TEXAS TRANSPORTATION INSTITUTE

NCHRP REPORT 350 TEST 4-12 OF THE ALASKA MULTI-STATE BRIDGE RAIL

by

C. Eugene Buth
Senior Research Engineer

William F. Williams
Assistant Research Engineer

Wanda L. Menges
Associate Research Specialist

and

Sandra K. Schoeneman
Research Associate

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16. Abstract

This report presents the details of the Alaska Multi-State Bridge Rail mounted on the curb and results of the single-unit truck test: National Cooperative Highway Research Program (NCHRP) *Report 350* test designation 4-12, which is the 8000-kg single-unit truck impacting the critical impact point (CIP) at 80 km/h and 15 degrees. The Alaska Multi-State Bridge Rail mounted on the curb met the required criteria specified for *NCHRP Report 350* test designation 4-12.

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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)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

(Revised September 1993)

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INTRODUCTION

PROBLEM

The Federal Highway Administration (FHWA) recently 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) For each test, *NCHRP Report 350* specifies the required crash tests for longitudinal barriers, such as bridge rails, for six performance levels as well as evaluation criteria for structural adequacy, occupant risk, and post-test vehicle trajectory. The Alaska Multi-State Bridge Railing mounted on the curb is to be evaluated according to specifications of test level four (TL-4) of *NCHRP Report 350.*

BACKGROUND

FHWA has required that all new roadside safety features to be installed on the National Highway System (NHS) after October 1998 meet the *NCHRP Report 350* performance evaluation guidelines. *NCHRP Report 230* were the previous guidelines used for testing most of the existing roadside safety features.(2) It is now required to evaluate the performance of the existing roadside safety features under the new guidelines.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this study is to crash test and evaluate the Alaska Multi-State Bridge Railing mounted on the curb 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.

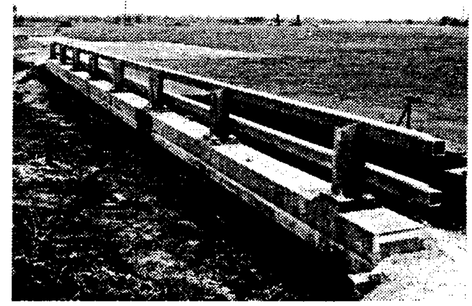
This report presents the details of the Alaska Multi-State Bridge Railing mounted on the curb and results of the single-unit truck test: *NCHRP Report 350* test designation 4-12, which is the 8000-kg single-unit truck impacting the CIP at 80 km/h and 15 degrees. The Alaska Multi-State Bridge Railing mounted on the curb met the required criteria specified for *NCHRP Report 350* test designation 4-12.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of a 2000-acre 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 placing of the Alaska Multi-State Bridge Rail is along a wide expanse of concrete aprons which 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 203-305 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 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 Alaska Multi-State Bridge Railing consists of two tubular steel rail elements mounted on steel wide flange posts bolted to the concrete curb and deck As part of this project TTI was contracted to design the bridge railing based on the current *American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications.*[(3)] TTI performed engineering calculations on current designs used by the sponsoring states and the results of this study are reflected in the test installation. The tube size was increased from 4.7 mm to 7.9 mm with a post spacing of 3050 mm. TTI also performed engineering calculations for a recommended deck design from Oregon Department of Transportation Standards which shows the curb reinforcing with #13 epoxy coated bars on 460 mm spacings (See Oregon Department of Transportation Bridge Design Section Drawing entitled "Standard 2 Tube Curb Mount Rail," dated September, 1987 and shown in appendix A). TTI prepared drawings for construction of the bridge rail 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 22.86 m. The bridge deck cantilever was 888 mm in width and

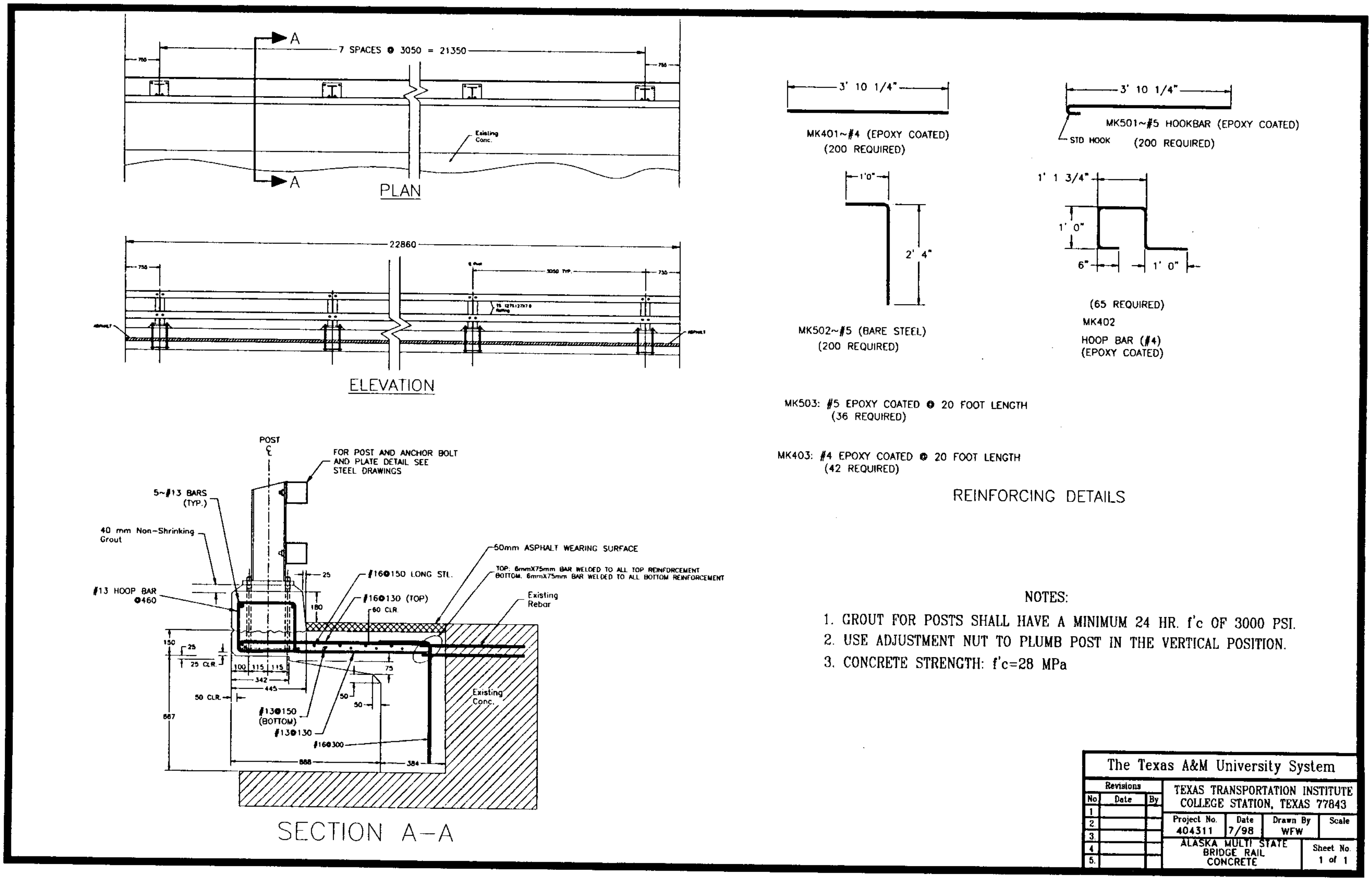


Figure 1. Details of the Alaska Multi-State Bridge Railing mounted on the curb (concrete).

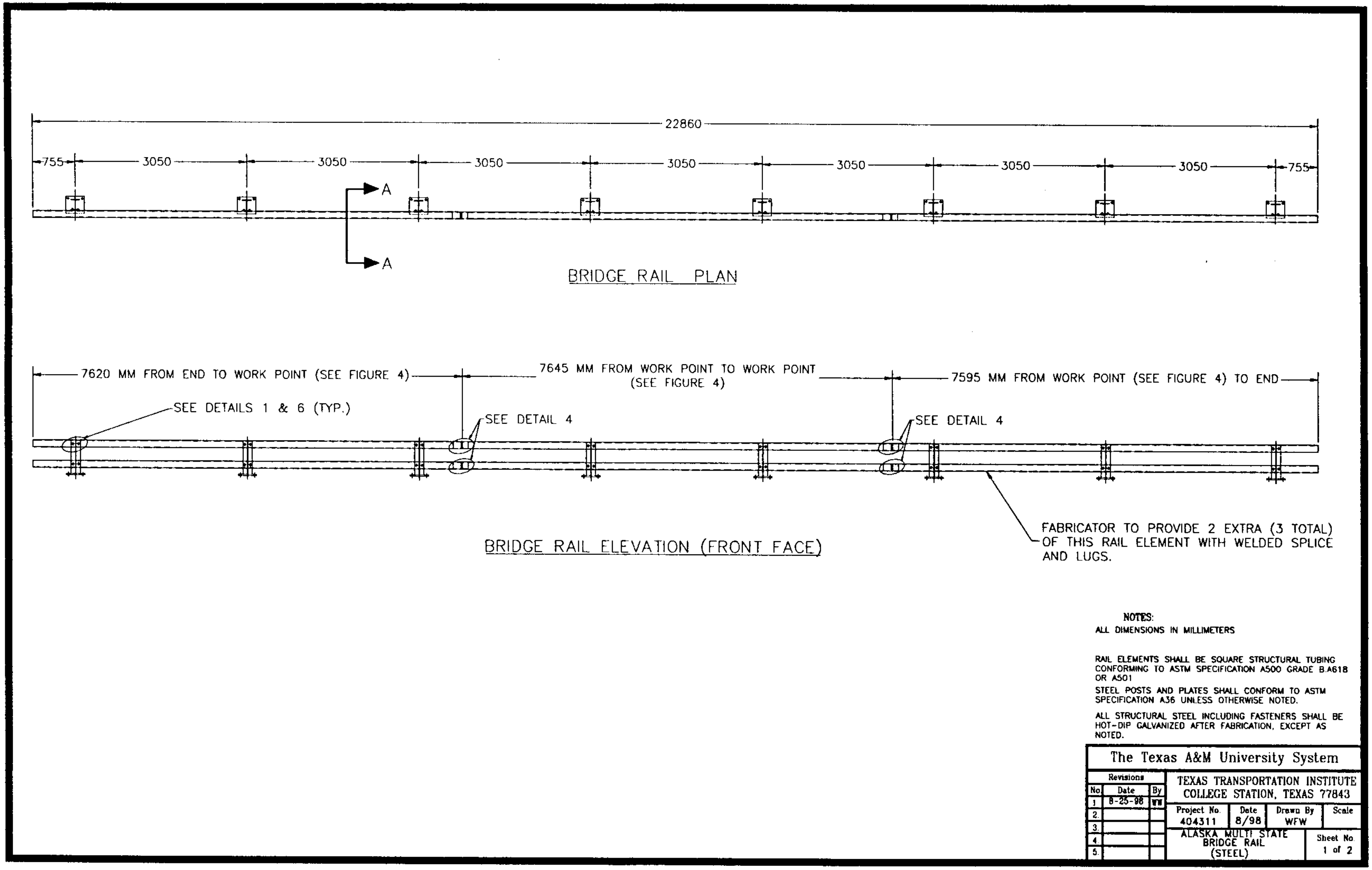


Figure 2. Details of the Alaska Multi-State Bridge Railing mounted on the curb (steel).

