Testing of State Roadside Safety Systems Volume III: Appendix B–Crash Testing and Evaluation of a Guardrail System for Low-fill Culvert

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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 three crash tests conducted on long-span nested W-beam guardrail designs for use over culverts. The first test (test no. 471470-2) was on a 3.81-m (12-ft, 6-in) span design. The second test (test no. 471470-4) was on a 5.72-m (18-ft, 9-in) span with a W-beam rail section on the rear of the guardrail. The third test (test no. 471470-5) was also on a 5.72-m (18-ft, 9-in) span, but without a W-beam rail section on the rear of the guardrail. All three crash tests corresponded to National Cooperative Highway Research Program (NCHRP) Report 230 test designation 10, involving a 2043-kg (4500-lb) passenger car impacting the guardrail at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 25 degrees. All three nested W-beam guardrail designs performed satisfactorily in the crash tests and met all evaluation criteria set forth in NCHRP Report 230.

This volume is the third in a series of 14 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 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 XI, Appendix J - Crash Testing and Evaluation of Existing Guardrail Systems; Volume XII, Appendix K - Crash Testing and Evaluation of the MELT; Volume XIII, Appendix L - Crash Testing and Evaluation of the Modified MELT; and Volume XIV, Appendix M - Laboratory and Pendulum Testing of 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 III 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.
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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 (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°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	lbf/in^2

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

(Revised September 1993)

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I. INTRODUCTION

A problem arises when a roadside guardrail needs to continue across a low-fill box culvert. Full embedment of the guardrail post(s) is not possible over the box culvert because of the shallow soil cover. Previous crash testing has demonstrated that posts with short embedment depths can be pulled out from the ground and subsequently fall into the path of the vehicle's tires. The resulting tire-post forces can then cause snagging and/or vaulting of the vehicle. For a steel-post guardrail system, one design that has been successfully crash tested is to bolt the short post(s) to the top of the box culvert. This eliminates the potential of the short post(s) being pulled out from the ground as well as increasing the load carrying capacity of the short post(s).(1)

However, this solution is not applicable to wood-post guardrail systems without switching from wood to steel posts for the segment over the low-fill box culvert. Also, this requires specially fabricated steel posts and increased installation costs. A computer simulation study was conducted as part of this project to evaluate alternate designs for use with wood-post guardrail systems over low-fill box culverts. The results of the simulation study suggested that a long-span nested W-beam rail with no posts over the culvert would be the best design among the alternatives evaluated. A maximum span length of 3.81 m (12 ft, 6 in) in conjunction with a minimum length of 7.62 m (25 ft) of nested W-beam rail were recommended for further evaluation with full-scale crash testing.(2)

Results of the first full-scale crash test (test no. 471470-2) indicated that this system performed very well with a span length of 3.81 m (12 ft, 6 in). In fact, the system performed so well that there is good reason to believe that it would work with an even longer span length. It was then suggested that the span length be increased to 5.72 m (18 ft, 9 in), with the minimum length of the nested W-beam rail increased to 11.43 m (37 ft, 6 in). Another suggestion was to add a W-beam rail section to the rear of the system to overlap the long span and provide added strength.

A second crash test (test no. 471470-4) was conducted on this 5.72-m- (18-ft, 9-in-) span-length nested W-beam guardrail system with a W-beam rail section added to the rear of the system, and the results indicated that this system also performed very well. The good performance of the system in the crash test indicated that the system would likely work without the W-beam rail section on the rear of the guardrail. This would reduce the cost of the installation, both in terms of material and labor. A third crash test (test no. 471470-5) was then conducted on this 5.72-m- (18-ft, 9-in-) span-length nested W-beam guardrail system without the W-beam rail section on the rear of the guardrail, also with successful results.

This report presents the results and evaluation of impact performance on these three crash tests, one for each of the three designs of the guardrail system for low-fill culvert. All three crash tests involved a 2043-kg (4500-lb) passenger car impacting the guardrail at a nominal speed and angle of 96.5 km/h (60 mi/h) and 25 degrees. Testing and evaluation was performed according to guidelines outlined in National Cooperative Highway Research Program (NCHRP) Report 230.(3)

II. STUDY APPROACH

2.1 TEST ARTICLE

A 45.7-m- (150-ft-) long test installation was constructed for this test, including 26.7 m (87.5 feet) of standard strong-post, blocked-out, W-beam wood-post (G4(2W)) guardrail for the length-of-need section, a 7.6-m (25-ft) turned down end anchorage on the downstream end, and a 11.4-m (37-ft, 6-in) breakaway cable terminal (BCT) anchorage on the upstream end. The standard guardrail installation included 152-mm × 203-mm × 1.82-m (6-in × 8-in × 6-ft) wood posts with 152-mm × 203-mm × 256-mm (6-in × 8-in × 14-in) wood blockouts, spaced 1.91 m (6 ft, 3 in) center to center. The W-beam rail sections are made of 12-gauge galvanized steel, 3.81 m (12 ft, 6 in) in length.

For the first test (test no. 471470-2), a 3.81-m (12-ft, 6-in) span was constructed in the center of the test installation to simulate the long span over a low-fill box culvert, as shown in figure 1. The minimum length of 7.62 m (25 ft) of nested W-beam rail was used, which allowed for nested rail over the culvert and one post span on either side of the culvert. Since only 3.8-m (12-ft, 6-in) W-beam rail elements were used, the 7.62 m (25 ft) of nested rail resulted in a splice in the middle of the long span rather than at a post. The completed test installation is shown in figures 2 through 4.

For the second test (test no. 471470-4), a 5.72-m (18-ft, 9-in) span was constructed in the center of the test installation (between posts 11 and 12) to simulate the long span over a low-fill box culvert, as shown in figure 5. Three 3.81-m (12-ft, 6-in) sections of nested W-beam were used, for a total length of 11.43 m (37 ft, 6 in), starting from post 9, extending over the culvert span of 5.72 m (18 ft, 9 in), and terminating at post 13. Two 3.81-m (12-ft, 6-in) sections of W-beam rails were added to the rear of the guardrail starting at post 11 (upstream end of the culvert span), extending over the culvert span, and terminating at post 13, for a total length of 7.62 m (25 ft). Photographs of this completed test installation are shown in figure 6.

For the third test (test no. 471470-5), the test installation was similar to that in the second test but without the W-beam rail section on the rear of the guardrail, as shown in figure 7. Photographs of the completed test installation are shown in figure 8.

2.2 CRASH TEST CONDITIONS

The three crash tests conducted on the three versions of the guardrail system for low-fill culvert corresponded to NCHRP Report 230 test designation 10, involving a 2043-kg (4500-lb) passenger car impacting the length-of-need section of the guardrail system at a nominal speed and angle of 96.5 km/h (60 mi/h) and 25 degrees. Based on results of a computer simulation study, the critical impact point was selected for each test to provide maximum deflection at the downstream post of the long span. For test 471470-2, the impact

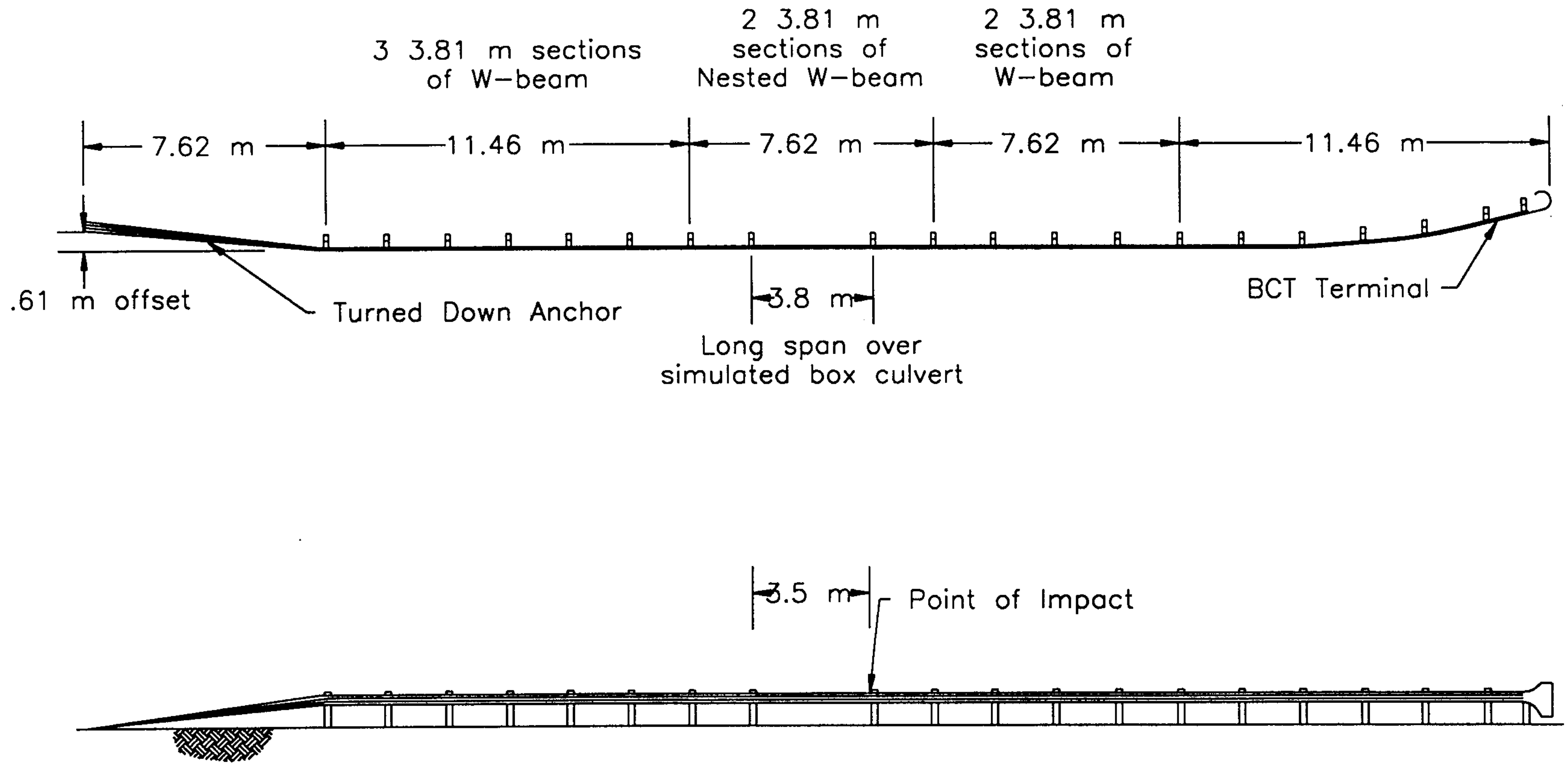


Figure 1. Schematics of installation for test 7147-2.

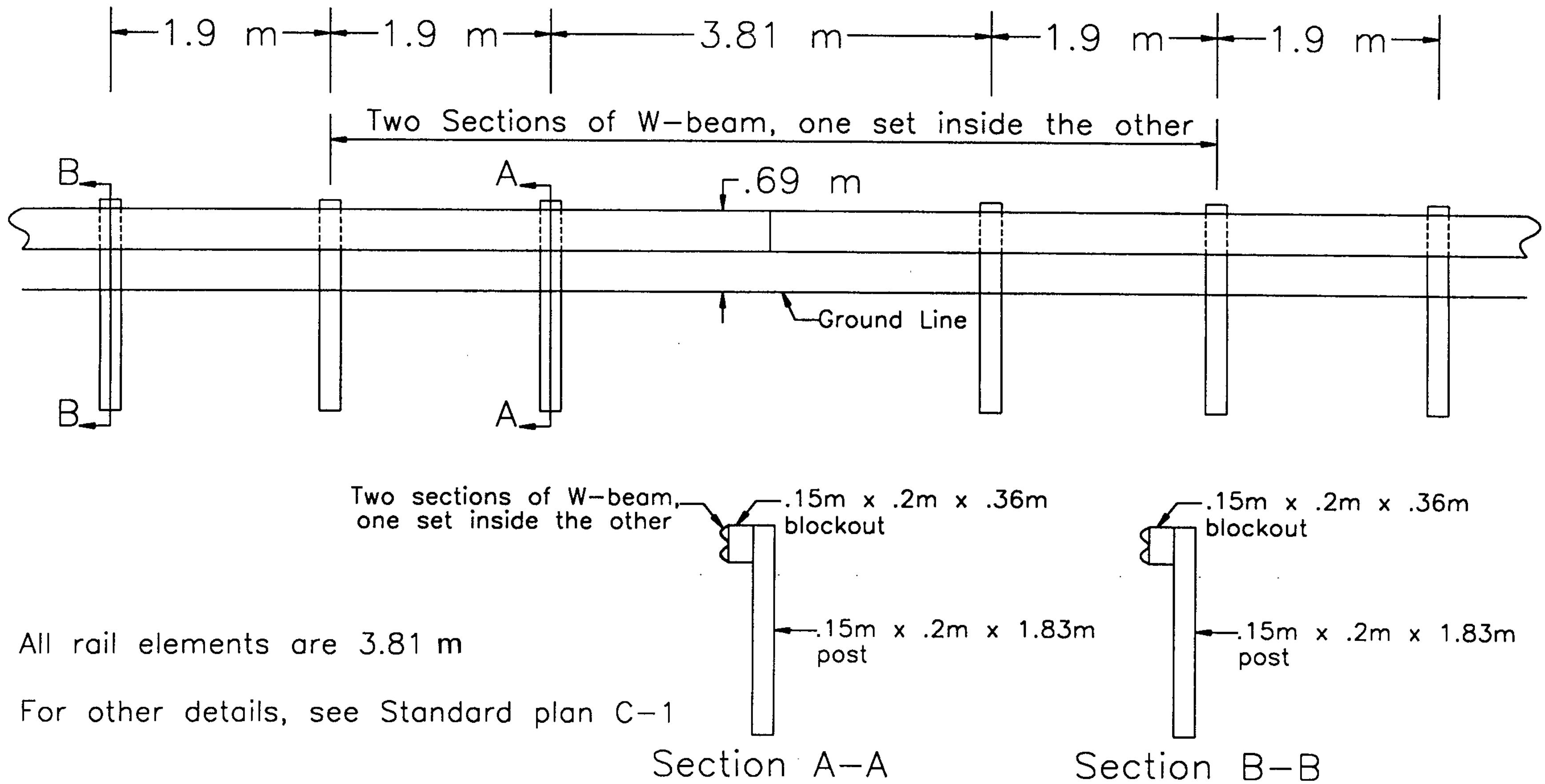
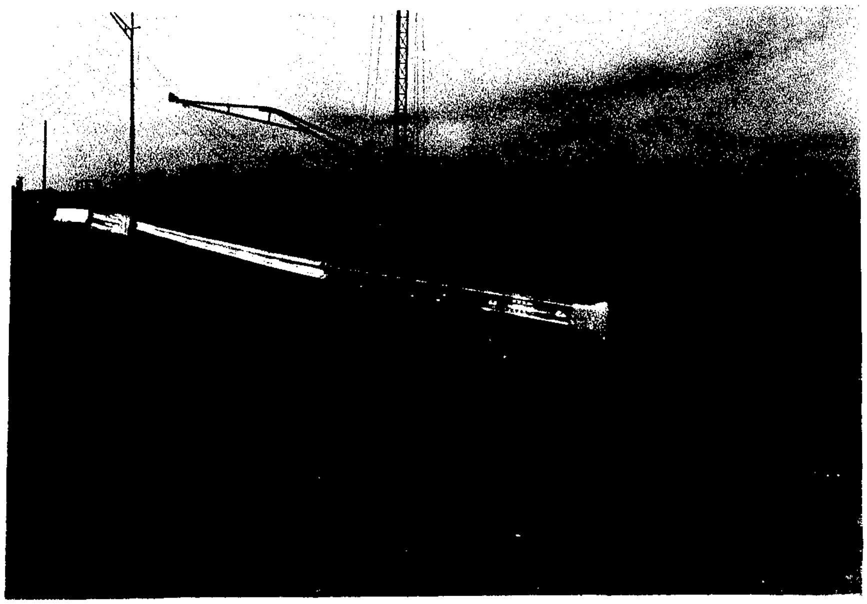


Figure 2. Details of long-span nested W-beam guardrail over low-fill culvert.



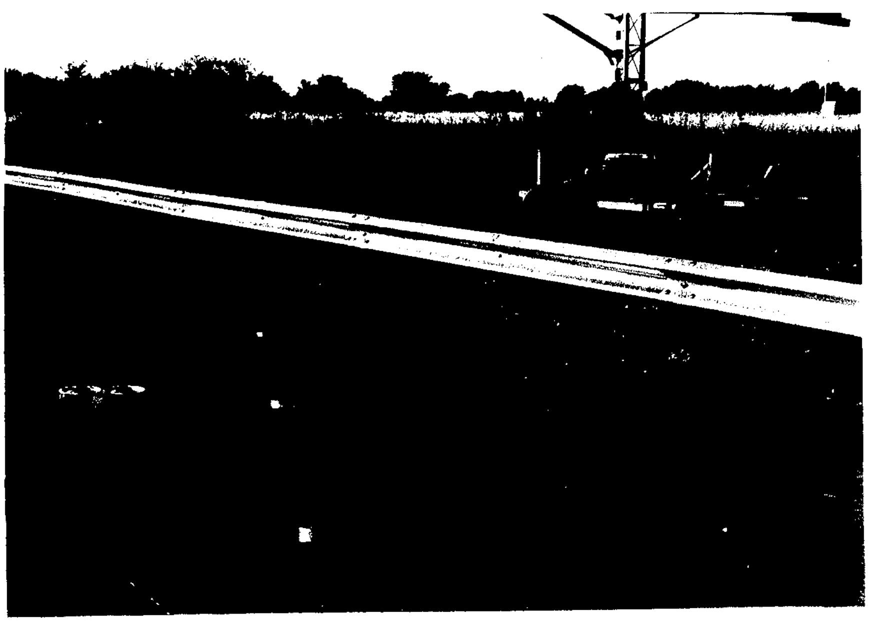


Figure 3. Washington nested W-beam wood-post guardrail with one post over culvert (before test 7147-2).

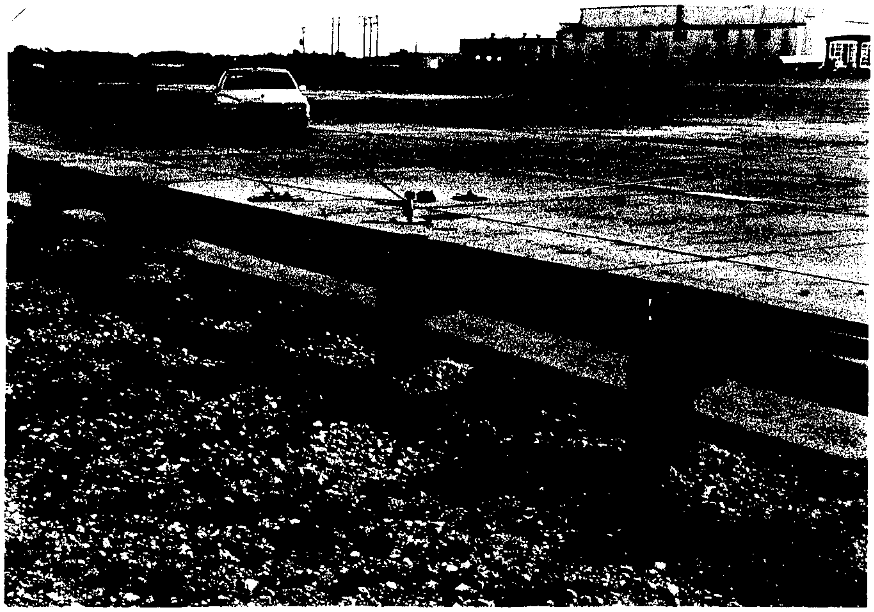


Figure 4. View of rear of Washington nested W-beam guardrail (test 7147-2).

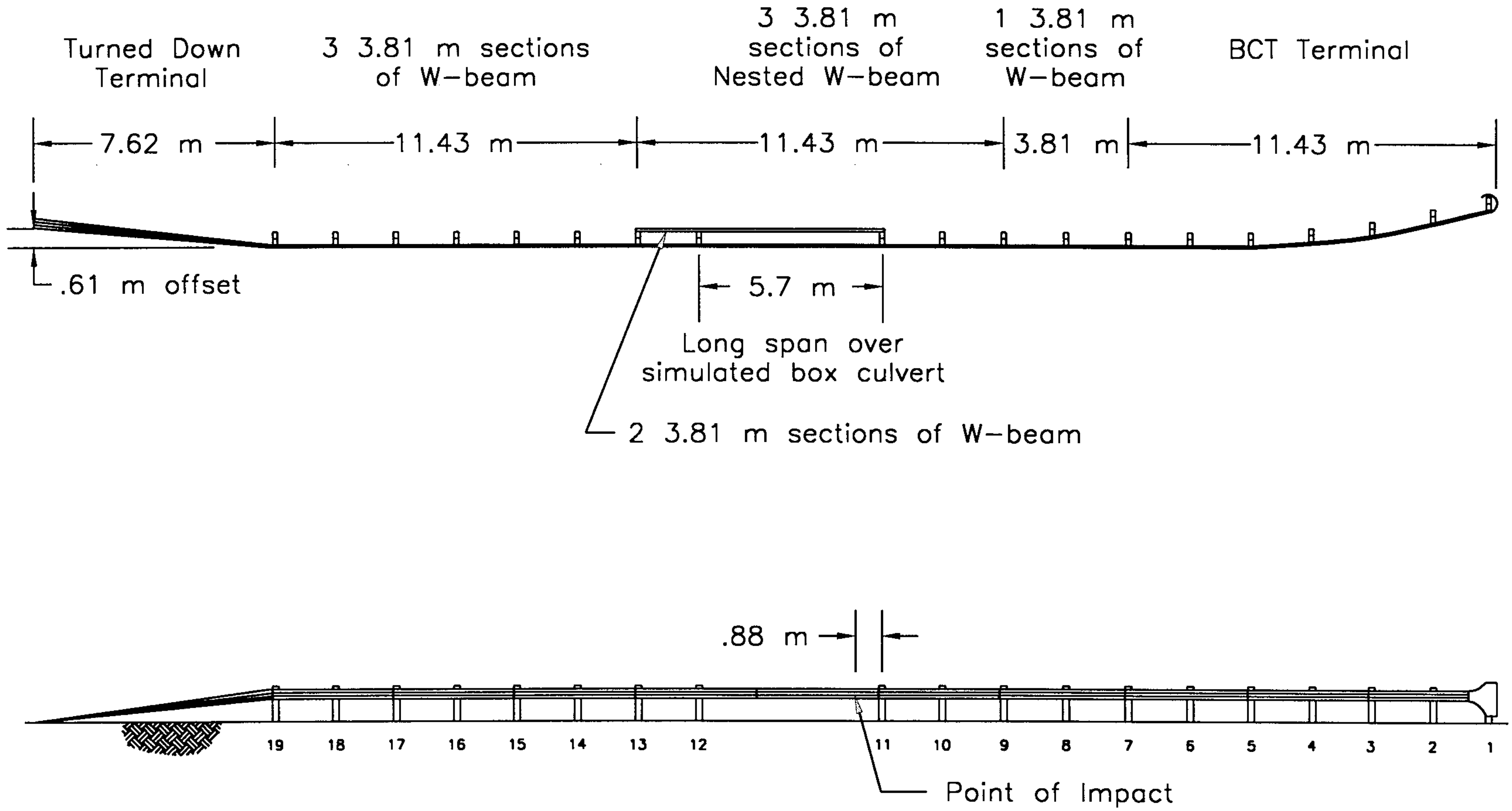


Figure 5. Details of Washington nested W-beam wood-post guardrail with two posts over culvert for test 7147-4.

