TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-88/1179-1		

4. Title and Subtitle

CRASH TEST OF MODIFIED TEXAS C202 BRIDGE RAIL

5. Report Date

June 1988

6. Performing Organization Code

7. Author(s)

T. J. Hirsch and Perry Romere

8. Performing Organization Report No.

Research Report 1179-1

9. Performing Organization Name and Address

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

10. Work Unit No.

11. Contract or Grant No.

Research Study 2-5-88-1179

12. Sponsoring Agency Name and Address

Texas State Dept. of Highways & Public Transportation
Transportation Planning Division
P. O. Box 5051
Austin, Texas 78763

13. Type of Report and Period Covered

Interim - September 1987
June 1988

14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Research Study Title: Crash Test of Modified C202 Bridge Rail

16. Abstract

In 1980 a standard Texas traffic rail type C202 was modified to increase its height and strength to restrain and redirect an 80,000 lb (36,300 kg) van type tractor-trailer under 50 mph (80.5 km/h), 15^{o} angle impacts. The concrete parapet was increased to 36 in. (91 cm) high, and an elliptical steel rail was mounted on steel posts to increase the rail height to 54 in. (137 cm). In 1980 one crash test was conducted on the bridge rail. The truck was restrained and smoothly redirected.

This promising high performance bridge rail was never tested with passenger cars as called for in NCHRP 230. The bridge rail was successfully crash tested with a 1,918 lb car at 61.3 mph and 21^{o} angle and also with a 4,400 lb car at 59.4 mph and 25.9^{o} angle.

17. Key Words

Bridge Rails, Traffic Barriers, Trucks
Heavy Vehicles, Highway Safety, Cars

18. Distribution Statement

No restriction. This document is available to the public through the National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	58	

Form DOT F 1700.7 (8-69)

CRASH TEST OF MODIFIED TEXAS C202 BRIDGE RAIL

by

T. J. Hirsch
Research Engineer & Principal Investigator

and

Perry Romere
Engineering Research Associate

Research Report 1179-1

on

Research Study No. 2-5-88-1179
Crash Test of Modified C202 Bridge Rail

Sponsored by

Texas State Department of Highways and Public Transportation

in cooperation with

The U.S. Department of Transportation
Federal Highway Administration

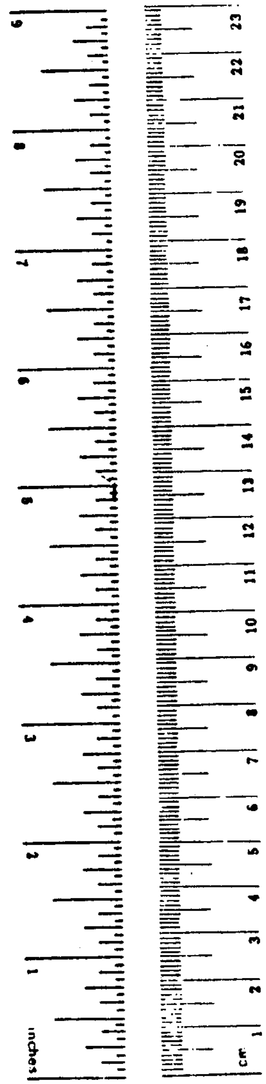
June 1988

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

METRIC CONVERSION FACTORS

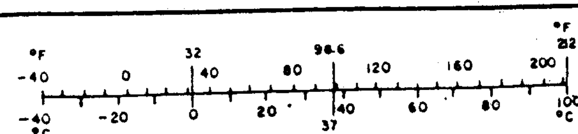
Approximate Conversions to Metric Measures

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	0.8	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 (2000 lb)	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 (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	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	35	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



DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

KEY WORDS

Bridge Rails, Traffic Barriers, Highway Safety, Trucks, Heavy Vehicles, Cars

ACKNOWLEDGMENTS

This research study was conducted under a cooperative program between the Texas Transportation Institute (TTI), the State Department of Highways and Public Transportation (SDHPT), and the Federal Highway Administration (FHWA). Dean Van Landuyt (Associate Designing Engineer, SDHPT) and John J. Panak (Bridge Designing Engineer, SDHPT) were closely involved in all phases of this study.

IMPLEMENTATION STATEMENT

As of the writing of this report, none of the findings or conclusions presented have been implemented.

ABSTRACT

In 1980 a standard Texas traffic rail type C202 was modified to increase its height and strength to restrain and redirect an 80,000 lb (36,300 kg) van type tractor-trailer under 50 mph (80.5 km/h), 15^{0} angle impacts. The concrete parapet was increased to 36 in. (91 cm) high, and an elliptical steel rail was mounted on steel posts to increase the rail height to 54 in. (137 cm). In 1980 one crash test was conducted on the bridge rail. The truck was restrained and smoothly redirected.

This promising high performance bridge rail was never tested with passenger cars as called for in NCHRP 230. The bridge rail was successfully crash tested with a 1,918 lb car at 61.3 mph and 21^{0} angle and also with a 4,400 lb car at 59.4 mph and 25.9^{0} angle.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The bridge rail tested here was selected and designed to restrain and redirect an 80,000 lb (36,287 kg) van type tractor-trailer in 1980 (1)*. The design was based on procedures and test data presented in References (2) and (8).

The basic rail was a modification of the concrete parapet, Texas traffic rail type C202. The modified C202 rail consists of a concrete beam element 13 in. (33 cm) wide and 23 in. (58 cm) deep, mounted 36 in. (91 cm) high on concrete posts located at 10 ft (3 m) center-to-center spacing. The concrete posts are 7 in. (19 cm) thick by 5 ft (1.5 m) long concrete walls with 5 ft (1.5 m) openings. The beam element contains considerable reinforcing steel and provides flexibility, thus minimizing cracking of the concrete when impacted by heavy vehicles. The modified C202 concrete parapet can be placed in long, continuous lengths giving good structural continuity and strength.

To increase the effective height of this bridge rail, another standard Texas steel rail designated as C4 was mounted on top of the concrete rail. The bridge deck strength was also increased in an attempt to minimize cracking or damage when the bridge rail is impacted by a heavy vehicle.

Research Report 230-4F (1) presented the results of a crash test on this bridge rail which successfully redirected an 80,000 lb (36,287 kg) van type tractor-trailer at nominally 50 mph (80 km/h) and 15^{0} angle. In addition to successfully redirecting the van type tractor-trailer, the modified C202 bridge rail with the C4 metal rail on top must also redirect a 1,800 lb (810 kg) automobile and a 4,500 lb (2,025 kg) automobile in order to meet all of the requirements set forth in NCHRP Report 230.

---

*Numbers in parentheses, thus (1), refer to corresponding item in the References.

DESCRIPTION OF BRIDGE RAIL AND DECK MODIFICATIONS

Drawings of this rail are shown in Figures 1 and 2. Figure 3 contains photographs comparing the size of the combination bridge rail with the van type tractor-trailer used in previous crash tests (1).

The strength of the standard Texas 7.5 in. (19 cm) thick bridge deck was increased by the addition of welded wire fabric centered under each post and along the deck steel to within 1 in. (2.5 cm) of the edge of the slab. A drawing of the welded wire fabric is shown in Figure 4. The deformed wire has a minimum yield strength of 70 ksi (48.3 kN/cm^2), and the smooth wire has a minimum yield strength of 65 ksi (44.9 kN/cm^2).

The concrete post was 13 in. (33 cm) high x 7 in. (17.8 cm) thick x 60 in. (152 cm) long with a 60 in. (152 cm) open space between each post. Each concrete post was anchored to the bridge deck by means of thirteen #4 bars (traffic side) and five #4 bars (field side). The thirteen #4 bars contained an 8 in. (20 cm) lap splice on top of the bridge deck which was intended as a breakaway connection.

The concrete rail on top of the post was 13 in. (33 cm) thick by 23 in. (58 cm) high for the entire length of the rail. It contained two sections of square spiral as shown, with ten #8 bars along the length of the rail. The twin spirals were used instead of a single spiral because the square spiral was available from a producer of Texas standard prestressed square piling which requires this type of spiral.

The steel rail on top of the modified C202 concrete rail was the Texas standard type C4 steel rail. It was made from 6 in. (15 cm) diameter standard steel pipe (ASTM A53 Grade B) shaped into an 8 in. x 4-7/8 in. (20 cm x 12.4 cm) ellipse and welded to a post and base plate made of 1 in. (2.54 cm) steel plates. This post was anchored to the concrete rail by means of four 3/4 in. diameter by 15 in. (38 cm) long A325 bolts. A high cast steel conical washer was installed under each bolt nut. These washers were evidently the standard being supplied by the fabricator for this type of Texas bridge rail. The standard drawing indicates that only "washers" are to be supplied.

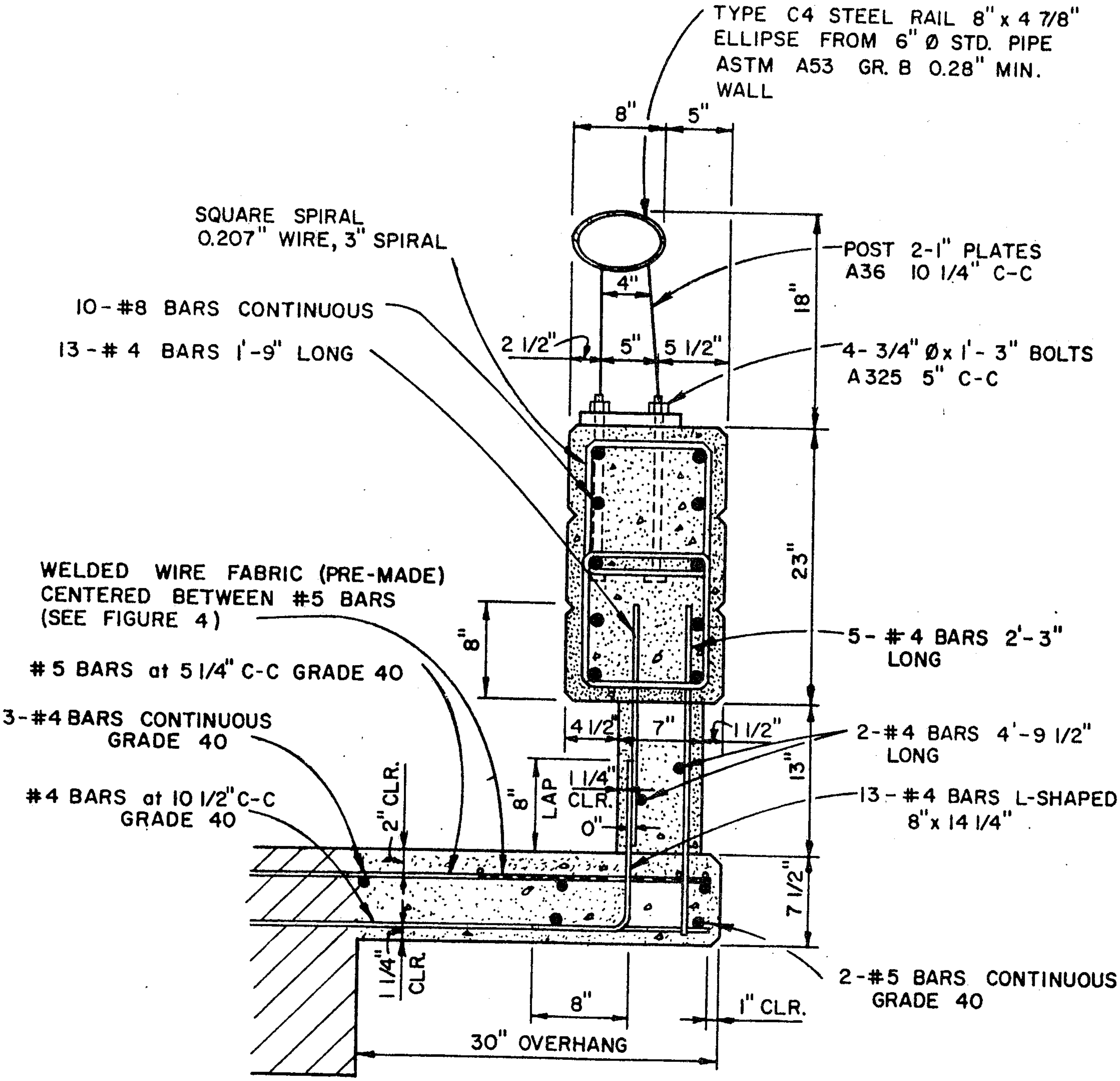


Figure 1. Cross Section of the Modified C202 Bridge Rail.

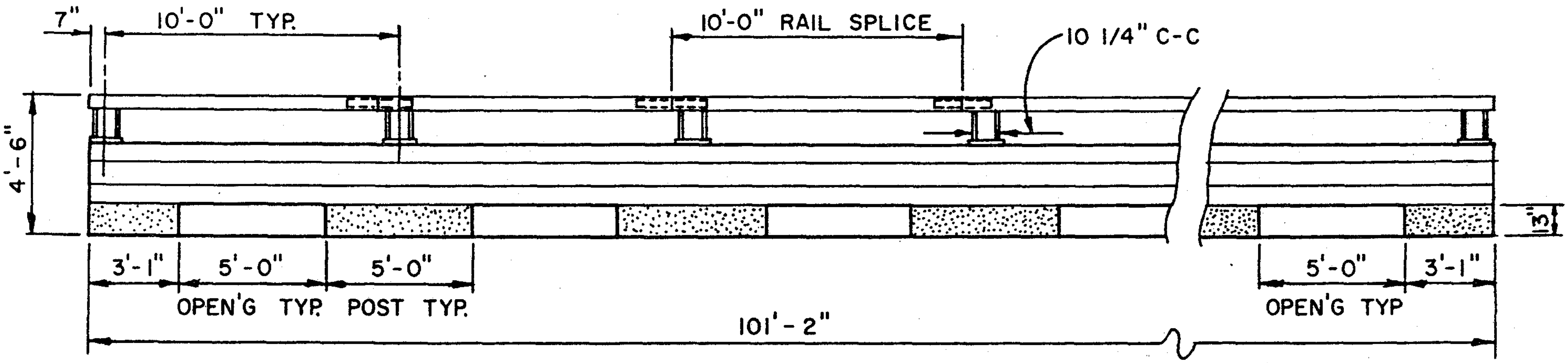


Figure 2. Elevation of the Modified C202 Bridge Rail.

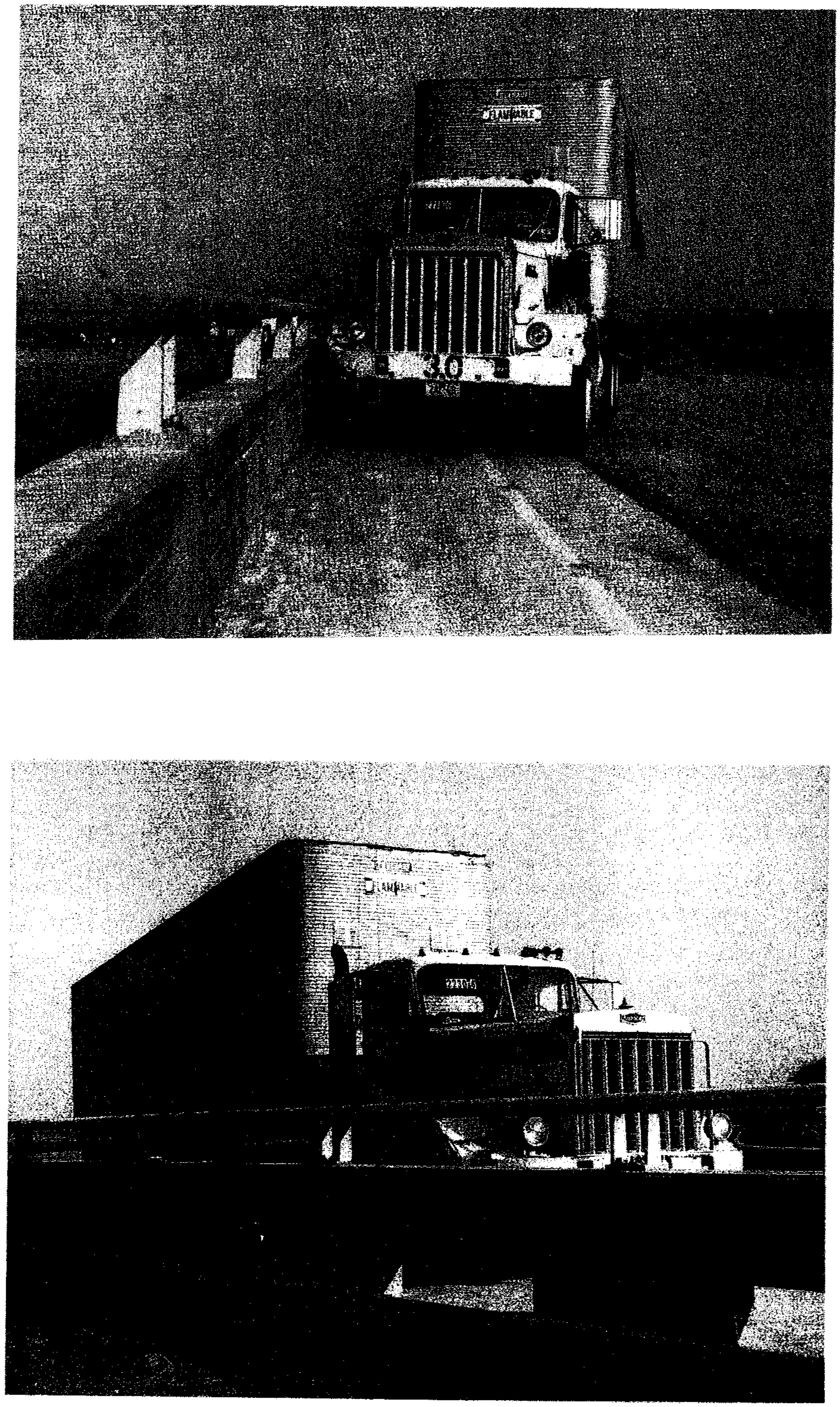


Figure 3. Comparison of the 80,000 lb Truck with Modified Combination Rail.

