TEXAS TRANSPORTATION INSTITUTE

NCHRP REPORT 350 TEST 4-21 OF THE ALASKA MULTI-STATE BRIDGE RAIL THRIE-BEAM TRANSITION

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KEY WORDS

Bridge railings, transition systems, crash testing, roadside safety

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16. Abstract

This report presents the details of the Alaska Multi-State Bridge Rail Transition and results of the pickup truck test: National Cooperative Highway Research Program (NCHRP) *Report 350* test designation 4-21, 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 Transition met the criteria specified for *NCHRP Report 350* test designation 4-21.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°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

LIST OF FIGURES

LIST OF TABLES

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] *NCHRP Report 350* specifies required crash tests for longitudinal barriers, such as bridge rails, and transitions, for six performance levels as well as evaluation criteria for structural adequacy, occupant risk, and post-test vehicle trajectory. The Alaska Multi-State Bridge Rail Thrie-Beam Transition is to be evaluated according to specifications of test level four (TL-4) of *NCHRP Report 350.*

BACKGROUND

FHWA has required that all new guardrail to bridge rail transitions to be installed on the National Highway (NHS) after October 2002 meet the *NCHRP Report 350* performance evaluation guidelines. *NCHRP Report 230* was the previous guideline used for testing most of the existing roadside safety features.[2] It is now required to evaluate the performance of new and/or 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 Rail Thrie-Beam Transition to Test Level 4 of *NCHRP Report 350.* In order to evaluate at TL-4, three full-scale crash tests on the transition are required. These include an 820-kg passenger car impacting the critical impact point (CIP) of the transition at a nominal impact speed and angle of 100 km/h and 20 degrees, a 2000-kg pickup truck impacting the CIP of the transition at a nominal impact speed and angle of 100 km/h and 25 degrees, and an 8000-kg single-unit truck impacting the CIP of the transition at a nominal speed and angle of 80 km/h and 15 degrees.

This report presents the details of the Alaska Multi-State Bridge Rail Thrie-Beam Transition and results of the pickup truck test: *NCHRP Report 350* test designation 4-21, which is the 2000-kg pickup truck impacting the CIP at 100 km/h and 25 degrees. The Alaska Multi-State Bridge Rail Thrie-Beam Transition met all criteria specified for *NCHRP Report 350* test designation 4-21.

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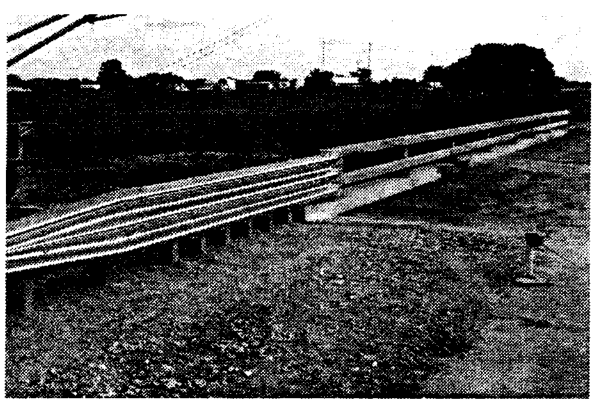
TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of an 809-hectare complex of research and training facilities situated 16 km northwest of the main campus of Texas A&M University. The site, formerly an Air Force Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for placing of the Alaska Multi-State Bridge Rail Thrie-Beam Transition 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, bridge rail and transition cross section.



Test Article – Design and Construction

The Alaska Multi State Thrie Beam Transition consists of two nested 12 gage Thrie Beams connecting to the end of the Alaska Two-Rail Bridge Rail using a Thrie Beam Terminal Connector. The terminal connector attaches to the bridge rail using a steel connection plate fabricated specially for the Alaska Two Rail Bridge Rail. The height of the Thrie Beam was 787 mm and a Thrie Beam to W-Beam transition piece was used to transition to a standard W-Beam Guardrail. The test installation consisted of 6.4 m transition, 7.6 m length of need of guardrail, and 11.4 m LET End Treatment. The total length of the installation was 25.4 m. The centerline distance between the last bridge post and the first post of the transition was 1145 mm.

The W150x13.5 posts used in the transition were 1982 mm in length and were embedded 1245 mm. W200x22 Steel blockouts were used in the Thrie Beam region and were 542 mm in length on the front face and 480 mm in length on the back face. W150x13.5 posts were also used in the length of need of guardrail. The guardrail posts were 1830 mm in length and embedded

1100 mm. W200x150 wood blockouts with a routed 10 mm groove were used in the guardrail section. Standard W150x200 wood posts and blockouts were used in the LET End Treatment.

Texas Transportation Institute (TTI) received a drawing from Alaska Department of Transportation entitled "2-Tube and 3-Tube Standard Curb Mount Rail" dated July 1992 and prepared by Oregon Department of Transportation Bridge Design Section. TTI used a modified version of the transition connection shown on this drawing for the test installation as part of this study. The connection plate consisted of a 560 mm x 340 mm x 13 mm plate supported by 102 mm x 10 mm x 824 mm plate welded to the field side of the connection plate. A 102 mm x 102 mm x10 mm angle, 824 mm in length was also used to support the connection plate. The angle and the plate were extended to support a 13 mm x 402 mm x 232 mm transition plate located between the bridge rails. The transition plate was added to prevent vehicles from snagging if a reverse vehicle impact was to occur at the connection. The mounting angle and plate behind the terminal connecting plate were coped so that the transition plate could slope back on an approximate 3.0(H):1.0(V) slope. The connection plate was also supported by a vertical angle supported by 19 mm studs welded to 5 mm end plates welded to the ends of the bridge rail tubes. The connection plate bolted to the bridge rail at the locations of the horizontal plate and angle and also to the vertical angle as shown on the transition connection details included with this report. A36 material was used to construct the transition connection plate. For additional information please see the test installation drawings included with this report.

TTI modified the curb at the end of the bridge deck by cutting the curb back 114 mm over a horizontal distance of 457 mm. This modification was also made to prevent excessive wheel snagging from occurring at his location. Details of the installation are shown in figures 1 and 2, and photographs of the completed installation are shown in figure 3.

Test Conditions

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

NCHRP Report 350 test designation 4-20: An 820-kg passenger car impacting the transition at the (critical impact point) CIP at a nominal speed and angle of 100 km/h and 20 degrees. The test is intended to evaluate occupant risk and post-impact trajectory.

NCHRP Report 350 test designation 4-21: A 2000-kg pickup truck impacting the transition at the (critical impact point) CIP at a nominal speed and angle of 100 km/h and 25 degrees. The test is intended to evaluate the strength of the section in containing and redirecting the 2000 kg vehicle.

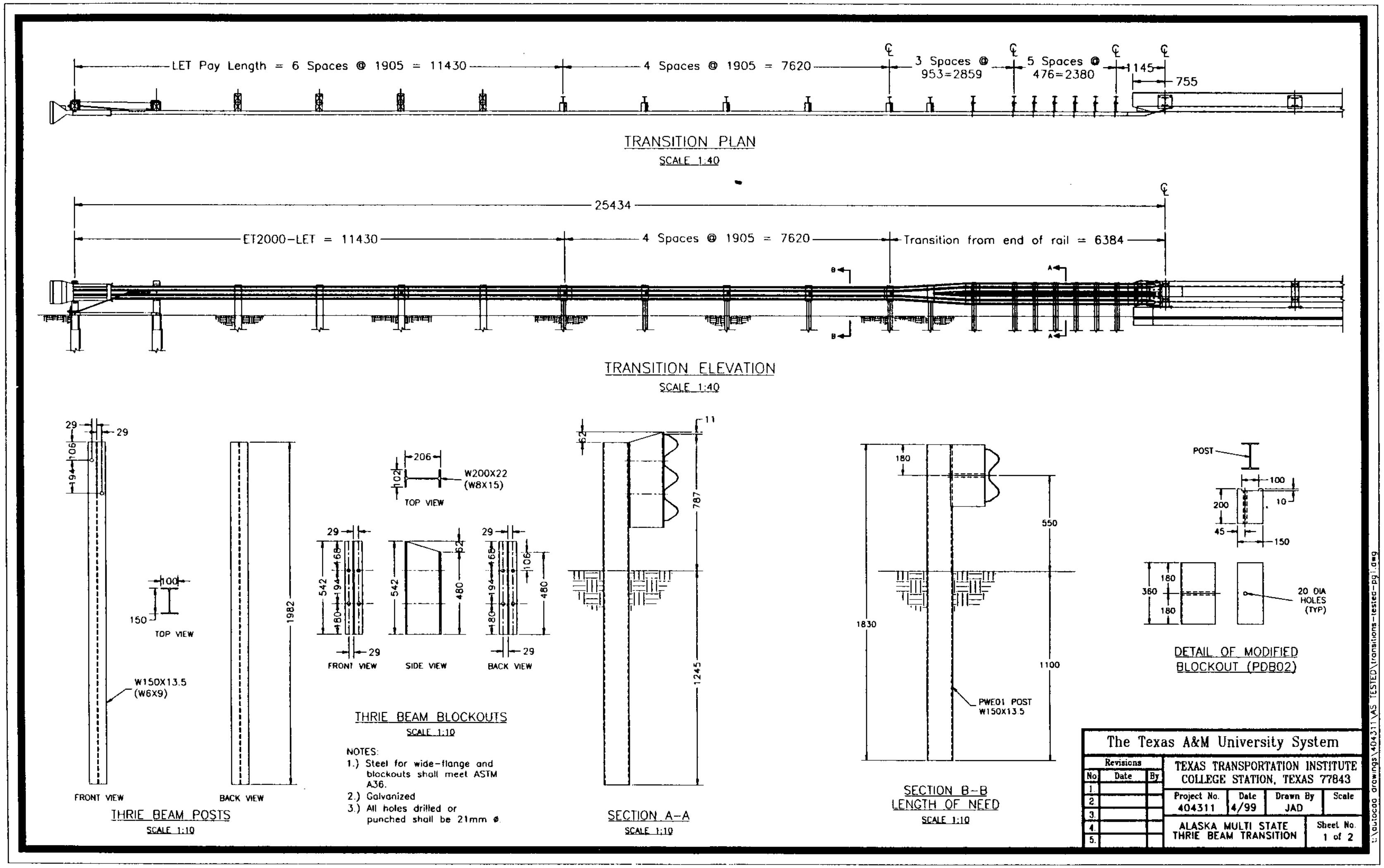


Figure 1. Details of the Alaska Multi-State Bridge Rail Thrie-Beam Transition.