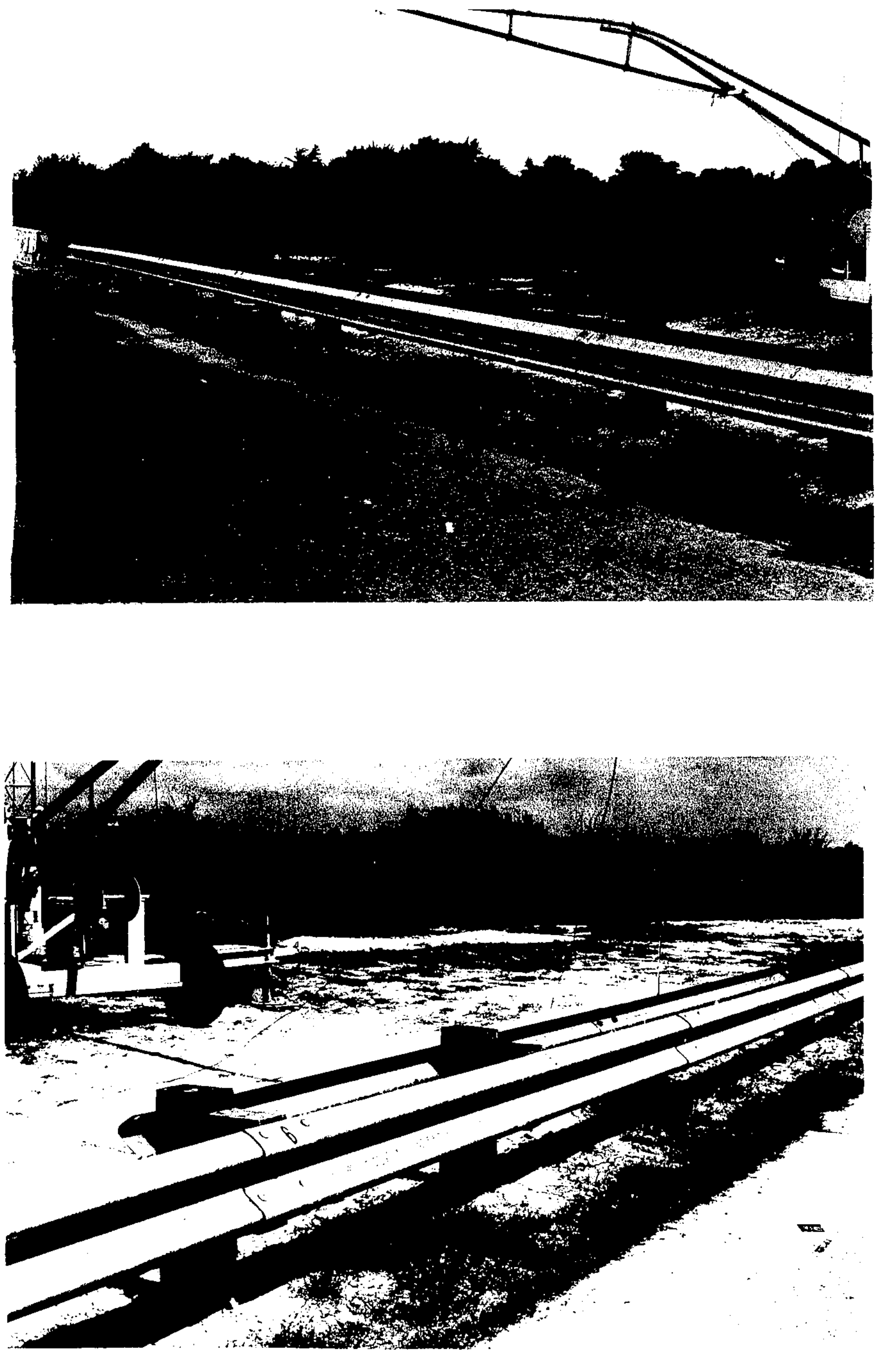


Figure 6. Washington nested W-beam wood-post guardrail with two posts over culvert and rear W-beam (before test 7147-4).

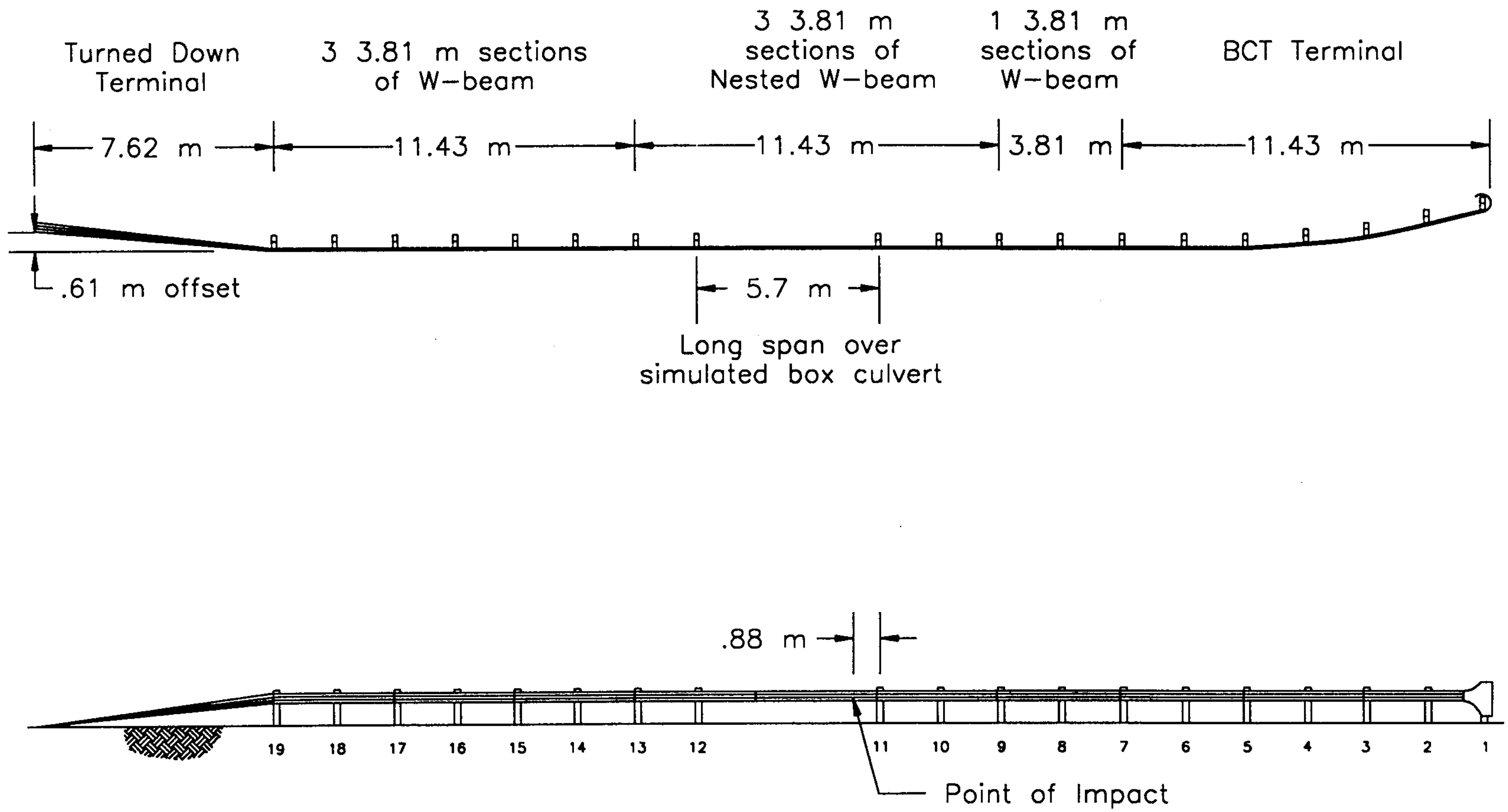


Figure 7. Washington nested W-beam wood-post guardrail with two posts over culvert for test 7147-5.

Figure 8. Washington nested W-beam wood-post guardrail with two posts over culvert (before test 7147-5).

point selected was 0.3 m (1 ft) downstream of post 12 (upstream post for the long span over the simulated culvert). The impact point selected for tests 47147-4 and 471470-5 was 0.9 m (2.9 ft) downstream of post 11 (upstream post for the long span over the simulated culvert).

2.3 CRASH TEST AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures were in accordance with guidelines presented in NCHRP Report 230.[3] Brief descriptions of these procedures are presented as follows.

2.3.1 Electronic Instrumentation and Data Processing

The crash test procedures were in accordance with guidelines presented in NCHRP Report 230. 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. Provision was made for the transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Pressure-sensitive contact switches on the bumper 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 Intermediate Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with a Class 180 filter, and digitized using a microcomputer, for analysis and evaluation of 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. Acceleration versus time curves for the longitudinal, lateral, and vertical directions are then plotted from the digitized data of the vehicle-mounted linear accelerometers using a commercially available software package (LOTUS 123).

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.001-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 perpendicular to the point of impact from the back of the guardrail system; another overhead with a field of view perpendicular to the ground and directly over the impact point; and a third placed to have a field of view parallel to and aligned with the guardrail system at the downstream end. A high-speed camera was also placed onboard the vehicle to record the motions of the dummy placed in the driver seat. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the guardrail system 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 3/4-in videotape camcorder, and still cameras were used for documentary purposes and to record 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 stretched along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. Another 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.

III. CRASH TEST RESULTS

As mentioned previously, three crash tests were conducted, one on each of the following three long-span nested W-beam guardrail designs:

1. A 3.81-m (12-ft, 6-in) span nested W-beam guardrail design (test no. 47147-2),

2. A 5.72-m (18-ft, 9-in) span nested W-beam guardrail design with a W-beam rail section in rear of guardrail (test no. 47147-4), and

2. A 5.72-m (18-ft, 9-in) span nested W-beam guardrail design without a W-beam rail section in rear of guardrail (test no. 47140-5).

Results of these three crash tests are presented in the following sections.

3.1 TEST 471470-2

A 1981 Cadillac Fleetwood, shown in figures 9 and 10, was used in test 471470-2. Test inertia weight of the vehicle was 2043 kg (4500 lb) and its gross static weight was 2120 kg (4669 lb). The height to the lower edge of the vehicle bumper was 381 mm (15.0 in) and it was 584 mm (23.0 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in figure 11. The vehicle was directed into the guardrail system 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 was traveling at a speed of 100.9 km/h (62.7 mi/h) when it impacted the guardrail system approximately 305 mm (1 ft) downstream of post 12 (upstream post for the long span over the simulated culvert). The impact point was selected to provide maximum deflection at the downstream post of the long span (post 13), based on results from the computer simulation study. The impact angle was 24.5 degrees.

At 0.050 s after initial impact, the vehicle began to redirect. As the vehicle continued forward, a slight pocket was formed at post 13. The right front tire of the vehicle contacted post 13 at 0.157 s, resulting in both front tires being turned abruptly to the right. The rear of the vehicle contacted the guardrail at 0.176 s, and at 0.228 s, the vehicle was traveling parallel to the guardrail system at a speed of 79.5 km/h (49.4 mi/h). The right front tire also contacted post 14 at 0.236 s. Maximum dynamic deflection of the guardrail was 0.9 m (3.1 ft), occurring at 0.313 s. The vehicle exited the guardrail at 0.524 s travelling at a speed of 67.9 km/h (42.2 mi/h), with an exit trajectory of 11.0 degrees. The brakes were applied after the vehicle cleared the test installation. The vehicle rotated clockwise and veered to the right because of the orientation of the front tires and damages sustained by the tires on the right

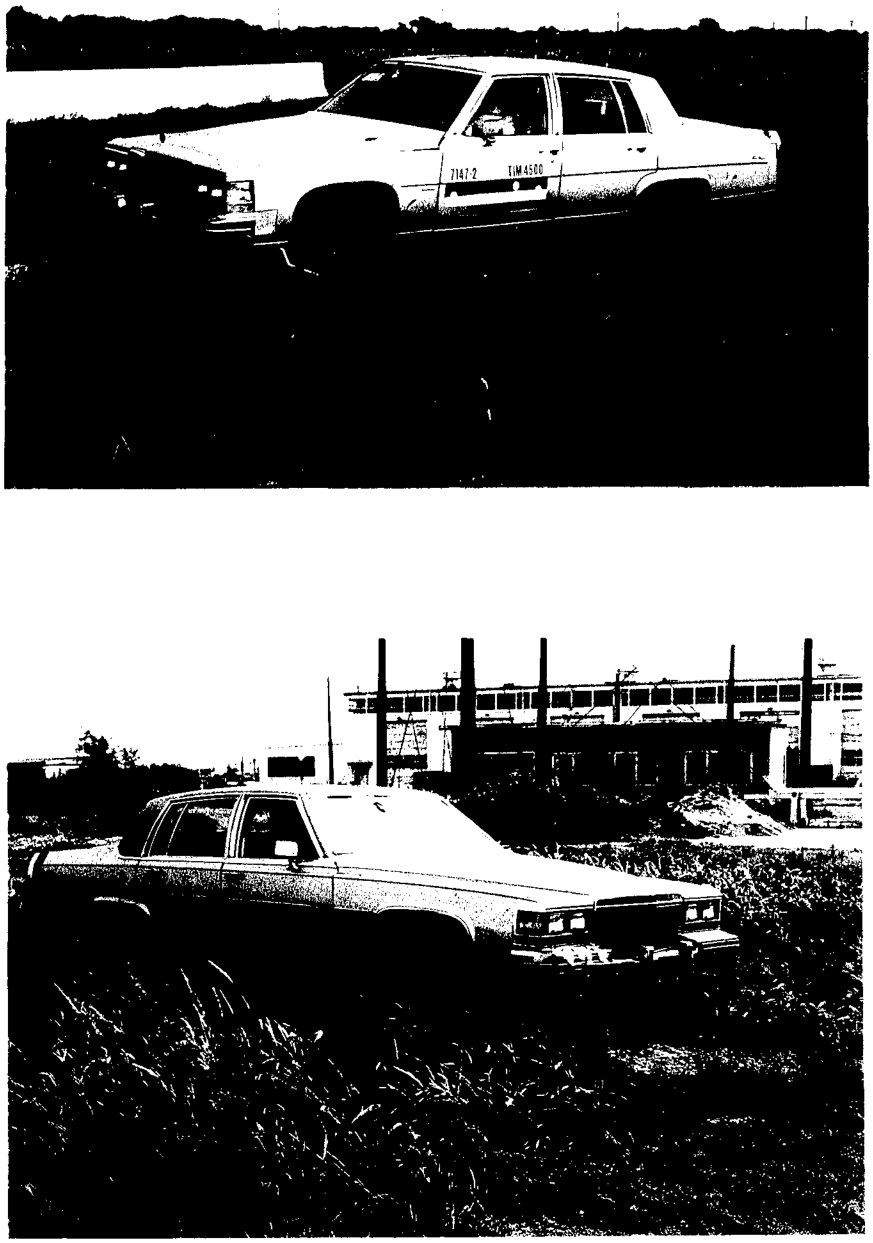


Figure 9. Vehicle prior to test 7147-2.

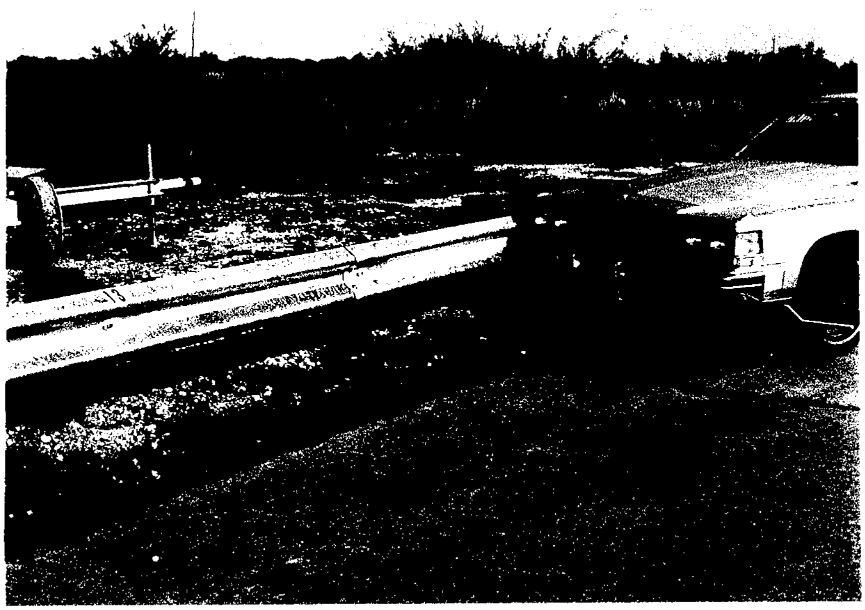


Figure 10. Vehicle/guardrail geometrics for test 7147-2.

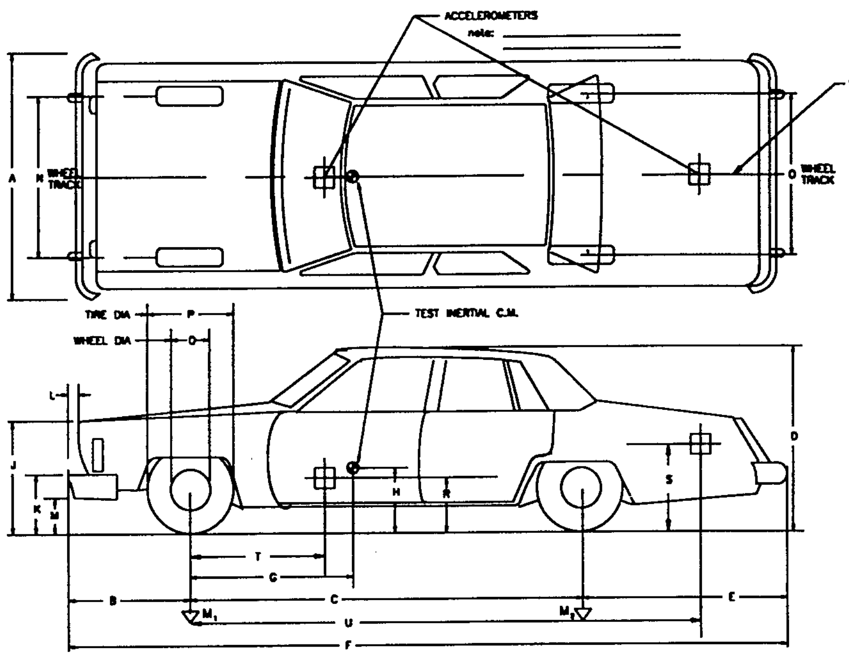
DATE: 09/25/90 TEST NO.: 471470-2 VIN NO.: 1G6AB9N7B9200147

YEAR: 1981 MAKE: Cadillac MODEL: Fleetwood

TIRE INFLATION PRESSURE: ______ ODOMETER: 06786 TIRE SIZE: P215 75R15

MASS DISTRIBUTION (kg) LF 575 RF 553 LR 456 RR 459

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: V-8

ENGINE CID: Diesel

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th male

MASS: 77 kg

SEAT POSITION: Driver's

GEOMETRY – (mm)

A 1956	E 1435	J 914	N 1575	R 483
B 1067	F 5588	K 584	O	S 610
C 3086	G 1382	L 114	P 686	T 991
D 1441.5	H	M 381	Q 413	U 4102

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1133	1128	1167
M_2	814	915	953
M_T	1930	2043	2120

Figure 11. Vehicle properties for test 7147-2.

side of the vehicle from impact with the guardrail. The front of the vehicle impacted the end of a concrete barrier section used to protect the downstream camera crew, and the vehicle came to rest next to the concrete barrier section, 53 m (173 ft) downstream from the point of initial impact. Sequential photographs of the test sequence are presented in figures 12 and 13.

3.1.2 Damage to Test Installation

The guardrail system received moderate damage, as shown in figure 14. The total length of contact of the vehicle with the guardrail system was 7.2 m (23.5 ft). The maximum permanent deformation of the W-beam rail element was 0.7 m (2.4 ft), located approximately 0.92 m (3 ft) upstream of post 13 (the downstream post of the long span). There was some flattening of the W-beam rail element at the lower corrugation upstream of post 13 as the vehicle pocketed slightly at the post and pressed the W-beam rail element against the blockout and the post.

Movements of post and rail at different posts are summarized in the table below:

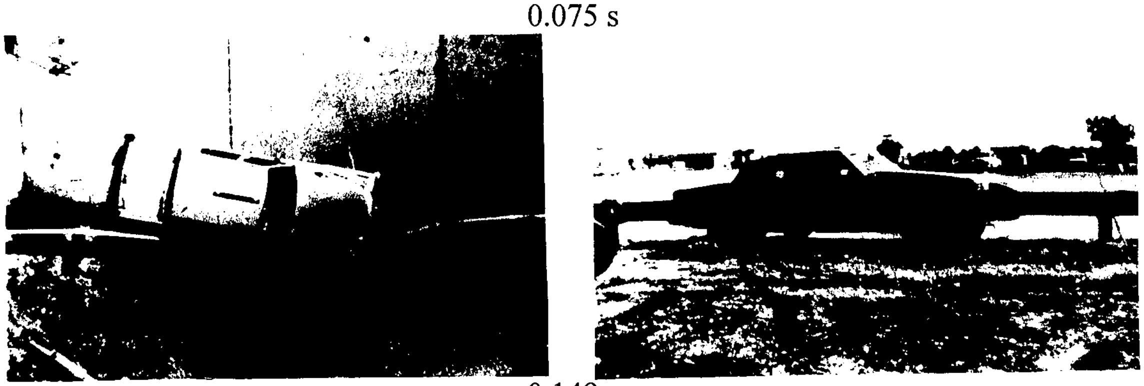
Table 1. Post and rail deflections for test 471470-2.

Post No.	Movement of Post		Comments
	Ground Level	Center of W-beam	
9	0	0	Blockout twisted
10	25 mm (1.0 in)	13 mm (0.5 in)	
11	38 mm (1.5 in)	38 mm (1.5 in)	
12	178 mm (7.0 in)	330 mm (13.0 in)	Blockout split
13	324 mm (12.75 in)	714 mm (28.5 in)	Blockout broken and separated from post. Bolt head pulled through nested W-beam rail.
14	216 mm (8.5 in)	406 mm (16.0 in)	Post and blockout split
15	57 mm (2.25 in)	114 mm (4.5 in)	Blockout split
16	6 mm (0.25 in)	6 mm (0.25 in)	
17	0	0	

As can be seen from table 1, post 13 was pushed back 324 mm (12.75 in) at ground level and 714 mm (28.5 in) at the center of the W-beam rail element. The blockout at post 13 was broken and separated from the post and the head of bolt attaching the rail to the blockout and post was pulled through the nested W-beam rail elements. There were also slight movements at the two end anchors.

