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Contracting Officer's Technical Representative (COTR) - Charles F. McDevitt - HSR-20

16. Abstract

An assortment of retrofit bridge railings and a retrofit transition were evaluated through full-scale crash testing. The assortment included:

1. A w-beam retrofit railing for a concrete baluster bridge railing (AASHTO performance level one).
2. A w-beam transition for the bridge railing above (NCHRP Report 350 test level two).
3. A double-tube pedestrian/bicycle railing mounted on the Illinois 2399-1 traffic railing (AASHTO performance level one).
4. A vandal protection fence on the New Jersey concrete safety shape bridge railing (AASHTO performance level two).
5. A thrie beam retrofit railing, a Delaware design, mounted on a 203-mm (8-inch) high safety curb (AASHTO performance level two and NCHRP Report 350 test level four).

All of the designs demonstrated acceptable performance.

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

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Form DOT F 1700.7 (8-69)

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (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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INTRODUCTION

Due to specific needs or constraints of individual States, new or modified low-cost W-beam retrofit railings are being designed and developed for existing bridge railings. To assure that these new or modified retrofit designs perform according to established guidelines, full-scale crash testing and evaluation was deemed necessary. The objective of this study is to crash test and evaluate these retrofit bridge railings and, where necessary, redesign the railings to improve their performance.

After review of the existing designs for structural adequacy and crashworthiness, several retrofit designs were selected. The W-beam retrofit for concrete baluster bridge railing was chosen and with the acceptable performance of the W-beam retrofit bridge railing the need developed for an appropriate transition. Two tests on each design were performed for evaluation.

Also, selected for evaluation was the double tube pedestrian/bicycle rail mounted on the Illinois 2399-1 traffic railing, the vandal protection fence mounted on the New Jersey Safety Shape Bridge Railing, and the Delaware retrofit bridge railing. One test was performed on each of these designs.

Testing of the W-beam retrofit for concrete baluster bridge railing was performed according to specifications set forth in the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings* for performance level one and the results of these tests were evaluated according to the limits specified therein.[1] AASHTO guidelines require two tests for performance level one. The first test involves an 817 kg (1800 lb) vehicle impacting the W-beam retrofit at a speed of 80 km/h (50 mi/h) and an angle of 20 degrees. The second test requires a 2452 kg (5400 lb) pickup truck traveling at 72 km/h (45 mi/h) and a 20 degree angle. Both of these tests were performed and are reported herein.

A W-beam retrofit transition between the W-beam retrofit concrete baluster bridge railing and the ET-2000 end treatment was designed and evaluated. Testing of the transition section was performed according to the recently accepted specifications set forth in National Cooperative Highway Research Program (NCHRP) Report 350 for test level two.[2] Level two requires one test with the 2000P vehicle [2000 kg (4404 lb) pickup] impacting the transition at 70 km/h (43.5 mi/h) and an angle of 25 degrees. Depending on the acceptable performance of this first test, a second test with an 820C vehicle [820 kg (1806 lb) sedan] impacting the transition at 70 km/h (43.5 mi/h) and 20 degree angle is specified. Both tests were conducted and the results reported herein.

The double tube pedestrian/bicycle rail mounted on the Illinois 2399-1 traffic railing testing was performed according to specifications set forth in the AASHTO *Guide Specifications for Bridge Railings* for performance level one and the results of the test was evaluated according to the limits specified therein. As stated earlier, AASHTO guidelines require two tests for performance level one. The first test involves an 817 kg (1800 lb) vehicle impacting the railing at a speed of 80 km/h (50 mi/h) and an angle of 20 degrees. The second test requires a 2452 kg (5400 lb) pickup truck traveling at 72 km/h (45 mi/h) and a 20 degree angle. The first test with the 817 kg (1800 lb) was performed and is reported herein.

The vandal protection fence mounted on the New Jersey Safety Shape bridge railing was also chosen for evaluation. Testing was performed according to specifications set forth in NCHRP Report 350 and the results were evaluated according to AASHTO *Guide Specifications for Bridge Railings* for performance level two. AASHTO guidelines require two tests for performance level two. The first test involves an 817 kg (1800 lb) vehicle impacting the railing at a speed of 96.5 km/h (60 mi/h) and an angle of 20 degrees. The second test requires a 2452 kg (5400 lb) pickup truck traveling at 96.5 km/h (60 mi/h) and a 20 degree angle. The second test with the 2452 kg (5400 lb) was performed and is reported herein.

Testing of the Delaware retrofit bridge railing was performed according to specifications set forth in NCHRP Report 350. The results of the test were evaluated according to AASHTO *Guide Specifications for Bridge Railings* for performance level two and to NCHRP Report 350 for test level four. AASHTO guidelines require three tests for performance level two. The first test involves an 817 kg (1800 lb) vehicle impacting the railing at a speed of 96.5 km/h (60 mi/h) and an angle of 20 degrees. The second test requires a 2452 kg (5400 lb) pickup truck traveling at 96.5 km/h (60 mi/h) and a 20 degree angle. An 8172 kg (18 000 lb) single-unit truck traveling at 80 km/h (50 mi/h) and a 15 degree angle are required for the third test for performance level two. NCHRP 350 also requires three tests for performance level four. The first test requires an 820C vehicle traveling 100 km/h (62.2 mi/h) and 20 degrees, the second a 2000P vehicle traveling 100 km/h (62.2 mi/h) and 25 degrees, and the third an 8000S vehicle traveling 80 km/h (50 mi/h) and 15 degrees. The third test with the single-unit truck was performed and is reported herein.

The test matrix for performance levels contained in AASHTO *Guide Specifications for Bridge Railings* is presented in table 1, and the test matrix for test levels 2, 3, and 4 for longitudinal barriers from NCHRP Report 350 is presented in table 2. Table 3 illustrates how each test performed under this study corresponds to these test matrices.

All crash testing was performed in accordance with procedures contained in NCHRP Report 350. A description of the testing and analysis procedures is presented in appendix A.

Table 1. AASHTO test matrix for bridge railings.

PERFORMANCE LEVELS	TEST SPEEDS -- mi/h			
	TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
	Small Automobile Wt = 1800 lb θ = 20 deg	Pickup Truck Wt = 5400 lb θ = 20 deg	Medium Single-Unit Truck Wt = 18,000 lb θ = 15 deg	Van-Type Tractor-Trailer Wt = 50,000 lb θ = 15 deg
PL-1	50	45		
PL-2	60	60	50	
PL-3	60	60		50

Metric Conversion: 1 lb = 0.454 kg
1 mi/h = 1.609 km/h

Table 2. NCHRP Report 350 test matrix for longitudinal barriers.

Test Level	Barrier Section	Test Designation	Impact Conditions		
			Vehicle	Nominal Speed (km/h)	Nominal Angle, θ (deg)
2	Length of Need	2-10 S2-10 2-21	820C 700C 2000P	70 70 70	20 20 25
	Transition	2-20 S2-20 2-21	820C 700C 2000P	70 70 70	20 20 25
3	Length of Need	3-10 S3-10 3-21	820C 700C 2000P	100 100 100	20 20 25
	Transition	3-20 S3-20 3-21	820C 700C 2000P	100 100 100	20 20 25
4	Length of Need	4-10 S4-10 4-11 4-12	820C 700C 2000P 8000S	100 100 100 80	20 20 25 15
	Transition	4-20 S4-20 4-21 4-22	820C 700C 2000P 8000S	100 100 100 80	20 20 25 15

1 kg = 2.202 lb
1 km/h = 0.621 mi/h

Table 3. Test articles and tests performed.

Test Article	Test No.	Test Conditions	AASHTO Test Designation	NCHRP Report 350 Test Designation
W-beam Retrofit for Concrete Baluster Bridge Railing	472070-1	817 kg ¦ 80 km/h ¦ 20 deg	PL1 Small Automobile Test	---
	472070-2	2452 kg ¦ 72 km/h ¦ 20 deg	PL1 Pickup Truck Test	---
W-beam Retrofit Transition	472070-3	2000 kg ¦ 70 km/h ¦ 25 deg	---	2-21
	472070-4	820 kg ¦ 70 km/h ¦ 20 deg	---	2-20
Double-Tube Pedestrian/Bicycle	472070-5	817 kg ¦ 80 km/h ¦ 20 deg	PL1 Small Automobile Test	---
Vandal Protection Fence	472070-6	2450 kg ¦ 100 km/h ¦ 20 deg	PL2 Pickup Truck Test	---
Delaware Retrofit	472070-7	8000 kg ¦ 80 km/h ¦ 15 deg	PL2 Single-Unit Truck Test	4-12

1 kg = 2.202 lb
1 km/h = 0.621 mi/h

W-BEAM RETROFIT BRIDGE RAILING

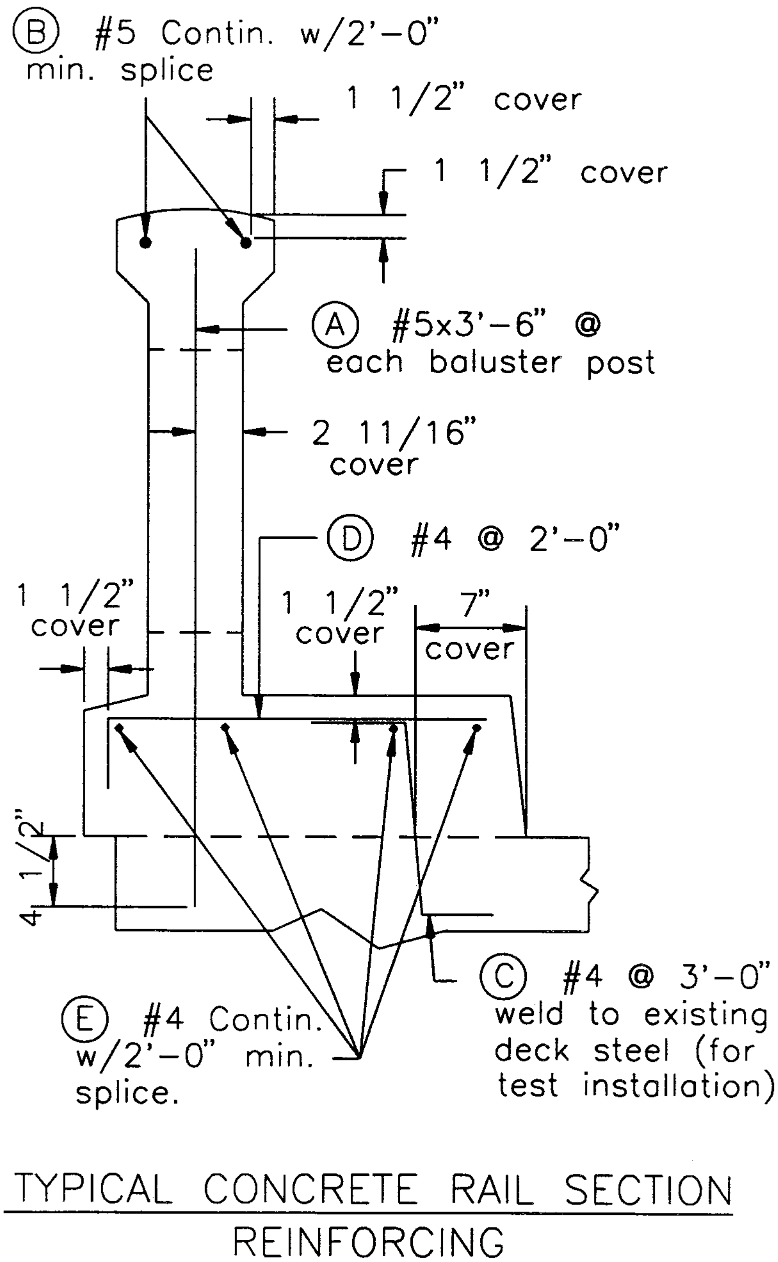
TEST ARTICLE

A concrete baluster bridge railing was constructed to serve as the existing bridge railing. It was then retrofitted with a blocked-out W-beam rail element.

The concrete baluster bridge railing consisted of three basic sections: the deck overhang, the curb and the railing. The deck overhang was constructed on an existing foundation. It was 203 mm (8 in) thick, contained #5 bars on 121 mm (4.75 in) centers in the top and #4 bars at 216 mm (8.5 in) centers in the bottom. Four continuous #4 bars were run through the top of the curb section with 0.6 m (2 ft) minimum splices. Transverse reinforcing consisted of #4 bars at 0.6 m (2 ft) centers on top of the longitudinal steel and "Z" shaped #4 bars at 0.9 m (3 ft) centers going between the deck and the curb section. The overall dimensions on the curb were 0.7 m (2 ft-4 in) wide by 229 mm (9 in) tall with a 25 mm (1 in) batter on the face of the curb.

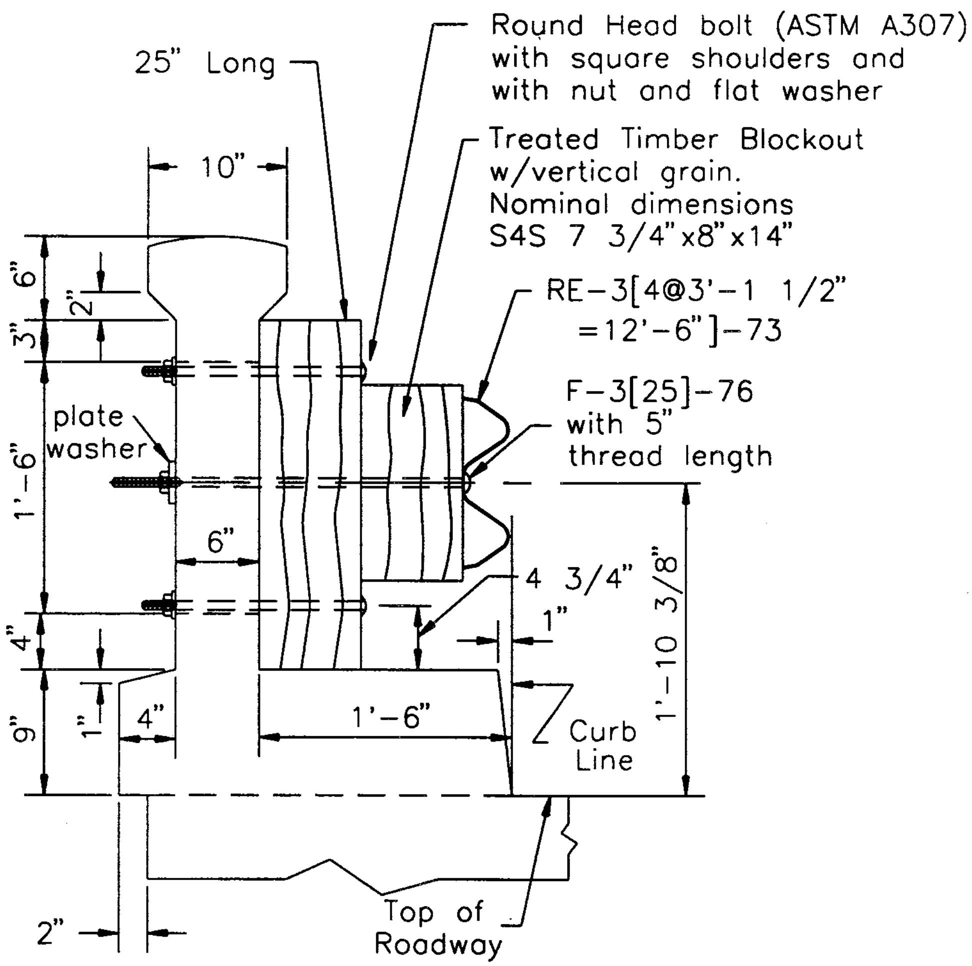
Both ends of the railing were made of a 1.8 m long by 254 mm wide by 787 mm high (6 ft long by 10 in wide by 31 in high) concrete section with rounded top. Vertical #5 bars were placed on 279 mm (11 in) centers through this portion. The midsection of the bridge railing was made of 152 mm thick by 203 mm wide (6 in thick by 8 in wide) posts with a continuous 254 mm (10 in) wide rounded top railing to mate with the end sections. Post spacings were 457 mm (18 in) throughout the midsection of the railing. Two continuous #5 bars were placed in the top of the railing with 0.6 m (2 ft) minimum splices. Chamfers were placed on all exposed corners. Compressive tests were run on two 28-day 152 mm by 305 mm (6 in by 12 in) cylinders. Failure occurred at 18 534 kPa (2690 psi) for both cylinders. Details of the concrete baluster bridge railing are shown in figure 1.

The retrofit W-beam rail element was mounted on the face of the existing concrete baluster bridge railing, as shown in the drawings in figure 2. Timber blockouts were used to align the face of the W-beam with the curb line. The W-beam was attached with F-3[25]-76 bolts with 127 mm (5 in) thread lengths. The blockouts were attached to the existing railing with 508 mm (20 in) A307 round head bolts with square shoulders. When attach points fell in void locations on the railing, a 102 mm by 137 mm by 635 mm (4 in by 5.4 in by 25 in) channel was placed vertically behind and spanning the void in the railing system. Photographs of the completed installation are presented in figures 3 and 4.



1 ft = 0.305 m
1 in = 25.4 mm

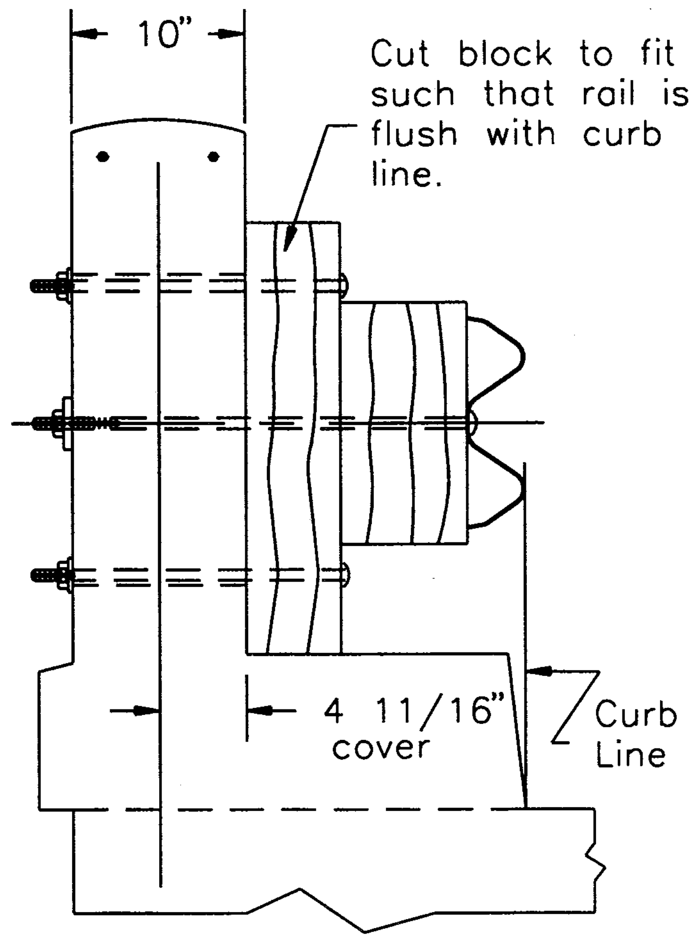
Figure 1. Drawings for concrete baluster bridge railing.



TYPICAL CONCRETE RAIL SECTION
WITH W-BEAM RETROFIT
WHEN ℄ 5/8"ø BOLT
CAN NOT GO THROUGH CONCRETE RAILING VOID

1 ft = 0.305 m
1 in = 25.4 mm

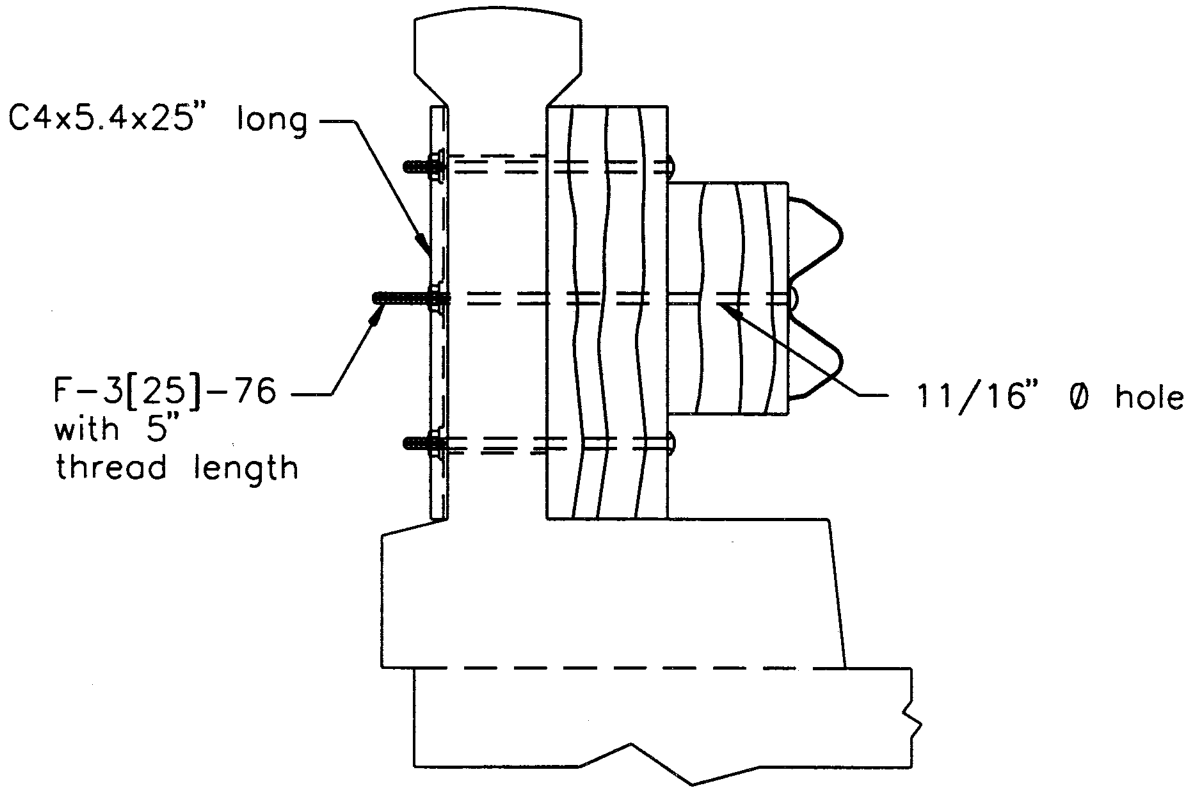
Figure 2. Drawings for W-beam retrofit for concrete baluster bridge railing.



SECTION AT END OF RAILING

1 ft = 0.305 m
1 in = 25.4 mm

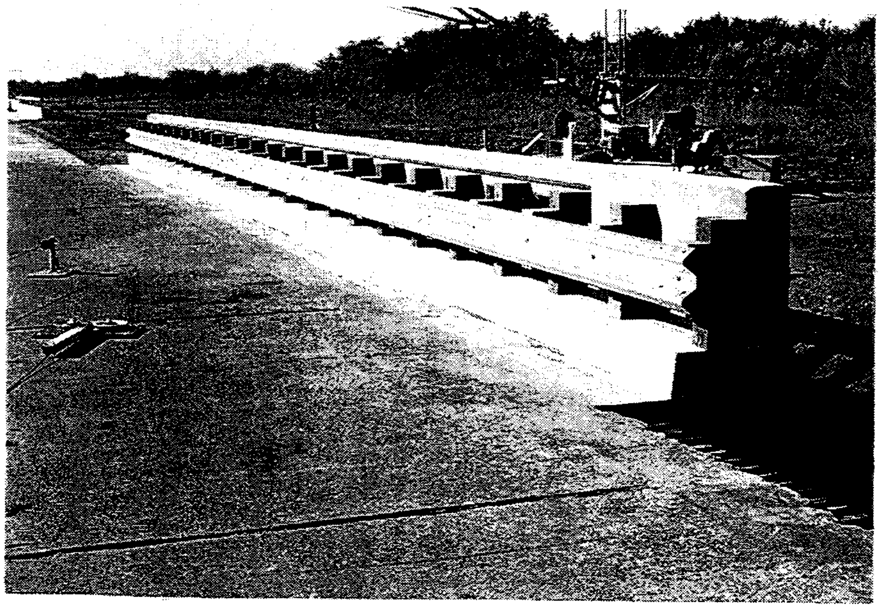
Figure 2. Drawings for W-beam retrofit for concrete baluster bridge railing (continued).



1 ft = 0.305 m
1 in = 25.4 mm

TYPICAL CONCRETE RAIL SECTION
WITH W-BEAM RETROFIT
WHEN ℄ 5/8"ø BOLT
CAN GO THROUGH CONCRETE RAILING VOID

Figure 2. Drawings for W-beam retrofit for concrete baluster bridge railing (continued).



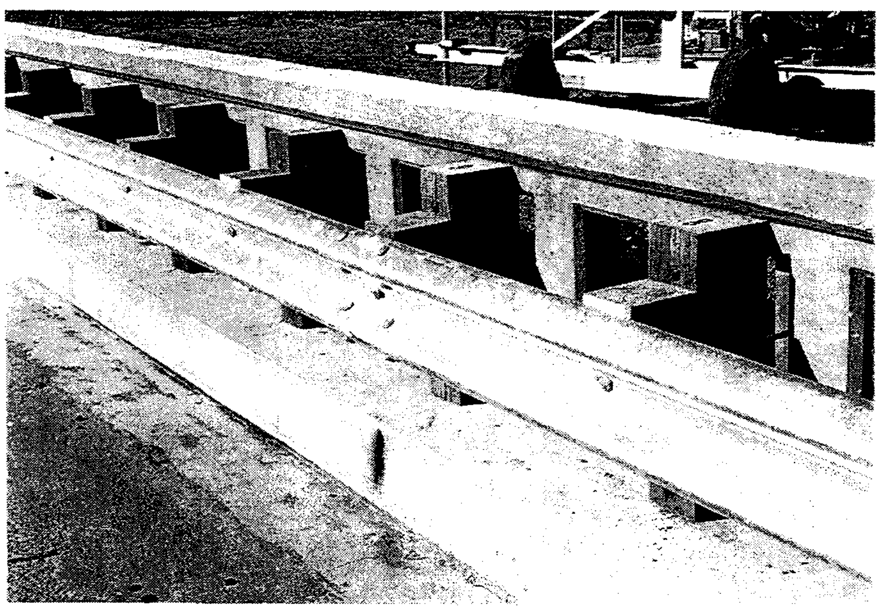
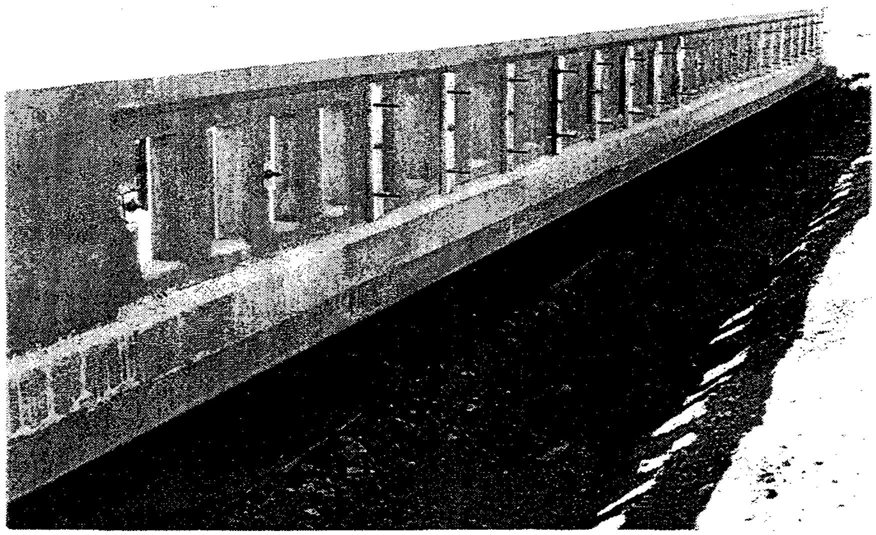


Figure 3. W-beam retrofit for concrete baluster bridge railing used for test 472070-1.
(traffic side)



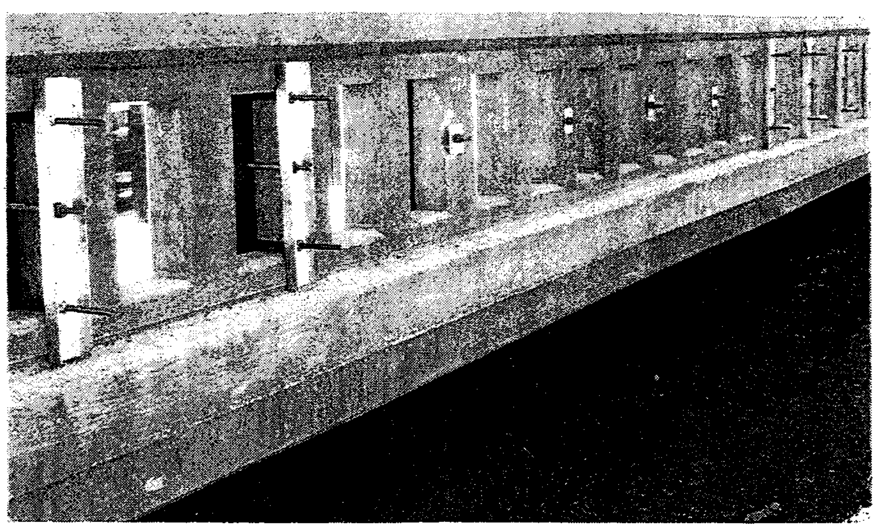


Figure 4. W-beam retrofit for concrete baluster bridge railing used for test 472070-1.
(field side)

CRASH TEST RESULTS

Test 472070-1

This test corresponds to the small automobile test for AASHTO performance level one which involves an 817-kg (1800-lb) vehicle impacting the W-beam retrofit at a nominal speed and angle of 80 km/h (50 mi/h) and 20 degrees. The critical impact point selected was at the one-third point of the installation. The purpose of this crash test is to evaluate the occupant risk of the length-of-need section.

Test Description

A 1988 Yugo GV, shown in figures 5 and 6, was used for the crash test. Test inertia weight of the vehicle was 817 kg (1800 lb) and its gross static weight was 892 kg (1965 lb). The height to the lower edge of the vehicle bumper was 356 mm (14.0 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 appendix B, figure 59. The vehicle was directed into the retrofit bridge railing using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

The vehicle impacted the retrofit bridge railing at post 9 at a speed of 82.0 km/h (50.9 mi/h) and angle of 20.7 degrees. As the vehicle impacted the W-beam guardrail the front of the vehicle began to deform, and the vehicle began to redirect 0.029 second after impact. The vehicle contacted post 10 at 0.044 second and at 0.093 second the windshield came loose from the frame. At 0.093 second the vehicle contacted post 11 and by 0.173 second the vehicle was traveling parallel to the installation at 70.2 km/h (43.6 mi/h). The rear of the vehicle contacted the W-beam rail element at 0.182 second and the vehicle lost contact with the retrofit bridge railing at 0.279 second. As the vehicle lost contact its speed was 69.2 km/h (43.0 mi/h) and the exit trajectory was 5.3 degrees. Brakes on the vehicle were applied at 2.5 seconds after initial impact. The brakes locked up and due to asymmetrical brake application, the vehicle skidded counterclockwise and subsequently came to rest upright 34 m (112.5 ft) downstream and 22 m (71.0 ft) forward of the point of impact. Photographs taken during the test sequence are shown in appendix C, figures 66 and 67.

Damage to Test Installation

As can be seen in figures 7 and 8, the installation received minimal damage. The curb received cosmetic damages only. There was no evidence of lateral movement of the timber blockouts. The W-beam was marred by tire marks and there was no measurable permanent deformation of the W-beam. The vehicle was in contact with the installation for 2.5 m (8.3 ft).

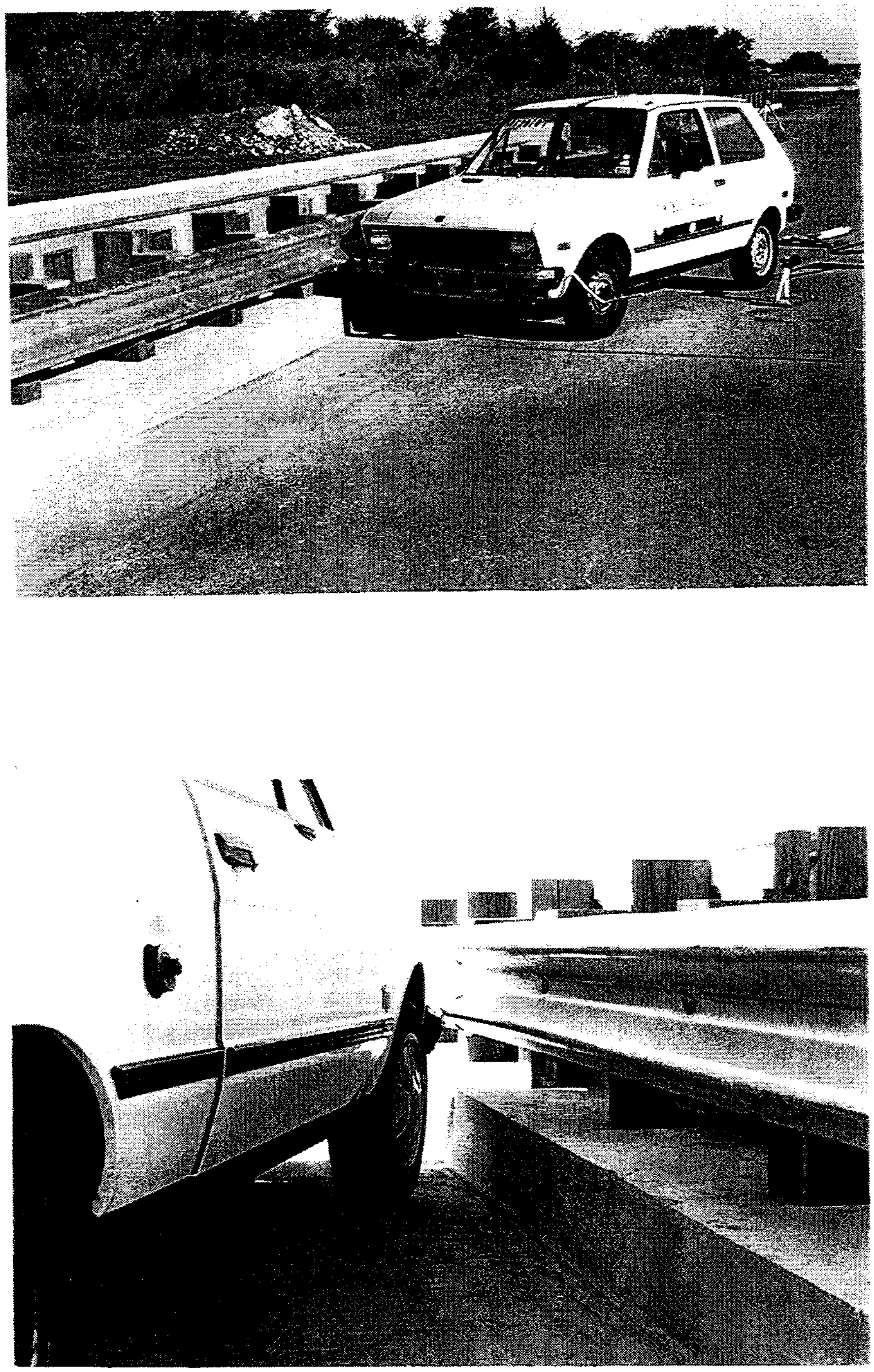


Figure 5. Vehicle/retrofit geometrics for test 472070-1.

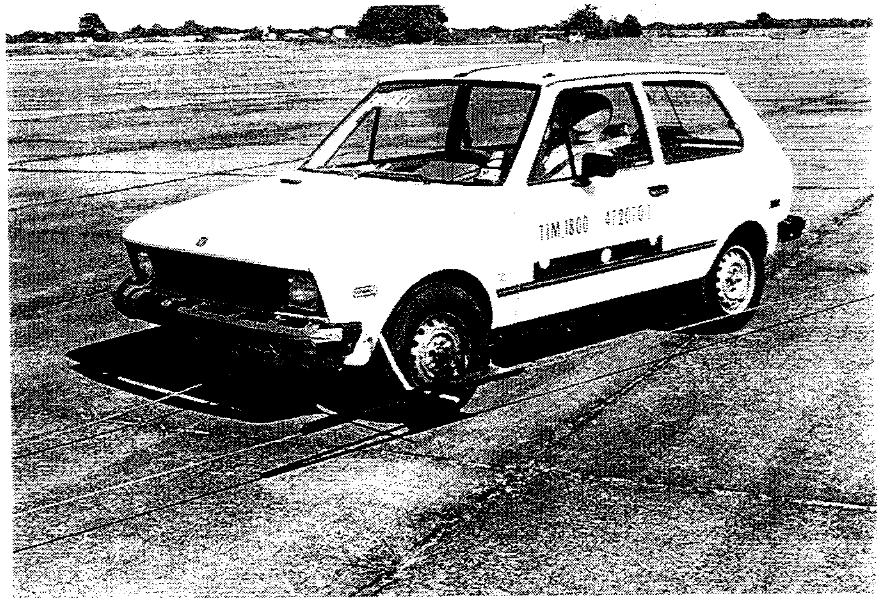


Figure 6. Vehicle prior to test 472070-1.

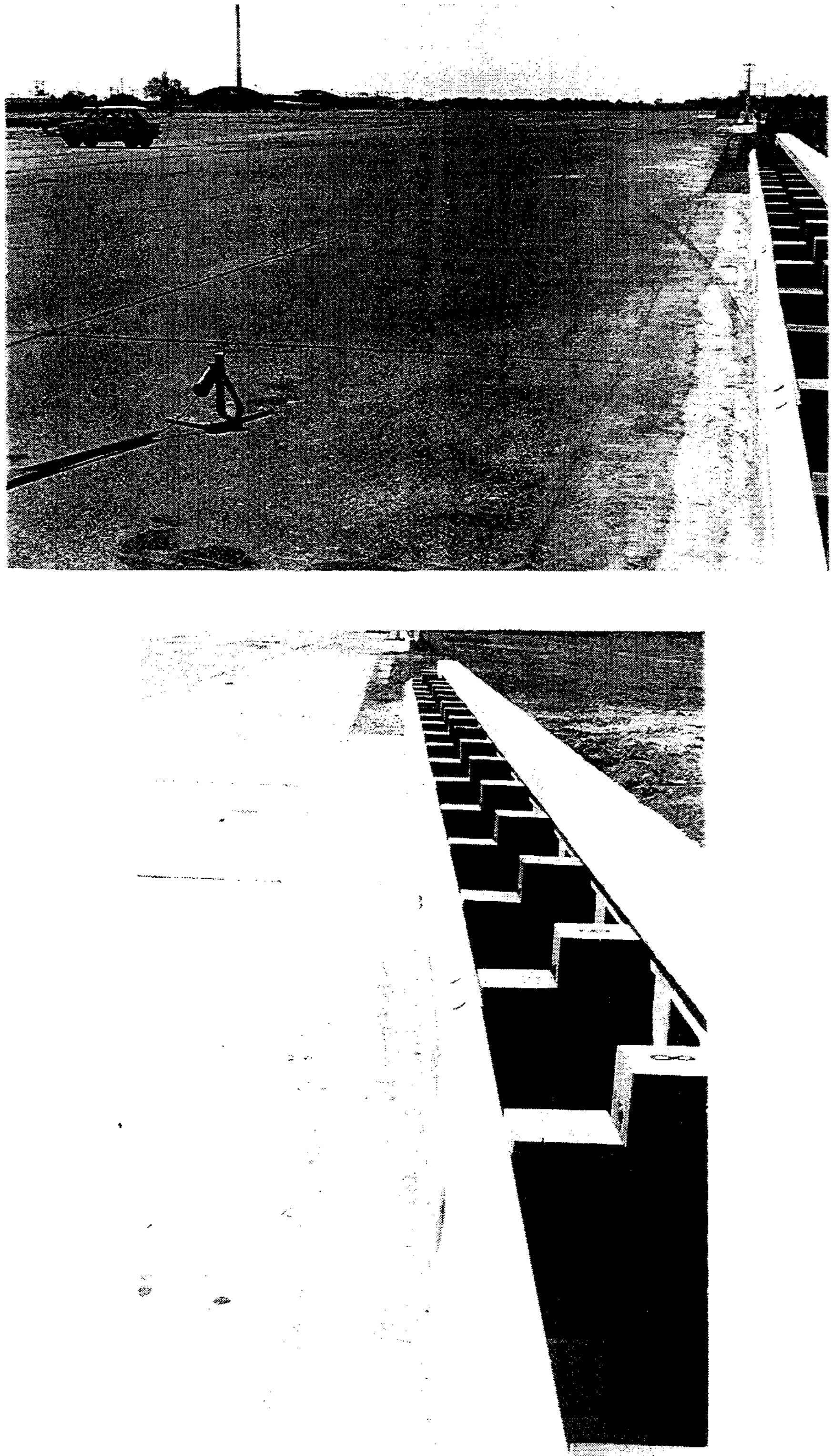


Figure 7. Site after test 472070-1.

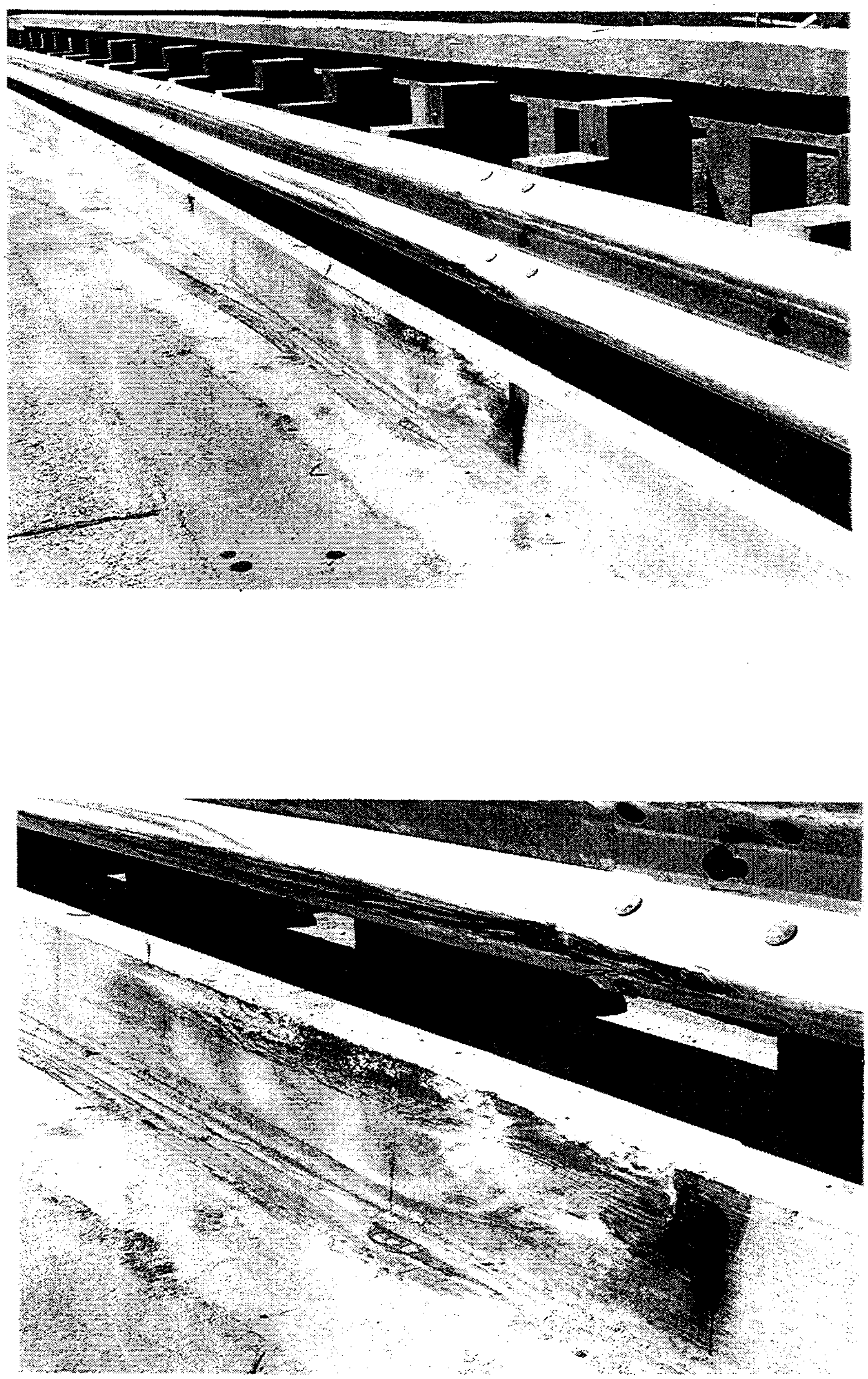


Figure 8. Damage to W-beam and curb after test 472070-1.

Damage to Test Vehicle

The vehicle sustained moderate damage to the front and right side as shown in figure 9. Maximum exterior crush at the right front corner at bumper height of the vehicle was 279 mm (11.0 in), and there was 13 mm (0.5 in) deformation into the occupant compartment at the right corner of the windshield frame. The sway bar and right side strut and lower control arm were bent. Damage was sustained by the front bumper, grill, hood, windshield, and right front wheel rim, and the entire right side was dented and scraped.

Occupant Risk Factors

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 4.1 m/s (13.5 ft/s) at 0.214 second, the highest 0.010-second average ridedown acceleration was -1.2 g between 0.229 and 0.239 second, and the maximum 0.050-second average acceleration was -5.5 g between 0.049 and 0.099 second. Lateral occupant impact velocity was 6.9 m/s (22.7 ft/s) at 0.101 second, the highest 0.010-second occupant ridedown acceleration was -4.4 g between 0.198 and 0.208 second and the maximum 0.050-second average acceleration was -10.8 g between 0.042 and 0.092 second. These data and other pertinent information from the test are summarized in figure 10. Vehicular angular displacements are displayed in appendix D, figure 80. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in appendix E, figures 86 through 88.

Test 472070-2

This was the pickup truck test required for AASHTO performance level one and involved a 2452 kg (5400 lb) pickup truck impacting the W-beam retrofit at a nominal speed and angle of 72 km/h (45 mi/h) and 20 degrees. The impact point selected was at the one-third point of the installation. The purpose of this test was to evaluate the strength of the length-of-need section in containing and redirecting the pickup.

Test Description

The W-beam retrofit sustained cosmetic damage only during the first test, therefore the retrofit was cleaned and repaired for use in the second test (as shown in figures 11 and 12). A 1986 Ford F250 pickup, shown in figures 13 and 14, was used for the second crash test. Test inertia weight of the vehicle was 2452 kg (5400 lb) and its gross static weight was 2528 kg (5569 lb). The height to the lower edge of the vehicle bumper was 419 mm (16.5 in) and it was 705 mm (27.8 in) to the upper edge of the bumper. Additional dimensions and

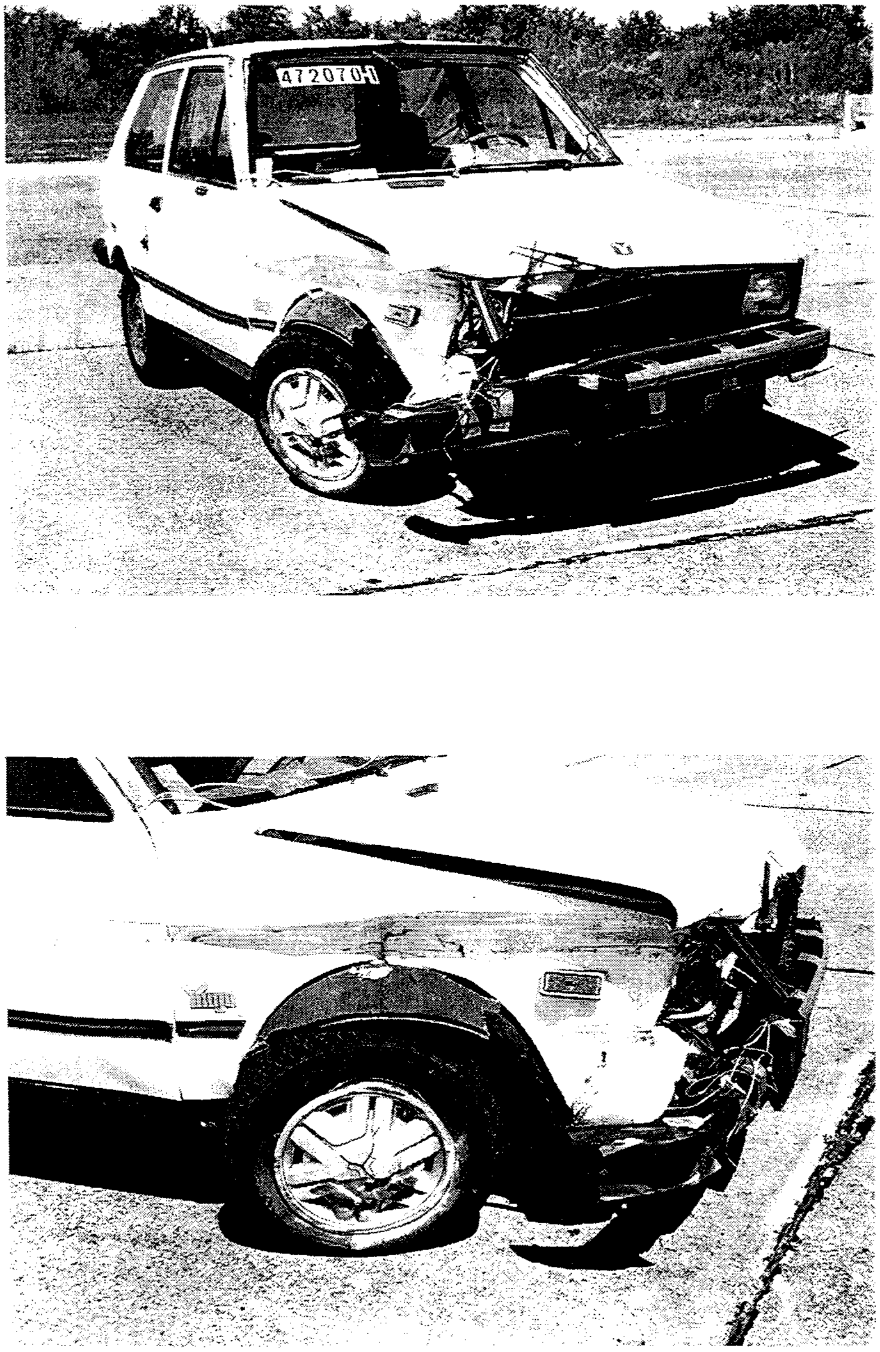
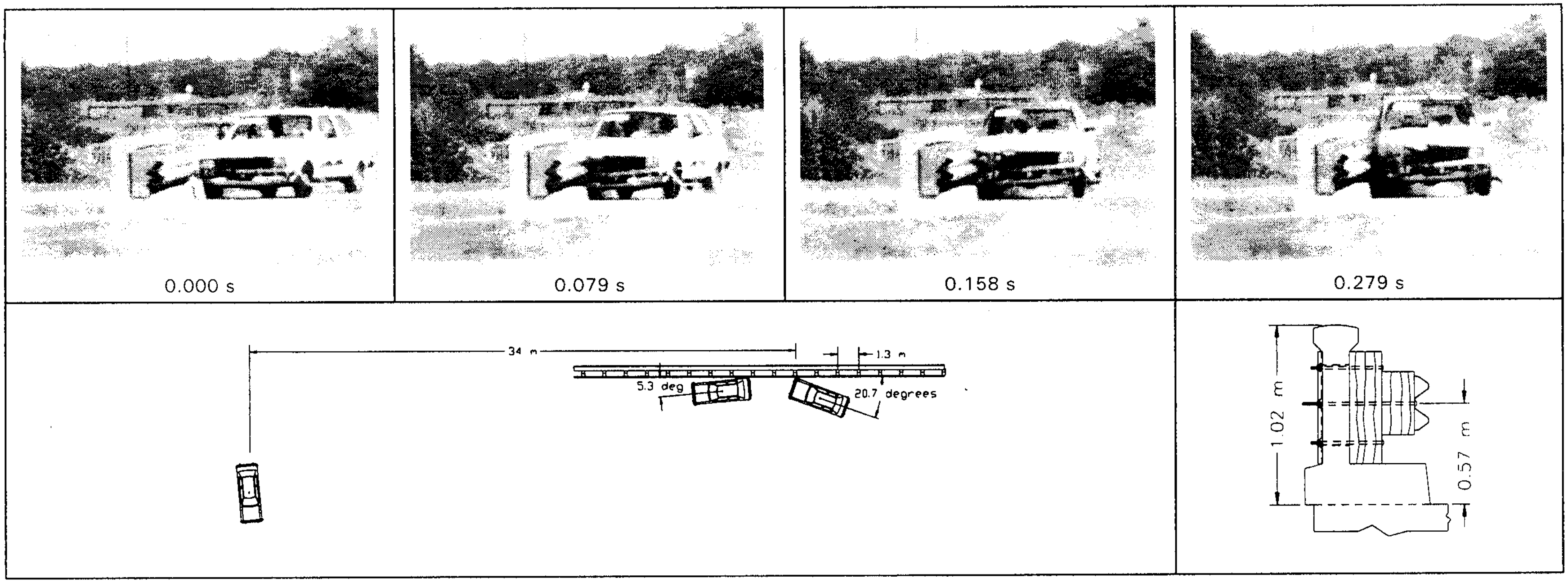


Figure 9. Vehicle after test 472070-1.

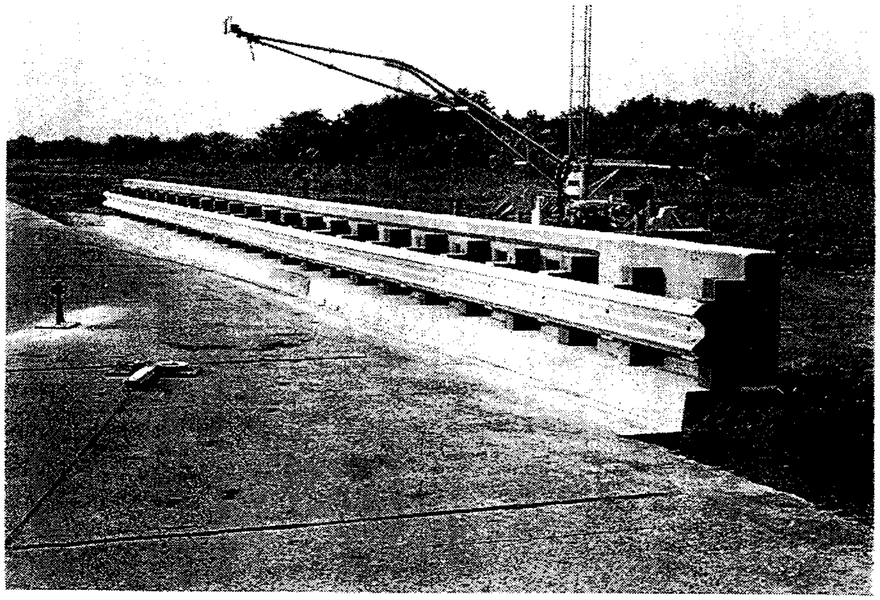


General Information	
Test Agency	Texas Transportation Institute
Test No.	472070-1
Date	09/29/93
Test Article	
Type	Bridge Railing
Name	W-Beam Retrofit
Installation Length (m)	23 (75 ft)
Size and/or dimension and material of key elements	0.7 m (2.4 ft) mount height W-Beam (ARTBA RE-3-73) on S4S timber blockouts
Soil Type and Condition	Not applicable
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Yugo GV
Mass (kg) Curb	820 (1807 lb)
Test Inertial	817 (1800 lb)
Dummy	75 (165 lb)
Gross Static	892 (1965 lb)

Impact Conditions	
Speed (km/h)	82.0 (50.9 mi/h)
Angle (deg)	20.7
Exit Conditions	
Speed (km/h)	69.2 (43.0 mi/h)
Angle (deg)	5.3
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.1 (13.5 ft/s)
y-direction	6.9 (22.7 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.2
y-direction	-4.4
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x-direction	-5.5
y-direction	-10.8
z-direction	-1.6

Test Article Deflections (m)	
Dynamic	Nil
Permanent	0.0
Vehicle Damage	
Exterior	
VDS	01RFQ4
CDC	01FREK2 & 01RDEW3
Interior	
OCDI	RF0000000
Maximum Exterior Vehicle Crush (mm)	279 (11.0 in)
Max. Occ. Compart. Deformation (mm)	13 (0.5 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	4.9
Max. Pitch Angle (deg)	-2.5
Max. Yaw Angle (deg)	-35.6

Figure 10. Summary of results for test 472070-1.



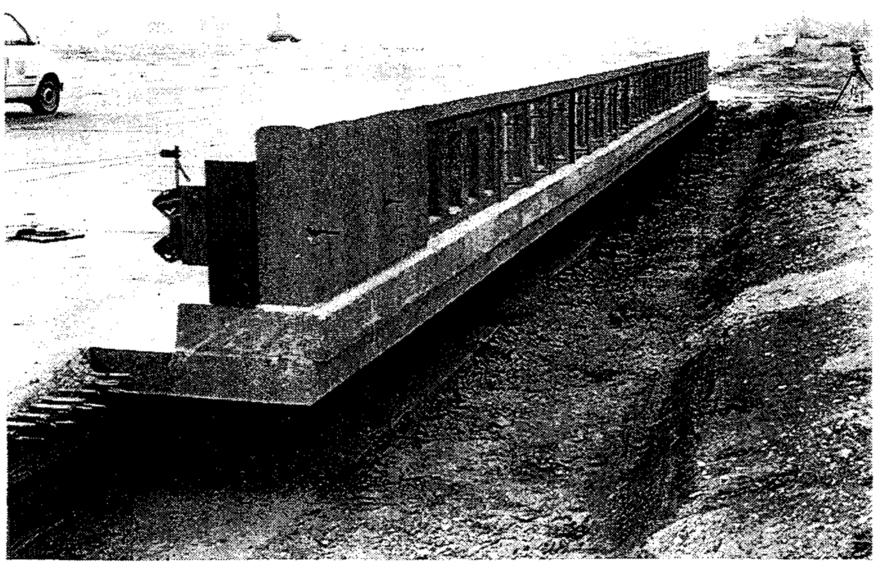


Figure 11. W-beam retrofit for baluster bridge railing before test 472070-2.

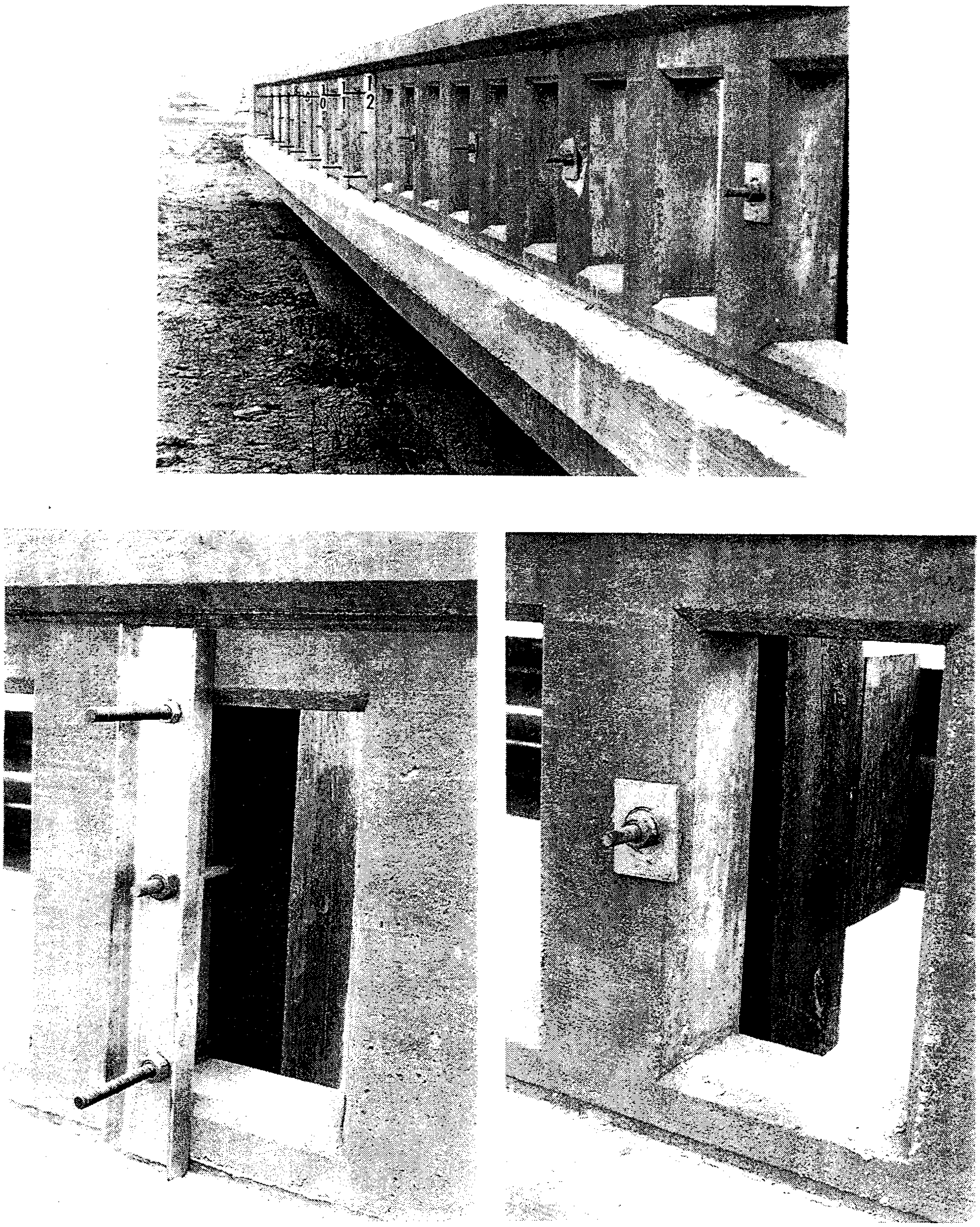


Figure 12. W-beam retrofit for baluster bridge railing (field side view).

Figure 13. Vehicle/retrofit geometrics for test 472070-2.

Figure 14. Vehicle prior to test 472070-2.

information on the vehicle are given in appendix B, figure 60. The vehicle was directed into the retrofit bridge railing using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

The vehicle impacted the retrofit bridge railing at post 8 (one-third point of installation) at a speed of 75.3 km/h (46.8 mi/h) and angle of 19.7 degrees. As the vehicle impacted the W-beam guardrail the front of the vehicle began to deform, and at 0.022 second the right front tire contacted the curb of the installation. The vehicle contacted the blockout at post 9 9 at 0.043 second and as the vehicle continued forward the right front tire began to steer clockwise. At 0.063 second after impact the vehicle began to redirect and at 0.066 second the right front wheel experienced another sudden steer input to the right. The vehicle contacted post 10 at 0.087 second and at 0.107 second the front axle broke. At 0.137 second the vehicle contacted post 11 and by 0.227 second the vehicle was traveling parallel to the installation at 62.8 km/h (39.0 mi/h). The rear of the vehicle contacted the W-beam rail element at 0.232 second and the vehicle lost contact with the retrofit bridge railing at 0.354 second. As the vehicle lost contact with the retrofit, the vehicle was traveling at a speed of 61.1 km/h (38.0 mi/h) and an exit trajectory of 8.7 degrees. Brakes on the vehicle were applied at 4.4 seconds after initial impact. The vehicle yawed clockwise and subsequently came to rest upright 38 m (125 ft) downstream and 14 m (47 ft) behind the point of impact. Sequential photographs are shown in appendix C, figures 68 and 69.

Damage to Test Installation

As can be seen in figure 15, the installation received minimal damage. The curb received cosmetic damage only. There was no evidence of lateral movement of the timber blockouts and the W-beam was marred by tire marks, dents and scrapes. Maximum permanent deformation of the W-beam was 64 mm (2.5 in) between posts 8 and 9. The vehicle was in contact with the installation for 4.3 m (14 ft).

Damage to Test Vehicle

The vehicle sustained moderate damage to the right front quarter with minor damage to the right side as shown in figure 16. Maximum exterior crush at the right front corner at bumper height of the vehicle was 381 mm (15.0 in), and there was 13 mm (0.5 in) deformation into the occupant compartment at the firewall and between the lower instrument panel and the floor panel. The transmission tunnel and, on the right side, the frame, I-beam, torsion bar, tie rod and center link were deformed. Damage was sustained to the front bumper, grill, hood, windshield, and right front wheel rim, and the entire right side was dented and scraped.

