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

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 360-mm long standard 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 vehicle impacted at a speed of 99.8 km/hr and an angle of 27.7 degrees. The test was unsuccessful due to the vehicle vaulting and landing on top of the guardrail with its right-side wheels contacting the ground behind the barrier system and then coming to rest on top of the downstream end of the guardrail. This unacceptable behavior was attributed to the failure of the W-beam guardrail to release properly from the guardrail posts. 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*. It was also concluded that the use of the routed wood blockouts did not contribute to the failure of the system.

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1 INTRODUCTION

1.1 Problem Statement

Michigan's Department of Transportation (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 National Cooperative Highway Research Program (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.

In order to assure compliance with NCHRP Report No. 350 safety performance evaluation criteria, Michigan's Type B guardrail was subjected to full-scale crash testing with a ¾-ton pickup (1). The test vehicle snagged on one of the guardrail posts and subsequently rolled over. The rollover appeared to be caused by premature suspension failure on the test vehicle. Therefore, another test of Michigan's Type B guardrail was determined to be appropriate. Based on recommendations from the Federal Highway Administration (FHWA), the retest was conducted with the guardrail installed at the standard 550-mm mounting height to the center of the guardrail element.

1.2 Objective

The objective of the research project was to evaluate the safety performance of the MDOT's Type B guardrail system when mounted at a height of 550 mm to the center of the guardrail element.

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* (2).

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 a ¾-ton pickup truck depends on the interaction of the front wheel and suspension and the W-beam (3-5). Essentially, the impacting vehicle is partially restrained as the front 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) (3). The pickup truck achieved a roll angle of 39 degrees during this test, but did not rollover. 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 (3). 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 (4). 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 (5). 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 (5).

Previously, the Midwest Roadside Safety Facility (MwRSF) completed the Phase I evaluation effort for the MDOT Type B (W-beam) longitudinal barrier design (1). For this study, a barrier configured with steel posts supporting 53.34 m of W-beam rail was constructed and unsuccessfully crash tested according to the NCHRP Report No. 350 criteria using a ¾-ton pickup truck.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as W-beam guardrail systems, must satisfy the safety performance criteria 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 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 guardrails perform satisfactorily when impacted by small cars, being essentially rigid (6-8), with no significant potential for occupant risk problems arising from vehicle pocketing or severe wheel snagging on the guardrail posts. 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 No. 350 Evaluation Criteria for 2000P Pickup Truck Crash Test (2)

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, 2, 28, and 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 augering 610-mm diameter holes approximately 1,092-mm deep and installing soil material in 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, 152-mm wide x 203-mm deep x 360-mm long standard wood offset-spacer blockouts were used to block the rail away from post nos. 3 through 27. This is in contrast to the system used in Design No. 1 (1) that was previously tested with double-tapered wood offset-spacer blockouts at the system's steel posts. For each wood blockout, two 16-penny, ungalvanized nails were installed 25-mm down from the top of the front face of the post and along the upstream and downstream edges 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 706 mm, as measured from the ground to the top of the rail. This is in contrast to the system used in Design No. 1 (1) that was previously tested with the mounting height of the W-beam rail at 686 mm from the ground to the top of the rail.

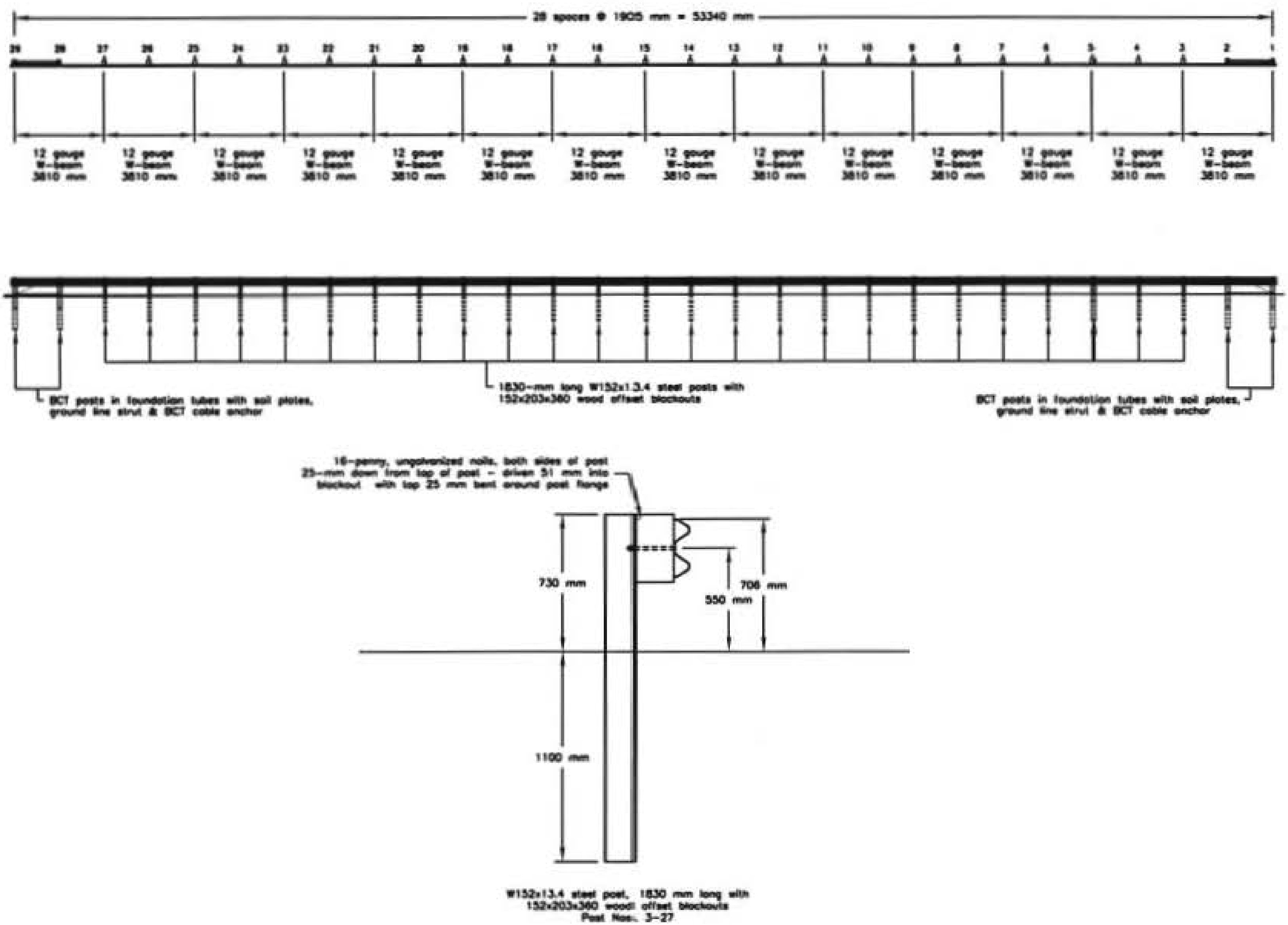


Figure 1. Modified Type B (W-beam) Longitudinal Barrier System

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

Figure 3. Simulated End Anchorage for Longitudinal Barrier System

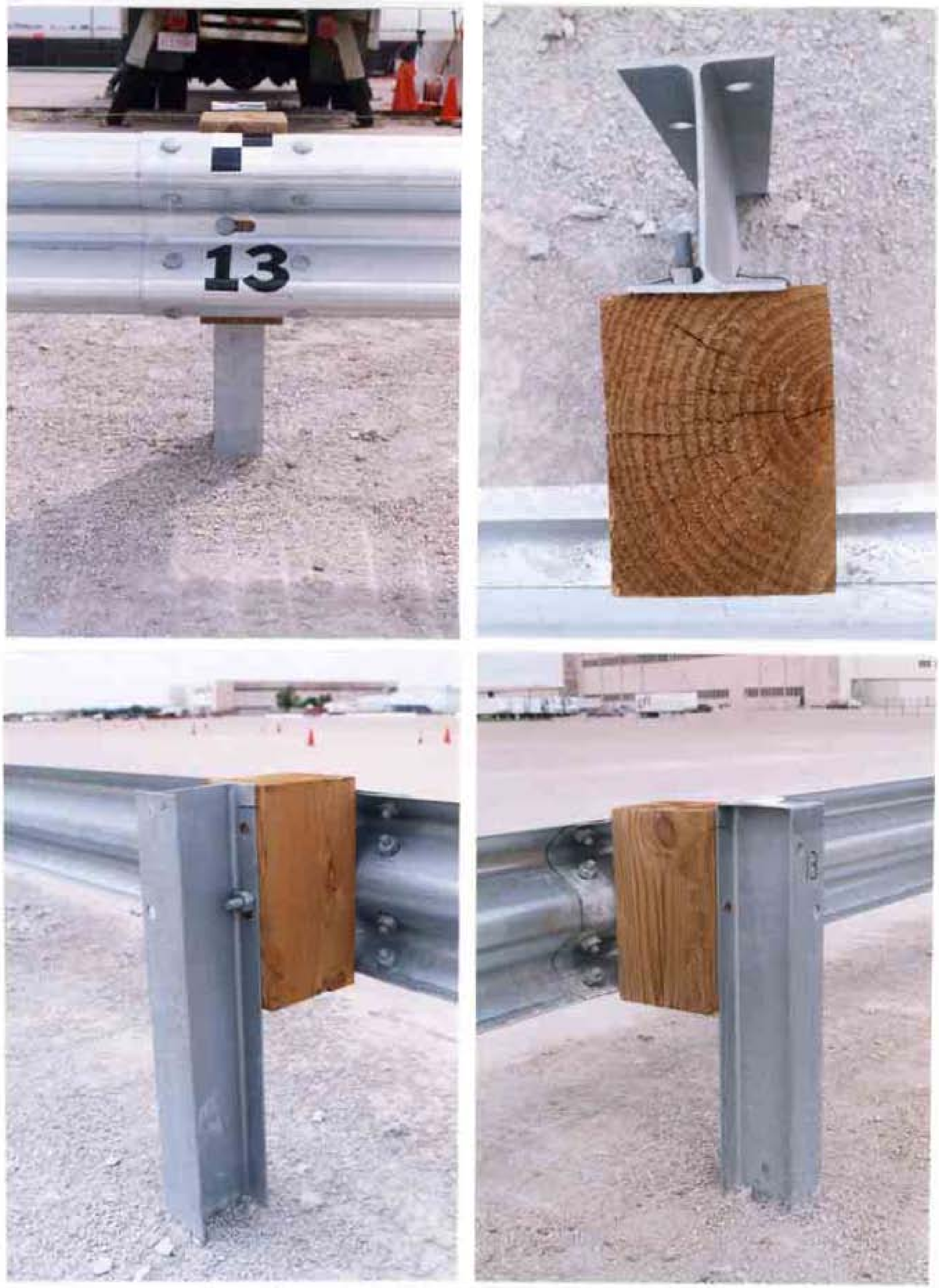


Figure 4. Post-to-Rail Attachment for the Type B (W-beam) Longitudinal Barrier System

5 TEST CONDITIONS

5.1 Test Facility

The testing facility is located at the Lincoln Air-Park on the northwest (NW) end of the Lincoln Municipal Airport and is approximately 8.0 km NW of the University of Nebraska-Lincoln.