0.000 s

0.075 s



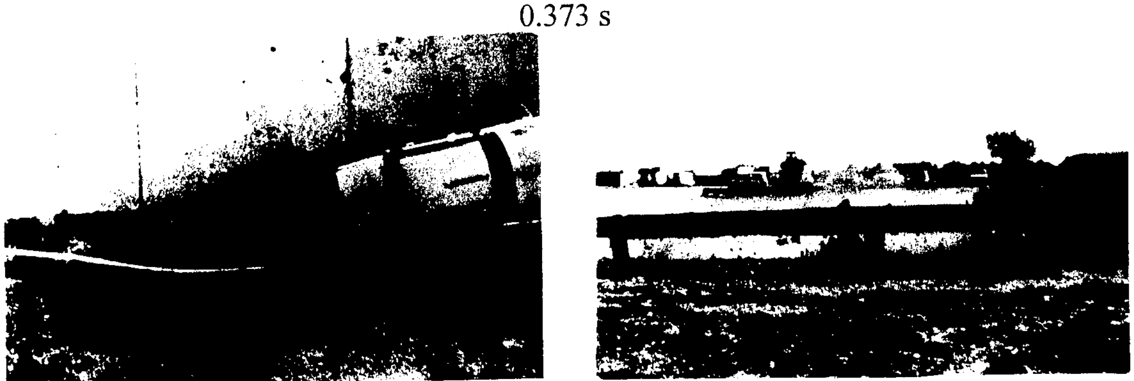
0.149 s

0.224 s

Figure 12. Sequential photographs for test 7147-2
(overhead and behind the rail views).

0.298 s

0.373 s



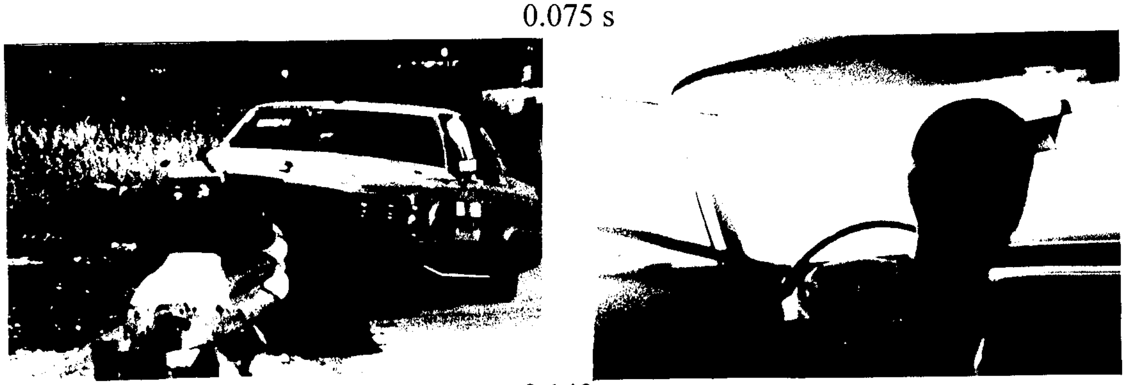
0.447 s

0.524 s

Figure 12. Sequential photographs for test 7147-2
(overhead and behind the rail views) (continued).

0.000 s

0.075 s



0.149 s

0.224 s

Figure 13. Sequential photographs for test 7147-2
(frontal and interior views).

Figure 13. Sequential photographs for test 7147-2
(frontal and interior views) (continued).

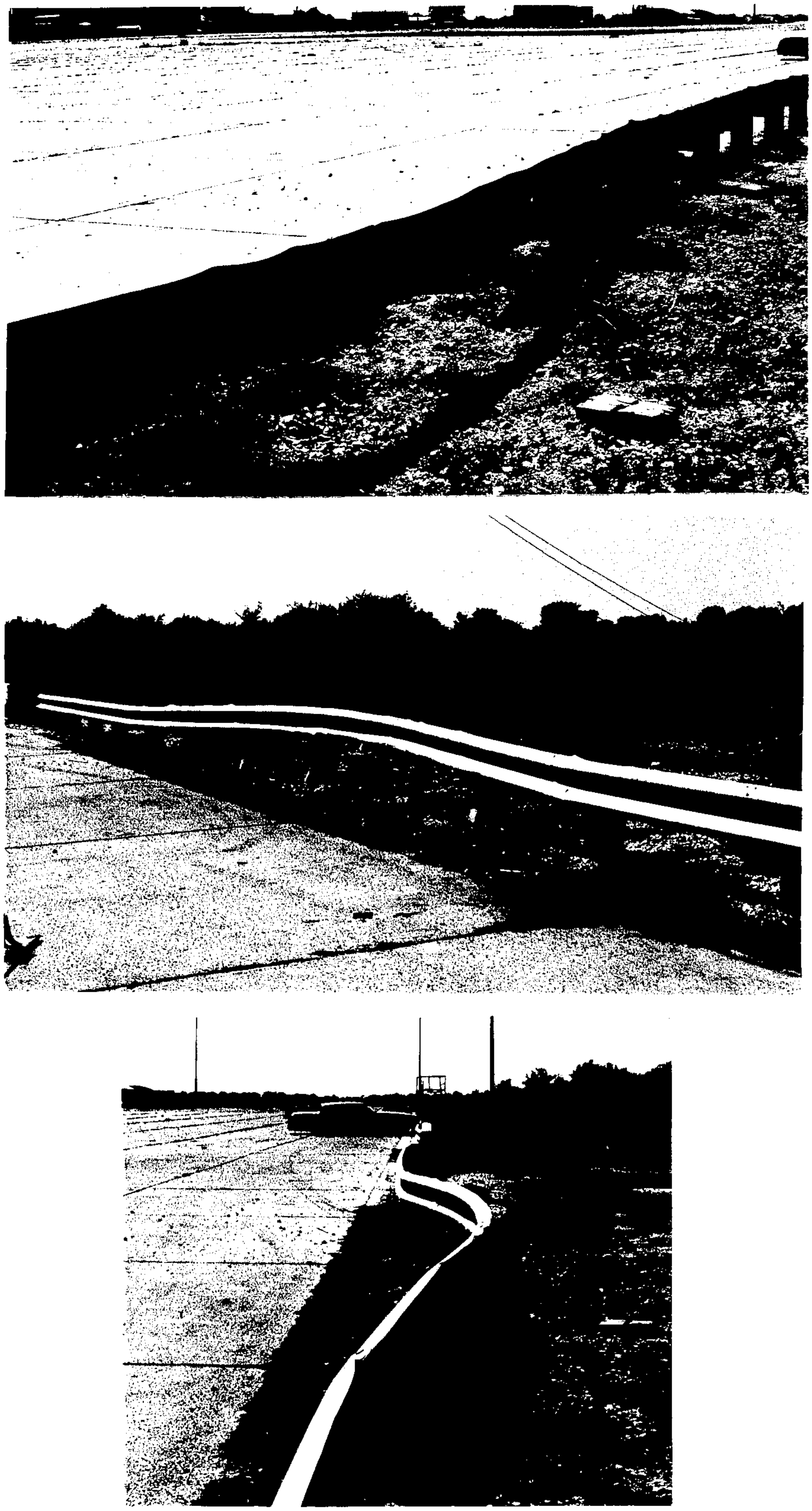


Figure 14. Damage to Washington nested W-beam guardrail after test 7147-2.

3.1.3 Vehicle Damage

The vehicle (shown in figure 15) sustained moderate damage to the right side. The tie rod was bent and the windshield was broken. There was damage to the front bumper, hood, grill, radiator and fan, right front quarter panel, right front and rear doors, right rear quarter panel, and the rear bumper. The wheelbase on the right side was shortened from 3.09 m (121.5 in) to 2.95 m (116.0 in). The right front and rear rims and tires were damaged from contact with the posts. Maximum crush to the vehicle was 330 mm (13.0 in) at the right front corner at bumper height. Note that much of the damage to the front of the vehicle was the result of the vehicle impacting the end of a concrete barrier near the end of the vehicle trajectory. It should also be noted that the test vehicle had a fiberglass header panel that made the damage to the front of the vehicle appear much worse than it really was.

3.1.4 Occupant Risk Values

Data from the electronic instrumentation were digitized for evaluation, and occupant risk factors were computed as follows. In the longitudinal direction, occupant impact velocity was 5.4 m/s (17.8 ft/s) at 0.248 s; the highest 0.010-s average ridedown acceleration was -6.5 g's from 0.304 to 0.314 s; and the 0.050-s average acceleration was -4.5 g's between 0.137 and 0.187 s. Lateral occupant impact velocity was 4.8 m/s (15.9 ft/s) at 0.139 s; the highest 0.010-s average ridedown acceleration was 12.9 g's from 0.160 to 0.170 s; and the maximum 0.050-s average acceleration was 7.1 g's between 0.196 and 0.246 s. The change in vehicle velocity at loss of contact was 33.0 km/h (20.5 mi/h) and the change in momentum was 18 690 N-s (4202 lb-s).

A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 16. Vehicle angular displacements are displayed in figure 17, and vehicular accelerations versus time traces filtered at 300 Hz are presented in figures 18 through 20.

3.2 TEST 471470-4

A 1979 Cadillac Sedan deVille, shown in figures 21 and 22, was used in test 471470-4. Test inertia weight of the vehicle was 2043 kg (4500 lb) and its gross static weight was 2120 kg (4670 lb). The height to the lower edge of the vehicle bumper was 311 mm (12.25 in) and it was 559 mm (22.0 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in figure 23. The vehicle was directed into the 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 was traveling at a speed of 90.4 km/h (56.2 mi/h) when it impacted the guardrail system approximately 0.9 m (2.9 ft) downstream of post 11 (upstream post for the

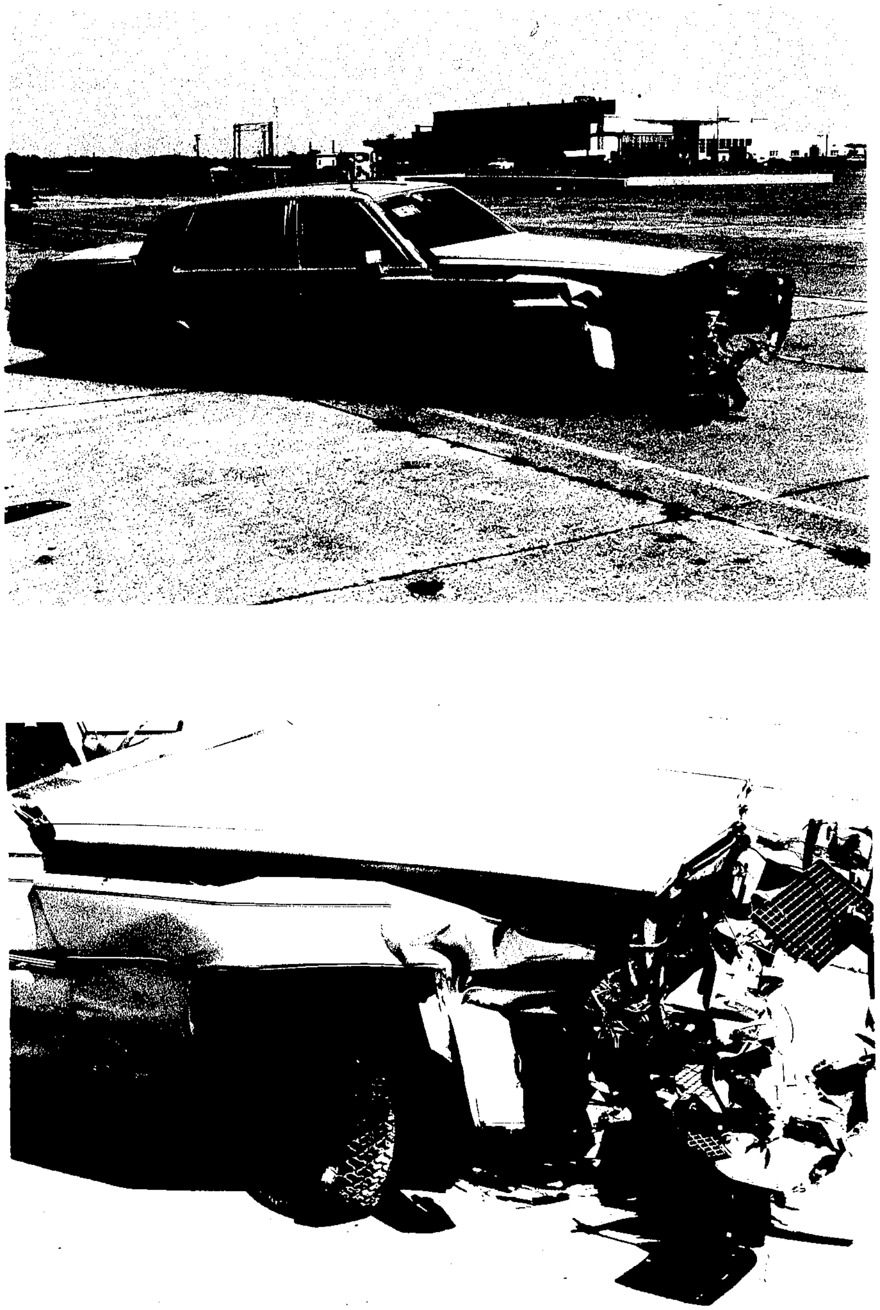
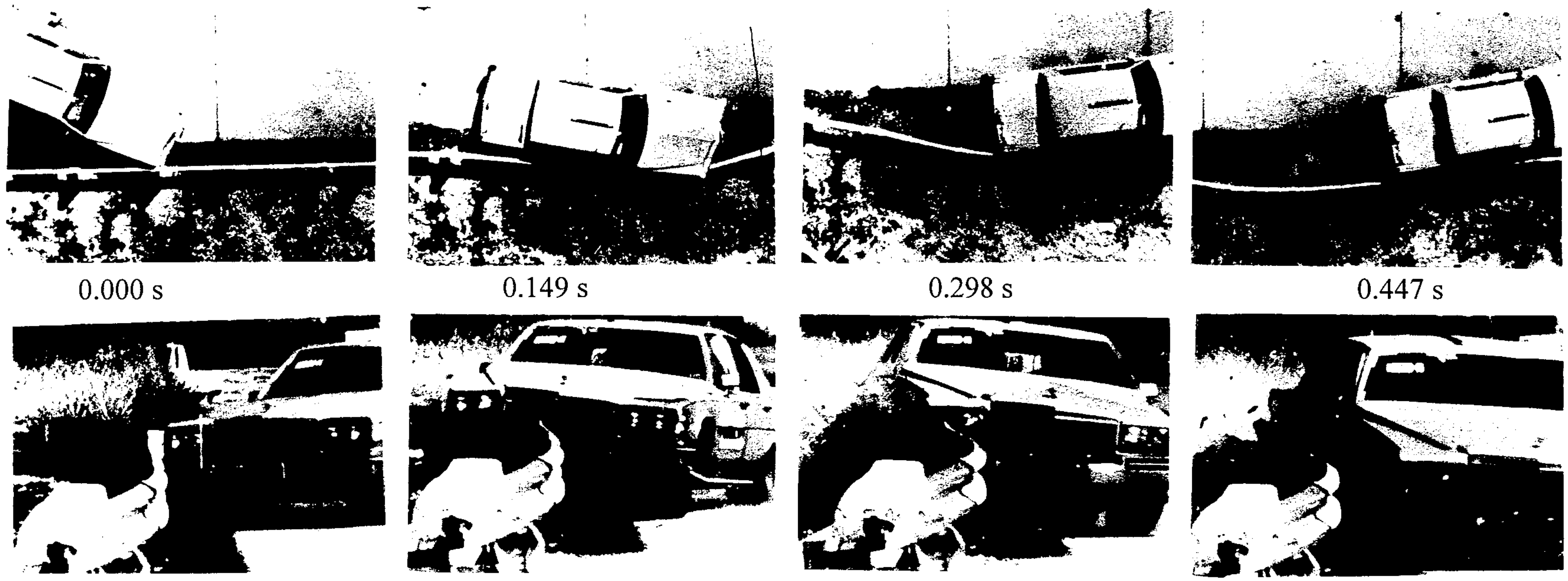
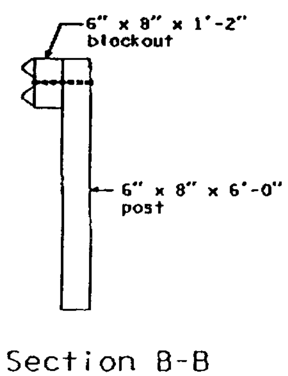


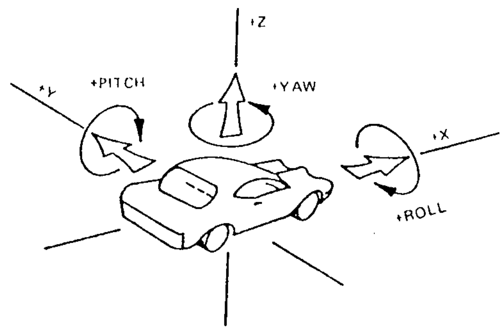
Figure 15. Damage to vehicle test 7147-2.





Test No.	7147-2	Impact Speed	100.9 km/h (62.7 mi/h)
Date	09/25/90	Impact Angle	24.5 deg
Test Installation	Washington Nested W-beam with Wood Posts	Speed at Parallel	79.5 km/h (49.4 mi/h)
		Exit Speed	67.9 km/h (42.2 mi/h)
Installation Length	46 m (150 ft)	Exit Trajectory	11.0 deg
Max. Dynamic Deflection	0.9 m (3.1 ft)	Vehicle Accelerations	
Max. Perm. Deformation	0.7 m (2.4 ft)	(Max. 0.050-s avg)	
Test Vehicle	1981 Cadillac Fleetwood	Longitudinal	-4.5 g's
Vehicle Weight		Lateral	7.1 g's
Test Inertia	2043 kg (4500 lb)	Occupant Impact Velocity	
Gross Static	2120 kg (4669 lb)	Longitudinal	5.4 m/s (17.8 ft/s)
Vehicle Damage Classification		Lateral	4.8 m/s (15.9 ft/s)
TAD	01FR5 & 01RD4	Occupant Ridedown Accelerations	
CDC	01FREK2 & 01RDEW3	Longitudinal	-6.5 g's
Maximum Vehicle Crush	330 mm (13.0 in)	Lateral	12.9 g's

Figure 16. Summary of results for test 7147-2.



Axes are vehicle fixed. Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

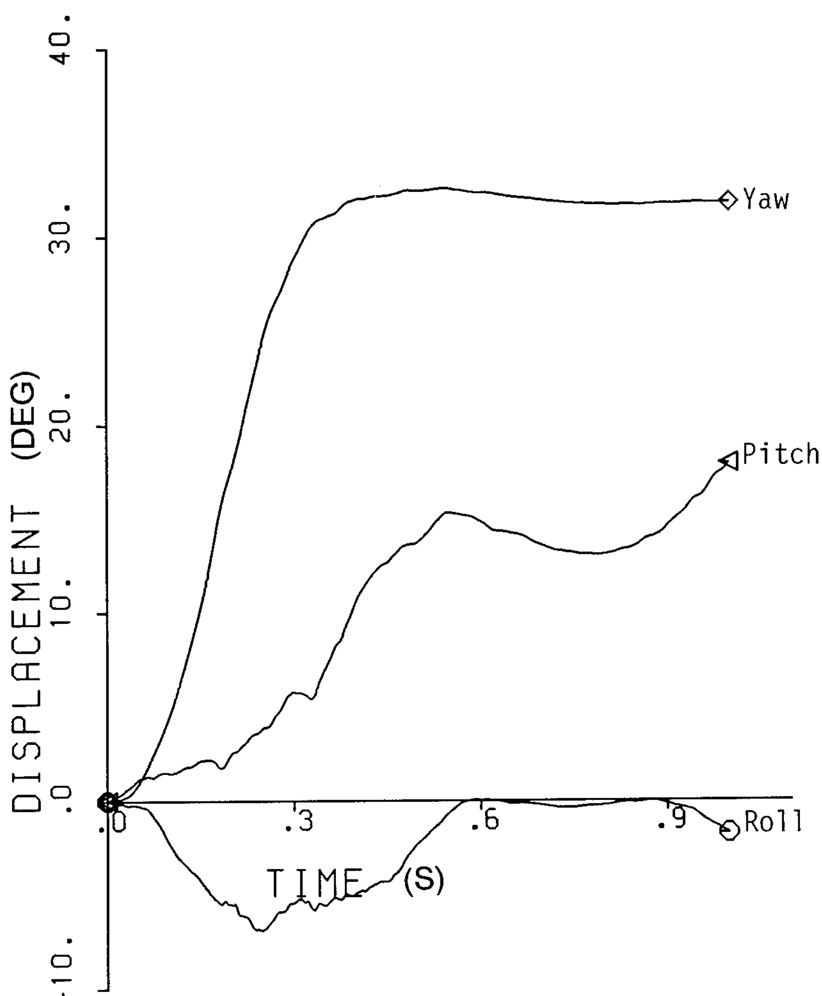


Figure 17. Vehicle angular displacements for test 7147-2.

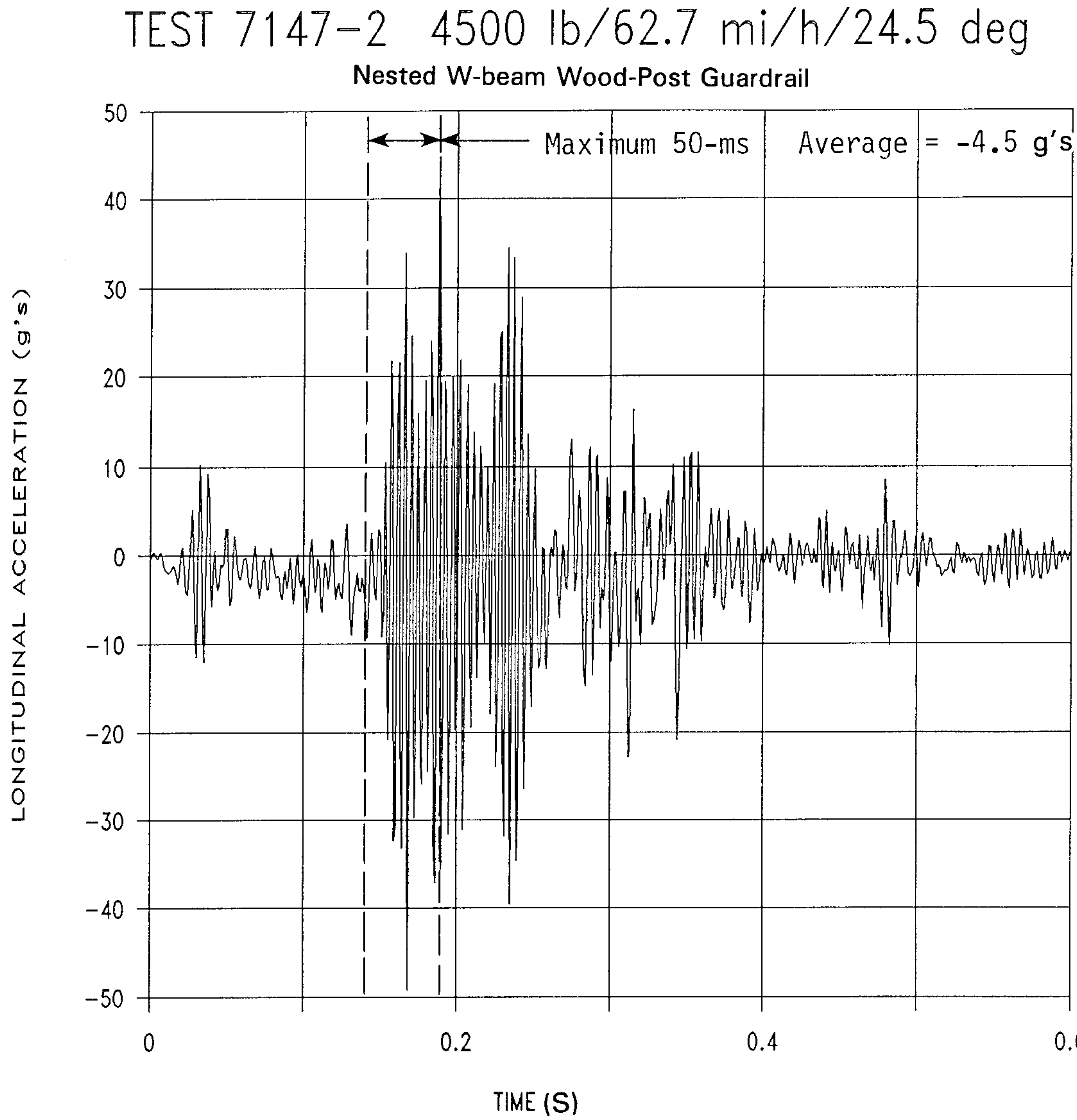


Figure 18. Vehicle longitudinal accelerometer trace for test 7147-2.

