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CONCEPT DEVELOPMENT OF A BULLNOSE GUARDRAIL SYSTEM FOR MEDIAN APPLICATIONS

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16. Abstract (Limit: 200 words)

The research study consisted of the design, fabrication, and full-scale vehicle crash testing of a bullnose barrier concept for the end treatment of median hazards. The bullnose concept consisted of a 12-gauge thrie beam rail supported by twenty-two wood posts, eleven posts on each side of the system. Horizontal slots were cut in the valleys of selected thrie beam sections to aid in vehicle capture as well as to reduce the buckling and bending capacities of the rail.

Two full-scale crash tests were performed, the first using a 2000-kg pickup truck and the second using an 820-kg small car. The first test, impacting at a speed of 101.4 km/h and an angle of 0.1 degrees at a ¼-point offset, was unsuccessful. Although the vehicle showed no potential for vehicle override, the thrie beam ruptured causing uncontrolled penetration of the vehicle behind the barrier. Consequently, the bullnose system was modified to include additional breakaway posts and horizontal slots in other thrie beam sections. The second test, impacting at a speed of 103.3 km/h and an angle of 3.4 degrees was determined to be successful according to the safety standards set forth by the Test Level 3 evaluation criteria described in the National Cooperative Highway Research Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. The data and information gathered from the development phase of this project will be used in the development of a computer simulation LS-DYNA model of the bullnose system as well as an improved bullnose guardrail design.

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

1 INTRODUCTION

1.1 Background and Problem Statement

The use of the divided highway separated by a median area has been a valuable safety feature in modern roadway design. The median allows a safe recovery area for errant vehicles to come to rest without impeding upon oncoming traffic. It is possible, however, that the median is not always a safe zone for vehicle recovery. Many roadway structures are built in the median such as bridge supports, drainage structures, and large sign supports. These structures present hazards to vehicles in the median.

There are three main treatments that have been used in the protection against median hazards such as crash cushions, open guardrails, and closed guardrail envelopes. Bridge piers are often treated by surrounding them with rigid barriers and placing crash cushions on each end. This alternative is very short and therefore reduces the number of run-off-road accidents to a minimum. Unfortunately, this type of treatment is very costly and therefore is hard to justify for most median situations. Another popular treatment involves using open guardrail envelopes. This design incorporates long runs of guardrail upstream from the hazards. Although this alternative is less expensive than crash cushion designs, the long runs of guardrail generate many guardrail related accidents, and when used in narrow medians, the backside of the guardrails can become a major hazard. Enclosed guardrail envelopes, called bullnose systems, involve wrapping the guardrail completely around the hazards. These designs are smaller and therefore generate fewer guardrail accidents. Further, bullnose designs are generally the least costly alternative. Unfortunately, bullnose guardrail designs have never met current safety standards. This report describes an effort to develop a new bullnose guardrail design that will meet modern safety standards.

1.2 Objective and Scope of Design

The objective of this research project was to develop and evaluate a bullnose guardrail system for the treatment of median hazards. This research focused on the development of several bullnose barrier concepts, the preliminary design of one concept, and the crash testing and evaluation of the selected design. Subsequently, the crash test results will be used to aid in computer simulation modeling as well as for redesigning the bullnose barrier for future compliance testing. The design of the bullnose guardrail system was conducted with a focus on safety, economy, reliability, ease of construction, and maintenance. The bullnose guardrail was developed to meet the Test Level 3 (TL-3) safety performance criteria provided in the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1).

Phase I of the design process, which is covered in this report, included two full-scale crash tests which will later provide information for redesign and computer simulation of the bullnose barrier system. In order to complete the design and implementation of the bullnose barrier design, a comprehensive set of full-scale compliance testing of the final bullnose design would have to be performed. The preliminary developmental testing of the bullnose barrier consisted of two full-scale crash tests. The first test used a 2000-kg pickup truck as an impact vehicle while the second used a 820-kg small car. Both full-scale tests were performed for a head-on impact with the bullnose at a target speed and angle of 100 km/h (62.1 mph) and 0 deg respectively. However, the small car test was conducted at a ¼-point offset on the nose section. The test results were analyzed, documented, and evaluated. Conclusions and recommendations were then made with regards to the safety performance of the bullnose barrier terminal.

1.3 Previous designs

In past years, several studies have been undertaken to evaluate the performance of closed guardrail median barriers or bullnose designs. These include studies by the Texas Transportation Institute (TTI) on the Minnesota and Colorado bullnose projects (2-3) as well as a study by the Southwest Research Institute, San Antonio, TX (4-5). The Minnesota and Colorado designs both used w-beam as the rail element, while the Southwest Research Institute (SWRI) design used a thrie-beam rail element. These three previous design concepts are shown in Figures 1 through 3.

The crash testing of the Minnesota design demonstrated good results, but the system was evaluated according to the criteria provided in NCHRP Report 153, *Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances* (6). The design met all criteria set forth at the time. In general, crash testing of the Colorado design also showed good results, although the design did have significant difficulty with a sedan impact at an angle. Specifically, the crash test which impacted downstream of the nose of the barrier at a 25 degree angle did not effectively redirect the vehicle. The safety criteria used in the Colorado design evaluation were from *Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances* (7). These criteria were satisfied for all but the sedan test at a 25 degree angle mentioned previously. The SWRI study performed 16 crash tests based on criteria set forth in NCHRP Report 230 (8). All evaluation criteria were not met for all tests. The researchers involved in this study concluded that bullnose barrier designs possess a great deal of promise for treatment of median hazards, even though they were unable to successfully develop a design that met all crash test safety standards.

In addition to the aforementioned studies pertaining to bullnose designs, several research efforts were performed on another guardrail system having a curved nose section of guardrail, such as the short-radius guardrail system (9-14). The results of these research studies were also reviewed in order to provide insight into the design of the new bullnose configuration.

The focus of this report was to investigate the feasibility of developing an improved bullnose guardrail design. The following sections describe the design, testing, and evaluation of an new bullnose barrier terminal concept.