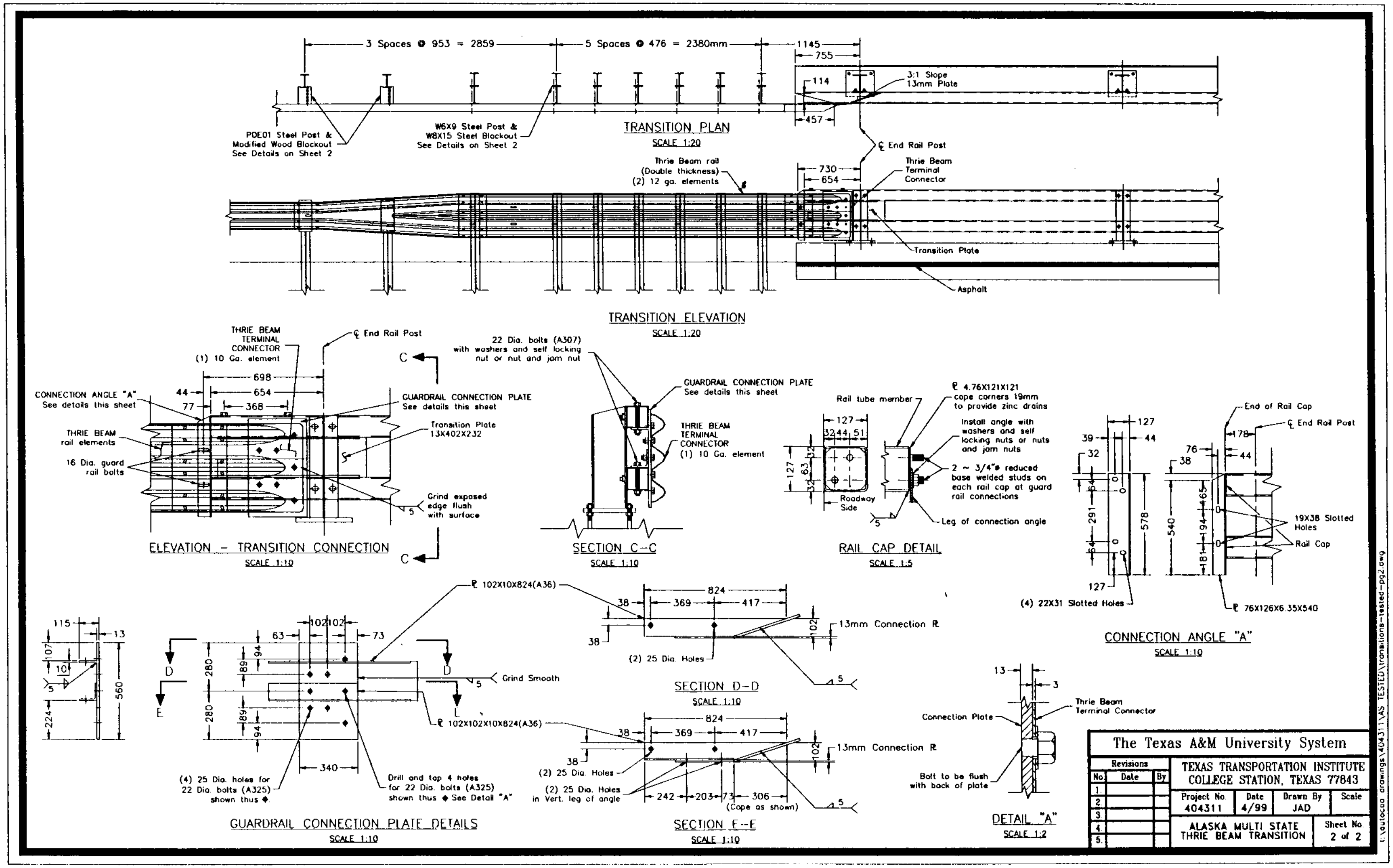


Figure 2. Details of the bridge rail connection of Alaska Multi-State Bridge Rail Thrie-Beam Transition.

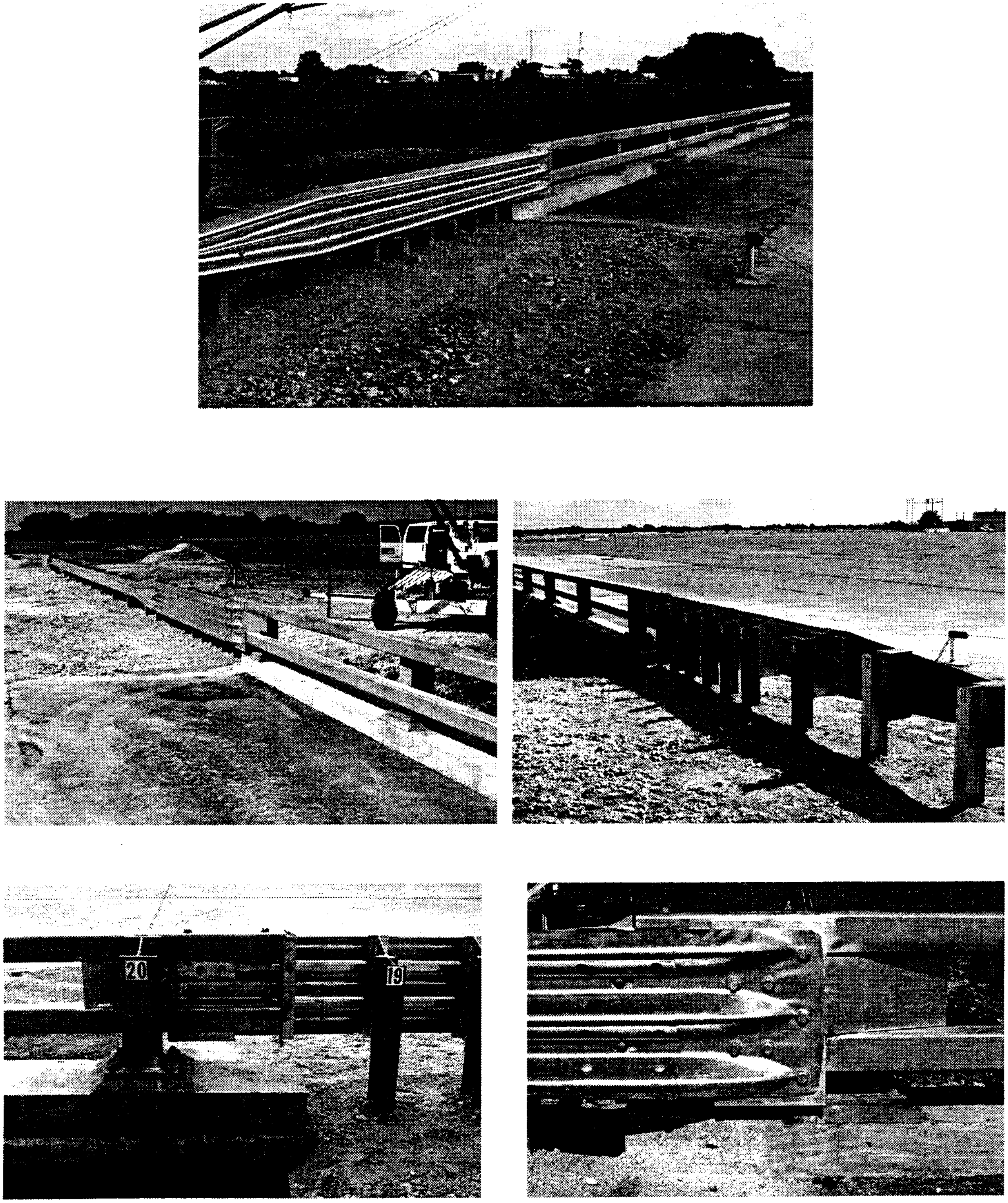


Figure 3. Alaska Multi-State Bridge Rail Thrie-Beam Transition prior to testing.

NCHRP Report 350 test designation 4-22: An 8000-kg single-unit truck impacting the transition at the (critical impact point) CIP at a nominal speed and angle of 80 km/h and 15 degrees. The test intended to evaluate the strength of the section in containing and redirecting the heavy truck.

NCHRP Report 350 test designation 4-21 was performed on the Alaska Multi-State Bridge Rail Transition. As recommended in *NCHRP Report 350*, the BARRIER VII simulation program was used to select the CIP for this test. The program indicated the CIP to be 2.1 m upstream from the centerline of the first bridge rail post.

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.*

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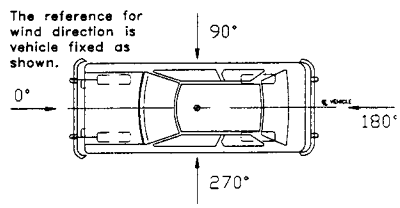
CRASH TEST 404311-5 (*NCHRP Report 350* TEST 4-21)

Test Vehicle

A 1994 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 385 mm and to the upper edge of the front bumper was 605 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 11. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Soil and Weather Conditions

The crash test was performed the morning of June 1, 1999. Six days prior to the test 36 mm of rainfall was recorded. No other rainfall was recorded for the remaining ten days prior to the test. Moisture content of the *NCHRP Report 350* standard soil used in the installation was 9.2 percent, 8.9 percent, and 9.0 percent at posts 14, 16, and 18, respectively. Weather conditions at the time of testing were as follows: Wind Speed: 6 km/h; Temperature: 31 °C; Relative Humidity: 56 percent.



Impact Description

The 2000P vehicle, while traveling at a speed of 100.6 km/h, impacted the transition at 2.1 m upstream of post 20 (the first bridge rail post) at an angle of 25.4 degrees. Shortly after impact posts 16, 17 and 18 moved and at 0.007 s, post 15 moved. At 0.010 s, post 19 moved, and at 0.023 s, the left front wheel steered toward the transition. By 0.033 s, the left front tire was traveling parallel with the rail element, and by 0.036 s, the left front tire began to angle underneath the rail element. At 0.044 s, the vehicle began to redirect and post 19 moved, and at 0.046 s, post 13 moved. By 0.054 s, the concrete began to crack at the rear of the test installation, and by 0.100 s, the right front tire lost contact with the ground. The rear of the vehicle contacted the rail element at 0.199 s, and at 0.210 s, the right rear tire lost contact with the ground. At 0.214 s, the vehicle was traveling parallel with the transition at a speed of 75.0 km/h, and at 0.218 s, the left front tire lost contact with the ground. The left front tire lost contact with the rail element at 0.269 s. The rear of the vehicle lost contact with the transition at 0.343 s, and was traveling at a speed of 75.6 km/h and an exit angle of 1.7 degrees. The left front, right rear and right front tires returned to the ground surface at 0.449 s, 0.569 s, and 0.579 s, respectively. Brakes on the vehicle were applied at 2.2 s after impact and the vehicle subsequently came to rest 58.5 m down from impact and 3.0 m behind the test installation. Sequential photographs of the test period are shown in appendix C, figures 13 and 14.

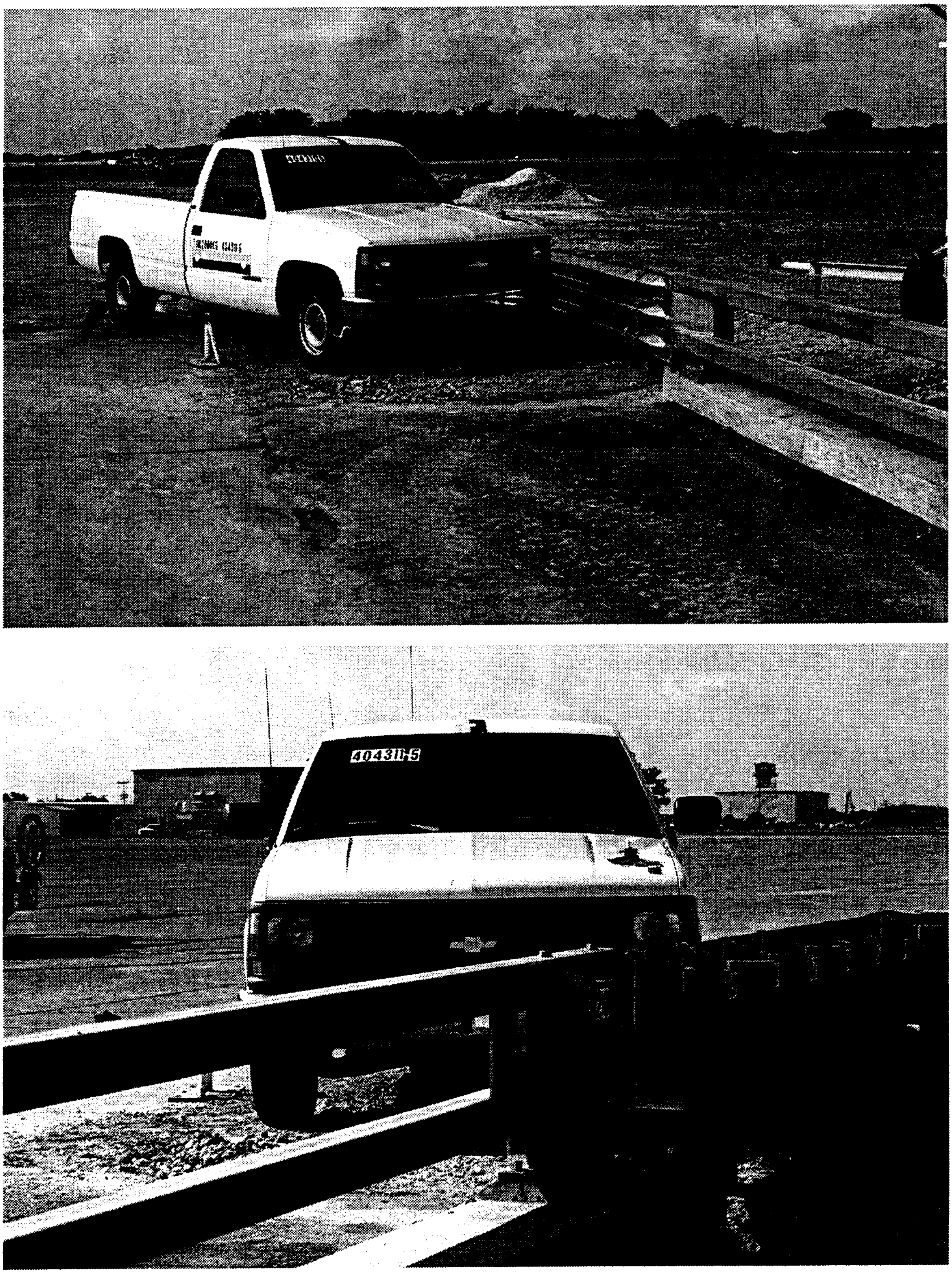


Figure 4. Vehicle/installation geometrics for test 404311-5.

