

SUMMARY OF THE NCHRP REPORT 350
CRASH TEST RESULTS FOR THE
CONNECTICUT TRUCK MOUNTED ATTENUATOR

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16. Abstract This report summarizes the results of four full-scale tests performed on the Connecticut Truck Mounted Attenuation System. All tests were conducted in accordance with the guidelines of NCHRP Report 350 for Test Level 2 devices. NCHRP Report 350 specifies two required and two optional tests. All four tests were conducted and all four tests passed all requirements. No repeat tests were required, and the results were uniformly excellent. This Truck Mounted Attenuator report is the first in a series of planned test reports which will document NCHRP Report 350 compliance of various Connecticut designed and developed impact attenuation systems.				
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Table of Contents

	<u>Page</u>
Title Page	i
Technical Report Documentation	ii
Disclaimer	iii
Acknowledgments	iv
Table of Contents	v
List of Tables	vi
List of Figures	vi
Background	1
Theoretical Basis for TMA	1
Description of the System	2
Previous Full-Scale Crash Testing Program	2
Truck-Mounted Attenuator Crash Testing	
Requirements of NCHRP Report 350	6
Connecticut TMA NCHRP Report 350	
Crash Test Program	8
Test No. 1 - NCHRP 350 Test 2-50	8
Test No. 2 - NCHRP 350 Test 2-51	10
Test No. 3 - NCHRP 350 Test 2-52	10
Test No. 4 - NCHRP 350 Test 2-53	10
Conclusion	11
References	12
Appendix	
Summary of Test Results and Typical	
Photos of NCHRP 350 Tests Performed	
NCHRP 350 Test 2-50	A-1
NCHRP 350 Test 2-51	A-6
NCHRP 350 Test 2-52	A-11
NCHRP 350 Test 2-53	A-16

List of Tables

	Page
Table 1 NCHRP Report 350 Test Level 2 TMA Test Matrix	9
Table 2 Summary of Crash Test Results	9

List of Figures

	Page
Figure 1 Detail Drawing of Connecticut TMA	3
Figure 2 Connecticut TMA	5
Figure 3 Impact Conditions for a TMA	7

APPENDIX

	Page
Figure 1-1 Summary of Results for NCHRP 350 Test 2-50	A-1
Figure 1-2 Vehicle/Support Geometrics Before Test 2-50	A-2
Figure 1-3 Deformed Cylinders After Test 2-50	A-3
Figure 1-4 Connecticut TMA After Test 2-50	A-4
Figure 1-5 Small Car After Test 2-50	A-5
Figure 2-1 Summary of Results for NCHRP 350 Test 2-51	A-6
Figure 2-2 Vehicle/Support Geometrics Before Test 2-51	A-7
Figure 2-3 Both Vehicle's Trajectory After Test 2-51	A-8
Figure 2-4 Connecticut TMA After Test 2-51	A-9
Figure 2-5 Pickup After Test 2-51	A-10
Figure 3-1 Summary of Results for NCHRP 350 Test 2-52	A-11
Figure 3-2 Vehicle/Support Geometrics Before Test 2-52	A-12
Figure 3-3 Both Vehicle's Trajectory After Test 2-52	A-13
Figure 3-4 Connecticut TMA After Test 2-52	A-14
Figure 3-5 Pickup After Test 2-52	A-15
Figure 4-1 Summary of Results for NCHRP 350 Test 3-53	A-16
Figure 4-2 Vehicle/Support Geometrics Before Test 2-53	A-17
Figure 4-3 Both Vehicle's Trajectory After Test 2-53	A-18
Figure 4-4 Connecticut TMA After Test 2-53	A-19
Figure 4-5 Pickup After Test 2-53	A-20

SUMMARY OF THE NCHRP REPORT 350 CRASH TEST
RESULTS FOR THE CONNECTICUT TRUCK MOUNTED ATTENUATOR

Background

In May 1975, the Connecticut Department of Transportation (C0nnDOT) initiated a research effort to design, build and crash test a truck mounted attenuator (TMA) constructed of steel tubular members /1,2,3/. The system was designed to protect C0nnDOT maintenance and construction personnel performing field duties. The truck mounted attenuator system has been in use for over 15 years, and approximately 60 units are currently being employed by C0nnDOT field personnel alone /3,4/. In fact, the very favorable accident experience of the portable system provided the incentive to apply the same engineering principles to the design and full scale crash testing to other crash cushion designs.

The TMA research was precipitated by the safety concerns of C0nnDOT field personnel. Increasingly, maintainers were exposed to errant motorists during the course of normal workdays. Initial research was performed at the University of Connecticut, and a feasibility study determined that thick-wall cylinders provided an excellent medium for dissipating the energy of an impacting vehicle.

Theoretical Basis for TMA

Kinetic energy is dissipated in the Connecticut TMA by plastically deforming four 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.

Description of the System

The Connecticut TMA is made up of the following three major components:

1. Service vehicle guidance frame;
2. Energy-absorbing cylinders; and,
3. Impacting plate assembly.

The impacting plate assembly is constructed of 6061-T6 aluminum, as is the aluminum tubing in the impacting plate assembly which slides inside the steel structural tubing in the service vehicle guidance frame during collapse of the device.

Figure 1 shows (in schematic form) the design configuration of the TMA. It is composed of four cylindrical members formed from straight (A-36) steel plate sections. The cylinders are bolted together and attached to the rear of the carrying vehicle. The two 5x5.82 channel sections are attached to the aluminum impacting plate to provide guidance for the system while it is collapsing. Varying views of the system are shown as Figure 2.

Previous Full-Scale Crash Testing Program

A program of full-scale crash tests were conducted (1975-78) at Calspan Corporation and the Texas Transportation Institute to test the design and effectiveness of the Connecticut TMA /3/. The excellent results obtained demonstrated conclusively that:

