SUMMARY OF THE NCHRP REPORT 350
CRASH TEST RESULTS FOR THE
CONNECTICUT IMPACT ATTENUATION SYSTEM (CIAS)

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December 2004

Report No.
2216–3-03-6

Research Project
SPR–2216

Connecticut Department of Transportation
Bureau of Engineering and Highway Operations
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A Project in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1.Report No. FHWA-CT-RD- 2216-3-03-6	**2. Government Accession No.**	**3. Recipients Catalog No.** 2216-3-03-6
4. Title and Subtitle Summary of the NCHRP Report 350 Crash Test Results for the Connecticut Impact-Attenuation System (CIAS)		**5. Report Date** December 2004
		6. Performing Organization Code SPR-2216
7. Author(s) Paul F. D'Attilio, Erika B. Smith		**8. Performing Organization Report No.** 2216-3-03-6
9. Performing Organization Name and Address Connecticut Department of Transportation Division of Research 280 West Street, Rocky Hill, CT 06067-3502		**10. Work Unit No. (TRIS)**
		11. Contract or Grant No. CT-SPR Study No. 2216
		13. Type of Report and Period Covered Final Report November 1993 – April 2002
12. Sponsoring Agency Name and Address Connecticut Department of Transportation Bureau of Engineering and Highway Operations 2800 Berlin Turnpike, Newington, CT 06131-7546		**14. Sponsoring Agency Code**

15. Supplementary Notes
A study conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract
This report on the Connecticut Impact-Attenuation System (CIAS) documents the National Cooperative Highway Research Program (NCHRP) Report 350 compliance of a Connecticut designed and developed impact-attenuation system. Background information about the system is also included, with information on previous crash testing, as well as the performance of field installation locations. Under the NCHRP Report 350, the system was initially classified as a redirective/nongating device. However, upon failure of the first test performed, the classification was modified to redirective/gating. NCHRP Report 350 specifies seven full-scale crash tests for redirective/gating devices. Two of the seven tests were not conducted on the CIAS because they are similar to tests conducted under the NCHRP Report 230 requirements, which the CIAS passed and one test, the reverse hit performance test was not deemed necessary, due to the locations where the systems will be used. The other four tests were conducted in accordance with the guidelines of NCHRP Report 350 for Test Level 3 devices. The CIAS passed all requirements for the test designations. In 2002, the Federal Highway Administration approved the use of the CIAS on the National Highway System at locations where opposite-direction impacts are unlikely.

17. Key Words Impact Attenuation System, crash tests, steel cylinders, impact loading	**18. Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA. 22161

19. Security Classif. (Of this report)	**20. Security Classif.(Of this page)**	**21. No. of Pages**	**20. Price**
Unclassified	Unclassified	70	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Acknowledgments

Special thanks are given to Dr. Charles E. Dougan for his support of this project throughout the design and implementation stages. Acknowledgement is made to Dr. John F. Carney, III, for all his work in the design of this crash system.

Appreciation is also expressed to Mr. Eric C. Lohrey for his management of the project throughout the design and testing phases. His organized and systematic method of maintaining records made completion of this report possible.

Gratefulness is also expressed to the Federal Highway Administration including Mr. Charles McDevitt for providing assistance in arranging for the tests and to Connecticut Division Staff, in particular Mr. Al Alonzi and Ms. Amy Jackson-Grove, for their commitment to this project.

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

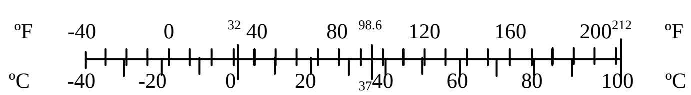
METRIC CONVERSION FACTORS

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	645.20	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 (2000lbs)	0.907	megagrams	Mg
		VOLUME		
floz	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

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	2.47	Acres	ac
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000lbs)	T
		VOLUME		
ml	milliliters	0.034	fluid ounces	floz
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



rev. 4-7-04

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Background

The Connecticut Impact-Attenuation System (CIAS) was developed by the Connecticut Department of Transportation (ConnDOT) in cooperation with the Federal Highway Administration (FHWA) to provide roadside safety in areas deemed high-hazard locations. These locations are along interstate highways, freeways and expressways in the gore area between the mainline and an exit ramp. The initial four locations were part of an experimental research project initiated in 1984 after the successful deployment of the Connecticut Truck Mounted Attenuator (CTMA). The CTMA was developed in 1975 to address the concerns ConnDOT maintenance personnel had of errant vehicles entering work zones along the roadside.

Like the CTMA, the CIAS is based on the principle of dissipating kinetic energy by plastically deforming thin-walled steel cylinders that are loaded laterally upon impact. The steel cylinders are designed such that controlled energy dissipation could be achieved under impact with both light weight and heavy vehicles [1]. This report gives a description of the system, presents the previous full-scale crash testing, as well as the requirements for evaluating the performance of these systems and their efficacy in terms of safety as addressed in the National Cooperative Highway Research Program (NCHRP) Report 350 – *Recommended Procedures for the Safety Performance Evaluation of Highway Features* [2]. Descriptions of the specific crash tests performed on the CIAS under the NCHRP Report 350 crash test criteria are also given.

Description of the System

The design configuration, including plan and elevation views of the CIAS is shown in Figure 1. Figure 2 shows an overhead picture of the system.

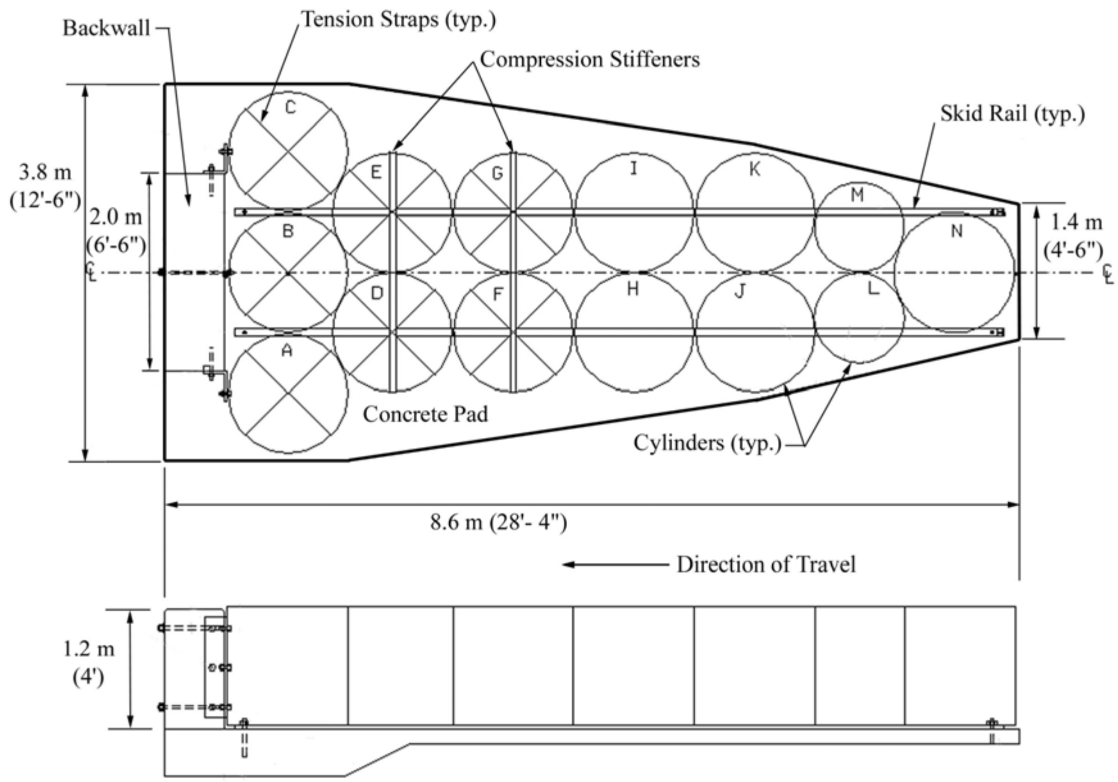

Figure 1. CIAS Plan and Elevation View Schematic

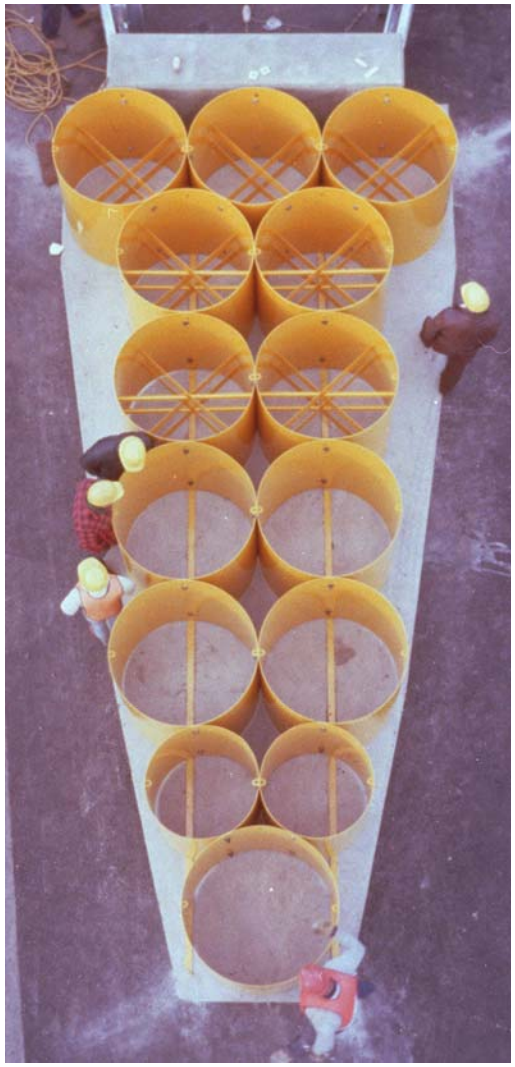

Figure 2. CIAS Overhead View[1]

The CIAS is made up of the following four basic components:

Fourteen (14) Steel Cylinders;

Skid Rails;

Concrete Base Pad and Backup wall;

Vinyl Cover.

The fourteen (14) steel cylinders are the energy-absorbing material of the system. They are all 1.2 m (4 ft) high and all are 1.2 m (4 ft) in diameter with the exception of the two in the second row

[1] System shown without vinyl cover.

(labeled as cylinders L and M in Figure 1), which have a diameter of 0.9 m (3 ft). The wall thicknesses of the cylinders range from 4.4 mm (11/64 in) to 7.9 mm (5/16 in). Two compression stiffeners, in the form of pipes with an inside diameter of 38 mm (1.5 in), are welded on one side in cylinders D, E, F, and G as shown in Figure 1. Each cylinder in the last three rows (labeled A through G in Figure 1) also contain four tension straps. The tension straps and the compression pipes help to insure that the crash cushion will respond in a stiff manner when subjected to a side impact near the rear of the unit. The four front rows of cylinders do not contain any straps or compression pipes. All cylinders are open-ended on both the top and bottom. The positioning of each cylinder is critical to the mode of the system's collapse when impacted by a vehicle [1].

The entire system rests on two 63.5 mm (2.5 in) wide by 12.7 mm (1/2 in) high by 7.75 m (25 ft,5 in) long skid rails, which contact some part of all fourteen cylinders. The rails are secured to the underlying concrete base pad, which is 8.6 m (28 ft,4 in) long, and varies in width from 1.4 m (4.5 ft) to 3.8 m (12.5 ft). A 2 m (6.5 ft) long x 1.2 m (4 ft) high x 0.6 m (2 ft) deep backup wall is located at the rear of the system. The steel reinforced concrete backup wall is secured to the concrete pad with two rows of dowels. The backup wall provides system anchorage and ensures proper collapse of the system.

Finally, the system is enclosed by a vinyl cover. 50 mm (2 in) wide straps are sewn to the cover and clips on the other end of the straps are either lag bolted to the backup wall or secured to the cylinders with pop rivets. The cover prevents the build up of snow, ice, and trash in the cylinders. It is also perforated with one or more 22.2 mm (7/8 in) holes per cylinder to prevent the ponding of surface water [3].

Previous NCHRP Report 230 Full-Scale Crash Testing

A program of full-scale crash tests was conducted from October 1982 to October 1983 at the Texas Transportation Institute, to test the design and effectiveness of the Connecticut Impact-Attenuation System under Transportation Research Circular (TRC) 191 requirements, as well as NCHRP Report 230 requirements. TRC 191 was published in 1978 to address minor changes from previously published circulars on full-scale crash testing [2]. NCHRP Report 230, entitled *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances,* was published in 1981 [4]. It addressed major changes that were needed to broaden the scope of previously published information regarding vehicle crash testing of roadside devices.

A total of nine full-scale crash tests were performed on the CIAS under these recommended procedures. The design of the CIAS evolved during the first phase of this testing program. By completion of the first 5 tests, changes had been made including the addition of skid rails and the cover, as well as changes to the height, number, bracing system, and steel thicknesses of the cylinders. The last four tests were performed with the same system specifications, and the results satisfied the impact performance standards with respect to both the TRC 191 and NCHRP Report 230 requirements [5]. These excellent results demonstrated conclusively that, upon impact, vehicles will be brought to a controlled stop when struck head-on or smoothly redirected around the hazard when controlling its stop is not possible due to the orientation of the impact [5]. In 1986, the CIAS was first approved by the FHWA as an experimental crash cushion available for installation on federal-aid highway projects.

Terminals and Crash Cushions Testing Requirements of NCHRP Report 350

NCHRP Report 350 uses three critical evaluation criteria to determine the safety and effectiveness of traffic attenuation systems. The first criterion addresses the structural adequacy of the attenuation system. [2] Depending on its intended function, the system may satisfy structural adequacy by redirecting the vehicle or by stopping the vehicle in a controlled manner.

The second criterion to be evaluated is Occupant Risk. NCHRP 350[3] uses two performance factors to assess the response of a hypothetical, unrestrained front seat occupant whose motion relative to the occupant compartment is dependent on vehicular accelerations. The two performance factors are (1) the lateral and longitudinal component of occupant velocity at impact with the surface and (2) the highest lateral and longitudinal component of resultant vehicular acceleration averaged over a 10-millisecond interval for the collision subsequent to occupant impact. The latter performance factor is referred to as ridedown acceleration. The maximum allowable limits for Occupant Impact Velocity and Occupant Ridedown Accelerations are 12 m/s (39 ft/s) and 20 g's (20 * 9.81 m/s^2 (32 ft/s^2)), respectively, as stated in NCHRP Report 350.

The third criterion is the post-impact vehicular trajectory. This is a measure of the potential of the trajectory of the vehicle to cause a subsequent multi-vehicle accident, thereby subjecting occupants of other vehicles to undue hazard or to subject the occupants of the impacting vehicle to secondary collisions with other fixed objects.[4]

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[2] NCHRP 350 page 52 section 5.2
[3] NCHRP 350 page 53 section 5.3
[4] NCHRP 350 page 55 section 5.4

According to the NCHRP Report 350, it is preferable that the vehicle trajectory and final stopping position intrude a minimum distance, if at all, into adjacent or opposing traffic lanes.

Using these three evaluation criterion, a given feature is 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 (700 kg (1543 lb), 820 kg (1808 lb), and 2000 kg (4409 lb), traveling at a nominal speed of 100 km/h (62 mph) [2].

Further classification of terminals and crash cushions includes gating or nongating terminals, and redirective or nonredirective crash cushions. Gating terminals are designed to allow controlled penetration along a portion of their length, and nongating terminals are designed to have full redirection capabilities along their entire length. A redirective crash cushion is designed to redirect a vehicle impacting the side of the cushion, and a nonredirective crash cushion is designed to decelerate the vehicle to a stop when impacted on the side [2]. The CIAS was designed and originally tested as a redirective/ nongating device. After the results of test designation 3-32, as presented below, the system was tested as a redirective/ gating device.

According to NCHRP Report 350, seven crash tests are recommended for evaluation of redirective/ gating crash cushions. They are designated as 3-30, 3-31, 3-32, 3-33, 3-34, 3-35, and 3-39. Tests 3-30, and 3-31 were not conducted on the CIAS because these three tests are similar to three tests conducted under the NCHRP Report 230 requirements, which the CIAS passed. Test 3-39, the reverse hit performance test, was also not performed because the system is not deployed in areas where a reverse direction hit will occur. Tests 3-32, 3-33 and 3-34 were performed on the CIAS to evaluate occupant risk and vehicle trajectory criteria. Test 3-35 is intended primarily to evaluate the ability of the device to contain and redirect (structural adequacy criteria) the vehicle within the trajectory criteria.

CIAS NCHRP Report 350 Crash Test Program

The NCHRP Report 350 crash test conditions for redirective/gating crash cushions are shown in Table 1. A total of five tests were performed on the CIAS using five different test designations. All five tests were performed at the Texas Transportation Institute (TTI) in College Station, Texas.

The results of the crash tests, as presented in the three reports from the Texas Transportation Institute, are summarized in Table 2. Highlights from the crash test reports of the five individual tests performed are discussed next.

Table 1. NCHRP Report 350 Crash Test Conditions for Redirective/Gating Crash Cushions

NCHRP Report 350 Test Designation	Vehicle Weight (kg)	Impact Speed (km/h)	Impact Angle (degrees)	Impact Point	Test Waived for NCHRP Report 350?
3-30	820	100	0	Head-on, offset	Yes
3-31	2000	100	0	Head-on, no offset	Yes
3-32	820	100	15	Head-on, no offset	No
3-33	2000	100	15	Head-on, no offset	No
3-34	820	100	15	Critical Impact Point	No
3-35	2000	100	20	Beginning of length of need	No
3-39	2000	100	20	Reverse direction	Yes

Table 2. Summary of CIAS Crash Test Results

NCHRP Report 350 Test Designation	**3-32**	**3-33**	**3-34**	**3-35**
Vehicle Mass (kg)	897	2075	896	2077
Vehicle Impact Velocity (km/h)	99.98	99.96	98.7	99.49
Impact Angle (degrees)	15.75	14.65	15.4	20.53
Impact Location	Nose/Center	Nose/Center	Side/ Critical Impact Point (CIP)	Side/ Beginning of Length of Need (LON)
Occupant Impact Velocity (m/s) * (max. allowable=12) **Longitudinal**	10	8	11	11
Lateral	2	2	2	6
Occupant Ridedown Acceleration (g's) * (max. allowable=20) **Longitudinal**	-12	-6	-20	-19
Lateral	-3	-7	-4	13
Assessment * Rounded to Nearest Integer	**Passed** All Evaluation Criteria.	**Passed** All Evaluation Criteria.	**Passed** All Evaluation Criteria.	**Passed** All Evaluation Criteria.

Test No. 405651-1, NCHRP Report 350 Test Designation 3-32

Test 3-32 was conducted using an 820 kg (1808 lb) automobile impacting the nose of the crash cushion at a nominal speed of 100 km/h (62 mph) and at an angle of 15 degrees.

The results for test 3-32 are that the vehicle was traveling at 99.98 km/h (62 mph), and impact with the CIAS was at 15.75 degrees. After the initial impact with the CIAS the vehicle yawed clockwise and came to rest behind the CIAS. Although the CIAS safely redirected the test vehicle after impact, the location where the vehicle came to rest prompted the FHWA to change the CIAS from a nongating to a gating crash cushion.

The occupant impact velocities and occupant ridedown accelerations for the longitudinal and lateral directions were all less than the maximum allowable amounts and, therefore, satisfied all evaluation criteria.

Test No. 405651-4, NCHRP Report 350 Test Designation 3-33

For this test (3-33), a 2000 kg (4409 lb) pickup truck impacts the nose of the CIAS at a speed of 100 km/h (62 mph) and an angle of 15 degrees. The results for test 3-33 are that the vehicle was traveling at 99.96 km/h (62 mph) and impact with the CIAS was at 14.65 degrees. After the vehicle struck the nose of the CIAS, it was redirected away from the attenuator collapsing 11 of the 14 cylinders, leaving the remaining three cylinders slightly deformed. The vehicle came to rest 5.5 m (18 ft) down from the nose of the attenuator and 13.7 m (44.9 ft) to the left of the CIAS. The occupant impact velocities and occupant ridedown accelerations for the longitudinal and lateral directions were all less than the maximum allowable amounts and, therefore, satisfied all evaluation criteria.

