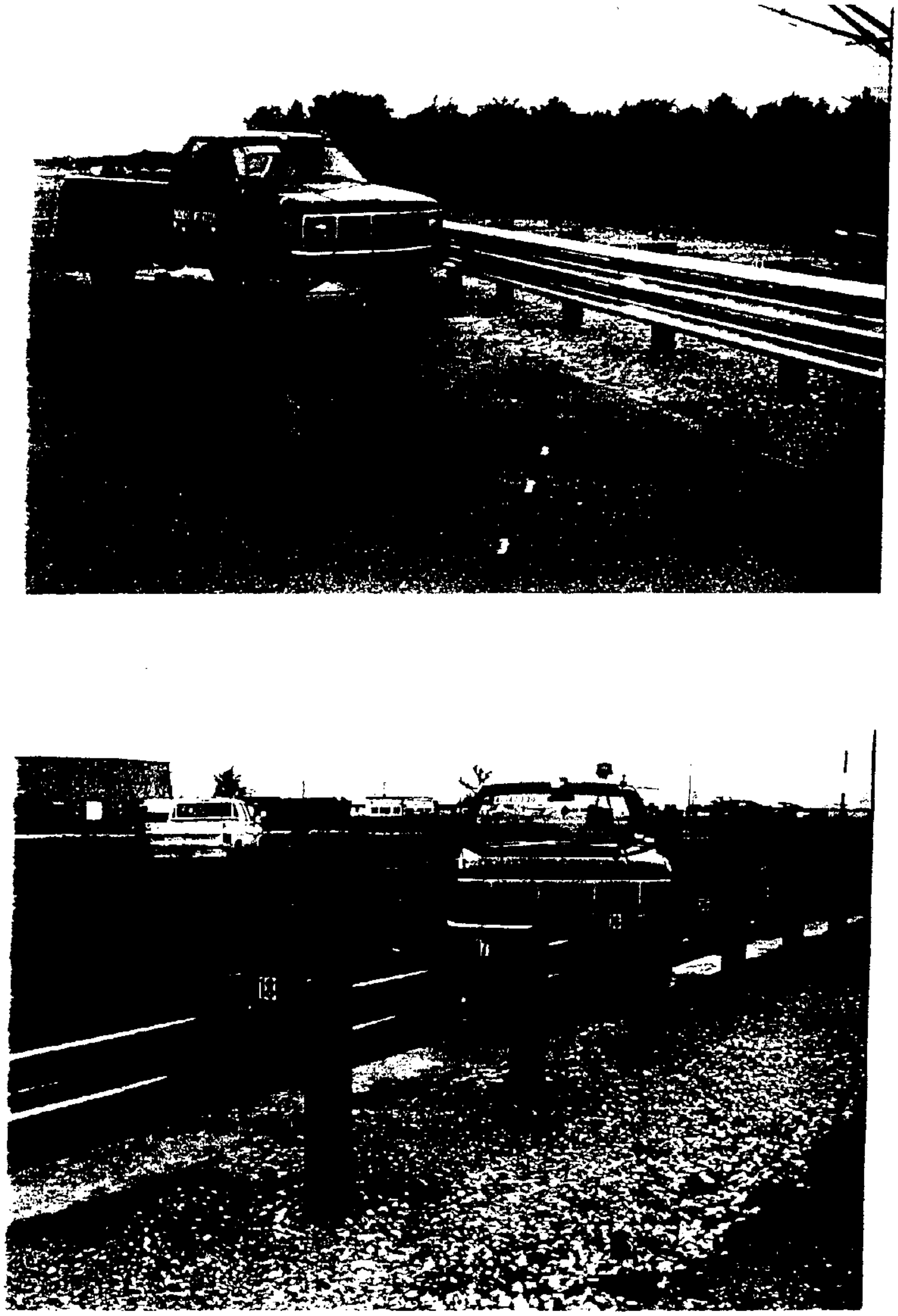


Figure 119. Vehicle/guardrail geometries for test 471470-30.

Figure 120. Vehicle before test 471470-30.

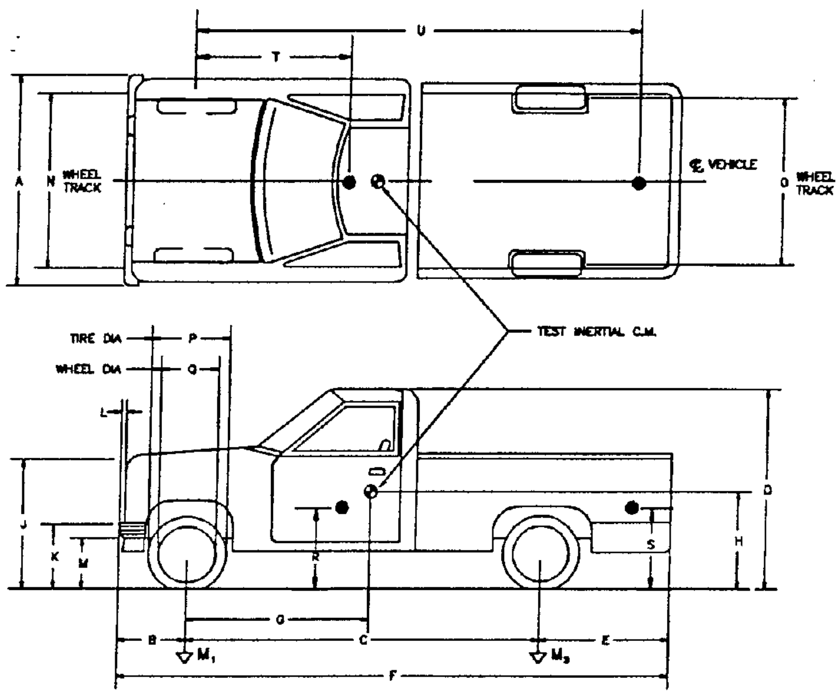
DATE: 01/11/95 TEST NO.: 471470-30 VIN NO.: 1GTGC24K8LE511847

YEAR: 1989 MAKE: GMC MODEL: 2500

TIRE INFLATION PRESSURE: ______ ODOMETER: 166121 TIRE SIZE: LT235/85R16

MASS DISTRIBUTION (kg) LF 544 RF 553 LR 459 RR 444

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 cyl EFT

ENGINE SIZE: 5.7 L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: ______

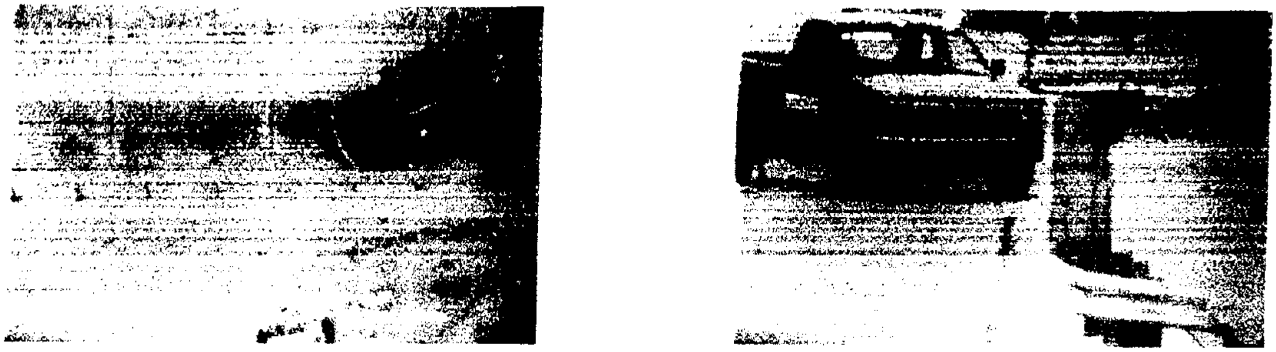
SEAT POSITION: ______

GEOMETRY – (mm)

A 1850	E 1340	J 1075	N 1570	R 730
B 796	F 5465	K 670	O 1630	S 1090
C 3335	G 1506	L 90	P 800	T 1495
D 1860	H	M 450	Q 445	U 4145

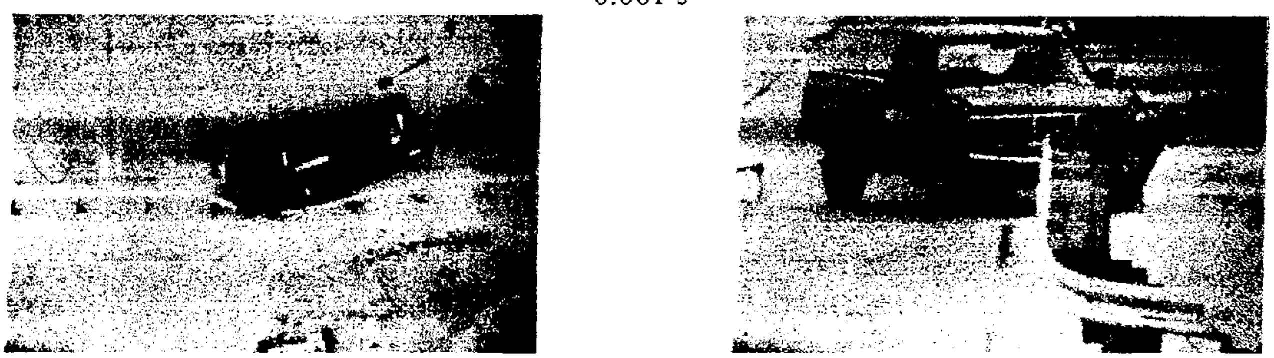
MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1168	1097	1144
M_2	875	903	932
M_T	2043	2000	2076

Figure 121. Vehicle properties for test 471470-30.

