TEXAS TRANSPORTATION INSTITUTE

NCHRP REPORT 350 TEST 4-10 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 small car test: National Cooperative Highway Research Program (NCHRP) Report 350 test designation 4-10, which is the 820-kg passenger car impacting the critical impact point (CIP) at 100 km/h and 20 degrees. The Alaska Multi-State Bridge Rail mounted on the curb met all requirements specified for NCHRP Report 350 test designation 4-10.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

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)

TABLE OF CONTENTS

Page

INTRODUCTION 1
PROBLEM 1
BACKGROUND 1
OBJECTIVES 1

TECHNICAL DISCUSSION 3
TEST PARAMETERS 3
Test Facility 3
Test Article – Design and Construction 3
Test Conditions 10
Evaluation Criteria 10
CRASH TEST 404311-1 13
Test Vehicle 13
Soil and Weather Conditions 13
Impact Description 13
Damage to Test Article 16
Vehicle Damage 16
Assessment of Test Results 16

SUMMARY AND CONCLUSIONS 25
SUMMARY OF FINDINGS 25
CONCLUSIONS 25

APPENDIX A. STANDARD 2 TUBE CURB MOUNT RAIL DRAWINGS 27

APPENDIX B. CRASH TEST PROCEDURES AND DATA ANALYSIS 29
ELECTRONIC INSTRUMENTATION AND DATA PROCESSING 29
ANTHROPOMORPHIC DUMMY INSTRUMENTATION 30
PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING 30
TEST VEHICLE PROPULSION AND GUIDANCE 31

APPENDIX C. TEST VEHICLE PROPERTIES AND INFORMATION 33

APPENDIX D. SEQUENTIAL PHOTOGRAPHS 37

APPENDIX E. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS 41

REFERENCES 45

LIST OF FIGURES

Figure No. Page

1 Details of the Alaska Multi-State Bridge Railing mounted on the curb (concrete) 4
2 Details of the Alaska Multi-State Bridge Railing mounted on the curb (steel) 5
3 Alaska Multi-State Bridge Railing mounted on the curb before test 404311-1 8
4 Details on field side of installation 9
5 Vehicle/installation geometrics for test 404311-1 14
6 Vehicle before test 404311-1 15
7 After impact trajectory for 404311-1 17
8 Installation after test 404311-1 18
9 Vehicle after test 404311-1 19
10 Interior of vehicle for test 404311-1 20
11 Summary of results for test 404311-1, NCHRP Report 350 test 4-10 22
12 Vehicle properties for test 404311-1 33
13 Sequential photographs for test 404311-1 (overhead and frontal views) 37
14 Sequential photographs for test 404311-1 (rear view) 39
15 Vehicular angular displacements for test 404311-1 41
16 Vehicle longitudinal accelerometer trace for test 404311-1 (accelerometer located at center of gravity) 42
17 Vehicle lateral accelerometer trace for test 404311-1 (accelerometer located at center of gravity) 43
18 Vehicle vertical accelerometer trace for test 404311-1 (accelerometer located at center of gravity) 44

LIST OF TABLES

Table No.		Page
1	Performance evaluation summary for test 404311-1, *NCHRP Report 350* test 4-10	26
2	Exterior crush measurements for test 404311-1	34
3	Occupant compartment measurements for test 404311-1	35

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

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 bridge rail 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.

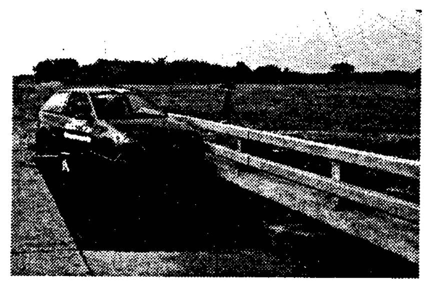
This report presents the details of the Alaska Multi-State Bridge Railing mounted on the curb and results of the small car test: *NCHRP Report 350* test designation 4-10, which is the 820-kg passenger car impacting the CIP at 100 km/h and 20 degrees. The Alaska Multi-State Bridge Railing mounted on the curb met all requirements specified for *NCHRP Report 350* test designation 4-10.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's 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 and Transition Systems 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, 2 and 3 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

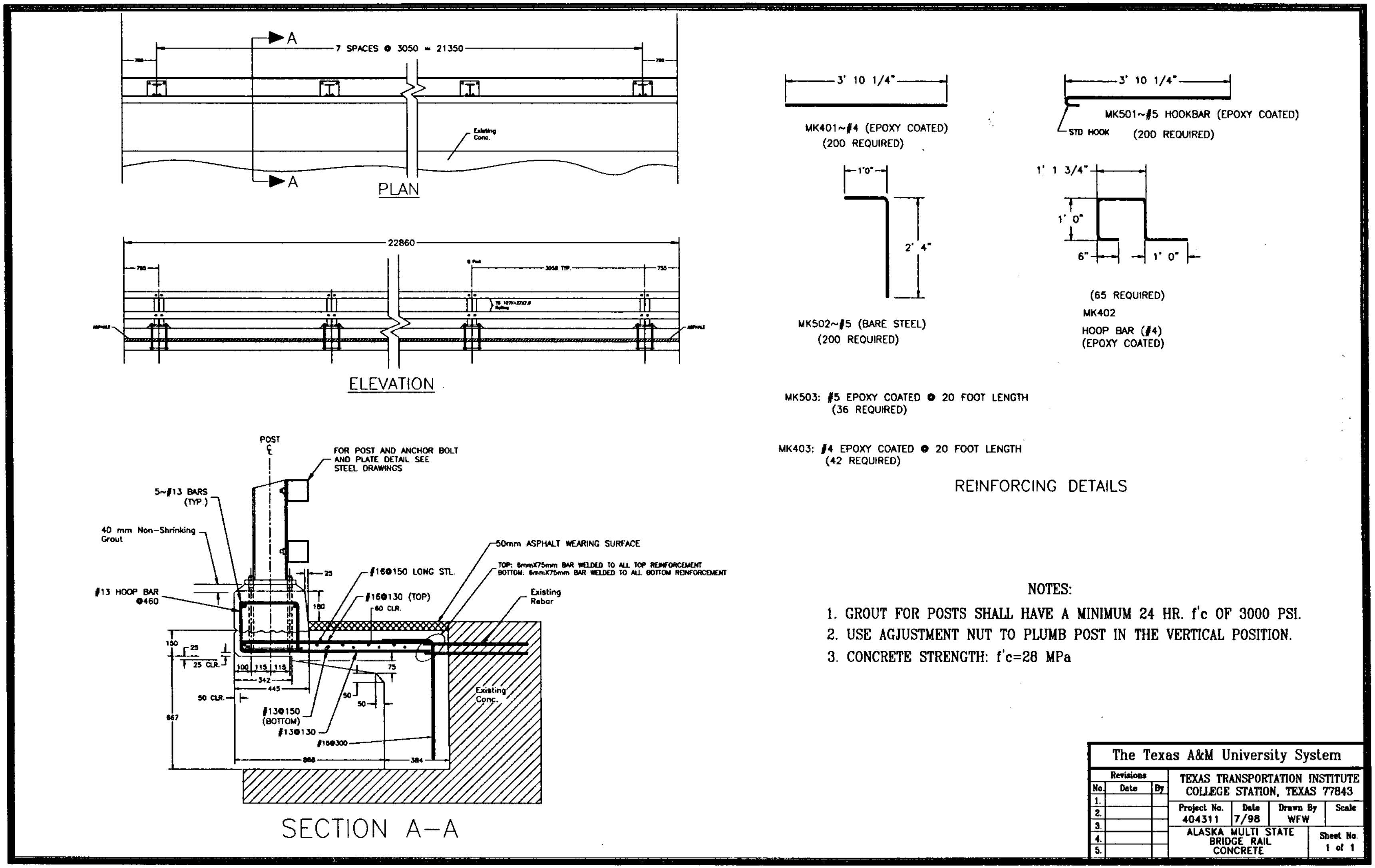


Figure 1. Details of the Alaska Multi-State Bridge Railing mounted on the curb (concrete).

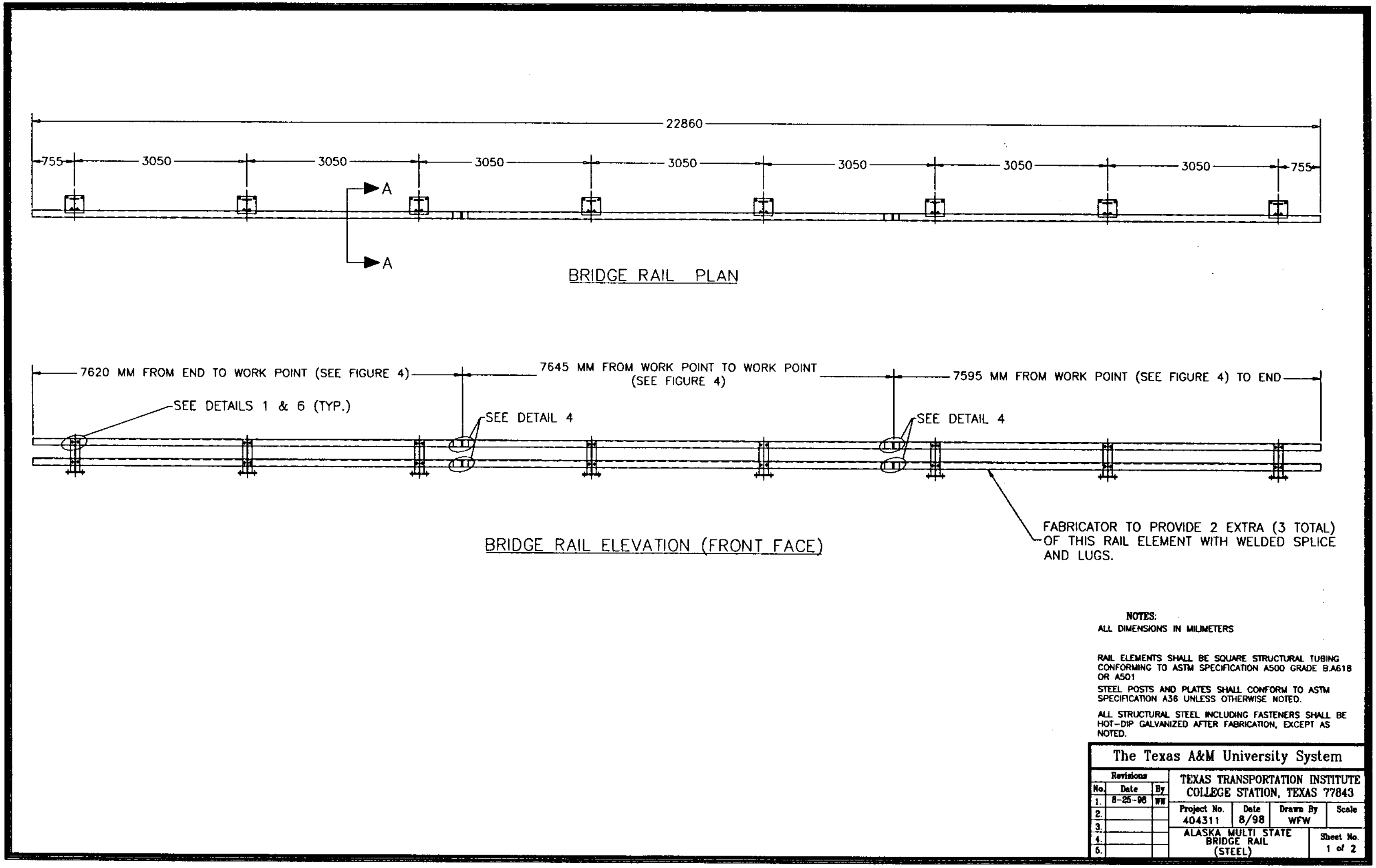


Figure 2. Details of the Alaska Multi-State Bridge Railing mounted on the curb (steel).