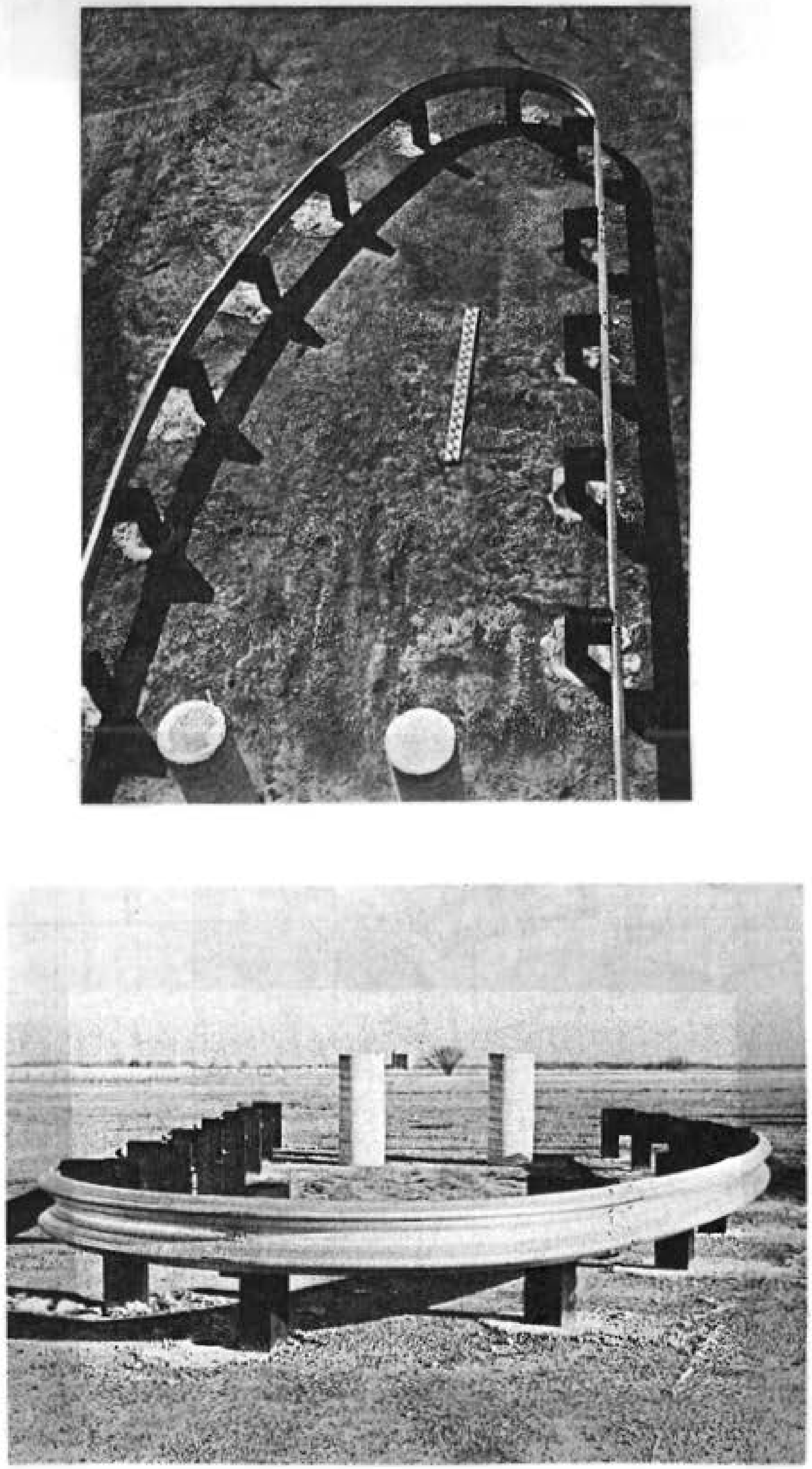
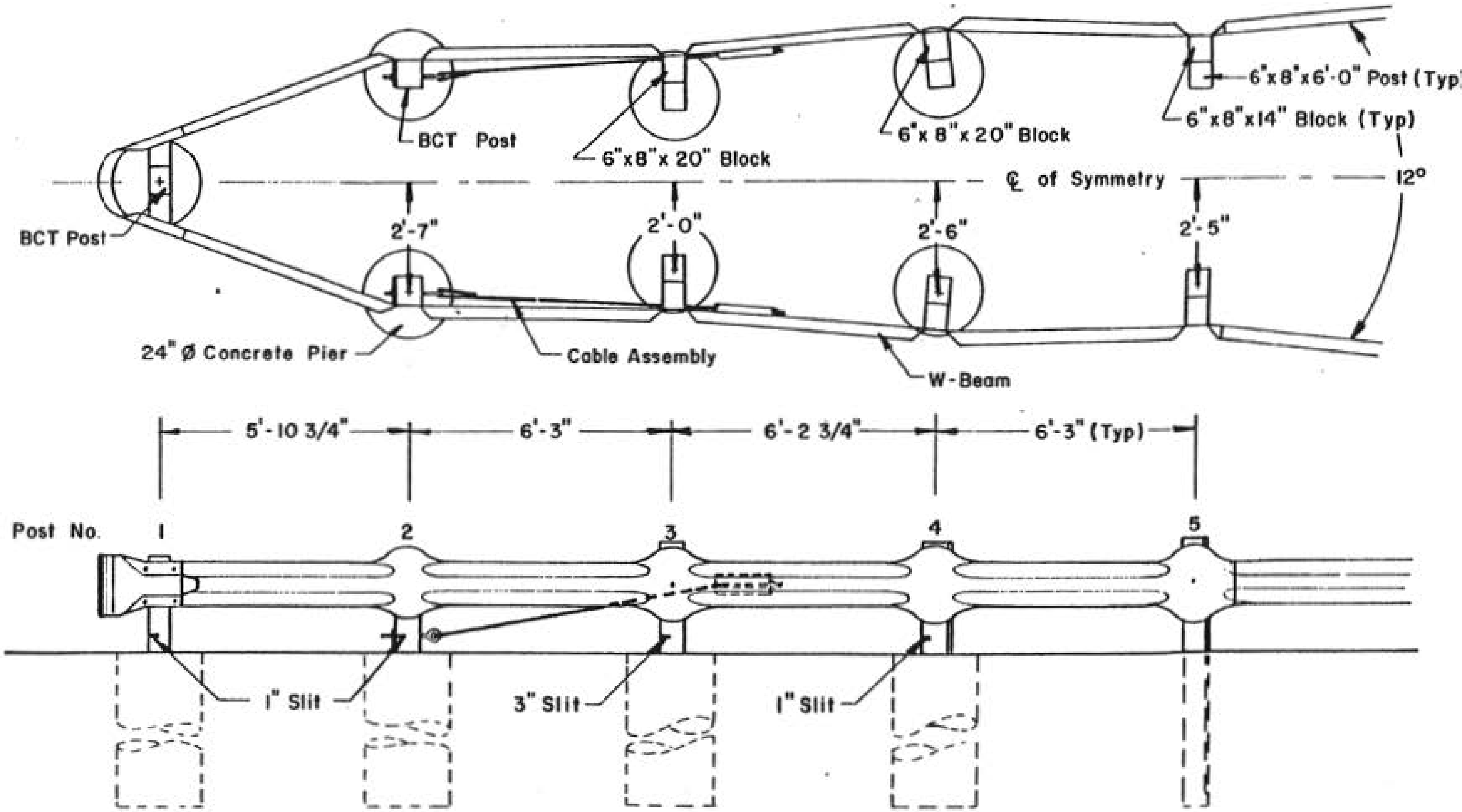


Figure 1. Minnesota Bullnose Barrier Design

NOTE: W-beam not attached at posts 2 and 4.



