CRASH TESTING AND EVALUATION OF THE NETC 2-BAR CURB-MOUNTED BRIDGE RAIL

King K. Mak and Wanda L. Menges

Prepared for
The New England Transportation Consortium

February 1998

NETCR-10

Prepared by:
Texas Transportation Institute
The Texas A & M University System
College Station, Texas

This report was sponsored by the New England Transportation Consortium, a cooperative effort of the Departments of Transportation and the Land Grant Universities of the six New England States, and the US Department of Transportation's Federal Highway Administration.

2/10/98

TEXAS TRANSPORTATION INSTITUTE

VOLUME IX: APPENDIX H - CRASH TESTING AND EVALUATION OF THE NETC PL-2 BRIDGE RAIL DESIGN

by

King K. Mak
Research Engineer

and

Wanda L. Menges
Assistant Research Specialist

Research Study No. RF 471470
Contract No. DTFH61-89-C-00089

"Testing of State Roadside Safety Systems"

Sponsored by

Federal Highway Administration
U. S. Department of Transportation
Washington, D.C.

FEBRUARY 1998

Texas Transportation Institute
THE TEXAS A & M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

FOREWORD

Because of specific needs or constraints of individual states, new or modified roadside safety hardware are being designed and developed on a continuing basis. To ensure that these new or modified designs perform according to established guidelines, full-scale crash testing and evaluation were deemed necessary. The objective of this study is to crash test and evaluate these roadside safety hardware and, where necessary, redesign the devices to improve their impact performance. The three major areas addressed in this study are the impact performance of bridge railings, transitions from guardrails to bridge railings, and end treatments for guardrails and median barriers.

Detailed drawings are presented for documentation, as well as a summary of findings and conclusions for each of the devices tested, and where necessary, recommendations for improvement.

A. George Ostensen, Director
Office of Safety and Traffic
Operations, Research and
Development

NOTICE

The contents of this report reflect the views of the authors who are solely responsible for the facts and accuracy of the data, and the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or Texas Transportation Institute. This report does not constitute a standard, specification, or regulation. In addition, the above listed agencies assume no liability for its contents or use thereof. The names of specific products or manufacturers listed herein does not imply endorsement of those products or manufacturers.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-98-044		

4. Title and Subtitle	5. Report Date
TESTING OF STATE ROADSIDE SAFETY SYSTEMS VOLUME IX APPENDIX H- CRASH TESTING AND EVALUATION OF THE NETC PL-2 BRIDGE RAIL DESIGN	June 1996 6. Performing Organization Code
7. Author(s) King K. Mak and Wanda L. Menges	8. Performing Organization Report No. Research Foundation 7147-Vol. IX
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. NCP No. 11. Contract or Grant No. DTFH61-89-C-00089
12. Sponsoring Agency Name and Address Office of Safety & Traffic Operations R&D Federal Highway Administration 6300 Georgetown Pike McLean, Virginia 22101-2296	13. Type of Report and Period Covered Draft Final Report November 1, 1989 - August 1996 14. Sponsoring Agency Code

15. Supplementary Notes

Contracting Officer's Technical Representative (COTR) - Charles F. McDevitt, HSR-20

16. Abstract

The purpose of this study is to crash test and evaluate new or modified roadside safety hardware and, where necessary, redesign the devices to improve their impact performance. The three major areas addressed in this study are the impact performance of bridge railings, transitions from guardrails to bridge railings, and end treatments for guardrails and median barriers.

This report presents the results of three crash tests conducted on a new bridge railing design by the New England Transportation Consortium (NETC) in accordance with guidelines set forth in the 1989 American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications on Bridge Railings* for a performance level 2 (PL-2) and National Cooperative Highway Research Program (NCHRP) Report 350 for test level 4 (TL-4). The first crash test (test no. 471470-18) involved an 817-kg (1800-lb) passenger car impacting the bridge rail at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees. The second crash test (test no. 471470-19) involved a 2452-kg (5400-lb) pickup truck impacting the bridge rail at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees. The bridge rail was judged to have performed satisfactorily in both tests. However, the bridge deck and curb section sustained some structural damage in the pickup truck redirection test. The design details for the bridge deck, curb section, and steel reinforcement were therefore revised for the third crash test (test no. 471470-29), which involved an 8000-kg (17 636-lb) single-unit truck impacting the bridge rail at a nominal impact speed and angle of 80 km/h (49.7 mi/h) and 15 degrees. The bridge rail was also judged to have performed satisfactorily in this single-unit truck redirection test.

This volume is the ninth in a series of 14 volumes for the final report. The other volumes in the series are: Volume I - Technical Report; Volume II, Appendix A - Crash Testing and Evaluation of a Michigan Thrie-Beam Transition Design; Volume III, Appendix B - Crash Testing and Evaluation of a Guardrail System for Low-Fill Culvert; Volume IV, Appendix C - Crash Testing and Evaluation of a Pennsylvania Transition Design; Volume V, Appendix D - Crash Testing and Evaluation of a Washington, DC, PL-1 Bridge Rail; Volume VI, Appendix E - Crash Testing and Evaluation of a Modified Breakaway Cable Terminal (BCT) Design; Volume VII, Appendix F - Crash Testing and Evaluation of the Minnesota Swing-Away Mailbox Support; Volume VIII, Appendix G - Crash Testing and Evaluation of the Single Slope Bridge Rail; Volume X, Appendix I - Crash Testing and Evaluation of a Mini-MELT for a W-Beam, Weak-Post (G2) Guardrail System; Volume XI, Appendix J - Crash Testing and Evaluation of Existing Guardrail Systems; Volume XI, Appendix J - Crash Testing and Evaluation of Existing Guardrail Systems; Volume XII, Appendix L - Crash Testing and Evaluation of the MELT; and Volume XIV, Appendix M - Laboratory and Pendulum Testing of Modified Breakaway Wooden Posts.

17. Key Words	18. Distribution Statement
Bridge railings, transitions, end treatments, guardrails, median barriers, terminals, roadside safety	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	83	

Form DOT F 1700.7 (8-69) Reproduction of completed page authorized

PREFACE

Because of specific needs or constraints of individual states, new or modified roadside safety hardware are being designed and developed on a continuing basis. To ensure that these new or modified designs perform according to established guidelines, full-scale crash testing and evaluation were deemed necessary. The objective of this study is to crash test and evaluate these roadside safety hardware and, where necessary, redesign the devices to improve their impact performance. The three major areas addressed in this study are the impact performance of bridge railings, transitions from guardrails to bridge railings, and end treatments for guardrails and median barriers.

This is Volume IX of a 14-volume series of final reports for this study. The 14 volumes are as follows:

Volume	Appendix	Title
I		Technical Report.
II	A	Crash Testing and Evaluation of a Michigan Thrie-Beam Transition Design.
III	B	Crash Testing and Evaluation of a Guardrail System for Low-Fill Culvert.
IV	C	Crash Testing and Evaluation of a Pennsylvania Transition Design.
V	D	Crash Testing and Evaluation of a Washington, DC, PL-1 Bridge Rail.
VI	E	Crash Testing and Evaluation of a Modified Breakaway Cable Terminal (BCT) Design.
VII	F	Crash Testing and Evaluation of the Minnesota Swing-Away Mailbox Support.
VIII	G	Crash Testing and Evaluation of the Single Slope Bridge Rail.
XI	H	Crash Testing and Evaluation of the NETC PL-2 Bridge Rail Design.
X	I	Crash Testing and Evaluation of a Mini-MELT for a W-Beam, Weak-Post (G2) Guardrail System.
XI	J	Crash Testing and Evaluation of Existing Guardrail Systems.
XII	K	Crash Testing and Evaluation of the MELT.
XIII	L	Crash Testing and Evaluation of the Modified MELT.
XIV	M	Laboratory and Pendulum Testing of Modified Breakaway Wooden Posts.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

I. INTRODUCTION

A new metal post-and-beam bridge rail with concrete curb was designed by the New England Transportation Consortium (NETC). This bridge railing system was designed to meet Performance Level 2 (PL-2) requirements set forth in the 1989 American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications For Bridge Railings* (hereinafter referred to as the Guide Specifications).[1] Three crash tests are required for evaluation of a PL-2 bridge railing in accordance with guidelines set forth in the Guide Specifications:

1. An 817-kg (1800-lb) passenger car impacting the bridge railing at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees.
2. A 2452-kg (5400-lb) pickup truck impacting the bridge railing at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees.
3. An 8172-kg (18 000-lb) pickup truck impacting the bridge railing at a nominal impact speed and angle of 80.5 km/h (50 mi/h) and 15 degrees.

The 817-kg (1800-lb) passenger car and the 2452-kg (5400-lb) pickup truck tests were conducted with successful results (test nos. 471470-18 and 471470-19). However, the bridge deck sustained structural damage in the pickup truck test. This resulted in some revisions to the design of the bridge deck to accommodate the higher loading anticipated with the single-unit truck crash test.

At the same time, the Federal Highway Administration (FHWA) adopted the National Cooperative Highway Research Program (NCHRP) Report 350[2] as the official guidelines for crash testing and evaluation of roadside safety features. The single-unit truck test under NCHRP Report 350 for test level 4 (TL-4) is similar to that under the Guide Specifications except for the weight of 8000 kg (17 636 lb) and impact speed of 80 km/h (49.7 mi/h). It was therefore decided to follow the guidelines under NCHRP Report 350 for the TL-4 single-unit truck test.

The redesigned NETC bridge deck and rail system was constructed. The single-unit truck test (test no. 471470-29) was then conducted and evaluated under NCHRP Report 350 guidelines with successful results.

Results of these three crash tests are presented in this report.

II. STUDY APPROACH

2.1 TEST ARTICLE

A schematic of the test installation is shown in figure 1, and photographs of the completed installation are shown in figure 2. The major components of the test installation are as follows:

1. A 30.5-m- (100-ft-) long, 203-mm- (8-in-) thick simulated bridge deck,
2. A 533-mm- (21-in-) wide, 229-mm- (9-in-) thick curb section,
3. 13 W6×25 rail posts mounted 2.4 m (8.0 ft) on center,
4. Two tubular steel rails. The top rail is a TS 203 mm × 102 mm × 7.9 mm (8 in × 4 in × 5/16 in) and the bottom rail is a TS 102 mm × 102 mm × 6.4 mm (4 in × 4 in × 1/4 in).

Brief descriptions of the test installation are presented as follows.

The simulated bridge deck consisted of a 203-mm- (8-in-) thick cantilevered concrete section with #5 bars on 152-mm (6-in) centers top and bottom. Stirrups, made of #5 bars, were on 305-mm (12-in) centers in the curb section. The curb section was 229-mm (9-in) thick with a 51-mm (2-in) shear key and 533-mm (21-in) wide, including a 127-mm- (5-in-) thick facing cast in a separate pour on the front of the curb to simulate a granite facing planned for use with the bridge railing. The face of the curb section protruded 152 mm (6 in) from the face of the tubular steel rails. Four 229-mm- (9-in-) long, 25-mm- (1-in-) diameter, double-threaded studs were placed in a 237-mm (9-3/8-in) × 330-mm (13-in) × 3.2-mm (1/8-in) spacer plate for anchoring of the rail posts.

The bridge railing consisted of two tubular steel sections. A TS 203-mm × 102-mm × 7.9-mm (8-in × 4-in × 5/16-in) rail element was attached to the top of the posts with two 152-mm- (6-in-) long, 19.1-mm- (3/4-in-) diameter round-headed bolts. The TS 102-mm × 102-mm × 6.4-mm (4-in × 4-in × 1/4-in) bottom rail was attached to the posts with similar bolts. The rail posts were fabricated from W6×25 steel-post sections shop welded to a 254-mm × 356-mm × 25.4-mm (10-in × 14-in × 1-in) steel base plate. The overall height of the rail post was 618 mm (24-3/8 in). The top of the top rail was 635 mm (25 in) above the top of the curb section, for a total height of 864 mm (34 in) above the pavement surface.

The bridge rail was successfully crash tested with a 817-kg (1800-lb) passenger car and a 2452-kg (5400-lb) pickup truck test (test nos. 471470-18 and 471470-19). However, the bridge deck sustained structural damage in the pickup truck test. This resulted in some revisions to the design of the bridge deck to accommodate the higher loading anticipated with the single-unit truck crash test. A schematic of the redesigned NETC bridge rail and deck test installation is shown in figure 3, and photographs of the completed installation are shown in figure 4.

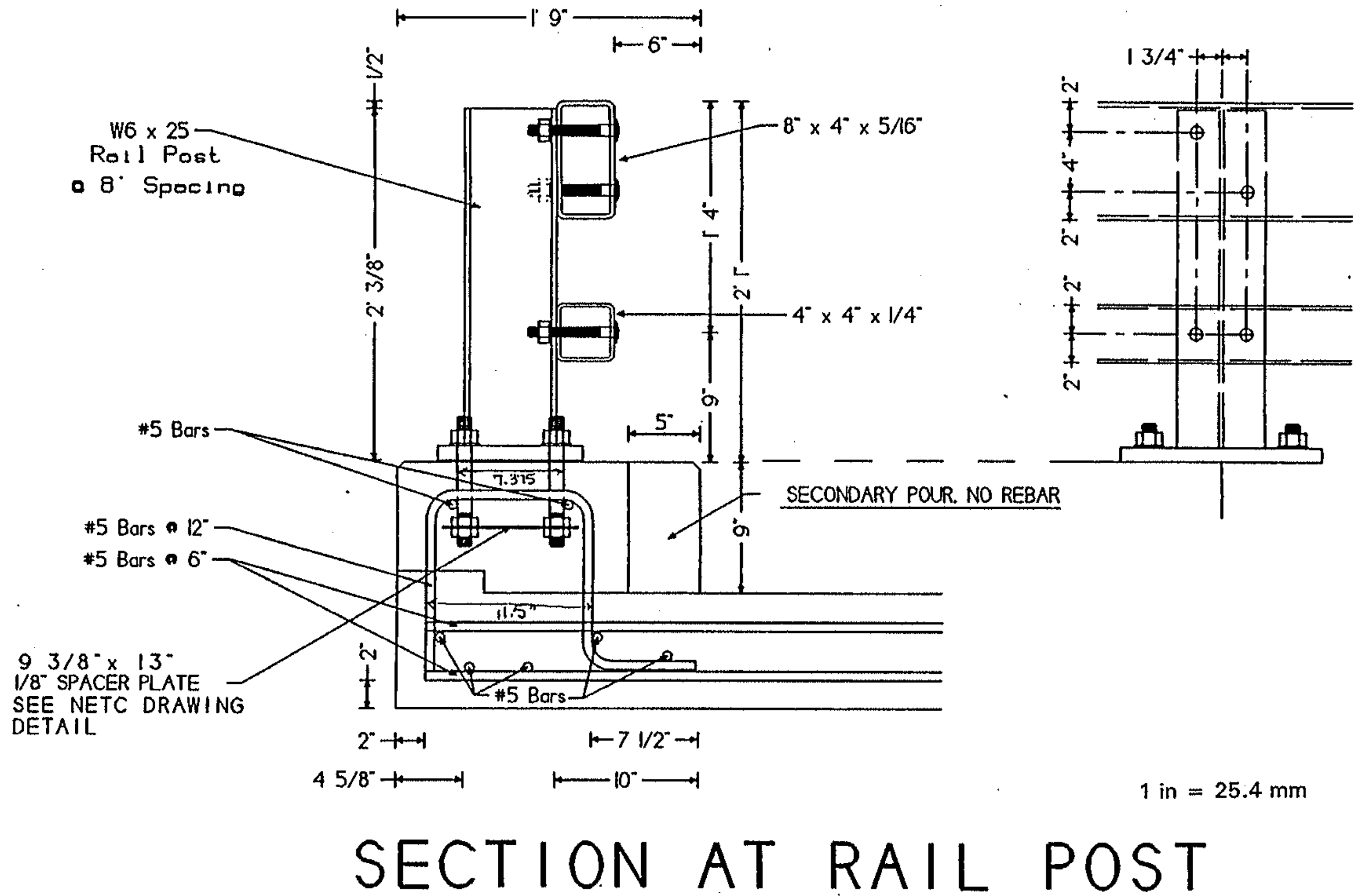


Figure 1. Schematic of the test installation for test 471470-18.

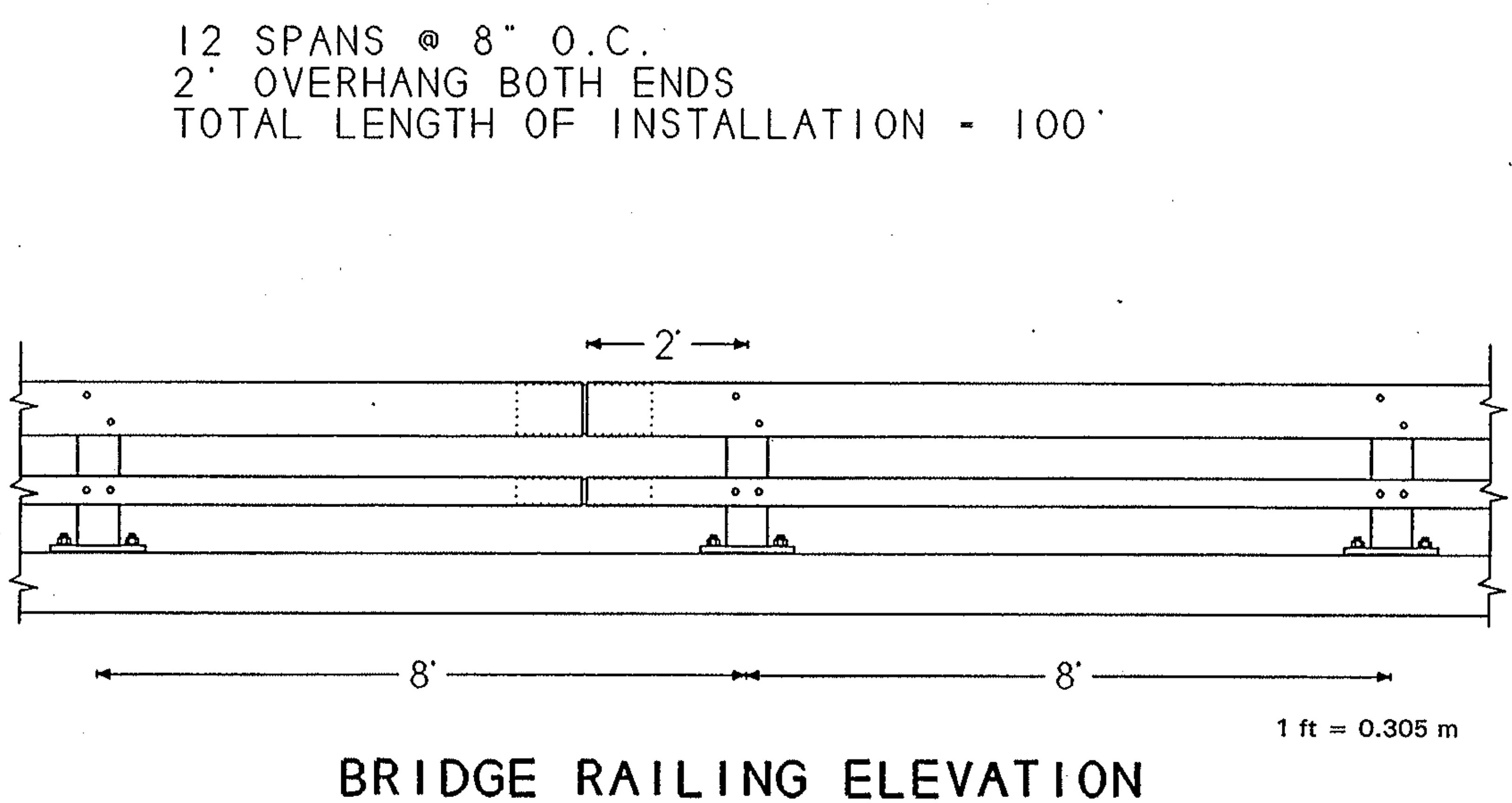


Figure 1. Schematic of the test installation for test 471470-18 (continued).

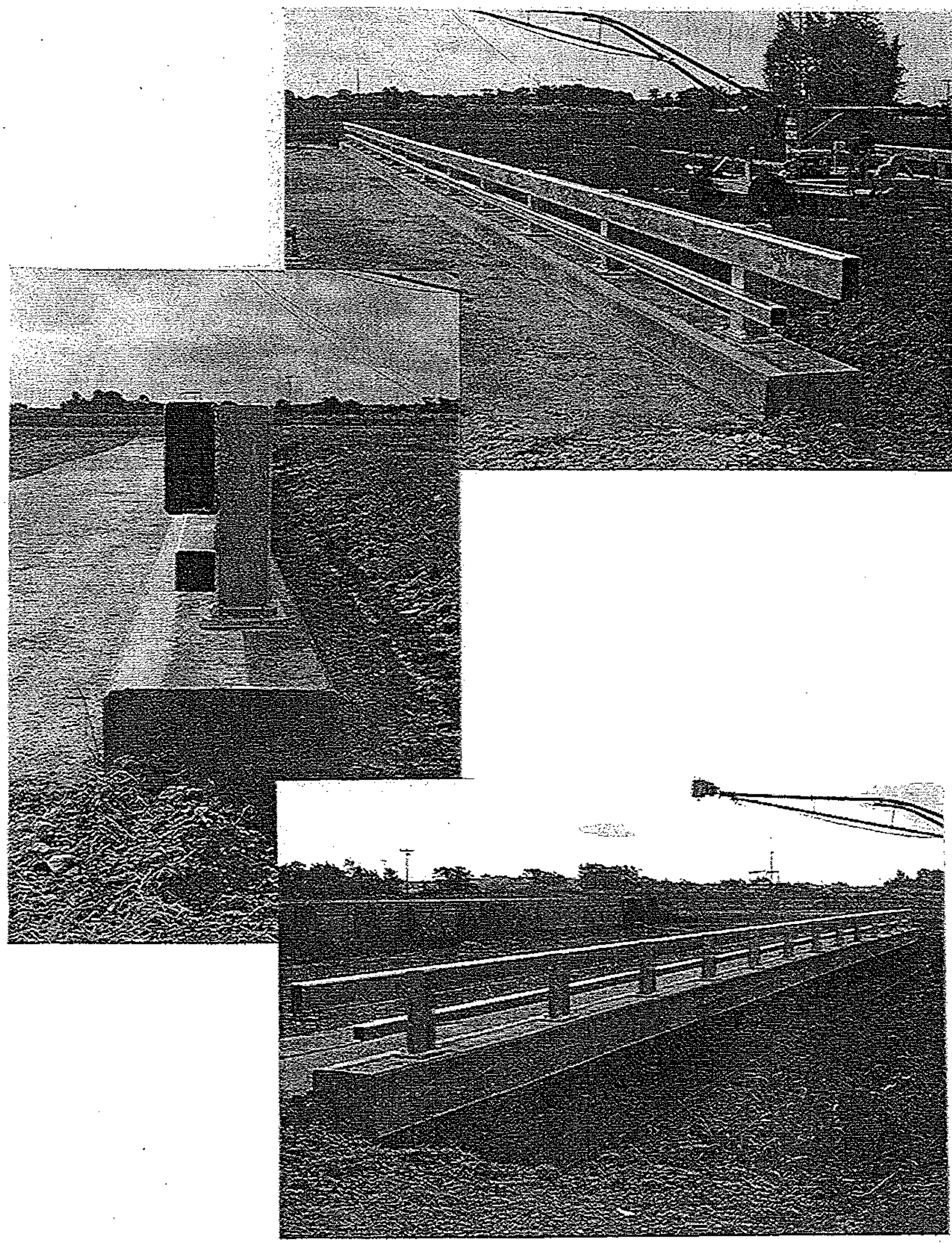


Figure 2. NETC bridge rail installation before test 471470-18.

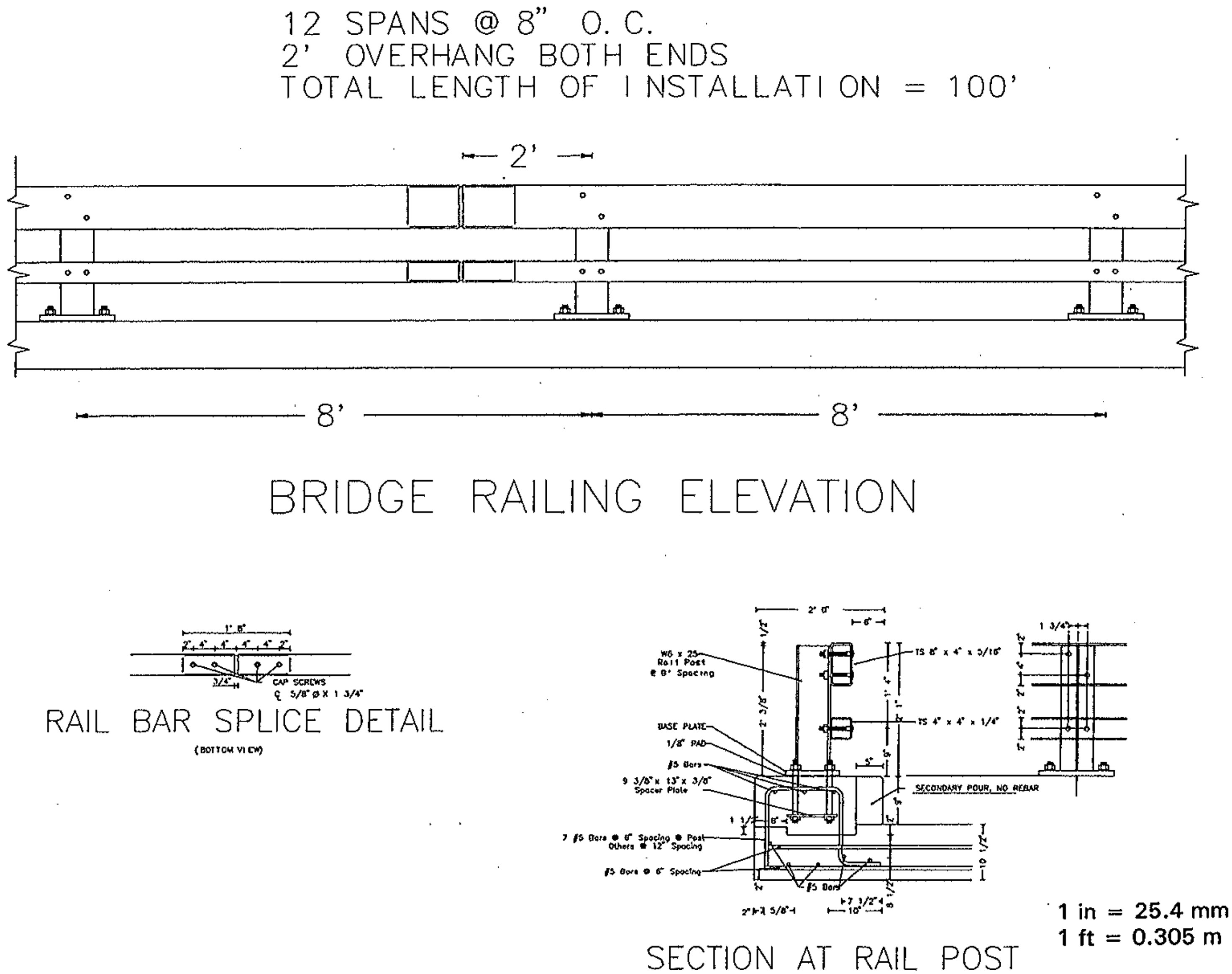


Figure 3: Schematic of the NETC bridge railing used in test 471470-29.

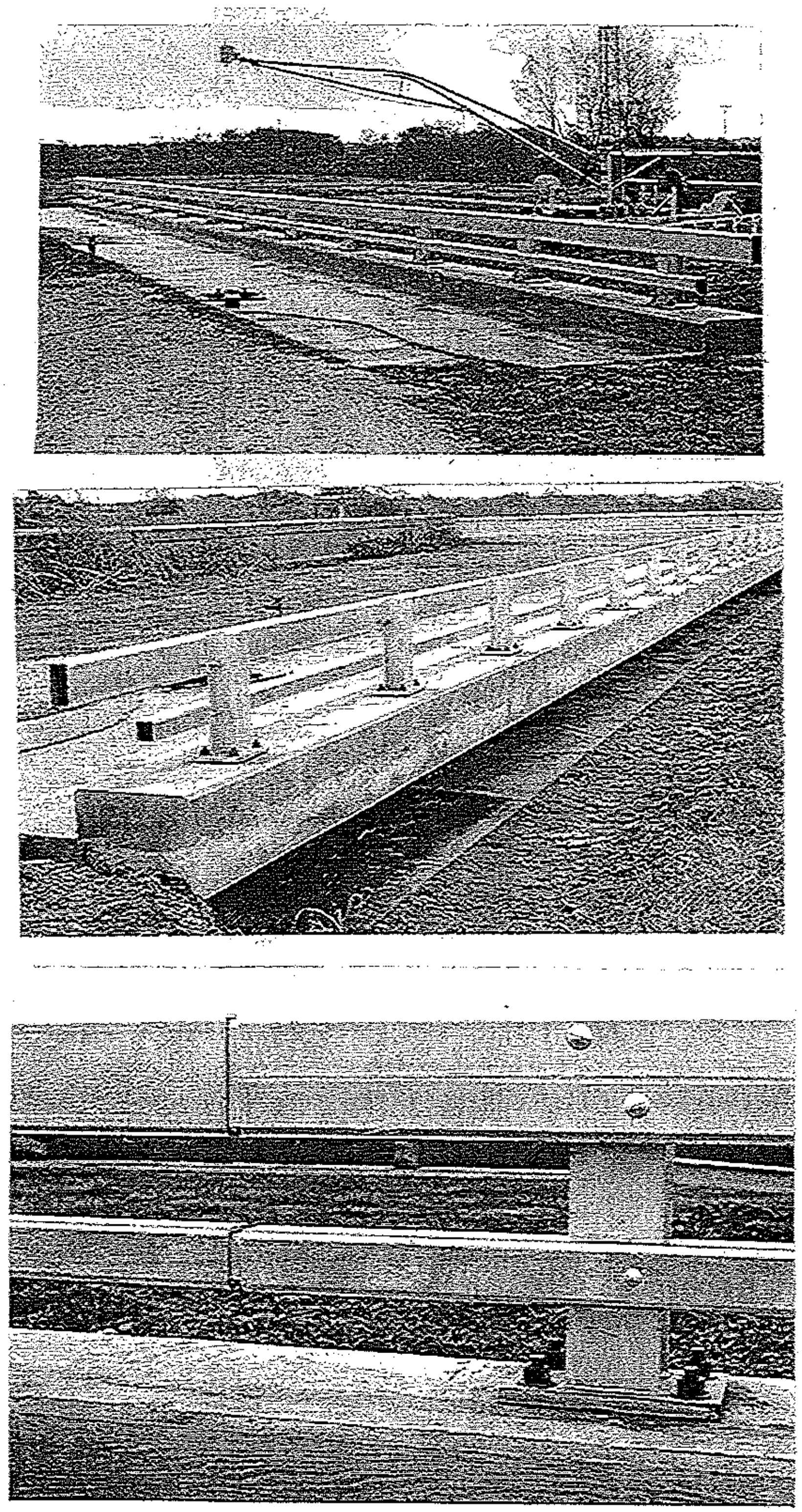


Figure 4. NETC bridge railing before test 471470-29.