Test No. 404231-7, NCHRP Report 350 Test Designation 3-34

Test 3-34 is conducted using an 820 kg (1808 lb) automobile and in this test the vehicle strikes the crash cushion at the critical impact point (CIP) at a speed of 100 km/h (62 mph) and an angle of 15 degrees. The CIP is a point along the longitudinal dimension of the crash cushions between the beginning of the system and before the length of need (LON) that when hit has the greatest potential for causing a failure of the test. Failure of the test under the recommended criteria would include excessive wheel snag, pocketing or structural failure of the system. The LON is defined as the part of the longitudinal barrier or terminal designed to contain and redirect an errant vehicle. The impact configuration for this test is shown in Figure 3.

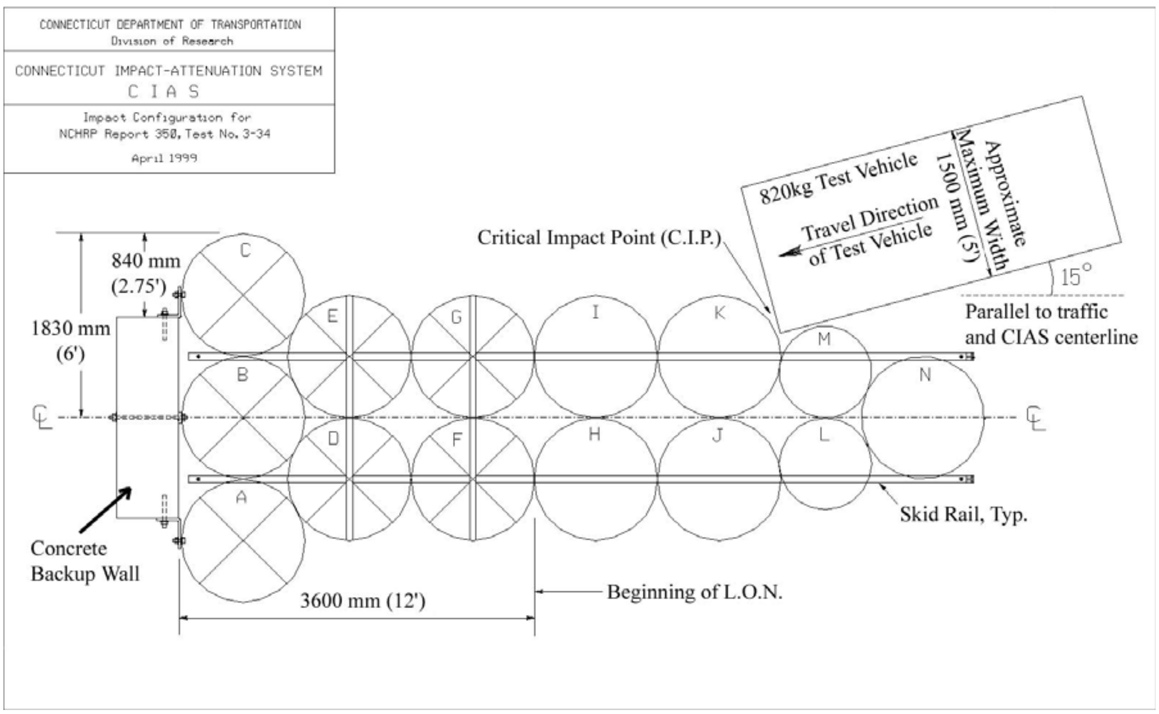

Figure 3. Impact Configuration for Test Designation 3-34

The results for test 3-34 are that the vehicle was traveling at 98.7 km/h (62 mph) and impact with the CIAS was at 15.4 degrees. After striking the attenuator at the CIP, the rear tires of the vehicle lost contact with the ground at 0.14 seconds. Then, at 0.52 seconds the vehicle lost contact with the CIAS and began traveling backwards for about 1.5 seconds before it came to rest at barrel G. Cylinders A, K, I and G were the most deformed, E and F were slightly deformed, and the remaining cylinders had little or no noticeable deformations.

The occupant impact velocities for the longitudinal and lateral directions were less than the maximum allowable amounts satisfying evaluation criteria. The occupant ridedown acceleration was at the threshold limit of 20 g's for the longitudinal direction and well below that limit for the lateral direction, thereby satisfying all evaluation criteria.

Test No. 405651-3, NCHRP Report 350 Test Designation 3-35

For this test (3-35) a 2000 kg (4409 lb) pickup truck impacts the CIAS at the Length of Need (LON) at a speed of 100 km/h (62 mph) and an angle of 20 degrees. The impact configuration for this test is shown in Figure 4.

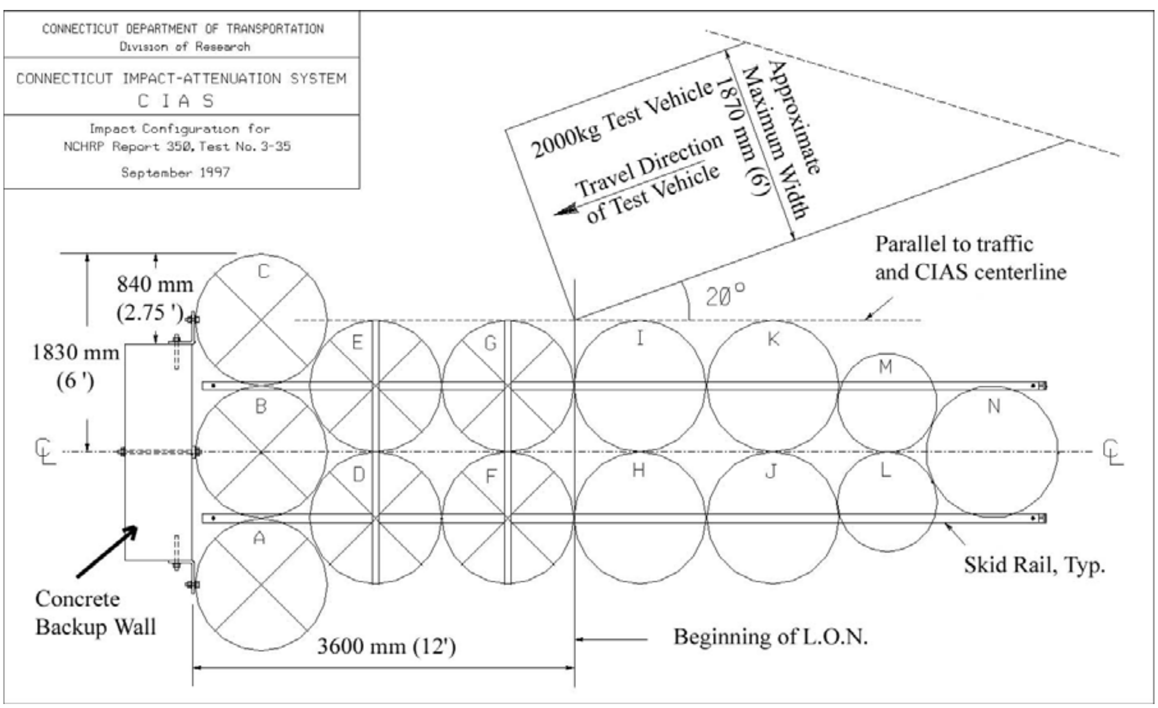

Figure 4. Impact Configuration for Test Designation 3-35

The results for test 3-35 are that the vehicle was traveling at 99.49 km/h (62 mph), and impact with the CIAS was at 20.53 degrees. After striking the attenuator, the vehicle traveled in a direction parallel to CIAS before coming to rest at 36.6 m (120 ft) down from and in line with the edge of the CIAS.

The occupant impact velocities and occupant ridedown accelerations for the longitudinal and lateral directions were less than the maximum allowable amounts and, therefore, satisfied all evaluation criteria.

Test No. 405651-2, NCHRP Report 350 Test Designation 3-38

Test 3-38 was conducted on the CIAS in May of 1996, prior to the FHWA changing the classification from a Redirective/Non-Gating Test Level 3 crash cushion to a Redirective/Gating Test Level 3 crash cushion. The result of test 3-32, specifically where the car came to rest, was the primary reason for this change.

For this test (3-38), a 2000 kg (4409 lb) pickup truck impacts the CIAS at a speed of 100 km/h (62 mph) and an angle of 20 degrees. The critical impact point (CIP) for this test is the location where the greatest potential for snagging or pocketing exists along the length of the attenuation system. It was decided that the CIP would be between cylinders I and G.

The results for test 3-38 are that the vehicle was traveling at 100.71 km/h (62 mph), and impact with the CIAS was at 19.94 degrees. After striking the attenuator, the vehicle was redirected, but not enough to prevent the left front end from snagging the rigid backup wall. The vehicle then came to rest 15 m (49.2 ft) down from the CIAS. As a result of the snagging, it was determined that the exit angle

(38.39 degrees) was greater than the allowable of 60% of the impact angle, and the damage that occurred to the occupant compartment was significant enough to deem the test unacceptable.

As a result of this test, the backup wall was modified to reduce the overall width of 2.7 m (9 ft) down to 2.0 m (6.5 ft). Subsequently, it was determined that test 3-35 would be required and would supersede the results of test 3-38.

CIAS Testing Summary

Upon initial testing, four out of the five test designations satisfied the requirements of NCHRP Report 350, however, the requirements for test designation 3-38 were not met. Subsequently, it was determined that this test was not needed, due to changing the classification from a nongating to gating device. In a letter dated April 9, 2002, the FHWA approved the use of the CIAS on the National Highway System in gore areas and other locations where traffic can pass on either side of the array and opposite-direction impacts are not a concern.

Conclusion

The Connecticut Impact-Attenuation System was developed after receiving favorable results from the Connecticut Truck-Mounted Attenuation System developed by the Connecticut Department of Transportation in cooperation with the Federal Highway Administration. The CIAS is a roadside highway safety feature intended for use in areas deemed as high hazard.

From May 1996 to April 1999, full scale crash testing took place at the Texas Transportation Institute on the CIAS. This testing was necessary for the system to meet the Federal NCHRP Report 350 requirements. After the October 1998 FHWA mandate, it was essential for the system to pass these requirements in order to be constructed along the National Highway System.

Five crash tests were conducted on the Connecticut Impact-Attenuation System using five different test designations of the NCHRP 350 requirements. After crash testing the device under Test Designation 3-32, it was decided to change the device from nongating to gating, allowing for controlled penetration along a portion of its length. Four out of the five test designations performed passed all of the requirements of the NCHRP Report 350. The fifth test did not meet the requirements, but this test is not required for gating devices, therefore, is not needed.

The overall performance of the CIAS led to the Federal Highway Administration’s approval of the use of the CIAS on the U.S. National Highway System where opposite-direction impacts are not a concern. State Departments of Transportation and other local jurisdictions are encouraged to consider the Connecticut Impact-Attenuation System for their roadway safety needs.

