CRASH TESTING OF MICHIGAN'S TYPE B (W-BEAM) GUARDRAIL SYSTEM

Submitted by

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16. Abstract (Limit: 200 words)

Michigan Department of Transportation's Type B (W-beam) longitudinal barrier system was constructed and crash tested. The barrier design was constructed with a 2.66-mm (12-gauge) thick W-beam rail totaling 53.34 m in length. The W-beam rail was supported by twenty-five W152x13.4 steel posts, each measuring 1,830-mm long, and four standard BCT posts, each measuring 1,080-mm long. Each of the steel posts had a 152x203 by 390-mm long double-tapered wood offset blockout. Post spacings were 1,905-mm on center.

The research study included full-scale vehicle crash testing, using a ¾-ton pickup truck. The test, impacting at a speed of 99.8 km/hr and an angle of 25.8 degrees, was unsuccessful due to vehicle rollover. The safety performance of Michigan's Type B (W-beam) longitudinal barrier system was determined to be unacceptable according to Test Level 3 (TL-3) evaluation criteria specified in NCHRP Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features.*

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1 INTRODUCTION

1.1 Problem Statement

For many years, the Michigan Department of Transportation (MDOT) has constructed a W-beam guardrail system along their highways. Although this guardrail system has performed acceptably in the field, no full-scale vehicle crash tests had been conducted on the system to evaluate its safety performance under current National Cooperative Highway Research Program (NCHRP) Report No. 350 requirements. However, in recent years, the safety performance of guardrail systems has been a concern to researchers and designers. Previous crash testing efforts on W-beam guardrail systems have had mixed results (1-3).

MDOT's Type B (W-beam) longitudinal barrier system has modest differences from barriers currently certified to Test Level 3 (TL-3) safety performance criteria NCHRP Report No. 350. The differences include: (1) a reduction in the midpoint mounting height of the W-beam rail from 550 mm to 530 mm; (2) the use of a non-routed blockout with a nail to resist block rotation rather than a routed wood blockout; (3) an increased blockout distance of 10 mm due to the use of a non-routed wood blockout; and (4) a decrease in post embedment depth by 2 mm. The change in mounting height and non-routed wood blockouts are the significant differences between the Michigan standard and existing compliant systems. The researchers believed that the use of non-routed wood blockouts should not adversely effect the guardrail system's safety performance. However, the slightly reduced W-beam mounting height could effect the interaction between the vehicle's front suspension and the W-beam. Due to the differences, it was decided that MDOT's Type B (W-beam) guardrail system should be crash tested and shown to meet current impact safety standards in order for its use to be continued on Federal-aid highways.

1.2 Objective

The objective of the research project was to evaluate the safety performance of the MDOT's Type B (W-beam) guardrail system. The guardrail system was evaluated according to the TL-3 safety performance criteria set forth in the NCHRP Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (4). In the case of unsatisfactory performance of the current design, another objective was the recommendation of design modifications to improve system performance.

1.3 Scope

The research objective was to be achieved by performing several tasks. First, a literature review was performed on the previous testing on W-beam guardrail systems. Next, a full-scale vehicle crash test was performed using a ¾-ton pickup truck, weighing approximately 2,000 kg, with a target impact speed and angle of 100.0 km/hr and 25 degrees, respectively. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made that pertain to the safety performance of the W-beam guardrail system.

2 LITERATURE REVIEW

The W-beam guardrail system is one of the most commonly used guardrail systems on our nation's highways. Previous testing has shown that containing and redirecting the impacting vehicle depends on the interaction of the front suspension and the W-beam (1-3). Essentially, the impacting vehicle is partially restrained as the tire is captured under the rail.

A W-beam, wood-post guardrail system was successfully tested according to TL-3 of NCHRP Report No. 350 by Texas Transportation Institute (TTI) (1). The guardrail system was constructed with 2.66-mm (12-gauge) thick guardrail elements and was supported by 152 mm x 203 mm timber posts with 152 mm x 203 mm by 356-mm long wooden blockouts. Post spacings were 1.9-m on center. The guardrail mounting height was 550 mm to the center of the W-beam rail element.

A W-beam, steel-post guardrail system was also tested according to TL-3 of NCHRP Report No. 350 by TTI (1). During the impact, the pickup truck was contained but after redirection the vehicle rolled onto its side, thus resulting in a failure of the NCHRP Report No. 350 crash test requirements. The guardrail system was constructed with 2.66-mm (12-gauge) thick guardrail elements and was supported by W152x12.6 steel posts with W152x12.6 by 356-mm long steel blockouts. Post spacings were 1.9-m on center. The guardrail mounting height was 550 mm to the center of the W-beam rail element.

Subsequently, TTI successfully developed and tested a modified W-beam, steel-post guardrail system according to TL-3 of NCHRP Report No. 350 (2). The key difference between the modified and previously tested W-beam system was the use of 152-mm wide x 203-mm deep x 360-mm long routed wood blockouts in place of the W152x12.6 by 356-mm long steel blockouts. The system was constructed with 2.66-mm (12-gauge) thick guardrail elements and was supported by W152x12.6 steel posts spaced 1.9-m on center. The guardrail mounting height was 550 mm to the center of the W-beam rail element.

A W-beam, round wood-post guardrail system was successfully tested with a pickup truck according to TL-3 of NCHRP Report No. 350 by TTI (3). The guardrail system was constructed with standard 2.66-mm (12-gauge) W-beam rail elements and was supported by 184-mm diameter posts with 146 mm x 146 mm by 356-mm long chamfered wooden blockouts that had one concave surface to match the curvature of the posts. Post spacings were 1,905-mm on center. This system was also certified to perform satisfactorily with an 820-kg small car without further testing due to the successful test of a similar system with a small car (3).

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as W-beam guardrail systems, must satisfy the requirements provided in NCHRP Report No. 350 to be accepted for use on new construction projects or as a replacement for existing designs not meeting current safety standards. According to Test Level 3 (TL-3) of NCHRP Report No. 350, W-beam guardrail systems must be subjected to two full-scale vehicle crash tests: (1) a 2,000-kg pickup truck impacting at a speed of 100.0 km/hr and at an angle of 25 degrees; and (2) an 820-kg small car impacting at a speed of 100.0 km/hr and at an angle of 20 degrees. However, W-beam barriers struck by small cars have been shown to meet safety performance standards, being essentially rigid (5-7), with no significant potential for occupant risk problems arising from vehicle pocketing or severe wheel snagging on the posts downstream of impact. Therefore, the 820-kg small car crash test was deemed unnecessary for this project.

3.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the barrier to contain, redirect, or allow controlled vehicle penetration in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle accidents. It is also an indicator for the potential safety hazard for the occupants of the other vehicles or the occupants of the impacting vehicle when subjected to secondary collisions with other fixed objects. These three evaluation criteria are defined in Table 1. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in NCHRP Report No. 350.

Table 1. NCHRP Report 350 Evaluation Criteria for 2000P Pickup Truck Crash Test (4)

Structural Adequacy	A. 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.
Occupant Risk	D. Detached elements, fragments or other debris from the test article should 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. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.
	F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.
	M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test devise.

4 GUARDRAIL DESIGN

The total length of the test installation was 53.34 m, as shown in Figure 1. Photographs of the test installation are shown in Figures 2 through 4. The test installation consisted of standard 12-gauge W-beam guardrail supported by steel posts and an anchorage system replicating a Breakaway Cable Terminal (BCT) on both the upstream and downstream ends but installed tangent to the guardrail system and without the buffer head.

The entire system was constructed with twenty-nine guardrail posts. Post nos. 3 through 27 were galvanized ASTM A36 steel W152x13.4 sections measuring 1,830-mm long. Post nos. 1 through 2 and 28 through 29 were timber posts measuring 140-mm wide x 190-mm deep x 1,080-mm long and were placed in steel foundation tubes. The timber posts and foundation tubes were part of an anchor system, similar to a BCT but installed tangent to the system, used to develop the required tensile capacity in the guardrail. Lap-splice connections between the rail sections were configured to reduce vehicle snagging at the splice during the crash test.

Post nos. 1 through 29 were spaced 1,905-mm on center. For post nos. 3 through 27, the soil embedment depth was 1,100 mm. The posts were placed in a compacted coarse, crushed limestone material that met Grading B of AASHTO M147-65 (1990) as found in NCHRP Report No. 350. The guardrail posts were installed by auguring 610-mm diameter holes approximately 1,092-mm deep and installing 152-mm to 203-mm lifts, with optimum moisture (7% by dry weight), tamped with air tamper to a density of approximately 21.4 kN/m^3.

In addition, 150-mm wide x 200-mm deep x 390-mm long double-tapered, wood offset-spacer blockouts were used to block the rail away from post nos. 3 through 27. For the test, two 16-penny, ungalvanized nails were installed 25-mm down from the top of the front-face of the post along both the upstream and downstream edges of the post for each wood blockout in order to prevent wood blockout rotation. The nails were driven 51 mm into the wood blockout and then the top 25 mm of the nail was bent around the post, as shown in Figures 1 and 4. MDOT's standard requires hot-dipped zinc coated nails.

All guardrail used throughout the installation consisted of 2.66-mm (12-gauge) thick W-beam rail. Specific details regarding the lengths and positions of guardrail sections are provided in Figure 1. The mounting height of the W-beam rail was 686 mm, as measured from the ground to the top of the rail.