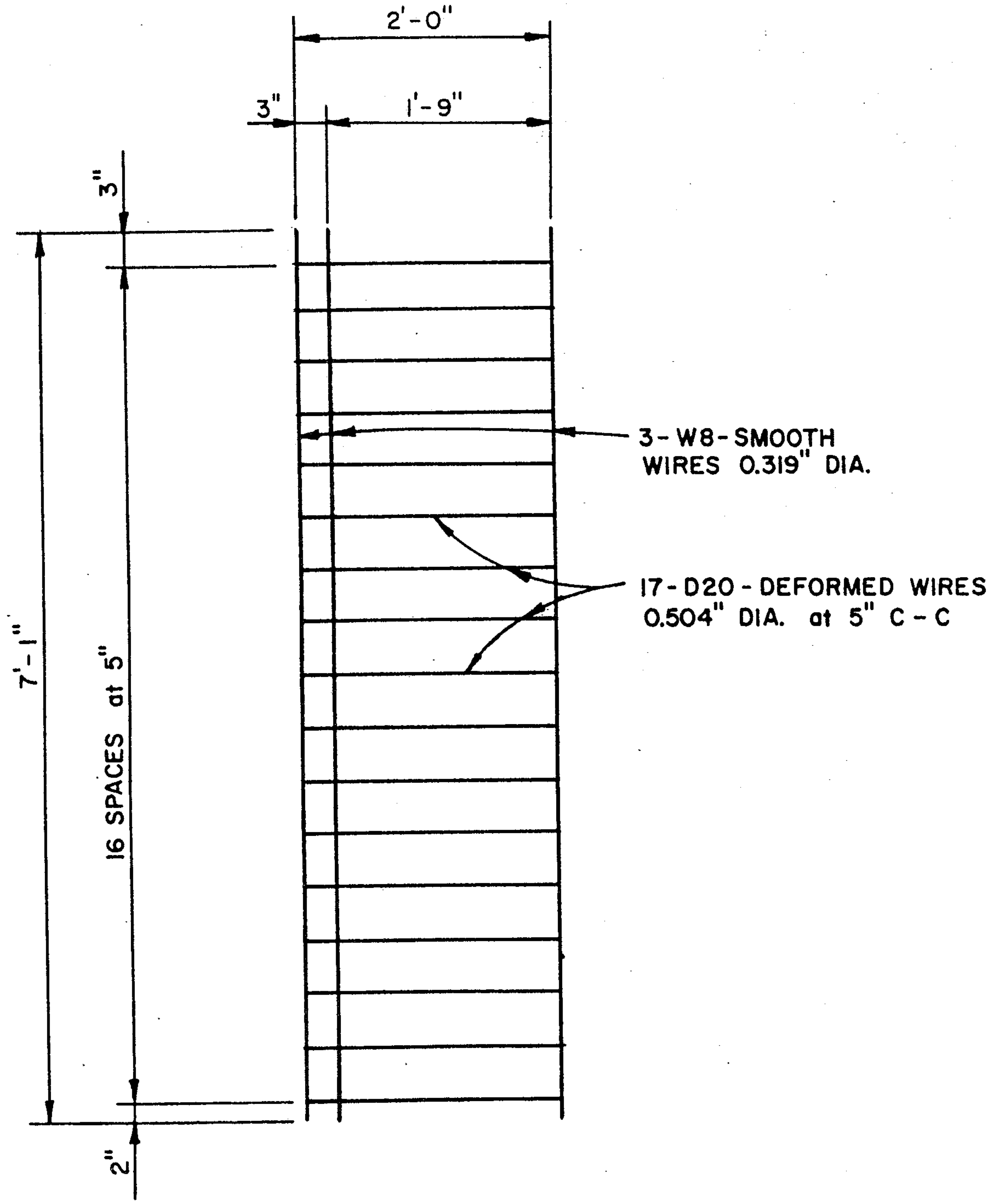


Figure 4. Detail of Special Slab Reinforcement used Under Each Concrete Post.

All steel bars in the concrete post and rail were grade 60, including the bent bars that anchor the post to the deck. The deck steel bars were grade 40. The concrete for the deck, post, and rail was such that its strength was 3,000 psi (2.068 kN/cm^2) at the time of the test.

HONDA CRASH TEST (1179-1)

This bridge rail was crash tested with a 1979 Honda Civic weighing 1,750 lb (795 kg) but with a gross weight of 1,918 lb (871 kg) including a dummy. A drawing showing the dimensions of this vehicle along with the weights on each axle is shown in Figure 5. Before and after test photographs of the Honda are presented in Figures 6 and 7.

The Honda impacted the rail at 61.3 mph (98.6 km/h) and 21^{0} angle. Impact occurred 7.0 ft upstream of post 11 and was smoothly redirected. The exit angle of the Honda was only 0.6^{0}, and it would have remained on the right hand shoulder and not reentered the traffic lanes. Figure 9 shows the bridge rail and test site immediately after test 1179-1. The Honda sustained damage to the right front and right side. The right front tire came in contact with post 11 which can be seen in Figure 9. This contact caused some damage to the front right wheel and suspension; however, it was still rolling after impact (see Figure 8). An anthropomorphic dummy was placed in the driver's seat for this test. Photographs showing the dummy's before and after test positions are presented in Figure 10. A summary of the crash test data is shown in Figure 11. Sequential photographs showing the overhead and frontal view of the crash test are shown in Appendix A.

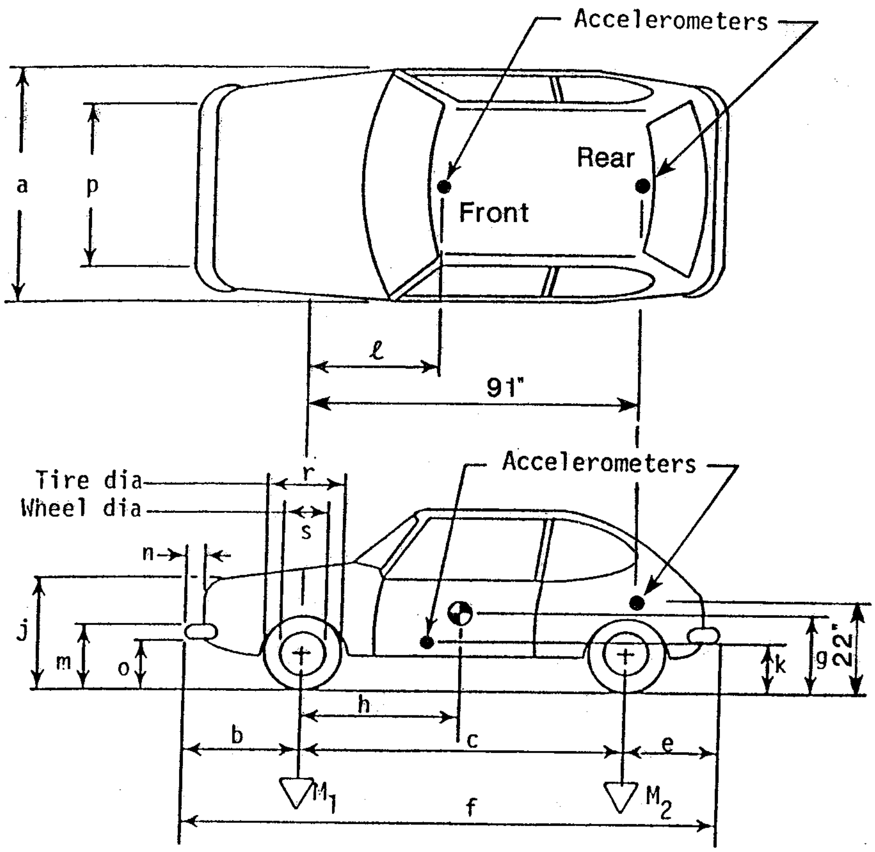
The Honda was equipped with roll, pitch, and yaw rate gyros and x, y, and z accelerometer group on the floor board 14.2 in. in front of the center of gravity, and an x and y accelerometer group 50.8 in. behind the center of gravity. Graphs of the filtered data from this instrumentation are presented in Appendix B. Figure B7 shows a plot of the max. 0.050 sec average accelerations along the vehicle length at 0.050 sec after impact. This is the time that the maximum lateral vehicle acceleration at the C.G. occurred.

The vehicle and barrier met all of the evaluation criteria required by NCHRP Report 230.

Date: ______ Test No.: 1179-1 VIN: SBC-7050817

Make: Honda Model: Civic Year: 1979 Odometer: 100,890

Tire Size: 155 SR12 Ply Rating: 2 Bias Ply: __ Belted: X Radial: __



Tire Condition: good __
fair X
badly worn __

Vehicle Geometry - inches

a	58	b	26
c	87	d*	51
e	27	f	140
g		h	36.2
i	----	j	31.25
k	14.5	ℓ	22
m	20.25	n	5.5
o	15.5	p	51
r	21	s	13.25

Engine Type: 4 cyl

Engine CID: ______

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

4-wheel weight for c.g. det. ℓf 533 rf 488 ℓr 375 rr 354

Mass - pounds	Curb	Test Inertial	Gross Static
M_1		1021	1103
M_2		729	815
M_T		1750	1918

Note any damage to vehicle prior to test:

*d = overall height of vehicle

Figure 5. Honda Dimensions, Empty Weights, and Loaded Weights.

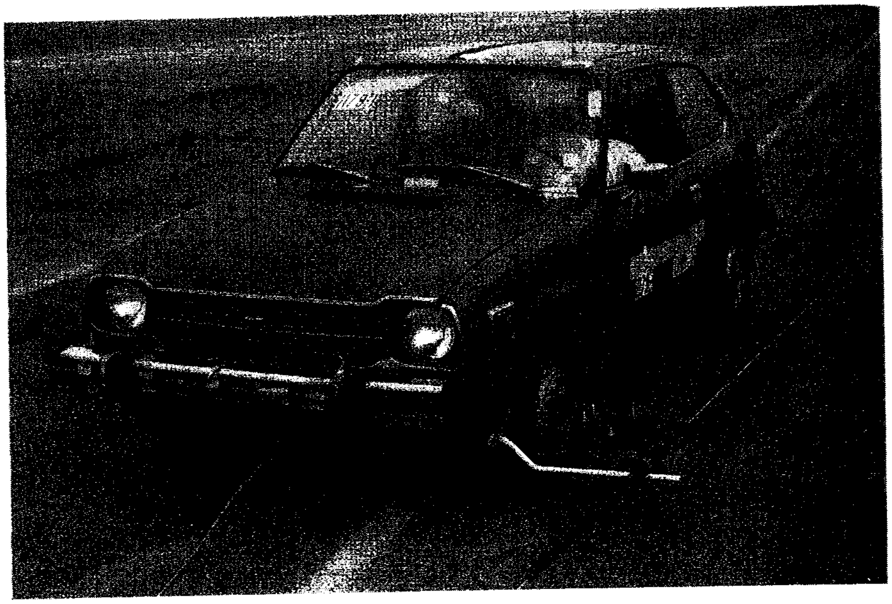


Figure 6. Vehicle before test 1179-1.

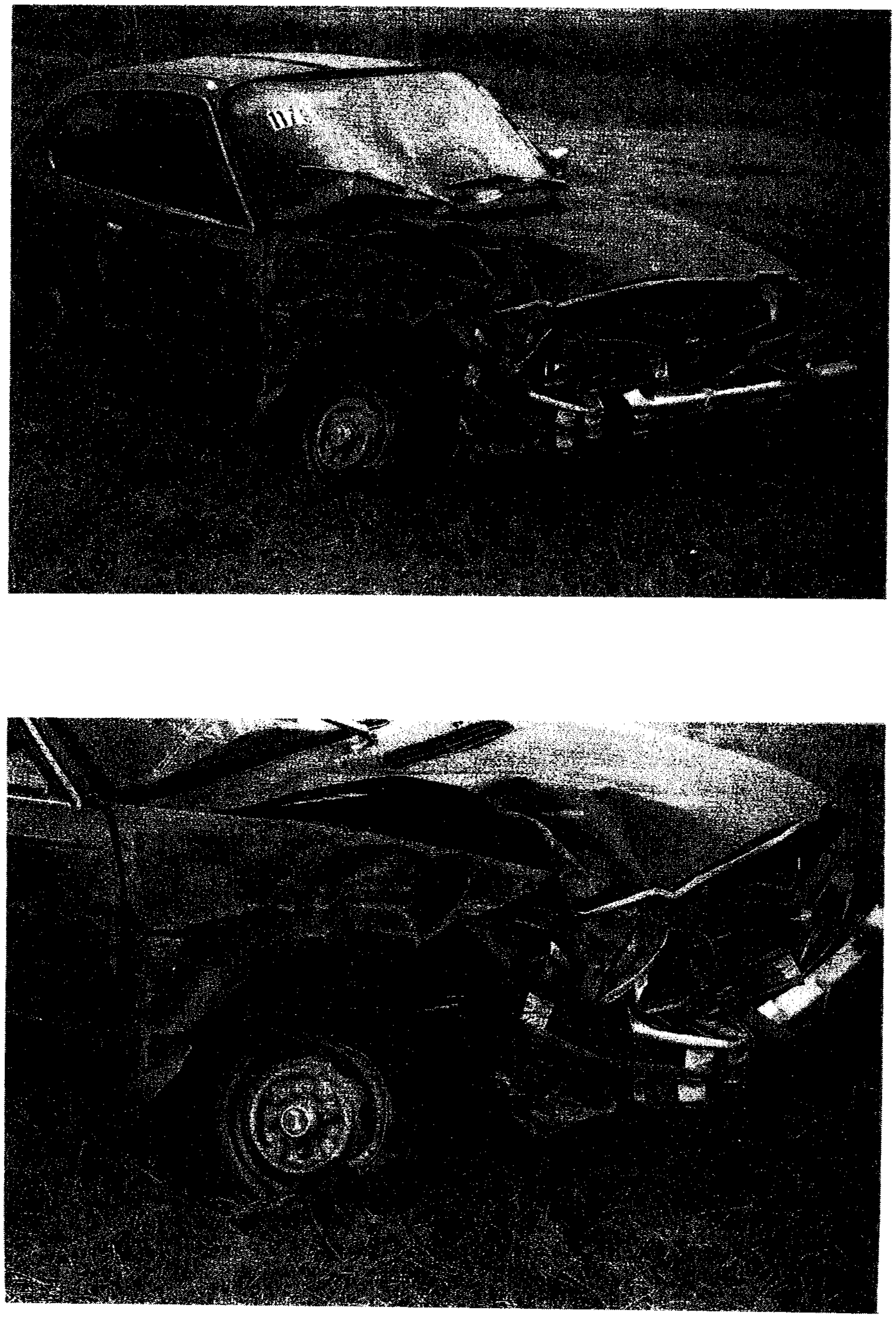


Figure 7. Vehicle after test 1179-1.

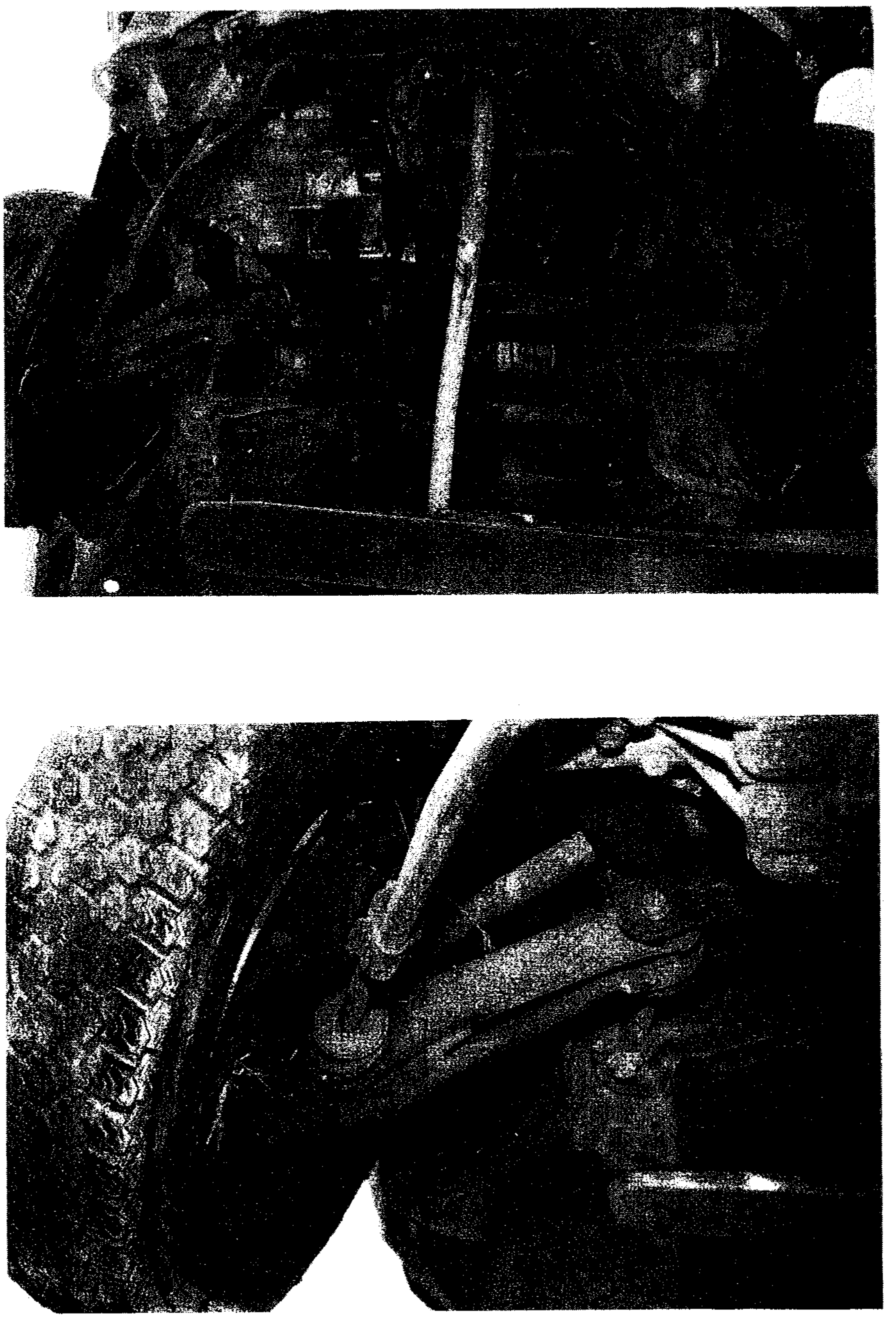


Figure 8. Damage to suspension of vehicle used in test 1179-1.

