NCHRP Report 350 Test 4-11 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
Turner-Fairbank Highway Research Center
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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 second 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, a 2000-kg pickup truck impacted the bridge rail at a nominal speed and angle of 100 km/h and 25 degrees. The bridge rail contained the vehicle and redirected it. At this time there is no widely accepted measure of occupant risks associated with deformations or intrusions into the passenger compartment. Of necessity, this factor must be assessed in large part by the judgment of the test agency and the user agency, or both. The researchers have concluded that this bridge rail did not meet evaluation criteria D and K for Test No. 4-11 in NCHRP Report 350 due to separation in the floor pan and excessive deformation of the occupant compartment.

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Director, Office of Safety
Research and Development

NOTICE

Technical Report Documentation Page

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16. Abstract

This report presents the details of the New York Two-Rail Curbless Bridge Railing and the results of the small car test—National Cooperative Highway Research Program (NCHRP) Report 350 test designation 4-11, which is the 2000-kg pickup truck impacting the critical impact point (CIP) at 100 km/h and 25 degrees. The New York Two-Rail Curbless Bridge Railing did not meet criteria D and K of NCHRP 350 test designation 4-11, due to separation in the floor pan and excessive deformation of the occupant compartment.

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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.

Symbol	When You Know	Multiply by	To Find	Symbol
		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 the 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 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. In order to evaluate the bridge railing to *NCHRP Report 350* 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 and the results of the pickup truck test—*NCHRP Report 350* test designation 4-11, which is the 2000-kg pickup truck impacting the CIP at 100 km/h and 25 degrees. The New York Two-Rail Curbless Bridge Railing did not meet criteria D and K of *NCHRP Report 350* test designation 4-11. For criterion D, the test failed the occupant compartment deformation requirements due to separation in the floor pan and excessive deformation into the occupant compartment. The resulting damage to the occupant compartment was judged to have potential for causing serious injury to the occupant. For criterion K, the vehicle intruded into adjacent traffic lanes; however, this criterion is preferable, not required.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's (TTI) Proving Ground consist of an 890-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 placement 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 the construction of the concrete deck installation and fabrication of the Two-Rail Bridge Railing System. Based on these details, TTI prepared separate 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 specified 28-day compressive strength of the concrete used to construct the deck was 27.6 MPa. Measured compressive strength at one day after the crash test (23 days of age) was 27.7 MPa. Prior to

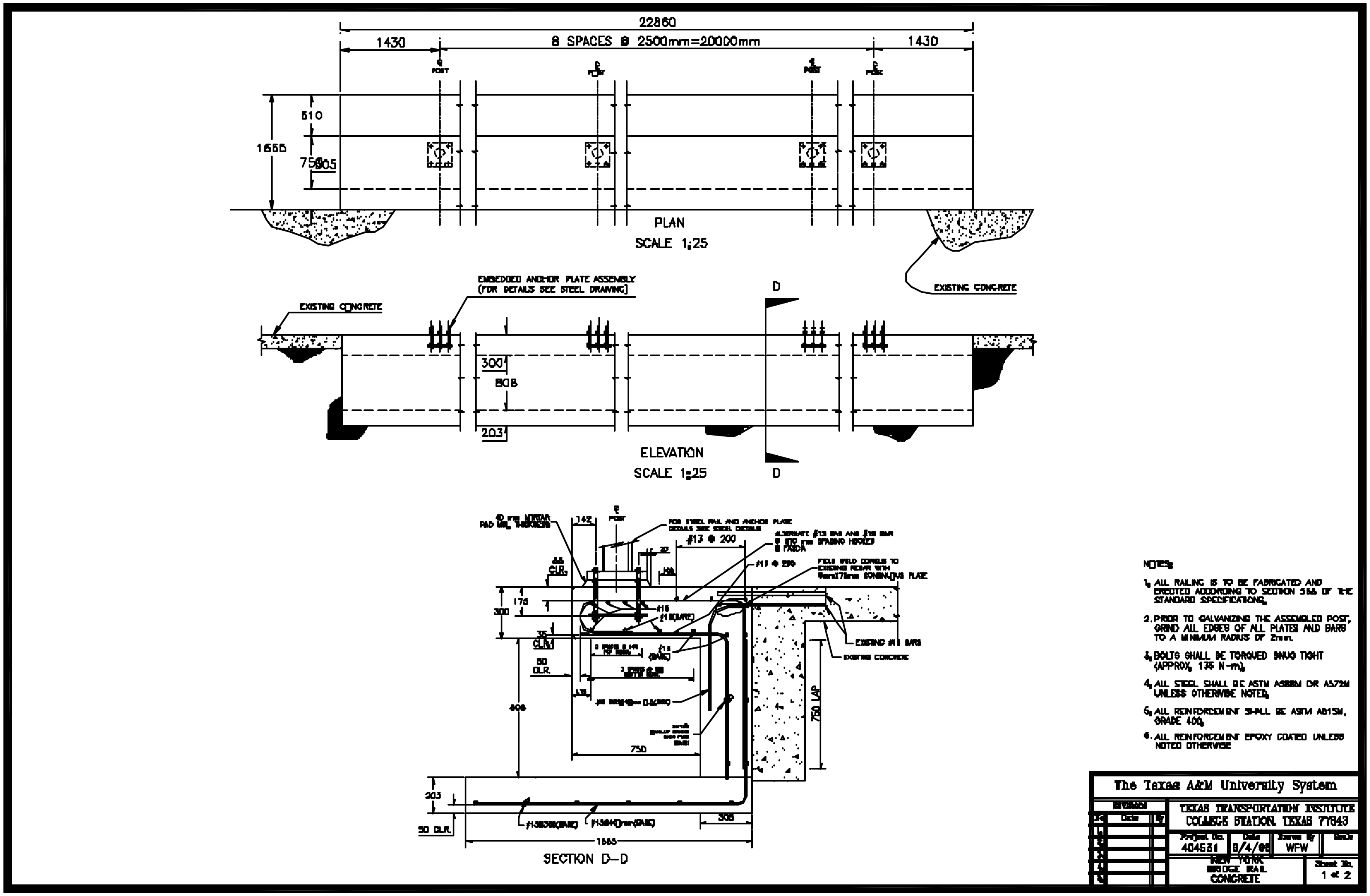


Figure 1. Details of the New York Curbless Two-Rail Bridge Railing for test 404531-1.

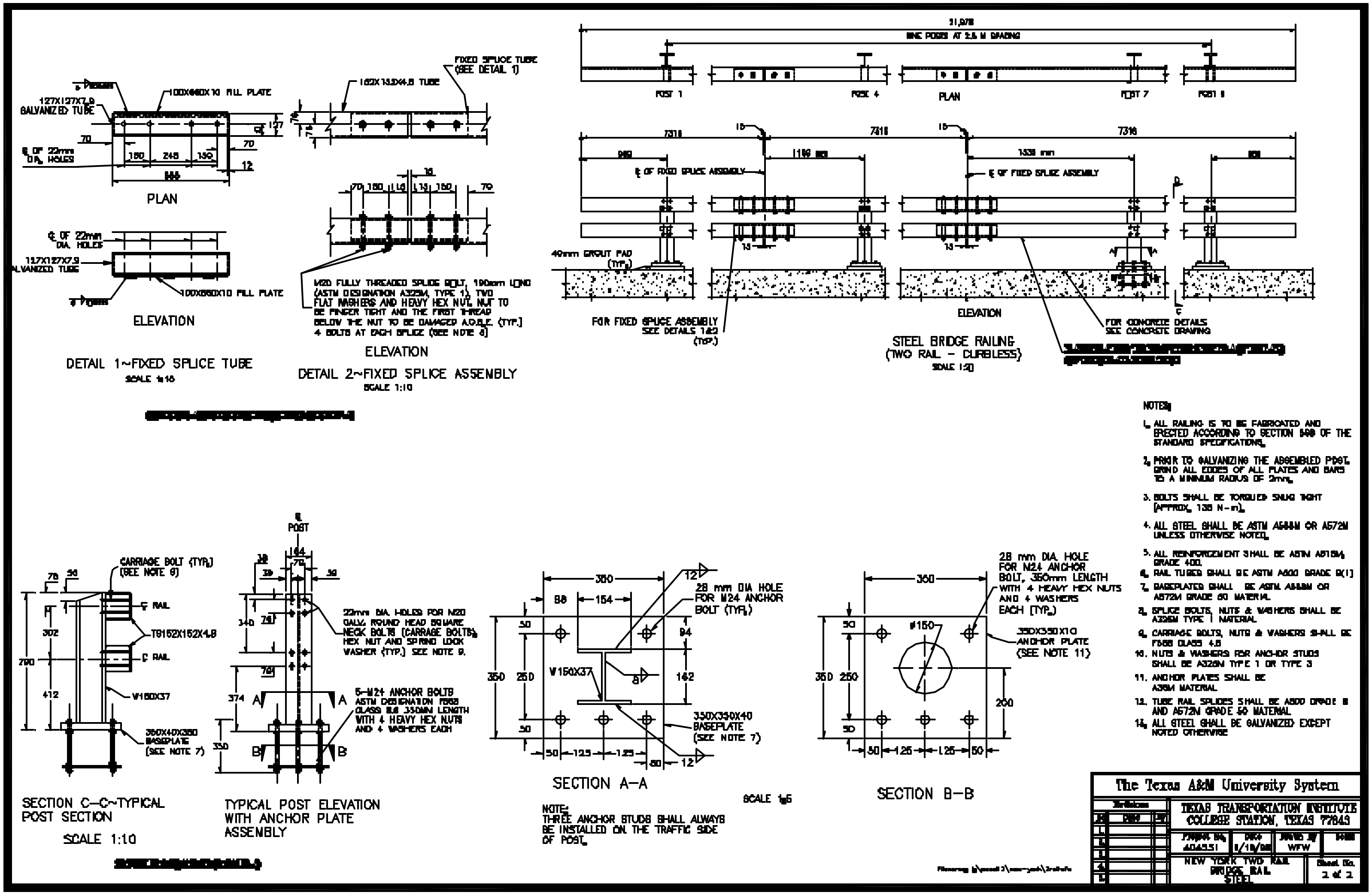


Figure 2. Layout of test installation.

constructing the deck, a concrete footing was constructed to provide additional support for the concrete deck. The footing measured 1665 mm in width and was 203 mm deep.

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 base plates 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 190-mm bolts. The splice tube bolts met the requirements for 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 materials. For additional information, see figures 1 and 2.

All material was galvanized except for the anchor bolts and anchor plates. The completed installation is shown in figures 3 and 4.

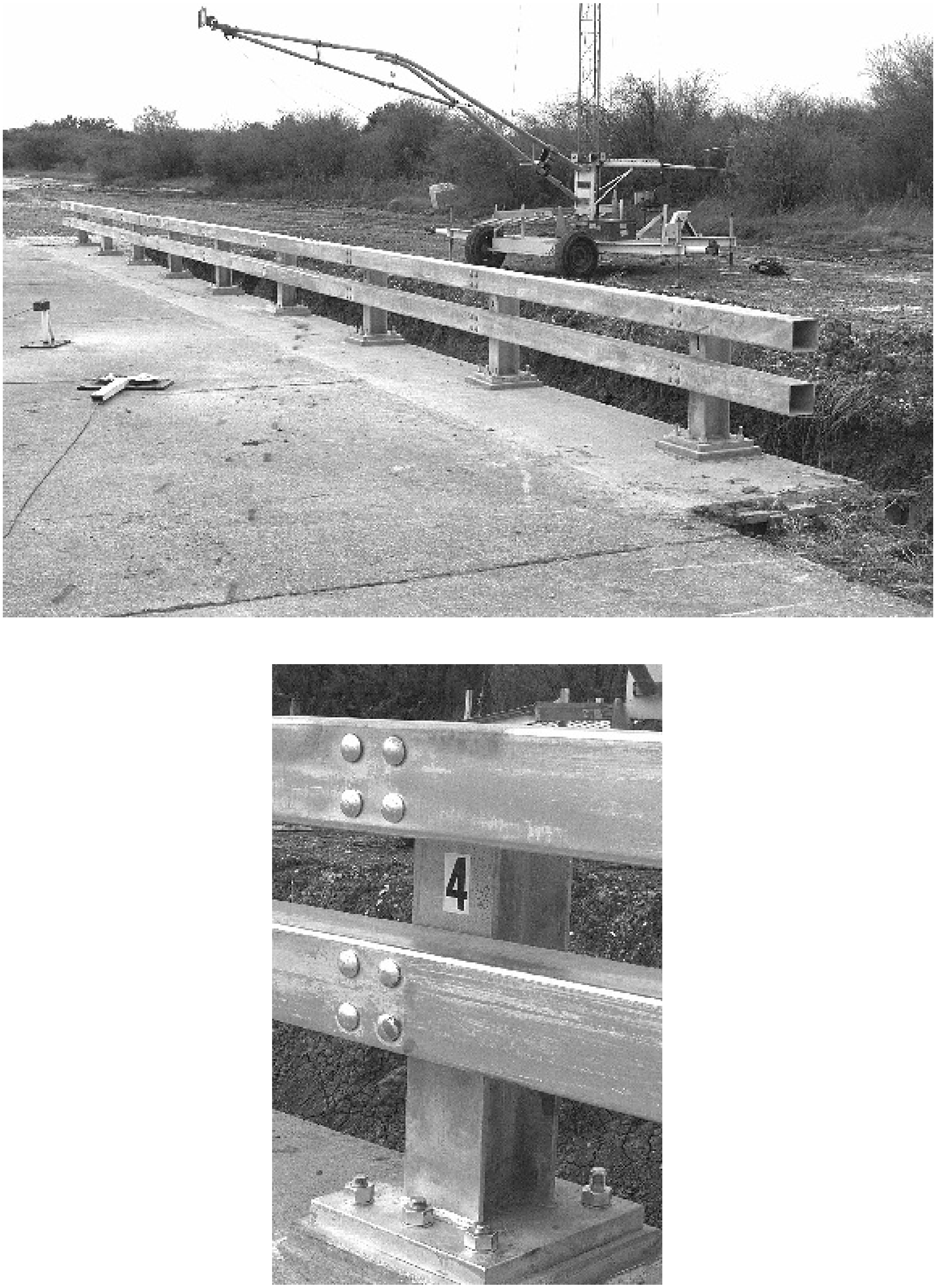


Figure 3. New York Two-Rail Curbless Bridge Railing before test 404531-2.

