Full-Scale Crash Evaluation of a Modified Eccentric Loader Terminal, Final Report

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FOREWORD

This report will be of interest to researchers and those who select, design, and locate traffic barriers. It presents the results of a series of tests that were intended to develop a version of the Modified Eccentric Loader Terminal (MELT) that meets the requirements for Test Level Three (TL-3) in the *National Cooperative Highway Research Program Report 350*. It was found that the performance of this particular MELT design was very sensitive to variations in soil moisture content and the strength of the wood posts. Consequently, these crash tests did not produce a TL-3 version of the MELT that was acceptable to FHWA for use on the National Highway System.

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Office of Safety
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16. Abstract

This report presents results of four of five *NCHRP Report 350* type crash tests conducted on a Modified Eccentric Loader Terminal (MELT) system for w-beam guardrails. All vehicles used in this test were 1990 and 1991 year models. As specified by the Federal Highway Administration (FHWA), the vehicles were light-duty, six-lug, ¾-ton Chevrolet C2500 pickup trucks. The terminal was subjected to one *NCHRP Report 350* Test 3-39 reverse angle impact test (MLT-1), which proved successful. The remaining tests were *NCHRP Report 350* Test 3-35 target impact conditions. The second test (MLT-2) indicated successful results, but target impact conditions were not met because of a malfunction of the vehicle tow control system. The FHWA opted to accept the results of this test based on the performance level of the *NCHRP Report 350* Test 2-35. The third test (MLT-3) was unsuccessful because the rail fractured during impact, allowing the vehicle to travel behind the barrier. It was the opinion of the FHWA that the posts used in the test were inferior, and the system was retested using selected structural-grade 1 posts. The retest (MLT-4) resulted in vehicle rollover, but the FHWA elected not to pay for this test because an electrical malfunction caused all of the high speed cameras to run prematurely; thus the results of this test are not reported herein. The final test (MLT-5) was a retest of MLT-4 using selected similar posts and new terminal components. The results of Test MLT-5 indicated compliance with the criteria in *NCHRP Report 350*.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	ac
ha	hectares	2.47	acres	mi^2
km^2	square kilometers	0.386	square miles	
VOLUME				
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised August 1992)

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INTRODUCTION

Five vehicle crash tests were performed by Southwest Research Institute, San Antonio, Texas, to evaluate the performance of a Modified Eccentric Loader Terminal (MELT). Specifically, tests designated as types 3-39, 2-35, and 3-35 in *NCHRP Report 350*[1] were performed. One of the tests was rejected by the FHWA due to insufficient high-speed film documentation. This test, MLT-4, resulted in a roll-over, and the results are not presented in this report. This report summarizes the other four tests, but does not contain all the details found in the individual test reports.

Since the same barrier configuration was utilized in all tests, the only variables between tests were impact velocities, angles, and direction. These are shown in table 1 along with the warrant for each type of test.

The text in the following sections briefly describes the test installation, vehicles, test sequences, and resulting damage to both the installation and vehicle. In addition, conclusions regarding barrier performance during each of the individual tests as well as an overall evaluation are offered.

TEST INSTALLATION

Facility

These tests were performed along and adjacent to the inactive East Runway at Brooks Air Force Base, San Antonio, Texas. The barrier was constructed at an angle to the runway, and the test vehicles were directed into the barrier at the selected angles and velocities.

Test Article

Barrier construction details are presented in figure 1. Briefly, the test installation consisted of a 1.5-m flared MELT system and 30.5 m of G4-2w-beam on 152-mm by 229-mm wood posts. The downstream end of the installation was a 1.9-m straight breakaway cable terminal (BCT). The 2.75-mm-thick w-beam was mounted on wood posts spaced at 1.9 m center to center.

Photographs of details of the barrier installation are shown in figure 2.

TEST VEHICLE, CONTROLS, AND DATA SYSTEMS

Vehicle and Dummy

Pretest photographs of the vehicles used are shown in figures 3 through 6. For all tests, an uninstrumented dummy was placed in the driver's seat of each vehicle and restrained with lap and shoulder belts.

Vehicle Controls

Each vehicle was guided to the impact location using a 6.4-mm-diameter x 457.2-m-long steel cable that passed through a guide tube/bracket attached to the left front wheel spindle. The cable was pretensioned and located alongside the run-up strip where it would not interfere with postimpact vehicle trajectory. Just prior to impact, the guide tube/bracket was sheared off, allowing the vehicle free trajectory.

Braking of each test vehicle was accomplished by use of an air cylinder attached to its brake pedal. The air cylinder was activated by a gas-charged accumulator through an intermediate solenoid valve. The solenoid valve was remotely controlled by the test conductor.

Each test vehicle was towed into the barrier using a cable/pulley system for reverse

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[1]Ross, H.E., Jr., Sicking, D.L., Zimmer, R.A., and Michie, J.D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," *NCHRP Report 350*, Washington, D.C., 1993.

towing, i.e., the tow vehicle moved away from the barrier as the test vehicle moved toward it. The tow cable was attached to the underside of the test vehicle and released just prior to impact. Vehicle impact speed control was achieved by means of an automatic controller attached to the engine distributor of the tow vehicle. After the tow vehicle accelerated to its predetermined test speed, the controller pulsed the ignition, maintaining the tow vehicle at that speed.

Electronic Data Acquisition

The test vehicles were instrumented with multiple accelerometers and one rate gyro; locations of these transducers in each vehicle are described in table 1. The accelerometers were oriented to obtain data in directions parallel to the longitudinal, lateral, or vertical axes of the vehicle, whereas the rate gyro was oriented to measure the yaw angular rate change the vehicle experienced during the impact sequence. All transducer data were recorded by a Pacific Instruments Model 5600 Data Acquisition System (DAS), which contained signal conditioners, amplifiers, appropriate SAEJ211 filters, and digitizers with onboard memory for up to 32 data channels at programmable sample rates to 100 kilohertz per channel. Digitized data were recorded in solid state non-volatile memory with a capacity of 65,000 data points per channel.

Film Data Acquisition

In addition to the electronic data, high-speed film coverage of all four tests included a camera onboard the vehicle as well as cameras adjacent to and overhead of the barrier installation.

Data Processing

Vehicle transducer data were downloaded to a personal computer after each test and processed through an Institute-developed computer program. This program utilized accelerometer and rate gyro data to determine vehicle acceleration (in longitudinal, lateral, and vertical directions), heading angle, velocity, and displacement as a function of time during each event. In addition, these data provided input to the program for calculation of the highest 50-millisecond (msec) average accelerations for the vehicle as well as occupant risk data, including impact velocities (with the interior of the vehicle) and 10-msec average ridedown accelerations. The output of this data was provided in either tabular or graphical form.

TEST DESCRIPTION

Test MLT-1. This was the first test of the series and utilized a 1990 Chevrolet, six-lug, light-duty C2500 pickup truck as the test vehicle. Gross test weight, including the dummy and instrumentation, was 2050 kg. Actual test conditions were 100.1 km/h and a 20° impact angle. Ambient temperature at test time was 15° C. As shown in the test summary diagram of figure 7, the vehicle impacted the barrier 0.5 m upstream of post 4. The vehicle fractured post 3, was smoothly redirected, and rolled to a stop 150 m downstream of impact. Figures 8 and 9 show the redirection sequence of the vehicle from overhead as well as behind the barrier viewpoints. The postimpact trajectory of the vehicle was such that it traveled in a relatively straight line after loss of contact with the barrier. Maximum 50-msec average accelerations measured from onboard transducer data indicated -1.1 G's longitudinal and 0 G's lateral.

Test MLT-2. The vehicle used in this test was a 1991 Chevrolet, six-lug, light-duty

C2500 pickup truck. Gross test weight, including the dummy and instrumentation, was 1970 kg. Actual test conditions were 80.6 km/h and a 20° impact angle. Ambient temperature was15° C. As shown in the test summary diagram of figure 10, the vehicle impacted the barrier at post 3 of the installation. The vehicle fractured posts 4 through 8, was smoothly redirected, and rolled to a stop 26 m downstream of impact. Figure 11 shows the redirection sequence of the vehicle from behind the barrier. Maximum 50-msec average accelerations measured from onboard transducer data indicated 4.5 G's longitudinal and 0.3 G's lateral.

Test MLT-3. The vehicle used in this test was a 1991 Chevrolet, six-lug, light-duty C2500 pickup truck. Gross test weight, including the dummy and instrumentation, was 2045 kg. Actual test conditions were 100.1 km/h and a 20.0° impact angle. Ambient temperature was 5° C. As shown in the test summary diagram of figure 12, the vehicle impacted the barrier at post 3 of the installation. The vehicle fractured posts 3 through 13, the w-beam rail section fractured, and the vehicle penetrated the system. The vehicle was braked to a stop 55 m downstream of impact behind the rail. Figures 13 and 14 show the impact sequence of the vehicle from above and behind the barrier. Maximum 50-msec average accelerations measured from onboard transducer data indicated 7.5 G's longitudinal and 1.5 G's lateral.

Test MLT-5. The vehicle used in this test was a 1991 Chevrolet, six-lug, light-duty C2500 pickup truck. Gross test weight, including the dummy and instrumentation, was 2045 kg. Actual test conditions were 98.3 km/h and a 19.8° impact angle. Ambient temperature was 35° C. As shown in the test summary diagram of figure 15, the vehicle impacted the barrier at post 3 of the installation. The vehicle fractured posts 5 through 8, was smoothly redirected, and rolled to a stop 36.2 m downstream of impact. Figures 16 and 17 show the impact sequence of the vehicle from above and behind the barrier. Maximum 50-msec average accelerations measured from onboard transducer data indicated -5.8 G's longitudinal and 4.6 G's lateral.

BARRIER DAMAGE

Test MLT-1. Damage to the barrier, as shown in figure 18, consisted of fracturing of post 3 and deformation of two 3.8-m sections of w-beam. Permanent barrier deflection was 0.1 m after the test.

Test MLT-2. Damage to the barrier, as shown in figure 19, consisted of fracturing at ground level of posts 4 through 8 and deformation of two 3.8-m sections of w-beam. Permanent barrier deflection was 0.4 m after the test.

Test MLT-3. Damage to the barrier, as shown in figure 20, consisted of fracturing at ground level of posts 3 through 13. The w-beam fractured at the downstream side of the splice at post 9. Five 3.8-m sections of w-beam were damaged as well as the MELT components.

Test MLT-5. Damage to the barrier, as shown in figure 21, consisted of fracturing at ground level of posts 5 through 8 and deformation of three 3.8-m sections of w-beam. Permanent barrier deflection was 1.1 m after the test.

VEHICLE DAMAGE

Test MLT-1. As shown in figure 22, the test vehicle sustained damage to the left front fender and along the left side, as well as damage to the headlight/grille area. The left side

of the front bumper was deformed rearward, and the left front suspension/wheel/tire displaced rearward. The left front tire was blown out as a result of the impact. The exterior vehicle damage scale was estimated to be 11-LFQ-2 using the VDS system and 11FFEN9 using the CDC system. The interior deformation of the occupant compartment was LF0000000 using the OCDI system. There was no deformation or intrusion into the occupant compartment.

Test MLT-2. Figure 23 shows that the test vehicle sustained damage to the left front fender and along the left side, as well as damage to the headlight/grille area. The left side of the front bumper was deformed rearward, and the left front suspension/wheel/tire displaced rearward and inward. All tires remained inflated during impact. The exterior vehicle damage scale was estimated to be 11-FQ-3 using the VDS system and 11FFEN9 using the CDC system. The interior deformation of the occupant compartment was LF0000000 using the OCDI system. There was no deformation or intrusion into the occupant compartment.

Test MLT-3. The test vehicle, as shown in figure 24, sustained significant sheet metal damage. The left front fender and side were damaged as well as the entire front bumper, grille/headlight area. The radiator and mounting shell was deformed into the engine compartment. All tires remained inflated during impact, although the left front tire deflated some time after impact. The exterior vehicle damage scale was estimated to be 11-FQ-4 using the VDS system and 11FFEW9 using the CDC system. The interior deformation of the occupant compartment was LF0000000 using the OCDI system. There was no deformation or intrusion into the occupant compartment.

Test MLT-5. Figure 25 shows that the test vehicle sustained damage to the left front fender and along the left side, as well as damage to the headlight/grille area. The left side of the front bumper was deformed rearward, and the left front suspension/wheel/tire displaced rearward and inward. All tires remained inflated during impact. The exterior vehicle damage scale was estimated to be 11-LFQ-3 using the VDS system and 11FFEW6 using the CDC system. The interior deformation of the occupant compartment was LF0000000 using the OCDI system. There was no deformation or intrusion into the occupant compartment.

EVALUATION OF TEST RESULTS

Performance evaluation of the barrier design is based on the criteria shown in table 5.1 titled "Safety Evaluation Guidelines," of *NCHRP Report 350.* The specific requirements applicable for each of the test types, i.e. 3-39, 2-35, and 3-35, are shown in tables 3 through 6 together with the test results. While the evaluation criteria were met for the first two tests, 3-39 and 2-35, only after optimizing the test conditions (i.e. Grade 1 structural grade lumber for the posts and dry compacted strong soil) was the barrier able to meet the criteria for test 3-35.

CONCLUSIONS

From these tests and the evaluations described in the preceding section, this modified MELT is not suitable for use on test level 3 (TL-3) roadways.

Table 1. Summary of test conditions.