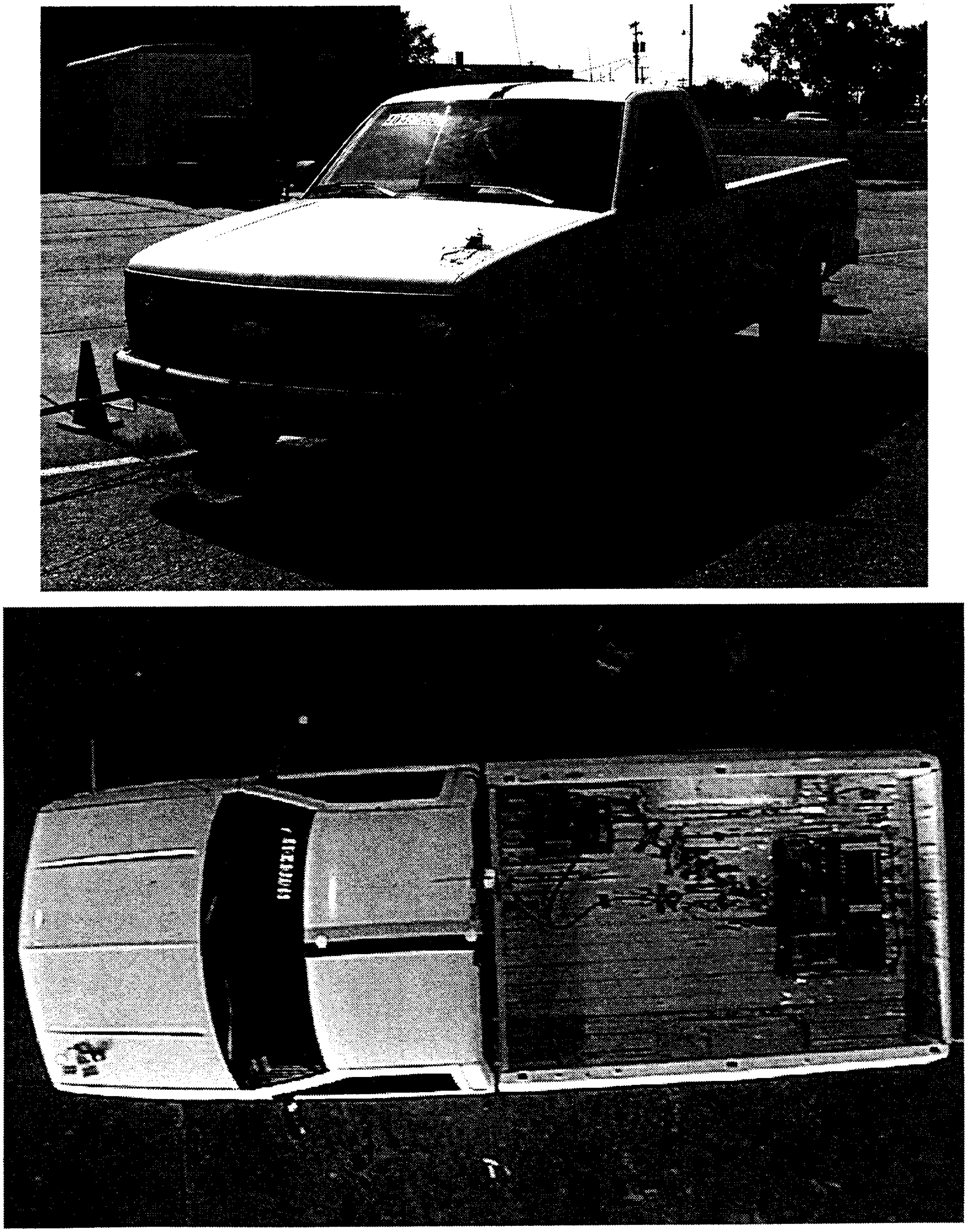


Figure 5. Vehicle before test 404311-5.

Damage to Test Article

The Alaska Multi-State Bridge Rail Transition received moderate damage as shown in figure 6 through 8. Tire marks were on the face of the curb at post 20 for a total of 1.1 m. The front connection bolt on the end shoe to the lower tube was pulled out. Cracks in the deck radiated outward from the bolts of the base plate at post 20 (the first bridge rail post). Total length of contact by the vehicle with the transition and bridge rail was 3.9 m. Maximum dynamic deflection of the top of the rail element was 131 mm and maximum permanent deformation was 50 mm at post 19.

Vehicle Damage

The vehicle sustained damage as shown in figure 9. Structural damage included upper A-arm, sway bar, left upper ball joint, left outer tie rod, floor pan and frame. The left front tire, wheel and quarter panel were crushed. The front bumper, hood, grill, radiator, and fan were deformed. The left rear quarter panel, tire rim and left rear bumper were also deformed. The windshield was shattered and the instrument panel was deformed. The driver's side door was pulled open 110 mm and the cab of the vehicle shifted outward 90 mm on the driver's side. Maximum exterior crush to the vehicle was 570 mm at the front bumper and 340 mm the left side of the bumper. Maximum deformation of the occupant compartment was 130 mm (12 percent reduction in space) to the floor pan behind the driver's seat to the right at the inside seat belt bolt and 104 mm to the lower portion of the kick panel area. The interior of the vehicle is shown in figure 10. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 2 and 3.

Occupant Risk Factors

Data from the tri-axial accelerometer, located at the vehicle center of gravity, were digitized to compute occupant impact velocity and ridedown accelerations. The occupant impact velocity and ridedown accelerations in the longitudinal axis only are required from these data for evaluation of criterion L of *NCHRP Report 350*. In the longitudinal direction, occupant impact velocity was 7.4 m/s at 0.158 s, maximum 0.010-s ridedown acceleration was 9.5 g's from 0.101 to 0.111 s, and the maximum 0.050-s average was -11.4 g's between 0.051 and 0.101 s. In the lateral direction, the occupant impact velocity was 7.6 m/s at 0.098 s, the highest 0.010-s occupant ridedown acceleration was 9.6 g's from 0.182 to 0.192 s, and the maximum 0.050-s average was 14.4 g's between 0.030 and 0.080 s. These data and other information pertinent to the test are presented in figure 11. Vehicle angular displacements and accelerations versus time traces are shown in appendix E, figures 15 through 18.

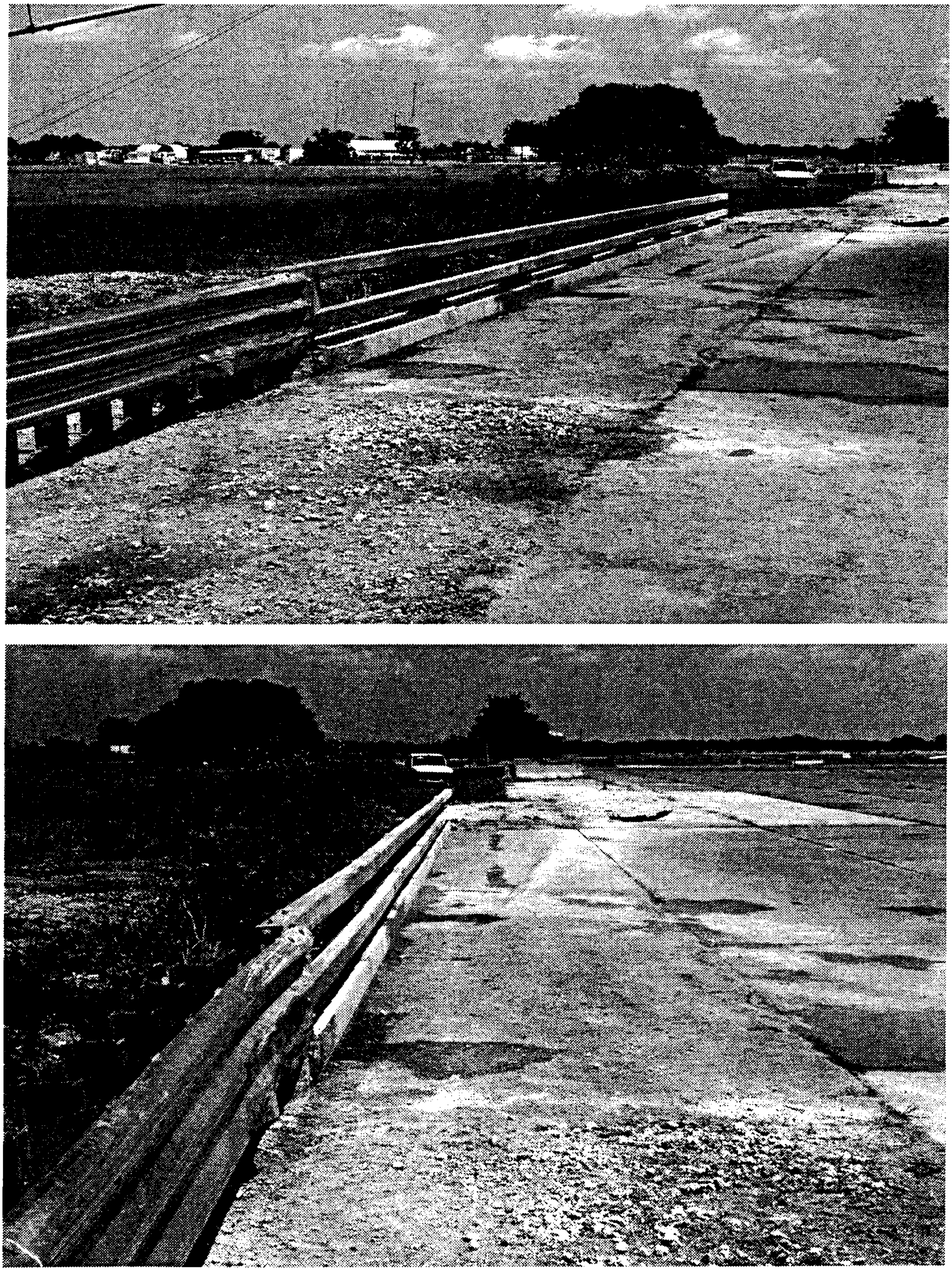


Figure 6. Vehicle trajectory path after test 404311-5.