Figure 4. Details on field side of installation.

Test Conditions

According to *NCHRP Report 350*, three tests are required to evaluate longitudinal barriers 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. The purpose of this test is to evaluate the overall performance of the LON section in general, and occupant risks 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 the 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 test reported herein corresponds to *NCHRP Report 350* test designation 4-11.

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.

- **Vehicle Trajectory**

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

L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.

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

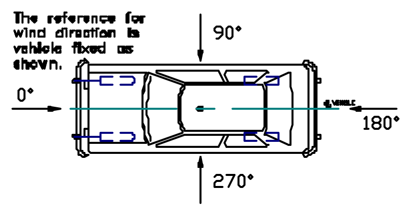
CRASH TEST 404531-2

Test Vehicle

A 1994 Chevrolet 2500 pickup, shown in figures 5 and 6, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2075 kg. The height to the lower edge of the vehicle front bumper was 390 mm and to the upper edge of the front bumper was 620 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 13. 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.

Soil and Weather Conditions

The crash test was performed the morning of October 27, 1998. A total of 178 mm of rain was recorded six days prior to the test but did not affect the test, as the bridge railing was installed on the concrete deck. No other rainfall occurred during the ten days prior to the study. Weather conditions at the time of testing were as follows: Wind Speed: 3 km/h; Wind Direction: 200 degrees with respect to the vehicle (vehicle traveling in southerly direction); Temperature: 25EC; Relative Humidity: 63 percent.



Impact Description

The vehicle, traveling at 101.7 km/h, impacted the two-rail bridge railing 1.3 m upstream from post 4 at a 25.4-degree angle. Shortly after impact, the lower rail element moved. At 0.007 s, the upper rail element deformed, and at 0.017 s, the right front tire contacted the lower bridge rail. By 0.019 s, the front right wheel steered left, and at 0.029 s, the front right tire was parallel with the bridge rail. The front right tire canted and the lower tire and rim traveled under the rail element at 0.034 s. At 0.035 s, the front left wheel steered left, and post 4 moved at 0.039 s. The vehicle began to redirect at 0.041 s. The first visible crack in the deck appeared on the field side of the installation at 0.049 s. At 0.056 s, the front right tire contacted the base of post 4, and at 0.060 s, the front left wheel steered right, toward the bridge rail. By 0.061 s, the front right tire contacted post 4, the concrete on the bridge deck surface in front of post 4 separated from the deck, and more cracks appeared on the field side of the installation. At 0.066 s, the farthest-most crack appeared downstream from post 4 on the field side of the installation. The right front tire deflated at 0.070 s, and the right rear tire contacted the lower rail element and traveled down the rail past post 4 at 0.178 s. Yawed toward the rail, the left rear side of the vehicle impacted the rail. Traveling at 84.2 km/h, the vehicle was parallel with the installation at 0.186 s. The left and right rear tires lost contact with the ground at 0.244 s. At

Figure 5. Vehicle/installation geometrics for test 404531-2.

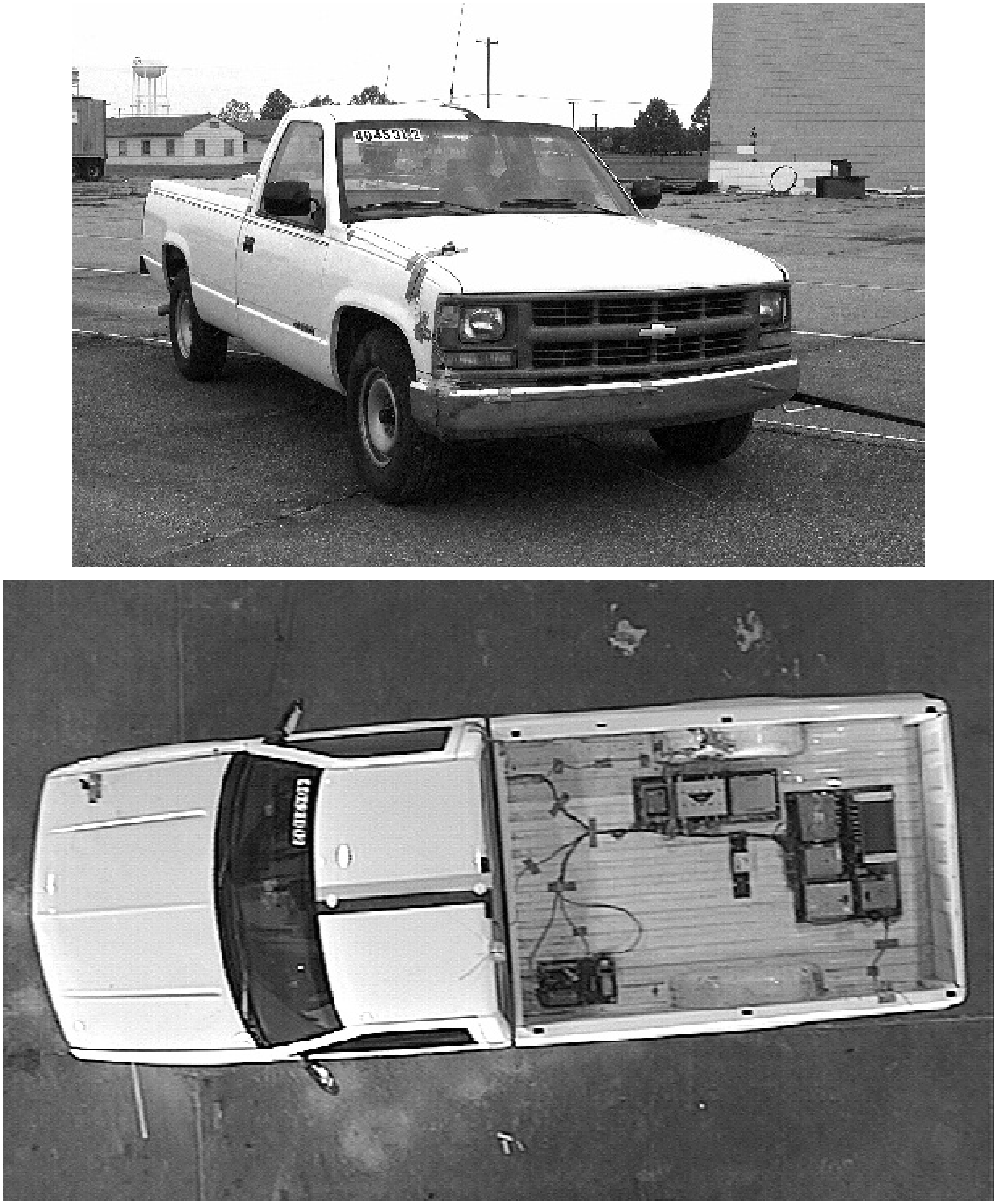


Figure 6. Vehicle before test 404531-2.

0.341 s, traveling at 83.4 km/h, the vehicle lost contact with the bridge railing at a 7.4-degree angle. The left and right rear tires returned to the road surface at 0.577 and 0.638 s, respectively. Brakes on the vehicle were applied at 1.6 s, bringing the vehicle to rest 69.3 m downstream and 12.2 m toward the traffic lanes. Sequential photographs of the test period are shown in appendix C, figures 14 and 15.

Damage to Test Article

Damage to the New York Two-Rail Curbless Bridge Railing is shown in figures 7 through 9. Tire marks extended 225 mm behind the rail element at impact and tire marks were on the edges of the front and rear flange on the impact side of post 4, on the front face of the post and on the front anchor bolts. The tubular element in the vicinity of post 4 was partially flattened and the four bolts connecting the lower element were partially pulled out and deformed (see figure 8). Numerous cracks in the concrete deck surrounded post 4 and part of the concrete deck was broken away. After removal of the broken concrete around post 4, the exposed reinforcement did not show any signs of damage (see figure 9). At post 5, tire marks were on the front flange on the impact side of the post and extended 200 mm behind the rail element. Total length of vehicle contact with the rail elements was 3.3 m.

Vehicle Damage

The vehicle sustained structural damage on the front right and the right side. The sway bar, tie rod, right front upper and lower A-arms, upper ball joint, right A-post, drive shaft, and transmission housing were all severely damaged. The front right portion of the bumper, hood, grill, fan, radiator, right front tire, and rim were damaged as shown in figure 10. The windshield was shattered and the right door was deformed outward 150 mm. The right front quarter panel and rear bed were dented. The front end of the vehicle shifted 150 mm to the left. At the rear of the vehicle on the right side, the rear tire and rim sustained damage, the rear axle was pushed back, and the rear U-bolts at the leaf springs were broken. The maximum exterior crush to the front bumper was 470 mm on the front and 340 mm on the right side. The floor pan was separated at the seam just above the upward curve (where the occupant's feet normally rest). The opening in the floor pan at the separation was judged to be wide enough to allow an occupant's foot to become jammed into the opening or go through (see lower photo in figure 11). This result was judged to have a potential for causing serious injury to the occupant. Maximum deformation of the occupant compartment was 199 mm (17.6-percent reduction in space) in the floor pan area and maximum reduction of space was 38.8 percent in the center floor pan to instrument panel area. The interior of the vehicle is shown in figure 11. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 3 and 4.

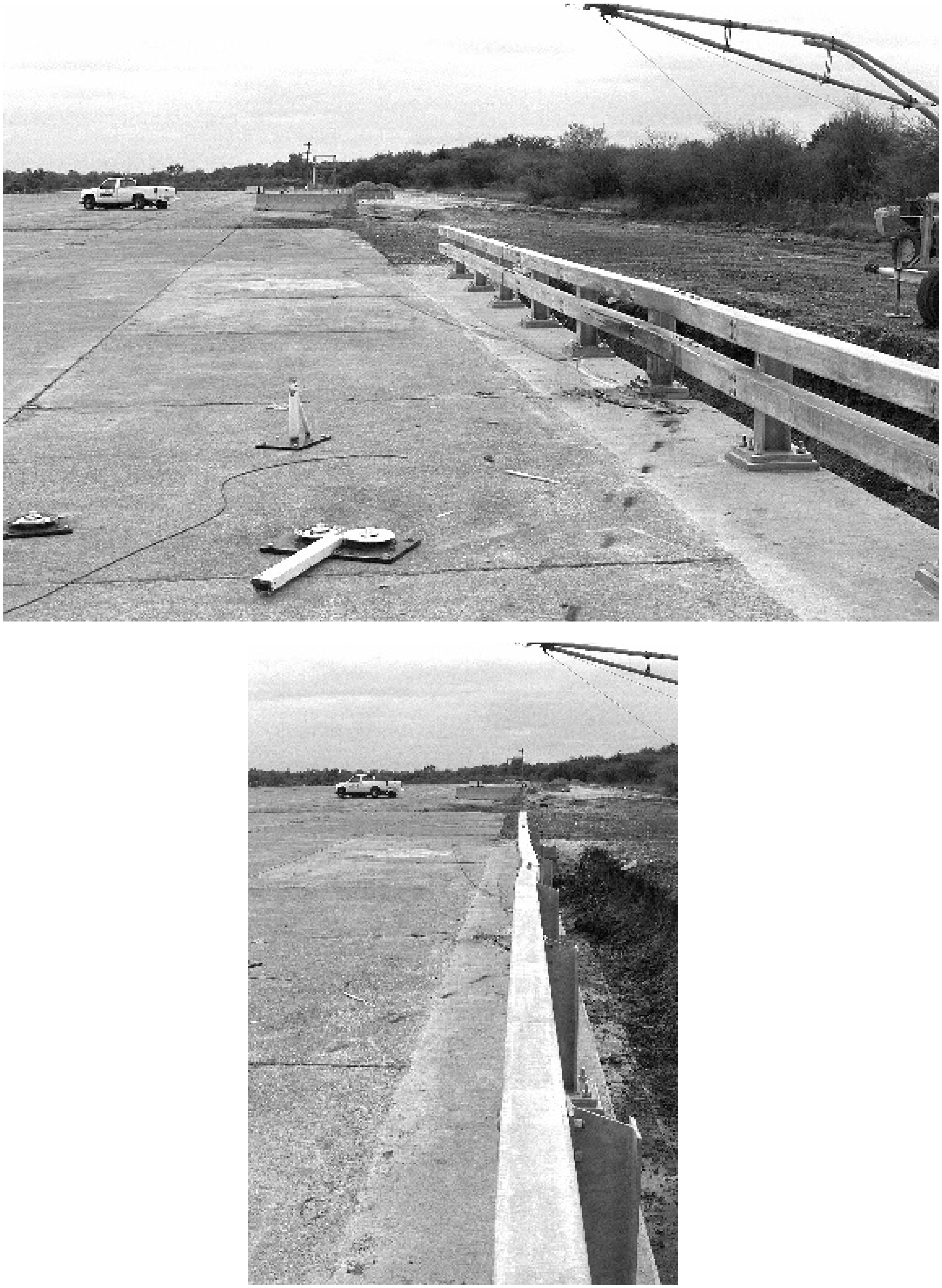


Figure 7. After-impact trajectory for test 404531-2.