Test Designation and *NCHRP 350* Test Type	Vehicle Type	Vehicle Weight (Kg)	Impact Velocity (Km/h)	Impact Angle (Deg)	Barrier Evaluation
MLT-1 (3-39)	1990 Chevrolet 6-lug, ¾ ton, light duty C2500 pickup truck	2,000	100	20	Occupant risk, vehicle trajectory
MLT-2 (2-35)	1991 Chevrolet 6-lug, ¾ ton, light duty C2500 pickup truck	2,000	80	20	Structural adequacy
MLT-3 (3-35)	1991 Chevrolet 6-lug, ¾ ton, light duty C2500 pickup truck	2,000	100	20	Structural adequacy
MLT-5 (3-35)	1991 Chevrolet 6-lug, ¾ ton, light duty C2500 pickup truck	2,000	100	20	Structural adequacy

Table 2. Vehicle data transducer locations.

Type	Location	Orientation	Applicability
Accelerometer	Center of gravity	Longitudinal axis	All tests
Accelerometer	Center of gravity	Lateral axis	All tests
Accelerometer	Center of gravity	Vertical axis	All tests
Rate Gyro	Center of gravity	Longitudinal axis	All tests
Accelerometer	Over rear axle	Longitudinal axis	All tests
Accelerometer	Over rear axle	Lateral axis	All tests
Accelerometer	Over rear axle	Vertical axis	All tests
Accelerometer	Top engine block	Longitudinal axis	All tests
Accelerometer	Bottom of engine block	Longitudinal axis	All tests
Accelerometer	Right front disc brake caliper	Longitudinal axis	All tests
Accelerometer	Left front disc brake caliper	Longitudinal axis	All tests
Accelerometer	Center of instrument panel	Longitudinal axis	All tests

Table 3. Test assessment summary - *NCHRP Report 350* test designation 3-39 - SwRI test number MLT-1.

Designation	Factor	Description			Test Results	Assessment
C	Structural Adequacy	Acceptable test article performance may be redirection, controlled penetration, or controlled stopping of the vehicle.			The vehicle was smoothly redirected.	**PASS**
D	Occupant Risk	Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries shall not be permitted.			Test article and its elements did not penetrate the occupant compartment.	**PASS**
F	Occupant Risk	The vehicle shall remain upright during and after collision, although moderate roll, pitching, and yawing are acceptable.			Vehicle remained upright during and after the collision.	**PASS**
H	Occupant Risk	Occupant impact velocities shall satisfy the following: Occupant Impact Velocity Limits (m/s)			Impact Velocity (m/s)	
		Component	**Preferred**	**Maximum**		
		Longitudinal	9	12	1.4	**PASS**
		Lateral	9	12	5.8	**PASS**
I	Occupant Risk	Occupant ridedown accelerations shall satisfy the following: Occupant Ridedown Acceleration Limits (g's)			Ridedown Acceleration (g's)	
		Component	**Preferred**	**Maximum**		
		Longitudinal	15	20	-0.3	**PASS**
		Lateral	15	20	-	**PASS**
K	Vehicle Trajectory	After collision, it is preferable that the vehicle trajectory not intrude into adjacent traffic lanes.			Vehicle did not intrude into adjacent traffic lanes.	**PASS**
N	Vehicle Trajectory	Vehicle trajectory behind the test article is acceptable.			The vehicle was smoothly redirected.	**PASS**

Table 4. Test assessment summary - *NCHRP Report 350* test designation 2-35 - SwRI test number MLT-2.

Designation	Factor	Description			Test Results	Assessment
A	Structural Adequacy	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.			The vehicle was smoothly redirected.	**PASS**
D	Occupant Risk	Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries shall not be permitted.			Test article and its elements did not penetrate the occupant compartment.	**PASS**
F	Occupant Risk	The vehicle shall remain upright during and after collision, although moderate roll, pitching, and yawing are acceptable.			Vehicle remained upright during and after the collision.	**PASS**
G	Occupant Risk	It is preferable, although not essential, that the vehicle remain upright during and after collision.			The vehicle remained upright during and after collision.	**PASS**
H	Occupant Risk	Occupant impact velocities shall satisfy the following: Occupant Impact Velocity Limits (m/s)			Impact Velocity (m/s)	
		Component	**Preferred**	**Maximum**		
		Longitudinal	9	9	4.5	**PASS**
		Lateral	12	12	0.3	**PASS**
I	Occupant Risk	Occupant ridedown accelerations shall satisfy the following: Occupant Ridedown Acceleration Limits (g's)			Ridedown Acceleration (g's)	
		Component	**Preferred**	**Maximum**		
		Longitudinal	15	20	-0.9	**PASS**
		Lateral	15	20	-7.1	**PASS**
K	Vehicle Trajectory	After collision, it is preferable that the vehicle trajectory not intrude into adjacent traffic lanes.			Vehicle did not intrude into adjacent traffic lanes.	**PASS**
L	Vehicle Trajectory	The occupant impact velocity in the longitudinal direction and the occupant ridedown acceleration in the longitudinal direction shall satisfy the following:				
		Longitudinal Criteria		**Maximum**	**Test Result**	
		Occupant Impact Velocity (m/s)		12	4.5	**PASS**
		Occupant Ridedown Acceleration (g's)		20	-0.9	**PASS**
M	Vehicle Trajectory	The exit angle from the test article preferably shall be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.			The exit angle was less than 60 percent of test impact angle.	**PASS**

Table 5. Test assessment summary - *NCHRP Report 350* Test Designation 3-35 - SwRI test number MLT-3.

Designation	Factor	Description			Test Results	Assessment
A	Structural Adequacy	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.			The vehicle penetrated the system.	**FAIL**
D	Occupant Risk	Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries shall not be permitted.			Test article and its elements did not penetrate the occupant compartment.	**PASS**
F	Occupant Risk	The vehicle shall remain upright during and after collision, although moderate roll, pitching, and yawing are acceptable.			Vehicle remained upright during and after the collision.	**PASS**
G	Occupant Risk	It is preferable, although not essential, that the vehicle remain upright during and after collision.			The vehicle remained upright during and after collision.	**PASS**
H	Occupant Risk	Occupant impact velocities shall satisfy the following: Occupant Impact Velocity Limits (m/s)			Impact Velocity (m/s)	
		Component	**Preferred**	**Maximum**		
		Longitudinal	9	12	7.5	**PASS**
		Lateral	9	12	1.5	**PASS**
I	Occupant Risk	Occupant ridedown accelerations shall satisfy the following: Occupant Ridedown Acceleration Limits (g's)			Ridedown Acceleration (g's)	
		Component	**Preferred**	**Maximum**		
		Longitudinal	15	20	-11.3	**PASS**
		Lateral	15	20	-7.0	**PASS**
K	Vehicle Trajectory	After collision, it is preferable that the vehicle trajectory not intrude into adjacent traffic lanes.			Vehicle did not intrude into adjacent traffic lanes.	**PASS**
L	Vehicle Trajectory	The occupant impact velocity in the longitudinal direction and the occupant ridedown acceleration in the longitudinal direction shall satisfy the following:				
		Longitudinal Criteria		**Maximum**	**Test Result**	
		Occupant Impact Velocity (m/s)		12	7.5	**PASS**
		Occupant Ridedown Acceleration (g's)		20	-11.3	**PASS**
M	Vehicle Trajectory	The exit angle from the test article preferably shall be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.			The vehicle penetrated the system.	**FAIL**

Table 6. Test assessment summary - *NCHRP Report 350* test designation 3-35 - SwRI test number MLT-5.

Designation	Factor	Description			Test Results	Assessment
A	Structural Adequacy	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.			The vehicle did not penetrate the system.	**PASS**
D	Occupant Risk	Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries shall not be permitted.			Test article and its elements did not penetrate the occupant compartment.	**PASS**
F	Occupant Risk	The vehicle shall remain upright during and after collision, although moderate roll, pitching, and yawing are acceptable.			Vehicle remained upright during and after the collision.	**PASS**
G	Occupant Risk	It is preferable, although not essential, that the vehicle remain upright during and after collision.			The vehicle remained upright during and after collision.	**PASS**
H	Occupant Risk	Occupant impact velocities shall satisfy the following: Occupant Impact Velocity Limits (m/s)			Impact Velocity (m/s)	
		Component	**Preferred**	**Maximum**		
		Longitudinal	9	12	3.6	**PASS**
		Lateral	9	12	0.4	**PASS**
I	Occupant Risk	Occupant ridedown accelerations shall satisfy the following: Occupant Ridedown Acceleration Limits (g's)			Ridedown Acceleration (g's)	
		Component	**Preferred**	**Maximum**		
		Longitudinal	15	20	-3.9	**PASS**
		Lateral	15	20	-7.1	**PASS**
K	Vehicle Trajectory	After collision, it is preferable that the vehicle trajectory not intrude into adjacent traffic lanes.			Vehicle did not intrude into adjacent traffic lanes.	**PASS**
L	Vehicle Trajectory	The occupant impact velocity in the longitudinal direction and the occupant ridedown acceleration in the longitudinal direction shall satisfy the following:				
		Longitudinal Criteria		**Maximum**	**Test Result**	
		Occupant Impact Velocity (m/s)		12	3.6	**PASS**
		Occupant Ridedown Acceleration (g's)		20	0.4	**PASS**
M	Vehicle Trajectory	The exit angle from the test article preferably shall be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.			The vehicle was smoothly redirected.	**PASS**

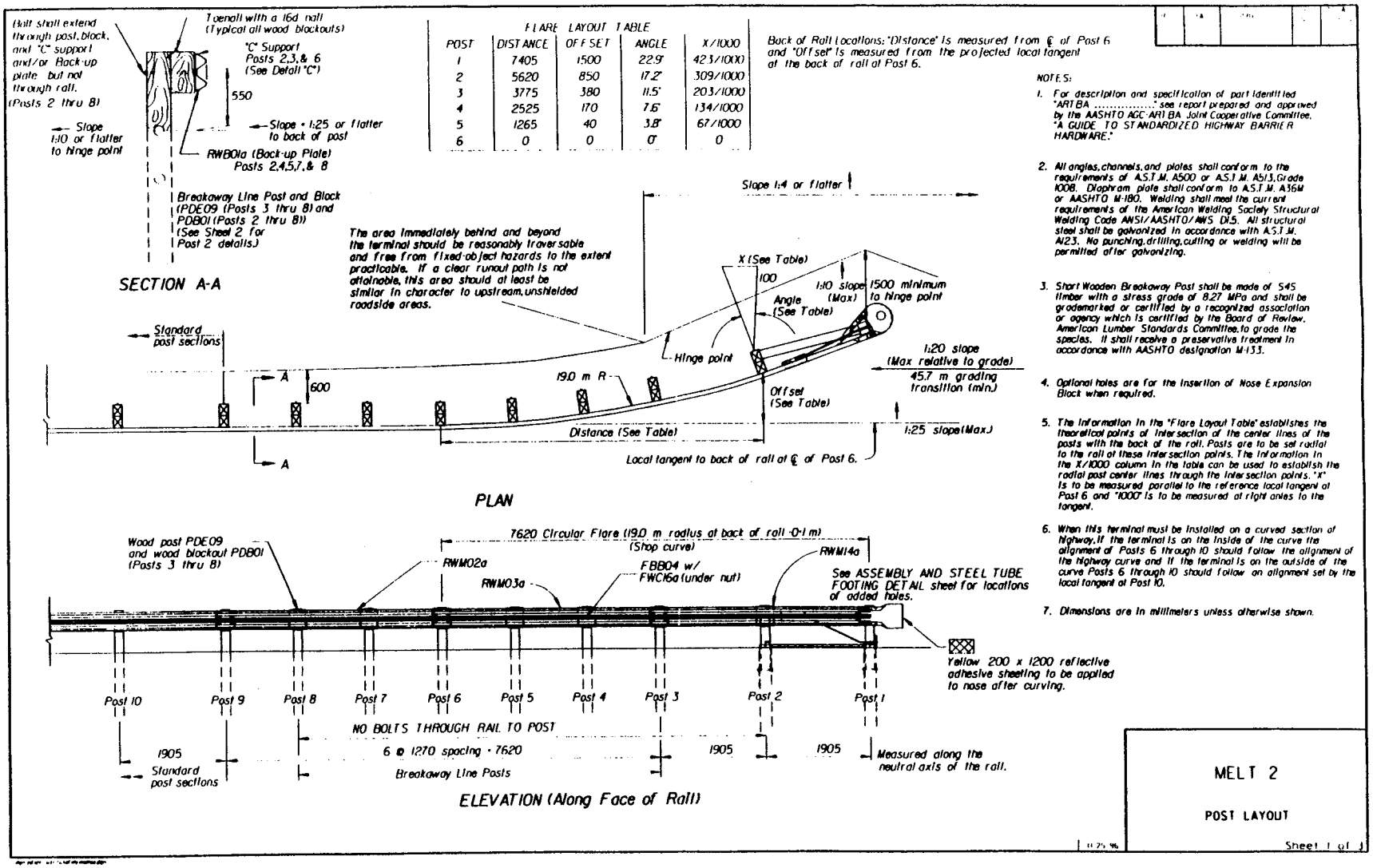


Figure 1. Barrier installation details.