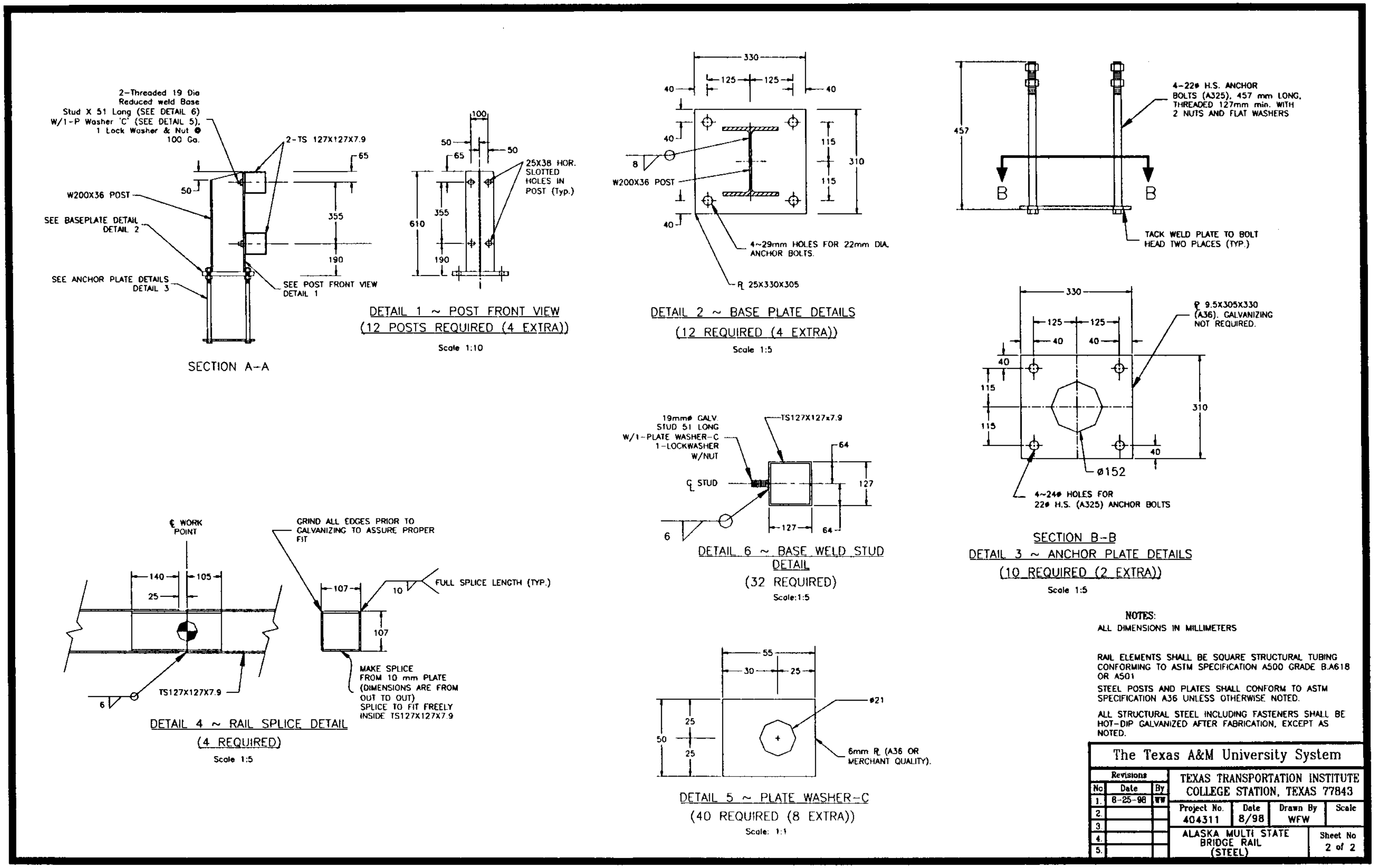


Figure 2. Details of the Alaska Multi-State Bridge Railing mounted on the curb (steel) (continued).

varied in thickness from 150 mm beneath a 180 mm tall curb to 250 mm thick. The bridge deck cantilever was constructed immediately adjacent to an existing concrete runway located at the TTI test facility. The test installation was constructed with a 50 mm asphalt wearing surface. The concrete deck was anchored to the runway by welding "L" shaped dowels to existing dowels located in the concrete runway. The "L" shaped dowels were reinforced by a vertical support wall that was constructed as part of the deck cantilever. The vertical support wall and the concrete deck cantilever were poured with one continuous concrete pour. The curb was constructed with a separate pour. The vertical support wall was 384 mm in width and served to anchor the deck to the existing runway. The 28-day compressive strength of the concrete used to construct the deck was 28 MPa.

Two layers of reinforcement were constructed in the deck and extended through the deck and welded to existing reinforcement in the runway. The bottom layer of transverse reinforcement was epoxy coated and consisted of two #13 bars at 130 mm spacings. The bottom longitudinal reinforcement consisted of two #13 bars immediately beneath the curb with four additional #13 bars in the deck at 150 mm spacings toward the traffic side of the cantilever. The top layer of transverse reinforcement consisted of #16 bars on 130 mm spacings with standard hooks. The hook extended approximately 100 mm and lapped the bottom transverse reinforcement. The top layer of longitudinal reinforcement consisted of four #16 bars on 150 mm spacings located beneath the top transverse reinforcement. The curb was reinforced with #13 "Hoop" Bars on 460 mm spacings. Two #13 longitudinal bars were located within the Hoop Bars beneath the top 90 degree bends in the "Hoop" Bars. All reinforcement used in the deck except the "L" shaped dowels was epoxy coated.

The Alaska Multi-State Bridge Rail consists of two TS 127x127x7.9 tubes supported by W200x36 posts on 3050 mm spacings. Each post was 610 mm in height and was continuously welded to a 330 mm x 310 mm x 25 mm baseplate with an 8 mm fillet weld. A 40 mm high strength cementitious grout pad was placed beneath each post. The posts were anchored into the concrete curb and deck using four 22 mm diameter bolts and 330 mm x 310 mm x 9.5 mm anchor plates. The anchor plates were embedded through the curb and into the concrete deck just above the bottom layer of reinforcement. The anchor plates, posts, and base plates were fabricated using A36 Material. The anchor bolt material met the requirements of ASTM A325 material. The centerline of the lower rail was located 410 mm from the top of the asphalt surface. The centerline of the upper rail was located 765 mm from the top of the asphalt surface. The rails were connected to each post using two 19 mm studs that bolted through the flange of the post on the traffic face. The rails were spliced together using a fixed splice tube fabricated from 10 mm plate that was welded to the inside of the tube. The splice was completed by inserting the fixed end inside the adjoining TS127x127x7.9 tube. The splice was not welded to the adjoining tube. The tube material met the requirements of ASTM A500 Grade B.A618 Material. The splice tube material met the requirements of ASTM A36 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.

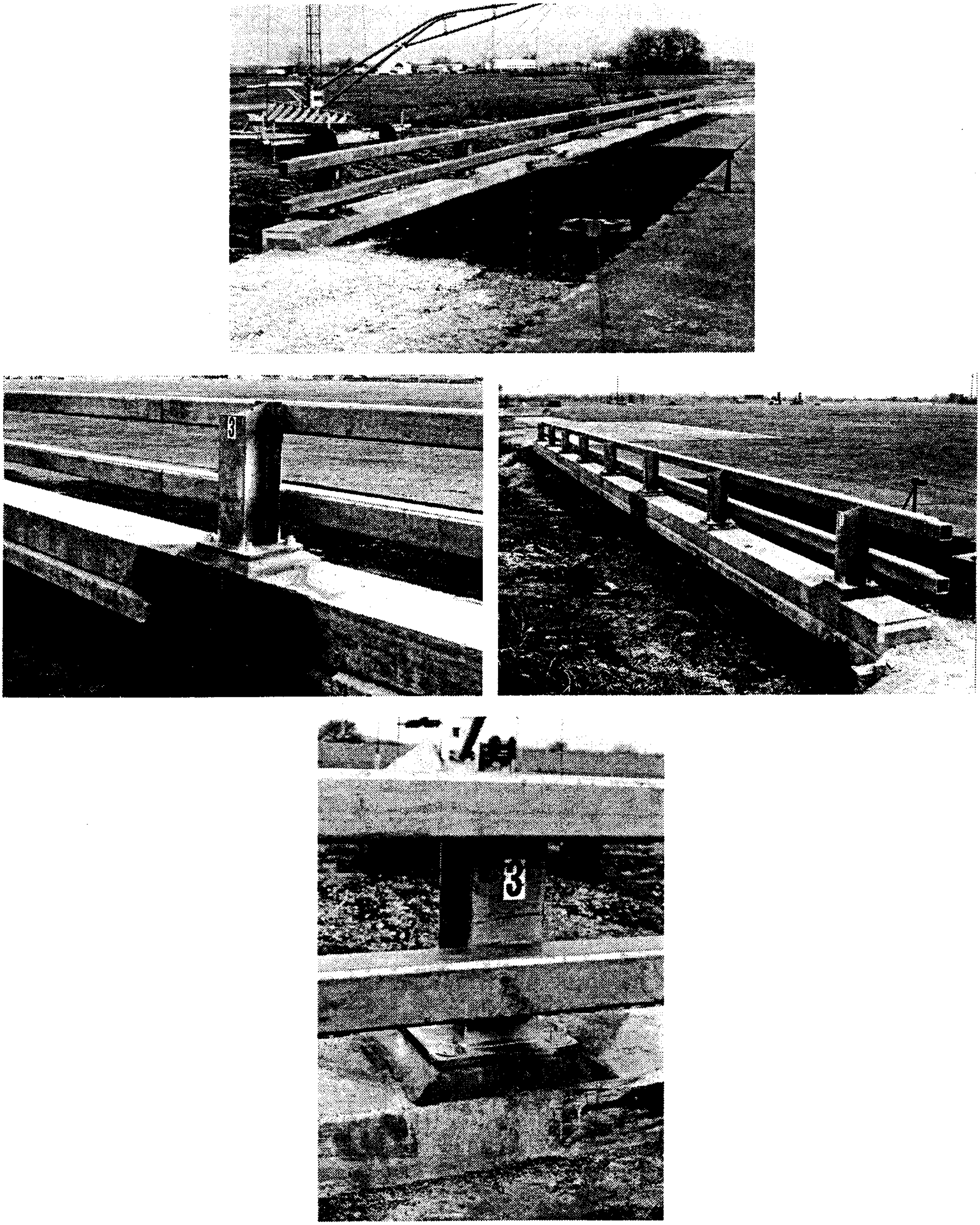


Figure 3. Alaska Multi-State Bridge Railing mounted on the curb before test 404311-3.

Test Conditions

According to *NCHRP Report 350,* three tests are required to evaluate longitudinal barriers, such as bridge rails, 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 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 section in containing and redirecting the heavy truck.

The test and results reported herein correspond to *NCHRP Report 350* test designation 4-12. *NCHRP Report 350* test designations 4-10 and 4-11 were detailed in an earlier report.[4,5]

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 B.

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.*

  G. *It is preferable, although not essential, that the vehicle remain upright during and after the collision.*

- **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.*

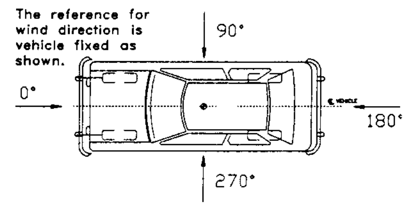
CRASH TEST 404311-3

Test Vehicle

A 1987 GMC 7000 single-unit truck, shown in figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 8000 kg, and its gross static weight was 8000 kg. The height to the lower edge of the vehicle front bumper was 520 mm and to the upper edge of the front bumper was 850 mm. Additional dimensions and information on the vehicle are given in appendix C, 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.

Soil and Weather Conditions

The crash test was performed the morning of January 7, 1999. No rainfall was recorded for the ten days prior to the test. Weather conditions at the time of testing were as follows: wind speed: 10 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling northerly direction); temperature: 24°C; relative humidity: 62 percent.



Impact Description

The 8000-kg single-unit truck impacted the Alaska Multi-State Bridge Railing 1.8 m upstream from post 3. Upon impact, the vehicle was traveling at a speed of 78.7 km/h and 14.9 degrees. Shortly after impact the left front tire contacted the rail element. At 0.015 s the lower rail moved, and at 0.025 s the upper rail element moved. The front left tire lost contact with the ground at 0.032 s, and the vehicle began to redirect at 0.042 s. At 0.076 s post 3 moved and at 0.086 s the concrete deck at post 3 cracked on each side, the cracks extended from the front down the rear side of the deck. The front right tire lost contact with the ground at 0.158 s and at 0.163 s the front right wheel steered away from the rail. By 0.184 s the right rear outer tire lost contact with the ground, and by 0.253 s the left front tire lost contact with the rail element. The right rear inner tire lost contact with the ground at 0.279 s. By 0.293 s the left rear tire contacted the rail element, and by 0.295 s the rear left corner of the box-van contacted the top rail element. At 0.299 s the vehicle was traveling parallel with the rail at a speed of 72.7 km/h. The cracked concrete deck at post 3 continued to crack more at 0.322 s. The left front tire returned to the ground at 0.374 s, and at 0.424 s the right rear inner tire lost contact with the ground. At 0.544 s the box-van lost contact with the rail element. The vehicle lost contact with the bridge railing at 0.723 s, traveling at a speed of 57.6 km/h at a 5.7 degree angle. At 0.821 s the left rear side of the box-van contacted the top of the rail element. By 1.011 s the front left tire dug into the soil and by 1.391 s the box-van completely lost contact with the bridge rail. The vehicle rolled onto its

Figure 4. Vehicle/installation geometrics for test 404311-3.

