TEXAS TRANSPORTATION INSTITUTE

NCHRP REPORT 350 TEST 4-22 OF THE ALASKA MULTI-STATE BRIDGE RAIL THRIE-BEAM TRANSITION

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COLLEGE STATION, TEXAS

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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 4-22, which is the 8000-kg single-unit truck impacting the critical impact point (CIP) at 80 km/h and 15 degrees. The Alaska Multi-State Bridge Rail Transition met all criteria specified for *NCHRP Report 350* test designation 4-22.

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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)

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INTRODUCTION

PROBLEM

The Federal Highway Administration (FHWA) recently adopted the National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, as the official guidelines for performance evaluation of roadside safety hardware.(1) *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* were the previous guidelines 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 single-unit truck test: *NCHRP Report 350* test designation 4-22, which is the 8000-kg single-unit truck impacting the CIP at 80 km/h and 15 degrees. The Alaska Multi-State Bridge Rail Thrie-Beam Transition met all criteria specified for *NCHRP Report 350* test designation 4-22.

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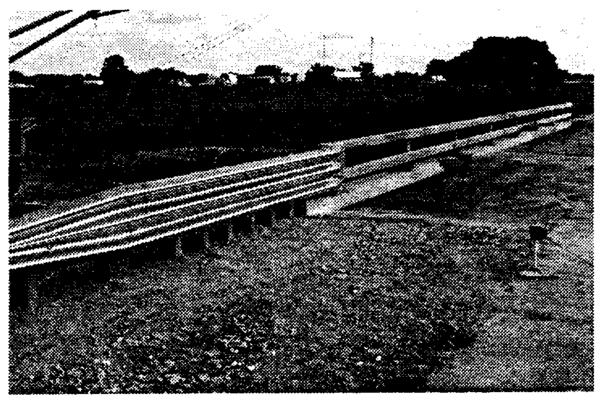
TECHNICAL DISCUSSION

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.

The concrete deck was damaged around the bridge deck post (Post 20) during Test 404311-5. For this test, TTI personnel removed all the broken and loose concrete from the damaged area and reconstructed concrete formwork for the repair. A concrete bonding agent was applied to the concrete surface and the damaged area was reconstructed using concrete with a minimum 28-day compressive strength of 34.5 MPa (5000 psi). After 11 days, (just prior to the test date), the compressive strength of the concrete was 35.1 MPa (5085 psi). The curb at the end of the deck was reconstructed with a 114 mm recess over a horizontal distance of 457 mm as shown on the drawing. Details of the installation are shown in figures 1 and 2, and photographs of the completed installation are shown in figures 3 and 4.

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.

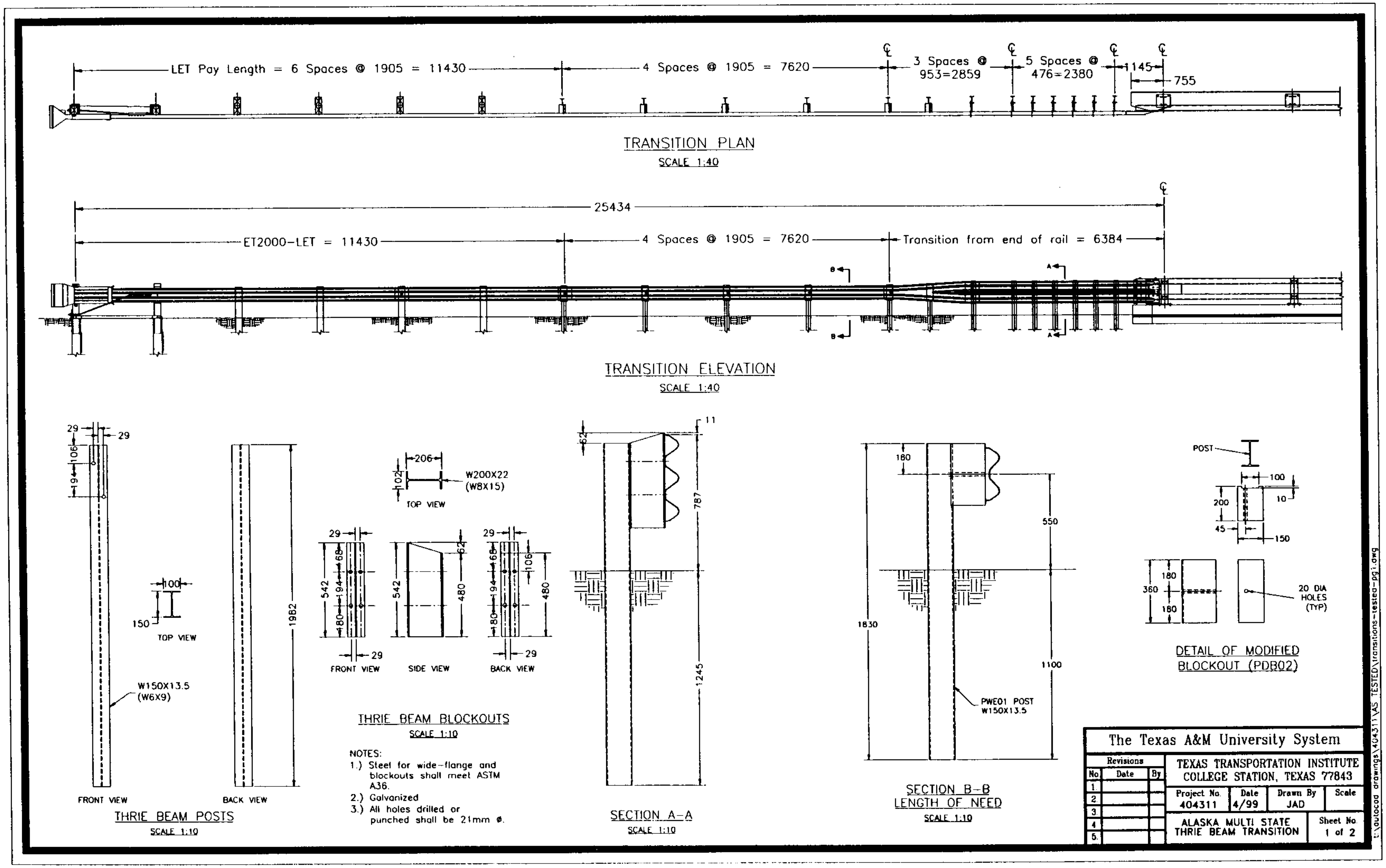


Figure 1. Details of the Alaska Multi-State Bridge Rail Thrie-Beam Transition.

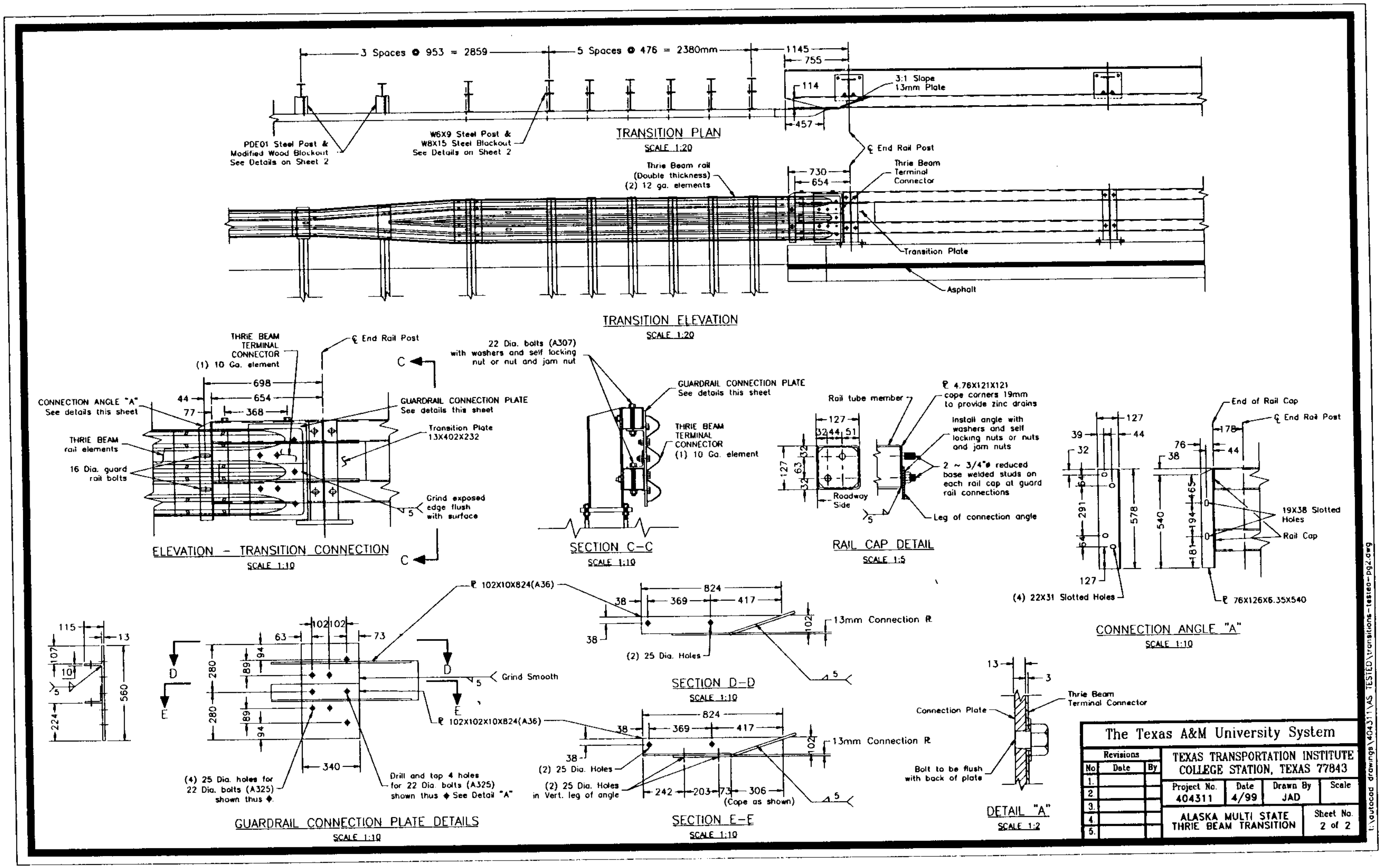


Figure 2. Details of the bridge rail connection of Alaska Multi-State Bridge Rail Thrie-Beam Transition.

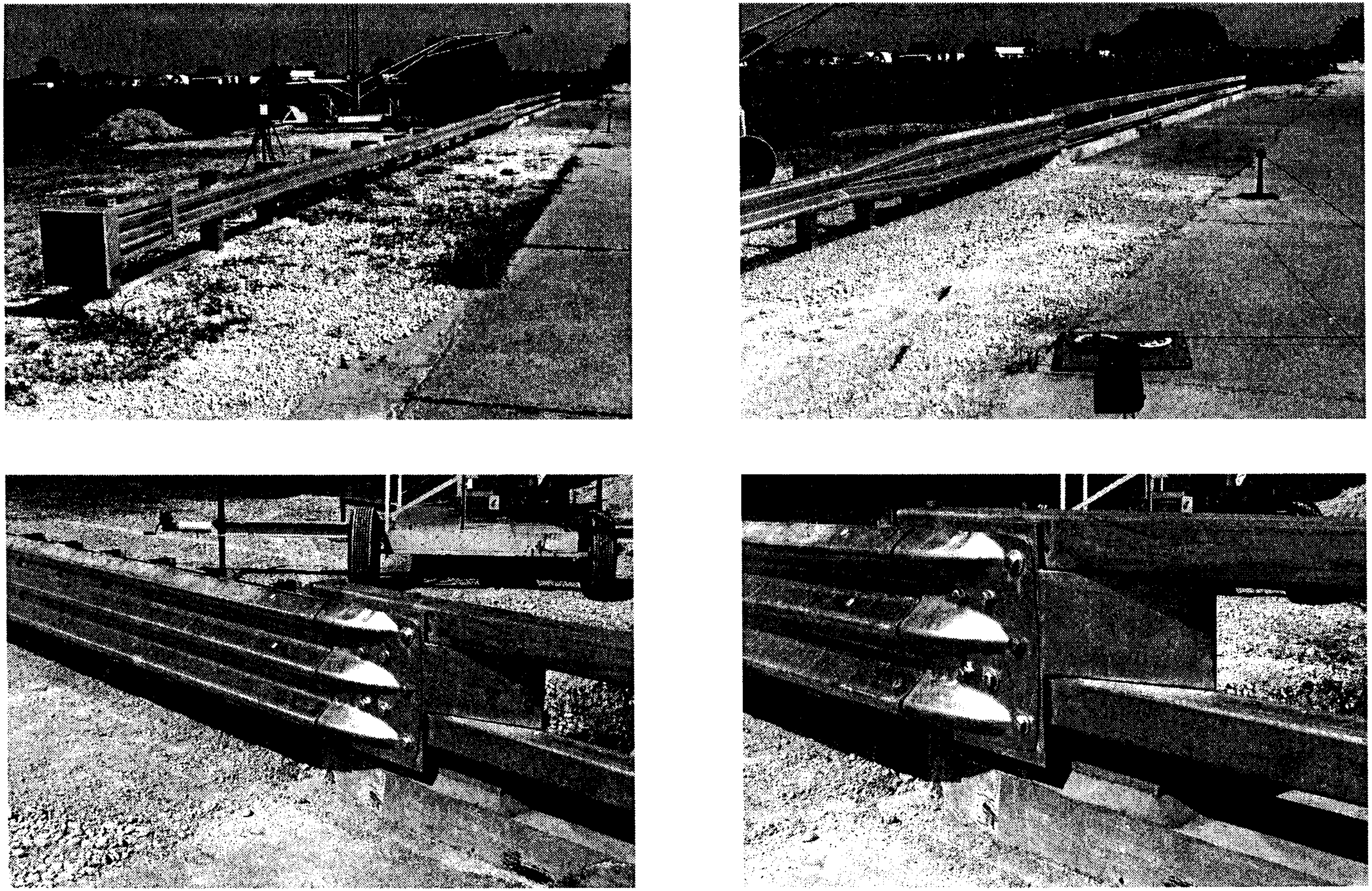


Figure 3. Alaska Multi-State Bridge Rail Thrie-Beam Transition (traffic side) prior to testing.

