Separator

368-1

(Numeric)

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TESTING AND EVALUATION OF WYOMING TUBE-TYPE BRIDGE RAIL

By

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and

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Research Report 0368-1
on
Project BR-NBIS(003)
Bridge Railing Crash-Test Program

Sponsored
By

Wyoming State Highway Department

in Cooperation with

Federal Highway Administration
U. S. Department of Transportation

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Texas Transportation Institute
Texas A&M University System
College Station, Texas 77843

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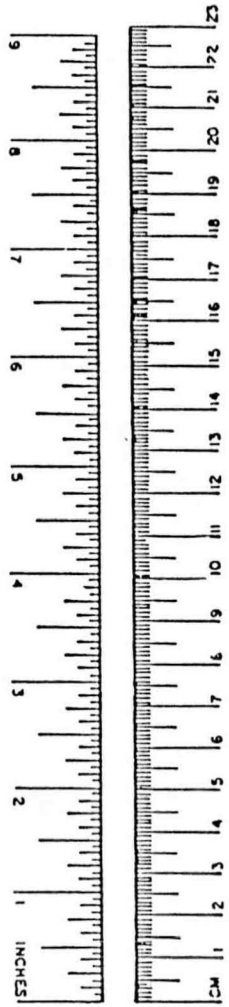
METRIC CONVERSION FACTORS

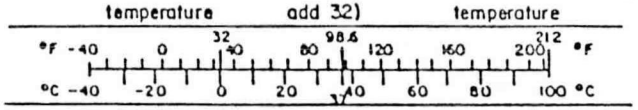
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
In	Inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
In^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons(2000lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares($10,000 m^2$)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000kg)	1.1	short tons	
	VOLUME			
ml	milliliters	8.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. INTRODUCTION

The Wyoming State Highway Department, in cooperation with the Federal Highway Administration (FHWA), contracted with the Texas Transportation Institute (TTI) to crash test and evaluate the performance of a steel tube-type bridge rail commonly used in the State of Wyoming.

The scope of the project included the design and construction of a simulated bridge deck, installation of the tube-type bridge rail, conduct of two crash tests in accordance with specifications outlined in NCHRP (National Cooperative Highway Research Program) Report 230, and evaluation of the crash test data.

General descriptions of the study approach, including those of the bridge rail, the test installation, and the crash test and data analysis procedures, are presented in Section II of this report. Data and evaluation results of the two crash tests are described in Section III and a summary of findings and conclusions is presented in Section IV. Information too bulky for inclusion in the main report is included as appendices.

II. STUDY APPROACH

Description of Bridge Rail and Installation

The Wyoming steel tube-type bridge rail consists of fabricated posts spaced 9 ft. 3 in. apart with two 6 in. x 2 in. x 0.25 in. tube-type beams. The metal rail sits on top of a 6-inch high curb for a total height of 29 inches above the pavement surface. The face of the curb is flush with those of the tube-type beams. The dimensions and details of the bridge rail installation used in this study are shown in Figure 1 and photographs of the test installation are shown in Figure 2. The test bridge rail was provided to TTI by a fabricator under direct contract to the Wyoming State Highway Department.

The 77-ft bridge rail was installed on a simulated bridge deck of the same length. The simulated bridge deck was designed and constructed in accordance with standard bridge specifications used by the Wyoming State Highway Department, including steel reinforcement and anchorage details. The curb was poured on top of the simulated bridge deck with the metal rail already in place.

Descriptions of Crash Tests

According to NCHRP Report 230, two crash tests are recommended for the evaluation of a bridge rail system. After consultation with the Wyoming State Highway Department and the Federal Highway Administration, the following two crash tests were conducted:

1. NCHRP Test Designation S13. 1,800 pound vehicle (1979 Honda Civic) impacting the bridge rail at a speed of 60 mph and an angle of 20 degrees. The point of impact was the centerline of the splice for the top rail.

2. NCHRP Test Designation 10. 4,500 pound vehicle (1979 Cadillac Sedan de Ville) impacting the bridge rail at a speed of 60 mph and an angle of 25 degrees. The point of impact was midway between the posts for the span containing the splice for the top rail.

The bridge rail was impacted with the left side of the vehicles due to restriction of space at the test site.

The crash test and data analysis procedures were in accordance with guidelines presented in NCHRP 230. The test vehicles were instrumented

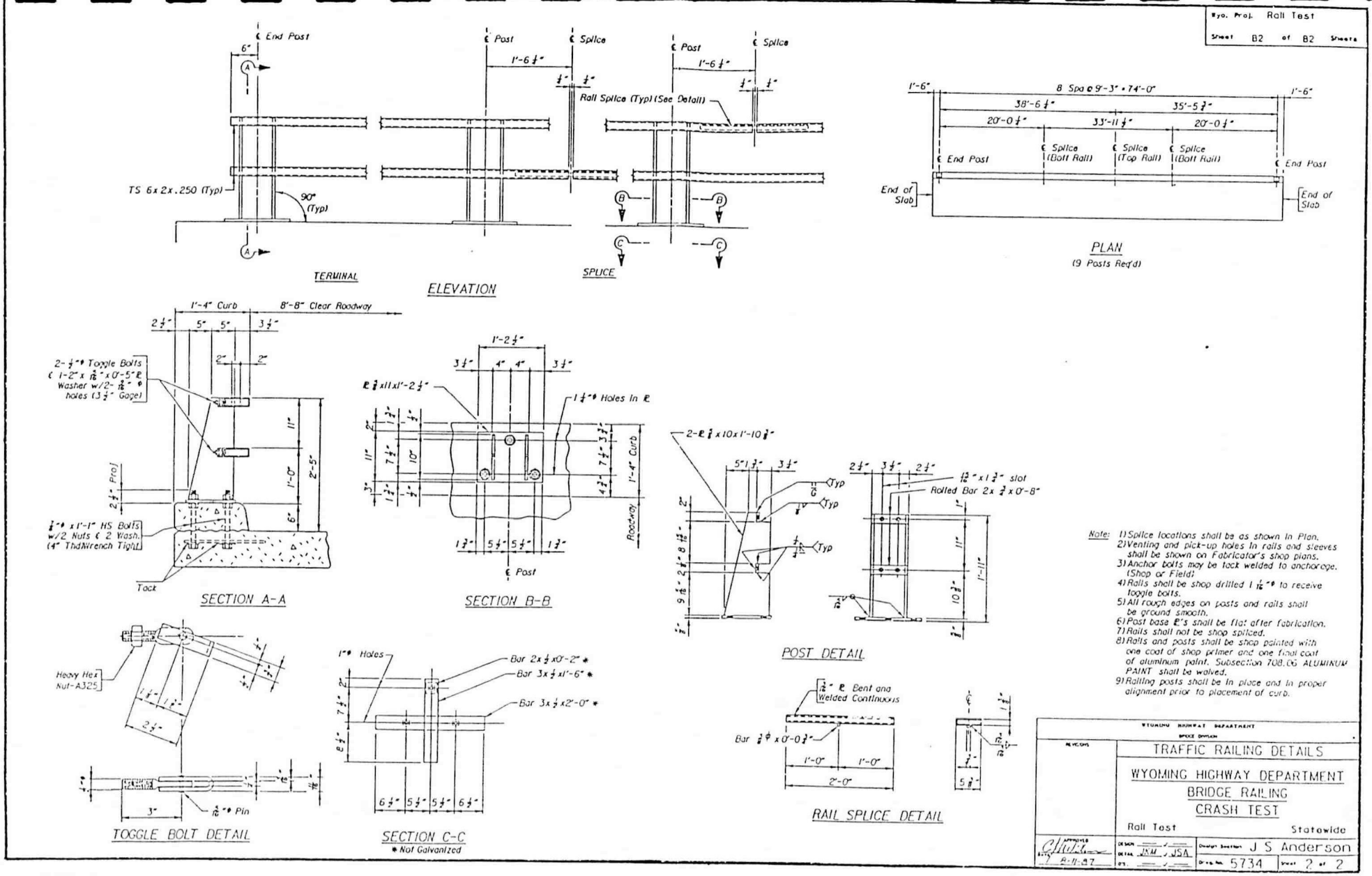


Figure 1. Details of Wyoming Tube-Type Bridge Rail

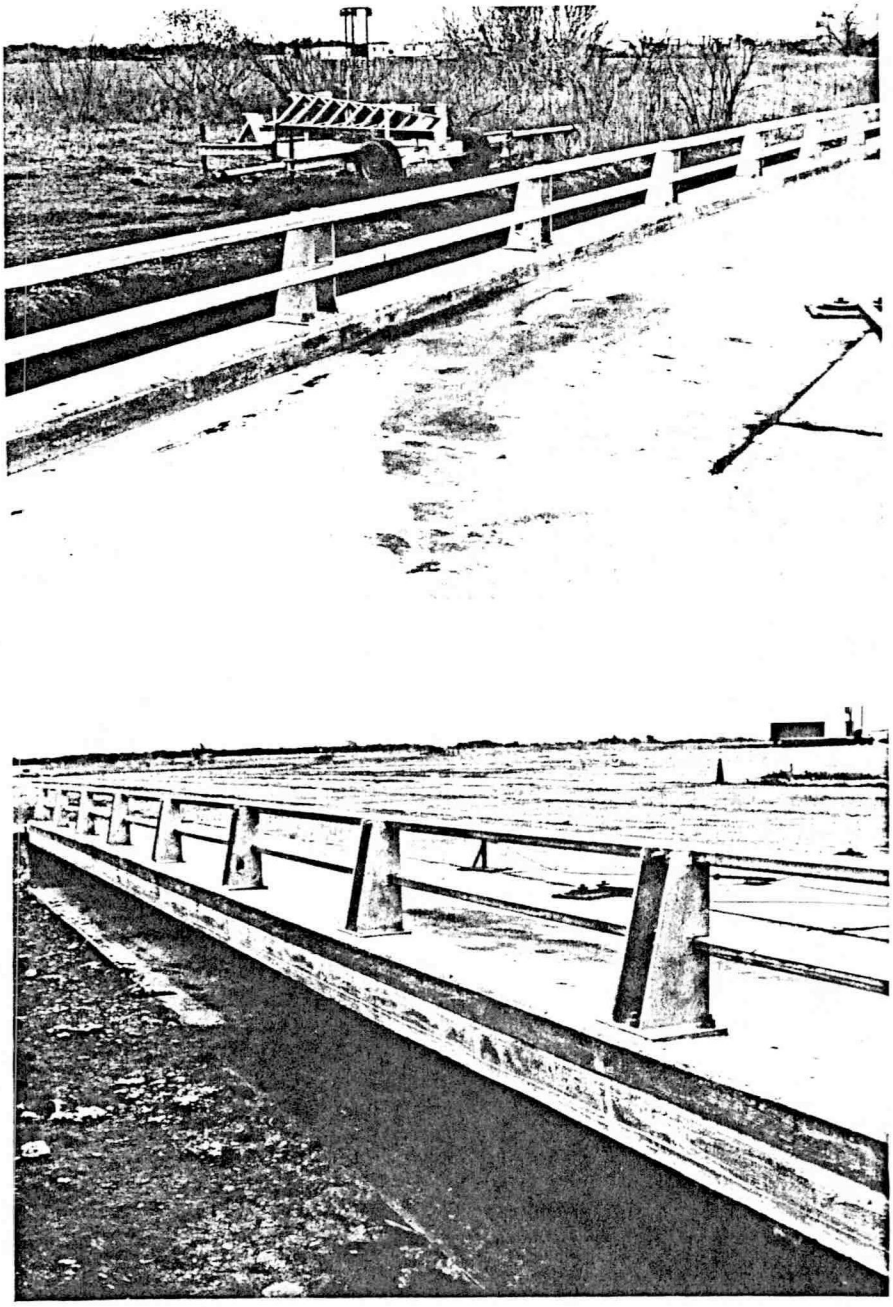


Figure 2. Wyoming Tube-Type Bridge Rail before test 0368-1.

with three rate transducers to measure roll, pitch, and yaw rates and a triaxial accelerometer near the vehicle center of gravity to measure acceleration levels. An uninstrumented 50 percentile male dummy was placed in the driver seat for the 1,800-pound car test, but not for the 4,500-pound car test.

The electronic signals from the accelerometers and transducers were telemetered to a base station for recording on magnetic tape and for display on a real-time strip chart. Provision was made for transmission of calibration signals before and after the test, and accurate time reference signal was simultaneously recorded with the data. Contact switches on the bumper were actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produced an "event" mark on the data record to establish the exact instant of impact.

Photographic coverage of the tests included two high-speed cameras, one overhead at the point of impact and the second in line with the barrier downstream from the point of impact. The films from these high-speed cameras were used to observe phenomena occurring during collision and to obtain time-event, displacement and angular data. A 16-mm movie camera, a 3/4-inch videotape, and still cameras were also be used for documentary purposes.

DATA ANALYSIS PROCEDURES

The analog data from the various accelerometers, transducers and load cells were digitized, using a microcomputer, for analysis and evaluation of performance. The digitized data were then analyzed using a number of computer programs: DIGITIZE, VEHICLE, and PLOTANGLE. Brief descriptions on each these 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, final occupant displacement, highest 0.010-second average. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period.

The VEHICLE program also uses digitized data from vehicle-mounted linear accelerometers to compute vehicle accelerations, areas enclosed by acceleration-time curves, changes in velocity, changes in momentum,

instantaneous forces, average forces, and maximum average accelerations over 0.050-second intervals in each of three directions. The VEHICLE program plots acceleration versus time curves for the longitudinal, lateral, and vertical directions.

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate charts to compute angular displacement in degrees at 0.001-second intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. It should be noted that these angular displacements are sequence dependent with the sequence being yaw-pitch-roll for the data presented in this report. 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.

III. CRASH TEST RESULTS

As mentioned previously, two crash tests recommended by NCHRP 230 were conducted on this steel tube-type bridge rail. These two tests were:

1. NCHRP Test Designation S13. 1,800 pound vehicle (1979 Honda Civic) impacting the bridge rail at a speed of 60 mph and an angle of 20 degrees. The point of impact was the centerline of the splice for the top rail.

2. NCHRP Test Designation 10. 4,500 pound vehicle (1979 Cadillac Sedan de Ville) impacting the bridge rail at a speed of 60 mph and an angle of 25 degrees. The point of impact was midway between the posts for the span containing the splice for the top rail.

Results from these two crash tests are presented as follows.

Test Number 1

A 1979 Honda Civic (shown in Figures 3 and 4) impacted the railing at 20.0 degrees and 61.1 miles per hour (98.3 km/h) using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 1800 pounds (816 kg) and its gross static mass was 1968 pounds (893 kg). The height to the lower edge of the vehicle bumper was 14.25 inches (36.2 cm) and 19.0 inches (48.3 cm) to the top of the bumper. Other dimensions and information on the vehicle are given in Figure 5.

The vehicle was free wheeling and unrestrained just prior to impact. The point of impact was the center of the splice for the top rail, approximately 38 feet downstream from the beginning of the bridge rail. Upon impact, the left front of the vehicle began to deform and, at 0.026 second (s), the left front tire contacted the curb, aired out, and went under the lower rail. Shortly thereafter, the vehicle began to redirect and, at 0.148 s, the rear of the vehicle came into contact with the rail.