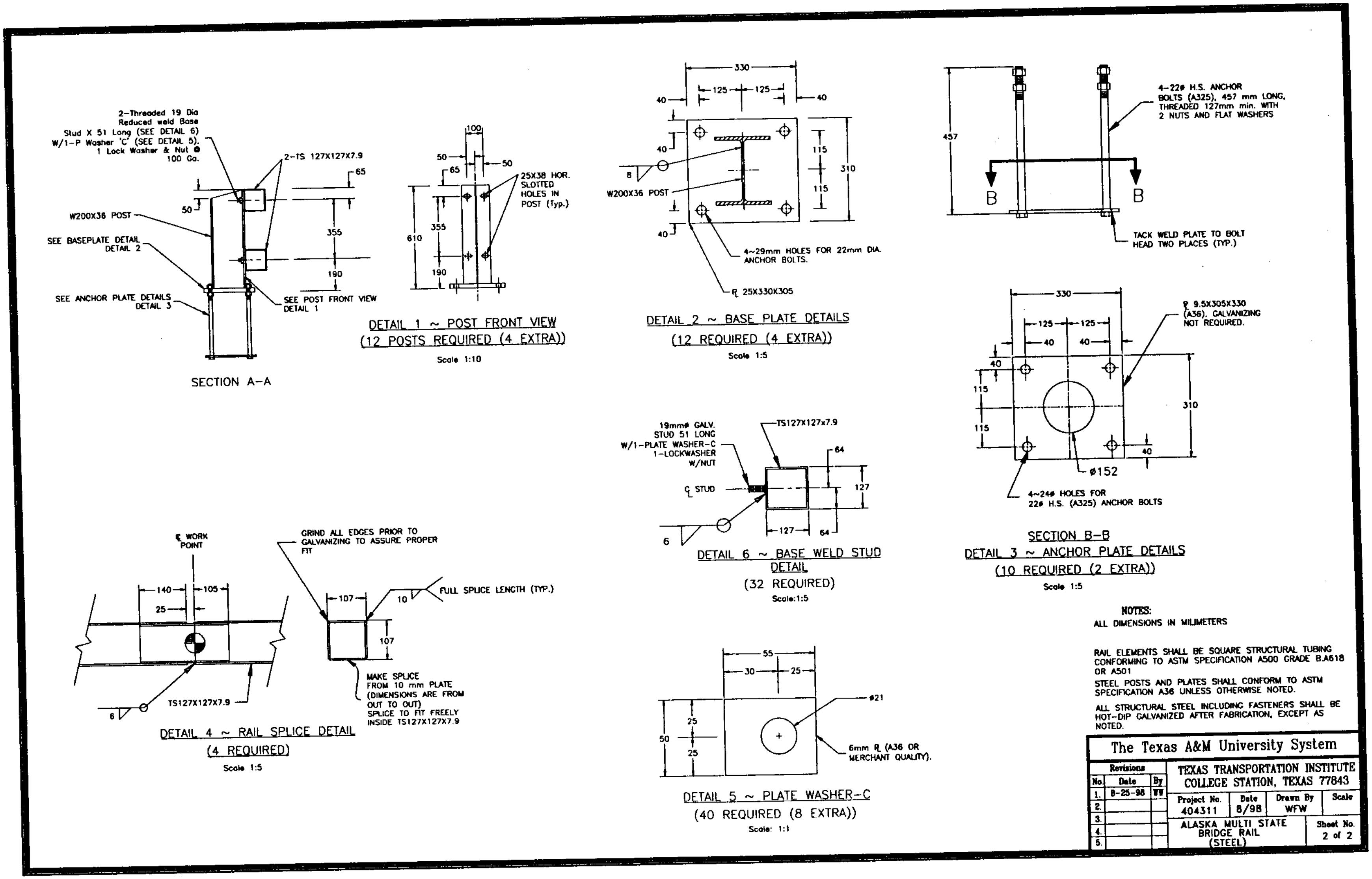


Figure 2. Details of the Alaska Multi-State Bridge Railing mounted on the curb (steel) (continued).

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 figures 3 and 4.

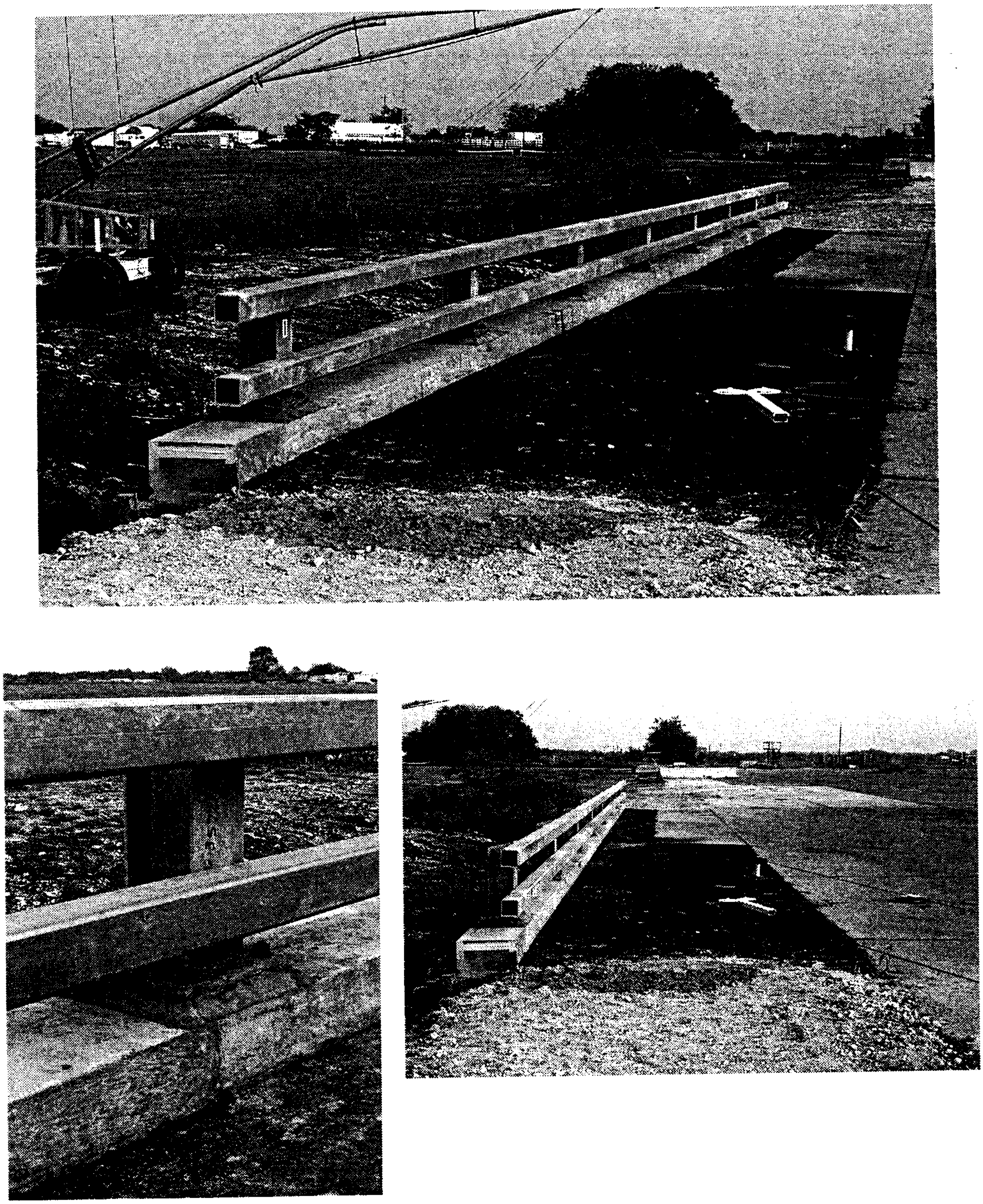


Figure 3. Alaska Multi-State Bridge Railing mounted on the curb before test 404311-1.

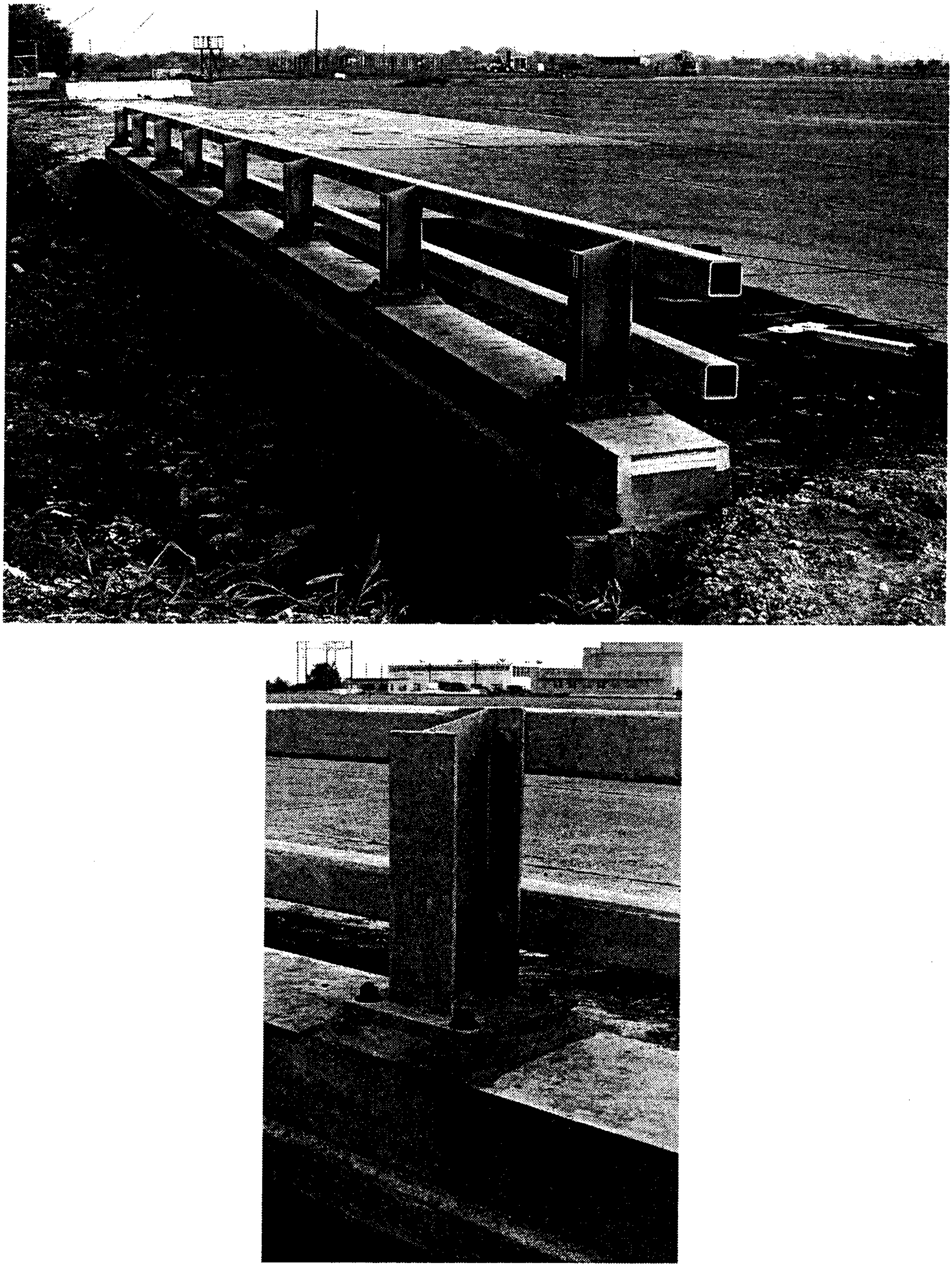


Figure 4. Details on field side of installation.