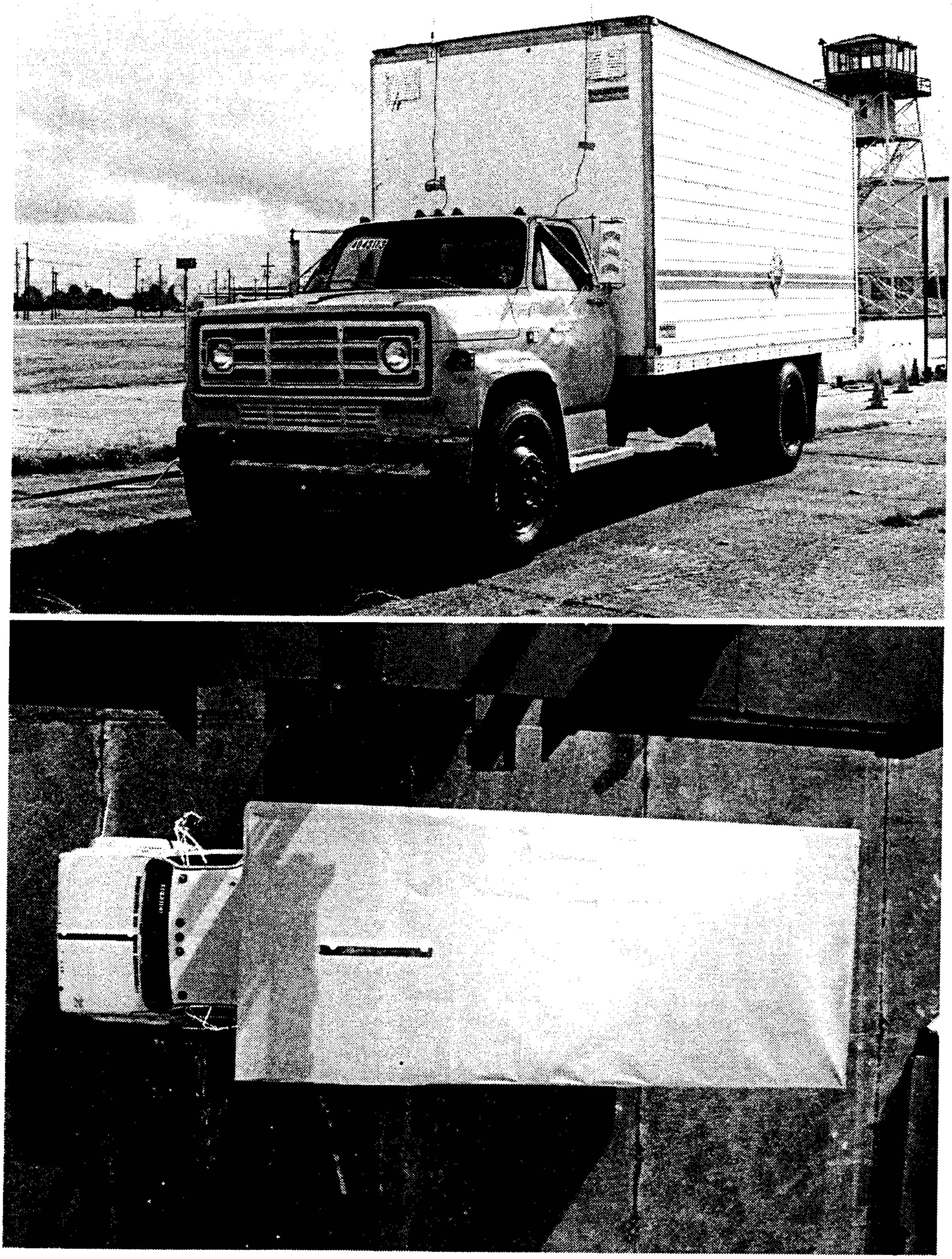


Figure 5. Vehicle before test 404311-3.

left side after exiting the installation at 2.609 s. The vehicle came to rest on its left side 64.7 m downstream and 13.7 m toward traffic. Sequential photographs of the test period are shown in appendix D, figures 12 and 13.

Damage to Test Article

Damage to the Alaska Multi-State Bridge Railing mounted on the curb is shown in figures 6 and 7. At impact the edge of the curb was scraped, and tire marks were along the face of the curb. The front face at post 3 was marred by contact with the vehicle and the curb was structurally damaged. Cracks in the bridge deck at post 3 radiated out from the front and rear bolts and the grout was missing at the front and sides of the base plate. The top rail element was deformed. Total length of contact of the vehicle with the bridge railing was 7.3 m. Maximum dynamic deflection of the rail element was not attainable due to the vehicle blocking view of the camera. Maximum permanent deformation was 5 mm.

Vehicle Damage

The vehicle sustained minor damages on the front left corner and left side as shown in figure 8. Structural damage was received by the left front springs and the left front axle was pushed back. Damage was also received by the bumper, left front fender and left front wheel. The left door, mirror, and step were deformed. The left side box of the vehicle was scraped. Maximum exterior crush to the vehicle was 150 mm and no deformation or intrusion into the occupant compartment occurred. The interior of the vehicle is shown in figure 9.

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 Alaska Multi-State Bridge Railing mounted on a curb contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation.

Figure 6. Vehicle trajectory path after test 404311-3.

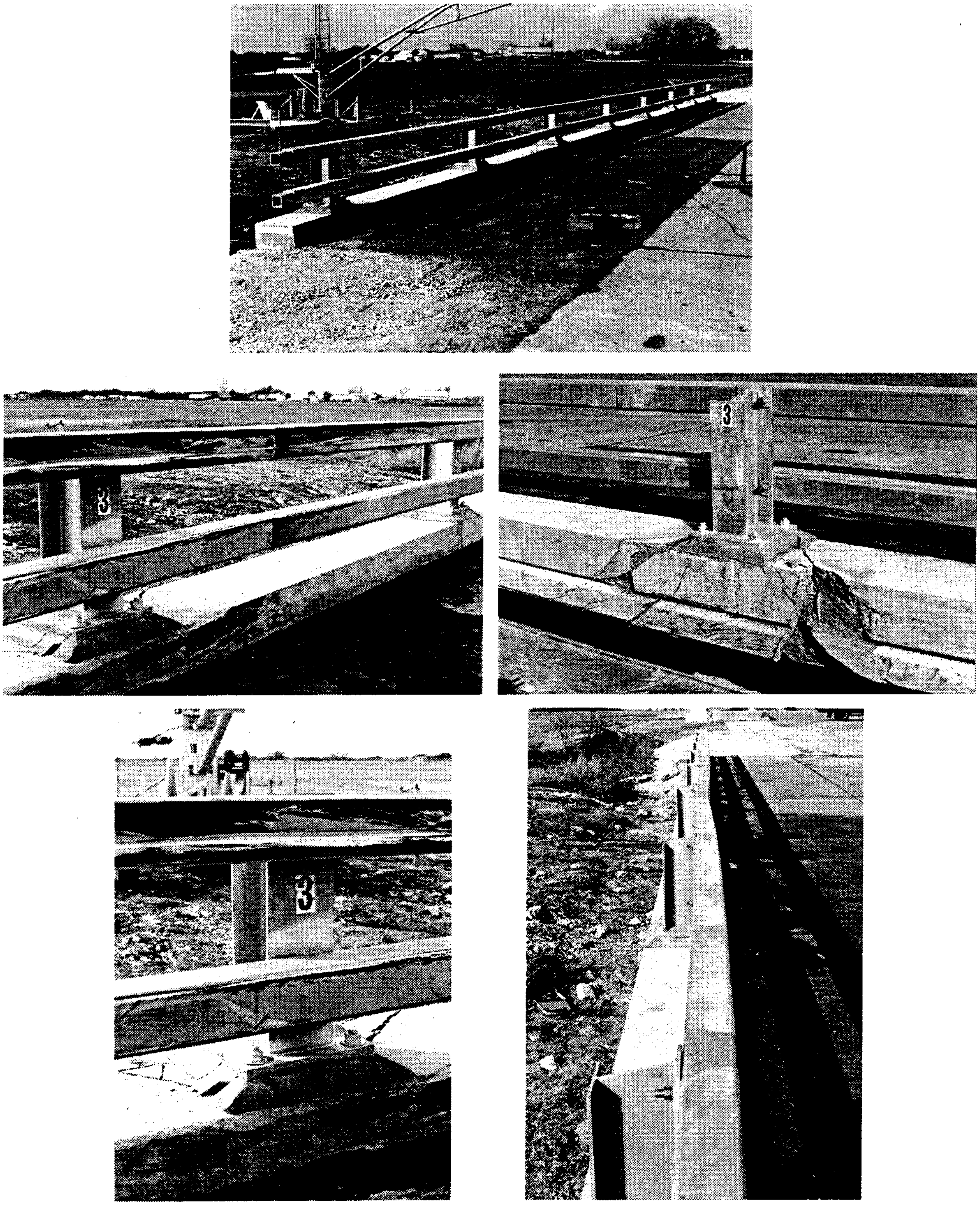


Figure 7. Installation after test 404311-3.

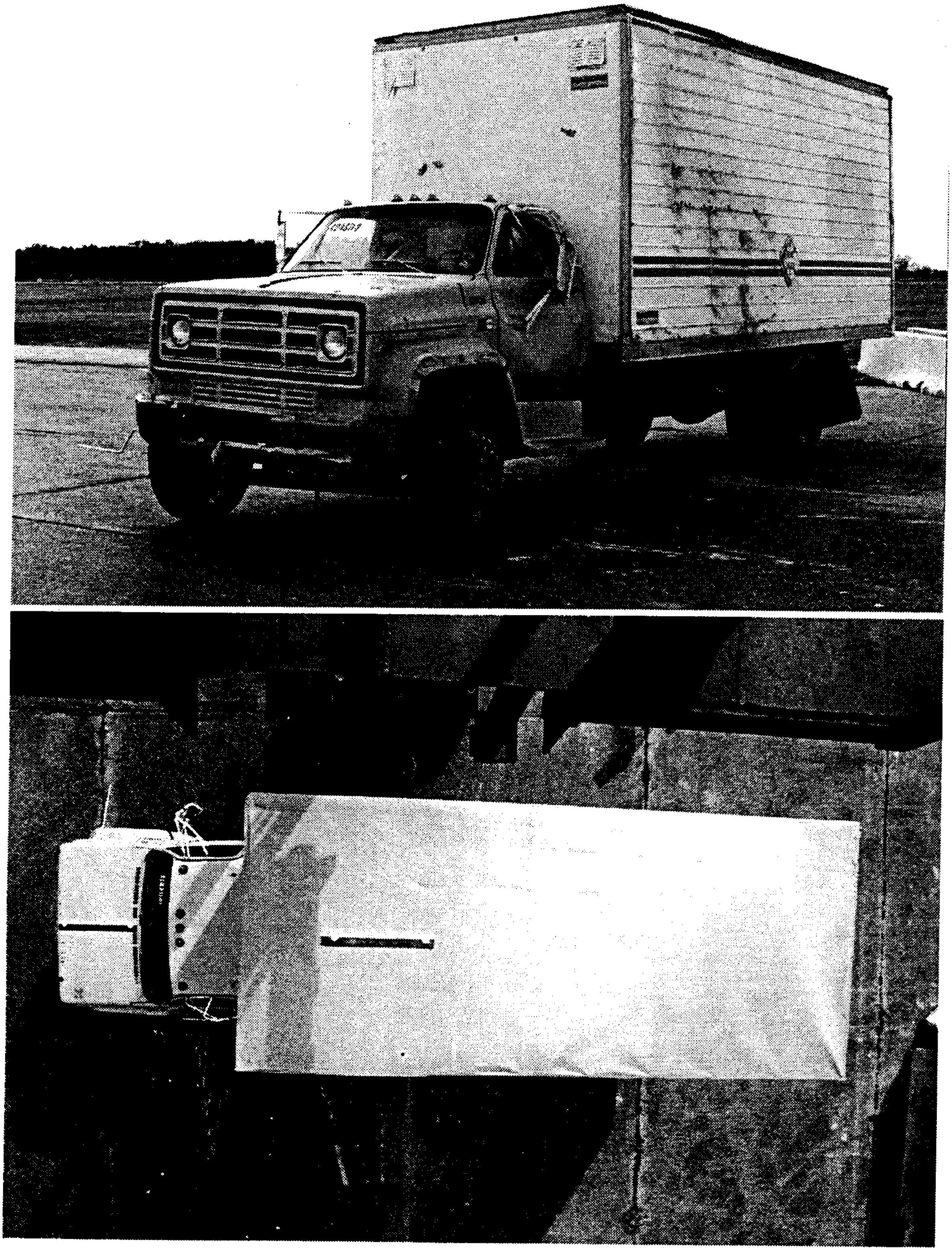
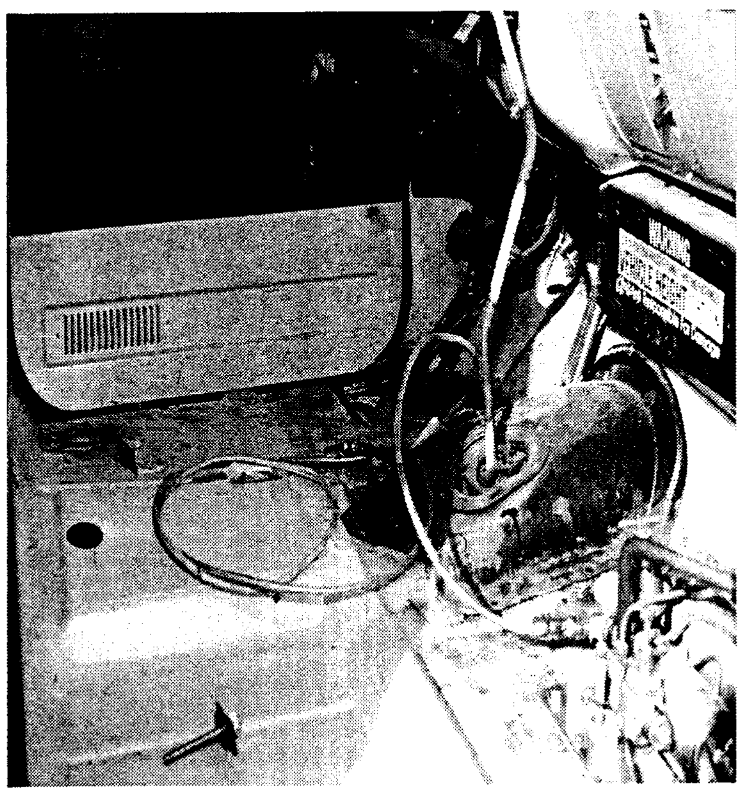