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APPENDIX A

CIAS Installation Details

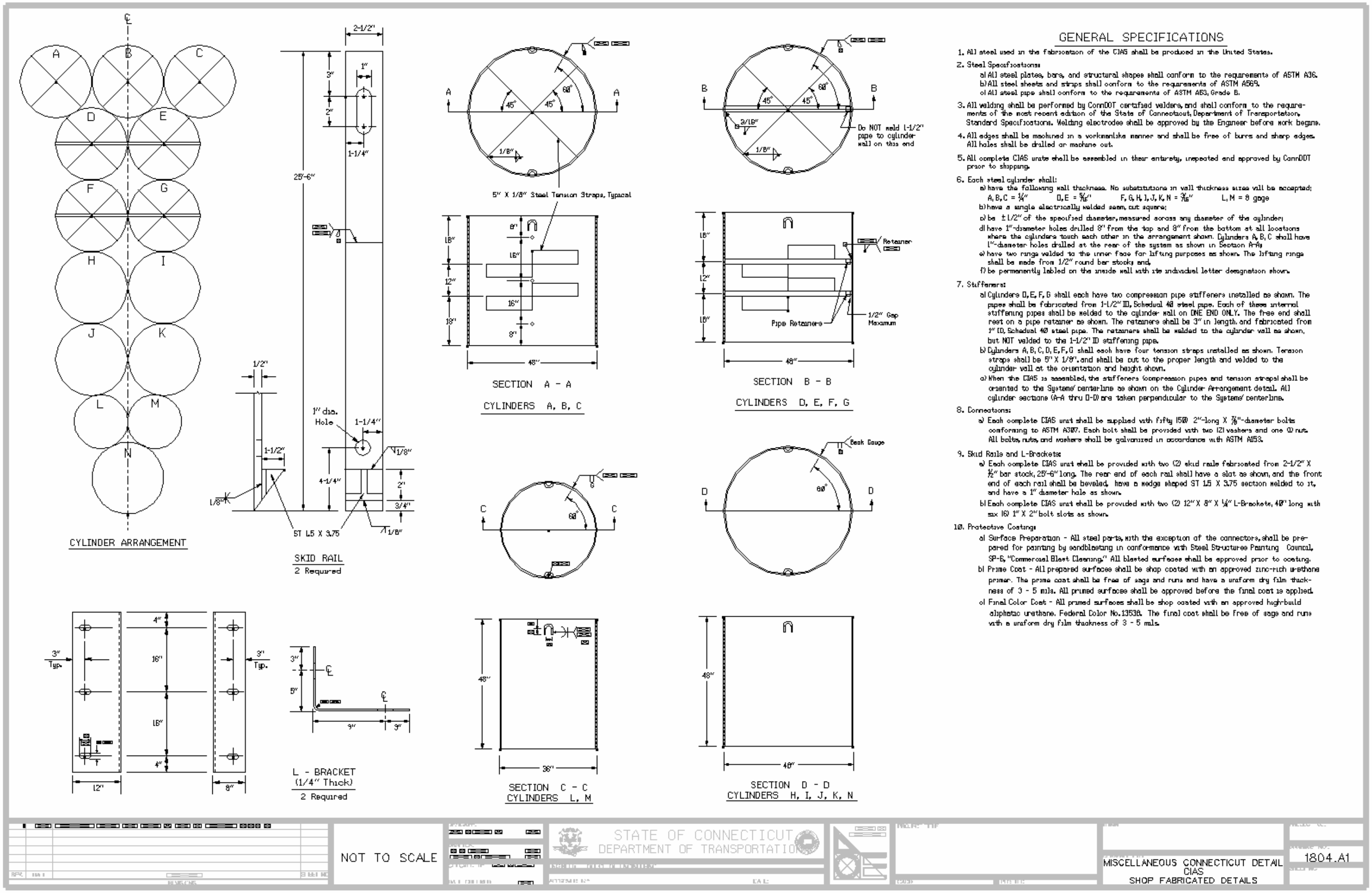


Figure A-1 Shop Fabricated Details

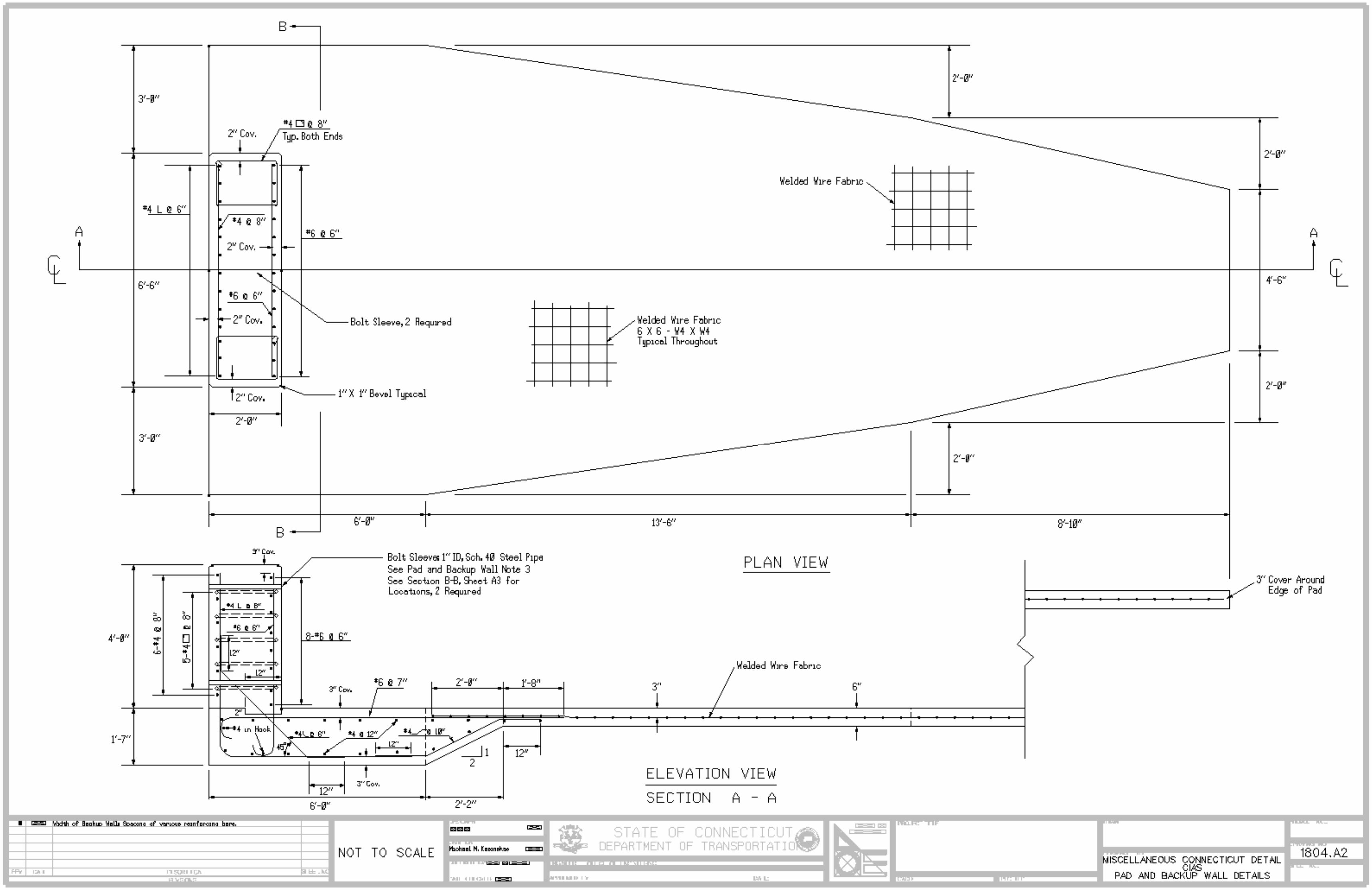


Figure A-2 Concrete Pad and Backup Wall Details

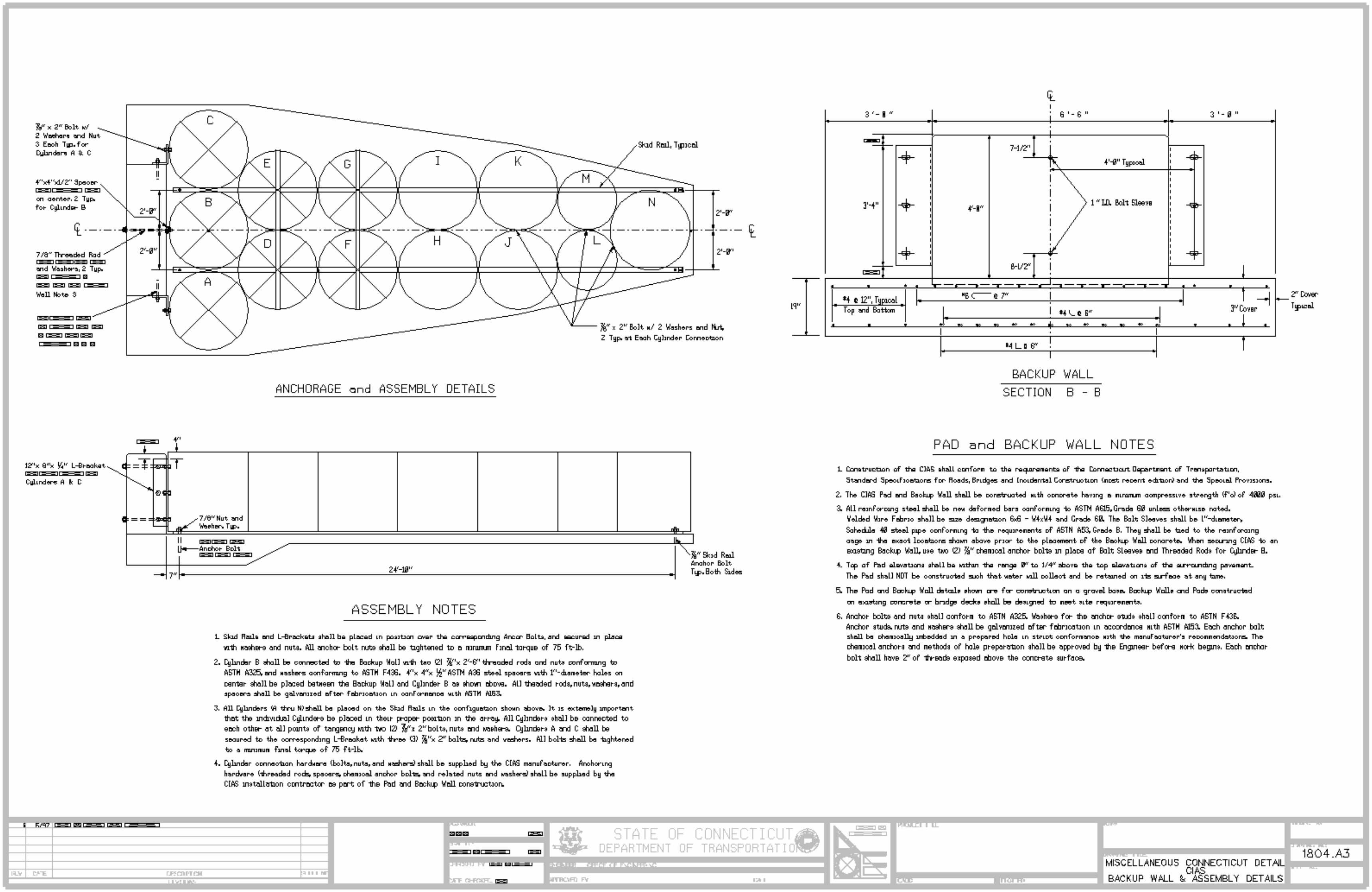


Figure A-3 Backup Wall and Assembly Details

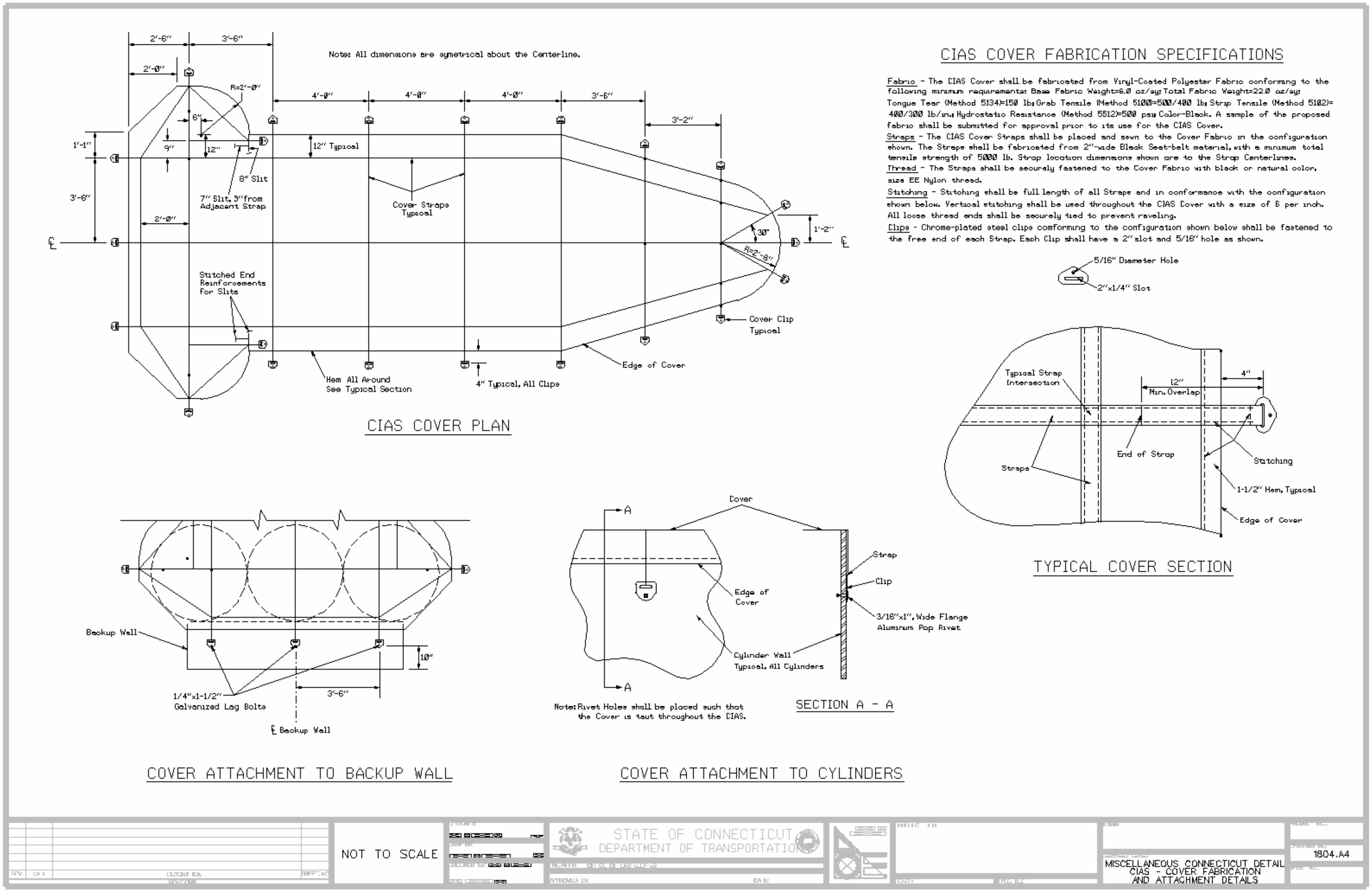


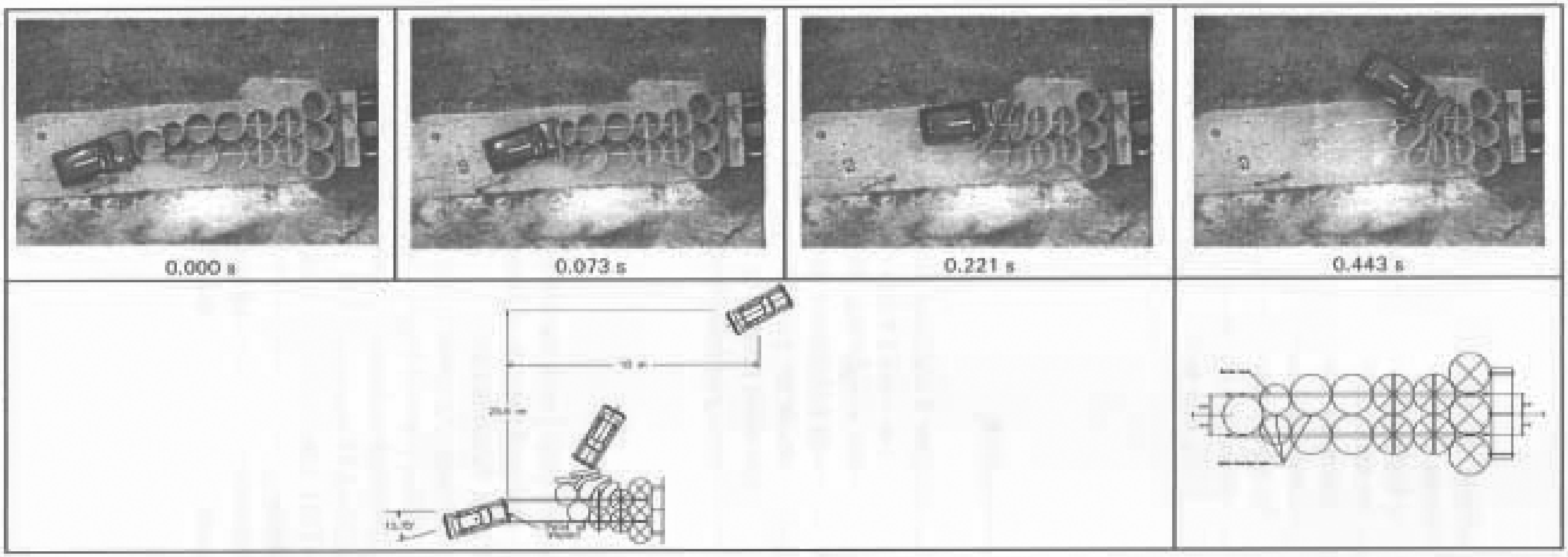
Figure A-4 Cover Fabrication and Attachment Details

APPENDIX B

Summary of Test Results and

Typical Photos of NCHRP Report 350 Tests Performed

NCHRP Report 350 TEST 3-32



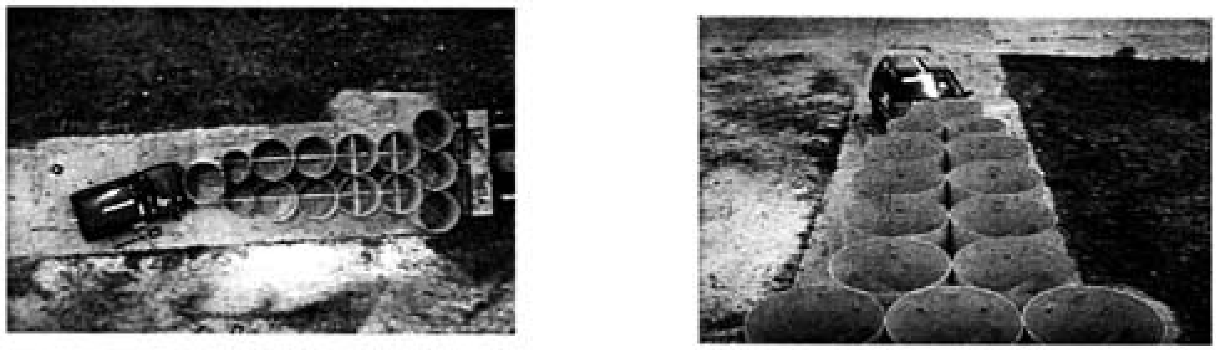
General Information	
Test Agency	Texas Transportation Institute
Test No.	405651-1
Date	06/13/96
Test Article	
Type	Crash Cushion
Name or Manufacturer	Connecticut Impact Att. System
Installation Length (m)	7.9
Size and/or dimension and material of key elements	14 @ steel pipe tubes of various size and thickness
Soil Type and Condition	Concrete Pavement, dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	791
Test Inertial	820
Dummy	77
Gross Static	897

Impact Conditions	
Speed (km/h)	99.98
Angle (deg)	15.75
Exit Conditions	
Speed (km/h)	27.53
Angle (deg)	118.04
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	10.00
y-direction	1.57
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-11.97
y-direction	-3.08
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-10.18
y-direction	-1.90
z-direction	-2.64

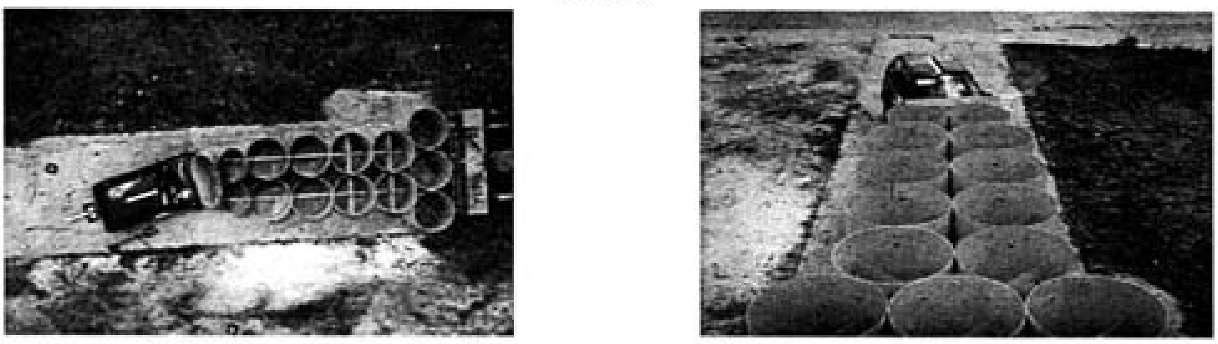
Test Article Deflections (m)	
Dynamic	2.93
Permanent	3.68
Vehicle Damage	
Exterior	
VDS	12FD5
CDC	12FDEW4
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	300
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	7.63
Max. Pitch Angle (deg)	7.51
Max. Yaw Angle (deg)	170.68

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

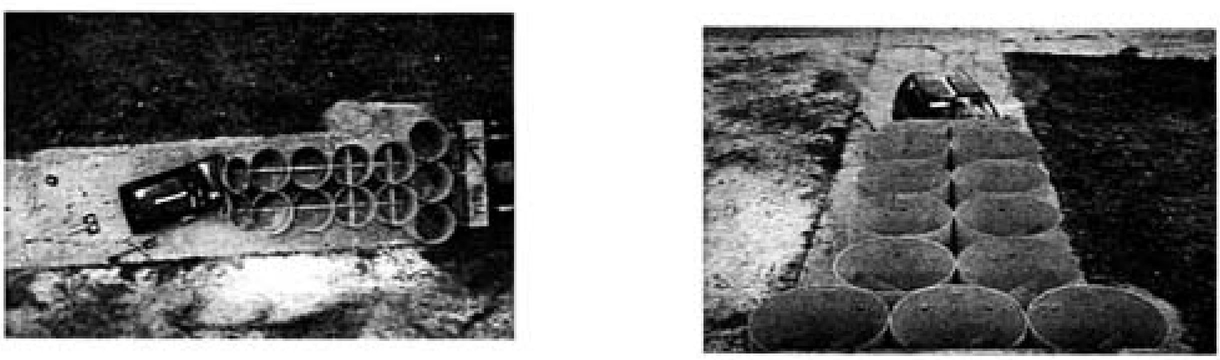
Figure B1-2 Vehicle/Installation Geometrics Before Test 3-32



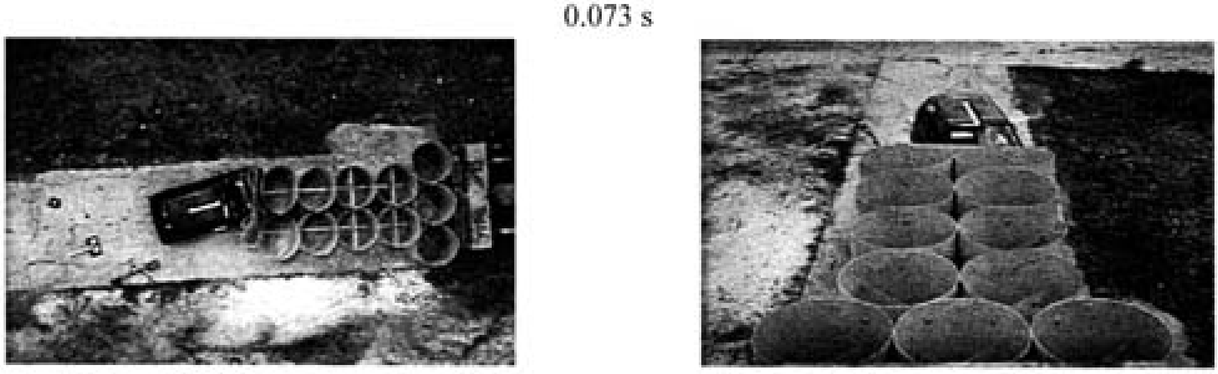
0.000 s



0.036 s

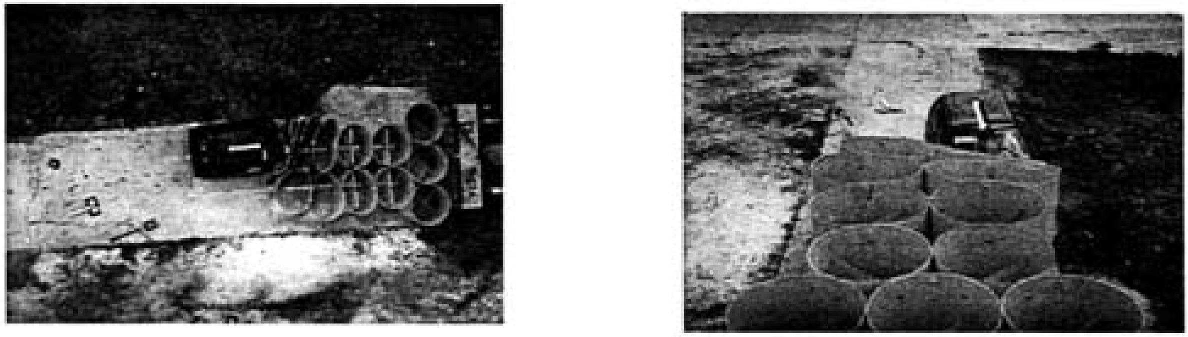


0.073 s

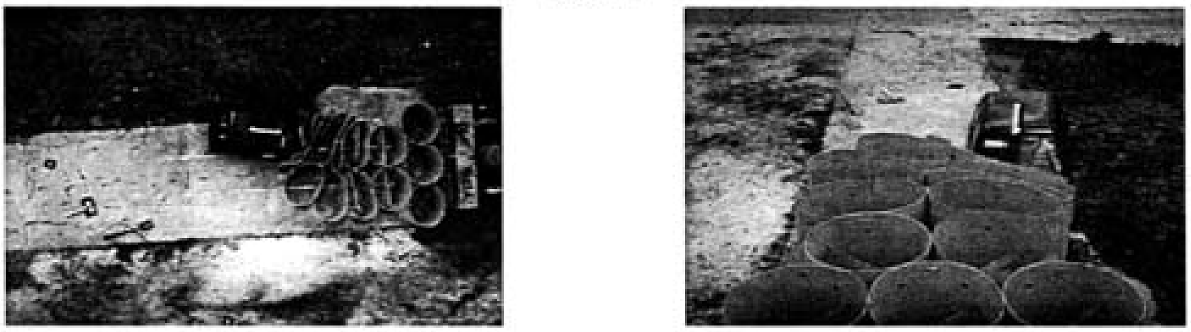


0.123 s

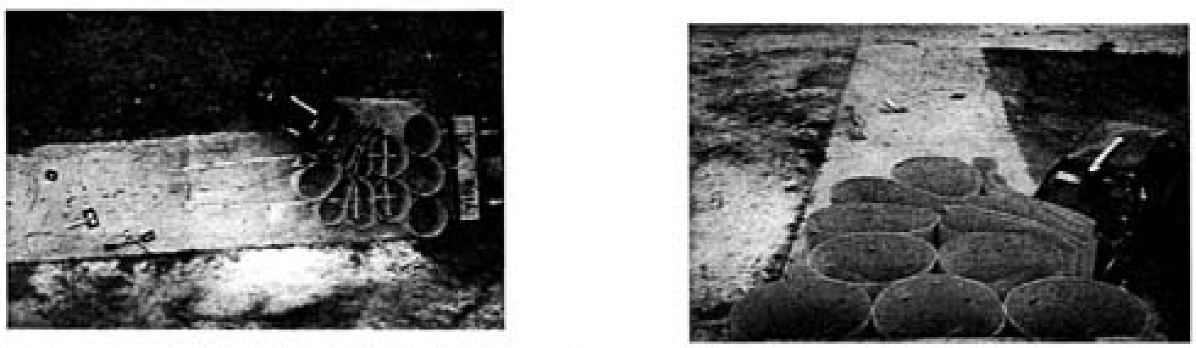
Figure B1-3 Sequential Photographs for Test 3-32
(overhead and frontal views)