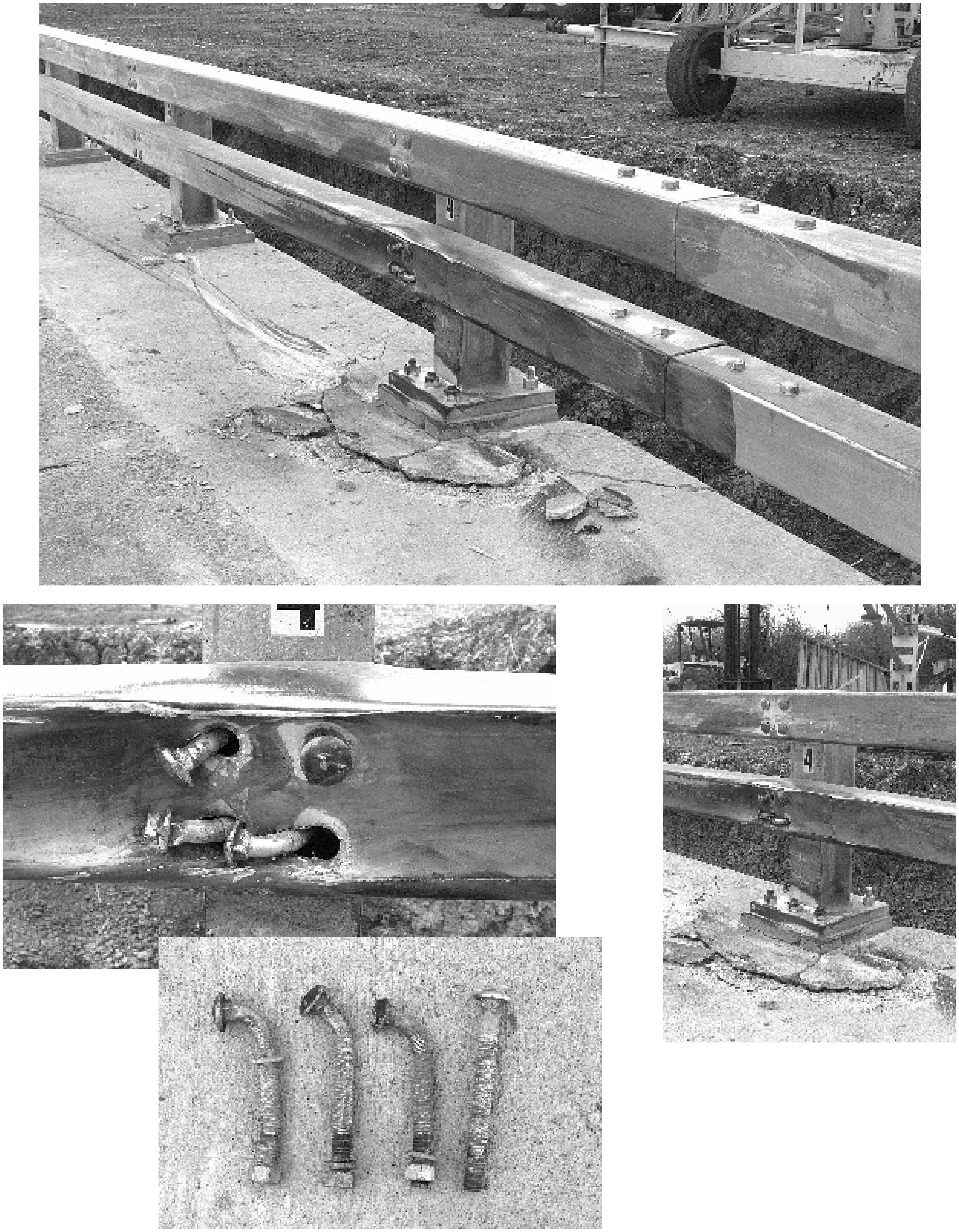
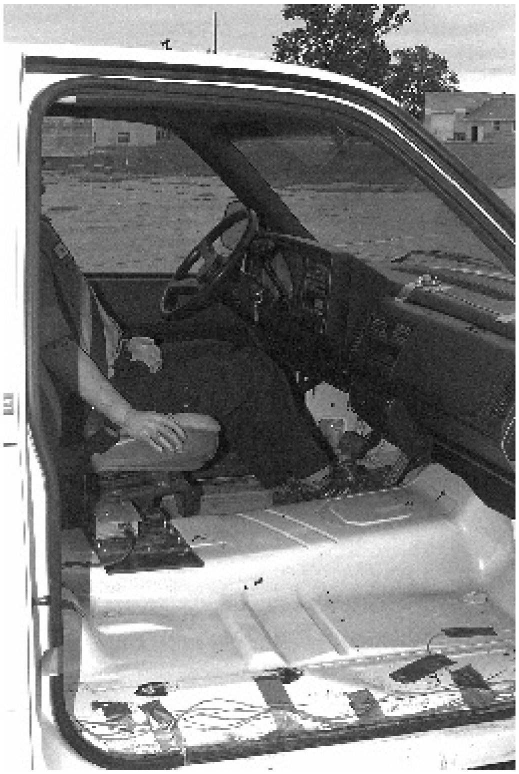


Figure 8. Damage to rail at post 4 after test 404531-2.

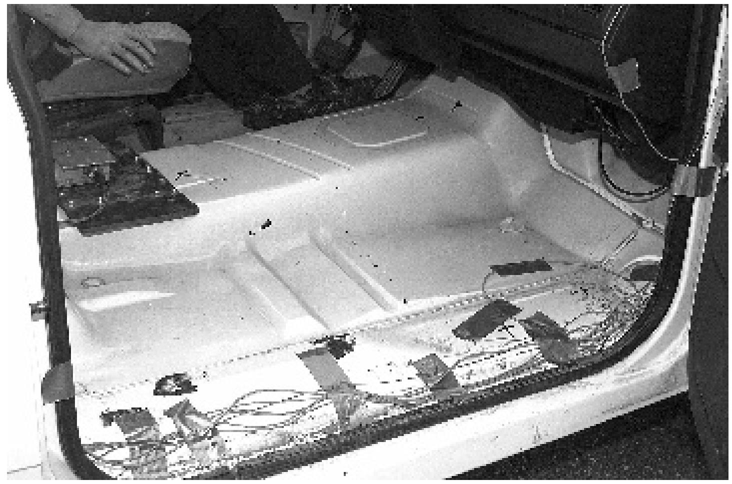
After removing concrete

Figure 9. Damage to deck at post 4 after test 404531-2.

Figure 10. Vehicle after test 404531-2.



Before test



After test

Figure 11. Interior of vehicle for test 404531-2.

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, override, or underride 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, or 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 the potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 199 mm (17.6-percent reduction in space) in the floor pan area and maximum reduction of space was 38.8 percent in the center floor pan to instrument panel area with separation of the floor pan just above the upward curve (where the occupant's feet normally rest).

  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 event.

- **Vehicle Trajectory**

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

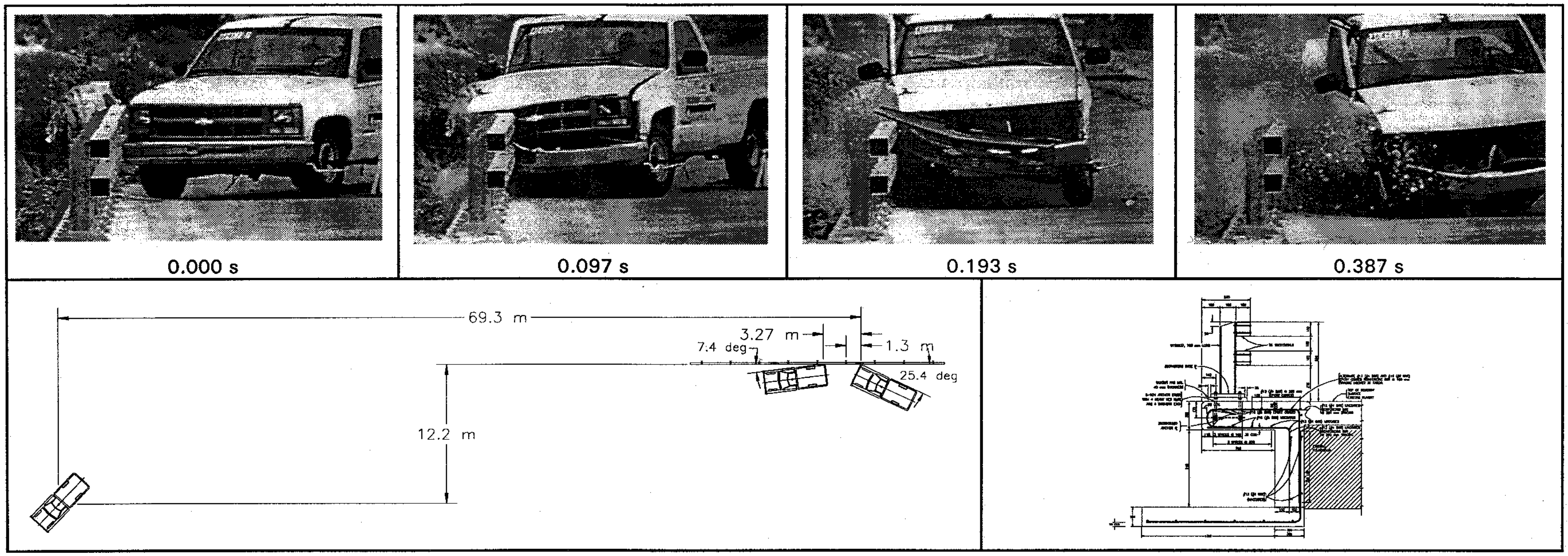
Intrusion into adjacent traffic lanes occurred as the vehicle came to rest 12.2 m toward traffic.

L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.*

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 7.1 m/s at 0.160 s, the highest 0.010-s occupant ridedown acceleration was -9.1 g's from 0.104 to 0.114 s, and the maximum 0.050-s average acceleration was -10.1 g's between 0.036 and 0.086 s. In the lateral direction, the occupant impact velocity was 7.2 m/s at 0.098 s, the highest 0.010-s occupant ridedown acceleration was -12.1 g's from 0.131 to 0.141 s, and the maximum 0.050-s average was -12.6 g's between 0.016 and 0.066 s. These data and other pertinent information from the test are summarized in figure 12. Vehicle angular displacements and accelerations versus time traces are presented in appendix D, figures 16 through 29.

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 7.4 degrees, which was less than 60 percent of the impact angle.



General Information	
Test Agency	Texas Transportation Institute
Test No.	404531-2
Date	10/27/98
Test Article	
Type	Bridge Railing
Name	New York 2-Rail Bridge Railing
Installation Length (m)	22.0
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	2000P
Model	1994 Chevrolet 2500 pickup truck
Mass (kg)	
Curb	1922
Test Inertial	2000
Dummy	75
Gross Static	2075

Impact Conditions	
Speed (km/h)	101.7
Angle (deg)	25.4
Exit Conditions	
Speed (km/h)	83.4
Angle (deg)	7.4
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.1
y-direction	7.2
THIV (km/h)	30.3
Ridedown Accelerations (g's)	
x-direction	-9.1
y-direction	-12.1
PHD (g's)	13.1
ASI	1.53
Max. 0.050-s Average (g's)	
x-direction	-10.1
y-direction	-12.6
z-direction	-5.8

Test Article Deflections (m)	
Dynamic	0.05
Permanent	nil
Vehicle Damage	
Exterior	
VDS	01RFQ5
CDC	01FREK3
Maximum Exterior Vehicle Crush (mm)	@01RYEW3 470
Interior	
OCDI	RF0214100
Max. Occ. Compart. Deformation (mm)	199
Max. Occ. Compart. Reduction of Space (%)	38.8
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	-32
Max. Pitch Angle (deg)	6
Max. Roll Angle (deg)	-5

Figure 12. Summary of results for test 404531-2, NCHRP Report 350 test 4-11.

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 others in the area. Maximum deformation of the occupant compartment was 199 mm (17.6 percent reduction of space) in the floor pan area and maximum reduction of space was 38.8 percent in the center floor pan to instrument panel area with separation of the floor pan just above the upward curve (where the occupant's feet normally rest). The opening in the floor pan at the separation was judged to be wide enough to allow an occupant's foot to become jammed into the opening or to go through (see lower photo in figure 11). The vehicle remained upright during and after the collision period. Intrusion into adjacent traffic lanes occurred as the vehicle came to rest 12.2 m toward traffic. Longitudinal occupant impact velocity was 7.2 m/s and longitudinal occupant ridedown was -12.1 g's. Exit angle at loss of contact was 7.4 degrees, which was less than 60 percent of the impact angle.

CONCLUSIONS AND RECOMMENDATIONS

The New York Two-Rail Curbless Bridge Railing did not meet criteria for D and K of *NCHRP Report 350* test designation 4-11, as shown in table 1. As stated previously, the separation and deformation of the occupant compartment was judged to have potential for causing serious injury (criterion D). The vehicle came to rest 12.2 m toward traffic lanes, which would intrude into adjacent traffic lanes (criterion K); however, this criterion is preferable, not required.

Damage to the concrete deck at one post location was extensive and would require major repairs. It is recommended that the post-to-deck connection be reviewed with the objective of reducing structural damage to the deck.

Table 1. Performance evaluation summary for test 404531-2, *NCHRP Report 350* test 4-11.

Test Agency: Texas Transportation Institute | Test No.: 404531-2 | Test Date: 10/27/98

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 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 nor show potential for penetrating the occupant compartment, nor 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 199 mm (17.6 percent reduction in space) in the floor pan area and maximum reduction of space was 38.8 percent in the center floor pan to instrument panel area. The floor pan separated, creating an opening in the vicinity of the occupant's feet. The resulting damage to the occupant compartment was judged to have potential for causing serious injury.	Fail
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
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	Intrusion into adjacent traffic lanes occurred as the vehicle came to rest 12.2 m toward traffic.	Fail*
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal occupant impact velocity was 7.2 m/s and longitudinal occupant ridedown was -12.1 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 at loss of contact was 7.4 degrees, which was less than 60 percent of the impact angle.	Pass*

*Criterion preferable, 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 404531-2.