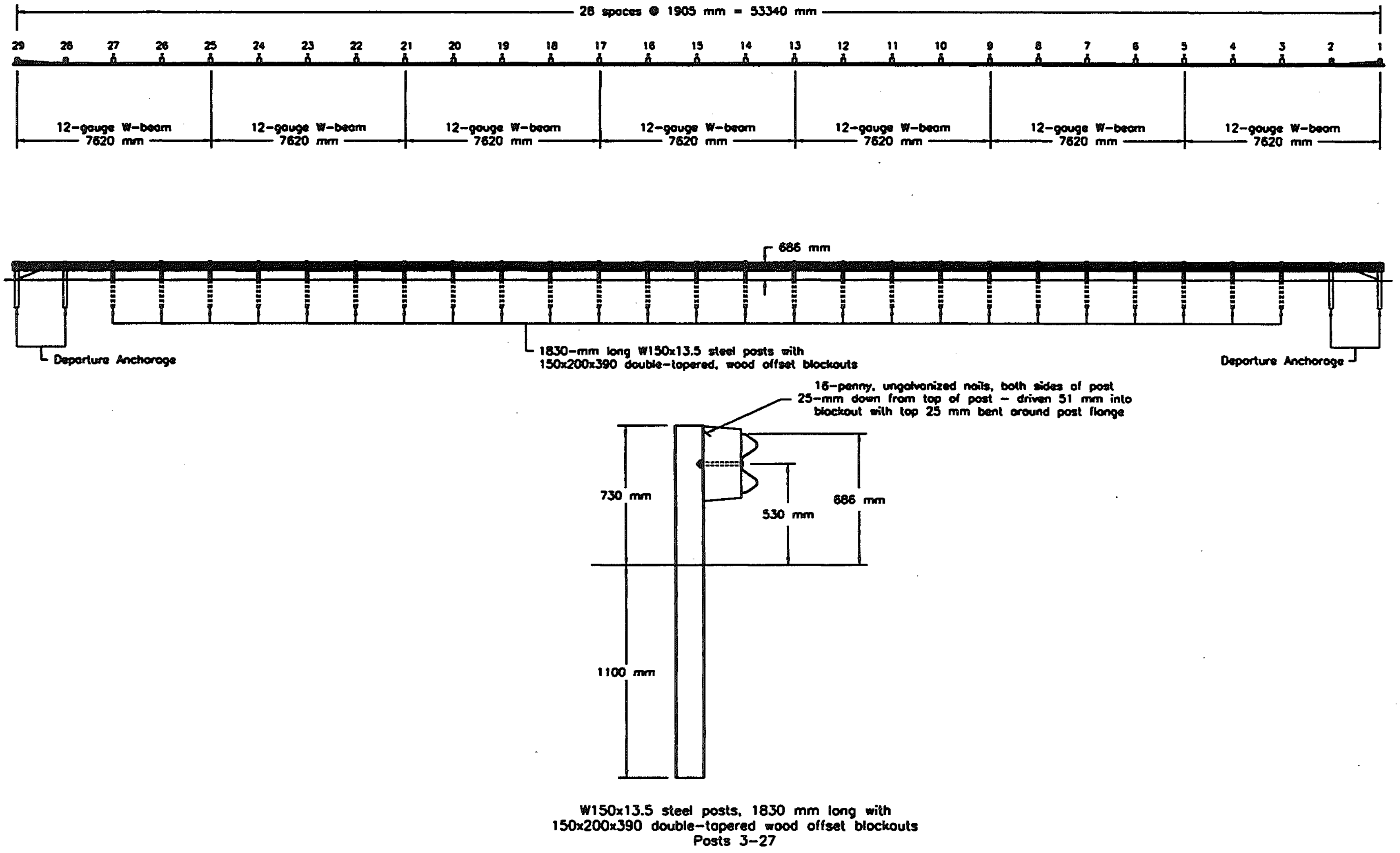


Figure 1. Type B (W-beam) Longitudinal Barrier System

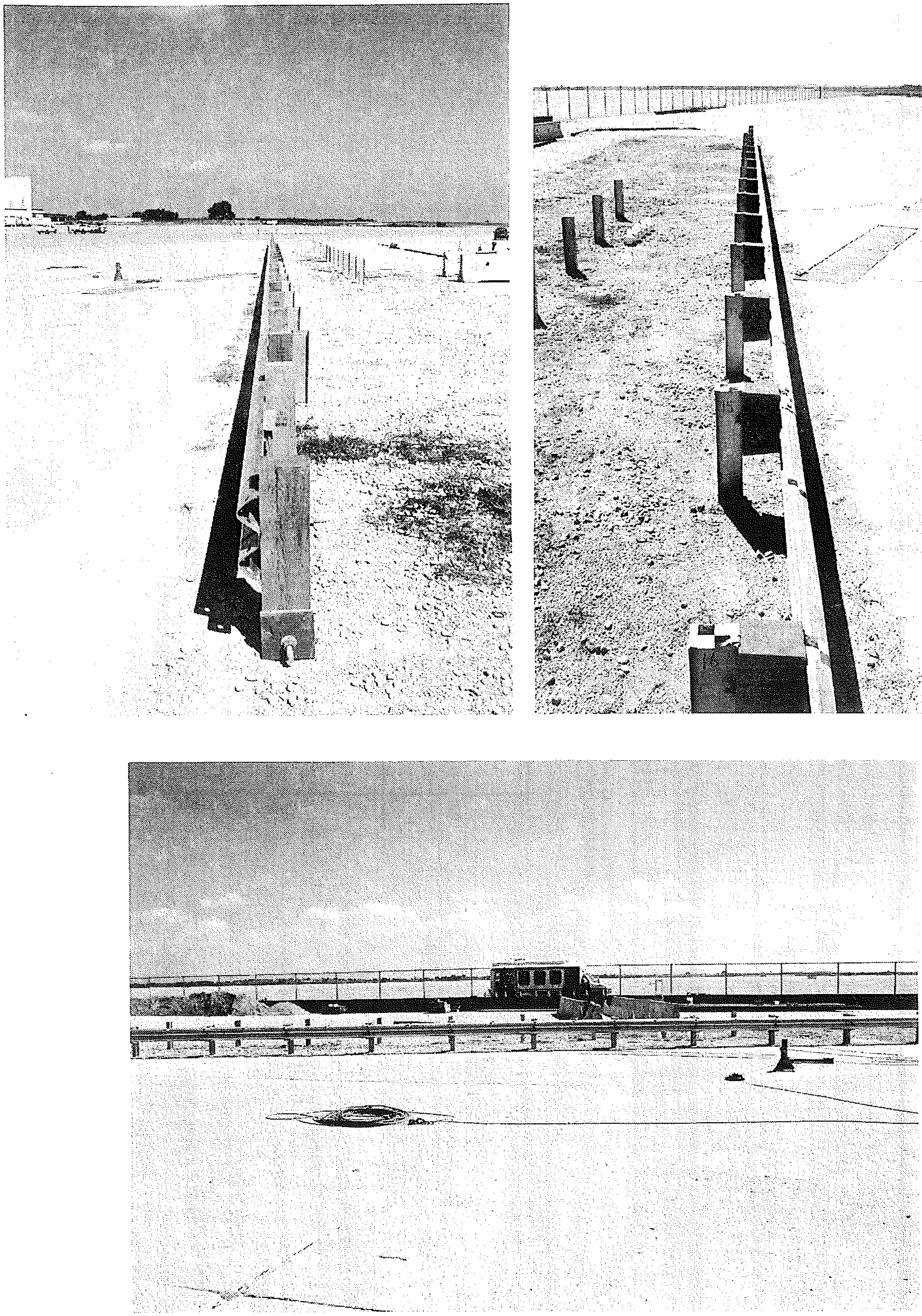


Figure 2. Type B (W-beam) Longitudinal Barrier System

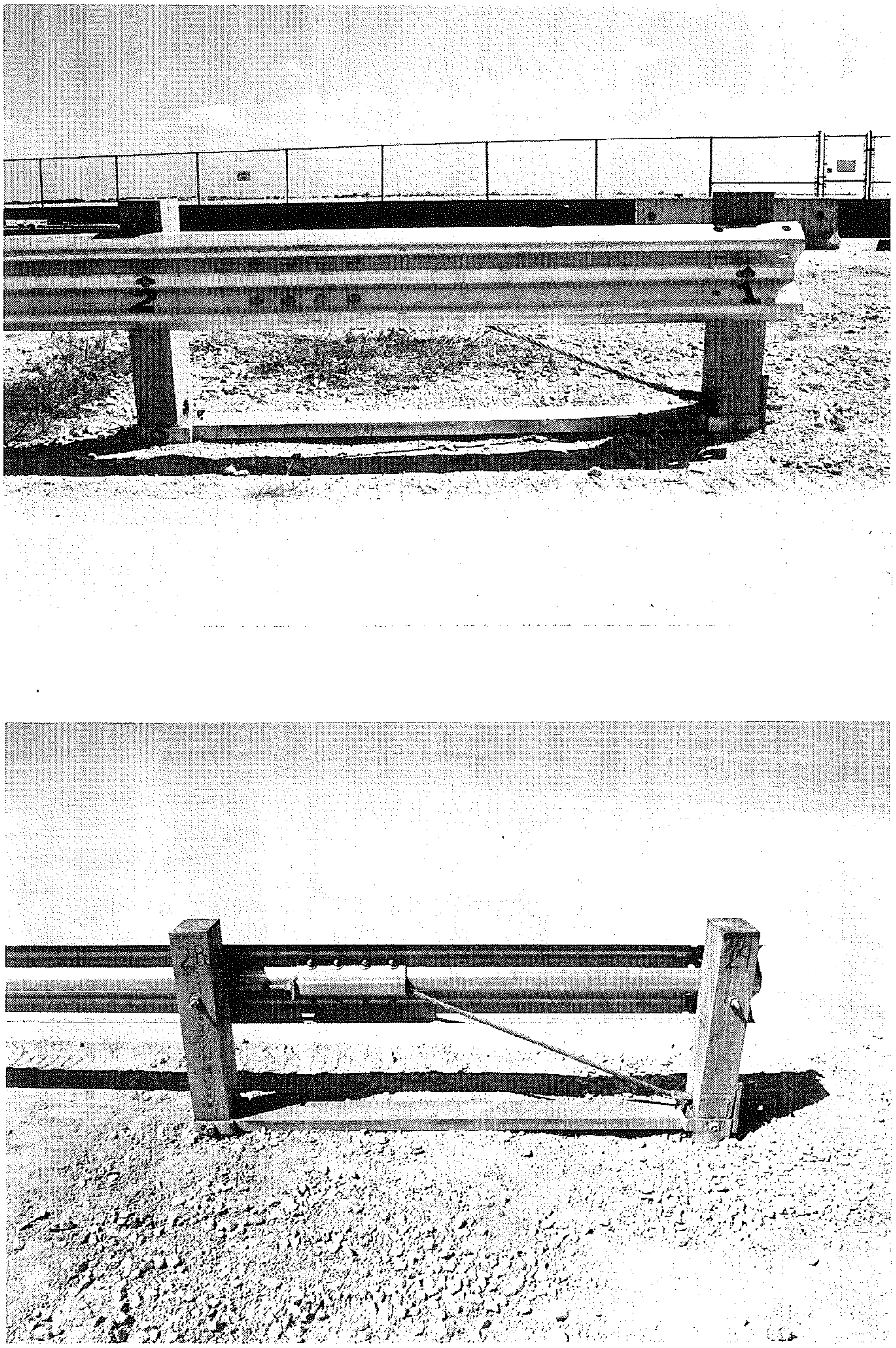


Figure 3. Simulated End Anchorage for Longitudinal Barrier System

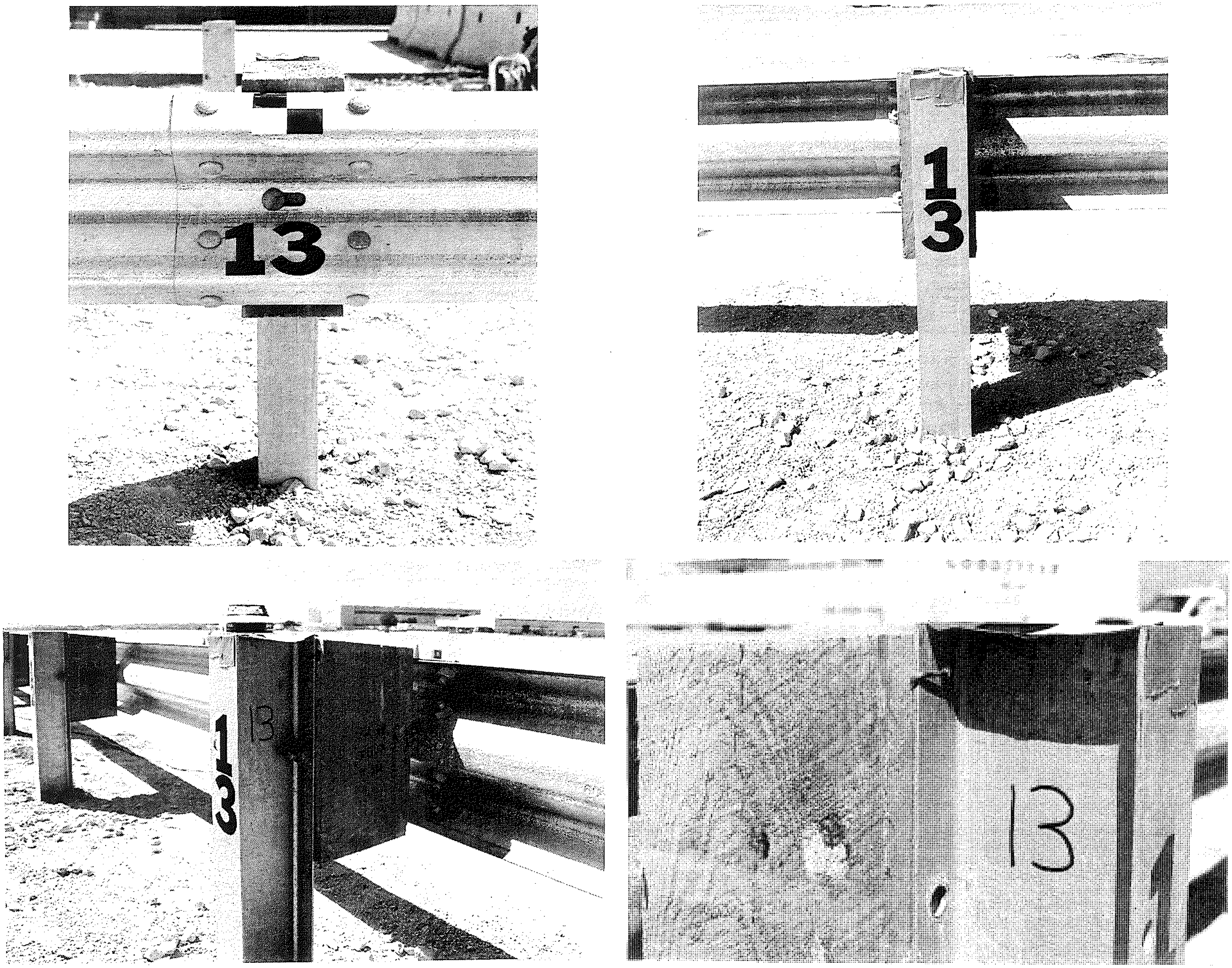


Figure 4. Post-to-Rail Attachment for the Type B (W-beam) Longitudinal Barrier System

5 TEST CONDITIONS

5.1 Test Facility

The testing facility is located at the Lincoln Air-Park on the NW end of the Lincoln Municipal Airport and is approximately 8.0 km NW of the University of Nebraska-Lincoln. The site is protected by a 2.44-m high chain-link security fence.

5.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the guardrail. A digital speedometer in the tow vehicle was utilized to increase the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (8) was used to steer the test vehicle. A guide-flag, attached to the front-left wheel and the guide cable, was sheared off before impacting the guardrail. The 9.5-mm diameter guide cable was tensioned to approximately 13.3 kN, and supported by hinged stanchions in the lateral and vertical directions and spaced at 30.48 m initially and at 15.24 m toward the end of the guidance system. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. The vehicle guidance system was approximately 457.2-m long.

5.3 Test Vehicle

For test MIW-1, a 1994 GMC 2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,007 kg. The test vehicle is shown in Figure 5, and vehicle dimensions are shown in Figure 6.

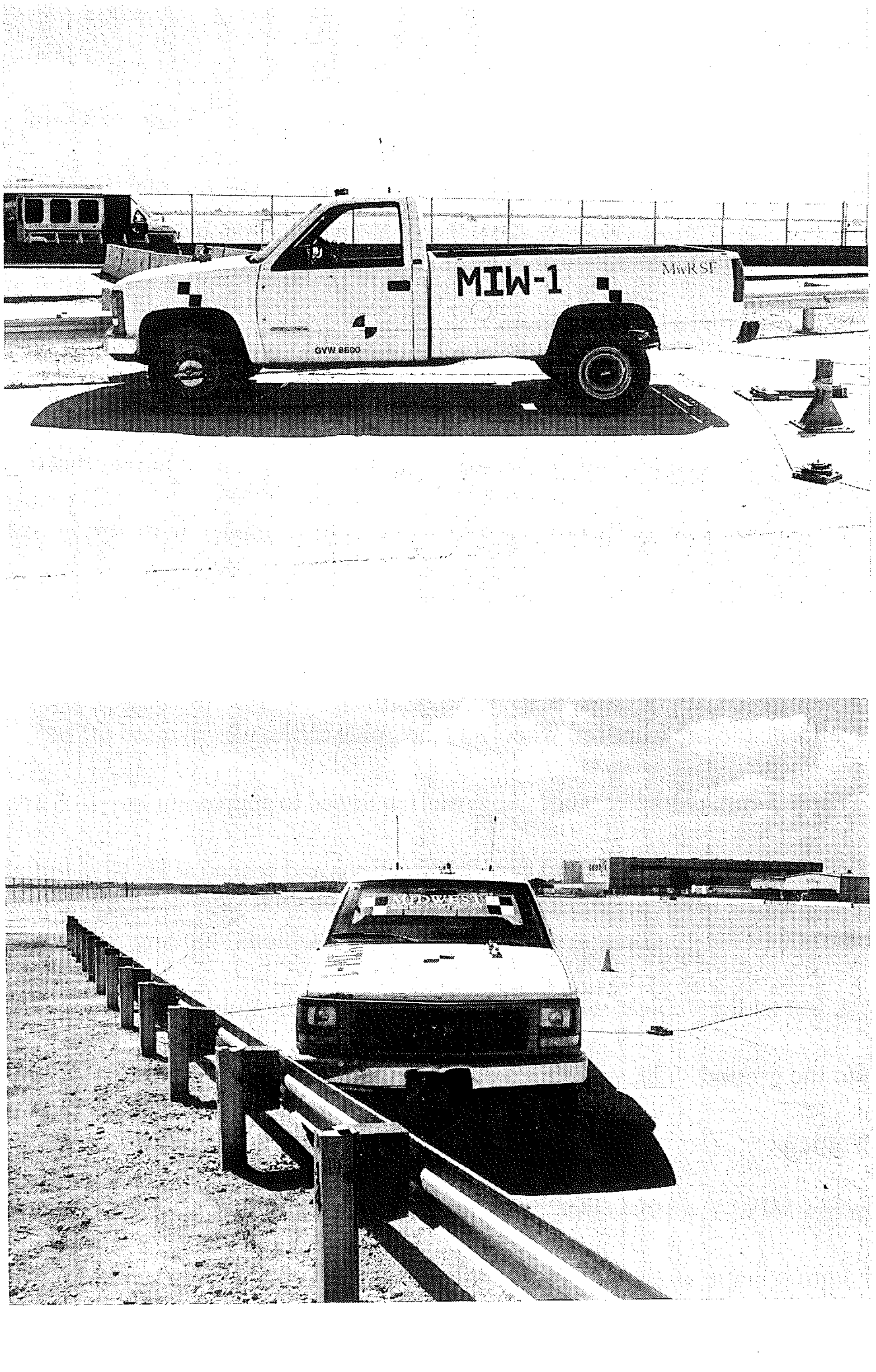


Figure 5. Test Vehicle, Test MIW-1

Date: 8/25/99 Test Number: MIW-1 Model: 2500

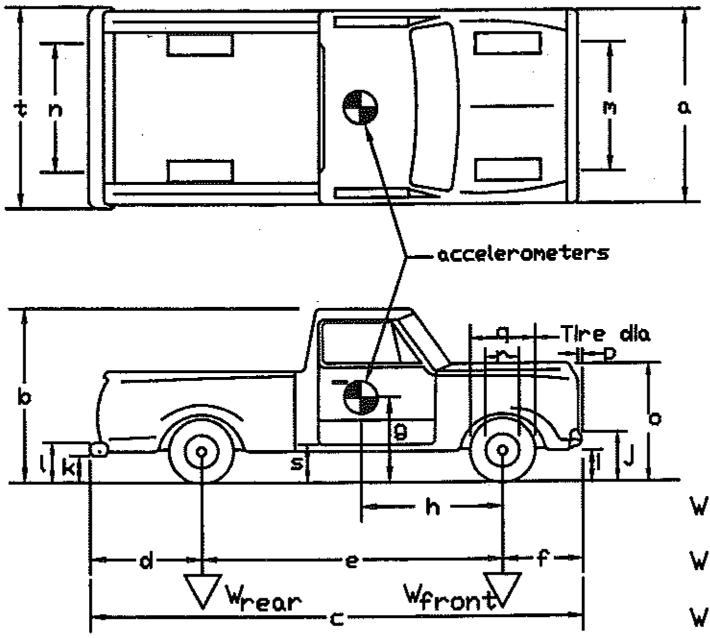
Make: GMC Vehicle I.D.#: 1GDGC24K0RE522202

Tire Size: 245/75R16 Year: 1994 Odometer: 207330

*(All Measurements Refer to Impacting Side)

Vehicle Geometry - mm

a 1892 b ---
c 5499 d 1295
e 3327 f 889
g 738 h 1409
i 489 j 648
k 603 l 794
m 1607 n 1619
o 1010 p 95
q 762 r 445
s 470 t 1867



Wheel Center Height Front 365
Wheel Center Height Rear 368
Wheel Well Clearance (FR) 889
Wheel Well Clearance (RR) 953

Engine Type V-8
Engine Size 5.7L 350CID
Transmission Type:
[✓ Automatic] or Manual
FWD or [✓ RWD] or 4WD

Weights - kg	Curb	Test Inertial	Gross Static
Wfront	1167	1157	1157
Wrear	854	850	850
Wtotal	2021	2007	2007

Note any damage prior to test: NONE

Figure 6. Vehicle Dimensions, Test MIW-1

For ¾-ton pickup trucks, the vertical component of the center of gravity (c.g.) is periodically measured using the Suspension Method (9) to determine if the c.g. falls within the specified range. However, for test MIW-1, the c.g. was not physically measured as it was estimated to be comparable to previously measured ¾-ton pickup trucks of the same make, model, year, and options. The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final center of gravity is shown in Figure 7.

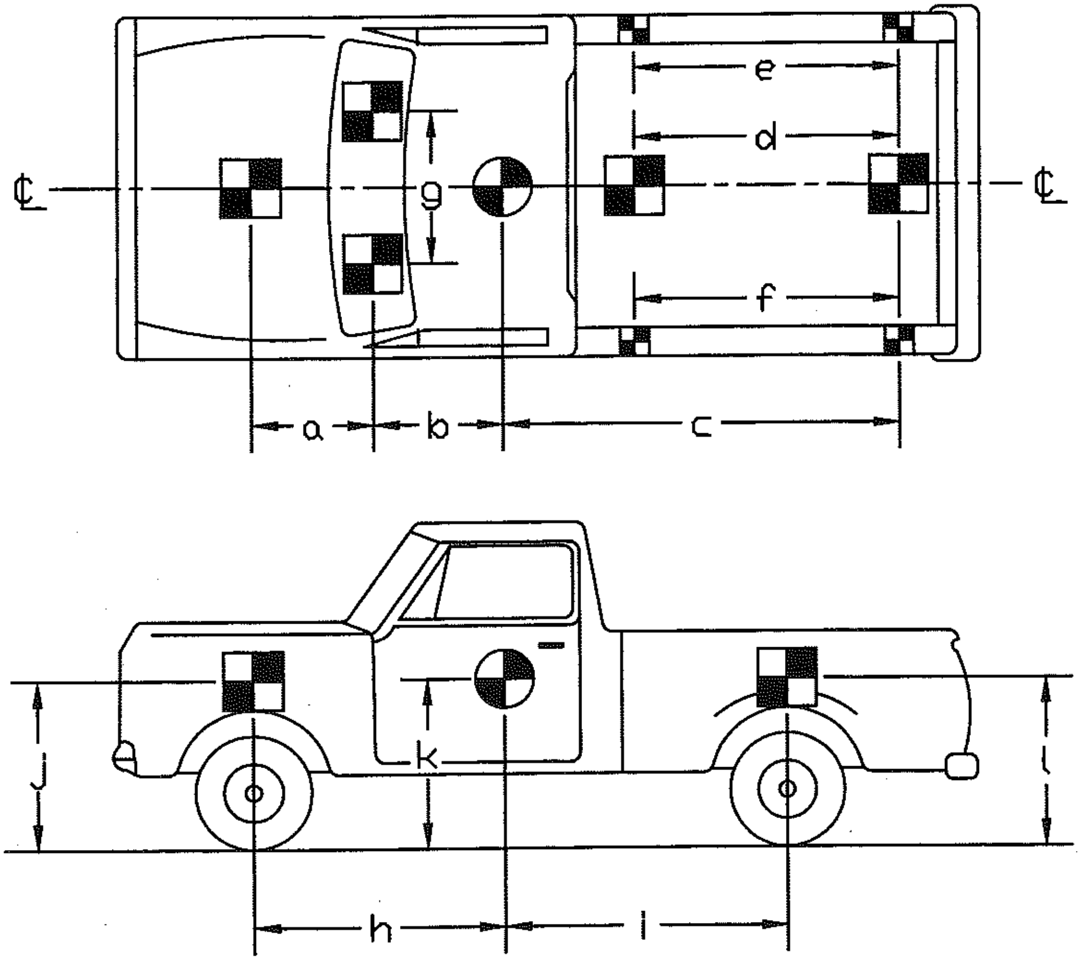
Square, black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film, as shown in Figure 7. One target was placed on the center of gravity on the driver's side door, the passenger's side door, and on the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for film analysis.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. Two 5B flash bulbs were mounted on both the hood and roof of the vehicle to pinpoint the time of impact with the guardrail on the high-speed film. The flash bulbs were fired by a pressure tape switch mounted on the front face of the bumper. A remote controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

5.4 Data Acquisition Systems

5.4.1 Accelerometers

One triaxial piezoresistive accelerometer system with a range of ±200 G's was used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 10,000



TEST #: MIW-1

TARGET GEOMETRY (mm)

a	972	b	724	c	2667	d	1721
e	2153	f	2153	g	959	h	1409
i	1911	j	991	k	738	l	1054

Figure 7. Vehicle Target Locations, Test MIW-1

Hz. The environmental shock and vibration sensor/recorder system, Model EDR-4M6, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-4 was configured with 6 Mb of RAM memory and a 1,500 Hz lowpass filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP" were used to digitize, analyze, and plot the accelerometer data.

A backup triaxial piezoresistive accelerometer system with a range of ±200 G's was also used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 Kb of RAM memory and a 1,120 Hz lowpass filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP" were used to digitize, analyze, and plot the accelerometer data.

5.4.2 Rate Transducer

A Humphrey 3-axis rate transducer with a range of 360 deg/sec in each of the three directions (pitch, roll, and yaw) was used to measure the rates of motion of the test vehicle. The rate transducer was rigidly attached to the vehicle near the center of gravity of the test vehicle. Rate transducer signals, excited by a 28 volt DC power source, were received through the three single-ended channels located externally on the EDR-4M6 and stored in the internal memory. The raw data measurements were then downloaded for analysis and plotted. Computer software, "DynaMax 1 (DM-1)" and "DADiSP" were used to digitize, analyze, and plot the rate transducer data.