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 (9) 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-2, a 1994 GMC 2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,034 kg. The test vehicle is shown in Figure 5, and vehicle dimensions are shown in Figure 6.

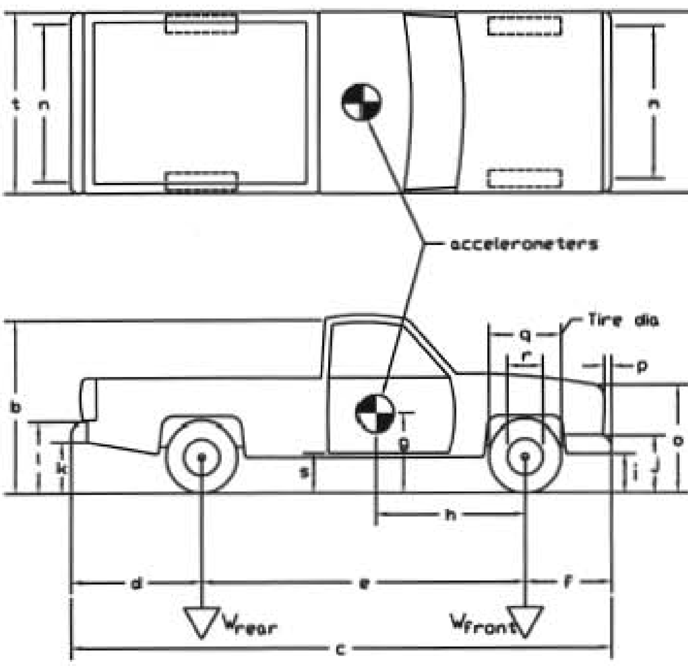
Figure 5. Test Vehicle, Test MIW-2

Date: 5/12/00 Test Number: MIW-2 Model: 2000 P

Make: GMC Vehicle I.D.#: 1GDGC24K9RE560253

Tire Size: LT 245/75 R16 Year: 1994 Odometer: 192,795

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm

a	1883	b	1829
c	5537	d	1295
e	3327	f	914
g	667	h	1429
i	445	j	660
k	610	l	787
m	1588	n	1619
o	1022	p	102
q	756	r	445
s	476	t	1848

Wheel Center Height Front 365

Wheel Center Height Rear 375

Wheel Well Clearance (FR) 895

Wheel Well Clearance (RR) 953

Engine Type 8 CYL. GAS

Engine Size 5.7 L 350 CID

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Weights - kg	Curb	Test Inertial	Gross Static
W_{front}	1172	1169	1169
W_{rear}	856	865	865
W_{total}	2028	2034	2034

Note any damage prior to test: NONE

Figure 6. Vehicle Dimensions, Test MIW-2

The Suspension Method (10) was used to determine the vertical component of the center of gravity (c.g.) for the ¾-ton pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the location of the center of gravity. The longitudinal component of the c.g. was determined using the measured axle weights. The center of gravity of the truck was found to be 667 mm above ground as shown, in Figure 7.

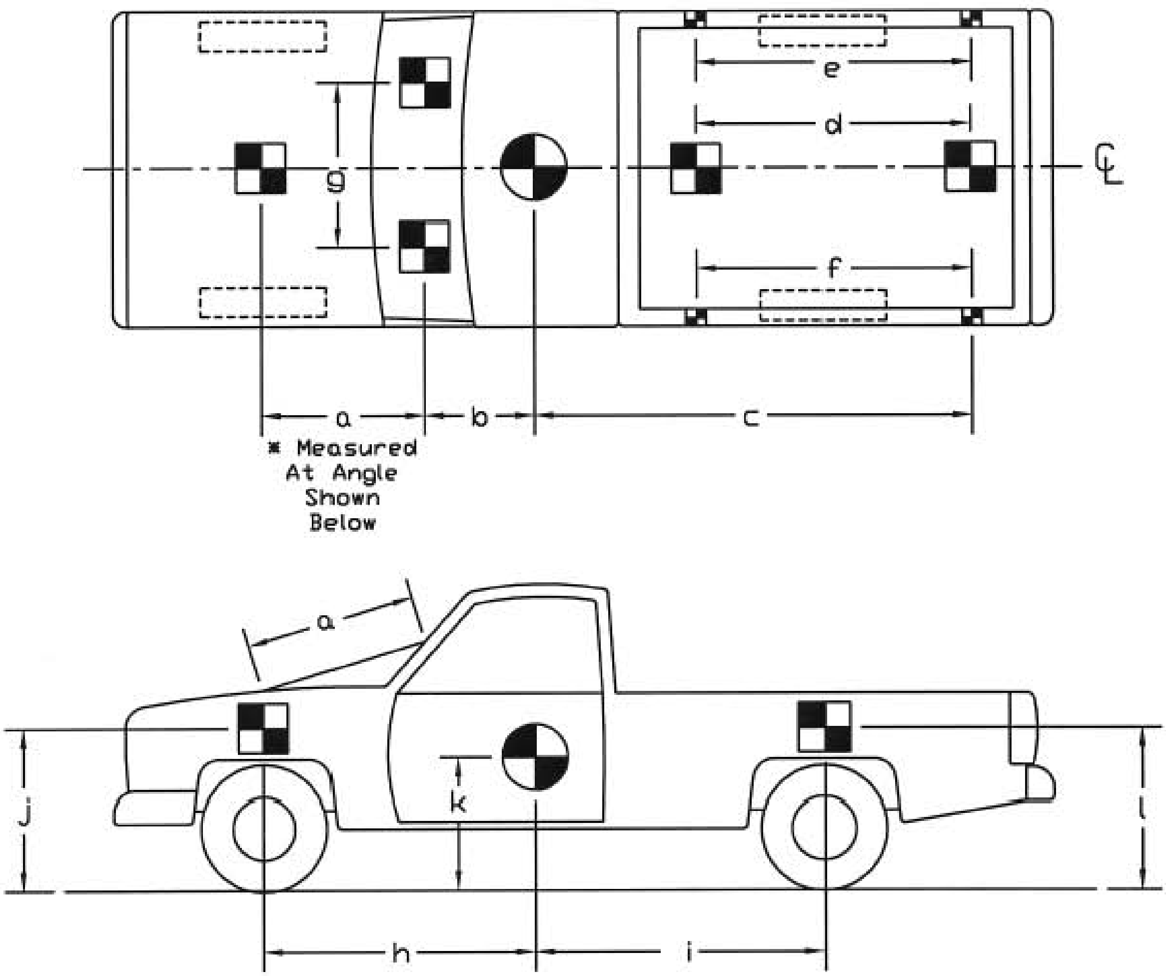
Square, black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film, as shown in Figure 7. Round, checkered targets were placed on the c.g. on the driver's side door, the passenger's side door, and on the roof of the vehicle. The remaining targets were located 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-2

TARGET GEOMETRY (mm)

a	902	d	1829	g	1022	j	1010
b	527	e	2153	h	1429	k	667
c	---	f	2153	i	1913	l	1060

Figure 7. Vehicle Target Locations, Test MIW-2

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-2, three high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. Two high-speed Red Lake E/cam digital video cameras, with operating speed range of 500 to 1000 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 Red Lake E/cam high-speed digital video camera, with an operating speed of 500 frames/sec, and a SVHS video camera were placed downstream and behind the barrier. Another Red Lake E/cam high-speed digital video camera, with an operating speed of 500 frames/sec, was placed upstream and behind the barrier. A Canon digital video camera was also placed upstream and behind the barrier, but closer to the impact point. A schematic of all ten camera locations for test MIW-2 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-2, 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.