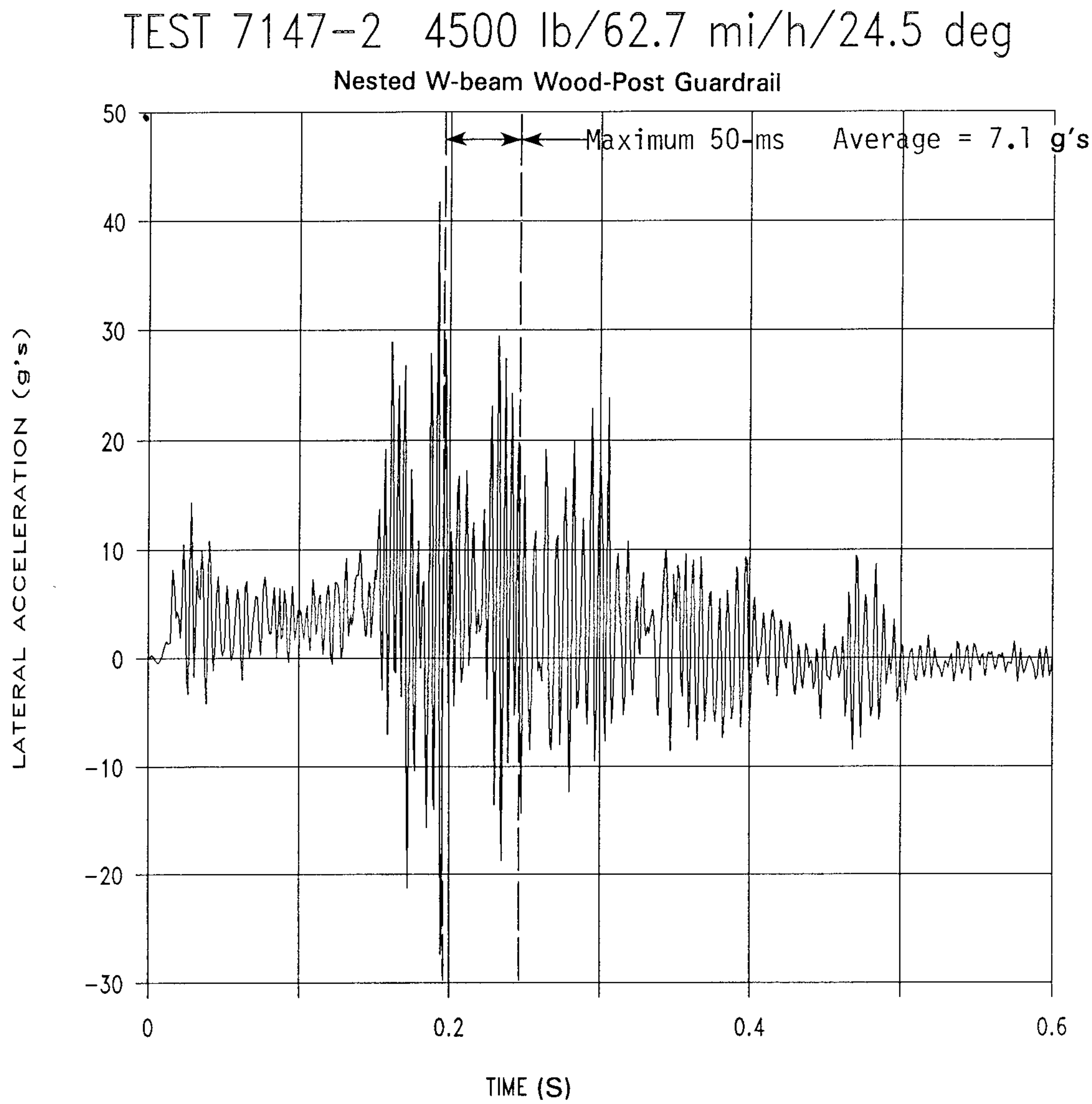


Figure 19. Vehicle lateral accelerometer trace for test 7147-2.

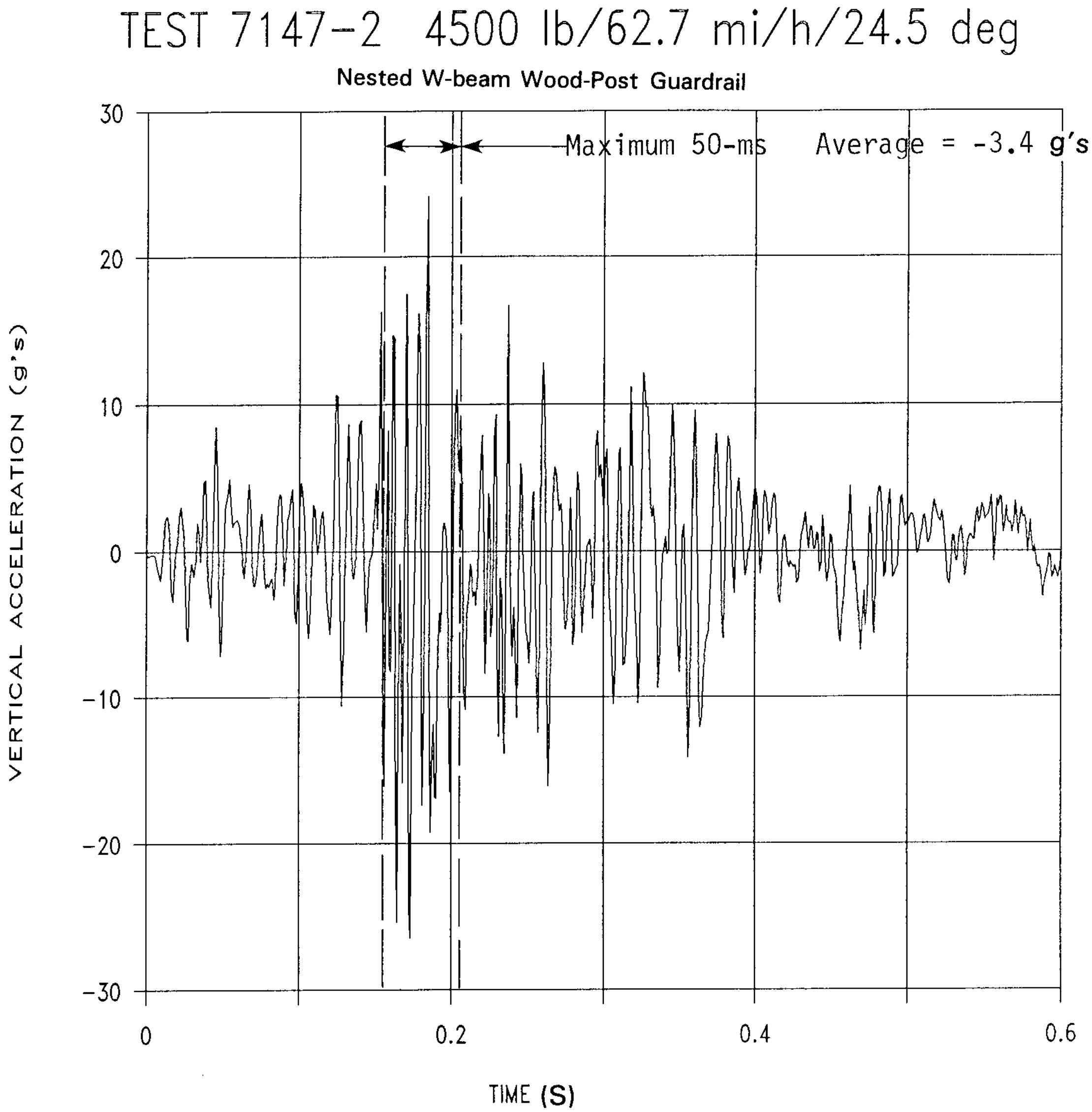
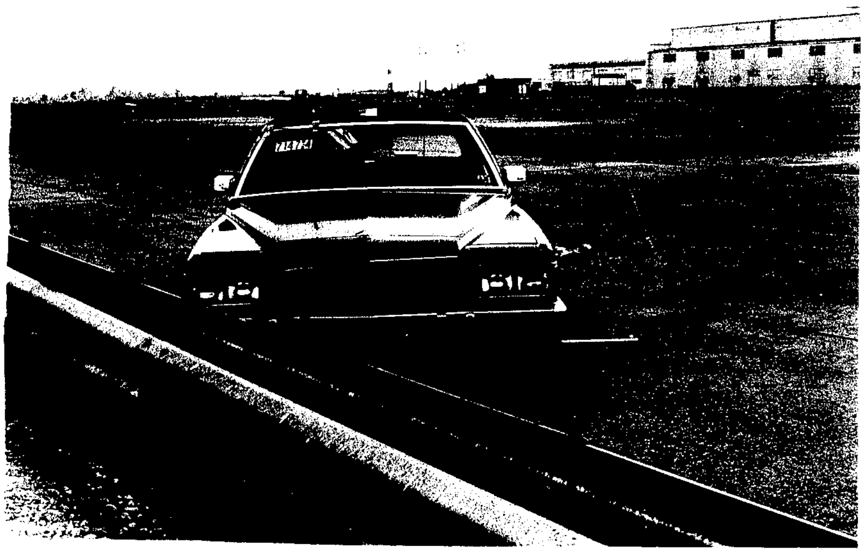


Figure 20. Vehicle vertical accelerometer trace for test 7147-2.

Figure 21. Vehicle prior to test 7147-4.



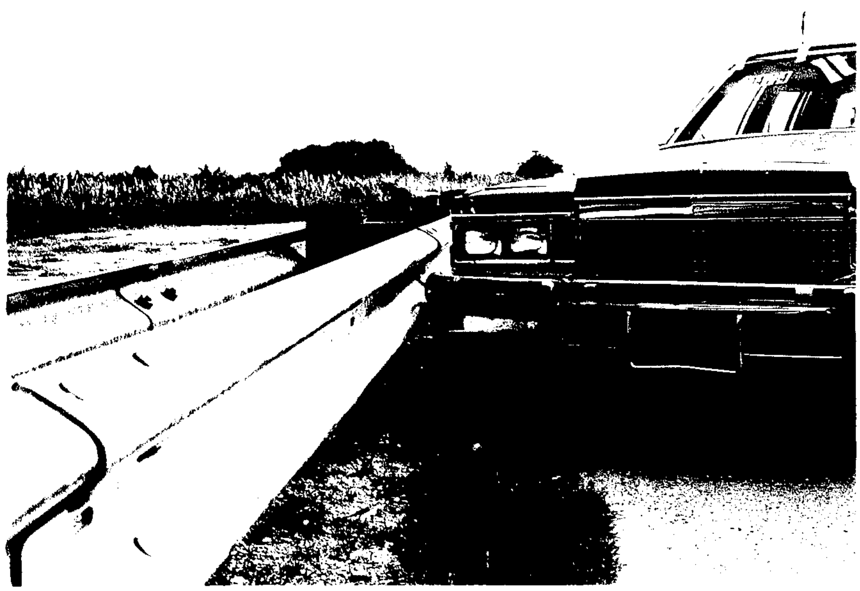


Figure 22. Vehicle/guardrail geometrics for test 7147-4.

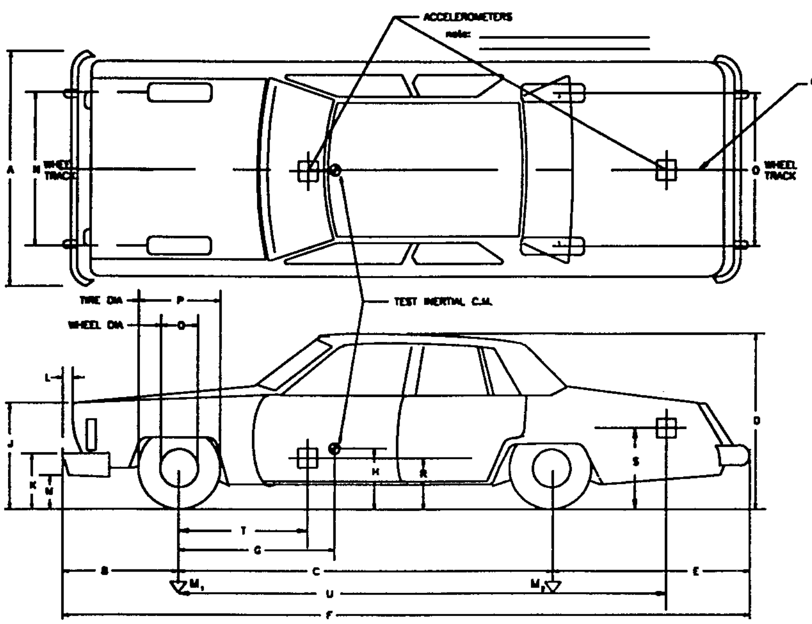
DATE: 05/28/91 TEST NO.: 471470-4 VIN NO.: 6D69S99137722

YEAR: 1979 MAKE: Cadillac MODEL: Sedan DeVelle

TIRE INFLATION PRESSURE: ______ ODOMETER: 133774 TIRE SIZE: P235 75R15

MASS DISTRIBUTION (kg) LF 596 RF 580 LR 437 RR 430

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



℄ VEHICLE

ENGINE TYPE: V-8

ENGINE CID: 7.0 L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th male

MASS: 77 kg

SEAT POSITION: Driver's

GEOMETRY – (mm)

A 1937	E 1435	J 876	N 4115	R 451
B 1073	F 5582	K 559	O	S 794
C 3073	G 1306	L 114	P 711	T 1359
D 1461	H	M 311	Q 413	U 4064

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1107	1176	1214
M_2	759	867	906
M_T	1866	2043	2120

Figure 23. Vehicle properties for test 7147-4.

long span over the simulated culvert). The impact point was selected to provide maximum deflection at the downstream post of the long span, based on results from the computer simulation study. The impact angle was 24.0 degrees.

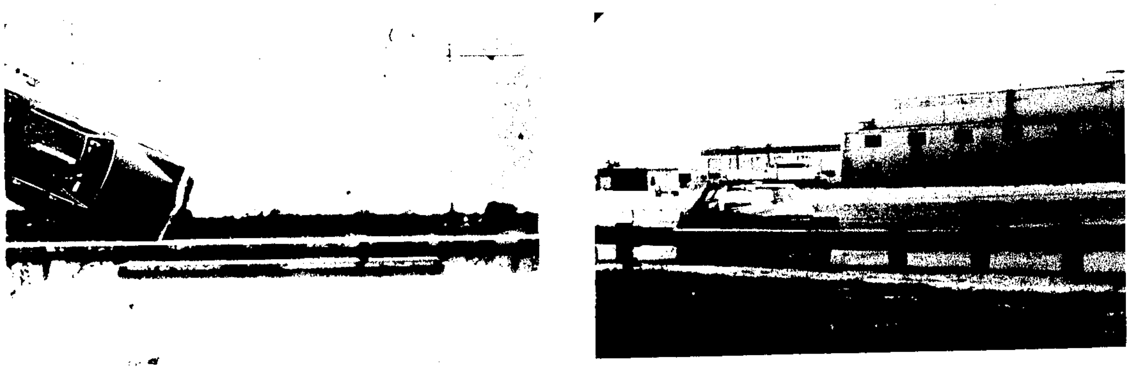
At 0.037 s after initial impact, the vehicle began to redirect. Contact was made with the W-beam on the rear of the posts at 0.071 s. The right front tire of the vehicle contacted post 12 at 0.202 s, resulting in both front tires being turned abruptly to the right. The rear of the vehicle contacted the guardrail at 0.205 s, and at 0.242 s, the vehicle was traveling parallel to the guardrail system at a speed of 71.9 km/h (44.7 mi/h). Maximum dynamic deflection of the guardrail was 0.9 m (3.1 ft) to the front rail, occurring at 0.313 s, and 0.64 m (2.1 ft) to the rear rail, occurring at 0.335 s. The vehicle exited the guardrail at 0.555 s traveling at a speed of 69.8 km/h (43.4 mi/h), with an exit trajectory of 12.3 degrees. The brakes were applied after the vehicle cleared the test installation. The vehicle rotated slightly clockwise and veered to the right because of the orientation of the front tires and damages sustained by the tires on the right side of the vehicle from impact with the guardrail. The front of the vehicle impacted another guardrail section used to protect the downstream camera crew, the vehicle then slid off the end of the barrier and came to rest 119 m (390 ft) downstream and 15 m (50 ft) behind the point of initial impact. Sequential photographs of the test sequence are presented in figures 24 and 25.

3.2.2 Damage to Test Installation

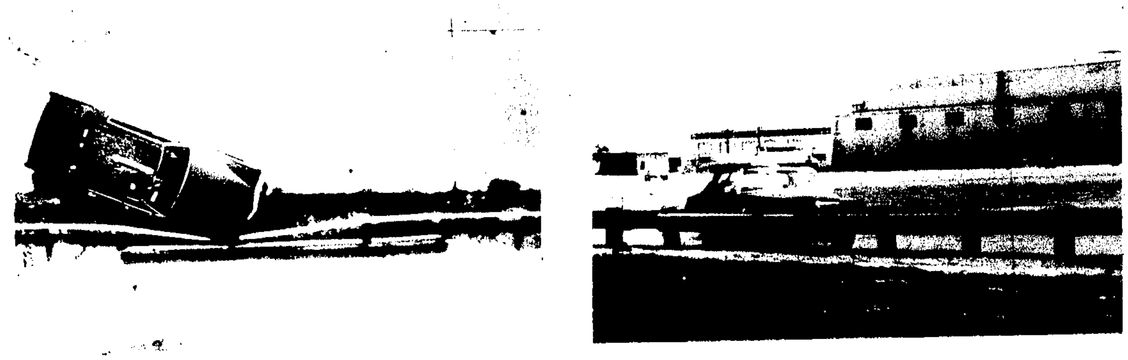
The guardrail system received moderate damage, as shown in figure 26. The maximum permanent deformation of the W-beam rail element was 0.7 m (2.3 ft), located approximately in the center of the long span. The rear rail element received a maximum permanent deflection of 0.54 m (21.25 in) at post 12. Movements of post and rail at different posts are summarized in the table below:

Table 2. Post and rail deflections for test 471470-4.

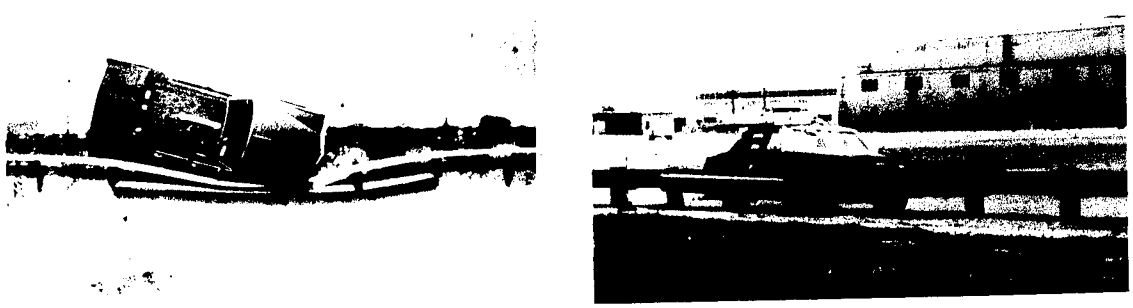
Post No.	Movement of Post			Comments
	Ground Level	Center of W-beam	Rear rail	
8	0	0	N/A	Bolt pulled out
9	0	0	N/A	
10	64 mm (2.5 in)	89 mm (3.5 in)	N/A	
11	152 mm (6.0 in)	254 mm (10.0 in)	305 mm (12.0 in)	
Center of span	N/A	699 mm (27.5 in)	381 mm (15.0 in)	
12	279 mm (11.0 in)	514 mm (20.25 in)	540 mm (21.25 in)	Bolt pulled out Blockout twisted
13	121 mm (4.75 in)	178 mm (7.0 in)	254 mm (10.0 in)	
14	13 mm (0.5 in)	13 mm (0.5 in)	N/A	
15	0	0	N/A	