Test Conditions

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

> **NCHRP Report 350 test designation 4-10**: an 820-kg passenger car impacting the critical impact point (CIP) in the length of need (LON) of the longitudinal barrier at a nominal speed and angle of 100 km/h and 20 degrees. The purpose of this test is to evaluate the overall performance of the LON section in general, and occupant risks in particular.
>
> **NCHRP Report 350 test designation 4-11**: A 2000-kg pickup truck impacting the CIP in the LON of the longitudinal barrier at a nominal speed and angle of 100 km/h and 25 degrees. The test is intended to evaluate the strength of 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 reported herein corresponds to NCHRP Report 350 test designation 4-10. Other tests will be detailed in subsequent reports.

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.*

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

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

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

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

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

- **Vehicle Trajectory**

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

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

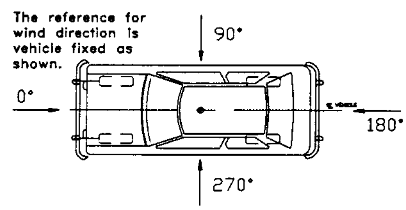
CRASH TEST 404311-1

Test Vehicle

A 1993 Geo Metro, shown in figures 5 and 6, was used for the crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. The height to the lower edge of the vehicle front bumper was 365 mm and to the upper edge of the front bumper was 510 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 12, 1998. A total of 38 mm of rain was recorded six days prior to the test but would not affect the test on the concrete deck. No other 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: 26°C; Relative Humidity: 73 percent.



Impact Description

The vehicle, traveling at 100.0 km/h, impacted the curb of the Alaska Multi-State Bridge Railing 1.1 m upstream from post 3 at a 20.8 degree angle. Shortly after impact, the bridge railing moved. At 0.015 s the front left tire contacted the concrete curb, and at 0.020 s the front left wheel steered to the right and became parallel with the bridge rail. The front left tire lost contact with the ground, while still in contact with the bridge rail at 0.025 s. The vehicle began to redirect at 0.032 s. By 0.039 s, the vehicle contacted post 3, and by 0.41 s, the front right wheel steered toward the rail. The front left corner of the vehicle snagged on post 3 and some sheet metal was pulled from the vehicle at 0.046 s. At 0.51 s the front left tire returned to the road surface, and at 0.071 s the hood latch of the vehicle released. The driver's side window shattered at 0.083 s. Traveling at 87.6 km/h, the vehicle was parallel to the rail at 0.132 s. At 0.147 s the rear of the vehicle contacted the rail elements, and at 0.183 s the right tire lost contact with the ground. The vehicle lost contact with the bridge railing at 0.278 s, traveling at a speed of 86.7 km/h at a 6.0 degree angle. At 0.484 s the hood of the vehicle flew back and hit the windshield. Brakes on the vehicle were applied at 2.6 s, bringing the vehicle to rest 51.8 m downstream from impact and 4.6 m behind the bridge railing. Sequential photographs of the test period are shown in appendix D, figures 13 and 14.

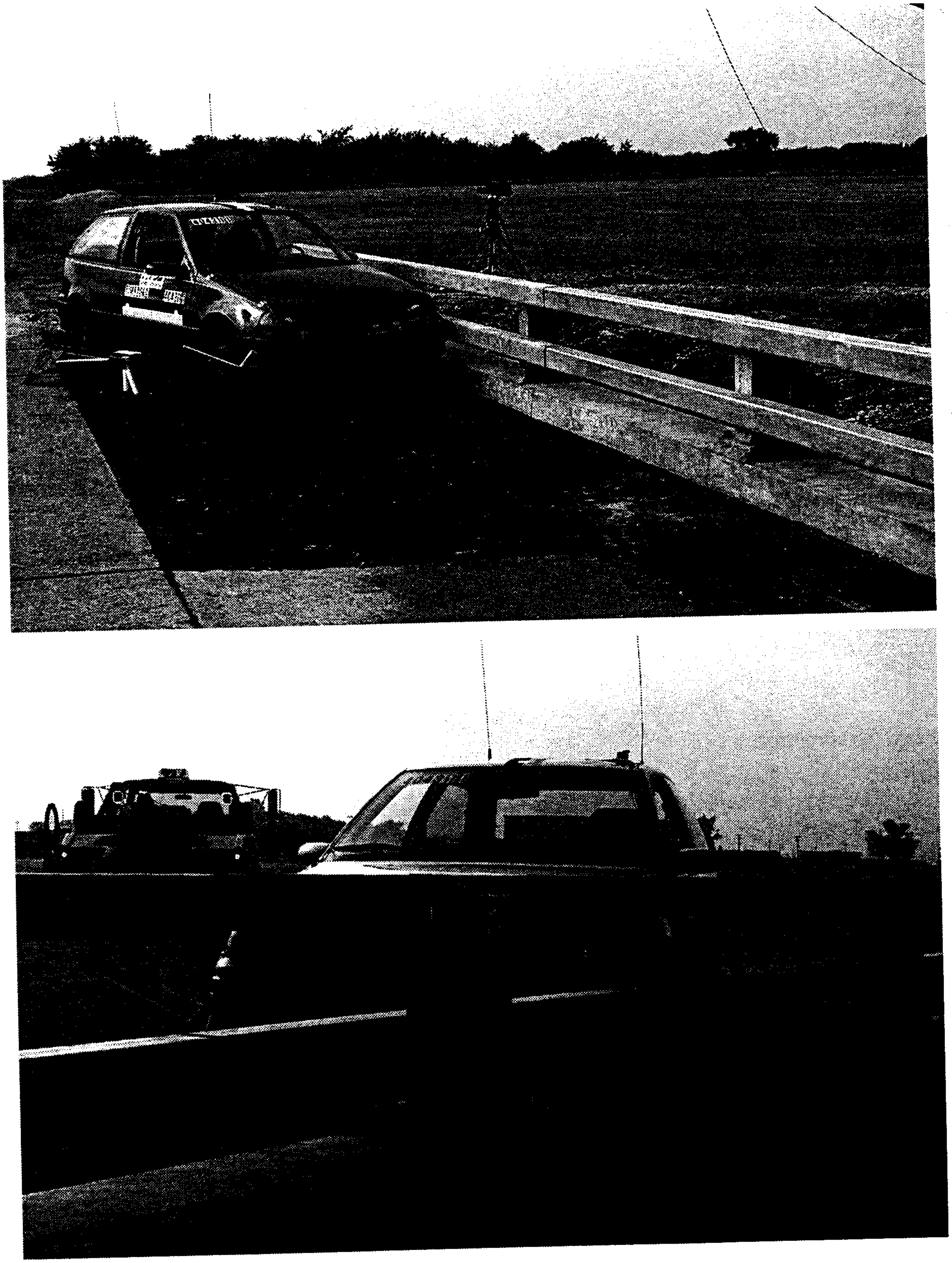


Figure 5. Vehicle/installation geometrics for test 404311-1.

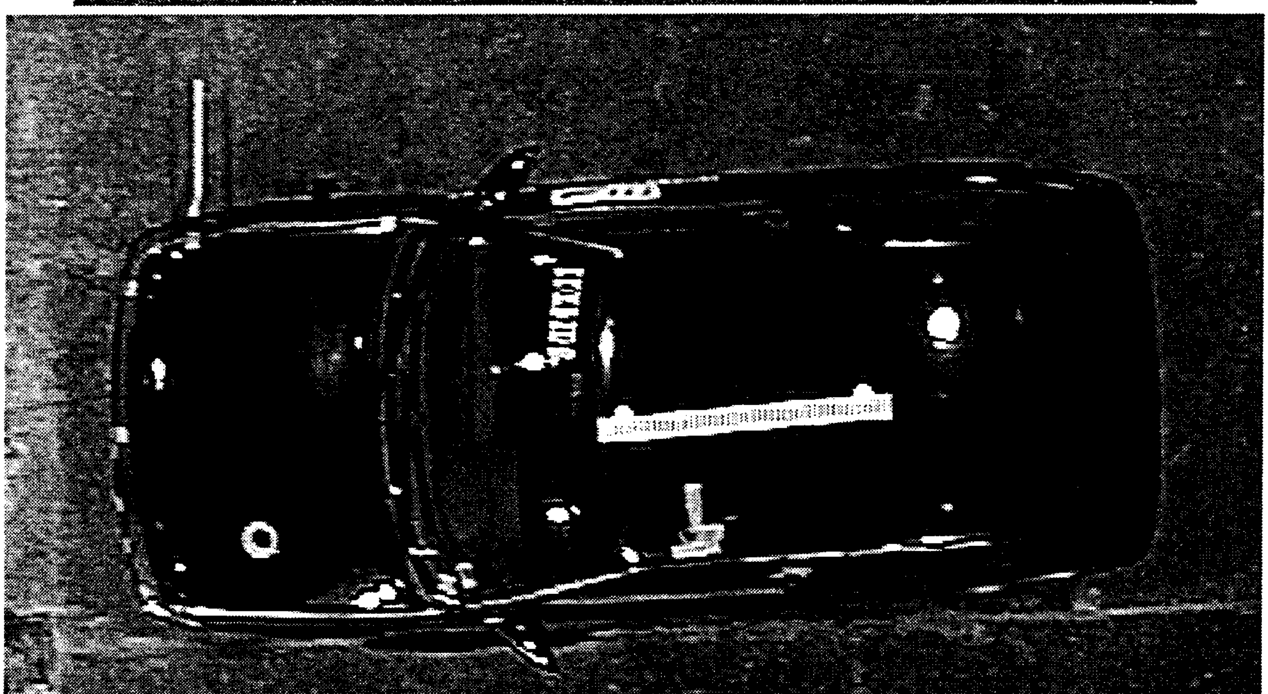


Figure 6. Vehicle before test 404311-1.

Damage to Test Article

Damage to the Alaska Multi-State Bridge Railing mounted on the curb is shown in figures 7 and 8. At impact the edge of the curb was scraped, and tire marks were along the face of the curb. The front face of post 3 was marred with red paint from the vehicle and the curb was chipped. Cosmetic damage with no measurable deformation occurred to the rail elements. The top rail was contacted, but did not move. Total length of contact of the vehicle with the bridge railing was 4.5 m.

Vehicle Damage

The vehicle sustained structural damage on the front left and left side. The left strut, CV joint, A-pillar and A-arm were severely damaged. The front left portion of the bumper, hood, grill, fan, radiator, left front tire and wheel were deformed as shown in figure 9. The windshield was shattered on the driver's side and the left front and rear quarter panels were deformed. The roof was buckled between the A and B pillars and deformed downward 20 mm. The maximum exterior crush to the left side of the bumper 700 mm above the ground was 200 mm. Maximum deformation of the occupant compartment was 47 mm (4 percent reduction in space) in the driver's side door, 36 mm (5 percent reduction in space) in the left firewall area and 30 mm (10 percent reduction in space) in the left 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 3 and 4.