Figure 8. Vehicle after test 404311-3.

Before test



After test

Figure 9. Interior of vehicle for test 404311-3.

- **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 was present to penetrate or to show potential for penetrating the occupant compartment, or present an undue hazard to others in the area.

  G. *It is preferable, although not essential, that the vehicle remain upright during and after the collision.*

  The vehicle rolled onto its left side after exiting the installation.

- **Vehicle Trajectory**

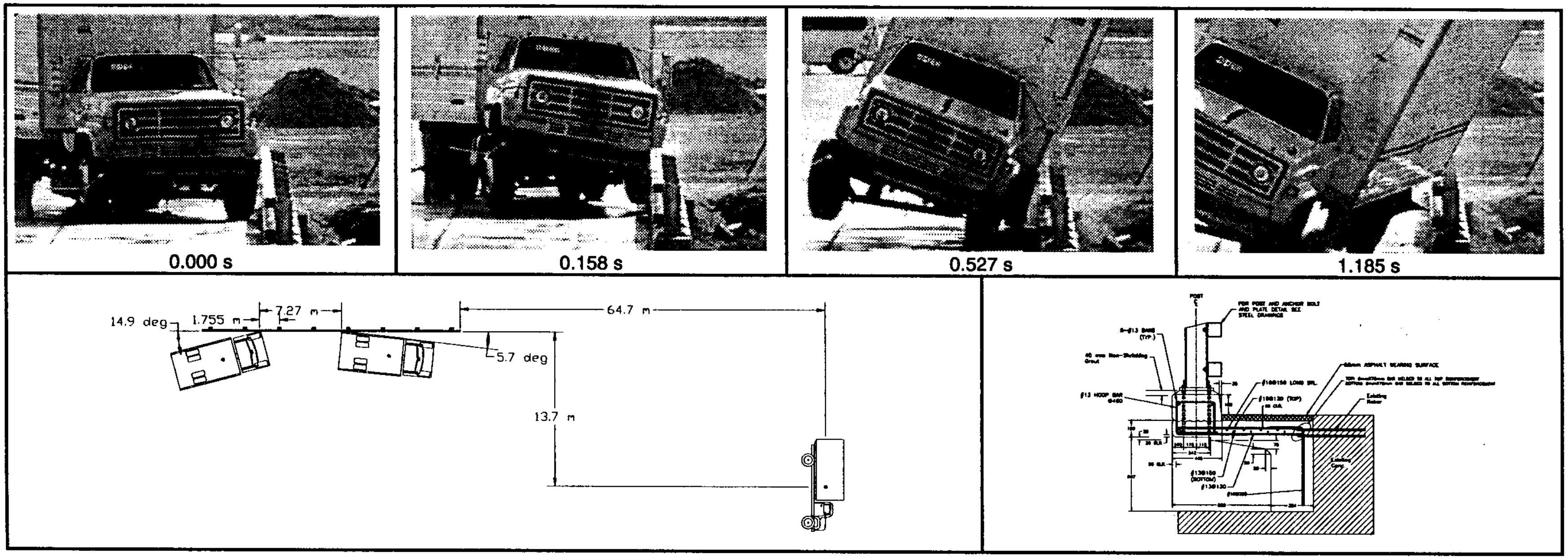
  K. *After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*

  Intrusion into adjacent traffic lanes occurred as the vehicle came to rest 13.7 m toward traffic.

  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 5.7 degrees which is less than 60 percent of the impact angle.

Data from the accelerometer located at the vehicle center of gravity were digitized for informational purposes only and were computed as follows. In the longitudinal direction, the occupant impact velocity was 2.3 m/s at 0.433 s, the highest 0.010-s occupant ridedown acceleration was -2.5 g's from 0.341 to 0.351 s, and the maximum 0.050-s average acceleration was -1.7 g's between 0.080 and 0.130 s. In the lateral direction, the occupant impact velocity was 3.5 m/s at 0.211 s, the highest 0.010-s occupant ridedown acceleration was 10.9 g's from 0.333 to 0.343 s, and the maximum 0.050-s average was 4.5 g's between 0.311 and 0.361 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 E, figures 14 through 21.



General Information	
Test Agency	Texas Transportation Institute
Test No.	404311-3
Date	01/07/99
Test Article	
Type	Bridge Rail
Name or Manufacturer	Alaska Bridge Rail
Installation Length (m)	22.9
Material or Key Elements	Tubular Steel Rail Elements on Steel Wide Flange Posts on Curb
Soil Type and Condition	Standard soil, dry
Test Vehicle	
Type	Production
Designation	8000S
Model	1987 GMC single-unit truck
Mass (kg)	
Curb	5384
Test Inertial	8000
Dummy	No Dummy
Gross Static	8000

Impact Conditions	
Speed (km/h)	78.7
Angle (deg)	14.9
Exit Conditions	
Speed (km/h)	57.6
Angle (deg)	5.7
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.3
y-direction	3.5
THIV (km/h)	14.8
Ridedown Accelerations (g's)	
x-direction	-2.5
y-direction	10.9
PHD (g's)	11.0
ASI	0.51
Max. 0.050-s Average (g's)	
x-direction	1.7
y-direction	4.5
z-direction	-1.5

Test Article Deflections (m)	
Dynamic	N/A
Permanent	0.005
Vehicle Damage	
Exterior	
VDS	N/A
CDC	N/A
Maximum Exterior Vehicle Crush (mm)	150
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	24
Max. Pitch Angle (deg)	3
Max. Roll Angle (deg)	-33

Figure 10. Summary of results for test 404311-3, NCHRP Report 350 test 4-12.

SUMMARY AND CONCLUSIONS

SUMMARY OF FINDINGS

The Alaska Multi-State Bridge Railing mounted on a curb contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. No detached elements, fragments or other debris from the test article were present to penetrate or to show potential for penetrating the occupant compartment, or present an undue hazard to others in the area. The vehicle rolled onto its left side after exiting the installation. Intrusion into adjacent traffic lanes occurred as the vehicle came to rest 13.7 m toward traffic. The exit angle at loss of contact was 5.7 degrees, which is less than 60 percent of the impact angle.

CONCLUSIONS

The Alaska Multi-State Bridge Railing mounted on the curb met all required criteria specified for *NCHRP 350* test designation 4-12. The vehicle rolled onto its left side after exiting the test installation; this criterion is preferable and not required. The vehicle came to rest 13.7 m toward traffic lanes, thereby intruding into adjacent traffic lanes; however, this criterion is also preferable and not required, as shown in table 1.

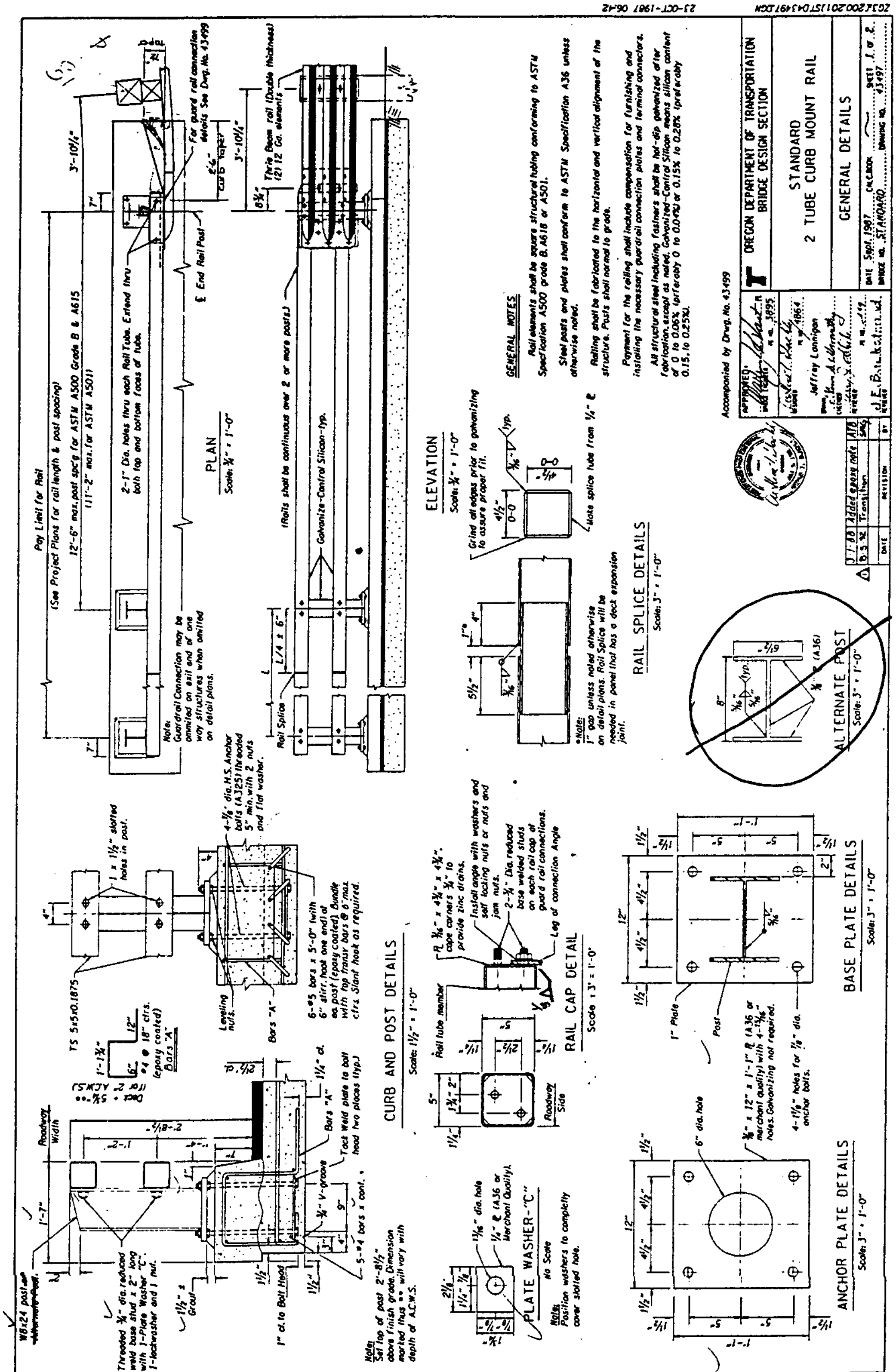
Table 1. Performance evaluation summary for test 404311-3, *NCHRP Report 350* test 4-12.