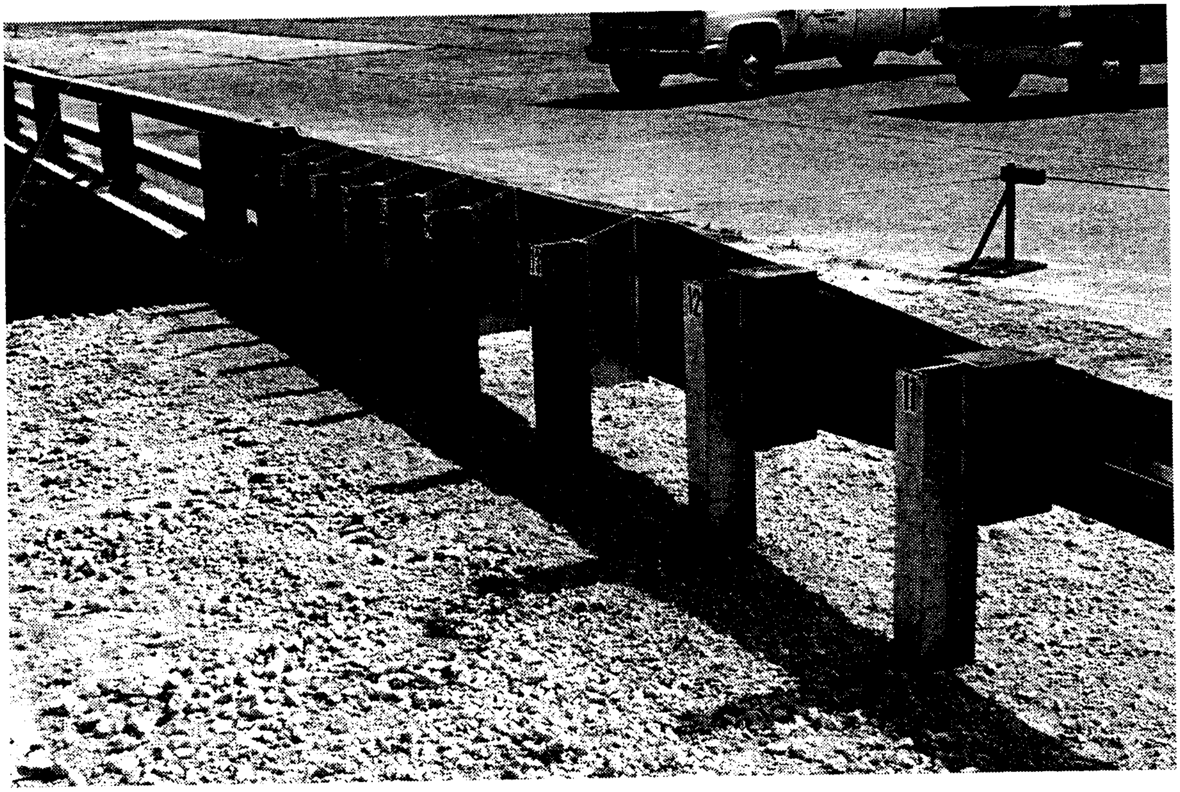


Figure 4. Alaska Multi-State Bridge Rail Thrie-Beam Transition (field side) prior to testing.

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.

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 4-22 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 2.29 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.*

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

- **Vehicle Trajectory**

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

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

CRASH TEST 404311-6 (*NCHRP Report 350* TEST 4-22)

As stated previously, the concrete deck was damaged around the bridge deck post (Post 20) during Test 404311-5. For this test, all the broken and loose concrete was removed from the damaged area and concrete formwork for the repair was constructed. A concrete bonding agent was applied to the concrete surface and the damaged area was repaired using concrete with a minimum 28-day compressive strength of 34.5 MPa (5000 psi). After 11 days, (just prior to the test date), the compressive strength of the concrete was 35.1 MPa (5085 psi). The curb at the end of the deck was reconstructed with a 114 mm recess over a horizontal distance of 457 mm as shown on the drawing. Details of the installation are shown in figures 1 and 2, and photographs of the completed installation are shown in figures 3 and 4.

Test Vehicle

A 1986 Ford F700 single-unit truck, shown in figures 5 and 6, was used for the crash test. Test inertia weight of the vehicle was 8000 kg, and its gross static weight was 8000 kg. The height to the lower edge of the vehicle front bumper was 450 mm and to the upper edge of the front bumper was 754 mm. Additional dimensions and information on the vehicle are given in appendix B, 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 June 16, 1999. Seven days prior to the test 30 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 7.8 percent, 8.7 percent, and 7.8 percent at posts 14, 17, and 19, respectively. Weather conditions at the time of testing were as follows: Wind Speed: 8 km/h; Temperature: 29°C; Relative Humidity: 53 percent.

Impact Description

The 8000S vehicle, while traveling at a speed of 80.2 km/h, impacted the transition at 2.1 m upstream of post 20 (the first bridge rail post) at an angle of 14.6 degrees. At 0.027 s after impact, posts 15 through 17 moved and at 0.029 s posts 18 and 19 moved. Post 14 moved at 0.032 s and the left front tire of the vehicle lost contact with the ground at 0.041 s. At 0.063 s post 20 moved and at 0.064 s the right front tire steered away from the installation. The left front tire returned to the ground at 0.104 s. At 0.108 s the bridge deck around post 20 cracked. The right front tire lost contact with the ground at 0.143 s and the left rear tire contacted the rail at 0.295 s. At0.336 s the vehicle was traveling parallel with the installation at a speed of 72.8 km/h. The left rear tire deflated at 0.371 s and the right rear tires lost contact with the ground at 0.377 s.

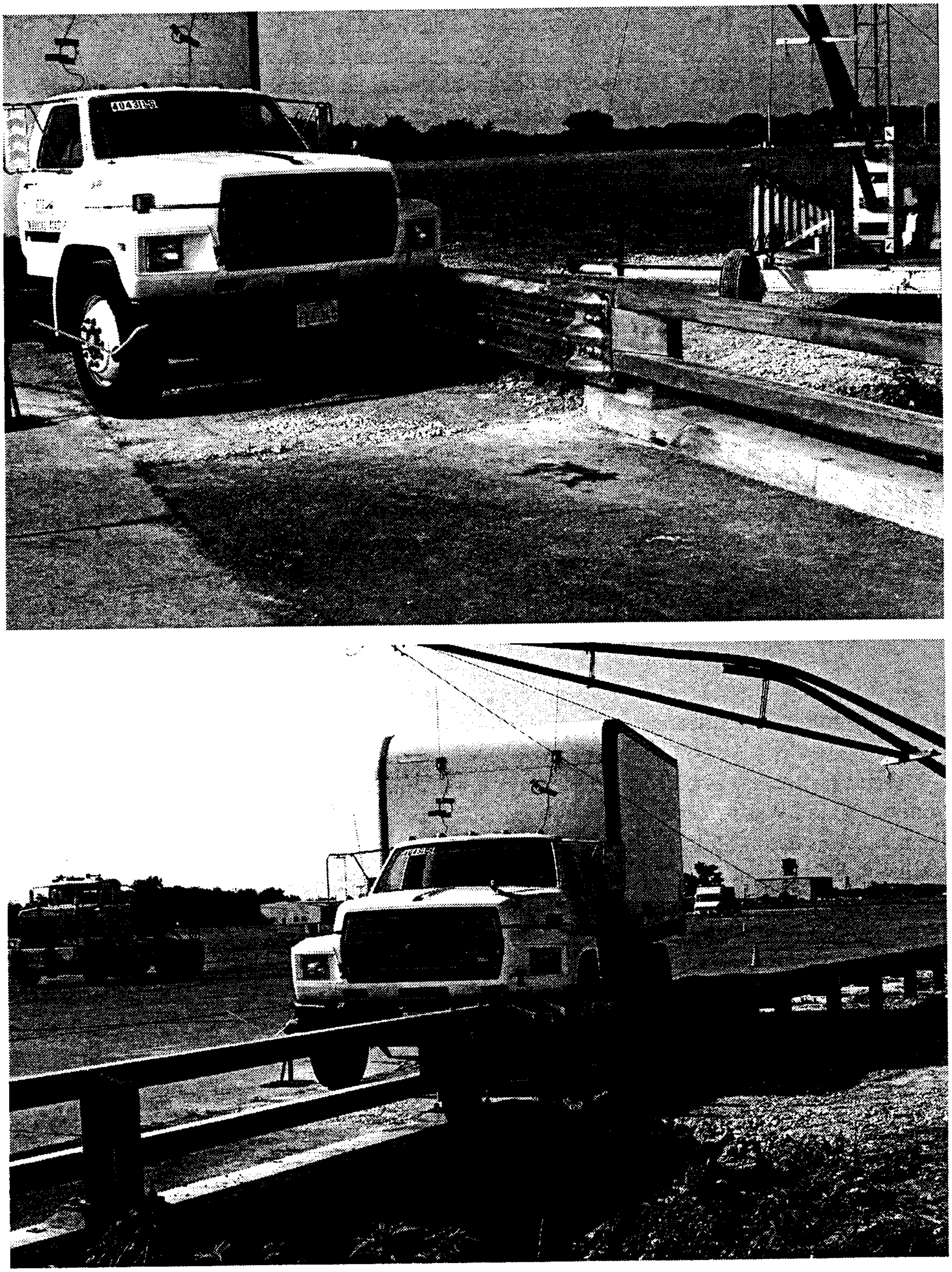


Figure 5. Vehicle/installation geometrics for test 404311-6.

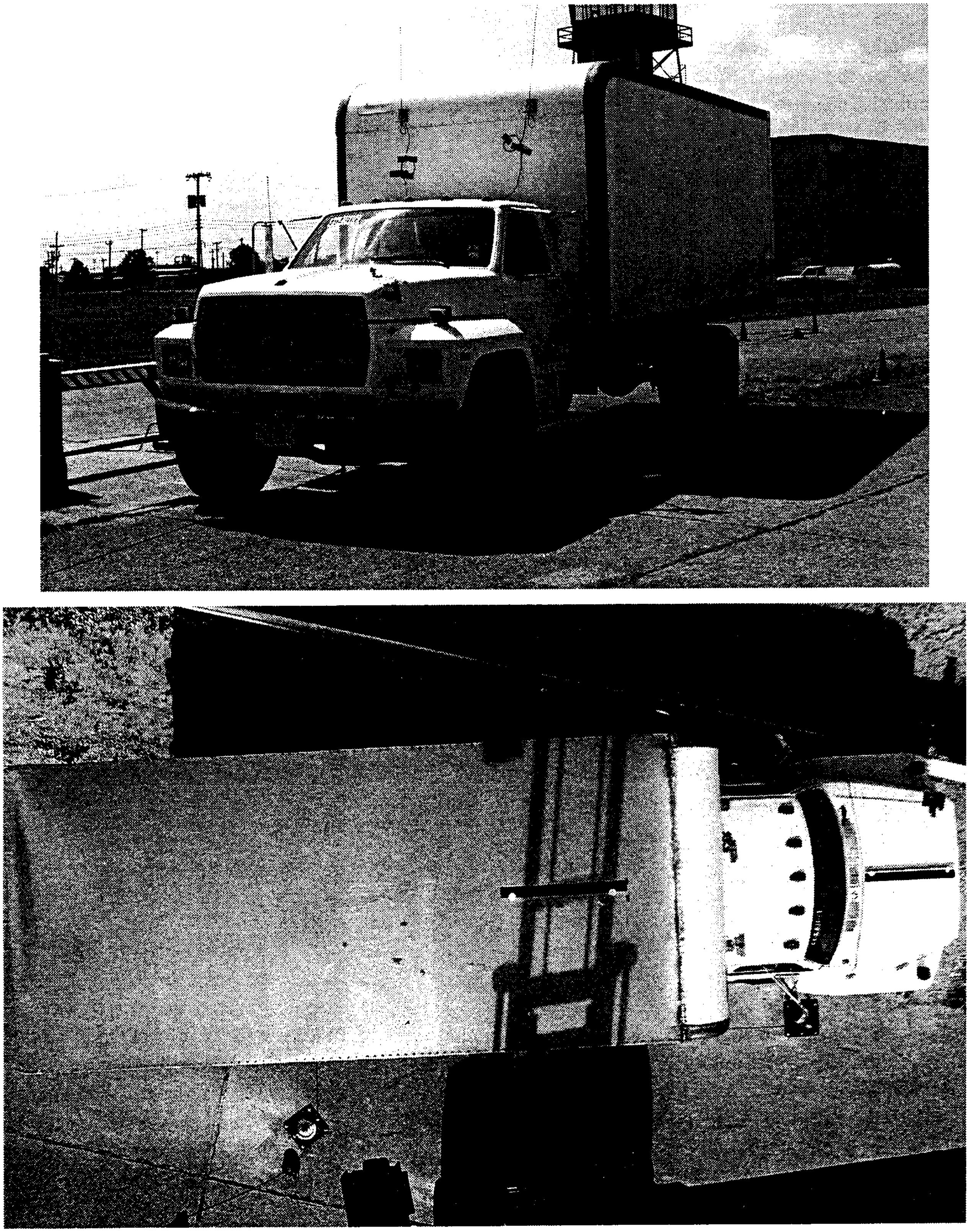


Figure 6. Vehicle before test 404311-6.