The major revisions from the initial design are summarized as follows:

1. The thickness of the bridge deck was increased from 203 mm (8 in) to 216 mm (8.5 in).
2. The curb and deck were widened from 533 mm (21 in) to 610 mm (24 in).
3. The outside cover on the anchor bolts was increased by 76 mm (3 in) from 117 mm (4-5/8 in) to 194 mm (7-5/8 in) to the centerline of the bolts.
4. Three additional stirrups were added at each post anchorage, resulting in a reduction in the stirrup spacing from 305 mm (12 in) to 152 mm (6 in) within the shear-moment zone.
5. An additional distribution bar was added within the new stirrup spacing.
6. The thickness of the spacer plate was increased from 3.2 mm (1/8 in) to 9.5 mm (3/8 in).
7. The length of the anchor bolts was increased from 229 mm (9 in) to 305 mm (12 in).

2.2 CRASH TEST CONDITIONS

Three crash tests are required for evaluation of a PL-2 bridge railing in accordance with guidelines set forth in the 1989 AASHTO Guide Specifications:

1. An 817-kg (1800-lb) passenger car impacting the bridge railing at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees.
2. A 2452-kg (5400-lb) pickup truck impacting the bridge railing at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees.
3. An 8172-kg (18 000-lb) single-unit truck impacting the bridge railing at a nominal impact speed and angle of 80.5 km/h (50 mi/h) and 15 degrees.

The small car (test no. 471470-18) and pickup truck (test no. 471470-19) crash tests were conducted and evaluated in accordance with guidelines set forth in the 1989 AASHTO Guide Specifications. FHWA subsequently adopted NCHRP Report 350 as the official guidelines for crash testing and evaluation of roadside safety features. The test conditions for the single-unit truck test (test no. 471470-29) were therefore revised according to guidelines set forth in NCHRP Report 350 for test level 4 (TL-4), which are similar to those outlined for Performance Level 2 (PL-2) in the 1989 AASHTO Guide Specifications except for slight variations in the test vehicle weight, 8000 kg (17 636 lb) versus 8172 kg (18 000 lb), and impact speed, 80 km/h (49.7 mi/h) versus 80.5 km/h (50 mi/h).

For the sake of consistency, the results for all three crash tests were evaluated under both sets of criteria for PL-2 in the 1989 AASHTO Guide Specifications and TL-4 in NCHRP Report 350.

2.3 CRASH TEST AND DATA ANALYSIS PROCEDURES

All crash test and data analysis procedures and evaluation criteria were conducted in accordance with guidelines set forth in National Cooperative Highway Research Program (NCHRP) Report 350 and the 1989 AASHTO *Guide Specifications for Bridge Railings.* Brief descriptions of the crash test and data analysis and evaluation procedures are presented as follows.

2.3.1 Electronic Instrumentation and Data Processing

The test vehicle was instrumented with three solid-state angular rate transducers to measure yaw, pitch, and roll rates; a triaxial accelerometer at the vehicle center of gravity to measure longitudinal, lateral, and vertical acceleration levels; and a biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. In addition, a biaxial accelerometer was placed in the front of the 8000-kg (17 636-lb) single-unit truck. The accelerometers were strain-gauge type with a linear millivolt output proportional to acceleration.

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

The multiplex of data channels, transmitted on one radio frequency, was received at a data acquisition station, and demultiplexed into separate tracks of Inter-Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with a SAE J211 Class 180 filter, and digitized using a microcomputer, for analysis and evaluation of impact performance. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions of the functions of these two computer programs are as follows.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 0.010-s average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 0.050-s intervals in each of the three directions are computed. Acceleration versus time curves for the longitudinal, lateral, and vertical directions are then plotted from the digitized data of the vehicle-mounted linear accelerometers using a commercially available software package (QUATTRO PRO).

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate charts to compute angular displacement in degrees at 0.00067-s 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.

2.3.2 Anthropomorphic Dummy Instrumentation

An anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the vehicle. The dummy was uninstrumented; however, a high-speed onboard camera recorded the motions of the dummy during the test sequence. No dummy was used in the test with the 8000-kg (17 636-lb) single-unit truck.

2.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included four high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed to have a field of view parallel to and aligned with the test installation at the downstream end; a third placed behind the railing in the vicinity of impact; and a fourth placed onboard the vehicle to record the motions of the dummy placed in the driver seat during the test sequence. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the bridge railing and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A 16-mm movie cine, a professional video camera and 3/4-in video recorder, along with 35-mm cameras were used for documentary purposes and to record conditions of the test vehicle and bridge railing system before and after the test.

2.3.4 Test Vehicle Propulsion and Guidance

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was stretched along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. Another steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. The system had a 2 to 1 speed ratio between the test and tow vehicle. Immediately prior to impact with the bridge railing system, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until it cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring it to a safe and controlled stop.

III. CRASH TEST RESULTS

As mentioned previously, the following three crash tests were conducted in the evaluation of the NETC bridge rail design:

1. An 817-kg (1800-lb) passenger car impacting the bridge railing at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees.
2. A 2452-kg (5400-lb) pickup truck impacting the bridge railing at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees.
3. An 8000-kg (17 636-lb) single-unit truck impacting the bridge railing at a nominal impact speed and angle of 80 km/h (49.7 mi/h) and 15 degrees.

Descriptions of the results of these three crash tests are presented in the following sections.

3.1 SMALL CAR REDIRECTION TEST (TEST NO. 471470-18)

A 1986 Yugo GV (figure 5) was used for the crash test. Test inertia mass of the vehicle was 817 kg (1800 lb) and its gross static mass was 894 kg (1970 lb). The height to the lower edge of the vehicle bumper was 238 mm (9.4 in) and it was 465 mm (18.3 in) to the top of the bumper. Additional dimensions and information on the test vehicle are given in figure 6. The position of the vehicle relative to the bridge railing prior to impact is shown in figure 7. The vehicle was directed into the bridge railing using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

3.1.1 Test Description

The vehicle impacted the bridge railing mid-span between posts 3 and 4 (post 1 was the first post at the upstream end of the bridge railing) or 1.02 m (40 in) downstream from post 3 at a speed of 100.9 km/h (62.7 mi/h) and an angle of 20.6 degrees. By 0.138 s after impact, the vehicle was traveling parallel to the bridge railing at a speed of 92.0 km/h (57.2 mi/h). The vehicle lost contact with the bridge railing at 0.241-s traveling at a speed of 88.7 km/h (55.1 mi/h) and at an exit angle of 2.2 degrees. The brakes on the vehicle were applied at 2.15 s after impact and the vehicle subsequently came to rest 64.6 m (212 ft) down from and 0.9 m (3 ft) in front of the point of impact. Sequential photographs of the impact are shown in figures 8 and 9.

3.1.2 Damage to Test Installation

As can be seen in figure 10, the bridge railing received minimal damage. The bridge railing and curb received only minor cosmetic damage. The vehicle was in contact with the

Figure 5. Vehicle before test 471470-18.

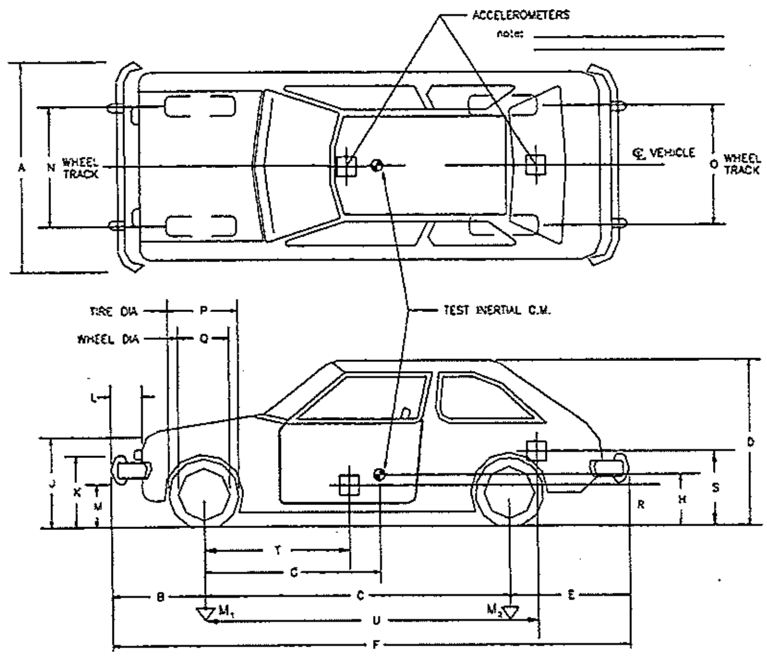
DATE: 7-22-93 TEST NO.: 471470-18 VIN NO.: VX1BA1213GH310936 MAKE: YUGO

MODEL: GV YEAR: 1986 ODOMETER: 27275 TIRE SIZE: 145R13

TIRE INFLATION PRESSURE: ____________

MASS DISTRIBUTION (kg) LF 252 RF 255 LR 159 RR 150

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 CYL

ENGINE CID: ____________

TRANSMISSION TYPE:

_ AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

N/A

DUMMY DATA:

TYPE: ____________

MASS: ____________

SEAT POSITION: ____________

GEOMETRY - (cm)

A 149	E 61.5	J 77.8	N 131.5	R 38
B 64	F 341.3	K 46.5	O 127.5	S 68
C 215.8	G 81.7	L 6.8	P 55	T 76
D 140	H	M 23.8	Q 36	U 240.5

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	518	508	543
M_2	291	309	351
M_T	809	817	894

Figure 6. Vehicle properties for test 471470-18.

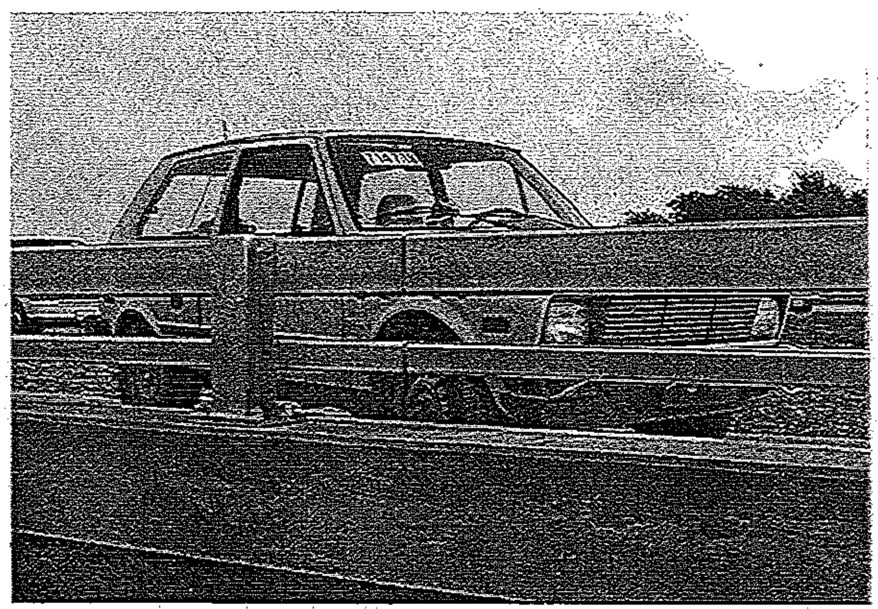


Figure 7. Vehicle/bridge rail geometrics for test 471470-18.

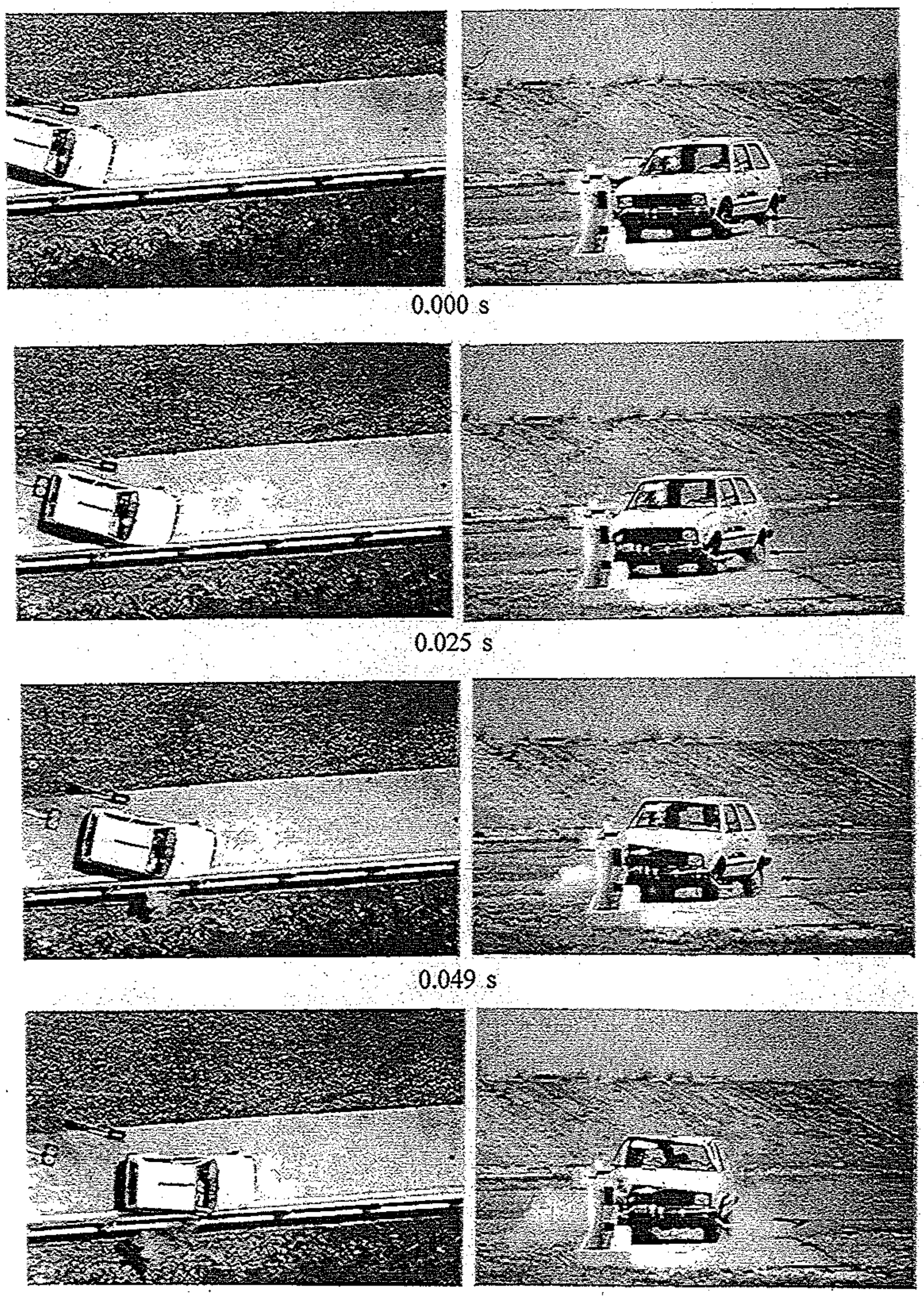
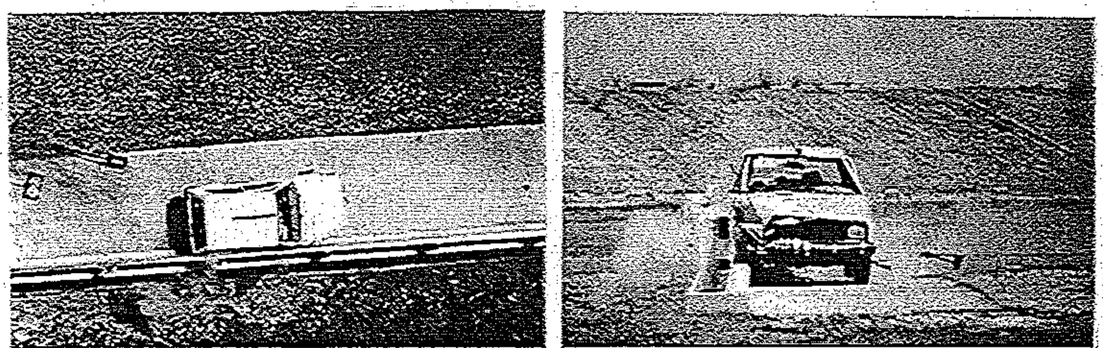
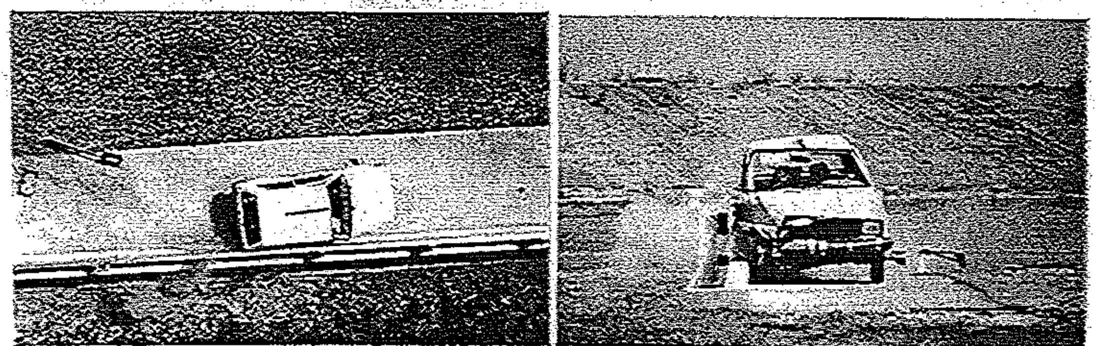


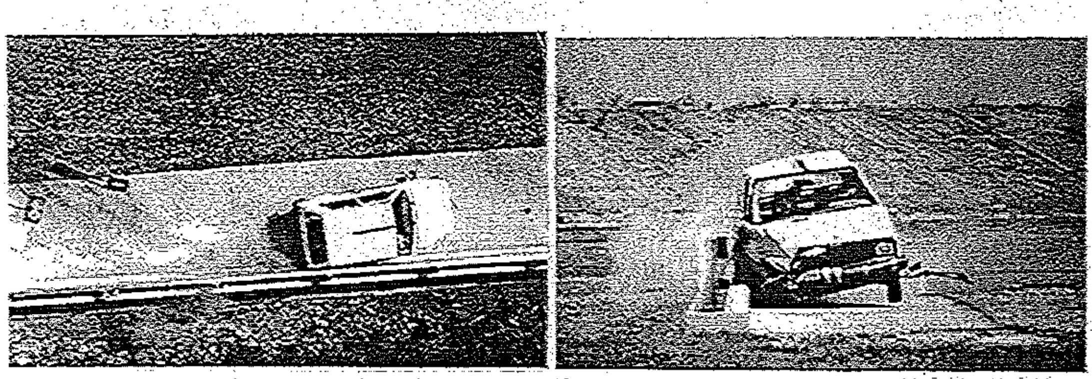
Figure 8. Sequential photographs for test 471470-18 (overhead and frontal views).



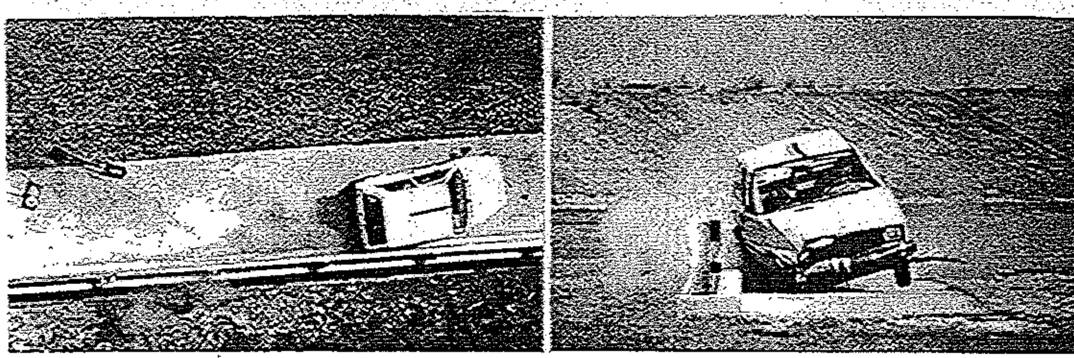
0.150 s



0.199 s



0.249 s



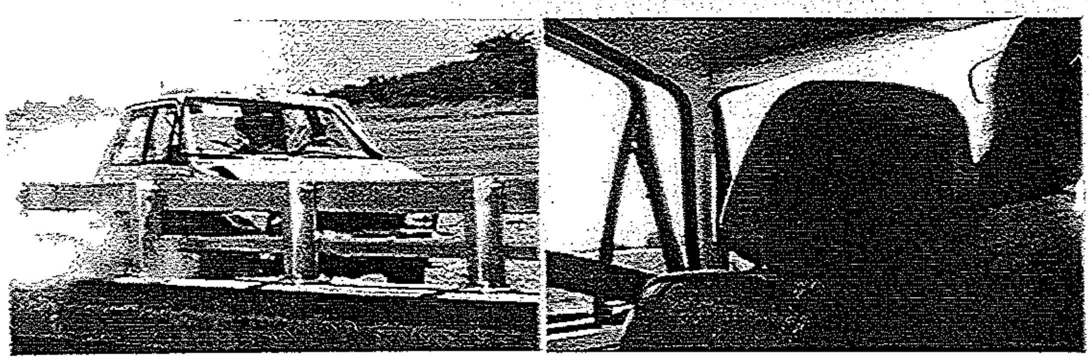
0.300 s

Figure 8. Sequential photographs for test 471470-18
(overhead and frontal views) (continued).

0.000 s

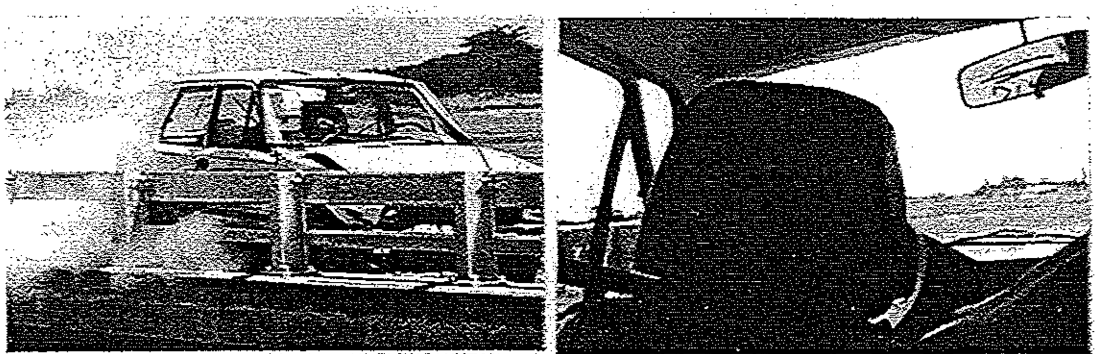
0.025 s

0.049 s

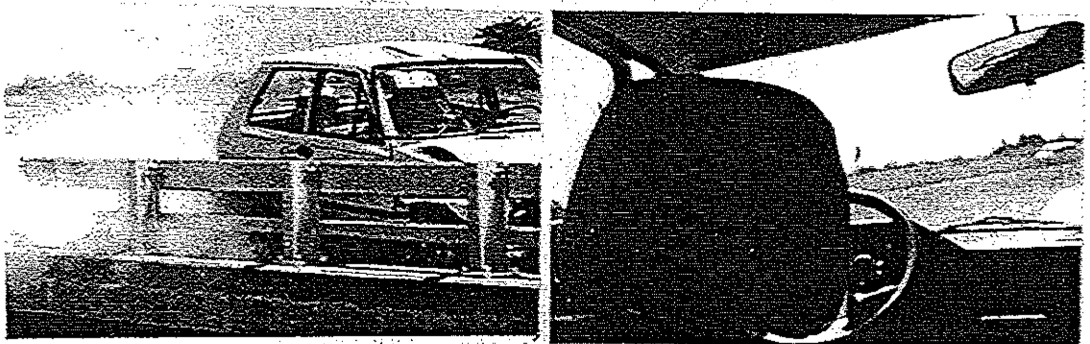


0.099 s

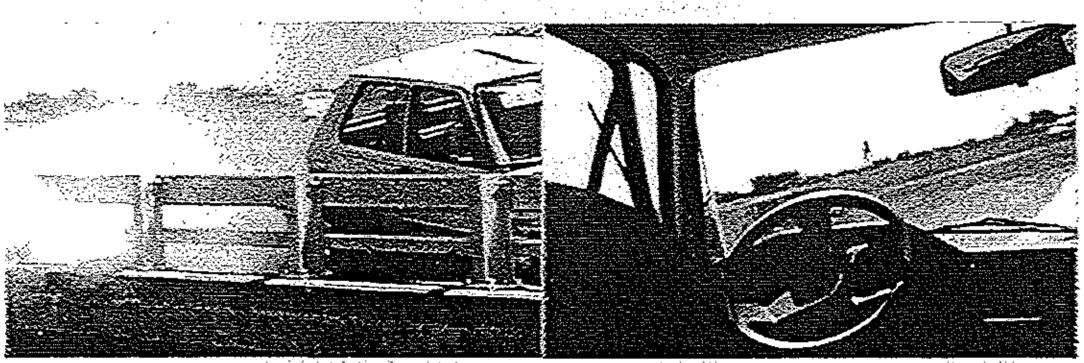
Figure 9. Sequential photographs for test 471470-18
(behind the rail and interior views).



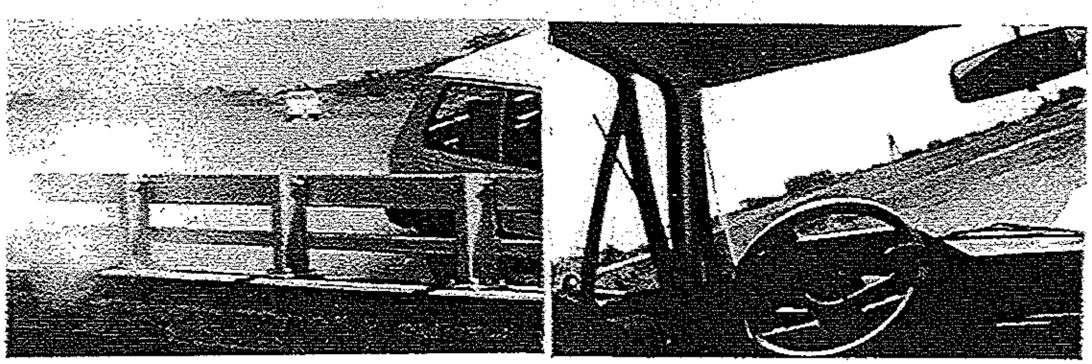
0.150 s



0.199 s

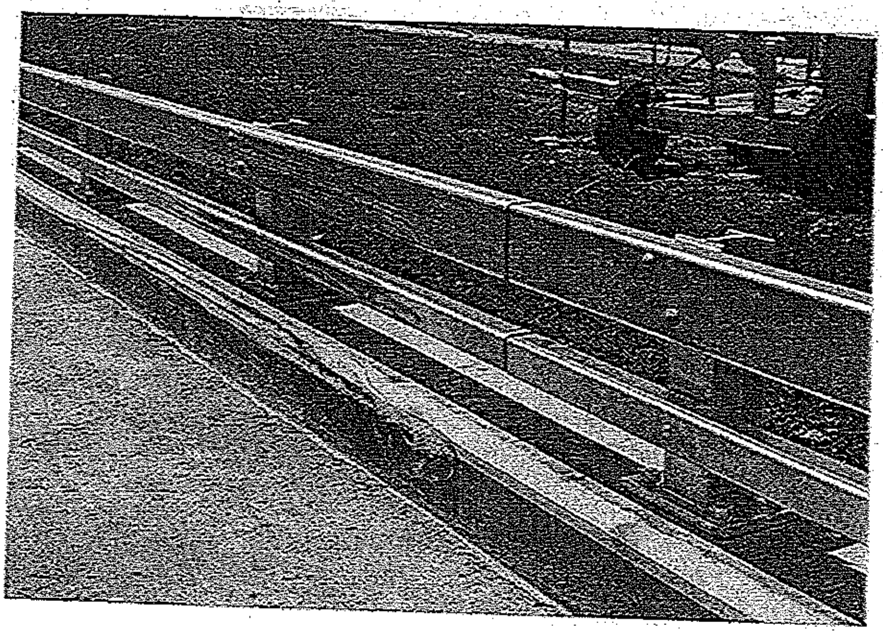


0.249 s



0.300 s

Figure 9. Sequential photographs for test 471470-18 (behind the rail and interior views) (continued).



