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16. Abstract

Research has developed railings to withstand impact loads from vehicles of ever-increasing size; however aesthetic considerations have been overshadowed by safety and structural requirements. The objective of this research study was to develop aesthetically pleasing, structurally sound railings that can serve as alternative railings in city or urban areas.

This report presents a new steel pipe bridge rail--Texas Type T421. This bridge rail is constructed of 5-in.-diameter steel pipe posts with a 5-in.-diameter steel pipe top rail 32 in. high and a 10-in.-diameter steel pipe lower rail.

The bridge rail was crash-tested and evaluated in accordance with NCHRP Report 230 for Service Level 2. Two crash tests were required--a 4,500 lb passenger car at 60 mph and 25^{o} impact angle and an 1,800 lb passenger car at 60 mph and 20^{o} impact angle.

In both tests the bridge rail contained and redirected the test vehicle. There were no detached elements or debris to present undue hazard to other traffic. The vehicle remained upright and relatively stable during the collision. The occupant/compartment impact velocities and 10-ms occupant ridedown accelerations were within the limits recommended in NCHRP Report 230. The vehicle trajectory at loss of contact indicates no intrusion into adjacent traffic lanes (exit angles of 5^{o} and 7.6^{o}).

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AESTHETICALLY PLEASING STEEL PIPE BRIDGE RAIL - TEXAS TYPE T421

by

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Research Report 1185-2

on

Research Study No. 2-5-88/89-1185
Aesthetically Pleasing Bridge Rails

Sponsored by

Texas State Department of Highways and Public Transportation

in cooperation with

The U.S. Department of Transportation
Federal Highway Administration

May 1990

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

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

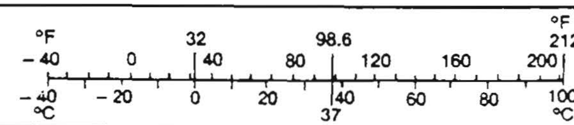
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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, 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 (Design Engineer, SDHPT), John J. Panak (Bridge Design Engineer, SDHPT), and Van M. McElroy (Supervising Bridge Engineer, SDHPT, Dallas) 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

Research has developed railings to withstand impact loads from vehicles of ever-increasing size; however aesthetic considerations have been overshadowed by safety and structural requirements. The objective of this research study was to develop aesthetically pleasing, structurally sound railings that can serve as alternative railings in city or urban areas.

This report presents a new steel pipe bridge rail--Texas Type T421. This bridge rail is constructed of 5-in.-diameter steel pipe posts with a 5-in.-diameter steel pipe top rail 32 in. high and a 10-in.-diameter steel pipe lower rail.

The bridge rail was crash-tested and evaluated in accordance with NCHRP Report 230. Two crash tests were required--a 4,500 lb passenger car at 60 mph and 25 degree impact angle and an 1,800 lb passenger car at 60 mph and 20 degree impact angle.

In both tests the bridge rail contained and redirected the test vehicle. There were no detached elements or debris to present undue hazard to other traffic. The vehicle remained upright and relatively stable during the collision. The occupant/compartment impact velocities and 10-ms occupant ridedown accelerations were within normally accepted limits. The vehicle trajectory at loss of contact indicates no intrusion into adjacent traffic lanes (exit angles of 5 degrees and 7.6 degrees).

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INTRODUCTION

Research has developed railings to withstand impact loads from vehicles of ever-increasing size; however aesthetic considerations have been overshadowed by safety and structural requirements. Engineers often fail to recognize the impact of our structures on the landscape, particularly in city or urban areas. Architects and developers often propose aesthetically pleasing railings that engineers cannot accept because of structural inadequacies. The objective of this research study was to develop aesthetically pleasing, structurally sound railings that can serve as alternative railings.

This study is attempting to develop one or more new concrete, steel, and aluminum railings or combination railings, some with curb and sidewalk.

This report presents a new steel pipe bridge rail--Texas Type T421. The research study advisory committee composed of

Luis Ybanez, Bridge Engineer, Bridge Division, Austin,
John J. Panak, Bridge Design Engineer, Bridge Division, Austin,
Dean Van Landuyt, Design Engineer, Bridge Division, Austin,
Van M. McElroy, Supervising Bridge Engineer, District 18, Dallas,
John V. Blain, Jr., District Design Engineer, District 18, Dallas,
John P. Kelley, Supervising Design Engineer, District 18, Dallas,
Don Simpson, Architect, Hellmuth, Obata, Kassabaum, Inc.,
Dave Retzsch, Architect, Hellmuth, Obata, Kassabaum, Inc.,
T. J. Hirsch, Research Engineer, TTI, and
W. Lynn Beason, Associate Research Engineer, TTI,

reviewed design sketches of twenty-two different bridge rail designs before selecting the new Texas Type T421 as its second priority.

DESCRIPTION OF BRIDGE RAIL
TEXAS TYPE T421

This bridge rail is constructed of standard steel pipe 5 in. and 10 in. in diameter. Figure 1 shows photographs of the steel pipe bridge rail installed on a typical simulated 8-in.-thick concrete bridge deck. Figures 2 and 3a show a cross section and side elevation of the T421 bridge rail. The top rail was 32 in. high and used 5-in.-diameter standard steel pipe. The lower rail uses 10-in.-diameter standard steel pipe. The 5-in.-diameter posts are sloping at a 10-degree angle so that the traffic side or face of the two rails is a vertical plane.

The standard steel pipe was of ASTM A53 type E grade B with a yield strength of 35 ksi and minimum ductility of 15% in a 2-in. gage length. The concrete reinforcing steel was ASTM A615 grade 60. Concrete cylinders taken from the simulated concrete deck yielded a compressive strength of 3,370 psi at 28 days of age (design f_c' was 3,600 psi).

The anchor bolts were ASTM A-321 threaded rods with tack welded nuts for heads and with hex nuts and washers. Nuts and washers for anchor bolts were of A-325 requirements. Nuts were tapped or chased after galvanizing. Bolts and nuts had class 2A and 2B fit tolerences. Base plate details are shown in Figure 3b. All other steel was ASTM A36.

This pipe rail was originally designed using steel tubing with a wall thickness of 0.25 in. and a yield strength of 42 ksi with a ductility of 23% in a 2-in. gage length (ASTM A500 grade B). Plastic analysis of this design yielded a strength of 66 kips at an effective height of 17.5 in. When the rail was fabricated, standard steel pipe was used because it was readily available. Either material should perform satisfactorily.

In the original design ten 7.5-ft-long bridge rail segments were to be installed for a total length of 75 ft. The fabricator chose to fabricate and install five 15-ft-long segments for a total length of 75 ft, as shown in Figure 4. Figure 3c shows the pipe splice details.

Figure 1a. T421 bridge rail installation.

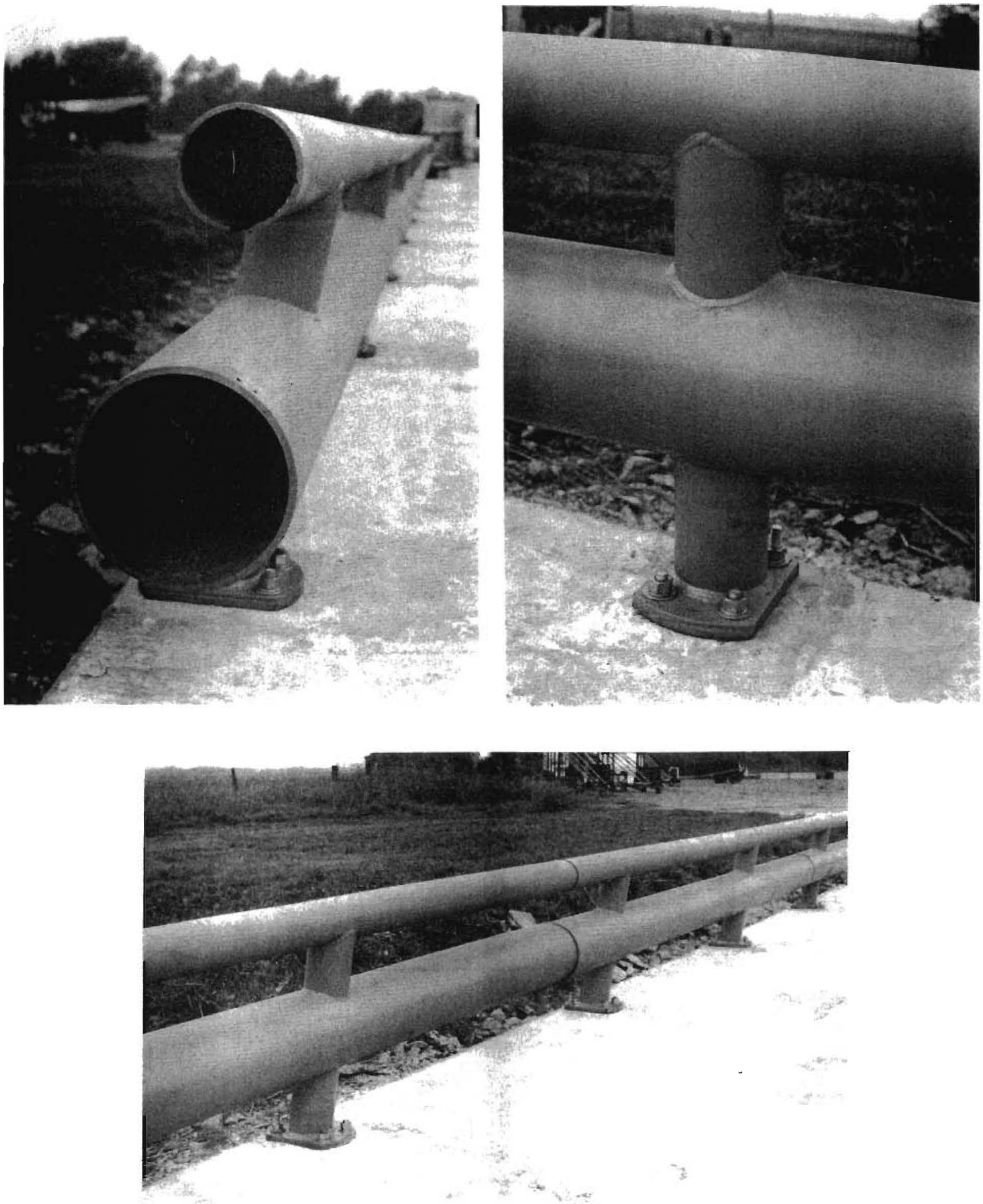


Figure 1b. T421 bridge rail installation.

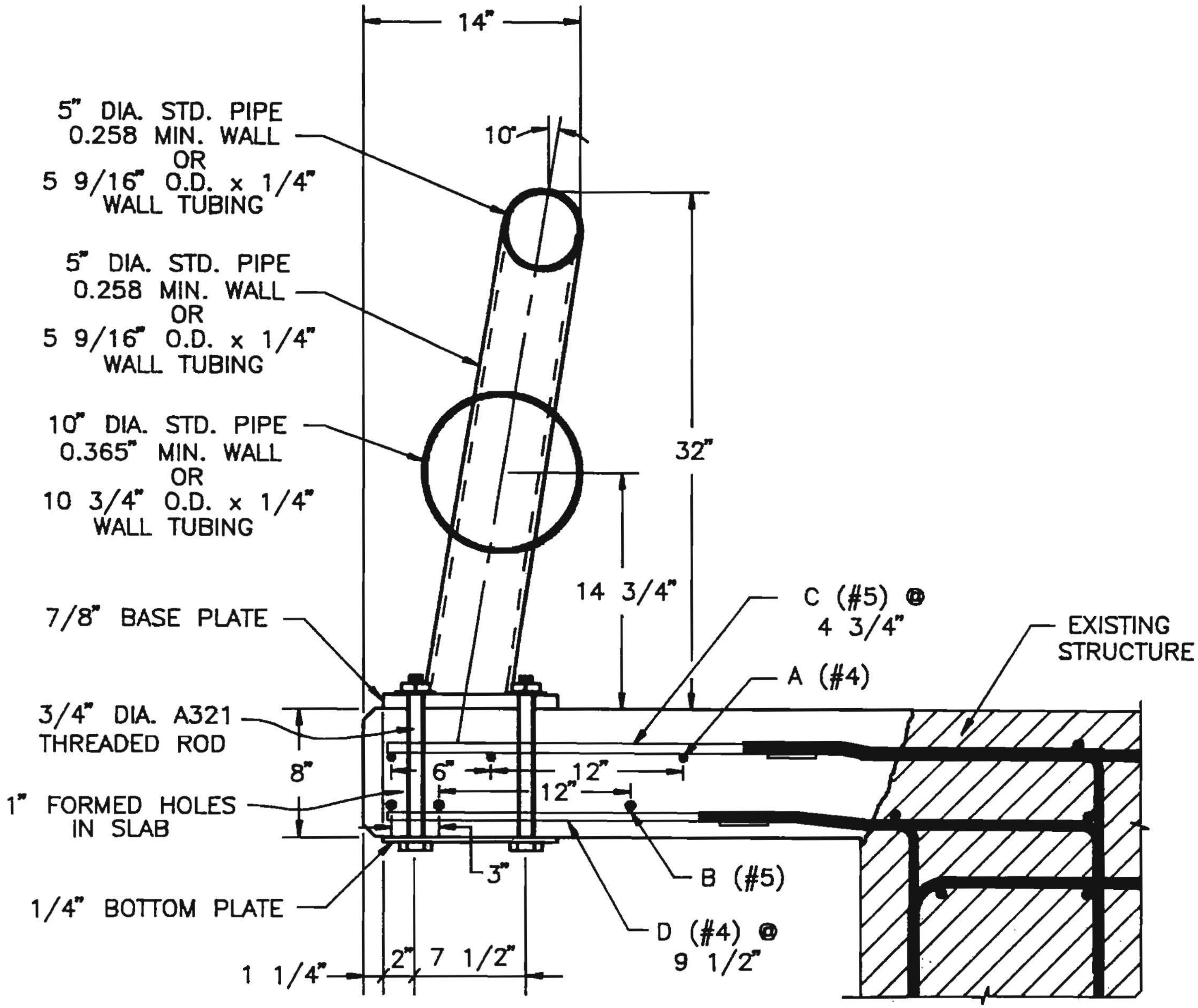


Figure 2. Cross section of T421 bridge rail.

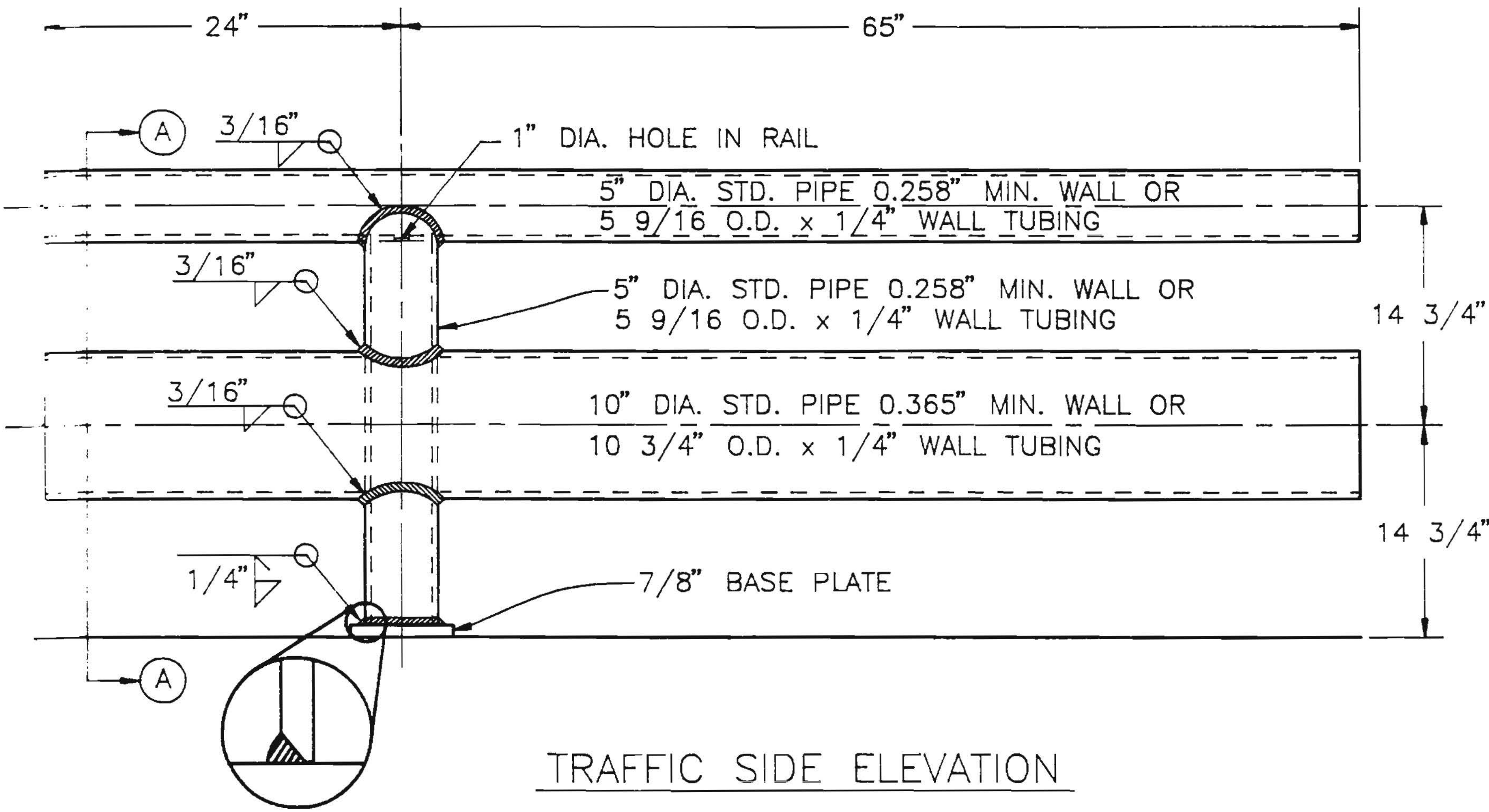


Figure 3a. Elevation of 7.5-foot-long segment of T421 bridge rail.