The right front tire returned to the ground at 0.491 s. At 0.816 s the vehicle lost contact with the installation and was traveling at a speed of 65.4 km/h and exit angle of approximately 1 degree. Brakes on the vehicle were applied at 4.0 s after impact. The vehicle bounced slightly from side to side and subsequently came to rest upright 73.2 m down from impact and 6.1 m towards the field side of the installation. Sequential photographs of the test period are shown in appendix C, figures 13 and 14.

Damage to Test Article

Minimal damage was sustained by the transition as shown in figures 7 and 8. However, structural damage was imparted to the bridge deck around post 20 (the first bridge rail post). Post 1 through post 14 were disturbed, post 15 moved back 5 mm and post 16 moved back 9 mm. Post 17 was pushed back 22 mm, post 18 was pushed back 44 mm and post 19 was pushed back 42 mm. The end of the curb at the edge of the bridge deck was cracked and pushed back 2 mm. The vehicle was in contact with the transition and bridge rail for a total of 5.0 m. Maximum dynamic deflection of the rail during the test was 77 mm and maximum permanent deformation of the rail was 49 mm.

Vehicle Damage

Damage to the vehicle is shown in figure 9. The left side of the front axle was separated from the vehicle and the left side spring, U-bolts, shock, rod ends and steering arm were damaged. The front bumper, grill, left front quarter panel, and left side door were deformed. The left front tire and wheel rim and the left rear outside tire and wheel rim were damaged. The lower edge of the box van was damaged and the floor pan on the left side was deformed slightly. Photographs of the interior of the vehicle are shown in figure 10.

Occupant Risk Factors

Occupant risk factors are not required for *NCHRP Report 350* test designation 4-22; however, for information purposes only, data from the tri-axial accelerometer, located at the vehicle center of gravity, were digitized to compute occupant impact velocity and ridedown accelerations. In the longitudinal direction, occupant impact velocity was 3.2 m/s at 0.359 s, maximum 0.010-s ridedown acceleration was -2.4 g's from 0.358 to 0.368 s, and the maximum 0.050-s average was -2.0 g's between 0.039 and 0.089 s. In the lateral direction, the occupant impact velocity was -3.4 m/s at 0.231 s, the highest 0.010-s occupant ridedown acceleration was 3.8 g's from 0.332 to 0.342 s, and the maximum 0.050-s average was 3.0's between 0.098 and 0.148 s. These data and other information pertinent to the test are presented in figure 10. Vehicle angular displacements and accelerations versus time traces are shown in appendix D, figures 15 through 22.

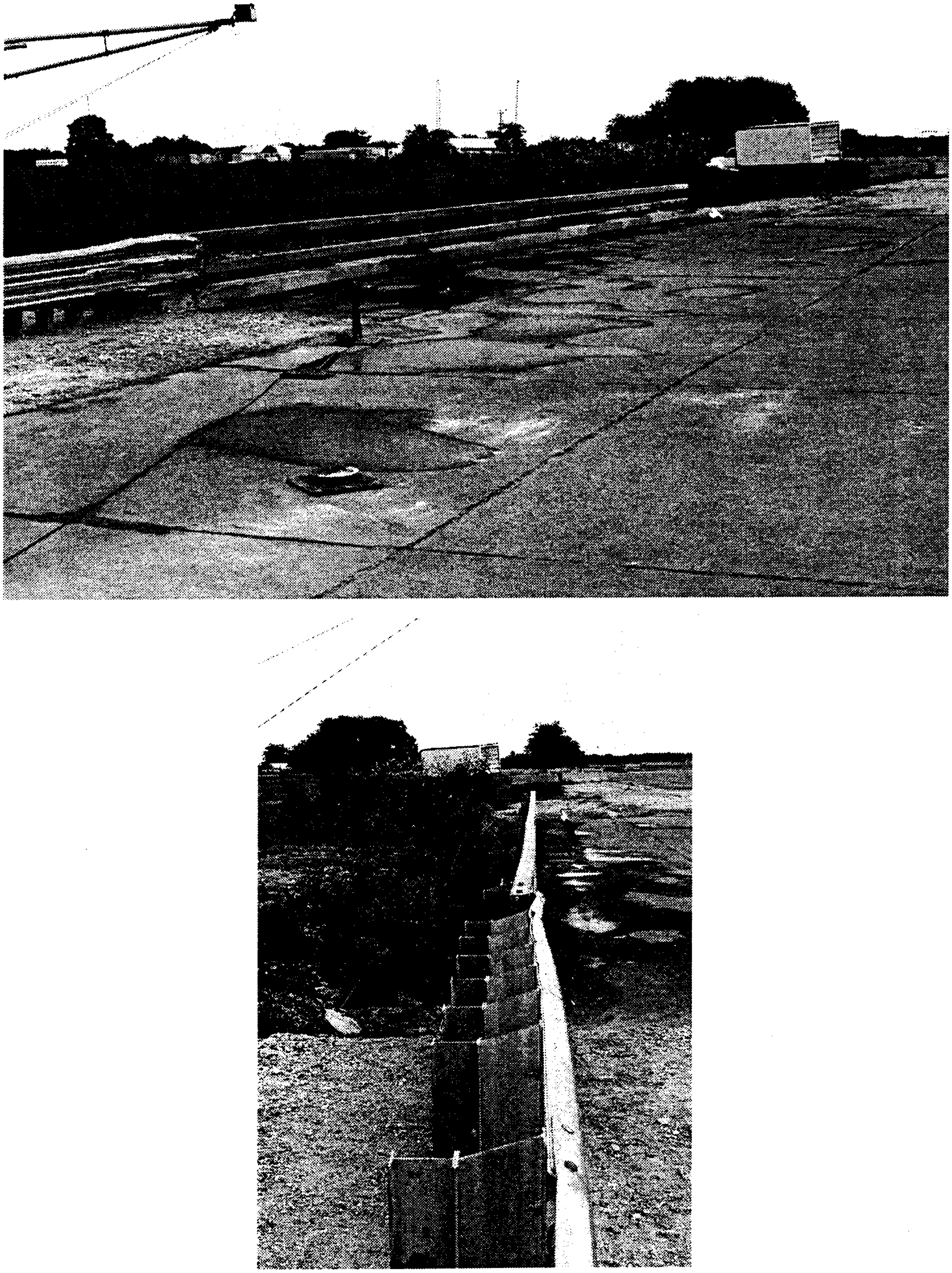


Figure 7. Vehicle trajectory path after test 404311-6.

Figure 8. Installation after test 404311-6.

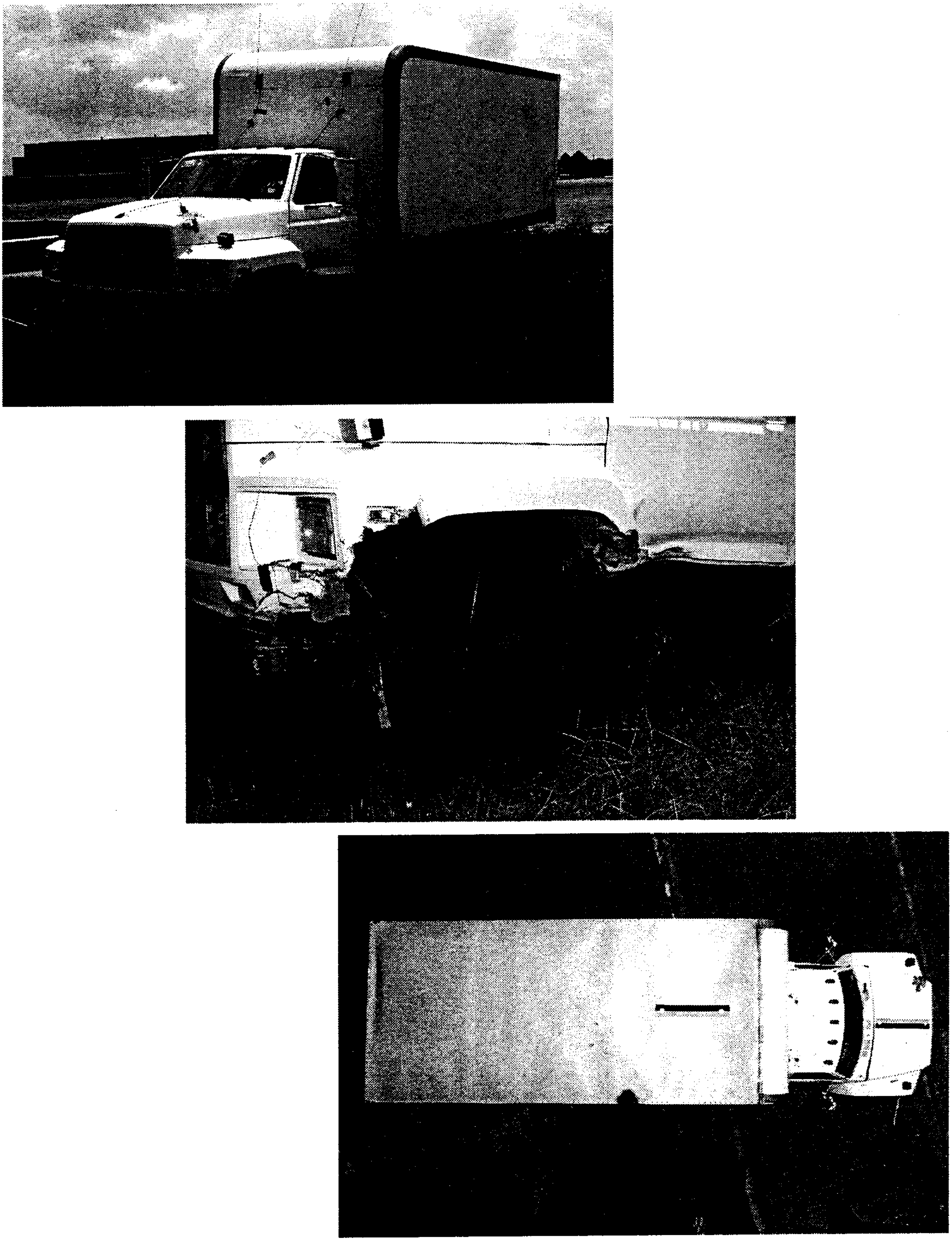
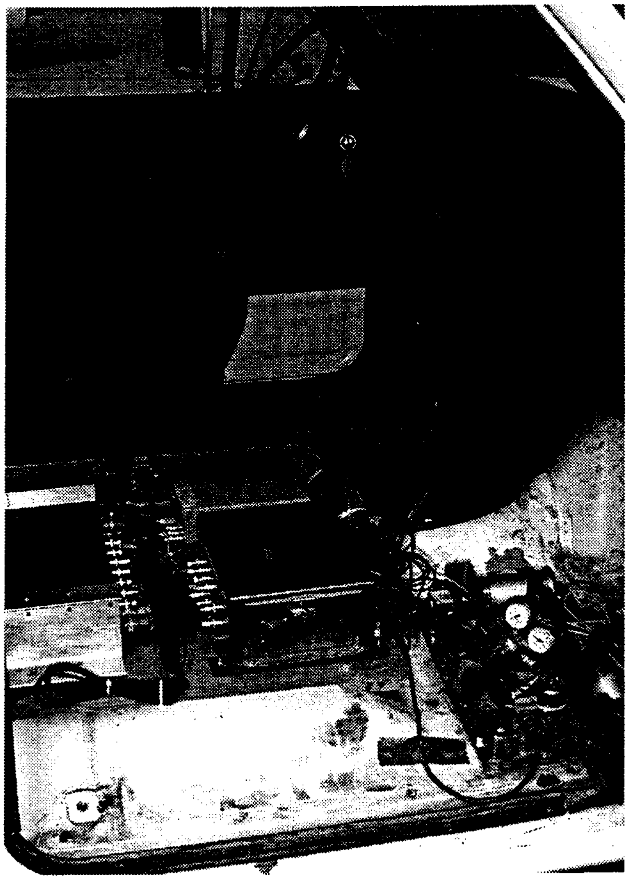


Figure 9. Vehicle after test 404311-6.