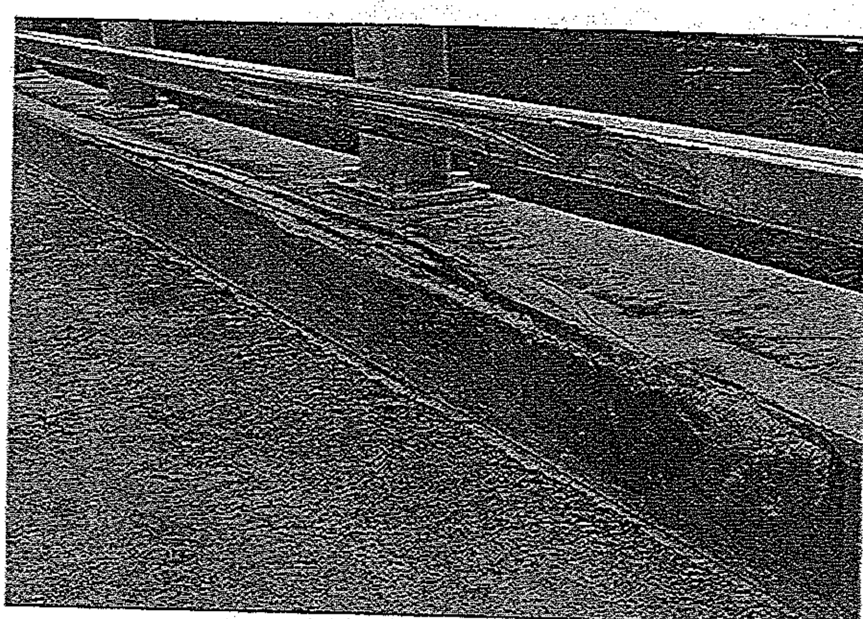


Figure 10. NETC bridge rail after test 471470-18.

bridge railing for a total length of 4.0 m (13.2 ft). Shown in figure 11 are photographs of the post-test vehicle trajectory.

3.1.3 Vehicle Damage

The vehicle sustained damage to the right side as shown in figure 12. Maximum crush at the right front corner at bumper height was 124 mm (4.9 in) and there was 20 mm (0.8 in) of crush at the right A-pillar. The wheelbase on the right side was shortened by 108 mm (4.3 in). The right front strut and sway bar were damaged. Also, damage was done to the front bumper, hood, grill, right front fender, right front rim, right door, right rear quarter panel, and right rear rim.

3.1.4 Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation, and occupant risk factors were computed as follows. In the longitudinal direction, occupant impact velocity was 5.2 m/s (16.9 ft/s) at 0.184 s; the highest 0.010-s average ridedown acceleration was -1.6 g's between 0.404 and 0.414 s; and the maximum 0.050-s average acceleration was -6.1 g's between 0.028 and 0.078 s. Lateral occupant impact velocity was 8.4 m/s (27.5 ft/s) at 0.082 s; the highest 0.010-s occupant ridedown acceleration was -6.8 g's between 0.112 and 0.122 s; and the maximum 0.050-s average acceleration was -15.2 g's between 0.019 and 0.069 s. The change in vehicle velocity at loss of contact was 12.2 km/h (7.6 mi/h) and the change in momentum was 1885 N-s (424 lb-s). These data and other pertinent information from the test are summarized in figure 13. Vehicular angular displacements are displayed in figure 14. Vehicular accelerations versus time traces filtered at SAE J211 (Class 180) are presented in figures 15 through 17.

3.2 PICKUP TRUCK REDIRECTION TEST (TEST NO. 471470-19)

A 1984 Ford F250 Pickup (figure 18) was used for the crash test. Test inertia mass of the vehicle was 2452 kg (5400 lb) and its gross static mass was 2528 kg (5568 lb). The height to the lower edge of the vehicle bumper was 432 mm (17.0 in) and it was 673 mm (26.5 in) to the top of the bumper. Additional dimensions and information on the test vehicle are given in figure 19. The position of the vehicle relative to the bridge railing prior to impact is shown in figure 20. The vehicle was directed into the bridge railing using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

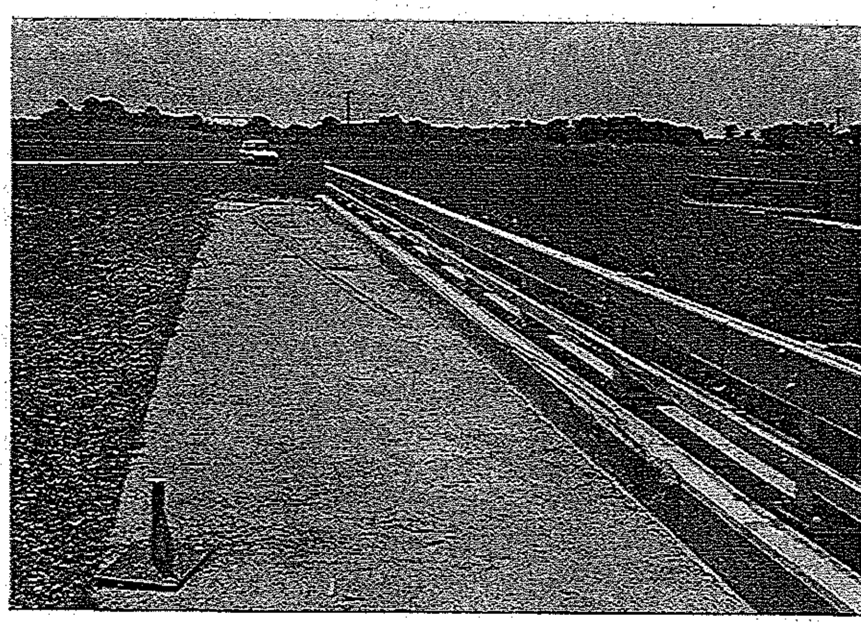
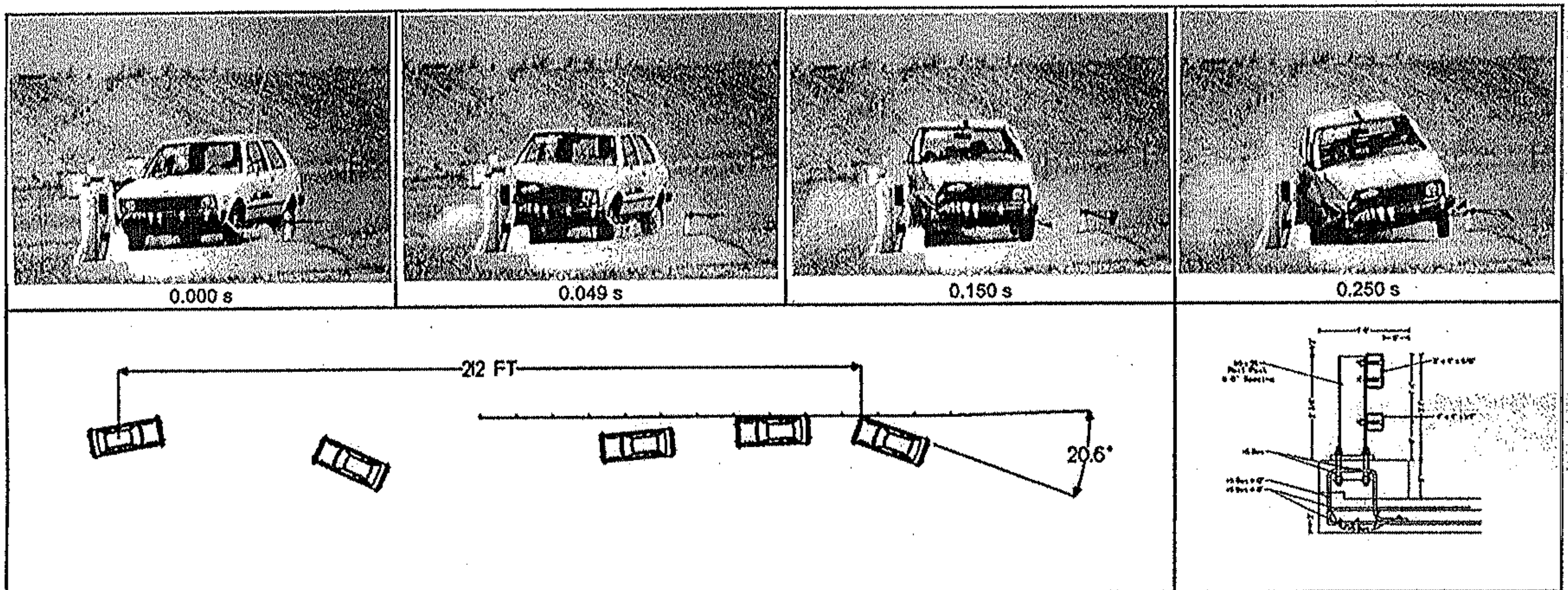


Figure 11. Test site after test 471470-18.

Figure 12. Vehicle after test 471470-18.



General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-18
Date	07/20/93
Test Article	
Type	Bridge Rail
	NETC Bridge Rail
Installation Length (m)	30.5 (100 ft)
Size and/or dimension and material of key elements	Tubular Steel Rail Elements on W6 X 25 Steel Posts @ 2.4 m on 241-mm Curb
Soil Type and Condition	Concrete Bridge Deck, Dry
Test Vehicle	
Type	Production Model
Designation	820 C
Model	1986 Yugo GV
Mass (kg) Curb	809 (1782 lb)
Test Inertial	817 (1800 lb)
Dummy	77 (170 lb)
Gross Static	894 (1970 lb)

Impact Conditions	
Speed (km/h)	100.9(62.7 mi/h)
Angle (deg)	20.6
Exit Conditions	
Speed (km/h)	88.7 (55.1 mi/h)
Angle (deg)	2.2
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.2 (16.9 ft/s)
y-direction	8.4 (27.5 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.6
y-direction	-6.8
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x-direction	-6.1
y-direction	-15.2
z-direction	-2.6

Test Article Deflections (mm)	
Dynamic	Not Available
Permanent	6 (0.25 in)
Vehicle Damage	
Exterior	
VDS	01RFQ-3
CDC	01FREK2
	03RDES1
Interior	
OCDI	RS0100000
Maximum Exterior Vehicle Crush (mm)	124 (4.9 in)
Max. Occ. Compart. Deformation (mm)	32 (1.3 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	15
Max. Pitch Angle (deg)	-7
Max. Yaw Angle (deg)	-32

Figure 13. Summary of results for test 471470-18.

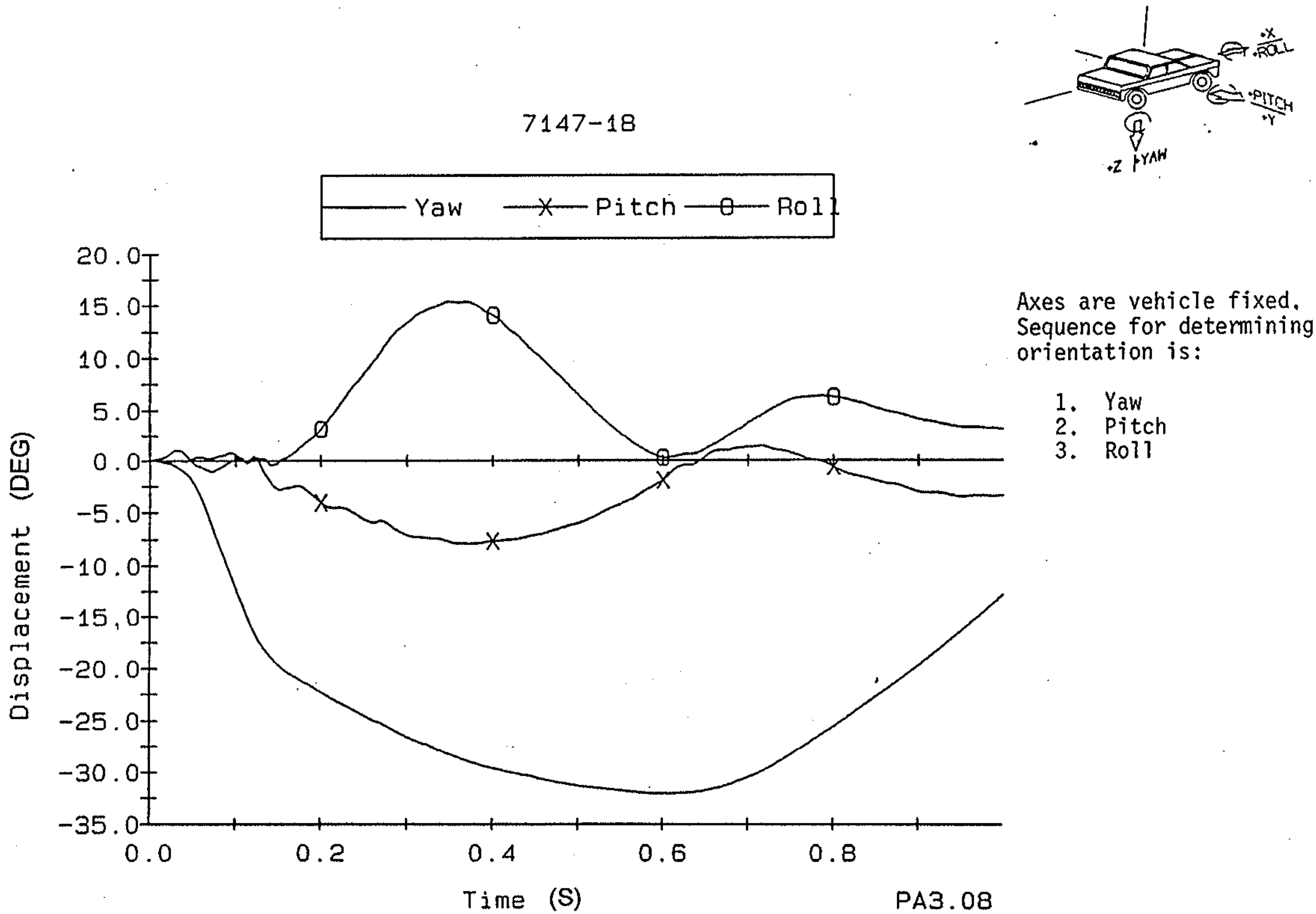


Figure 14. Vehicle angular displacements for test 471470-18.

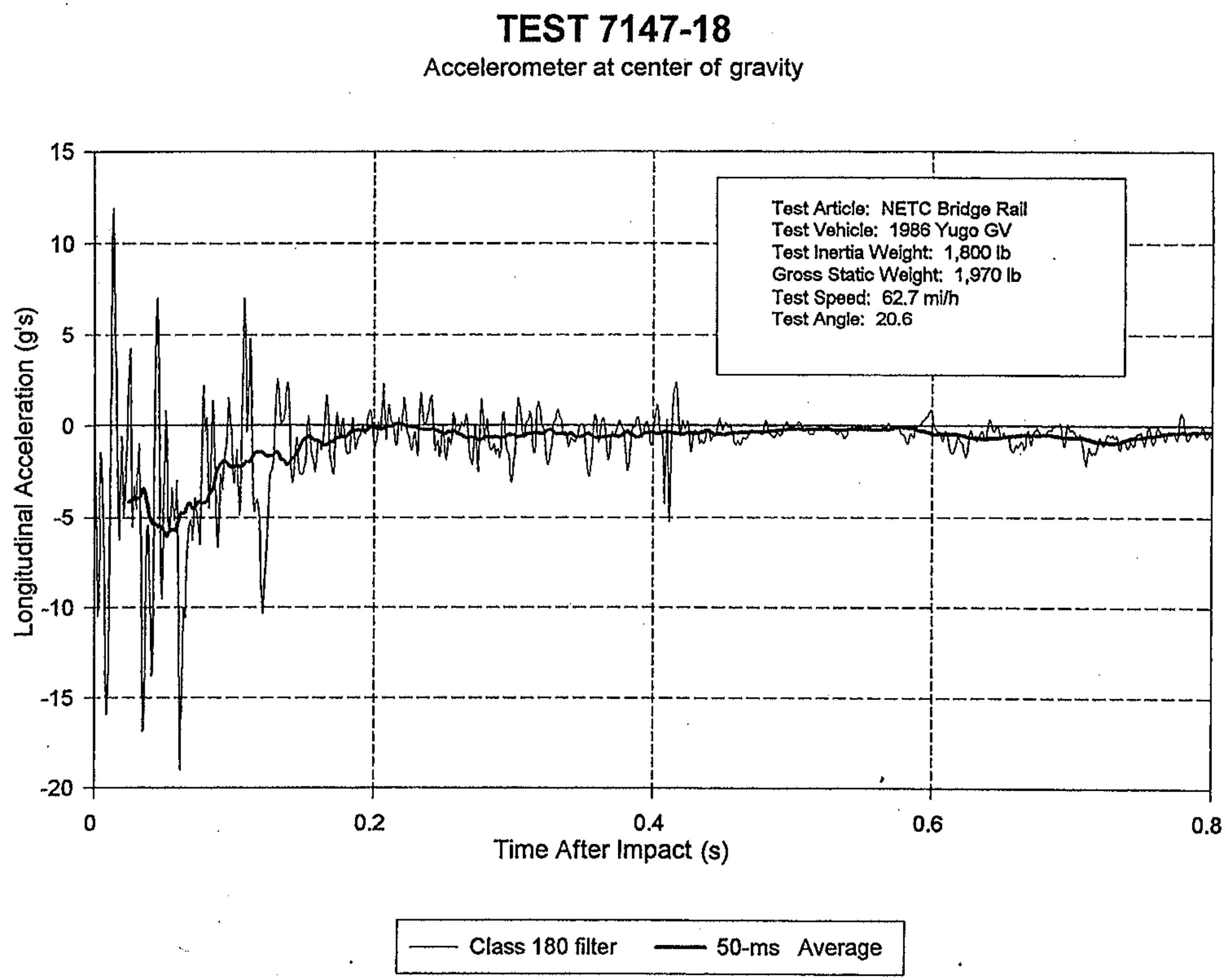


Figure 15. Longitudinal accelerometer trace for test 471470-18.

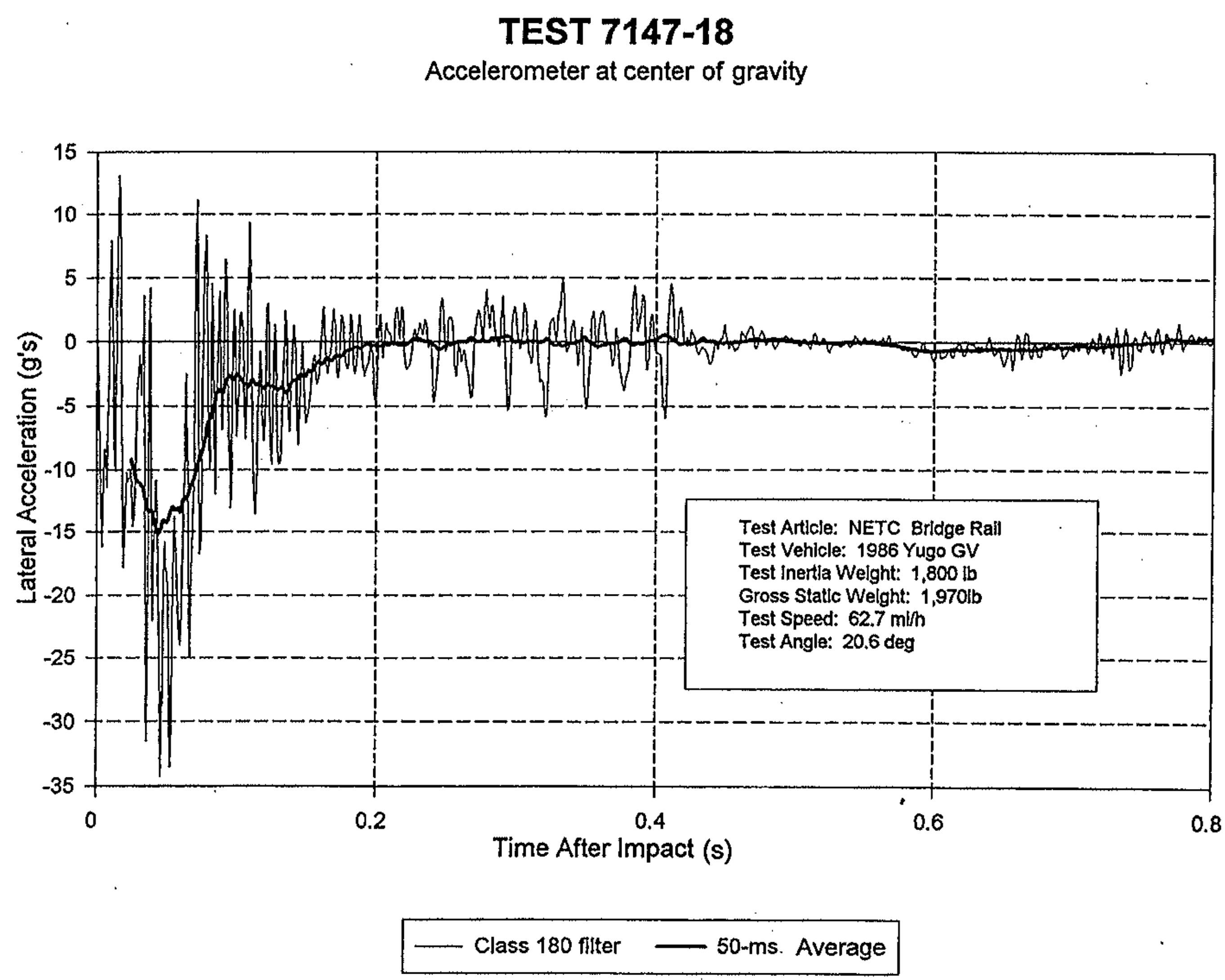


Figure 16. Lateral accelerometer trace for test 471470-18.

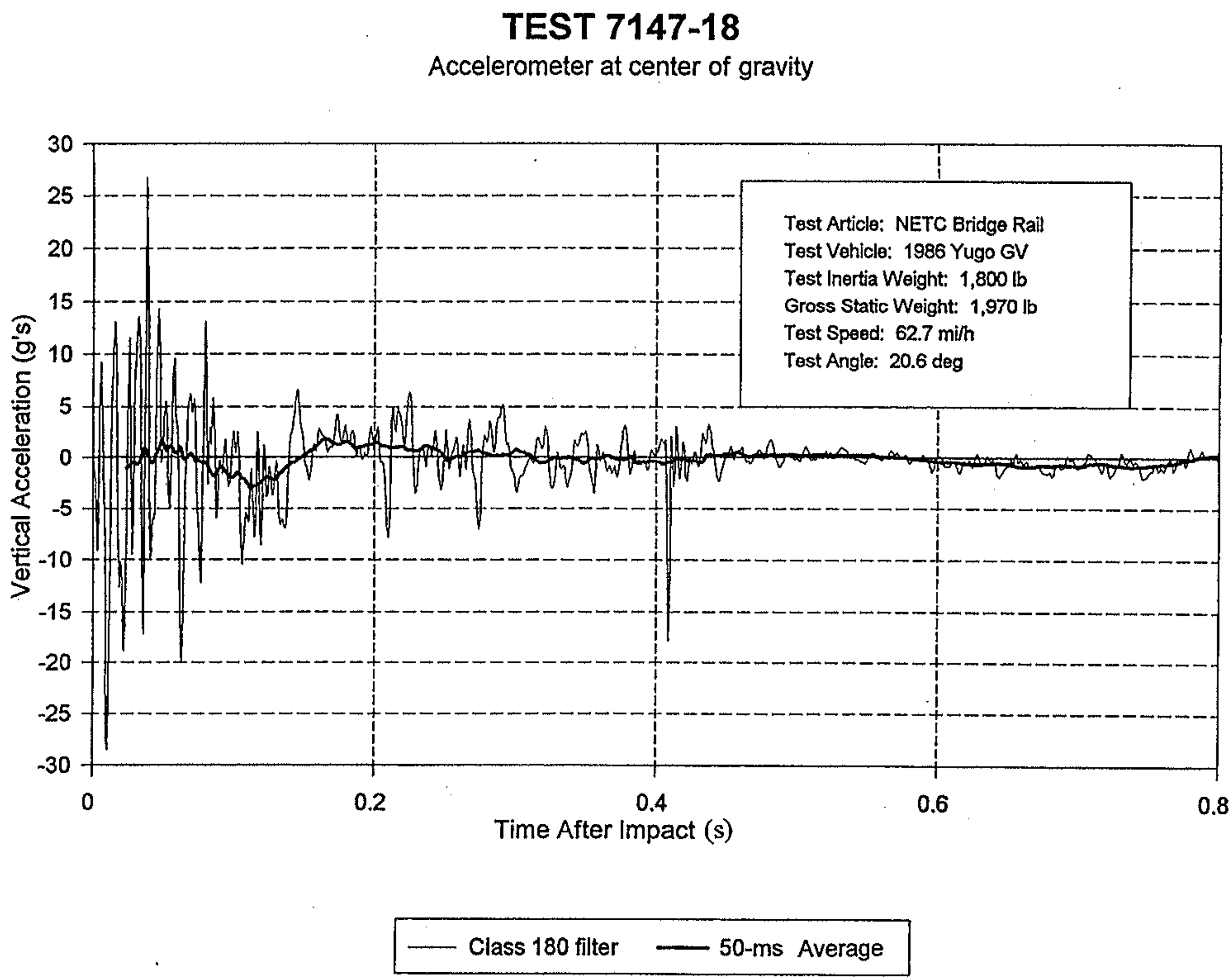


Figure 17. Vertical accelerometer trace for test 471470-18.

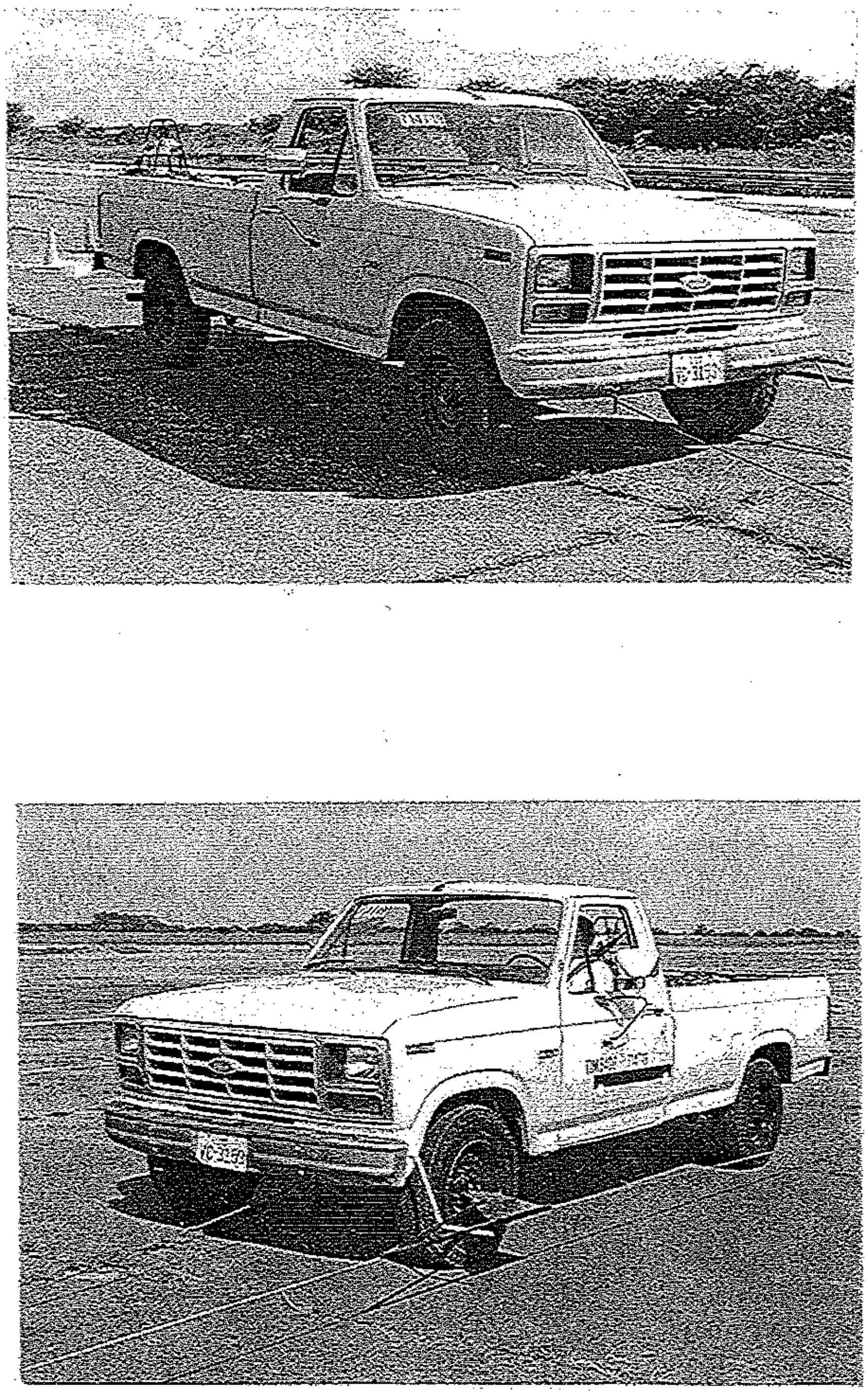


Figure 18. Vehicle before test 471470-19.