The vehicle lost contact with the rail at approximately 0.168 s after impact, traveling at a speed of 49.7 mph (80.0 km/h) and at an exit angle of 7.1 degrees. As the vehicle exited the rail, the brakes were applied. The vehicle yawed counterclockwise and came to rest 150 feet (45.7 m) from the point of impact. Sequential photographs of the test are shown in Figure 6.

The rail received very minor damages, as shown in Figure 7. The permanent residual deformation was 0.19 inch (0.48 cm) vertically and 0.25 inch (0.64 cm) laterally for the bottom rail and 0.25 inch (0.64 cm)

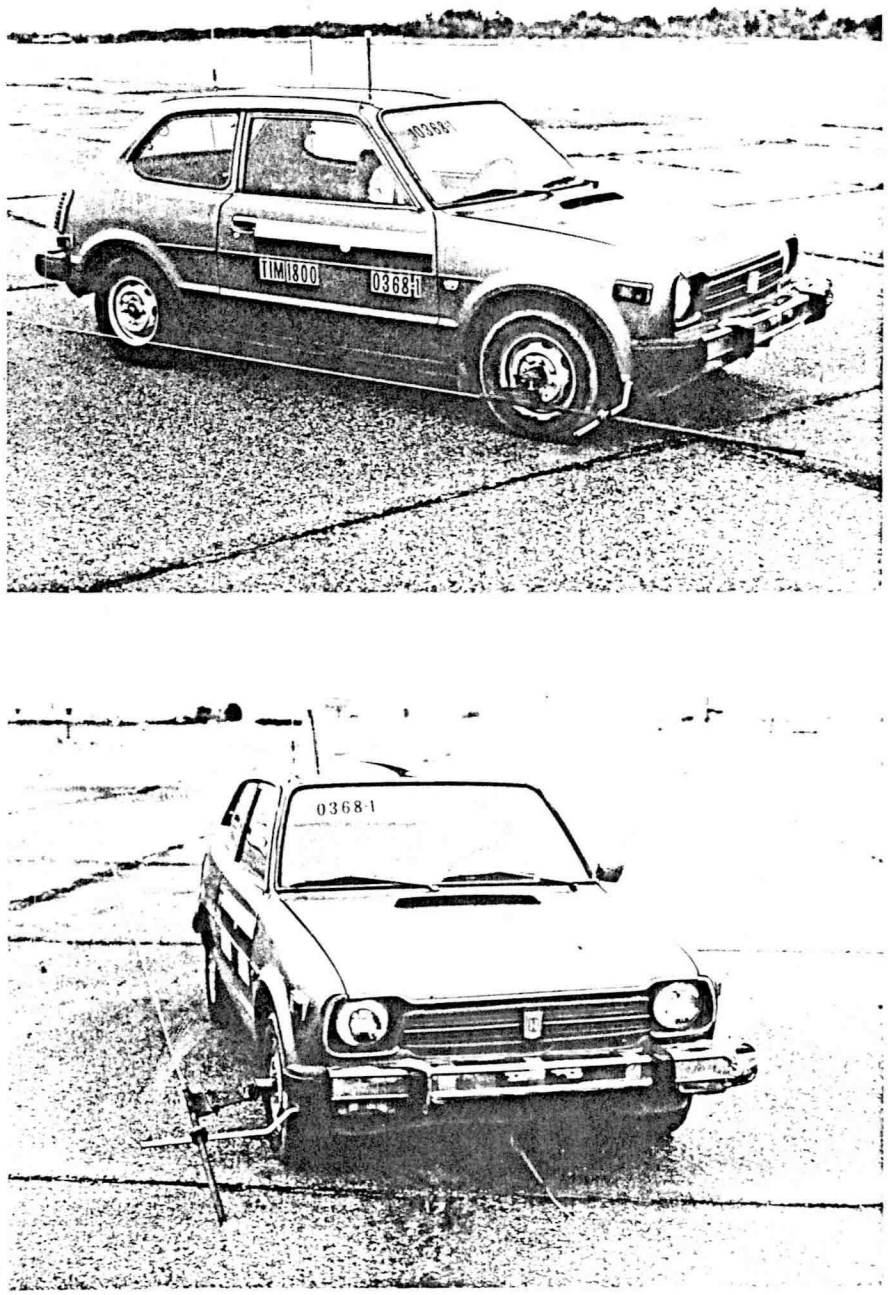


Figure 3. Vehicle before test 0368-1.

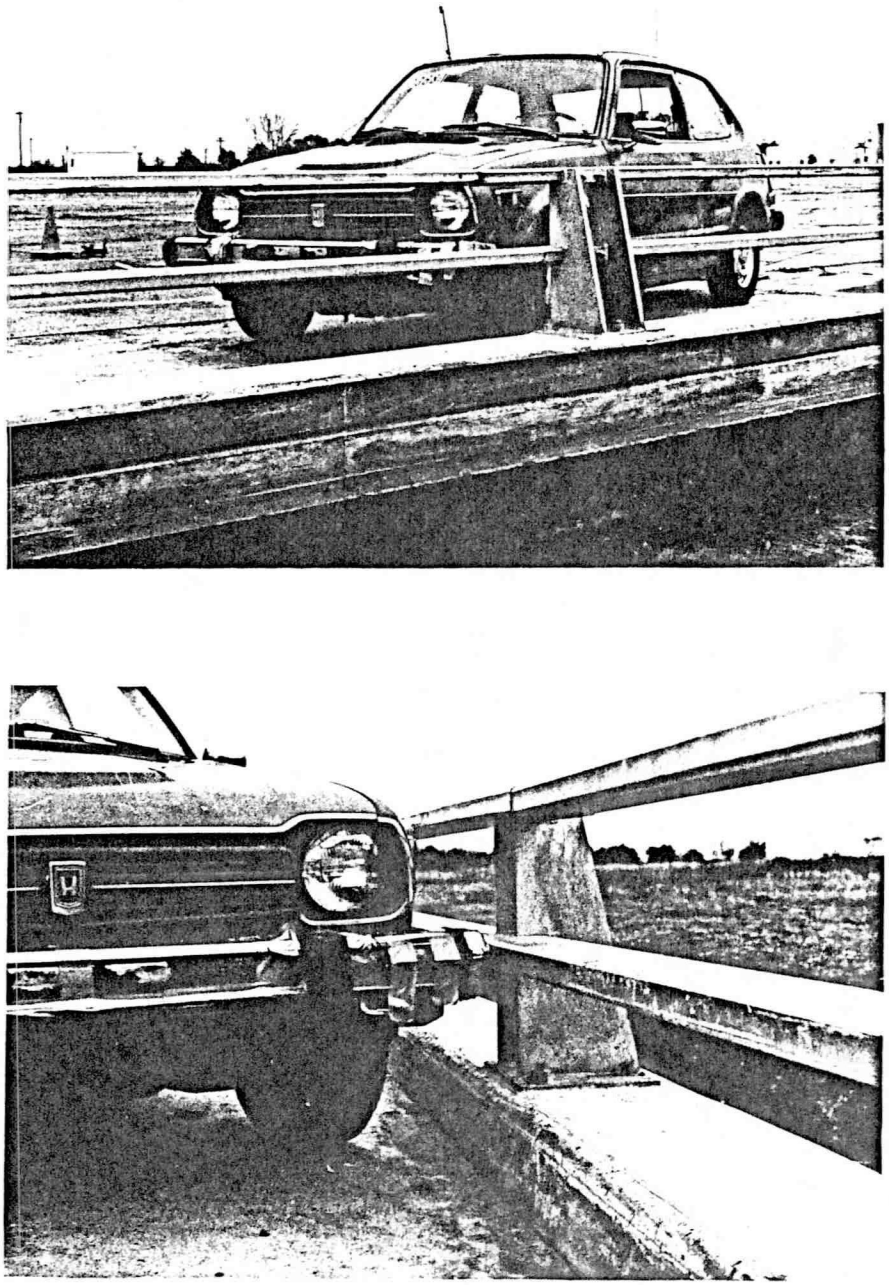
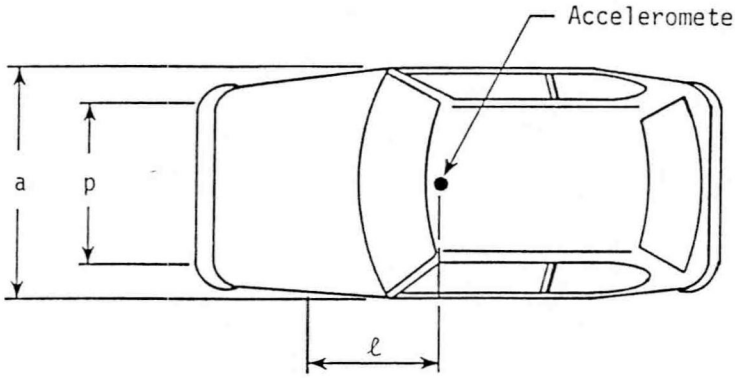


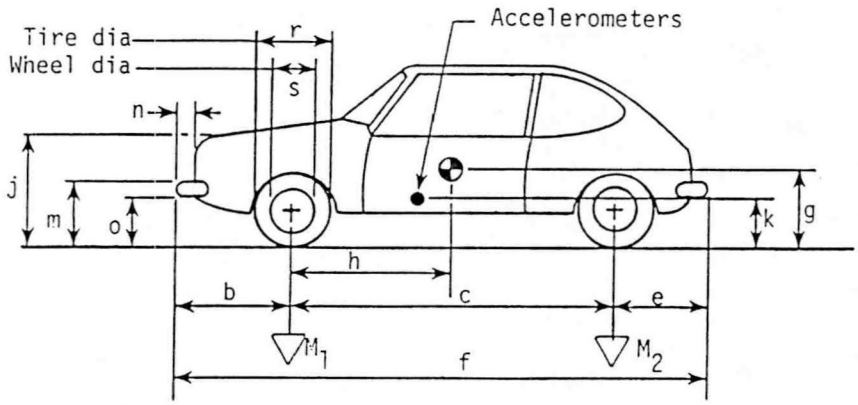
Figure 4. Rail/vehicle geometrics for test 0368-1.

Date: 2-9-88 Test No.: 0368-1 VIN: SBC-7008854

Make: Honda Model: Civic Year: 1979 Odometer: 84584

Tire Size: 155 SR12/765 Ply Rating: 1 ply Bias Ply: X Belted: ___ Radial: ___





4-wheel weight for c.g. det. ℓf 548 rf 520 ℓr 370 rr 362

Mass - pounds	Curb	Test Inertial	Gross Static
M_1		1068	1152
M_2		732	816
M_T		1800	1968

Note any damage to vehicle prior to test:

*d = overall height of vehicle

Tire Condition: good ___
fair X
badly worn ___

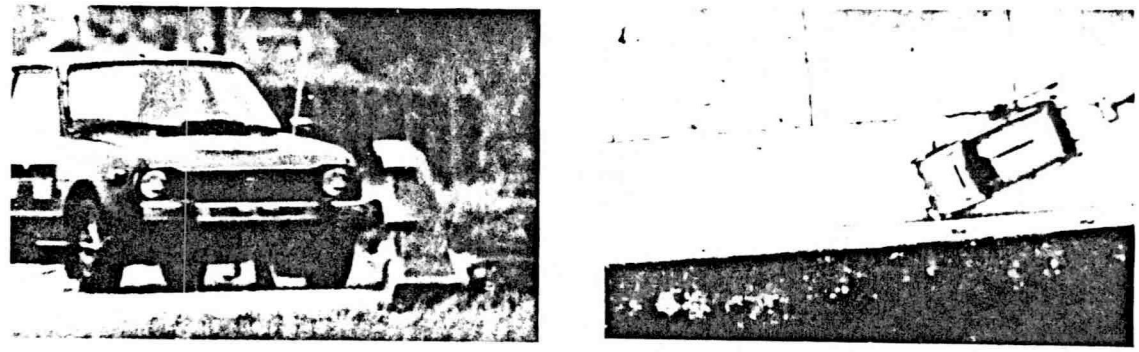
Vehicle Geometry - inches

a	59	b	27
c	86.5	d*	51
e	27	f	140.5
g		h	35.18
i	----	j	28.5
k	12.75	ℓ	22.5
m	19	n	5.5
o	14.25	p	51.75
r	21.25	s	13.25

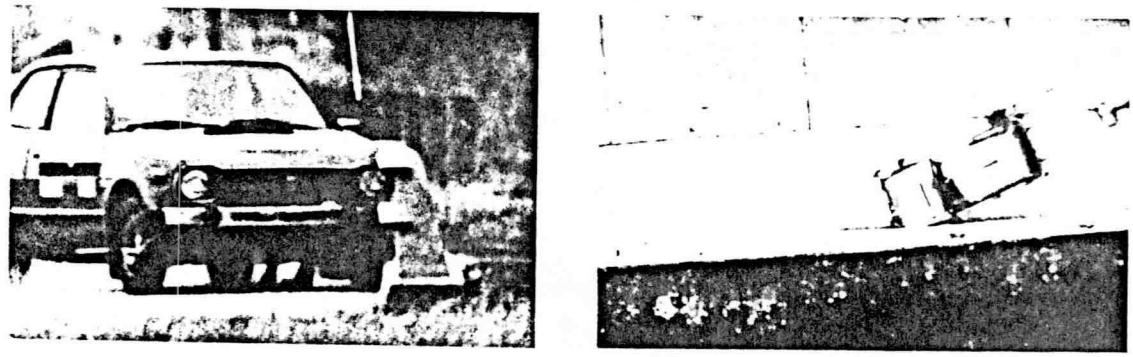
Engine Type: 4 cyl
Engine CID: 76
Transmission Type:
Automatic or (Manual)
(FWD) or RWD or 4WD
Body Type: Hatch
Steering Column Collapse Mechanism:
___Behind wheel units
___Convoluted tube
___Cylindrical mesh units
___Embedded ball
___NOT collapsible
___Other energy absorption
___Unknown

Brakes:
Front: disc X drum ___
Rear: disc ___ drum X

Figure 5. Test vehicle properties (0368-1).



0.000 s

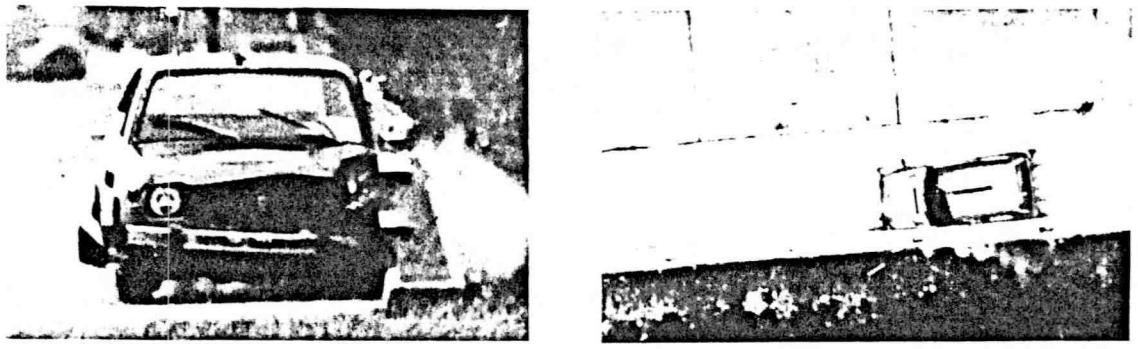


0.029 s

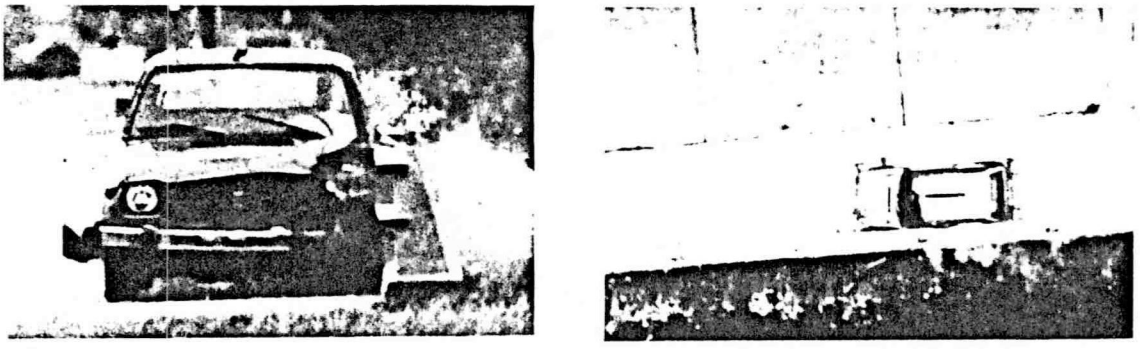
0.058 s

0.086 s

Figure 6. Sequential photographs for test 0368-1.

