TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-91/1185-3F		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
AESTHETICALLY PLEASING CONCRETE COMBINATION PEDESTRIAN-TRAFFIC BRIDGE RAIL - TEXAS TYPE C411	5. February 1991/Revised 6.
7. Author(s): T.J. Hirsch, C.E. Buth, and Wanda Campise	8. Performing Organization Report No.: Research Report 1185-3F
9. Performing Organization Name and Address: Texas Transportation Institute Texas A&M University College Station, Texas 77843-3135	10. Work Unit No. 11. Contract or Grant No.: Research Study 2-5-89/90-1185
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: Final - September 1989 - August 1990 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Research Study Title: Aesthetically Pleasing Bridge Rails

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 concrete combination pedestrian-traffic bridge rail--Texas Type C411.

This bridge rail was constructed of reinforced concrete 42 in. high by 12 in. thick and contains 6 in. wide by 28 in. high openings at 18 in. center-to-center longitudinal spacing. The combination pedestrian-traffic bridge rail was located on a 6 ft wide sidewalk with 8 in. high curb separating it from the traffic.

The bridge rail was developed for use on urban streets where the speed limit would be 45 mph or less. Service Level 1 of NCHRP 230 and Performance Level 1 of the 1989 AASHTO Guide Specifications for Bridge Railings were considered inappropriate.

NCHRP Project C22-7, "Update of Roadside Safety Hardware Crash Test Specifications," and NCHRP Project 12-33, "Development of a Comprehensive Bridge Specification and Commentary," were seriously considering a different test matrix at the time these tests were conducted. It was decided to use a 4,500 lb car at 45 mph and 25 degree impact angle and an 1,900 lb car at 45 mph and 20 degree impact angle.

The new C411 bridge rail performed very well under these two crash tests. The crash test results easily met the usual safety evaluation criteria. The C411 should be safe for use on low speed, 45 mph or less, roadways.

17. Key Words	18. Distribution Statement
Bridge Rails, Traffic Barriers, Highway Safety, Pedestrian - Cars	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	63	

Form DOT F 1700.7 (8-69)

AESTHETICALLY PLEASING CONCRETE COMBINATION PEDESTRIAN-TRAFFIC BRIDGE RAIL - TEXAS TYPE C411

by

T. J. Hirsch
Research Engineer & Principal Investigator

C. E. Buth
Research Engineer

and

Wanda L. Campise
Research Associate

Research Report 1185-3F

on

Research Study No. 2-5-89/90-1185
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

October 1990

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

METRIC (SI*) CONVERSION FACTORS

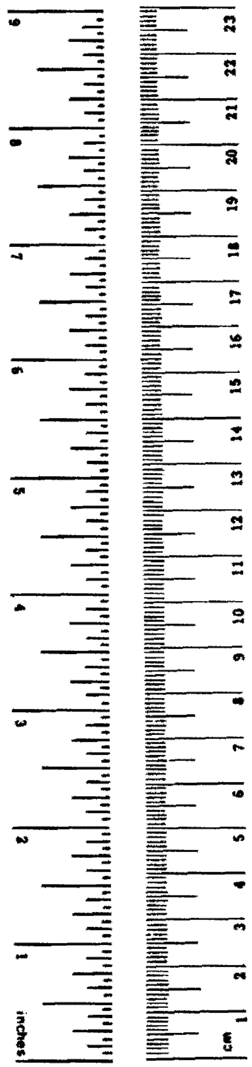
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	centimetres squared	cm^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)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
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

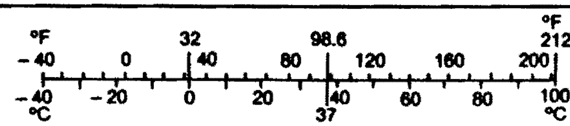


APPROXIMATE CONVERSIONS TO SI UNITS

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

KEY WORDS

Bridge Rails, Traffic Barriers, Highway Safety, Pedestrian - 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 (Designing Engineer, SDHPT), John J. Panak (Bridge Designing 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 concrete combination pedestrian-traffic bridge rail - Texas Type C411.

This bridge rail was constructed of reinforced concrete 42 in. high by 12 in. thick and contains 6 in. wide by 28 in. high openings at 18 in. center-to-center longitudinal spacing. The combination pedestrian-traffic bridge rail was located on a 6 ft wide sidewalk with 8 in. high curb separating it from the traffic.

The C411 was developed for use on urban streets where the speed limit would be 45 mph or less. Service Level 1 of NCHRP 230 and Performance Level 1 of the 1989 AASHTO Guide Specifications for Bridge Railings were considered inappropriate.

NCHRP Project C22-7, "Update of Roadside Safety Hardware Crash Test Specifications," and NCHRP Project 12-33, "Development of a Comprehensive Bridge Specification and Commentary," were seriously considering a different test matrix at the time these tests were conducted. It was decided to use a 4,500 lb car at 45 mph and 25 degree impact angle and an 1,900 lb car at 45 mph and 20 degree impact angle.

The new C411 bridge rail performed very well under these two crash tests. The crash test results easily met the usual safety evaluation criteria. The C411 should be safe for use on low speed, 45 mph or less, roadways.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 was 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 open type concrete combination pedestrian-traffic bridge rail--Texas Type C411. The research study advisory committee composed of

Luis Ybanez, Bridge Engineer, Bridge Division, Austin,
John J. Panak, Bridge Designing Engineer, Bridge Division, Austin,
Dean Van Landuyt, Designing 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 C411 as its third priority.

DESCRIPTION OF BRIDGE RAIL
TEXAS TYPE C411

This bridge rail was constructed of reinforced concrete 42 in. high by 12 in. thick and contains 6 in. wide by 28 in. high openings at 18 in. center-to-center longitudinal spacing. The combination pedestrian-traffic bridge rail was located on a 6 ft wide sidewalk with 8 in. high curb separating it from the traffic. Figures 1, 2, and 3 present an elevation, cross section, and plan view of the C411 rail. The sidewalk deck is a 7.75 in. thick typical Texas bridge slab design in accordance with AASHTO specifications (4)*.

Figure 4 shows a photograph of the bridge rail installation prior to crash testing. The installation was 47 ft 4 in. long. The three pilasters are not super strong posts as they appear to be. They contain styrofoam blocks 10.5 in. by 13 in. by 31 in., (void) which means the pilasters are similar to the 6 in. by 28 in. openings. The use of the pilasters is thus optional since they did not contribute to the bridge rail strength as built and crash tested.

This bridge rail was designed using a failure mechanism (or yield line) method of analysis (1). The design strength of the concrete was f_c = 3,600 psi and the yield strength of reinforcing steel was f_y = 60,000 psi. The top beam was nominally 7 in. wide and 10 to 12 in. thick (b = 7 in. and d = 8.25 in.), yielding an ultimate moment capacity of 20.0 kip-ft. The posts were 10 in. wide and 10 in. thick (b = 10 in. and d = 8 in.), yielding an ultimate moment capacity of 20.6 kip-ft. With a moment arm of 3.5 ft, each post could resist a lateral load of about 5.9 kips. Figure 5 presents a summary of the failure mechanism analysis of the strength of the T411 bridge rail. The failure load would be about 51.4 kips or more over five spans or 7.5 ft length of bridge rail.

---

* Numbers in parentheses, thus (4), refer to corresponding item in References.

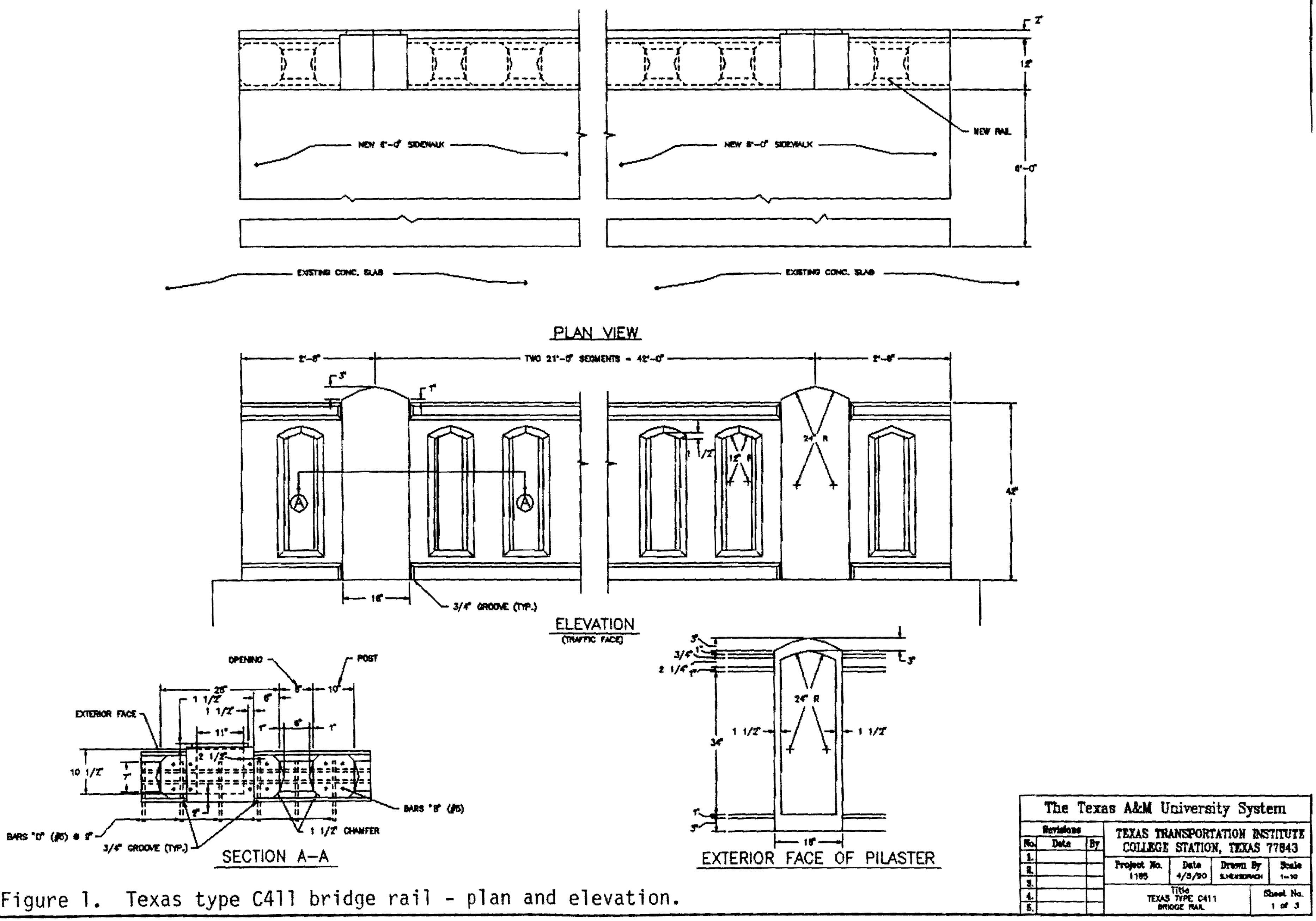
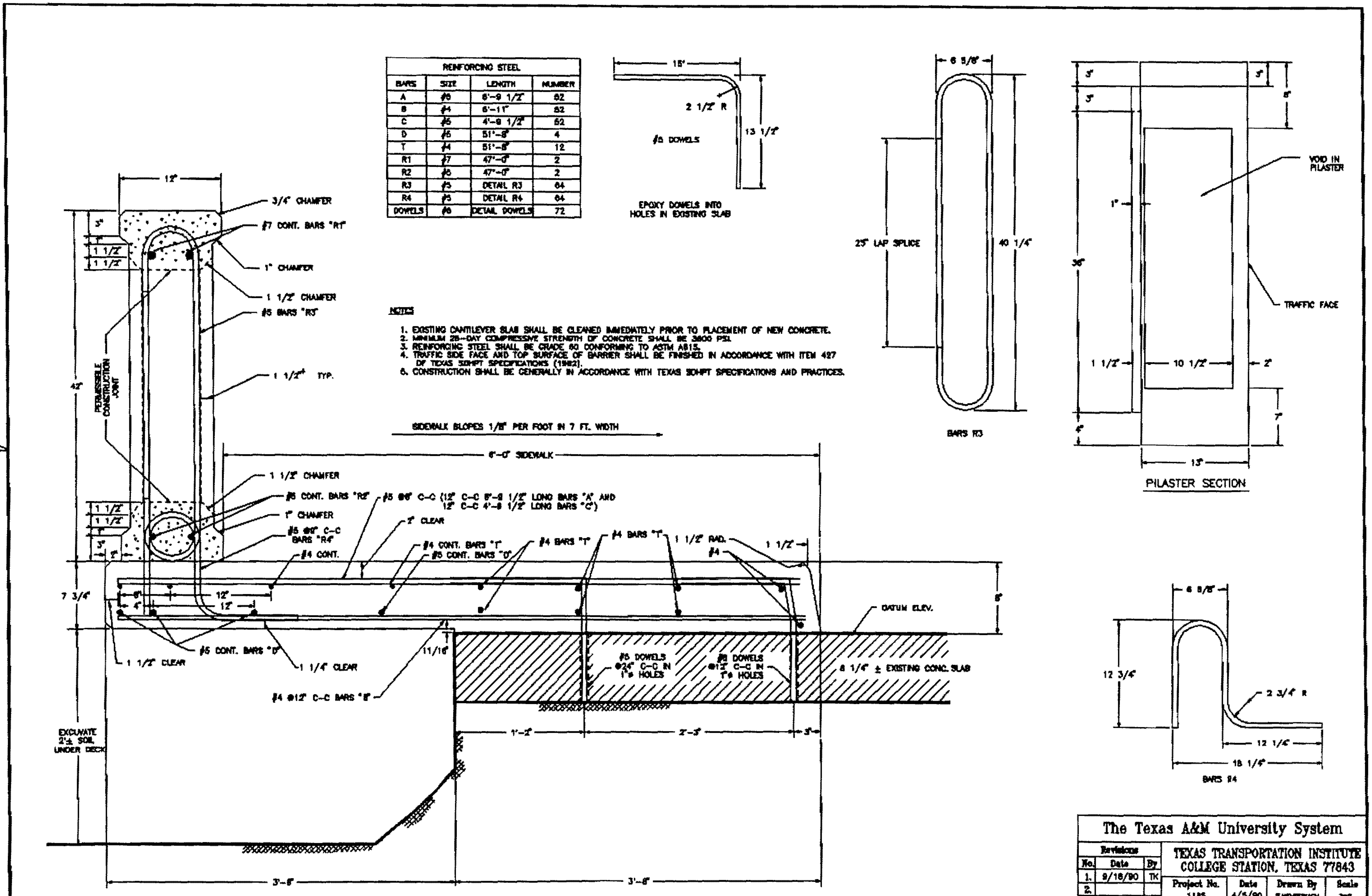


Figure 1. Texas type C411 bridge rail - plan and elevation.



REINFORCING STEEL			
BARS	SIZE	LENGTH	NUMBER
A	#5	6'-9 1/2"	62
B	#4	6'-11"	62
C	#5	4'-9 1/2"	62
D	#6	51'-8"	4
T	#4	51'-8"	12
R1	#7	47'-0"	2
R2	#6	47'-0"	2
R3	#5	DETAIL R3	64
R4	#5	DETAIL R4	64
DOWELS	#6	DETAIL DOWELS	72

NOTES

1. EXISTING CANTILEVER SLAB SHALL BE CLEANED IMMEDIATELY PRIOR TO PLACEMENT OF NEW CONCRETE.
2. MINIMUM 28-DAY COMPRESSIVE STRENGTH OF CONCRETE SHALL BE 3600 PSI.
3. REINFORCING STEEL SHALL BE GRADE 60 CONFORMING TO ASTM A615.
4. TRAFFIC SIDE FACE AND TOP SURFACE OF BARRIER SHALL BE FINISHED IN ACCORDANCE WITH ITEM 427 OF TEXAS SDHPT SPECIFICATIONS (1982).
5. CONSTRUCTION SHALL BE GENERALLY IN ACCORDANCE WITH TEXAS SDHPT SPECIFICATIONS AND PRACTICES.

Figure 2. Texas type C411 bridge rail - cross section.

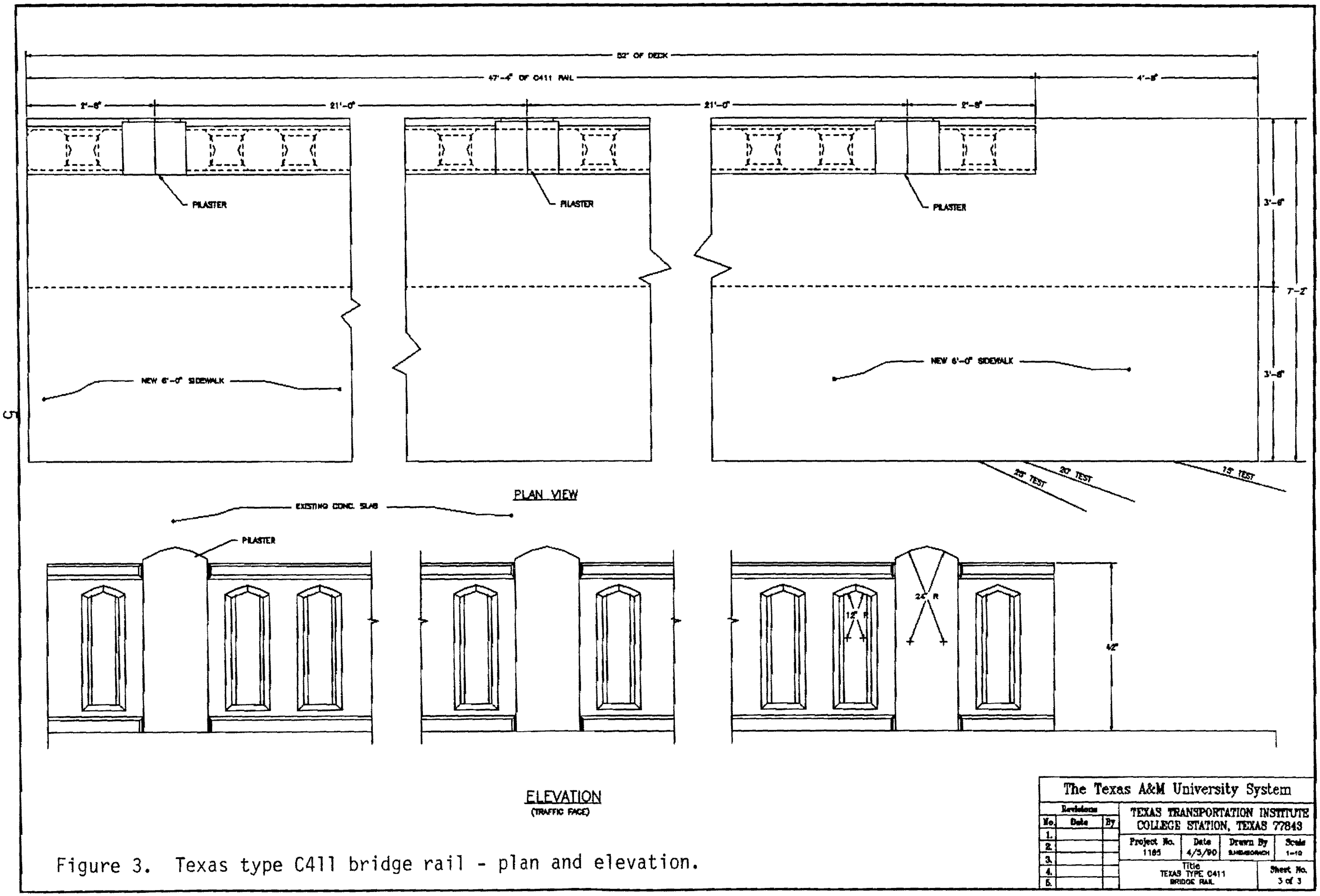


Figure 3. Texas type C411 bridge rail - plan and elevation.

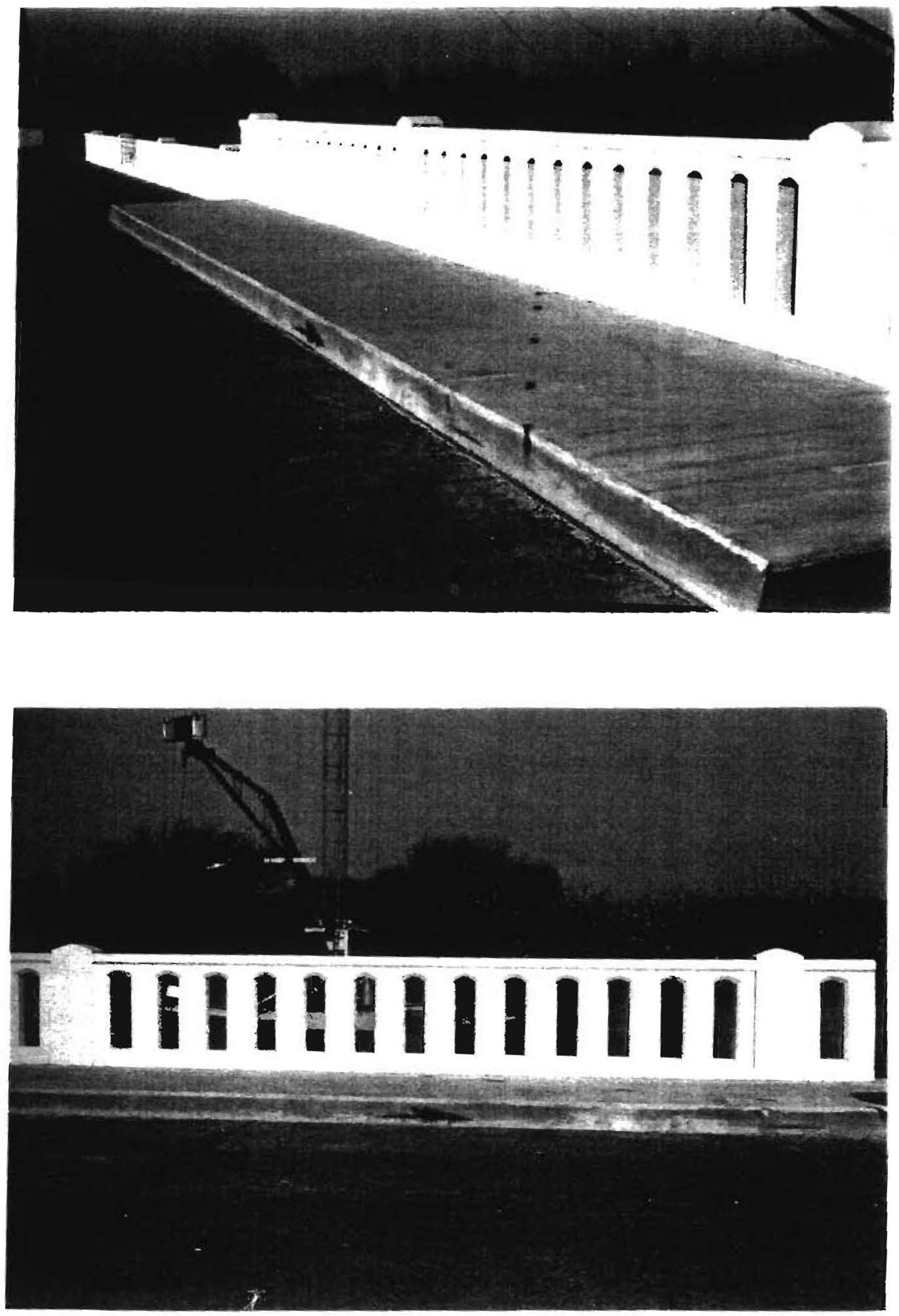


Figure 4. Bridge rail prior to test 1185-5.

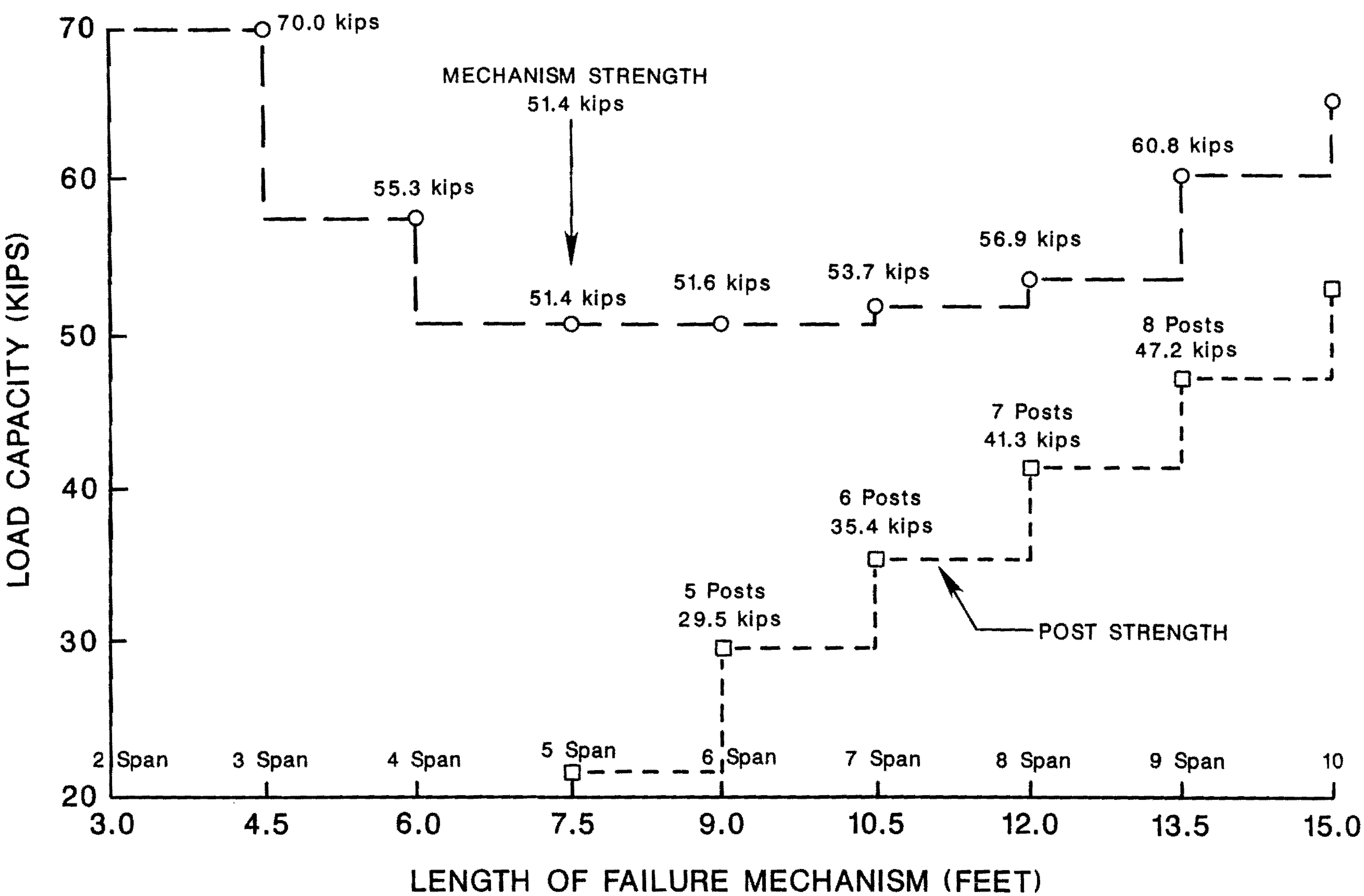
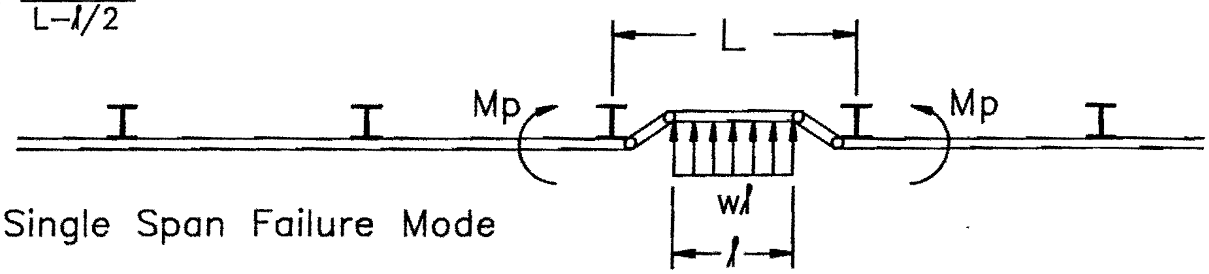


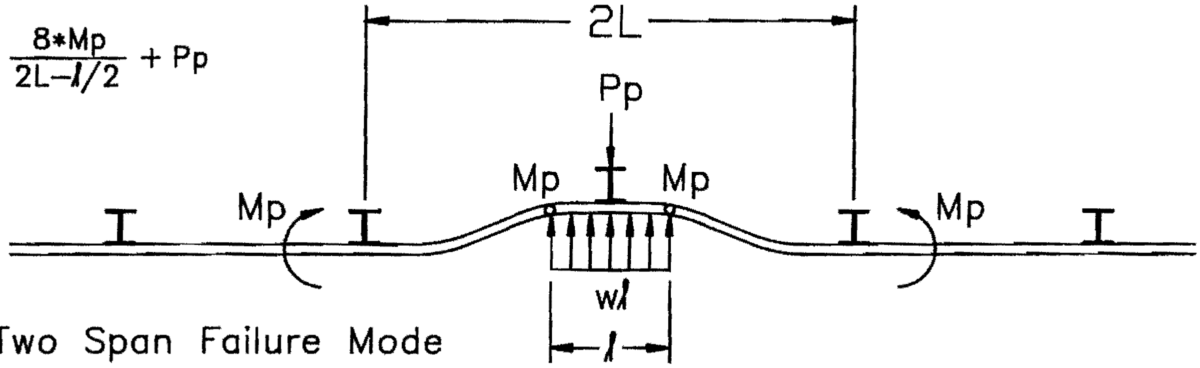
FIGURE 5. FAILURE MECHANISM ANALYSIS OF THE TEXAS C411 BRIDGE RAIL.

$$w\ell = \frac{8*Mp}{L-\ell/2}$$



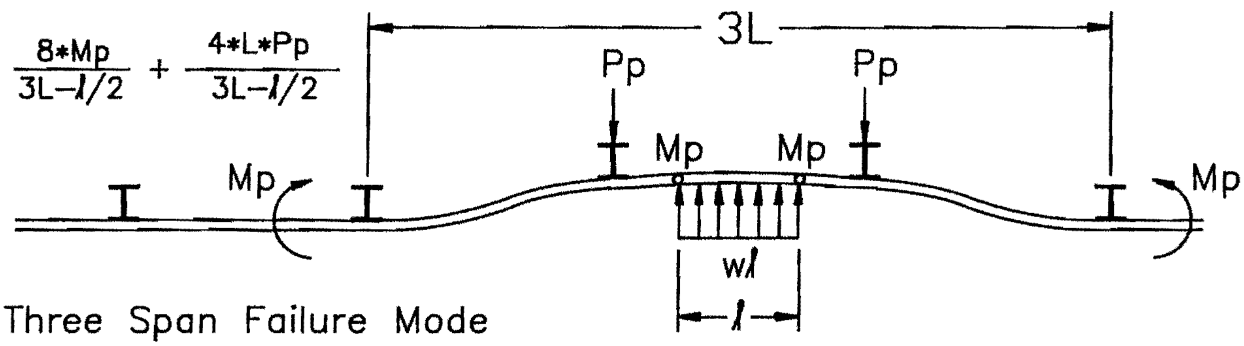
(A) Single Span Failure Mode

$$w\ell = \frac{8*Mp}{2L-\ell/2} + Pp$$



(B) Two Span Failure Mode

$$w\ell = \frac{8*Mp}{3L-\ell/2} + \frac{4*L*Pp}{3L-\ell/2}$$



(C) Three Span Failure Mode

L = post spacing

Mp = plastic or yield line capacity of rail

Pp = ultimate load capacity of a single post

$w\ell$ = total ultimate vehicle impact load

ℓ = length of distributed vehicle impact load

PLAN VIEW

FIGURE 6. POSSIBLE FAILURE MODES FOR BEAM AND POST BARRIERS

(D) Four Span Failure Mode

$$wl = \frac{8M_p}{4L-l/2} + \frac{4P_pL}{4L-l/2} + P_p$$

(E) Five Span Failure Mode

$$wl = \frac{8M_p}{5L-l/2} + \frac{12P_pL}{5L-l/2}$$

(F) Six Span Failure Mode

$$wl = \frac{8M_p}{6L-l/2} + \frac{12P_pL}{6L-l/2} + P_p$$

(G) Seven Span Failure Mode

$$wl = \frac{8M_p}{7L-l/2} + \frac{24P_pL}{7L-l/2}$$

(H) Eight Span Failure Mode

$$wl = \frac{8M_p}{8L-l/2} + \frac{24P_pL}{8L-l/2} + P_p$$

The equations above for the ultimate horizontal load capacity (wl) satisfy all equations of static equilibrium. A simpler equation (which does not quite satisfy equations of static equilibrium for forces and moments in the beam) is as follows:

(I) $$wl = \frac{8M_p}{NL-l/2} + \sum_{0}^{NL} P_p$$

where N = number of spans in the failure mechanism.