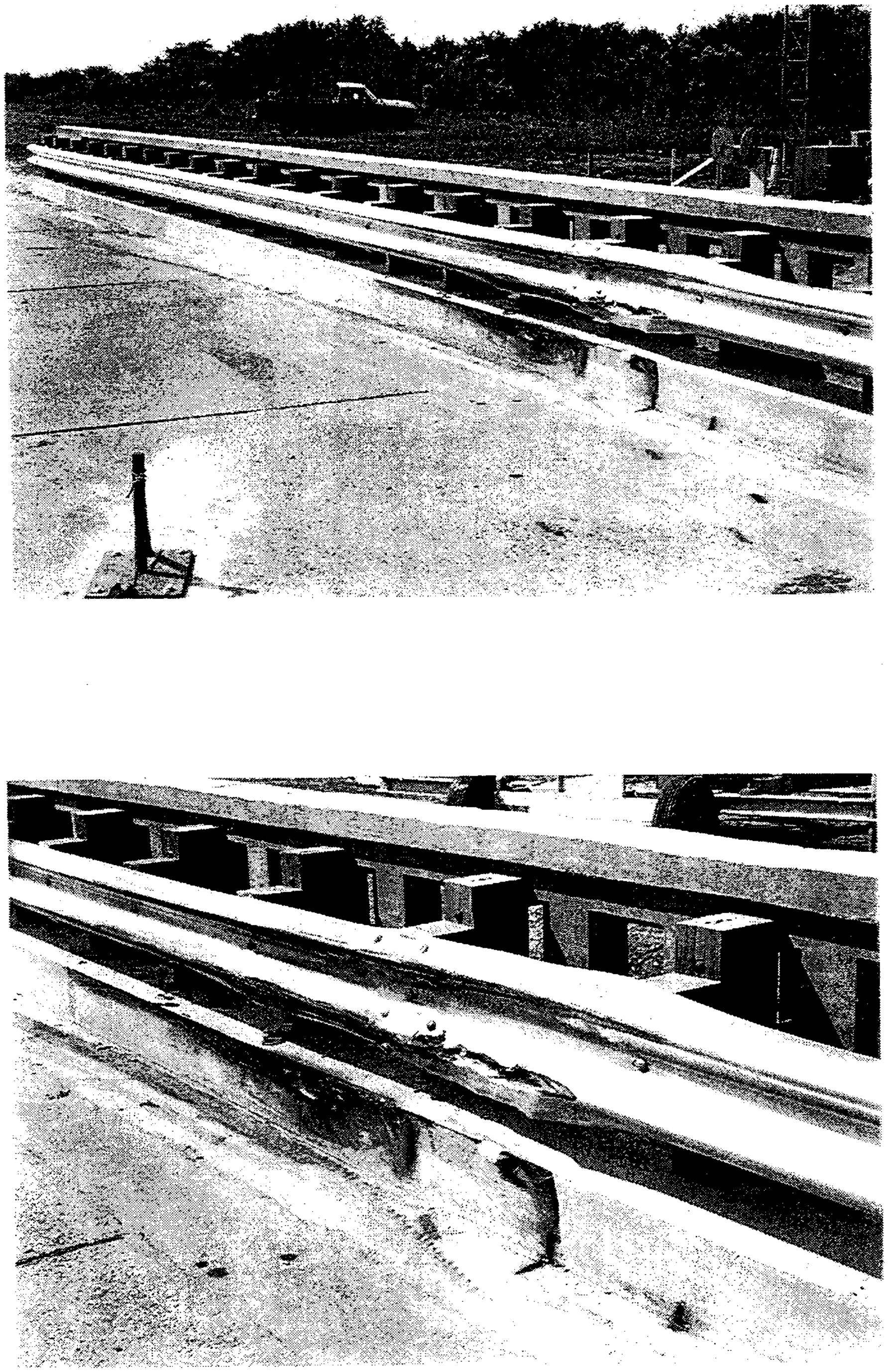


Figure 15. W-beam retrofit after test 472070-2.

Figure 16. Vehicle after test 472070-2.

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 3.9 m/s (12.7 ft/s) at 0.247 second, the highest 0.010-second average ridedown acceleration was 3.0 g between 0.270 and 0.280 second, and the maximum 0.050-second average acceleration was -4.5 g between 0.061 and 0.110 second. Lateral occupant impact velocity was 4.7 m/s (15.5 ft/s) at 0.153 second, the highest 0.010-s occupant ridedown acceleration was -9.1 g between 0.294 and 0.304 second and the maximum 0.050-second average acceleration was -8.2 g between 0.066 and 0.116 second. These data and other pertinent information from the test are summarized in figure 17. Vehicular angular displacements are displayed in appendix D, figure 81. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in appendix E, figures 89 through 91.

FINDINGS AND CONCLUSIONS

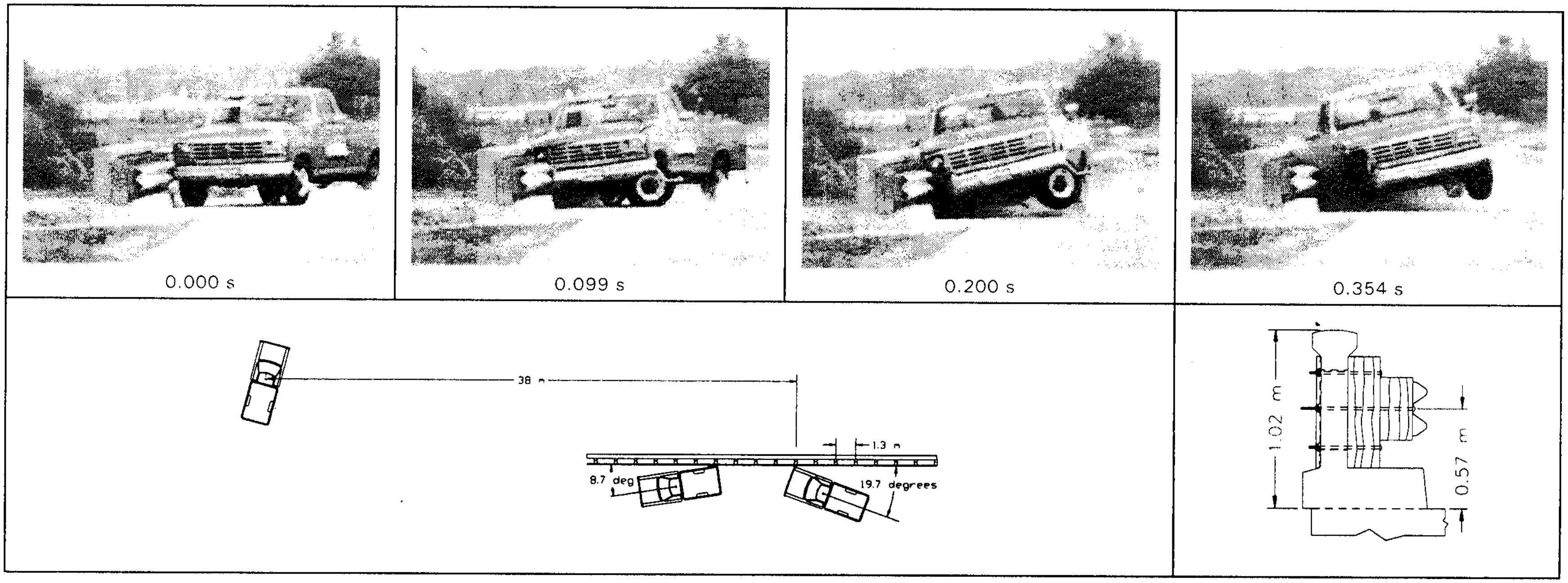
Summary of Findings

In the first test, the W-beam retrofit for concrete baluster bridge railing functioned as intended by containing and redirecting the vehicle with no deflection of the W-beam guardrail. There were no detached elements or debris to present undue hazard to occupants of the vehicle or others in the area. The vehicle sustained moderate damage with very minimal deformation into the passenger compartment. The vehicle remained upright and stable during the collision period. The W-beam retrofit smoothly redirected the vehicle with the effective coefficient of friction calculated at 0.22. The occupant impact velocities were within the AASHTO limits as were the occupant ridedown accelerations. The exit trajectory of the vehicle was within the 12 degree limit.

The W-beam retrofit functioned as intended during the second test by containing and redirecting the vehicle with minimal deflection of the W-beam guardrail. There was no debris or detached elements to exhibit undue hazard to occupants of the vehicle or others in the area. The vehicle received moderate damage with minimal deformation into the occupant compartment. The vehicle remained upright and relatively stable during the collision period. Redirection of the vehicle was considered smooth with a fair effective coefficient of friction calculated at 0.32. The occupant impact velocities and ridedown accelerations were well within the AASHTO limits and the exit trajectory was satisfactory.

Conclusions

The W-beam retrofit for concrete baluster bridge railing met the AASHTO criteria for both performance level one tests. as shown in tables 4 and 5. Therefore, the impact performance of the W-beam retrofit for concrete baluster bridge railing was judged satisfactory.



General Information	
Test Agency	Texas Transportation Institute
Test No.	472070-2
Date	10/05/93
Test Article	
Type	Bridge Railing
Name	W-Beam Retrofit
Installation Length (m)	23 (75 ft)
Size and/or dimension and material of key elements	0.7 m (2.4 ft) mount height W-Beam (ARTBA RE-3-73) on S4S timber blockouts
Soil Type and Condition	Not applicable
Test Vehicle	
Type	Production
Designation	2452P
Model	1986 Ford F250
Mass (kg) Curb	1930 (4252 lb)
Test Inertial	2452 (5400 lb)
Dummy	75 (165 lb)
Gross Static	2528 (5569 lb)

Impact Conditions	
Speed (km/h)	75.3 (46.8 mi/h)
Angle (deg)	19.7
Exit Conditions	
Speed (km/h)	61.1 (39.0 mi/h)
Angle (deg)	8.7
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.9 (12.7 ft/s)
y-direction	4.7 (15.5 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	3.0
y-direction	-9.1
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x direction	4.5
y direction	8.2
z direction	2.1

Test Article Deflections (mm)	
Dynamic	Nil
Permanent	64 (2.5 in)
Vehicle Damage	
Exterior	
VDS	01RFQ4
CDC	01FREK2 & 01RDEW3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	381 (15.0 in)
Max. Occ. Compart. Deformation (mm)	13 (0.5 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	11.9
Max. Pitch Angle (deg)	5.3
Max. Yaw Angle (deg)	22.0

Figure 17. Summary of results for test 472070-2.

Table 4. Assessment of results of test with small vehicle on W-beam retrofit for concrete baluster bridge railing (according to AASHTO PL1 small automobile test).

Test Agency: Texas Transportation Institute | Test No.: 472070-1 | Test Date: 09/29/93

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
A. The test shall contain the vehicle; neither the vehicle no its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	The W-beam retrofit for concrete baluster bridge railing contained the vehicle.	Pass
B. 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.	There were no detached elements or other debris from the test article to penetrate or exhibit undue hazard to occupants of the vehicle or other traffic.	Pass
C. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was no penetration of the passenger compartment and minimal deformation into the compartment.	Pass
D. The vehicle shall remain upright during and after collision.	The vehicle remained upright during and after the test.	Pass
E. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected with minimal intrusion into adjacent traffic lanes.	Pass
F. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment .22 — Good	Pass
G. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 4.1 (13.5); Lateral 6.9 (22.7) Occupant Ridedown Accelerations - g's Longitudinal -1.2; Lateral -4.4	Pass
H. Vehicle exit angle from the barrier shall not be more than 12 degrees.	The exit angle as the vehicle lost contact with the retrofit was 5.3 degrees.	Pass

**A, B, C, D, and G are required. E, F, and H are desired.*

Table 5. Assessment of results of test with pickup on W-beam retrofit for concrete baluster bridge railing (according to AASHTO PL1 pickup truck test).

Test Agency: Texas Transportation Institute | Test No.: 472070-2 | Test Date: 10/05/93

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
A. The test shall contain the vehicle; neither the vehicle no its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	The W-beam retrofit for concrete baluster bridge railing contained the vehicle.	Pass
B. 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.	There were no detached elements or other debris from the test article to penetrate or show undue hazard to the occupants of the vehicle or other traffic.	Pass
C. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was no penetration of the passenger compartment and minimal deformation into the compartment.	Pass
D. The vehicle shall remain upright during and after collision.	The vehicle remained upright during and after the test.	Pass
E. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected with minimal intrusion into adjacent traffic lanes.	Pass
F. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ: .32 Assessment: Fair	Pass
G. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal: 9.2 (30); Lateral: 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal: 15; Lateral: 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal: 3.9 (12.7); Lateral: 4.7 (15.5) Occupant Ridedown Accelerations - g's Longitudinal: 3.0; Lateral: -9.1	Pass
H. Vehicle exit angle from the barrier shall not be more than 12 degrees.	The exit angle as the vehicle lost contact with the retrofit was 8.7 degrees.	Pass

**A, B, C, and D are required. E, F, G, and H are desired.*

W-BEAM RETROFIT TRANSITION

TEST ARTICLE

The W-beam retrofit transition serves to transition from a standard G4(1S) guardrail system to the W-beam retrofit concrete baluster bridge railing. A concrete baluster bridge railing constructed for the previous testing served as the existing bridge railing. This bridge railing had been retrofitted with a blocked-out W-beam rail element as described in the previous section of this report. A detailed description of the retrofit transition follows.

Drawings of the prototype test installation are presented in figure 18. Two (nested) 12 gauge, W-beam rail elements are connected to the end of the bridge rail and extend 3.8 m (12 ft-6 in). A single 12 gauge rail element is used throughout the remaining length. The three posts adjacent to the bridge rail are 1.98 m (6 ft-6 in) long and the remaining posts are 1.82 m (6 ft) long. The two post spaces adjacent to the bridge rail are 0.95 m (3 ft-11/2 in) and the remaining post spacing is 1.91 m (6 ft-3 in). A C6x8 rubrail is mounted with its top flange on the top surface of the curb as shown in Detail A of figure 18 and photographs in figure 19. The rubrail extends 1.91 m (6 ft-3 in) from the end of the bridge and then bends to the back side of the third post (see figure 20). A standard ET 2000 end treatment was used to anchor the end of the guardrail. Photographs of the complete installation as tested are displayed in figure 21.

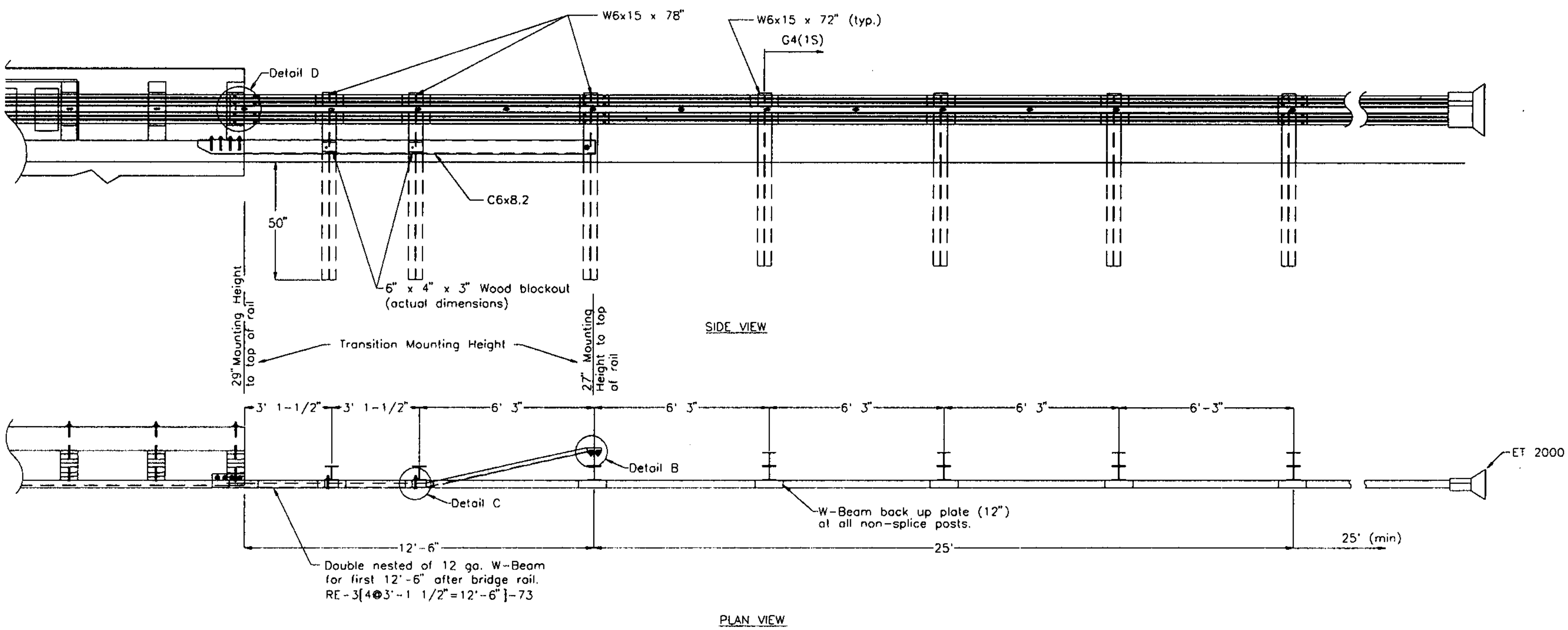
CRASH TEST RESULTS

Test 472070-3

This test corresponds to NCHRP Report 350 test designation 2-21 and involves a 2000 kg (4405 lb) pickup truck impacting the transition at a nominal speed and angle of 70 km/h (43.5 mi/h) and 25 degrees. The critical impact point selected was 2.4 m (8.0 ft) from the end of the bridge railing. The purpose of the test is to evaluate the strength of the transition in containing and redirecting the pickup.

Test Description

A 1986 Ford F250 pickup, shown in figure 22, was used for the crash test. Test inertia weight of the vehicle was 2000 kg (4405 lb) and its gross static weight was 2076 kg (4573 lb). The height to the lower edge of the vehicle bumper was 495 mm (19.5 in) and it was 720 mm (28.3 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in appendix B, figure 61. The vehicle was directed into the retrofit transition using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.



1 ft = 0.305 m
1 in = 25.4 mm

Figure 18. W-beam retrofit transition for W-beam retrofit concrete baluster bridge railing.

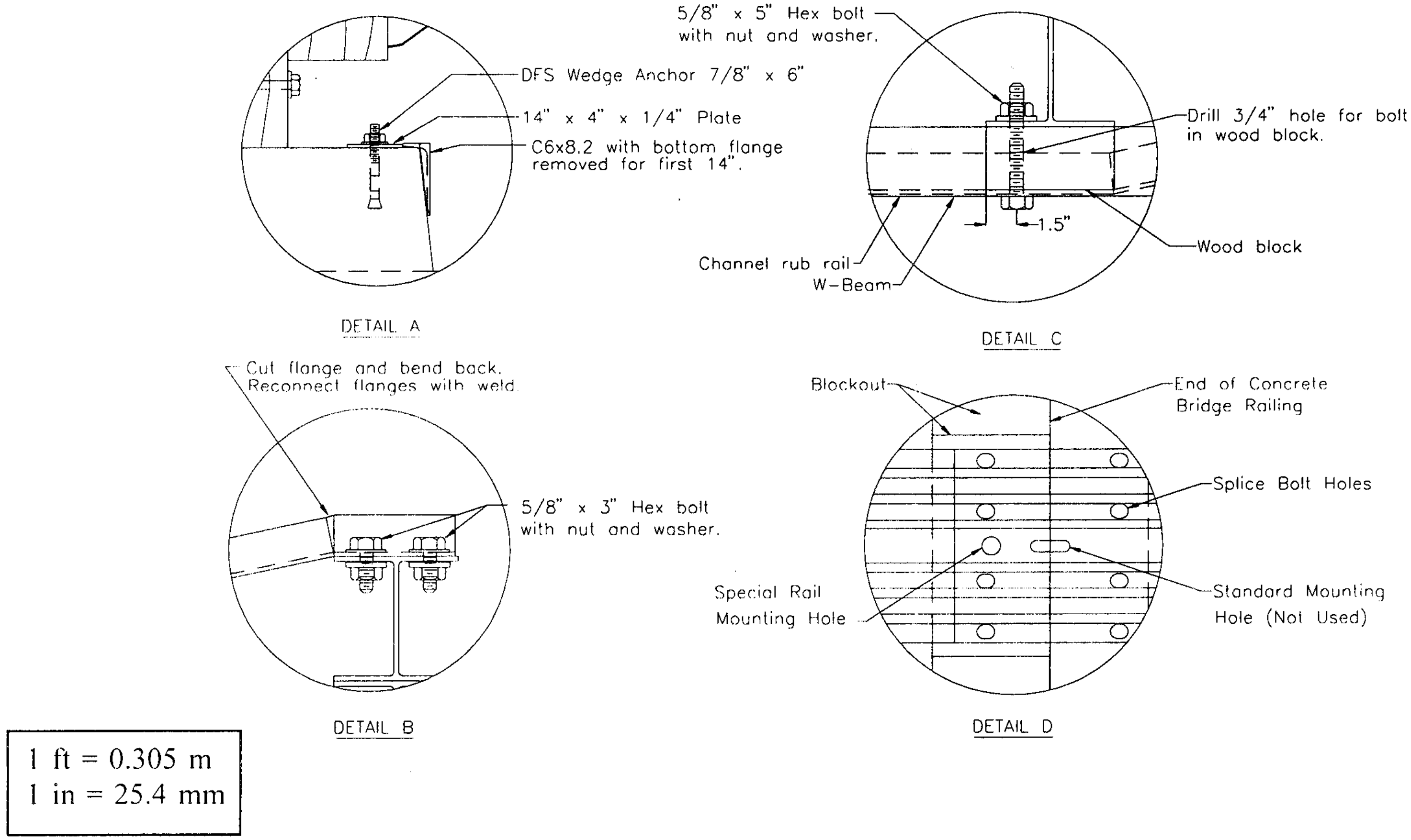
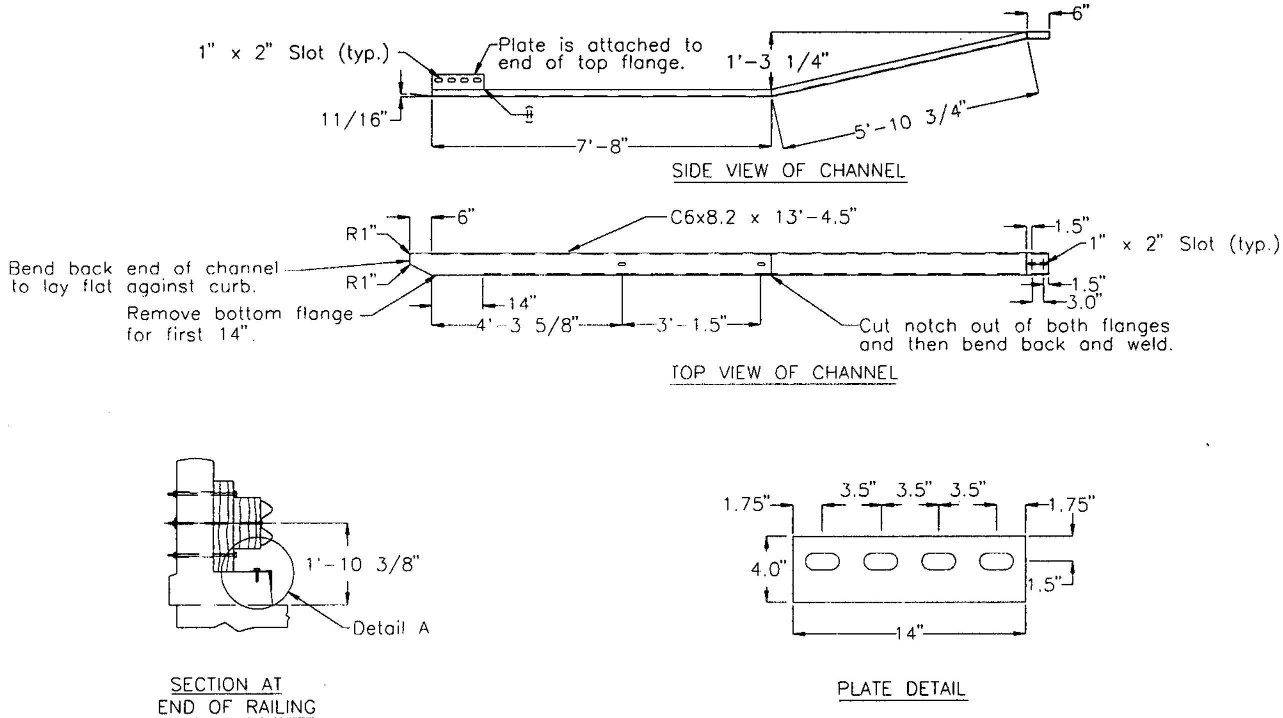


Figure 18. W-beam retrofit transition for W-beam retrofit concrete baluster bridge railing (continued).



1 ft = 0.305 m
1 in = 25.4 mm

Figure 18. W-beam retrofit transition for W-beam retrofit concrete baluster bridge railing (continued).

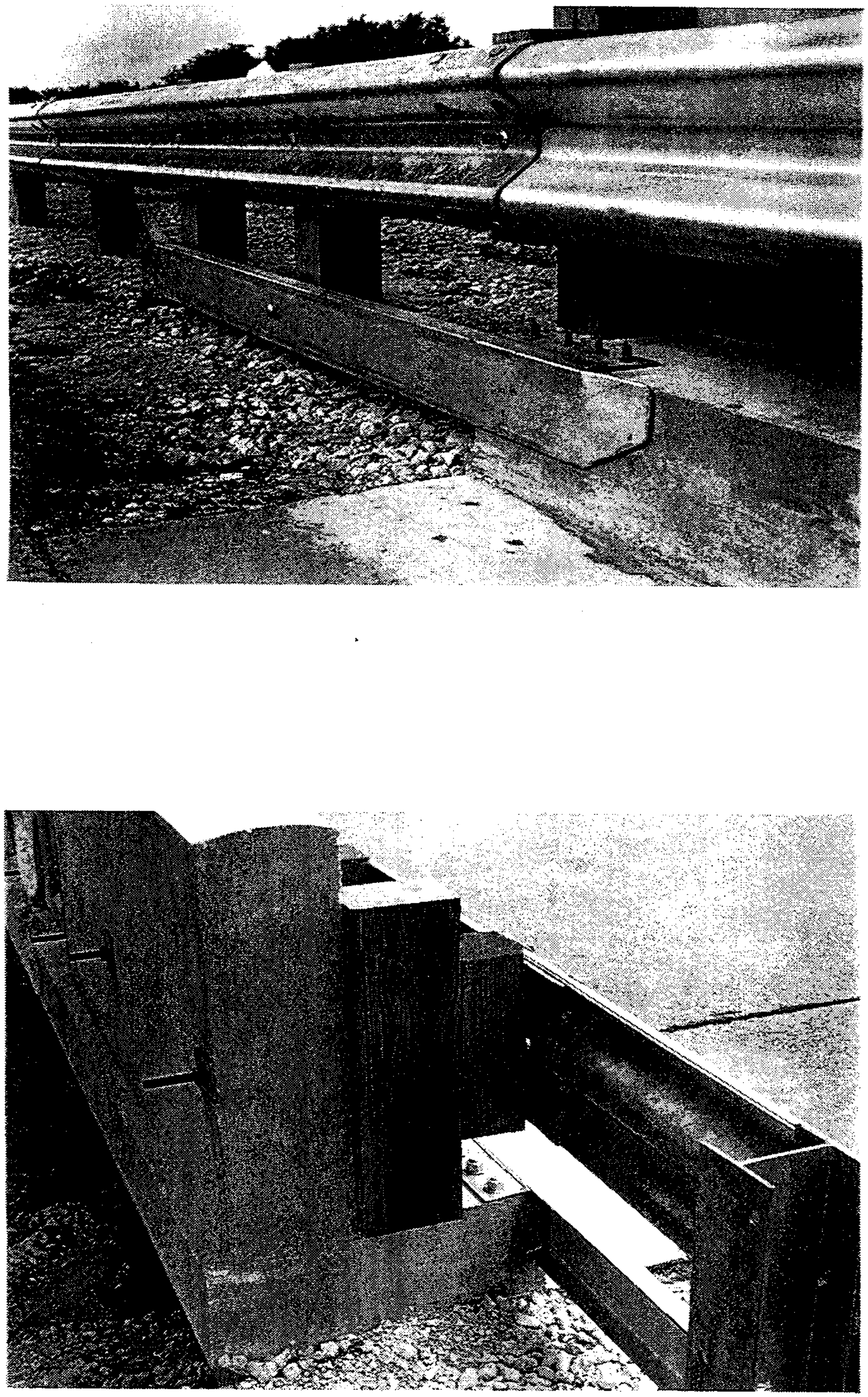


Figure 19. Retrofit transition connection to bridge railing.

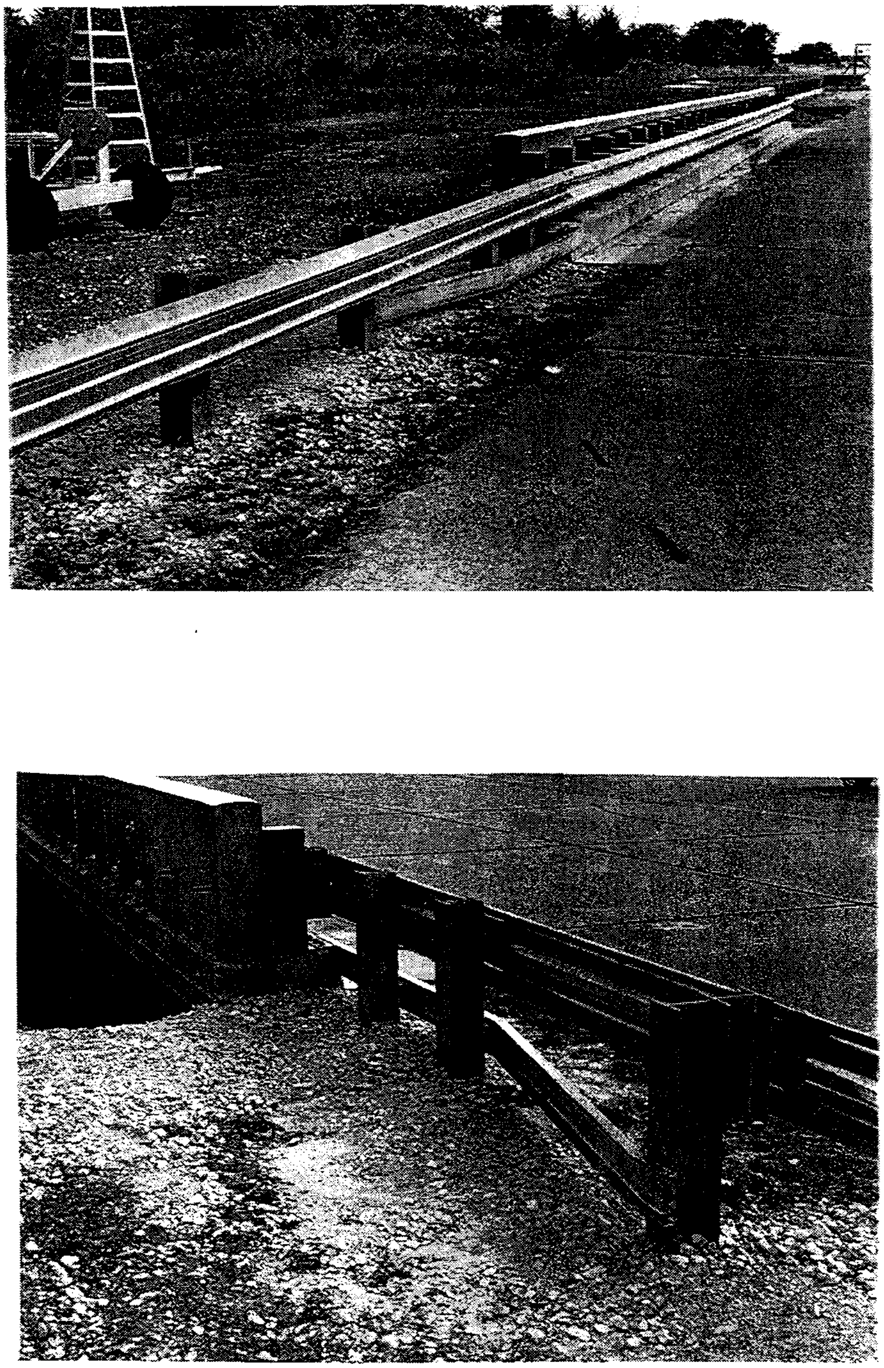
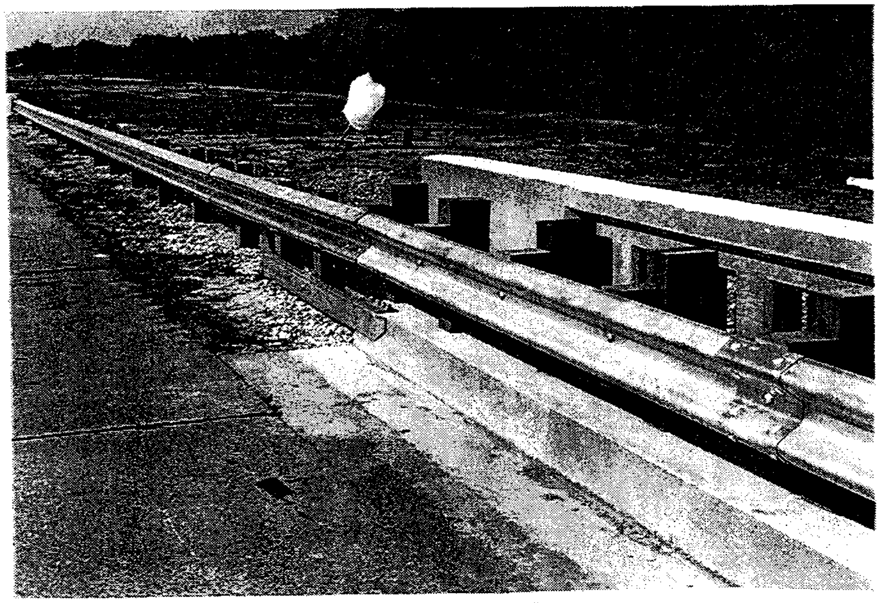


Figure 20. W-beam retrofit transition used for tests 472070-3 and 4.



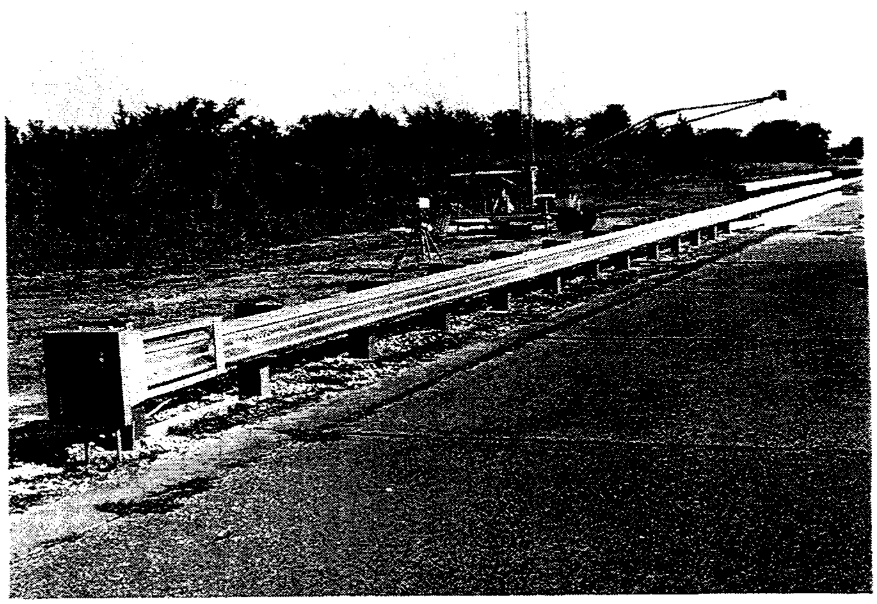


Figure 21. W-beam retrofit transition installation for test 472070-3 and 4.

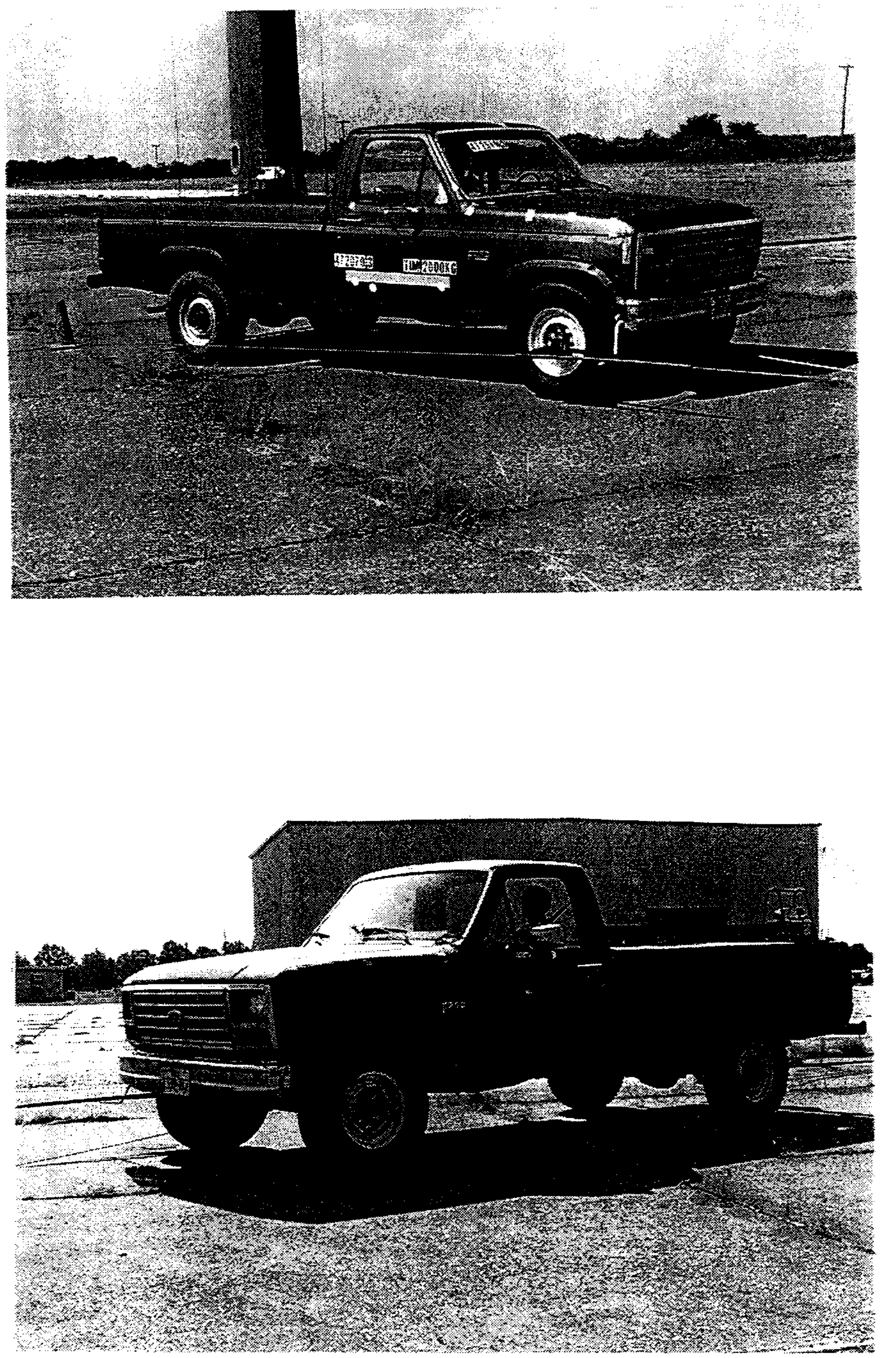


Figure 22. Vehicle prior to test 472070-3.

The vehicle impacted the retrofit transition 2.4 m (7.9 ft) from the end of the bridge railing at a speed of 73.1 km/h (45.4 mi/h) and angle of 26.3 degrees. The vehicle began to redirect 0.056 s after impact and the left front tire rode up onto the rubrail. As the vehicle continued forward the tire became pinched between the rubrail, the W-beam rail element, and the post. The tire aired out at 0.087 second and there was an abruptly steer input to the front wheels at 0.104 second. The left front of the vehicle contacted the end section of the retrofit bridge railing at 0.117 second. Maximum dynamic deflection of the transition was 297 mm (11.7 in) at 0.150 second. The front of the vehicle became airborne at 0.184 second, and by 0.270 second the vehicle was traveling parallel to the installation at 48.6 km/h (30.2 mi/h). The rear of the vehicle contacted the W-beam at 0.313 second and the vehicle lost contact with the retrofit bridge railing at 0.440 second. The vehicle yawed counterclockwise as it lost contact traveling at a speed of 45.0 km/h (28.0 mi/h) and the exit trajectory of 12.4 degrees. Brakes on the vehicle were applied at 3.5 seconds after initial impact. The brakes locked up and due to asymmetrical brake application, the vehicle skidded clockwise and subsequently came to rest upright 34 m (144 ft) downstream and aligned with the point of impact. Sequential photographs are shown in appendix C, figures 70 and 71.

Damage to Test Installation

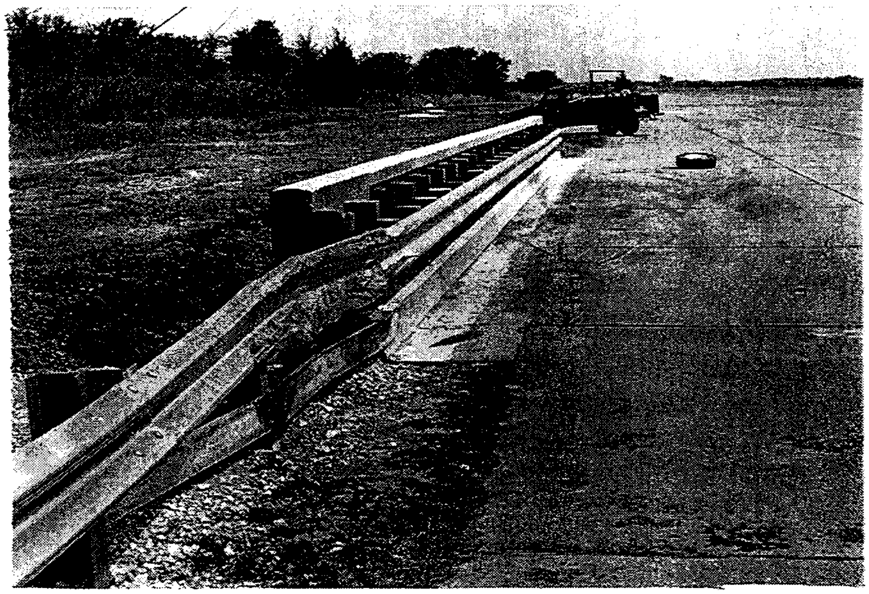
As can be seen in figures 23 and 24, the installation received moderate damage. The first seven posts from the end of the bridge railing were displaced laterally toward the bridge rail. Maximum permanent deformation was 140 mm (5.5 in) at post 2. The first wood post and blockout on the bridge railing were damaged and the end of the concrete parapet was chipped. The vehicle was in contact with the installation for 3.8 m (12.4 ft).

Damage to Test Vehicle

The vehicle sustained moderate damage to the front and left side as shown in figure 25. Maximum exterior crush at the right front corner at bumper height of the vehicle was 380 mm (15.0 in), and there was 24 mm (0.9 in) deformation into the occupant compartment at the center of the floorpan area. The left front wheel, caliper, and rotor were pulled off the vehicle as shown in figure 26. The left front frame, tie rod, shock, radius arm, and I-beam were bent. The steering shaft broke at the box to the pittman arm. There was also damage to the front bumper, hood, grill, radiator, left front quarter-panel, door, left rear quarter-panel and left rear wheel rim.

Occupant Risk Factors

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 7.6 m/s (24.8 ft/s) at 0.192 second, the highest 0.010-second average ridedown acceleration was -10.0 g between 0.152 and 0.162 second, and the



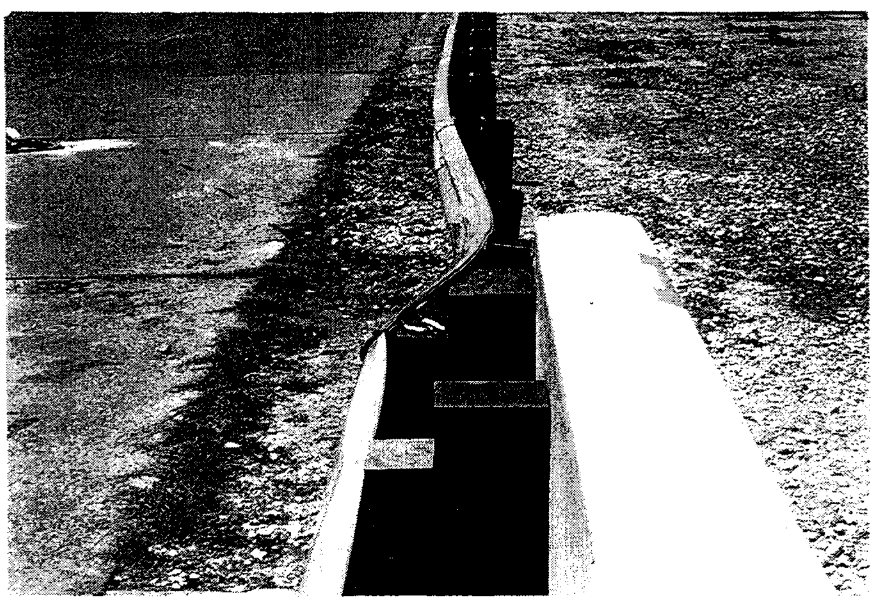
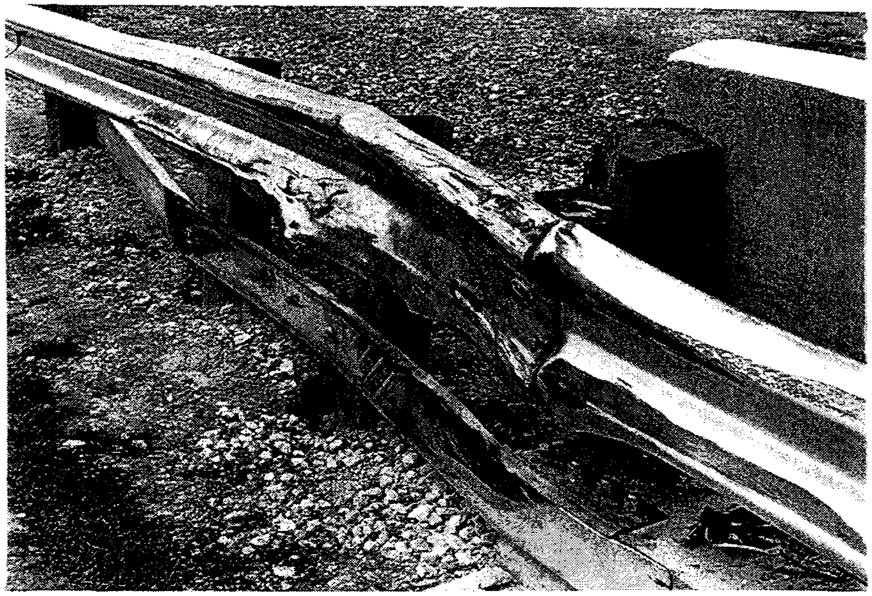


Figure 23. Site after test 472070-3.



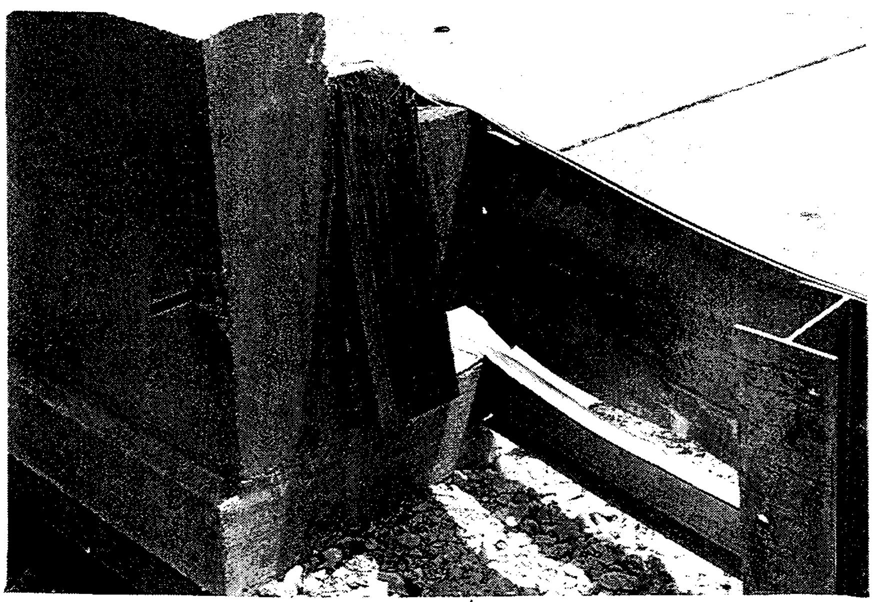


Figure 24. Damage to W-beam and bridge railing end post after test 472070-3.

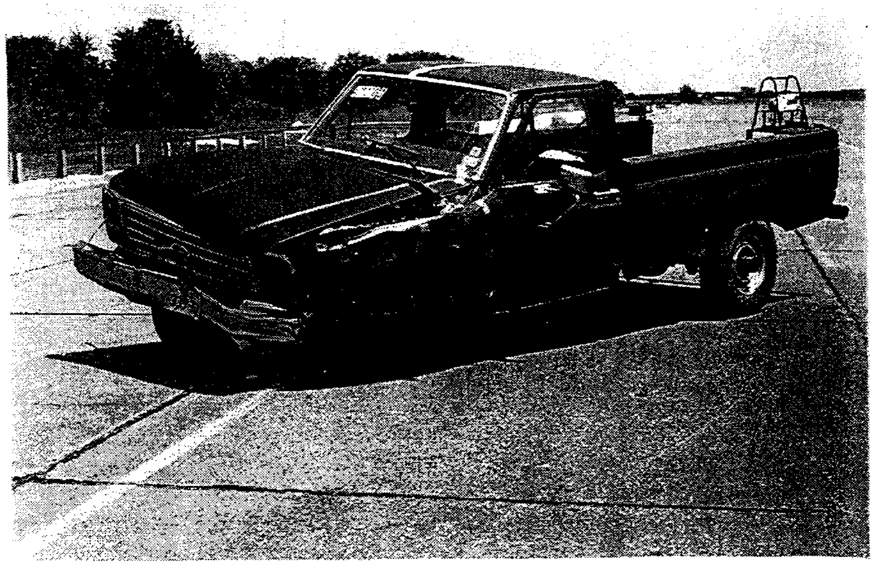


Figure 25. Vehicle after test 472070-3.

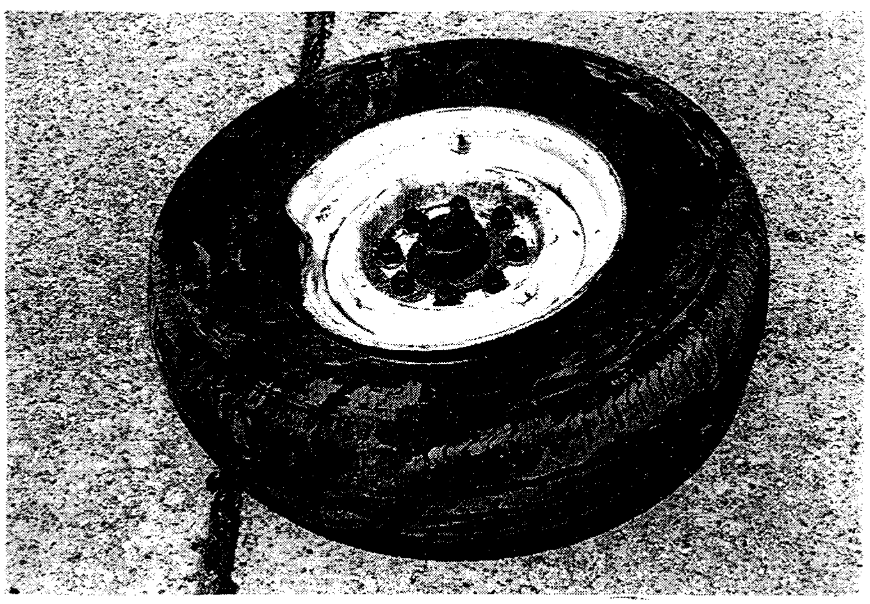


Figure 26. Damage to left wheel of vehicle after test 472070-3.

maximum 0.050-second average acceleration was -7.7 g between 0.109 and 0.159 second. Lateral occupant impact velocity was 6.7 m/s (22.0 ft/s) at 0.153 second, the highest 0.010-second occupant ridedown acceleration was 11.6 g between 0.383 and 0.393 second and the maximum 0.050-second average acceleration was 8.4 g between 0.106 and 0.156 second. These data and other pertinent information from the test are summarized in figure 27. Vehicular angular displacements are displayed in appendix D, figure 82. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in appendix E, figures 92 through 94.

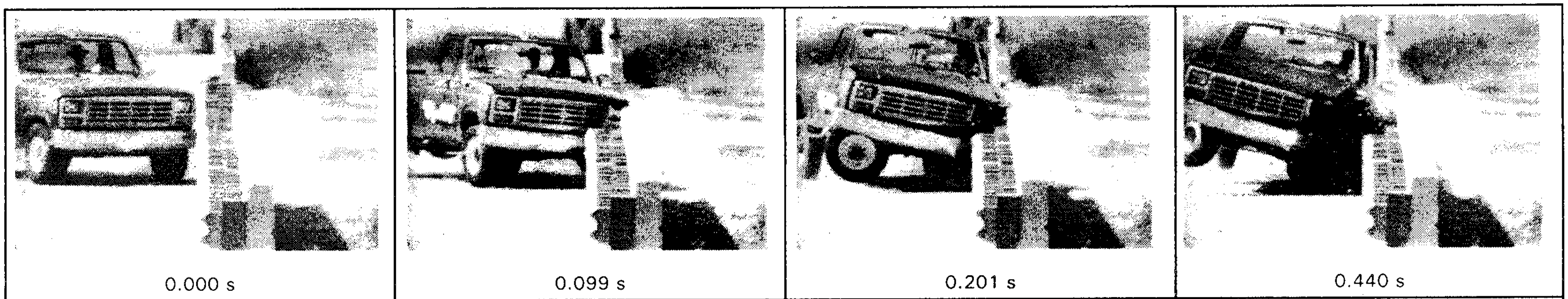
Test 472070-4

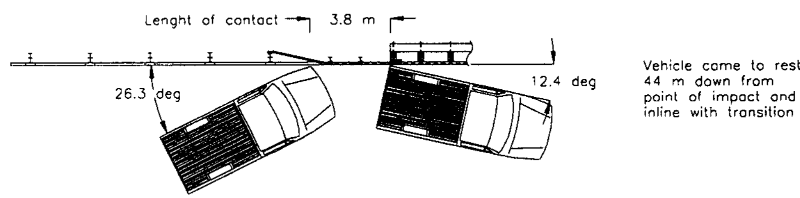
This test corresponds to NCHRP Report 350 test designation 2-20 and involves an 820 kg (1806 lb) vehicle impacting the transition at a nominal speed and angle of 70 km/h (43.5 mi/h) and 20 degrees. The critical impact point selected was 1.5 m (5.0 ft) from the end of the bridge rail. The purpose of this test is to evaluate occupant risk and post-impact trajectory.

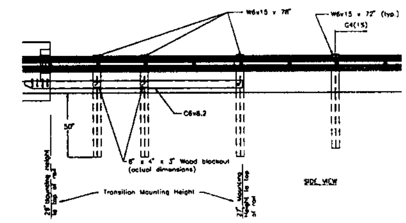
Test Description

The W-beam retrofit transition was repaired for use in the second test. A 1988 Ford Festiva, shown in figures 28 and 29, was directed into the retrofit transition. Test inertia weight of the vehicle was 820 kg (1806 lb) and its gross static weight was 897 kg (1976 lb). The height to the lower edge of the vehicle bumper was 247 mm (9.7 in) and it was 540 mm (21.3 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in appendix B, figure 62. The vehicle was directed into the retrofit bridge railing using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

The vehicle impacted the retrofit 1.4 m (4.6 ft) from the end of the bridge railing at a speed of 70.4 km/h (43.8 mi/h) and angle of 19.7 degrees. As the vehicle impacted the W-beam rail element the front of the vehicle began to deform. At 0.012 second post 1 began to move rearward and at 0.040 second after impact the vehicle began to redirect. A maximum dynamic deflection of the W-beam of 63.5 mm (2.5 in) occurred at 0.047 second. At 0.069 second the left front of the vehicle contacted the first post on the bridge railing. The dummy impacted the driver side door and the glass shattered at 0.089 second. By 0.161 second the vehicle was traveling parallel to the installation at a speed 61.8 km/h (38.4 mi/h). The rear of the vehicle contacted the W-beam rail element at 0.176 second and the vehicle lost contact with the retrofit bridge railing at 0.243 second. As the vehicle lost contact with the retrofit, the vehicle was traveling at a speed of 60.0 km/h (37.3 mi/h) and its exit trajectory of 8.5 degrees. Brakes on the vehicle were applied at 2.3 second after initial impact. The vehicle yawed clockwise and subsequently came to rest upright 33 m (109 ft) downstream and 23 m (75 ft) forward of the point of impact. Sequential photographs are shown in appendix C, figures 72 and 73.







General Information	
Test Agency	Texas Transportation Institute
Test No.	472070-3
Date	07/08/94
Test Article	
Type	Transition
Name	W-beam Retrofit
Installation Length (m)	19 m (62.5 ft)
Size and/or dimension and material of key elements	Nested W-beam on steel posts
Soil Type and Condition	Strong soil, dry
Test Vehicle	
Type	Production Model
Designation	2000P
Model	1986 Ford F250
Mass (kg) Curb	1960 (4317 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	73.1 (45.4 mi/h)
Angle (deg)	26.3
Exit Conditions	
Speed (km/h)	45.0 (28.0 mi/h)
Angle (deg)	12.4
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.6 (24.8 ft/s)
y-direction	6.7 (22.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-10.0
y-direction	11.6
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-7.7
y-direction	8.4
z-direction	3.5

Test Article Deflections (m)	
Dynamic	N/A
Permanent	0.14 (0.5 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ5
CDC	11FLEK3 & 11LDEW3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	380 (15.0 in)
Max. Occ. Compart. Deformation (mm)	24 (0.9 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	33
Max. Pitch Angle (deg)	-9
Max. Yaw Angle (deg)	-16

Figure 27. Summary of results for test 472020-3.

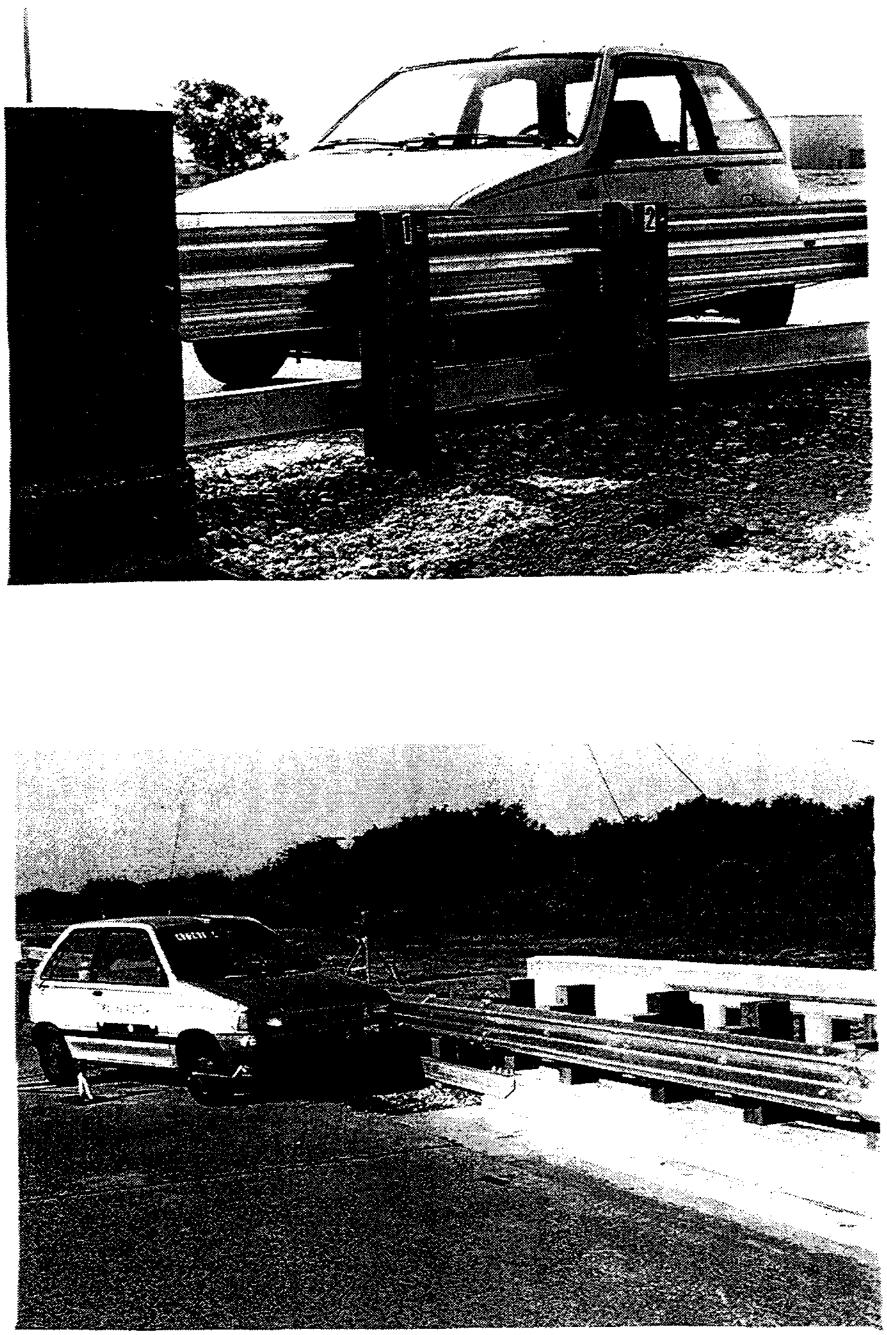


Figure 28. Vehicle/retrofit geometrics for test 472070-4.

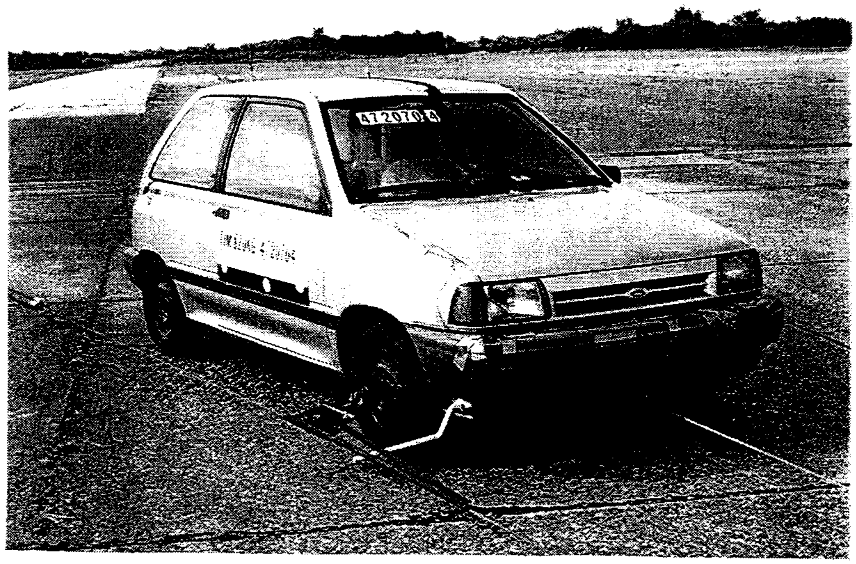


Figure 29. Vehicle prior to test 472070-4.

Damage to Test Installation

As can be seen in figure 30, the installation received minimal damage, which was mostly cosmetic. Maximum permanent deformation of the W-beam was 6.4 mm (0.25 in) at post 1. The vehicle was in contact with the installation for 2.1 m (6.8 ft).

Damage to Test Vehicle

The vehicle sustained moderate damage to the left front quarter with minor damage to the left side as shown in figure 31. Maximum exterior crush at the left front corner at bumper height of the vehicle was 190 mm (7.5 in), and there was no deformation into the occupant compartment. Damage was sustained to the left front strut, front bumper, grill, hood, left front wheel rim, and rear hatch. The entire left side was dented and scraped.

