NCHRP Report 350 Test 4-10 of the New York Two-Rail Curbless Bridge Railing

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U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
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FOREWORD

This report will be of interest to researchers and those who select, locate, and design traffic barriers. It documents the results of a crash test of a New York Two-Rail Bridge Rail. This was the first test of a series intended to evaluate this new bridge rail design. The objective was to see if it meets Test Level Four (TL-4) in NCHRP Report 350. In this test, an 820-kg small car impacted the bridge rail at a nominal speed and angle of 100 km/h and 20 degrees. The test results met all of the evaluation criteria for the test designated as no. 4-10 in NCHRP Report 350.

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Director, Office of Safety
Research and Development

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16. Abstract

This report presents the details of the New York Two-Rail Curbless Bridge Railing study and the results of the small car test: National Cooperative Highway Research Program (NCHRP) Report 350 test designation 4-10, which is the 820-kg passenger car impacting the critical impact point (CIP) at 100 km/h and 20 degrees. The New York Two-Rail Curbless Bridge Railing met all requirements specified for NCHRP 350 test designation 4-10.

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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)		
EF	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	EC
		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)		
EC	Celcius temperature	1.8C+32	Fahrenheit temperature	EF
		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)

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INTRODUCTION

PROBLEM

Recently, the Federal Highway Administration (FHWA) adopted National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, as the official guidelines for performance evaluation of roadside safety hardware.[1] *NCHRP Report 350* specifies the required crash tests for longitudinal barriers, such as bridge railings, for six performance levels, as well as evaluation criteria for structural adequacy, occupant risk, and post-test vehicle trajectory for each test. The New York Two-Rail Curbless Bridge Railing is to be evaluated according to the specifications of test level four (TL-4) of *NCHRP Report 350*.

BACKGROUND

After October 1998, FHWA has required that all new roadside safety features to be installed on the National Highway System (NHS) meet the *NCHRP Report 350* performance evaluation guidelines. Most of the existing roadside safety features were tested according to the previous guidelines contained in *NCHRP Report 230*.[2] Therefore, it is necessary to test existing roadside safety features to evaluate how they would perform under the new guidelines.

OBJECTIVES

The objective of this study is to crash test and evaluate the New York Two-Rail Curbless Bridge Railing to test level 4 of *NCHRP Report 350*. In order to evaluate at TL-4, three full-scale crash tests on the length of need (LON) of the longitudinal barrier are required. These include an 820-kg passenger car impacting the critical impact point (CIP) at a nominal impact speed and angle of 100 km/h and 20 degrees, a 2000-kg pickup truck impacting the CIP at a nominal impact speed and angle of 100 km/h and 25 degrees, and an 8000-kg single-unit truck impacting the CIP at a nominal impact speed and angle of 80 km/h and 15 degrees.

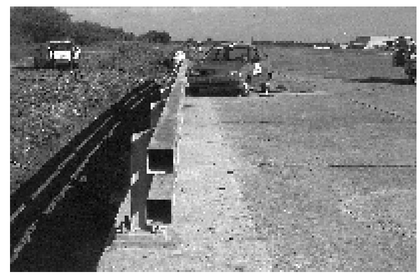
This report presents the details of the New York Two-Rail Curbless Bridge Railing study and the results of the small car test: *NCHRP Report 350* test designation 4-10, which is the 820-kg passenger car impacting the CIP at 100 km/h and 20 degrees. The New York Two-Rail Curbless Bridge Railing met all requirements specified for *NCHRP Report 350* test designation 4-10.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's (TTI) Proving Ground consist of an 809-hectare complex of research and training facilities situated 16 km northwest of the main campus of Texas A&M University. The site, formerly an air force base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for the placing of the bridge railing is along the edge of a wide expanse of concrete aprons that were originally used as parking aprons for military aircraft. These aprons consist of unreinforced jointed concrete pavement in 3.8-m by 4.6-m blocks (as shown in the adjacent photo) nominally 203 to 305 mm deep. The aprons and runways are about 50 years old and the joints have some displacement, but are otherwise flat and level. The soil was excavated at the edge of the apron and a section of the apron was broken off and sufficient reinforcing bars were added to join to the simulated bridge deck. The following section includes the details of the bridge deck and bridge rail cross section.



Test Article – Design and Construction

The New York Two-Rail Curbless Bridge Railing is a steel-beam and steel-post system on a concrete bridge deck. TTI received a drawing from the New York Department of Transportation entitled "Proposed Test Details Steel Bridge Railing Two Rail." This drawing provided details for construction of the concrete deck installation and fabrication of the Two-Rail Bridge Railing system. Based on these details, TTI prepared drawings for construction of the bridge railing test installation. These drawings are shown as figures 1 and 2 in this report.

For this project, a simulated concrete bridge deck cantilever was constructed. The total length of the test installation was 21.98 m. The bridge deck cantilever was 750 mm in width and 300 mm thick. The bridge deck cantilever was constructed immediately adjacent to an existing concrete runway located at the TTI test facility. The concrete deck was anchored to the runway by welding "L"-shaped dowels to existing dowels located in the concrete runway. The 28-day compressive strength of the concrete used to construct the deck was 27.6 MPa. Prior to constructing the deck, a concrete footing was constructed to provide additional support for the concrete deck. The footing measured 1665 mm in width and 203 mm in depth.

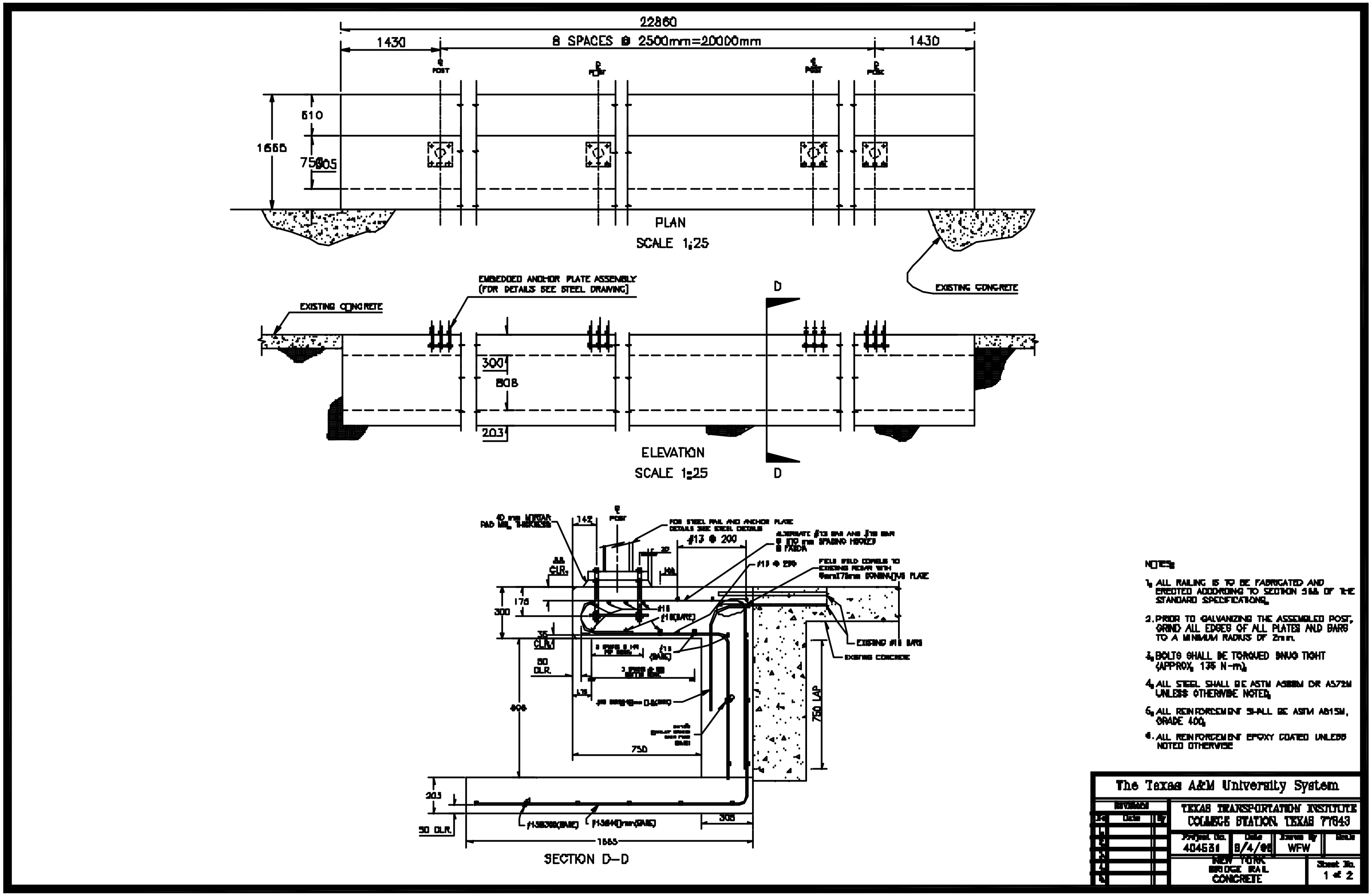


Figure 1. Details of the New York Curbless Two-Rail Bridge Railing for test 404531-1.

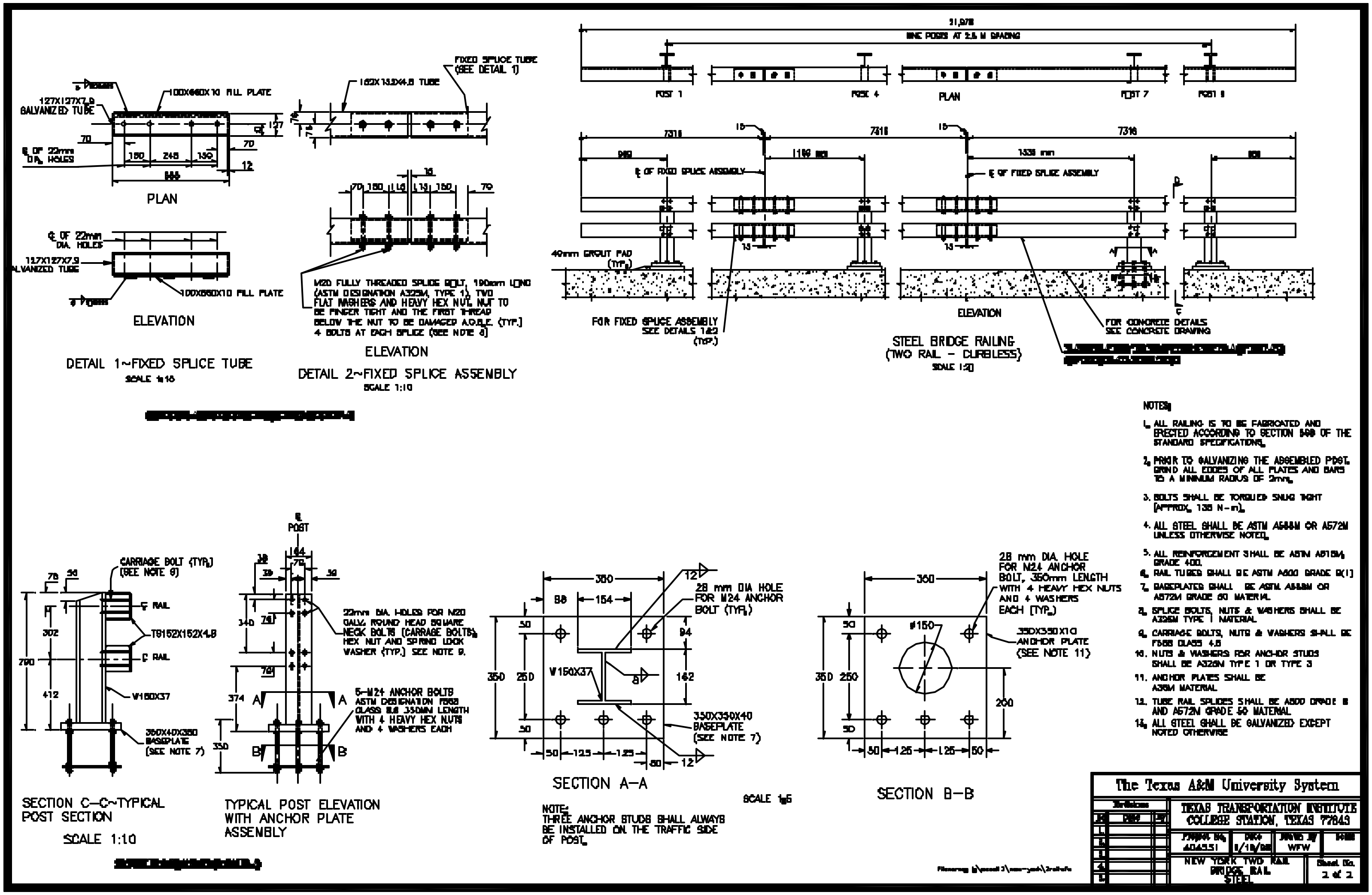


Figure 2. Layout of test installation.

After construction of the footing, form work was constructed for a vertical support wall and the concrete deck cantilever. The vertical support wall and the concrete deck cantilever were poured with one continuous concrete pour. The vertical support wall was 305 mm in width and served to anchor the deck to the existing runway and footing. Two layers of reinforcement were constructed in the deck and extended through the deck into the vertical support wall. The bottom layer of transverse reinforcement was epoxy coated and consisted of #13 bars at 200-mm spacings. The bottom longitudinal reinforcement consisted of four bars on 200-mm spacings. The outer three longitudinal bars were #16 bars and the innermost bar (traffic side) was a #13 bar. The outermost (field side) bottom longitudinal bar was epoxy coated. Longitudinal reinforcement in the vertical support consisted of three #13 “bare steel” bars on each face.