Equation (I) was used to analyze this rail (Figure 5).

Figure 6 (Continued). Possible failure modes for beam and post barriers.

CRASH TESTS

The Texas Type C411 was developed for use on urban streets where the speed limit would be 45 mph or less. The selection of a crash test matrix posed a problem. Service Level 1 of NCHRP 230 (3) would indicate a 4,500 lb car at 60 mph and a 15 degree impact angle for the strength test and an 1,800 lb car at 60 mph and 20 degree impact angle for geometry evaluation. The 1989 AASHTO Guide Specifications for Bridge Railings (9), Performance Level 1, would indicate testing with a 5,400 lb pickup truck at 45 mph and 20 degree impact angle and an 1,800 lb car at 50 mph and 20 degree impact angle.

Both of these documents were in the process of being revised by NCHRP Project C22-7, "Update of Roadside Safety Hardware Crash Test Specifications," and NCHRP Project 12-33, "Development of a Comprehensive Bridge Specification and Commentary." These two projects were seriously considering the severity level test matrix shown in Table 1 at the time these tests were conducted. It was, therefore, decided to use Severity Level 2 from Table 1. This was a 4,500 lb car (not truck) at 45 mph and 25 degree impact angle and an 1,900 lb car at 45 mph and 20 degree impact angle.

Table 1. Test Severity Levels, Vehicles, Weights, Angles and Speeds

Test Vehicle Description and Impact Angles			Severity Level (SL) and Test Speed mph					
Vehicle Description	**W (kips)**	**θ (degrees)**	**SL-1**	**SL-2**	**SL-3**	**SL-4**	**SL-5**	**SL-6**
Small Automobile	1.9	20	30	45	60	60	60	60
Pickup Truck or Sports Wagon Truck	4.5	25	30	45	60	60*	60*	60*
Medium Single Unit Truck	18.0	15				50		
Van Type Tractor-Trailer	80.0	15					50	
Tank Type Tractor-Trailer	80.0	15						50

*These tests should be conducted unless it can be conclusively shown that these tests would be no more severe than the small automobile test (above) and the truck test (below).

TEST DESCRIPTION 1185-5

The 1982 Honda Civic (Figures 7 and 8) was directed into the bridge rail installation using a reverse tow and guidance system. Test inertia mass of the vehicle was 1,800 lb (808 kg) and its gross static mass was 1,970 lb (894 kg). The height to the lower edge of the vehicle bumper was 15.0 in. (38.1 cm) and it was 20.5 in. (52.1 cm) to the top of the bumper. Other dimensions and information on the test vehicle are given in Figure C1 of Appendix C. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact with the curb was 45.5 mph (73.2 km/h) and the angle of impact was 20.1 degrees. The vehicle impacted the curb approximately 8 ft (2.4 m) from the end of the sidewalk. As the vehicle rode up the curb, the right front wheel twisted counter-clockwise, and as it rode onto the sidewalk, the vehicle redirected slightly. At 0.322 second, the vehicle impacted the bridge rail 28 ft (8.5 m) from the end of the rail traveling at 43.0 mph (69.2 km/h) and an angle of 17.8 degrees. The vehicle was also airborne at this time and began to redirect significantly at 0.371 second. At 0.626 second the vehicle was traveling parallel with the bridge rail at a speed of 34.1 mph (54.9 km/h), and at 0.632 second the rear of the vehicle hit the bridge rail. The vehicle lost contact with the bridge rail at 0.761 second traveling at 32.2 mph (51.8 km/h) and exit trajectory of 2.7 degrees. The front of the vehicle rode off the sidewalk at 0.781 second and touched ground at 0.932 second after impact. The brakes were then applied and the vehicle yawed counter-clockwise and subsequently came to rest 105 ft (32.0 m) down and 25 ft (7.6 m) in front of the point of impact. Sequential photographs are shown in Figures B1 and B2 of Appendix B.

As can be seen in Figure 9, the rail received minimal cosmetic damage. There were tire marks on the face of the bridge rail from the point of impact continuing down 11 ft (3.4 m). There was some scraping and gouging along the edges of the portholes.

The vehicle sustained moderate damage to the right side as shown in Figures 10 and 11. Maximum crush at the right front corner at bumper height was 9.0 in. (22.9 cm). The right front and rear rims were bent and the tires damaged. There was damage to the hood, grill, bumper, right front quarter panel, the right door, the right rear quarter panel and the rear bumper.

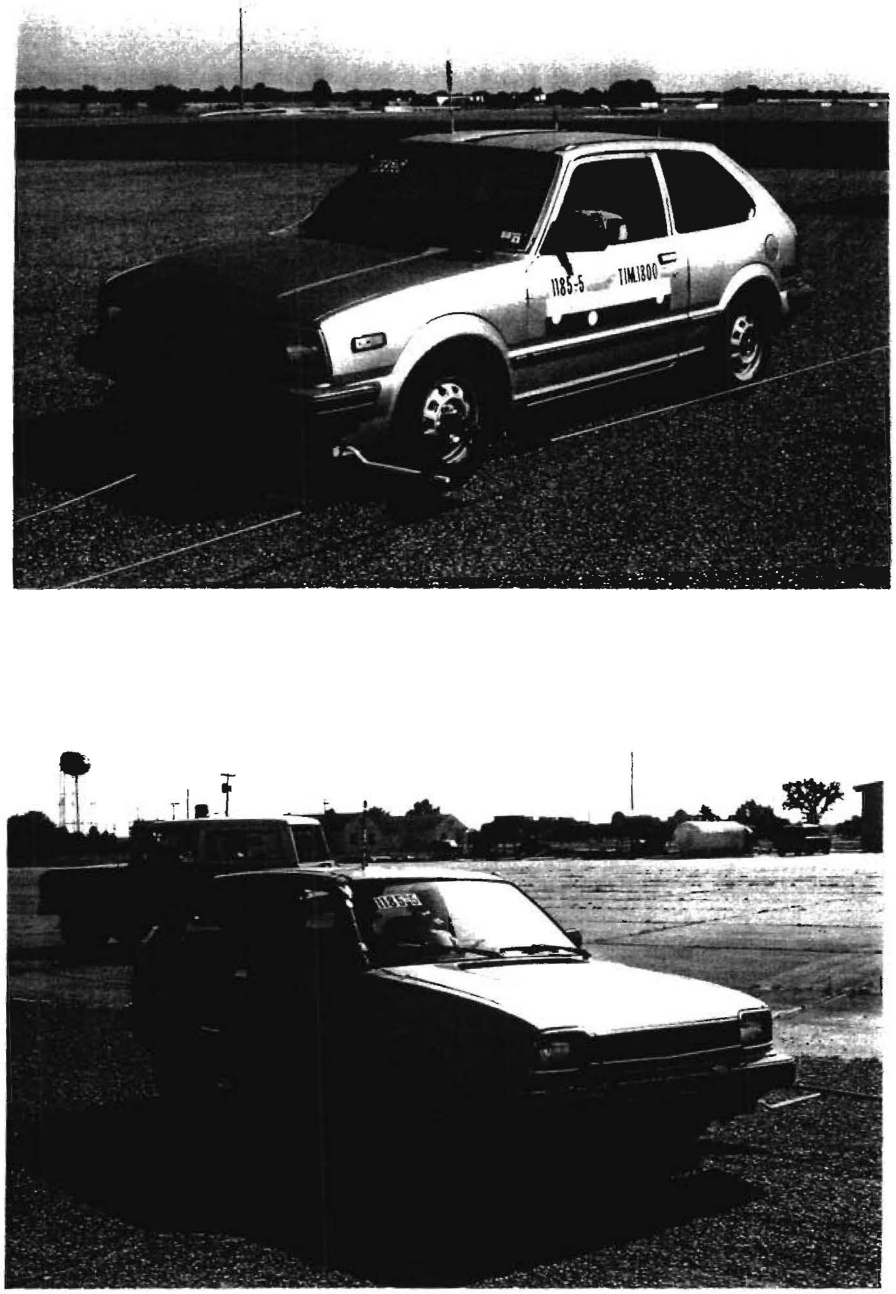
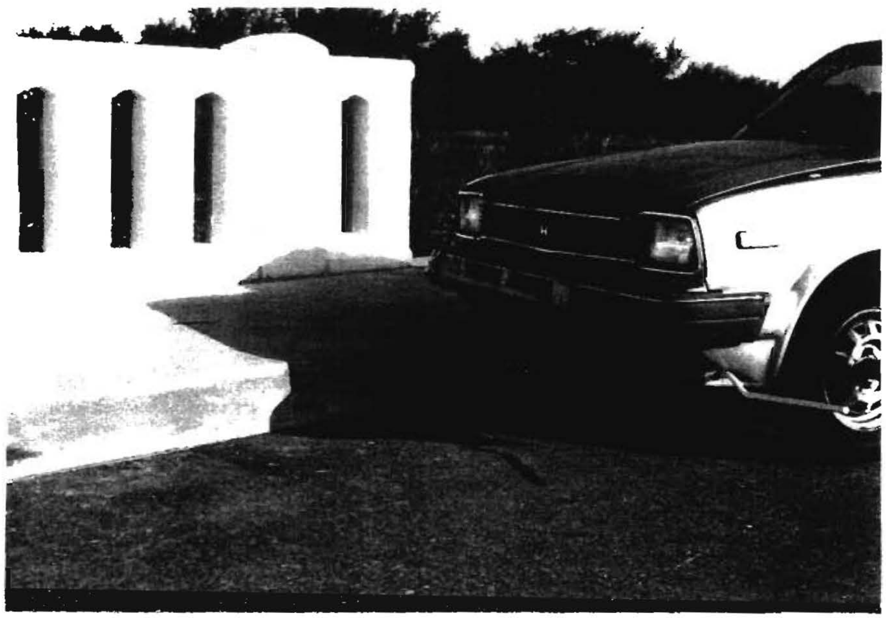


Figure 7. Vehicle before test 1185-5.



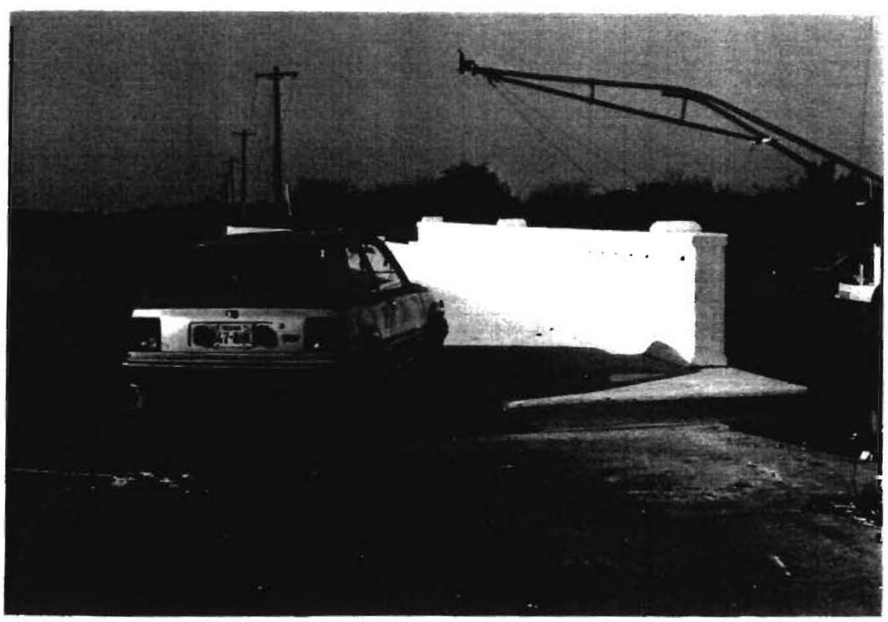


Figure 8. Vehicle/bridge rail installation geometrics for test 1185-5.

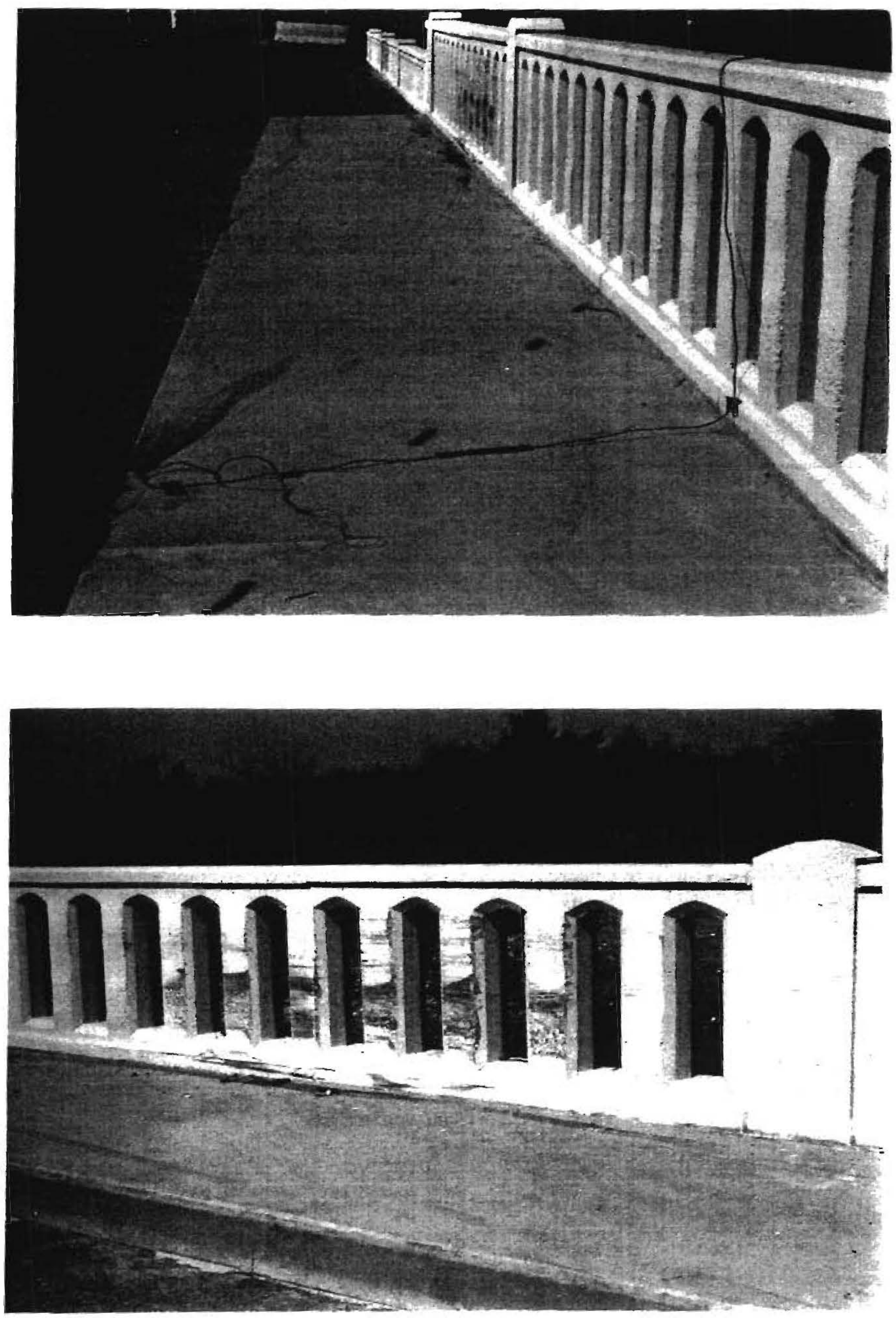


Figure 9. Bridge rail after test 1185-5.

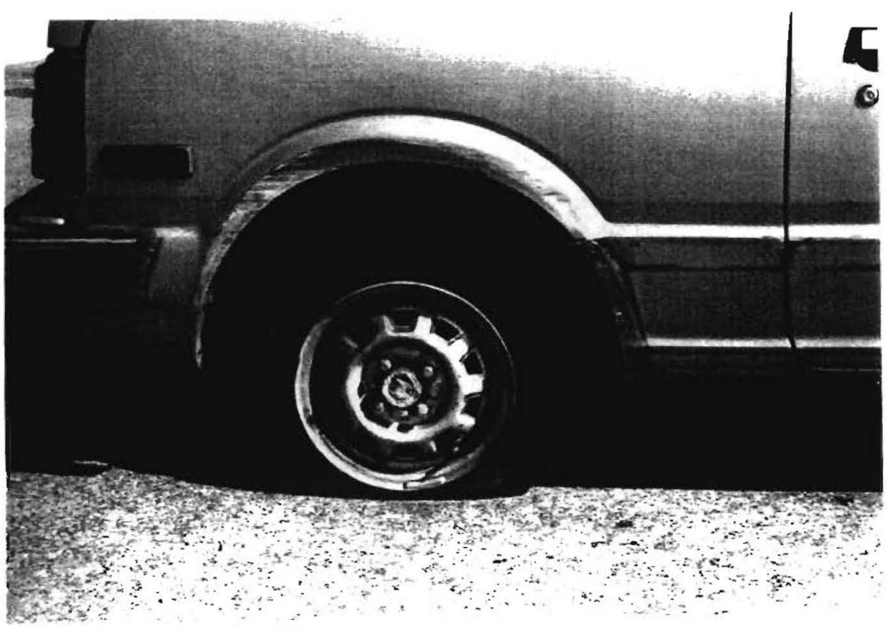


Figure 10. Damage to right side of vehicle, test 1185-5.

Figure 11. Vehicle after test 1185-5.

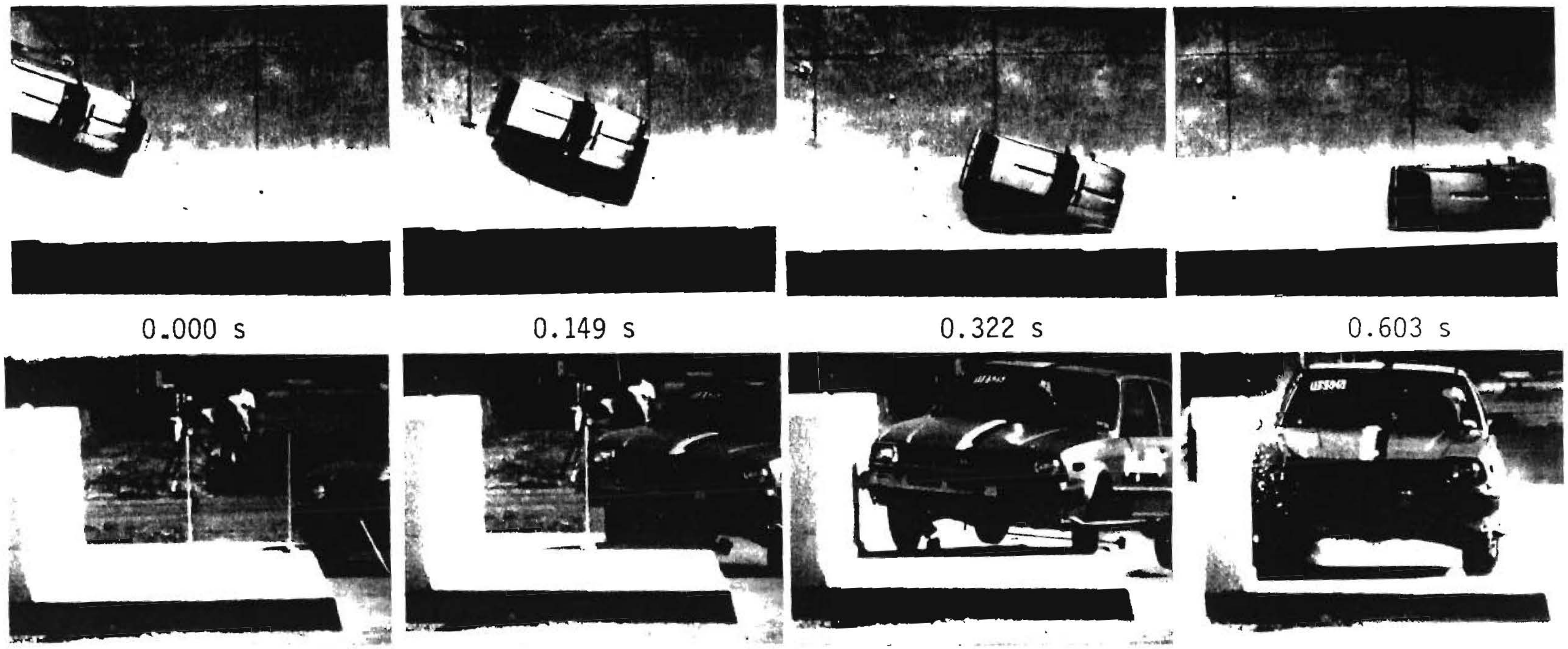
TEST RESULTS 1185-5

The speed of the vehicle as it impacted the curb was 45.5 mph (73.2 km/h) and the angle of impact was 20.1 degrees. As the vehicle impacted the bridge rail, it was traveling at 43.3 mph (69.7 km/h) and 17.8 degrees. The speed of the vehicle as it was parallel to the bridge rail was 34.1 mph (54.9 km/h). Exit speed was 32.2 mph (51.8 km/h) and exit trajectory was 2.7 degrees. Occupant impact velocity was 12.1 ft/s (3.7 m/s) in the longitudinal direction and 7.3 ft/s (2.2 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -4.6 g (longitudinal) and 7.4 g (lateral). These data and other pertinent information from the test are summarized in Figure 12. Vehicular angular displacements are displayed in Figure C2 of Appendix C.

Vehicular accelerations versus time traces filtered at 300 Hz are presented in Figures C3 through C6 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 -3.6 g (longitudinal) and 4.0 g (lateral).

CONCLUSIONS

The bridge rail contained and smoothly redirected the test vehicle with no lateral movement or cracking 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 occupant/compartment impact velocities and 10-ms occupant ridedown accelerations were within the usual recommended limits. The vehicle trajectory at loss of contact indicates no intrusion into adjacent traffic lanes.



Test No. 1185-5
Date 07/03/90

Test Installation . . . Texas Type C411 Bridge Rail
Installation Length . . 52 ft (16 m)

Vehicle . . . . 1982 Honda Civic
Vehicle Weight
  Test Inertia . . . . . 1,800 lb (817 kg)
  Gross Static . . . . . 1,970 lb (894 kg)
Vehicle Damage Classification
  TAD 01RFQ4
  CDC . . . . 01FREK1 & 01RFES3
Maximum Vehicle Crush . 9.0 in (22.9 cm)

Impact Speed . . . 45.5 mi/h (73.2 km/h)
Impact Angle . . . 20.1 degrees
Speed at Parallel . 34.1 mi/h (54.9 km/h)
Exit Speed . . . . 32.2 mi/h (51.8 km/h)
Exit Trajectory . . 2.7 degrees
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal . . -3.6 g
  Lateral . . . . . 4.0 g
Occupant Impact Velocity
  Longitudinal . . 12.1 ft/s (3.7 m/s)
  Lateral . . . . . 7.3 ft/s (2.2 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . -4.6 g
  Lateral . . . . . 7.4 g

Figure 12. Summary of results for test 1185-5.

TEST DESCRIPTION 1185-6

The 1982 Oldsmobile 98 (Figures 13 and 14) was directed into the bridge rail installation using a reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 lb (2,043 km). The height to the lower edge of the vehicle bumper was 12.25 in. (31.1 cm) and it was 20.75 in. (52.7 cm) to the top of the bumper. Other dimensions and information on the test vehicle are given in Figure E1 of Appendix E. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 47.0 mph (75.6 km/h) and the angle of impact was 25.4 degrees. The vehicle impacted the curb approximately 5.75 ft (1.75 m) from the end of the sidewalk. As the right front tire rode up the curb and onto the sidewalk, the vehicle redirected slightly. At 0.177 second, the vehicle impacted the bridge rail 14 ft (4.3 m) from the end of the rail traveling at 46.7 mph (75.1 km/h) and an angle of 22.7 degrees. The right front wheel and tire was mangled in the porthole at 0.237 second, and the vehicle began to redirect significantly at 0.246 second. At 0.492 second, the vehicle was traveling parallel with the bridge rail at a speed of 32.1 mph (51.6 km/h) and at 0.567 second, the rear of the vehicle hit the bridge rail. The vehicle lost contact with the bridge rail at 0.658 second traveling at 28.9 mph (46.5 km/h) and exit of trajectory of 3.5 degrees. The undercarriage of the vehicle bottomed out on the curb at 0.744 second, and the vehicle rode off the sidewalk at 1.466 second after impact. The brakes were then applied and the vehicle yawed clockwise and subsequently came to rest 105 ft (32.0 m) down from the point of impact. Sequential photographs are shown in Figures D1 and D2 of Appendix D.

As can be seen in Figure 15, the rail received moderate cosmetic damage. There were tire marks on the face of the bridge rail from the point of impact continuing down 15 ft (4.6 m). There was some scraping and gouging along the edges of the portholes.

The vehicle sustained damage to the right side as shown in Figures 16 and 17. Maximum crush at the right front corner at bumper height was 14.0 in. (35.6 cm). The floorpan and subframe of the vehicle was bent. The right A-arm, tie rod, and sway bar were damaged. The windshield was cracked and the roof bent. The right front and rear rims were bent and the tires damaged. There was damage to the hood, grill, front bumper,

Figure 13. Vehicle before test 1185-6.

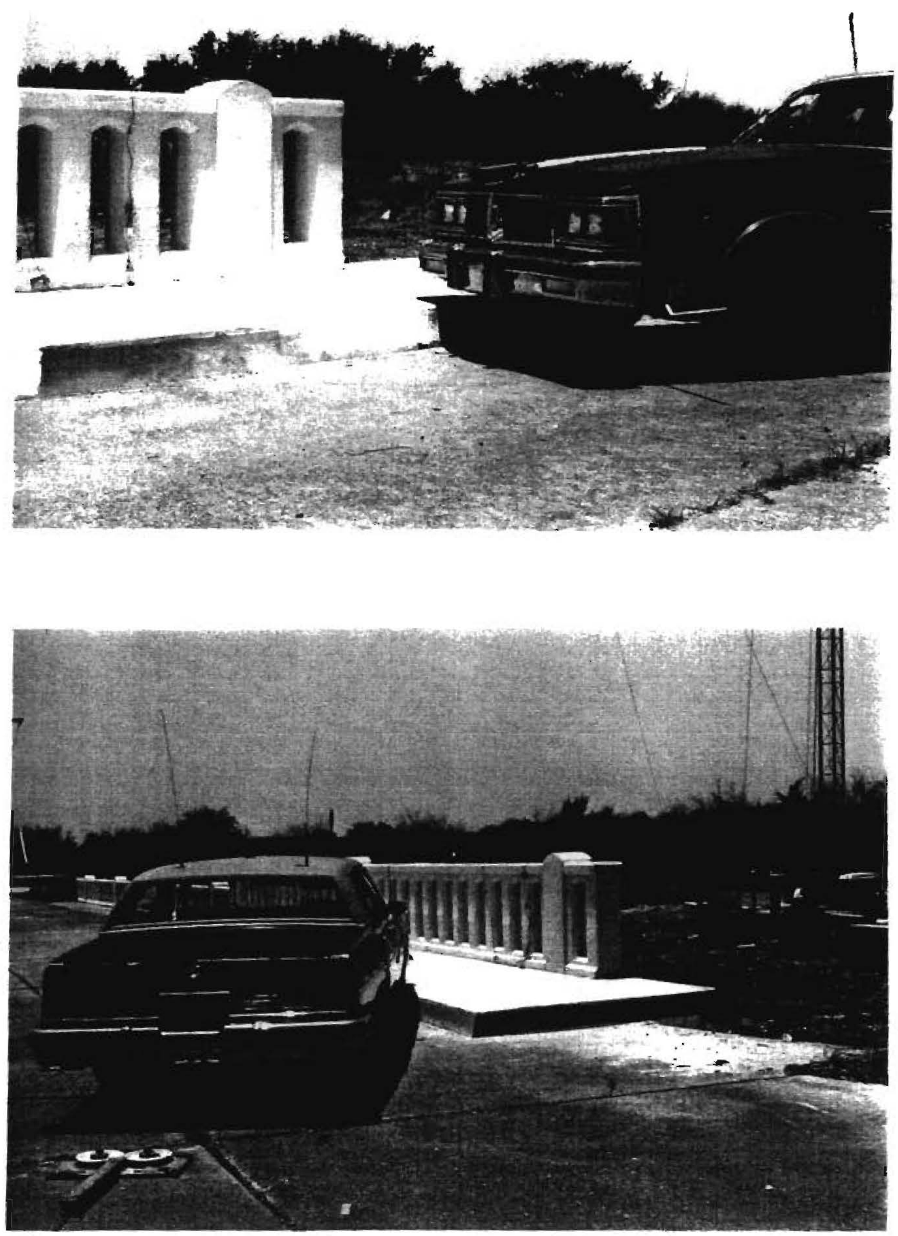


Figure 14. Vehicle/bridge rail installation geometrics for test 1185-6.

Figure 15. Bridge rail after test 1185-6.

Figure 16. Damage to right side of vehicle, test 1185-6.