Assessment of Test Results

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

- **Structural Adequacy**

    A. *Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*

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

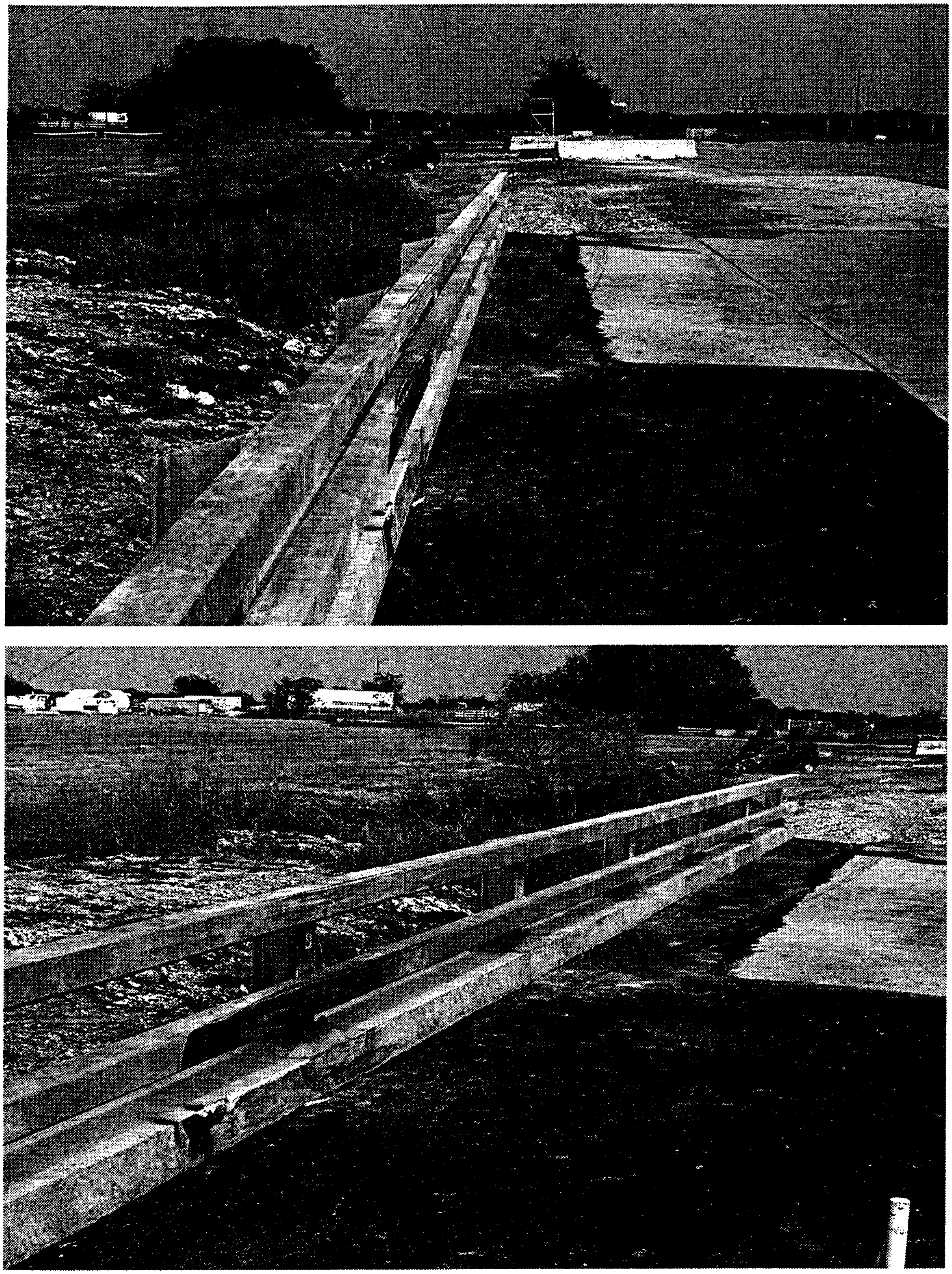


Figure 7. After impact trajectory for 404311-1.

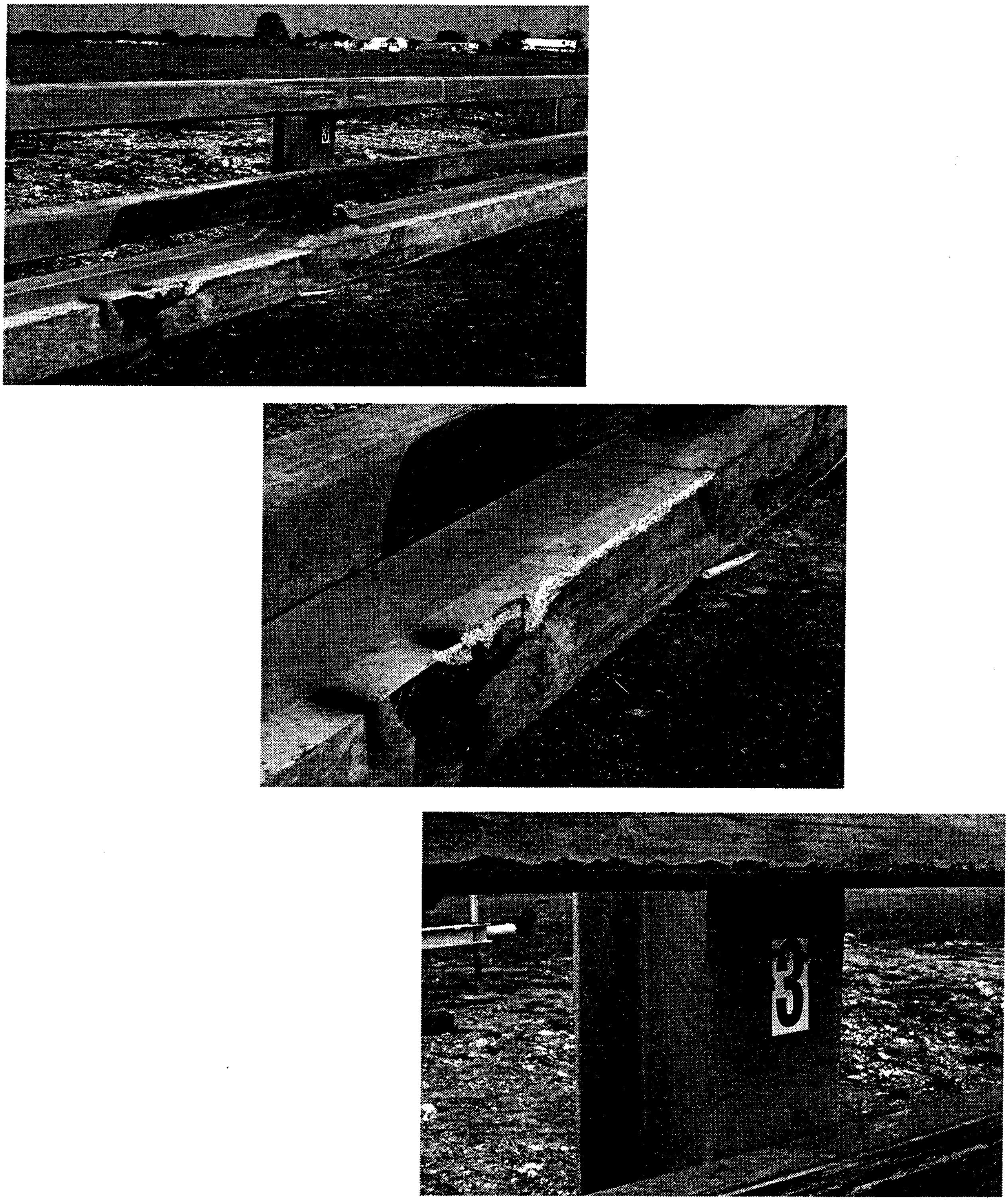


Figure 8. Installation after test 404311-1.

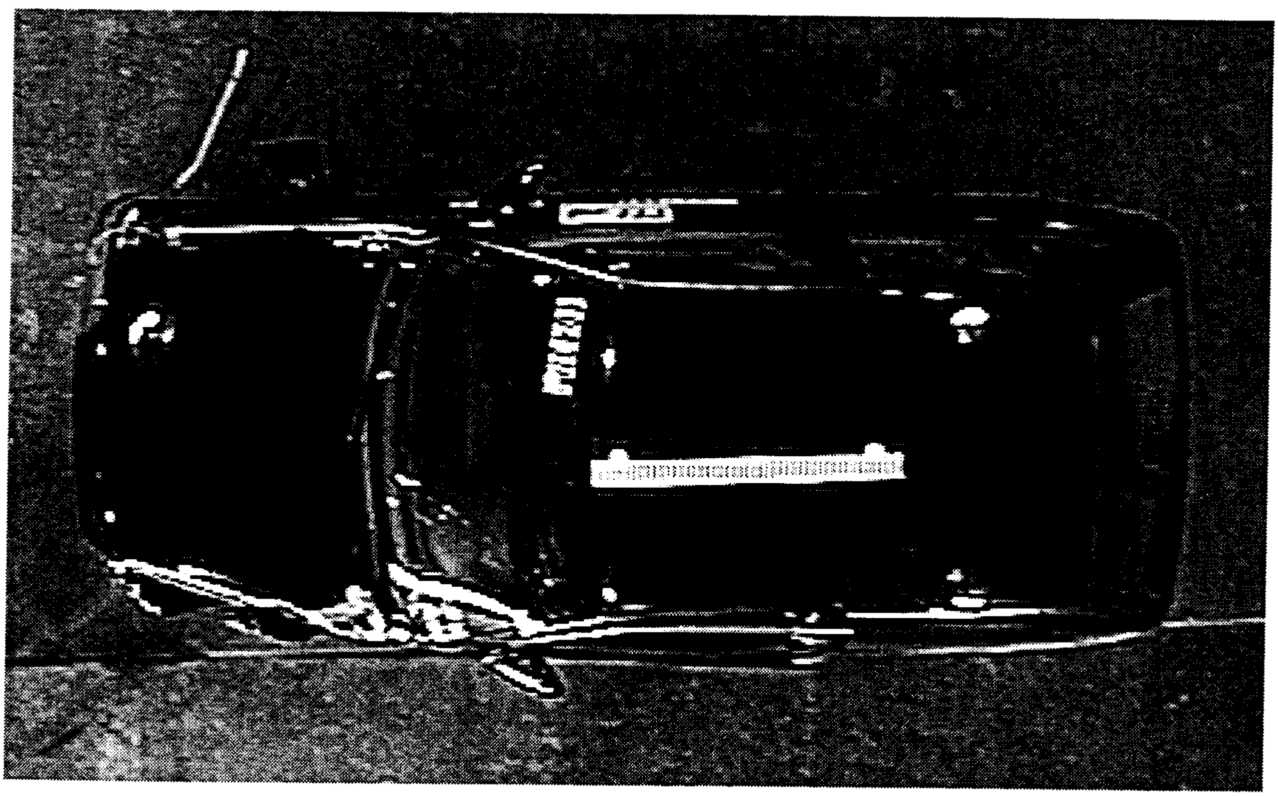
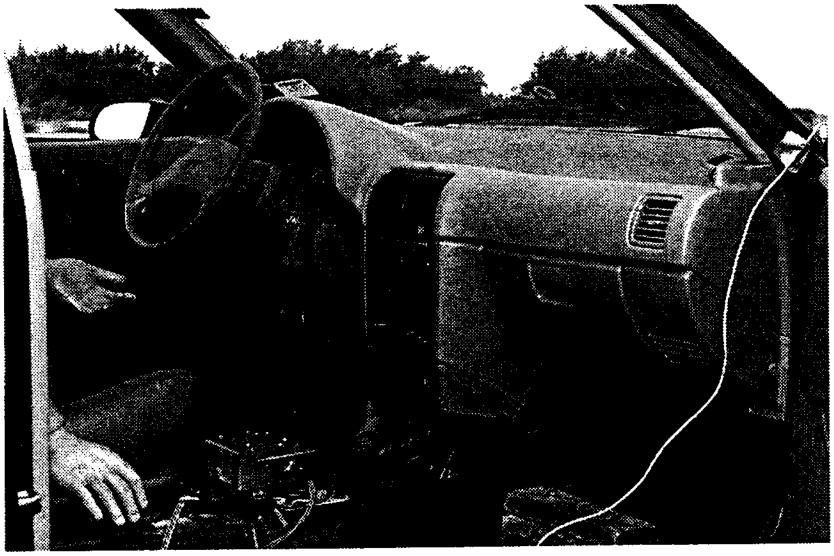
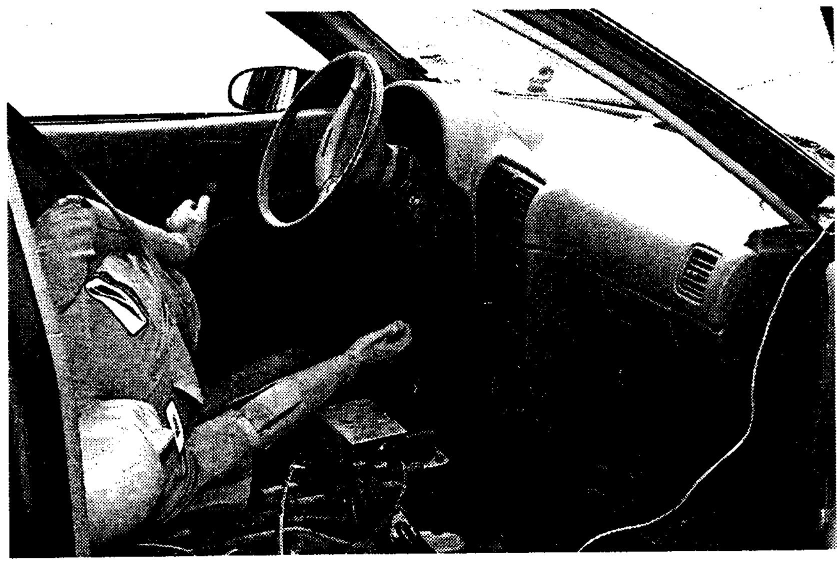