The top layer of transverse reinforcement consisted of alternating #13 and #19 bars on 100-mm spacings. The transverse bars were hooked using a 90-mm radius. The hook extended an additional 215 mm and lapped the bottom transverse reinforcement. Starting from the field side of the deck towards the traffic side, the longitudinal reinforcement consisted of four #16 bars on 100-mm spacings located beneath the top transverse reinforcement with three #13 bars on 200-mm spacings located above the top transverse reinforcement. All reinforcement used in the top layer of reinforcement was epoxy coated.

The New York Two-Rail Bridge Railing consists of two TS 152x152x4.8 tubes supported by W150x37 posts on 2500-mm spacings. Each post was 790 mm in height and was continuously welded to a 350-mm x 350-mm x 38-mm baseplate with a 12-mm fillet weld. A 40-mm high-strength cementitious grout pad was placed beneath each post. The posts were anchored into the concrete deck using five M24 anchor bolts and 350-mm x 350-mm x 10-mm anchor plates. Three of the five anchor bolts were located on the traffic face of the posts. The anchor plates were embedded into the concrete deck 175 mm from the top surface of the deck. The anchor plates were fabricated using A36 Material. The anchor bolt material met the requirements of specification ASTM F568 Class 8.8. The posts and the baseplates were fabricated using A572M Grade 50 material. The lower rail was located 412 mm from the top of the deck and the upper rail was located 714 mm from the top of the deck. The rails were connected to each post using four M20 galvanized round head square neck (carriage) bolts. The round heads of the bolts were located on the traffic face of the rail and bolted through the rail and the front flange of the post. The rails were spliced together using a fixed splice tube fabricated from TS127x127x7.9 tube with two 100-mm x 660-mm x 10-mm plates welded on two sides of the tube. The splice tube was connected to the rail tubes using four M19 x 190-mm bolts. The splice tube bolts met the requirements of ASTM A325 Type 1 material. The bridge rail tubes met the requirements of ASTM A500 Grade B material. The tube rail splices met the requirements of ASTM A500 Grade B and A572M Grade 50 material. For additional information, see figures 1 and 2.

All material was galvanized except the anchor bolts and anchor plates. The completed installation is shown in figure 3.

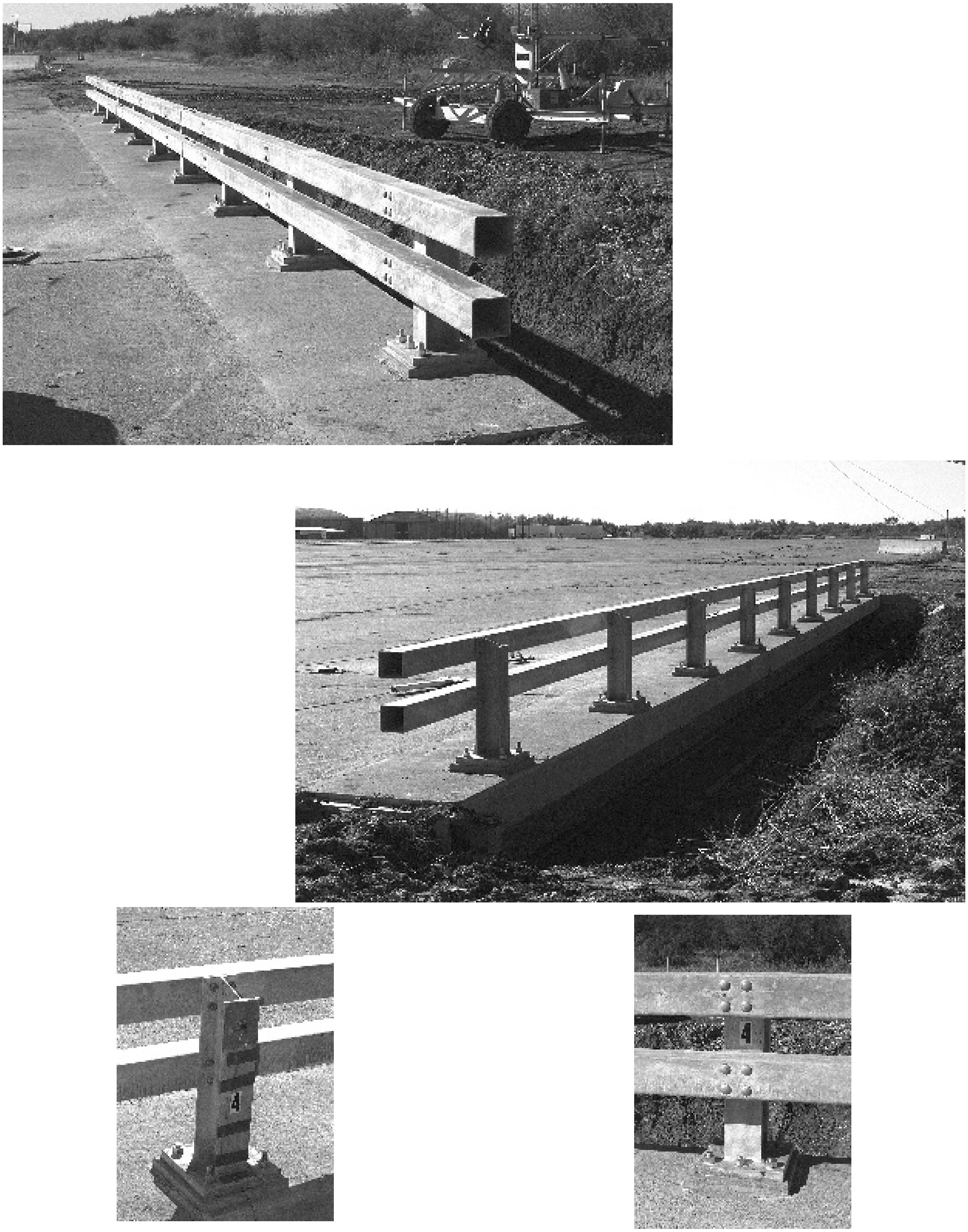


Figure 3. New York Two-Rail Curbless Bridge Railing prior to testing.

Test Conditions

According to *NCHRP Report 350*, three tests are required to evaluate longitudinal barriers, such as bridge railings, to test level four (TL-4) and are as described below.

> ***NCHRP Report 350*** **test designation 4-10**: An 820-kg passenger car impacting the (critical impact point) CIP in the length of need (LON) of the longitudinal barrier at a nominal speed and angle of 100 km/h and 20 degrees. This purpose of this test is to evaluate the overall performance of the LON section in general, and occupant risk in particular.
>
> ***NCHRP Report 350*** **test designation 4-11**: A 2000-kg pickup truck impacting the CIP in the LON of the longitudinal barrier at a nominal speed and angle of 100 km/h and 25 degrees. The test is intended to evaluate the strength of section in containing and redirecting the pickup truck.
>
> ***NCHRP Report 350*** **test designation 4-12**: An 8000-kg single-unit truck impacting the CIP in the LON of the longitudinal barrier at a nominal speed and angle of 80 km/h and 15 degrees. The test is intended to evaluate the strength of the section in containing and redirecting the heavy truck.

The crash test reported herein (test 404531-1) corresponds to *NCHRP Report 350* test designation 4-10.

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented in appendix A.

Evaluation Criteria

The crash test performed was evaluated in accordance with the criteria presented in *NCHRP Report 350*. As stated in *NCHRP Report 350*, "Safety performance of a highway appurtenance cannot be measured directly, but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision." Accordingly, the following safety evaluation criteria from table 5.1 of *NCHRP Report 350* were used to evaluate the crash test reported herein:

- **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.*

- **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. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*

F. *The vehicle should remain upright during and after collision, although moderate roll, pitching, and yawing are acceptable.*

H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity - m/s	
Preferred	*Maximum*
9	*12*

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations - g's	
Preferred	*Maximum*
15	*20*

- **Vehicle Trajectory**

K. *After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

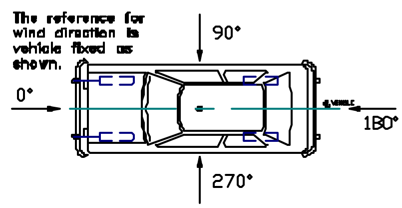
CRASH TEST 404531-1 (NCHRP REPORT 350 TEST 4-10)

Test Vehicle

A 1993 Ford Festiva, shown in figures 4 and 5, was used for the crash test. Test inertial weight of the vehicle was 820 kg, and its gross static weight was 896 kg. The height to the lower edge of the vehicle front bumper was 395 mm and height to the upper edge of the front bumper was 550 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 11. 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.

Weather Conditions

The crash test was performed the morning of October 23, 1998. A total of 178 mm of rain was recorded 2 days prior to the test, but this did not affect the test as the bridge railing was installed on the concrete deck. No other rainfall occurred during the 10 days prior to the test. Weather conditions at the time of testing were as follows: Wind Speed: 6 km/h; Wind Direction: 200 degrees with respect to the vehicle (vehicle traveling in a southerly direction); Temperature: 16EC; Relative Humidity: 37 percent.



Impact Description

The vehicle, traveling at 100 km/h, impacted the two-rail bridge railing 1.2 m upstream from post 4, at a 19.1-degree angle. Shortly after impact, the bottom rail showed movement. At 0.010 s, the right front wheel steered left then traveled parallel with the rail. The upper rail moved at 0.012 s. At 0.017 s, the vehicle's right front wheel continued to steer left. Post 4 deformed at 0.019 s. At 0.024 s, the right front wheel canted as the upper part of the tire was pushed down from the lower bridge railing. The vehicle began to redirect at 0.038 s. The right front tire contacted the concrete and metal base of post 4 at 0.056 s, and at 0.066 s, the right front tire contacted post 4. At 0.068 s, the right-side passenger door window shattered, and at 0.097 s, the rear of the vehicle impacted the bridge railing. Traveling at 89.1 km/h, the vehicle was moving parallel to the rail element at 0.113 s. At 0.165 s, the left front tire steered right. At 0.224 s, traveling at 85.3 km/h, the vehicle lost contact with the bridge railing at a 0.8-degree angle. Brakes on the vehicle were applied at 1.4 s, bringing the vehicle to rest 52.7 m downstream from impact and 9.1 m behind the installation. Sequential photographs of the test period are shown in appendix C, figures 12 and 13.

Figure 4. Vehicle/installation geometrics for test 404531-1.

Figure 5. Vehicle before test 404531-1.

Damage to Test Article

Damage to the New York Two-Rail Curbless Bridge Railing is shown in figures 6 and 7. Tire marks were on the baseplate and nuts at impact. No cracks in the deck were noticed after the test. There was cosmetic damage with no measurable deformation of the rail elements. Total length of vehicle contact with the rail element was 3.0 m.

Vehicle Damage

The vehicle sustained structural damage on the front right and right side. The sway bar, A-arm, motor support, and right strut and axle were all severely damaged. The front right portion of the bumper, fan, radiator, hood, tire, and wheel were damaged as shown in figure 8. The right front and rear quarter panels and right door were dented. The left front tire also sustained damage. The roof had a slight buckle on the passenger side. The maximum exterior crush was 190 mm, measured near bumper height on the right side. Maximum deformation of the occupant compartment was 15 mm (2-percent reduction in space) in the right firewall area. The door and the floor pan were deformed. The interior of the vehicle is shown in figure 9. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 3 and 4.

Assessment of Test Results

As stated previously, the following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

- **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 New York Two-Rail Curbless Bridge Railing contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation.

- **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. Deformation of,*

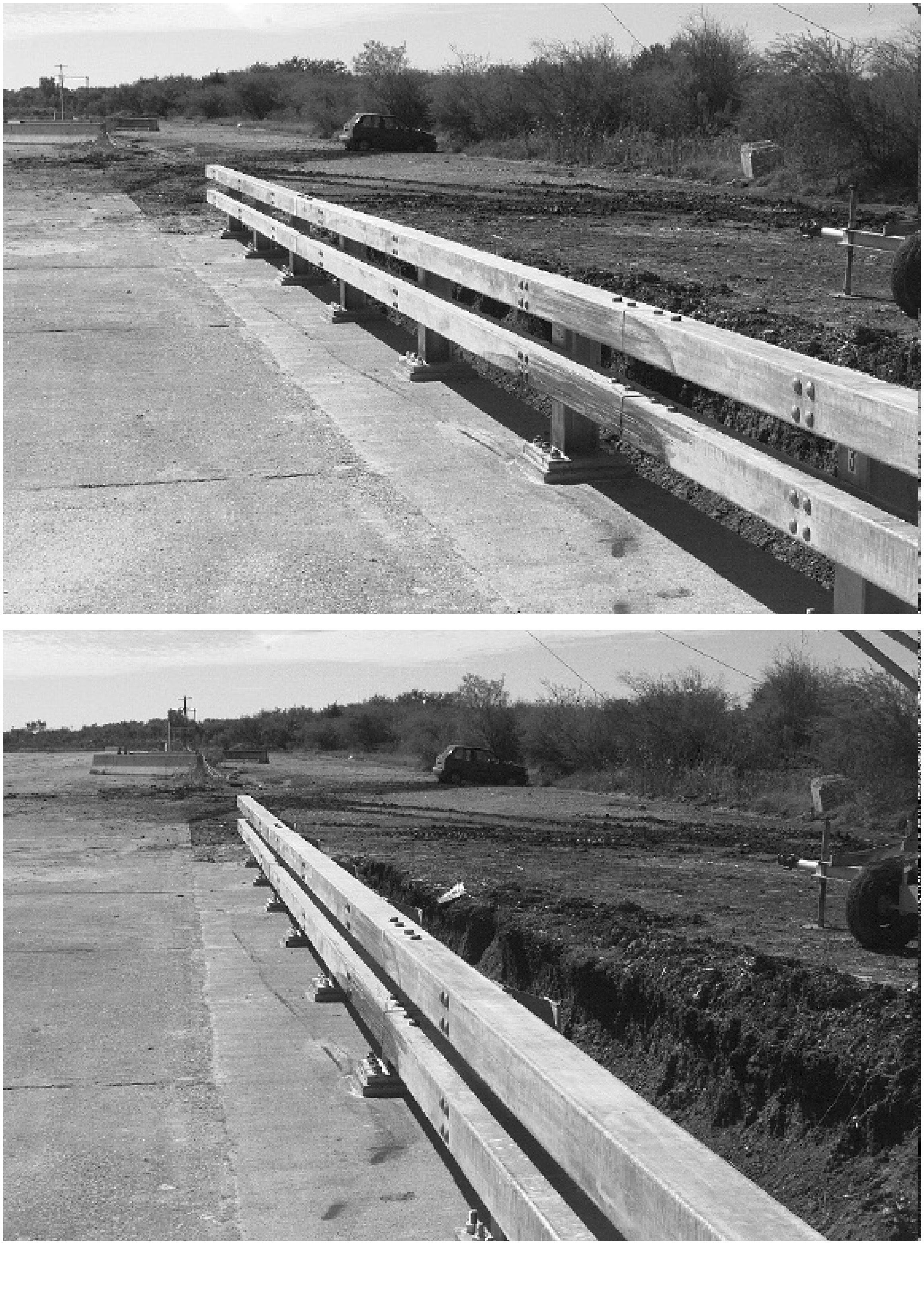


Figure 6. Vehicle trajectory path after test 404531-1.