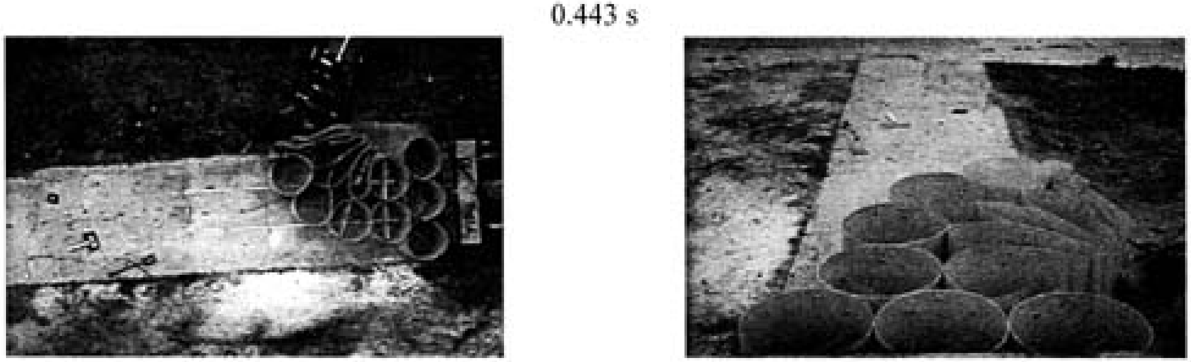
0.221 s



0.295 s



0.443 s



0.763 s

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

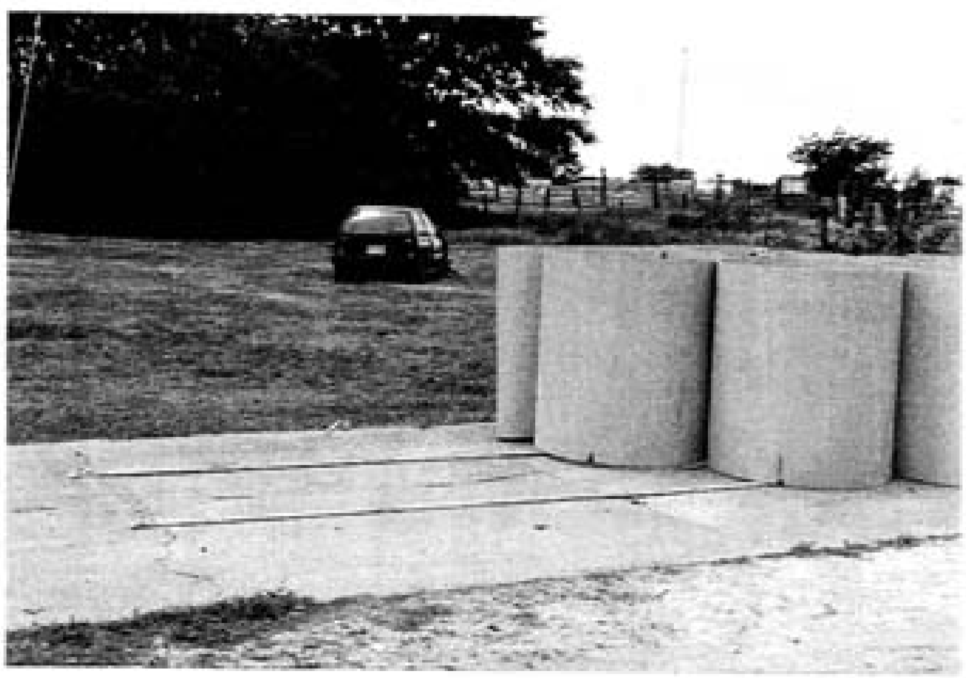
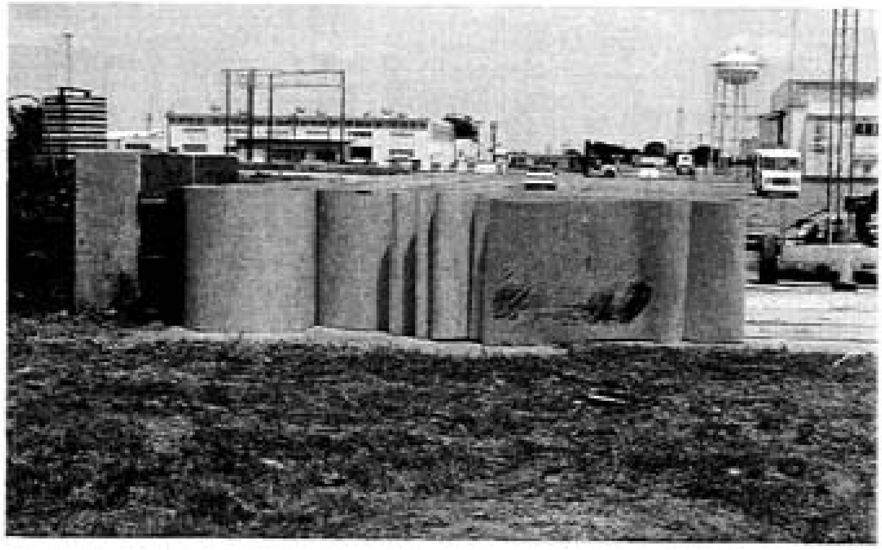
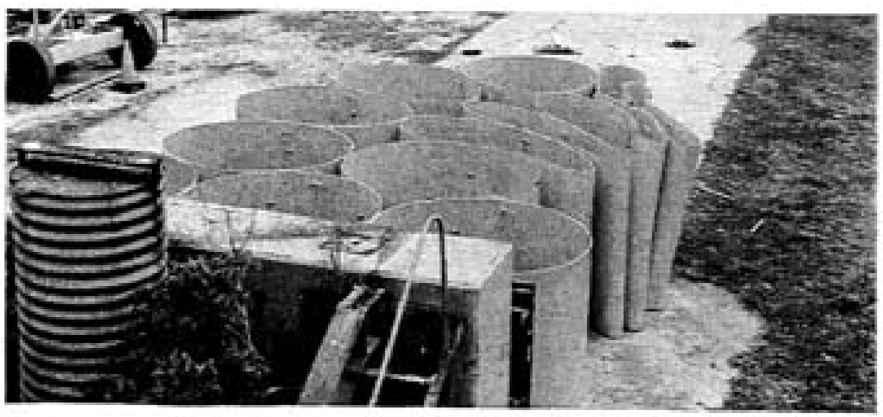


Figure B1-5 Installation After Test 3-32





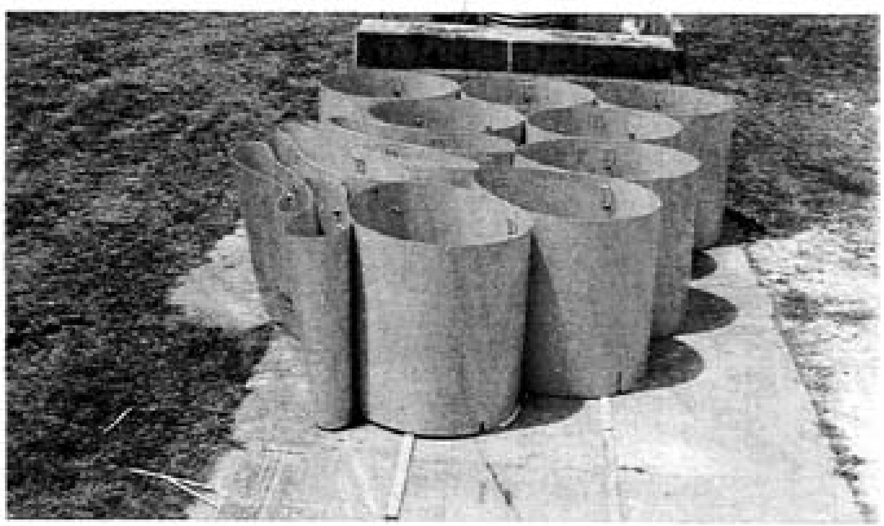
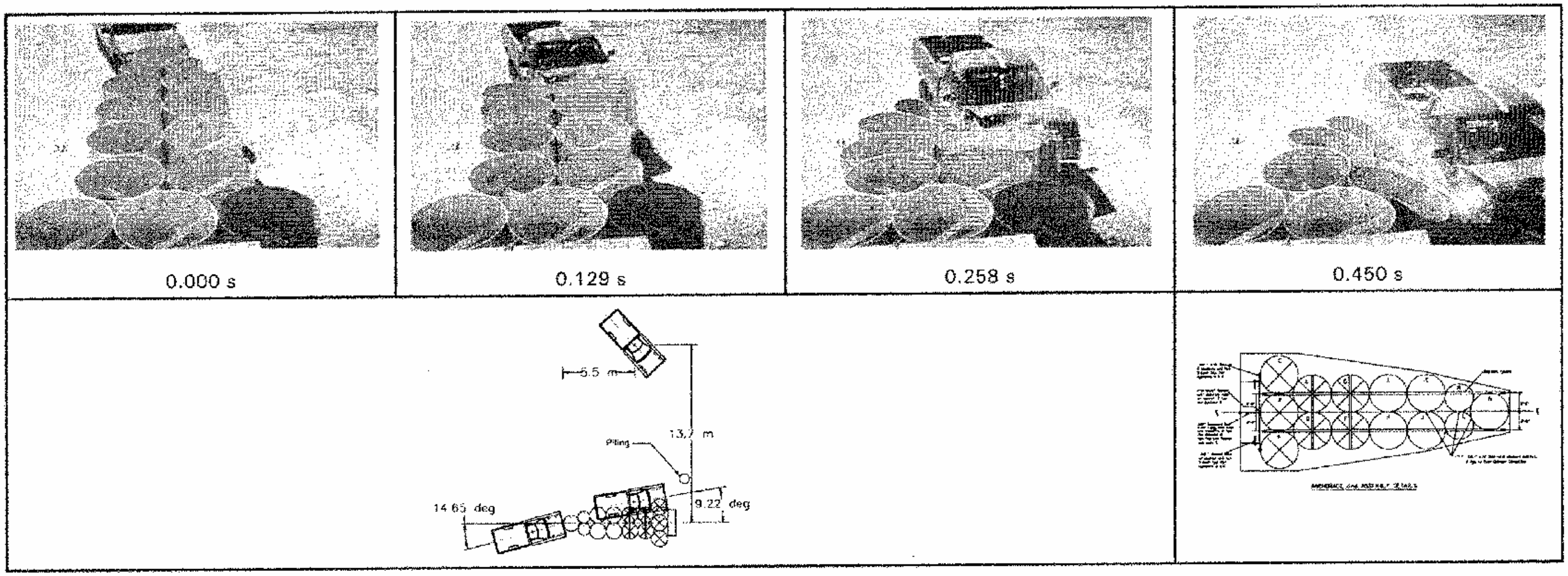


Figure B1-6 Installation After Test 3-32 continued

Figure B1-7 Vehicle After Test 3-32

NCHRP 350 Test 3-33

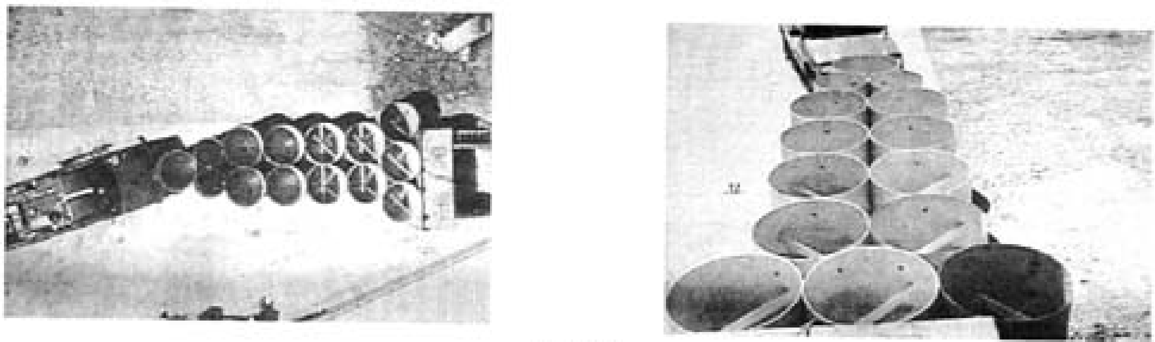


General Information	
Test Agency	Texas Transportation Institute
Test No.	405651-4
Date	10/27/97
Test Article	
Type	Crash Cushion
Name	Connecticut Imp. Attn. System
Installation Length (m)	8.0
Size and/or dimension and material of key elements	14 @1.22 m tall steel pipe tubes of various diameter & thickness
Soil Type and Condition	Concrete pavement, dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1992 GMC 2500 pickup
Mass (kg) Curb	2016
Test Inertial	2000
Dummy	75
Gross Static	2075

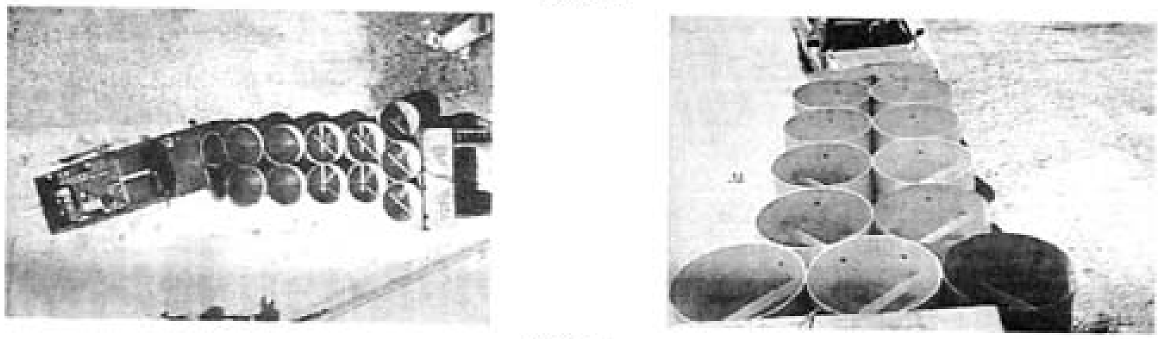
Impact Conditions	
Speed (km/h)	99.96
Angle (deg)	14.65
Exit Conditions	
Speed (km/h)	48.81
Angle (deg)	9.22
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.54
y-direction	2.37
Ridedown Accelerations (g's)	
x-direction	-6.07
y-direction	-7.17
Max. 0.050-s Average (g's)	
x-direction	-6.34
y-direction	-2.82
z-direction	3.05

Test Article Deflections (m)	
Dynamic	4.17
Permanent	3.83
Vehicle Damage	
Exterior	
VDS	12FD3
CDC	12FDEW3
Maximum Exterior Vehicle Crush (mm)	620
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	8
Post-Impact Behavior (during 0.6 s after impact)	
Max. Roll Angle (deg)	-5.7
Max. Pitch Angle (deg)	-2.8
Max. Yaw Angle (deg)	6.2

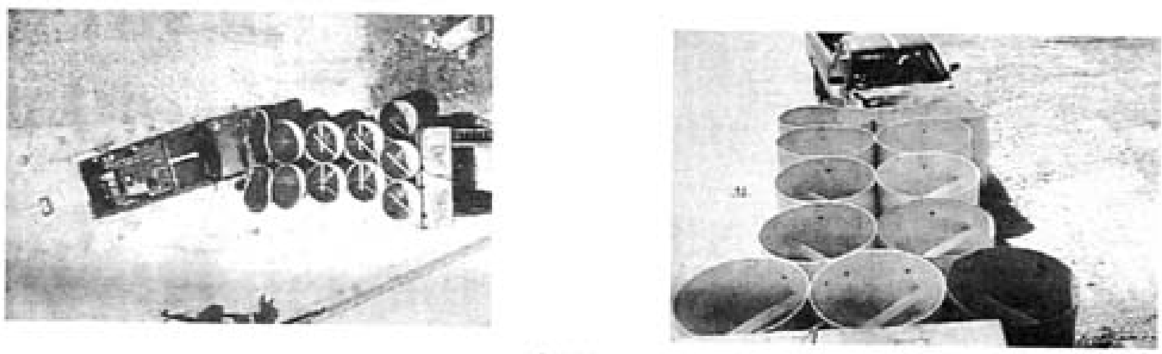
Figure B2-1 Summary of Results for Test 3-33



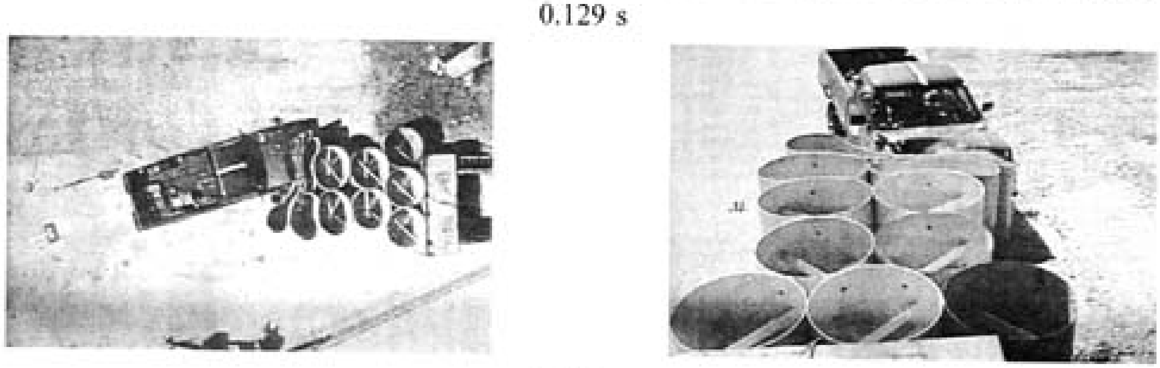
0.000 s



0.064 s

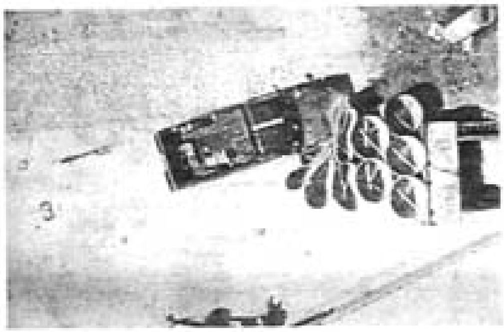


0.129 s

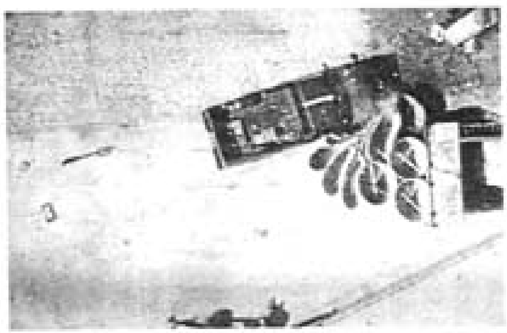
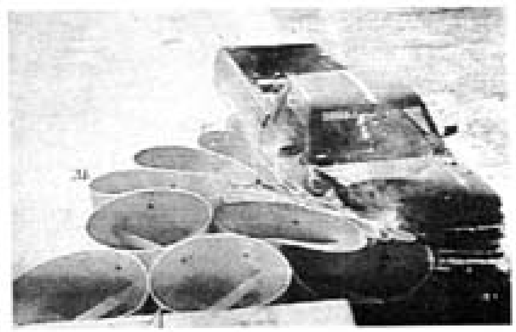


