SUMMARY OF THE NCHRP REPORT 350
CRASH TEST RESULTS FOR THE
NARROW CONNECTICUT IMPACT ATTENUATION SYSTEM

Prepared by:

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A Project in cooperation with the

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16. Abstract

This report on the Narrow Connecticut Impact Attenuation System (NCIAS) is another in a series of test reports that document NCHRP Report 350 compliance of various Connecticut-designed and -developed impact attenuation systems. The report summarizes the results of six full-scale crash tests performed on the NCIAS. All tests were conducted in accordance with the guidelines of NCHRP Report 350 for Test Level 3 devices. NCHRP Report 350 specifies eight tests for redirective, non-gating devices. Three of the eight tests were not conducted on the NCIAS because they are similar to three tests conducted under the NCHRP Report 230 requirements, which the NCIAS passed. The five remaining tests were performed. One test was repeated after one of the cylinders was strengthened. The NCIAS passed all requirements for 4 out of the 5 test designations. It did not pass the requirements for the reverse hit test; therefore, it is required that the installation of the NCIAS not be at locations where it may be struck from the reverse direction. FHWA has approved the use of the NCIAS on the National Highway System at locations where reverse-direction impacts are unlikely.

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Thanks are given to Mr. Donald A. Larsen and Ms. Dionysia F. Oliveira who provided assistance in the completion and review of this report.

METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO METRIC MEASURES

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
mi^2	square miles	2.59	square kilometers	km^2
ac	Acres	0.405	hectares	ha
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb.)	0.907	megagrams (metric ton)	Mg (t)
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
TEMPERATURE (exact)				
ºF	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	ºC
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 METRIC MEASURES

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
km^2	square kilometers	0.386	square miles	mi^2
ha	hectares (10,000 m^2)	2.47	acres	ac
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (t)	megagrams (1000 kg) (metric ton)	1.103	short tons (2000 lb)	T
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
TEMPERATURE (exact)				
ºC	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	ºF
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

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SUMMARY OF THE NCHRP REPORT 350 CRASH TEST RESULTS FOR THE NARROW CONNECTICUT IMPACT ATTENUATION SYSTEM

Background

In 1985, the Connecticut Department of Transportation (ConnDOT) initiated a research effort to design, build, and crash test the Narrow Connecticut Impact Attenuation System (NCIAS). As a roadside highway safety feature, a goal of the NCIAS is to provide a forgiving roadway and roadside for an errant motorist [1]. Federal guidelines also state that the safety goal is met when the feature either contains and redirects the vehicle away from a hazardous area, decelerates the vehicle to a stop over a relatively short distance, readily breaks away or fractures or yields, allows a controlled penetration, or is traversable, without causing serious injuries to the vehicle's occupants or to other motorists, pedestrians, or work zone personnel [1]. To help meet highway safety goals, the NCIAS was designed as an end treatment for concrete safety shape barriers and other narrow hazards.

The NCIAS is the third in a series of cylindrical steel impact-attenuation devices that have been designed by Dr. John F. Carney, III and developed by ConnDOT in cooperation with the Federal Highway Administration (FHWA). The other two devices developed include the Connecticut Truck-Mounted Attenuator (CTMA) and the Connecticut Impact Attenuation System (CIAS). Based upon favorable results from these two devices, development began on the NCIAS for use at width-restricted locations, i.e., too narrow for installation of the CIAS [2].

Upon successful completion of crash tests for the National Cooperative Highway Research Program (NCHRP) 230 testing requirements and after receiving Federal approval for field deployment as an experimental crash cushion, five locations were selected in Connecticut for installation of the NCIAS. These locations were then field evaluated between January 1991 and June 1994. The purpose of this evaluation was to test the performance of a safety device under actual traffic conditions, which provide a much wider range of impact scenarios than are possible with controlled crash tests. The conclusions made from the field tests indicate that the NCIAS was successful in preventing serious injury to the occupants of impacting vehicles, under a variety of impact conditions [3].

In 1993, new federal standards under NCHRP Report 350 were published. Connecticut requested the NCIAS be tested under these new standards at a Test Level 3 for redirective/non-gating devices. This testing began in October 1997 and was completed by June 1998. Starting in October 1998, the Federal government mandated only highway safety appurtenances that have met the criteria set forth in NCHRP Report 350 may be constructed along the National Highway System (NHS). Upon successful completion of these tests, the FHWA approved use of the NCIAS on the NHS in locations where reverse-direction impacts are not likely (see Appendix C for approval letter).

Theoretical Basis for NCIAS

Kinetic energy is dissipated in the Narrow Connecticut Impact Attenuation System by plastically deforming the thin-walled steel cylinders, which are loaded laterally when impacted. The deformation process involves the formation of plastic zones in the cylinders. There are typically four such zones, which are created in each cylinder during the collapse process. After accounting for the strain—rate sensitivity of the steel cylinders, which results in an increased energy dissipation capacity under impact loading conditions, the steel cylinder diameters, lengths, and individual wall thicknesses were designed such that controlled energy dissipation could be achieved under impact with both light weight and heavy vehicles [4].

Description of the System

The Narrow Connecticut Impact Attenuation System is made up of the following five basic components [2]:

1. Concrete Base Pad and Barrier Curb End Treatment;
2. Anchored Components (e.g. back-up structure, cylinder retainer plates, anchor plates and skid rails);
3. Eight (8) Steel Cylinders;
4. Two (2) 1-inch (25.4 mm) Diameter Wire Ropes; and,
5. Vinyl-Coated Polyester Cover.

The system is securely anchored to a sound concrete pad which is 30-ft (9 m) long, 10-ft (3 m) wide, and designed to resist heavy uplifting and overturning loads, which may be incurred during severe side impacts of the NCIAS. The anchored components are semi-permanently bolted to the base pad with 7/8-in (22 mm) chemically anchored studs and are intended to remain undamaged during a system impact. The components consist of the free-standing back-up structure, two (2) skid rails, three (3) cylinder retainer plates, and two (2) front anchor plates.

The eight (8) steel cylinders are employed as the energy-absorbing material and are all 3-ft (0.9 m) in diameter, 4-ft (1.2 m) high and have wall thicknesses ranging from 1/8-in (3.2 mm) to 3/8-in (9.5 mm). The wire ropes are used to control lateral deflection of the

NCIAS and provide a smooth redirecting response under side-impact conditions. They consist of two (2) 1-in (25.4 mm) diameter wire ropes placed along each side of the NCIAS. The last basic component is the vinyl-coated polyester cover, which is attached to the top of the cylinders to prevent the build-up of snow, ice, and debris inside the cylinders.

Figure 1 shows (in schematic form) the design configuration of the NCIAS. Figure 2 shows a picture of the system at the gore area of Exit 7 on Route 2 Eastbound in Glastonbury, CT.

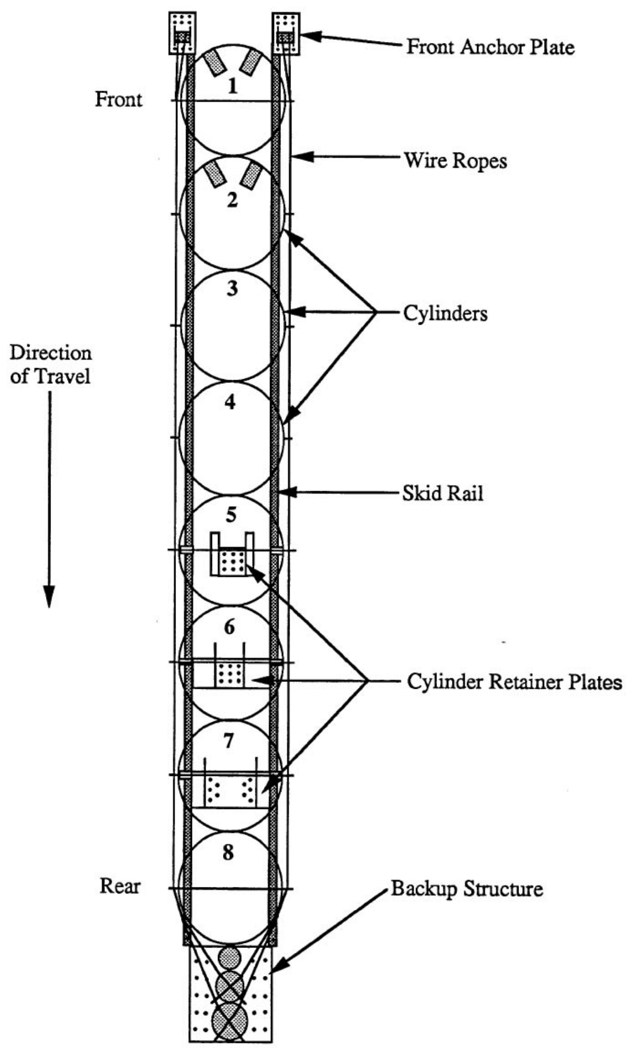

Figure 1. NCIAS Plan View Schematic

Figure 2. NCIAS system at Exit 7 on Route 2 Eastbound in Glastonbury, CT

Previous NCHRP Report 230 Full-Scale Crash Testing

A program of full—scale crash tests was conducted (1987—1988) at Ensco, Inc.'s testing facility in Georgetown, Delaware, to test the design and effectiveness of the Narrow Connecticut Impact Attenuation System under NCHRP Report 230 requirements. A total of eleven (11) full-scale crash tests were performed. The excellent results obtained demonstrated conclusively that, upon impact, vehicles either decelerate within acceptable limits, or are smoothly redirected in a controlled manner [5].

Terminals and Crash Cushions Testing Requirements of NCHRP Report 350

NCHRP Report 350, entitled *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, was published in 1993. The purpose of the report is to present uniform guidelines for the crash testing of both permanent and temporary highway safety features and recommended evaluation criteria to assess test results [1]. Using the guidelines, a given feature may be tested to one of six "test levels". Most crash-tested safety features in use in the United States, including terminals and crash cushions, are tested at Test Level 3, which is acceptable for a wide range of high-speed arterial highways. Test Level 3 uses three different vehicle types (1543 lb (700 kg), 1808 lb (820 kg), 4409 lb (2000 kg)) traveling at a nominal speed of 62 mph (100 km/h).

The NCIAS was designed and tested as a redirective/non-gating device, at Test Level 3. A redirective/non-gating device is a device that is designed to contain and redirect vehicles that impact anywhere along the side of the device.

According to NCHRP Report 350, eight crash tests are recommended for evaluation of redirective/non-gating crash cushions. They are designated as 3-30, 3-31, 3-32, 3-33, 3-36, 3-37, 3-38, and 3-39. Tests 3-30, 3-31, and 3-36 were not conducted on the NCIAS because these three tests are similar to three tests conducted under the NCHRP Report 230 requirements, which the NCIAS passed. Tests 3-32 and 3-33 were performed on the NCIAS to evaluate occupant risk and vehicle trajectory criteria. Test 3-37 was performed to evaluate structural adequacy and vehicle trajectory criteria. Test 3-38 was performed to evaluate the potential for pocketing or snagging at the juncture with the object the device is shielding or terminating. Test 3-39 was performed to evaluate the performance of a terminal or crash cushion for a reverse hit.

NCIAS NCHRP Report 350 Crash Test Program

The NCHRP Report 350 crash test conditions for crash cushions are shown in Table 1. A total of six tests were performed on the NCIAS using five different test designations. All six tests were performed at the Texas Transportation Institute (TTI) in College Station, Texas. The first four tests were on the original design and the last two were on the NCIAS with a strengthened cylinder 8. Cylinder 8 was strengthened after Crash Test 3-38 was performed and the system failed the first time.

The crash test results are summarized in Table 2, and representative photos of the crash tests performed are contained in Appendix B of this report. Four out of the five test designations satisfied the requirements of NCHRP Report 350. The complete crash test reports are available to the reader upon request to the Connecticut Department of Transportation, Division of Research. Highlights from the crash test reports [6] of the six individual tests performed are discussed below.

Test No. 404231-2, NCHRP Report 350 Test Designation 3-32

This test involves an 1808 lb (820 kg) automobile impacting the nose of the NCIAS at a nominal speed of 62 mph (100 km/h) and angle of 15 degrees. The occupant impact velocity and the occupant ridedown acceleration for both the longitudinal and lateral directions were less than the maximum allowable amounts (see Table 2). All of the evaluation criteria were satisfied.

Table 1. NCHRP Report 350 Crash Test Conditions for Crash Cushions

NCHRP Report 350 Test Designation	**Vehicle**	**Impact Speed** (km/h)	**Impact Angle** (deg)	**Impact Point**
3-32	820C	100	15	Head-on, no offset
3-33	2000P	100	15	Head-on, no offset
3-37	2000P	100	20	Beginning of length of need
3-38	2000P	100	20	Critical impact point
3-39	2000P	100	20	Reverse direction

Table 2. Summary of NCIAS Crash Test Results

NCHRP Report 350 Test Designation	3-32	3-33	3-37	3-38(1)	3-38(2) (Retest)	3-39
Vehicle Mass (kg)	820	2000	2000	2000	2000	2000
Impact Speed (km/h)	98.9	99.3	97.2	95.9	100.1	99.7
Impact Angle (degrees)	14.4	14.7	20.2	20.8	19.6	20.6
Vehicle Impact Location	Nose	Nose	Interface of cylinders 1 and 2	Center of cylinder 7	Center of cylinder 7	Midpoint
Occupant impact velocity (m/s) (12 max, 9 max preferred)						
Longitudinal	10.0	8.5	7.7	8.9	7.6	10.1
Lateral	2.8	3.0	5.4	4.7	4.7	6.4
Occupant ridedown acceleration (g's) (20 max, 15 max preferred)						
Longitudinal	12.4	12.3	17.7	13.1	9.6	26.8
Lateral	3.2	5.9	19.5	11.7	11.2	20.3
Maximum Occupant Compartment Deformation (mm)	8	0	39	320	167	340
Assessment	Passed	Passed	Passed	Failed	Passed	Failed

Test No. 404231-1, NCHRP Report 350 Test Designation 3-33

In Crash Test 3—33, a 4409 lb (2000 kg) pick-up truck impacts the nose of the NCIAS with the same nominal speed of 62 mph (100 km/h) and angle of impact of 15 degrees as test 3-32. The occupant impact velocity and the occupant ridedown acceleration for both the longitudinal and lateral directions were less than the maximum allowable amounts (see Table 2). All of the evaluation criteria were satisfied.

Test No. 404231-3, NCHRP Report 350 Test Designation 3-37

This test uses a 4409 lb (2000 kg) pick-up truck which impacts the NCIAS at the beginning of the length of need at a speed of 62 mph (100 km/h) and an impact angle of 20 degrees. The length of need was determined to be at the interface of cylinders 1 and 2. The occupant impact velocity and the occupant ridedown acceleration for both the longitudinal and lateral directions were less than the maximum allowable amounts (see Table 2). Even though the occupant ridedown acceleration was higher than the preferred amount of 50 ft/s (15 m/s), it was still less than the maximum allowed of 65 ft/s (20 m/s); therefore, all the evaluation criteria were satisfied.

Test Nos. 404231-4 and 404231-5, NCHRP Report 350 Test Designation 3-38

This test also uses a 4409 lb (2000 kg) pick-up truck at a speed of 62 mph (100 km/h) and an impact angle of 20 degrees; however, the vehicle impacts the NCIAS at the critical impact point. This impact point, as agreed upon by the FHWA and the Connecticut Department of Transportation, is at the center of cylinder 7 (see Figure 3).

Although the occupant impact velocity and the occupant ridedown acceleration were less than the maximum allowable amounts, there was a

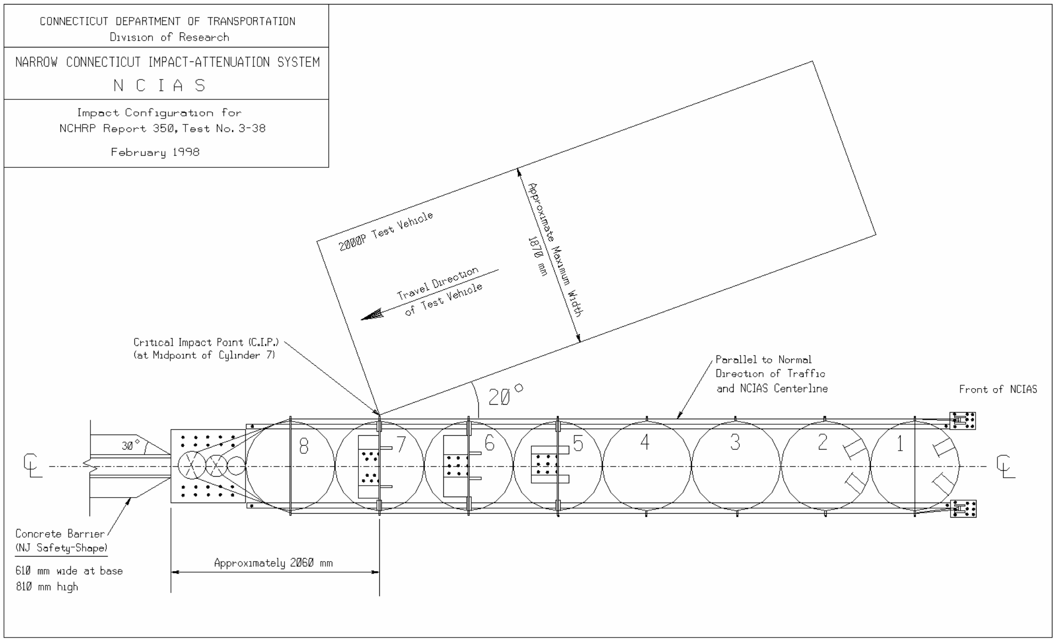

Figure 3. Impact Configuration for Test No. 3-38

significant amount of occupant compartment deformation. The maximum reduction in space in the firewall to instrument panel area was 71 percent, which could cause serious injury. This test on the NCIAS was, therefore, not acceptable.

The significant amount of occupant compartment deformation was caused when cylinder 8 deformed, allowing the front wheel to contact the backup structure and concrete median barrier. Cylinder 8 was then strengthened, as noted below, and as shown in Figure 4.

1. A second transverse compression pipe was added below the first pipe.

2. Two notches were cut in the bottom-rear of cylinder 8 to allow the cylinder wall to pass over the anchor bolts that anchor the backup structure.

3. The four 29 mm shank eye bolts for the wire ropes were replaced by four standard 13 mm U-bolts.

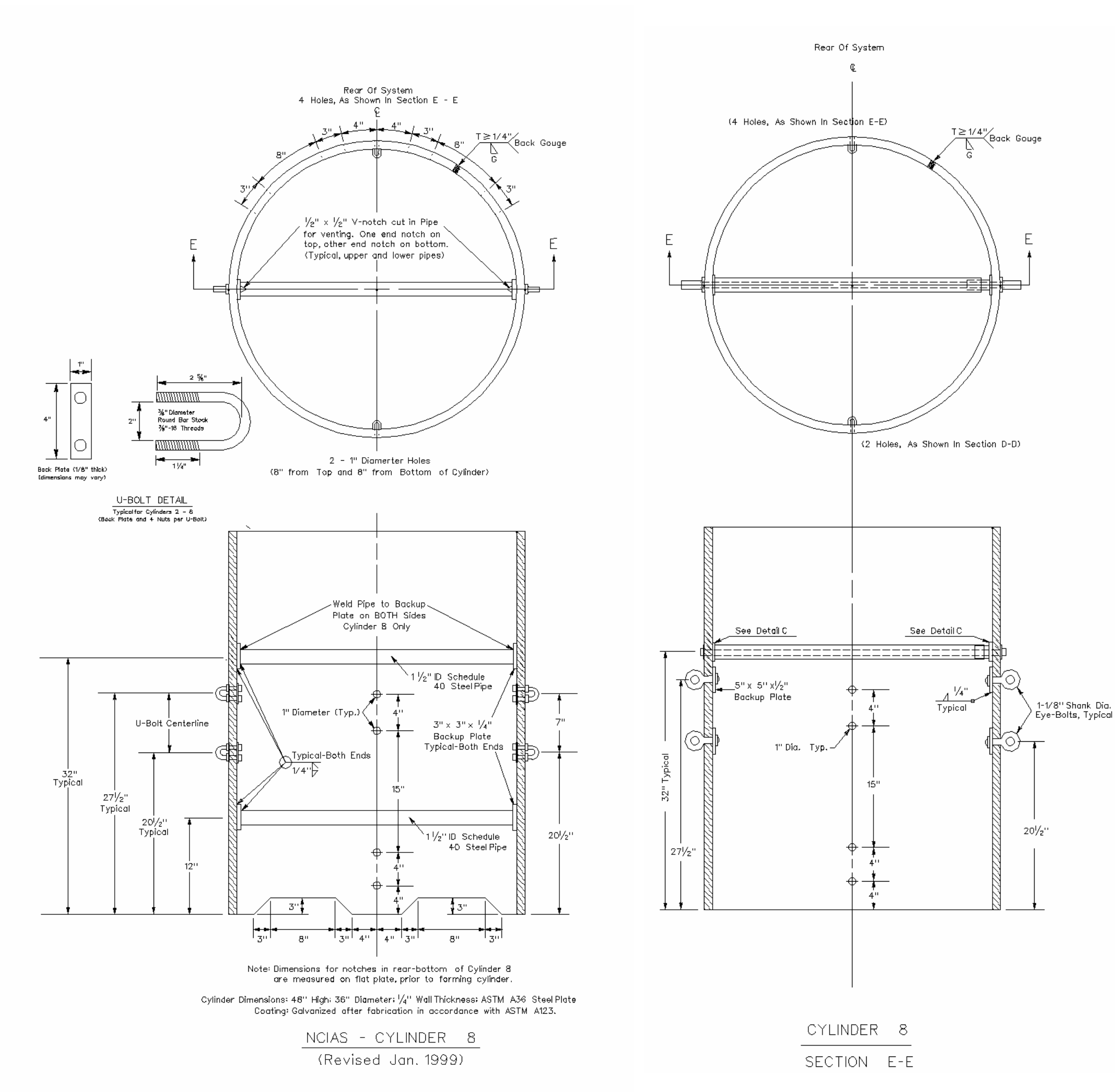

Figure 4. Cylinder 8 - Revised and Original

With this laterally strengthened cylinder 8, the test was repeated. The NCIAS then performed acceptably for all criteria specified for Crash Test 3-38. The modifications to cylinder 8 would not affect the outcome of the previous tests so those were not repeated [6].

Test No. 404231-6, NCHRP Report 350 Test Designation 3-39

In Crash Test 3-39, a 4409 lb (2000 kg) pick-up truck impacts the midpoint of the NCIAS in the reverse direction at a nominal speed of 62 mph (100 km/h) at an angle of 20 degrees. The impact point was determined to be at the interface of cylinders 4 and 5, or 11 inches (270 mm) downstream of the centerline of cylinder 4 (see Figure 5). The occupant impact velocity for both the longitudinal and lateral directions was less than the maximum allowable amount (see Table 2). The occupant ridedown acceleration for both the longitudinal and lateral directions, however, was greater than the maximum allowable amount (see Table 2). Therefore, due to this high occupant ridedown acceleration and due to significant deformation of the occupant compartment, the NCIAS did not meet the requirements of NCHRP Report 350 test designation 3-39.

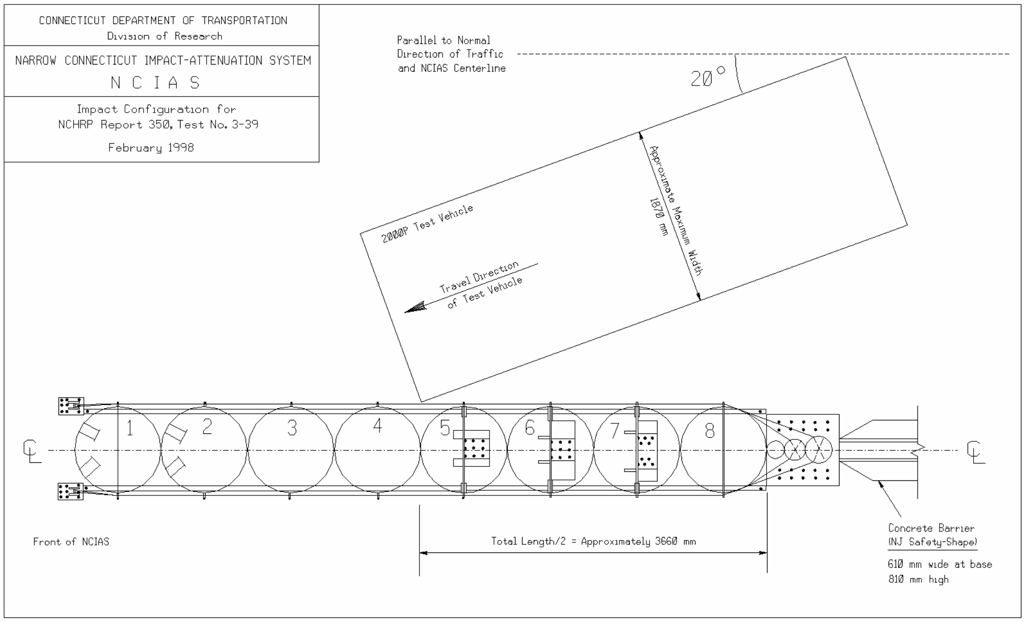

Figure 5. Impact Configuration for Test No. 3-39

Conclusion

The Narrow Connecticut Impact Attenuation System was developed upon receiving favorable results from two other impact-attenuation systems developed by the Connecticut Department of Transportation in cooperation with the Federal Highway Administration. The NCIAS is a roadside highway safety feature intended for use as an end treatment for concrete safety shape barriers and other narrow hazards.

From October 1997 to June 1998, full scale crash testing took place at the Texas Transportation Institute on the NCIAS. This testing was necessary for the system to meet the Federal NCHRP Report 350 requirements. It was essential for the system to pass the requirements in order to be constructed along the National Highway System at anytime after October 1998.