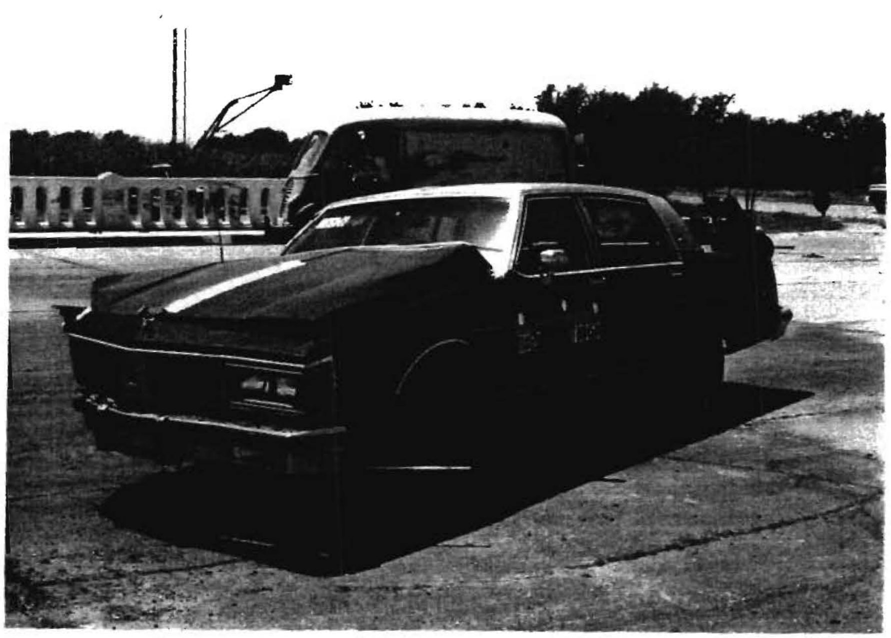


Figure 17. Vehicle after test 1185-6.

radiator and fan, right front quarter panel, the right front and rear doors, the right rear quarter panel and the rear bumper.

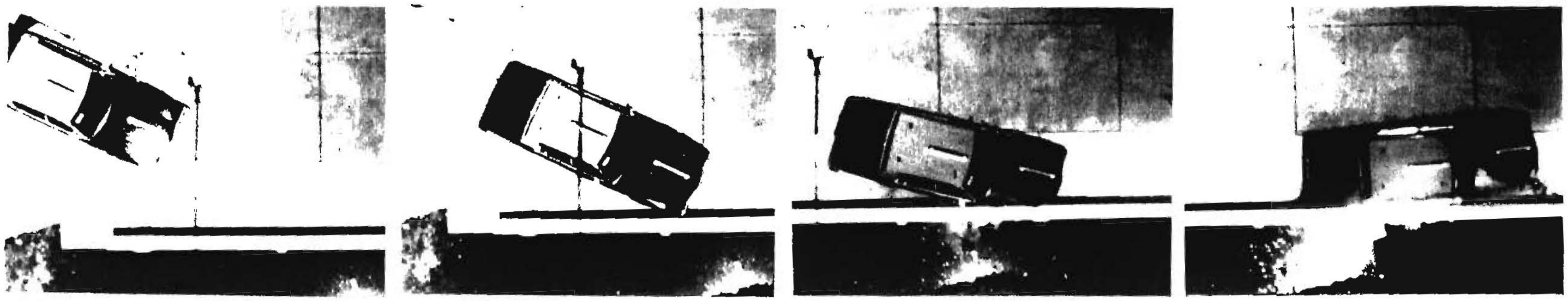
TEST RESULTS 1185-6

The speed of the vehicle as it impacted the curb was 47.0 mph (75.6 km/h) and the angle of impact was 25.4 degrees. As the vehicle impacted the bridge rail, it was traveling at 46.7 mph (75.1 km/h) and 22.7 degrees. The speed of the vehicle as it was parallel to the bridge rail was 32.1 mph (51.6 km/h). Exit speed was 28.9 mph (46.5 km/h) and exit trajectory was 3.5 degrees. Occupant impact velocity was 23.2 ft/s (7.1 m/s) in the longitudinal direction and 17.1 ft/s (5.2 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -4.8 g (longitudinal) and 8.5 g (lateral). These data and other pertinent information from the test are summarized in Figure 18. Vehicular angular displacements are displayed in Figure E2 of Appendix E.

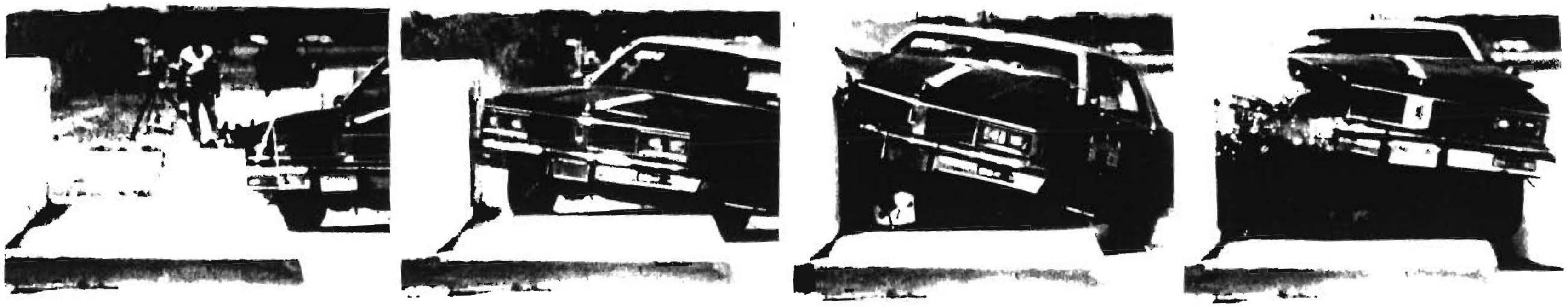
Vehicular accelerations versus time traces filtered at 300 Hz are presented in Figures E3 through E7 of Appendix E. These data were further analyzed to obtain 0.050-second average accelerations versus time. The maximum 0.050-second averages measured at the center of gravity were -6.6 g (longitudinal) and 6.2 g (lateral).

CONCLUSIONS

The bridge rail contained and smoothly redirected the test vehicle with no lateral movement or cracking 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 occupant/compartment impact velocities and 10-ms occupant ridedown accelerations were within the usual recommended limits. The vehicle trajectory at loss of contact indicates no intrusion into adjacent traffic lanes.



0.000 s   0.177 s   0.349 s   0.549 s



Test No. 1185-6
Date 07/03/90

Test Installation . . . Texas Type C411 Bridge Rail
Installation Length . . 52 ft (16 m)

Vehicle . . . . 1982 Oldsmobile 98
Vehicle Weight
  Test Inertia . . . . . . 4,500 lb (2,043 kg
Vehicle Damage Classification
  TAD 01RFQ6
  CDC . . . . 01FREK3 & OFRFES3
Maximum Vehicle Crush . 14.0 in (35.6 cm)

Impact Speed . . . 47.0 mi/h (75.6 km/h)
Impact Angle . . . 25.4 degrees
Speed at Parallel . 32.1 mi/h (51.6 km/h)
Exit Speed . . . . 28.9 mi/h (46.5 km/h)
Exit Trajectory . . 3.5 degrees
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal . . -6.6 g
  Lateral . . . . . 6.2 g
Occupant Impact Velocity
  Longitudinal . . 23.2 ft/s (7.1 m/s)
  Lateral . . . . . 17.1 ft/s (5.2 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . -4.8 g
  Lateral . . . . . 8.5 g

Figure 18. Summary of results for test 1185-6.

SUMMARY and CONCLUSIONS

This was probably the first time a combination pedestrian-traffic bridge rail mounted on an 8 in. high curb and 6 ft wide sidewalk has been designed and crash tested. This type rail was developed for use where city streets pass over federal aid or interstate highways or other hazards. The combination pedestrian-traffic rail would only be exposed to moderate speed (45 mph) vehicles. NCHRP Report 230's (3) low service level crash test (SL-1) called for a 4,500 lb car traveling 60 mph and impacting at a 15 degree angle and a second test with an 1,800 lb car impacting at 60 mph and 20 degree angle. The 1989 Guide Specifications for Bridge Railings' (9) low performance level (PL-1) called for a crash test with a 5,400 lb pickup truck impacting at 45 mph and 20 degree angle and a second test with an 1,800 lb car impacting at 50 mph and 20 degree angle. Neither of these two crash tests seemed appropriate for this type traffic rail and its intended location on low speed (less than 50 mph) city streets.

Table 1, which is now being considered by two NCHRP-AASHTO research projects, seemed appropriate because the 1,900 lb car and 4,500 lb pickup truck would both impact at 45 mph at 20 degree and 25 degree angles, respectively. (Note: a 4,500 lb car was used here.)

The 8 in. high curb, 6 ft wide sidewalk and 42 in. high combination pedestrian-vehicle bridge rail performed very well in the two crash tests. Appendix F of the 1977 Guide for Selecting, Locating, and Designing Traffic Barriers (14) presents automobile trajectory data predicted by the HVOSM computer model when an automobile impacts curbs of various heights.

The data generated by the HVOSM computer model of an automobile predicted that these two vehicles would vault so that the bumper would be 14 in. to 18 in. higher than normal when it impacts the bridge rail behind the 8 in. high curb and 6 ft wide sidewalk. The crash tests showed the Honda bumper was only 4 in. higher than normal and the Oldsmobile bumper was only 3.5 in. to 7.5 in. higher (the bumper was 3.5 in. higher on initial impact and continued to climb to 7.5 in. higher 0.25 sec later). The normal bumper height of the Honda was 20.5 in. and that of the Oldsmobile was 20.75 in. when parked on a level surface. During the Oldsmobile test the right front and rear tires blew out and the wheel rims were bent during the curb impact.

In the strength test with the 4,500 lb vehicle at 47.0 mph and 25.4 degree angle, the change in speed and angle after the curb impact until the rail impact was only -0.3 mph and -2.7 degrees. The conclusion is that the effect of the 8 in. high curb and 6 ft wide sidewalk on the vehicle impact with the bridge rail was not as significant as engineers had once thought.

While the crash tests variables used were not those recommended by the crash test matrix of NCHRP 230 or the 1989 Guide Specifications for Bridge Railings, Tables 2 and 3 compare the test results with the usual safety evaluation criteria presented in these documents. The crash test results indicate that this C411 bridge rail should be safe for use on low speed (45 mph) or less roads.

Table 2. Safety Evaluation of Crash Test No. 1185-5
C411 Bridge Rail (1,900 lb/45 mph/20 deg)

Usual Safety Evaluation 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	.55	Marginal	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	12.1	7.3	
Occupant Ridedown Accelerations - g's		Occupant Ridedown Accelerations - g's		Pass
Longitudinal	Lateral	Longitudinal	Lateral	
15	15	-4.6	7.4	
Exit angle shall be less than 12 degrees		Exit angle was 2.7 degrees		Pass

Table 3. Safety Evaluation of Crash Test No. 1185-6
C411 Bridge Rail (4,500 lb/45 mph/25 deg)

Usual Safety Evaluation 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	.51	Marginal	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	23.2	17.1	
Occupant Ridedown Accelerations - g's		Occupant Ridedown Accelerations - g's		Pass
Longitudinal	Lateral	Longitudinal	Lateral	
15	15	-4.8	8.5	
Exit angle shall be less than 15 degrees		Exit angle was 5.0 degrees		Pass

REFERENCES

1. 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.

2. 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.

3. 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.

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

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.

6. Olson, R.M., et al., "Tentative Service Requirements for Bridge Rail Systems," NCHRP Report 86, Washington, D.C., 1970.

7. 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.

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

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

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.

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

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.

13. Hirsch, T.J., C.E. Buth, W.L. Campise, and D. Kaderka, "Aesthetically Pleasing Steel Pipe Bridge Rail - Texas Type T421," Research Report 1185-2, Texas Transportation Institute, Texas A&M University, Nov. 1989.

14. Guide for Selecting, Locating, and Designing Traffic Barriers, American Association of State Highway and Transportation Officials, 1977.

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. 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.

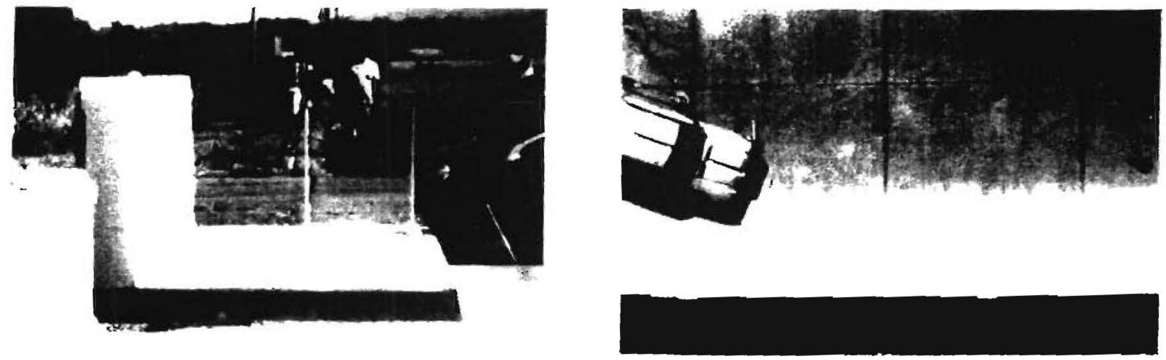
The VEHICLE program also uses digitized data from vehicle-mounted linear accelerometers to compute vehicle accelerations, areas enclosed by acceleration-time curves, changes in velocity, changes in momentum, instantaneous forces, average forces, and maximum average accelerations over 0.050-second intervals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

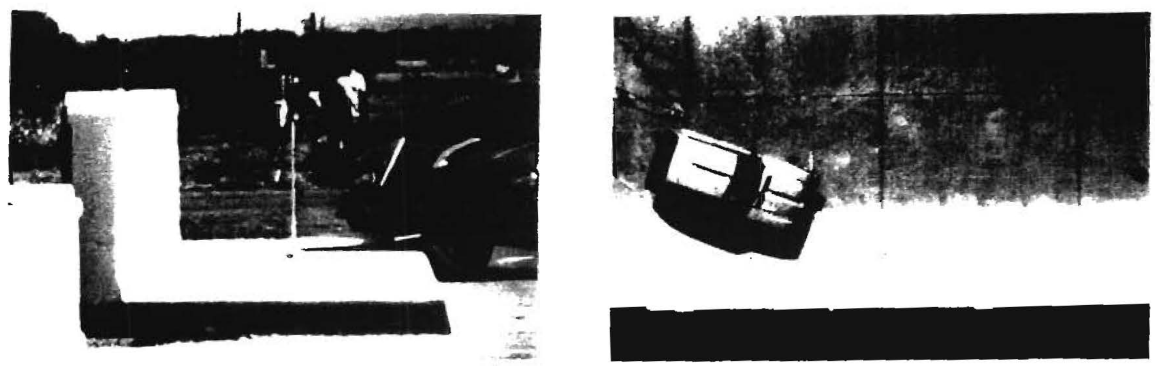
Still photography, real-time cine, and video were used to record conditions of the test vehicle and bridge rail before and after the test. Video and real-time and high-speed cine were used to document the test. One high-speed camera was placed to have a field of view parallel to and aligned with the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

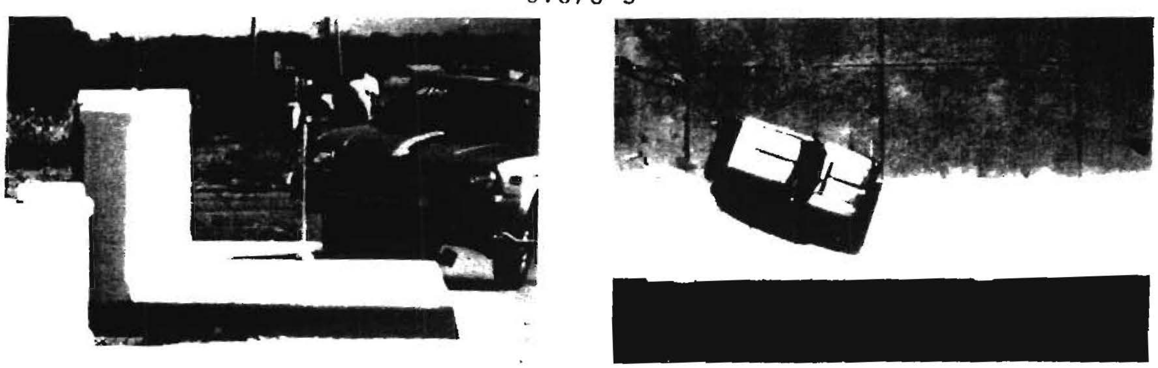
Sequential Photographs of Test 1185-5



0.000 s



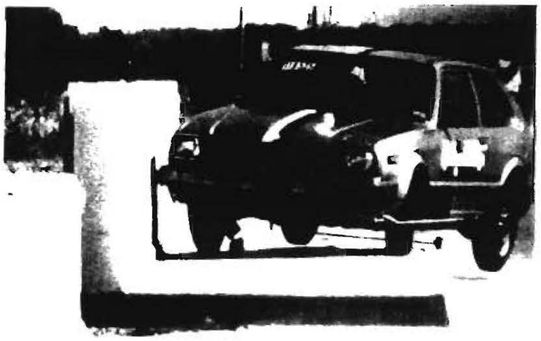
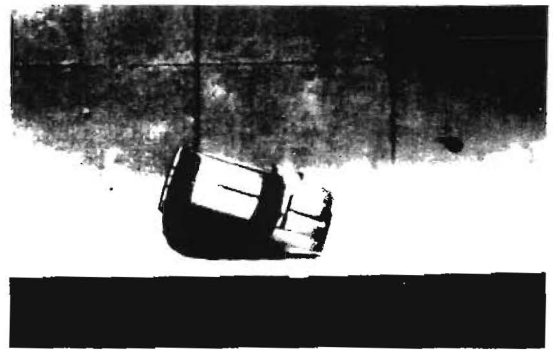
0.075 s



0.149 s

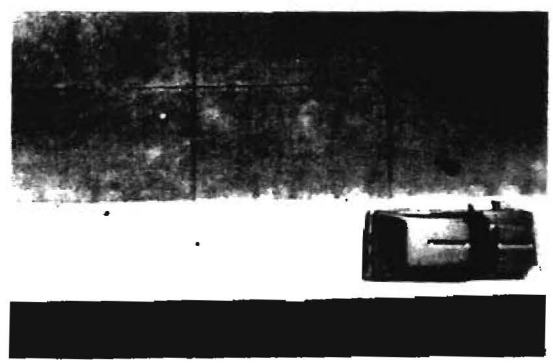
0.224 s

Figure B1. Sequential photographs for test 1185-5.

0.322 s


0.460 s

0.603 s


0.761 s

Figure B1. Sequential photographs for test 1185-5.
(Continued)

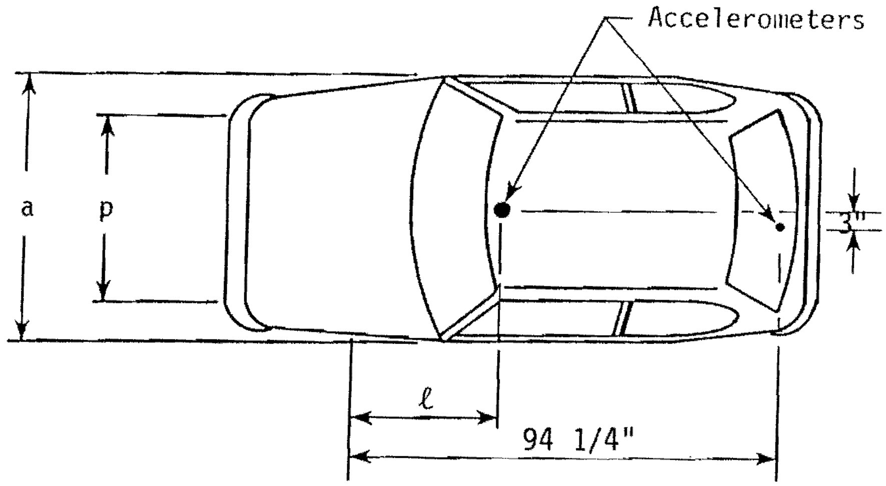
APPENDIX C

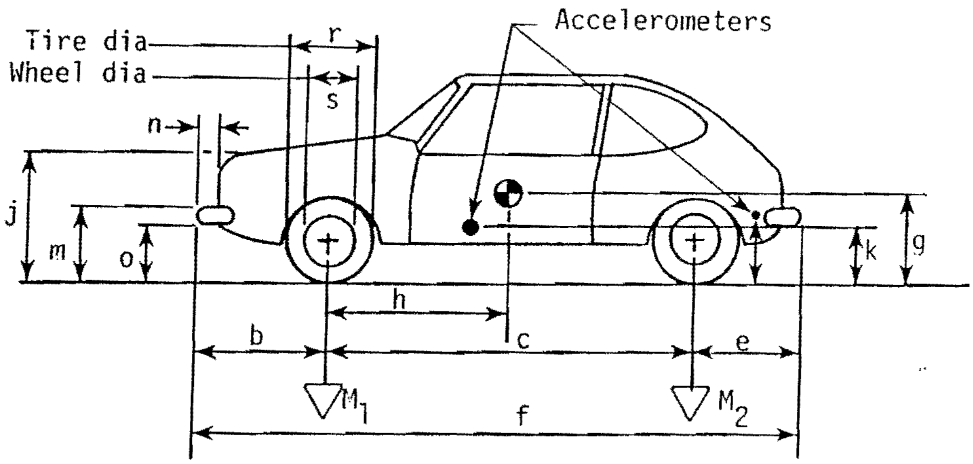
Electronic Accelerometer, Roll, Pitch, and Yaw Data Test 1185-5

Date: ______ Test No.: 1185-5 VIN: JHMSL5328CS017095

Make: Honda Model: Civic Year: 1982 Odometer: 104346

Tire Size: P175 80R13 Ply Rating: ______ Bias Ply: __ Belted: __ Radial: X





4-wheel weight for c.g. det. ℓf 568 rf 557 ℓr 353 rr 322

Mass - pounds	Curb	Test Inertial	Gross Static
M_1		1125	1207
M_2		675	763
M_T		1800	1970

Note any damage to vehicle prior to test:

Crack in windshield (marked)

Tire Condition: good __ fair X badly worn __

Vehicle Geometry - inches

a	62 3/4	b	30
c	88 1/4	d*	53
e	29	f	147 1/4
g		h	33.1
i	----	j	29
k	16 3/4	ℓ	27 1/2
m	20 1/2	n	4
o	15	p	53 3/4
r	23	s	14 1/4

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

*d = overall height of vehicle

Figure Cl. Test vehicle properties (test 1185-5).

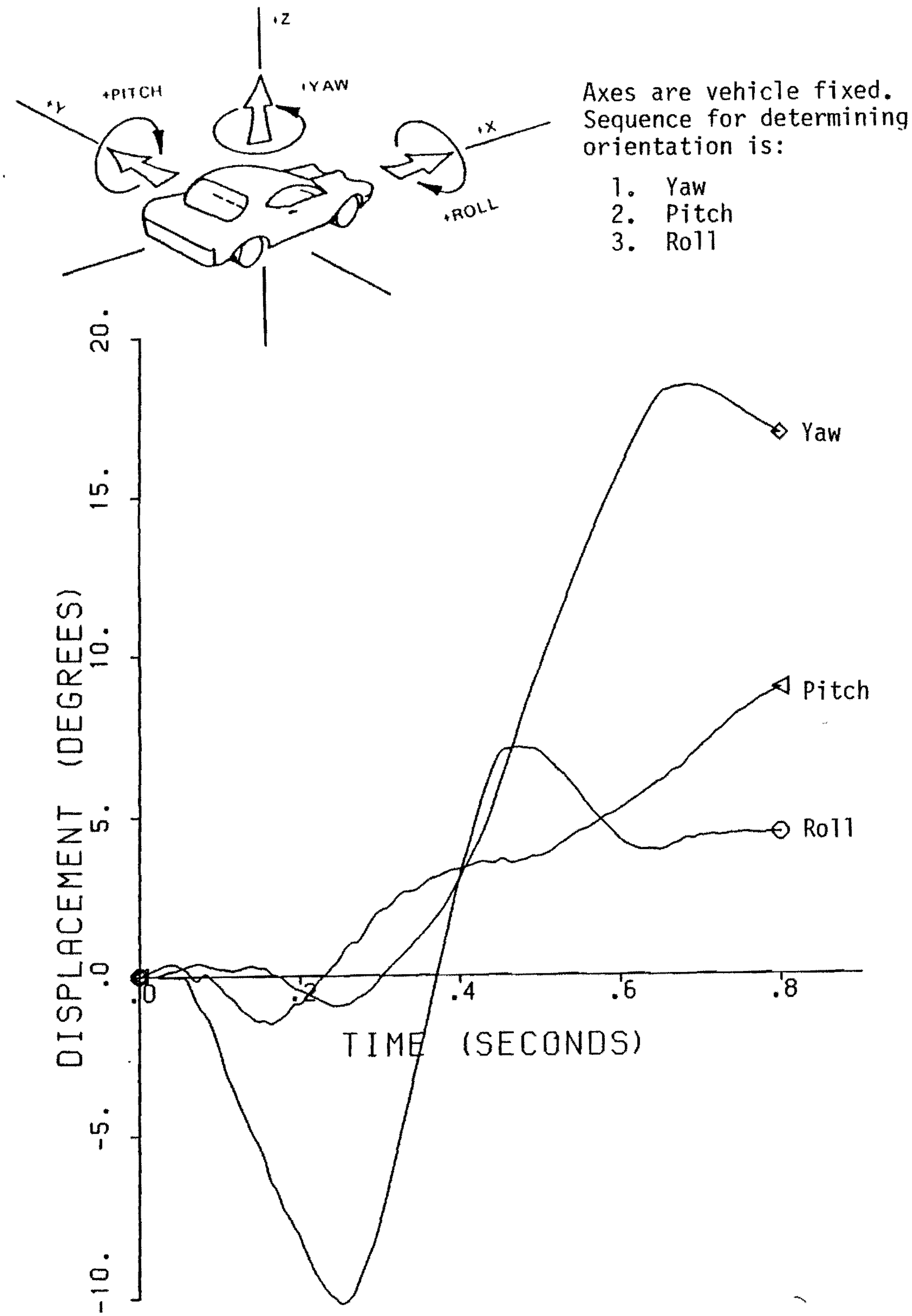


Figure C2. Vehicle angular displacement for test 1185-5.

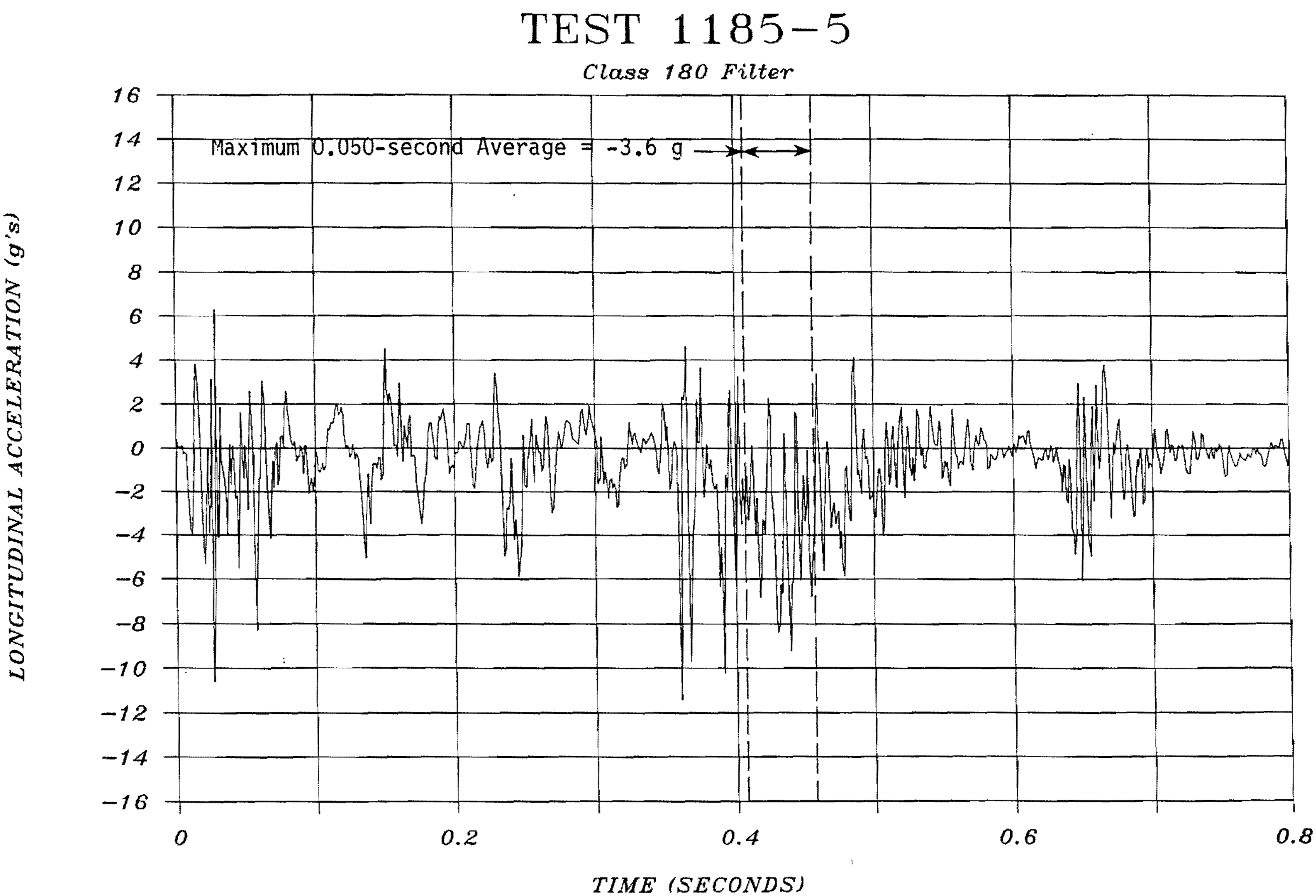


Figure C3. Vehicle longitudinal accelerometer trace for test 1185-5. (near center-of-gravity)