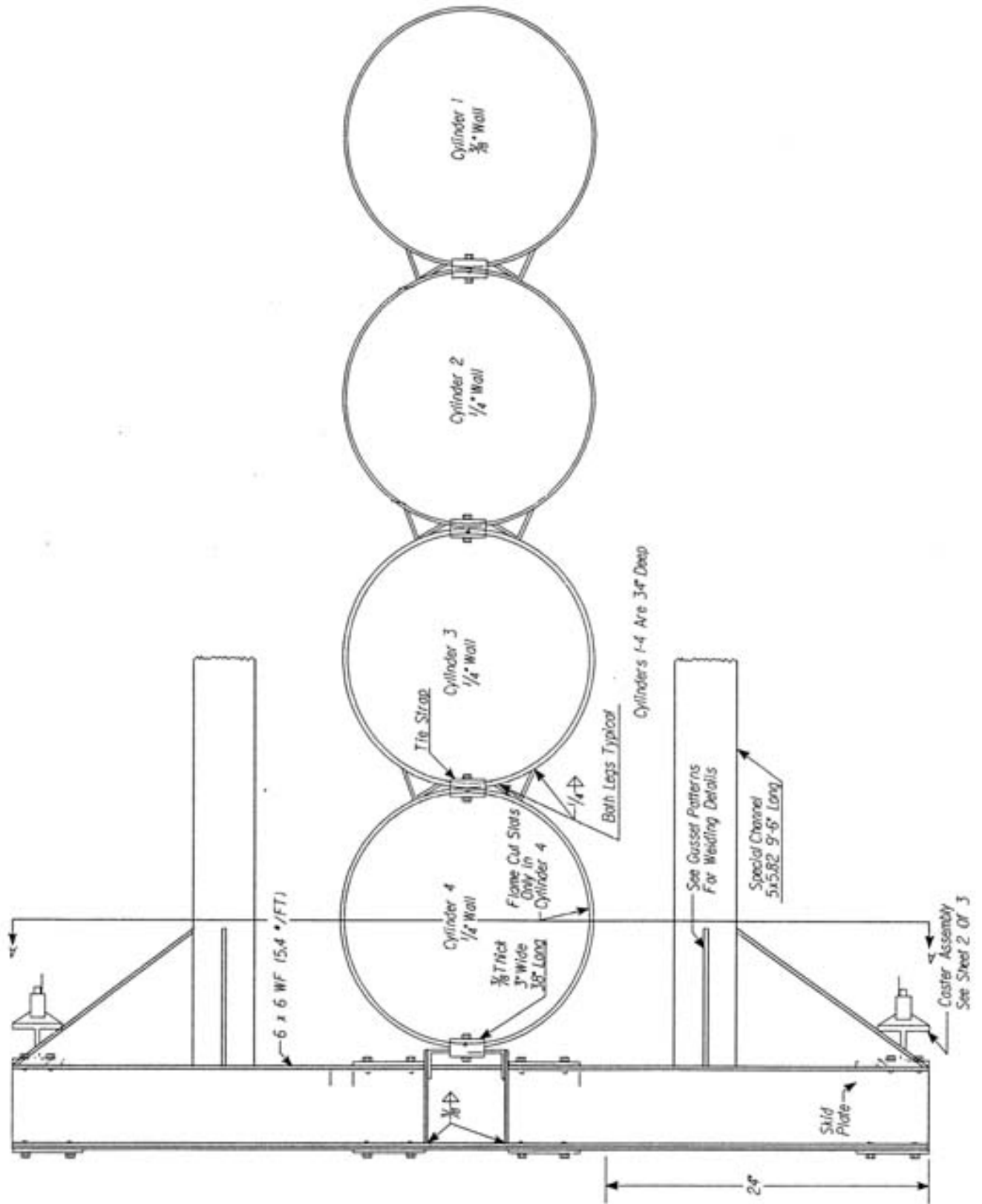


Figure 1 Detail Drawing of Connecticut TMA

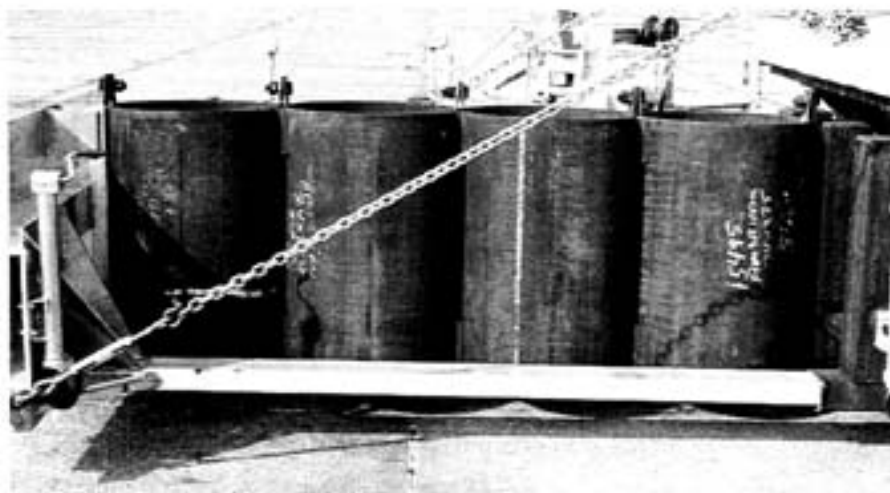
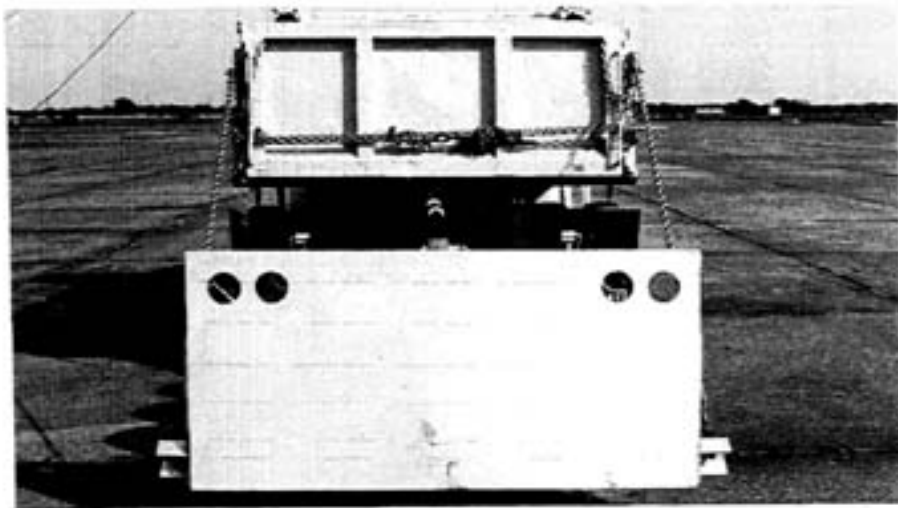


Figure 2 Connecticut TMA

1. The TMA absorbs the impacting energy in such a way that the accelerations to which the automobile and service vehicle are subjected are acceptably safe for the occupants of both vehicles.
2. The unit is inexpensive to repair. All that is required is to insert new cylinders into the system.
3. There is no tendency for the impacting automobile to nose-dive under or catapult over the TMA. In the event of an eccentric hit, intrusion of the impacting vehicle into adjacent traffic lanes is minimal.
4. The TMA is easily attached to and removed from the carrying vehicle. It is compact and designed for use in curved and hilly roads.

Truck Mounted Attenuator Crash Testing Requirements of NCHRP Report 350

NCHRP Report 350, /5/ entitled "Recommended Procedures for the Safety Performance Evaluation of Highway Features," was published in 1993. It was the first document of its kind to consider the crash testing of TMA's. Two different TMA Test Levels are presented. Test Level 2, the basic level, deals with 70 km/h crash test conditions, while Test Level 3 prescribes impact speeds of 100 km/h. With the exception of these two different impact speeds, both test levels are associated with the same required crash test matrix. This consists of the four impact conditions illustrated in Figure 3, where test number 50 involves a 820 kg automobile and tests 51, 52 and 53 employ 2000 kg pickup trucks. Note from Figure 3 that tests 52 and 53 are optional tests, while tests 50 and 51 are required.

There are two sets of evaluation criteria set forth in NCHRP Report 350 for truck mounted attenuators. One set applies to the impacting vehicle and its occupants, and the other set applies to the support vehicle and its driver. For both the impacting vehicle and its occupants and the support vehicle and its driver, occupant risk and vehicle trajectory are major concerns. In addition,

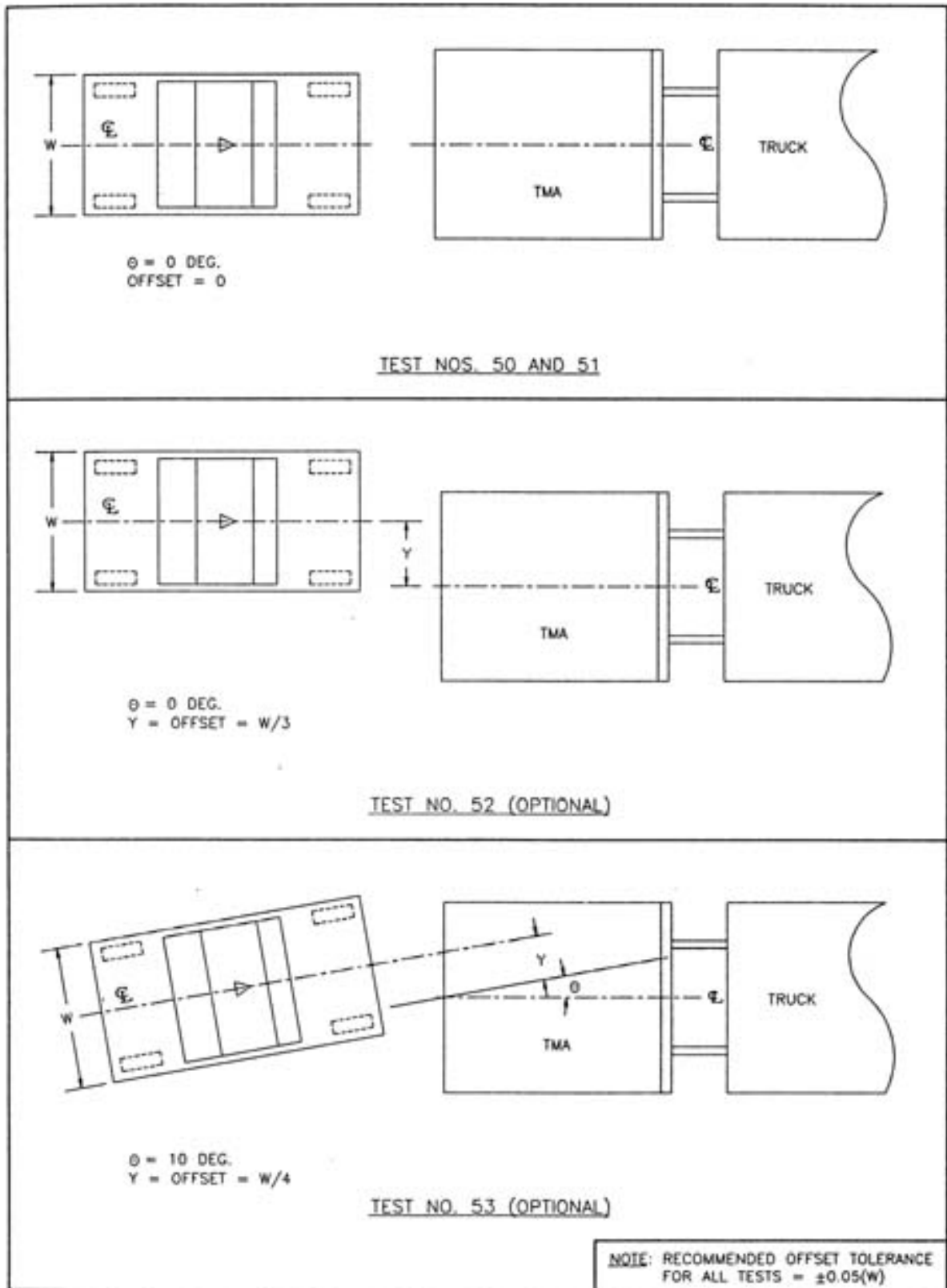


Figure 3 Impact Conditions for a TMA

since the TMA is attached to the support vehicle, the structural adequacy and performance of the TMA is of paramount interest.