Six crash tests were conducted on the Narrow Connecticut Impact Attenuation System using five different test designations of the NCHRP

350 requirements. Two crash tests were performed on test designation 3-38 because the NCIAS failed the original test. After modification to one of the cylinders, the NCIAS passed the requirements for that test designation. Four out of the five test designations performed passed all of the requirements of the NCHRP Report 350. The NCIAS did not pass the crash test for test designation 3-39, which is intended to evaluate the performance of a terminal or crash cushion for a reverse hit. The overall performance of the NCIAS led to the Federal Highway Administration's approval of the use of the NCIAS on the U.S. National Highway System where reverse-direction impacts are not likely. Appendix C includes the full approval letter.

Detailed crash test information on these four tests is available upon request. Complete design and construction details are given in Appendix A. Videotapes of the tests performed on the system are also available to interested parties.

Although there is a patent on the product described herein, the device is not a proprietary item. The plans can be used by others to reproduce the system. Plans and more information are also available at ConnDOT's web page:

http://www.dot.state.ct.us/1103/NCIAS-information.htm

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APPENDIX A

NCIAS Installation Details

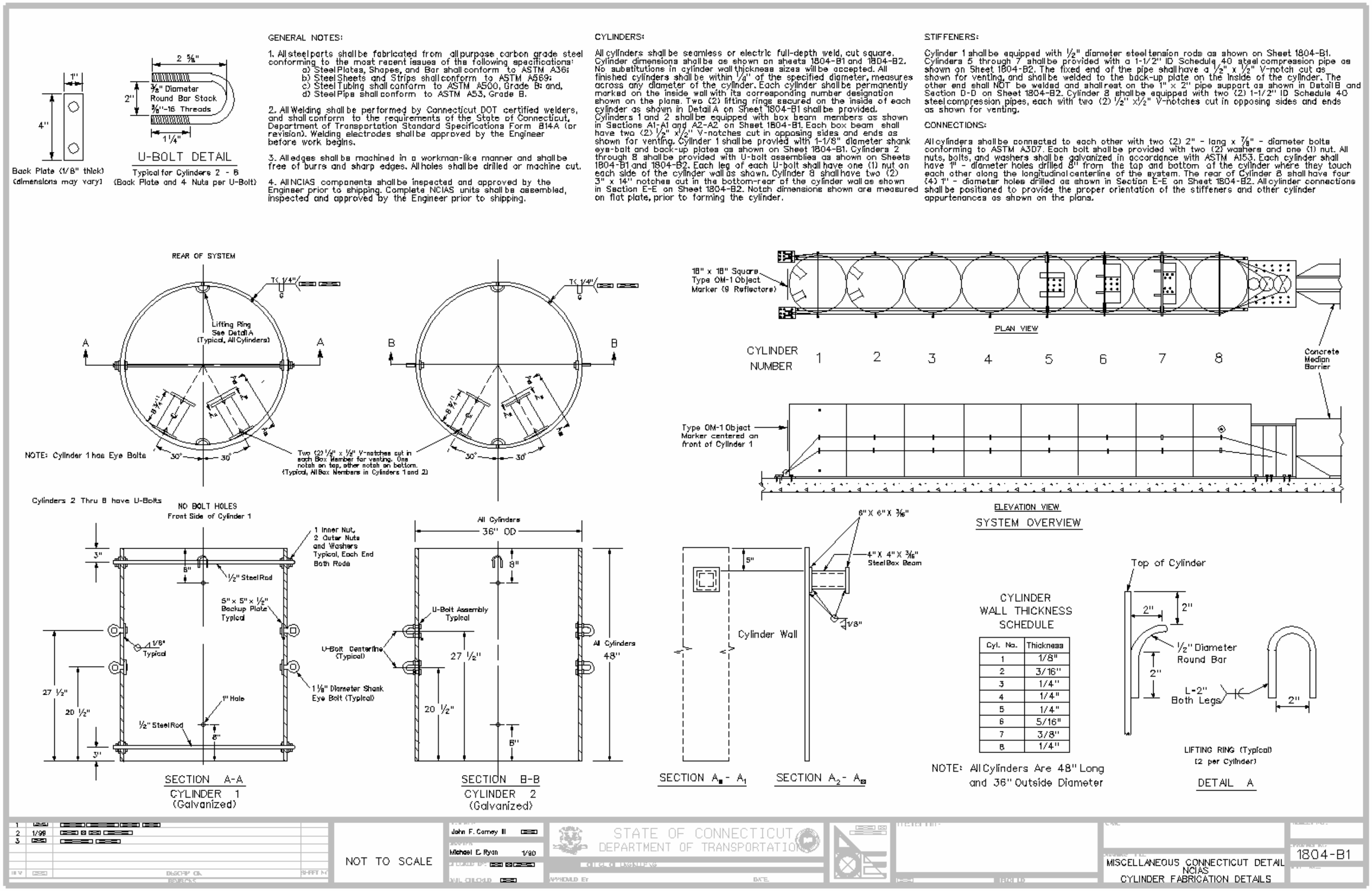


Figure A-1 Cylinder Fabrication Details

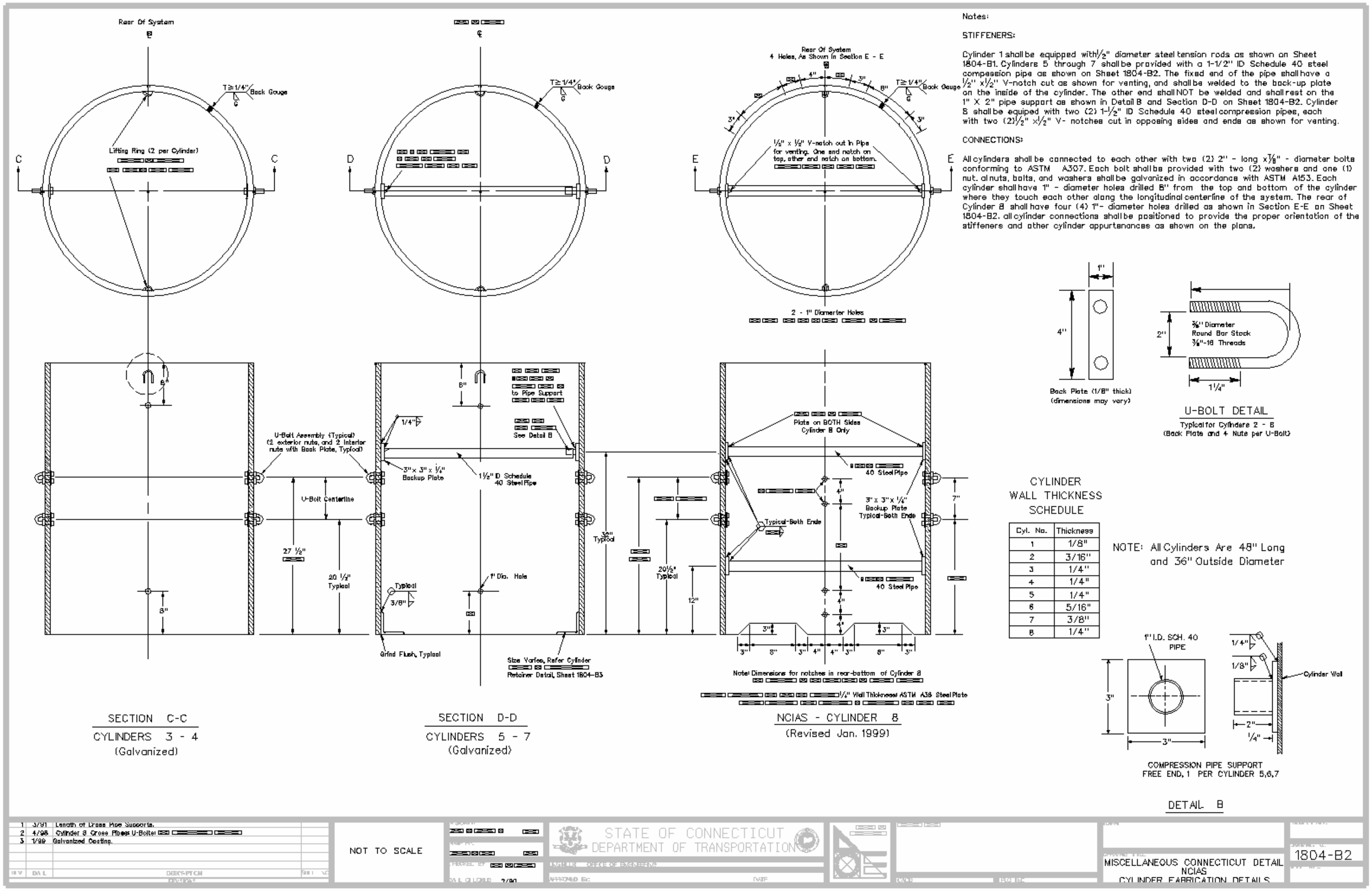


Figure A-2 Cylinder Fabrication Details continued

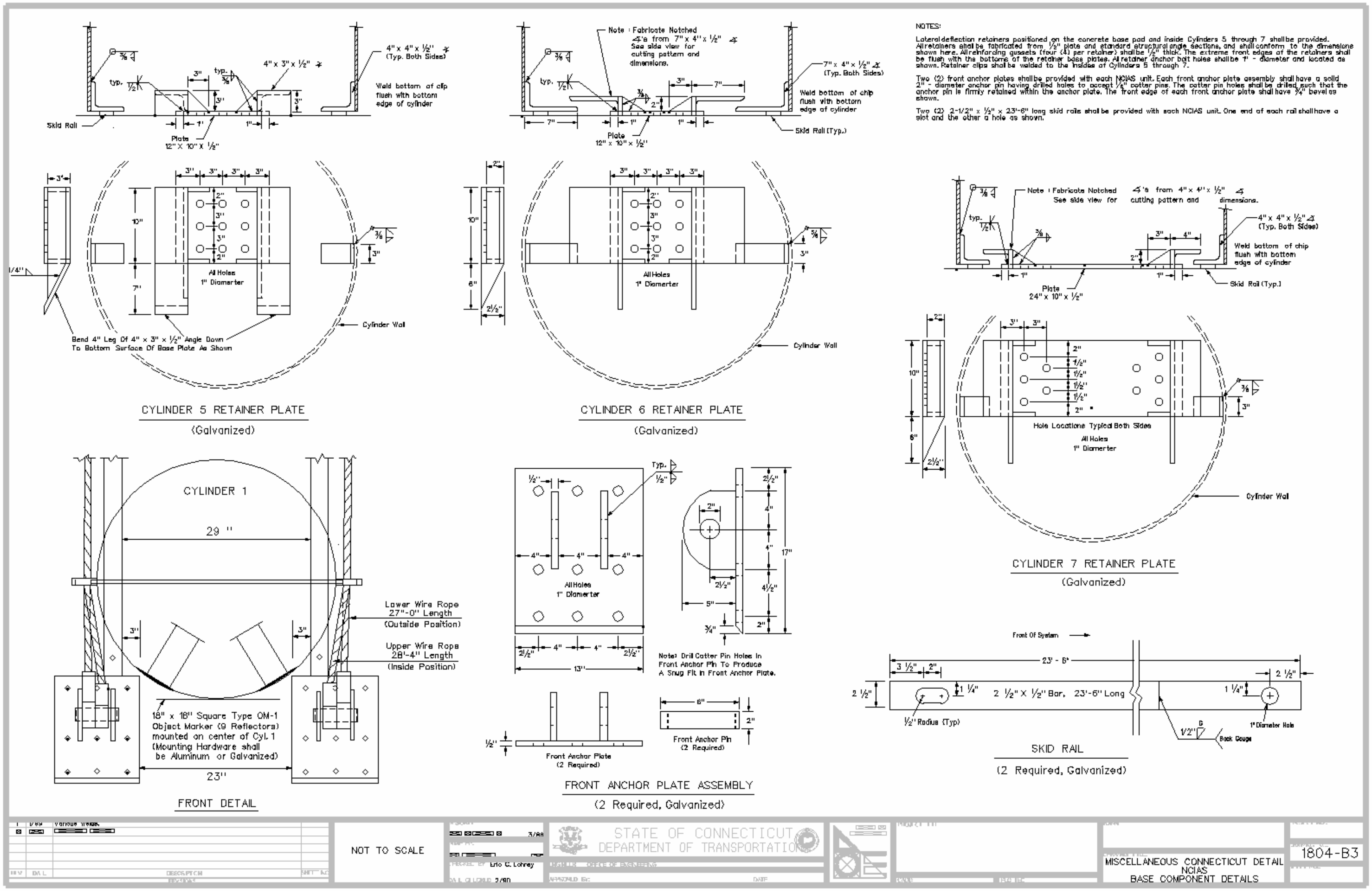


Figure A-3 Base Component Details

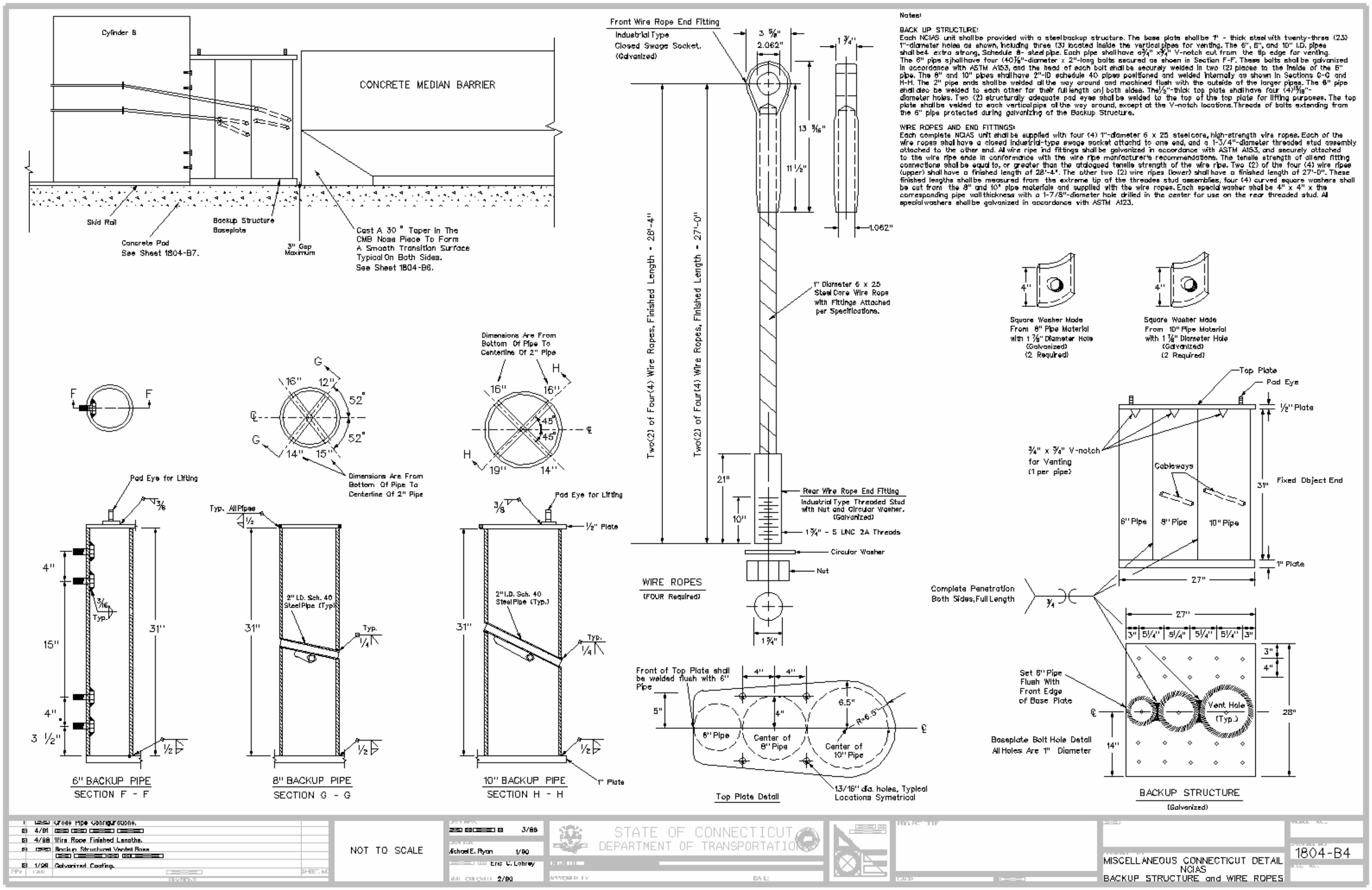


Figure A-4 Backup Structure and Wire Ropes

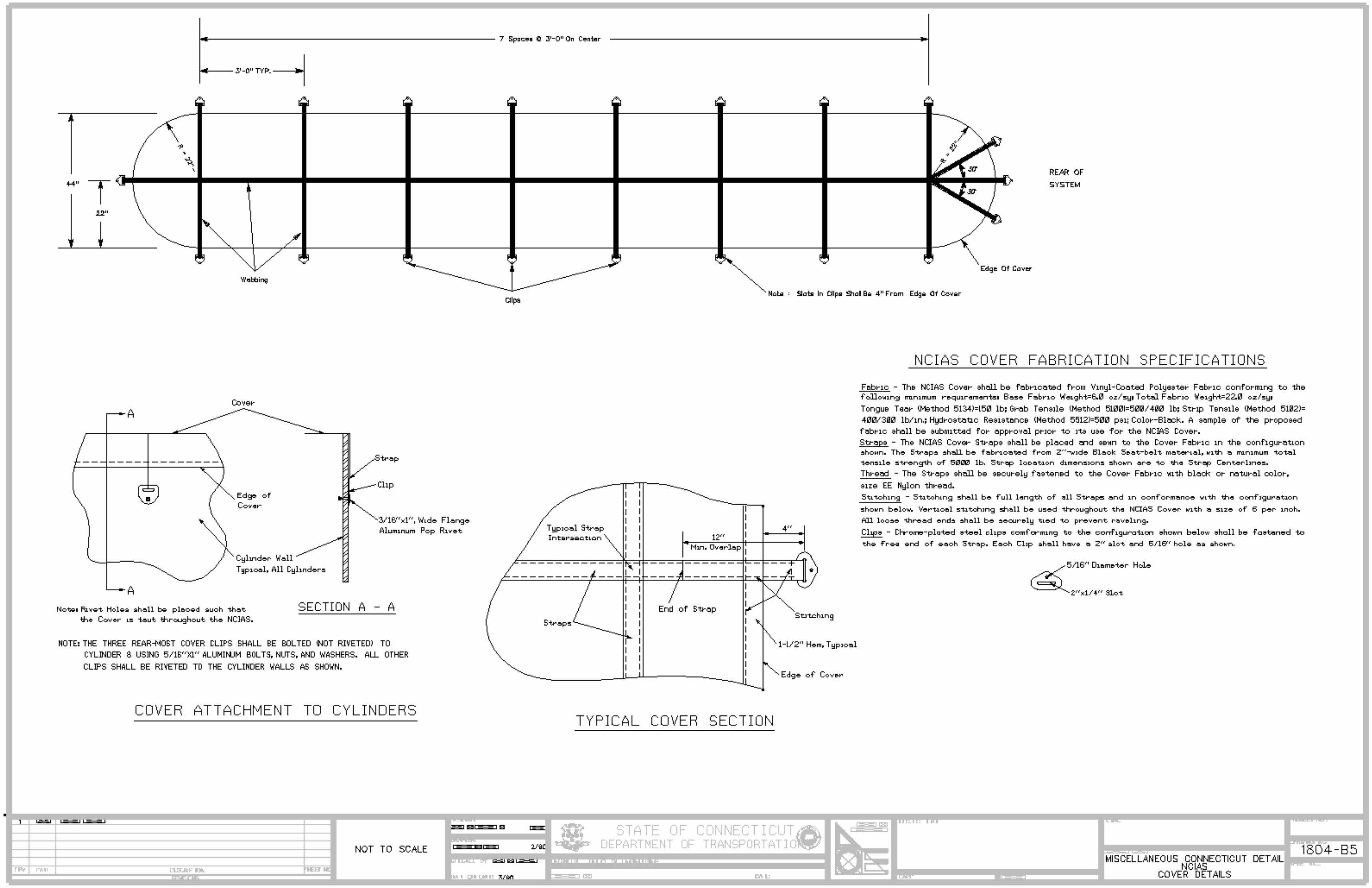


Figure A-5 Cover Details

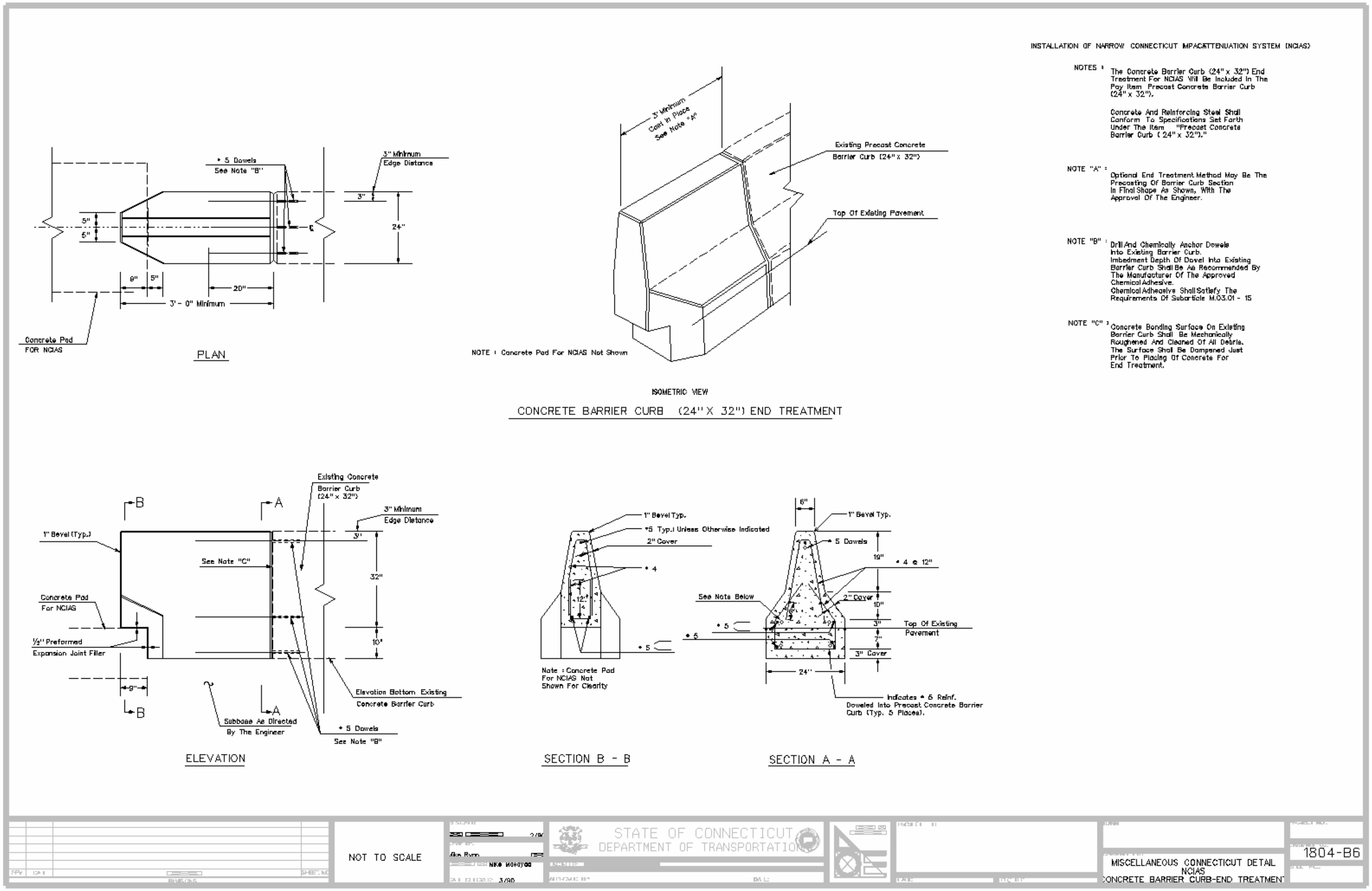


Figure A-6 Concrete Barrier Curb – End Treatment

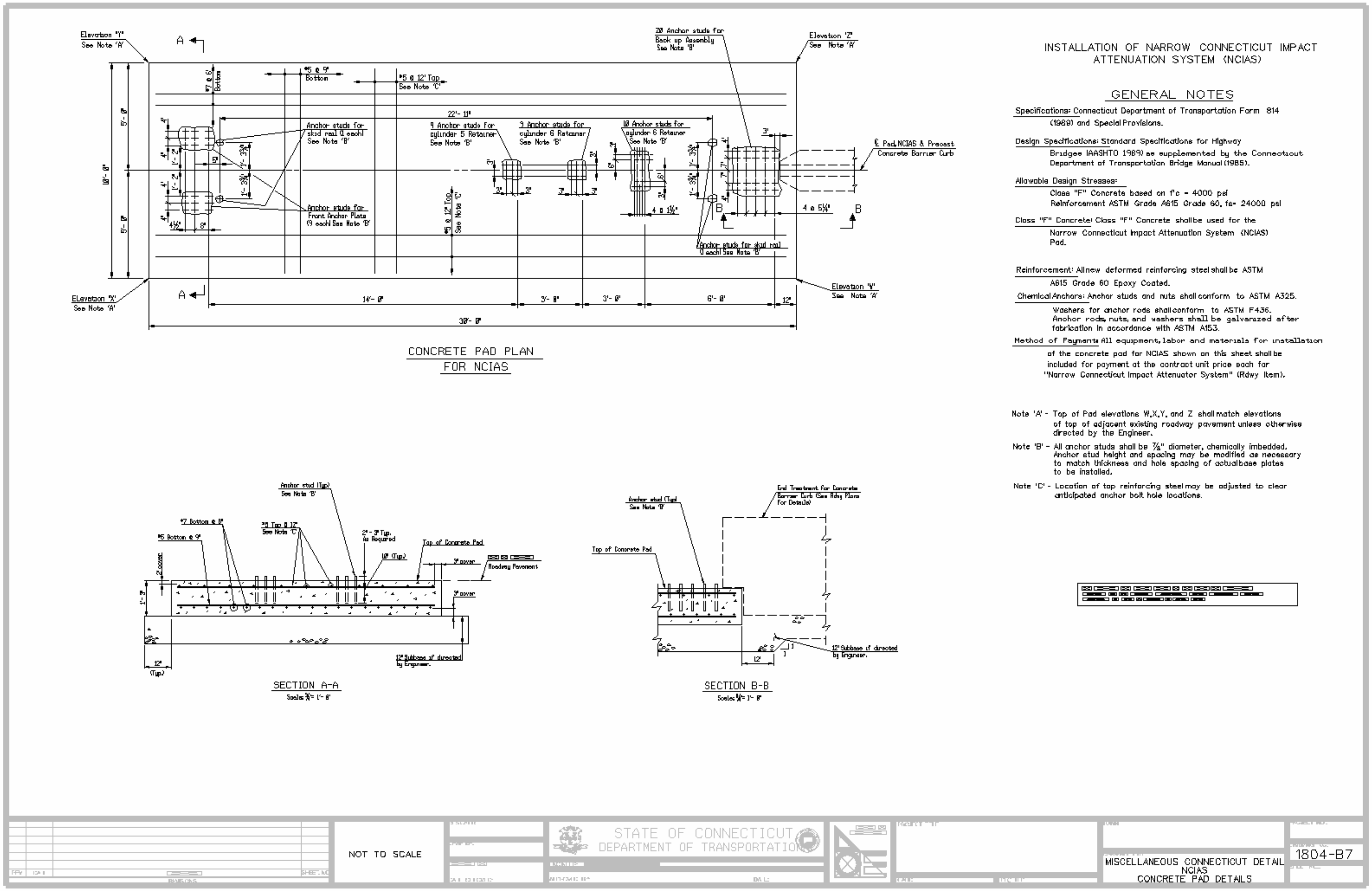
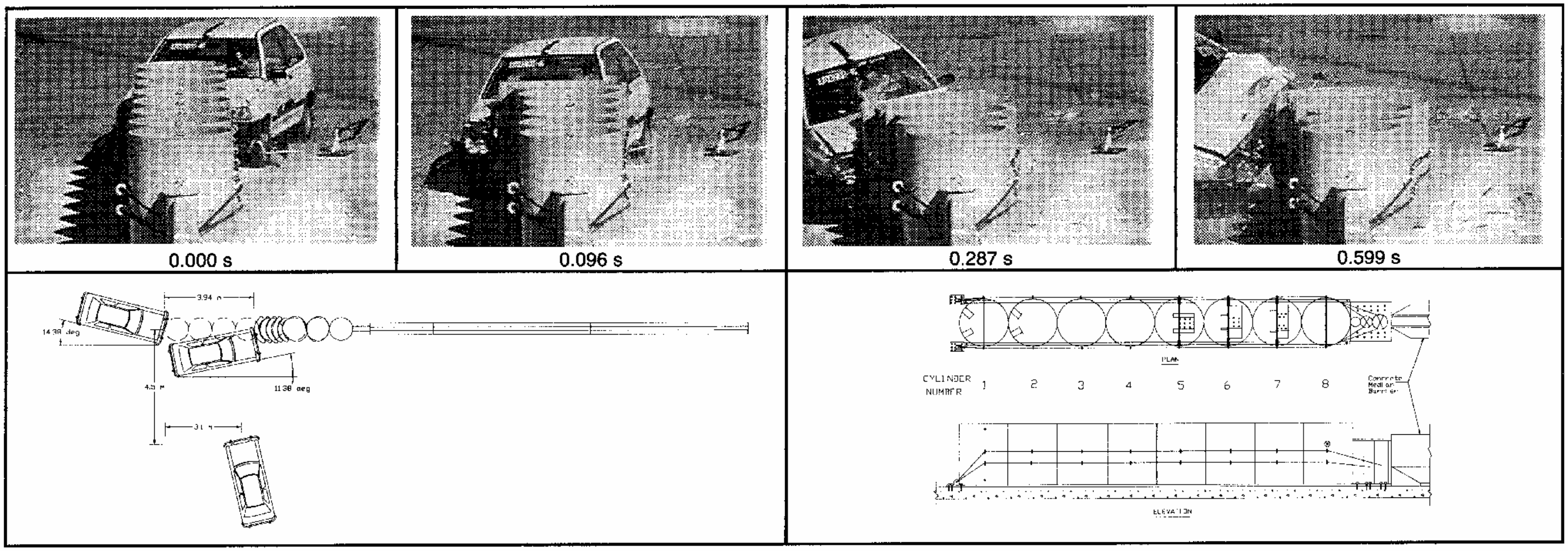