0.194 s

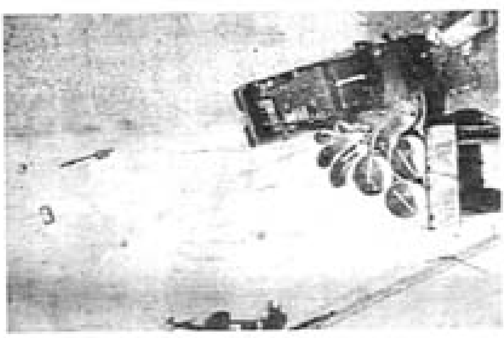
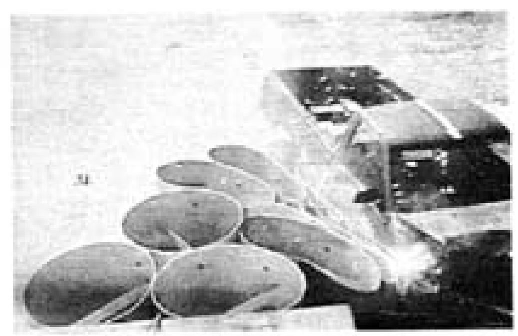
Figure B2-2 Sequential Photographs for Test 3-33 (overhead and frontal views)



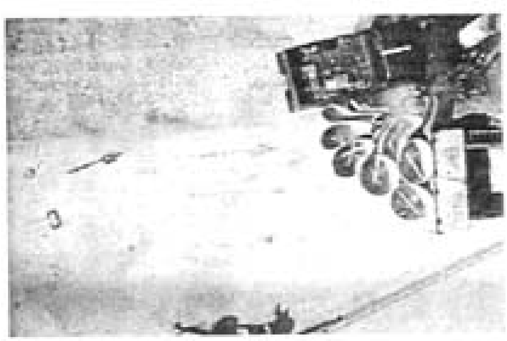
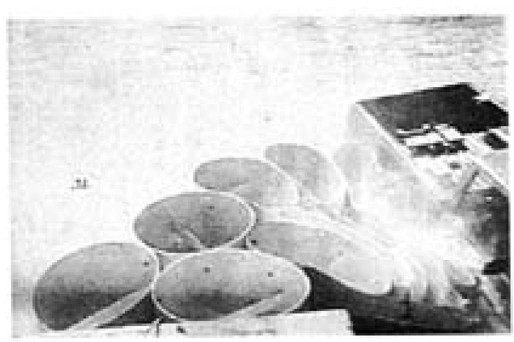

0.258 s

0.354 s

0.450 s

0.579 s

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

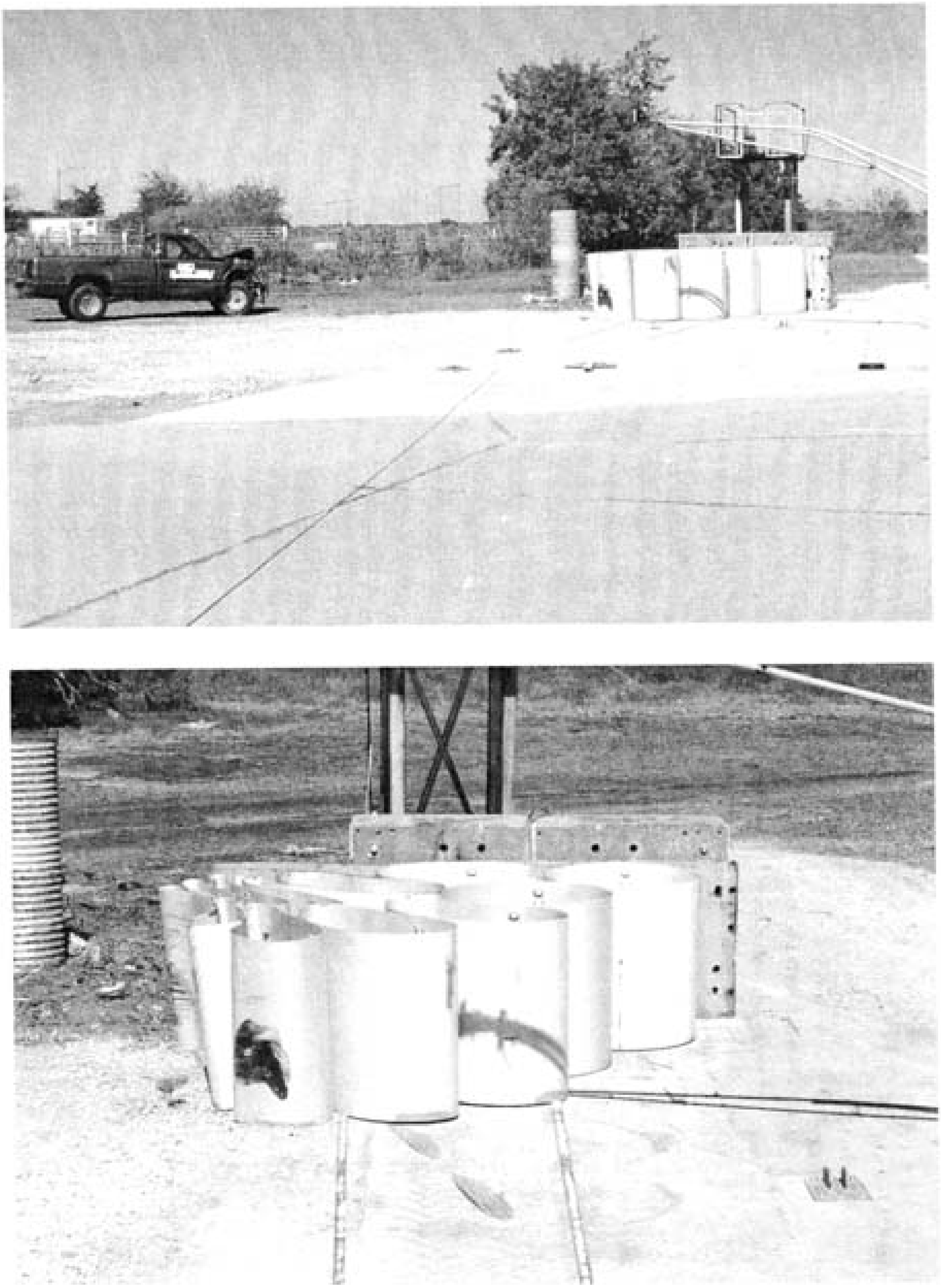


Figure B2-4 Installation After Test 3-33

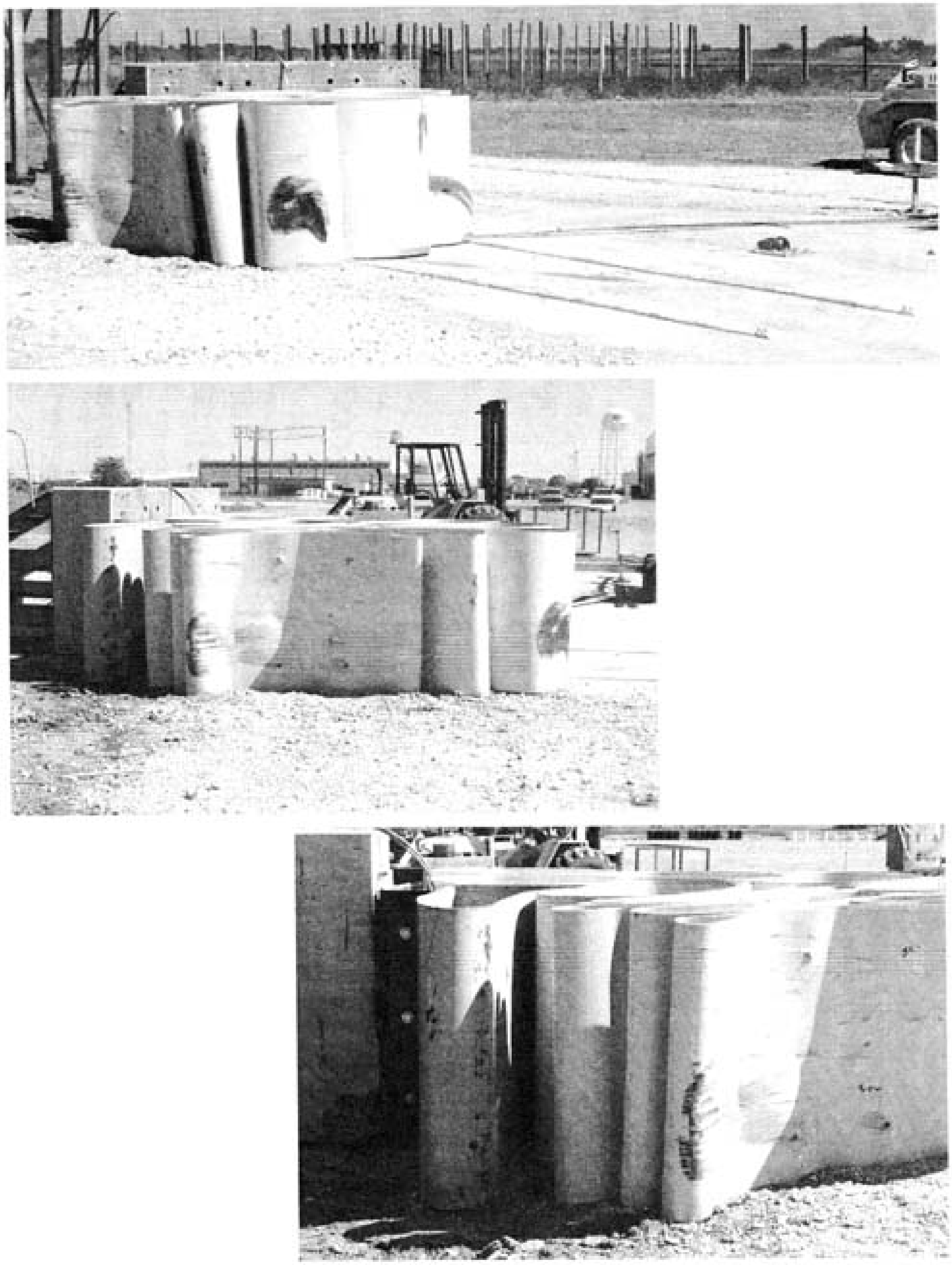


Figure B2-5 Installation After Test 3-33 continued

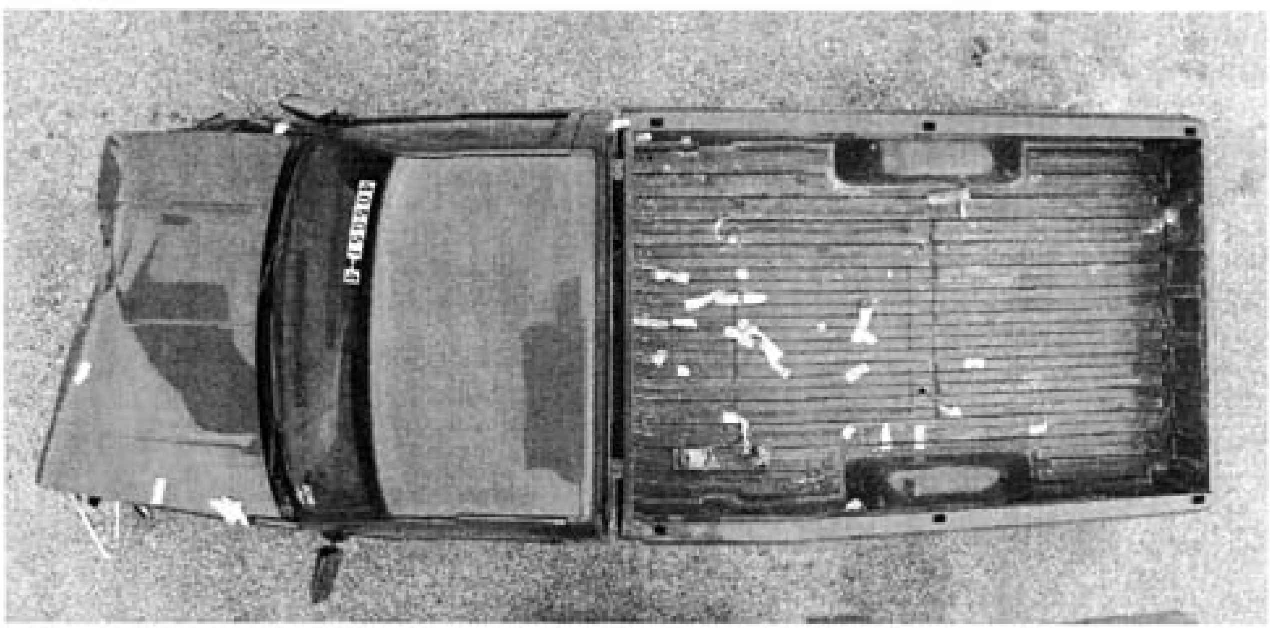


Figure B2-6 Vehicle After Test 3-33

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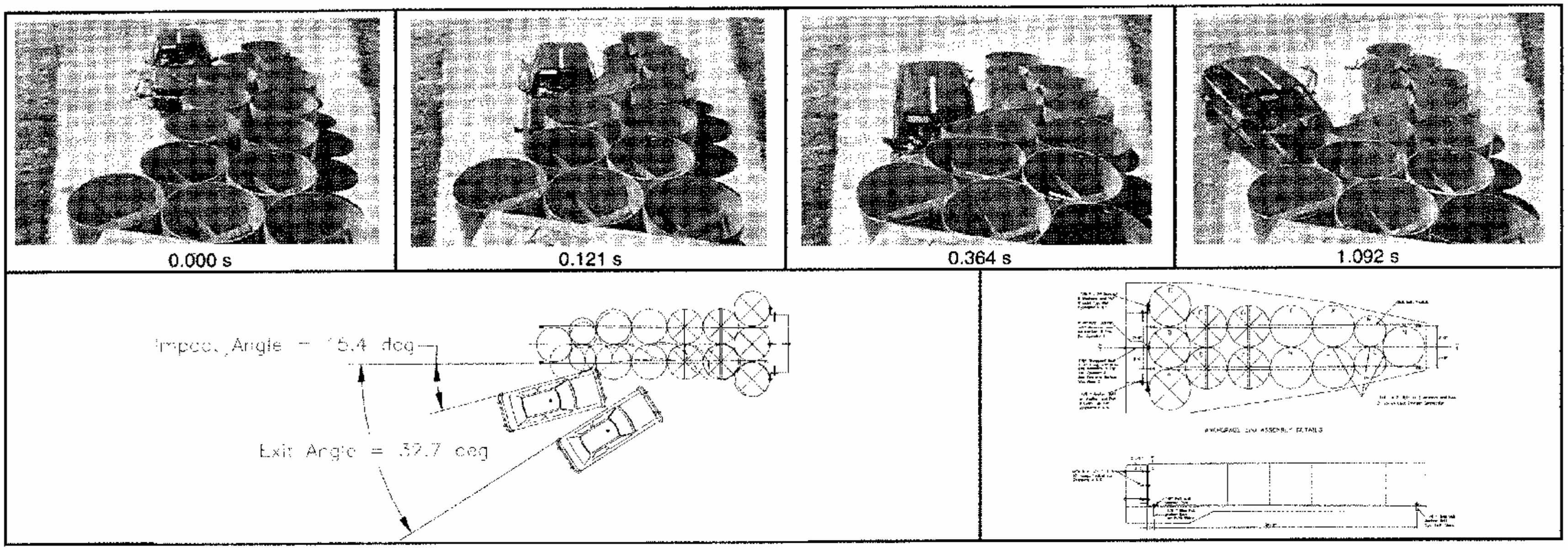


General Information	
Test Agency	Texas Transportation Institute
Test No.	404231-7
Date	04/19/99
Test Article	
Type	Crash Cushion
Name	Conn. Impact Atten. System (CIAS)
Installation Length (m)	8.0
Material or Key Elements	14 each 1.22 mm Tall Steel Pipe Cylinders of Various Wall Thickness
Soil Type and Condition	Concrete Pavement, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1993 Geo Metro
Mass (kg)	
Curb	771
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	98.7
Angle (deg)	15.4
Exit Conditions	
Speed (km/h)	10.7
Angle (deg)	32.7
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	10.7
y-direction	1.5
THIV (km/h)	38.6
Ridedown Accelerations (g's)	
x-direction	-20.5
y-direction	-4.2
PHD (g's)	20.7
ASI	1.52
Max. 0.050-s Average (g's)	
x-direction	-18.2
y-direction	-1.9
z-direction	2.9

Test Article Deflections (m)	
Lateral	0.93
Permanent	0.58
Vehicle Damage	
Exterior	
VDS	12FD4
CDC	12FDEK3 & 12FEW3
Maximum Exterior Vehicle Crush (mm)	340
Interior	
OCDI	FS0012000
Max. Occ. Compart. Deformation (mm)	32
Post-Impact Behavior	
(during 1.0 s after impact)	
Max. Yaw Angle (deg)	-39
Max. Pitch Angle (deg)	-25
Max. Roll Angle (deg)	-10

Figure B3-1 Summary of Results for Test 3-34

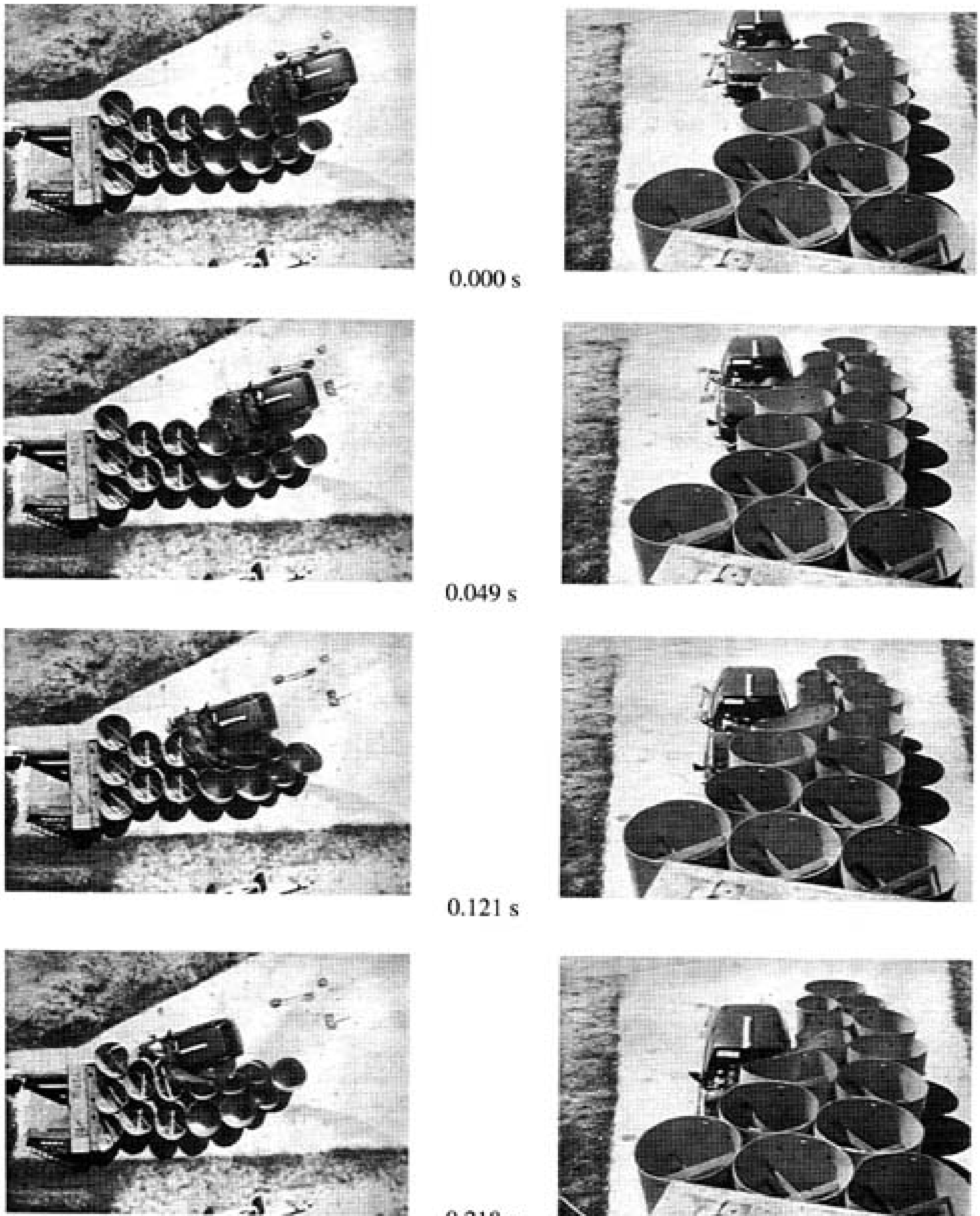


Figure B3-2 Sequential Photographs for Test 3-34 (overhead and frontal views)