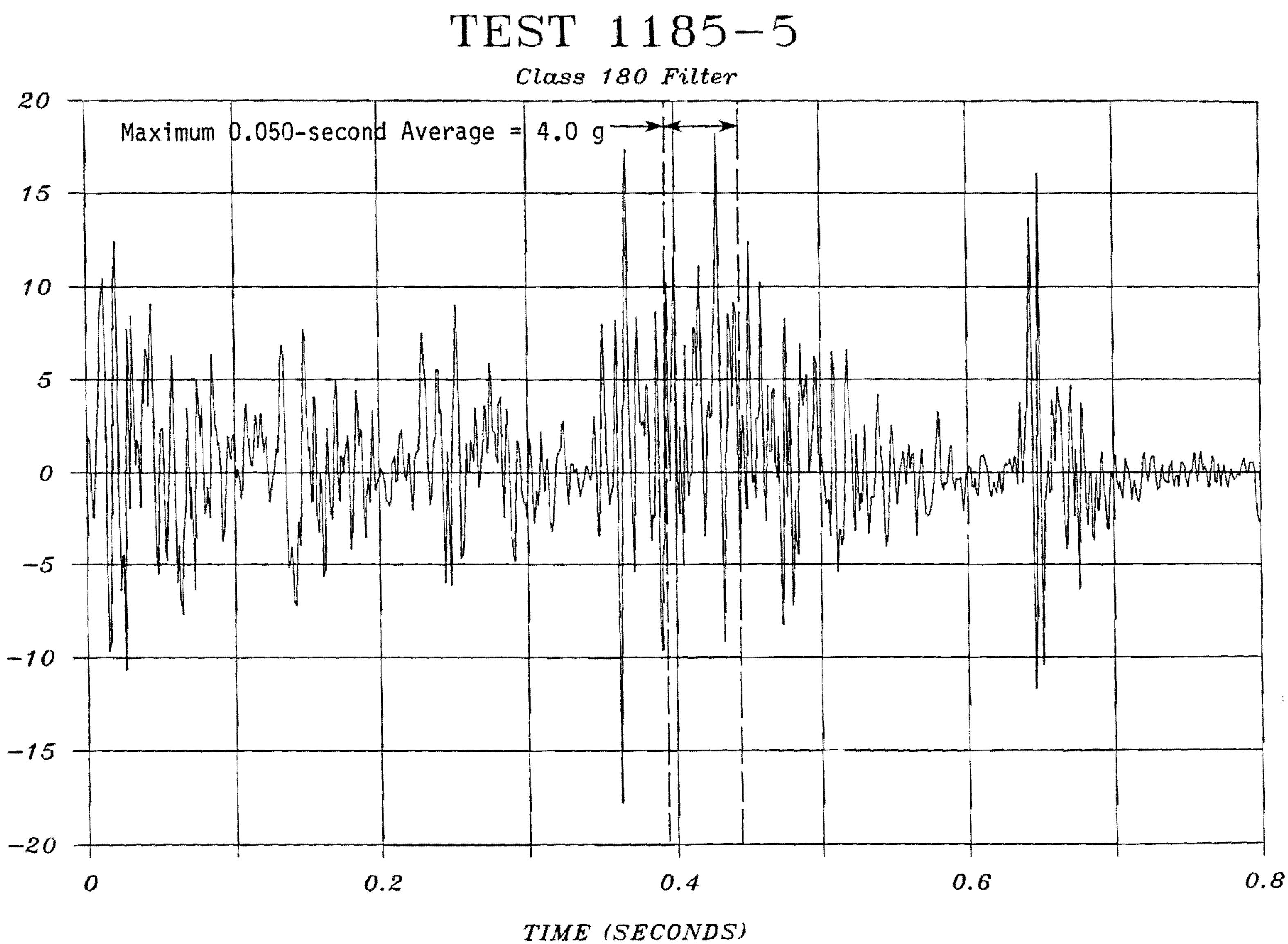


Figure C4. Vehicle lateral accelerometer trace for test 1185-5. (near center-of-gravity)

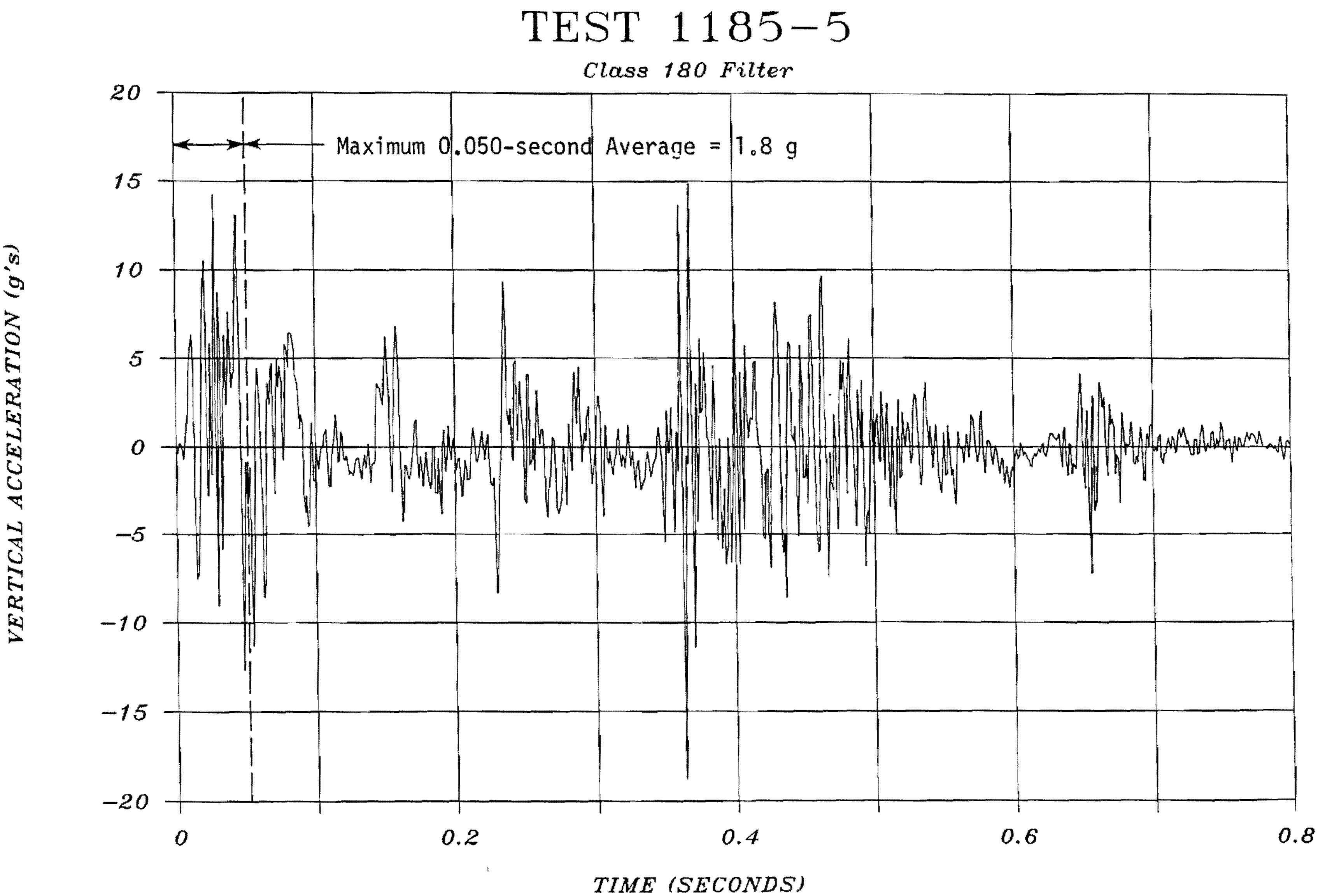


Figure C5. Vehicle vertical accelerometer trace for test 1185-5.
(near center-of-gravity)

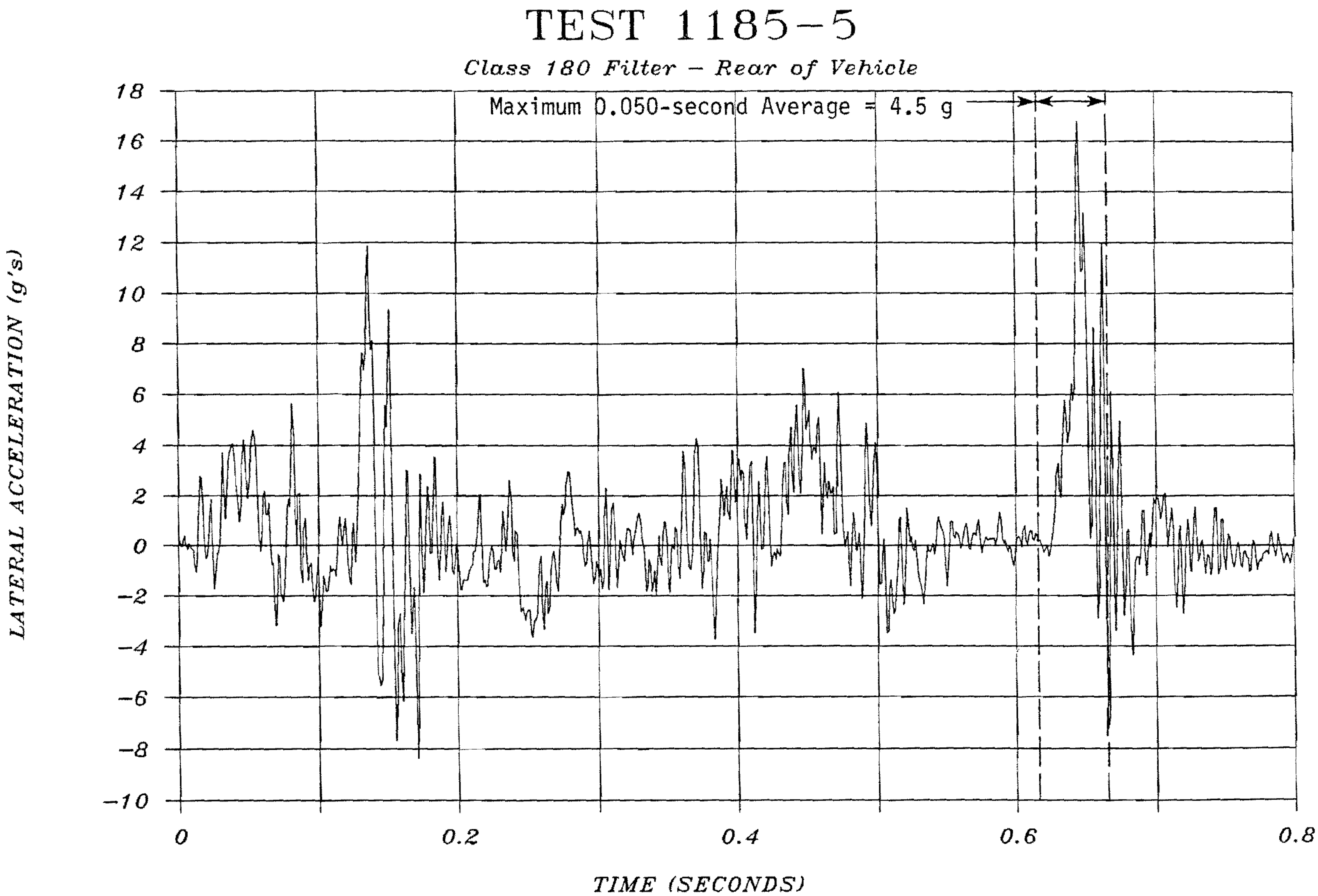
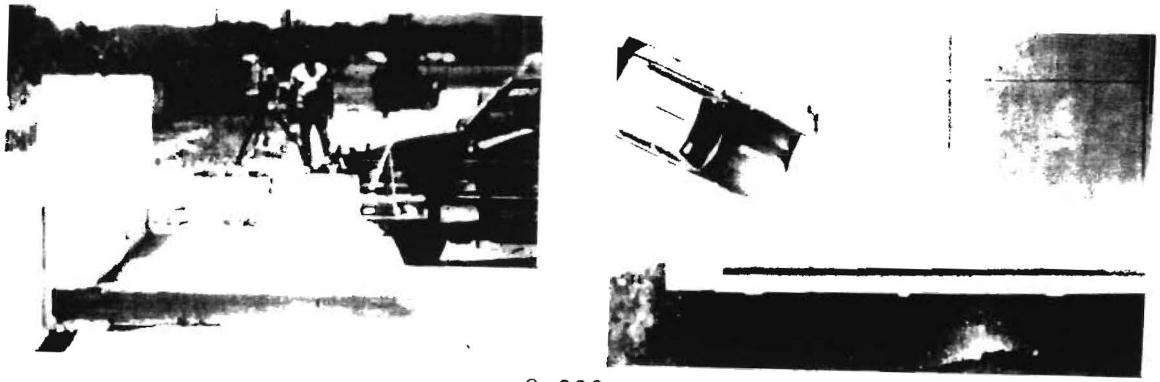


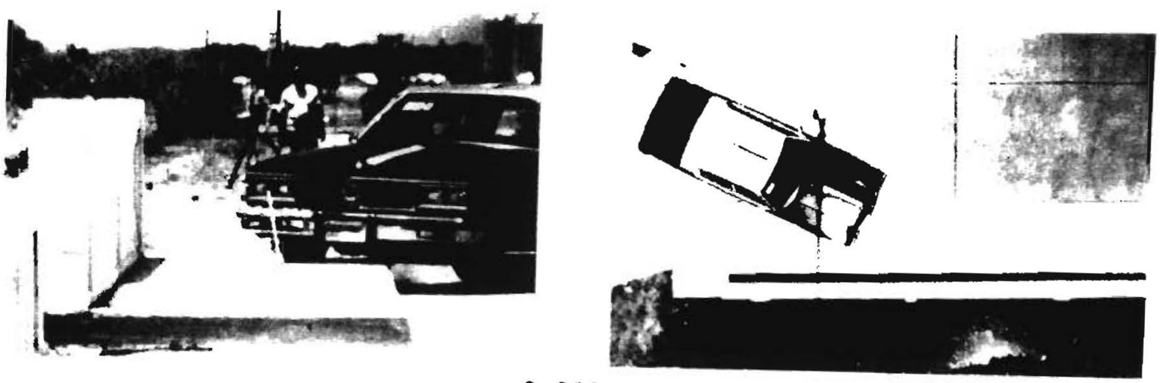
Figure . Vehicle lateral accelerometer trace for test 1185-5 (rear of vehicle)

APPENDIX D

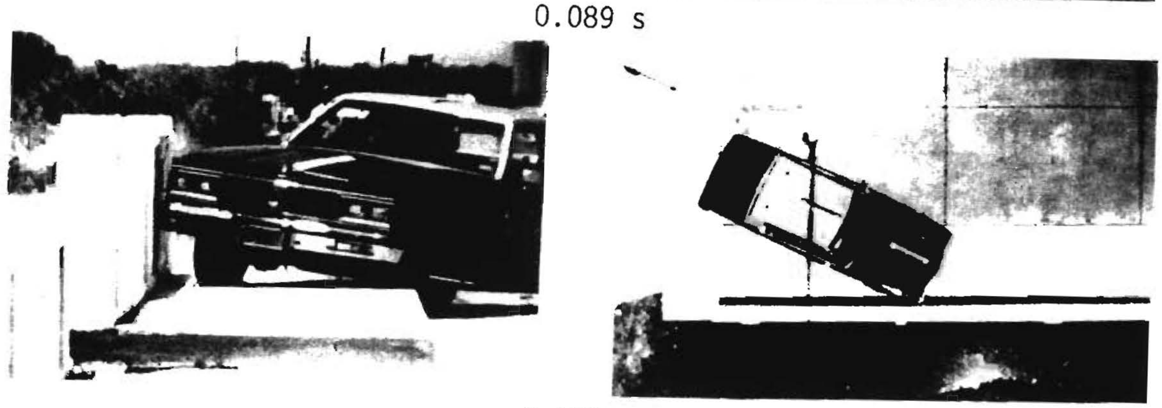
Sequential Photographs of Test 1185-6



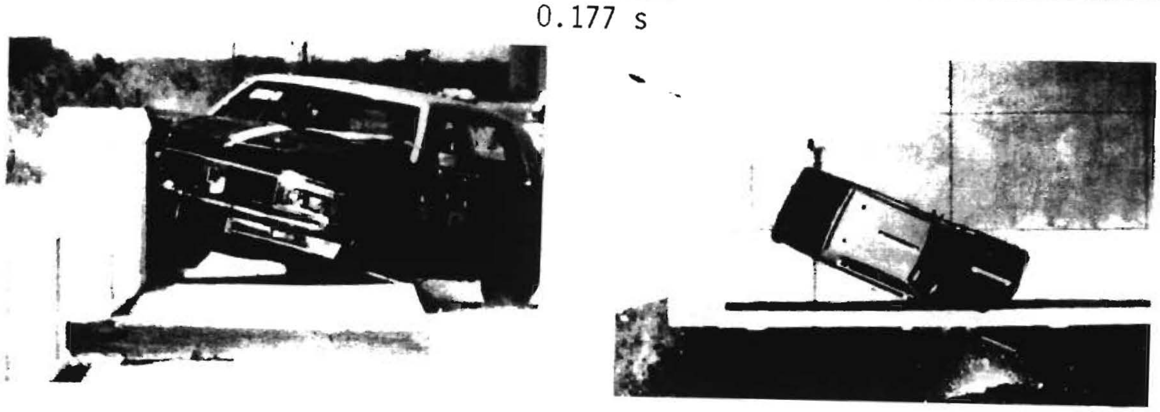
0.000 s



0.089 s



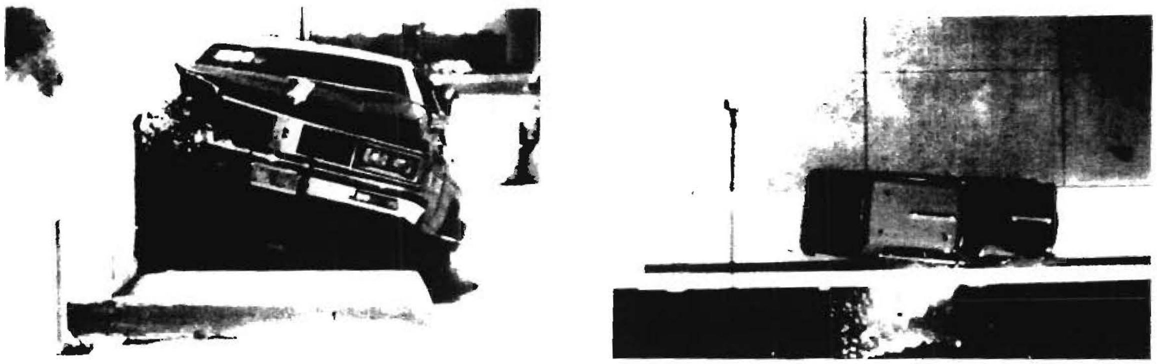
0.177 s



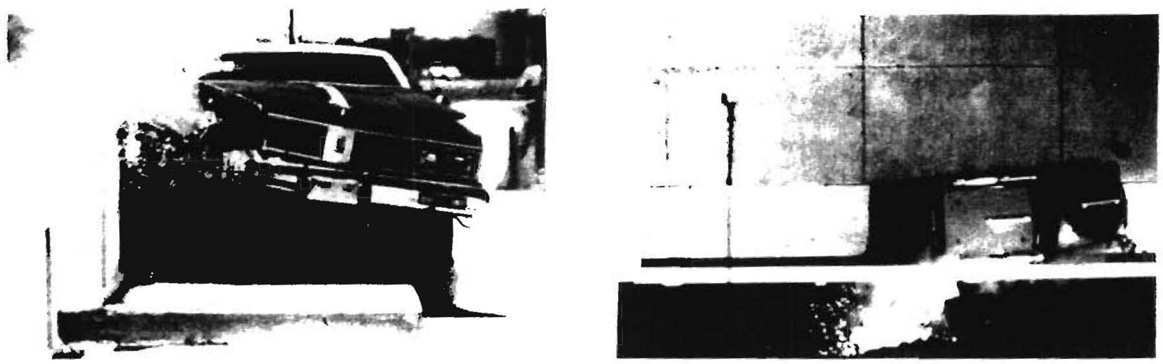
0.263 s

Figure D1. Sequential photographs for test 1185-6.

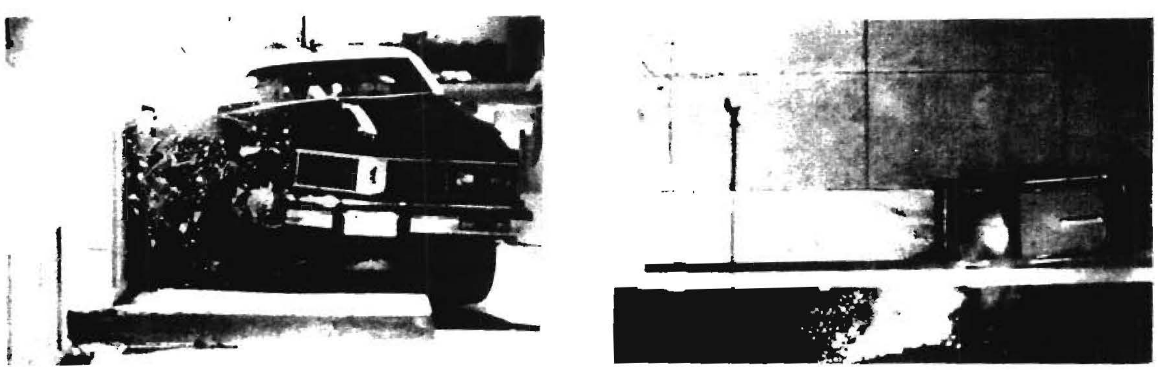
0.349 s



0.435 s



0.549 s



0.658 s

Figure D1. Sequential photographs for test 1185-6.
(Continued)

APPENDIX E

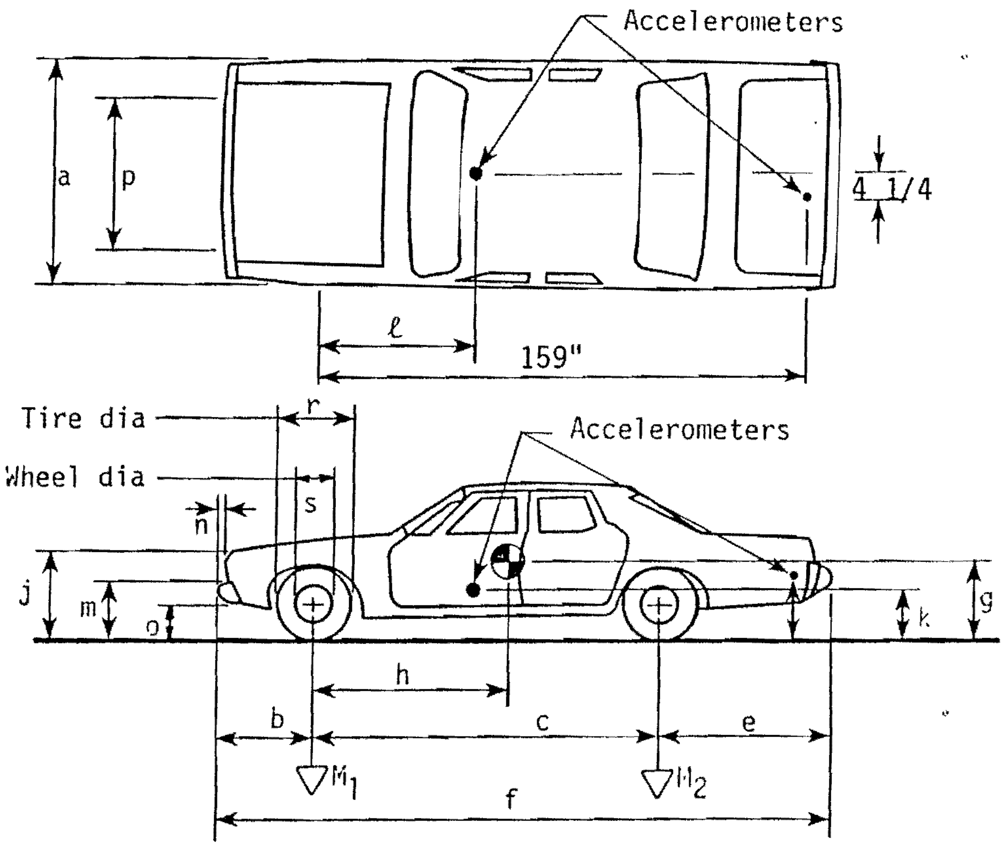
Electronic Accelerometer, Roll, Pitch, and Yaw Data Test 1185-6

Date: ______ Test No.: 1185-6 VIN: 163AW69N4CM133944

Make: Oldsmobile Model: Ninety-eight Year: 1982 Odometer: 86762

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

Tire Condition: good ___
fair X
badly worn ___



Vehicle Geometry - inches

a	75 1/2	b	43 3/4
c	119	d*	58 1/2
e	56	f	218 3/4
g		h	125.5
i	----	j	33 1/2
k		ℓ	
m	20 3/4	n	5
o	12 1/4	p	61 3/4
r	28	s	16 1/4

Engine Type: V-8

Engine CID: 350 Diesel

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

Body Type: 4-Door

Steering Column Collapse Mechanism:

___ Behind wheel units
___ Convoluted tube
___ Cylindrical mesh units
___ Embedded ball
___ NOT collapsible
___ Other energy absorption
___ Unknown

Brakes:

Front: disc X drum ___

Rear: disc ___ drum X

4-wheel weight for c.g. det. ℓf 1276 rf 1325 ℓr 974 rr 925

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2443	2601	
M_2	1588	1899	
M_T	4031	4500	

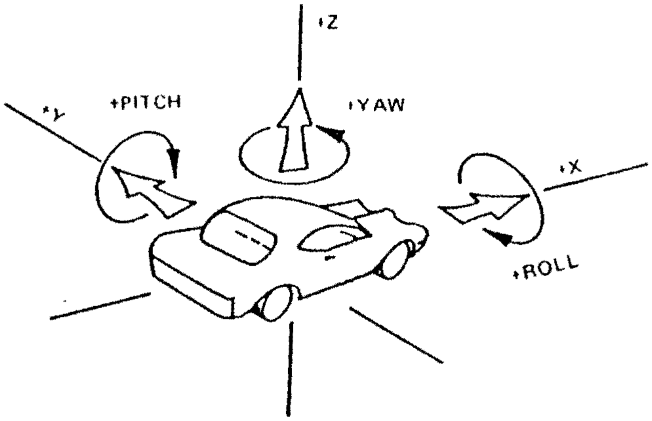
Note any damage to vehicle prior to test:

______

______

*d = overall height of vehicle

Figure E1. Test vehicle properties (1185-6).



Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

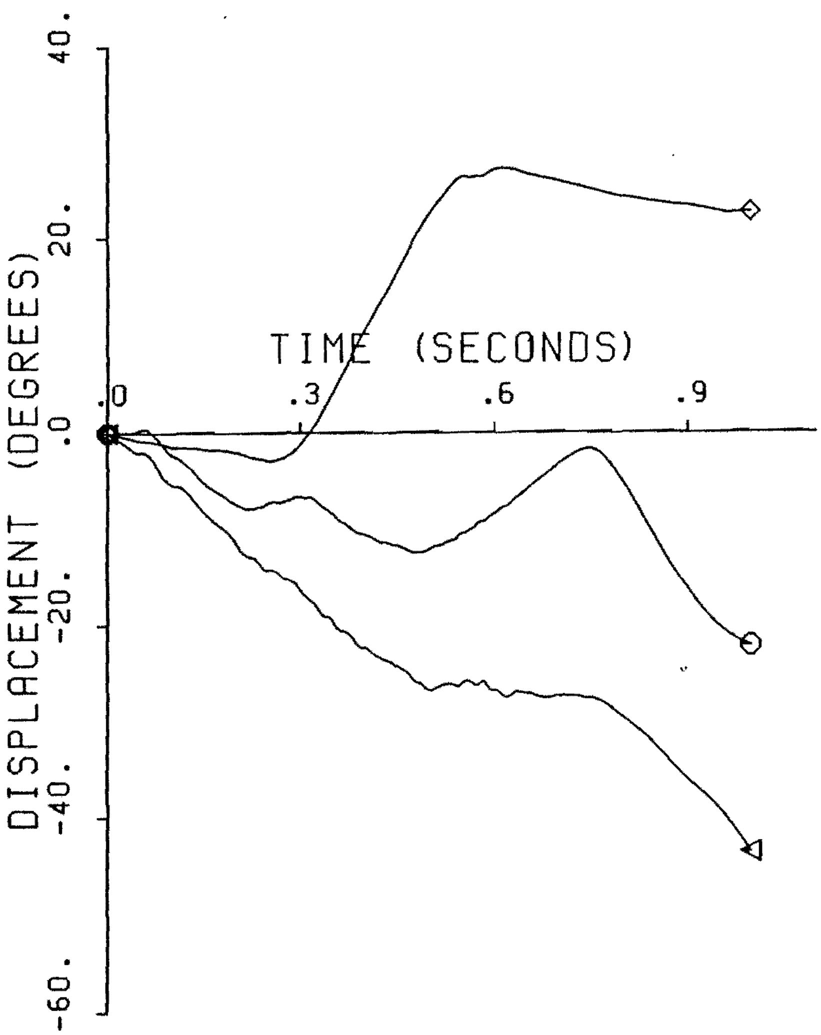


Figure E2. Vehicle angular displacements for test 1185-6

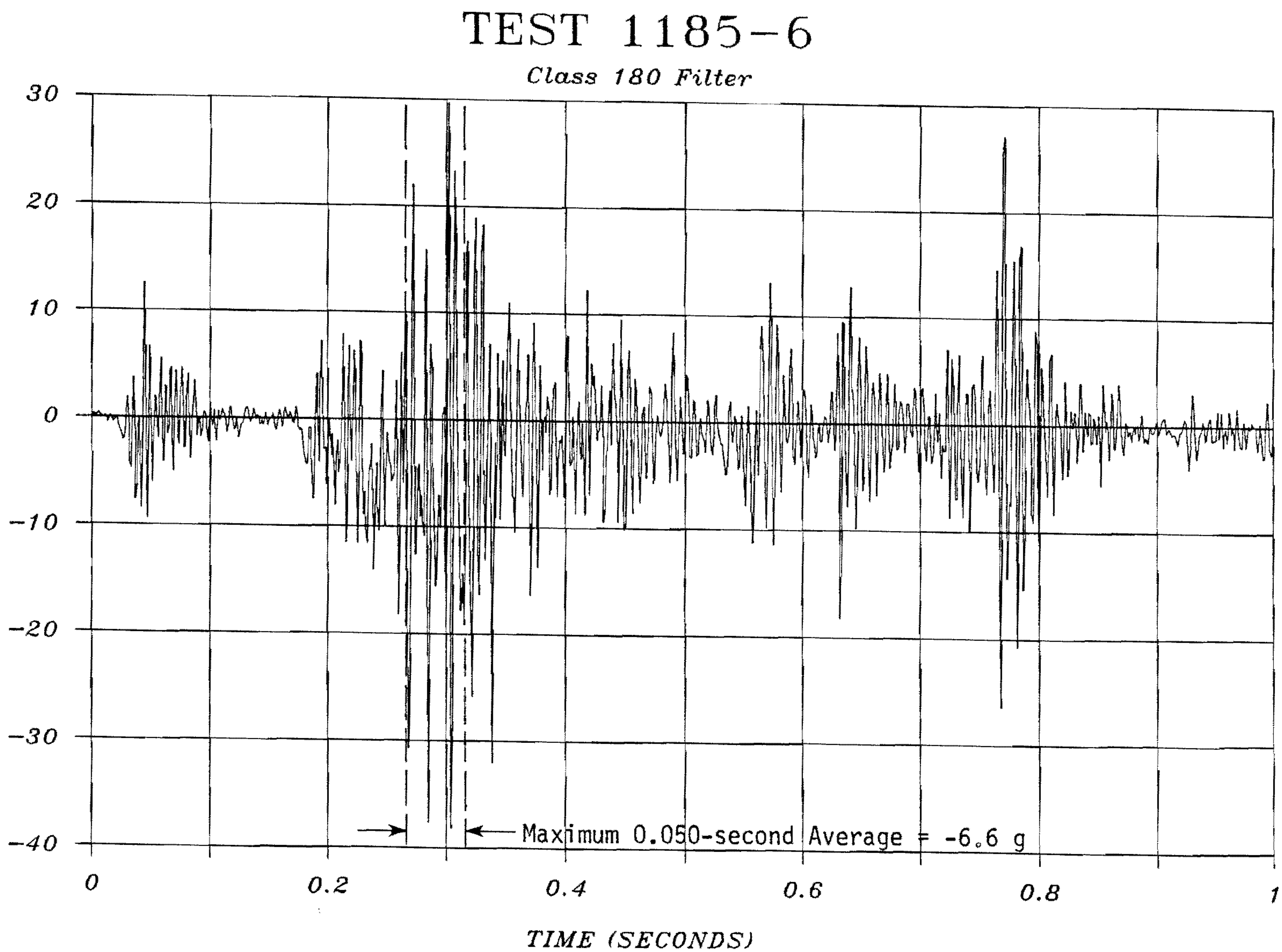


Figure E3. Vehicle longitudinal accelerometer trace for test 1185-6 (near center-of-gravity)