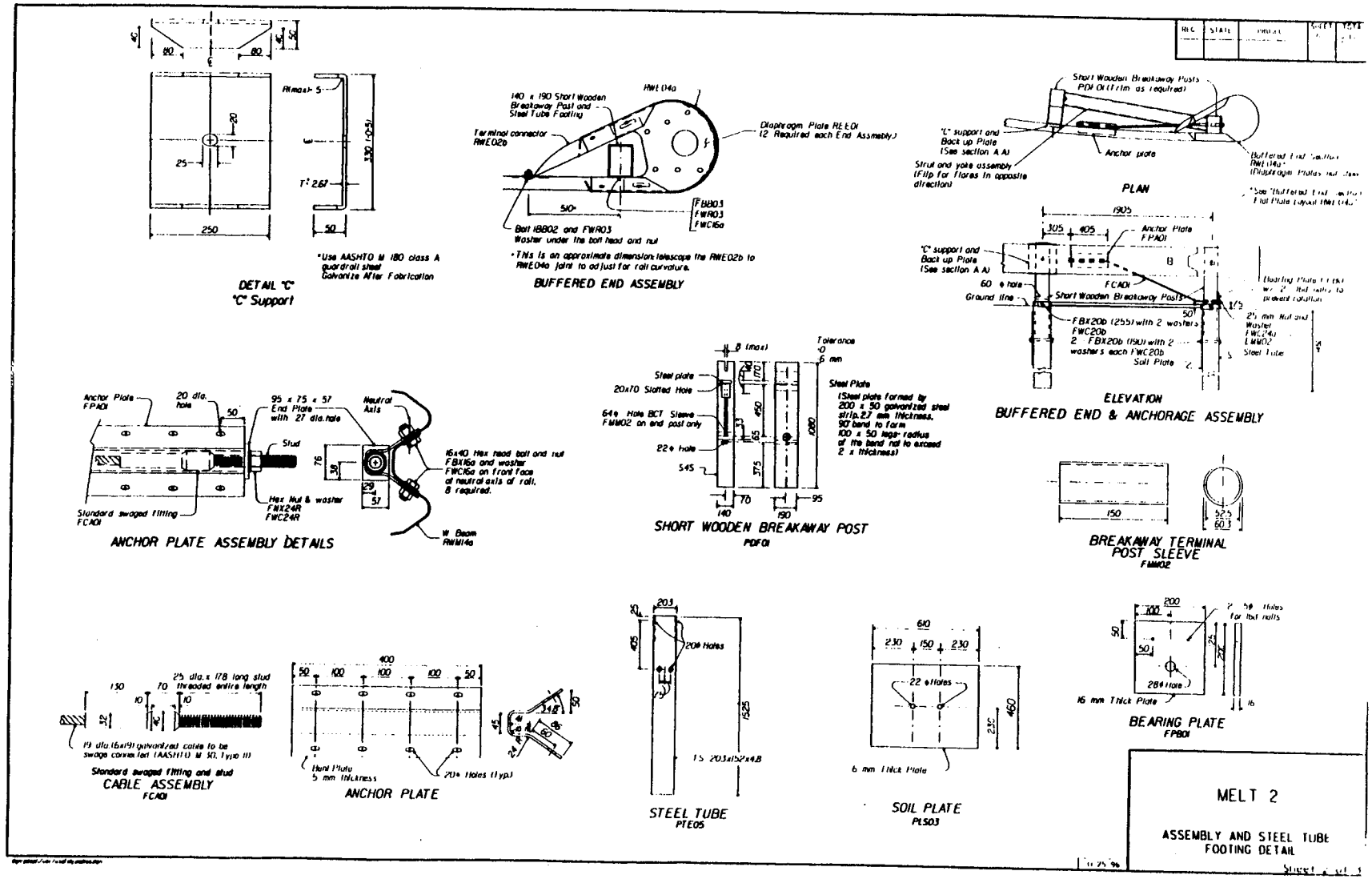


Figure 1. Barrier installation details (continued).

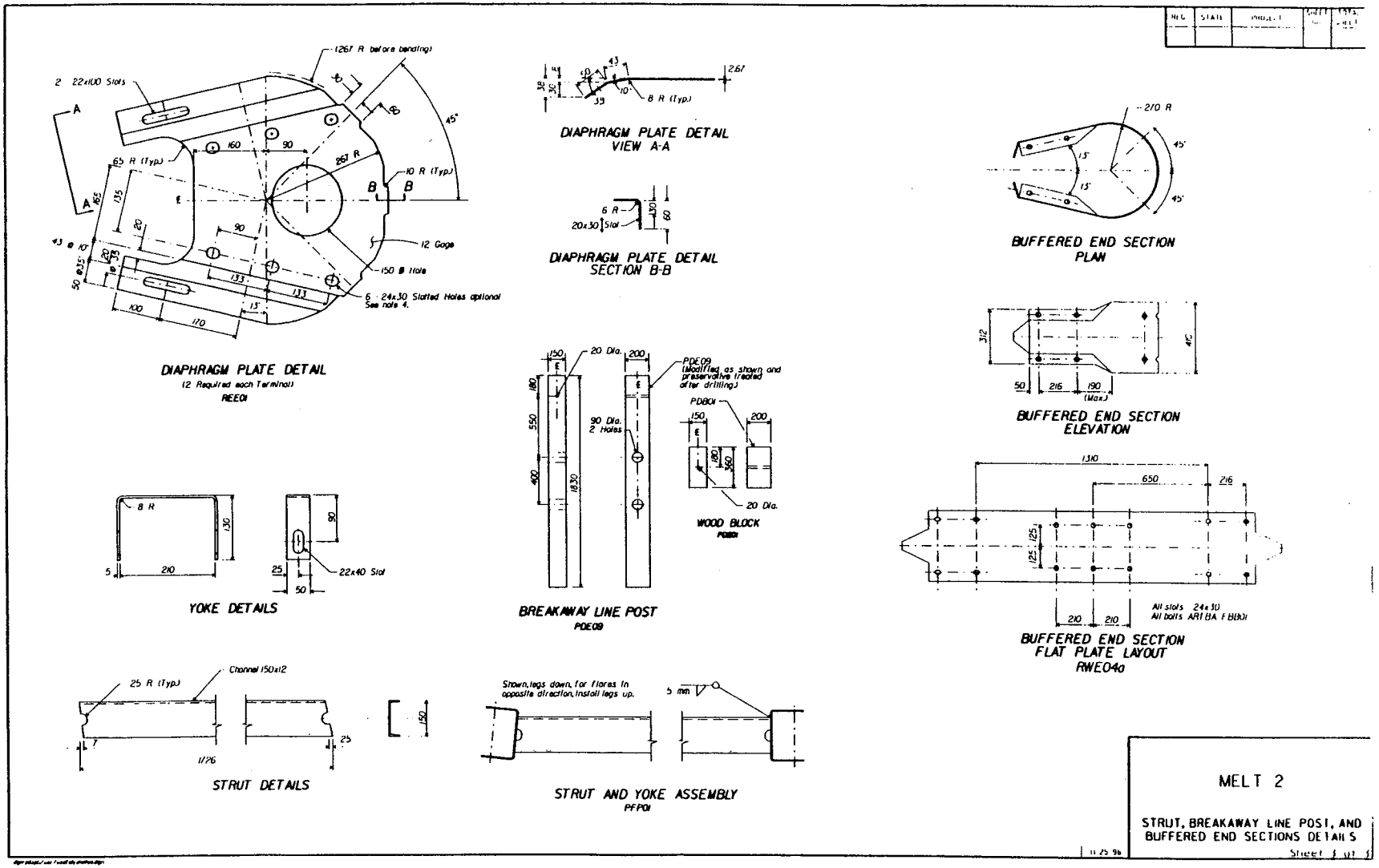


Figure 1. Barrier installation details (continued).

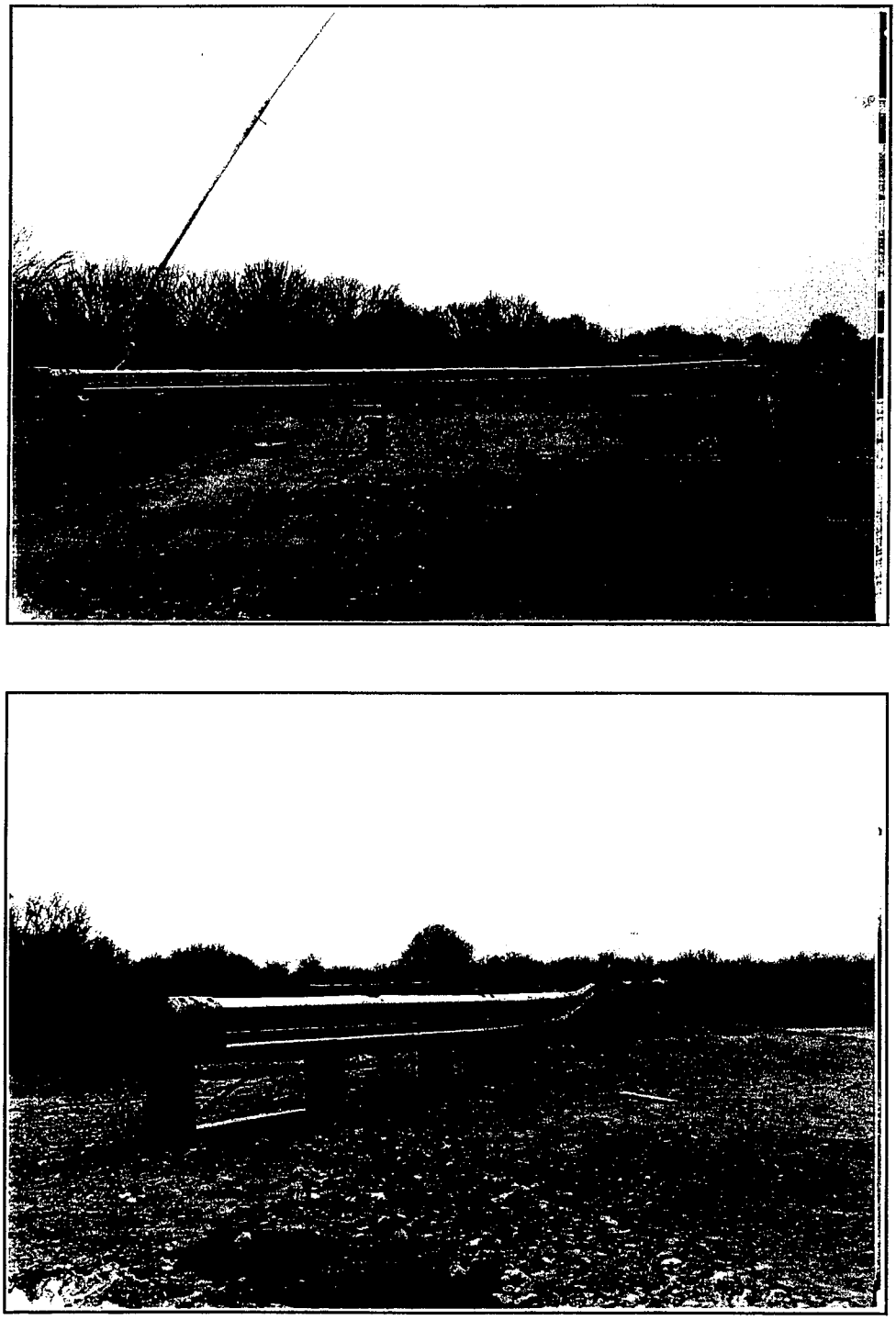
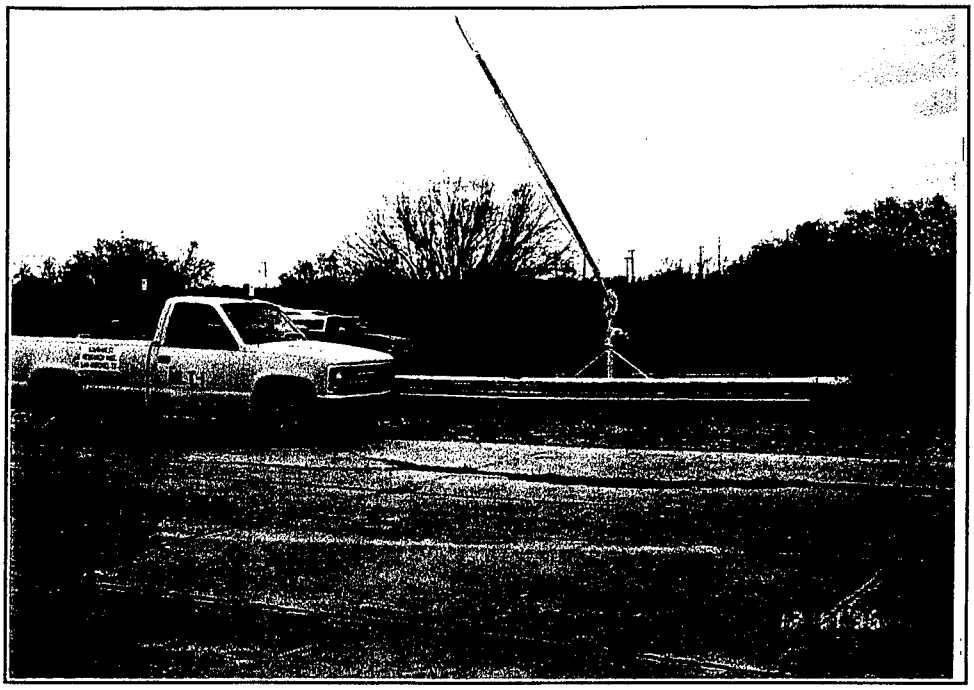


Figure 2. Barrier photographs.

Figure 2. Barrier photographs (continued).



