CRASH TESTS OF R4 RETROFIT AND OPEN PARAPET BRIDGE RAILS

MICHIGAN DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY DIVISION

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CRASH TESTS OF R4 RETROFIT AND OPEN PARAPET BRIDGE RAILS

FINAL REPORT

Prepared for:

MICHIGAN DEPARTMENT OF TRANSPORTATION
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This study was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract Full-scale crash testing was performed on two different bridge rail systems. The first was a proposed thrie-beam retrofit for the Michigan Department of Transportatio's (MDOT) R4 railing system. The second rail was MDOT's open parapet rail system. Although neither system is currently specified, there are 148,000 ft of R4 bridge railing, and 281,000 ft of open parapet railing in use on Michigan's trunkline system. All testing followed the requirements set out in NCHRP 230 and the AASHTO Guideline Specifications for Bridge Railings. Both systems were tested with an 1,800-lb car, a 5,400-lb pickup truck, and an 18,000-lb straight truck. The success of these tests on the proposed R4 retrofit bridge rail indicate that it meets all of the required criteria of the AASHTO Guide Specifications for Bridge Railings, performance level 2, as well as all pertinent criteria of NCHRP 230. On the open parapet rail system, the 5,400-lb pickup truck test was a failure due to an intrusion into the passenger compartment. The 18,000-lb truck test was a failure due to the detachment of the aluminum tube rail and the potential for that rail to create a hazard to other traffic. The open parapet rail was modified by removing the aluminum tube rail, and retested with a 5,400-lb pickup truck. This test was a failure since the integrity of the passenger compartment was not maintained.

17. Key Words bridge rail, crash testing, thrie-beam rail, open parapet rail, retrofit.	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

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INTRODUCTION

Over the last decade, a heavier emphasis has been placed on the strength and safety of guardrails and bridge rails. It is now required that all bridge rail installed on new federally funded projects be approved by the Federal Highway Administration (FHWA). The only way for a bridge rail design to receive this type of approval is if it has been subjected to a full-scale crash test. Even if an existing bridge rail is being updated with Federal funds, this requirement still applies, and the railing must be brought into compliance with the new FHWA guidelines. NCHRP Report 230, published in 1982, and the AASHTO Guide Specifications for Bridge Railings, published in 1989, contain criteria for testing and evaluating bridge rails.

The Michigan Department of Transportation (MDOT) owns and maintains 148,000 ft of R4 bridge railing on rural and urban highways. This rail consists of concrete posts with an ornamental steel grid between posts. The use of a thrie beam retrofit for this bridge rail would provide an inexpensive method for bringing the R4 railing into compliance with the FHWA guidelines.

MDOT also owns and maintains 281,000 ft of Open Parapet bridge railing. This type of bridge rail was constructed before safety shape rails came into common use. If it can be proven by crash testing, that the existing railing meets the standards, costly modifications would not be needed to comply with current FHWA guidelines.

A two task effort was undertaken to evaluate the crashworthiness of the thrie beam retrofit of the R4 railing and the crashworthiness of the Open Parapet railing according to test criteria contained in NCHRP Report 230 and the AASHTO Guide Specifications for Bridge Railings, performance level 2.

TASK A - FULL-SCALE TESTS OF THE R4 RETROFIT BRIDGE RAIL

1. R4 RETROFIT BRIDGE RAIL

The test device was the MDOT R4 Retrofit Bridge Rail. This bridge rail featured a 68-ft deck, 10-in by 32.5-in brushblock the entire length of the rail, seven 12-in by 16-in by 40-in posts with nominal 6-in by 8-in wood blockouts. Six 11-ft, 7.75-in lengths of 10 gauge thrie beam spanned the area between posts. This rail was manufactured. No flame cutting of the section or the holes is allowed. Two 0.875-in bolts connect the thrie beam through the blocks to the posts. Standard 0.875-in round flat washers are used between the rail and the bolt head and special 0.25-in by 3-in square washers are used between the nut and the post. The standard MDOT steel R4 railing, mounted between the posts, was not removed. The top of the thrie beam was 34 in above the deck and the top of the posts were 50 in above the deck. The entire system was 68 ft long.

This bridge rail system was attached to a rigid, simulated support structure in order to simulate the effects of a bridge deck fascia cantilever. A pit was excavated and the bottom filled with crusher run type soil and compacted to provide a firm base. A slab was poured on this base as a footer for the support. An upright wall and an undercut were poured to tie the support into the previously existing concrete deck. The lateral deck bars extended from the undercut. The rebar details were taken from MDOT plans and 40 grade rebar was used throughout the R4 Retrofit Bridge Rail.

The concrete used was specially formulated to have cured to the desired strength window (3000 lb/in^2 plus 15 percent, minus 0 percent) in 28 days. The deck, brushblock and posts were poured on July 11, 1989, July 25, 1989 and July 26, 1989, respectively. The average 28-day breaking strengths were 3335, 3060 and 3418 lb/in^2, respectively. The deck strength was evaluated using standard cylinders. Due to a cylinder quality problem, the brushblock and post strengths were evaluated using a Schmidt Hammer in situ.

Figure 1 shows the bridge rail dimensions. Figure 2 shows the simulated support structure and the bridge rail cantilever.

a. Test 1952-1-89

(1). Test Device

The test device was the MDOT R4 Retrofit Bridge Rail. Figure 3 shows the test site layout. Figure 4 shows pretest photographs of the bridge rail system.

(2). Test Vehicle

The test vehicle was a 1982 Honda Civic. The target inertial vehicle weight was 1800 lb. The vehicle weighed approximately 1750 lb empty. With the instrumentation (no ballast was required) the inertial weight of the vehicle was 1829 lb. The target gross vehicle weight was 1950 lb. The gross vehicle weight was 1972 lb. The inertial weight consists of all weight items rigidly attached to the vehicle. The gross weight includes non-attached weight, such as the dummy.

X-, y- and z-axis accelerometers were mounted in the car along with roll and yaw rate gyros. One uninstrumented dummy was placed in the vehicle in the driver seat and was unrestrained. Pretest photographs of the test vehicle are shown in figure 5. Table 1 lists important parameters of the test vehicle, comparing the actual parameters with the AASHTO Guide Specifications for Bridge Railings requirements.

Table 1. Vehicle parameters, test 1952-1-89.

Item	Actual	Specification
Empty Weight	~1750 lb	n/a
Ballast	0 lb	n/a
Total Weight, Inertial	1829 lb	1800 lb
Total Weight, Gross	1972 lb	1950 lb
H_{cg}	20 in	20 ± 1 in
A (front to cg), Inertial	5.4 ft	5.4 ± 0.1 ft
B (width)	5.2 ft	5.5 ft
Vehicle Length	147.5 in	
Vehicle Wheelbase	88 in	
Wheel/Tire Size	155 SR13	

(3). Impact Description

Review of the high speed films, fifth wheel and speed trap data indicated that the test vehicle impacted at 61.5 mi/h and 20 degrees. This review also indicated that the right corner of the vehicle impacted the rail at the desired point.

Upon impact, the vehicle was deformed by the rail. The right front tire deflated upon striking the brushblock and the vehicle rose up on top of the brushblock. The vehicle yawed around and exited the rail at 4.5 degrees. As the vehicle was redirecting, the vehicle pitched forward and rolled toward the right side, onto the right front corner. The vehicle pitched approximately 20 degrees and rolled approximately 15 degrees while yawing. The vehicle came to rest 205 ft past the impact point, 40 ft in front of the rail, at 45 degrees to the line of the rail.

Upon impact, the unrestrained driver dummy impacted the door with its shoulder and pushed the passenger side door out 2 to 3 in. The dummy had its legs and torso up near the passenger side roof while the car was pitched forward. The dummy came to rest on the passenger seat with its head on the floor.

A summary of test conditions and results are shown in figure 6. Data analysis was performed. The vehicle x-axis and y-axis, 100 Hz acceleration traces are shown in figure 7.

(4). Vehicle Damage

Damage occurred to the right front wheel and suspension, the right rear wheel, hood, bumper and entire right side of the vehicle. The passenger side door window was broken and the door was wedged out 2 to 3 in by the dummy impact. Posttest photographs of the vehicle are shown in figure 8.

(5). Bridge Rail Damage

The bridge rail suffered very little damage. There were tire marks on the thrie beam for 101 in starting 5 in past the target impact line (see subsection c). There was tire scuff on the brushblock for 161 in starting 13 in prior to the target impact line. Minor spalling of the brushblock occurred for 106 in starting 6 in prior to the target impact line. There was no measurable deflection of the rail. Posttest photographs of the bridge rail are shown in figure 9.

(6). Test Evaluation

This test was evaluated using both the AASHTO Guide Specifications for Bridge Railings and NCHRP 230. The following is an item by item evaluation using these two guidelines.

- <u>AASHTO Guide Specifications for Bridge Railings</u>:

Required Criteria:

a. The vehicle was contained by the test article.
b. There were no detached elements.
c. Integrity of the passenger compartment was maintained.
d. The vehicle remained upright.
g. Delta-V and Ridedown values within limits.

Desirable Criteria:

- e. The vehicle was smoothly redirected.
- f. Vehicle railing interaction: mu = 0.50, assessment: Marginal.
- h. The exit angle was less than 12° (exit angle was 4.5°). Vehicle was within 20 ft of the rail, 100 ft downstream of the impact point.

MEETS ALL REQUIRED CRITERIA.

■ NCHRP 230:

- a. The test article smoothly redirected the vehicle.
- d. There were no detached elements.
- e. The vehicle remained upright during and after the collision. Integrity of the passenger compartment was maintained.
- h. Vehicle trajectory and stopping position did not intrude into adjacent traffic lanes.
- i. Because the vehicle trajectory and stopping position did not intrude into adjacent traffic lanes, vehicle speed change and exit angle criteria do not apply.

MEETS ALL CRITERIA.

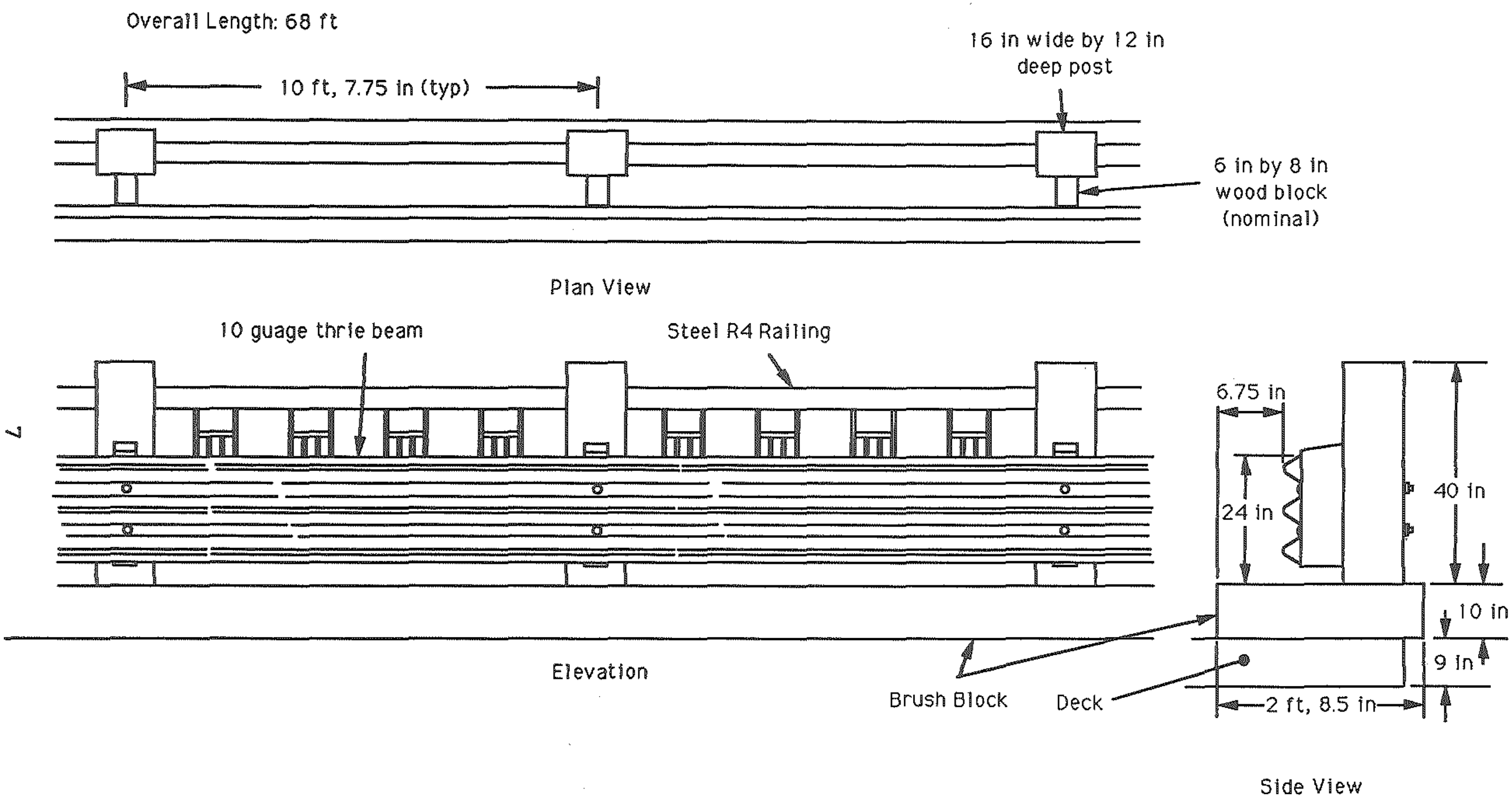


Figure 1. MDOT R4 Retrofit bridge rail.

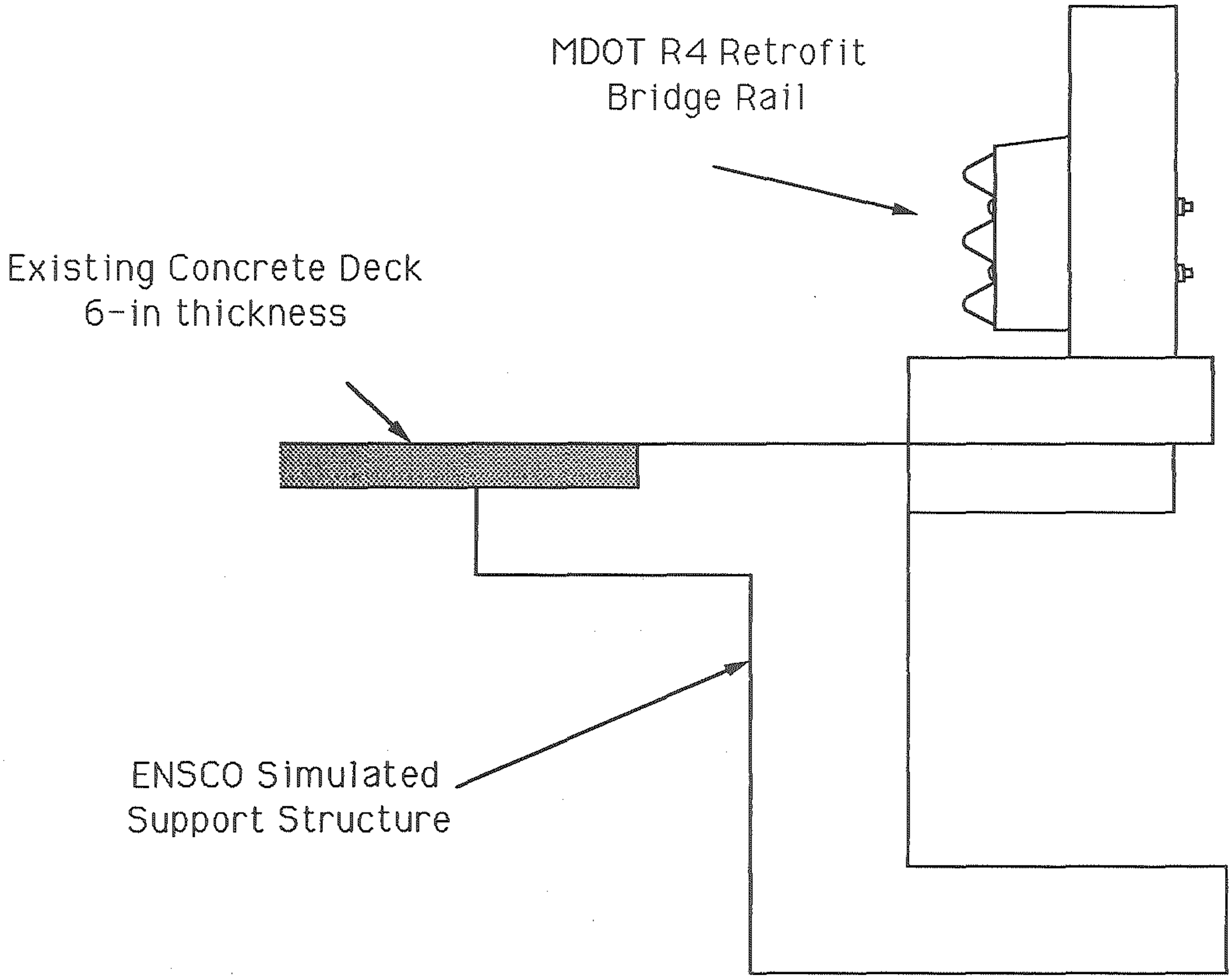


Figure 2. Simulated support structure and bridge rail cantilever.

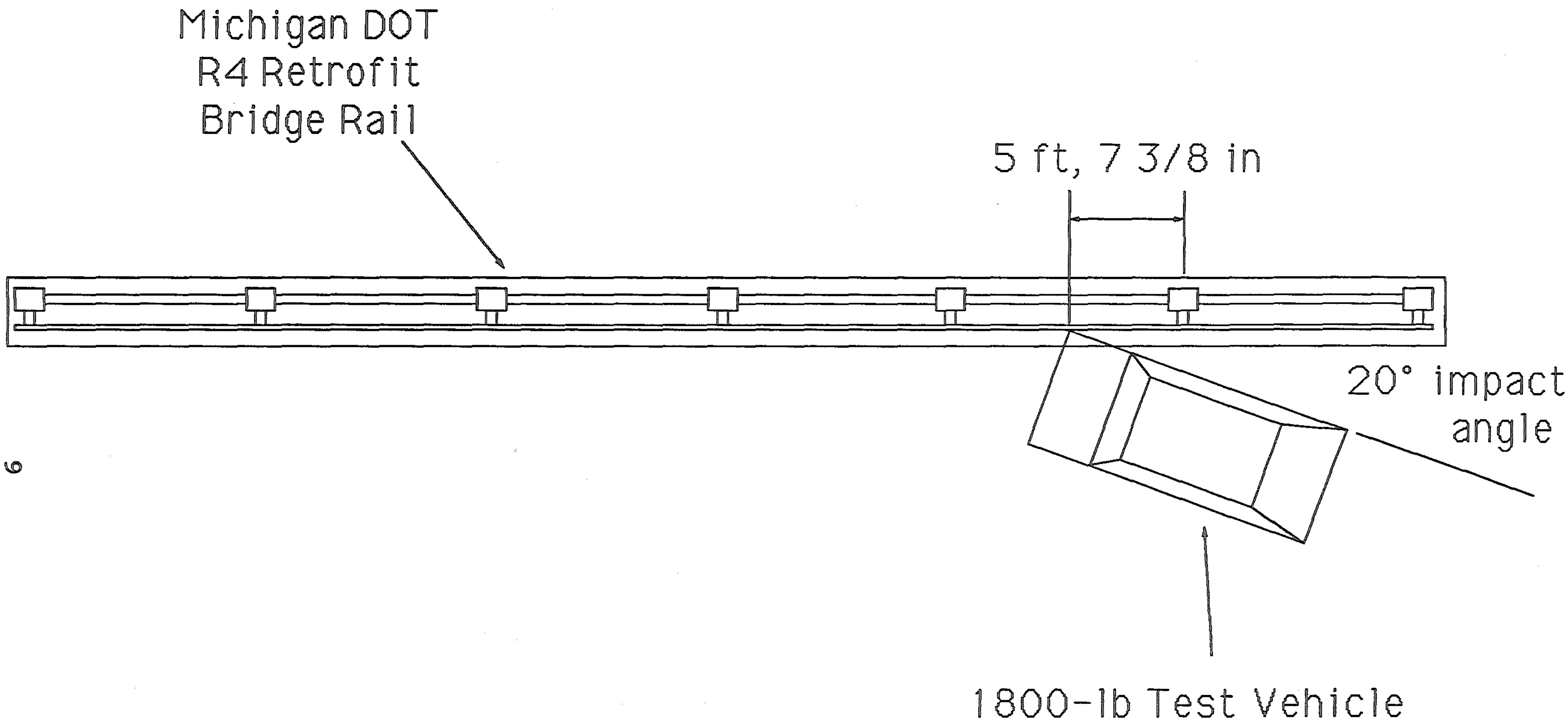


Figure 3. Test site layout, test 1952-1-89.

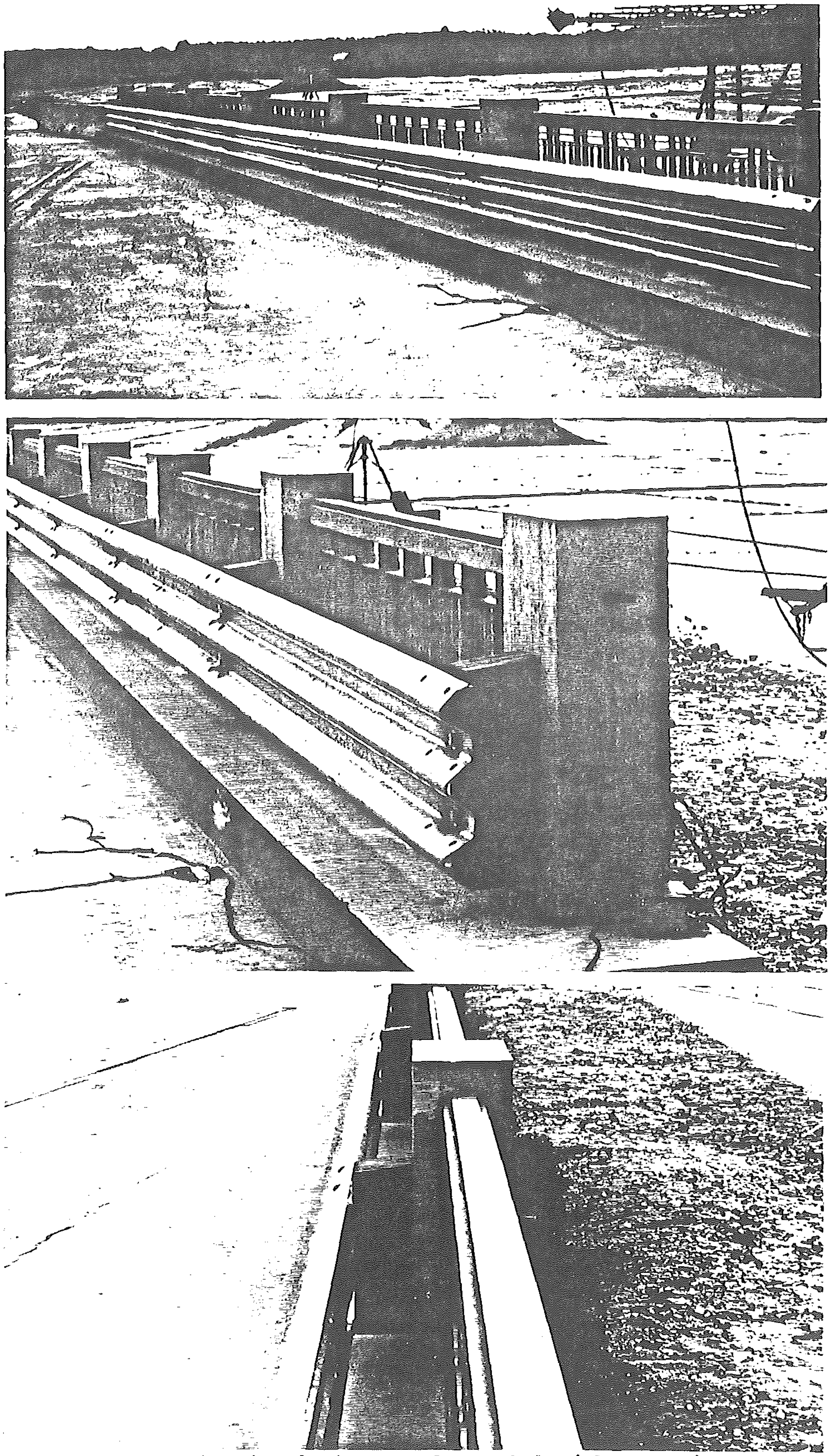


Figure 4. Pretest photographs of bridge rail system, test 1952-1-89.

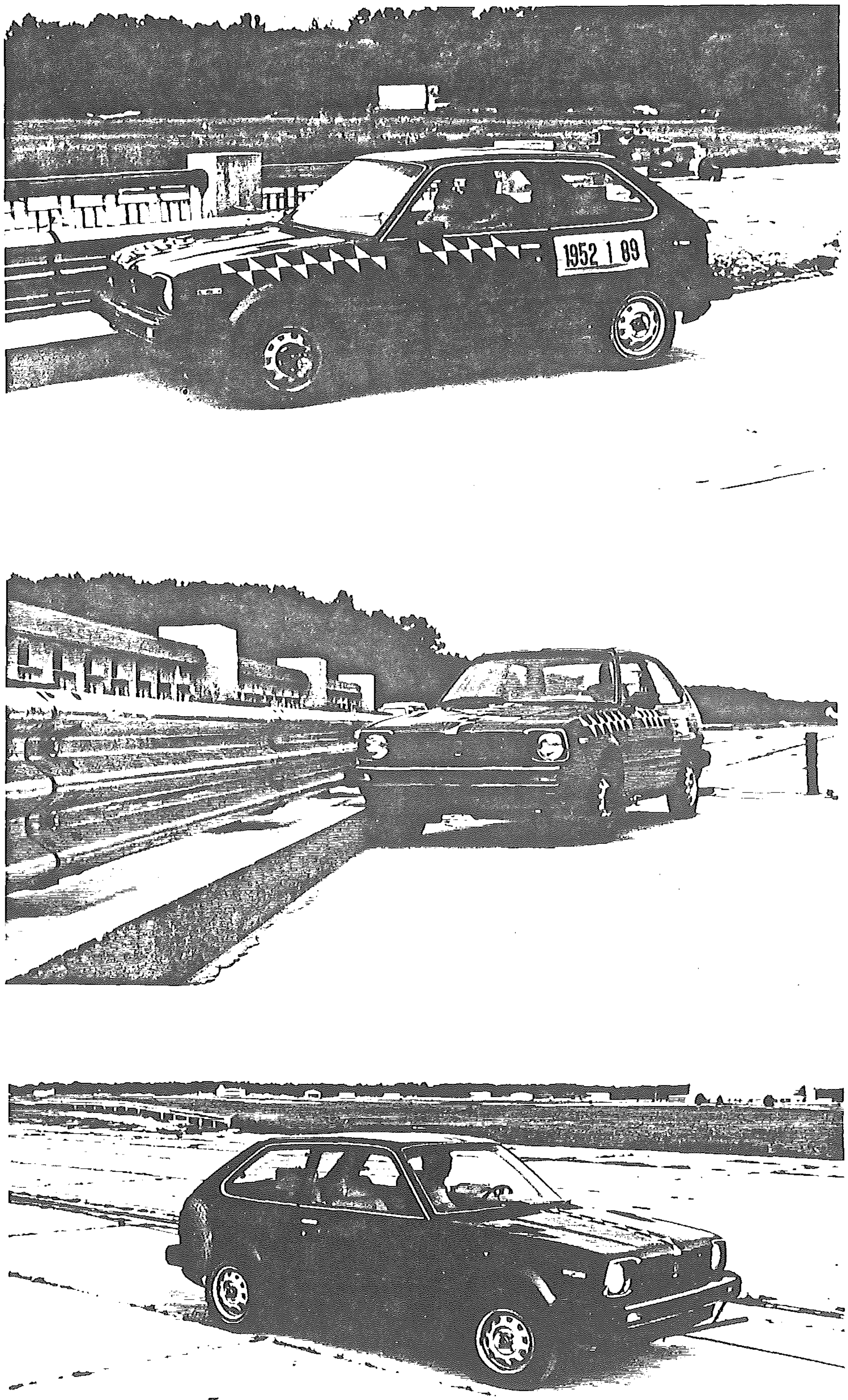
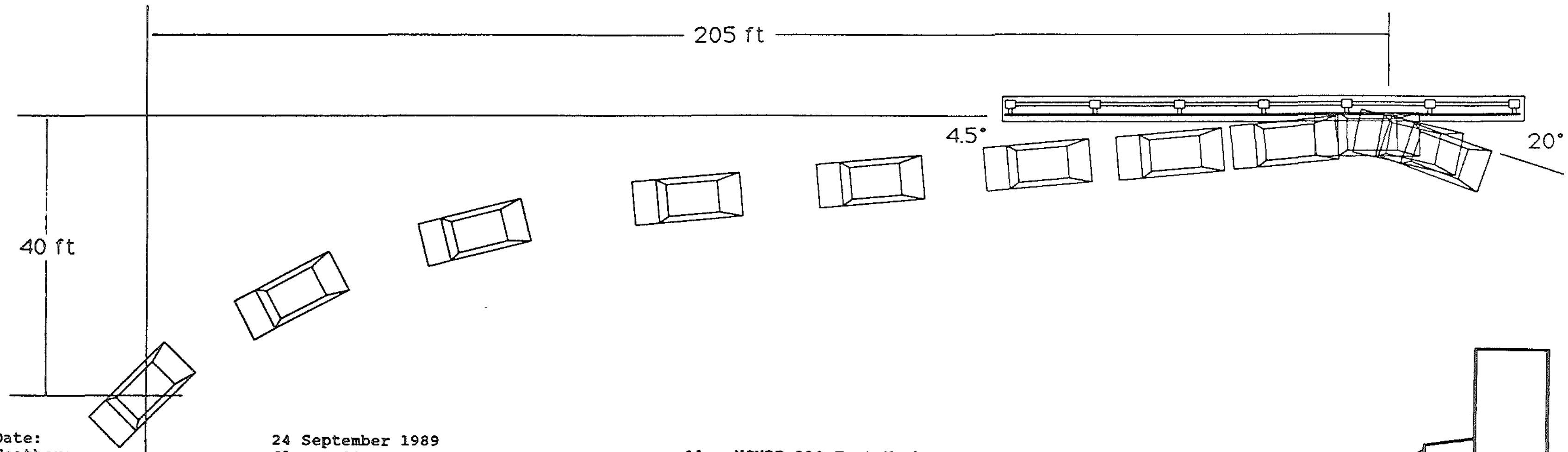


Figure 5. Pretest photographs of test vehicle, test 1952-1-89.