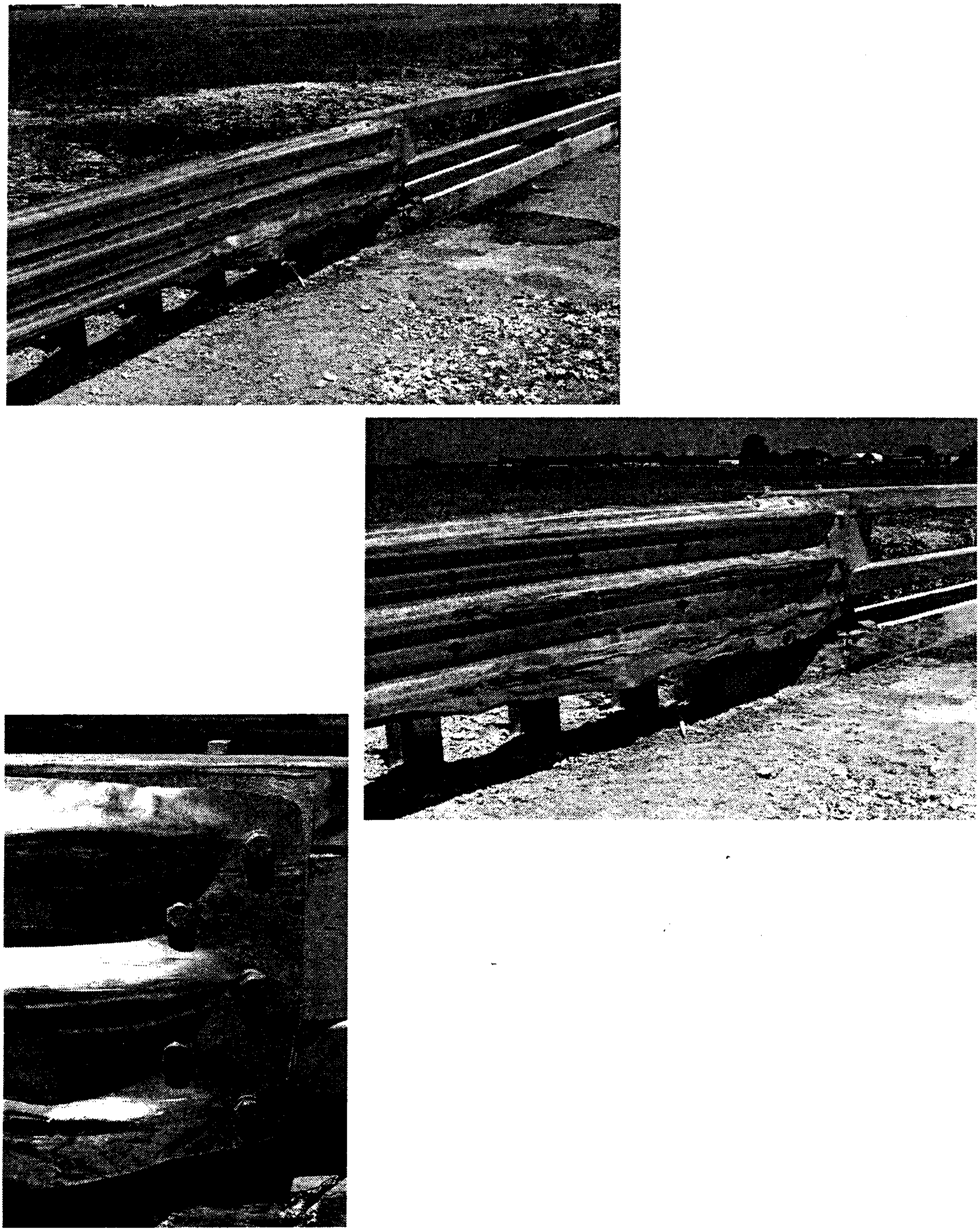


Figure 7. Installation after test 404311-5.

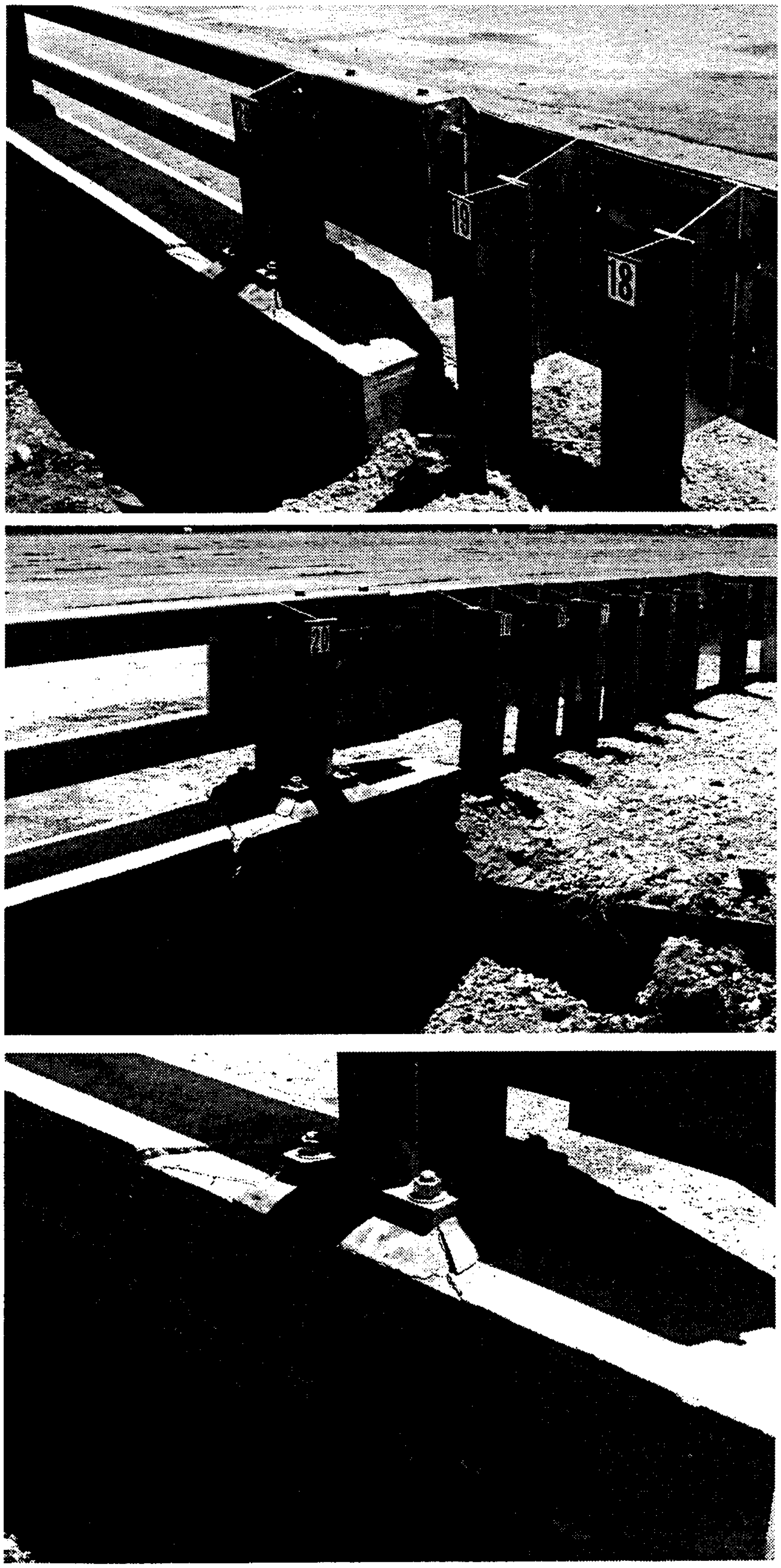


Figure 8. Damage to field side of test installation after test 404311-5.

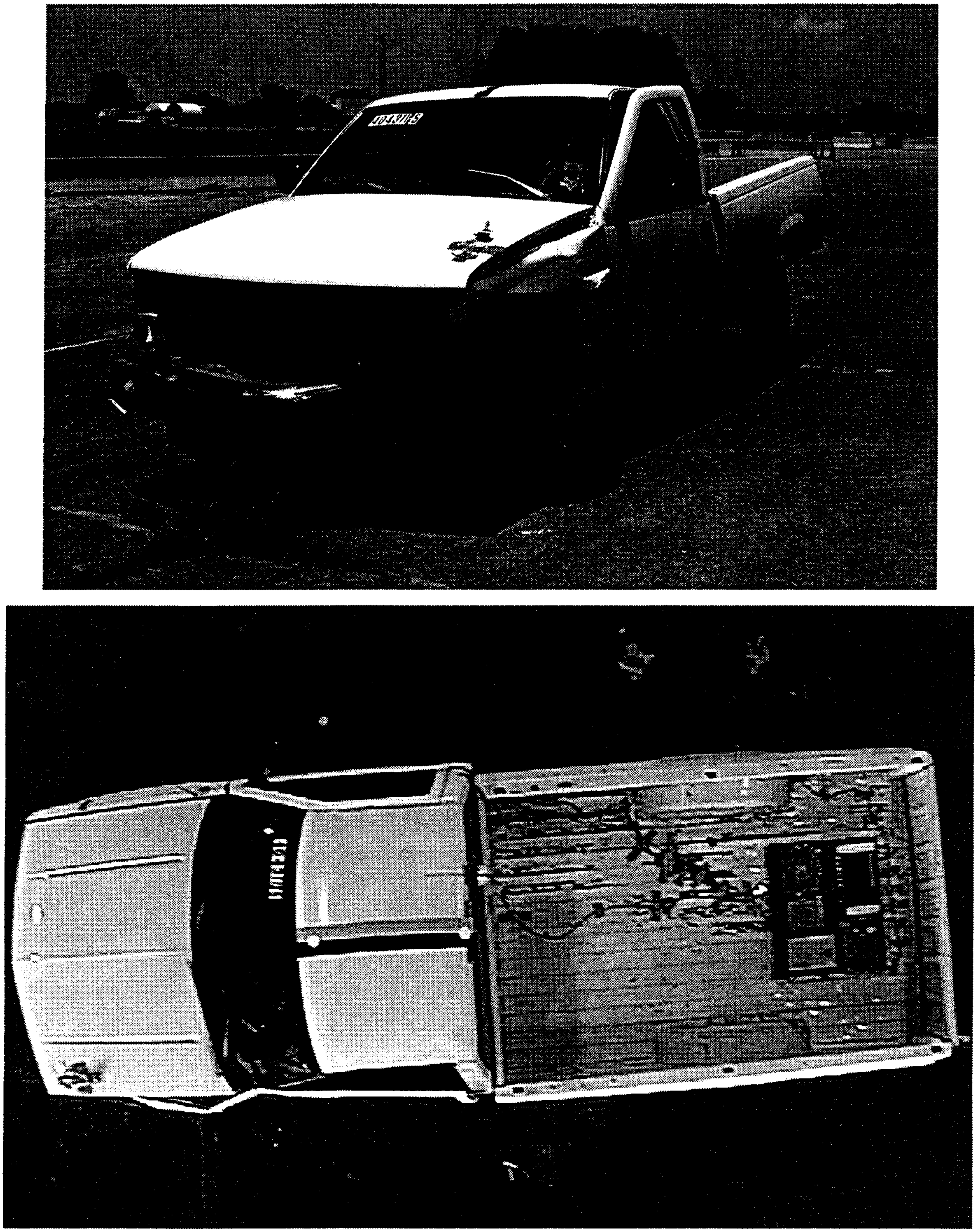
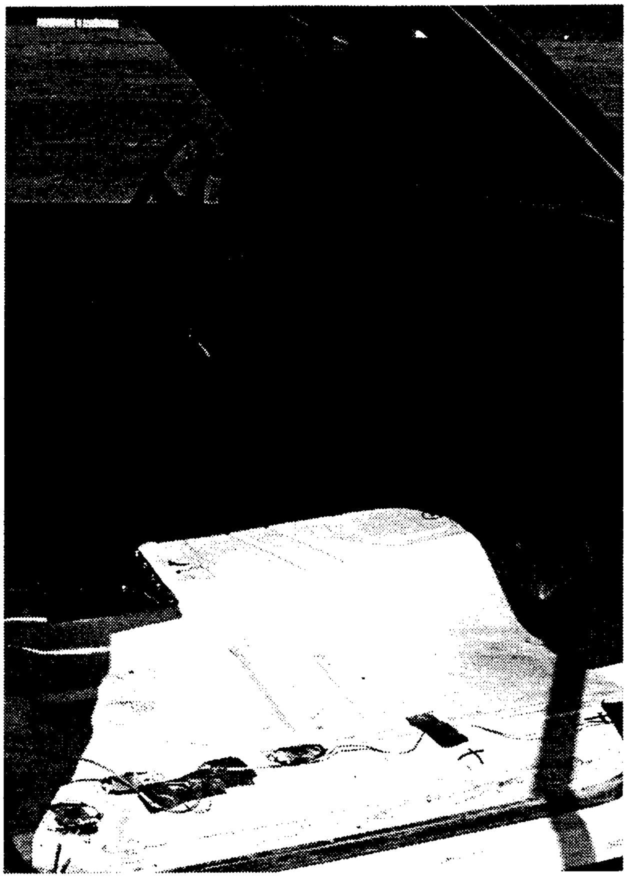
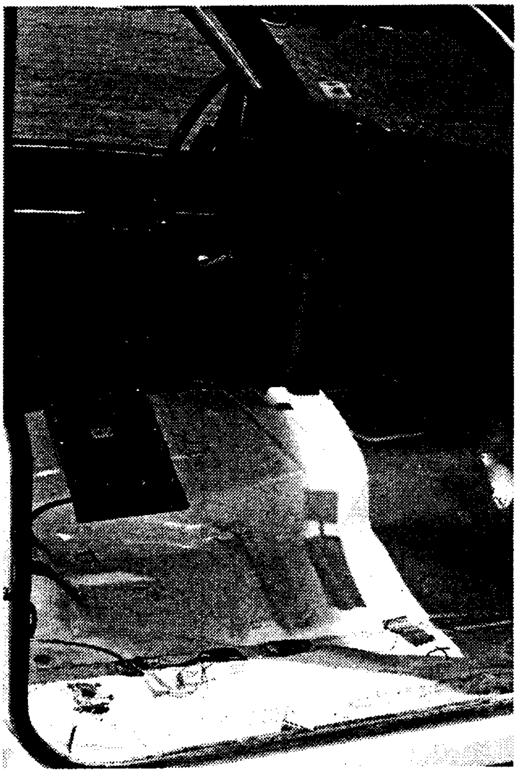


Figure 9. Vehicle after test 404311-5.