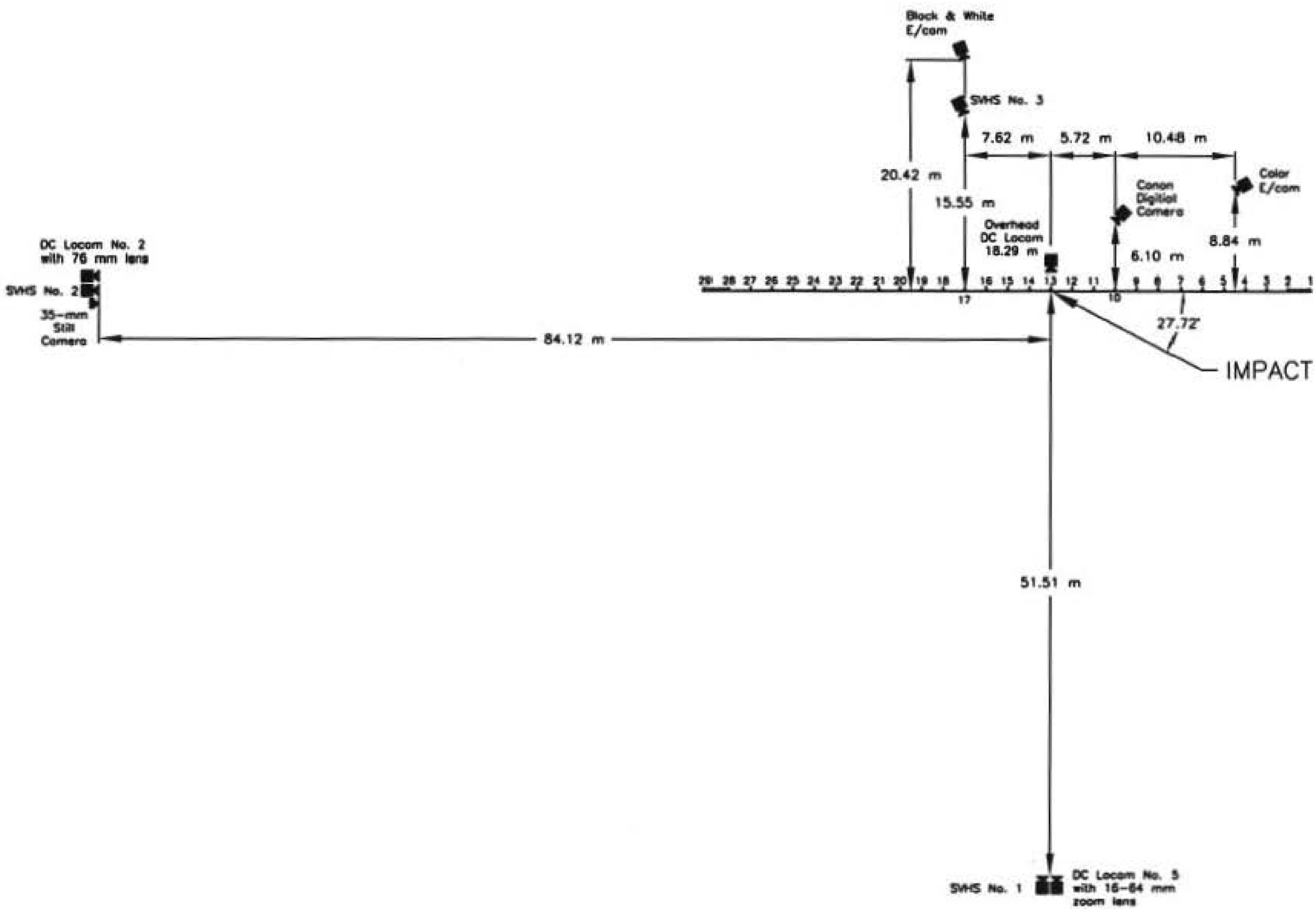


Figure 8. Location of High-Speed Cameras, Test MIW-2

6 CRASH TEST NO. 2

6.1 Test MIW-2

The 2,034-kg pickup truck impacted the W-beam guardrail system at a speed of 99.8 km/hr and an angle of 27.7 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 0.046 sec after impact, the right-front corner of the vehicle, which was at the midspan between post nos. 13 and 14, crushed inward. At 0.059 sec, post no. 14 quickly rotated backward. At 0.069 sec, the right-front corner of the vehicle continued to crush inward as post no. 13 had rotated backward to its maximum deflection. At 0.083 sec, the right-front corner of the vehicle was at post no. 14, and post no. 15 began to show movement. At 0.129 sec, the right-front corner of the vehicle was at the midspan between post nos. 14 and 15. At this same time, post no. 14 reached its maximum deflection as the truck began to redirect. At 0.134 sec, the guardrail released from post no. 14. At 0.158 sec, the front bumper rose above the top of the rail. At 0.192 sec, the right-front tire impacted post no. 15 and was deflated. At this same time, the front end of the vehicle began to pitch upward and the left-front tire was airborne. At 0.220 sec, the front of the vehicle was at post no. 16. At 0.307 sec, the front of the vehicle was at post no. 17, and the rear bumper contacted the rail. At 0.383 sec, the right-rear tire impacted post no. 15 and was deflated. At 0.432 sec, the right-rear tire, which had been riding along the traffic-side face of the rail, lost contact and was located on the back side of the rail. At 0.44 sec, the vehicle reached its maximum pitch angle of approximately 14 degrees. At 0.458 sec, the left-rear tire was airborne. At 0.541 sec, the vehicle, which was partially airborne, began to roll away from the rail that was positioned along the longitudinal midpoint of the vehicle. At 0.640 sec, the vehicle was completely airborne and free from the rail. At 0.810 sec, the vehicle returned to an unpitched state. At 1.074 sec, the left-front tire contacted the ground. At 1.234 sec, the right-rear tire contacted the ground on the backside of the guardrail. At 1.480 sec, the right-rear tire became airborne behind the guardrail with the vehicle positioned on top of the guardrail. At 1.760 sec, the left-rear tire contacted the ground behind the guardrail. At 1.9 sec, the vehicle reached its maximum roll angle of approximately 24 degrees toward the rail. The vehicle's post-impact trajectory is shown in Figure 9. The vehicle came to rest 28.58-m downstream from impact and on top of the guardrail between post nos. 26 and 29 with the left-front tire located 0.61-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 25. Barrier damage consisted mostly of deformed W-beam, contact marks on a guardrail section, and deformed guardrail posts. The W-beam damage consisted of major deformation and flattening of the impacted section between post nos. 13 and 15. Contact marks were found on the guardrail between post nos. 13 and 17. The top of the W-beam rail, downstream of post no. 21, was damage from the truck riding along the rail. A 559-mm long cut was found on the bottom peak starting 76-mm upstream of post no. 14.

Steel post nos. 3 through 13 and 17 through 19 moved backward slightly. Three steel posts, post nos. 14 through 16, rotated in the soil and bent toward the ground. A 406-mm long tire contact mark was found along the front face of post no. 14. The top of post no. 15 was also slightly damaged. The tops of steel post nos. 20 through 27 were contacted and damaged extensively by the vehicle. The wooden blockout at post no. 14 split down the middle but was still attached. Contact marks were found on the wooden blockout at post no. 15. A piece of the wooden blockout at post no. 16 was removed. Both the upstream and downstream anchorage systems move slightly, but the posts were not damaged, except for post no. 28 which was split along its length.

The permanent set of the guardrail and posts is shown in Figures 17 through 18 and 22 through 25. The cable anchor ends encountered slight permanent set deformations, as shown in Figure 25. The maximum lateral dynamic post and rail deflections were 1,084 mm at post no. 15 and 772 mm at the midspan between post nos. 15 and 16, respectively, as determined from the high-speed film analysis.

6.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 26 and 27. Interior occupant compartment deformations were determined to be negligible. The majority of the vehicle damage occurred to the vehicle's right side. The right-front fender was crushed inward and downward, and the right side of the front bumper was also bent toward the engine compartment. The right-front wheel assembly was deformed to approximately a 90 degree bend and pushed toward the firewall. Major damage was found on the inside of the right-front tire rim as well as tie-rod disengagement. The lower ball joint connection and the sway bar connection to the A-frame were deformed. The right side of the vehicle's frame was deformed extensively from the rear fender to the rear bumper. In addition, contact marks were observed on the inside of the right-rear wheel well. The outer side wall of the right-rear tire and the inner side wall of the right-front tire were slashed. Wood pieces were embedded into the A-frame and the connection between the drive shaft and rear end. Small contact marks were found on the outside surface of the right-front tire and the lower front corner of the right-side door. The headlight, parking light, and fog light on the right-side broke. Minimal damage was found on the right side of the grill. No other damage to the vehicle was observed.

6.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be 7.35 m/sec and 3.89 m/sec, respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 9.04 g's and 9.94 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

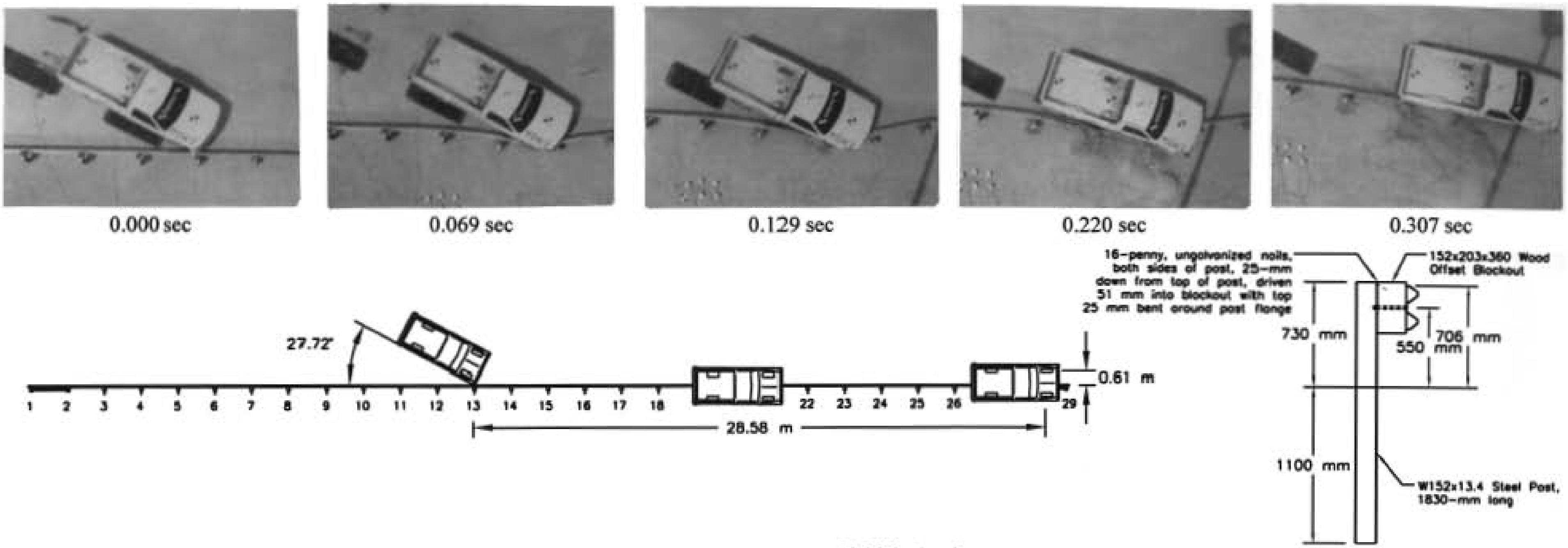
Michigan's Type B W-beam guardrail system successfully contained the 2000P test vehicle, and the vehicle remained stable and upright throughout the test. However, the system did not successfully redirect the vehicle as the right-side wheels contacted the ground behind the guardrail system during the impact sequence. The vehicle subsequently came to rest on top of the guardrail. As a result, the guardrail system's performance was determined to be unacceptable according to the NCHRP Report No. 350 criteria.

The cause of this unacceptable behavior is attributed to the failure of the W-beam to release quickly from the guardrail posts. The splice in the W-beam rail element remained attached to post no. 15 until the right-front tire contacted the post. During this time, the post rotated downward approximately 250 mm. Although the blockout reduced the magnitude of the downward motion, this post attachment caused the W-beam to be pulled down during a period when it is normally lifted up to retain the impacting vehicle's front tire. As a result, the tire was forced out from under the guardrail when it struck post no. 15, and the wheel began to climb the barrier as the test vehicle progressed. This wheel climb lead to vehicle vaulting and the failure of the system to successfully redirect the test vehicle.

Careful inspection of the damaged guardrail system and photos of the barrier prior to impact revealed that the post bolts were installed near the downstream end of the slot in the rail element. Testing of the post bolt pullout strengths has shown that bolts installed near the end of the slot generate higher forces before being pulled through the rail. This installation detail may have helped prevent the post bolt from becoming detached from the rail element.

It is the opinion of the authors that the wooden blockouts used in the Type B guardrail system did not contribute to this failure. A full-scale crash test of a nested guardrail system utilizing routed wood blockouts demonstrated that post bolts sometimes do not pull out of a double ply guardrail system (11). Hence it is not surprising that post bolts will occasionally fail to pull through a lap splice, regardless of the blockout configuration.

Finally, the vehicle's impact angle was measured to be approximately 27.7 degrees or 2.7 degrees greater than the 25 degree target angle. Although this larger impact angle increased the actual impact severity of the test, it is not believed to be sufficient to cause the observed failure. Recent crash testing of W-beam barriers at angles in excess of 28 degrees has exhibited acceptable safety performance (11).