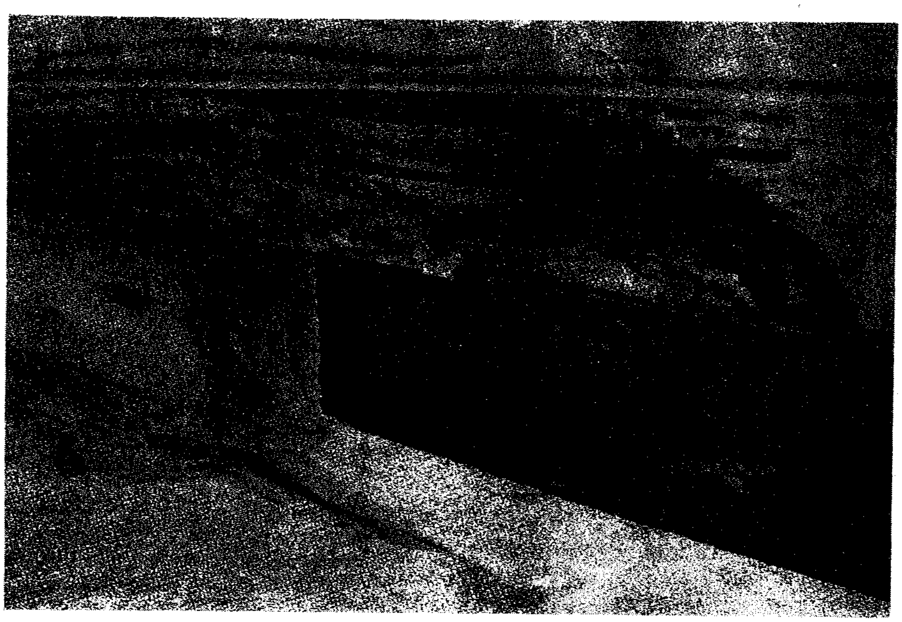


Figure 9. Bridge rail after test 1179-1.

Figure 10. Anthropomorphic dummy before and after test 1179-1.

0.000 s 0.064 s 0.131 s 0.200 s

Test No	1179-1
Date.	11/24/87
Test Installation	C202 Bridge Rail with C4 Steel Rail
Length of Installation. . . .	101 ft (31 m)
Vehicle	1979 Honda Civic
Vehicle Weight	
Test Inertia.	1,750 lb (795 kg)
Gross Static.	1,918 lb (871 kg)
Vehicle Damage Classification	
TAD	01RFQ5
CDC	01RYAS4

Impact Speed	61.3 mi/h (98.6 km/h)
Impact Angle	21.0 deg
Exit Speed	44.5 mi/h (71.6 km/h)
Exit Angle	0.6 deg
Vehicle Accelerations at C.G. (Max. 0.050-sec Avg)	
Longitudinal	-10.2 g
Lateral.	+14.0 g
Occupant Impact Velocity	
Longitudinal	23.3 ft/s (7.1 m/s)
Lateral.	25.7 ft/s (7.8 m/s)
Occupant Ridedown Accelerations	
Longitudinal	2.0 g
Lateral.	-9.3 g

Figure 11. Summary of results for test 1179-1.

CADILLAC CRASH TEST (1179-2)

This bridge rail was crash tested with a 1979 Cadillac weighing 4,400 lb (1,998 kg). A drawing showing the dimensions of this vehicle along with the weights on each axle is shown in Figure 12. Before and after test photographs of the Cadillac are presented in Figures 13 and 14.

The Cadillac impacted the rail at 59.4 mph (95.6 km/h) and 25.9^{o} angle. Impact occurred 7.5 ft upstream of post 11 and was smoothly redirected. Figure 15 shows the bridge rail and test site immediately after test 1179-2. The Cadillac sustained damage to the right front and right side. The right front tire made light contact with concrete post 11 and the hood came in contact with the metal post directly above concrete post 11. This post contact caused slight damage to the front right tire and suspension; however, it was still rolling after contact. Severe damage to the hood resulted when it contacted the steel post and it cracked the right front windshield which is shown in Figure 14. The hood pushed the windshield inward several inches but did not penetrate the passenger compartment.

A summary of the crash data is shown in Figure 17. Sequential photographs showing the overhead and frontal view of the crash test are shown in Appendix C.

The Cadillac was equipped with roll, pitch, and yaw rate gyro's and x, y, and z accelerometers on the floorboard 16.2 in. in front of the center of gravity and an x and y accelerometer group 104.8 in. behind the center of gravity. Graphs of the filtered data from this instrumentation are presented in Appendix D. Figure #7 shows a plot of the max. 0.050 sec average acceleration along the vehicle length at 0.075 sec after impact. This is the time that the maximum lateral vehicle acceleration at the C.G. occurred.

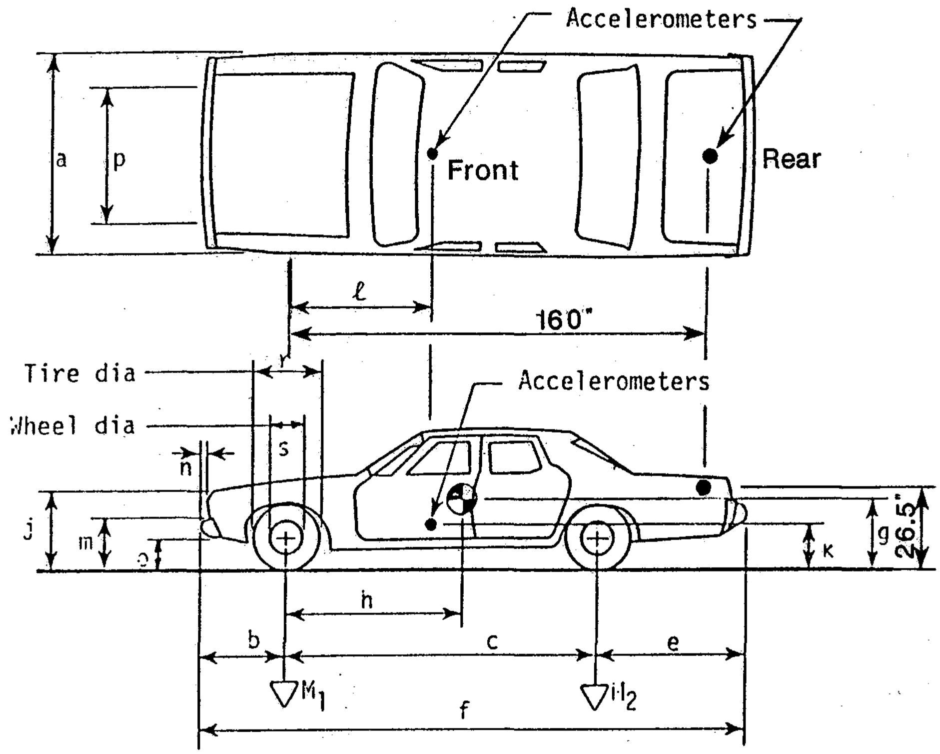
The vehicle and barrier met all of the evaluation criteria required by NCHRP Report 230.

Date: 12-1-87 Test No.: 1179-2 VIN: 6D4759C362837

Make: Cadillac Model: Copedeville Year: 1979 Odometer: 134722

Tire Size: P235 75R15 Ply Rating: 2 Bias Ply: X Belted: ___ Radial: ___

Tire Condition: good ___ fair X badly worn ___



Vehicle Geometry - inches

a	76	b	40
c	121.5	d*	56.75
e	56	f	217.5
g		h	55.2
i	----	j	37
k	21	ℓ	39
m	23.5	n	4
o	12	p	62
r	28	s	16.25

Engine Type: V8

Engine CID: 7.0

Transmission Type: (Automatic) or Manual

FWD or (RWD) or 4WD

Body Type: 2-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

4-wheel weight for c.g. det. ℓf 1180 rf 1220 ℓr 1004 rr 996

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2451	2400	
M_2	1749	2000	
M_T	4200	4400	

Note any damage to vehicle prior to test:

*d = overall height of vehicle

Figure 12. Cadillac Dimensions, Empty Weights, and Loaded Weights.

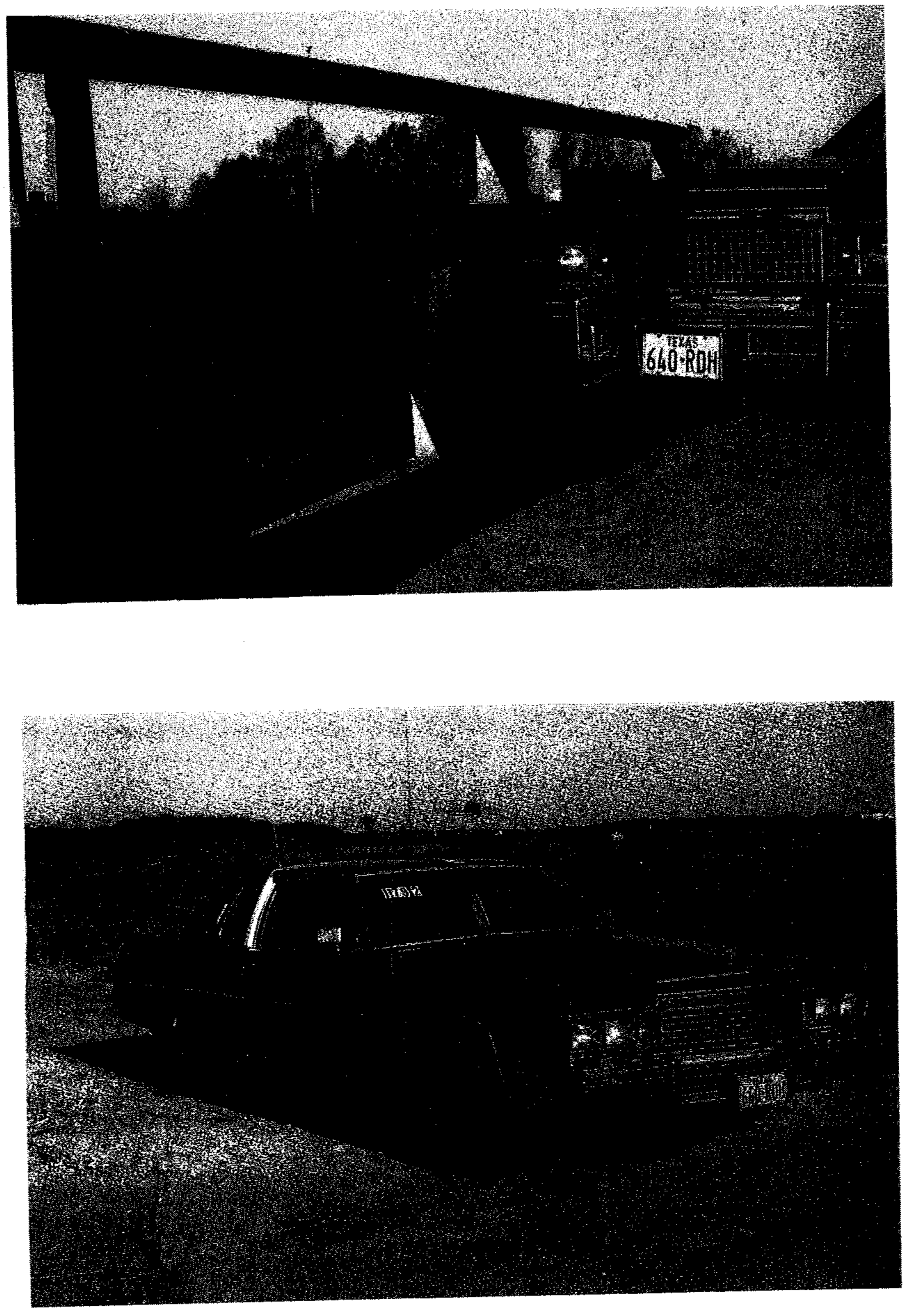


Figure 13. Vehicle before test 1179-2.

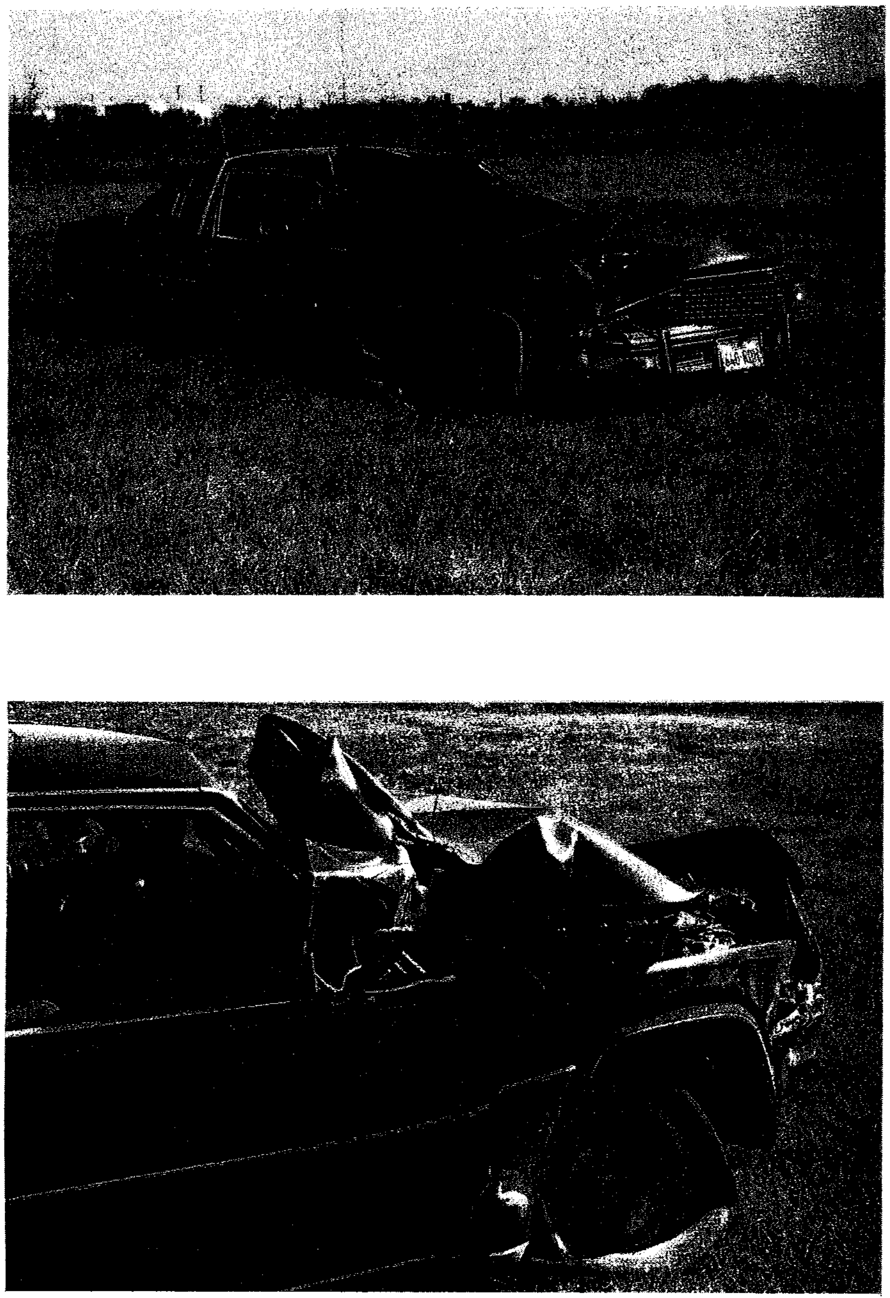


Figure 14. Vehicle after test 1179-2.

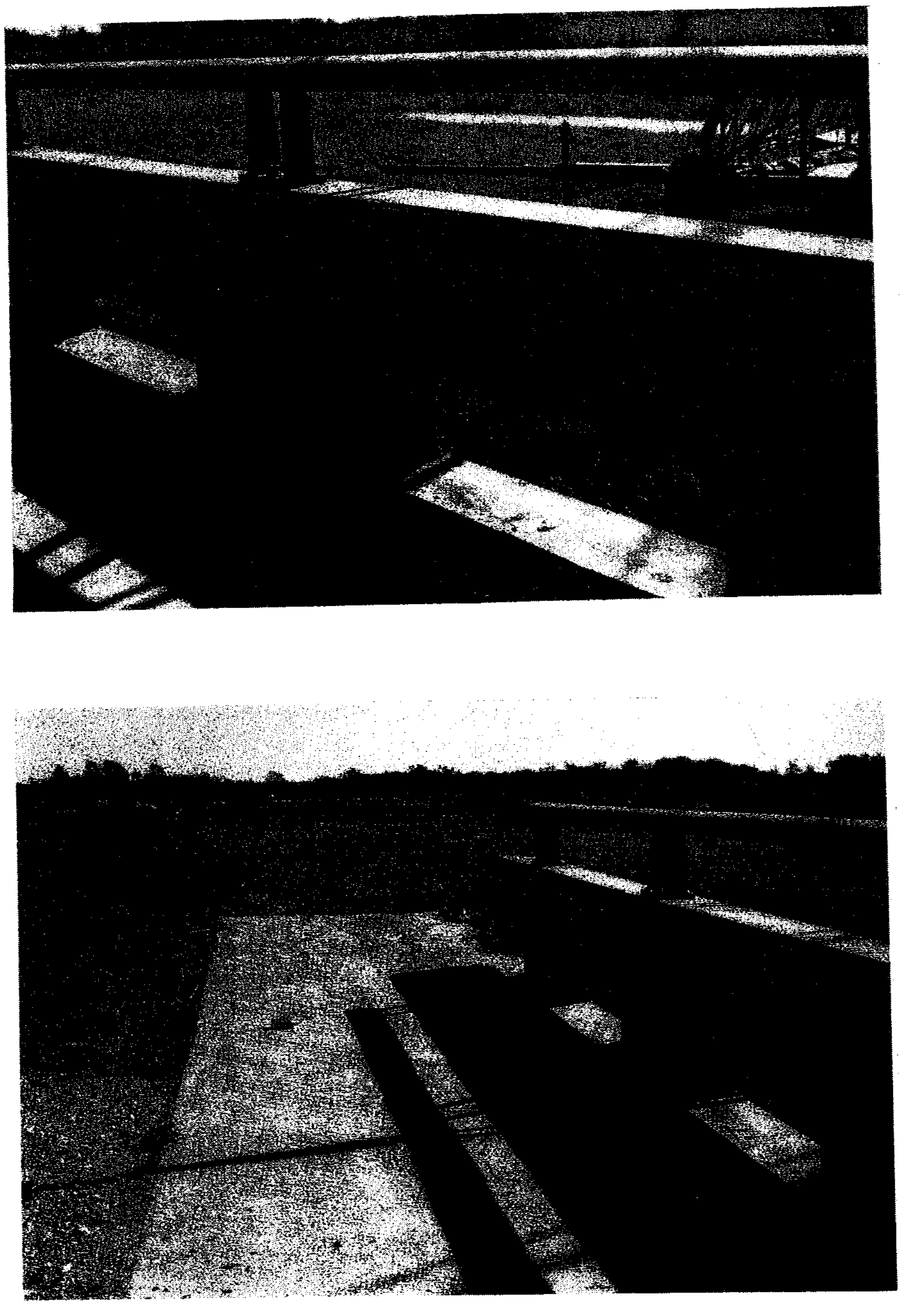


Figure 15. Bridge rail after test 1179-2.

