TEXAS TRANSPORTATION INSTITUTE

NCHRP REPORT 350 TEST 4-11 OF THE ALASKA MULTI-STATE BRIDGE RAIL

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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 pickup truck 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 Alaska Multi-State Bridge Rail mounted on the curb met the required criteria specified for *NCHRP Report 350* test designation 4-11.

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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.

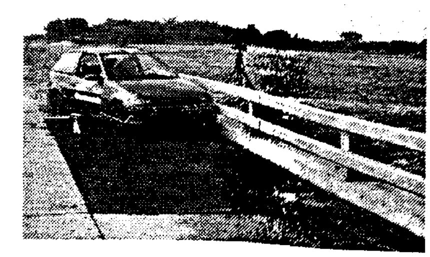
This report presents the details of the Alaska Multi-State Bridge Railing mounted on the curb and results of the pickup truck test: *NCHRP Report 350* test designation 4-11, which is the 2000-kg pickup truck impacting the CIP at 100 km/h and 25 degrees. The Alaska Multi-State Bridge Railing mounted on the curb met the required criteria specified for *NCHRP Report 350* test designation 4-11. The vehicle came to rest 24.4 m toward traffic lanes, thereby intruding into adjacent traffic lanes. However this criteria is preferred, not required.

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 Bridge Design (LRFD) Specifications.*[3] TTI performed engineering calculations on current designs used by Alaska and the results of this study are reflected in the test installation. As a result of this study, 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 separate 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

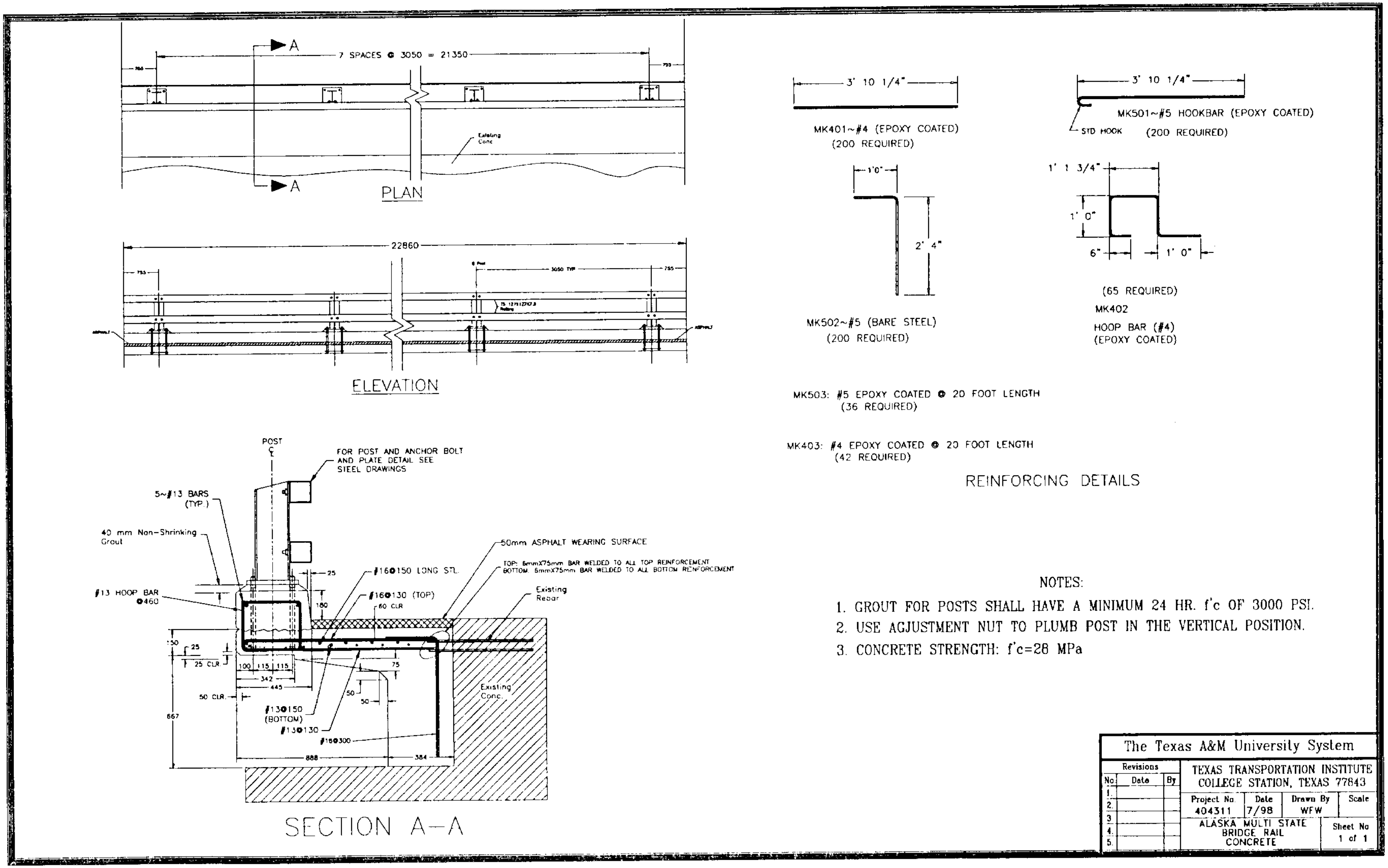


Figure 1. Details of the Alaska Multi-State Bridge Railing mounted on the curb (concrete).

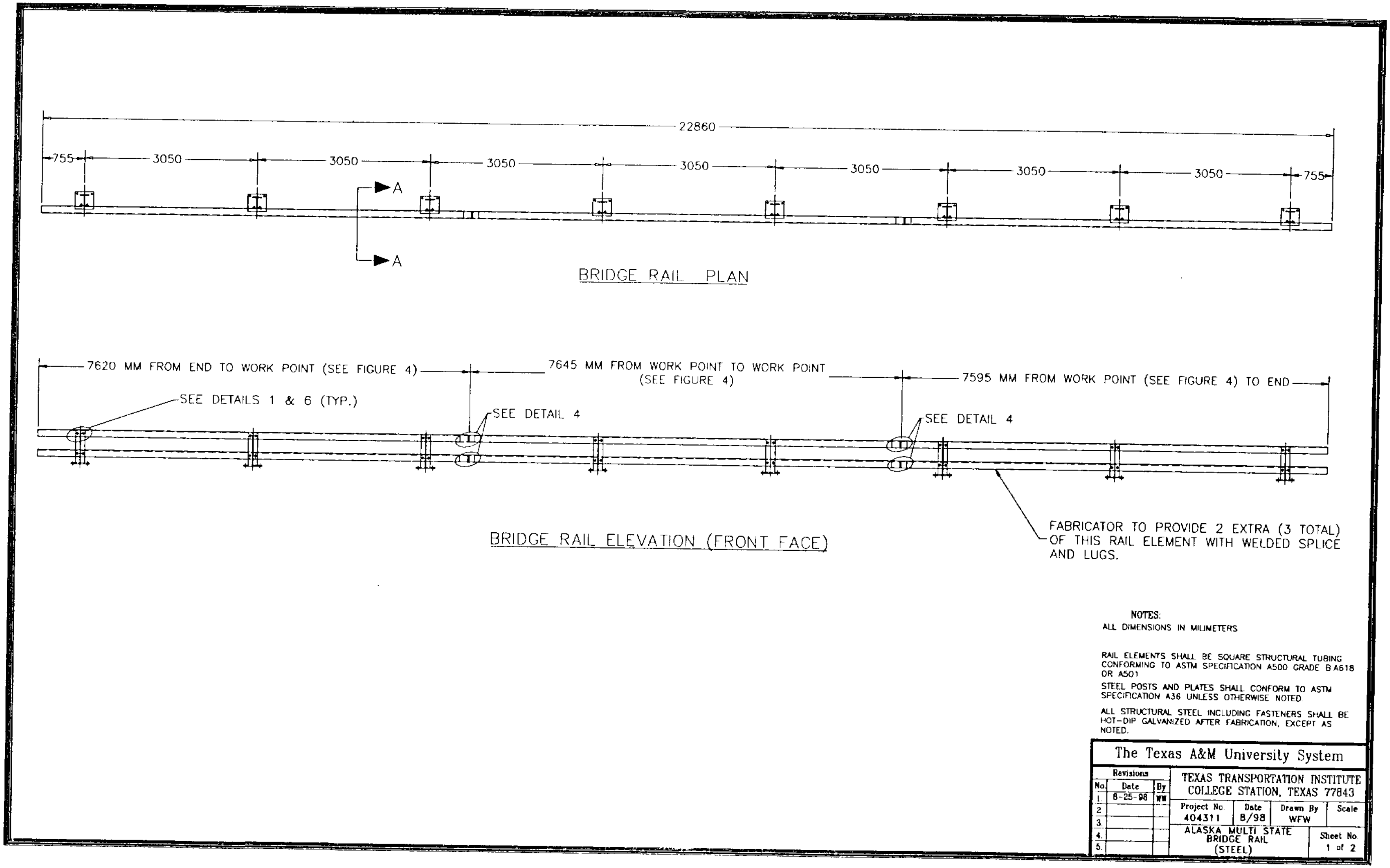


Figure 2. Details of the Alaska Multi-State Bridge Railing mounted on the curb (steel).

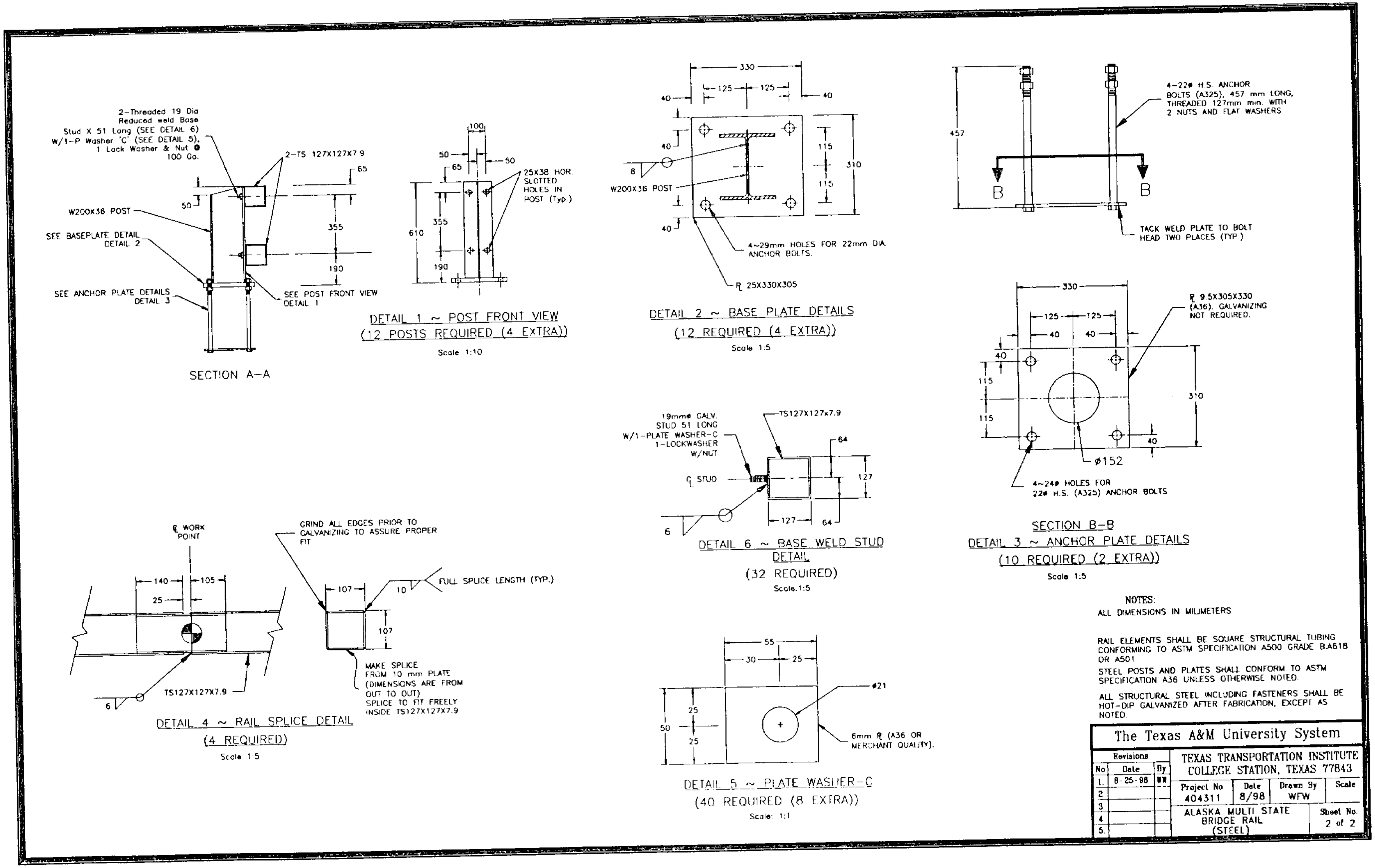


Figure 2. Details of the Alaska Multi-State Bridge Railing mounted on the curb (steel) (continued).