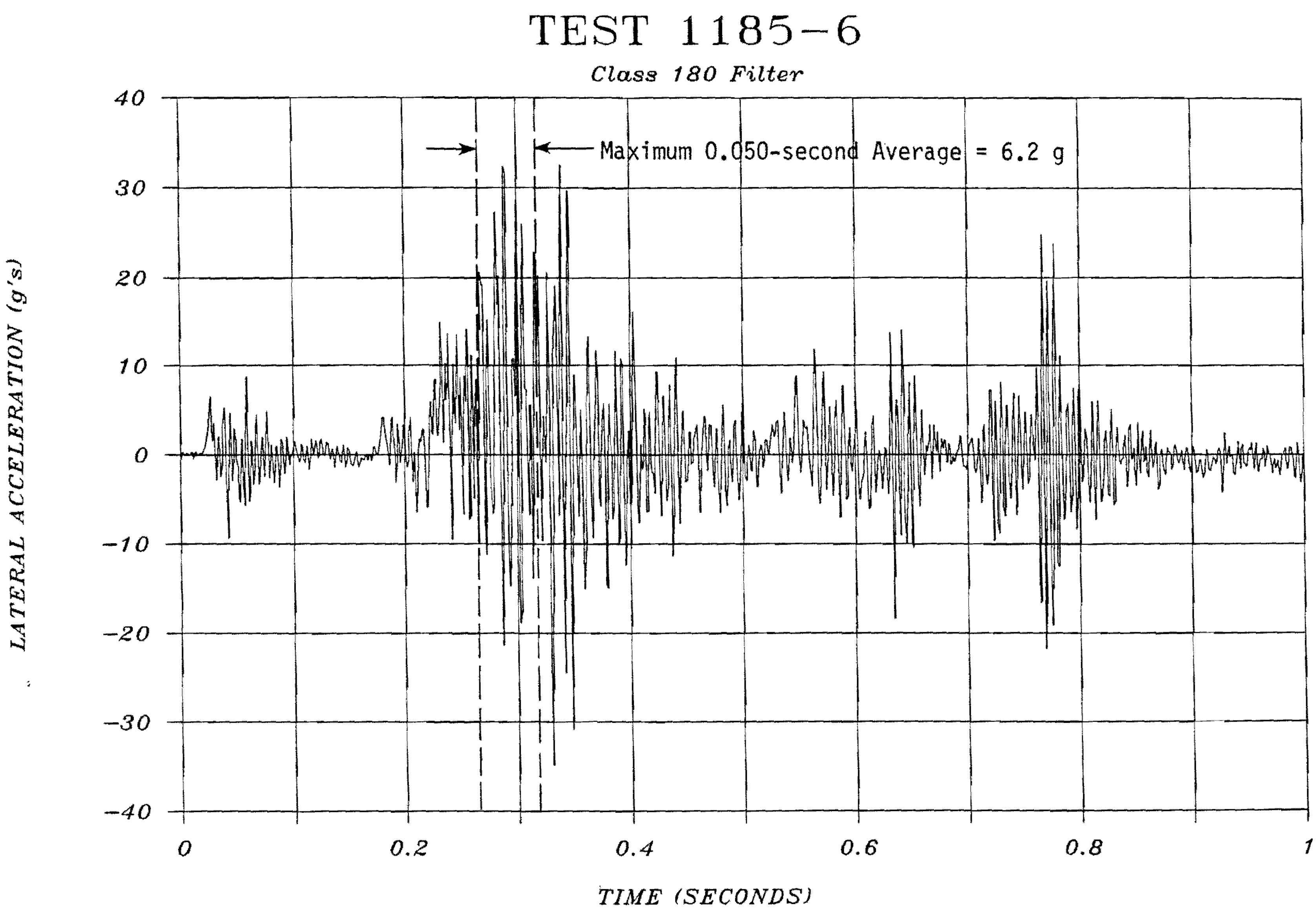


Figure E4. Vehicle lateral accelerometer trace for test 1185-6 (near center-of-gravity)

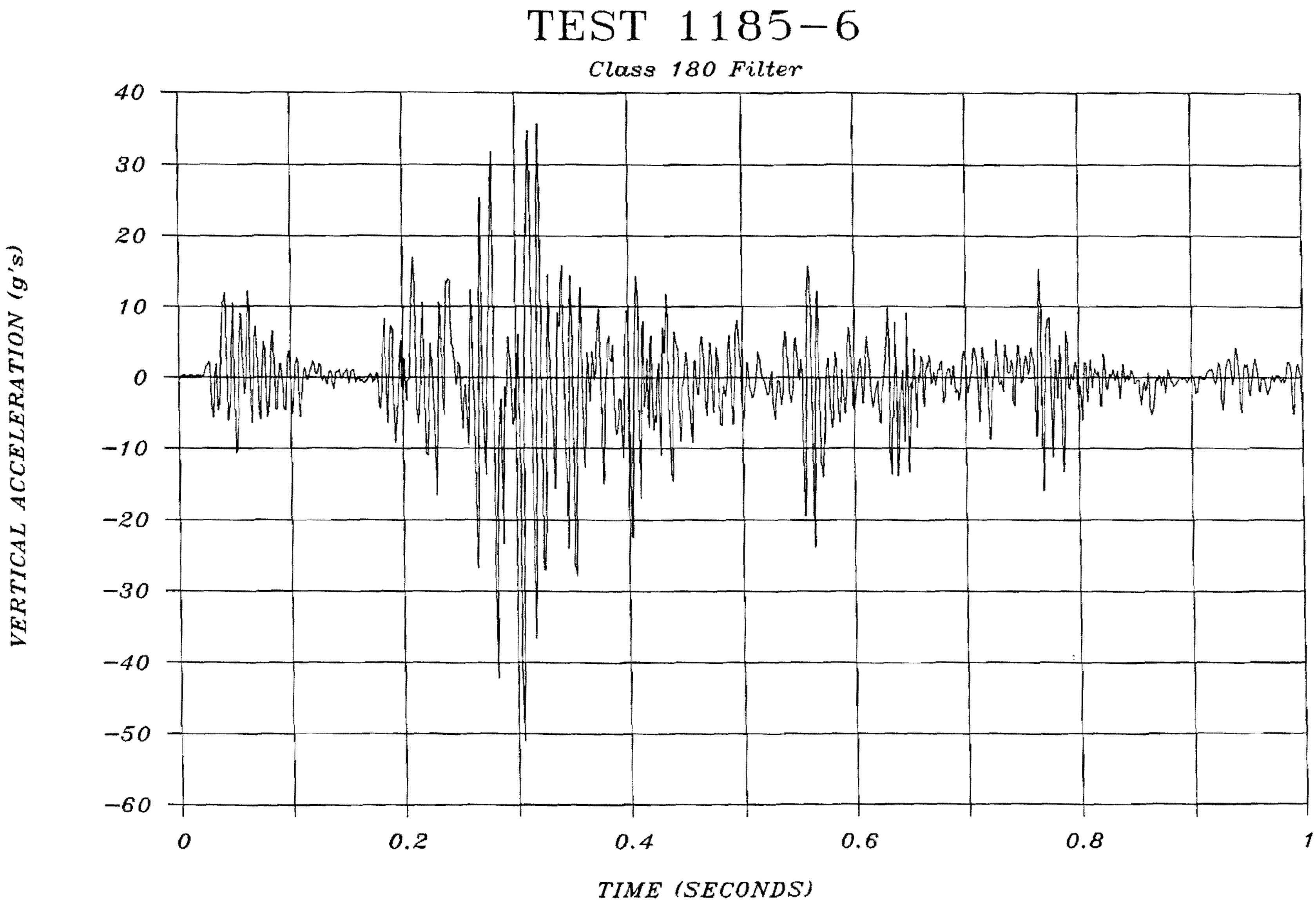


Figure E5. Vehicle vertical accelerometer trace for test 1185-6
(near center-of-gravity)

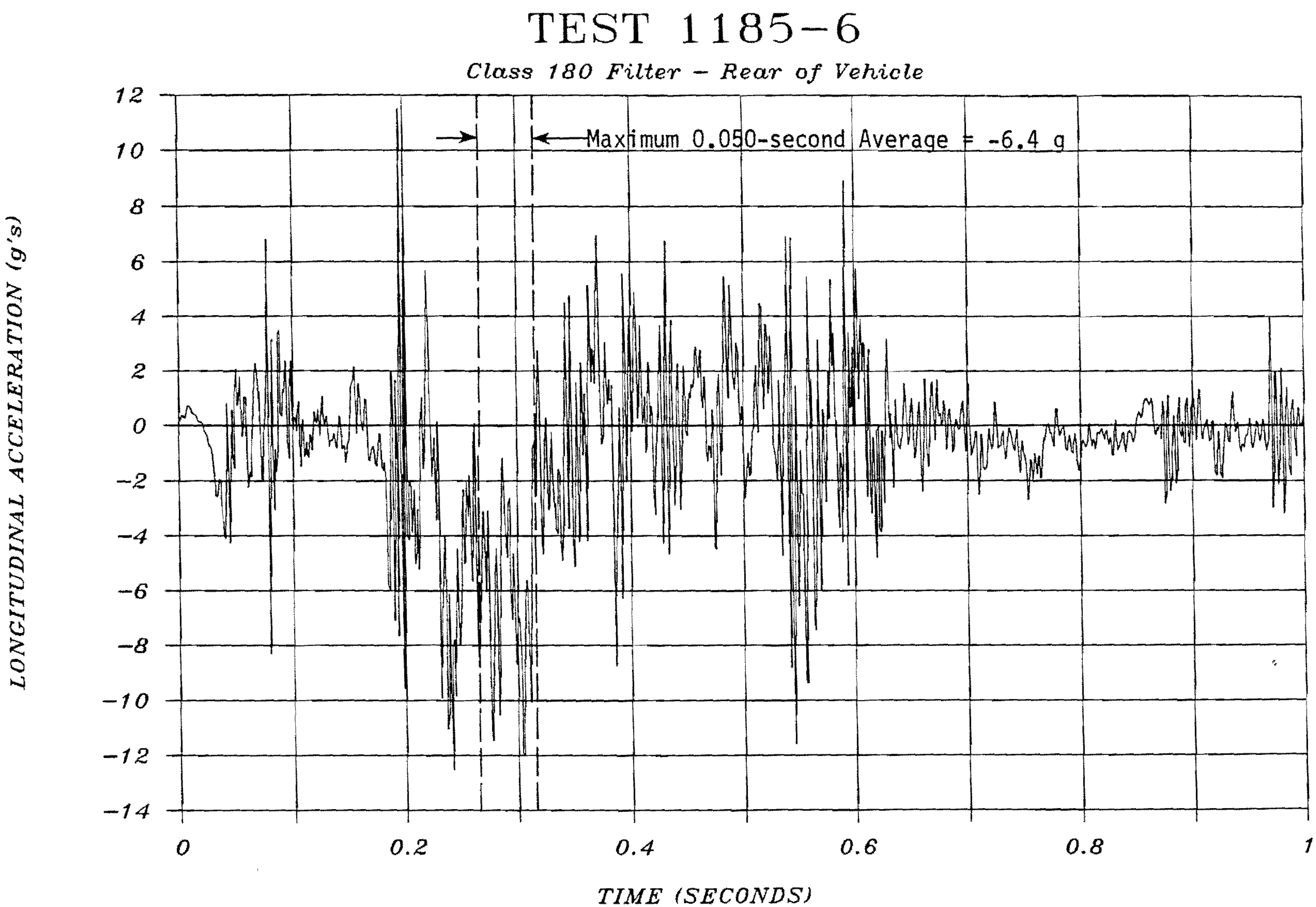


Figure E6. Vehicle longitudinal accelerometer trace for test 1185-6 (rear of vehicle)

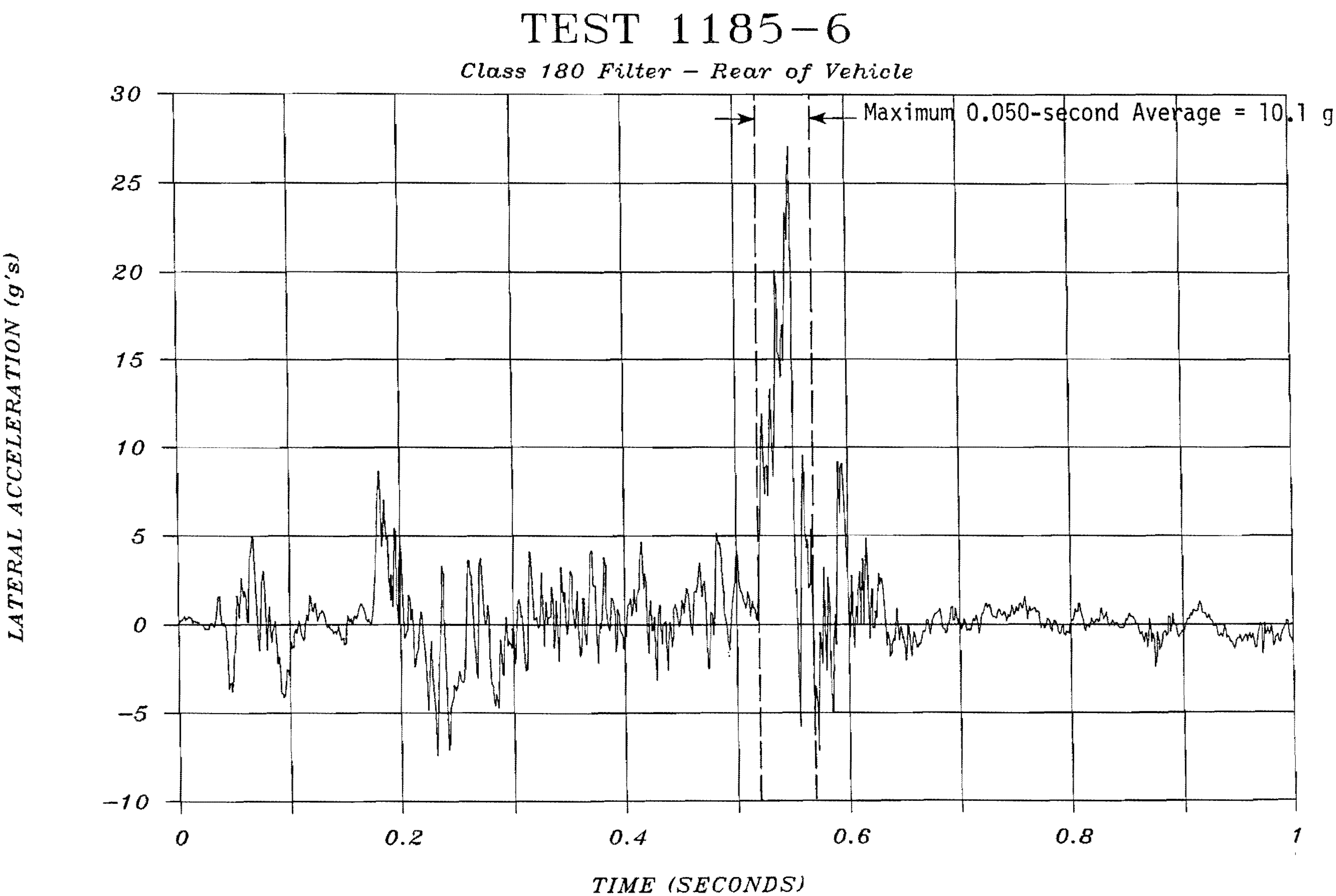


Figure E7. Vehicle lateral accelerometer trace for test 1185-6 (rear of vehicle)

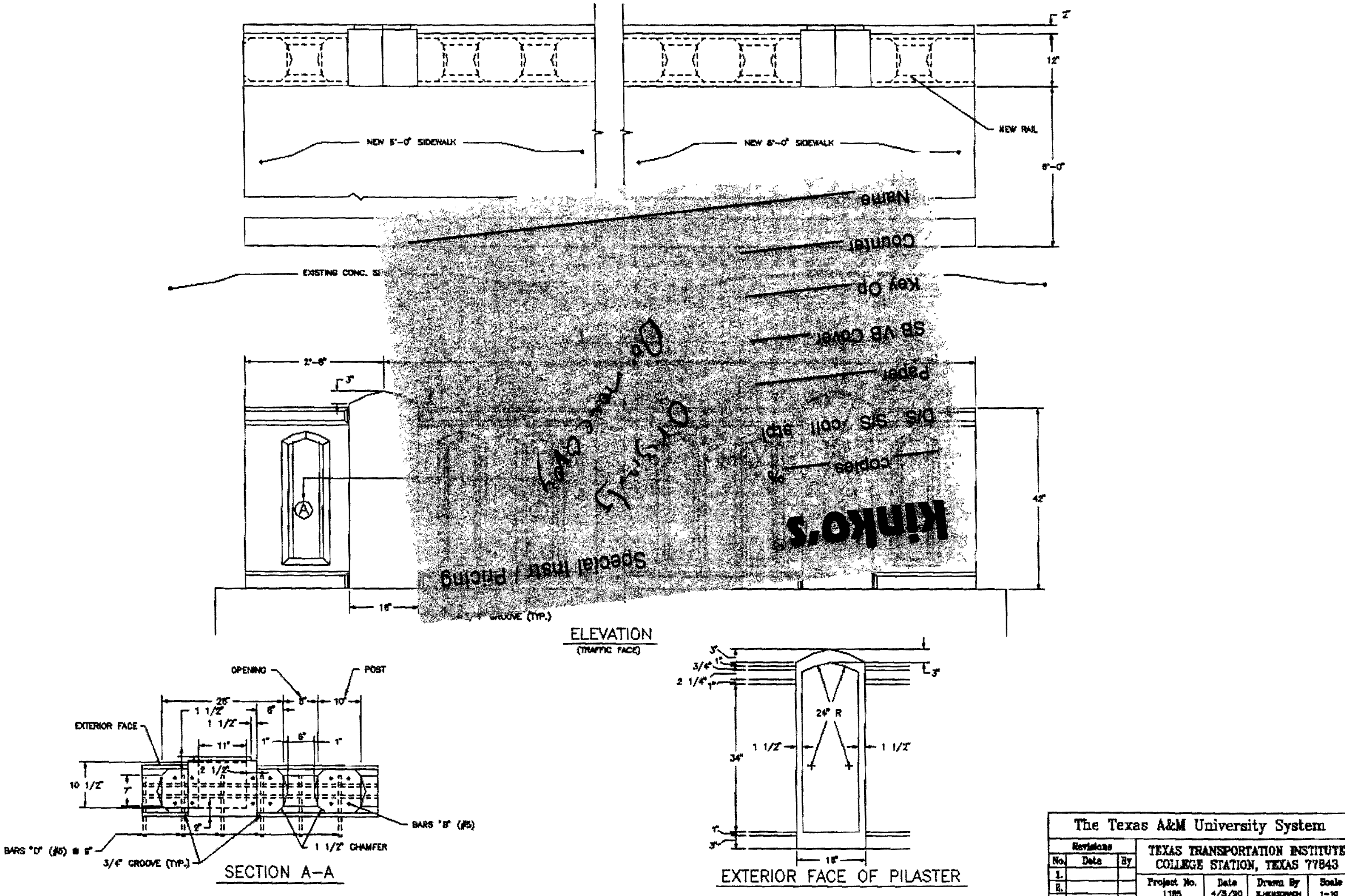
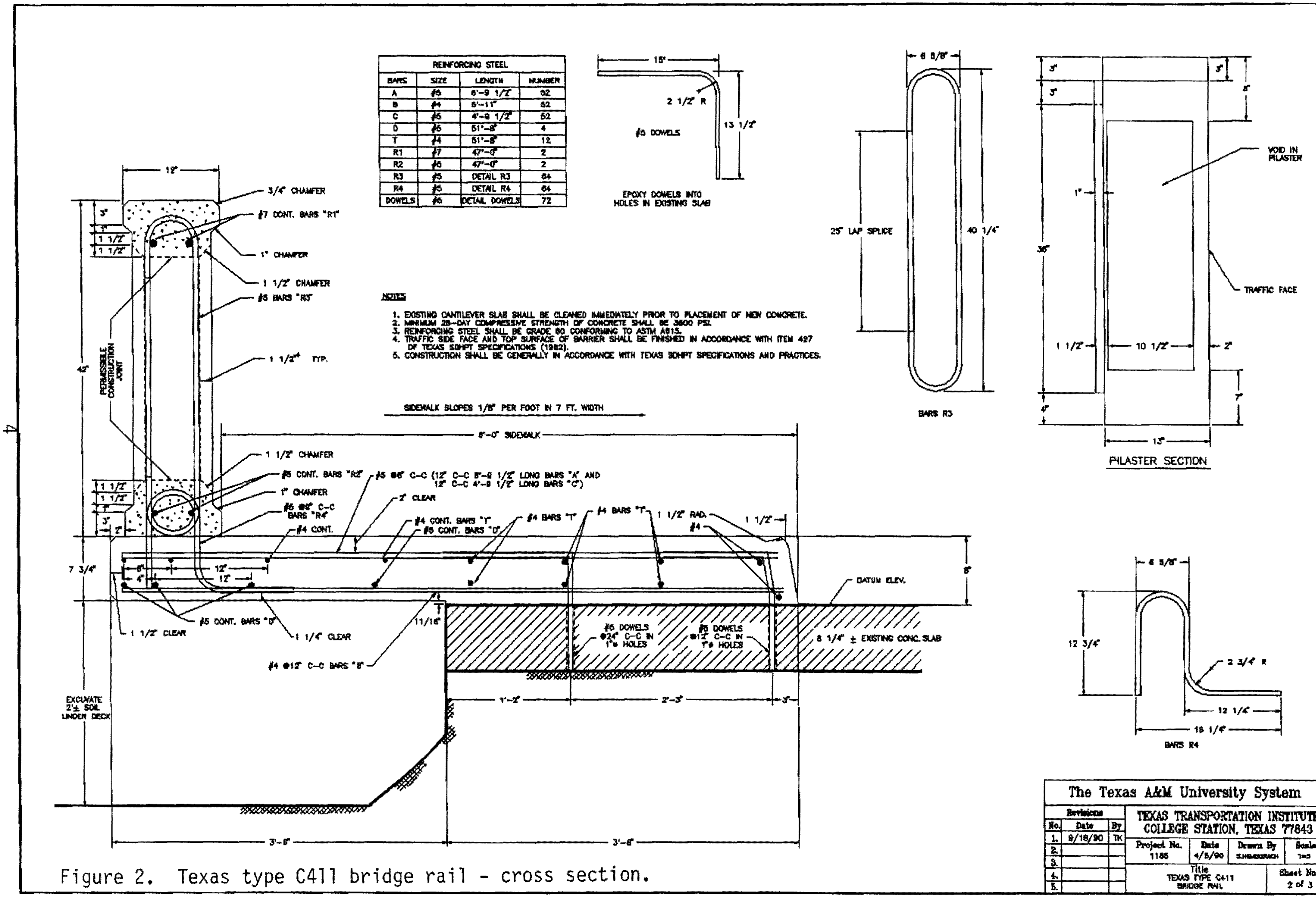
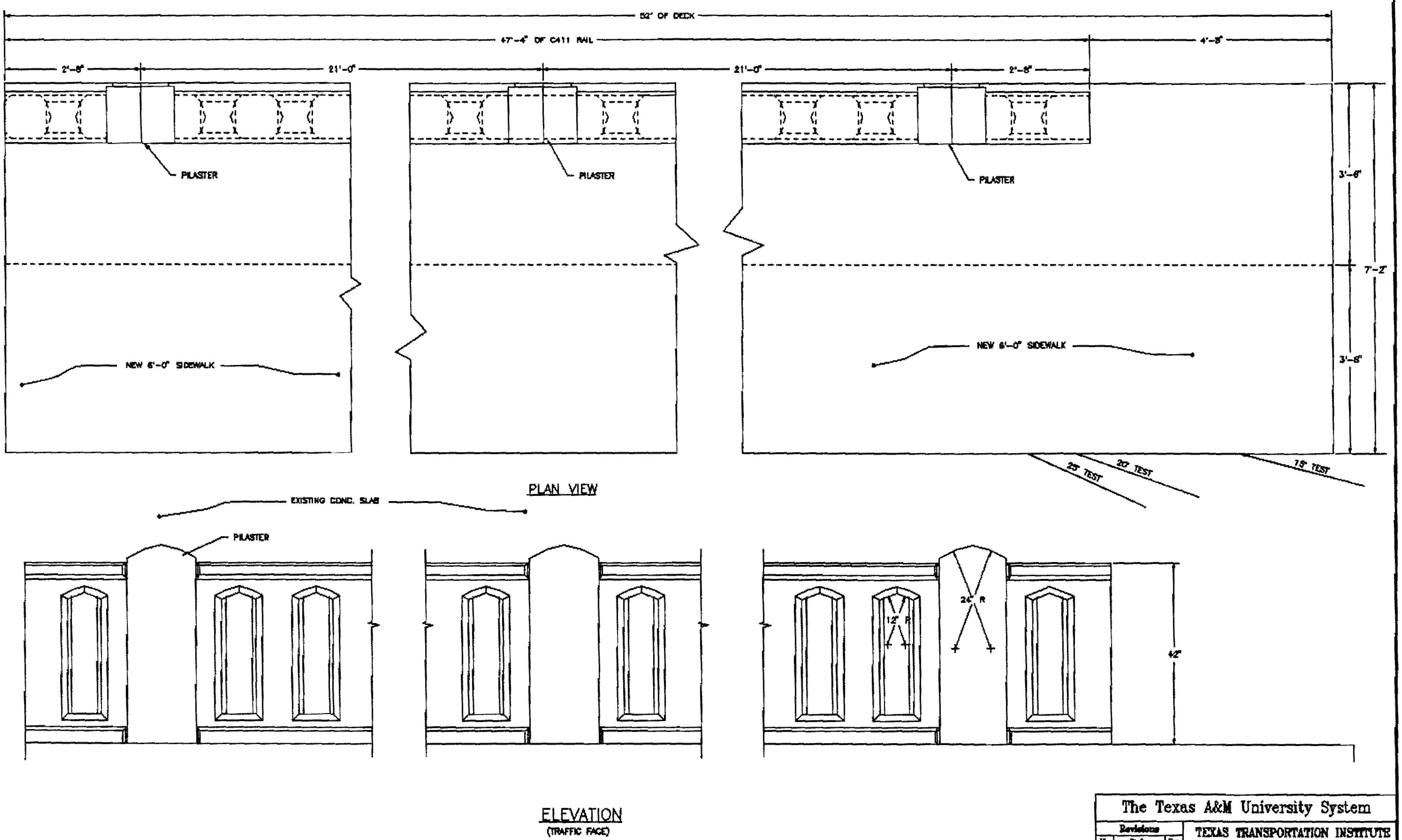


Figure 1. Texas type C411 bridge rail - plan and elevation.



REINFORCING STEEL			
BARS	SIZE	LENGTH	NUMBER
A	#5	8'-9 1/2"	62
B	#4	5'-11"	62
C	#5	4'-9 1/2"	62
D	#6	51'-8"	4
T	#4	51'-8"	12
R1	#7	47'-0"	2
R2	#6	47'-0"	2
R3	#5	DETAIL R3	64
R4	#5	DETAIL R4	64
DOWELS	#6	DETAIL DOWELS	72

Figure 2. Texas type C411 bridge rail - cross section.



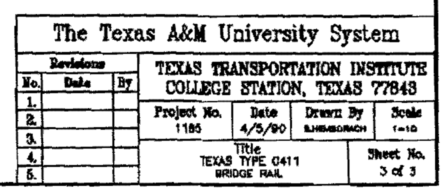


Figure 3. Texas type C411 bridge rail - plan and elevation.

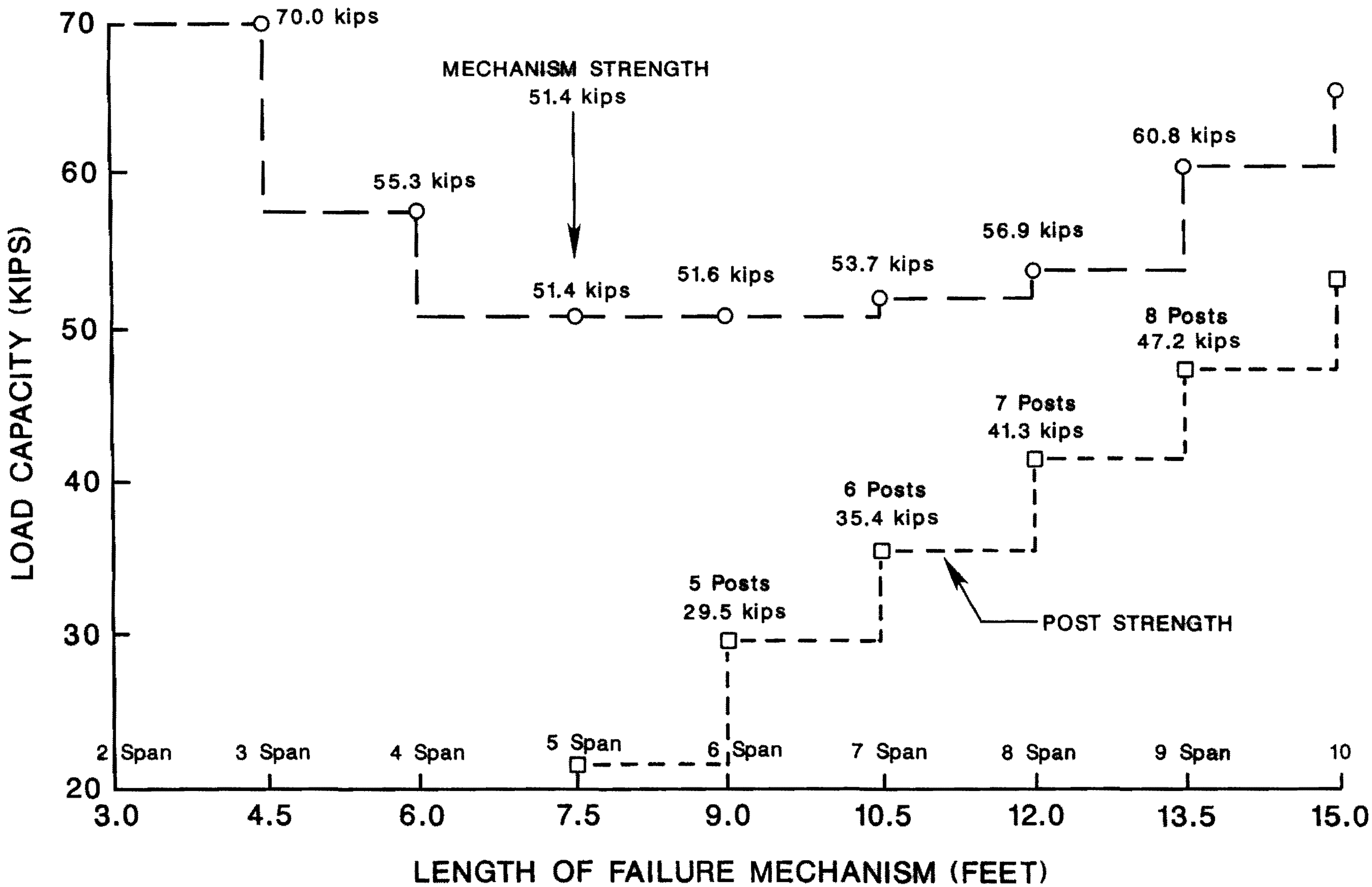
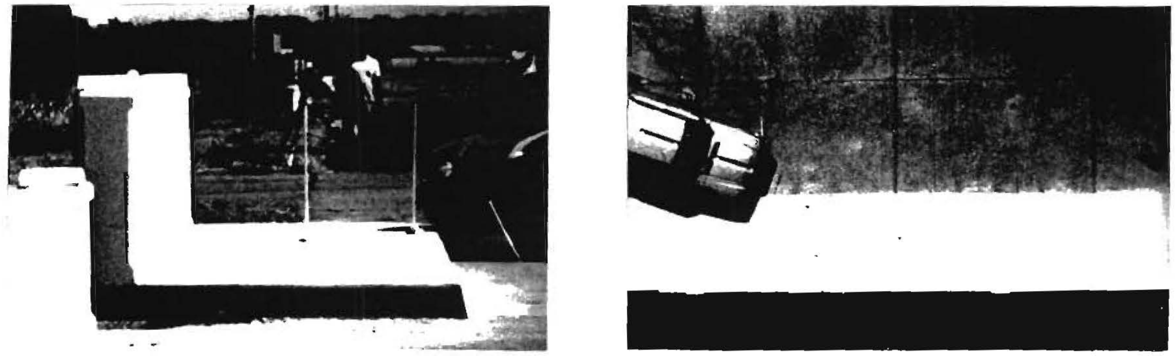
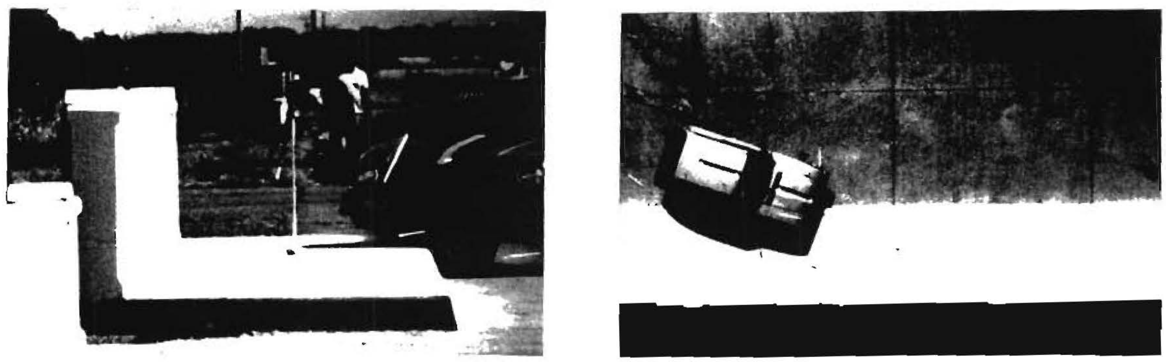


FIGURE 5. FAILURE MECHANISM ANALYSIS OF THE TEXAS C411 BRIDGE RAIL.

