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16. Abstract

The Texas Type T202 concrete bridge rail is an extremely popular bridge rail in the state of Texas. The T202 rail consists of a concrete beam element 10 in. (25.4 cm) wide by 14 in. (35.6 cm) deep, mounted 27 in. (68.6 cm) high on concrete posts located 10 ft (3 m) apart, 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 between them. The beam element provides flexibility thus minimizing the need for frequent joints to control cracking. Thus, the T202 rail can be placed in long continuous lengths (up to 200 ft or more), giving good structural continuity and strength.

In 1979 the Modified T202 bridge rail (the T202 with an aluminum rail on top), was successfully crash tested with an 1,800 lb Honda at 59.4 mph (95.6 km/hr) and a 15 degree angle. The aluminum rail on top never contacted the Honda and thus had no influence on the test results. In order to qualify the T202 bridge rail for use on federal aid highways, it had to be crash tested with a 4,500 lb (2,045 kg) car at 60 mph (96.6 km/hr) and a 25 degree angle.

This report briefly summarizes the results of the Honda test conducted in 1979 and also presents the results of the 4,500 lb (2,045 kg) car at 60 mph (96.6 km/hr) and a 25 degree angle.

The bridge rail contained and smoothly redirected the test venicle. This test and the Honda test met all the safety evaluation criteria of NCHRP Report 230.

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CRASH TEST OF TEXAS T202 BRIDGE RAIL

by

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Research Report 1179-2

on

Research Study No. 2-5-88/89-1179
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

May 1989

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

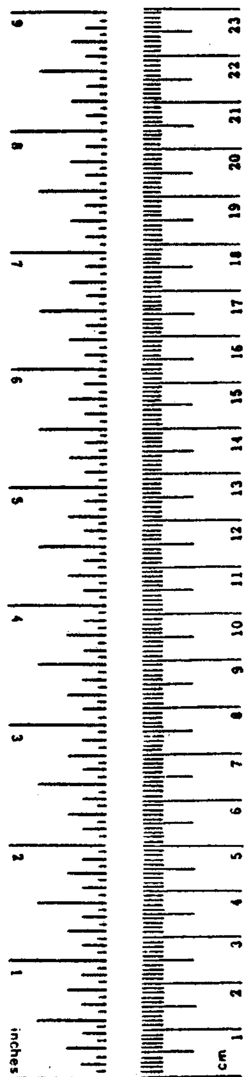
VOLUME

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)

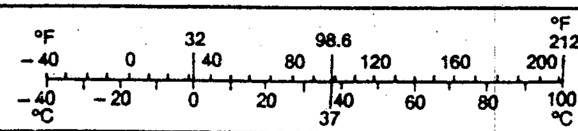
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

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 Railings, 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) and John J. Panak (Bridge Design 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

The Texas Type T202 concrete bridge rail is an extremely popular bridge rail in the state of Texas. The T202 rail consists of a concrete beam element 10 in. (25.4 cm) wide by 14 in. (35.6 cm) deep, mounted 27 in. (68.6 cm) high on concrete posts located 10 ft (3 m) apart, 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 between them. The beam element provides flexibility thus minimizing the need for frequent joints to control cracking. Thus, the T202 rail can be placed in long continuous lengths (up to 200 ft or more), giving good structural continuity and strength.

In 1979 the Modified T202 bridge rail (the T202 with an aluminum rail on top), was successfully crash tested with an 1,800 lb Honda at 59.4 mph (95.6 km/hr) and a 15 degree angle. The aluminum rail on top never contacted the Honda and thus had no influence on the test results. In order to qualify the T202 bridge rail for use on federal aid highways, it had to be crash tested with a 4,500 lb (2,045 kg) car at 60 mph (96.6 km/hr) and a 25 degree angle.

This report briefly summarizes the results of the Honda test conducted in 1979 and also presents the results of the 4,500 lb (2,045 kg) car at 60 mph (96.6 km/hr) and a 25 degree angle.

The bridge rail contained and smoothly redirected the test vehicle. This test and the Honda test met all the safety evaluation criteria of NCHRP Report 230.

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INTRODUCTION

The Texas Type T202 concrete bridge rail is an extremely popular bridge rail in the state of Texas. The T202 rail, shown by Figure 1, consists of a concrete beam element 10 in. (25.4 cm) wide by 14 in. (35.6 cm) deep mounted 27 in. (68.6 cm) high on concrete posts located 10 ft (3 m) apart, 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 between them. The beam element provides flexibility (as compared to a solid concrete wall), thus minimizing the need for frequent joints (every 35 to 40 ft) to control cracking. Thus the T202 rail can be placed in long continuous lengths (up to 200 ft or more), giving good structural continuity and strength.

In 1979 the Modified T202 bridge rail, shown by Figure 2 (the T202 with an aluminum rail on top), was successfully crash tested with an 1,800 lb Honda at 59.4 mph (95.6 km/hr) and a 15 degree angle (1). This test corresponds to Test No. 12 of NCHRP 230 (5). The aluminum rail on top never contacted the Honda and thus had no influence on the test results. Therefore, in order to qualify the T202 bridge rail for use on federal aid highways, it had to be crash tested with a 4,500 lb (2,045 kg) car at 60 mph (96.6 km/hr) and a 25 degree angle (NCHRP Test No. 10).

This report will briefly summarize the results of the Honda test conducted in 1979 and also present the results of the Oldsmobile (4,500 lb - 2,045 kg) test conducted in 1989.

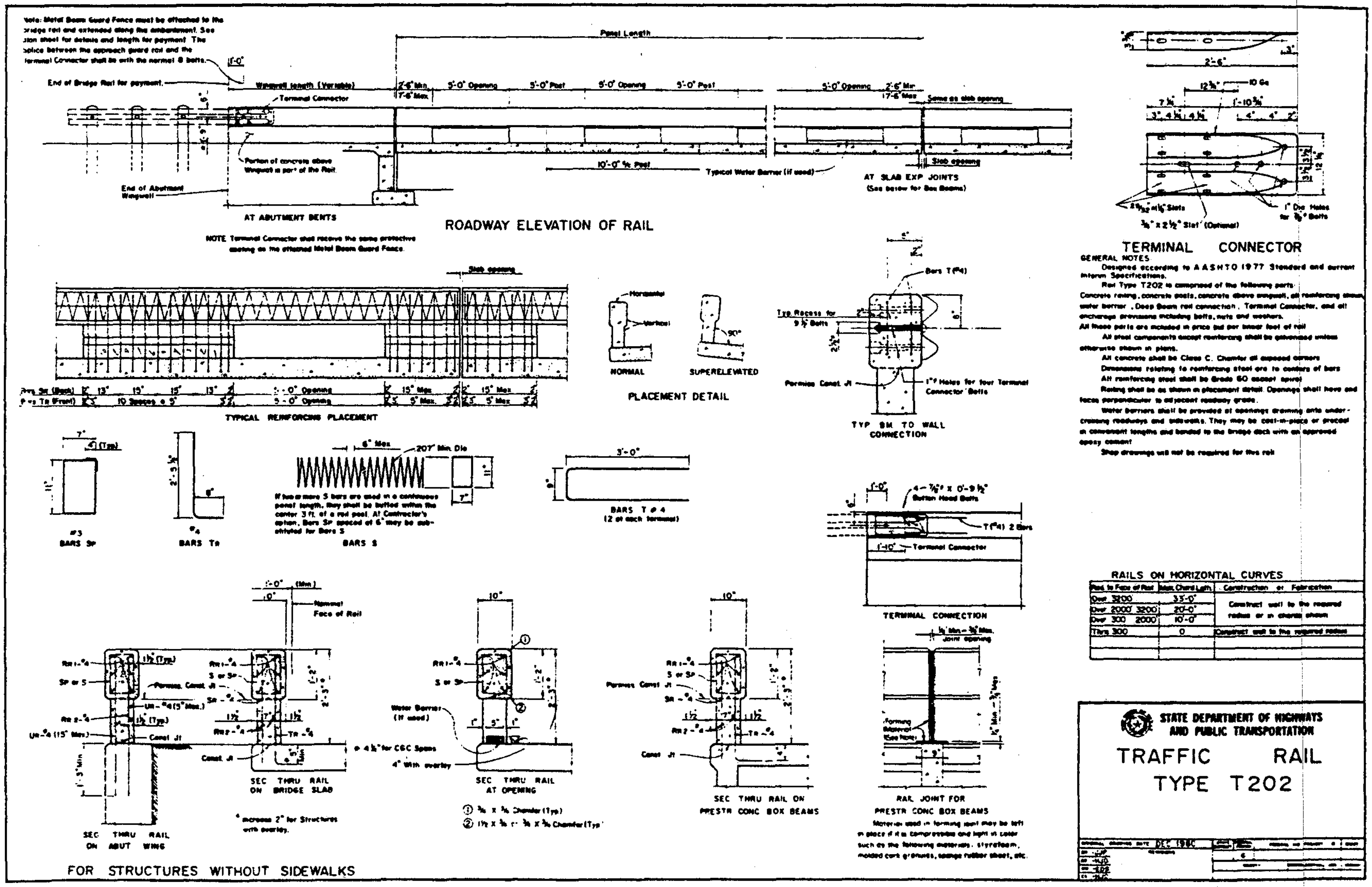


Figure 1. Traffic Rail Type T202.