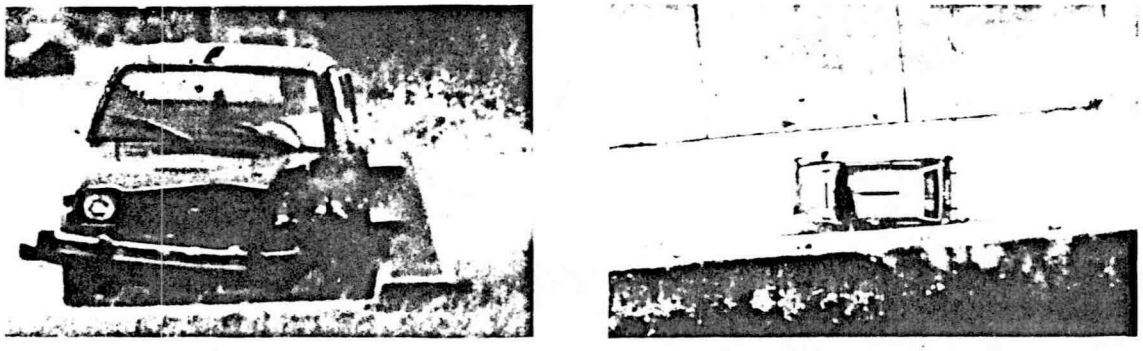


0.115 s



0.144 s

0.173 s



0.204 s

Figure 6. Sequential photographs for test 0368-1. (Continued)

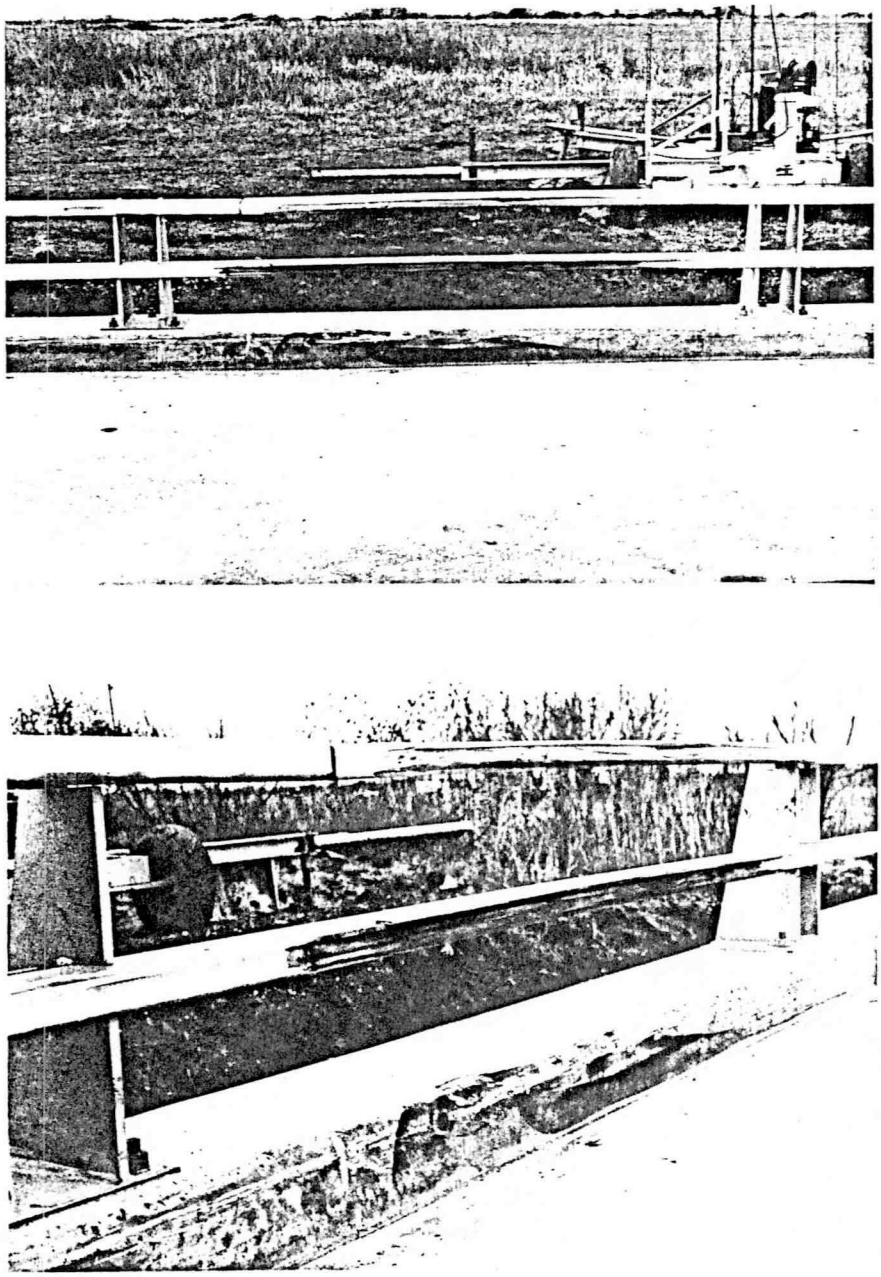


Figure 7. Wyoming Tube-Type Bridge Rail after test 0368-1.

vertically and 0.19 inch (0.48 cm) laterally for the top rail. The only repair necessary after the test was to loosen the bolts attaching the rail elements to two posts and realign the rail elements. The vehicle was in contact with the rail a total of 8.1 feet (2.47 m).

The vehicle received severe damages, as shown in Figure 8. The hood and entire left side of the vehicle was severely dented and scraped. Maximum crush was 7.0 inches (17.8 cm) at the left front corner of the vehicle. The left door became ajar and the window glass was broken. There was also damage to the front bumper, left front strut assembly, tire rim, and windshield.

The severity of the damages sustained by the vehicle could be partially attributed to the narrowness of the rail elements. It appears that the deformed sheet metal on the left front of the vehicle was momentarily wedged between the two rail elements, resulting in some vertical movement and deformation in the rail elements.

A summary of the test results and other information pertinent to this test are given in Figure 9. The maximum 0.050-second average acceleration experienced by the vehicle was 8.0 g in the longitudinal direction and 16.5 g in the lateral direction. Vehicle angular displacements are plotted in Figure 10 and vehicle accelerometer traces are displayed in Figures 11 through 13. Occupant impact velocity in the longitudinal direction was 20.89 feet per second (6.4 m/s) and 30.89 feet per second (9.42 m/s) in the lateral direction. The highest 0.10 s occupant ridedown accelerations were 2.67 g (longitudinal) and 10.13 g (lateral). It should be noted, however, that occupant impact velocity and ridedown accelerations are not applicable for this test and are reported for information purposes only.

In summary, the rail contained and smoothly redirected the vehicle with little lateral movement of the barrier. There was no debris or detached elements. There was minimal deformation and intrusion into the occupant compartment. The vehicle trajectory at loss of contact with the rail indicates minimum potential intrusion into the adjacent traffic lanes. The vehicle remained upright and stable during the initial test period and after leaving the rail.

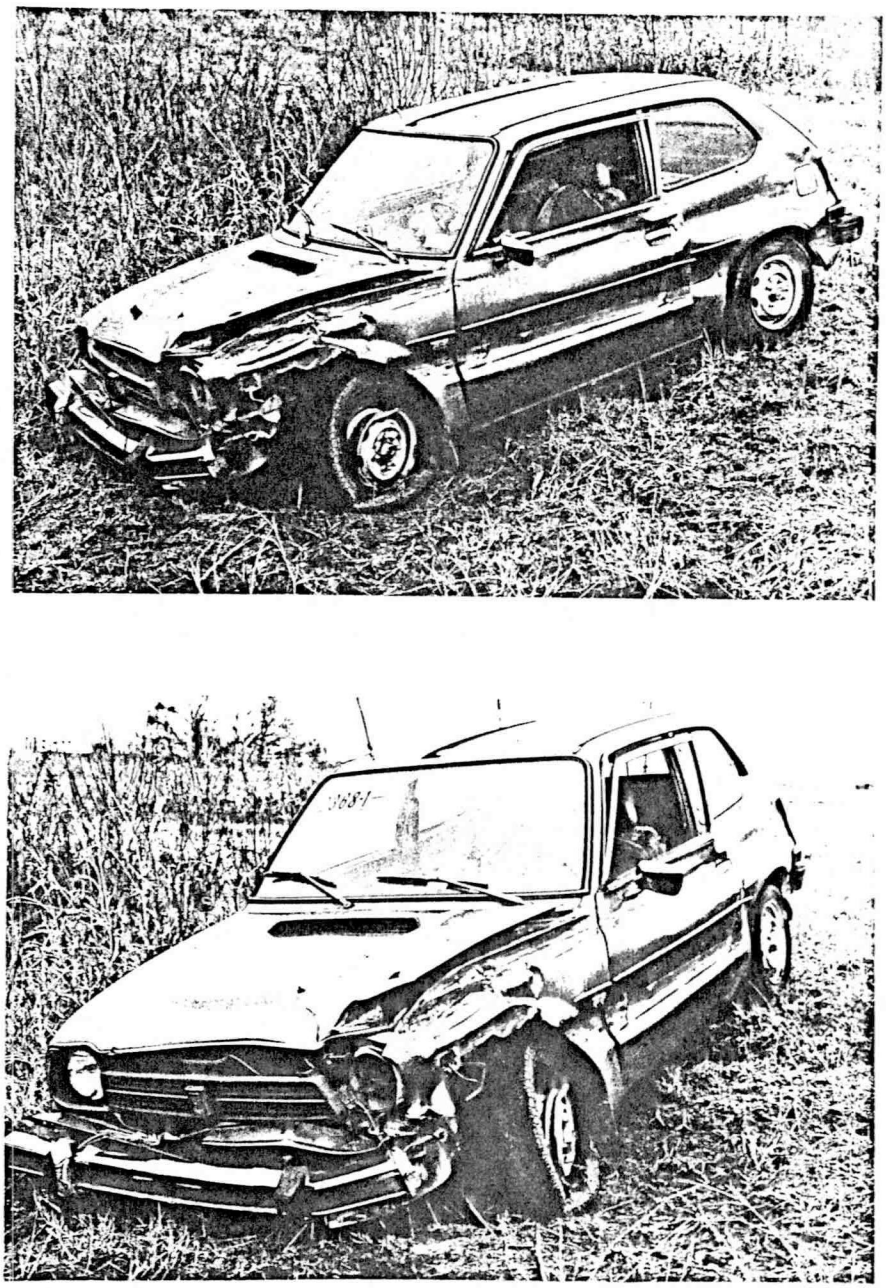
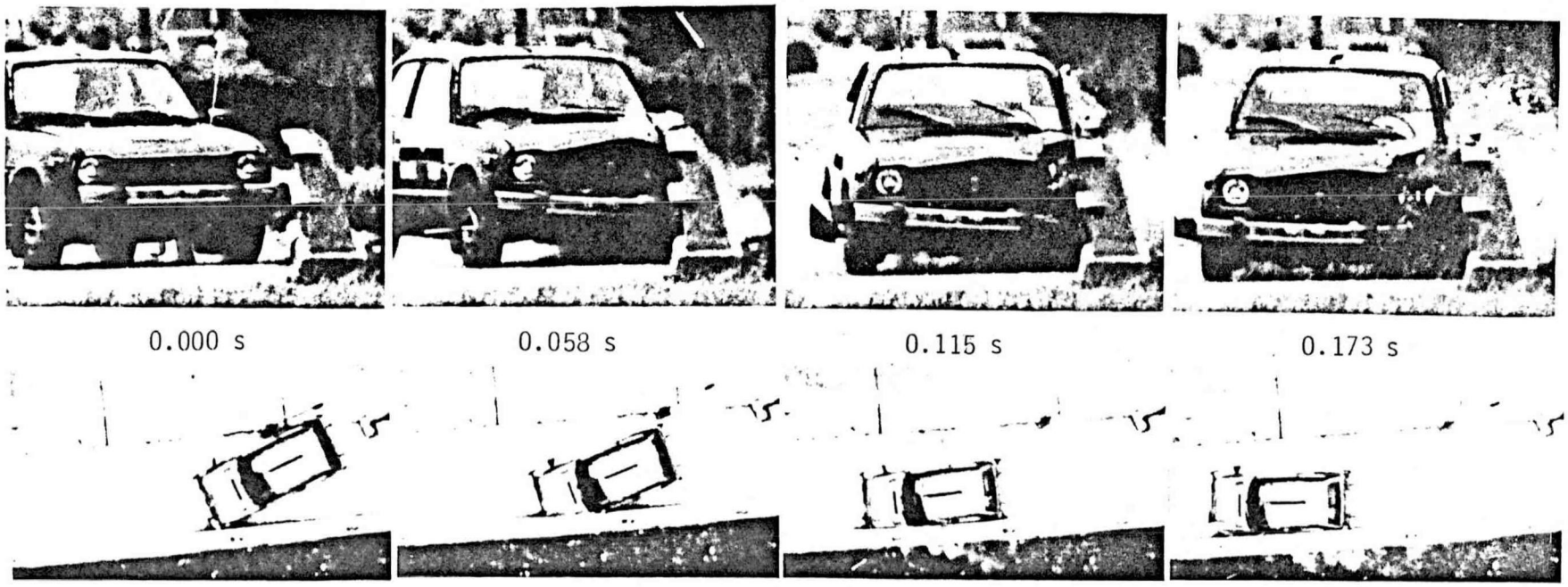
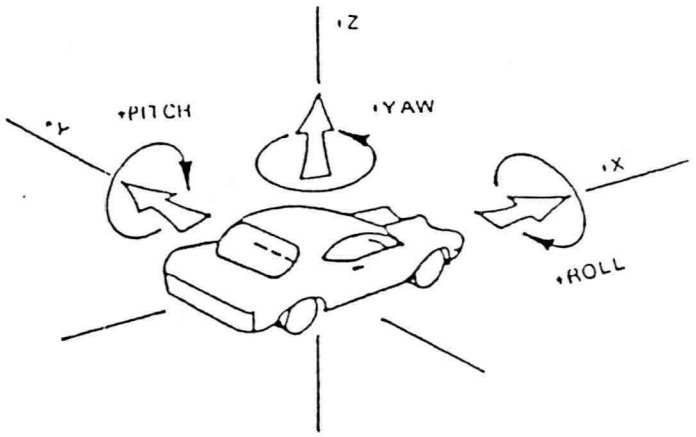


Figure 8. Vehicle after test 0368-1.