- Test Number MIW-2
- Date 5/12/00
- 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 .... 706 mm
- Steel Posts
  - Post Nos. 3 - 27 .... W152x13.4 by 1,830-mm long
- Wood Spacer Blocks
  - Post Nos. 3 - 27 .... 152 mm x 203 mm by 360-mm long
- Soil Type .... Grading B - AASHTO M 147-65 (1990)
- Vehicle Model .... 1994 GMC 2500 2WD
  - Curb .... 2,0281 kg
  - Test Inertial .... 2,034 kg
  - Gross Static .... 2,034 kg
- Vehicle Speed
  - Impact .... 99.8 km/hr
  - Exit .... NA
- Vehicle Angle
  - Impact .... 27.7 degrees
  - Exit .... NA
- Vehicle Snagging .... Minor wheel snag on post no. 14
- Vehicle Pocketing .... None
- Vehicle Stability .... Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal .... 9.04 < 20 G's
  - Lateral (not required) 9.94
- Occupant Impact Velocity
  - Longitudinal .... 7.35 < 12 m/s
  - Lateral (not required) 3.89
- Vehicle Damage .... Moderate
  - TAD[12] 1-RFQ-4
  - SAE[13] 1-RFE3
- Vehicle Stopping Distance .... 28.58 m downstream, 0.61 m traffic-side face
- Barrier Damage .... Moderate
- Maximum Deflections
  - Dynamic – Post .... 772 mm
  - Dynamic – Rail .... 1,084 mm

Figure 9. Summary of Test Results and Sequential Photographs, Test MIW-2

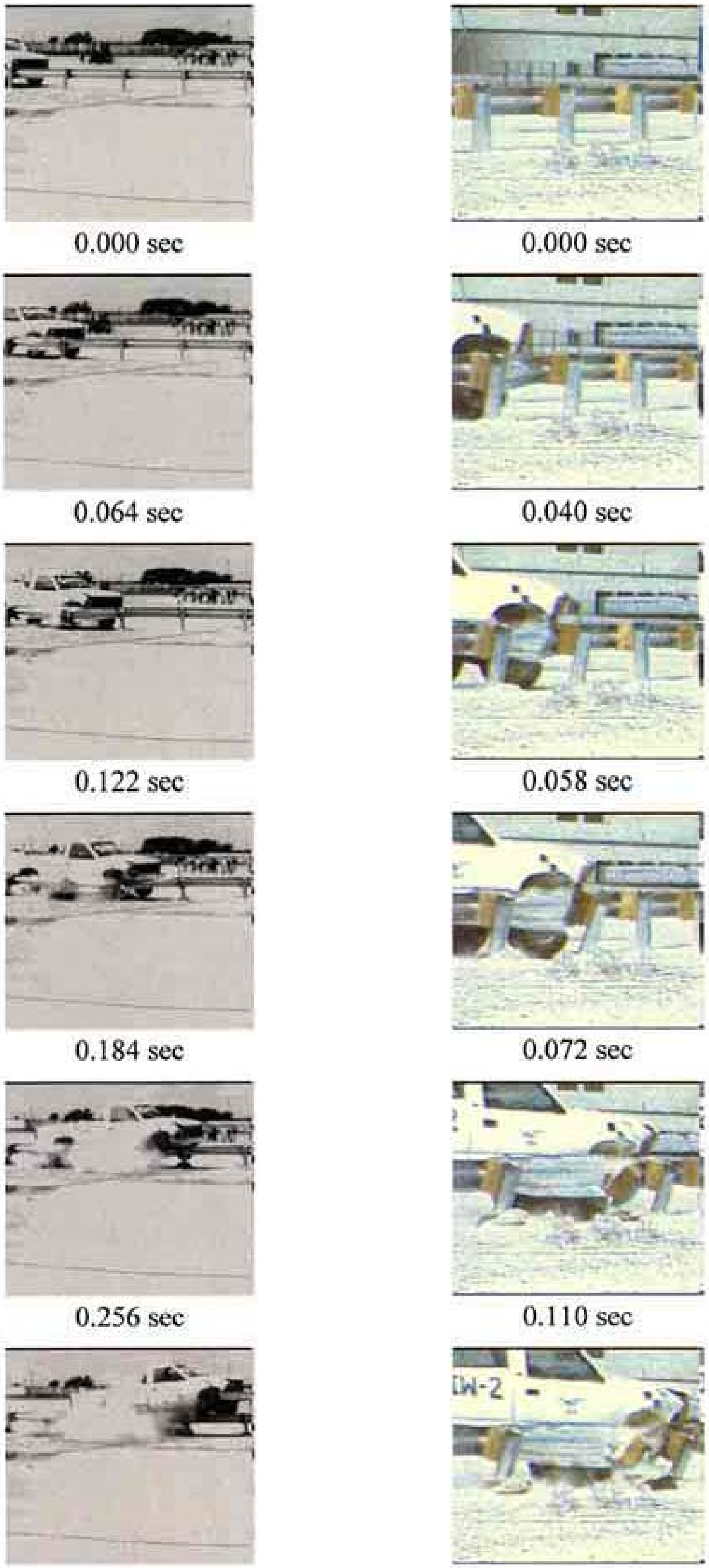
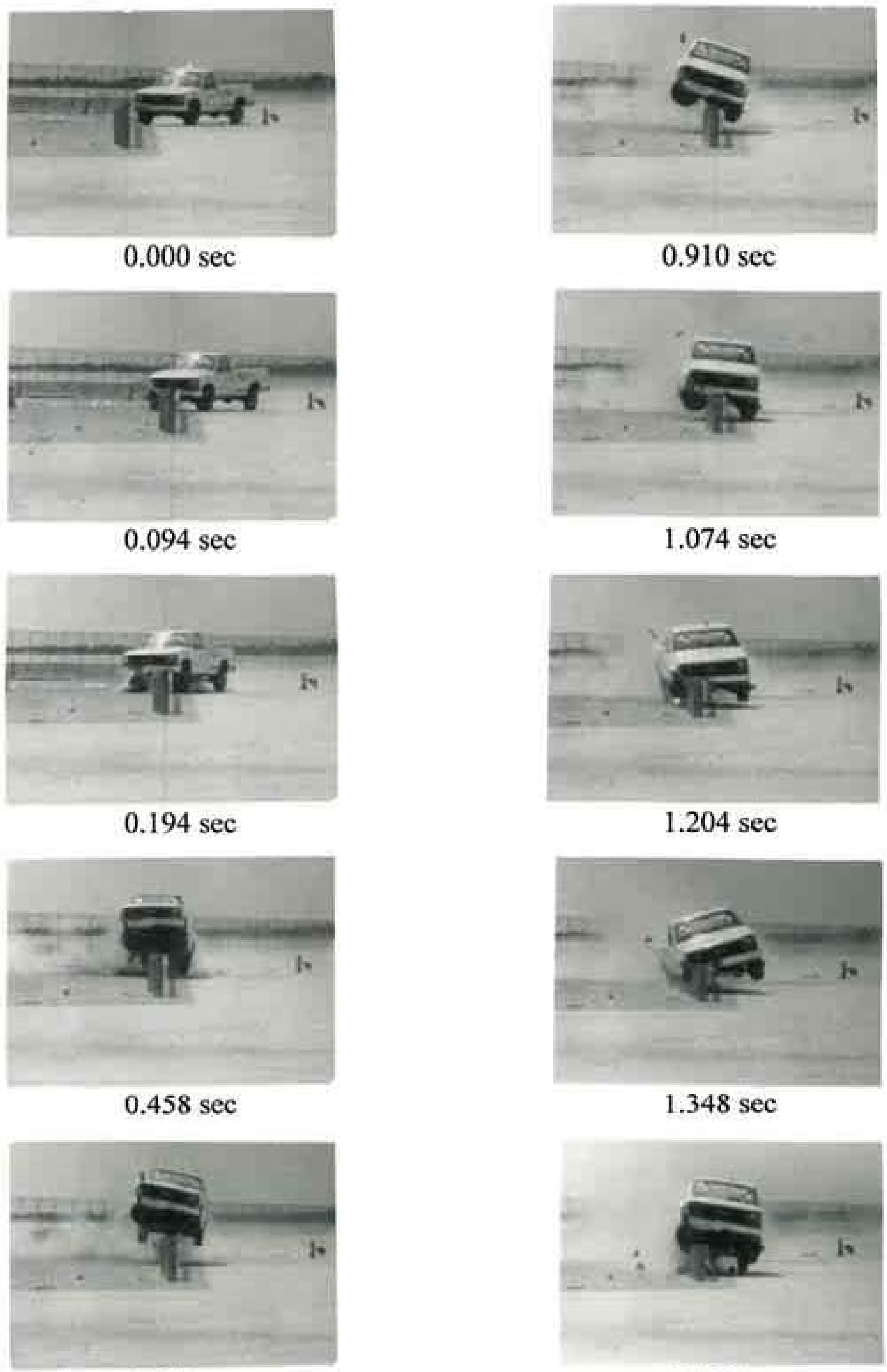


Figure 10. Additional Sequential Photographs, Test MIW-2



0.000 sec | 0.910 sec
0.094 sec | 1.074 sec
0.194 sec | 1.204 sec
0.458 sec | 1.348 sec
0.640 sec | 1.760 sec