Before test

After test



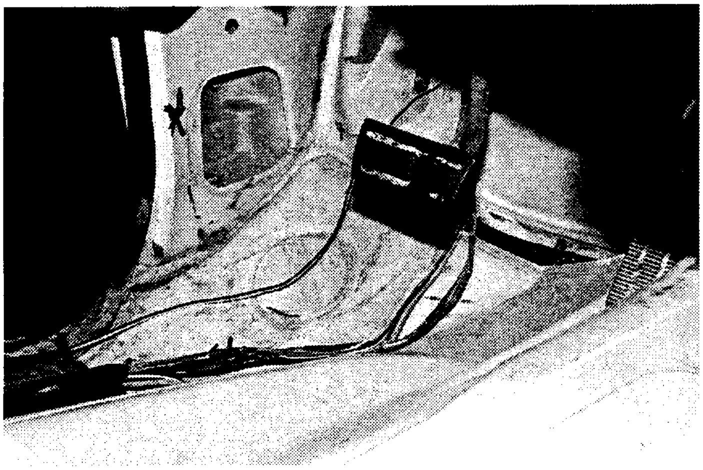
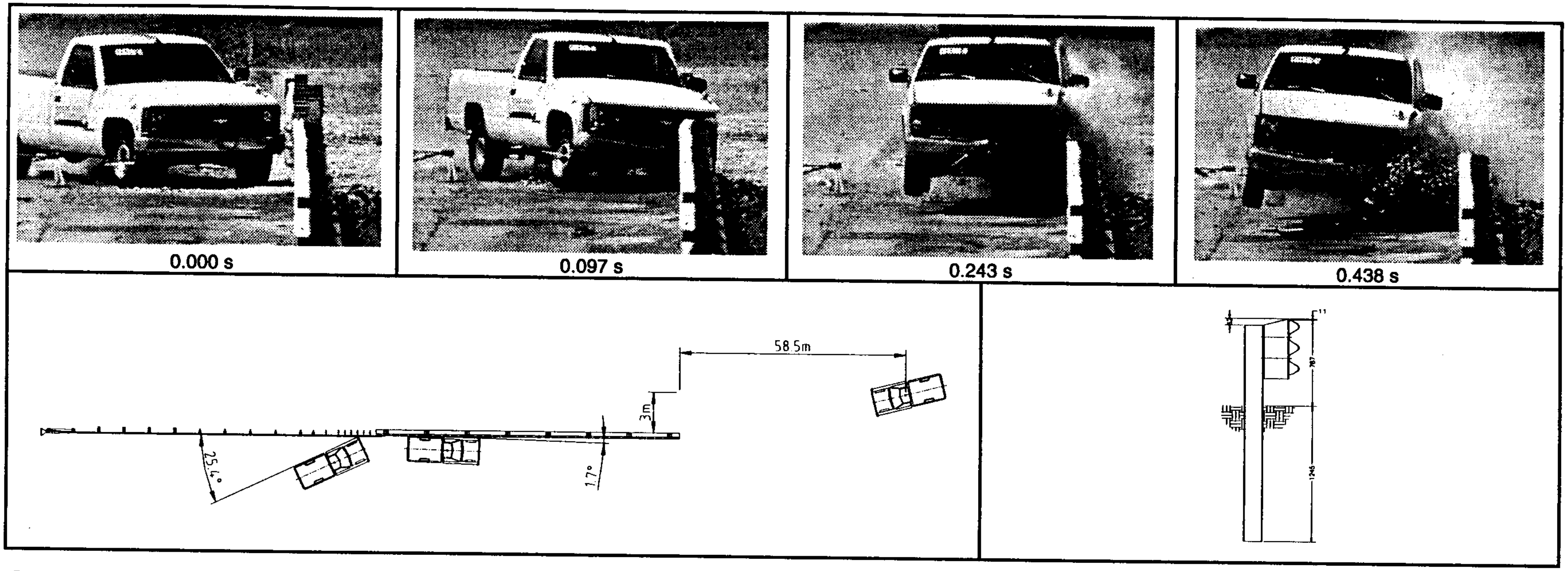


Figure 10. Interior of vehicle for test 404311-5.



General Information

Test Agency	Texas Transportation Institute
Test No.	404311-5
Date	06/01/99

Test Article

Type	Transition
Name	Alaska Multi-State Thrie Beam Transition
Installation Length (m)	25.4
Material or Key Elements	Thrie Beam Attached to Alaska Multi-State Bridge Rail

Soil Type and Condition .... Standard Soil, Dry

Test Vehicle

Type	Production
Designation	2000P
Model	1994 Chevrolet 2500 pickup truck
Mass (kg)	
Curb	1982
Test Inertial	2000
Dummy	No dummy
Gross Static	2000

Impact Conditions

Speed (km/h)	100.6
Angle (deg)	25.4

Exit Conditions

Speed (km/h)	75.6
Angle (deg)	1.7

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	7.4
y-direction	7.6
THIV (km/h)	35.0
Ridedown Accelerations (g's)	
x-direction	9.5
y-direction	9.6
PHD (g's)	12.7
ASI	1.84
Max. 0.050-s Average (g's)	
x-direction	-11.4
y-direction	14.4
z-direction	-6.2

Test Article Deflections (m)

Dynamic	0.131
Permanent	0.50

Vehicle Damage

Exterior	
VDS	11LFQ4
CDC	11FLEK3 & 11LDEW3
Maximum Exterior Vehicle Crush (mm)	570
Interior	
OCDI	LF02020001
Max. Occ. Compart. Deformation (mm)	130

Post-Impact Behavior
(during 1.0 s after impact)

Max. Yaw Angle (deg)	28
Max. Pitch Angle (deg)	-4
Max. Roll Angle (deg)	-7

Figure 11. Summary of Results for test 404311-5, *NCHRP Report 350* test 4-21.

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 Rail Thrie-Beam Transition contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection was 131 mm.

- **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 or 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 130 mm (12 percent reduction in space) to the floor pan behind the driver's seat to the right at the inside seat belt bolt and 104 mm to the lower portion of the kick panel area.

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

The 2000P vehicle remained upright during and after the collision period.

- **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 3.0 m behind the test installation.

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

Longitudinal occupant impact velocity was 7.4 m/s and longitudinal occupant ridedown acceleration was 9.5 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.*

Exit angle at loss of contact was 1.7 degrees which was 7 percent of the impact angle.

SUMMARY AND CONCLUSIONS

SUMMARY OF FINDINGS

The Alaska Multi-State Bridge Rail Thrie-Beam Transition contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum permanent deformation was 50 mm. No detached elements, fragments or other debris were present to penetrate or 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 130 mm (12 percent reduction in space) to the floor pan behind the driver's seat to the right at the inside seat belt bolt and 104 mm (20 percent reduction in space) to the lower portion of the kick panel area. The 2000P vehicle remained upright during and after the collision period. The vehicle did not intrude into adjacent traffic lanes as it came to rest 3.0 m behind the test installation. Longitudinal occupant impact velocity was 7.4 m/s and longitudinal occupant ridedown acceleration was 9.5 g's. Exit angle at loss of contact was 1.7 degrees which was 7 percent of the impact angle.

CONCLUSIONS

As shown in table 1, the Alaska Multi-State Bridge Rail Thrie-Beam Transition met all criteria for test *NCHRP Report 350* test designation 4-21.

Table 1. Performance evaluation summary for test 404311-5, *NCHRP Report 350* test 4-21.

Test Agency: Texas Transportation Institute — Test No.: 404311-5 — Test Date: 06/01/99

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Alaska Multi-Sate Bridge Rail Thrie-Beam Transition contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum permanent deformation was 50 mm.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	No detached elements, fragments or other debris were present to penetrate or to show potential for penetrating the occupant compartment not to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 130 mm (12 percent reduction in space) to the floor pan behind the driver's seat to the right at the inside seat belt bolt and 104 mm to the lower portion of the kick panel area.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The 2000P 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.	The vehicle did not intrude into adjacent traffic lanes as it came to rest 3.0 m behind the test installation.	Pass*
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal occupant impact velocity = 7.4 m/s Longitudinal ridedown acceleration = 9.5 g's	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Exit angle at loss of contact was 1.7 degrees which was 7 percent of the impact angle.	Pass*

*Criterion K and M are preferable, not required.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

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

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with 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 provide the capability of an R-Cal or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15 channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals, from the test vehicle, are recorded minutes before the test and also immediately afterwards. A crystal controlled time reference signal is simultaneously recorded with the data. Pressure-sensitive switches on the bumper of the impacting vehicle are actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an "event" mark on the data record to establish the exact instant of contact with the installation.

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

All accelerometers are calibrated annually according to SAE J211 *4.6.1* by means of 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) 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 0.0005-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 820C vehicle. The dummy was un-instrumented. Use of a dummy in the 2000P vehicle is optional according to *NCHRP Report 350* and there was no dummy used in the tests with 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.

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APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

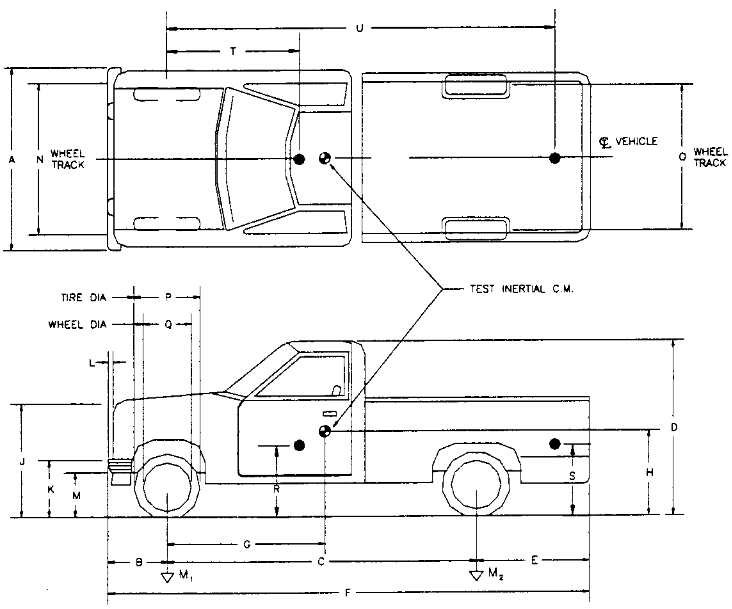
DATE: 6/1/99 TEST NO.: 404311-5 VIN NO.: 1GCFC24K1RE108474

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

TIRE INFLATION PRESSURE: ______ ODOMETER: 189091 TIRE SIZE: 225 75R16

MASS DISTRIBUTION (kg) LF 559 RF 543 LR 454 RR 444

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL.