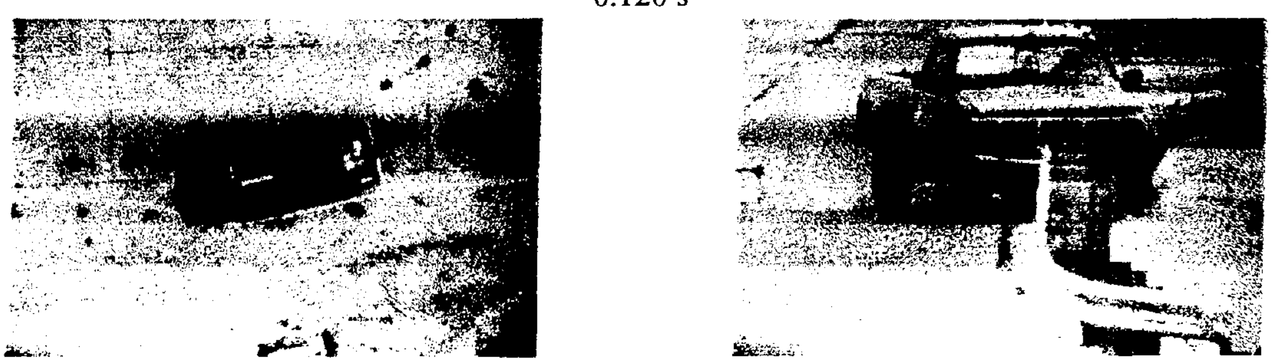


0.000 s

0.061 s

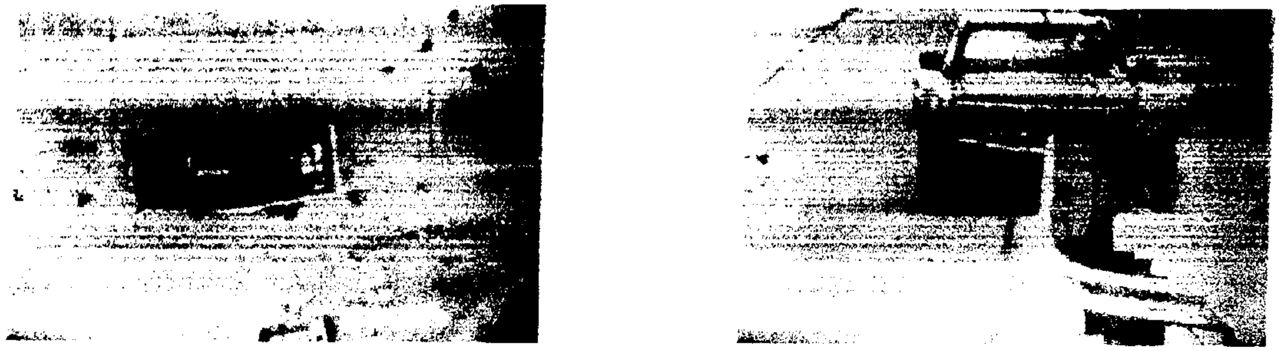


0.120 s

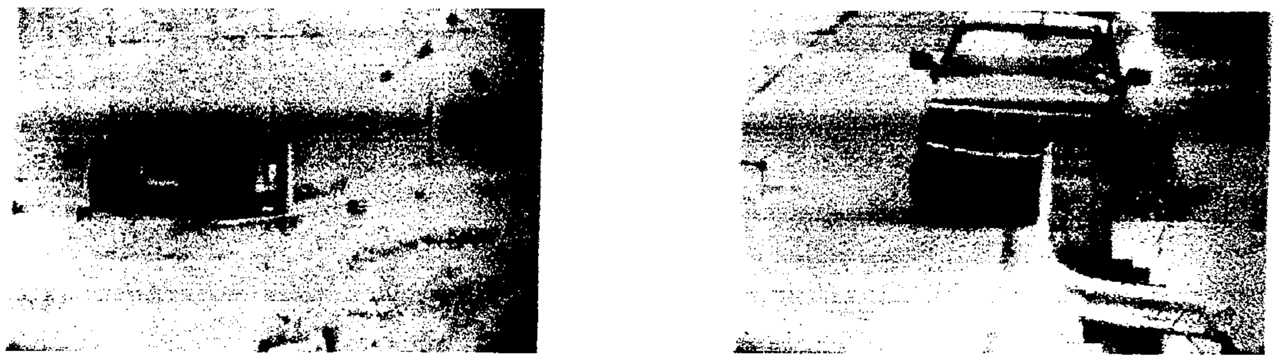


0.181 s

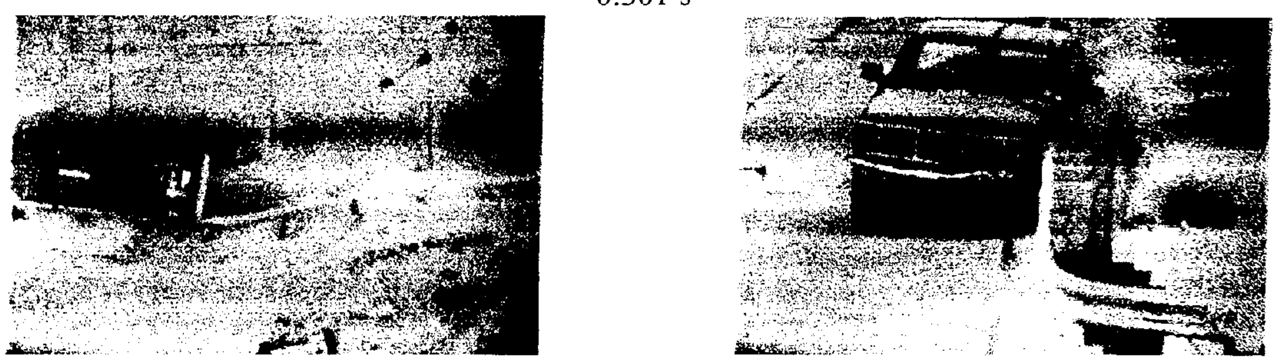
Figure 122. Sequential photographs for test 471470-30 (overhead and frontal views).