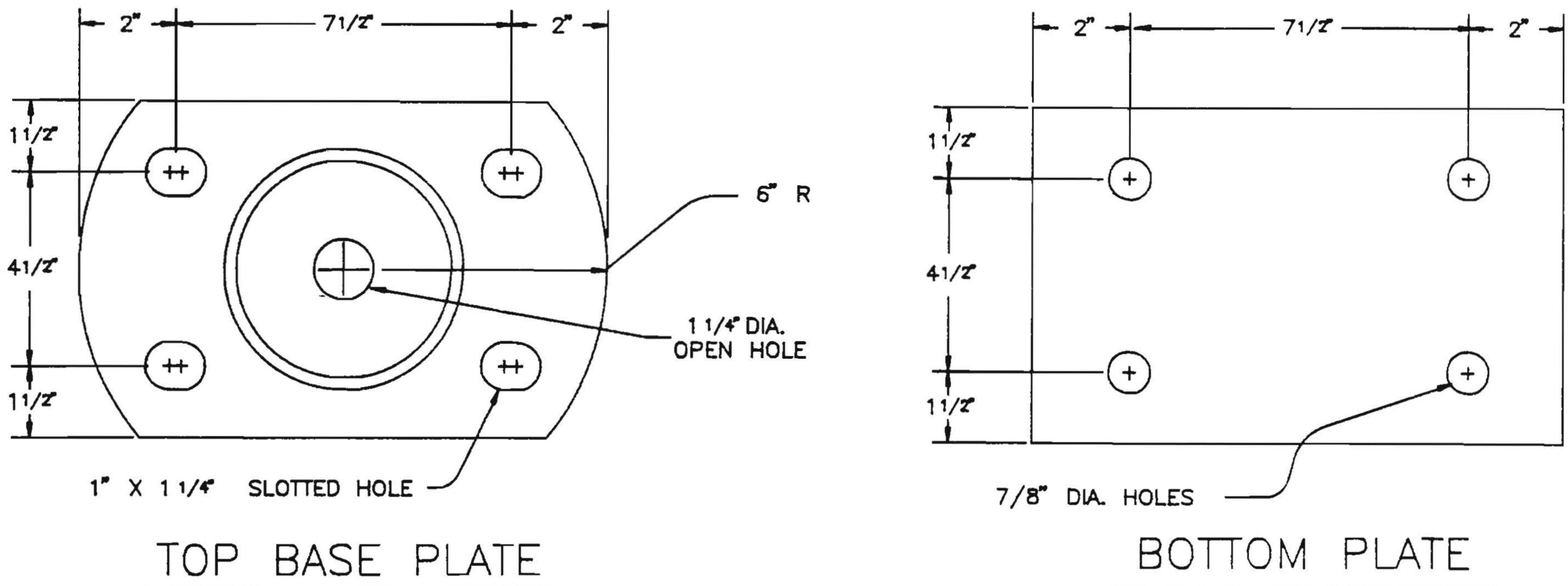


Figure 3b. Base plate details.

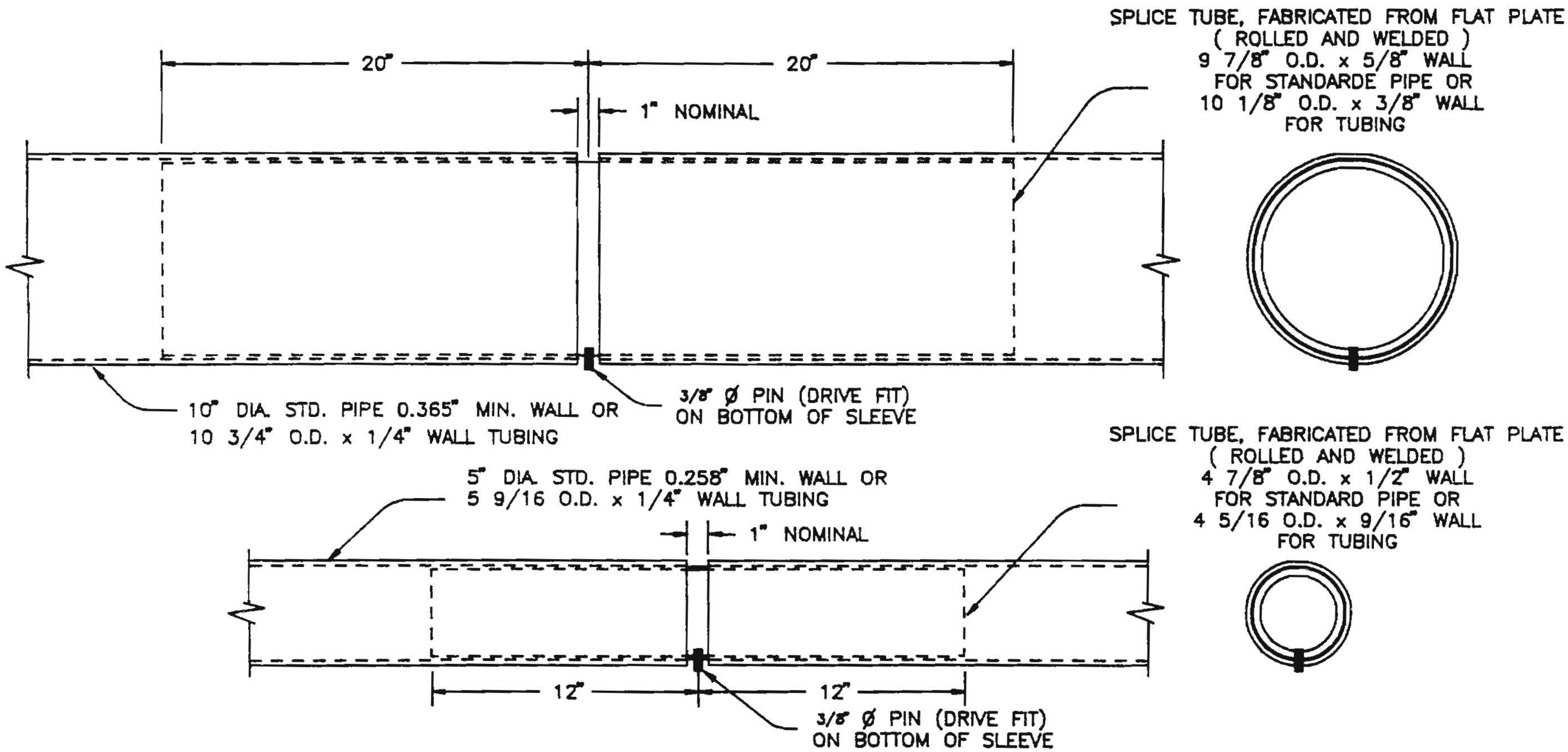


Figure 3c. Splice details.

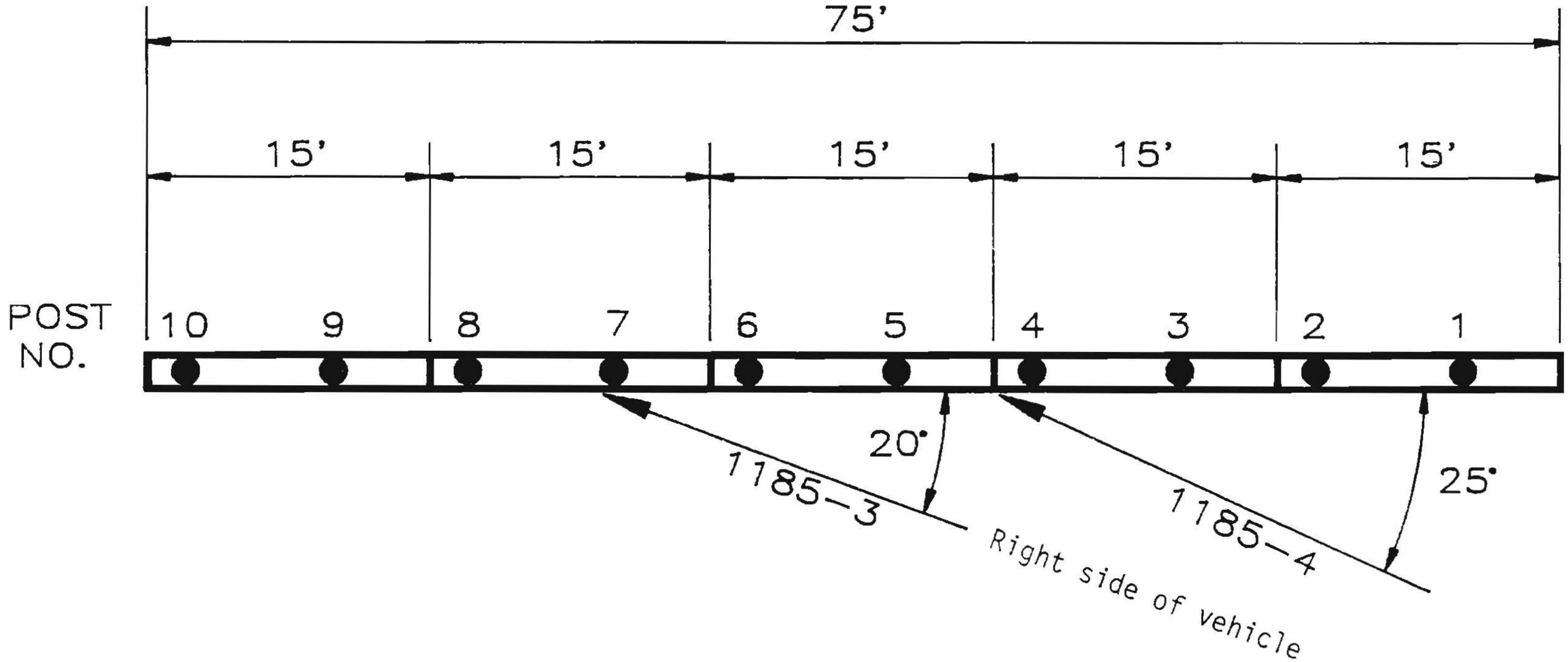


FIGURE 4. PLAN VIEW OF T421 BRIDGE RAIL INSTALLATION AND VEHICLE IMPACT POINTS.

CRASH TESTS

In order to qualify this bridge rail for use on federal-aid highways, it was crash-tested and evaluated in accordance with NCHRP Report 230 (3). Two crash tests were required--Test Designation S13 with an 1,800 lb passenger car at 60 mph and 20 degree impact angle and Test Designation 10 with a 4,500 lb passenger car at 60 mph and 25 degree impact angle.

A description of the instrumentation and data analysis is presented in Appendix A.

TEST DESCRIPTION 1185-3

The 1980 Honda Civic (Figure 1) was directed into the T421 bridge rail using a reverse tow and guidance system. Test inertia mass of the vehicle was 1,800 lb (808 kg). The height to the lower edge of the vehicle bumper was 15.0 in. (36.1 cm) and it was 20.0 in. (50.8 cm) to the top of the bumper. Other dimensions and information on the test vehicle are given in Figure 5. The vehicle was free-wheeling and unrestrained just prior to impact.

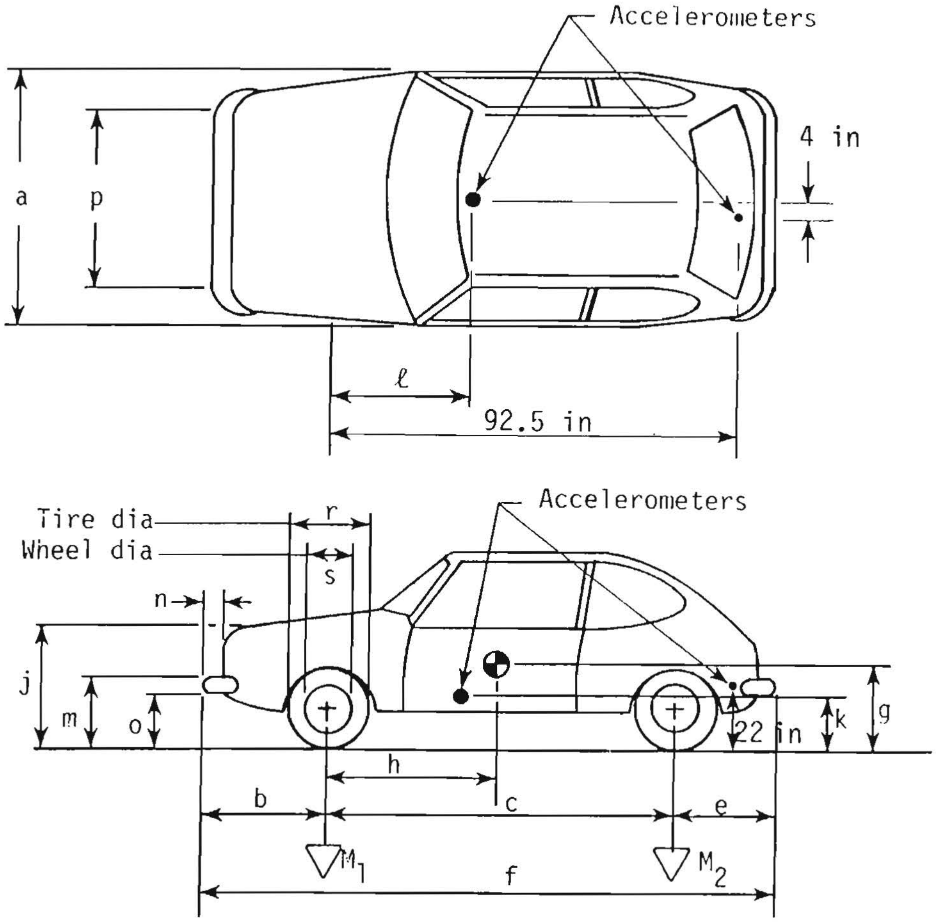
The speed of the vehicle at impact was 59.7 mph (96.1 km/h) and the angle of impact was 21.4 degrees. The right front bumper of the vehicle impacted the bridge rail 5 ft (1.5 m) upstream of post 7. The right front wheel made contact with the lower pipe member shortly after impact. The vehicle began to redirect at 0.042 seconds. By 0.060 seconds the vehicle had deformed to the A-pillar which caused the windshield to break. The right front wheel became wedged under the lower pipe member and impacted the lower part of post 7. At 0.162 seconds the vehicle was traveling parallel with the bridge rail at a speed of 49.7 mph (79.2 km/h). The vehicle exited the rail at 0.237 seconds traveling at 49.2 mph (79.2 km/h) and 5.0 degrees. As the vehicle left the test site, the brakes were applied. The vehicle yawed clockwise almost 180 degrees and subsequently came to rest 270 ft (82 m) from the point of impact. Sequential photographs are shown in Appendix B.

As can be seen in Figure 6, the rail received minimal cosmetic damage. Tire marks appeared 3 in. (7.6 cm) behind the traffic edge of the baseplate of post 7 before impacting the lower part of the post and riding over the baseplate. The vehicle was in contact with the rail for 9.25 ft (2.8 m).