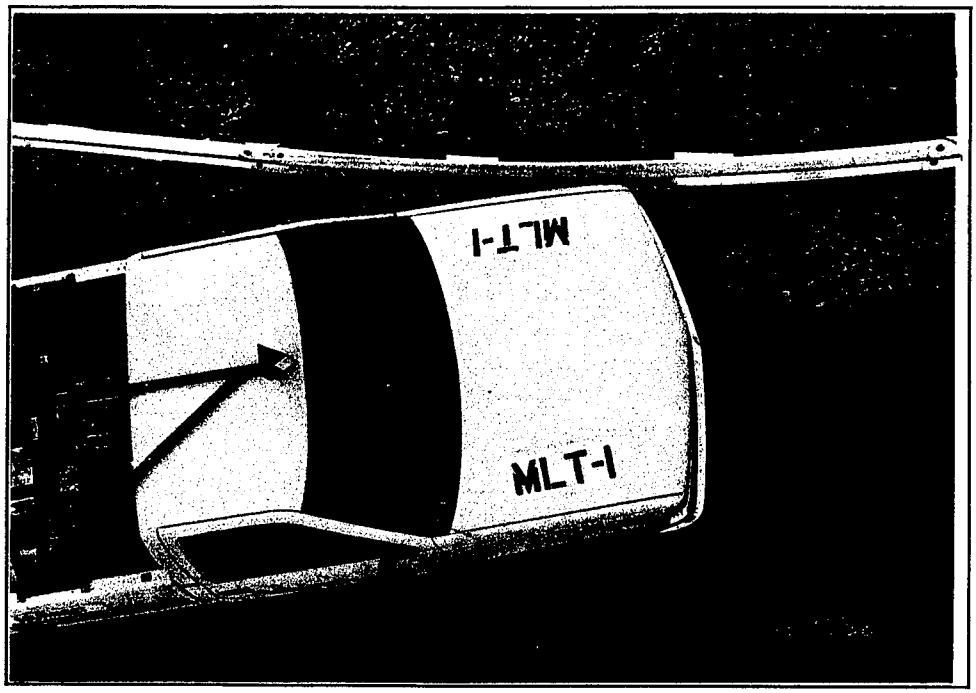


Figure 3. Vehicle photographs - Test MLT-1.

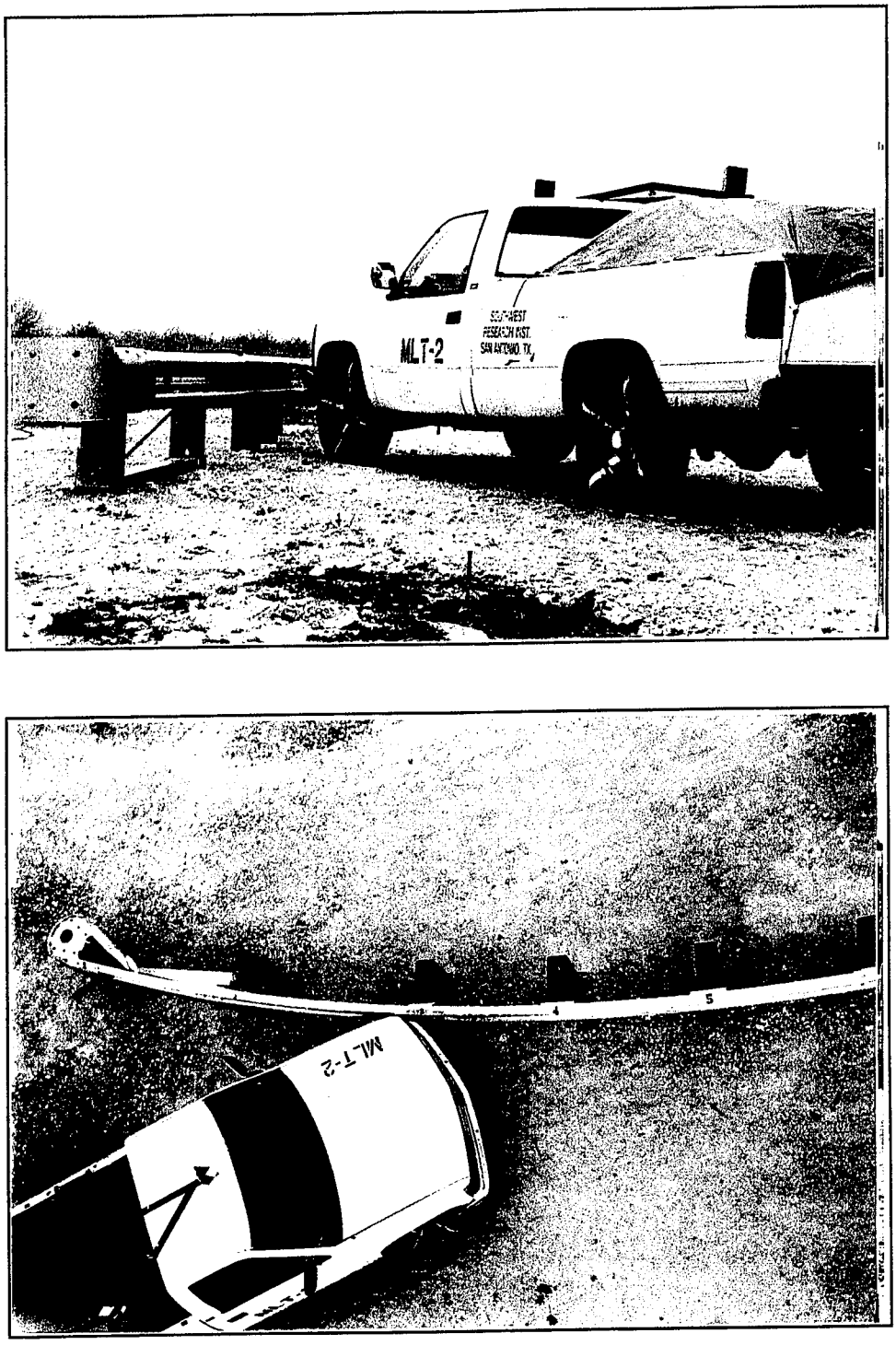
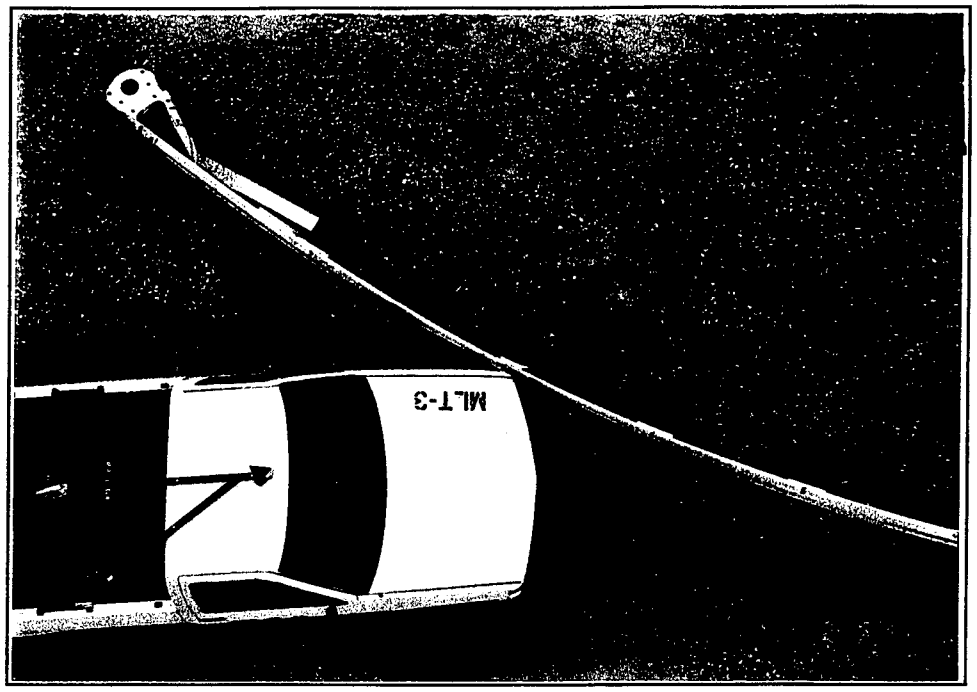


Figure 4. Vehicle photographs - Test MLT-2.



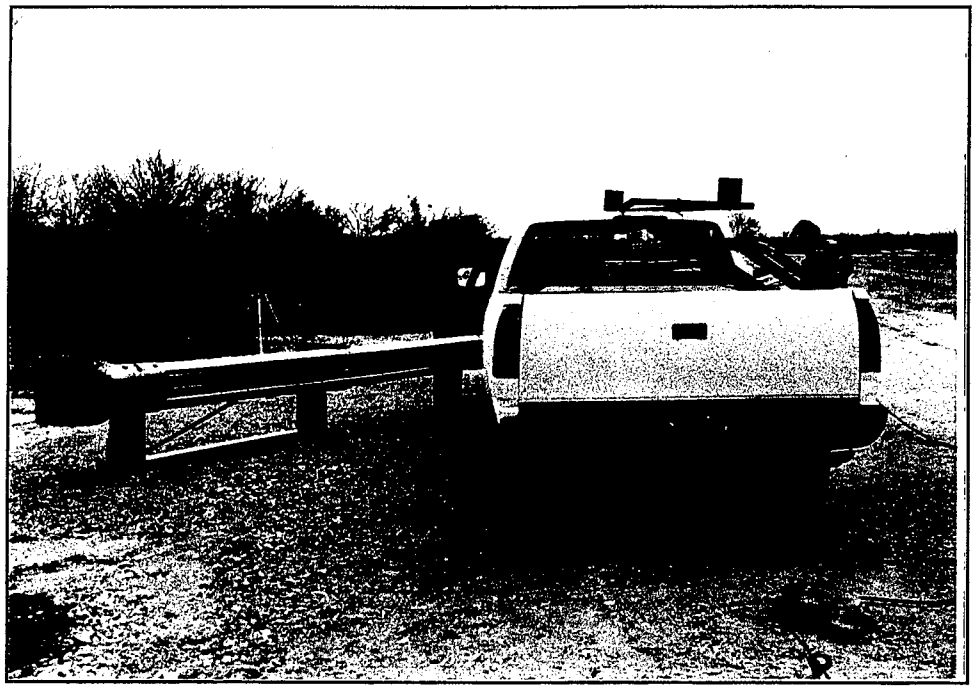
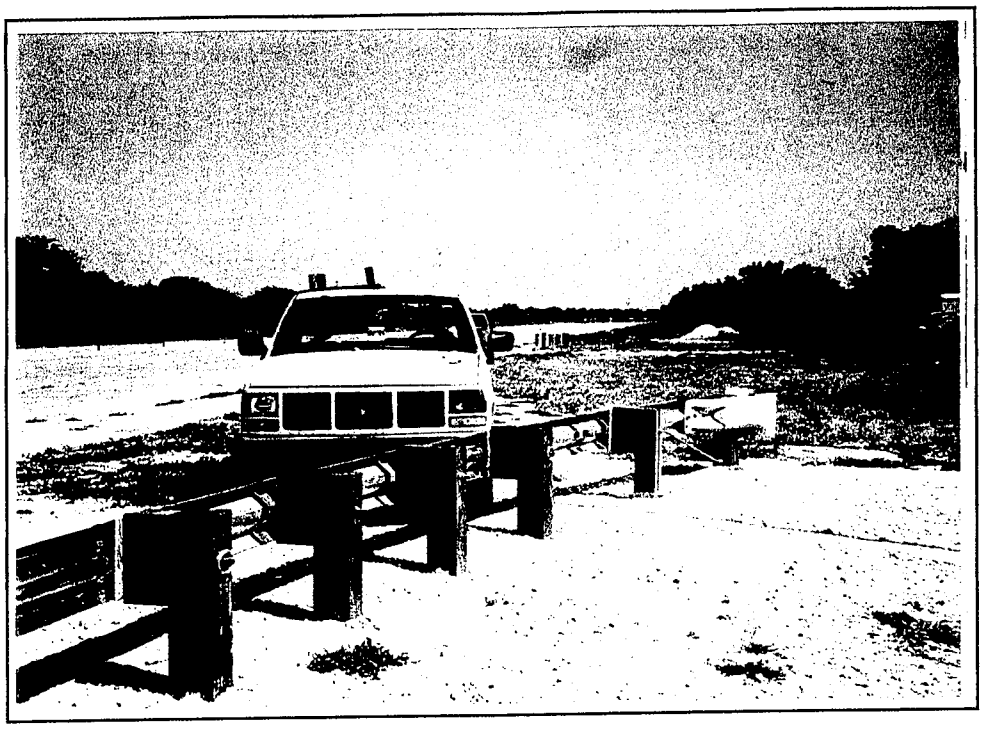


Figure 5. Vehicle photographs - Test MLT-3.