Test Agency: Texas Transportation Institute | Test No.: 404311-3 | Test Date: 01/07/99

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 Alaska Multi-State Bridge Railing mounted on curb and deck 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 or to show potential for penetrating the occupant compartment, or present an undue hazard to other traffic.	Pass
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The vehicle rolled onto its left side after exiting the installation.	Fail*
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 13.7 m toward traffic lanes.	Pass*
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Exit angle at loss of contact was 5.7 degrees which was less than 60 percent of the impact angle.	Pass*

*Criterion G, K, and M are preferable, not required.

APPENDIX A. STANDARD 2 TUBE CURB MOUNT RAIL DRAWINGS



5-8.3

APPENDIX B. 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 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 volt maximum level. The signal conditioners also provides 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 (I.R.I.G.), 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, (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine, filtered with Society of Automotive Engineers (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 SAE J211 *4.6.1* by means of a 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 Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations will be made at 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 instructs 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

Use of a dummy in the 8000S vehicle is optional according to *NCHRP Report 350* and there was no dummy used in the test.

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 conditions 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 C. TEST VEHICLE PROPERTIES AND INFORMATION

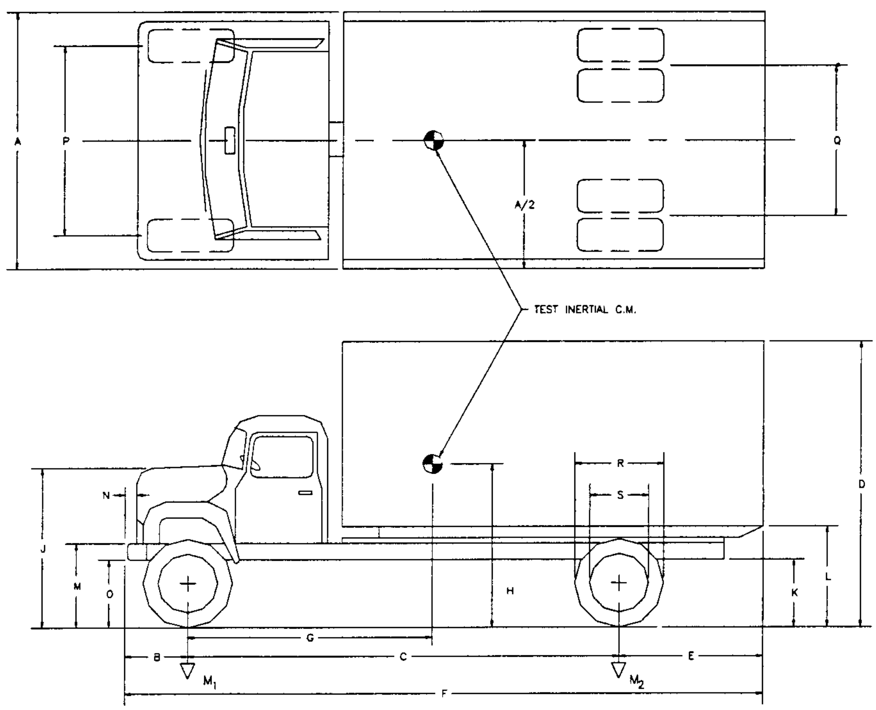
DATE: 1/7/99 TEST NO.: 404311-3 VIN NO.: 1GDL7D1B4HV508627

MODEL: 7000 YEAR: 1987 ODOMETER: 150362 TIRE SIZE: 11R22.5

MAKE: GMC

MASS DISTRIBUTION (kg) LF 1550 RF 1588 LR 2372 RR 2490

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



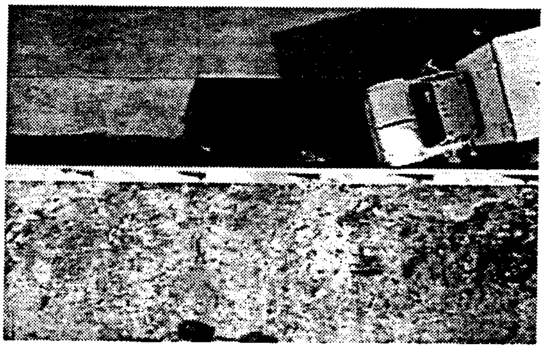
GEOMETRY–(mm)

A 2430	D 3680	G 3117.8	K 710	N 110	Q 1800
B 800	E 2310	H 1234.4	L 1220	O 520	R 1040
C 5130	F 8240	J 1600	M 850	P 200	S 600

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	2255	3138	
M_2	3129	4862	
M_T	5384	8000	

Figure 11. Vehicle properties for test 404311-3.

APPENDIX D. SEQUENTIAL PHOTOGRAPHS



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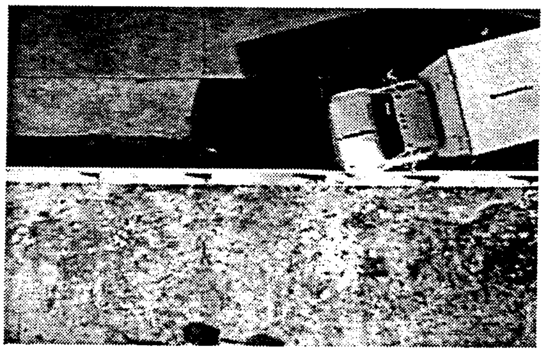

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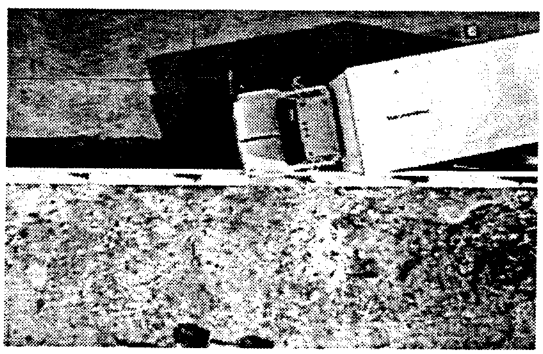

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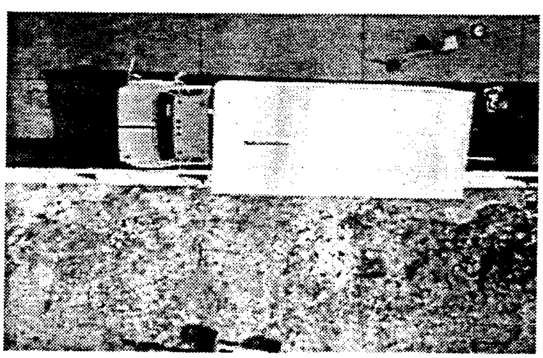

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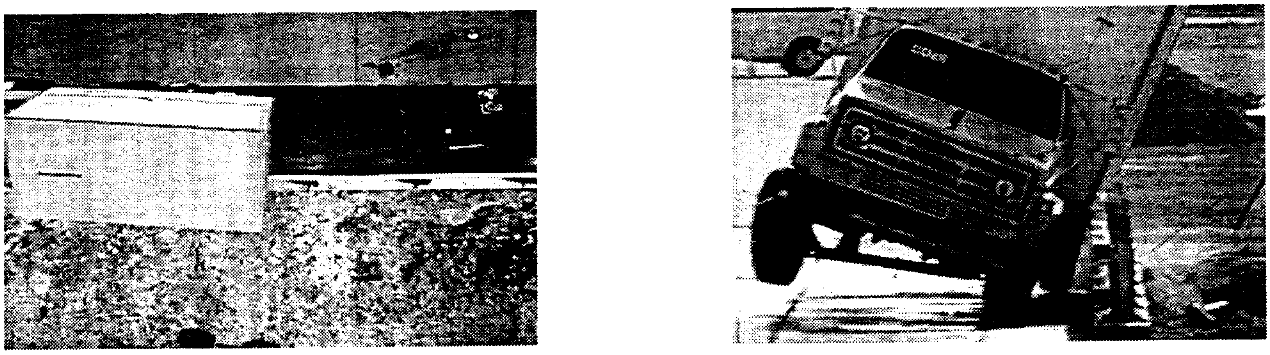
Figure 12. Sequential photographs for test 404311-3 (overhead and frontal views).



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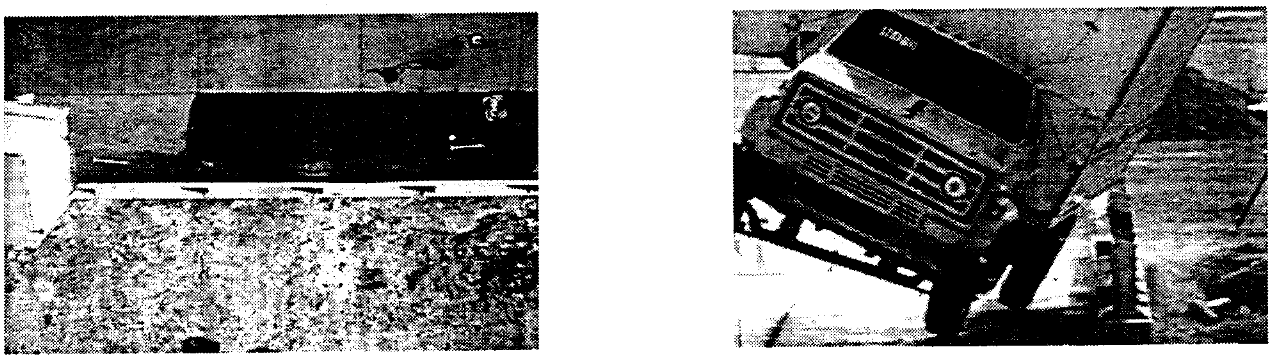

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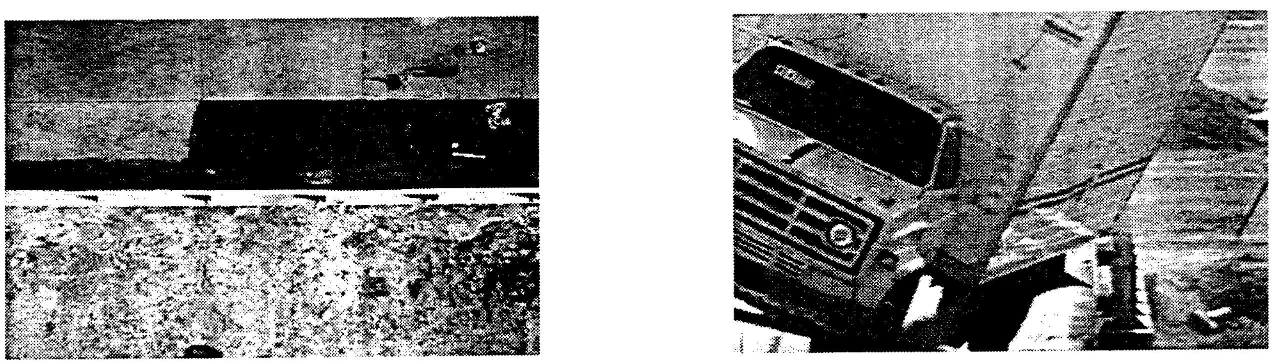

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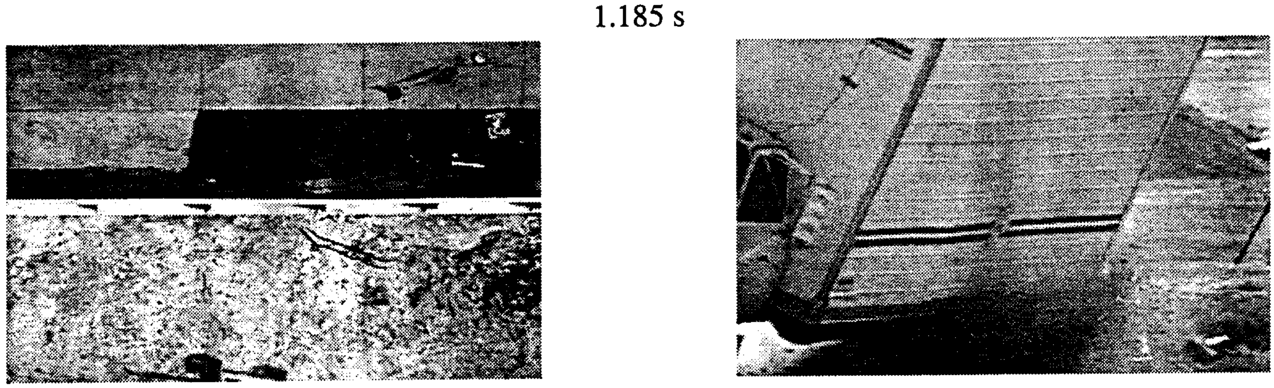
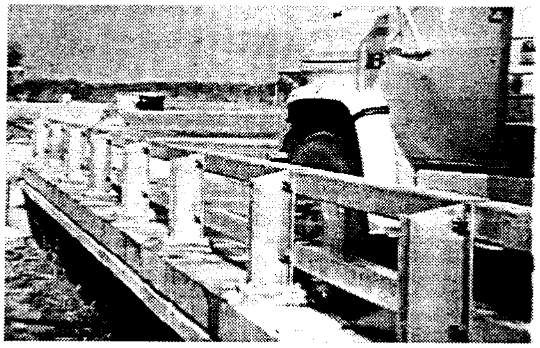


1.580 s

Figure 12. Sequential photographs for test 404311-3 (overhead and frontal views) (continued).