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 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 #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 were 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 a 8 mm fillet weld. A 40 mm high strength cementous 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.

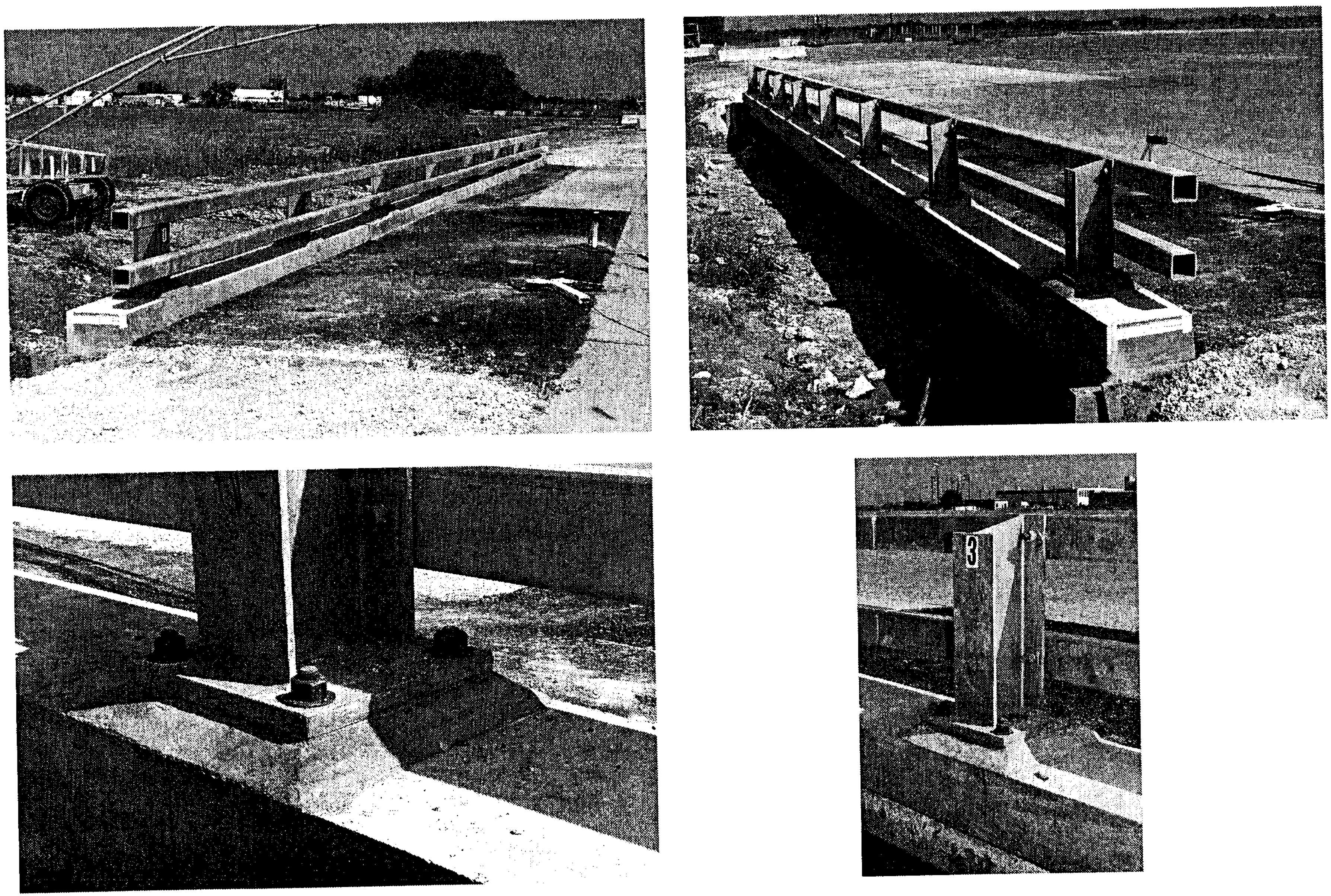


Figure 3. Alaska Multi-State Bridge Railing mounted on the curb before test 404311-2.

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**: A 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 4-11. *NCHRP Report 350* test designation 4-10 was detailed in an earlier report and test designation 4-12 will be detailed in a subsequent report.

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 time of vehicle loss of contact with the test device.*

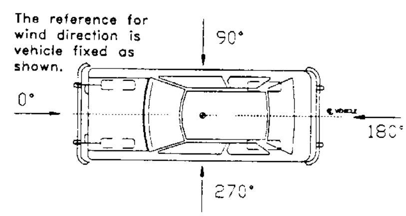
CRASH TEST 404311-2

Test Vehicle

A 1995 Chevrolet 2500 pickup truck, shown in figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2000 kg. The height to the lower edge of the vehicle front bumper was 430 mm and to the upper edge of the front bumper was 655 mm. Additional dimensions and information on the vehicle are given in appendix C, figure 12. 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 14, 1998. A total of 38 mm of rain was recorded eight days prior to the test but would not affect the test on the concrete deck. No rainfall was recorded for the ten days prior to the test. Weather conditions at the time of testing were as follows: Wind Speed: 0 km/h; Wind Direction: 0 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); Temperature: 30°C; Relative Humidity: 39 percent.



Impact Description

Traveling at 100.7 km/h the vehicle impacted the curb of the Alaska Multi-State Bridge Railing 1.3 m upstream from post 3 at a 25.8 degree angle. Shortly after the vehicle impacted the lower rail element, the bumper of the vehicle impacted with the upper rail element. The lower and upper rail moved at 0.002 and 0.007 s, respectively. At 0.008 s the front left tire impacted with the lower rail element, and at 0.015 s the left front tire contacted with the concrete curb and the wheel steered to the right. Post 3 moved at 0.029 s and the left front tire deflated at 0.031 s. The bumper pushed between the upper and lower rails to impact with post 3 at 0.032 s, and at 0.033 s the front right wheel steered toward the right. At 0.034 s bumper of the vehicle snagged on post 3. The vehicle began to redirect at 0.049 s. By 0.061 s, the concrete base of the bridge deck cracked on the field side of the installation, and by 0.069 s, the front bumper separated from the vehicle. The windshield shattered at 0.075 s, and at 0.090 s the right front tire lost contact with the road surface. At 0.139 s the left front tire lost contact with the road surface while still in contact with the bridge rail, and at 0.152 s the right rear tire lost contact with the road surface. The rear of the vehicle impacted the upper rail element at 0.186 s, and at 0.198 s the left rear tire lost contact with the road surface. Traveling at 86.4 km/h, the vehicle was moving parallel to the rail at 0.208 s. At 0.219 s the front of the vehicle moved out from between the bridge rail elements, and at 0.228 s the bumper of the vehicle went between the upper and lower rail elements between posts 3 and 4 and came to rest behind the bridge rail. At 0.340 s the left rear

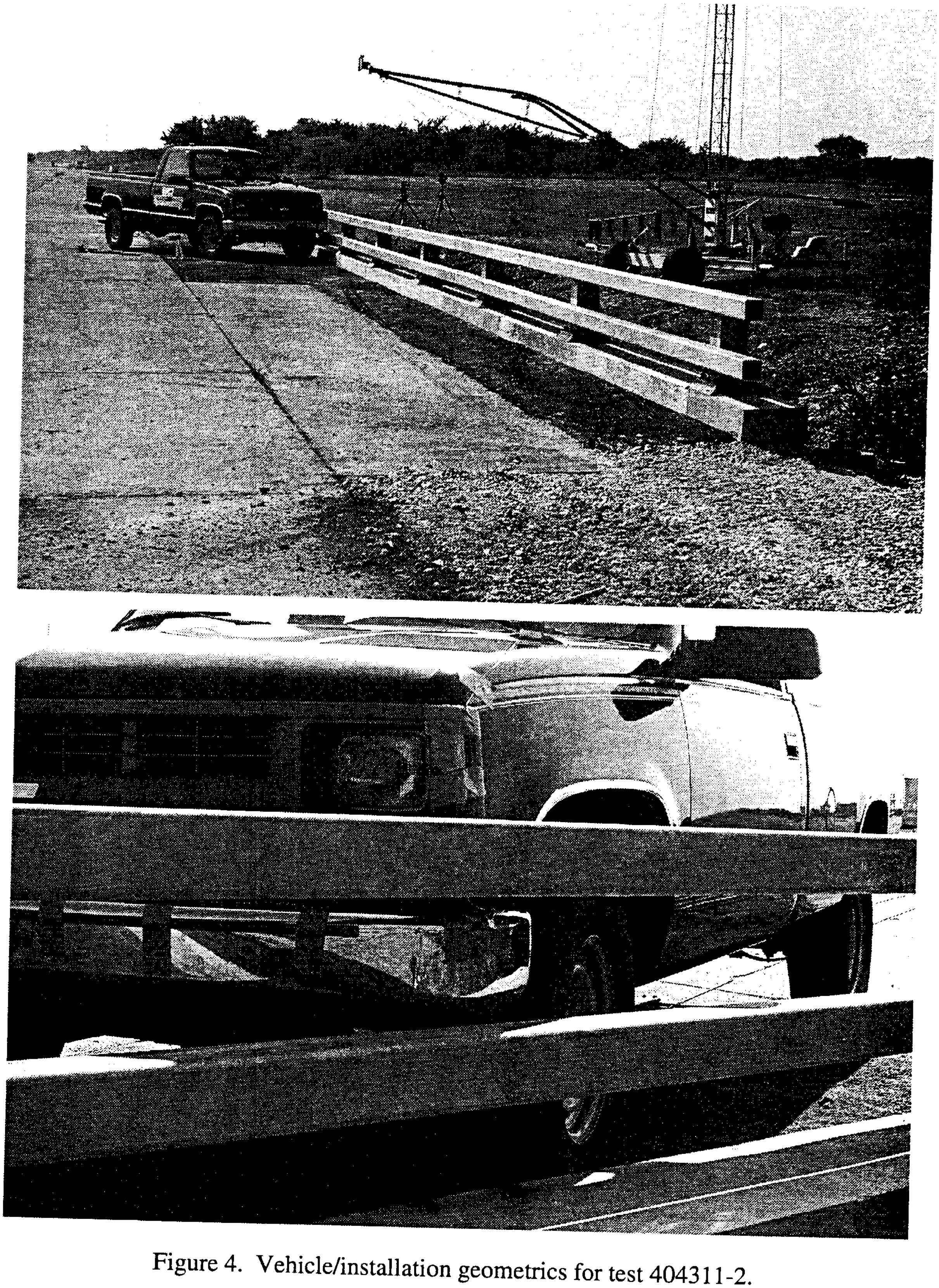


Figure 4. Vehicle/installation geometrics for test 404311-2.