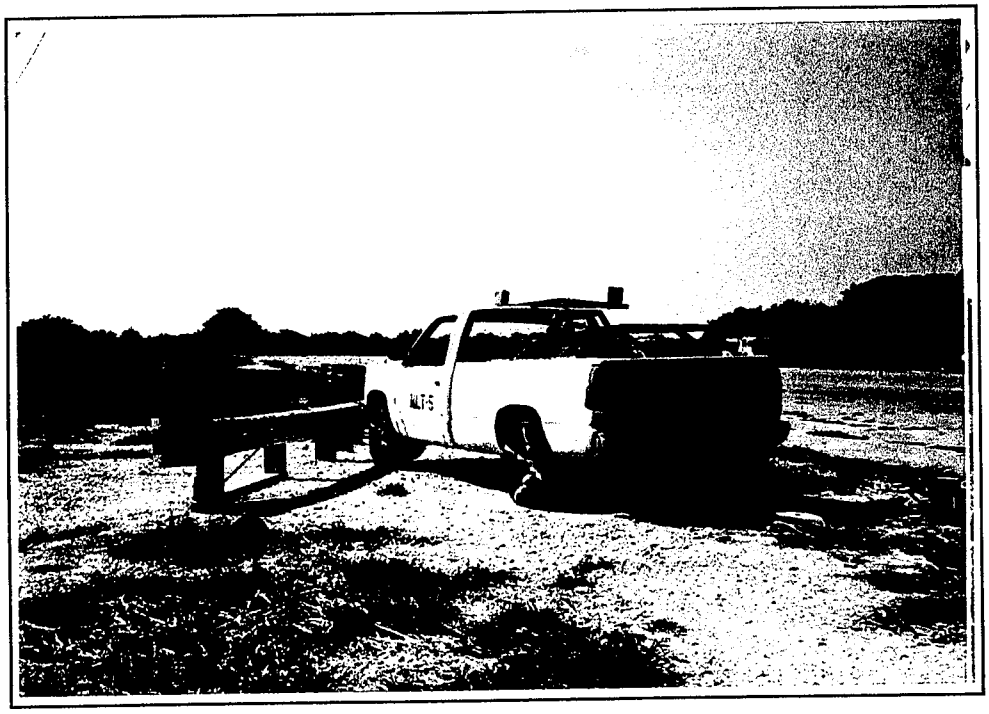
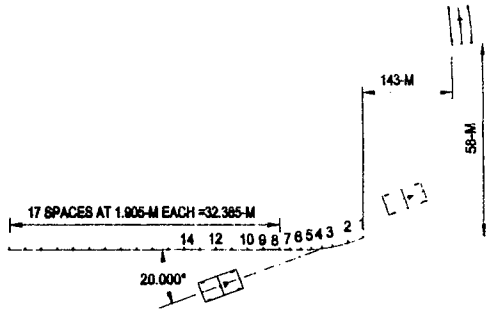


Figure 6. Vehicle photographs - Test MLT-5.



4. General Information		7. Test Vehicle (Continued)			
Test Agency	Southwest Research Institute	Mass (kg) Dummy(s)	75	y-direction	-
Test Number	MLT-1	Mass (kg) Gross Static	2,050	11. Test Article Deflection (m)	
Test Date	12/17/96	8. Impact Conditions		Dynamic	0.8
5. Test Article		Speed (km/h)	100.1	Permanent	0.1
Type	End Terminal	Angle (deg)	20.0	12. Vehicle Damage	
Installation Length (m)	41.9	9. Exit Conditions		Exterior	
Barrier	Flared MELT	Speed (km/h)	95.7	VDS	11LFQ2
6. Soil Type and Condition	Standard Soil, Dry Compacted	Angle (deg)	11.3	CDC	11FFEN9
7. Test Vehicle		10. Occupant Risk Values		Interior	
Type	Production Model	Impact Velocity (m/s)		OCDI	LF0000000
Designation	2000P	x-direction	1.4	13. Post-Impact Vehicular Behavior	
Model	1990 Chevy C2500	y-direction	5.8	Maximum Roll Angle (deg)	5
Mass (kg) Curb	1,975	Ridedown Acceleration (g's)		Maximum Pitch Angle (deg)	0
Mass (kg) Test Inertial	1,975	x-direction	-0.3	Maximum Yaw Angle (deg)	0

Figure 7. Impact sequence and summary of test conditions and results - Test MLT-1.

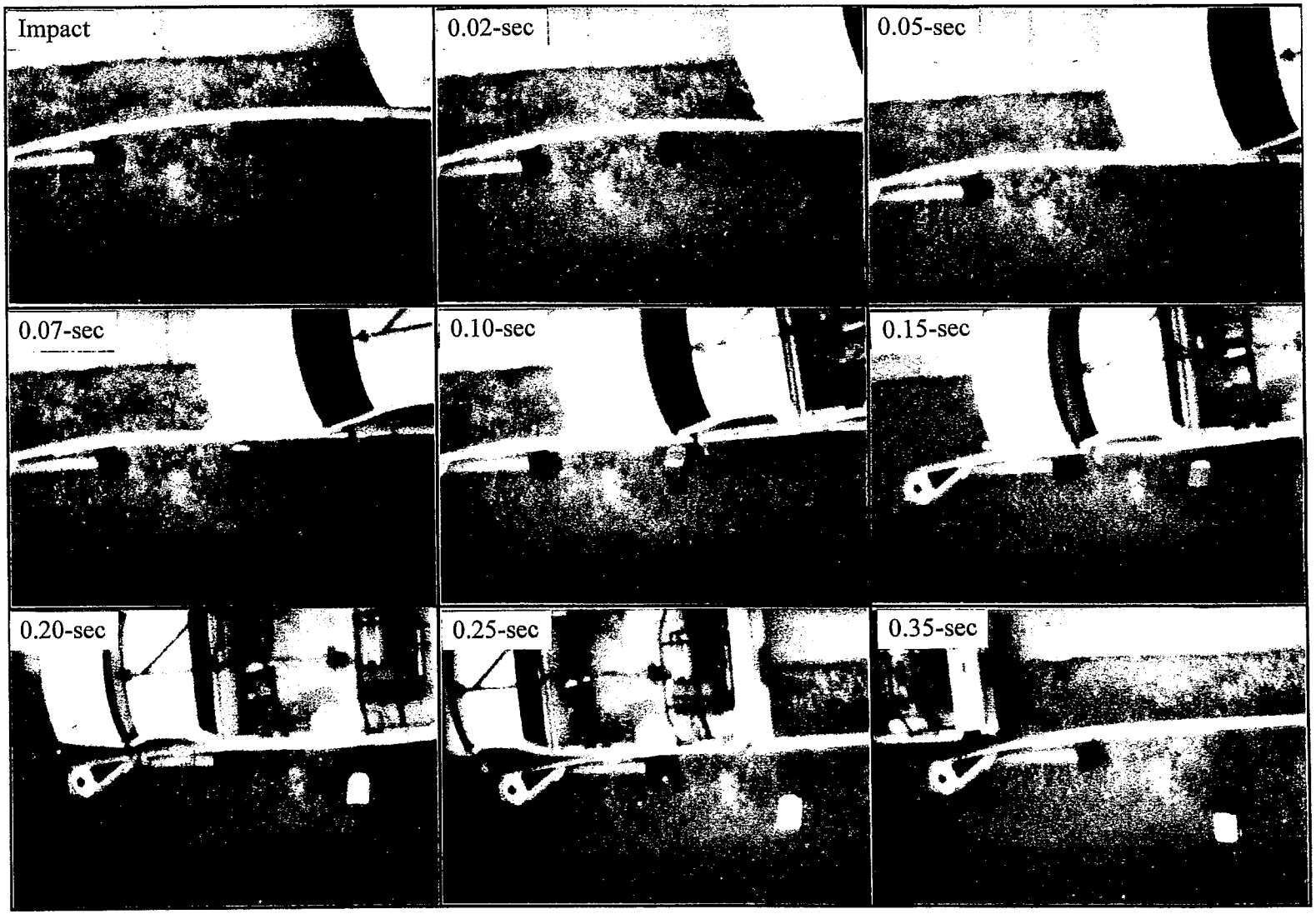
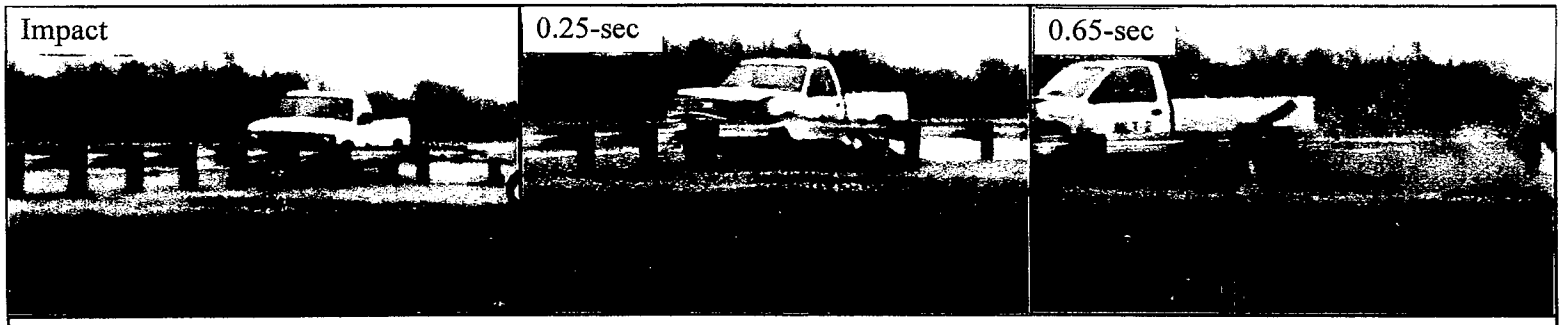
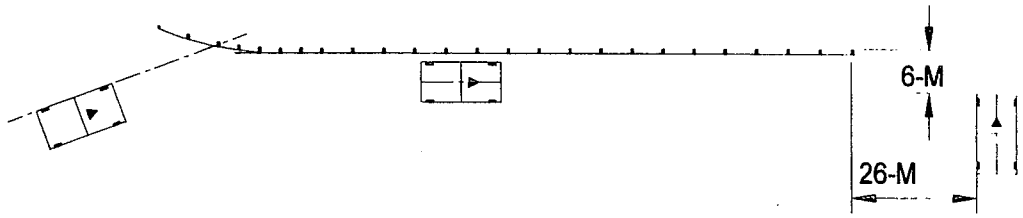


Figure 8. Overhead sequential photographs - Test MLT-1.

Figure 9. Sequential photographs - Test MLT-1.





4. General Information		7. Test Vehicle (Continued)			
Test Agency	Southwest Research Institute	Mass (kg) Dummy(s)	75	y-direction	-7.1
Test Number	MLT-2	Mass (kg) Gross Static	2,055	11. Test Article Deflection (m)	
Test Date	1/23/97	8. Impact Conditions		Dynamic	1.0 (est.)
5. Test Article		Speed (km/h)	80.6	Permanent	.4
Type	End Terminal	Angle (deg)	20.0	12. Vehicle Damage	
Installation Length (m)	41.9	9. Exit Conditions		Exterior	
Barrier	Flared MELT	Speed (km/h)	60.1	VDS	11FQ2
6. Soil Type and Condition	Standard Soil, Dry Compacted	Angle (deg)	5.8	CDC	11FFEN9
7. Test Vehicle		10. Occupant Risk Values		Interior	
Type	Production Model	Impact Velocity (m/s)		OCDI	LF0000000
Designation	2000P	x-direction	4.5	13. Post-Impact Vehicular Behavior	
Model	1991 Chevy C2500	y-direction	0.3	Maximum Roll Angle (deg)	10
Mass (kg) Curb	1,980	Ridedown Acceleration (g's)		Maximum Pitch Angle (deg)	2
Mass (kg) Test Inertial	1,980	x-direction	-0.9	Maximum Yaw Angle (deg)	0

Figure 10. Impact sequence and summary of test conditions and results - Test MLT-2.

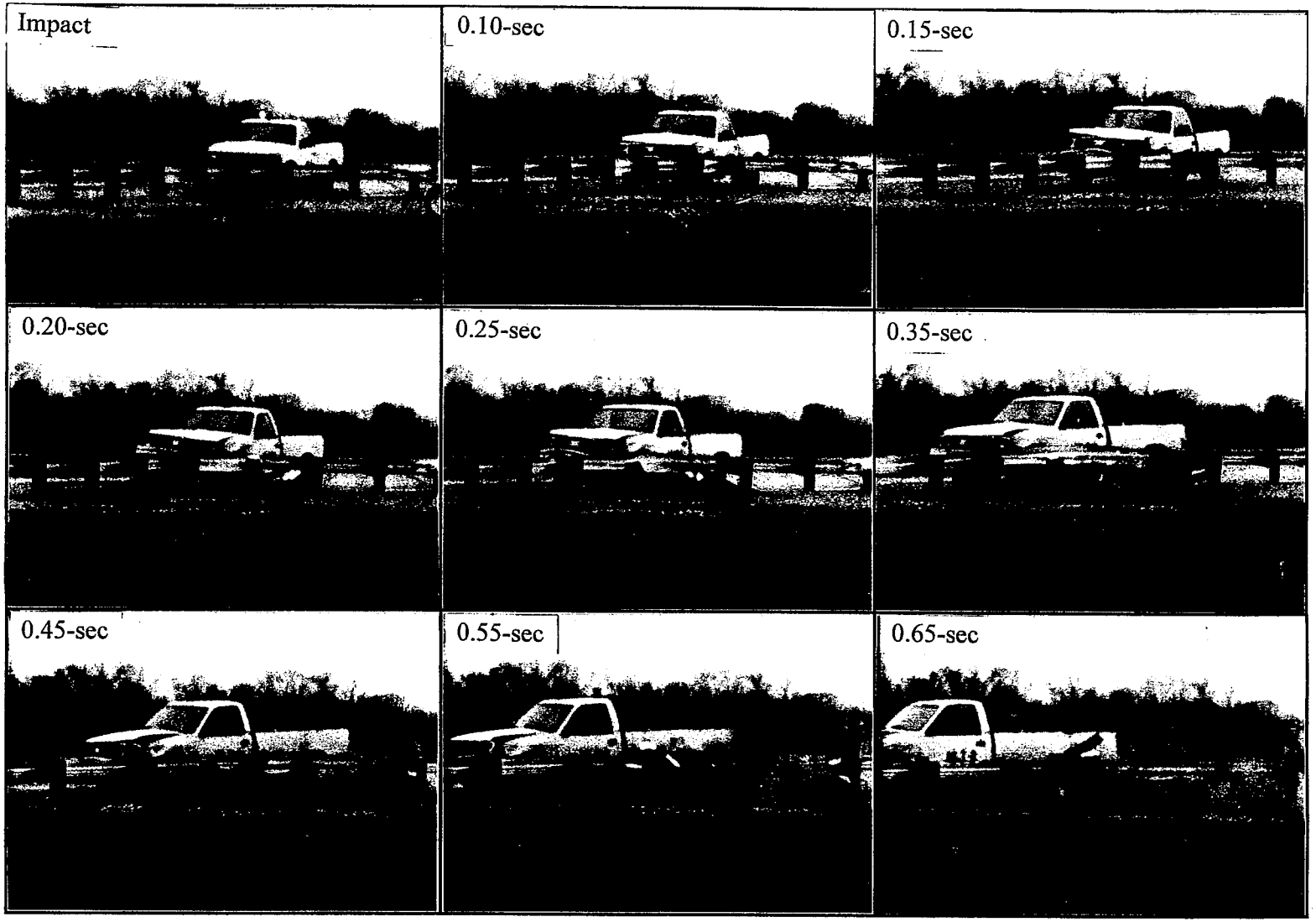
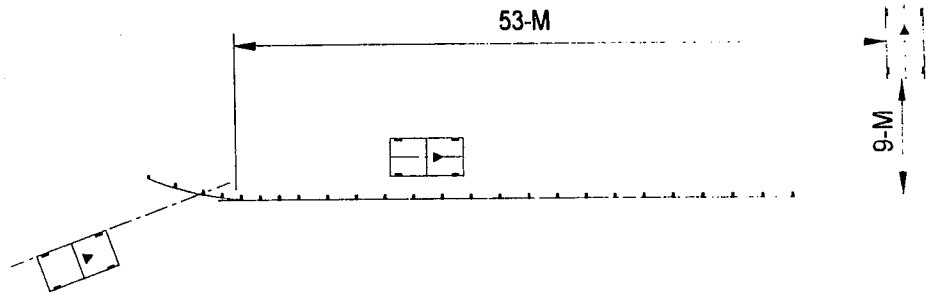


Figure 11. Sequential photographs - Test MLT-2.