Test No	0368-1	Impact Speed	61.1 mi/h (98.3 km/h)
Date	02/09/88	Impact Angle	20.0 deg
Test Installation	Wyoming Tube-Type Bridge Rail	Exit Speed	49.7 mi/h (80.0 km/h)
		Exit Angle	7.1 deg
Length of Installation	77 ft (23.5 m)	Vehicle Accelerations (Max. 0.050-sec Avg)	
Vehicle	1979 Honda Civic	Longitudinal	-8.0 g
Vehicle Weight		Lateral	-16.5 g
Test Inertia	1,800 lb (816 kg)	Occupant Impact Velocity	
Gross Static	1,968 lb (893 kg)	Longitudinal	20.89 ft/s (6.4 m/s)
Vehicle Damage Classification		Lateral	30.89 ft/s (9.4 m/s)
TAD	11LFQ5	Occupant Ridedown Accelerations	
CDC	11FLES2 & 11LFES3	Longitudinal	-2.7 g
Maximum Vehicle Crush	7.0 in (17.8 cm)	Lateral	-10.1 g
Max. Perm. Rail Deformation	0.25 (0.64 cm)		

Figure 9. Summary of results for test 0368-1.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

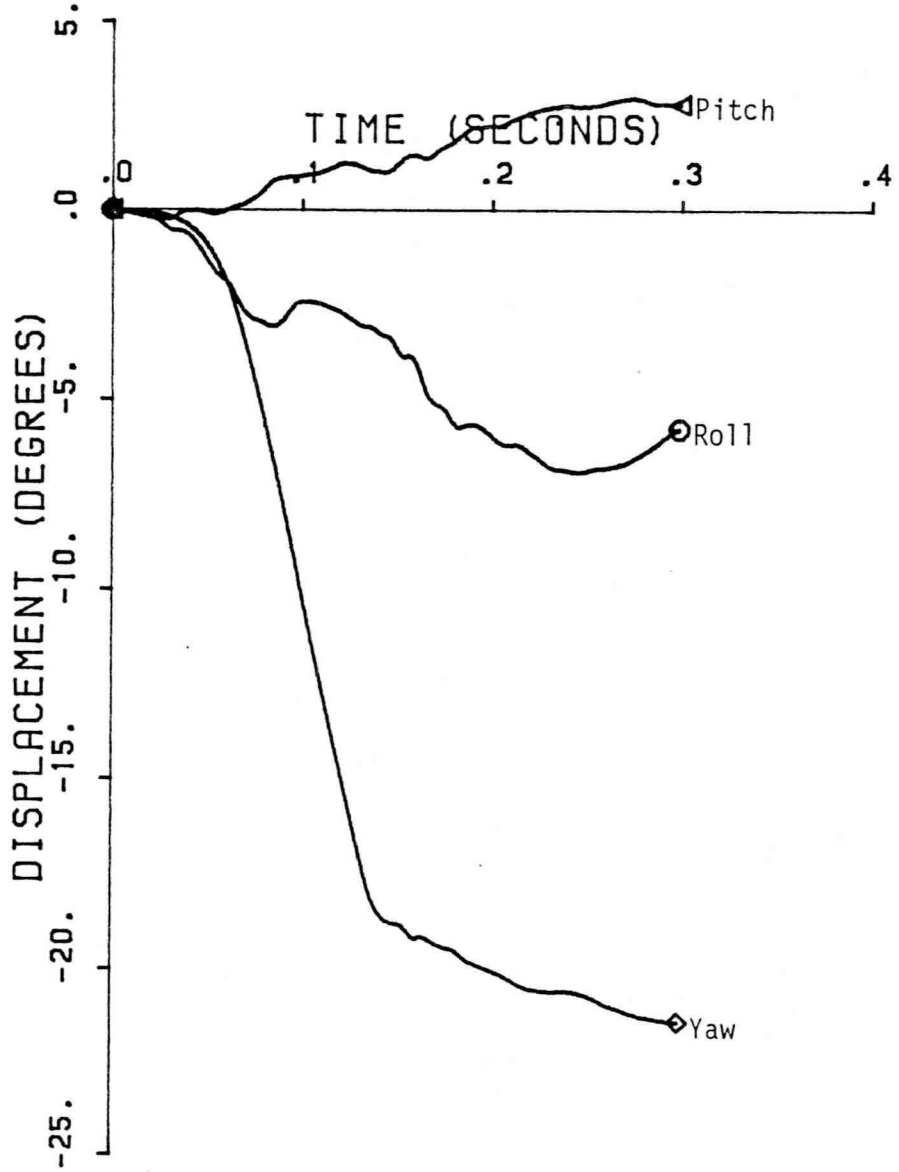


Figure 10. Vehicle Angular Displacements for test 0368-1.

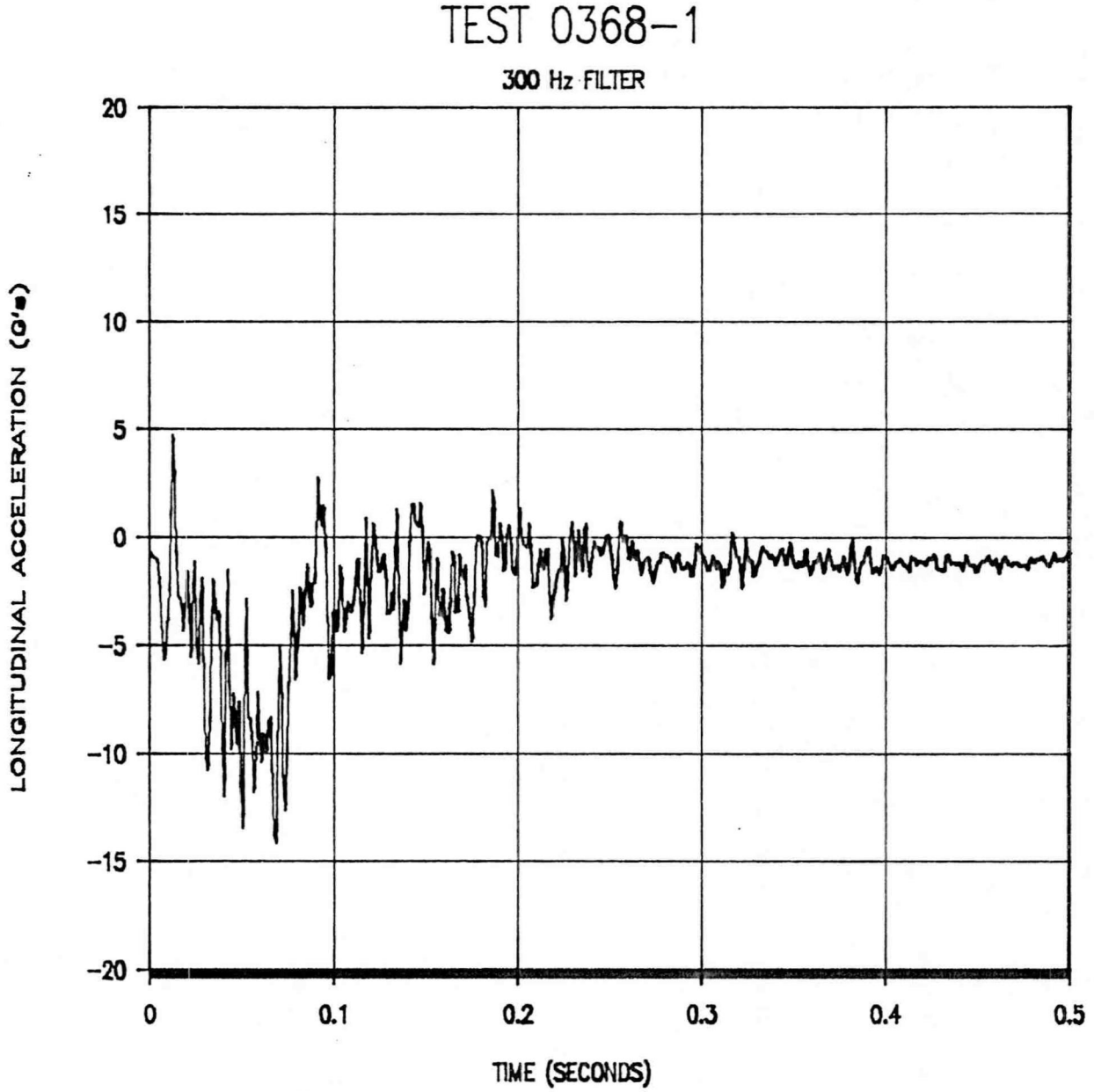


Figure 11. Longitudinal accelerometer trace for test 0368-1.

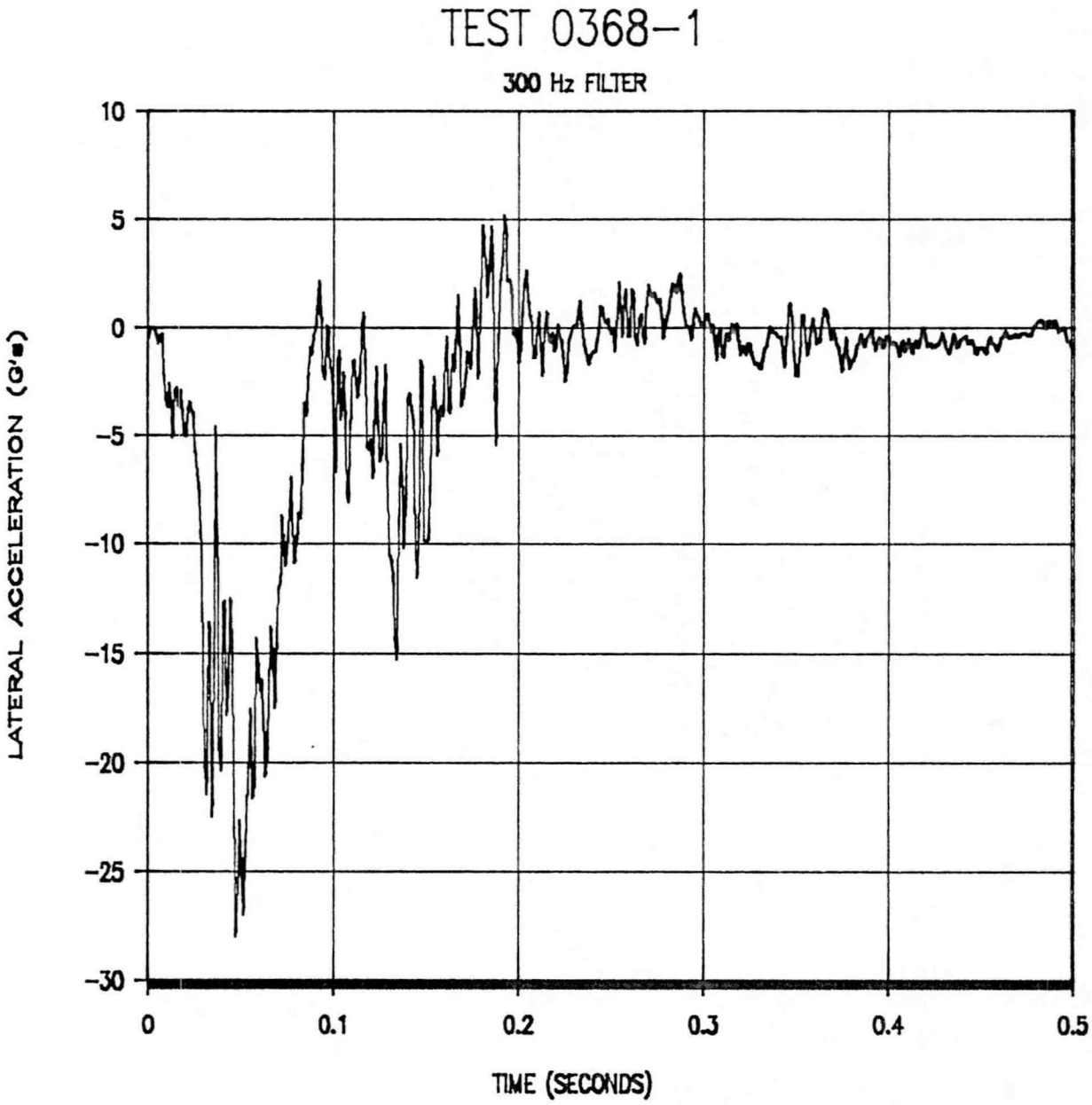


Figure 12. Lateral accelerometer trace for test 0368-1.

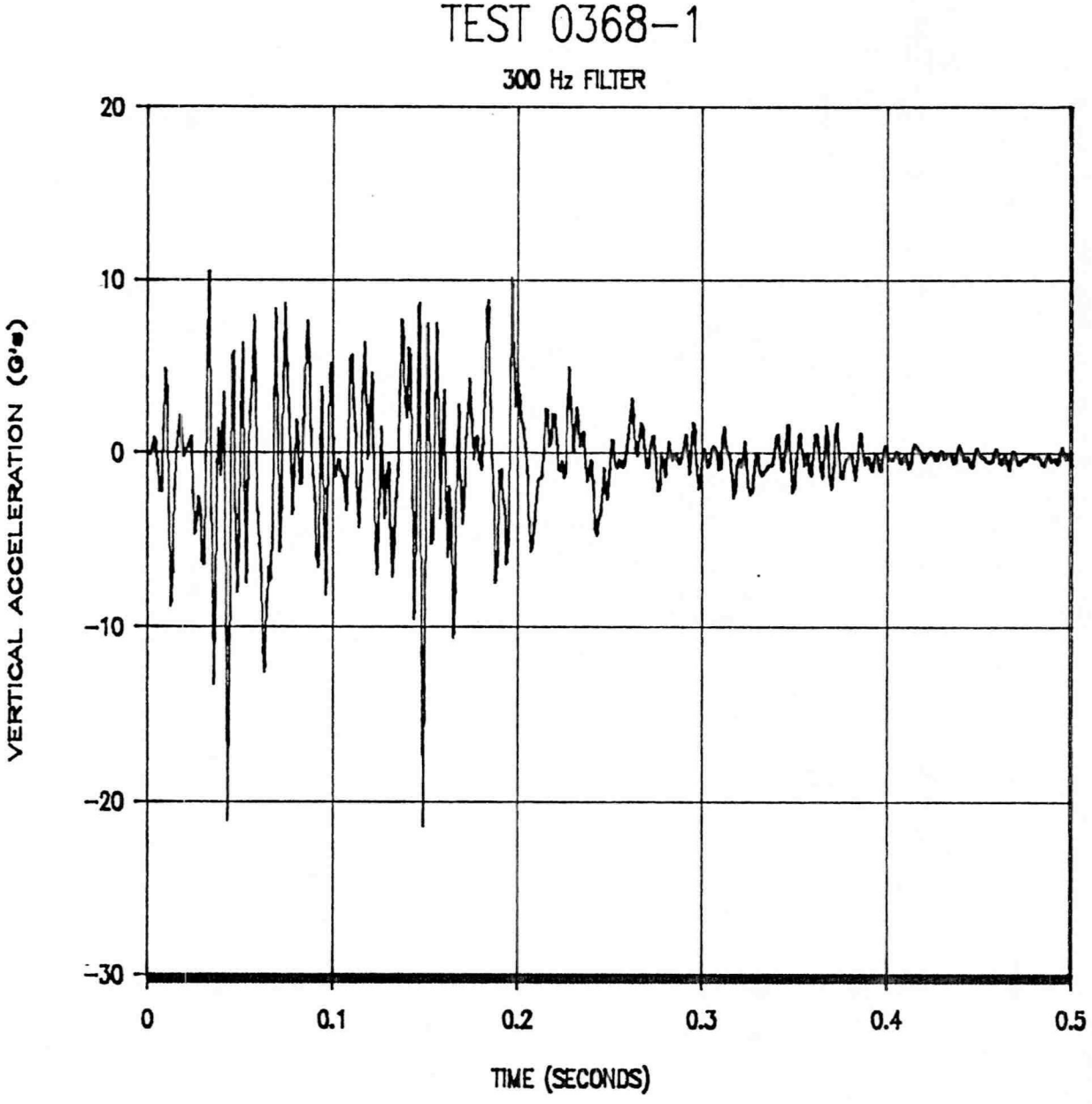


Figure 13. Vertical accelerometer trace for test 0368-1.