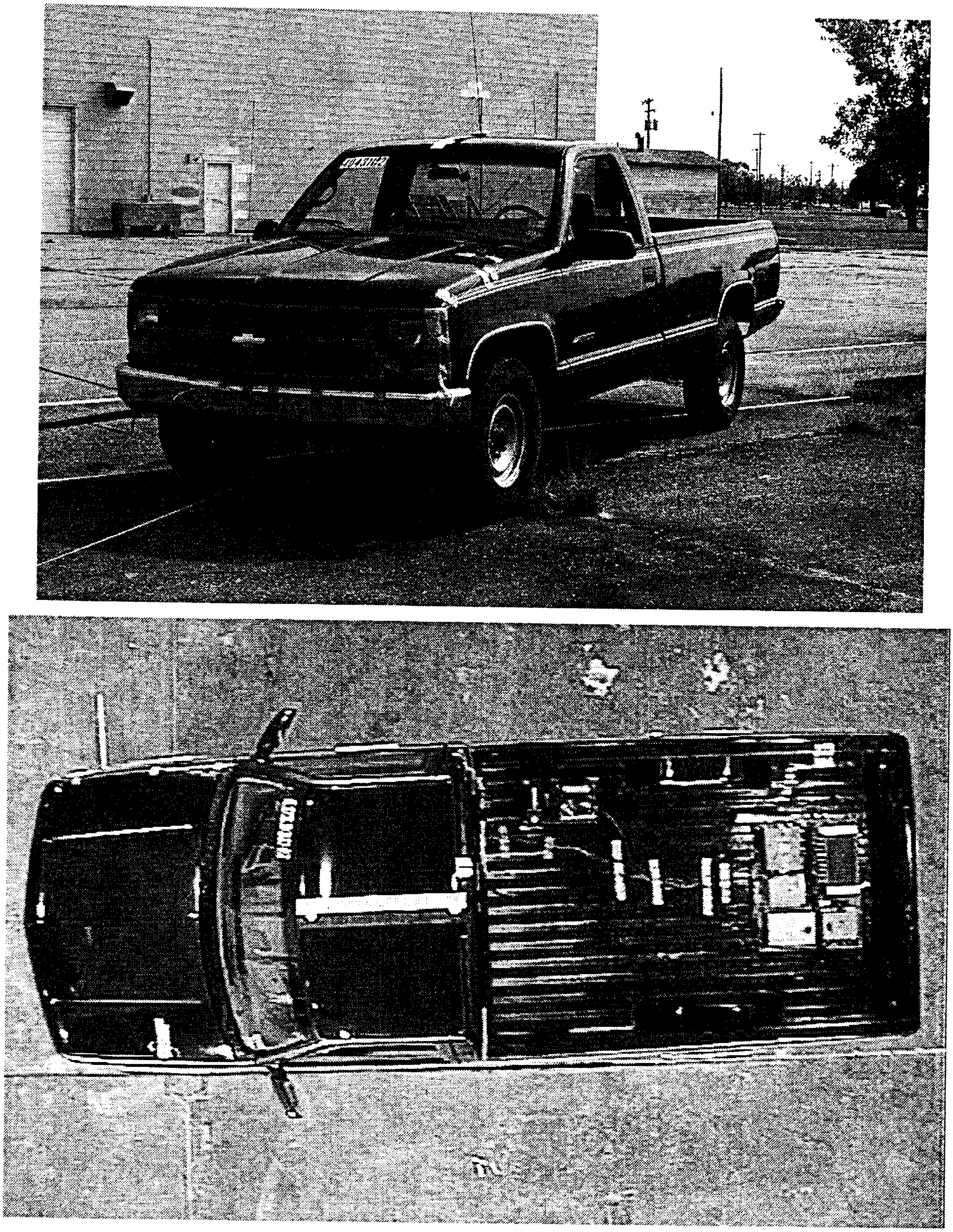


Figure 5. Vehicle before test 404311-2.

tire returned to the ground. The vehicle lost contact with the bridge railing at 0.341 s, traveling at a speed of 84.9 km/h at a 5.8 degree angle. At 0.448 s the left front tire returned to the ground, and at 0.502 s the right front tire exits the screen. The right front tire and right rear tires returned to the ground at an estimated time of 0.716 and 0.747 s, respectively. Brakes on the vehicle were applied at 1.5 s, and the vehicle subsequently came to rest 60.9 m downstream from impact and 24.4 m toward the lanes of traffic. Sequential photographs of the test period are shown in appendix D, figures 13 and 14.

Damage to Test Article

Damage to the Alaska Multi-State Bridge Railing mounted on the curb is shown in figures 6 thru 8. At impact the edge of the curb was scraped, and tire marks were along the face of the curb. Deflection at post 3 during the test was 0.40 m. Cracks in the bridge deck radiated out from the front and rear bolts and at post 3 the grout was missing at the front and sides of the base plate. The front face of post 3 was marred with blue paint from the vehicle and the curb was chipped. Total length of contact of the vehicle with the bridge railing was 4.8 m.

Vehicle Damage

The vehicle sustained structural damage to the sway bar, left outer tie rod, left frame rail and left A-arm. The front left portion of the bumper, hood, grill, fan and radiator were deformed as shown in figure 9. Both left side tires and rims were damaged. The windshield was shattered and the left door had a gap that measured 170 mm. The left front and rear quarter panels were dented. The cab of the vehicle was pushed against the bed of the vehicle and the driver's side dash was bent up and pushed forward. The maximum exterior crush to the radiator support was 540 mm and at 900 mm above the ground to the left side of the bumper measured 405 mm. Maximum deformation of the occupant compartment was 115 mm (7 percent reduction in space) in the lateral direction near the occupant's feet, 60 mm (4 percent reduction in space) in the firewall area and 37 mm (3 percent reduction in space) in the floor pan area. The interior of the vehicle is shown in figure 10. Exterior vehicle crush and occupant compartment measurements are shown in appendix C, tables 2 and 3.

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*

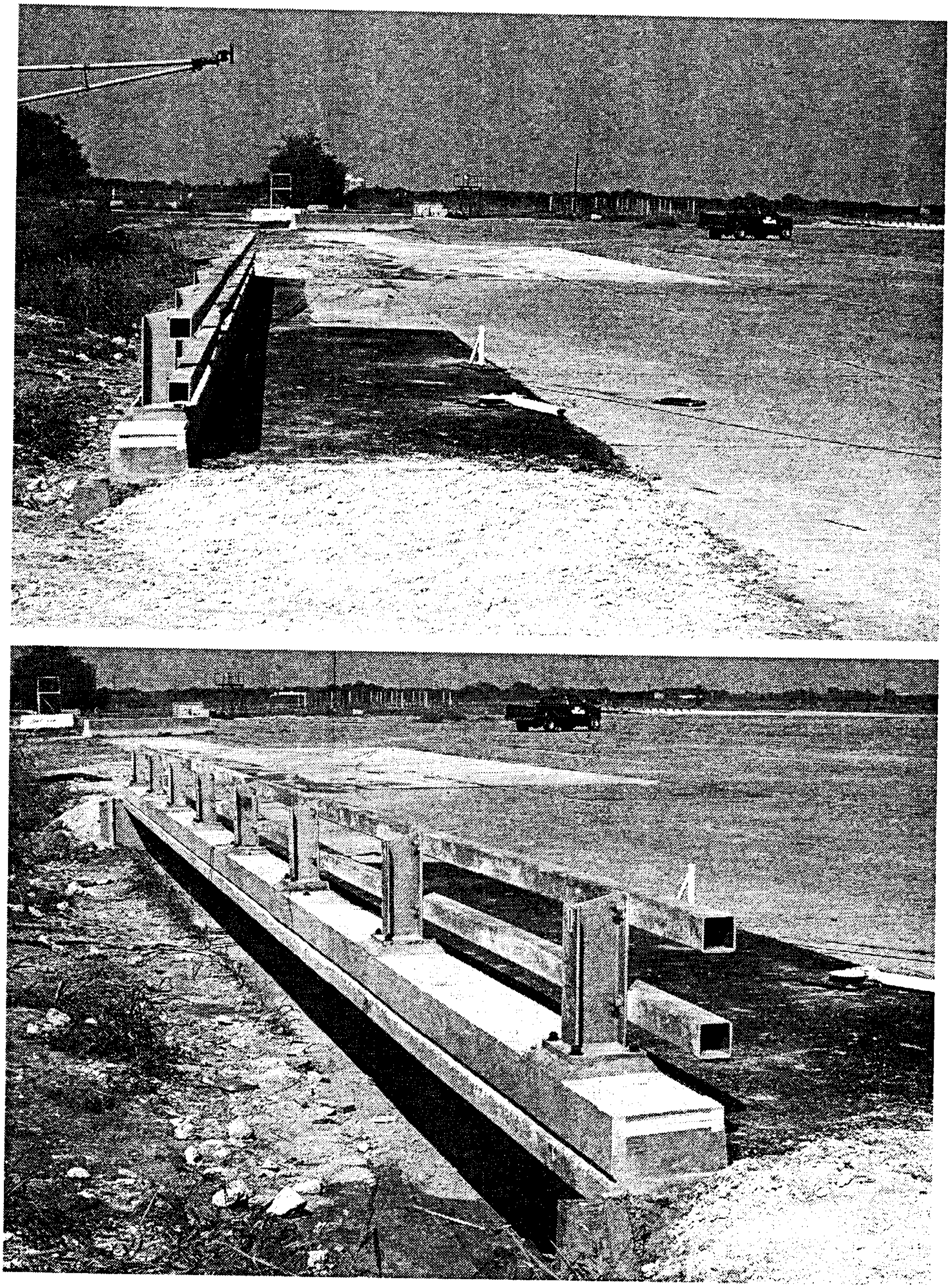


Figure 6. After impact trajectory for 404311-2.

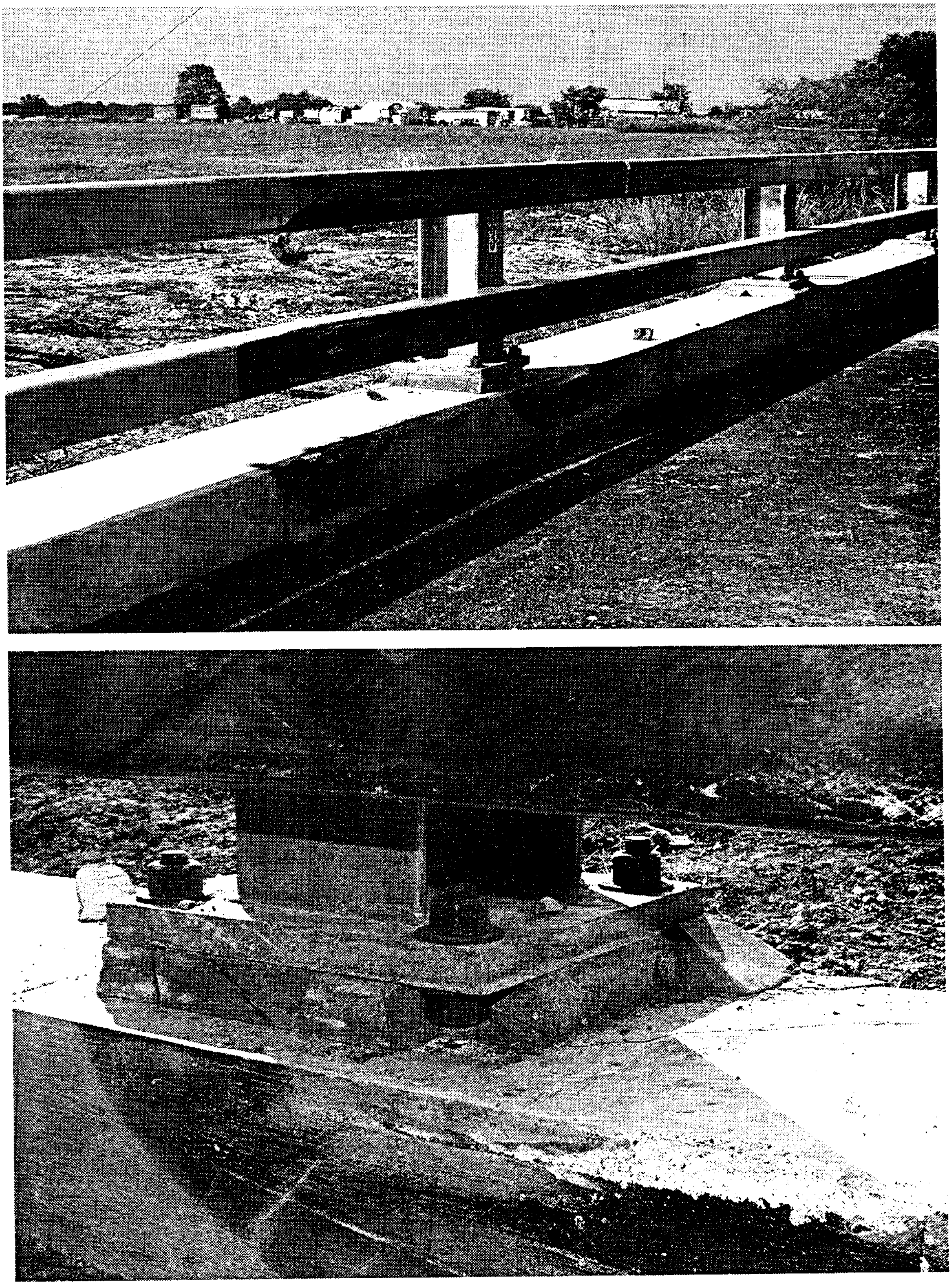


Figure 7. Damage to rail at post 3 after test 404311-2.