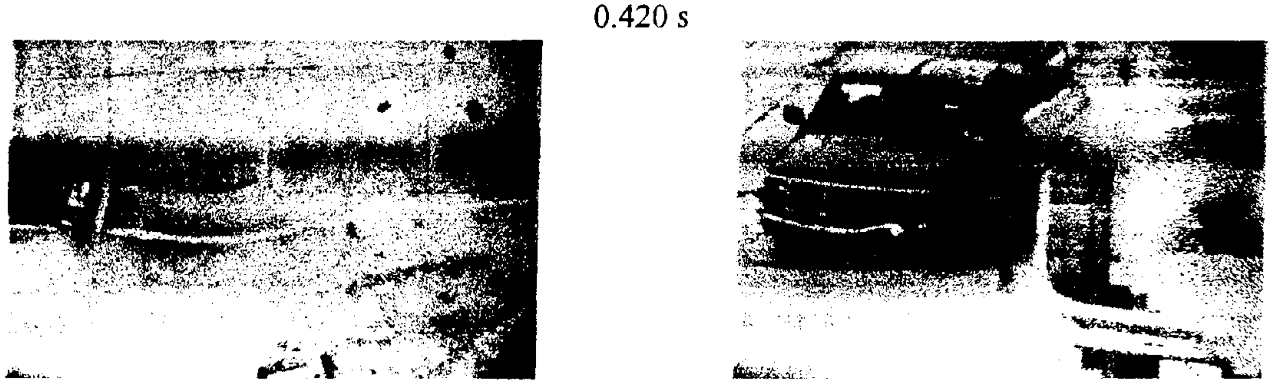
0.240 s



0.301 s

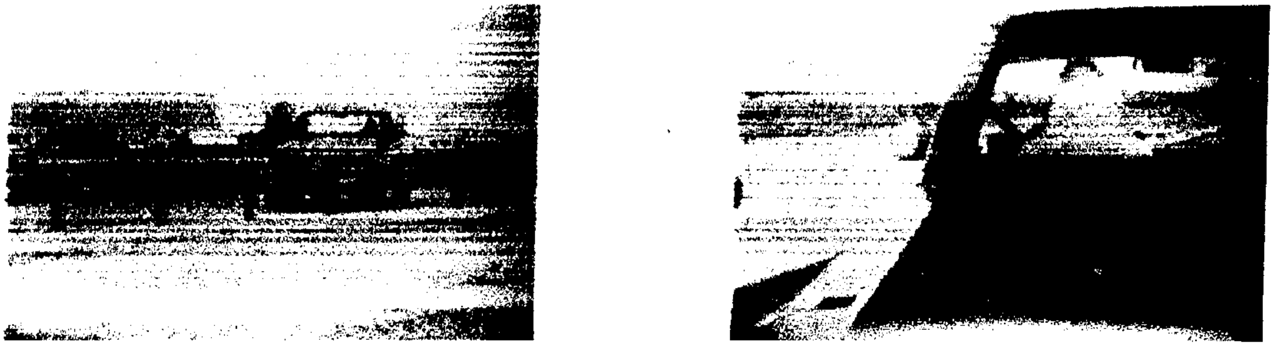


0.420 s

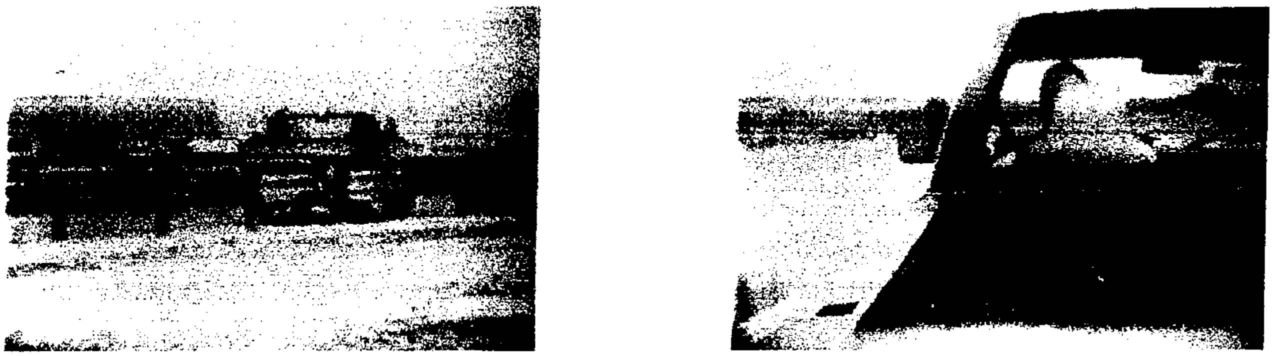


0.560 s

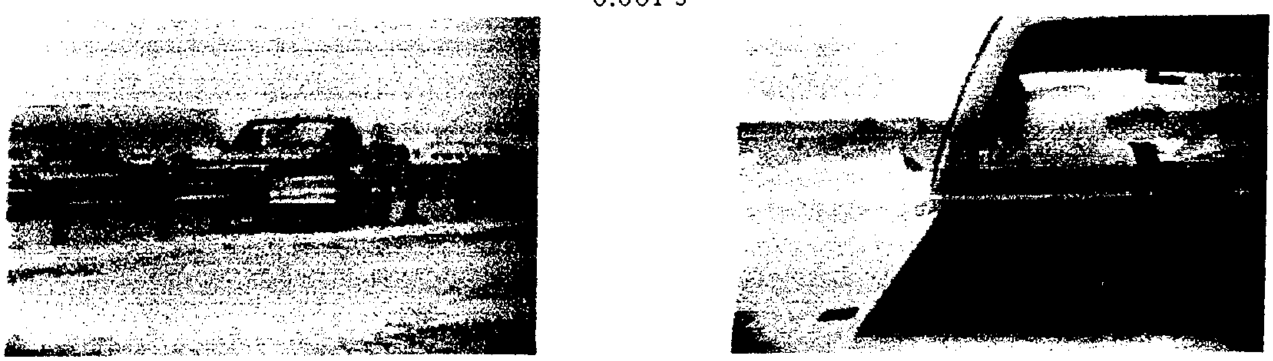
Figure 122. Sequential photographs for test 471470-36 (overhead and frontal views) (continued).



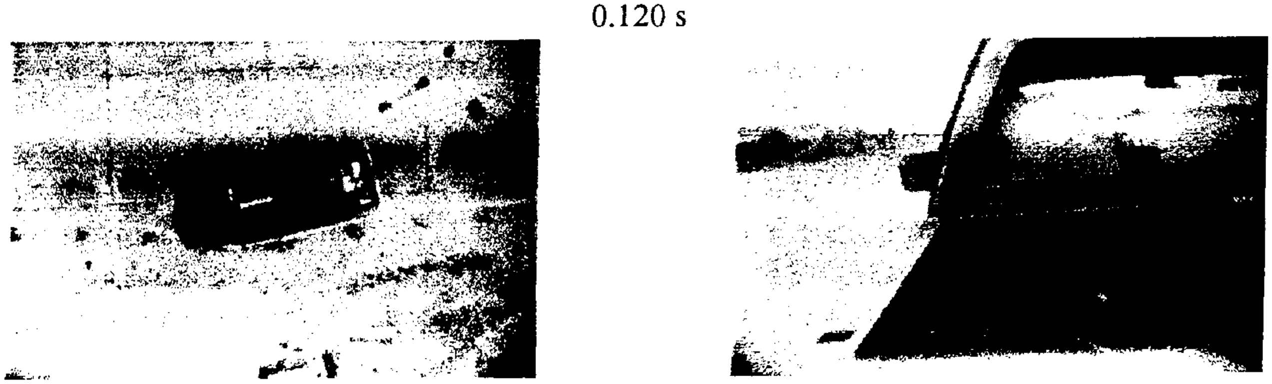
0.000 s



0.061 s

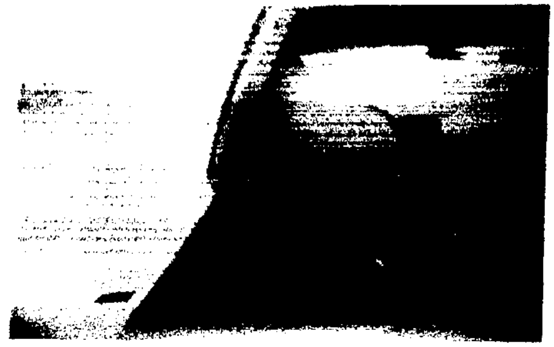


0.120 s

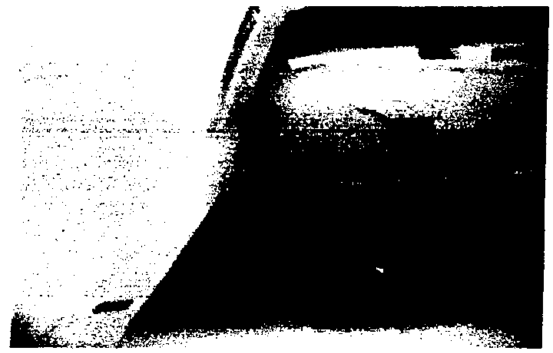


0.181 s

Figure 123. Sequential photographs for test 47147?-3? (rear and interior views).

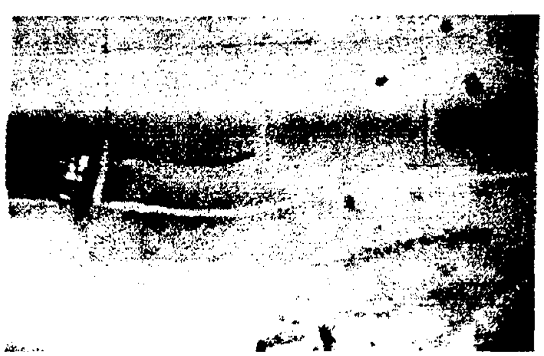


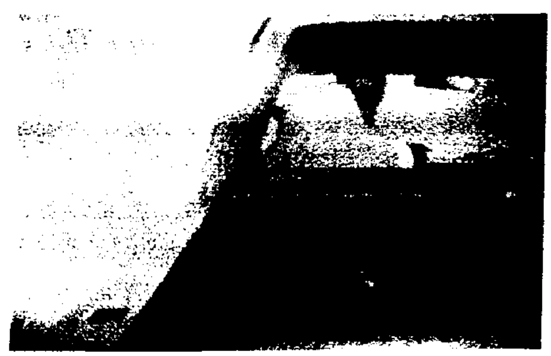
0.240 s



0.301 s

0.420 s





0.560 s

Figure 123. Sequential photographs for test 471470-36 (rear and interior views) (continued).