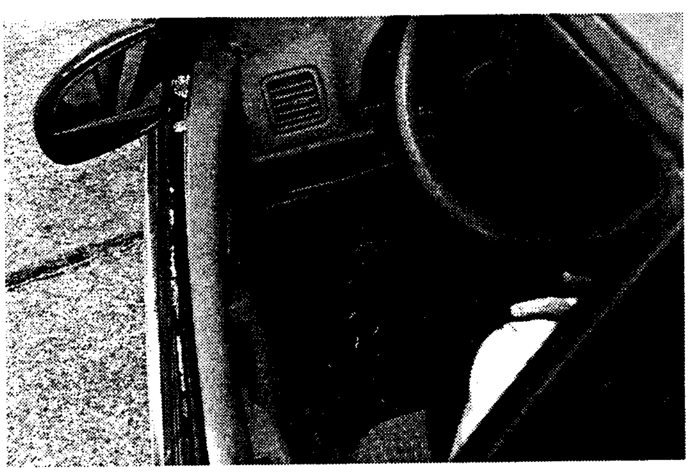
Figure 9. Vehicle after test 404311-1.



Before test



After test



After test

Figure 10. Interior of vehicle for test 404311-1.

- **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, nor to present undue hazard to others in the area. Minimal deformations occurred to the occupant compartment and were judged to not cause serious injury.

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.

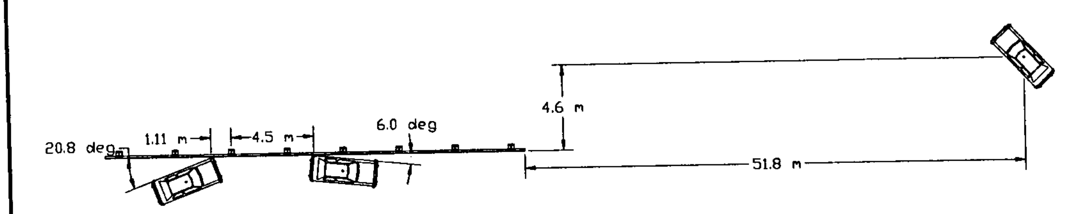
H. *Occupant impact velocities should satisfy the following:*

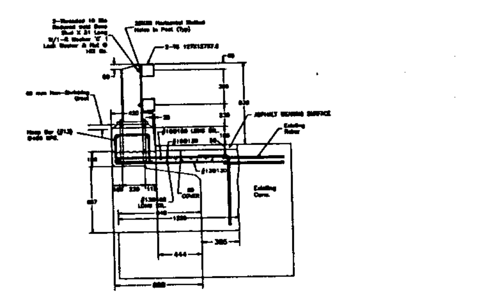
Longitudinal and Lateral Occupant Impact Velocity - m/s	
Preferred	*Maximum*
9	*12*

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

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

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 4.7 m/s at 0.179 s, the highest 0.010-s occupant ridedown acceleration was -4.4 g's from 0.083 to 0.093 s, and the maximum 0.050-s average acceleration was -8.6 g's between 0.018 and 0.068 s. In the lateral direction, the occupant impact velocity was -8.3 m/s at 0.083 s, the highest 0.010-s occupant ridedown acceleration was 13.4 g's from 0.148 to 0.158 s, and the maximum 0.050-s average was 15.0 g's between 0.020 and 0.070 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.





General Information	
Test Agency	Texas Transportation Institute
Test No.	404311-1
Date	10/12/98
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	Concrete deck, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1993 Geo Metro
Mass (kg)	
Curb	758
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	100.0
Angle (deg)	20.8
Exit Conditions	
Speed (km/h)	86.7
Angle (deg)	6.0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.7
y-direction	-8.3
THIV (km/h)	31.4
Ridedown Accelerations (g's)	
x-direction	-4.4
y-direction	13.4
PHD (g's)	14.5
ASI	1.80
Max. 0.050-s Average (g's)	
x-direction	-8.6
y-direction	15.0
z-direction	3.9

Test Article Deflections (m)	
Dynamic	nil
Permanent	nil
Vehicle Damage	
Exterior	
VDS	11LFQ4
CDC	11FLEK2 & 11LYEW3
Maximum Exterior Vehicle Crush (mm)	200
Interior	
OCDI	LF0012100
Max. Occ. Compart. Deformation (mm)	47
Post-Impact Behavior	
(during 1.0 s after impact)	
Max. Yaw Angle (deg)	31
Max. Pitch Angle (deg)	-4
Max. Roll Angle (deg)	-11

Figure 11. Summary of results for test 404311-1, NCHRP Report 350 test 4-10.

- **Vehicle Trajectory**

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

The vehicle did not intrude into adjacent traffic lanes as it came to rest behind the installation.

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

The exit angle at loss of contact was 6.0 degrees which was less than 60 percent of the impact angle.

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 an undue hazard to other traffic. Maximum deformation of the occupant compartment was 47 mm (4 percent reduction in space) in the driver's side door. The vehicle remained upright during and after the collision period. Occupant risk facts were within the limits specified in *NCHRP Report 350.* Minimal, if any, intrusion into adjacent traffic lanes occurred after the vehicle lost contact with the bridge rail. Exit angle at loss of contact was 6.0 degrees which was less than 60 percent of the impact angle.

CONCLUSIONS

The Alaska Multi-State Bridge Railing mounted on the curb met all requirements specified for *NCHRP Report 350* test designation 4-10, as shown in table 1.

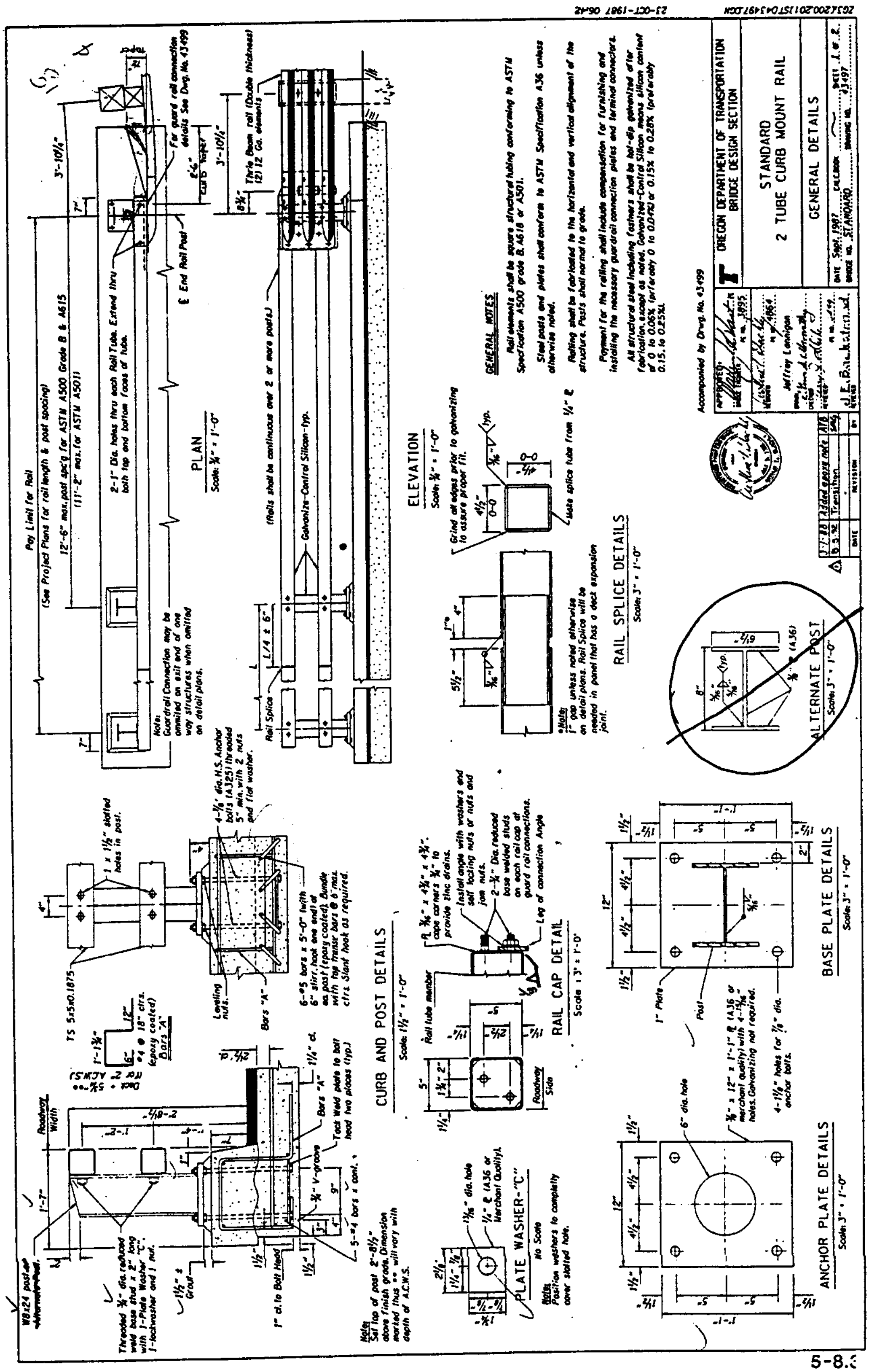
Table 1. Performance evaluation summary for test 404311-1, *NCHRP Report 350* test 4-10.