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

6 LUG

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	1850	E	1250	J	1015	N	1600	R	690
B	830	F	5430	K	605	O	1620	S	880
C	3350	G	1504.2	L	85	P	740	T	1480
D	1790	H		M	385	Q	445	U	410

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1166	1102	
M_2	816	898	
M_T	1982	2000	

Figure 12. Vehicle properties for test 404311-5.

Table 2. Exterior crush measurements for test 404311-5.

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		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	Front bumper	1060	570	580	570	450	330	220	10	20	-290
2	810 mm above ground	1060	340	1170	100	150	210	290	340	340	+1480

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

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

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

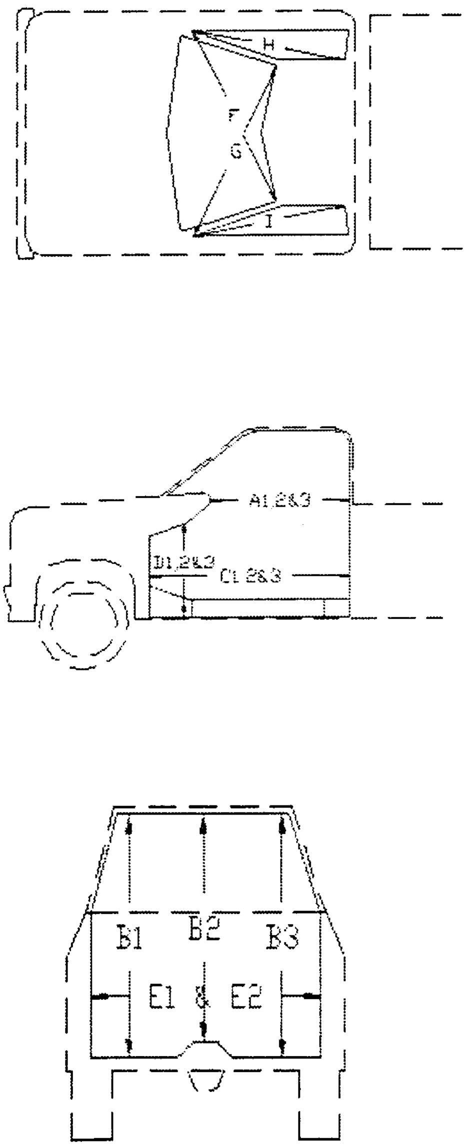
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***Measure and document on the vehicle diagram the location of the maximum crush.
Note: Use as many lines/columns as necessary to describe each damage profile.

Table 3. Occupant compartment measurements for test 404311-5.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1040	1036
A2	1084	1091
A3	1045	1051
B1	1075	1060
B2	1065	935
B3	1082	1073
C1	1385	1341
C2	1262	1245
C3	1372	1372
D1	309	370
D2	97	80
D3	310	316
E1	1597	1605
E2	1592	1620
F	1470	1455
G	1470	1460
H	900	900
I	900	880
J	1524	1420

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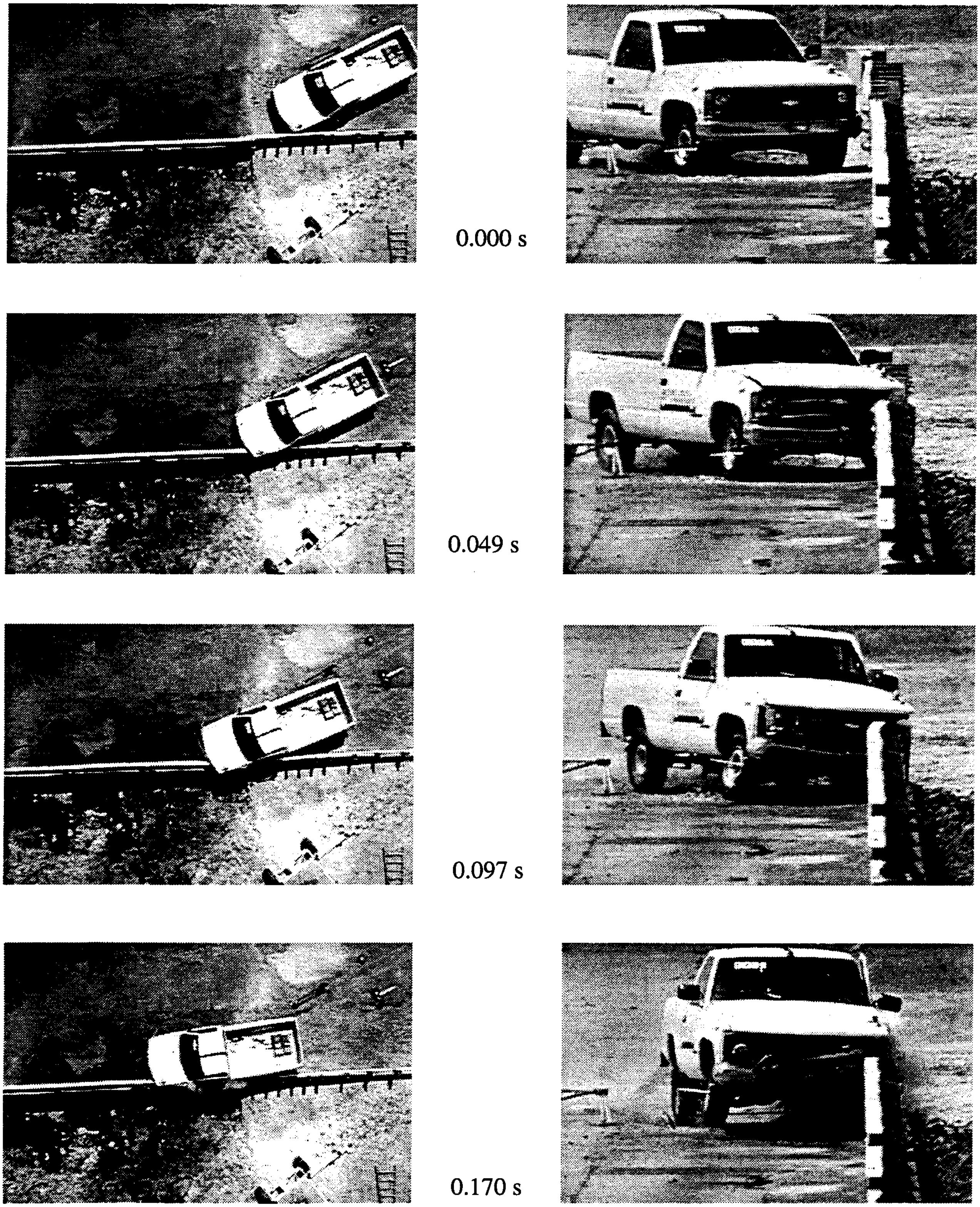
APPENDIX C. SEQUENTIAL PHOTOGRAPHS



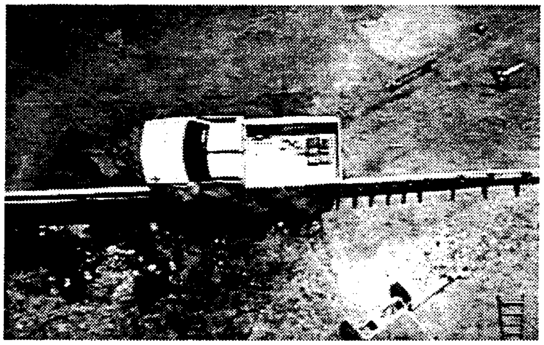
0.000 s

0.049 s

0.097 s

0.170 s

Figure 13. Sequential photographs for test 404311-5
(overhead and frontal views).



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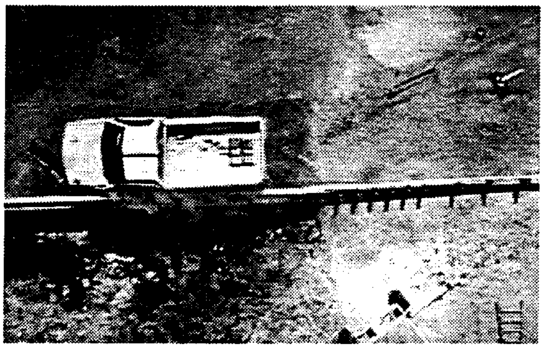

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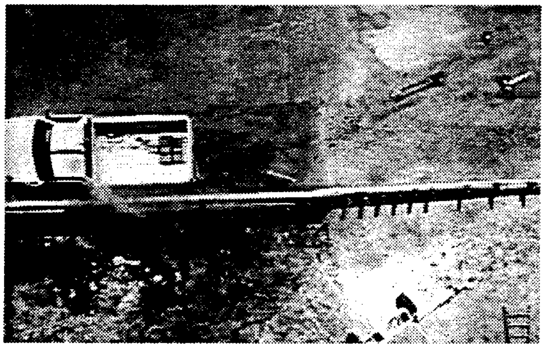

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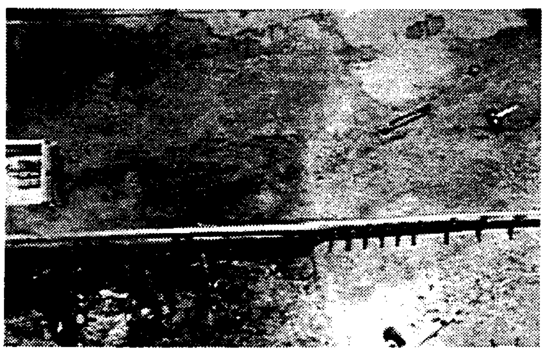

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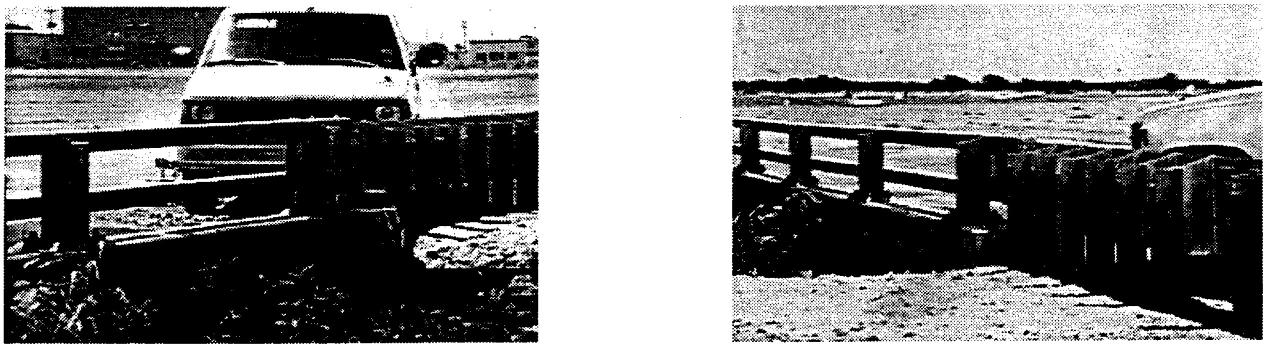
Figure 13. Sequential photographs for test 404311-5 (overhead and frontal views) (continued).