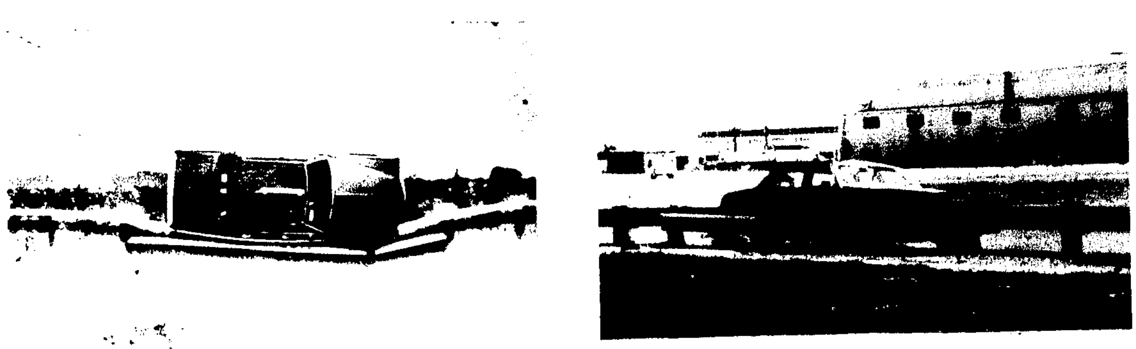
0.000 s



0.074 s

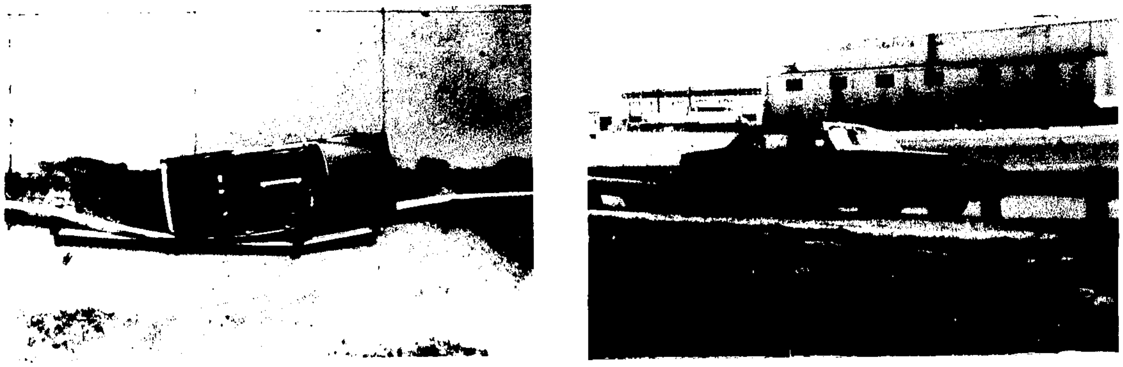


0.149 s

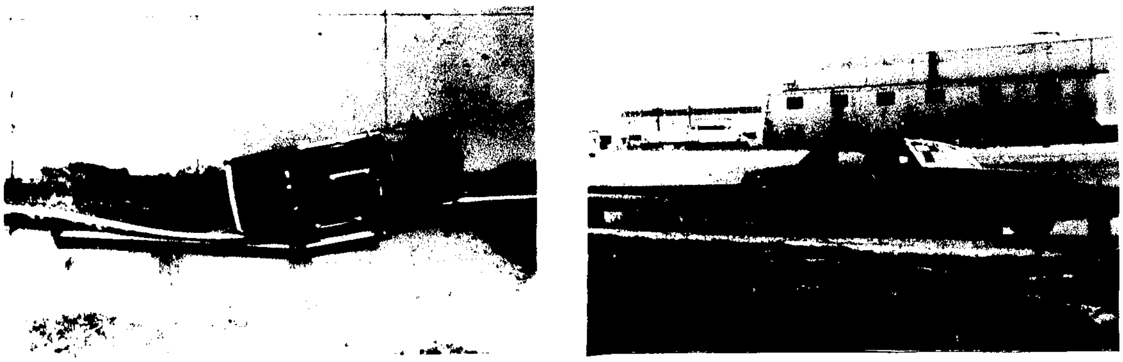


0.223 s

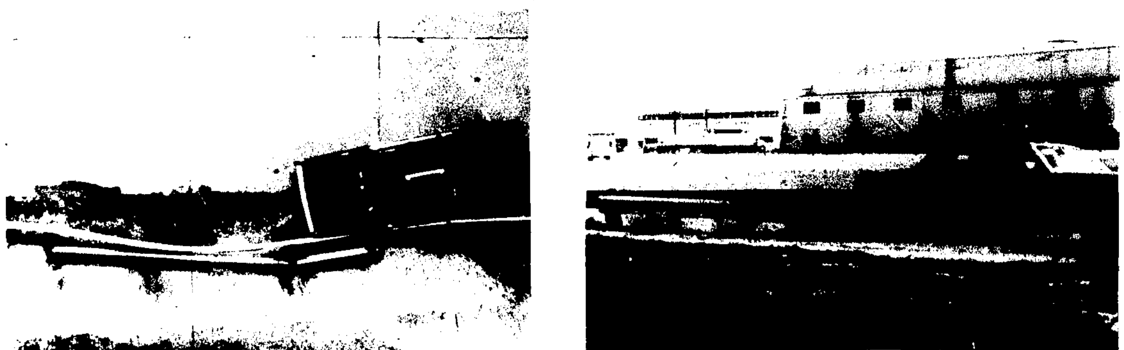
Figure 24. Sequential photographs for test 7147-4
(overhead and behind the rail views).



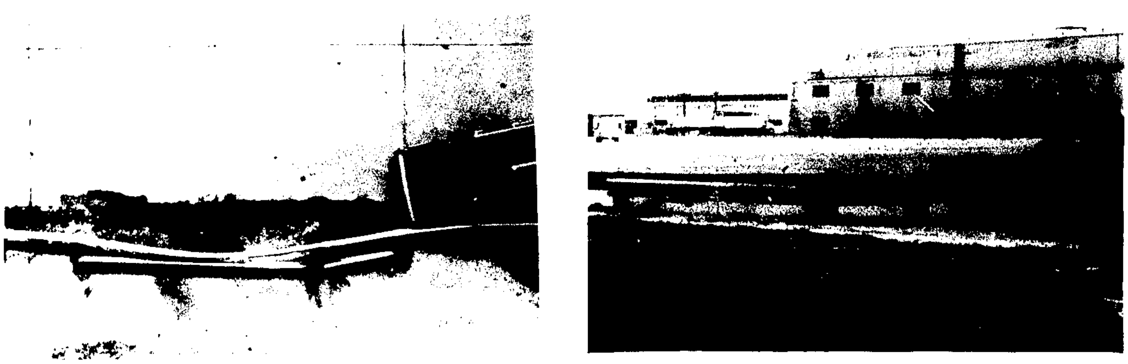
0.298 s



0.372 s



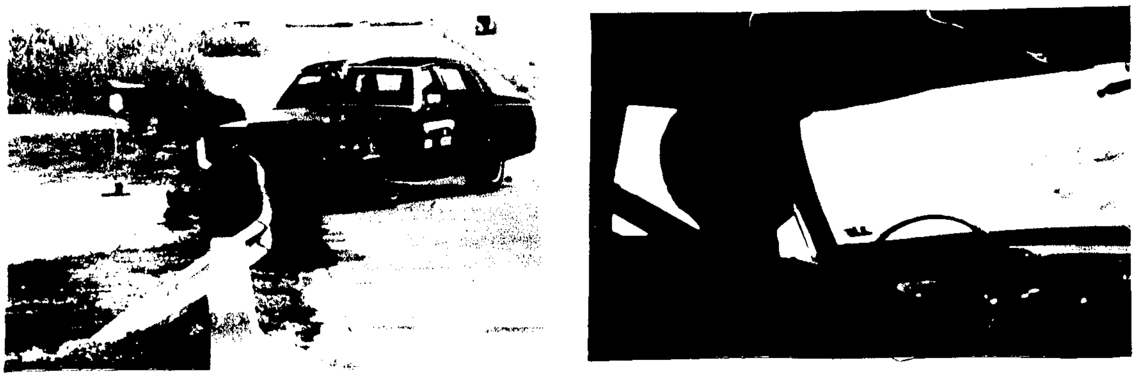
0.465 s



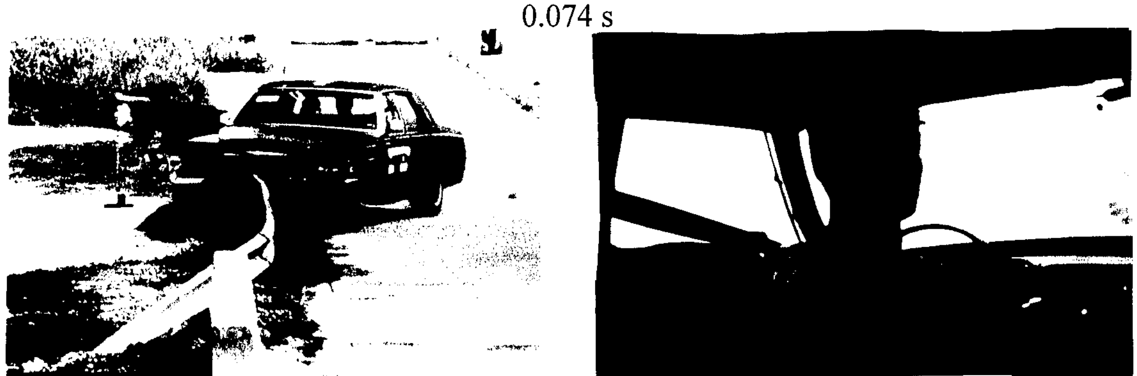
0.555 s

Figure 24. Sequential photographs for test 7147-4 (overhead and behind the rail views) (continued).

0.000 s



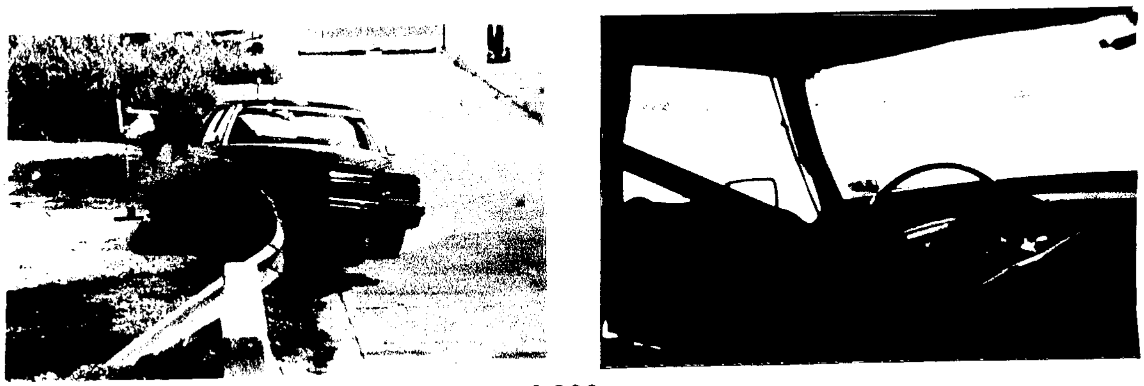
0.074 s



0.149 s

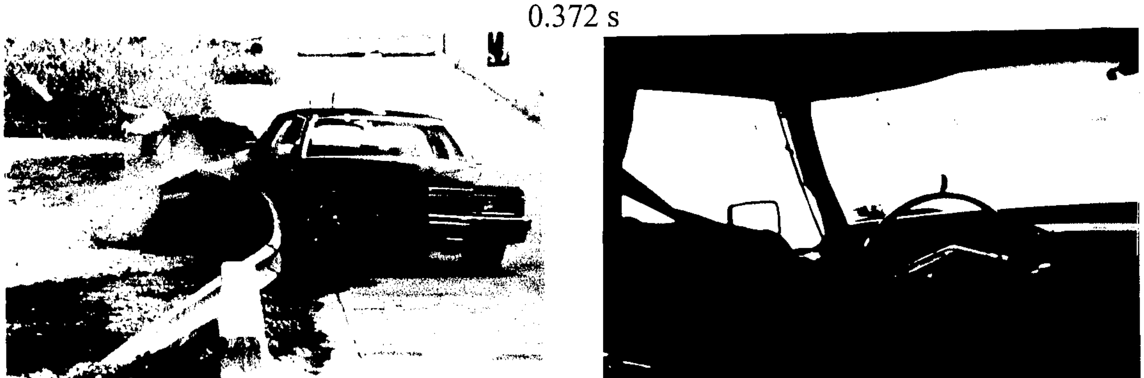
0.223 s

Figure 25. Sequential photographs for test 7147-4
(frontal and interior views).



0.298 s

0.372 s



0.465 s

0.555 s

Figure 25. Sequential photographs for test 7147-4
(frontal and interior views) (continued).

Figure 26. Damage to Washington nested W-beam guardrail after test 7147-4.

As can be seen from table 2, post 12 was pushed back 279 mm (11.0 in) at ground level and 0.51 m (20.25 in) at the center of the W-beam rail element. The blockout at post 11 was twisted and the head of the bolt attaching the rail to the blockout and post was pulled through the nested W-beam rail elements. There was no movement at the two end anchors.

3.2.3 Vehicle Damage

The vehicle (shown in figure 27) sustained moderate damage to the right side. The tie rod and lower control arm on the right side were damaged. There was damage to the front bumper, hood, grill, right front quarter panel, right front and rear doors, right rear quarter panel, and the rear bumper. The wheelbase on the right side was shortened from 3.07 m (121.0 in) to 3.06 m (120.5 in). The right front tire and rim were damaged from contact with the posts. Maximum crush to the vehicle was 229 mm (9.0 in) at the right front corner at bumper height. Note that much of the damage to the side of the vehicle (note the tear in the door panels in figure 28) was the result of the vehicle impacting the other guardrail near the end of the vehicle trajectory.

3.2.4 Occupant Risk Values

Data from the electronic instrumentation were digitized for evaluation and occupant risk factors were computed as follows. In the longitudinal direction, occupant impact velocity was 4.5 m/s (14.8 ft/s) at 0.287 s; the highest 0.010-s average ridedown acceleration was -2.8 g's from 0.317 to 0.327 s; and the 0.050-s average acceleration was -2.7 g's between 0.155 and 0.205 s. Lateral occupant impact velocity was 4.5 m/s (14.7 ft/s) at 0.169 s; the highest 0.010-s average ridedown acceleration was 9.0 g's from 0.260 to 0.270 s; and the maximum 0.050-s average acceleration was 7.1 g's between 0.218 and 0.268 s. The change in vehicle velocity at loss of contact was 20.6 km/h (12.8 mi/h) and the change in momentum was 11 672 N-s (2624 lb-s).

A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 29. Vehicle angular displacements are displayed in figure 30, and vehicular accelerations versus time traces filtered at 300 Hz are presented in figures 31 through 33.

3.3 TEST 471470-5

A 1982 Oldsmobile Regency 98, shown in figures 34 and 35, was used in test 471470-5. Test inertia weight of the vehicle was 2043 kg (4500 lb) and its gross static weight was 2120 kg (4670 lb). The height to the lower edge of the vehicle bumper was 298 mm (11.75 in) and it was 489 mm (19.25 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in figure 36. The vehicle was directed into the guardrail system using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

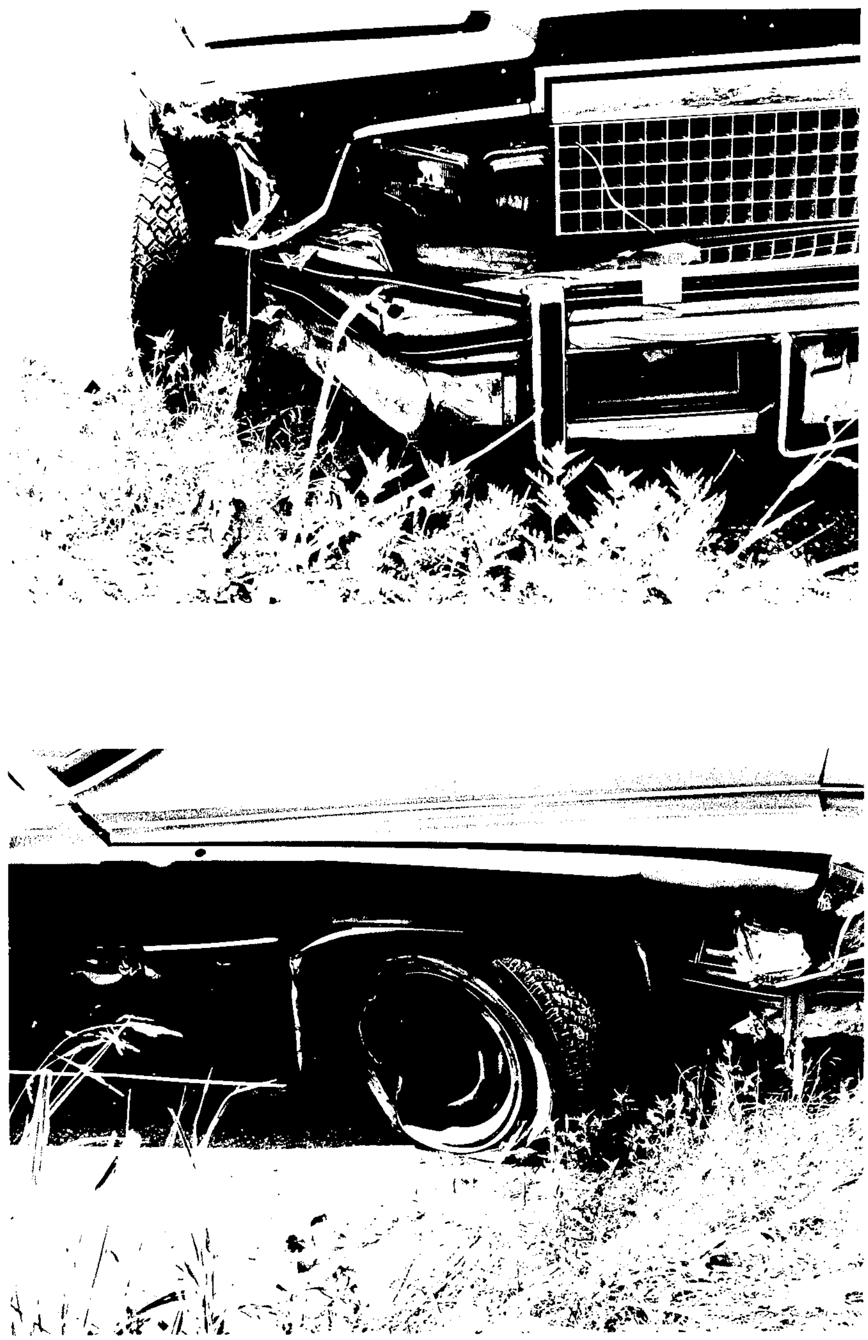


Figure 27. Vehicle after test 7147-4.

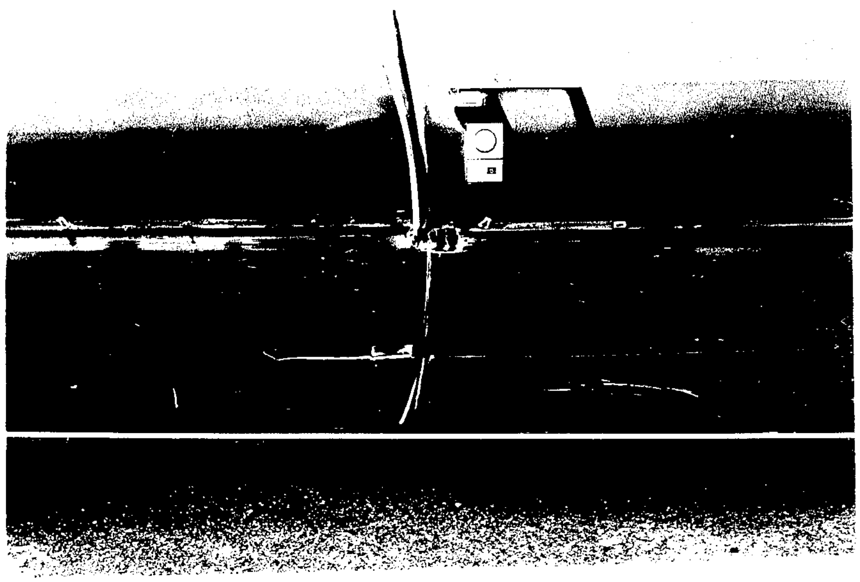
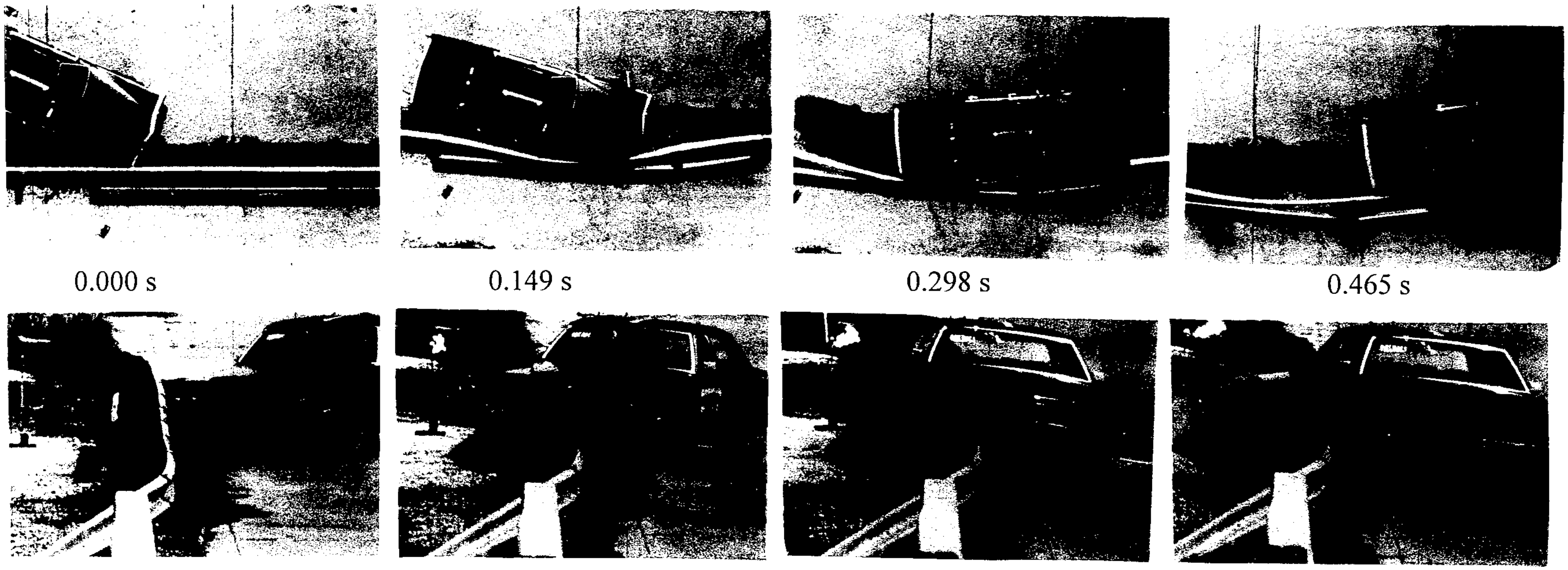
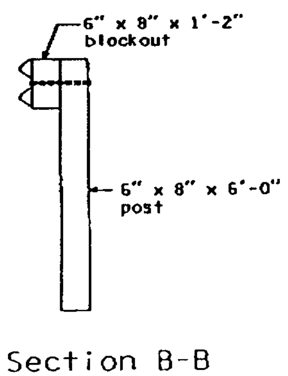


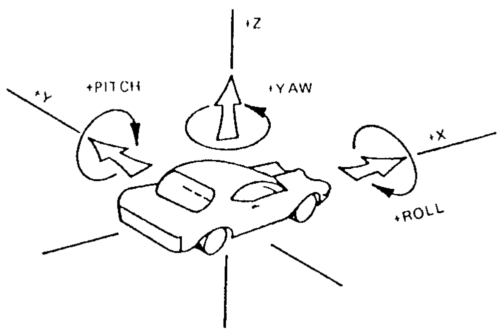
Figure 28. Secondary impact and damage.