5.4.3 High-Speed Photography

For test MIW-1, five high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. A Locam, with a wide-angle

12.5-mm lens, was placed above the test installation to provide a field of view perpendicular to the ground. A Locam with a 76 mm lens, a SVHS video camera, and a 35-mm still camera were placed downstream from the impact point and had a field of view parallel to the barrier. A Locam, with a 16 to 64-mm zoom lens, and a SVHS video camera were placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A Locam and a SVHS video camera were placed downstream and behind the barrier. Another Locam was placed upstream and behind the barrier. A schematic of all nine camera locations for test MIW-1 is shown in Figure 8. The film was analyzed using the Vanguard Motion Analyzer. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

5.4.4 Pressure Tape Switches

For test MIW-1, five pressure-activated tape switches, spaced at 2-m intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the left-front tire of the test vehicle passed over it. Test vehicle speed was determined from electronic timing mark data recorded on "Test Point" software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

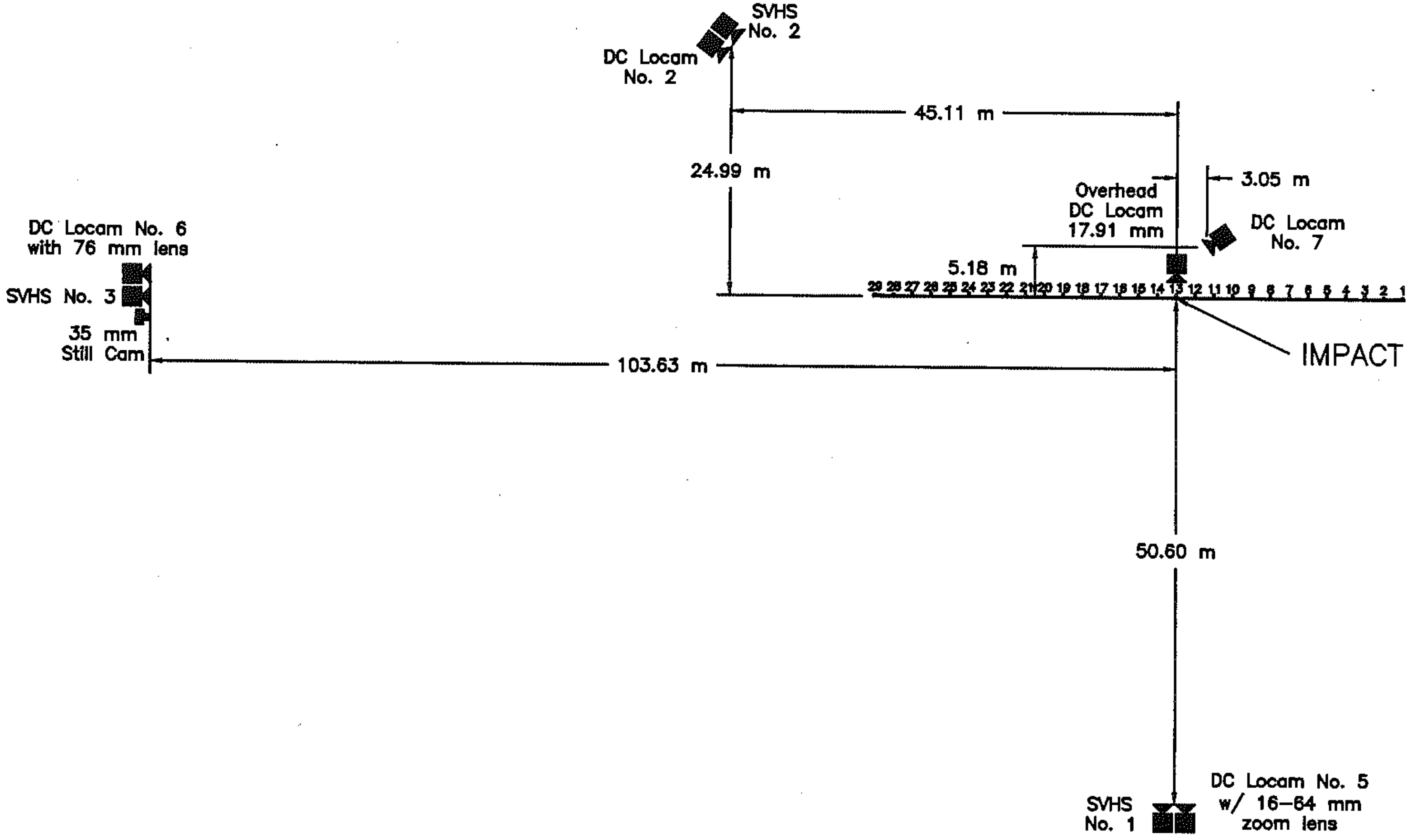


Figure 8. Location of High-Speed Cameras, Test MIW-1

6 CRASH TEST NO. 1

6.1 Test MIW-1

The 2,007-kg pickup truck impacted the W-beam guardrail system at a speed of 99.8 km/hr and an angle of 25.8 degrees. A summary of the test results and the sequential photographs are shown in Figure 9. Additional sequential photographs are shown in Figures 10 through 11. Documentary photographs of the crash test are shown in Figures 12 through 14.

6.2 Test Description

Initial impact occurred at the center of post no. 13, as shown in Figure 15. Upon impact with the guardrail, post no. 13 rotated backward. At 0.032 sec after impact, the right-front corner of the vehicle, which was at the midspan between post nos. 13 and 14, crushed inward except for the engine hood which protruded over the top of the guardrail. By this time, post no. 13 had moved backward and post no. 14 was twisted but without translating backward. At 0.057 sec, the right-front tire collapsed under the guardrail. At 0.060 sec, post nos. 13 and 14 had rotated backward about the same distance. At 0.072 sec, the right-front corner of the vehicle was at post no. 14, which continued to rotate backward. At this same time, post no. 15 began to show movement. At 0.123 sec, there was very little, if any, vehicle redirection with the right-front corner slightly past the midspan of post no. 14 and 15. During this same moment, a majority of the right-front fender was protruding over the guardrail. At 0.153 sec, the right-front corner of the vehicle was at post no. 15, and the test vehicle, with the right-side door frame cracked open, began to redirect. At this same time, post nos. 14 and 15 had rotated backward about the same distance, and post no. 16 continued to rotate. At 0.207 sec, the vehicle's right-front corner was positioned at the midspan between post nos. 15 and 16. In addition, the left-front tire was airborne with the rear-end yawed counter-clockwise (CCW) toward the guardrail. At 0.239 sec, the right side of the vehicle was parallel to against the deformed guardrail position with the vehicle's right-front corner slightly downstream of post no. 16. At 0.274 sec, the guardrail between post nos. 13 and 14 was twisting and laying down as the right-rear corner of the vehicle protruded over the top of the guardrail. At 0.297 sec, the left-rear tire was airborne. The vehicle became parallel to the tangent of the original guardrail's position at 0.302 sec after impact with a velocity of 56.8 km/hr. At this same time, the vehicle's right-front and right-rear corners were slightly upstream of post nos. 17 and 15, respectively. At 0.354 sec, the vehicle rolled clockwise (CW) with the vehicle's right-rear corner hanging well over the guardrail and the vehicle's entire right side leaning against the barrier. At 0.391 sec, the vehicle's right-front corner was at post no. 18, and the rear bumper and fender were above the top of the guardrail. At 0.414 sec, the vehicle began to exit the guardrail. At 0.420 sec and with the vehicle's right-rear corner at post no. 15, the vehicle continued to roll CW as it was positioned over the top of the guardrail along its entire length. At 0.458 sec, with the right-front corner of the vehicle at post no. 18, the right-rear bumper hooked over the top of the guardrail. At 0.556 sec, the right-front tire collapsed under the vehicle, increasing the potential for vehicular instabilities. At 0.563 sec after impact, the vehicle encountered significant roll motion while continuing to protrude over the top of the guardrail. At 0.721 sec, the vehicle's rear-end was airborne and out of contact with the guardrail. At 0.868 sec, the vehicle continued to roll CW to a position approximately perpendicular to the ground and with only the right-front corner of the vehicle in contact with the concrete tarmac. The vehicle's post-impact trajectory is shown in Figure 9. The vehicle came to rest 34.17-m downstream from impact and 10.97-m laterally away from the traffic-side of the rail, as shown in Figures 9 and 16.

6.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 17 through 24. Barrier damage consisted mostly of deformed W-beam, contact marks on a guardrail section, and deformed guardrail posts. The W-beam damage consisted of moderate deformation and flattening of the lower portion of the impacted section between post nos. 13 and 14. Contact marks were found on the guardrail between post nos. 13 and 17. The W-beam rail at post nos. 13 through 15 was creased where the spacer block bears against the rail. The W-beam rail, 152-mm upstream of post no. 13, had a minor crease on the upper portion, while the W-beam rail's upper portion was creased 152-mm downstream of post no. 17. The W-beam rail was pulled off of post nos. 14 and 15.

Steel post nos. 3 through 10 and 19 through 27 moved backward slightly. Steel post nos. 11, 12, 17, and 18 were twisted and slightly rotated backward. Four steel posts, post nos. 13 through 16, were twisted and bent toward the ground. A 356-mm long tire contact mark was found along the upstream side of the front face of post no. 14. The lower-front face of post no. 15 was also slightly damaged. Both the upstream and downstream anchorage systems move slightly, but the posts were not damaged.

The permanent set of the guardrail and posts is shown in Figures 17 through 18 and 21 through 24. The cable anchor ends encountered slight permanent set deformations, as shown in Figure 24. The maximum lateral permanent set rail and post deflections were approximately 625 mm at the centerline of post no. 15 and 581 mm at post no. 15, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 1,002 mm at the centerline of post no. 15 and 741 mm at post no. 15, respectively, as determined from the high-speed film analysis.

6.4 Vehicle Damage

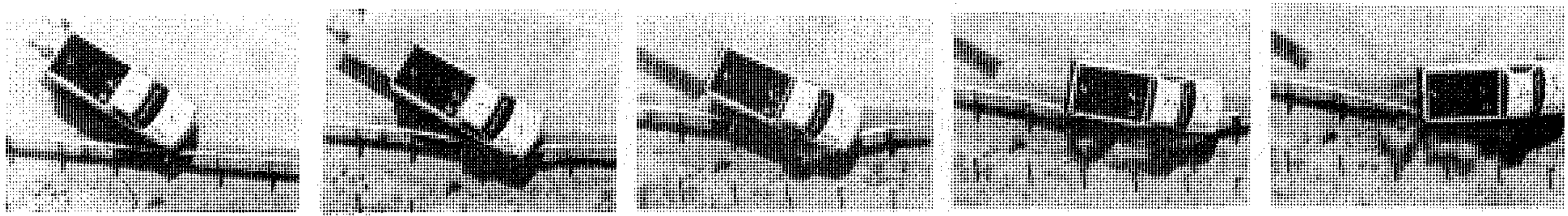
Exterior vehicle damage was extensive, as shown in Figures 25 and 26. Interior occupant compartment deformations were determined to be negligible. The front bumper buckled at the centerline of the bumper and ripped at the right-front bumper attachment. The right-front quarter panel was crushed downward, and the right side of the front bumper was also bent back toward the engine compartment. The right-front wheel assembly was deformed to approximately a 90 degree bend and pushed into the frame. In addition, contact marks were observed on the rim as well as tie-rod disengagement. Small contact marks were found on the lower right side of the rear fender, the right-rear bumper, the outside surface of the right-rear tire, the lower right side of the truck box, and the right-side door. The roof, the A and B-pillars, and the left-front fender were crushed and deformed due to vehicle rollover. The windshield was cracked and deformed on the left side. Both the left- and right-side door windows were shattered. The rear window remained undamaged.

6.5 Occupant Risk Values

The normalized longitudinal and lateral occupant impact velocities were determined to be 6.35 m/sec and 4.33 m/sec, respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 7.43 g's and 12.98 g's, respectively. It is noted that the occupant impact velocities (OIV) and occupant ridedown decelerations (ORD) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 9. Results are shown graphically in Appendix A. Due to technical difficulties, the rate transducer did not collect the roll, pitch, and yaw data. However, roll, pitch, and yaw data were collected from film analysis and are shown graphically in Appendix B.

6.6 Discussion

The analysis of the test results for test MIW-1 showed that the W-beam guardrail contained the vehicle but inadequately redirected the vehicle, since the vehicle did not remain upright after collision with the guardrail. Detached elements and debris from the test article did not penetrate or show potential for penetrating the occupant compartment. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. After collision, the vehicle's trajectory intruded slightly into adjacent traffic lanes but was determined to be acceptable. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test MIW-1 conducted on MDOT's Type B (W-Beam) Guardrail System was determined to be unacceptable according to the NCHRP Report No. 350 criteria.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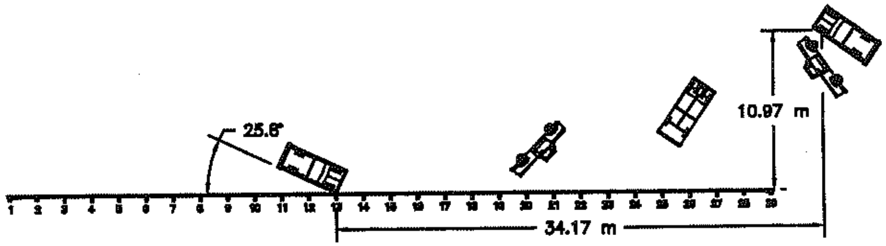

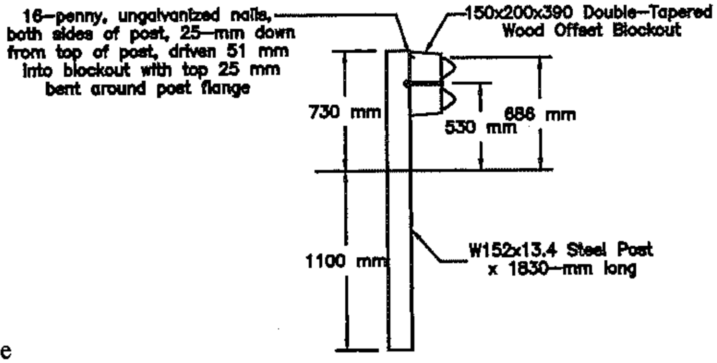

● Test Number	MIW-1
● Date	8/25/99
● Appurtenance	Michigan's Type B (W-beam) guardrail system
● Total Length	53.34 m
● Steel W-Beam (Nested)	
Thickness	2.66 mm
Top Mounting Height	686 mm
● Steel Posts	
Post Nos. 3 - 27	W152x13.4 by 1,830-mm long
● Wood Spacer Blocks	
Post Nos. 3 - 27	150 mm x 200 mm by 360-mm long
● Soil Type	Grading B - AASHTO M 147-65 (1990)
● Vehicle Model	1994 GMC 2500 2WD
Curb	2,021 kg
Test Inertial	2,007 kg
Gross Static	2,007 kg
● Vehicle Speed	
Impact	99.8 km/hr
Exit	NA

● Vehicle Angle	
Impact	25.8 degrees
Exit	NA
● Vehicle Snagging	Minor wheel snagging on post no. 14
● Vehicle Pocketing	Minor
● Vehicle Stability	Vehicle rollover
● Occupant Ridedown Deceleration (10 msec avg.)	
Longitudinal	7.43 < 20 G's
Lateral (not required)	12.98
● Occupant Impact Velocity (Normalized)	
Longitudinal	6.35 < 12 m/s
Lateral (not required)	4.33
● Vehicle Damage	Extensive
TAD[10]	NA
SAE[11]	NA
● Vehicle Stopping Distance	34.17 m downstream 10.97 m traffic-side face
● Barrier Damage	Moderate
● Maximum Deflections	
Permanent Set	625 mm
Dynamic	1,002 mm

Figure 9. Summary of Test Results and Sequential Photographs, Test MIW-1

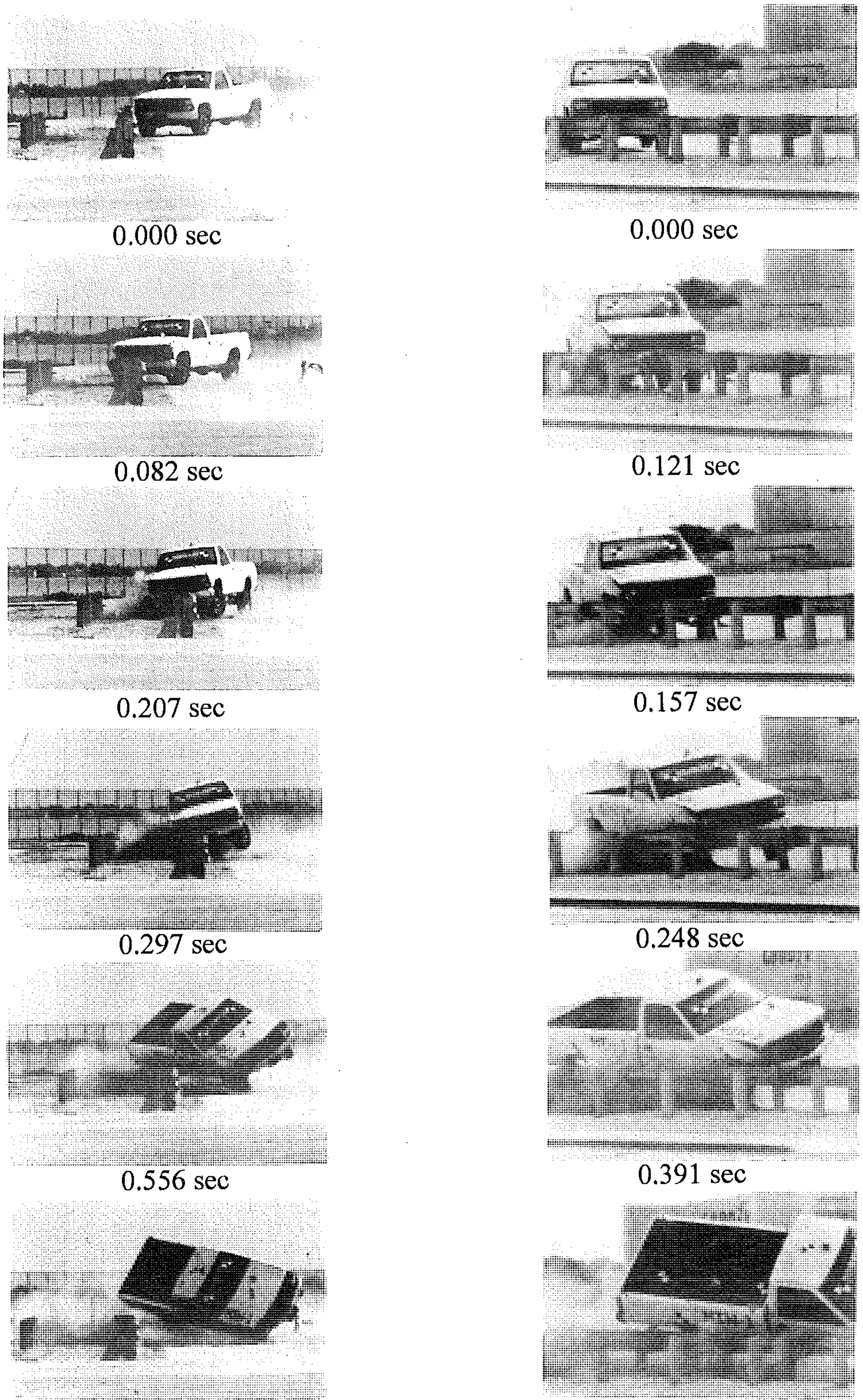

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Figure 10. Additional Sequential Photographs, Test MIW-1