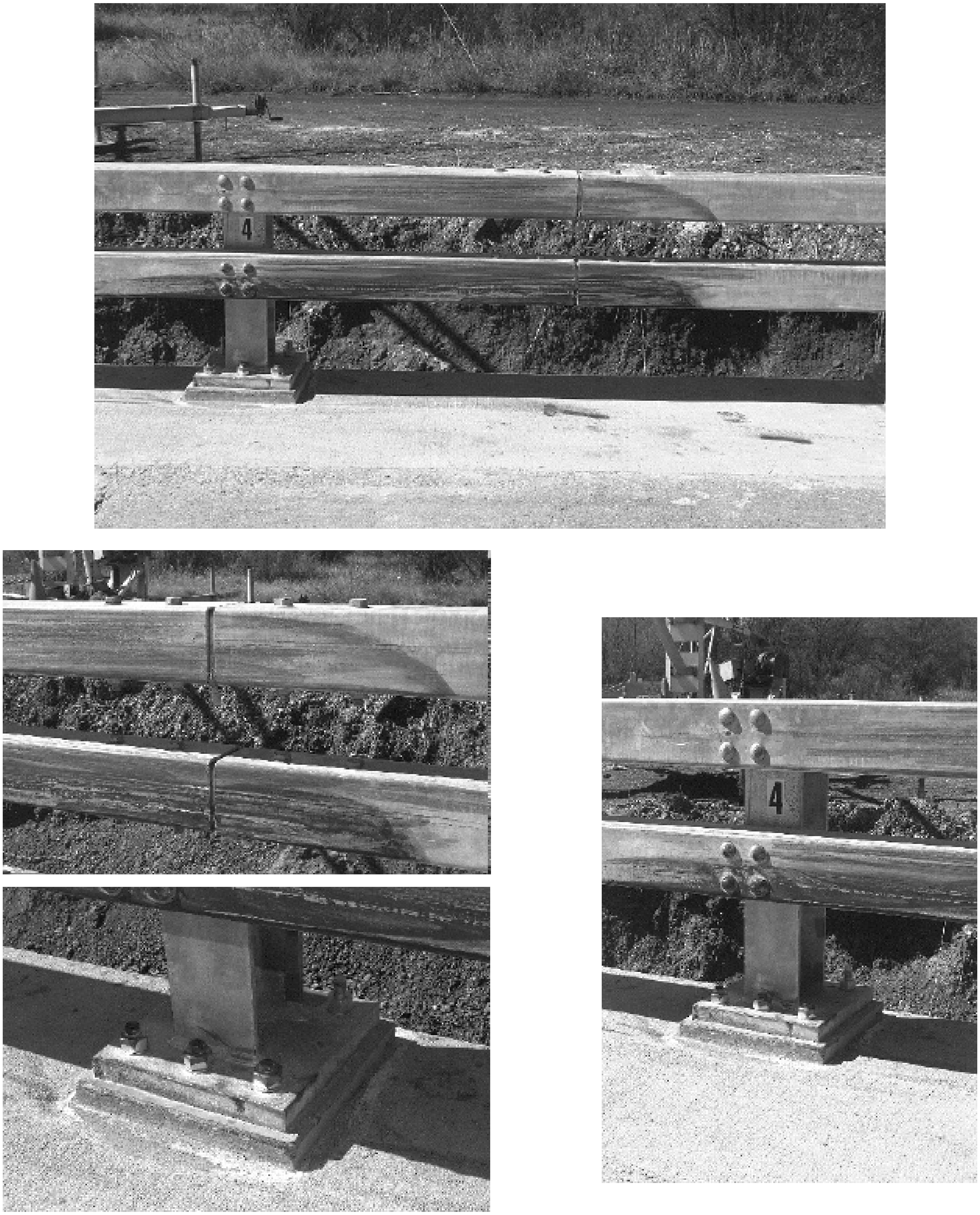


Figure 7. Installation after test 404531-1.

Figure 8. Vehicle after test 404531-1.

Before test

After test

Figure 9. Interior of vehicle for test 404531-1.

and intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

No detached elements, fragments, or other debris from the test article were present to penetrate or to show potential for penetrating the occupant compartment. Minimal deformation occurred to the occupant compartment, 15 mm (2% reduction in space) in the right firewall area

F. *The vehicle should remain upright during and after collision, although moderate roll, pitching, and yawing are acceptable.*

The vehicle remained upright during and after the collision period.

H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity - m/s	
Preferred	*Maximum*
9	*12*

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations - g's	
Preferred	*Maximum*
15	*20*

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 4.7 m/s at 0.196 s, the highest 0.010-s occupant ridedown acceleration was -2.5 g’s from 0.132 to 0.142 s, and the maximum 0.050-s average acceleration was -6.3 g’s between 0.034 and 0.084 s. In the lateral direction, the occupant impact velocity was 7.5 m/s at 0.085 s, the highest 0.010-s occupant ridedown acceleration was -11.3 g’s from 0.126 to 0.136 s, and the maximum 0.050-s average was -13.9 g’s between 0.022 and 0.072 s. These data and other pertinent information from the test are summarized in figure 10. Vehicle angular displacements and accelerations versus time traces are presented in appendix D, figures 14 through 25.

- **Vehicle Trajectory**

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 as it came to rest behind the installation

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

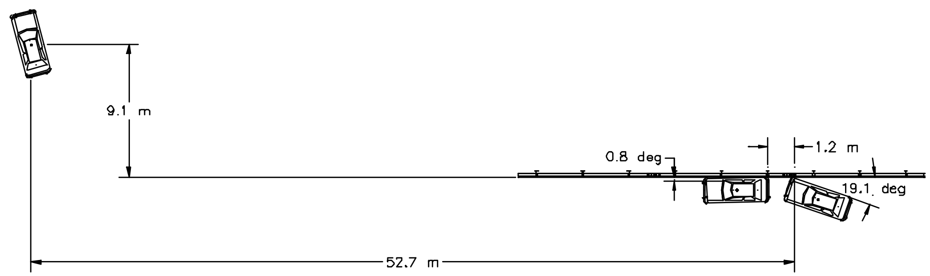
The exit angle at loss of contact was 0.8 degrees, which was significantly less than 60 percent of the impact angle.

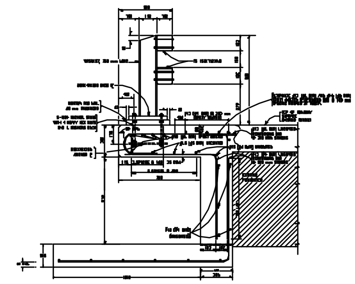
0.000 s

0.048 s

0.108 s

0.228 s





General Information

Test Agency	Texas Transportation Institute
Test No.	404531-1
Date	10/23/98
Test Article	
Type	Bridge Railing
Name or Manufacturer	New York Two-Rail Bridge Railing
Installation Length (m)	22.9
Material or Key Elements	Tubular Steel Rail Elements on Steel Wide-Flange Posts on deck
Soil Type and Condition	Concrete Deck, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1993 Ford Festiva
Mass (kg)	
Curb	814
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions

Speed (km/h)	99.9
Angle (deg)	19.1
Exit Conditions	
Speed (km/h)	85.3
Angle (deg)	0.8
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.7
y-direction	7.5
THIV (km/h)	29.4
Ridedown Accelerations (g's)	
x-direction	-2.5
y-direction	-11.3
PHD (g's)	11.4
ASI	1.62
Max. 0.050-s Average (g's)	
x-direction	-6.3
y-direction	-13.9
z-direction	1.8

Test Article Deflections (m)

Dynamic	nil
Permanent	nil
Vehicle Damage	
Exterior	
VDS	01RFQ2
CDC	01FREK2 & 01RFEW2
Maximum Exterior Vehicle Crush (mm)	190
Interior	
OCDI	RF0000000
Max. Occ. Compart. Deformation (mm)	15
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	-17
Max. Pitch Angle (deg)	-3
Max. Roll Angle (deg)	-8

Figure 10. Summary of results for test 404531-1, *NCHRP Report 350* test 4-10.

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF FINDINGS

The New York Two-Rail Curbless Bridge Railing contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. No detached elements, fragments, or other debris were present to penetrate nor to show potential for penetrating the occupant compartment, nor to present an undue hazard to other traffic. Maximum deformation of the occupant compartment was 15 mm (2% reduction of space) in the right firewall area. The vehicle remained upright during and after the collision period. Occupant risk factors were within the limits specified in *NCHRP Report 350*. No intrusion into adjacent traffic lanes occurred after the vehicle lost contact with the bridge railing as the vehicle came to rest behind the installation. Exit angle at loss of contact was 0.8 degrees, which was less than 60 percent of the impact angle.

CONCLUSIONS

The New York Two-Rail Curbless Bridge Railing met all requirements specified for *NCHRP Report 350* test designation 4-10.

Table 1. Performance evaluation summary for test 404531-1, *NCHRP Report 350* test 4-10.

Test Agency: Texas Transportation Institute | Test No.: 404531-1 | Test Date: 10/23/98

NCHRP Report 350 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 New York Two-Rail Curbless Bridge Railing contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation	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.	No detached elements, fragments, or other debris were present to penetrate nor to show potential for penetrating the occupant compartment, nor to present an undue hazard to other traffic. Maximum deformation of the occupant compartment was 15 mm (2% reduction in space) in the right firewall area.	Pass
F. The vehicle should remain upright during and after collision, although moderate roll, pitching, and yawing are acceptable.	The vehicle remained upright during and after the collision period.	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 = 4.7 Lateral occupant impact velocity = 7.5	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 = -2.5 g's Lateral ridedown acceleration = -11.3 g's	Pass
Vehicle Trajectory K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	No intrusion occurred after the vehicle lost contact with the bridge railing.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.	Exit angle at loss of contact was 0.8 degrees, which was less than 60 percent of the impact angle.	Pass

*Criteria K and M are preferable, but not required.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with five uniaxial accelerometers mounted in the following locations: (1) center top surface of the instrument panel; (2) inside end of right front wheel spindle; (3) inside end of left front wheel spindle; (4) top of engine block; and (5) bottom of engine block. The exact location of each accelerometer was measured and is reported in table 1. These accelerometers were ENDEVCO Model 7264A low-mass piezoresistive accelerometers with a ±2000-g range.

Table 2. Locations of vehicle accelerometers for test 404531-1.

Location	**X (mm) (distance from front axle)**	**Y (mm) (distance from centerline)**	**Z (mm) (distance from ground)**	**Data Axis**
Instrument panel	0	0	0	+X
Right front wheel spindle	+60	+700	-220	-Y
Left front wheel spindle	+60	-700	-220	+X
Top of engine block	+170	0	-755	+X
Bottom of engine block	+170	+25	-300	+X
Vehicle c.g.	-900	0	-390	+X,+Y,+Z
Vehicle rear axle	-2420	-180	-480	+X,+Y

Reference point:	X=0 at front axle	Y=0 at centerline	Z=0 at ground
Sign convention:	+X=forward	+Y=right	+Z=down

On-board data acquisition is provided by a 16-channel Prosig P4010 system. Each analog channel has integral signal conditioning, fixed-frequency anti-alias filtering, and a programmable transducer bridge power supply. Each P4010 four-channel POD contains 1 Mb of battery-backed memory allowing for more than 13 s of storage at a maximum of 10,000 samples per second per channel. All channels are synchronized by a common external clock. The accuracy of this system is ±0.1%.

In addition, the test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center of gravity to measure longitudinal, lateral, and vertical acceleration levels; and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO Model 2262CA, piezoresistive accelerometers with a ±100-g range.

The accelerometers are strain-gage type with a linear millivolt output proportional to acceleration. Rate-of-turn transducers are solid state, gas flow units designed for high g service. Signal conditioners and amplifiers in the test vehicle increase the low-level signals to a ±2.5-V maximum level. The signal conditioners also provide the capability of an R-Cal or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15-channel, constant bandwidth, Inter-Range Instrumentation Group (IRIG), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals from the test vehicle are recorded minutes before the test and also immediately afterwards. A crystal-controlled time reference signal is simultaneously recorded with the data. Pressure-sensitive switches on the bumper of the impacting vehicle are 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 produces an "event" mark on the data record to establish the exact instant of contact with the installation.