4. General Information		**7. Test Vehicle (Continued)**			
Test Agency	Southwest Research Institute	Mass (kg) Dummy(s)	75	y-direction	-7.0
Test Number	MLT-3	Mass (kg) Gross Static	2,045	**11. Test Article Deflection (m)**	
Test Date	2/5/97	**8. Impact Conditions**		Dynamic	-
5. Test Article		Speed (km/h)	100.1	Permanent	-
Type	End Terminal	Angle (deg)	20.0	**12. Vehicle Damage**	
Installation Length (m)	41.9	**9. Exit Conditions**		Exterior	
Barrier	Flared MELT	Speed (km/h)	65.9	VDS	11LFQ4
6. Soil Type and Condition	Standard Soil, Dry Compacted	Angle (deg)	8.2	CDC	11FFEW9
7. Test Vehicle		**10. Occupant Risk Values**		Interior	
Type	Production Model	Impact Velocity (m/s)		OCDI	LF0000000
Designation	2000P	x-direction	7.5	**13. Post-Impact Vehicular Behavior**	
Model	1991 Chevy C2500	y-direction	1.5	Maximum Roll Angle (deg)	15
Mass (kg) Curb	1,970	Ridedown Acceleration (g's)		Maximum Pitch Angle (deg)	5
Mass (kg) Test Inertial	1,970	x-direction	-11.3	Maximum Yaw Angle (deg)	0

Figure 12. Impact sequence and summary of test conditions and results - Test MLT-3.

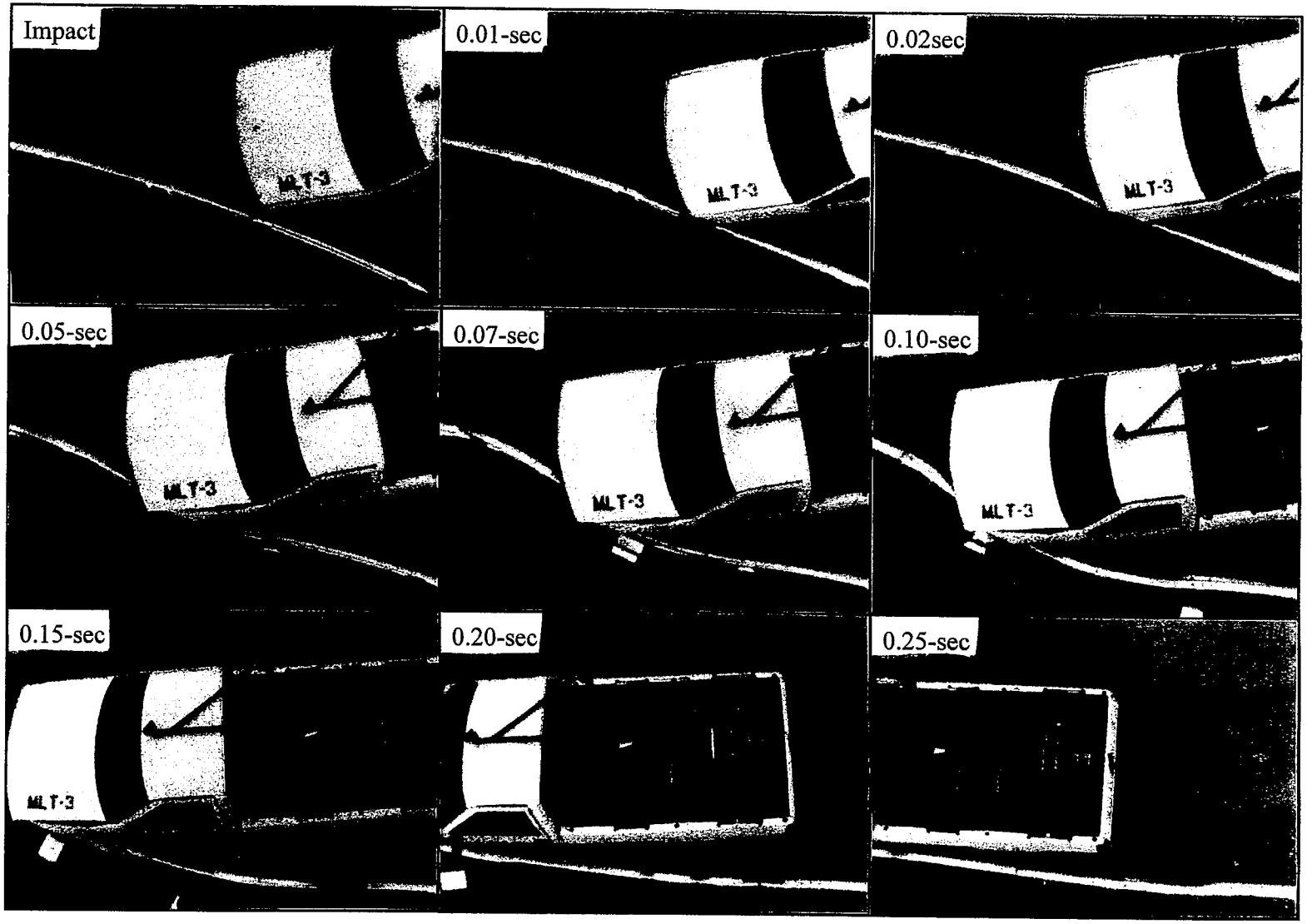


Figure 13. Overhead sequential photographs - Test MLT-3.

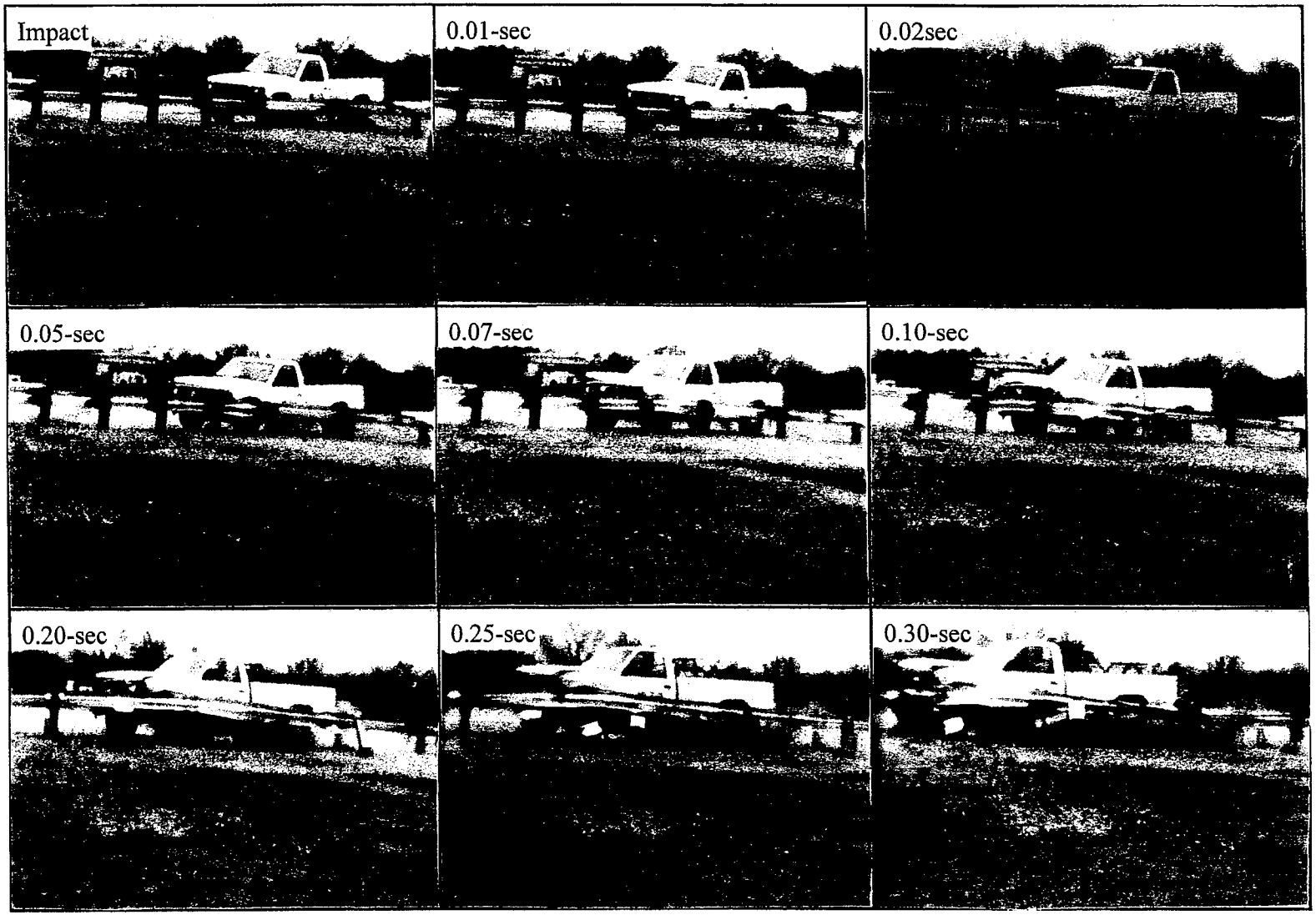
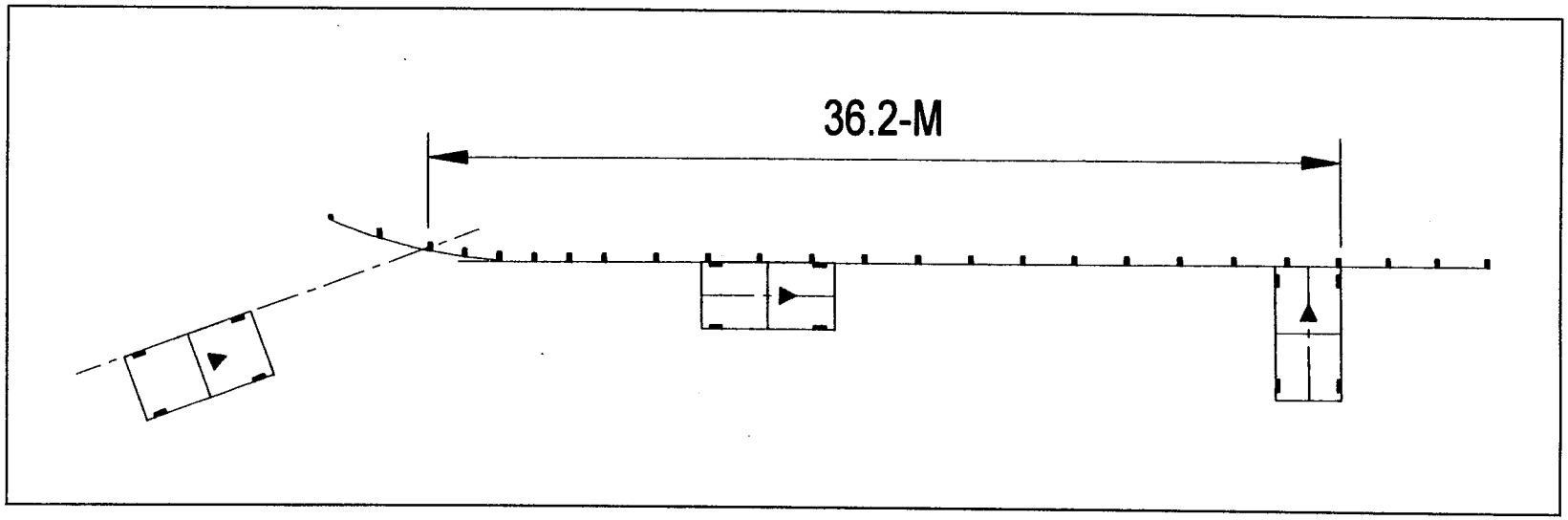


Figure 14. Sequential photographs - Test MLT-3.