Connecticut TMA NCHRP Report 350 Crash Test Program

The Connecticut TMA is a Test Level 2 device, and the NCHRP Report 350 Test Level 2 TMA crash test matrix is presented in Table 1. All four crash tests, the two required and the two optional tests, were conducted at the Texas Transportation Institute (TTI). **Each of the four tests satisfied all of the requirements of NCHRP Report 350.** The crash test results are summarized in Table 2, and representative photos of the crash tests performed are contained in the Appendix to this report. The complete crash test reports are available to the reader on request. However, the highlights of the four individual tests performed are discussed below.

Test No. 1-NCHRP Report 350 Test 2-50

This test involves a 820 kg automobile impacting the TMA head-on with no offset at 70 km/h. It is a difficult test to pass because of the added requirement that the service vehicle not be allowed to move forward during the test. This is accomplished by butting the front end of the service vehicle against a rigid barrier. This test was conducted as part of a TTI project entitled "Comparative Crash Test Conducted on Seven Different Makes and Models of Truck Mounted Attenuators /6/. The crash test details are shown in Figures 1-1 through 1-5 in the Appendix. Although the impact speed of 72.9 km/h resulted in a kinetic energy overload of 8.5 percent all test requirements were met. The occupant impact velocity was 11.50 m/s (the maximum allowable value is 12 m/s), and the ridedown acceleration was 14.00 g's (below the preferred value of 15 g's).

Table 1. NCHRP Report 350 Test Level 2 TMA Test Matrix

NCHRP Report 350 Test Designation	Vehicle	Impact Speed (km/h)	Impact Angle (deg.)	Impact Point
2-50	820C	70	0	Head-on, no offset
2-51	2000P	70	0	Head-on, no offset
2-52	2000P	70	0	Head-on, width/3 offset
2-53	2000P	70	15	Angled, width/4 offset

Table 2. Summary of Crash Test Results

NCHRP Report 350 Test Designation	2-50	2-51	2-52	2-53
Vehicle mass (kg)	817	2000	2000	2000
Impact speed (km/h)	72.9	70.9	70.3	69.6
Impact Angle (degrees)	0	0	0	10.3
Vehicle impact location	Nose	Nose	Veh. width/3 offset	Veh. width/4 offset
Occupant impact velocity (m/s)				
Longitudinal (12 max. allowable)	11.50	8.38	8.63	8.81
Lateral (12 max. allowable)	1.50	0.71	1.47	1.46
Occupant ridedown acceleration (peak 10 ms avg g's)				
Longitudinal (20 max. allowable)	14.00	15.65	15.08	10.68
Lateral (20 max. allowable)	0.90	1.56	4.03	4.81
Assessment	Passed all requirements	Passed all requirements	Passed all requirements	Passed all requirements

Test No. 2-NCHRP Report 350 Test 2-51

In test 2-51, a 2000 kg pick-up truck impacts the TMA head-on with zero offset. This impact condition is the same as in test 3-50 except for the fact that the service vehicle is allowed to move forward during this test. The pre-test configuration and post-test details are presented in Figures 2-1 through 2-5 in the Appendix. The impact velocity was 70.9 km/h and all the test requirements were again satisfied. The occupant impact velocity was 8.38 m/s (below the preferred value of 9 m/s), and the occupant ridedown deceleration was 15.65 g's.

Test No. 3-NCHRP Report 350 Test 2-52

This optional crash test is similar to Test 2-51 in that a 2000 kg pickup truck impacts the TMA head-on. However, in this test, the impacting vehicle is offset with respect to the TMA a distance of 1/3 of its width. This impact condition is shown in Figure 3-2, and the test results are illustrated in Figures 3-1, 3-3, 3-4, and 3--5 in the Appendix. All test requirements were again met. The impact velocity was 70.3 km/h, the occupant impact velocity was a low 8.63 m/s, and the ridedown deceleration was 15.08 g's.

Test No. 4 - NCHRP Report 350 Test 2-53

Optional test 2-53 is a demanding one which measures the TMA's ability to arrest a 2000 kg pickup impacting the device at a 15 degree angle and a width/4 offset. The geometrics for this impact are shown in Figure 4-2 and Figures 4-1, 4-3, 4-4, and 4-5 in the Appendix show the post-impact results. In this test, both the occupant impact velocity value of 8.81 m/s and the occupant ridedown deceleration value of 10.68 g's were below the respective preferred values of 9 m/s and 15 g's. The impact velocity in this test was 69.6 km/h.

Conclusion

In summary, four crash test were conducted, and all four tests passed all of the requirements of NCHRP Report 350. Three of the four occupant impact velocities were below the preferred value of 9 m/s, and all four occupant ridedown decelerations were either under or just over the preferred value of 15 g's. The maximum allowable occupant ridedown deceleration in NCHRP Report 350 is 20 g's.

Detailed crash test information on these four tests are available on request. Complete design and construction details as well as video tapes of tests performed on the system are also available to interested parties.

As a result of this successful test program, the Connecticut TMA has been presented to the Federal Highway Administration for approval to be used on the U.S. National Highway System.

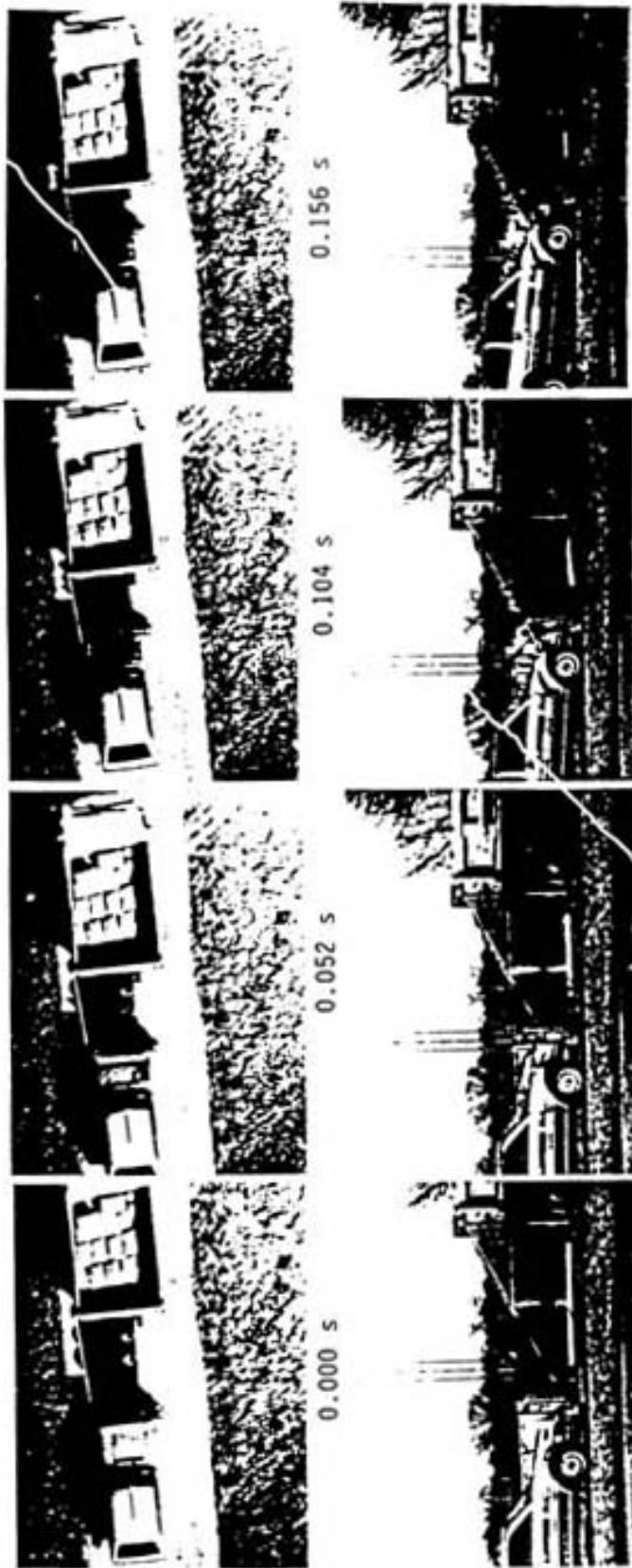
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APPENDIX