Date: 8-22-89 Test No.: 1185-3 VIN: JHMSL4319BS010589

Make: Honda Model: Civic Year: 1980 Odometer: 117212

Tire Size: 155 SR12 Ply Rating: ____ Bias Ply: __ Belted: __ Radial: x



Tire Condition: good __
fair x
badly worn __

Vehicle Geometry - inches

a	62.0	b	29.0
c	88.5	d*	52.5
e	28.0	f	145.5
g		h	33.6
i	----	j	29.75
k	16.25	ℓ	28.5
m	20.0	n	4.0
o	15.0	p	54.25
r	21.5	s	13.25

Engine Type: 4 cylinder

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 591 rf 525 ℓr 334 rr 350

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	1149	1116	
M_2	663	684	
M_T	1812	1800	

Note any damage to vehicle prior to test:

____

____

*d = overall height of vehicle

Figure 5. Vehicle properties (Test 1185-3)

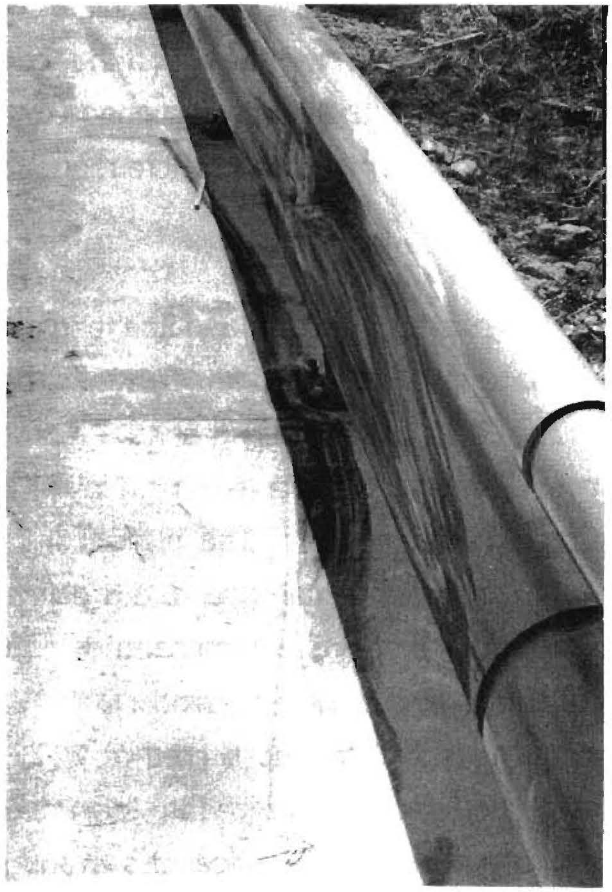


Figure 6. T421 bridge rail after Honda impact.

The vehicle sustained severe damage to the right side, as shown in Figure 7. Maximum crush at the right front bumper height was 10.0 in. (25.4 cm). The c.v. joint and right strut were damaged. The right front rim was bent and the tire damaged. The roof was bent and the windshield was broken. There was damage to the hood, grill, bumper, right front quarter panel, the right door and glass, the right rear quarter panel and the rear bumper.

TEST RESULTS

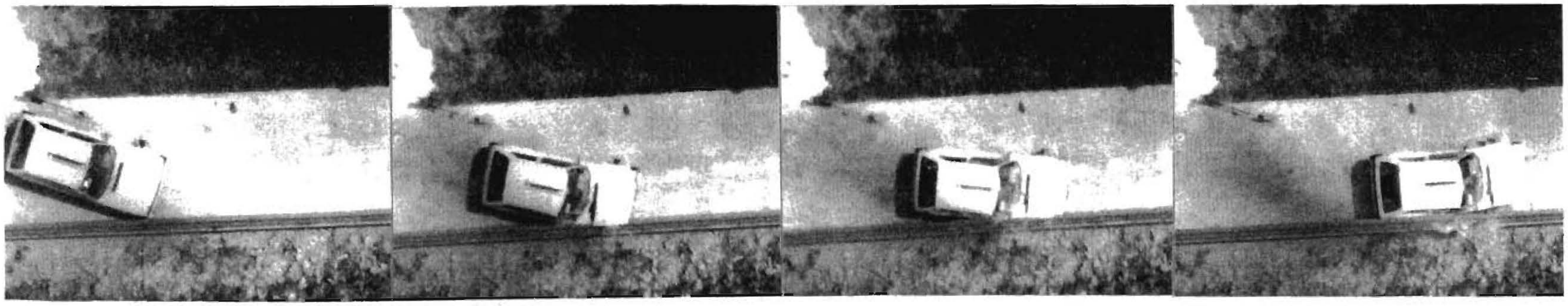
Impact speed was 59.7 mph (96.1 km/h) and the angle of impact was 21.4 degrees. The vehicle was traveling 49.7 mph (80.0 km/h) as it became parallel at 0.162 sec. The vehicle exited the rail at 0.237 sec traveling at 49.2 mph (79.2 km/h) and 5.0 degrees. Occupant impact velocity was 21.8 ft/s (6.6 m/s) in the longitudinal direction and 24.5 ft/s (7.5 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -3.9 g (longitudinal) and -6.3 g (lateral). These data and other pertinent information from the test are summarized in Figure 8 and Table 1. Vehicular angular displacements are displayed in Appendix C.

Vehicular accelerations versus time traces filtered at 300 Hz are presented in Appendix C. These data were further analyzed to obtain 0.050-second average accelerations versus time. The maximum 0.050-second average accelerations at the center of gravity were -8.4 g (longitudinal) and 12.7 g (lateral).

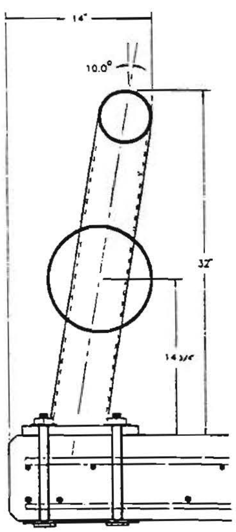
CONCLUSIONS

The T421 bridge rail contained and redirected the test vehicle with no lateral movement of the bridge rail. There were no detached elements or debris to present undue hazard to other traffic. The vehicle remained upright and relatively stable during the collision. The longitudinal occupant/compartment impact velocity and 10-ms occupant ridedown accelerations were within the limits recommended in NCHRP Report 230. The vehicle trajectory at loss of contact was 5 degrees which is less than the recommended limit of 60% of the impact angle (12.8 degrees for this test).

Figure 7. Honda before and after impact with T421 bridge rail.



0.000 s 0.075 s 0.112 s 0.187 s



Test No. 1185-3
Date 08/22/89

Test Installation . . . T421 Bridge Rail
Length of Installation . 75 ft (23 m)

Vehicle . . . . 1980 Honda Civic
Vehicle Weight
  Test Inertia . . . . . 1,800 lb (817 kg)
Vehicle Damage Classification
  TAD . . . . 01FR6 & 01RD6
  CDC . . . . 01FZEK4 & 01RDES4
Maximum Vehicle Crush . 10.0 in (25.4 cm)

Impact Speed . . . 59.7 mi/h (96.1 km/h)
Impact Angle . . . 21.4 degrees
Speed at Parallel . 49.7 mi/h (80.0 km/h)
Exit Speed . . . . 49.2 mi/h (79.2 km/h)
Exit Trajectory . . 5.0 degrees
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal . . -8.4 g
  Lateral . . . . . 12.7 g
Occupant Impact Velocity
  Longitudinal . . 21.8 ft/s (6.6 m/s)
  Lateral . . . . . 24.5 ft/s (7.5 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . -3.9 g
  Lateral . . . . . 6.3 g

Figure 8. Summary of results for test 1185-3.

TABLE 1. EVALUATION OF CRASH TEST NO. 1185-3.
T421 Bridge Rail (1,800 lb/60 mi/h/20 deg)

USUAL CRITERIA	TEST RESULTS	PASS/FAIL*
Must contain vehicle	Vehicle was contained	Pass
Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
Passenger compartment must have essentially no deformation	Minimal deformation	Pass
Vehicle must remain upright	Vehicle did remain upright	Pass
Must smoothly redirect the vehicle	Vehicle was redirected	Pass
Effective coefficient of friction (9) μ — Assessment 0 - .25 — Good .26 - .35 — Fair > .35 — Marginal	μ — Assessment .27 — Fair	Pass
Shall be less than Occupant Impact Velocity - fps Longitudinal 30, Lateral 25	Occupant Impact Velocity - fps Longitudinal 21.8, Lateral 24.5	Pass
Occupant Ridedown Accelerations - g's Longitudinal 15, Lateral 15	Occupant Ridedown Accelerations - g's Longitudinal -3.9, Lateral 6.3	Pass
Exit angle shall be less than 12.8 degrees	Exit angle was 5.0 degrees	Pass

TEST DESCRIPTION 1185-4

The 1982 Oldsmobile 98 (Figure 9) was directed into the T421 bridge rail using a reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 lb (2,043 kg). The height to the lower edge of the vehicle bumper was 12.25 in. (31.1 cm) and it was 20.0 in. (50.8 cm) to the top of the bumper. Other dimensions and information on the test vehicle are given in Figure 10. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 62.4 mph (100.4 km/h) and the angle of impact was 26.6 degrees. The right front bumper of the vehicle impacted the bridge rail 5 ft (1.5 m) upstream of post 5. The right front wheel made contact with the lower pipe member shortly after impact. The vehicle began to redirect at 0.067 seconds. By 0.075 seconds the vehicle had deformed to the A-pillar and the windshield broke. As the vehicle continued forward, the front bumper was forced between the upper and lower pipe member and impacted the middle portion of the post. At the same time the right front wheel became wedged under the lower pipe element and impacted the lower portion of post 5. At 0.204 seconds the vehicle began to move parallel with the bridge rail traveling at a speed of 47.6 mph (76.6 km/h). The rear of the vehicle impacted the bridge rail at 0.219 seconds and the rear bumper was forced between the upper and lower pipe elements and impacted the middle portion of the post. The vehicle lost contact with the bridge rail at 0.348 seconds traveling at 44.6 mph (71.8 km/h) and 7.6 degrees. Shortly after the vehicle left the test site, the brakes were applied and the vehicle yawed clockwise and subsequently came to rest 225 ft (69 m) from the point of impact. Sequential photographs are shown in Appendix D.

As can be seen in Figures 11, 12, and 13, the rail received minor damage and the slab received moderate damage. The vehicle impacted the rail between post 4 and 5. The bases on both posts 4 and 5 were pushed back approximately 0.25 in. (0.6 cm).. The bridge deck behind post 4 was cracked. Tire marks appeared 5 in. (12.7 cm) behind the traffic edge of the baseplate of post 5 before the tire impacted the lower part of the post. The bridge deck around post 5 was broken, as shown in Figure 12. There were tire marks on the base of post 6 and, shortly thereafter, the vehicle left the rail. The vehicle was in contact with the bridge rail for 15.5 ft (4.7 m).

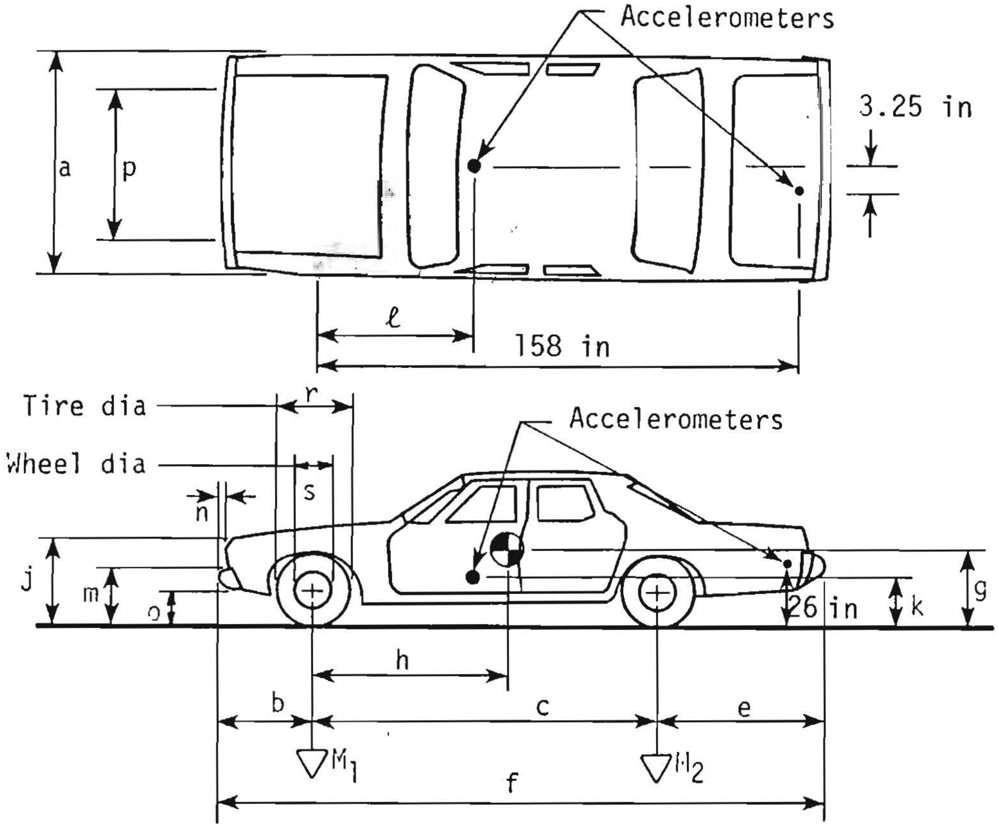
Figure 9. Oldsmobile before and after impact
with T421 bridge rail.

Date: 8-24-89 Test No.: 1185-4 VIN: 1G3AW69N6CM141463

Make: Oldsmobile Model: 98 Year: 1982 Odometer: 29415

Tire Size: P225/75R-15 Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: x

Tire Condition: good ___ fair x badly worn ___



Vehicle Geometry - inches

a	76.0	b	42.0
c	119.0	d*	57.5
e	55.5	f	216.5
g		h	51.7
i	----	j	32.0
k	20.0	ℓ	32.25
m	20.0	n	5.0
o	12.25	p	61.5
r	27.75	s	16.5

4-wheel weight for c.g. det. ℓf 1253 rf 1292 ℓr 992 rr 963

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2458	2545	
M_2	1563	1955	
M_T	4021	4500	

Note any damage to vehicle prior to test:

____

____

*d = overall height of vehicle

Engine Type: 8 - diesel

Engine CID: 5.7

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Body Type: 4-door sedan

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 10. Vehicle properties (Test 1185-4)

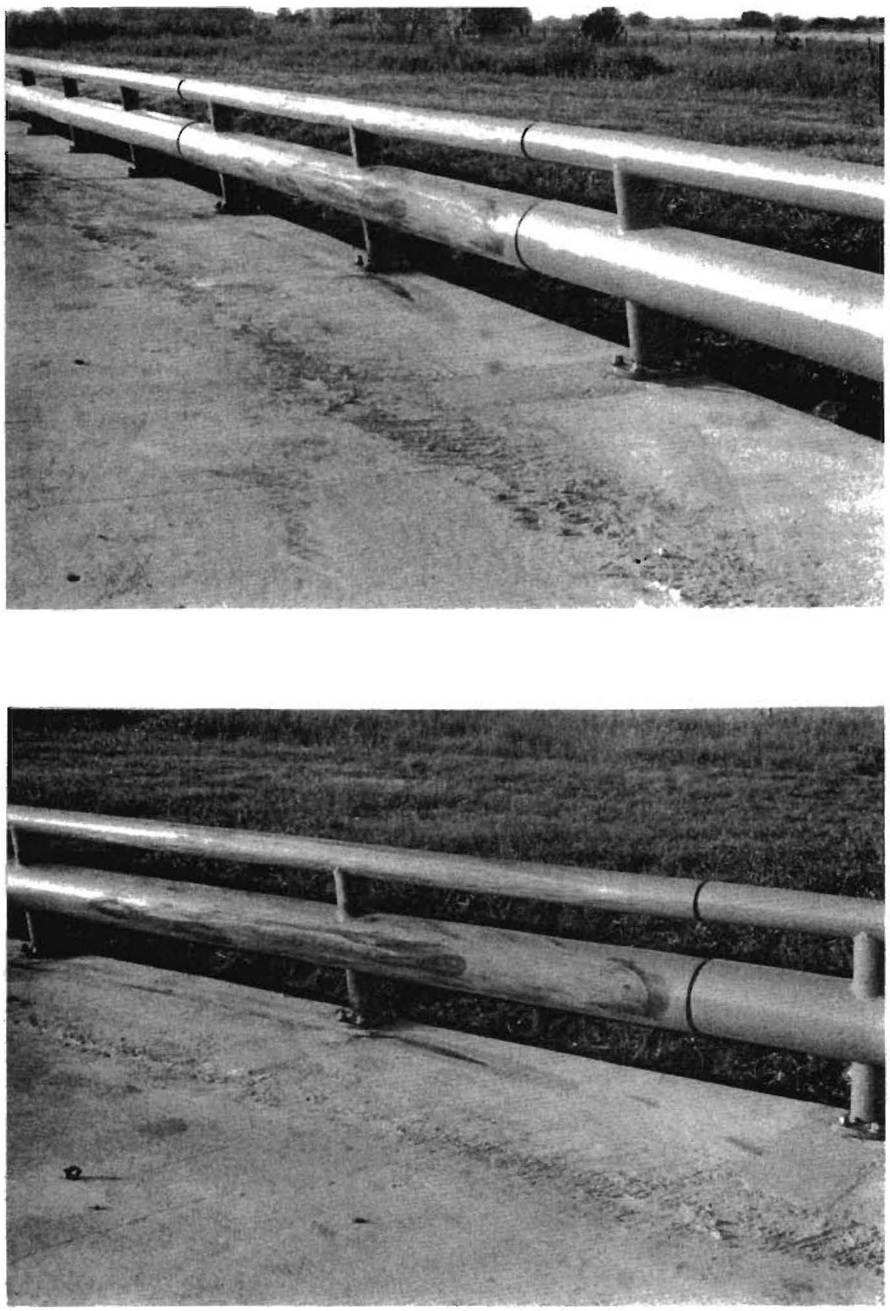


Figure 11. T421 bridge rail after Oldsmobile impact.