Test Number 2

A 1979 Cadillac Sedan de Ville (shown in Figures 14 and 15) impacted the railing at an impact speed of 63.3 miles per hour (101.9 km/h) and at an angle of 25.0 degrees using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,510 pounds (2045.7 kg) including instrumentation. The height to the lower edge of the vehicle bumper was 11.0 inches (27.9 cm) and 22.0 inches (55.9 cm) to the top of the bumper. Other dimensions and information on the vehicle are given in Figure 16.

The vehicle was free wheeling and unrestrained just prior to impact. The point of impact was midway between the posts for the span containing the splice for the top rail, approximately 40 feet downstream from the beginning of the rail. Upon impact, the left front of the vehicle began to deform and at 0.027 second, the left front tire contacted the curb, aired out, and went under the lower rail. Shortly thereafter, the deflated front tire and deformed sheet metal of the vehicle contacted the first post downstream from the impact point. The vehicle then began to redirect and, at 0.189 s, the rear of the vehicle came into contact with the rail.

The vehicle lost contact with the rail at approximately 0.316 s after impact, traveling at a speed of 45.9 miles per hour (73.9 km/h) and an exit angle of 4.6 degrees. As the vehicle exited the rail, the brakes were applied. The vehicle yawed clockwise and came to rest 210 feet (64.0 m) from the point of impact. Sequential photographs of the test are shown in Figure 17.

The rail itself received minor damages as shown in Figure 18. The permanent residual deformation was 1.25 inches (3.18 cm) vertically and 0.75 inch (1.91 cm) laterally for the bottom rail and 0.50 inch (1.27 cm) vertically and 0.44 inch (1.11 cm) laterally for the top rail. The vehicle was in contact with the rail a total of 10.6 feet (3.23 m). Diagonal stress cracks were found on the concrete bridge deck around the post immediately downstream from the point of impact and a small piece of concrete was broken off behind the post. Photographs showing the stress cracks and spall in the concrete bridge deck are shown in Figure 19.

The vehicle received severe damages, as shown in Figures 20 and 21. The front end of the car was shifted to the right and the sub-frame was severely bent. Maximum crush was 18.0 inches (45.7 cm) at the left front corner of the vehicle. The entire left side of the vehicle was dented and

Figure 14. Vehicle before test 0368-2.

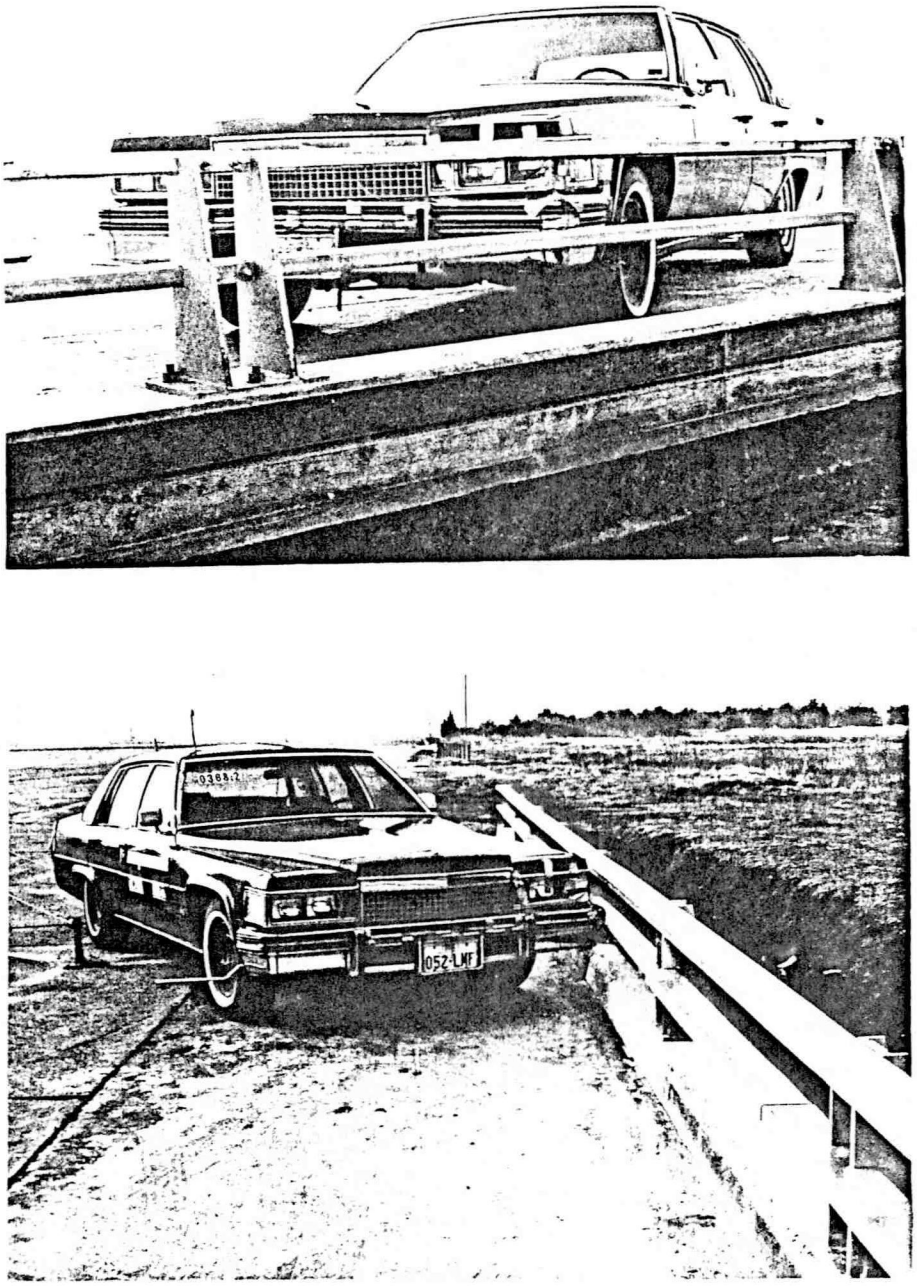


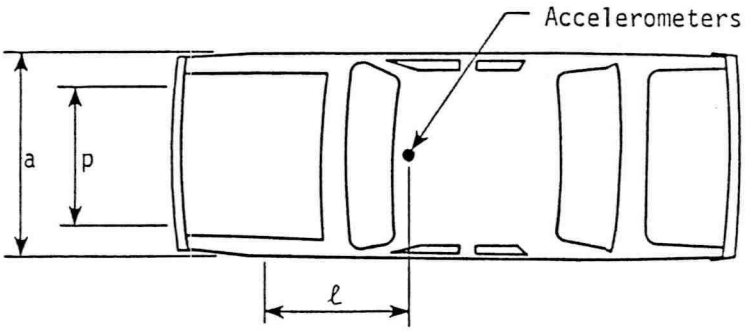
Figure 15. Rail/vehicle geometrics for test 0368-2.

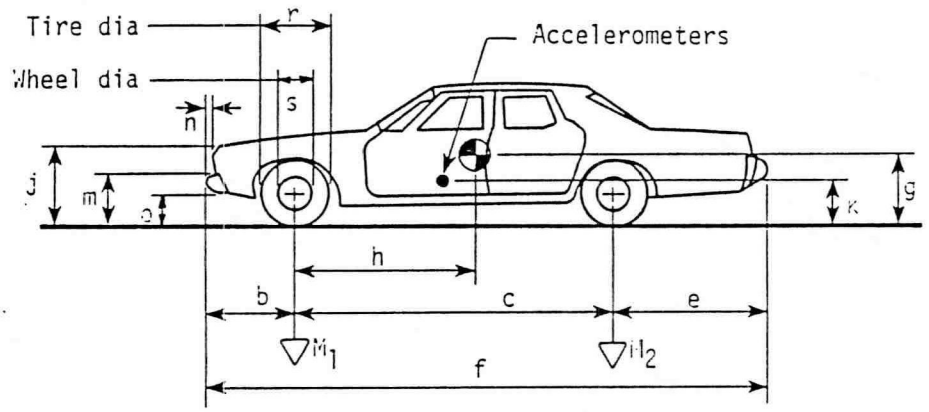
Date: 2-10-88 Test No.: 0368-2 VIN: 6D6959C350842

Make: Cadillac Model: Sedan Deville Year: 1979 Odometer: 134695

Tire Size: P225/75R15 Ply Rating: 4 Bias Ply: ___ Belted: ___ Radial: X

Tire Condition: good ___
fair X
badly worn ___





Vehicle Geometry - inches

a	76.5	b	39.25
c	120.5	d*	57.5
e	56.5	f	216.25
g		h	55.9
i	----	j	35.25
k	20	ℓ	36
m	22	n	3
o	11	p	62.25
r	28.25	s	16.25

4-wheel weight for c.g. det. ℓf 1182 rf 1236 ℓr 1044 rr 1048

Mass - pounds	Curb	Test Inertial	Gross Static
M_1		2418	
M_2		2092	
M_T		4510	

Note any damage to vehicle prior to test:

*d = overall height of vehicle

Engine Type: V8

Engine CID: 7.0 liter

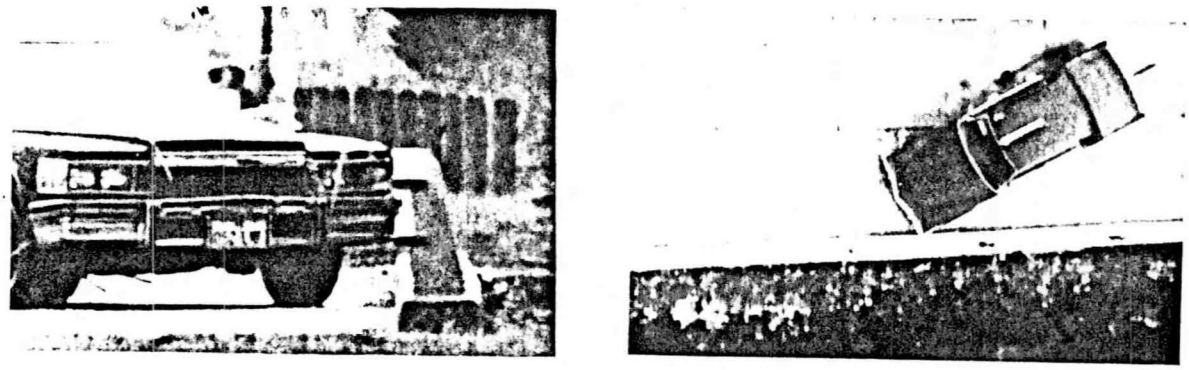
Transmission Type:
(Automatic) or Manual
FWD or (RWD) or 4WD

Body Type: 4-door

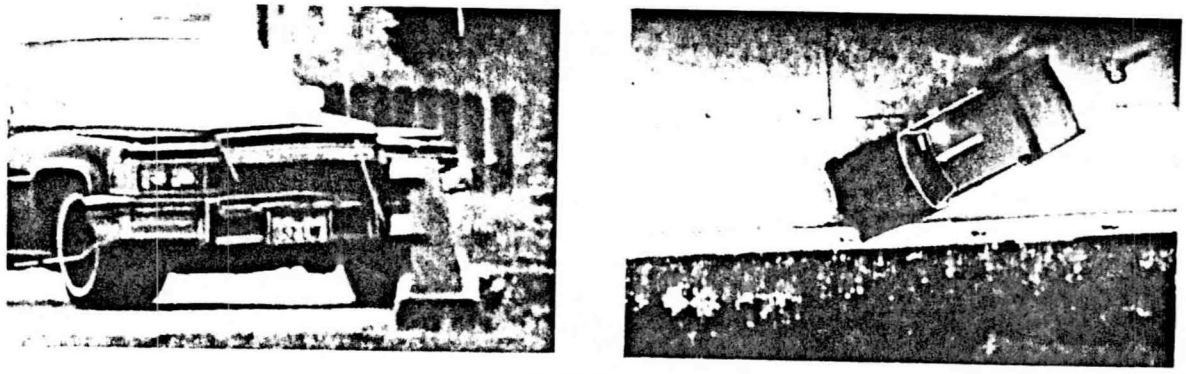
Steering Column Collapse Mechanism:
__Behind wheel units
__Convoluted tube
__Cylindrical mesh units
__Embedded ball
__NOT collapsible
__Other energy absorption
__Unknown

Brakes:
Front: disc X drum ___
Rear: disc ___ drum X

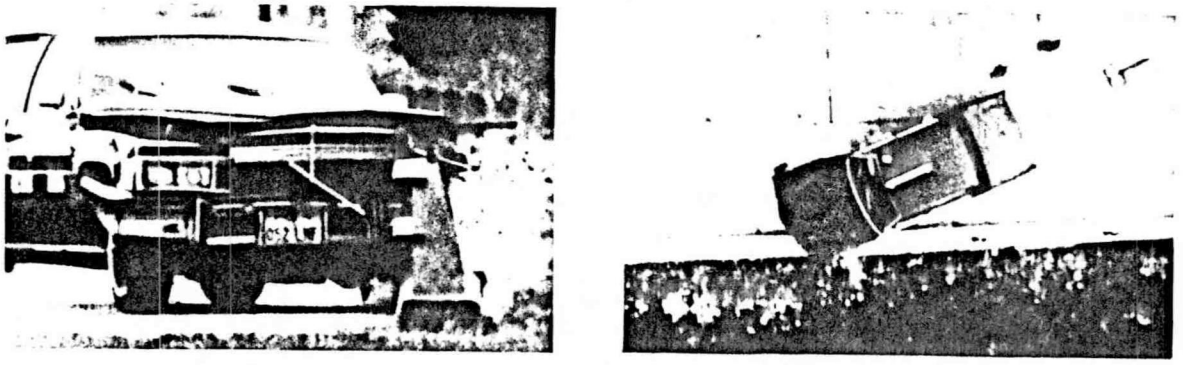
Figure 16. Test vehicle properties (0368-2).