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

NCHRP 350 Test 2-50



Test No. 09910-9
 Date 01/25/90
 Test Article Truck Mounted Attenuator
 Manufacturer Connecticut
 TMA Truck 1950 Ford Dump Truck (#2)
 Weight without TMA 14,010 lb (6,361 kg)
 Weight with TMA 16,130 lb (7,323 kg)
 Test Vehicle 1982 Honda Civic
 Weight 1,800 lb (817 kg)
 Impact Speed 45.3 mi/h (72.9 km/h)
 Maximum Vehicle Crush 7.0 in (17.7 cm)
 Vehicle Damage Classification
 TAD 12FD3
 CDC 12FDEW3

Maximum Truck Displacement N/A (fixed position)
 Maximum TMA Crush 44.1 in (1.1 m)
 Vehicle Accelerations
 (Maximum 50 ms Average at c.g.)
 Vehicle Longitudinal -14.2 g
 Vehicle Lateral -1.5 g
 Truck Cab Longitudinal N/A
 Occupant Impact Velocity
 Longitudinal 37.8 ft/s (11.5 m/s)
 Lateral 4.8 ft/s (1.5 m/s)
 Occupant Ridedown Accelerations
 Longitudinal -14.0 g
 Lateral -0.9 g

Figure 1-1 Summary of Results for NCHRP Test 2-50

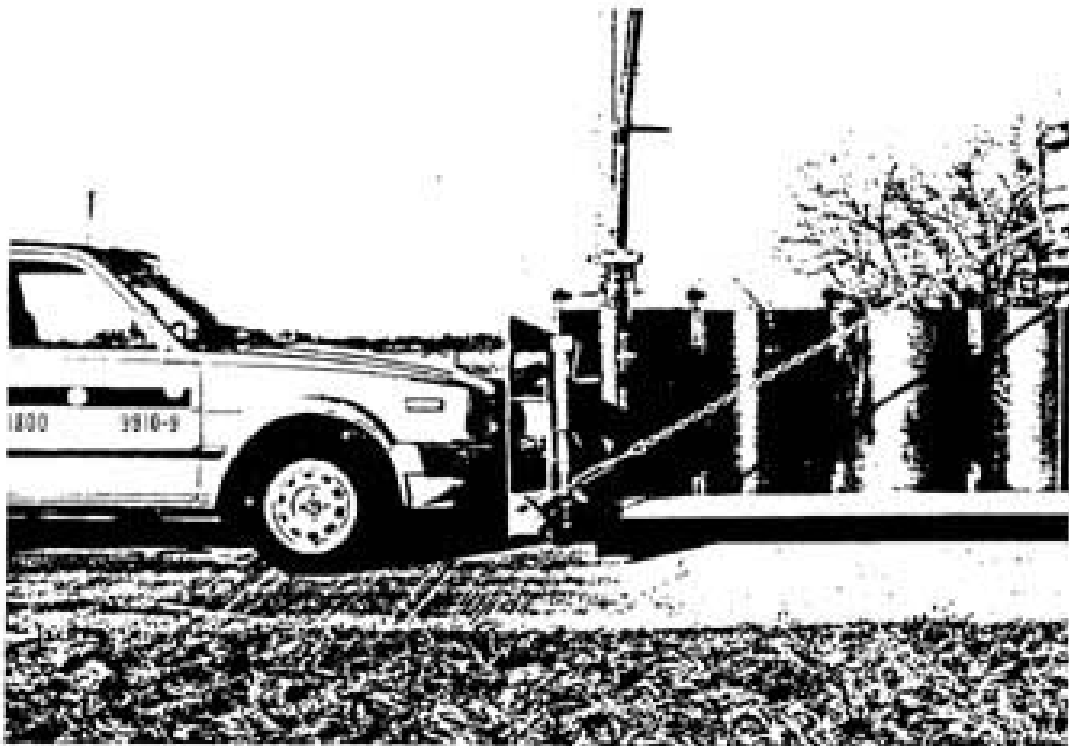


Figure 1-2 Vehicle/Support Geometrics Before Test 2-50

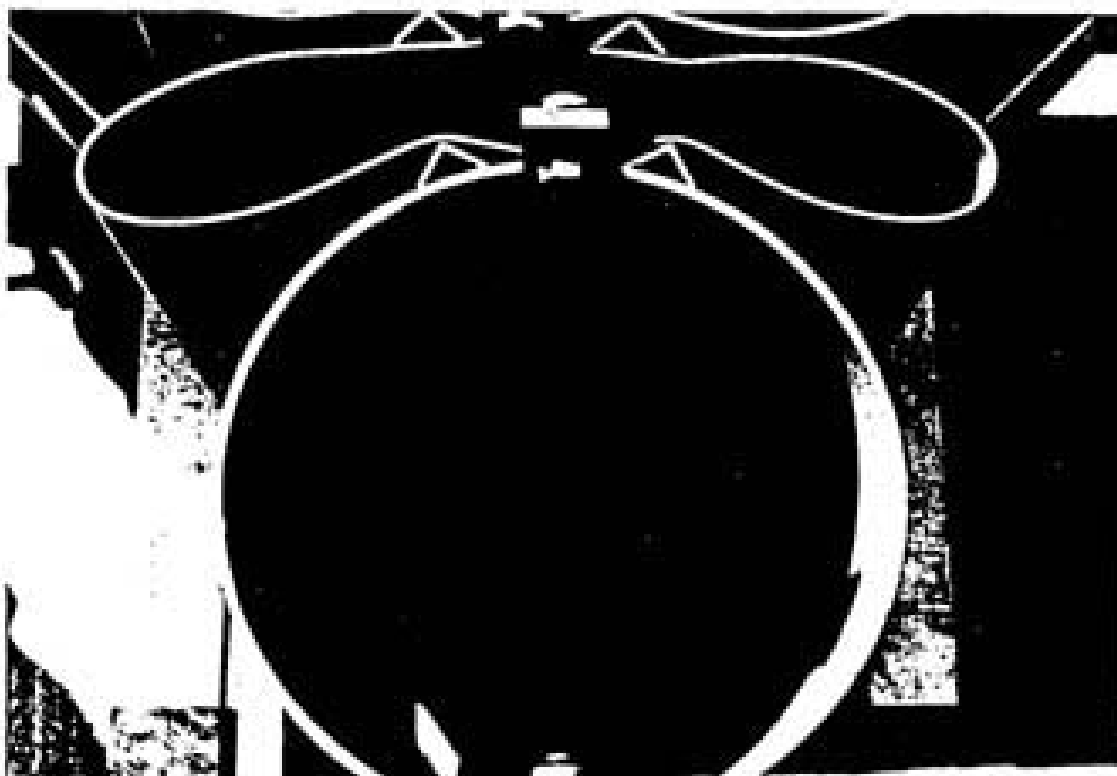
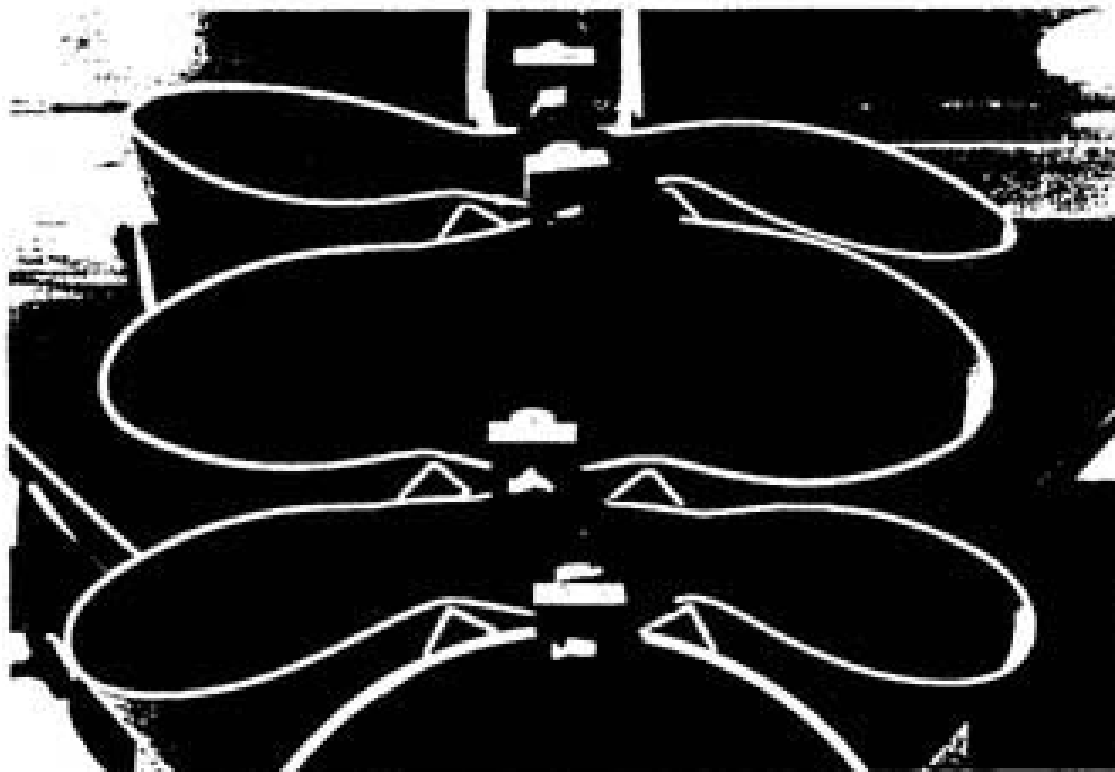