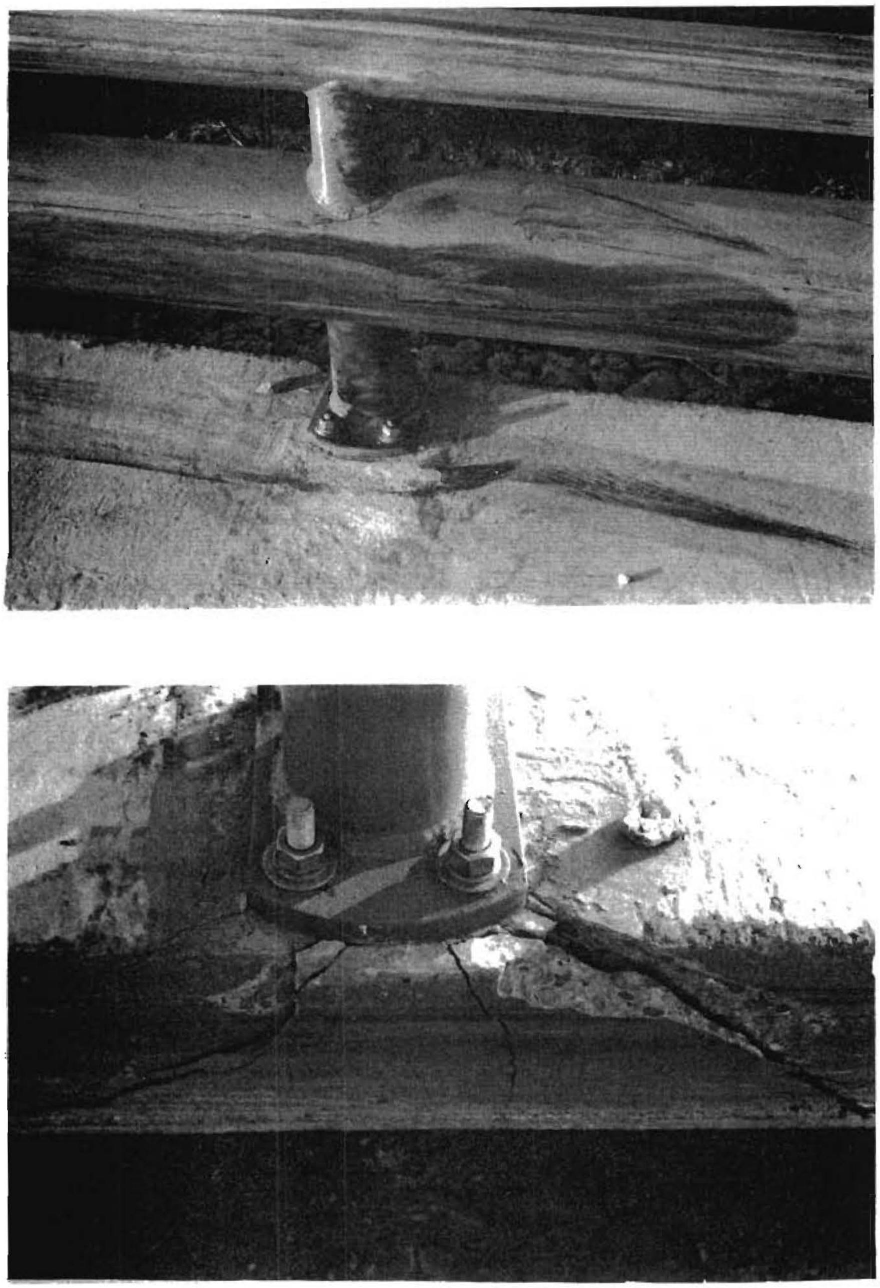
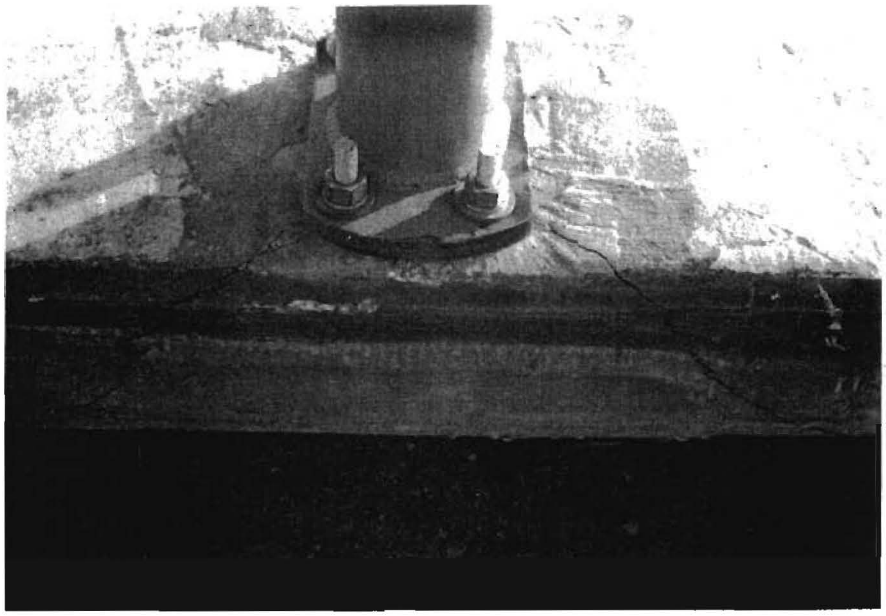


Figure 12. Damage at post 5.



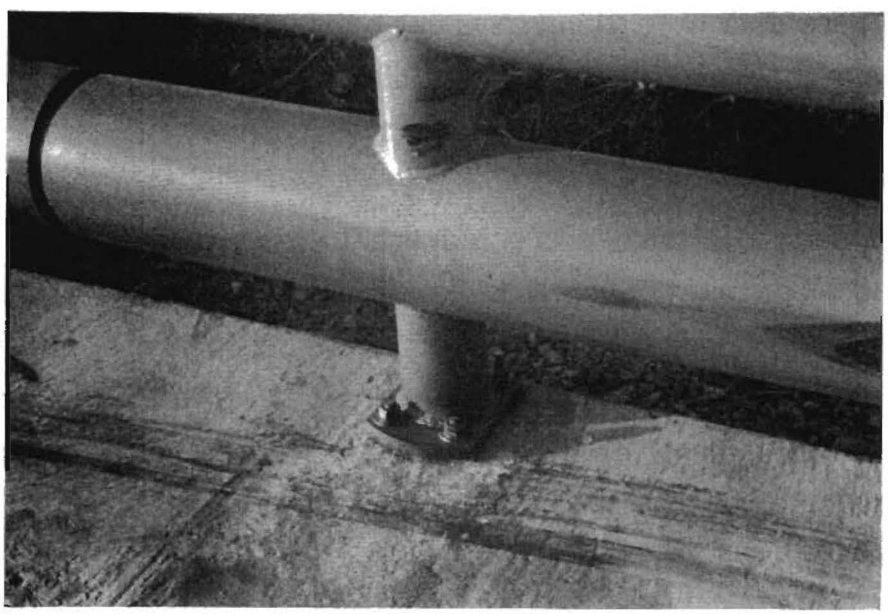


Figure 13. Post 4 and post 6 after Oldsmobile impact.

The vehicle sustained severe damage to the right side, as shown in Figure 9. Maximum crush at the right front corner at bumper height was 18.0 in. (45.7 cm). The right front axle was pushed back 15.0 in. (38.1 cm). The right A-arm, sway bar, tie rod, and upper and lower ball joints were damaged and the subframe was bent. The instrument panel in the passenger compartment was bent as well as the floor pan and roof, and the windshield was broken. The right front and rear rims were bent and the tires damaged. There was damage to the hood, grill, front bumper, right front quarter panel, the right front and rear doors, the right rear quarter panel and the rear bumper.

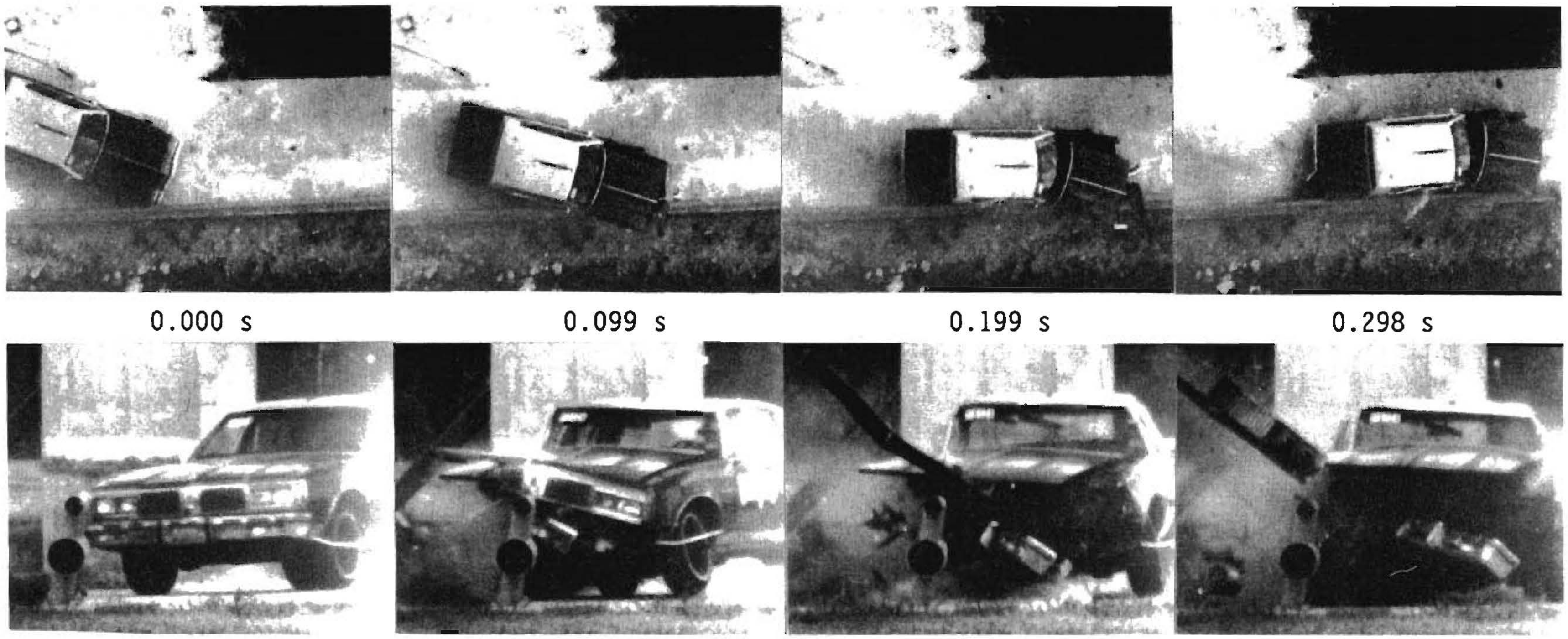
TEST RESULTS

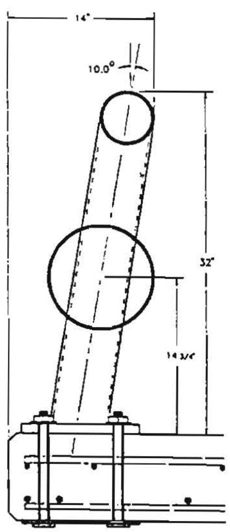
Impact speed was 62.4 mph (100.4 km/h) and the angle of impact was 26.0 degrees. The vehicle was traveling at 47.6 mph (76.6 km/h) as it began moving parallel to the bridge rail. The vehicle exited the rail at 44.6 mph (71.8 km/h) and 7.6 degrees. Occupant impact velocity was 26.8 ft/s (8.2 m/s) in the longitudinal direction and 20.1 ft/s (6.1 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -6.8 g (longitudinal) and 8.7 g (lateral). These data and other pertinent information from the test are summarized in Figure 14 and Table 2. Vehicular angular displacements are displayed in Appendix E.

Vehicular accelerations versus time traces filtered at 300 Hz are presented in Appendix E. These data were then further analyzed to obtain 0.050-second average accelerations versus time. The maximum 0.050-second average accelerations at the center of gravity were -16.1 g (longitudinal) and 11.1 g (lateral).

CONCLUSIONS

The bridge rail contained and redirected the test vehicle with minimal lateral movement of the bridge rail. The vehicle remained upright and relatively stable during the collision. Occupant/compartment impact velocities and occupant ridedown accelerations were within the limits recommended in NCHRP Report 230. The vehicle trajectory at loss of contact was 7.6 degrees which was less than the recommended limit of 60% of the impact angle (15.6 degrees in this case).





Test No. 1185-4
Date 08/24/89

Test Installation . . . T421 Bridge Rail
Length of Installation . 75 ft (23 m)

Vehicle . . . . 1982 Oldsmobile 98
Vehicle Weight
  Test Inertia . . . . . 4,500 lb (2,043 kg)
Vehicle Damage Classification
  TAD . . . . 01FR6 & 01RD6
  CDC . . . . 01FZEK4 & 01RDES4
Maximum Vehicle Crush . 18.0 in (45.7 cm)

Impact Speed . . . 62.4 mi/h (100.4 km/h)
Impact Angle . . . 26.6 degrees
Speed at Parallel . 47.6 mi/h (76.6 km/h)
Exit Speed . . . . 44.6 mi/h (71.8 km/h)
Exit Trajectory . . 7.6 degrees
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal . .-16.1 g
  Lateral . . . . . 11.1 g
Occupant Impact Velocity
  Longitudinal . . 26.8 ft/s (8.2 m/s)
  Lateral . . . . . 20.1 ft/s (6.1 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . -6.8 g
  Lateral . . . . . 8.7 g

Figure 14. Summary of results for test 1185-4.

TABLE 2. EVALUATION OF CRASH TEST NO. 1185-4.
T421 Bridge Rail (4,500 lb/60 mi/h/25 deg)

CRITERIA		TEST RESULTS		PASS/FAIL*
Must contain vehicle		Vehicle was contained		Pass
Debris shall not penetrate passenger compartment		No debris penetrated passenger compartment		Pass
Passenger compartment must have essentially no deformation		Minimal deformation		Pass
Vehicle must remain upright		Vehicle did remain upright		Pass
Must smoothly redirect the vehicle		Vehicle was redirected		Pass
Effective coefficient of friction (9)				
μ	Assessment	μ	Assessment	
0 - .25	Good	.29	Fair	Pass
.26 - .35	Fair			
> .35	Marginal			
Shall be less than				
Occupant Impact Velocity - fps		Occupant Impact Velocity - fps		Pass
Longitudinal	Lateral	Longitudinal	Lateral	
30	25	26.8	20.1	
Occupant Ridedown Accelerations - g's		Occupant Ridedown Accelerations - g's		Pass
Longitudinal	Lateral	Longitudinal	Lateral	
15	15	-6.8	8.7	
Exit angle shall be less than 16.0 degrees		Exit angle was 7.6 degrees		Pass

SUMMARY and CONCLUSIONS

The new aesthetic bridge rail T421 performed very well when crash-tested in accordance with NCHRP 230 test 10 and test S13. It met all of the safety evaluation guidelines of NCHRP 230 (Tables 1 and 2 and Appendix F).

None of the pipes incurred any collapse nor was there any yielding of these members. The base plates in test 10 moved without yielding by virtue of the rotation allowed at the splices. Therefore, repairs of the rail itself would consist of cleaning and/or repainting after an accident.

Punching shear cracks developed in the bridge deck typical of crash tests on steel beam and posts bridge rails. These only occurred from the 4,500 lb car impacting at 62.4 mph and 26.6 degrees. This was a very severe impact which most bridge rail installations rarely experience.