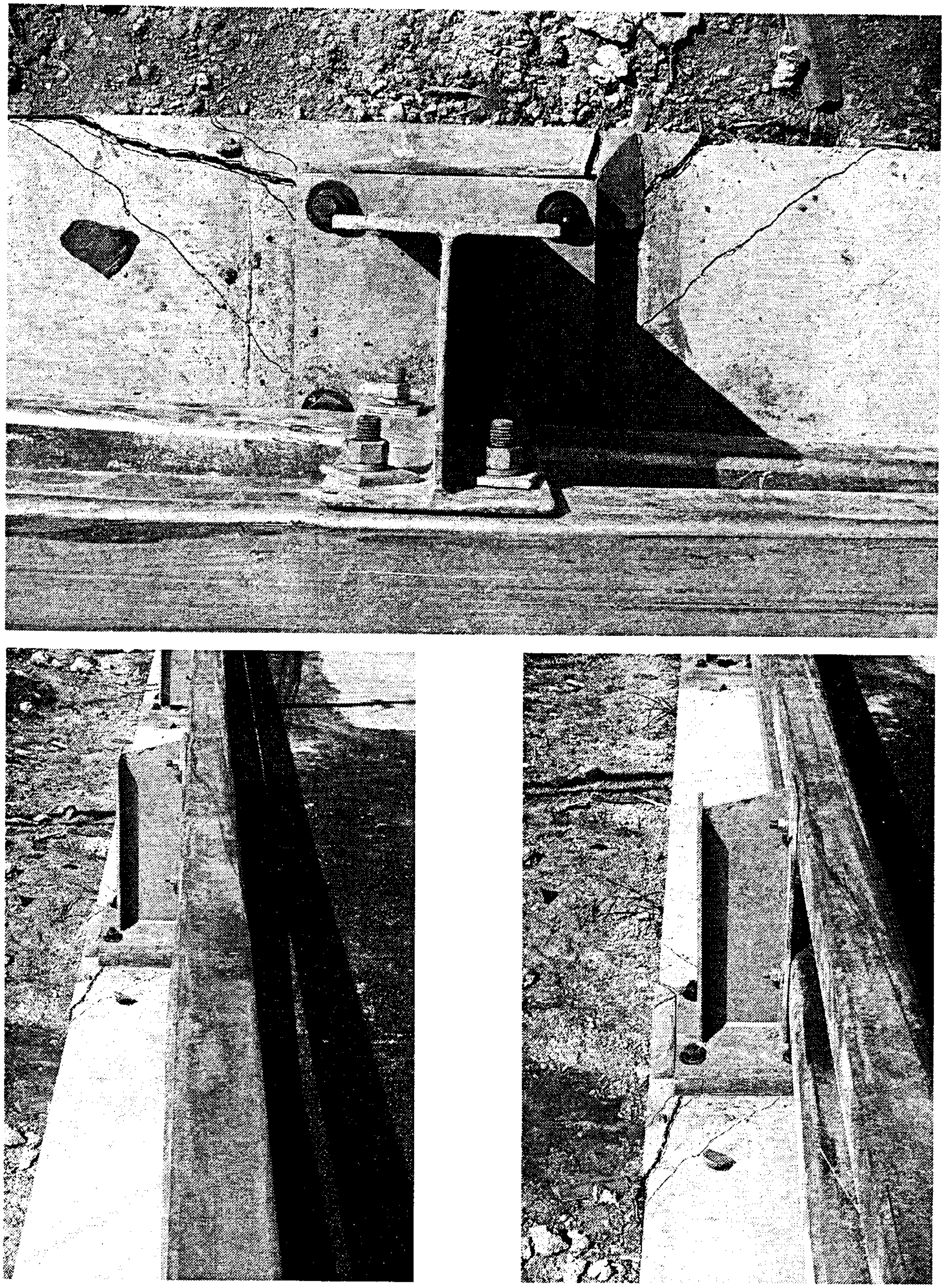


Figure 8. Damage to deck at post 3 after test 404311-2.

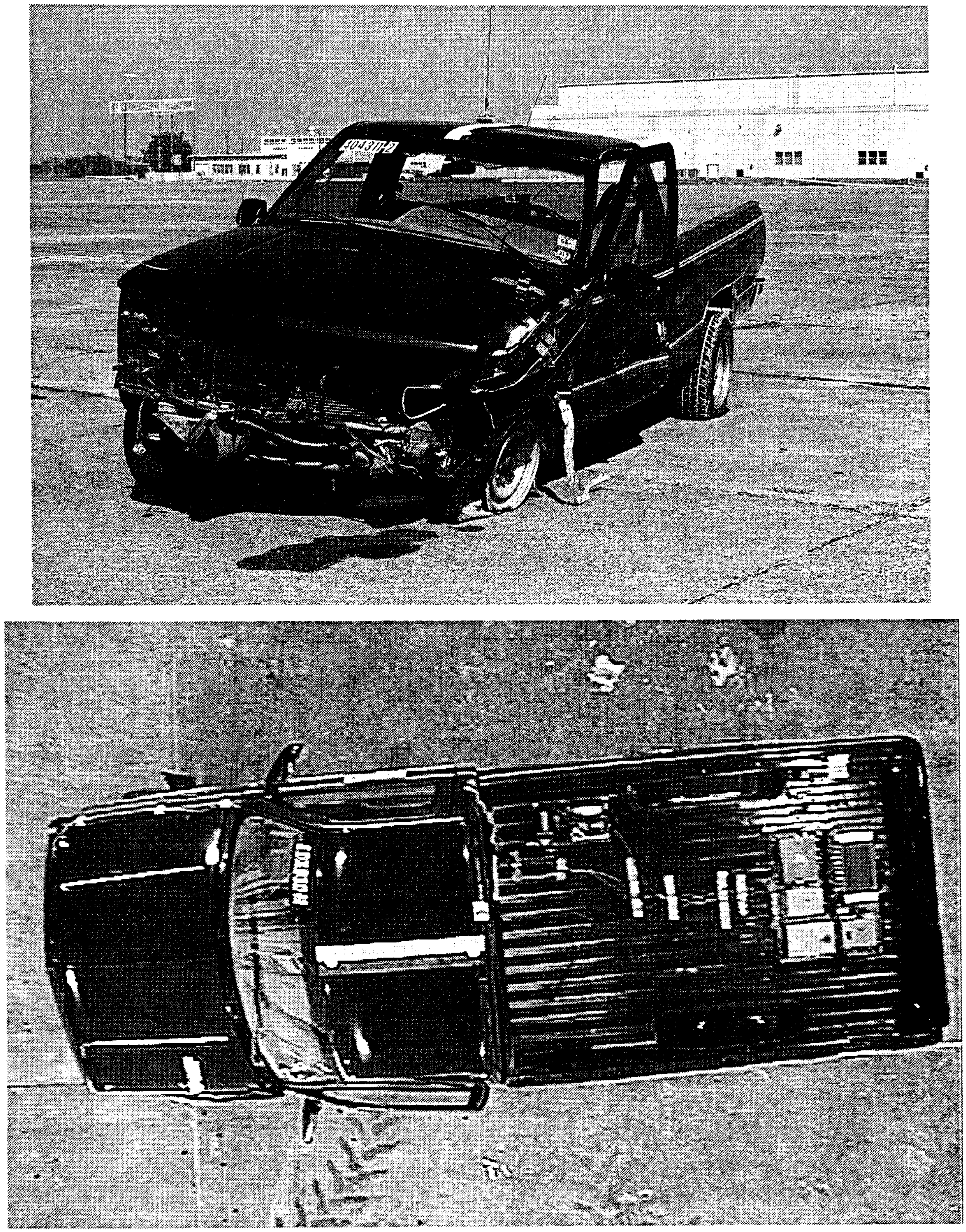
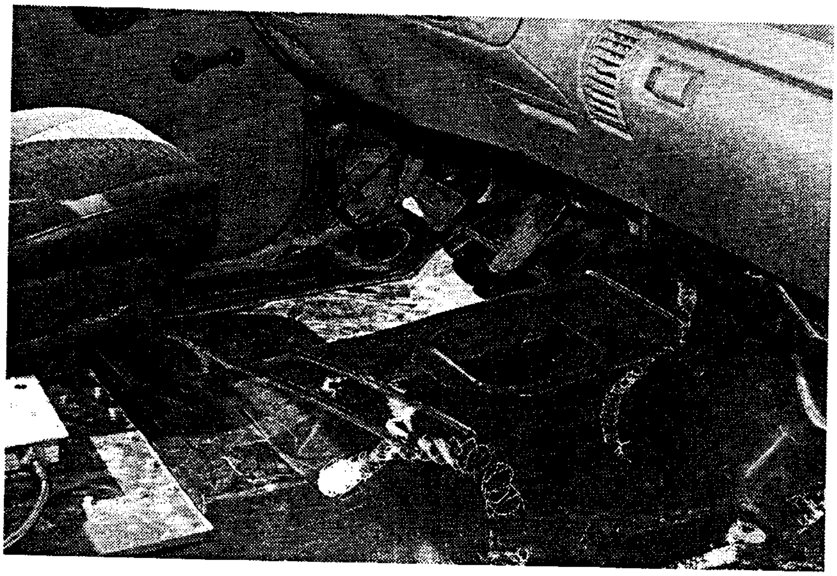
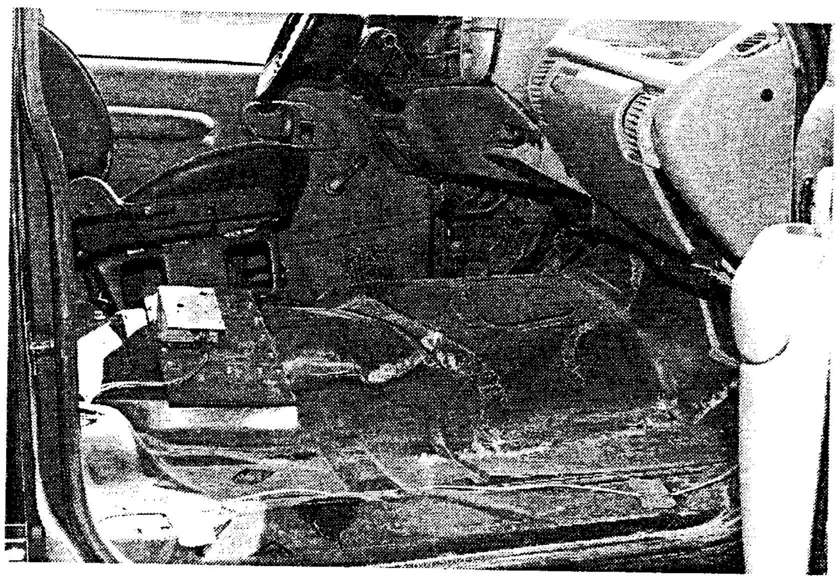


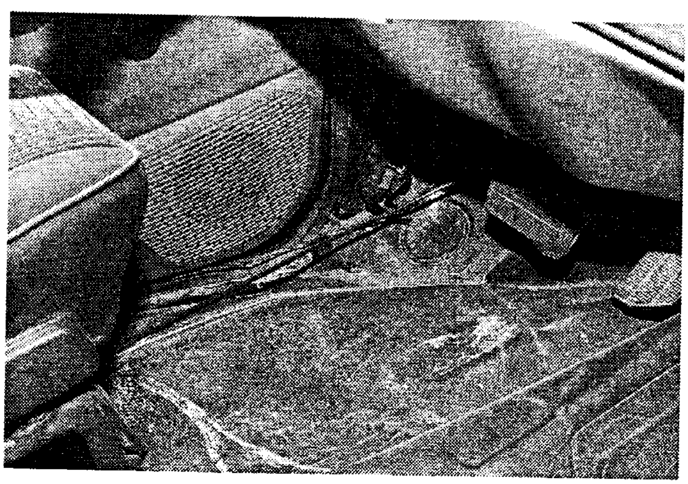
Figure 9. Vehicle after test 404311-2.