Location	X (mm) (distance from front axle)	Y (mm) (distance from centerline)	Z (mm) (distance from ground)	Data Axis
Instrument panel	-660	0	1235	+X
Right front wheel spindle	0	+720	-365	-Y
Left front wheel spindle	0	-720	-365	+X
Top of engine block	+80	0	-875	+X
Bottom of engine block	-310	0	-340	+X
Vehicle c.g.	-1460	0	-695	+X,+Y,+Z
Vehicle rear axle	-3350	0	-840	+X,+Y,+Z

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 (according to 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) [formerly National Bureau of Standards] 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 of 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 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

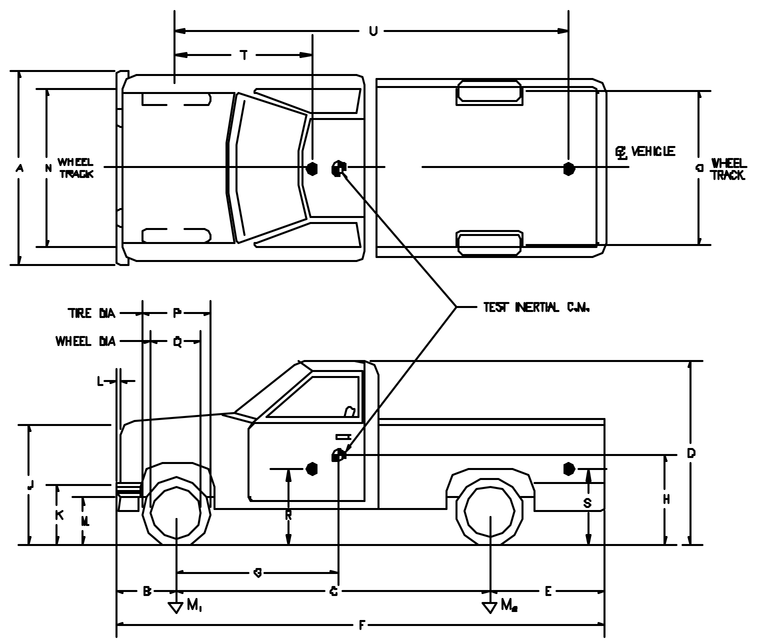
DATE: 10-27-98 TEST NO.: 404531-2 VIN NO.: 1GCFC24K2RE139524

YEAR: 1994 MAKE: CHEVY MODEL: 2500 P/U

TIRE INFLATION PRESSURE: ______ ODOMETER: 137364 TIRE SIZE: LT 245 75R16

MASS DISTRIBUTION (kg) LF 558 RF 517 LR 466 RR 459

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL.

ENGINE CID: 5.7L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

6 LUGS

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A	1870	E	1300	J	103	N	1600	R	660
B	770	F	5420	K	620	O	1625	S	860
C	3350	G	1549.4	L	80	P	770	T	1490
D	1760	H		M	390	Q	445	U	3350

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1100	1075	1118
M_2	822	925	957
M_T	1922	2000	2075

Figure 13. Vehicle properties for test 404531-2.

Table 3. Exterior crush measurements for test 404531-2.

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	At front bumper	800	470	600	0	50	105	180	310	470	+300
2	Above front bumper	800	340	1120	130	190	220	260	320	340	+1480

[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.

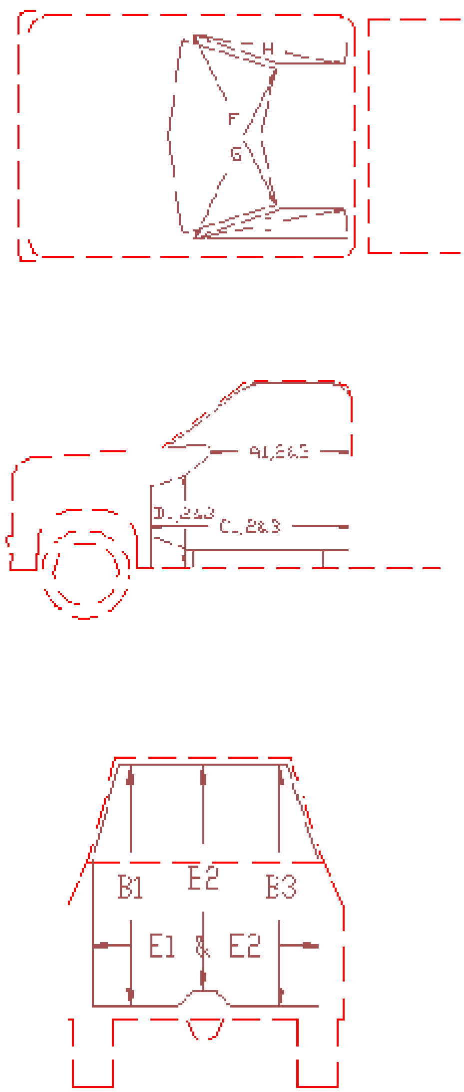
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 404531-2.

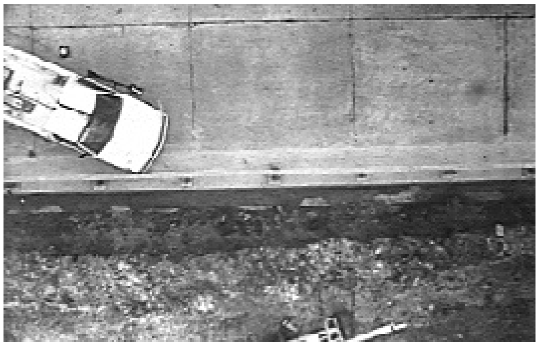
Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1030	1045
A2	1082	1070
A3	1045	1025
B1	1075	1075
B2	1054	935
B3	1090	1131
C1	1374	1374
C2	1262	1230
C3	1372	1325
D1	306	312
D2	98	60
D3	310	420
E1	1591	1575
E2	1589	1595
F	1475	1450
G	1475	1465
H	900	870
I	900	900
Maximum floor pan to roof	1129	930
Maximum lateral deformation near occupants feet	1520	1390

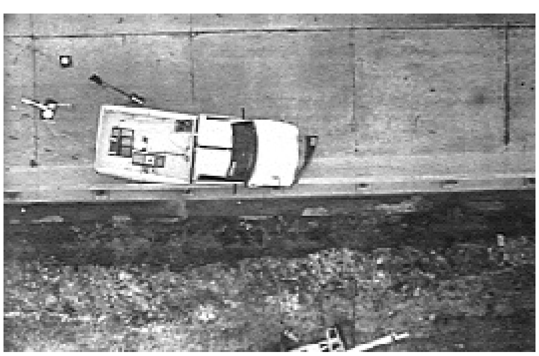
APPENDIX C. SEQUENTIAL PHOTOGRAPHS




0.000 s

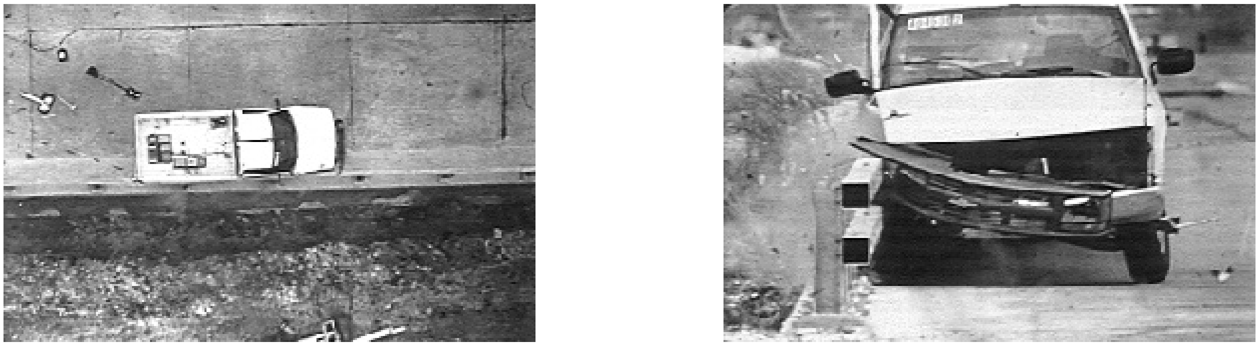

0.048 s


0.097 s




0.145 s

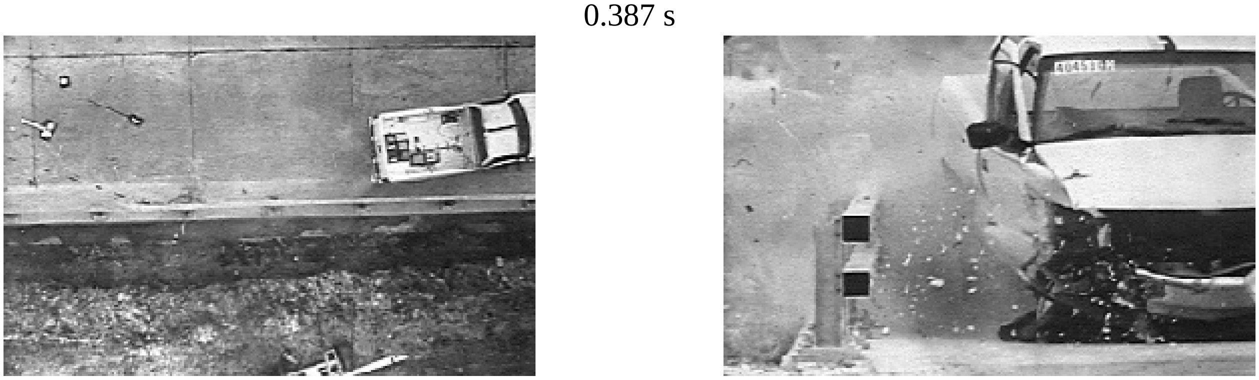
Figure 14. Sequential photographs for test 404531-2
(overhead and frontal views).



0.193 s

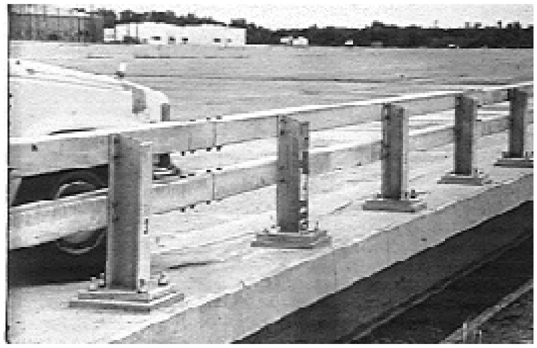
0.266 s

0.387 s



0.483 s

Figure 14. Sequential photographs for test 404531-2
(overhead and frontal views) (continued).



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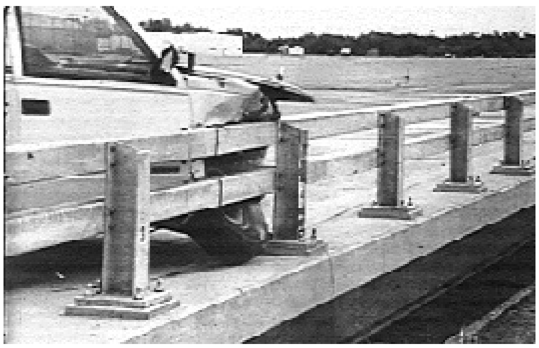

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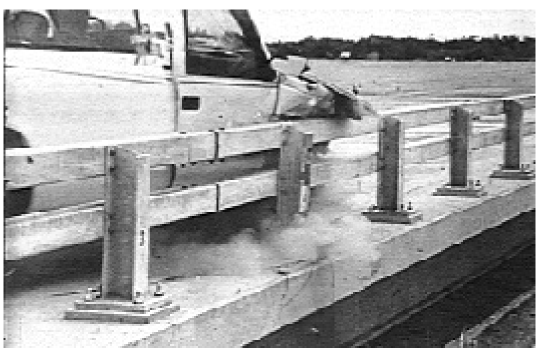

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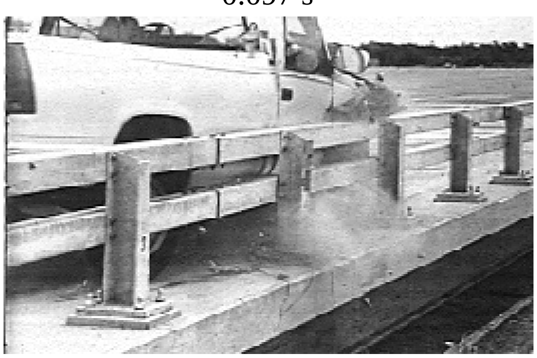

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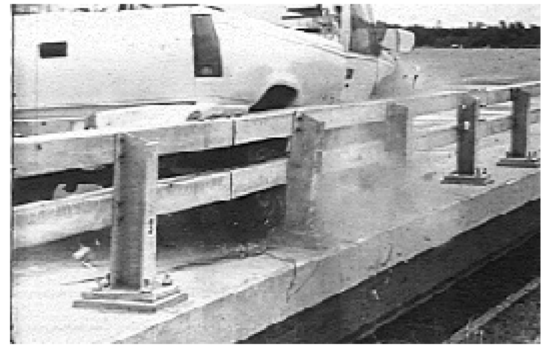

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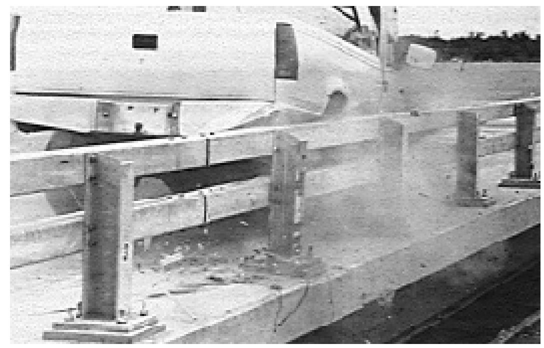

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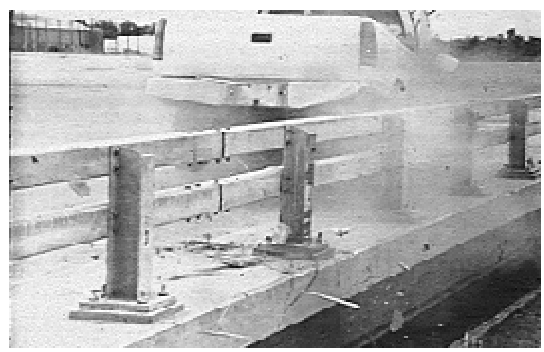
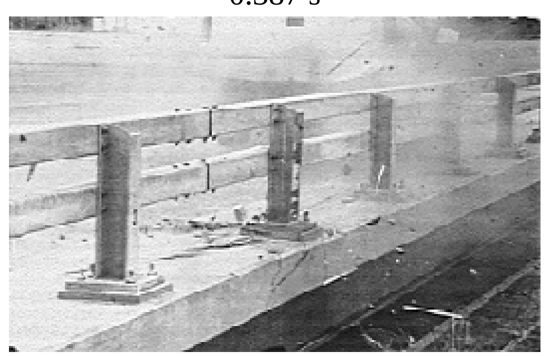


0.387 s



0.483 s

Figure 15. Sequential photographs for test 404531-2 (rear view).