Test No.	7147-4	Impact Speed	90.4 km/h (56.2 mi/h)
Date	05/28/91	Impact Angle	24.0 deg
Test Installation	Washington Nested W-beam with Wood Posts	Speed at Parallel	71.9 km/h (44.7 mi/h)
Installation Length	46 m (150 ft)	Exit Speed	69.8 km/h (43.4 mi/h)
Max. Dynamic Deflection	0.9 m (3.1 ft)	Exit Trajectory	12.3 deg
Max. Perm. Deformation	0.7 m (2.3 ft)	Vehicle Accelerations (Max. 0.050-s avg)	
Test Vehicle	1979 Cadillac Sedan deVille	Longitudinal	-2.7 g's
Vehicle Weight		Lateral	7.1 g's
Test Inertia	2043 kg (4500 lb)	Occupant Impact Velocity	
Gross Static	2120 kg (4670 lb)	Longitudinal	4.5 m/s (14.8 ft/s)
Vehicle Damage Classification		Lateral	4.5 m/s (14.7 ft/s)
TAD	01FR4 & 01RD3	Occupant Ridedown Accelerations	
CDC	01FREK2 & 01RDEW2	Longitudinal	-2.8 g's
Maximum Vehicle Crush	229 mm (9.0 in)	Lateral	9.0 g's

Figure 29. Summary of results for test 7147-4.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

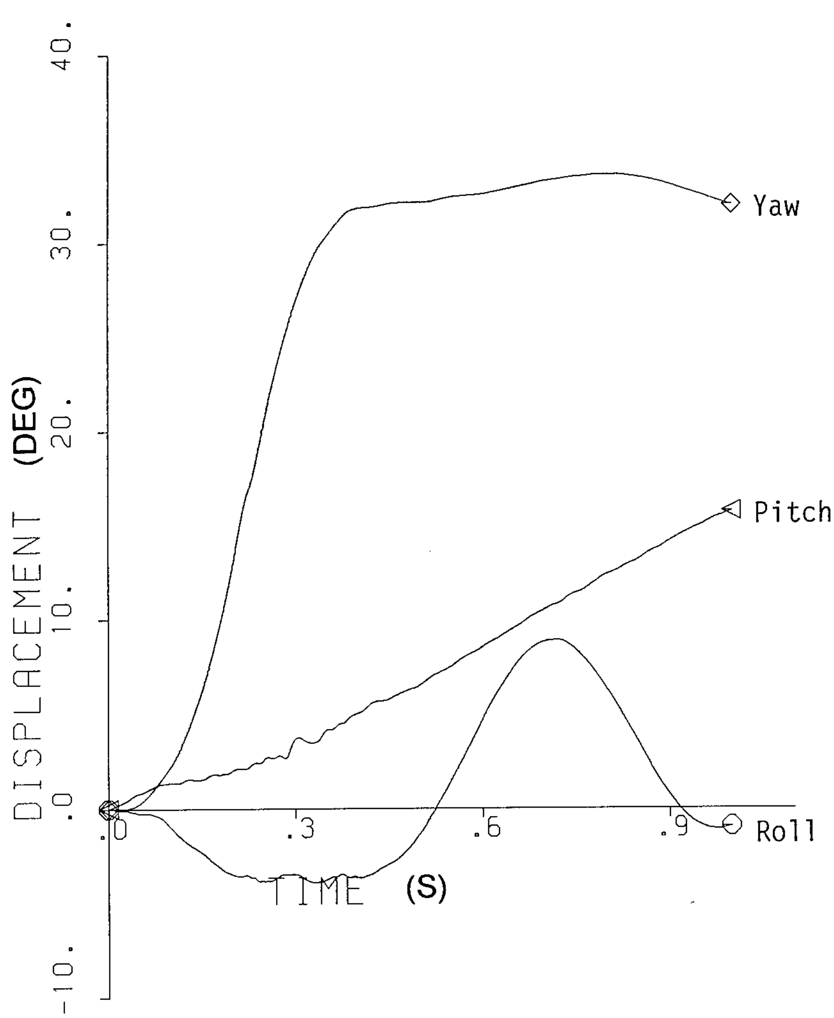


Figure 30. Vehicle angular displacements for test 7147-4.

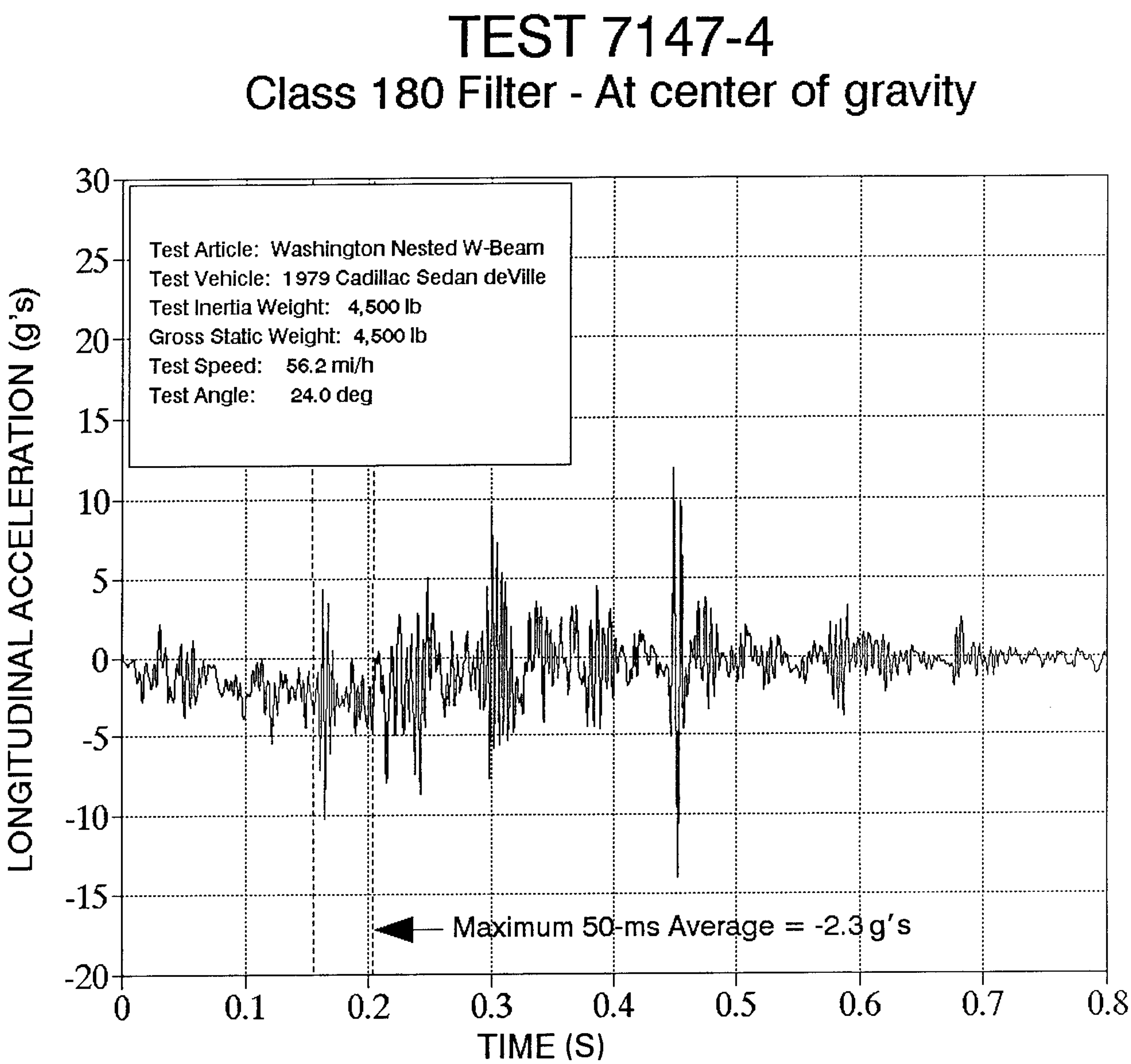


Figure 31. Vehicle longitudinal accelerometer trace for test 7147-4.

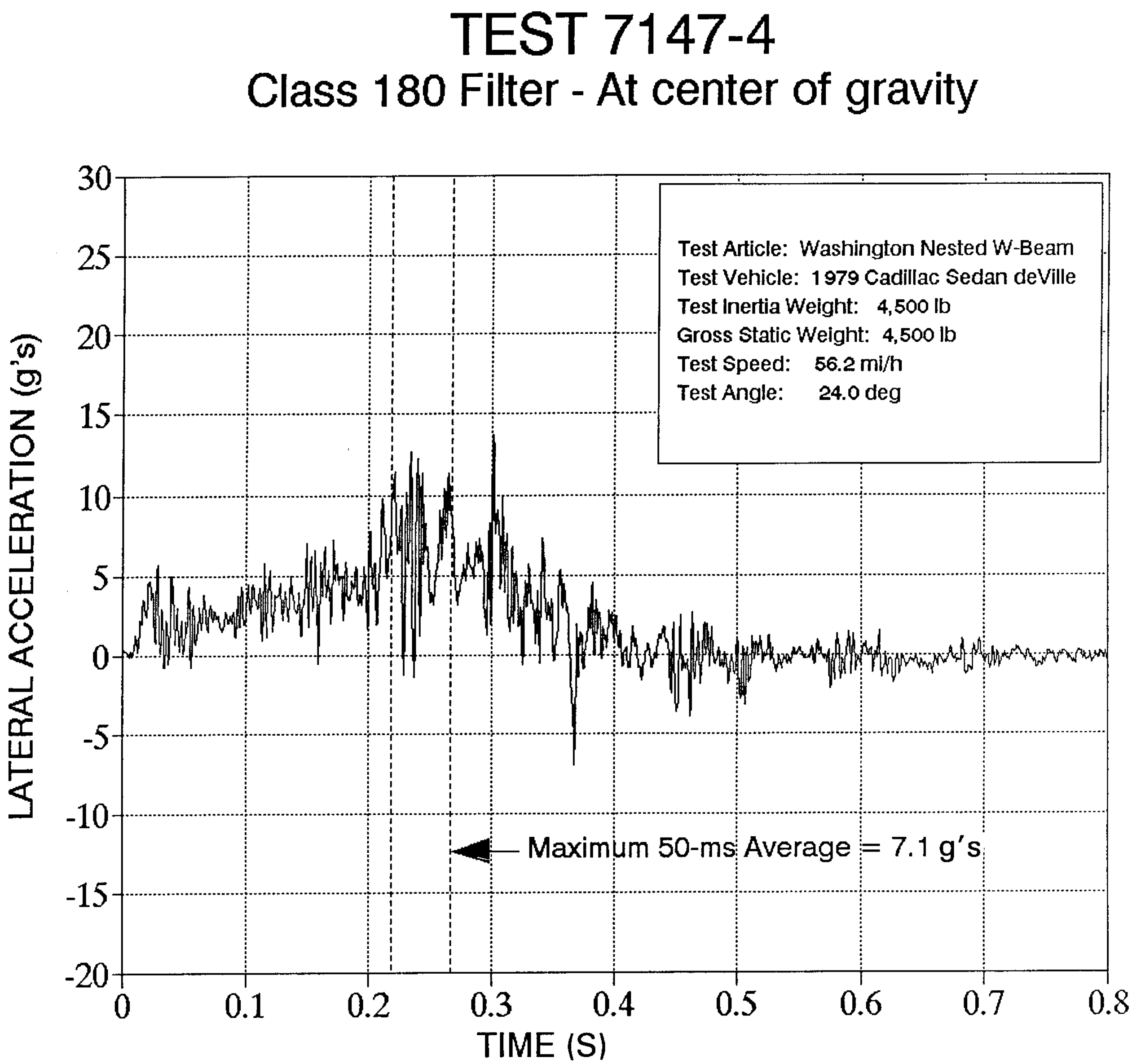


Figure 32. Vehicle lateral accelerometer trace for test 7147-4.

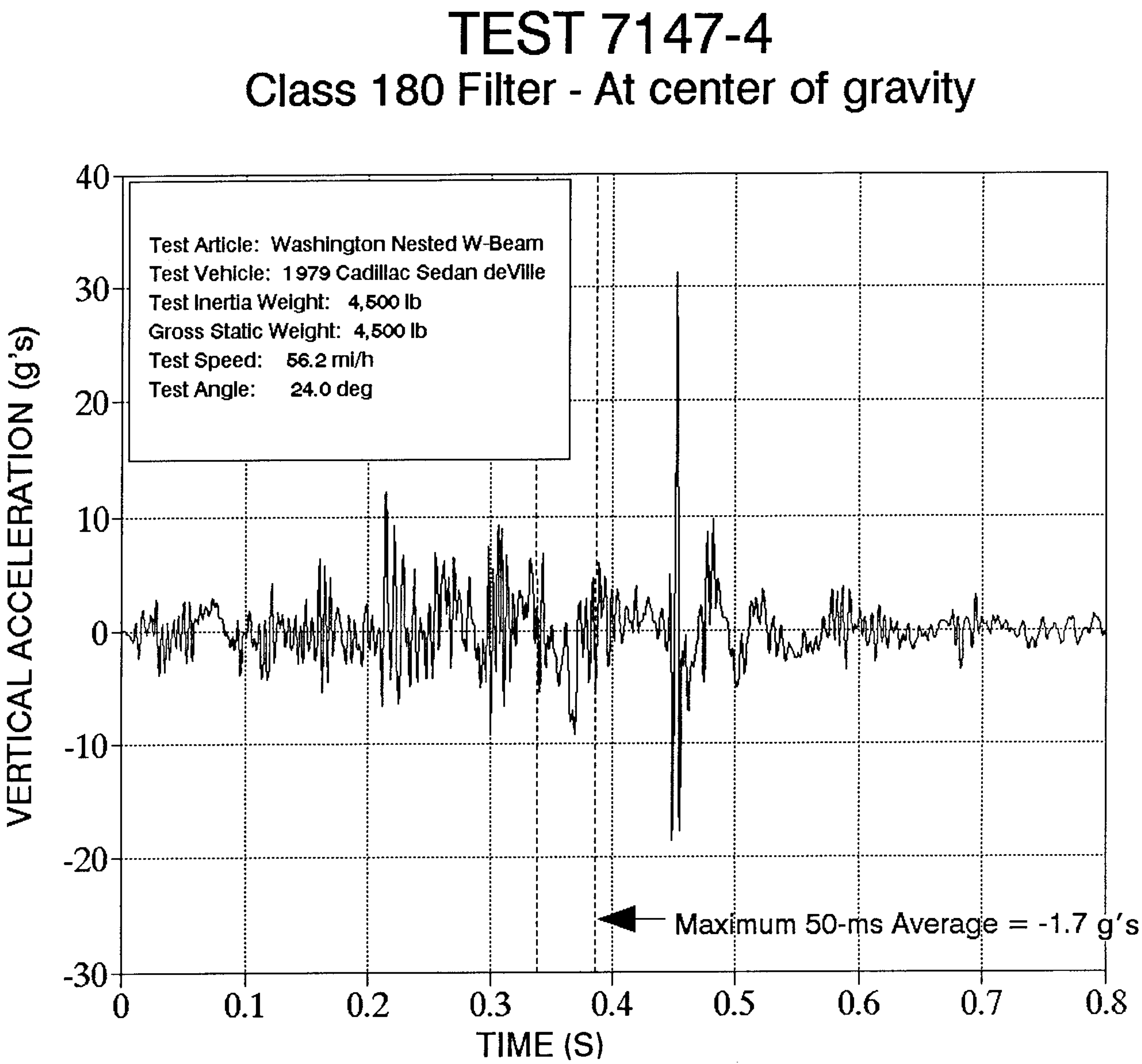


Figure 33. Vehicle vertical accelerometer trace for test 7147-4.

Figure 34. Vehicle prior to test 7147-5.

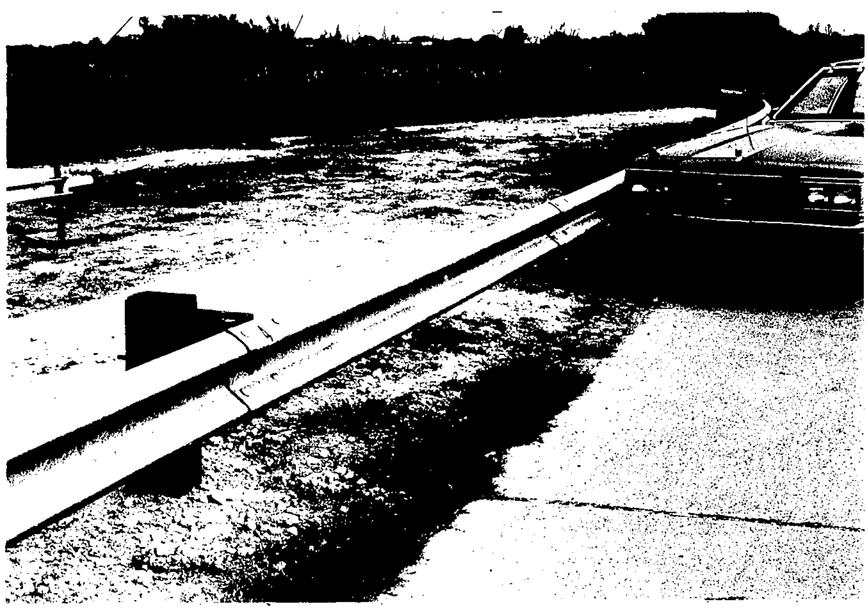


Figure 35. Vehicle/guardrail geometrics for test 7147-5.

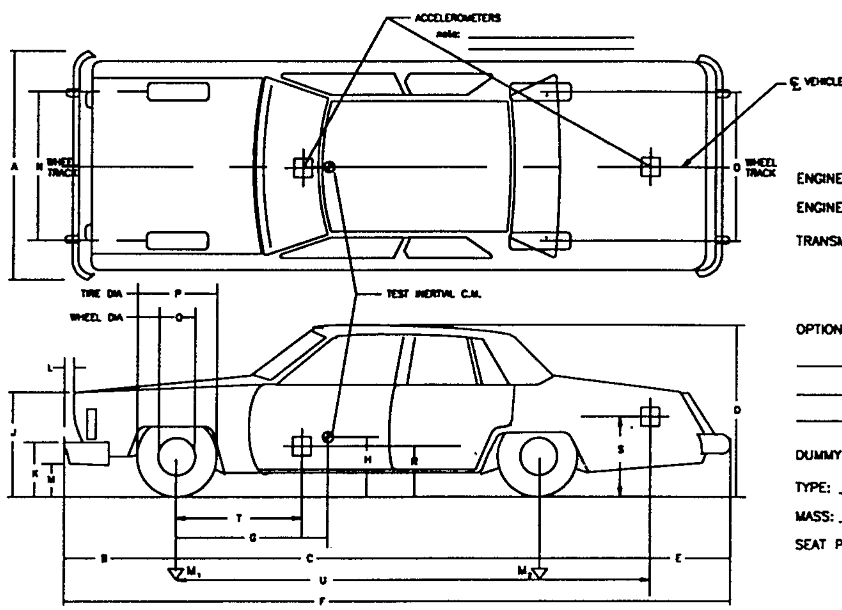
DATE: 05/30/91 TEST NO.: 471470-5 VIN NO.: 1G3AW69N3CM115371

YEAR: 1982 MAKE: Olds MODEL: Regency 98

TIRE INFLATION PRESSURE: ______ ODOMETER: 87443 TIRE SIZE: P225 75R15

MASS DISTRIBUTION (kg) LF 566 RF 570 LR 450 RR 458

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: V-8

ENGINE CID: 350 Diesel

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th male

MASS: 77 kg

SEAT POSITION: Driver's

GEOMETRY - (mm)

A 1924	E 1410	J 819	N 1581	R 432
B 1105	F 5537	K 489	O	S 762
C 3023	G 1341	L 140	P 692	T 1283
D 1448	H	M 298.5	Q 413	U 4026

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1125	1136	1174
M_2	720	907	946
M_T	1845	2043	2120

Figure 36. Vehicle properties for test 7147-5.

3.3.1 Test Description

The vehicle was traveling at a speed of 98.0 km/h (60.9 mi/h) when it impacted the guardrail system approximately 0.9 m (2.9 ft) downstream of post 11 (upstream post for the long span over the simulated culvert). The impact point was selected to provide maximum deflection at the downstream post of the long span, based on results from the computer simulation study. The impact angle was 25.1 degrees.

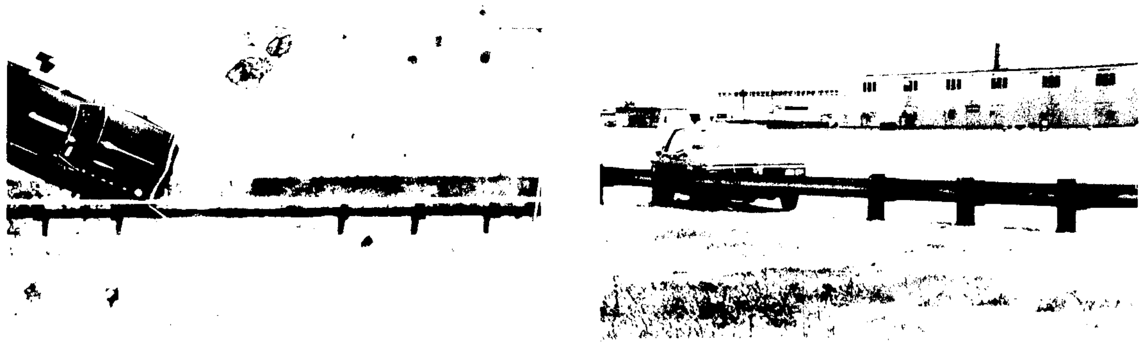
At 0.042 s after initial impact, the vehicle began to redirect. The right front tire of the vehicle contacted post 12 at 0.194 s, resulting in both front tires being turned abruptly to the right. The rear of the vehicle contacted the guardrail at 0.179 s, and at 0.229 s, the vehicle was traveling parallel to the guardrail system at a speed of 78.2 km/h (48.6 mi/h). Maximum dynamic deflection of the guardrail was 1.0 m (3.2 ft) to the front rail, occurring at 0.328 s. The vehicle exited the guardrail at 0.557 s traveling at a speed of 71.1 km/h (44.2 mi/h), with an exit trajectory of 10.4 degrees. The brakes were applied after the vehicle cleared the test installation. The vehicle rotated slightly clockwise and veered to the right because of the orientation of the front tires and damages sustained by the tires on the right side of the vehicle from impact with the guardrail. The front of the vehicle impacted another guardrail installation used to protect the downstream camera crew, and the vehicle came to rest against this barrier, 86.9 m (285 ft) downstream from the point of initial impact. Sequential photographs of the test sequence are presented in figures 37 and 38.

3.3.2 Damage to Test Installation

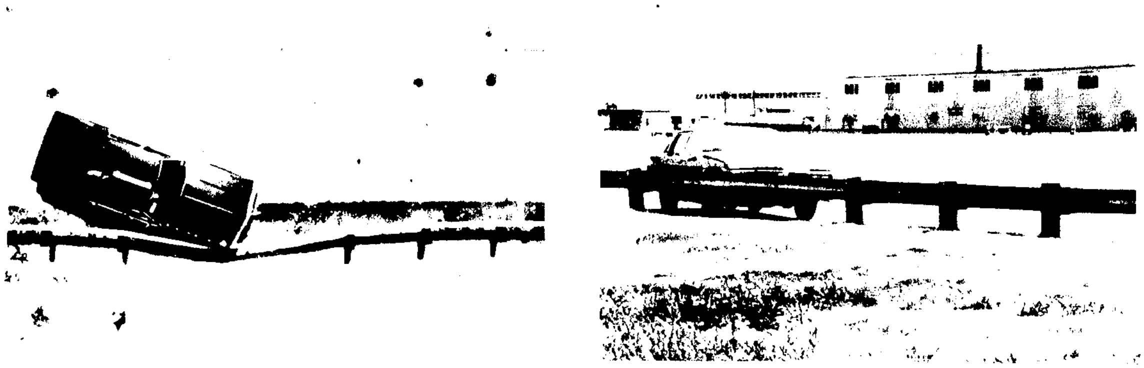
The guardrail system received moderate damage, as shown in figure 39. The maximum permanent deformation of the W-beam rail element was 0.8 m (2.5 ft), located approximately in the center of the long span. Movements of post and rail at different posts are summarized in the following table:

Table 3. Post and rail deflections for test 471470-5.