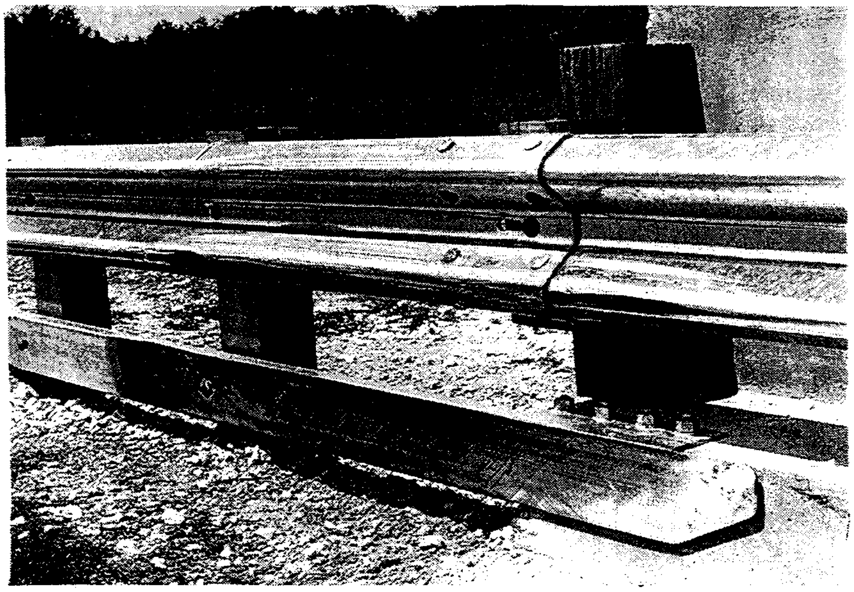
Occupant Risk Factors

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 3.9 m/s (12.8 ft/s) at 0.232 second, the highest 0.010-second average ridedown acceleration was -2.1 g between 0.214 and 0.224 second, and the maximum 0.050-second average acceleration was -4.7 g between 0.045 and 0.095 second. Lateral occupant impact velocity was -5.7 m/s (-18.8 ft/s) at 0.119 second, the highest 0.010-second occupant ridedown acceleration was 7.2 g between 0.209 and 0.219 second and the maximum 0.050-second average acceleration was 8.3 g between 0.045 and 0.095 second. These data and other pertinent information from the test are summarized in figure 32. Vehicular angular displacements were not available for this test due to instrumentation failure. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in appendix E, figures 95 through 97.

FINDINGS AND CONCLUSIONS

Summary of Findings

In the first test, the W-beam retrofit transition for the retrofit concrete baluster bridge railing functioned as intended by containing and redirecting the vehicle with moderate deflection of the W-beam guardrail. There were no detached elements or debris to present undue hazard to occupants of the vehicle or others in the area. The vehicle sustained moderate damage with very minimal deformation into the passenger compartment. The vehicle remained upright and stable during the collision period. The occupant impact velocities were within the NCHRP Report 350 limits as were the occupant ridedown accelerations. The exit trajectory of the vehicle was within the limit.



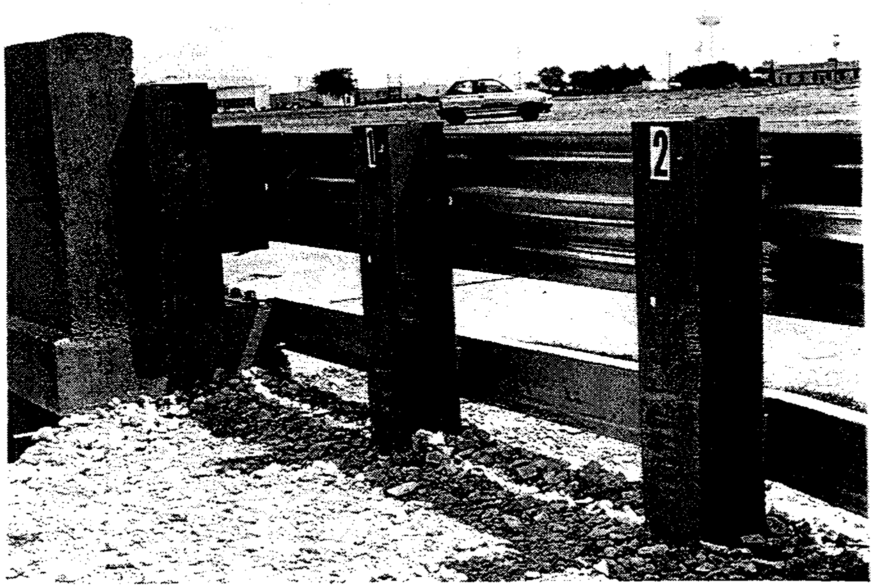


Figure 30. W-beam retrofit after test 472070-4.

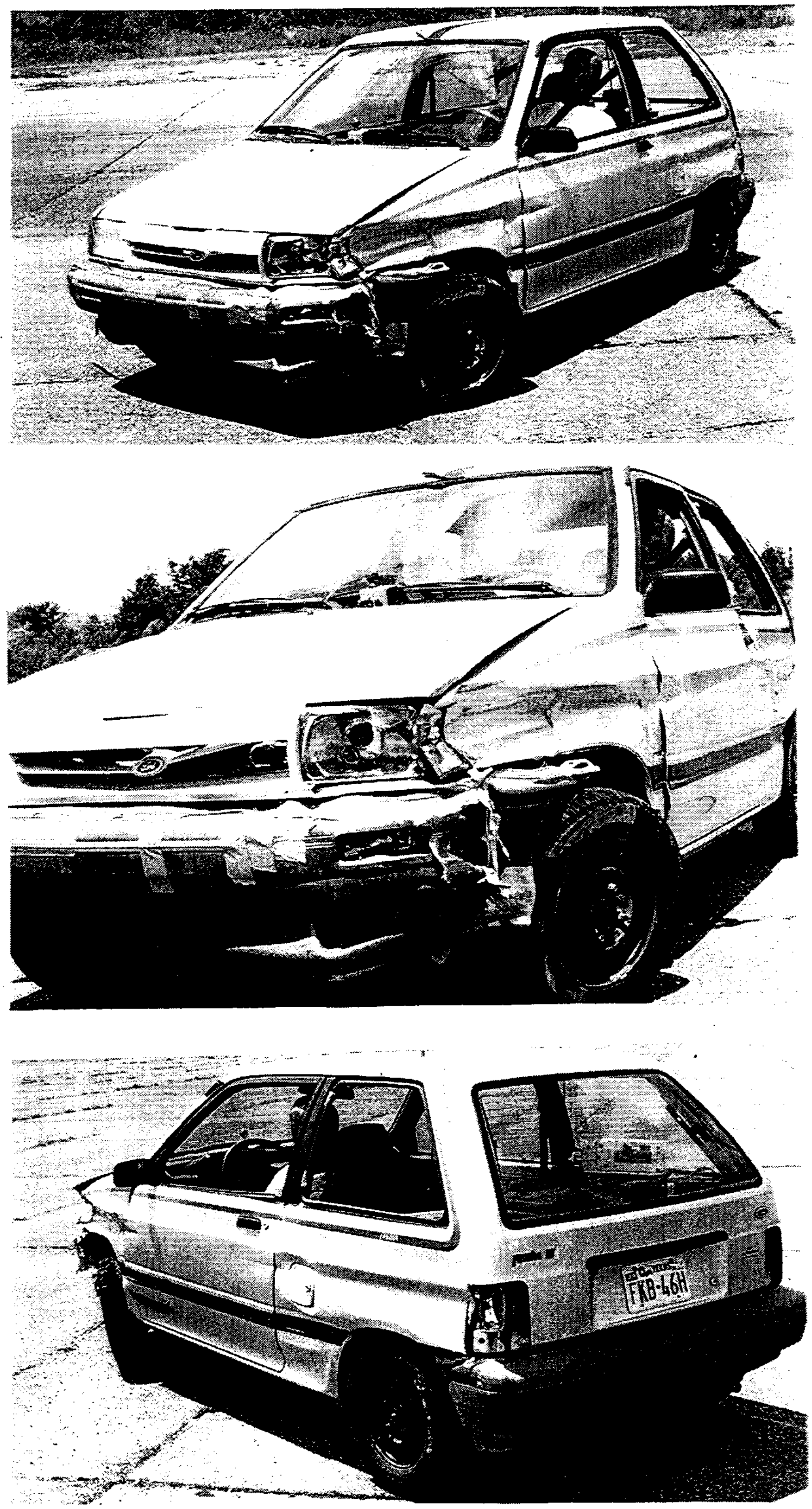
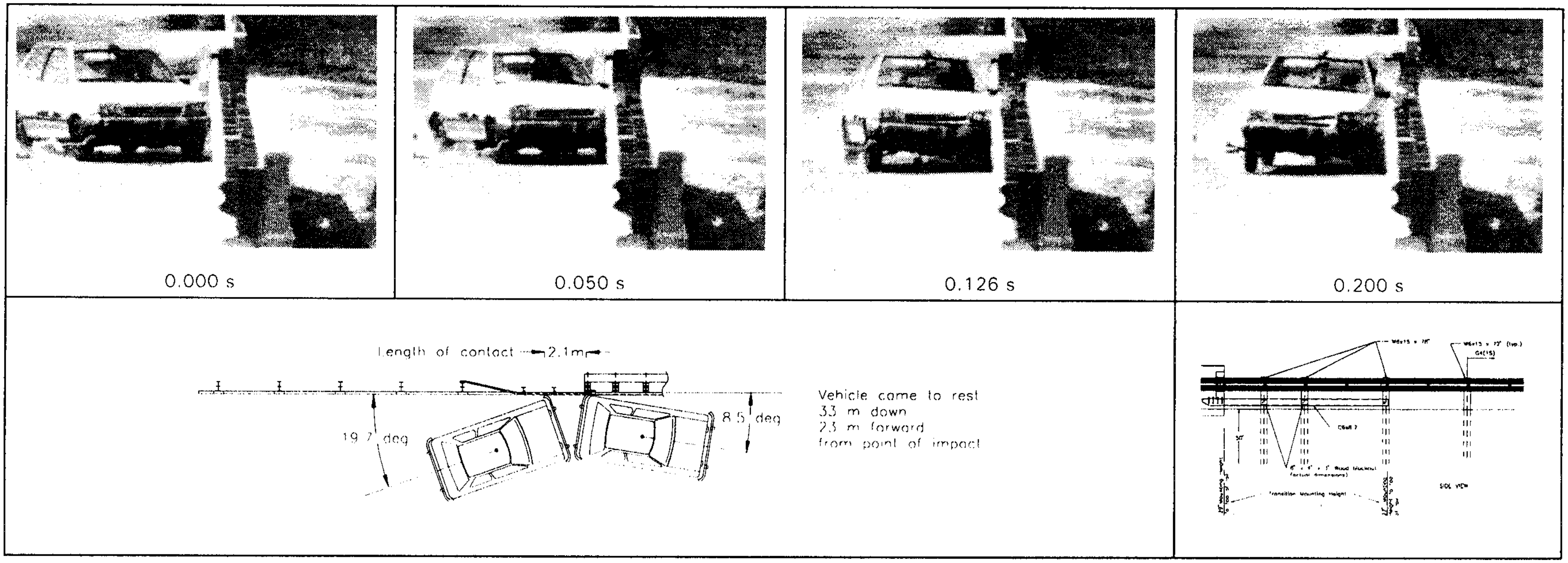


Figure 31. Vehicle after test 472070-4.



General Information	
Test Agency	Texas Transportation Institute
Test No.	472070-4
Date	08/02/94
Test Article	
Type	Transition
Name	W-beam Retrofit
Installation Length (m)	19 (62.5 ft)
Size and/or dimension and material of key elements	Nested W-beam on steel posts
Soil Type and Condition	Strong soil, dry
Test Vehicle	
Type	Production Model
Designation	820C
Model	1988 Ford Festiva L
Mass (kg) Curb	804 (1771 lb)
Test Inertial	820 (1806 lb)
Dummy	75 (165 lb)
Gross Static	897 (1976 lb)

Impact Conditions	
Speed (km/h)	70.4 (43.8 mi/h)
Angle (deg)	19.7
Exit Conditions	
Speed (km/h)	60.0 (37.3 mi/h)
Angle (deg)	8.5
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.9 (12.8 ft/s)
y-direction	5.7 (18.8ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-2.1
y direction	7.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.7
y-direction	8.3
z-direction	-1.1

Test Article Deflections (m)	
Dynamic	0.06 (0.21 ft)
Permanent	0.01 (0.02 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ5
CDC	11FLEK3 & 11LDEW3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	190 (7.5 in)
Max. Occ. Compart. Deformation (mm)	0 (0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	Instrumen-
Max. Pitch Angle (deg)	tation
Max. Yaw Angle (deg)	Failure

Figure 32. Summary of results for test 472020-4.

The W-beam retrofit functioned as intended during the small automobile test by containing and redirecting the vehicle with minimal deflection of the W-beam guardrail. There were no detached elements or debris to exhibit undue hazard to occupants of the vehicle or others in the area. The vehicle received moderate damage with no deformation into the occupant compartment. The vehicle remained upright and relatively stable during the collision period. The occupant impact velocities and ridedown accelerations were well within the NCHRP Report 350 limits and the exit trajectory was satisfactory.

Conclusions

The W-beam retrofit transition for retrofit concrete baluster bridge railing met the NCHRP Report 350 criteria for both performance level two tests, as shown in tables 6 and 7. Therefore, the impact performance of the W-beam retrofit transition for the retrofit concrete baluster bridge railing was judged satisfactory.

Table 6. Assessment of results of test with the 2000P vehicle on the W-beam retrofit transition (according to NCHRP Report 350 test 2-21).

Test Agency: Texas Transportation Institute | Test No.: 472070-3 | Test Date: 07/08/94

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The retrofit transition contained and smoothly redirected the vehicle. The vehicle did not penetrate, underride or override the installation.. The maximum lateral deflection was 140 mm (5.5 in).	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate the occupant compartment or present undue hazard to other traffic, etc. There was minimal deformation [24 mm (0.9 in)] in the floorpan area of the occupant compartment. This deformation was judged as not sufficient to cause serious injury.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable during and after the collision sequence.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	Exit trajectory of the vehicle at loss of contact with the transition indicated no 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.	The longitudinal occupant impact velocity was 7.6 m/s (24.8 ft/s) and the longitudinal occupant ridedown acceleration was -10.0 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 12.4 degrees which is less than 15.8 degrees (or 60 percent of 26.3 degrees).	Pass

Table 7. Assessment of results of test with the 820C vehicle on the W-beam retrofit transition (according to NCHRP Report 350 test 2-20).

Test Agency: Texas Transportation Institute | Test No.: 472070-4 | Test Date: 08/02/94

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The retrofit transition contained and redirected the vehicle. The vehicle did not penetrate, underride or override the installation and there was minimal lateral deflection [maximum deflection of 63.5 mm (2.5 in)].	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 present hazard to the occupants or other traffic. There was no deformation of, nor 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 stable during the collision sequence.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component: Longitudinal and lateral; Preferred: 9; Maximum: 12	Longitudinal Occupant Impact Velocity = 3.9 m/s (12.8 ft/s) Lateral Occupant Impact Velocity = 5.7 m/s (18.8 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (G's) Component: Longitudinal and lateral; Preferred: 15; Maximum: 20	Longitudinal Ridedown Acceleration = -2.1 G Lateral Ridedown Acceleration = 7.2 G	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	Vehicle trajectory at loss of contact indicated minimal intrusion into adjacent traffic lanes.	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Exit angle at loss of contact was 8.5 degrees which was less than 11.8 degrees (or 60 percent of 19.7 degrees).	Pass

DOUBLE TUBE PEDESTRIAN/BICYCLE ON ILLINOIS 2399-1 TRAFFIC RAILING

TEST ARTICLE

The Illinois 2399-1 traffic railing used during a previous contract was used as the retrofit railing. The double tube pedestrian/bicycle railing was attached to the existing traffic railing. Total installation length was 30 m (100 ft). A cross section of the prototype test installation is shown in figure 33 and photographs of the completed installation are shown in figure 34.

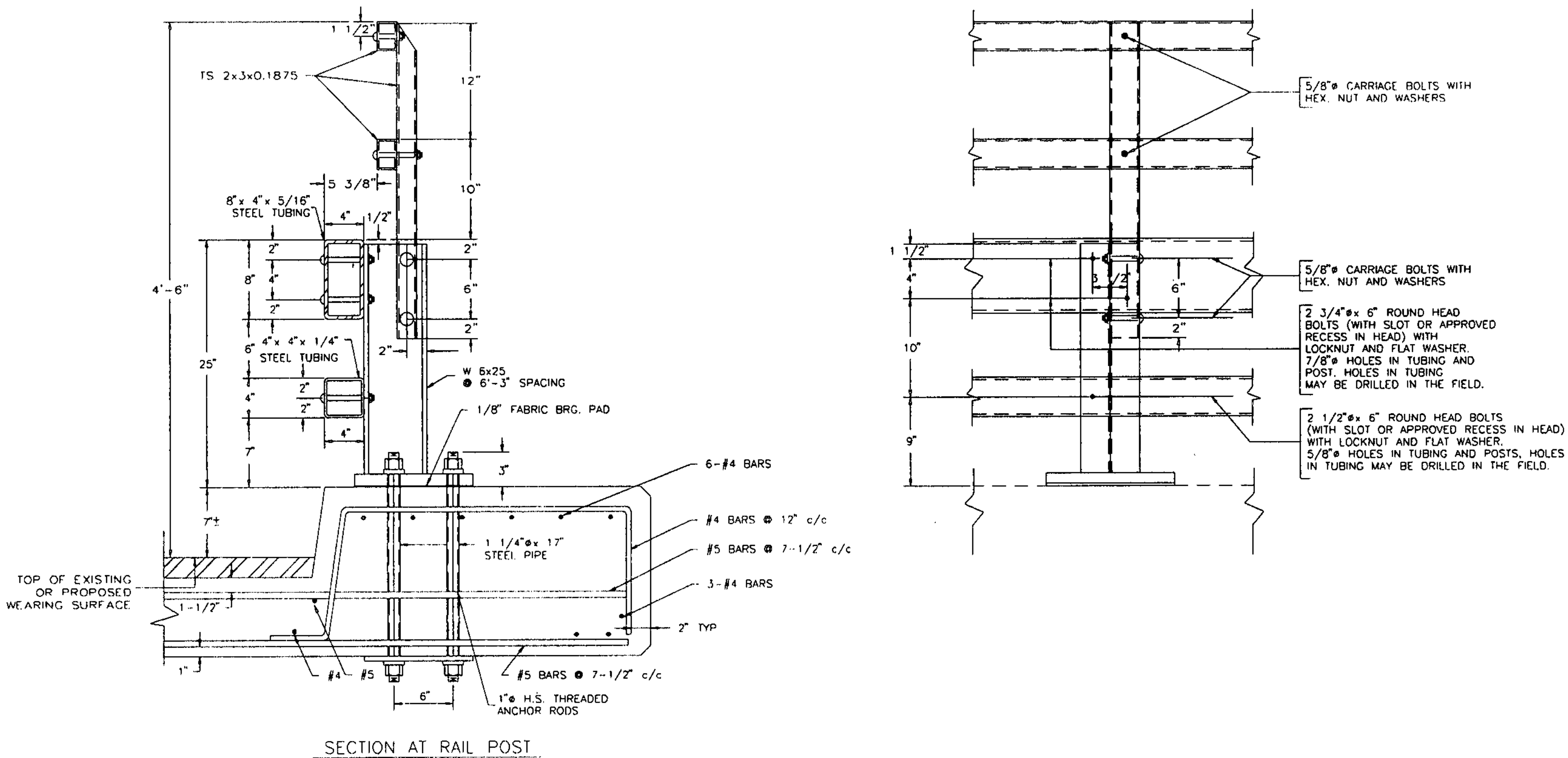
The Illinois 2399-1 traffic railing consisted of W6x25 posts spaced at 1.9 m (6ft-3in). A 203 by 102 by 8 mm (TS8x4x0.3125) tubular steel element was mounted on the posts with two 70-mm dia. by 152-mm (2 ¾-in dia. by 6-in) round head bolts. Height of the upper metal railing above the top of the curb was 635 mm (25 in). The lower element was a 102 by 102 by 6 mm (TS4x4x0.25) tubular steel element mounted to the post with one 64 mm dia. by 152 mm (2 ½ in dia. by 6 in) round head bolt. Height of the lower metal railing above the curb was 279 mm (11 in). Total height of the top of the Illinois 2399-1 above the wearing surface was 813 mm (32 in).

The double tube pedestrian/bicycle railing consisted of 813 mm (32 in) long sections of 51 by 76 by 5 mm (TS2x3x0.1875) tubular steel elements attached to the back of the W6x25 posts of the Illinois 2399-1 traffic railing using two 16 mm (5/8 in) carriage bolts. Two 51 by 76 by 5 mm (TS2x3x0.1875) rail elements were attached to the 813 mm (32 in) upright sections using 16 mm (5/8 in) carriage bolts. Height of the top of the pedestrian/bicycle railing above the wearing surface was 1.4 m (4 ft-6 in).

CRASH TEST RESULTS

Test 472070-5

One crash test was conducted on the pedestrian/bicycle railing mounted on the Illinois 2399-1 traffic railing. The test was the small automobile test for AASHTO performance level one test. The test involves an 817 kg (1800 lb) vehicle, impacting the length-of-need section at a nominal speed and angle of 80 km/h (50 mi/h) and 20 degrees. The critical impact point (CIP) selected was to be near the 1/3 point of the test installation. The purpose of this crash test is to evaluate the occupant risk of the length-of-need section of the combination pedestrian/bicycle railing on the Illinois 2399-1 traffic railing. A brief description of the results of the crash test is presented in the following section.



1 ft = 0.305 m
1 in = 25.4 mm

Figure 33. Cross section of double tube pedestrian/bicycle railing on the Illinois 2399-1 traffic railing.

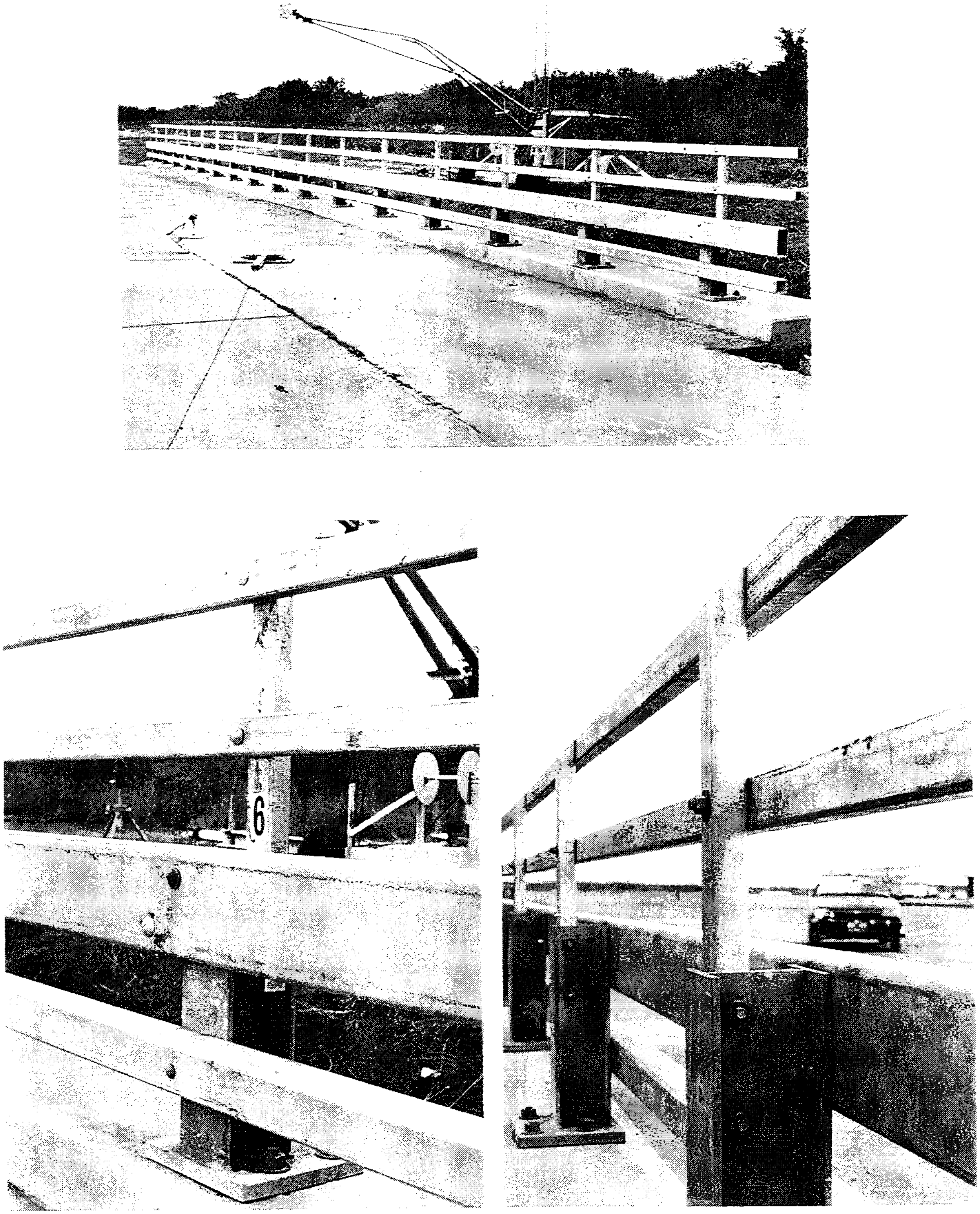


Figure 34. Pedestrian/bicycle railing on the Illinois 2399-1 traffic railing.

Test Description

A 1988 Chevrolet Sprint (shown in figures 35 and 36) with a test inertia weight of 820 kg (1806 lb) was used for the crash test. The gross static weight of the vehicle was 896 kg (1974 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 515 mm (20.3 in) and 330 mm (13.0 in), respectively. Additional dimensions and information on the vehicle are given in appendix B, figure 63. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

The vehicle contacted the length-of-need section of the traffic railing midspan between post 5 and 6. The vehicle was traveling at a speed of 82.7 km/h (51.4 mi/h) and at an angle of 19.6 degrees at time of impact. Redirection of the vehicle began at 0.027 second. The front of the vehicle reached post 6 at 0.037 second and post 7 at 0.118 second. The vehicle became parallel with the installation at 0.130 second, traveling at 74.8 km/h (46.5 mi/h). At 0.140 second the rear of the vehicle made contact with the railing. The vehicle lost initial contact with the traffic railing at 0.213 second, traveling at a speed of 74.5 km/h (46.3 mi/h) and an exit angle of approximately 5.1 degrees. As the vehicle continued forward, the wheel steered the vehicle back toward the railing. The vehicle contacted the end of the traffic railing at 0.929 second and rode off the end. Brakes were applied as the vehicle exited the test area, and the vehicle subsequently came to rest 52 m (172 ft) beyond and 10 m (33 ft) to the traffic side of the initial point of impact. Sequential photographs are shown in appendix C, figures 74 and 75.

Damage to Test Installation

As seen in figure 37, the installation minimal damage. There were tire marks on the face of the curb and both metal rail elements of the Illinois 2399-1 traffic railing. The curb was chipped slightly at the point of impact. Length of initial contact with the traffic railing was 3.0 m (10 ft). The vehicle contacted the traffic railing again near the end leaving only tire marks on the face of the curb and lower element. There was no contact with the pedestrian/bicycle railing.

Damage to Test Vehicle

The vehicle sustained minimal damage as shown in figure 38. The strut and front axle on the right side were damaged. The front bumper, right front quarter panel, both doors, and rear quarter panel were scraped. Maximum exterior crush at the right front corner of the vehicle was 140 mm (5.5 in) and there was no deformation into the occupant compartment.

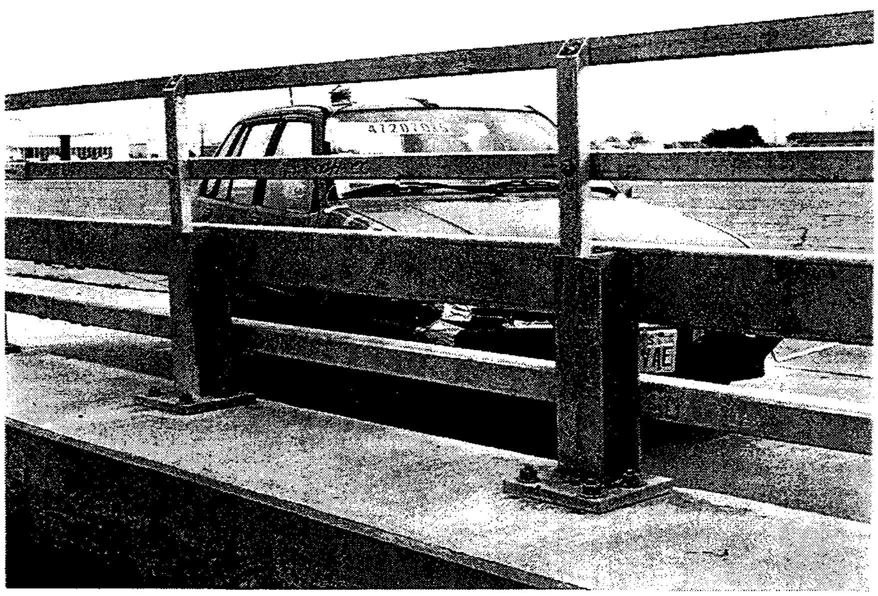


Figure 35. Vehicle/traffic railing geometrics for test 472070-5.

Figure 36. Vehicle prior to test 472070-5.

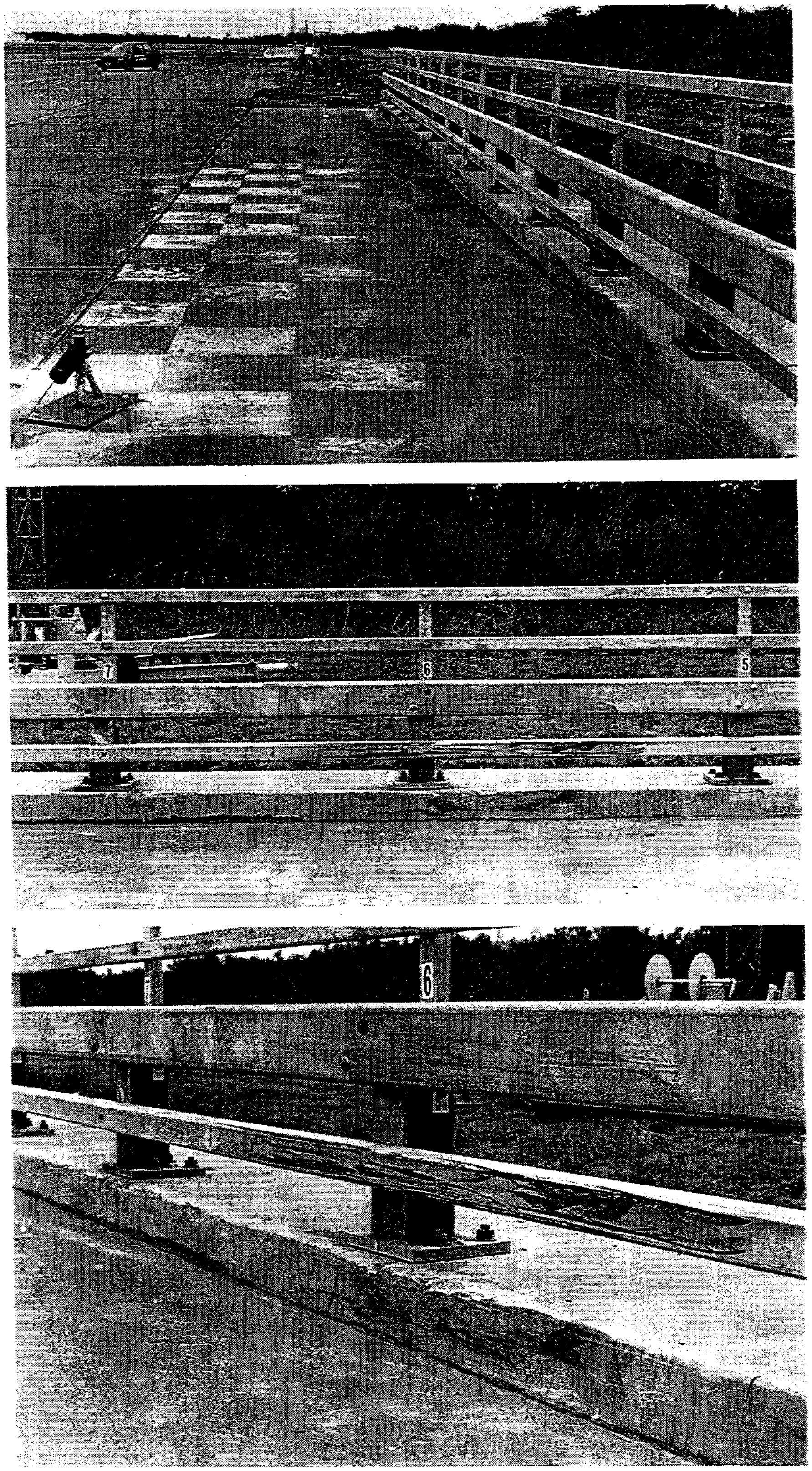
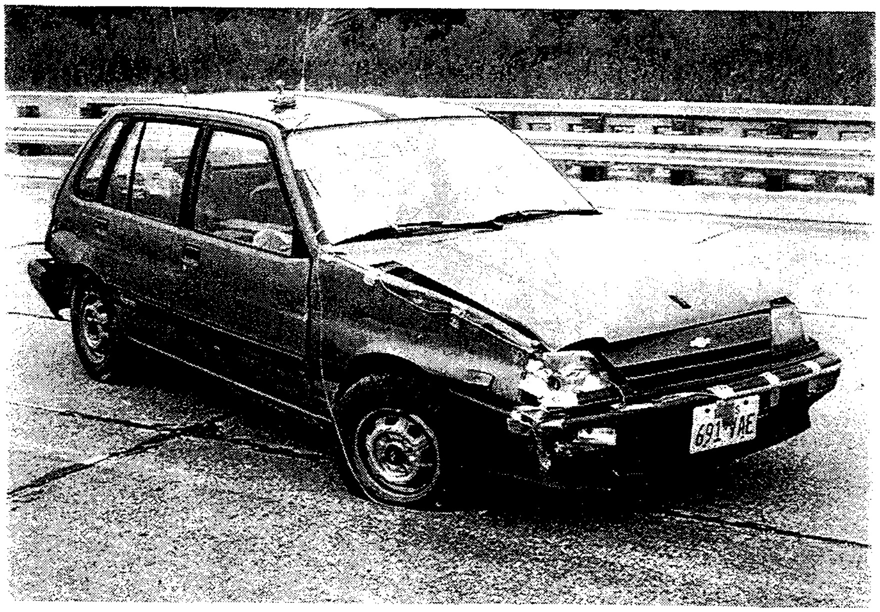


Figure 37. Pedestrian/bicycle railing on Illinois 2399-1 after test 472070-5.



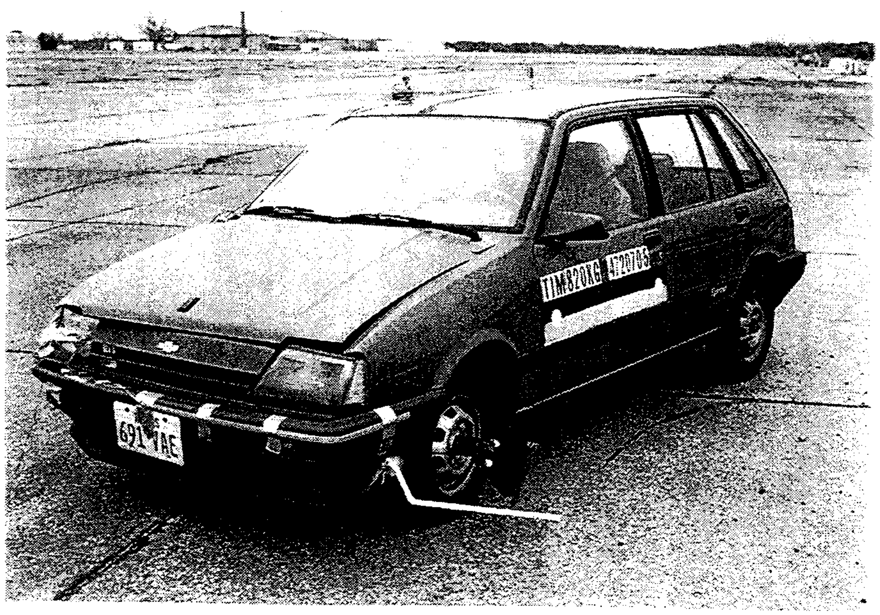


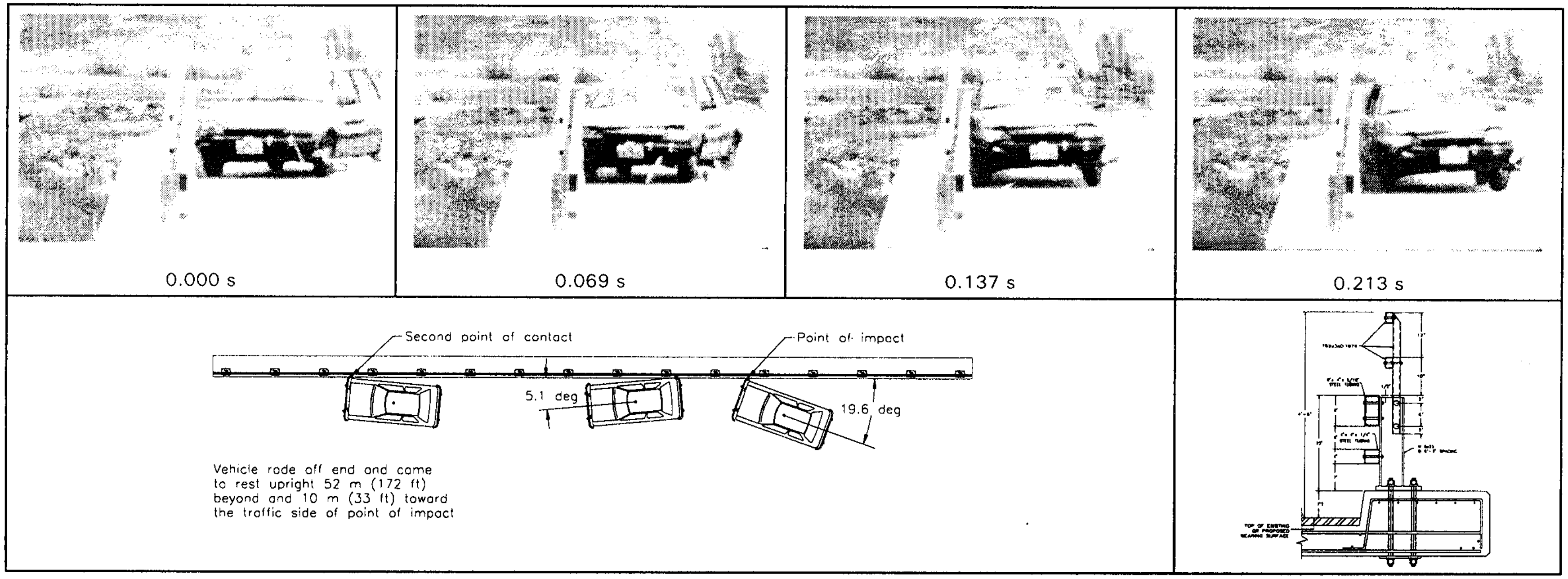
Figure 38. Vehicle after test 472070-5.

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 5.7 m/s (18.6 ft/s) at 0.100 second, the highest 0.010-second lateral occupant ridedown acceleration was -13.1 g between 0.140 and 0.150 second, and the maximum 0.050-second average acceleration was -10.0 g between 0.021 and 0.071 second. In the longitudinal direction, the occupant impact velocity was 3.3 m/s (10.8 ft/s), the highest 0.010-second occupant ridedown acceleration was -3.4 g between 0.937 and 0.947 second, and the maximum 0.050-second average was -4.3 g between 0.022 and 0.072 second. These data and other information pertinent to the test are summarized in figure 39. Vehicular angular displacements during the test are displayed in appendix D, figure 83. Vehicular accelerations versus time traces filtered at 60 Hz are presented in appendix E, figures 98 through 100.

FINDINGS AND CONCLUSIONS

The double tube pedestrian/bicycle railing mounted on the Illinois 2399-1 traffic railing successfully contained and redirected the vehicle and met all evaluation criteria set forth in the AASHTO *Guide Specifications for Bridge Railings* PL1 conditions for the small car test. The vehicle did not penetrate or go over the installation. There was no measurable deformation to the railing. There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained minimal damage with no 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 5.1 degrees. The coefficient of friction was calculated at 0.11. The occupant risk factors were well within the desirable limits. In summary, the impact performance of the double tube pedestrian/bicycle railing on the Illinois 2399-1 traffic railing was considered satisfactory according to guidelines set forth by AASHTO, as shown in table 8.



General Information	
Test Agency	Texas Transportation Institute
Test No.	472070-5
Date	01/25/95
Test Article	
Type	Pedestrian/Bicycle Railing
Name	Double Tube Ped/Bicycle railing on Illinois 2399-1 traffic railing
Installation Length (m)	30 m (100 ft)
Key elements	TS2x3x0.1875 railings on Illinois 2399-1 traffic railing
Soil Type and Condition	N/A
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Chevrolet Sprint
Mass (kg) Curb	713 (1570 lb)
Test Inertial	820 (1806 lb)
Dummy	76 (167 lb)
Gross Static	896 (1974 lb)

Impact Conditions	
Speed (km/h)	82.7 (51.4 mi/h)
Angle (deg)	19.6
Exit Conditions	
Speed (km/h)	74.5 (46.3 mi/h)
Angle (deg)	5.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.3 (10.8 ft/s)
y-direction	5.7 (18.6 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-3.4
y-direction	-13.1
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.3
y-direction	-10.0
z-direction	-1.3

Test Article Deflections (m)	
Dynamic	nil
Permanent	nil
Vehicle Damage	
Exterior	
VDS	01RD2
CDC	01RDES2
Interior	
OCDI	AS0000000
Maximum Exterior	
Vehicle Crush (mm)	140 (5.5 in)
Max. Occ. Compart.	
Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	-8.9
Max. Pitch Angle (deg)	4.6
Max. Yaw Angle (deg)	-21.7

Figure 39. Summary of results for test 472070-5.

Table 8. Assessment of results of test with small car on pedestrian/bicycle traffic railing (according to AASHTO PL1 small automobile test).

Test Agency: Texas Transportation Institute — Test No.: 472070-5 — Test Date: 01/25/95

	AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
A.	The test shall contain the vehicle: neither the vehicle no its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	Vehicle was contained. There was no measurable deflection of the metal rail elements.	Pass
B.	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.	There were no detached elements or other debris to penetrate or show undue hazard to other traffic.	Pass
C.	Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	No deformation occurred to the occupant compartment.	Pass
D.	The vehicle shall remain upright during and after collision.	The vehicle remained upright during and after the collision.	Pass
E.	The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
F.	The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment .11 — Good	Pass
G.	The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 3.3 (10.8); Lateral 5.7 (18.6) Occupant Ridedown Accelerations - g's Longitudinal -3.4; Lateral -13.1	Pass
H.	Vehicle exit angle from the barrier shall not be more than 12 degrees.	Exit angle was approximately 5.1 degrees.	Pass

**A, B, C, D, and G are required. E, F, and H are desired.*

VANDAL PROTECTION FENCE ON NEW JERSEY SAFETY SHAPE BRIDGE RAILING

TEST ARTICLE

The New Jersey safety shape bridge railing used during a previous contract was used as the retrofit railing. The vandal protection fence was attached to the existing bridge railing. Total installation length was 30 m (100 ft). A cross section of the prototype test installation is shown in figure 40 and photographs of the completed installation are shown in figures 41 and 42.

The total height of the New Jersey safety shape is 813 mm (32 in). Thickness of the unit is 381 mm (15 in) at its base and varies along the height, tapering to a minimum of 152 mm (6 in) at the top. Eight 13 mm (#4) longitudinal bars were used in the safety shape. The vertical steel was 16 mm (#5) stirrups at 203 mm (8 in) spacing. Specified concrete strength was 24 804 kPa (3600 psi) at 28 days, and specified steel yield was 413 400 kPa (60,000 psi). The cantilevered deck was supported on a foundation so that the deck overhang was 991 mm (39 in).

The vandal protection fence was mounted on 2.2 m (7.3 ft) long by 73 mm (2.875 in) OD (schedule 40 pipe) straight posts mounted to the back of the safety shape with two clamps and anchored with 0.625 mm by 76 mm (5/8 in by 3 in) anchor bolts. The clamps were formed from 76 mm (3.0 in) wide by 6.35 mm (0.25 in) flat steel. The first post is placed 0.3 m (1 ft) from the end of the safety shape with the next post at 2.7 m (9.0 ft), then 8 spaces at 3.0 m (10.0 ft), and ending with one spaced at 2.7 m (9.0 ft). Attached to these posts are three 42 mm (1.66 in) OD (schedule 40 pipe) horizontal line rails spaced at 0.9 m (3.0 ft) with 25 mm by 25 mm (1 in by 1 in) wire fabric (11 gage core wires, PVC coated). Height to the top of the fence is 1.8 m (6.0 ft) above the safety shape. Total height of the installation is 2.6 m (8.7 ft) above the roadway surface.

CRASH TEST RESULTS

Test 472070-6

One crash test was conducted on the vandal protection fence mounted on the New Jersey safety shape bridge railing. The test was the AASHTO performance level two pickup truck test with a 2450 kg (5400 lb) pickup, impacting the length-of-need section at a nominal speed and angle of 100 km/h (62.2 mi/h) and 20 degrees. The impact point was selected to be near the 1/3 point of the test installation. The purpose of this crash test is to evaluate the strength of the section in containing and redirecting the pickup and the interaction of the vehicle with the fence.

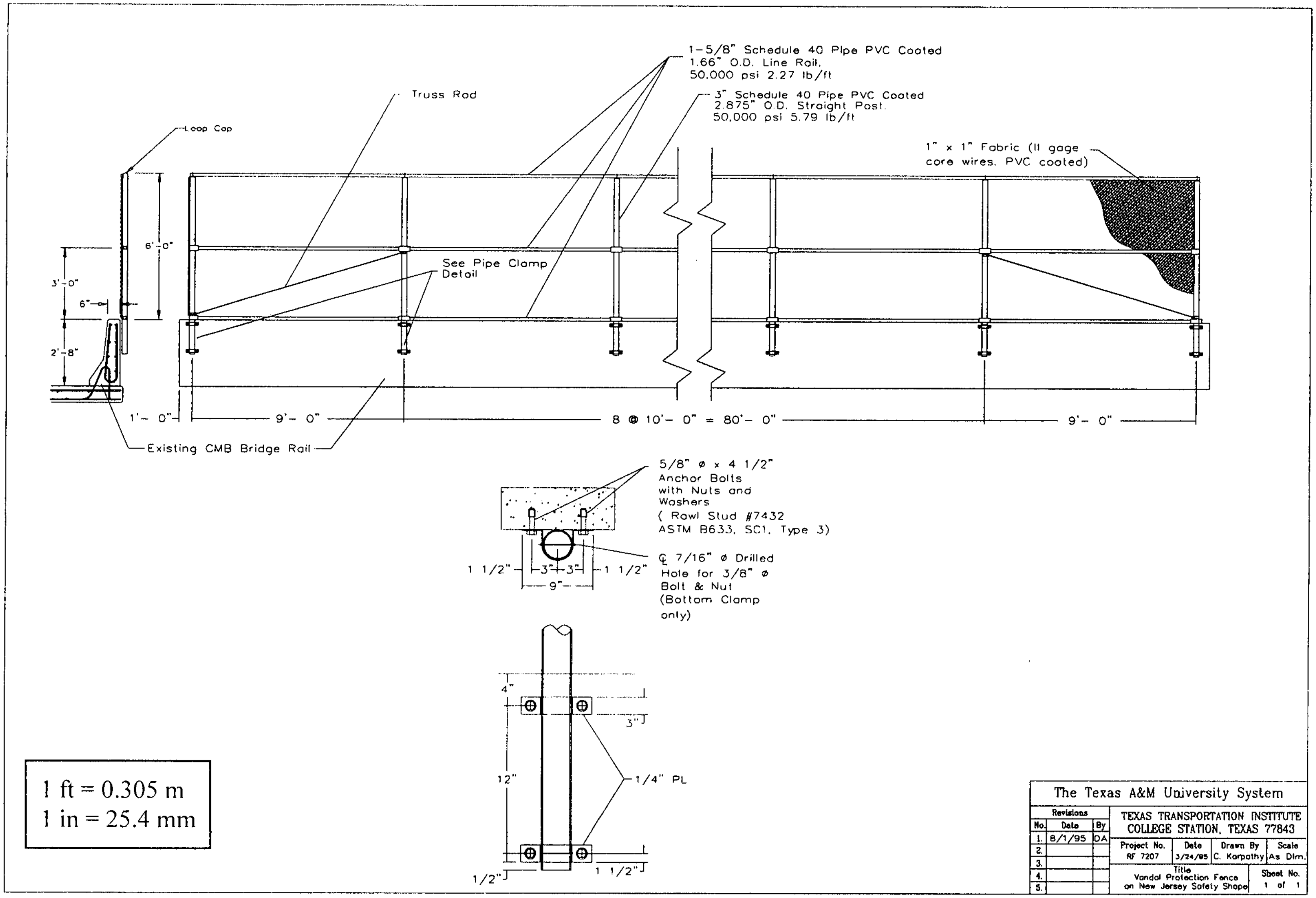


Figure 40. Details of vandal protection fence on New Jersey safety shape bridge railing.

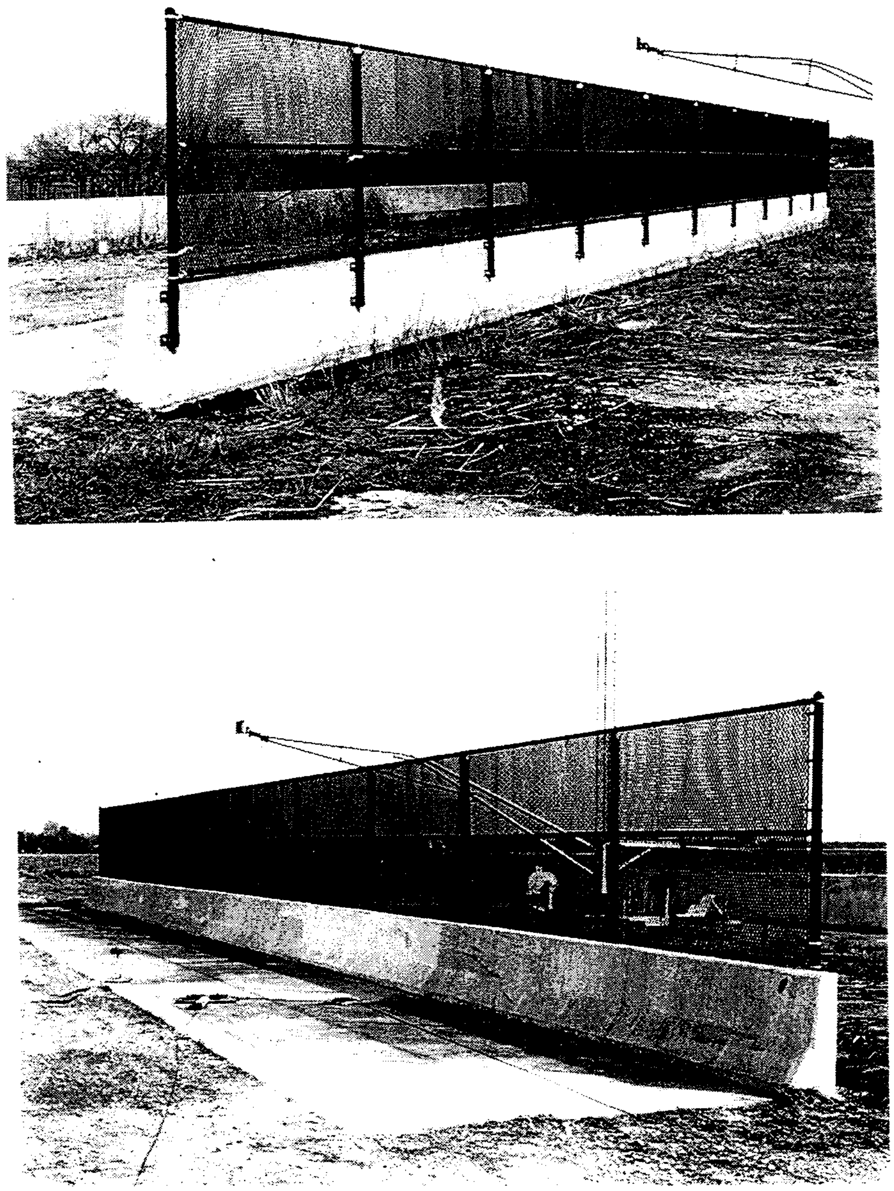


Figure 41. Vandal protection fence on the New Jersey safety shape bridge railing.

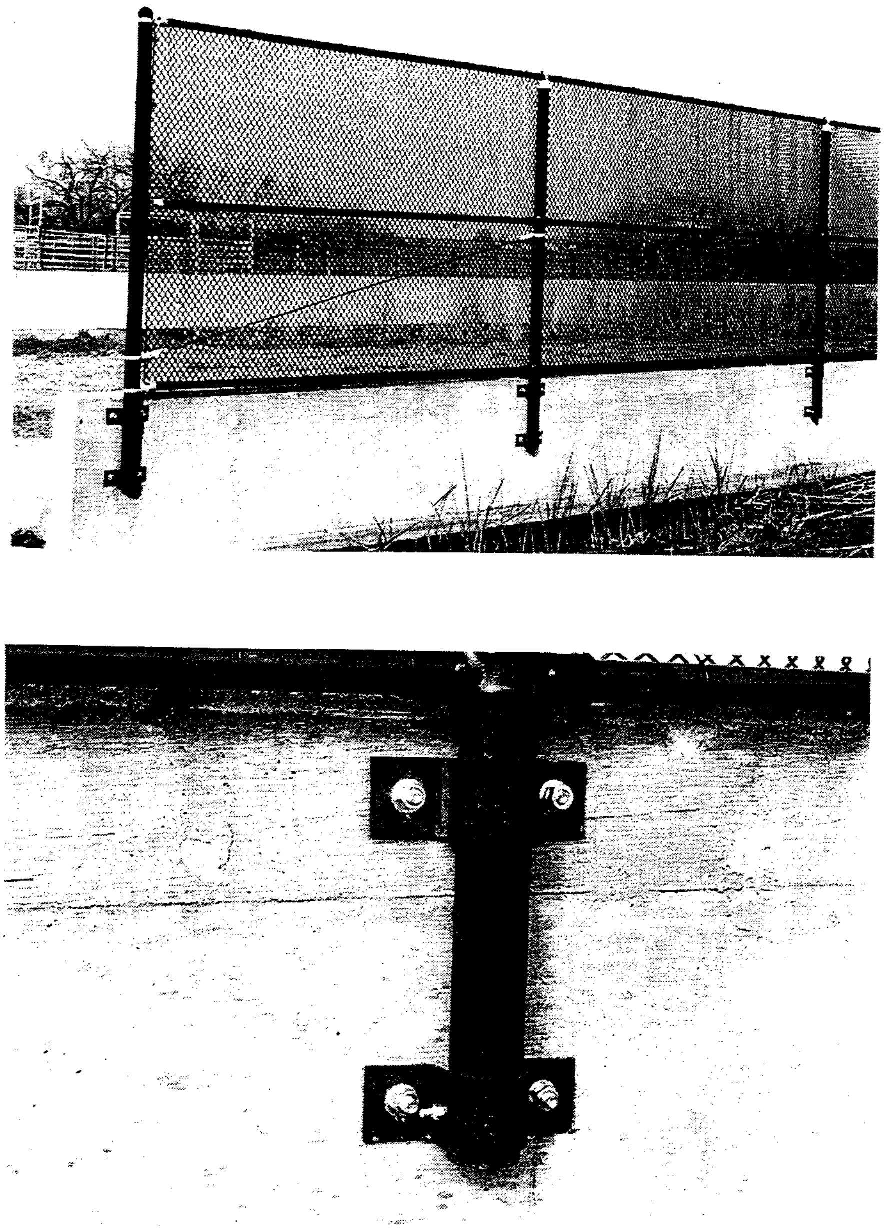


Figure 42. Connection of the vandal protection fence to the New Jersey safety shape.

Test Description

A 1991 Ford F250 (shown in figures 43 and 44) with a test inertia weight of 2540 kg (5397 lb) was used for the crash test. The gross static weight of the vehicle was 2525 kg (5562 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 740 mm (29.1 in) and 450 mm (17.7 in), respectively. Additional dimensions and information on the vehicle are given in appendix B, figure 64. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

The vehicle bumper contacted the length-of-need section of the New Jersey safety shape 1.02 m (3.33 ft) downstream of post 4 of the vandal protection fence. The vehicle was traveling at a speed of 79.6 km/h (49.5 mi/h) and an exit angle of approximately 4.4 degrees. Contact with the fence occurred at 0.032 second and redirection of the vehicle began at 0.039 second. The middle horizontal line rail pulled out of the post 5 connection at 0.089 second. Maximum deflection of the fence of 142 mm (5.6 in) occurred at 0.110 second. The bumper of the vehicle reached the top of the safety shape at 0.121 second and the front of the vehicle became airborne at 0.138 second. At 0.181 second the vehicle became parallel with the installation, traveling at 83.8 km/h (52.1 mi/h). The rear of the vehicle made contact with the safety shape at 0.195 second and the vehicle became totally airborne at 0.223 second. The vehicle lost contact with the safety shape at 0.274 second, traveling at a speed of 79.6 km/h (49.5 mi/h) and an exit angle of approximately 4.4 degrees. At 0.665 second the vehicle touched ground and yawed clockwise. Brakes were applied as the vehicle exited the test area, and the vehicle subsequently came to rest 28 m (91 ft) beyond and 3 m (9 ft) to the traffic side of the initial point of impact. Sequential photographs are shown in appendix C, figures 76 and 77.

Damage to Test Installation

As seen in figure 45, the installation received minimal damage. There were tire marks on the face of the safety shape and the lower edge of the wire fabric was pushed behind the lower horizontal line rail between post 5 and 6. The middle horizontal line rail was disconnected on the upstream side at the post 5 location and the post 5 anchor was pushed back 13 mm (0.5 in) as shown in figure 46. Maximum dynamic deflection of the fence was 142 mm (5.6 in) (measured at the top of the rail) and maximum residual deformation was 76 mm (3.0 in). Total length of contact with the installation was 5.2 m (17.0 ft).

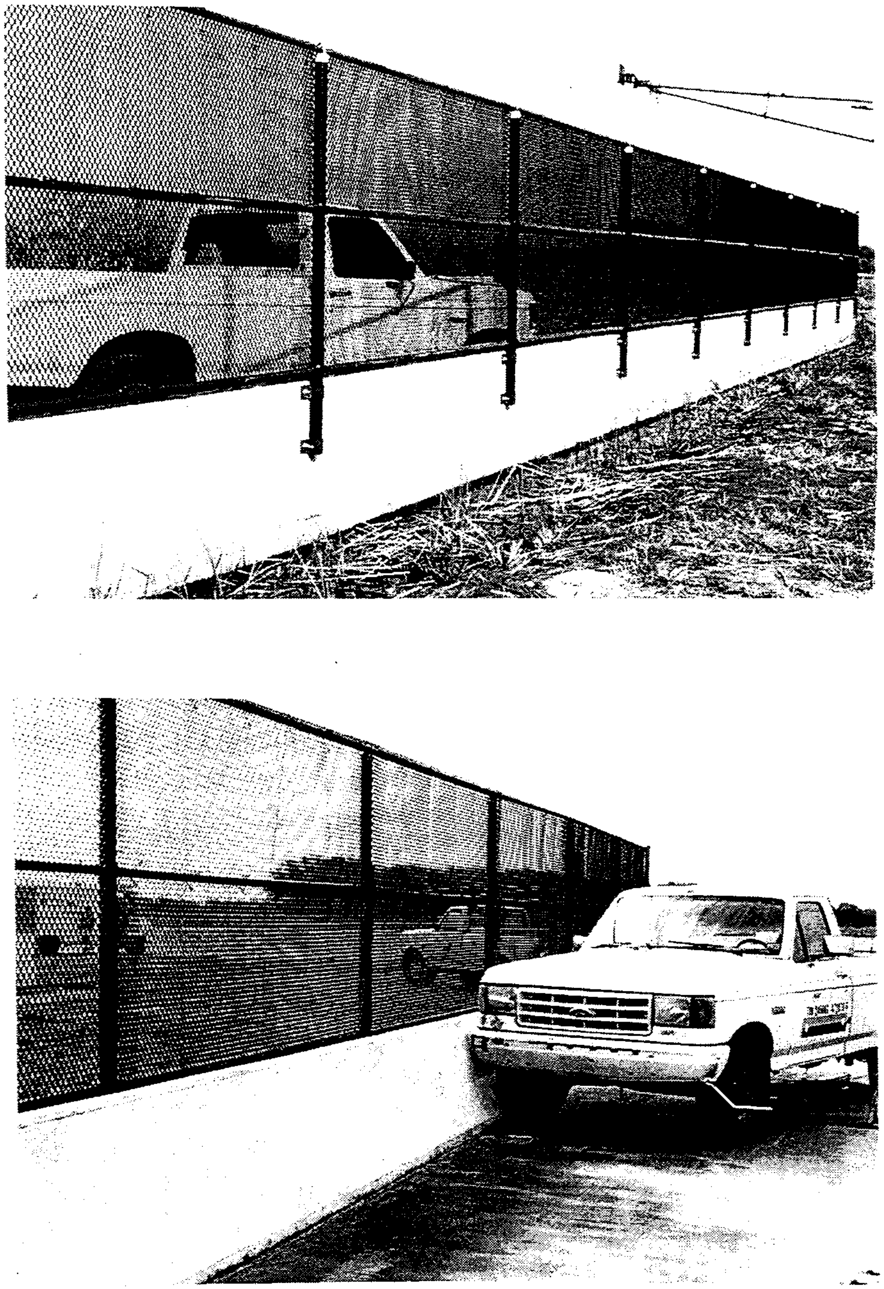


Figure 43. Vehicle/bridge rail geometrics for test 472070-6.