Before test



After test



After test

Figure 10. Interior of vehicle for test 404311-2.

although controlled lateral deflection of the test article is acceptable.

The Alaska Multi-State 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 were present to penetrate nor to show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 115 mm (7% reduction in space) in the lateral deformation near the occupant's feet.

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.*

The vehicle came to rest 24.4 m toward traffic lanes and intruded into adjacent traffic lanes.

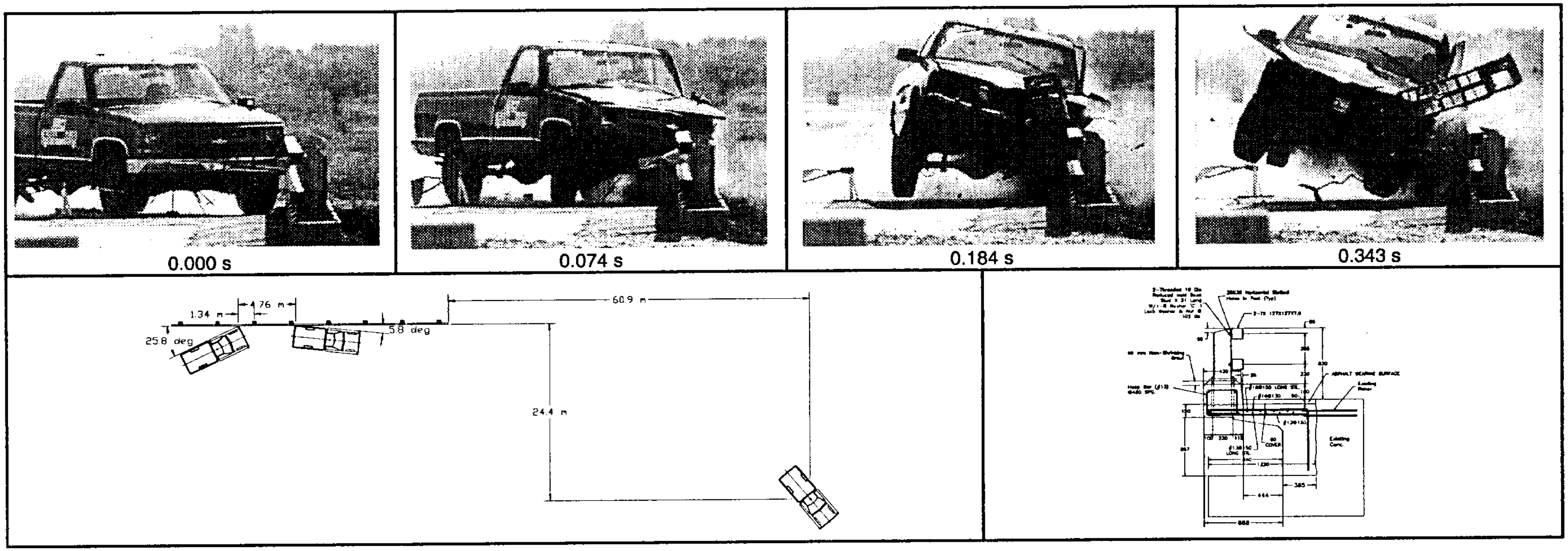
L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown* acceleration in the longitudinal direction should not exceed 20 g's.

In the longitudinal direction, the occupant impact velocity was 6.1 m/s at 0.092 s, the highest 0.010-s occupant ridedown acceleration was -6.9 g's from 0.116 to 0.126 s, and the maximum 0.050-s average acceleration was -8.2 g's between 0.029 and 0.079 s. In the lateral direction, the occupant impact velocity was

-7.4 m/s at 0.092 s, the highest 0.010-s occupant ridedown acceleration was 6.1 g's from 0.217 to 0.227 s, and the maximum 0.050-s average was 13.8 g's between 0.022 and 0.072 s. These data and other pertinent information from the test are summarized in figure 11. Vehicle angular displacements and accelerations versus time traces are presented in appendix E, figures 15 through 18.

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



General Information		**Impact Conditions**		**Test Article Deflections** (m)	
Test Agency	Texas Transportation Institute	Speed (km/h)	100.7	Dynamic	N/A
Test No.	404311-2	Angle (deg)	25.8	Permanent	0.04
Date	10/14/98	**Exit Conditions**		**Vehicle Damage**	
Test Article		Speed (km/h)	84.9	Exterior	
Type	Bridge Rail	Angle (deg)	5.8	VDS	11LFQ5
Name	Alaska Bridge Rail	**Occupant Risk Values**		CDC	11FYEK3 &11LYEW3
Installation Length (m)	xx.x	Impact Velocity (m/s)			
Material or Key Elements	Tubular Steel Rail Elements on Steel Wide Flange Posts on Curb	x-direction	6.1	Maximum Exterior	
		y-direction	-7.4	Vehicle Crush (mm)	540
Soil Type and Condition	Concrete deck, Dry	THIV (km/h)	29.8	Interior	
Test Vehicle		Ridedown Accelerations (g's)		OCDI	LF1112000
Type	Production	x-direction	-6.9	Max. Occ. Compart.	
Designation	2000P	y-direction	6.1	Deformation (mm)	115
Model	1995 Chevrolet 2500 Pickup Truck	PHD (g's)	12.0	**Post-Impact Behavior**	
Mass (kg)		ASI	1.66	(during 1.0 s after impact)	
Curb	2104	Max. 0.050-s Average (g's)		Max. Yaw Angle (deg)	40
Test Inertial	2000	x-direction	-8.2	Max. Pitch Angle (deg)	-5
Dummy	No dummy	y-direction	13.8	Max. Roll Angle (deg)	-21
Gross Static	2000	z-direction	-6.4		

Figure 11. Summary of results for test 404311-2, *NCHRP Report 350* test 4-11.

SUMMARY AND CONCLUSIONS

SUMMARY OF FINDINGS

The Alaska Multi-State Bridge Railing mounted on the curb 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 undue hazard to other traffic. Maximum deformation of the occupant compartment was 115 mm (7 percent reduction in space) in the lateral deformation near the occupant's feet. The vehicle remained upright during and after the collision period. The vehicle came to rest 24.4 m toward traffic lanes indicating intrusion into adjacent traffic lanes after the vehicle lost contact with the bridge rail. Longitudinal occupant impact velocity was 6.1 m/s and longitudinal occupant ridedown was -6.9 g's. Exit angle at loss of contact was 5.8 degrees which was less than 60 percent of the impact angle.

CONCLUSIONS

The Alaska Multi-State Bridge Railing mounted on the curb met all required criterion specified for *NCHRP Report 350* test designation 4-11. The vehicle came to rest 24.4 m toward traffic lanes and as such did not meet the vehicle intrusion criterion; however, this criterion is preferable and not required, as shown in table 1.

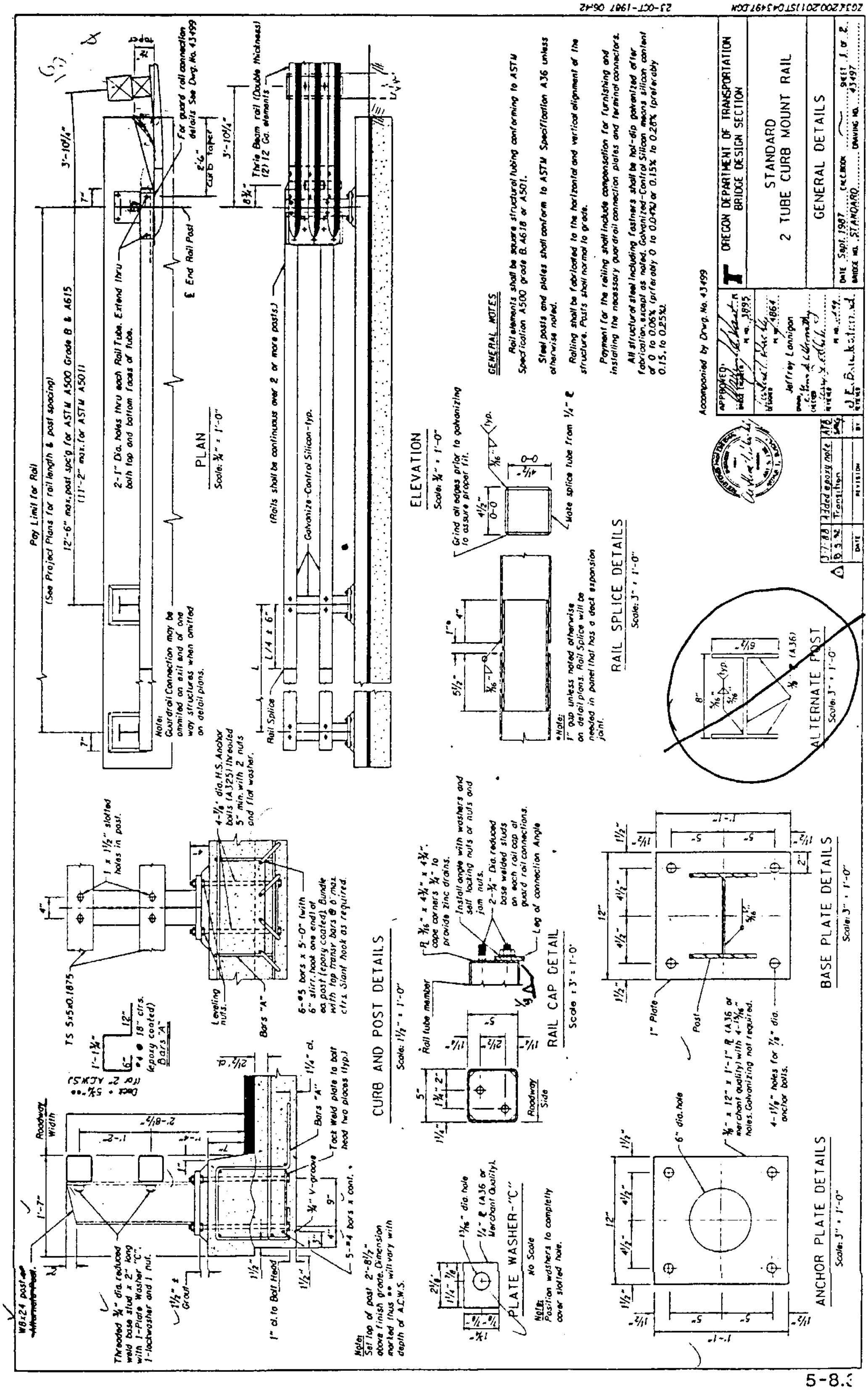
Table 1. Performance evaluation summary for test 404311-2, *NCHRP Report 350* test 4-11.

Test Agency: Texas Transportation Institute | Test No.: 404311-2 | Test Date: 10/14/98

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 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 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 47 mm (4% reduction in space) in the drivers side door.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
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 24.4 m toward traffic lanes.	Fail*
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 6.1 m/s and longitudinal occupant ridedown was -6.9 g's.	
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 5.8 degrees which was less than 60 percent of the impact angle.	Pass*

*Criterion K and M preferable, not required.

APPENDIX A. STANDARD 2 TUBE CURB MOUNT RAIL DRAWINGS



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 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 (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) (formerly the 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 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

The use of a dummy is optional for NCHRP Report 350 test designation 3-11; therefore, a dummy was not placed in the 2000P vehicle.