4. General Information		7. Test Vehicle (Continued)			
Test Agency	Southwest Research Institute	Mass (kg) Dummy(s)	75	y-direction	-7.1
Test Number	MLT-5	Mass (kg) Gross Static	2,041	**11. Test Article Deflection (m)**	
Test Date	7/17/97	**8. Impact Conditions**		Dynamic	4.2
5. Test Article		Speed (km/h)	98.3	Permanent	3.1
Type	End Terminal	Angle (deg)	19.8	**12. Vehicle Damage**	
Installation Length (m)	41.9	**9. Exit Conditions**		Exterior	
Barrier	Flared MELT	Speed (km/h)	0	VDS	11LFQ3
6. Soil Type and Condition	Standard Soil, Dry Compacted	Angle (deg)	0	CDC	11FFEW6
7. Test Vehicle		**10. Occupant Risk Values**		Interior	
Type	Production Model	Impact Velocity (m/s)		OCDI	LF0000000
Designation	2000P	x-direction	3.6	**13. Post-Impact Vehicular Behavior**	
Model	1991 Chevy C2500	y-direction	0.4	Maximum Roll Angle (deg)	20°
Mass (kg) Curb	1,970	Ridedown Acceleration (g's)		Maximum Pitch Angle (deg)	10°
Mass (kg) Test Inertial	1,970	x-direction	-3.9	Maximum Yaw Angle (deg)	5°

Figure 15. Impact sequence and summary of test conditions and results - Test MLT-5

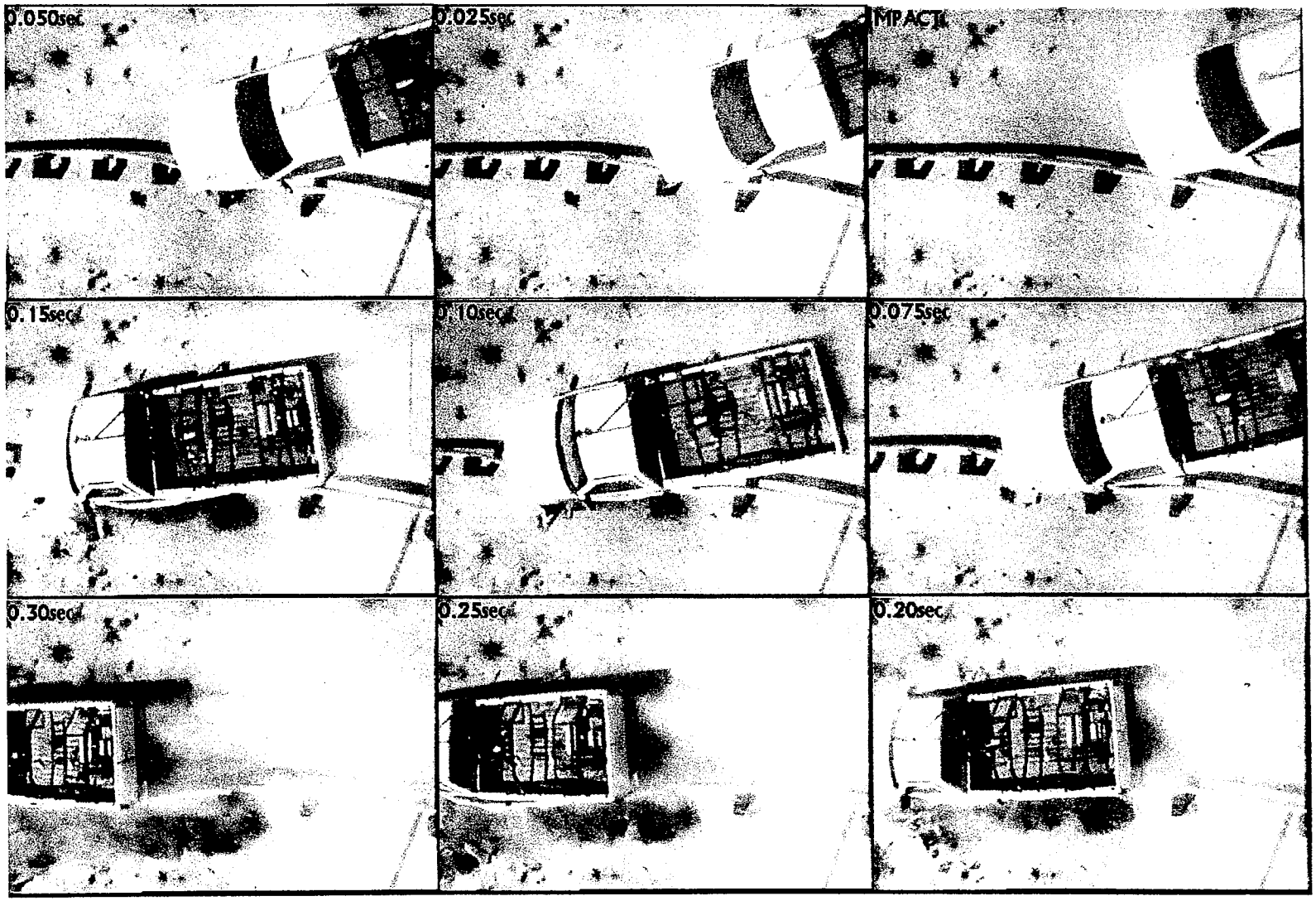


Figure 16. Overhead sequential photographs - Test MLT-5.

Figure 17. Sequential photographs - Test MLT-5.

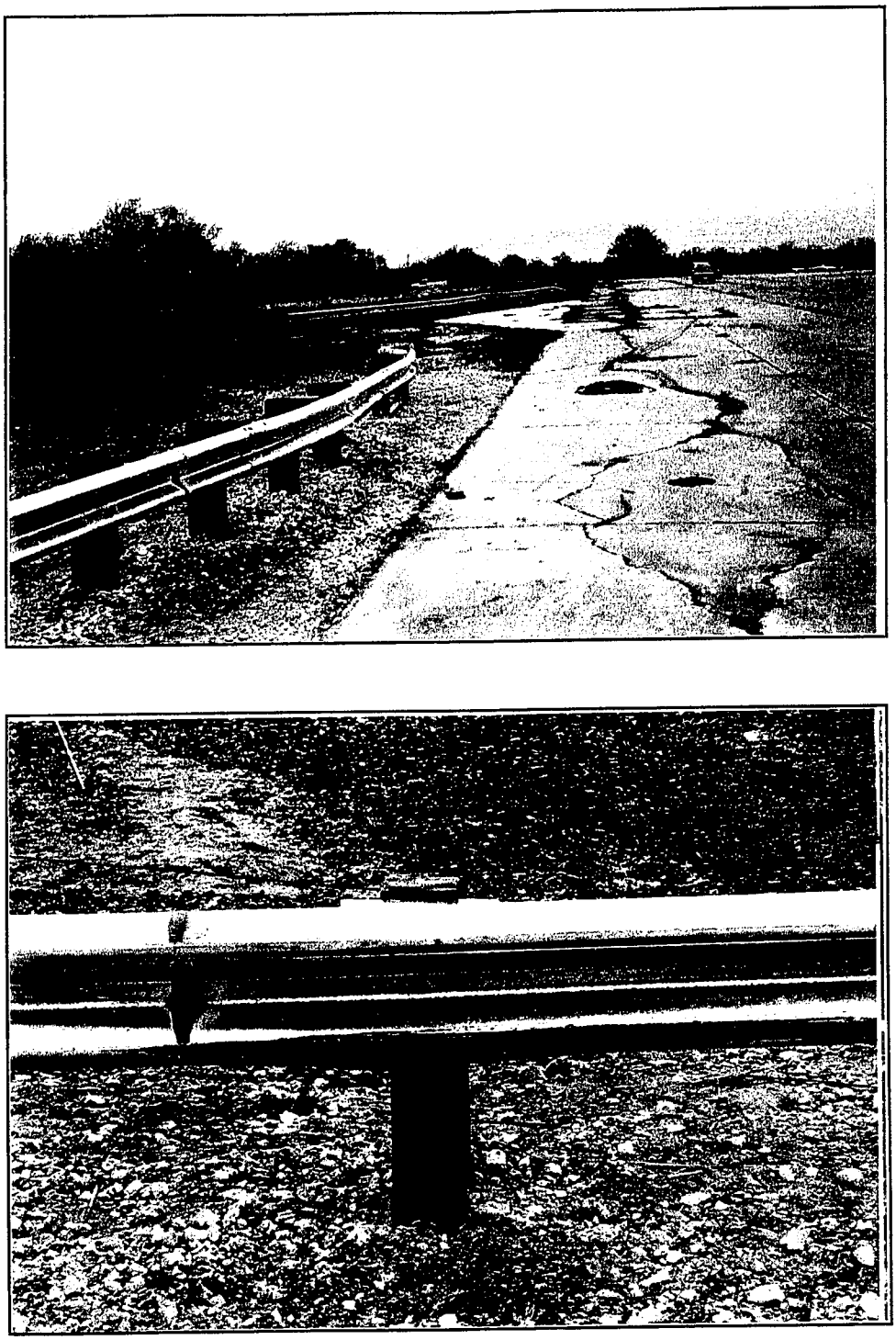


Figure 18. Barrier damage photographs - Test MLT-1.

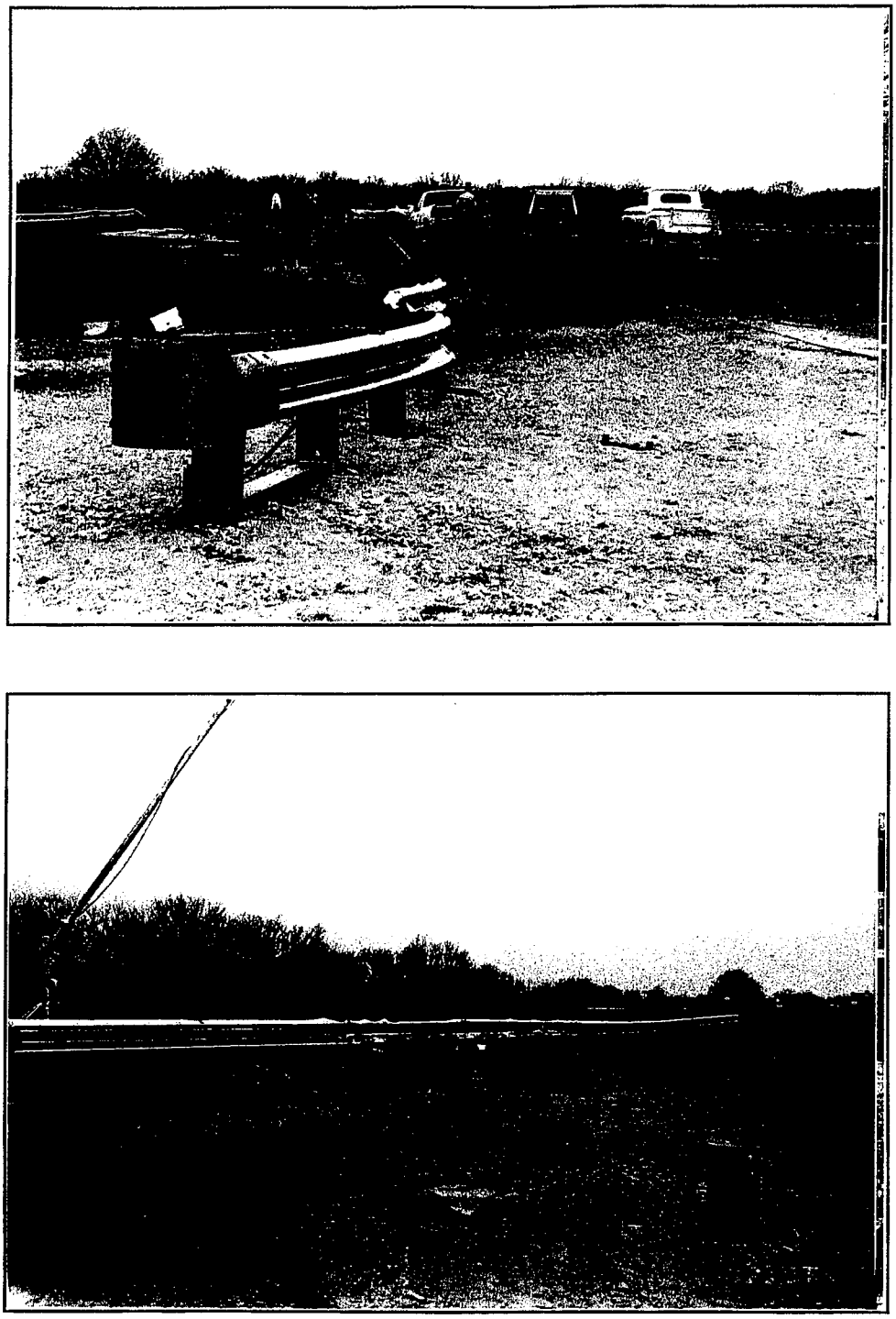


Figure 19. Barrier damage photographs - Test MLT-2.