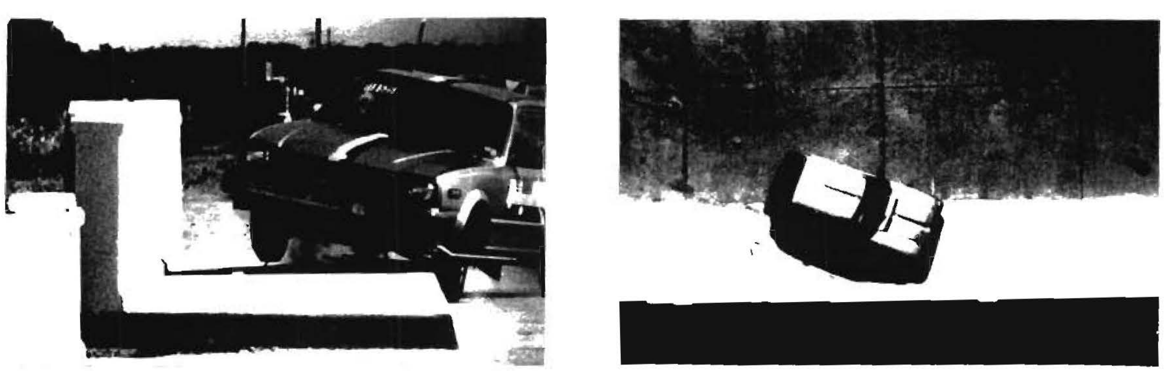


0.000 s



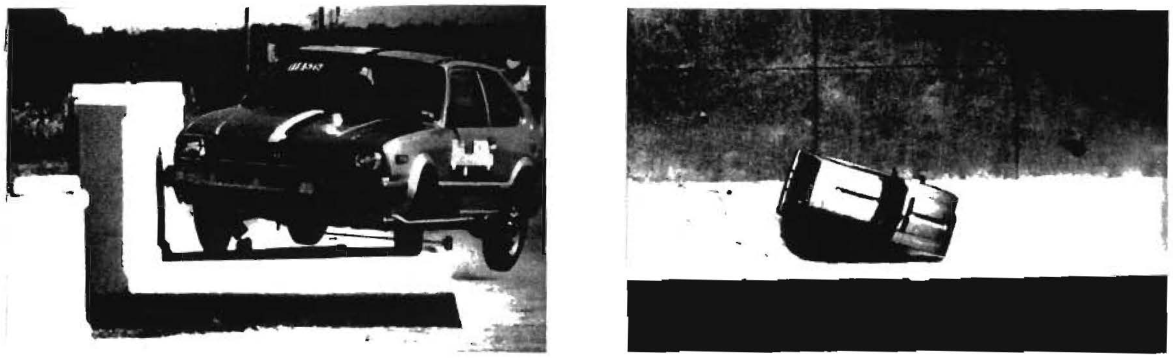
0.075 s

0.149 s

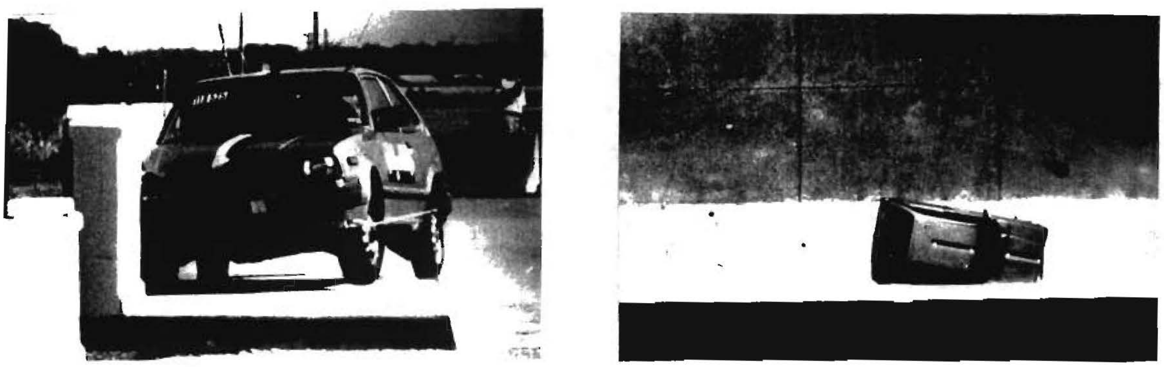


0.224 s

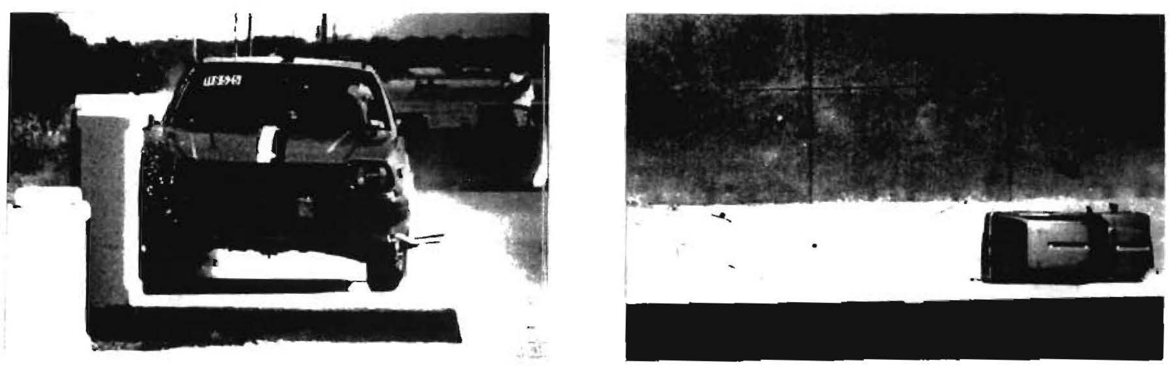
Figure B1. Sequential photographs for test 1185-5.



0.322 s



0.460 s



0.603 s

0.761 s

Figure B1. Sequential photographs for test 1185-5. (Continued)

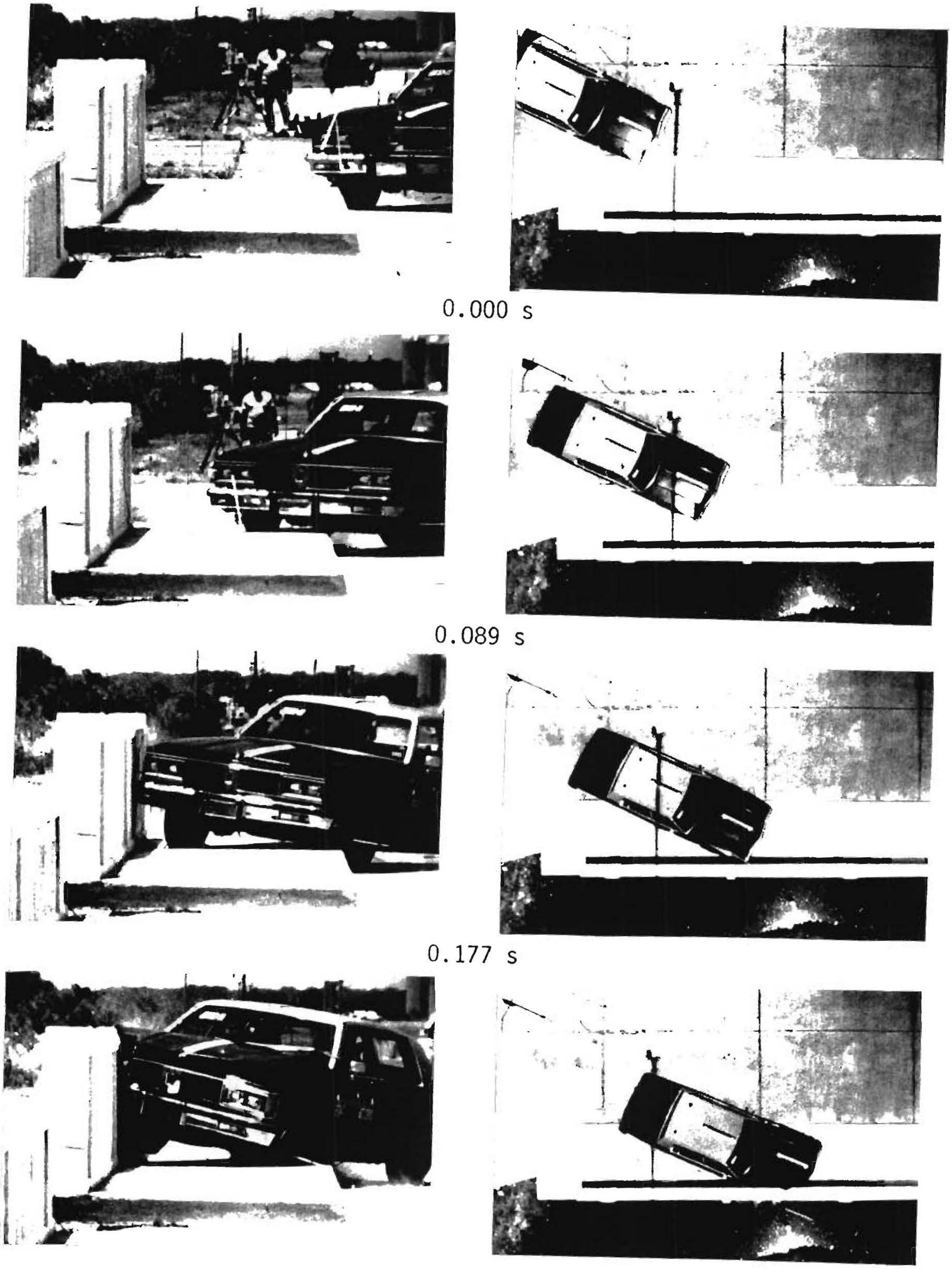
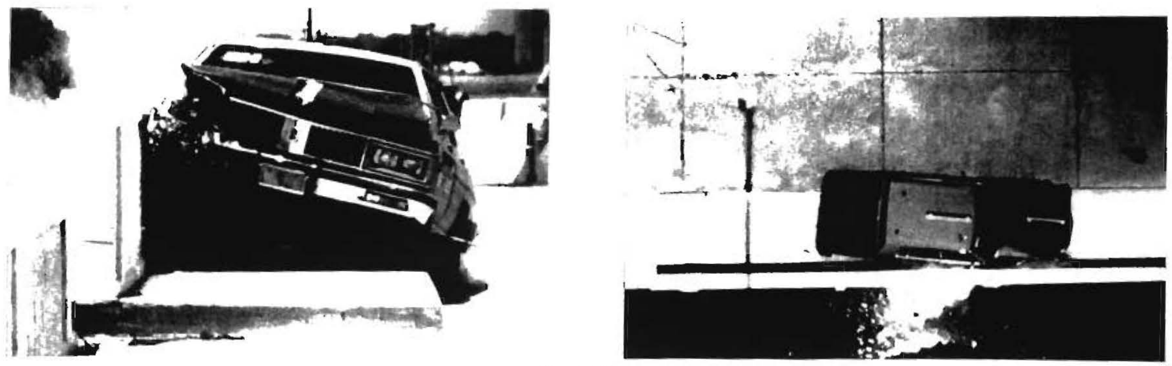
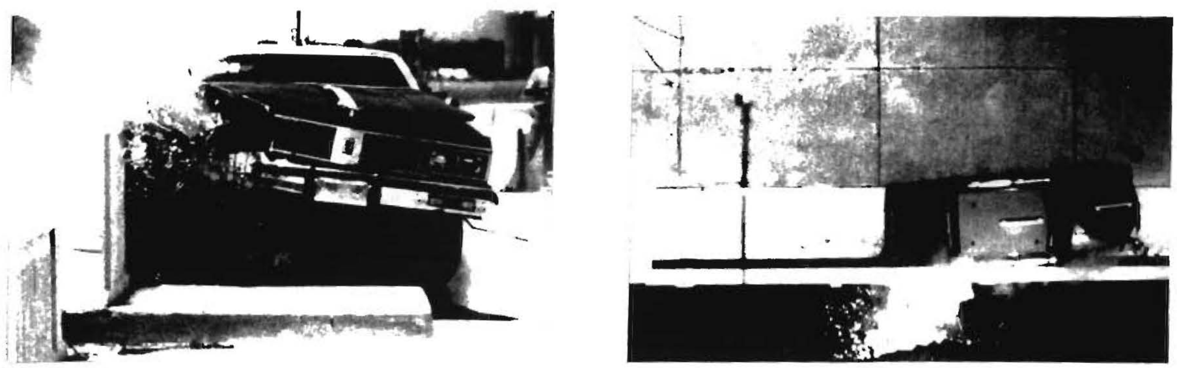


Figure D1. Sequential photographs for test 1185-6.

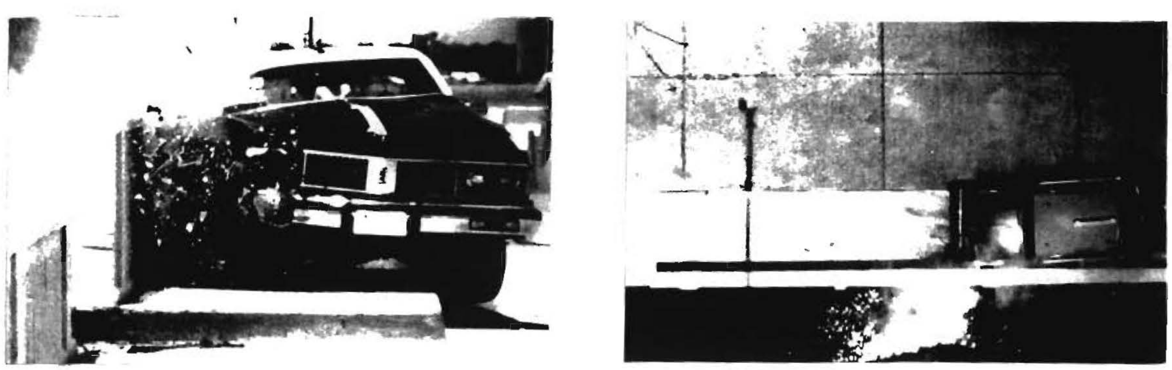
0.349 s



0.435 s



0.549 s



0.658 s

Figure D1. Sequential photographs for test 1185-6. (Continued)

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-91/1185-3F		

4. Title and Subtitle	5. Report Date
AESTHETICALLY PLEASING CONCRETE COMBINATION PEDESTRIAN-TRAFFIC BRIDGE RAIL - TEXAS TYPE C411	February 1991/Revised
	6. Performing Organization Code
7. Author's: T.J. Hirsch, C.E. Buth, and Wanda Campise	8. Performing Organization Report No. Research Report 1185-3F
9. Performing Organization Name and Address: Texas Transportation Institute, Texas A&M University, College Station, Texas 77843-3135	10. Work Unit No.
	11. Contract or Grant No. Research Study 2-5-89/90-1185
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: Final - September 1989 - August 1990
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Research Study Title: Aesthetically Pleasing Bridge Rails

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 concrete combination pedestrian-traffic bridge rail--Texas Type C411.

This bridge rail was constructed of reinforced concrete 42 in. high by 12 in. thick and contains 6 in. wide by 28 in. high openings at 18 in. center-to-center longitudinal spacing. The combination pedestrian-traffic bridge rail was located on a 6 ft wide sidewalk with 8 in. high curb separating it from the traffic.

The bridge rail was developed for use on urban streets where the speed limit would be 45 mph or less. Service Level 1 of NCHRP 230 and Performance Level 1 of the 1989 AASHTO Guide Specifications for Bridge Railings were considered inappropriate.

NCHRP Project C22-7, "Update of Roadside Safety Hardware Crash Test Specifications," and NCHRP Project 12-33, "Development of a Comprehensive Bridge Specification and Commentary," were seriously considering a different test matrix at the time these tests were conducted. It was decided to use a 4,500 lb car at 45 mph and 25 degree impact angle and an 1,900 lb car at 45 mph and 20 degree impact angle.

The new C411 bridge rail performed very well under these two crash tests. The crash test results easily met the usual safety evaluation criteria. The C411 should be safe for use on low speed, 45 mph or less, roadways.

17. Key Words	18. Distribution Statement
Bridge Rails, Traffic Barriers, Highway Safety, Pedestrian - Cars	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	63	

Form DOT F 1700.7 (8-69)

AESTHETICALLY PLEASING CONCRETE COMBINATION PEDESTRIAN-TRAFFIC BRIDGE RAIL - TEXAS TYPE C411

by

T. J. Hirsch
Research Engineer & Principal Investigator

C. E. Buth
Research Engineer

and

Wanda L. Campise
Research Associate

Research Report 1185-3F

on

Research Study No. 2-5-89/90-1185
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

October 1990

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

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

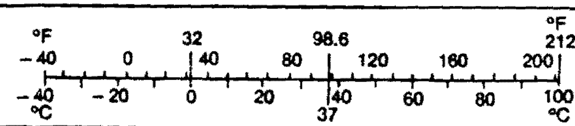
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
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)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
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			
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)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
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)			
°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, Pedestrian - 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 (Designing Engineer, SDHPT), John J. Panak (Bridge Designing 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 concrete combination pedestrian-traffic bridge rail - Texas Type C411.

This bridge rail was constructed of reinforced concrete 42 in. high by 12 in. thick and contains 6 in. wide by 28 in. high openings at 18 in. center-to-center longitudinal spacing. The combination pedestrian-traffic bridge rail was located on a 6 ft wide sidewalk with 8 in. high curb separating it from the traffic.

The C411 was developed for use on urban streets where the speed limit would be 45 mph or less. Service Level 1 of NCHRP 230 and Performance Level 1 of the 1989 AASHTO Guide Specifications for Bridge Railings were considered inappropriate.

NCHRP Project C22-7, "Update of Roadside Safety Hardware Crash Test Specifications," and NCHRP Project 12-33, "Development of a Comprehensive Bridge Specification and Commentary," were seriously considering a different test matrix at the time these tests were conducted. It was decided to use a 4,500 lb car at 45 mph and 25 degree impact angle and an 1,900 lb car at 45 mph and 20 degree impact angle.

The new C411 bridge rail performed very well under these two crash tests. The crash test results easily met the usual safety evaluation criteria. The C411 should be safe for use on low speed, 45 mph or less, roadways.

TABLE OF CONTENTS

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 was 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 open type concrete combination pedestrian-traffic bridge rail--Texas Type C411. The research study advisory committee composed of

Luis Ybanez, Bridge Engineer, Bridge Division, Austin,
John J. Panak, Bridge Designing Engineer, Bridge Division, Austin,
Dean Van Landuyt, Designing 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 C411 as its third priority.

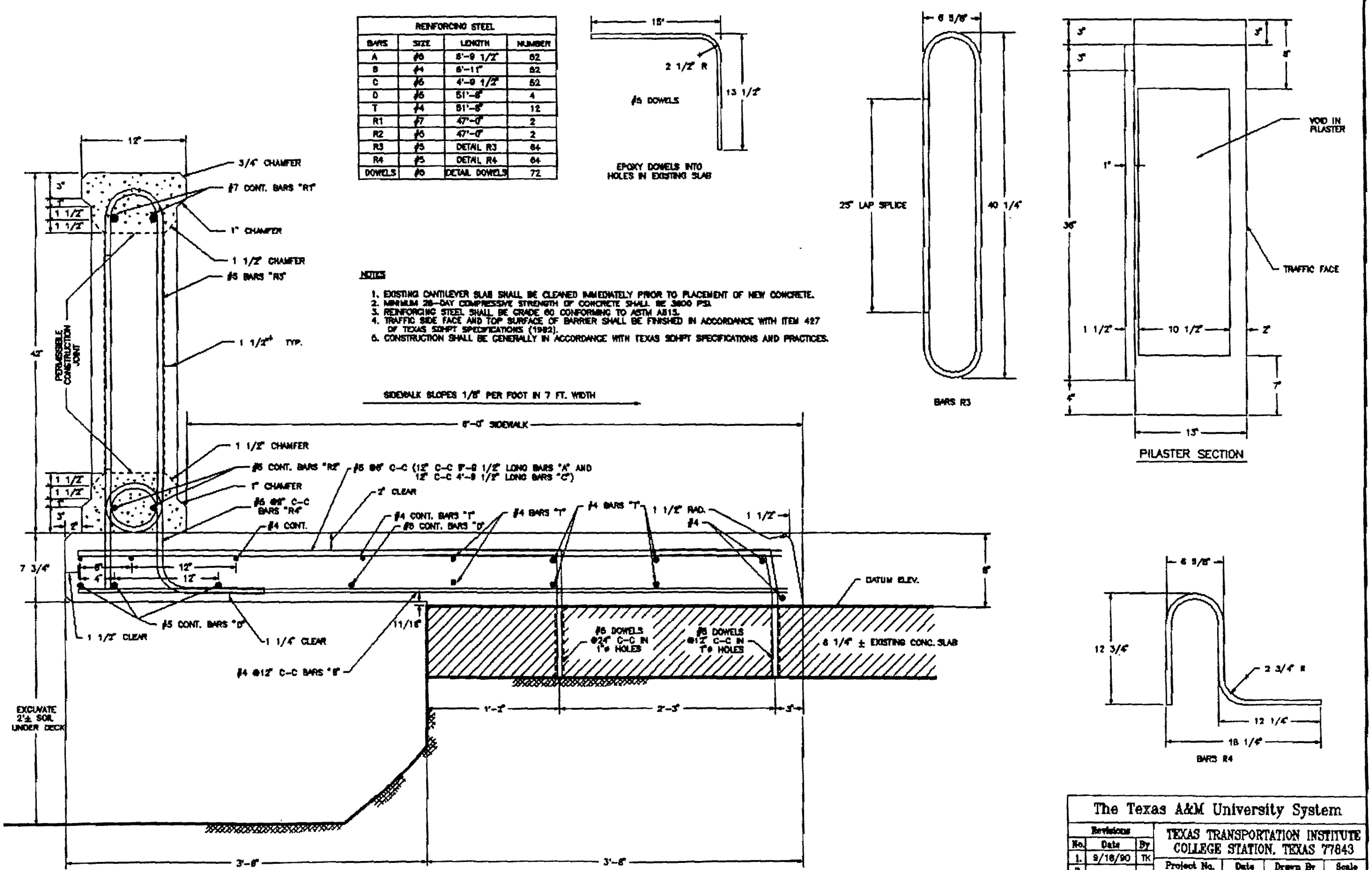
DESCRIPTION OF BRIDGE RAIL
TEXAS TYPE C411

This bridge rail was constructed of reinforced concrete 42 in. high by 12 in. thick and contains 6 in. wide by 28 in. high openings at 18 in. center-to-center longitudinal spacing. The combination pedestrian-traffic bridge rail was located on a 6 ft wide sidewalk with 8 in. high curb separating it from the traffic. Figures 1, 2, and 3 present an elevation, cross section, and plan view of the C411 rail. The sidewalk deck is a 7.75 in. thick typical Texas bridge slab design in accordance with AASHTO specifications (4)*.

Figure 4 shows a photograph of the bridge rail installation prior to crash testing. The installation was 47 ft 4 in. long. The three pilasters are not super strong posts as they appear to be. They contain styrofoam blocks 10.5 in. by 13 in. by 31 in., (void) which means the pilasters are similar to the 6 in. by 28 in. openings. The use of the pilasters is thus optional since they did not contribute to the bridge rail strength as built and crash tested.

This bridge rail was designed using a failure mechanism (or yield line) method of analysis (1). The design strength of the concrete was f_c = 3,600 psi and the yield strength of reinforcing steel was f_y = 60,000 psi. The top beam was nominally 7 in. wide and 10 to 12 in. thick (b = 7 in. and d = 8.25 in.), yielding an ultimate moment capacity of 20.0 kip-ft. The posts were 10 in. wide and 10 in. thick (b = 10 in. and d = 8 in.), yielding an ultimate moment capacity of 20.6 kip-ft. With a moment arm of 3.5 ft, each post could resist a lateral load of about 5.9 kips. Figure 5 presents a summary of the failure mechanism analysis of the strength of the T411 bridge rail. The failure load would be about 51.4 kips or more over five spans or 7.5 ft length of bridge rail.

* Numbers in parentheses, thus (4), refer to corresponding item in References.



REINFORCING STEEL			
BARS	SIZE	LENGTH	NUMBER
A	#6	8'-9 1/2"	62
B	#4	8'-11"	62
C	#5	4'-9 1/2"	62
D	#5	51'-8"	4
T	#4	51'-8"	12
R1	#7	47'-0"	2
R2	#6	47'-0"	2
R3	#5	DETAIL R3	64
R4	#5	DETAIL R4	64
DOWELS	#6	DETAIL DOWELS	72

NOTES

1. EXISTING CANTILEVER SLAB SHALL BE CLEANED IMMEDIATELY PRIOR TO PLACEMENT OF NEW CONCRETE.
2. MINIMUM 28-DAY COMPRESSIVE STRENGTH OF CONCRETE SHALL BE 3600 PSI.
3. REINFORCING STEEL SHALL BE GRADE 60 CONFORMING TO ASTM A615.
4. TRAFFIC SIDE FACE AND TOP SURFACE OF BARRIER SHALL BE FINISHED IN ACCORDANCE WITH ITEM 427 OF TEXAS SDHPT SPECIFICATIONS (1982).
5. CONSTRUCTION SHALL BE GENERALLY IN ACCORDANCE WITH TEXAS SDHPT SPECIFICATIONS AND PRACTICES.

The Texas A&M University System

TEXAS TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS 77843

Revisions			Project No.	Date	Drawn By	Scale
No.	Date	By	1185	4/5/90		
1.	9/18/90	TK	Title: TEXAS TYPE C411 BRIDGE RAIL		Sheet No. 2 of 3	
2.						
3.						
4.						
5.						

Figure 2. Texas type C411 bridge rail - cross section.