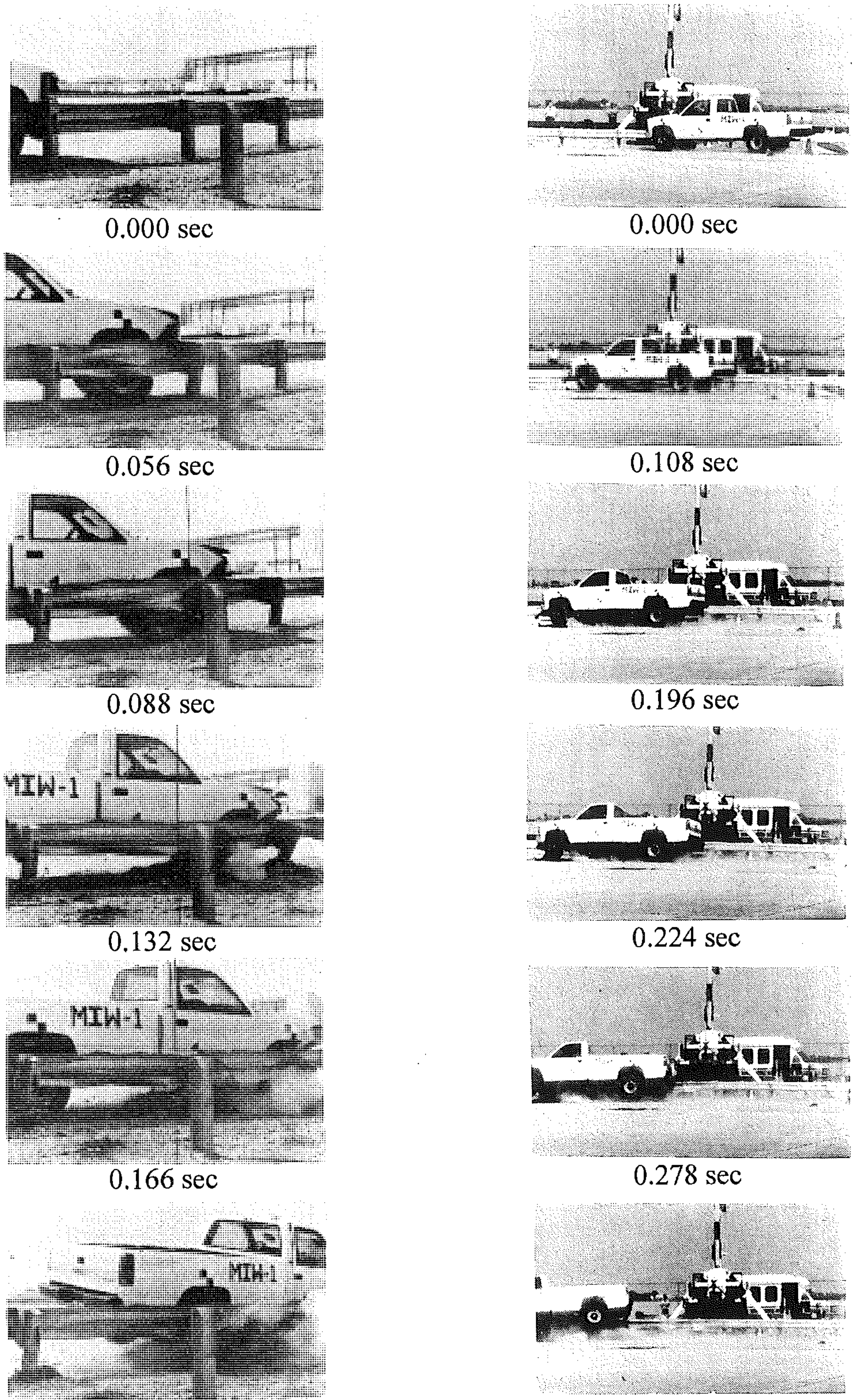

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Figure 11. Additional Sequential Photographs, Test MIW-1