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5. Noel, J.S., T.J. Hirsch, C.E. Buth, and A. Arnold, "Loads on Bridge Railings," Transportation Research Record 796, Transportation Research Board, Jan. 1981.

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10. Arnold, A.G., and T.J. Hirsch, "Bridge Deck Designs for Railing Impacts," Research Report 295-1F, Texas Transportation Institute, Texas A&M University, Aug. 1985.

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12. Hirsch, T.J., C.E. Buth, W.L. Campise, and D. Kaderka, "Aesthetically Pleasing Concrete Beam and Posts Bridge Rail - Texas Type T411," Research Report 1185-1, Texas Transportation Institute, Texas A&M University, Mar. 1989.

APPENDIX A

Instrumentation and Data Analysis

APPENDIX A

INSTRUMENTATION AND DATA ANALYSIS

The vehicle was equipped with triaxial accelerometers mounted near the center of gravity to measure x, y, and z components of acceleration and biaxial accelerometer in the trunk to measure x and y accelerations at the rear of the vehicle. In addition, yaw, pitch, and roll rates were measured by onboard instruments. The electronic signals 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 an 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 instant of impact. Data from the electronic transducers were digitized using a microcomputer for analysis and evaluation of performance.

Analog data obtained from the electronic transducers were digitized and then analyzed on a microcomputer using three computer programs: DIGITIZE, VEHICLE, and PLOTANGLE.

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 of vehicle acceleration after occupant/compartment impact, and time of 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 herein. 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.

Still photography, real-time cine, and video were used to record conditions of the test vehicle and bridge rail before and after the test. Video and real-time and high-speed cine were used to document the test. One high-speed camera was placed to have a field of view parallel to and aligned with the bridge rail at the downstream end, one was placed over the bridge rail to have a field of view perpendicular to the ground, another was placed perpendicular to the front of the bridge rail, and one was placed behind the bridge rail. The films from these cameras were used to observe phenomena occurring during collision and obtain time-event, displacement, and angular data.

APPENDIX B

Sequential Photographs of Test 1185-3

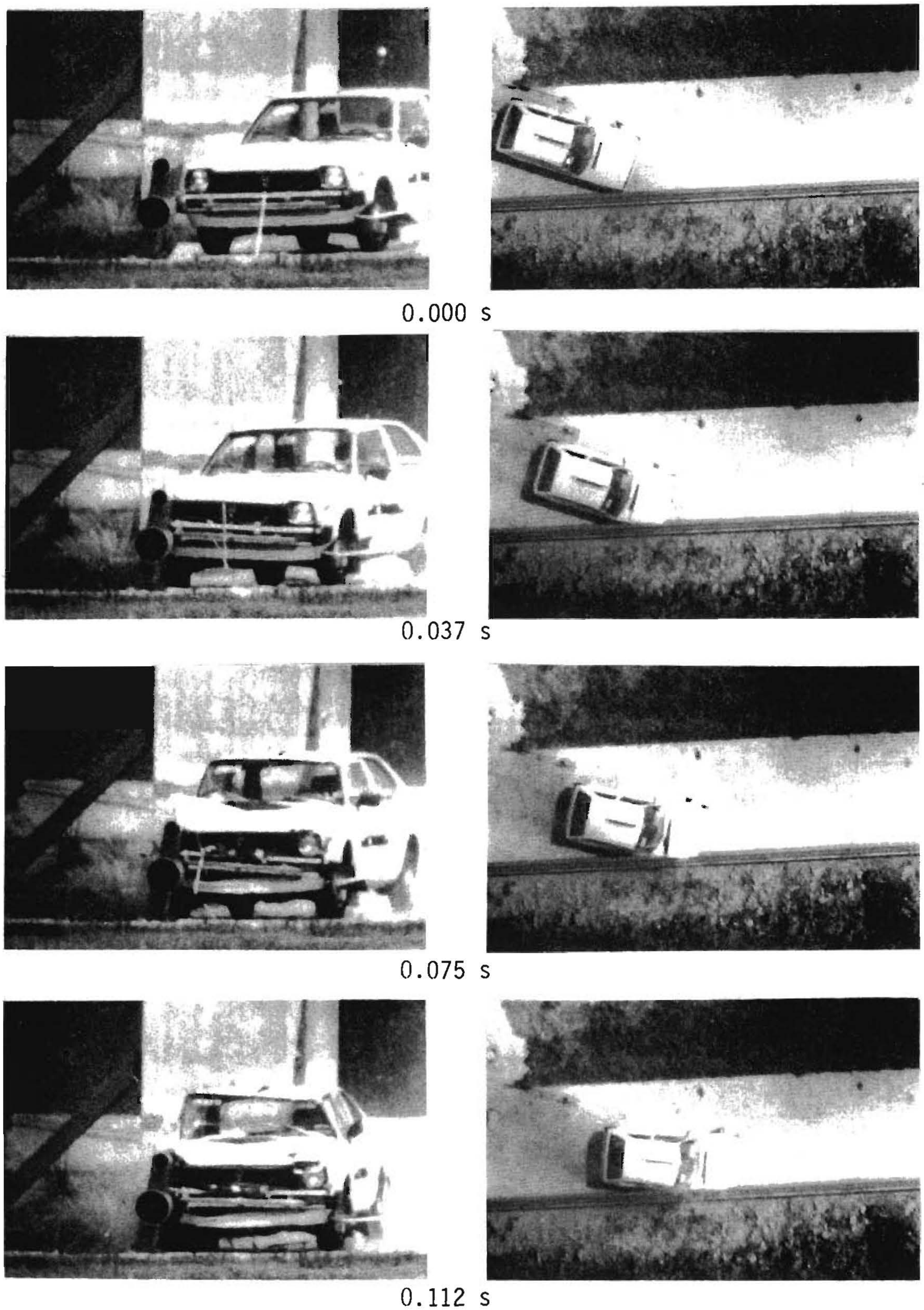
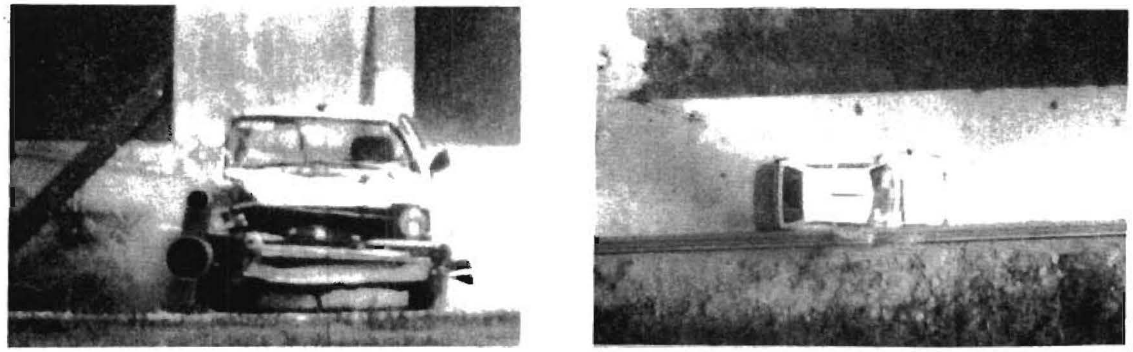
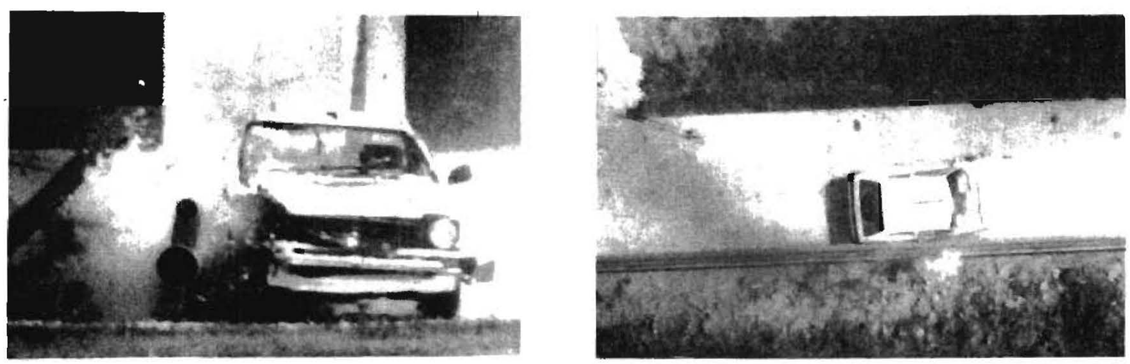


Figure B1. Sequential photographs for test 1185-3.



0.150 s

0.187 s



0.225 s

0.300 s

Figure B1. Sequential photographs for test 1185-3.
(Continued)

APPENDIX C

Electronic Accelerometer, Roll, Pitch, and Yaw Data Test 1185-3

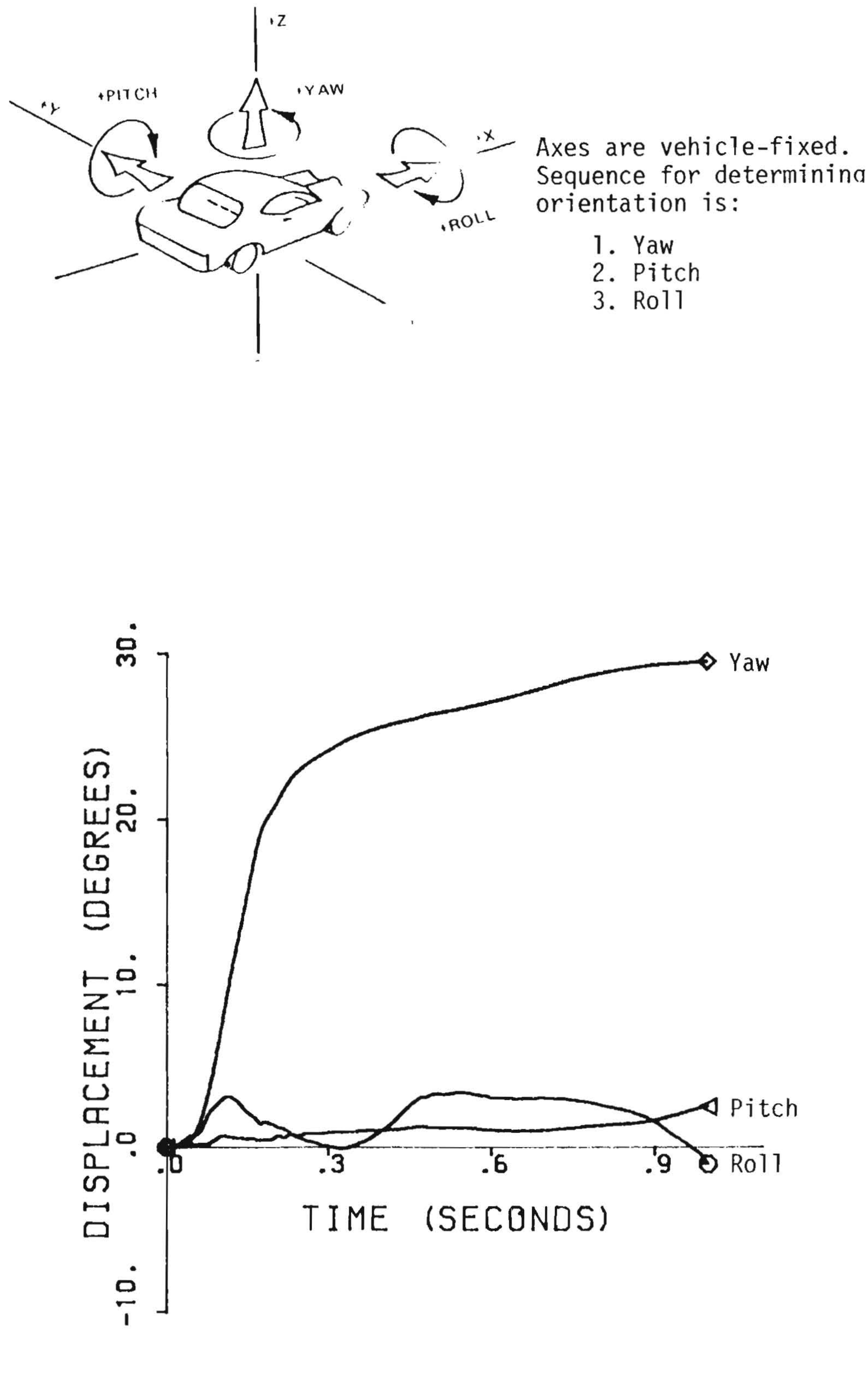


Figure C1. Vehicle angular displacements for test 1185-3.

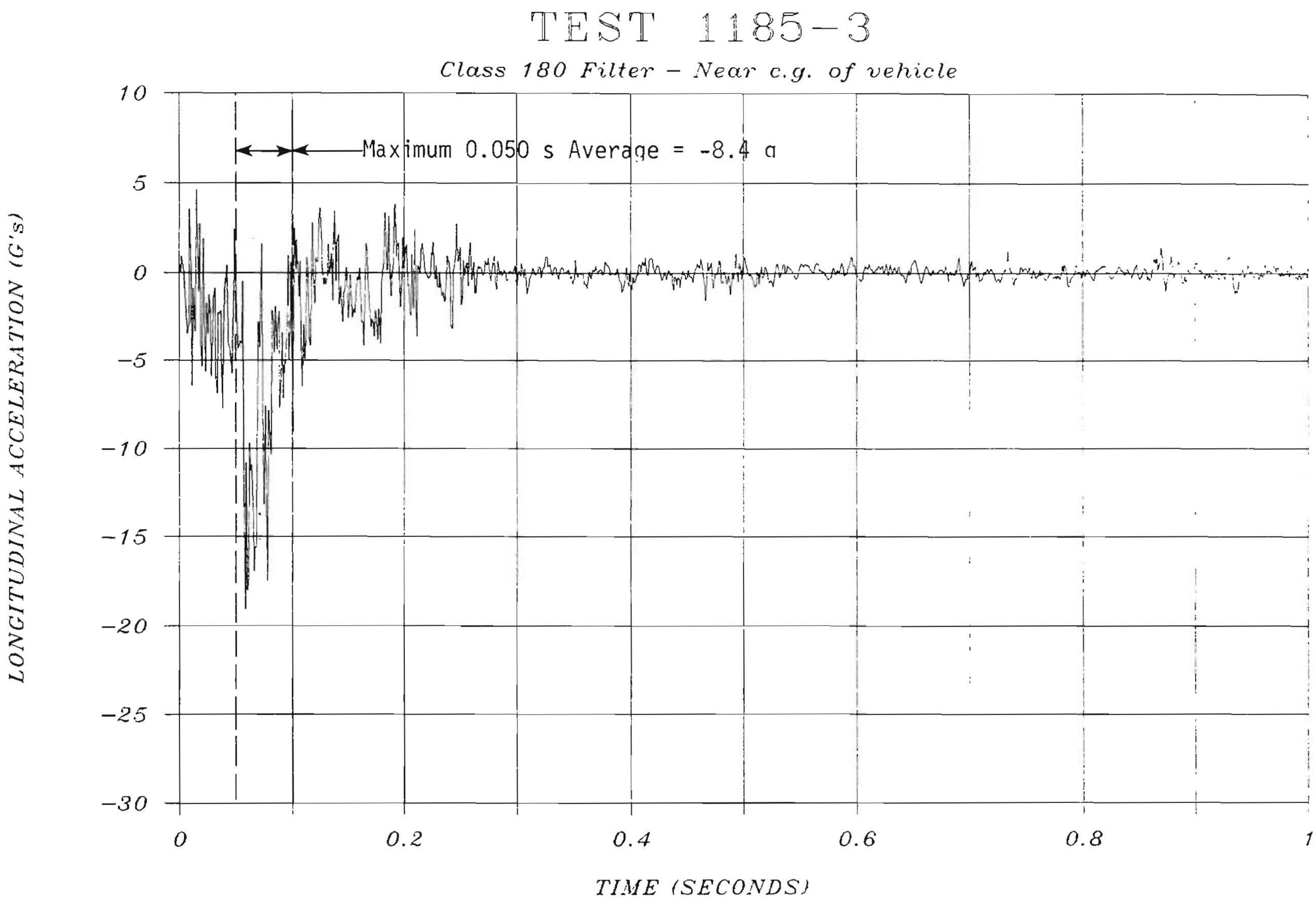


Figure C2. Vehicle longitudinal accelerometer trace for test 1185-3 (near center-of-gravity of vehicle).