Metric Conversions:

1 ft = 0.305 m
1 in. = 2.54 cm

Figure 2. Colorado Bullnose Barrier Design

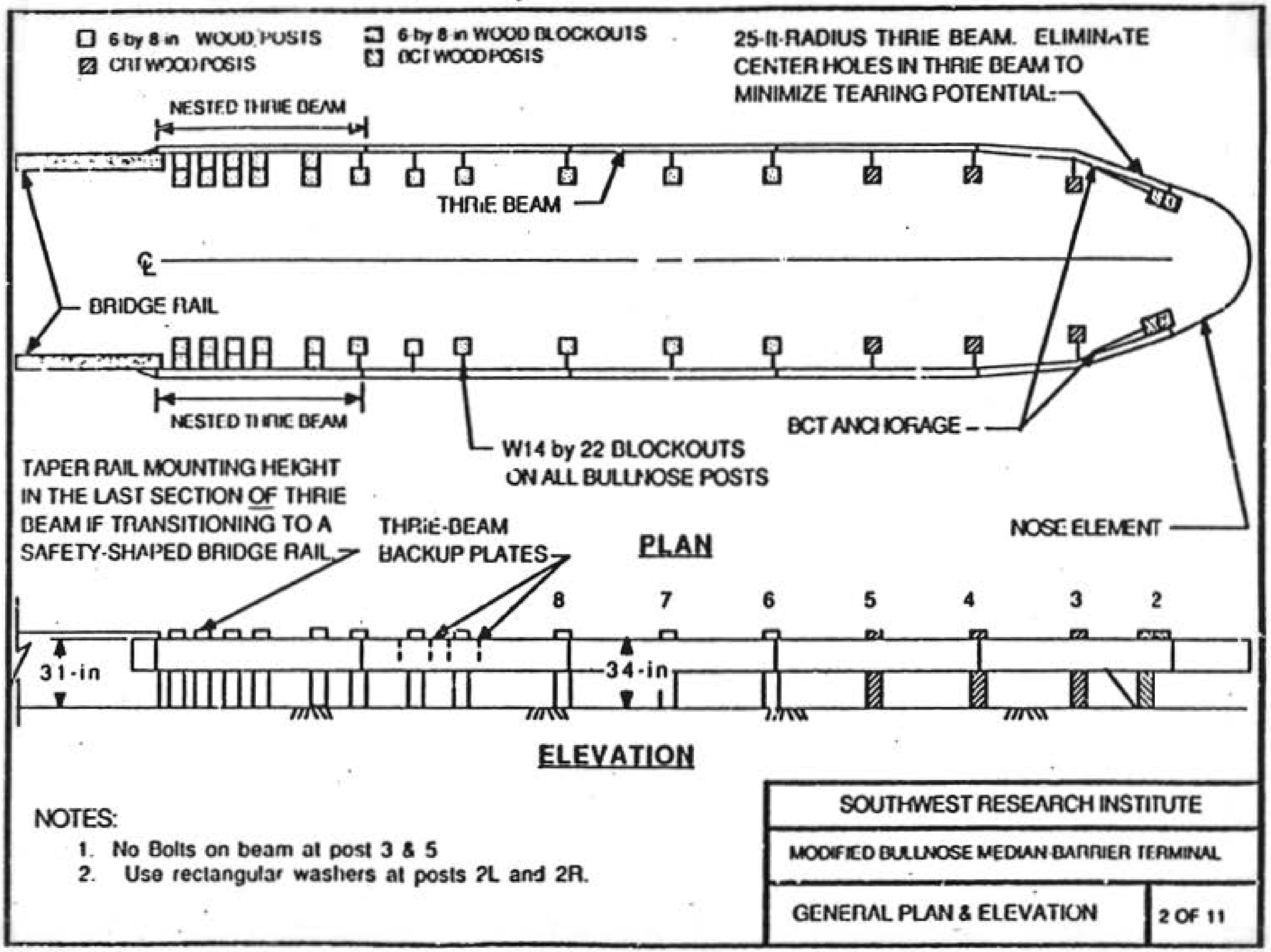


Figure 3. Southwest Research Institute Bullnose Barrier Design

2 BARRIER DESIGN

2.1 Rail Concepts

The initial design of the bullnose barrier began with a series of preliminary design concepts. The preliminary designs were divided by the choice of guardrail beam shape used in the design. The first set of preliminary designs were based on using a stacked W-beam guardrail that would facilitate the capture of various size vehicles. The stacked W-beam barrier configurations proposed are shown in Figures 4 through 5. The W-beam systems were designed to have horizontal slots cut in the valley of the beam. The slots cut into the rail aid the beam in capturing the vehicle and help prevent the vehicle from overriding or underriding the rail.

The other preliminary design concept was based on using a slotted thrie beam guardrail. The thrie beam design allowed the use of a single beam to catch different size vehicles. Horizontal slots cut in the valleys of the thrie beam aid in the capture of the impacting vehicle. It was believed that the slots would prevent potential overriding of the guardrail by pickups and underriding of the guardrail by small cars. Previous testing of short radius thrie beam guardrails suggested that the use of an unslotted rail would not be capable of capturing an impacting pickup truck and preventing underride of a small car (14). However, the concept of using a thrie beam rail rather than multiple W-beam rails allowed for a simpler design because connections and blockouts for only one beam were needed.

The use of a thrie beam rail simplified the bullnose design since it did not require the use of a more complicated stacked W-beam rail. Thus, the bullnose barrier would be easier to construct and maintain, and have lower overall construction material costs. Thus, the slotted thrie beam system was chosen for further evaluation.