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: 10-14-98 TEST NO.: 404311-2 VIN NO.: 1GCGC24K0SE1288953

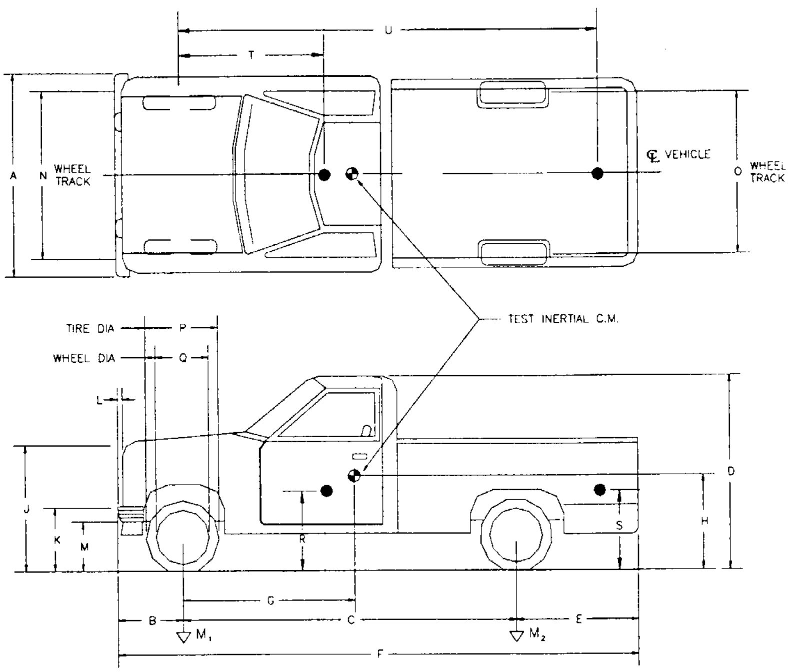
YEAR: 1995 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 115771 TIRE SIZE: LT245 75R16

MASS DISTRIBUTION (kg) LF 552 RF 549 LR 440 RR 459

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

CRACK IN WINDSHIELD MARKED



● Denotes accelerometer location.

NOTES: R-1COTOLT

ENGINE TYPE: 8CYL

ENGINE CID: 5.7L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY - (mm)

A	860	E	1320	J	1080	N	1600	R	720
B	780	F	5450	K	655	O	1620	S	920
C	3350	G	1505.8	L	70	P	770	T	1490
D	1830	H		M	430	Q	445	U	4050

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1235	1101	
M_2	869	899	
M_T	2104	2000	

Figure 12. Vehicle properties for test 404311-2.

Table 2. Exterior crush measurements for test 404311-2.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	**Side Damage**
Undeformed end width ________	Bowing: B1 ____ X1 ____
Corner shift: A1 ________	B2 ____ X2 ____
A2 ________	
End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing constant $\frac{X1 + X2}{2}$ = ______

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		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	At radiator support	820	540	1060	540	310	180	115	50	0	-140
2	900 mm above ground	820	405	1980	55	80	125	160	200	405	+840

[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.

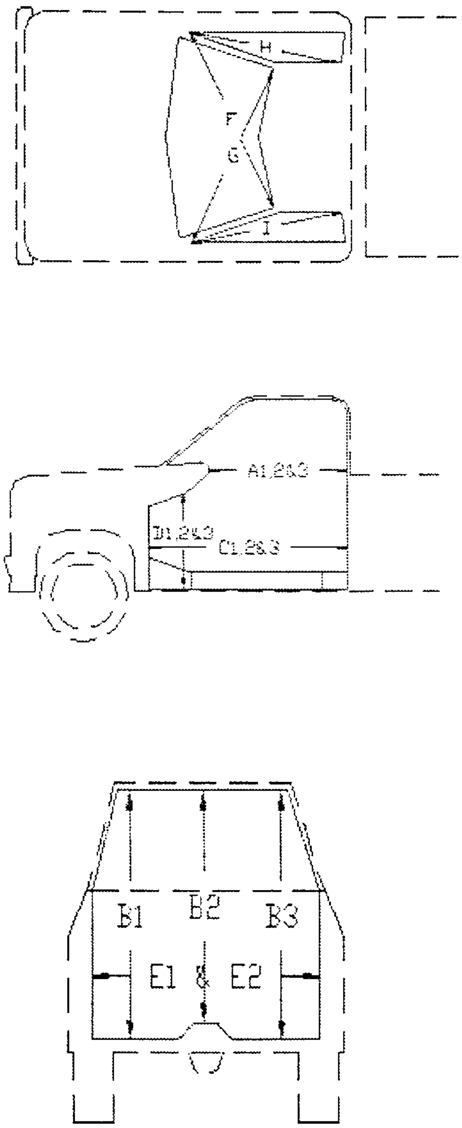
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 3. Occupant compartment measurements for test 404311-2.

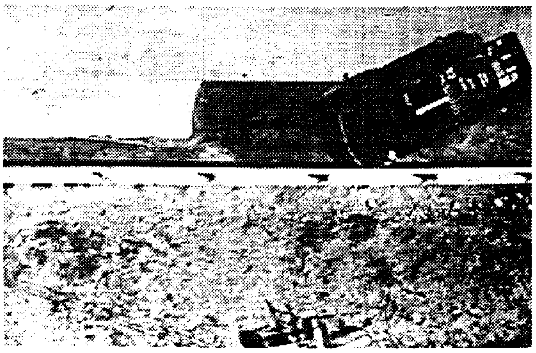
Truck

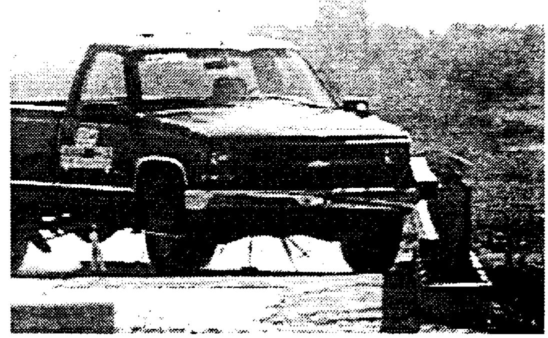
Occupant Compartment Deformation



	BEFORE	AFTER
A1	870	858
A2	897	885
A3	910	910
B1	1075	1020
B2	1072	1035
B3	1075	1075
C1	1380	1320
C2	1261	1242
C3	1375	1370
D1	316	260
D2	158	158
D3	312	322
E1	1582	1566
E2	1590	1605
F	1465	1465
G	1465	1455
H	900	900
I	900	885
Lateral deformation near occupant's feet	1520	1405

APPENDIX D. SEQUENTIAL PHOTOGRAPHS





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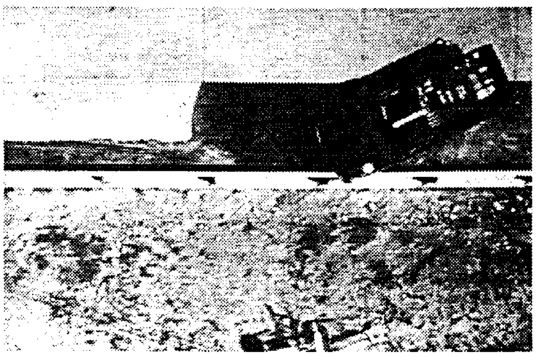

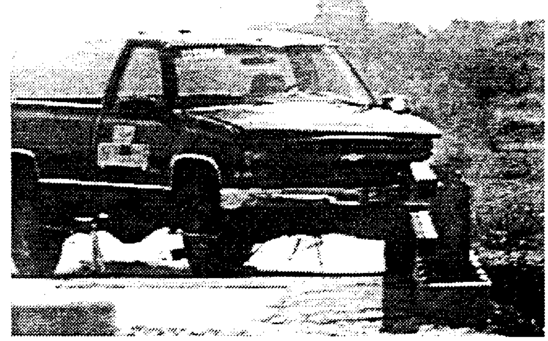

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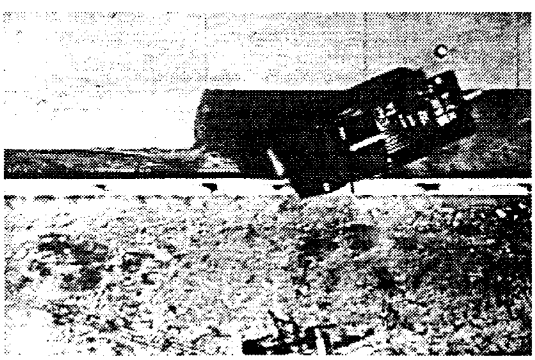

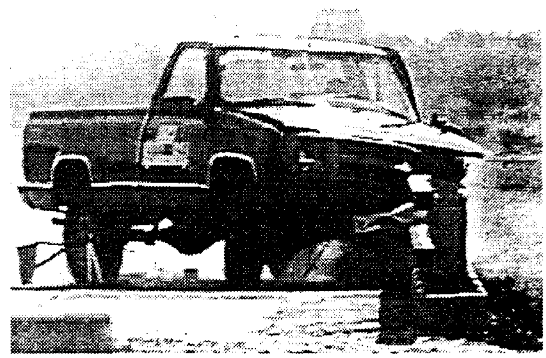

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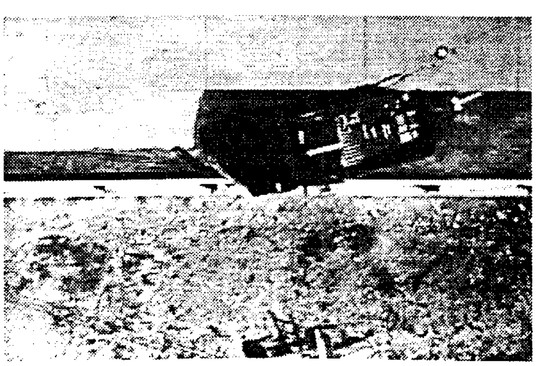

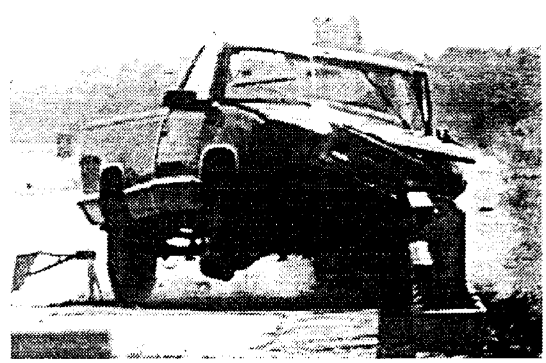

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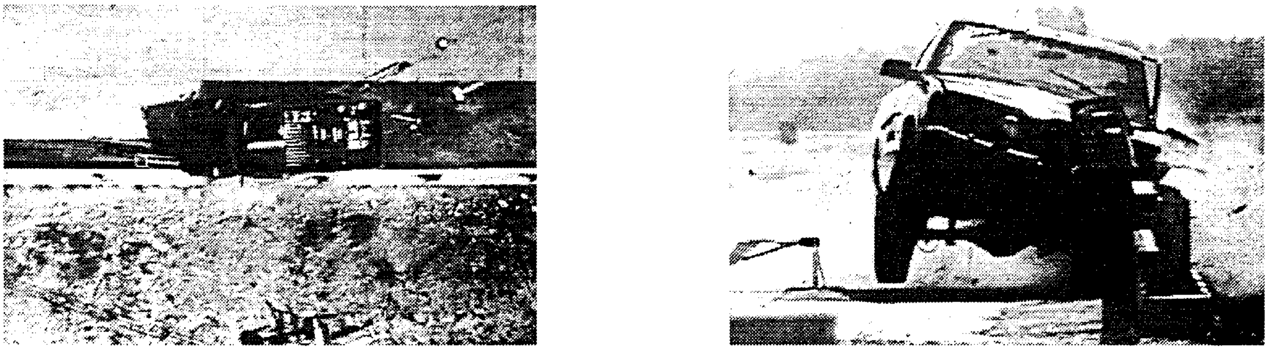
Figure 13. Sequential photographs for test 404311-2 (overhead and frontal views).