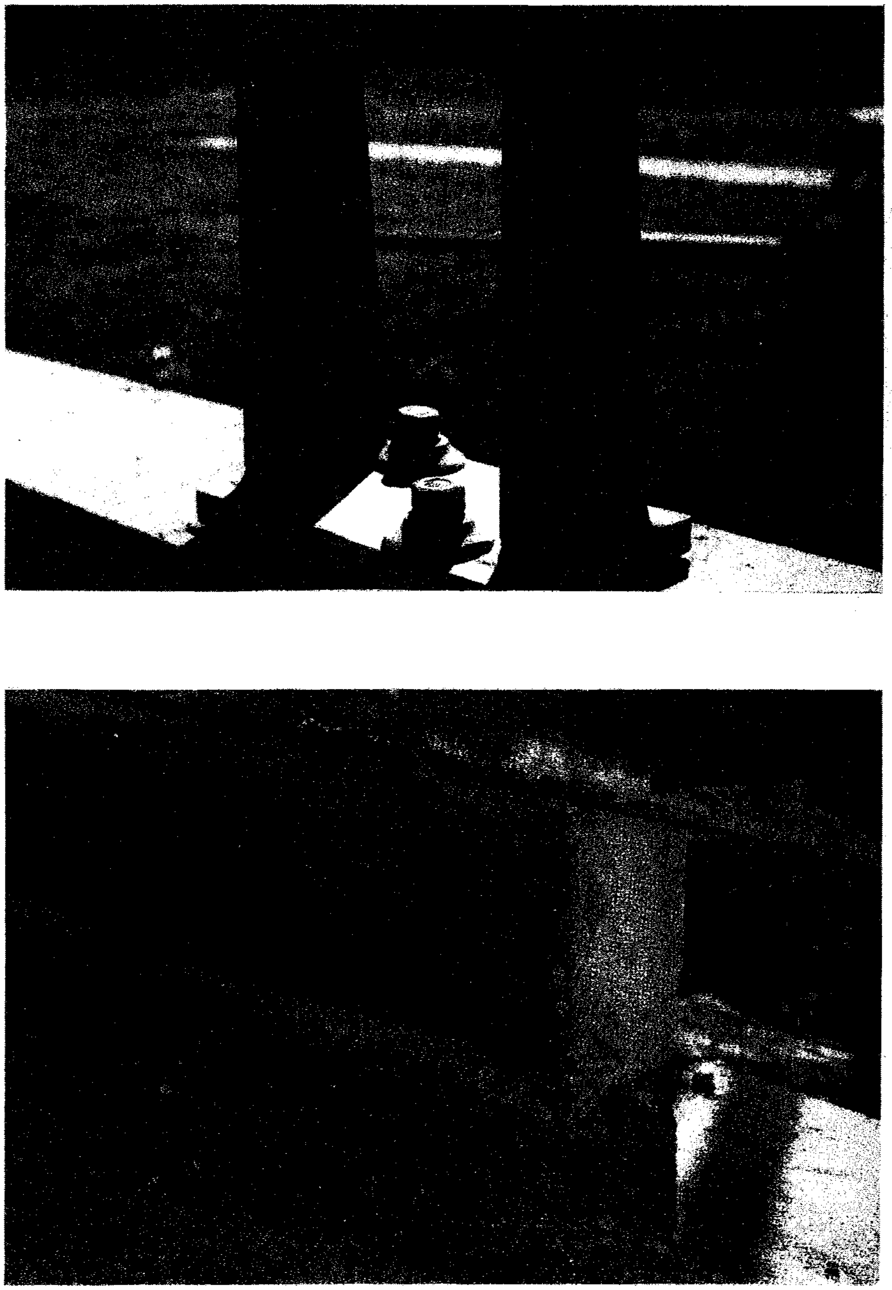
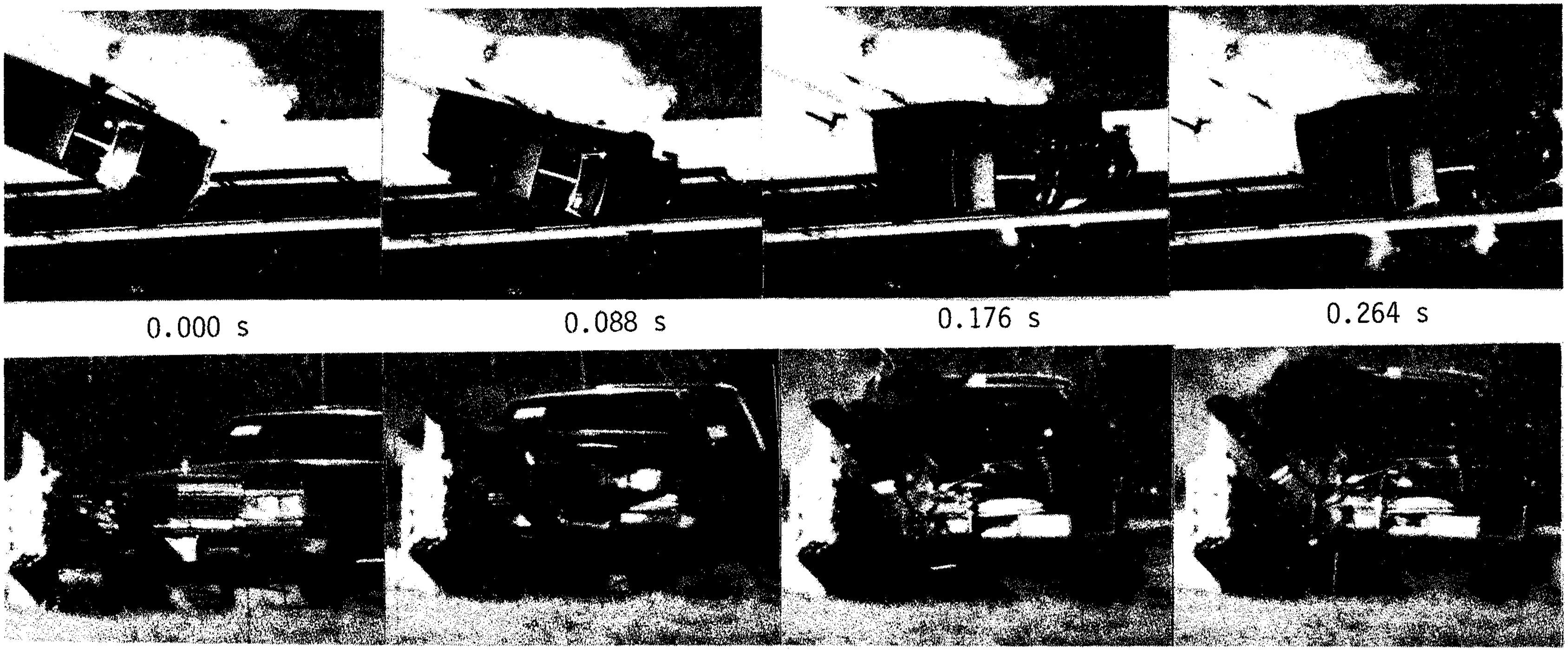


Figure 16. Damage to upper and lower posts after test 1179-2.



Test No	1179-2
Date.	12/01/87
Test Installation	C202 Bridge Rail with C4 Steel Rail
Length of Installation. . . .	101 ft (31 m)
Vehicle	1979 Cadillac
Vehicle Weight	
Test Inertia.	4,400 lb (1,998 kg)
Vehicle Damage Classification	
TAD	01RFQ6
CDC	01RYAS4

Impact Speed	59.4 mi/h (95.6 km/h)
Impact Angle	25.9 deg
Exit Speed	44.5 mi/h (71.6 km/h)
Exit Angle	2.0 deg
Vehicle Accelerations at C.G. (Max. 0.050-sec Avg)	
Longitudinal	-9.7 g
Lateral.	+14.3 g
Occupant Impact Velocity	
Longitudinal	23.9 ft/s (7.3 m/s)
Lateral.	27.3 ft/s (8.3 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-4.9 g
Lateral.	-16.7 g

Figure 17. Summary of results for test 1179-2.

DISCUSSION OF RESULTS

The Honda Civic test was NCHRP Test Designation S13 and the Cadillac test was Test Designation 10. For a beam and post system, NCHRP 230 calls for the impact point to be at mid-span for both tests. However, to determine if the front wheel or hood will contact the posts, NCHRP suggests using a more vulnerable impact location. This was done in these two tests. The impact point was moved 2.0 ft and 2.5 ft respectively further upstream of the mid-span location and the critical post.

The Honda Civic impacted 4.5 ft upstream of the leading edge of the concrete post, and the wheel did contact the post. The damage to the wheel and suspension was moderate, but the wheel was still rolling after impact. The vehicle trajectory was excellent with a departure angle of only 0.6 degrees, and the vehicle would not have returned to the traffic lanes. This test was successful and met the evaluation criteria required by NCHRP Report 230.

The Cadillac impacted 5 ft upstream of the leading edge of the concrete post and 7 ft upstream of the leading edge of the steel post. The Cadillac wheel did contact the concrete post and the damage to the wheel and suspension was moderate. The wheel was still rolling after impact, and the vehicle trajectory was good with a departure angle of only 2.0 degrees. The hood contacted the steel post and was severely damaged. The hood pushed the right front windshield inward several inches but it did not penetrate or intrude into the passenger compartment. Consequently, the Cadillac test is judged successful.

Late model vehicles in the 4,500 lb class are very difficult to obtain. This was a 1979 model with a very large hood which protruded 16 in. over the top of the concrete parapet. Similar vehicles (1977 Plymouths) used in tests reported in reference (9) had hoods which protruded 14 in. (Test OBR-2) and 12 in. (Test NCBR-2) over the bridge rails. Such vehicles are not representative of modern passenger cars which have much smaller and different shaped hoods. The older passenger car hoods extended to within one or two inches of the outside edge of the car. Modern smaller hoods terminate six to eight inches inside the outside car edge and are usually shielded by the fenders. A classic example of this is the 1,800 lb Honda Civic used in NCHRP 230 Test No. S13 (see Figure 6). Hood contact with posts have never been observed in tests with this vehicle.

NCHRP Report No. 230 recommends that for longitudinal barriers, the impact position should be midway between the posts. In this study the impact positions were selected to be as severe as possible. This was done in order to provide test data on railing geometrics that would help refine the railing geometrics design guidelines that were presented in reference 8.

Other crash test agencies have almost never moved the impact point far enough upstream of the leading edge of the posts to permit maximum underride of the wheel or override of the hood to achieve this level of interaction (see reference 9). The vehicle and barrier met the evaluation criteria required by NCHRP Report 230.

SUMMARY AND CONCLUSIONS

A standard Texas traffic rail type C202 was modified by increasing its height and strengthened so that it could restrain and redirect an 80,000 lb van type truck or tractor-trailer. The modified C202 rail consisted of a concrete beam element 13 in. (33 cm) wide and 23 in. (58 cm) deep, mounted 36 in. (91 cm) high on concrete posts located at 10 ft (3.0 m) center-to-center spacing. The concrete posts were 7 in. (19 cm) thick by 5 ft (1.5 m) long concrete walls with 5 ft (1.5 m) openings between each post. To increase the effective height of the bridge rail, a standard type C4 steel rail was mounted on top of the concrete rail.

As reported in Research Report 230-4F (1), a crash test was conducted on this bridge rail with a 79,770 lb (36,184 kg) van type tractor-trailer impacting the rail at 49.1 mph (79.0 km/h) and 15^{o}. The vehicle was smoothly redirected. Damage to the truck and rail was moderate.

This high performance bridge rail has now been successfully crash tested with a 1,918 lb car at 61.3 mph and 21^{o} angle and also with a 4,400 lb car at 59.4 mph and 25.9^{o} angle. The results of both tests met the evaluation criteria in NCHRP Report No. 230. The test with the Cadillac sedan was more critical than a test with a 5,400 lb pickup truck at 60 mph and 20 deg. Therefore, the barrier is also considered to meet the requirements for performance level 3 (PL-3) in the new AASHTO Guide Specifications for Bridge Railings (10).

For new construction, consideration should be given to forming a 2 in. chamfer on the traffic side edge of the post. This will further reduce the potential for wheel snagging on the posts.

REFERENCES

1. Hirsch, T. J., and A. Arnold, "Bridge Rail to Restrain and Redirect 80,000 lb Trucks," Research Report 230-4F, Texas Transportation Institute, Texas A&M University, Aug. 1981.

2. Hirsch, T. J., "Analytical Evaluation of Texas Bridge Rails to Contain Buses and Trucks," Research Report 230-2, Texas Transportation Institute, Texas A&M University, Aug. 1978.

3. Hirsch, T. J., "Bridge Rail to Restrain and Redirect Buses," Research Report 230-3, Texas Transportation Institute, Texas A&M University, Feb. 1981.

4. Michie, Jarvis D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, Transportation Research Board, National Research Council, Washington, D.C., Mar. 1981.

5. Standard Specifications for Highway Bridges, Twelfth Edition, American Association of State Highway and Transportation Officials, Washington, D.C., 1977.

6. Hirsch, T. J., and E. R. Post, "Truck Tests on Texas Concrete Median Barrier," Research Report 146-7, Texas Transportation Institute, Texas A&M University, Dec. 1972.

7. "Tentative Service Requirements for Bridge Rail Systems," NCHRP Report 86, Washington, D.C., 1970.

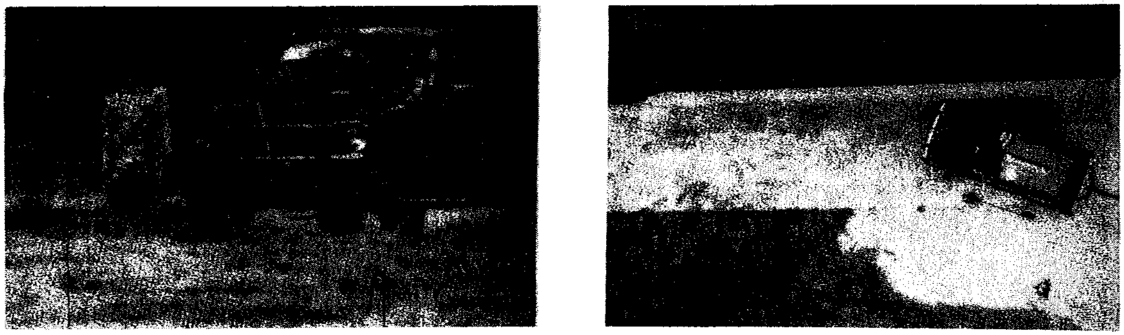
8. Buth, C. E., "Safer Bridge Railings," Vol. 1, 2, 3, and 4, Report No. FHWA/RD-82-072, Texas Transportation Institute, Texas A&M University, June 1984.

9. Bronstad, M. E., et al., "Bridge Rail Designs and Performance Standards," Volume I: Research Report, Report No. FHWA/RD-87/049, February 1987.

10. "Guide Specifications for Bridge Railings - An Alternative Bridge Railing Specification in the AASHTO Standard Specifications for Highway Bridges," American Association of State Highway Officials, 1988.

APPENDIX A

SEQUENTIAL PHOTOGRAPHS OF TEST 1179-1



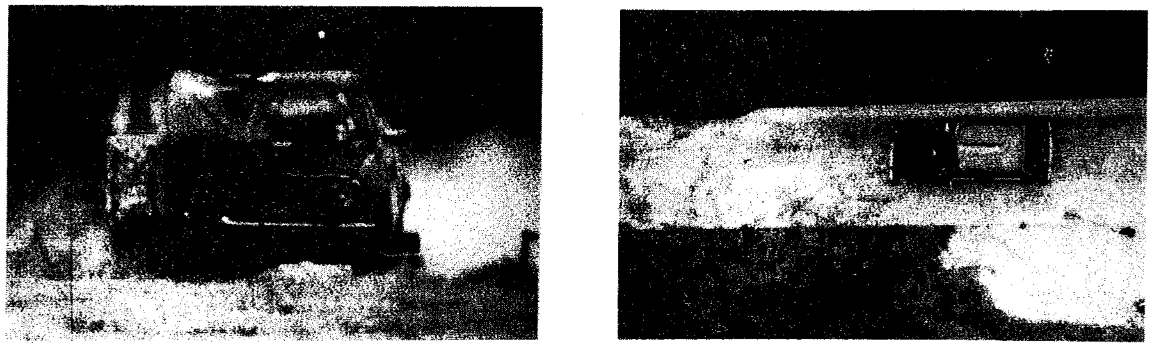
0.000 s

0.032 s

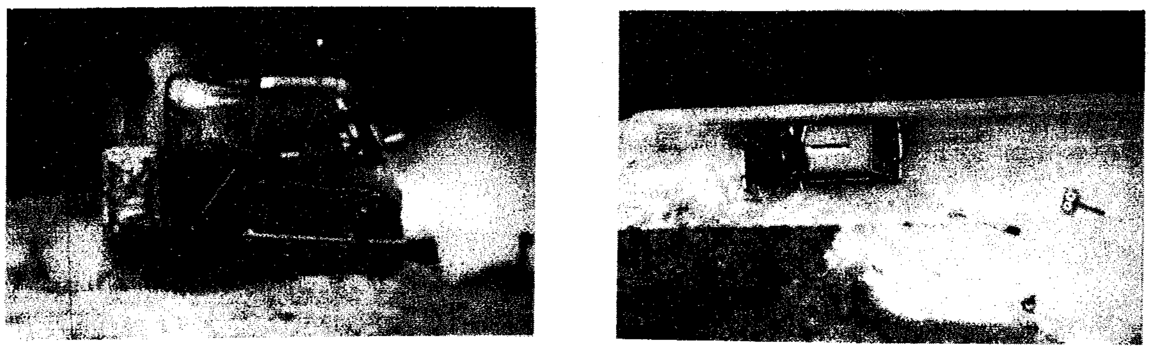
0.064 s

0.096 s

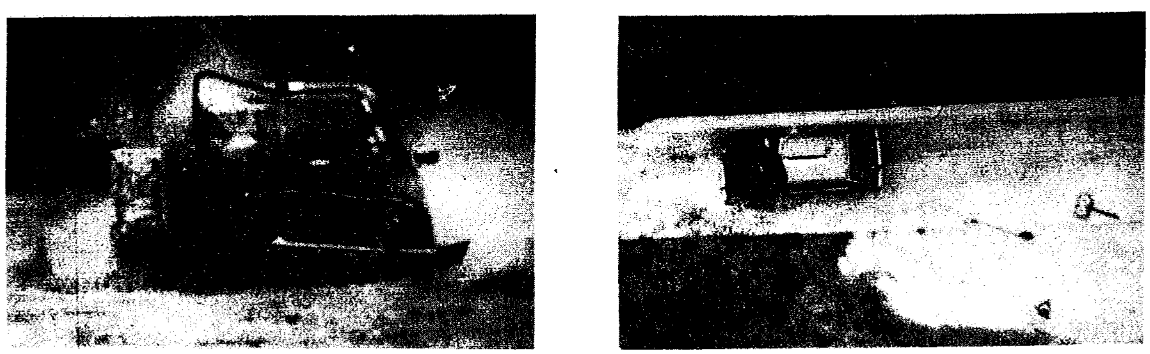
Figure A1. Sequential photographs for test 1179-1.