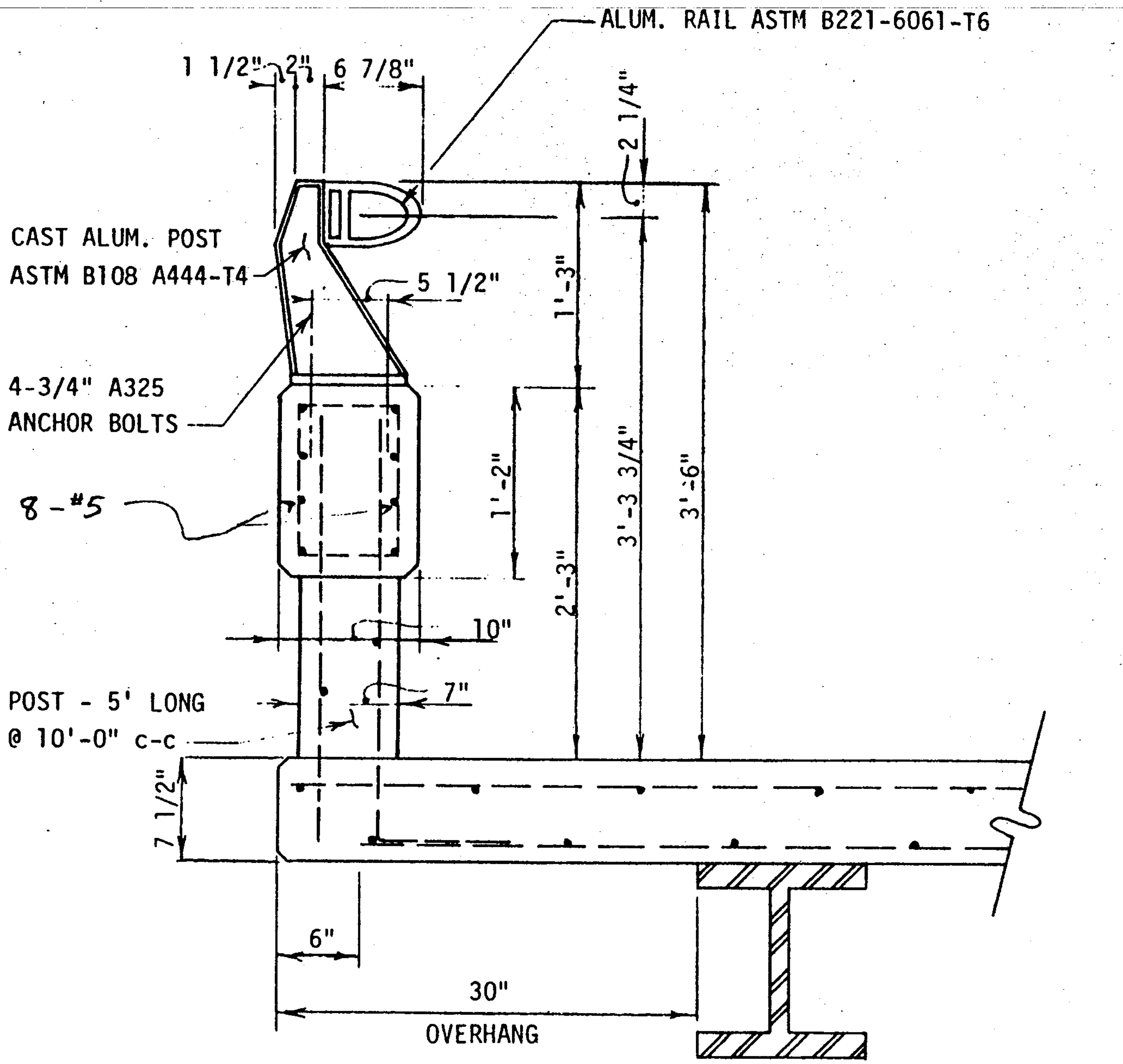
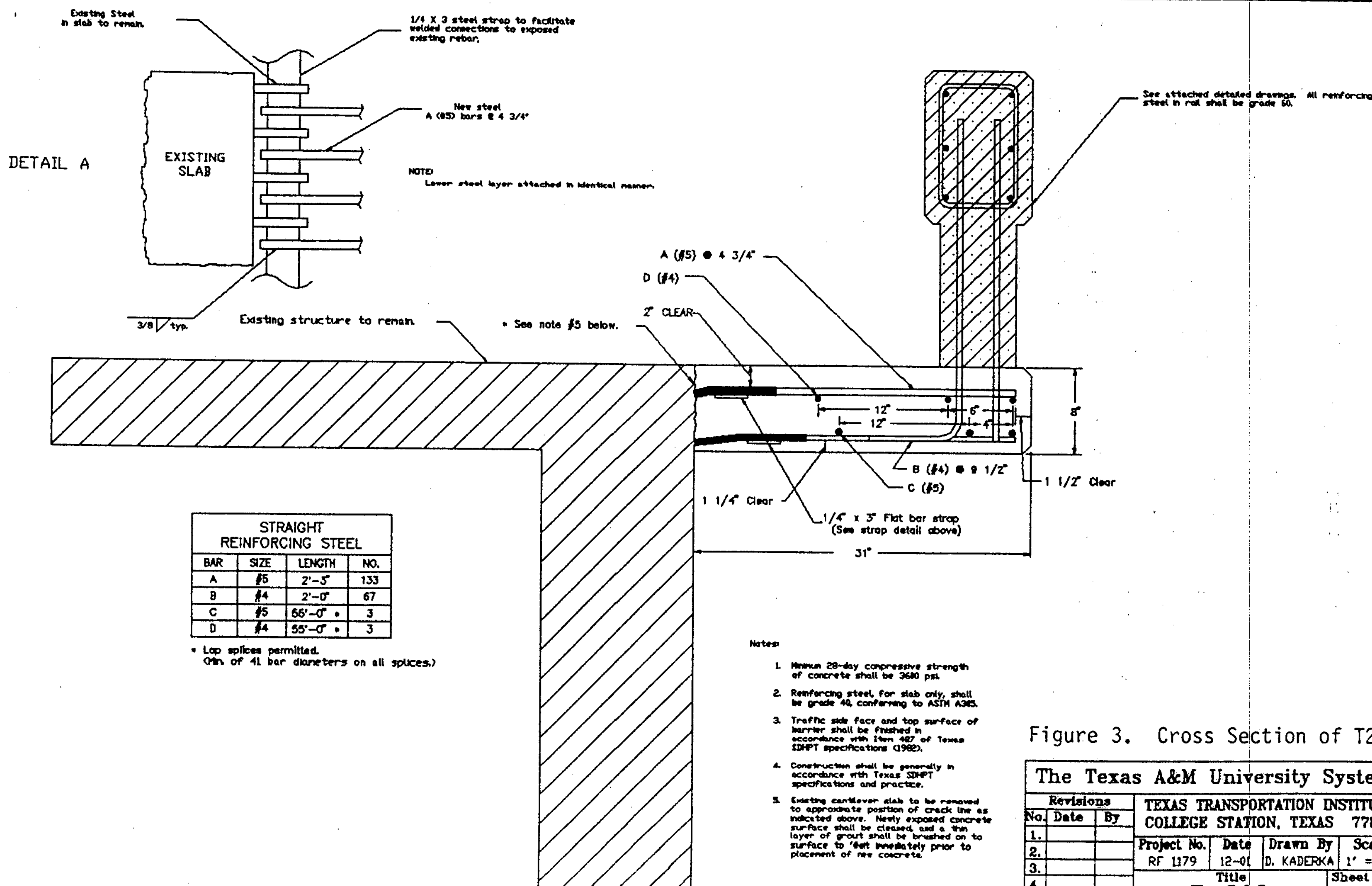


Figure 2. Cross Section of Modified T202 Bridge Rail used in Honda Test 2230-4.

DESCRIPTION OF BRIDGE RAIL

Figure 3 shows a cross section of the T202 bridge rail and deck and Figure 4 shows a plan view of the 52.5 ft length of bridge rail and deck as installed for crash testing. The concrete bridge deck was a typical 8 in. thick slab reinforced with No. 5 steel bars at 4.75 in. center-to-center spacing at the top and No. 4 bars at 9.5 in. center-to-center spacing on the bottom. The installation consisted of six posts and five 10 ft spans.

Figure 5 shows the bridge rail and Oldsmobile before the crash test. The automobile impacted the bridge rail midspan between post Nos. 2 and 3.



STRAIGHT REINFORCING STEEL			
BAR	SIZE	LENGTH	NO.
A	#5	2'-3"	133
B	#4	2'-0"	67
C	#5	56'-0" *	3
D	#4	55'-0" *	3

* Lap splices permitted.
(Min. of 41 bar diameters on all splices.)

Notes:

1. Minimum 28-day compressive strength of concrete shall be 3600 psi.
2. Reinforcing steel, for slab only, shall be grade 40, conforming to ASTM A305.
3. Traffic side face and top surface of barrier shall be finished in accordance with Item 427 of Texas SDHPT specifications (1982).
4. Construction shall be generally in accordance with Texas SDHPT specifications and practice.
5. Existing cantilever slab to be removed to approximate position of crack line as indicated above. Newly exposed concrete surface shall be cleaned, and a thin layer of grout shall be brushed on to surface to 'wet' immediately prior to placement of new concrete.

Figure 3. Cross Section of T202

The Texas A&M University System						
Revisions			TEXAS TRANSPORTATION INSTITUTE COLLEGE STATION, TEXAS 77843			
No.	Date	By	Project No.	Date	Drawn By	Scale
1.			RF 1179	12-01	D. KADERKA	1' = 4'
2.			Title			Sheet No.
3.			T 202			1 of 3
4.						
5.						

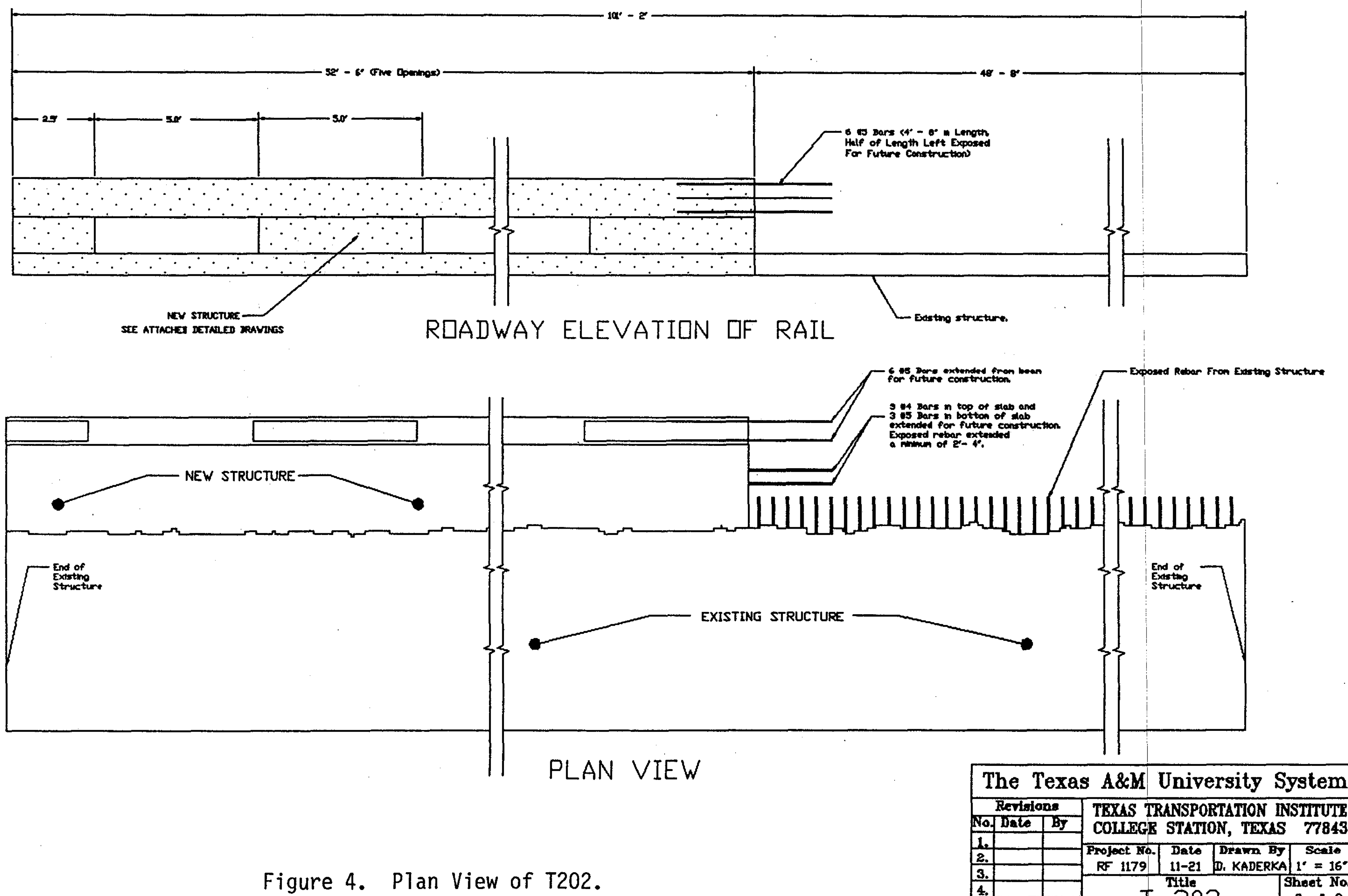
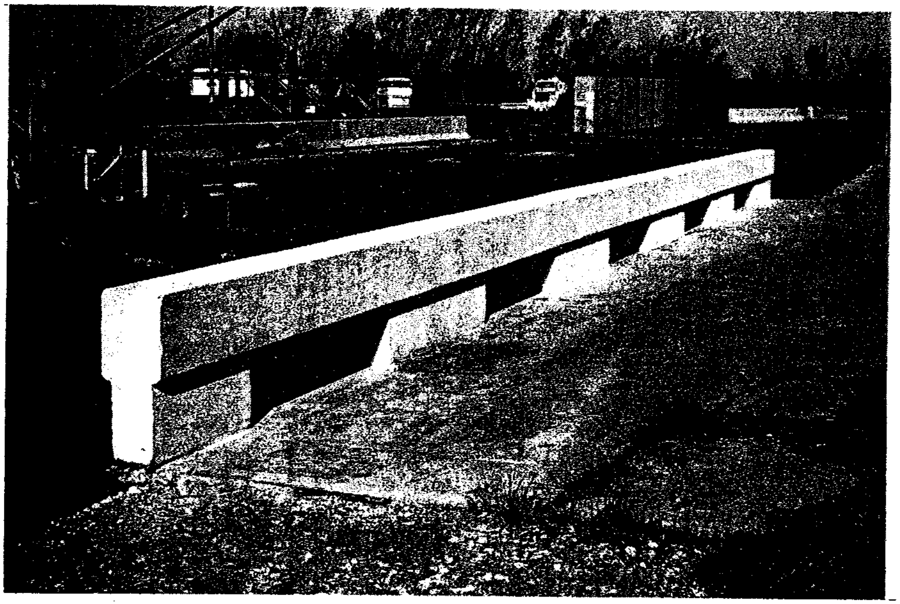
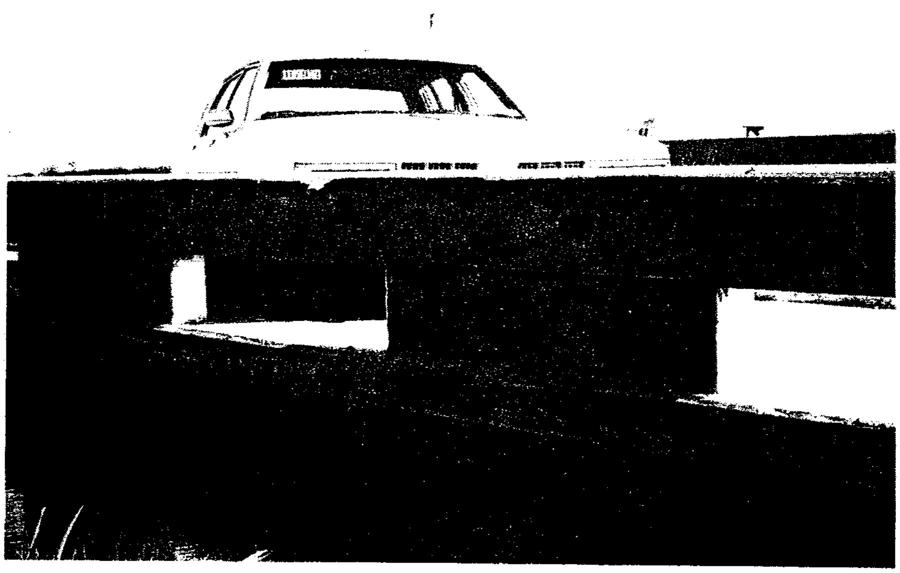


Figure 4. Plan View of T202.