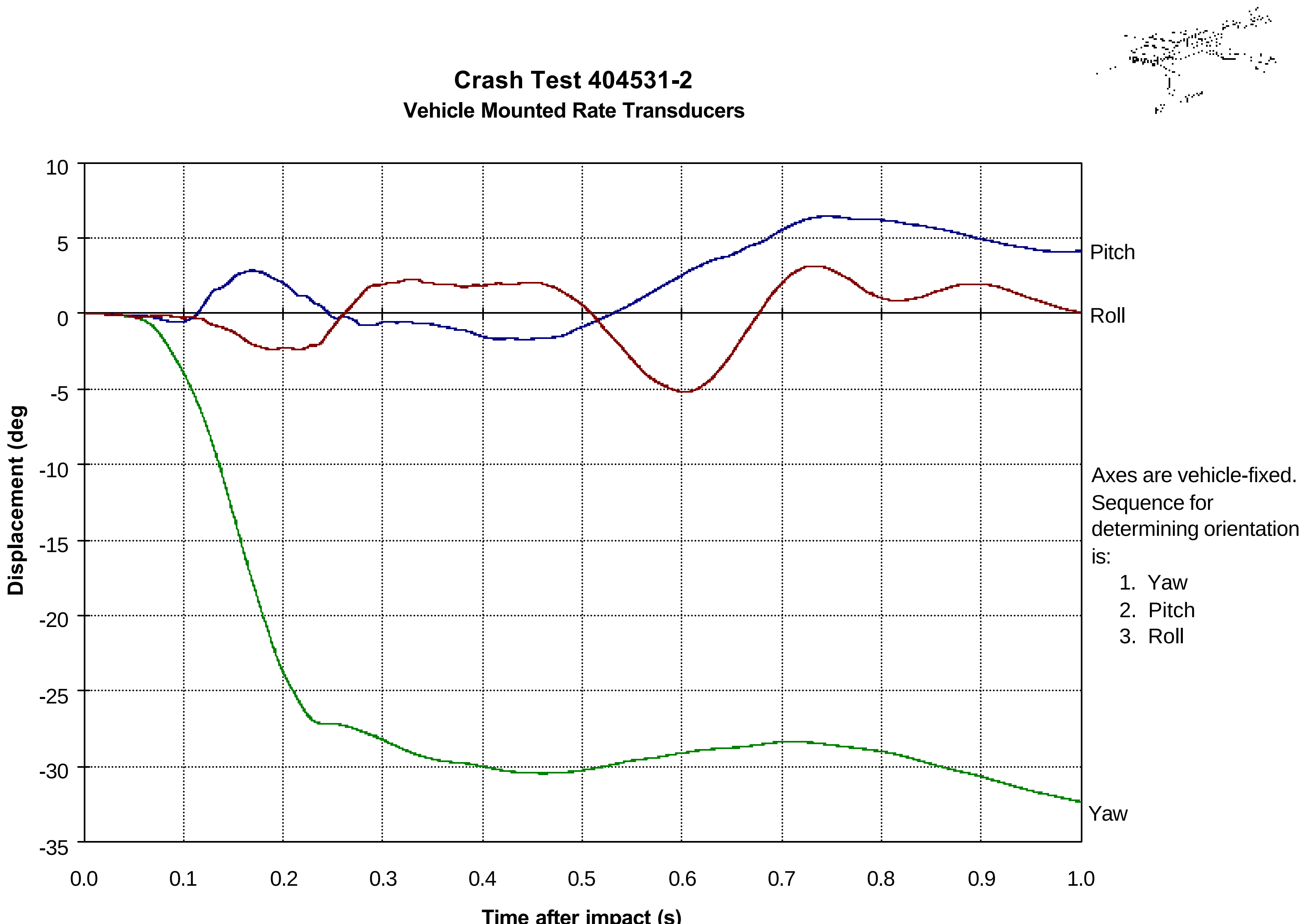


Figure 16. Vehicular angular displacements for test 404531-2.

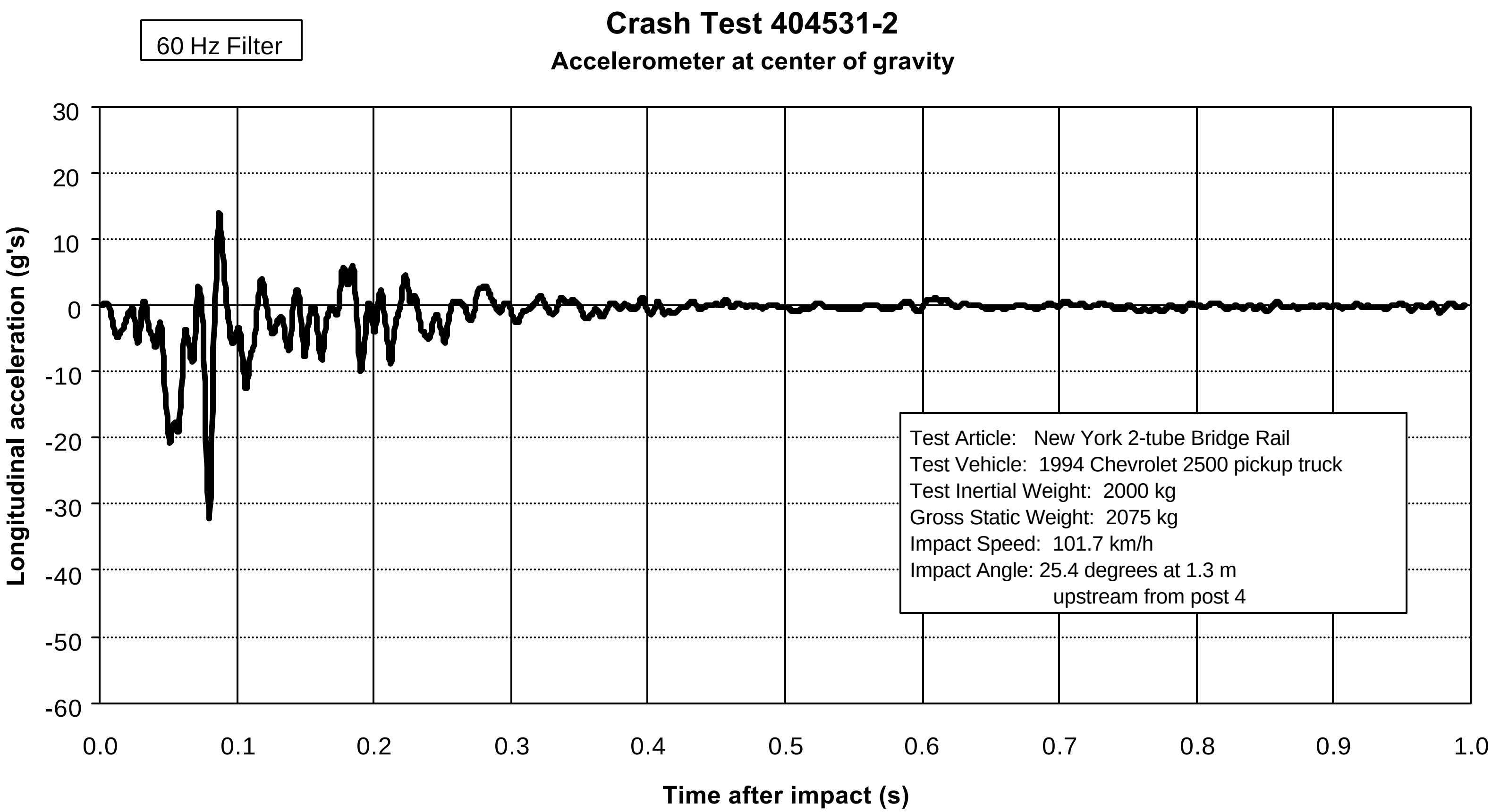


Figure 17. Vehicle longitudinal accelerometer trace for test 404531-2 (accelerometer located at center of gravity).

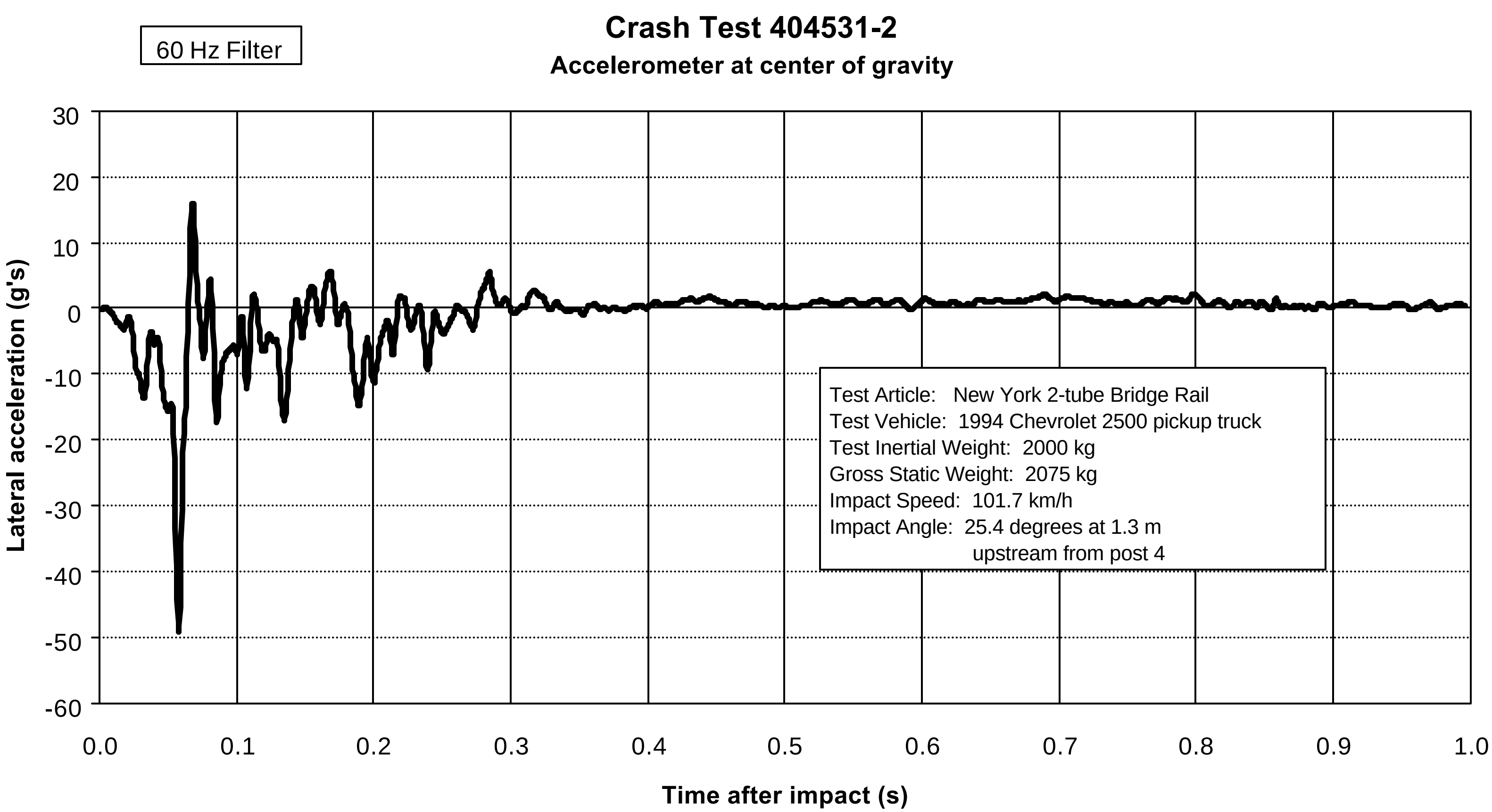


Figure 18. Vehicle lateral accelerometer trace for test 404531-2
(accelerometer located at center of gravity).