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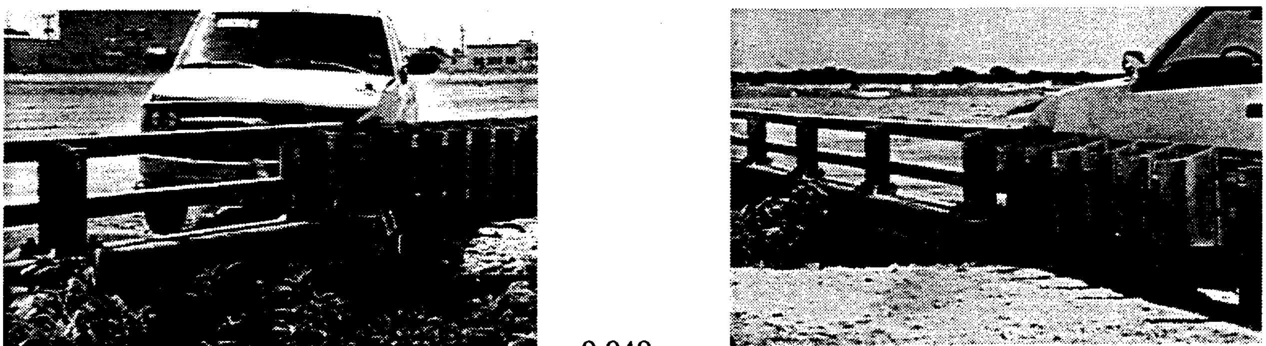

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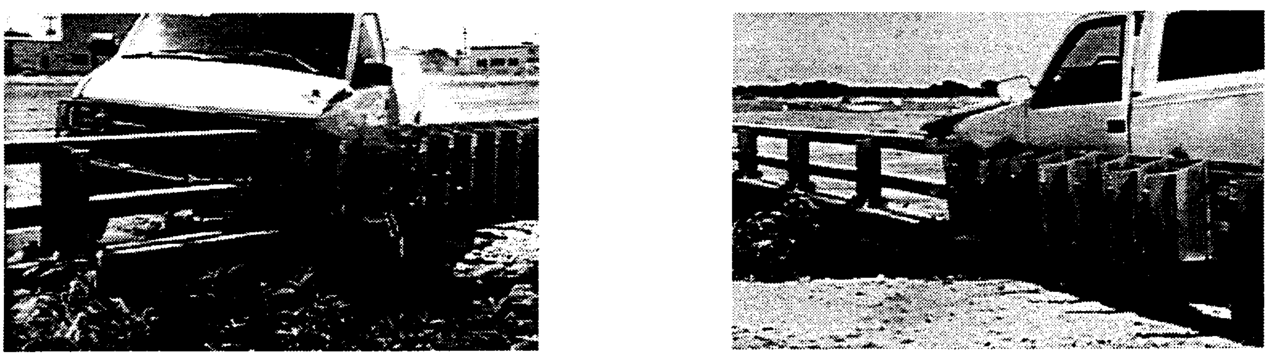

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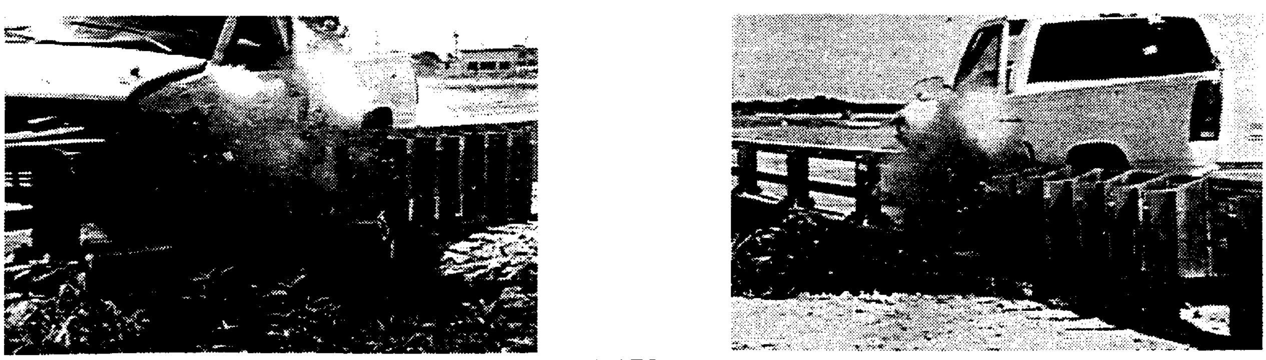

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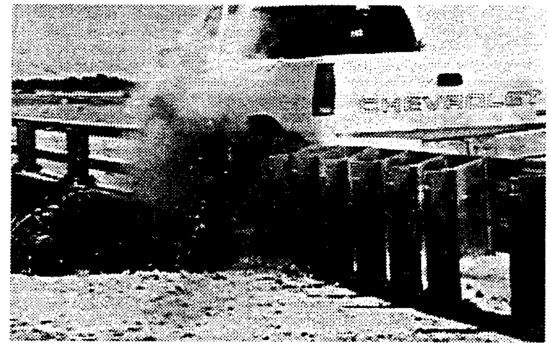
Figure 14. Sequential photographs for test 404311-5 (rear views).

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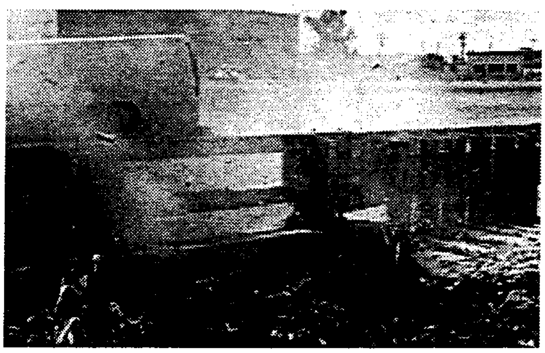
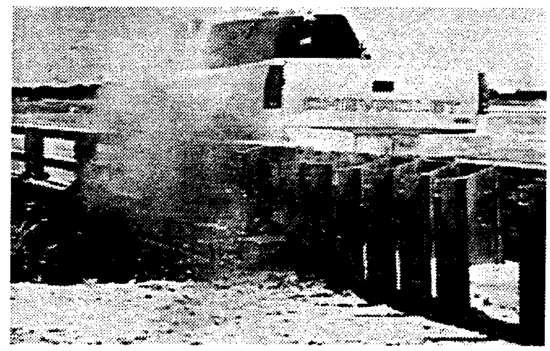

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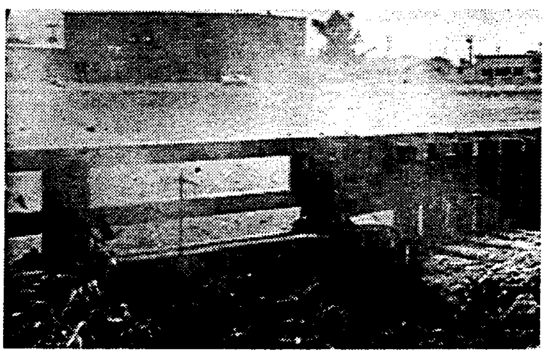
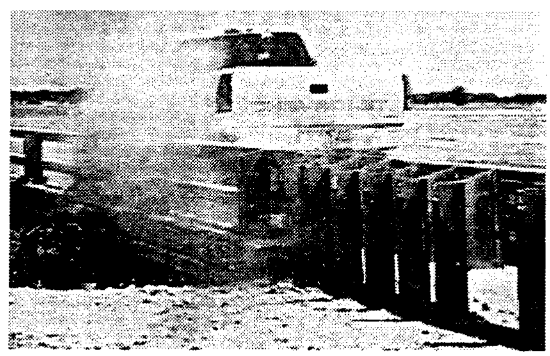

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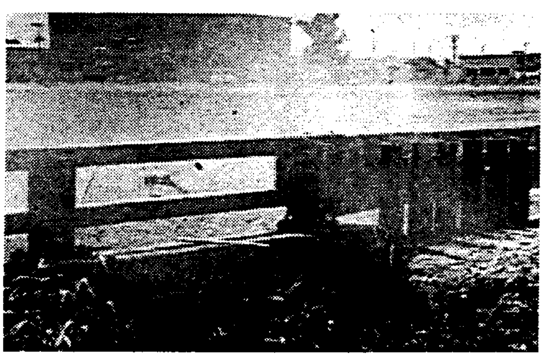
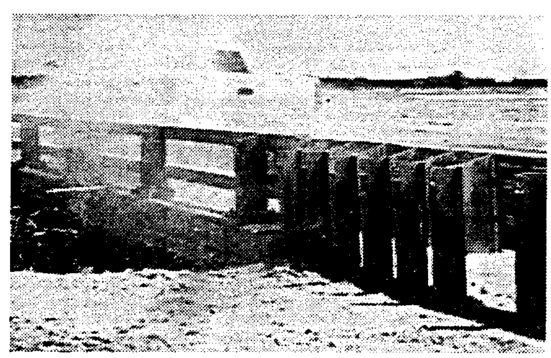

0.680 s

Figure 14. Sequential photographs for test 404311-5
(rear views) (continued).

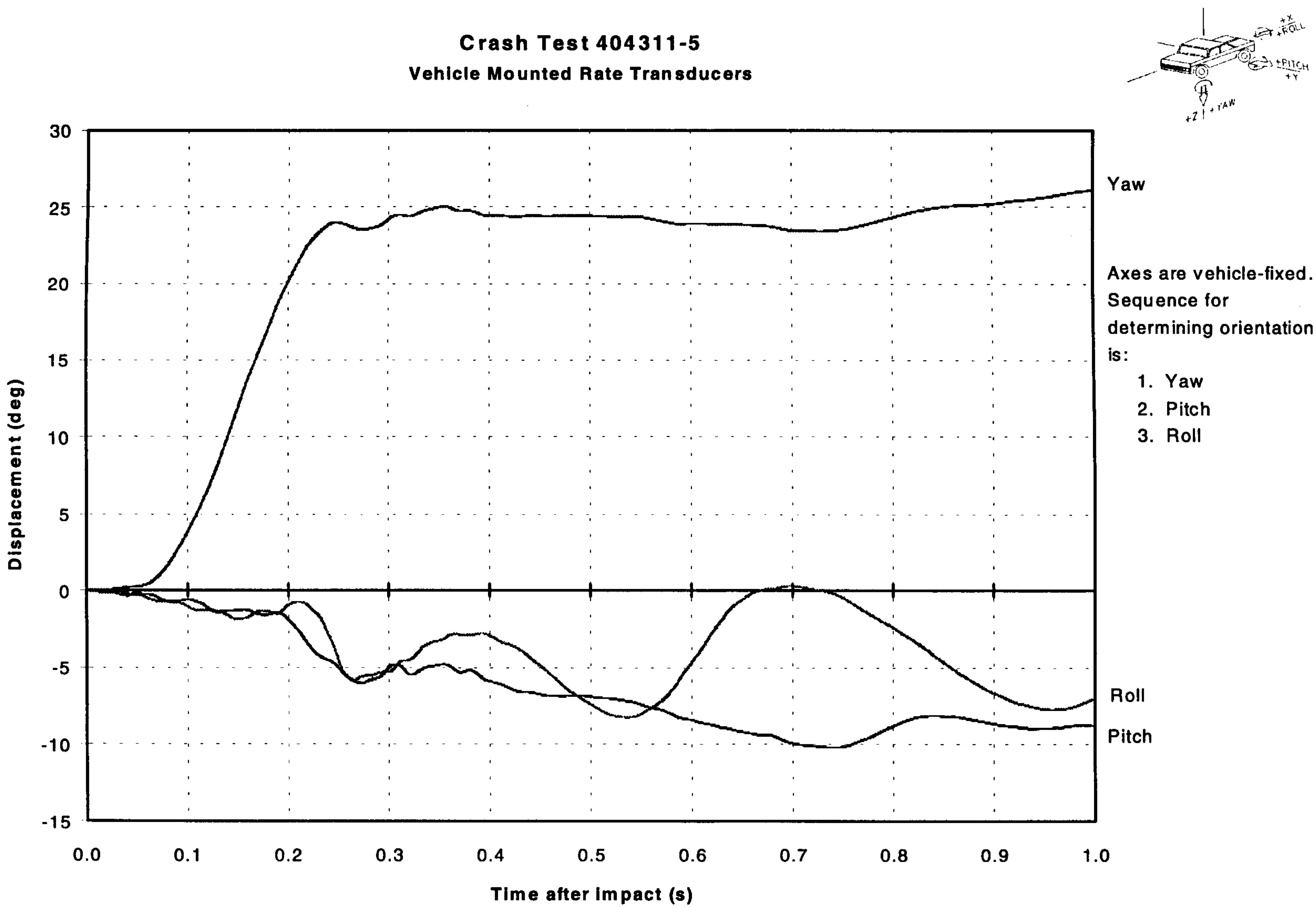

Figure 15. Vehicular angular displacements for test 404311-5.