Figure 1-3 Deformed Cylinders After Test 2-50

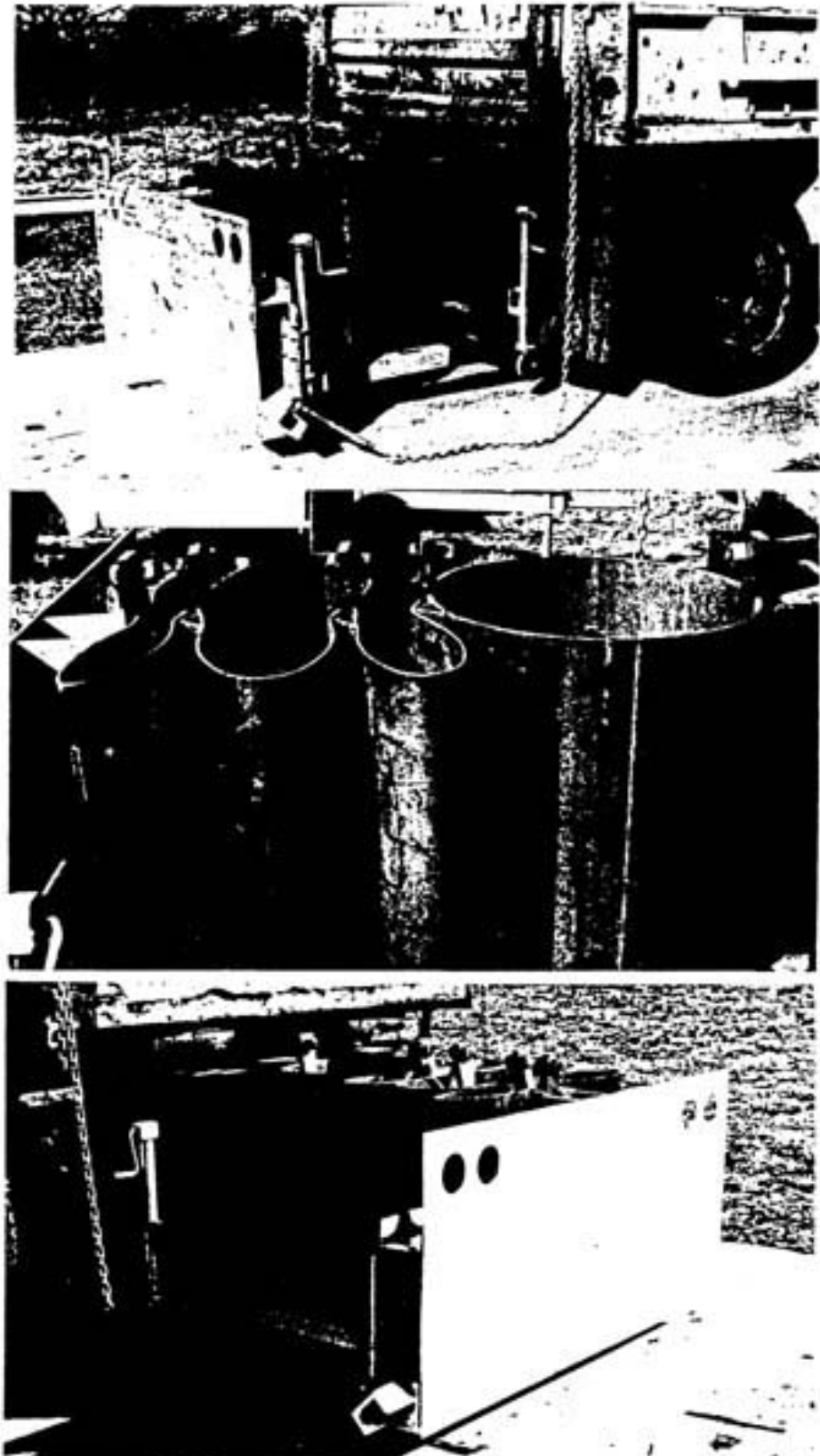
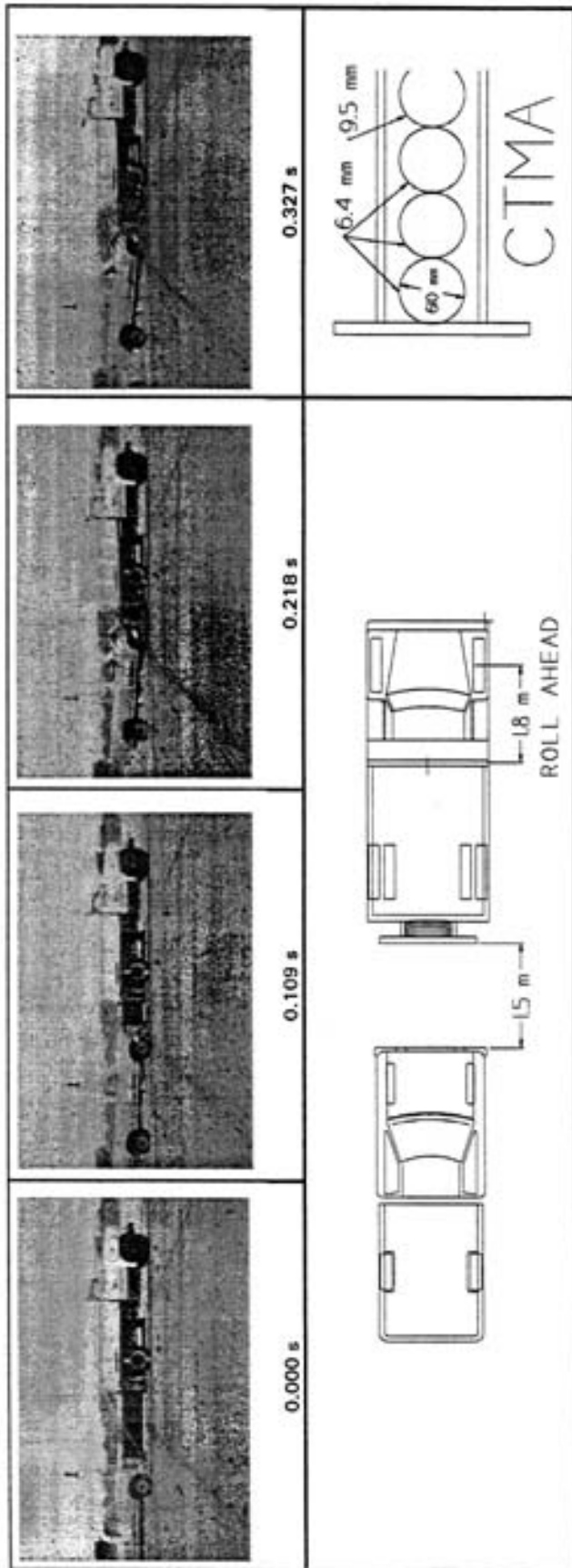


Figure 1-4 Connecticut TMA After Test 2-50



Figure 1-5 Small Car After Test 2-50

NCHRP 350 Test 2-51



General Information		Texas Transportation Institute		Impact Conditions		Test Article Deflections (m)	
Test Agency	.....	405241-1	.....	Speed (km/h)	.....	Dynamic	.....
Test No.	.....	11/2/94	.....	Angle (deg)	.....	Permanent	.....
Date	.....	Truck Mounted Attenuator	.....	Exit Conditions	.....	Vehicle Damage	.....
Test Article	.....	Connecticut	.....	Speed (km/h)	0	Exterior	.....
Type	.....	2.40 m (7.88 ft)	.....	Angle (deg)	N/A	VDS	.....
Name or Manufacturer	.....	6.4 & 9.5 mm Thick wall	.....	Occupant Risk Values	.....	CDC	.....
Installation Length (m)	.....	0.70 m Diameter Cylinders	.....	Impact Velocity (m/s)	.....	Interior	.....
Size and/or dimension	.....	N/A	.....	x-direction	.....	OCDI	.....
and material of key	.....	Production	.....	y-direction	.....	Maximum Exterior	.....
elements	.....	2000P	.....	Roll-down Accelerations (g's)	.....	Vehicle Crush (mm)	.....
Test Vehicle	.....	1988 Ford F250 Custom	.....	x-direction	-15.65	Max. Occ. Compart.	.....
Type	.....	2068 (4559 lb)	.....	y-direction	1.56	Deformation (mm)	.....
Designation	.....	2000 (4409 lb)	.....	Support x-direction	8.37	Post-Impact Behavior	.....
Model	.....	N/A	.....	ASI (optional)	.....	Max. Roll Angle (deg)	.....
Mass (kg) Curb	.....	2000 (4409 lb)	.....	Max. 0.050-sec Average (g's)	.....	Max. Pitch Angle (deg)	.....
Test Inertial	.....	N/A	.....	x-direction	-13.23	Max. Yaw Angle (deg)	.....
Dummy	.....	2000 (4409 lb)	.....	y-direction	-1.13		
Gross Static	.....	2000 (4409 lb)	.....	z-direction	4.73		