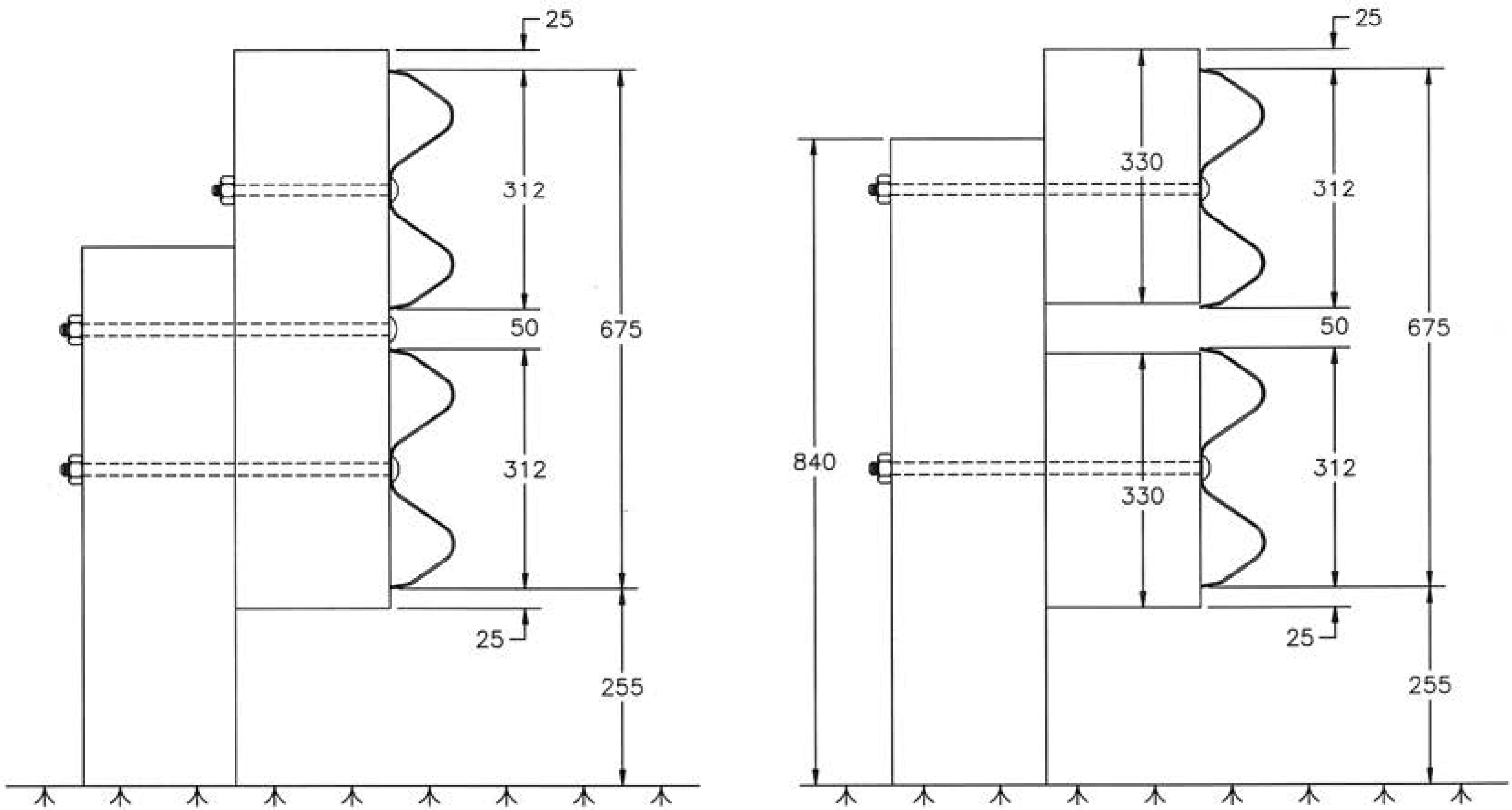


Figure 4. Preliminary W-Beam Bullnose Barrier Design Concepts

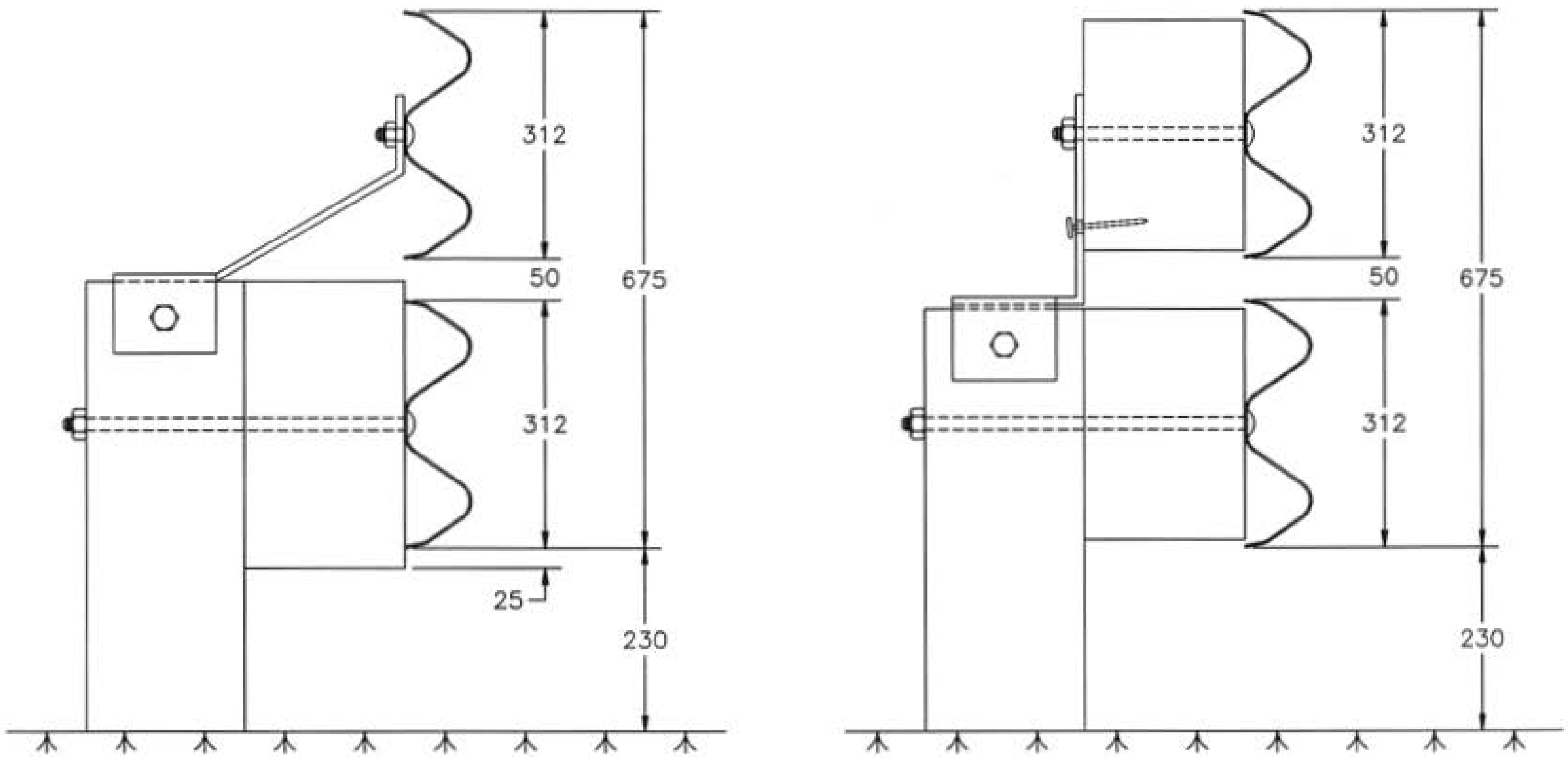


Figure 5. Preliminary W-Beam Bullnose Barrier Design Concepts

2.2 Nose Section Design

The worst case scenario for bullnose guardrails is when they are used in a narrow median. In this situation, the rail element is forced to bend through an angle of 180 degrees as the vehicle progresses into the system. Thus, narrow systems subject the rail element to higher strains and as a result cause higher vehicle decelerations. Therefore, after reviewing the Pooled Fund member states' bullnose standards, a 4,500 mm design was selected for use in the current study. The shape of the nose section was chosen after analysis of prior bullnose (2-5) and short radius guardrail designs (9-14). The nose section was formed using one 1,580-mm radius curved section of guardrail with one 10,400-mm radius curved section attached to each end of the nose section. The overall shape was chosen using simple curves to simplify the design and fabrication of the rail. The curve radii were sized based on ease of fabrication as well as to maintain the design width of the system.

The front-end section of the bullnose barrier was designed without a post at the centerline of the nose. The Minnesota and Colorado designs, mentioned previously, both used a post at the centerline of the nose section that created problems during impact. The end post tends to rotate back after impact, creating a potential for vaulting of the vehicle over the rail. It was determined that a nose section without the centerline post would have sufficient structural strength to maintain the shape of the rail while not causing the vaulting hazard.

2.3 Final Barrier Design Details

The complete layout of the bullnose barrier system used for the first test is shown in Figure 6. A one-half barrier system was designed for testing purposes to limit costs and time of construction for the design. The bullnose barrier was 4,500-mm wide by 20,144-mm long. The system was constructed with twenty-two wood posts with eleven posts positioned on each side of the system.