Before test

After test

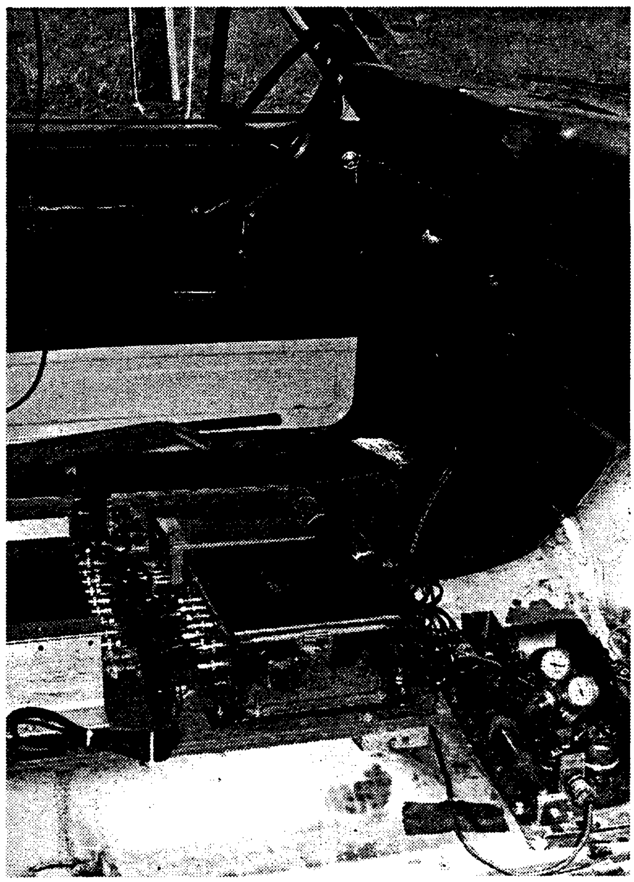
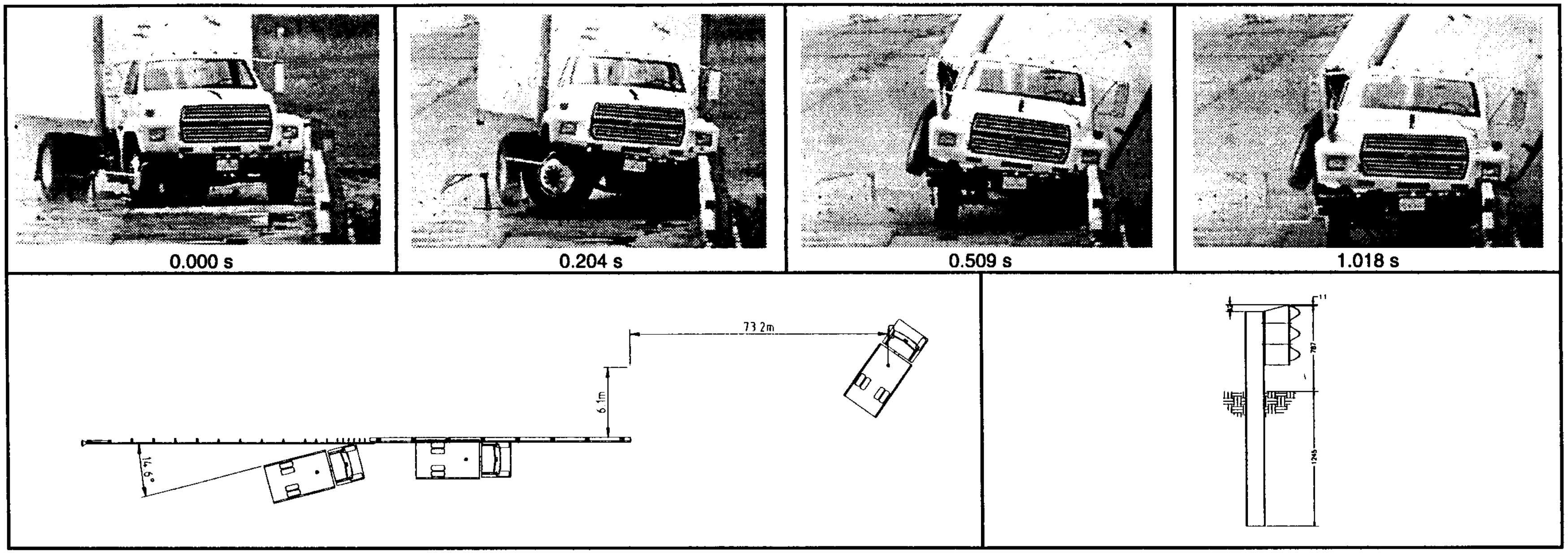


Figure 10. Interior of vehicle for test 404311-6.



General Information	
Test Agency	Texas Transportation Institute
Test No.	404311-6
Date	06/16/99
Test Article	
Type	Transition
Name or Manufacturer	Alaska Multi-State Thrie Beam Transition
	25.4
Installation Length (m)	Thrie Beam Attached to Alaska Multi-State
Material or Key Elements	Bridge Rail Transition
	Standard Soil, Dry
Soil Type and Condition	
Test Vehicle	Production
Type	8000S
Designation	1986 Ford F700 single-unit truck
Model	
Mass (kg)	5135
Curb	8000
Test Inertial	No dummy
Dummy	8000
Gross Static	

Impact Conditions	
Speed (km/h)	49.9
Angle (deg)	14.6
Exit Conditions	
Speed (km/h)	65.4
Angle (deg)	approx. 1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.2
y-direction	-3.4
THIV (km/h)	13.8
Ridedown Accelerations (g's)	
x-direction	-2.4
y-direction	3.8
PHD (g's)	4.0
ASI	0.34
Max. 0.050-s Average (g's)	
x-direction	-2.0
y-direction	3.0
z-direction	-1.9

Test Article Deflections (m)	
Dynamic	0.077
Permanent	0.049
Vehicle Damage	
Exterior	
VDS	N/A
CDC	N/A
Maximum Exterior	
Vehicle Crush (mm)	N/A
Interior	
OCDI	FS0000000
Max. Occ. Compart.	
Deformation (mm)	N/A
Post-Impact Behavior	
(during 1.0 s after impact)	
Max. Yaw Angle (deg)	16
Max. Pitch Angle (deg)	-5
Max. Roll Angle (deg)	-10

Figure 11. Summary of results for test 404311-6, *NCHRP Report 350* test 4-22.

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 Transition contained and redirected the 8000S vehicle. The vehicle did not penetrate, underride, or override the installation, however, structural damage did occur to the bridge deck. Maximum dynamic deflection of the rail was 77 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. Deformation of the occupant compartment was minimal, but not measurable.

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

  The 8000S 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 8000S vehicle did 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.*

Exit angle at loss of contact was not attainable from the overhead camera. However, estimating from tire marks at the test site, the exit angle was approximately 1 degree which was less that 60 percent of the impact angle.

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SUMMARY AND CONCLUSIONS

SUMMARY OF FINDINGS

The Alaska Multi-State Bridge Rail Transition contained and redirected the 8000S vehicle. The vehicle did not penetrate, underride, or override the installation, however, structural damage did occur to the bridge deck. Maximum dynamic deflection of the rail was 77 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. Deformation of the occupant compartment was minimal, but not measurable. The 8000S vehicle remained upright during and after the collision period. The 8000S vehicle did not intrude into adjacent traffic lanes. Exit angle at loss of contact was not attainable from the overhead camera. However, estimating from tire marks at the test site, the exit angle was approximately 1 degree which was less that 60 percent of the impact angle.

CONCLUSIONS

As shown in table 1, the Alaska Multi-State Bridge Rail Thrie-Beam Transition met all criteria specified for *NCHRP Report 350* test designation 4-22.

Table 1. Performance evaluation summary for test 404311-6, *NCHRP Report 350* test 4-22.

Test Agency: Texas Transportation Institute | Test No.: 404311-6 | Test Date: 06/16/99

NCHRP Report 350 **Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Alaska Multi-State Bridge Rail Transition contained and redirected the 8000S vehicle. The vehicle did not penetrate, underride, or override the installation, however, structural damage did occur to the bridge deck. Maximum dynamic deflection of the rail was 77 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, nor to present undue hazard to others in the area. Deformation of the occupant compartment was minimal, but not measurable.	Pass
G. It is preferable, although not essential, that the vehicle should remain upright during and after collision.	The 8000S 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 8000S vehicle did not intrude into adjacent traffic lanes.	Pass*
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Exit angle at loss of contact was not attainable from the overhead camera. However, estimating from tire marks at the test site, the exit angle was approximately 1 degree which was less that 60 percent of the impact angle.	Pass*

*Criterion G, 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 biaxial accelerometer in the cab of the truck and over the rear axle of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO Model 2262CA, piezoresistive accelerometers with a ±100 g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Rate of turn transducers are solid state, gas flow units designed for high g service. Signal conditioners and amplifiers in the test vehicle increase the low level signals to a ±2.5 volt maximum level. The signal conditioners also provides the capability of an R-Cal or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15 channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals, from the test vehicle, are recorded minutes before the test and also immediately afterwards. A crystal controlled time reference signal is simultaneously recorded with the data. Pressure sensitive switches on the bumper of the impacting vehicle are actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an "event" mark on the data record to establish the exact instant of contact with the installation.

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

All accelerometers are calibrated annually according to SAE J211 *4.6.1* by means of a ENDEVCO 2901, precision primary vibration standard. This device along with its support instruments is returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations will be made at any time a data channel is suspected of any anomalies.

The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are provided as follows.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers were then filtered with a 60 Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions were plotted using a commercially available software package (Excel).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0005-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

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

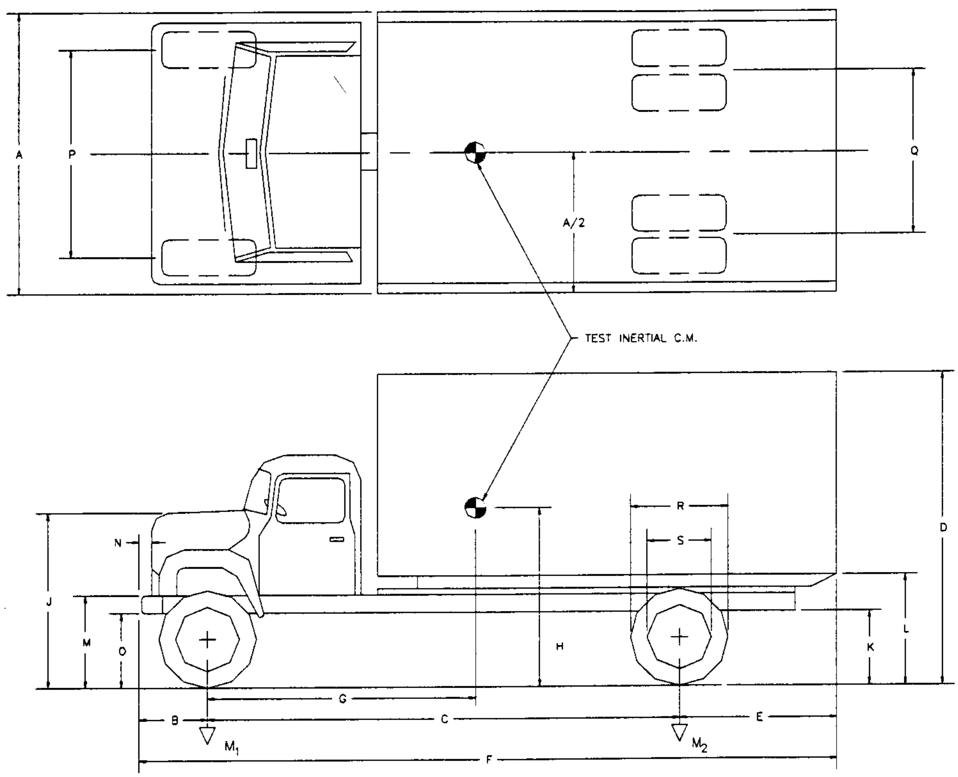
DATE: 6-16-99 TEST NO.: 404311-6 VIN NO.: 1FDNF70H9GVA45482

YEAR: 1986 MAKE: FORD ODOMETER: 174149 TIRE SIZE: 11R22.5

MODEL: 6000

MASS DISTRIBUTION (kg) LF 1683 RF 1637 LR 2227 RR 2453

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



GEOMETRY-(mm)

A 2380	D 3435	G 3068.3	K 765	N 50	Q 1840
B 813	E 2240	H 1235	L 1270	O 450	R 1040
C 5245	F 8298	J 1520	M 754	P 2000	S 590

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	2309	3320	
M_2	2726	4680	
M_T	5135	8000	

Figure 12. Vehicle properties for test 404311-6.