Date: 24 September 1989
Weather: Clear, 80° F

Test Vehicle: 1982 Honda Civic

Device Configuration: Michigan DOT R4 Retrofit Bridge Rail, 68-ft deck, 10-in by 32.5-in brushblock, 12-in by 16-in by 40-in posts, 6-in by 8-in wood blockouts, 10 gauge thrie beam, thrie beam 34 in height, posts 50 in height (above deck)

1. Vehicle Weight:
   - Planned, Inertial: 1800 ± 50 lb
   - Actual, Inertial: 1829 lb
   - Planned, Gross: 1950 ± 50 lb
   - Actual, Gross: 1972 lb

2. Number of Occupants: One

3. Occupant Model: Part 572, 50th percentile male, uninstrumented

4. Occupant Location: Driver Seat, Unrestrained

3. Impact:

	Speed	Angle (a)	Location
Planned:	60.0 mi/h	20°	Midspan posts 2 and 3
Actual:	61.5 mi/h	20°	Midspan posts 2 and 3

Tolerances:
   - Speed: -1.0, +2.5 mi/h
   - Angle: -1.0, +2.5 degrees

6. Redirection Angle: 4.5 degrees

7. Redirection Speed: 48.8 mi/h (71.6 ft/s)

8. Total Speed Change: 12.7 mi/h (18.6 ft/s)

9. Total Momentum Change: 1139 lb-sec

10. Vehicle Damage Index: (SAE J224a) 01RFEW2

11. NCHRP 230 Test Number: S13
    AASHTO Test Type: PL2

12. NCHRP 230 Impact Severity:

$$\frac{m(V \sin a)^2}{2}$$

27.0 kip-ft (Spec: 23 to 29 kip-ft)

13. Vehicle Analysis:

	Observed	NCHRP 230 Design/ Limit Values	AASHTO Limits
Longitudinal:			
Delta-V at 2 ft:	-20 ft/s	30/40 ft/s	30 ft/s
Ridedown Acceleration:	-3 g's	15/20 g's	15 g's
Lateral:			
Delta-V at 1 ft:	25 ft/s	20/30 ft/s	25 ft/s
Ridedown Acceleration:	7 g's	15/20 g's	15 g's

TRC 191:

Peak 50 ms acceleration:
   - Longitudinal: -6.9 g's
   - Lateral: 13.5 g's

14. Vehicle-Railing Interaction Coefficient of Friction:

$$mu = \frac{\cos theta - V_p/V}{\sin theta}$$

mu	assessment
0.50	Marginal

V_p = 47.3 mi/h (69.4 ft/s)

15. Test Results Conclusion:

AASHTO Guide Specifications for Bridge Railings: MEETS ALL REQUIRED CRITERIA.

NCHRP 230: MEETS ALL CRITERIA.

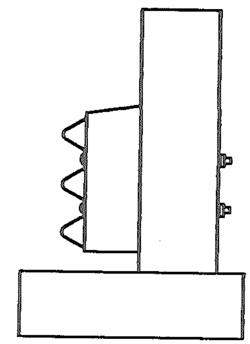
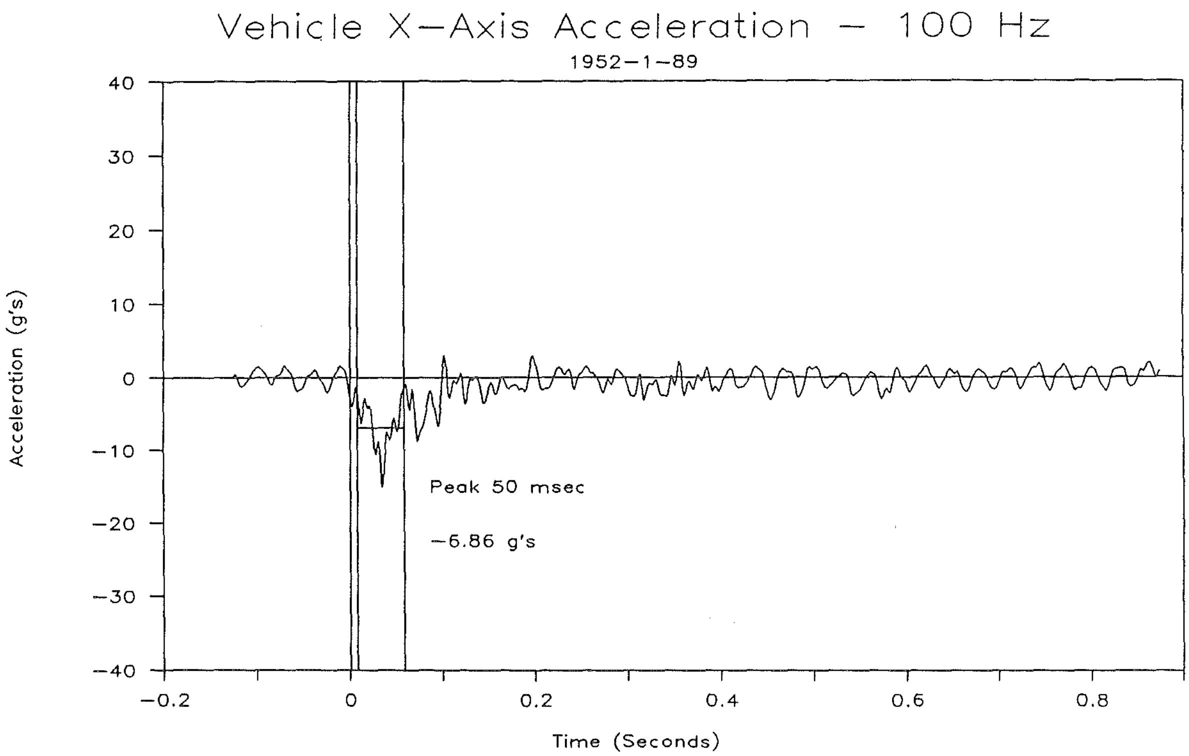


Figure 6. Test summary, test 1952-1-89.



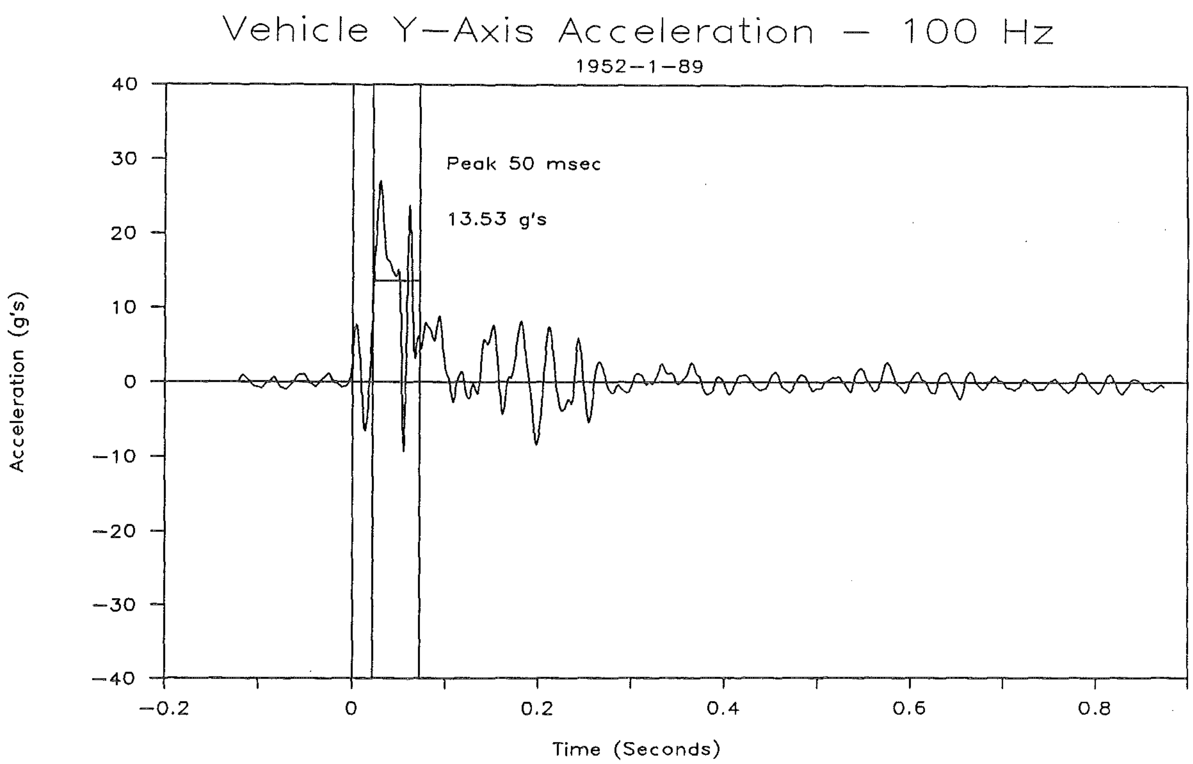


Figure 7. Vehicle acceleration, test 1952-1-89.

Figure 8. Posttest photographs of test vehicle, test 1952-1-89.

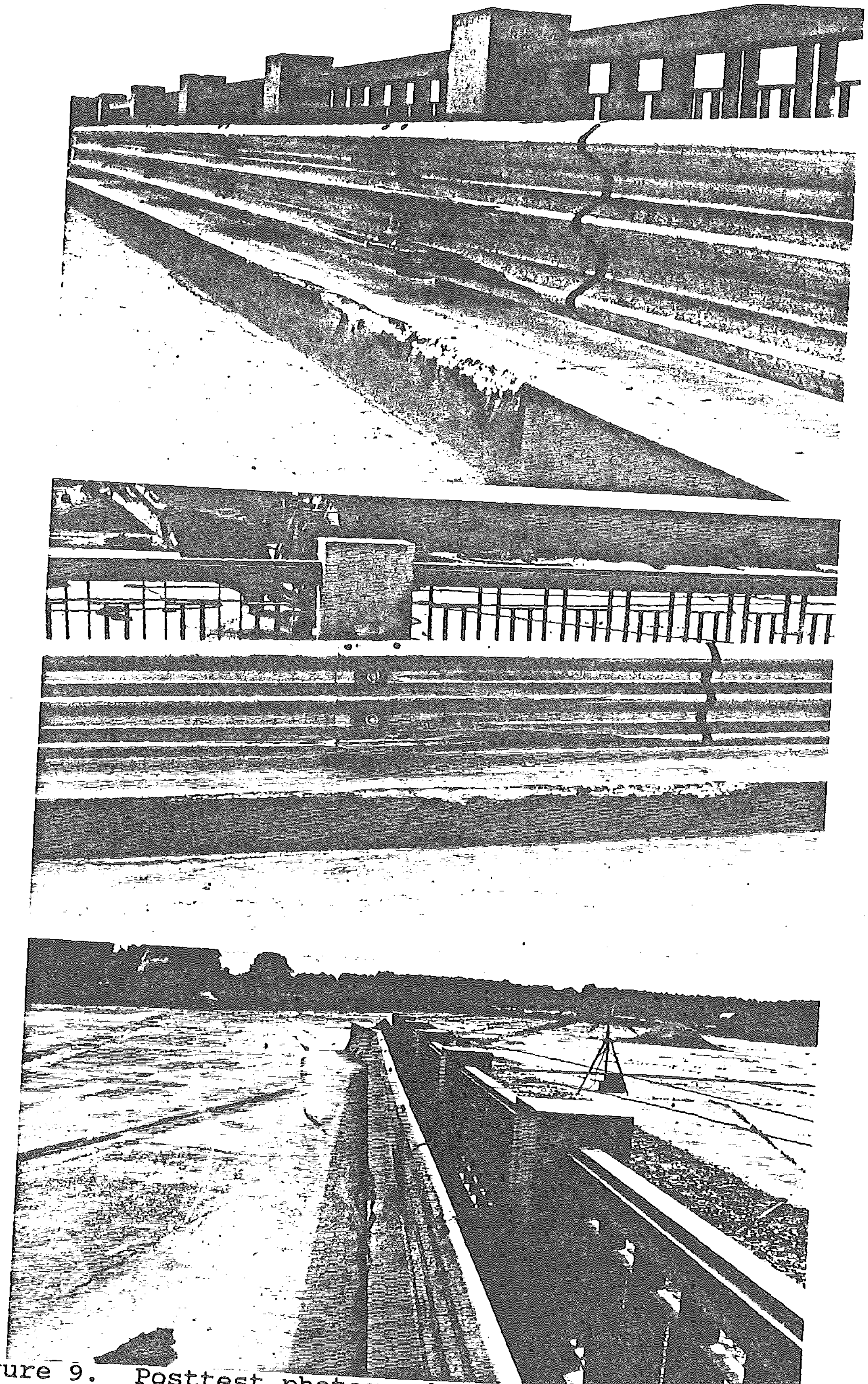


Figure 9. Posttest photographs of bridge rail system, test 1952-1-89.

b. Test 1952-2-89

(1). Test Device

The test device was the MDOT R4 Retrofit Bridge Rail. Figure 10 shows the test site layout. Figure 11 shows pretest photographs of the bridge rail system.

(2). Test Vehicle

The test vehicle was a 1983 Ford F150 pickup. The target inertial vehicle weight was 5400 lb. The vehicle weighed approximately 4000 lb empty. Approximately 1400 lb of ballast were added. The ballasted inertial weight of the truck was 5411 lb. The gross vehicle weight was 5724 lb.

Two dummies were placed in the vehicle. The driver was unrestrained while the passenger was restrained. X-, y- and z-axis accelerometers were mounted in the cab of the truck along with roll and yaw rate gyros. Pretest photographs of the test vehicle are shown in figure 12. Table 2 lists important parameters of the test truck, comparing the actual parameters with the AASHTO Guide Specifications for Bridge Railings requirements.

Table 2. Vehicle parameters, test 1952-2-89.

Item	Actual	Specification
Empty Weight	~4000 lb	n/a
Ballast	~1400 lb	n/a
Total Weight, Inertial	5411 lb	5400 lb
Total Weight, Gross	5724 lb	n/a
H_{cg}	27 in	27 ± 1 in
A (front to cg), Inertial	8.50 ft	8.5 ± 0.1 ft
B (width)	6.42 ft	6.5 ft
Truck Length	214 in	
Truck Wheelbase	132.5 in	
Wheel/Tire Size	235 85R15	
Truck Box Size	8 ft long by 1.5 ft high by 5.5 ft wide	
Ground to box floor	27 in	

(3). Impact Description

Review of the high speed films and fifth wheel data indicated that the test vehicle impacted at 60.6 mi/h and 20 degrees. This review also indicated that the right corner of the vehicle impacted the desired point.

Upon impact, the vehicle penetrated into the rail approximately 12 in before beginning to redirect. The vehicle yawed around to parallel to the rail and the rear of the truck slapped against the rail. Both tires deflated upon striking the brushblock. As the vehicle was redirecting, the vehicle pitched forward and rolled toward the right side, onto the right front corner. The vehicle pitched approximately 10 degrees and rolled approximately 20 degrees while yawing. The vehicle redirected at 11.5 degrees. The vehicle came to rest 215 ft past the impact point, 12.5 ft behind the front of the rail, at 95 degrees to the line of the rail.

Upon impact, the unrestrained driver dummy flew into the passenger dummy and impacted the passenger side door with its shoulder, pushing the passenger side door out and breaking the passenger side window. The driver dummy had its entire torso out of the passenger side window and was up near the passenger side roof while the vehicle was pitched forward. The passenger remained seated throughout the impact. The driver came to rest with its chest on the knees of the passenger.

A summary of test conditions and results are shown in figure 13. Data analysis was performed. The vehicle x-axis and y-axis, 100 Hz acceleration traces are shown in figure 14.

(4). Vehicle Damage

Damage occurred to the right front wheel and suspension, the right rear wheel, hood, bumper and entire right side of the vehicle. The passenger side door window was broken and the door was wedged out by the dummy impact. The impact caused the vehicle to bend toward the driver side. The front of the truck was pushed 17 in out of line. Posttest photographs of the truck are shown in figure 15.

(5). Bridge Rail Damage

The bridge rail suffered major structural damage during this impact. Posts 3 and 4 were pushed back approximately 8 and 4 in, respectively, at the top of the post. Damage to the brushblock and deck occurred at post 3 and damage occurred to the brushblock at post 4. In both cases, the damage pattern was semicircular around the post.

The damage at post 3 consisted of cracking in the brushblock and deck. The brushblock was damaged 30 in before and 35 in past the post. The deck suffered damage 30 in before and 6 in after the post. The deck was cracked for 6 in back under the edge.

The damage at post 4 was less severe and only occurred in the brushblock and the post. The brushblock was damaged 18 in before and after the post. Another crack ran from the upstream corner of the post to 32 in before the post on the edge of the brushblock.

Spalling occurred to the top portions of posts 3 and 4 above the top of the guardrail. The maximum permanent guardrail deflection occurred 8 ft past post 2 and was 7.5 in.

This damage was repaired in preparation for the next test. When the damaged areas were removed, it was discovered that post 2 also had hairline cracks near the base of the post and was also removed.

Posttest photographs of the bridge rail are shown in figure 16.

(6). Test Evaluation

This test was evaluated using the AASHTO Guide Specifications for Bridge Railings. The following is an item by item evaluation using this guideline.

- AASHTO Guide Specifications for Bridge Railings:

Required Criteria:

a. The vehicle was contained by the test article.
b. There were no detached elements.
c. Integrity of the passenger compartment was maintained.
d. The vehicle remained upright.

Desirable Criteria:

e. The vehicle was smoothly redirected.
f. Vehicle railing interaction: mu = 0.73, assessment: Marginal.
g. Delta-V and Ridedown values within limits.
h. The exit angle was less than 12°. The vehicle was within 20 ft of the rail, 100 ft downstream of the impact point.

MEETS ALL REQUIRED CRITERIA.

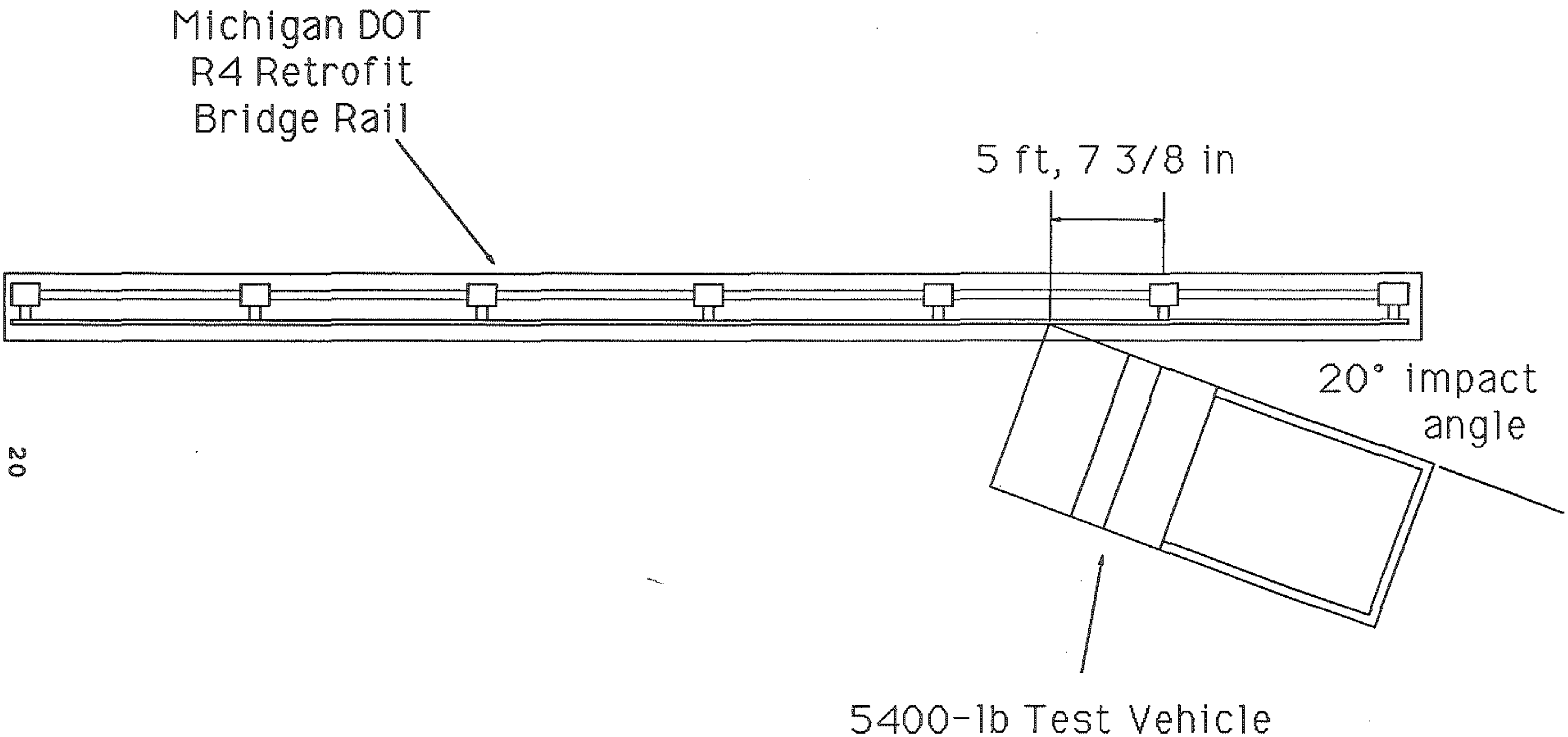


Figure 10. Test site layout, test 1952-2-89.

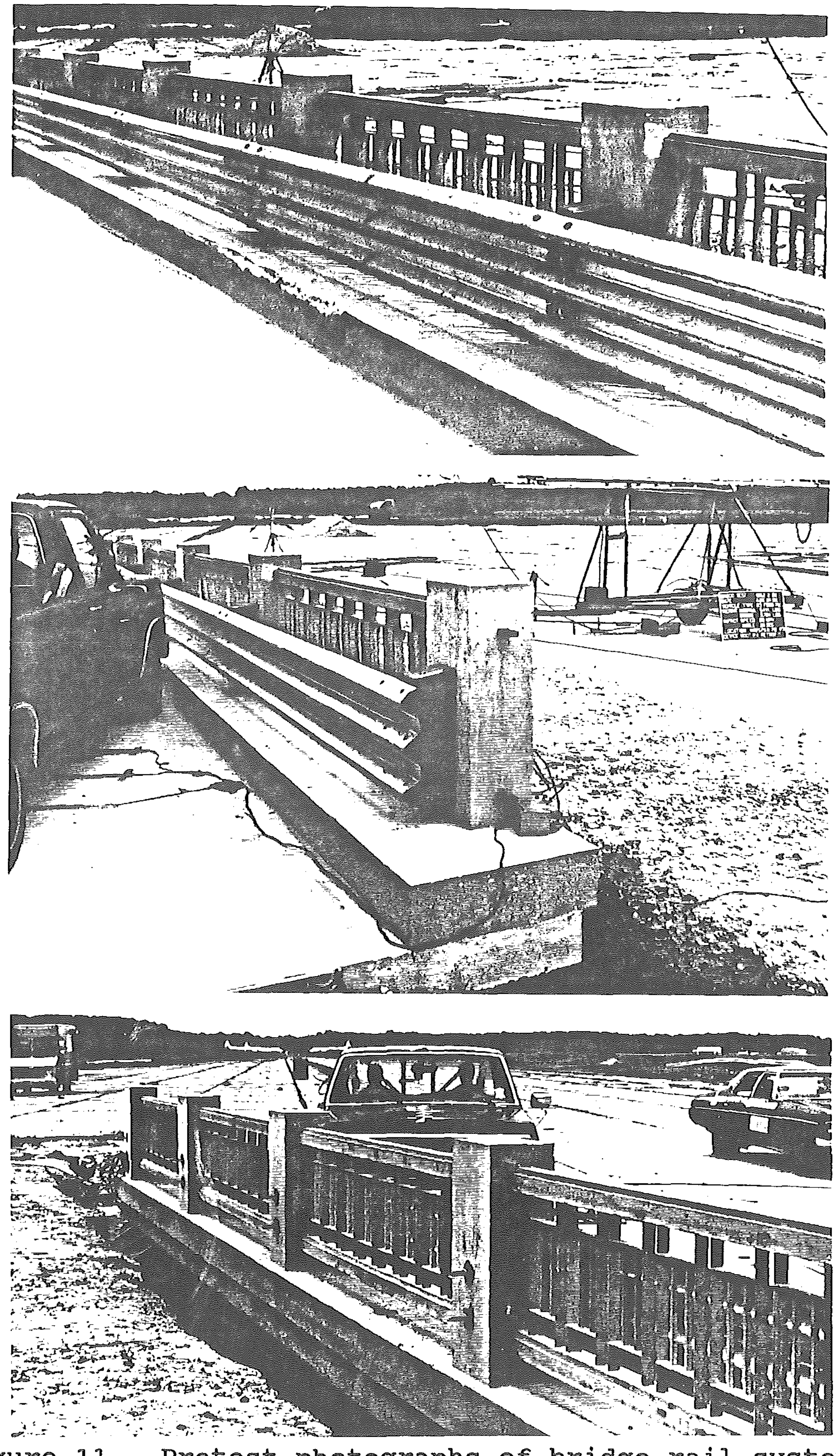


Figure 11. Pretest photographs of bridge rail system, test 1952-2-89.

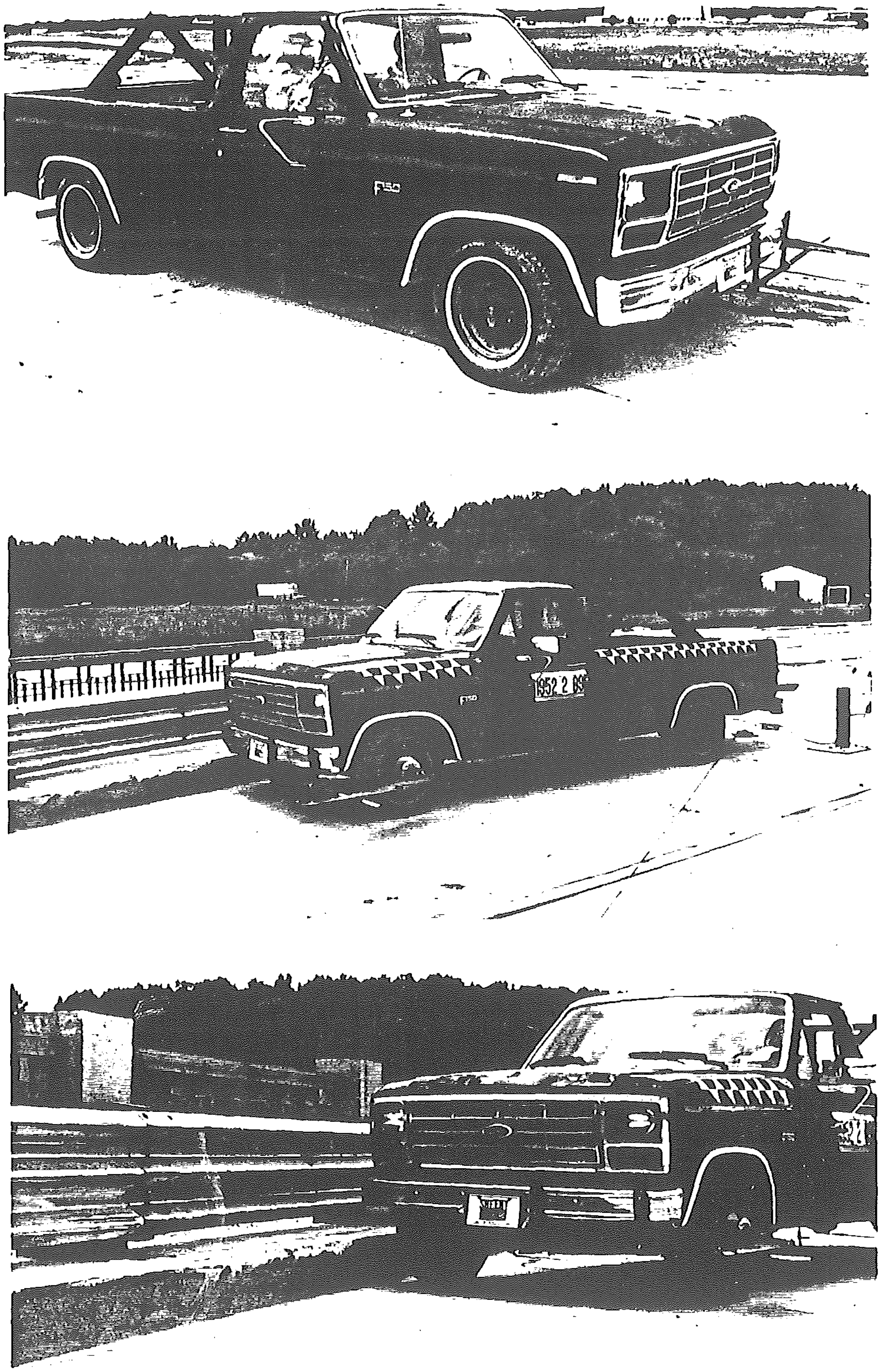
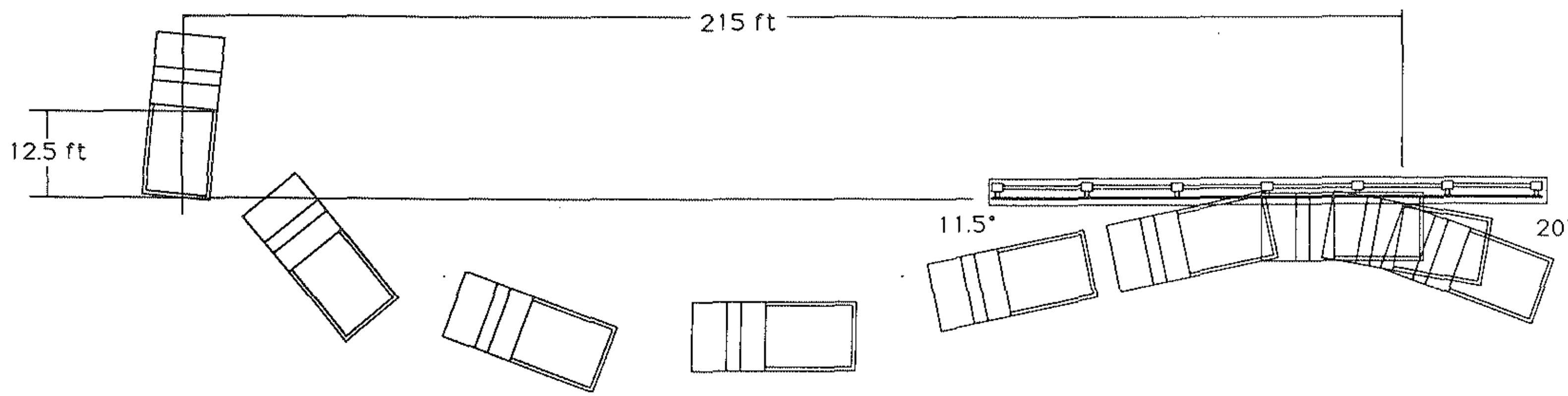


Figure 12. Pretest photographs of test vehicle, test 1952-2-89.



Date:	24 September 1989
Weather:	Clear, 80° F
Test Vehicle:	1983 Ford F150 Pickup
Device Configuration:	Michigan DOT R4 Retrofit Bridge Rail, 68-ft deck, 10-in by 32.5-in brushblock, 12-in by 16-in by 40-in posts, 6-in by 8-in wood blockouts, 10 gauge thrie beam, thrie beam 34 in height, posts 50 in height (above deck)

1. Vehicle Weight:
   - Planned, Inertial: 5400 lb
   - Actual, Inertial: 5411 lb
   - Actual, Gross: 5724 lb
2. Number of Occupants: Two
3. Occupant Model: Part 572, 50 percentile male
4. Occupant Locations: Driver Seat, Unrestrained; Passenger Seat, Restrained
5. Impact:

	Speed	Angle	Location
Planned:	60.0 mi/h	20°	Midspan posts 2 and 3
Actual:	60.6 mi/h	20°	Midspan posts 2 and 3

   Tolerances: Speed: -1.0, +2.5 mi/h; Angle: -1.0, +2.5 degrees

6. Redirection Angle: 11.5 degrees
7. Redirection Speed: 39.1 mi/h (57.4 ft/s)
8. Total Speed Change: 21.5 mi/h (31.5 ft/s)
9. Total Momentum Change: 5600 lb-sec
10. Vehicle Damage Index: (SAE J224a) 01RFEW2
11. AASHTO Test Type: PL2
12. Vehicle Analysis:

	Observed	AASHTO Limits
NCHRP 230:		
Longitudinal:		
Delta-V at 2 ft:	-23 ft/s	30 ft/s
Ridedown Acceleration:	-10 g's	15 g's
Lateral:		
Delta-V at 1 ft:	19 ft/s	25 ft/s
Ridedown Acceleration:	12 g's	15 g's
TRC 191:		
Peak 50 ms acceleration:		
Longitudinal:	-7.7 g's	
Lateral:	11.1 g's	

13. Vehicle-Railing Interaction Coefficient of Friction:

$$mu = \frac{\cos\theta - V_p/V}{\sin\theta}$$

mu	assessment
0.73	Marginal

V_p = 41.9 mi/h (61.4 ft/s)

14. Test Results Conclusion:

   AASHTO Guide Specifications for Bridge Railings: MEETS ALL REQUIRED CRITERIA.