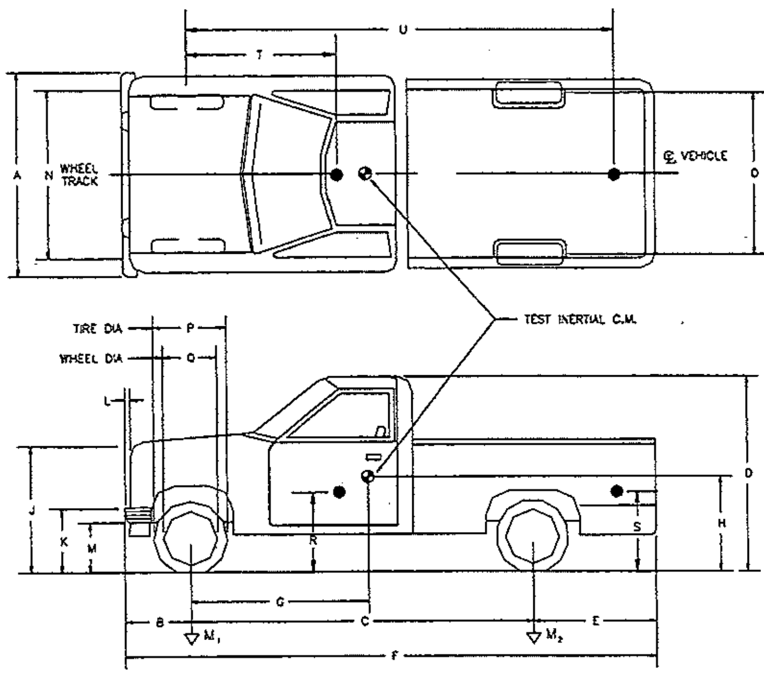
DATE: 7-22-93 TEST NO.: 471470-19 VIN NO.: 1FTHF25L9FKA13830

YEAR: 1984 MAKE: FORD MODEL: F 250

TIRE INFLATION PRESSURE: ______ ODOMETER: 92125 TIRE SIZE: 9.5 - 16.5

MASS DISTRIBUTION (kg) LF 554 RF 563 LR 642 RR 692

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: V-8

ENGINE CID: 7.5L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: ______

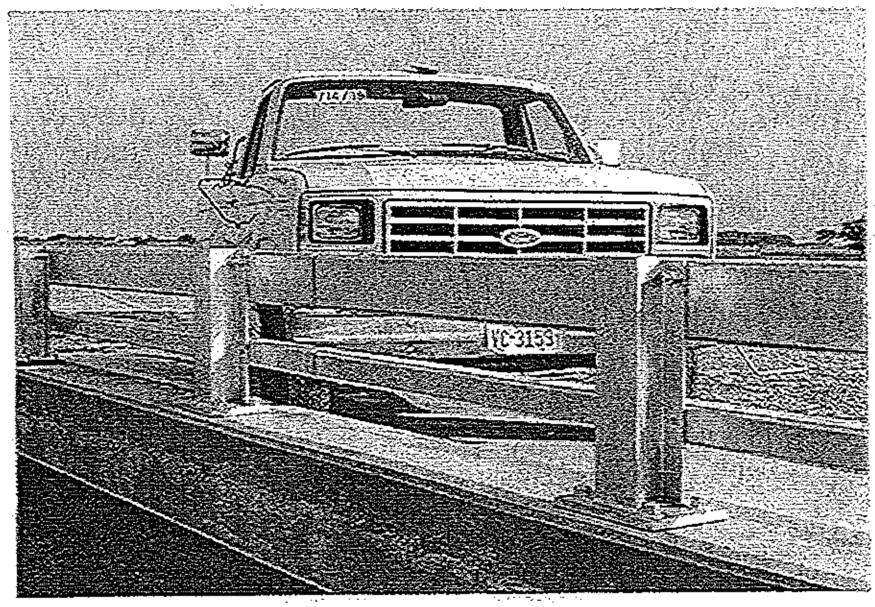
SEAT POSITION: ______

GEOMETRY - (cm)

A	191.8	E	125.1	J	123.2	N	167	R	76.2
B	72.4	F	535.9	K	67.3	O	163.8	S	95.3
C	338.5	G	184.2	L	2.54	P	73.6	T	187.3
D	181.6	H	xxxx	M	43.2	Q	43.8	U	427.4

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1183	1117	1163
M_2	797	1335	1365
M_1	1980	2452	2528

Figure 19. Vehicle properties for test 471470-19.



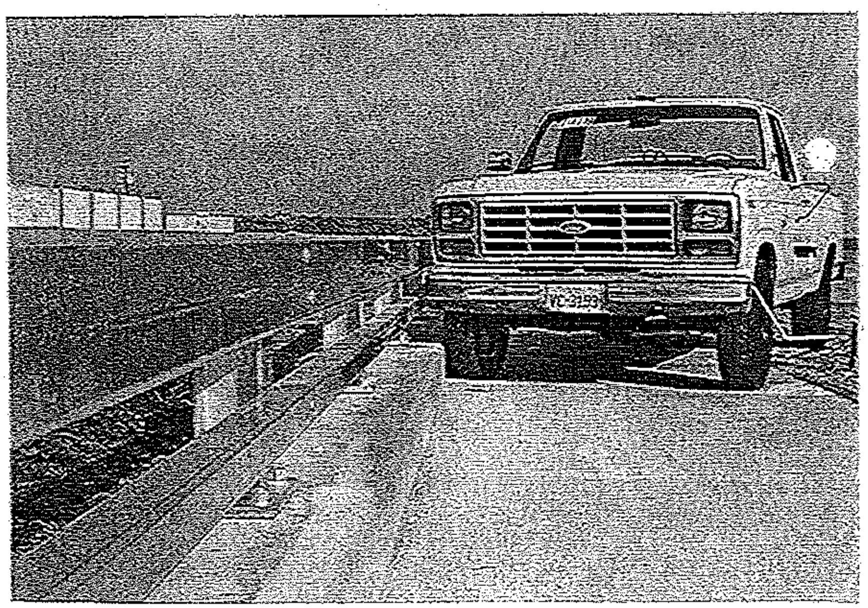


Figure 20. Vehicle/bridge rail geometrics for test 471470-19.

3.2.1 Test Description

The vehicle impacted the bridge railing between posts 3 and 4 (post 1 was the first post at the upstream end of the bridge railing) or 0.3 m (12 in) downstream from post 3 at a speed of 92.2 km/h (57.3 mi/h) and an angle of 20.6 degrees. By 0.183 s after impact, the vehicle was traveling parallel to the bridge railing at a speed of 82.5 km/h (51.3 mi/h). The vehicle lost contact with the bridge railing at 0.369 s, traveling at a speed of 78.2 km/h (48.6 mi/h) and at an exit angle of 2.2 degrees. The brakes on the vehicle were applied at 2.3 s after impact and the vehicle subsequently came to rest 77.0 m (252.5 ft) down from and 3.7 m (12 ft) behind the point of impact. Sequential photographs of the impact are shown in figures 21 and 22.

3.2.2 Damage to Test Installation

As can be seen in figure 23, the bridge railing received only cosmetic damage. However, the curb section and bridge deck sustained structural damage at the two posts immediately upstream and downstream of the point of impact (posts 3 and 4). It appears from the damage patterns that the curb section and bridge deck failed under the combination of bending and shear forces (principally shear), as evidenced by the 45-degree cracks starting at the anchor bolts. This suggested that there might not be sufficient concrete cover and steel reinforcement around the anchorage bolts to resist the forces acting on the post and anchorage assembly during impact. Photographs showing the shear cracks are shown in figures 24 and 25. The vehicle was in contact with the bridge railing for a total length of 6.1 m (19.9 ft).

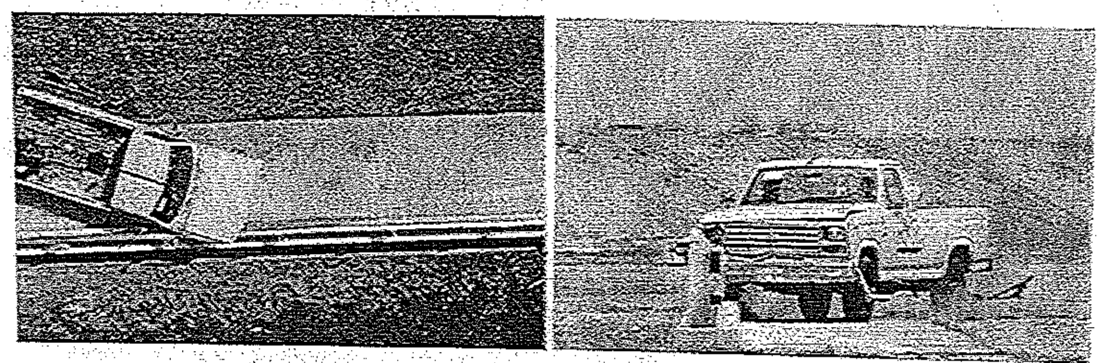
3.2.3 Vehicle Damage

The vehicle sustained damage to the right side, as shown in figure 26. Maximum crush at the right front corner at bumper height was 254 mm (10.0 in) and there was 25 mm (1.0 in) of crush at the right A-pillar. The wheelbase on the right side was shortened by 32 mm (1.75 in). The tie rod and right radius arm were damaged. Also, damage was done to the front bumper, hood, grill, right front fender, right front rim, right door, right rear bumper, and right rear tire and rim.

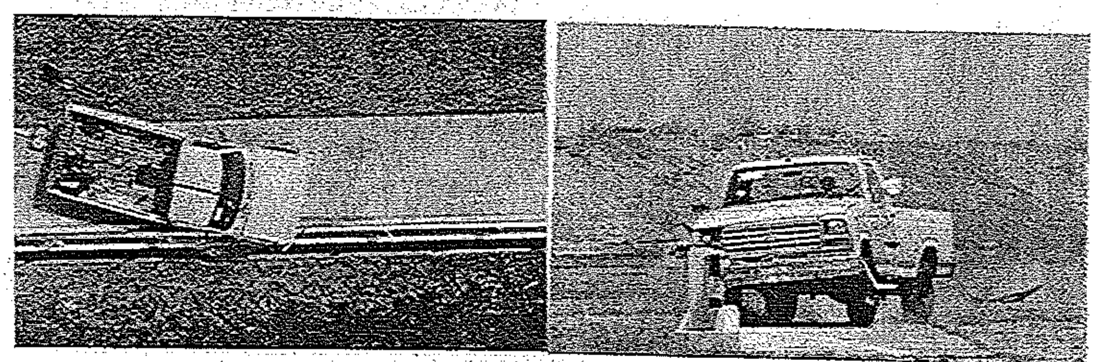
3.2.4 Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation, and occupant risk factors were computed as follows. In the longitudinal direction, occupant impact velocity was 3.7 m/s (12.2 ft/s) at 0.258 s; the highest 0.010-s average ridedown acceleration was -2.5 g's between 0.284 and 0.294 s; and the maximum 0.050-s average acceleration was -3.4 g's between 0.019 and 0.069 s. Lateral occupant impact velocity was 6.6 m/s (21.5 ft/s) at 0.128 s; the highest 0.010-s occupant ridedown

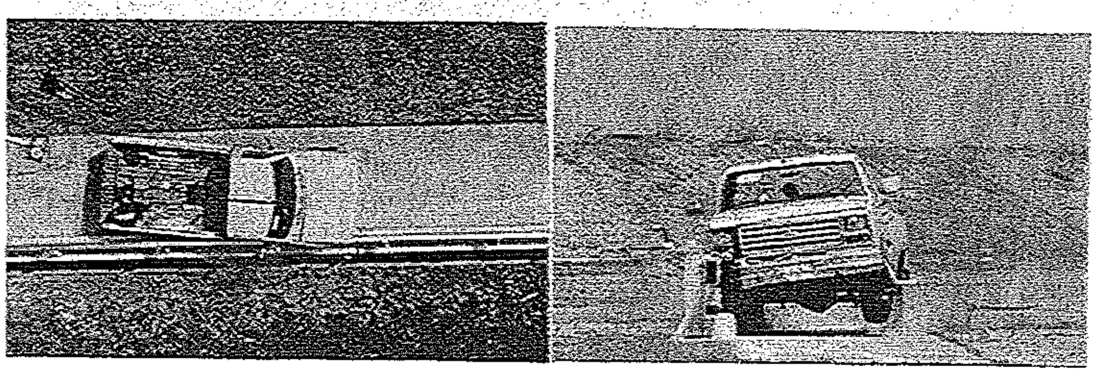
0.000 s



0.049 s

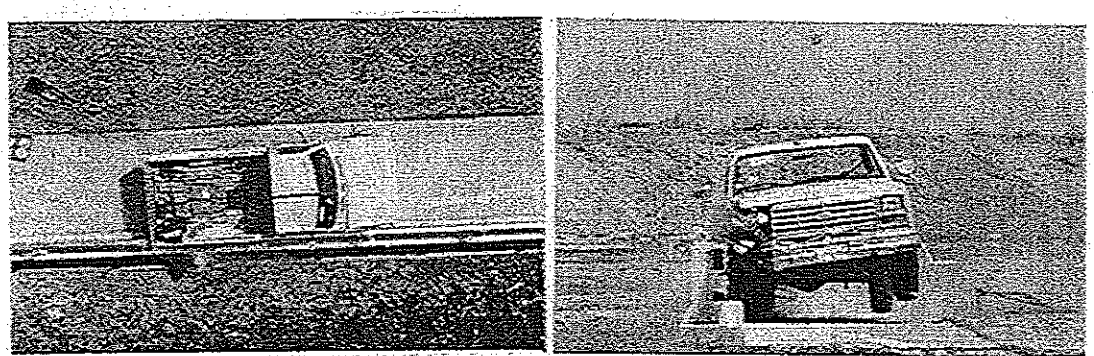


0.100 s

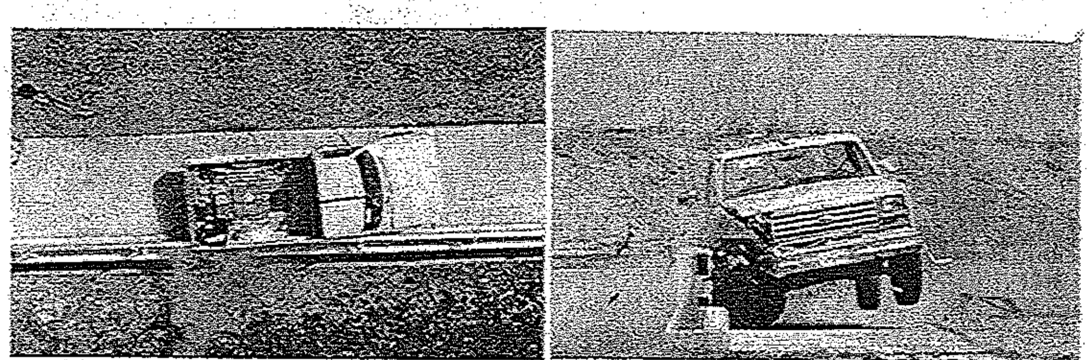


0.149 s

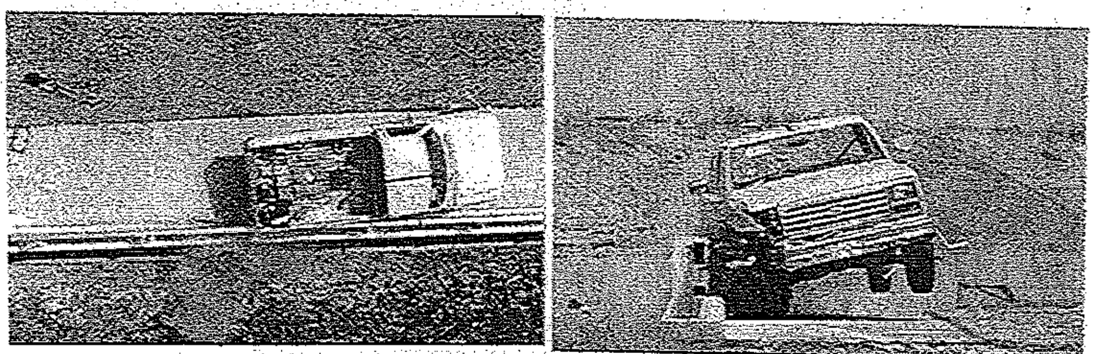
Figure 21. Sequential photographs for test 471470-19 (overhead and frontal views).



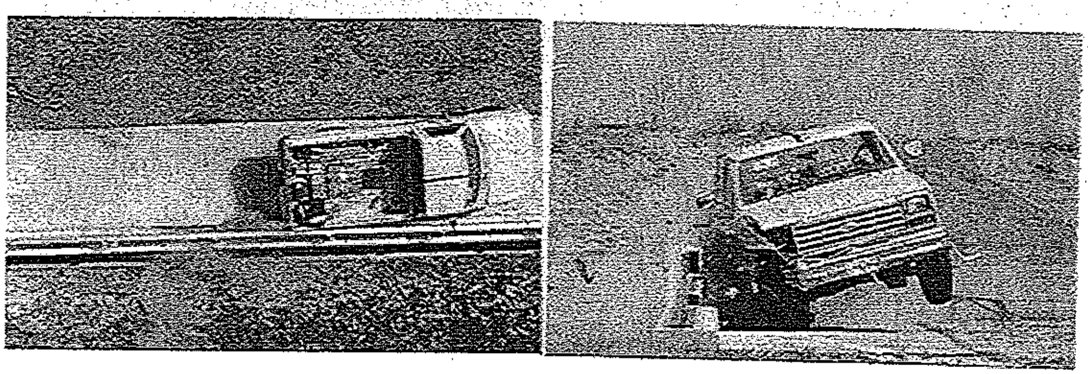
0.201 s



0.249 s

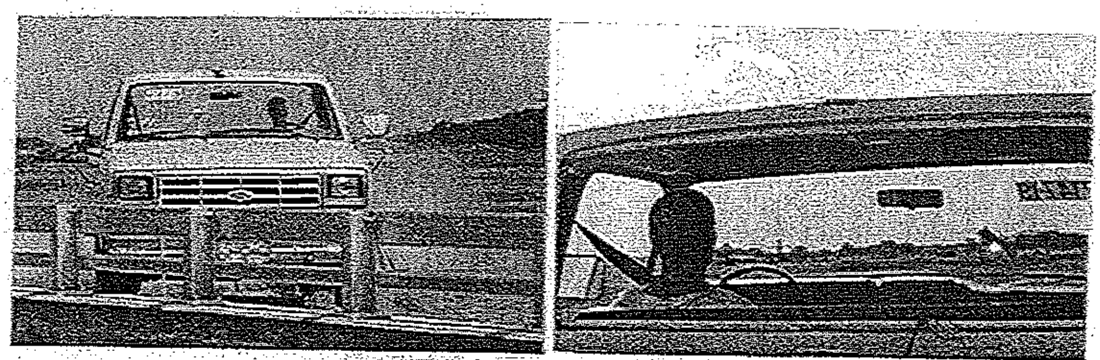


0.301 s



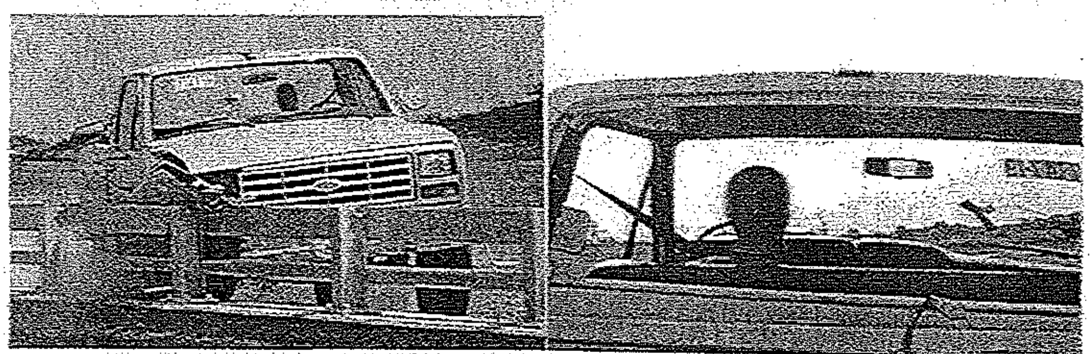
0.369 s

Figure 21. Sequential photographs for test 471470-19 (overhead and frontal views) (continued).



0.000 s

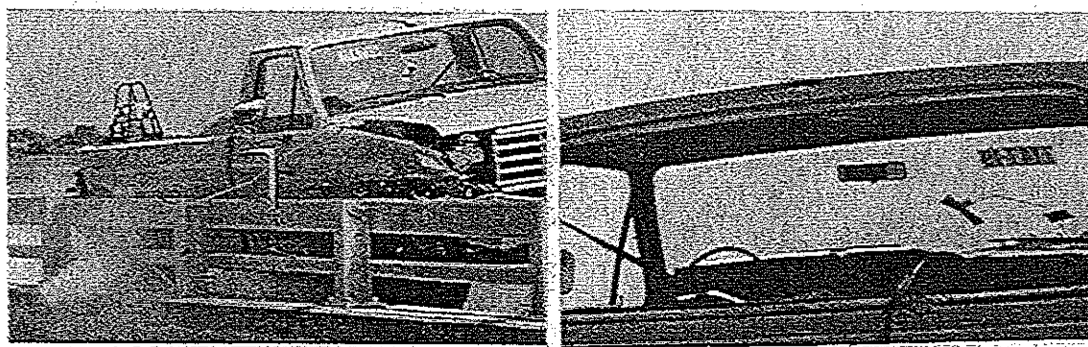
0.049 s



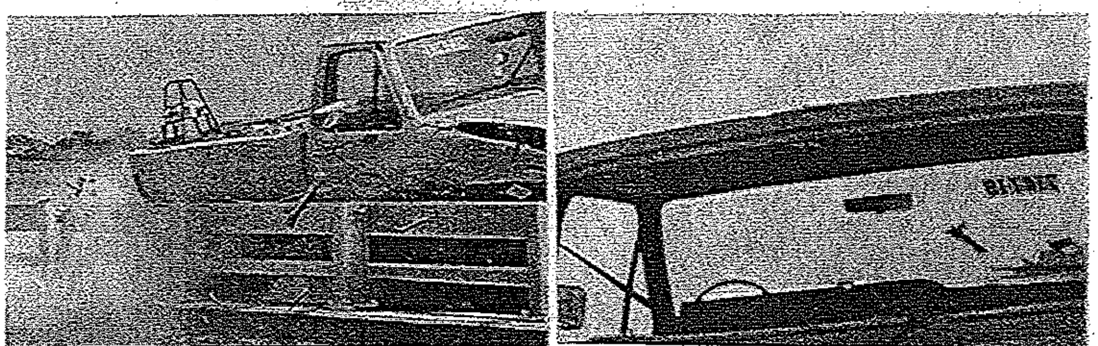
0.100 s

0.149 s

Figure 22. Sequential photographs for test 471470-19
(behind the rail and interior views).

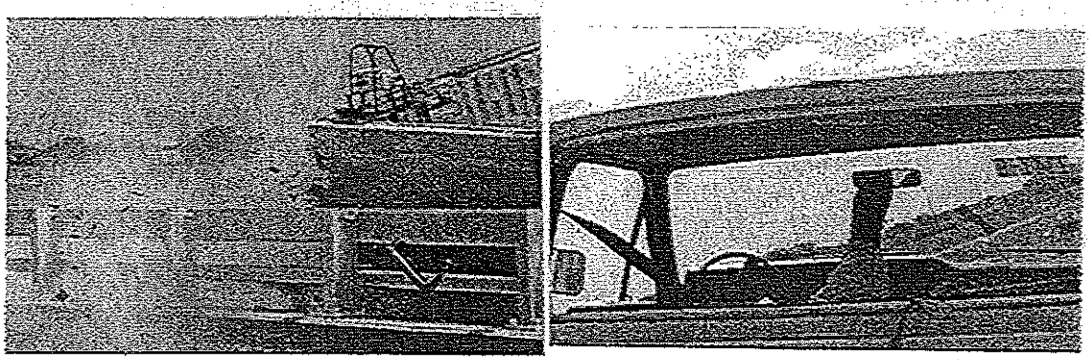


0.201 s



0.249 s

0.301 s



0.369 s

Figure 22. Sequential photographs for test 471470-19
(behind the rail and interior views) (continued).

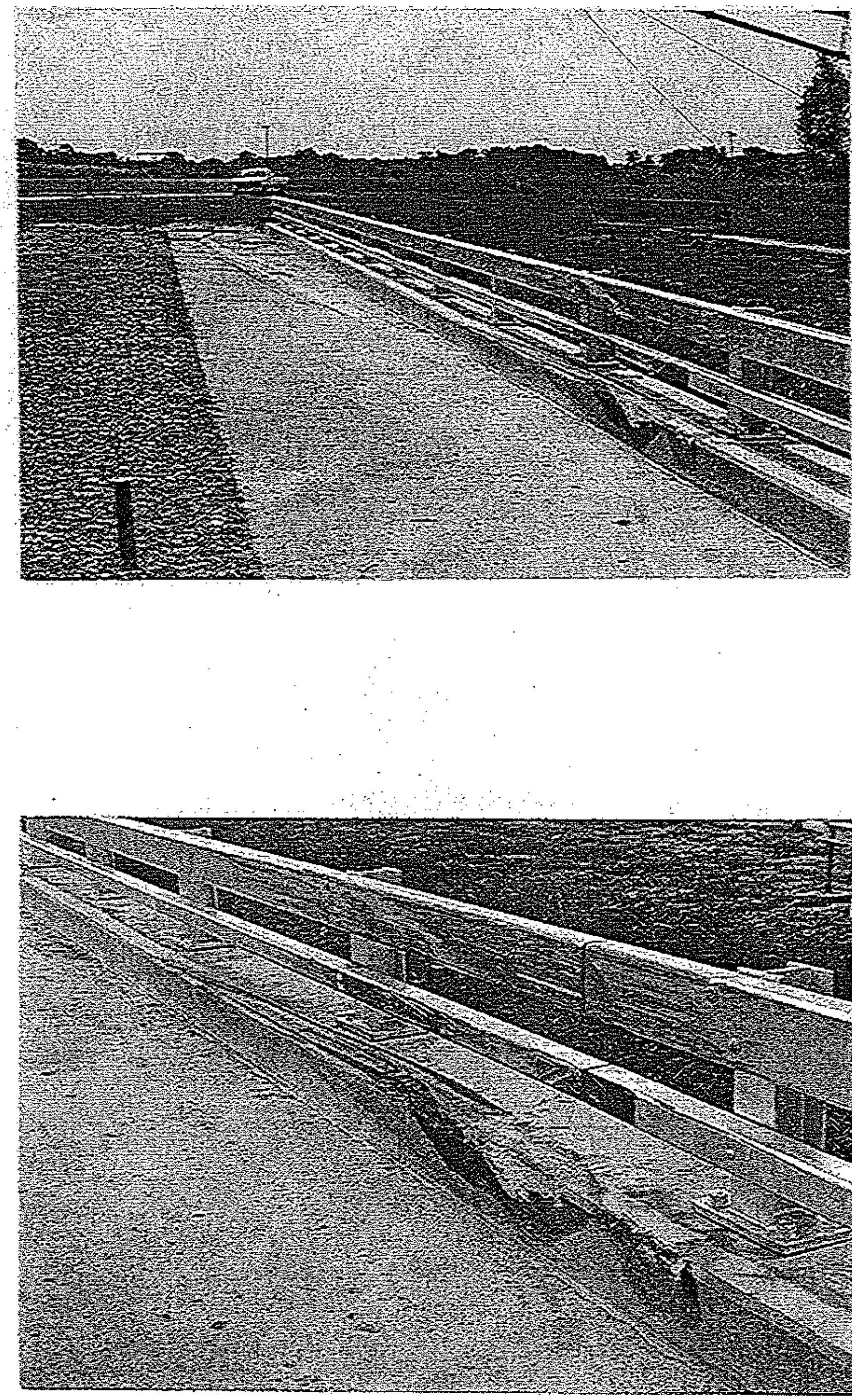


Figure 23. NETC bridge rail installation after test 471470-19.