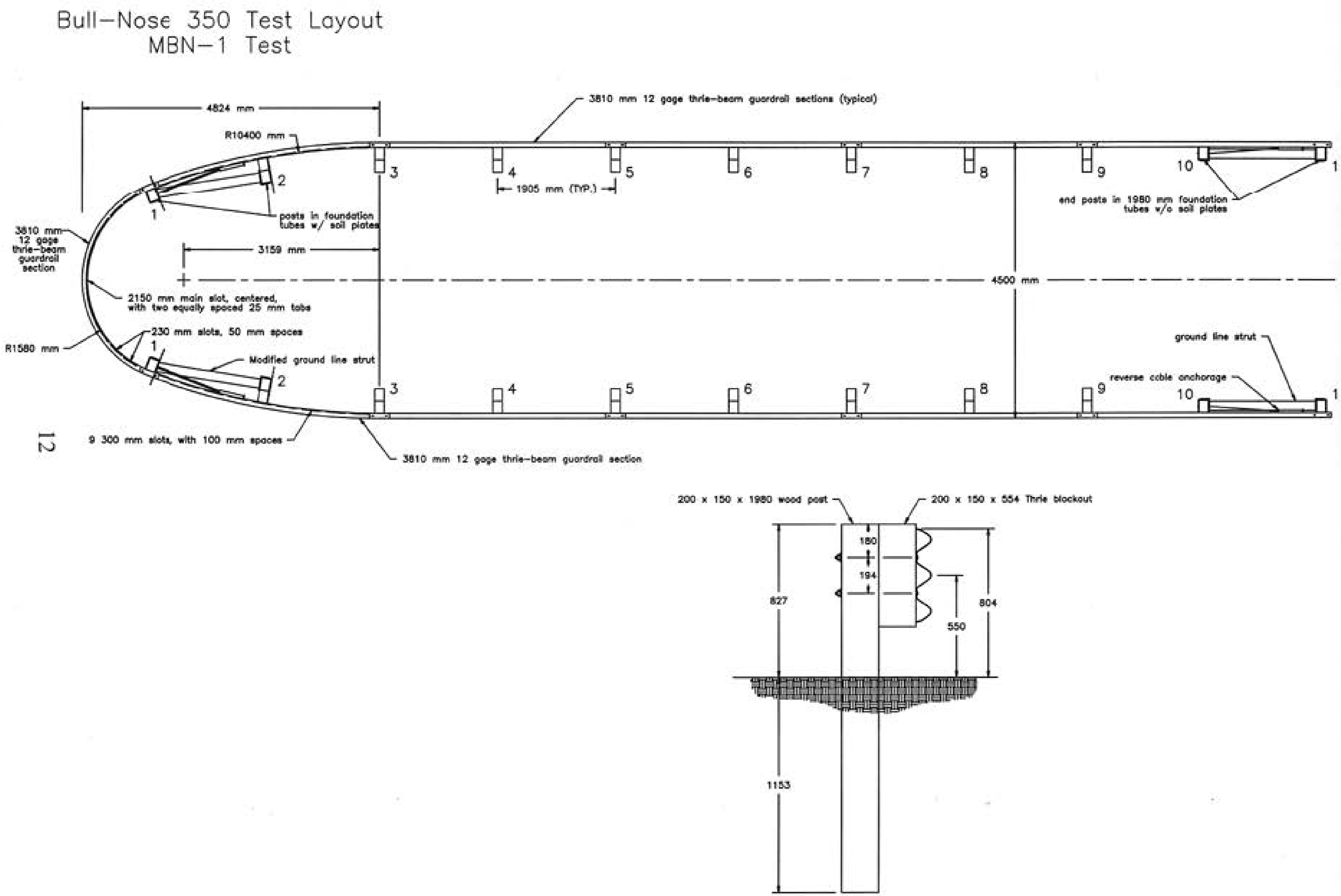


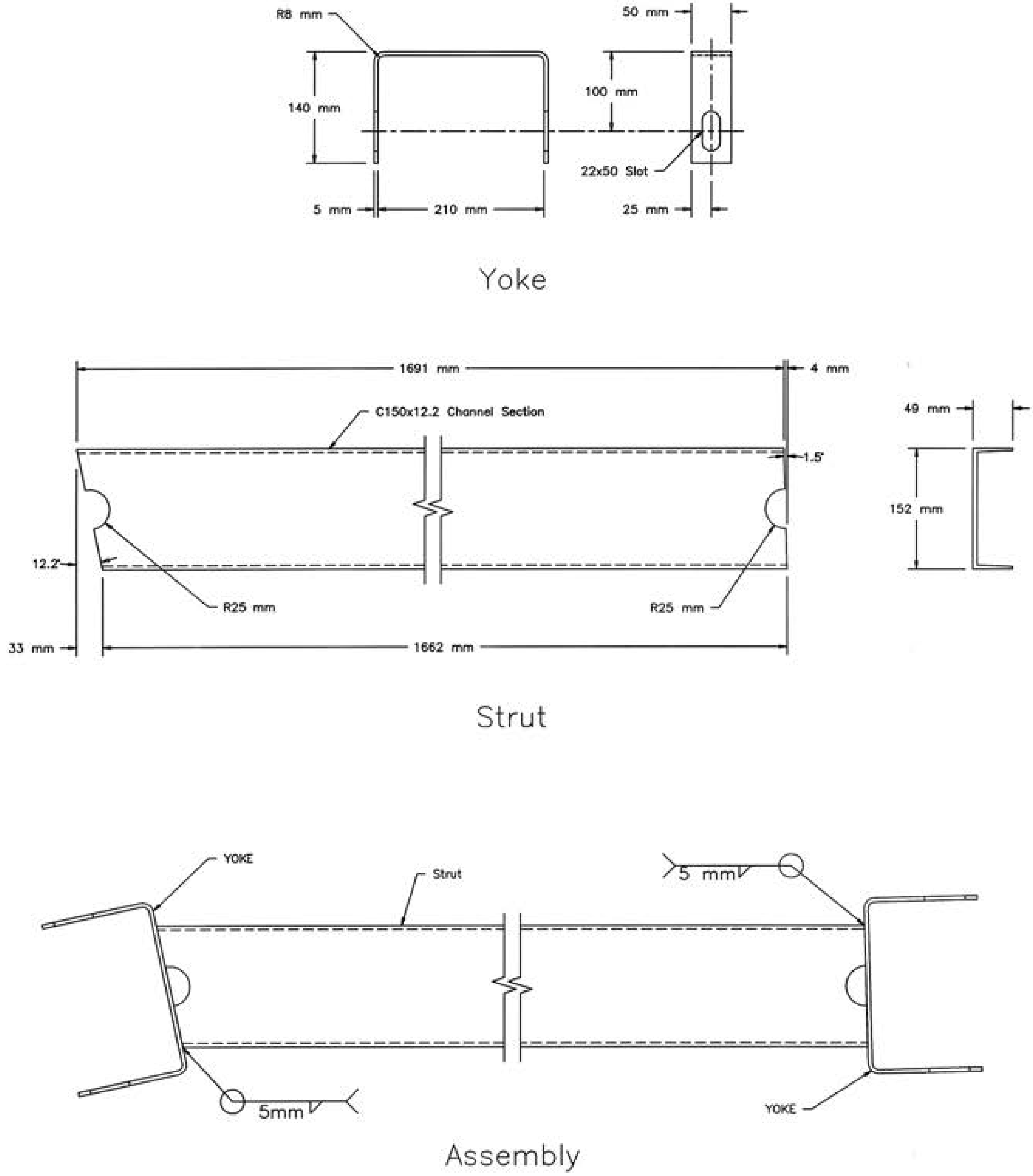
Figure 6. Bullnose Barrier Design Layout

The first two posts on each side of the system were 140-mm wide by 190.5-mm deep BCT (Breakaway Cable Terminal) posts set in foundation tubes with soil plates and groundline channel strut. Post no. 1 on each side of the barrier used no blockout while post no. 2 on each side used a 200-mm deep by 150-mm wide by 554-mm long thrie blockout. The next seven posts along both sides of the bullnose barrier are standard 200-mm deep by 150-mm wide by 1,980-mm long wood posts spaced 1,905-mm apart as shown in Figure 6. Each of these posts uses a 200-mm deep by 150-mm wide by 554-mm long thrie blockout to space the rail away from the post. The top mounting height of the rail was 804 mm as measured from the ground surface. Posts nos. 3 through 9 had a soil embedment depth of 1,153 mm. The last two posts on each side of the bullnose barrier were 140-mm wide by 190.5-mm deep BCT posts set in foundation tubes without soil plates but with a groundline channel strut.

A modified ground strut, shown in Figure 7, between posts nos. 1 and 2 on each side of the system was designed to compensate for the curve of the nose section. The ground strut was altered by angling the upstream yoke of the strut 12.2 degrees.

A cable anchor system was used between the first and second posts on each side of the system to develop the tensile strength of the thrie beam guardrail downstream of the post no. 2. A reverse cable anchor system was used between post nos. 10 and 11 to replicate the rail strength of an actual installation. This setup was used for testing purposes only in order to simulate the effects of a complete bullnose barrier terminal system with both halves connected.

The guardrail used throughout the bullnose barrier consisted of 12-gauge steel thrie beam. The eleven 3,810-mm long sections of thrie beam were spliced together with a standard lap splice on each end of the section. The nose section of the rail consists of a 3,810 mm long section of



NOTE: Strut cs shown for one side of the system, for other side the mirror image is required.

Figure 7. Modified Groundline Strut

12-gauge thrie beam bent into a 1,580 mm radius, as shown in Figure 8. The nose section is cut with slots in the valleys to aid in vehicle capture as shown in Figure 9. There are six 700-mm slots centered about the midspan of the rail, three in each valley. Each of the slots is separated by a 25-mm gap. In addition, eight smaller 230-mm long slots, four on each end of the rail section, are also cut with a 50-mm gap between them. All slots are 25-mm wide.

The second rail section on each side of the bullnose system is bent to form a 10,400-mm radius curve, as shown in Figure 8. These sections are cut with different slot patterns, as shown in Figure 10. The first two slots on each end are cut 290-mm long. The fourteen slots in between are each cut 300-mm long. A 100-mm gap separates each slot. The eight remaining rail sections of the system consist of standard 12-gauge thrie beam spliced together at the ends.

Photographs of the assembled bullnose barrier system are shown in Figures 11 through 12.