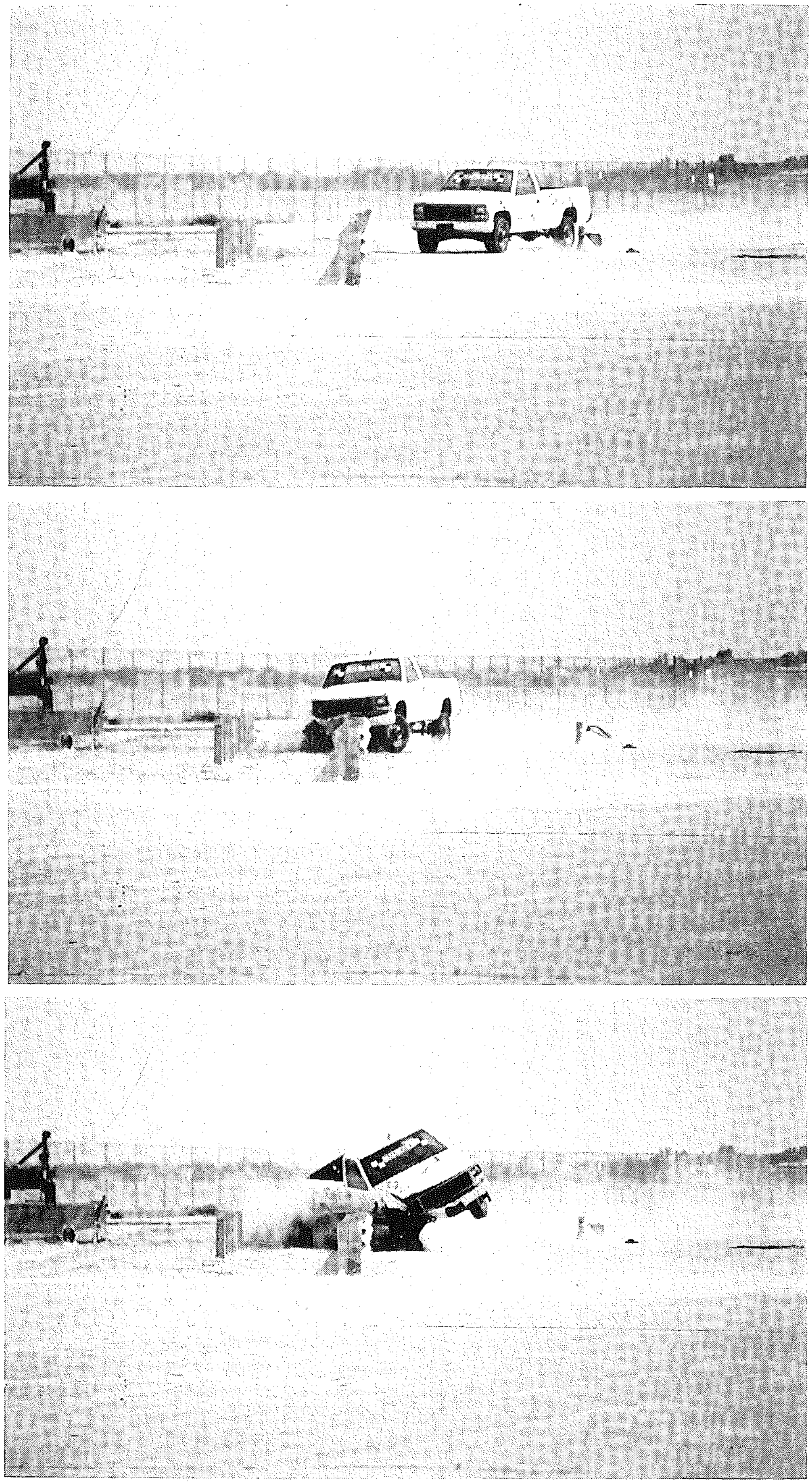


Figure 12. Documentary Photographs, Test MIW-1

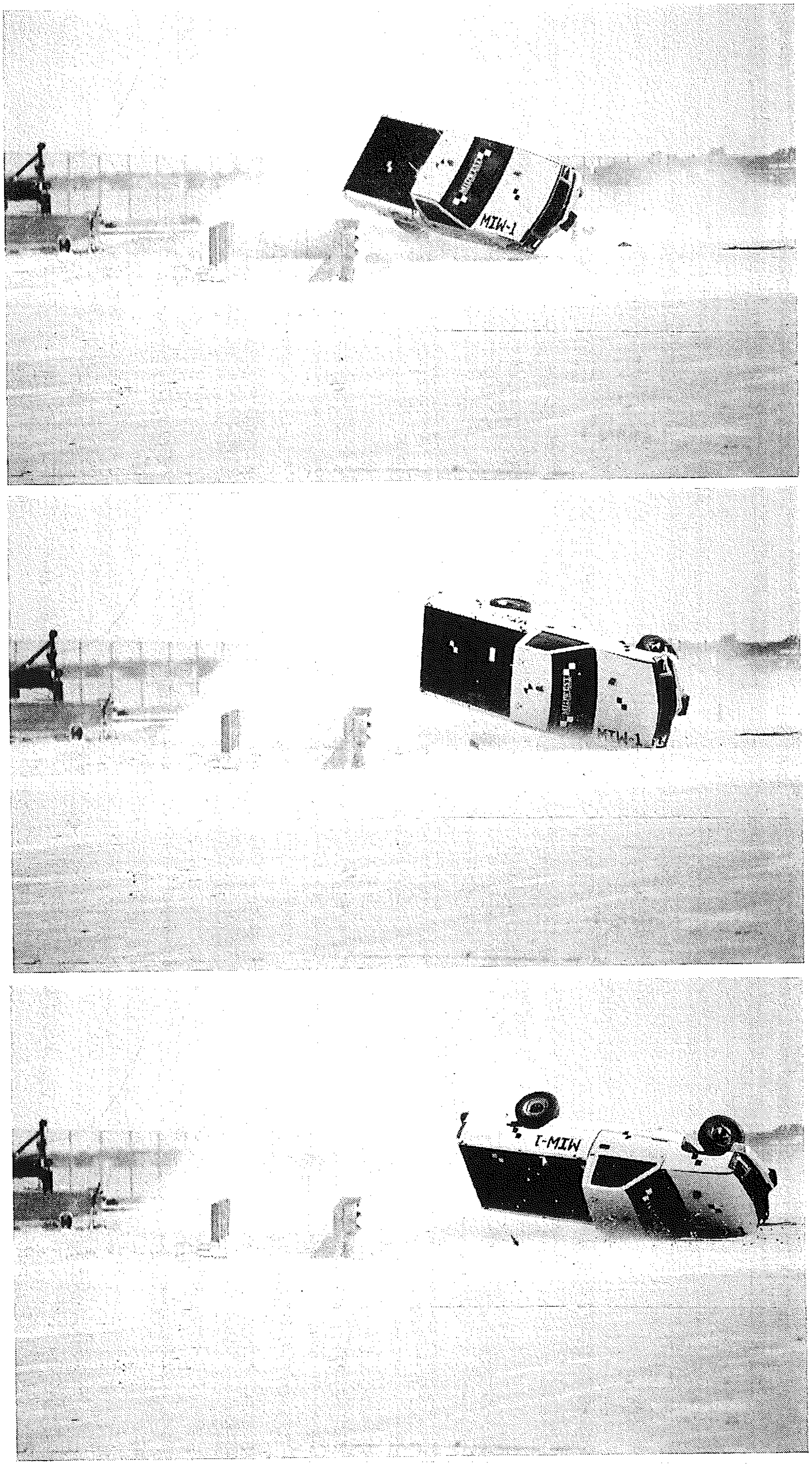


Figure 13. Documentary Photographs, Test MIW-1

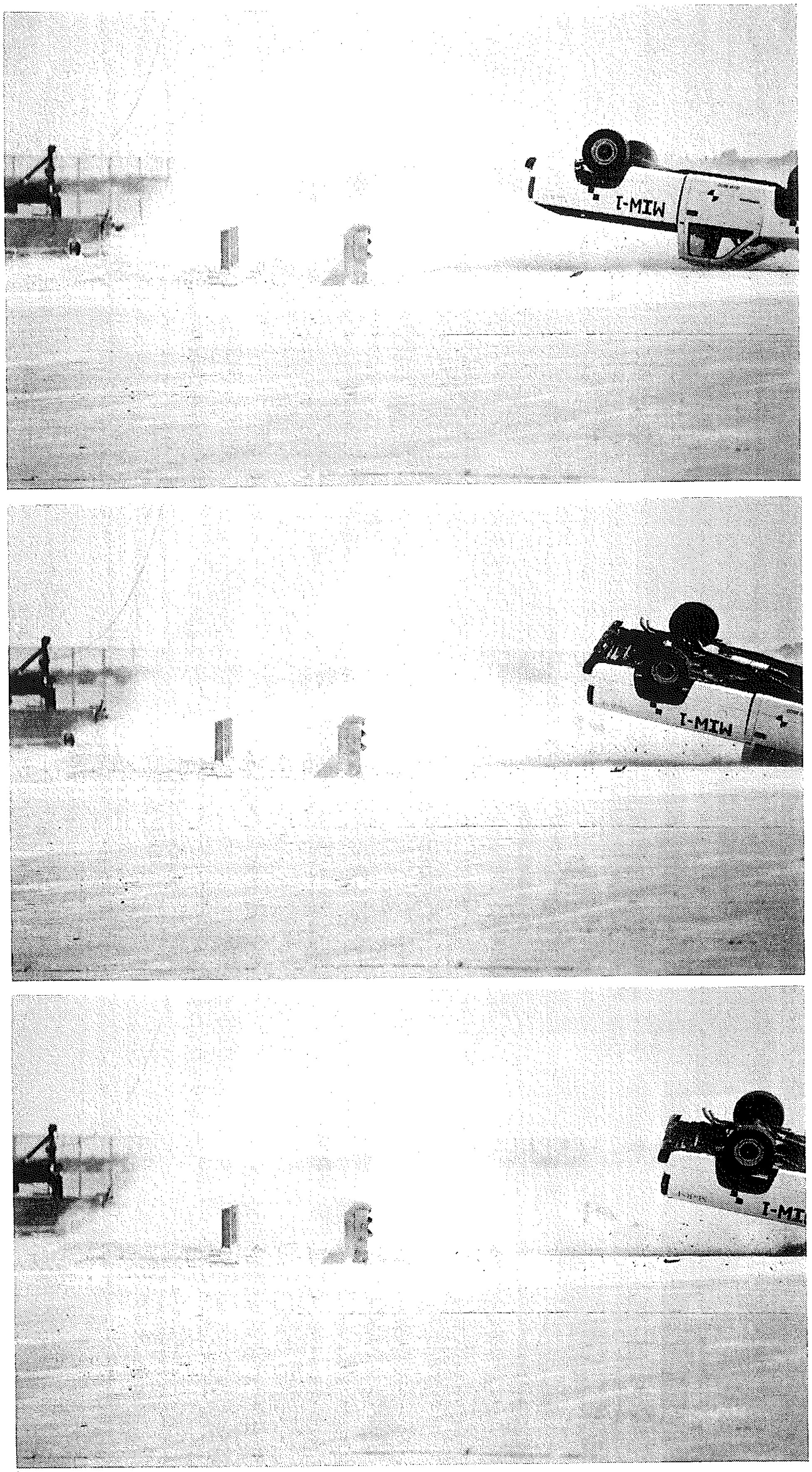


Figure 14. Documentary Photographs, Test MIW-1

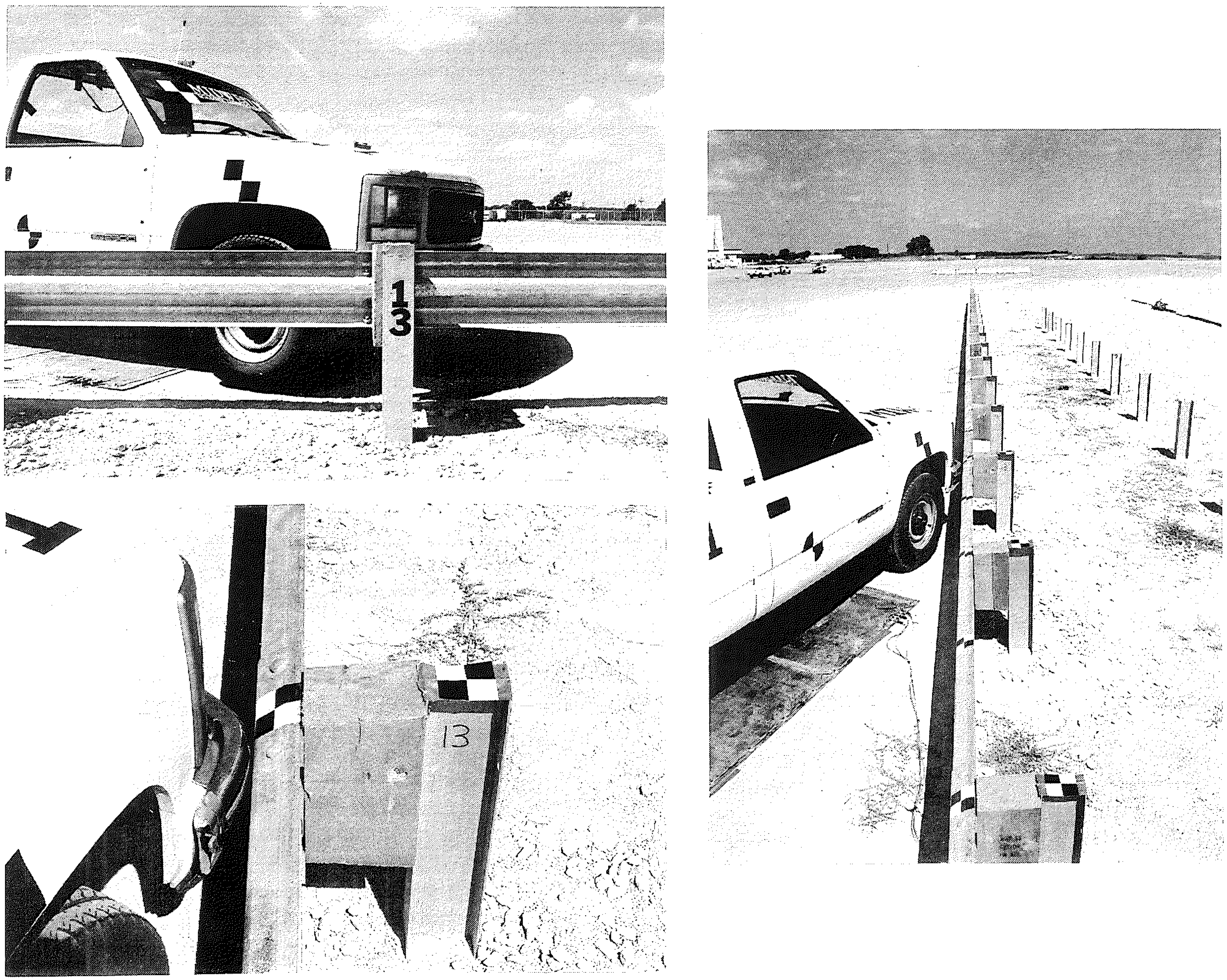


Figure 15. Impact Location, Test MIW-1

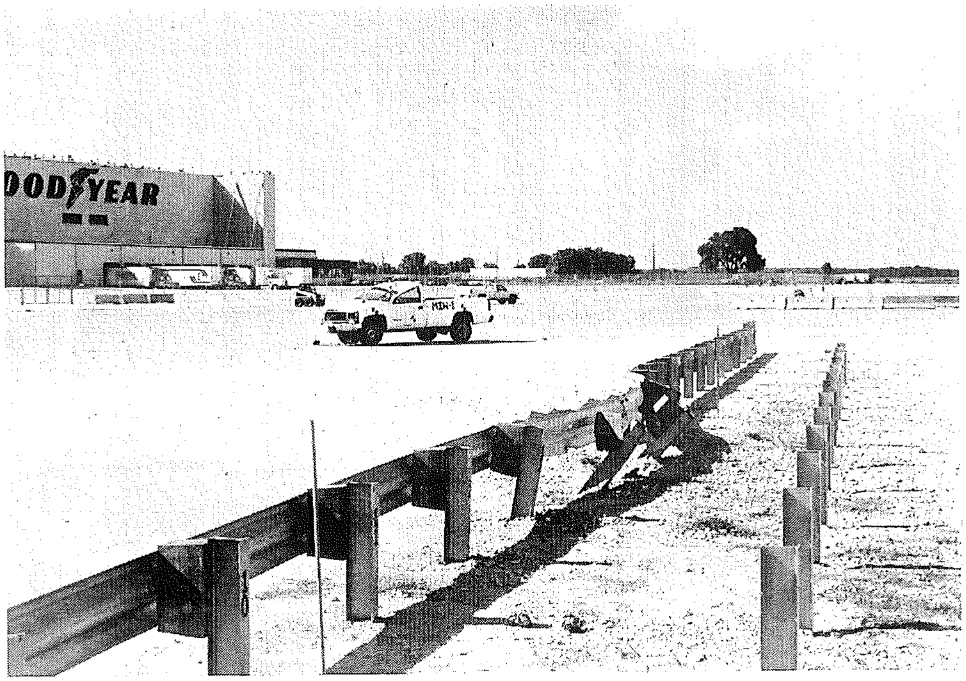


Figure 16. Final Vehicle Location, Test MIW-1

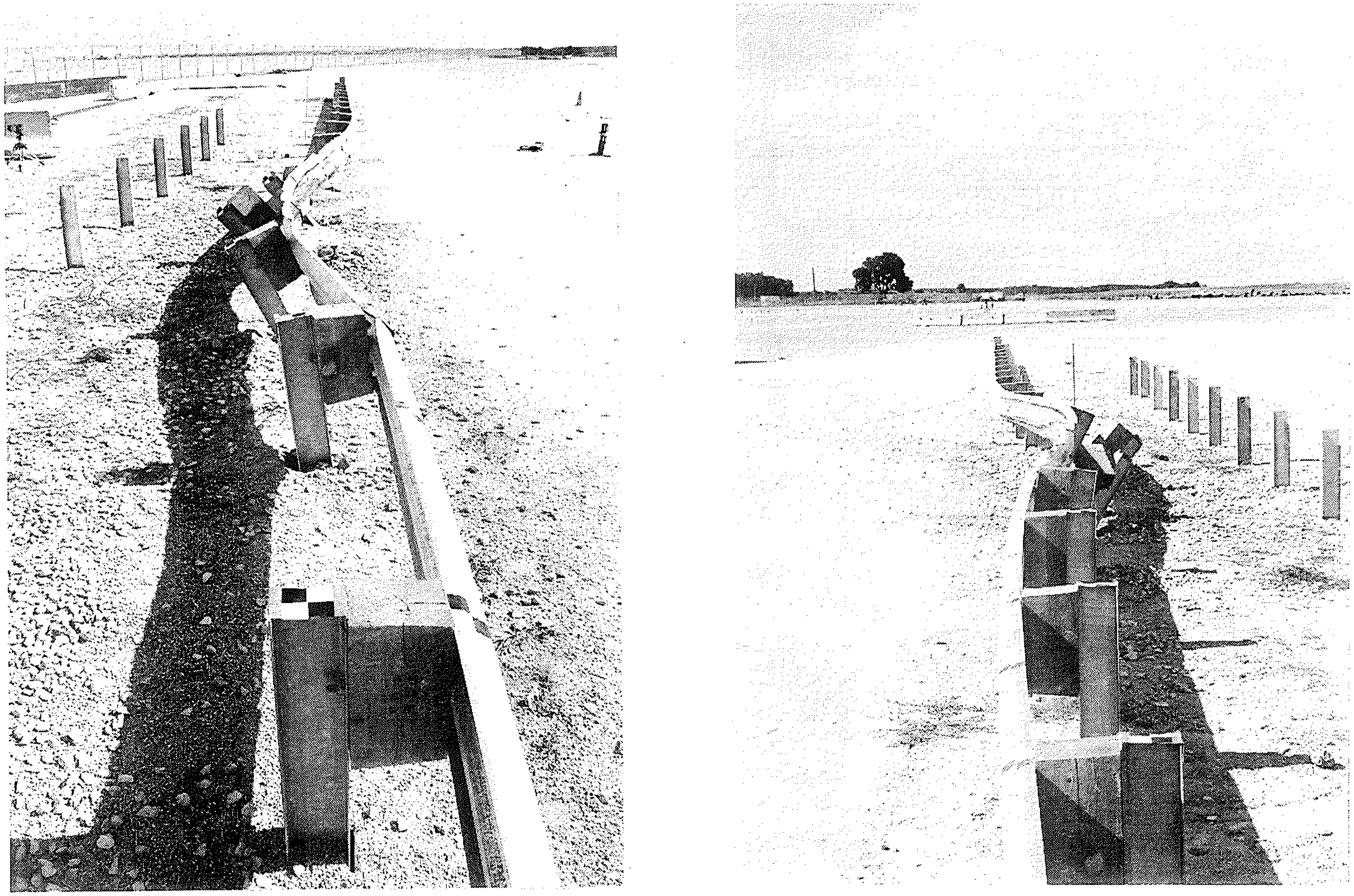


Figure 17. Type B Longitudinal Barrier Damage, Test MIW-1

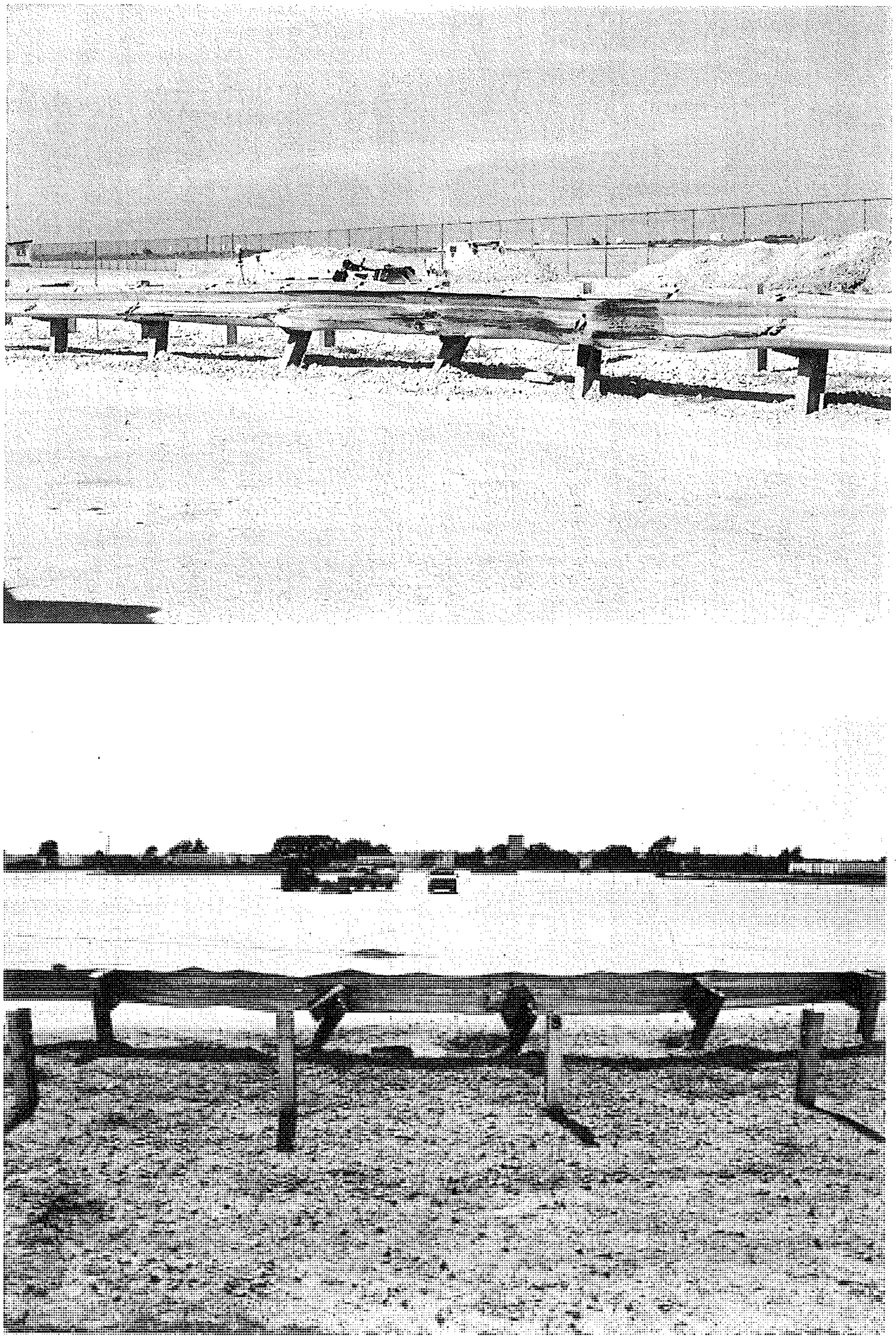


Figure 18. Type B Longitudinal Barrier Damage, Test MIW-1

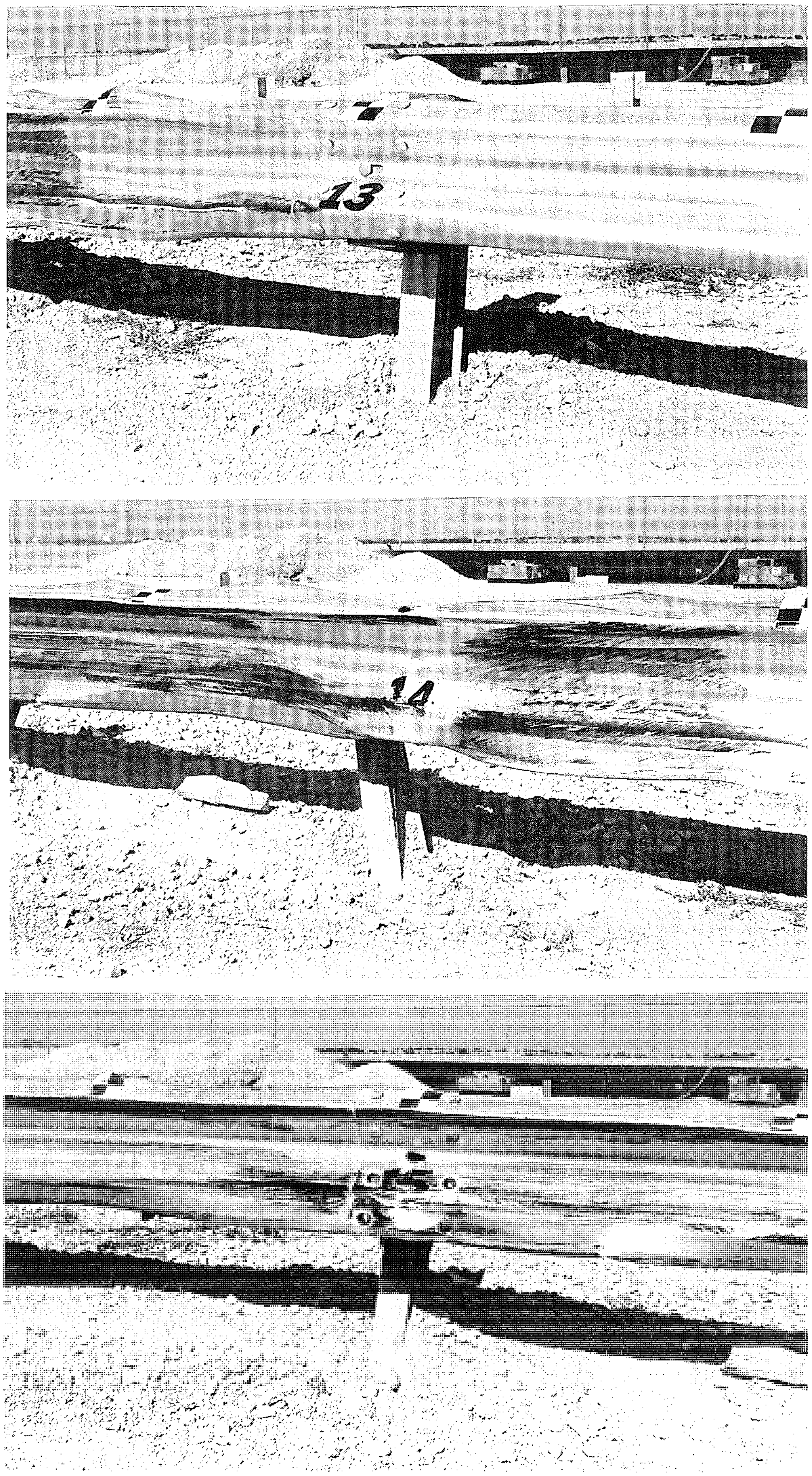


Figure 19. Type B Longitudinal Barrier Rail and Post Damage, Test MIW-1

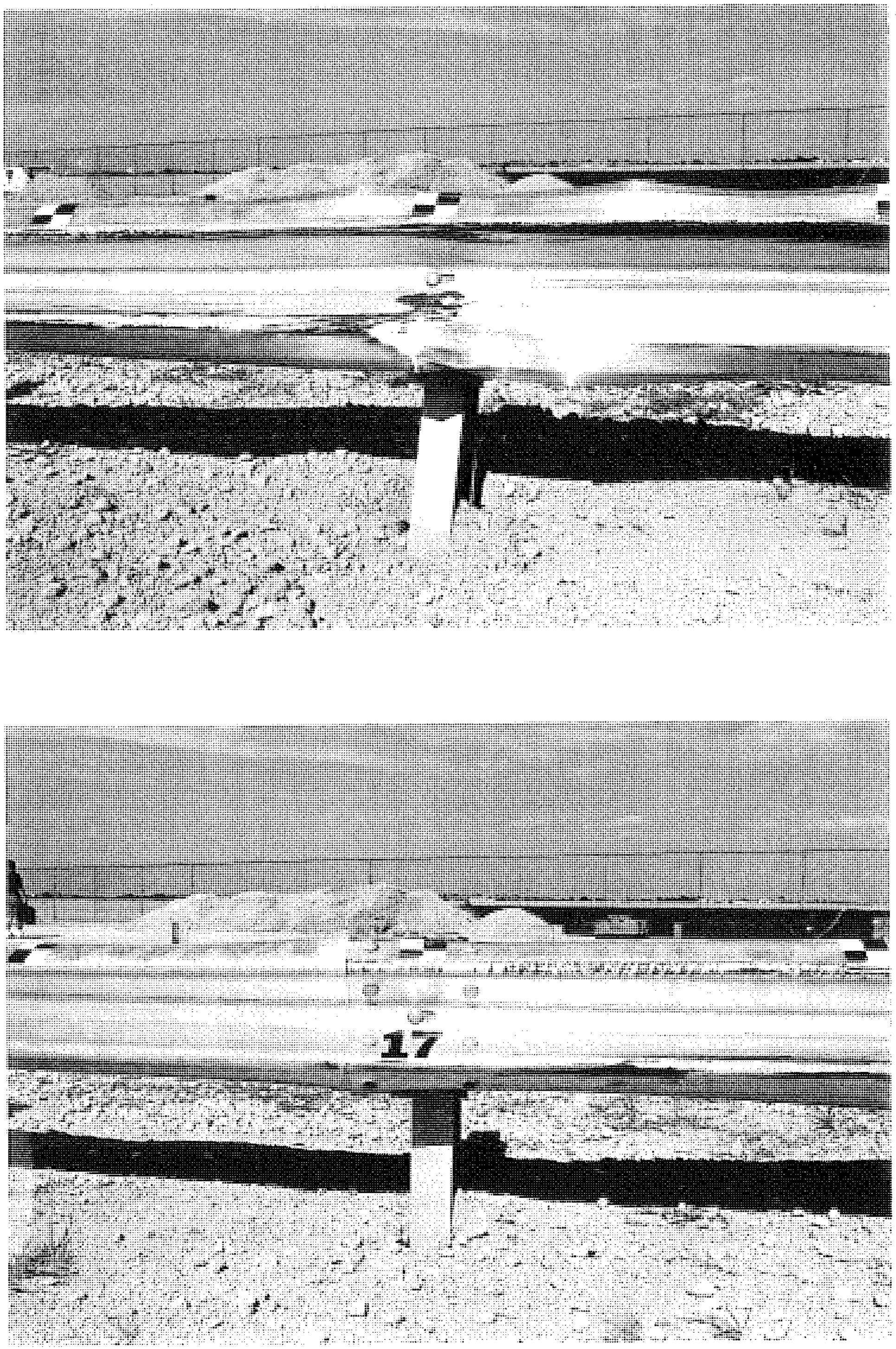
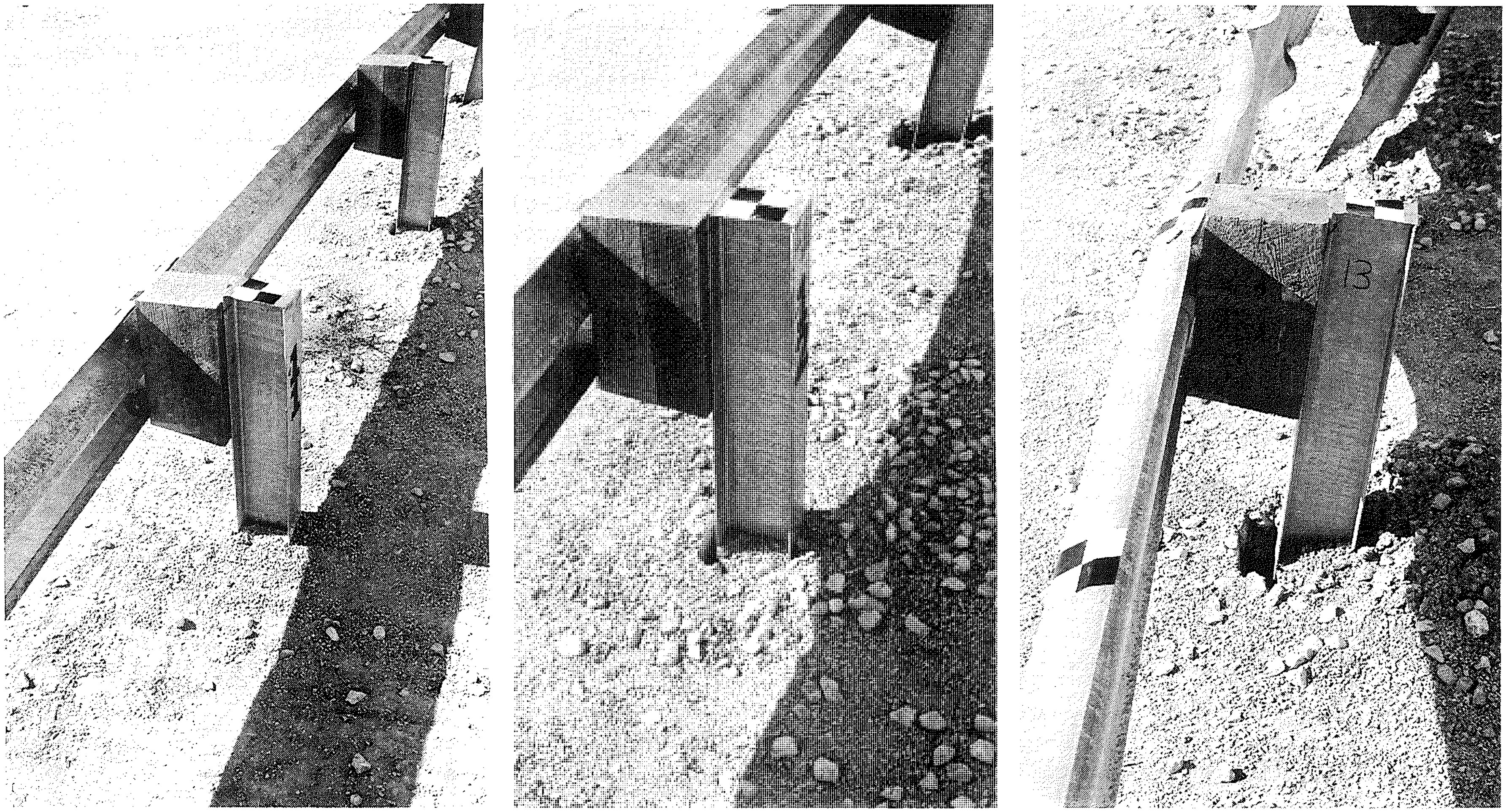


Figure 20. Type B Longitudinal Barrier Rail and Post Damage, Test MIW-1

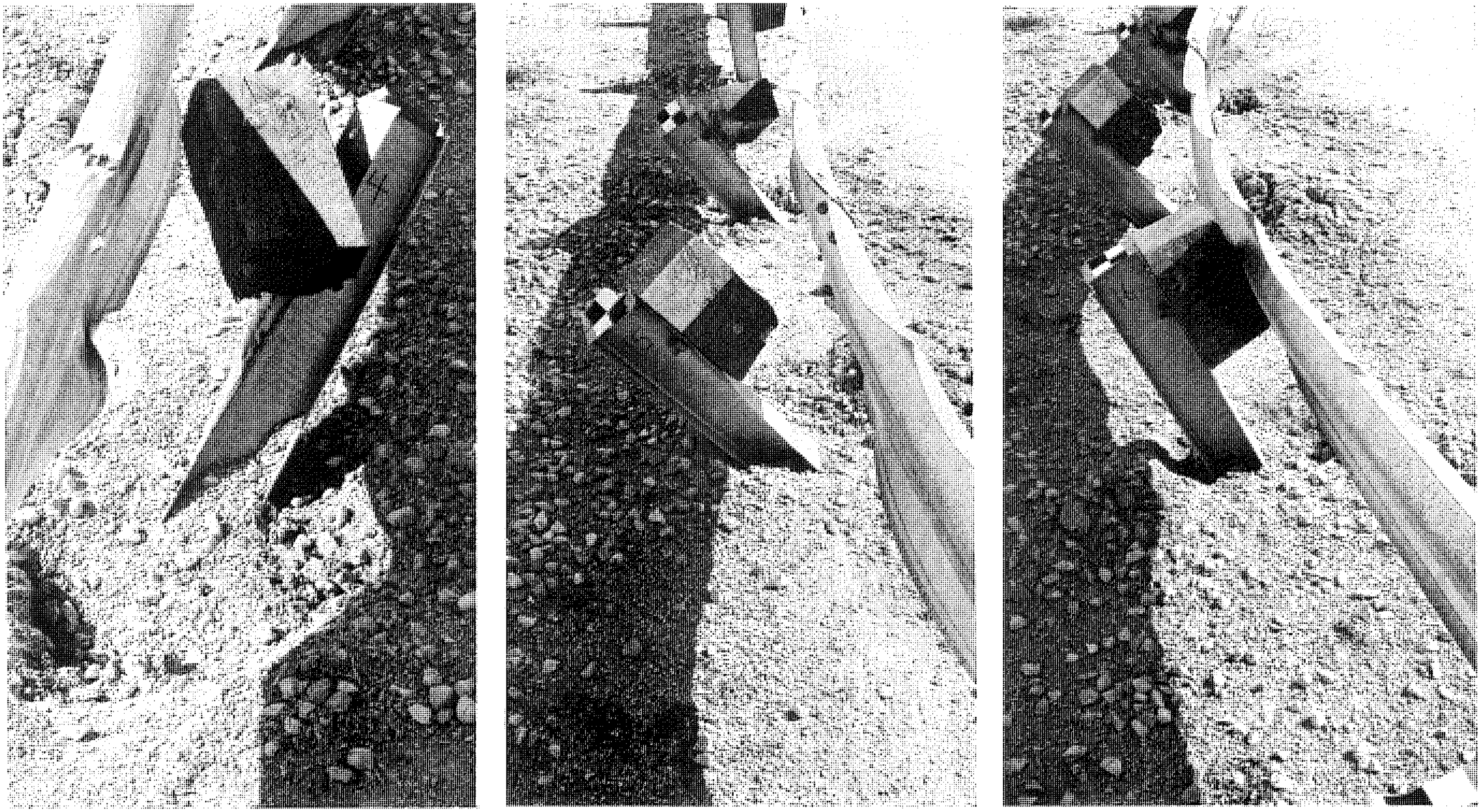


Post No. 11

Post No. 12

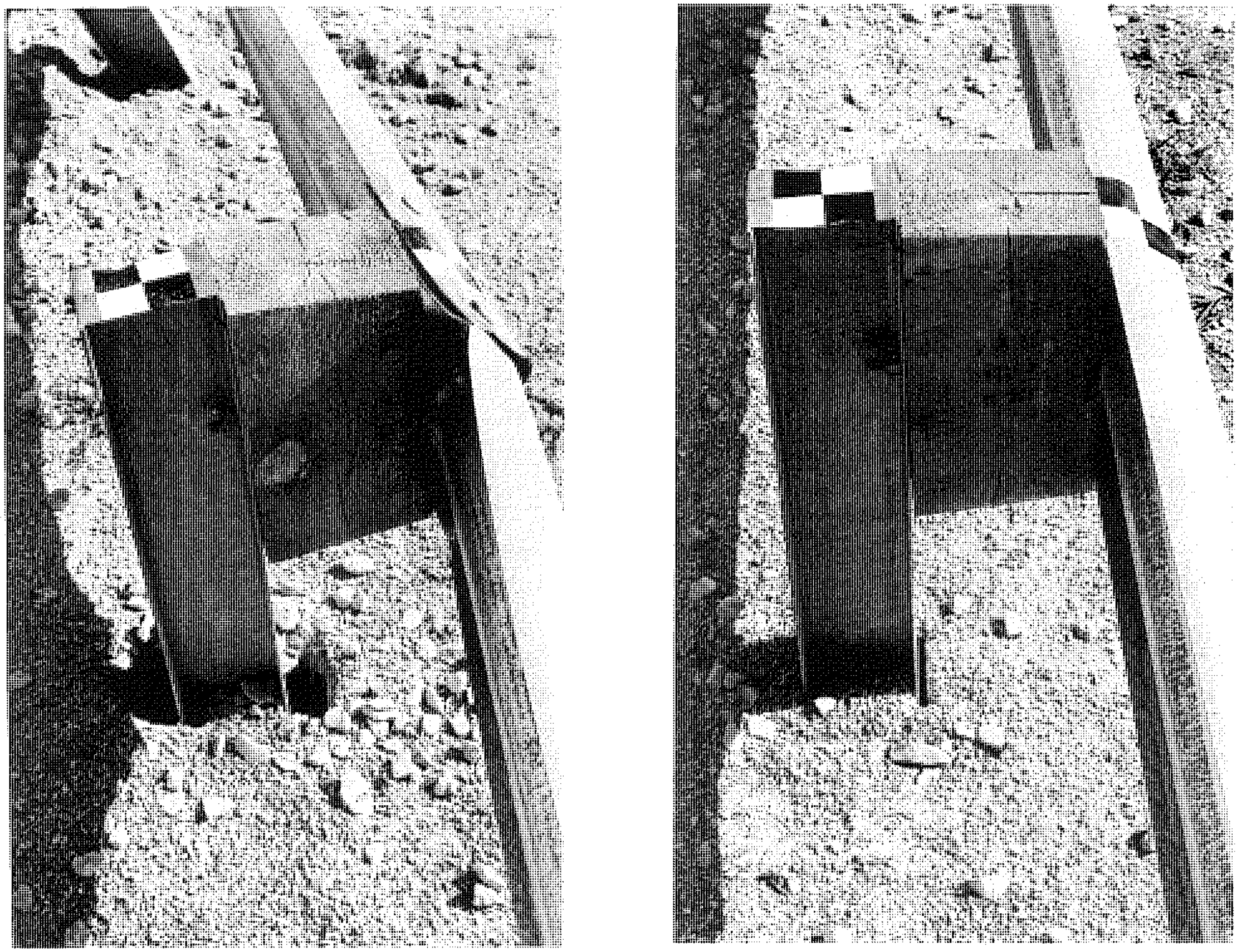
Post No. 13

Figure 21. Final Post Position – Post Nos. 11 through 13, Test MIW-1



Post No. 14 Post No. 15 Post No. 16

Figure 22. Final Post Positions – Post Nos. 14 through 16, Test MIW-1



Post No. 17

Post No. 18

Figure 23. Final Post Positions – Post Nos. 17 and 18, Test MIW-1

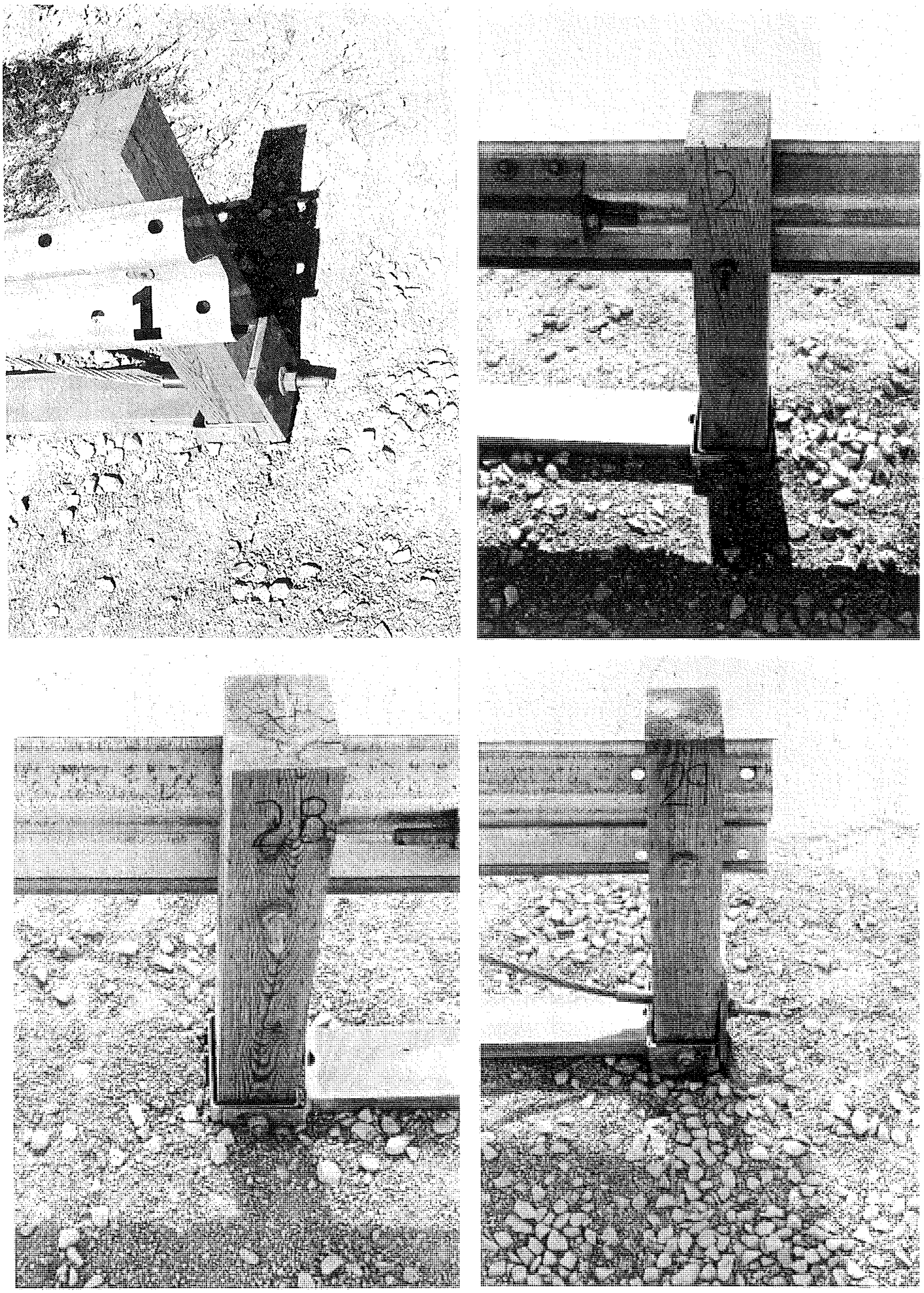


Figure 24. Permanent Set Deflections of End Anchorages, Test MIW-1

Figure 25. Vehicle Damage, Test MIW-1

Figure 26. Front-End Vehicle Damage, Test MIW-1

7 SUMMARY AND CONCLUSIONS

MDOT's Type B (W-beam) longitudinal barrier design was constructed and full-scale vehicle crash tested. The barrier system was configured with steel posts supporting 53.34 m of W-beam rail. A full-scale vehicle crash test was performed with a ¾-ton pickup truck on the guardrail system according to the TL-3 safety performance criteria presented in NCHRP Report No. 350. The crash test, test no. MIW-1, failed due to vehicle rollover. After reviewing the test results of test no. MIW-1, MwRSF researchers were unable to definitely determine the cause of vehicle rollover. However, differences between the results of test no. MIW-1 and earlier successful tests were identified and are related primarily to the test vehicle and the soil in which the tested guardrail was installed. The system design differences of non-routed wood blockouts and reduced guardrail mounting height did not appear to have an adverse influence on the results of this test.