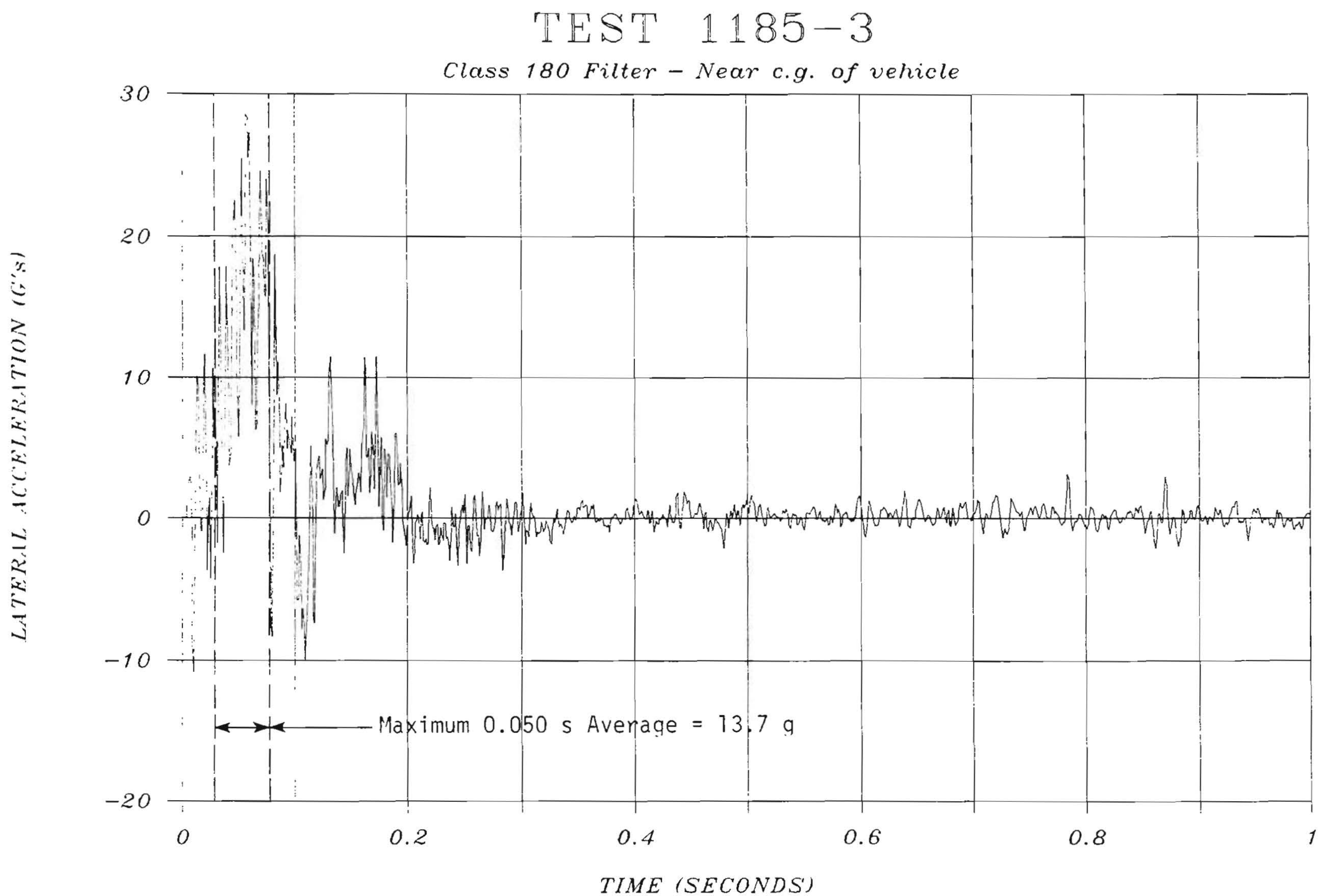


Figure C3. Vehicle lateral accelerometer trace for test 1185-3 (near center-of-gravity of vehicle).

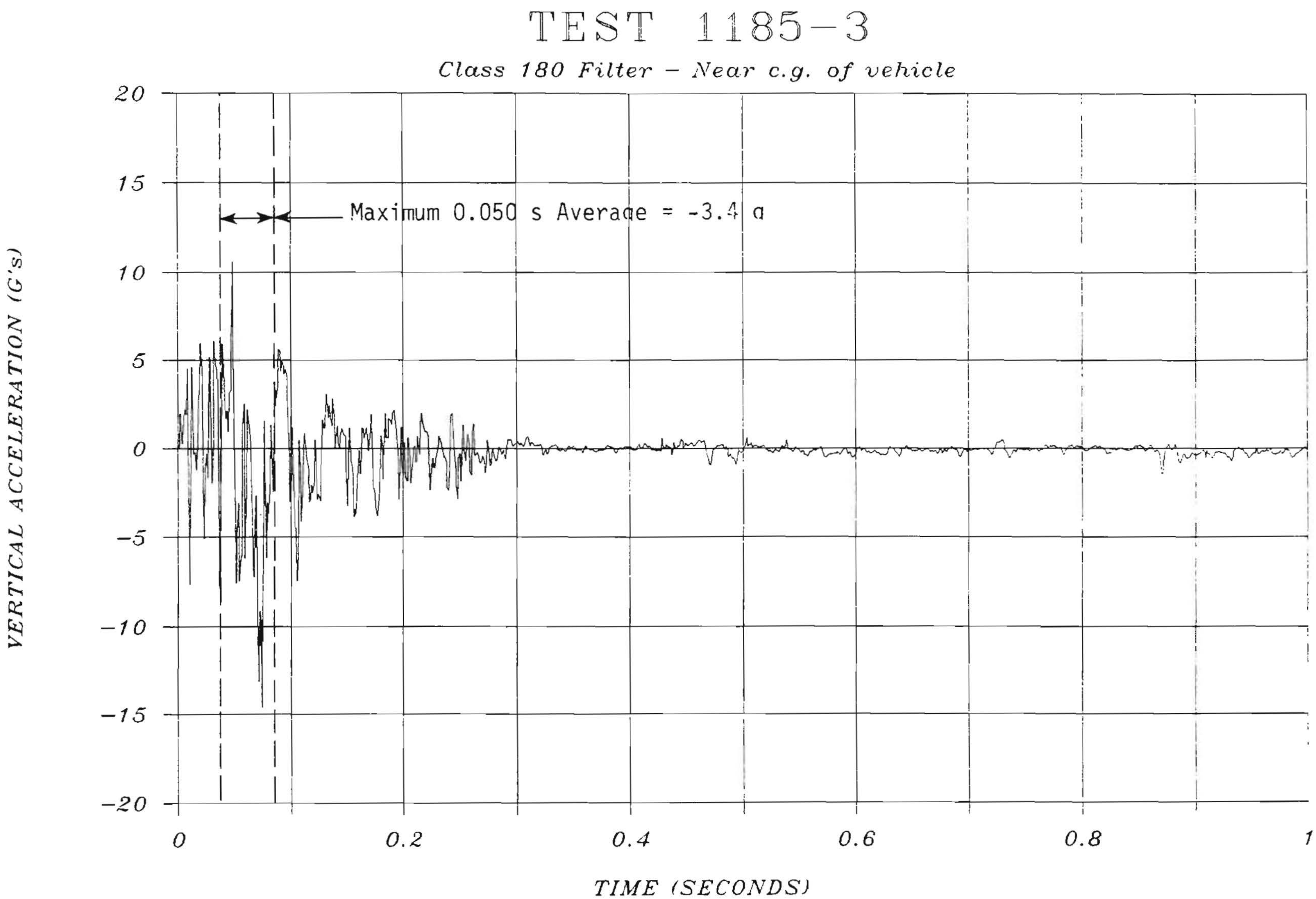


Figure C4. Vehicle vertical accelerometer trace for test 1185-3 (near center-of-gravity of vehicle).

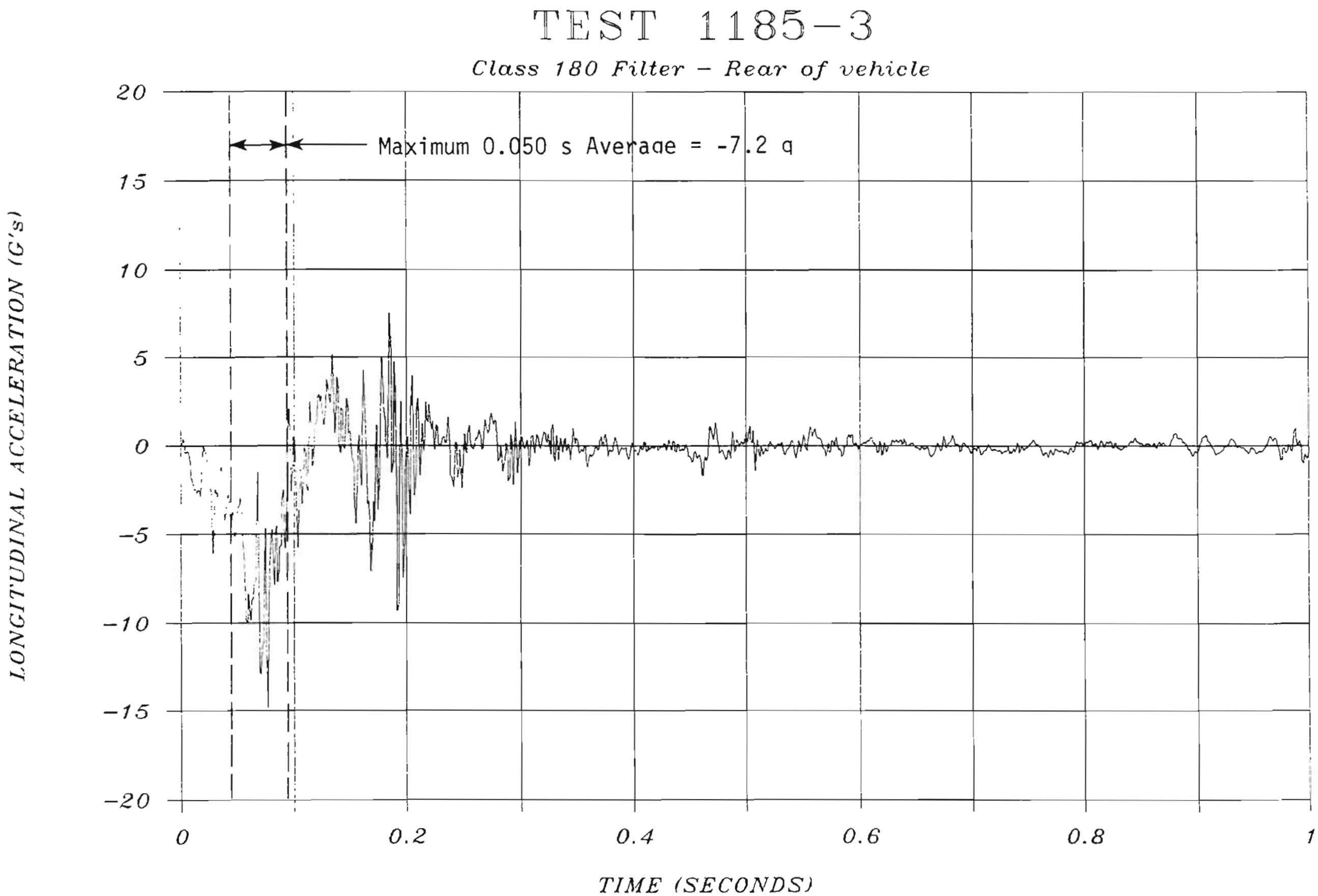


Figure C5. Vehicle longitudinal accelerometer trace for test 1185-3 (rear of vehicle).

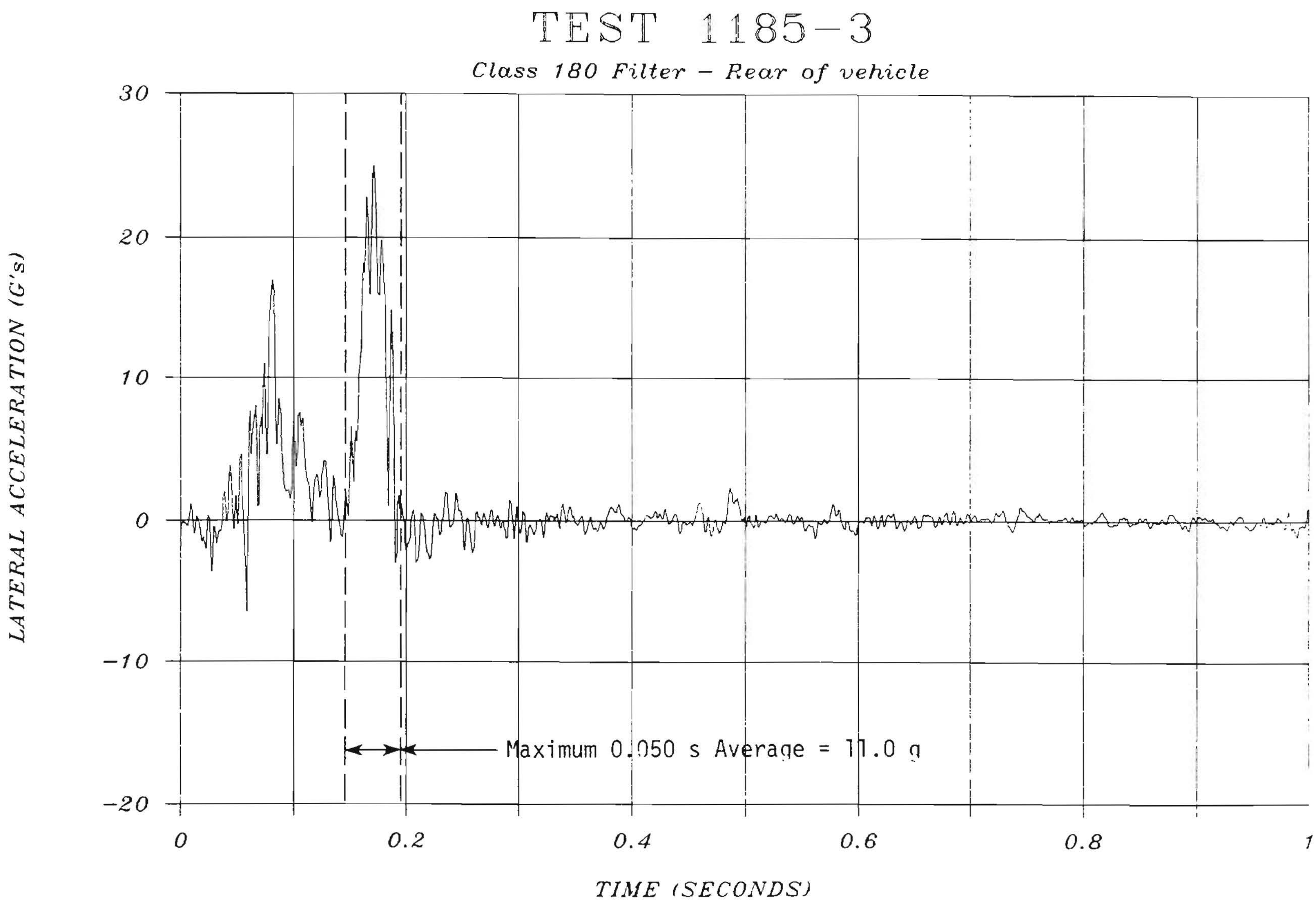
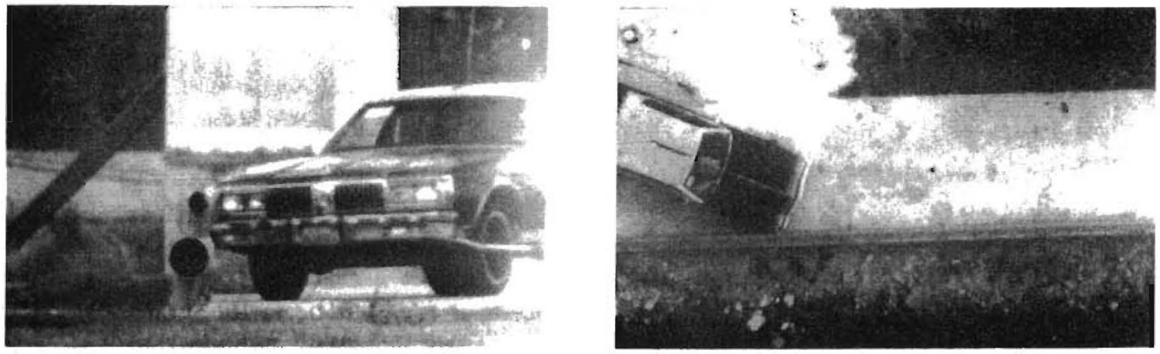


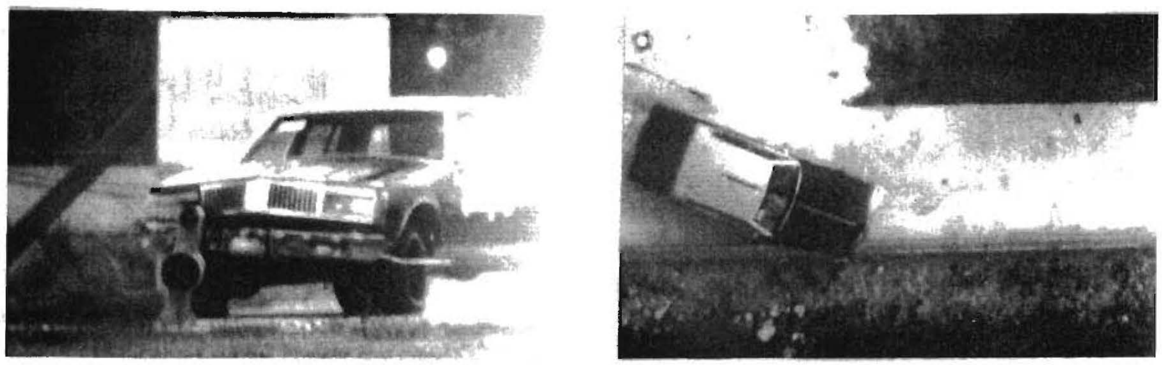
Figure C6. Vehicle lateral accelerometer trace for test 1185-3 (rear of vehicle).