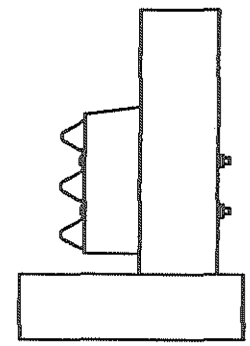
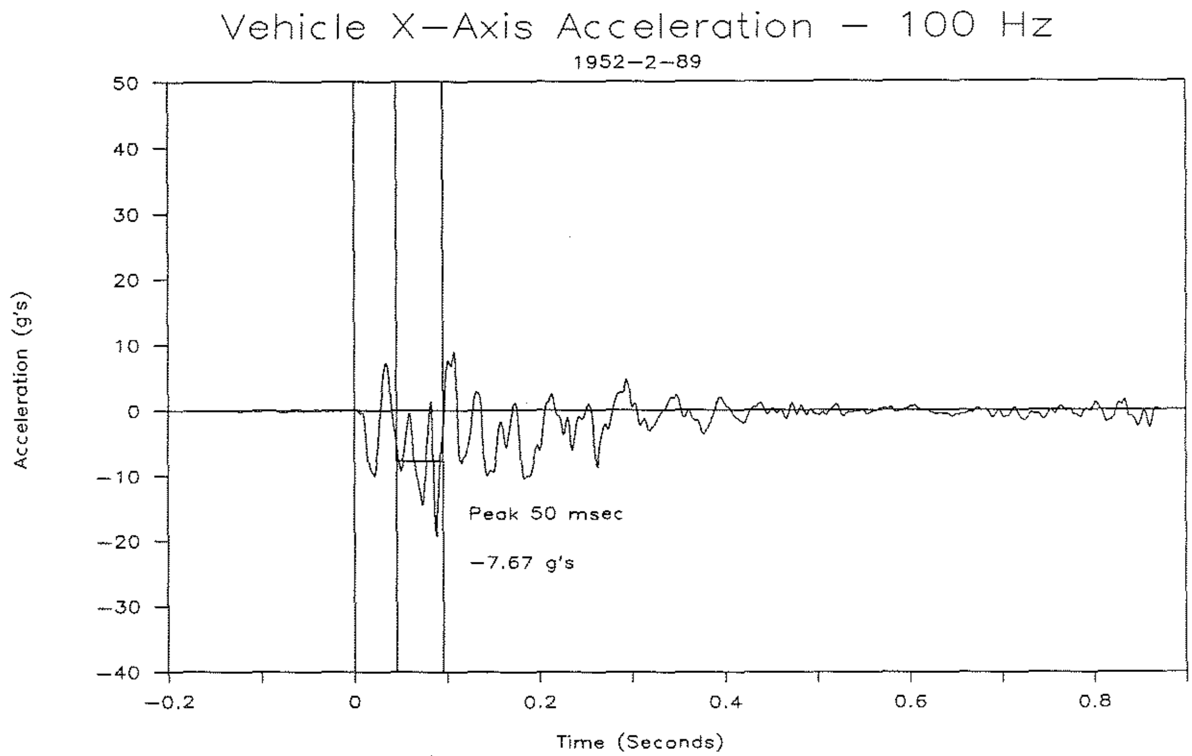


Figure 13. Test summary, test 1952-2-89.



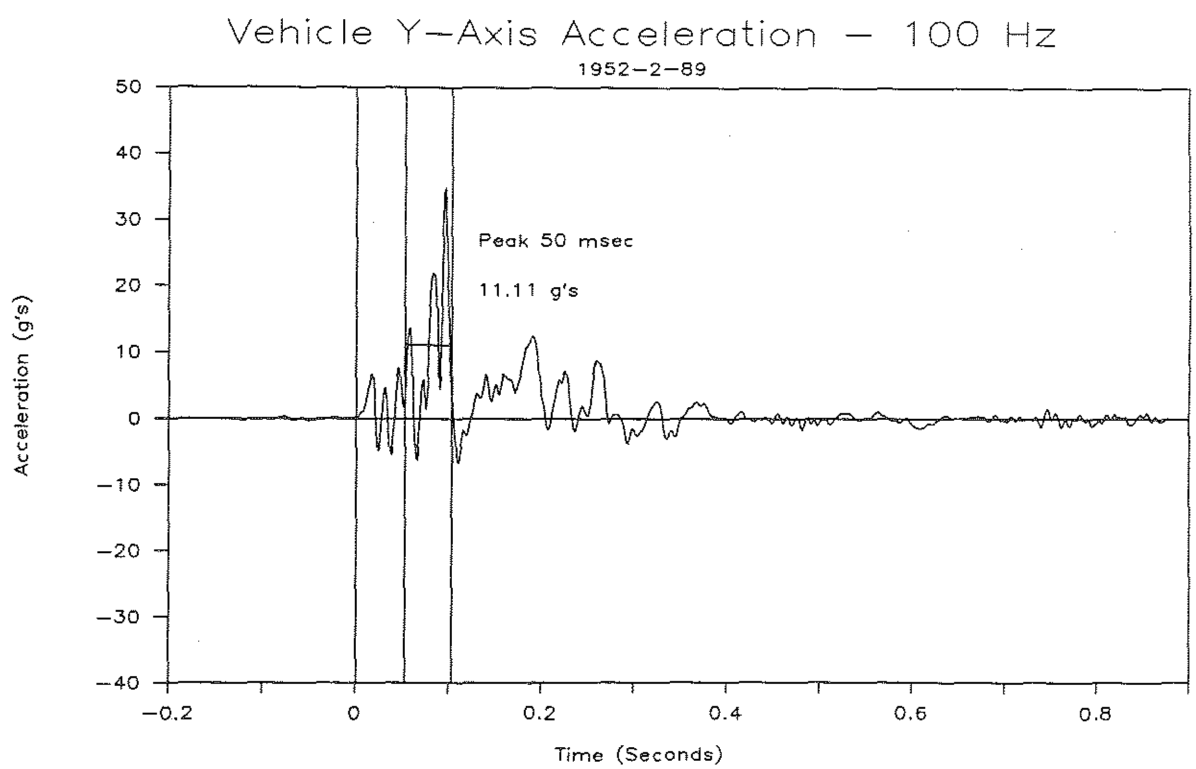


Figure 14. Vehicle acceleration, test 1952-2-89.

Figure 15. Posttest photographs of test vehicle, test 1952-2-89.

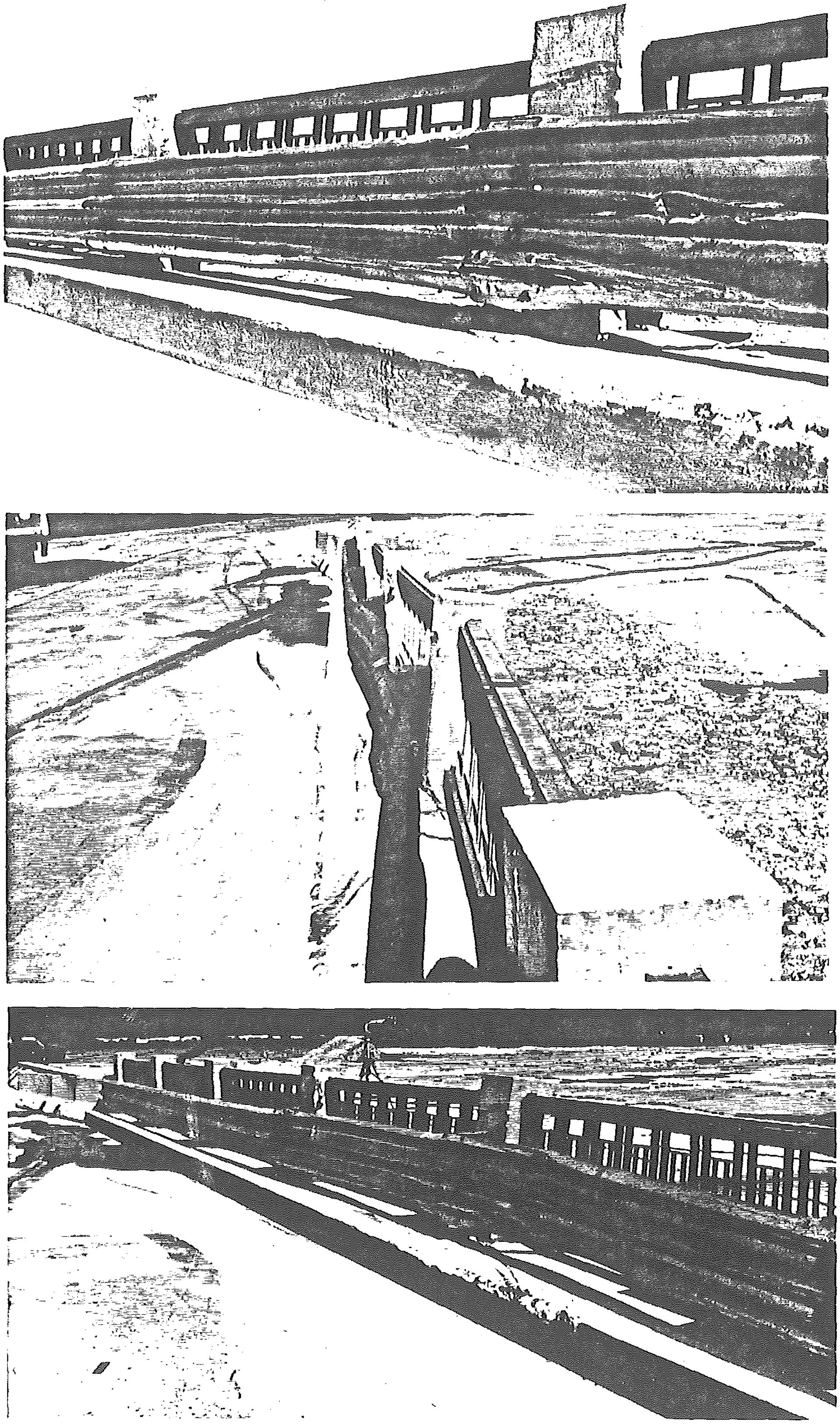
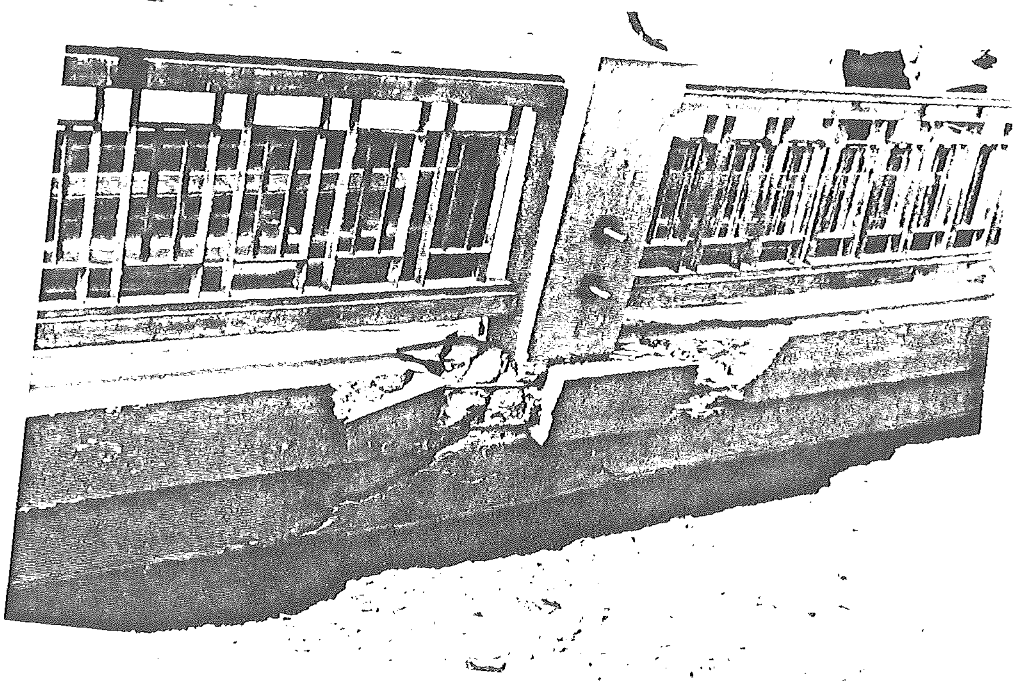


Figure 16. Posttest photographs of bridge rail system, test 1952-2-89.



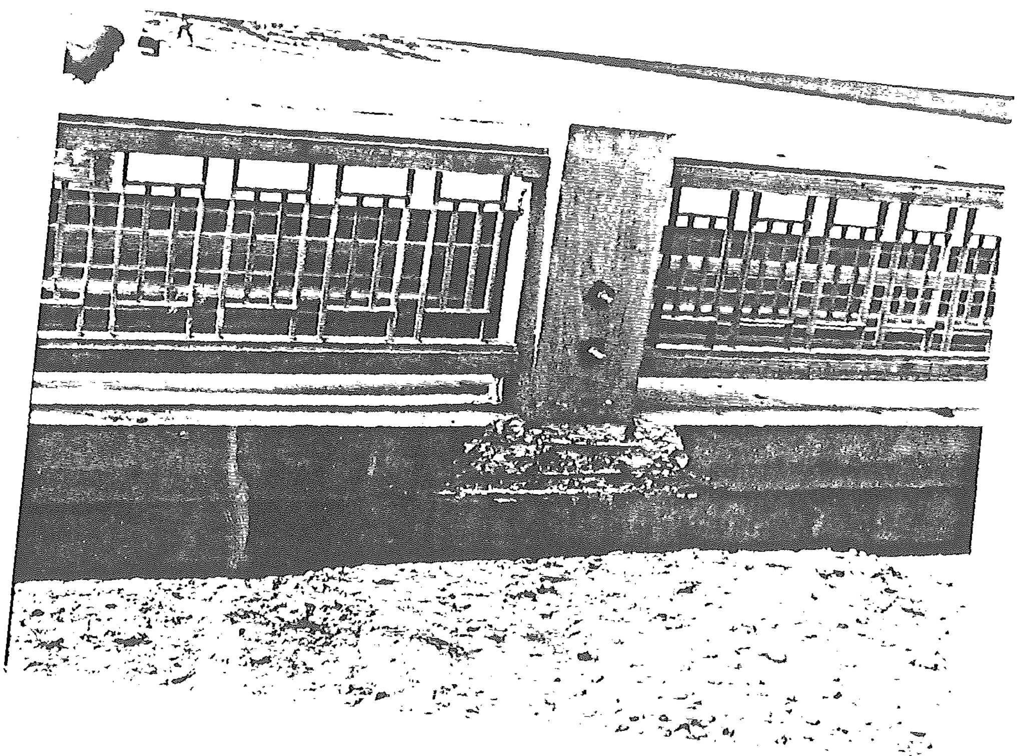


Figure 16 (cont). Posttest photographs of bridge rail system, test 1952-2-89.

c. Test 1952-3-89

(1). Test Device

The test device was the MDOT R4 Retrofit Bridge Rail.

This bridge rail was also used in tests 1952-1-89 and 1952-2-89. There was considerable damage to the bridge rail after test 2. Posts 2, 3 and 4 were removed and replaced. A 6-ft length and a 5-ft length of the brushblock were removed and repaired around posts 3 and 4, respectively. A 3-ft and a 1-ft length of deck were removed and repaired around posts 3 and 4, respectively. The concrete repair work took place in September 1989. The deck, brushblock and posts were poured on September 12, September 12 and September 13, respectively. Because the post strength in this design is critical to transmit almost all of the impact load to the deck, the test was conducted when the post strength was within the required window (3000 lb/in^2 plus 15 percent, minus 0 percent). On the test date, the cylinder breaking strength for the posts was 3104 lb/in^2. The cylinder breaking strength for the deck and brushblock was 4014 lb/in^2.

Figure 17 shows the test site layout. Figure 18 shows pretest photographs of the bridge rail system.

(2). Test Vehicle

The test vehicle was a 1973 International Loadstar 1600. The target vehicle weight was 18000 lb. The vehicle weighed approximately 11300 lb empty. Approximately 6700 lb of straw and sand ballast were added. The ballasted weight of the truck was 18000 lb.

X-, y- and z-axis accelerometers were mounted in the cab of the truck along with roll and yaw rate gyros. Pretest photographs of the test vehicle are shown in figure 19. Table 3 lists important parameters of the test truck, comparing the actual parameters with the AASHTO Guide Specifications for Bridge Railings requirements.

Table 3. Vehicle parameters, test 1952-3-89.

Item	Actual	Specification
Empty Weight	~11300 lb	n/a
Ballast	~6700 lb	n/a
Total Weight	18000 lb	18000 lb
H_{cg}	49.2 in	49 ± 1 in
A (front to cg)	12.8 ft	12.8 ± 0.2 ft
B (width)	7.5 ft	7.5 ft
Truck Length	29 ft, 6 in	
Truck Wheelbase	18 ft, 1 in	
Wheel/Tire Size	11R22.5	
Truck Box Size	20 ft long by 8 ft high by 7.5 ft wide	
Ground to top of box	11 ft, 11 in	

(3). Impact Description

Review of the high speed films and speed trap data indicated that the test vehicle impacted at a speed of 49.0 mi/h and an angle of 15 degrees. This review also indicated that the right corner of the vehicle impacted the rail 6 in downstream of the desired impact point.

Upon impact, the vehicle penetrated into the rail approximately 5 in. The truck rolled toward the rail approximately 20 degrees and pitched forward approximately 20 degrees. The rear wheels left the ground while the truck was pitching. The vehicle rolled back to upright and was redirected at 3 degrees. The vehicle came to rest 165 ft downstream of impact, in line with the rail. Debris was found between the rail and the steel fence from the impact point to the end of the rail. Four blockouts were damaged. Also the passenger side, bottom corner of the box was torn open from the contact with the rail. From this, it is possible to suppose that the box of the truck was locked under the back side of the top of the thrie beam. The passenger side, bottom corner of the box impacted post 4, which also caused some of the damage.

A summary of test conditions and results are shown in figure 20. Data analysis was performed. The vehicle x-axis and y-axis, 100 Hz acceleration traces are shown in figure 21.

(4). Vehicle Damage

The chassis at the front of the truck was damaged and twisted. The hood came open and the front axle was torn from the frame and pushed under the truck. However, the occupant compartment was not intruded. The rail side of the vehicle was damaged from impacting the rail, posts and blockouts during the impact event. A 4-ft by 4-ft hole was torn in the impact side corner of the box of the truck. Minor truck parts, ballast and debris were wedged between the posts, blockouts and rail. All tires on the impact side were deflated from contact with the brushblock and the wheels were damaged. Posttest photographs of the truck are shown in figure 22.

(5). Bridge Rail Damage

The bridge rail was damaged from the impact point downstream 45 ft. Four blockouts were damaged from impacts with the truck box. Posts 3 and 4 were damaged and showed cracks. Post 3 was cracked around the bottom and in a cone extending to the back of the brushblock. Post 4 was cracked around the bottom and through the post in two other places. The cracks did not extend into the brushblock. Post 4 also was spalled at the top from the impact with the truck box. The deck was not damaged. The maximum permanent thrie beam rail deflection was 3 in. Posttest photographs of the bridge rail are shown in figure 23.

(6). Test Evaluation

This test was evaluated using the AASHTO Guide Specifications for Bridge Railings. The following is an item by item evaluation using this guideline.

- <u>AASHTO Guide Specifications for Bridge Railings</u>:

Required Criteria:

a. The vehicle was contained by the test article.
b. There were no detached elements.
c. Integrity of the passenger compartment was maintained.

Desirable Criteria:

d. The vehicle remained upright.
e. The vehicle was smoothly redirected.
f. Vehicle railing interaction:
mu = 0.86, assessment: Marginal.
h. The exit angle was less than 12°. The vehicle was within 20 ft of the rail, 100 ft downstream of the impact point.

MEETS ALL REQUIRED CRITERIA.

2. CONCLUSIONS

The MDOT R4 Retrofit Bridge Rail was successfully tested with an 1800-lb car, a 5400-lb pickup truck and an 18,000-lb straight truck. These tests indicate that this bridge rail configuration meets all the required criteria of the AASHTO Guide Specifications for Bridge Railings, performance level 2, and all pertinent criteria of NCHRP 230.

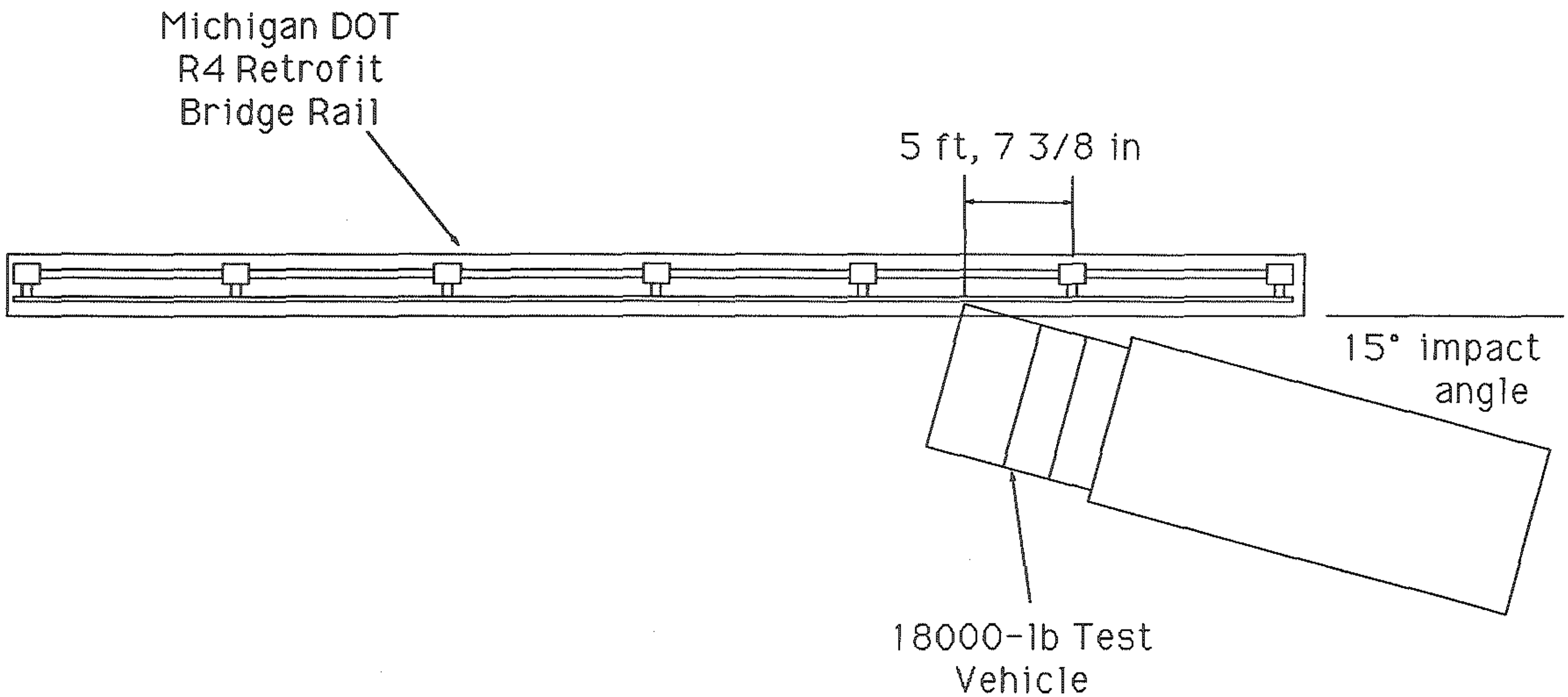


Figure 17. Test site layout, test 1952-3-89.

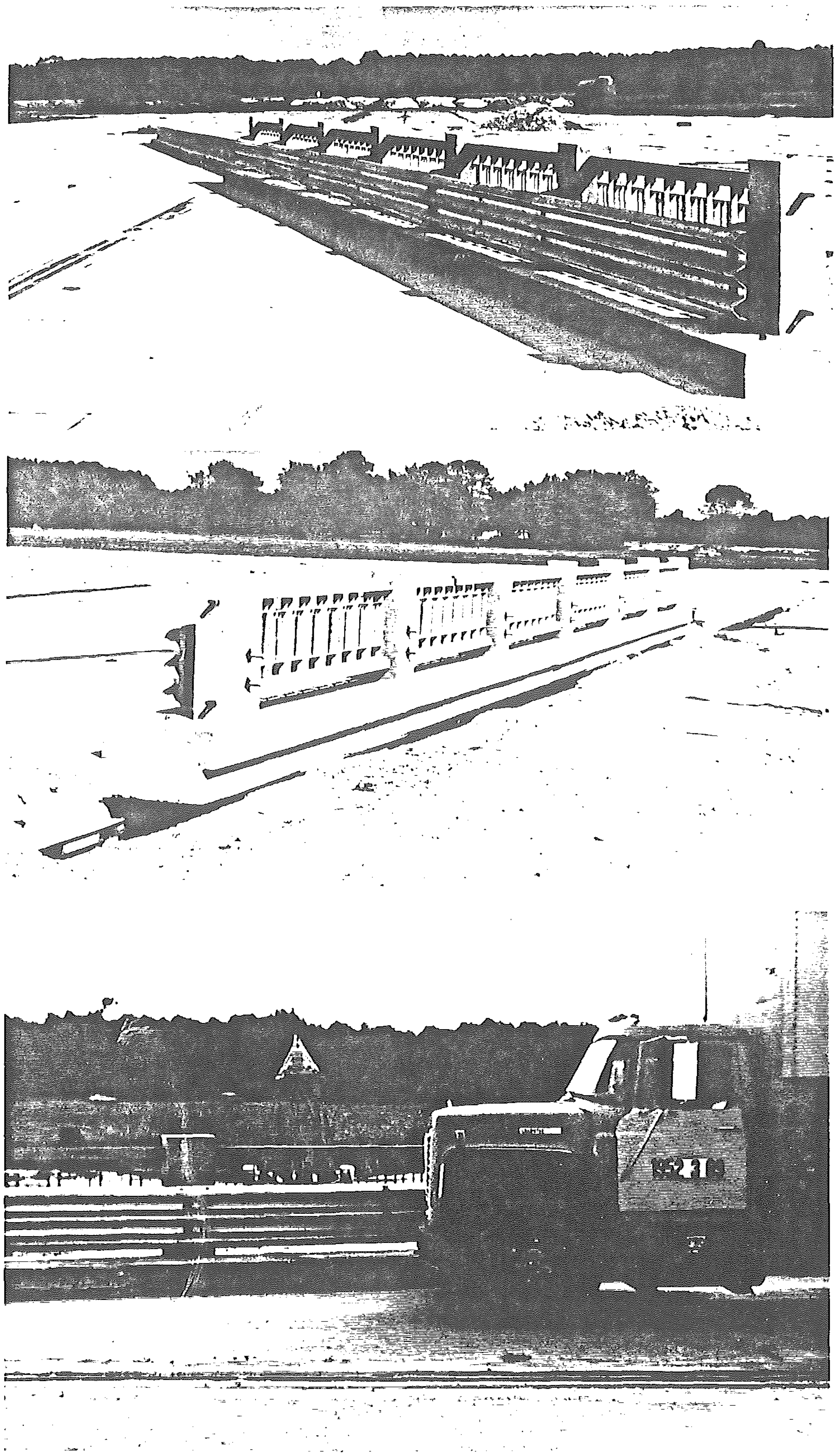


Figure 18. Pretest photographs of bridge rail system, test 1952-3-89.

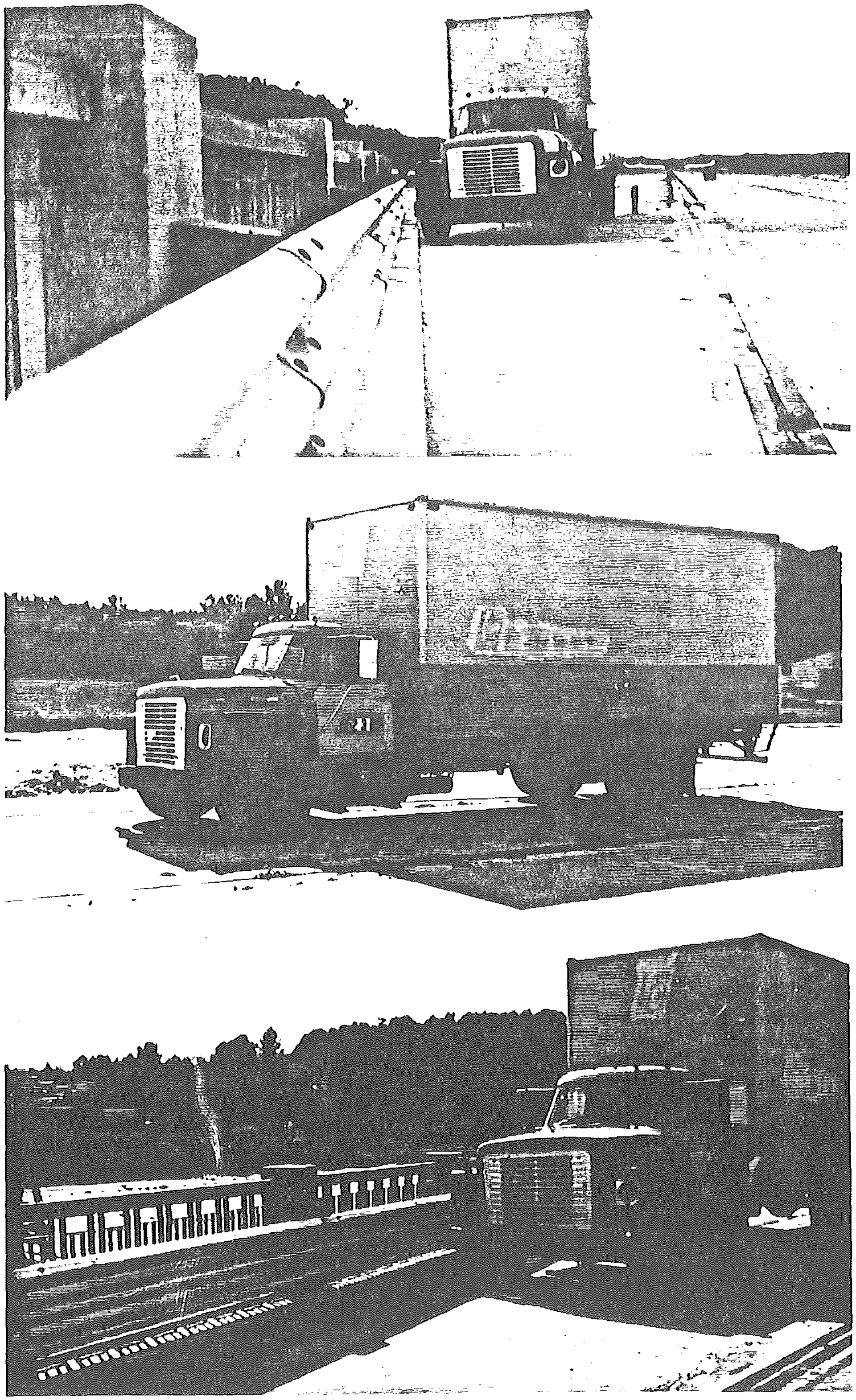
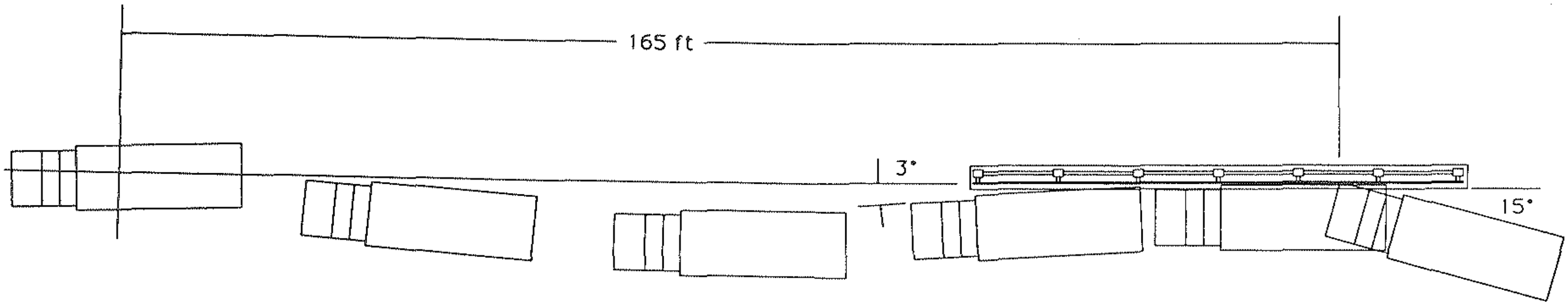


Figure 19. Pretest photographs of test vehicle, test 1952-3-89.