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APPENDIX C. SEQUENTIAL PHOTOGRAPHS

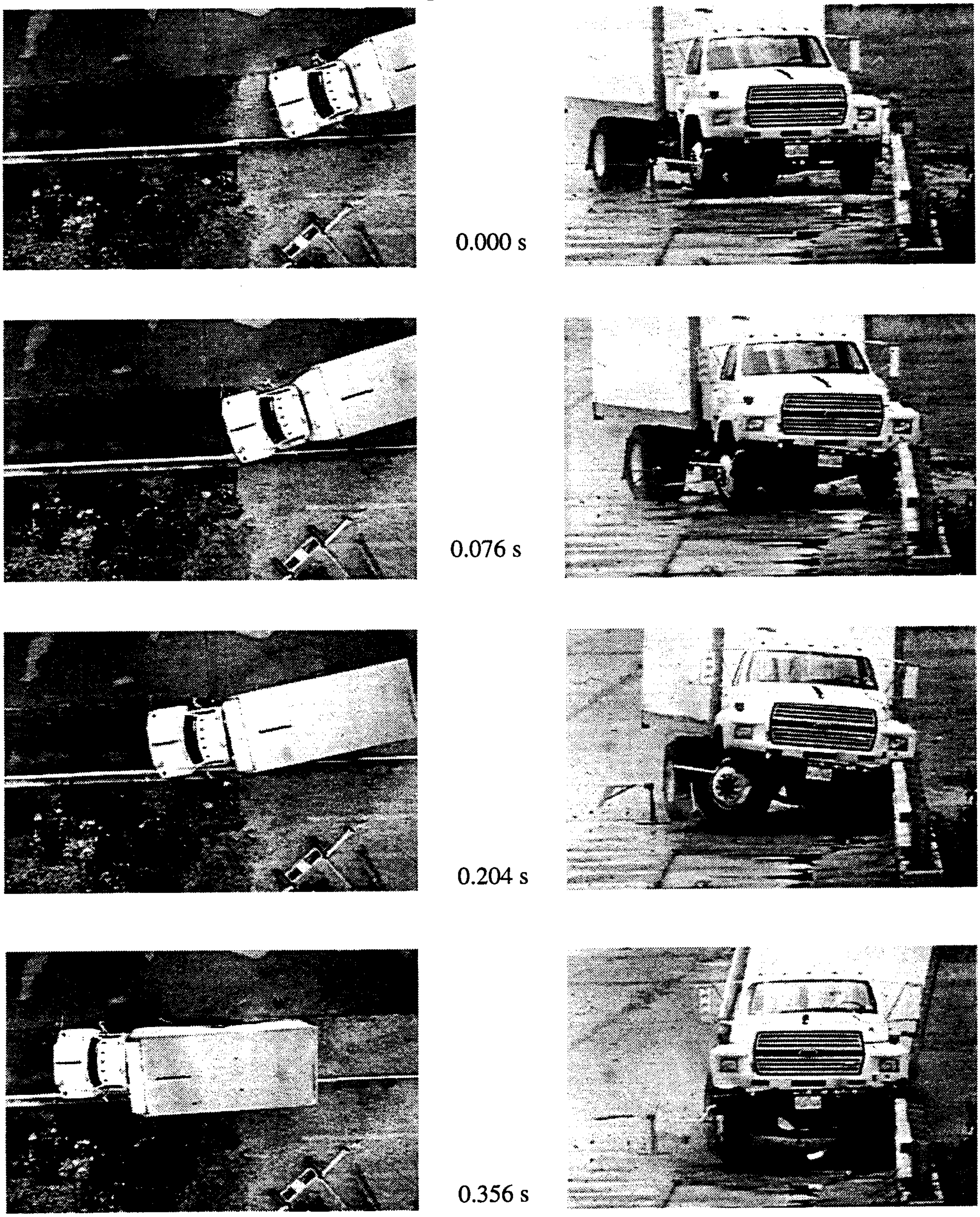
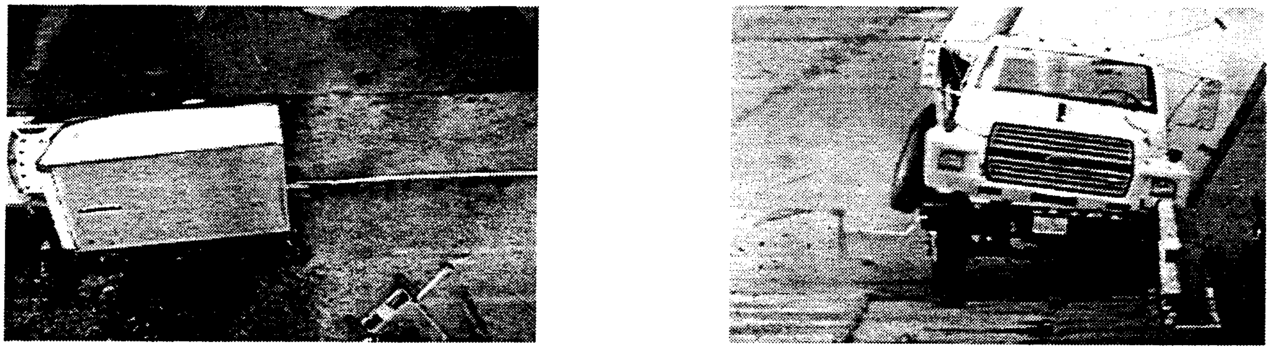


Figure 13. Sequential photographs for test 404311-6
(overhead and frontal views).



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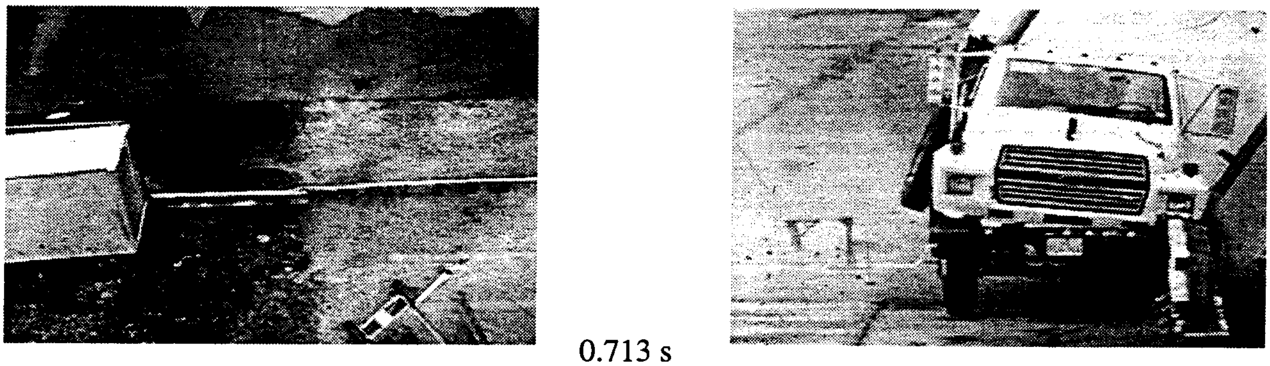
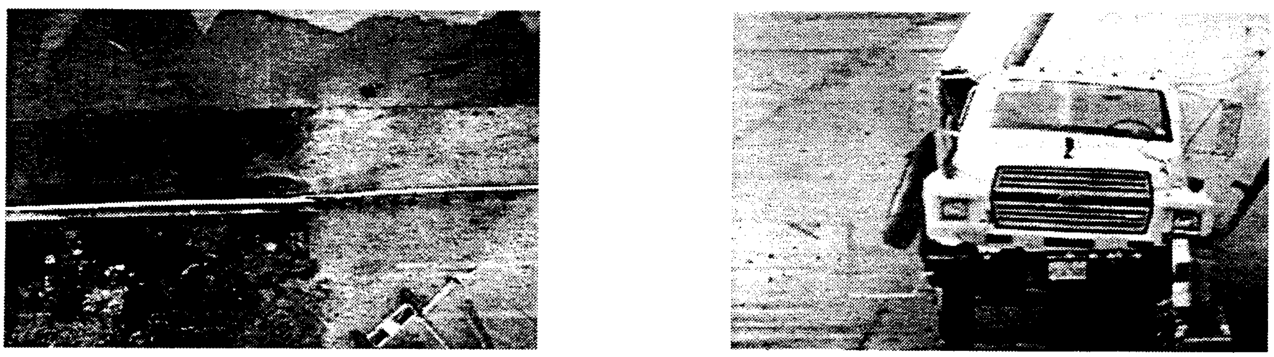
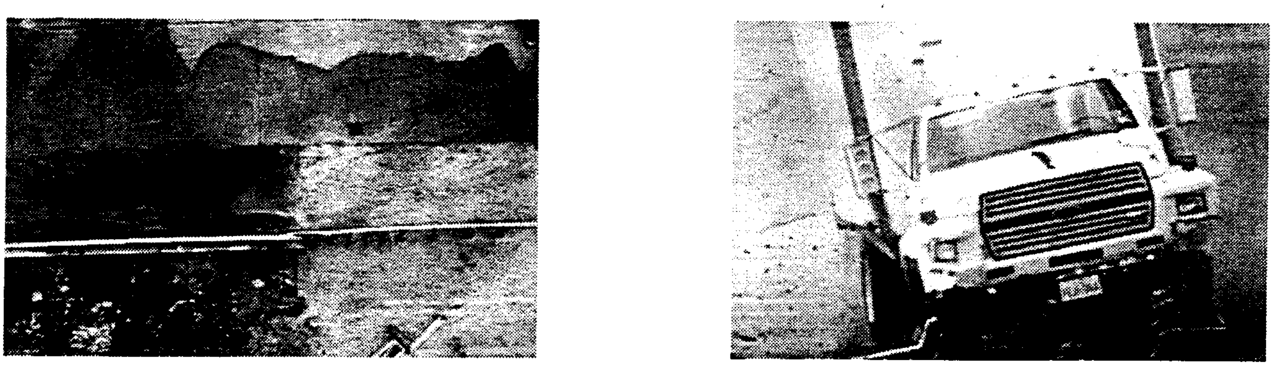


0.713 s

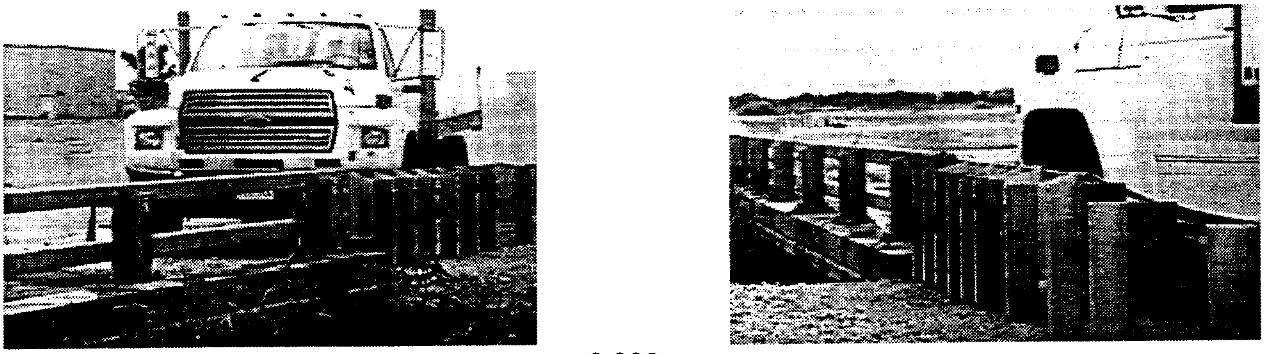


1.018 s

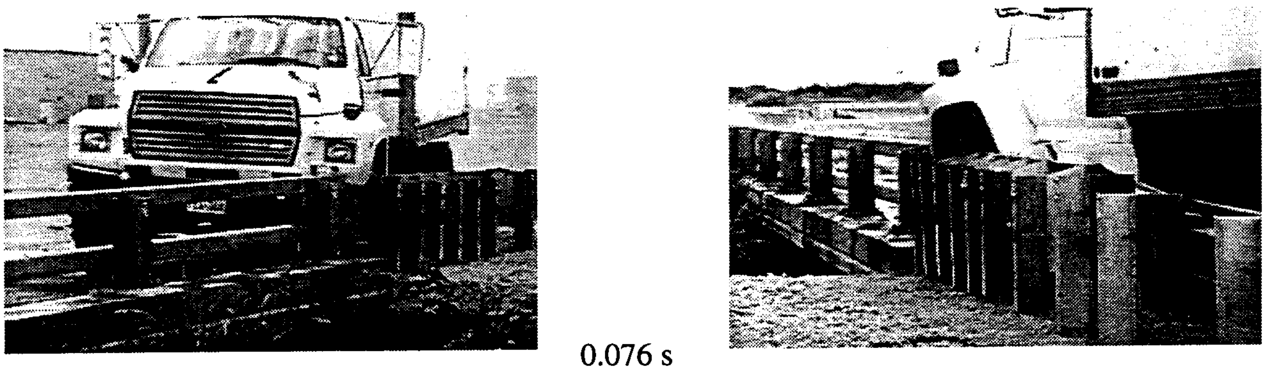


1.527 s

Figure 13. Sequential photographs for test 404311-6 (overhead and frontal views) (continued).