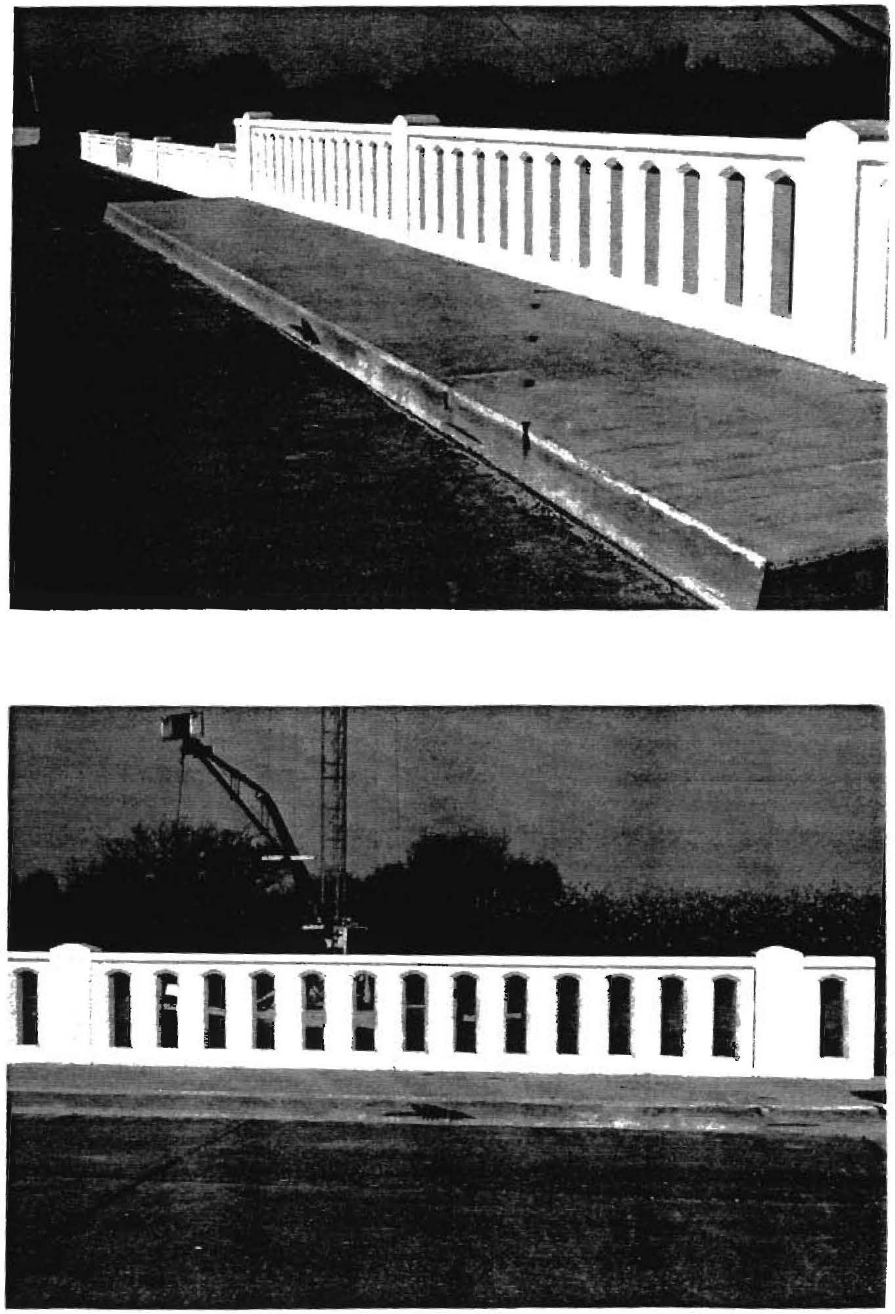
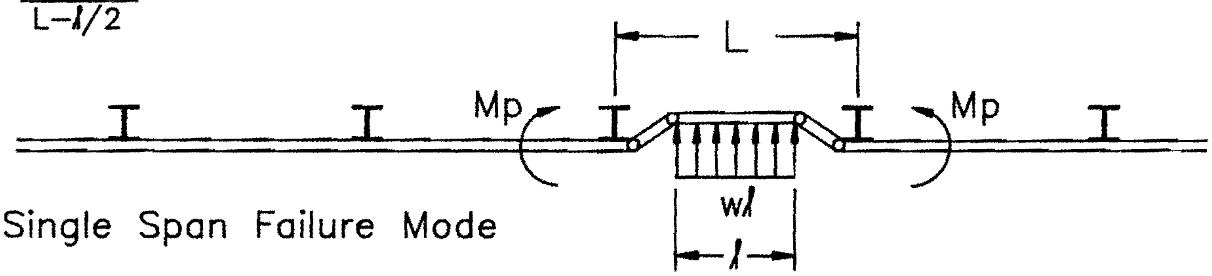


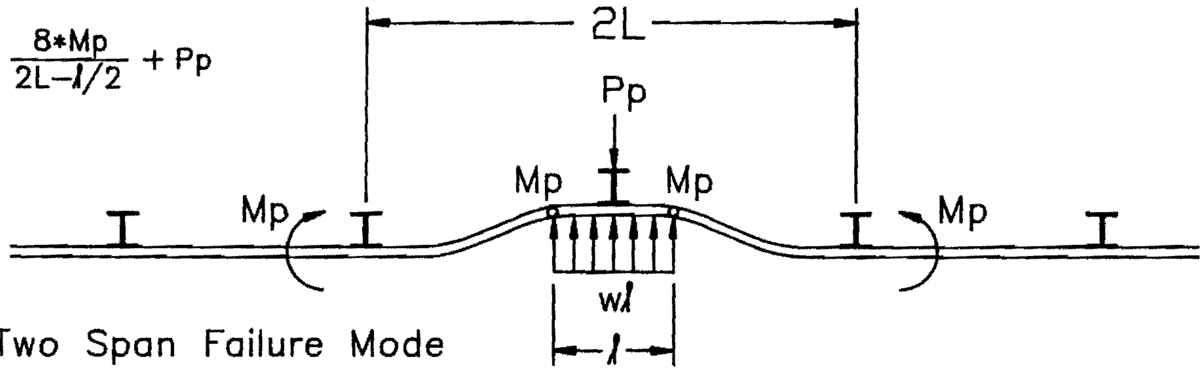
Figure 4. Bridge rail prior to test 1185-5.

$$wl = \frac{8*Mp}{L-l/2}$$



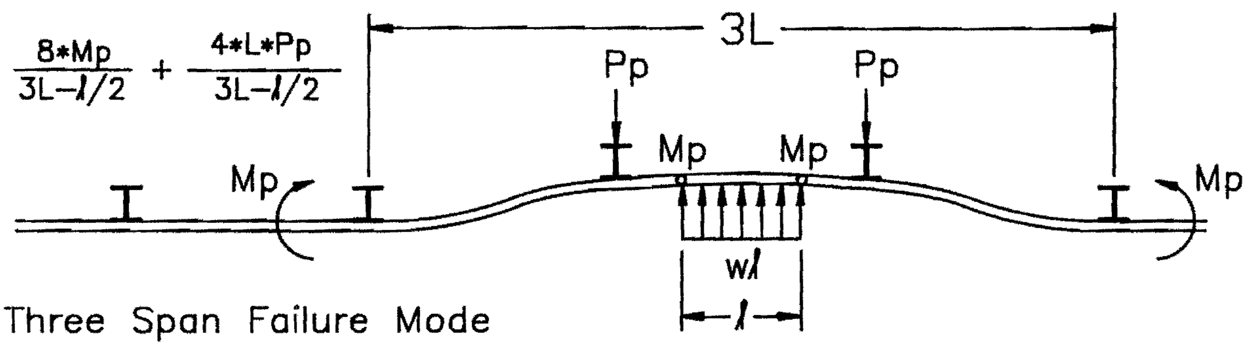
(A) Single Span Failure Mode

$$wl = \frac{8*Mp}{2L-l/2} + Pp$$



(B) Two Span Failure Mode

$$wl = \frac{8*Mp}{3L-l/2} + \frac{4*L*Pp}{3L-l/2}$$



(C) Three Span Failure Mode

L = post spacing

Mp = plastic or yield line capacity of rail

Pp = ultimate load capacity of a single post

wl = total ultimate vehicle impact load

l = length of distributed vehicle impact load

PLAN VIEW

FIGURE 8. POSSIBLE FAILURE MODES FOR BEAM AND POST BARRIERS

CRASH TESTS

The Texas Type C411 was developed for use on urban streets where the speed limit would be 45 mph or less. The selection of a crash test matrix posed a problem. Service Level 1 of NCHRP 230 (3) would indicate a 4,500 lb car at 60 mph and a 15 degree impact angle for the strength test and an 1,800 lb car at 60 mph and 20 degree impact angle for geometry evaluation. The 1989 AASHTO Guide Specifications for Bridge Railings (9), Performance Level 1, would indicate testing with a 5,400 lb pickup truck at 45 mph and 20 degree impact angle and an 1,800 lb car at 50 mph and 20 degree impact angle.

Both of these documents were in the process of being revised by NCHRP Project C22-7, "Update of Roadside Safety Hardware Crash Test Specifications," and NCHRP Project 12-33, "Development of a Comprehensive Bridge Specification and Commentary." These two projects were seriously considering the severity level test matrix shown in Table 1 at the time these tests were conducted. It was, therefore, decided to use Severity Level 2 from Table 1. This was a 4,500 lb car (not truck) at 45 mph and 25 degree impact angle and an 1,900 lb car at 45 mph and 20 degree impact angle.

TEST DESCRIPTION 1185-5

The 1982 Honda Civic (Figures 7 and 8) was directed into the bridge rail installation using a reverse tow and guidance system. Test inertia mass of the vehicle was 1,800 lb (808 kg) and its gross static mass was 1,970 lb (894 kg). The height to the lower edge of the vehicle bumper was 15.0 in. (38.1 cm) and it was 20.5 in. (52.1 cm) to the top of the bumper. Other dimensions and information on the test vehicle are given in Figure C1 of Appendix C. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact with the curb was 45.5 mph (73.2 km/h) and the angle of impact was 20.1 degrees. The vehicle impacted the curb approximately 8 ft (2.4 m) from the end of the sidewalk. As the vehicle rode up the curb, the right front wheel twisted counter-clockwise, and as it rode onto the sidewalk, the vehicle redirected slightly. At 0.322 second, the vehicle impacted the bridge rail 28 ft (8.5 m) from the end of the rail traveling at 43.0 mph (69.2 km/h) and an angle of 17.8 degrees. The vehicle was also airborne at this time and began to redirect significantly at 0.371 second. At 0.626 second the vehicle was traveling parallel with the bridge rail at a speed of 34.1 mph (54.9 km/h), and at 0.632 second the rear of the vehicle hit the bridge rail. The vehicle lost contact with the bridge rail at 0.761 second traveling at 32.2 mph (51.8 km/h) and exit trajectory of 2.7 degrees. The front of the vehicle rode off the sidewalk at 0.781 second and touched ground at 0.932 second after impact. The brakes were then applied and the vehicle yawed counter-clockwise and subsequently came to rest 105 ft (32.0 m) down and 25 ft (7.6 m) in front of the point of impact. Sequential photographs are shown in Figures B1 and B2 of Appendix B.

As can be seen in Figure 9, the rail received minimal cosmetic damage. There were tire marks on the face of the bridge rail from the point of impact continuing down 11 ft (3.4 m). There was some scraping and gouging along the edges of the portholes.

The vehicle sustained moderate damage to the right side as shown in Figures 10 and 11. Maximum crush at the right front corner at bumper height was 9.0 in. (22.9 cm). The right front and rear rims were bent and the tires damaged. There was damage to the hood, grill, bumper, right front quarter panel, the right door, the right rear quarter panel and the rear bumper.

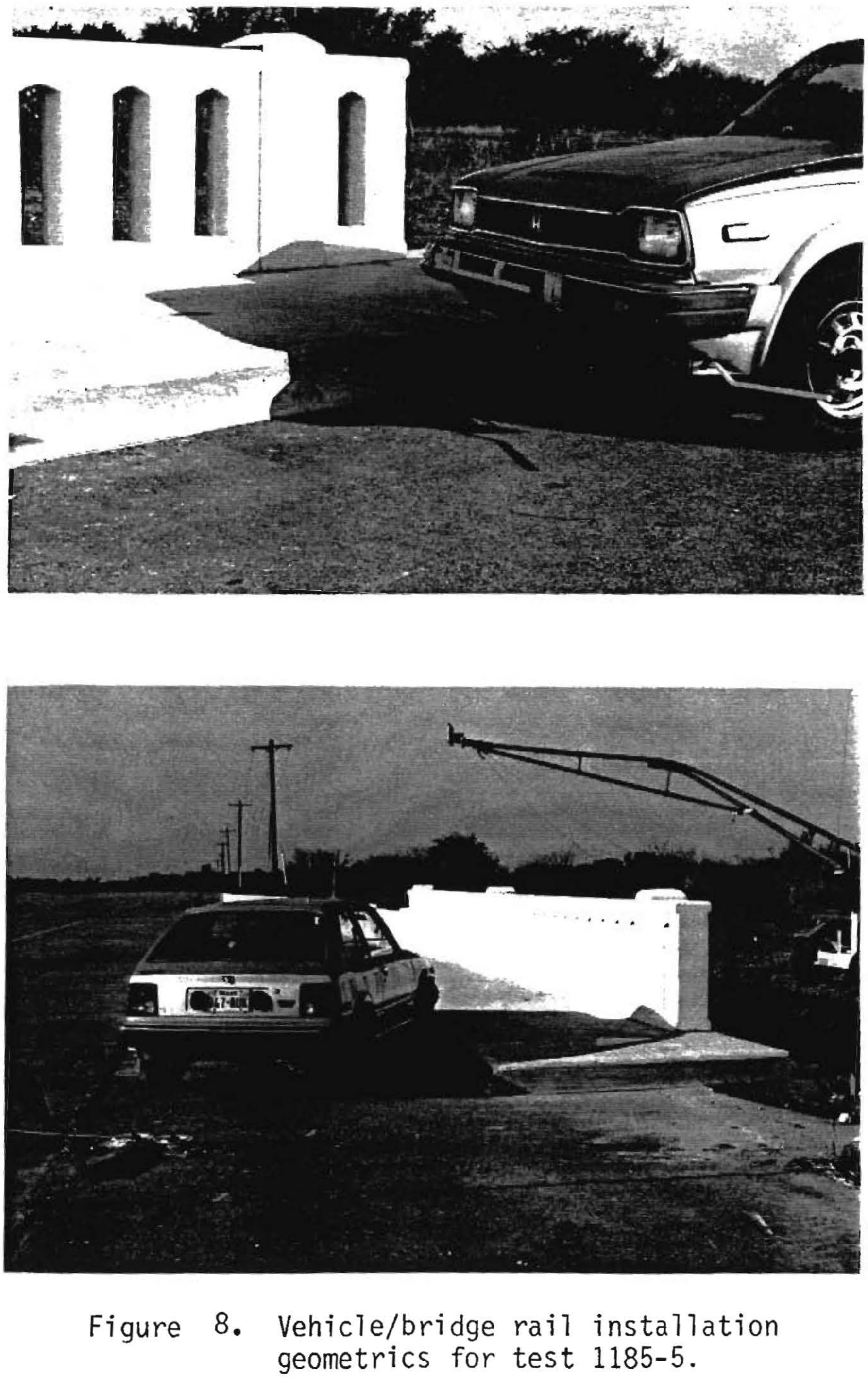


Figure 8. Vehicle/bridge rail installation geometrics for test 1185-5.

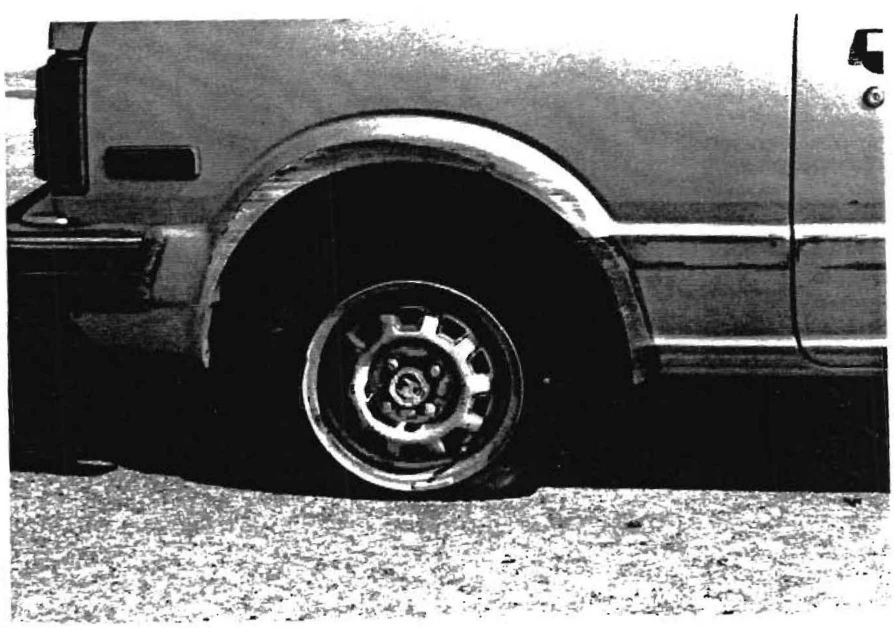


Figure 10. Damage to right side of vehicle, test 1185-5.

TEST RESULTS 1185-5

The speed of the vehicle as it impacted the curb was 45.5 mph (73.2 km/h) and the angle of impact was 20.1 degrees. As the vehicle impacted the bridge rail, it was traveling at 43.3 mph (69.7 km/h) and 17.8 degrees. The speed of the vehicle as it was parallel to the bridge rail was 34.1 mph (54.9 km/h). Exit speed was 32.2 mph (51.8 km/h) and exit trajectory was 2.7 degrees. Occupant impact velocity was 12.1 ft/s (3.7 m/s) in the longitudinal direction and 7.3 ft/s (2.2 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -4.6 g (longitudinal) and 7.4 g (lateral). These data and other pertinent information from the test are summarized in Figure 12. Vehicular angular displacements are displayed in Figure C2 of Appendix C.

Vehicular accelerations versus time traces filtered at 300 Hz are presented in Figures C3 through C6 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 -3.6 g (longitudinal) and 4.0 g (lateral).

CONCLUSIONS

The bridge rail contained and smoothly redirected the test vehicle with no lateral movement or cracking 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 occupant/compartment impact velocities and 10-ms occupant ridedown accelerations were within the usual recommended limits. The vehicle trajectory at loss of contact indicates no intrusion into adjacent traffic lanes.

TEST DESCRIPTION 1185-6

The 1982 Oldsmobile 98 (Figures 13 and 14) was directed into the bridge rail installation using a reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 lb (2,043 km). The height to the lower edge of the vehicle bumper was 12.25 in. (31.1 cm) and it was 20.75 in. (52.7 cm) to the top of the bumper. Other dimensions and information on the test vehicle are given in Figure E1 of Appendix E. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 47.0 mph (75.6 km/h) and the angle of impact was 25.4 degrees. The vehicle impacted the curb approximately 5.75 ft (1.75 m) from the end of the sidewalk. As the right front tire rode up the curb and onto the sidewalk, the vehicle redirected slightly. At 0.177 second, the vehicle impacted the bridge rail 14 ft (4.3 m) from the end of the rail traveling at 46.7 mph (75.1 km/h) and an angle of 22.7 degrees. The right front wheel and tire was mangled in the porthole at 0.237 second, and the vehicle began to redirect significantly at 0.246 second. At 0.492 second, the vehicle was traveling parallel with the bridge rail at a speed of 32.1 mph (51.6 km/h) and at 0.567 second, the rear of the vehicle hit the bridge rail. The vehicle lost contact with the bridge rail at 0.658 second traveling at 28.9 mph (46.5 km/h) and exit of trajectory of 3.5 degrees. The undercarriage of the vehicle bottomed out on the curb at 0.744 second, and the vehicle rode off the sidewalk at 1.466 second after impact. The brakes were then applied and the vehicle yawed clockwise and subsequently came to rest 105 ft (32.0 m) down from the point of impact. Sequential photographs are shown in Figures D1 and D2 of Appendix D.

As can be seen in Figure 15, the rail received moderate cosmetic damage. There were tire marks on the face of the bridge rail from the point of impact continuing down 15 ft (4.6 m). There was some scraping and gouging along the edges of the portholes.

The vehicle sustained damage to the right side as shown in Figures 16 and 17. Maximum crush at the right front corner at bumper height was 14.0 in. (35.6 cm). The floorpan and subframe of the vehicle was bent. The right A-arm, tie rod, and sway bar were damaged. The windshield was cracked and the roof bent. The right front and rear rims were bent and the tires damaged. There was damage to the hood, grill, front bumper,

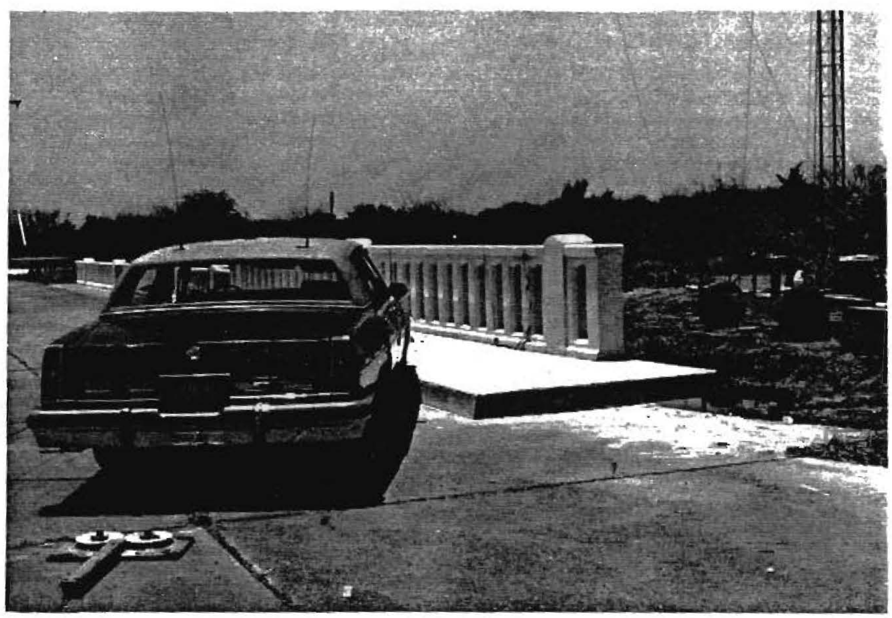


Figure 14. Vehicle/bridge rail installation geometrics for test 1185-6.

Figure 16. Damage to right side of vehicle, test 1185-6.

radiator and fan, right front quarter panel, the right front and rear doors, the right rear quarter panel and the rear bumper.

TEST RESULTS 1185-6

The speed of the vehicle as it impacted the curb was 47.0 mph (75.6 km/h) and the angle of impact was 25.4 degrees. As the vehicle impacted the bridge rail, it was traveling at 46.7 mph (75.1 km/h) and 22.7 degrees. The speed of the vehicle as it was parallel to the bridge rail was 32.1 mph (51.6 km/h). Exit speed was 28.9 mph (46.5 km/h) and exit trajectory was 3.5 degrees. Occupant impact velocity was 23.2 ft/s (7.1 m/s) in the longitudinal direction and 17.1 ft/s (5.2 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -4.8 g (longitudinal) and 8.5 g (lateral). These data and other pertinent information from the test are summarized in Figure 18. Vehicular angular displacements are displayed in Figure E2 of Appendix E.

Vehicular accelerations versus time traces filtered at 300 Hz are presented in Figures E3 through E7 of Appendix E. 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 -6.6 g (longitudinal) and 6.2 g (lateral).

CONCLUSIONS

The bridge rail contained and smoothly redirected the test vehicle with no lateral movement or cracking 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 occupant/compartment impact velocities and 10-ms occupant ridedown accelerations were within the usual recommended limits. The vehicle trajectory at loss of contact indicates no intrusion into adjacent traffic lanes.

SUMMARY and CONCLUSIONS

This was probably the first time a combination pedestrian-traffic bridge rail mounted on an 8 in. high curb and 6 ft wide sidewalk has been designed and crash tested. This type rail was developed for use where city streets pass over federal aid or interstate highways or other hazards. The combination pedestrian-traffic rail would only be exposed to moderate speed (45 mph) vehicles. NCHRP Report 230's (3) low service level crash test (SL-1) called for a 4,500 lb car traveling 60 mph and impacting at a 15 degree angle and a second test with an 1,800 lb car impacting at 60 mph and 20 degree angle. The 1989 Guide Specifications for Bridge Railings' (9) low performance level (PL-1) called for a crash test with a 5,400 lb pickup truck impacting at 45 mph and 20 degree angle and a second test with an 1,800 lb car impacting at 50 mph and 20 degree angle. Neither of these two crash tests seemed appropriate for this type traffic rail and its intended location on low speed (less than 50 mph) city streets.

Table 1, which is now being considered by two NCHRP-AASHTO research projects, seemed appropriate because the 1,900 lb car and 4,500 lb pickup truck would both impact at 45 mph at 20 degree and 25 degree angles, respectively. (Note: a 4,500 lb car was used here.)

The 8 in. high curb, 6 ft wide sidewalk and 42 in. high combination pedestrian-vehicle bridge rail performed very well in the two crash tests. Appendix F of the 1977 Guide for Selecting, Locating, and Designing Traffic Barriers (14) presents automobile trajectory data predicted by the HVOSM computer model when an automobile impacts curbs of various heights.

The data generated by the HVOSM computer model of an automobile predicted that these two vehicles would vault so that the bumper would be 14 in. to 18 in. higher than normal when it impacts the bridge rail behind the 8 in. high curb and 6 ft wide sidewalk. The crash tests showed the Honda bumper was only 4 in. higher than normal and the Oldsmobile bumper was only 3.5 in. to 7.5 in. higher (the bumper was 3.5 in. higher on initial impact and continued to climb to 7.5 in. higher 0.25 sec later). The normal bumper height of the Honda was 20.5 in. and that of the Oldsmobile was 20.75 in. when parked on

Table 2. Safety Evaluation of Crash Test No. 1185-5
C411 Bridge Rail (1,900 lb/45 mph/20 deg)

Usual Safety Evaluation 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	.55	Marginal	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	12.1	7.3	
Occupant Ridedown Accelerations - g's		Occupant Ridedown Accelerations - g's		Pass
Longitudinal	Lateral	Longitudinal	Lateral	
15	15	-4.6	7.4	
Exit angle shall be less than 12 degrees		Exit angle was 2.7 degrees		Pass

REFERENCES

1. 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.

2. 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.

3. 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.

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

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.

6. Olson, R.M., et al., "Tentative Service Requirements for Bridge Rail Systems," NCHRP Report 86, Washington, D.C., 1970.

7. 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.

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

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

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.

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

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. 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.

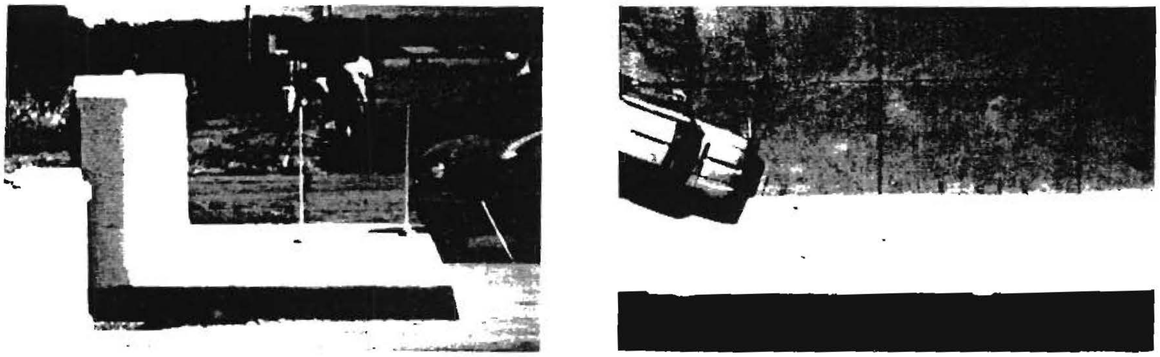
The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, final occupant displacement, highest 0.010-second average of vehicle acceleration after occupant/compartment 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 plots acceleration versus time curves for the longitudinal, lateral, and vertical directions.

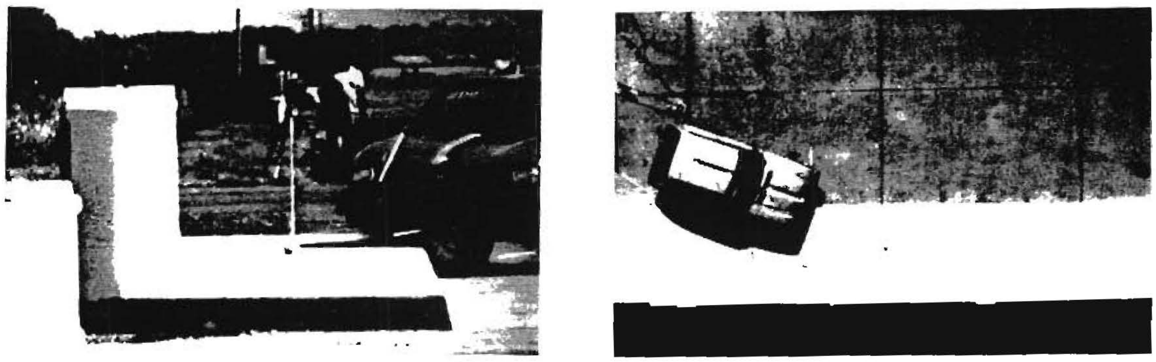
The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate

APPENDIX B

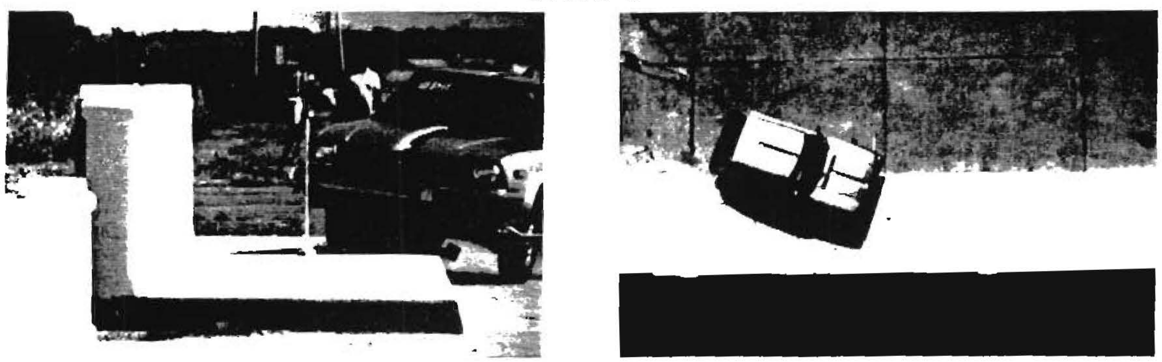
Sequential Photographs of Test 1185-5



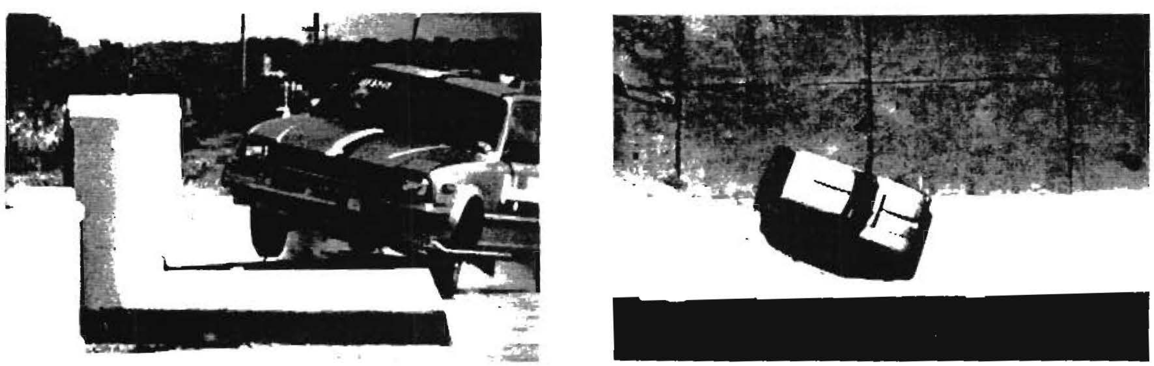
0.000 s



0.075 s



0.149 s



0.224 s

Figure B1. Sequential photographs for test 1185-5.