Date:	11 October 1989
Weather:	Clear, 60° F
Test Vehicle:	1973 International Loadstar 1600
Device Configuration:	Michigan DOT R4 Retrofit Bridge Rail, 68-ft deck, 10-in by 32.5-in brushblock, 12-in by 16-in by 40-in posts, 6-in by 8-in wood blockouts, 10 gauge thrie beam, thrie beam 34 in height, posts 50 in height (above deck)

1. Vehicle Weight:
   Planned, Inertial: 18,000 lb
   Actual, Inertial: 18,000 lb
2. Number of Occupants: None
3. Occupant Model: n/a
4. Occupant Locations: n/a
5. Impact:

	Speed	Angle	Location
Planned:	50.0 mi/h	15°	Midspan posts 2 and 3
Actual:	49.0 mi/h	15°	Midspan posts 2 and 3

   Tolerances: Speed: -1.0, +2.5 mi/h
   Angle: -1.0, +2.5 degrees
6. Redirection Angle: 3 degrees
7. Redirection Speed: 23.4 mi/h (34.4 ft/s)
8. Total Speed Change: 25.6 mi/h (37.5 ft/s)
9. Total Momentum Change: 20,963 lb-sec
10. Vehicle Damage Index: n/a
    (SAE J224a)
11. AASHTO Test Type: PL2
12. Vehicle Analysis:

	Observed	AASHTO Limits
NCHRP 230:		
Longitudinal:		
Delta-V at 2 ft:	-16 ft/s	30 ft/s
Ridedown Acceleration:	-7 g's	15 g's
Lateral:		
Delta-V at 1 ft:	13 ft/s	25 ft/s
Ridedown Acceleration:	3 g's	15 g's
TRC 191:		
Peak 50 ms acceleration:		
Longitudinal:	-9.8 g's	
Lateral:	3.8 g's	

13. Vehicle-Railing Interaction Coefficient of Friction:

$$mu = \frac{\text{Cos theta} - V_p/V}{\text{Sin theta}}$$

mu	assessment
0.86	Marginal

V_p = 36.4 mi/h (53.4 ft/s)

14. Test Results Conclusion:
    AASHTO Guide Specifications for Bridge Railings: MEETS ALL REQUIRED CRITERIA.

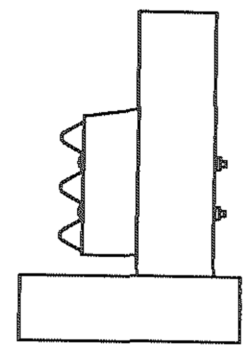
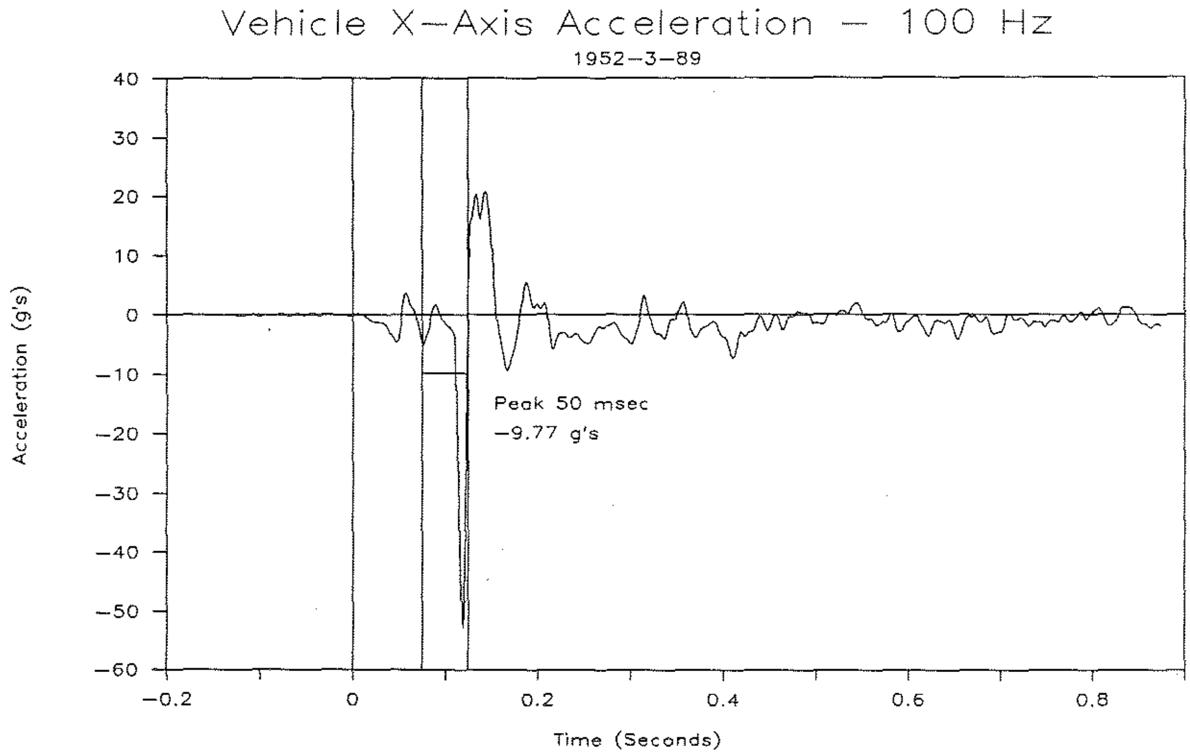


Figure 20. Test summary, test 1952-3-89.



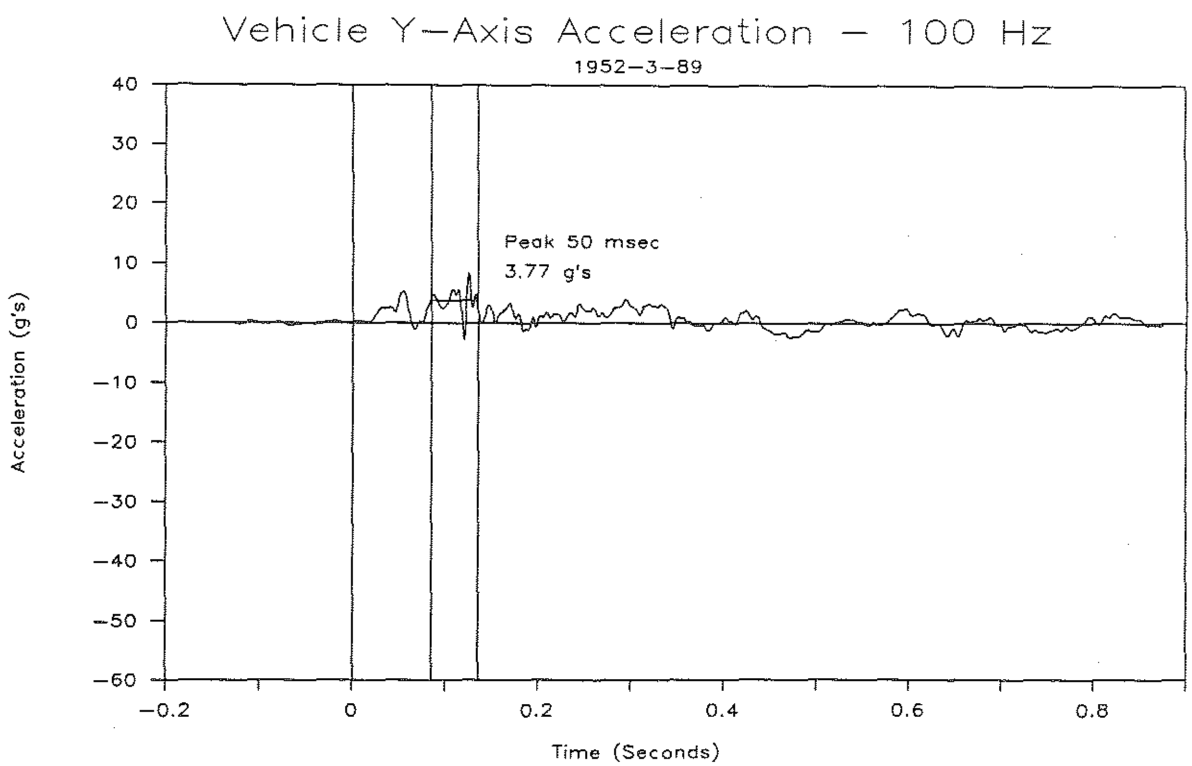


Figure 21. Vehicle acceleration, test 1952-3-89.

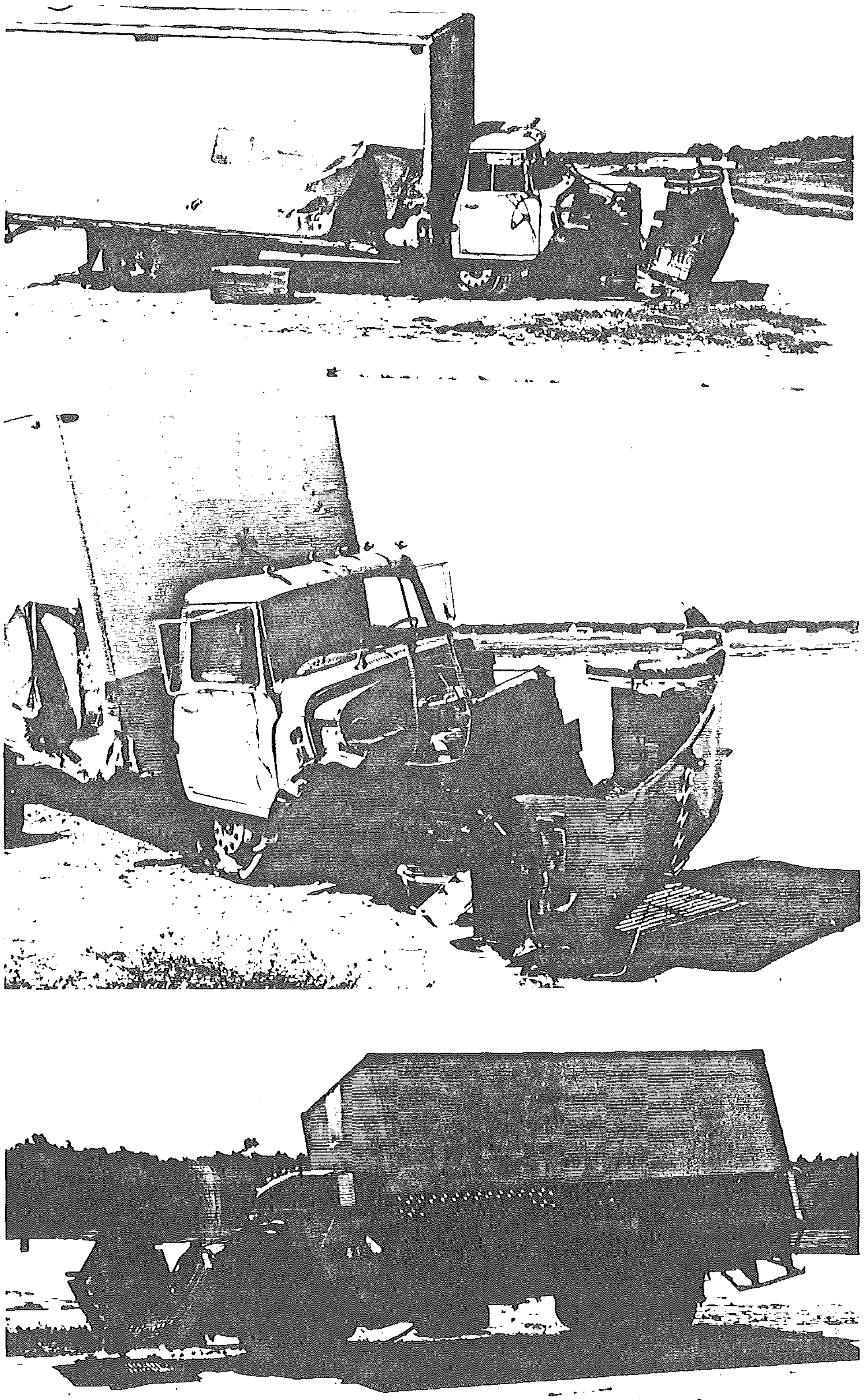


Figure 22. Posttest photographs of test vehicle, test 1952-3-89.

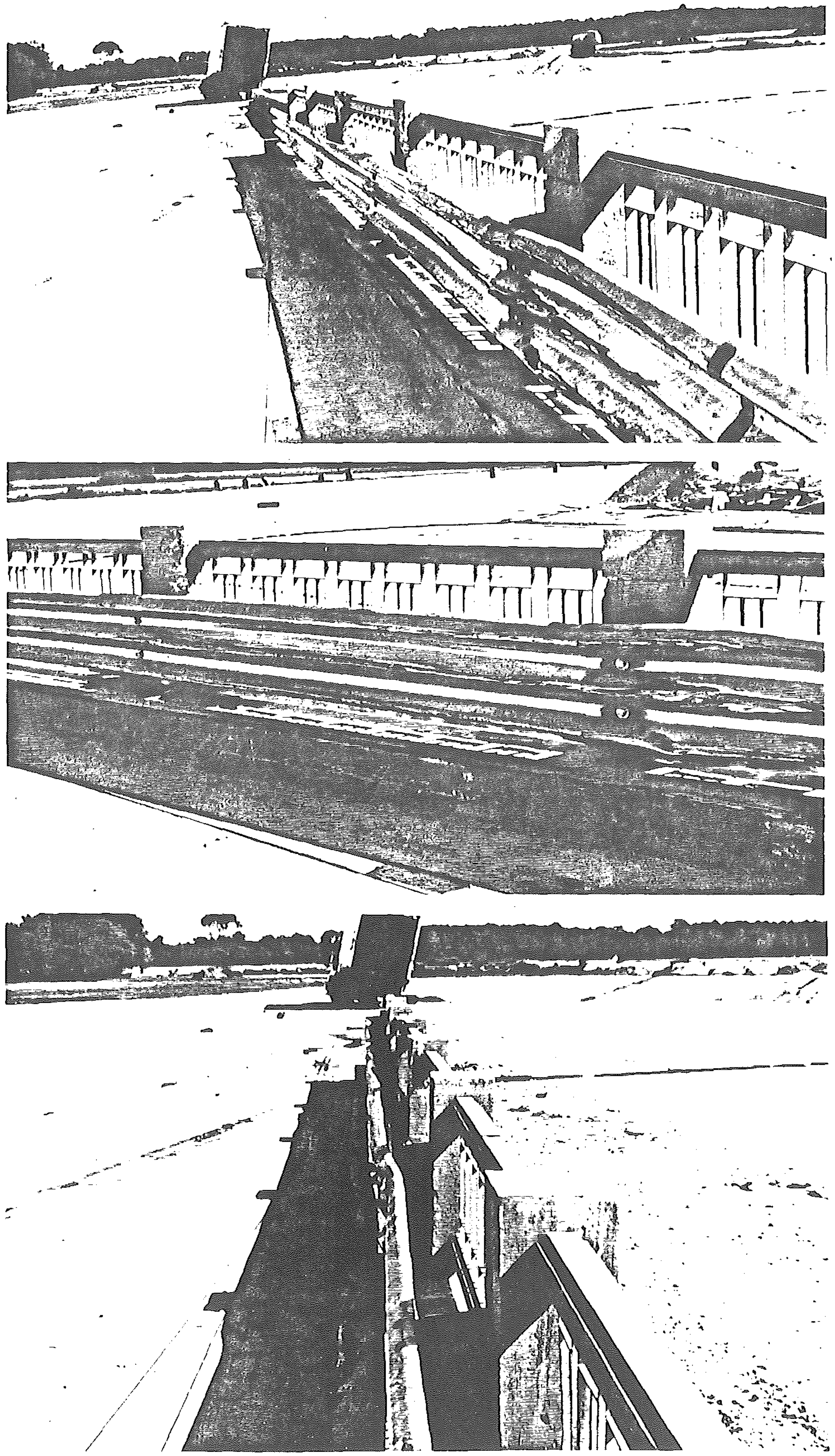


Figure 23. Posttest photographs of bridge rail system, test 1952-3-89.

TASK B - FULL-SCALE TESTS OF THE OPEN PARAPET BRIDGE RAIL

1. OPEN PARAPET BRIDGE RAIL

The test device was the MDOT Open Parapet Bridge Rail. This bridge rail featured a 78-ft, 8-in deck and a 10-in by 23.5-in brushblock the entire length of the rail. The posts were 10.5 in by 15 in on 4-ft, 9-in centers. The rail was 12 in by 15 in with a standard aluminum tube railing mounted to the top of the rail. The gap between the bottom of the rail and the top of the brushblock was 12 in.

This bridge rail system was attached to a rigid, simulated support structure in order to simulate the effects of a bridge deck fascia cantilever. A pit was excavated and the bottom filled with crusher run type soil and compacted to provide a firm base. A slab was poured on this base as a footer for the support. An upright wall and an undercut were poured to tie the support into the previously existing concrete deck. The lateral deck bars extended from the undercut. The rebar details were taken from MDOT plans and 40 grade rebar was used throughout the Open Parapet Bridge Rail.

The concrete used was specially formulated to have cured to the desired strength window (4000 lb/in^2 plus 15 percent, minus 0 percent) in 28 days. The deck, brushblock and posts and rail were poured during November 1989. The average 28-day breaking strengths of the deck and post and rail pours were 4290 and 4077 lb/in^2, respectively. These strengths were evaluated using standard cylinders.

Figure 24 shows the bridge rail dimensions. Figure 25 shows the simulated support structure and the bridge rail cantilever.

a. Test 1952-4-90

(1). Test Device

The test device was the MDOT Open Parapet Bridge Rail. Figure 26 shows the test site layout. Figure 27 shows pretest photographs of the bridge rail system.

(2). Test Vehicle

The test vehicle was a 1983 Honda Civic. The target inertial vehicle weight was 1800 lb. The vehicle weighed approximately 1720 lb empty. With the instrumentation and 30 lb of ballast, the inertial weight of the vehicle was 1797 lb. The target gross vehicle weight was 1950 lb. The gross vehicle weight was 1958 lb.

X-, y- and z-axis accelerometers were mounted in the car along with roll and yaw rate gyros. One uninstrumented dummy was placed in the vehicle in the driver seat and was unrestrained. Pretest photographs of the test vehicle are shown in figure 28. Table 4 lists important parameters of the test vehicle, comparing the actual parameters with the AASHTO Guide Specifications for Bridge Railings requirements.

Table 4. Vehicle parameters, test 1952-4-90.

Item	Actual	Specification
Empty Weight	~1720 lb	n/a
Ballast	30 lb	n/a
Total Weight, Inertial	1797 lb	1800 lb
Total Weight, Gross	1958 lb	1950 lb
H_{cg}	20 in	20 ± 1 in
A (front to cg), Inertial	5.4 ft	5.4 ± 0.1 ft
B (width)	5.0 ft	5.5 ft
Vehicle Length	150 in	
Vehicle Wheelbase	90 in	
Wheel/Tire Size	155 SR13	

(3). Impact Description

Review of the high speed films, fifth wheel and speed trap data indicated that the test vehicle impacted at 61.0 mi/h and 20 degrees. This review also indicated that the right corner of the vehicle impacted the rail at the desired point.

Upon impact, the vehicle was deformed by the rail. The vehicle then rode up on top of the brushblock. The vehicle yawed around and exited the rail at 3 degrees. As the vehicle was redirecting, the vehicle pitched forward and rolled toward the left side, as it rolled off the brushblock onto the deck. The vehicle came to rest 212 ft past the impact point, 45 ft behind the front of the rail, after yawing 180 degrees, in relation to the rail.

Upon impact, the unrestrained driver dummy impacted the passenger side door with its shoulder and pushed the door out. The dummy came to rest with its head and torso in the passenger seat and its legs on the driver seat, leaning on the dashboard.

A summary of test conditions and results are shown in figure 29. Due to a data cable failure, no electronic data was recorded.

(4). Vehicle Damage

Damage occurred to the right front wheel and suspension, the hood, bumper and entire right side of the vehicle. The passenger side door was wedged out by the dummy impact. Posttest photographs of the vehicle are shown in figure 30.

(5). Bridge Rail Damage

The bridge rail suffered very little damage. There was vehicle paint, tire and wheel scrub on the rail for 16.5 ft, starting 1.5 ft before the impact point (see subsection 3). There was tire scrub on the brushblock for 20 ft, starting 3 ft before the impact point. There were scrub marks on posts 6 and 7. From the tire marks, it can be concluded that the right front tire was completely on the brushblock. Scrub on the rail covered the entire face of the rail (up to the level of the top bevel). There was no damage other than minor spalling of the brushblock and posts 6 and 7. There was no measurable deflection of the rail. Posttest photographs of the bridge rail are shown in figure 31.

(6). Test Evaluation

This test was evaluated using both the AASHTO Guide Specifications for Bridge Railings and NCHRP 230. The following is an item by item evaluation using these two guidelines.

- <u>AASHTO Guide Specifications for Bridge Railings</u>:

Required Criteria:

a. The vehicle was contained by the test article.
b. There were no detached elements.
c. Integrity of the passenger compartment was maintained.
d. The vehicle remained upright.
g. **<u>No electronic data was recorded. This criterion cannot be evaluated</u>.**

Desirable Criteria:

e. The vehicle was smoothly redirected.
f. Vehicle railing interaction: mu = 0.71, assessment: Marginal.
h. The exit angle was less than 12° (exit angle was 3°). Vehicle was within 20 ft of the rail, 100 ft downstream of the impact point.

TEST <u>FAILS</u>. No electronic data was recorded. Criterion G cannot be evaluated.

■ <u>NCHRP 230</u>:

a. The test article smoothly redirected the vehicle.
d. There were no detached elements.
e. The vehicle remained upright during and after the collision. Integrity of the passenger compartment was maintained.
h. Vehicle trajectory and stopping position did not intrude into adjacent traffic lanes.
i. Because the vehicle trajectory and stopping position did not intrude into adjacent traffic lanes, vehicle speed change and exit angle criteria do not apply.

MEETS ALL CRITERIA.

(Aluminum tube
railing removed
for test 7)

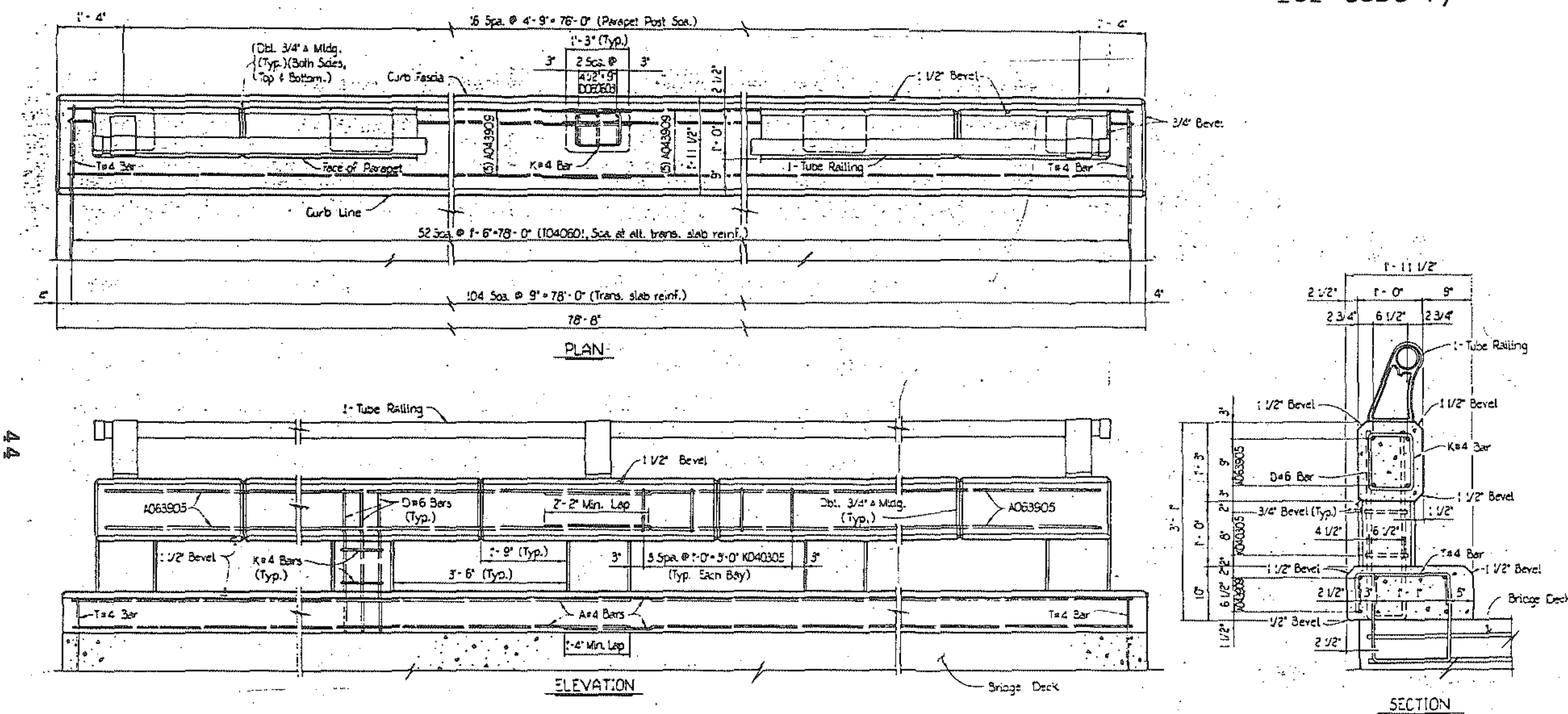


Figure 24. MDOT Open Parapet bridge rail.

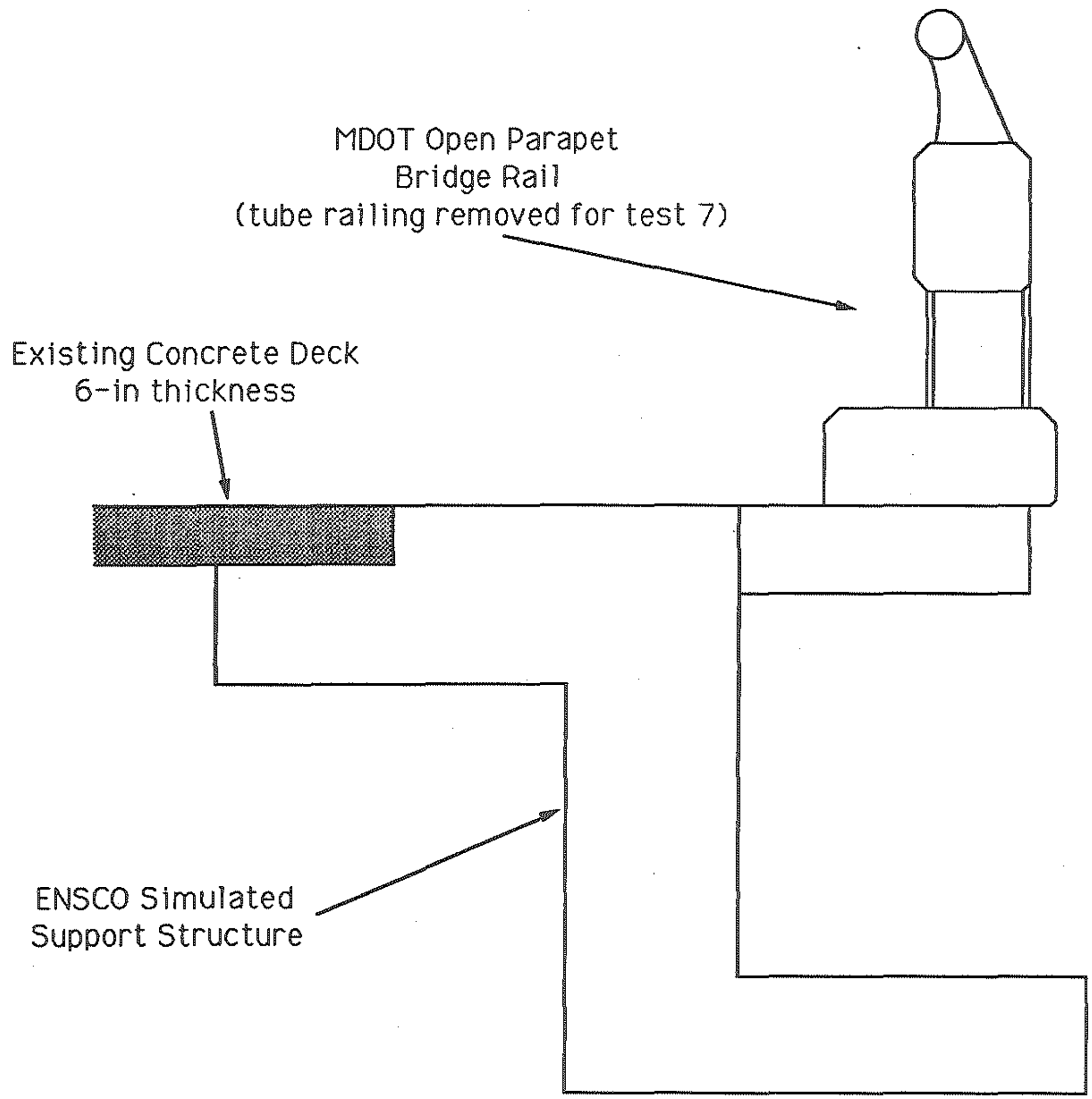


Figure 25. Simulated support structure and bridge rail cantilever.