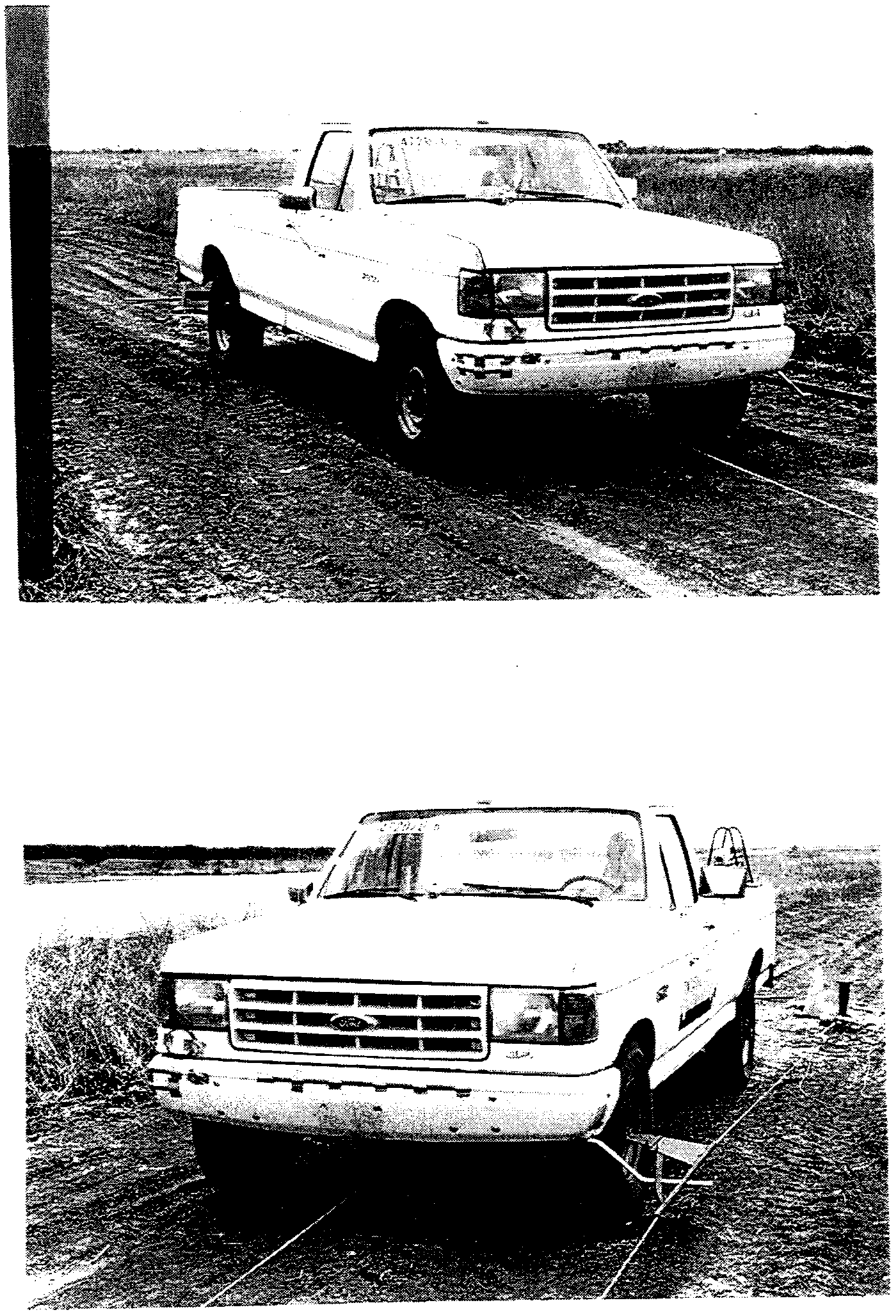
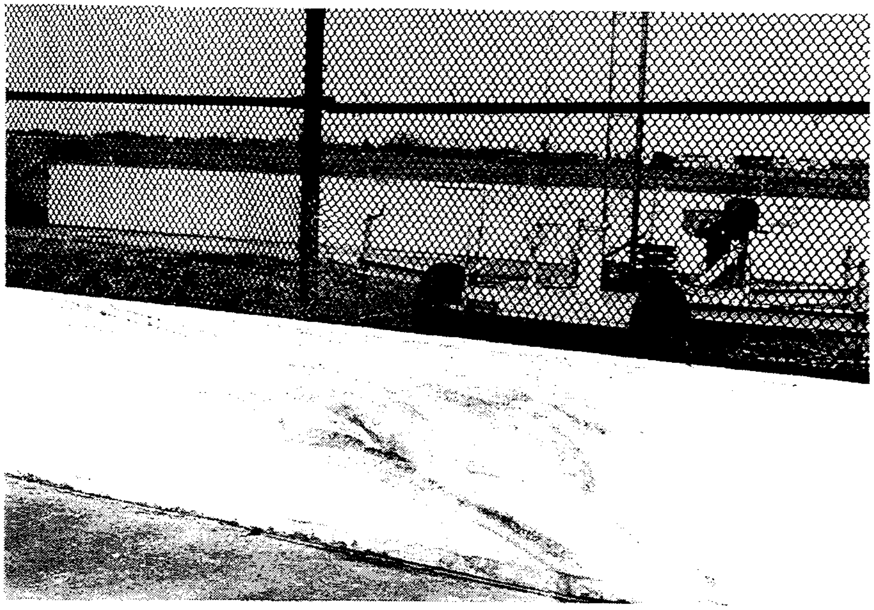


Figure 44. Vehicle prior to test 472070-6.



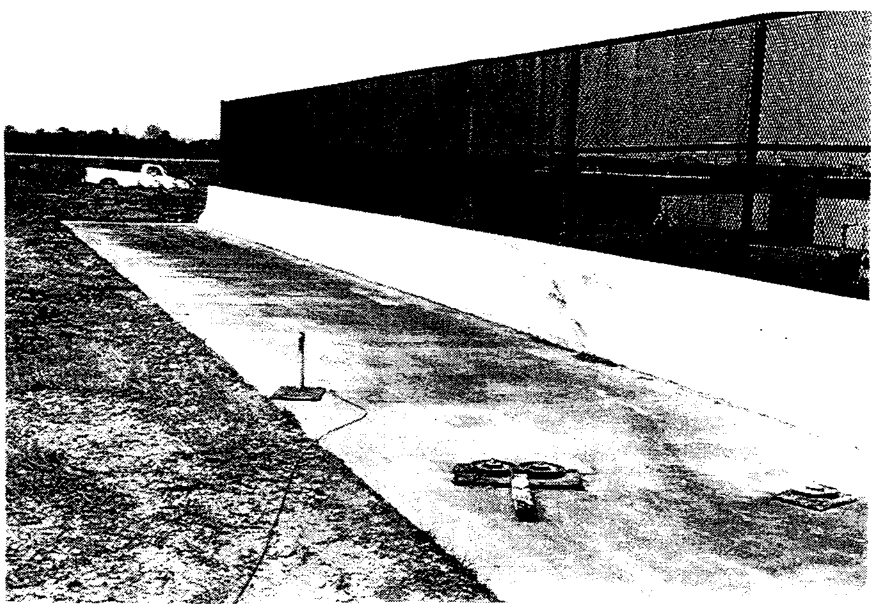


Figure 45. Vandal protection fence on New Jersey safety shape after test 472070-6.

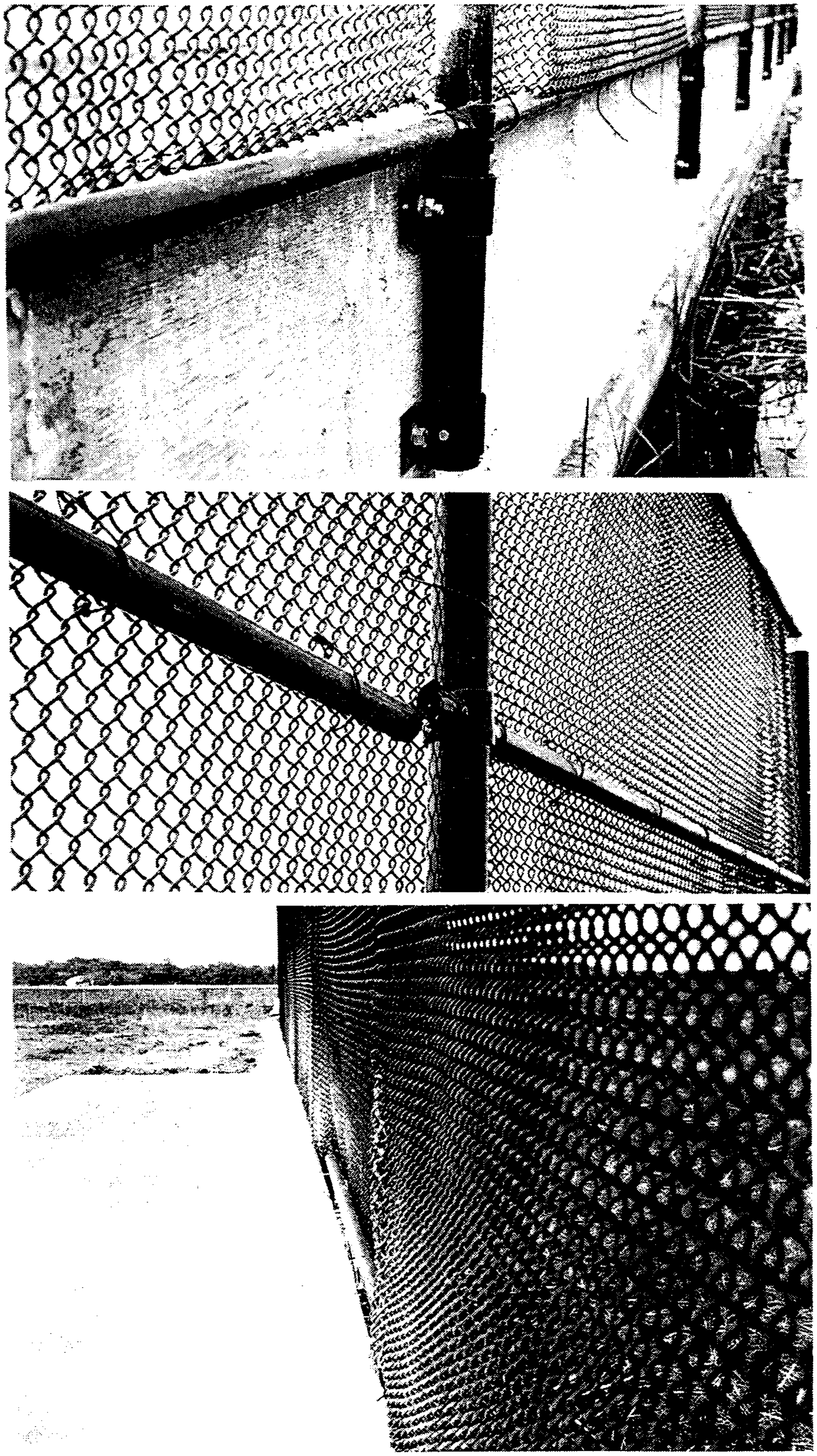


Figure 46. Damage to vandal protection fence after test 472070-6.

Damage to Test Vehicle

The vehicle sustained moderate damage as shown in figure 47. The stabilizer bar, floorpan, frame and front axle on the right side were bent and the windshield was cracked. The front bumper, hood, grill, right front quarter panel, both doors, and rear quarter panel were damaged. There was a small fold running diagonally in the floorpan of the occupant compartment. Maximum exterior crush at the right front corner of the vehicle was 170 mm (6.7 in). There was 70 mm (2.8 in) deformation into the occupant compartment of the firewall on the passenger side of the vehicle.

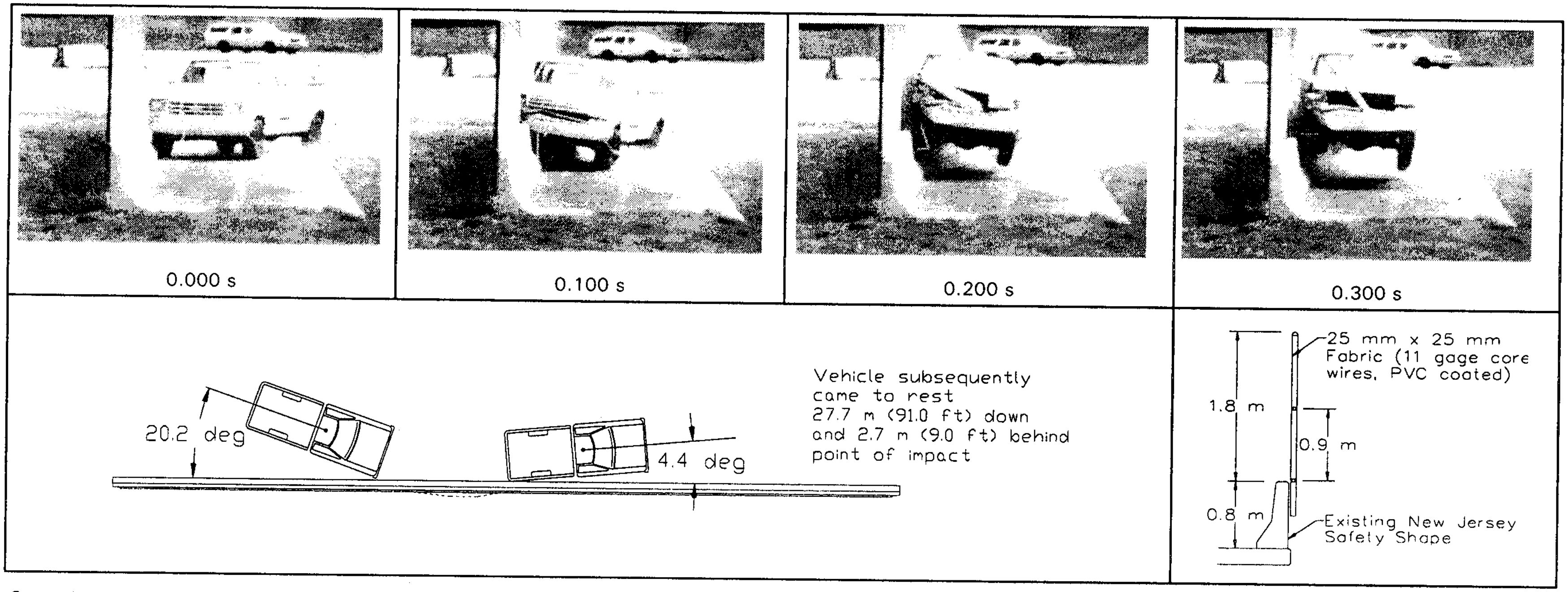
Occupant Risk Values

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. The longitudinal occupant impact velocity was 5.0 m/s (16.5 ft/s) at 0.184 second, the highest 0.010-second longitudinal occupant ridedown acceleration was -5.6 g between 0.184 and 0.194 second, and the maximum 0.050-second average was -8.4 g between 0.025 and 0.075 second. Lateral occupant impact velocity was 2.8 m/s (9.1 ft/s) at 0.226 second, the highest 0.010-second lateral occupant ridedown acceleration was -7.6 g between 0.195 second and 0.205 second, and the maximum 0.050-second average acceleration was -5.4 g between 0.780 and 0.830 second. These data and other information pertinent to the test are summarized in figure 48. Vehicular angular displacements during the test are displayed in appendix D, figure 84. Vehicular accelerations versus time traces filtered at 60 Hz are presented in appendix E, figures 101 through 103.

FINDINGS AND CONCLUSIONS

The vandal protection fence mounted on the New Jersey safety shape bridge railing successfully contained and redirected the vehicle and met all evaluation criteria set forth in the AASHTO *Guide Specifications for Bridge Railings* PL2 conditions for the pickup test. The vehicle did not penetrate or go over the installation. There was no measurable deformation to the safety shape and maximum deflection of the fence was 142 mm (5.6 in) measured at the top of the fence. Presence of the fence itself did not result in adverse performance. There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained moderate damage with minimal deformation (70 mm (2.8 in)) 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 4.4 degrees. The coefficient of friction was calculated at 0.32. The occupant risk factors were well within the desirable limits. In summary, the impact performance of the vandal protection fence on the New Jersey safety shape bridge railing was considered satisfactory according to guidelines set forth by AASHTO, as shown in table 9.

Figure 47. Vehicle after test 472070-6.



General Information	
Test Agency	Texas Transportation Institute
Test No.	472070-6
Date	03/10/95
Test Article	
Type	Retrofit Bridge Rail
Name	Vandal Protection Fence on NJSS
Installation Length (m)	30 m (100 ft)
Size and/or dimension and material of key elements	1.8 m (6.0 ft) tall 25 mm x 25 mm (1 in x 1 in) Fabric (11 gauge core wires,PVC coated)
Soil Type and Condition	on bridge deck, dry
Test Vehicle	
Type	Production
Designation	Pickup
Model	1991 Ford F250
Mass (kg) Curb	2208 (4863 lb)
Test Inertial	2450 (5397 lb)
Dummy	75 (165 lb)
Gross Static	2525 (5562 lb)

Impact Conditions	
Speed (km/h)	101.1 (62.8 mi/h)
Angle (deg)	20.2
Exit Conditions	
Speed (km/h)	79.6 (49.5 mi/h)
Angle (deg)	4.4
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.0 (16.5 ft/s)
y-direction	2.8 (9.1 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-5.6
y-direction	-7.6
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-8.4
y-direction	-5.4
z-direction	-8.0

Test Article Deflections (m)	
Dynamic	0.14 (0.47 ft)
Permanent	0.08 (0.25 ft)
Vehicle Damage	
Exterior	
VDS	0IRFQ5
CDC	01FREK2 & 01RDES3
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	170 (6.7 in)
Max. Occ. Compart. Deformation (mm)	70 (2.8 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	30
Max. Pitch Angle (deg)	9
Max. Yaw Angle (deg)	-19

Figure 48. Summary of results for test 472070-6.

Table 9. Assessment of results of test with the pickup on the vandal protection fence (according to AASHTO PL2 pickup truck test).

Test Agency: Texas Transportation Institute | Test No.: 472070-6 | Test Date: 03/10/95

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
A. The test shall contain the vehicle: neither the vehicle no its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	Vehicle was contained. There was no measurable deflection of the safety shape and only 142 mm (5.6 in) deflection of the fence.	Pass
B. 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.	There were no detached elements or other debris to penetrate or show undue hazard to other traffic.	Pass
C. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was 70 mm (2.8 in) deformation to the occupant compartment.	Pass
D. The vehicle shall remain upright during and after collision.	The vehicle remained upright during and after the collision.	Pass
E. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
F. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment .32 — Fair	Pass
G. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30) — Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15 — Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 5.0 (16.5) — Lateral 2.8 (9.1) Occupant Ridedown Accelerations - g's Longitudinal -5.6 — Lateral -7.6	Pass
H. Vehicle exit angle from the barrier shall not be more than 12 degrees.	Exit angle was approximately 4.4 degrees.	Pass

**A, B, C, and D are required. E, F, G, and H are desired.*

DELAWARE RETROFIT BRIDGE RAILING

TEST ARTICLE

A prototype Delaware retrofit bridge railing was constructed for this crash test. Total installation length was 30 m (100 ft) as shown in figure 49. A cross section of the prototype test installation is shown in figure 50 and photographs of the completed installation are shown in figure 51. The simulated deck and curb with reinforcing steel without a bridge railing was constructed. Then the retrofit railing was added to duplicate construction of a retrofit railing in the field.

Concrete strength measured from standard 152 mm by 305 mm (6 in by 12 in) test cylinders was 29 696 kPa (4310 psi). Static load pull-out tests were performed on the traffic-side anchor bolts after the crash test was performed. The average ultimate pull-out strength of three anchors was 27 871 kg (61 390 lb) with the lowest being 25 905 kg (57 060 lb).

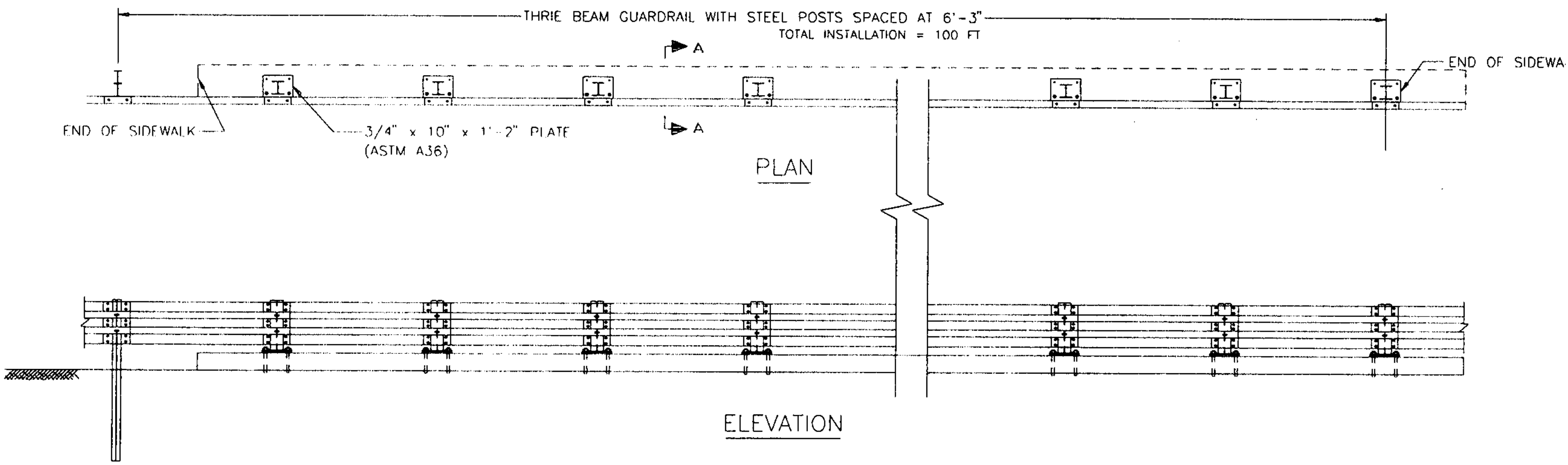
CRASH TEST RESULTS

Test 472070-7

One crash test was conducted on the Delaware retrofit bridge railing. The test was an AASHTO performance level two single-unit truck test and NCHRP Report 350 test designation 4-12 with a 8000 kg (17 621 lb) single-unit truck, impacting the length-of-need section at a nominal speed and angle of 80 km/h (50 mi/h) and 15 degrees. The impact point was selected to be 1.04 m (3.4 ft) upstream of the splice near the 1/3 point of the test installation. The purpose of this crash test is to evaluate the strength of the section in containing and redirecting the single-unit truck. A brief description of the results of the crash test is presented in the following section.

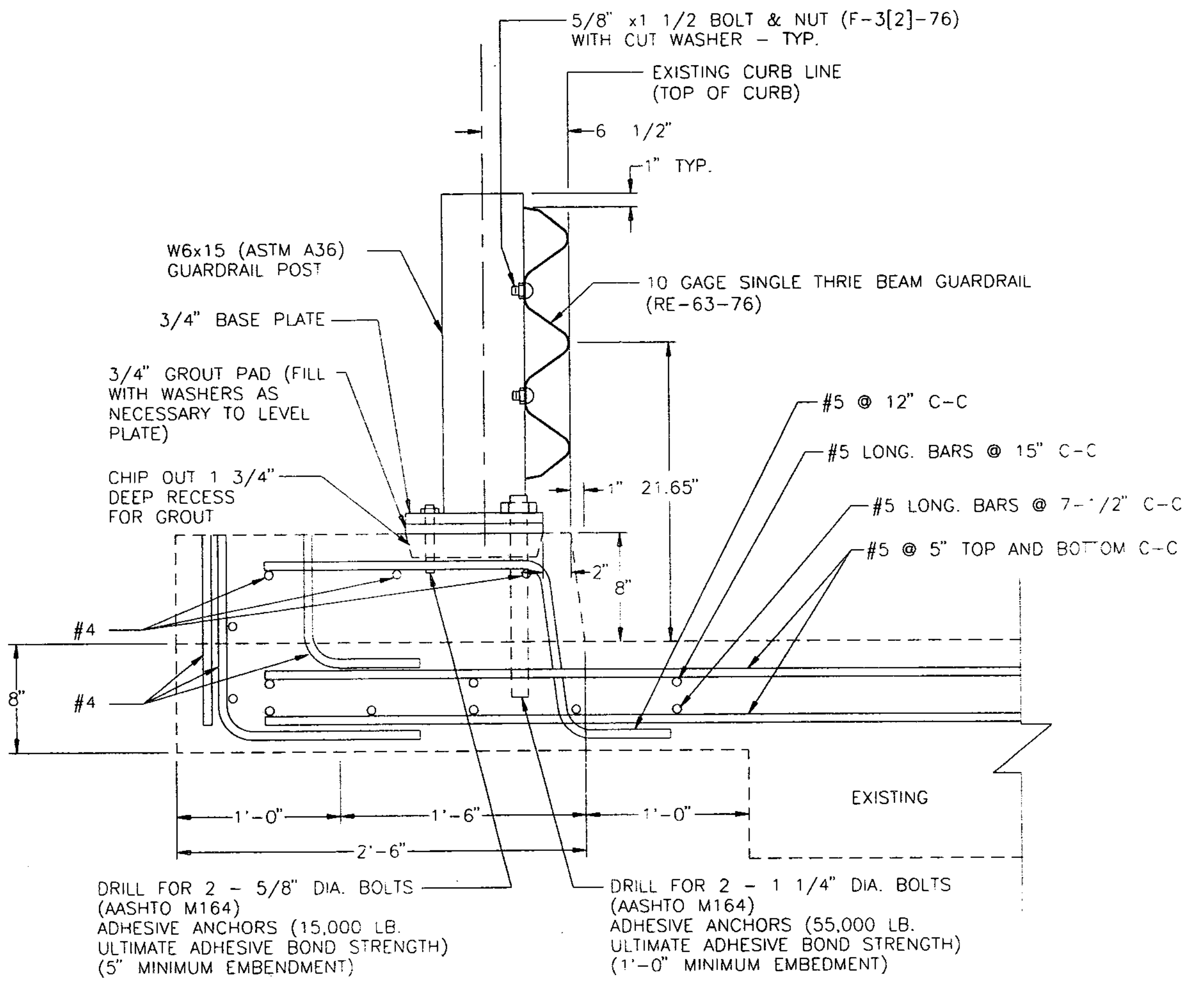
Test Description

A 1985 GMC single-unit truck (shown in figures 52 and 53) was used for the crash test. The empty weight of the vehicle was 4722 kg (10 401 lb) and test inertia weight was 8000 kg (17 621 lb). The heights to the upper and lower edges of the vehicle bumper were 860 mm (33.9 in) and 540 mm (21.3 in), respectively. Additional dimensions and information on the vehicle are given in appendix B, figure 65. 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.



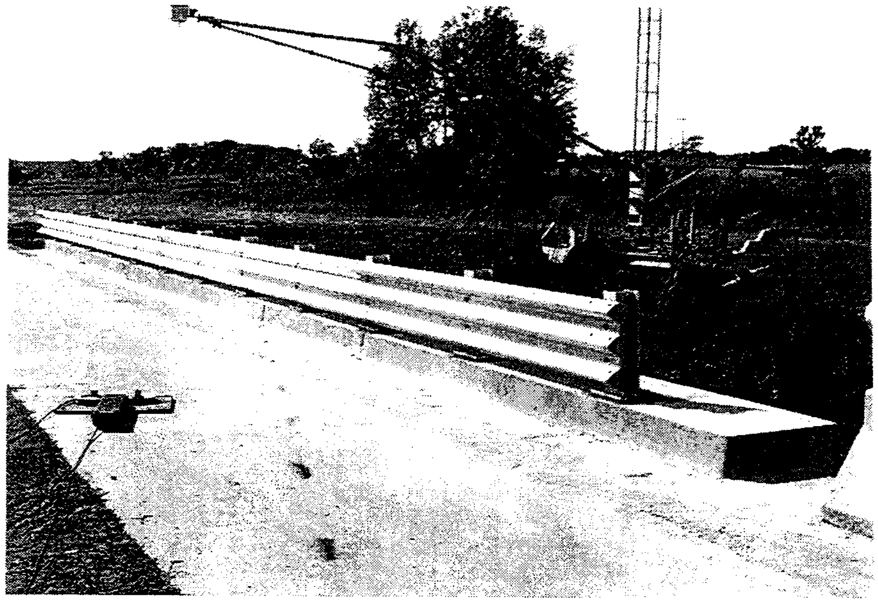
1 ft = 0.305 m
1 in = 25.4 mm

Figure 49. Layout of the Delaware retrofit bridge railing.



1 ft = 0.305 m
1 in = 25.4 mm

Figure 50. Cross section of the Delaware retrofit bridge railing.



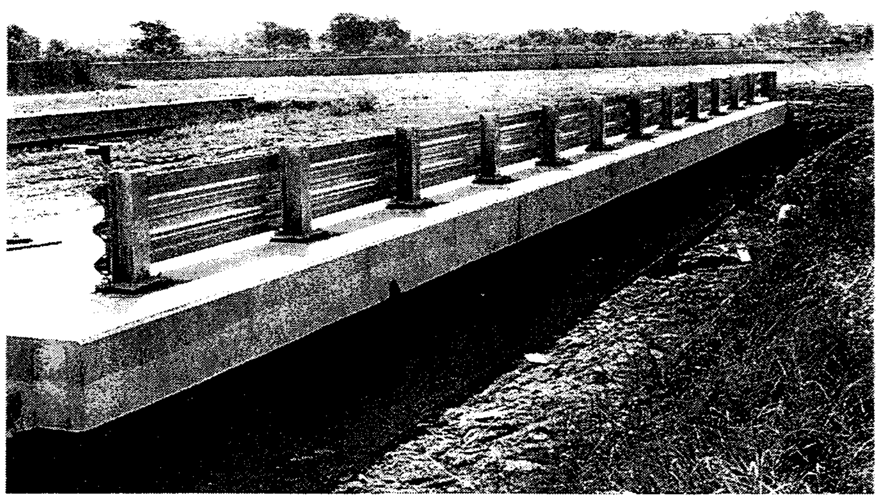


Figure 51. Delaware retrofit bridge railing installation.

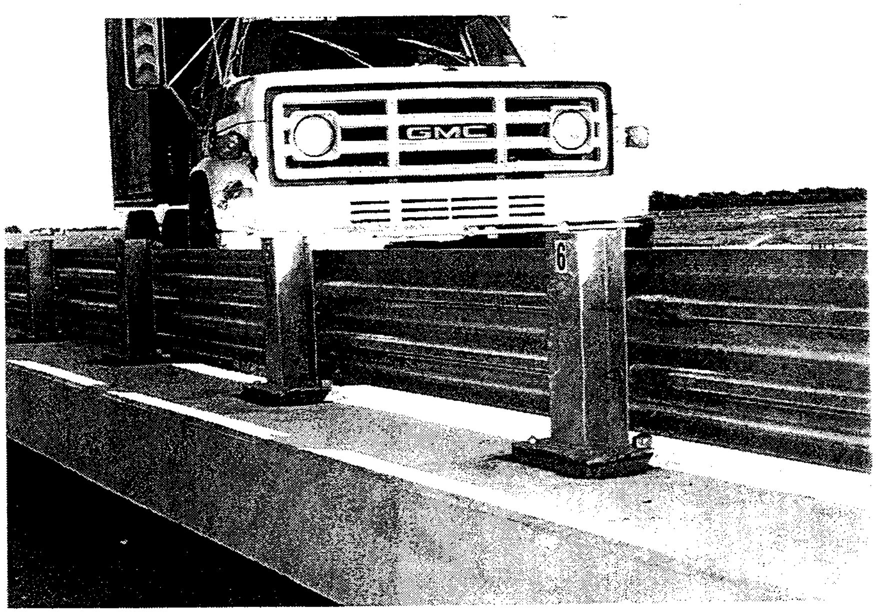


Figure 52. Vehicle/bridge rail geometrics for test 472070-7.

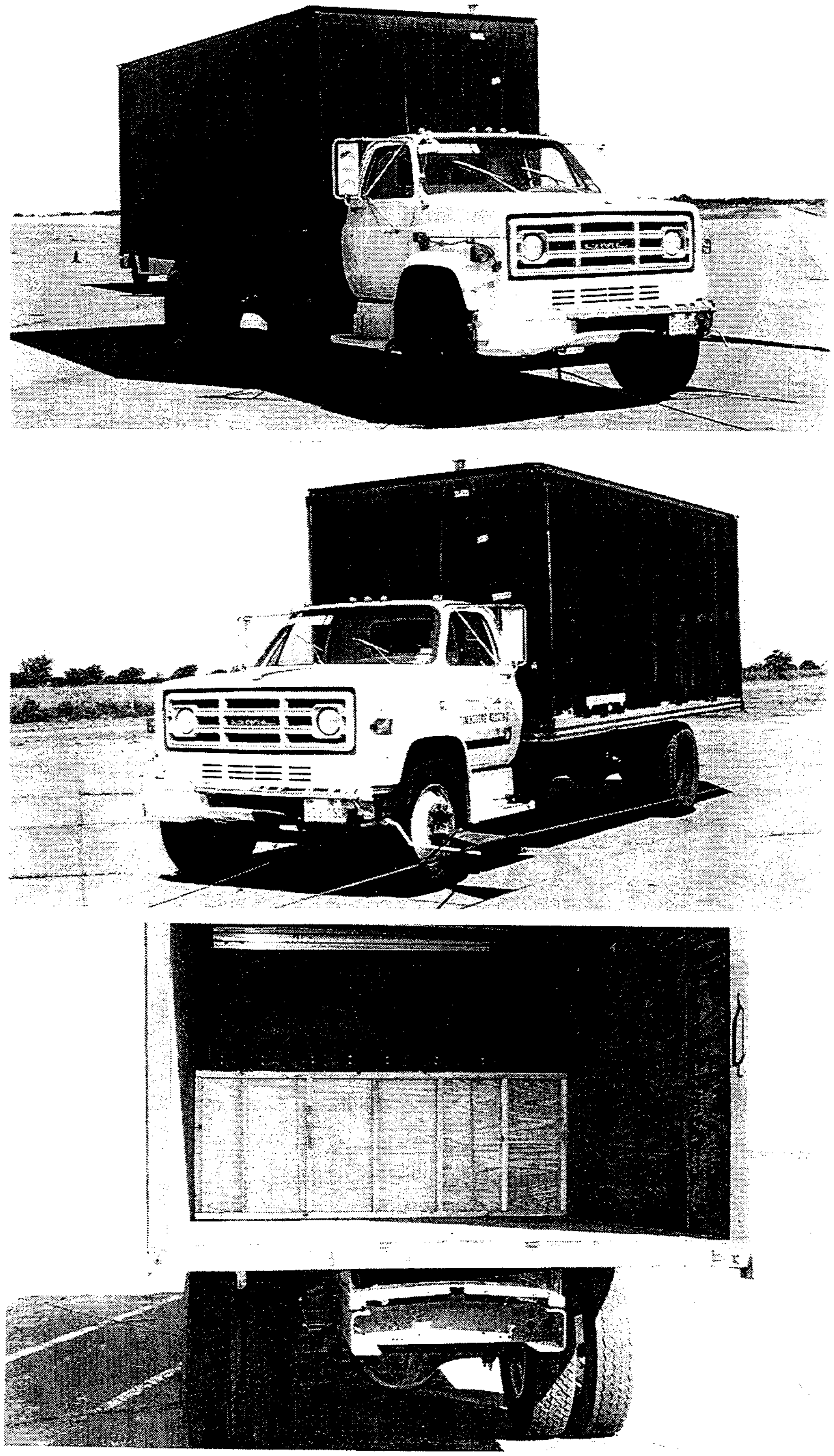


Figure 53. Vehicle prior to test 472070-7.

The vehicle bumper contacted the length-of-need section of the Delaware retrofit bridge railing 0.5 m (1.6 ft) downstream of post 4. The vehicle was traveling at a speed of 83.1 km/h (51.7 mi/h) and at an angle of 14.2 degrees at time of impact. Redirection of the vehicle began at 0.119 second. The rear of the vehicle made contact with the bridge railing at 0.297 second. At 0.343 second the vehicle became parallel with the installation, traveling at 77.1 km/h (47.9 mi/h). The vehicle continued to roll clockwise onto the bridge railing with the box-van riding on top of the thrie beam element. The vehicle reached a maximum roll angle of 44 degrees at 1.097 second before it rode off the end of the bridge railing and righted itself. As the vehicle exited the installation, it was traveling at a speed of 63.5 km/h (39.5 mi/h) and exit angle of approximately 0 degrees. Brakes were applied as the vehicle exited the test area, and the vehicle subsequently came to rest 53.7 m (176.5 ft) beyond the point of impact and aligned with the traffic face of the bridge railing. Sequential photographs are shown in appendix C, figures 78 and 79.

Damage to Test Installation

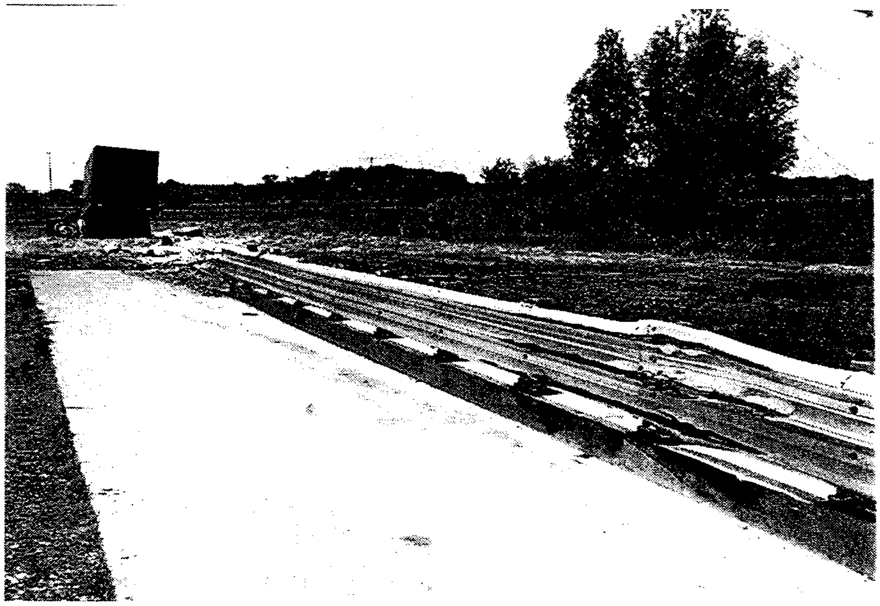
As seen in figures 54 through 56, the installation received moderate damage. There were tire marks on the face of the curb from the point of impact for 4.1 m (13.3 ft). Initial length of contact with the thrie beam rail element was 5.1 m (16.8 ft). Maximum residual deformation was 114 mm (4.5 in) near post 5. The grout around post 4 and 5 was disturbed, but there were no cracks in the curb. The box-van made contact with the tops of post 5 through 13. Post 8 through 10 were twisted about their vertical axis and post 11 was bent slightly. The thrie beam element was pulled away from post 13 and the post was bent laterally. Total length of contact with the installation was 18.6 m (61.0 ft).

Damage to Test Vehicle

The vehicle sustained moderate damage as shown in figure 57. The front axle was separated from the vehicle. There was damage to the front suspension, springs, U-bolts, and steering arm. Damage was also done to the bumper, hood, grill, right front quarter-panel, right door, fuel tank, and right rear outside rim and tire. The right side and floor of the box-van was torn open. Maximum exterior crush at the right front corner of the vehicle was 320 mm (12.6 in).

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 at 0.241 second. The longitudinal occupant impact velocity was 2.9 m/s (9.6 ft/s) at 0.402 second, the highest 0.010-second longitudinal occupant ridedown acceleration was -4.1 g between 0.548 and 0.558 second, and the maximum 0.050-second



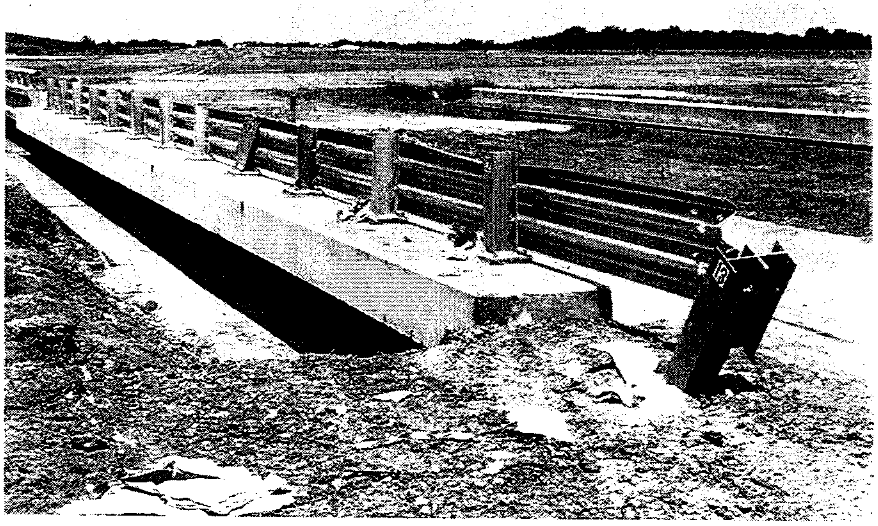


Figure 54. Delaware retrofit bridge railing after test 472070-7.

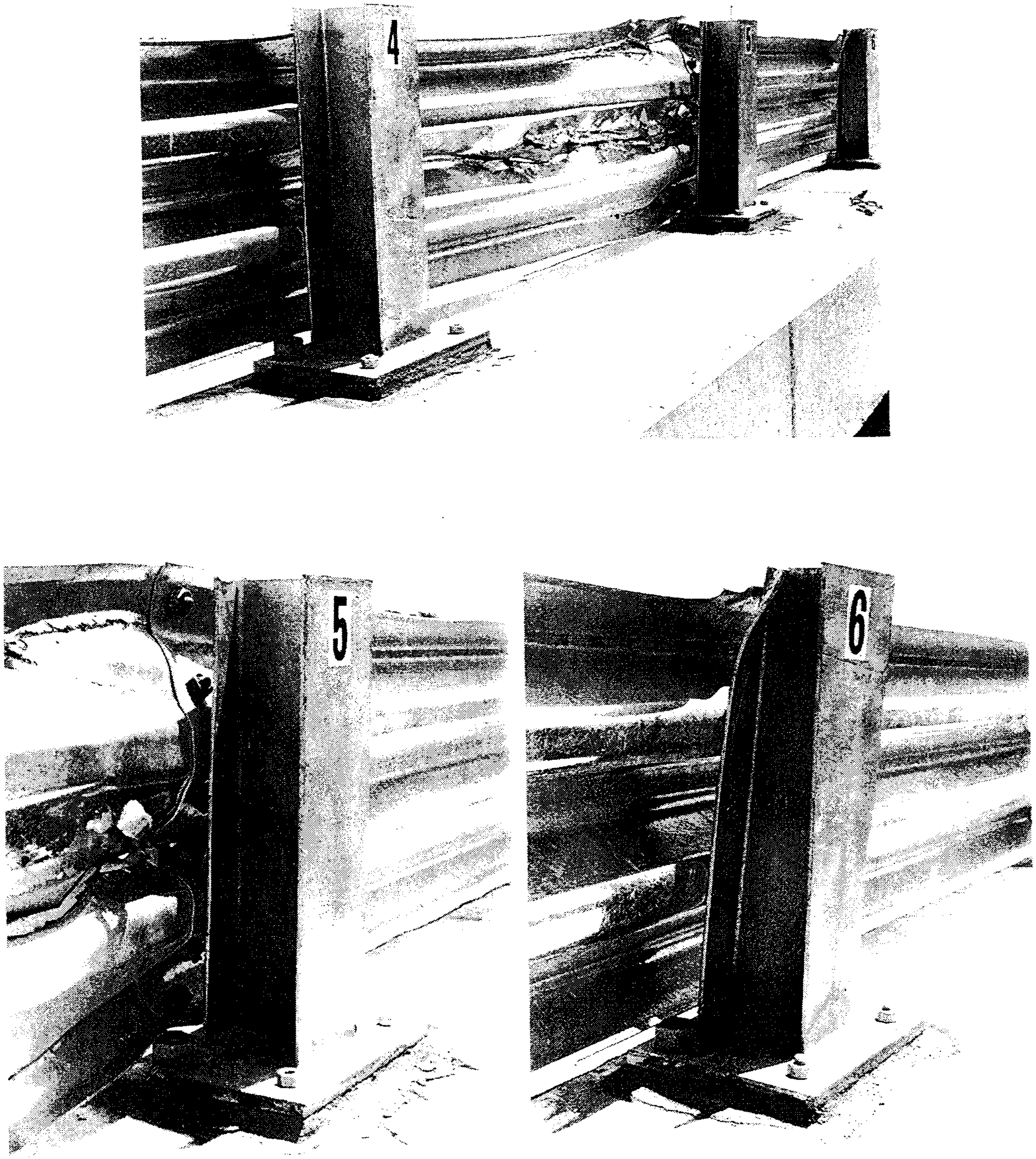


Figure 55. Damage to posts 4 through 6 after test 472070-7.

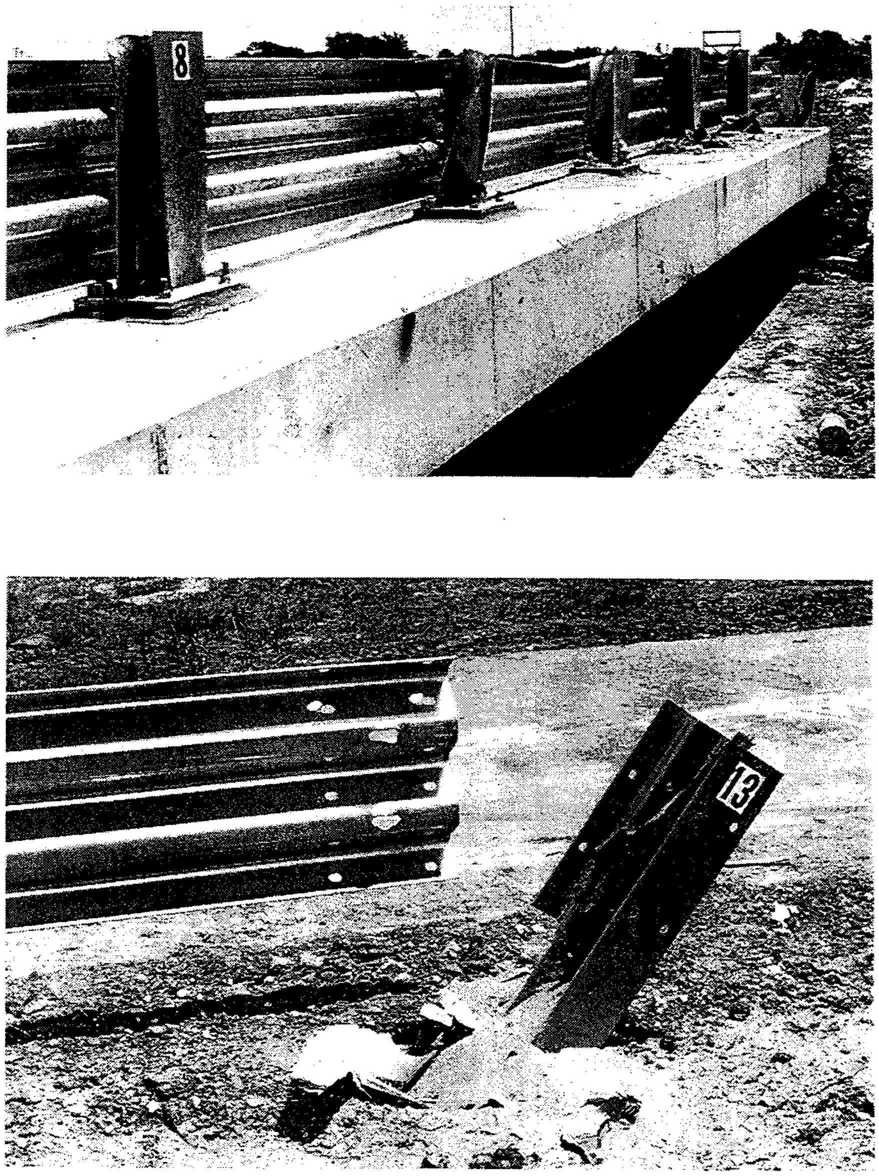


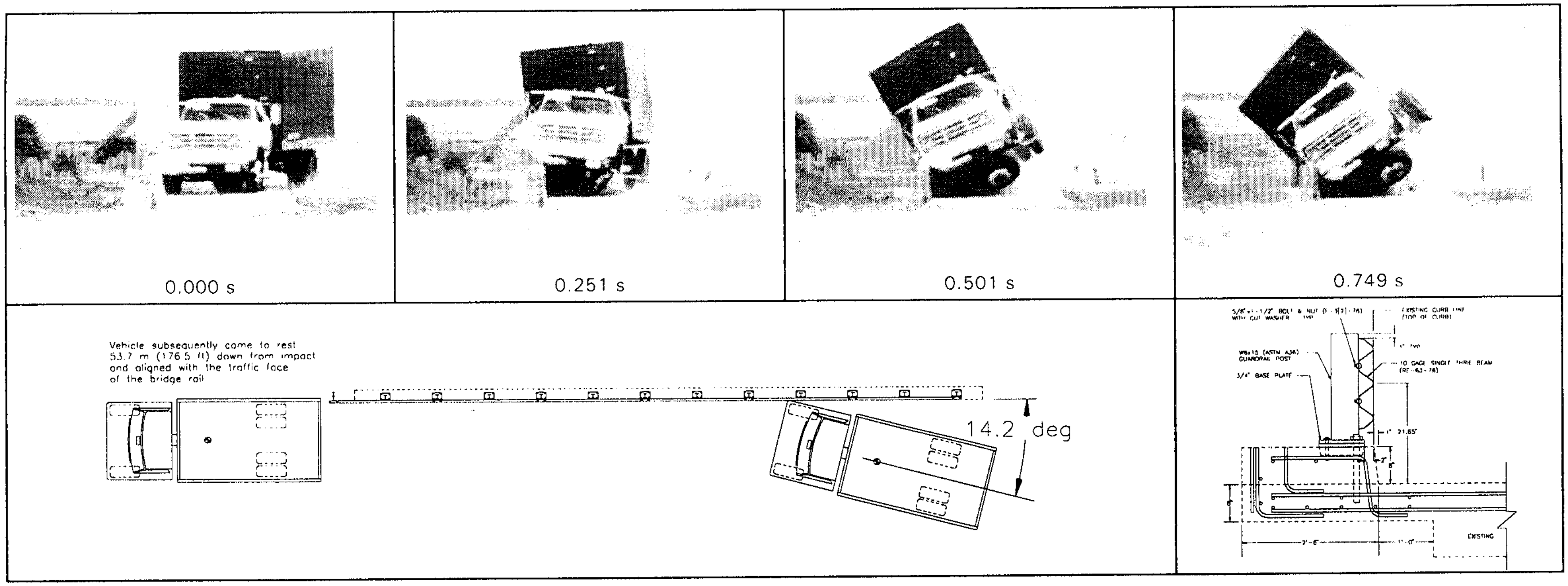
Figure 56. Damage to posts 8 through 13 after test 472070-7.

Figure 57. Vehicle after test 472070-7.

average was -2.5 g between 0.526 and 0.576 second. Lateral occupant impact velocity was 3.3 m/s (10.7 ft/s) at 0.241 second. the highest 0.010-second lateral occupant ridedown acceleration was -5.8 g between 0.613 second and 0.623 second, and the maximum 0.050-second average acceleration was -3.0 g between 0.310 and 0.360 second. These data and other information pertinent to the test are summarized in figure 58. Vehicular angular displacements during the test are displayed in appendix D, figure 85. Vehicular accelerations versus time traces filtered at 60 Hz are presented in appendix E, figures 104 through 110.

FINDINGS AND CONCLUSIONS

The Delaware retrofit bridge railing successfully contained and redirected the vehicle and met all evaluation criteria set forth for the AASHTO *Guide Specifications for Bridge Railings* PL2 test for the single-unit truck test and the NCHRP Report 350 test no. 4-12 test. The vehicle did not penetrate or go over the installation. The maximum deflection of the bridge railing was 114 mm (4.5 in). There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained moderate damage with no 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 0 degrees. The coefficient of friction was calculated at 0.17. The occupant risk factors were well within the desirable limits. In summary, the impact performance of the Delaware retrofit bridge railing was considered satisfactory according to guidelines set forth by AASHTO, as shown in table 10, and NCHRP Report 350, as shown in table 11.



General Information	
Test Agency	Texas Transportation Institute
Test No.	472070-7
Date	05/02/95
Test Article	
Type	Bridge Rail
Name	Delaware
Installation Length (m)	30 m (100 ft)
Size and/or dimension and material of key elements	10 gauge thrie beam on W6x15 steel posts on 203 mm (8 in) curb
Soil Type and Condition	Bridge deck, dry
Test Vehicle	
Type	Production
Designation	8000S
Model	1985 GMC 6000
Mass (kg) Curb	4722 (10 401 lb)
Test Inertial	8000 (17 621 lb)
Dummy	No Dummy
Gross Static	8000 (17 621 lb)

Impact Conditions	
Speed (km/h)	83.1 (51.7 mi/h)
Angle (deg)	14.2
Exit Conditions	
Speed (km/h)	63.5 (39.5 mi/h)
Angle (deg)	approx. 0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.9 (9.6 ft/s)
y-direction	3.3 (10.7 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.1
y-direction	-5.8
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-2.5
y-direction	-3.0
z-direction	2.1

Test Article Deflections (mm)	
Dynamic	N/A
Permanent	114 (4.5 in)
Vehicle Damage	
Exterior	
VDS	
CDC	
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	320 (12.6 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	44
Max. Pitch Angle (deg)	-8
Max. Yaw Angle (deg)	-13

Figure 58. Summary of results for test 472070-7.

Table 10. Assessment of results of test with single-unit truck on Delaware bridge rail (according to AASHTO PL2 single-unit truck test).

Test Agency: Texas Transportation Institute | Test No.: 472070-7 | Test Date: 05/02/95

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
A. The test shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	Vehicle was contained; neither the vehicle nor its cargo penetrated or went over the bridge rail. There was 114 mm (4.5 in) maximum deflection of the bridge rail.	Pass
B. 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.	There were no detached elements or other debris to penetrate or show undue hazard to other traffic.	Pass
C. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was no deformation to the occupant compartment.	Pass
D. The vehicle shall remain upright during and after collision.	The vehicle remained upright during and after the collision.	Pass
E. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
F. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment .17 — Good	Pass
G. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 2.9 (9.6); Lateral 3.3 (10.7) Occupant Ridedown Accelerations - g's Longitudinal -4.1; Lateral -5.8	N/A
H. Vehicle exit angle from the barrier shall not be more than 12 degrees.	Exit angle was approximately 0 degrees.	Pass

**A, B, and C are required. D, E, F, and H are desired. G is not applicable for this test.*

Table 11. Assessment of results of test with single-unit truck on Delaware bridge rail (according to NCHRP Report 350 test 4-12).

Test Agency: Texas Transportation Institute | Test No.: 472070-7 | Test Date: 05/02/95

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Delaware bridge rail contained and redirected the vehicle; the vehicle did not penetrate, underride or override the bridge rail. There was a maximum deformation of the bridge rail of 114 mm (4.5 in).	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 debris to show potential for penetrating the occupant compartment or to present undue hazard to other traffic. There was no deformation into the occupant compartment.	Pass
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	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.	The vehicle came to rest 54 m (177 ft) down from the point of impact and aligned with the traffic face of the bridge rail	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 exit angle was approximately 0 degrees.	Pass

APPENDIX A.
CRASH TEST AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures were in accordance with guidelines presented in NCHRP Report 350.[2] Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicles were instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer near the vehicle center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels; and a biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. In the 8000S (or 18 000 lb) single-unit truck, an additional biaxial accelerometer was placed in the front of the vehicle. 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 test installation.

The multiplex of data channels, transmitted on one radio frequency, were received at the data acquisition station, and demultiplexed into separate tracks of Inter-Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with an SAE J211 filter, and digitized using a microcomputer, for analysis and evaluation of impact performance. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are provided as follows.

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

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

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 small cars and pickups. The dummy was un-instrumented; however, a high-speed onboard camera recorded the motions of the dummy during the test. No dummy was used in the 8000S (18 000 lb) single-unit truck.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one placed behind the installation at an angle; one 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 installation at the downstream end. A fourth high-speed camera was placed on-board the small cars and pickups to observe the motions of the dummy. A flash bulb activated by pressure sensitive tapeswitches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement and angular data. A 16-mm movie cine, a Betacam and a VHS-format video camera and recorder, and still cameras were used for documentary purposes to record the conditions of the test vehicle and test installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. The system had 2 to 1 speed ratio between the test and tow vehicle. 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 it cleared the immediate area of the test site. at which time brakes on the vehicle were activated to bring it to a safe and controlled stop.

APPENDIX B.
VEHICLE PROPERTIES

This section provides additional physical properties of the vehicles used during the crash tests performed under this study.

DATE: 09/29/93 TEST NO.: 472070-1 VIN NO.: VX1BA121SJK397919 MAKE: Yugo

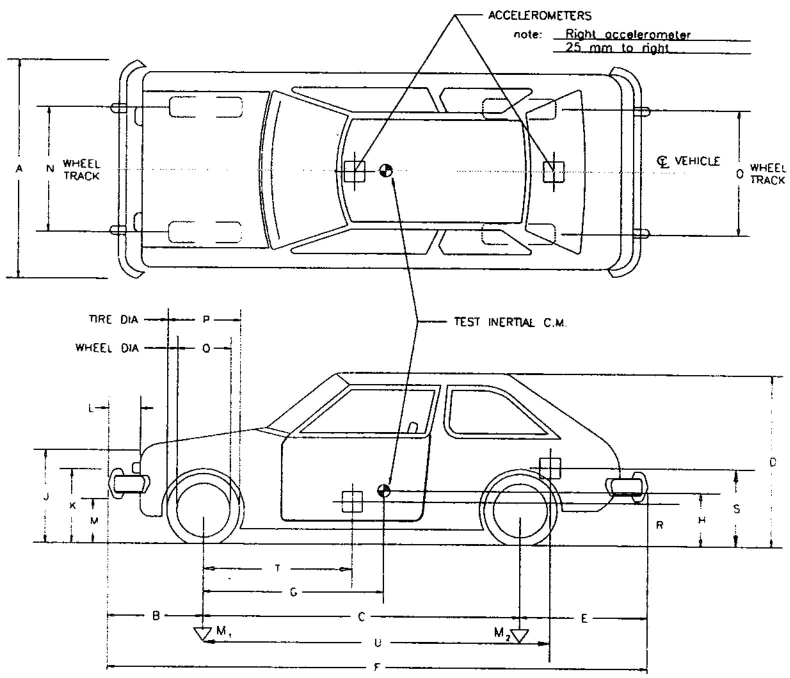
MODEL: GV YEAR 1988 ODOMETER: 40335 TIRE SIZE: 155 R 13

TIRE INFLATION PRESSURE: ______

MASS DISTRIBUTION (kg) LF 266 RF 245 LR 143 RR 163

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Small crack in windshield (marked)



ENGINE TYPE: 4 cylinder

ENGINE CID: 1100 cc

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1461	E	610	J	762	N	1308	R	375
B	699	F	3448	K	559	O	1257	S	673
C	2140	G		L	70	P	591	T	781
D	1397	H		M	356	Q	356	U	2388

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	541	511	545
M_2	277	306	347
M_T	818	817	892

Figure 59. Vehicle properties for test 472070-1.

DATE: 10-05-93 TEST NO.: 472070-2 VIN NO.: 2FTHF25H2GCA83154 MAKE: Ford

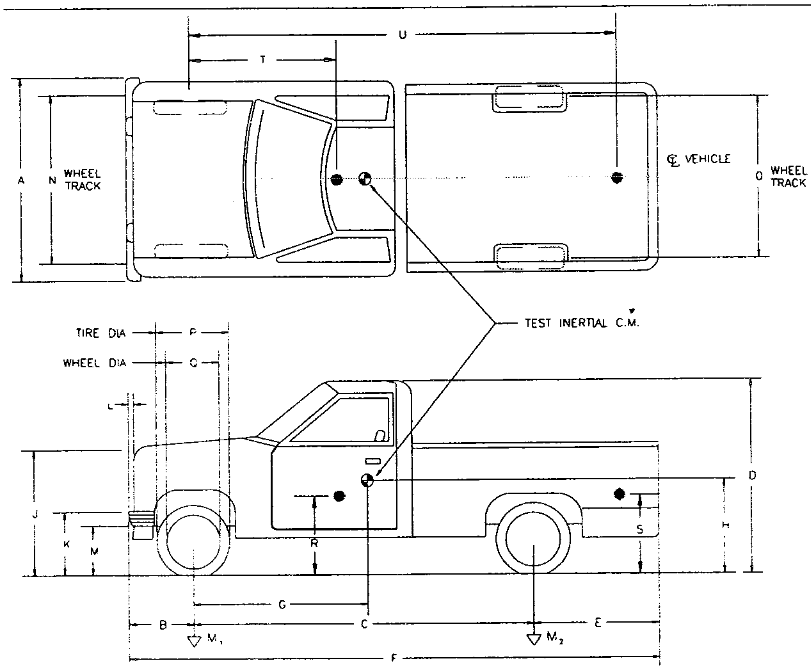
MODEL: F250 YEAR: 1986 ODOMETER: 78241 GVW:

TIRE SIZE: 7.50 R16 LT TIRE INFLATION PRESSURE: TREAD TYPE: Highway

MASS DISTRIBUTION (kg) LF 555 RF 553 LR 656 RR 687

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Crack in windshield (marked)



● Denotes accelerometer location.

NOTES:

ENGINE TYPE: 8 cylinder gas

ENGINE CID: 5.8 L

TRANSMISSION TYPE:

X AUTO

— MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1918	E	1321	J	1143	N	1657	R	768
B	737	F	5436	K	705	O	1638	S	978
C	3378	G	1852	L	38	P	806	T	1880
D	1842	H		M	419	Q	440	U	4267

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1107	1108	1153
M_2	824	1344	1375
M_T	1931	2452	2528

Figure 60. Vehicle properties for test 472070-2.

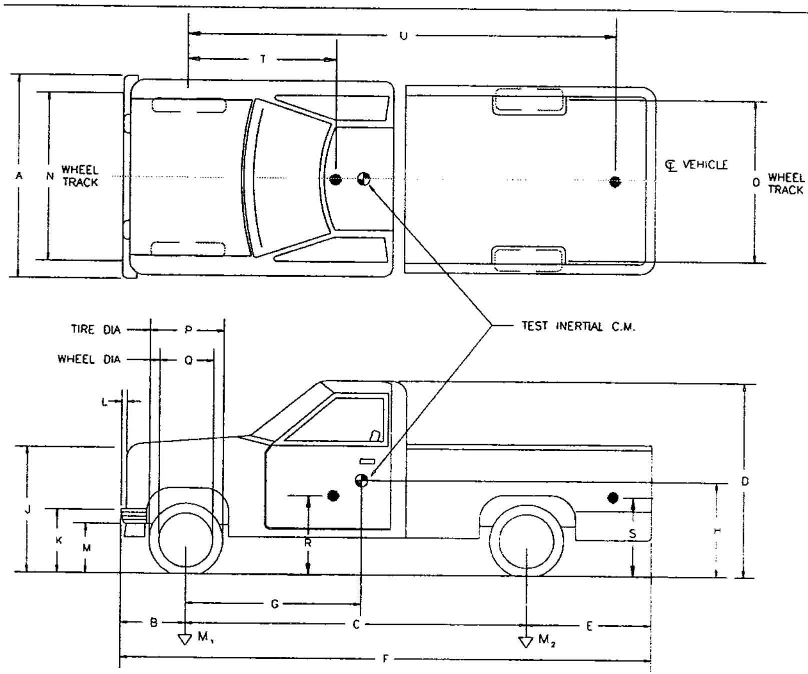
DATE: 07/08/94 TEST NO.: 472070-3 VIN NO.: 1FTHF25H9GKA13260 MAKE: Ford

MODEL: F250 YEAR: 1986 ODOMETER: 92664 GVW: 3900

TIRE SIZE: P 235 85R16 TIRE INFLATION PRESSURE: ______ TREAD TYPE: ______

MASS DISTRIBUTION (kg) LF 553 RF 537 LR 451 RR 459

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 cyl gas

ENGINE CID: 5.8 L

TRANSMISSION TYPE:

X AUTO

— MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc. male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1900	E	1310	J	1195	N	1680	R	770
B	680	F	5370	K	720	O	1630	S	1030
C	3380	G	1538	L	45	P	795	T	1520
D	1890	H		M	495	Q	445	U	4160

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1066	1090	1134
M_2	894	910	942
M_T	1960	2000	2076

Figure 61. Vehicle properties for test 472070-3.

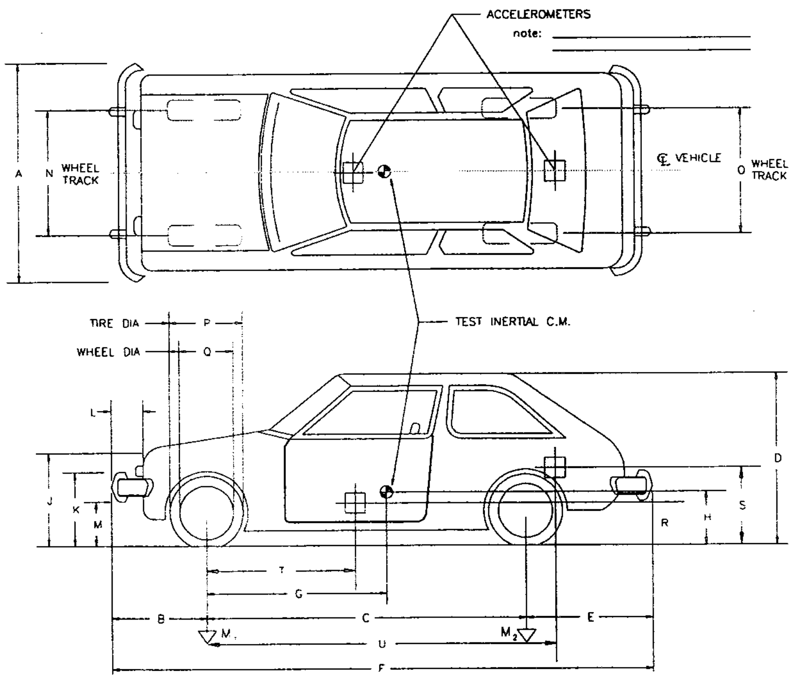
DATE: 08/02/94 TEST NO.: 472070-4 VIN NO.: KNJBT06K8J6153570 MAKE: Ford

MODEL: Festiva L YEAR: 1988 ODOMETER: 138494 TIRE SIZE: 155 R12

TIRE INFLATION PRESSURE:

MASS DISTRIBUTION (kg) LF 250 RF 259 LR 164 RR 147

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cyl gas

ENGINE CID: 1.3 liter

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc. male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1510	E	570	J	790	N	1403	R	380
B	640	F	3510	K	540	O	1385	S	560
C	2300	G	872	L	101	P	535	T	905
D	1410	H		M	247	Q	335	U	2485

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	525	509	549
M_2	279	311	348
M_T	804	820	897

Figure 62. Vehicle properties for test 472070-4.