Post No. 6 5 4 3 2 1





Post No. 2 3

Figure 5. T202 Bridge Rail and 1981 Oldsmobile before Test 1179-3.

CRASH TESTS

OLDSMOBILE CRASH TEST 1179-3

The 1981 Oldsmobile Ninety-Eight was directed into the 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 11.0 in. (27.9 cm), and it was 19.0 in. (48.3 cm) to the top of the bumper. Other dimensions and information on the test vehicle are given in Figure 6. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 59.2 mi/h (95.3 km/h) and the angle of impact was 26.0 degrees. The vehicle impacted the bridge rail approximately 18 ft (5.5 m) from the end. The right front wheel made contact with the bridge rail shortly after impact. The vehicle began to redirect at 0.057 seconds. By 0.113 seconds the vehicle had deformed to the A-pillar and the windshield broke. At 0.219 seconds, the vehicle began to move parallel with the bridge rail, traveling at a speed of 44.5 mi/h (71.6 km/h). The rear of the vehicle impacted the bridge rail at 0.224 seconds. The vehicle lost contact with the bridge rail at 0.373 seconds traveling at 42.8 mi/h (68.9 km/h) and a 9.0 degree exit angle. The brakes were then applied and the vehicle yawed clockwise and subsequently came to rest 125 ft (30.5 m) from the point of impact. Figure 7 shows the bridge rail and vehicle after the test. Sequential photographs are shown in Appendix B.

As can be seen in Figure 8, there were tire marks on the face of the bridge rail for a distance of 11 ft (3.4 m). There were also marks on post 3 just downstream of impact. Hairline cracks were also in evidence at various locations in the immediate vicinity of the collision, along the top, front and rear side of the rail, and also in the bridge deck itself (see Figures 9 and 10).

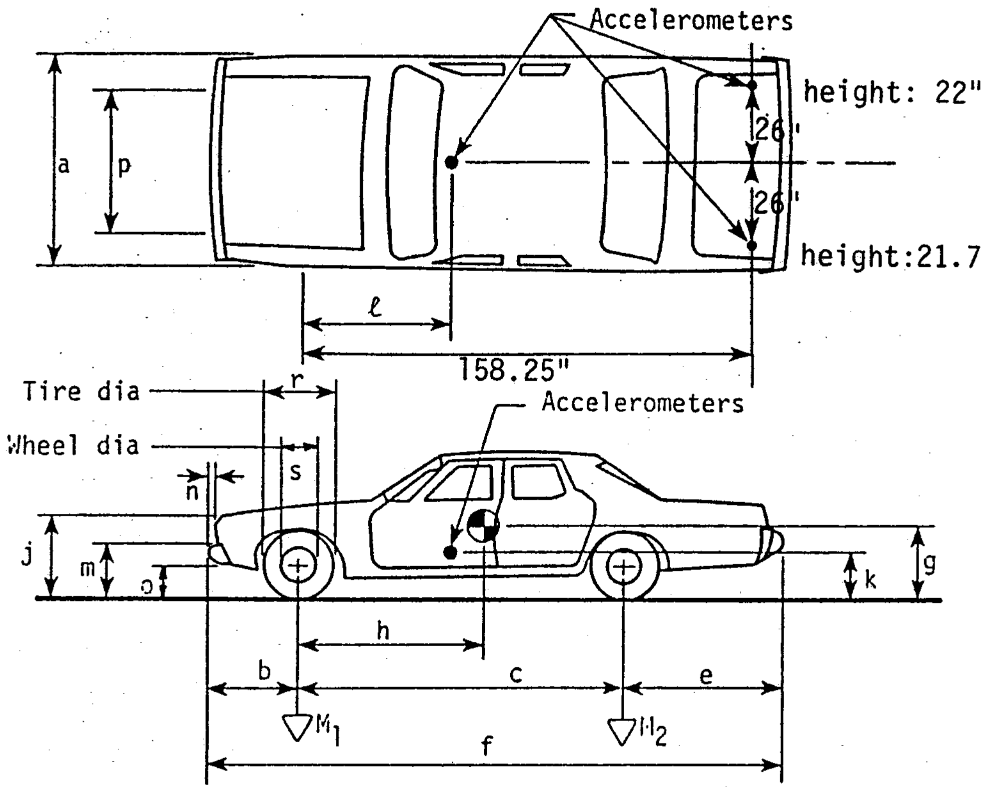
The vehicle sustained severe damage to the right side, as shown by Figures 11 and 12. Maximum crush at the right front corner at bumper height was 14.0 in. (35.6 cm). The right A-arm, the tie rod, and the upper and lower ball joints were damaged and the subframe was bent. The instrument panel in the passenger compartment was bent as well as the floor pan and roof, and the windshield was broken. The right front rim was bent and the tire damaged. There was damage to the hood, grill, bumper, right front quarter panel, the right front and rear doors, the right rear quarter panel and the rear bumper.

Date: ______ Test No.: 1179-3 VIN: 1G3AX69NXBM235227

Make: Oldsmobile Model: Ninty Eight Year: 1981 Odometer: 00847

Tire Size: 75R-15 Ply Rating: 4 Bias Ply: __ Belted: __ Radial: x

Tire Condition: good __
fair x
badly worn __



Vehicle Geometry - inches

a	75.75	b	43.5
c	119.0	d*	58.0
e	56.5	f	219.0
g		h	52.2
i	----	j	31.5
k	19.75	ℓ	33.5
m	19.0	n	6.0
o	11.0	p	61.75
r	27.5	s	16.5

Engine Type: V8

Engine CID: 350 diesel

Transmission Type:

<u>Automatic</u> or Manual

FWD or <u>RWD</u> 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

4-wheel weight for c.g. det. ℓf 1287 rf 1240 ℓr 989 rr 984

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2485	2527	
M_2	1637	1973	
M_T	4122	4500	

Note any damage to vehicle prior to test:

______

______

*d = overall height of vehicle

Figure 6. Test Vehicle Properties (Test 1179-3).

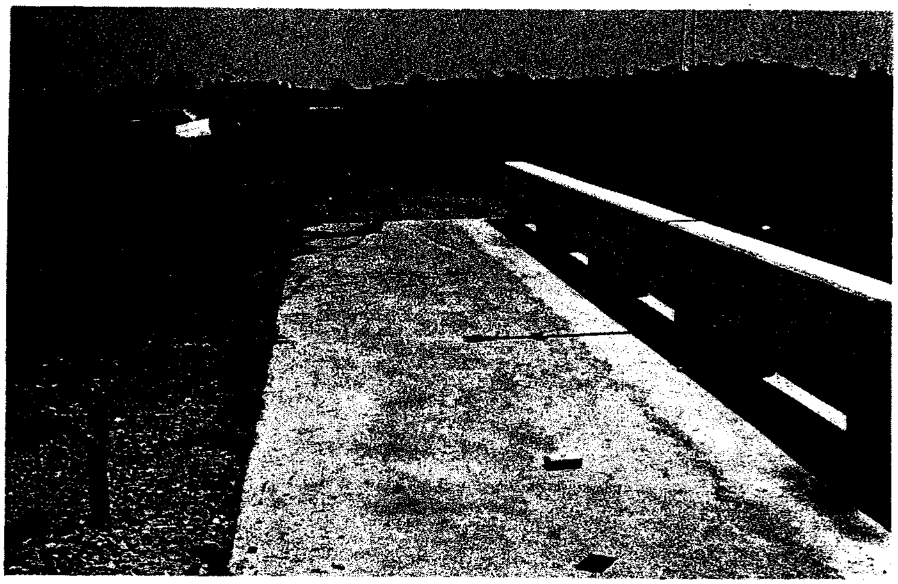
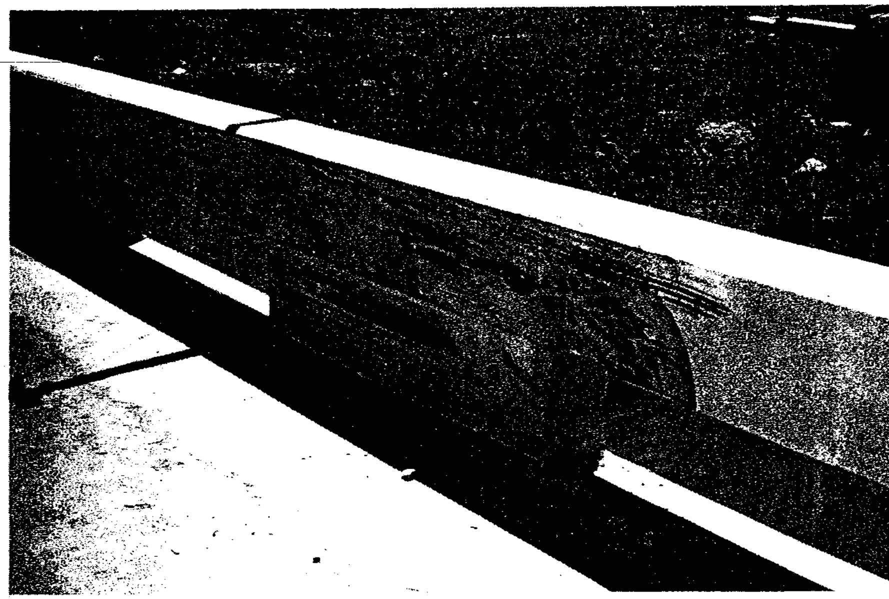


Figure 7. Bridge Rail and Vehicle after the Crash Test.