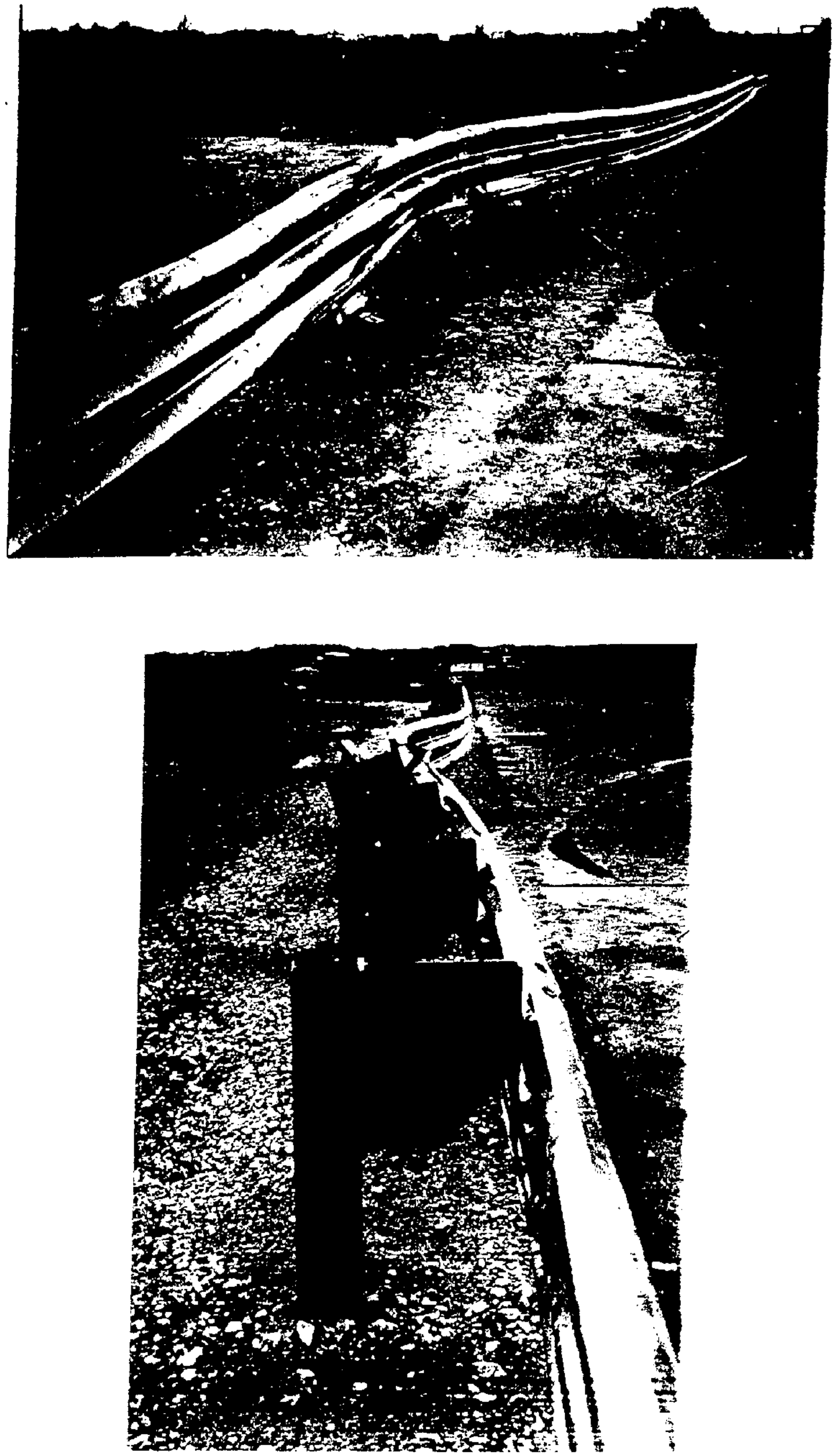


Figure 124. Modified thrie-beam guardrail after test 471470-30.

Figure 125. Damage to post in test 471470-30.

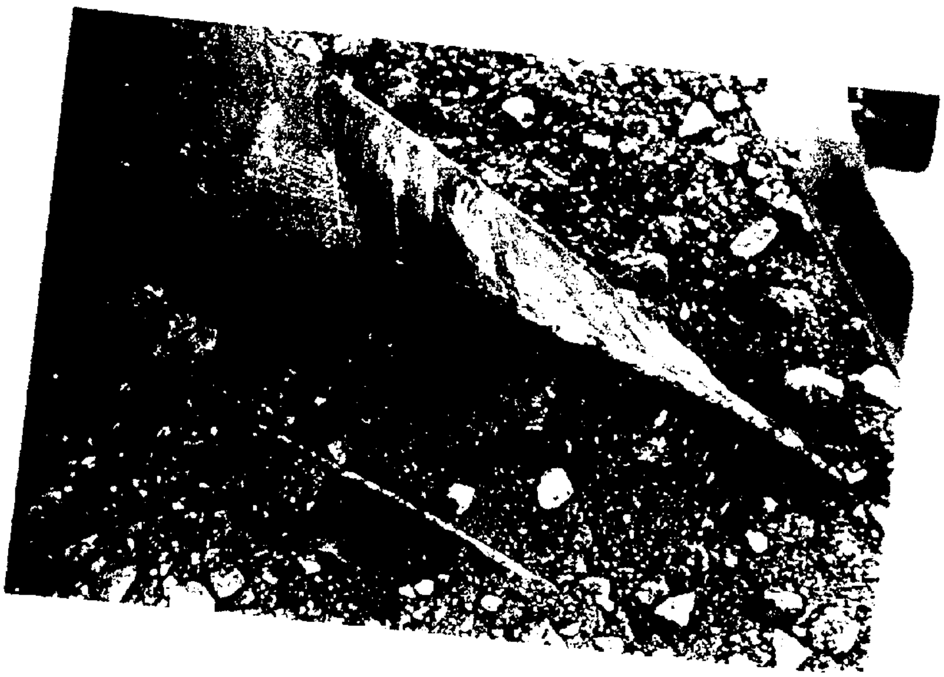


Figure 126. Damage to thrie beam and post flange at post 17.

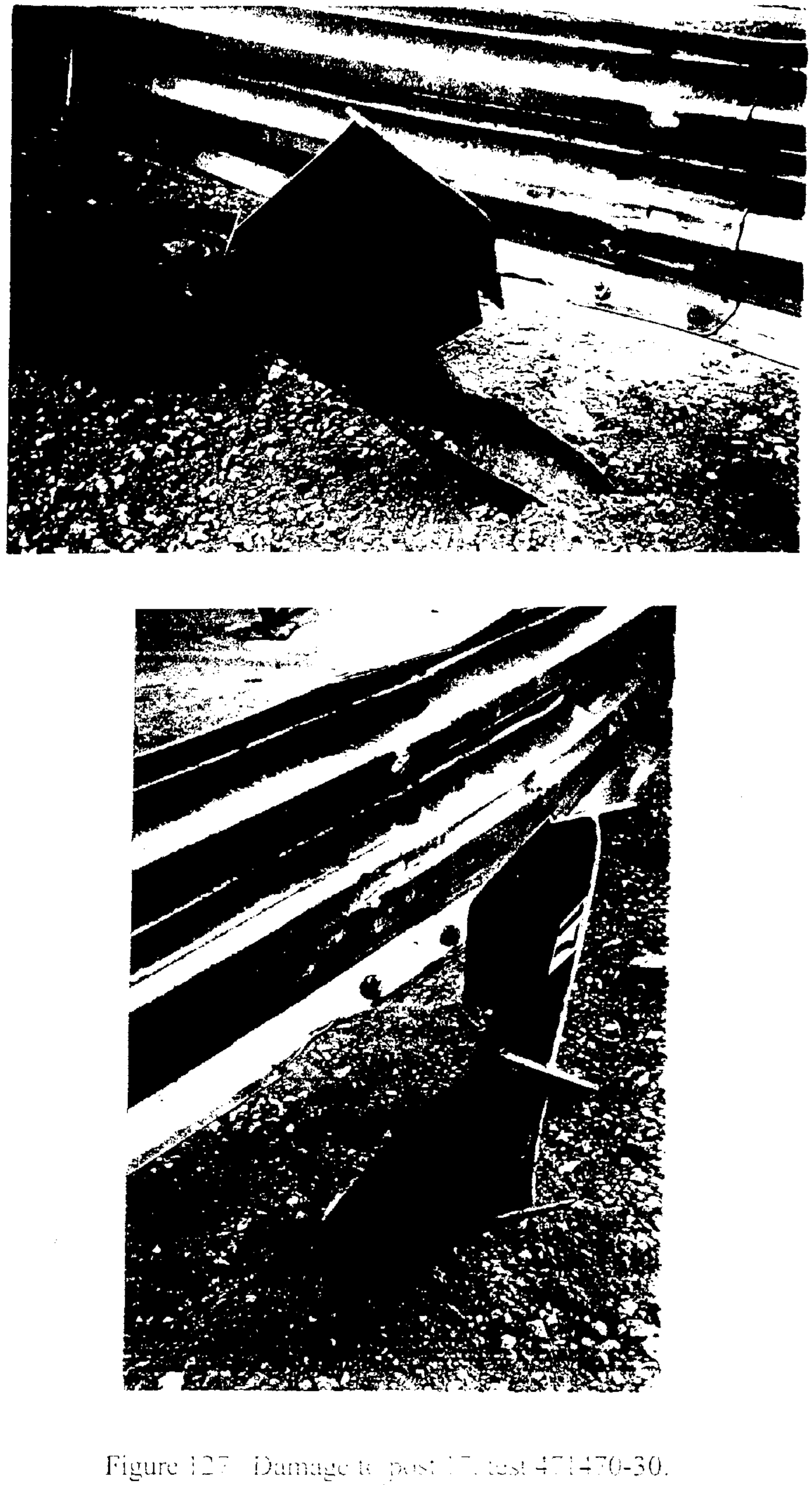


Figure 127. Damage to post 17, test 471470-30.

Figure 128. Damage at post 18, test 471470-3[illegible]

the face of post 16 and the back side of post 17. The thrie-beam rail element was separated from post 17, and the flanges on post 17 showed evidence of wheel contact. Posts 16, 17, and 18 were twisted severely. The lateral deflections recorded at posts 14 through 20 are noted in table 7.

Table 7. Lateral post deflections for test 471470-30.

Post 14 .... 25 mm (1.0 in)	Post 18 .... 90 mm (3.5 in)
Post 15 .... 108 mm (4.3 in)	Post 19 .... 90 mm (3.5 in)
Post 16 .... 216 mm (8.5 in)	Post 20 .... 22 mm (0.9 in)
Post 17 .... 216 mm (8.5 in)	

Maximum dynamic deflection of the thrie-beam rail element was 1.02 m (3.4 ft). Maximum permanent deformation of the installation was 0.61 m (2.0 ft) just upstream of post 17. Total length of contact of the vehicle with the installation was 8.0 m (26.1 ft).