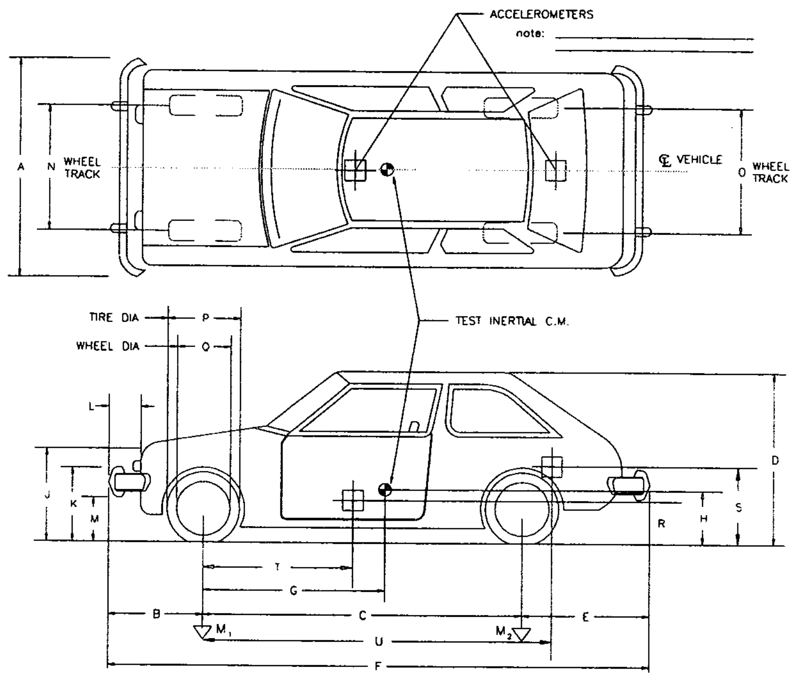
DATE: 01/25/95 TEST NO.: 472070-5 VIN NO.: JG1MR6154JK712644

YEAR: 1988 MAKE: Chevrolet MODEL: Sprint

TIRE INFLATION PRESSURE: ______ ODOMETER: 89012 TIRE SIZE: P145/80R12

MASS DISTRIBUTION (kg) LF 257 RF 233 LR 169 RR 161

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 cylinder

ENGINE CID: 1.0 liter

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc. male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1450	E	650	J	740	N	1330	R	400
B	720	F	3715	K	515	O	1300	S	725
C	2345	G	943.7	L	165	P	535	T	980
D	1340	H		M	330	Q	335	U	2695

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	430	490	531
M_2	283	330	365
M_T	713	820	896

Figure 63. Vehicle properties for test 472070-5.

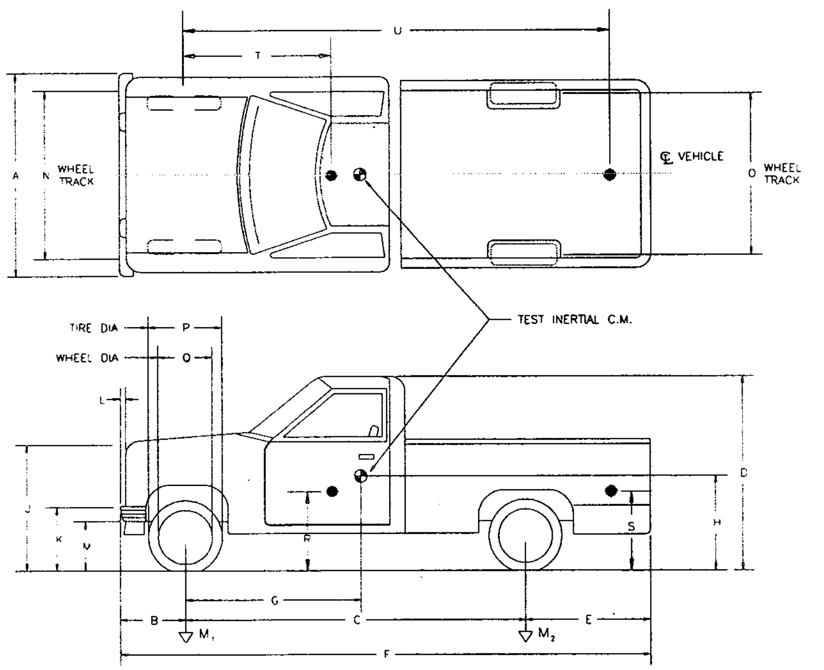
DATE: 03/10/95 TEST NO.: 472070-6 VIN NO.: 1FTHF25G6MNA35976

YEAR: 1991 MAKE: Ford MODEL: F250 Custom

TIRE INFLATION PRESSURE: ______ ODOMETER: 96720 TIRE SIZE: LT235/85R16

MASS DISTRIBUTION (kg) LF 578 RF 596 LR 664 RR 612

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 cyl

ENGINE CID: 7.3 L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc. male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1910	E	1310	J	1235	N	1665	R	800
B	815	F	5505	K	740	O	1650	S	1070
C	3380	G	1757.6	L	950	P	805	T	1875
D	1880	H		M	450	Q	455	U	850

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1255	1174	1220
M_2	953	1274	1305
M_T	2208	2450	2525

Figure 64. Vehicle properties for test 472070-6.

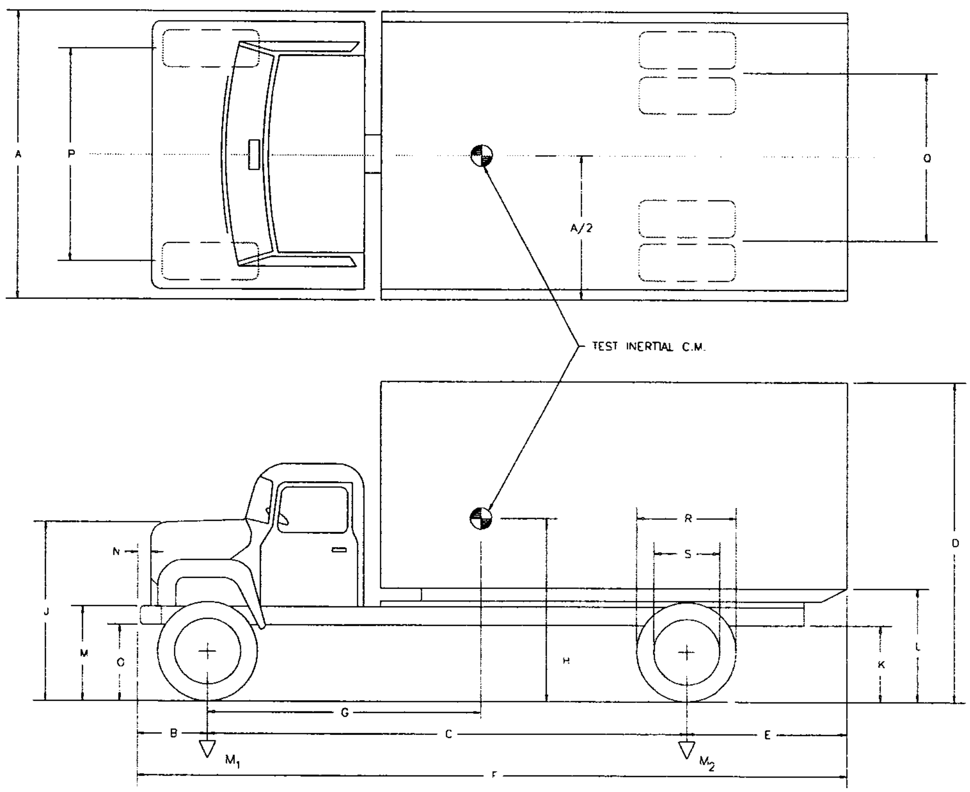
DATE: 05/02/95 TEST NO.: 472070-7 VIN NO.: 1GDG7D1B6FV606430 MAKE: GMC

MODEL: 6000 YEAR: 1985 ODOMETER: ______ TIRE SIZE: 11R22.5

MASS DISTRIBUTION (kg) LF 1560 RF 1778 LR 2367 RR 2295

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Front bumper dented. Windshield cracked.



GEOMETRY–(mm)

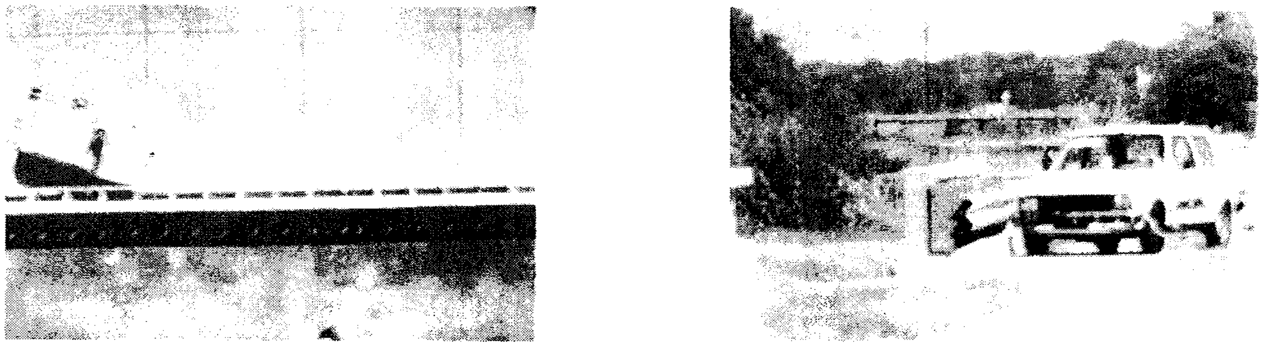
A 2260	D 3379	G 3109	K 735	N 85	Q 1820
B 760	E 2070	H 1245	L 1180	O 540	R 1040
C 5335	F 8165	J 1600	M 860	P 1930	S 600

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	2282	3338	
M_2	2440	4662	
M_T	4722	8000	

Figure 65. Vehicle properties for test 472070-7.

APPENDIX C.
SEQUENTIAL PHOTOGRAPHS

This section contains photographs from high-speed film taken during crash tests performed under this study.



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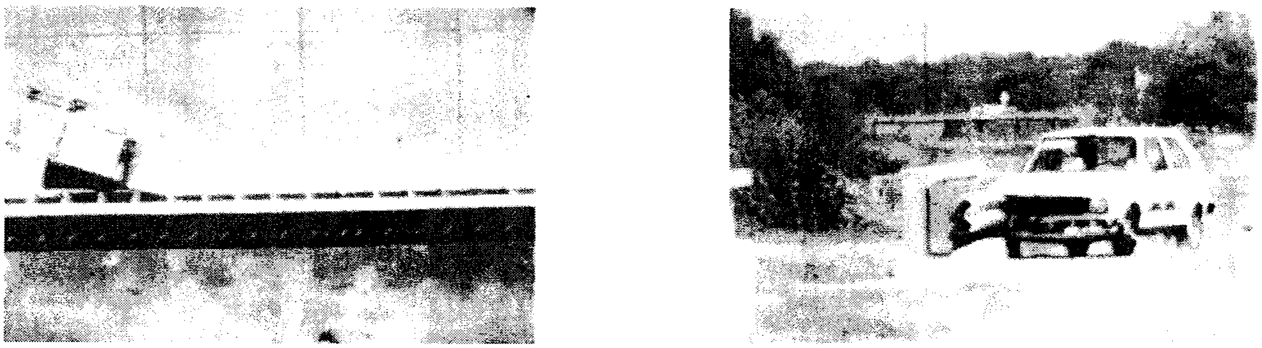
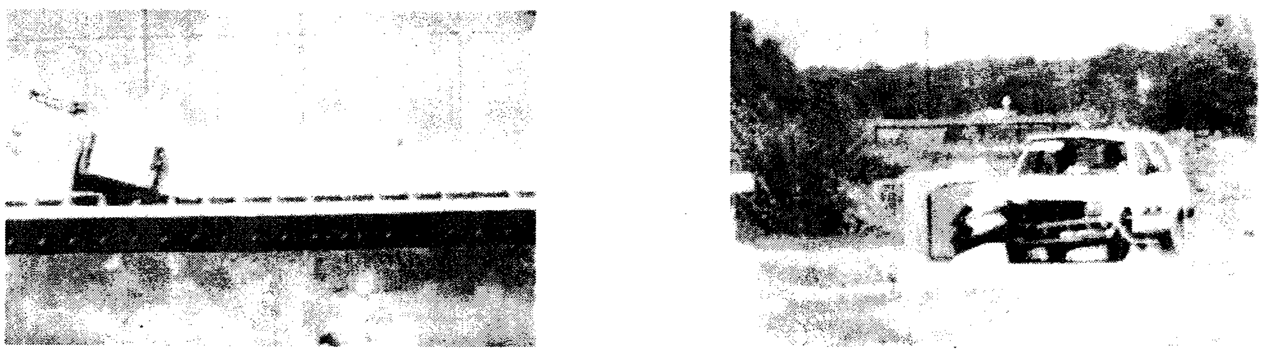
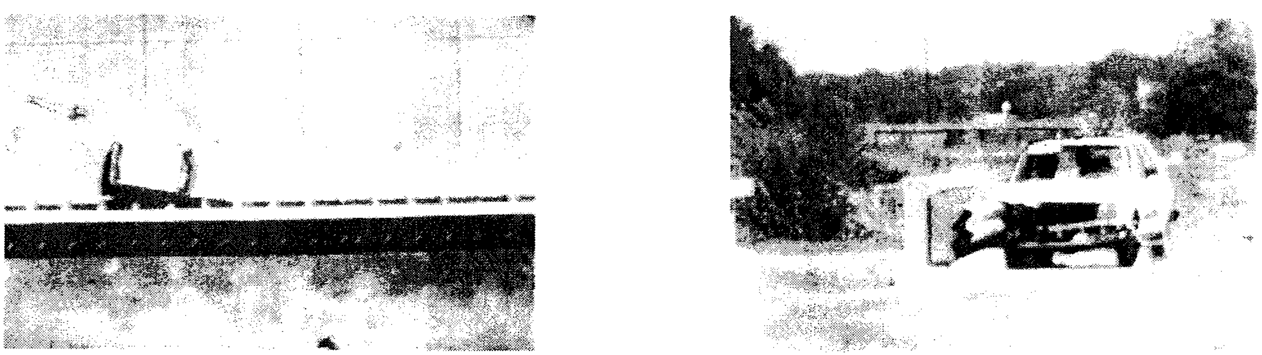


0.040 s

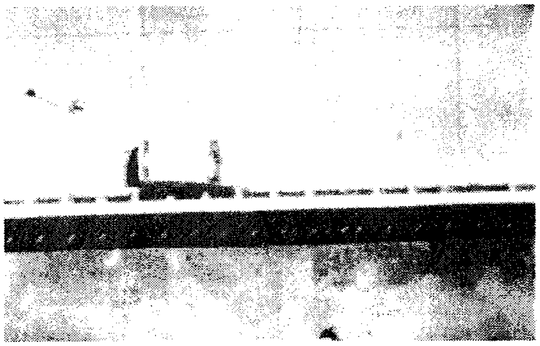
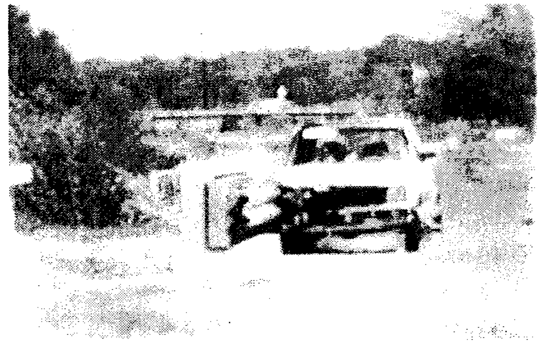


0.079 s

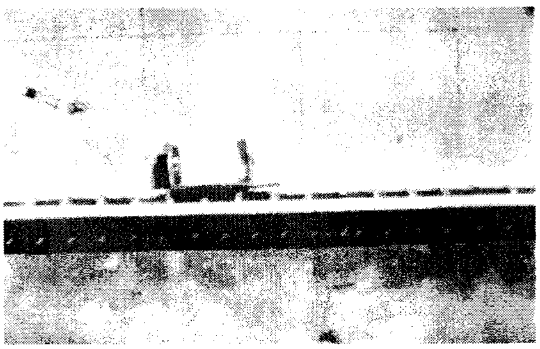


0.119 s

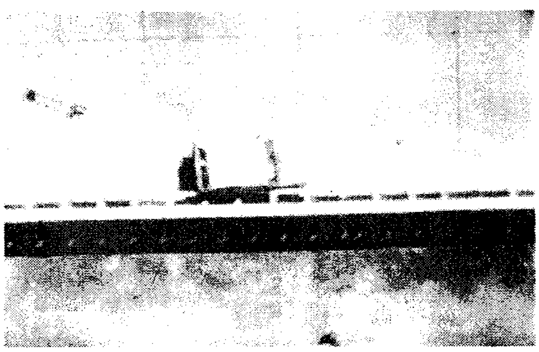
Figure 66. Sequential photographs for test 472070-1 (overhead and frontal views).

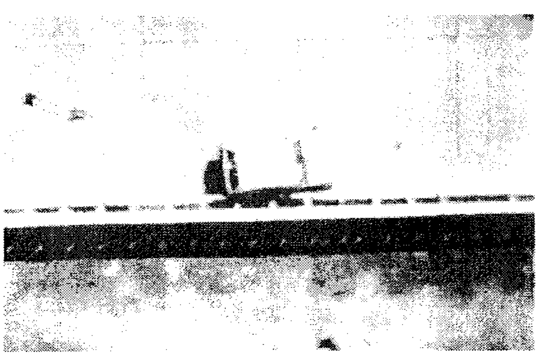
0.158 s




0.200 s

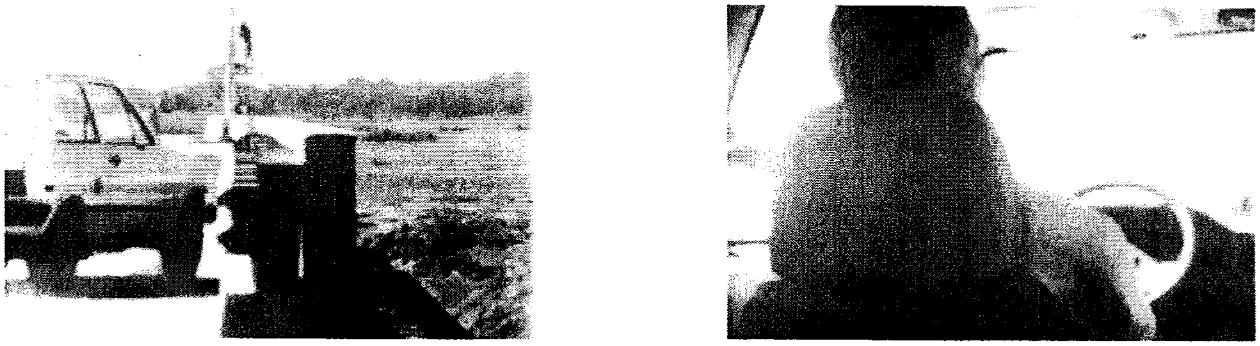



0.240 s

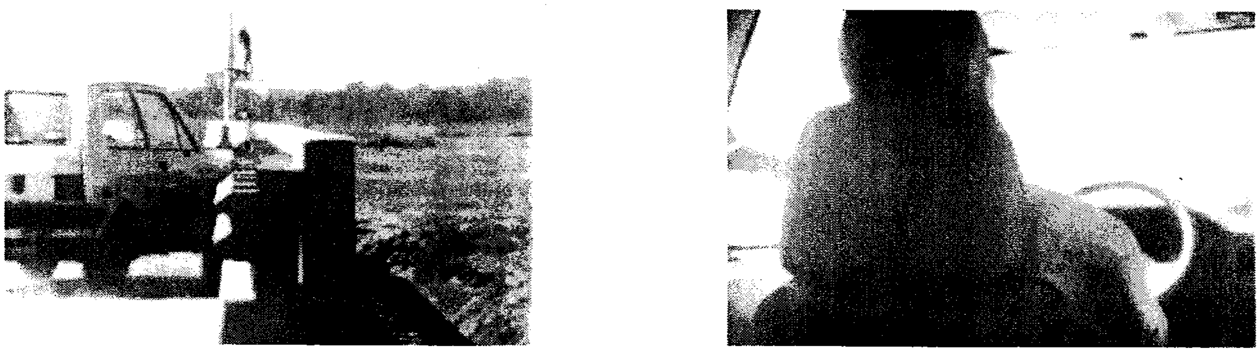



0.279 s

Figure 66. Sequential photographs for test 472070-1 (overhead and frontal views) (continued).

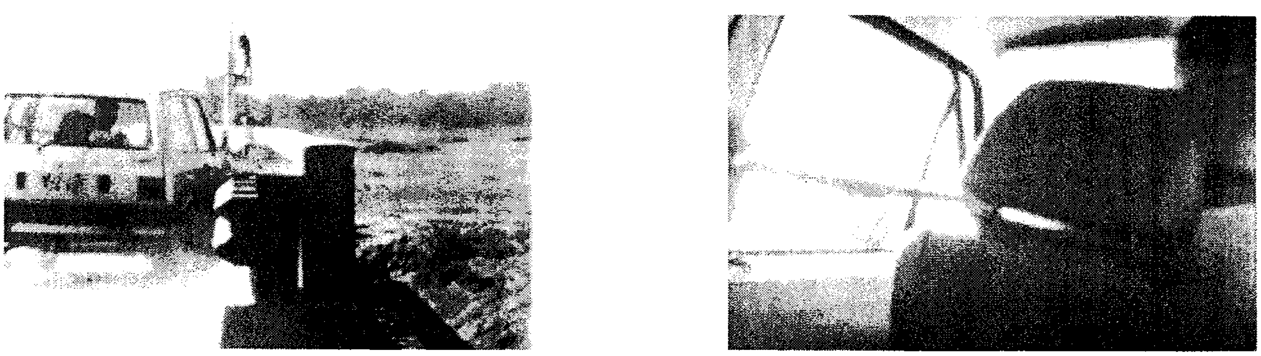


0.000 s



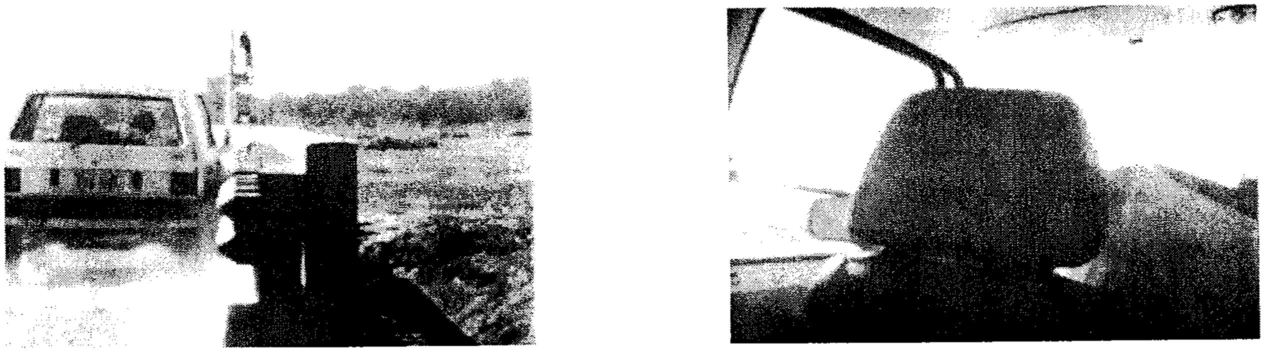
0.040 s

0.079 s

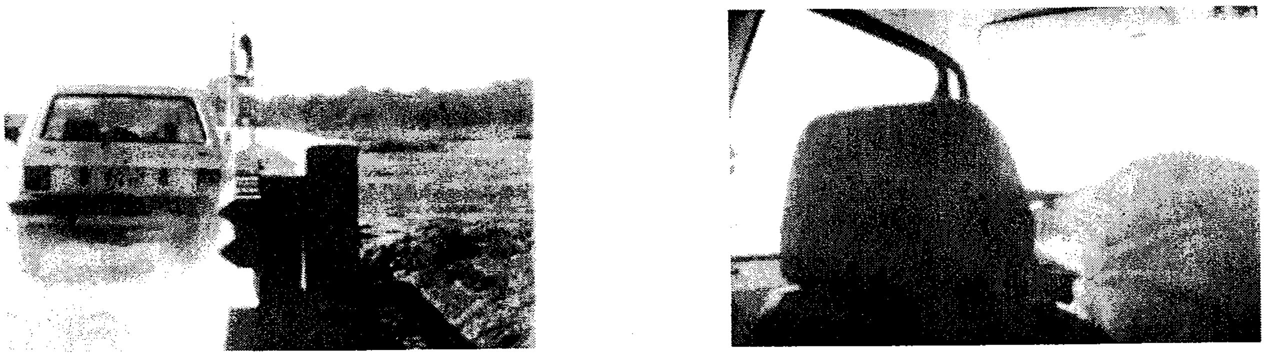


0.119 s

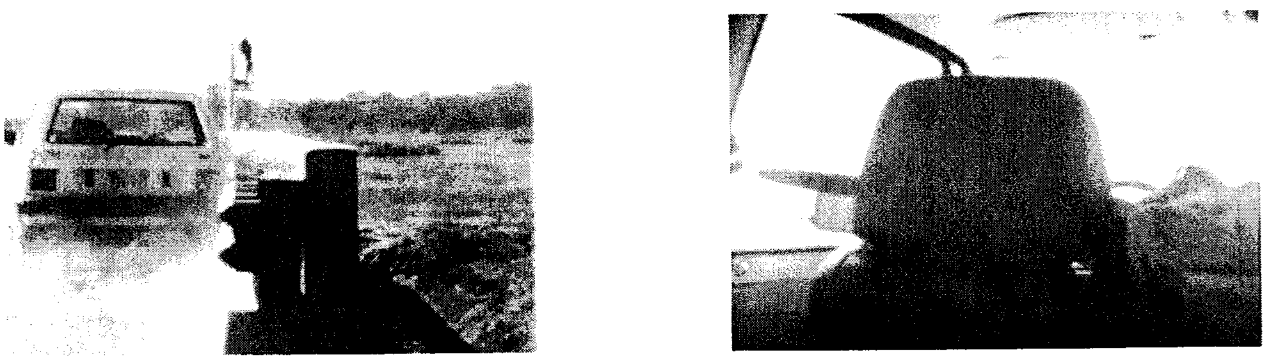
Figure 67. Sequential photographs for test 472070-1
(rear and onboard views).



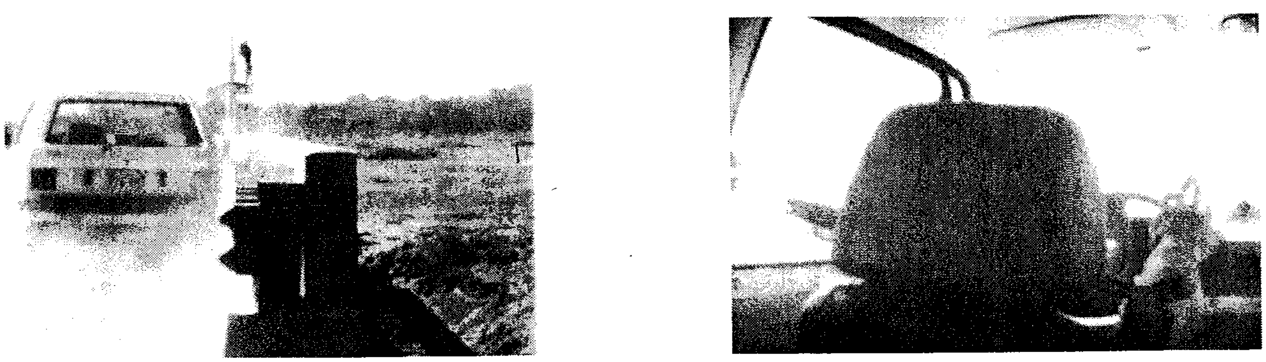
0.158 s



0.200 s

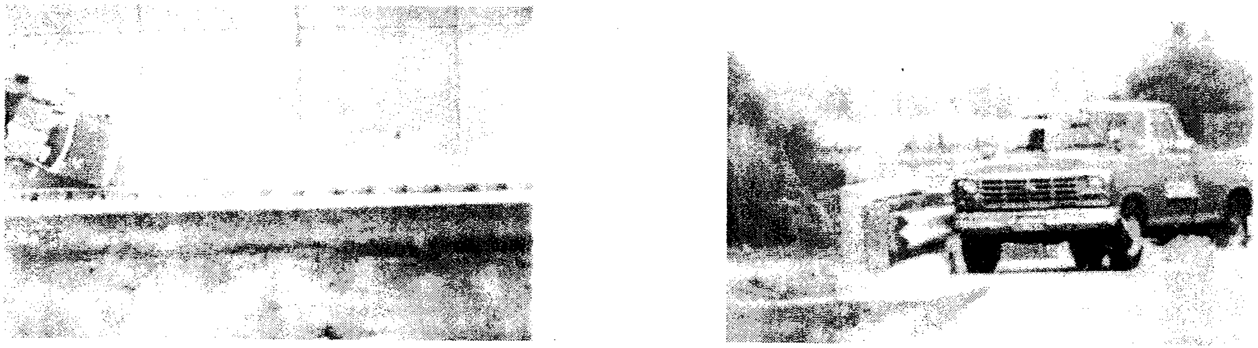


0.240 s

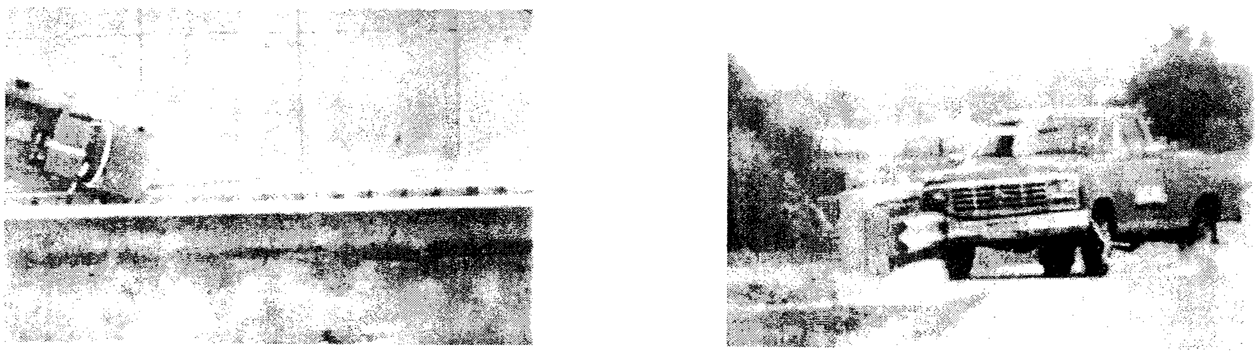


0.279 s

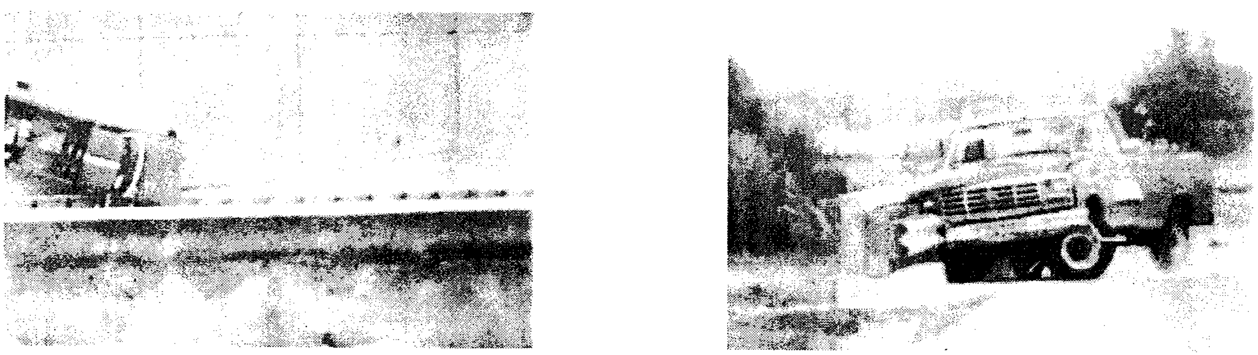
Figure 67. Sequential photographs for test 472070-1
(rear and onboard views) (continued).



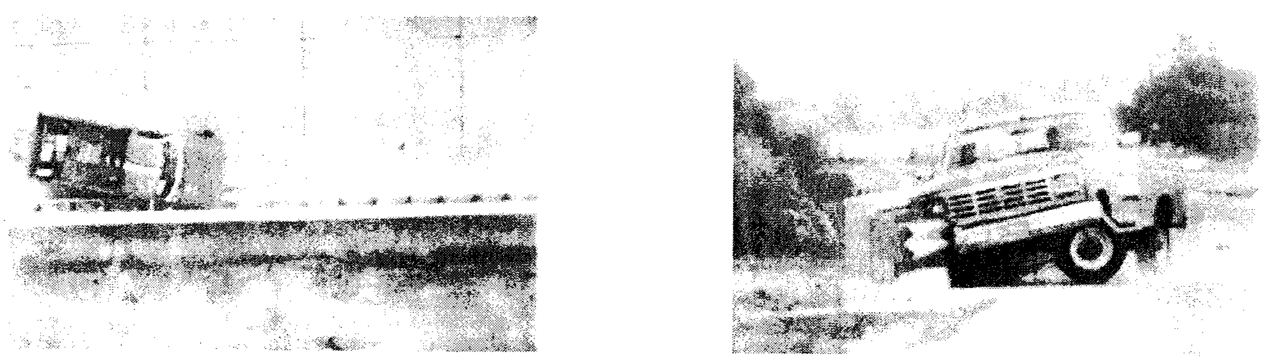
0.000 s



0.049 s

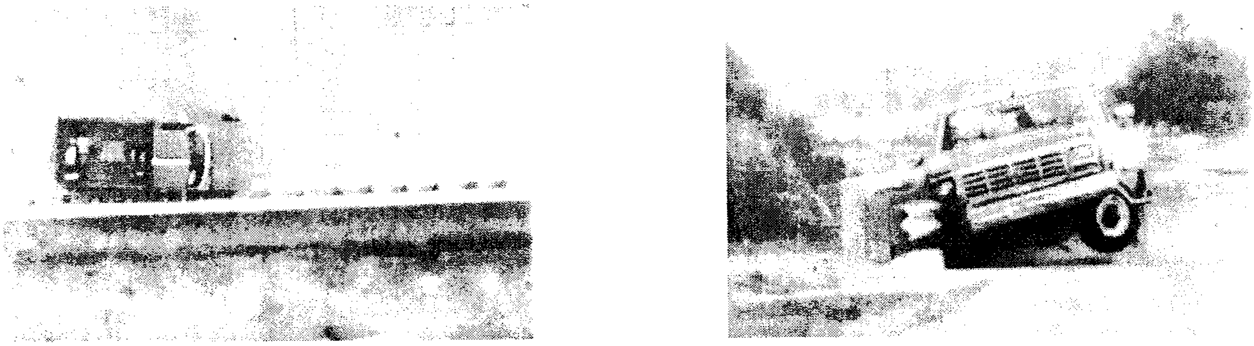


0.099 s

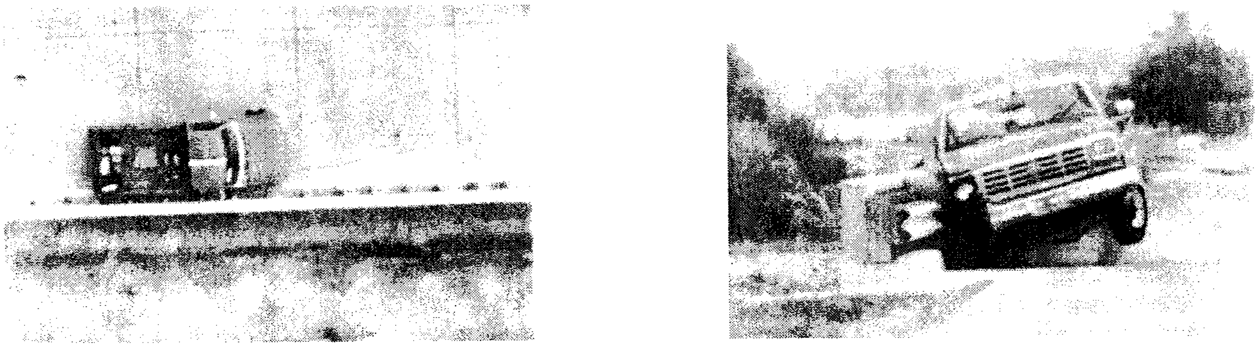


0.151 s

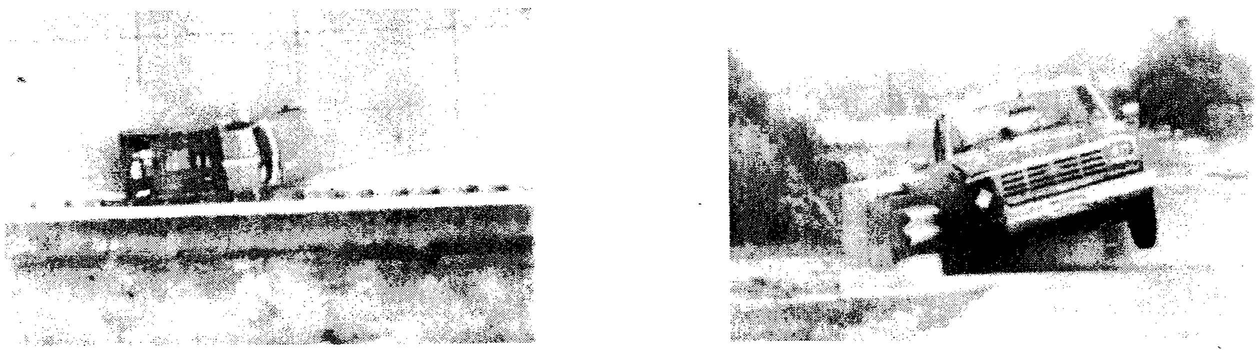
Figure 68. Sequential photographs for test 472070-2 (overhead and frontal views).



0.200 s



0.250 s



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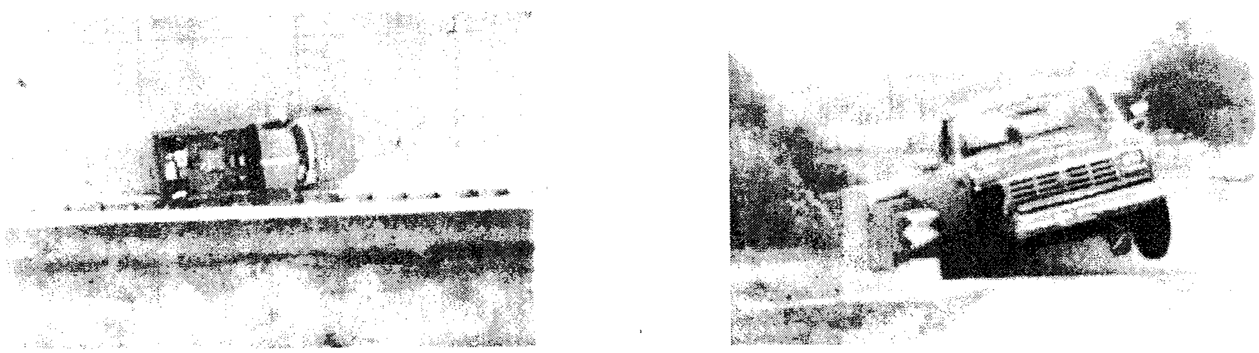
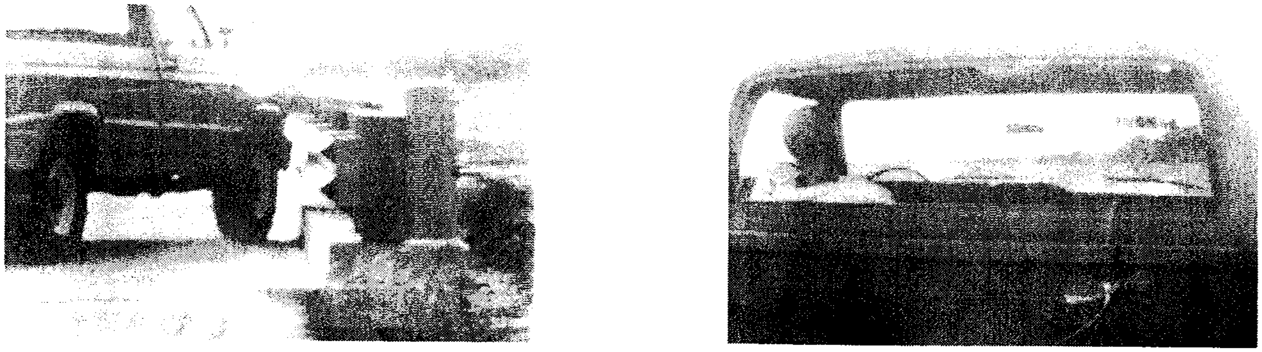
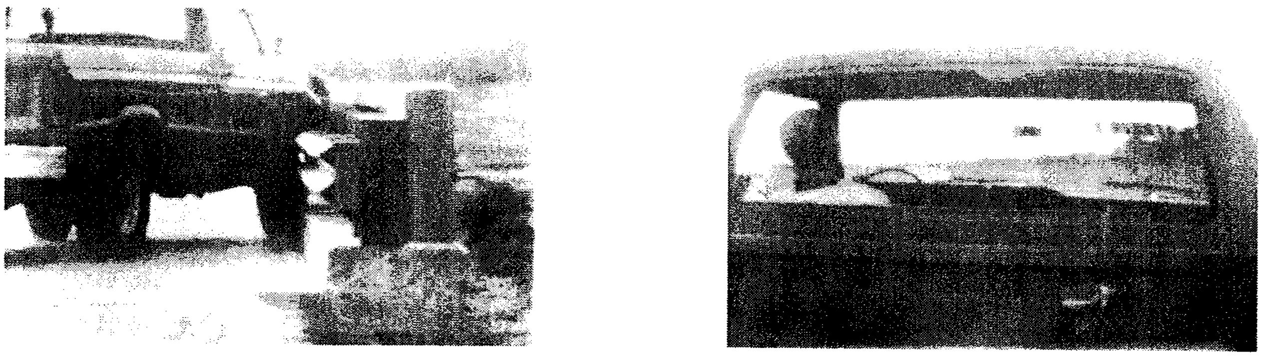


0.354 s

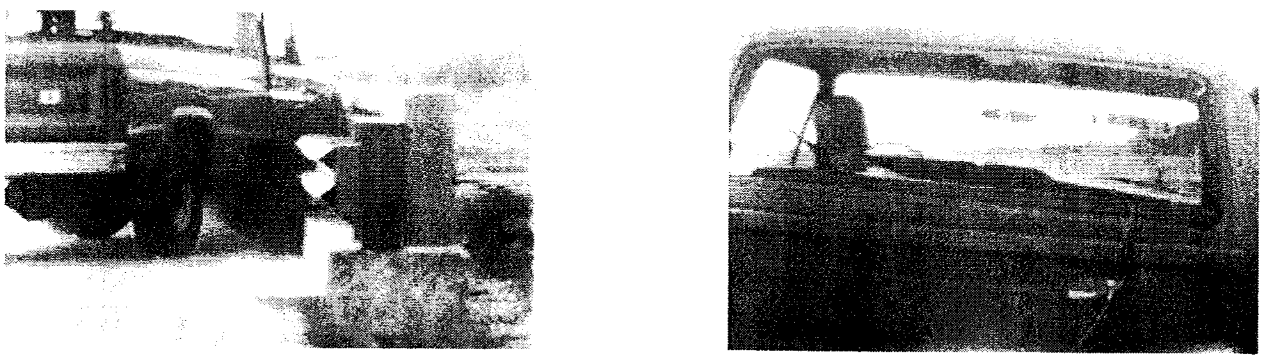
Figure 68. Sequential photographs for test 472070-2
(overhead and frontal views) (continued).



0.000 s



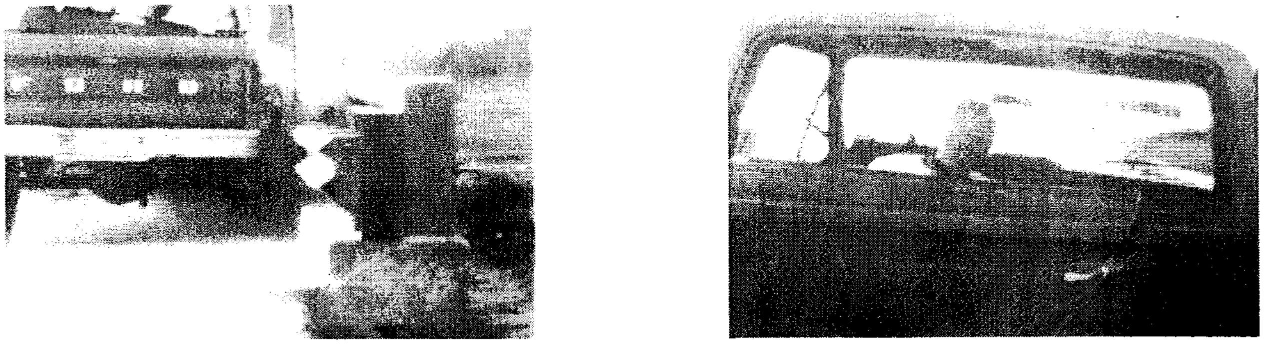
0.049 s



0.099 s

0.151 s

Figure 69. Sequential photographs for test 472070-2 (rear and onboard views).



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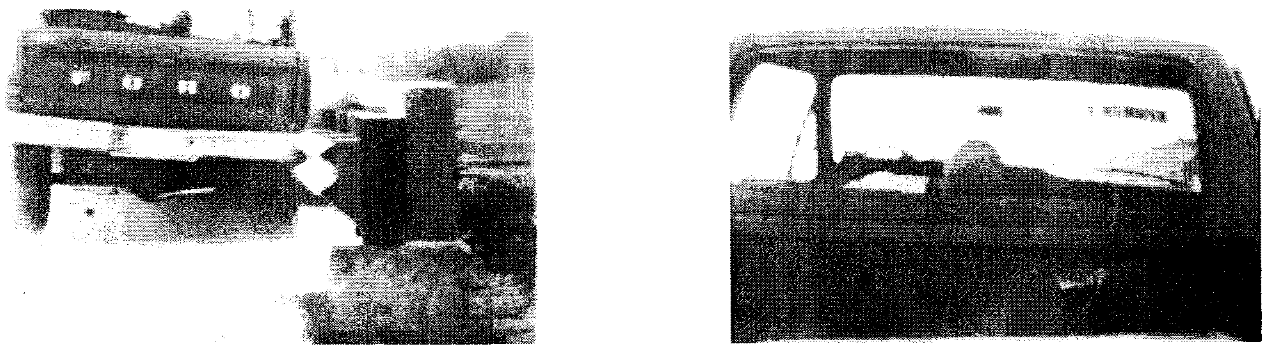

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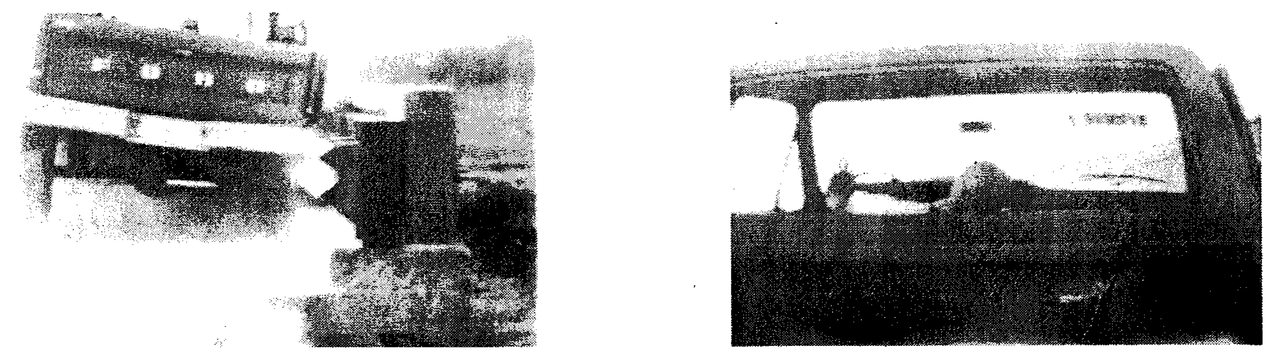

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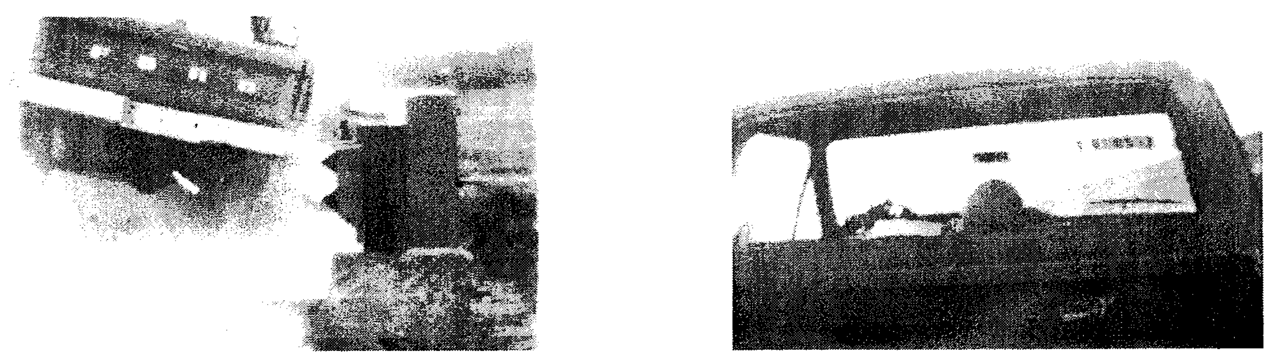
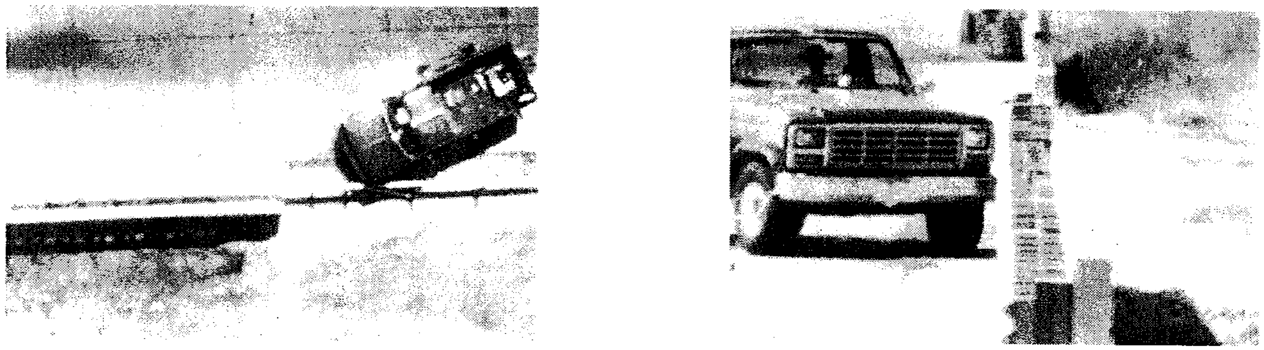


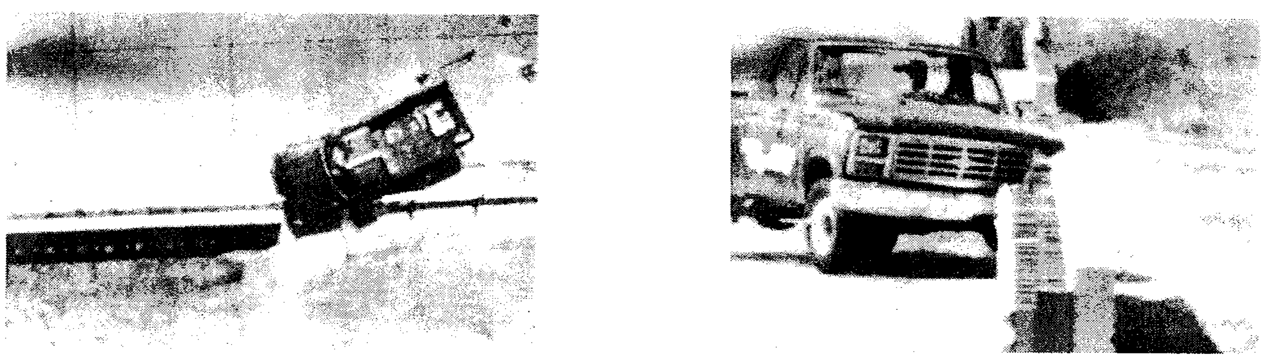
0.354 s

Figure 69. Sequential photographs for test 472070-2
(rear and onboard views) (continued).

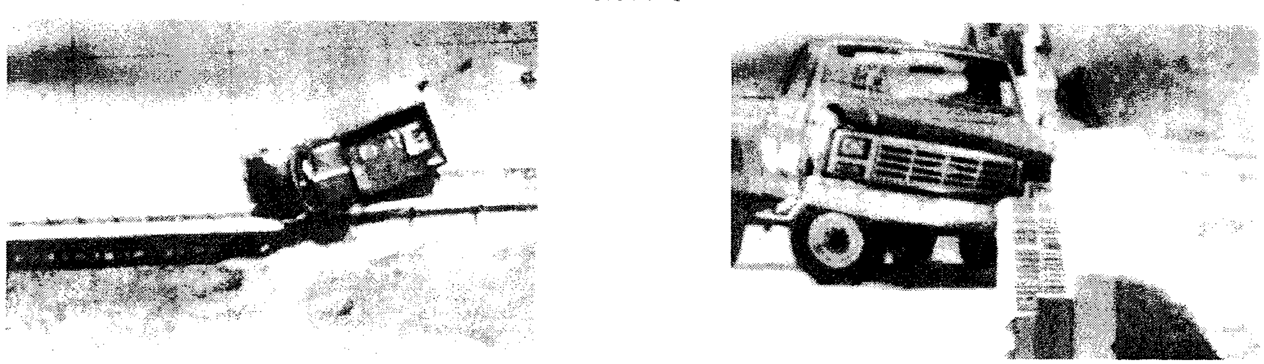


0.000 s

0.050 s

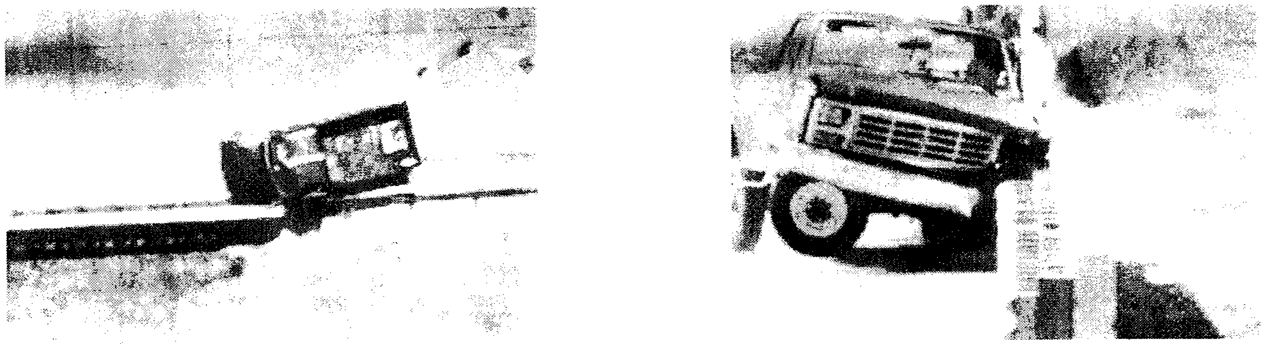


0.099 s

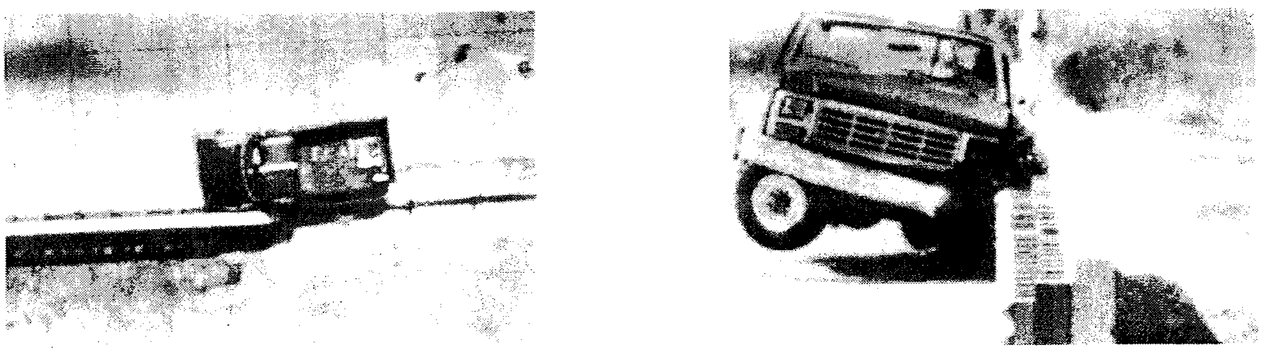


0.150 s

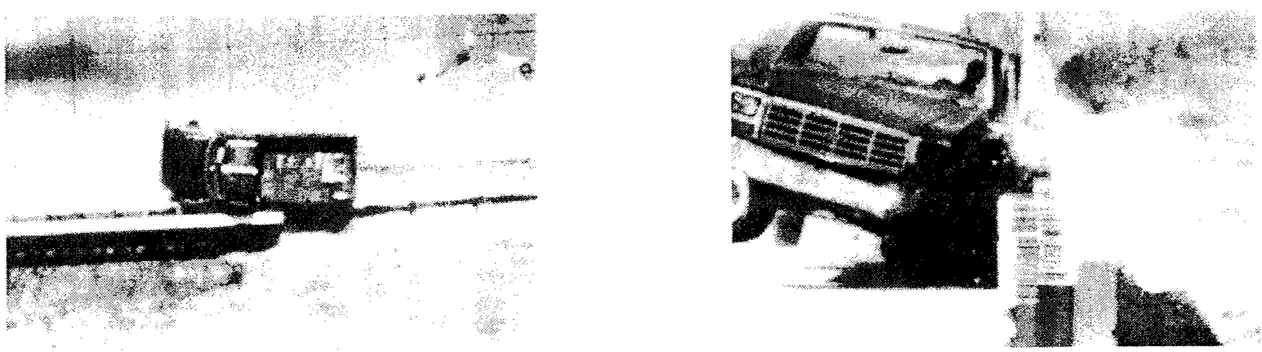
Figure 70. Sequential photographs for test 472070-3 (overhead and frontal views).



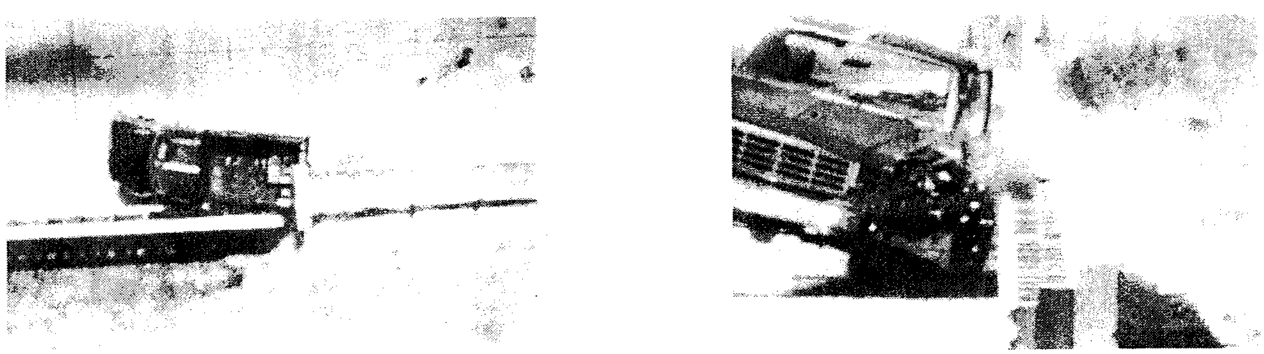
0.201 s



0.249 s



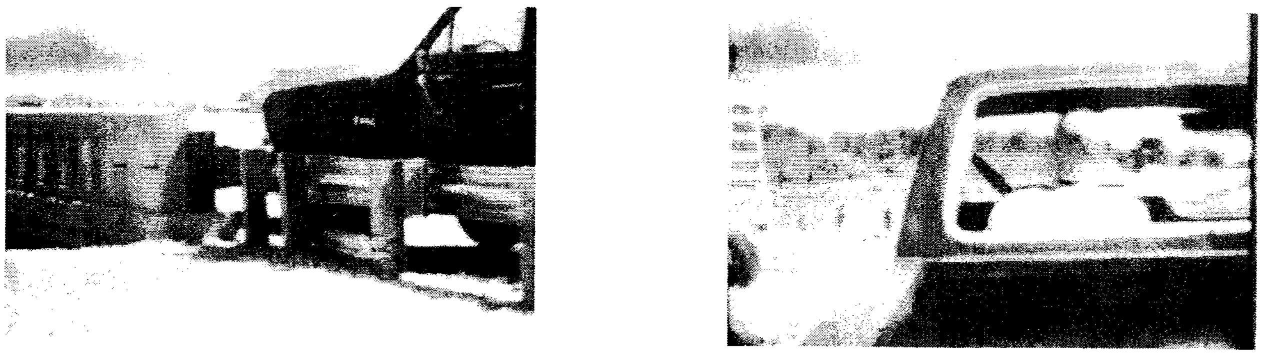
0.326 s



0.440 s

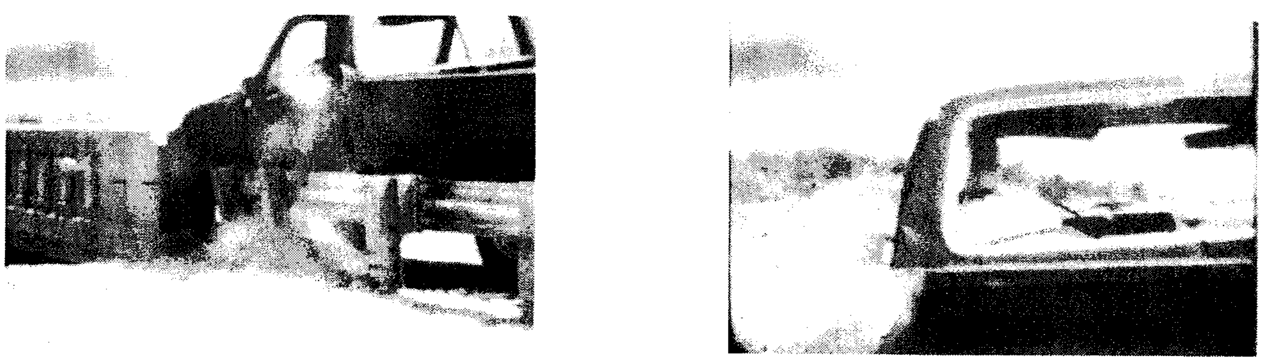
Figure 70. Sequential photographs for test 472070-3 (overhead and frontal views) (continued).