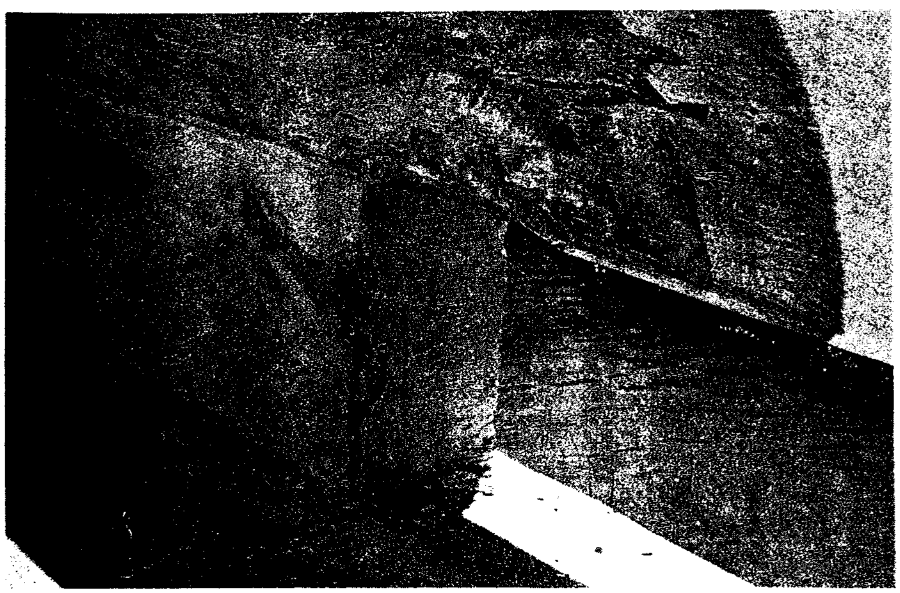
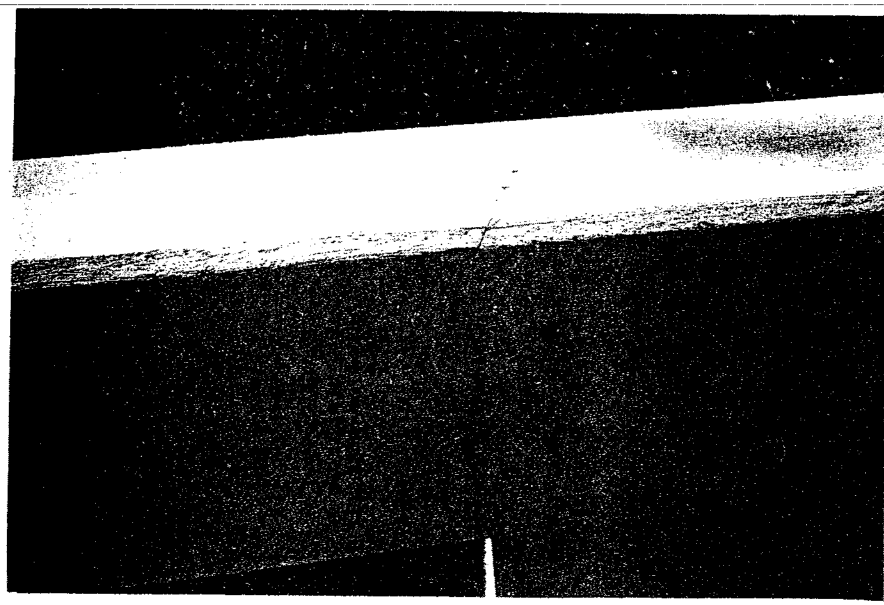
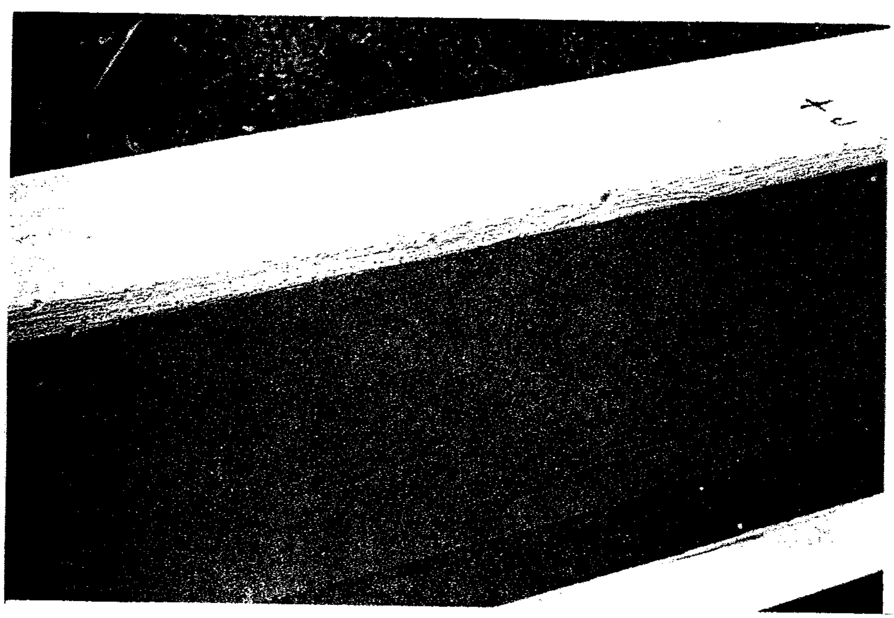


Figure 8. Post 3 of T202 Bridge Rail after Test 1179-3.

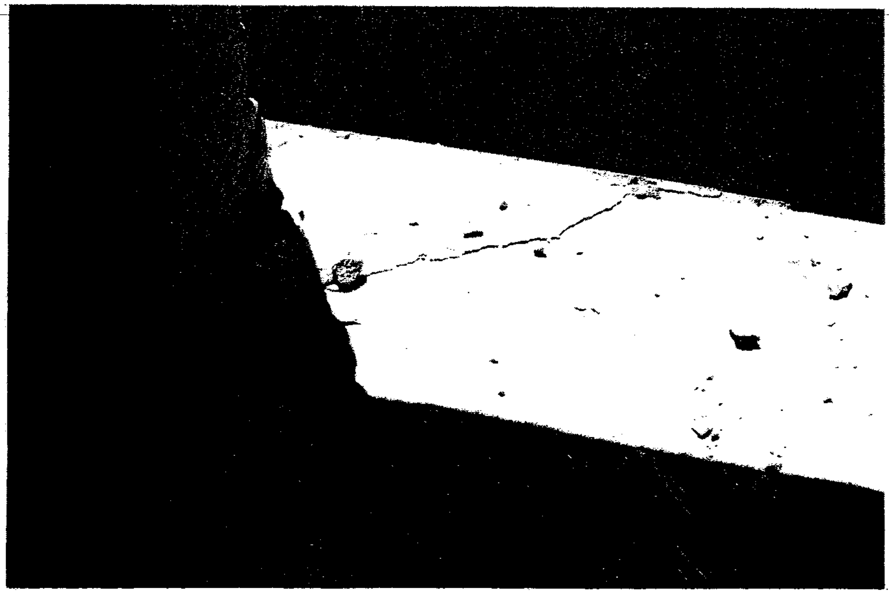


Post 2



Post 4

Figure 9. Cracks in Bridge Rail at Posts 2 and 4.



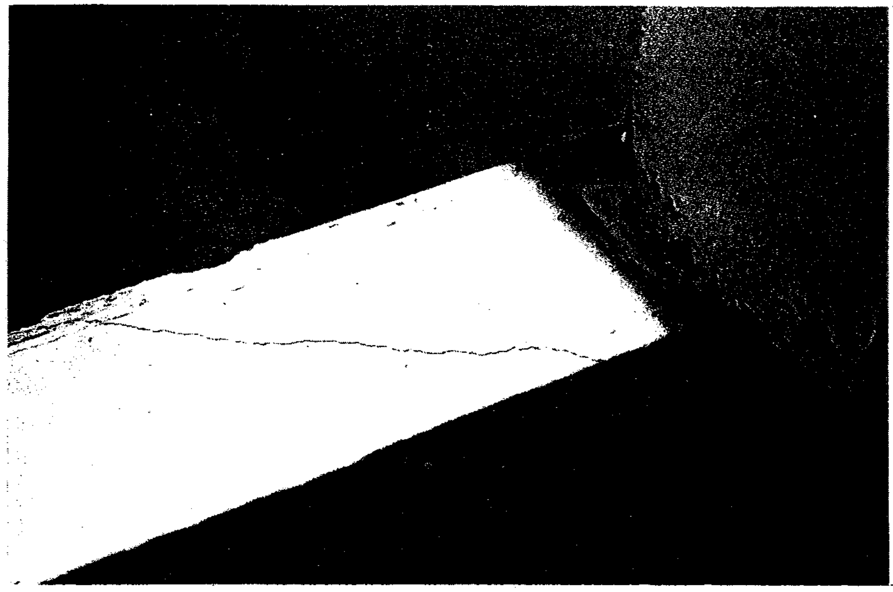


Figure 10. Cracks in bridge deck at post 3.

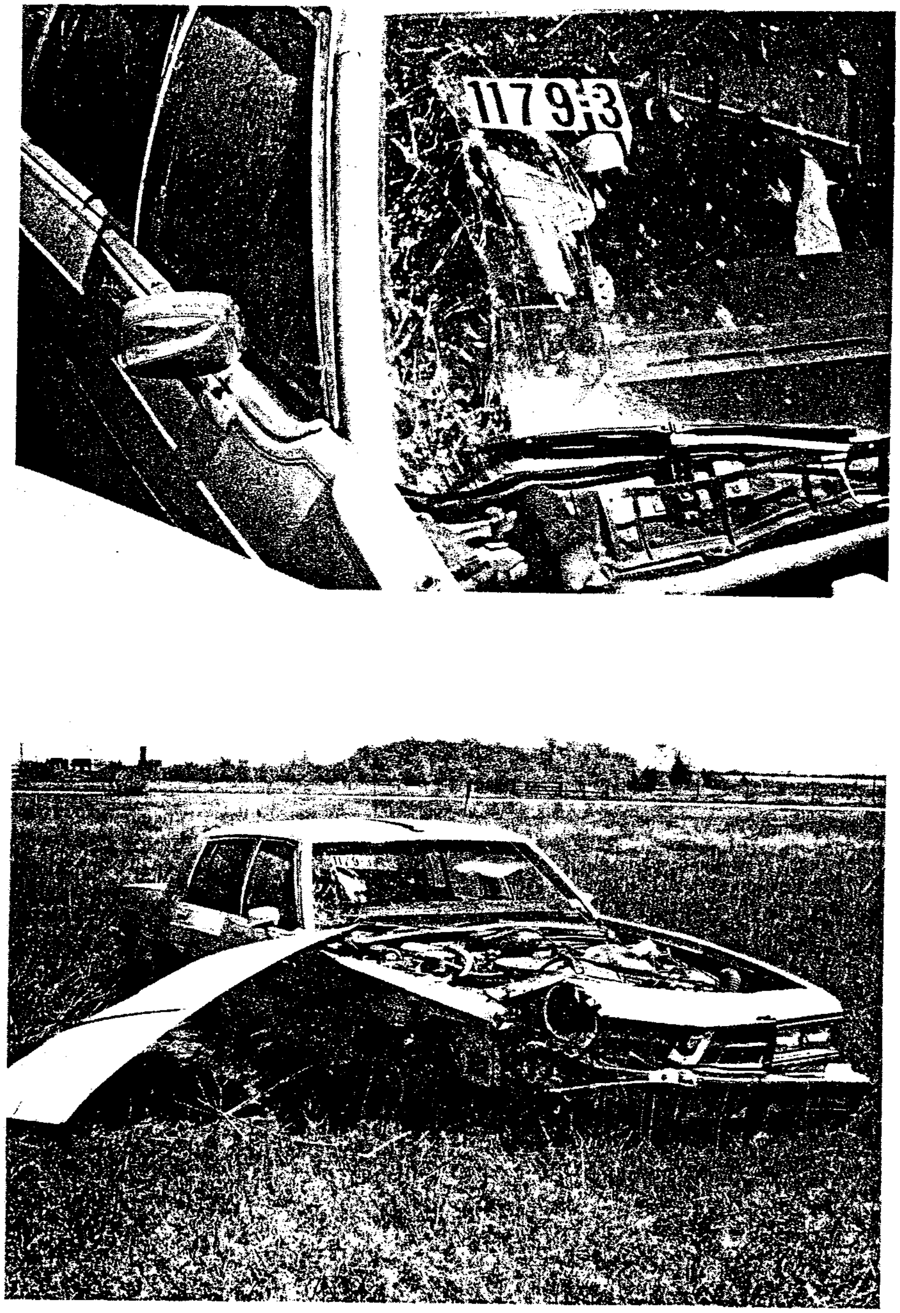
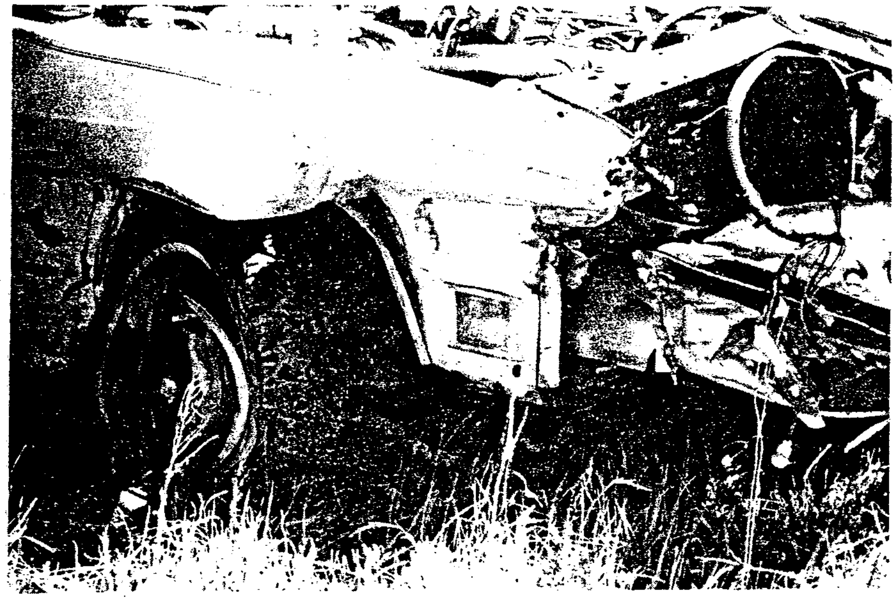


Figure 11. Damage to Windshield and Right Front of Vehicle after Test 1179-3.