Figure A-7 Concrete Pad Details

APPENDIX B

Summary of Test Results and Typical Photos of NCHRP 350 Tests Performed

NCHRP 350 Test 3-32



General Information	
Test Agency	Texas Transportation Institute
Test No.	404231-2
Date	12/15/97
Test Article	
Type	Crash Cushion
Name or Manufacturer	Narrow Conn. Imp. Attn. System
Installation Length (m)	7.3
Size and/or dimension and material of key elements	8 each 914 O.D. x 1219 mm tall steel pipe cylinders of various wall thickness
Soil Type and Condition	Concrete pavement, dry
Test Vehicle	
Type	Production
Designation	820C
Model	1990 Ford Festiva
Mass (kg) Curb	810
Test Inertial	820
Dummy	75
Gross Static	895

Impact Conditions	
Speed (km/h)	98.9
Angle (deg)	14.4
Exit Conditions	
Speed (km/h)	12.6
Angle (deg)	11.4
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	10.0
y-direction	2.8
Ridedown Accelerations (g's)	
x-direction	-12.4
y-direction	-3.2
Max. 0.050-s Average (g's)	
x-direction	-12.7
y-direction	-2.1
z-direction	-2.1

Test Article Deflections (m)	
Dynamic	3.94
Permanent	3.44
Vehicle Damage	
Exterior	
VDS	11LFQ4
CDC	11LFEW3
Maximum Exterior Vehicle Crush (mm)	310
Interior	
OCDI	LF0000000
Max. Occ. Compart. Deformation (mm)	8
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	-109
Max. Pitch Angle (deg)	-8
Max. Roll Angle (deg)	29

Figure B1-1 Summary of Results for Test 3-32

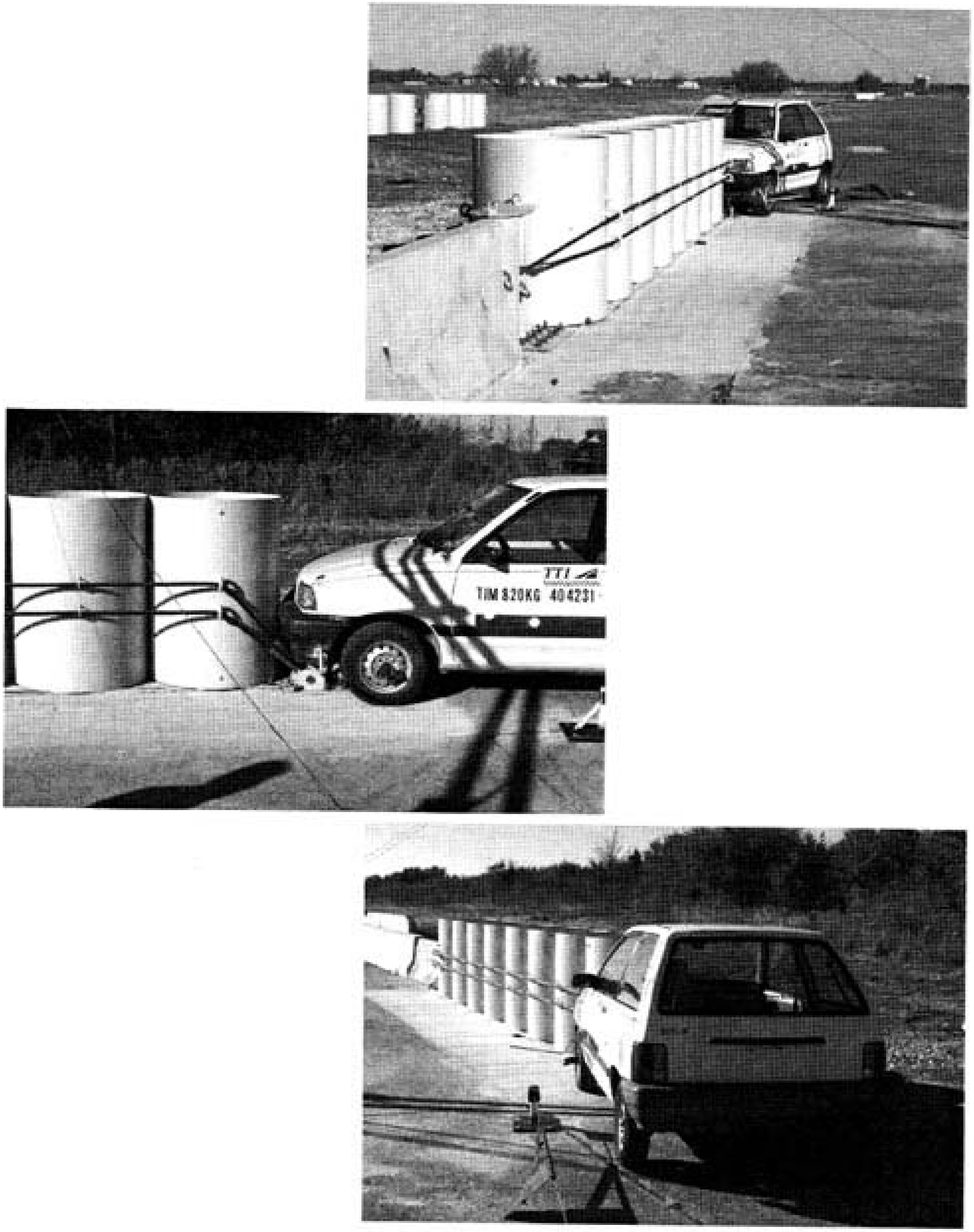


Figure B1-2 Vehicle/Installation Geometrics Before Test 3-32

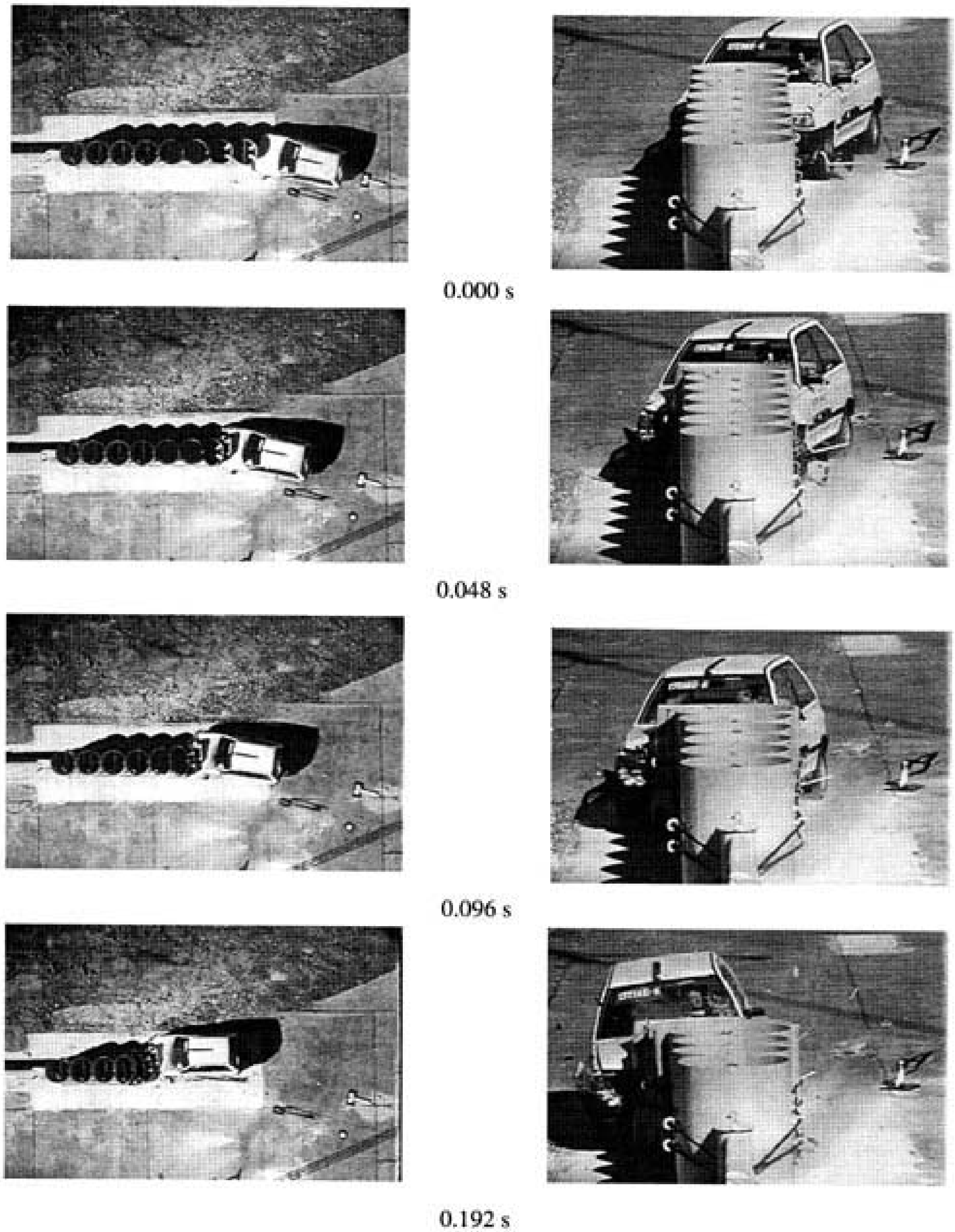
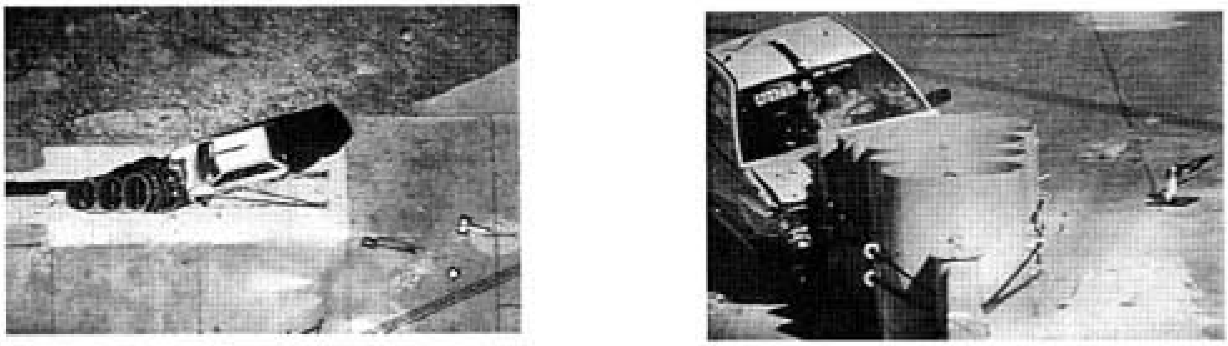
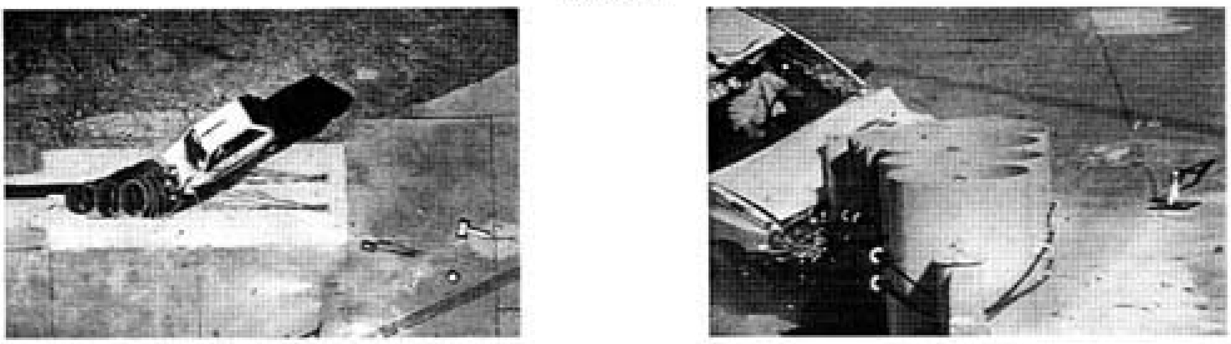


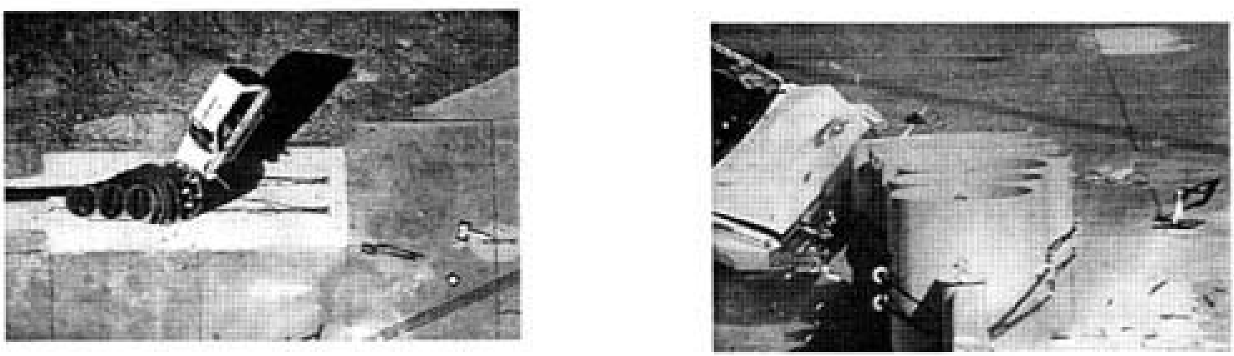
Figure B1-3 Sequential Photographs for Test 3-32 (overhead and frontal views)



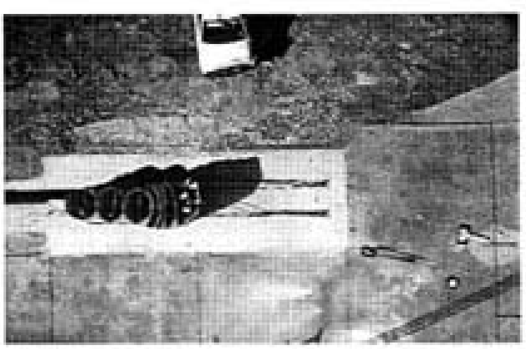
0.287 s



0.431 s



0.599 s



No Picture Available

2.395 s

Figure B1-4 Sequential Photographs for Test 3-32 continued (overhead and frontal views)

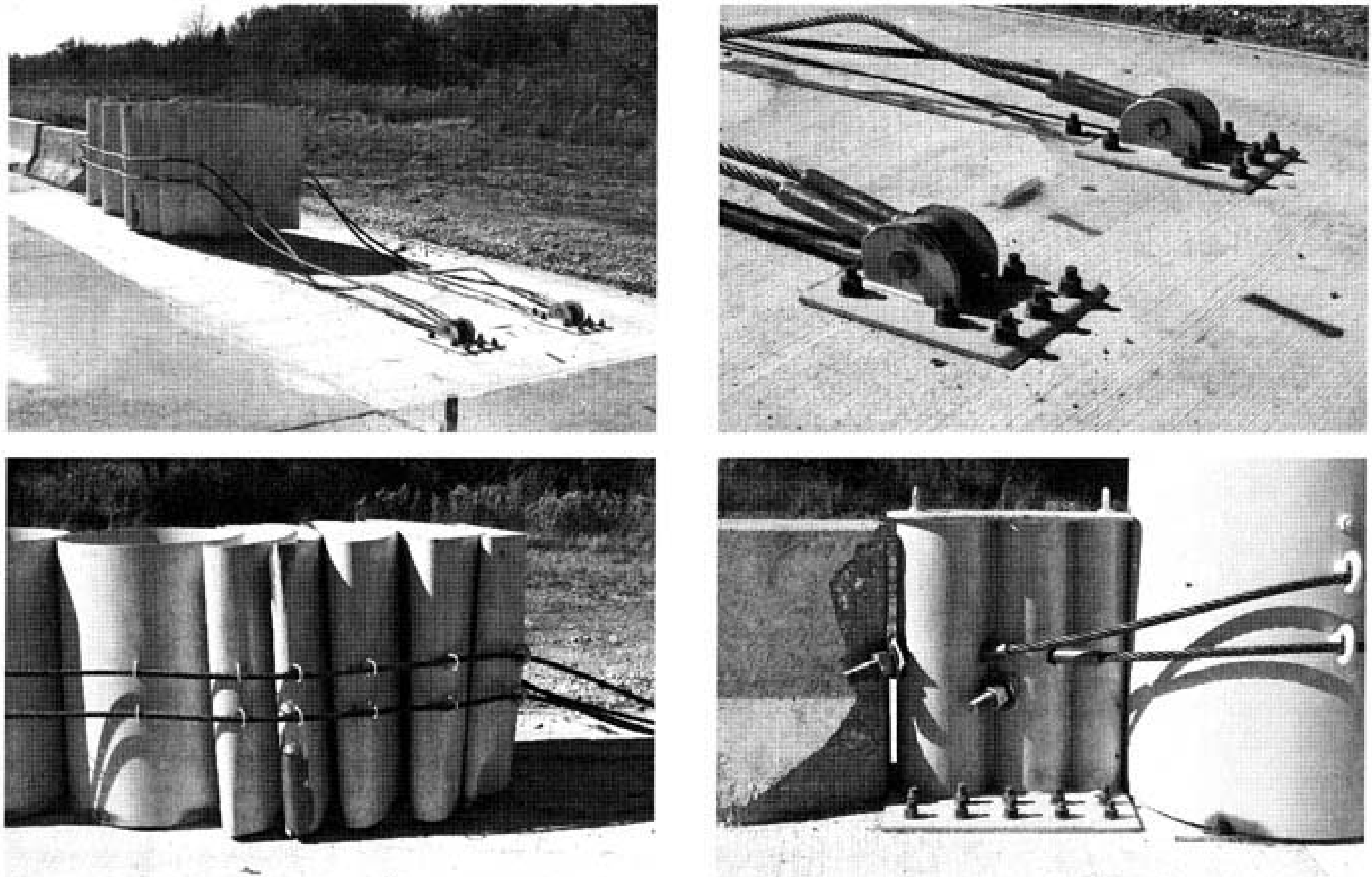


Figure B1-5 Installation After Test 3-32

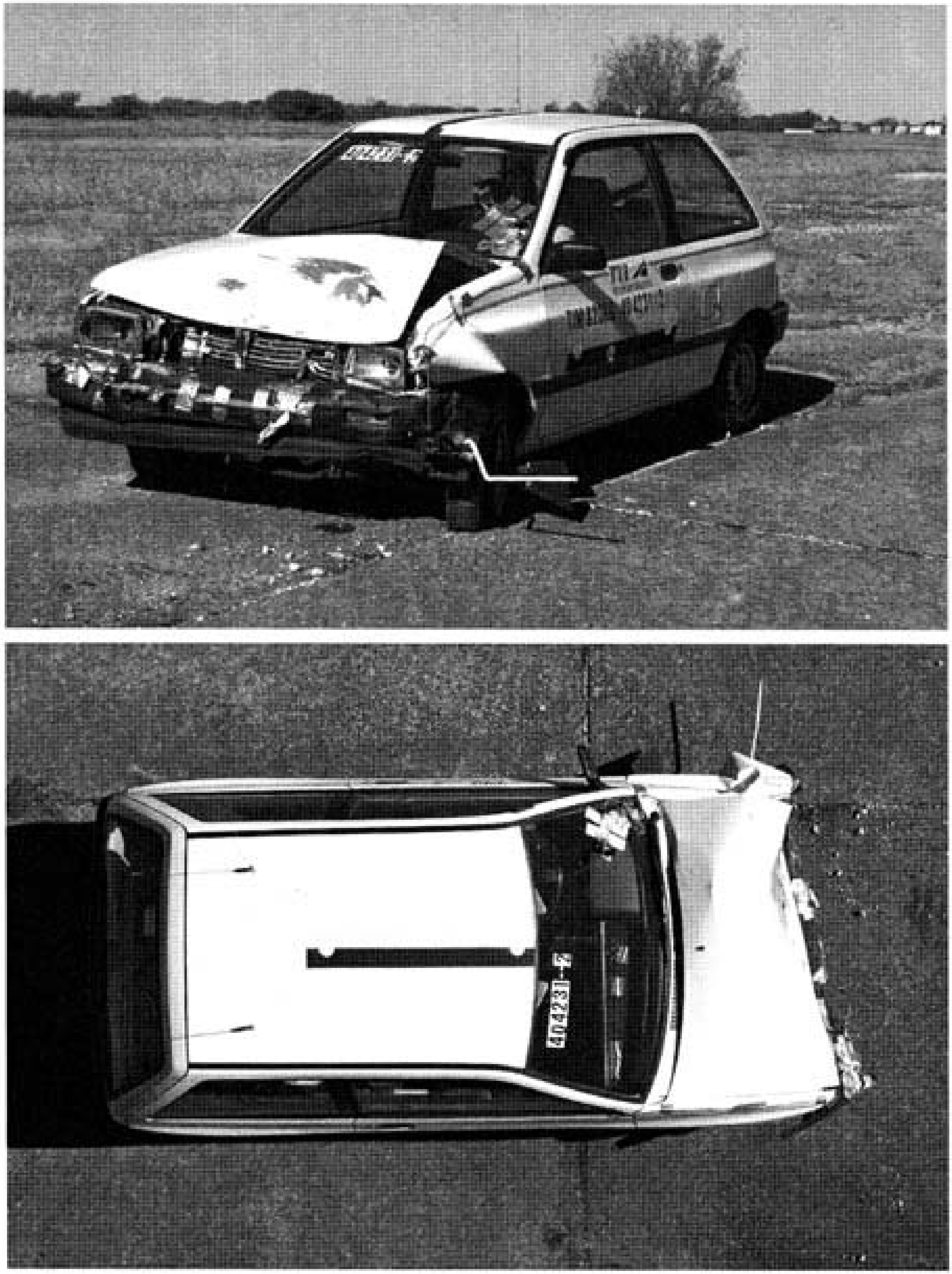
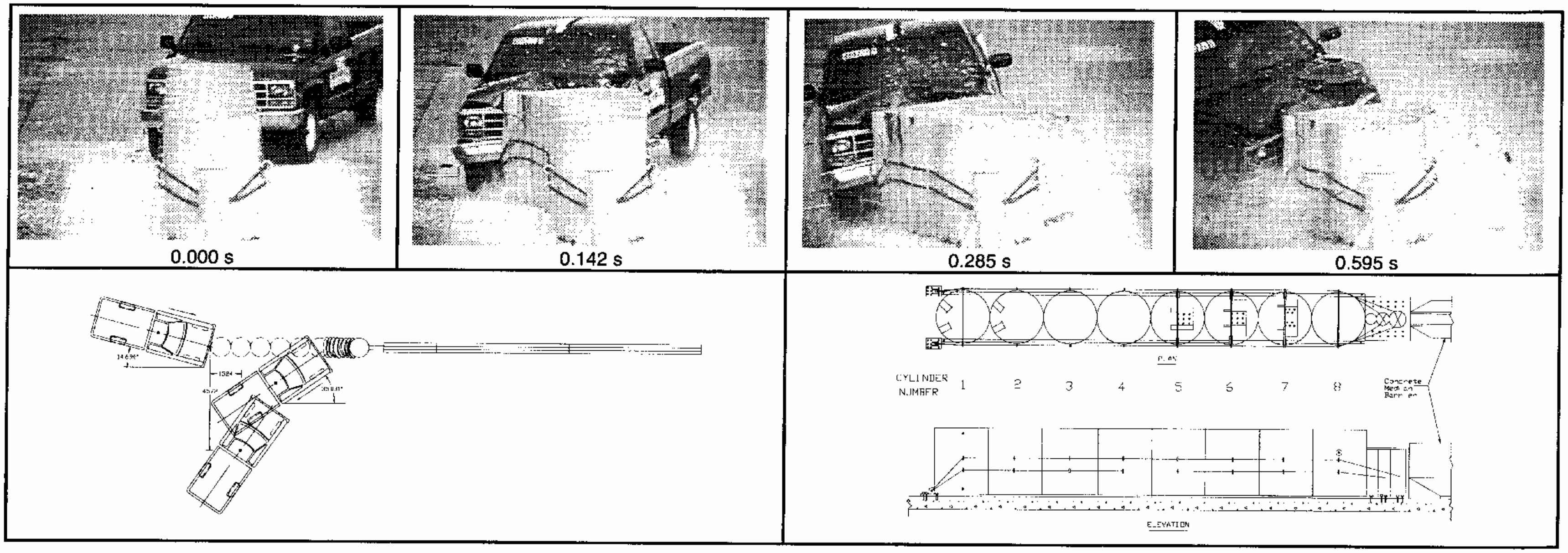