0.000 s



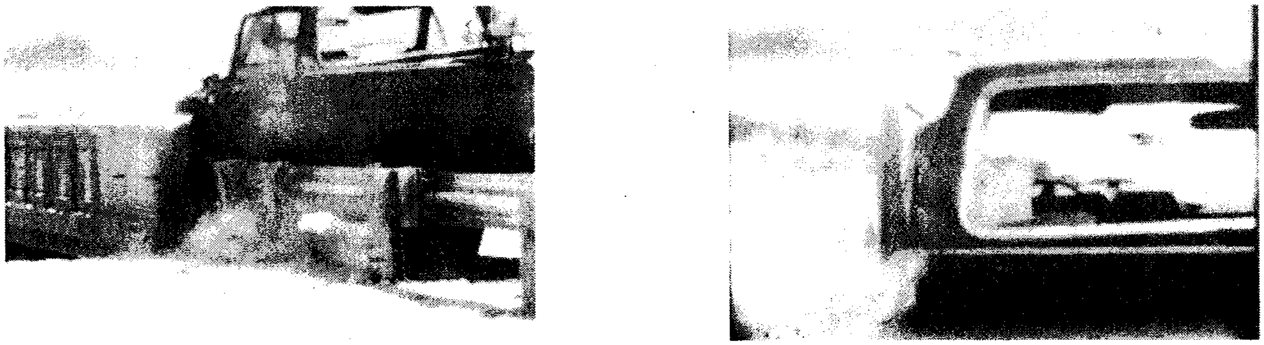
0.050 s

0.099 s

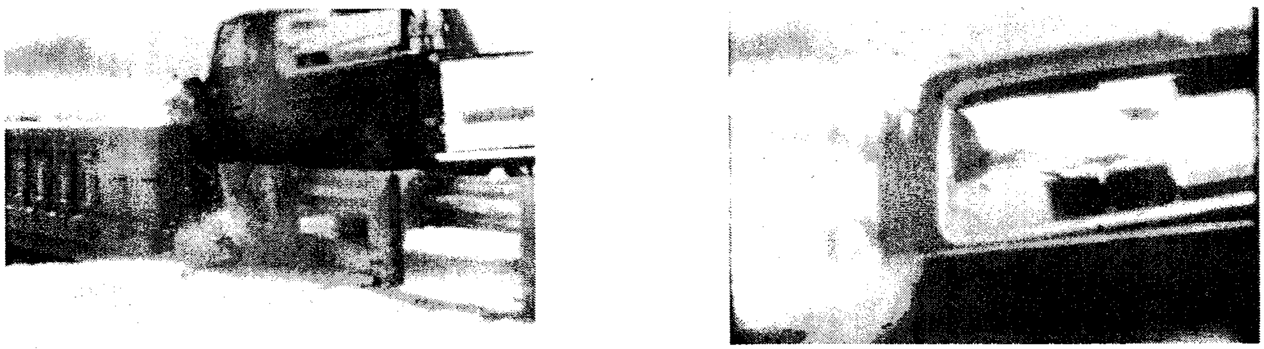


0.150 s

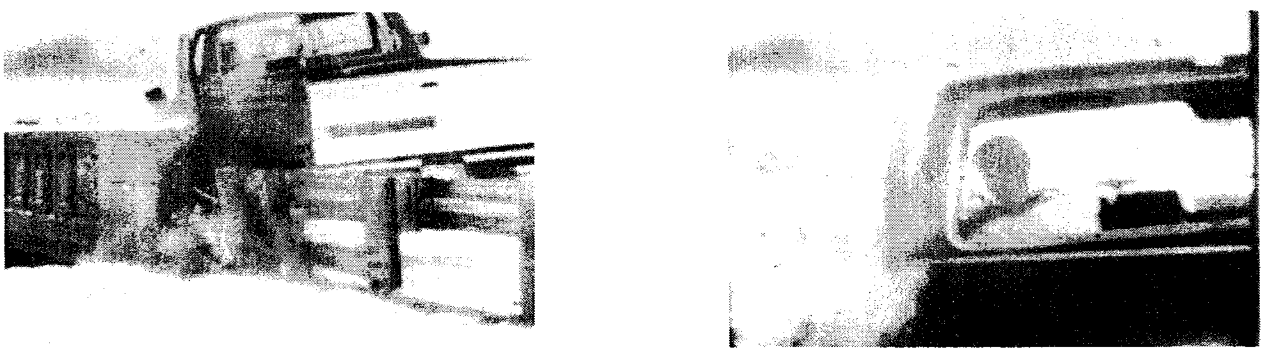
Figure 71. Sequential photographs for test 472070-3 (rear and onboard views).



0.201 s



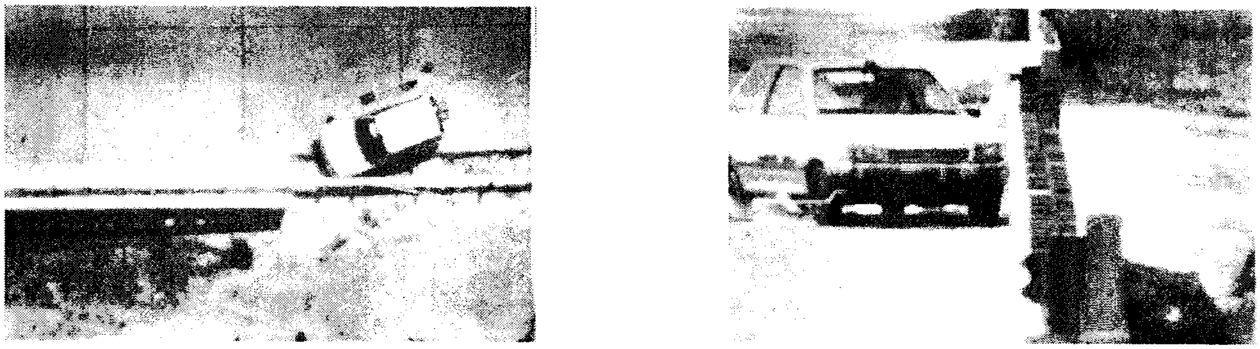
0.249 s



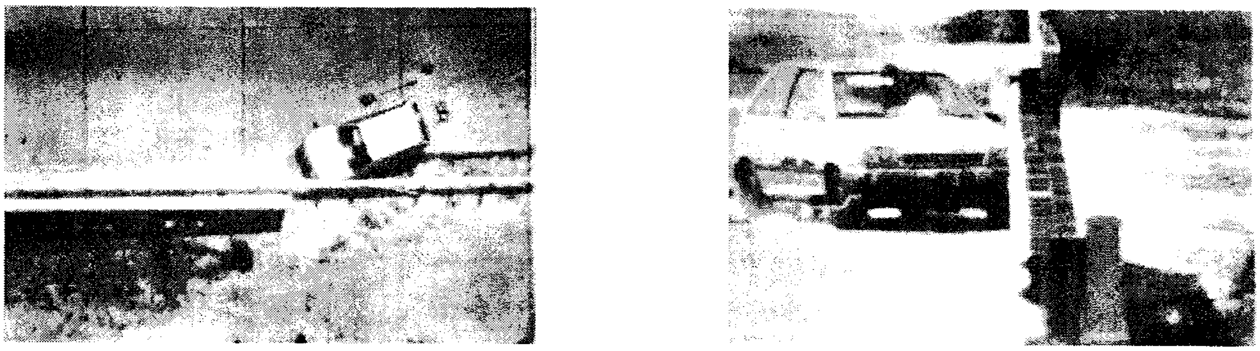
0.326 s

0.440 s

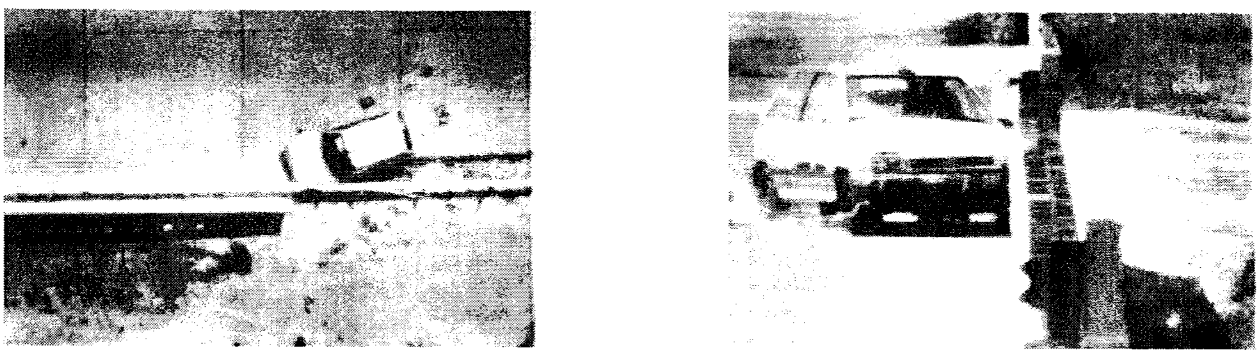
Figure 71. Sequential photographs for test 472070-3 (rear and onboard views) (continued).



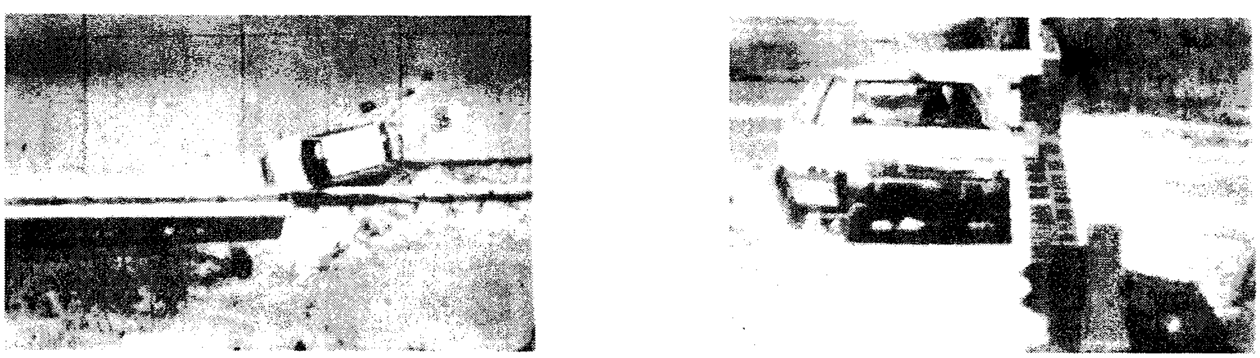
0.000 s



0.025 s

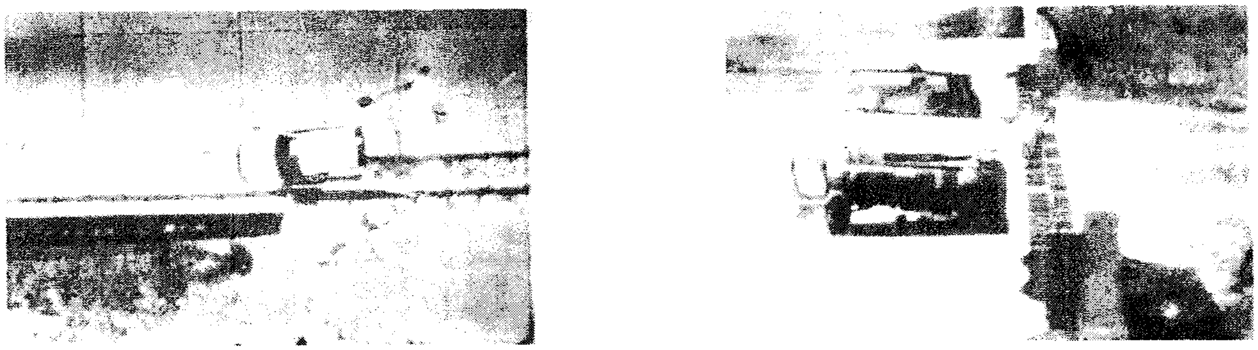


0.050 s

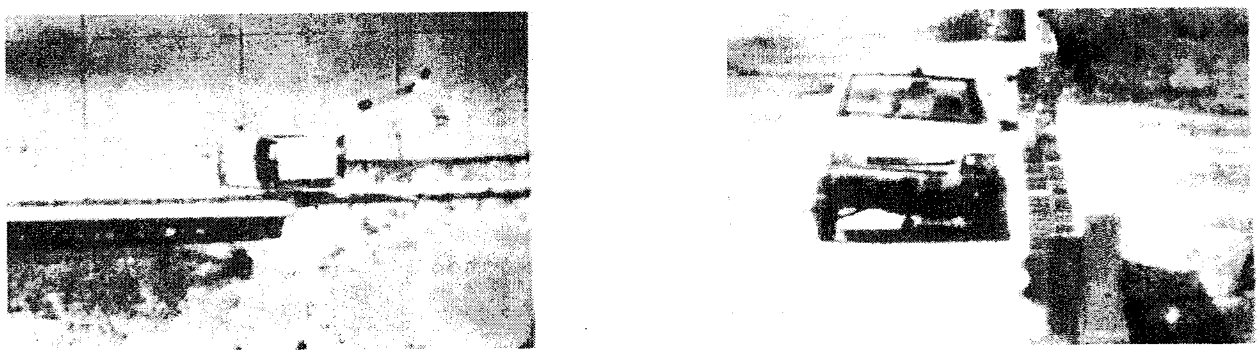


0.084 s

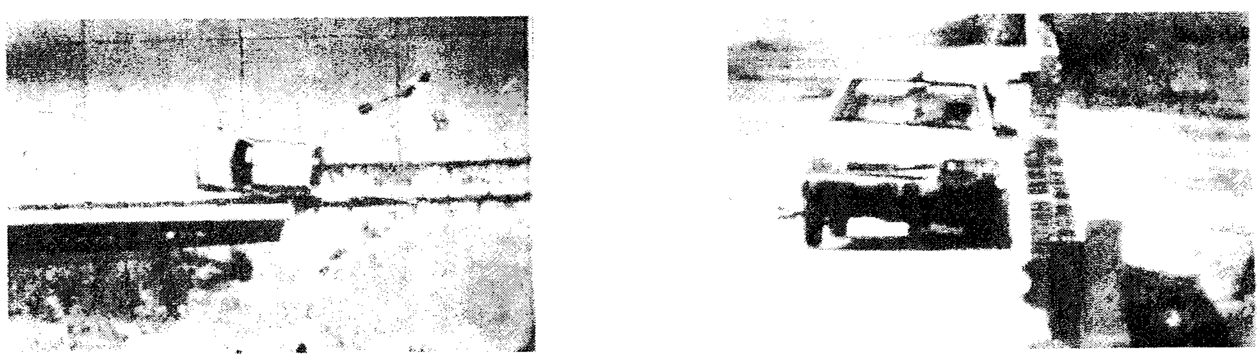
Figure 72. Sequential photographs for test 472070-4
(overhead and frontal views).



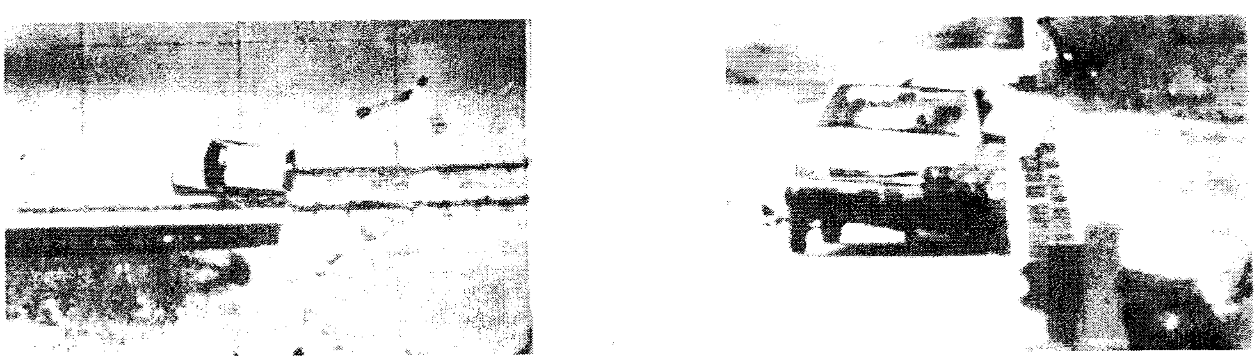
0.126 s



0.161 s

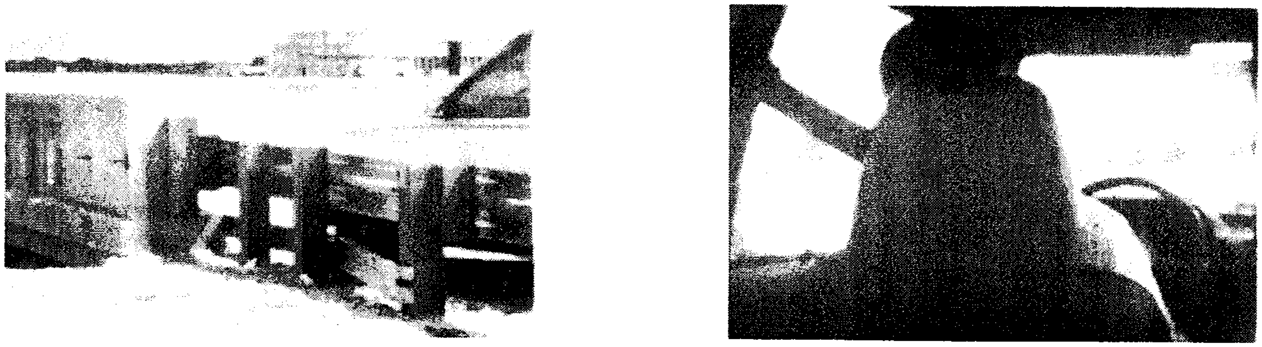


0.200 s

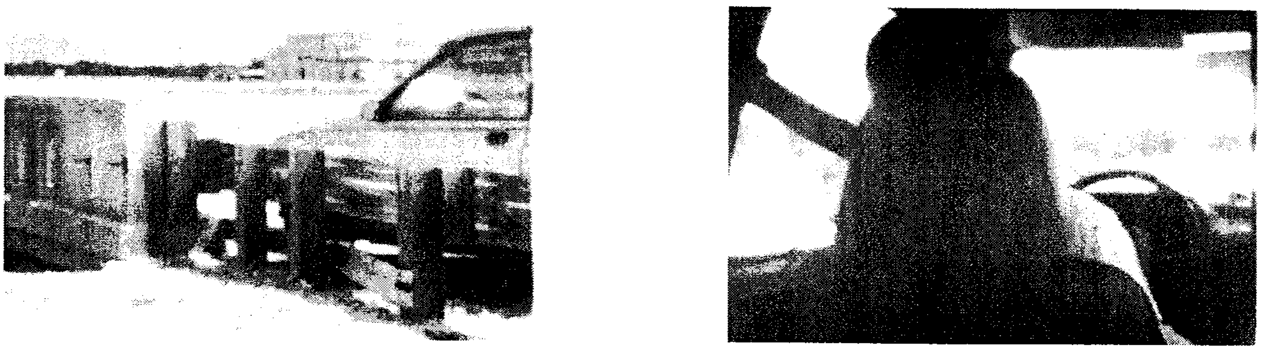


0.243 s

Figure 72. Sequential photographs for test 472070-4
(overhead and frontal views) (continued).

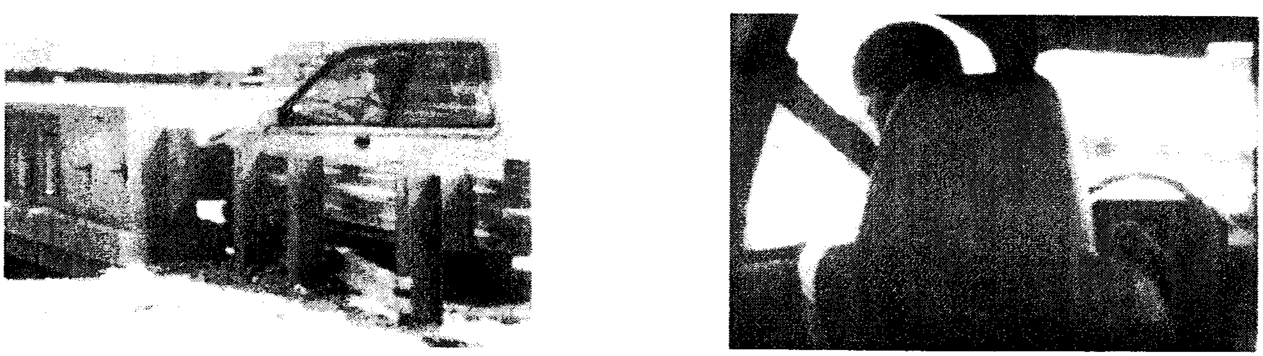


0.000 s



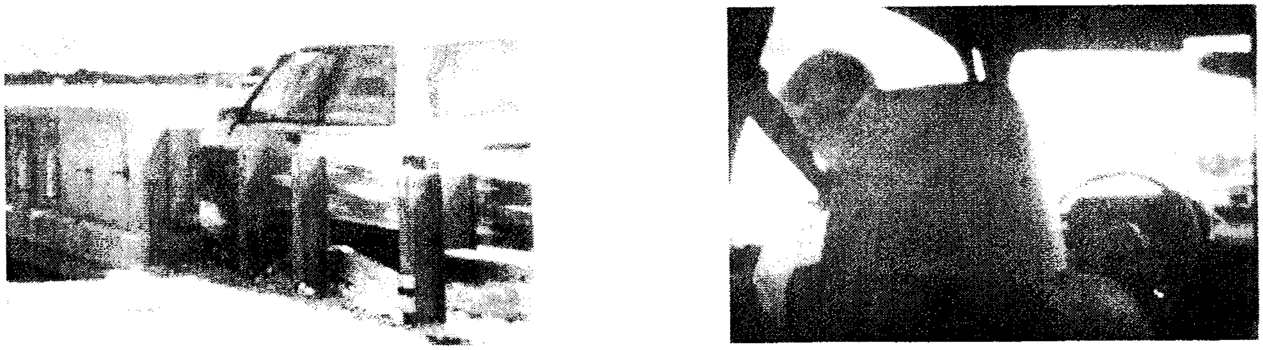
0.025 s

0.050 s

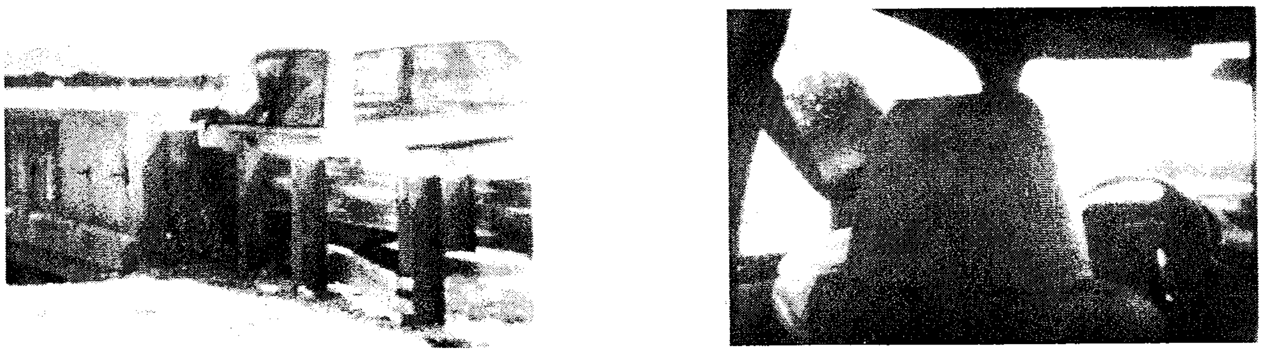


0.084 s

Figure 73. Sequential photographs for test 472070-4
(rear and onboard views).

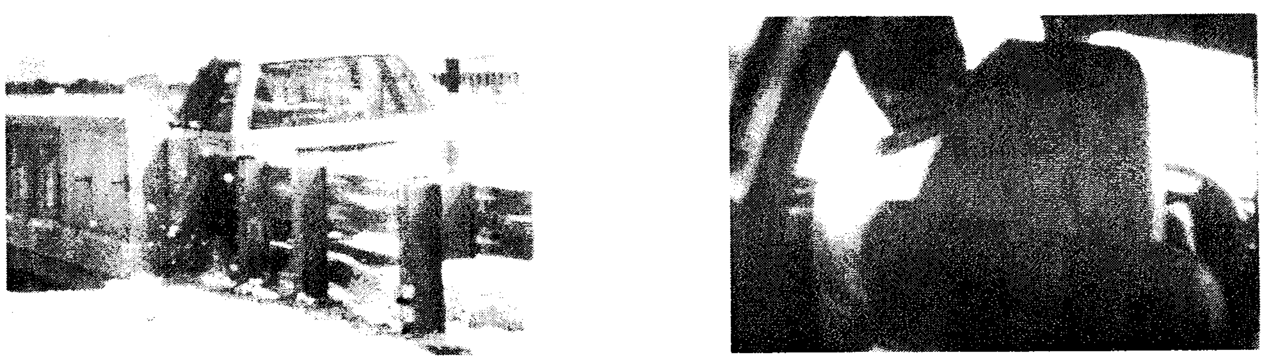


0.126 s



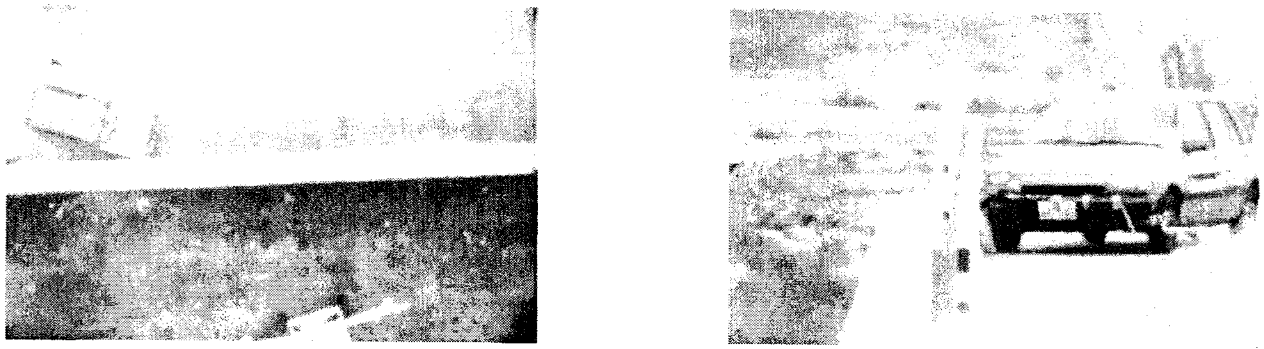
0.161 s

0.200 s

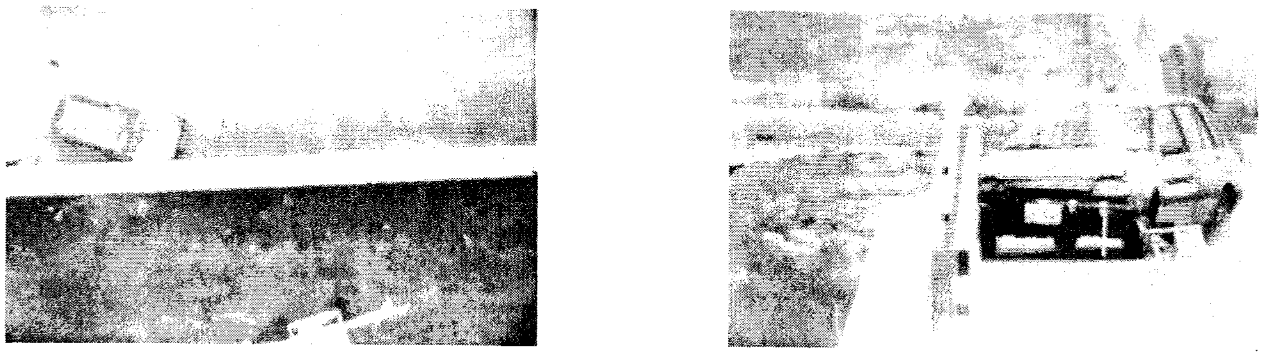


0.243 s

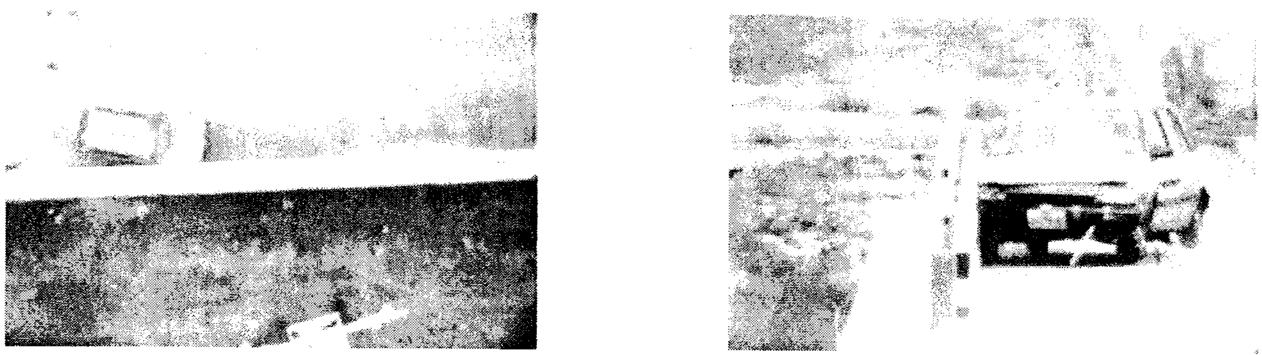
Figure 73. Sequential photographs for test 472070-4
(rear and onboard views) (continued).



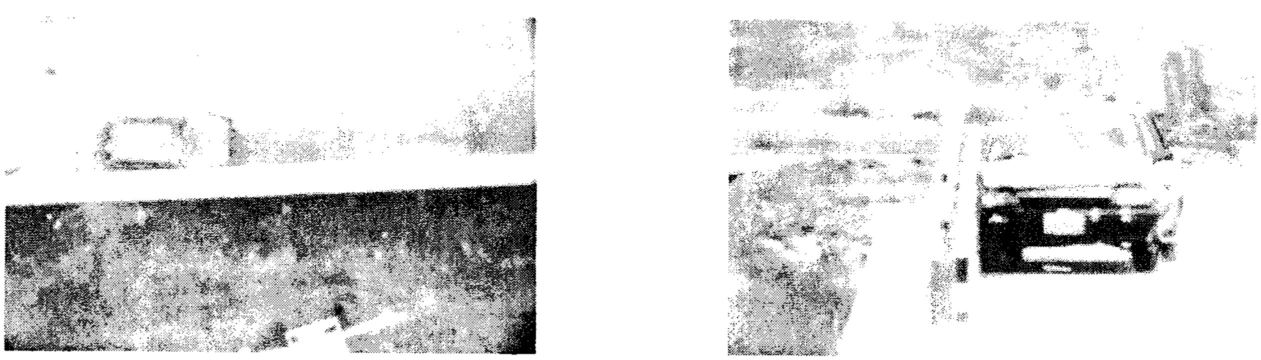
0.000 s



0.034 s

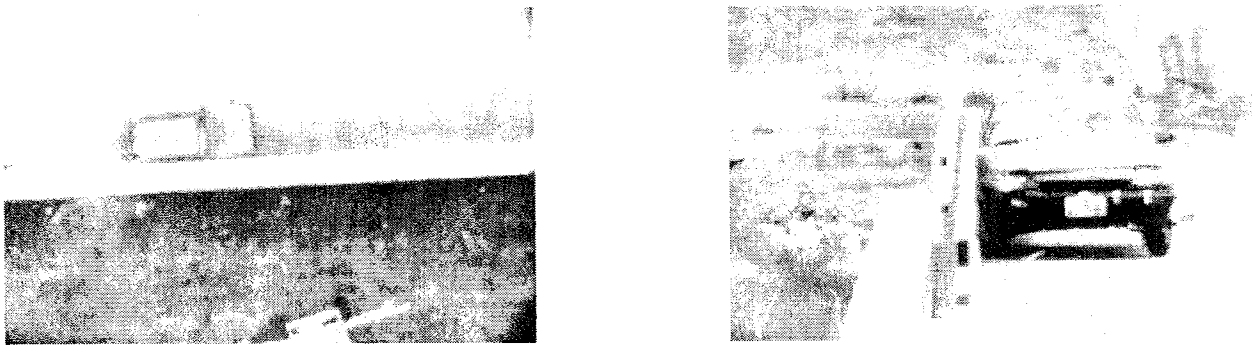


0.069 s

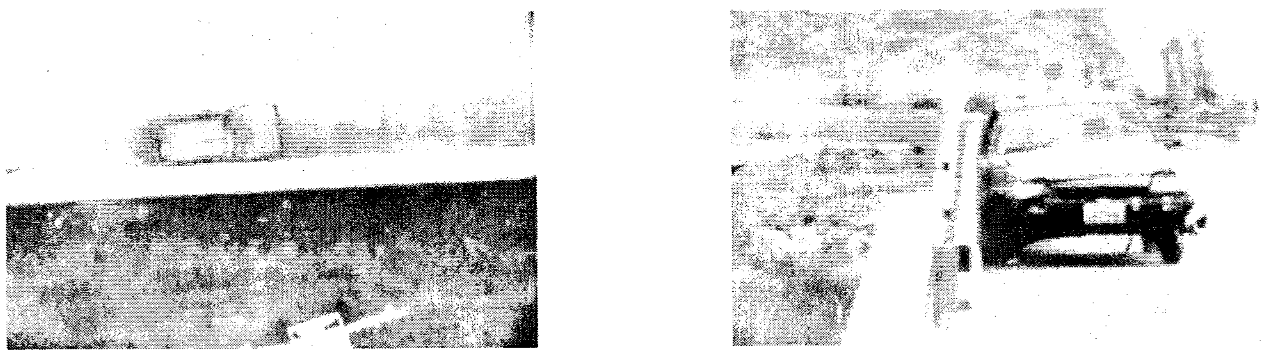


0.103 s

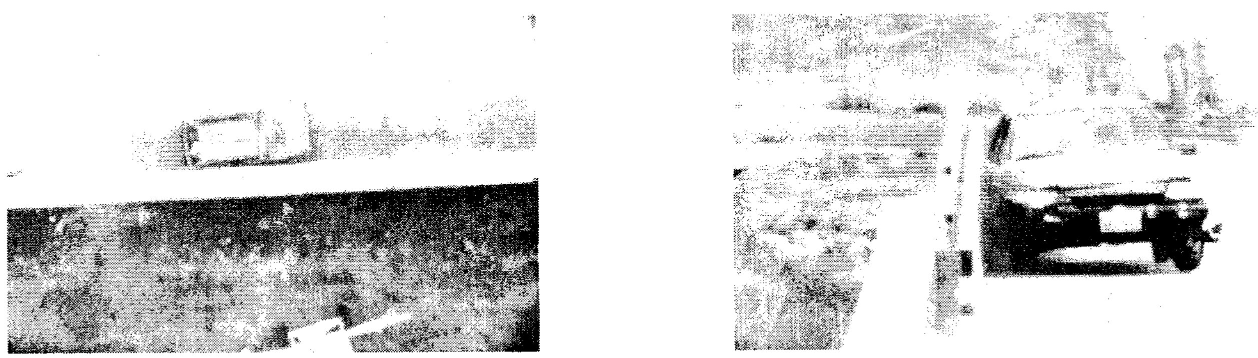
Figure 74. Sequential photographs for test 472070-5
(overhead and frontal views).



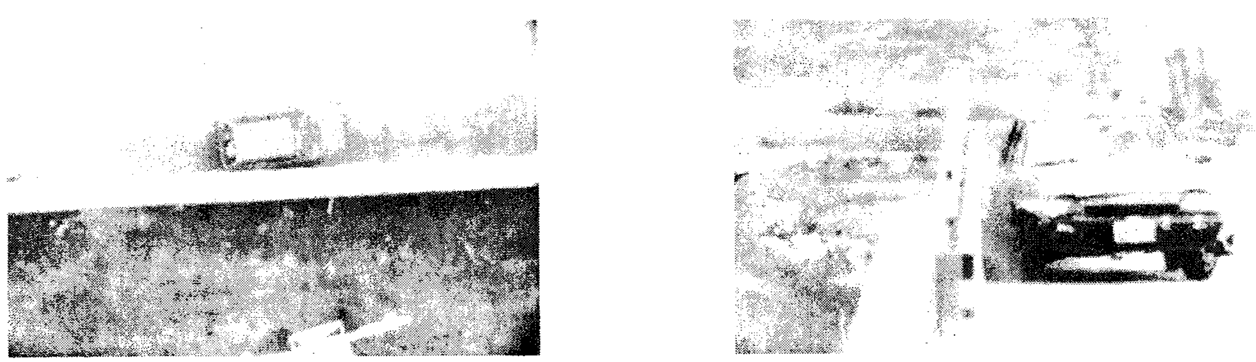
0.137 s



0.172 s



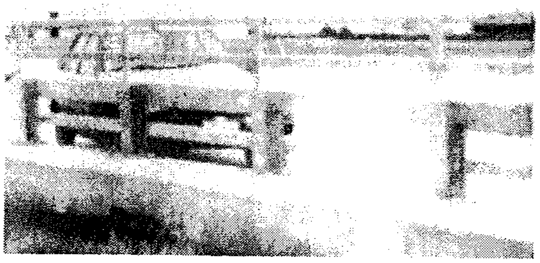
0.213 s



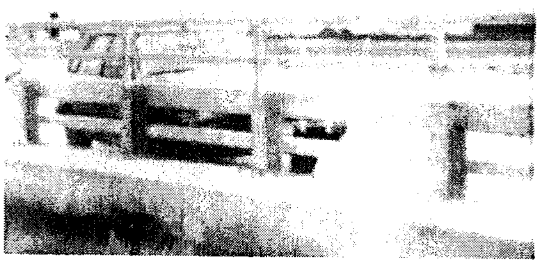
0.262 s

Figure 74. Sequential photographs for test 472070-5 (overhead and frontal views) (continued).

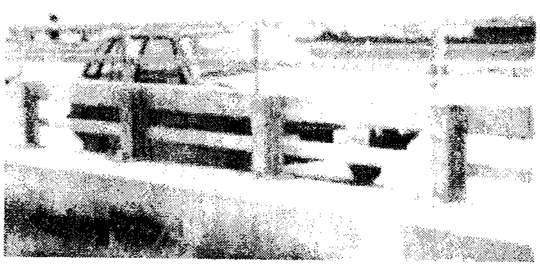
0.000 s



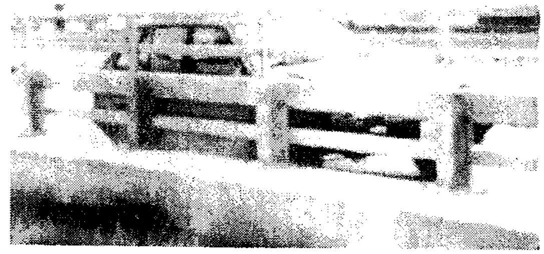
0.034 s



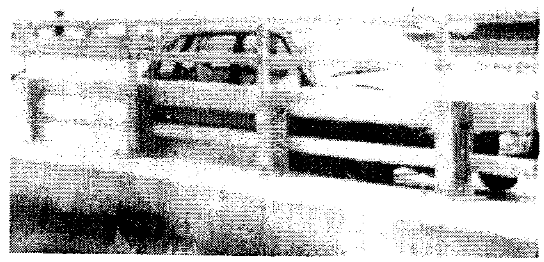
0.069 s



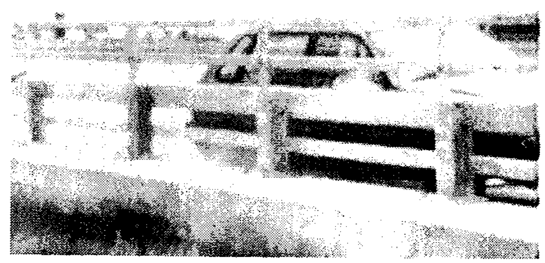
0.103 s



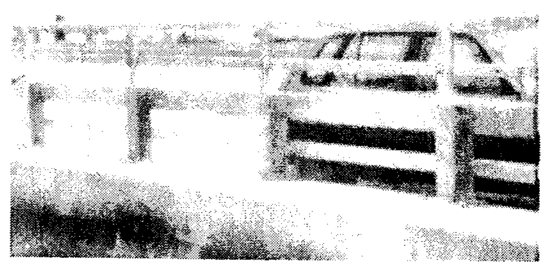
0.137 s



0.172 s

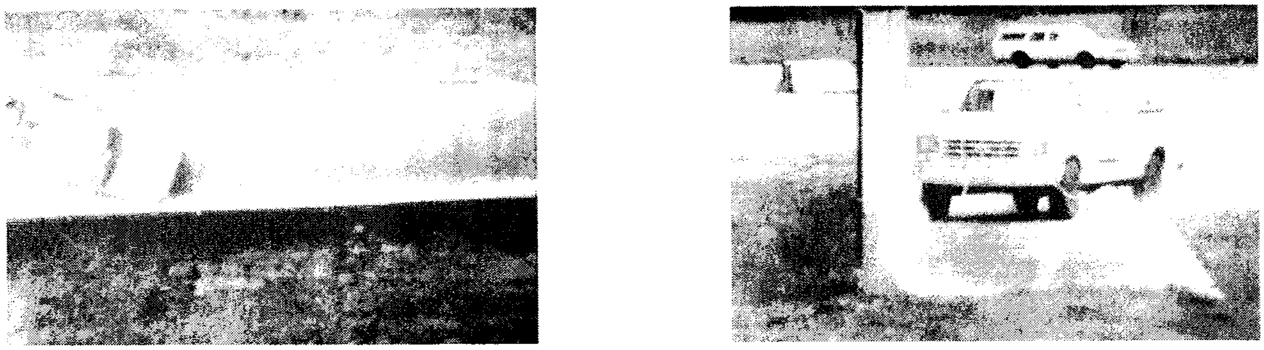


0.213 s

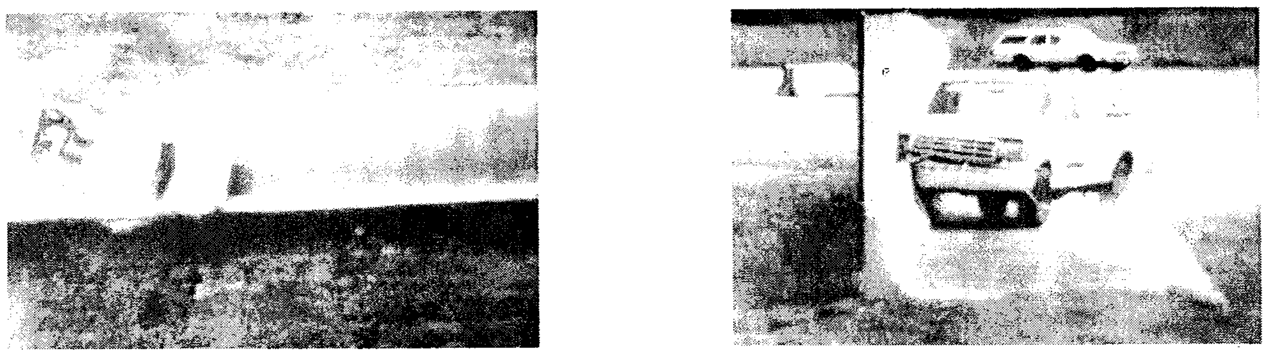


0.262 s

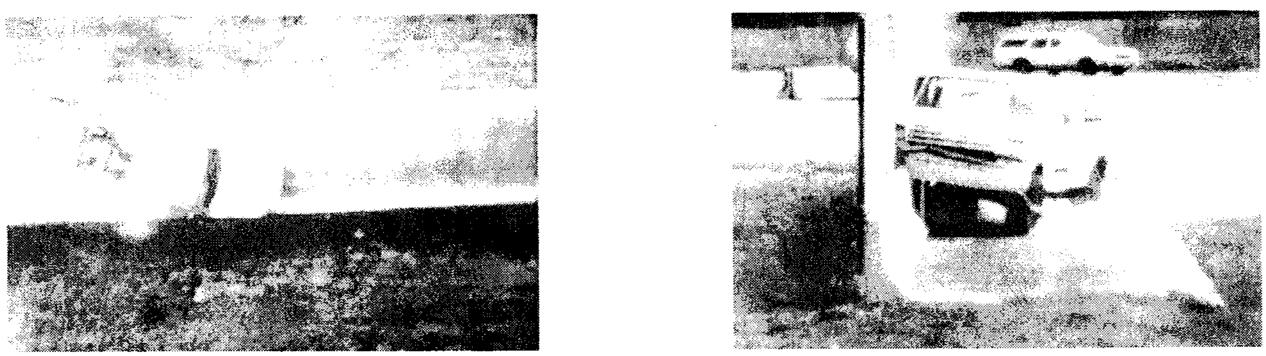
Figure 75. Sequential photographs for test 472070-5 (rear view).



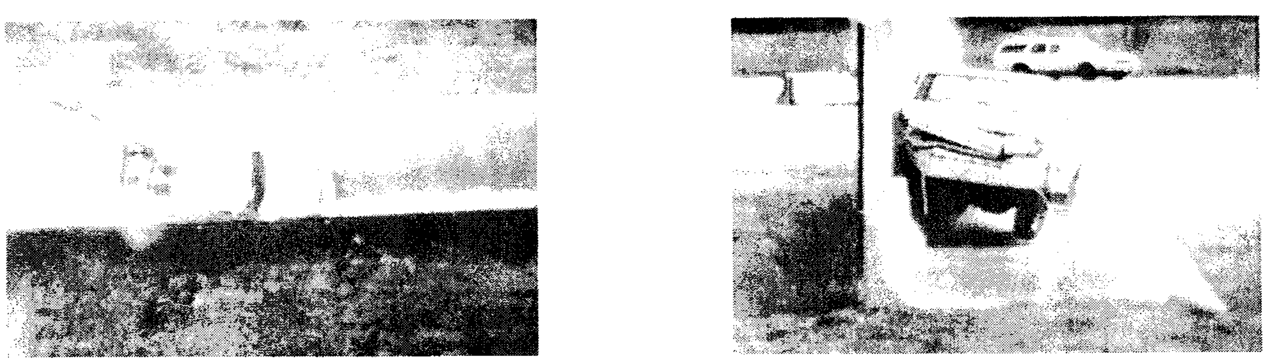
0.000 s



0.051 s

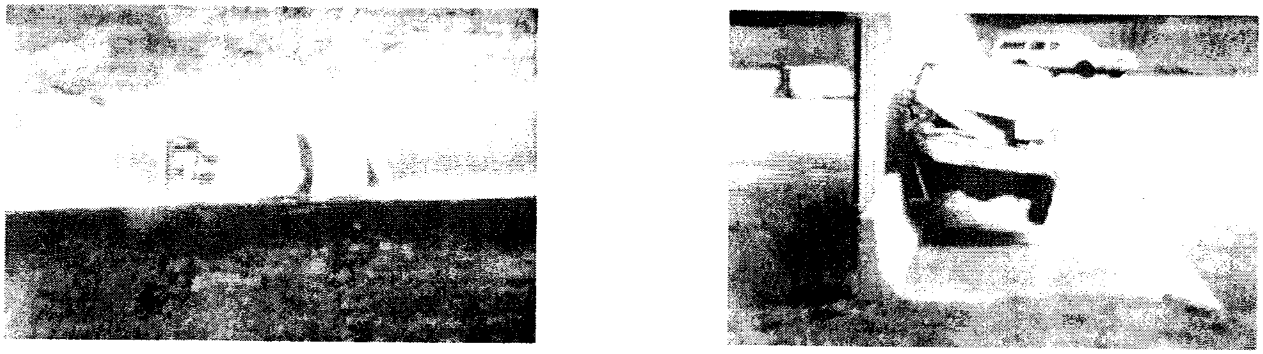


0.100 s

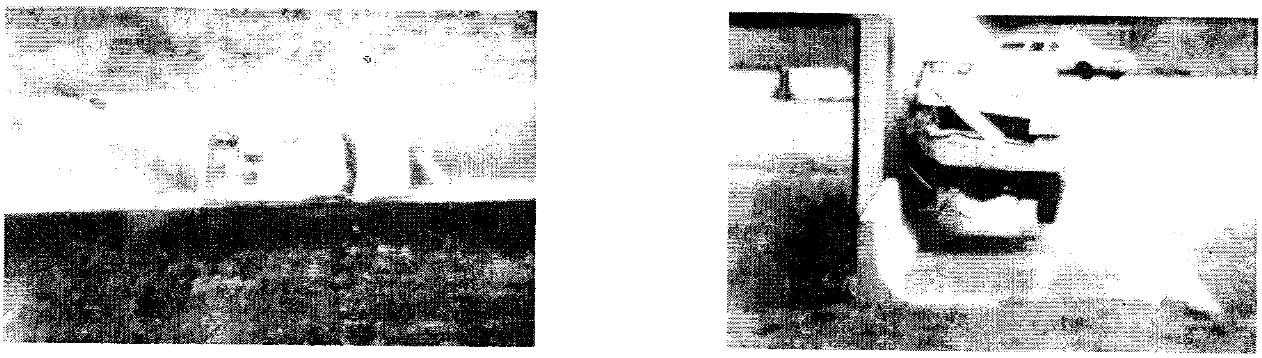


0.149 s

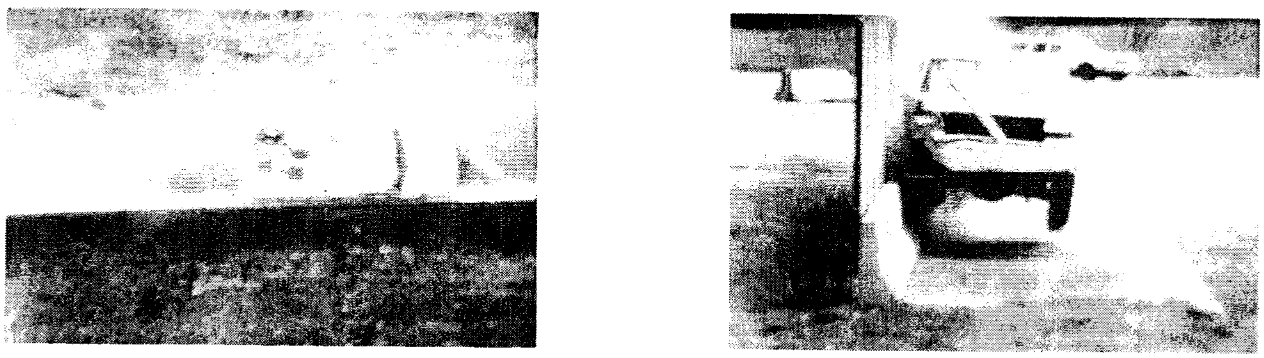
Figure 76. Sequential photographs for test 472070-6
(overhead and frontal views).



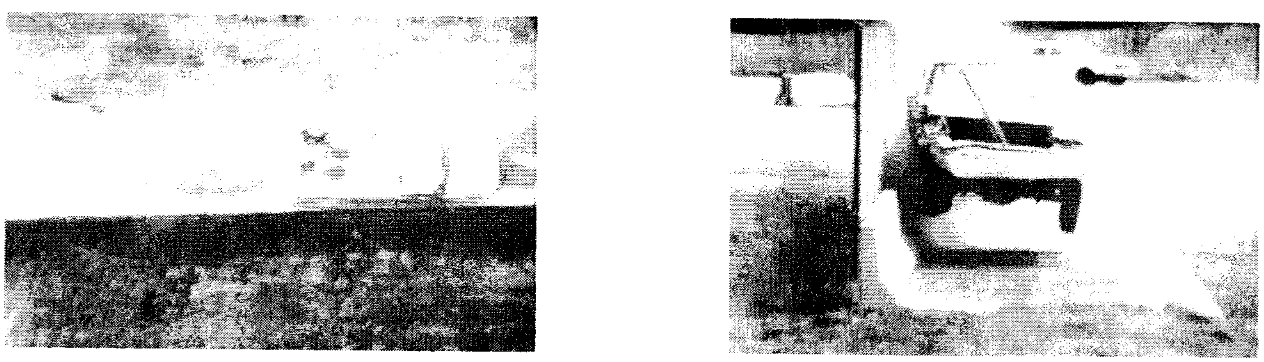
0.200 s



0.249 s



0.300 s



0.349 s

Figure 76. Sequential photographs for test 472070-6
(overhead and frontal views) (continued).

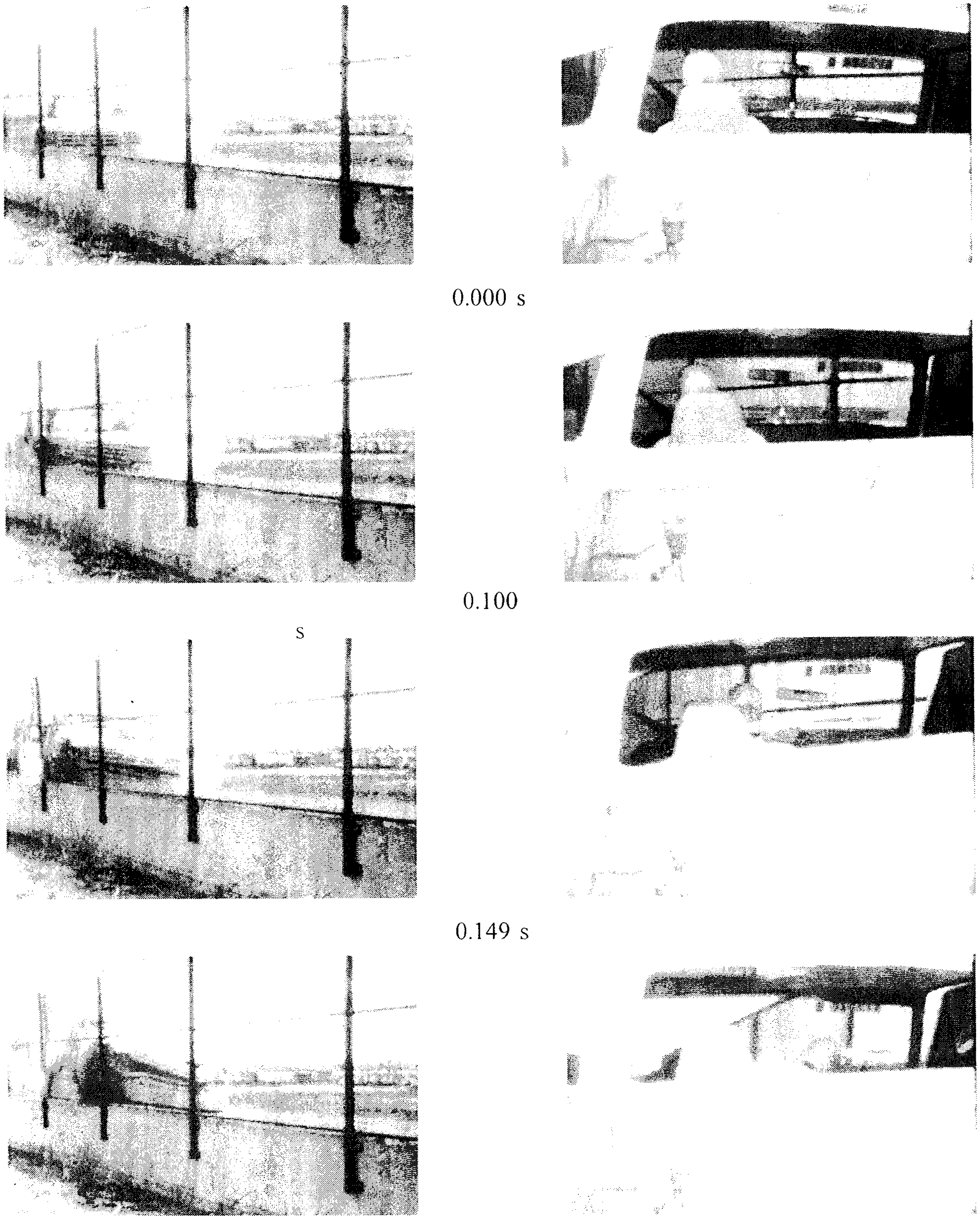
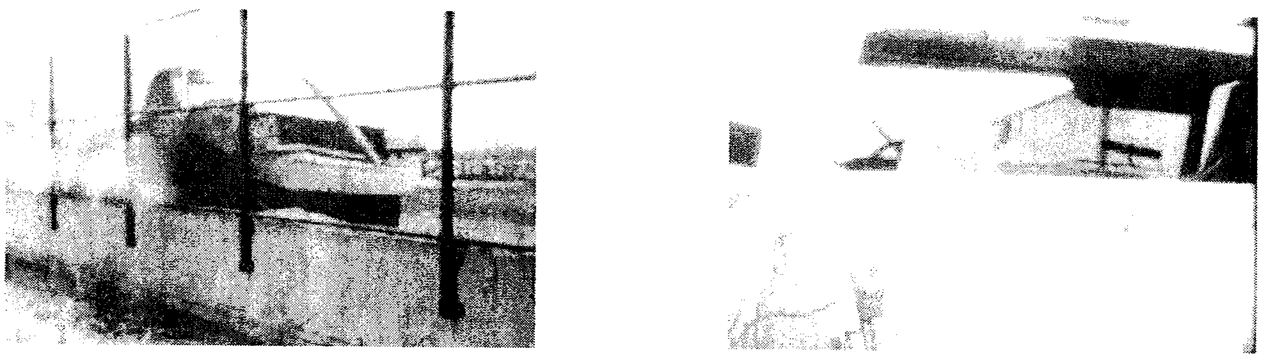
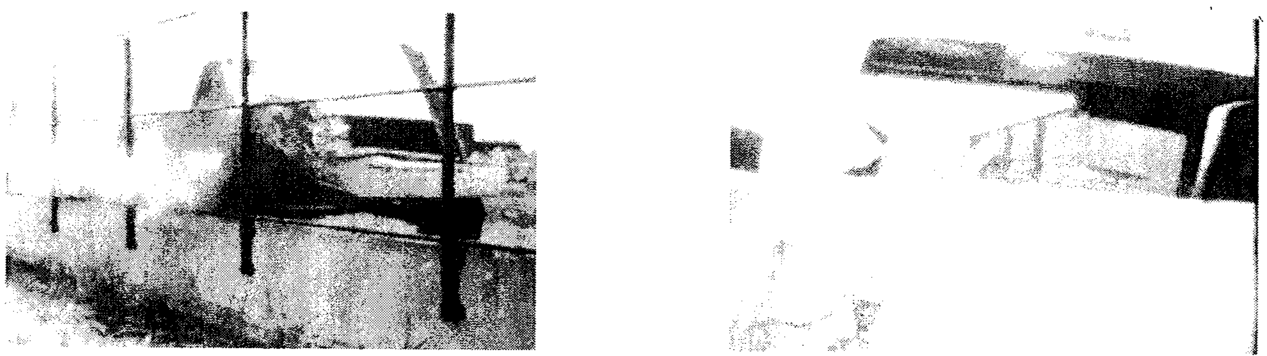


Figure 77. Sequential photographs for test 472070-6 (rear and onboard views).

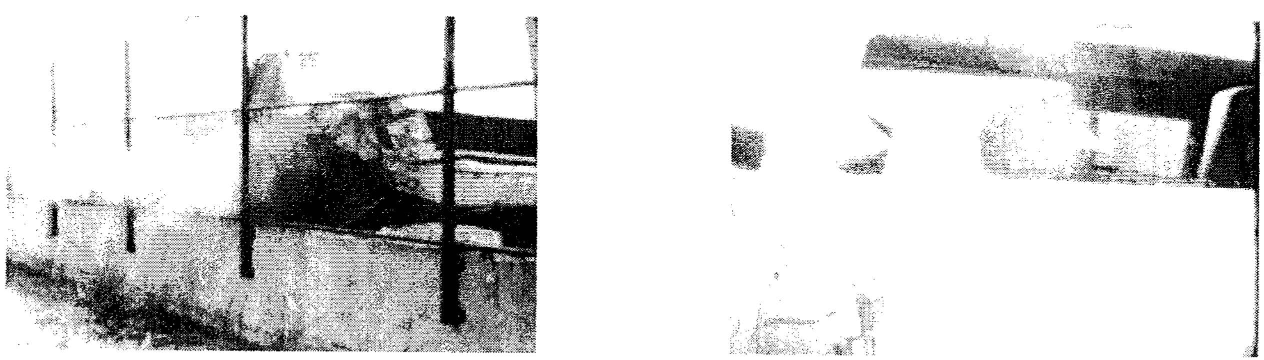
0.200 s



0.249 s

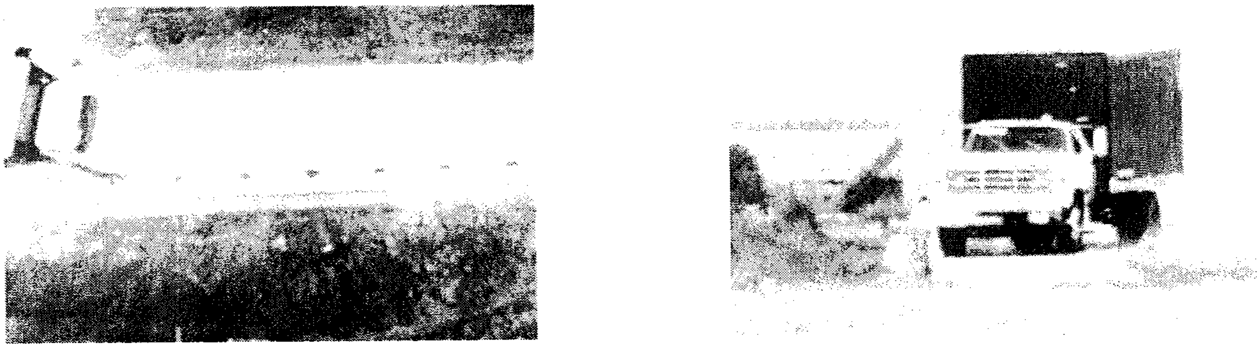


0.300 s

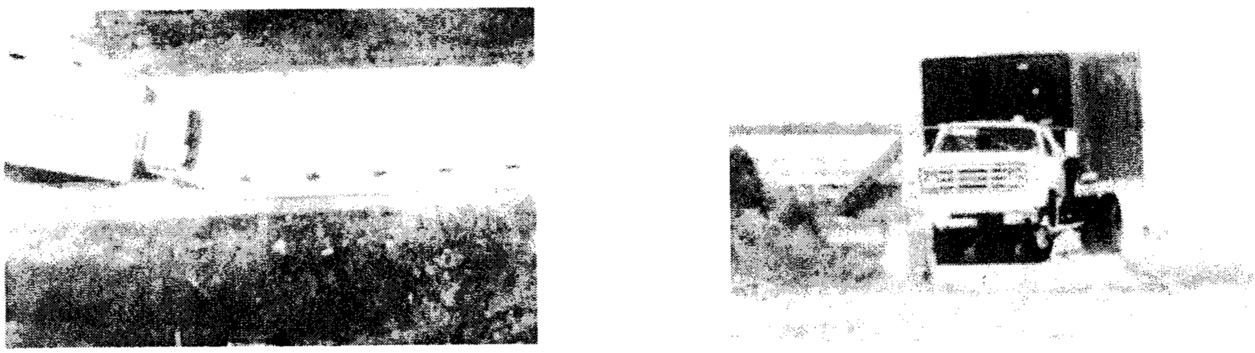


0.349 s

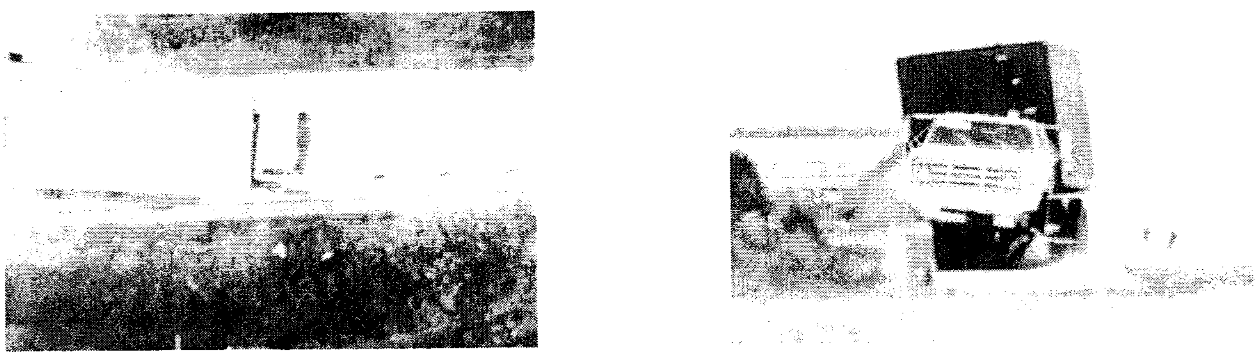
Figure 77. Sequential photographs for test 472070-6
(rear and onboard views) (continued).