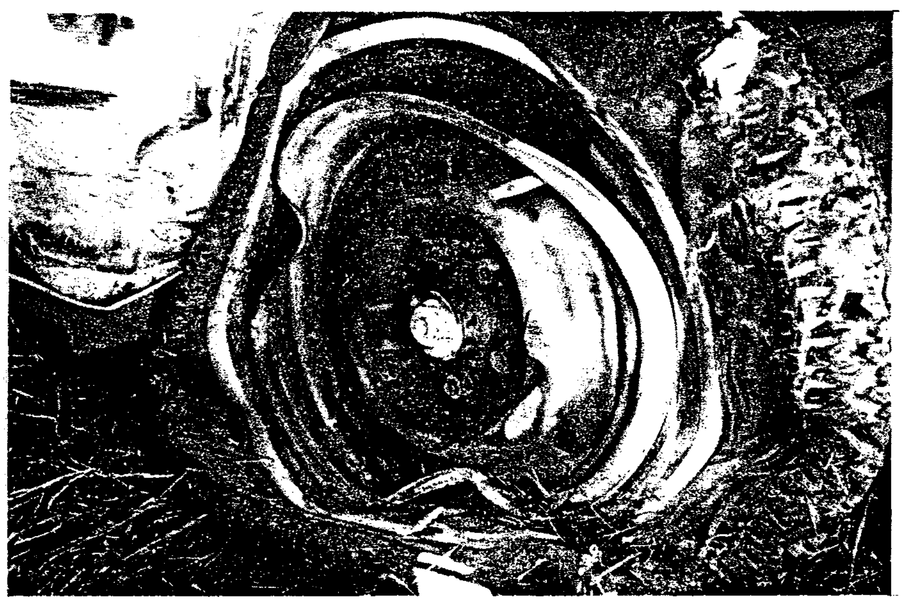


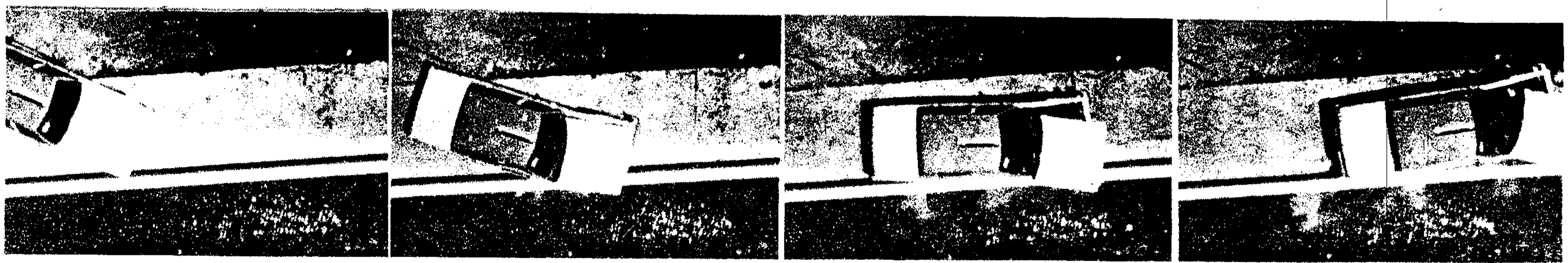
Figure 12. Damage to Right Front Wheel of Vehicle.

TEST RESULTS

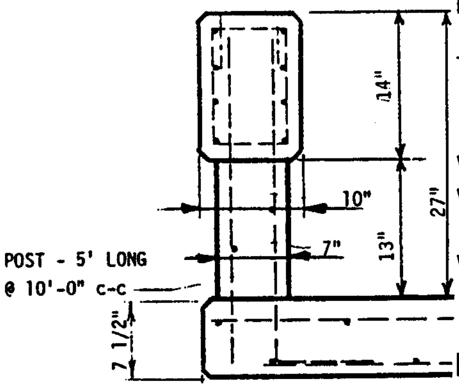
Impact speed was 59.2 mi/h (95.3 km/h) and the angle of impact was 26.0 degrees. The vehicle exited the rail at 42.8 mi/h (68.9 km/h) and 9.0 degrees. NCHRP Report 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted at 15 degree impact angles. These limits do not apply to tests conducted at 25 degree impact angles but were computed and reported for information only. Occupant impact velocity was 29.4 ft/s (9.0 m/s) in the longitudinal direction and 23.6 ft/s (7.2 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -5.8 g (longitudinal) and 5.9 g (lateral). These data and other pertinent information from the test are summarized in Figure 13. Vehicular angular displacements and vehicular accelerations versus time traces filtered with Class 180 filters are presented in Appendix C. These data were further analyzed to obtain 0.050-second average accelerations versus time. The maximum 0.050-second averages measured at the center of gravity were -11.8 g (longitudinal) and 11.0 g (lateral).

CONCLUSIONS

The bridge rail contained and smoothly redirected the test vehicle with minimal lateral movement of the bridge rail. There was evidence of slight cracking in the bridge rail and the bridge deck in the immediate vicinity of the collision. The vehicle remained upright and relatively stable during the collision. The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes (exit angle 9 degrees). This test met all the safety evaluation criteria of NCHRP Report 230.



0.000 s 0.100 s 0.199 s 0.311 s



Test No. 1179-3
Date 03/30/89

Test Installation . . . T202 Bridge Rail
Installation length . . 52.5 ft (16 m)

Vehicle . . . . 1981 Oldsmobile 98
Vehicle Weight
  Test Inertia . . . . . 4,500 lb (2,043 kg)
Vehicle Damage Classification
  TAD . . . . 01FR4 & 01RD6
  CDC . . . . 01FZEK3 & 01RDEW3
Maximum Vehicle Crush . 14.0 in (35.6 cm)

Impact Speed . . . 59.2 mi/h (95.3 km/h)
Impact Angle . . . 26.0 degrees
Speed at Parallel . 44.5 mi/h (71.6 km/h)
Exit Speed . . . . 42.8 mi/h (68.9 km/h)
Exit Trajectory . . 9.0 degrees
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal . . -11.8 g
  Lateral . . . . . 11.0 g
Occupant Impact Velocity
  Longitudinal . . 29.4 ft/s (9.0 m/s)
  Lateral . . . . . 23.6 ft/s (7.2 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . -5.8 g
  Lateral . . . . . 5.9 g

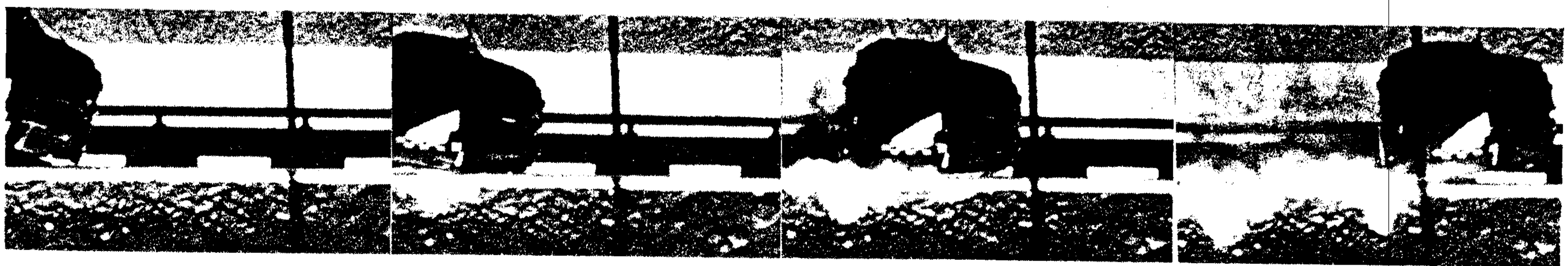
Figure 13. Summary of results for test 1179-3.

HONDA CRASH TEST 2230-4

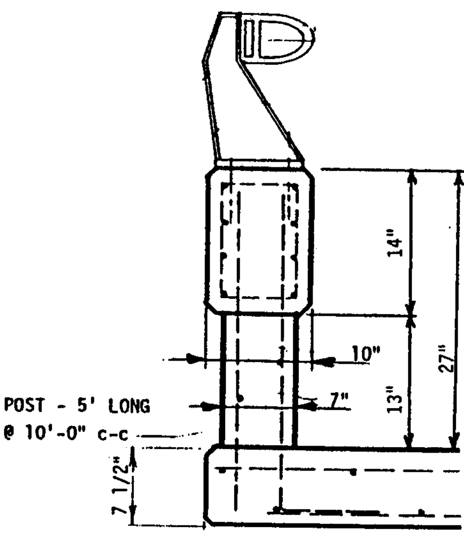
Figure 14 presents a summary of the Honda crash test conducted in 1980 and reported in Research Report 230-3 (reference 1). The 1,800 lb (817 kg) Honda impacted the bridge rail at 59.4 mi/h (95.6 km/h) and a 15.0 degree angle. The impact point was at midspan between two posts. The vehicle exit speed was 43.4 mi/h and 6.5 degrees.

The safety evaluation guidelines of NCHRP Report 230 (see Appendix D) apply to this particular test since it would be Test No. 12 in the recommended minimum test matrix.

The summary of the crash test data presented in Figure 14 meets these requirements with only one exception--vehicle trajectory--Item I. This item says, "In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 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." The exit angle was 6.5 degrees which is less than the 9 degrees recommended and the change in speed of the vehicle was 16 mph which is 1 mph greater than the 15 mph recommended overall. This test 2230-4 is considered to meet these safety evaluation criteria.



0.000 s | 0.069 s | 0.161 s | 0.305 s



Test No. 2230-4
Date 02/06/80

Test Installation . Mod. T202 Bridge Rail
Installation length . . 101 ft (31 m)

Vehicle . . . . 1974 Honda Civic
Vehicle Weight
  Test Inertia . . . . . 1,800 lb (817 kg)
Vehicle Damage Classification
  TAD 01RFQ4
  CDC 01RFEE7

Impact Speed . . . 59.4 mi/h (95.6 km/h)
Impact Angle . . . 15.0 degrees
Speed at Parallel . 47.4 mi/h (76.3 km/h)
Exit Speed . . . . 43.4 mi/h (69.9 km/h)
Exit Trajectory . . 6.5 degrees
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal . . -6.6 g
  Lateral . . . . . 12.2 g
Occupant Impact Velocity
  Longitudinal . . 23 ft/s (7 m/s)
  Lateral . . . . . 22 ft/s (6.7 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . -1 g
  Lateral . . . . . 4 g

Figure 14. Summary of results for test 2230-4.

SUMMARY and CONCLUSIONS

The basic 27 in. high Texas Type T202 concrete bridge traffic railing has now been crash tested in accordance with NCHRP 230 Tests No. 10 and No. 12, the recommended minimum test matrix required for Service Level 2. The bridge rail contained and smoothly redirected the test vehicle and has met the safety evaluation criteria of NCHRP 230.

REFERENCES

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

2. Hirsch, T.J., and Perry Romere, "Crash Test of Modified Texas C202 Bridge Rail," Research Report 1179-1, Texas Transportation Institute, Texas A&M University, June 1988.

3. 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.

4. Hirsch, T.J., "Longitudinal Barriers for Buses and Trucks, State of the Art," Research Report 416-2F, Texas Transportation Institute, Texas A&M University, Feb. 1986.

5. 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.

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

7. 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.

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

9. 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.

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

11. Guide Specifications for Bridge Railings-1989, an alternative bridge railing specification in the AASHTO Standard Specifications for Highway Bridges, American Association of State Highway Officials, 1983.

12. 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.

13. Hirsch, T.J., "Longitudinal Barriers for Buses and Trucks," Transportation Research Record 1052, Transportation Research Board, 1986.

0.000 s | 0.088 s | 0.176 s | 0.264 s

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.

APPENDIX A

Instrumentation and Data Analysis

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. In addition, yaw, pitch, and roll rates were measured by on-board 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.