Post No.	Movement of Post		Comments
	Ground Level	Center of W-beam	
9	19 mm (0.75 in)	6 mm (0.25 in)	
10	25 mm (1.0 in)	38 mm (1.5 in)	
11	133 mm (5.25 in)	254 mm (10.0 in)	
Center of span	N/A	762 mm (30.0 in)	
12	419 mm (16.5 in)	584 mm (23.0 in)	Blockout separated from post and rail element. Post split.
13	279 mm (11.0 in)	508 mm (20.0 in)	
14	38 mm (1.5 in)	64 mm (2.5 in)	
15	6 mm (0.25 in)	25 mm (1.0 in)	



0.000 s



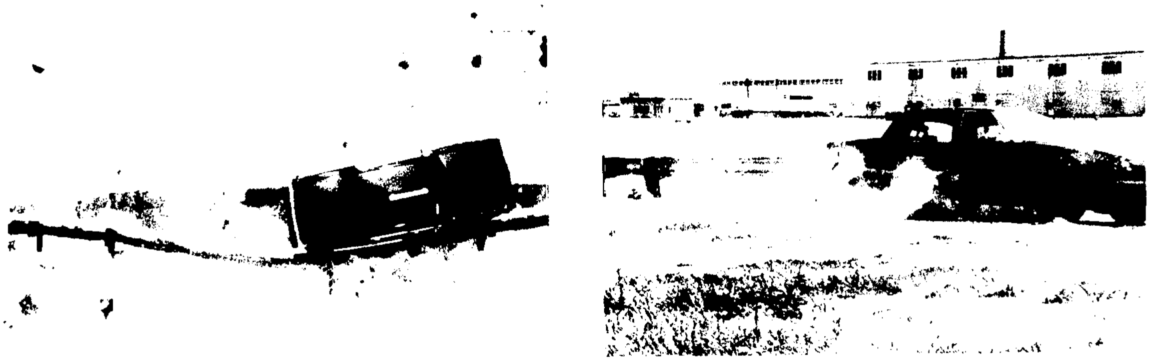
0.074 s

0.149 s

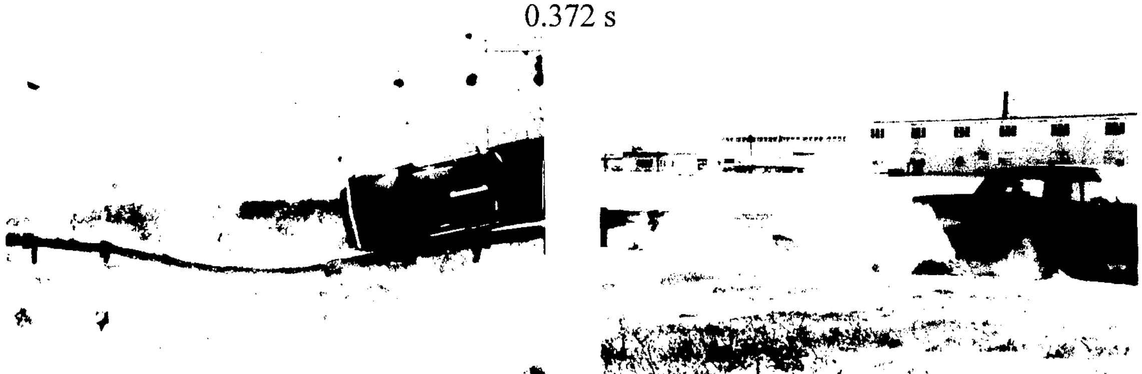
0.223 s

Figure 37. Sequential photographs for test 7147-5
(overhead and behind the rail views).

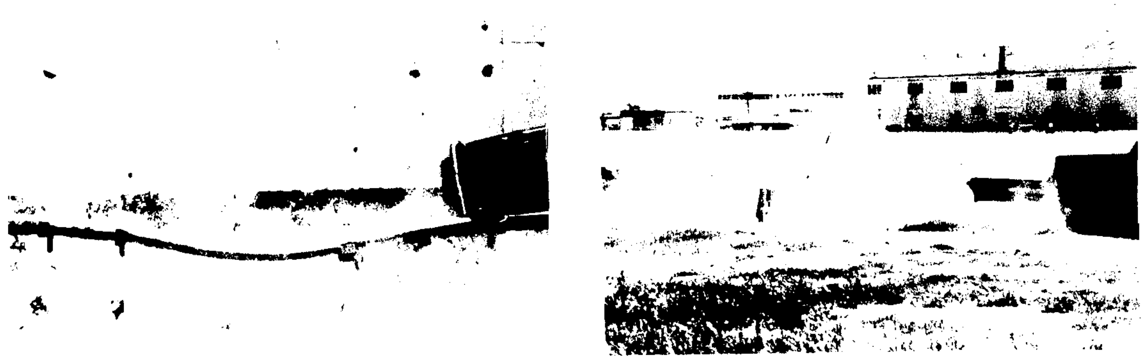
0.298 s



0.372 s



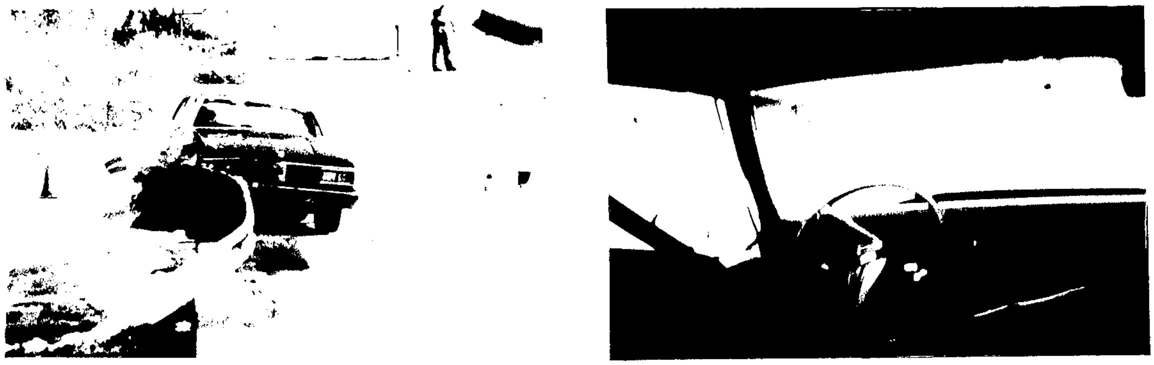
0.447 s



0.557 s

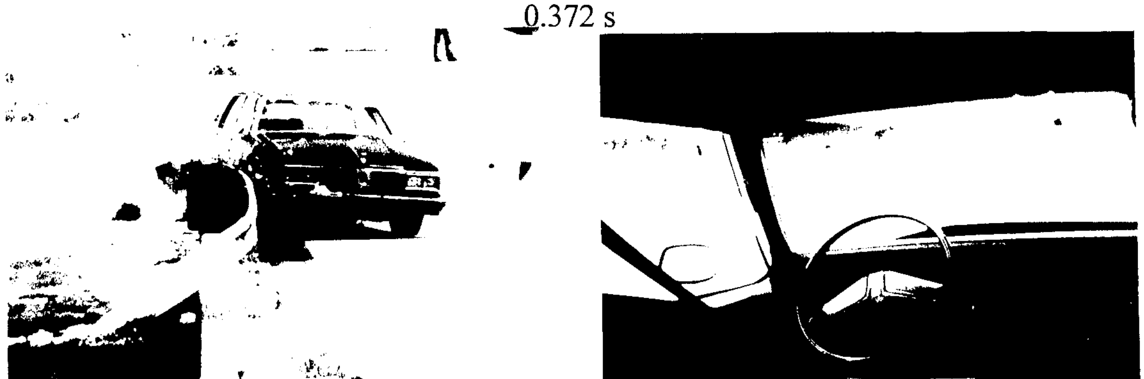
Figure 37. Sequential photographs for test 7147-5 (overhead and behind the rail views) (continued).

Figure 38. Sequential photographs for test 7147-5
(frontal and interior views).



0.298 s

0.372 s



0.447 s

0.557 s

Figure 38. Sequential photographs for test 7147-5
(frontal and interior views) (continued).

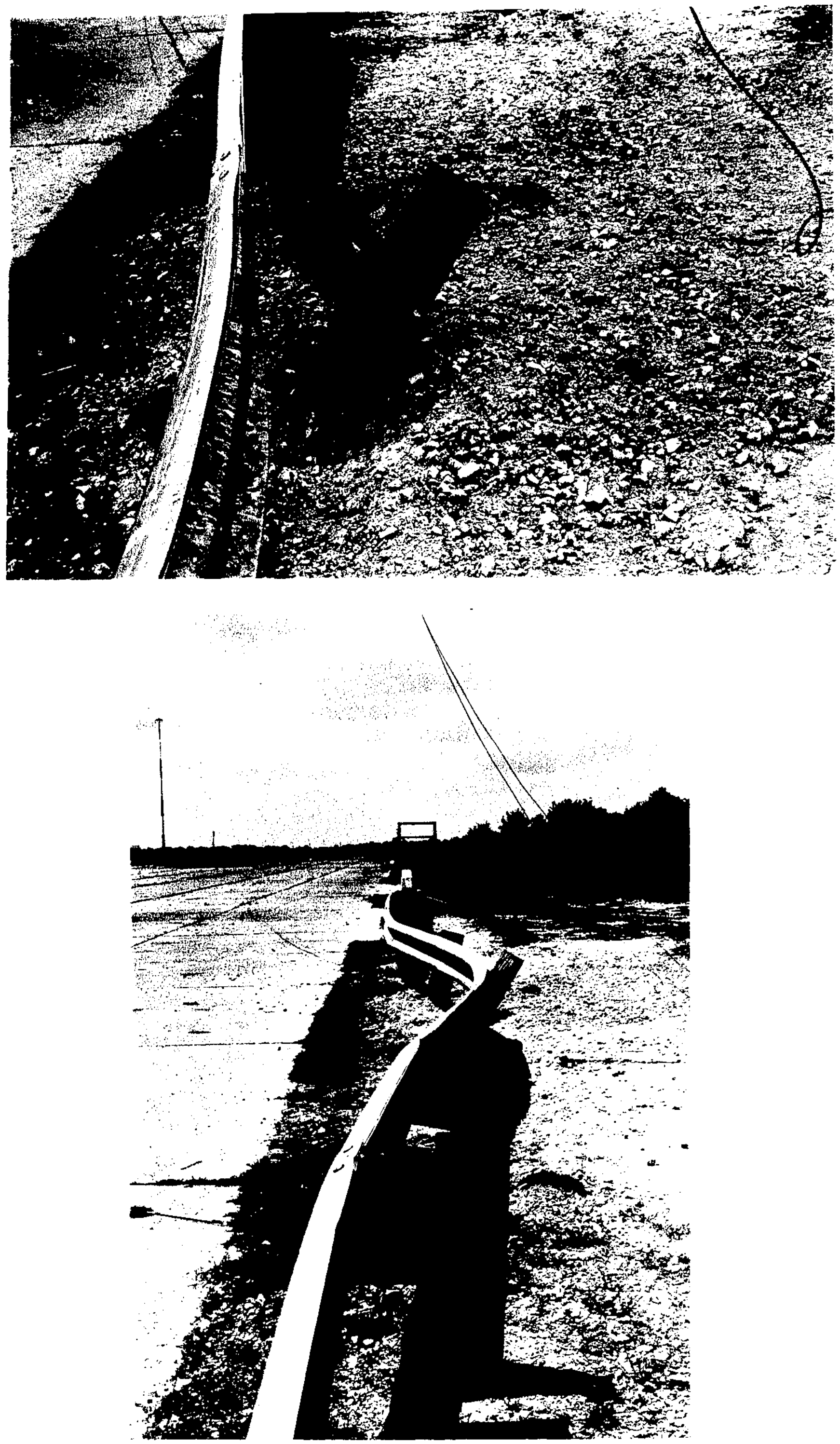


Figure 39. Washington nested W-beam guardrail after test 7147-5.

As can be seen from table 3, post 12 was pushed back 419 mm (16.5 in) at ground level and 584 mm (23.0 in) at the center of the W-beam rail element. The blockout at post 11 was separated from the post and rail elements and the post was split. There was no movement at the two end anchors.

3.3.3 Vehicle Damage

The vehicle (shown in figure 40) sustained moderate damage to the right side. The upper control arm on the right side was damaged. There was damage to the front bumper, hood, grill, right front quarter panel, right front and rear doors, right rear quarter panel, and the rear bumper. The wheelbase on the right side was shortened from 3.02 m (119.0 in) to 2.97 m (117.0 in). The right front and rear tires and rims were damaged from contact with the posts. Maximum crush to the vehicle was 203 mm (8.0 in) at the right front corner at bumper height.

3.3.4 Occupant Risk Values

Data from the electronic instrumentation were digitized for evaluation, and occupant risk factors were computed as follows. In the longitudinal direction, occupant impact velocity was 4.5 m/s (14.7 ft/s) at 0.291 s; the highest 0.010-s average ridedown acceleration was -3.5 g's from 0.306 to 0.316 s; and the 0.050-s average acceleration was -2.7 g's between 0.184 and 0.234 s. Lateral occupant impact velocity was 4.3 m/s (14.2 ft/s) at 0.173 s; the highest 0.010-s average ridedown acceleration was 9.7 g's from 0.183 to 0.193 s; and the maximum 0.050-s average acceleration was 6.8 g's between 0.177 and 0.227 s. The change in vehicle velocity at loss of contact was 26.9 km/h (16.7 mi/h) and the change in momentum was 15 225 N-s (3423 lb-s).

A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 41. Vehicle angular displacements are displayed in figure 42, and vehicular accelerations versus time traces filtered at 300 Hz are presented in figures 43 through 45.

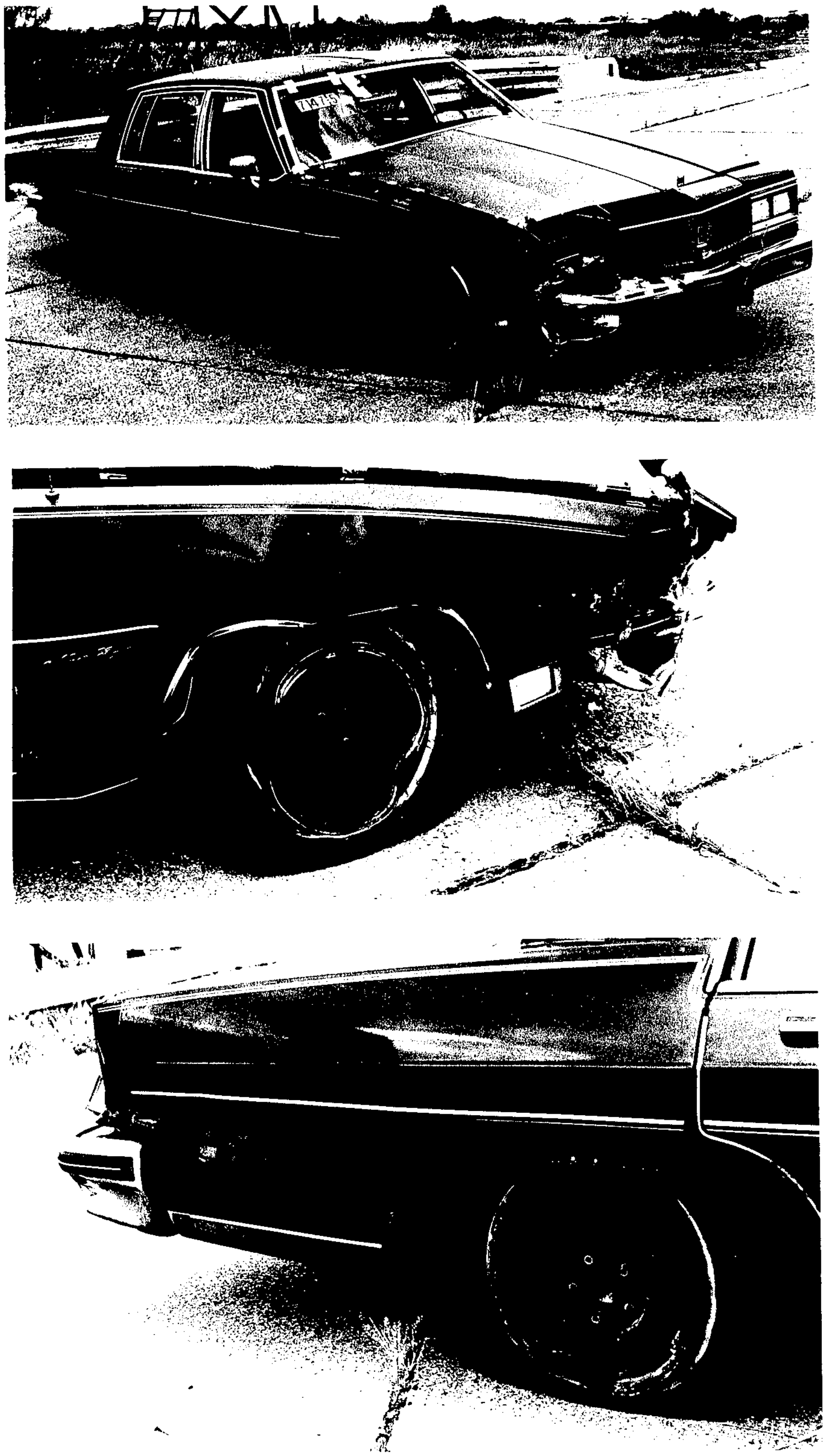
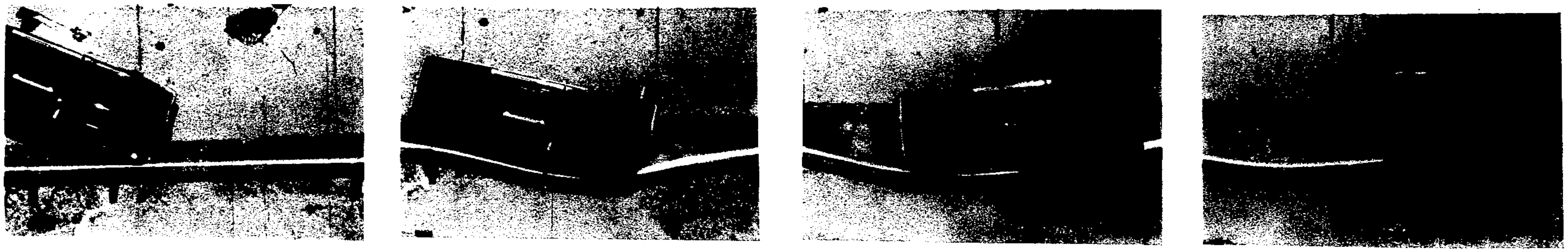
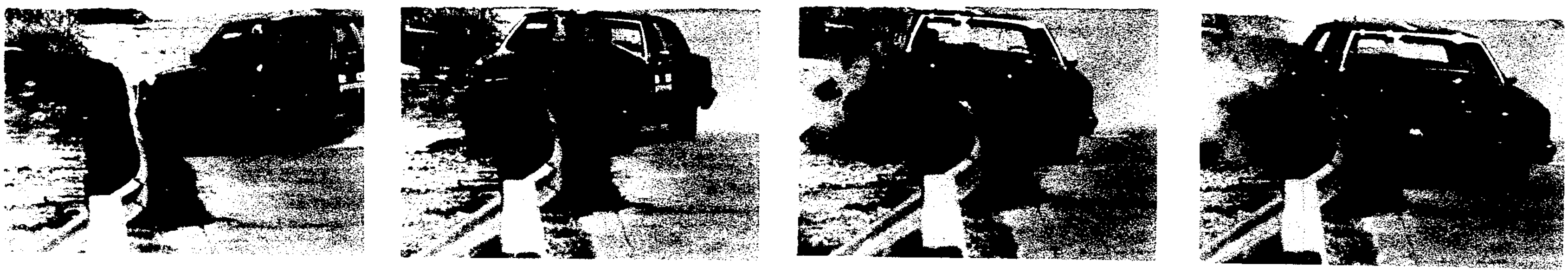
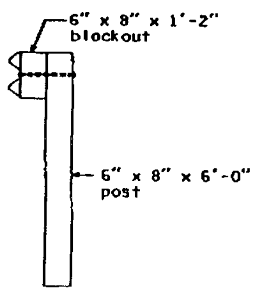


Figure 40. Damage to vehicle after test 7147-5.



0.000 s | 0.149 s | 0.298 s | 0.447 s

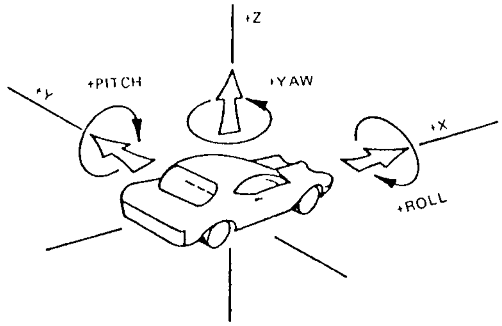




Section B-B

Test No.	7147-5	Impact Speed	98.0 km/h (60.9 mi/h)
Date	05/30/91	Impact Angle	25.1 deg
Test Installation	Washington Nested W-beam with Wood Posts	Speed at Parallel	78.2 km/h (48.6 mi/h)
		Exit Speed	71.1 km/h (44.2 mi/h)
Installation Length	46 m (150 ft)	Exit Trajectory	10.4 deg
Max. Dynamic Deflection	1.0 m (3.2 ft)	Vehicle Accelerations	
Max. Perm. Deformation	0.8 m (2.5 ft)	(Max. 0.050-s avg)	
Test Vehicle	1982 Oldsmobile Rgency 98	Longitudinal	-2.7 g's
Vehicle Weight		Lateral	6.8 g's
Test Inertia	2043 kg (4500 lb)	Occupant Impact Velocity	
Gross Static	2120 kg (4670 lb)	Longitudinal	4.5 m/s (14.7 ft/s)
Vehicle Damage Classification		Lateral	4.3 m/s (14.2 ft/s)
TAD	01FR4 & 01RD3	Occupant Ridedown Accelerations	
CDC	01FREK2 & 01RDEW2	Longitudinal	-3.5 g's
Maximum Vehicle Crush	203 mm (8.0 in)	Lateral	9.7 g's

Figure 41. Summary of results for test 7147-5.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

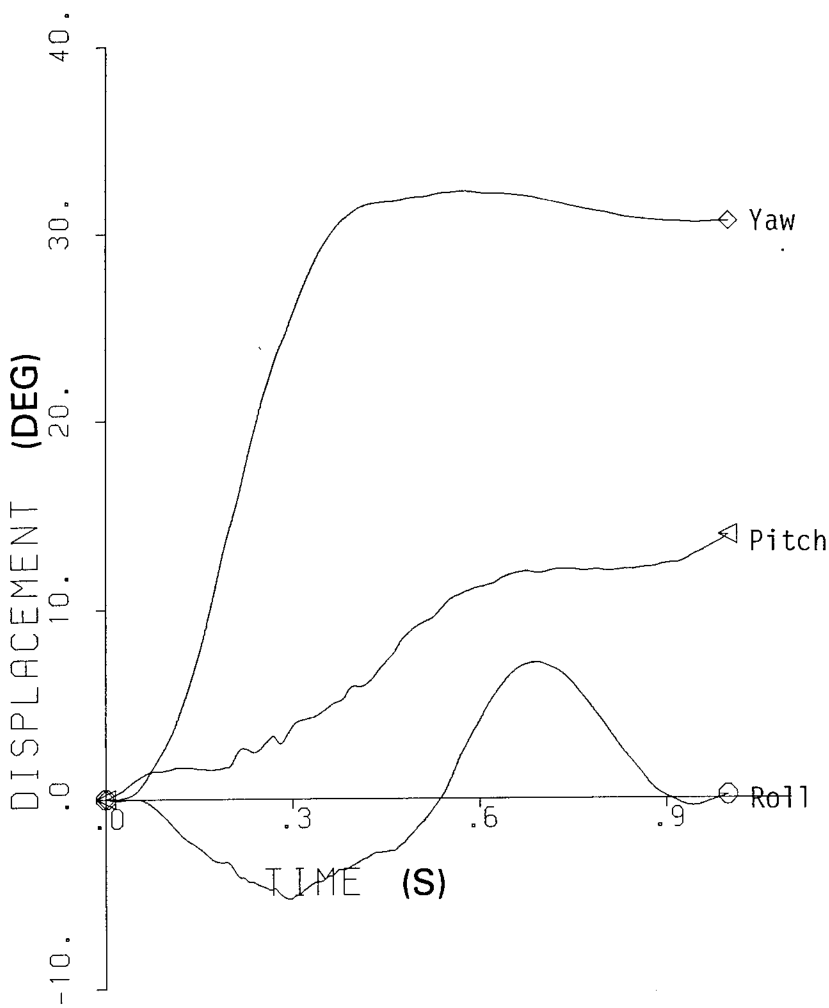


Figure 42. Vehicle angular displacements for test 7147-5.