Figure B1-6 Vehicle After Test 3-32

NCHRP 350 Test 3-33



General Information
- Test Agency . . . . Texas Transportation Institute
- Test No. 404231-1
- Date 10/28/97

Test Article
- Type . . . . Crash Cushion
- Name . . . . Narrow Conn. Imp. Atten. System
- Installation Length (m) 7.35
- Size and/or dimension and material of key elements . . . . 8 each 914 O.D. x 1219 mm tall steel pipe cylinders of various wall thickness

Soil Type and Condition . . . . Concrete pavement, dry

Test Vehicle Production
- Type 2000P
- Designation . . . . 1992 Chevrolet 2500 pickup
- Model 2033
- Mass (kg) Curb 2000
  - Test Inertial 76
  - Dummy 2076
  - Gross Static . . . . .

Impact Conditions
- Speed (km/h) 99.3
- Angle (deg) 14.7

Exit Conditions
- Speed (km/h) 10.9
- Angle (deg) . . . . 35 behind

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 8.5
  - y-direction 3.0
- Ridedown Accelerations (g's)
  - x-direction . . . . -12.3
  - y-direction . . . . -5.9
- Max. 0.050-s Average (g's)
  - x-direction . . . . -10.4
  - y-direction . . . . -2.7
  - z-direction 2.4

Test Article Deflections (m)
- Dynamic 2.27
- Permanent 2.12

Vehicle Damage
- Exterior
  - VDS 12FD4
  - CDC 12FDEW3
- Maximum Exterior
  - Vehicle Crush (mm) 260
- Interior
  - OCDI FS0000000
- Max. Occ. Compart.
  - Deformation (mm) 0

Post-Impact Behavior
(during 1.0 s after impact)
- Max. Yaw Angle (deg) . . . . . . -72
- Max. Pitch Angle (deg) . . . . . . -7
- Max. Roll Angle (deg) 19

Figure B2-1 Summary of Results for Test 3-33

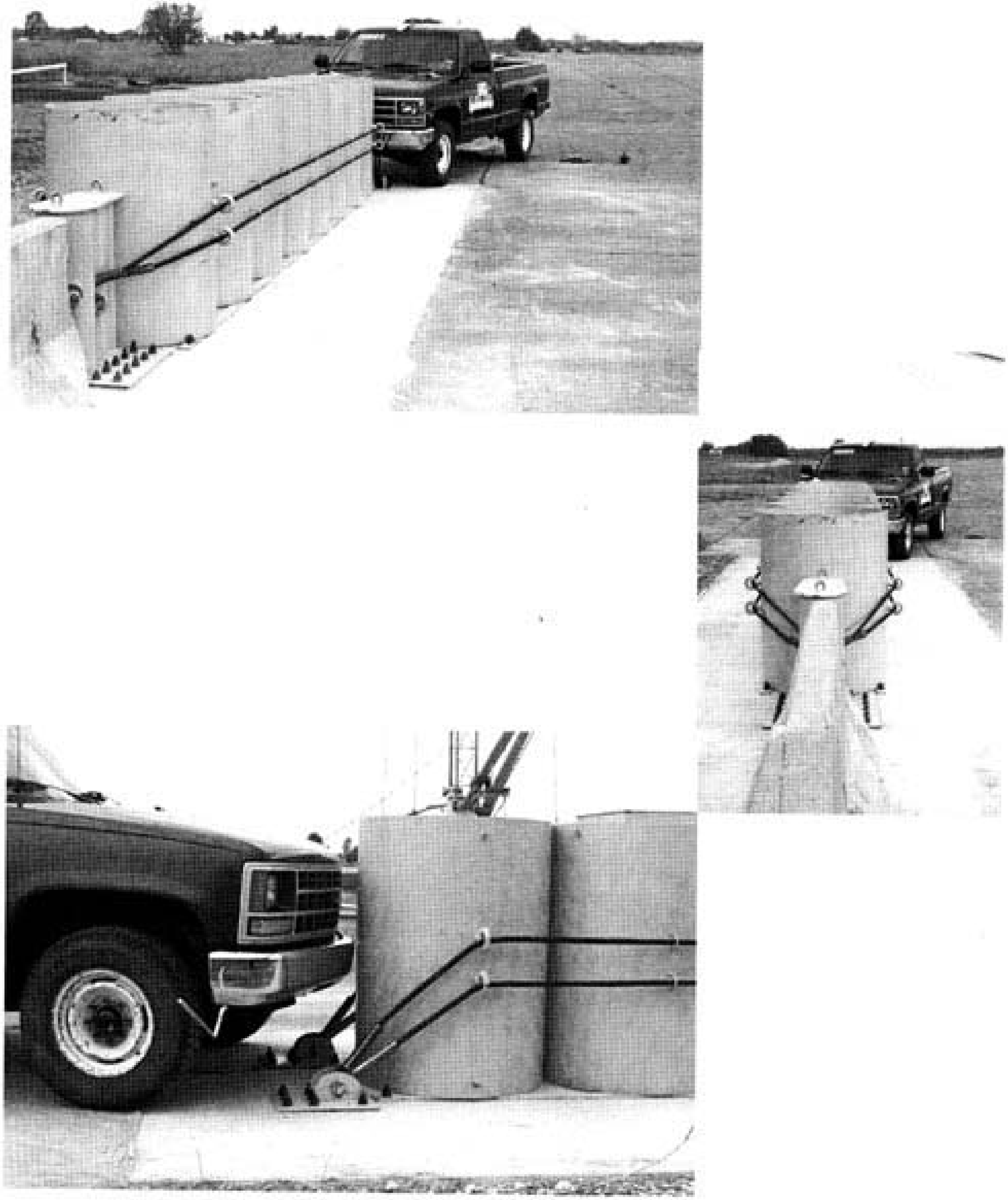
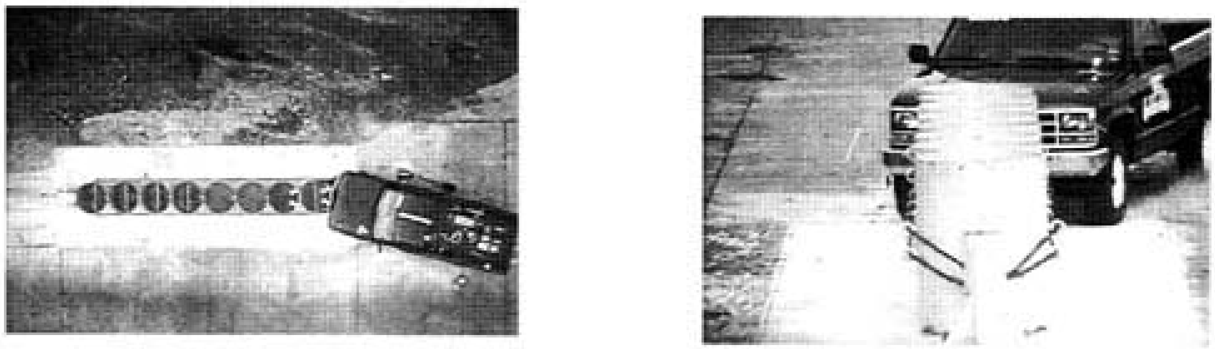
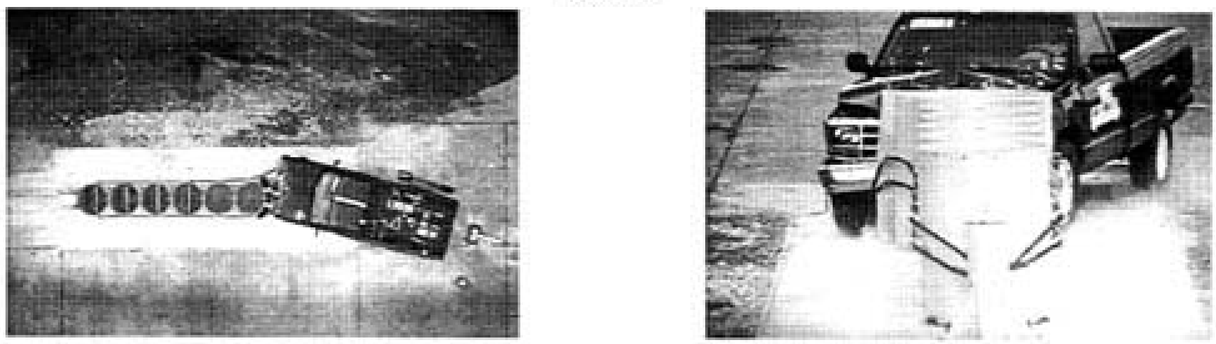


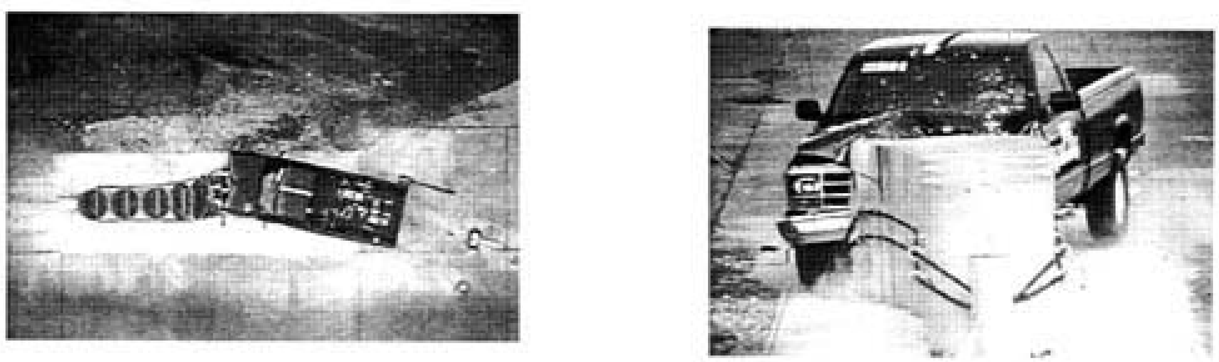
Figure B2-2 Vehicle/Installation Geometrics Before Test 3-33



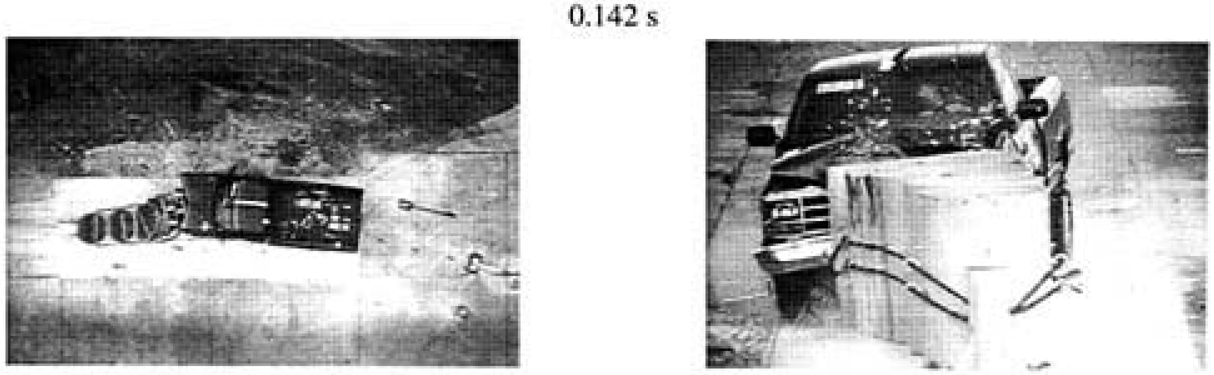
0.000 s



0.071 s

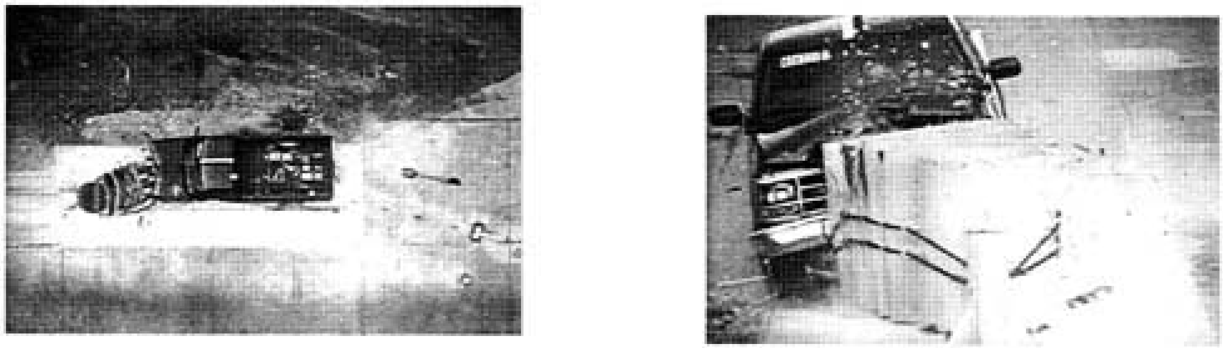


0.142 s

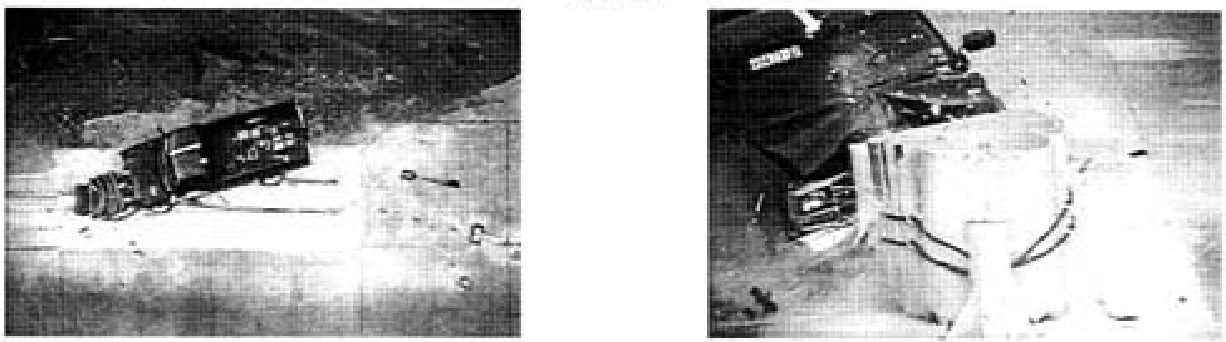


0.214 s

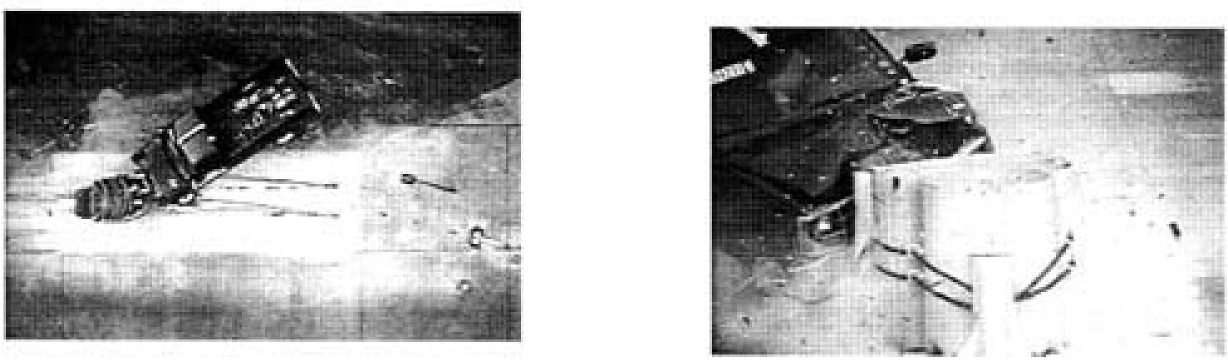
Figure B2-3 Sequential Photographs for Test 3-33 (overhead and frontal views)



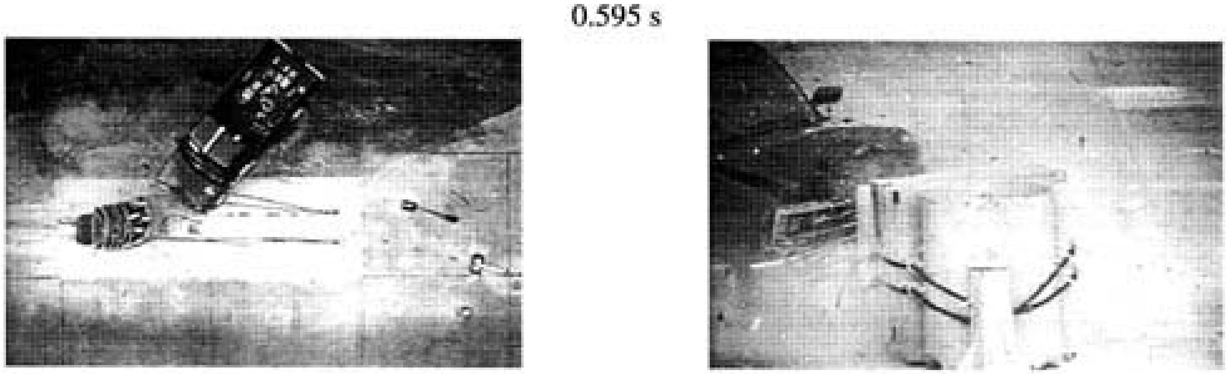
0.285 s



0.405 s



0.595 s



0.834 s

Figure B2-4 Sequential Photographs for Test 3-33 continued (overhead and frontal views)

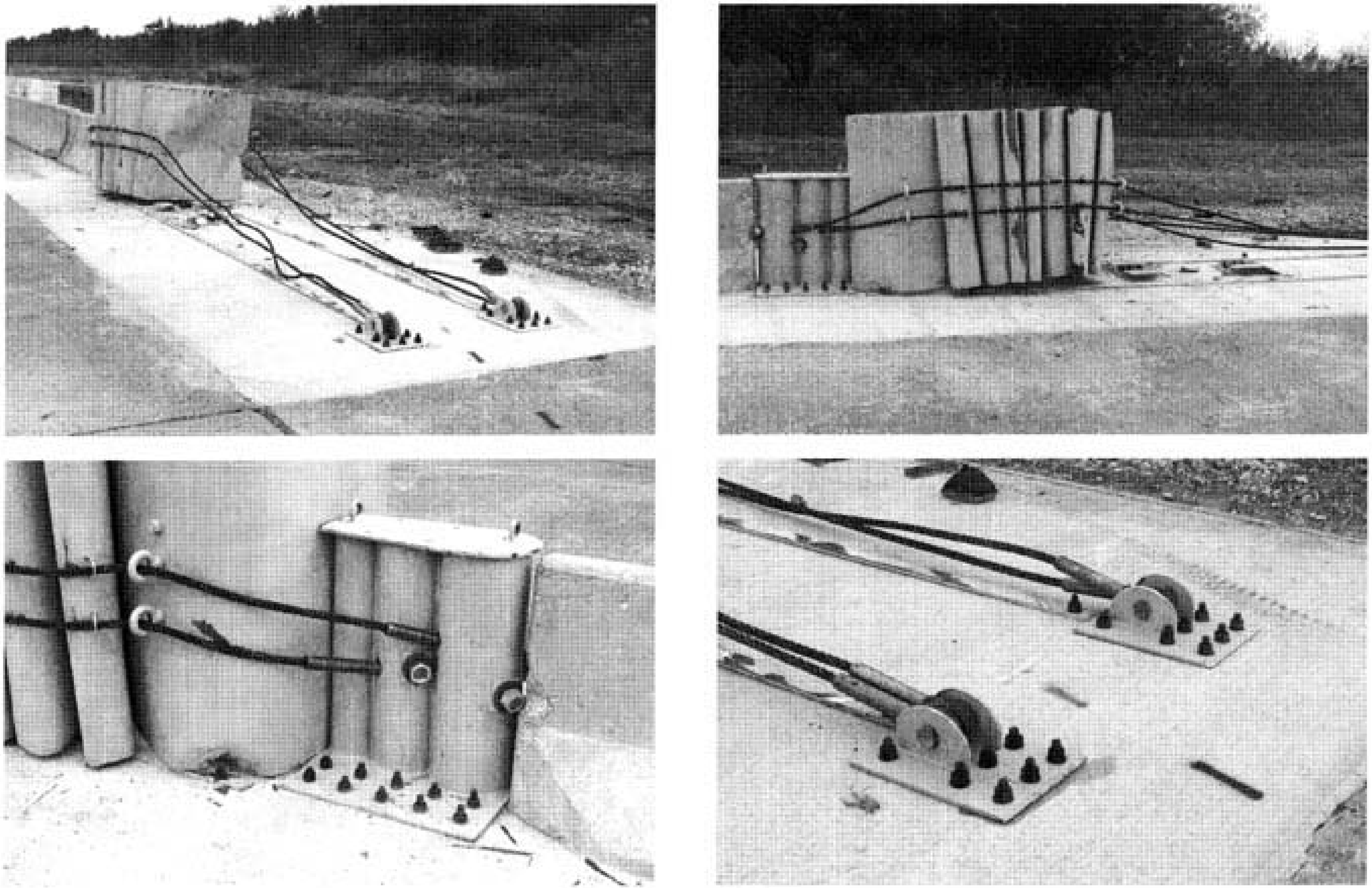


Figure B2-5 Installation After Test 3-33

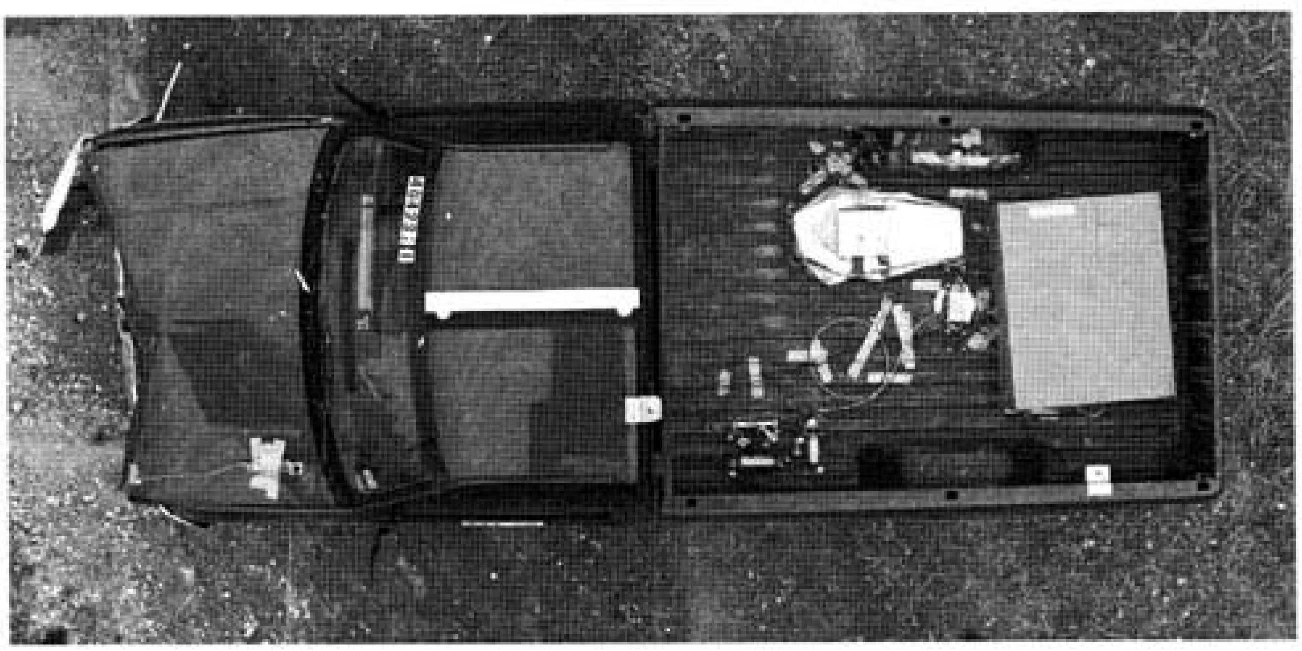
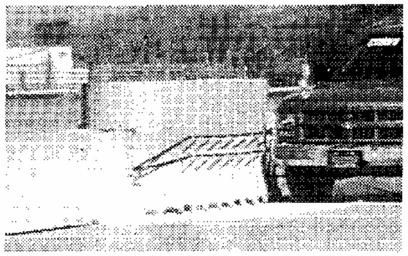
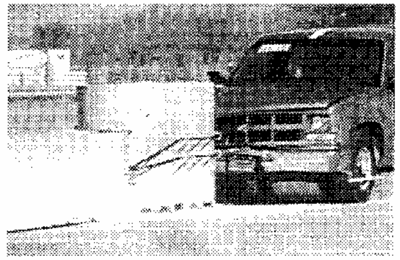