0.000 s



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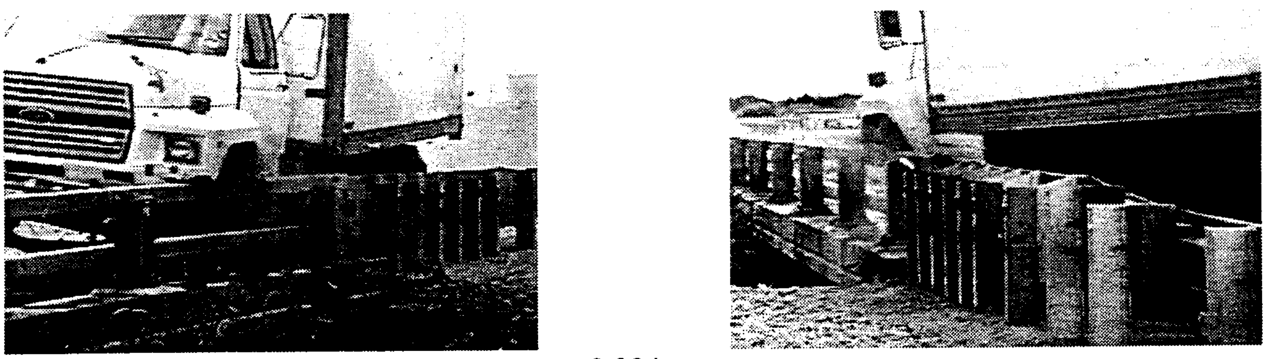

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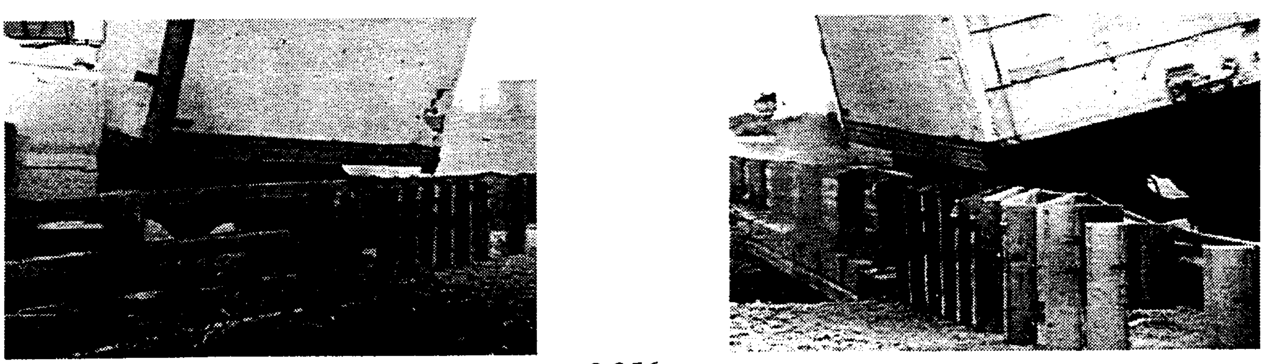
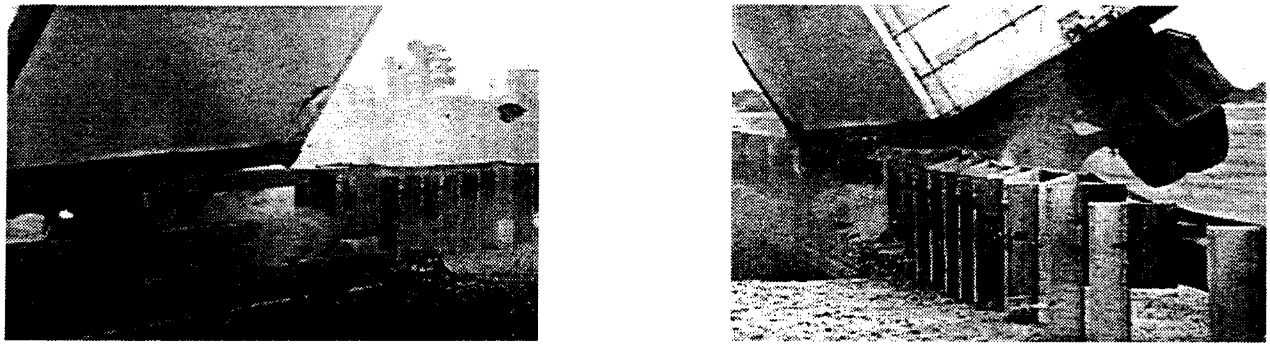


0.356 s

Figure 14. Sequential photographs for test 404311-6
(rear views).



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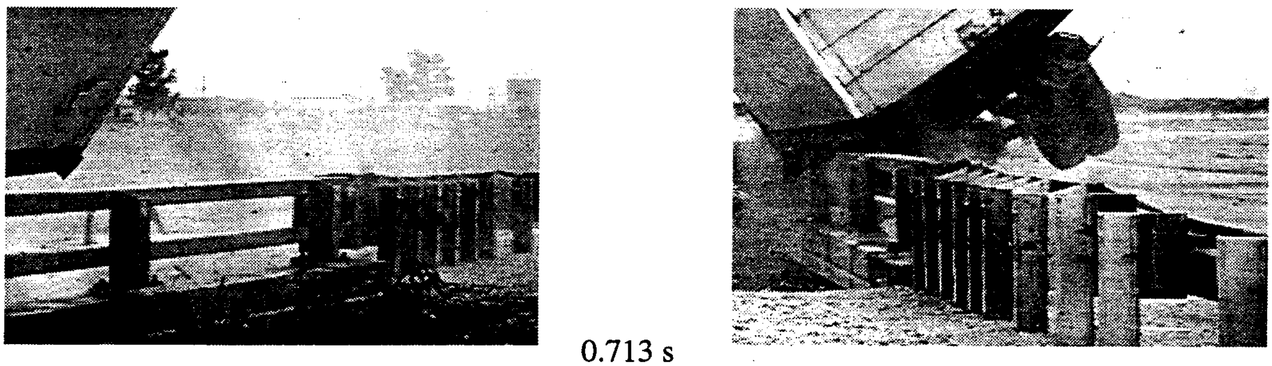
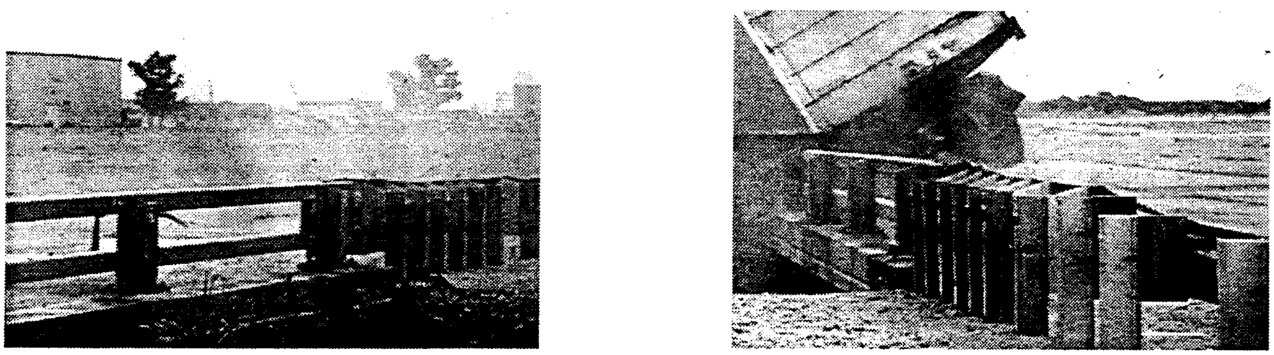


0.713 s



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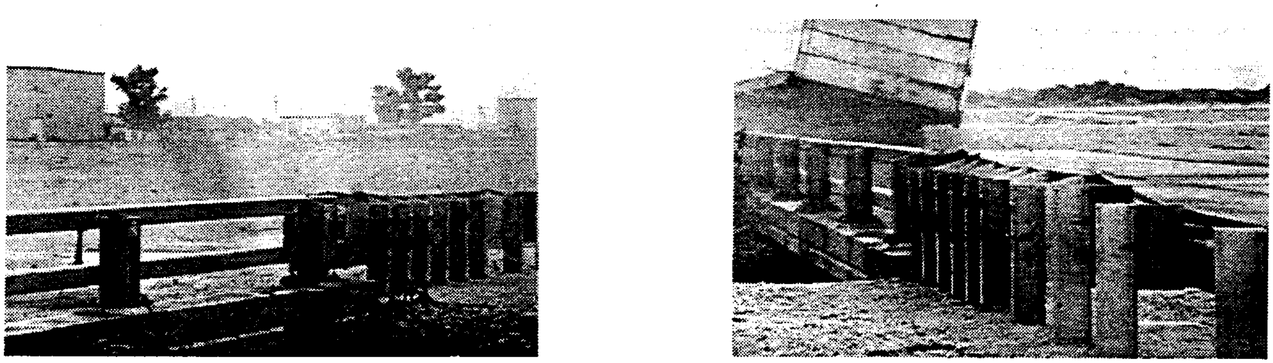

1.527 s

Figure 14. Sequential photographs for test 404311-6
(rear views) (continued).

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

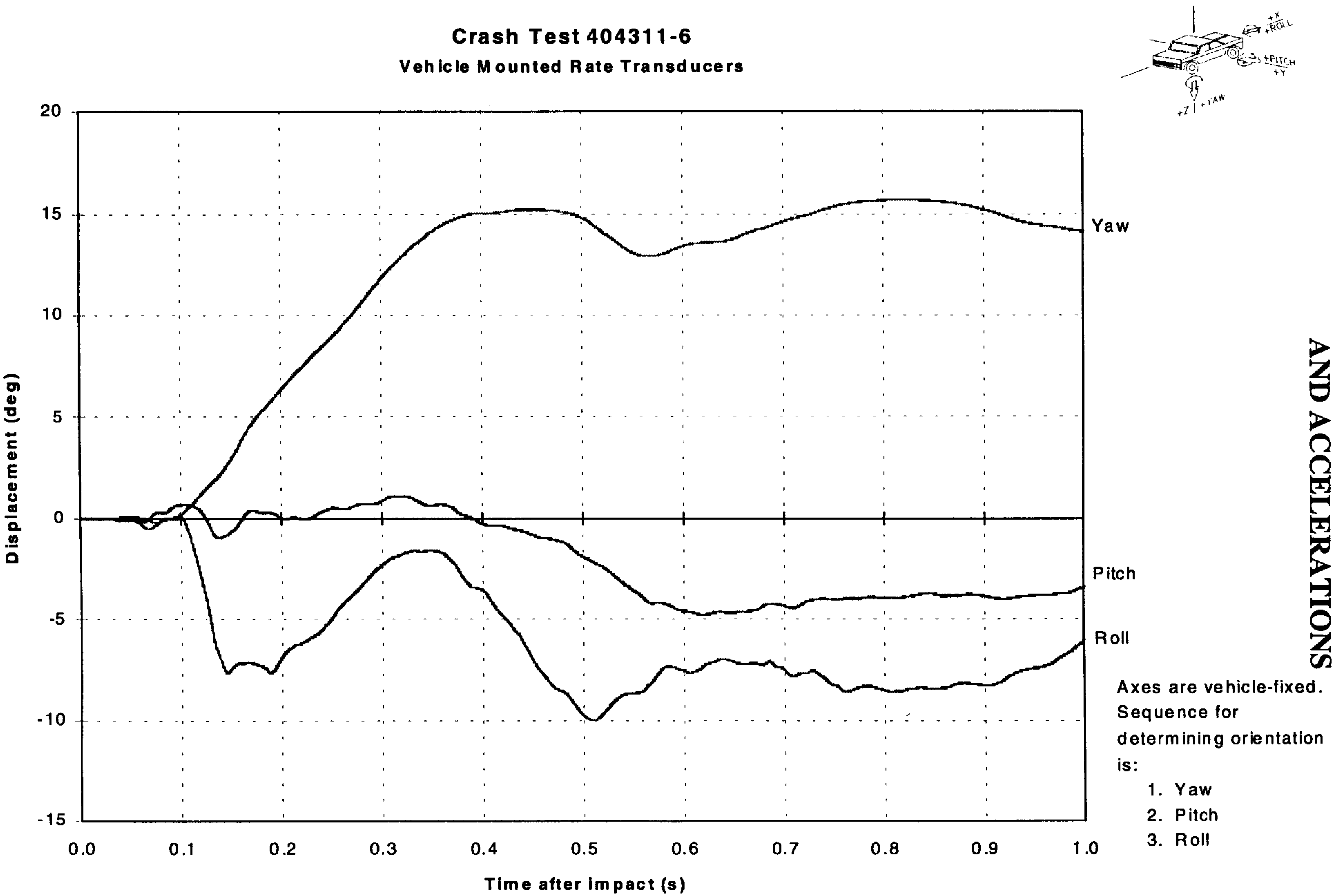

Figure 15. Vehicular angular displacements for test 404311-6.