The multiplex of data channels transmitted on one radio frequency is received at the data acquisition station, and demultiplexed onto separate tracks of a 28-track (IRIG) tape recorder. After the test, the data are played back from the tape machine, filtered with SAE J211 filters, and digitized using a microcomputer, at 2000 samples per second per channel, for analysis and evaluation of impact performance.

All accelerometers are calibrated annually by the Society of Automotive Engineers ((SAE) J211 *4.6.1*) by means of an ENDEVCO 2901, precision primary vibration standard. This device, along with its support instruments, is returned to the factory annually for a National Institute of Standards and Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations will be made any time a data channel is suspected of any anomalies.

The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are provided 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 10-ms 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 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers were then filtered with a 60-Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions were plotted using a commercially available software package (Excel).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0002-s intervals and then instructed a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. 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.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

An Alderson Research Laboratories Hybrid II, 50th-percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the vehicle. The dummy was not instrumented.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation 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 BetaCam, a VHS-format video camera and recorder, and still cameras were used to record and document the condition of the test vehicle and installation before and after the test.

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 tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional 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. A 2-to-1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle 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.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

DATE: 10-23-98 TEST NO.: 404531-1 VIN NO.: KWJPT06H1P6107226

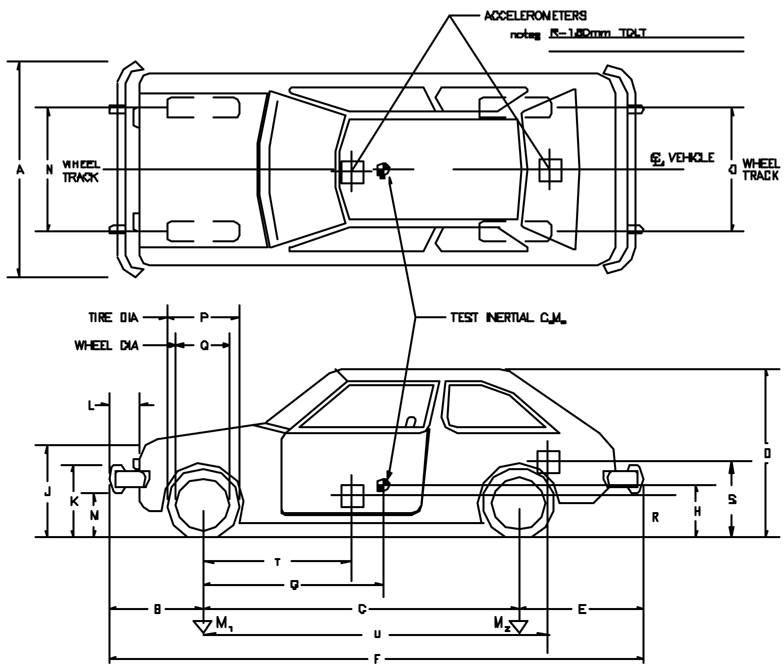
YEAR: 1993 MAKE: FORD MODEL: FESTIVA

TIRE INFLATION PRESSURE: ______ ODOMETER: 85031 TIRE SIZE: 155R12

1st Use: X 2nd or More Use: ___ Minor Damage Charged to Project: ______

MASS DISTRIBUTION (kg) LF 259 RF 251 LR 153 RR 157

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 CYL.

ENGINE CID: 1.3L

TRANSMISSION TYPE:

___ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A 1500	E 550	J 760	N 1405	R 390
B 640	F 3490	K 550	O 1400	S 480
C 2300	G 869.5	L 120	P 540	T 900
D 1450	H	M 395	Q 330	U 2420

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	530	510	548
M_2	284	310	348
M_T	814	820	896

Figure 11. Vehicle properties for test 404531-1.

Table 3. Exterior crush measurements for test 404531-1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant X1 % X2 , 2 _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width ** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Top front bumper	600	150	520	0	10	25	25	90	150	+470
2	Above front wheel well	600	190	1200	0	40	80	12 0	16 0	190	+1040

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

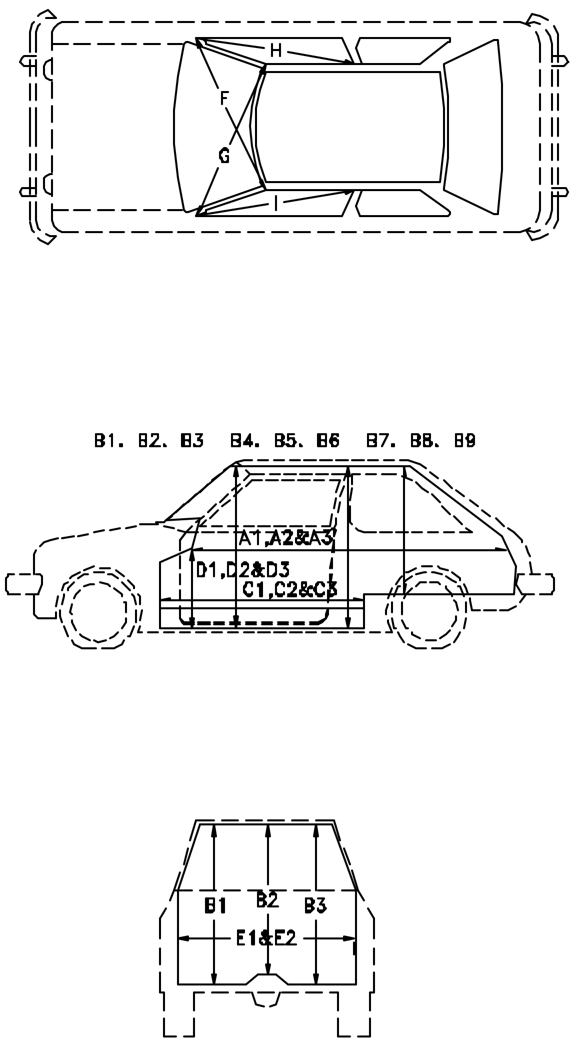
***Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.

Table 4. Occupant compartment measurements for test 404531-1.

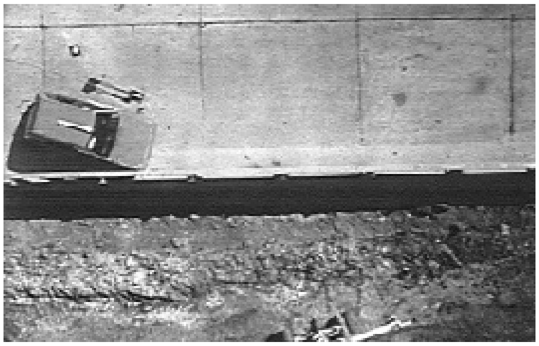
Small Car

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1548	1548
A2	2032	2032
A3	1550	1550
B1	995	995
B2	934	934
B3	1058	1053
B4	970	970
B5	973	973
B6	970	970
B7	860	860
B8	847	847
B9	838	838
C1	629	629
C2	625	625
C3	635	620
D1	327	327
D2	225	225
D3	330	337
E1	1252	1257
E2	1245	1260
F	1190	1190
G	1190	1185
H	900	895
I	900	900

APPENDIX C. SEQUENTIAL PHOTOGRAPHS



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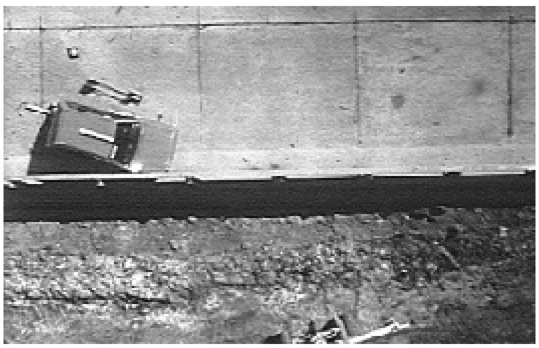

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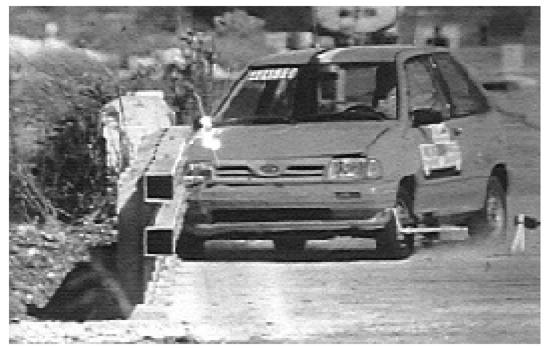

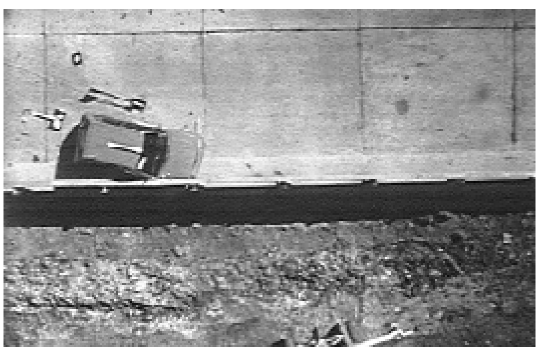

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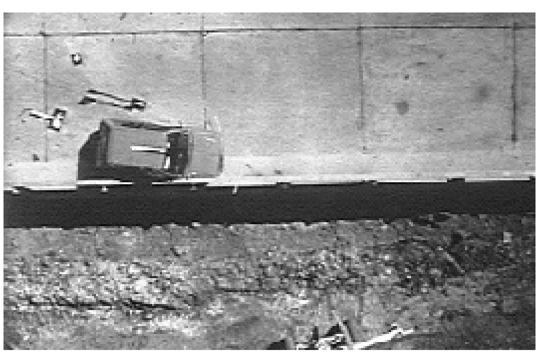

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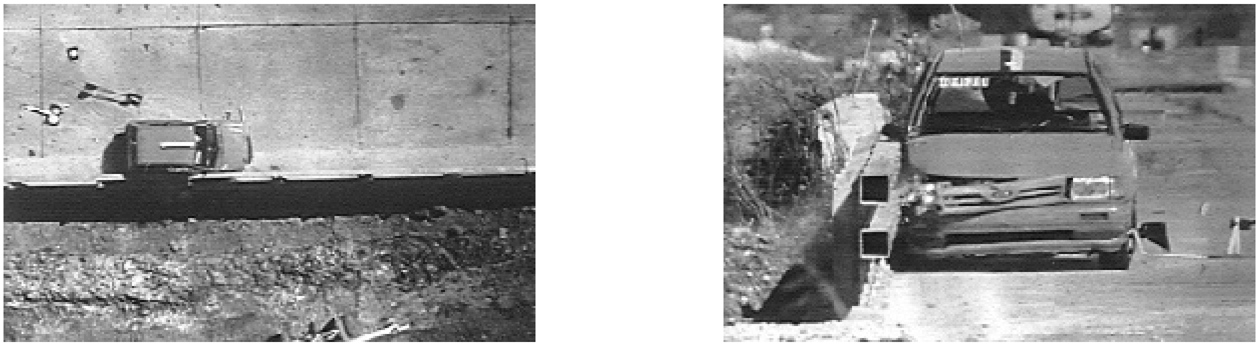
Figure 12. Sequential photographs for test 404531-1
(overhead and frontal views).



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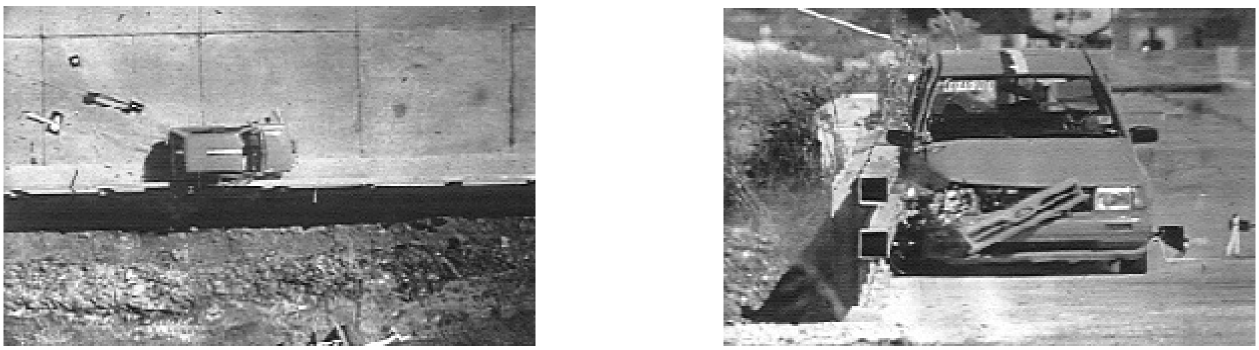
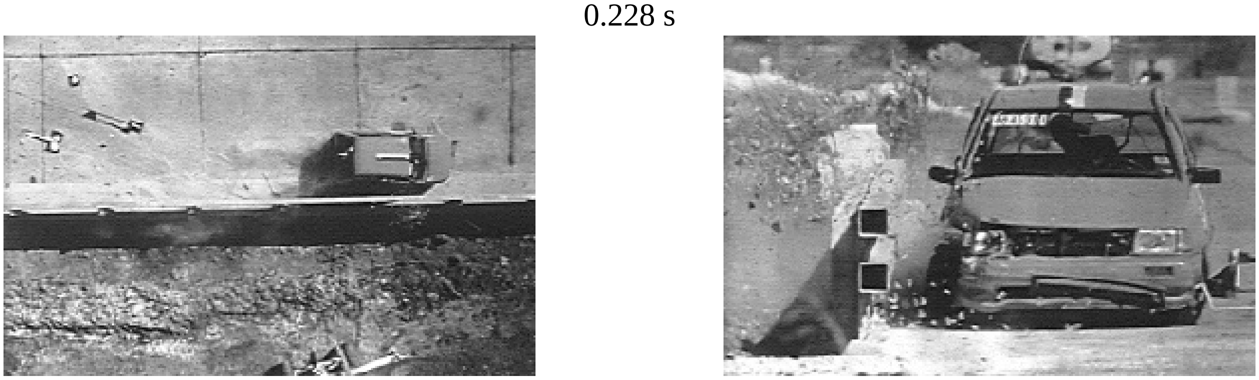


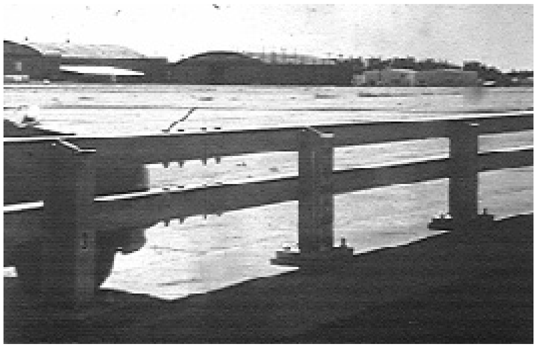
0.156 s

0.228 s



0.349 s

Figure 12. Sequential photographs for test 404531-1
(overhead and frontal views) (continued).