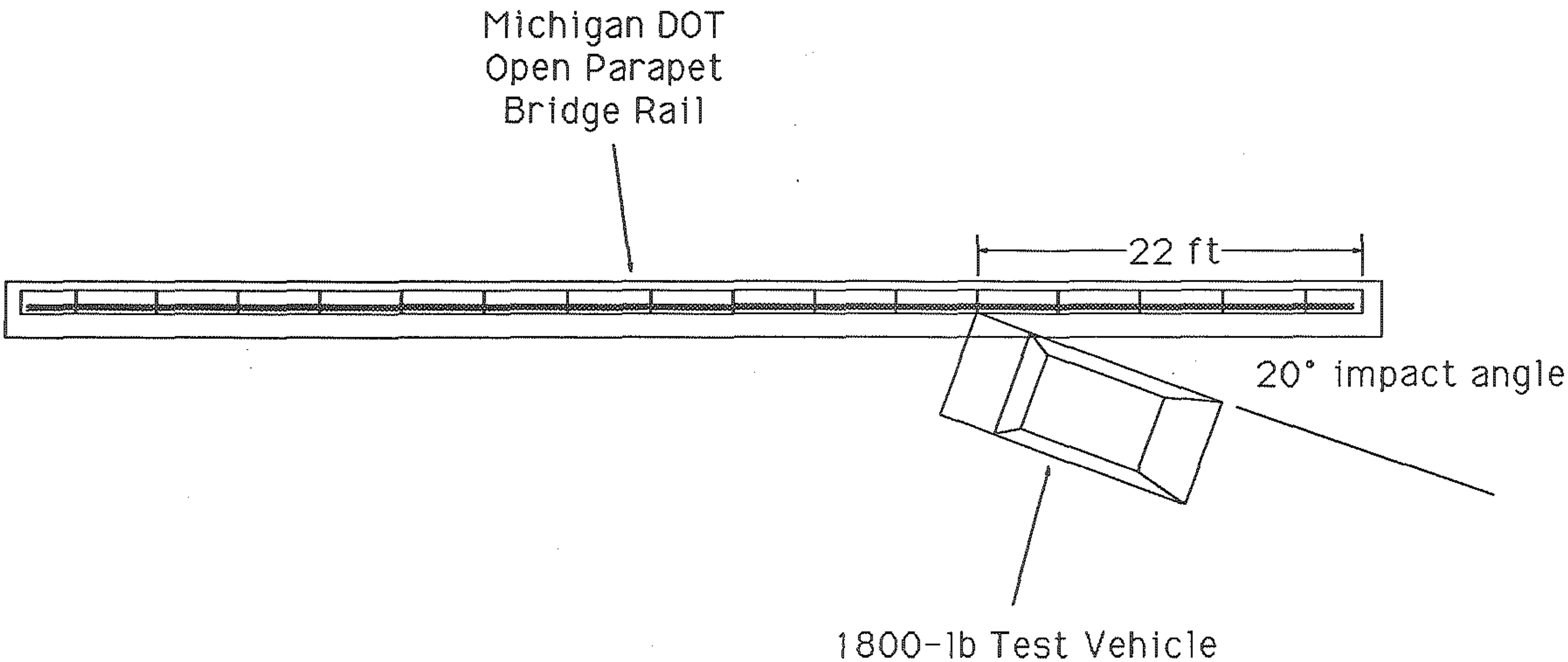


Figure 26. Test site layout, test 1952-4-90.

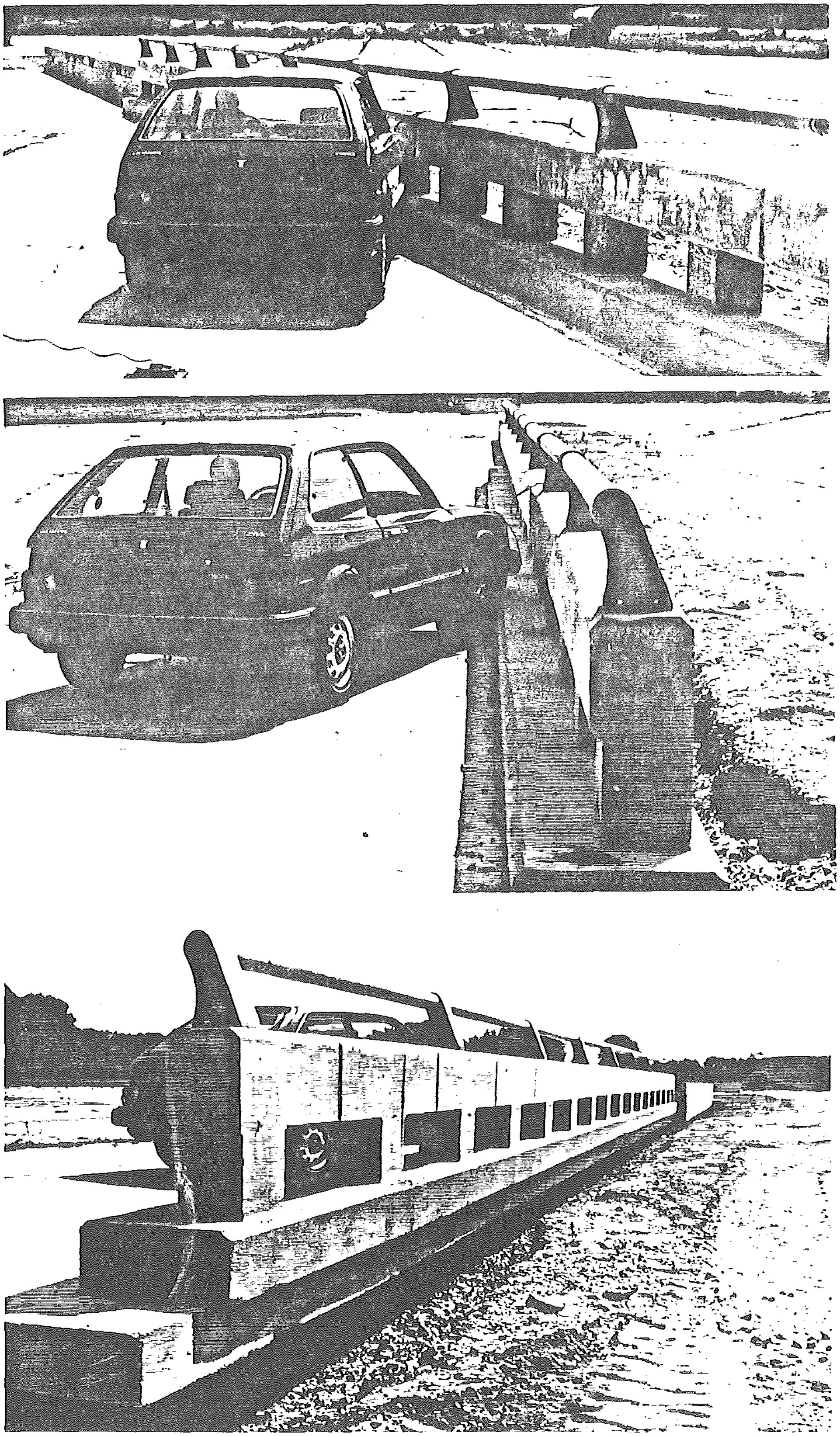


Figure 27. Pretest photographs of bridge rail system, test 1952-4-90.

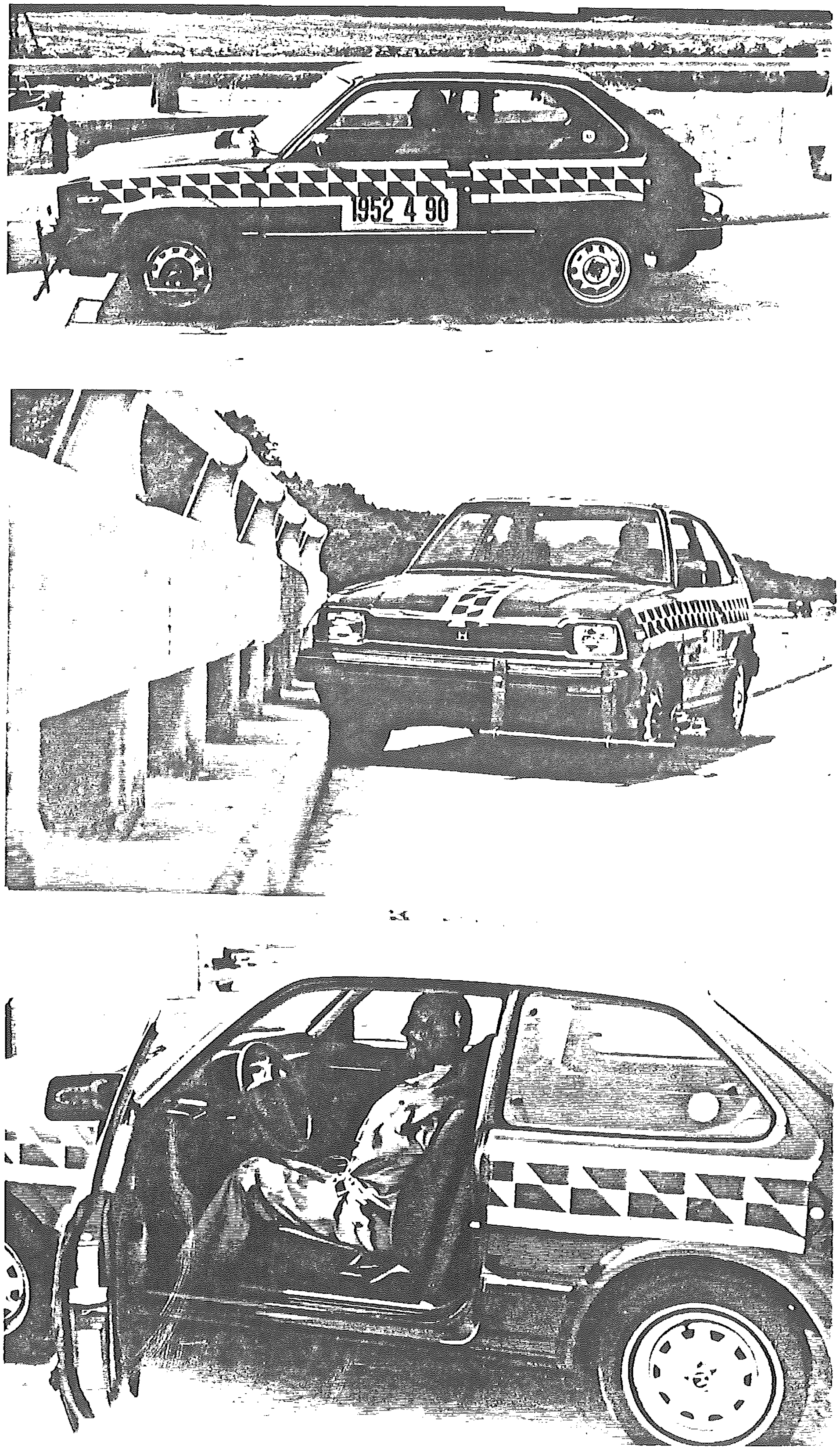
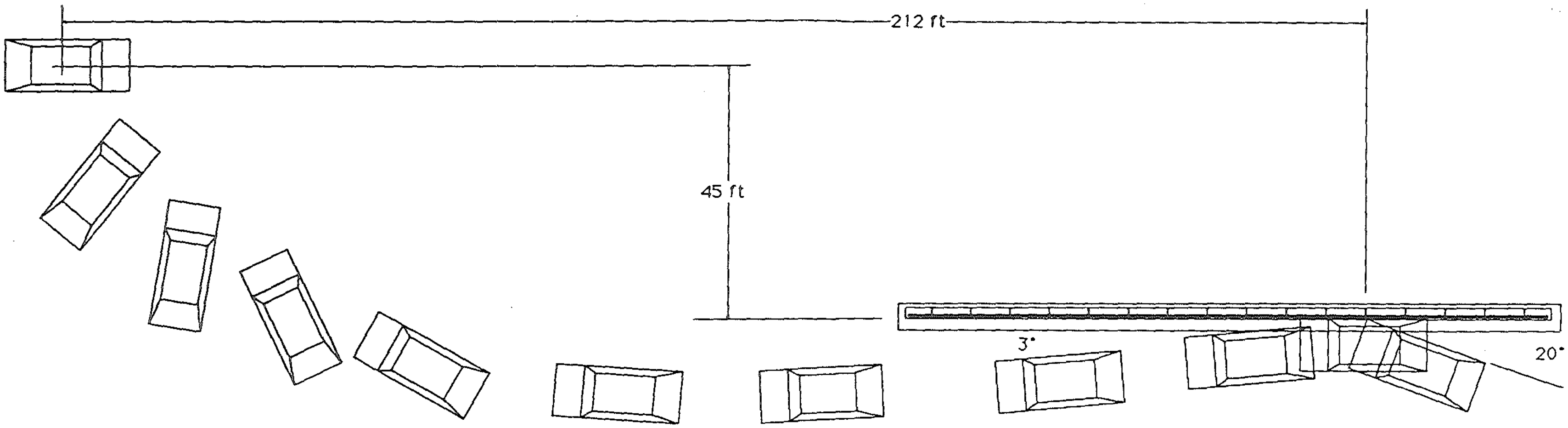


Figure 28. Pretest photographs of test vehicle, test 1952-4-90.



Date:	19 June 1990
Weather:	Hazy, 80° F
Test Vehicle:	1983 Honda Civic
Device Configuration:	Michigan DOT Open Parapet Bridge Rail, 78-ft, 8-in deck, 10-in by 23.5-in brushblock, 10.5-in by 15-in posts, 12-in by 15-in rail, 12 in from bottom of rail to top of brushblock. Aluminum tube railing mounted to top of rail.

1. Vehicle Weight:
   - Planned, Inertial: 1800 ± 50 lb
   - Actual, Inertial: 1797 lb
   - Planned, Gross: 1950 ± 50 lb
   - Actual, Gross: 1958 lb
2. Number of Occupants: One
3. Occupant Model: Part 572, 50th percentile male, uninstrumented
4. Occupant Location: Driver Seat, Unrestrained
5. Impact:

	Speed	Angle (a)	Location
Planned:	60.0 mi/h	20°	Midspan posts 5 and 6
Actual:	61.0 mi/h	20°	Midspan posts 5 and 6

   Tolerances: Speed: -1.0, +2.5 mi/h; Angle: -1.0, +2.5 degrees

6. Redirection Angle: 3 degrees
7. Redirection Speed: n/a(1)
8. Total Speed Change: n/a(1)
9. Total Momentum Change: n/a(1)
10. Vehicle Damage Index: (SAE J224a) 01RFEW2
11. NCHRP 230 Test Number: S13
    AASHTO Test Type: PL2
12. Vehicle Analysis:

    Due to a data cable failure, no electronic data was recorded.
13. NCHRP 230 Impact Severity:

    $\frac{m(V \sin a)^2}{2}$ 26.1 kip-ft (Spec: 23 to 29 kip-ft)
14. Vehicle-Railing Interaction Coefficient of Friction:

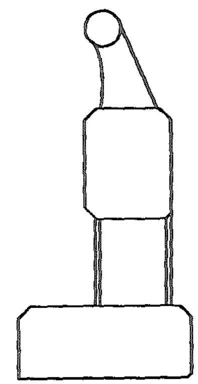
    $mu = \frac{\text{Cos theta} - V_P/V}{\text{Sin theta}}$

mu	assessment
0.71	Marginal

    V_P = 42.6 mi/h (62.5 ft/s)
15. Test Results Conclusion:

    AASHTO Guide Specifications for Bridge Railings: **TEST FAILS.** No electronic data was recorded. Criterion G cannot be evaluated.

    NCHRP 230: **MEETS ALL CRITERIA**



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(1) Redirection speed not able to be calculated.

Figure 29. Test summary, test 1952-4-90.

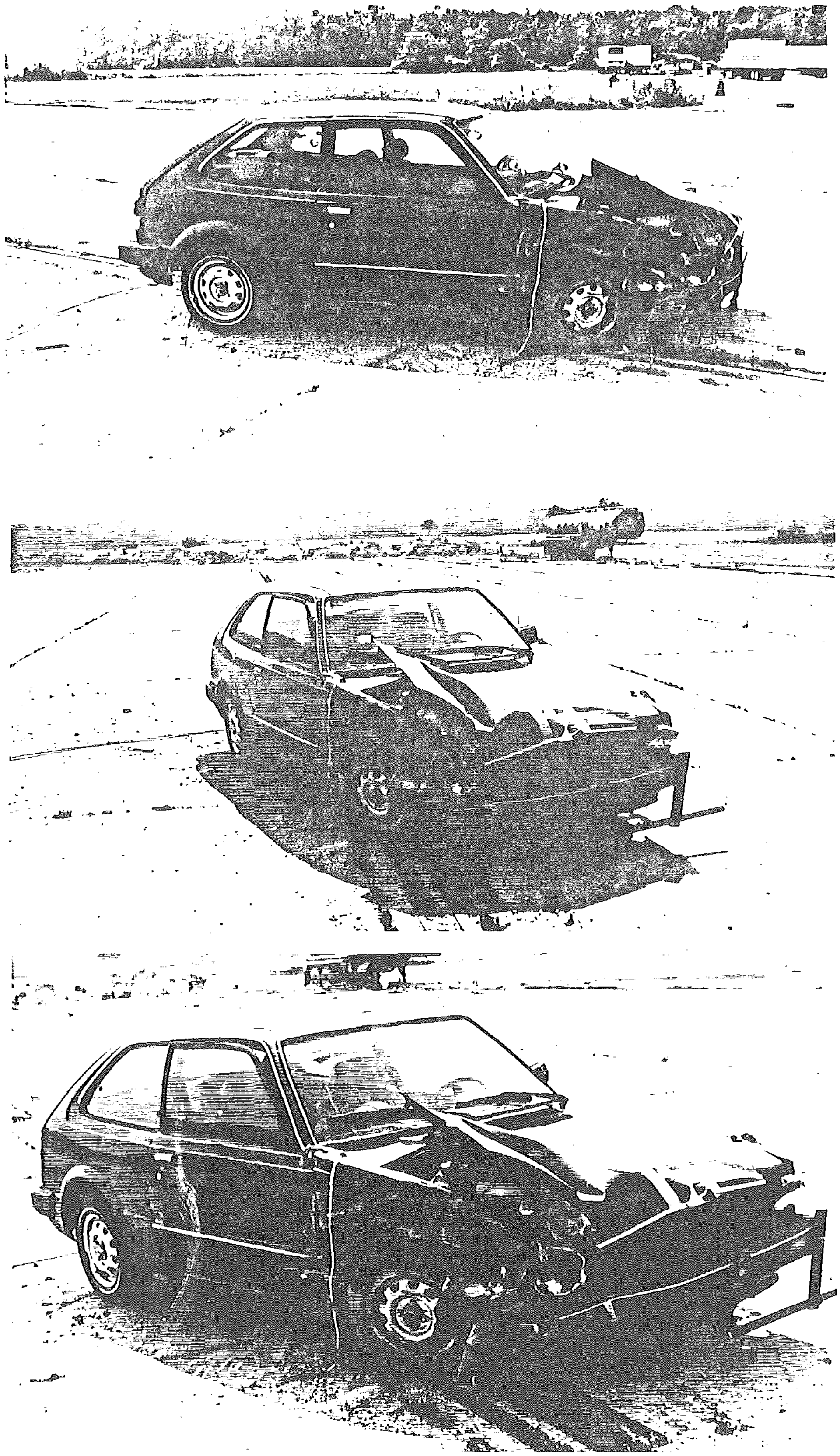


Figure 30. Posttest photographs of test vehicle, test 1952-4-90.

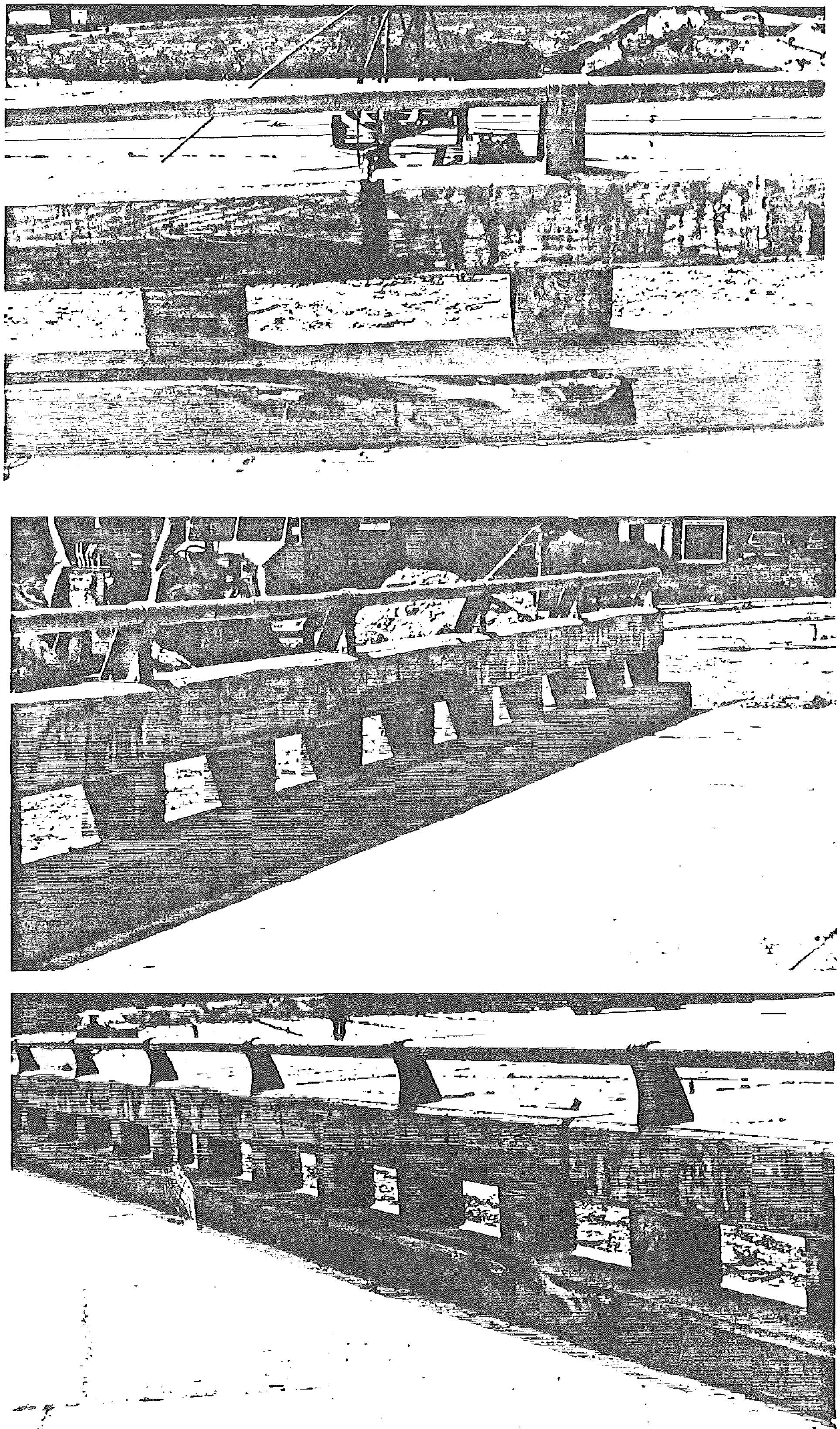


Figure 31. Posttest photographs of bridge rail system, test 1952-4-90.

b. **Test 1952-5-90**

(1). **Test Device**

The test device was the MDOT Open Parapet Bridge Rail. Figure 32 shows the test site layout. Figure 33 shows pretest photographs of the bridge rail system.

(2). **Test Vehicle**

The test vehicle was a 1984 GMC C1500 pickup. The target inertial vehicle weight was 5400 lb. The vehicle weighed approximately 4000 lb empty. Approximately 1400 lb of ballast were added. The ballasted inertial weight of the truck was 5409 lb. The gross vehicle weight was 5760 lb.

Two dummies were placed in the vehicle. The driver was unrestrained while the passenger was restrained. X-, y- and z-axis accelerometers were mounted in the cab of the truck along with roll and yaw rate gyros. Pretest photographs of the test vehicle are shown in figure 34. Table 5 lists important parameters of the test truck, comparing the actual parameters with the AASHTO Guide Specifications for Bridge Railings requirements.

Table 5. Vehicle parameters, test 1952-5-90.

Item	Actual	Specification
Empty Weight	~4000 lb	n/a
Ballast	~1400 lb	n/a
Total Weight, Inertial	5409 lb	5400 lb
Total Weight, Gross	5760 lb	n/a
H_{cg}	27 in	27 ± 1 in
A (front to cg), Inertial	8.60 ft	8.5 ± 0.1 ft
B (width)	6.33 ft	6.5 ft
Truck Length	216 in	
Truck Wheelbase	132 in	
Wheel/Tire Size	195 75R15	
Truck Box Size	8 ft long by 1.5 ft high by 5.5 ft wide	
Ground to box floor	27 in	

(3). Impact Description

Review of the high speed films, speed trap and fifth wheel data indicated that the test vehicle impacted at 62.2 mi/h and 20 degrees. This review also indicated that the right corner of the vehicle impacted the desired point.

Upon impact, the right front corner of the vehicle deformed and the vehicle rode up on top of the brushblock. The hood did not bend, but went up over the top of the concrete rail. The front corner of the hood caught on the next post of the aluminum tube railing and caused the hood to be pushed back into the windshield and the occupant compartment. The front fender of the vehicle also caught on the tube railing post and was torn from the truck. The windshield was popped out due to the deformation of the a-pillars. The passenger side door was damaged and the outer panel of the front of the truck box was also torn from the truck. This severe snagging kept the vehicle from redirecting or even becoming parallel with the rail. Due to the snagging, the vehicle yawed approximately -45 degrees to the rail (using right-hand rule coordinate system). The vehicle continued downstream slowly yawing positively. The vehicle came to rest 180 ft past the impact point, 1 ft in front of the rail, at 10 degrees to the line of the rail.

Upon impact, the unrestrained driver dummy slid toward the passenger dummy. The passenger dummy impacted the passenger side door with its shoulder, pushing the passenger side door out. The hood penetrated into the compartment pinning the dummies and keeping them from moving. The hood further penetrated and pushed the dummies back into the rear glass, causing it to shatter. Obviously, both passengers would have been severely harmed by the hood. The driver came to rest in the middle of the seat between the passenger and the dashboard. The passenger came to rest lying on the seat toward the driver side.

A summary of test conditions and results are shown in figure 35. Data analysis was performed. The vehicle x-axis and y-axis, 100 Hz acceleration traces are shown in figure 36.

(4). Vehicle Damage

Damage occurred to the front and entire right side of the vehicle. The hood was pushed into the occupant compartment. The occupant compartment was severely deformed. The right front fender was torn from the truck. The passenger side door was deformed. The right panel of the truck box was torn from its welds and wrapped around the rear of the vehicle. The front suspension was damaged. The truck buckled at the front of the bed due to the loss of structural integrity. Posttest photographs of the truck are shown in figure 37.

(5). Bridge Rail Damage

The bridge rail suffered considerable cosmetic damage but no major structural damage during this impact. There was scrub on the brushblock from 2.5 ft before impact to the end of the system. There was major scrub on the rail for 13 ft beginning 1 ft upstream of impact. Minor scrub on the rail continued for another 47 ft. There was major scrub on posts 6 through 9 and minor scrub on the rest of the downstream posts. Spalling occurred to the brushblock, posts 6 and 7 and the front bottom corner of the rail. Tube railing posts 4 and 5 were impacted by the hood and front fender and the tube railing was scraped for 30 ft beginning at impact. Posttest photographs of the bridge rail are shown in figure 38.

(6). Test Evaluation

This test was evaluated using the AASHTO Guide Specifications for Bridge Railings. The following is an item by item evaluation using this guideline.

- AASHTO Guide Specifications for Bridge Railings:

Required Criteria:

a. The vehicle was contained by the test article.
b. There were no detached elements.
c. **Integrity of the passenger compartment was not maintained. The hood intruded into the occupant compartment.**
d. The vehicle remained upright.

Desirable Criteria:

e. **The vehicle was not smoothly redirected.**
f. Vehicle railing interaction:
   not computed (vehicle never became parallel with the rail due to snagging of the vehicle).
g. **Longitudinal delta-V exceeded limit.**
h. The exit angle was less than 12°. The vehicle was within 20 ft of the rail, 100 ft downstream of the impact point.

TEST ARTICLE FAILS DUE TO OCCUPANT COMPARTMENT INTRUSION.

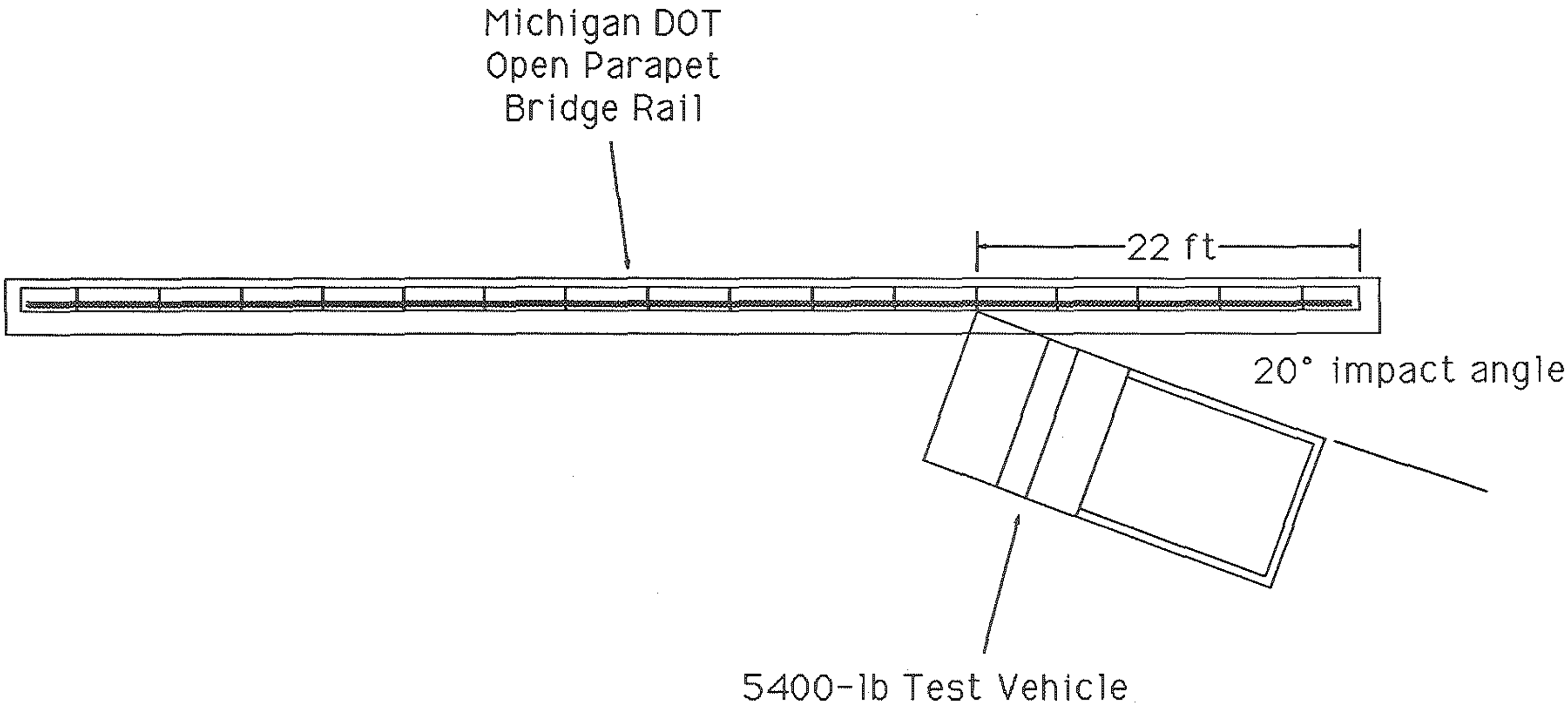


Figure 32. Test site layout, test 1952-5-90.