Figure 2-1 Summary of Results for NCHRP 350 Test 2-51

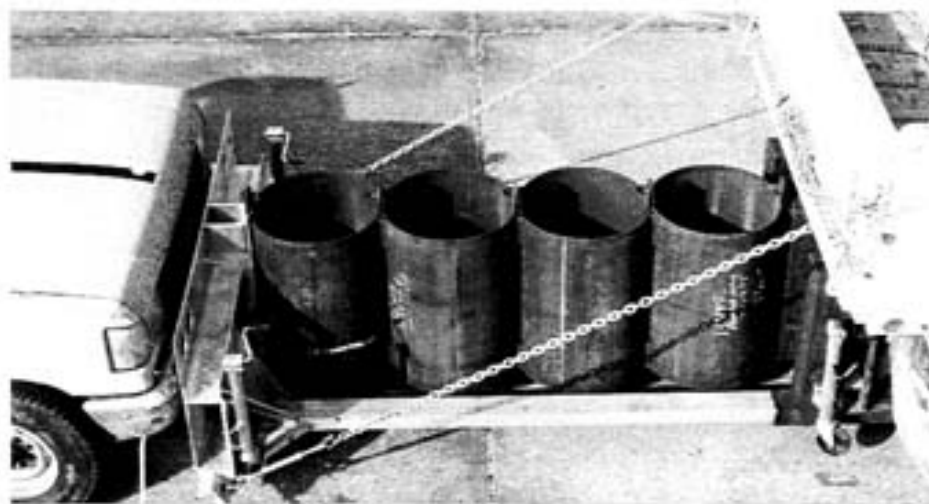


Figure 2-2 Vehicle/Support Geometrics Before Test 2-51



Figure 2-3 Both Vehicle's Trajectory After Test 2-51

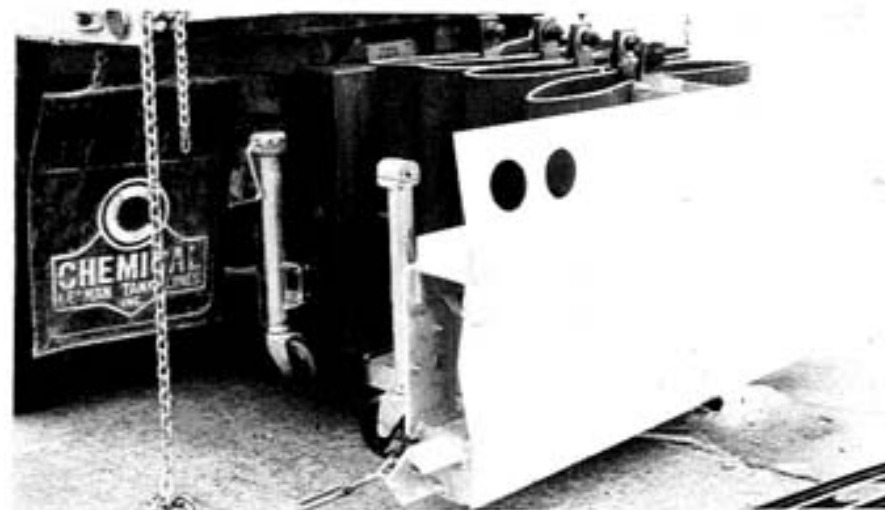
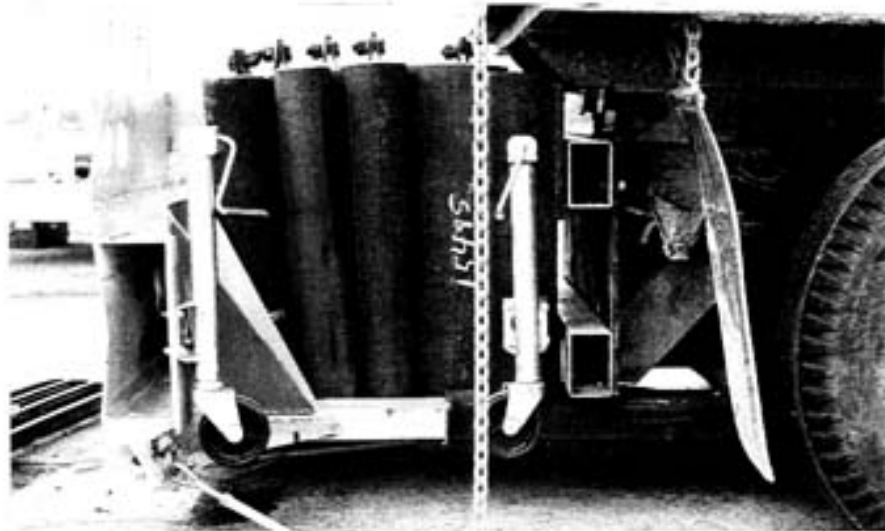
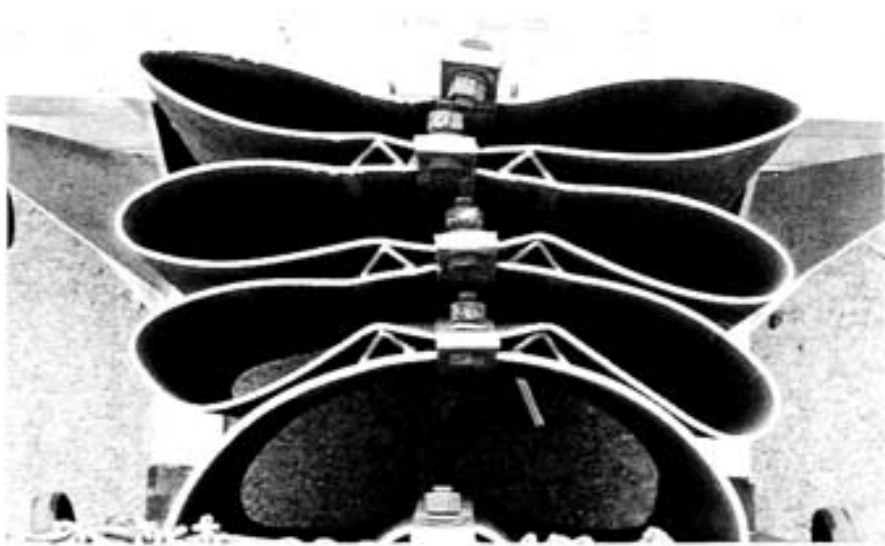
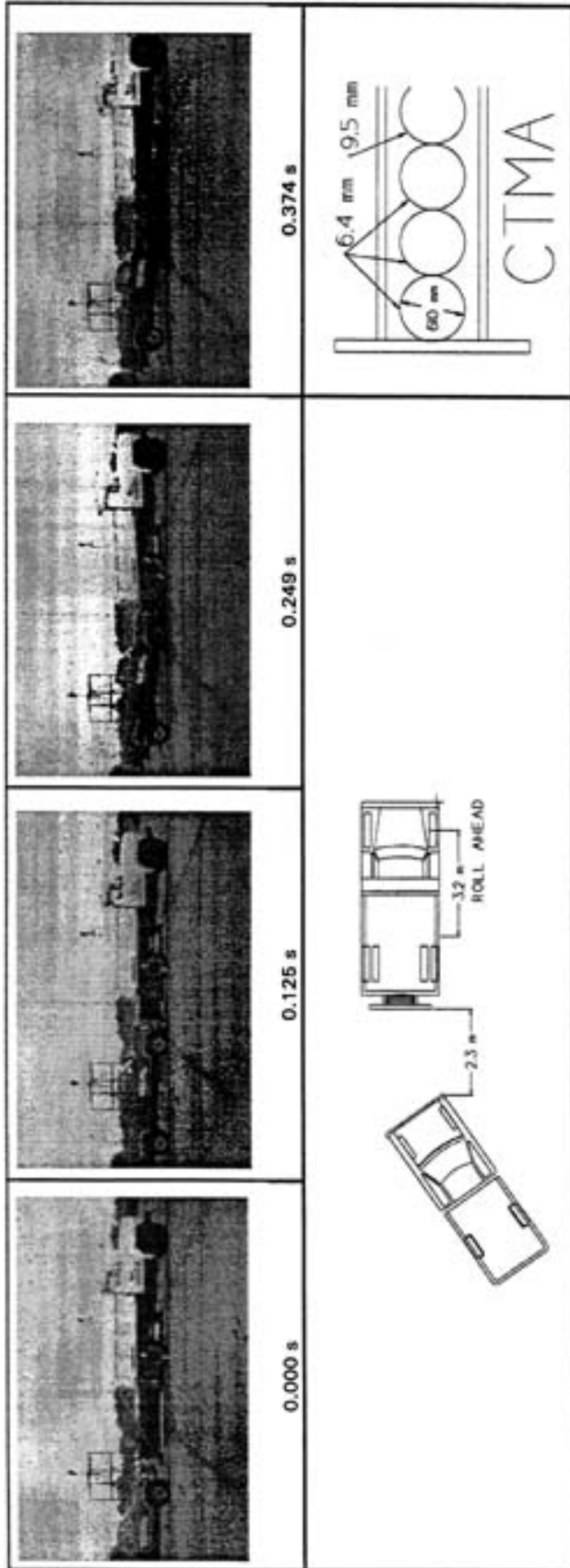