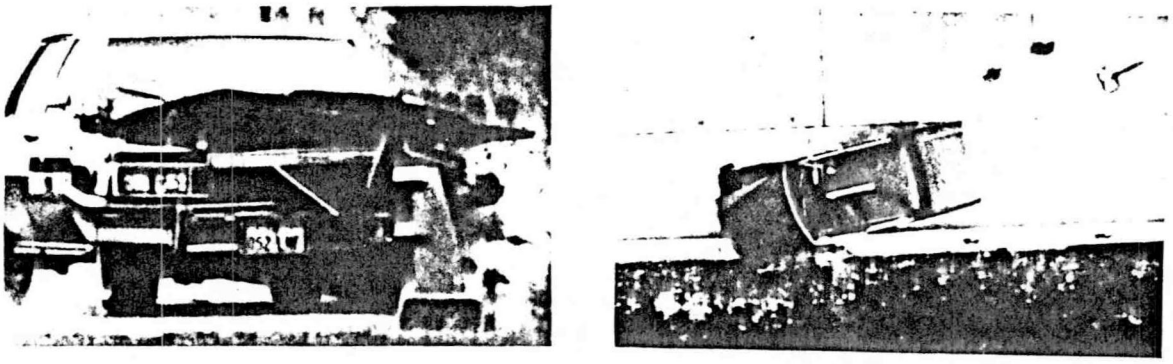
0.000 s



0.044 s

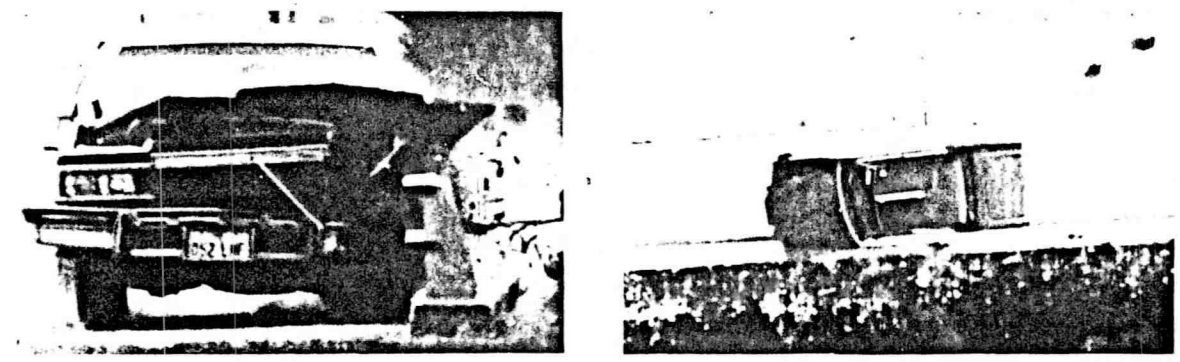


0.087 s

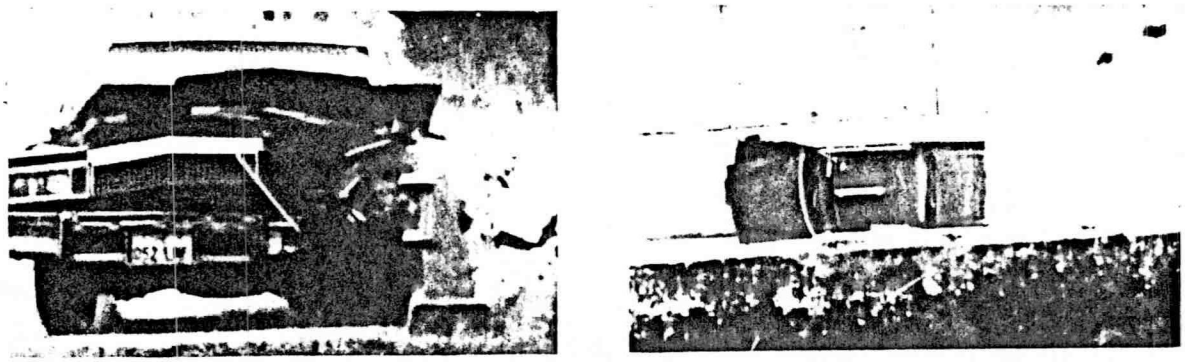


0.131 s

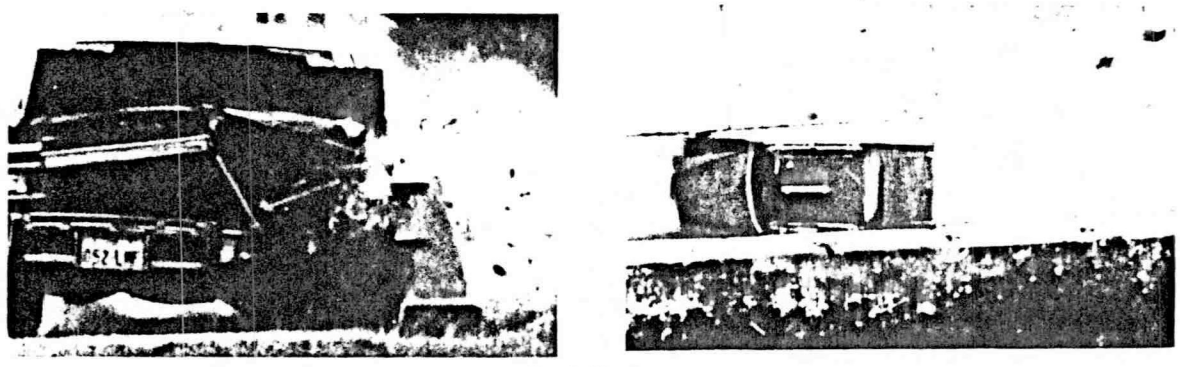
Figure 17. Sequential photographs for test 0368-2.



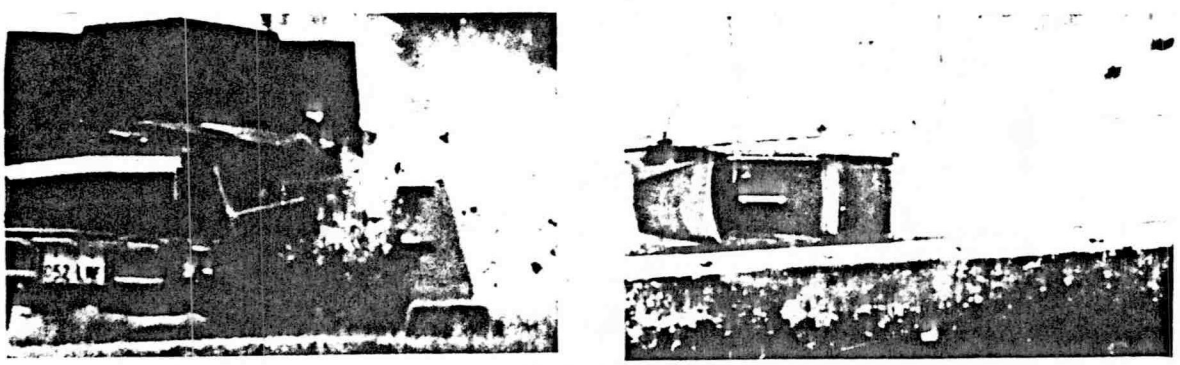
0.177 s



0.223 s



0.270 s



0.316 s

Figure 17. Sequential photographs for test 0368-2. (Continued)

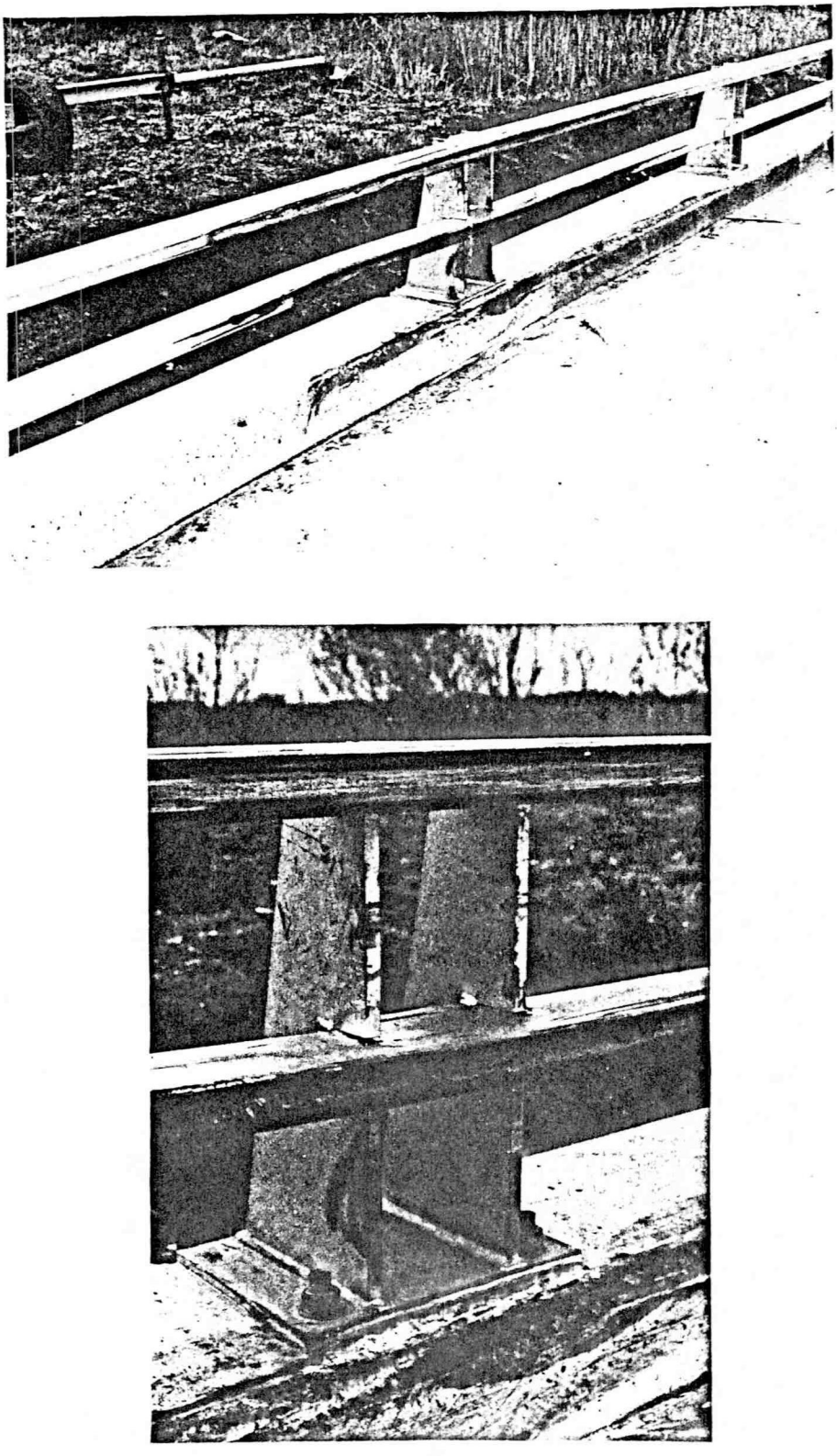


Figure 18. Wyoming Tube-Type Bridge Rail after test 0368-2.

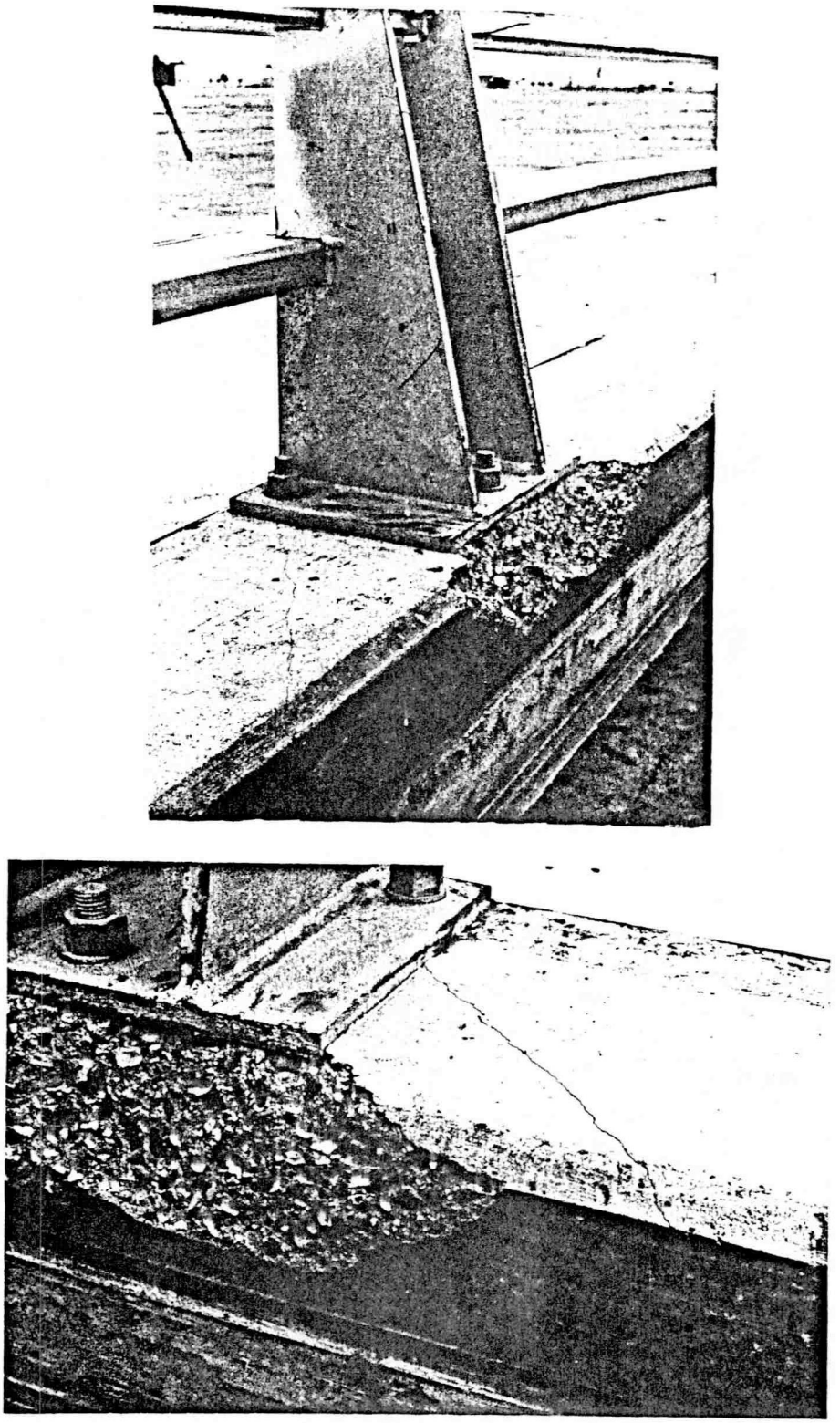


Figure 19. Damage to rear of post after test 0368-2.