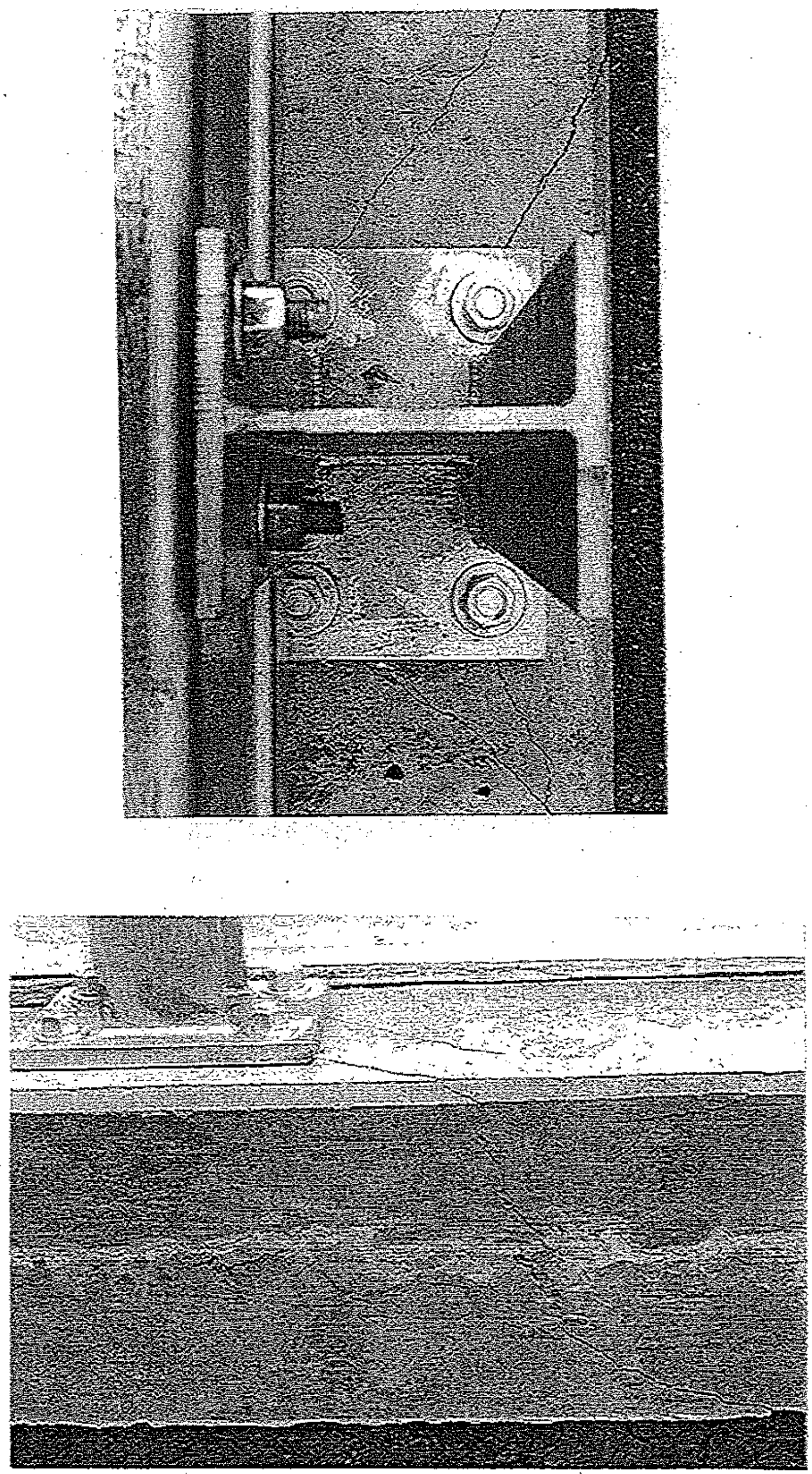


Figure 24. Cracks at post 4, test 471470-19.

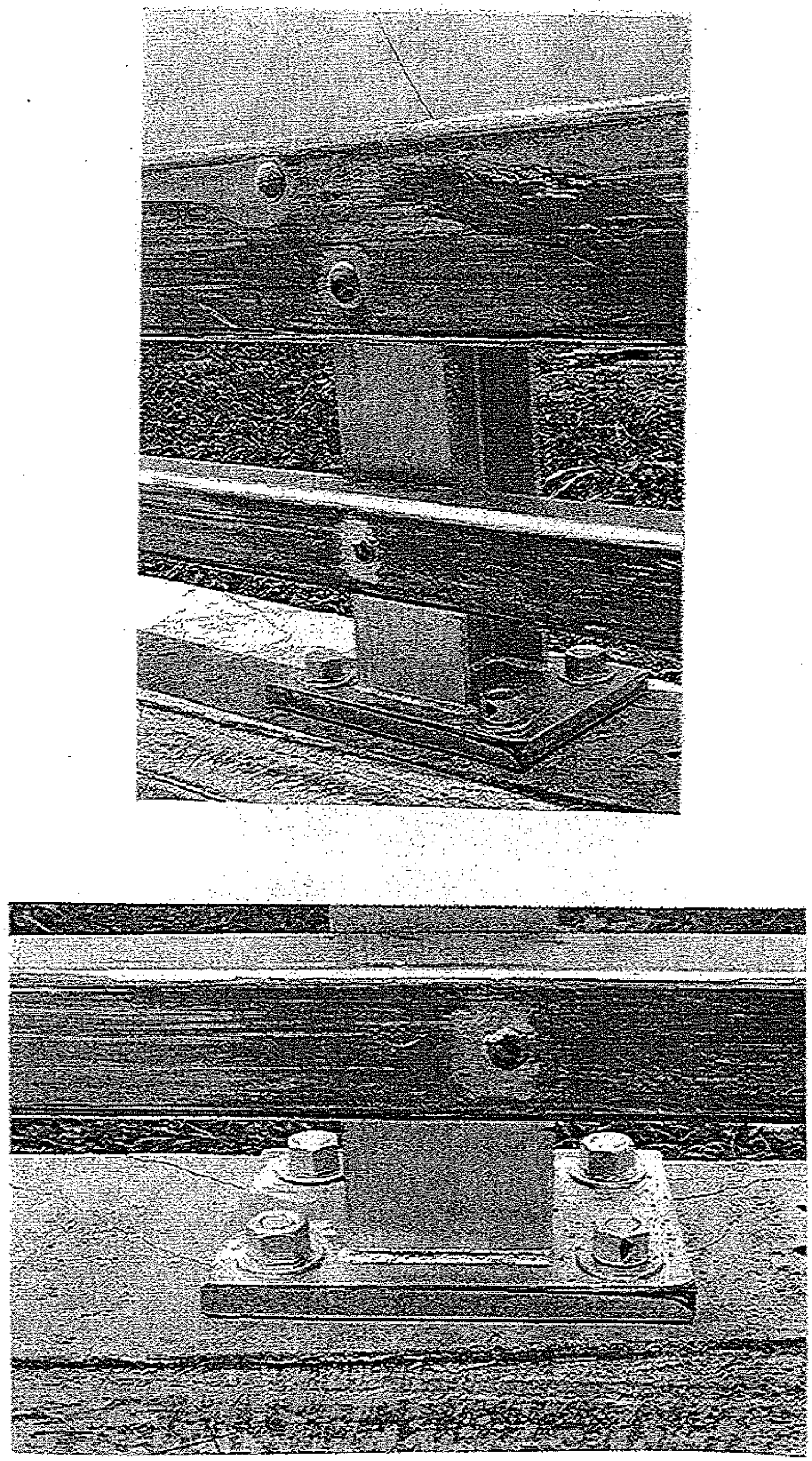
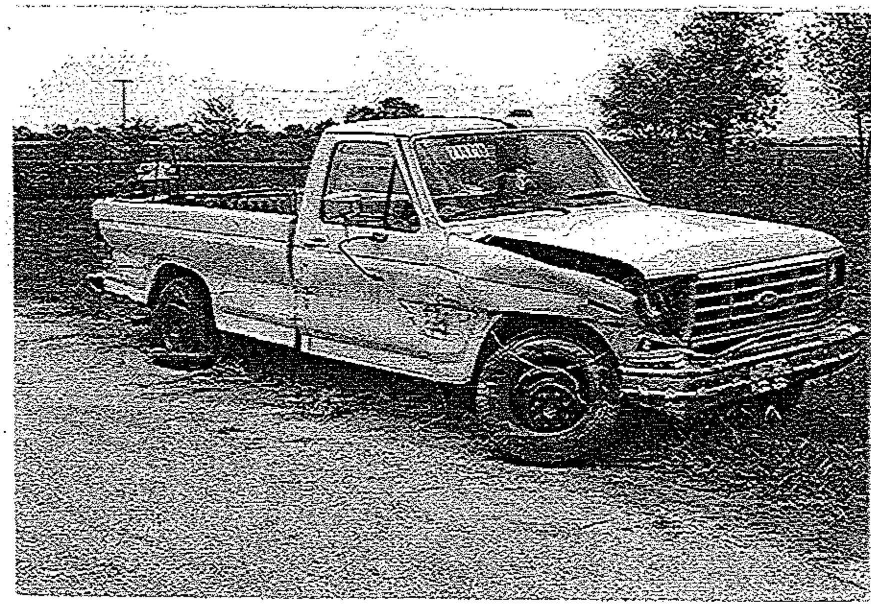


Figure 25. Damage to bridge rail at post 4, test 471470-19.



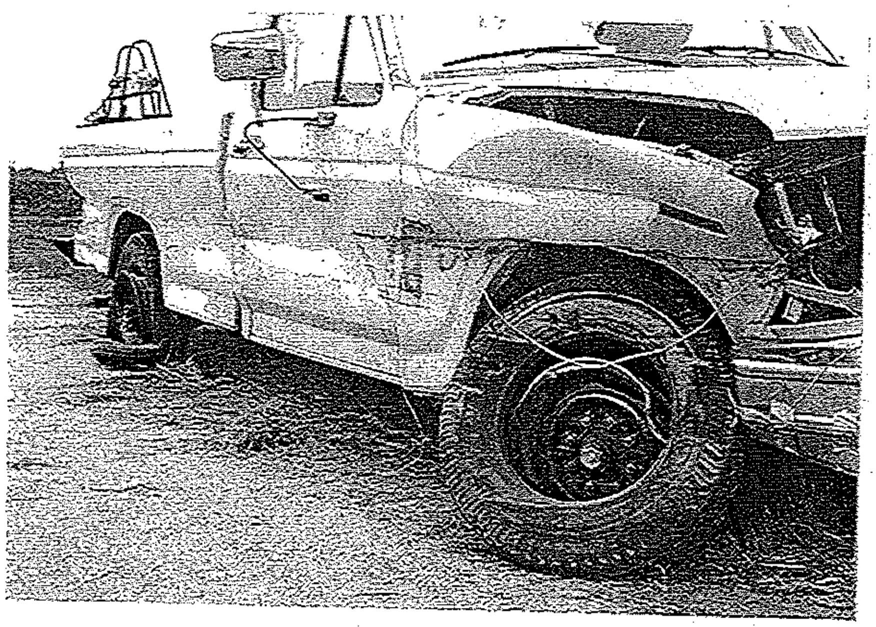


Figure 26. Vehicle after test for test 471470-19.

acceleration was -12.2 g's between 0.229 and 0.239 s; and the maximum 0.050-s average acceleration was -10.3 g's between 0.062 and 0.112 s. The change in vehicle velocity at loss of contact was 14.0 km/h (8.7 mi/h) and the change in momentum was 9540 N-s (2145 lb-s). These data and other pertinent information from the test are summarized in figure 27. Vehicular angular displacements are displayed in figure 28. Vehicular accelerations versus time traces filtered at SAE J211 (Class 180) are presented in figures 29 through 31.

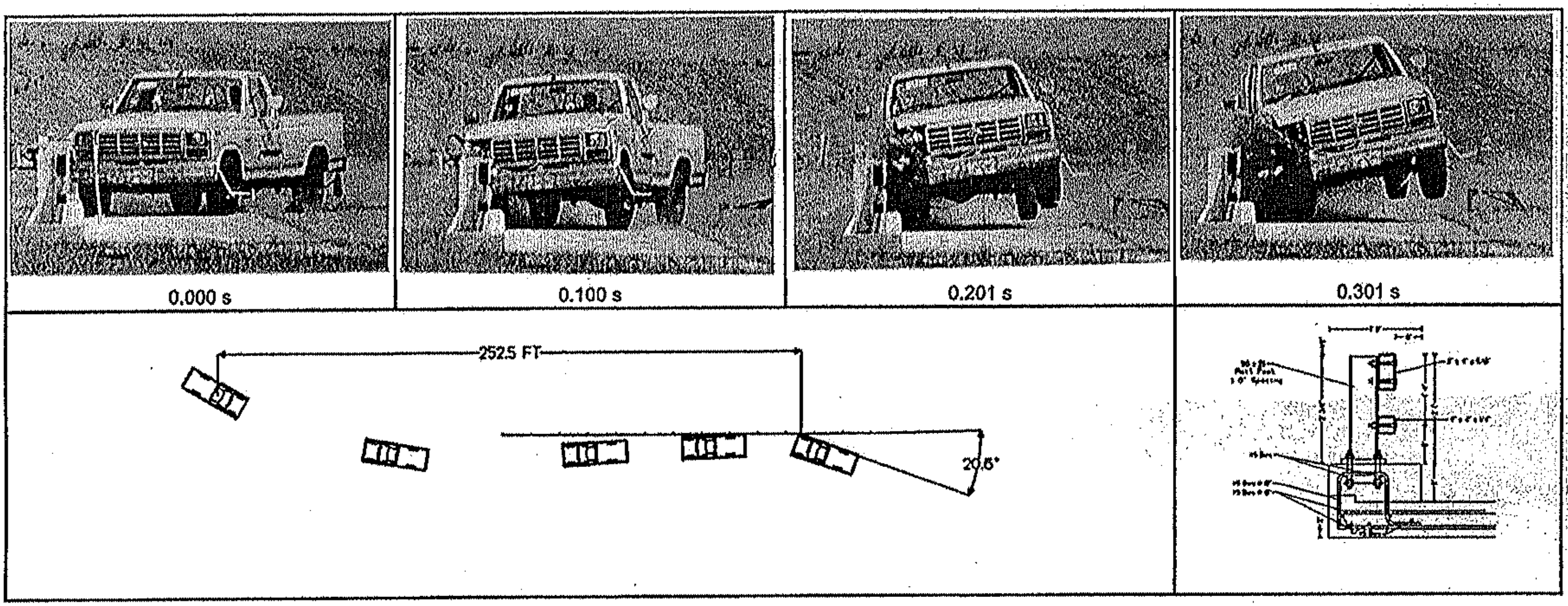
3.3 SINGLE-UNIT TRUCK REDIRECTION TEST (TEST NO. 471470-29)

As discussed previously, the curb section and bridge deck sustained structural damage at the two posts immediately upstream and downstream of the point of impact in the pickup truck redirection test (test no. 471470-19). This resulted in some revisions to the design details for the bridge deck, curb section, and the steel reinforcement. The revisions included: increasing the thickness of the bridge deck; widening the width of the curb and deck to increase the cover on the anchor bolts; additional stirrups and distribution bar at the post anchors; and increasing the thickness of the spacer plate and the length of the anchor bolts. The redesigned bridge deck and curb section was constructed and evaluated in this crash test.

A 1980 GMC 6000 single-unit truck (shown in figures 32 and 33) was used for the crash test. The empty weight of the vehicle was 5574 kg (12 278 lb) and the test inertia weight was 8000 kg (17 636 lb). The heights to the upper and lower edges of the vehicle bumper were 830 mm (32.7 in) and 484 mm (19.1 in), respectively. Additional dimensions and information on the vehicle are given in figure 34. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

3.3.1 Test Description

The target impact point was midspan between posts 4 and 5. However, the vehicle drifted to the right after release from the guidance system and the vehicle impacted the bridge rail 152 mm (6 in) downstream of post 4. The vehicle was traveling at a speed and angle of 81.7 km/h (50.8 mi/h) and 15.5 degrees at the point of impact. The right front corner of the vehicle bumper contacted the rail and the right front tire contacted the curb simultaneously at the time of impact. Redirection of the vehicle began at 0.034 s. Shortly after impact, the right front tire began to climb up the face of the curb, reaching the top at 0.041 s. The right front corner of the vehicle contacted the top of post 5 and the left front tire became airborne at 0.182 s. The right rear tire aired out at 0.233 s. The vehicle became parallel with the installation at 0.260 s, traveling at 76.4 km/h (47.5 mi/h). At 0.267 s, the rear of the vehicle contacted the bridge rail. By 0.291 s, the right front corner of the vehicle reached post 6; however, there was no direct contact with the post.



General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-19
Date	07/22/93
Test Article	
Type	Bridge Rail
	NETC Bridge Rail
Installation Length (m)	30.5 (100 ft)
Size and/or Dimension and Material of Key Elements	Tubular Steel Rail Elements on W6 X 25 Steel Posts @ 2.4 m on 241-mm Curb
Soil Type and Condition	Concrete Bridge Deck, Dry
Test Vehicle	
Type	Production Model
Designation	2000 P
Model	1984 Ford F250 Pickup
Mass (kg) Curb	1980 (4361 lb)
Test Inertial	2452 (5400 lb)
Dummy	76 (168 lb)
Gross Static	2528 (5568 lb)

Impact Conditions	
Speed (km/h)	92.2 (57.3 mi/h)
Angle (deg)	20.6
Exit Conditions	
Speed (km/h)	78.2 (48.6 mi/h)
Angle (deg)	2.2
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.7 (12.2 ft/s)
y-direction	6.6 (21.5 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-2.5
y-direction	-12.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x-direction	-3.4
y-direction	-10.3
z-direction	-2.4

Test Article Deflections (mm)	
Dynamic	Not Available
Permanent	6 (0.25 in)
Vehicle Damage	
Exterior	
VDS	01RFQ-3
CDC	01FREK2
	03RDES1
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	254 (10.0 in)
Max. Occ. Compart. Deformation (mm)	25 (1.0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	26
Max. Pitch Angle (deg)	-5
Max. Yaw Angle (deg)	-25

Figure 27. Summary of results for test 471470-19.

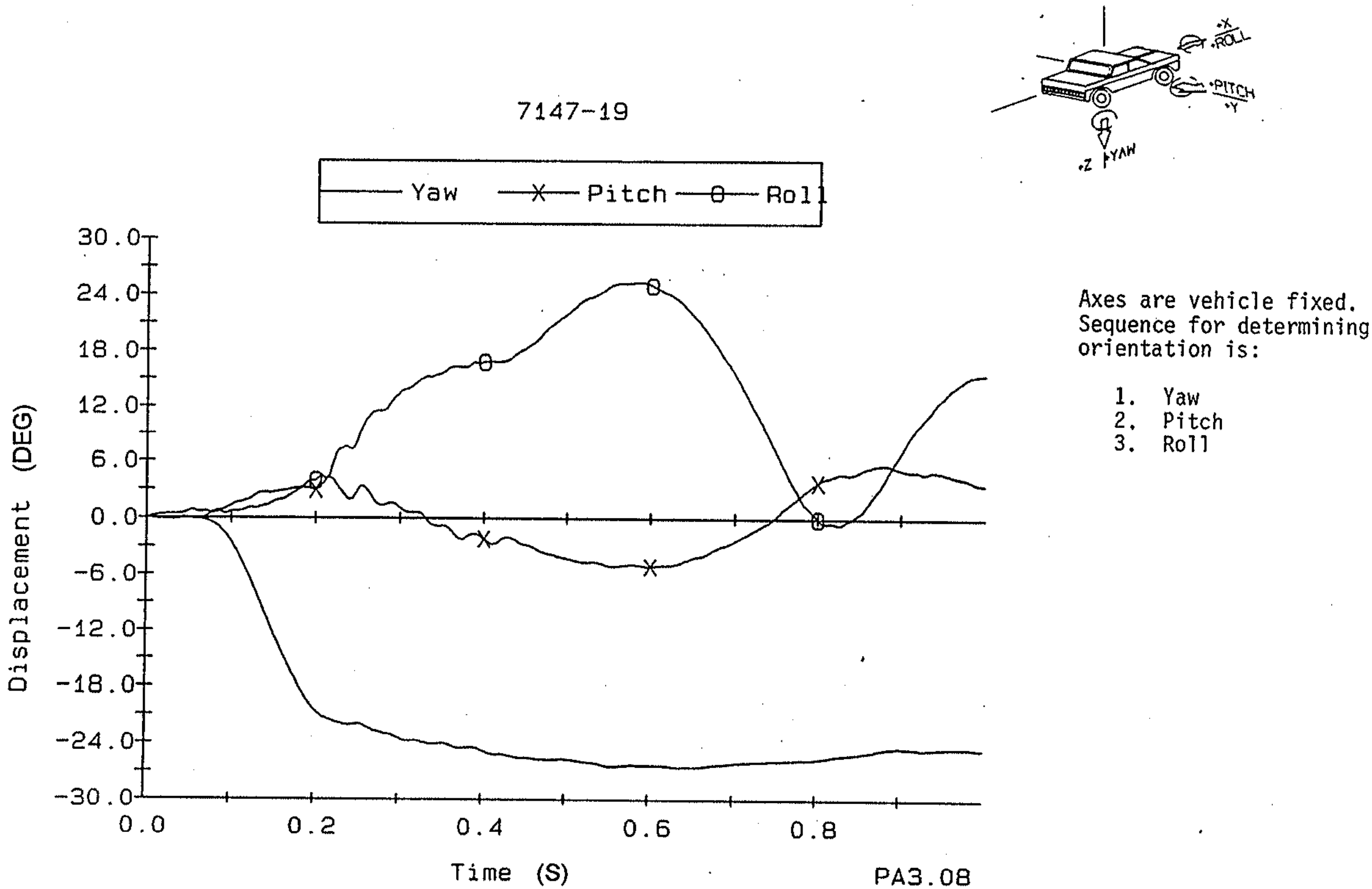


Figure 28. Vehicle angular displacements for test 471470-19.

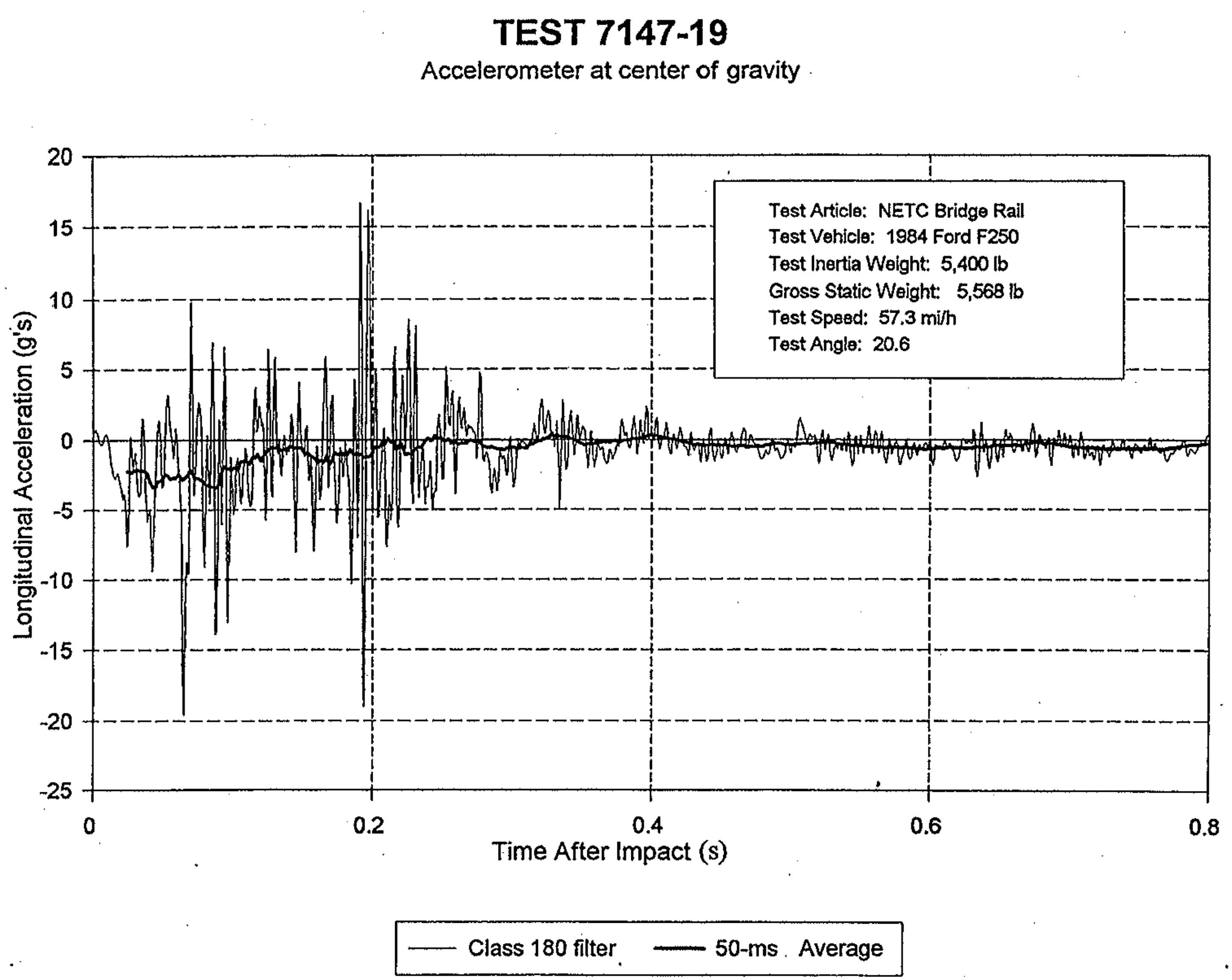


Figure 29. Longitudinal accelerometer trace for test 471470-19.

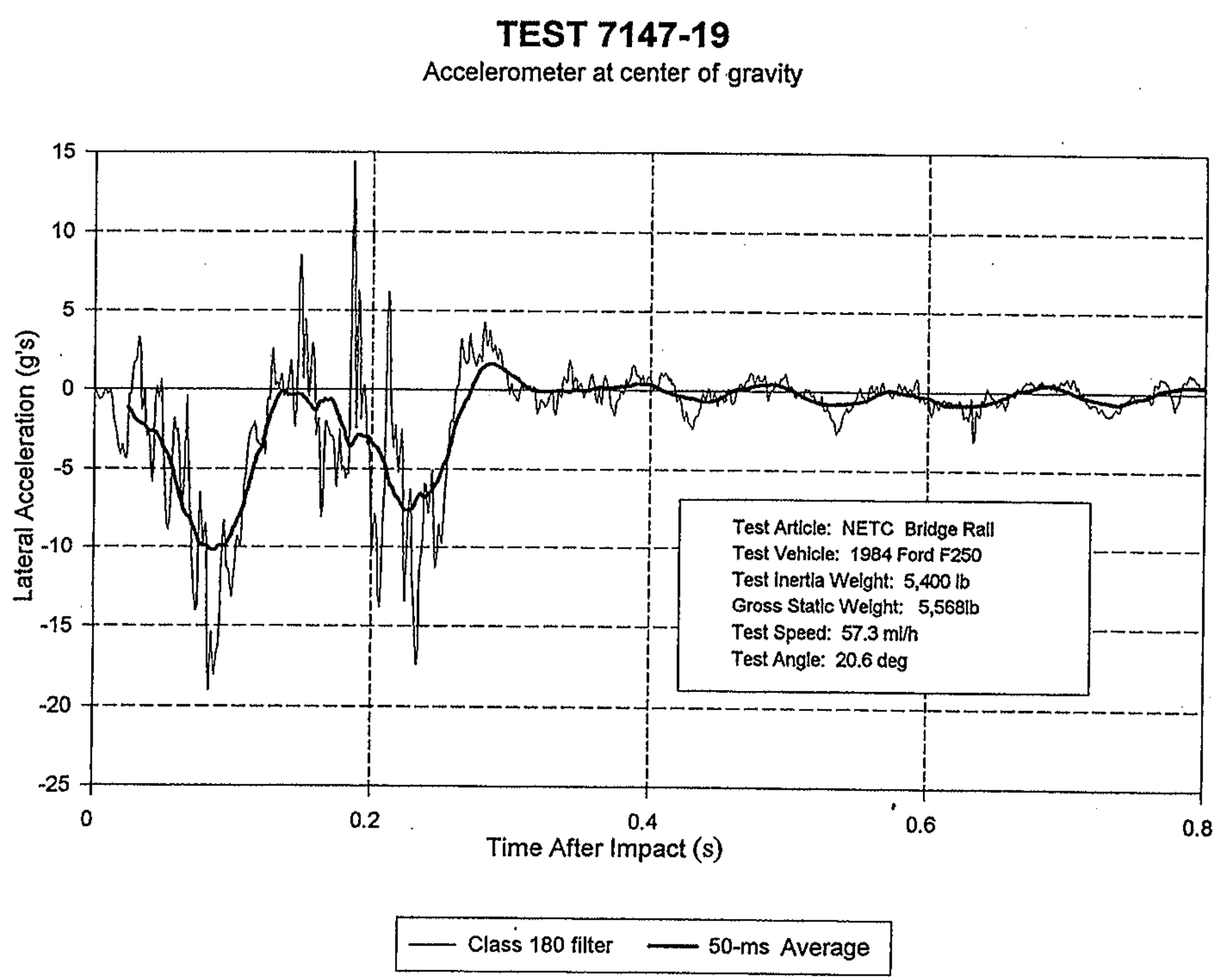


Figure 30. Lateral accelerometer trace for test 471470-19.