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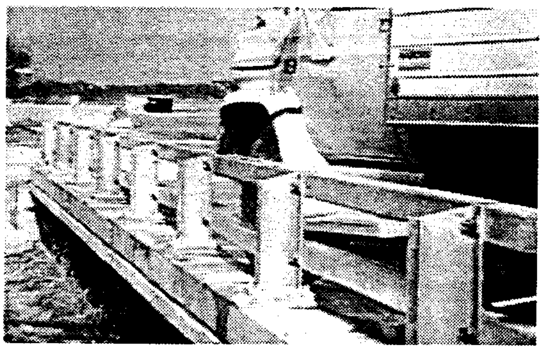

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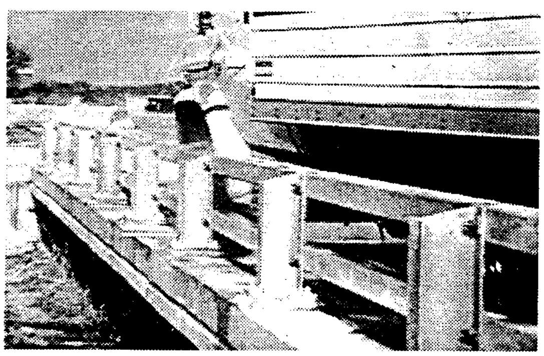

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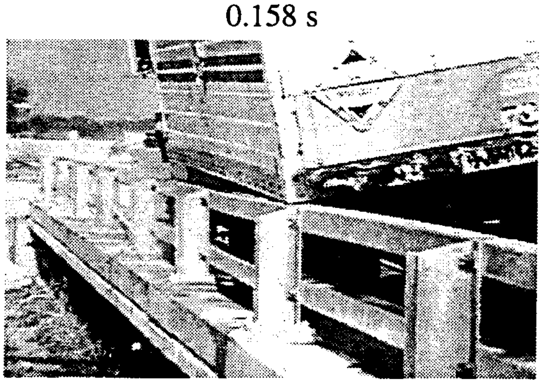

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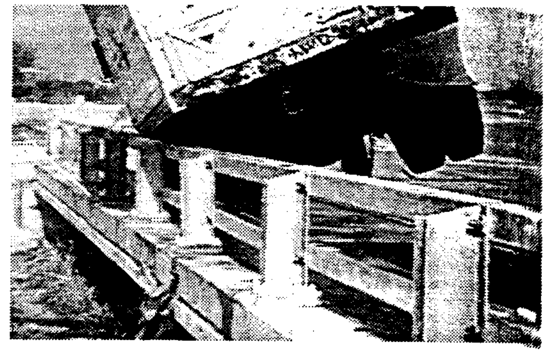

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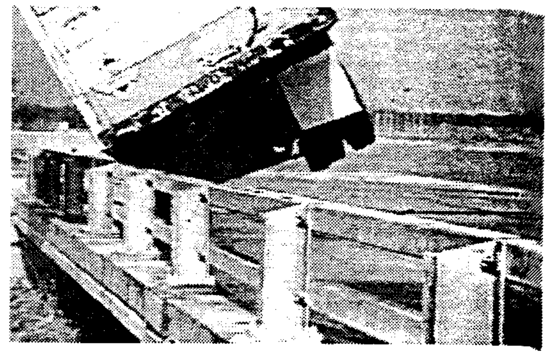

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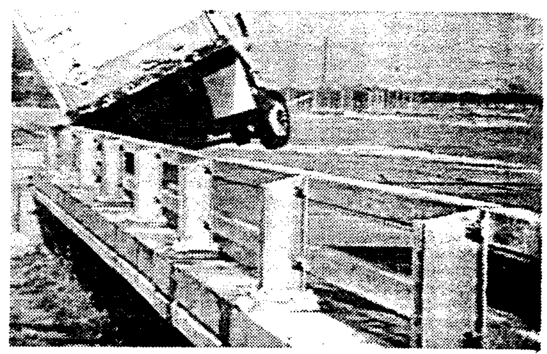

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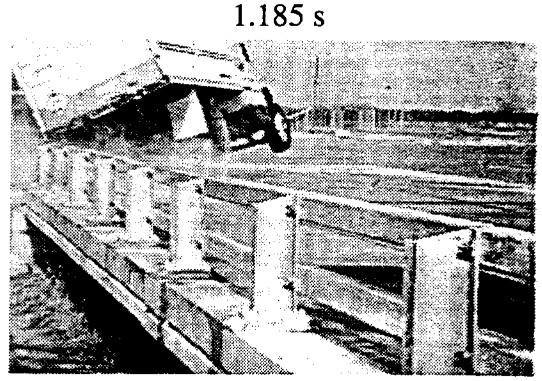

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Figure 13. Sequential photographs for test 404311-3 (rear view).

APPENDIX E. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

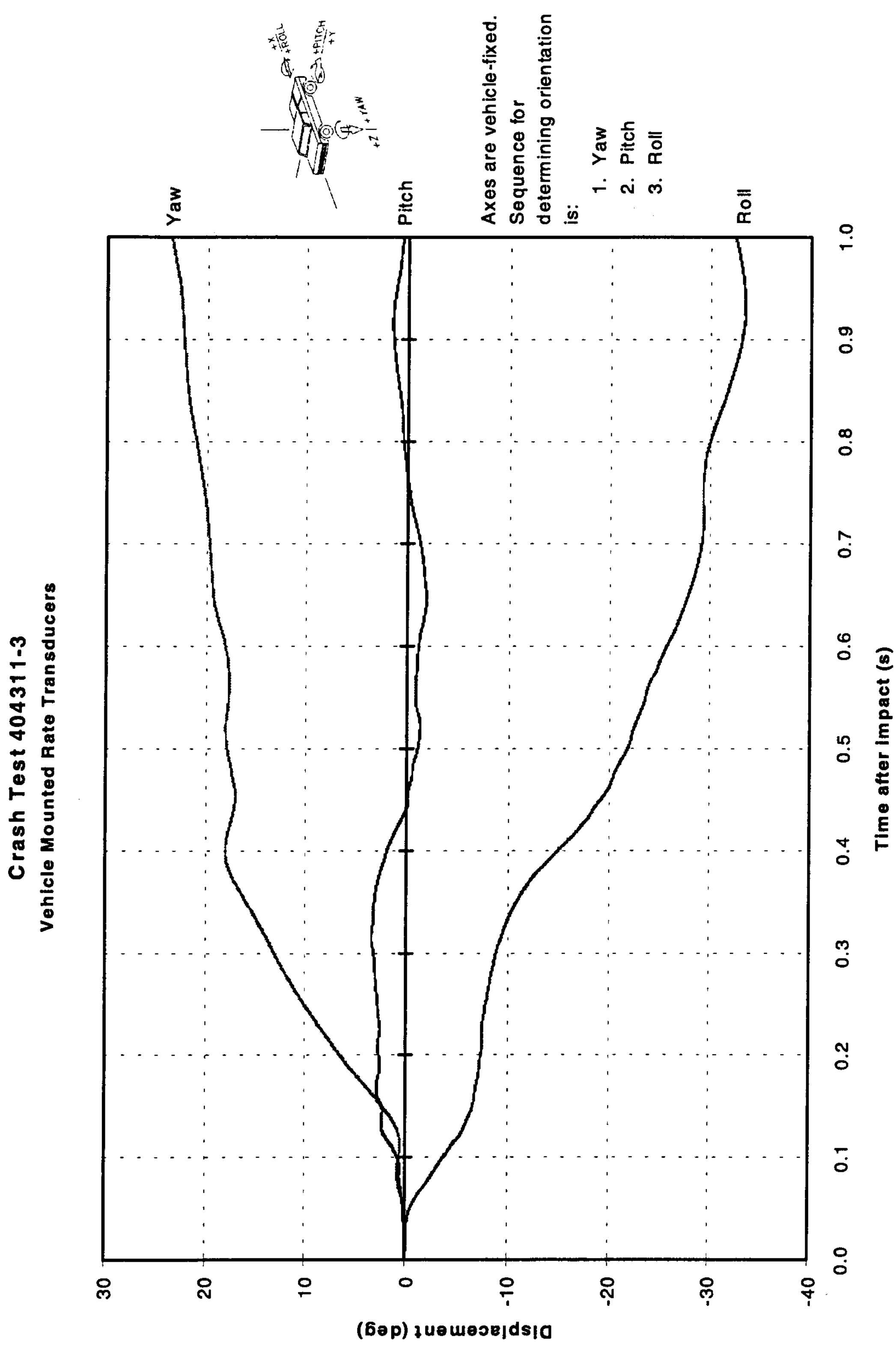

Figure 14. Vehicular angular displacements for test 404311-3.

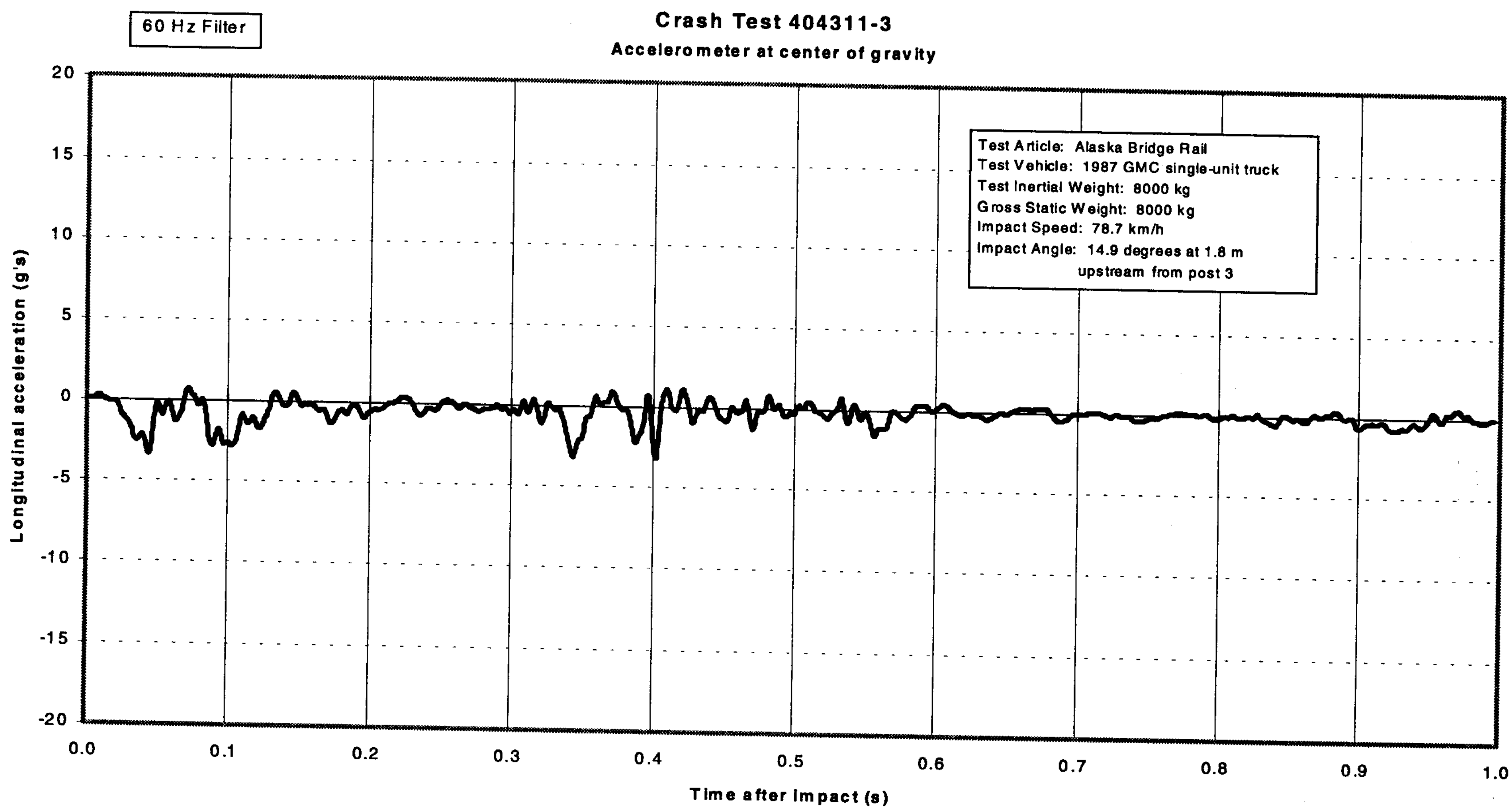

Figure 15. Vehicle longitudinal accelerometer trace for test 404311-3 (accelerometer located at center of gravity).