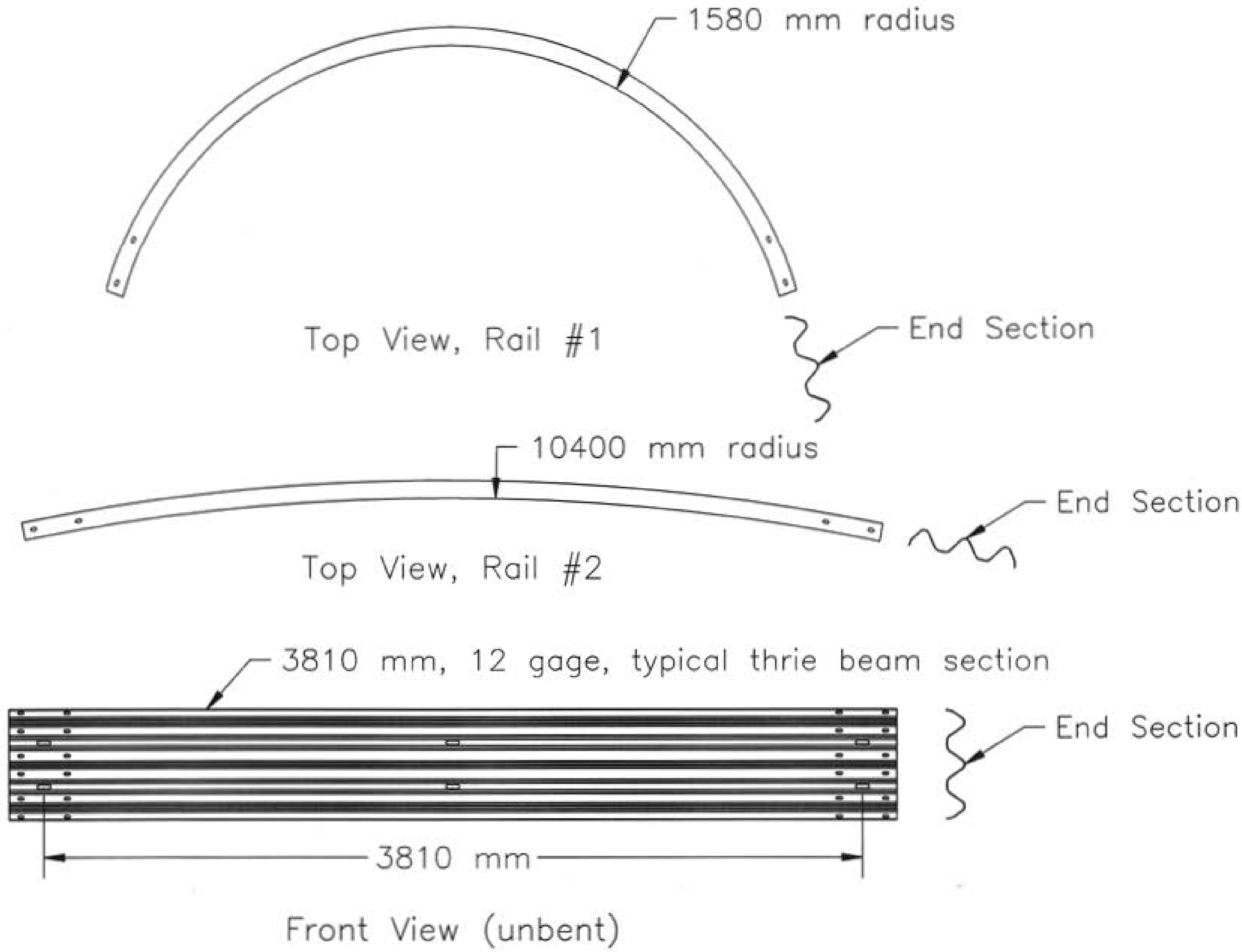
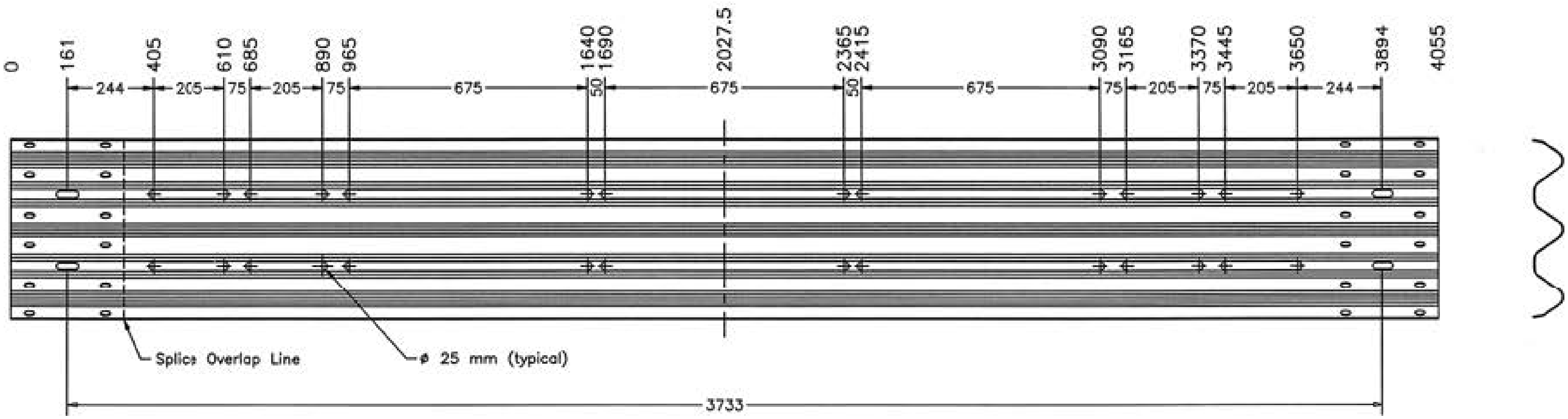
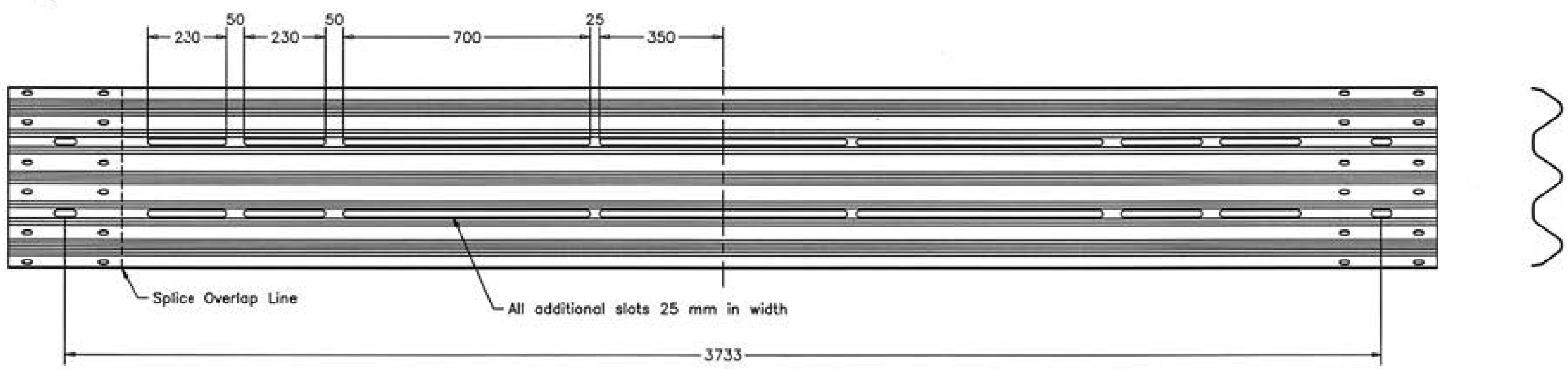