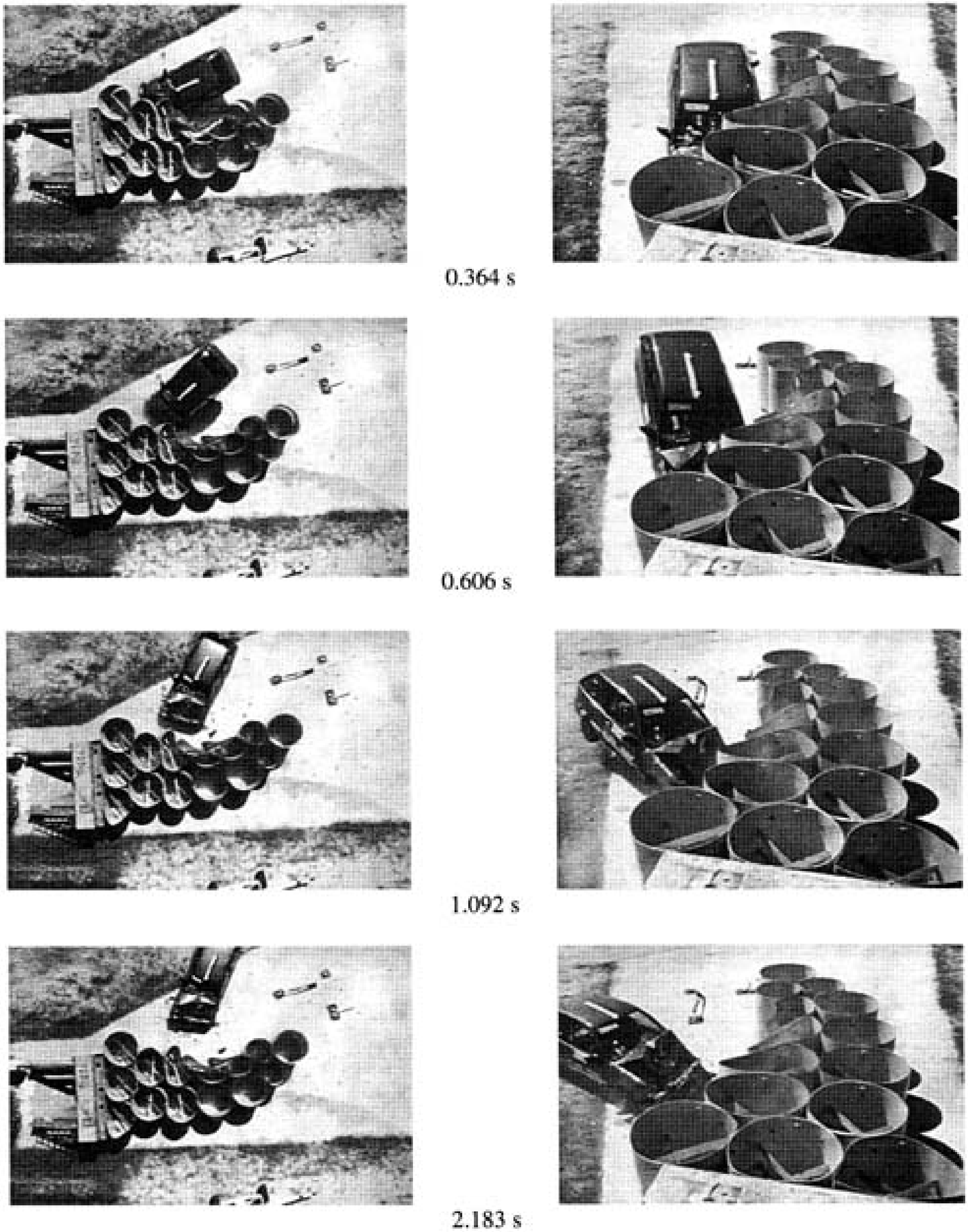
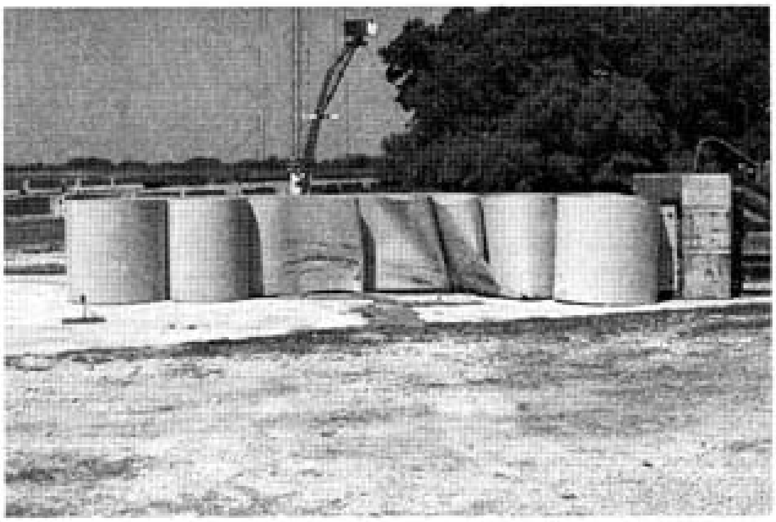
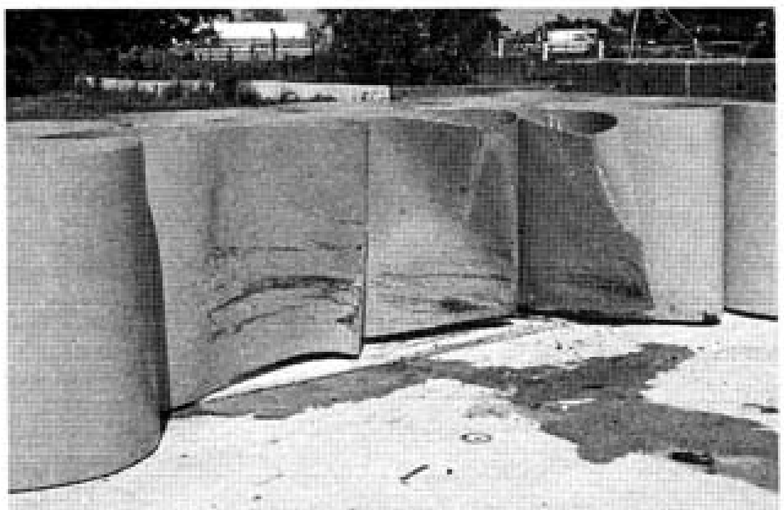


Figure B3-3 Sequential Photographs for Test 3-34 continued (overhead and frontal views)

Figure B3-4 Installation After Test 3-34





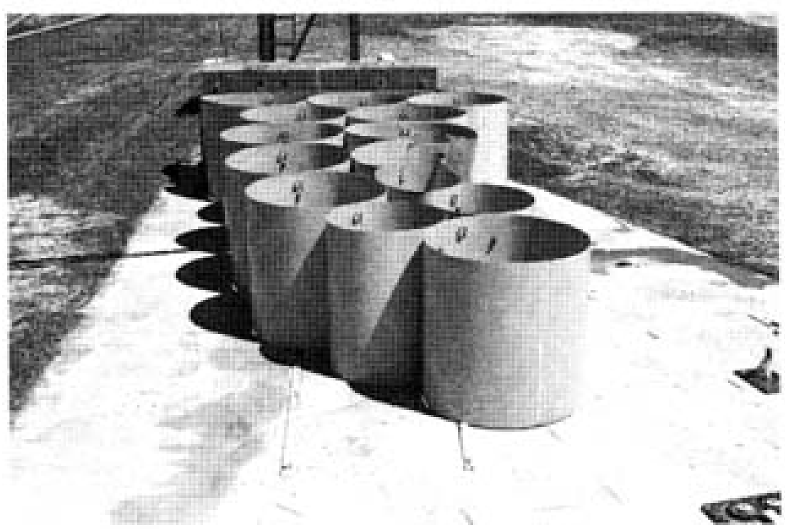


Figure B3-5 Installation After Test 3-34 continued

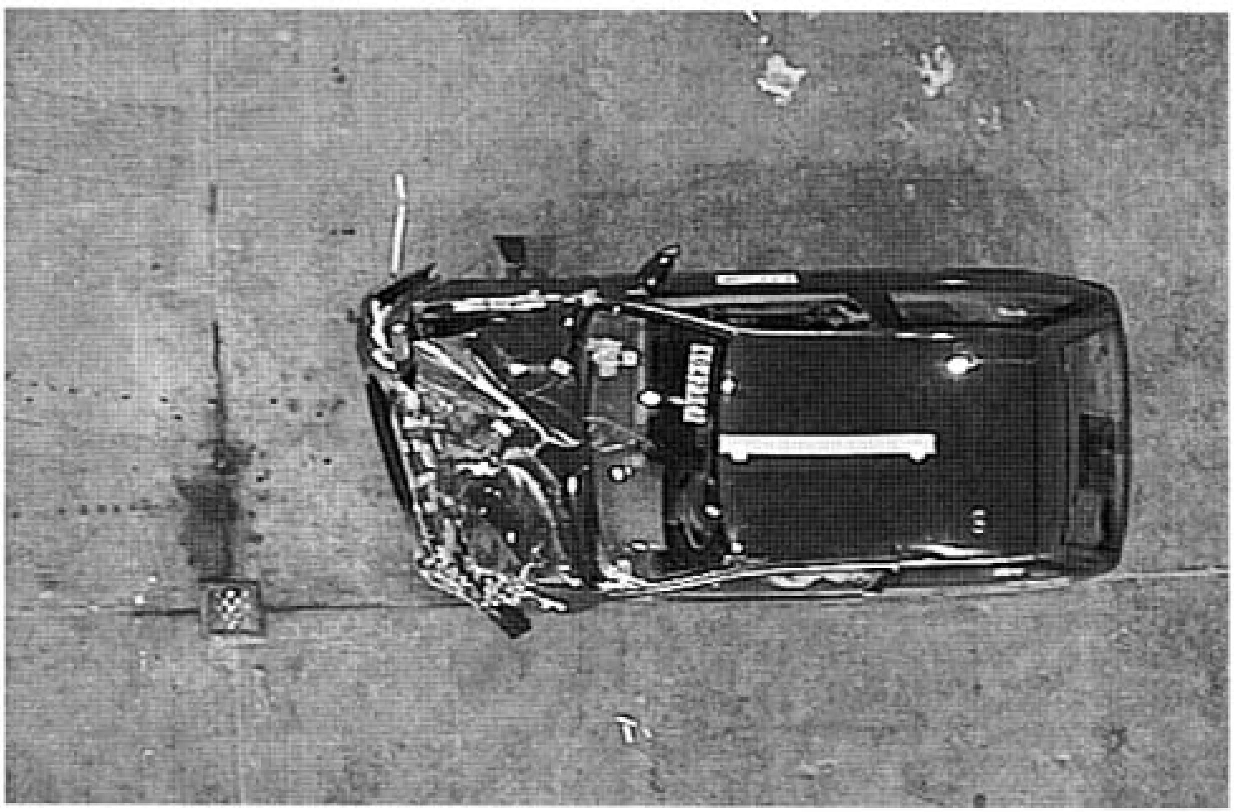


Figure B3-6 Vehicle After Test 3-34

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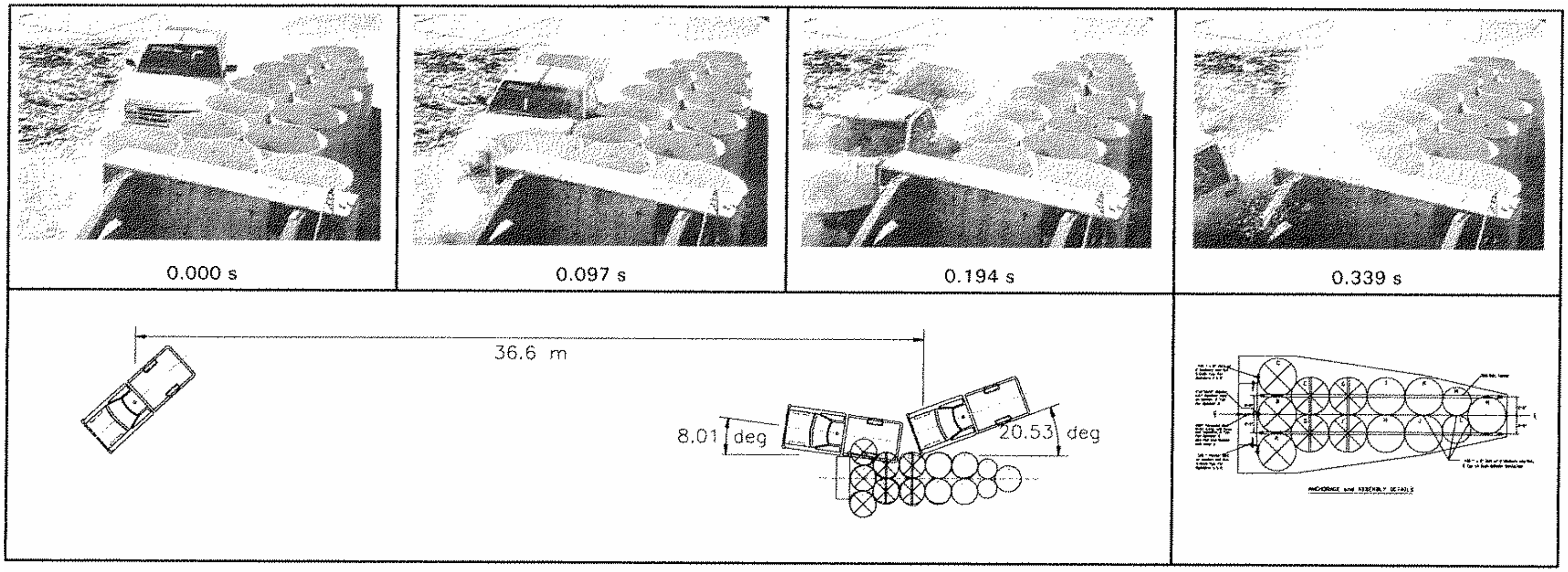


General Information
- Test Agency .... Texas Transportation Institute
- Test No. 405651-3
- Date 10/14/97

Test Article
- Type .... Crash Cushion
- Name .... Connecticut Imp. Attn. System
- Installation Length (m) 8.0
- Size and/or dimension and material of key elements .... 14 @1.22 m tall steel pipe tubes of various diameter & thickness

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

Test Vehicle
- Type .... Production
- Designation 2000P
- Model .... 1992 Chevrolet 2500 pickup
- Mass (kg) Curb 1901
  - Test Inertial 2000
  - Dummy 77
  - Gross Static 2077

Impact Conditions
- Speed (km/h) 99.49
- Angle (deg) 20.53

Exit Conditions
- Speed (km/h) 51.08
- Angle (deg) 8.01

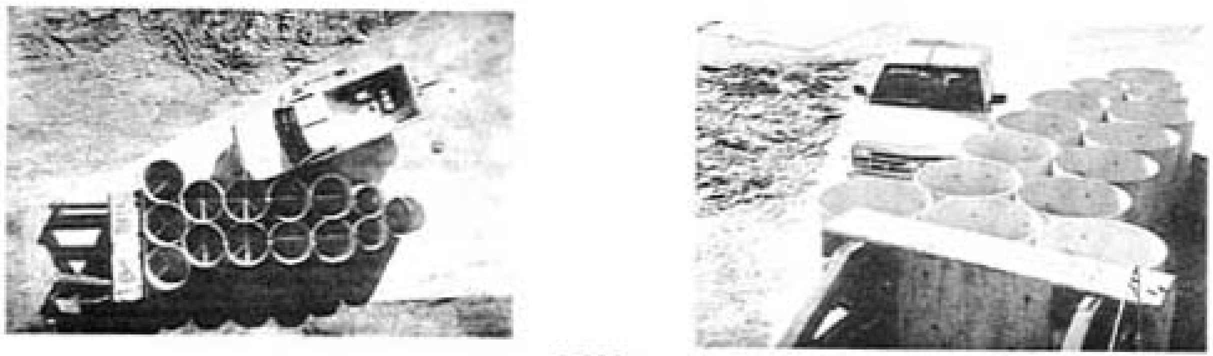
Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 10.88
  - y-direction 5.98
- Ridedown Accelerations (g's)
  - x-direction .... -18.81
  - y-direction 13.46
- Max. 0.050-s Average (g's)
  - x-direction .... -12.57
  - y-direction 8.54
  - z-direction 7.78

Test Article Deflections (m)
- Dynamic 0.89
- Permanent 0.74

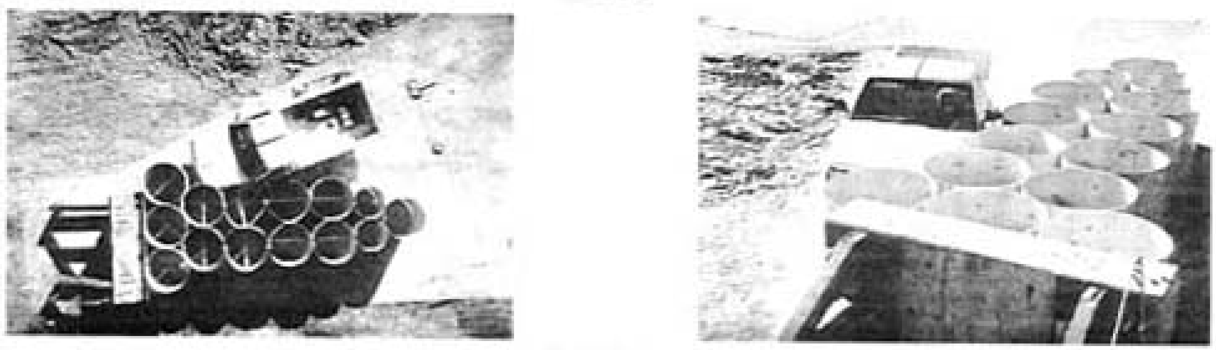
Vehicle Damage
- Exterior
  - VDS 11LFQ5
  - CDC .... 11FLEK3 & 11LDEW2
- Maximum Exterior Vehicle Crush (mm) 640
- Interior
  - OCDI LF0021000
- Max. Occ. Compart. Deformation (mm) 110

Post-Impact Behavior (during 1.0 s after impact)
- Max. Roll Angle (deg) 24.1
- Max. Pitch Angle (deg) .... -7.8
- Max. Yaw Angle (deg) .... -2.7

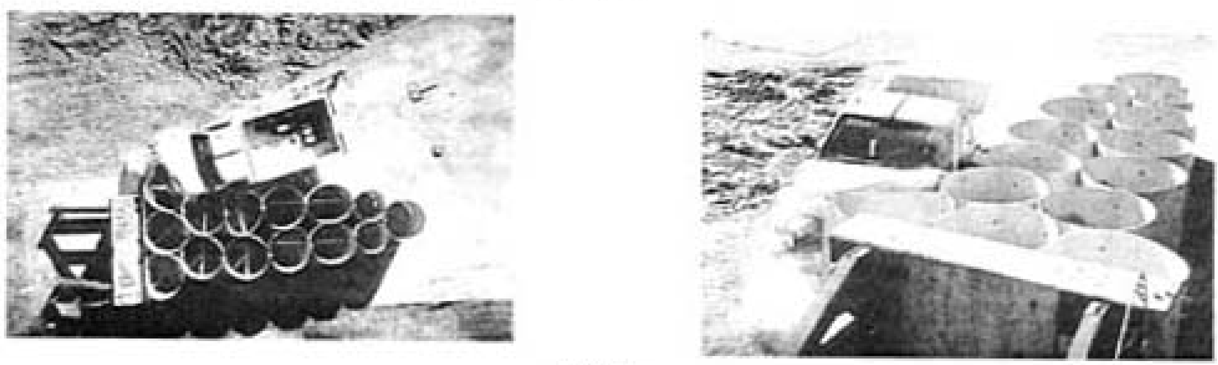
Figure B4-1 Summary of Results for Test 3-35