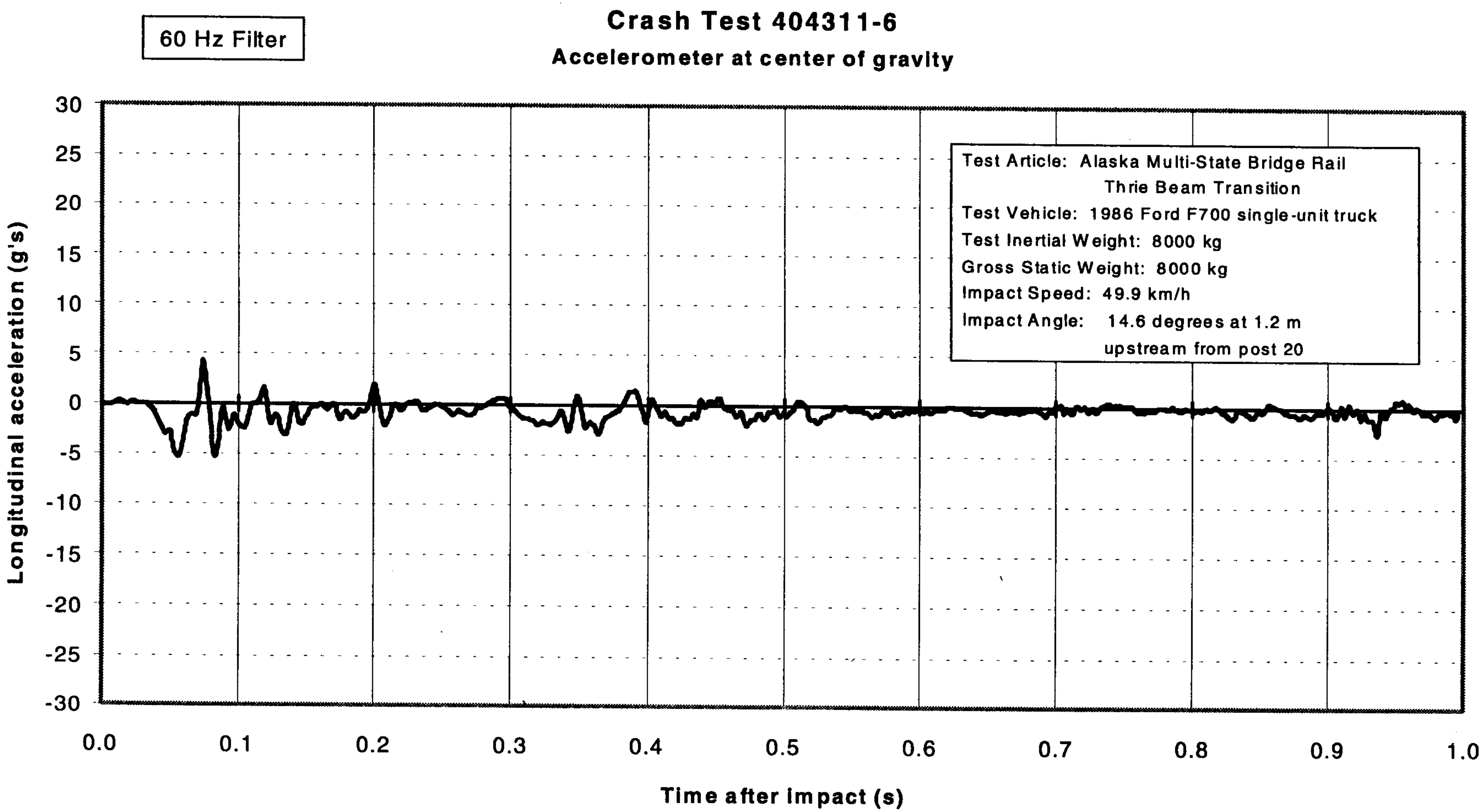

Figure 16. Vehicle longitudinal accelerometer trace for test 404311-6 (accelerometer located at center of gravity).

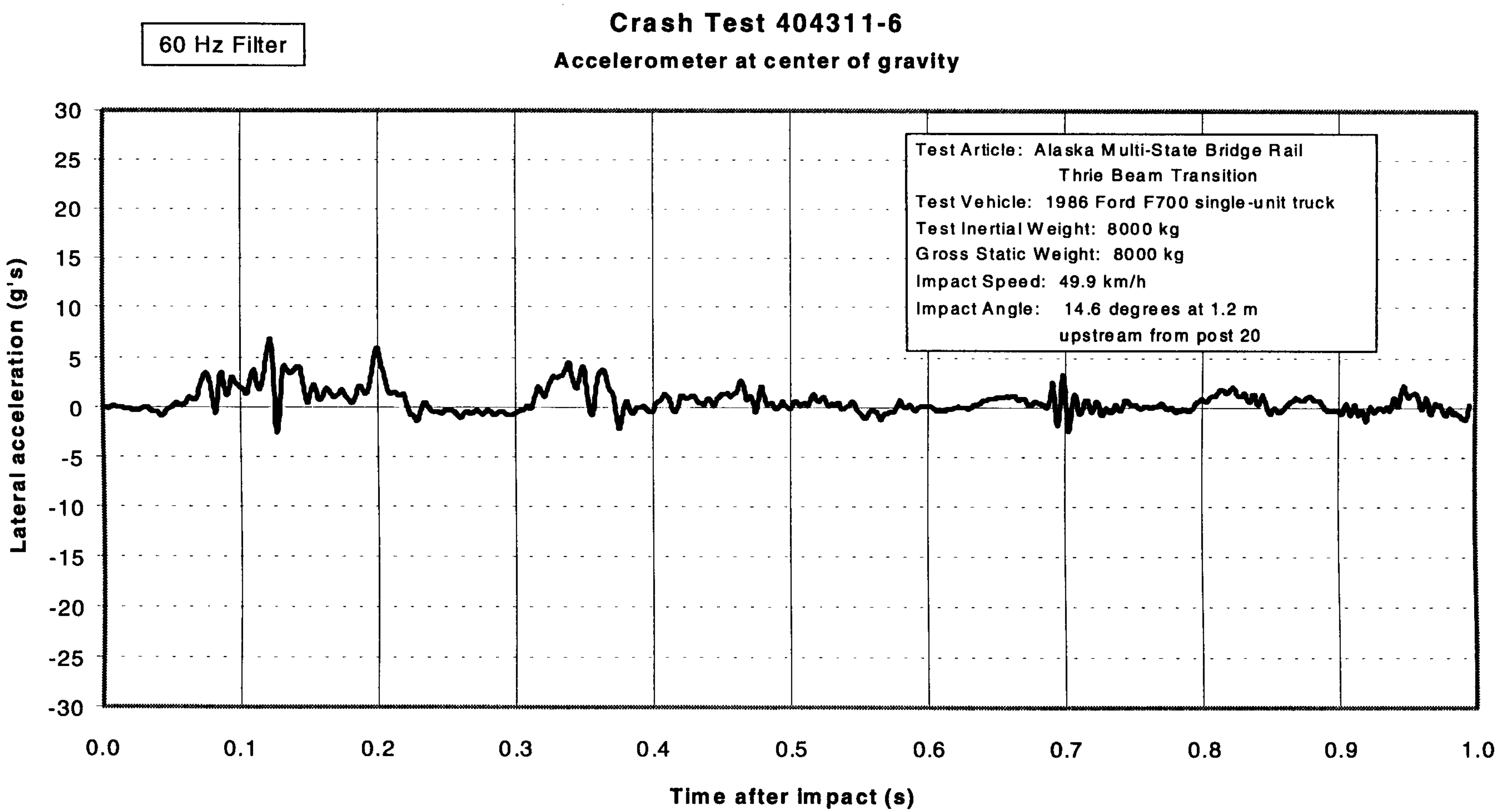

Figure 17. Vehicle lateral accelerometer trace for test 404311-6
(accelerometer located at center of gravity).

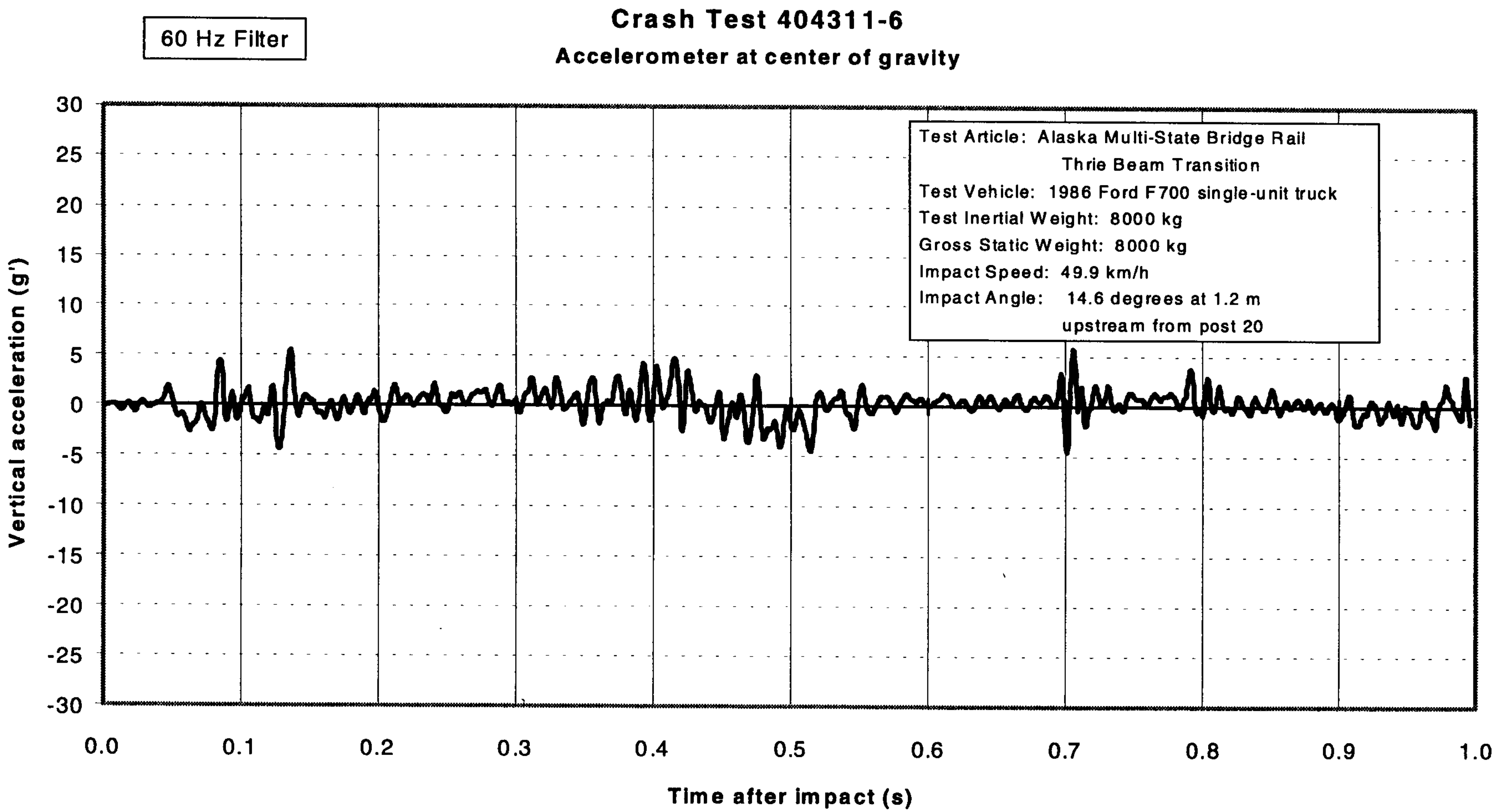

Figure 18. Vehicle vertical accelerometer trace for test 404311-6
(accelerometer located at center of gravity).

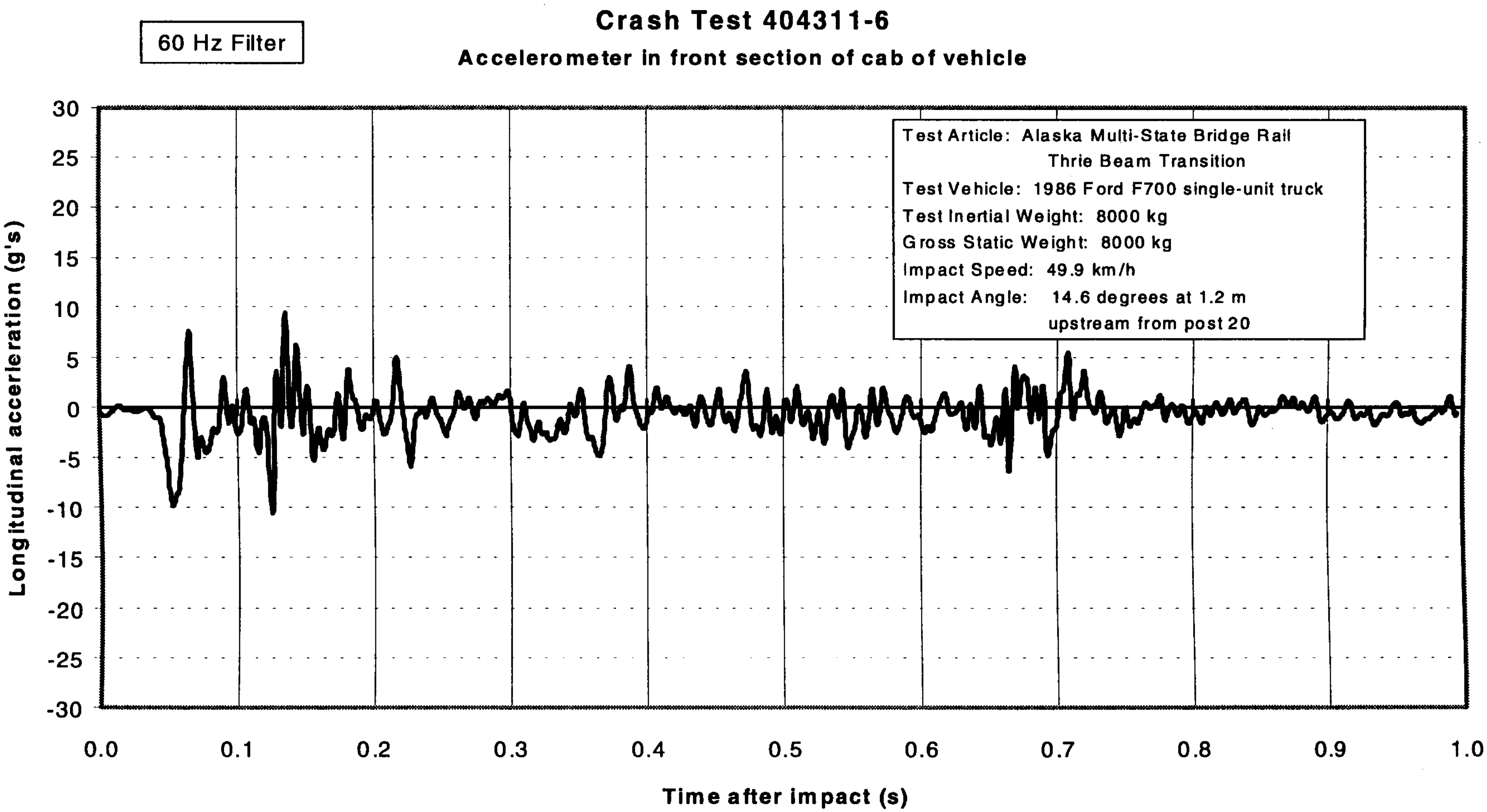

Figure 19. Vehicle longitudinal accelerometer trace for test 404311-6
(accelerometer located in cab of vehicle).