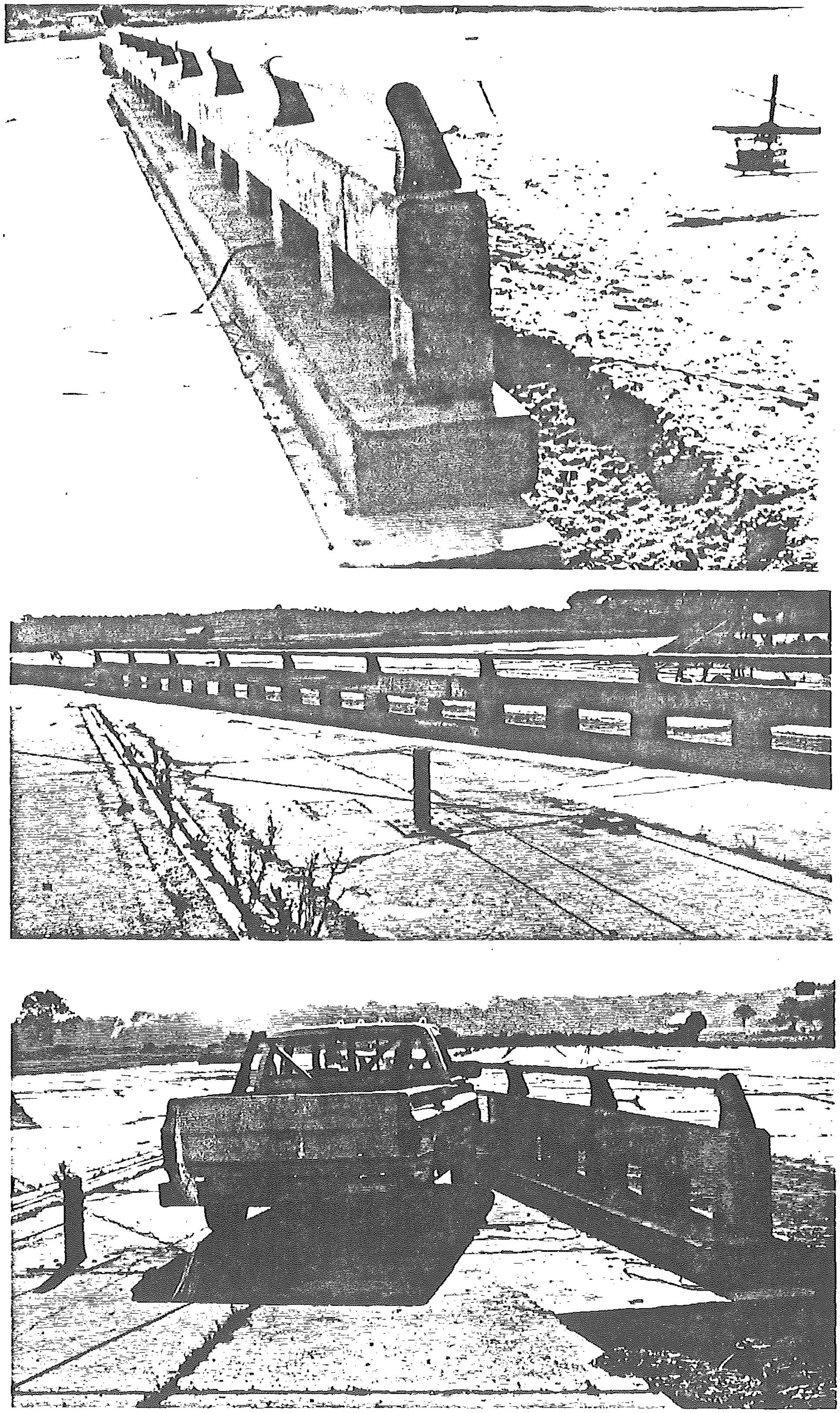


Figure 33. Pretest photographs of bridge rail system, test 1952-5-90.

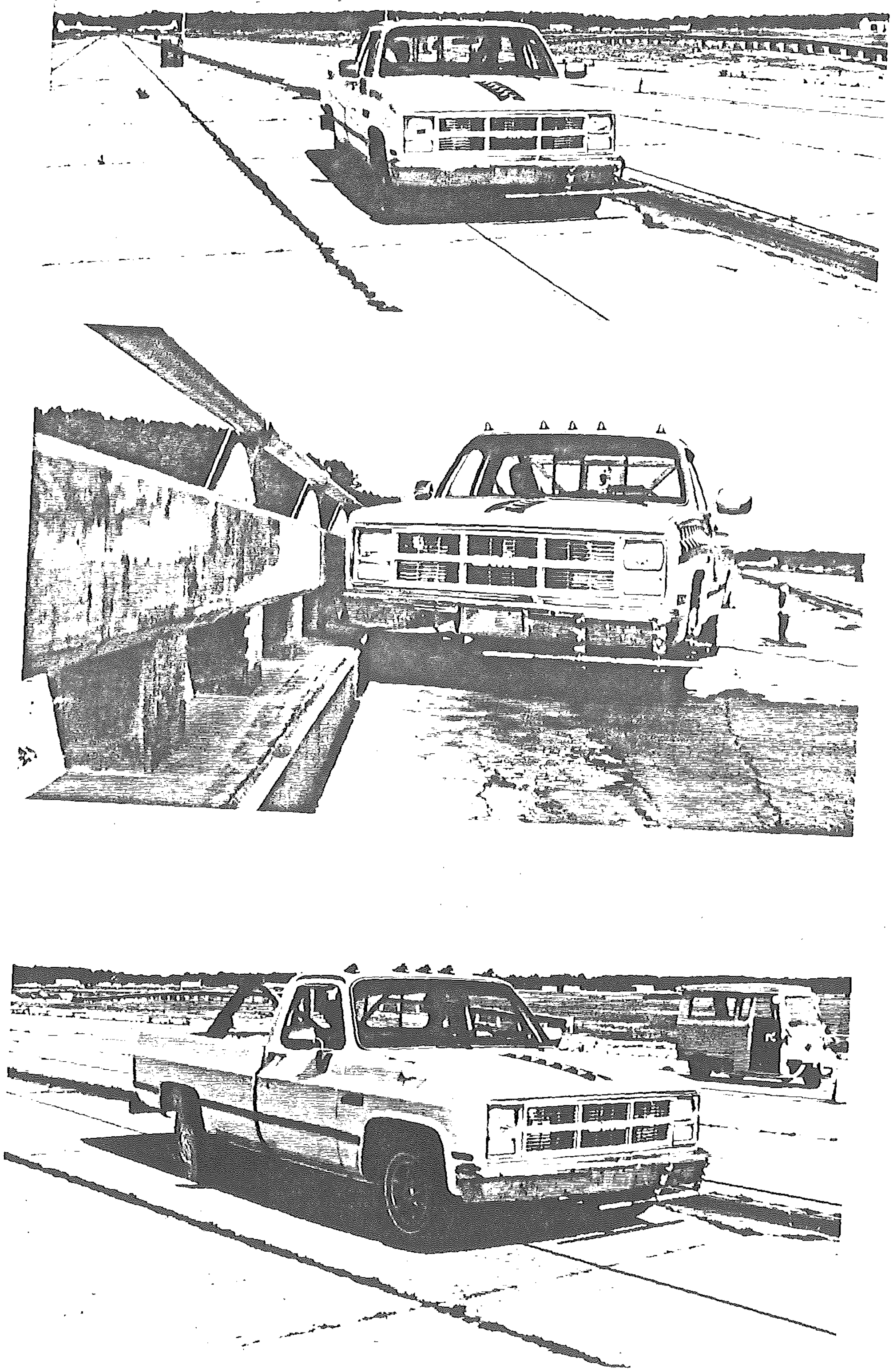
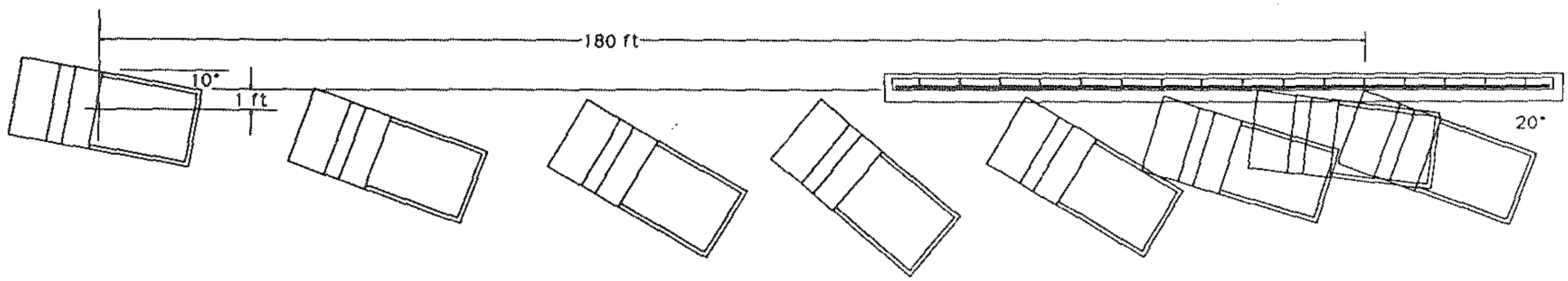


Figure 34. Pretest photographs of test vehicle, test 1952-5-90.



Date:	20 June 1990
Weather:	Clear, 80° F
Test Vehicle:	1984 GMC C1500 Pickup
Device Configuration:	Michigan DOT Open Parapet Bridge Rail, 78-ft, 8-in deck, 10-in by 23.5-in brushblock, 10.5-in by 15-in posts, 12-in by 15-in rail, 12 in from bottom of rail to top of brushblock. Aluminum tube railing mounted to top of rail.

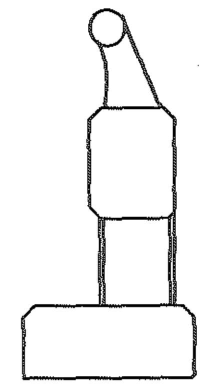
1. Vehicle Weight:
   - Planned, Inertial: 5400 lb
   - Actual, Inertial: 5406 lb
   - Actual, Gross: 5760 lb
2. Number of Occupants: Two
3. Occupant Model: Part 572, 50 percentile male
4. Occupant Locations: Driver Seat, Unrestrained; Passenger Seat, Restrained
5. Impact:

	Speed	Angle	Location
Planned:	60.0 mi/h	20°	Midspan posts 5 and 6
Actual:	62.2 mi/h	20°	Midspan posts 5 and 6

   Tolerances: Speed: -1.0, +2.5 mi/h; Angle: -1.0, +2.5 degrees

6. Redirection Angle: n/a(1)
7. Redirection Speed: n/a(1)
8. Total Speed Change: n/a(1)
9. Total Momentum Change: n/a(1)
10. Vehicle Damage Index: (SAE J224a) 01RFEW3
11. AASHTO Test Type: PL2
12. Vehicle Analysis:

	Observed	AASHTO Limits
NCHRP 230:		
Longitudinal:		
Delta-V at 2 ft:	-31 ft/s	30 ft/s
Ridedown Acceleration:	-11 g's	15 g's
Lateral:		
Delta-V at 1 ft:	24 ft/s	25 ft/s
Ridedown Acceleration:	9 g's	15 g's
TRC 191:		
Peak 50 ms acceleration:		
Longitudinal:	-9.9 g's	
Lateral:	10.4 g's	



13. Vehicle-Railing Interaction Coefficient of Friction:

   $$mu = \frac{\cos theta - V_p/V}{\sin theta}$$

   mu: n/a(2) — assessment: n/a(2)

   V_p = n/a(2)

14. Test Results Conclusion:

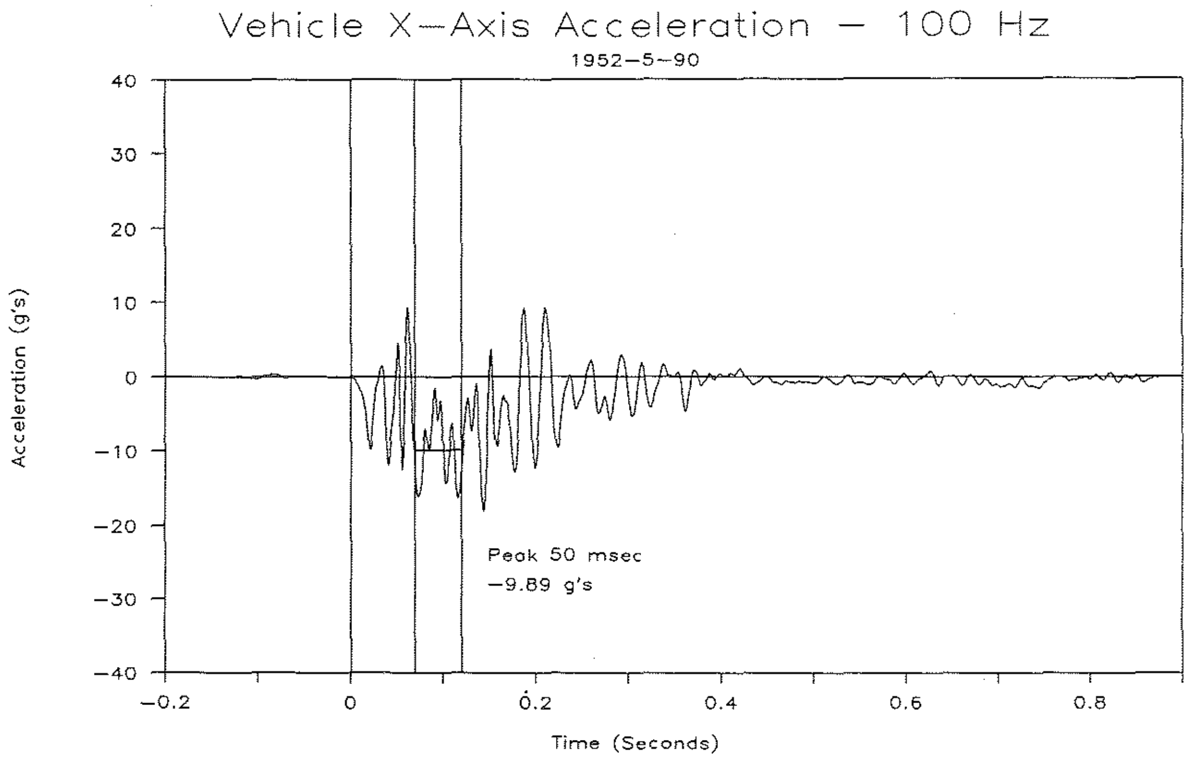
   AASHTO Guide Specifications for Bridge Railings: **TEST ARTICLE FAILS DUE TO OCCUPANT COMPARTMENT INTRUSION.**

---

(1) Vehicle was not redirected away from the rail. Vehicle x-axis never pointed downstream away from the rail. Vehicle velocity vector pointed approximately 7.5 degrees away from the bridge rail.

(2) Vehicle never became parallel with the rail due to snagging of the vehicle.

Figure 35. Test summary, test 1952-5-90.



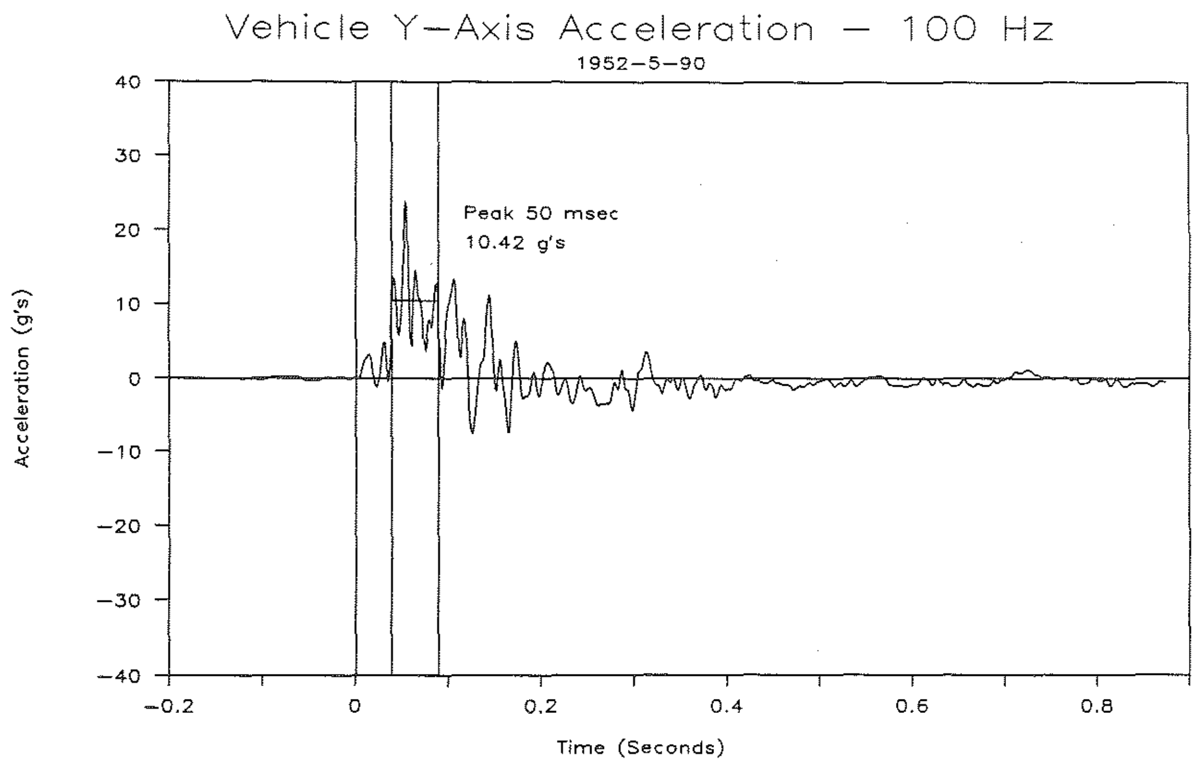


Figure 36. Vehicle acceleration, test 1952-5-90.

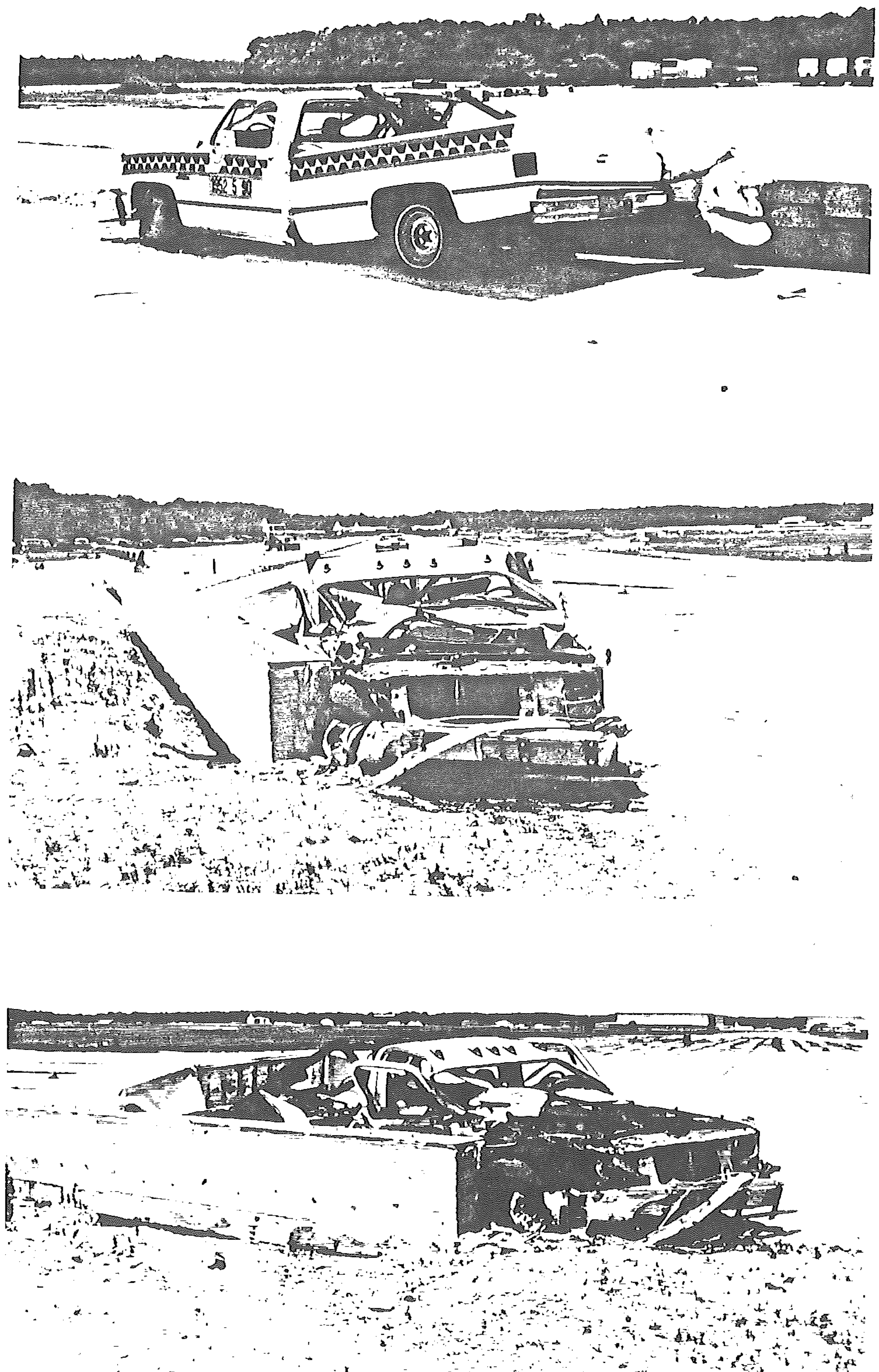


Figure 37. Posttest photographs of test vehicle, test 1952-5-90.

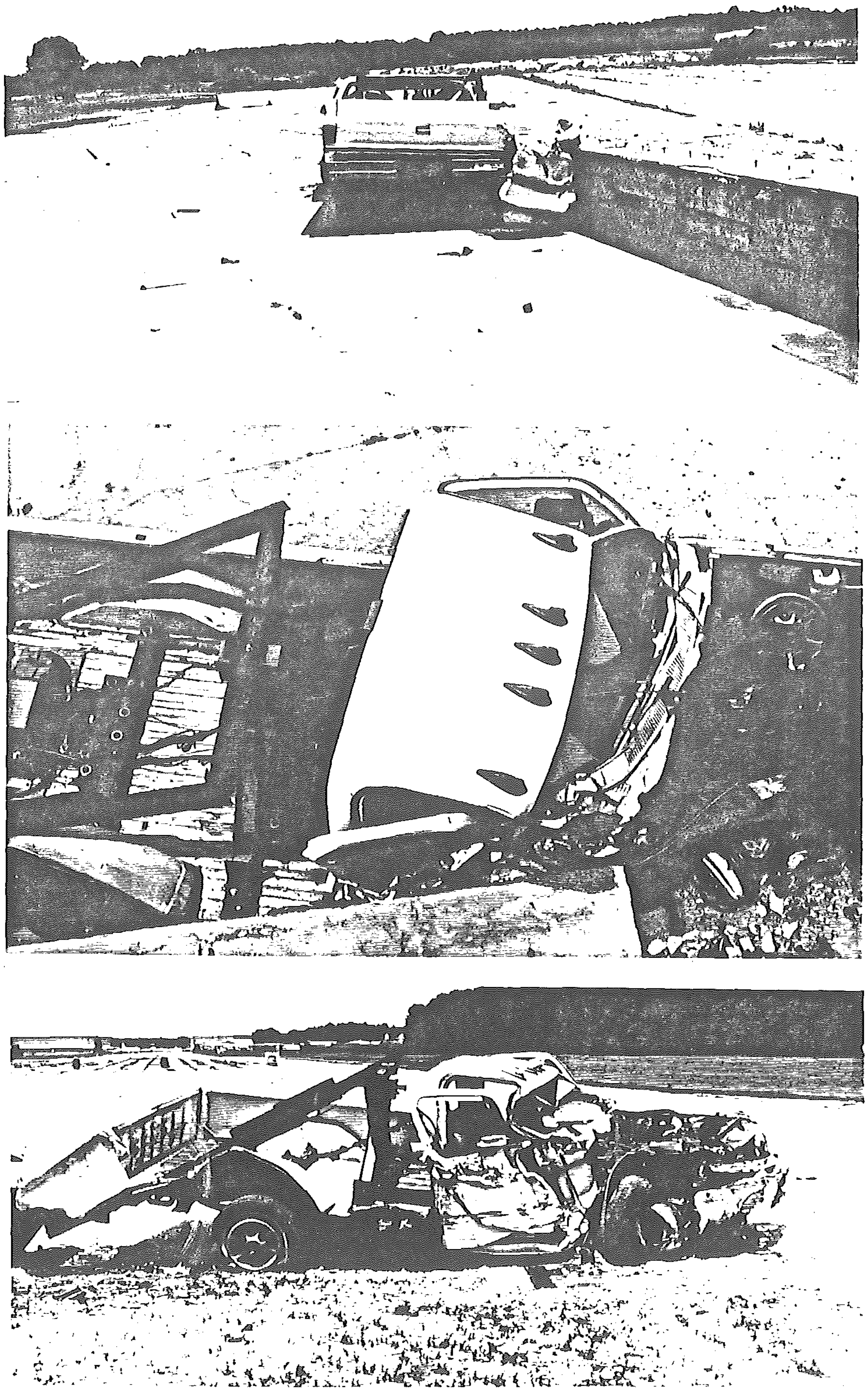


Figure 37 (continued). Posttest photographs of test vehicle, test 1952-5-90.

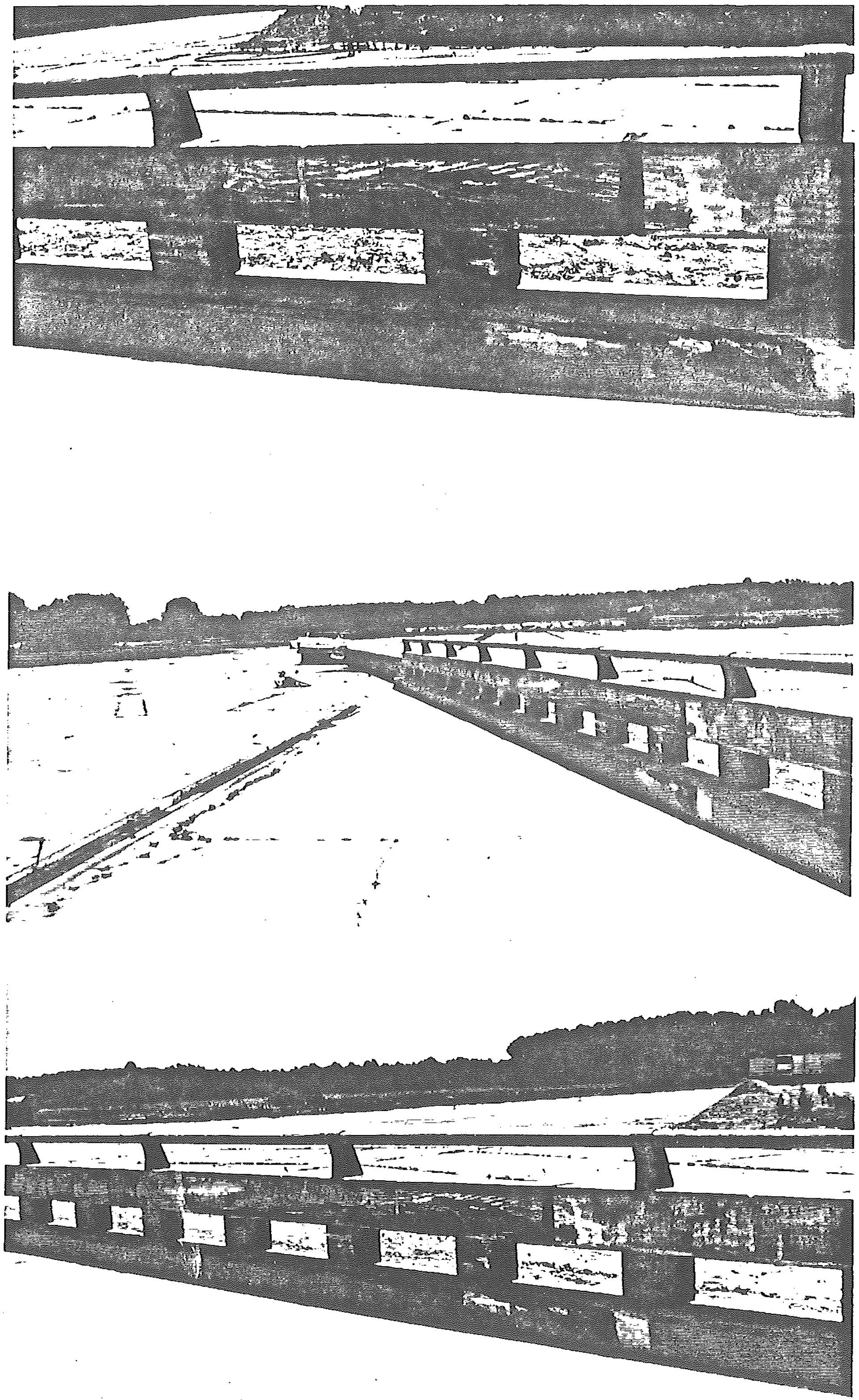


Figure 38. Posttest photographs of bridge rail system, test 1952-5-90.

c. Test 1952-6-90

(1). Test Device

The test device was the MDOT Open Parapet Bridge Rail. Figure 39 shows the test site layout. Figure 40 shows pretest photographs of the bridge rail system.

(2). Test Vehicle

The test vehicle was a 1975 International Loadstar 1600. The target vehicle weight was 18000 lb. The vehicle weighed approximately 12800 lb empty. Approximately 5200 lb of straw and sand ballast were added. The ballasted weight of the truck was 18000 lb.

X-, y- and z-axis accelerometers were mounted in the cab of the truck along with roll and yaw rate gyros. Pretest photographs of the test vehicle are shown in figure 41. Table 6 lists important parameters of the test truck, comparing the actual parameters with the AASHTO Guide Specifications for Bridge Railings requirements.

Table 6. Vehicle parameters, test 1952-6-90.

Item	Actual	Specification
Empty Weight	~12800 lb	n/a
Ballast	~5200 lb	n/a
Total Weight	18000 lb	18000 lb
H_{cg}	48.4 in	49 ± 1 in
A (front to cg)	12.7 ft	12.8 ± 0.2 ft
B (width)	7.5 ft	7.5 ft
Truck Length	29 ft, 10 in	
Truck Wheelbase	18 ft, 2 in	
Wheel/Tire Size	11R22.5	
Truck Box Size	20 ft long by 8 ft high by 7.5 ft wide	
Ground to top of box	11 ft, 9 in	

(3). Impact Description

Review of the high speed films and fifth wheel data indicated that the test vehicle impacted at 50.7 mi/h and 15 degrees. This review also indicated that the right corner of the vehicle impacted the rail at the desired point.

Upon impact, the vehicle front end was deformed by the rail. The cab of the truck initially rolled away from the rail but as the body of the truck engaged the rail, the entire vehicle rolled into the rail. The truck rolled toward the rail approximately 20 degrees and pitched forward approximately 15 degrees. The rear wheels left the ground while the truck was pitching. The vehicle rolled back to upright and continued downstream yawing back into the rail, reaching a maximum yaw angle of approximately 20 degrees. The vehicle was not really redirected by the rail, in that the vehicle x-axis never yawed around and pointed away from the rail. The vehicle velocity vector pointed approximately 2 degrees away from the bridge rail. The front corner of the box knocked the aluminum tube railing and posts off the top of the concrete rail from the impact point up to the last rail section. The vehicle came to rest 135 ft downstream of impact, in line with the rail, at 20 degrees to the rail.

A summary of test conditions and results are shown in figure 42. Data analysis was performed. The vehicle x-axis and y-axis, 100 Hz acceleration traces are shown in figure 43.

(4). Vehicle Damage

The chassis at the front of the truck was damaged and twisted. The hood came open and the windshield popped out. The right front wheel and tire were damaged and the front axle was pushed under the truck. However, the occupant compartment was not intruded. The rail side of the vehicle was damaged from impacting the concrete and aluminum tube rails. The impact side front corner of the box was damaged due to impacts with the tube railing posts. Posttest photographs of the truck are shown in figure 44.

(5). Bridge Rail Damage

The bridge rail suffered major spalling for 7 ft beginning at the impact point. One 30-lb chunk was spalled from the bottom of the rail between the impact point and post 7. The aluminum tube railing was mostly destroyed. Tube railing posts 4 through 8 were sheared off above the bolts and tubes 3 through 7 were scattered away from the bridge rail. Other than the major spalling and the destruction of the tube railing, the remaining damage was cosmetic in nature. There was scrub on the brushblock from 2 ft prior to impact to the downstream end. There was scrub on the rail for 17 ft beginning at impact and minor spalling occurred between posts 7 and 8. There was scrub on and spalling occurred to concrete posts 7 and 8. Slight spalling also occurred to the brushblock prior to impact. Posttest photographs of the bridge rail are shown in figure 45.