Figure 11. Additional Sequential Photographs, Test MIW-2

Figure 12. Documentary Photographs, Test MIW-2

Figure 13. Documentary Photographs, Test MIW-2

Figure 14. Documentary Photographs, Test MIW-2

Figure 15. Impact Location, Test MIW-2

Figure 16. Final Vehicle Location, Test MIW-2

Figure 17. Type B Longitudinal Barrier Damage, Test MIW-2

Figure 18. Type B Longitudinal Barrier Damage, Test MIW-2

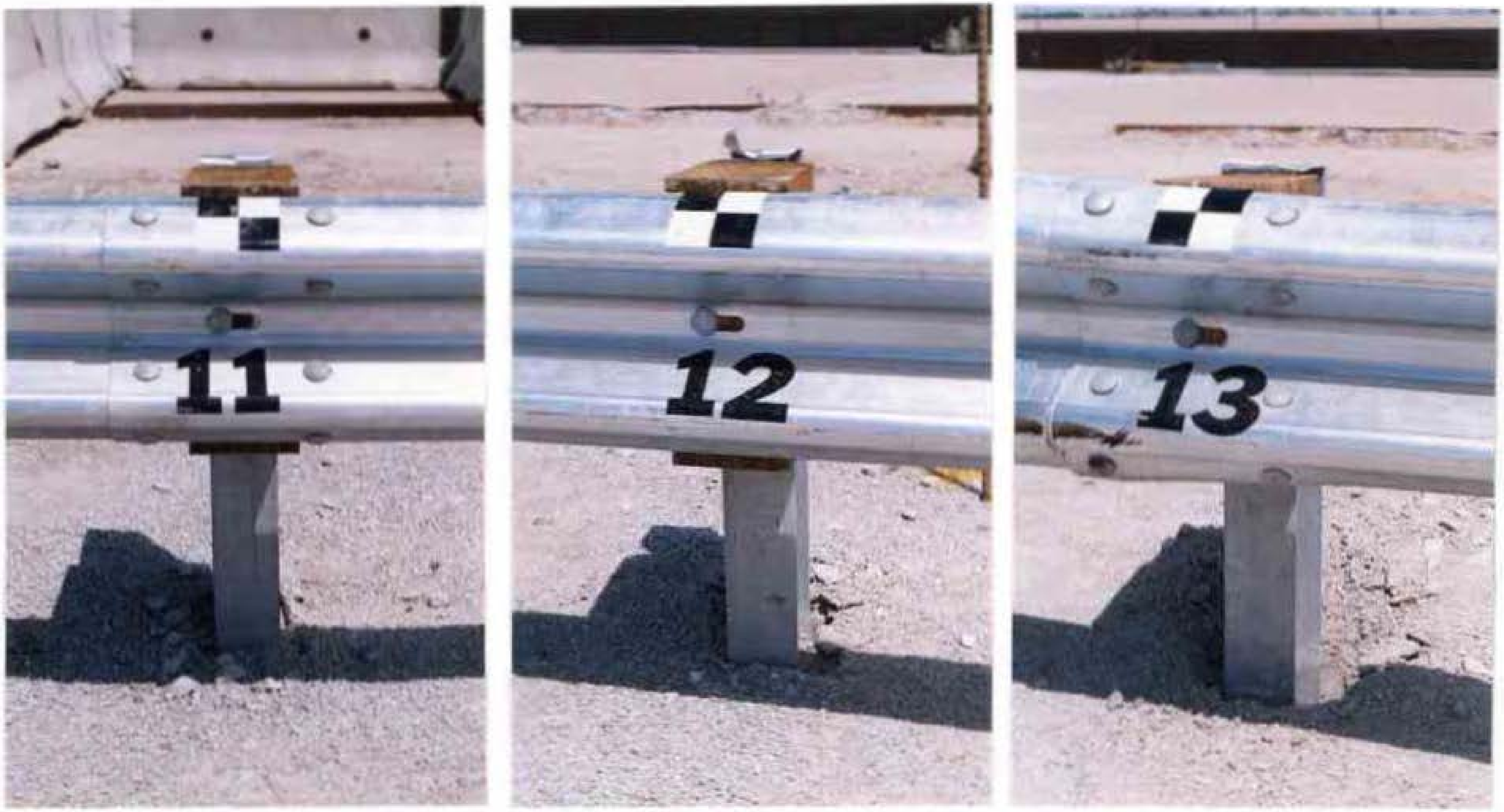


Figure 19. Type B Longitudinal Barrier Rail and Post Damage, Test MIW-2

Figure 20. Type B Longitudinal Barrier Rail and Post Damage, Test MIW-2

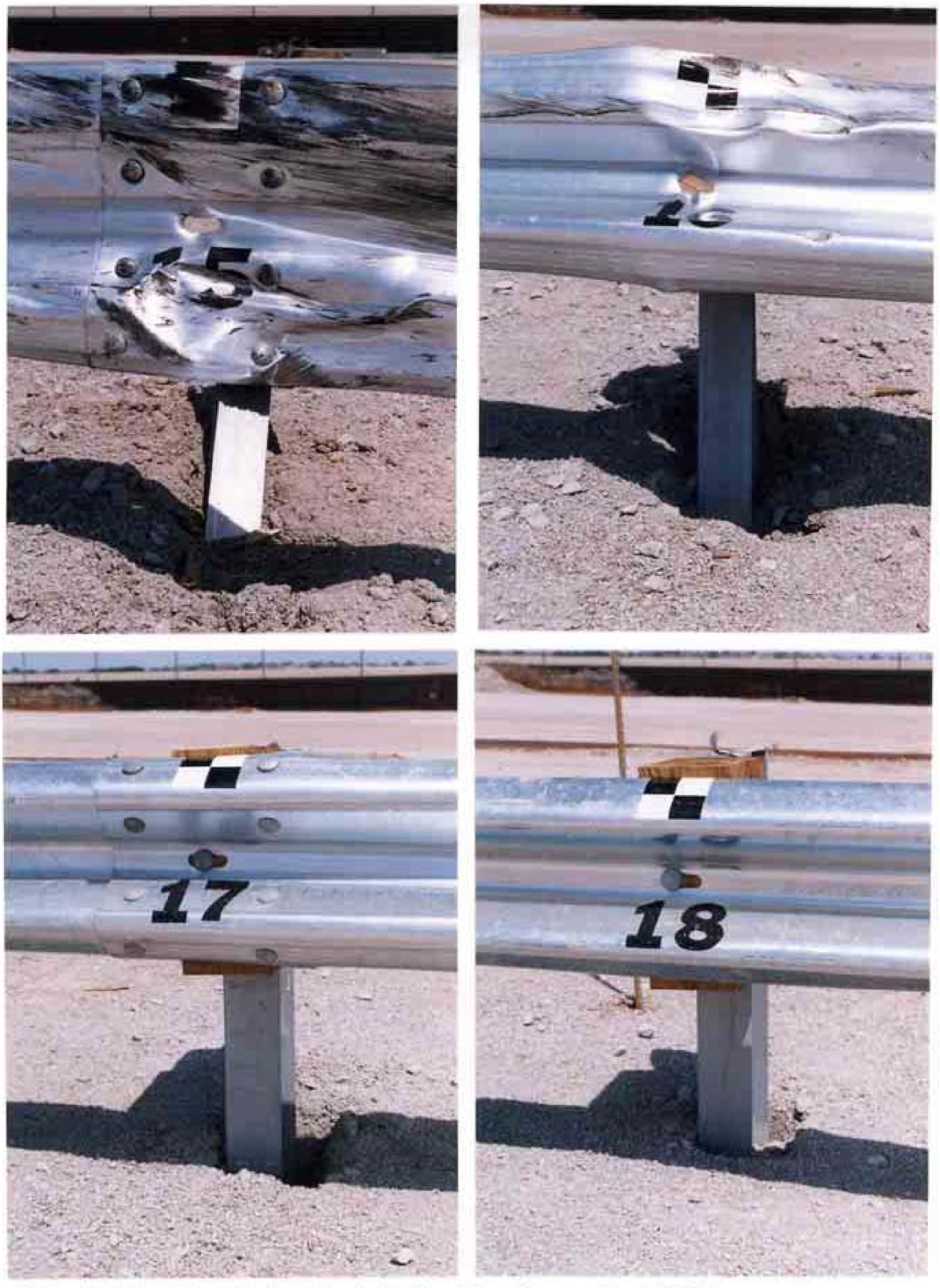


Figure 21. Type B Longitudinal Barrier Rail and Post Damage, Test MIW-2

Post No. 12

Post No. 13

Figure 22. Final Post Position – Post Nos. 12 and 13, Test MIW-2

Post No. 14

Post No. 15

Figure 23. Final Post Positions – Post Nos. 14 and 15, Test MIW-2

Post No. 16

Post No. 17

Figure 24. Final Post Positions – Post Nos. 16 and 17, Test MIW-2

Figure 25. Permanent Set Deflections of End Anchorages, Test MIW-2

Figure 26. Vehicle Damage, Test MIW-2

Figure 27. Front-End Vehicle and Rear-Tire Damage, Test MIW-2

7 SUMMARY AND CONCLUSIONS

MDOT's Type B W-beam guardrail system was constructed with a mounting height of 550 mm to the center of the rail element. The system was then subjected to one full-scale crash test with a ¾-ton pickup truck according to the TL-3 safety performance evaluation criteria contained in NCHRP Report No. 350. The crash test, test no. MIW-2, failed to provide an acceptable safety performance. During the impact, the vehicle vaulted and landed on top of the guardrail with its right-side wheels contacting the ground behind the barrier system and then came to rest on top of the downstream end of the guardrail system.

Evaluation of the crash test films and the before and after photographic documentation indicated that the test failure was caused when the post bolt did not pull through the W-beam rail element at post no. 15. The post bolt may have required a higher pullout force because the post bolts were originally installed near the end of the slot in the W-beam guardrail. 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-2
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.	U
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.	S
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.	S

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

8 RECOMMENDATIONS

The Michigan Type B (W-beam) longitudinal barrier with a mounting height of 550 mm to the center of the rail element, as described in this report, was not successfully crash tested according to the criteria found in NCHRP Report No. 350. Due to the vehicle landing on top of the guardrail system and contacting the ground behind the system, test MIW-2 was judged to be a failure.

Analysis of test MIW-2 indicates that the failure of the W-beam rail to release from the guardrail posts was a significant contributor to the launching of the vehicle. However, there is no indication that the wood blockouts contributed to this failure. It is also noted that previous test results indicate that Test 3-11 is near the upper limit of strong-post W-beam guardrail. Relatively small variances, such as post bolts that are near the end of the rail slot so that the release of the rail is restricted, may cause problems with any strong-post W-beam guardrail. There is no indication that the blockouts used in conjunction with strong-post W-beam guardrail contributed to the failure of the Michigan Type B longitudinal barrier.