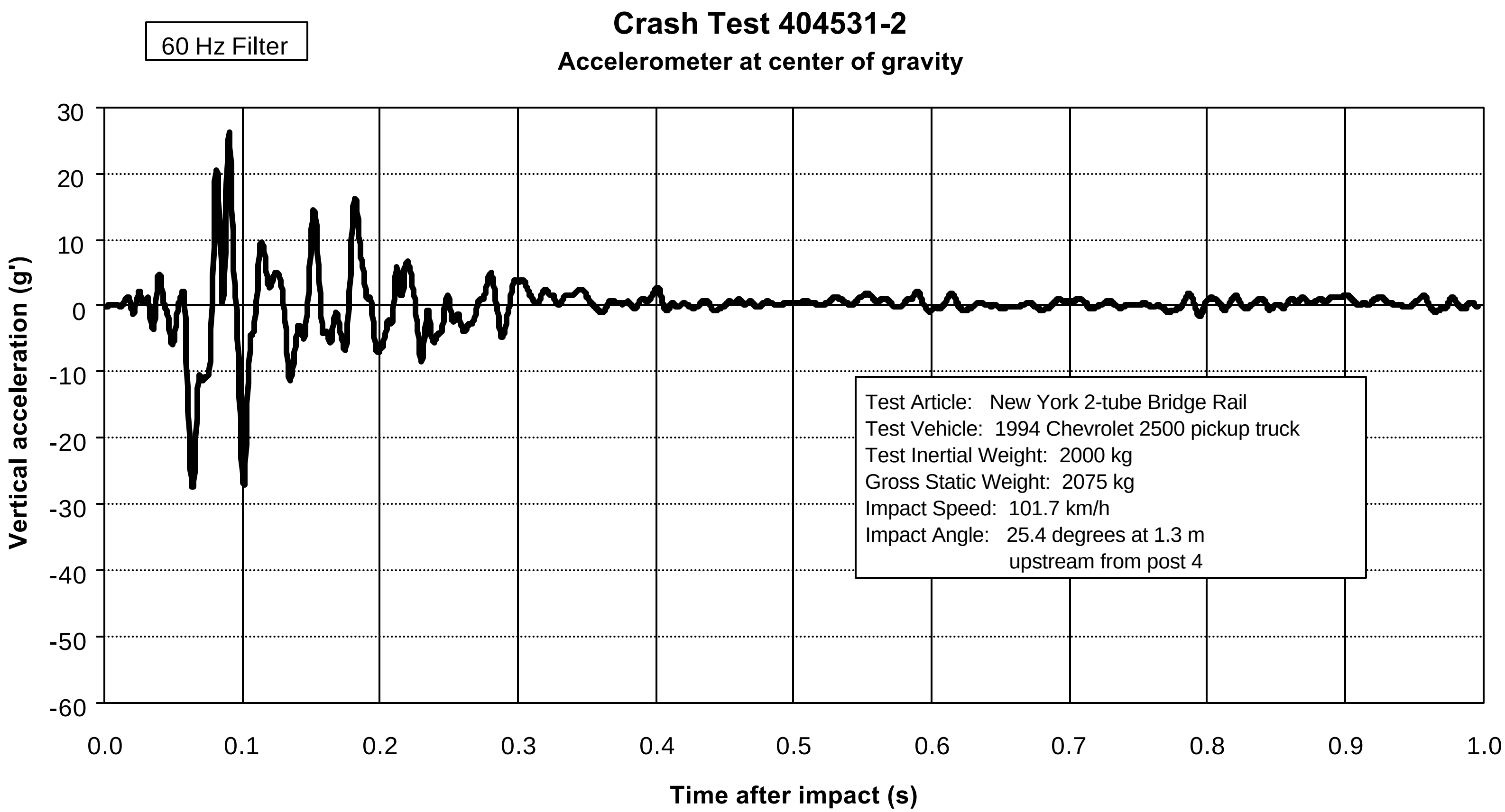


Figure 19. Vehicle vertical accelerometer trace for test 404531-2
(accelerometer located at center of gravity).

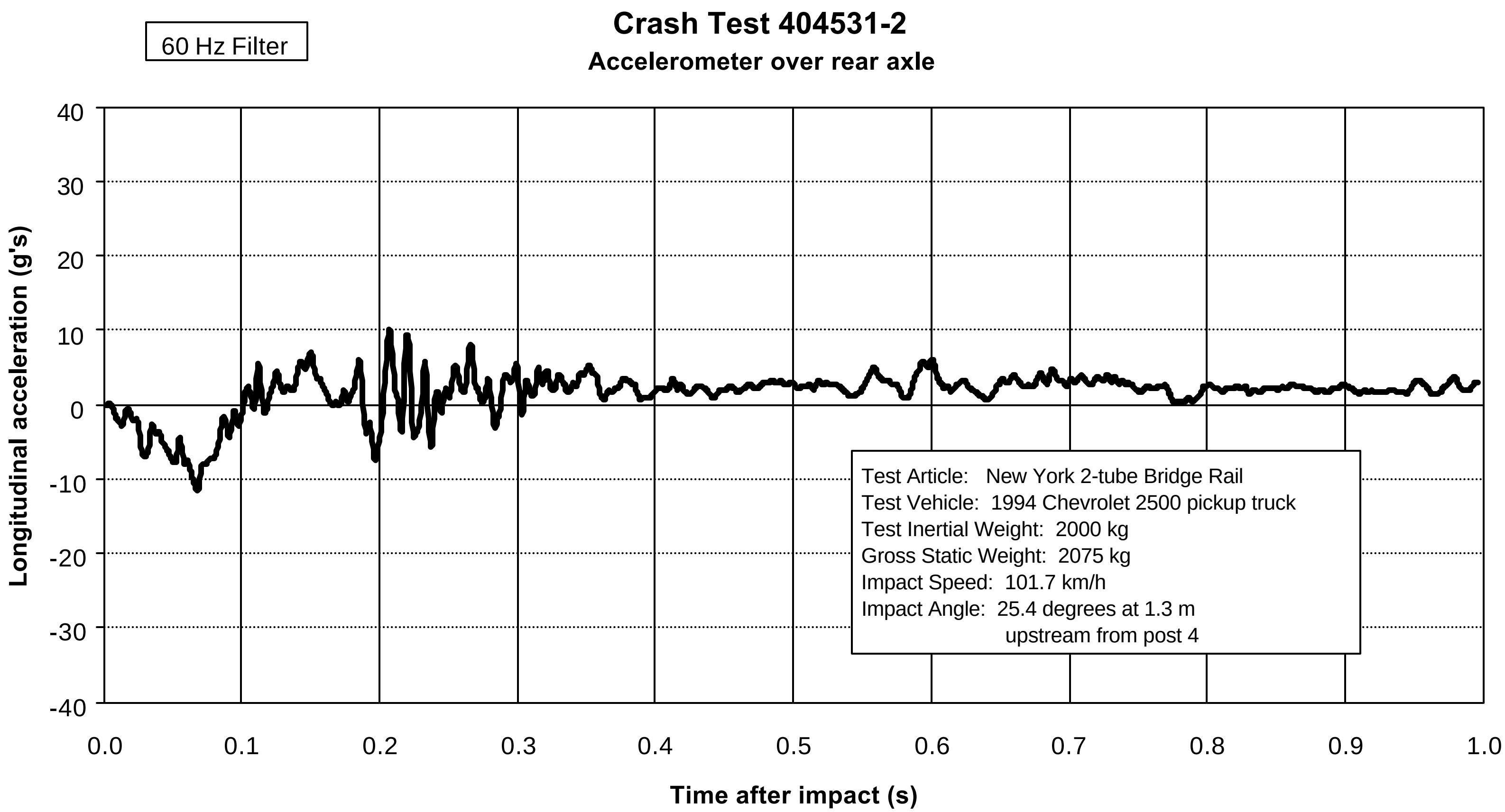


Figure 20. Vehicle longitudinal accelerometer trace for test 404531-2
(accelerometer located over rear axle).

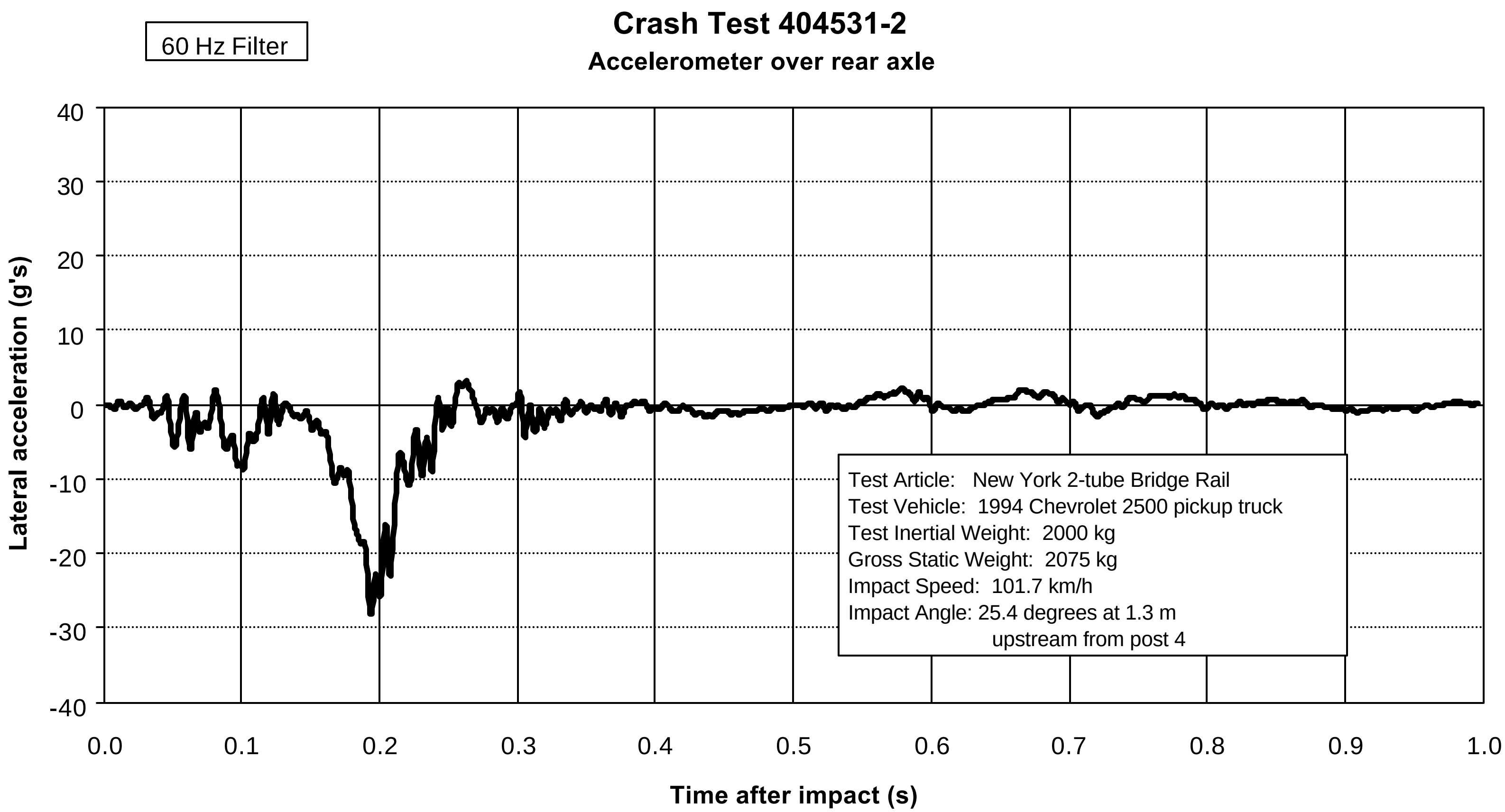


Figure 21. Vehicle lateral accelerometer trace for test 404531-2
(accelerometer located over rear axle).

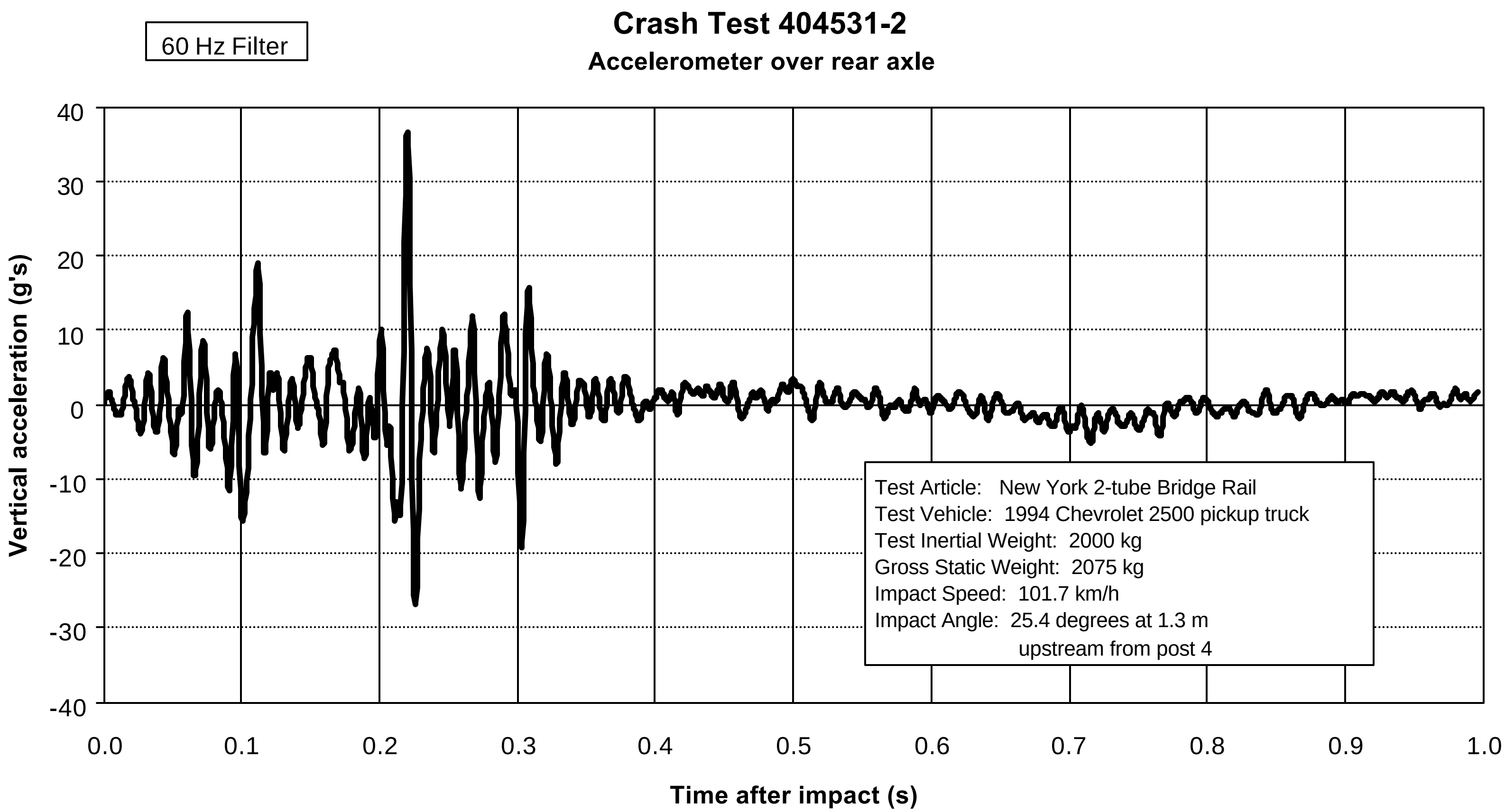


Figure 22. Vehicle vertical accelerometer trace for test 404531-2
(accelerometer located over rear axle).