An analysis of the test results revealed that the vehicle's steering linkage failed immediately after impact. Although this problem should not have been sufficient to entirely explain the poor performance during the crash test, there is reasonably strong evidence that this type of suspension failure can adversely affect the performance of the guardrail. The strong post, W-beam guardrail captures pickup trucks when the front tire on the impact side is forced under the rail element. The suspension failure observed during this test prevented the guardrail from capturing the pickup truck's tire.

Further analysis revealed that although the vertical c.g. heights of previous test vehicles used in successful W-beam tests are unknown, numerous measurements have indicated that there is a variation in the c.g. height from one vehicle to the next. For newer pickup trucks, there is a general trend toward higher c.g. heights. Therefore, it is probable that the c.g. height of the ¾-ton vehicle used in the crash test was higher than that used in earlier successful testing.

The resistence to post rotation in the soil during test no. MIW-1 appeared to be higher than that associated with comparable prior successful guardrail tests. However, it should be noted that standardized post installation procedures and NCHRP Report No. 350 soil specifications were followed for test no. MIW-1. During this test, only three guardrail posts experienced significant deformation and all of these posts bent at a point between 254 mm and 279 mm below the ground surface. Frequently, during this type of crash, the steel posts do not bend but merely rotate in the soil. Typically, when steel posts bend during this type of test, the bend point is generally lower in the ground, nearly 457 mm below ground line. As the soil stiffness increases, the bend point would move upward toward the ground line.