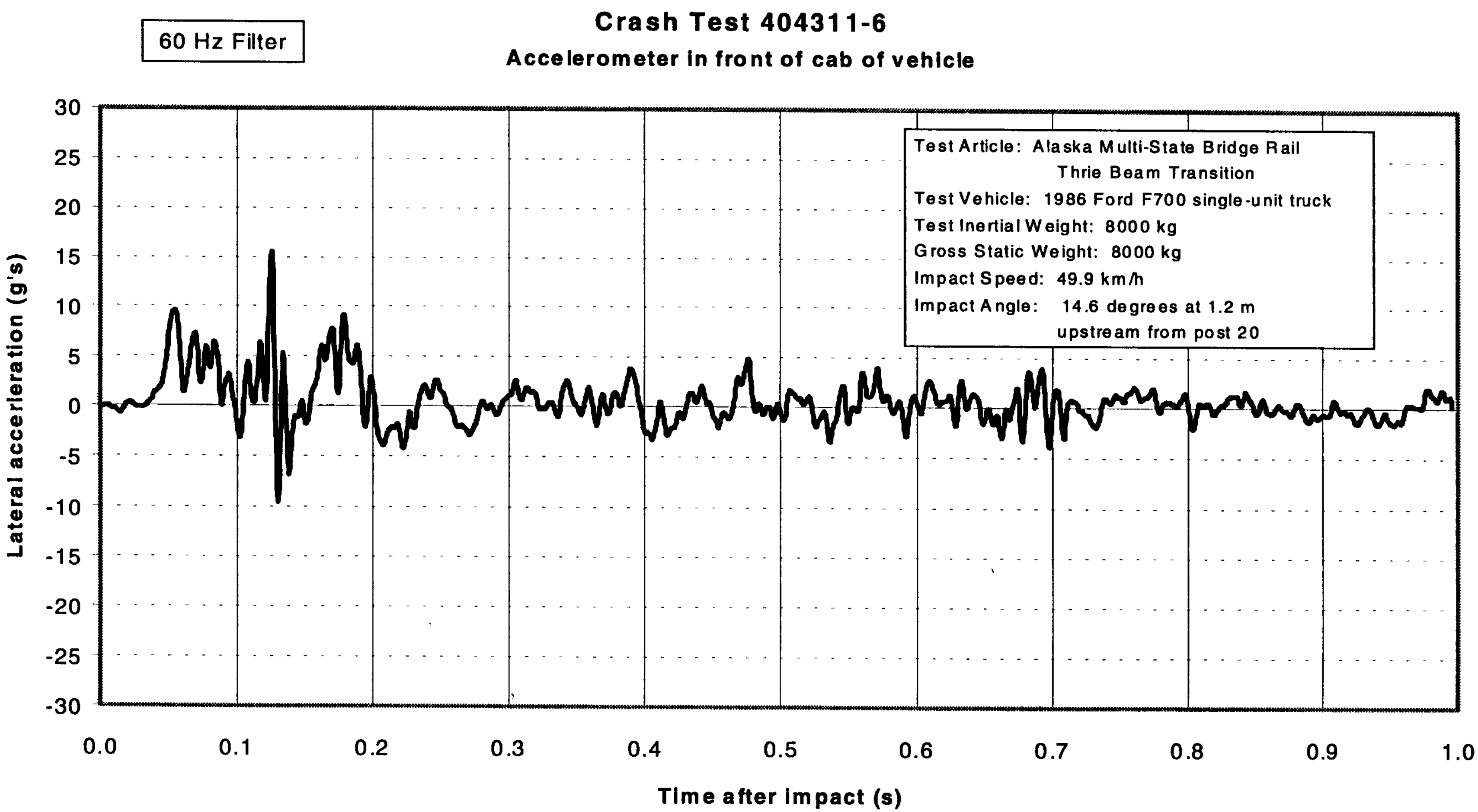

Figure 20. Vehicle lateral accelerometer trace for test 404311-6 (accelerometer located in cab of vehicle).

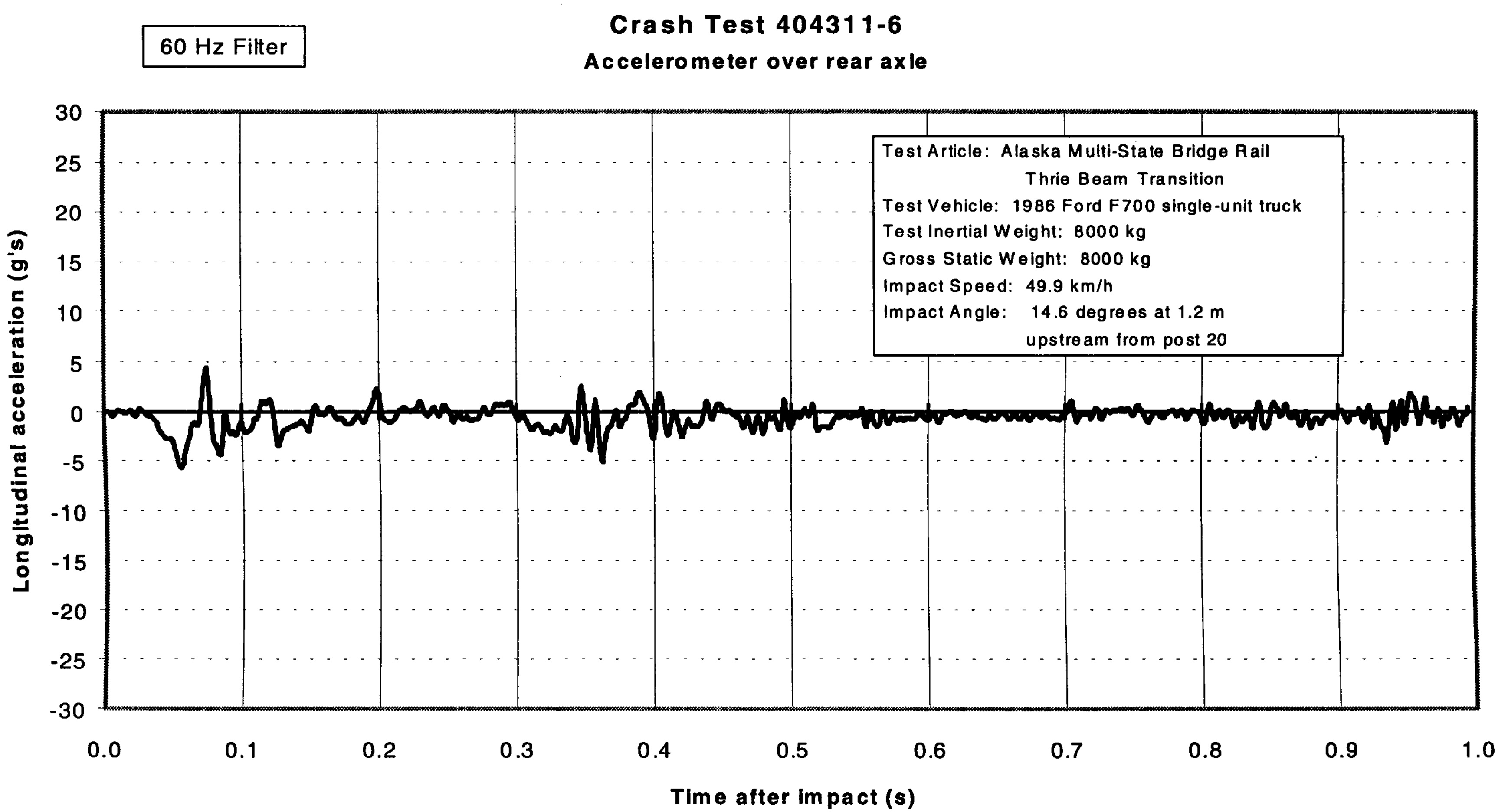

Figure 21. Vehicle longitudinal accelerometer trace for test 404311-6
(accelerometer located over rear axle).

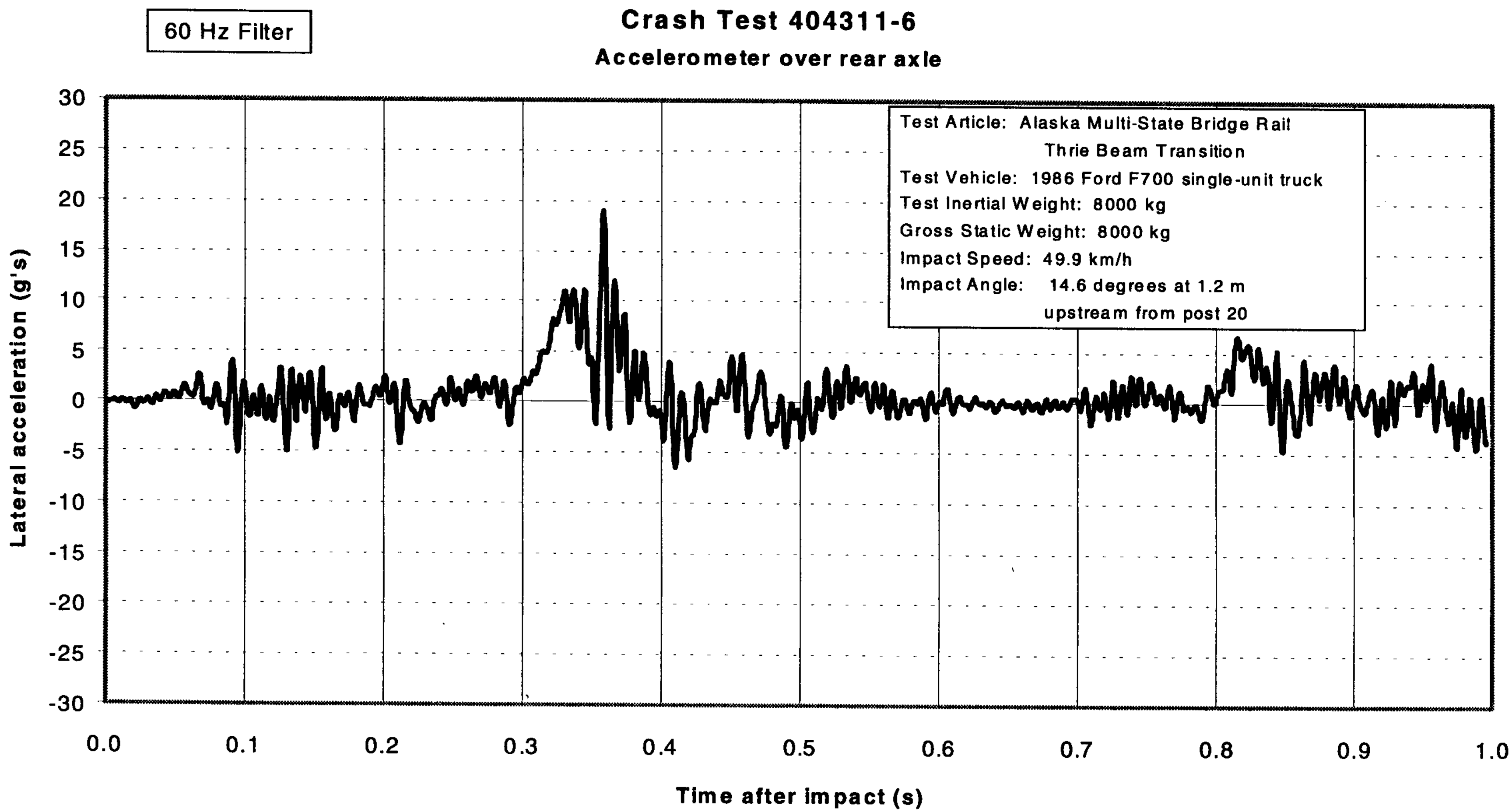

Figure 22. Vehicle lateral accelerometer trace for test 404311-6
(accelerometer located over rear axle).

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.