Test Agency: Texas Transportation Institute | Test No.: 404311-1 | Test Date: 10/12/98

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 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 percent reduction in space) in the driver's 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 the after the collision period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and lateral / 9 / 12	Longitudinal occupant impact velocity = 4.7 Lateral occupant impact velocity = -8.3	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component / Preferred / Maximum Longitudinal and lateral / 15 / 20	Longitudinal ridedown acceleration = -4.4 g's Lateral ridedown acceleration = 13.4 g's	Pass
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	No intrusion occurred after the vehicle lost contact with the bridge rail.	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 6.0 degrees which was less than 60 percent of the impact angle.	Pass

*Criterion 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 SAE J211 filters, and digitized using a microcomputer, at 2000 samples per second per channel, for analysis and evaluation of impact performance.

All accelerometers are calibrated annually according to Society of Automotive Engineers SAE J211 *4.6.1* by means of an ENDEVCO 2901, precision primary vibration standard. This device along with its support instruments is returned to the factory annually for a National Institute of Standards 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

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the vehicle. The dummy was un-instrumented.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement and angular data. A BetaCam, a VHS-format video camera and recorder, and still cameras were used to record and document 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: 10-12-98 TEST NO.: 404311-1 VIN NO.: 1C1MR2462P6777912

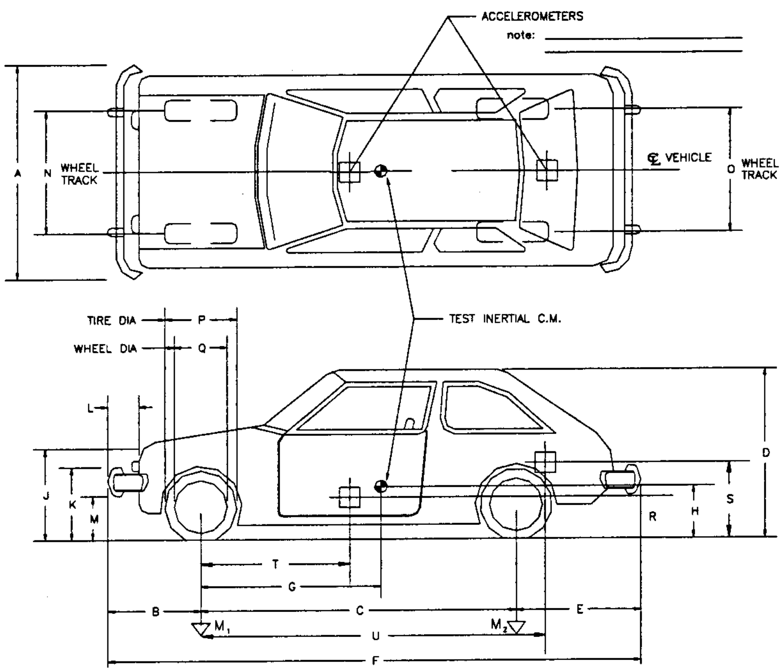
YEAR: 1993 MAKE: GEO MODEL: METRO

TIRE INFLATION PRESSURE: ______ ODOMETER: 60858 TIRE SIZE: 155R12

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

MASS DISTRIBUTION (kg) LF 243 RF 237 LR 178 RR 162

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 CYL.

ENGINE CID: 1.0L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1390	E	630	J	660	N	1370	R	370
B	740	F	3635	K	510	O	1355	S	545
C	2265	G	939.1	L	75	P	330	T	920
D	1330	H		M	365	Q	335	U	2425

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	458	480	511
M_2	290	340	385
M_T	758	820	896

Figure 12. Vehicle properties for test 404311-1.

Table 2. Exterior crush measurements for test 404311-1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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 Width ** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Top Front Bumper	600	90	660	90	70	50	40	25	0	-330
2	700 mm Above Ground	600	200	1000	0	40	65	115	160	130	+900

[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).

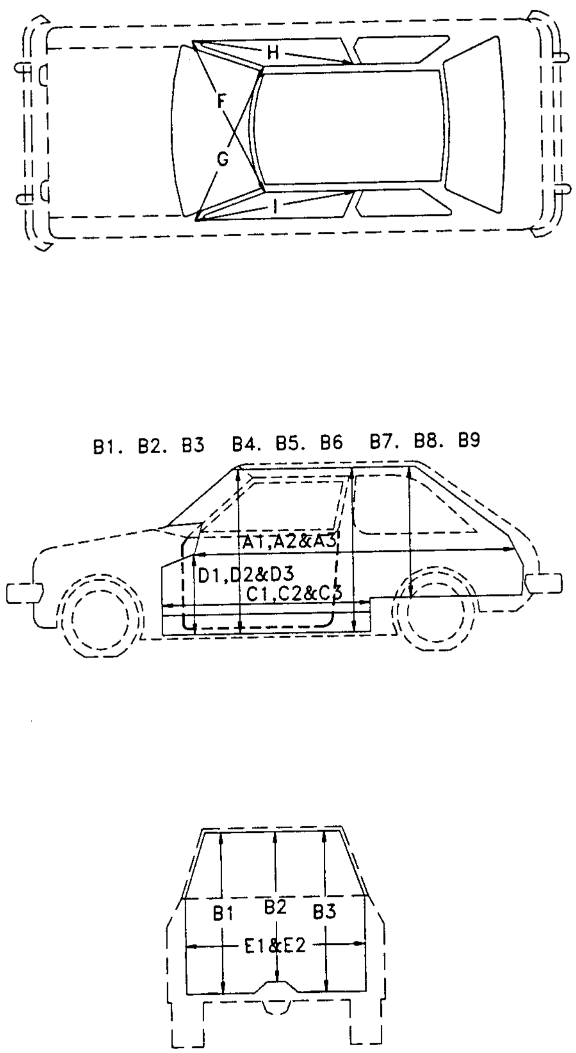
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 3. Occupant compartment measurements for test 404311-1.

Small Car

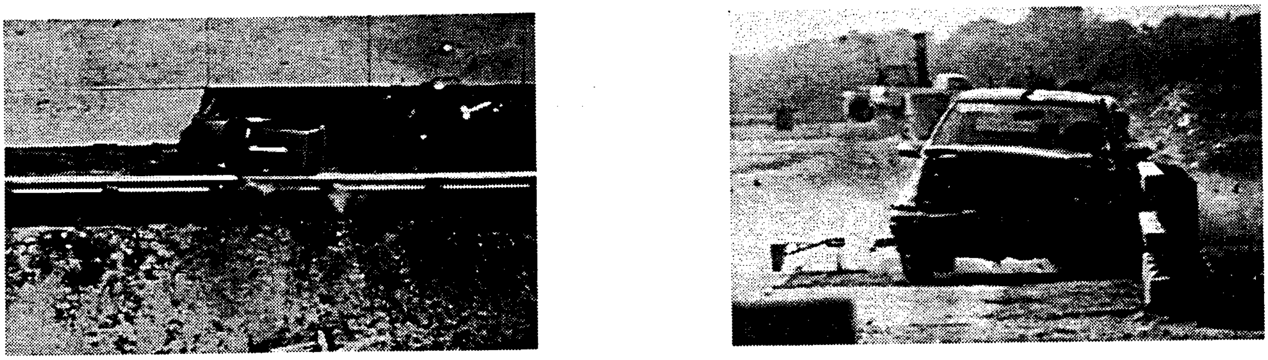
Occupant Compartment Deformation



	BEFORE	AFTER
A1	510	1480
A2	2065	2065
A3	510	510
B1	973	990
B2	915	910
B3	965	965
B4	950	935
B5	842	842
B6	945	945
B7	650	650
B8	660	660
B9	640	640
C1	706	670
C2	690	690
C3	700	700
D1	290	320
D2	100	90
D3	292	292
E1	1230	1260
E2	1238	1285
F	1215	1215
G	1215	1205
H	900	900
I	900	890

APPENDIX D. SEQUENTIAL PHOTOGRAPHS

Figure 13. Sequential photographs for test 404311-1
(overhead and frontal views).



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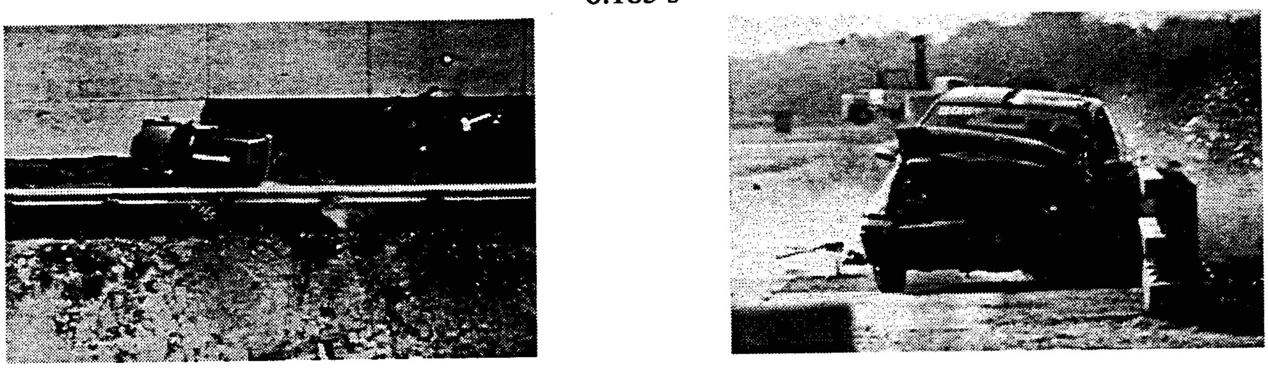

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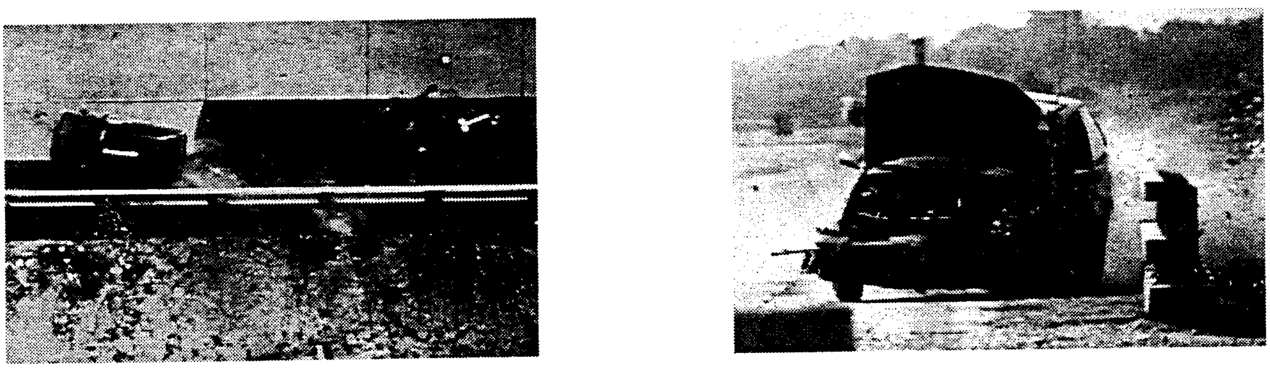