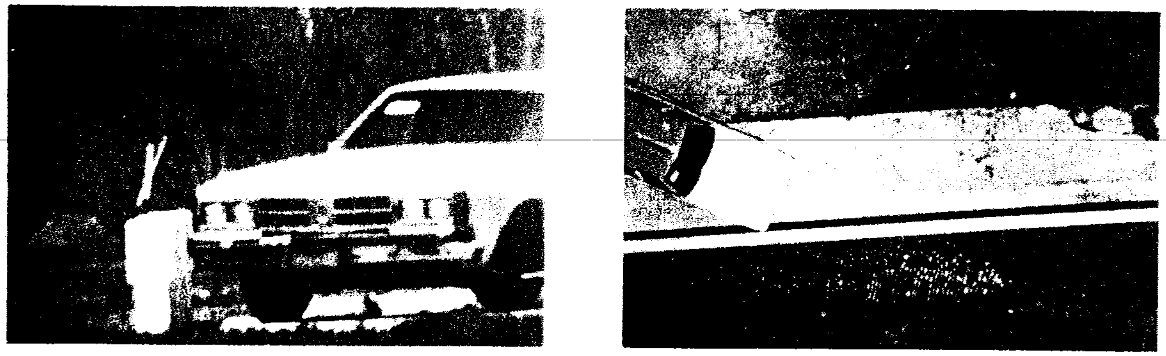
The VEHICLE program also uses digitized data from vehicle-mounted linear accelerometers to compute vehicle accelerations, areas enclosed by acceleration-time curves, changes in velocity, changes in momentum, instantaneous forces, average forces, and maximum average accelerations over 0.050-second intervals in each of three directions. The VEHICLE program also 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.

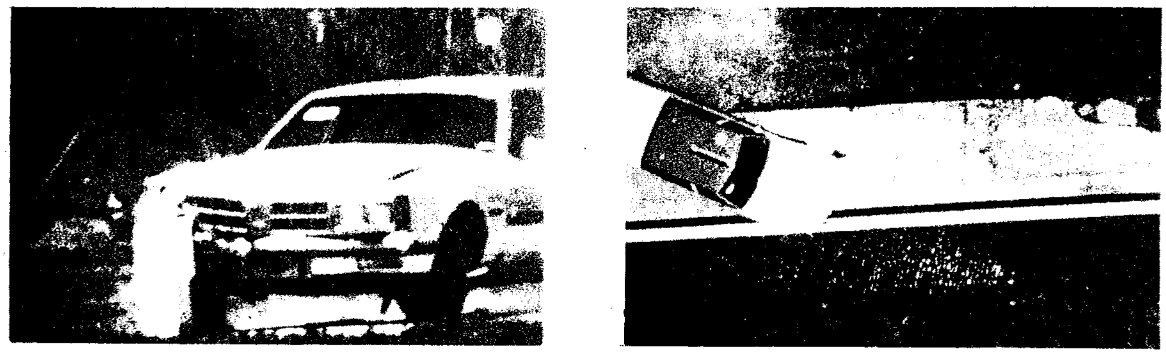
Still photography, real-time cine, and video were used to record conditions of the test vehicle and bridge rail before and after the test. Video and real-time and high-speed cine were used to document the test. One high-speed camera was placed to have a field of view parallel to and aligned with the 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

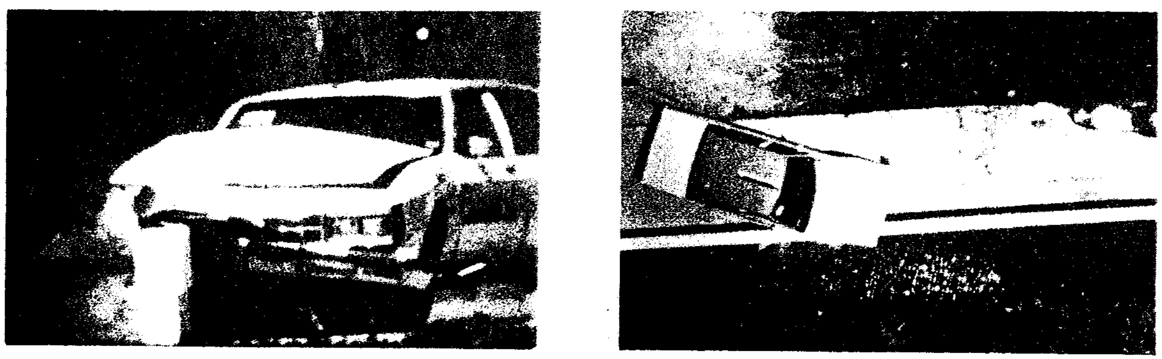
Sequential Photographs of Test 1179-3



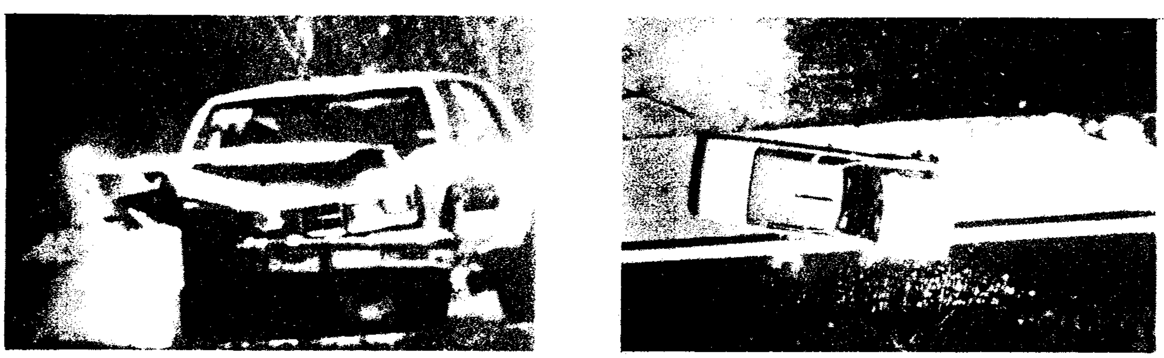
0.000 s



0.050 s



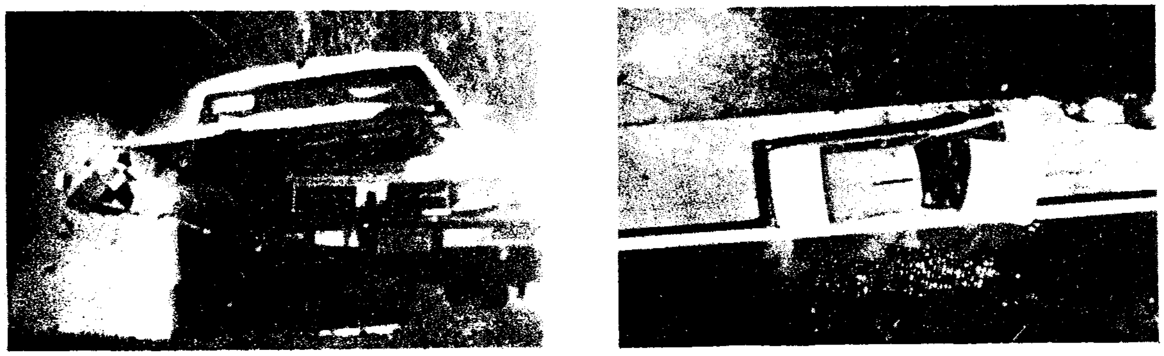
0.100 s



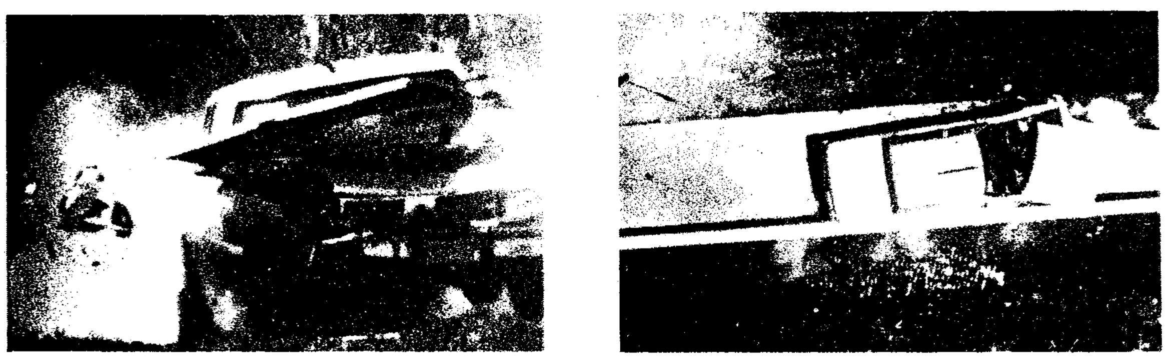
0.149 s

Figure B-1. Sequential photographs for test 1179-3.

0.199 s



0.249 s



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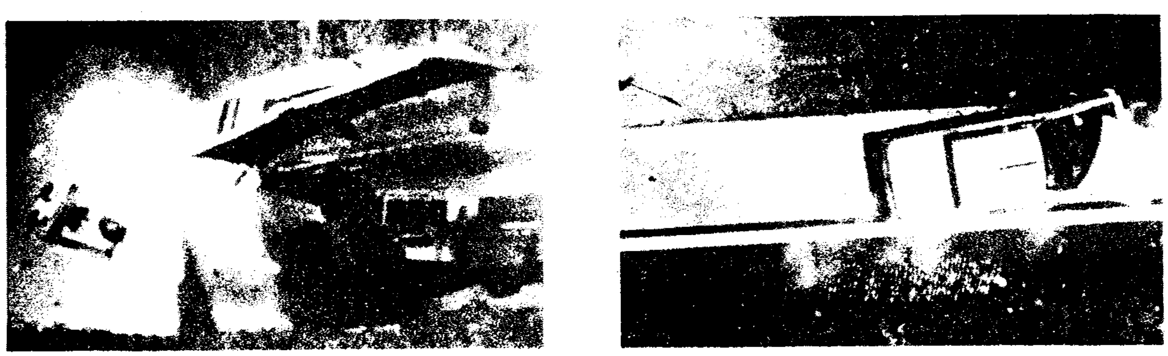
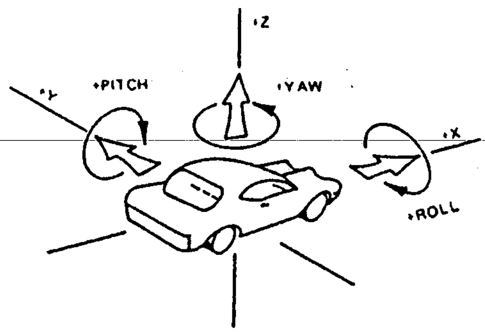


0.373 s

Figure B-1. Sequential photographs for test 1179-3 (continued).

APPENDIX C

Electronic Accelerometer, Roll, Pitch, and Yaw Data Test 1179-3



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

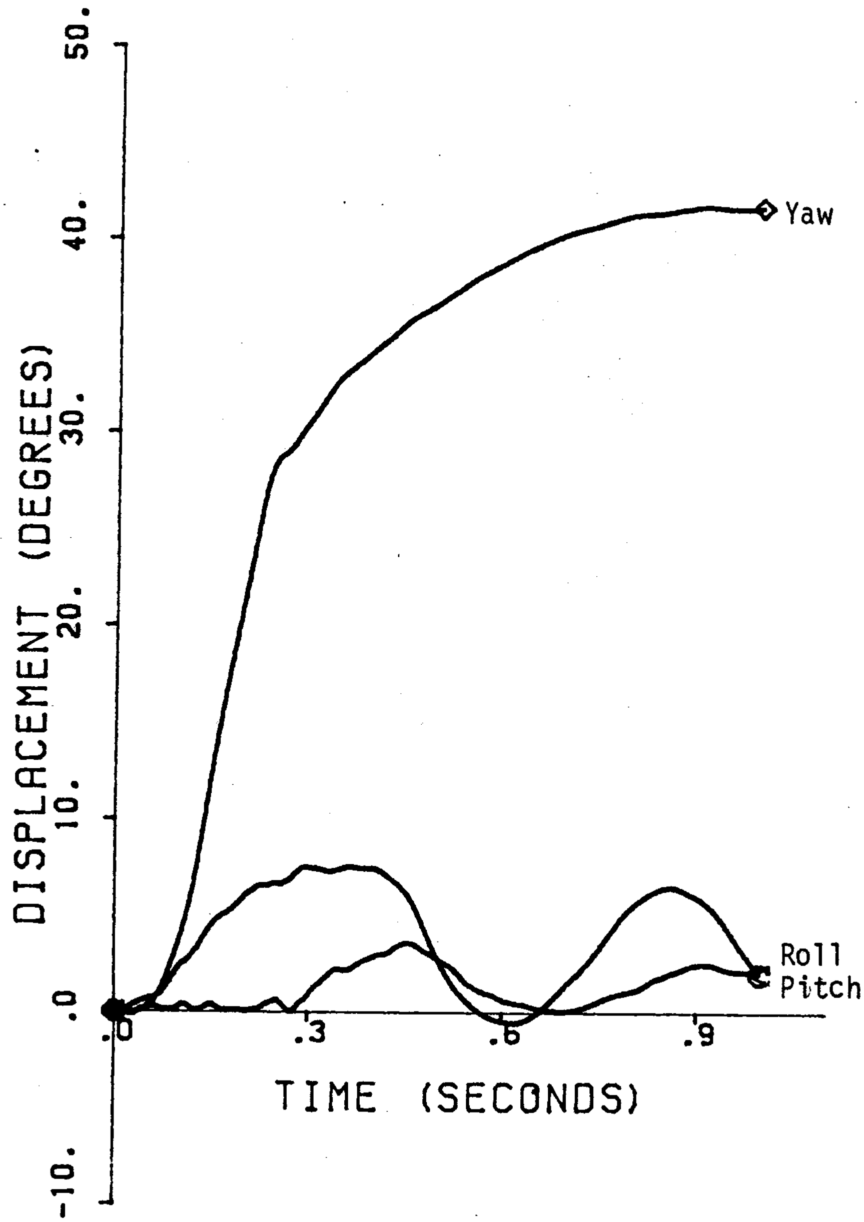


Figure C-1. Vehicle angular displacements for test 1179-3.