Figure 2-4 Connecticut TMA After Test 2-51



Figure 2-5 Pickup After Test 2-51

NCHRP 350 Test 2-52



General Information		Texas Transportation Institute		Impact Conditions		Test Article Deflections (m)	
Test Agency	.....	405241-2	.....	Speed (km/h)	.....	Dynamic	.....
Test No.	.....	11/3/94	.....	Angle (deg)	.....	Permanent	.....
Date	.....	Truck Mounted Attenuator	.....	Exit Conditions	.....	Vehicle Damage	.....
Test Article	.....	Connecticut	.....	Speed (km/h)	.....	Exterior	.....
Type	.....	2.40 m (7.88 ft)	.....	Angle (deg)	.....	VDS	.....
Name or Manufacturer	.....	6.4 & 9.5 mm Thick wall	.....	Occupant Risk Values	.....	CDC	.....
Installation Length (m)	.....	0.70 m Diameter Cylinders	.....	Impact Velocity (m/s)	.....	Interior	.....
Size and/or dimension	.....	N/A	.....	x-direction	.....	OCDI	.....
and material of key	.....	Production	.....	y-direction	.....	Maximum Exterior	.....
elements	.....	2000P	.....	Ridedown Accelerations (g's)	.....	Vehicle Crush (mm)	.....
Soil Type and Condition	.....	1989 Chevrolet C2500	.....	x-direction	.....	Max. Occ. Compart.	.....
Test Vehicle	.....	2000 (4416 lb)	.....	y-direction	.....	Deformation (mm)	.....
Type	.....	2000 (4409 lb)	.....	z-direction	.....	Post-Impact Behavior	.....
Designation	.....	N/A	.....	ASI (optional)	.....	Max. Roll Angle (deg)	.....
Model	.....	2000 (4409 lb)	.....	Max. 0.050-sec Average (g's)	.....	Max. Pitch Angle (deg)	.....
Mass (kg) Curb	.....	2000 (4409 lb)	.....	x-direction	.....	Max. Yaw Angle (deg)	.....
Test Inertial	.....	N/A	.....	y-direction	.....	
Dummy	.....	2000 (4409 lb)	.....	z-direction	.....	
Gross Static	.....		.....		.....