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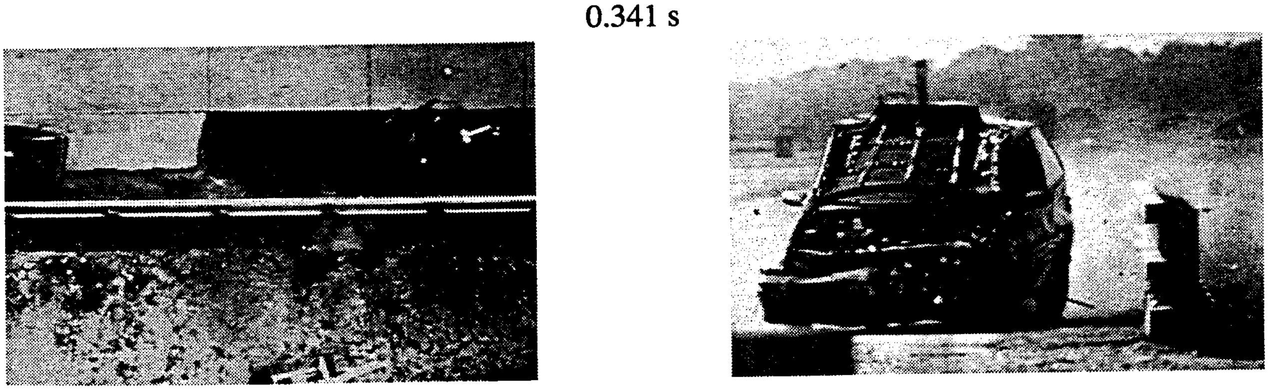
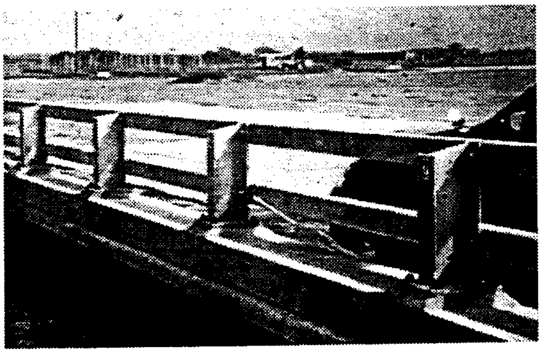


0.488 s

Figure 13. Sequential photographs for test 404311-1
(overhead and frontal views) (continued).



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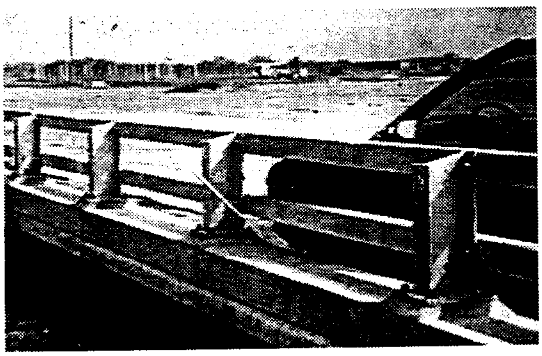

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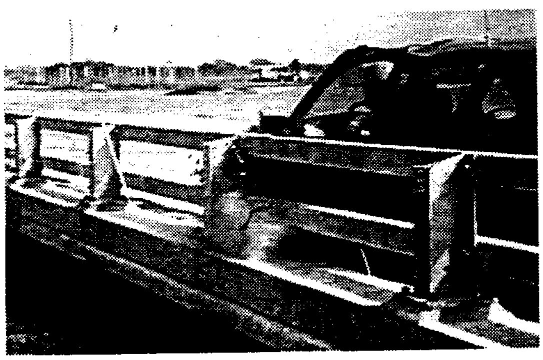

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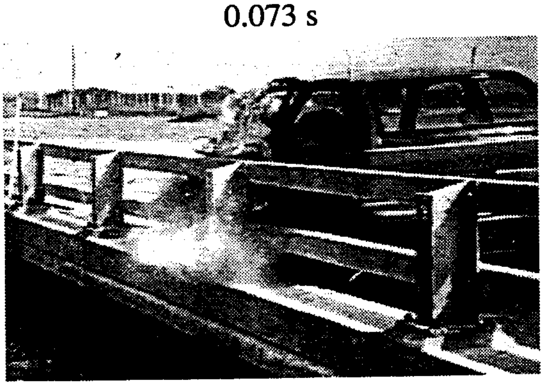

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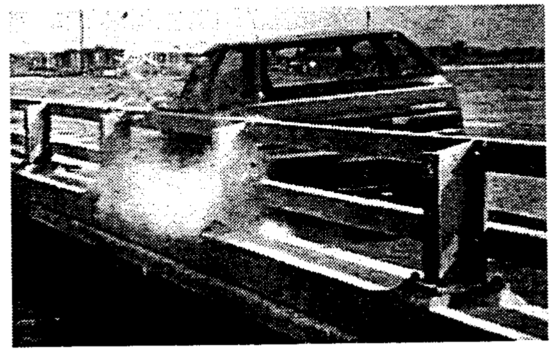

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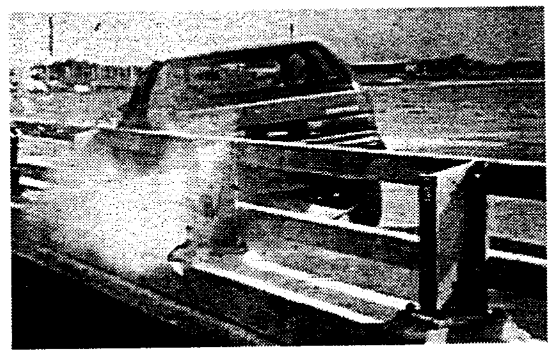

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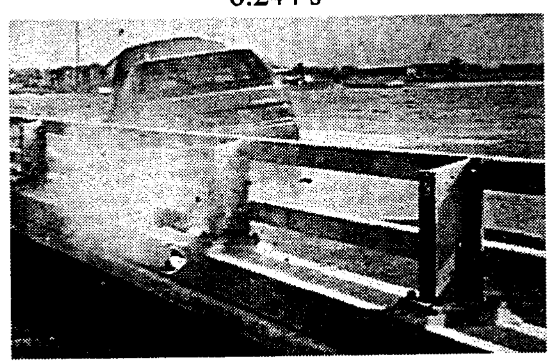

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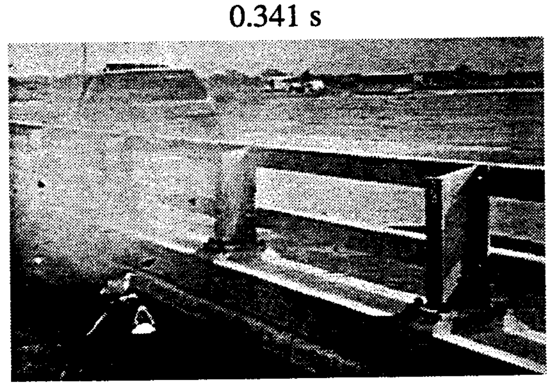

0.488 s

Figure 14. Sequential photographs for test 404311-1 (rear view).

APPENDIX E. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

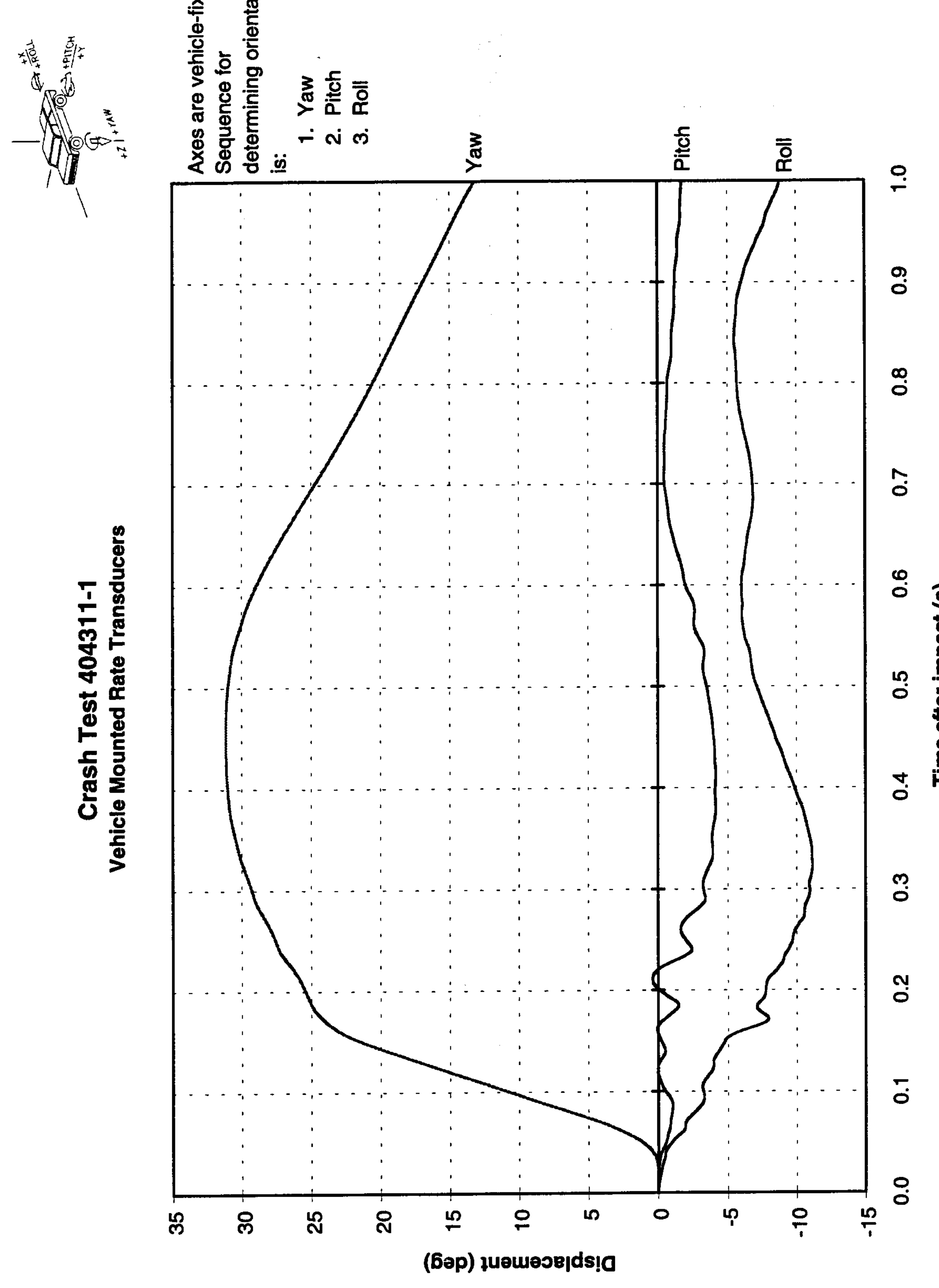

Figure 15. Vehicular angular displacements for test 404311-1.