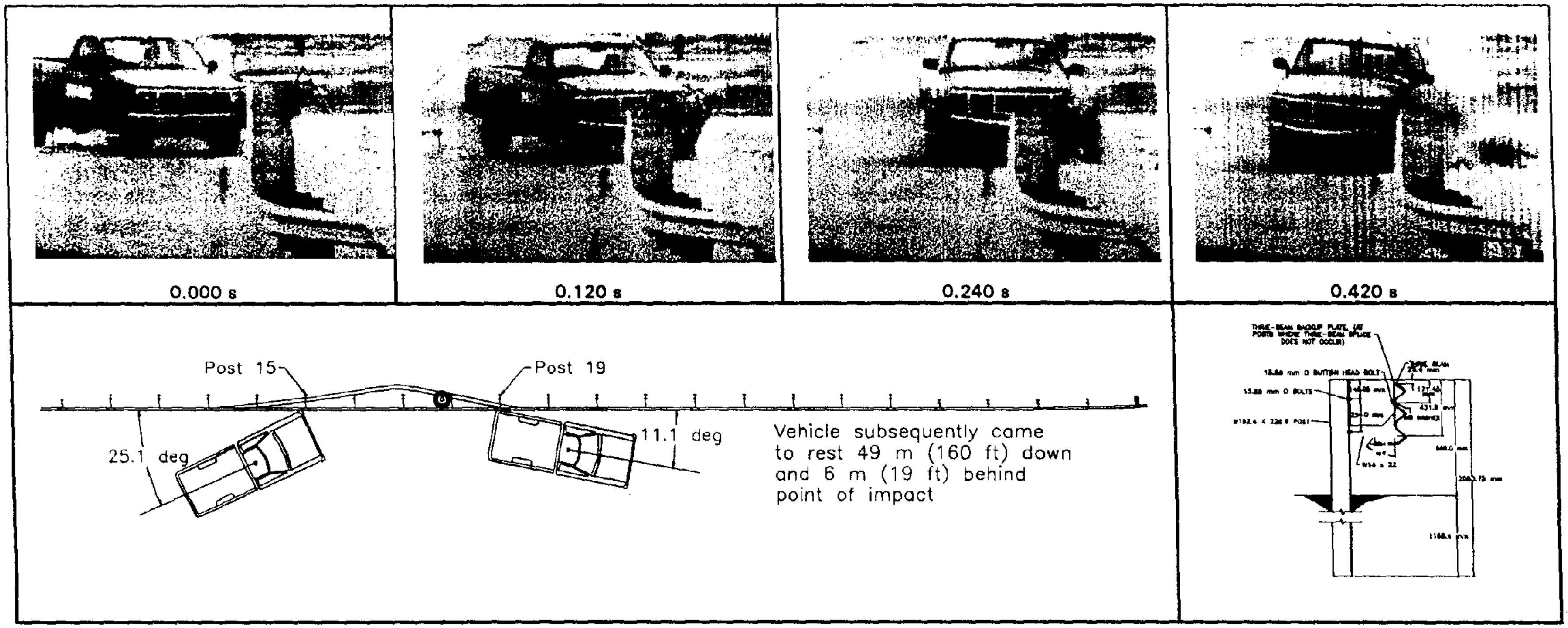
3.8.3 Vehicle Damage

The vehicle sustained moderate damage, as shown in figure 129. The upper and lower A-arms, stabilizer bar, frame, tie rod ends, and spindle on the left side were damaged. The left front wheel assembly was torn from the vehicle's axle. The front bumper, grill, left front quarter panel, and both doors also were damaged. Maximum exterior crush at the left front corner of the vehicle was 430 mm (16.9 in) and there was deformation at the floorpan area of 16 mm (0.6 in).

3.8.4 Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. Occupant contact first occurred in the lateral direction. Lateral occupant impact velocity was 5.2 m/s (17.1 ft/s) at 0.146 s; the highest 0.010-s lateral occupant ridedown acceleration was 9.0 g's between 0.223 and 0.233 s; and the maximum 0.050-s average acceleration was 5.2 g's between 0.101 and 0.151 s. In the longitudinal direction, the occupant impact velocity was 7.8 m/s (25.6 ft/s); the highest 0.010-s occupant ridedown acceleration was -9.7 g's between 0.163 and 0.173 s; and the maximum 0.050-s average was -6.2 g's between 0.156 and 0.206 s. These data and other information pertinent to the test are summarized in figure 130. Vehicle angular displacements during the test are displayed in figure 131. Vehicular accelerations versus time traces filtered at 60 Hz are presented in figures 132 through 134.

Figure 129. Vehicle after test 471470-30

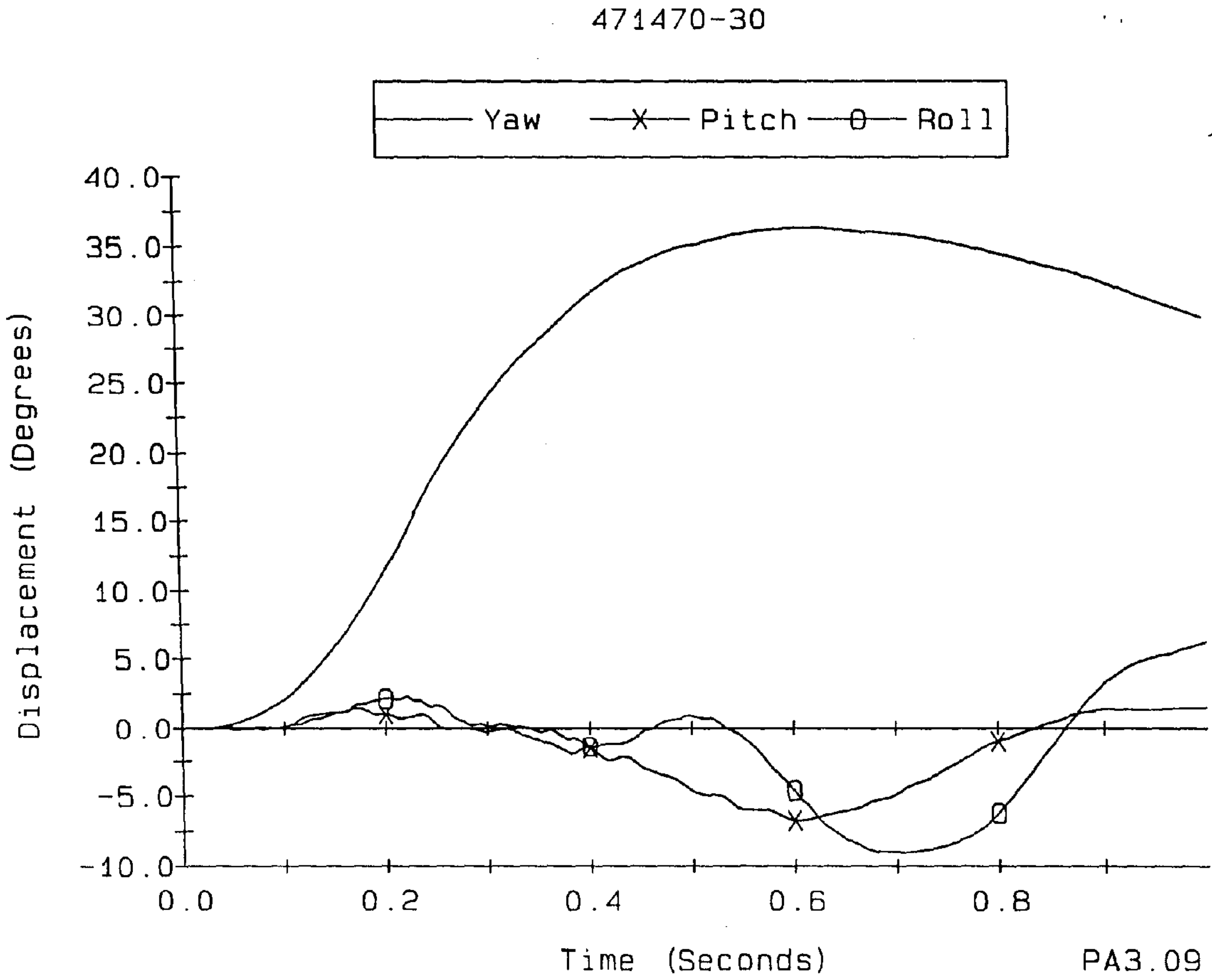


General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-30
Date	01/11/95
Test Article	
Type	Guardrail
Name or Manufacturer	Modified Thrie beam
Installation Length (m)	53 m (175 ft)
Size and/or Dimension and Material of Key Elements	Thrie Beam on W6x9 Post and M14x18 Spacer with Cutout
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 GMC 2500 Pickup
Mass (kg) Curb	2043 (4500 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	100.2 (62.3 mi/h)
Angle (deg)	25.1
Exit Conditions	
Speed (km/h)	67.4 (41.9mi/h)
Angle (deg)	11.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.8 (25.6 ft/s)
y-direction	5.2 (17.1 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-9.7
y-direction	9.0
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.2
y-direction	5.2
z-direction	-2.9

Test Article Deflections (m)	
Dynamic	1.02 (3.4 ft)
Permanent	0.61 (2.0 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ4
CDC	11FLEK3 & 11LYEW4
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	430 (16.9 in)
Max. Occ. Compart. Deformation (mm)	16 (0.6 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-9
Max. Pitch Angle (deg)	-7
Max. Yaw Angle (deg)	36

Figure 130. Summary of results for test 471470-30.