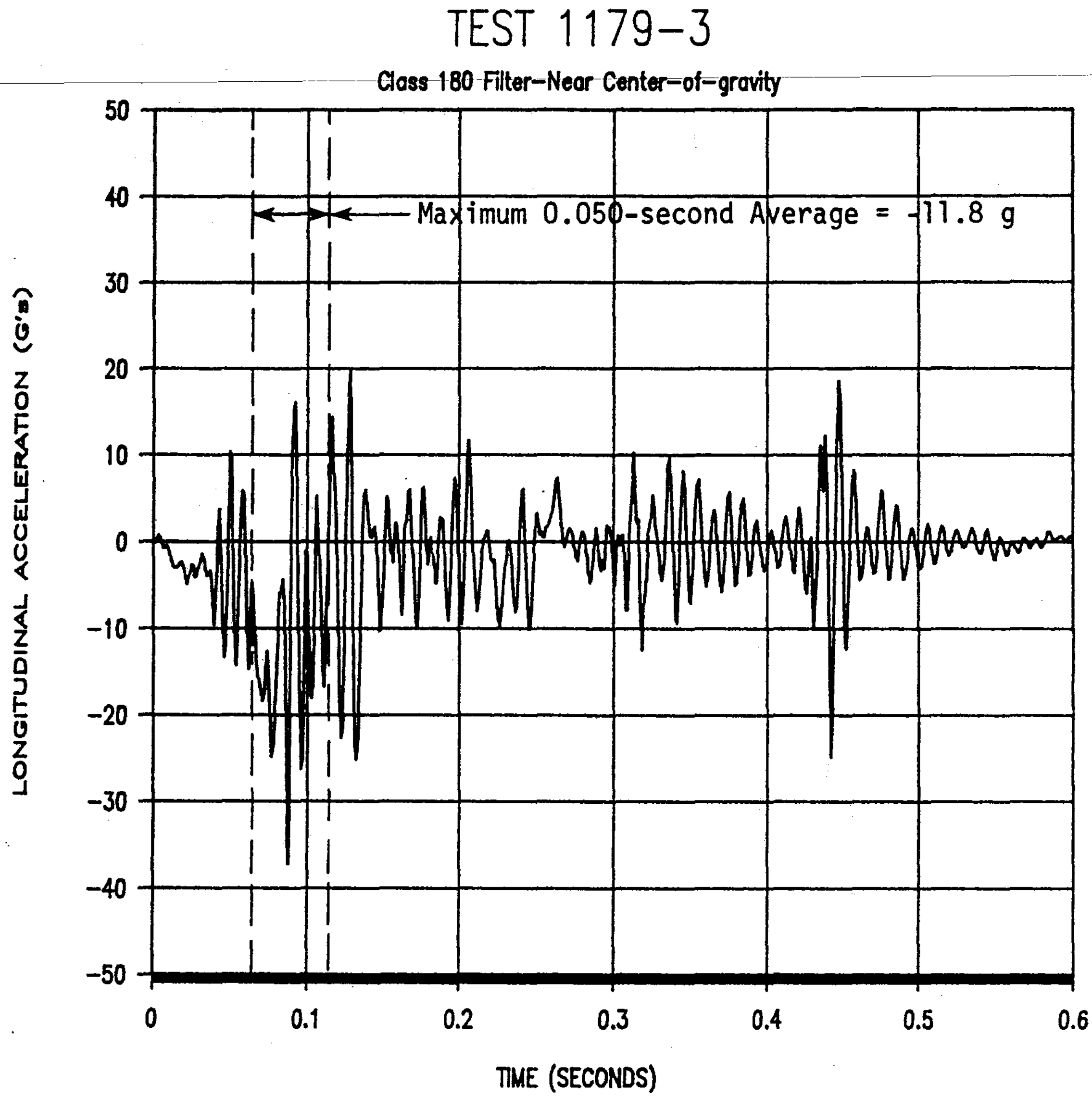


Figure C-2. Vehicle longitudinal accelerometer trace for test 1179-3 (near center-of-gravity).

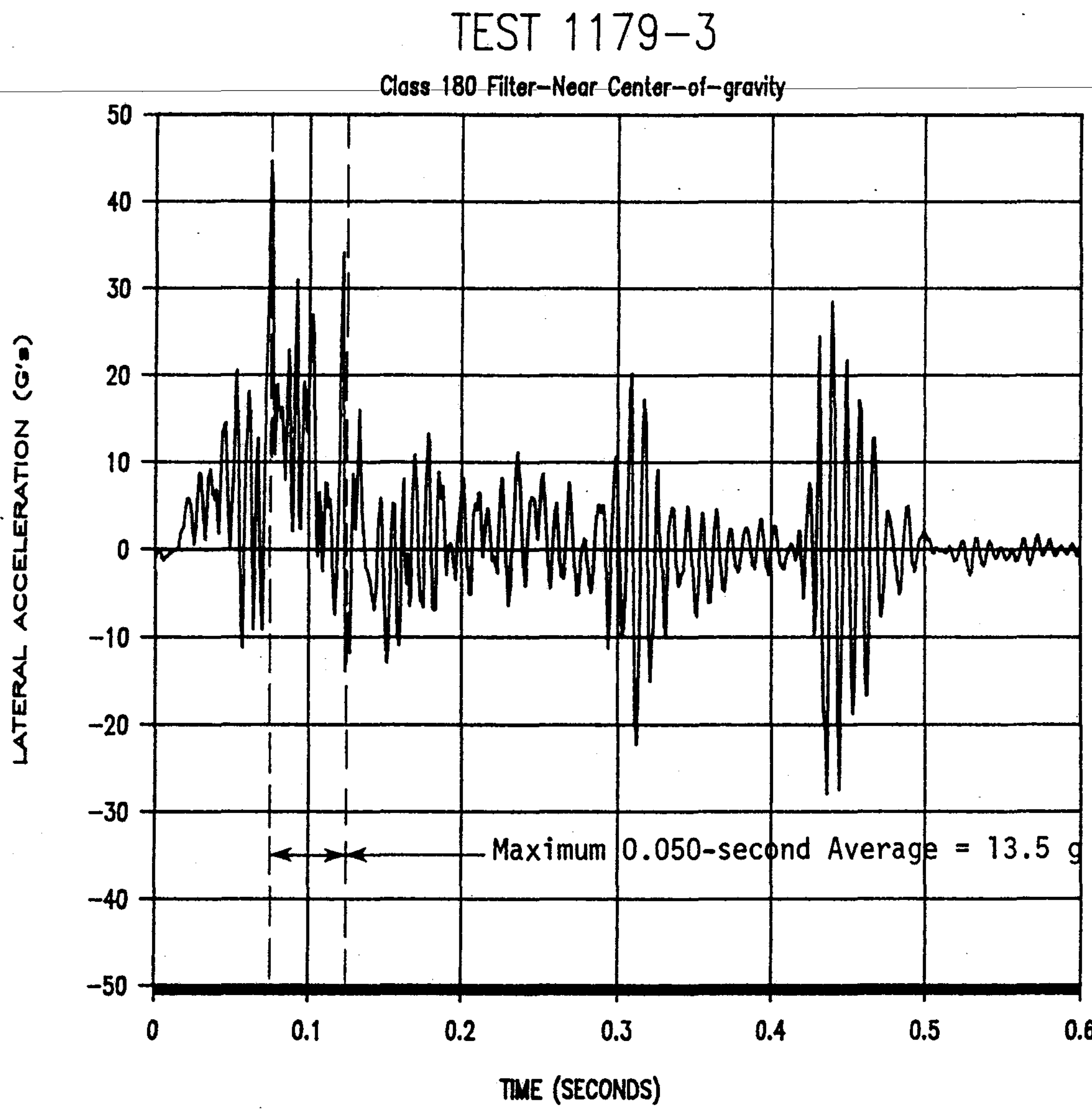


Figure C-3. Vehicle lateral accelerometer trace for test 1179-3 (near center-of-gravity).

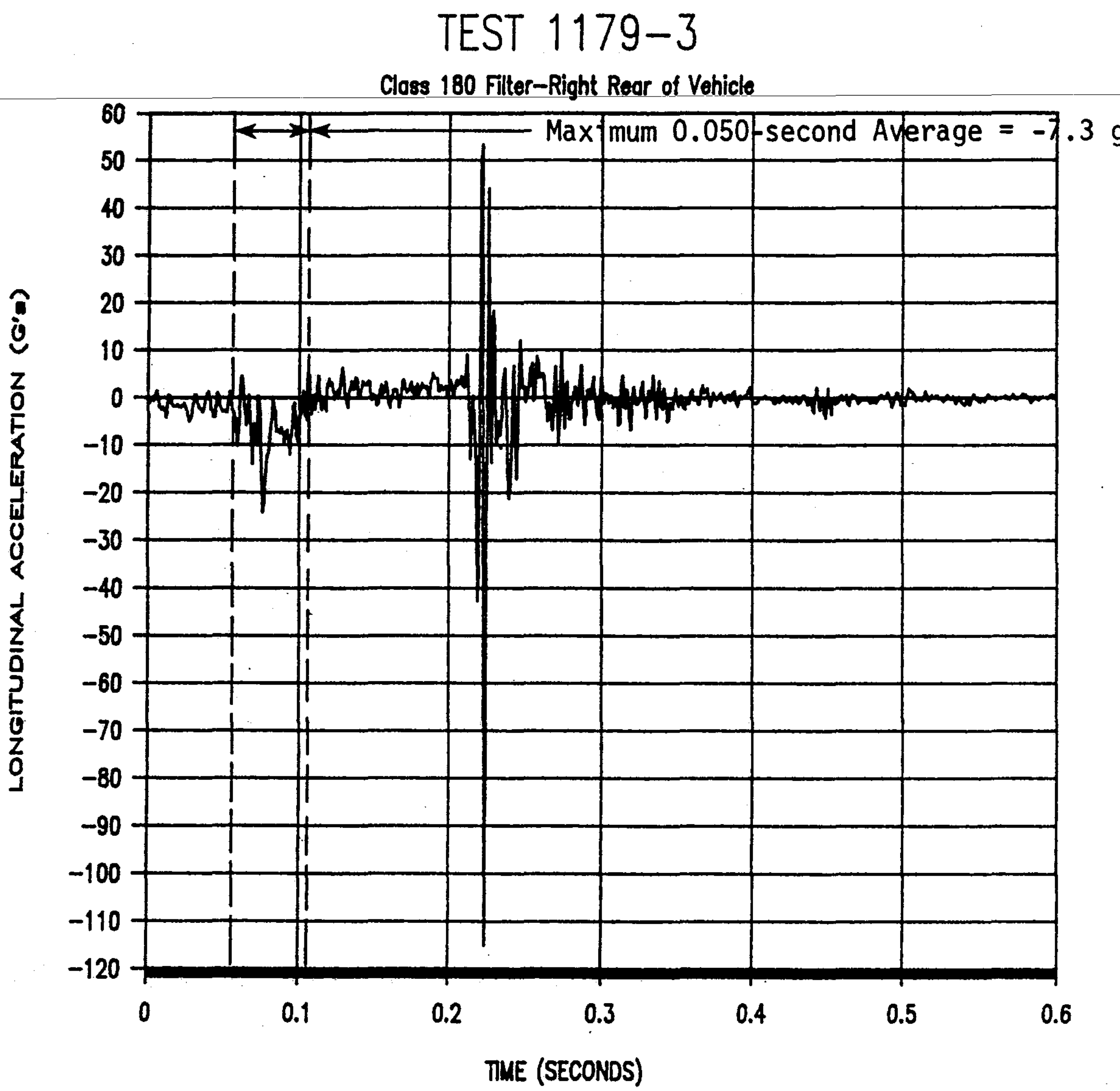


Figure C-8. Vehicle longitudinal accelerometer trace for test 1179-3 (right rear of vehicle).