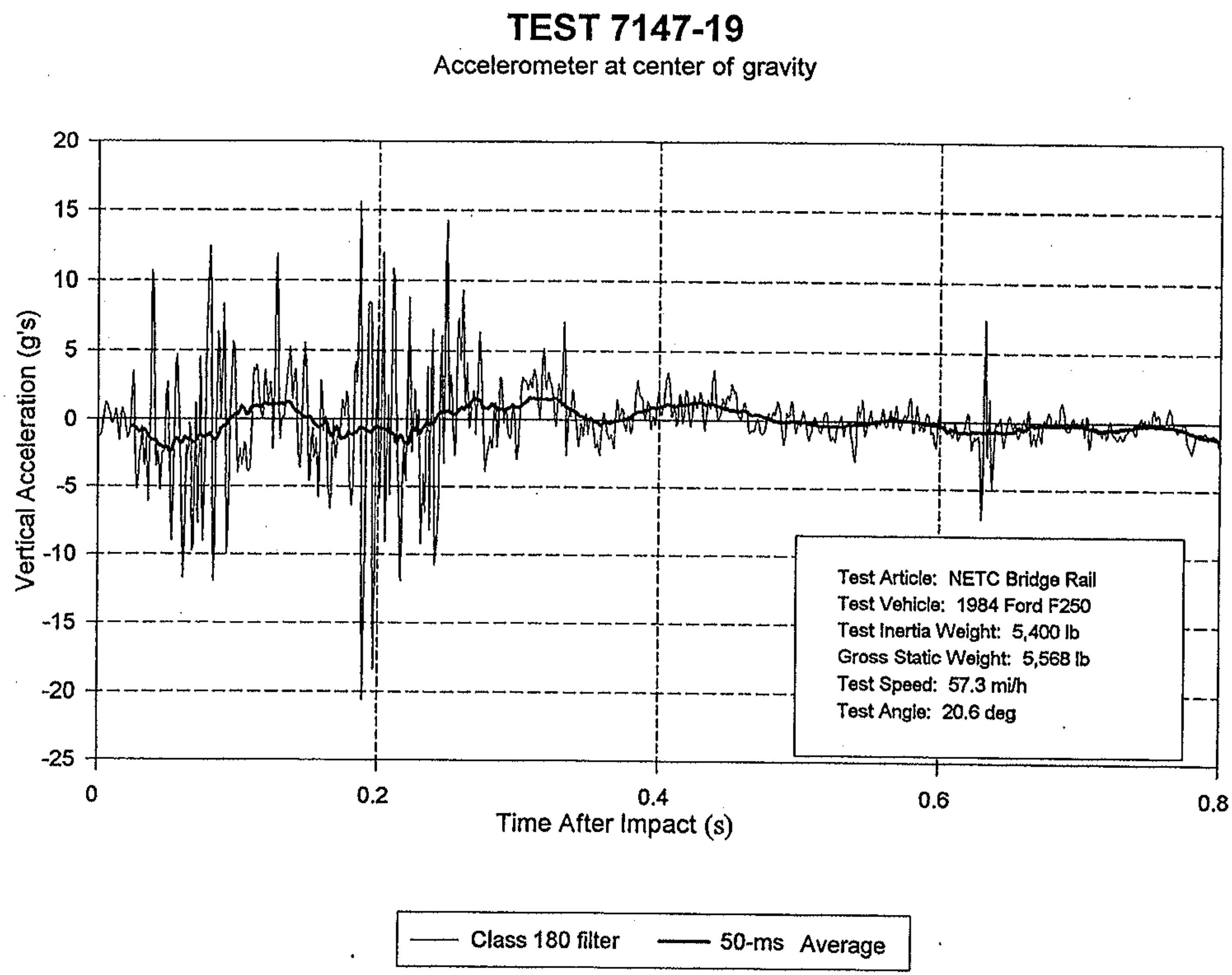


Figure 31. Vertical accelerometer trace for test 471470-19.

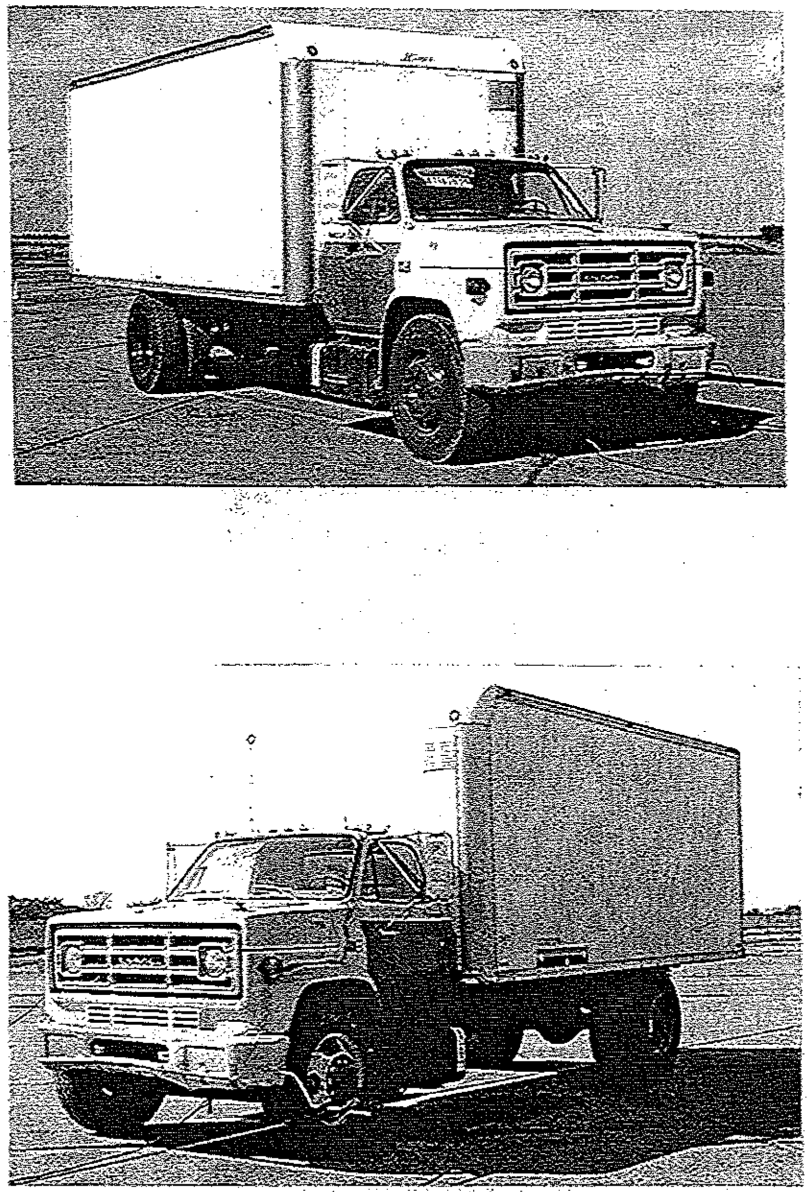


Figure 32. Vehicle before test 471470-29.

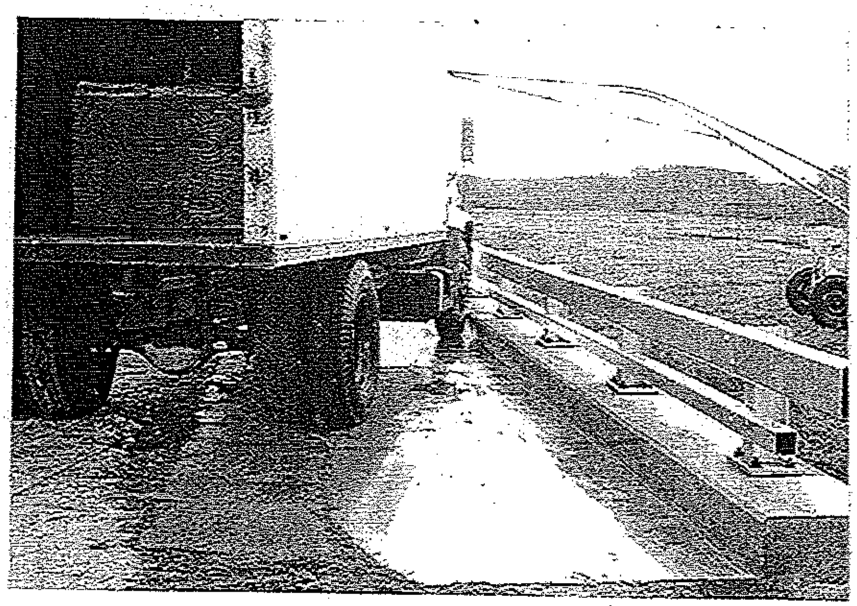


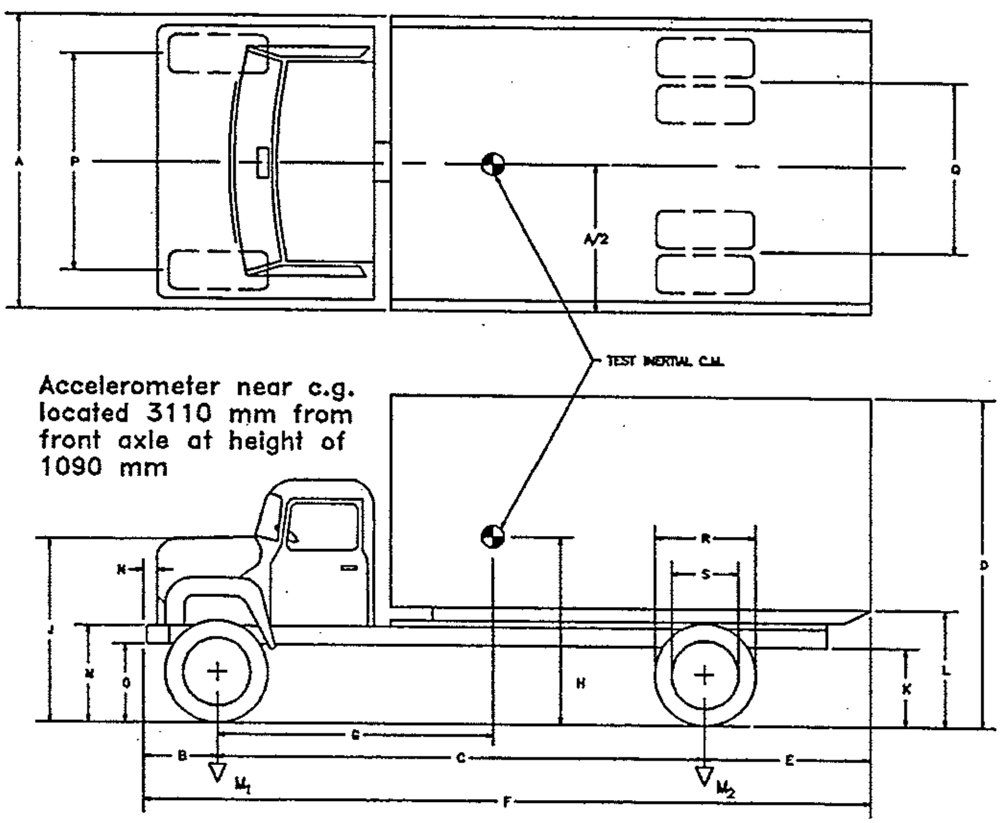
Figure 33. Vehicle/bridge railing geometrics for test 471470-29.

DATE: 12-08-94 TEST NO.: 471470-29 VIN NO.: T16DBAV562710 MAKE: GMC
MODEL: 6000 YEAR: 1980 ODOMETER: 35117 TIRE SIZE: 11R22.5

MASS DISTRIBUTION (kg) LF 1596 RF 1555 LR 2454 RR 2395

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Bumper bent in middle



GEOMETRY-(mm)

A 2270	D 33464	G 3141	K 780	N 70	Q 1790
B 787	E 2180	H 1240	L 1230	O 484	R 1060
C 5182	F 8149	J 1580	M 830	P 1935	S 595

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	2549	3151	
M_2	3025	4849	
M_T	5574	8000	

Figure 34. Vehicle properties for test 471470-29.

The right front corner of the box contacted the top of the upper rail element at 0.468 s. By 0.496 s, the cab of the vehicle reached a maximum clockwise roll of 26 degrees and began to roll counterclockwise while the box was still rotating clockwise. The box became partially separated from the frame of the vehicle and the box rode along the top of the rail. The vehicle rode off the end of the rail at an exit angle of approximately 2.0 degrees toward the bridge rail. The vehicle brakes were applied as the vehicle exited the test area, and subsequently came to rest 55 m (180 ft) downstream from the point of impact and parallel with the installation. Sequential photographs are shown in figures 35 and 36.

3.3.2 Damage to Test Installation

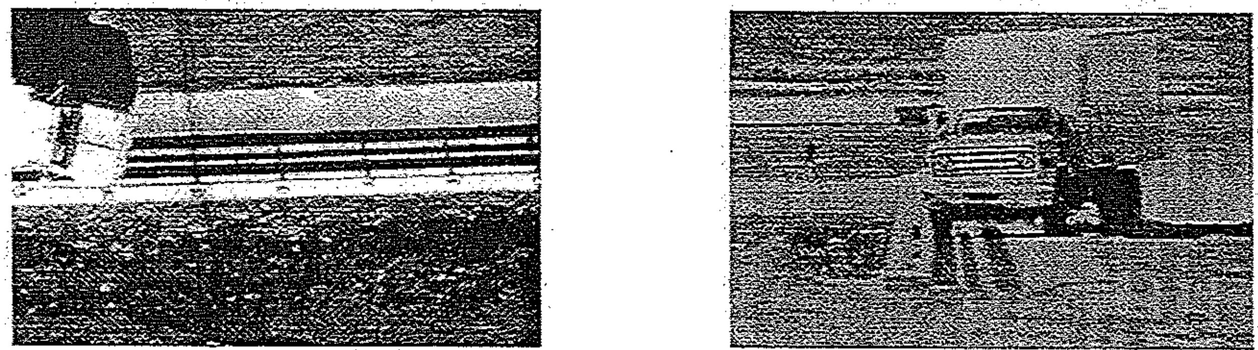
As seen in figures 37 through 39, the bridge rail and deck test installation received moderate damage. There were tire marks and gouges on the face of the rail and curb. The length of contact with the curb was 5.5 m (18.0 ft), and length of the initial contact with the rail element was 4.3 m (14.0 ft). The box of the truck was in contact with the upper part of the rail from post 8 to the end of the test installation with tire marks on the face of the rail between posts 8 and 10. The bolts on the lower rail at posts 3, 4, and 5 were sheared off.

3.3.3 Vehicle Damage

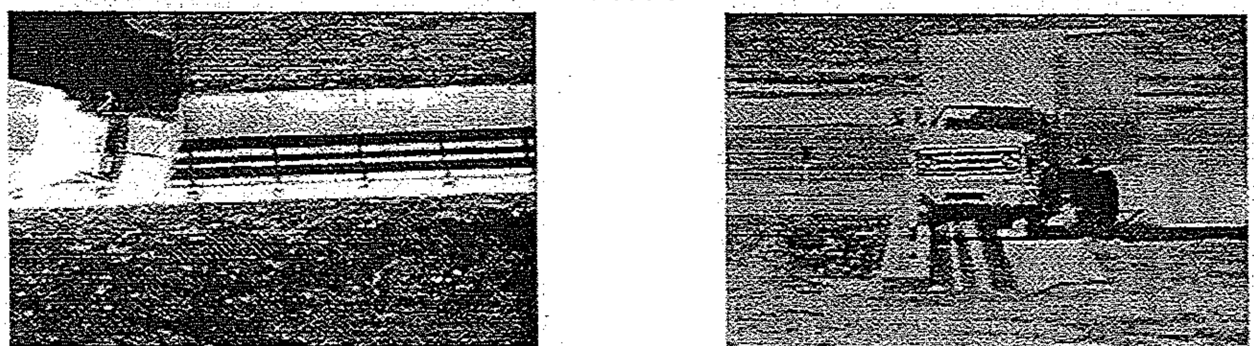
The vehicle sustained minimal damage, as shown in figures 40 and 41. Maximum exterior crush at the right front corner of the vehicle was 120 mm (4.7 in) and there was no deformation or intrusion into the occupant compartment. The right-side spring U-bolts were damaged and the right front tire and wheel were pushed rearward into the fuel tank. The box was partially separated from the frame and shifted to the right. The bumper, hood, right front quarter panel, and right door were also damaged.

3.3.4 Occupant Risk Values

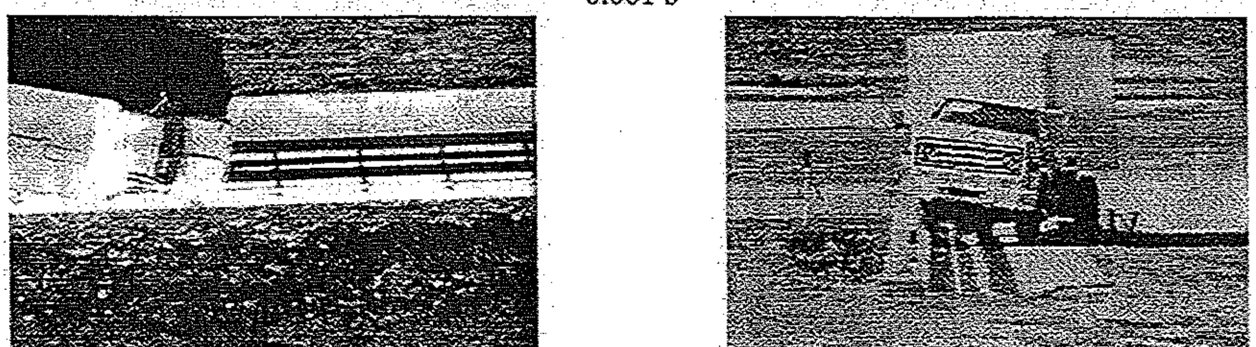
Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. Occupant contact first occurred in the lateral direction. Lateral occupant impact velocity was 3.6 m/s (12.0 ft/s) at 0.201 s; the highest 0.010-s lateral occupant ridedown acceleration was -3.2 g's between 0.219 and 0.229 s; and the maximum 0.050-s average acceleration was -2.6 g's between 0.136 and 0.186 s. In the longitudinal direction, the occupant impact velocity was 2.3 m/s (7.5 ft/s); the highest 0.010-s occupant ridedown acceleration was -4.0 g's between 0.831 and 0.841 s; and the maximum 0.050-s average was -1.8 g's between 0.809 and 0.859 s. These data and other information pertinent to the test are summarized in figure 42. Vehicle angular displacements during the test are displayed in figure 43. Vehicular accelerations versus time traces filtered at 60 Hz are presented in figures 44 through 50.



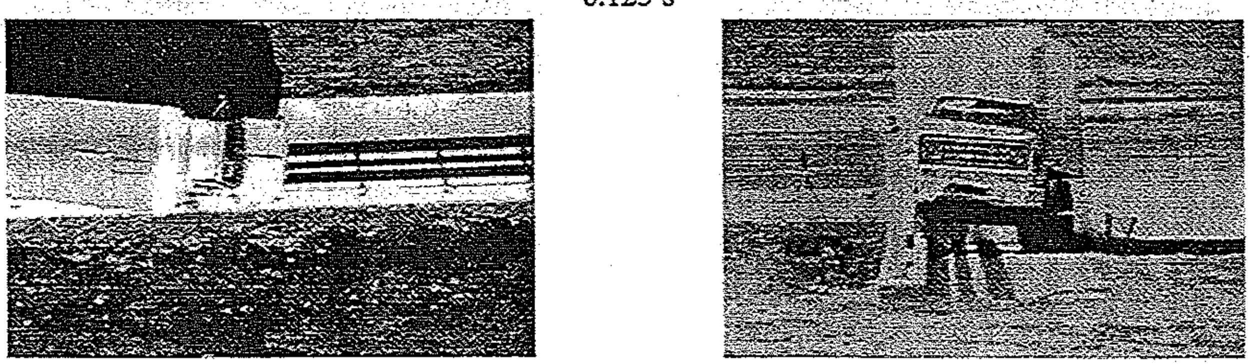
0.000 s



0.061 s

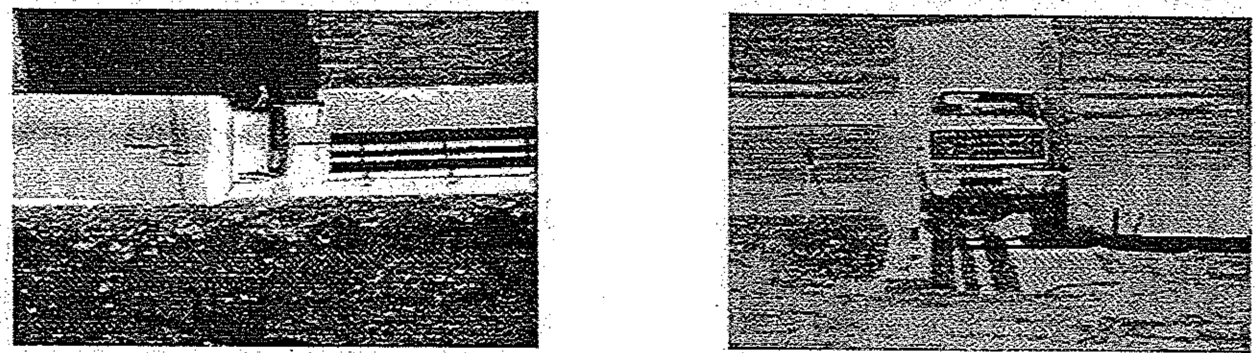


0.125 s



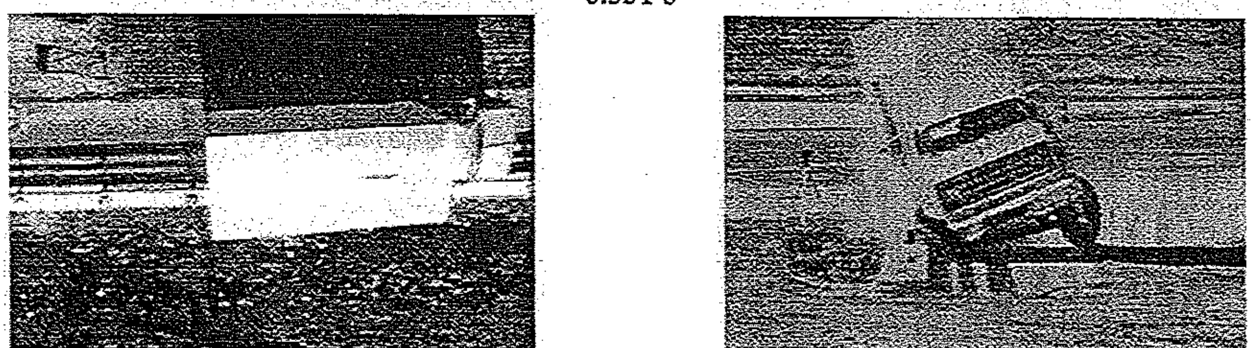
0.201 s

Figure 35. Sequential photographs for test 471470-29
(overhead and frontal views).

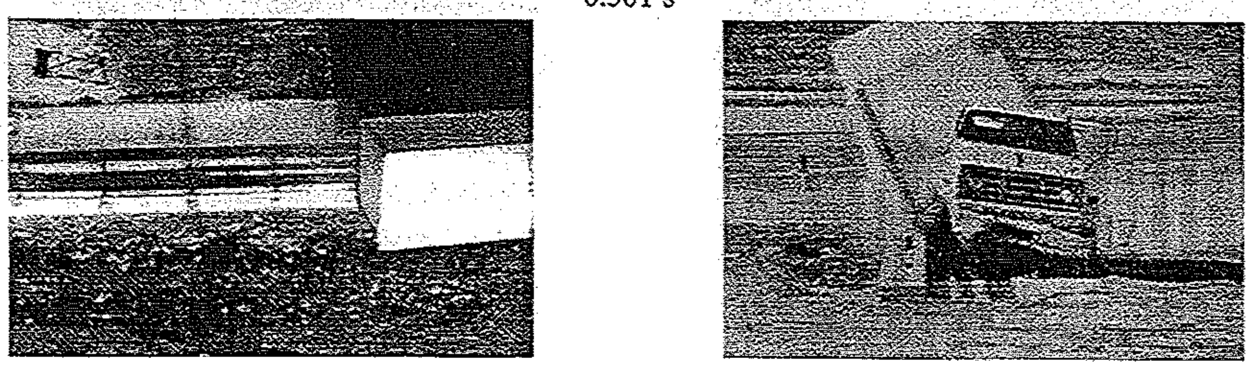


0.250 s

0.351 s

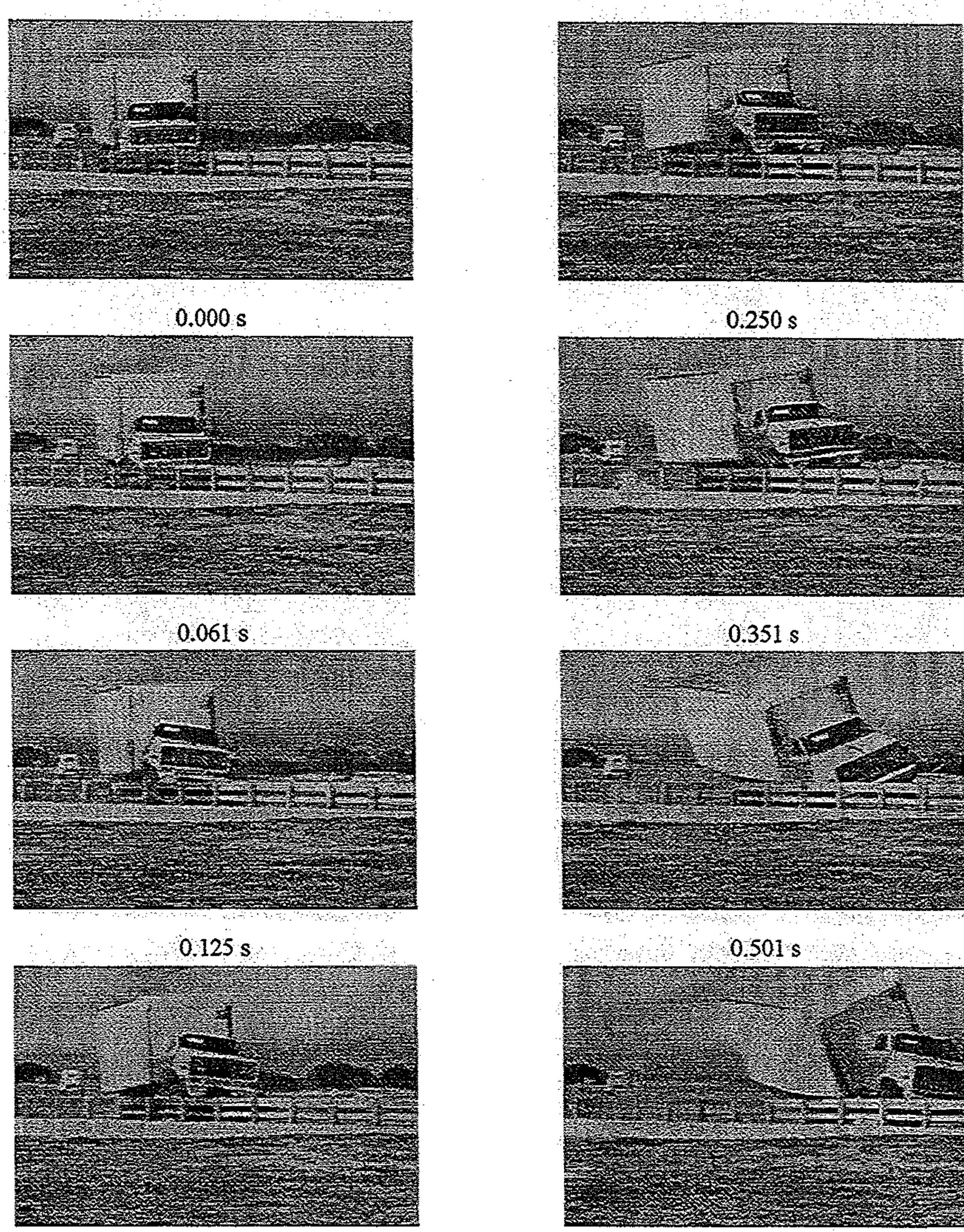


0.501 s



0.699 s

Figure 35. Sequential photographs for test 471470-29 (overhead and frontal views) (continued).



0.000 s

0.061 s

0.125 s

0.201 s

0.250 s

0.351 s

0.501 s

0.699 s

Figure 36. Sequential photographs for test 471470-29 (rear view).