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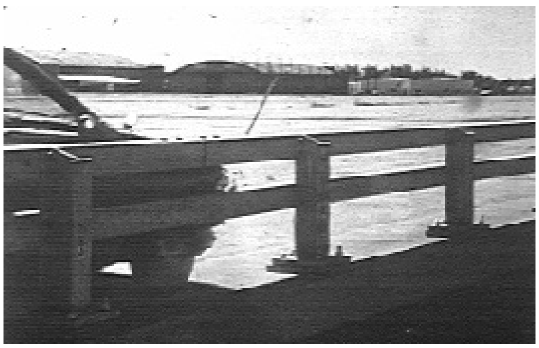

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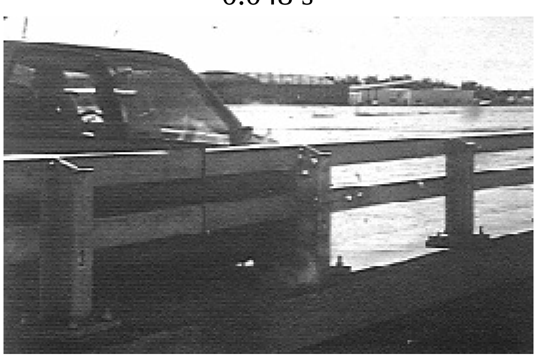

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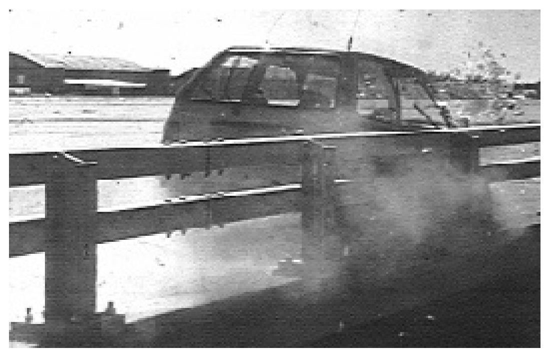

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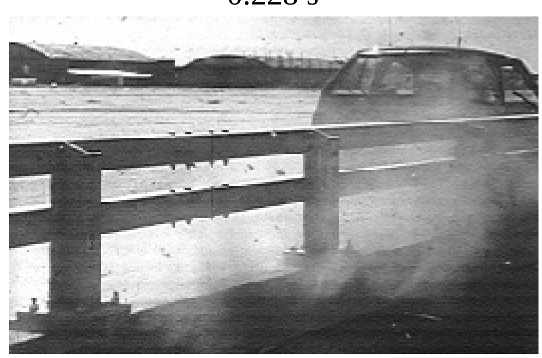

0.349 s

Figure 13. Sequential photographs for test 404531-1
(rear view).

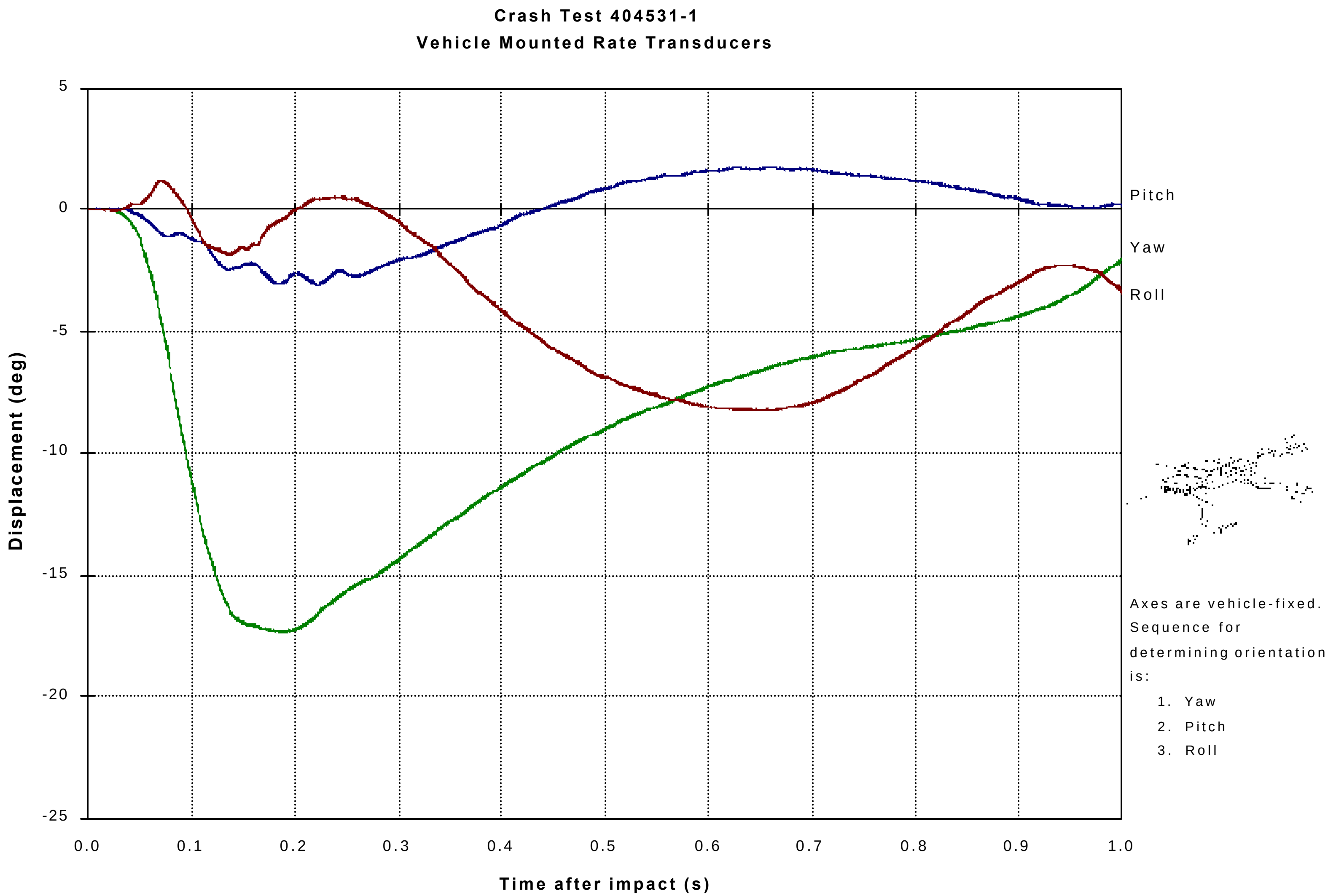

Figure 14. Vehicular angular displacements for test 404531-1.

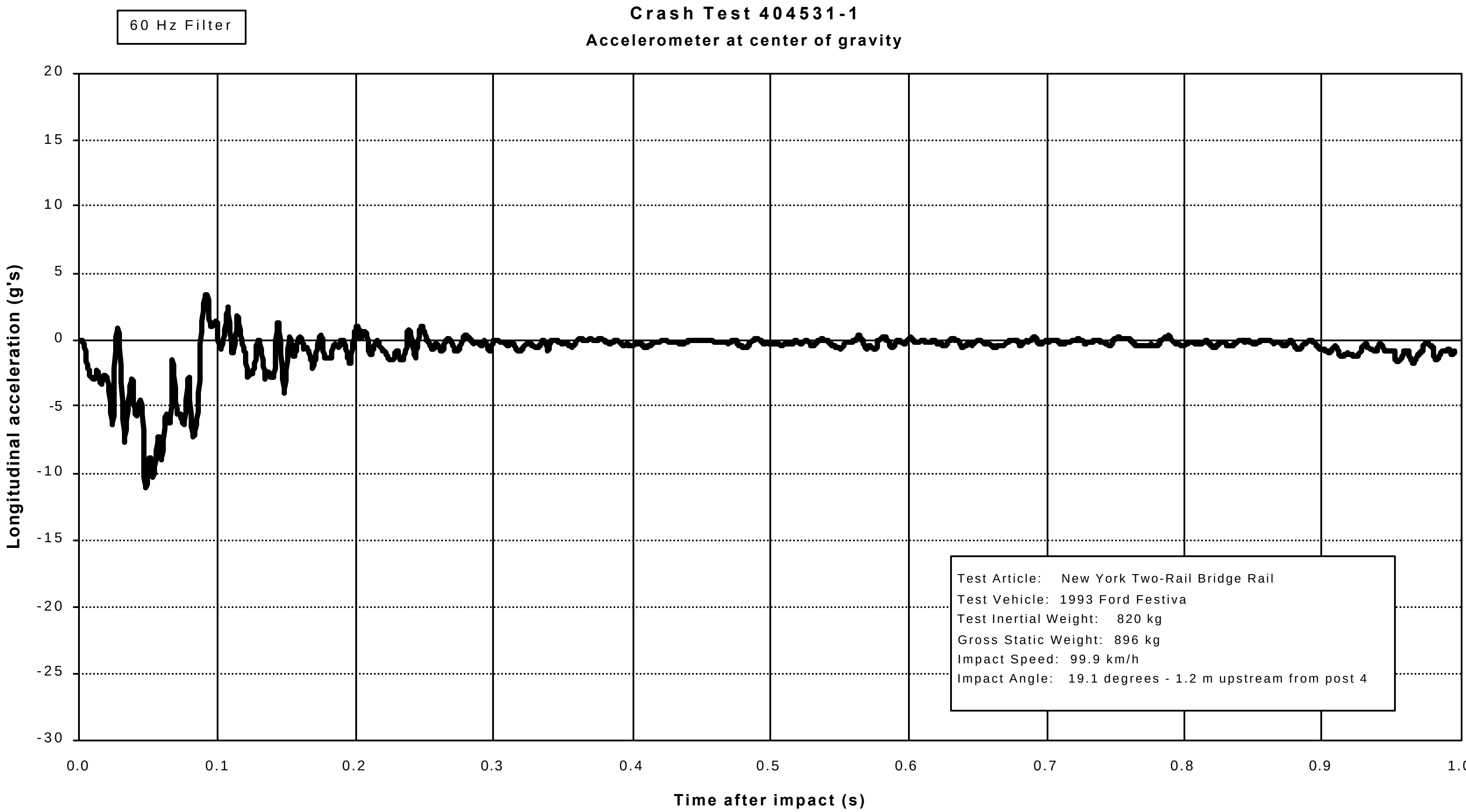

Figure 15. Vehicle longitudinal accelerometer trace for test 404531-1 (accelerometer located at center of gravity).