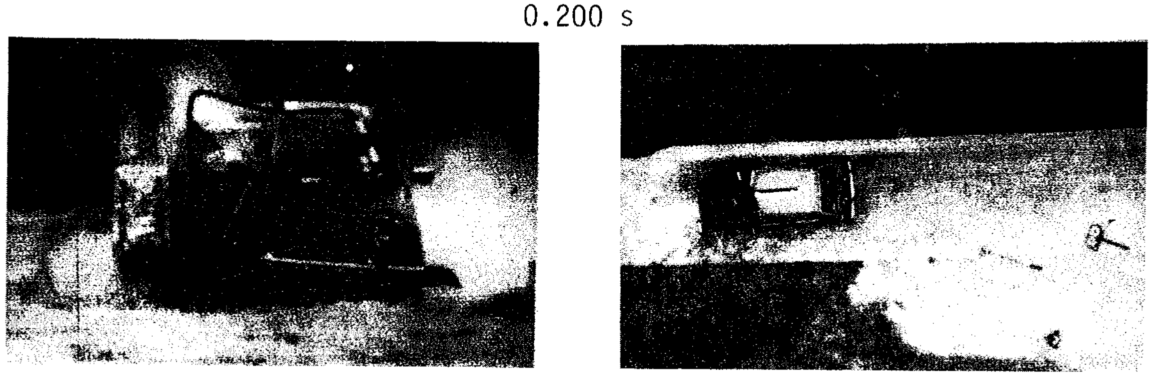
0.131 s



0.165 s

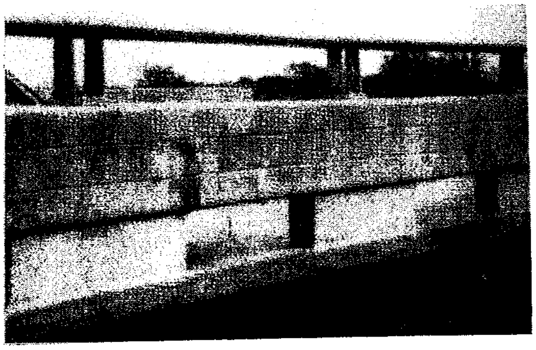


0.200 s

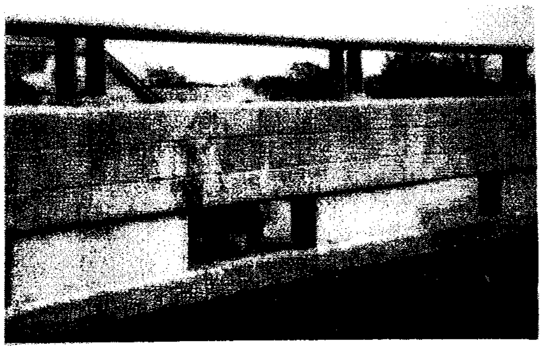


0.237 s

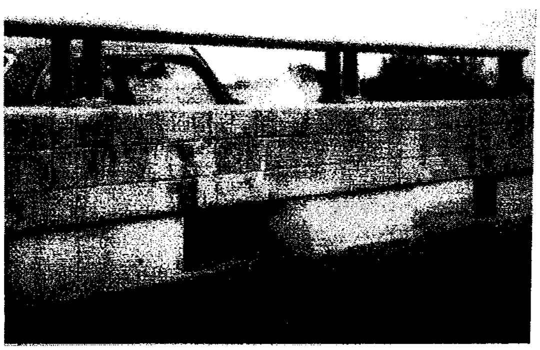
Figure A1. Sequential photographs for test 1179-1. (Continued)



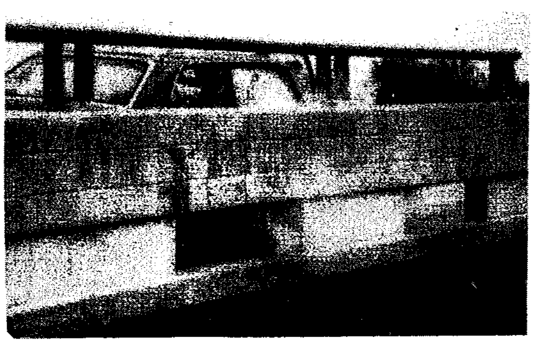
0.000 s



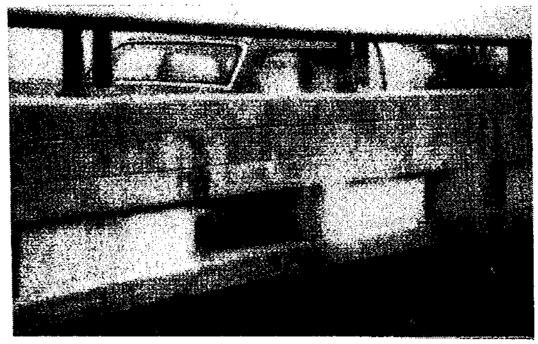
0.032 s



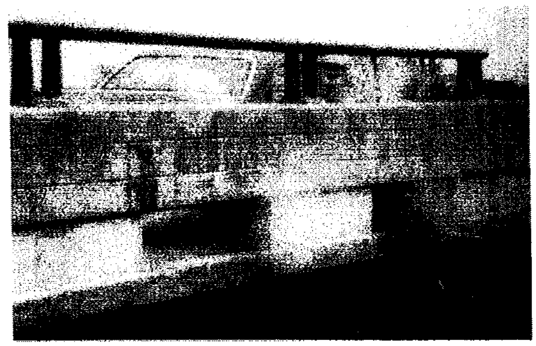
0.064 s



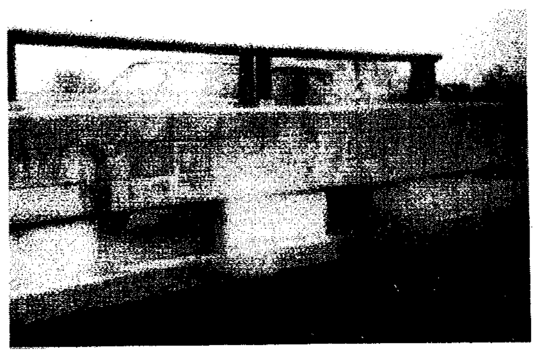
0.096 s



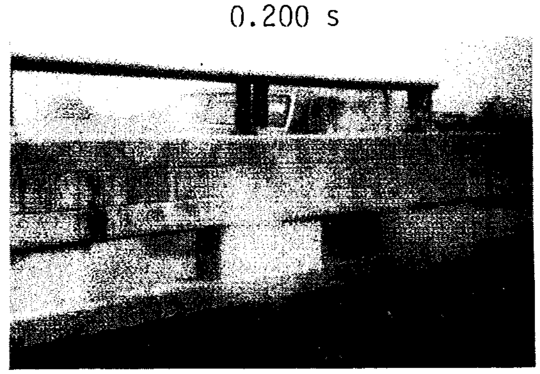
0.131 s



0.165 s



0.200 s

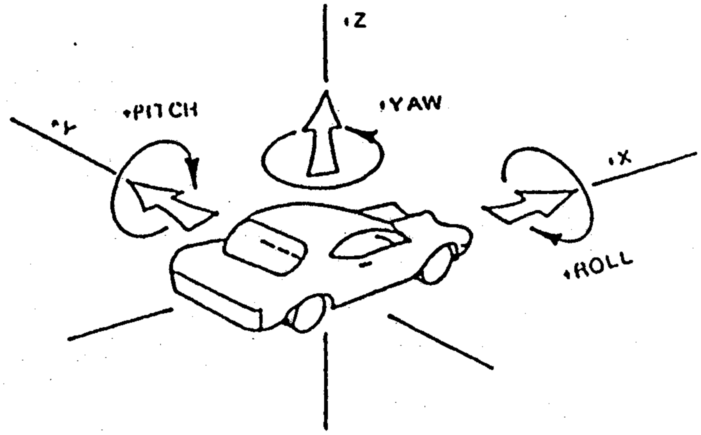


0.237 s

Figure A1. Sequential photographs for test 1179-1. (Continued)

APPENDIX B

ELECTRONIC ACCELEROMETER, ROLL, PITCH, AND YAW DATA TEST 1179-1



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

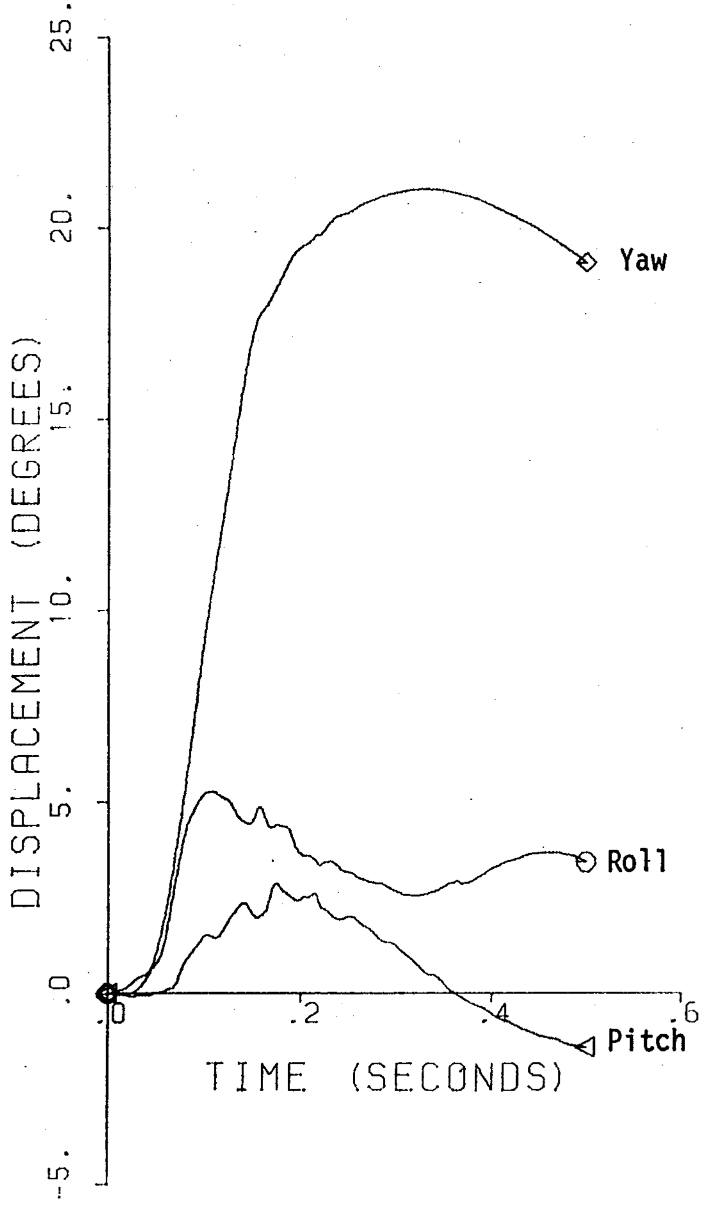


Figure B1. Vehicle angular displacements for test 1179-1.

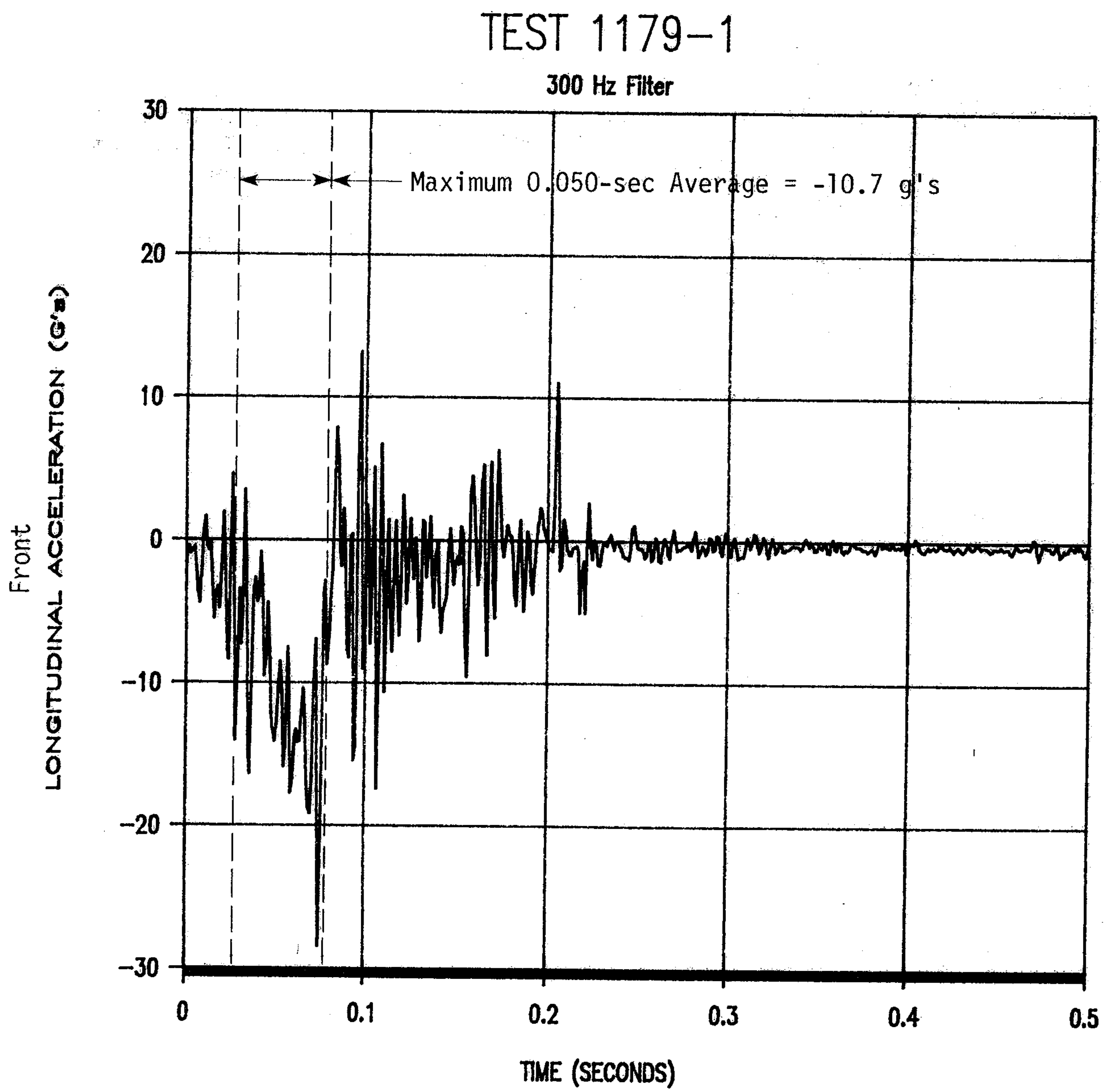


Figure B2. Front Longitudinal Accelerometer Trace for Test 1179-1.

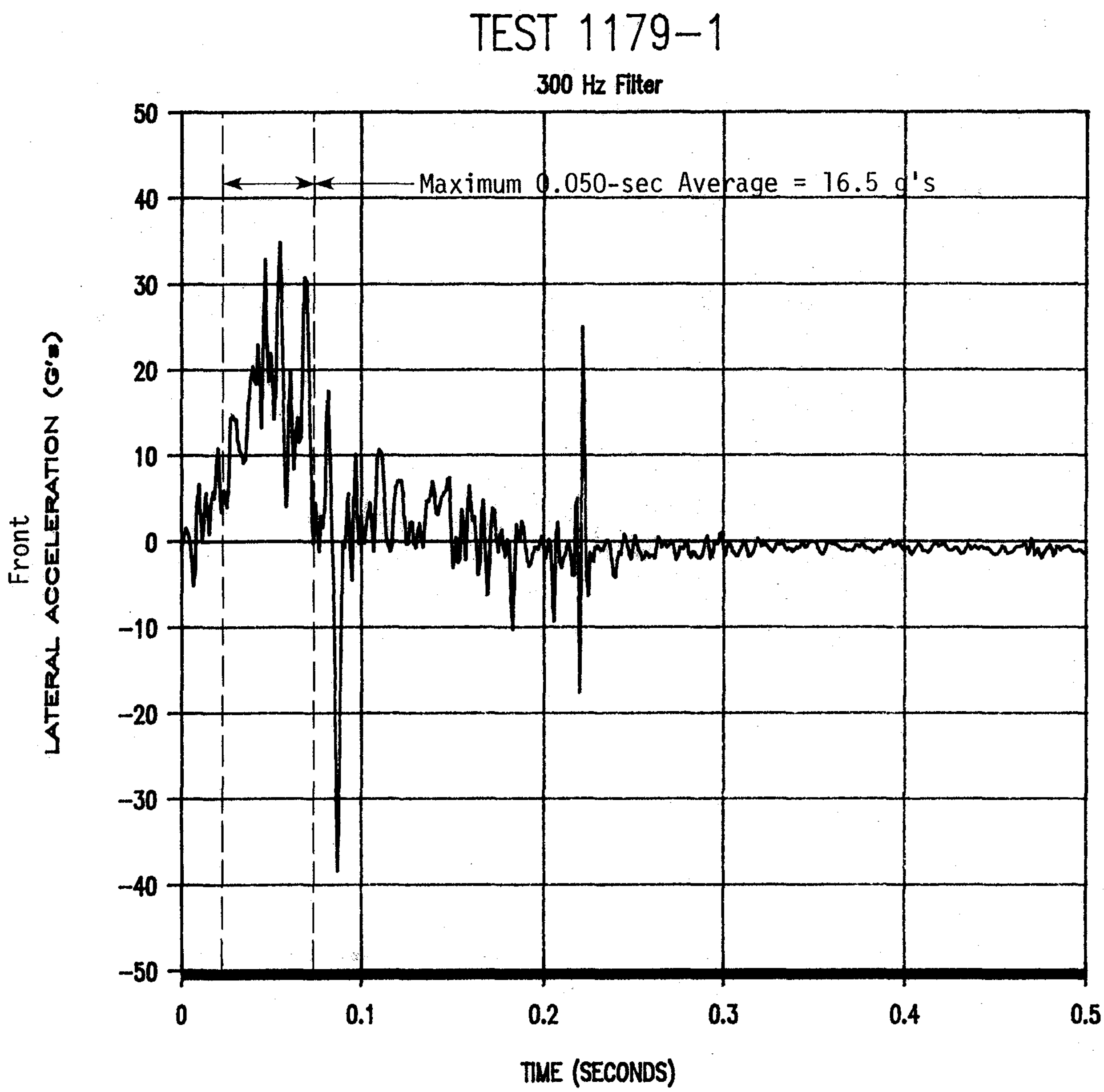


Figure B3. Front Lateral Accelerometer Trace for Test 1179-1.