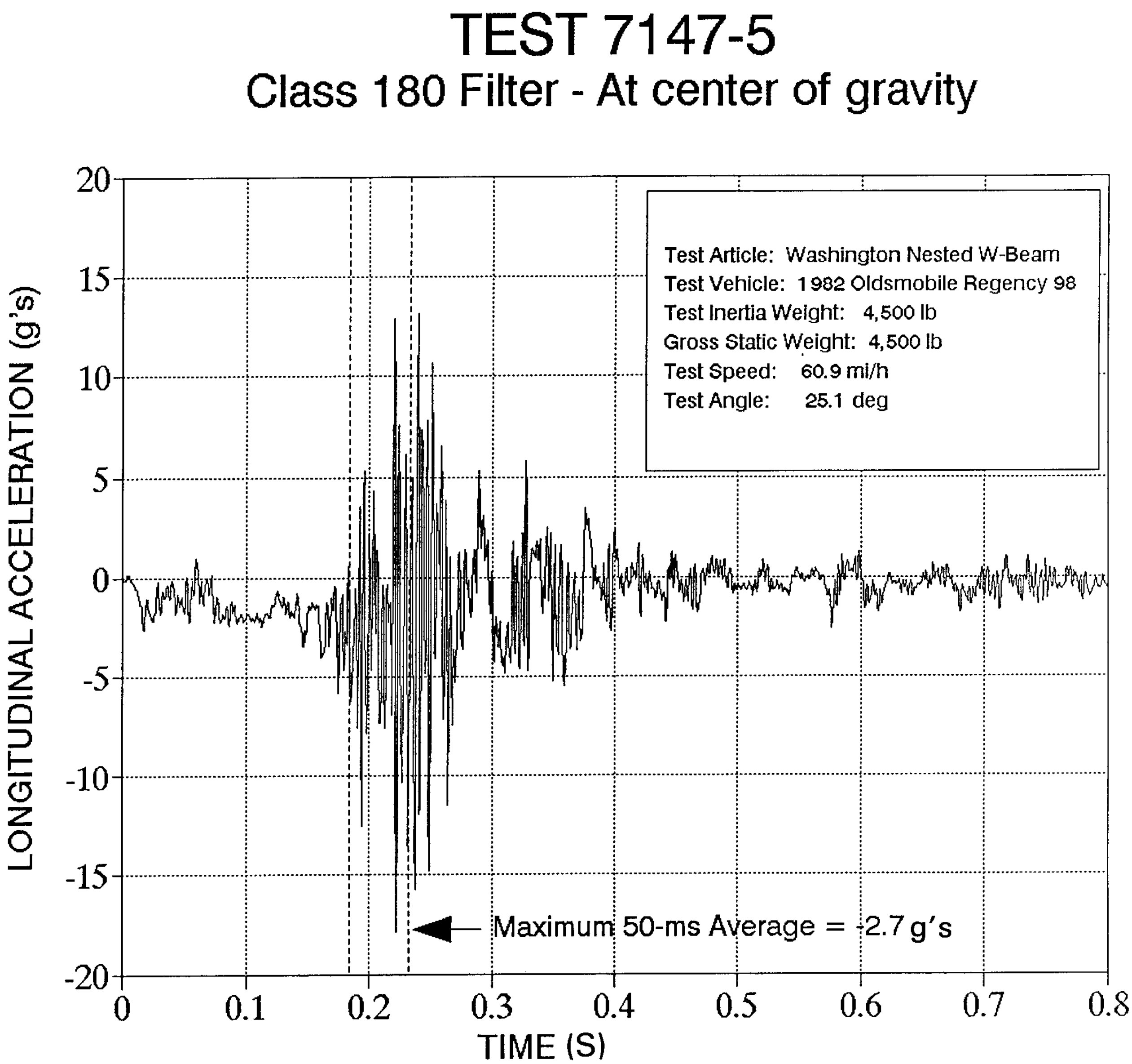


Figure 43. Vehicle longitudinal accelerometer trace for test 7147-5.

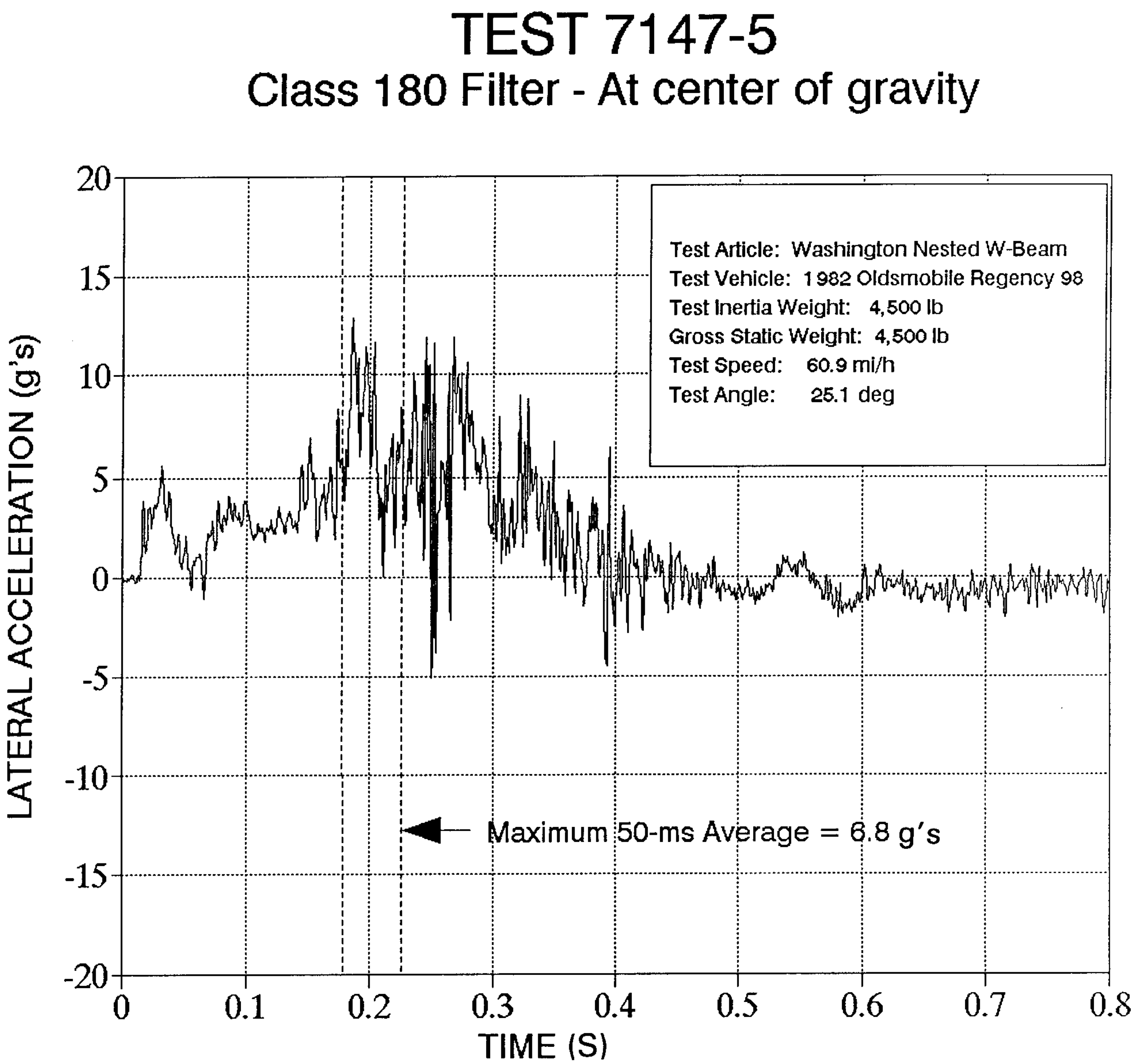


Figure 44. Vehicle lateral accelerometer trace for test 7147-5.

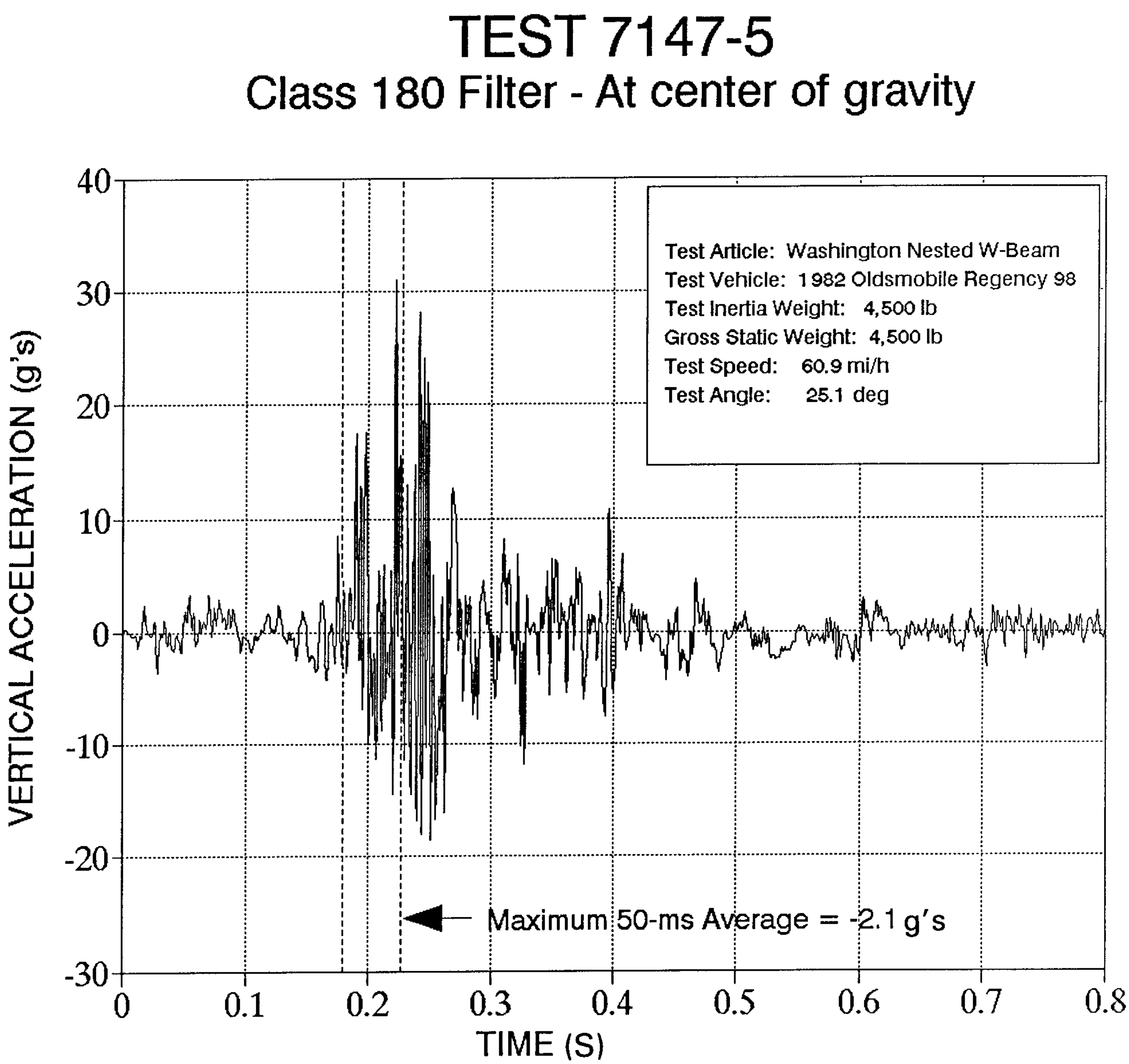


Figure 45. Vehicle vertical accelerometer trace for test 7147-5.

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

Three long-span, nested W-beam guardrail designs for use over culverts were crash tested and evaluated, including:

1. A 3.81-m (12-ft, 6-in) span nested W-beam guardrail design (test no. 471470-2),

2. A 5.72-m (18-ft, 9-in) span nested W-beam guardrail design with a W-beam rail section in rear of guardrail (test no. 471470-4), and

2. A 5.72-m (18-ft, 9-in) span nested W-beam guardrail design without a W-beam rail section in rear of guardrail (test no. 471470-5).

The 3.81-m (12-ft, 6-in) long-span, nested W-beam guardrail design performed very well in test 471470-2, as shown in the performance evaluation summary in table 4. The vehicle was smoothly redirected and did not penetrate or go over the guardrail system. There were no detached elements or debris to show potential for penetration of the occupant compartment or to present an undue hazard to other traffic. The vehicle remained upright and stable during the impact with the guardrail and after exiting the test installation. There was some intrusion into the occupant compartment, but essentially no deformation of the compartment. Vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes.

The occupant impact velocities and ridedown accelerations for both the longitudinal and the lateral directions were well below the desirable values outlined in NCHRP Report 230 guidelines. There was some slight pocketing and tire contact at the downstream post of the long span, but their effects were very minor and did not significantly affect the vehicle kinematics or trajectory. The velocity change of 33.0 km/h (20.5 mi/h) was higher than the recommended limit of 24.1 km/h (15 mi/h) according to NCHRP Report 230 guidelines. However, the exit angle of 11.0 degrees was considerably less than 60 percent of the impact angle.

One suggested change is to increase the length of the nested rail from the minimum of 7.62 m (25 ft) to 11.43 m (37 ft, 6 in) and add a W-beam rail section to the rear of the system to overlap the long span and provide added strength. This suggested change would not affect the impact performance of the system to any degree, but would eliminate the need to have a splice in the middle of the long span, which could be mistaken as a missing post.

The 5.72-m (18-ft, 9-in) long-span nested W-beam guardrail system with a W-beam rail section at the rear of the guardrail performed very well in crash test 471470-4, as shown in the performance evaluation summary in table 5. The vehicle was smoothly redirected and did not penetrate or go over the guardrail system. There were no detached elements or debris to show potential for penetration of the occupant compartment or to present an undue hazard to other traffic. The vehicle remained upright and stable during the impact with the guardrail and after exiting the test installation. There was no intrusion into the occupant compartment, and no deformation of the compartment. Vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes.

The occupant impact velocities and ridedown accelerations for both the longitudinal and the lateral directions were well below the desirable values outlined in NCHRP Report 230 guidelines. There was some slight pocketing and tire contact at the downstream post of the long span, but their effects were very minor and did not significantly affect the vehicle kinematics or trajectory. The velocity change and exit angle were within the recommended limit according to NCHRP Report 230 guidelines.

It should be noted that the actual impact speed of 90.4 km/h (56.2 mi/h) and impact angle of 24 degrees were considerably lower than the target impact speed of 96.5 km/h (60 mi/h) and impact angle of 25 degrees. However, the guardrail system performed so well in the crash test that there is little question that the guardrail system would have performed satisfactorily with the nominal impact conditions.

The good performance of the system in test 471470-4 indicated that the system would work well without the W-beam rail section on the rear of the guardrail. This would reduce the cost of the installation, both in terms of material and labor.

The 5.72-m (18-ft, 9-in) long-span nested W-beam guardrail system without the rear W-beam rail element also performed very well in test 471470-5, as shown in the performance evaluation summary in table 6. The vehicle was smoothly redirected and did not penetrate or go over the guardrail system. There were no detached elements or debris to show potential for penetration of the occupant compartment or to present an undue hazard to other traffic. The vehicle remained upright and stable during the impact with the guardrail and after exiting the test installation. There was no intrusion into the occupant compartment, and no deformation of the compartment. Vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes.

The occupant impact velocities and ridedown accelerations for both the longitudinal and the lateral directions were well below the desirable values outlined in NCHRP Report 230 guidelines. There was some slight pocketing and tire contact at the downstream post of the long span, but their effects were very minor and did not significantly affect the vehicle kinematics or trajectory. The velocity change was slightly higher than the recommended limit of 24.1 km/h (15 mi/h), but the exit angle of 10.4 degrees was considerably less than 60 percent of the impact angle.

In summary, all three long-span nested W-beam guardrail designs for use over culverts performed very well in crash tests and met all evaluation criteria set forth in NCHRP Report 230. It is therefore recommended that the nested W-beam guardrail design without the W-beam rail section in the rear of the guardrail be approved for field implementation for culverts with clear spans up to 5.72 m (18 ft, 9 in).

Table 4. Assessment of results of test 471470-2 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-2 | Test Date: 09/25/90

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article shall contain and redirect the vehicle; the vehicle should not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	The vehicle did not penetrate or go over the barrier and was smoothly redirected.	Pass
D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	No debris showed potential for penetrating passenger compartment or presenting undue hazard to other traffic.	Pass
Occupant Risk		
E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	Vehicle remained upright and stable during collision. There was essentially no deformation or intrusion into the passenger compartment.	Pass
F. Impact velocity of hypothetical front seat passenger against the vehicle interior shall be less than Occupant Impact Velocity Limits (m/s): Longitudinal 12.2 (40 ft/s); Lateral 9.1 (30 ft/s)	Longitudinal Impact Velocity = 5.4 m/s (17.8 ft/s) Lateral Impact Velocity = 4.8 m/s (15.9 ft/s)	N/A
and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger contact should be less than: Occupant Ridedown Acceleration Limits (g's): Longitudinal 20; Lateral 20	Longitudinal Occupant Ridedown = -6.5 g's Lateral Occupant Ridedown = 12.9 g's	N/A
Vehicle Trajectory		
H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	Vehicle came to rest 53 m (173 ft) downstream and aligned with the point of impact.	Pass
I. In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 24.1 km/h (15 mi/h) and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	Velocity change 33.0 km/h (20.5 mi/h) (>24.1 km/h (15 mi/h); exit angle 11.0 degrees (<14.7 degrees or 60 percent of 24.5 degrees)	Marginal

Table 5. Assessment of results of test 471470-4 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-4 | Test Date: 05/28/91

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article shall contain and redirect the vehicle; the vehicle should not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	The vehicle did not penetrate or go over the barrier and was smoothly redirected.	Pass
D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	No debris showed potential for penetrating passenger compartment or presenting undue hazard to other traffic.	Pass
Occupant Risk		
E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	Vehicle remained upright and stable during collision. There was no deformation or intrusion into the passenger compartment.	Pass
F. Impact velocity of hypothetical front seat passenger against the vehicle interior shall be less than Occupant Impact Velocity Limits (m/s): Longitudinal 12.2 (40 ft/s); Lateral 9.1 (30 ft/s)	Longitudinal Impact Velocity = 4.5 m/s (14.8 ft/s) Lateral Impact Velocity = 4.5 m/s (14.6 ft/s)	N/A
and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger contact should be less than: Occupant Ridedown Acceleration Limits (g's): Longitudinal 20; Lateral 20	Longitudinal Occupant Ridedown = -2.8 g's Lateral Occupant Ridedown = 9.0 g's	N/A
Vehicle Trajectory		
H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	Vehicle came to rest 119 m (390 ft) downstream and 15 m (50 ft) behind the point of impact.	Pass
I. In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 24.1 km/h (15 mi/h) and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	Velocity change 20.6 km/h (12.8 mi/h) (<24.1 km/h (15 mi/h); exit angle 12.3 degrees (<14.4 degrees or 60 percent of 24.0 degrees)	Pass

Table 6. Assessment of results of test 471470-5 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-5 | Test Date: 05/30/91

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
A. Test article shall contain and redirect the vehicle; the vehicle should not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	The vehicle did not penetrate or go over the barrier and was smoothly redirected.	Pass
D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	No debris showed potential for penetrating passenger compartment or presenting undue hazard to other traffic.	Pass
<u>Occupant Risk</u>		
E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	Vehicle remained upright and stable during collision. There was no deformation or intrusion into the passenger compartment.	Pass
F. Impact velocity of hypothetical front seat passenger against the vehicle interior shall be less than Occupant Impact Velocity Limits (m/s): Longitudinal 12.2 (40 ft/s); Lateral 9.1 (30 ft/s)	Longitudinal Impact Velocity = 4.5 m/s (14.7 ft/s) Lateral Impact Velocity = 4.3 m/s (14.2 ft/s)	N/A
and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger contact should be less than: Occupant Ridedown Acceleration Limits (g's): Longitudinal 20; Lateral 20	Longitudinal Occupant Ridedown = -3.5 g's Lateral Occupant Ridedown = 9.7 g's	N/A
<u>Vehicle Trajectory</u>		
H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	Vehicle came to rest 86.9 m (285 ft) downstream and even with the point of impact.	Pass
I. In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 24.1 km/h (15 mi/h) and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	Velocity change 26.9 km/h (16.7 mi/h) (>24.1 km/h (15 mi/h); exit angle 10.4 degrees (<15.1 degrees or 60 percent of 25.1 degrees)	Pass

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1. Hirsch, T. J., and Beggs, D., *Use of Guardrails on Low-Fill Bridge Length Culverts*, Research Report 405-2F, Texas Transportation Institute, Texas A&M University System, College Station, Texas, August 1987.

2. Bligh, R. P., and Mak, K. K., *Analysis of Guardrail over Low-Fill Culverts*, Interim Report on Task A, Subtask 1, Contract No. DTFH61-89-C-00089, Texas Transportation Institute, Texas A&M University System, College Station, Texas, September 1990.

3. Michie, J. D., *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, NCHRP Report 230, Transportation Research Board, Washington, DC, March 1981.