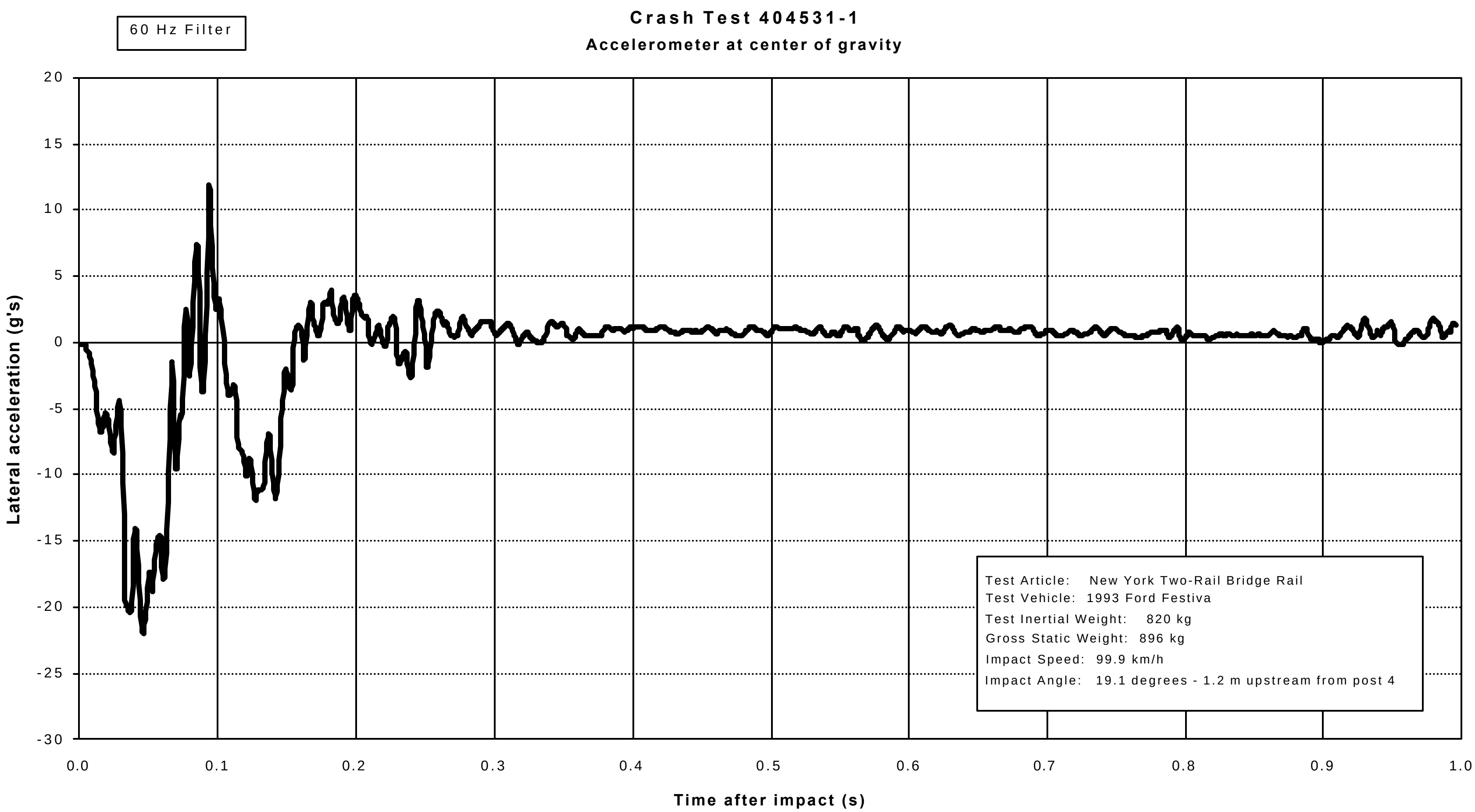

Figure 16. Vehicle lateral accelerometer trace for test 404531-1 (accelerometer located at center of gravity).

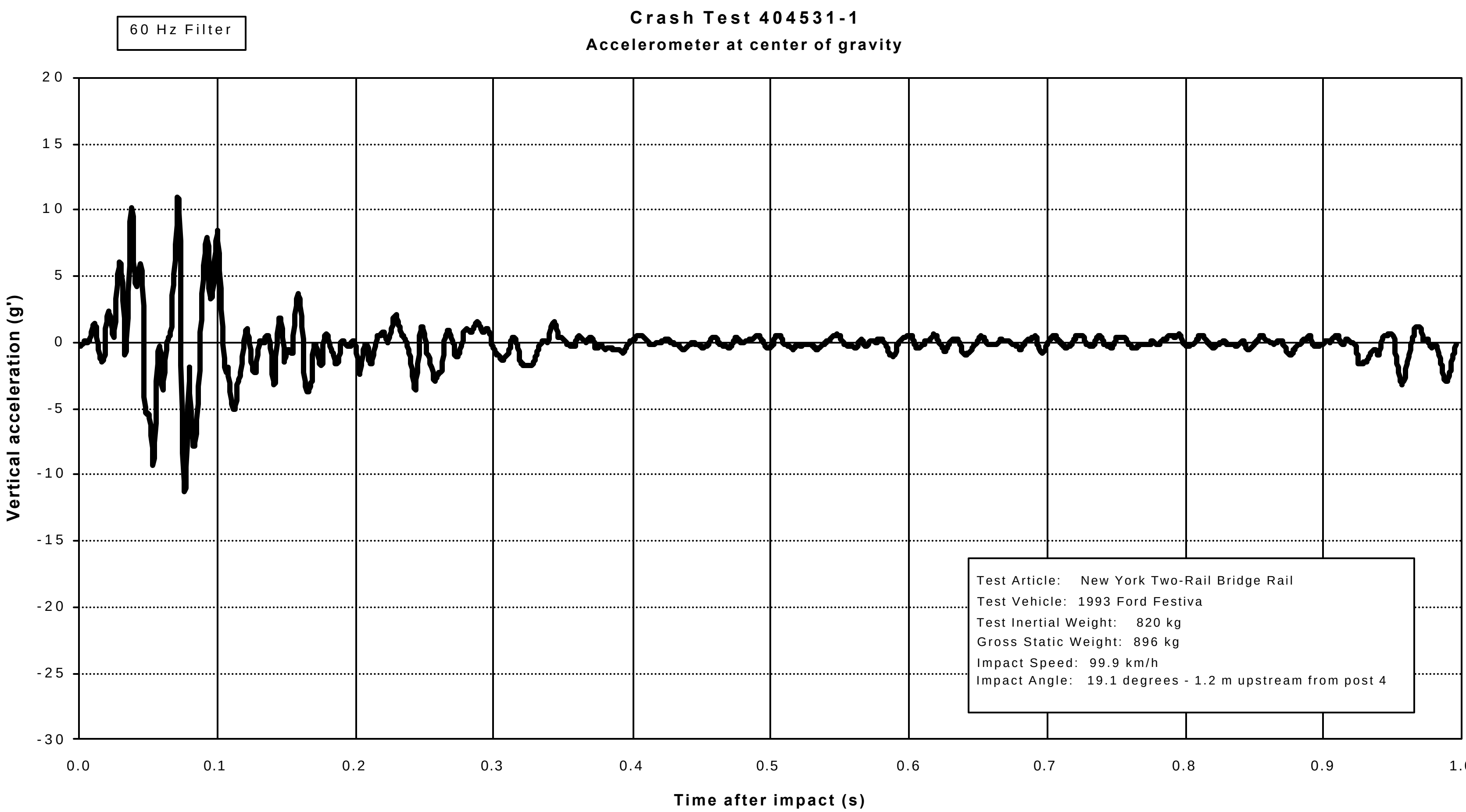

Figure 17. Vehicle vertical accelerometer trace for test 404531-1 (accelerometer located at center of gravity).

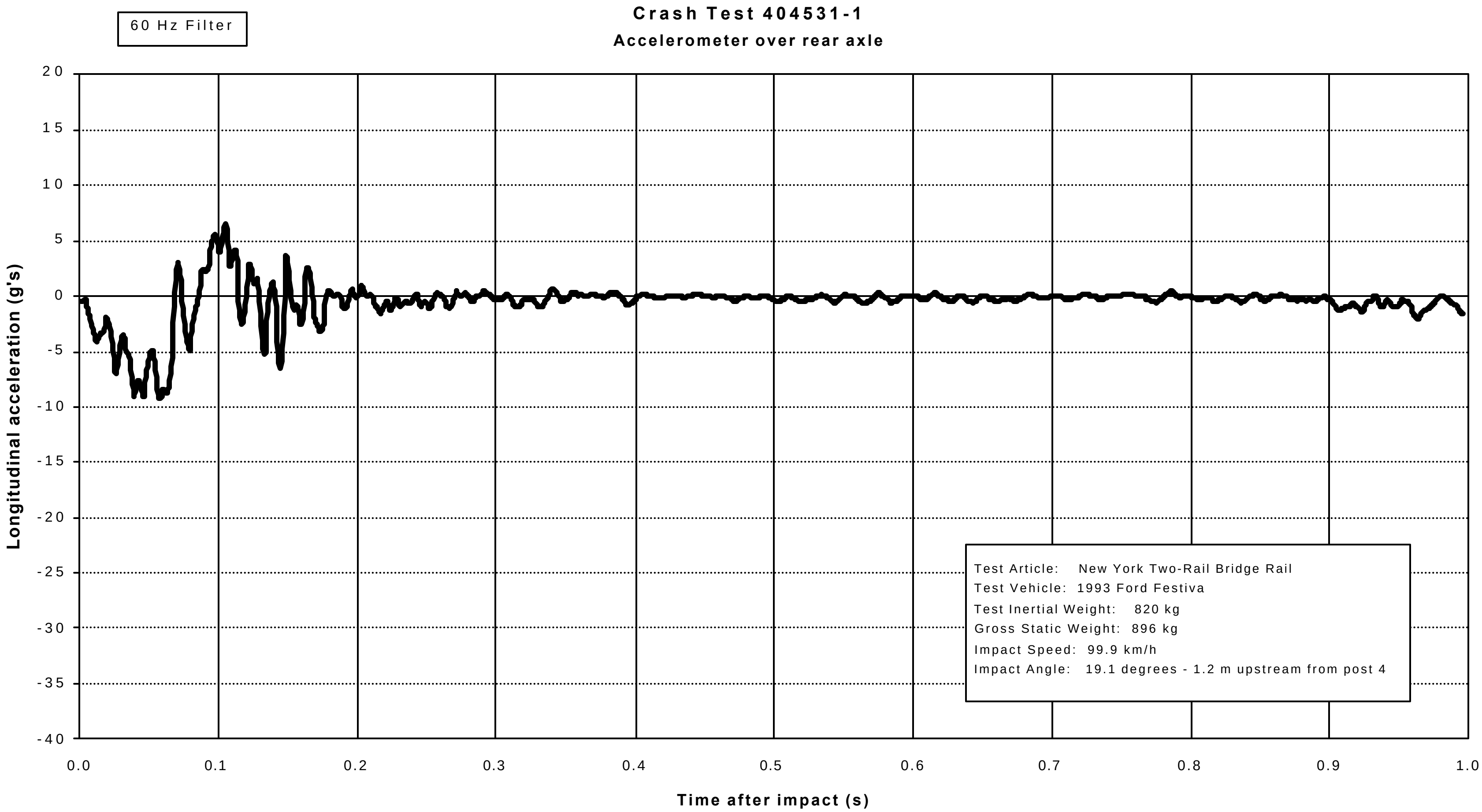

Figure 18. Vehicle longitudinal accelerometer trace for test 404531-1 (accelerometer located over rear axle).

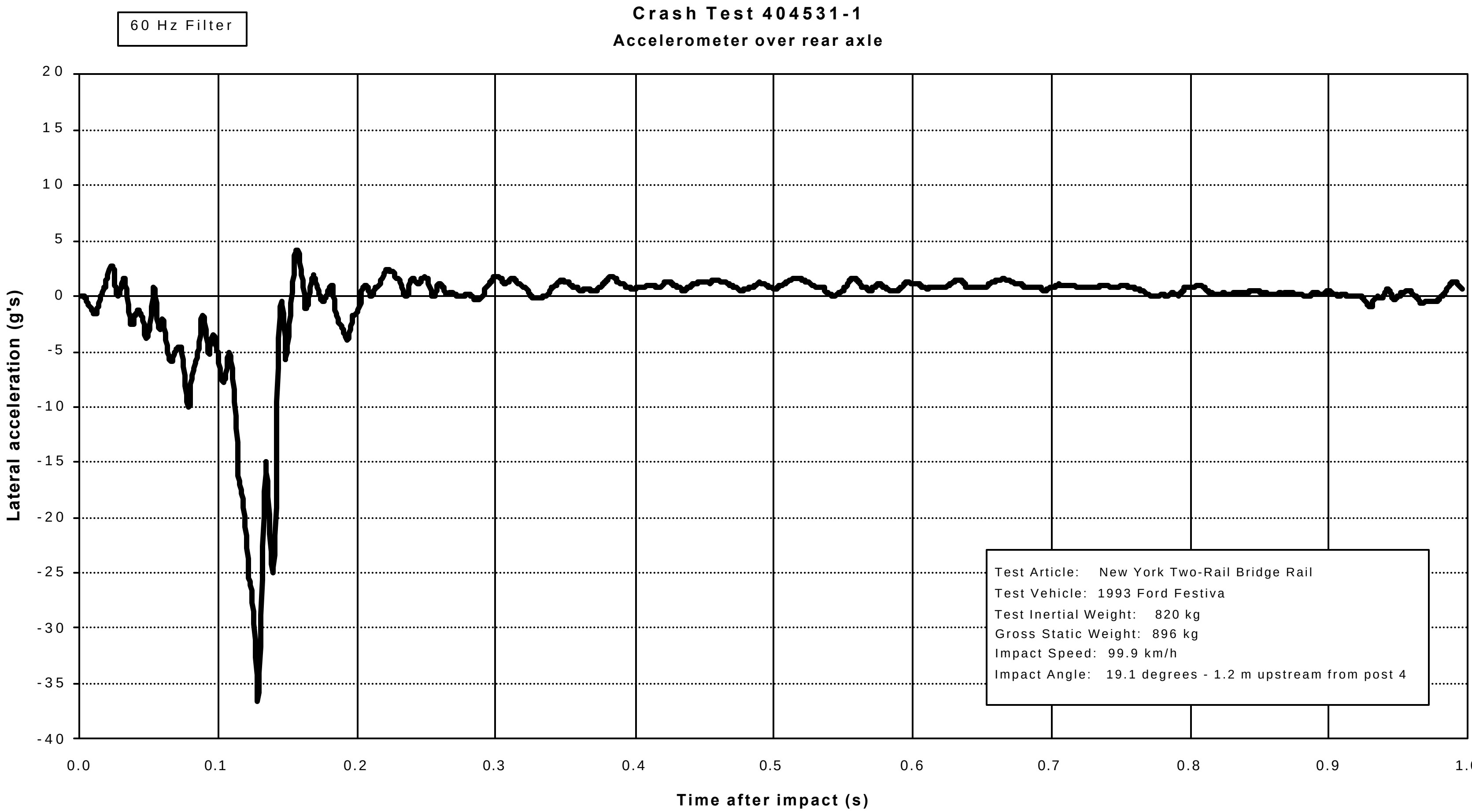

Figure 19. Vehicle lateral accelerometer trace for test 404531-1 (accelerometer located over rear axle).