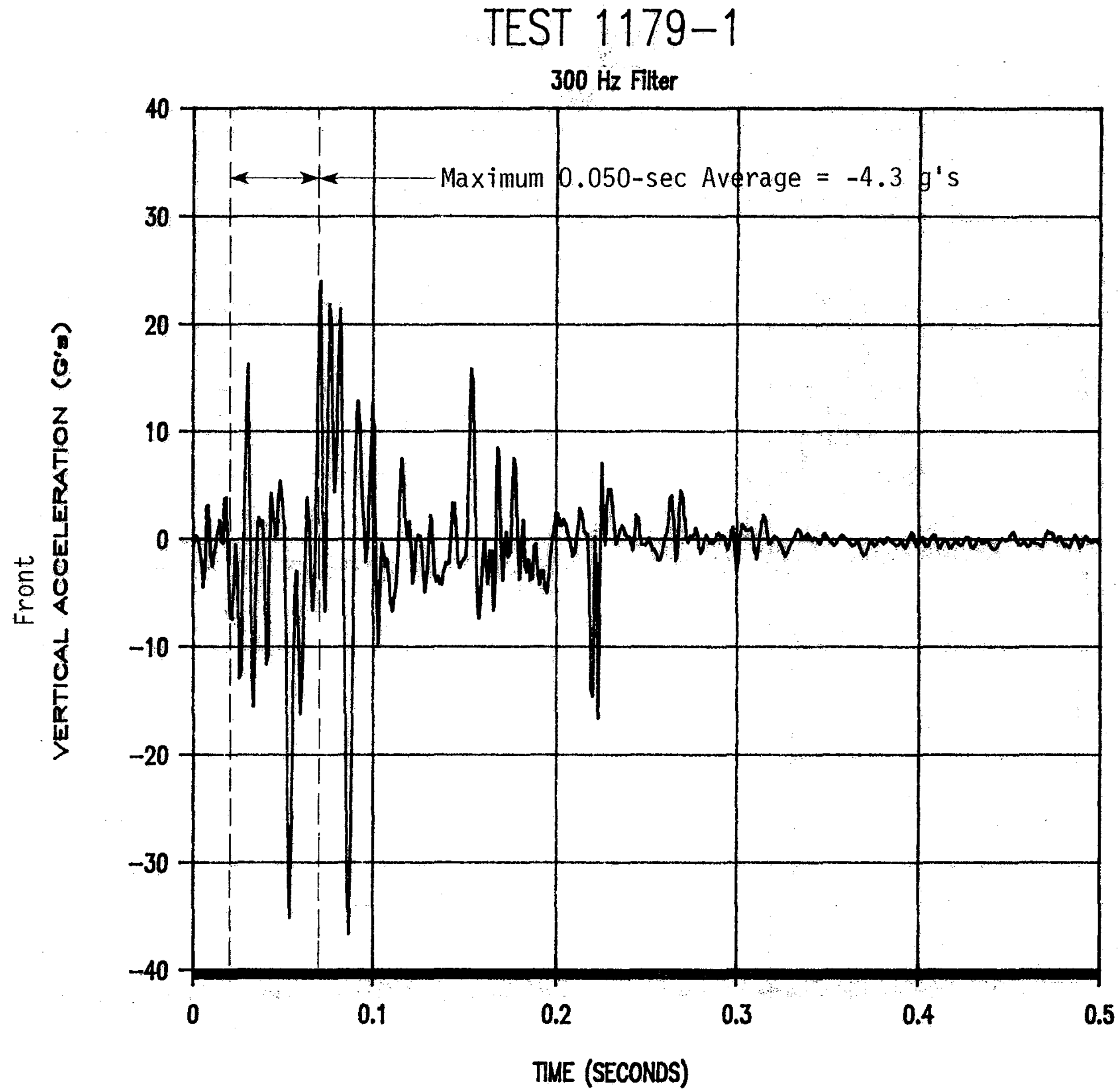


Figure B4. Front Vertical Accelerometer Trace for Test 1179-1.

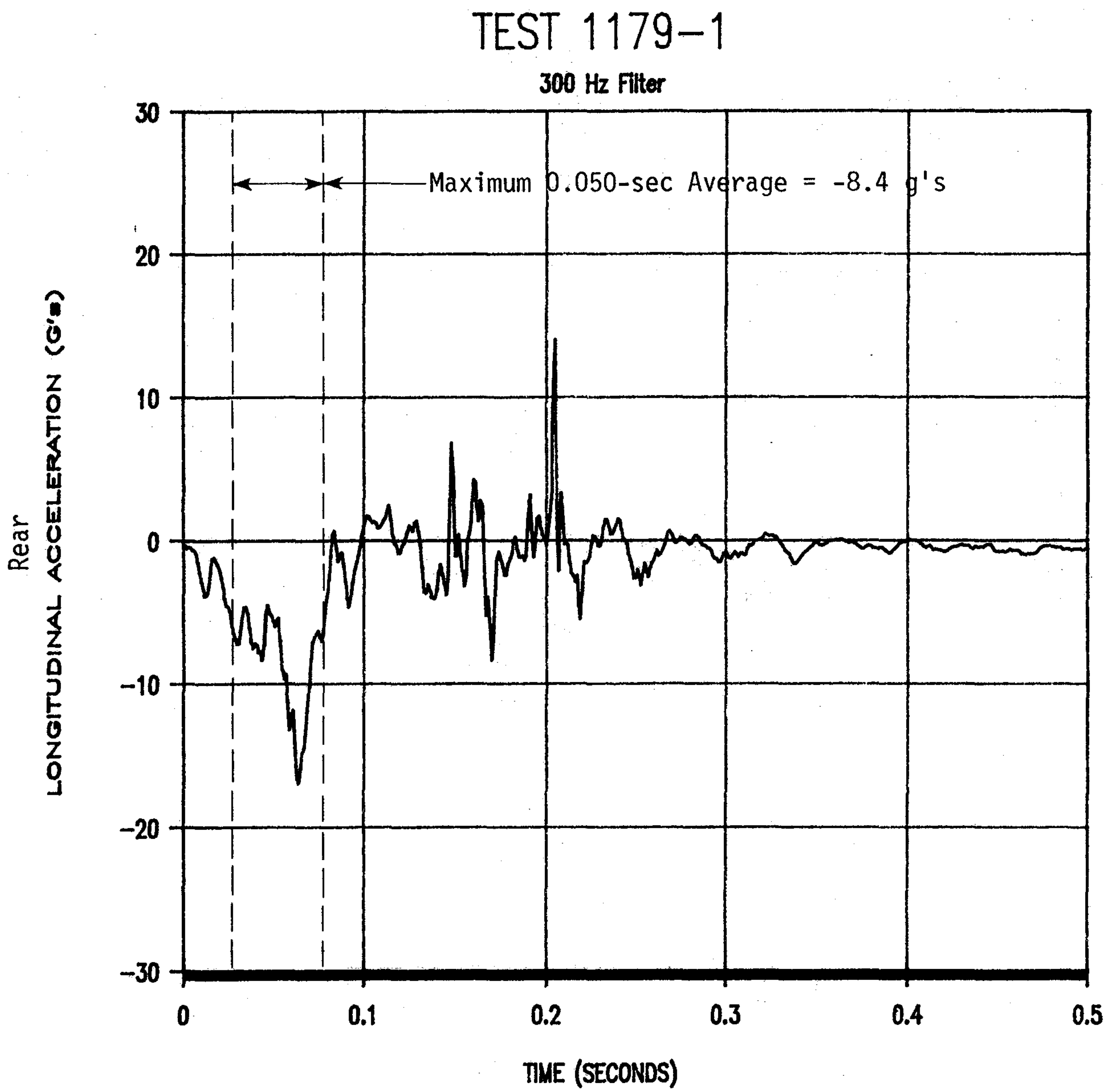


Figure B5. Rear Longitudinal Accelerometer Trace for Test 1179-1.

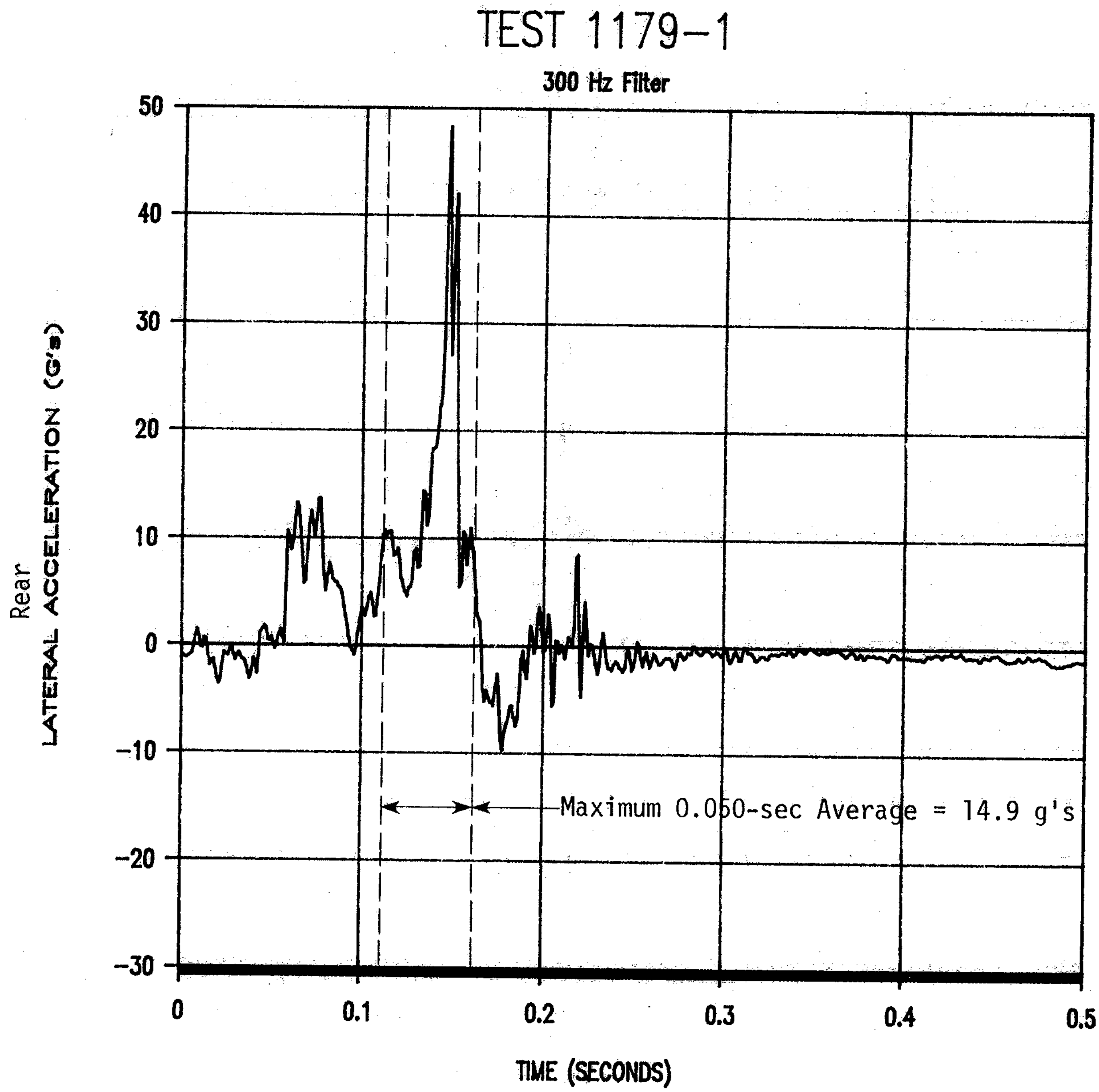


Figure B6. Rear Lateral Accelerometer Trace for Test 1179-1.

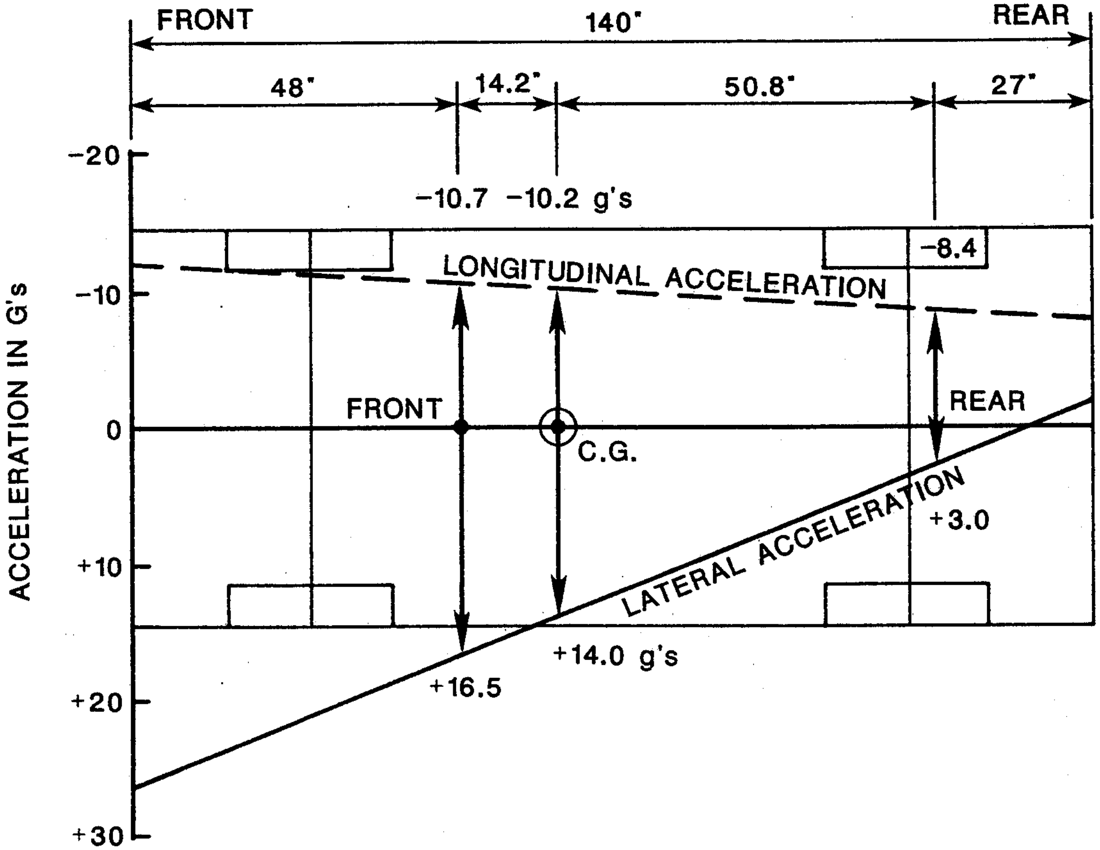
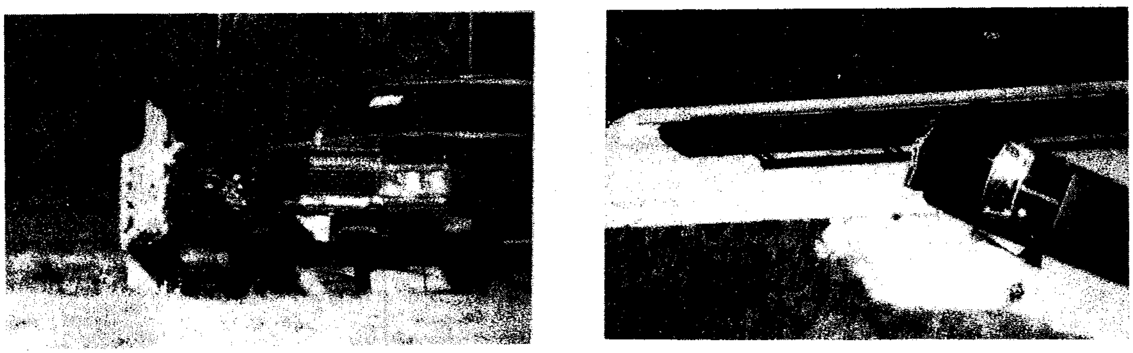


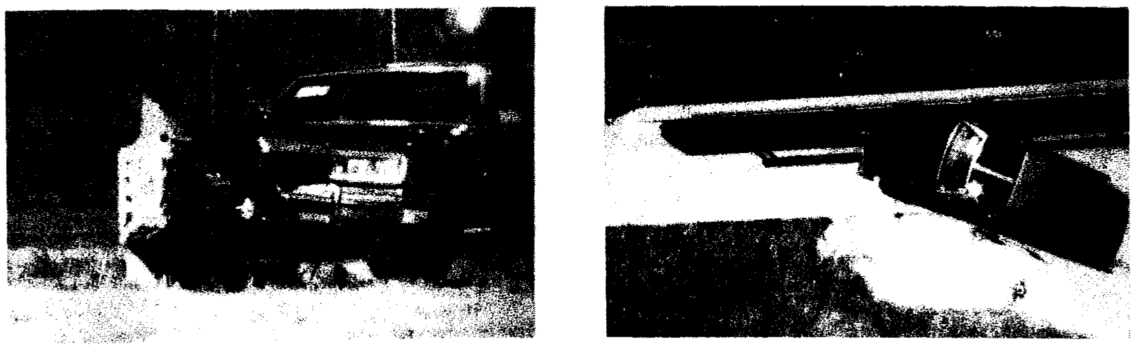
Figure B7. Test 1179-1 Graph of Max. 0.050 sec. Average Acceleration Along Vehicle Length at 0.050 sec. after Impact