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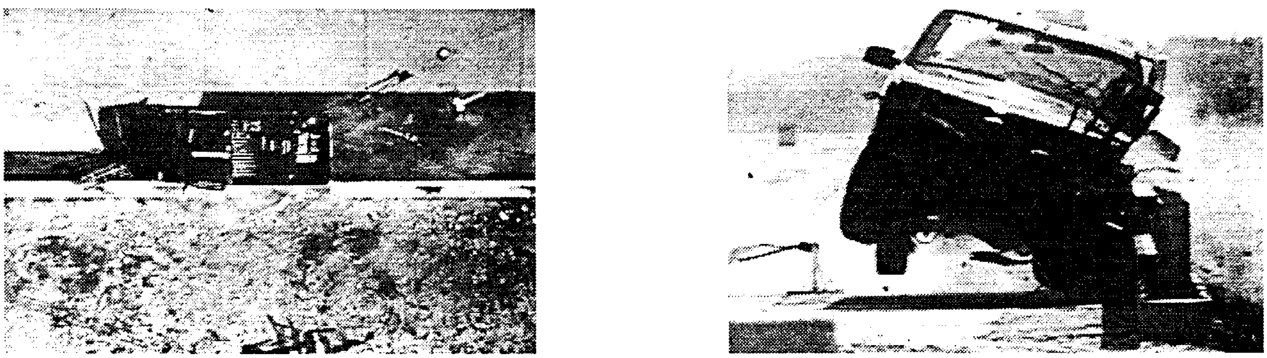

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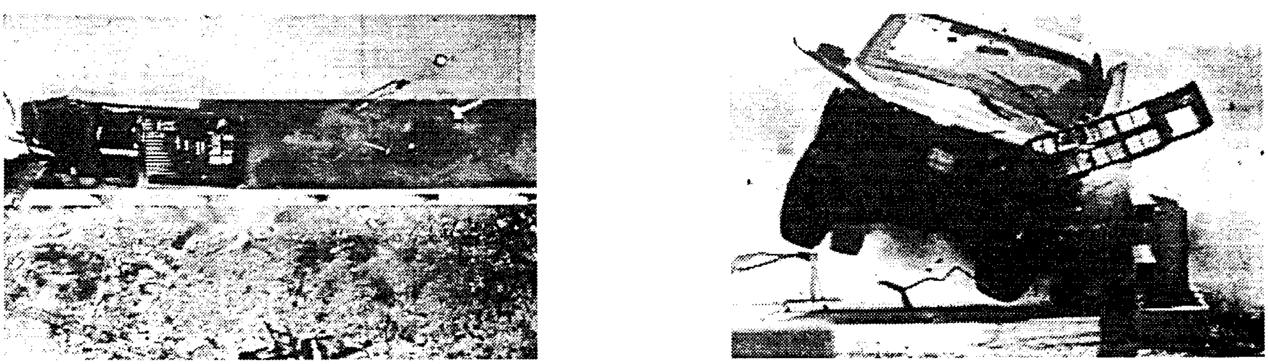

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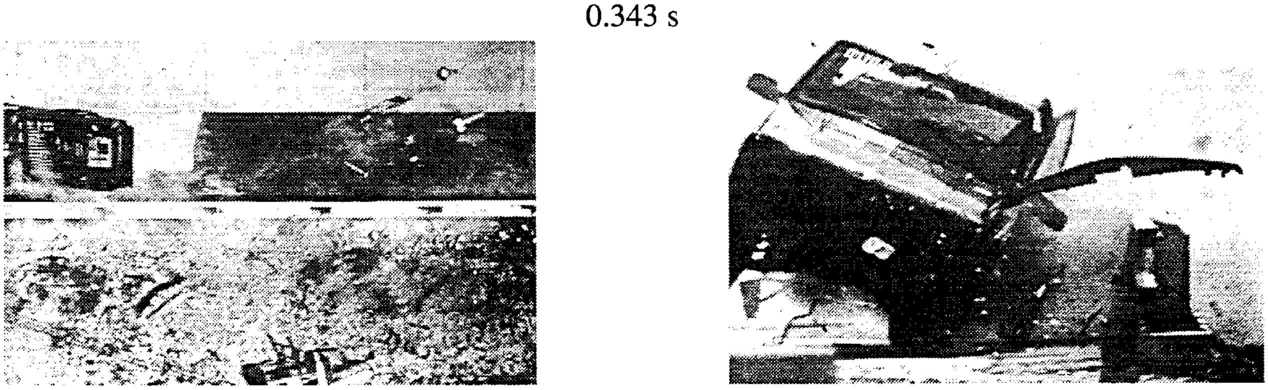

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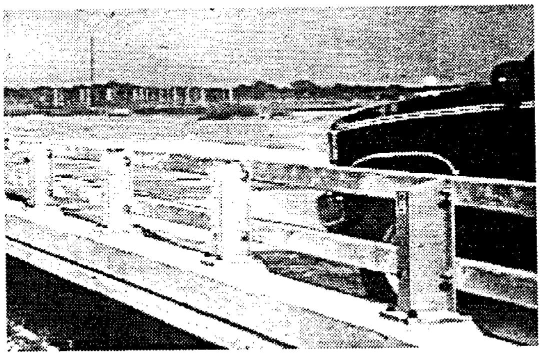
Figure 13. Sequential photographs for test 404311-2
(overhead and frontal views) (continued).



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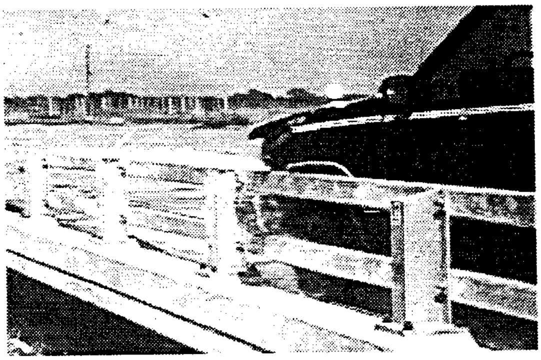

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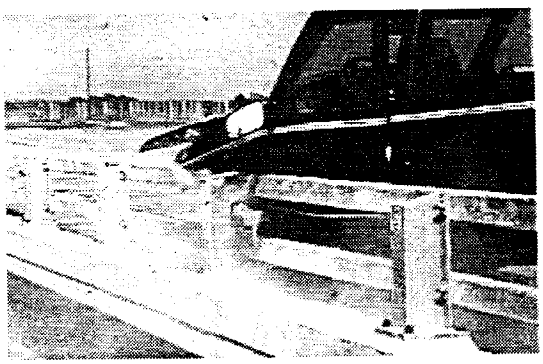

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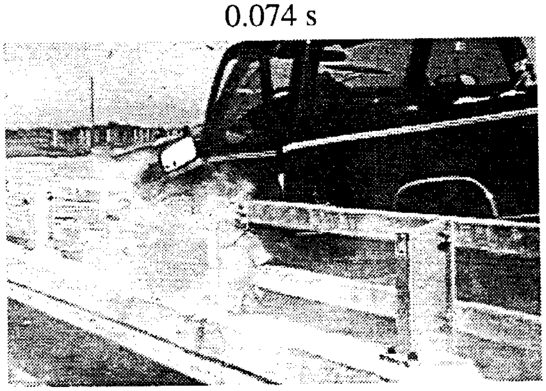

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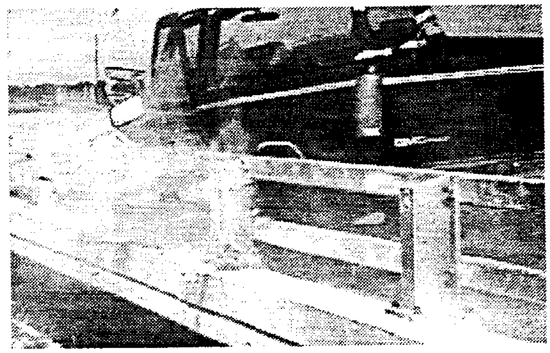

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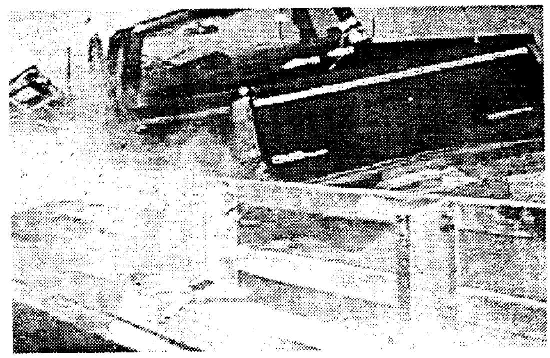

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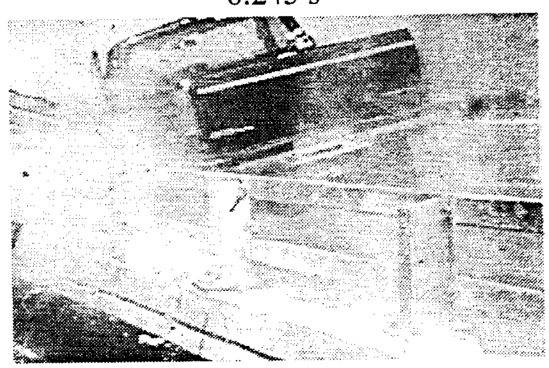

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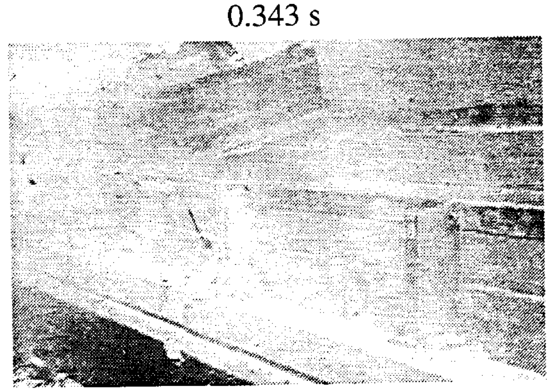

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Figure 14. Sequential photographs for test 404311-2 (rear view).