(6). Test Evaluation

This test was evaluated using the AASHTO Guide Specifications for Bridge Railings. The following is an item by item evaluation using this guideline.

- AASHTO Guide Specifications for Bridge Railings:

Required Criteria:

a. The vehicle was contained by the test article.
b. **The aluminum tube railing was detached from the concrete bridge rail. The railing showed potential for penetration of the occupant compartment and creating a hazard to other traffic.**
c. Integrity of the passenger compartment was maintained.

Desirable Criteria:

d. The vehicle remained upright.
e. **The vehicle was not smoothly redirected**.
f. Vehicle railing interaction:
mu = 0.68, assessment: Marginal.
h. The exit angle was less than 12°. The vehicle was within 20 ft of the rail, 100 ft downstream of the impact point.

TEST ARTICLE FAILS DUE TO DETACHED ELEMENTS OF ALUMINUM TUBE RAILING SHOWING POTENTIAL FOR PENETRATION OF THE OCCUPANT COMPARTMENT AND CREATING A HAZARD TO OTHER TRAFFIC.

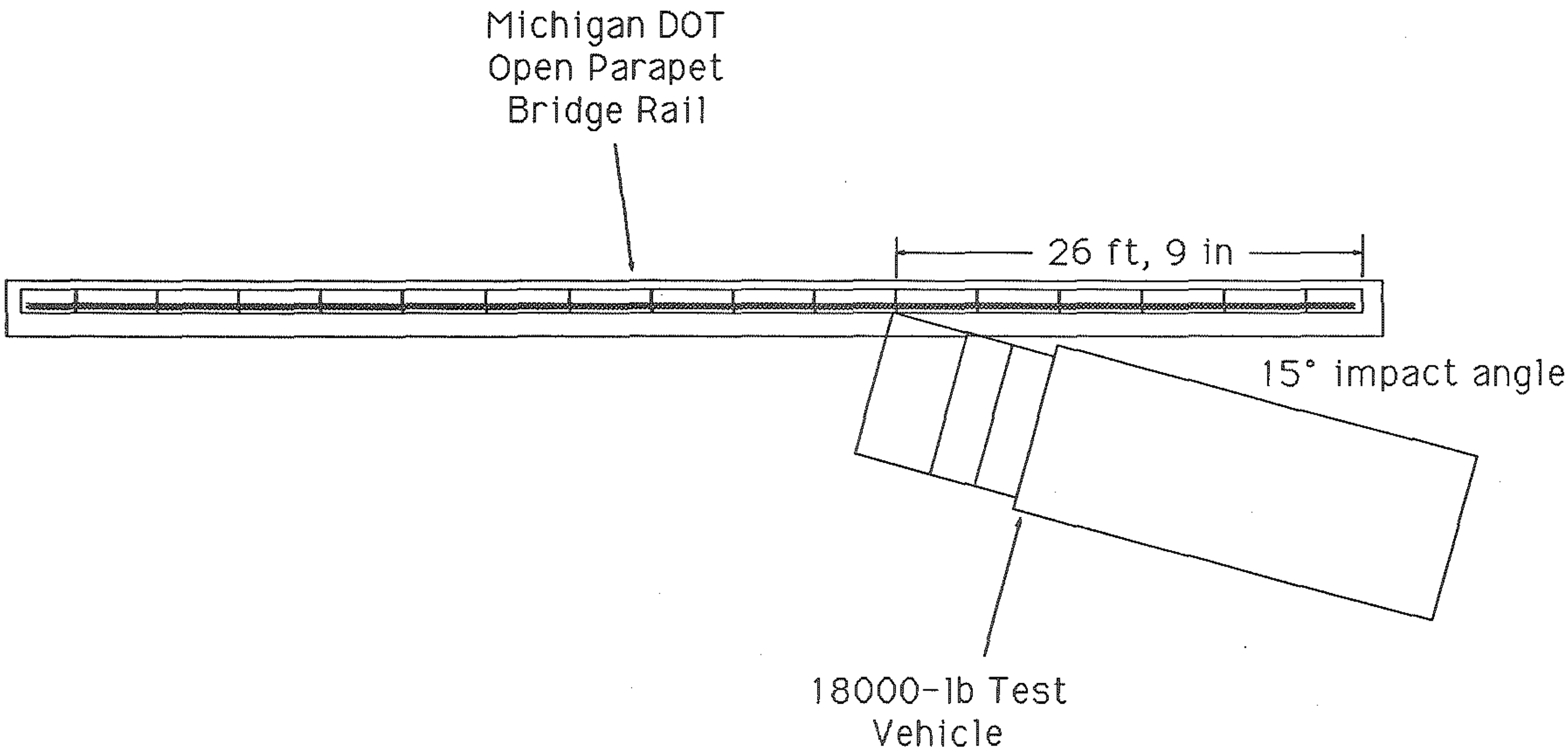


Figure 39. Test site layout, test 1952-6-90.

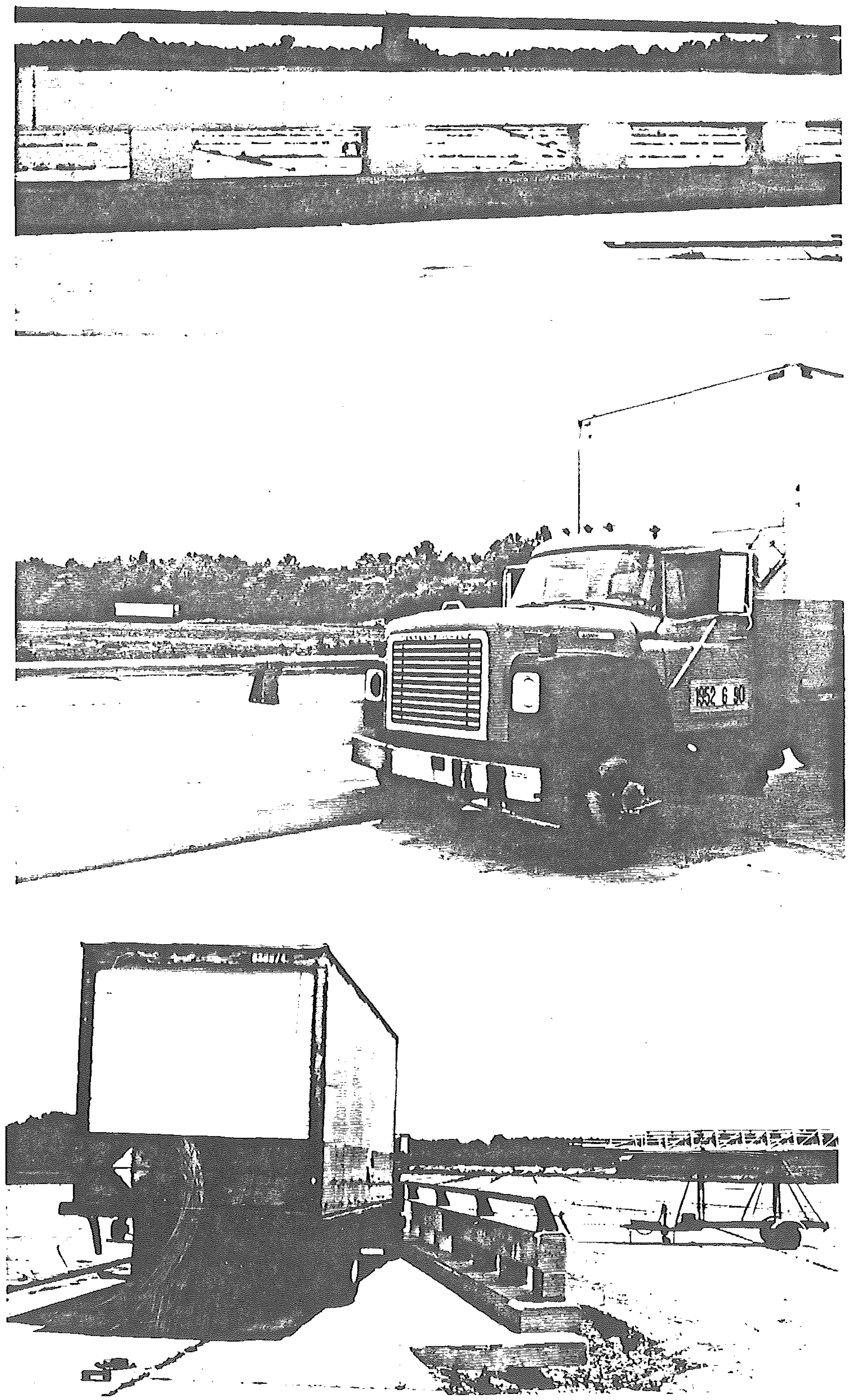


Figure 40. Pretest photographs of bridge rail system, test 1952-6-90.

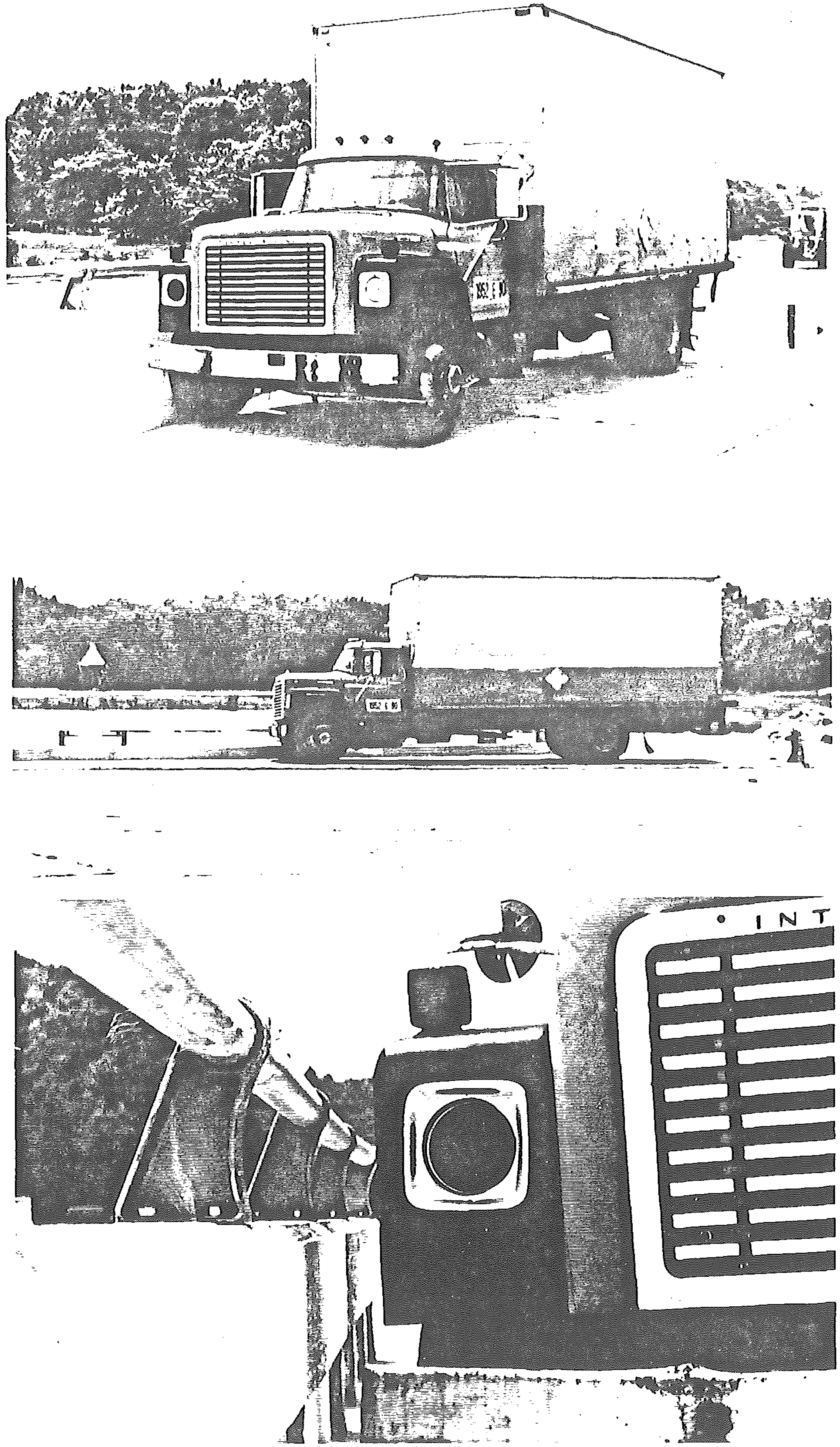
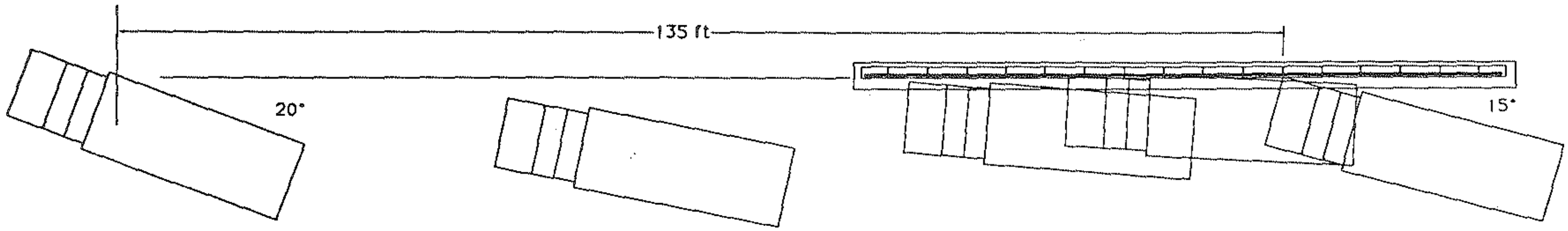


Figure 41. Pretest photographs of test vehicle, test 1952-6-90.



Date: 5 July 1990
Weather: Clear, 80° F

Test Vehicle: 1975 International Loadstar 1600

Device Configuration: Michigan DOT Open Parapet Bridge Rail, 78-ft, 8-in deck, 10-in by 23.5-in brushblock, 10.5-in by 15-in posts, 12-in by 15-in rail, 12 in from bottom of rail to top of brushblock. Aluminum tube railing mounted to top of rail.

1. Vehicle Weight:
   - Planned, Inertial: 18,000 lb
   - Actual, Inertial: 18,000 lb
2. Number of Occupants: None
3. Occupant Model: n/a
4. Occupant Locations: n/a
5. Impact:

	Speed	Angle	Location
Planned:	50.0 mi/h	15°	Midspan posts 6 and 7
Actual:	50.7 mi/h	15°	Midspan posts 6 and 7

   Tolerances: Speed: -1.0, +2.5 mi/h; Angle: -1.0, +2.5 degrees

6. Redirection Angle: 2 degrees
7. Redirection Speed: n/a [1]
8. Total Speed Change: n/a [1]
9. Total Momentum Change: n/a [1]
10. Vehicle Damage Index: (SAE J224a) n/a
11. AASHTO Test Type: PL2
12. Vehicle Analysis:

	Observed	AASHTO Limits
NCHRP 230:		
Longitudinal:		
Delta-V at 2 ft:	n/a[2]	30 ft/s
Ridedown Acceleration:	n/a[2]	15 g's
Lateral:		
Delta-V at 1 ft:	n/a[2]	25 ft/s
Ridedown Acceleration:	n/a[2]	15 g's
TRC 191:		
Peak 50 ms acceleration:		
Longitudinal:	-4.0 g's	
Lateral:	4.3 g's	

13. Vehicle-Railing Interaction Coefficient of Friction:

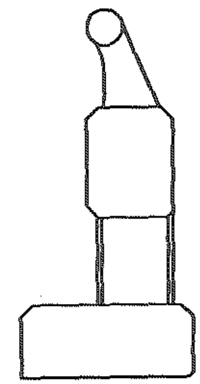
$$mu = \frac{\cos\theta - V_p/V}{\sin\theta}$$

mu	assessment
0.68	Marginal

V_p = 40.1 mi/h (58.8 ft/s)

14. Test Results Conclusion:

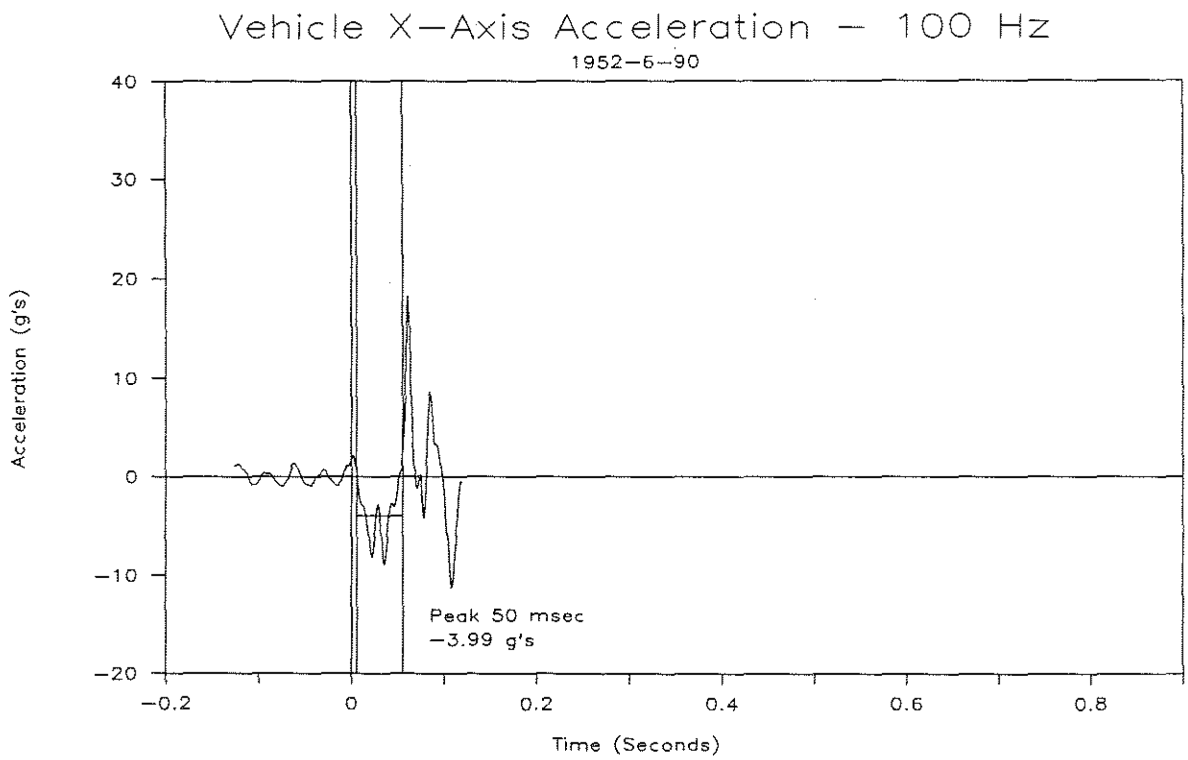
AASHTO Guide Specifications for Bridge Railings: TEST ARTICLE FAILS DUE TO DETACHED ELEMENTS OF ALUMINUM TUBE RAILING SHOWING POTENTIAL FOR PENETRATION OF THE OCCUPANT COMPARTMENT AND CREATING A HAZARD TO OTHER TRAFFIC.



(1) Redirection speed not able to be calculated.

(2) Due to a data cable failure, only 125 milliseconds of data were recorded. No hypothetical occupant impacts were detected in that time span.

Figure 42. Test summary, test 1952-6-90.



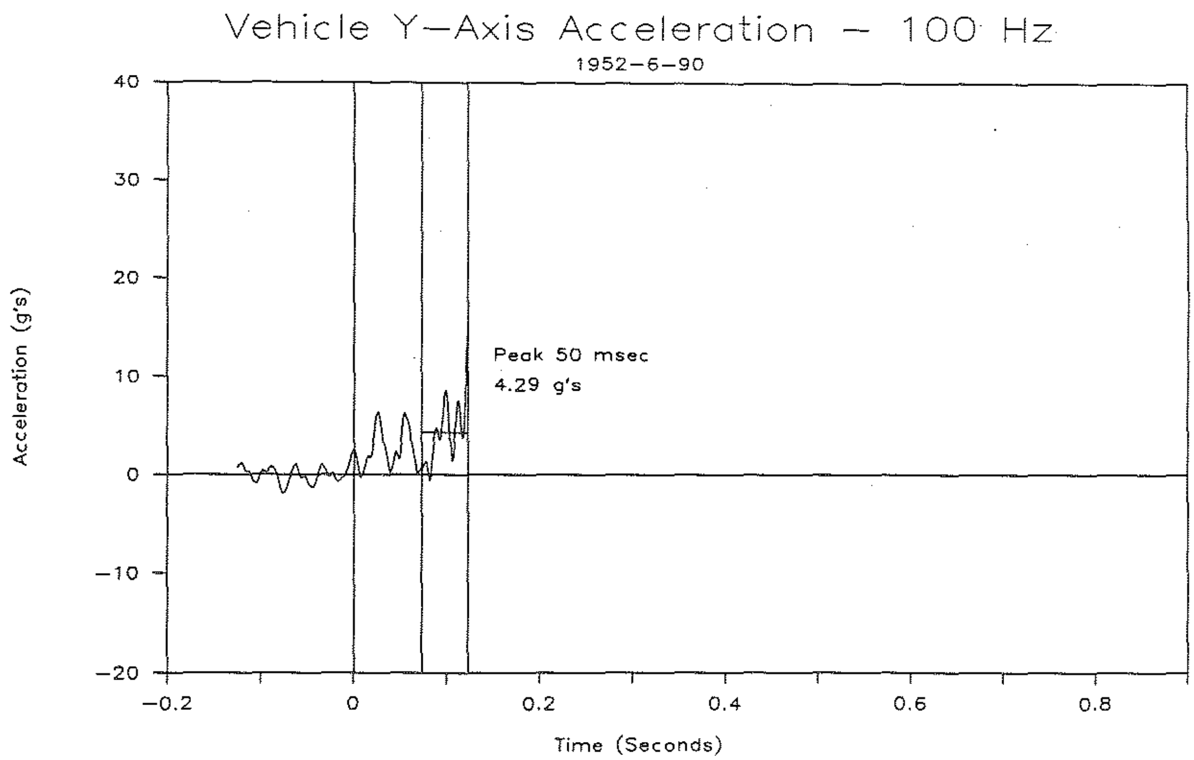


Figure 43. Vehicle acceleration, test 1952-6-90.

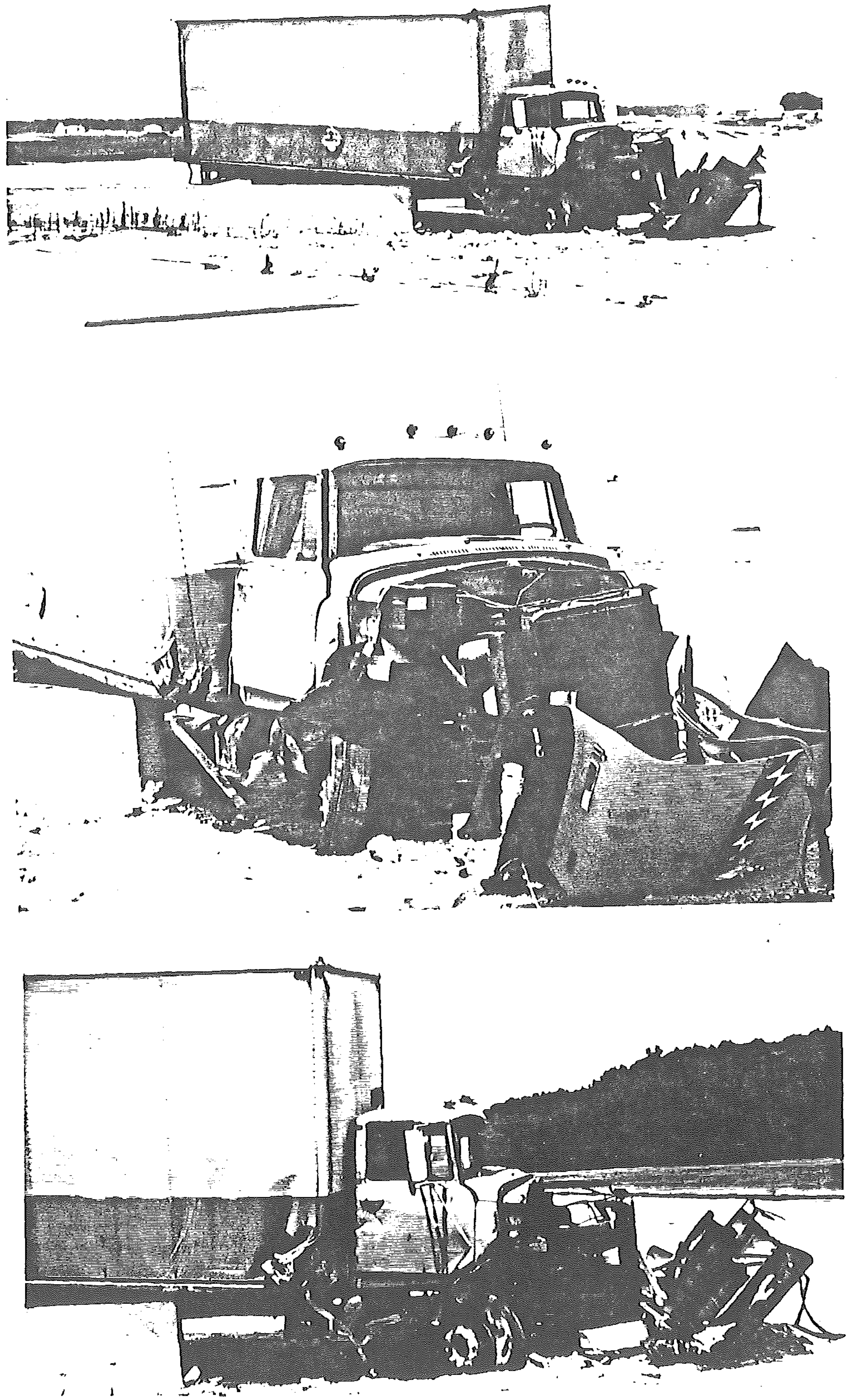


Figure 44. Posttest photographs of test vehicle, test 1952-6-90.

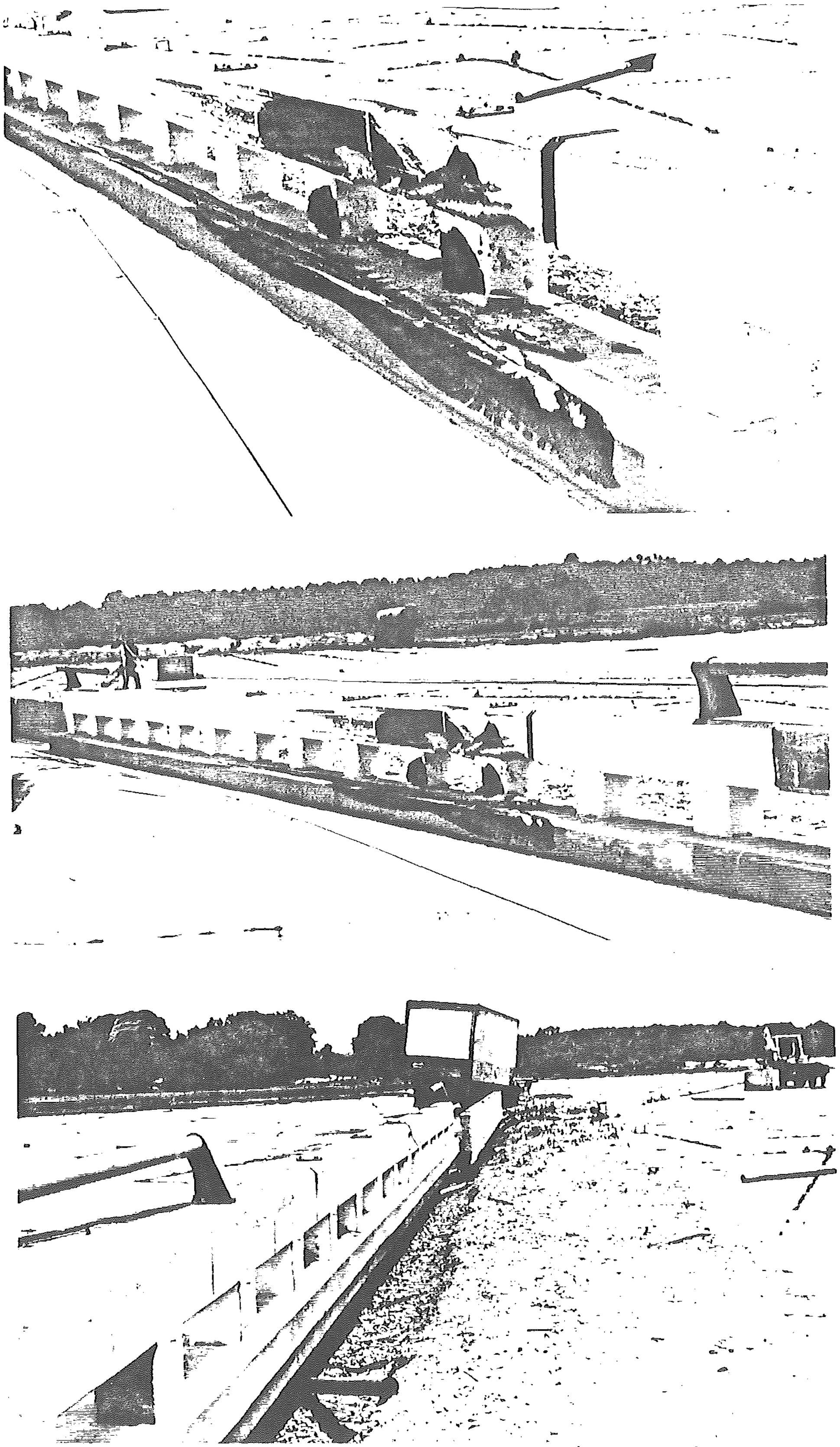


Figure 45. Posttest photographs of bridge rail system, test 1952-6-90.

2. MODIFIED OPEN PARAPET BRIDGE RAIL

a. Test 1952-7-91

(1). Test Device

The reaction of the aluminum tube rail to the impact of the 5400-lb pickup truck and the 18,000-lb straight truck was the main reason for the failure of the MDOT Open Parapet Bridge Rail. For this reason, the test device was modified by the removal of the aluminum tube rail from the top of the bridge railing. Figure 46 shows the test site layout. Figure 47 shows pretest photographs of the bridge rail system.

(2). Test Vehicle

The test vehicle was a 1982 Chevrolet C10 pickup. The target inertial vehicle weight was 5400 lb. The vehicle weighed approximately 3900 lb empty. Approximately 1500 lb of ballast were added. The ballasted inertial weight of the truck was 5403 lb. The gross vehicle weight was 5730 lb.

Two dummies were placed in the vehicle. The driver was unrestrained while the passenger was restrained. X-, y- and z-axis accelerometers were mounted in the cab of the truck along with roll and yaw rate gyros. Pretest photographs of the test vehicle are shown in figure 48. Table 7 lists important parameters of the test truck, comparing the actual parameters with the AASHTO Guide Specifications for Bridge Railings requirements.

(3). Impact Description

Review of the high speed films, speed trap and fifth wheel data indicated that the test vehicle impacted at 61.2 mi/h and 20 degrees. This review also indicated that the right corner of the vehicle impacted the desired point. The desired impact point was defined as midspan between posts 5 and 6 at the front face of the rail. With the face of the rail 9 in behind the front of the brushblock, the vehicle would actually impact the brushblock upstream of the impact line.

Table 7. Vehicle parameters, test 1952-7-91.