APPENDIX C

SEQUENTIAL PHOTOGRAPHS OF TEST 1179-2

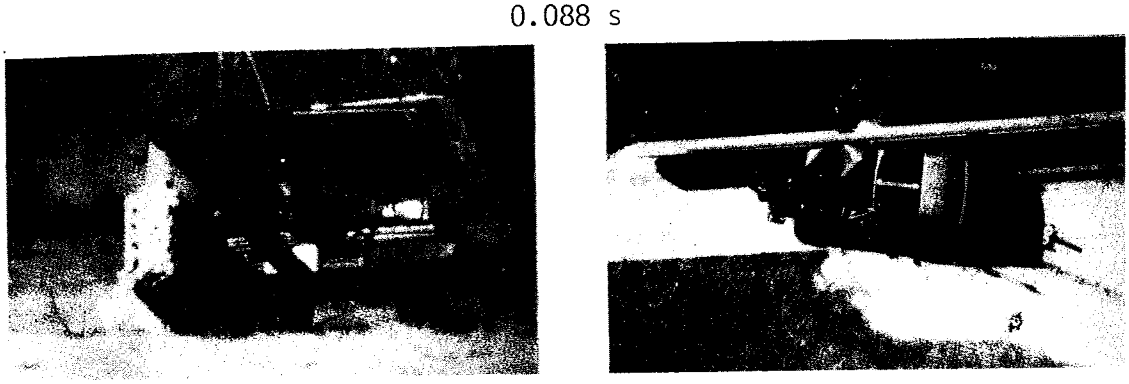


0.000 s



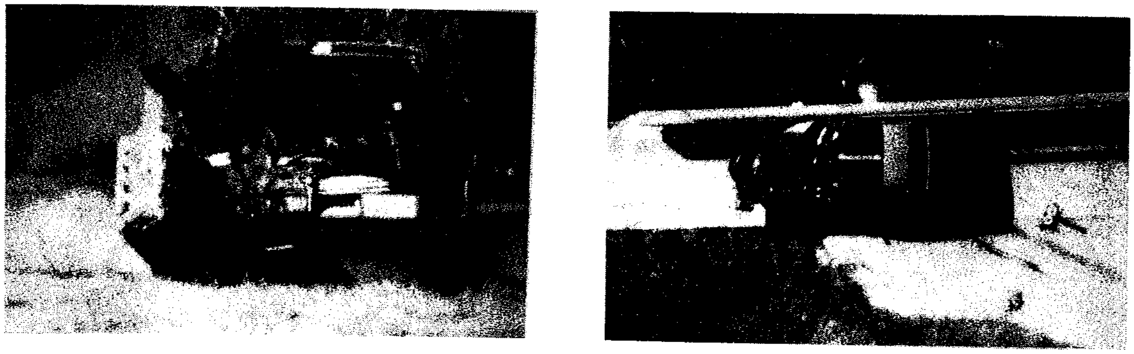
0.044 s

0.088 s



0.132 s

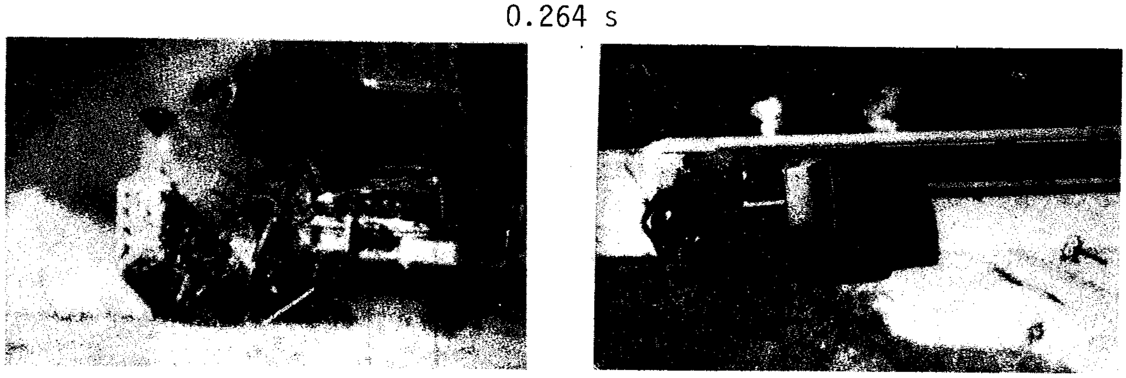
Figure C1. Sequential photographs for test 1179-2.



0.176 s

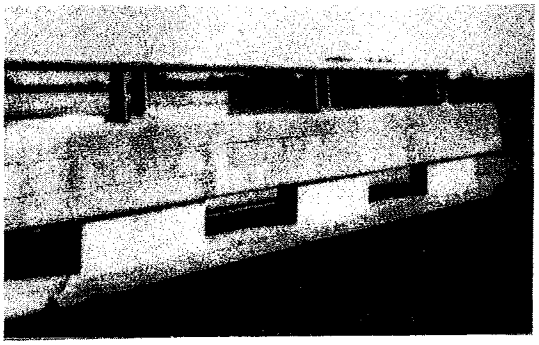
0.220 s

0.264 s

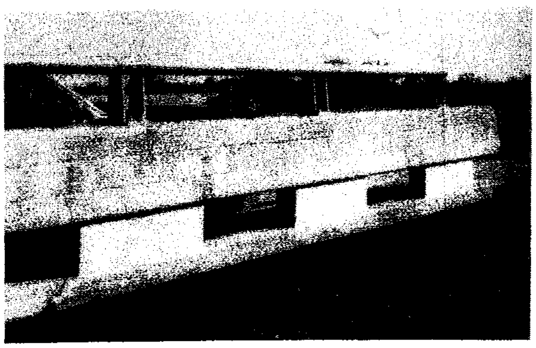


0.305 s

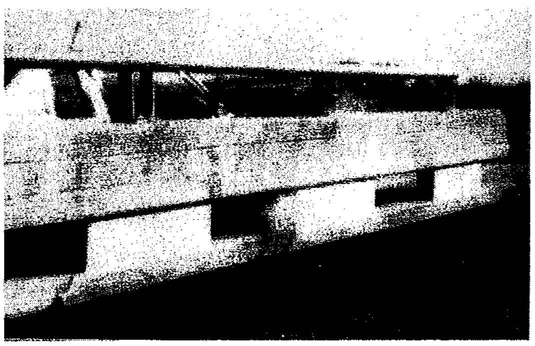
Figure C1. Sequential photographs for test 1179-2.
(Continued)



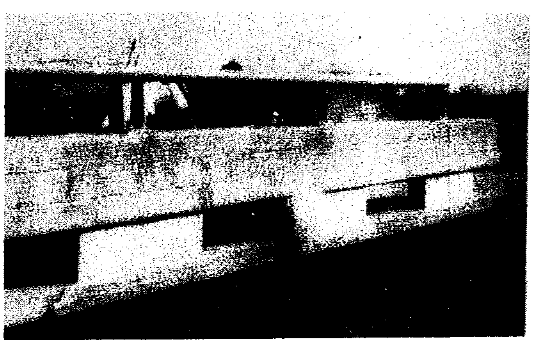
0.000 s



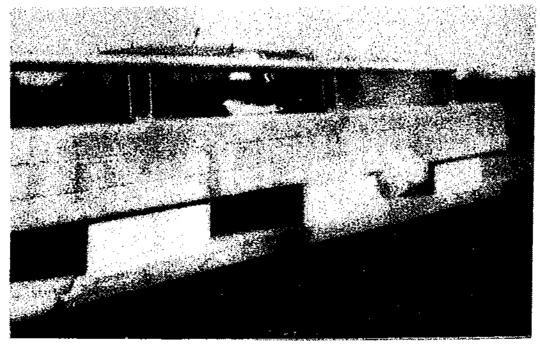
0.044 s



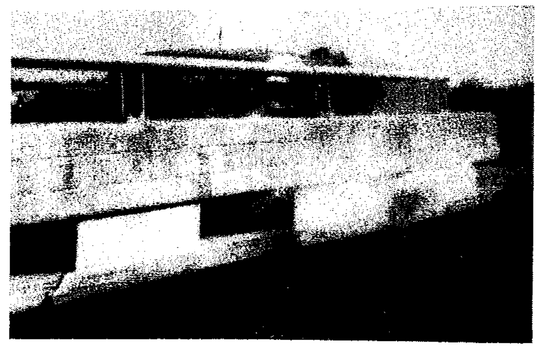
0.088 s



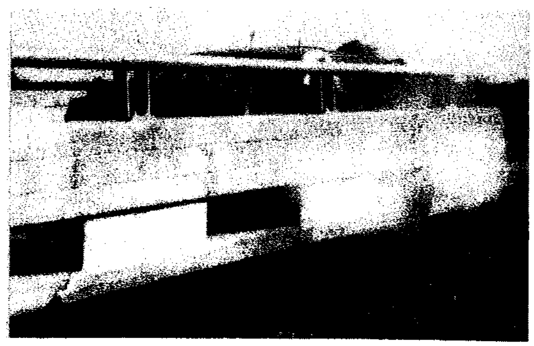
0.132 s



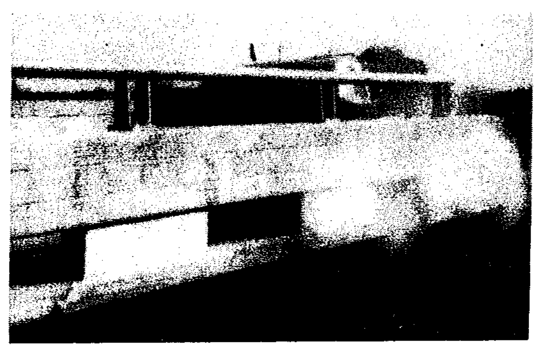
0.176 s



0.220 s



0.264 s

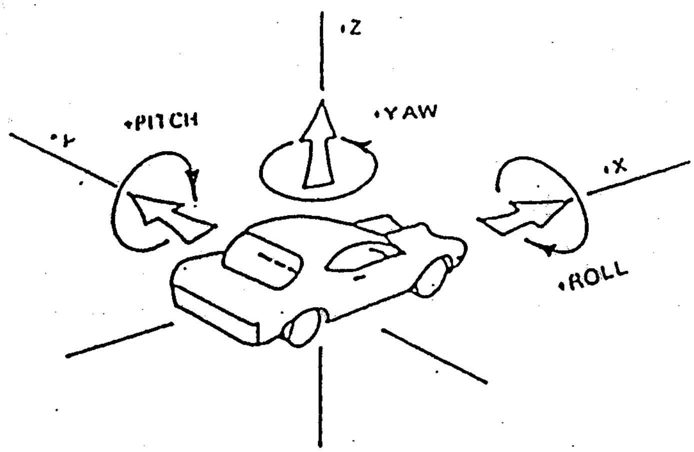


0.305 s

Figure C1. Sequential photographs for test 1179-2. (Continued)

APPENDIX D

ELECTRONIC ACCELEROMETER, ROLL, PITCH, AND YAW DATA TEST 1179-2



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

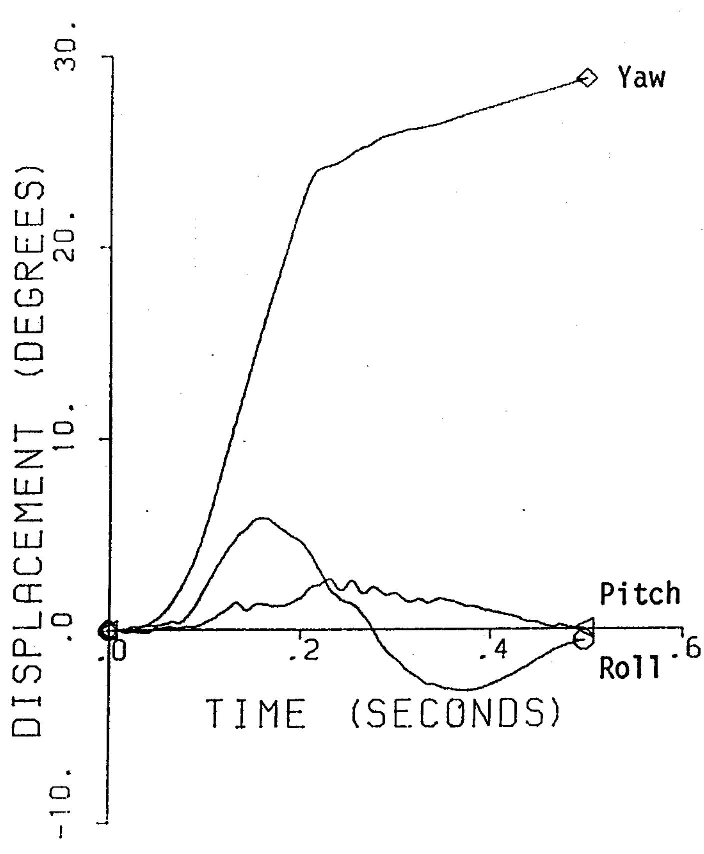


Figure D1. Vehicle angular displacements for test 1179-2.

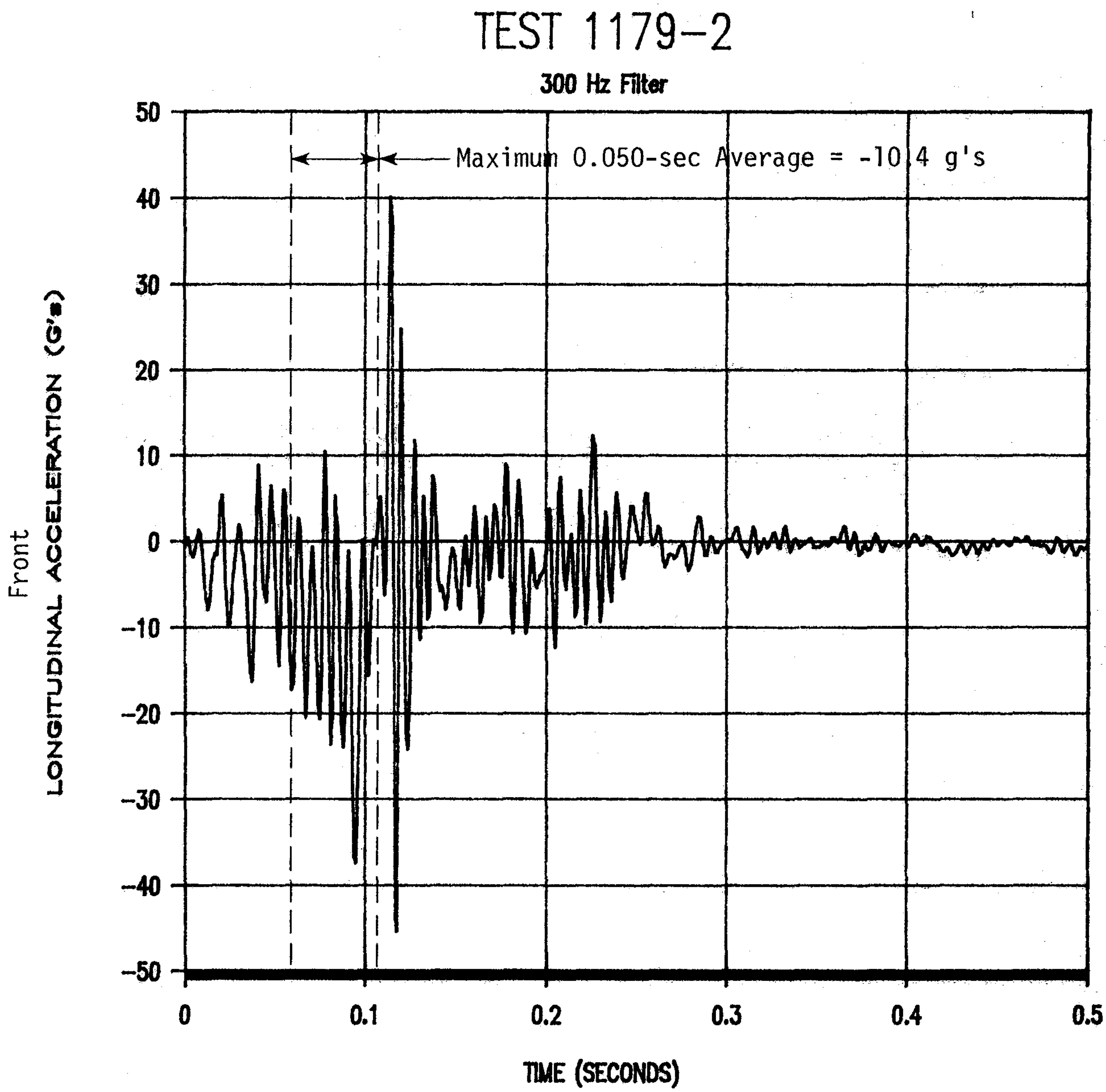


Figure D2. Front Longitudinal Accelerometer Trace for Test 1179-2.