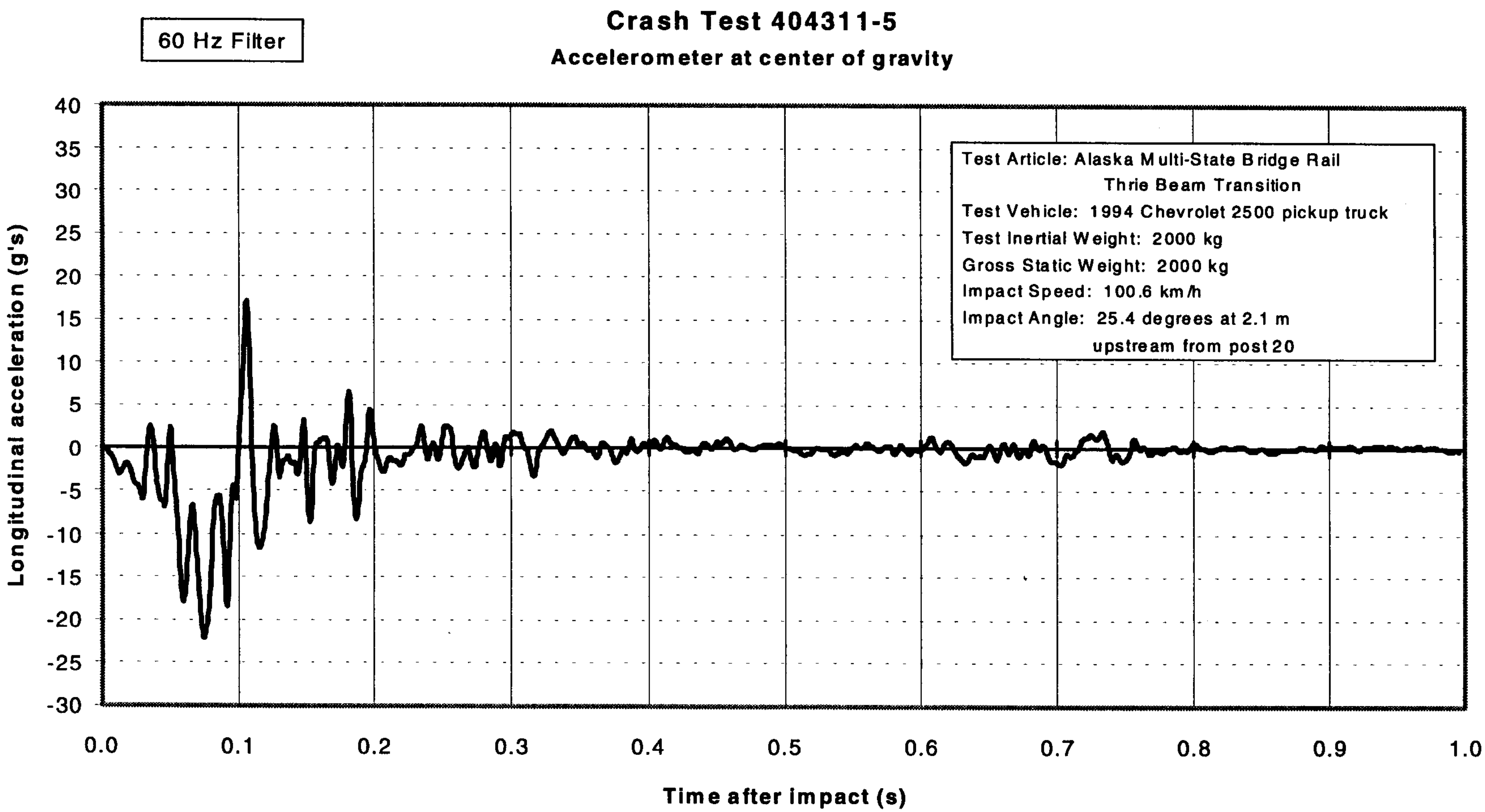

Figure 16. Vehicle longitudinal accelerometer trace for test 404311-5 (accelerometer located at center of gravity).

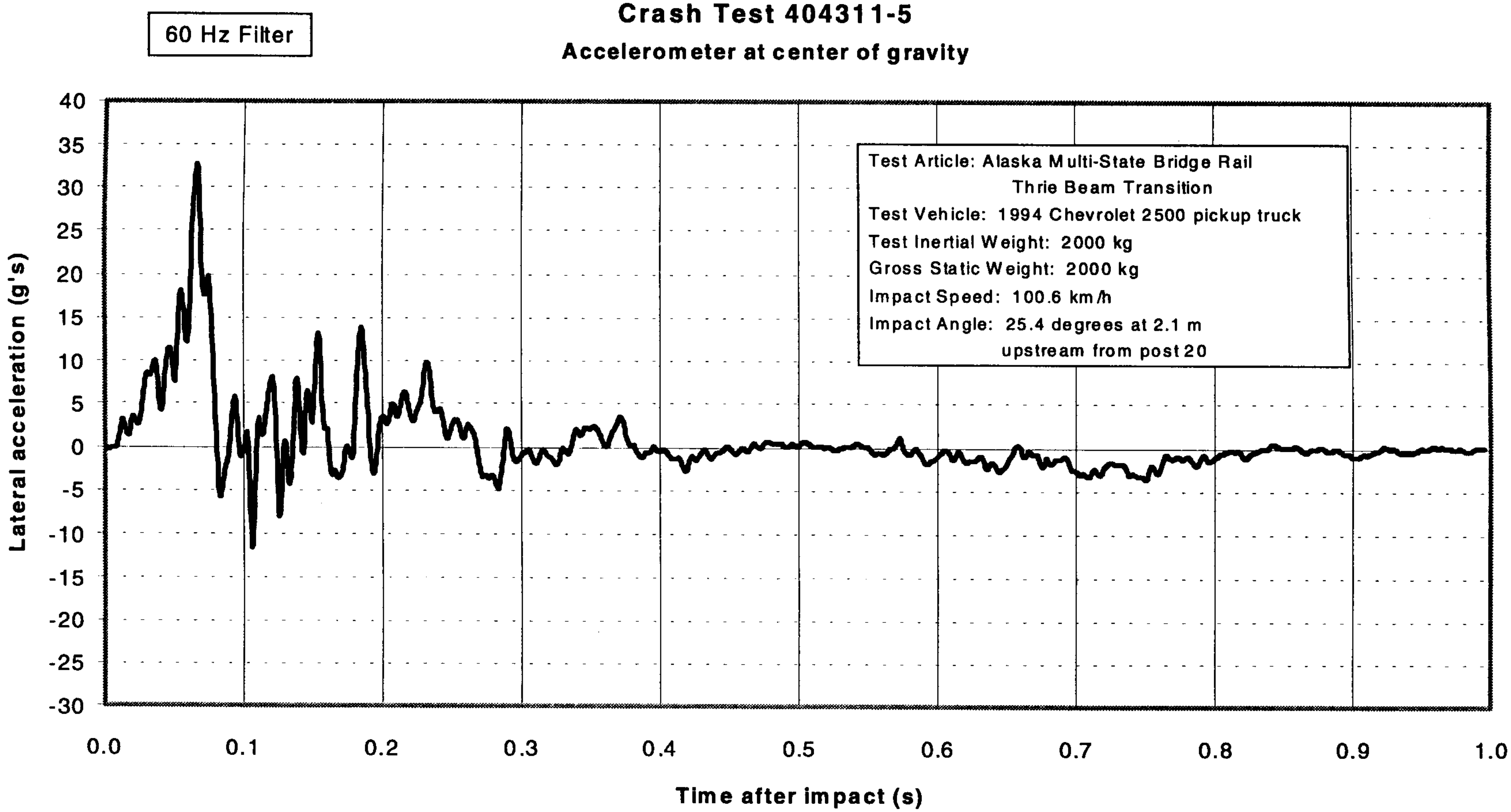

Figure 17. Vehicle lateral accelerometer trace for test 404311-5 (accelerometer located at center of gravity).

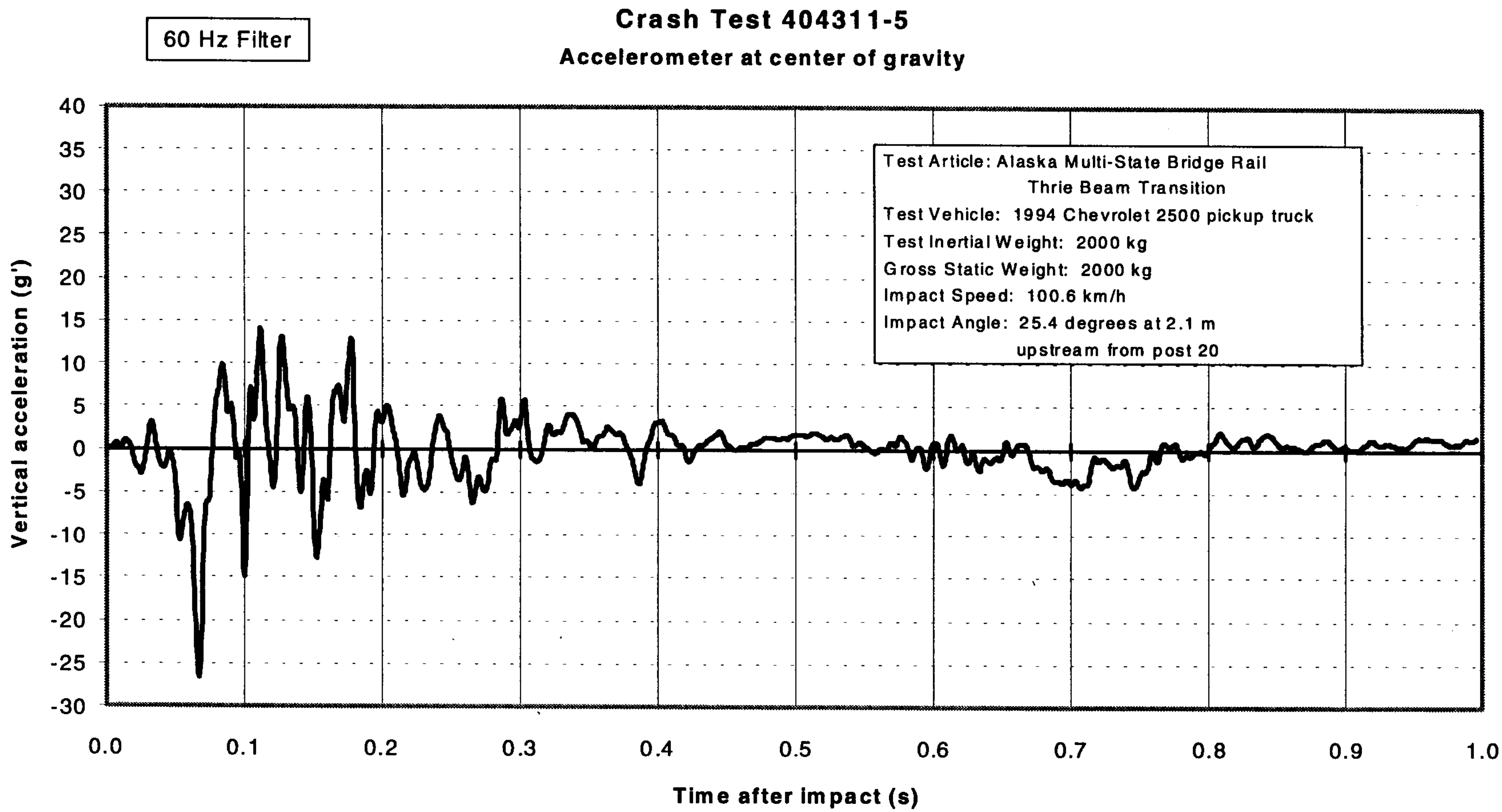

Figure 18. Vehicle vertical accelerometer trace for test 404311-5
(accelerometer located at center of gravity).

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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.