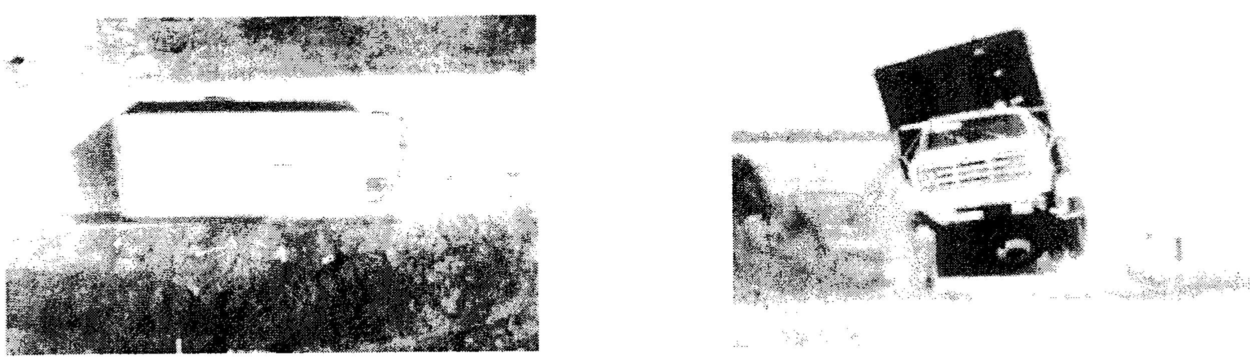
0.000 s



0.124 s

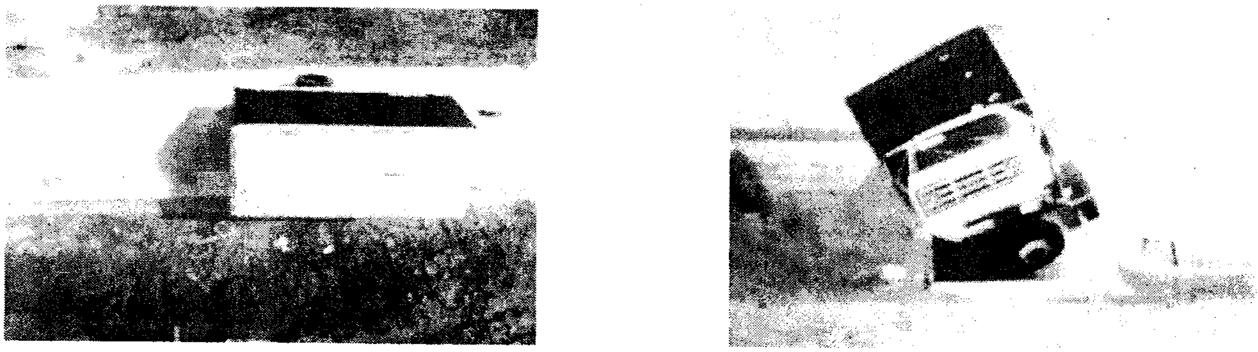


0.251 s

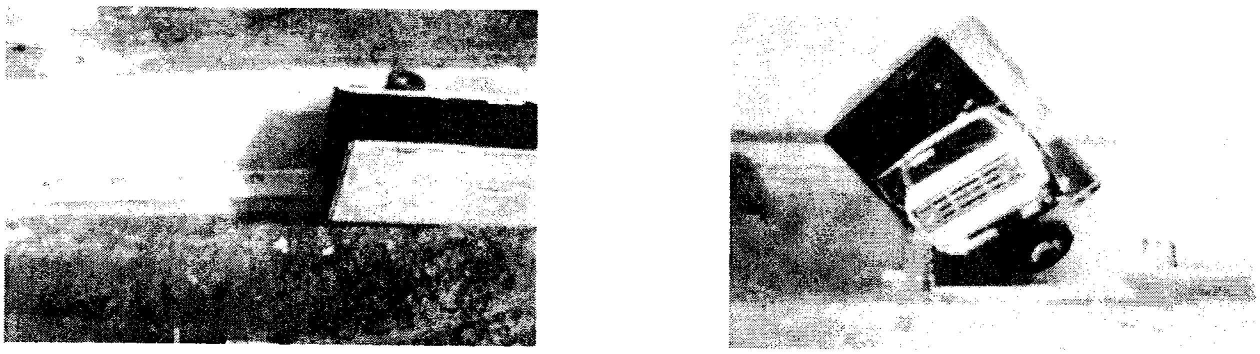


0.375 s

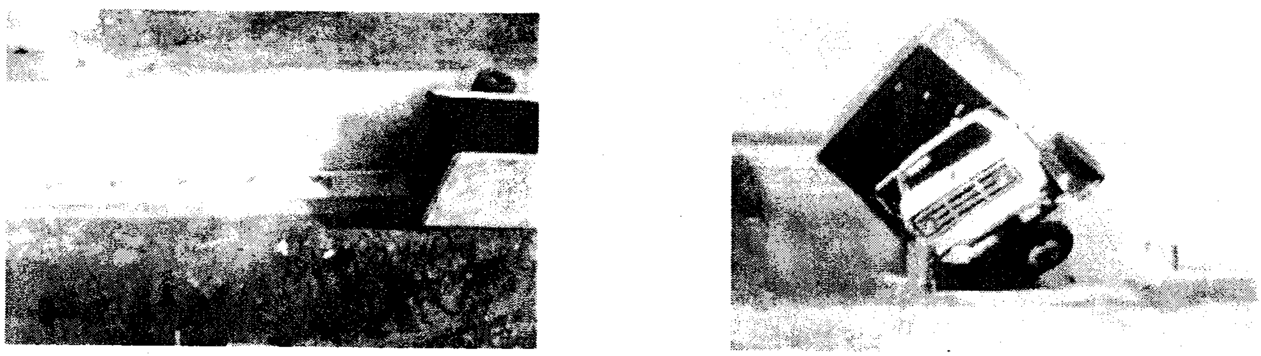
Figure 78. Sequential photographs for test 472070-7 (overhead and frontal views).



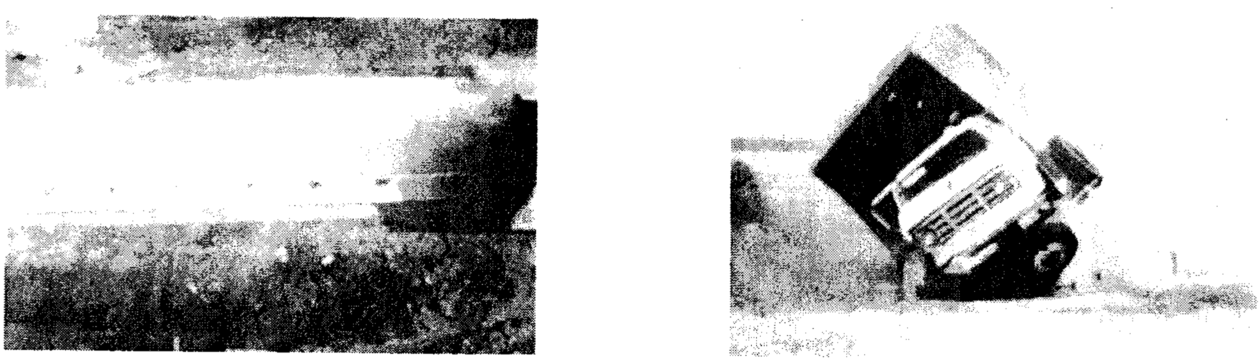
0.501 s



0.625 s

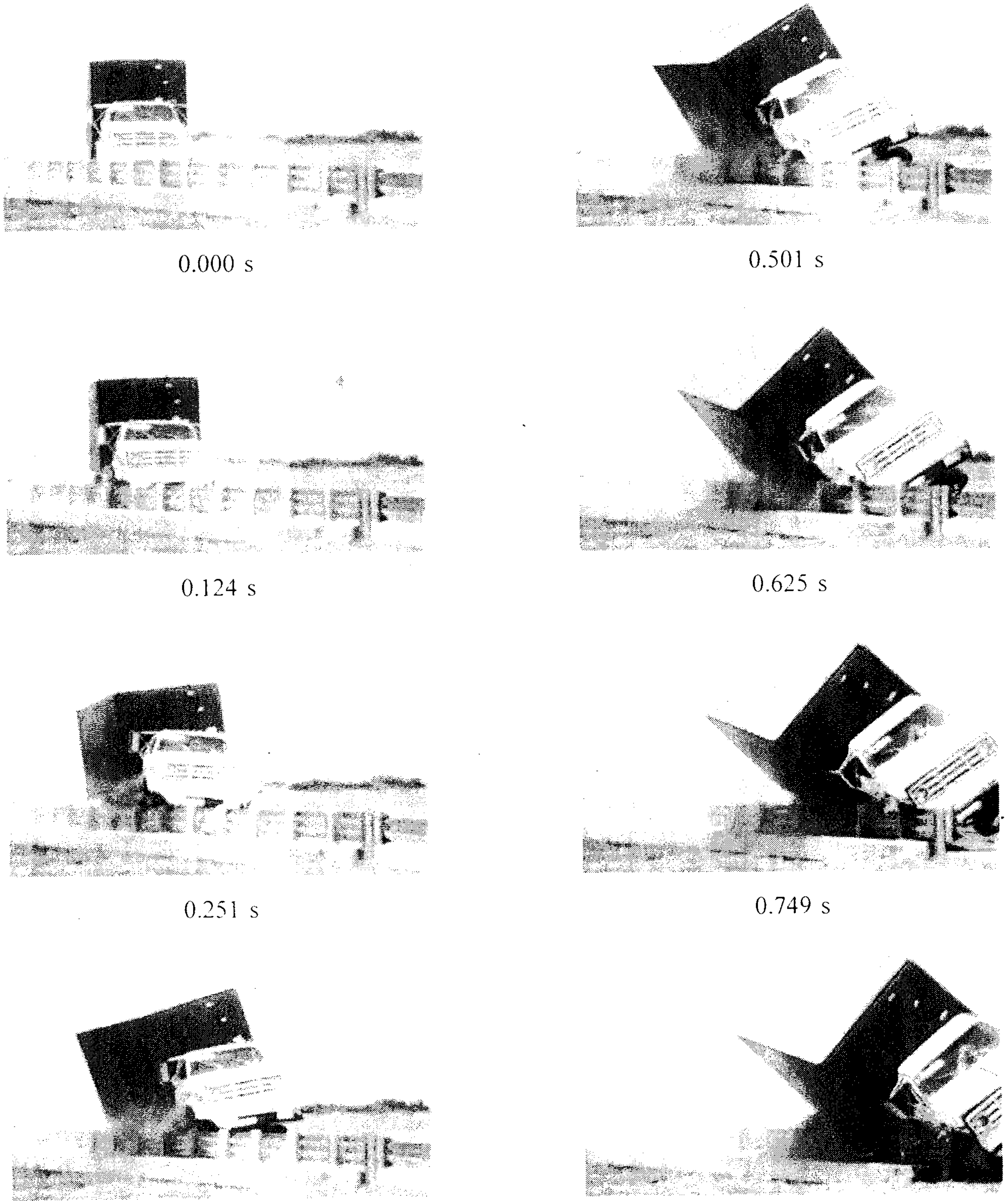


0.749 s



0.876 s

Figure 78. Sequential photographs for test 472070-7 (overhead and frontal views) (continued).



0.000 s

0.124 s

0.251 s

0.375 s

0.501 s

0.625 s

0.749 s

0.876 s

Figure 79. Sequential photographs for test 472070-7 (rear view).

APPENDIX D.
VEHICLE ANGULAR DISPLACEMENTS

This section contains graphs of the angular displacements exhibited by the vehicles during the crash tests performed under this study. Due to instrumentation failure of the rate gyros during test 472070-4, vehicle angular displacement data was not available for that test.

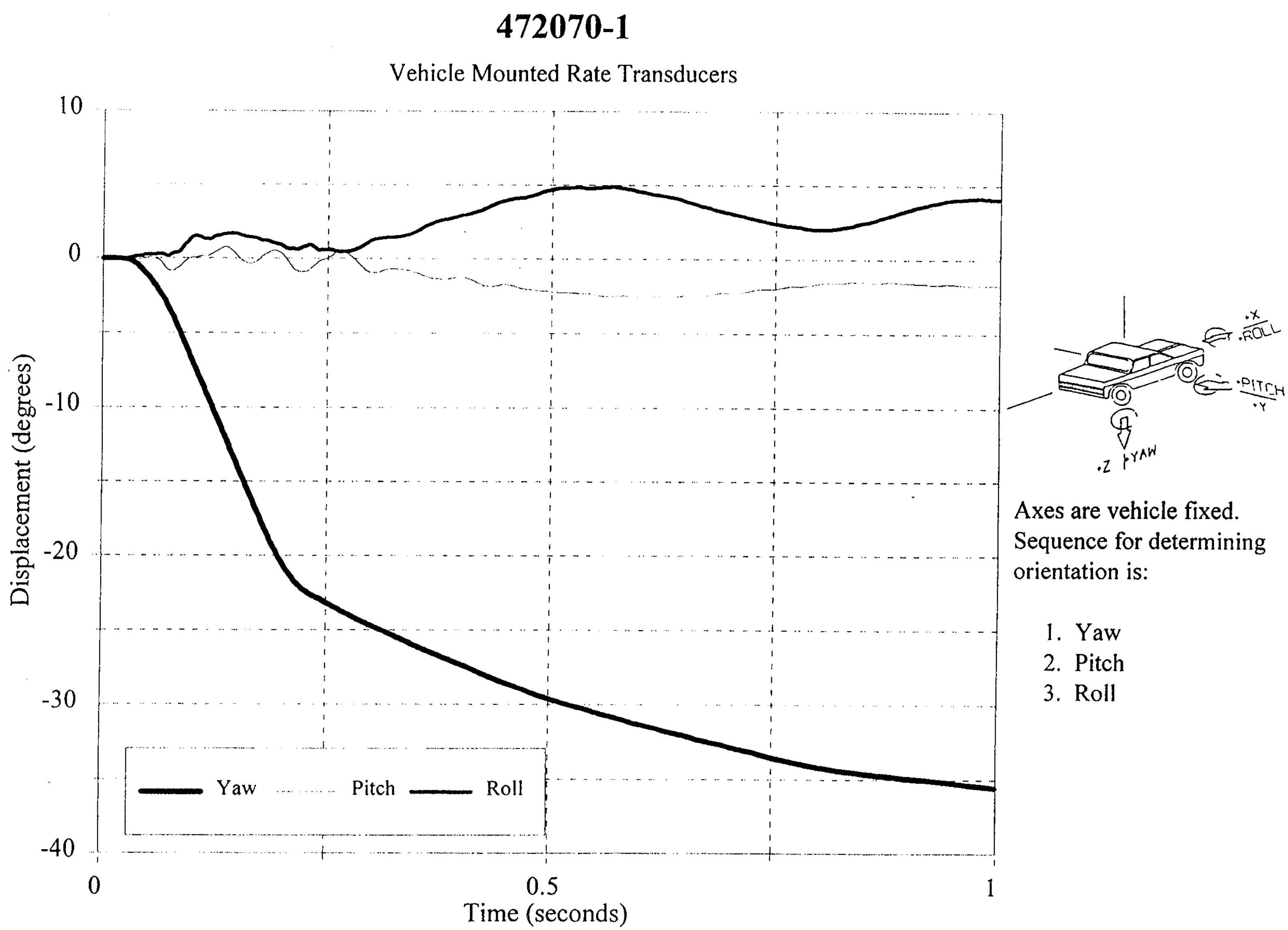


Figure 80. Vehicle angular displacements for test 472070-1.

472070-2

Vehicle Mounted Rate Transducers

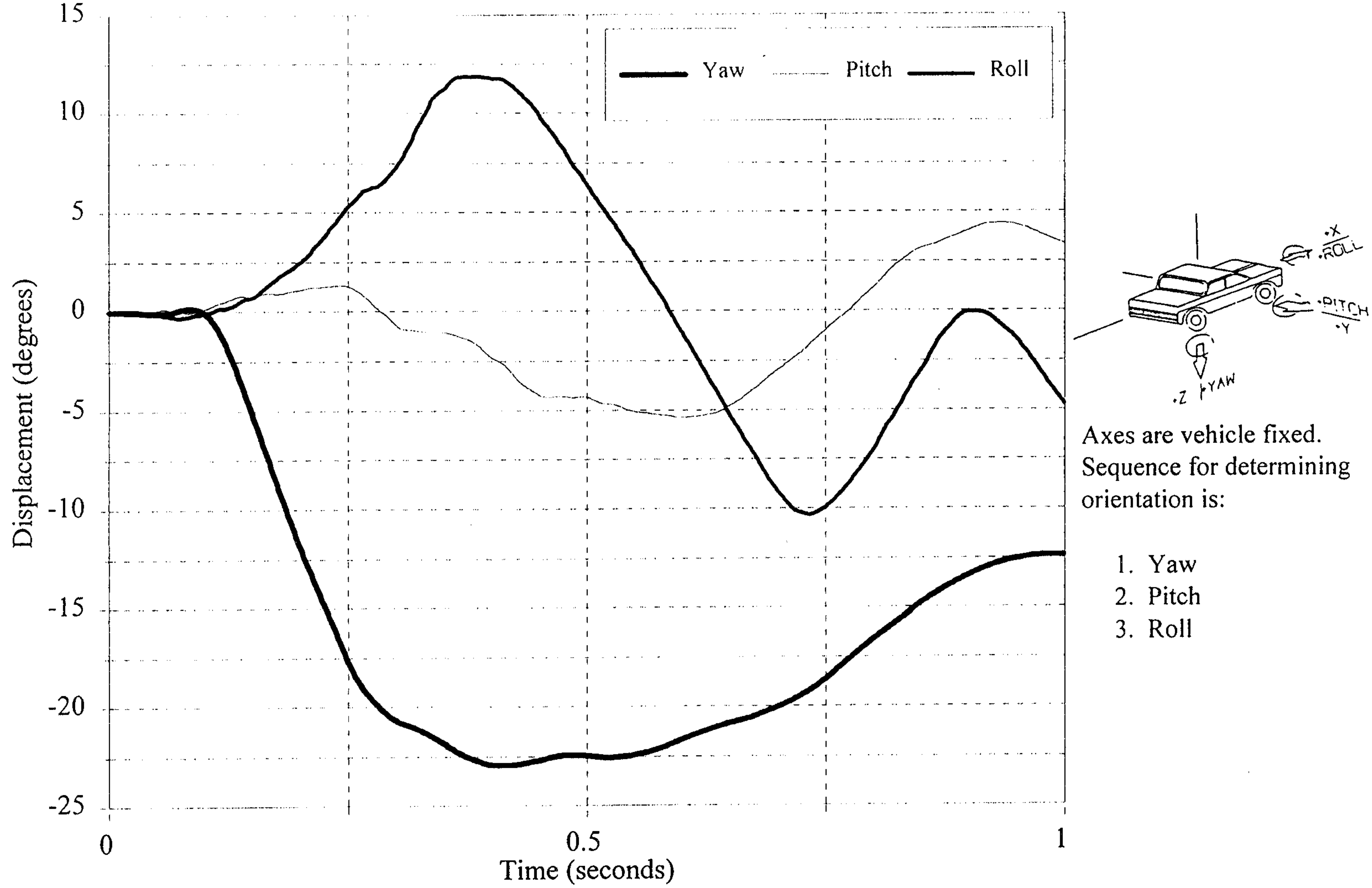


Figure 81. Vehicle angular displacements for test 472070-2.

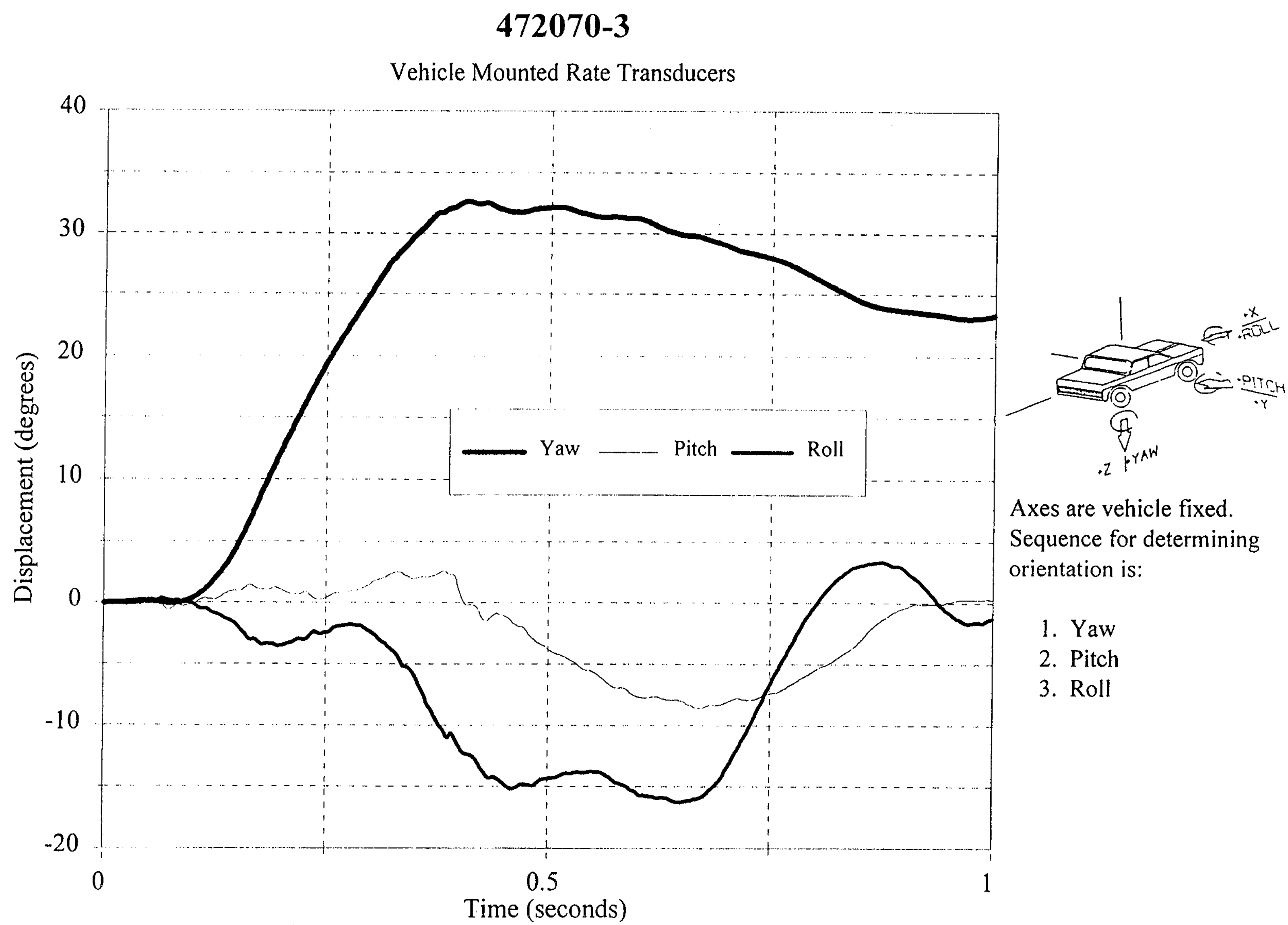
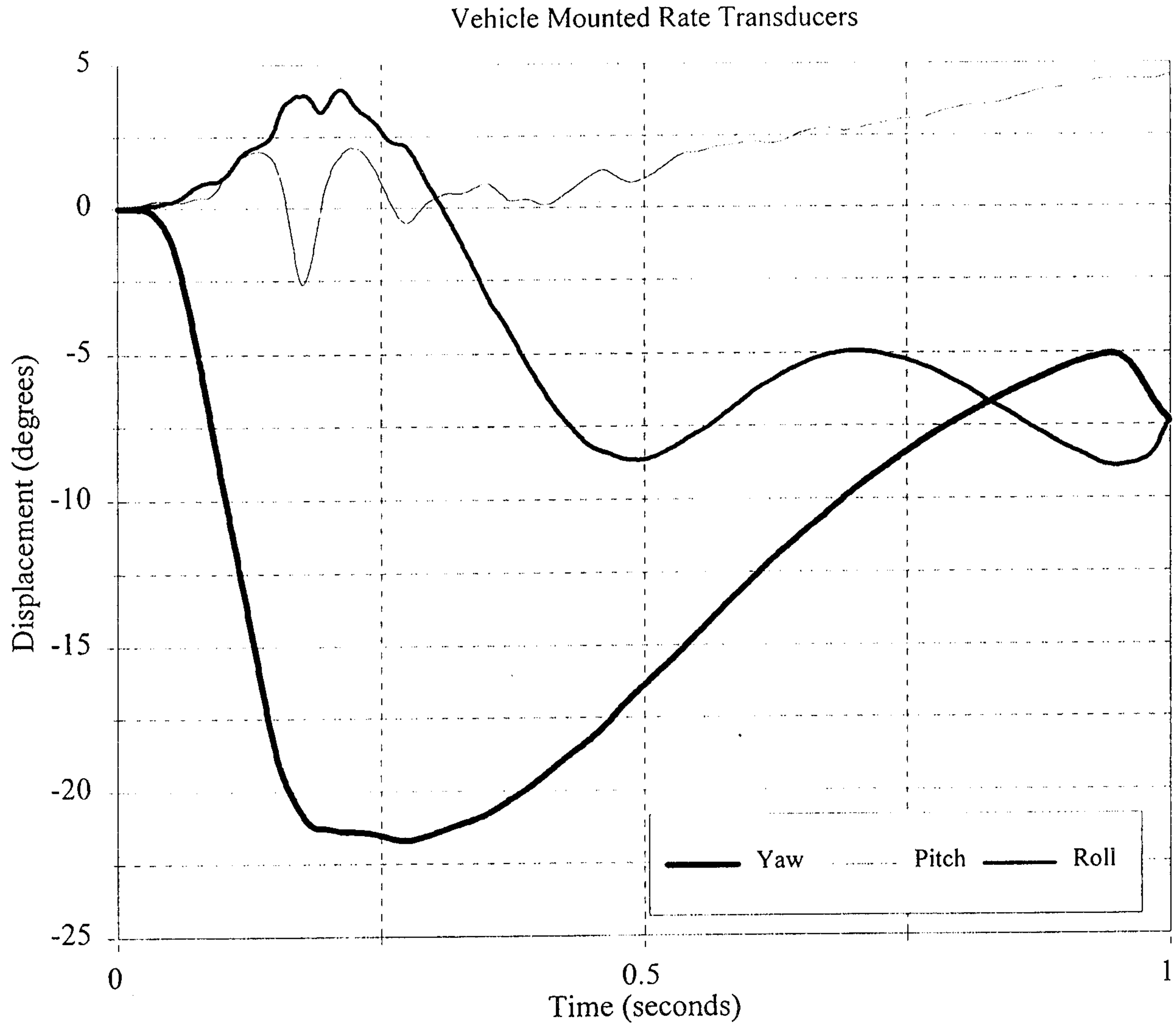
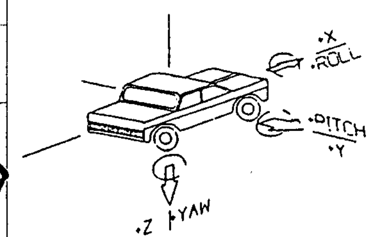


Figure 82. Vehicle angular displacements for test 472070-3.

472070-5





Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

Figure 83. Vehicle angular displacements for test 472070-5.

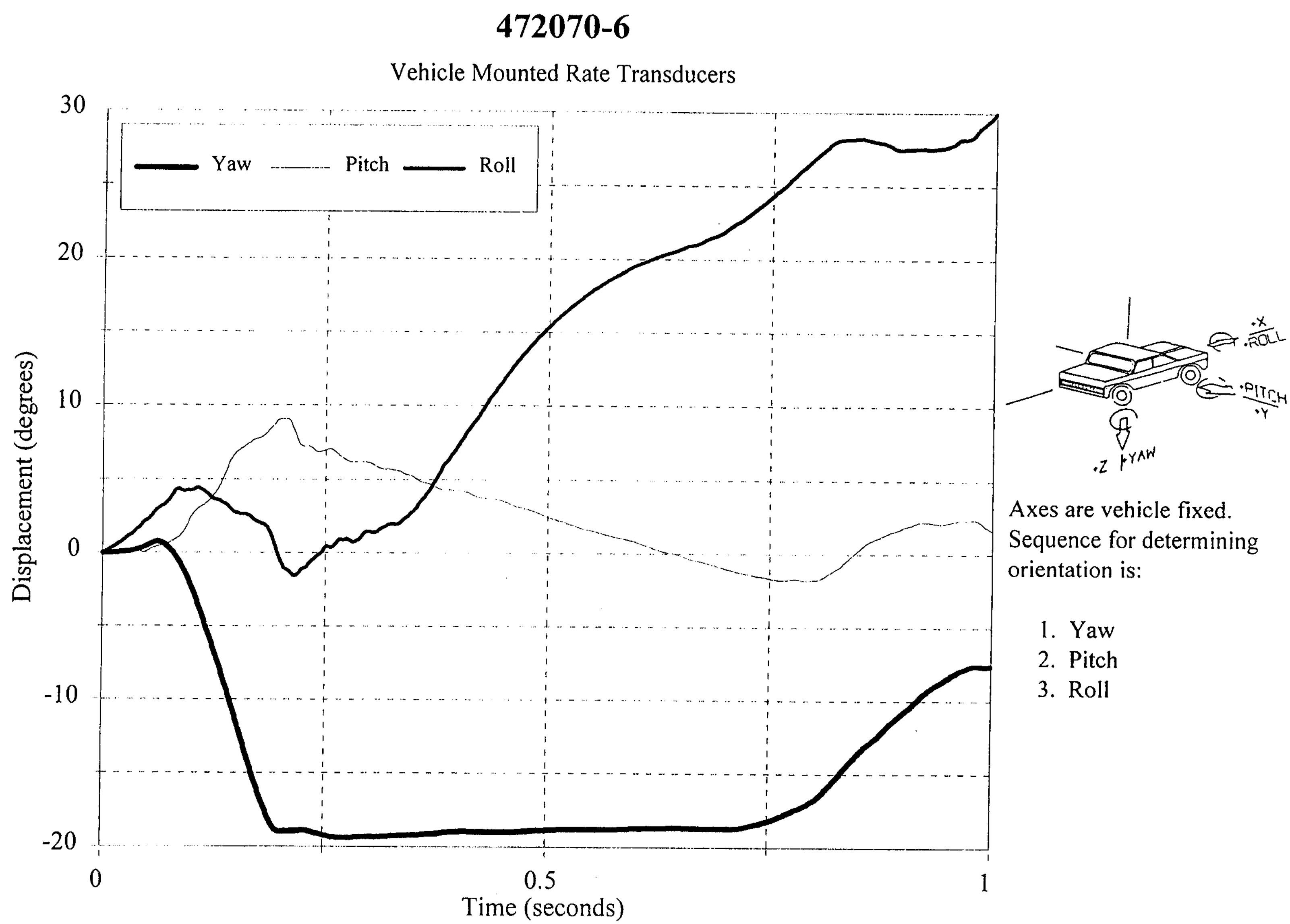


Figure 84. Vehicle angular displacements for test 472070-6.

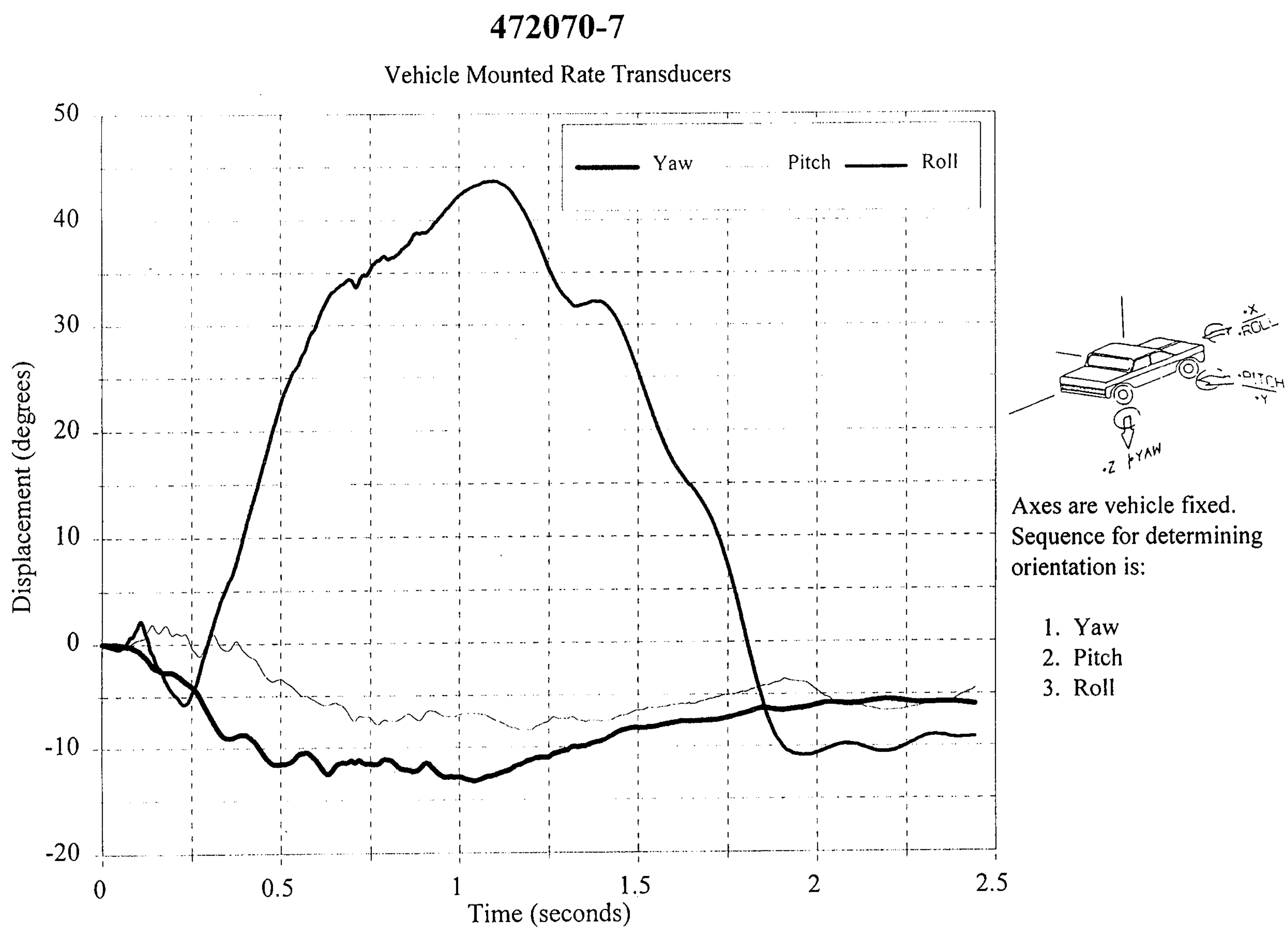


Figure 85. Vehicle angular displacements for test 472070-7.

APPENDIX E.
VEHICLE ACCELEROMETER TRACES

This section contains graphs of the accelerometer data recorded during the crash tests performed under this study.

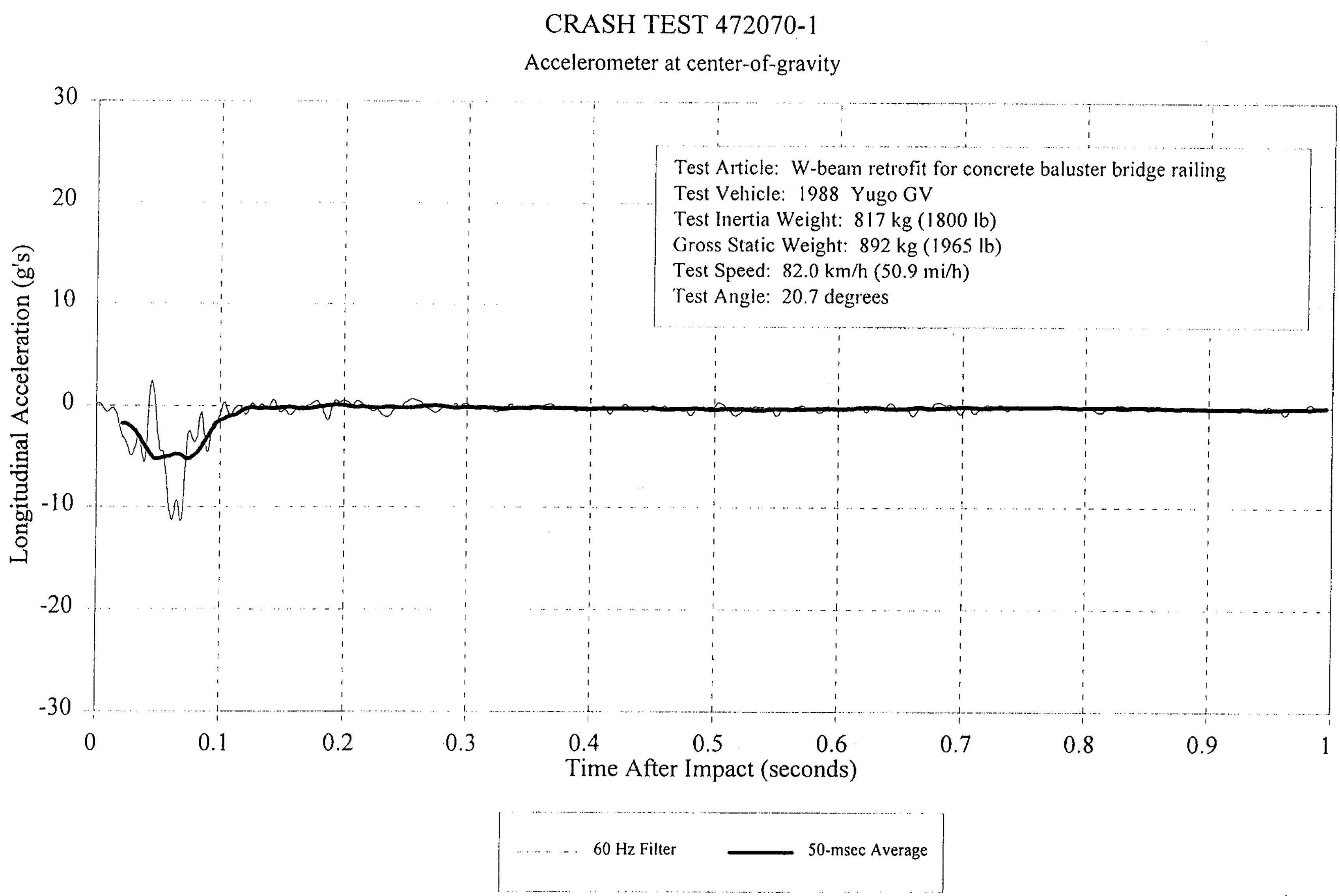


Figure 86. Vehicle longitudinal accelerometer trace for test 472070-1.

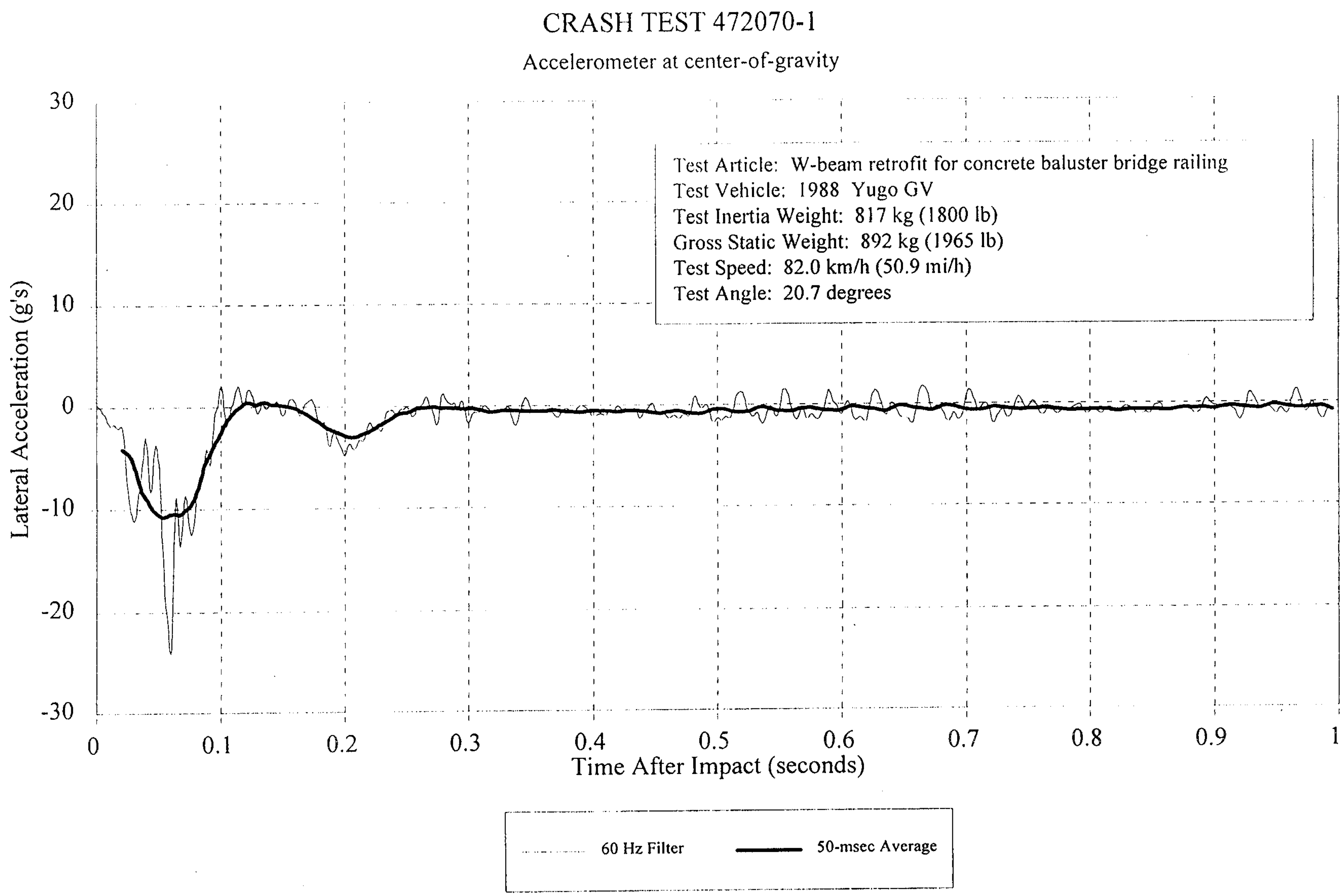


Figure 87. Vehicle lateral accelerometer trace for test 472070-1.

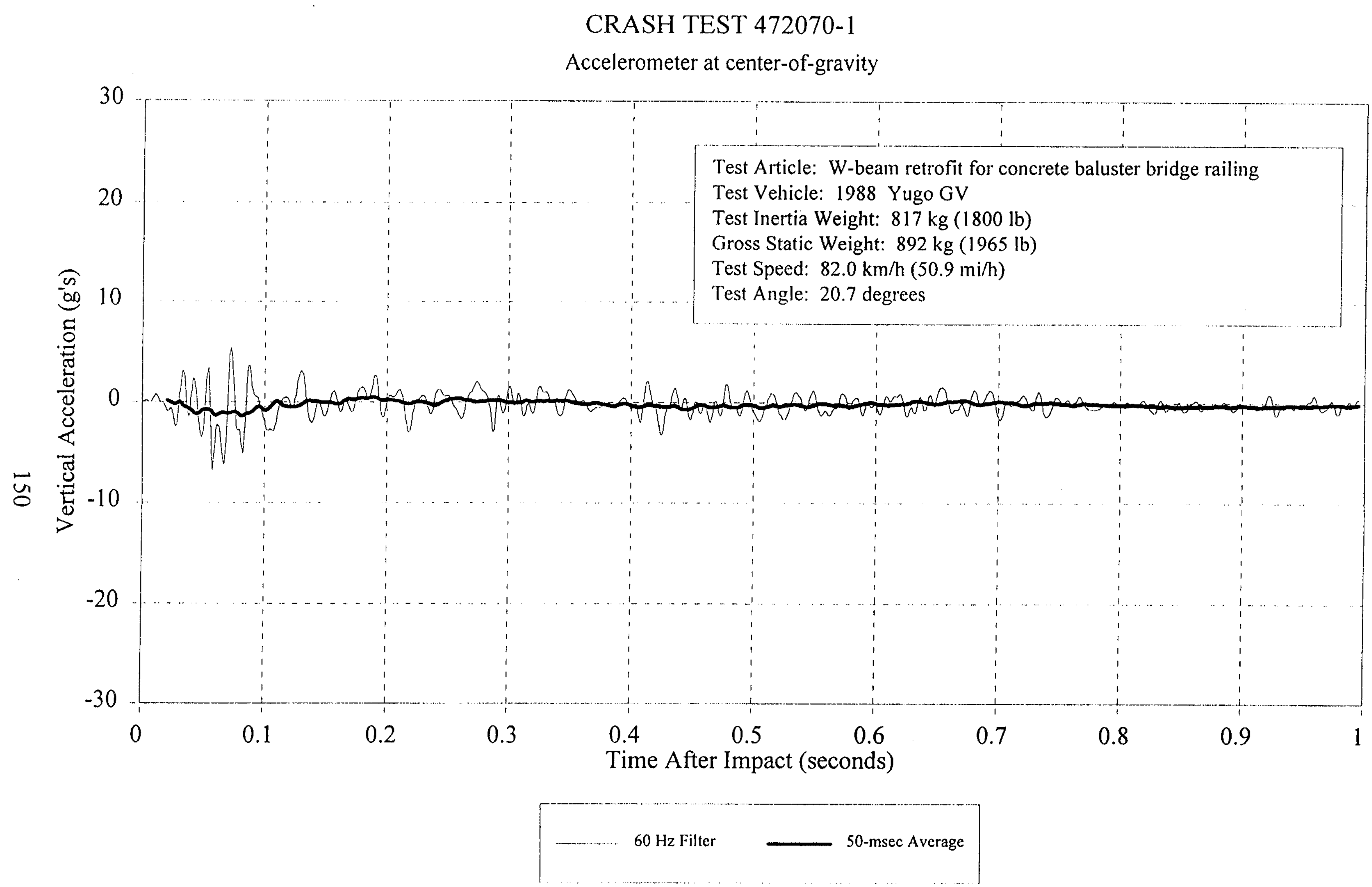


Figure 88. Vehicle vertical accelerometer trace for test 472070-1.

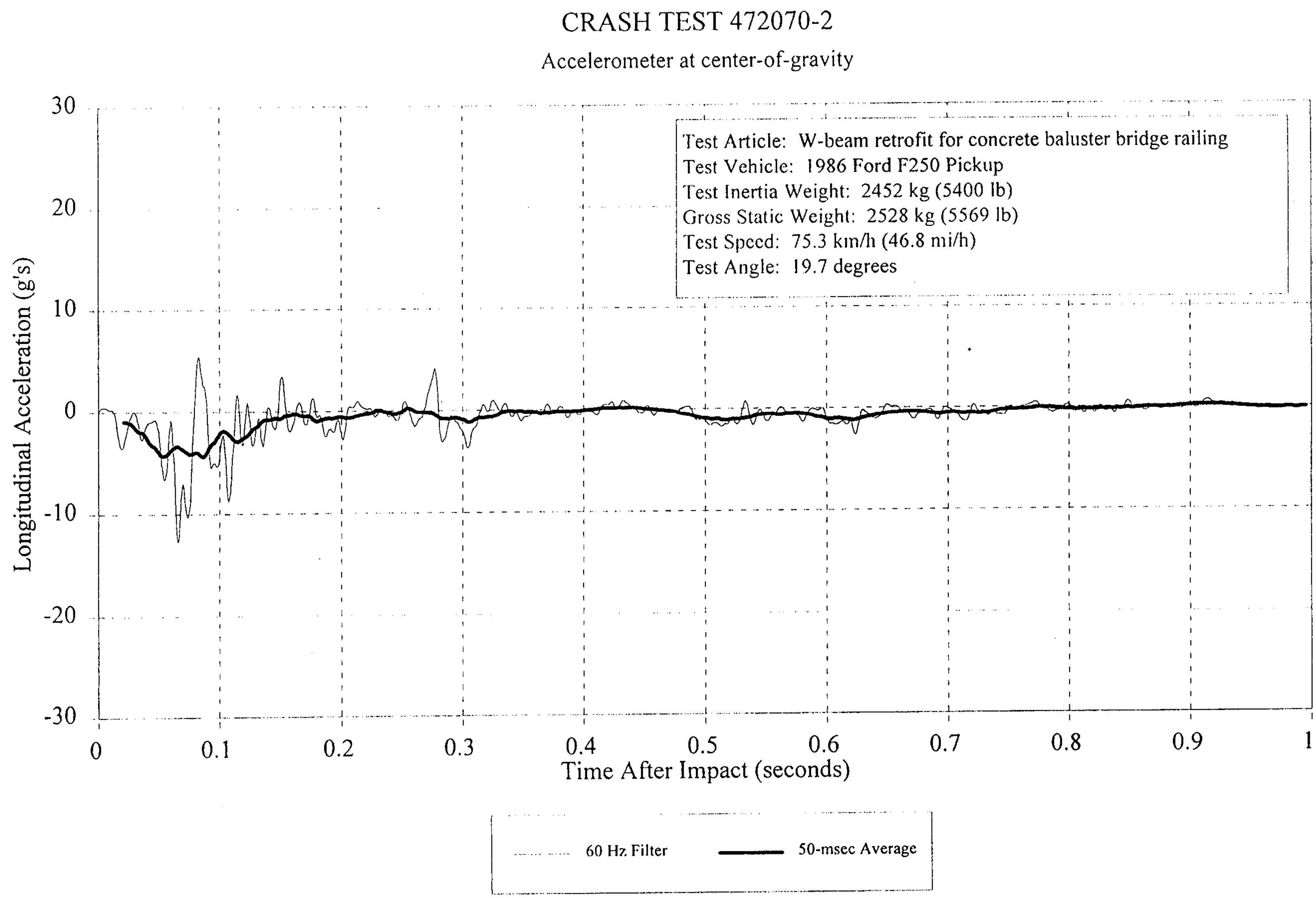


Figure 89. Vehicle longitudinal accelerometer trace for test 472070-2.

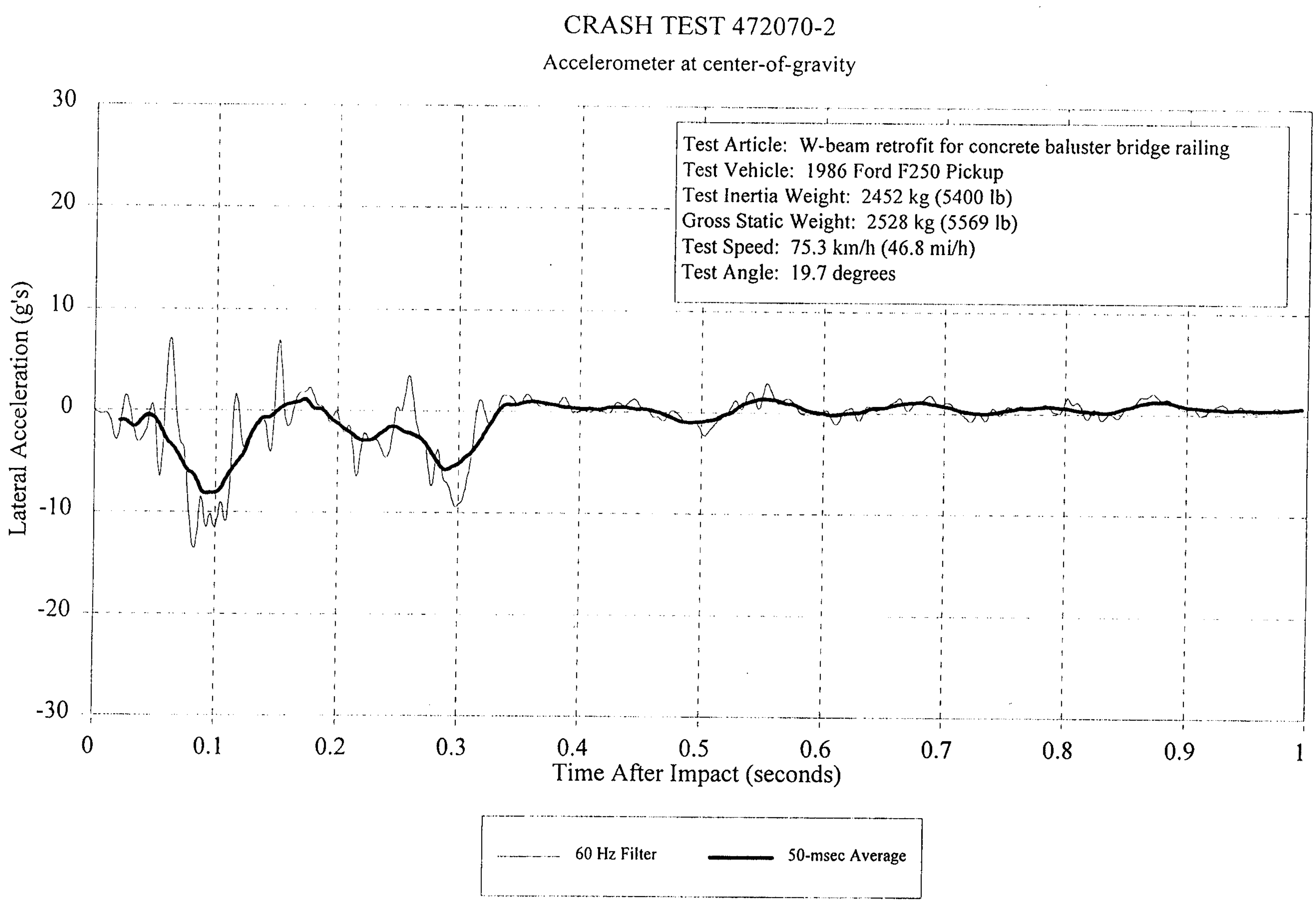


Figure 90. Vehicle lateral accelerometer trace for test 472070-2.

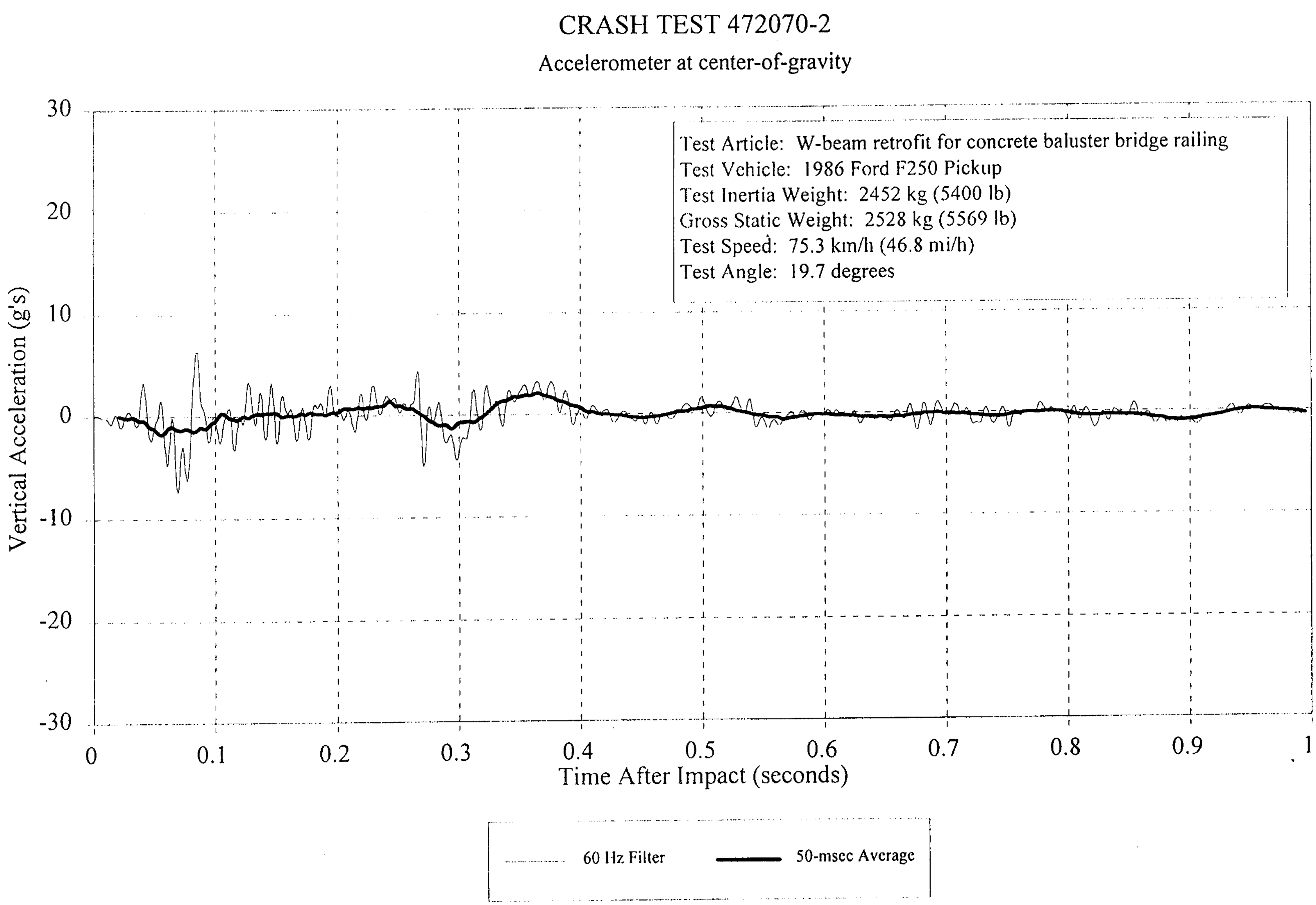


Figure 91. Vehicle vertical accelerometer trace for test 472070-2.

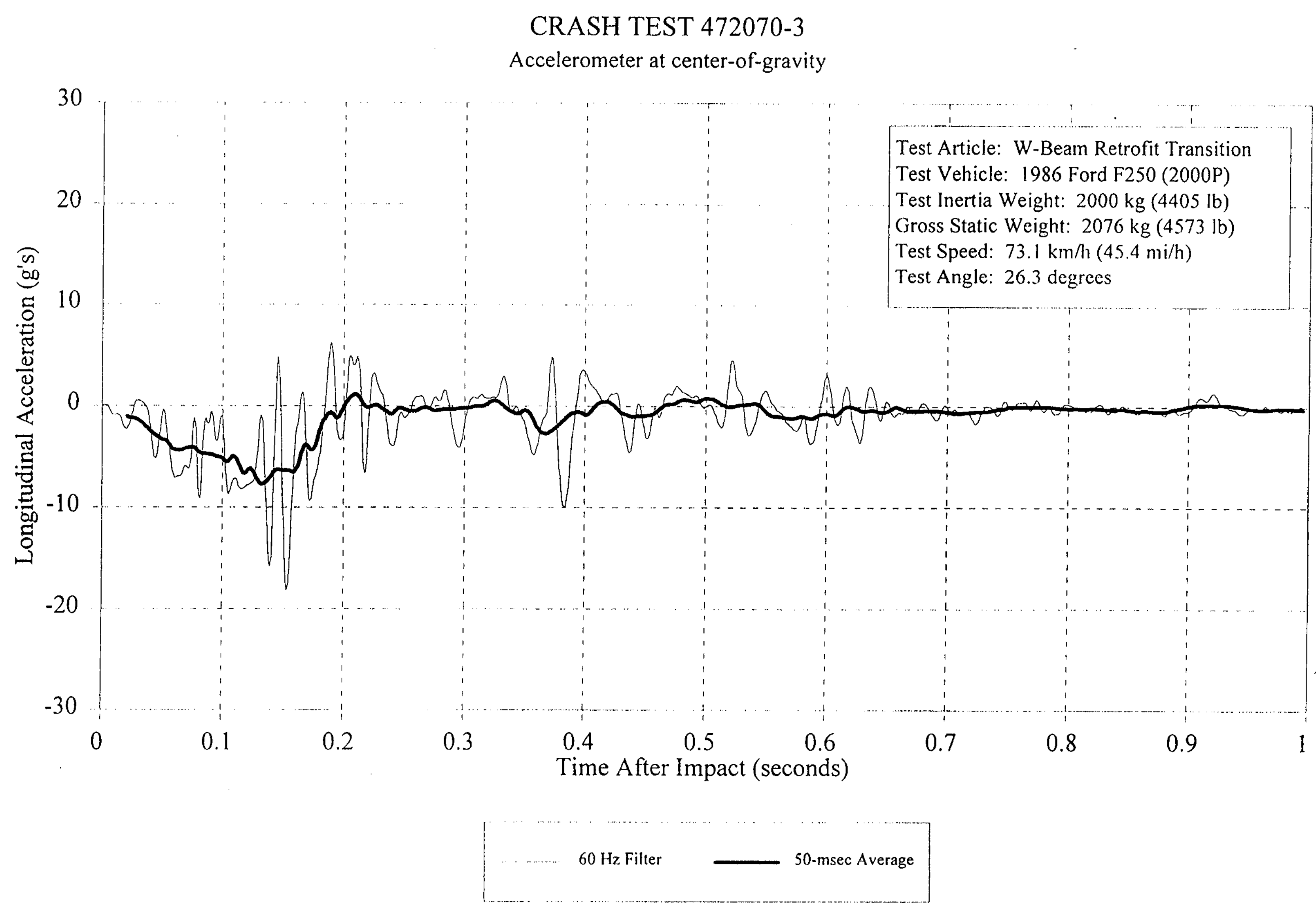


Figure 92. Vehicle longitudinal accelerometer trace for test 472070-3.

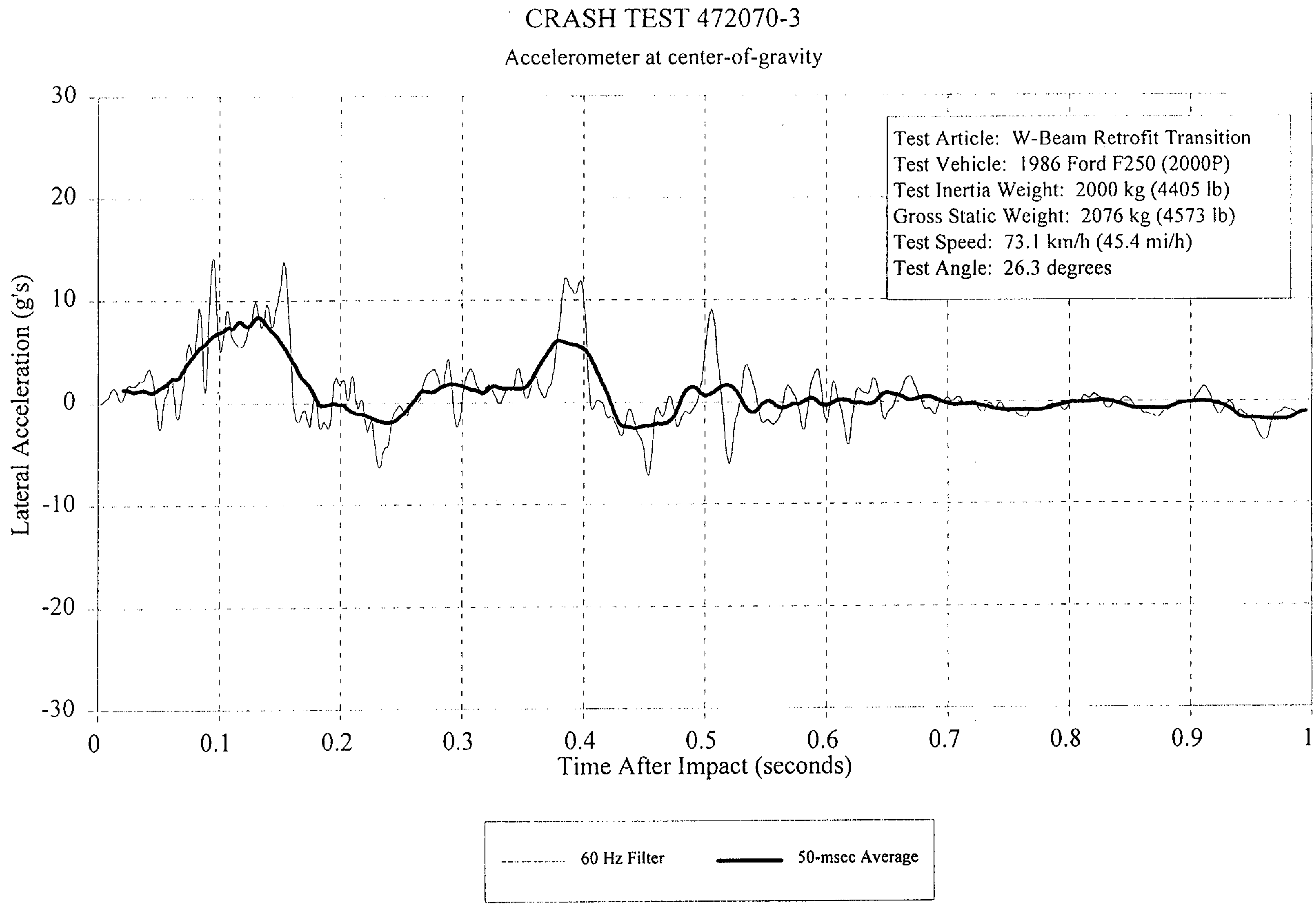


Figure 93. Vehicle lateral accelerometer trace for test 472070-3.