9 REFERENCES

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10 APPENDICES

APPENDIX A

Accelerometer Data Analysis, Test MIW-2

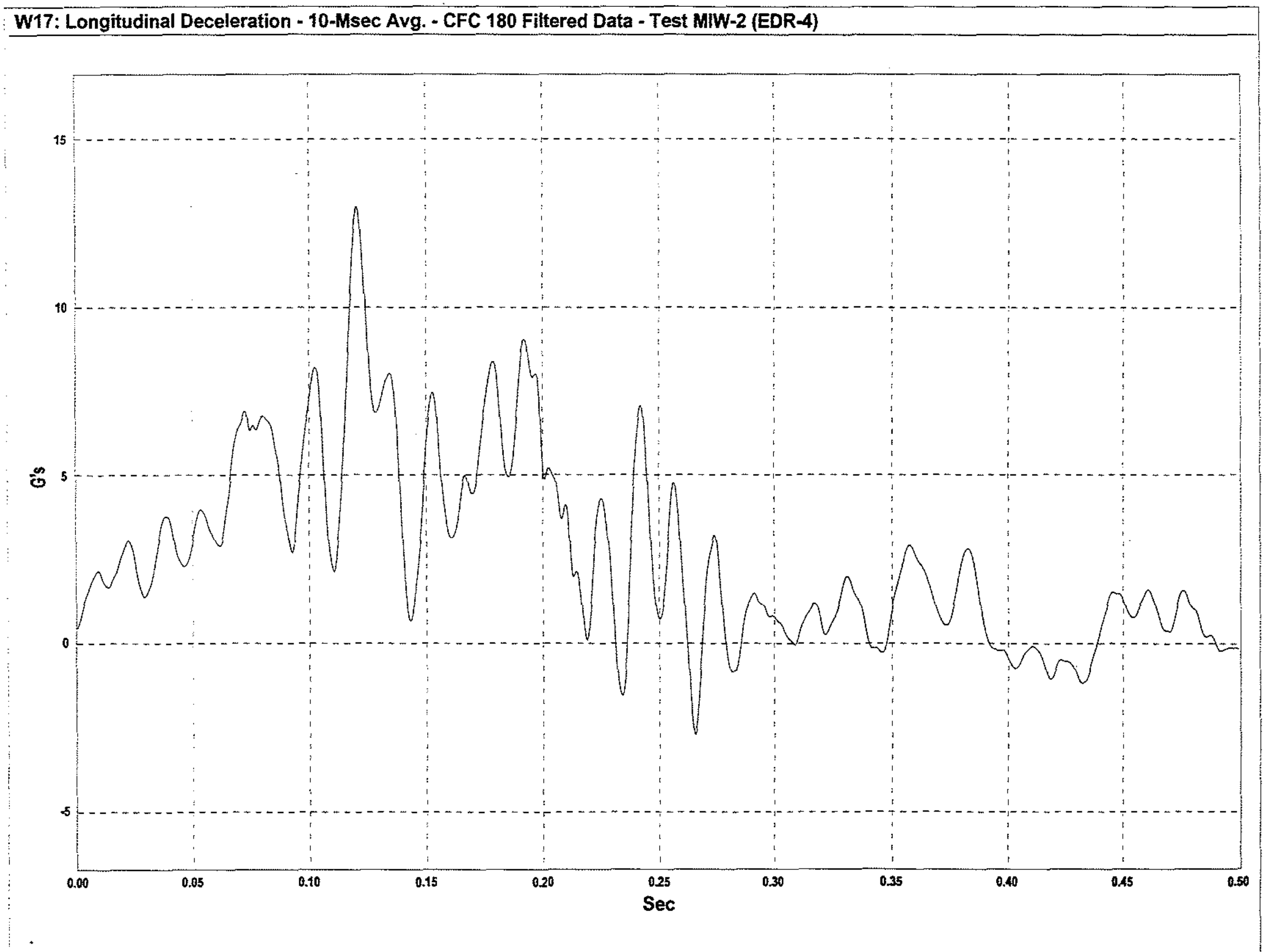

Figure A-1. Graph of Longitudinal Deceleration, Test MIW-2

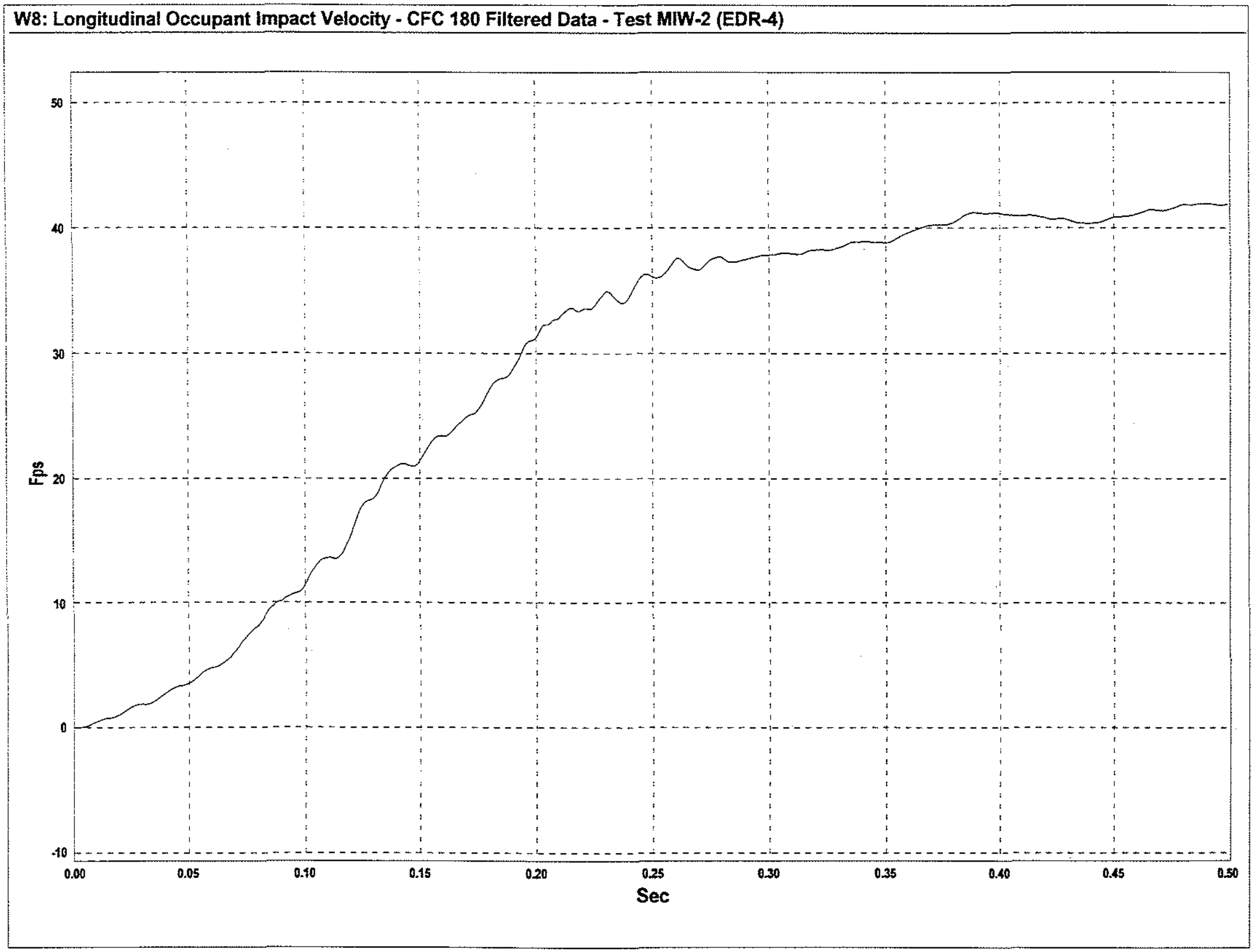

Figure A-2. Graph of Longitudinal Occupant Impact Velocity, Test MIW-2

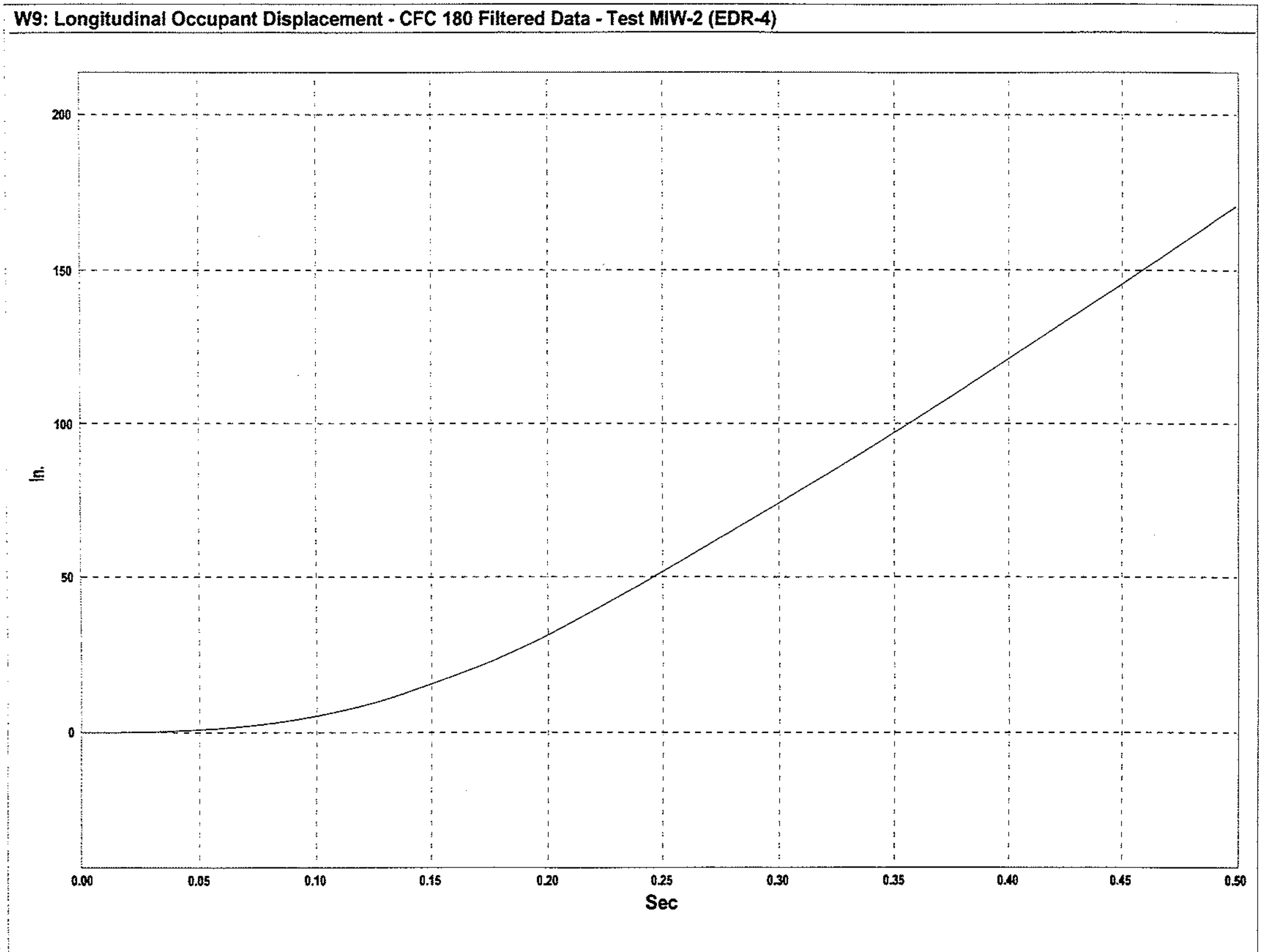