Figure B2-6 Vehicle After Test 3-33

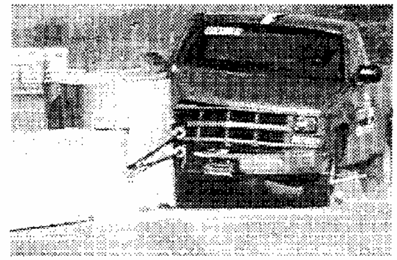
NCHRP 350 Test 3-37



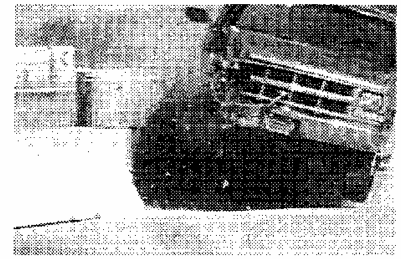
0.000 s



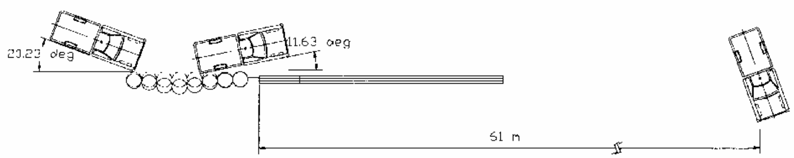
0.095 s

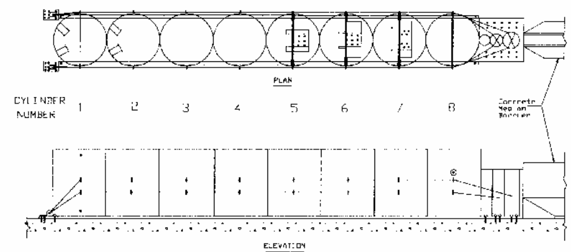


0.239 s



0.429 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	404231-3
Date	12/16/97
Test Article	
Type	Crash Cushion
Name	Narrow Conn. Imp. Atten. System
Installation Length (m)	7.31
Size and/or dimension and material of key elements	8 each 914 O.D. x 1219 mm tall steel pipe cylinders of various wall thickness
Soil Type and Condition	Concrete Pavement, dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1994 Chevrolet 2500 pickup
Mass (kg) Curb	1885
Test Inertial	2000
Dummy	76
Gross Static	2076

Impact Conditions	
Speed (km/h)	97.2
Angle (deg)	20.2
Exit Conditions	
Speed (km/h)	61.5
Angle (deg)	11.6
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.7
y-direction	5.4
Ridedown Accelerations (g's)	
x-direction	-17.7
y-direction	-19.5
Max. 0.050-s Average (g's)	
x-direction	-8.5
y-direction	-7.6
z-direction	7.4

Test Article Deflections (m)	
Dynamic	0.64
Permanent	0.44
Vehicle Damage	
Exterior	
VDS	01RFQ5
CDC	01FREK3 & 01RYEW3
Maximum Exterior Vehicle Crush (mm)	550
Interior	
OCDI	FS0103000
Max. Occ. Compart. Deformation (mm)	39
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	-25
Max. Pitch Angle (deg)	7
Max. Roll Angle (deg)	-11

Figure B3-1 Summary of Results for Test 3-37

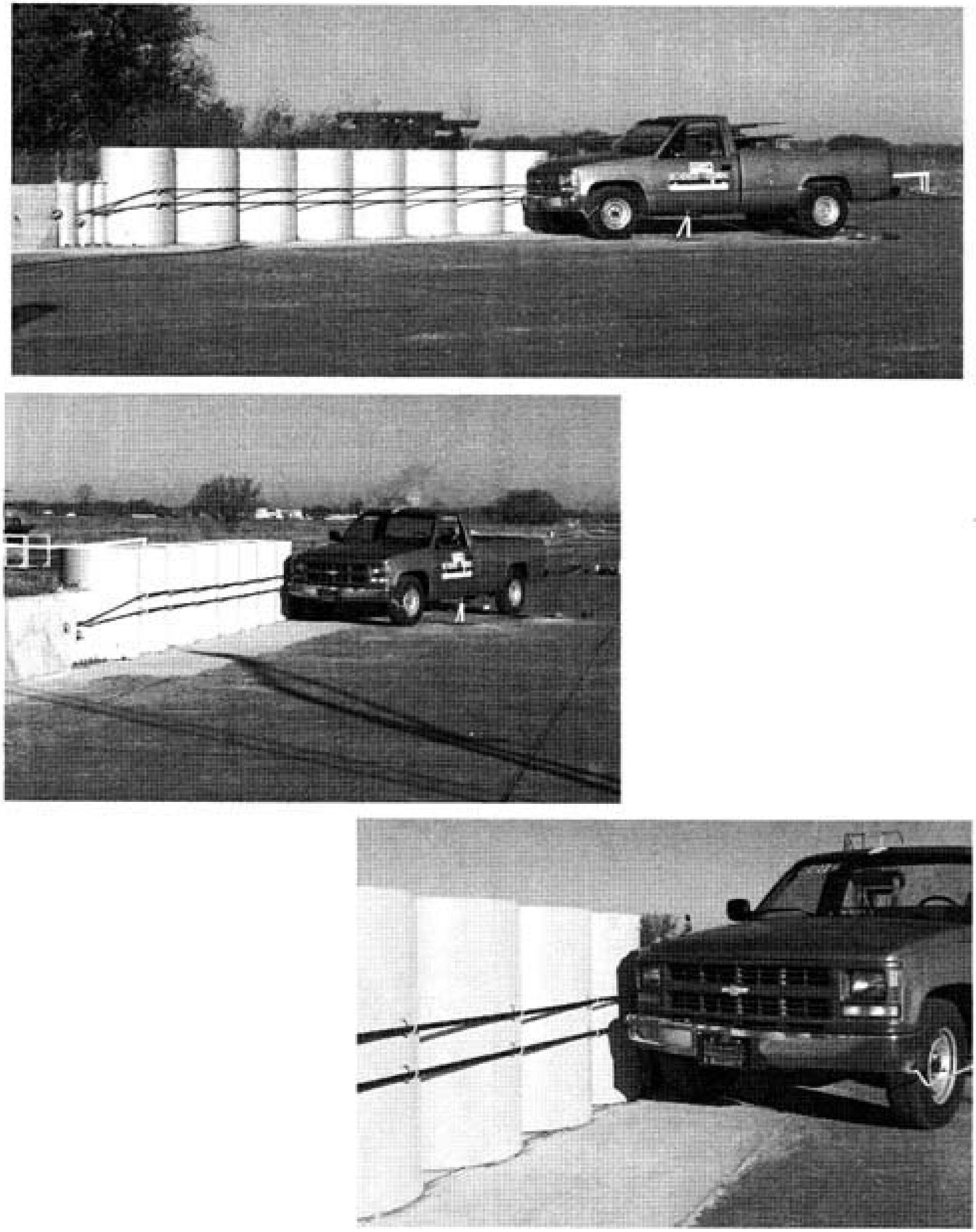


Figure B3-2 Vehicle/Installation Geometrics Before Test 3-37

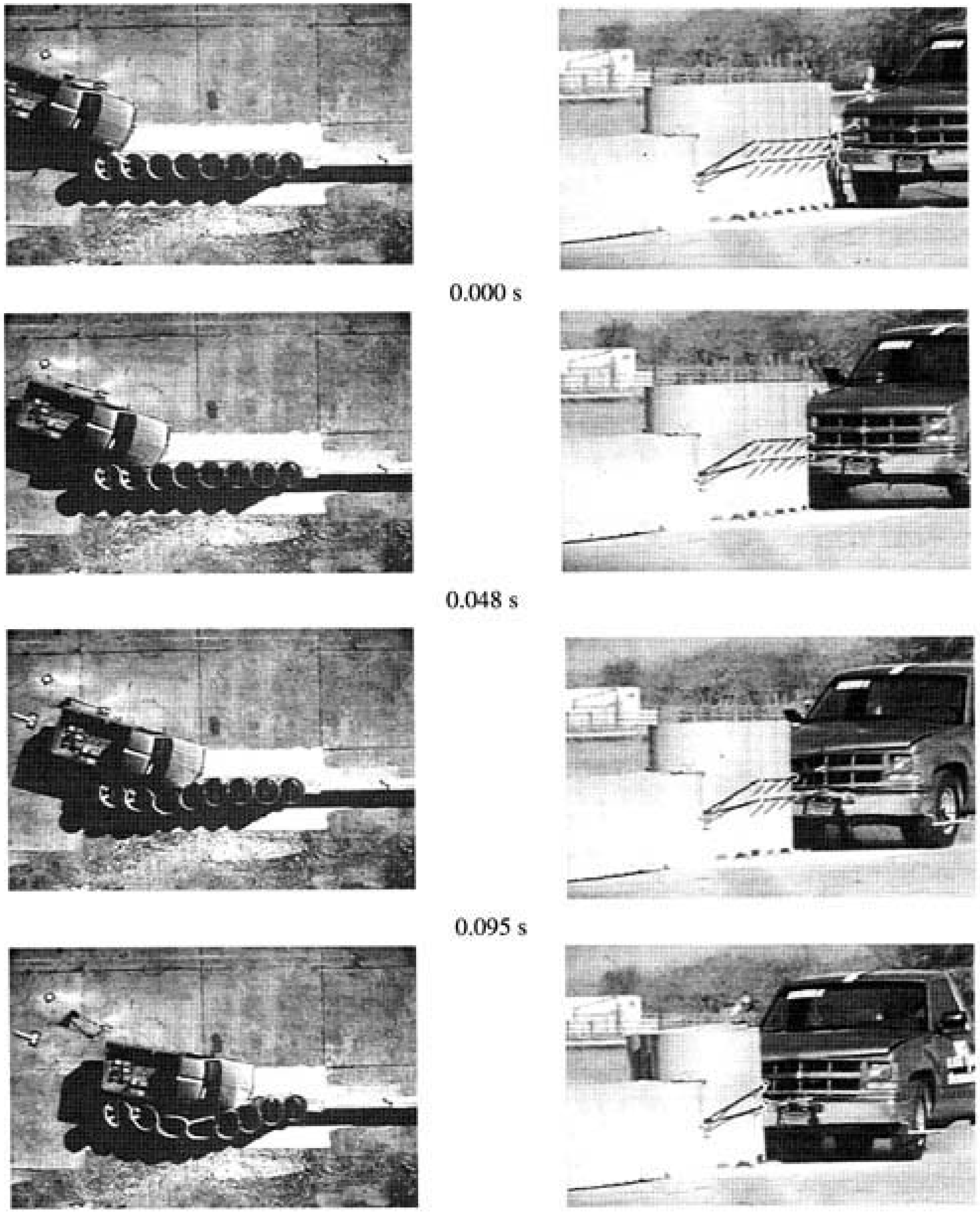
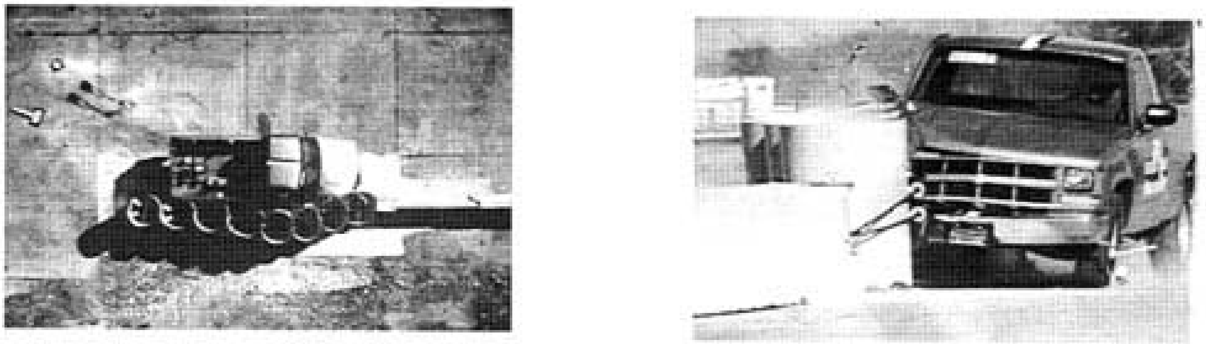
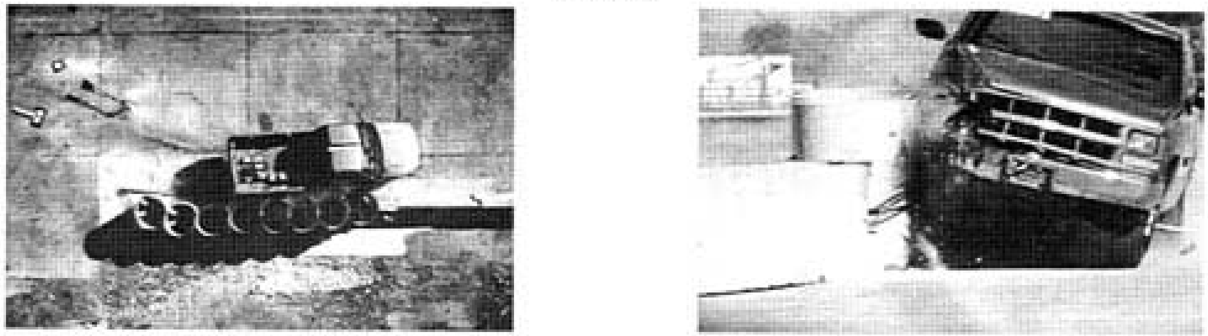


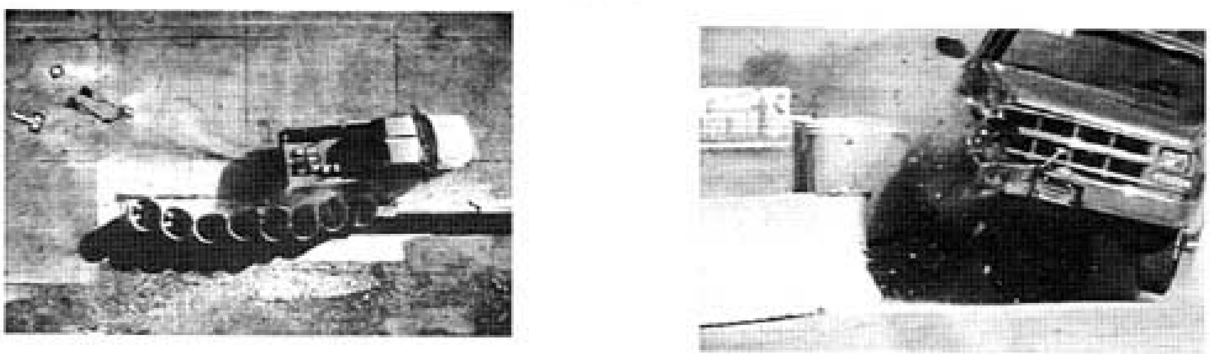
Figure B3-3 Sequential Photographs for Test 3-37 (overhead and frontal views)



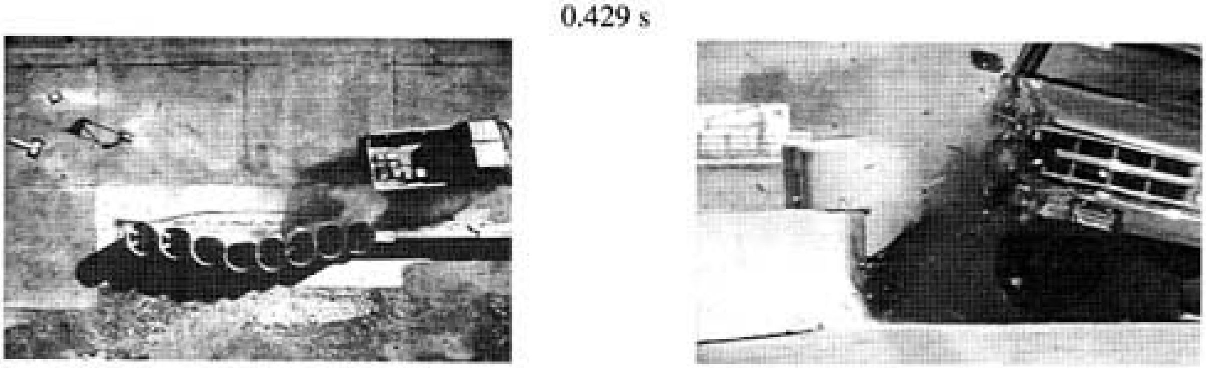
0.239 s



0.334 s



0.429 s



0.572 s

Figure B3-4 Sequential Photographs for Test 3-37 continued (overhead and frontal views)

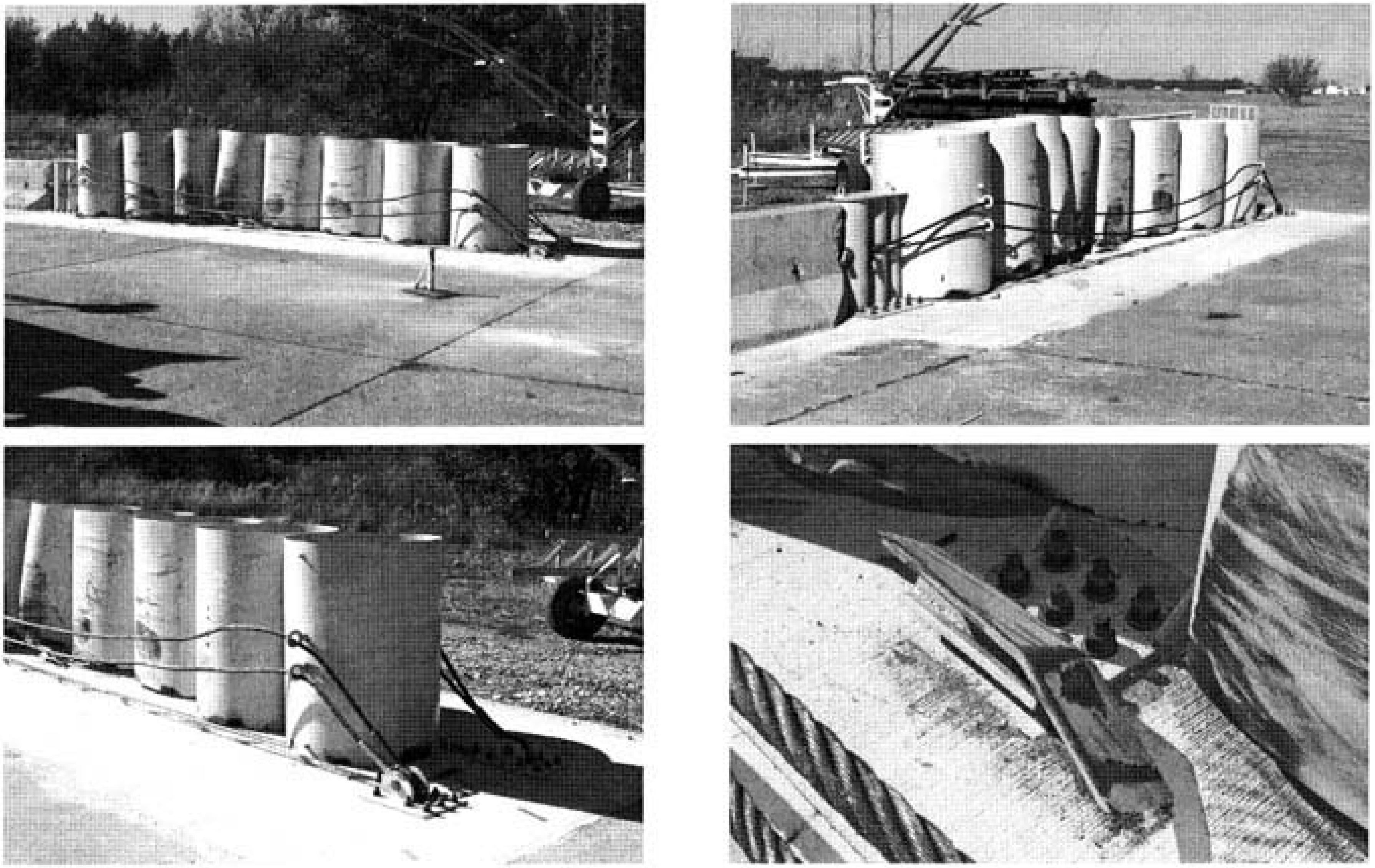


Figure B3-5 Installation After Test 3-37

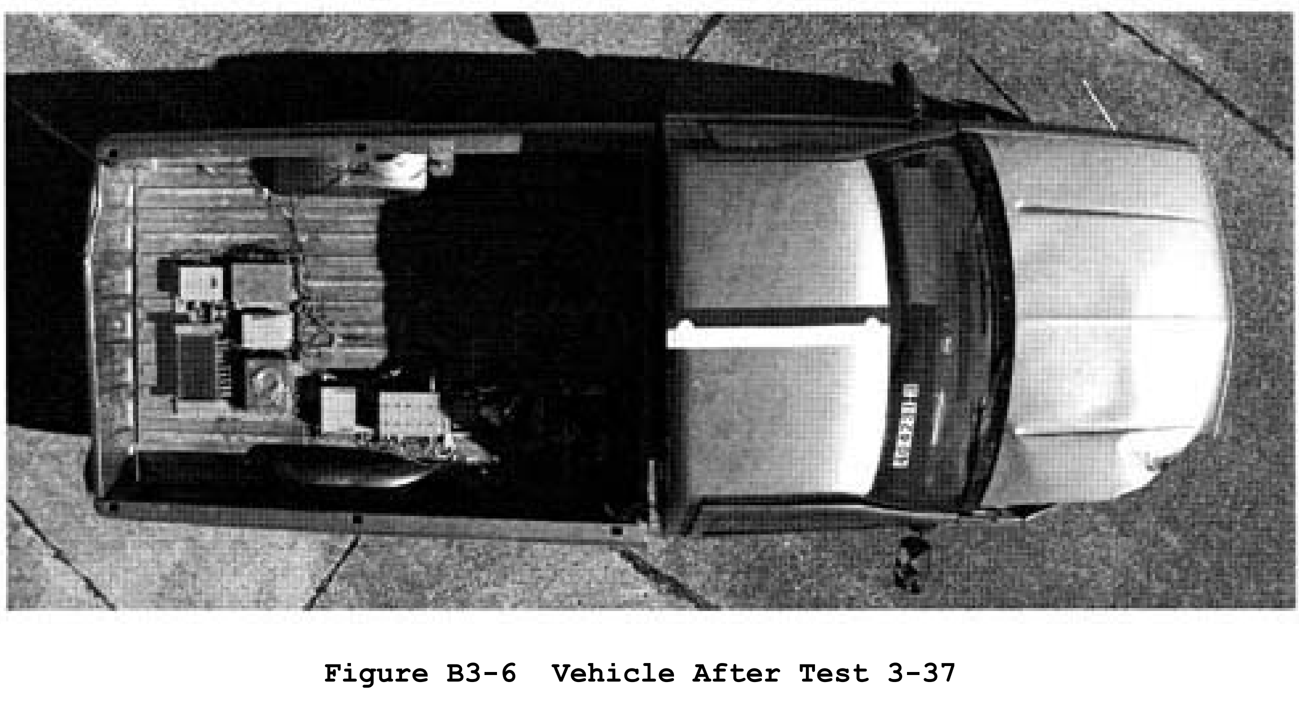
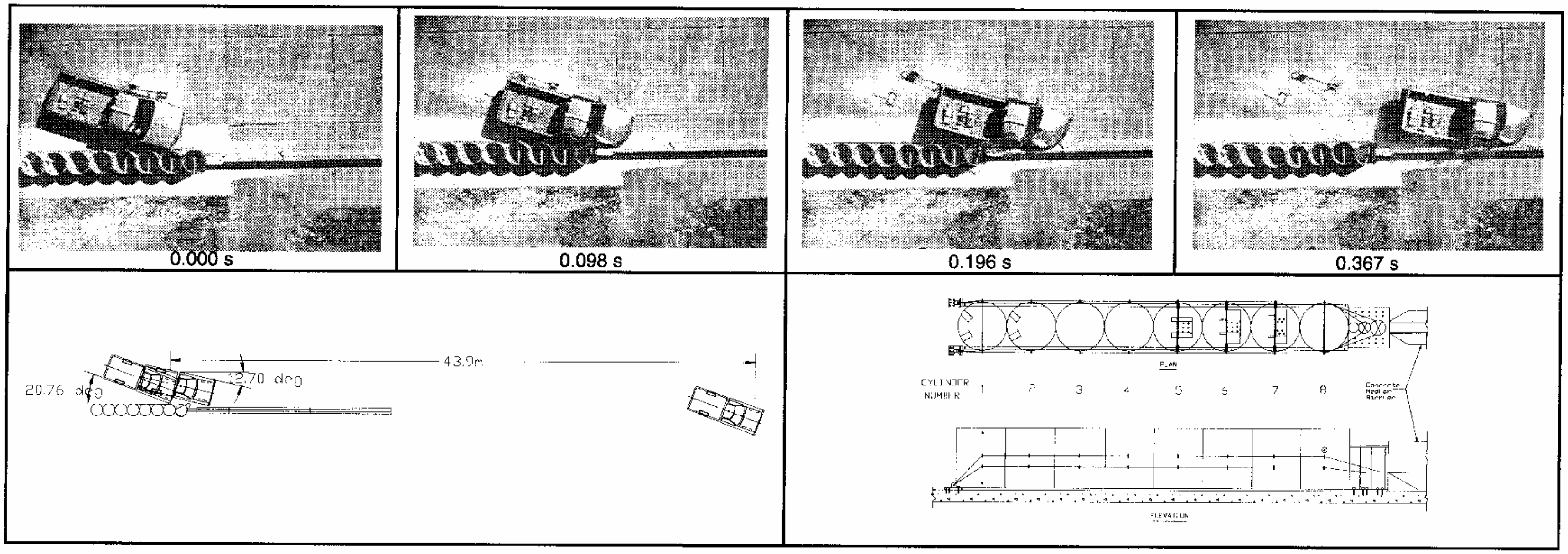