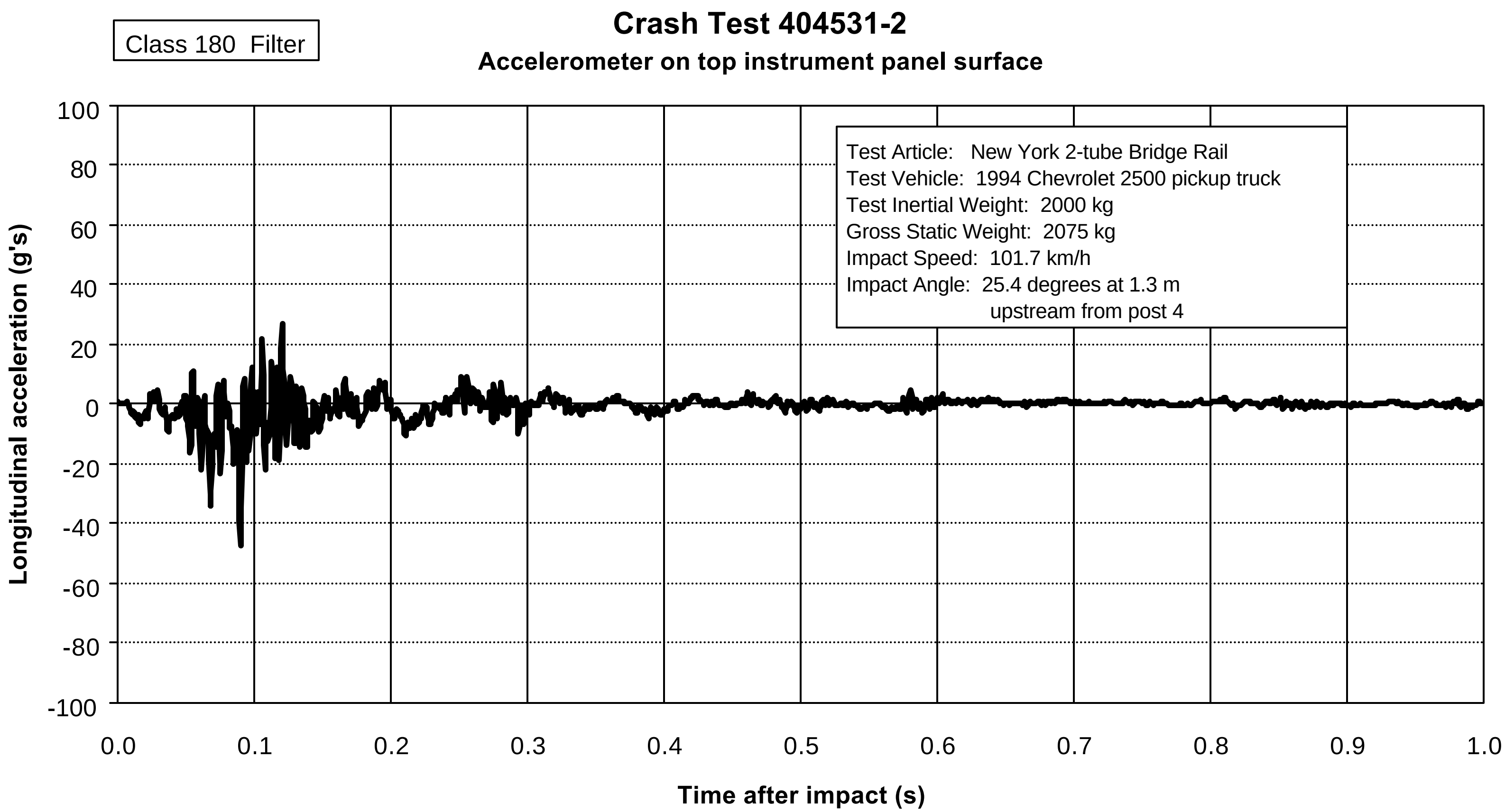


Figure 23. Vehicle longitudinal accelerometer trace for test 404531-2 (accelerometer located on top surface of instrument panel).

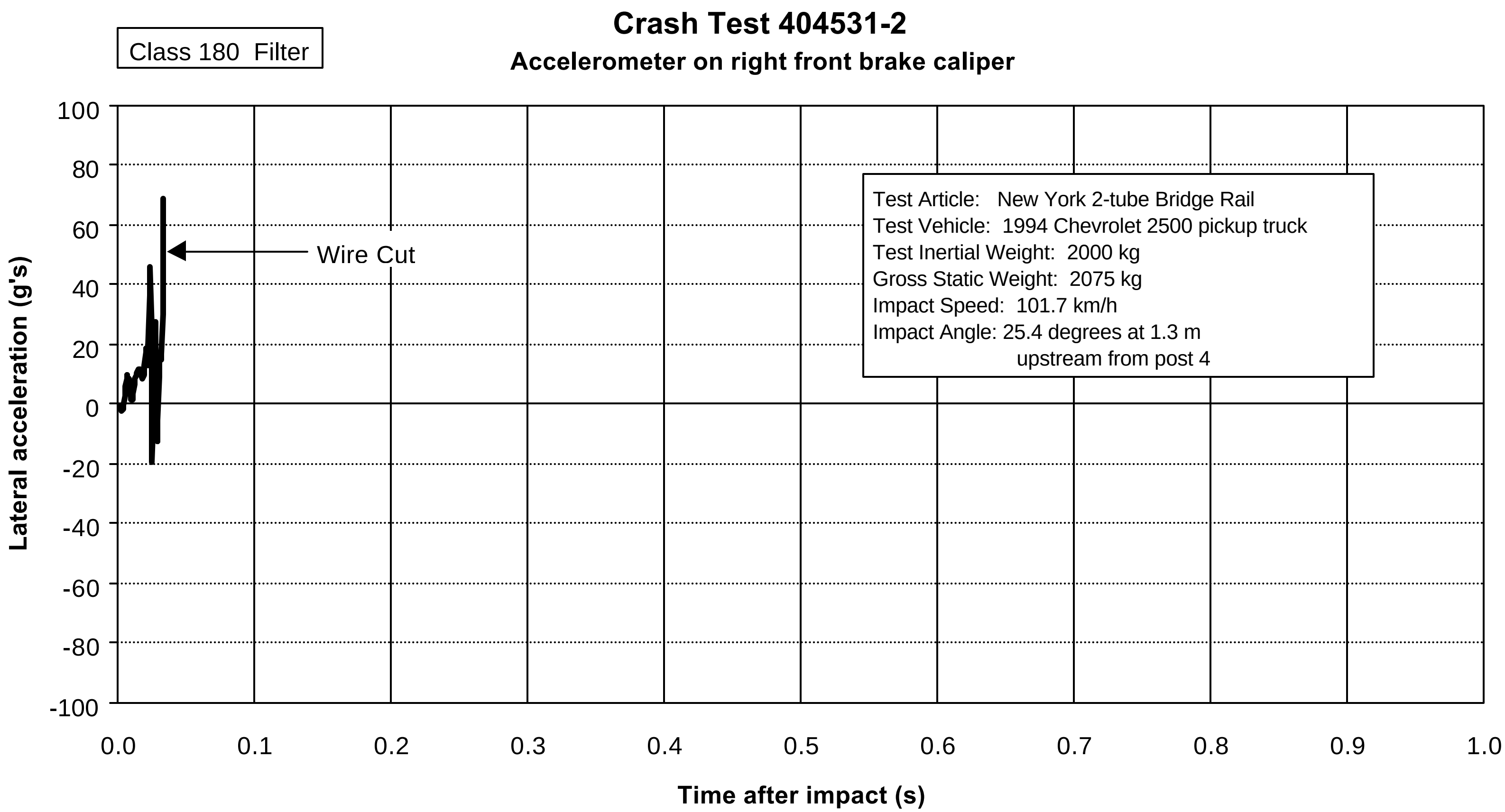


Figure 24. Vehicle lateral accelerometer trace for test 404531-2
(accelerometer located on right front brake caliper).

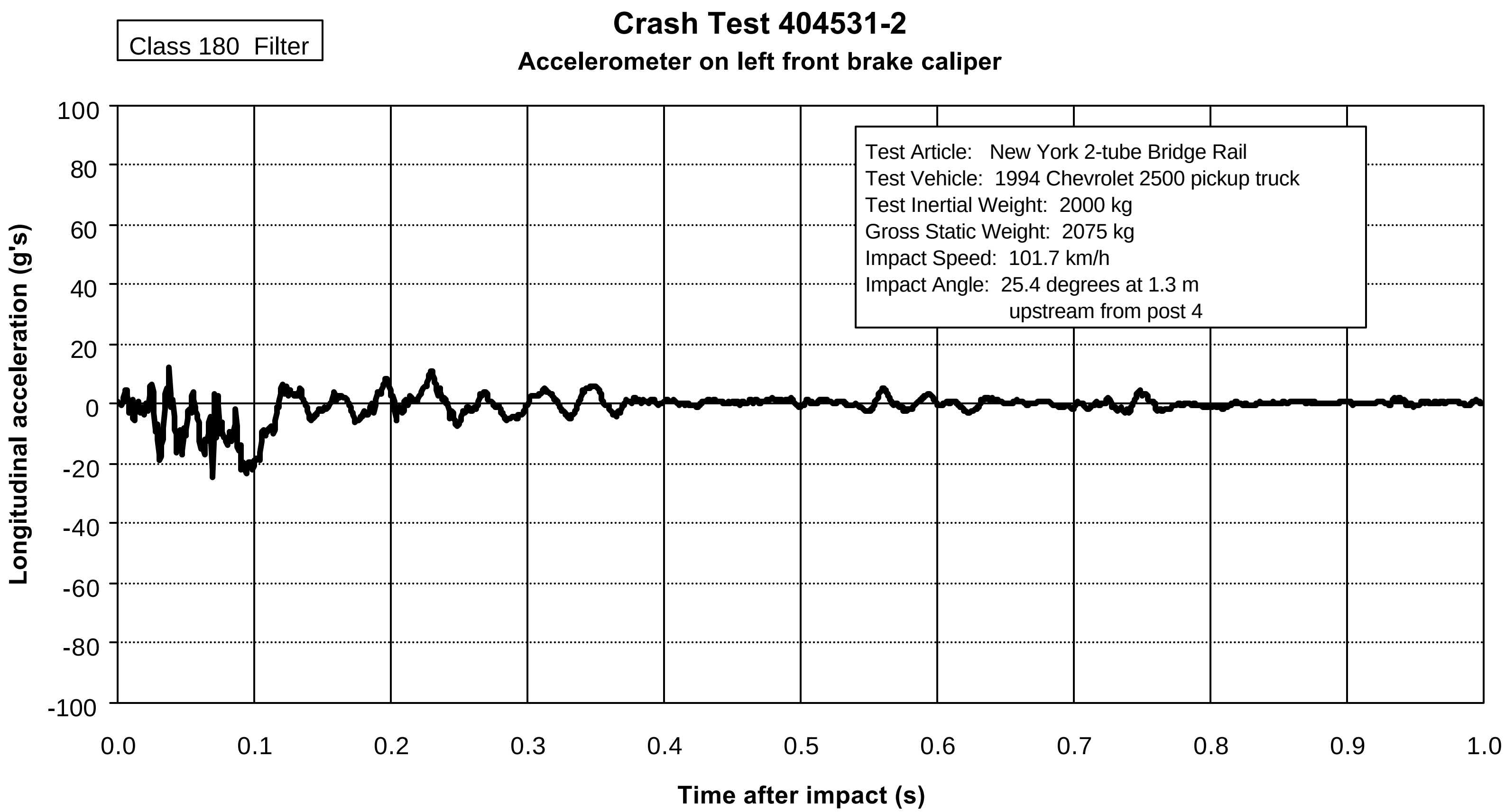


Figure 25. Vehicle longitudinal accelerometer trace for test 404531-2
(accelerometer located on left front brake caliper).