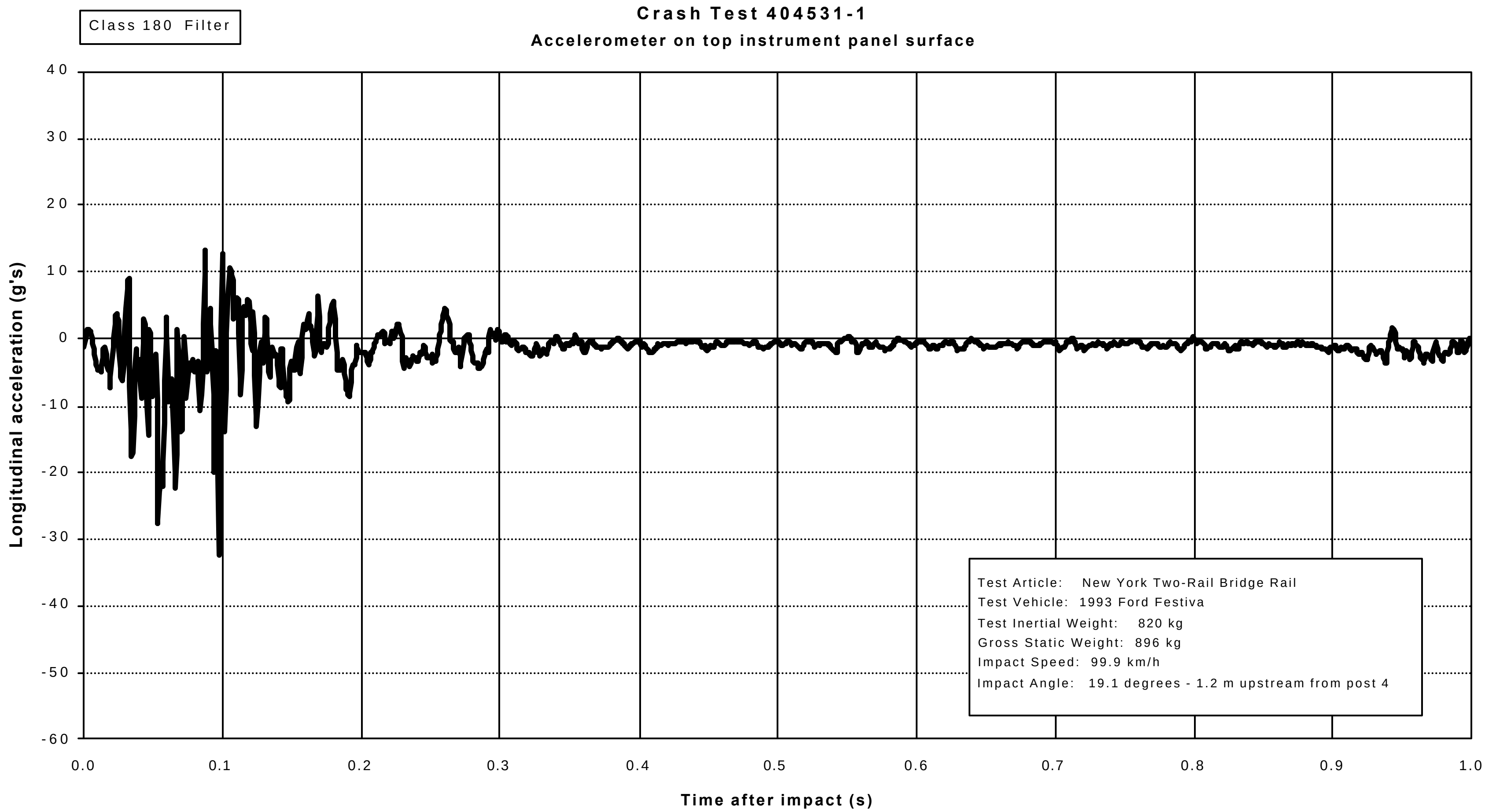

Figure 20. Vehicle longitudinal accelerometer trace for test 404531-1 (accelerometer located on top surface of instrument panel).

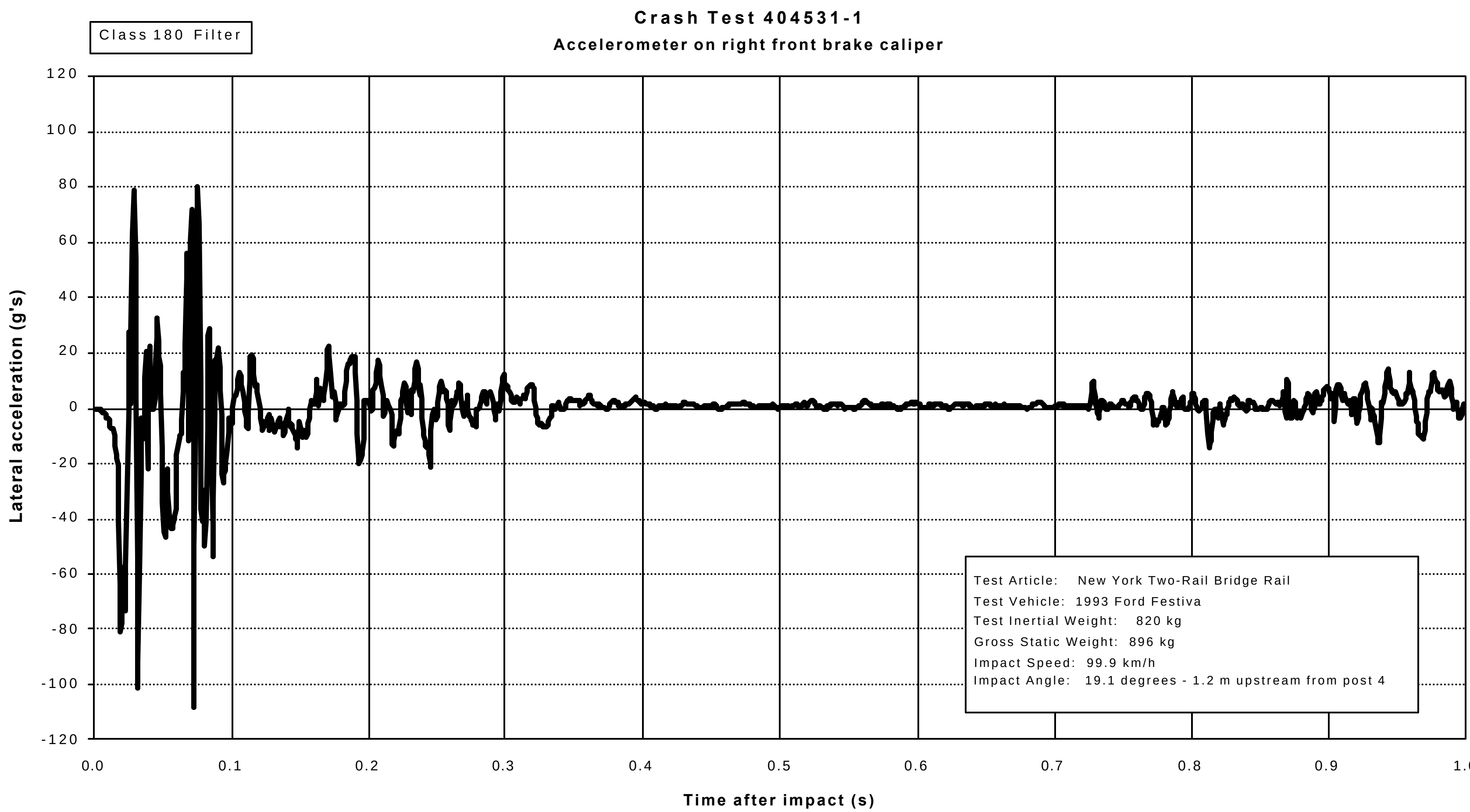

Figure 21. Vehicle lateral accelerometer trace for test 404531-1
(accelerometer located on right front brake caliper).

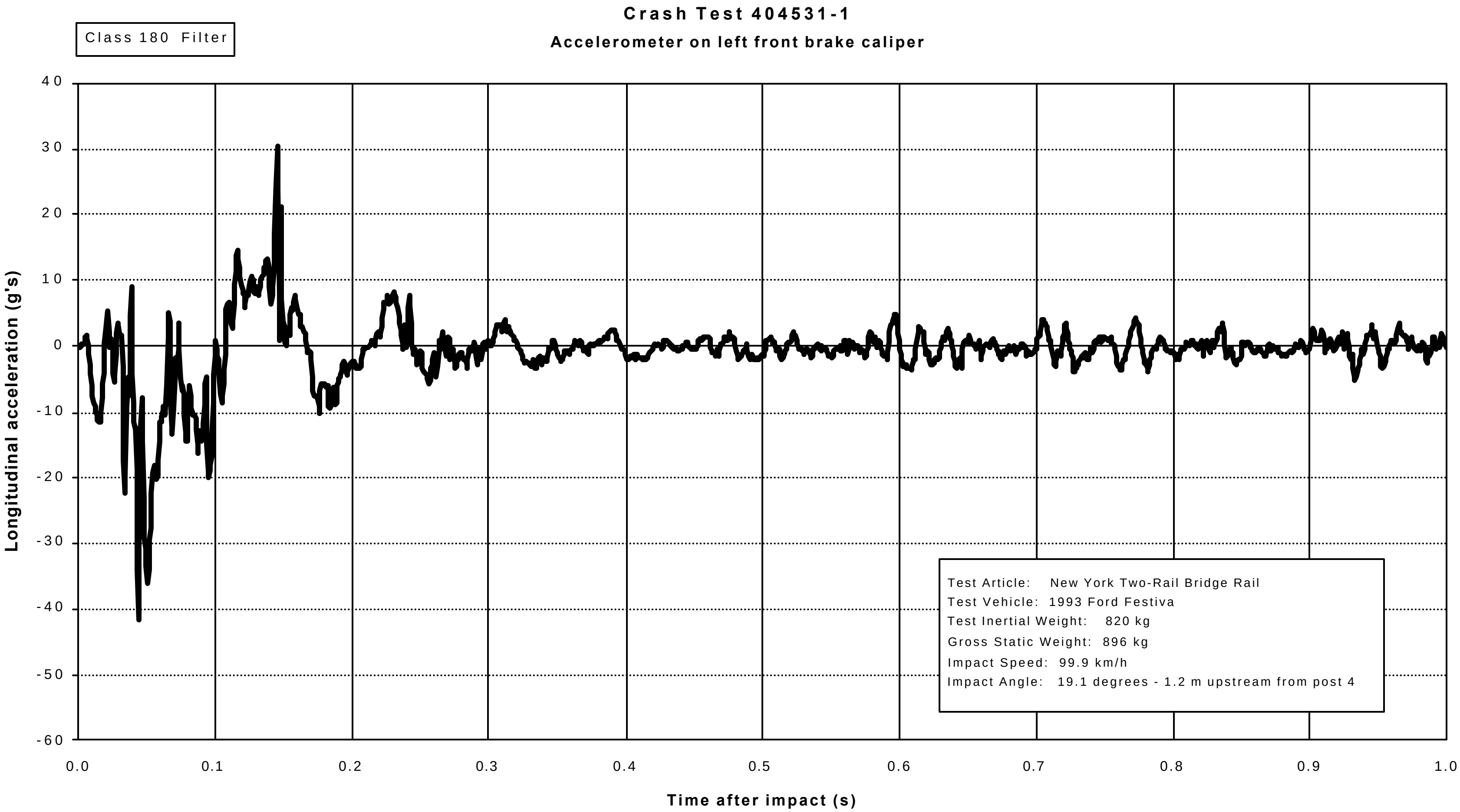

Figure 22. Vehicle longitudinal accelerometer trace for test 404531-1 (accelerometer located on left front brake caliper).

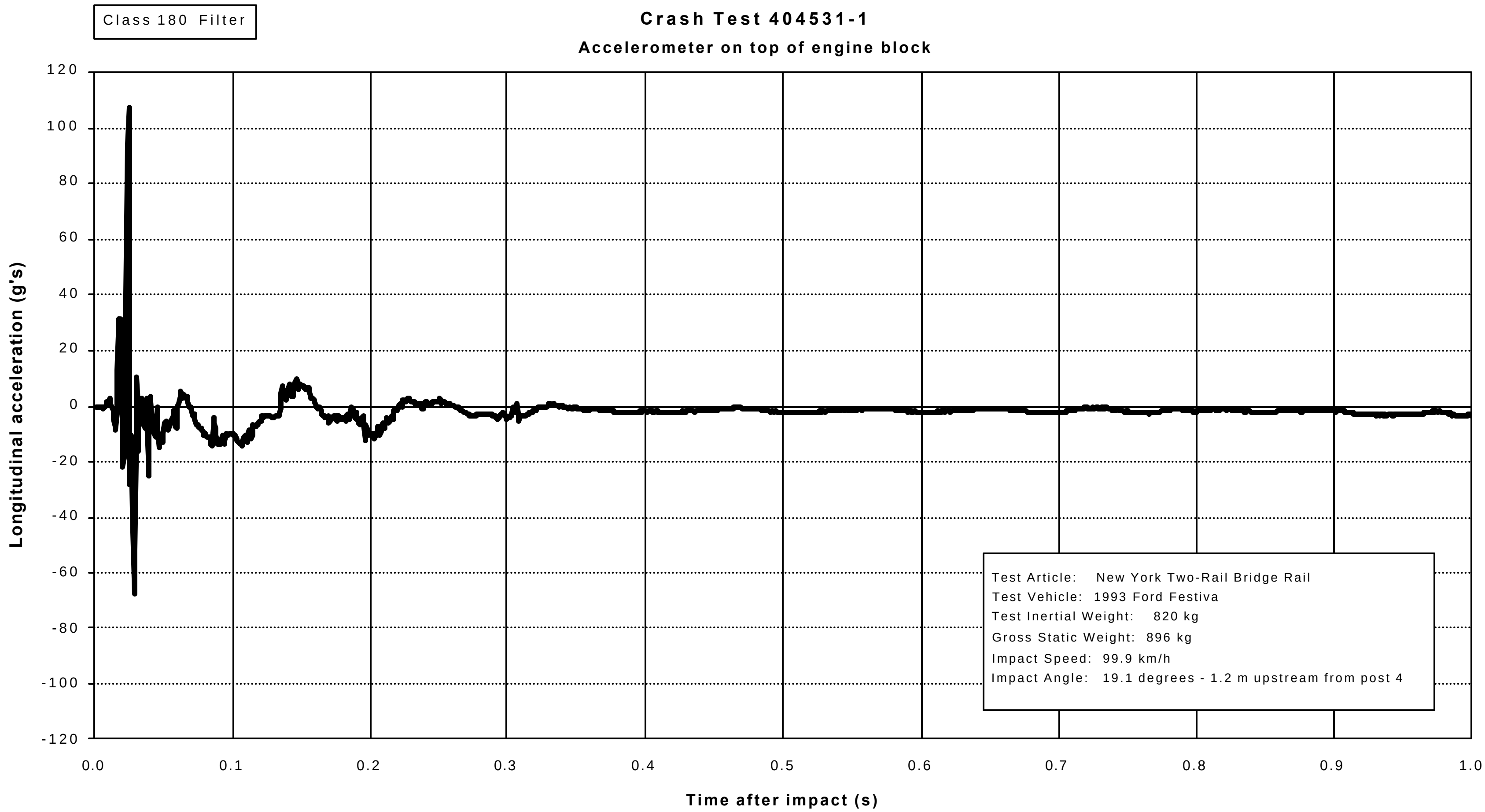

Figure 23. Vehicle longitudinal accelerometer trace for test 404531-1 (accelerometer located on top of engine block).