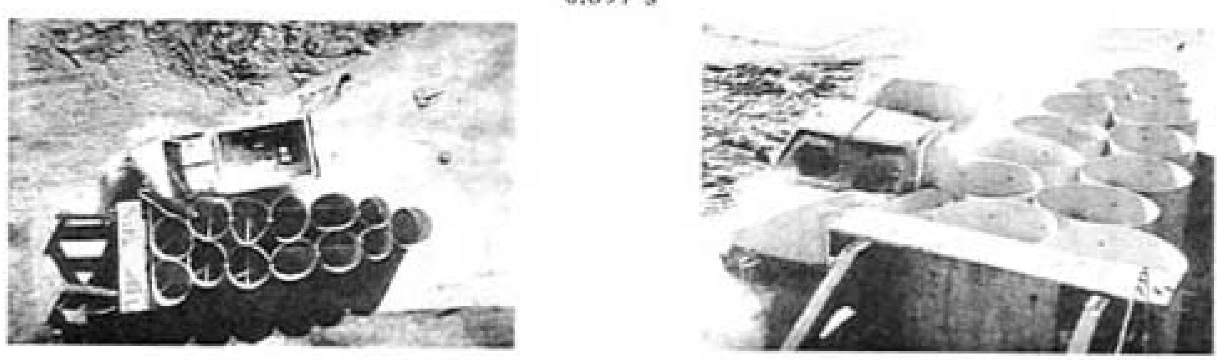
0.000 s



0.048 s

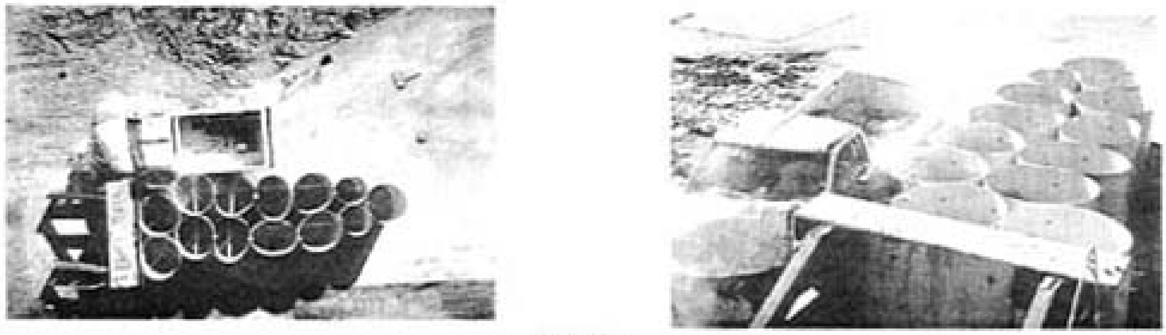


0.097 s



0.145 s

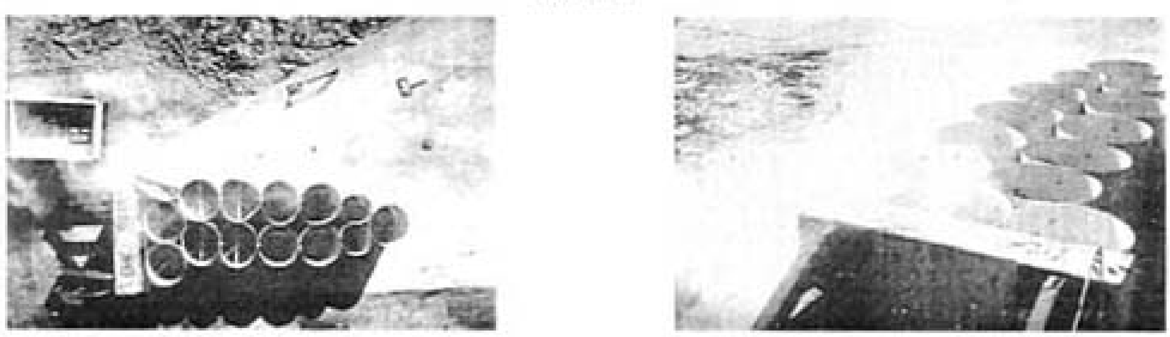
Figure B4-2 Sequential Photographs for Test 3-35 (overhead and frontal views)



0.194 s

0.242 s

0.339 s



0.558 s

Figure B4-3 Sequential Photographs for Test 3-35 continued (overhead and frontal views)

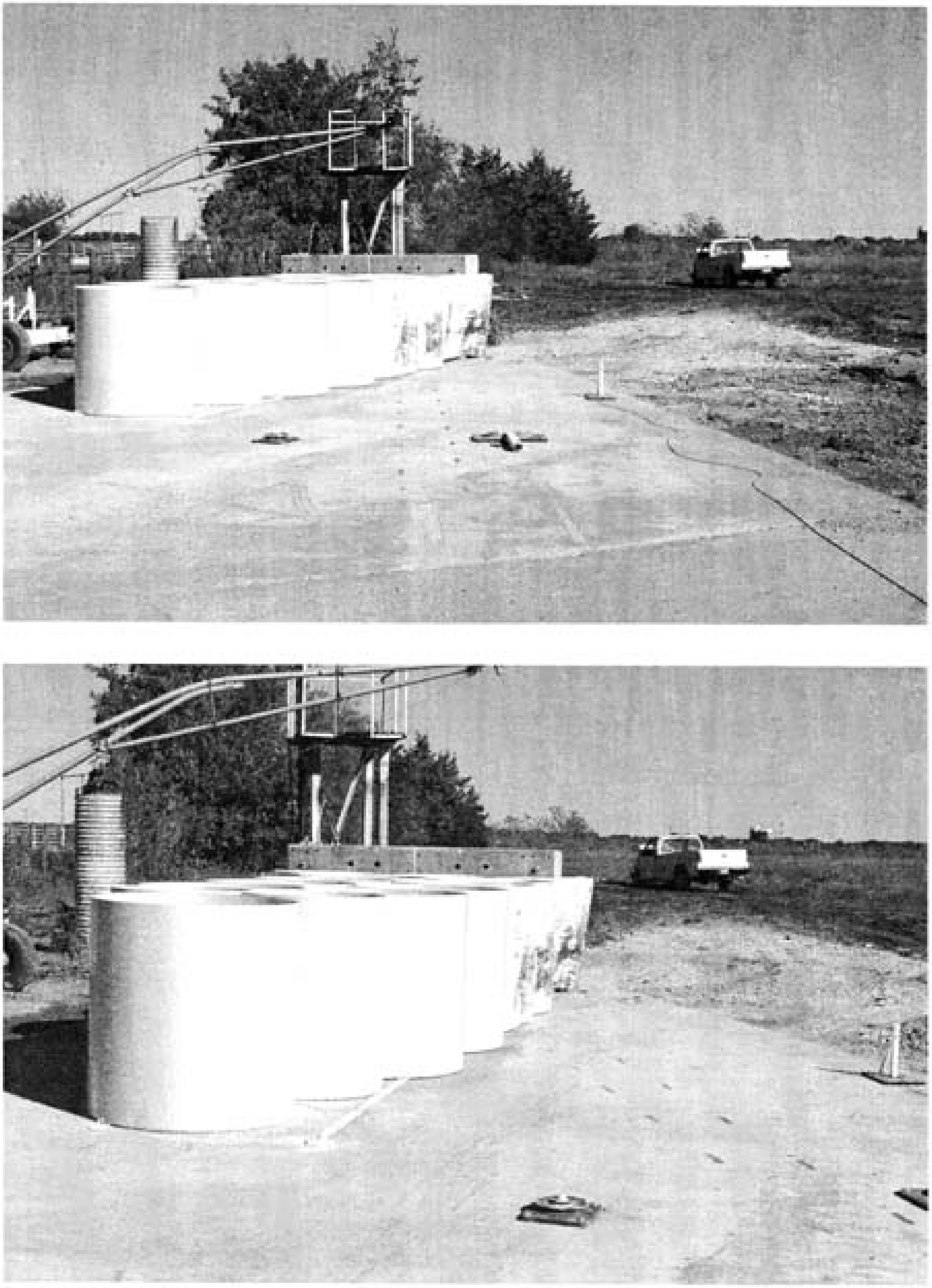
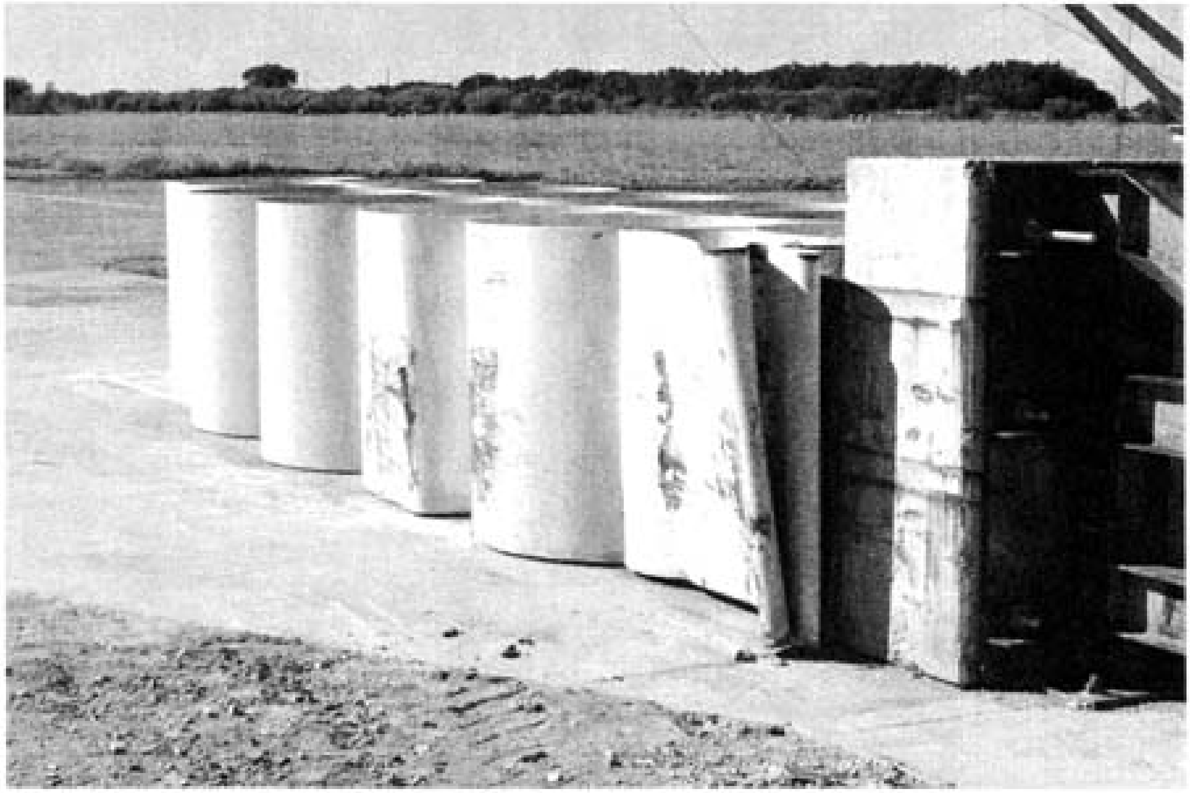


Figure B4-4 Installation After Test 3-35



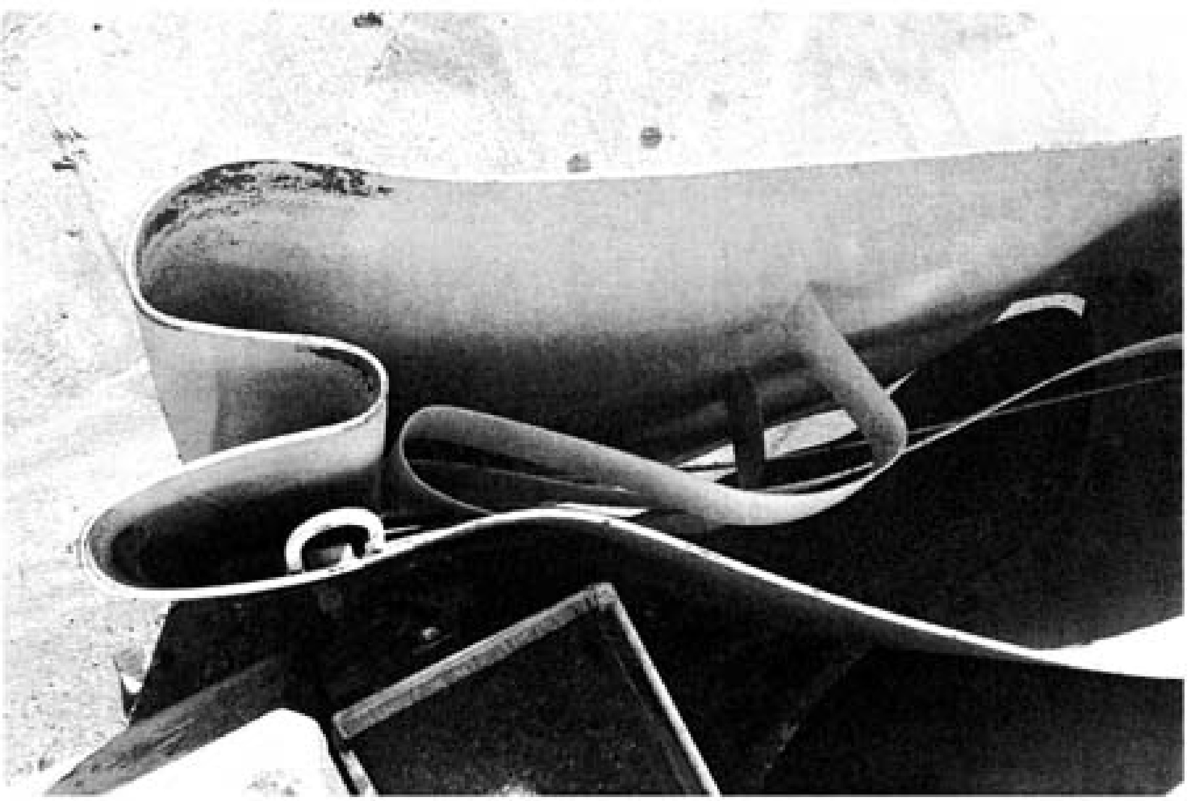


Figure B4-5 Installation After Test 3-35 continued

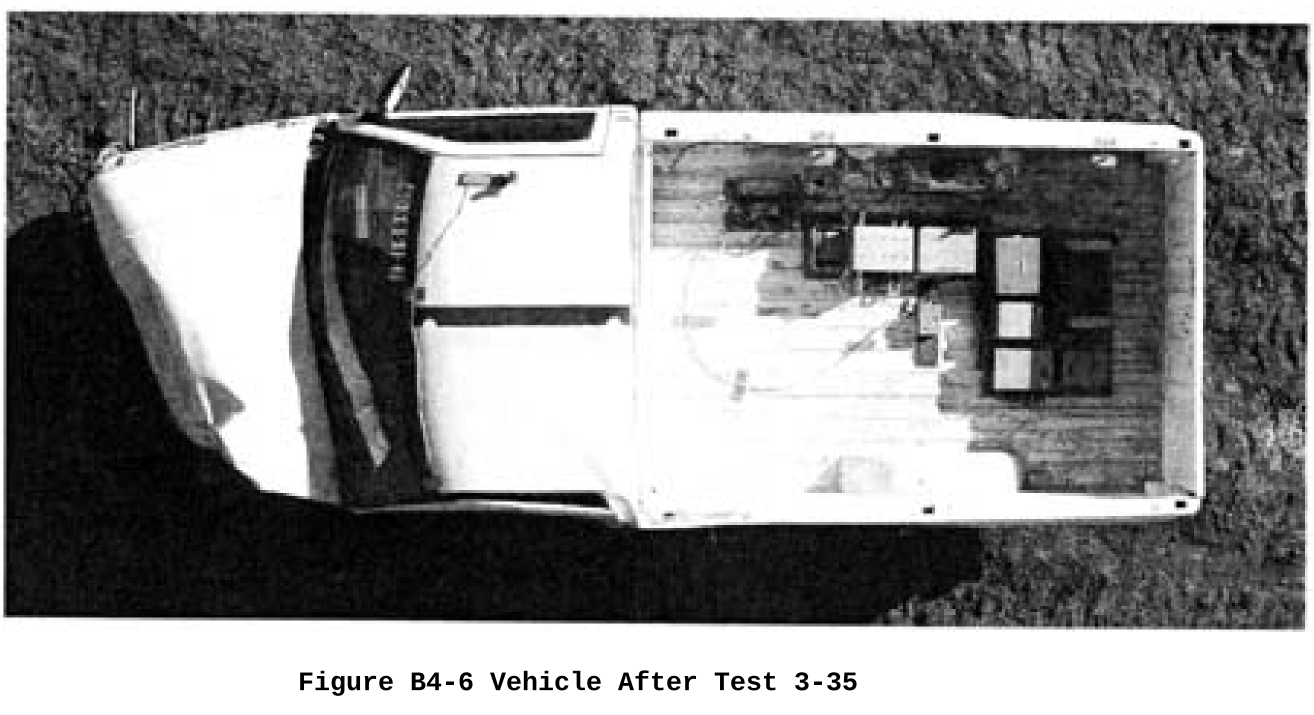


Figure B4-6 Vehicle After Test 3-35

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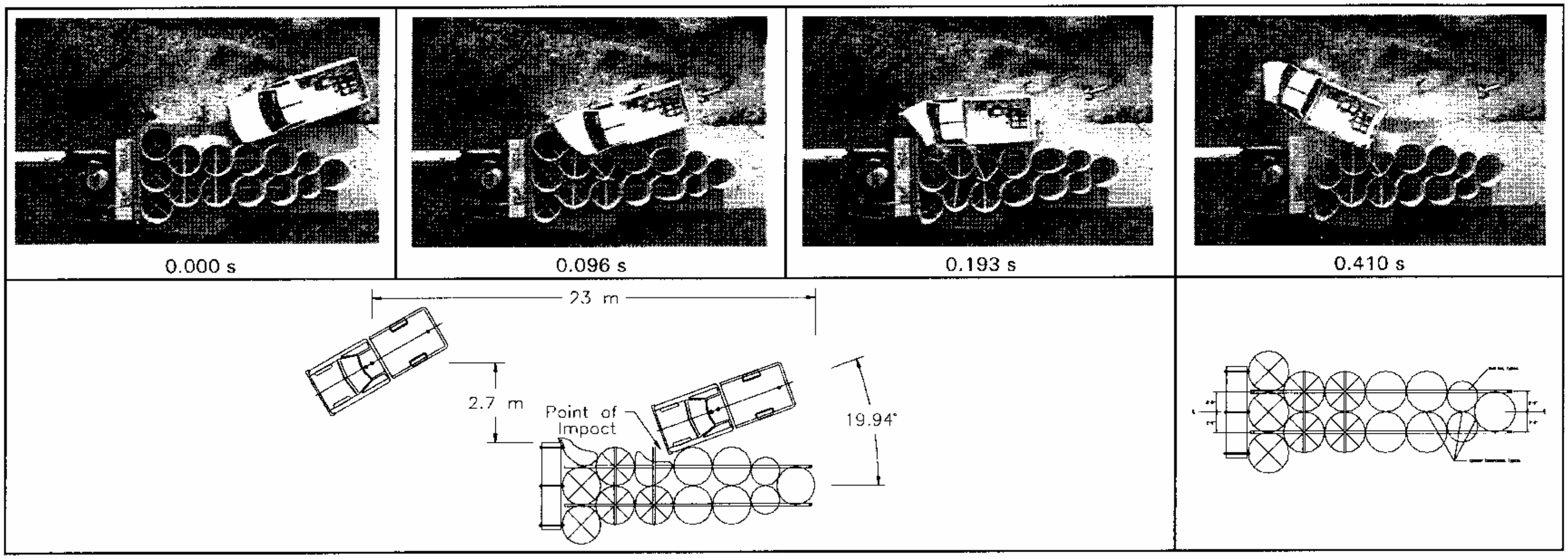