APPENDIX E. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

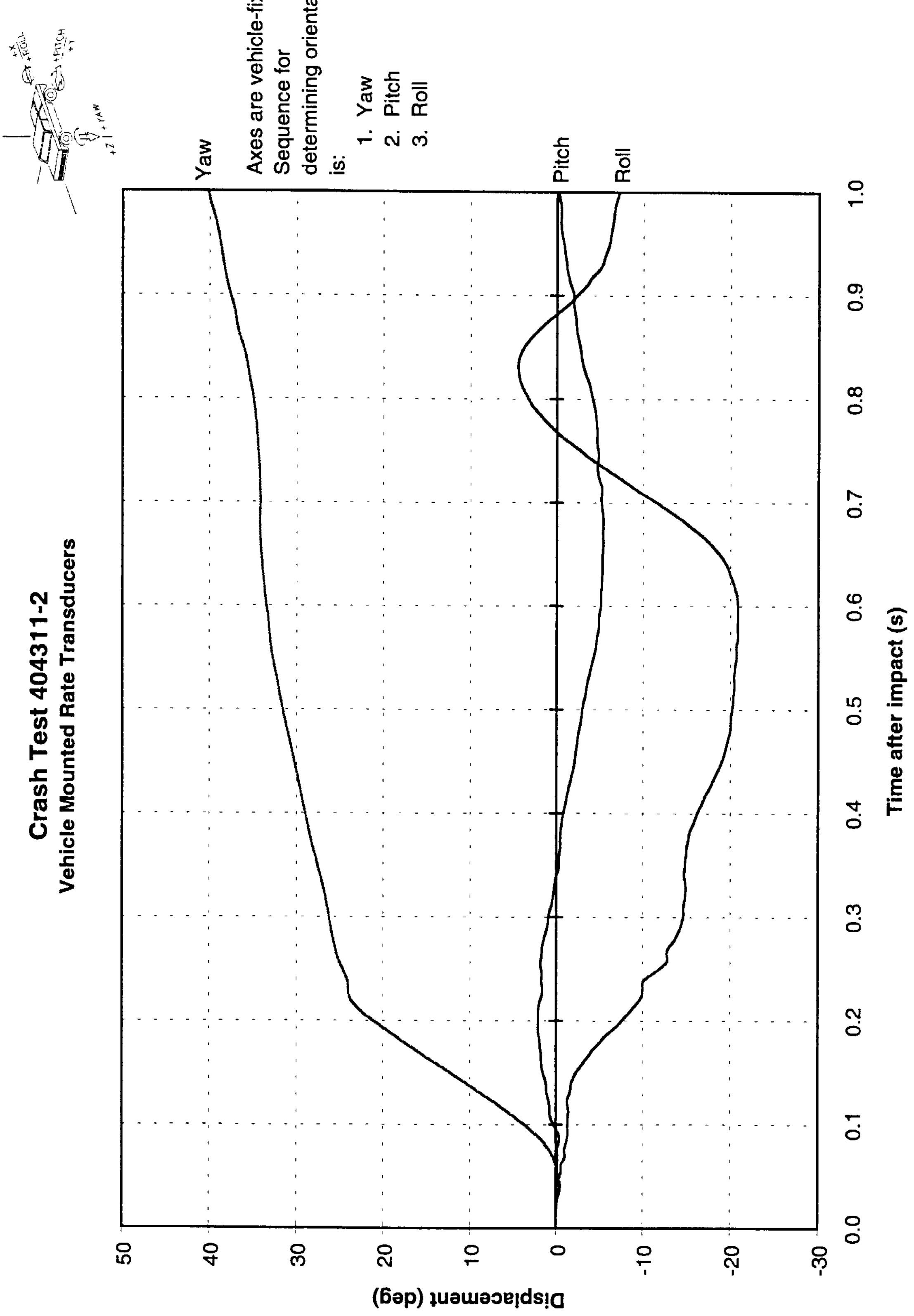

Figure 15. Vehicular angular displacements for test 404311-2

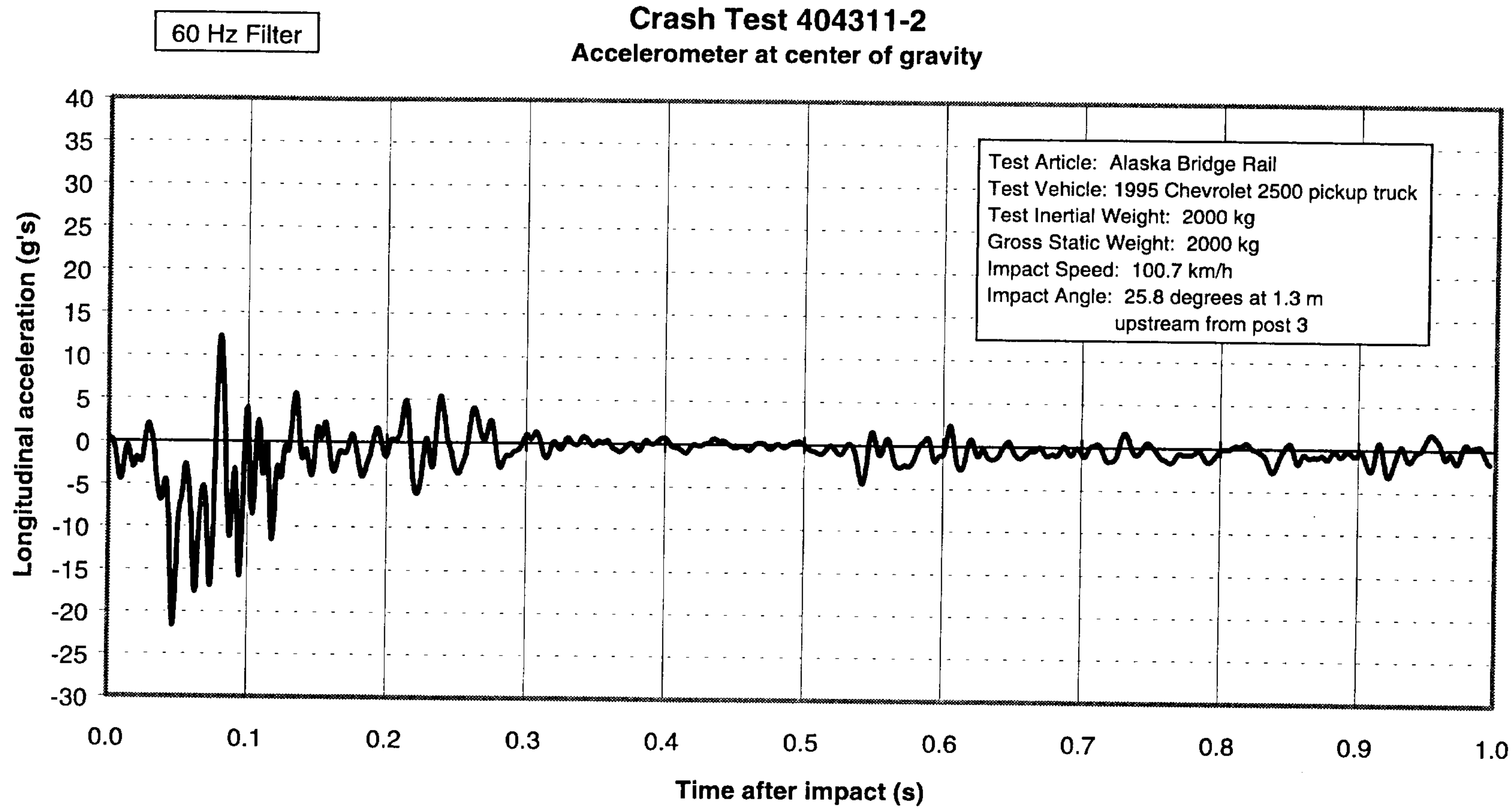

Figure 16. Vehicle longitudinal accelerometer trace for test 404311-2 (accelerometer located at center of gravity).

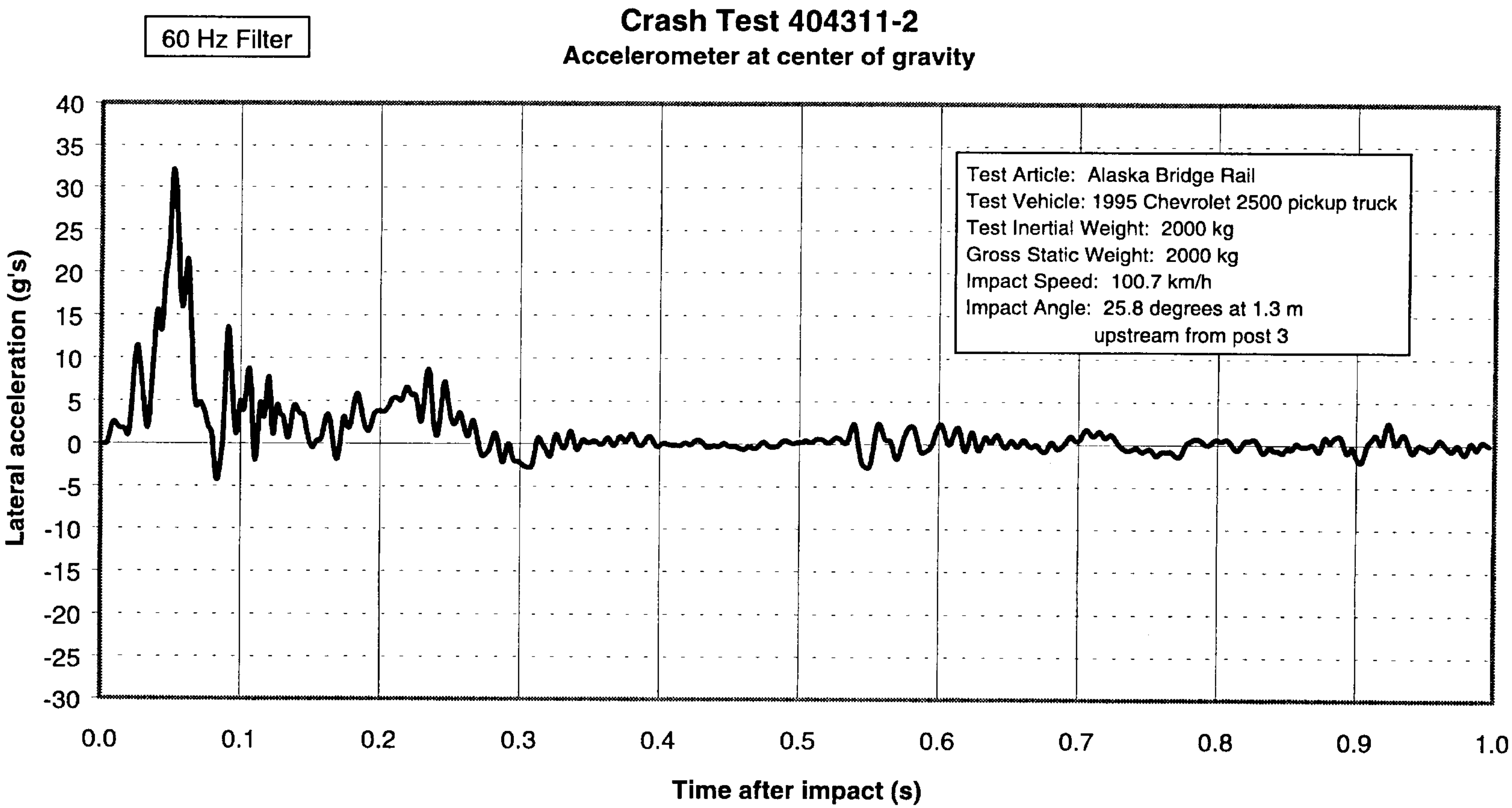

Figure 17. Vehicle lateral accelerometer trace for test 404311-2 (accelerometer located at center of gravity).

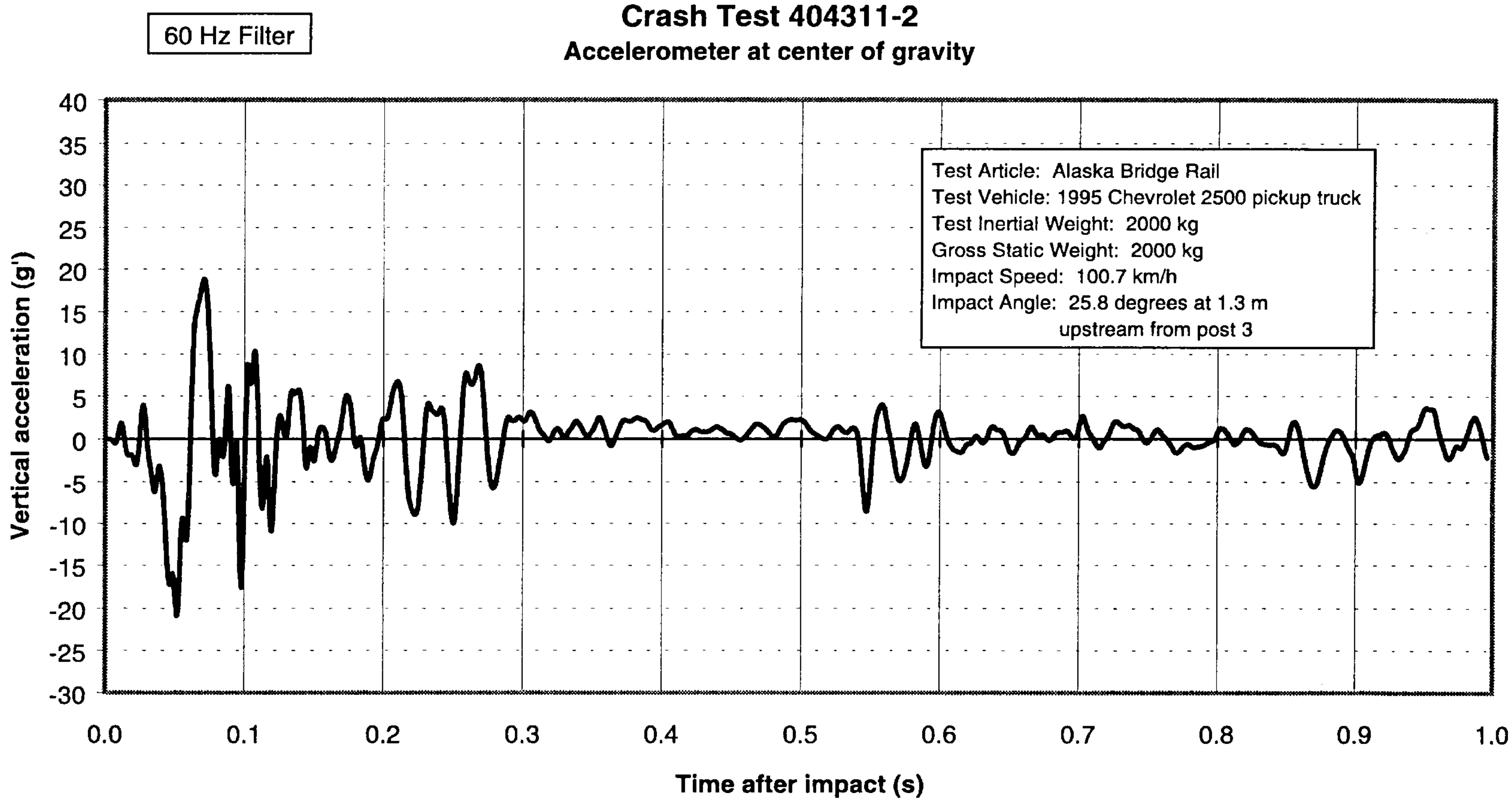

Figure 18. Vehicle vertical accelerometer trace for test 404311-2 (accelerometer located at center of gravity).

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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.

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.