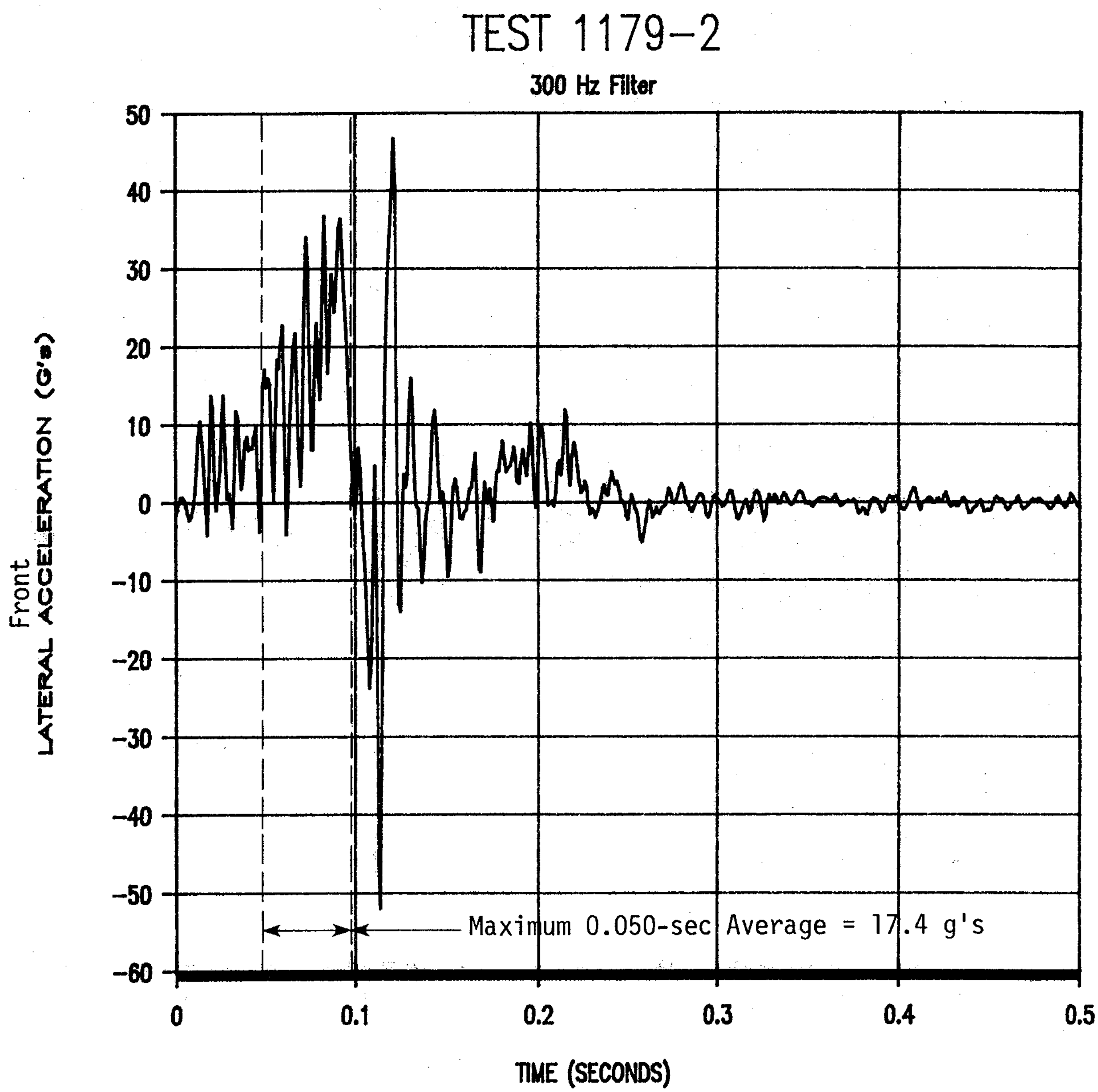


Figure D3. Front Lateral Accelerometer Trace for Test 1179-2.

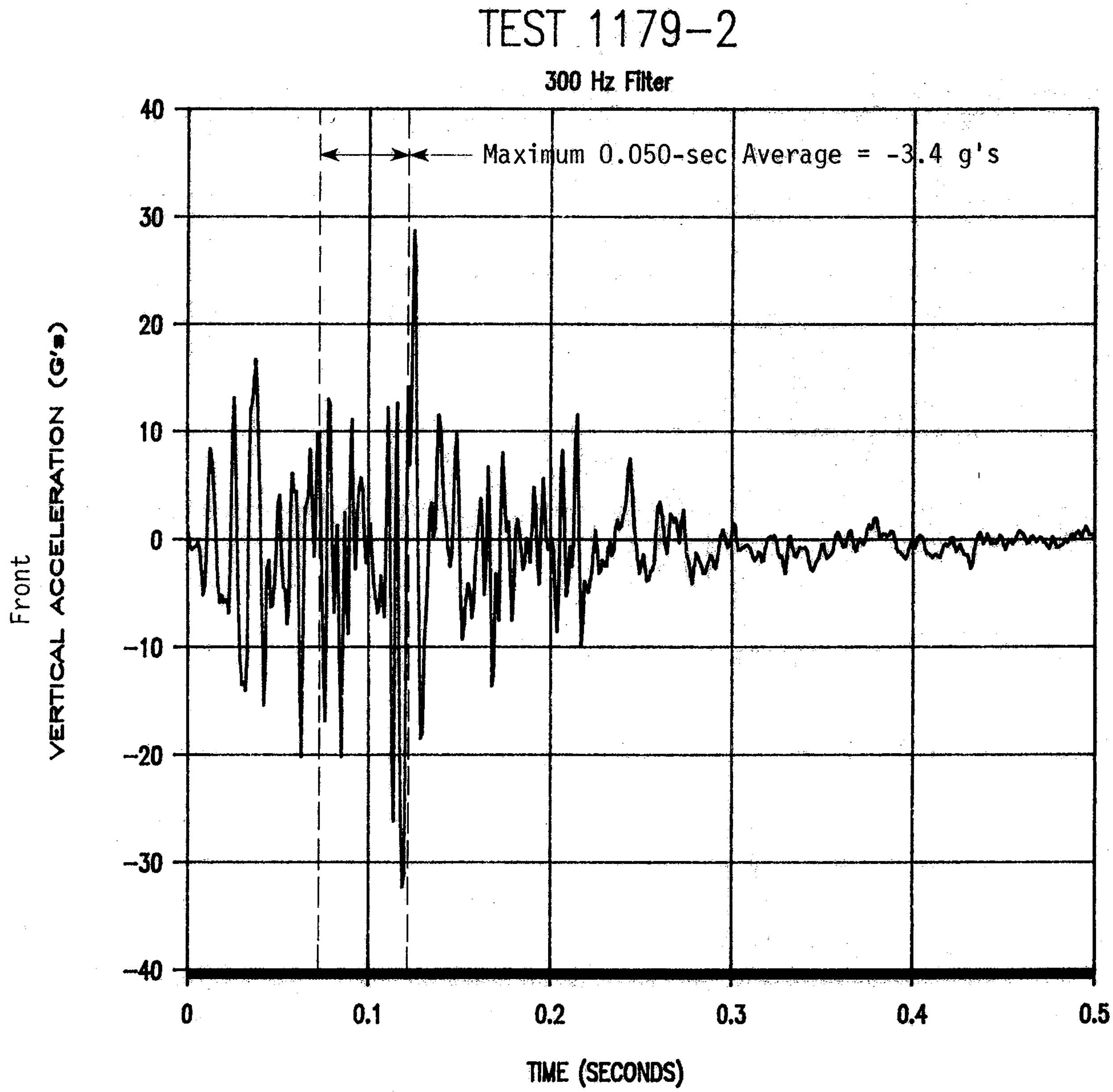


Figure D4. Front Vertical Accelerometer Trace for Test 1179-2.

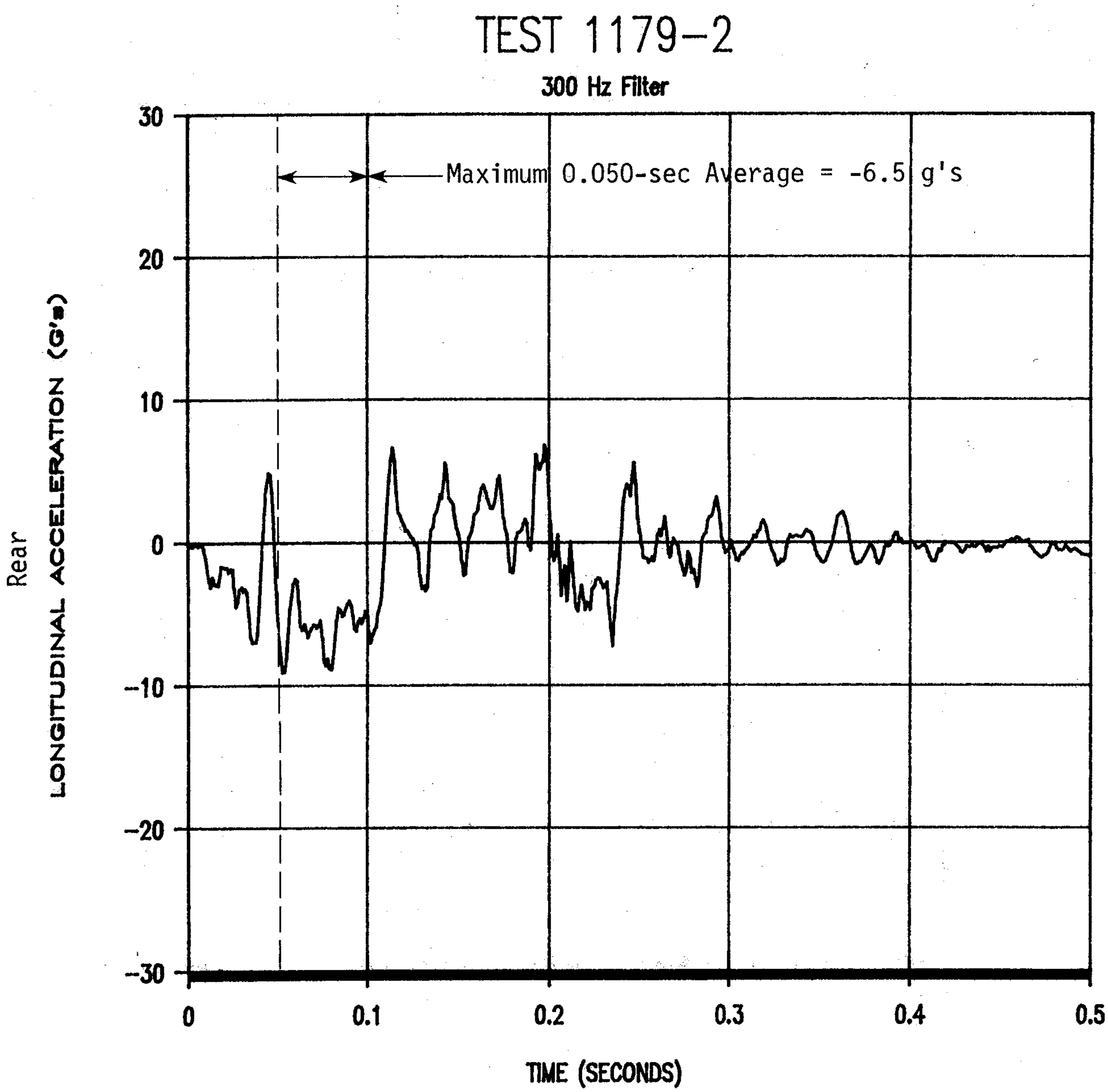


Figure D5. Rear Longitudinal Accelerometer Trace for Test 1179-2.

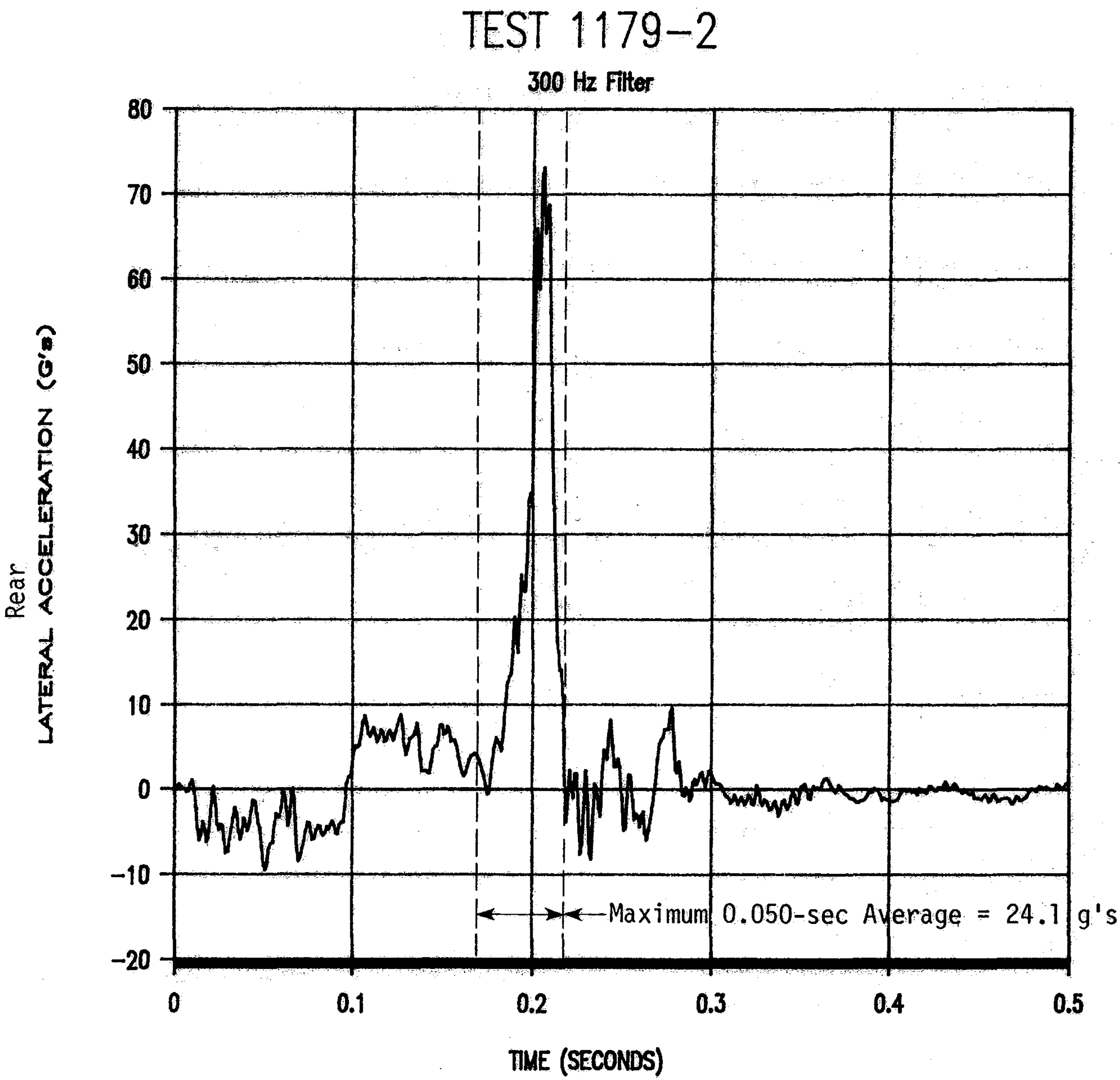


Figure D6. Rear Lateral Accelerometer Trace for Test 1179-2.

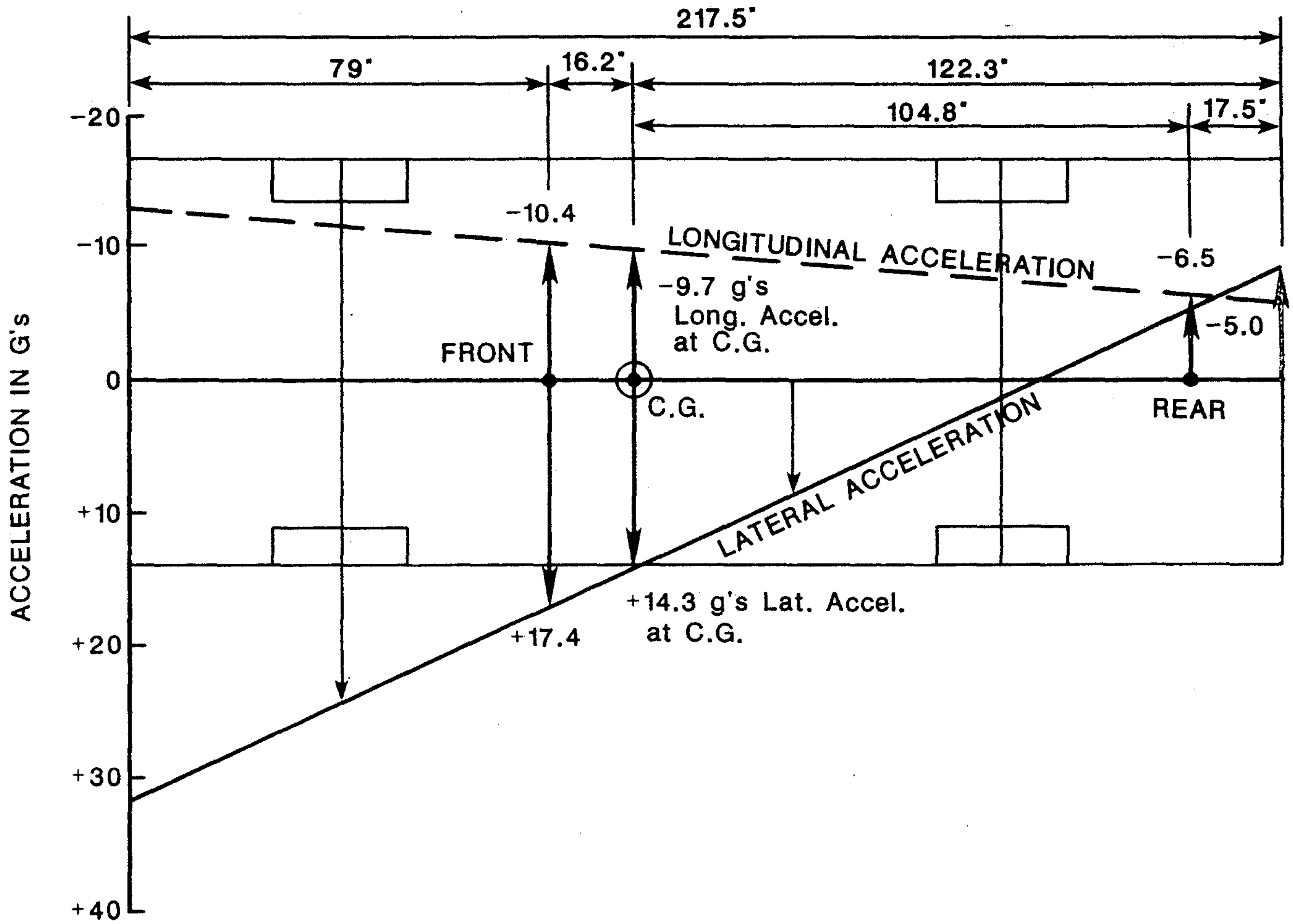


Figure D7. Test 1179-2 Graph of Max. 0.050 sec. Average Acceleration Along Vehicle Length at 0.075 sec. after Impact