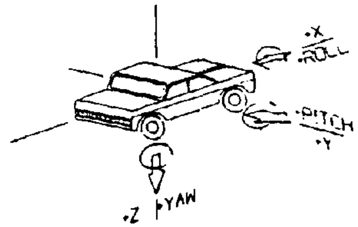


Figure 131. Vehicle angular displacements during test 471470-30.

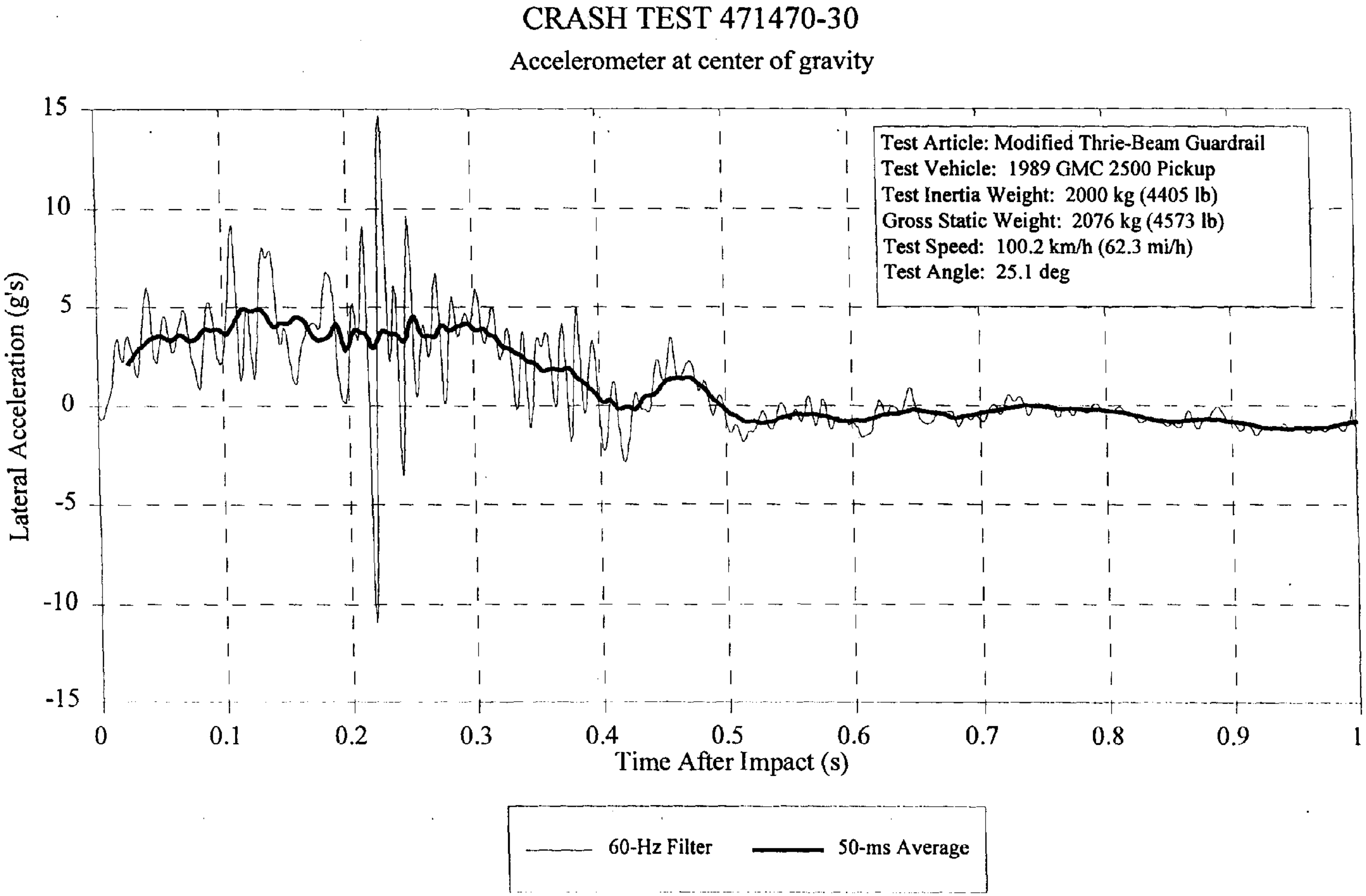


Figure 133. Vehicle lateral accelerometer trace for test 471470-30.

CRASH TEST 471470-30

Accelerometer at center of gravity

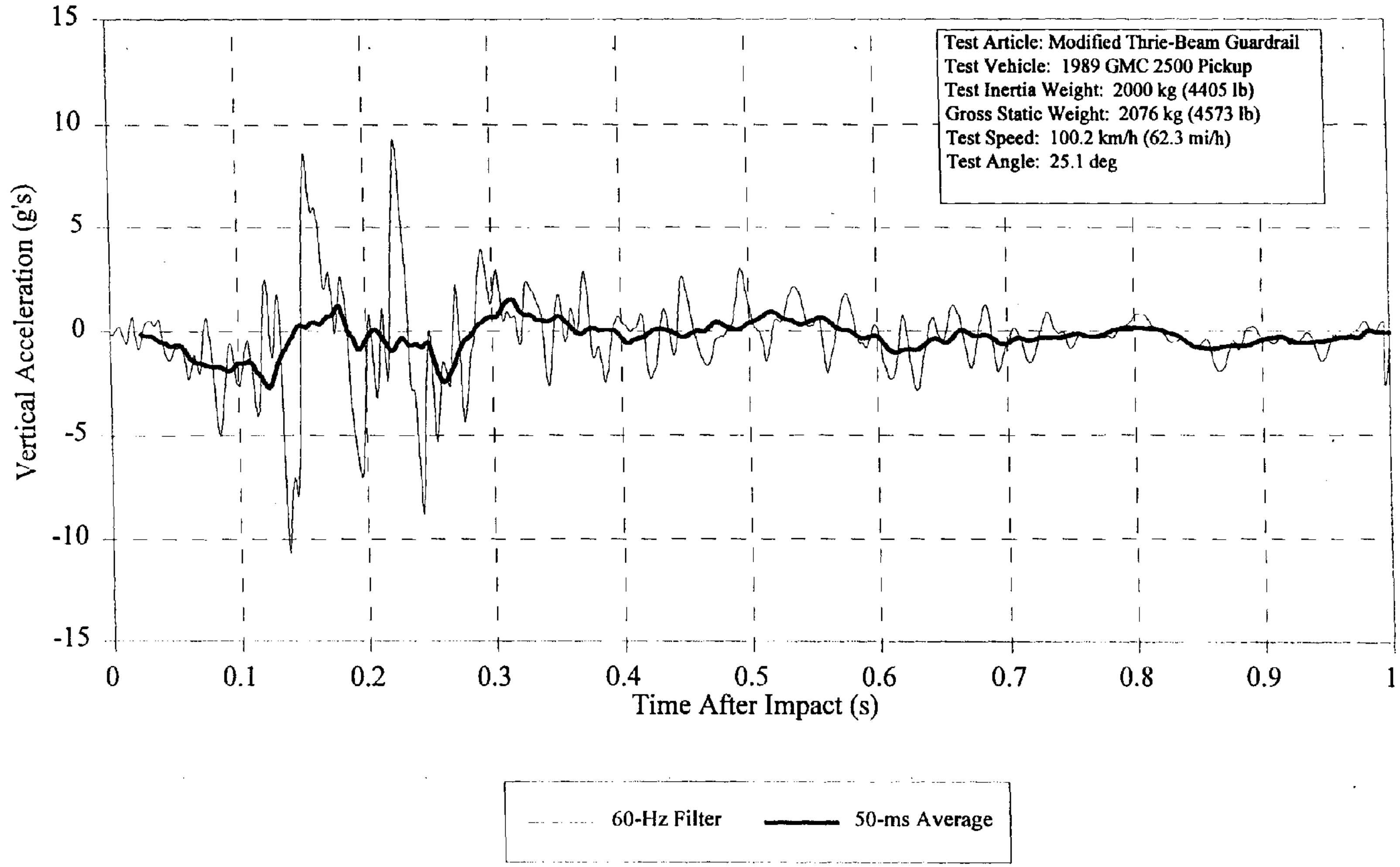


Figure 134. Vehicle vertical accelerometer trace for test 471470-30.

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

4.1 CABLE (G1) GUARDRAIL SYSTEM

The vehicle was successfully contained and smoothly redirected by the cable (G1) guardrail system under test level 3 conditions. The maximum dynamic deflection of the guardrail was 2.4 m (7.8 ft). There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained moderate damage with no intrusion or deformation into the passenger compartment. The vehicle remained upright and stable during and after the impact sequence. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic as the vehicle exited the installation with a trajectory of 2.0 degrees. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the cable (G1) guardrail system was considered satisfactory according to guidelines set forth in NCHRP Report 350, as shown in table 8.