Item	Actual	Specification
Empty Weight	~3900 lb	n/a
Ballast	~1500 lb	n/a
Total Weight, Inertial	5403 lb	5400 lb
Total Weight, Gross	5730 lb	n/a
H_{cg}	27 in	27 ± 1 in
A (front to cg), Inertial	8.45 ft	8.5 ± 0.1 ft
B (width)	6.33 ft	6.5 ft
Truck Length	216 in	
Truck Wheelbase	132 in	
Wheel/Tire Size	195 75R15	
Truck Box Size	8 ft long by 1.5 ft high by 5.5 ft wide	
Ground to box floor	27 in	

Upon impact, the right front corner of the vehicle deformed significantly, with the hood passing over the top of the concrete rail. The vehicle rode up on top of the brushblock. The suspension and wheel/tire were pushed back. The windshield was popped out due to the deformation of the cab. The passenger side door was damaged due to the impact from the passenger dummy. The vehicle continued downstream slowly yawing positively. The vehicle came to rest 185 ft past the impact point, 2 ft behind the front face of the rail, at a slight angle to the line of the rail.

Upon impact, the unrestrained driver dummy slid toward the passenger dummy. The passenger dummy impacted the passenger side door with its shoulder, pushing the passenger side door out. The windshield popped out due to the deformation of the cab. The driver came to rest with its head on the middle of the dashboard. The passenger came to rest lying on the seat toward the driver side, behind the driver.

A summary of test conditions and results are shown in figure 49. Data analysis was performed. The x-axis and y-axis, 100 Hz acceleration traces are shown in figure 50.

(4). Vehicle Damage

Damage occurred to the front and entire right side of the vehicle. The bumper and front fender were pushed into the engine compartment. The front suspension and wheel/tire were pushed back and deformed the occupant compartment. The windshield had popped out due to deformation of the cab. The passenger side door was deformed and the passenger side window had been punched out by the impact of the dummy's head. Posttest photographs of the truck are shown in figure 51.

(5). Bridge Rail Damage

The bridge rail suffered some cosmetic damage but no structural damage during this impact. There was scrub on the brushblock for 40 ft beginning 2.5 ft before impact. There was major scrub on the rail for 15 ft beginning 1.5 ft upstream of impact. Minor scrub on the rail continued for another 30 ft. There was major scrub on posts 6 through 8. Spalling occurred to the brushblock, rail and posts 6 through 8. The patch on the underside of the midspan posts 7 and 8 rail was spalled off in this impact. Posttest photographs of the bridge rail are shown in figure 52.

(6). Test Evaluation

This test was evaluated using the AASHTO Guide Specifications for Bridge Railings. The following is an item by item evaluation using this guideline.

- AASHTO Guide Specifications for Bridge Railings:

Required Criteria:

a. The vehicle was contained by the test article.
b. There were no detached elements.
c. **Integrity of the passenger compartment was not maintained. The suspension and tire/wheel deformed the occupant compartment.**
d. The vehicle remained upright.

Desirable Criteria:

e. The vehicle was smoothly redirected.
f. Vehicle railing interaction:
mu = 0.84, assessment: Marginal
g. **Longitudinal Ridedown value greater than limits.**
h. The exit angle was less than 12°. The vehicle was within 20 ft of the rail, 100 ft downstream of the impact point.

TEST ARTICLE FAILS DUE TO OCCUPANT COMPARTMENT DEFORMATION.

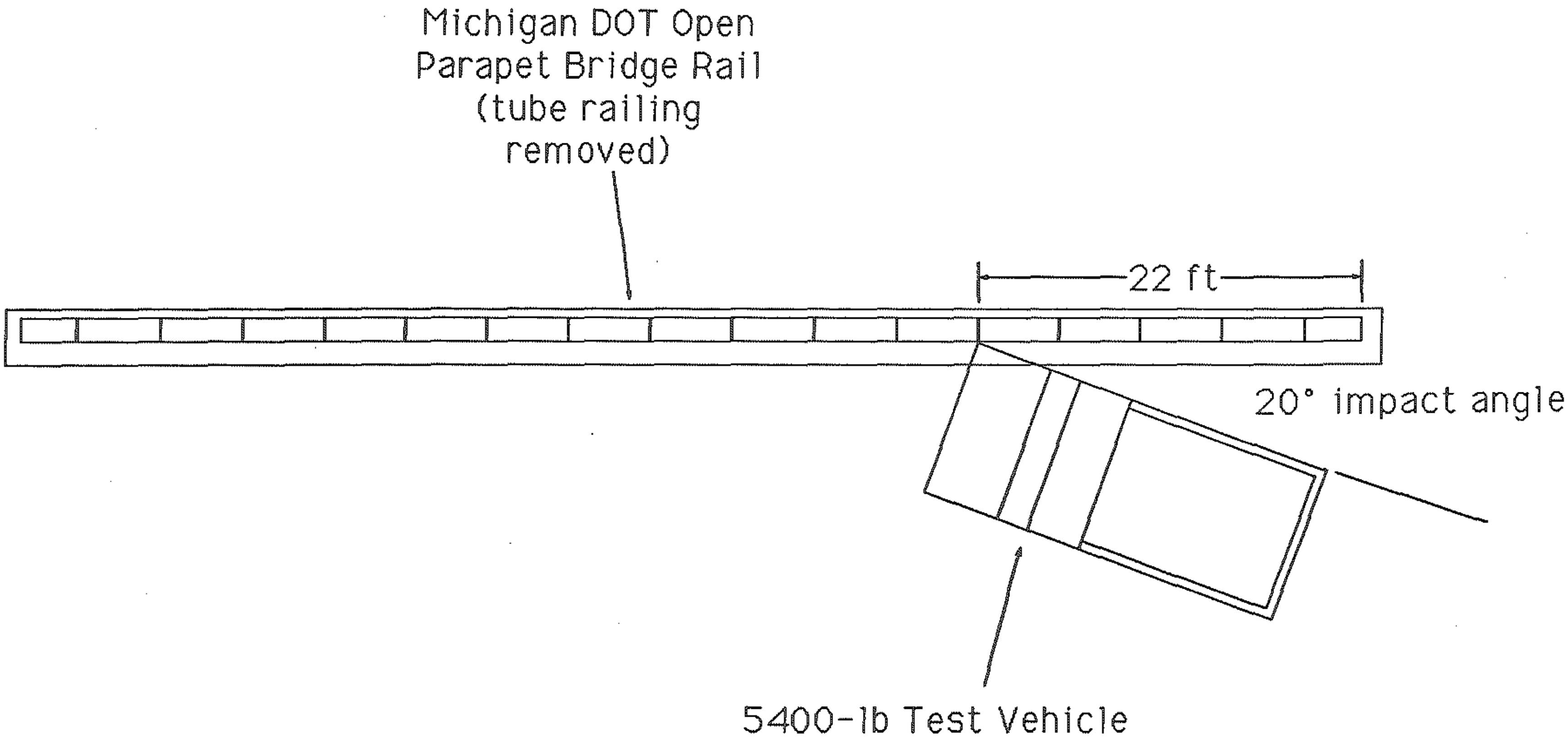


Figure 46. Test site layout, test 1952-7-91.

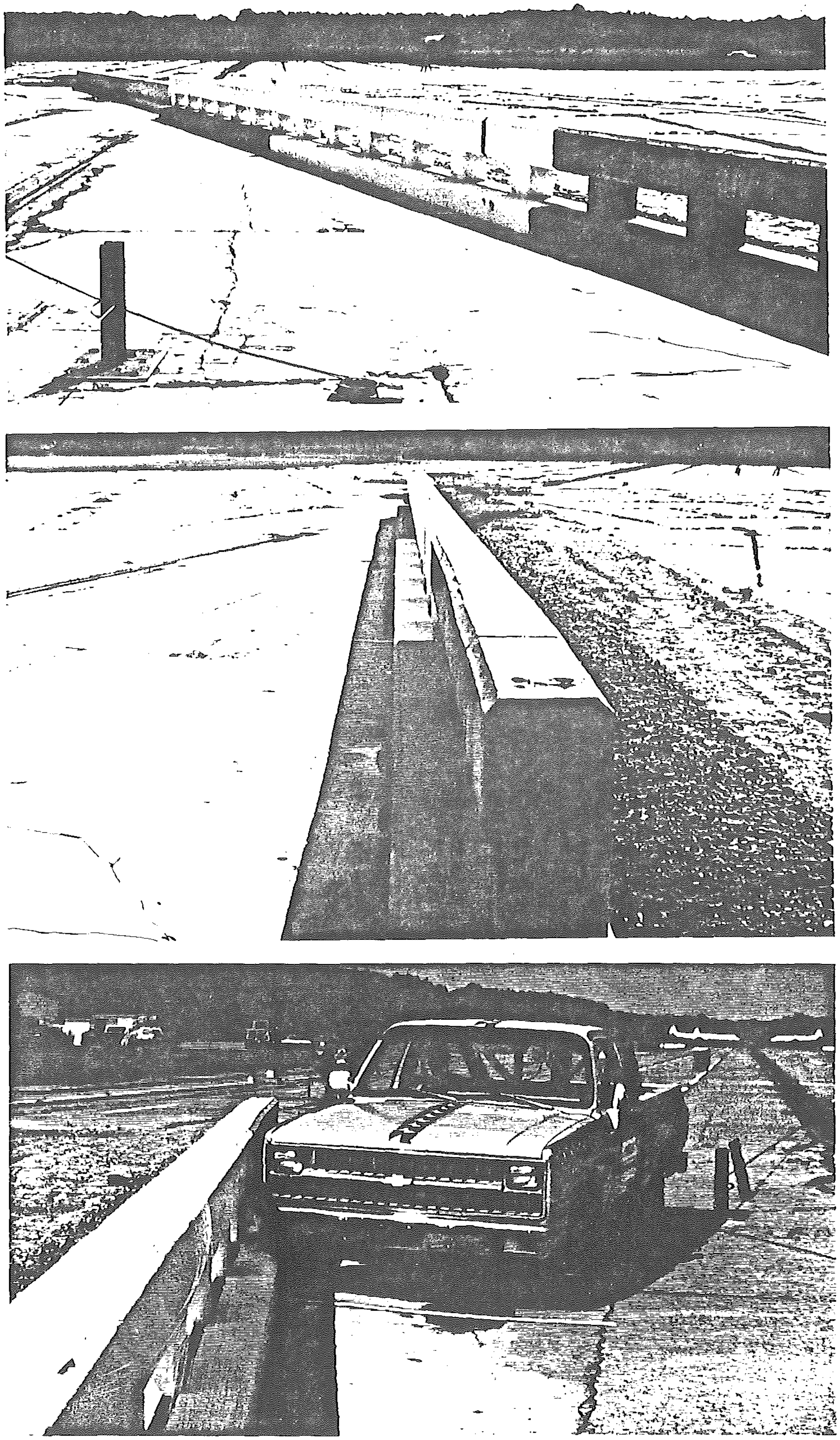


Figure 47. Pretest photographs of bridge rail system, test 1952-7-91.

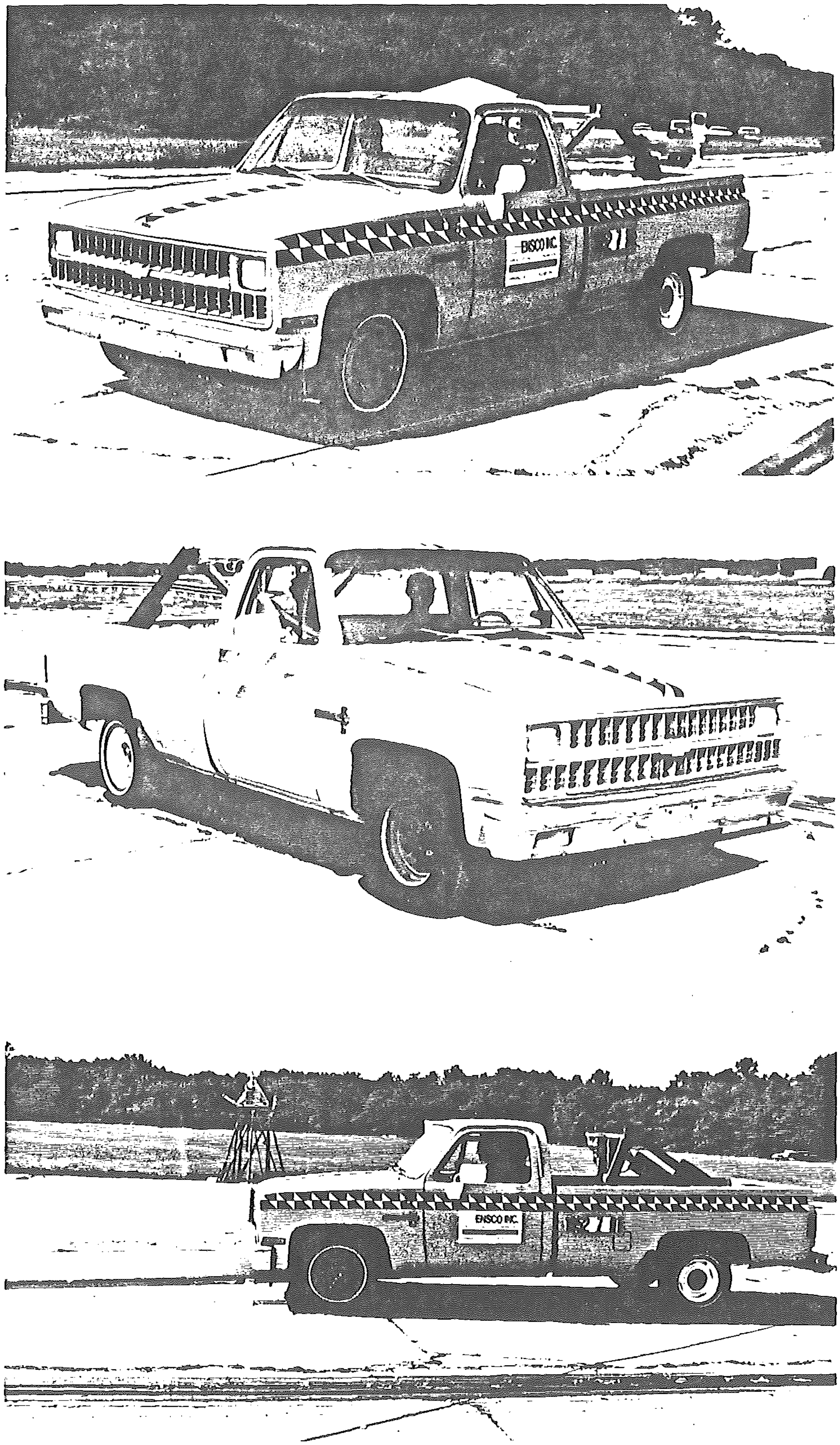
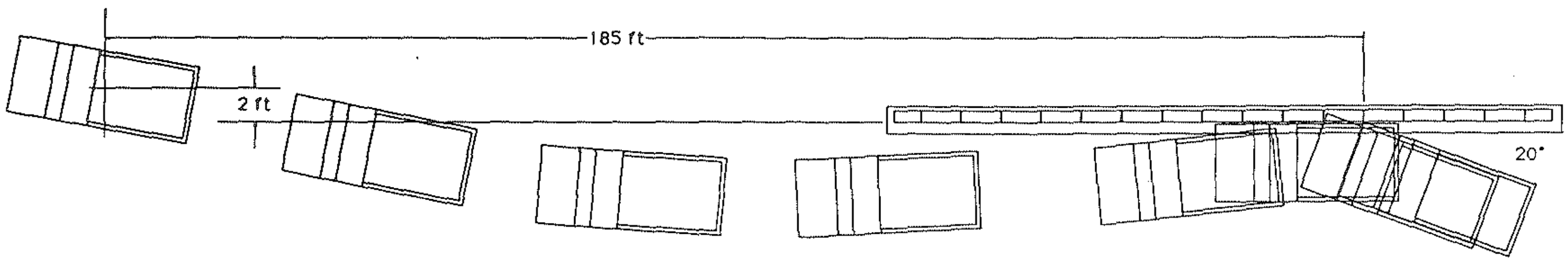


Figure 48. Pretest photographs of test vehicle, test 1952-7-91.



Date: 21 August 1991
Weather: Clear, 80° F

Test Vehicle: 1982 Chevrolet C10 Pickup

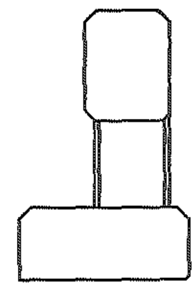
Device Configuration: Michigan DOT Open Parapet Bridge Rail, with aluminum tube railing removed. 78-ft, 8-in deck, 10-in by 23.5-in brushblock, 10.5-in by 15-in posts, 12-in by 15-in rail, 12 in from bottom of rail to top of brushblock.

1. Vehicle Weight:
   - Planned, Inertial: 5400 lb
   - Actual, Inertial: 5403 lb
   - Actual, Gross: 5730 lb
2. Number of Occupants: Two
3. Occupant Model: Part 572, 50 percentile male
4. Occupant Locations: Driver Seat, Unrestrained; Passenger Seat, Restrained
5. Impact:

	Speed	Angle	Location
Planned:	60.0 mi/h	20°	Midspan posts 5 and 6
Actual:	61.2 mi/h	20°	Midspan posts 5 and 6

   Tolerances: Speed: -1.0, +2.5 mi/h; Angle: -1.0, +2.5 degrees

6. Redirection Angle: 4.5 degrees
7. Redirection Speed: 33.8 mi/h (49.6 ft/s)
8. Total Speed Change: 27.4 mi/h (40.1 ft/s)
9. Total Momentum Change: 7136 lb-sec
10. Vehicle Damage Index: (SAE J224a) 01RFEW3
11. AASHTO Test Type: PL2



12. Vehicle Analysis:

	Observed	AASHTO Limits
NCHRP 230:		
Longitudinal:		
Delta-V at 2 ft:	-25 ft/s	30 ft/s
Ridedown Acceleration:	-17 g's	15 g's
Lateral:		
Delta-V at 1 ft:	23 ft/s	25 ft/s
Ridedown Acceleration:	14 g's	15 g's
TRC 191:		
Peak 50 ms acceleration:		
Longitudinal:	-8.4 g's	
Lateral:	10.3 g's	

13. Vehicle-Railing Interaction Coefficient of Friction:

$$mu = \frac{\text{Cos theta} - V_P/V}{\text{Sin theta}}$$

mu	assessment
0.84	Marginal

V_p = 39.9 (58.5 ft/s)

14. Test Results Conclusion:

AASHTO Guide Specifications for Bridge Railings: **TEST ARTICLE FAILS DUE TO OCCUPANT COMPARTMENT DEFORMATION.**

Figure 49. Test summary, test 1952-7-91.

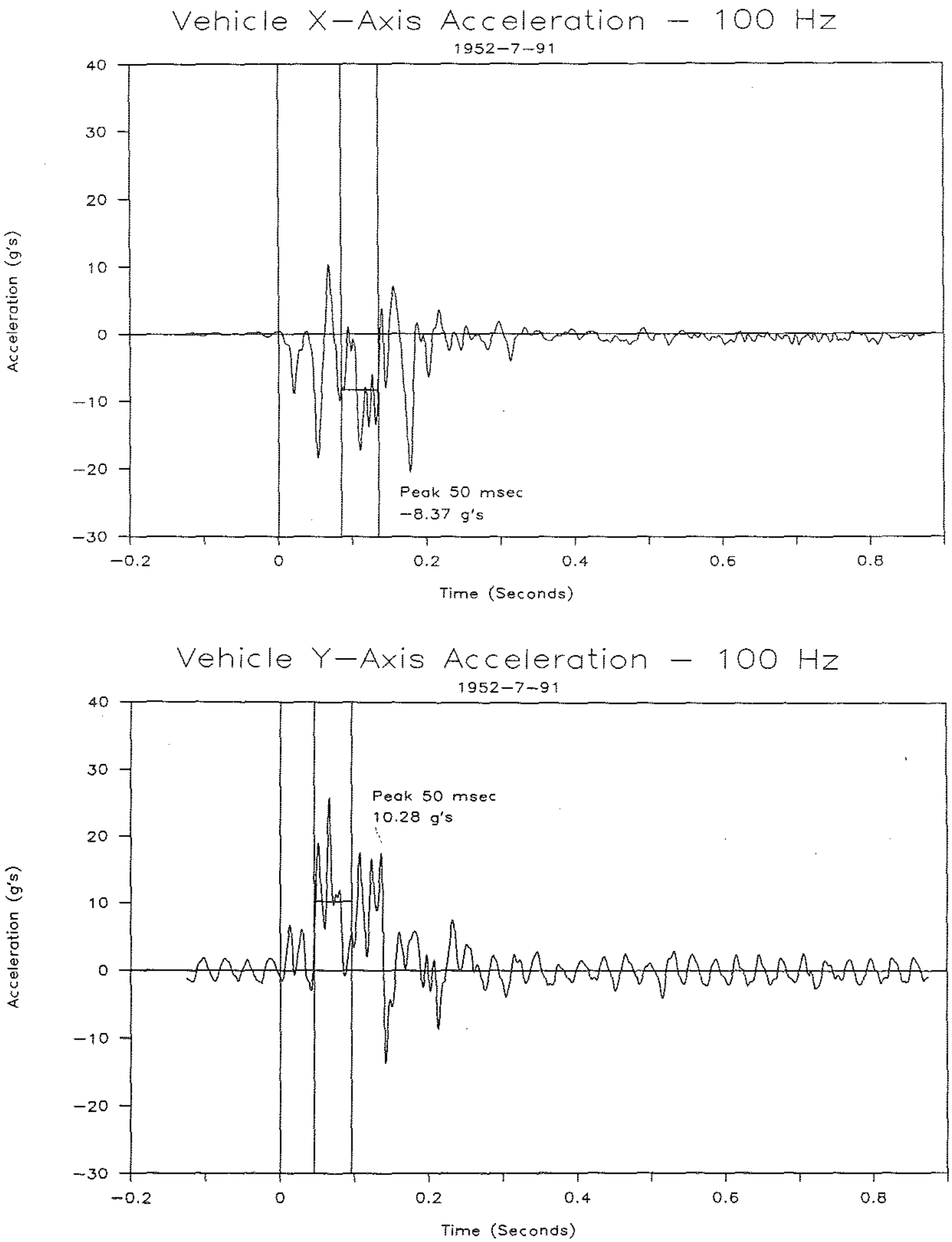


Figure 50. Vehicle acceleration, test 1952-7-91.

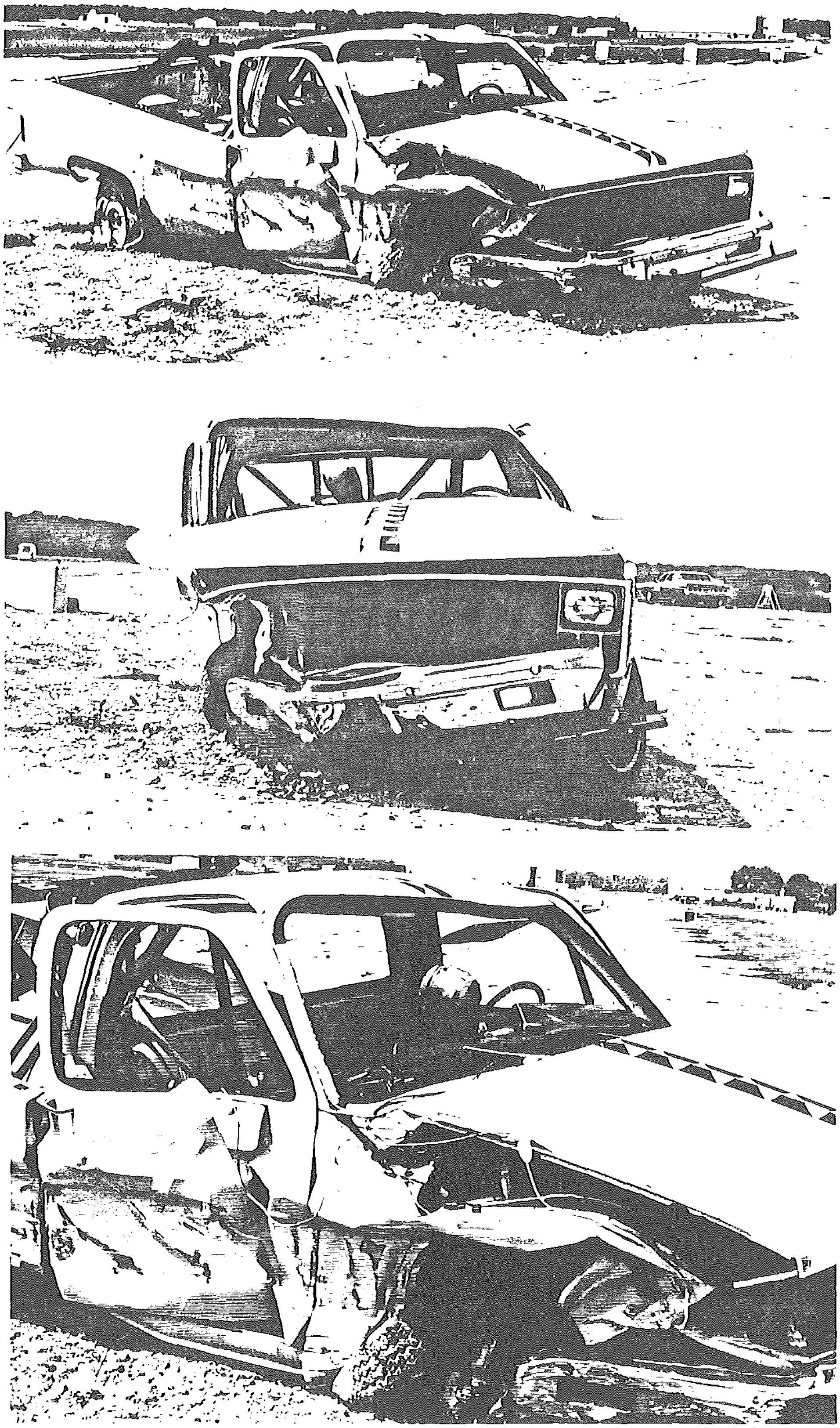


Figure 51. Posttest photographs of test vehicle, test 1952-7-91.

Figure 51 (continued). Posttest photographs of test vehicle, test 1952-7-91.

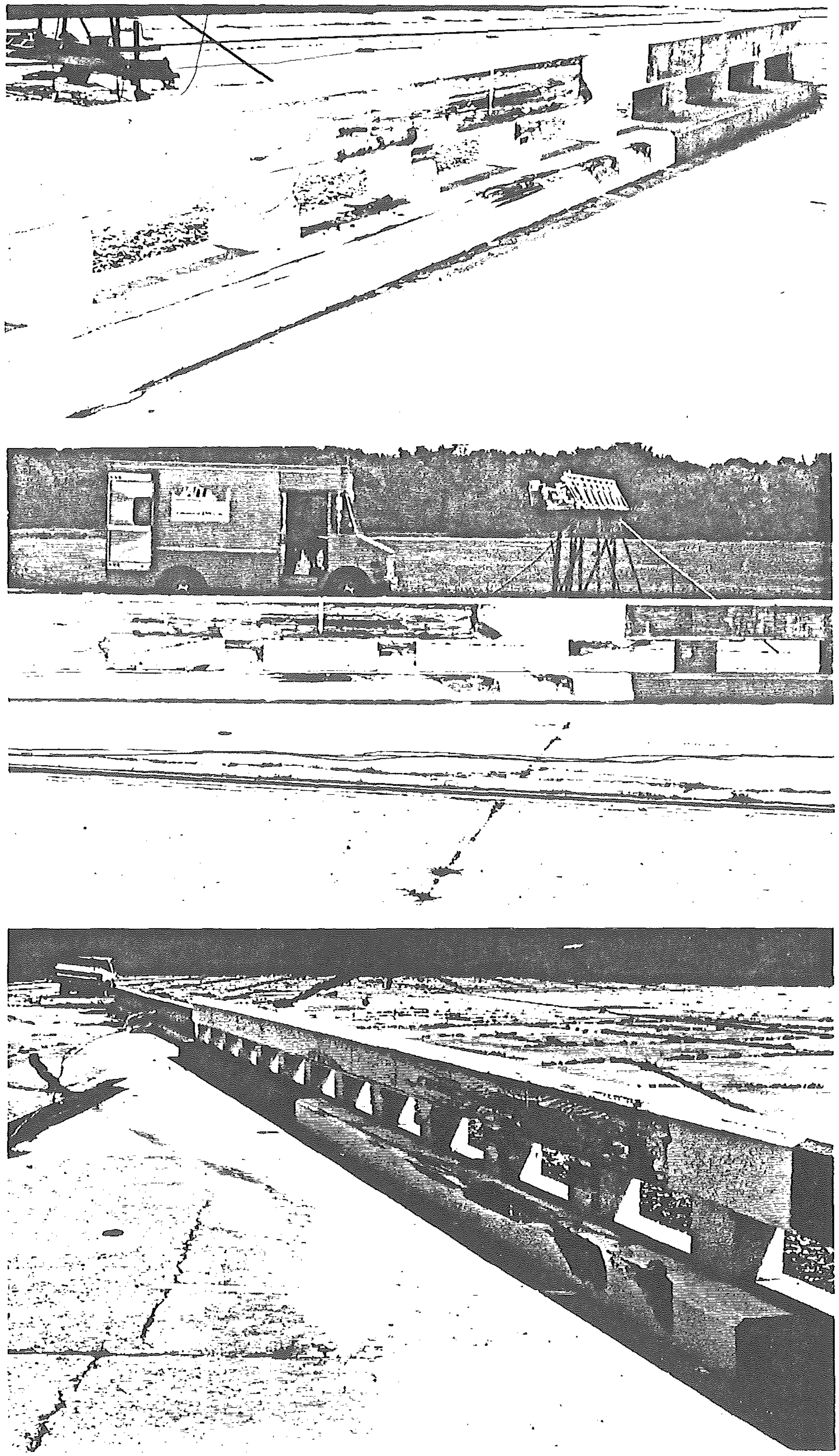


Figure 52. Posttest photographs of bridge rail system, test 1952-7-91.

3. CONCLUSIONS

a. Open Parapet Bridge Rail

The Open Parapet Bridge Rail was tested with an 1800-lb car, a 5400-lb pickup truck and an 18,000-lb straight truck, with the following conclusions:

(1). The 1800-lb car test was <u>not</u> successful. The data needed to calculate the delta-V and ridedown acceleration values was not collected, and this is a required criterion. All of the available data collected indicated that this test met all other required criteria for NCHRP 230 and the AASHTO Guide Specifications for Bridge Railings.

(2). The 5400-lb pickup truck test was <u>not</u> successful. This test failed AASHTO Guide Specifications for Bridge Railings required criterion c. Integrity of the passenger compartment was not maintained when the hood penetrated into the occupant compartment. Furthermore, the test also failed desirable criteria e., f. and g. The vehicle snagged causing undesirable yaw of the vehicle, the vehicle-railing interaction could not be computed because the vehicle never became parallel with the rail and the longitudinal delta-V exceeded the limit.

(3). The 18,000-lb straight truck test was <u>not</u> successful. This test failed AASHTO Guide Specifications for Bridge Railings required criterion b. The aluminum tube railing was detached from the concrete bridge rail. The railing showed the potential for penetration of the occupant compartment and creation of a hazard to other traffic. Furthermore, the test also failed desirable criteria e. and f. The vehicle snagged causing undesirable yaw of the vehicle and the vehicle-railing interaction could not be computed because the vehicle never became parallel with the rail.

b. Modified Open Parapet Bridge Rail

The test of the Modified Open Parapet Bridge Rail with the 5400-lb pickup truck was **not** successful. This test failed AASHTO Guide Specifications for Bridge Railings required criterion c. Integrity of the passenger compartment was not maintained when the suspension and tire/wheel deformed the occupant compartment. Furthermore, the test also failed desirable criterion g. The longitudinal ridedown acceleration exceeded the limit. Removal of the aluminum tube railing, however, eliminated the problem of hood snag on the tube railing posts, as occurred in test 1952-5-90.

REFERENCES

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