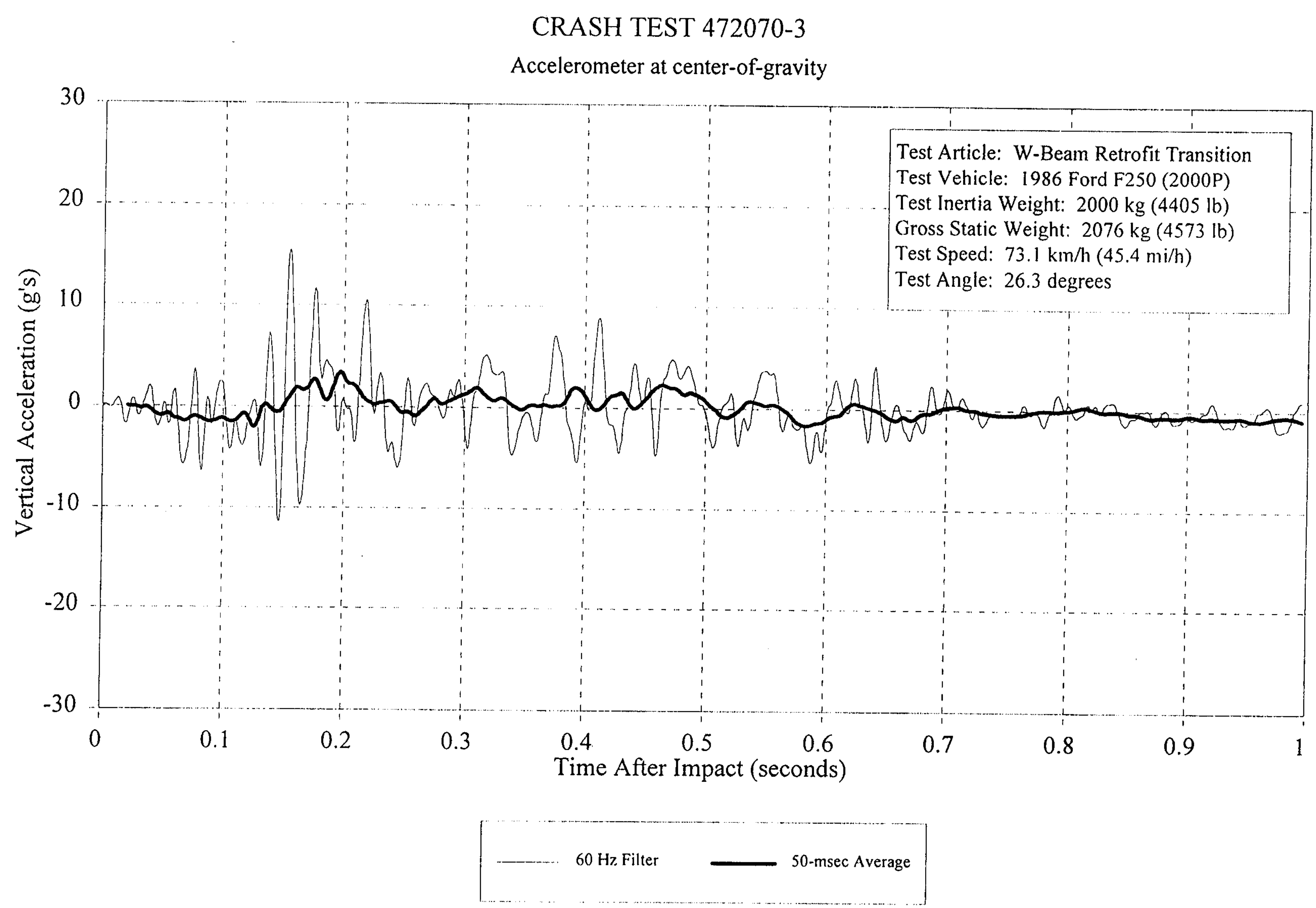


Figure 94. Vehicle vertical accelerometer trace for test 472070-3.

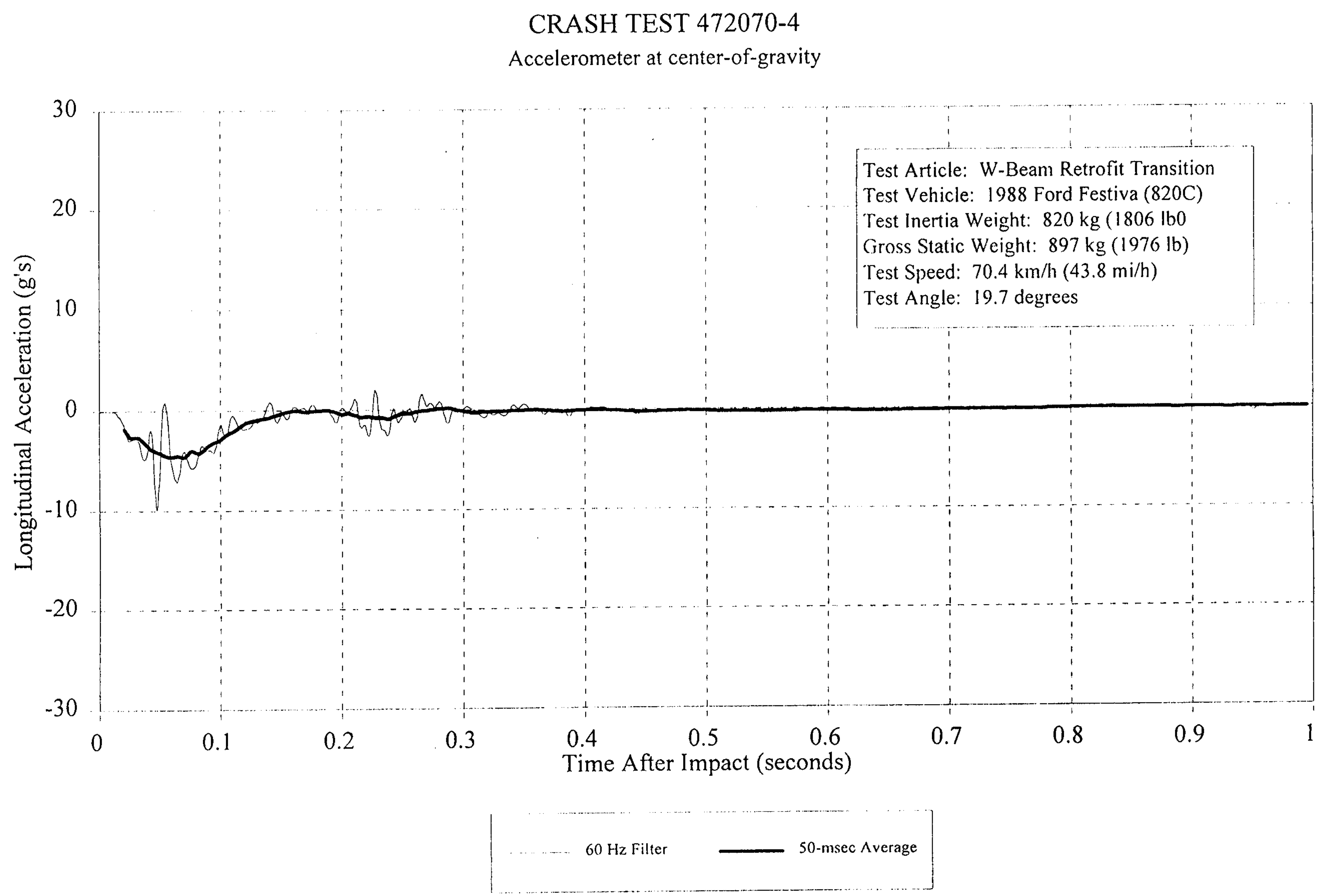


Figure 95. Vehicle longitudinal accelerometer trace for test 472070-4.

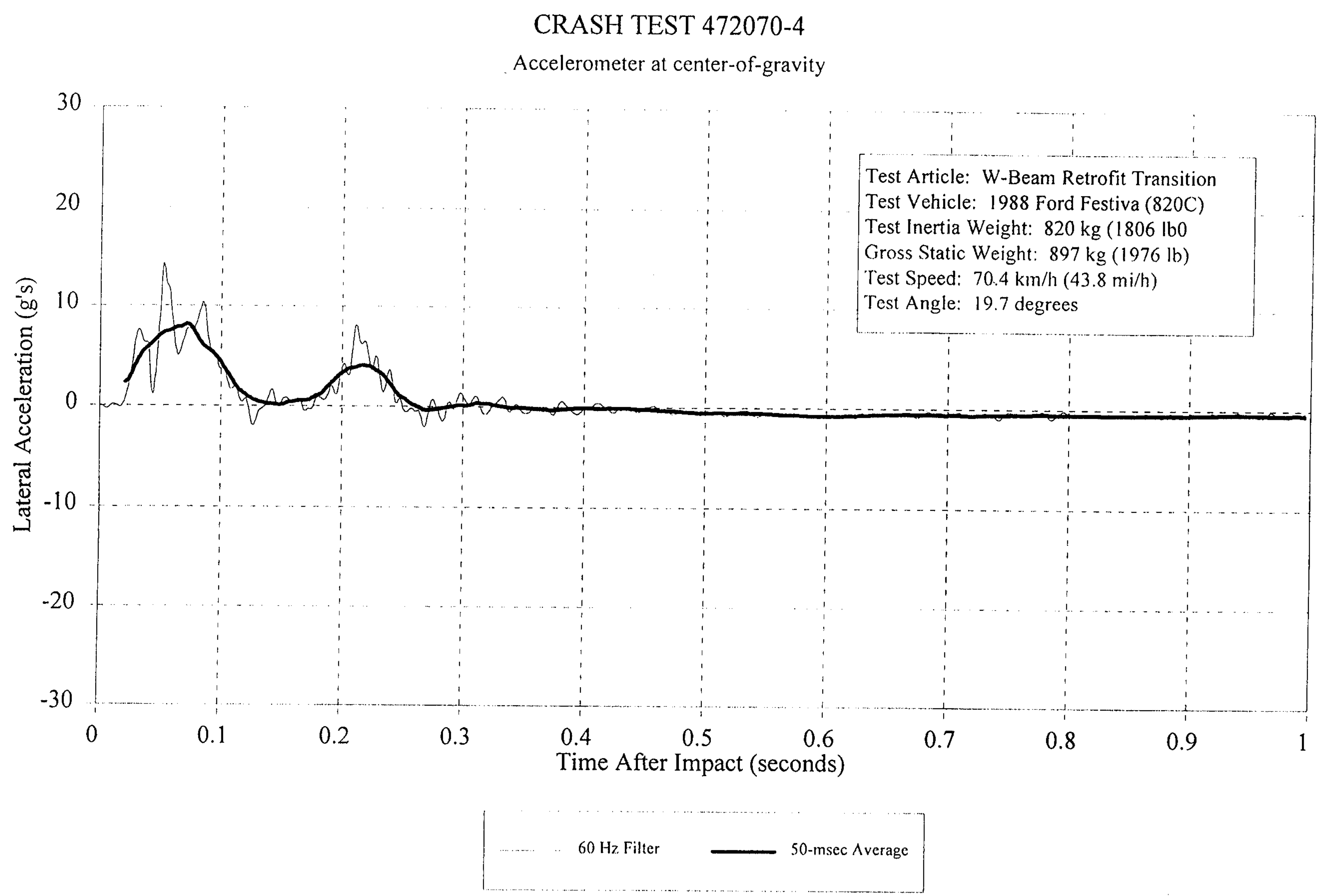


Figure 96. Vehicle lateral accelerometer trace for test 472070-4.

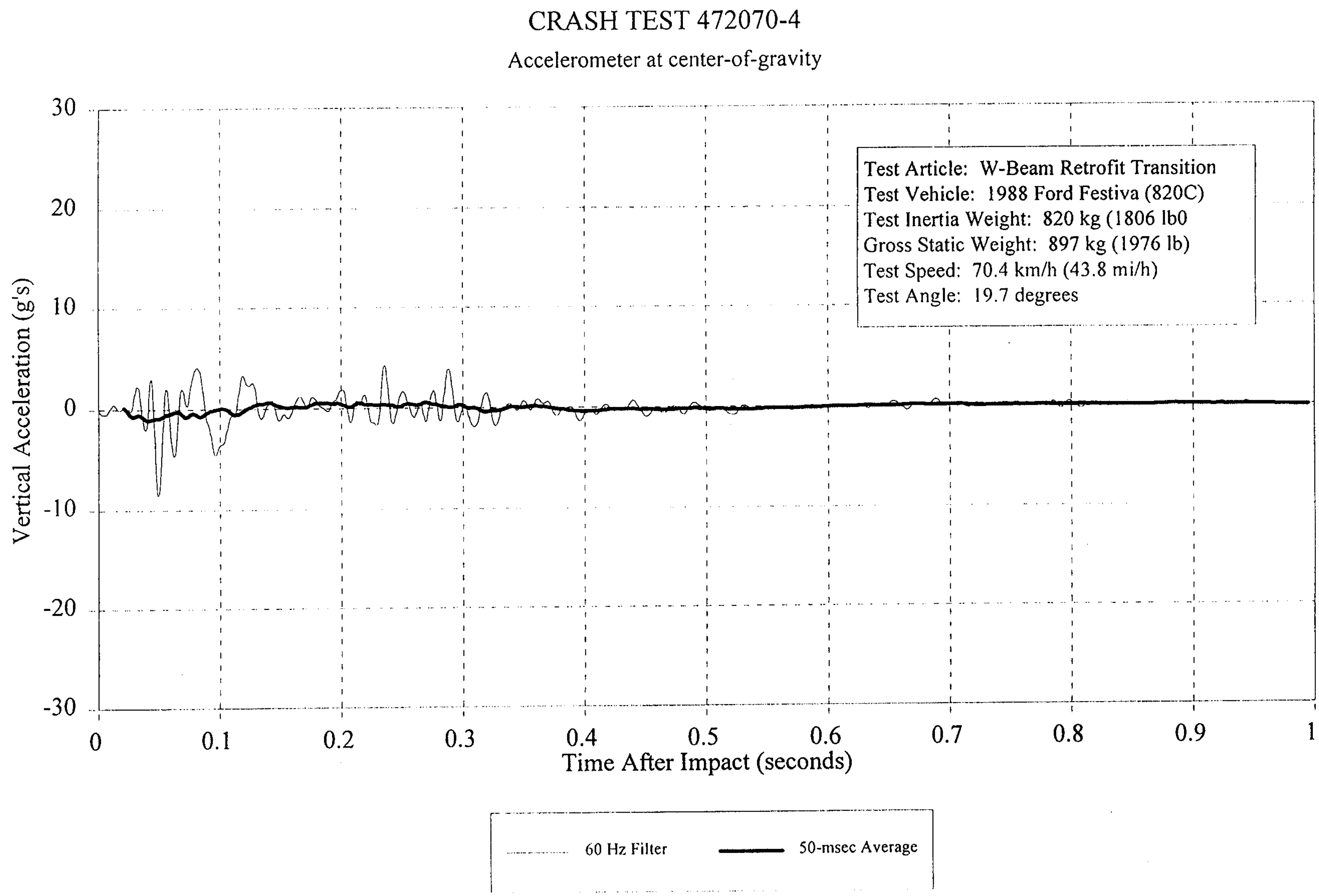


Figure 97. Vehicle vertical accelerometer trace for test 472070-4.

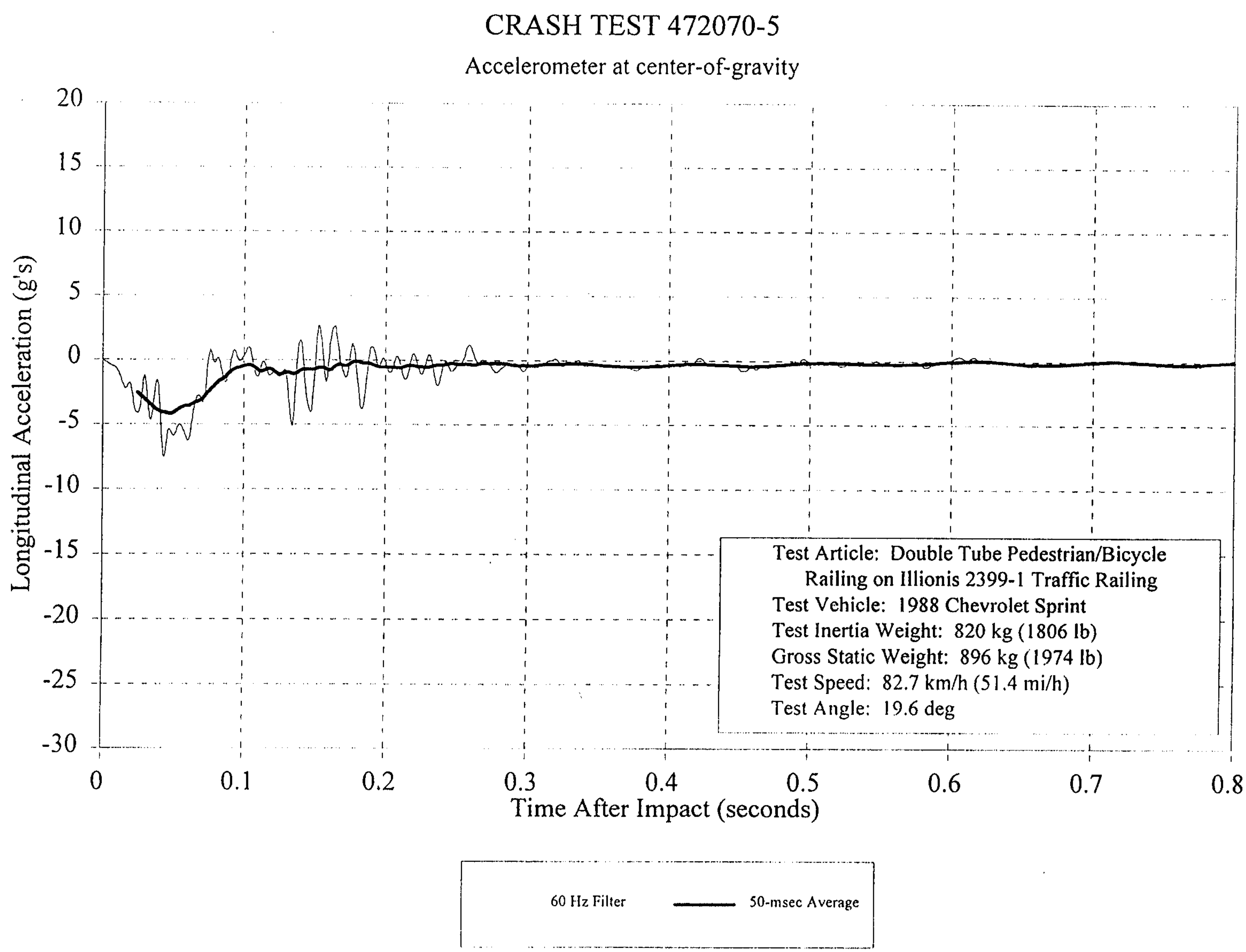


Figure 98. Vehicle longitudinal accelerometer trace for test 472070-5.

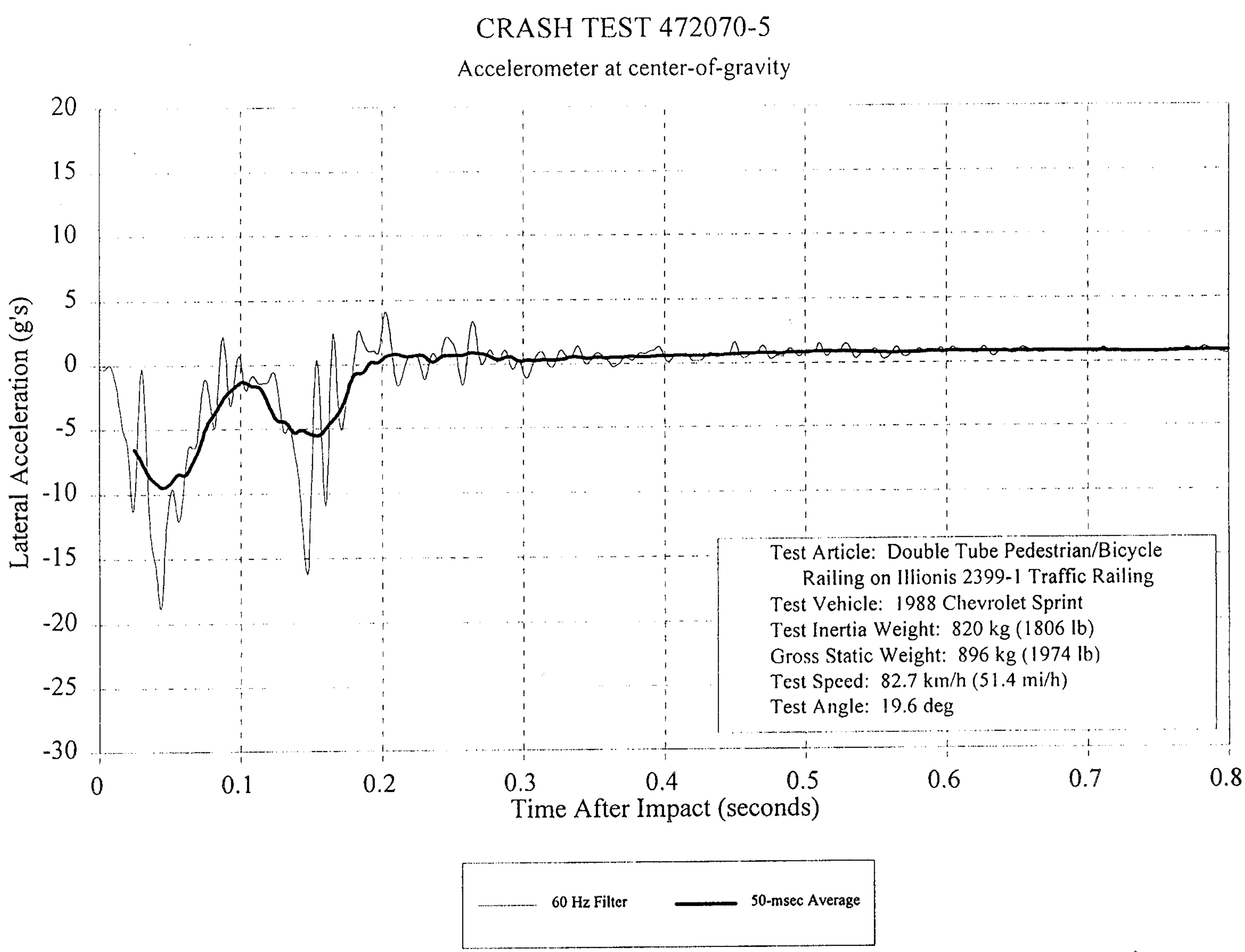


Figure 99. Vehicle lateral accelerometer trace for test 472070-5.

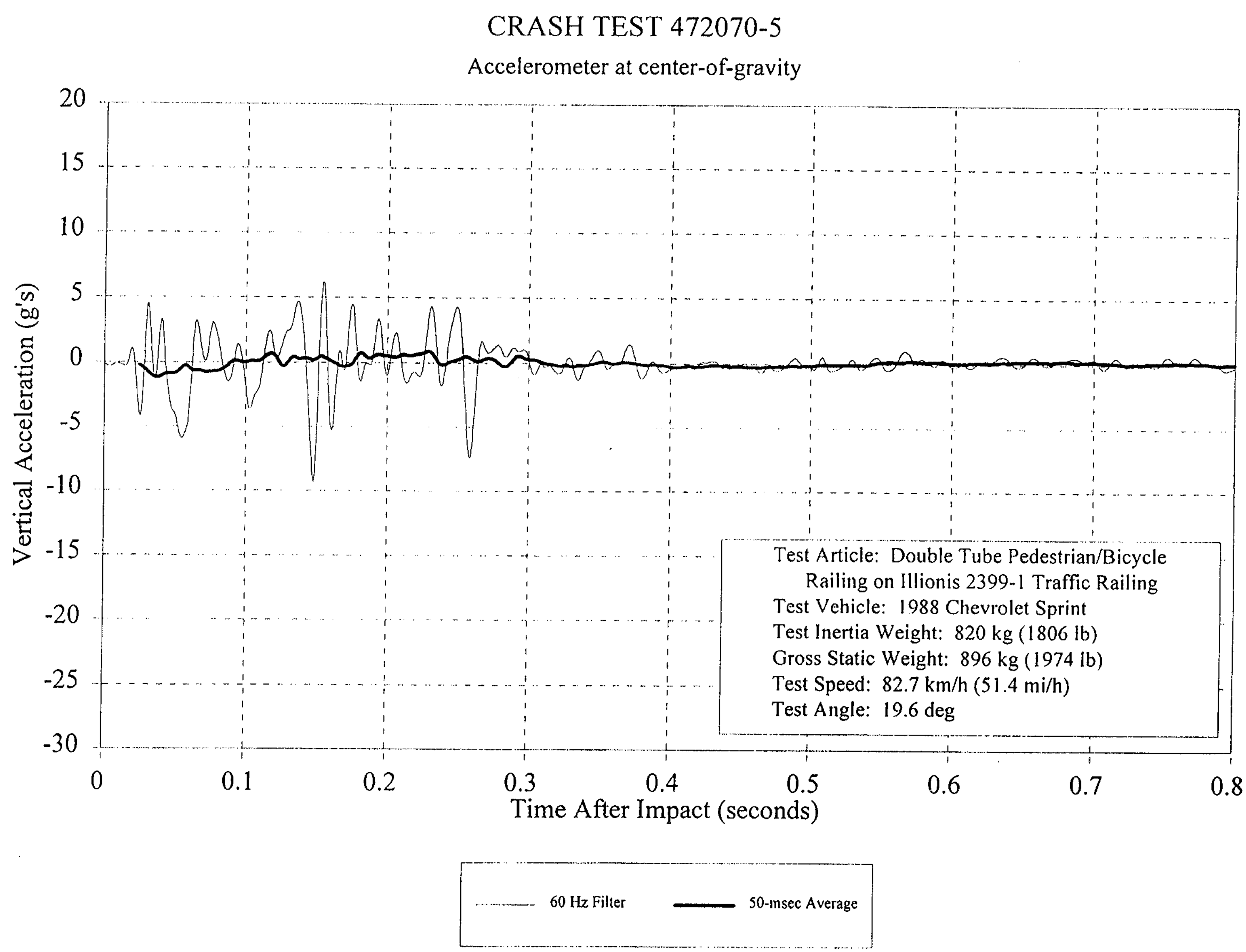


Figure 100. Vehicle vertical accelerometer trace for test 472070-5.

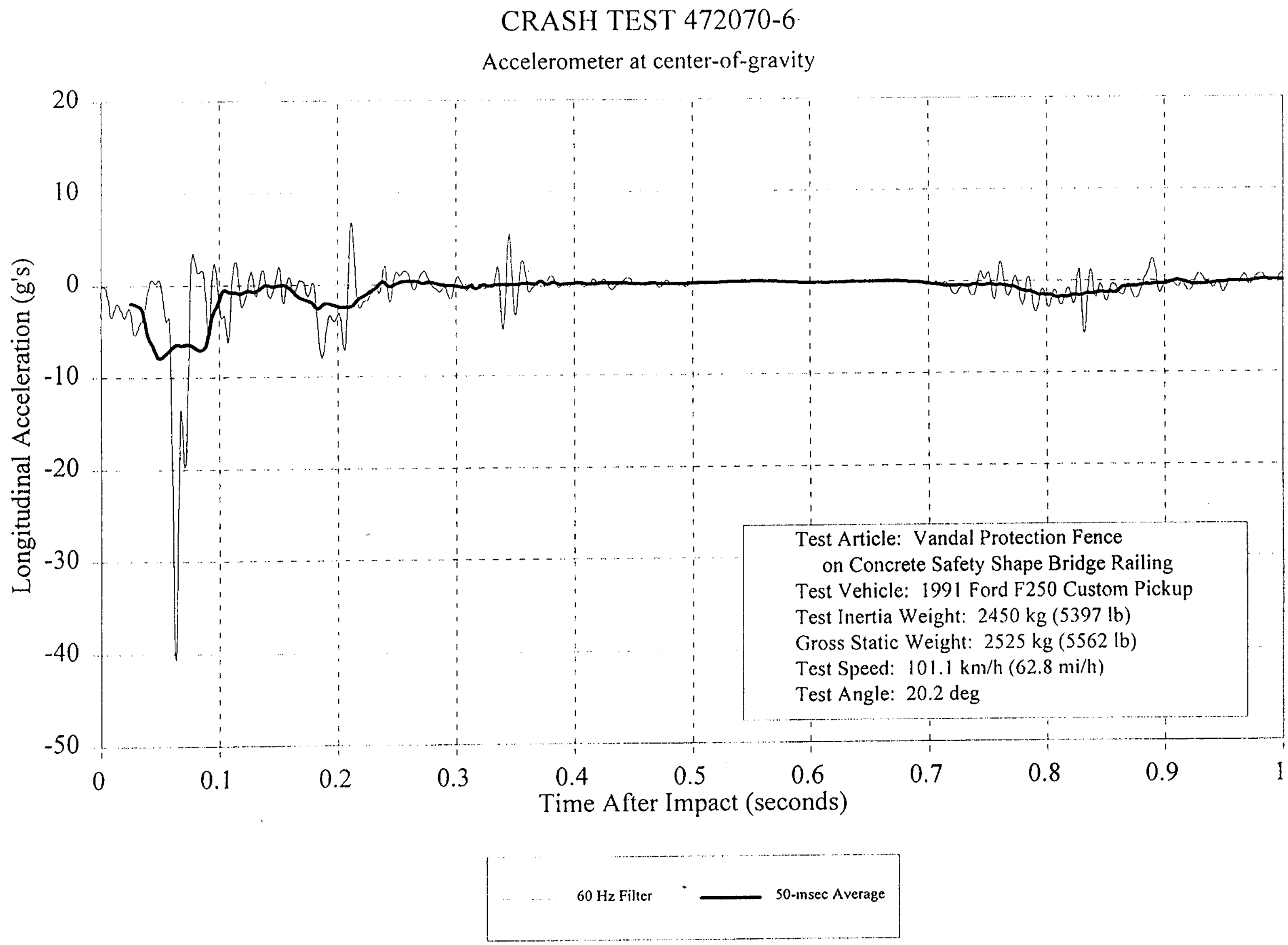


Figure 101. Vehicle longitudinal accelerometer trace for test 472070-6.

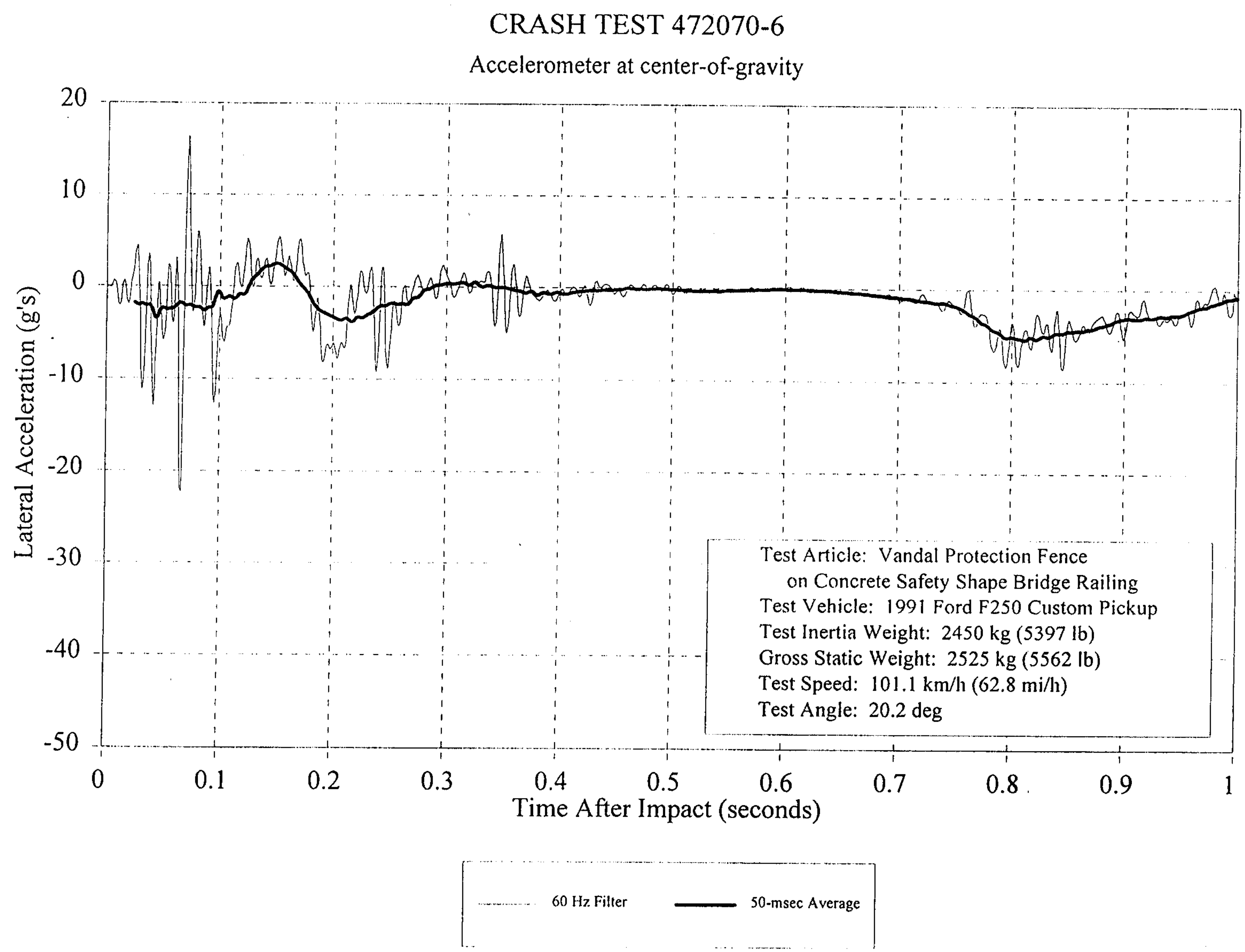


Figure 102. Vehicle lateral accelerometer trace for test 472070-6.

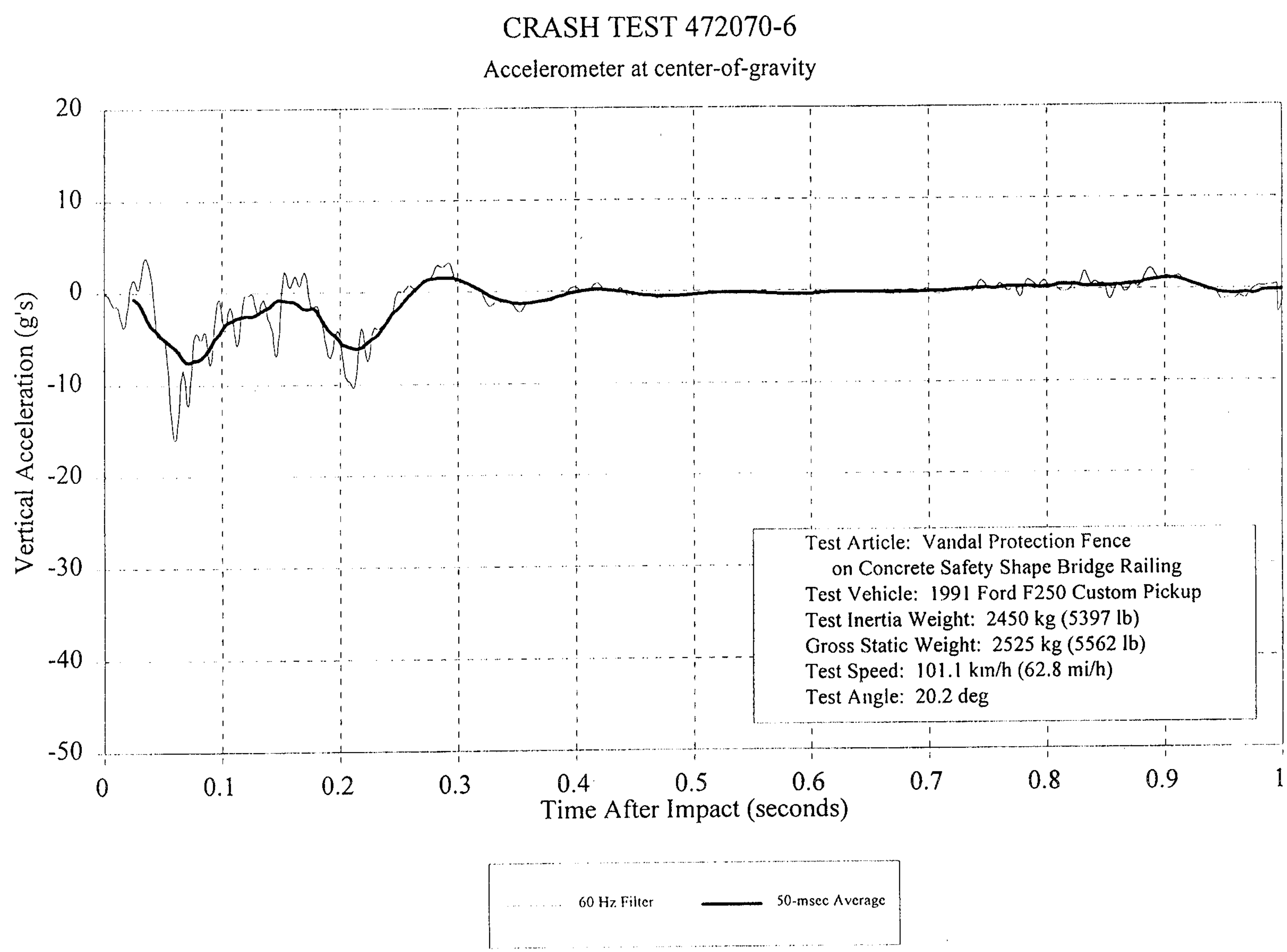


Figure 103. Vehicle vertical accelerometer trace for test 472070-6.

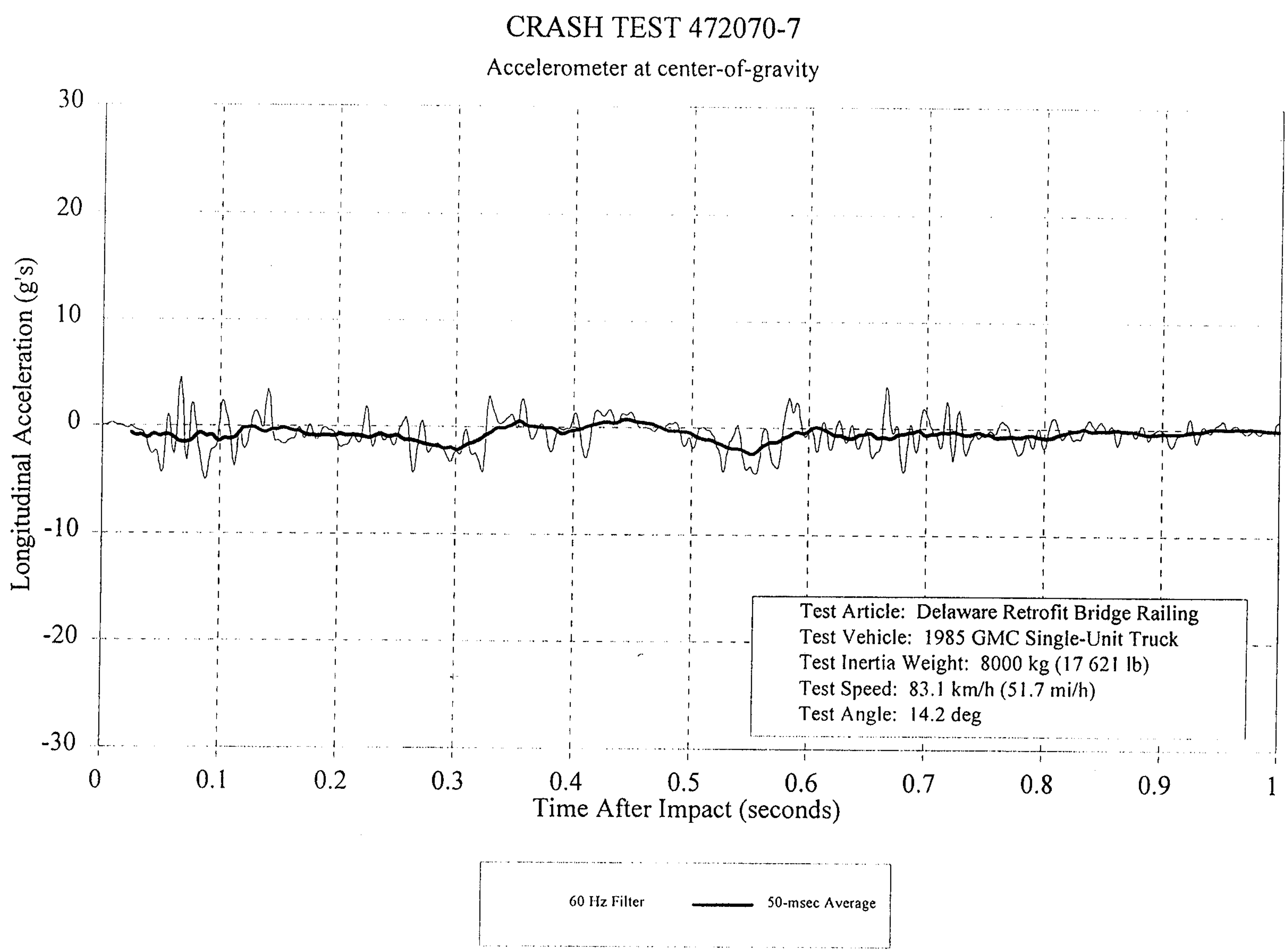


Figure 104. Vehicle longitudinal accelerometer trace for test 472070-7 (accelerometer located at center-of-gravity).

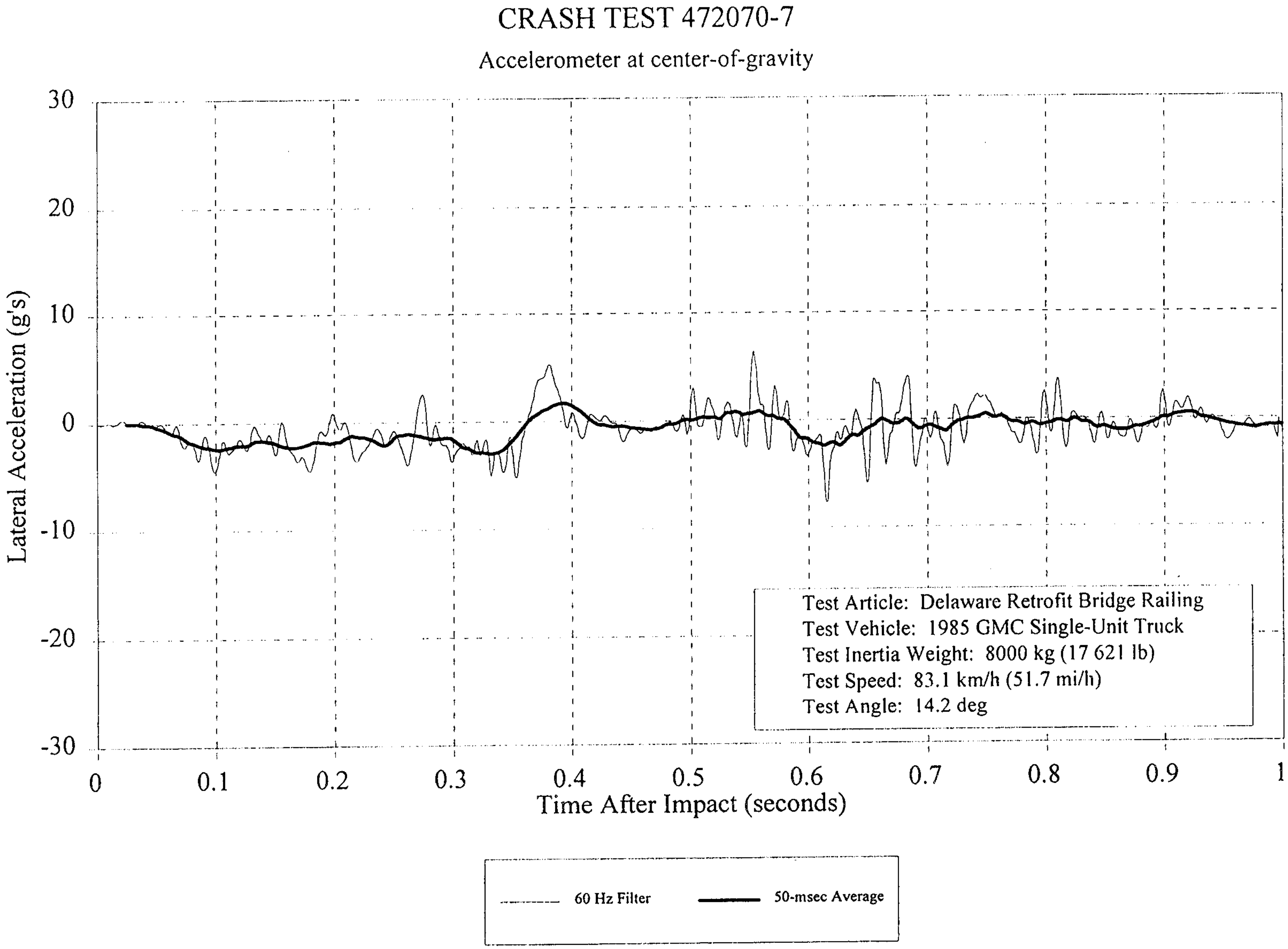


Figure 105. Vehicle lateral accelerometer trace for test 472070-7
(accelerometer located at center-of-gravity).

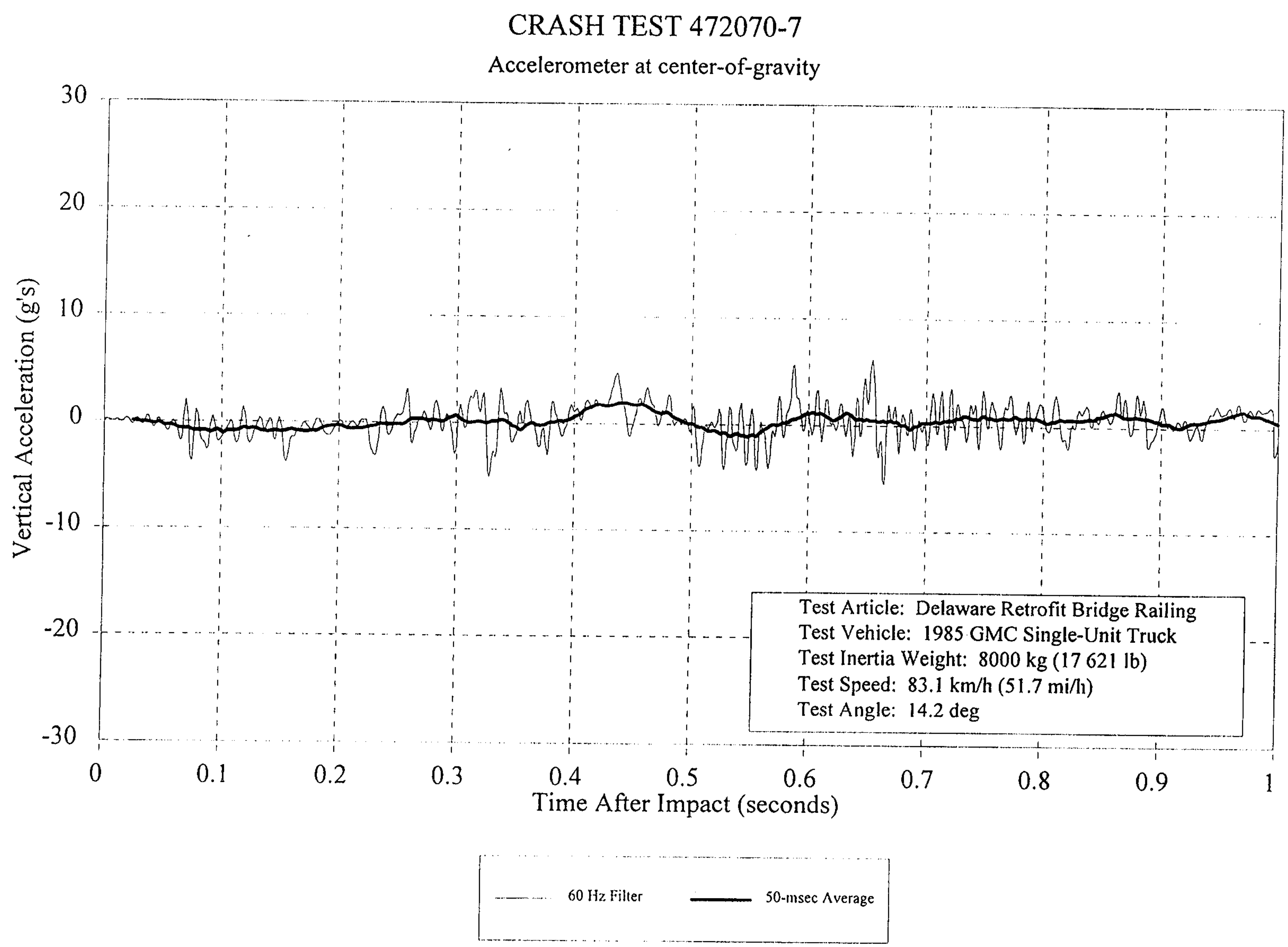


Figure 106. Vehicle vertical accelerometer trace for test 472070-7 (accelerometer located at center-of-gravity).

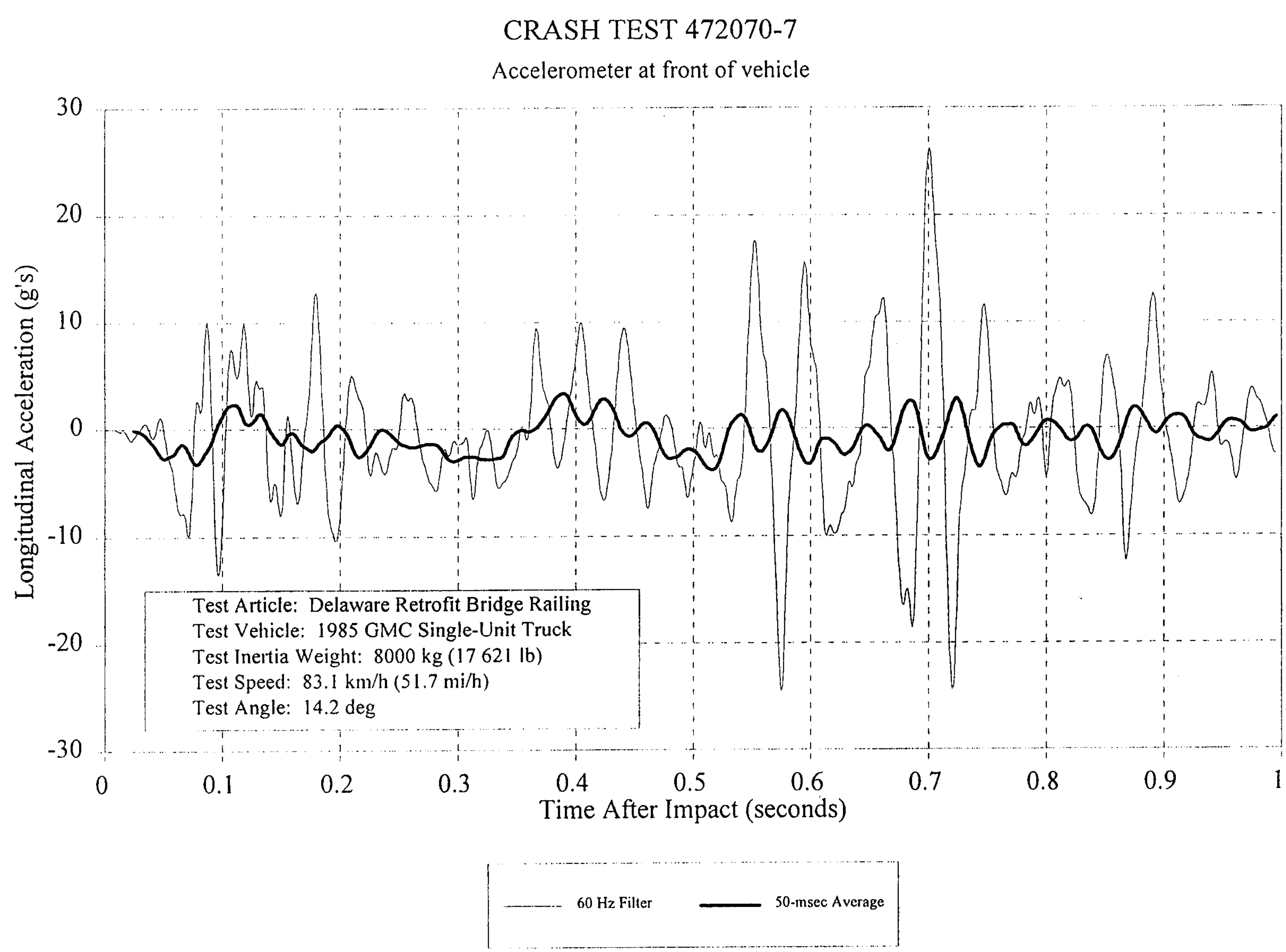


Figure 107. Vehicle longitudinal accelerometer trace for test 472070-7 (accelerometer located at front of vehicle).

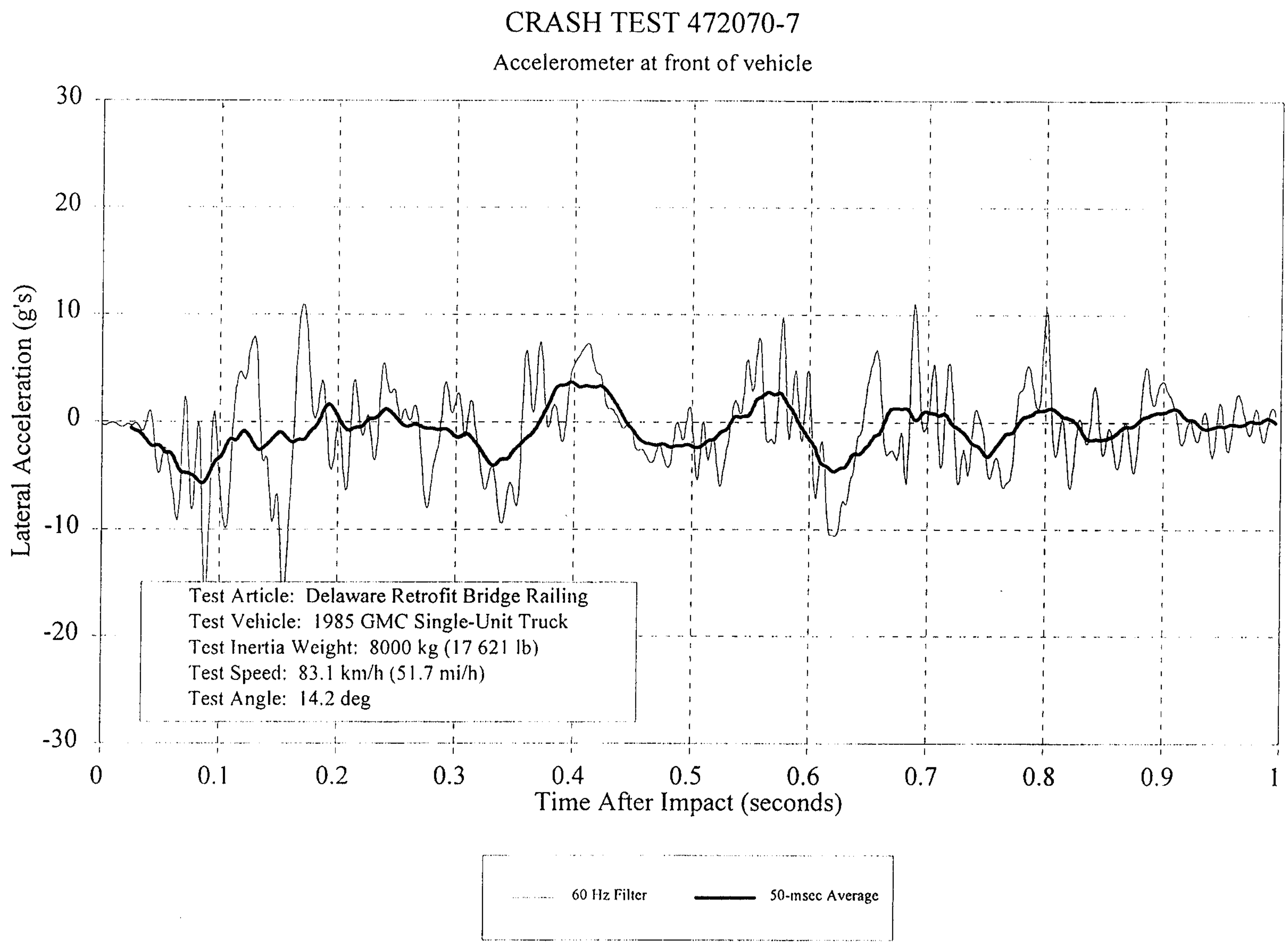


Figure 108. Vehicle lateral accelerometer trace for test 472070-7 (accelerometer located at front of vehicle).

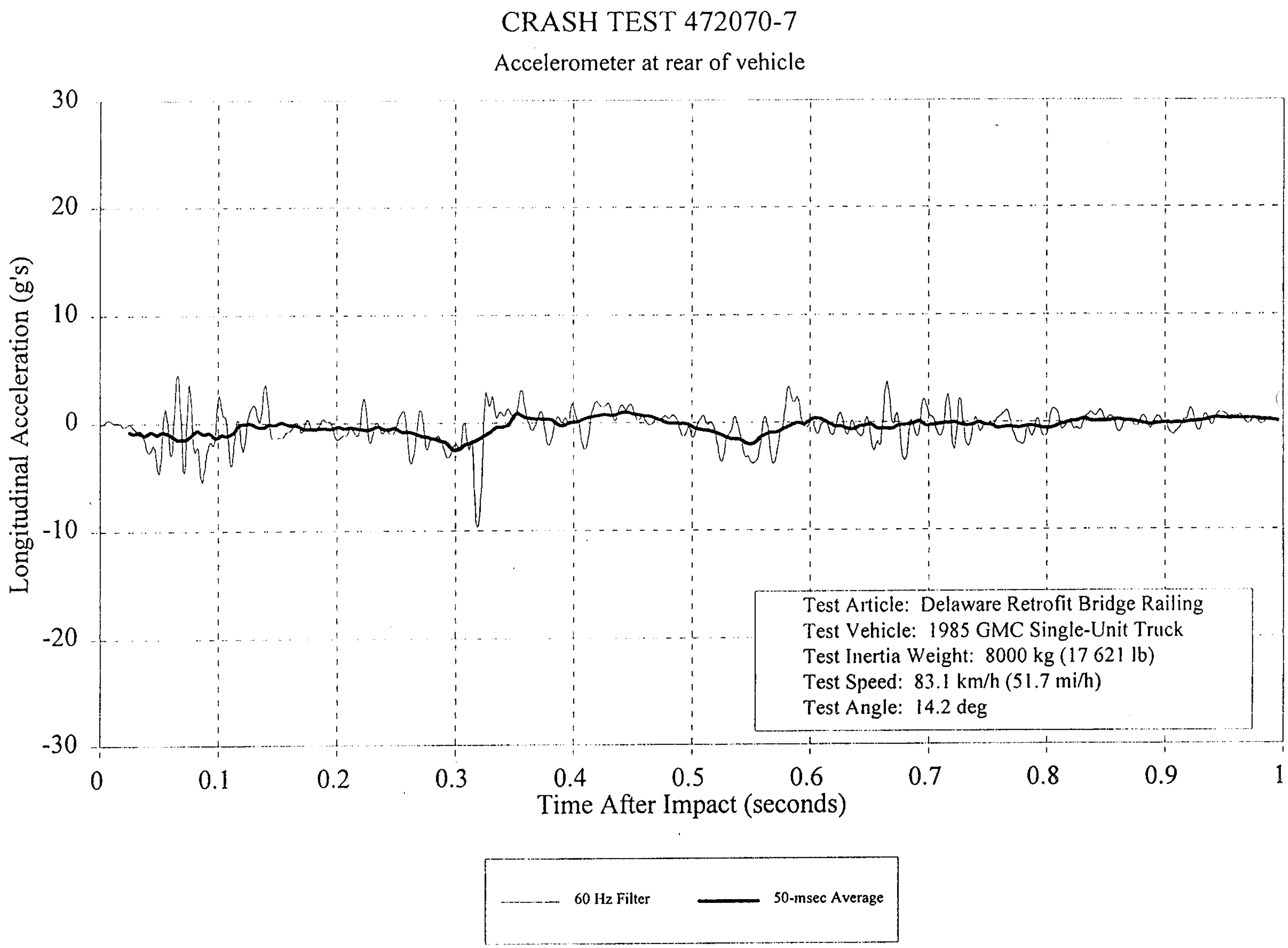


Figure 109. Vehicle longitudinal accelerometer trace for test 472070-7 (accelerometer located at rear of vehicle).

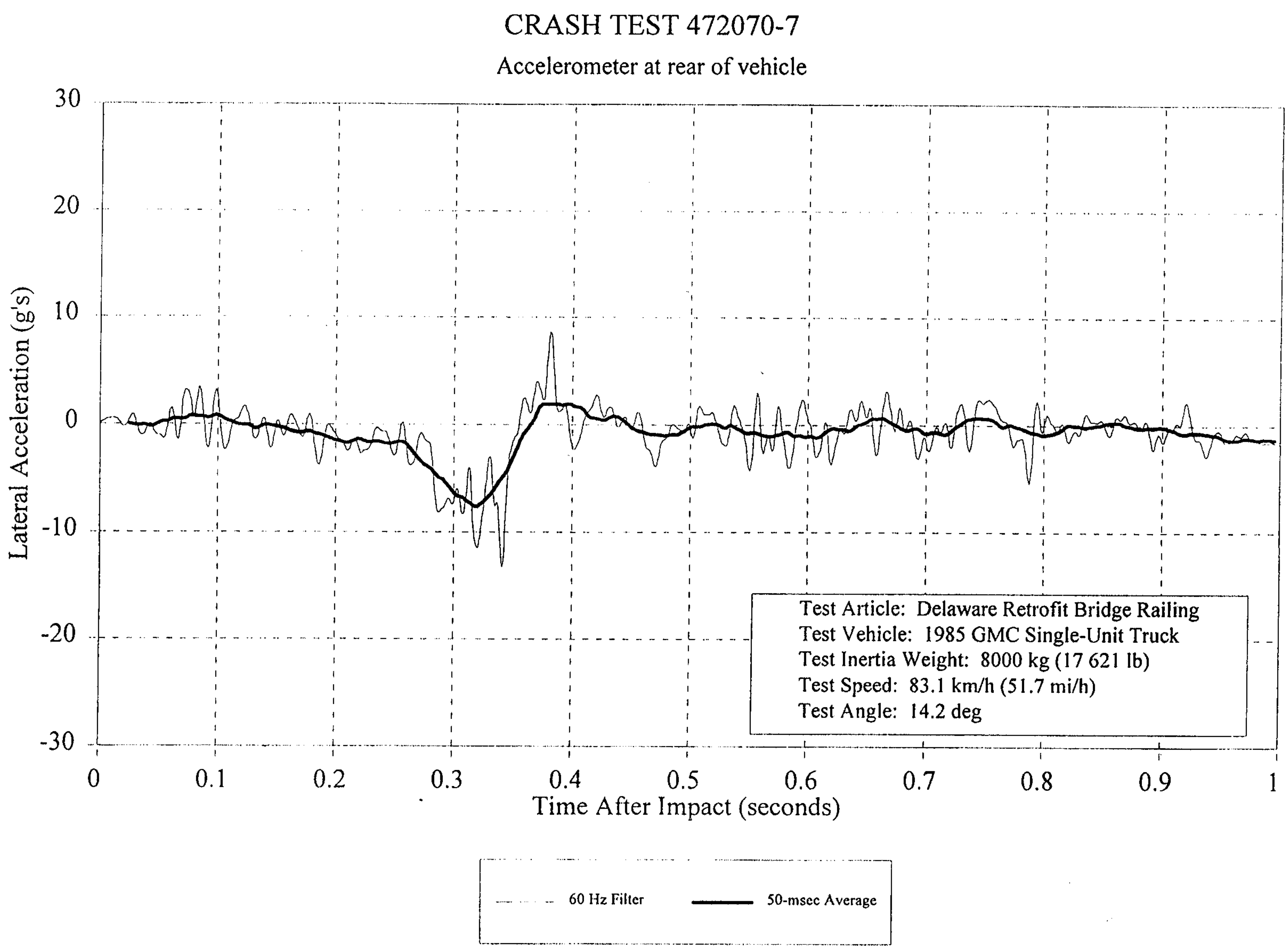


Figure 110. Vehicle lateral accelerometer trace for test 472070-7 (accelerometer located at rear of vehicle).

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