It should be noted that the impact speed of 95.1 km/h (59.1 mi/h) was lower than the target impact speed of 100 km/h (62.2 mi/h). However, the impact angle of 26.7 degrees was greater than the target impact angle of 25 degrees. Consequently, the impact severity (IS) value of the test was 141.2 kJ, which was actually higher than the nominal IS value of 138.1 kJ for the target impact speed and angle. Furthermore, based on the test results, there is no reason to believe that the cable (G1) guardrail system would perform any differently at the target impact speed and angle.

4.2 W-BEAM, WEAK-POST (G2) GUARDRAIL SYSTEM

The W-beam, weak-post (G2) guardrail system was crash tested under both test level 3 (test no. 471470-21) and test level 2 (test no. 471470-22) conditions. Summaries of the results of the two tests are shown in tables 9 and 10, respectively.

The W-beam, weak-post (G2) guardrail system failed to contain and redirect the impacting vehicle at test level 3 conditions. The left front, left rear, and right front tires of the vehicle overrode the guardrail and exited only when the end of the guardrail installation was reached. It is evident from reviewing the high-speed film that, had there been a longer run of guardrail, the vehicle would likely have vaulted over the guardrail completely. The best scenario is for the vehicle to straddle the guardrail until it came to rest. Otherwise, the G2 guardrail system performed well with respect to the other evaluation criteria. There was no debris or detached elements from the installation that would pose undue hazard to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during and after the impact even though it was astride the guardrail. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic. The occupant risk factors were all well within the desirable limits set forth in NCHRP Report 350.

Table 8. Assessment of results of test with cable (G1) guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-28 | Test Date: 11/15/94

NCHRP 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 guardrail contained and redirected the vehicle. The vehicle did not penetrate or go 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 elements or debris to pose any undue hazard to adjacent traffic. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively 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.	There was minimal, if any, intrusion 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 = 4.3 m/s Longitudinal Ridedown Acceleration = -4.0 g's	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact was approximately 2 degrees, which was less than 60 percent of the test impact angle 26.7 degrees.	Pass

Table 9. Assessment of results of test with W-beam, weak-post (G2) guardrail system (test level 3).

Test Agency: Texas Transportation Institute | Test No.: 471470-21 | Test Date: 09/09/93

NCHRP 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 left front, left rear, and right front tires of the vehicle overrode the guardrail before reaching the end of the test installation.	Fail
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	The only debris to separate a significant distance from the installation were the washers used in attaching the W-beam to the posts. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively stable throughout the test period; however, it did mount the installation.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was no vehicle intrusion 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 = 4.9 m/s Longitudinal Ridedown Acceleration = -4.2 g's.	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The vehicle remained on top of the guardrail until the end of the installation.	Pass

Table 10. Assessment of results of test with W-beam, weak-post (G2) guardrail system (test level 2).

Test Agency: Texas Transportation Institute | Test No.: 471470-22 | Test Date: 01/06/94

NCHRP 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 guardrail contained and redirected the vehicle.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was no detached elements or debris to pose any undue hazard to adjacent traffic. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively 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.	There was no vehicle intrusion 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 = 4.6 m/s Longitudinal Ridedown Acceleration = -4.8 g's.	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle of 9.5 degrees was less than 60 percent of the test impact angle (15 degrees).	Pass

The W-beam, weak-post (G2) guardrail system successfully contained and redirected the impacting vehicle under test level 2 conditions. There was no debris or detached elements from the installation that would pose undue hazard to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during and after the impact. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic. The occupant risk factors were all well within the desirable limits set forth in NCHRP Report 350.

In summary, the impact performance of the W-beam, weak-post (G2) guardrail system was considered unsatisfactory from the structural adequacy standpoint under NCHRP Report 350 test level 3, but performed satisfactorily under test level 2 conditions.

4.3 BOX-BEAM (G3) GUARDRAIL SYSTEM

The box-beam (G3) guardrail system successfully contained and redirected the vehicle. The maximum dynamic deflection of the guardrail was 1.15 m (3.8 ft). There were no detached elements or debris to exhibit an undue hazard to adjacent traffic. The vehicle sustained moderate damage with minimal deformation into the passenger compartment. The vehicle remained upright and stable during the impact sequence and after exiting the guardrail. The trajectory of the vehicle was judged to have posed minimal, if any, potential hazard to adjacent traffic, as the vehicle exited the installation with a trajectory of approximately 0.7 degree toward the guardrail. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350.

The impact speed of 95.2 km/h (59.1 mi/h) was slightly slower than the lower tolerance limit of 96 km/h (59.7 mi/h), i.e., for a nominal impact speed of 100 km/h (62.2 mi/h) and a tolerance of -4 km/h (-2.5 mi/h). The impact angle of 25.5 degrees was higher than the nominal impact angle of 25 degrees. The resulting impact severity (IS) of 129.6 kJ (95.6 kip-ft) was above the lower IS tolerance limit of 127.3 kJ (93.9 kip-ft), i.e., for a nominal IS of 138.1 kJ (101.9 kip-ft) and a tolerance of -10.8 kJ (-8.0 kip-ft). Furthermore, there is no reason to believe that the box-beam (G3) guardrail system would have performed any differently with a slightly higher impact speed.

In summary, the impact performance of the box-beam (G3) guardrail system was considered satisfactory according to evaluation criteria set forth in NCHRP Report 350, as shown in table 11.

4.4 W-BEAM, STRONG-POST (G4) GUARDRAIL SYSTEMS

The W-beam, strong-post (G4) guardrail was crash tested for both wood-post, G4(2W), and steel-post, G4(1S), systems. Summaries of the results are presented in tables 12 and 13, respectively.

Table 11. Assessment of results of test with box-beam (G3) guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-33 | Test Date: 04/13/95

NCHRP 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 guardrail contained and redirected the vehicle through controlled lateral deflection. The vehicle did not penetrate or go 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 elements or debris to pose any undue hazard to adjacent traffic. There was minimal deformation into the occupant compartment and it was considered non life-threatening.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively stable during the collision and after exiting the test installation.	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal, if any, intrusion 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 = 6.3 m/s Longitudinal Ridedown Acceleration = -5.8 g's	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact was approximately 0.7 degrees toward the guardrail.	Pass

Table 12. Assessment of results of test with W-beam, wood-post (G4(2W)) guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-26 | Test Date: 05/25/94

NCHRP 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 guardrail contained and redirected the vehicle. The vehicle did not penetrate or go 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 elements or debris to pose any undue hazard to adjacent traffic. There was minimal deformation of the occupant compartment and it was considered non life-threatening.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively 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.	There was minimal vehicle intrusion 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 = 7.5 m/s Longitudinal Ridedown Acceleration = -11.6 g's.	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle of 8.1 degrees was less than 60 percent of the test impact angle (25 degrees).	Pass

Table 13. Assessment of results of test with W-beam, steel-post (G4(1S)) guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-27 | Test Date: 06/09/94

NCHRP 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 guardrail contained and redirected the vehicle. The vehicle did not penetrate or go 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 elements or debris to pose any undue hazard to adjacent traffic. There was minimal deformation of the occupant compartment and it was considered non life-threatening.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle rolled onto its left side after exiting the guardrail system.	Fail
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal vehicle intrusion 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 = 7.5 m/s Longitudinal Ridedown Acceleration = -7.9 g's	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle of 5.2 degrees was less than 60 percent of the test impact angle (25 degrees).	Pass

In the test with the G4(2W) guardrail system, the vehicle was successfully contained and smoothly redirected. The maximum dynamic deflection of the guardrail was 0.8 m (2.7 ft). There were no detached elements or debris to exhibit an undue hazard to adjacent traffic. The vehicle sustained moderate damage with minimal deformation into the passenger compartment. The vehicle attained a maximum roll angle of 39 degrees, but remained upright during and after the impact sequence. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic, as the vehicle exited the installation with a trajectory of 8.1 degrees. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the G4(2W) guardrail system was considered acceptable according to guidelines set forth in NCHRP Report 350.

In the test with the G4(1S) guardrail system, the vehicle was contained and redirected by the guardrail, but the vehicle rolled over onto its left side (impact side) after exiting from the test installation. The maximum dynamic deflection of the guardrail was 1.01 m (3.3 ft). There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained severe damage, mostly due to rolling over onto its left side. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic, as the vehicle exited the installation with a trajectory of 5.2 degrees. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the G4(1S) guardrail system was considered unsatisfactory due to the rollover of the vehicle onto its left side.

The initial concern with these two strong-post, W-beam guardrail systems was that the mounting height may not be high enough to prevent the 2000P vehicle from vaulting or going over the guardrail. It was theorized that the bumper of the 2000P vehicle could potentially override the W-beam rail element and that the front tire could ride up on a post, resulting in the vehicle vaulting or going over the guardrail. There was no indication of this problem in either of the two crash tests. However, it should be noted that there are wide variations in the bumper heights of 3/4-ton pickup trucks. The 1988 and 1989 Chevrolet 2500 pickup trucks used in these two crash tests were selected to have an average or representative bumper height and do not have the highest possible bumper heights. Thus, the results from these crash tests may not totally eliminate this potential concern.

The G4(2W) and G4(1S) guardrail systems are generally considered to be compatible in performance and are used interchangeably. However, the vehicle remained upright in the G4(2W) test, but rollover over on its side in the G4(1S) test. These two length-of-need strength tests were almost identical, including the setups of the test installations, the nominal impact conditions, and the test vehicles. This provided an opportunity to directly compare between the performance of the two guardrail systems.