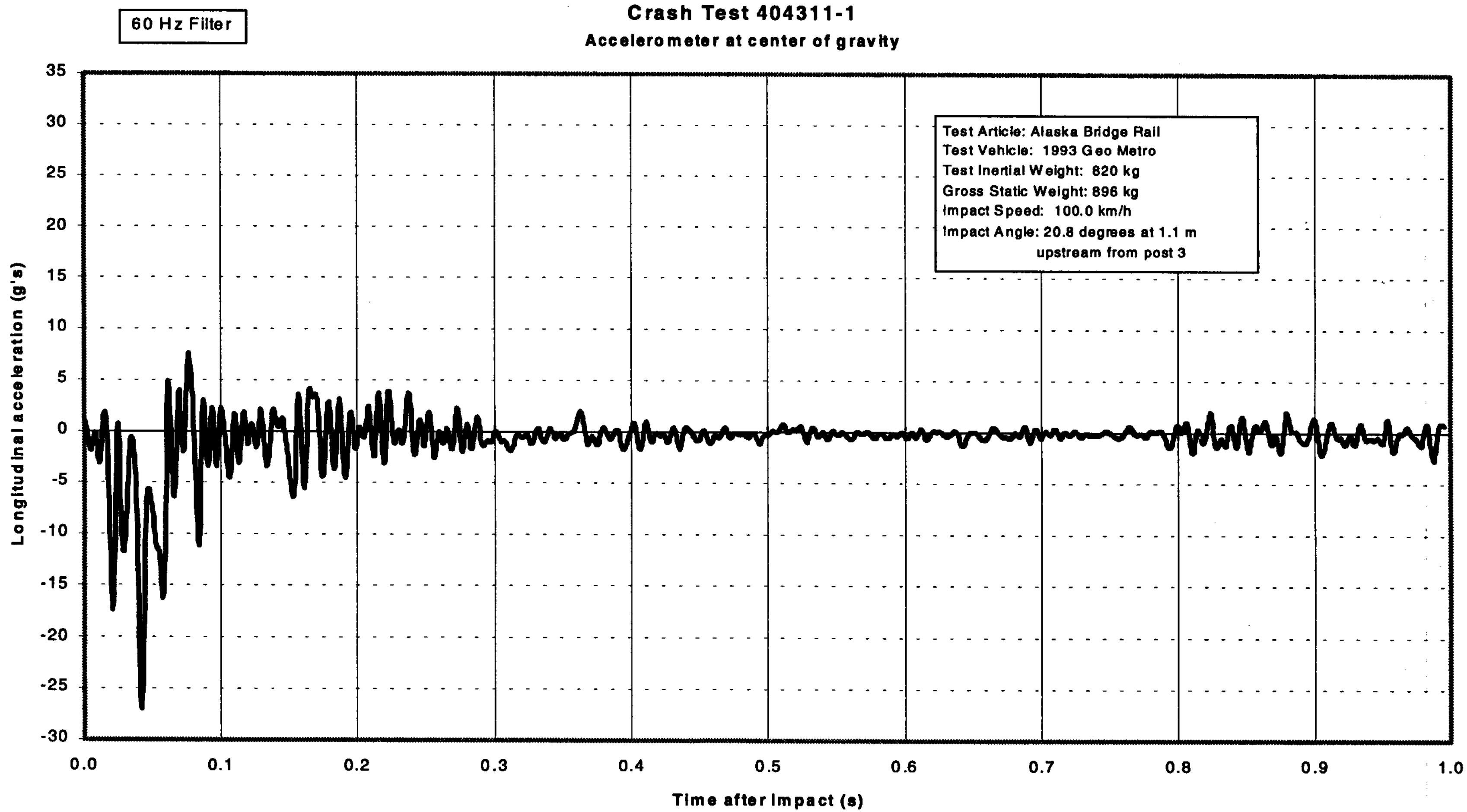

Figure 16. Vehicle longitudinal accelerometer trace for test 404311-1 (accelerometer located at center of gravity).

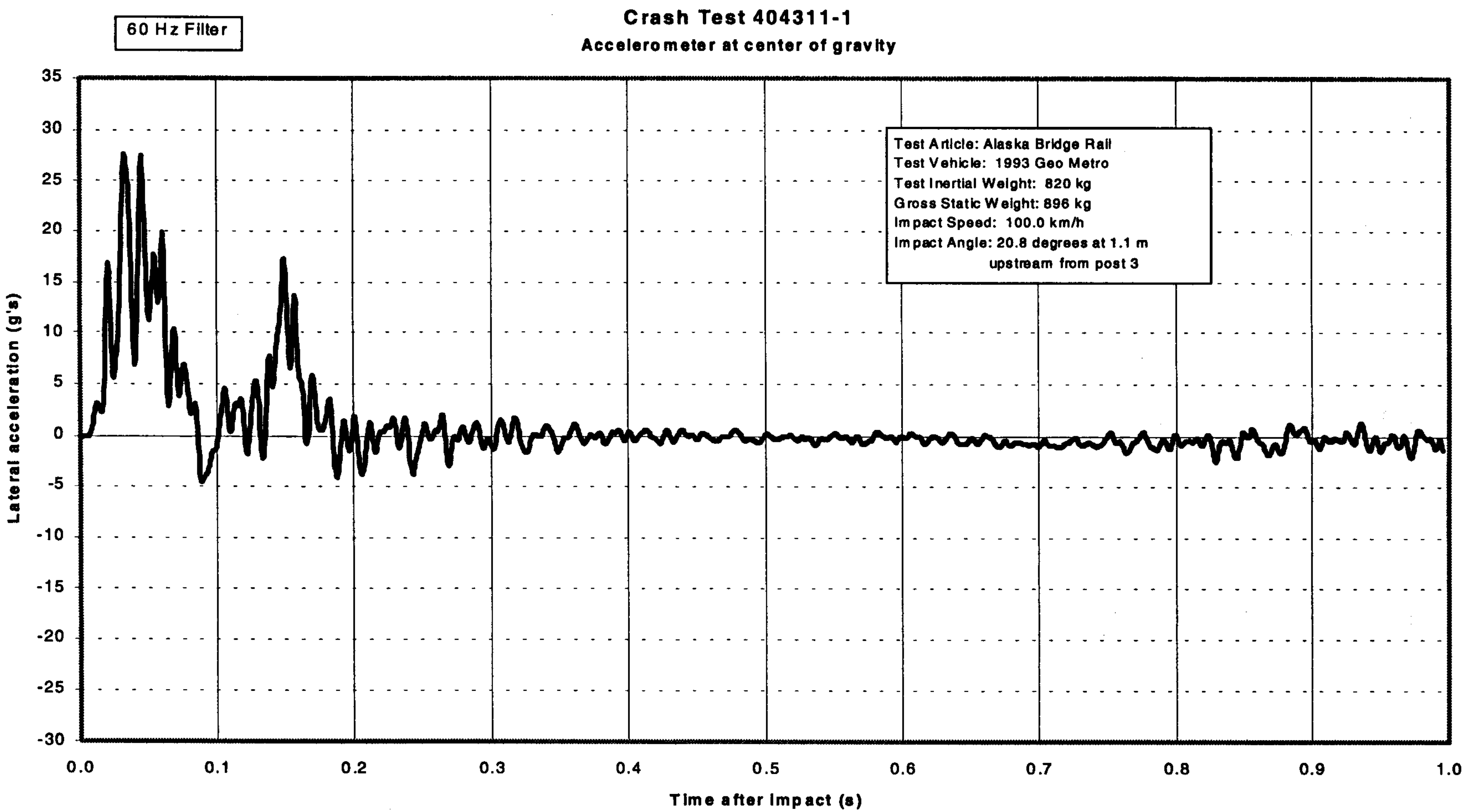

Figure 17. Vehicle lateral accelerometer trace for test 404311-1 (accelerometer located at center of gravity).

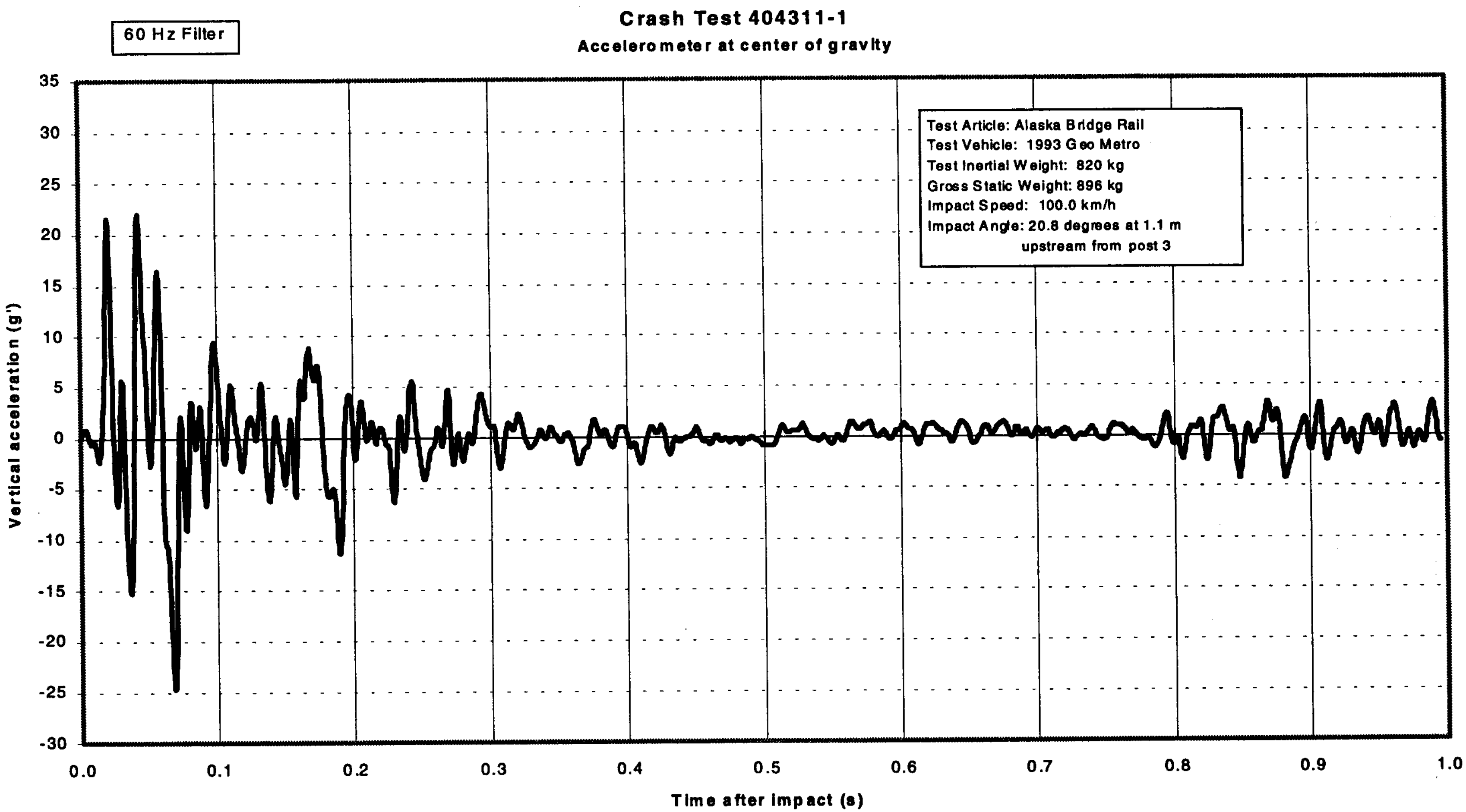

Figure 18. Vehicle vertical accelerometer trace for test 404311-1 (accelerometer located at center of gravity).

REFERENCES

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

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

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