Figure 3-1 Summary of Results for NCHRP 350 Test 2-52

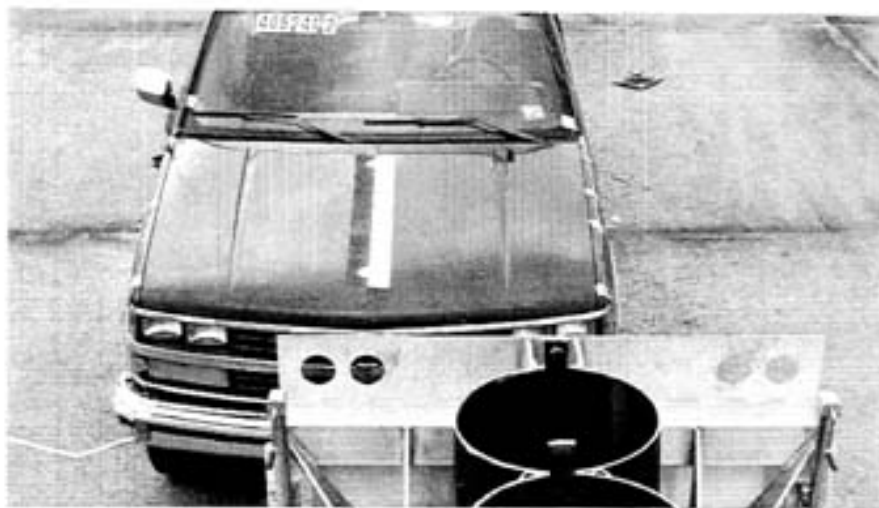


Figure 3-2 Vehicle/Support Geometrics Before Test 2-52

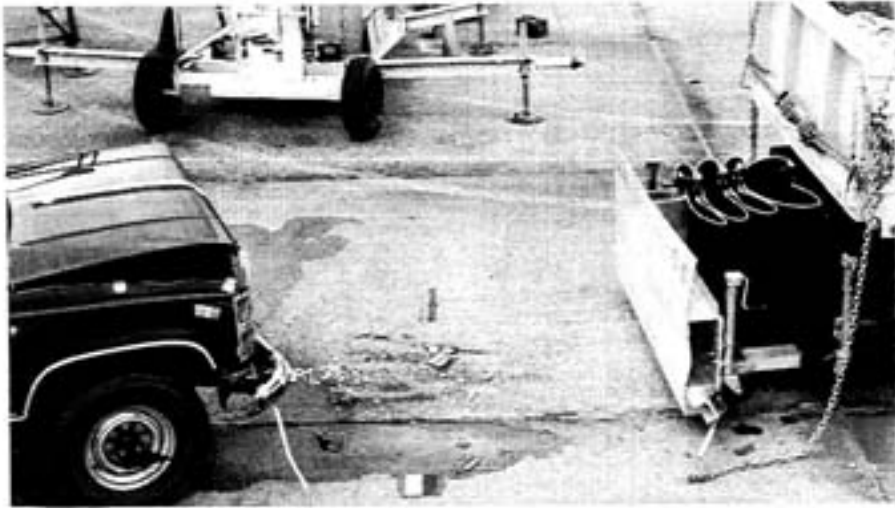


Figure 3-3 Both Vehicle's Trajectory After Test 2-52

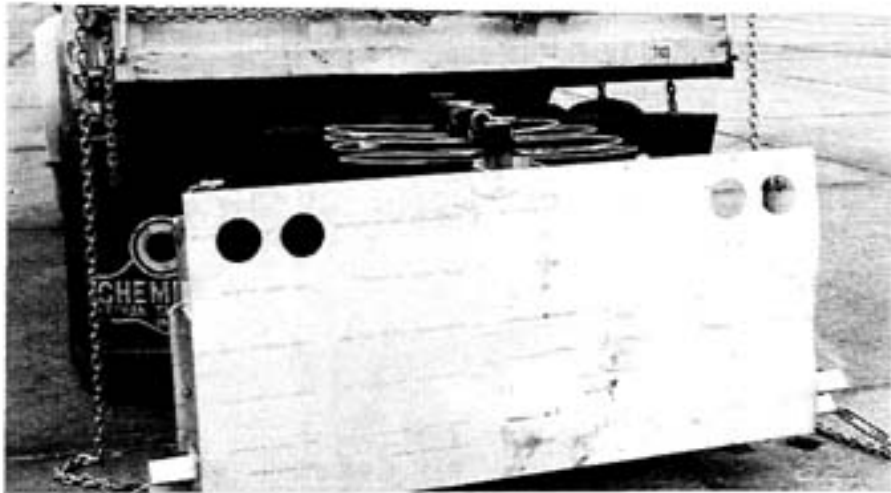


Figure 3-4 Connecticut TMA After Test 2-52



Figure 3-5 Pickup After Test 2-52

NCHRP 350 Test 2-53

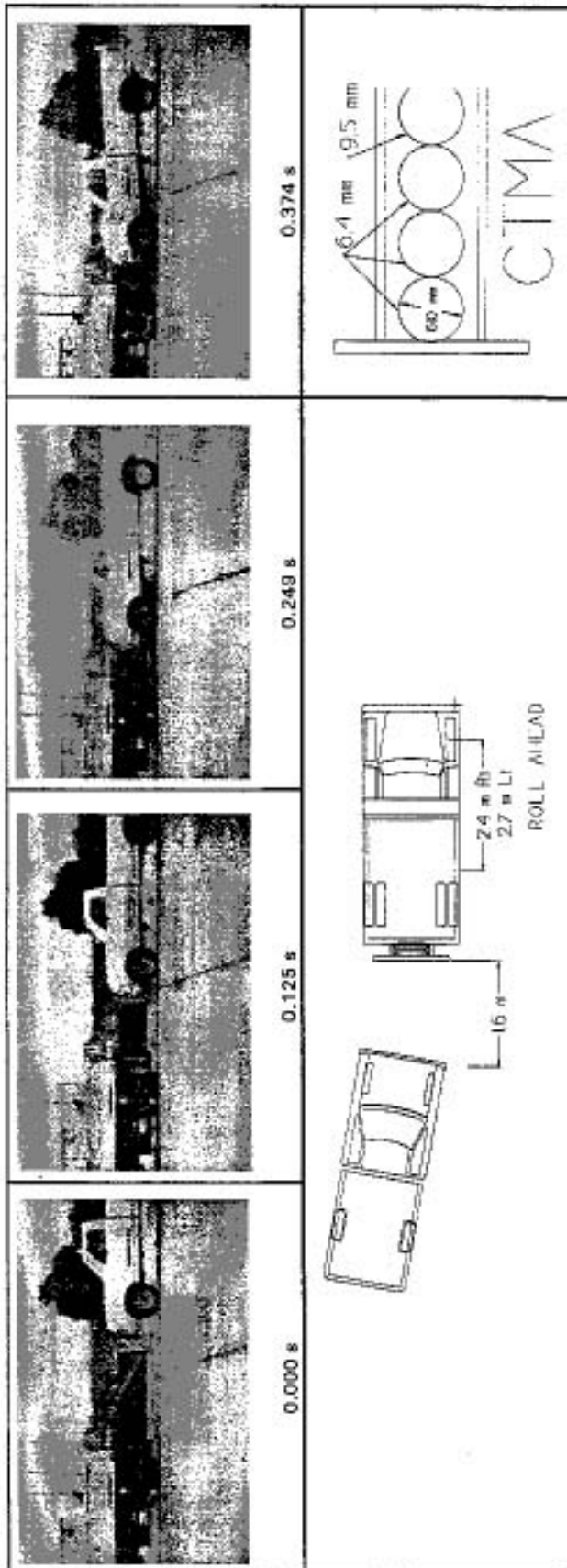


Figure 4-1 Summary of Results for NCHRP 350 Test 3-53

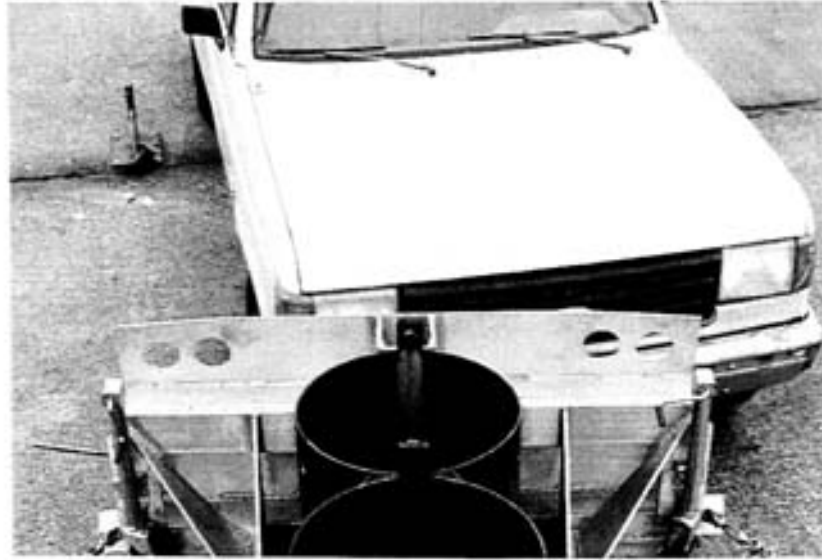


Figure 4-2 Vehicle/Support Geometrics Before Test 2-53



Figure 4-3 Both Vehicle's Trajectory After Test 2-53

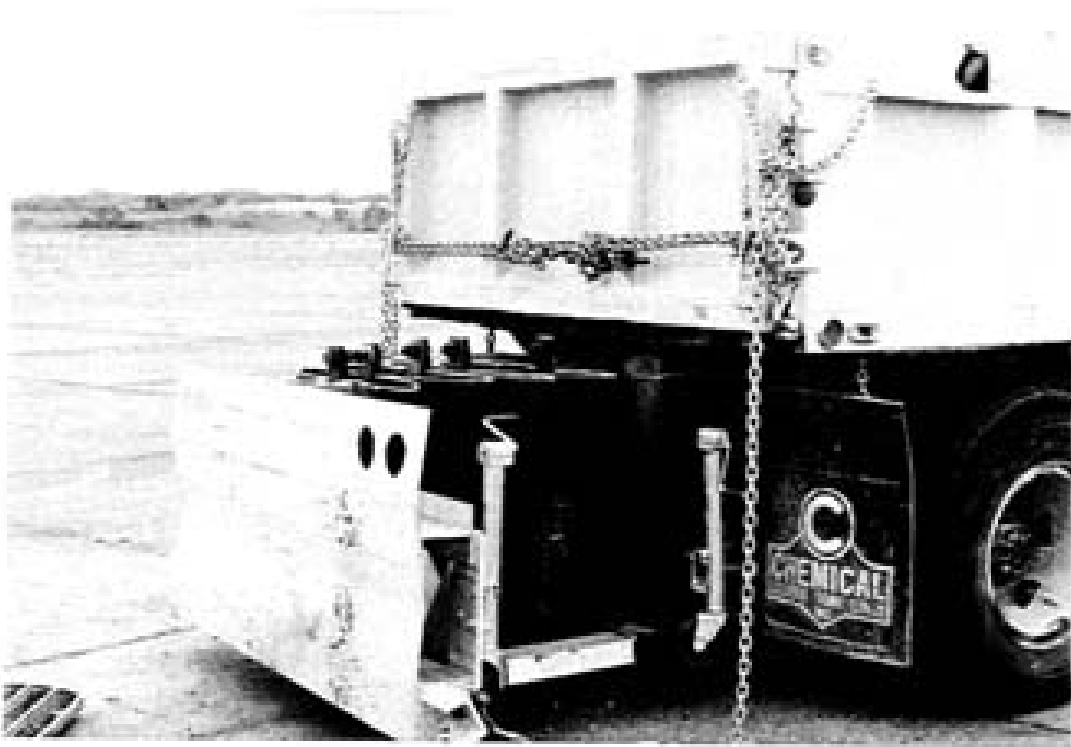
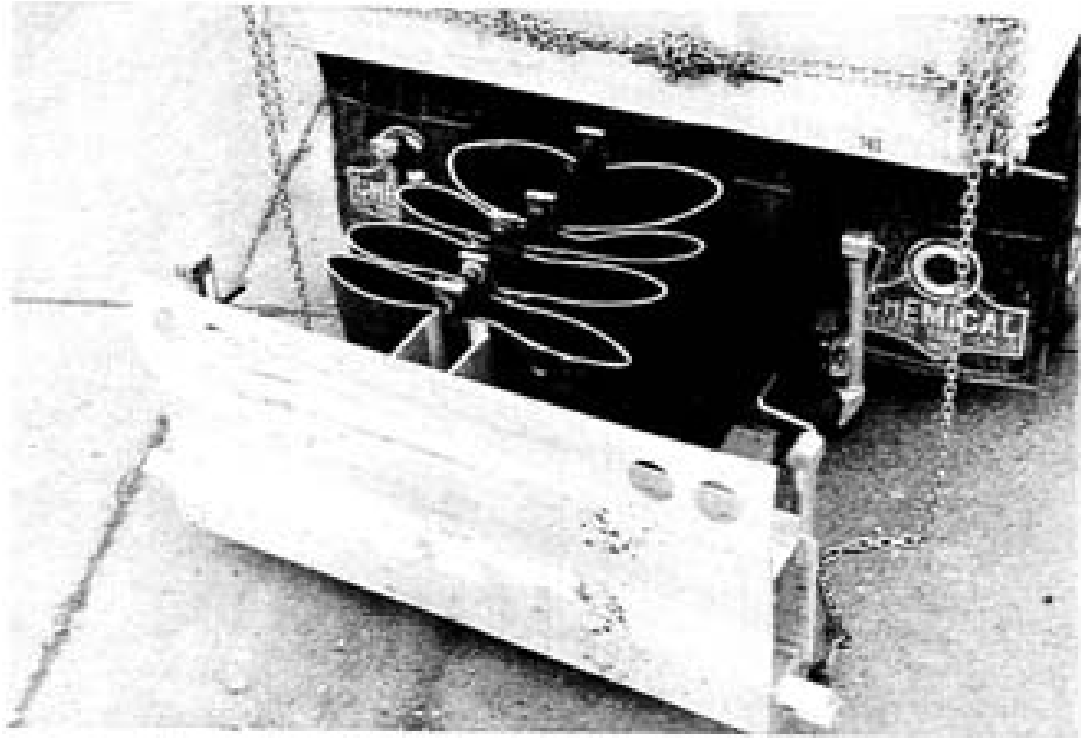


Figure 4-4 Connecticut TMA After Test 2-53



Figure 4-5 Pickup After Test 2-53