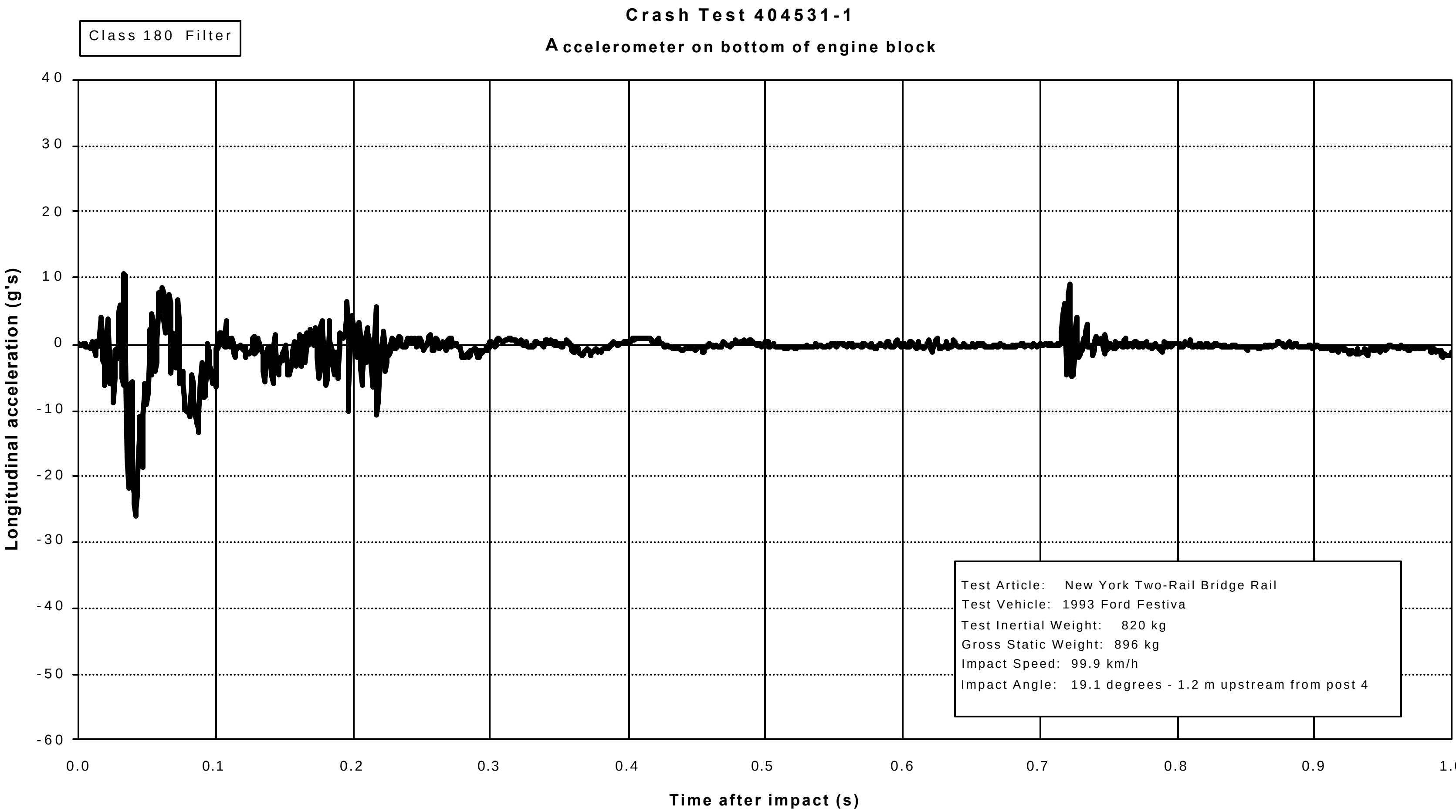

Figure 24. Vehicle longitudinal accelerometer trace for test 404531-1 (accelerometer located on bottom of engine block).

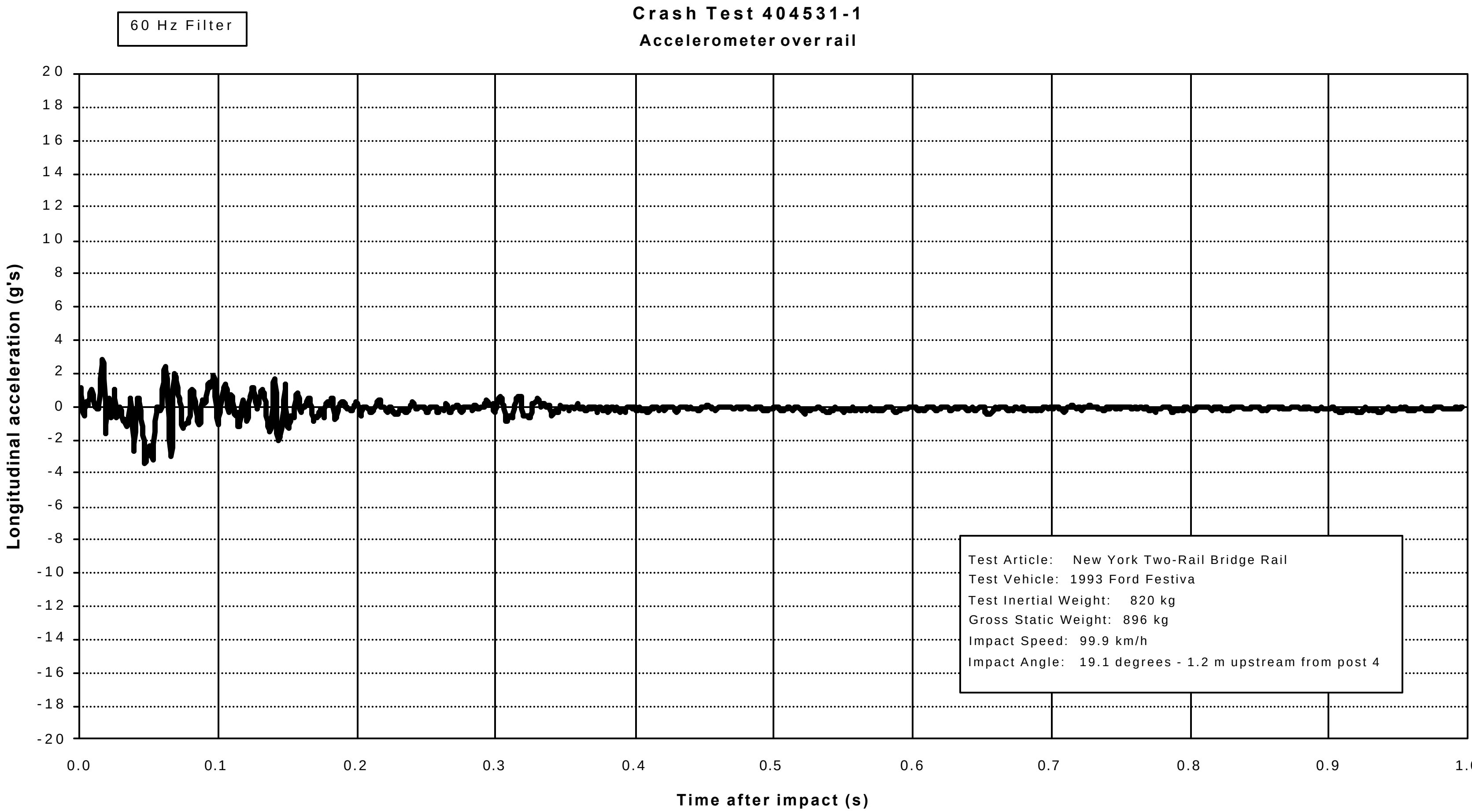

Figure 25. Bridge railing longitudinal accelerometer trace for test 404531-1 (accelerometer located over bridge railing at post 4).

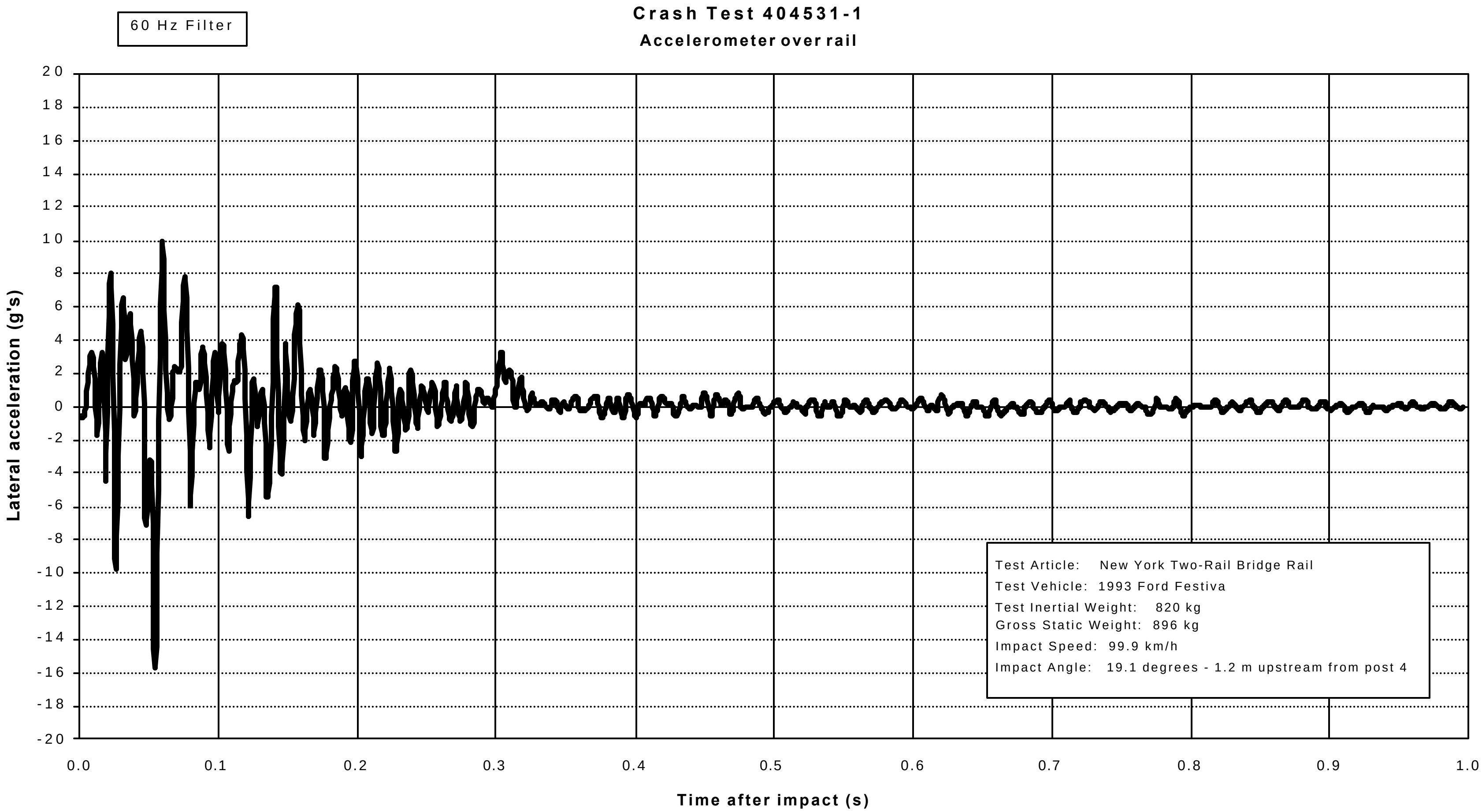

Figure 26. Bridge railing lateral accelerometer trace for test 404531-1 (accelerometer located over bridge railing at post 4).

REFERENCES

1. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer and J. D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

2. Jarvis D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program Report 230, Transportation Research Board, National Research Council, Washington, D.C., March 1981.