APPENDIX D

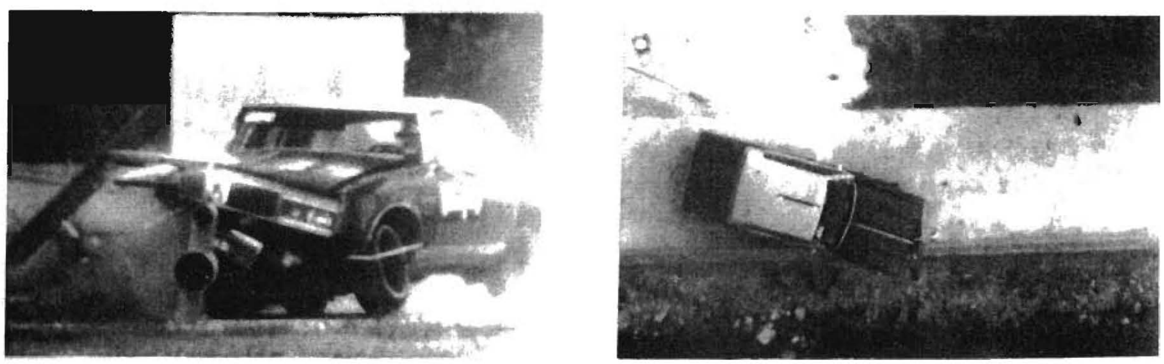
Sequential Photographs of Test 1185-4



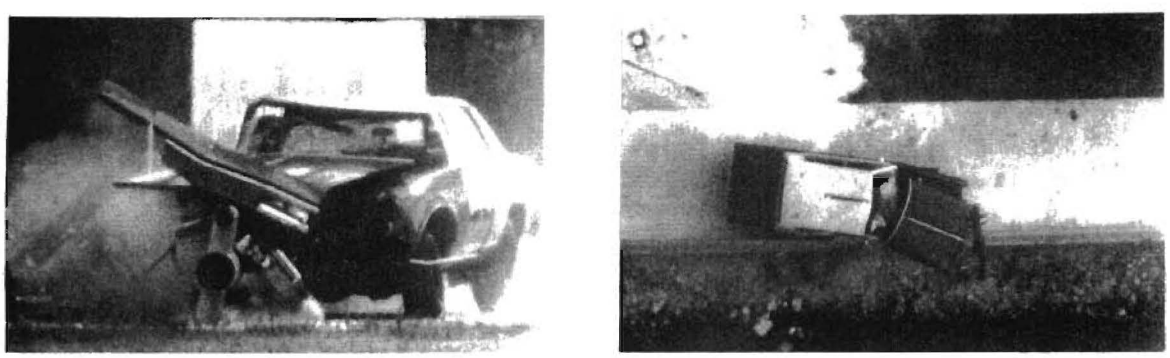
0.000 s



0.050 s

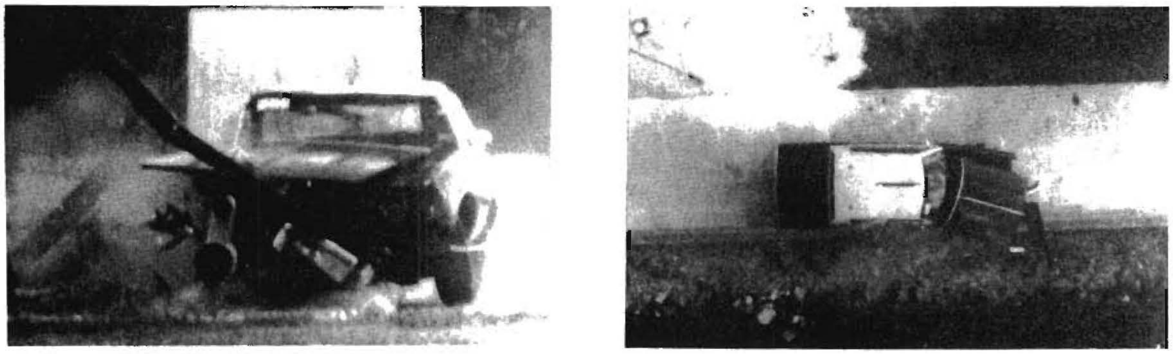


0.099 s



0.149 s

Figure D1. Sequential photographs for test 1185-4.



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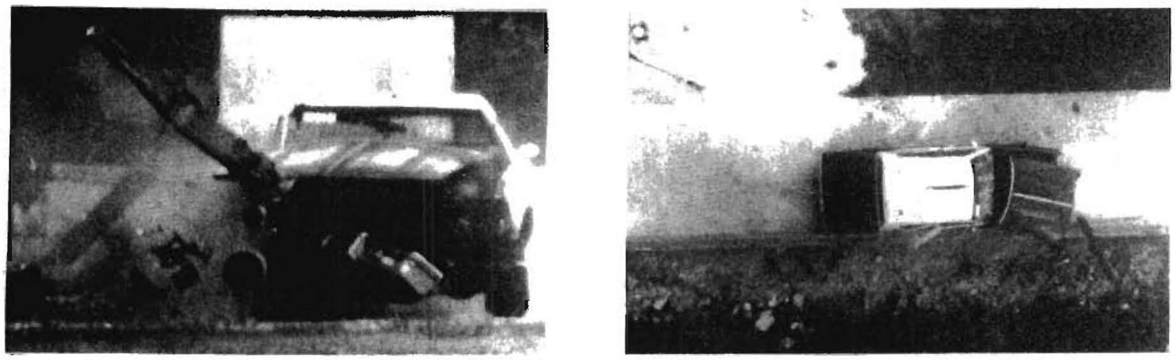
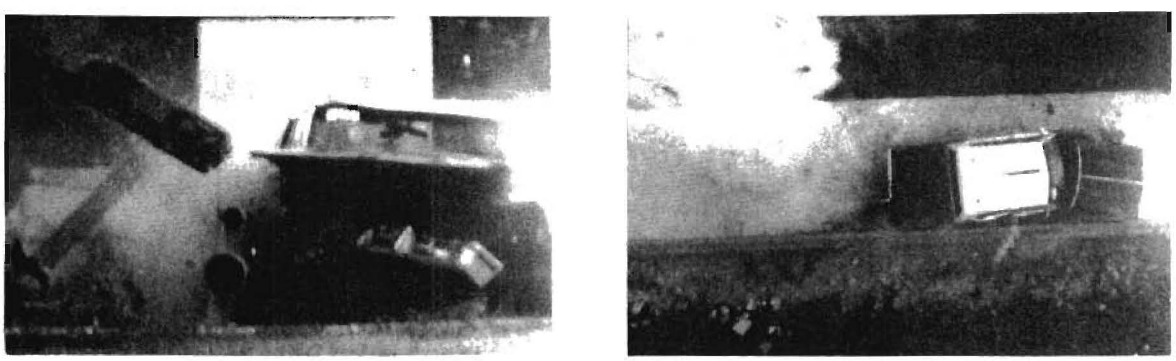


0.249 s

0.298 s

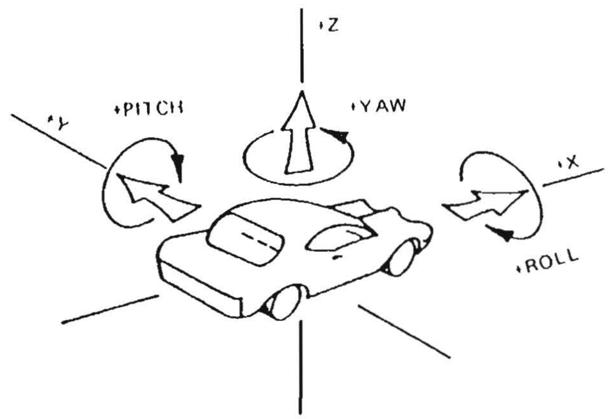


0.348 s

Figure D1. Sequential photographs for test 1185-4. (Continued)

APPENDIX E

Electronic Accelerometer, Roll, Pitch, and Yaw Data Test 1185-4



Axes are vehicle fixed. Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

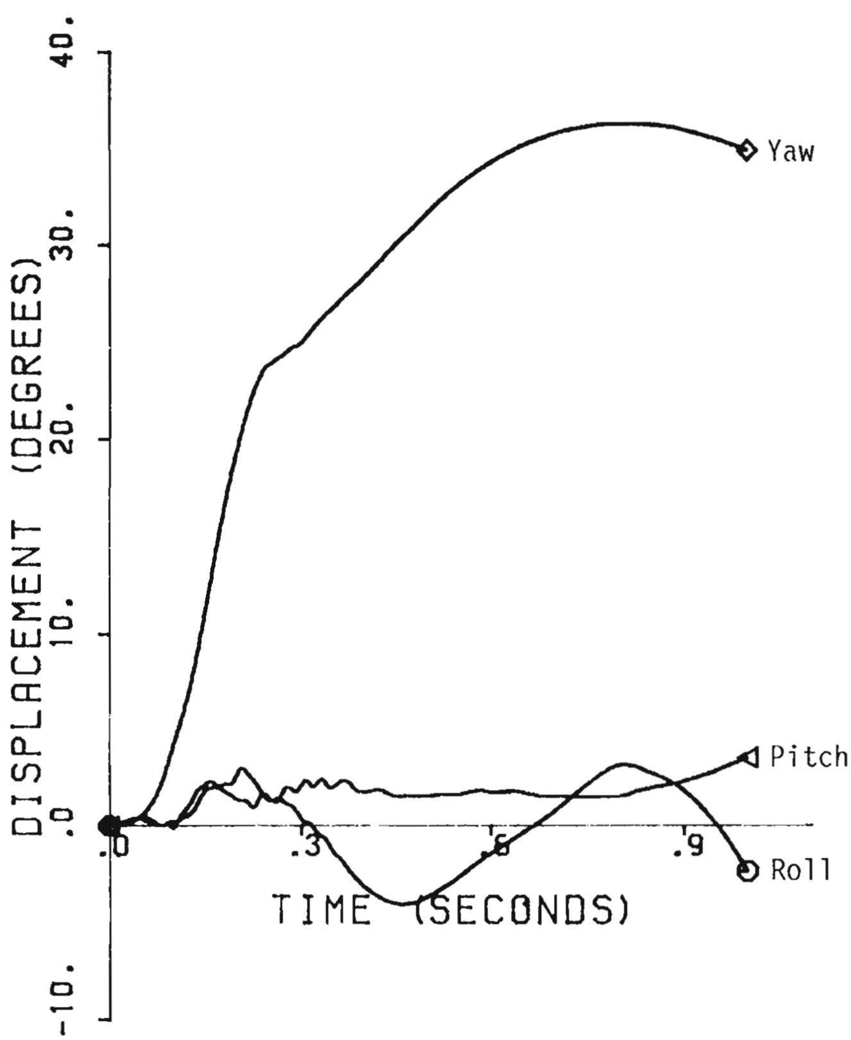


Figure E1. Vehicle angular displacements for test 1185-4.

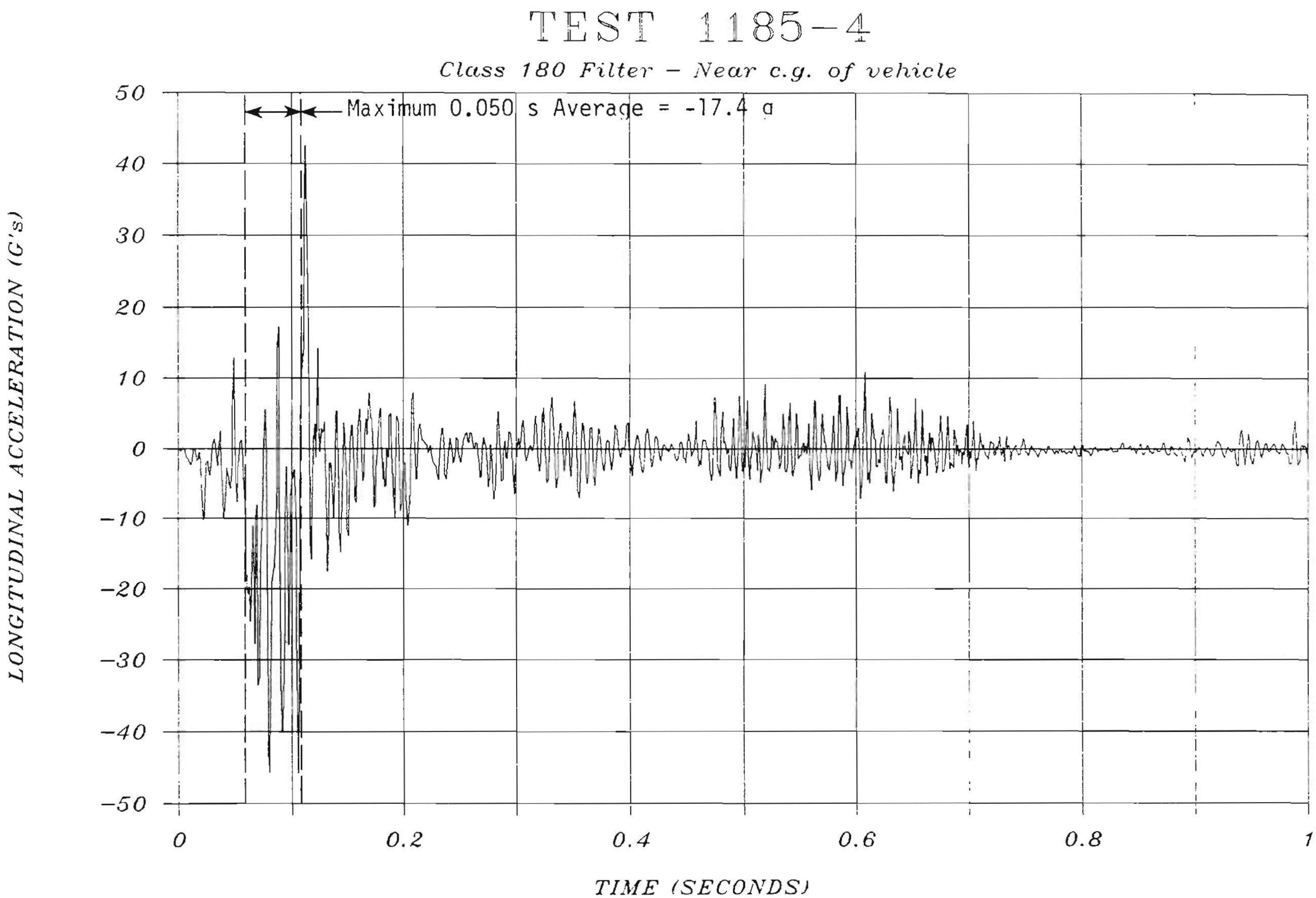


Figure E2. Vehicle longitudinal accelerometer trace for test 1185-4 (near center-of-gravity of vehicle).