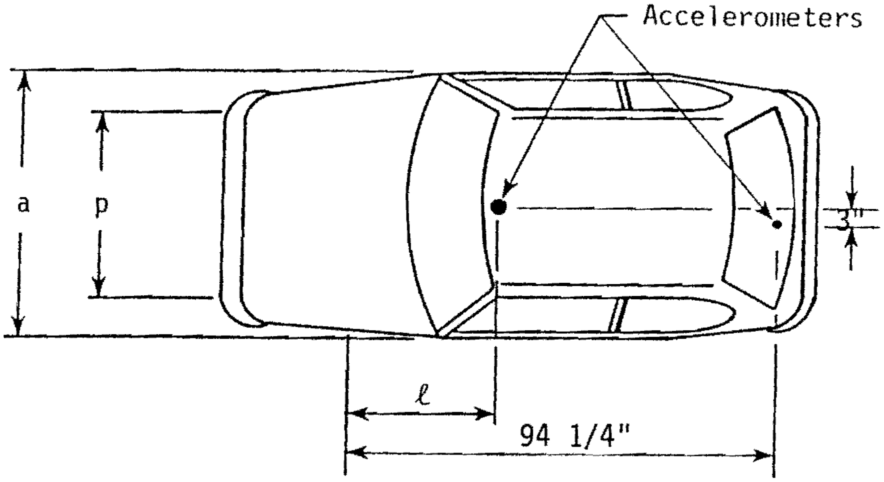
APPENDIX C

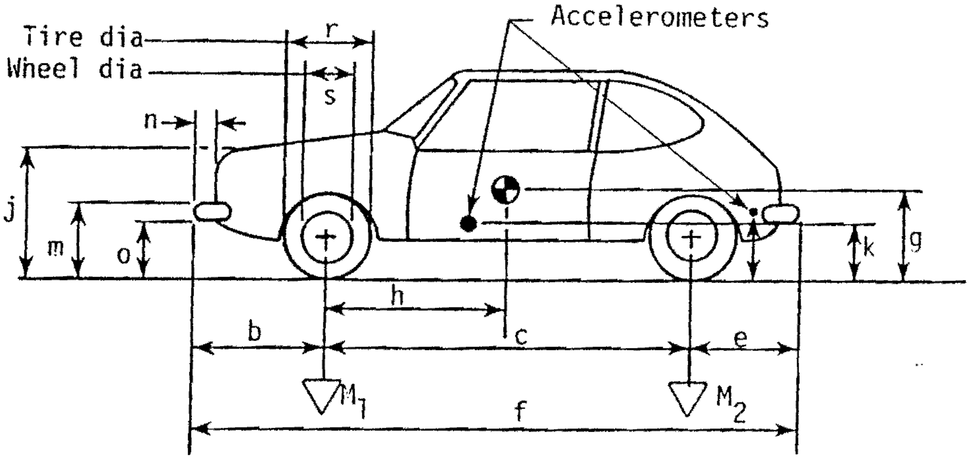
Electronic Accelerometer, Roll, Pitch, and Yaw Data Test 1185-5

Date: ______ Test No.: 1185-5 VIN: JHMSL5328CS017095

Make: Honda Model: Civic Year: 1982 Odometer: 104346

Tire Size: P175 80R13 Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: X





Tire Condition: good ___
fair X
badly worn ___

Vehicle Geometry - inches

a	62 3/4	b	30
c	88 1/4	d*	53
e	29	f	147 1/4
g		h	33.1
i	----	j	29
k	16 3/4	ℓ	27 1/2
m	20 1/2	n	4
o	15	p	53 3/4
r	23	s	14 1/4

4-wheel weight for c.g. det. ℓf 568 rf 557 ℓr 353 rr 322

Mass - pounds	Curb	Test Inertial	Gross Static
M_1		1125	1207
M_2		675	763
M_T		1800	1970

Note any damage to vehicle prior to test:

Crack in windshield (marked)

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

*d = overall height of vehicle

Figure C1. Test vehicle properties (test 1185-5).

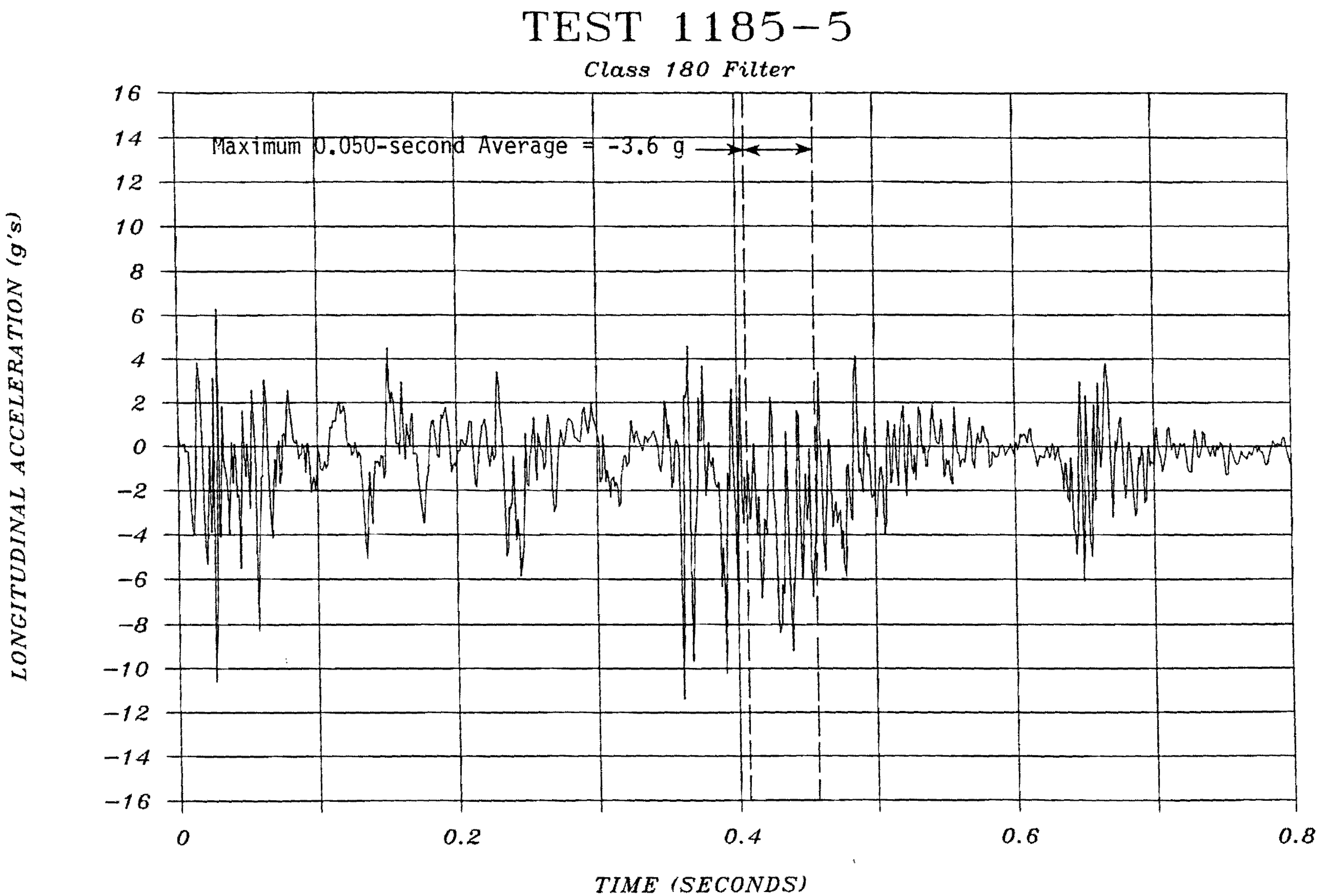


Figure C3. Vehicle longitudinal accelerometer trace for test 1185-5.
(near center-of-gravity)

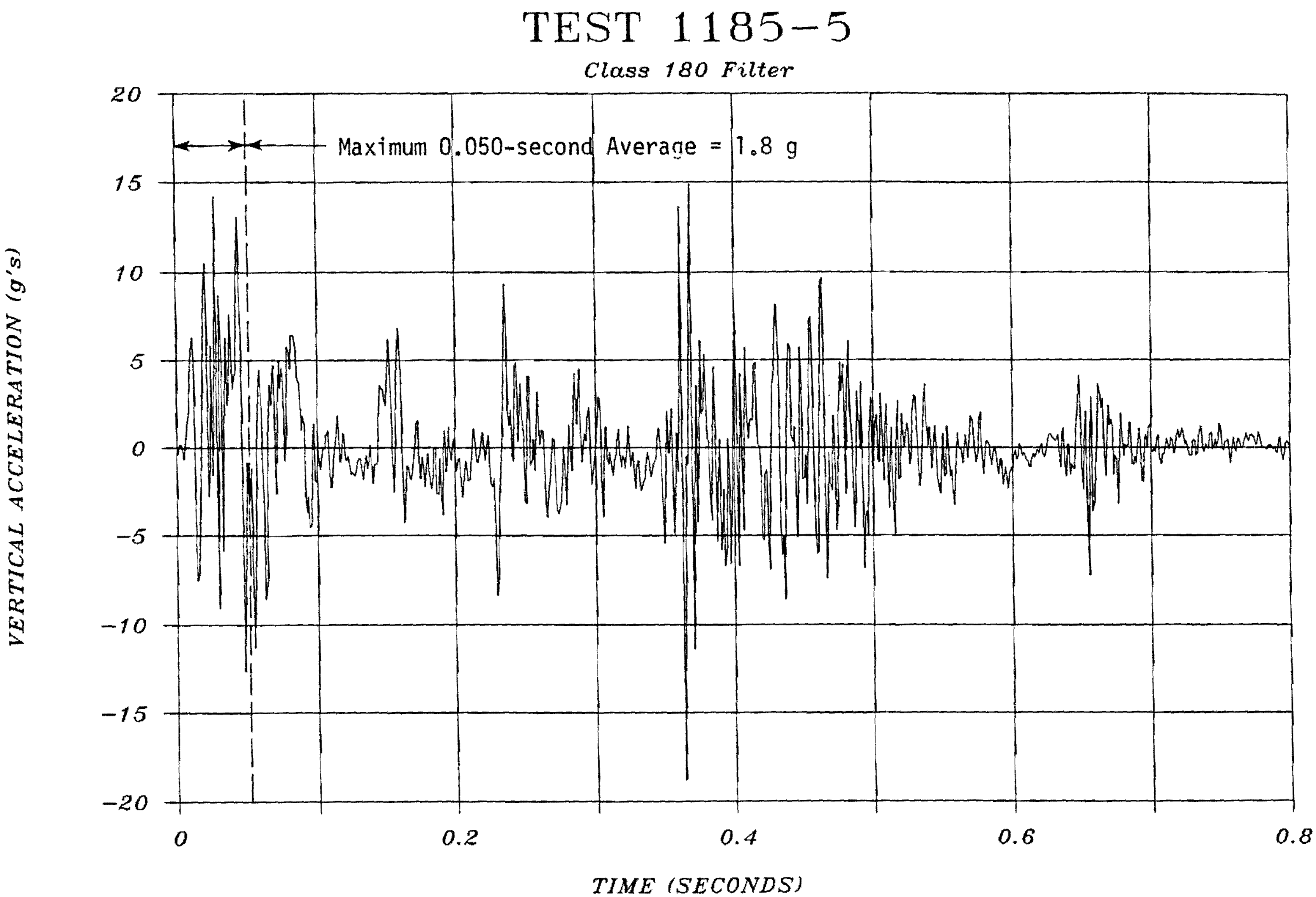
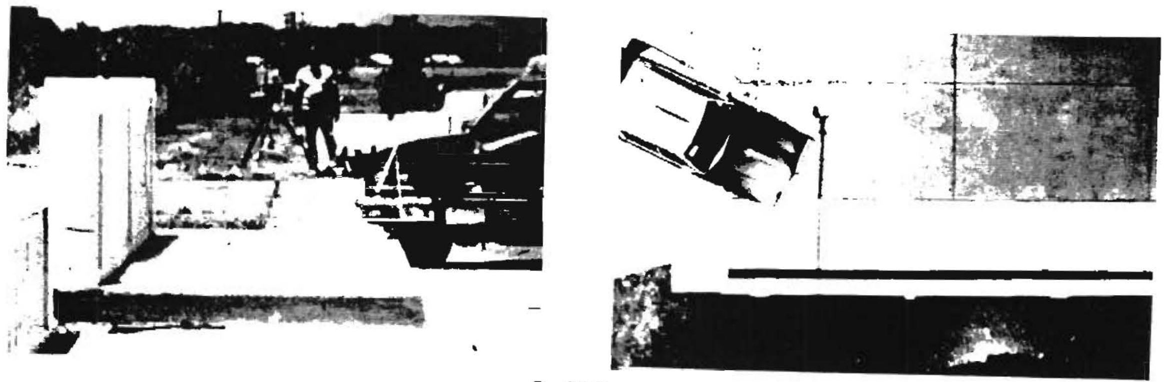


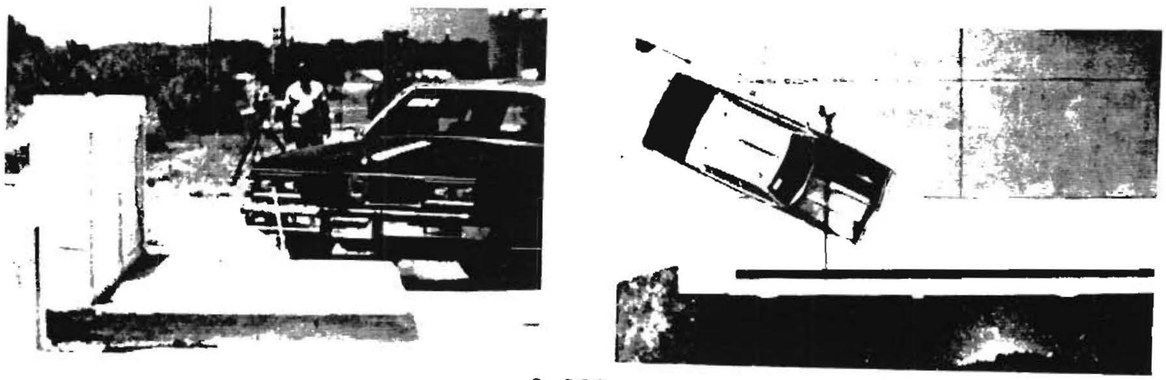
Figure C5. Vehicle vertical accelerometer trace for test 1185-5.
(near center-of-gravity)

APPENDIX D

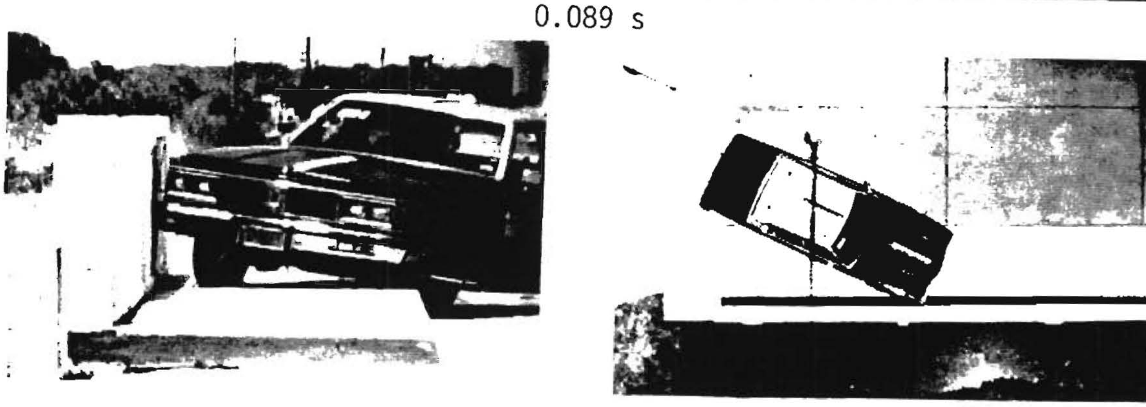
Sequential Photographs of Test 1185-6



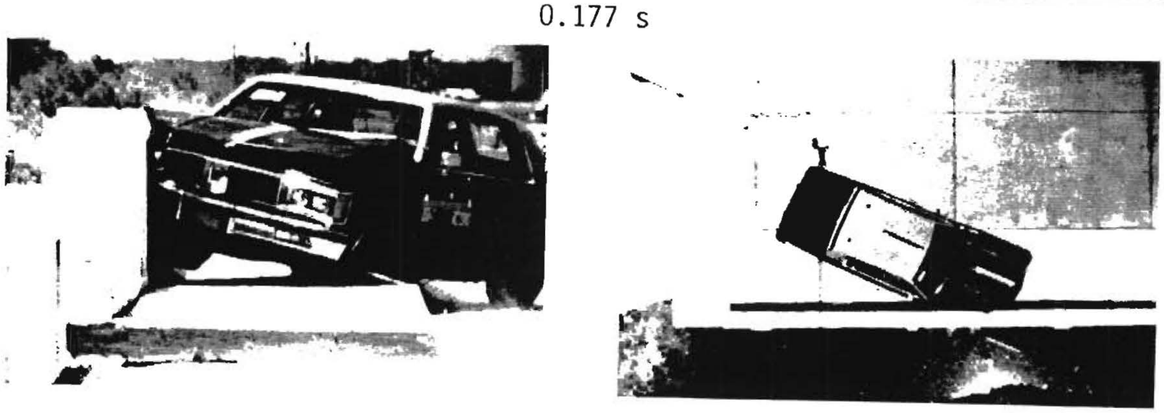
0.000 s



0.089 s



0.177 s



0.263 s

Figure D1. Sequential photographs for test 1185-6.

APPENDIX E

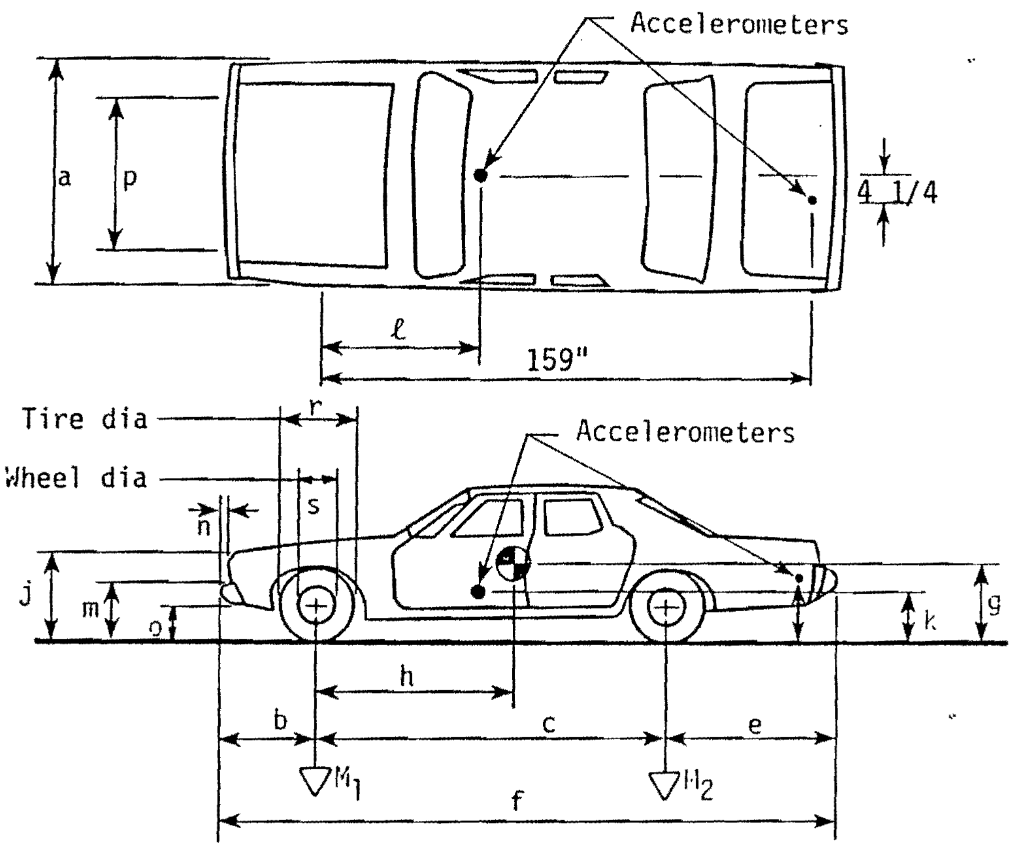
Electronic Accelerometer, Roll, Pitch, and Yaw Data Test 1185-6

Date: ____ Test No.: 1185-6 VIN: 163AW69N4CM133944

Make: Oldsmobile Model: Ninety-eight Year: 1982 Odometer: 86762

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

Tire Condition: good __ fair X badly worn __



Vehicle Geometry - inches

a	75 1/2	b	43 3/4
c	119	d*	58 1/2
e	56	f	218 3/4
g		h	125.5
i	----	j	33 1/2
k		ℓ	
m	20 3/4	n	5
o	12 1/4	p	61 3/4
r	28	s	16 1/4

Engine Type: V-8

Engine CID: 350 Diesel

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Body Type: 4-Door

Steering Column Collapse Mechanism:

__ Behind wheel units
__ Convoluted tube
__ Cylindrical mesh units
__ Embedded ball
__ NOT collapsible
__ Other energy absorption
__ Unknown

Brakes:

Front: disc X drum __

Rear: disc __ drum X

4-wheel weight for c.g. det. ℓf 1276 rf 1325 ℓr 974 rr 925

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2443	2601	
M_2	1588	1899	
M_T	4031	4500	

Note any damage to vehicle prior to test:

______

______

*d = overall height of vehicle

Figure E1. Test vehicle properties (1185-6).

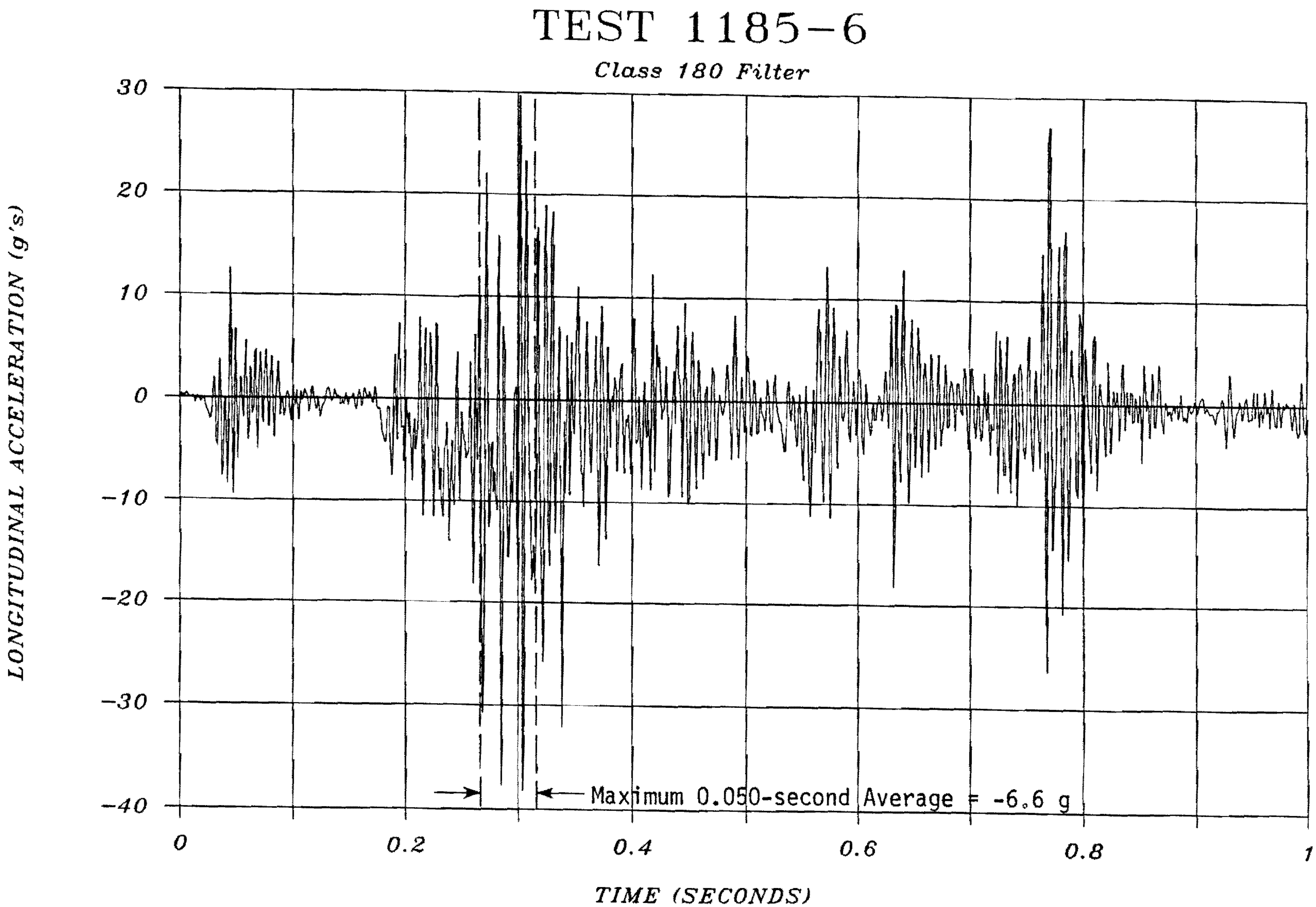


Figure E3. Vehicle longitudinal accelerometer trace for test 1185-6 (near center-of-gravity)

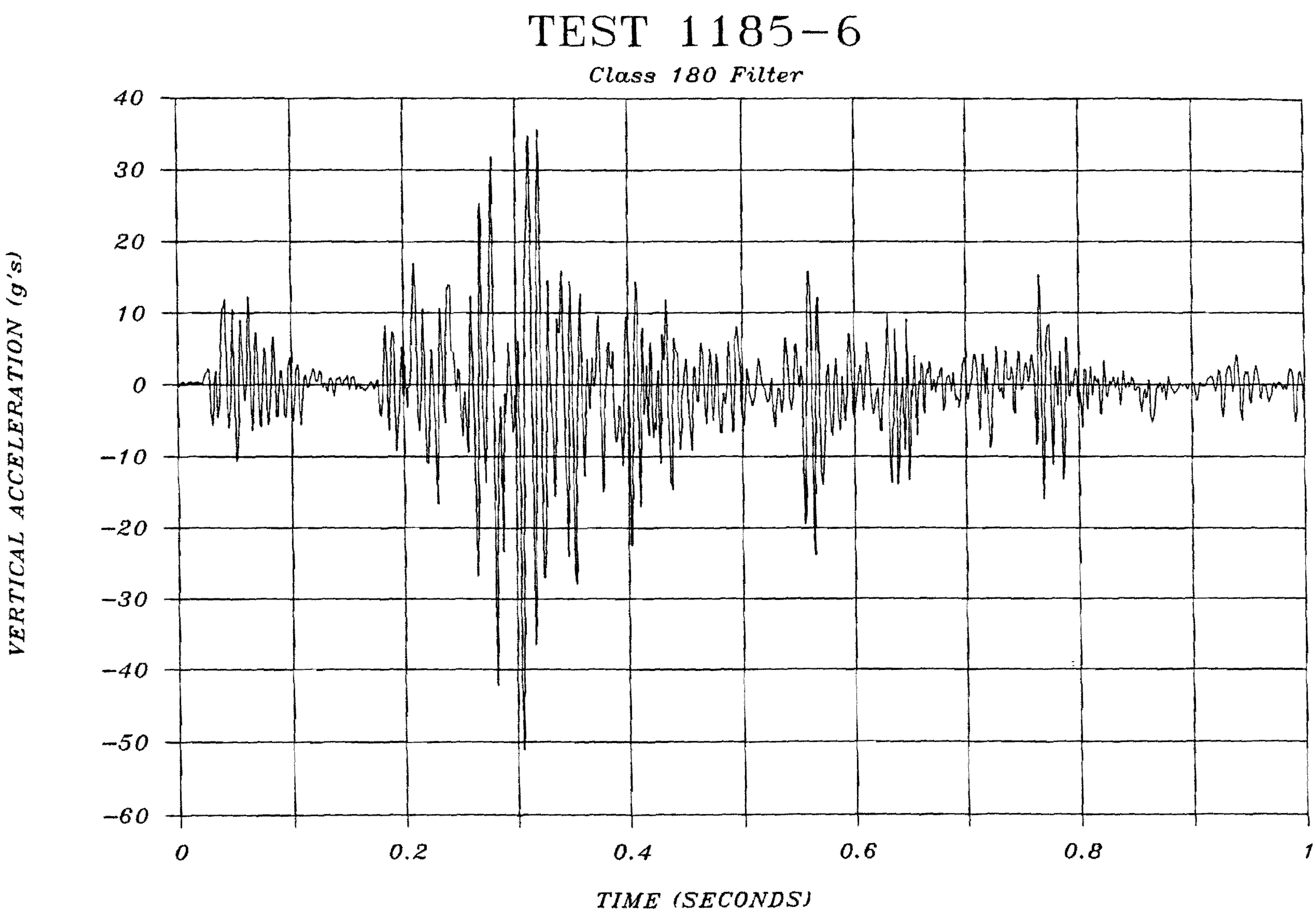


Figure E5. Vehicle vertical accelerometer trace for test 1185-6 (near center-of-gravity)

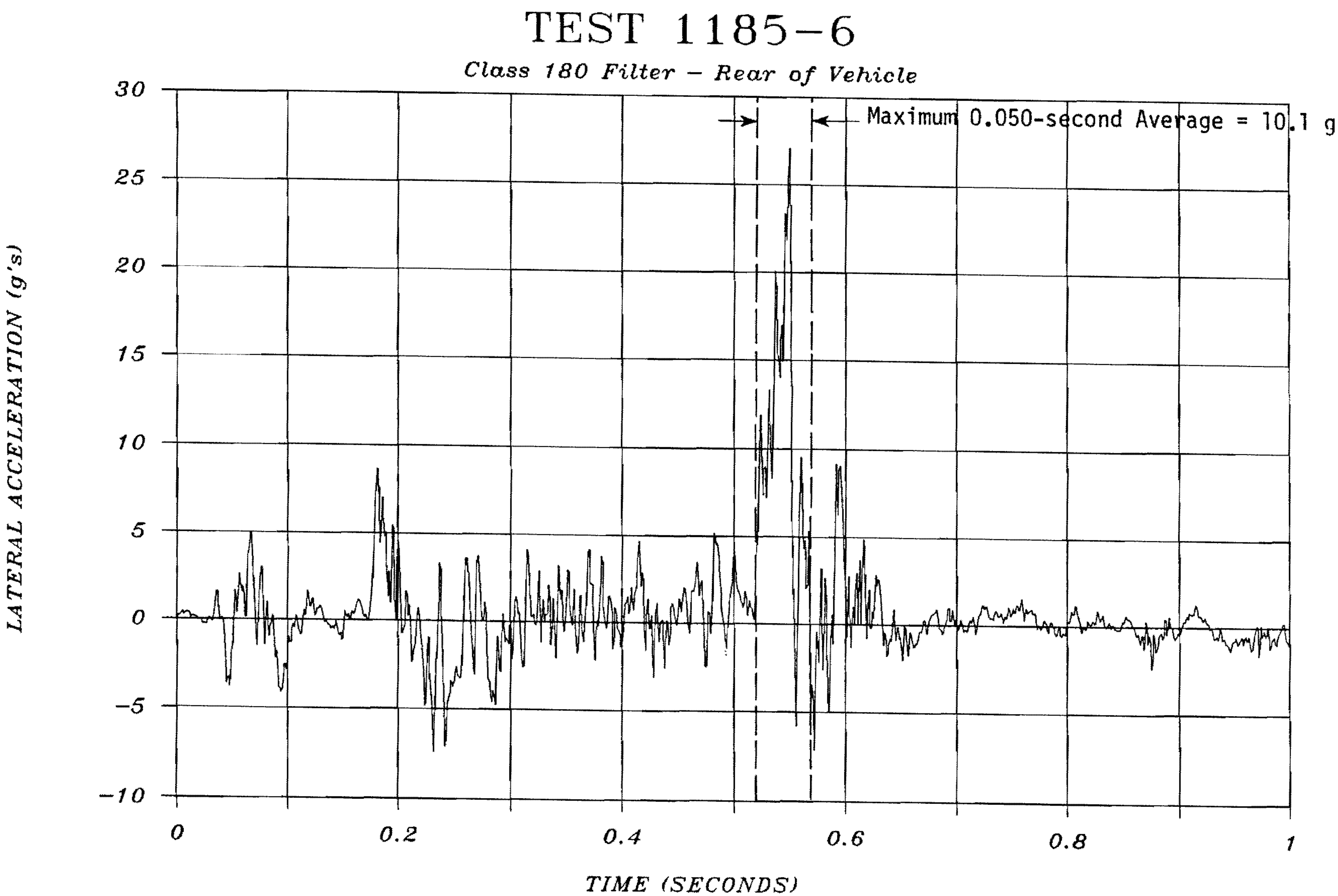


Figure E7. Vehicle lateral accelerometer trace for test 1185-6 (rear of vehicle)