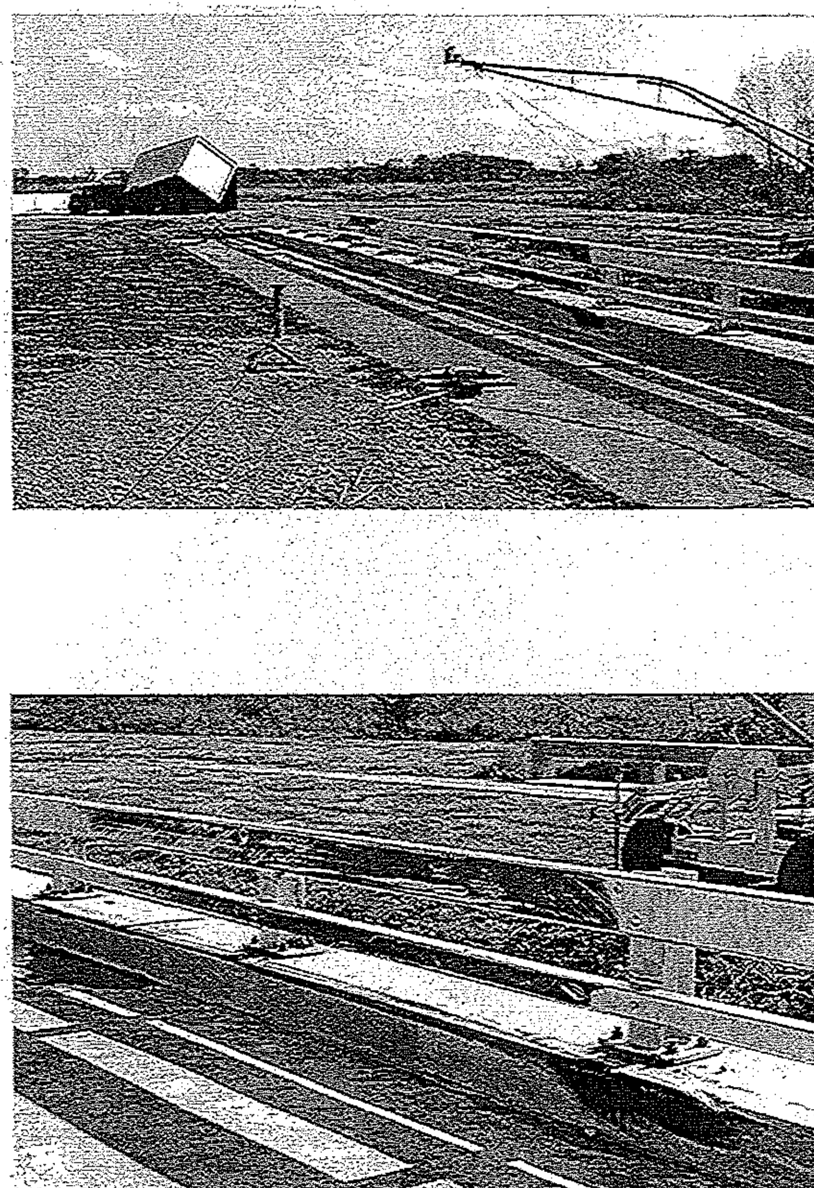


Figure 37. NETC bridge railing after test 471470-29.

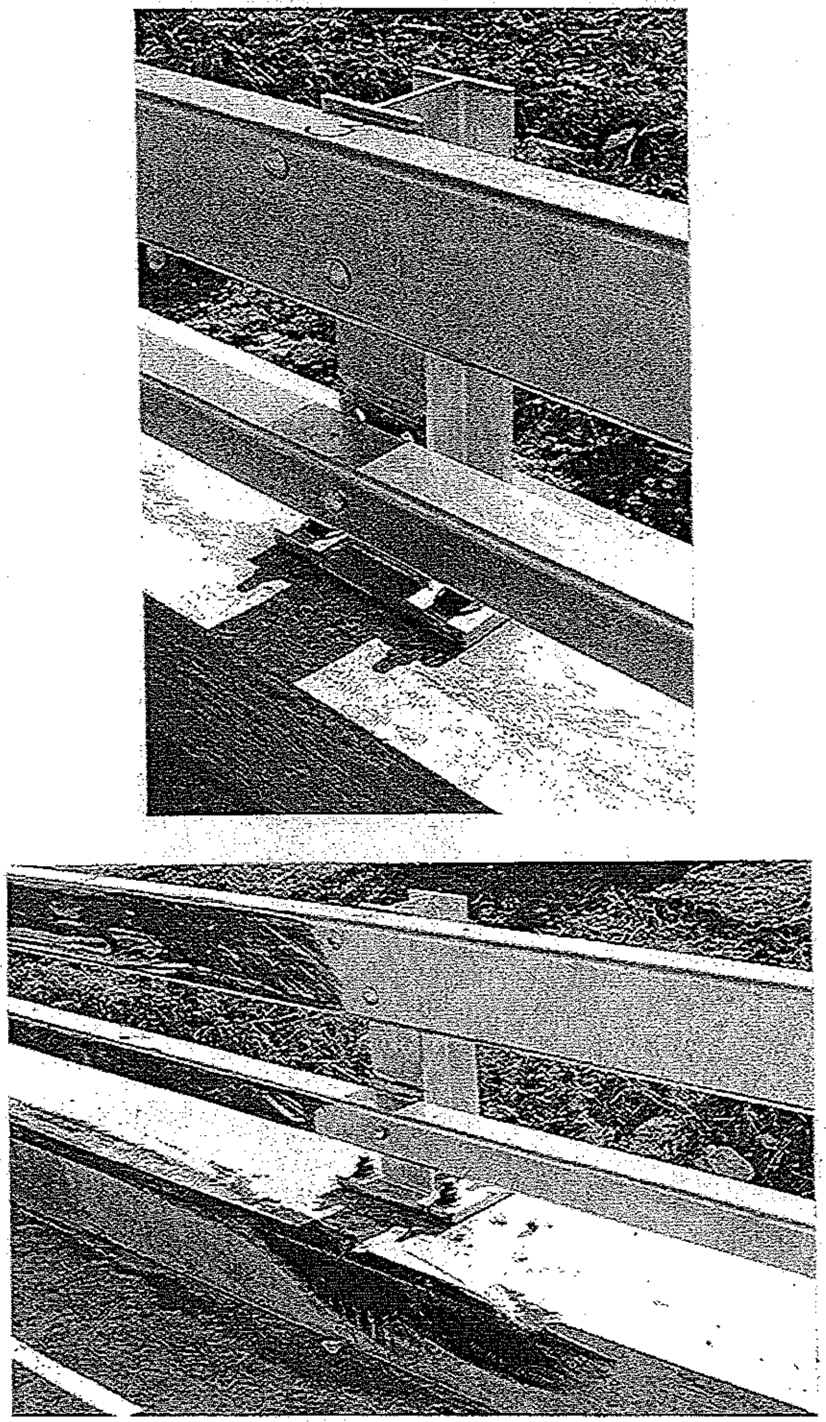


Figure 38. Damage at posts 3 and 4 after test 471470-29.

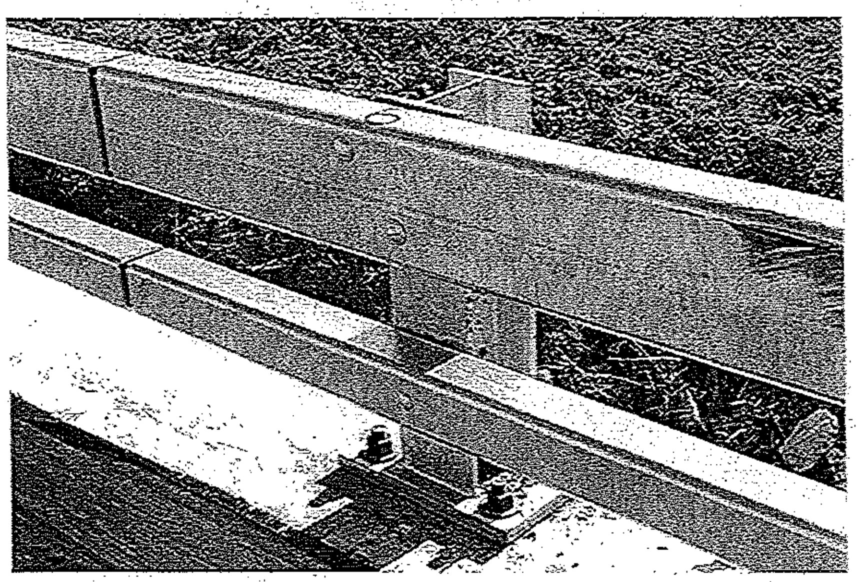


Figure 39. Damage at posts 5 and 6 after test 471470-29.

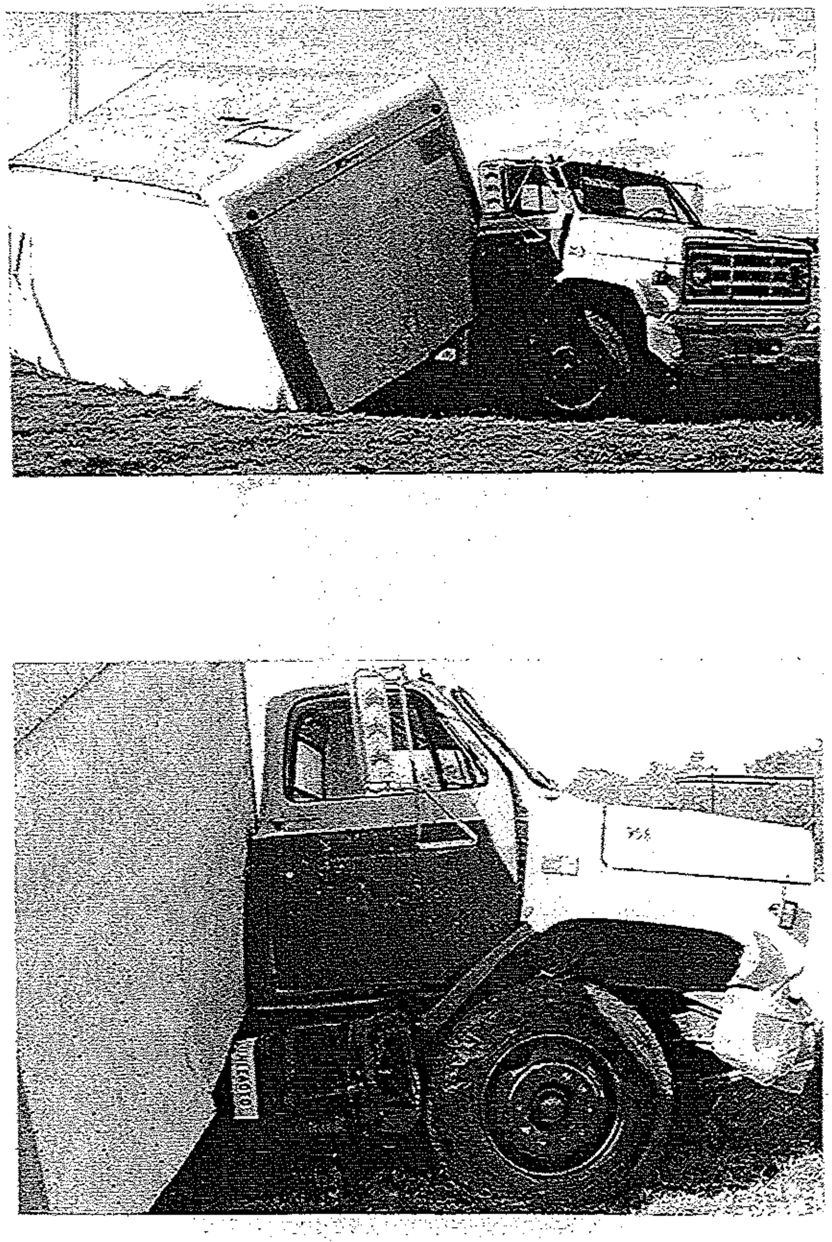


Figure 40. Vehicle after test 471470-29.

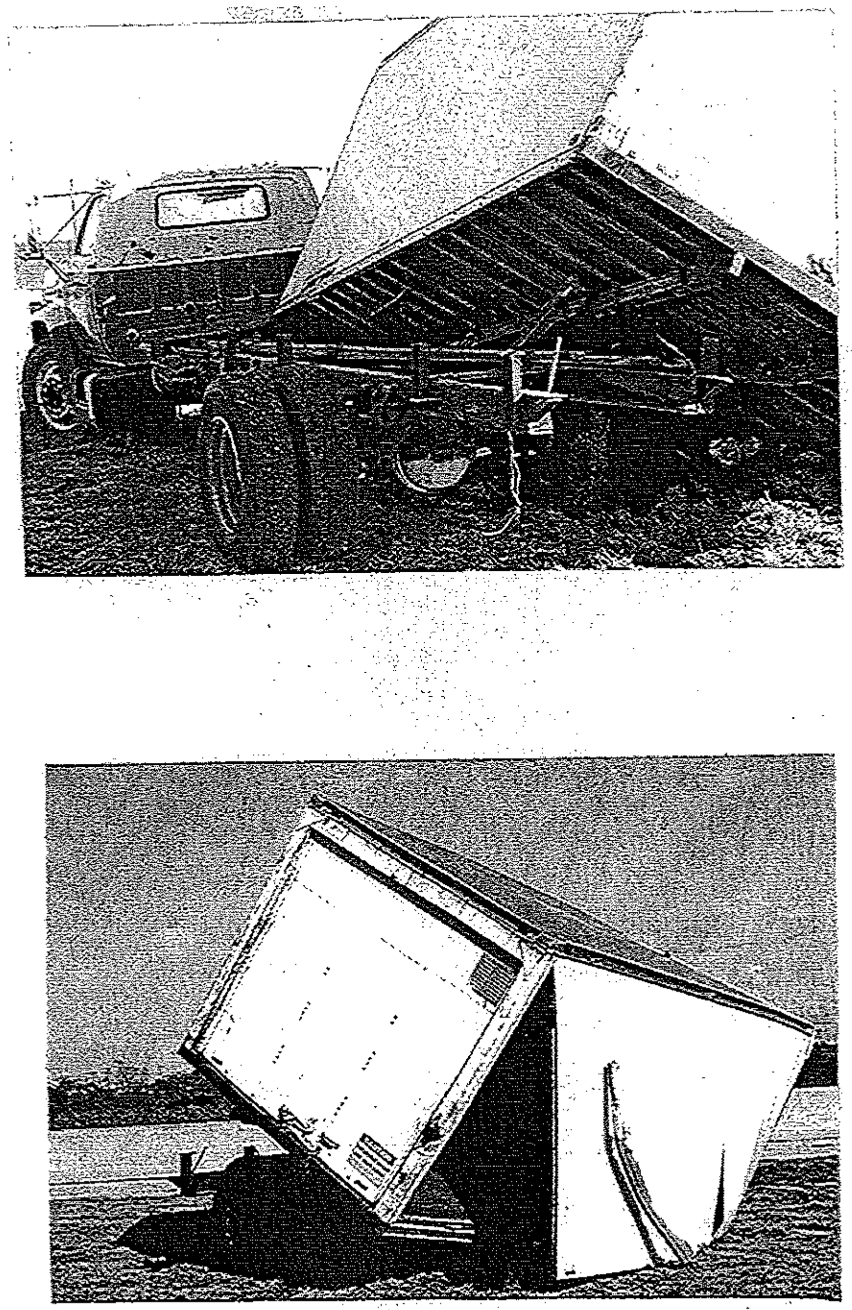
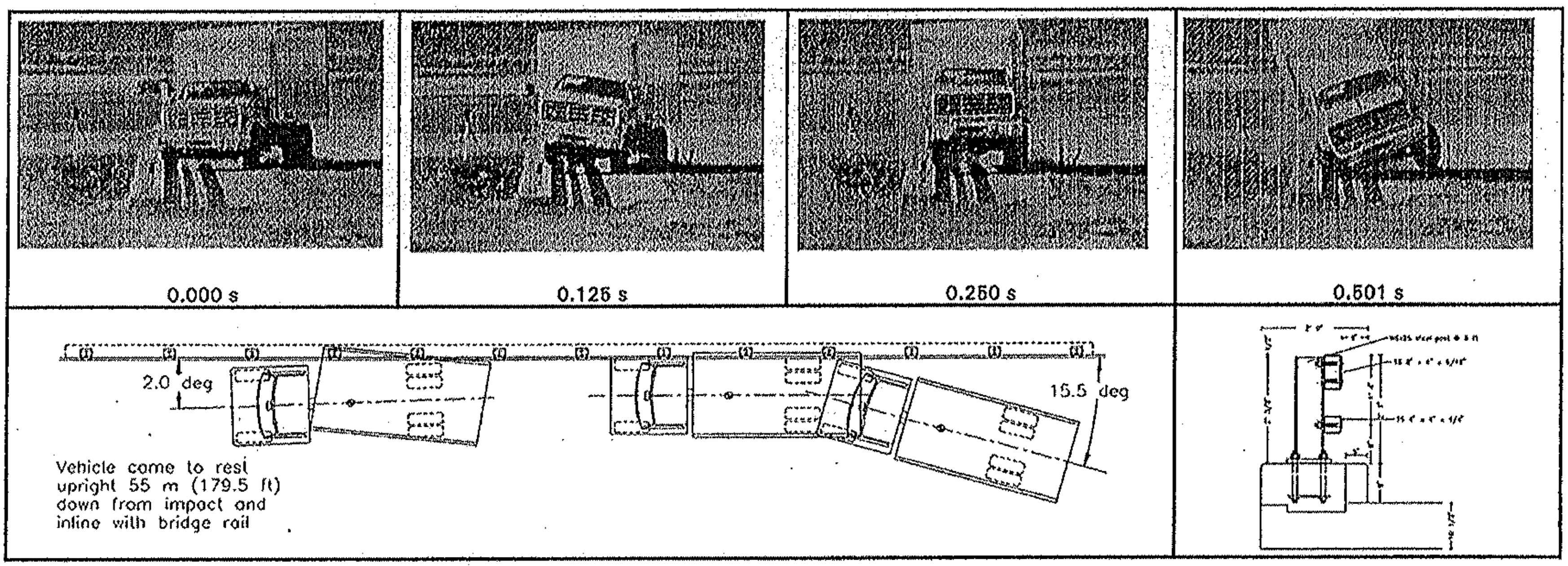


Figure 41. Damage to van-box after test 471470-29.



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-29
Date	12/08/94
Test Article	
Type	Bridge Rail
Name or Manufacturer	NETC Bridge Rail
Installation Length (m)	30.5 m (100 ft)
Size and/or Dimension and Material of Key Elements	Tubular Steel Rail Elements on W6x25 Steel Post @ 2.4 m on 241 mm curb
Soil Type and Condition	Concrete Bridge Deck, Dry
Test Vehicle	
Type	Single-Unit Truck
Designation	8000S
Model	1980 GMC 6000
Mass (kg) Curb	5574 (12 278 lb)
Test Inertial	8000 (17 621 lb)
Dummy	N/A
Gross Static	8000 (17 621 lb)

Impact Conditions	
Speed (km/h)	81.7 (50.8 mi/h)
Angle (deg)	15.5
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	2.0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.3 (7.5 ft/s)
y-direction	3.6 (12.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.0
y-direction	-3.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-1.8
y-direction	-2.6
z-direction	3.5

Test Article Deflections (m)	
Dynamic	nil
Permanent	nil
Vehicle Damage	
Exterior	
VDS	01RFQ2
CDC	01FRLK1 & 01RFEW2
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	120 (4.7 in)
Max. Occ. Compart. Deformation (mm)	0 (0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	19
Max. Pitch Angle (deg)	-8
Max. Yaw Angle (deg)	-16

Figure 42. Summary of results for test 471470-29.

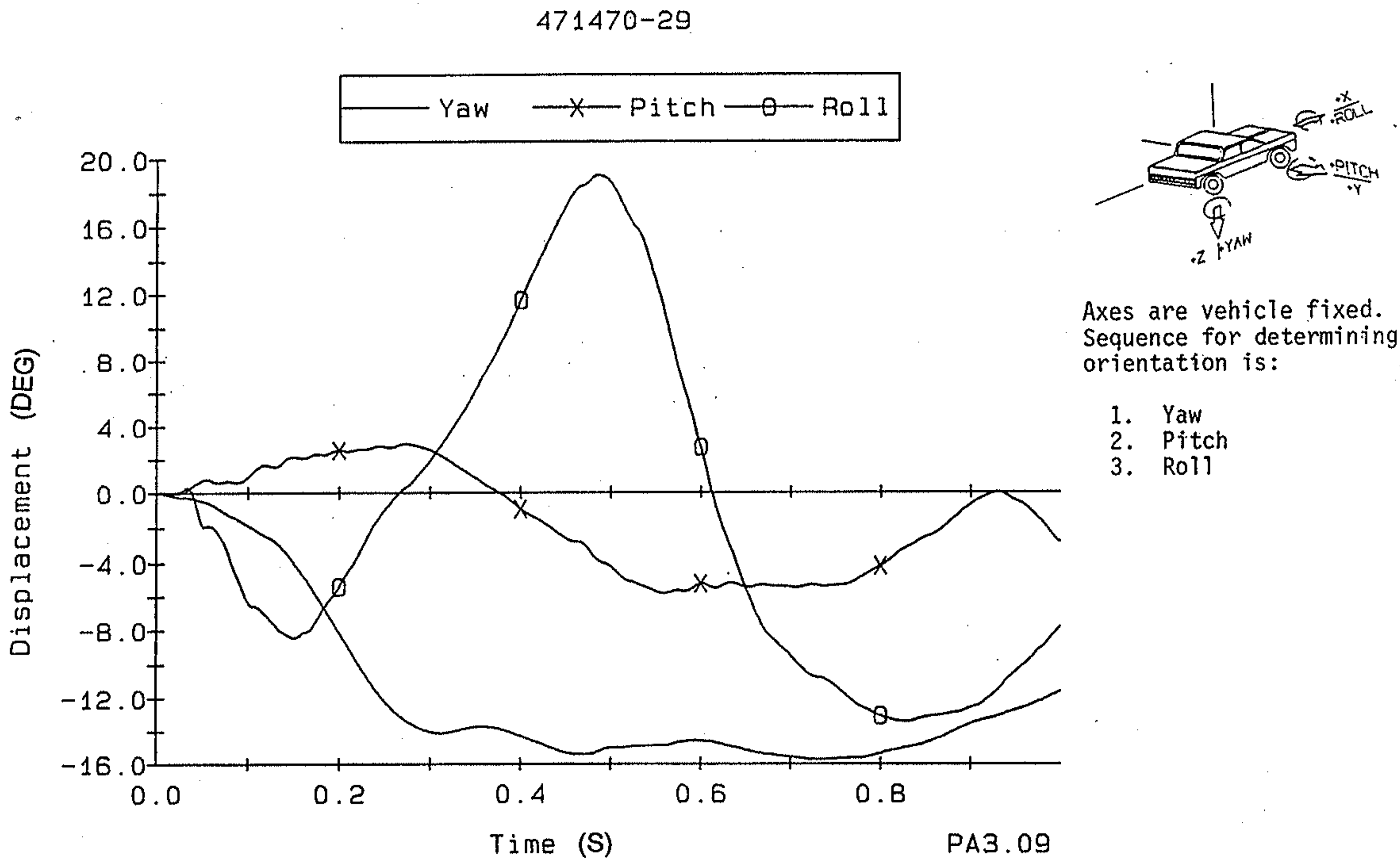


Figure 43. Vehicle angular displacements for test 471470-29.

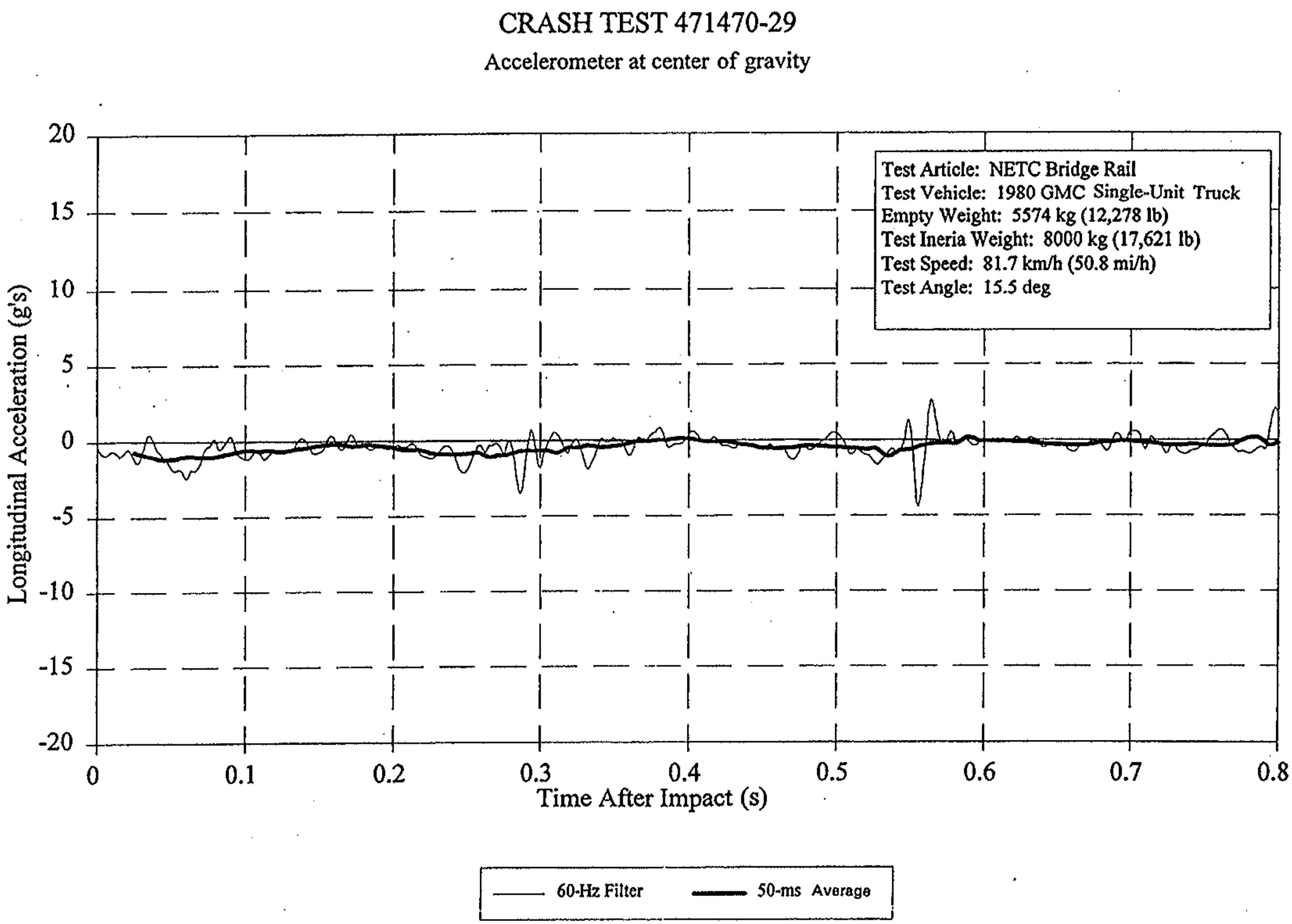


Figure 44. Vehicle longitudinal accelerometer trace for test 471470-29 (accelerometer located at center of gravity).

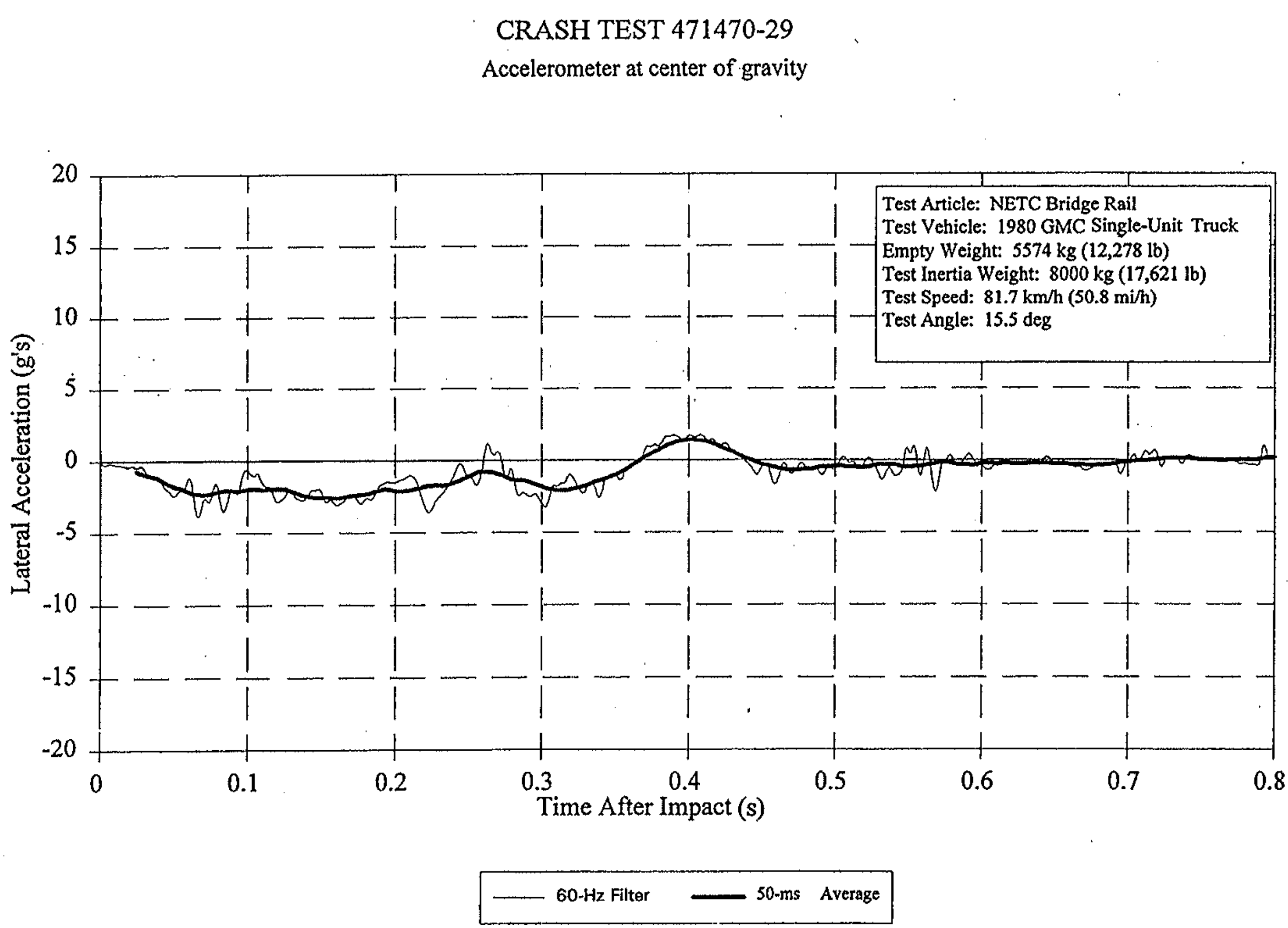


Figure 45. Vehicle lateral accelerometer trace for test 4714700-29 (accelerometer located at center of gravity).