Table 14 summarizes the test parameters and the behavior of the vehicles and the guardrail systems for these two tests. The impact conditions for the steel-post G4(1S) guardrail system were slightly more severe than those for the wood-post G4(2W) guardrail system, particularly for the impact angle (26.1 versus 24.3 degrees). The maximum dynamic deflection for the steel-post G4(1S) guardrail system was somewhat more than the wood-post G4(2W) guardrail system, 1.01 m (3.3 ft) versus 0.82 m (2.7 ft). The time and location of the maximum dynamic deflections were very similar as were the maximum permanent deflections. This difference in deflection could be partially attributed to the slightly higher impact speed and angle in the G4(1S) guardrail system test. Another possibility is that the G4(1S) guardrail system, with lower bending strength for the steel posts, has less lateral stiffness and thus allowed more deflection.

Table 14. Comparison between test results for the strong-post, W-beam systems.

DESCRIPTION	G4(1S) GUARDRAIL	G4(2W) GUARDRAIL
Impact Conditions Speed Angle	 101.4 km/h (63.0 mi/h) 26.1 deg	 100.8 km/h (62.6 mi/h) 24.3 deg
Maximum Dynamic Deflection Deflection Location Time	 1.01 m (3.3 ft) Near post 16 0.365 s	 0.82 m (2.7 ft) Near post 16 0.371 s
Maximum Permanent Deflection Deflection Location	 0.73 m (2.4 ft) Between posts 15 and 16	 0.69 m (2.25 ft) Between posts 15 and 16
Parallel with Installation Time Speed Distance to Parallel	 0.274 s 66.0 km\h (41.0 mi/h) 6.7 m (21.9 ft)	 0.249 s 74.3 km/h (46.3 mi/h) 6.0 m (19.6 ft)
Exit from Installation Time Speed Angle Roll Angle	 0.530 s 58.7 km/h (36.5 mi/h) 5.2 deg -28 deg	 0.513 s 70.8 km/h (44.0 mi/h) 8.1 deg -25 deg
Length of Contact	8.1 m (26.5 ft)	6.9 m (22.7 ft)
Maximum Roll Angle	90 deg	39 deg

The time to parallel for the G4(1S) guardrail system was slightly longer than that of the G4(2W) guardrail system, 0.274 s versus 0.249 s, with a lower vehicular speed, 66.0 km/h (41.0 mi/h) versus 74.3 km/h (46.3 mi/h). The time to exit from the test installation was approximately the same for both guardrail systems, but the exit speed and angle were lower and the total length of contact was longer for the G4(1S) guardrail system. The 28-degree roll angle of the vehicle at exit from the test installation for the G4(1S) guardrail system was only slightly higher than the 25 degrees for the G4(2W) guardrail system. The maximum roll angle of the vehicle in the test with the G4(2W) guardrail system was 39 degrees, while the vehicle in the test with the G4(1S) guardrail system rolled onto its left side after exiting from the test installation. The differences could be attributed to the more severe snagging of the left front tire of the vehicle on the posts for the G4(1S) guardrail system. In fact, it appeared from review of the high-speed film that the snagging of the left front tire of the vehicle on the posts was what initiated the roll in the test with the G4(1S) guardrail system. It is expected that the steel-post G4(1S) guardrail system would have more problems with snagging on the posts because of the shallower blockout depth (6 in versus 8 in for the wood-post G4(2W) guardrail system), the shape of the steel posts, and the larger dynamic deflection.

It can be concluded from the test results that the performances of both strong-post, W-beam guardrail systems are marginal under the NCHRP Report 350 test level 3 conditions. The G4(2W) guardrail system appears to perform better than the G4(1S) guardrail system, but the vehicle did attain a maximum roll angle of 39 degrees and there was evidence of post contact in the test with the G4(2W) guardrail system. Many factors could potentially affect the performance of a guardrail system, such as variations in impact conditions (i.e., impact speed and angle), materials and construction of the test installation, and properties of the test vehicle (e.g., bumper height, length of front overhang, etc.). Accounting for all these influencing factors in a single crash test is not possible, and it is conceivable that different performance results may arise even within the range of allowable variations in one or more of these factors.

As mentioned previously, it appears that the major problem with the G4(1S) guardrail system is snagging on the posts, and this problem needs to be resolved for the G4(1S) guardrail system to perform satisfactorily under the NCHRP Report 350 test conditions. As mentioned previously, the snagging problem can be attributed to the shallower blockout depth, the shape of the steel posts, and the larger dynamic deflection. There are many potential remedial measures, such as increasing the blockout depth, using a different shape for the steel posts, e.g., C-post, and/or using a heavier section for the steel posts. Further research into these and other remedial measures is recommended.

4.5 THRIE-BEAM (G9) GUARDRAIL SYSTEM

The thrie-beam (G9) guardrail system successfully contained and redirected the vehicle. The maximum dynamic deflection of the guardrail was 1.07 m (3.5 ft). There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained extensive damage, with 114-mm (4.5-in) deformation into the passenger compartment. The vehicle exited the test installation at a high roll angle and subsequently rolled two and a quarter revolutions after exiting the test installation. The exit trajectory of the vehicle was judged to have posed potential hazard to adjacent traffic, as the vehicle exited the installation with an angle of approximately 35 degrees. The occupant risk factors were within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the thrie-beam (G9) guardrail system was judged to be unsatisfactory according to evaluation criteria set forth in NCHRP Report 350 because of post-impact rollover, as shown in table 15.

Table 15. Assessment of results of test with thrie-beam (G9) guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-31 | Test Date: 04/14/95

NCHRP 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 guardrail contained and redirected the vehicle. The vehicle did not penetrate or go 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 elements or debris to pose any undue hazard to adjacent traffic. There was 114-mm (4.5-in) deformation downward from the roof into the occupant compartment over the passenger side due to post-impact rollover.	Fail
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during the impact with the guardrail; however, as the vehicle exited from the test installation, it had attained a roll angle of -45 degrees. The vehicle subsequently rolled over two and a quarter revolutions after exiting the guardrail and came to rest on its left side.	Fail
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle showed potential for intrusion into adjacent traffic lanes.	Fail
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 8.0 m/s Longitudinal Ridedown Acceleration = -7.0 g's.	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact was approximately 35 degrees, which was less than 60 percent of the test impact angle 21.6 degrees.	Fail

The unsatisfactory performance of the thrie-beam (G9) guardrail system was somewhat unexpected, particularly the violence of the rollover. The left front tire of the vehicle snagged on two posts, which could account for the high exit angle of 35 degrees. The maximum dynamic deflection of 1.07 m (3.5 ft) was higher than expected and it appeared that the deformed guardrail served as a ramp to destabilize the vehicle, as evidenced by the high roll angle of -45 degrees at exit from the guardrail system. There are some potential remedial measures, such as increasing the blockout depth, shortening the length of the blockout, eliminating the lower rail bolt, and/or using heavier section for the steel posts. Further research into these and other remedial measures is recommended.

4.6 MODIFIED THRIE-BEAM GUARDRAIL SYSTEM

The modified thrie-beam guardrail system successfully contained and redirected the vehicle and met all evaluation criteria set forth in NCHRP Report 350 for test level 3 conditions. The maximum dynamic deflection of the guardrail was 1.02 m (3.4 ft). There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained moderate damage with minimal deformation or intrusion into the passenger compartment. The vehicle remained upright and stable during and after the impact sequence. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic, as the vehicle exited the installation with a trajectory of 11.1 degrees. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the modified thrie-beam guardrail system was considered satisfactory according to guidelines set forth in NCHRP Report 350, as shown in table 16.

The relatively large dynamic deflection sustained by the guardrail system and the snagging of the left wheel assembly with post 17 were somewhat unexpected given the stiffness of the thrie-beam rail element and the 457-mm (18-in) deep blockout. The soil condition was checked and found to be a little damp, but not to the extent that it would adversely affect the bearing capacity of the soil. Review of the high-speed film showed that posts 16 through 18 were severely twisted from the vehicle impact as the thrie-beam rail element deflected. The W6 x 9 steel posts are relatively weak in torsion to begin with. The added moment arm due to the deep blockout aggravated the torsional moment acting on the posts. As the posts twisted, the blockouts essentially collapsed. This in effect increased the dynamic deflection of the guardrail by 457 mm (18 in). In other words, without the collapse of the blockout, the dynamic deflection would have been 563 mm (22 in) instead of 1.02 m (3.4 ft). Also, the collapse of the blockout allowed the left front wheel assembly of the vehicle to come into direct contact with post 17, resulting in the wheel assembly being torn off the vehicle. However, even with the wheel snagging on the post, the modified thrie-beam guardrail system successfully contained and redirected the vehicle with no indication of vehicle instability or unacceptable occupant risk factors.

Table 16. Assessment of results of test with modified thrie-beam guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-30 | Test Date: 01/11/95

NCHRP 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 guardrail contained and redirected the vehicle through controlled lateral deflection. The vehicle did not penetrate or go 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 elements or debris to pose any undue hazard to adjacent traffic. There was minimal deformation into the occupant compartment and was it considered non life-threatening.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively 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.	There was minimal intrusion 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 = 7.8 m/s Longitudinal Ridedown Acceleration = -9.7 g's.	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact was approximately 11.1 degrees, which was less than 60 percent of the test impact angle of 25.1 degrees.	Pass

REFERENCES

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

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