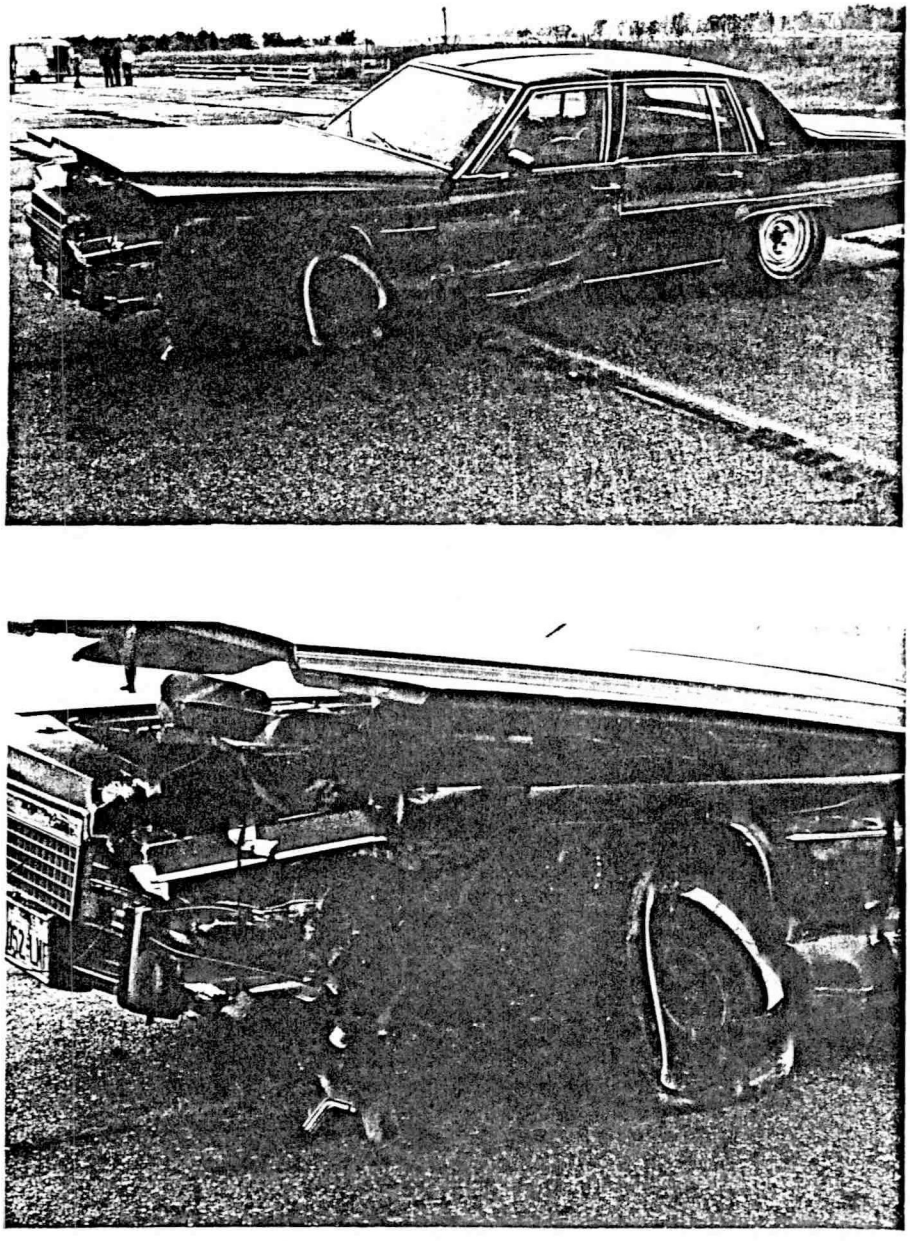
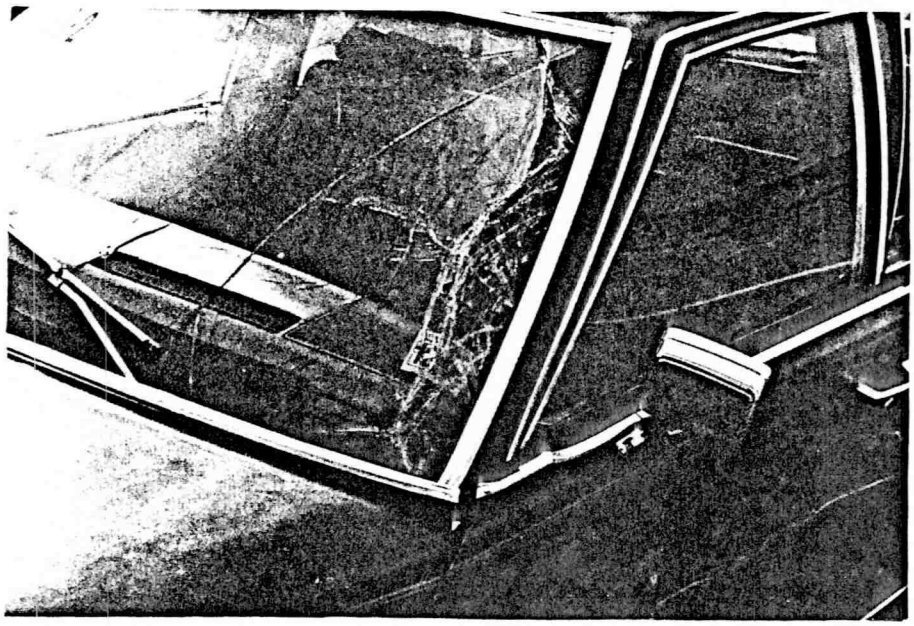


Figure 20. Vehicle after test 0368-2.



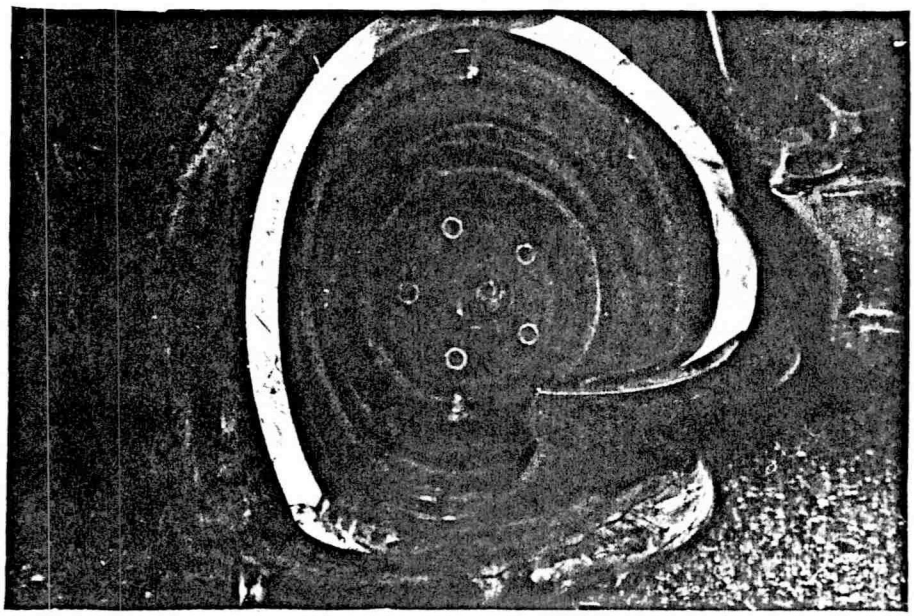


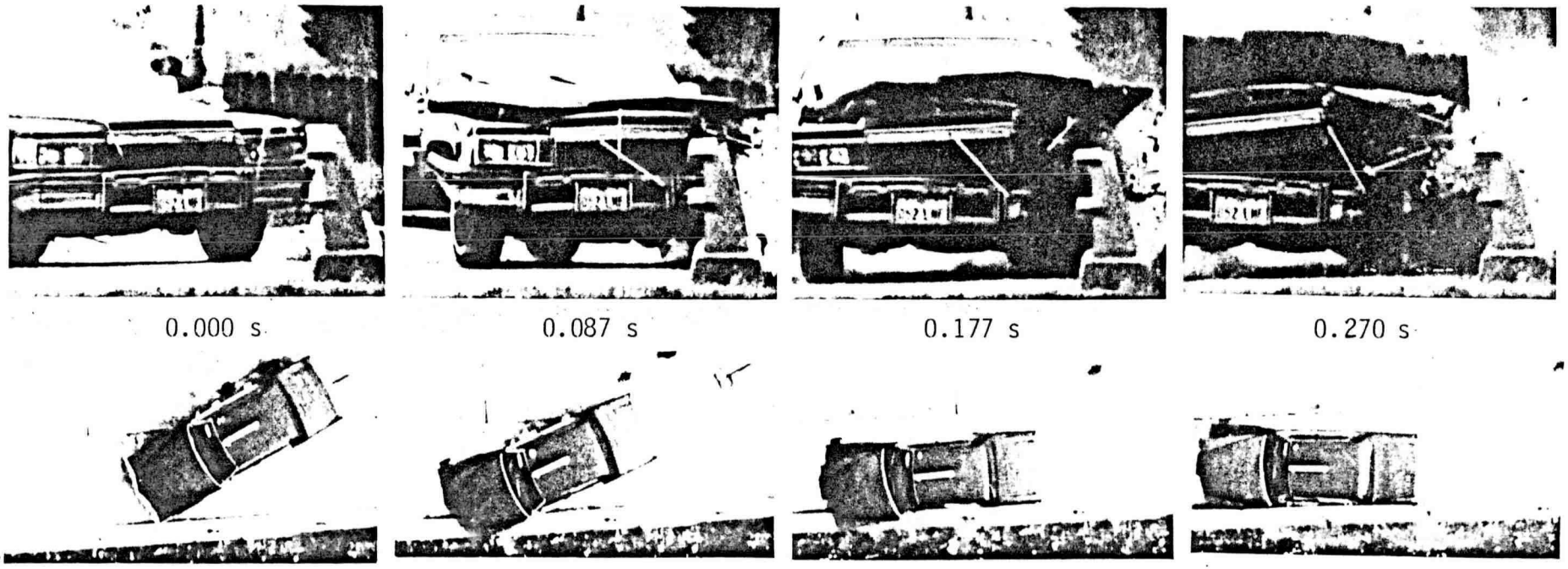
Figure 21. Windshield and tire/rim damage.

scraped. There was also considerable damage to the roof, front bumper, hood, tire rim, right front fender, and windshield.

Again, the narrowness of the two rail elements may have partially contributed to the severe damages sustained by the vehicle. The deformed sheet metal on the left front of the vehicle was momentarily wedged between the two rail elements, resulting in some vertical movement and deformation in the rail elements. The deformed sheet metal also contacted the post immediately downstream from the point of impact as well as the deflated left front tire. The hood latches (both primary and secondary) of the vehicle were disengaged by the impact and part of the hood slid across the top of the top rail element.

A summary of the test results and other information pertinent to this test are given in Figure 22. The maximum 0.050-second average acceleration experienced by the vehicle was 9.6 g in the longitudinal direction and 14.7 g in the lateral direction. Vehicle angular displacements are plotted in Figure 23 and vehicle accelerometer traces are displayed in Figures 24 through 26. Occupant impact velocity in the longitudinal direction was 25.1 feet per second (7.7 m/s) and 29.5 feet per second (9.0 m/s) in the lateral direction. The highest 0.10 s occupant ridedown accelerations were 5.8 g (longitudinal) and 12.2 g (lateral). It should be noted, however, that occupant impact velocity and ridedown accelerations are not applicable for this test and are reported for information purposes only.

In summary, the rail contained and redirected the vehicle with little lateral movement of the barrier. There was no debris or detached elements. There was minimal deformation and intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the initial test period and after leaving the rail.



Test No	0368-2
Date	02/10/88
Test Installation	Wyoming Tube-Type Bridge Rail
Length of Installation	77 ft (23.5 m)
Vehicle	1979 Cadillac Sedan Deville
Vehicle Weight	
Test Inertia	4,510 lb (2,045.7 kg)
Vehicle Damage Classification	
TAD	11LFQ6
CDC	11FLEK3 & 11LYES4
Maximum Vehicle Crush	18.0 in (45.7 cm)
Max. Perm. Rail Deformation	1.25 (3.2 cm)

Impact Speed	63.3 mi/h (101.9 km/h)
Impact Angle	25.0 deg
Exit Speed	45.9 mi/h (73.9 km/h)
Exit Angle	4.6 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal	-9.6 g
Lateral	-14.7 g
Occupant Impact Velocity	
Longitudinal	25.1 ft/s (7.7 m/s)
Lateral	29.5 ft/s (9.0 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-5.8 g
Lateral	-12.2 g

Figure 22. Summary of results for test 0368-2.

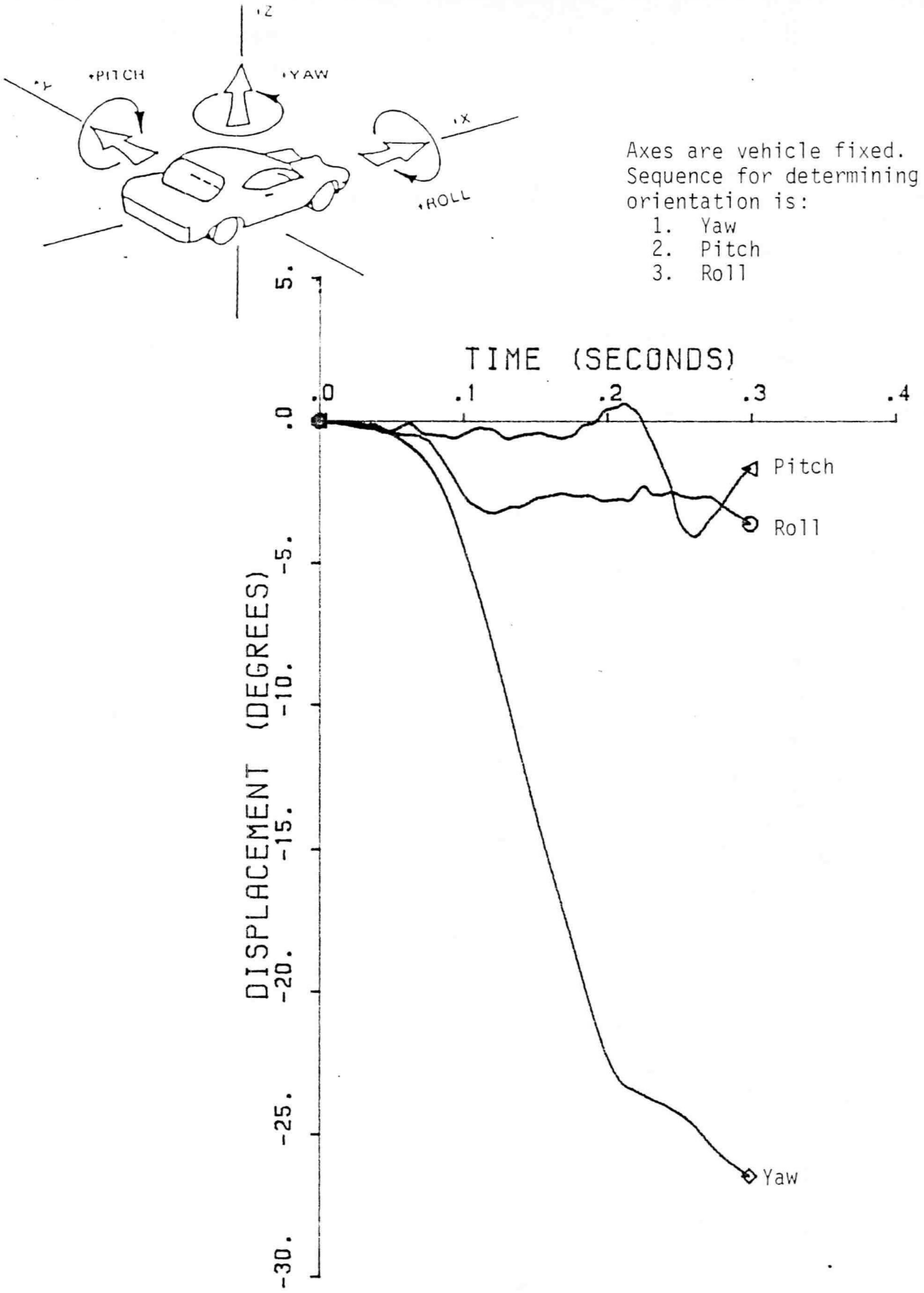


Figure 23. Vehicle Angular Displacements for test 0368-2.