Figure B3-6 Vehicle After Test 3-37

NCHRP 350 Test 3-38(1)



General Information
- Test Agency .... Texas Transportation Institute
- Test No. 404231-4
- Date 03/02/98

Test Article
- Type .... Crash Cushion
- Name .... Narrow Conn. Imp. Atten. System
- Installation Length (m) 7.31
- Material or Key Elements .... 8 each 914 O.D. x 1219 mm Tall Steel Pipe Cylinders of Various Wall Thickness

Soil Type and Condition .... Concrete Pavement, Dry

Test Vehicle
- Type .... Production
- Designation 2000P
- Model .... 1994 Chevrolet 2500 Pickup Truck
- Mass (kg) Curb 1864
  - Test Inertial 2000
  - Dummy 75
  - Gross Static 2075

Impact Conditions
- Speed (km/h) 95.9
- Angle (deg) 20.8

Exit Conditions
- Speed (km/h) 67.7
- Angle (deg) 12.7

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 8.9
  - y-direction 4.7
- Ridedown Accelerations (g's)
  - x-direction .... -13.1
  - y-direction .... -11.7
- Max. 0.050-s Average (g's)
  - x-direction .... -8.8
  - y-direction .... -9.0
  - z-direction 4.7

Test Article Deflections (m)
- Dynamic .... N/A
- Permanent 0.35

Vehicle Damage
- Exterior
  - VDS 01RFQ7
  - CDC .... 01FZEK4 & 01RYEW4
- Maximum Exterior Vehicle Crush (mm) 320
- Interior
  - OCDI FS1038010
- Max. Occ. Compart. Deformation (mm) 0

Post-Impact Behavior
(during 1.0 s after impact)
- Max. Yaw Angle (deg) 11
- Max. Pitch Angle (deg) ...... -11
- Max. Roll Angle (deg) .... -19

Figure B4-1 Summary of Results for Test 3-38(1)

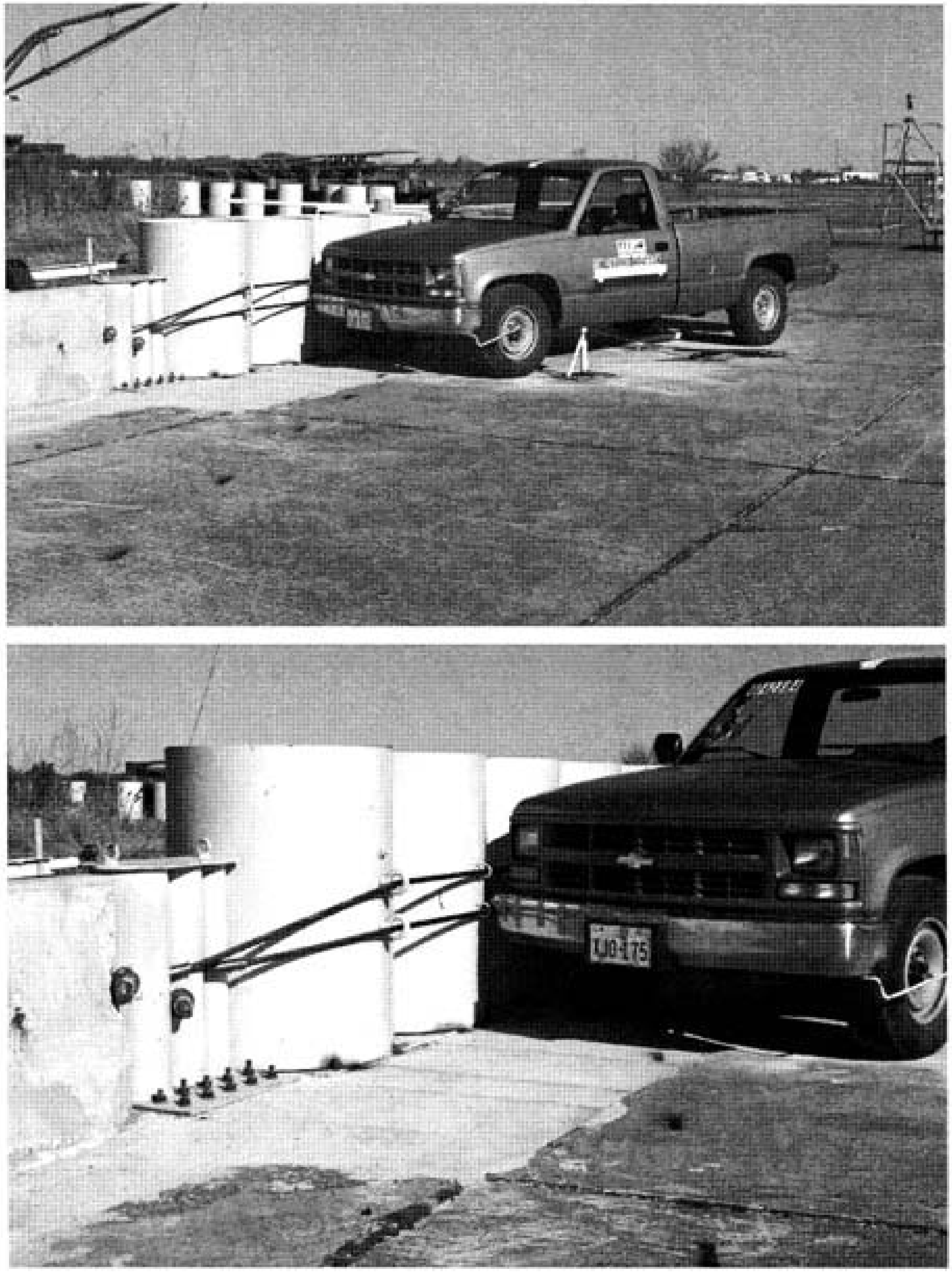


Figure B4-2 Vehicle/Installation Geometrics Before Test 3-38(1)

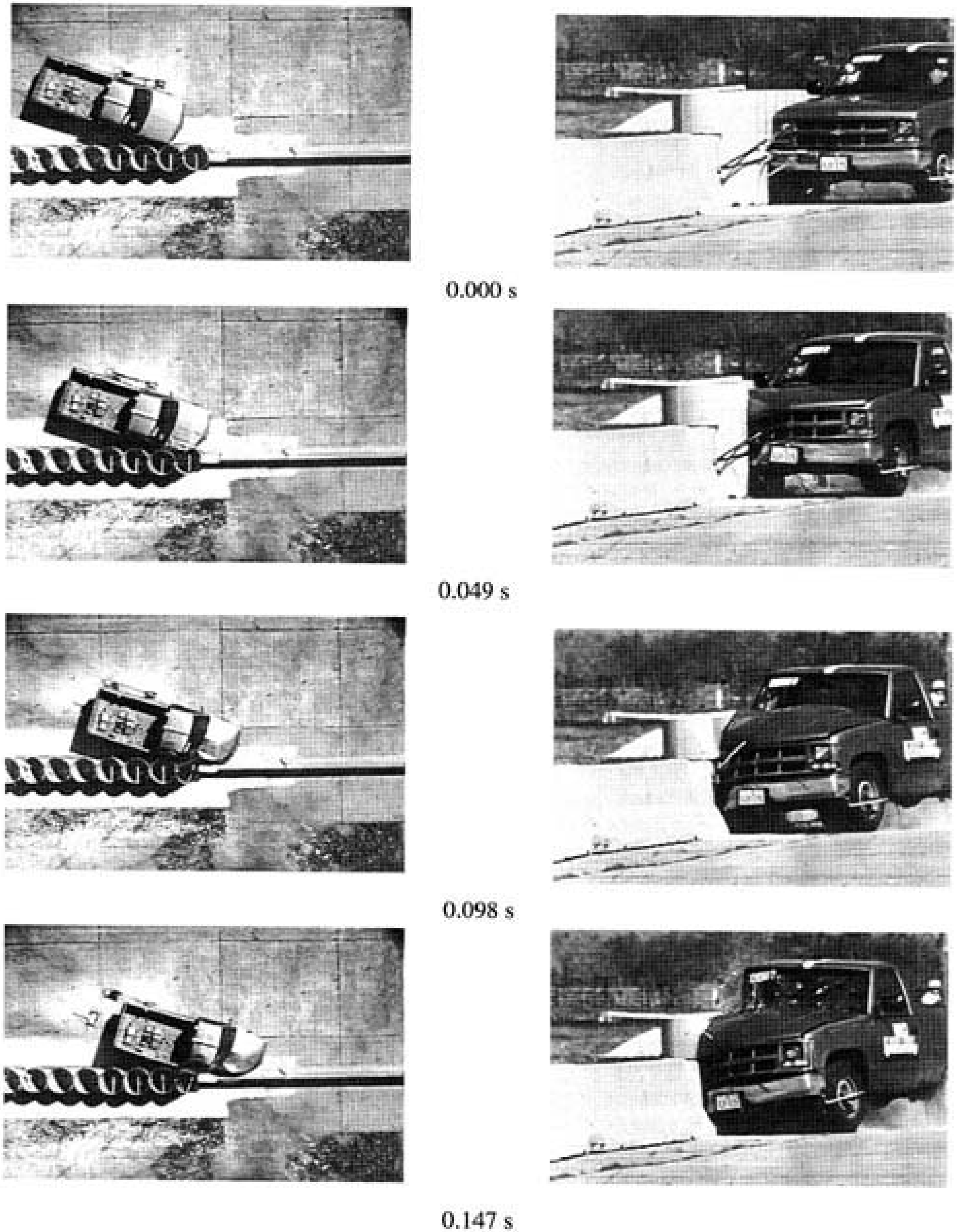
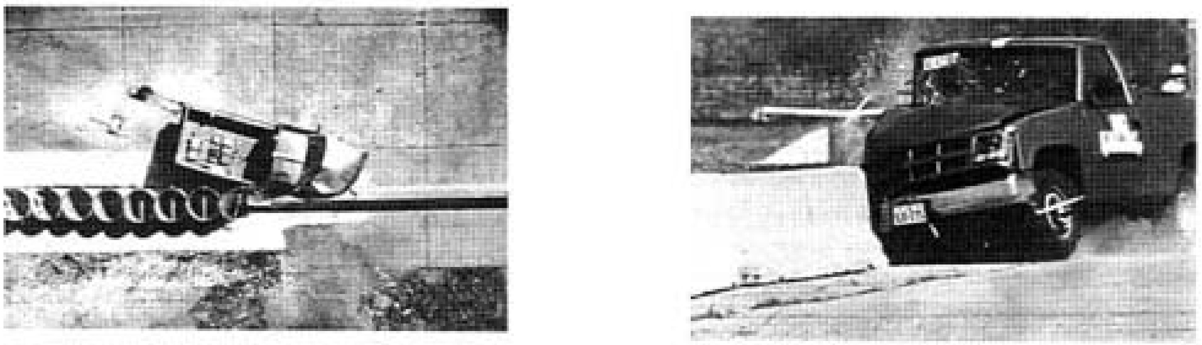
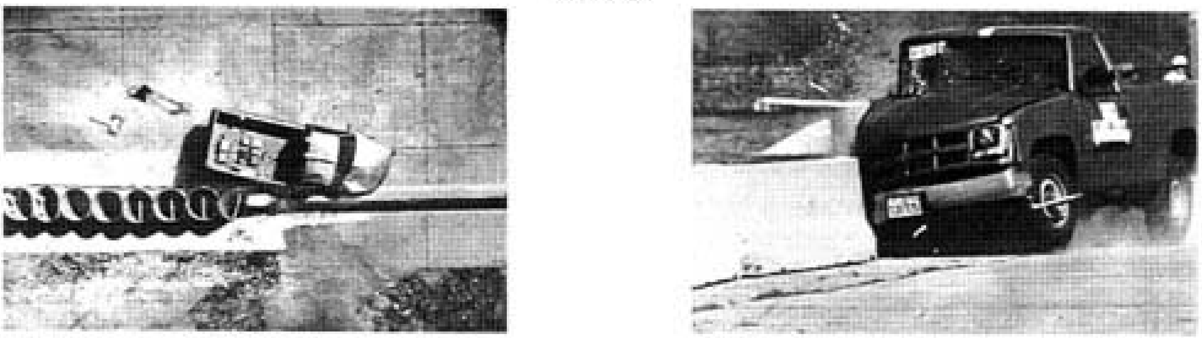


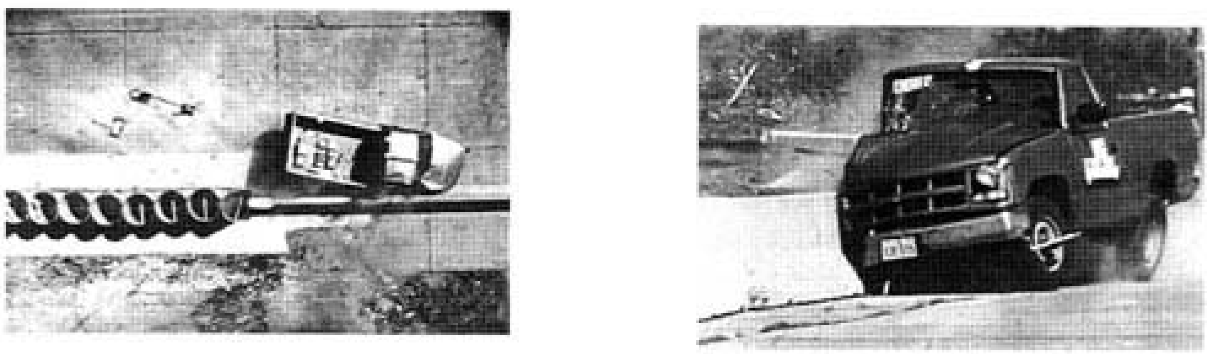
Figure B4-3 Sequential Photographs for Test 3-38(1) (overhead and frontal views)



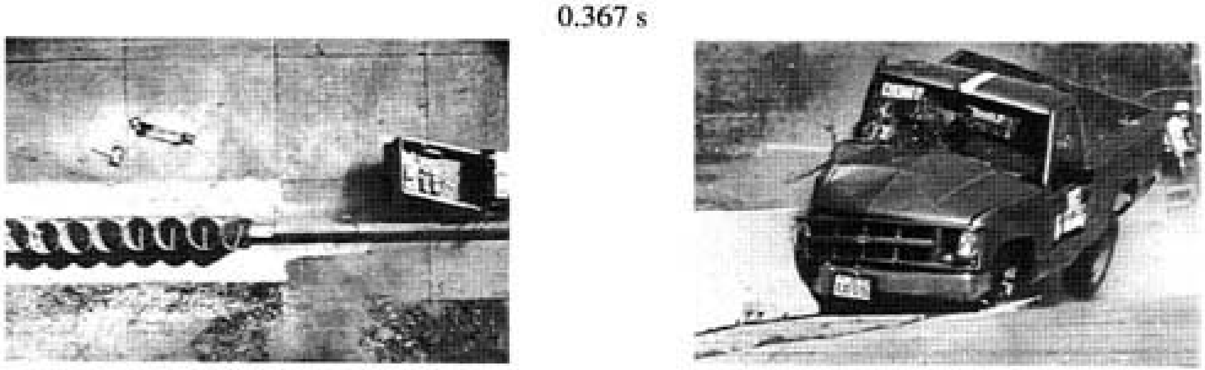
0.196 s



0.245 s



0.367 s



0.539 s

Figure B4-4 Sequential Photographs for Test 3-38(1) continued (overhead and frontal views)

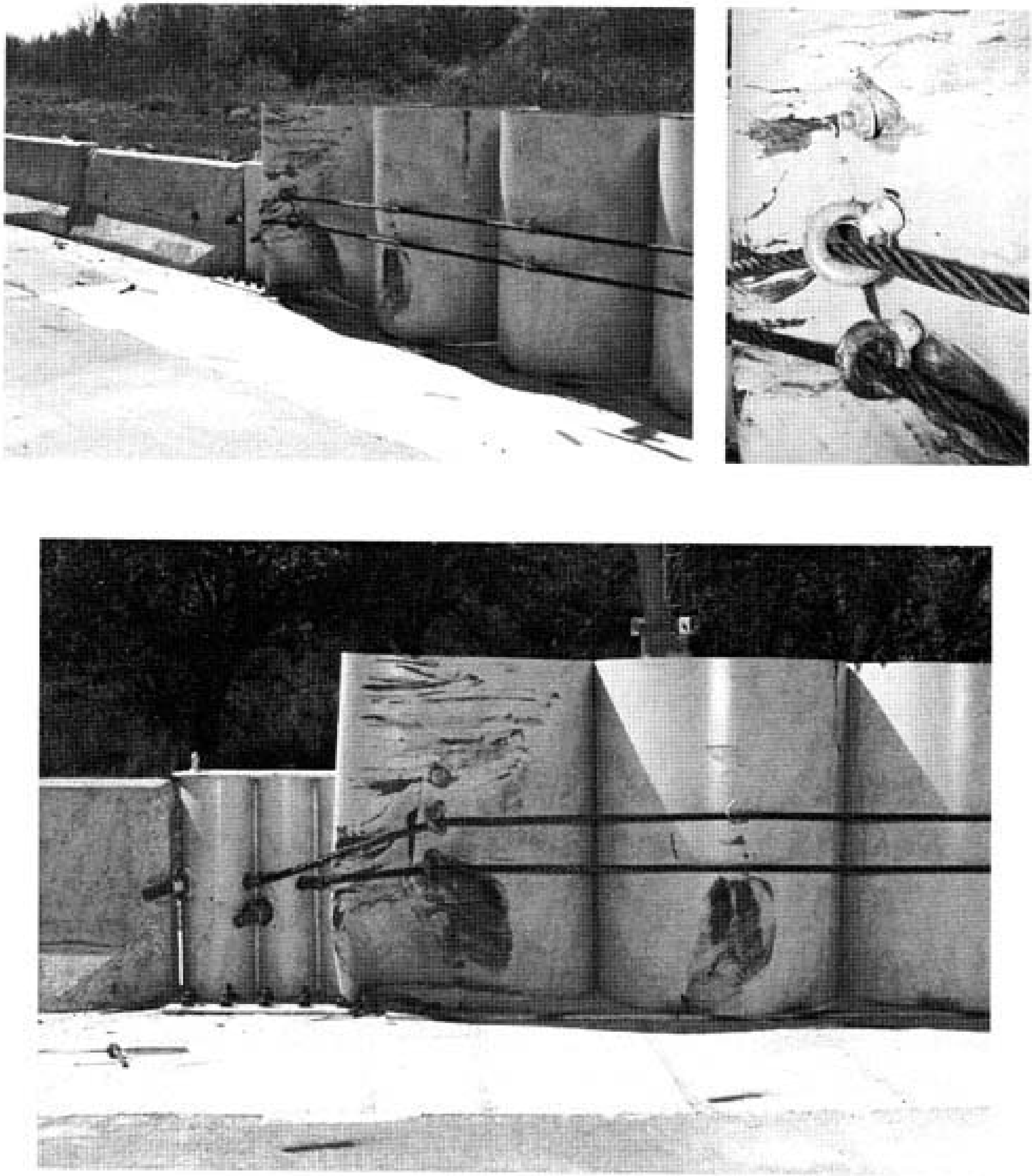


Figure B4-5 Installation After Test 3-38(1)

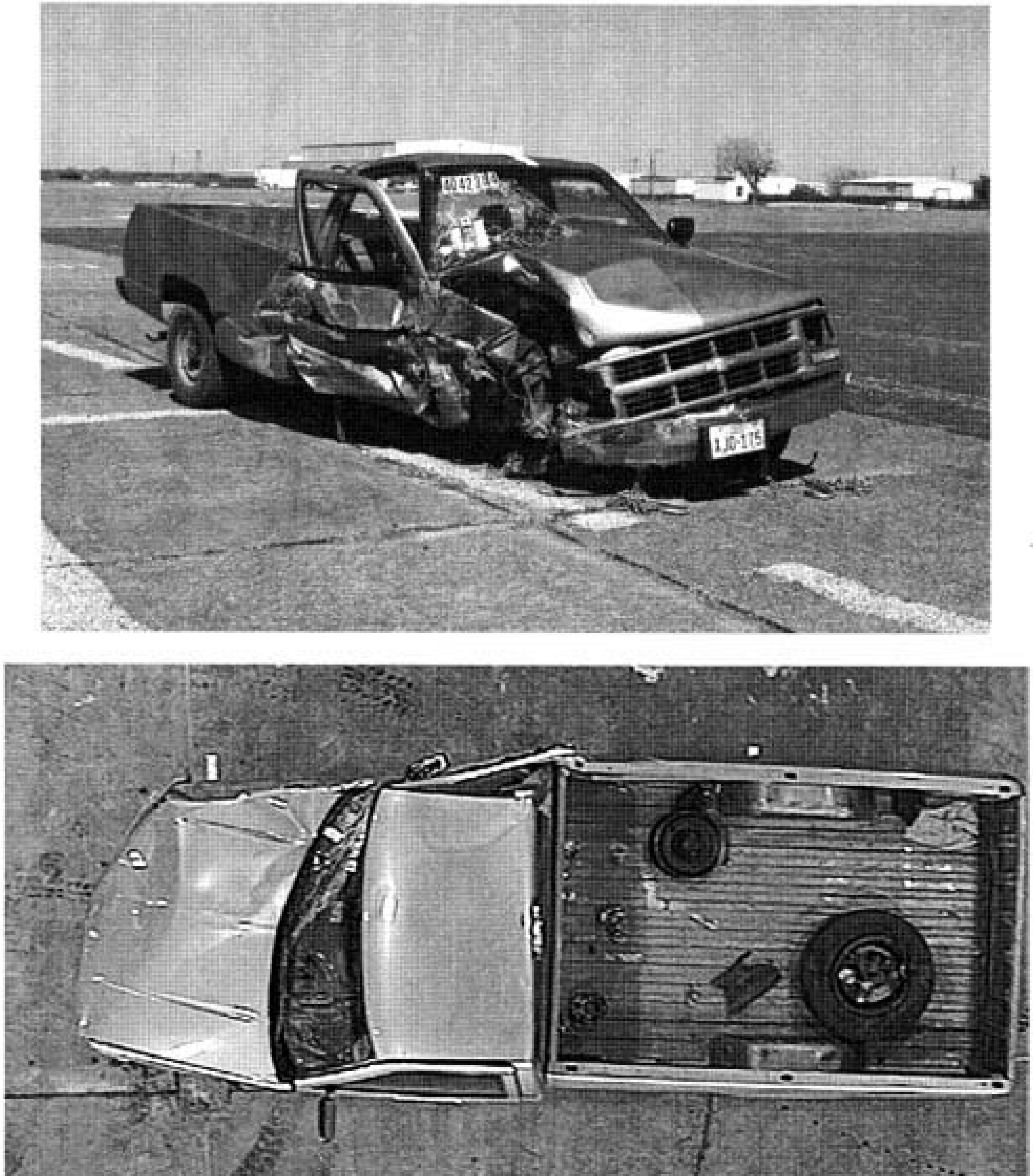
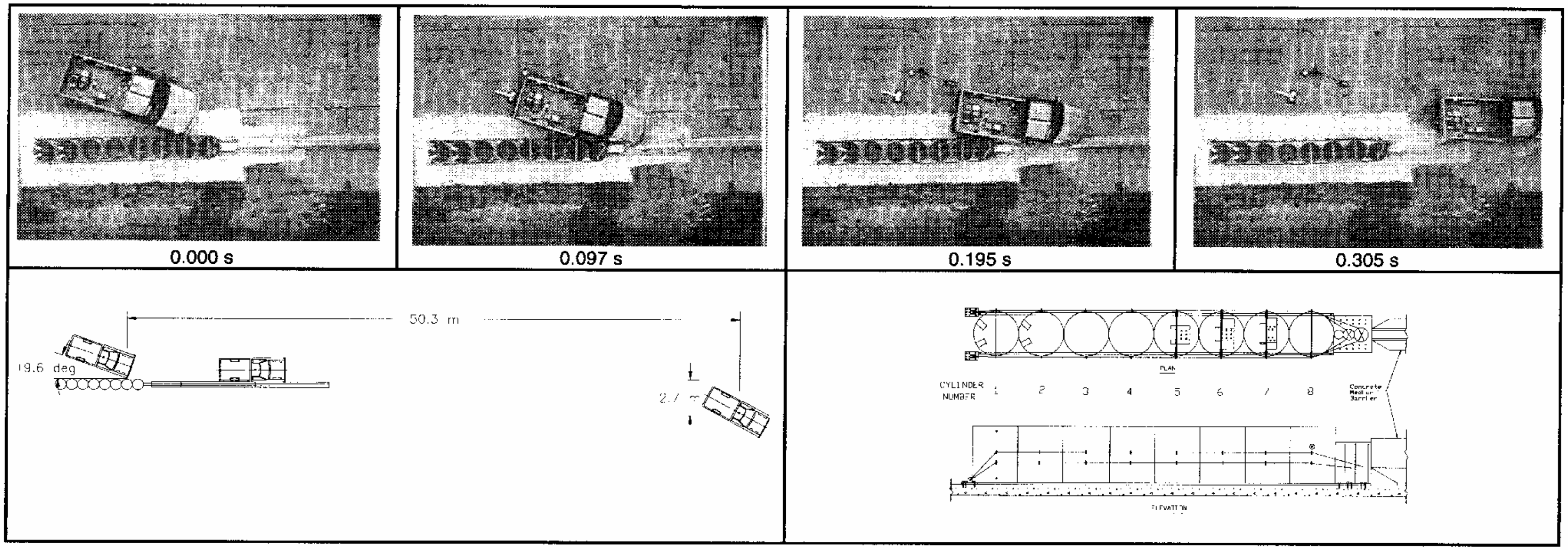