In the results of test no. MIW-1, no significant lateral torsional buckling was observed in the guardrail posts. Increasing post resistance to lateral torsional buckling would not have improved the performance of the guardrail during the test. The mounting height of 686 mm is only 20 mm below that used in all previous successful guardrail testing. As mentioned previously, test vehicle c.g. heights have much greater variation than 20 mm. Tire diameters on the test vehicles also vary greatly. Therefore, the 20 mm reduction in mounting height is not believed to be a contributing factor to the failure observed in test no. MIW-1. A summary of the safety performance evaluation is provided in Table 2.

Table 2. Summary of Safety Performance Evaluation Results - MDOT's Type B Barrier System

Evaluation Factors	Evaluation Criteria	Test MIW-1
Structural Adequacy	A. 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.	S
Occupant Risk	B. Detached elements, fragments or other debris from the test article should 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. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	S
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	U
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.	S
	M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test devise.	U

S - (Satisfactory)
M - (Marginal)
U - (Unsatisfactory)
NA - Not Available

8 RECOMMENDATIONS

Michigan's Type B (W-beam) longitudinal barrier, as described in this report, was not successfully crash tested according to the criteria found in NCHRP Report No. 350. Although there are indications that this failure may be primarily related to the test vehicle and soil conditions, the results of test no. MIW-1 indicate that this design was not a suitable design for used on Federal-aid highways.

As previously mentioned, the use of non-routed wood blockouts and a slightly reduced guardrail height were not believed to have an adverse influence on the results of test MIW-1. However, MwRSF researchers are concerned: (1) that the test vehicle's suspension failed prematurely prior to the front wheel becoming engaged with the guardrail; (2) that the vehicle's c.g. may have been higher than those used in prior successful W-beam tests since they are largely unknown; and (3) that the post-soil forces were higher than those observed previously.

Therefore, it is recommended that this system be retested without any changes.

9 REFERENCES

1. Mak, K.K., Bligh, R.P., and Menges, W.L., *Testing of State Roadside Safety Systems, Volume XI: Appendix J - Crash Test and Evaluation of Existing Guardrail Systems*, Draft Report No. FHWA/RD-95/XXX, Submitted to the Office of Safety and Traffic Operations, Federal Highway Administration, Performed by Texas Transportation Institute, December 1995.

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11. *Collision Deformation Classification - Recommended Practice J224 March 1980,* Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