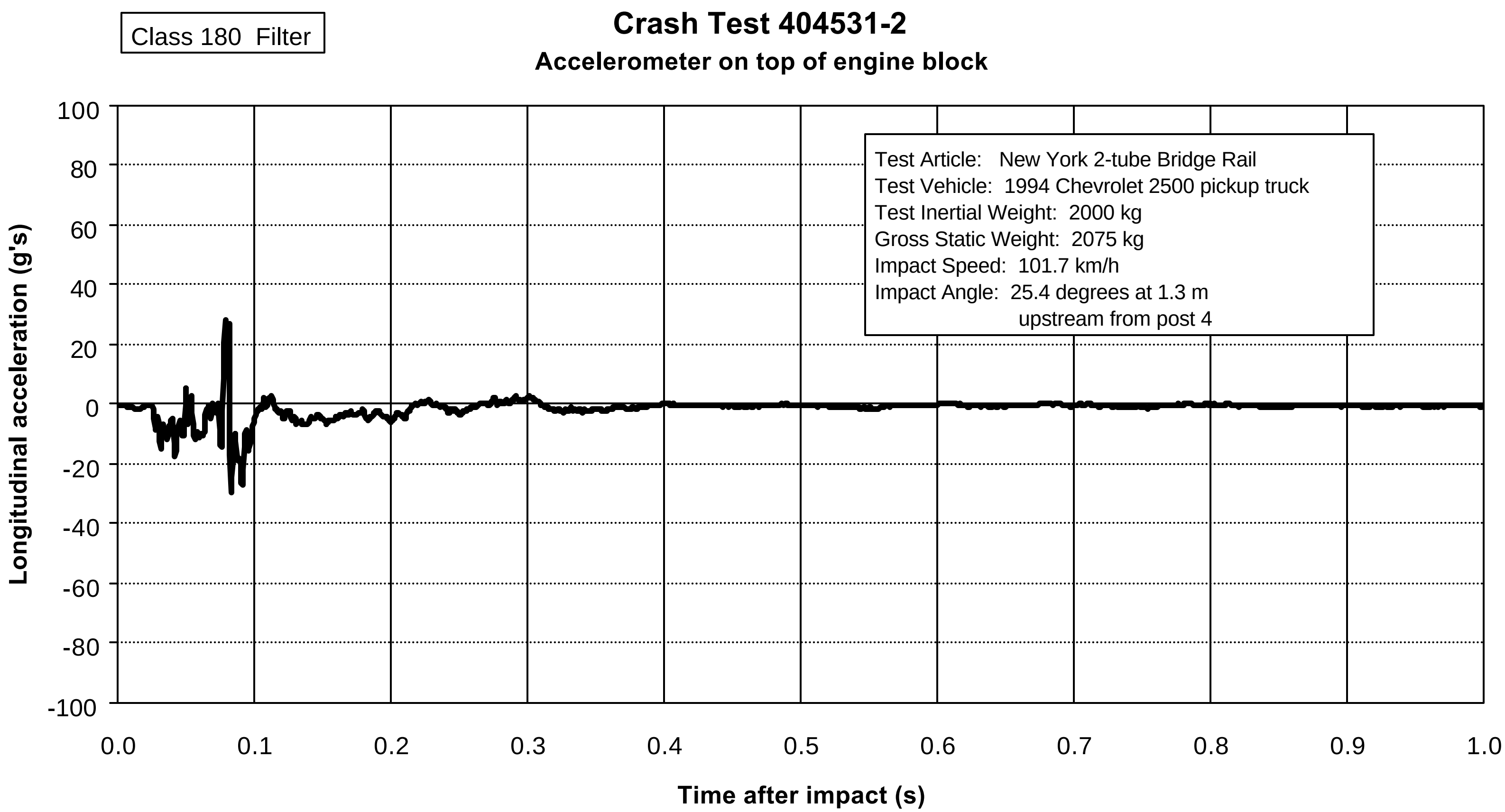


Figure 26. Vehicle longitudinal accelerometer trace for test 404531-2
(accelerometer located on top of engine block).

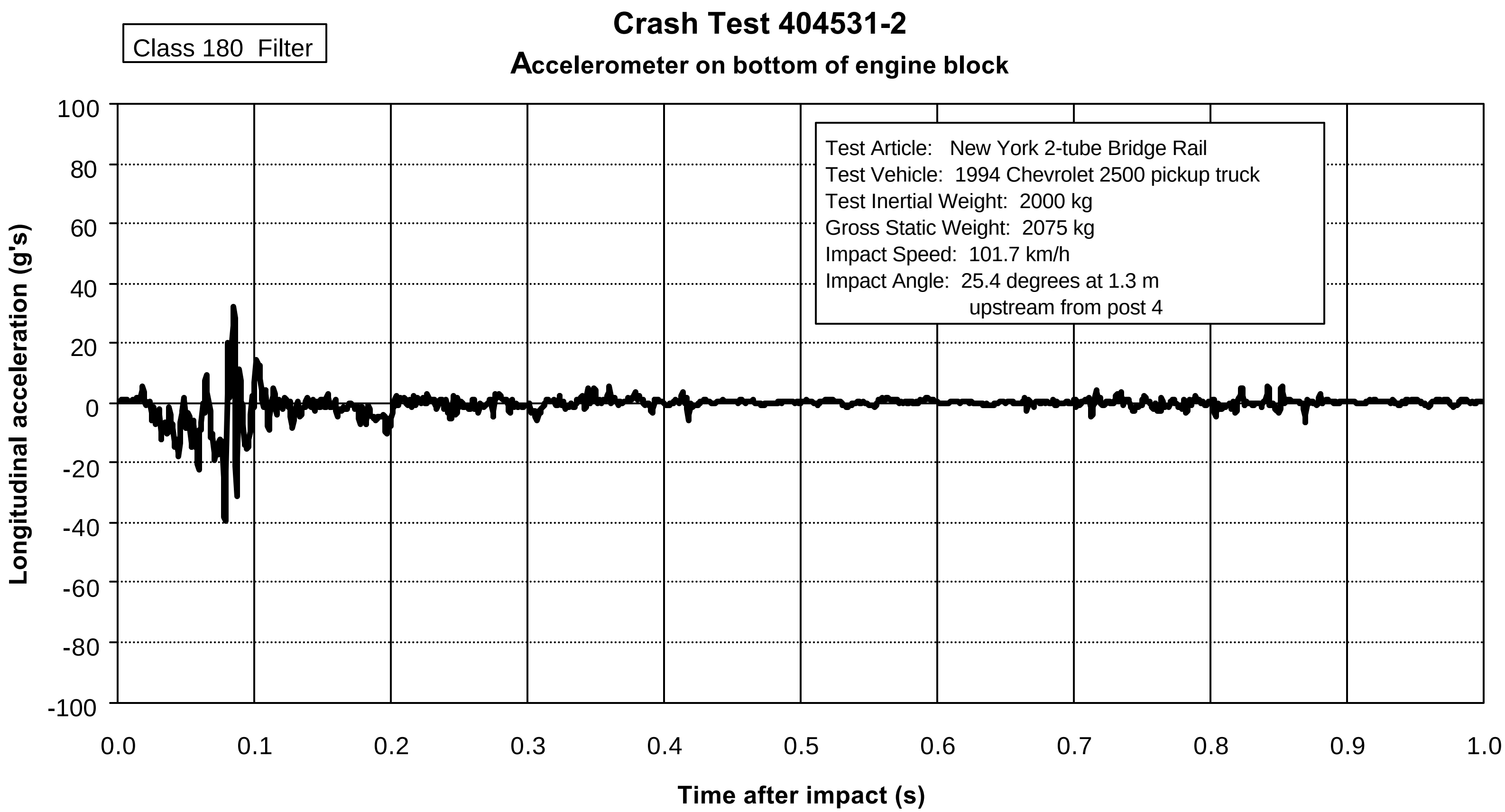


Figure 27. Vehicle longitudinal accelerometer trace for test 404531-2
(accelerometer located on bottom of engine block).

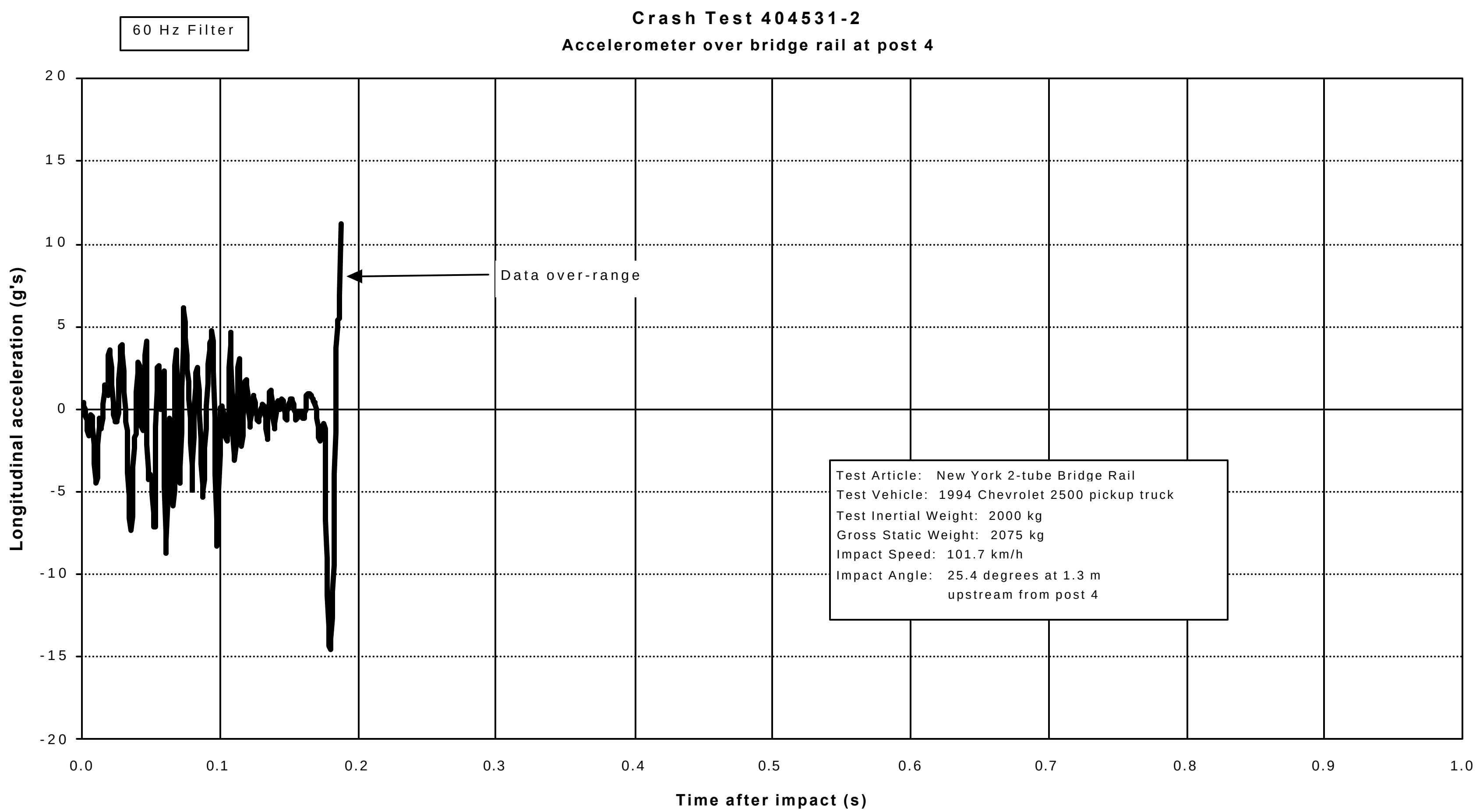


Figure 28. Bridge rail longitudinal accelerometer trace for test 404531-2 (accelerometer located over bridge rail at post 4).

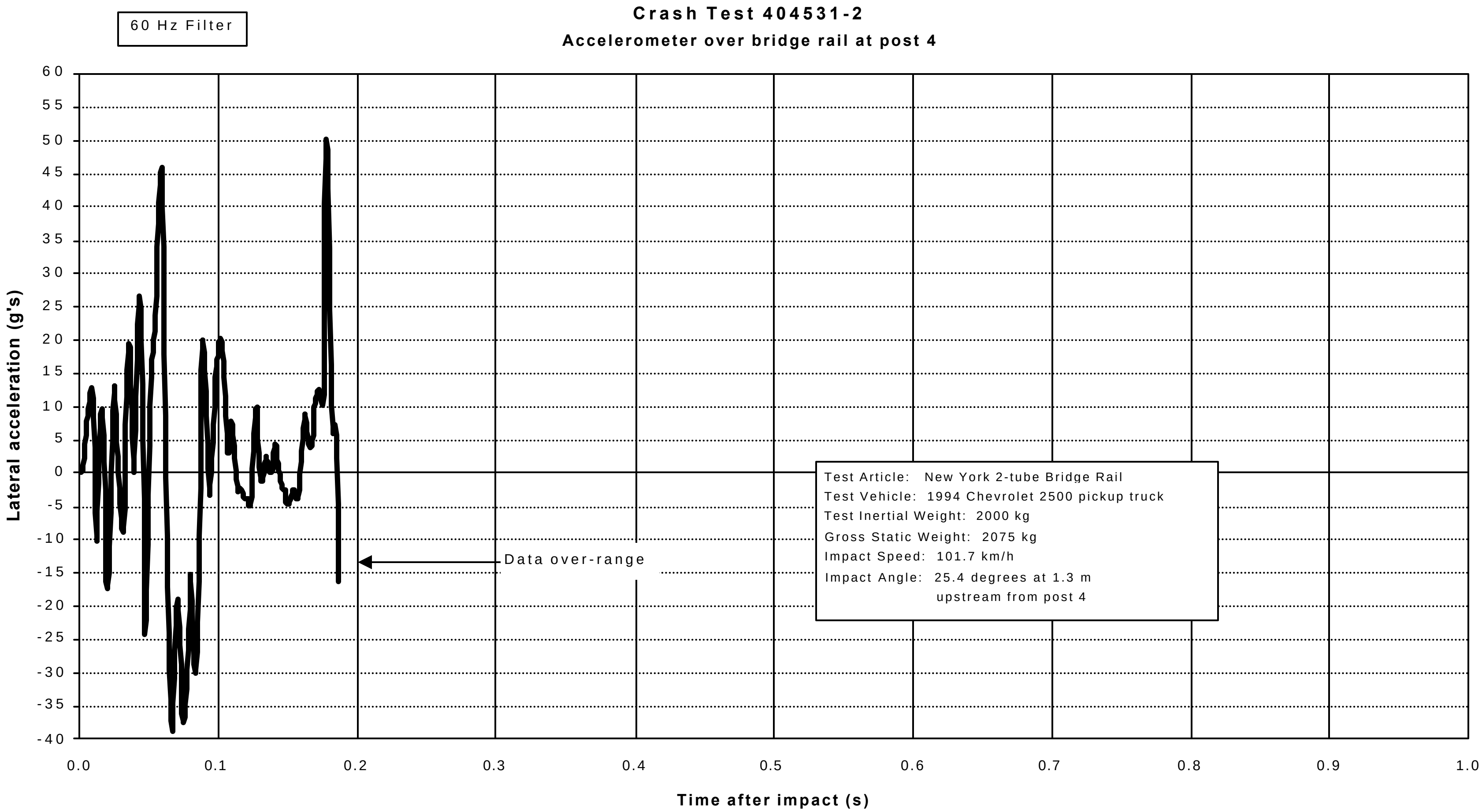


Figure 29. Bridge rail lateral accelerometer trace for test 404531-2 (accelerometer located over bridge rail at post 4).

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.