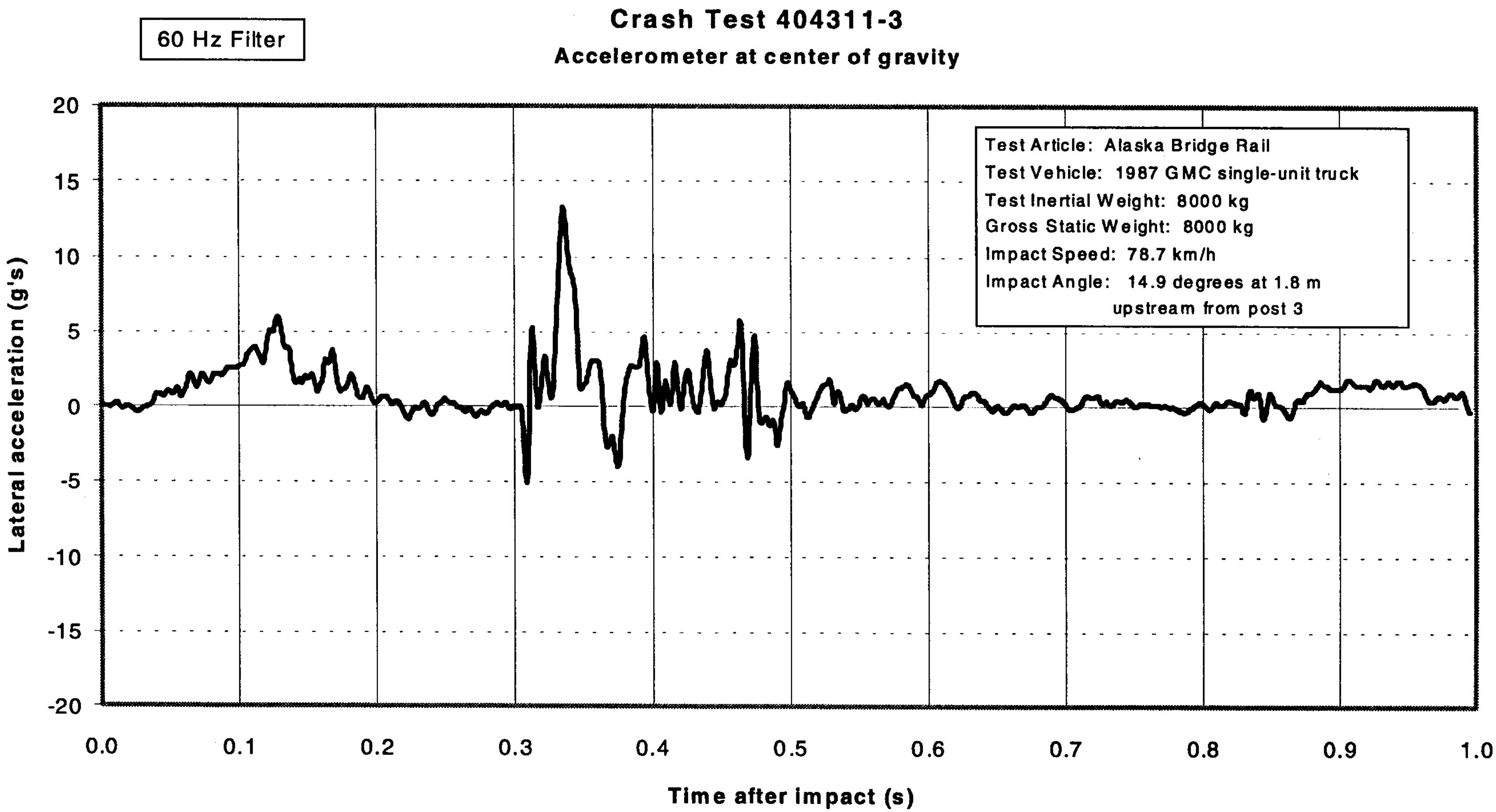

Figure 16. Vehicle lateral accelerometer trace for test 404311-3 (accelerometer located at center of gravity).

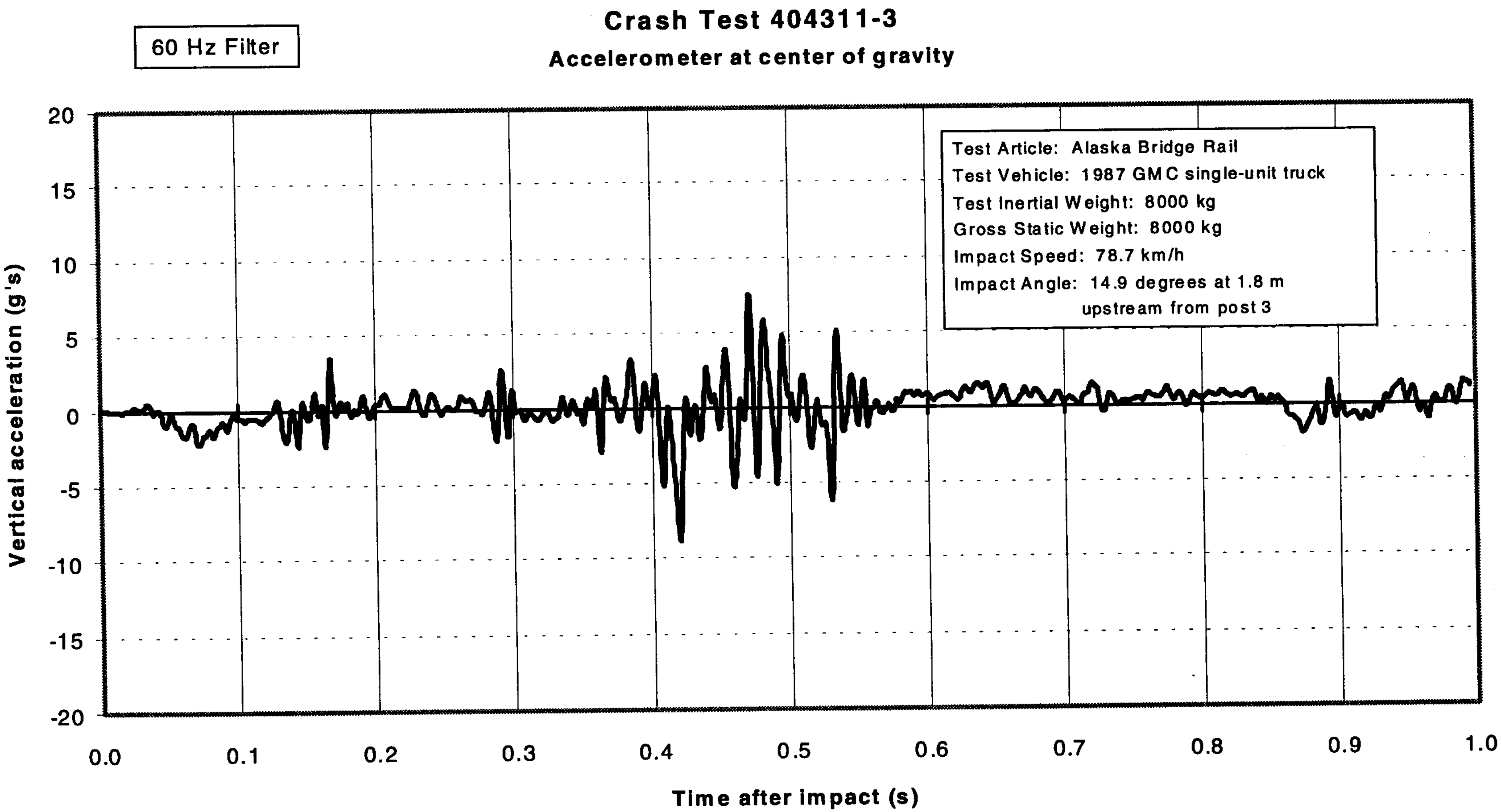

Figure 17. Vehicle vertical accelerometer trace for test 404311-3
(accelerometer located at center of gravity).

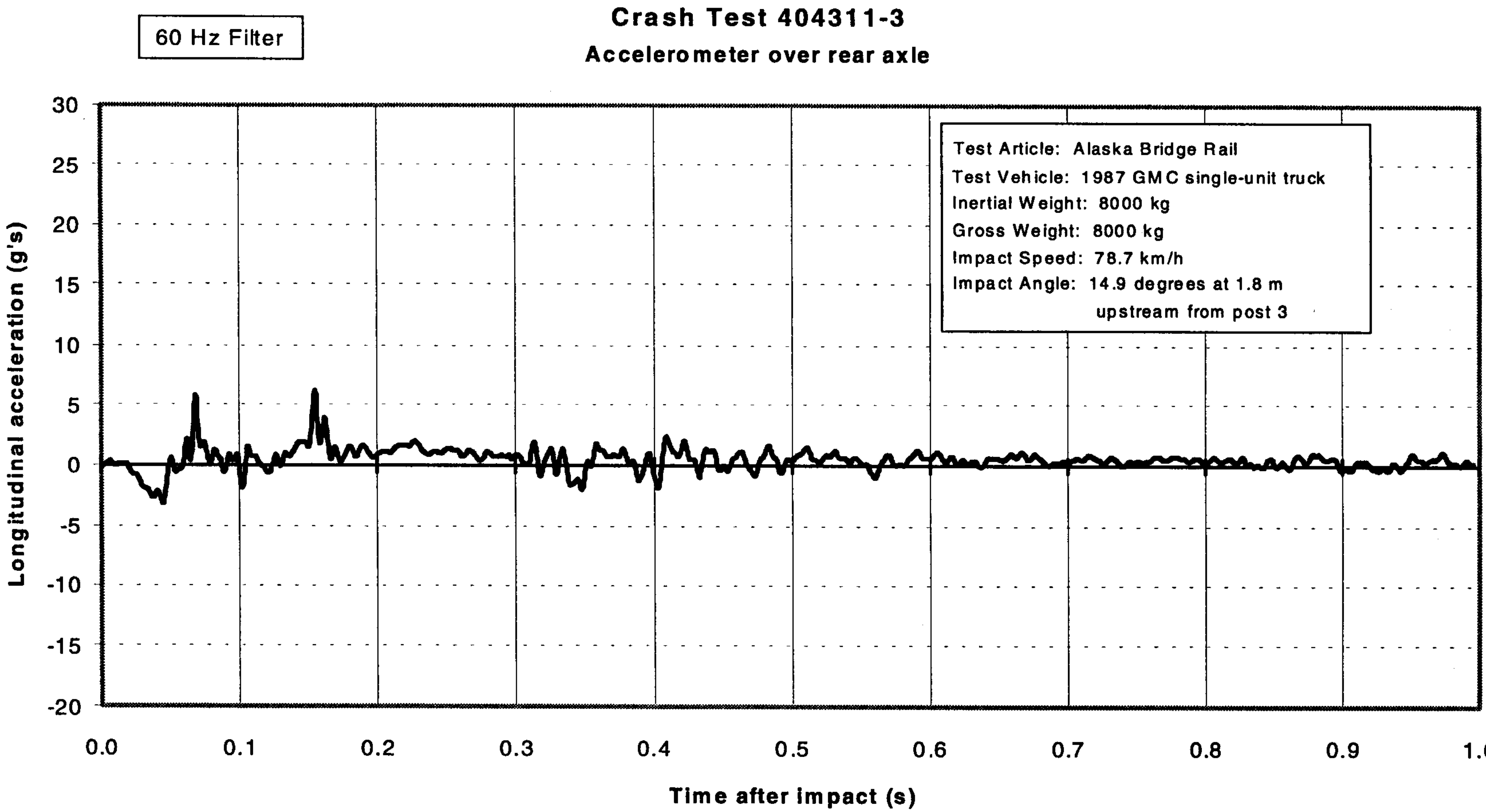

Figure 18. Vehicle longitudinal accelerometer trace for test 404311-3 (accelerometer located over rear axle).