10 APPENDICES

APPENDIX A

Accelerometer Data Analysis, Test MIW-1

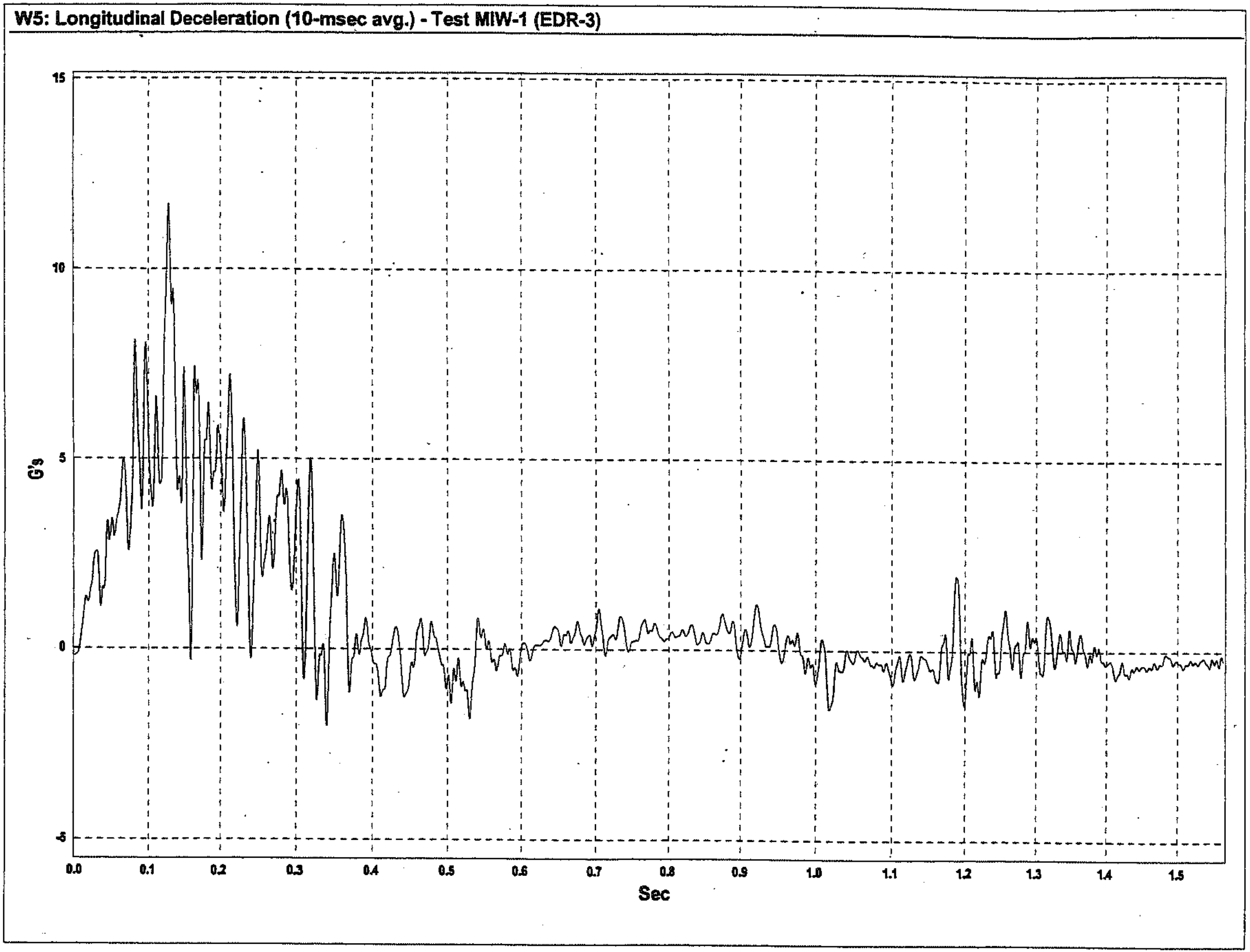

Figure A-1. Graph of Longitudinal Deceleration, Test MIW-1

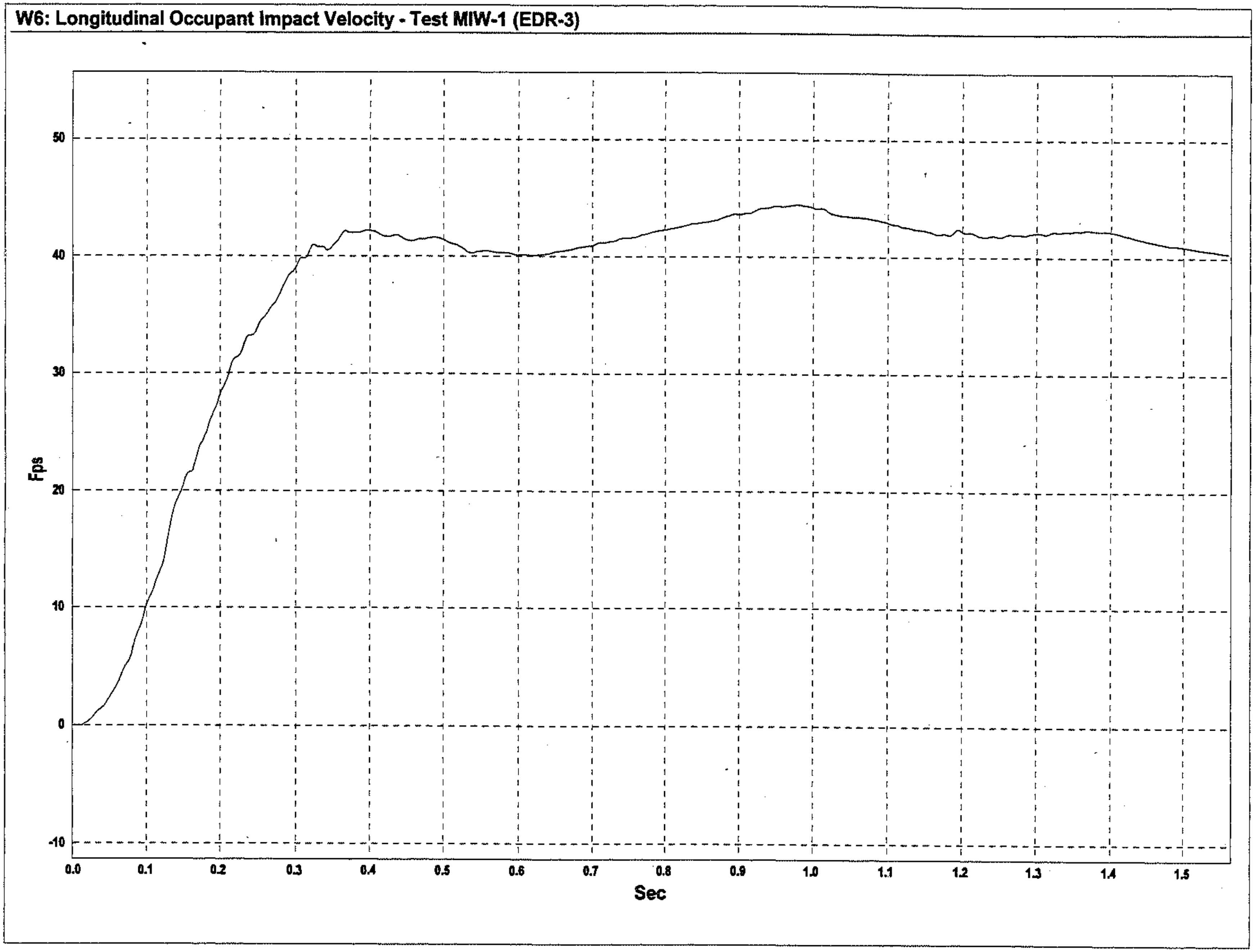

Figure A-2. Graph of Longitudinal Occupant Impact Velocity, Test MIW-1

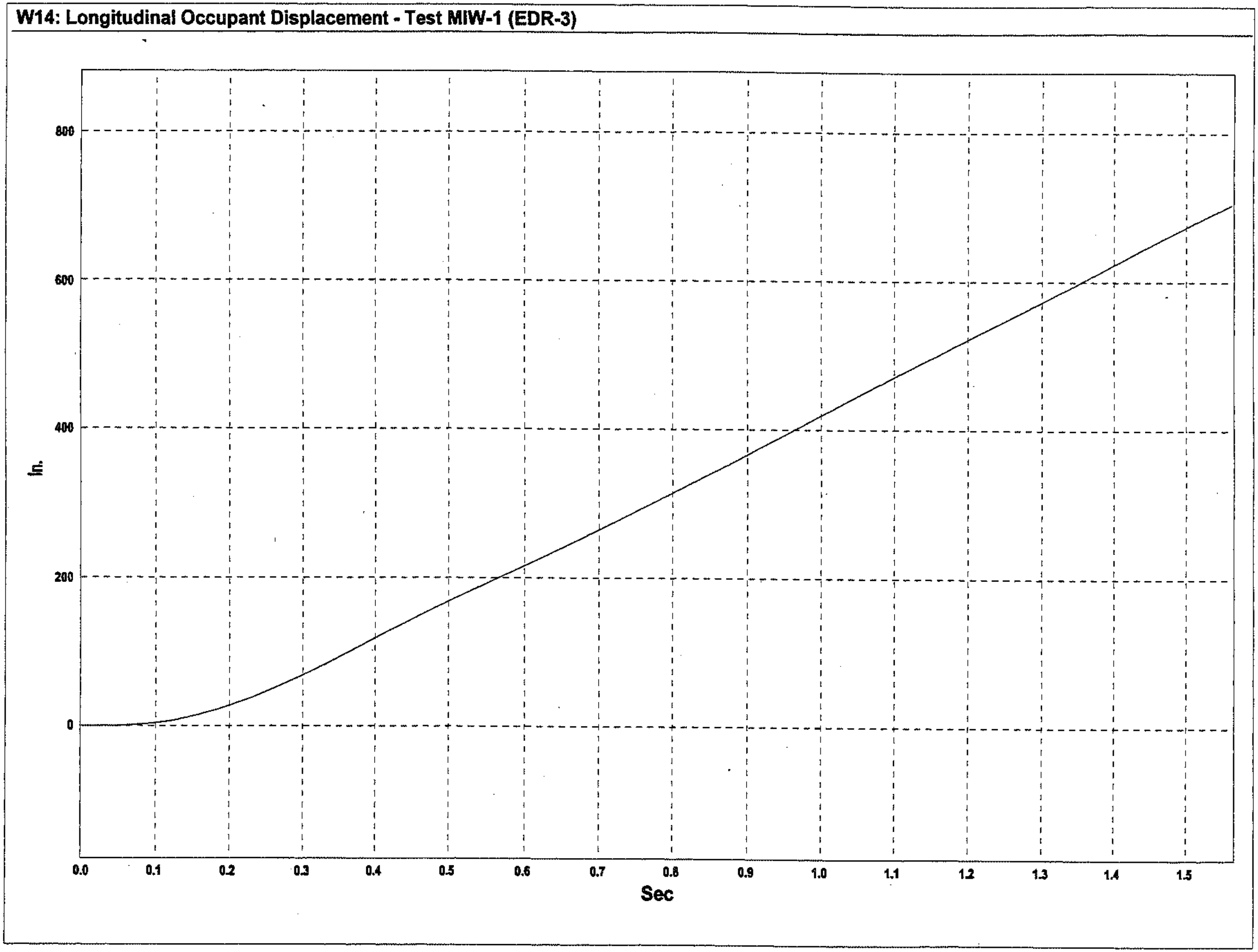

Figure A-3. Graph of Longitudinal Occupant Displacement, Test MIW-1

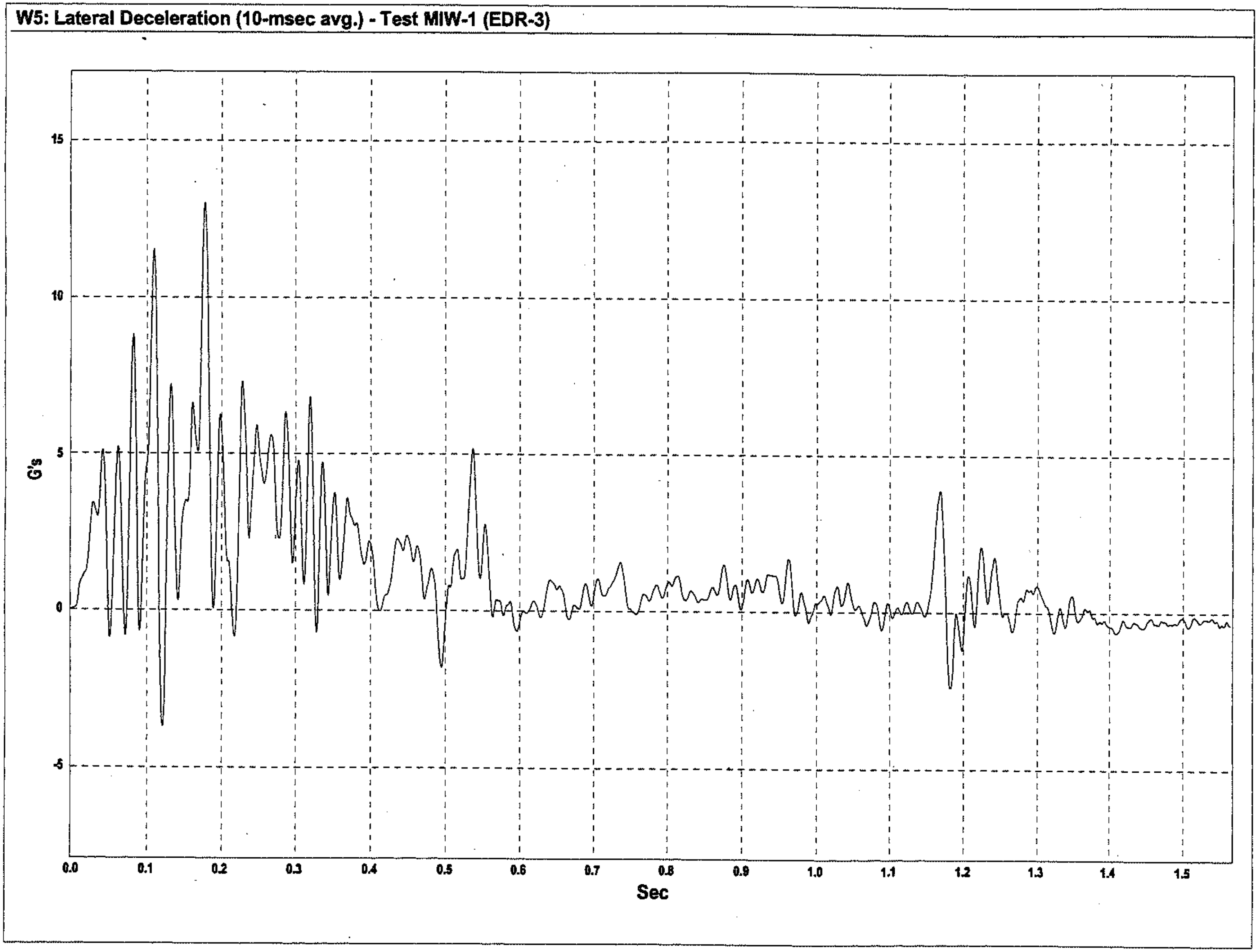

Figure A-4. Graph of Lateral Deceleration, Test MIW-1

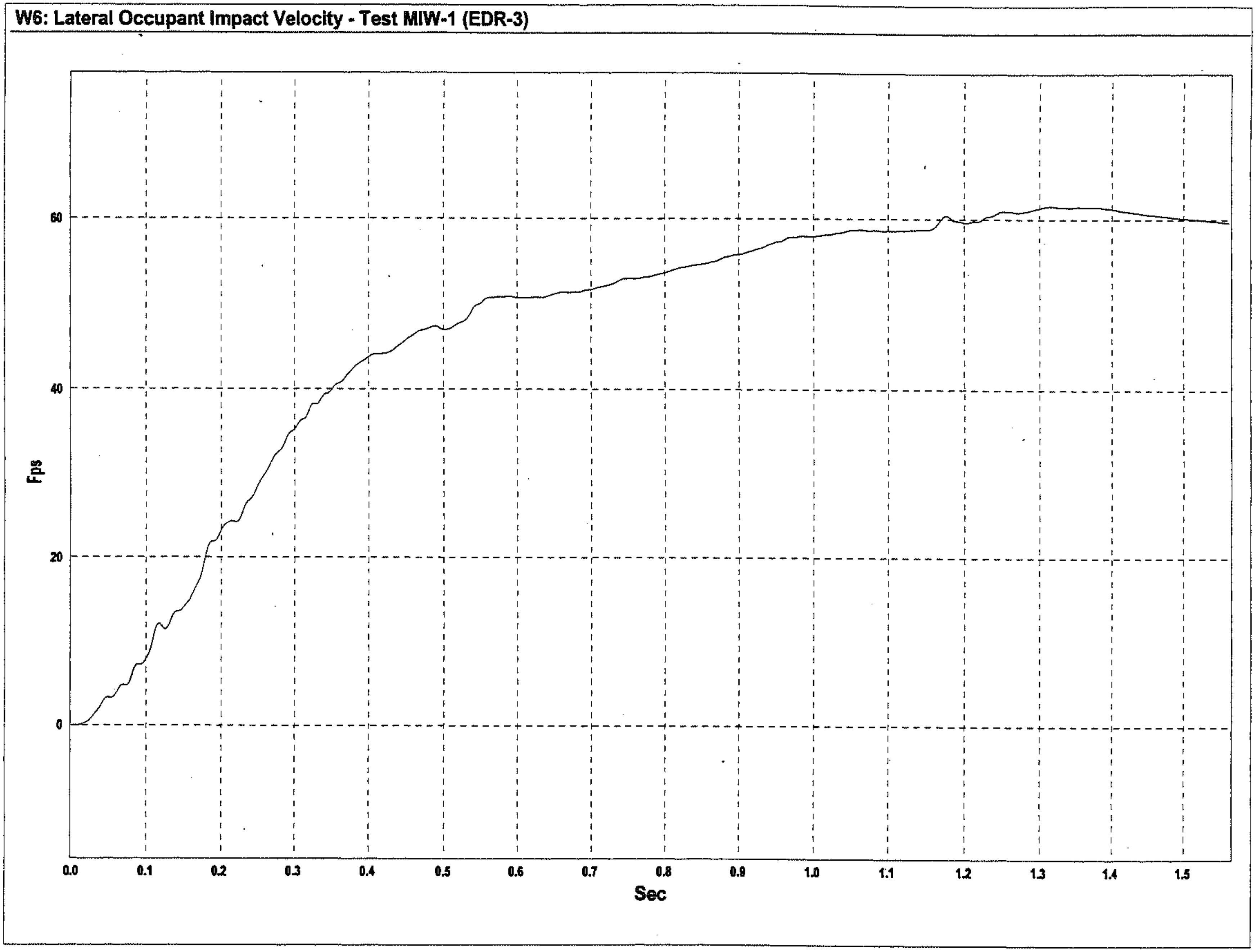

Figure A-5. Graph of Lateral Occupant Impact Velocity, Test MIW-1

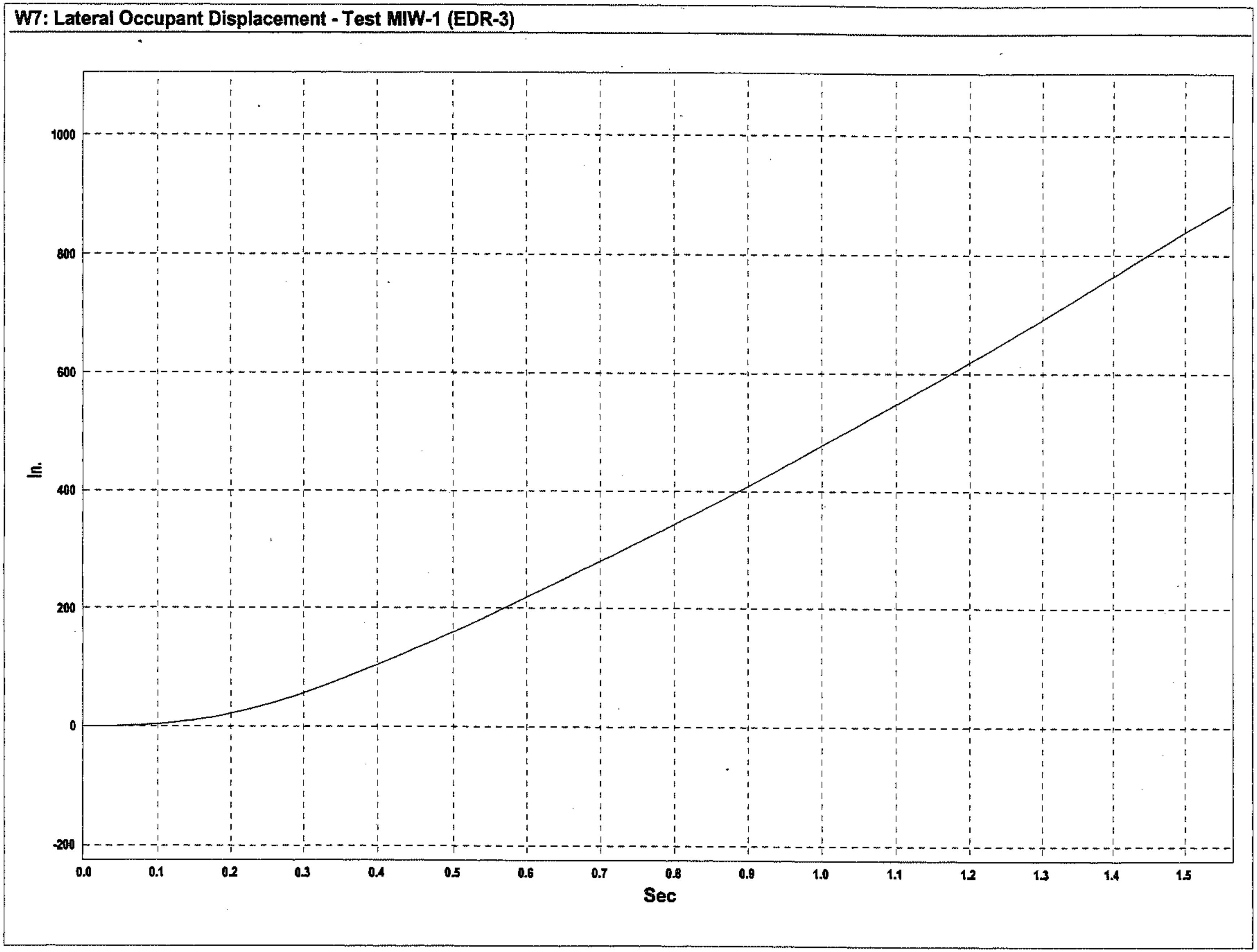

Figure A-6. Graph of Lateral Occupant Displacement, Test MIW-1

APPENDIX B

Roll, Pitch, and Yaw Data Analysis, Test MIW-1

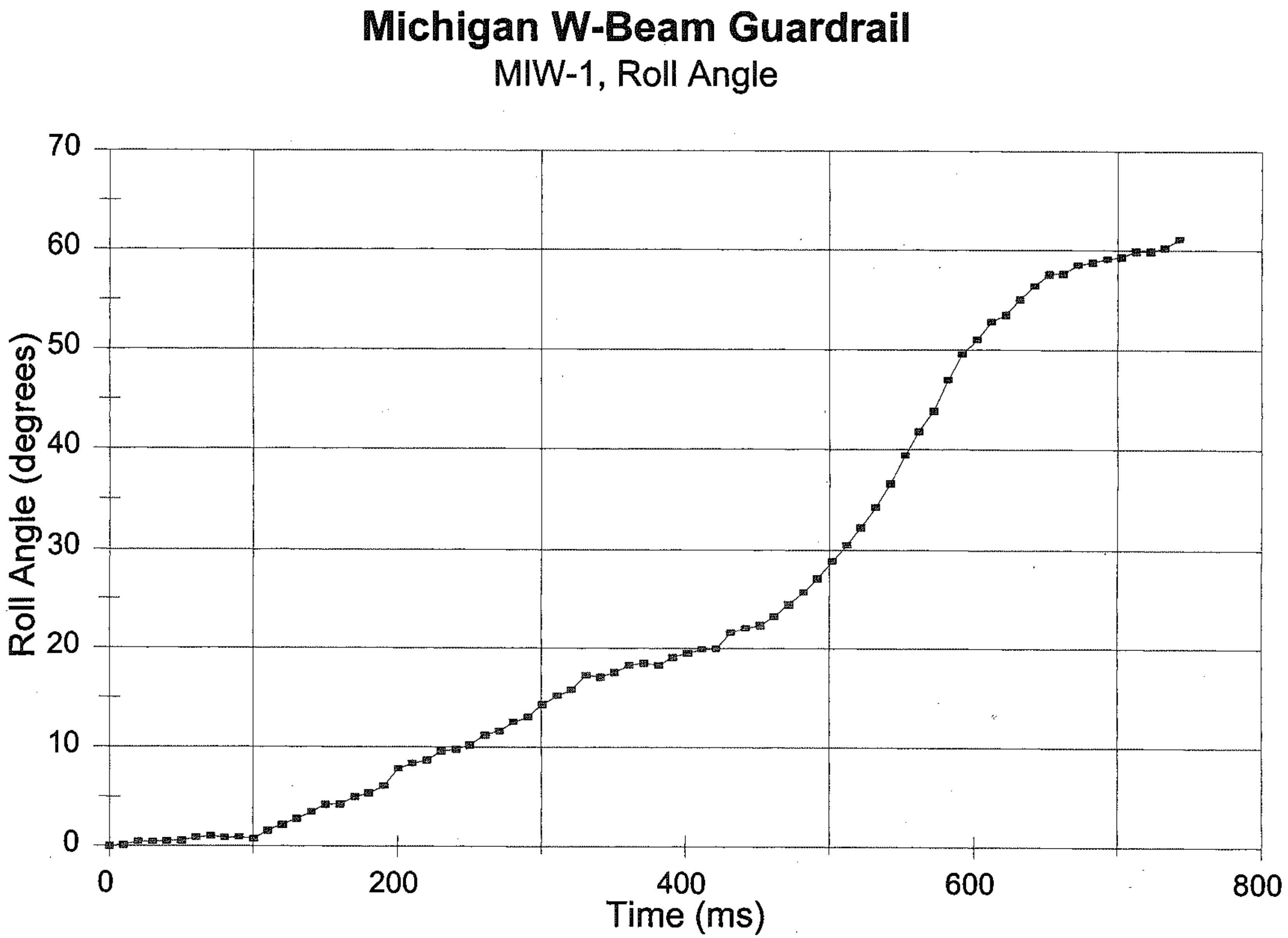

Figure B-1. Graph of Roll Angular Displacement, Test MIW-1

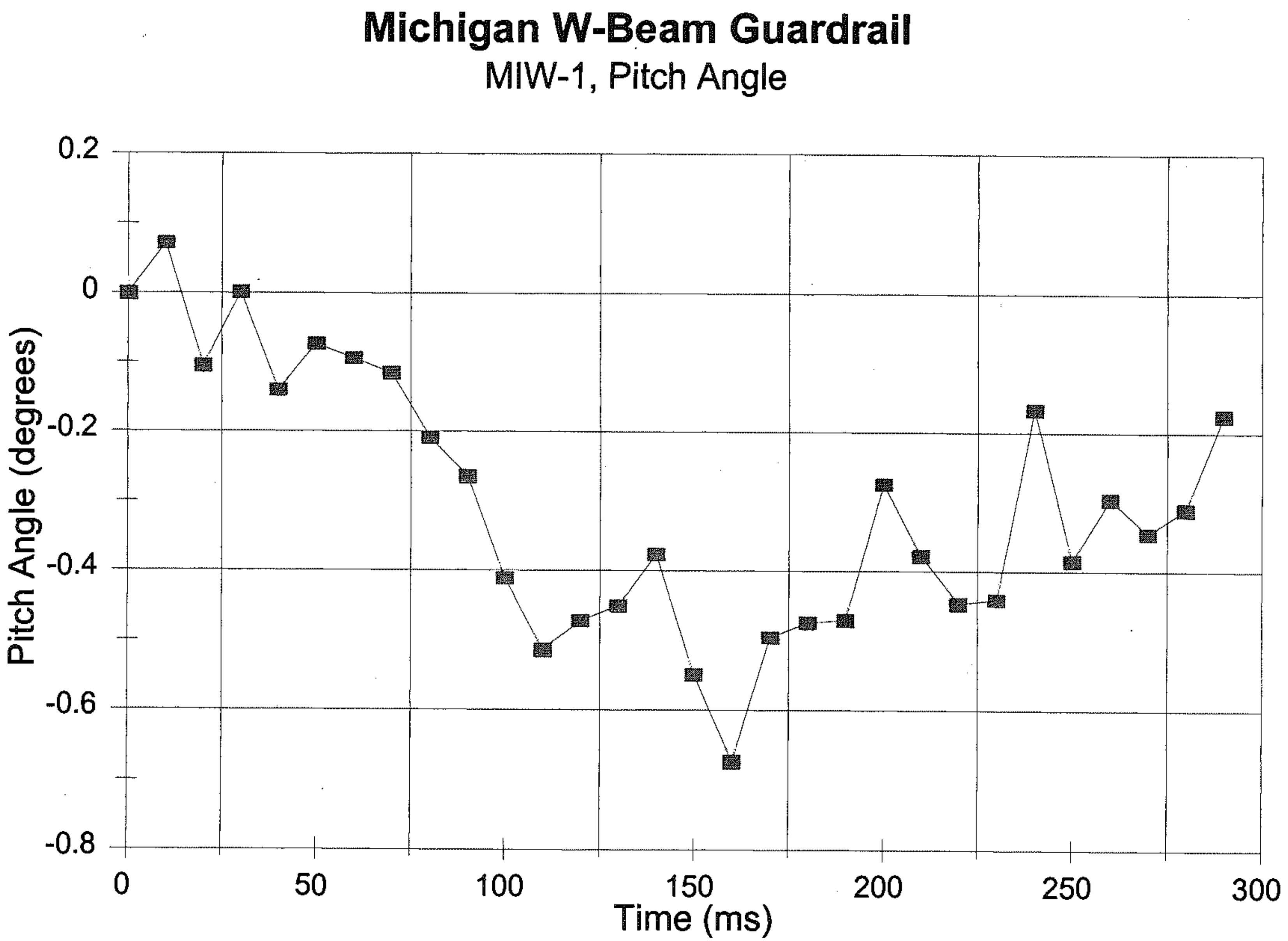

Figure B-2. Graph of Pitch Angular Displacement, Test MIW-1

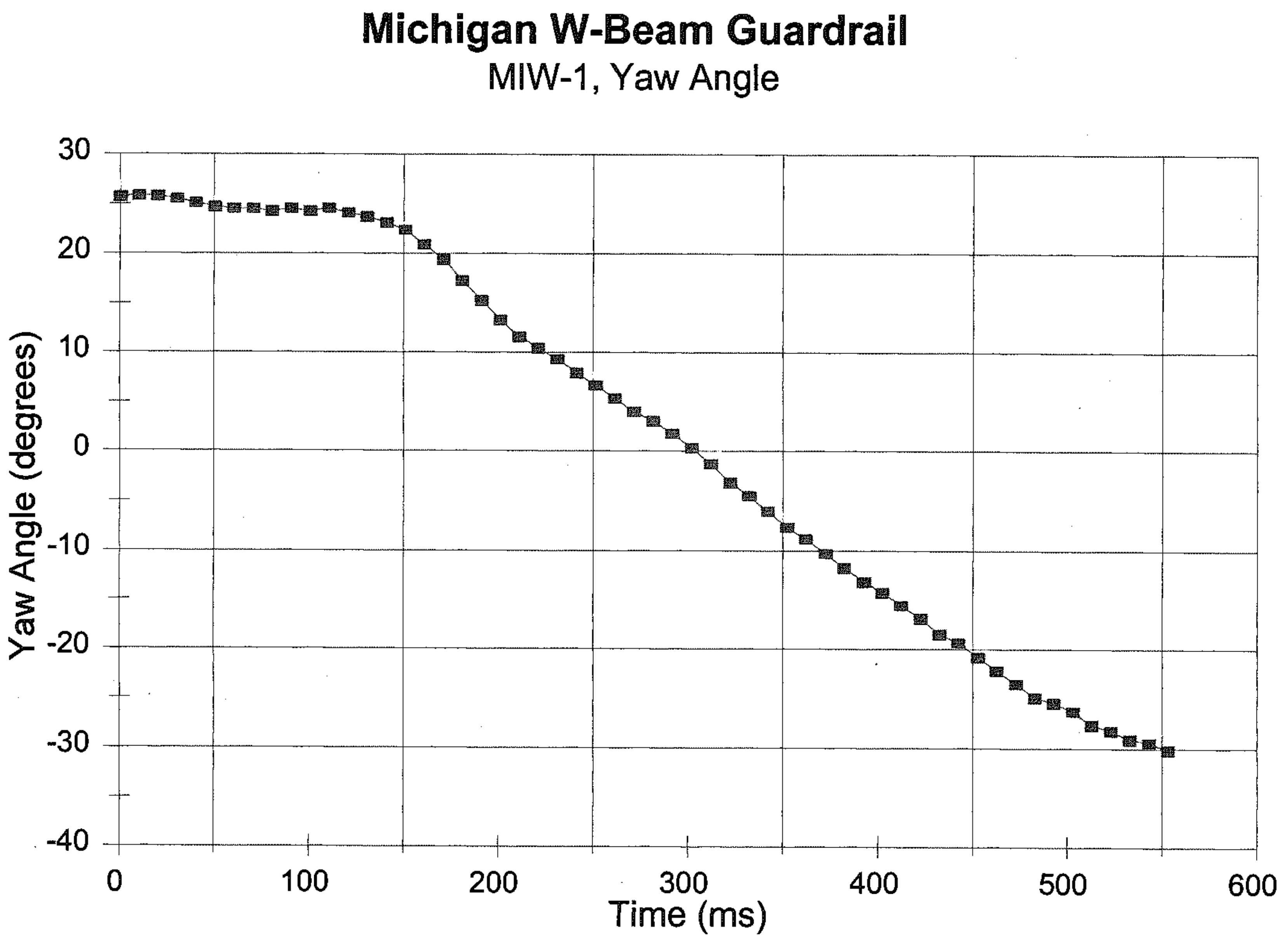

Figure B-3. Graph of Yaw Angular Displacement, Test MIW-1