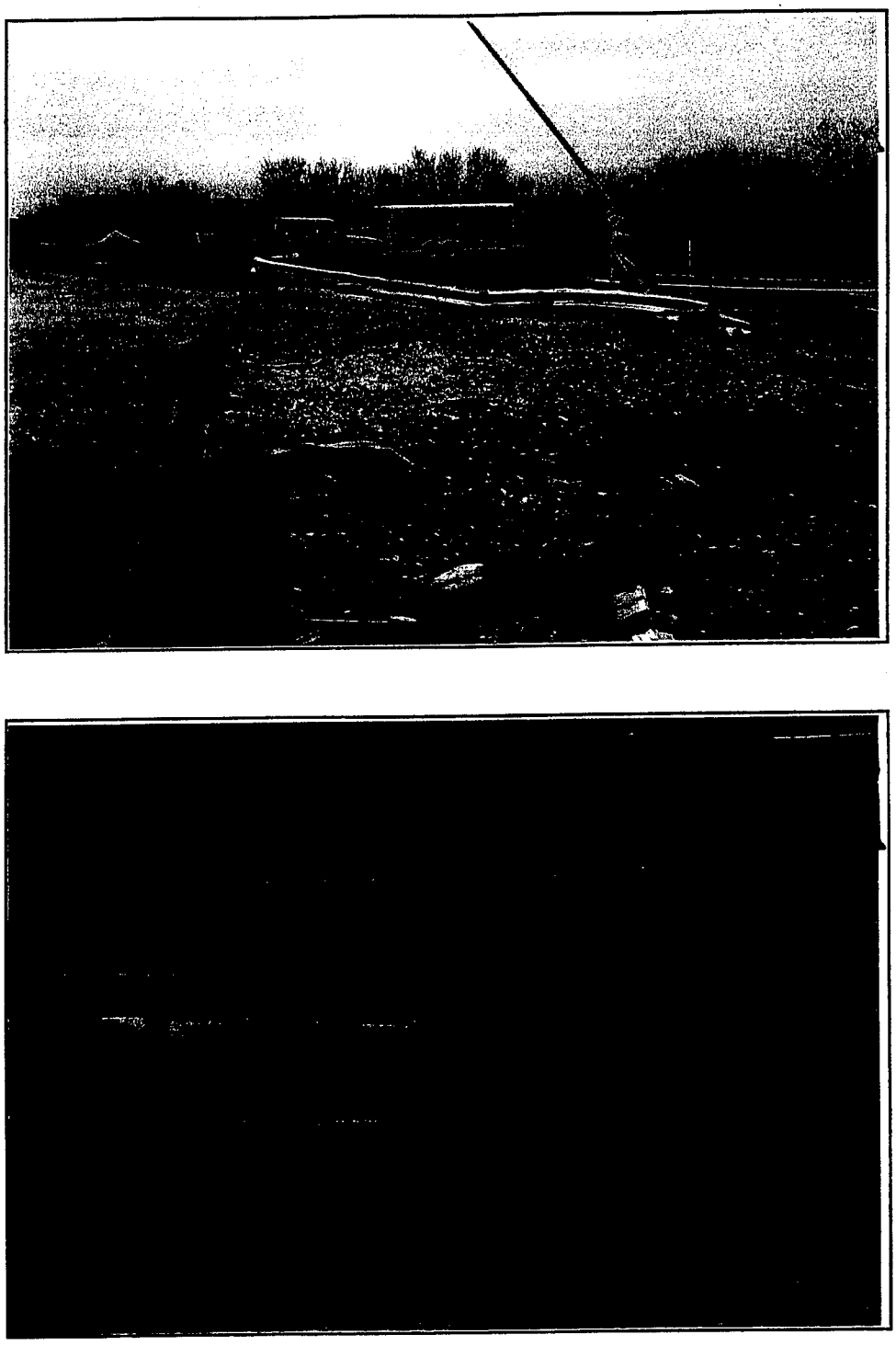


Figure 20. Barrier damage photographs - Test MLT-3.

Figure 21. Barrier damage photographs - Test MLT-5.

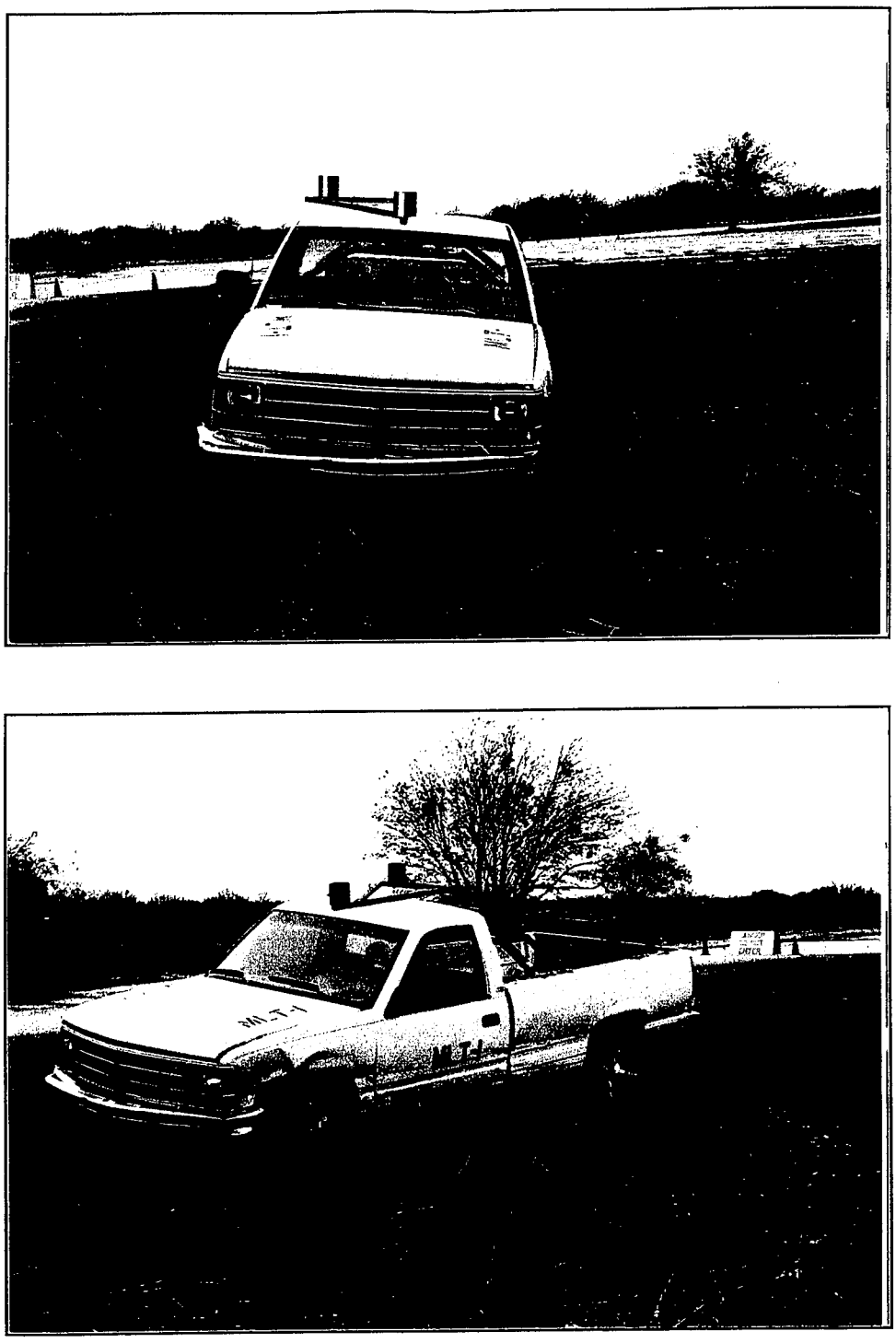


Figure 22. Vehicle damage photographs - Test MLT-1.

Figure 23. Vehicle damage photographs - Test MLT-2.

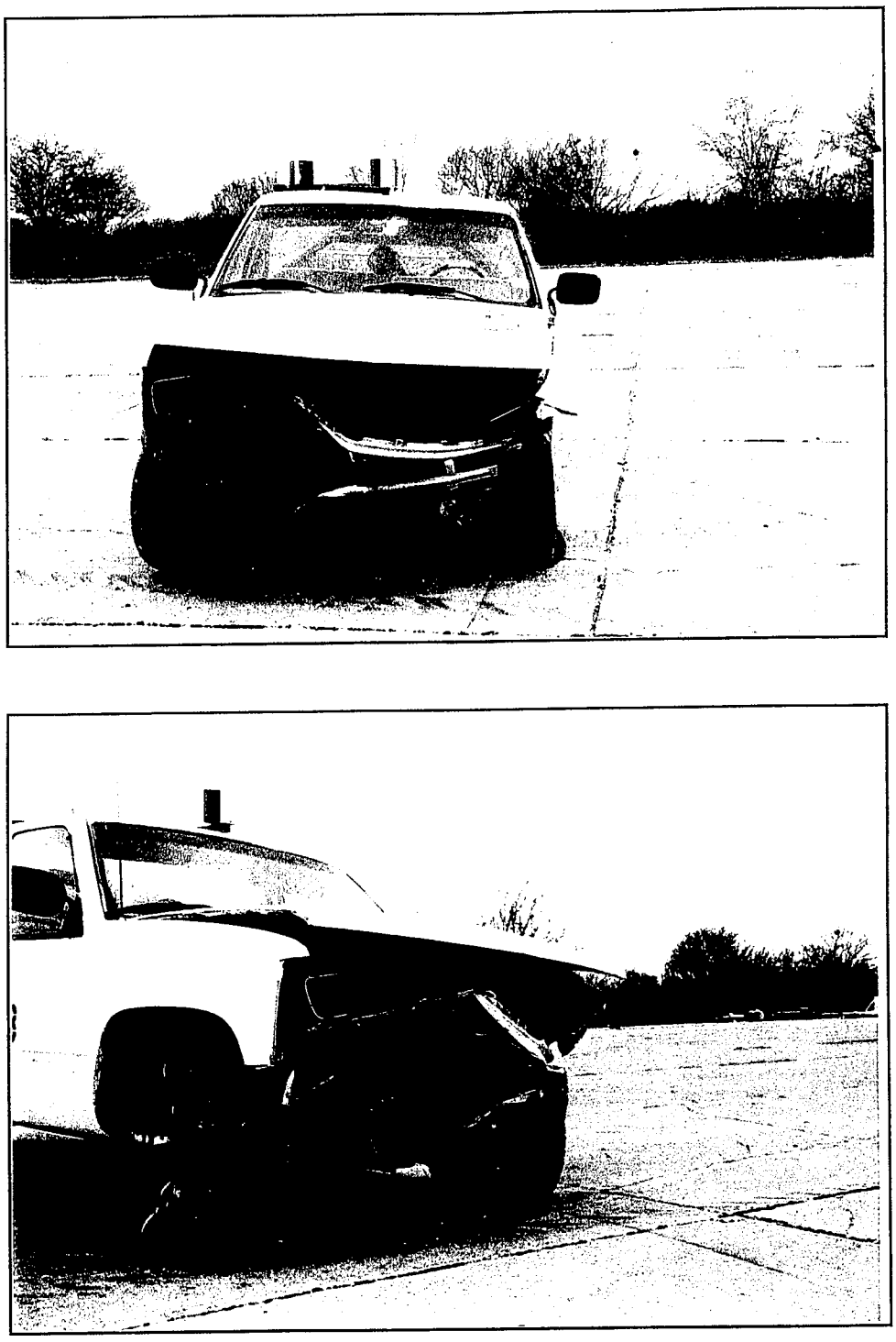


Figure 24. Vehicle damage photographs - Test MLT-3.

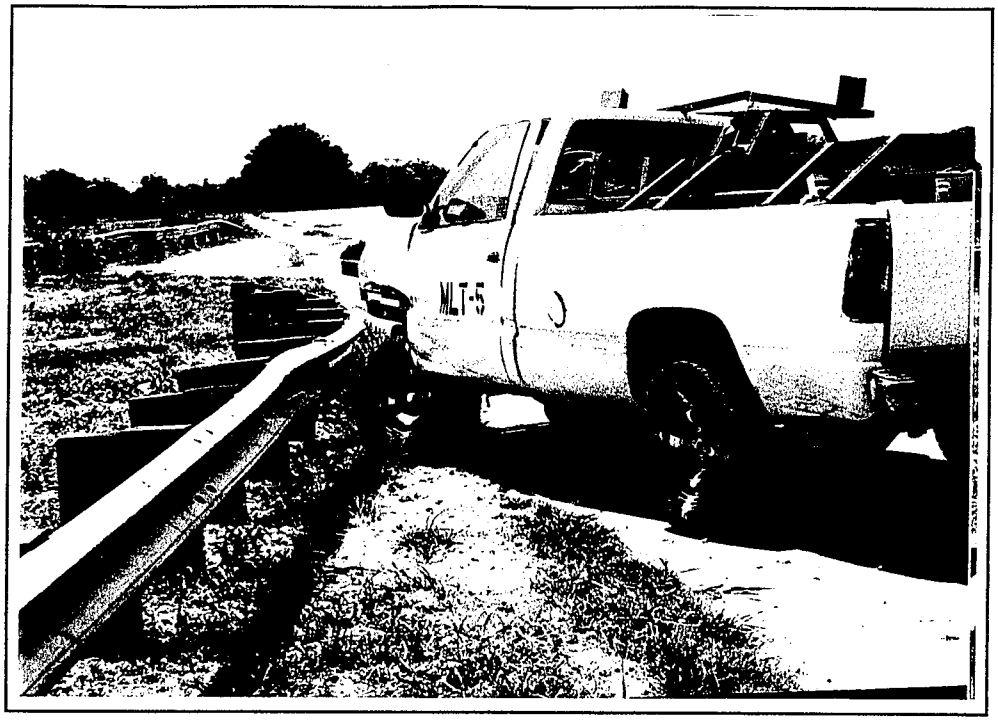


Figure 25. Vehicle damage photographs - Test MLT-5.