General Information	
Test Agency	Texas Transportation Institute
Test No.	405651-2
Date	05/15/96
Test Article	
Type	Crash Cushion
Name or Manufacturer	Connecticut Impact Att. System
Installation Length (m)	7.9
Size and/or dimension and material of key elements	14 @ steel pipe tubes of various size and thickness
Soil Type and Condition	Concrete pavement, dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1990 Chevrolet 2500 pickup
Mass (kg) Curb	1916
Test Inertial	2000
Dummy	No Dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	100.71
Angle (deg)	19.94
Exit Conditions	
Speed (km/h)	27.20
Angle (deg)	38.39
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	11.28
y-direction	23.29
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-18.67
y-direction	10.35
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-15.38
y-direction	11.03
z-direction	6.15

Test Article Deflections (m)	
Dynamic	N/A
Permanent	0.5
Vehicle Damage	
Exterior	
VDS	12FL5
CDC	12FYEW5
Interior	
OCDI	LF2020001
Maximum Exterior Vehicle Crush (mm)	1015
Max. Occ. Compart. Deformation (mm)	185
Post-Impact Behavior	
Max. Roll Angle (deg)	-19.54
Max. Pitch Angle (deg)	6.75
Max. Yaw Angle (deg)	50.69

Figure B5-1 Summary of Results for Test 3-38

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

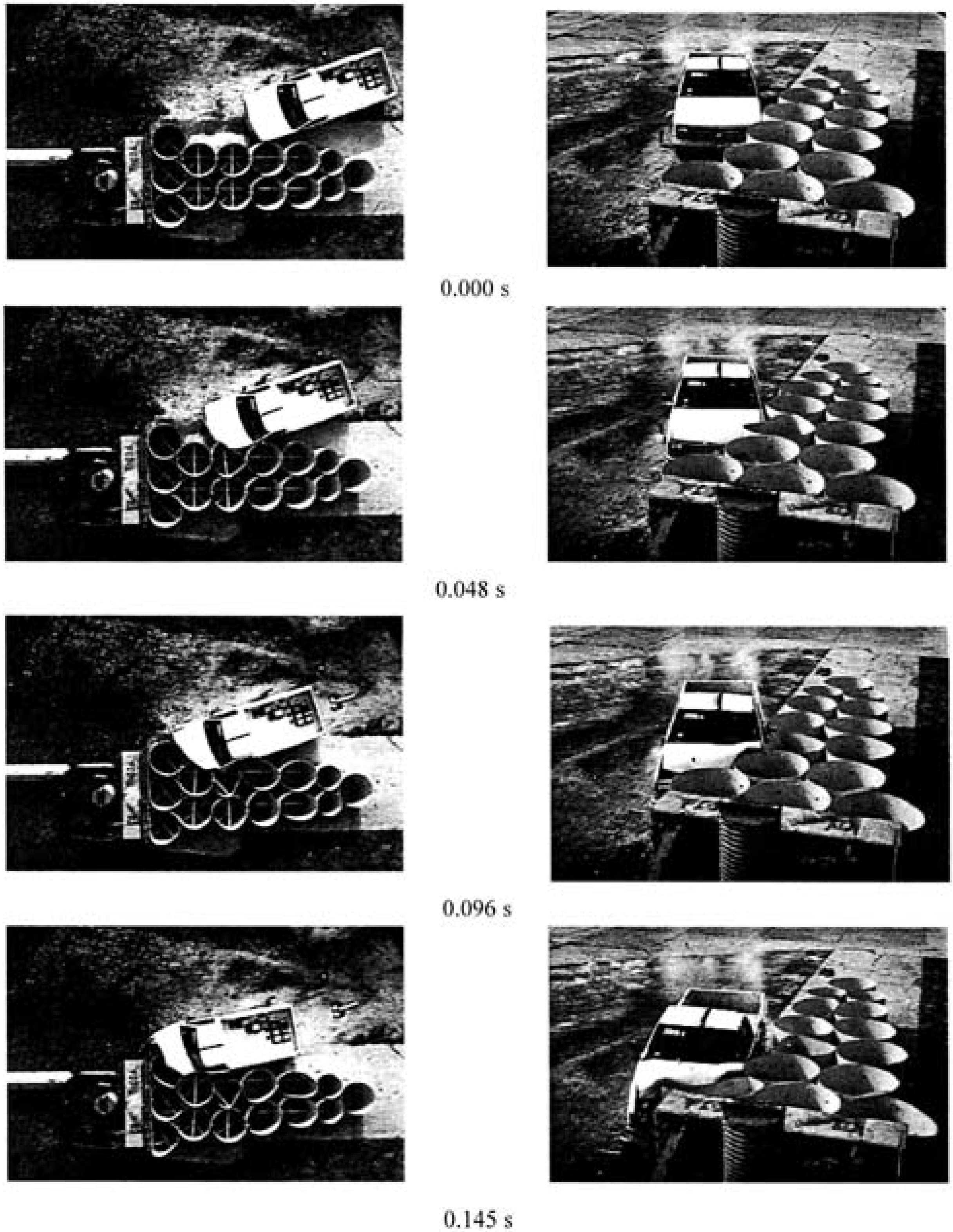

Figure B5-3 Sequential Photographs for Test 3-38 (overhead and frontal views)

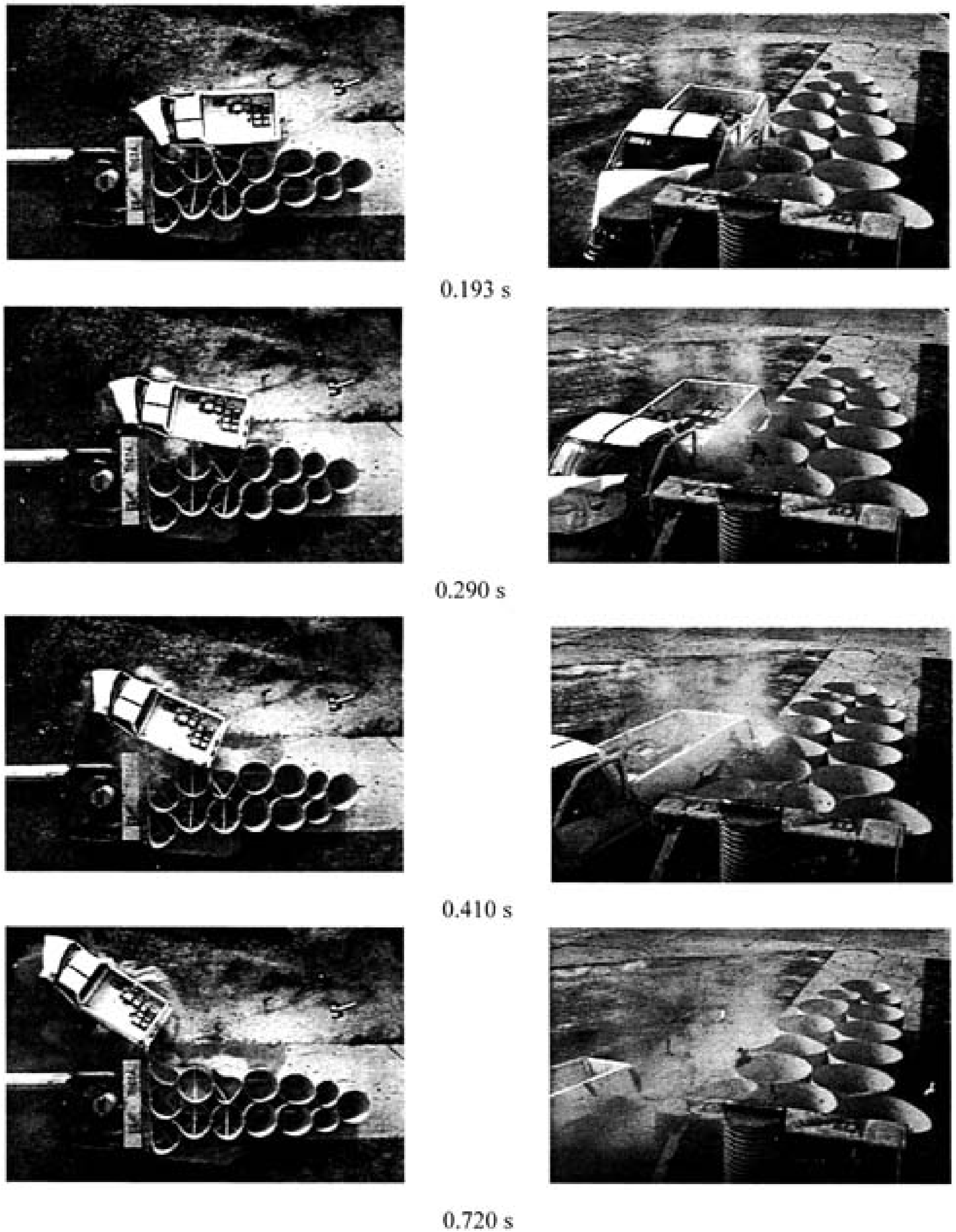

Figure B5-4 Sequential Photographs for Test 3-38 continued (overhead and frontal views)

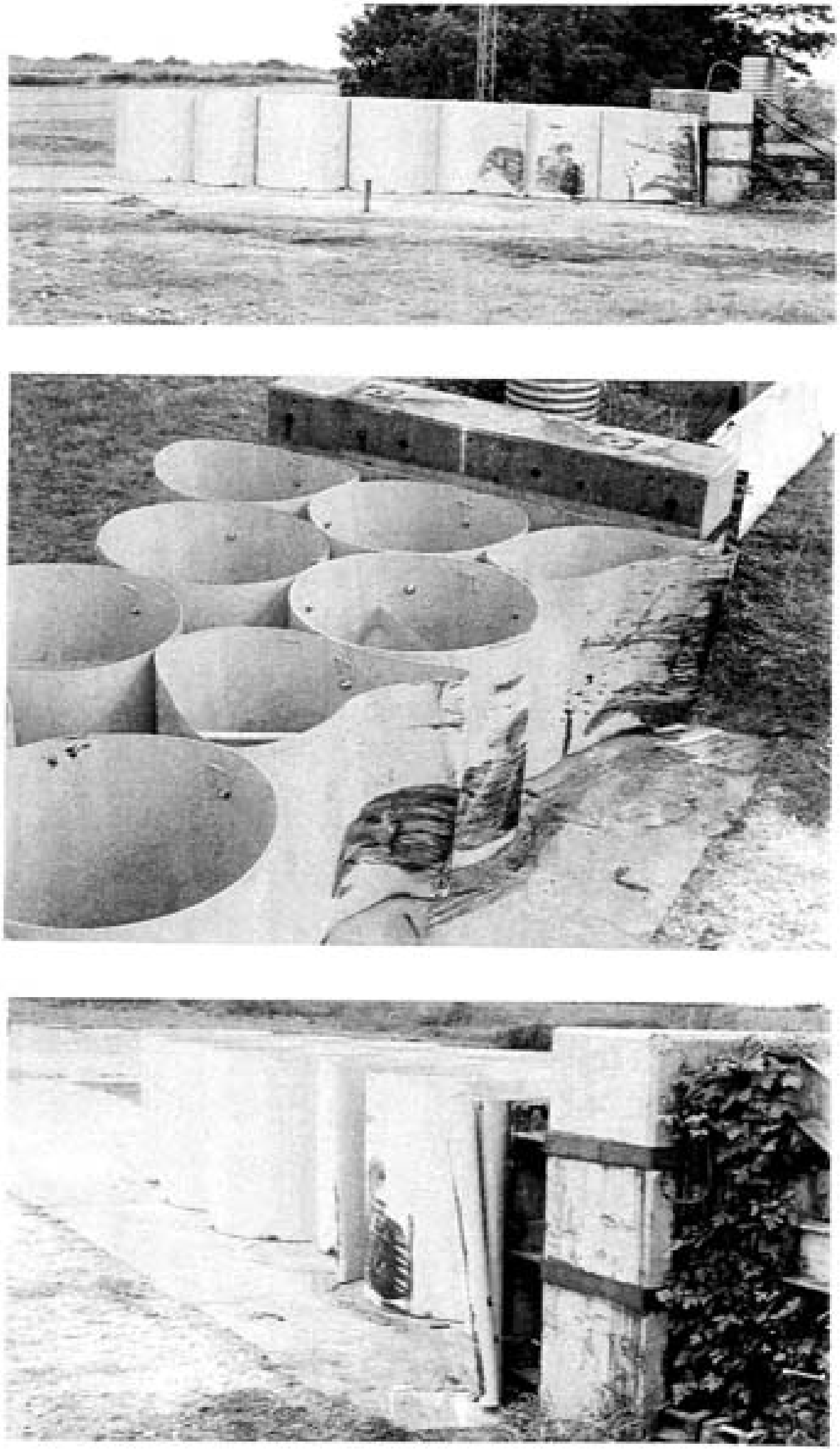

Figure B5-5 Installation After Test 3-38

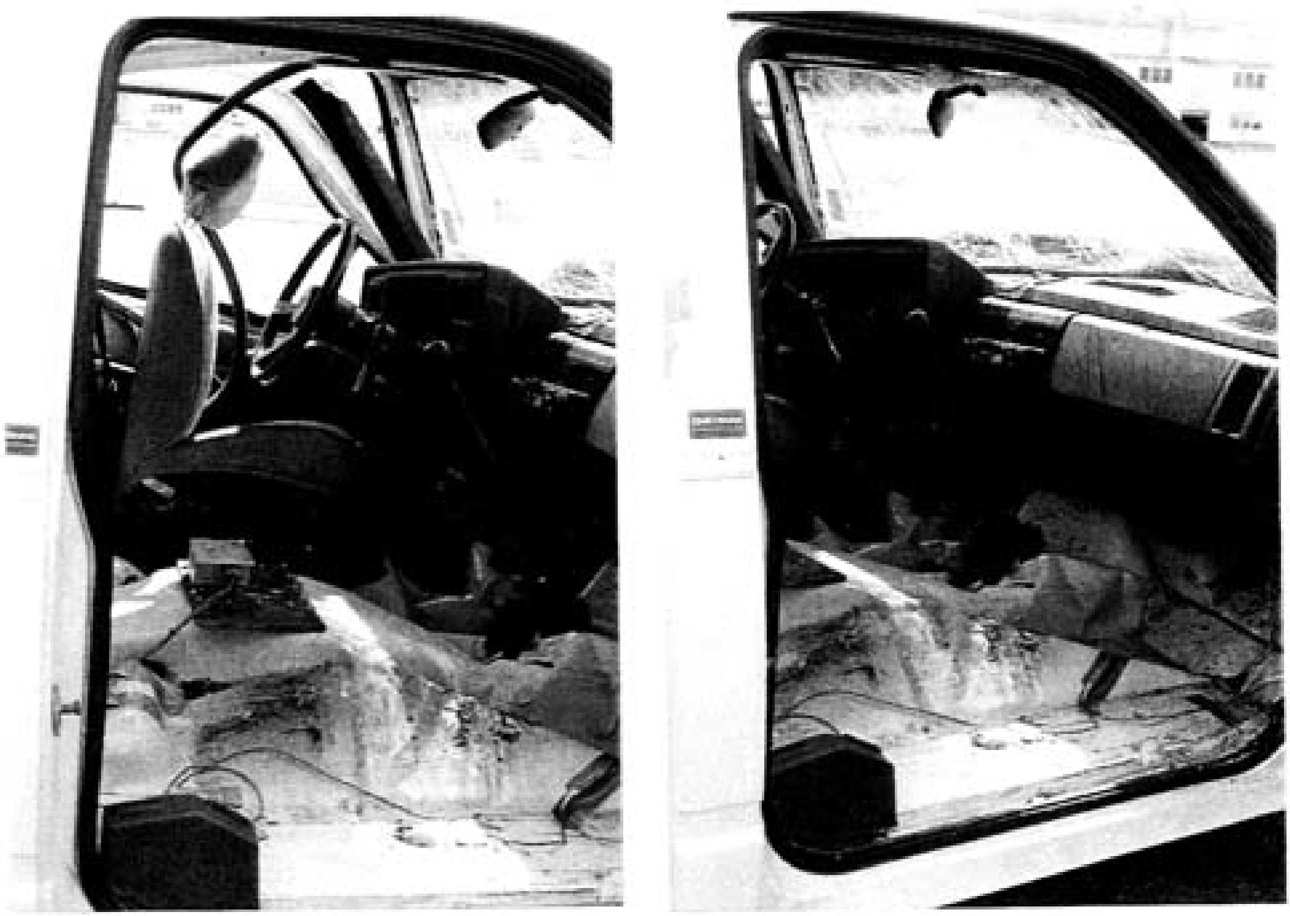

Figure B5-6 Vehicle After Test 3-38

APPENDIX C

Federal Highway Approval Letter

for use of the CIAS on the National Highway System

at Locations Where Opposite-Direction Impacts are Not a Concern

April 9, 2002

HSA-10/CC-77

Keith R. Lane, P.E.
Director of Research and Materials
Bureau of Engineering and Highway Operations
Connecticut Department of transportation
280 West Street
Rocky Hill, Connecticut 06067-3502

Dear Mr. Lane:

With your October 10, 2001 letter to Mr. Frederick Wright, former Federal Highway Administration Program Manager for the Safety Core Business Unit, you sent the final test report in a series of tests conducted over the past six years to certify the Connecticut Impact Attenuation System (CIAS) as a National Cooperative Highway Research Program (NCHRP) Report 350 test level 3 (TL-3) crash cushion.

The CIAS is a unique attenuator that "captures" vehicles impacting at or near the nose and along its front sides, while redirecting vehicles impacting near the back of the unit. As shown in greater detail in Enclosure 1, the CIAS consists of twelve steel cylinders 1.22 m in diameter and two cylinders 0.91 m in diameter. Each cylinder is 1.22-m high. Wall thickness varies from 6.35 mm for the three cylinders attached to the backup structure to 7.94 mm for the next two cylinders to 4.76 mm for the remaining large-diameter cylinders. The two 0.91 m diameter cylinders are made from 8-gauge plate steel. The CIAS array is set on two steel skid rails bolted to a concrete pad and connected to a 1980-mm wide backup wall with L-brackets on each side of the wall. These L-brackets are the only significant modification from the original design. They serve to offset the rear-most cylinders 610 mm from the edge of the wall to minimize vehicular snagging at this point.

NCHRP Report 350 tests 3-32, 3-33, 3-34 and 3-35 (note: test 3-35 was originally run as test 3-38) were successfully conducted. I consider tests 3-35 and 3-38 to be essentially the same tests for the CIAS design and note that test 3-35 demonstrated an acceptable redirectional capability of the CIAS in a side impact near the back of the array after the design was modified as noted above. Test 3-30 is similar to the head-on small car test run under NCHRP Report 230 guidelines and was waived as previously agreed by our respective staff members. Test 3-31 was considered unnecessary based on the results of test 3-33. Consequently, the CIAS, as tested, may be considered an NCHRP Report 350 TL-3 crash cushion and may be used on the National Highway System in gore areas and other locations where traffic can pass on either side of the array and opposite-direction impacts are not a concern.

I understand that the CIAS, while patented, is not proprietary and that plans, specifications, and additional information on its cost and performance can be

obtained through Mr. James Sime, Manager of Research, at (860) 258-0309 or via e-mail at james.sime@po.state.ct.us .

Sincerely yours,

(original signed by A. George Ostensen)

A. George Ostensen
Program Manager, Safety

Enclosure