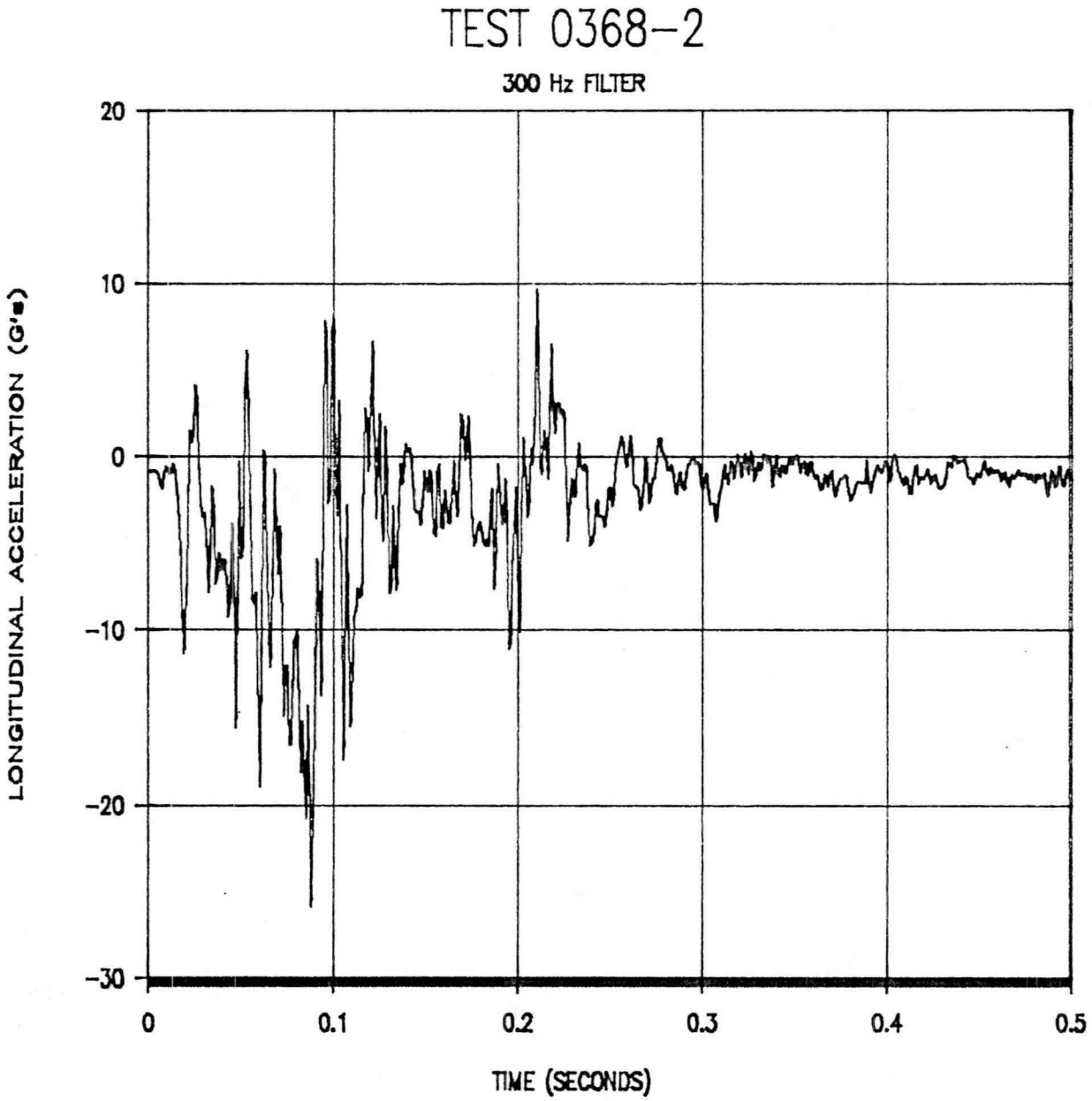


Figure 24. Longitudinal accelerometer trace for test 0368-2.

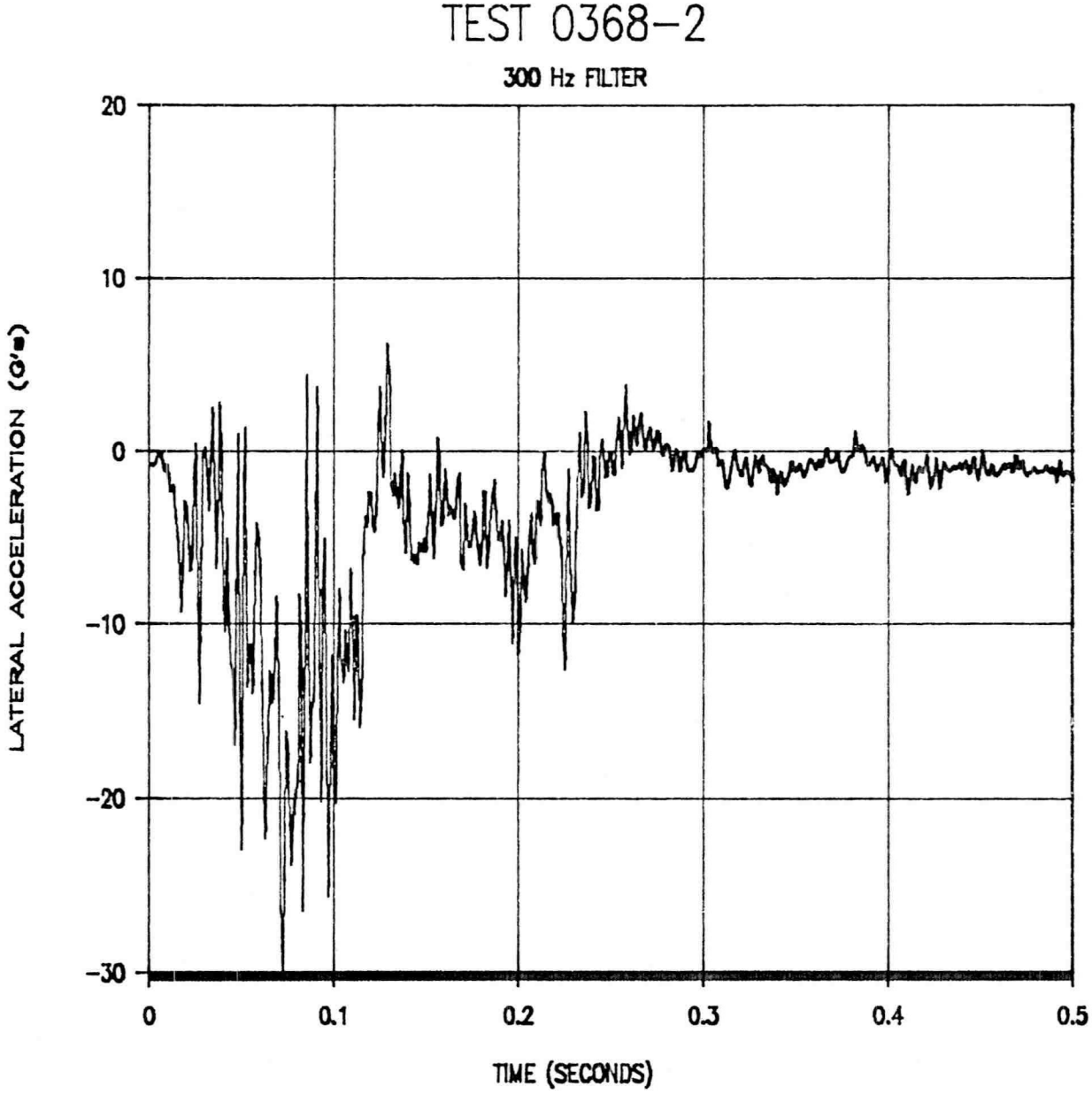


Figure 25. Lateral accelerometer trace for test 0368-2.

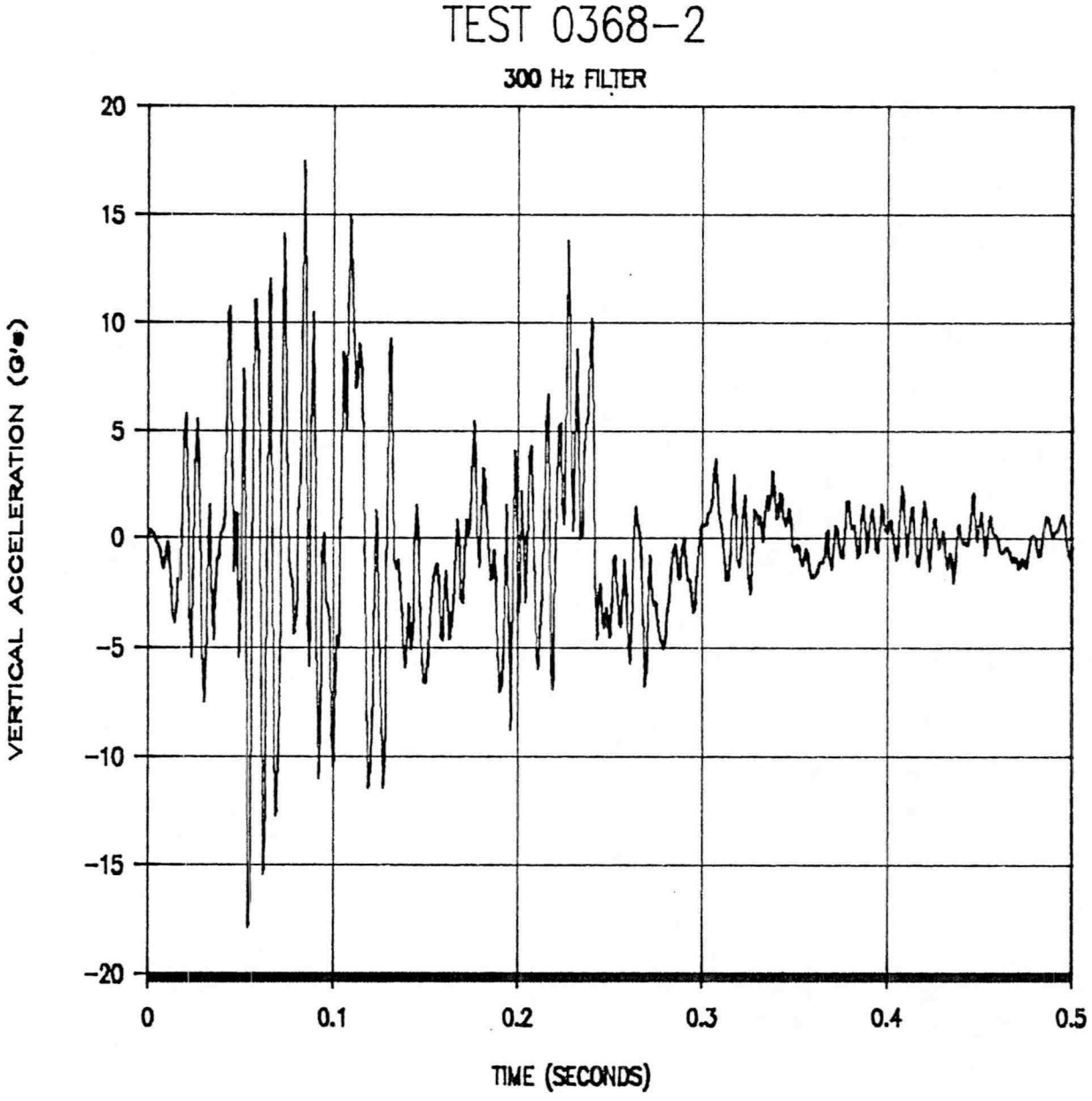


Figure 26. Vertical accelerometer trace for test 0368-2.

IV. FINDINGS AND CONCLUSIONS

Results of the two crash tests indicate that the Wyoming tube-type bridge rail system generally meets with the guidelines set forth in NCHRP Report 230. Discussions on the evaluation criteria and results for each of the two crash tests are presented in this section.

Test Number 1

The objectives and criteria for evaluation of the first test - Test S13 (1800S/60mph/20deg) are, according to NCHRP Report 230, as follows:

> The objective of this test is to investigate the dynamic interactions of the small car with redirective barriers. Because the 1800S vehicle has small diameter wheels, generally with the forward wheels being driven, there is concern that a forward wheel will wedge under the lower beam of a beam and post system and snag on a post. . . . Goals for this test are: (1) that the vehicle should be smoothly redirected without exhibiting any tendency to snag on post or other elements or to pocket, (2) that the vehicle should remain upright throughout the collision, and (3) its after-collision trajectory should not present undue hazard to other traffic.

The Wyoming tube-type bridge rail meets all three criteria outlined above. First, the vehicle was smoothly redirected without any snagging or pocketing. The damages sustained by the vehicle was fairly severe, part of which may be attributable to the narrowness of the two tube-type rail elements. The deformation of the sheet metal on the vehicle was such that the sheet metal was momentarily wedged between the two rail elements. However, it did not significantly affect the smooth redirection of the vehicle.

Secondly, the vehicle remained upright throughout the collision without exhibiting any tendency of rollover or instability. Finally, the after collision trajectory of the vehicle did not appear to present any undue hazard to other traffic. The exit angle of the vehicle was only 7.1 degrees which is substantially less than 60 percent of the impact angle (i.e., 14 degrees). The speed change of 11.4 miles per hour is less than the recommended maximum of 15 miles per hour.

Test Number 2

The objectives and criteria for evaluation of the second test - Test 10 (4500S/60mph/25deg) are, according to NCHRP Report 230, as follows:

This test is considered primarily a strength test of the installation in preventing the vehicle from penetrating or vaulting over the system. The vehicle should be smoothly redirected without exhibiting any tendency to snag on posts or other elements or to pocket. Moreover, the vehicle should remain upright throughout the collision, and its after-collision trajectory should not present undue hazard to the vehicle occupants or to other traffic.

The Wyoming tube-type bridge rail system meets all of the criteria outlined above. First, the bridge rail system successfully contained the vehicle with only minor damages to the bridge rail and the bridge deck. The vehicle was smoothly redirected although the post immediately downstream of the point of impact was contacted by both the left front tire and deformed sheet metal at the left front of the vehicle. It should be noted that the tire was already deflated at the time of contact with the post. More importantly, contact of the tire and sheet metal with the post did not significantly affect the smooth redirection of the vehicle. There was no indications of any abrupt deceleration or change in the vehicle trajectory.

Secondly, the vehicle remained upright throughout the collision without exhibiting any tendency of rollover or instability. Finally, the after collision trajectory of the vehicle did not appear to present any undue hazard to other traffic. The exit angle of the vehicle was only 4.6 degrees which was substantially less than 60 percent of the impact angle. The speed change of 17.4 miles per hour is slightly higher than the recommended maximum of 15 miles per hour. Part of the speed change could be attributed to the momentary wedging of the sheet metal between the two rail elements. Also, the slight exit angle of the vehicle would indicate minimal potential for intrusion into the adjacent traffic by the redirected vehicle.

Summary

In summary, the Wyoming tube-type bridge rail system meets with the requirements as set forth in NCHRP Report 230 for the two crash test conditions tested under this project.