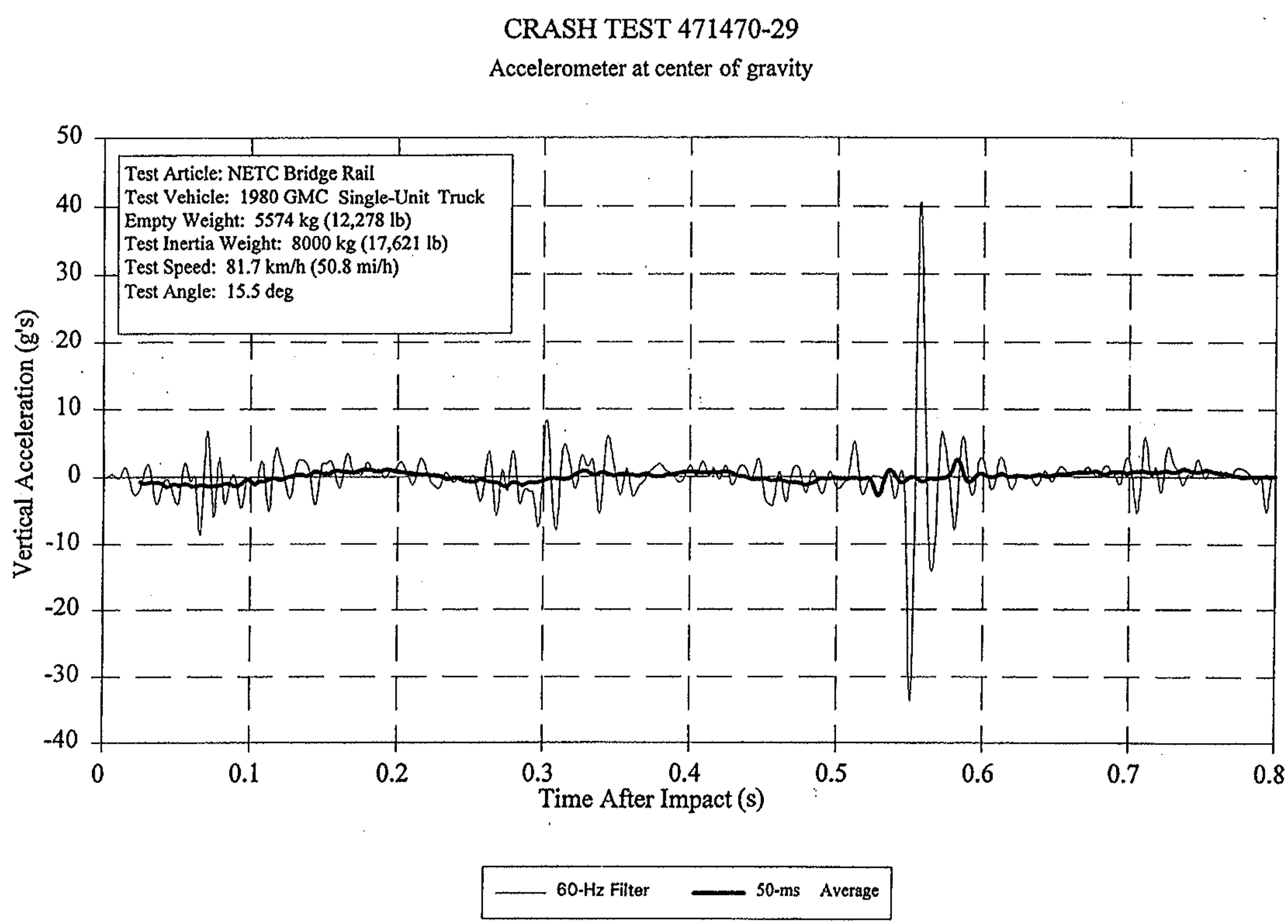


Figure 46. Vehicle vertical accelerometer trace for test 471470-29 (accelerometer located at center of gravity).

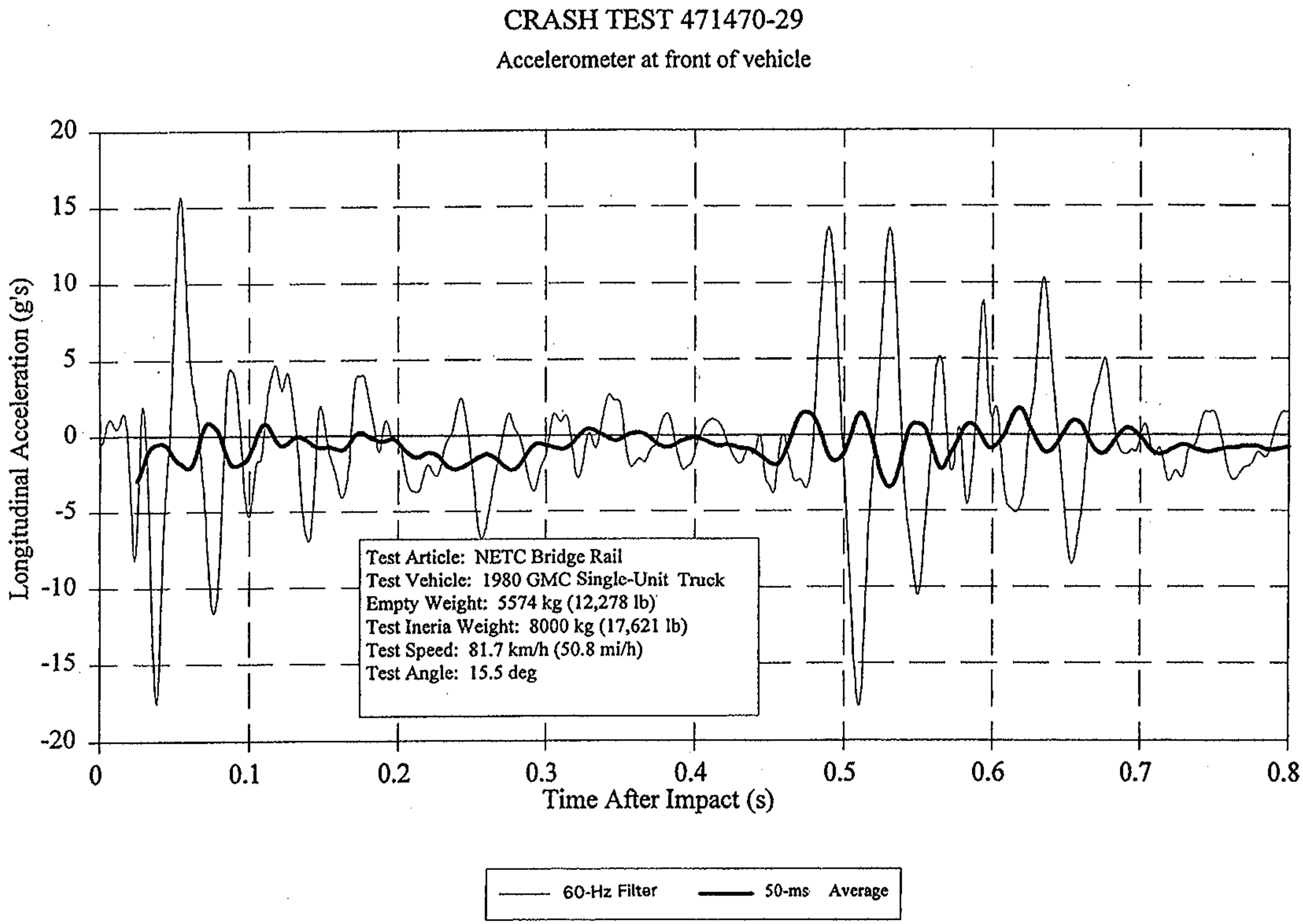


Figure 47. Vehicle longitudinal accelerometer trace for test 471470-29 (accelerometer located at front of vehicle).

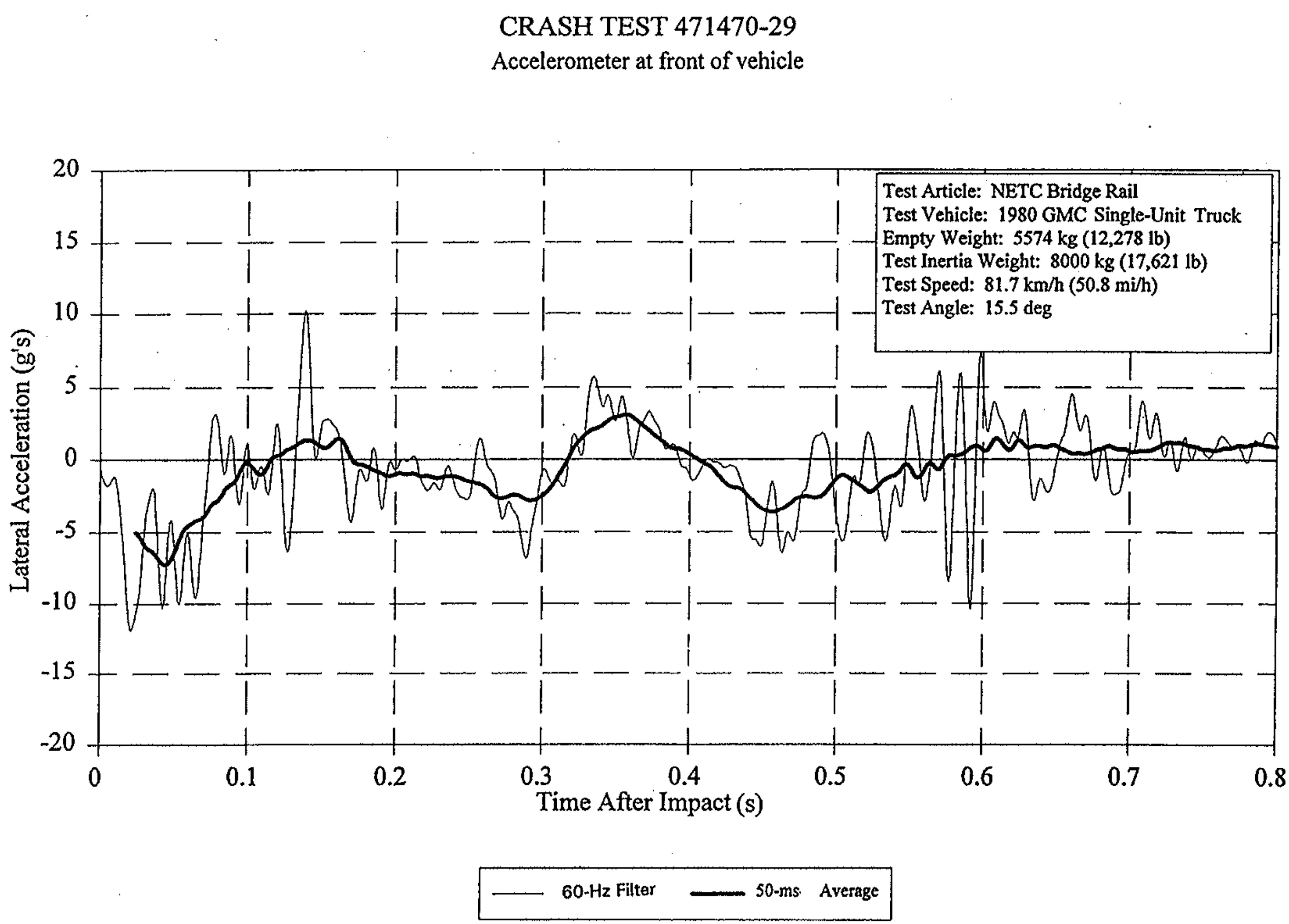


Figure 48. Vehicle lateral accelerometer trace for test 471470-29 (accelerometer located at front of vehicle).

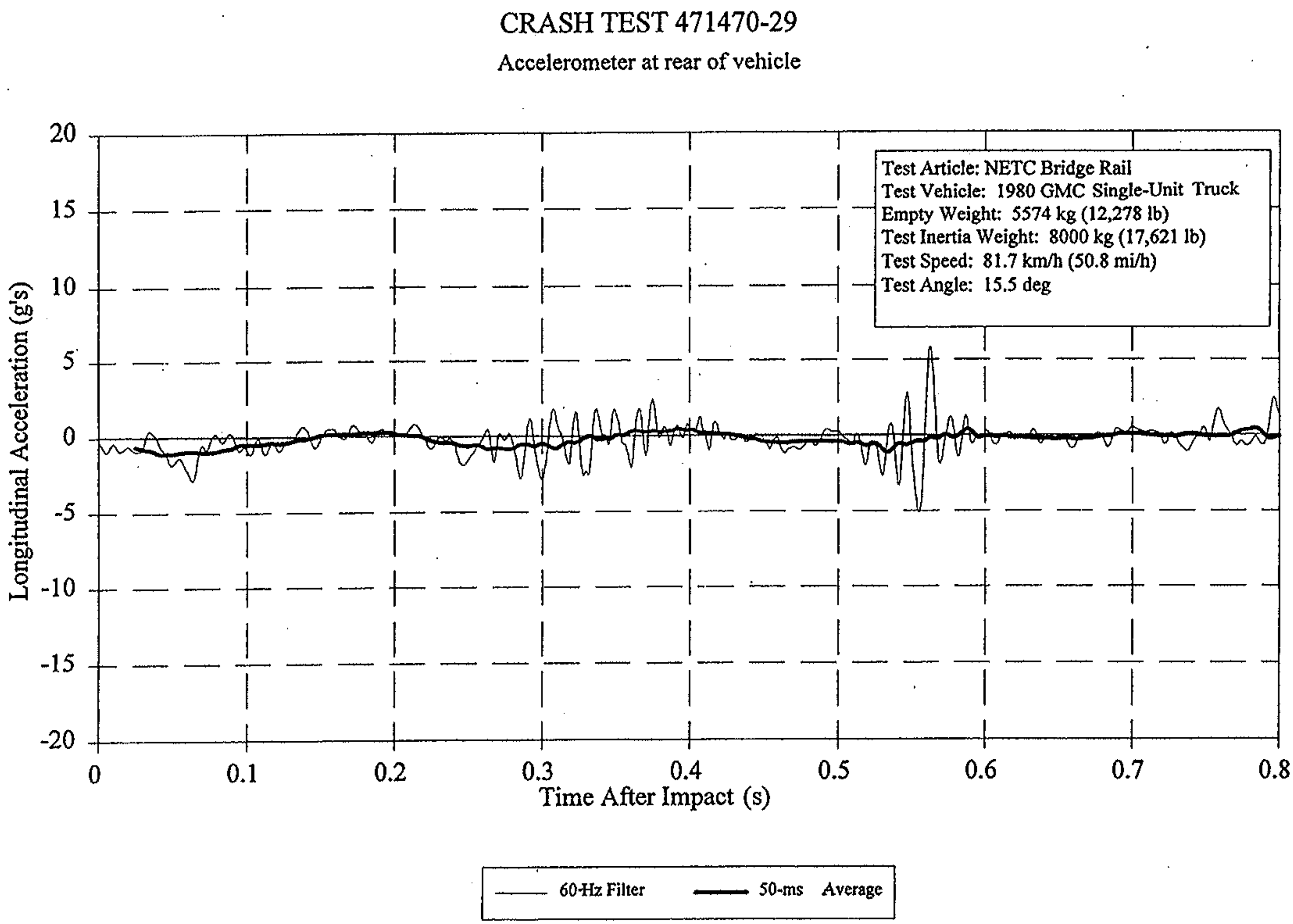


Figure 49. Vehicle longitudinal accelerometer trace for test 4714700-29 (accelerometer located at rear of vehicle).

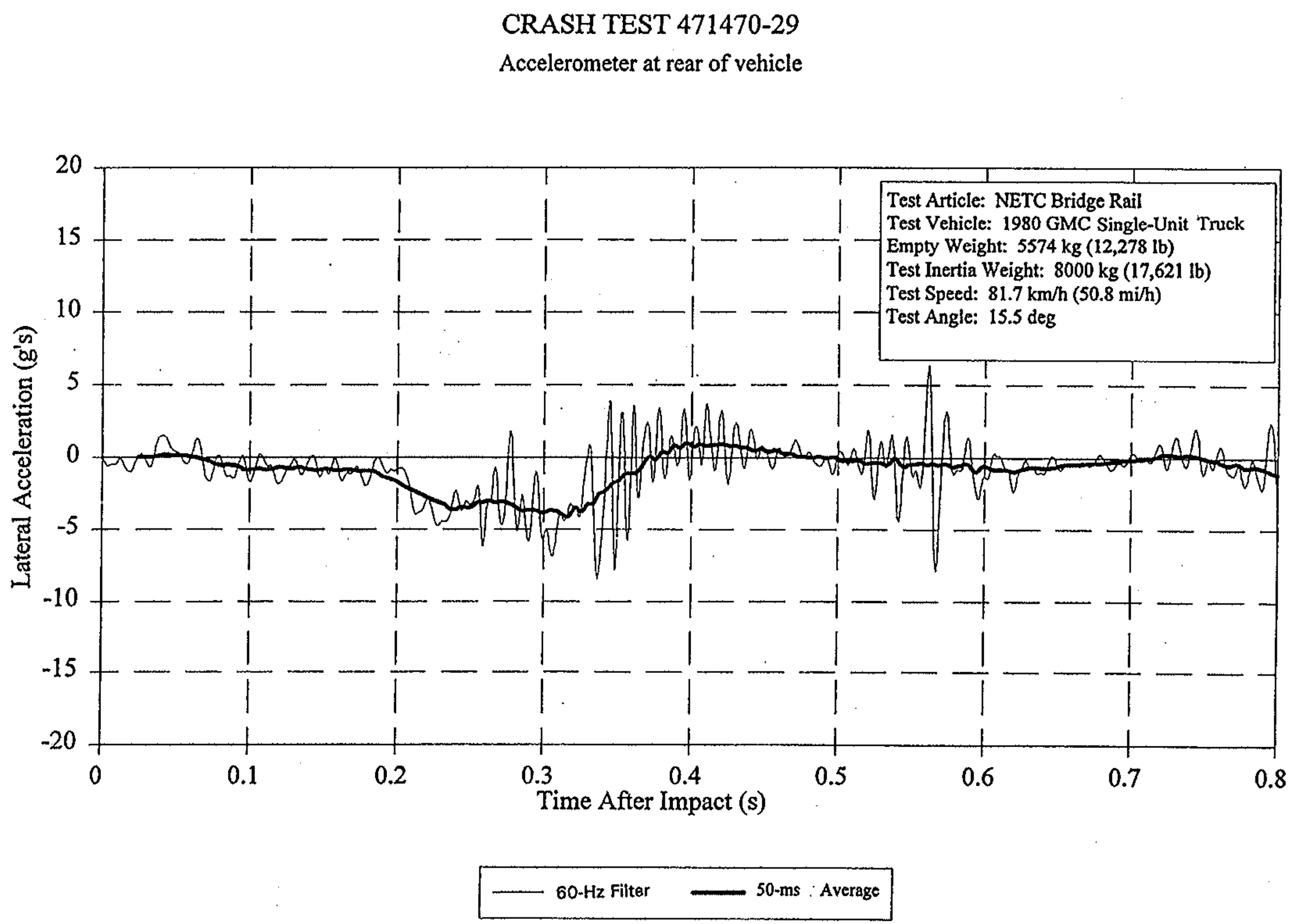


Figure 50. Vehicle lateral accelerometer trace for test 471470-29 (accelerometer located at rear of vehicle).

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

The NETC bridge rail design was evaluated in accordance with guidelines set forth in both the 1989 AASHTO *Guide Specifications for Bridge Railings* for performance level 2 (PL-2) and NCHRP Report 350 for test level 4 (TL-4). Three crash tests were conducted:

1. Small car redirection test (test no. 471470-18);
2. Pickup truck redirection test (test no. 471470-19); and
3. Single-unit truck redirection test (test no. 471470-29).

For the small car redirection test (test no. 471470-18), the NETC bridge rail is considered to have successfully met all evaluation criteria set forth in both the 1989 AASHTO *Guide Specifications for Bridge Railings* and NCHRP Report 350, summaries of which are shown in tables 1 and 2, respectively. The bridge railing contained and smoothly redirected the test vehicle. The bridge railing received only cosmetic damage with minimal lateral movement of the bridge railing and posts. There was no debris or detached elements from the bridge railing that could potentially intrude into the occupant compartment or pose undue hazard to adjacent traffic. The vehicle remained upright and stable during the collision sequence. The lateral occupant impact velocity of 8.4 m/s (27.5 ft/s) was slightly higher than the specified limit of 7.6 m/s (25 ft/s) according to the Guide Specifications. However, it should be noted that the impact speed and angle of 100.9 km/h (62.7 mi/h) and 20.6 degrees were also slightly higher than the nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees. If the impact angle and speed are normalized, the lateral occupant impact velocity would fall below the specified limit of 7.6 m/s (25 ft/s). Furthermore, the occupant impact velocity of 8.4 m/s (27.5 ft/s) was less than the preferred limit of 9.0 m/s (29.5 ft/s) recommended under NCHRP Report 350. The longitudinal occupant impact velocity and occupant ridedown accelerations were well within the specified limits. Velocity change of the vehicle during the collision was 12.2 km/h (7.6 mi/h). The vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes.

In the pickup truck redirection test (test no. 471470-19), the bridge rail also successfully met all evaluation criteria set forth in the 1989 AASHTO *Guide Specifications for Bridge Railings* and NCHRP Report 350, summaries of which are shown in tables 3 and 4, respectively. The bridge railing contained and smoothly redirected the test vehicle. The bridge railing received only minor damage; however, there were stress cracks at the two posts immediately upstream and downstream of the point of impact (posts 3 and 4), starting at the anchor bolts and propagating through the curb section and the bridge deck. There was no debris or detached elements from the bridge railing that could potentially intrude into the occupant compartment or pose undue hazard to adjacent traffic. The vehicle remained upright and stable during the collision sequence. The occupant impact velocities and occupant ridedown accelerations for this test are well within the specified limits set forth in the Guide Specifications and NCHRP Report 350. Velocity change of the vehicle during the collision was 14.0 km/h (8.7 mi/h). The vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes. The impact speed of 92.2 km/h (57.3 mi/h) was lower than the specified speed of 96.5 km/h (60 mi/h). However, given the good impact performance of the bridge railing, it was judged that the bridge railing would have performed satisfactorily had the impact speed been at the specified impact speed.

As mentioned above, the curb section and bridge deck sustained structural damage at the two posts immediately upstream and downstream of the point of impact in the pickup truck redirection test (test no. 471470-19). Consequently, the design details for the bridge deck, curb section, and steel reinforcement were revised to provide more anchorage capacity. The test installation with the revised bridge deck and curb section was constructed and crash tested in the single unit truck redirection test (test no. 471470-29). The NETC bridge rail met all evaluation criteria set forth both in the 1989 AASHTO *Guide Specifications for Bridge Railings* and NCHRP Report 350, summaries of which are shown in tables 5 and 6, respectively. The bridge railing contained and smoothly redirected the test vehicle. The bridge railing received moderate damage, but there was no structural damage to the bridge deck and curb section, indicating that the design modifications worked as intended. There were tire marks and gouges on the face of the rail and the curb section, and the bolts on the lower rail sheared off at posts 3, 4, and 5. There was no debris or detached elements from the bridge railing that could potentially intrude into the occupant compartment or pose undue hazard to adjacent traffic. The vehicle remained upright and stable during the collision sequence. The occupant impact velocities and occupant ridedown accelerations for this test are well within the specified limits set forth in the Guide Specifications and NCHRP Report 350. Velocity change of the vehicle during the collision was 14.0 km/h (8.7 mi/h). The vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes.

In summary, the revised NETC bridge rail and deck design met all evaluation criteria for a Performance Level 2 (PL-2) bridge railing set forth in the 1989 AASHTO Guide Specifications and test level 4 (TL-4) conditions in NCHRP Report 350.

Table 1. Assessment of results of test no. 471470-18 on NETC bridge rail (according to 1989 AASHTO Guide).

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a. The test shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	The vehicle was contained.	Pass
b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	There was no debris to penetrate the occupant compartment or present undue hazard to other traffic.	Pass
c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was no deformation or intrusion into the occupant compartment.	Pass
d. The vehicle shall remain upright during and after collision.	The vehicle remained upright.	Pass
e. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment .07 — Good	Pass
g. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 5.2 (16.9); Lateral 8.4 (27.5) Occupant Ridedown Accelerations - g's Longitudinal -1.6; Lateral -6.8	Fail Pass
h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 30 m (100 ft) plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 6 m (20 ft) from the line of the traffic face of the railing.	Exit angle was 2.2 degrees. The vehicle came to rest 65 m (212 ft) down and 1 m (3 ft) forward of the point of impact.	Pass

*A, B, C, D and G are required. E, F, and H are desired.

Table 2. Assessment of results of test no. 471470-18 on NETC bridge rail (according to NCHRP 350).

Test Agency: Texas Transportation Institute | Test No.: 7147-18 | Test Date: 07/20/93

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The bridge rail contained and redirected the vehicle.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was no debris to show potential for penetration of the occupant compartment or to present undue hazard to other traffic. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable during and after the collision.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and lateral / 9 / 12	Longitudinal Occupant Impact Velocity = 5.2 m/s (16.9 ft/s) Lateral Occupant Impact Velocity = 8.4 m/s (27.5 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component / Preferred / Maximum Longitudinal and lateral / 15 / 20	Longitudinal Ridedown Acceleration = -1.6 g's Lateral Ridedown Acceleration = -6.8 g's	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	Exit angle was 2.2 degrees. Vehicle came to rest 65 m (212 ft) down from and 1 m (3 ft) forward of point of impact.	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Exit angle was less than 60 percent of the test impact angle.	Pass

Table 3. Assessment of results of test no. 471470-19 on NETC bridge rail (according to 1989 AASHTO Guide).

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a. The test shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	The vehicle was contained.	Pass
b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	There was no debris to penetrate the occupant compartment or present undue hazard to other traffic.	Pass
c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was minimal deformation (13 mm (0.5 in)) into the occupant compartment.	Pass
d. The vehicle shall remain upright during and after collision.	The vehicle remained upright.	Pass
e. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment .12 — Good	Pass
g. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 3.7 (12.2); Lateral 6.6 (21.5) Occupant Ridedown Accelerations - g's Longitudinal -2.5; Lateral -12.2	Pass Pass
h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 30 m (100 ft) plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 6 m (20 ft) from the line of the traffic face of the railing.	Exit angle was 2.2 degrees. The vehicle came to rest 77 m (252 ft) down and 4 m (12 ft) behind the point of impact.	Pass

*A, B, C, and D are required. E, F, G, and H are desired.

Table 4. Assessment of results of test no. 471470-19 on NETC bridge rail (according to NCHRP 350).

Test Agency: Texas Transportation Institute | Test No.: 7147-19 | Test Date: 07/22/93

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The bridge rail contained and redirected the vehicle.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was no debris to show potential for penetration of the occupant compartment or to present undue hazard to other traffic. There was minimal deformation (13 mm (0.5 in)) into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable during and after the collision.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	Exit angle was 2.2 degrees. Vehicle came to rest 77 m (252 ft) down from and 4 m (12 ft) behind the point of impact.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 3.7 m/s (12.2 ft/s) Longitudinal Ridedown Acceleration = -1.2. g's	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Exit angle was less than 60 percent of the test impact angle.	Pass

Table 5. Assessment of results of test no. 471470-29 on NETC bridge rail (according to 1989 AASHTO Guide).

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a. The test shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	Vehicle was contained. There was no measurable deflection of the metal rail elements.	Pass
b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	There were no detached elements or other debris to penetrate or show undue hazard to other traffic.	Pass
c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	No deformation occurred to the occupant compartment.	Pass
d. The vehicle shall remain upright during and after collision.	The vehicle remained upright during and after the collision.	Pass
e. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment .11 — Good	Pass
g. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 2.3 (7.5); Lateral 3.6 (12.0) Occupant Ridedown Accelerations - g's Longitudinal -4.0; Lateral -3.2	N/A
h. Vehicle exit angle from the barrier shall not be more than 12 degrees.	Exit angle was approximately 2 degrees toward the bridge rail.	Pass

*A, B, and C are required. D, E, F, and H are desired. G is not applicable for this test.

Table 6. Assessment of results of test no. 471470-29 on NETC bridge rail (according to NCHRP Report 350).

Test Agency: Texas Transportation Institute | Test No.: 471470-29 | Test Date: 12/08/94

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The test article contained and redirected the vehicle with no measurable deflection of the metal rail elements.	Pass
<u>Occupant Risk</u>		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate or show potential hazard to others. There was no deformation or intrusion into the occupant compartment.	Pass
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The vehicle remained upright during and after the collision.	Pass
<u>Vehicle Trajectory</u>		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The vehicle rode off the end of the bridge rail at an approximate yaw of 2 degrees toward the bridge rail.	Pass

REFERENCES

1. *Guide Specifications For Bridge Railings*, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, 1989.

2. Ross, Jr., H. E., Sicking, D. L., Zimmer, R. A., and Michie, J. D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, NCHRP Report 350, Transportation Research Board, Washington, DC, 1993.