Figure B4-6 Vehicle After Test 3-38(1)

NCHRP 350 Test 3-38(2)



General Information

Test Agency	Texas Transportation Institute
Test No.	404231-5
Date	06/08/98

Test Article

Type	Crash Cushion
Name or Manufacturer	Mod. Narrow Conn. Imp. Atten. Sys
Installation Length (m)	7.31
Material or Key Elements	8 @ 914O.D.x1219mm Tall Steel Pipe Cylinders of Various Wall Thickness

Soil Type and Condition .... Concrete Pavement, Dry

Test Vehicle

Type	Production
Designation	2000P
Model	1994 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1891
Test Inertial	2000
Dummy	75
Gross Static	2075

Impact Conditions

Speed (km/h)	100.1
Angle (deg)	19.6

Exit Conditions

Speed (km/h)	79.6
Angle (deg)	1.2

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	7.6
y-direction	4.7
Ridedown Accelerations (g's)	
x-direction	-9.6
y-direction	-11.23
Max. 0.050-s Average (g's)	
x-direction	-8.0
y-direction	-9.4
z-direction	5.4

Test Article Deflections (m)

Dynamic	0.24
Permanent	0.23

Vehicle Damage

Exterior	
VDS	01RFQ6
CDC	01RDEW4
Maximum Exterior Vehicle Crush (mm)	600
Interior	
OCDI	RF1210000
Max. Occ. Compart. Deformation (mm)	167

Post-Impact Behavior
(during 1.0 s after impact)

Max. Yaw Angle (deg)	-18
Max. Pitch Angle (deg)	-9
Max. Roll Angle (deg)	-9

Figure B5-1 Summary of Results for Test 3-38(2)

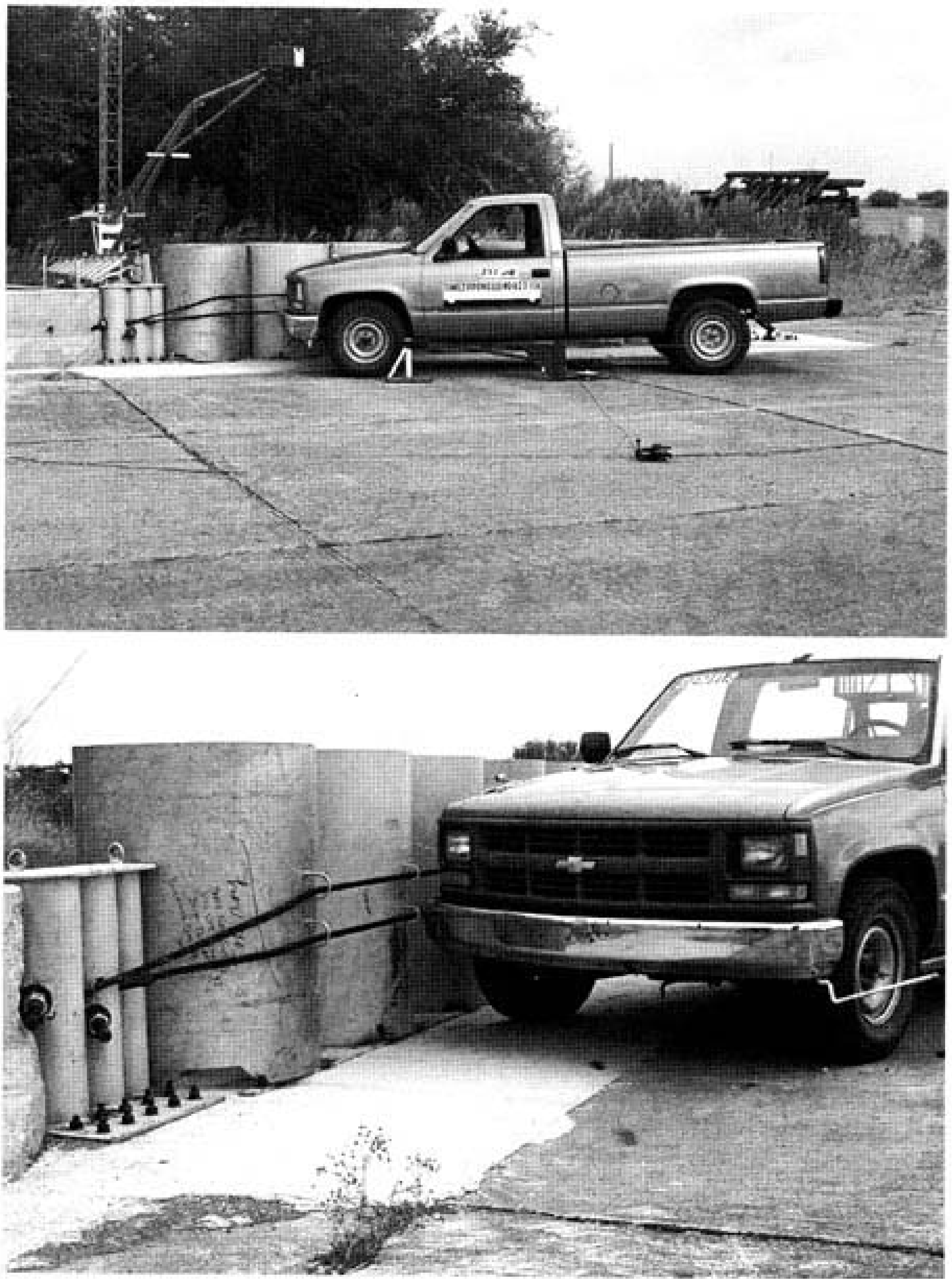
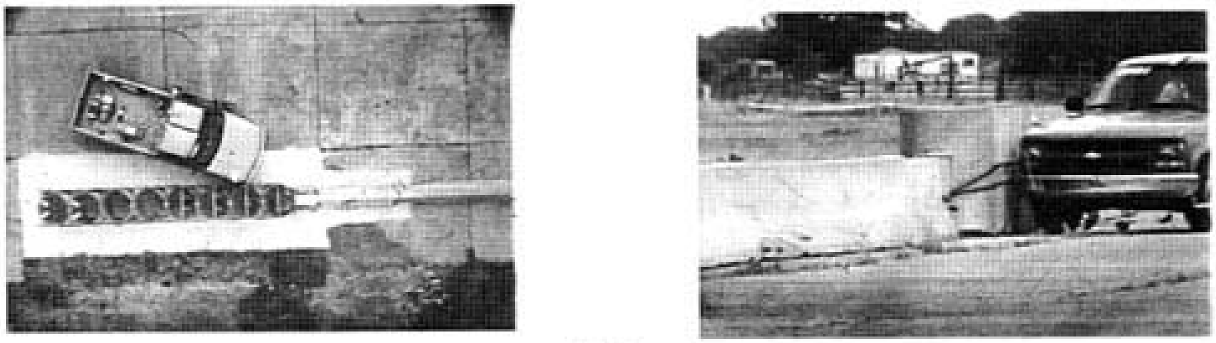
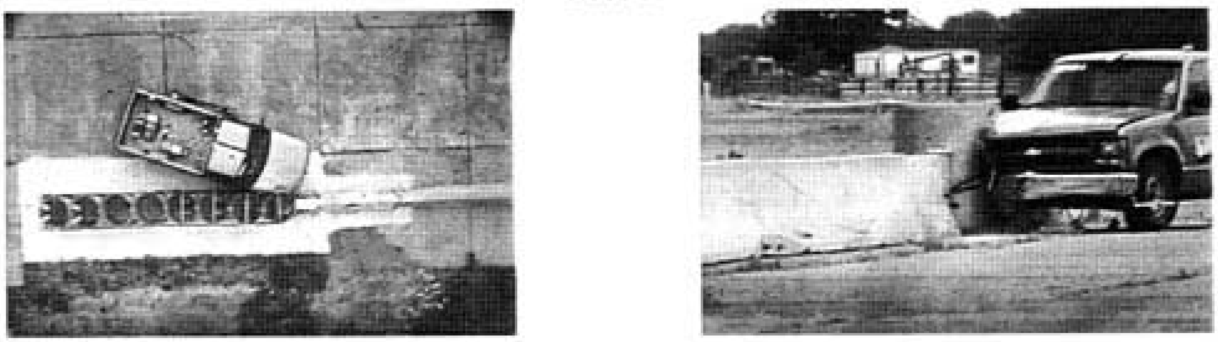


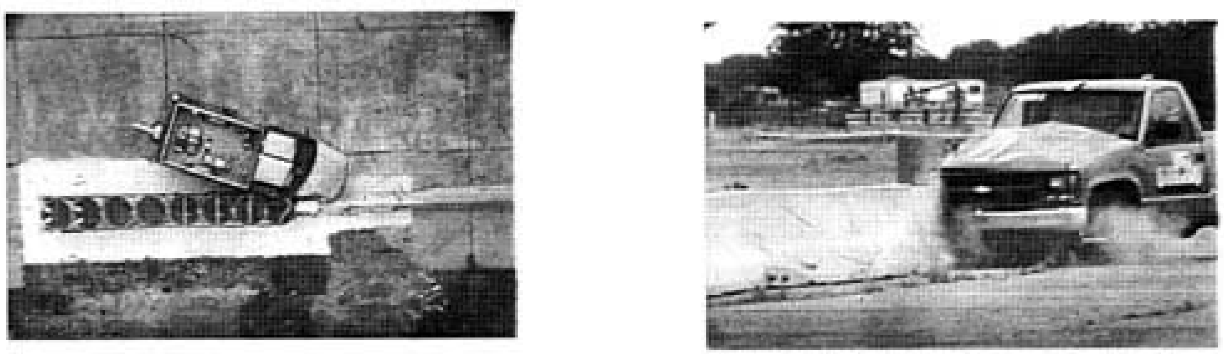
Figure B5-2 Vehicle/Installation Geometrics Before Test 3-38(2)



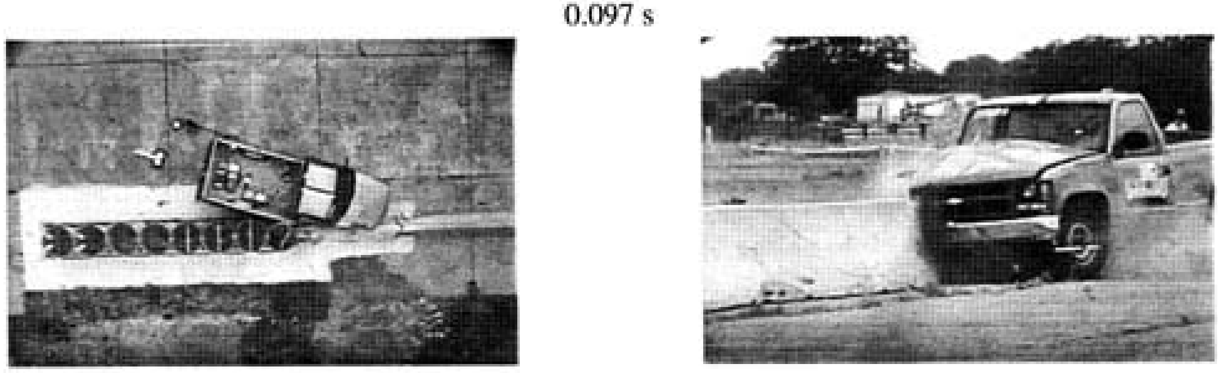
0.000 s



0.048 s

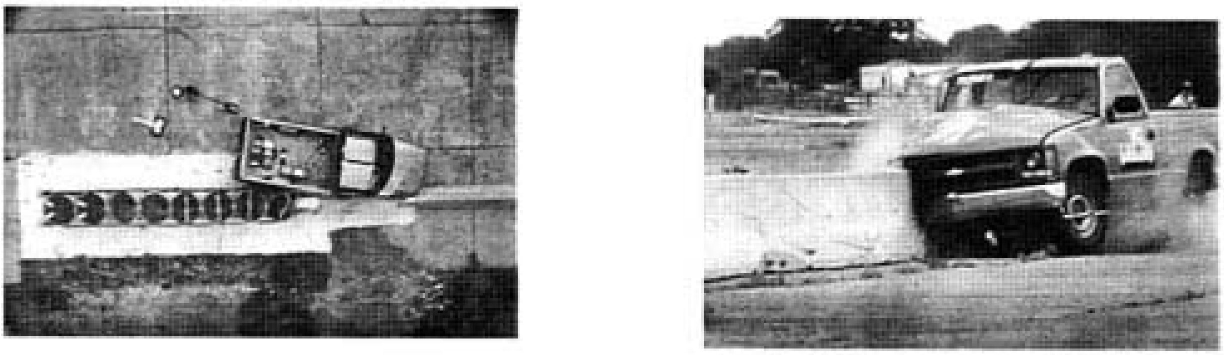


0.097 s



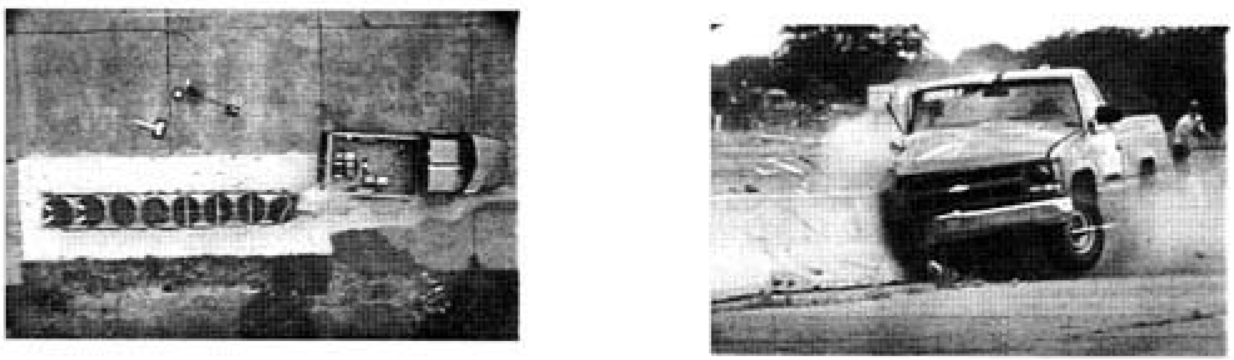
0.146 s

Figure B5-3 Sequential Photographs for Test 3-38(2) (overhead and frontal views)

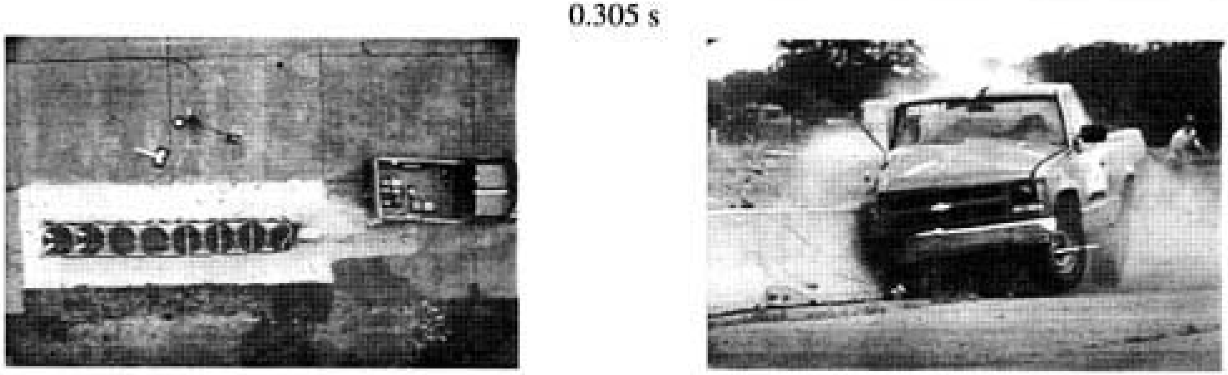


0.195 s

0.244 s



0.305 s



0.366 s

Figure B5-4 Sequential Photographs for Test 3-38(2) continued (overhead and frontal views)

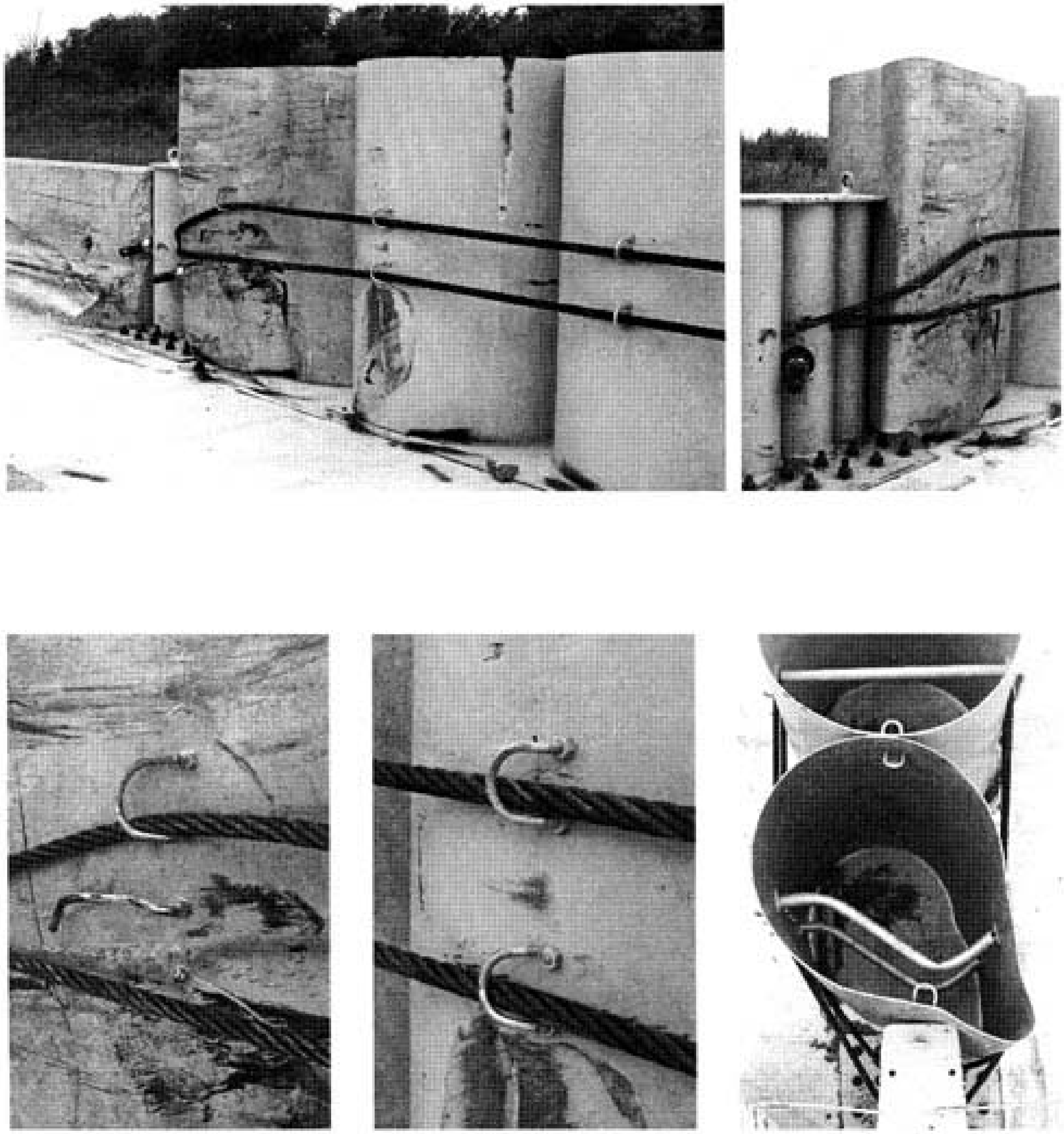


Figure B5-5 Installation After Test 3-38(2)

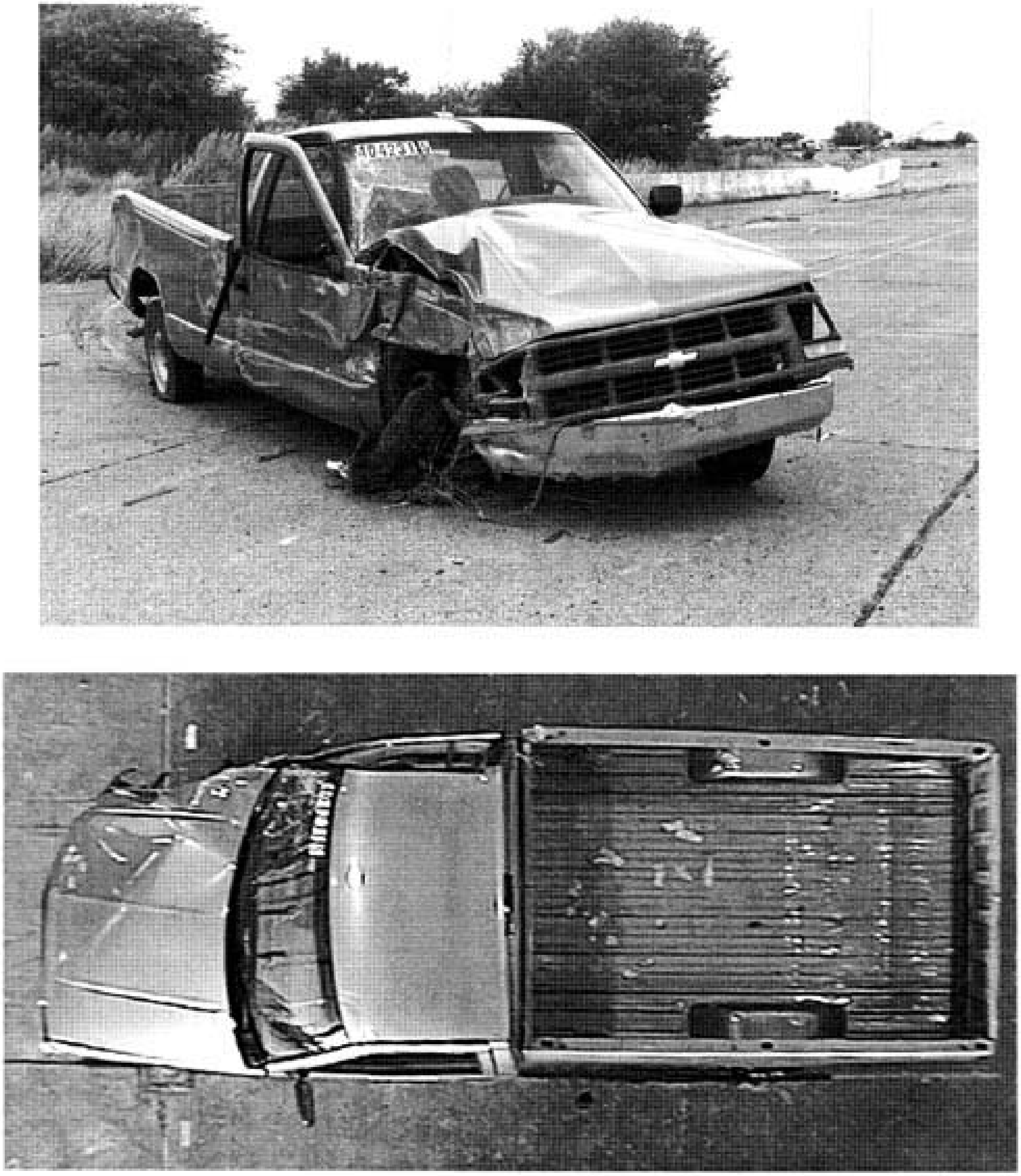
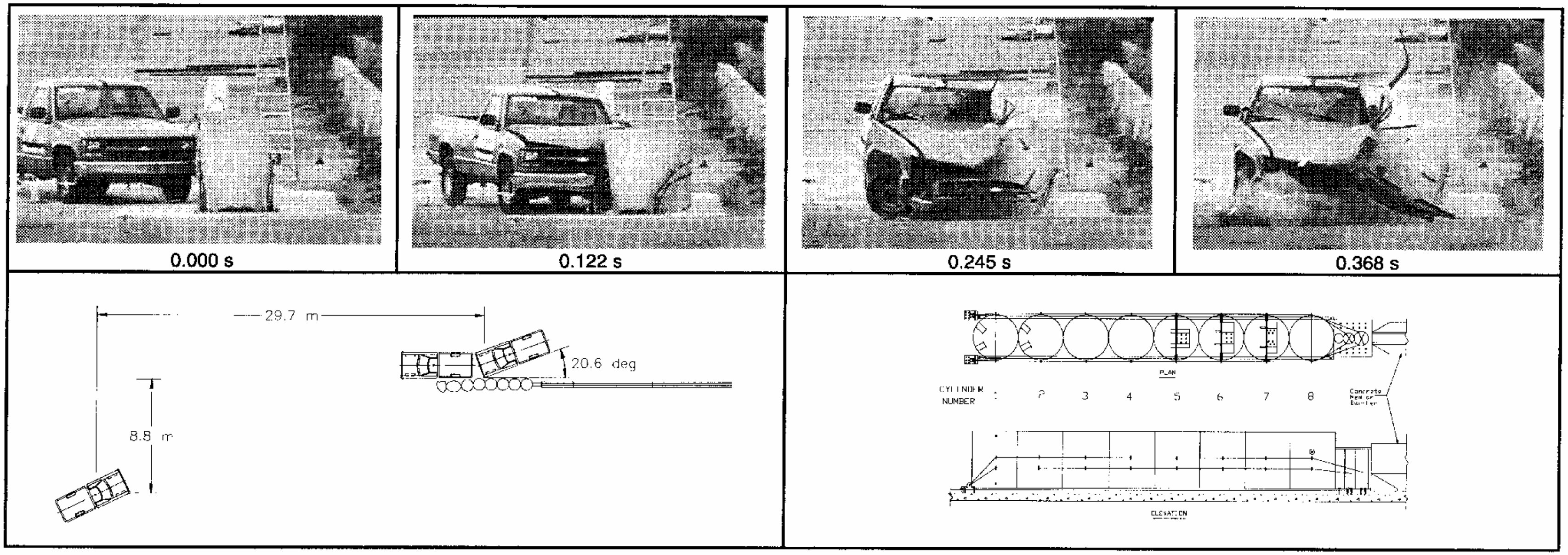