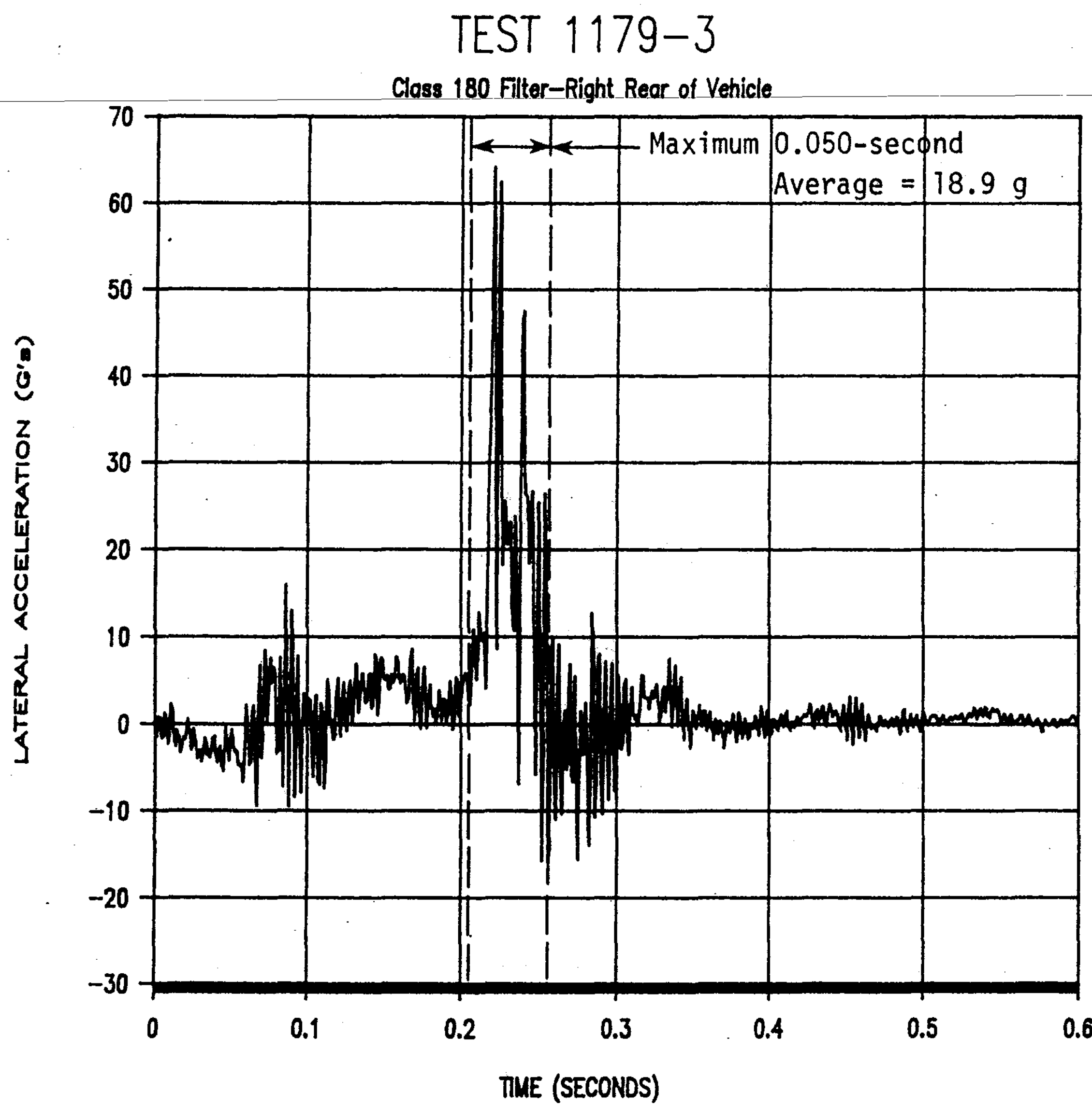


Figure C-9. Vehicle lateral accelerometer trace for test 1179-3 (right rear of vehicle).

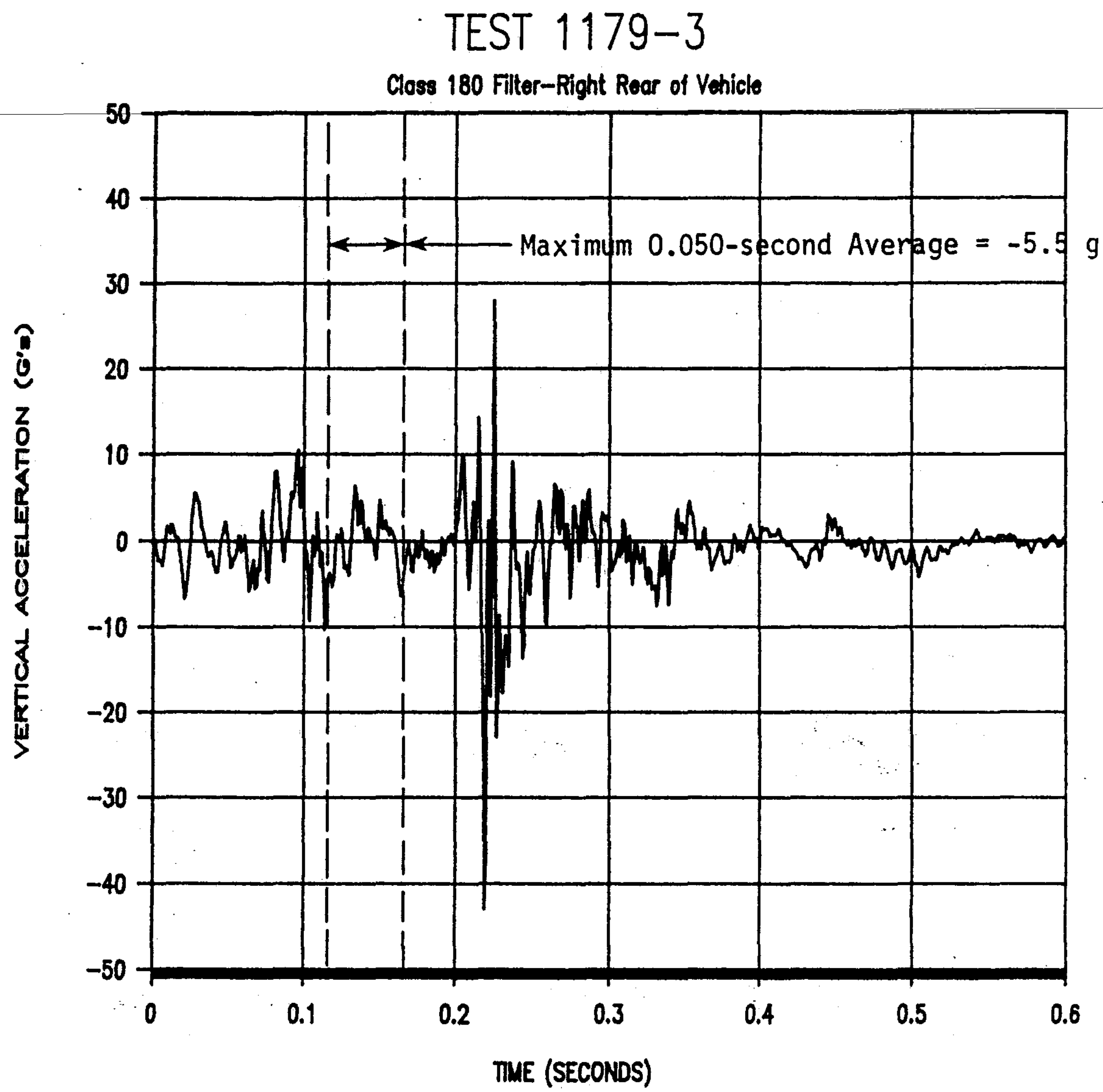


Figure C-10. Vehicle vertical accelerometer trace for test 1179-3 (right rear of vehicle).

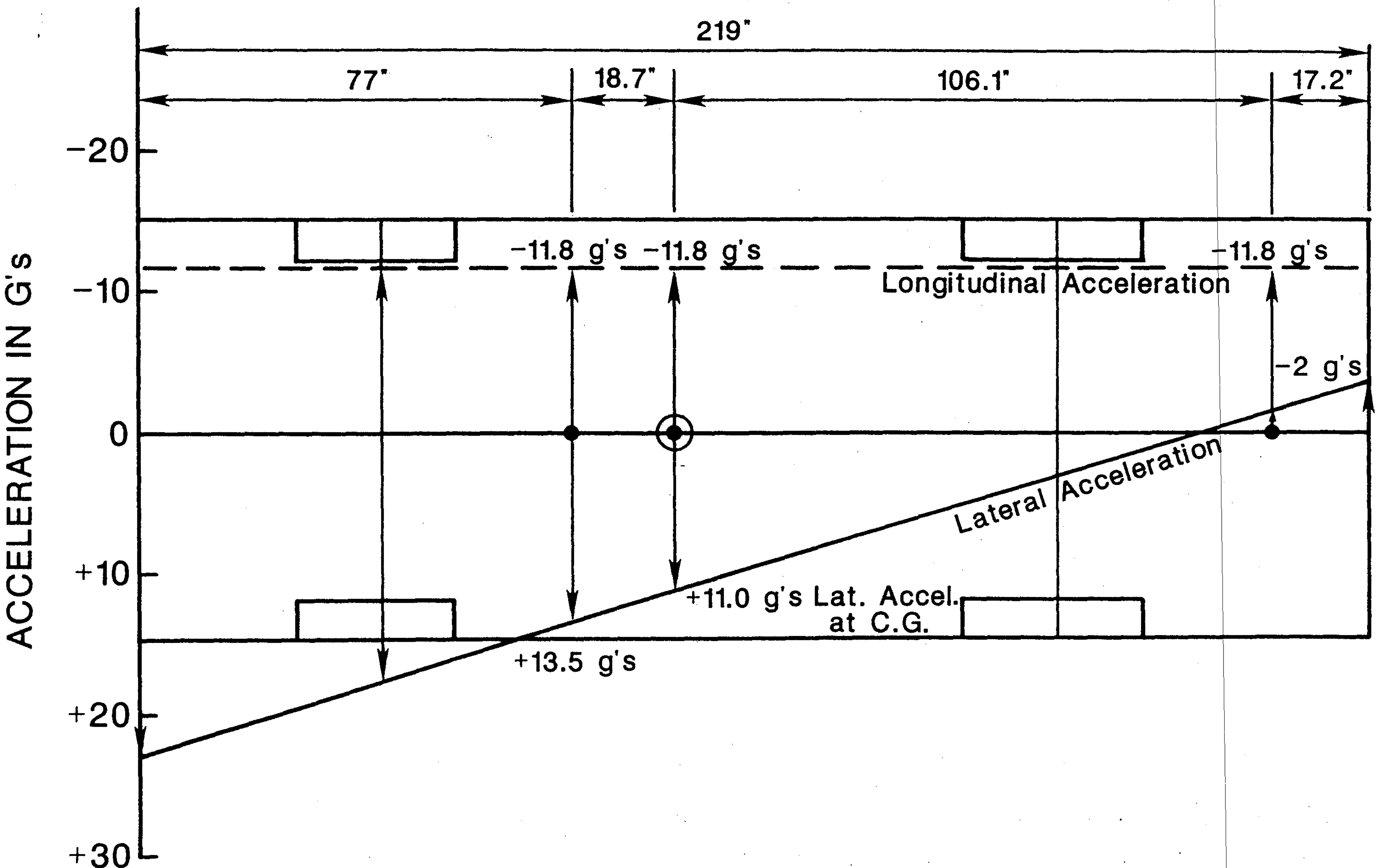


Figure C-11. Graph of max. 0.050 sec average accelerations along vehicle length at 0.100 sec after impact of test 1179-3.

APPENDIX D

Bridge Rail Safety Evaluation Guidelines

TABLE 6. 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