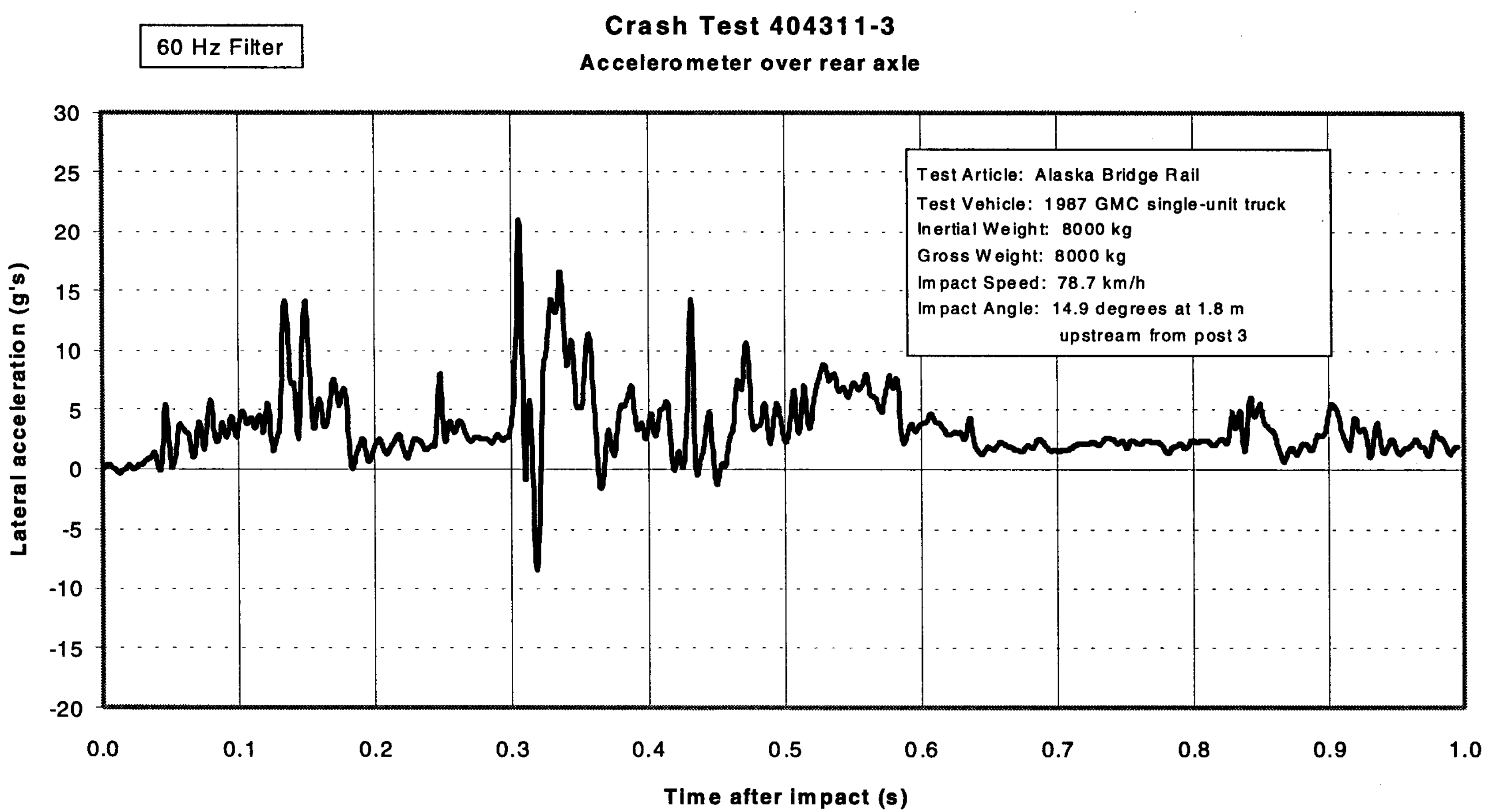

Figure 19. Vehicle lateral accelerometer trace for test 404311-3 (accelerometer located over rear axle).

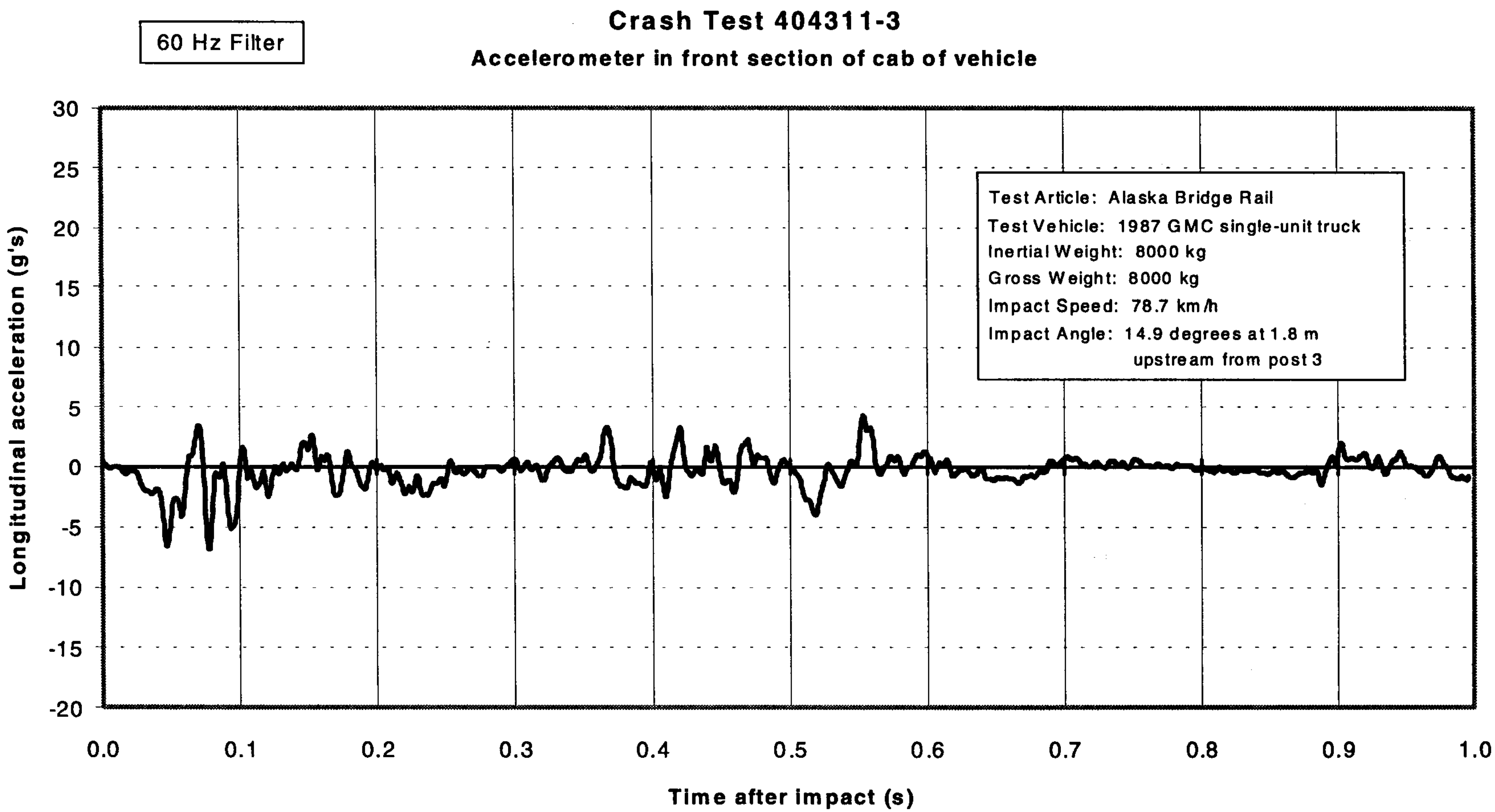

Figure 20. Vehicle longitudinal accelerometer trace for test 404311-3 (accelerometer located in front cab).

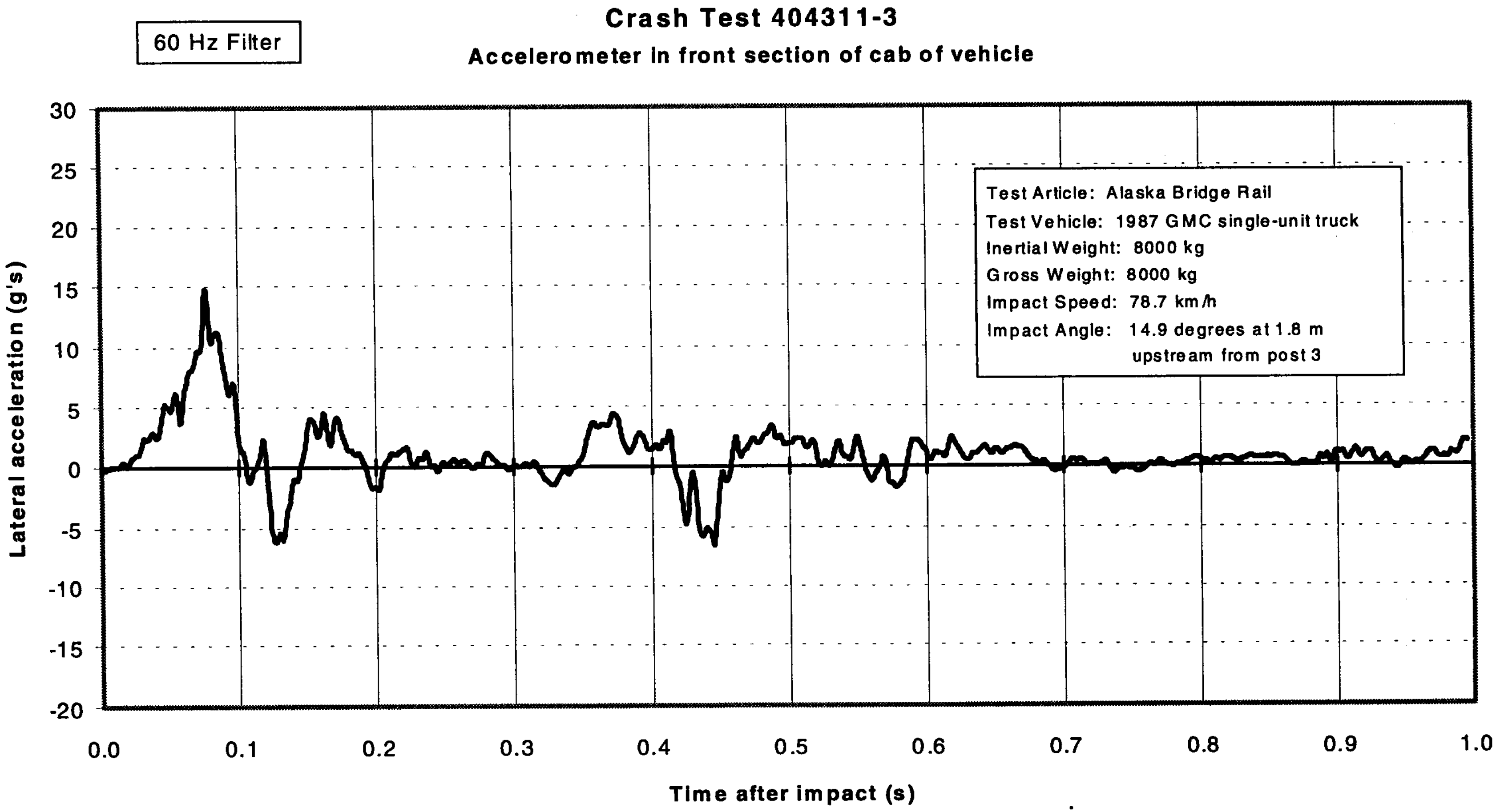

Figure 21. Vehicle lateral accelerometer trace for test 404311-3 (accelerometer located in front cab).

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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.

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3. *AASHTO LRFD Bridge Design Specifications*, First Edition, American Association of State Highway and Transportation Officials, Washington, D.C., 1994.

4. C. Eugene Buth, William F. Williams, Wanda L. Menges and Sandra K. Schoeneman, *NCHRP Report 350 Test 4-10 of the Alaska Multi-State Bridge Rail*, TTI Research Report 404311-1 for Contract No. T97232, Texas Transportation Institute, The Texas A&M University System, College Station, TX, December 1998.

5. C. Eugene Buth, William F. Williams, Wanda L. Menges and Sandra K. Schoeneman, *NCHRP Report 350 Test 4-11 of the Alaska Multi-State Bridge Rail*, TTI Research Report 404311-2 for Contract No. T97232, Texas Transportation Institute, The Texas A&M University System, College Station, TX, December 1998.