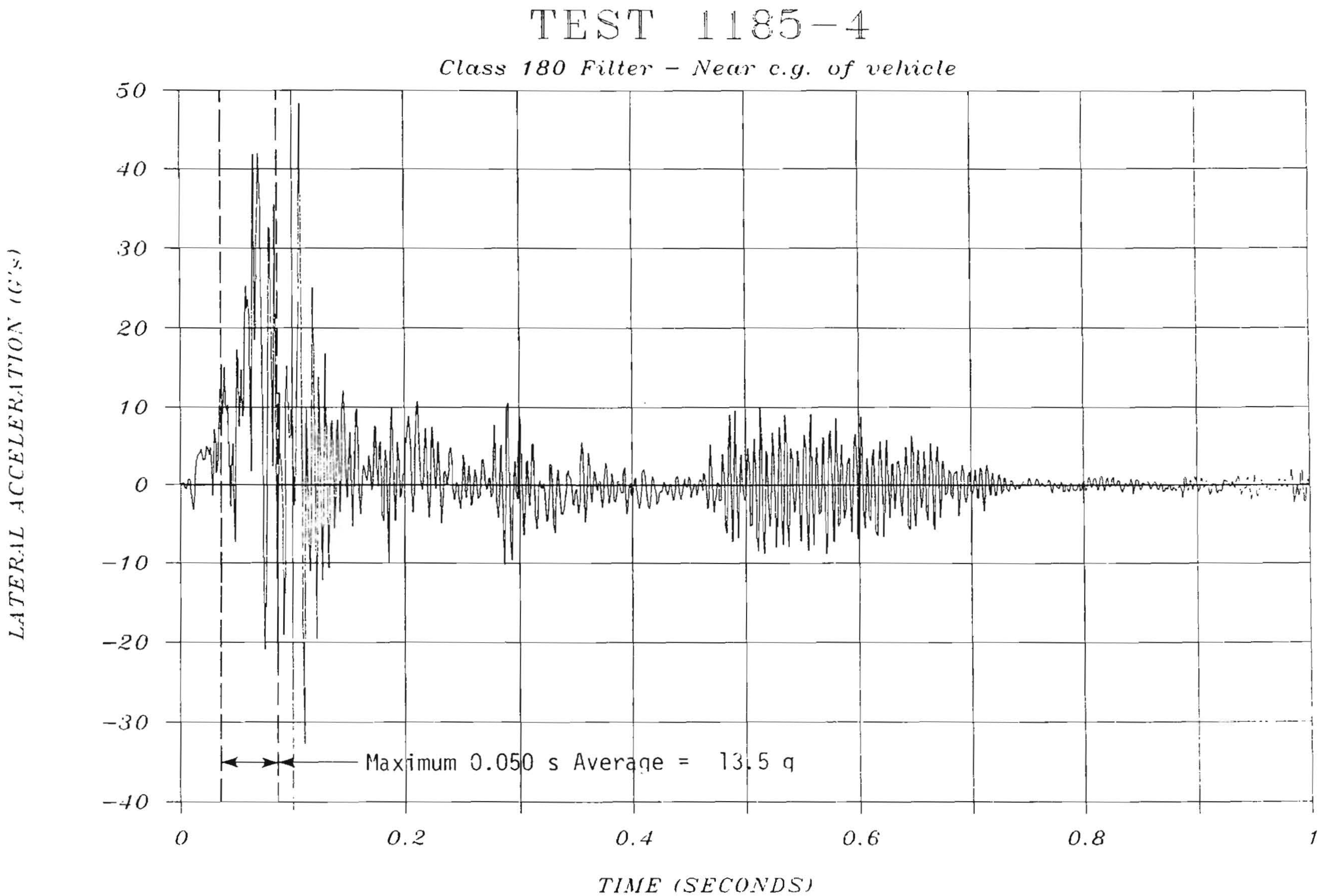


Figure E3. Vehicle lateral accelerometer trace for test 1185-4 (near center-of-gravity of vehicle).

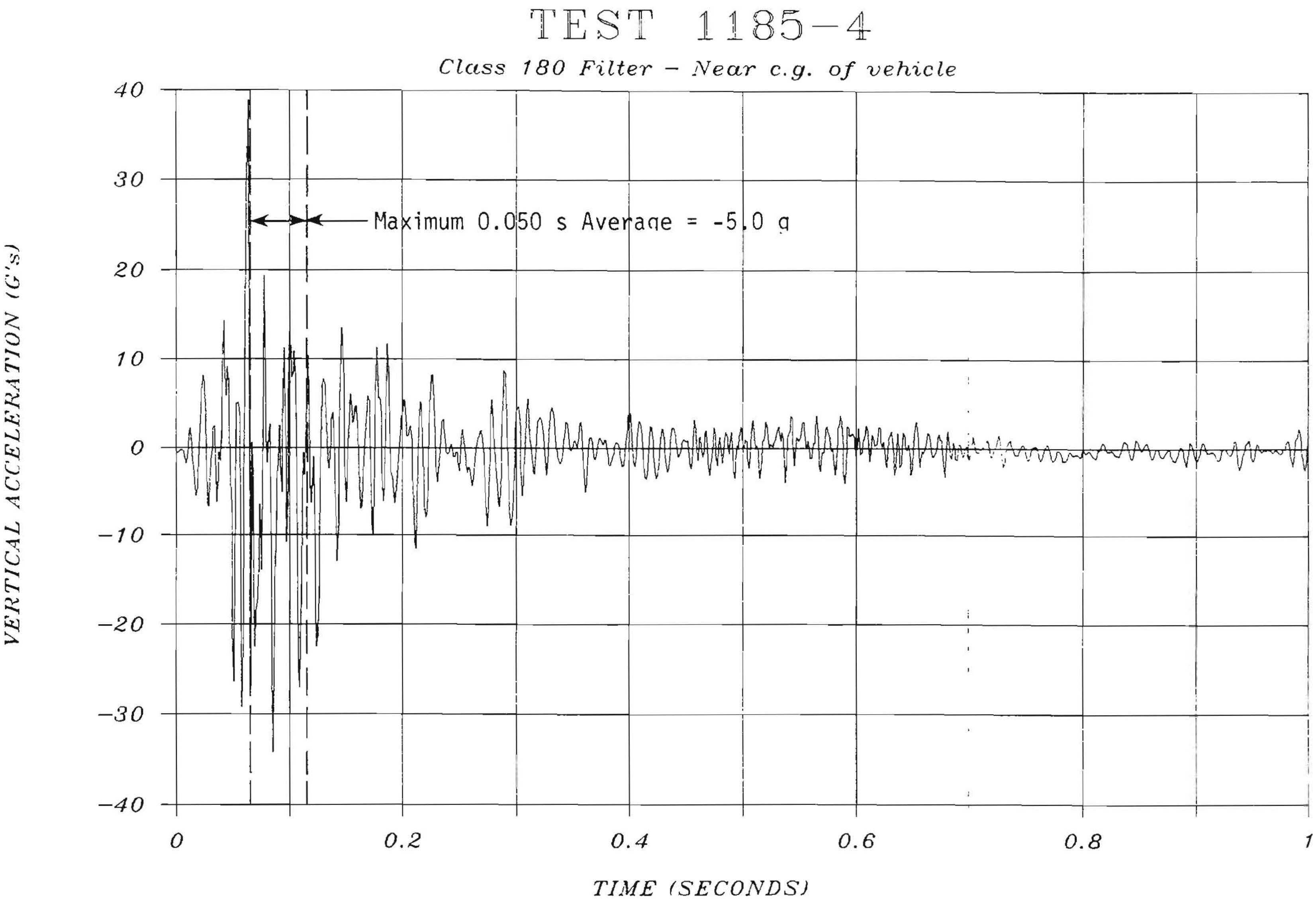


Figure E4. Vehicle vertical accelerometer trace for test 1185-4 (near center-of-gravity of vehicle).

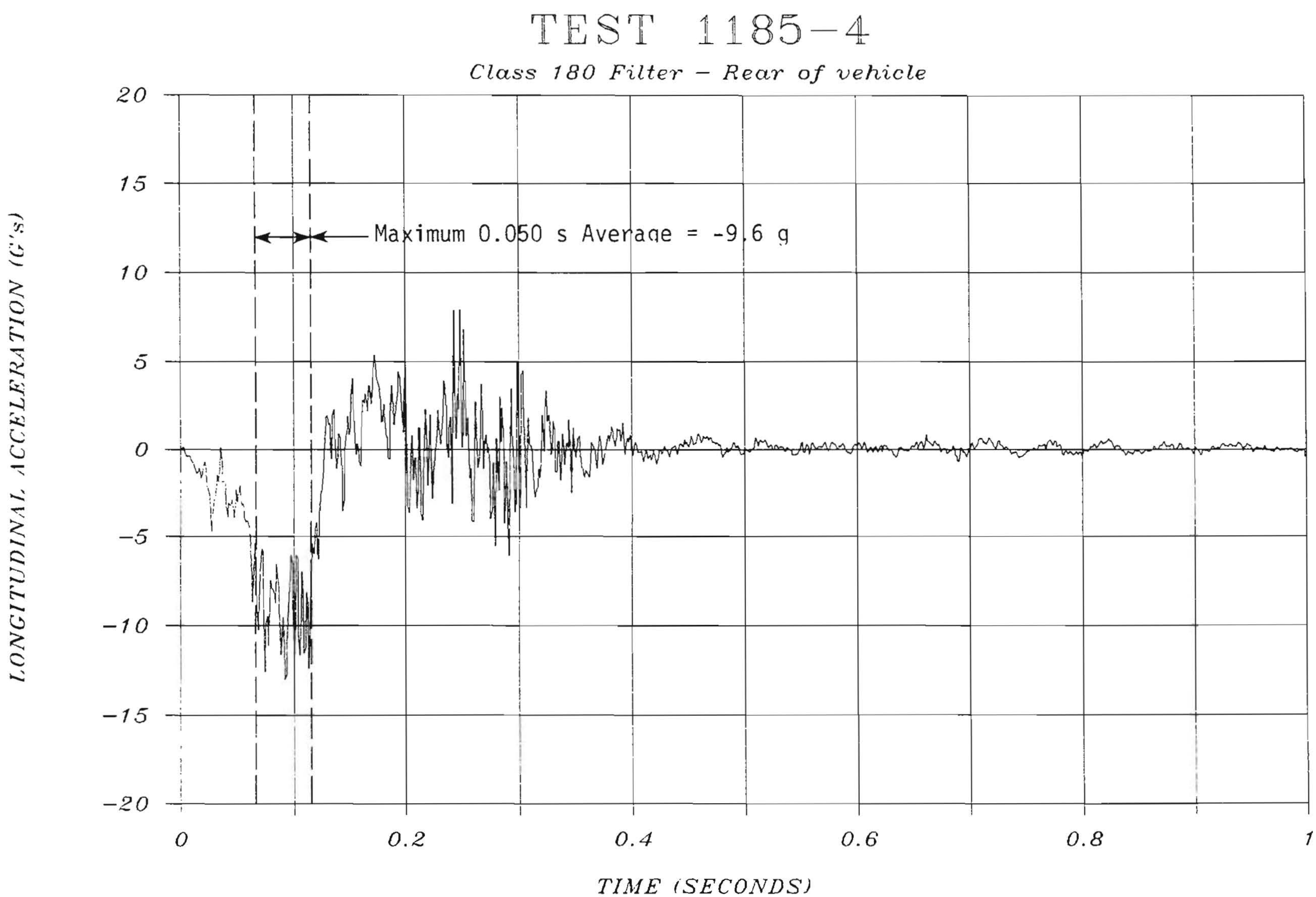


Figure E5. Vehicle longitudinal accelerometer trace for test 1185-4 (rear of vehicle).

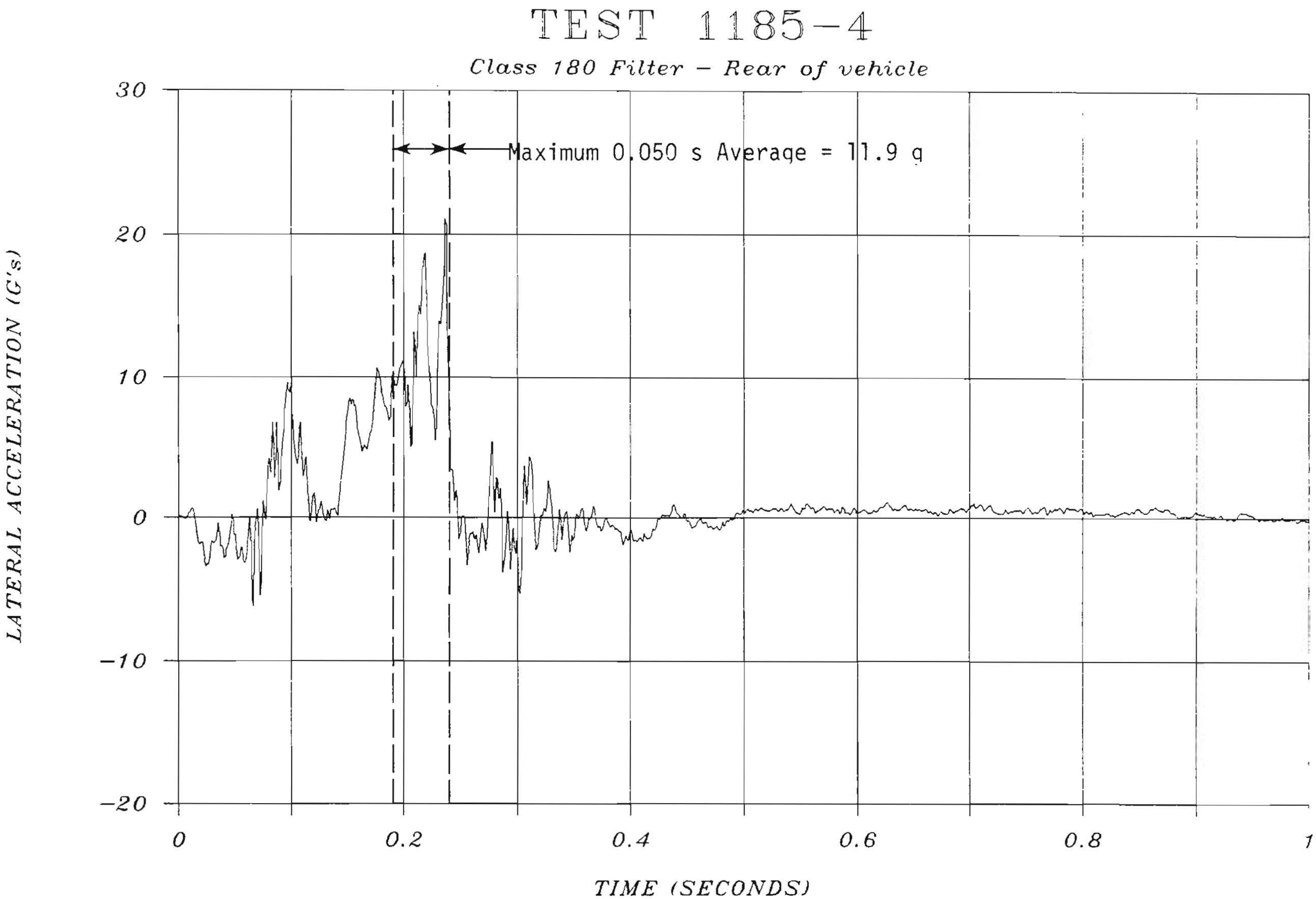


Figure E6. Vehicle lateral accelerometer trace for test 1185-4 (rear of vehicle).

APPENDIX F

Safety Evaluation Guidelines

Table F1. NCHRP Safety Evaluation Guidelines.

Evaluation Factors		Evaluation Criteria	Applicable to Minimum Matrix Test Conditions (see Table 3)
Structural Adequacy	A.	Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	10, 11, 12, 30, 40
	B.	The test article shall readily activate in a predictable manner by breaking away or yielding.	60, 61, 62, 63
	C.	Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle	41, 42, 43, 44, 45, 50, 51, 52, 53, 54
	D.	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	All
Occupant Risk	E.	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	All
	F.	Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24 in. (0.61m) forward and 12 in. (0.30m) lateral displacements, shall be less than: Occupant Impact Velocity-fps Longitudinal: $40/F_1$ — Lateral: $30/F_2$ and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations—g's Longitudinal: $20/F_3$ — Lateral: $20/F_4$ where F_1, F_2, F_3, and F_4 are appropriate acceptance factors (see Table 8, Chapter 4 for suggested values).	11, 12, 41, 42, 43, 44, 45, 50, 51, 52, 54, 60, 61, 62, 63
	G.	(Supplementary) Anthropometric dummy responses should be less than those specified by FMVSS 208, i.e., resultant chest acceleration of 60g, Head Injury Criteria of 1000, and femur force of 2250 lb (10 kN) and by FMVSS 214, i.e., resultant chest acceleration of 60 g, Head Injury Criteria of 1000 and occupant lateral impact velocity of 30 fps (9.1 m/s).	11, 12, 41, 42, 43, 44, 45, 50, 51, 52, 54, 60, 61, 62, 63
Vehicle Trajectory	H.	After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	All
	I.	In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	10, 11, 12, 30, 40, 42, 44, 53
	J.	Vehicle trajectory behind the test article is acceptable.	41, 42, 43, 44, 45, 50, 51, 53, 54, 60, 61, 62, 63