Figure A-3. Graph of Longitudinal Occupant Displacement, Test MIW-2

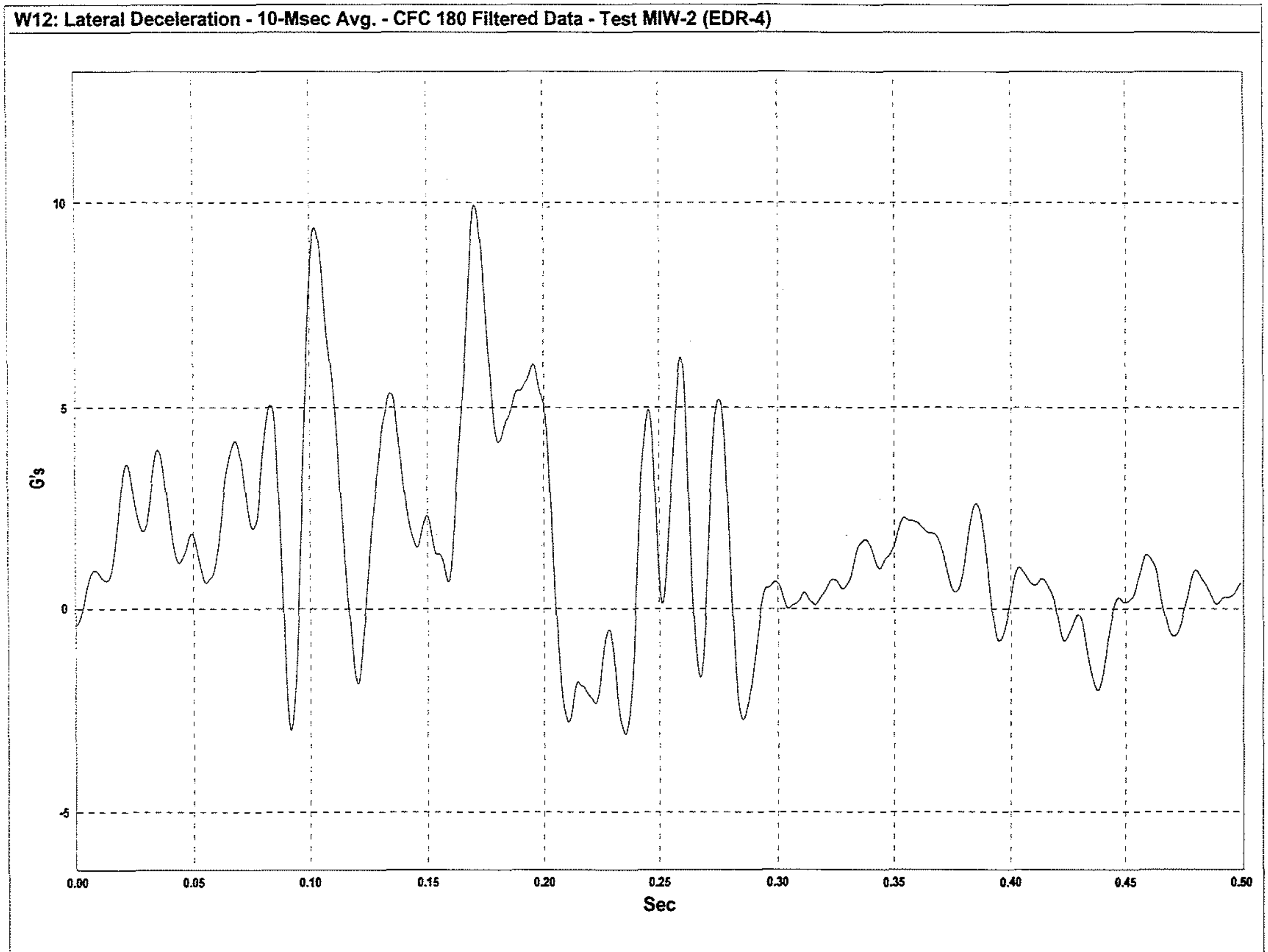

Figure A-4. Graph of Lateral Deceleration, Test MIW-2

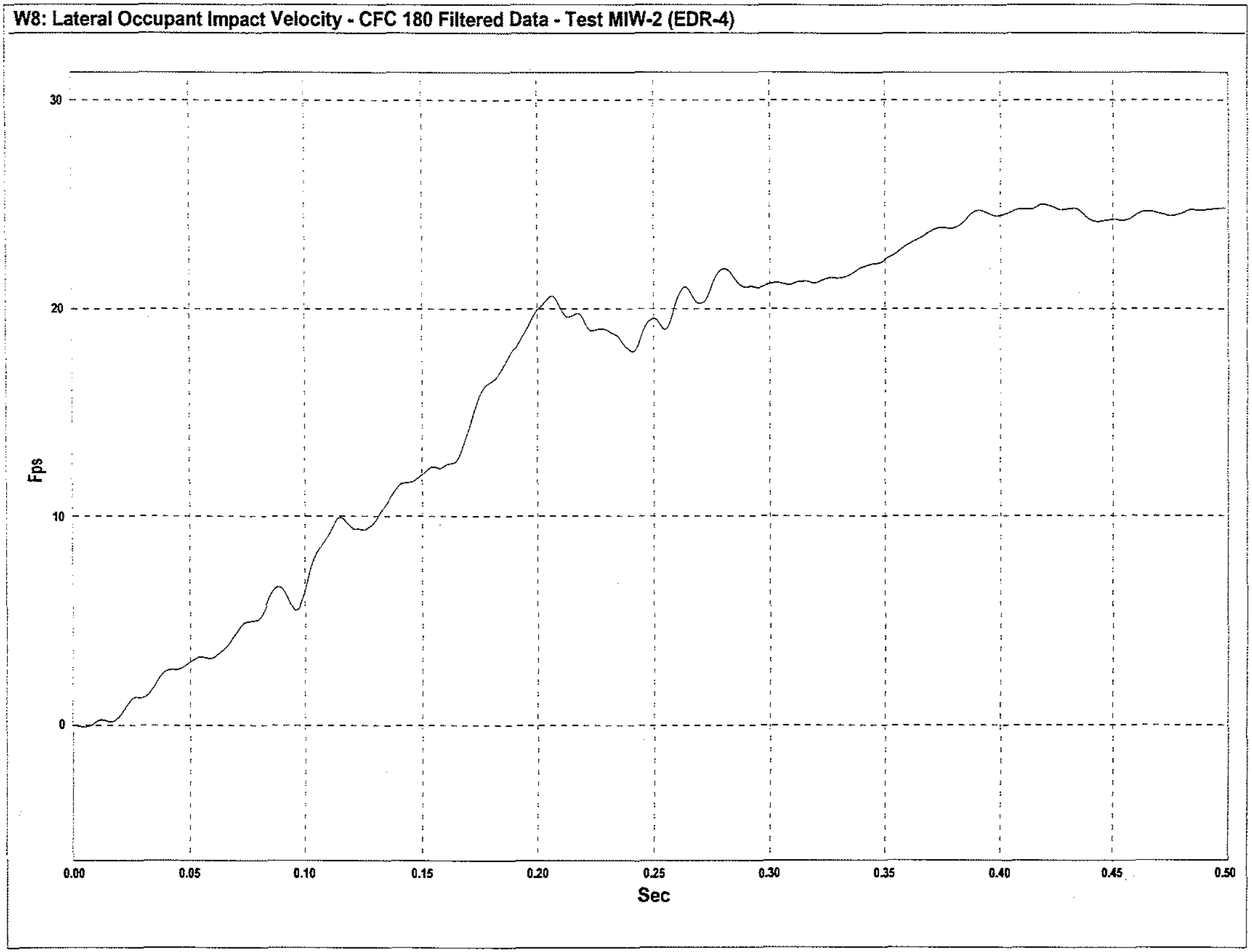

Figure A-5. Graph of Lateral Occupant Impact Velocity, Test MIW-2

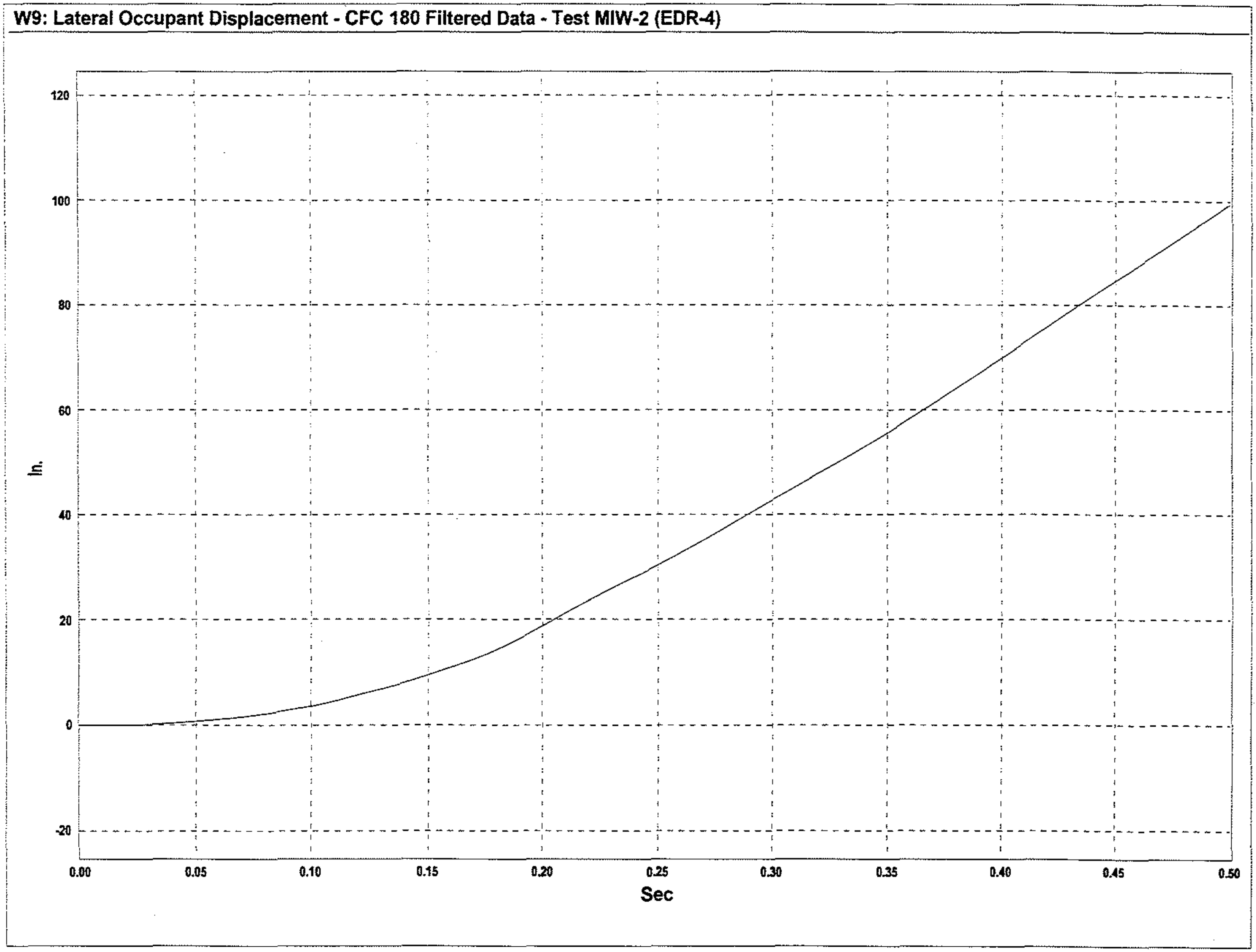

Figure A-6. Graph of Lateral Occupant Displacement, Test MIW-2