Figure B5-6 Vehicle After Test 3-38(2)

NCHRP 350 Test 3-39



General Information
- Test Agency . . . . Texas Transportation Institute
- Test No. 404231-6
- Date 06/09/98

Test Article
- Type . . . . Crash Cushion
- Name . . . . Mod Narrow Conn. Imp. Atten. System
- Installation Length (m) 7.31
- Material or Key Elements . . . 8 @ 914O.D.x1219mm Tall Steel Pipe Cylinders of Various Wall Thickness

Soil Type and Condition . . . . Concrete Pavement, Dry

Test Vehicle
- Type . . . . Production
- Designation 2000P
- Model . . . . 1994 Chevrolet 2500 Pickup Truck
- Mass (kg)
  - Curb 1883
  - Test Inertial 2000
  - Dummy 75
  - Gross Static 2075

Impact Conditions
- Speed (km/h) 99.7
- Angle (deg) 20.6

Exit Conditions
- Speed (km/h) 51.1
- Angle (deg) 1.7

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 10.1
  - y-direction 6.4
- Ridedown Accelerations (g's)
  - x-direction . . . . -26.8
  - y-direction 20.3
- Max. 0.050-s Average (g's)
  - x-direction . . . . -14.0
  - y-direction 8.0
  - z-direction 7.7

Test Article Deflections (m)
- Dynamic 0.51
- Permanent 0.23

Vehicle Damage
- Exterior
  - VDS 11LD6
  - CDC 11LDEW5
- Maximum Exterior
  - Vehicle Crush (mm) 1080
- Interior
  - OCDI LF3130000
- Max. Occ. Compart.
  - Deformation (mm) 340

Post-Impact Behavior
- (during 1.0 s after impact)
- Max. Yaw Angle (deg) 28
- Max. Pitch Angle (deg) . . . . . . -4
- Max. Roll Angle (deg) . . . . -5

Figure B6-1 Summary of Results for Test 3-39

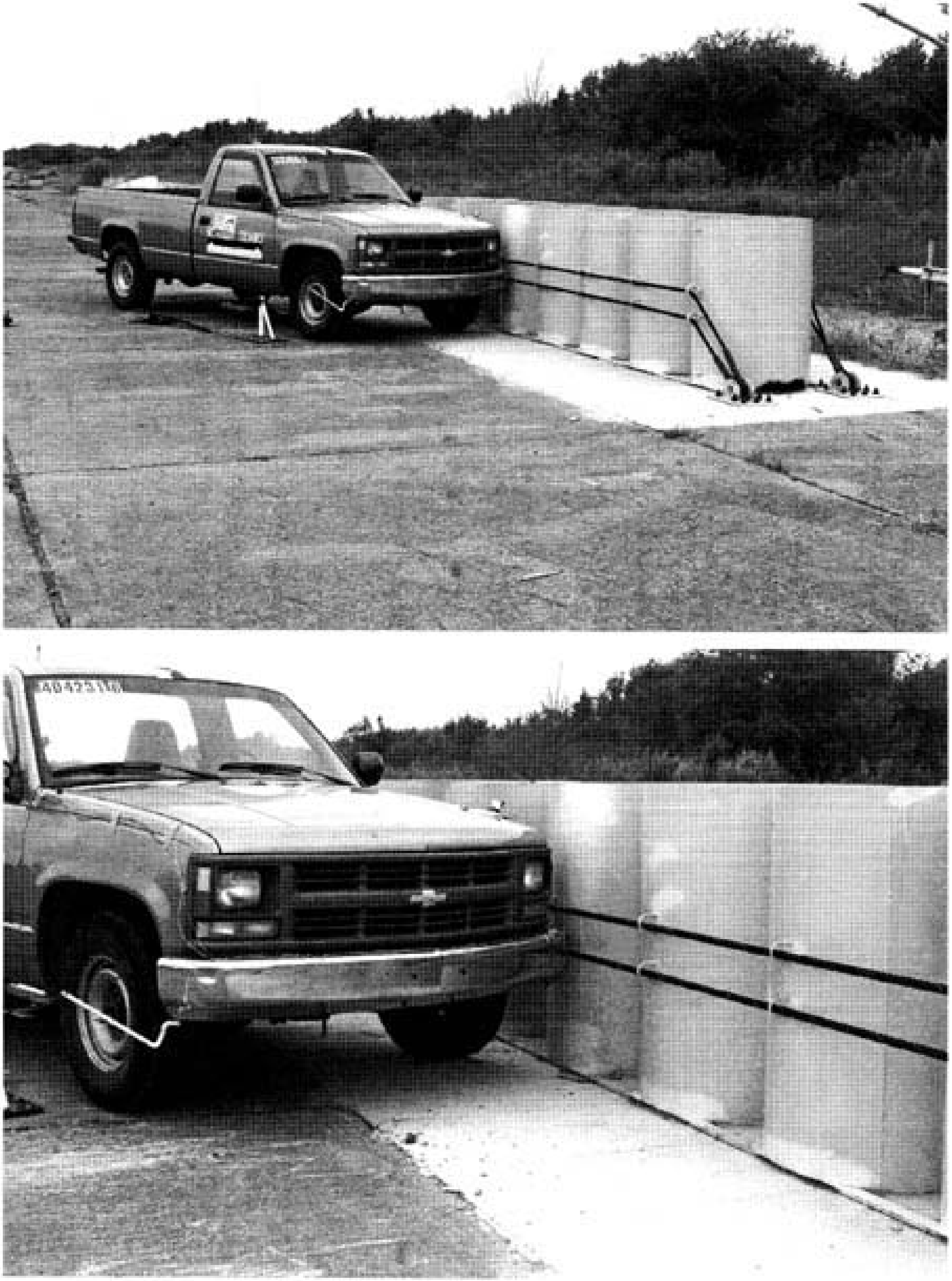
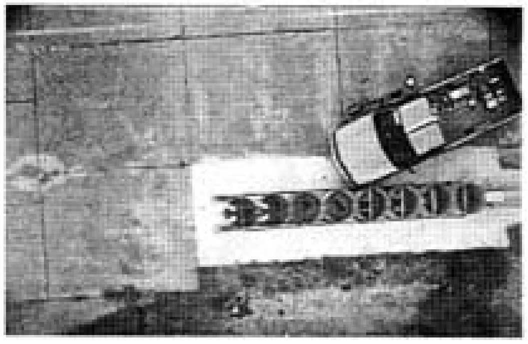
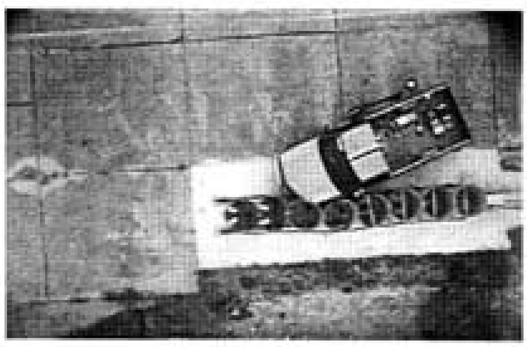
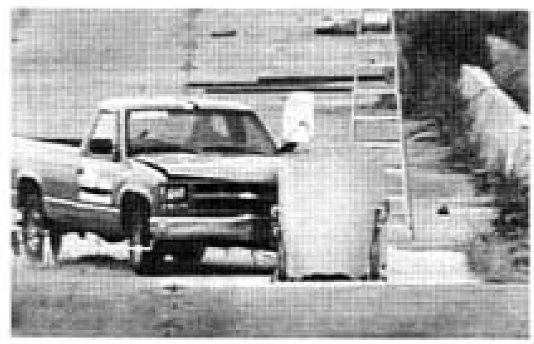


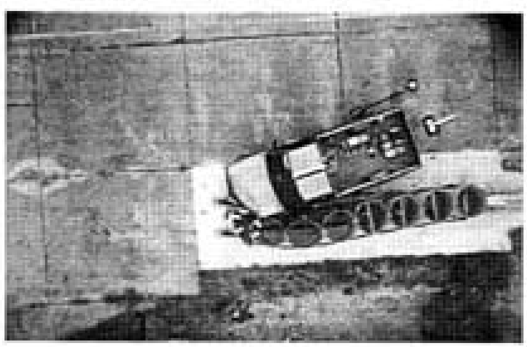
Figure B6-2 Vehicle/Installation Geometrics Before Test 3-39



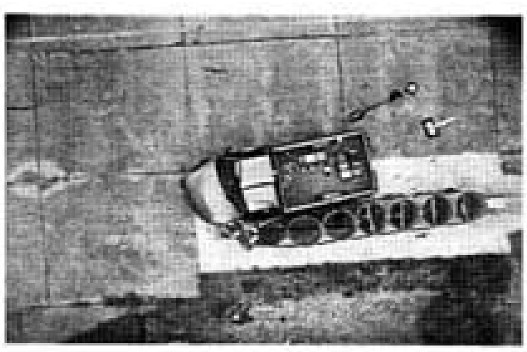

0.000 s

0.061 s

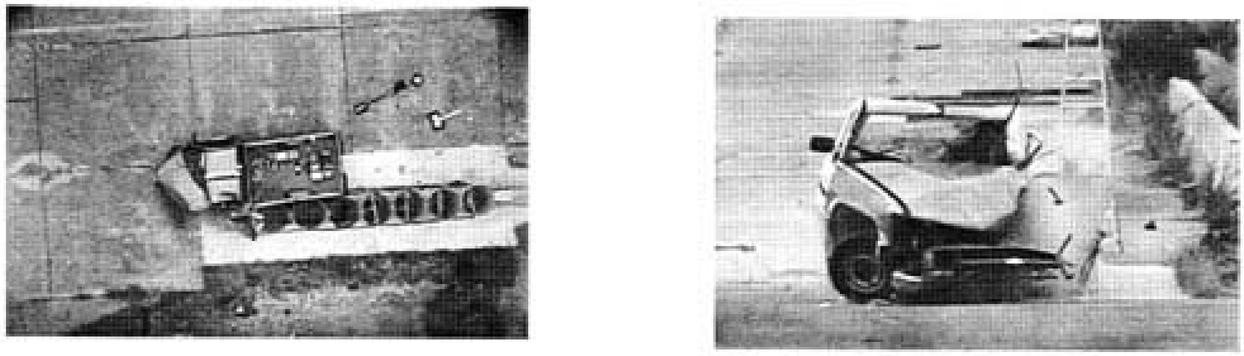



0.122 s

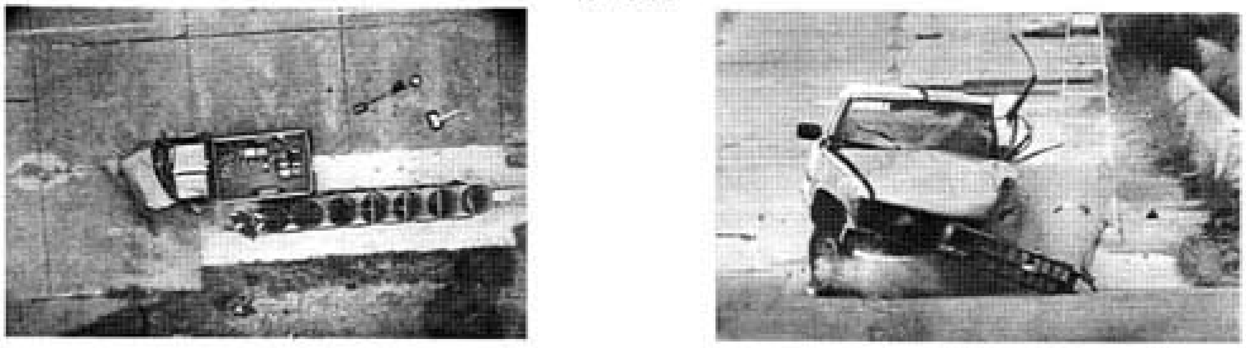



0.184 s

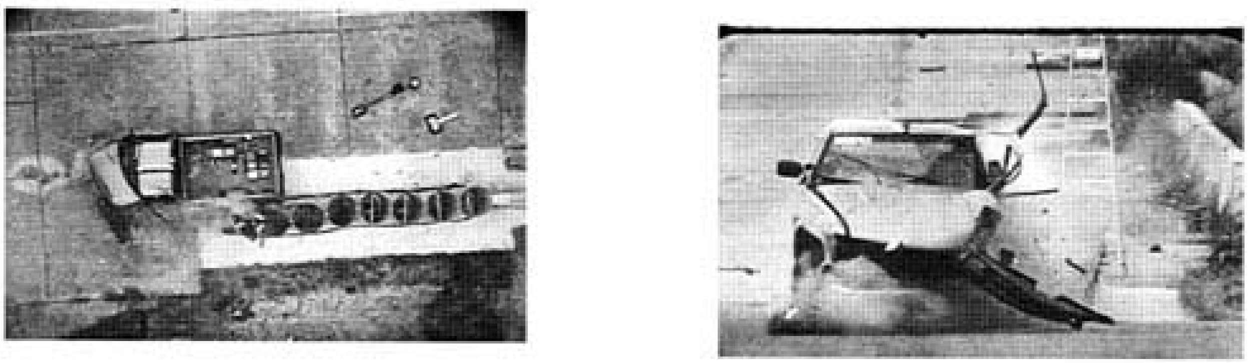
Figure B6-3 Sequential Photographs for Test 3-39 (overhead and frontal views)



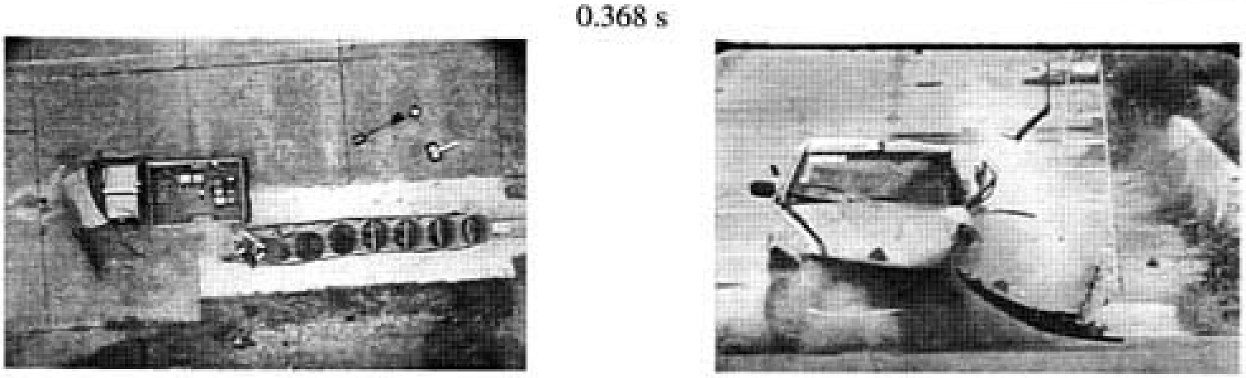
0.245 s



0.307 s



0.368 s



0.430 s

Figure B6-4 Sequential Photographs for Test 3-39 continued (overhead and frontal views)

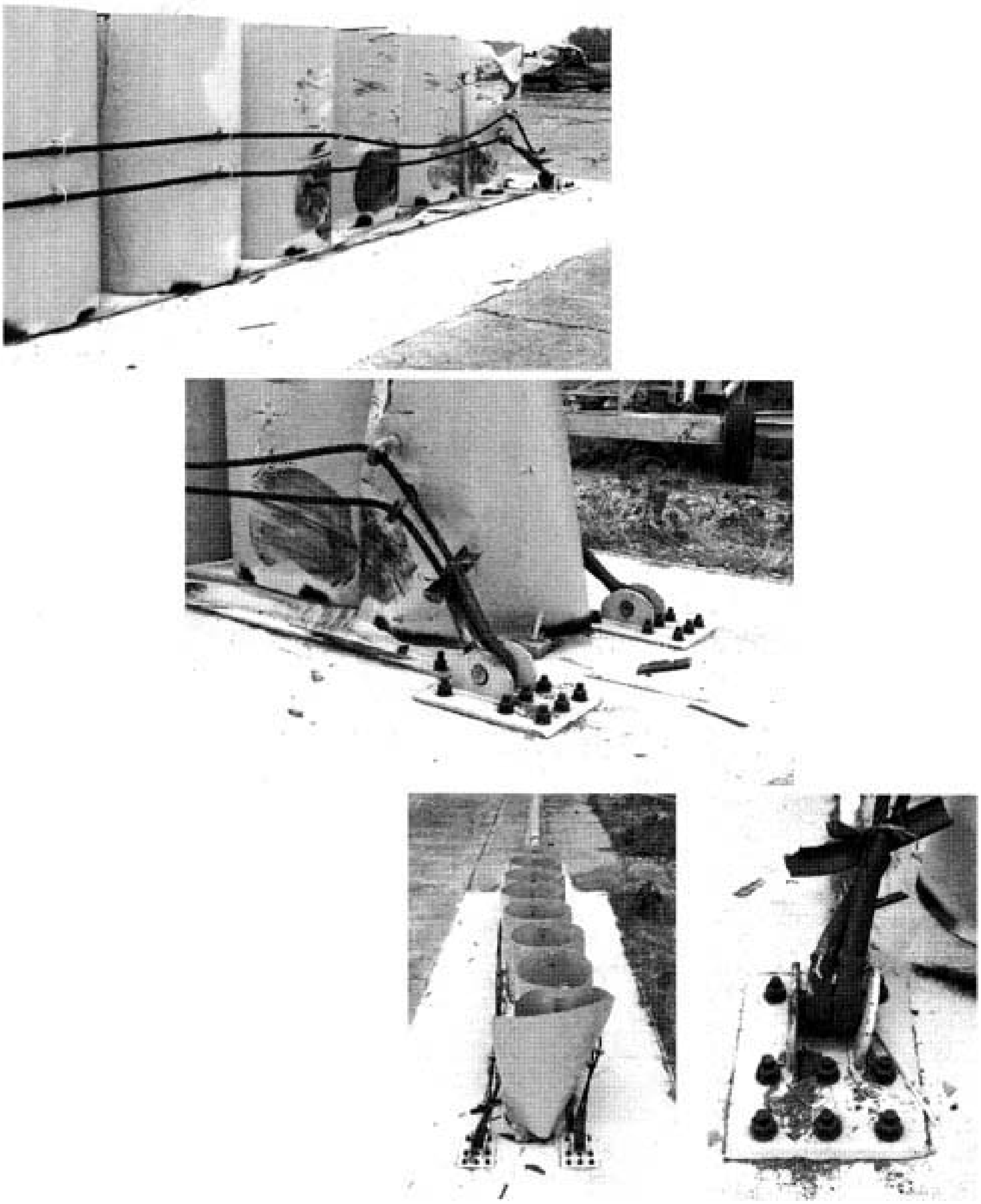


Figure B6-5 Installation After Test 3-39

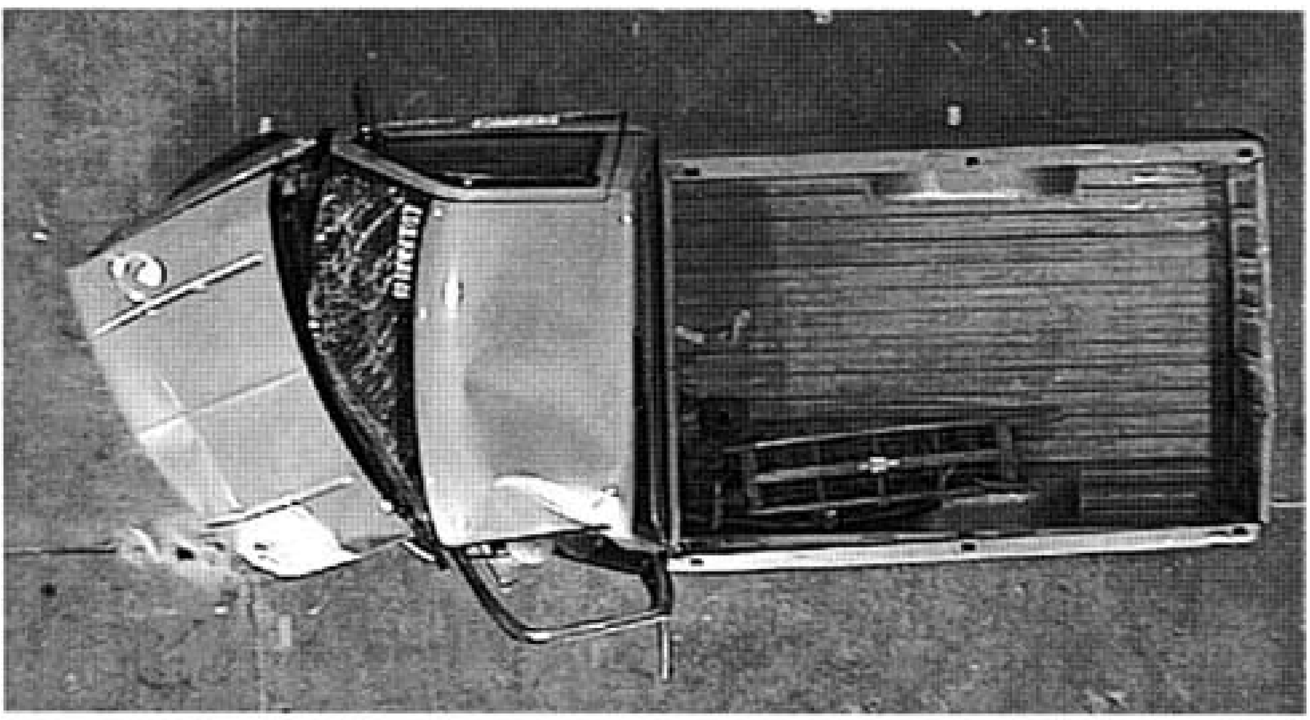


Figure B6-6 Vehicle After Test 3-39

APPENDIX C

Federal Highway Approval Letter for Use of the NCIAS on the NHS at Locations Where Reverse-Direction Impacts are Unlikely

U.S. Department of Transportation
Federal Highway Administration

400 Seventh St., S.W.
Washington, D.C. 20590

March 26, 1999

Refer to: HMHS-1

Keith R. Lane, P.E.
Director of Research and Materials
Connecticut Department of Transportation
280 West Street
Rocky Hill, CT 06067-3502

Dear Mr. Lane:

In your February 22, 1999 letter to the Director of the Federal Highway Administration's Office of Engineering, you requested acceptance of the Narrow Connecticut Impact Attenuation System (NCIAS) as an NCHRP Report 350 test level 3 (TL-3) crash cushion for use on the National Highway System (NHS). To support your request, you also sent us two copies each of crash test reports prepared by the Texas Transportation Institute on Report 350 tests 3-32, 3-33, 3-37, 3-38, and 3-39. These were the tests recommended by Mr. Dwight A. Horne in his April 18, 1997, response to Dr. Charles E. Dougan.

The NCIAS consists of eight steel cylinders in a single row with two anchored wire ropes along each side. All cylinders are 900 mm in diameter and 1200 mm tall. Wall thicknesses vary from 3.2 mm to 9.5 mm. Enclosure 1 shows the general configuration and details of the first two cylinders.

We have reviewed the information you submitted and concur that the appropriate Report 350 evaluation criteria were met for tests 3-32, 3-33, and 3-37. We noted that test 3-38 was repeated after an initial failure (excessive passenger compartment deformation) and that the additional stiffening of cylinder No. 8 produced satisfactory results. We noted also that the reverse-direction hit (test 3-39) resulted in vehicle snagging and unacceptable passenger compartment intrusion. In lieu of additional design changes and further testing, you opted to prohibit the use of the NCIAS in locations where wrong-way hits are likely. Enclosure 2 consists of summary sheets of the tests run under Report 350.

Based on our review, we consider the NCIAS to meet the evaluation criteria for an NCHRP Report 350 crash cushion at TL-3 and it may be used on the NHS (at locations where reverse-direction impacts are unlikely) when selected by a transportation agency. Although the NCIAS is patented, we understand that the rights to manufacture and use the system are non-proprietary and that plans and specifications may be obtained through your office.

Sincerely yours,

Dwight A. Horne

Dwight A. Horne
Director, Office of Highway Safety
Infrastructure

2 Enclosures
Acceptance Letter CC-58