APPENDIX B

Roll, Pitch, and Yaw Data Analysis, Test MIW-2

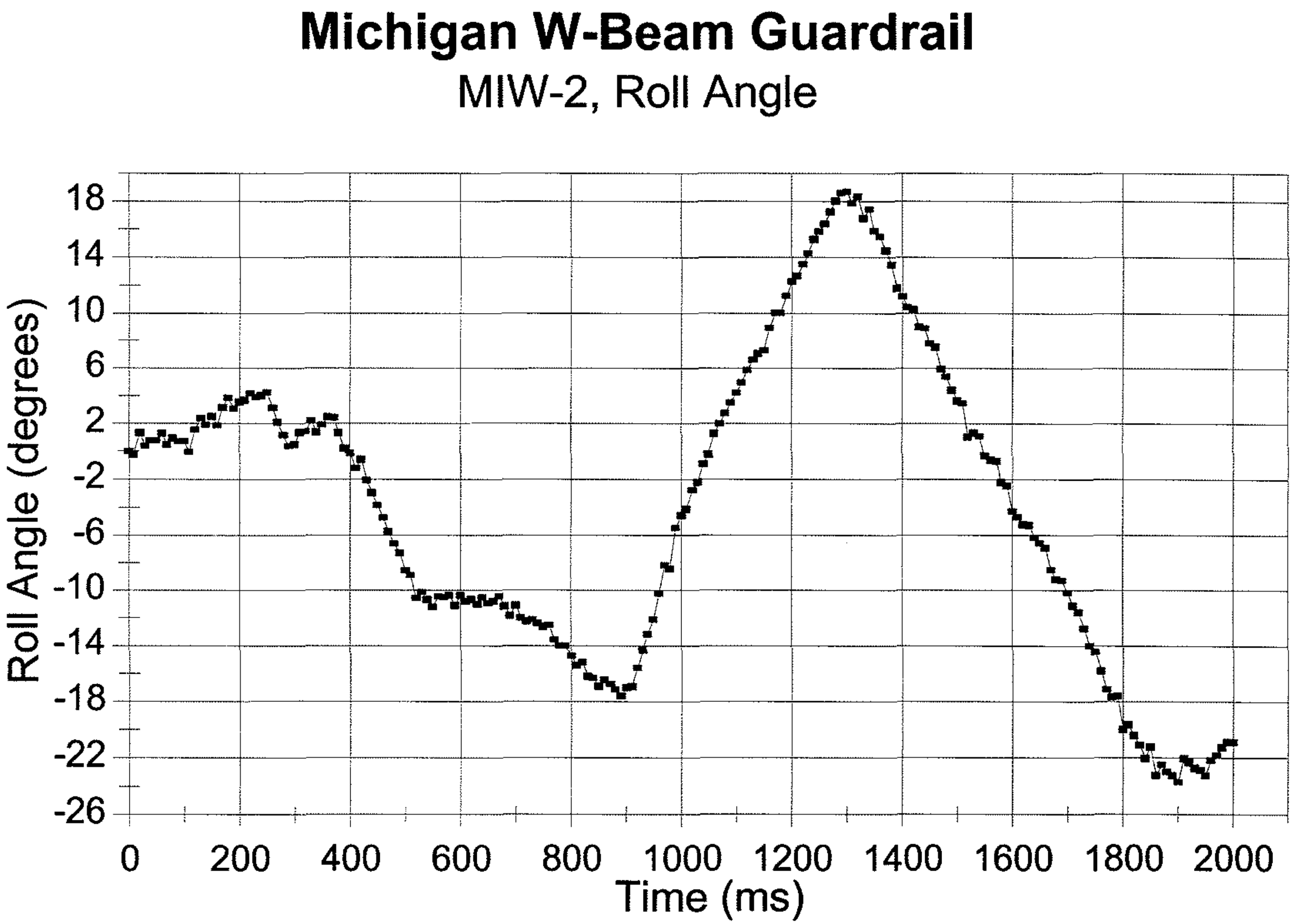

Figure B-1. Graph of Roll Angular Displacements, Test MIW-2

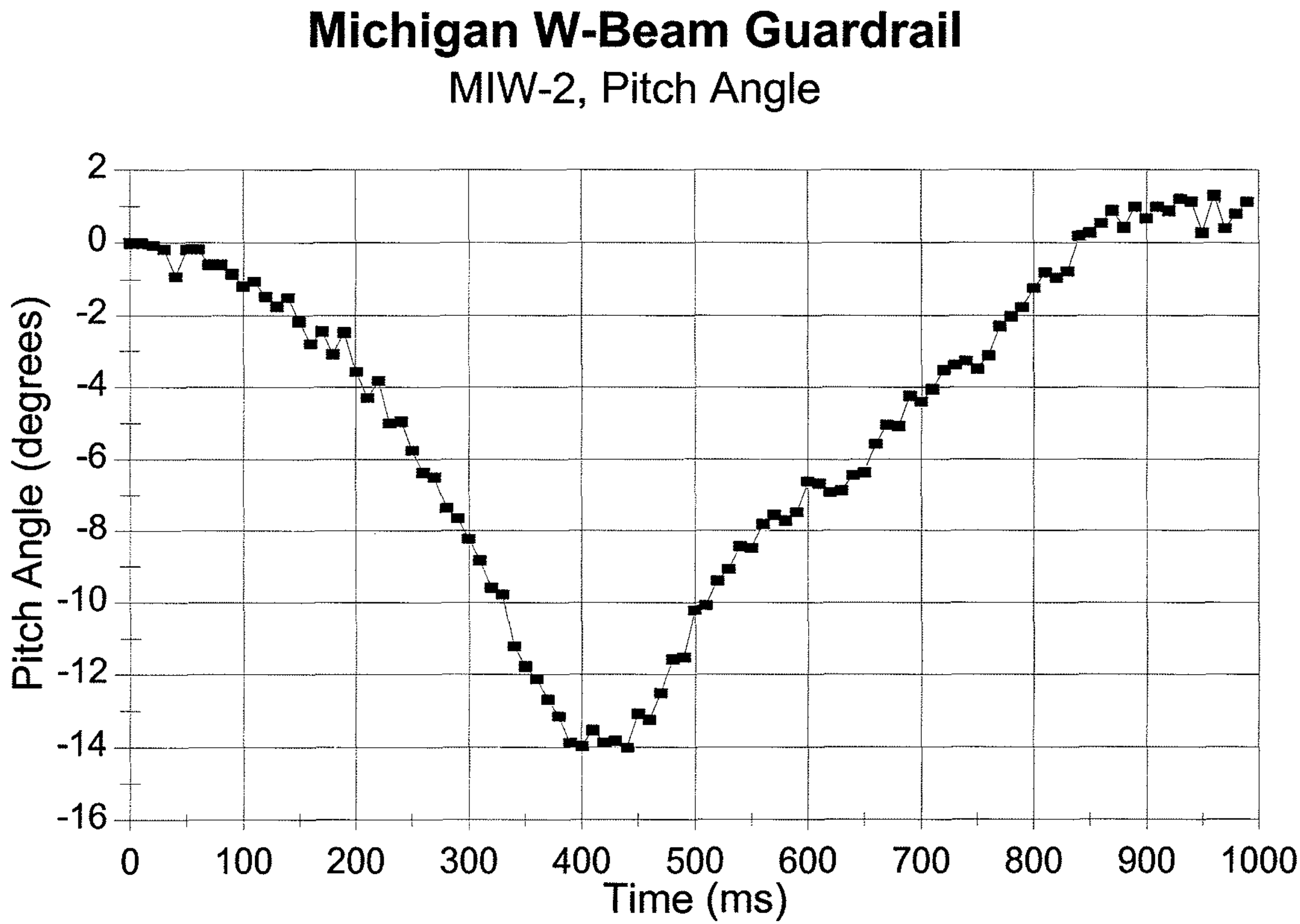

Figure B-2. Graph of Pitch Angular Displacements, Test MIW-2

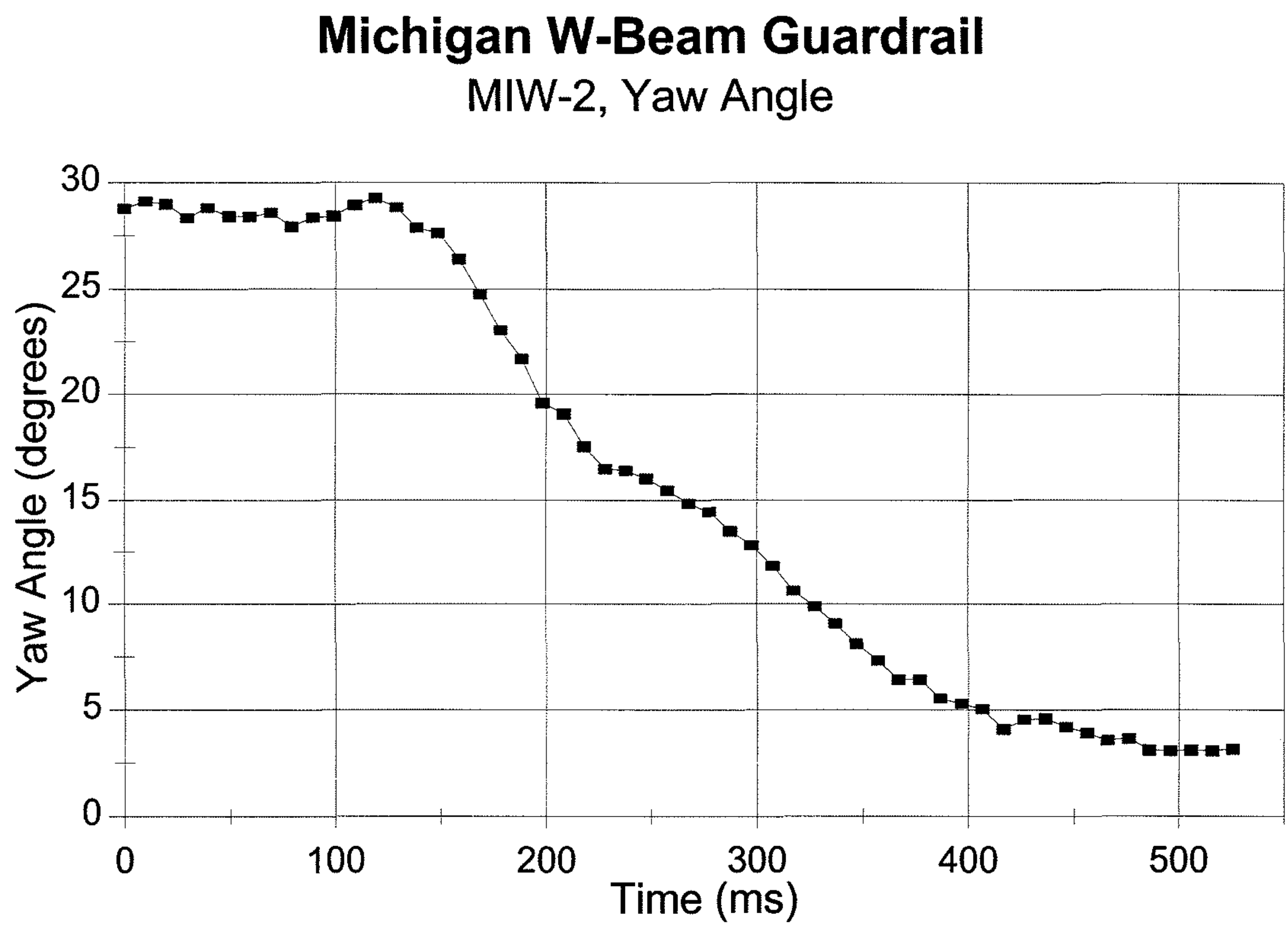

Figure B-3. Graph of Yaw Angular Displacements, Test MIW-2