Figure 8. Layout of Bullnose Rails No. 1 and 2

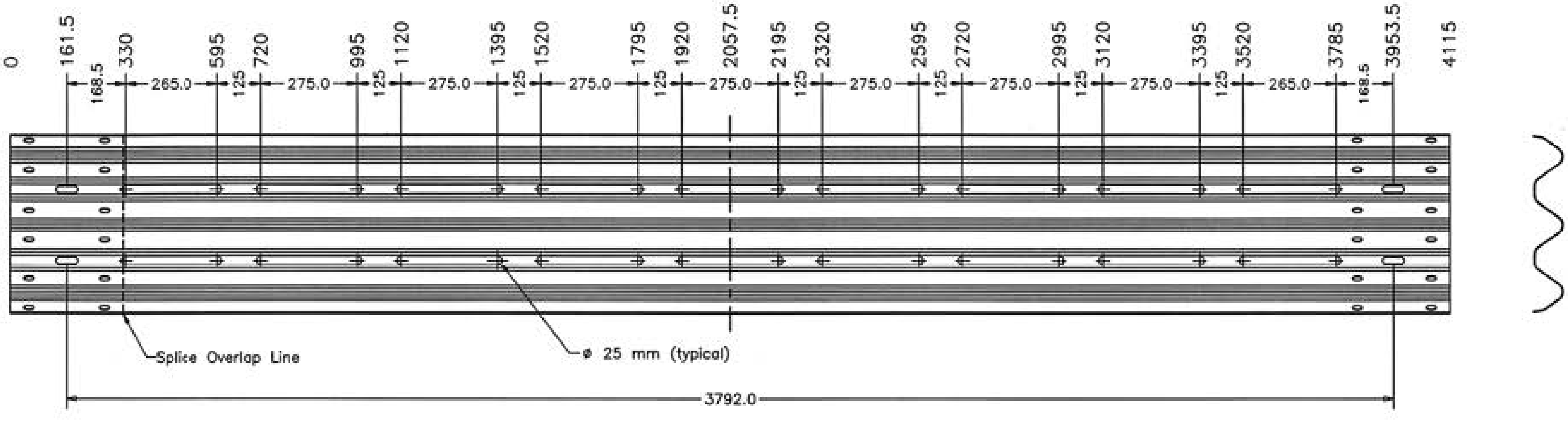


Rail Section 1 ("Nose" Section, MBN−1)

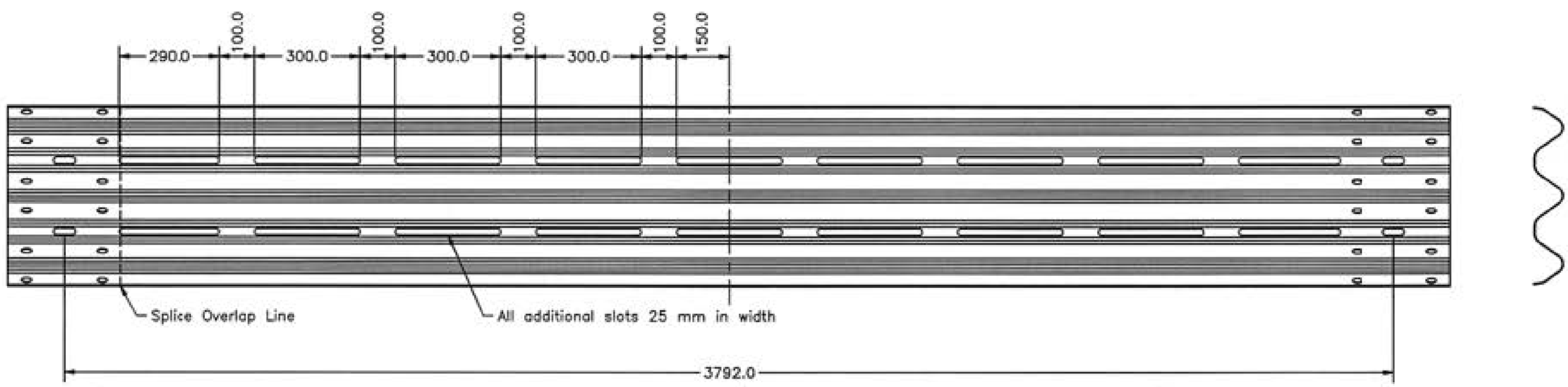


Rail Section 1 ("Nose" Section, MBN−1)

Figure 9. Rail Section No. 1 Detail



Rail Section 2 (MBN-1)



Rail Section 2 (MBN-1)

Figure 10. Rail Section No. 2 Detail

Figure 11. Bullnose Barrier Design

Figure 12. Bullnose Barrier Design

3 PERFORMANCE EVALUATION CRITERIA

3.1 Test Requirements

Terminals and crash cushions, such as bullnose barrier terminals, must satisfy the requirements provided in NCHRP Report No. 350 (1) in order to be accepted for use on new construction projects or as a replacement for existing barriers not meeting current safety standards. The bullnose barrier terminal is defined as a gating device and must fulfill the requirements for gating terminals. A gating device is one designed to allow controlled penetration of the vehicle when impacted between the beginning and the end of the length of need. According to NCHRP Report No. 350, terminals and crash cushions must be subjected to seven full-scale vehicle crash tests, four using a 2000-kg pickup truck and three using an 820-kg small car. The required 2000-kg pickup truck crash tests for a Test Level 3 (TL-3) device are: (1) Test 3-31, a 100 km/h impact at a nominal angle of 0 degrees on the tip of the barrier nose; (2) Test 3-33, a 100 km/h impact at a nominal angle of 15 degrees on the tip of the barrier nose; (3) Test 3-35, a 100 km/h impact at a nominal angle of 20 degrees on the beginning of the LON (Length-of-Need); and (4) Test 3-39, a 100 km/h impact at a nominal angle of 20 deg on a point at the length of the terminal divided by two. The required 820-kg small car crash tests for a TL-3 device are: (1) Test 3-30, a 100 km/h impact at a nominal angle of 0 degrees on the tip of the barrier nose with a 1/4-point offset; (2) Test 3-32, a 100 km/h impact at a nominal angle of 15 degrees on the tip of the barrier nose; (3) Test 3-34, a 100 km/h impact at a nominal angle of 15 degrees on the CIP (Critical Impact Point). A diagram showing the impact location for the seven crash tests is shown in Figure 13.

As previously mentioned, only two full-scale crash tests were conducted for this report, tests 3-30 and 3-31. These two tests were run as a preliminary safety evaluation of the bullnose barrier

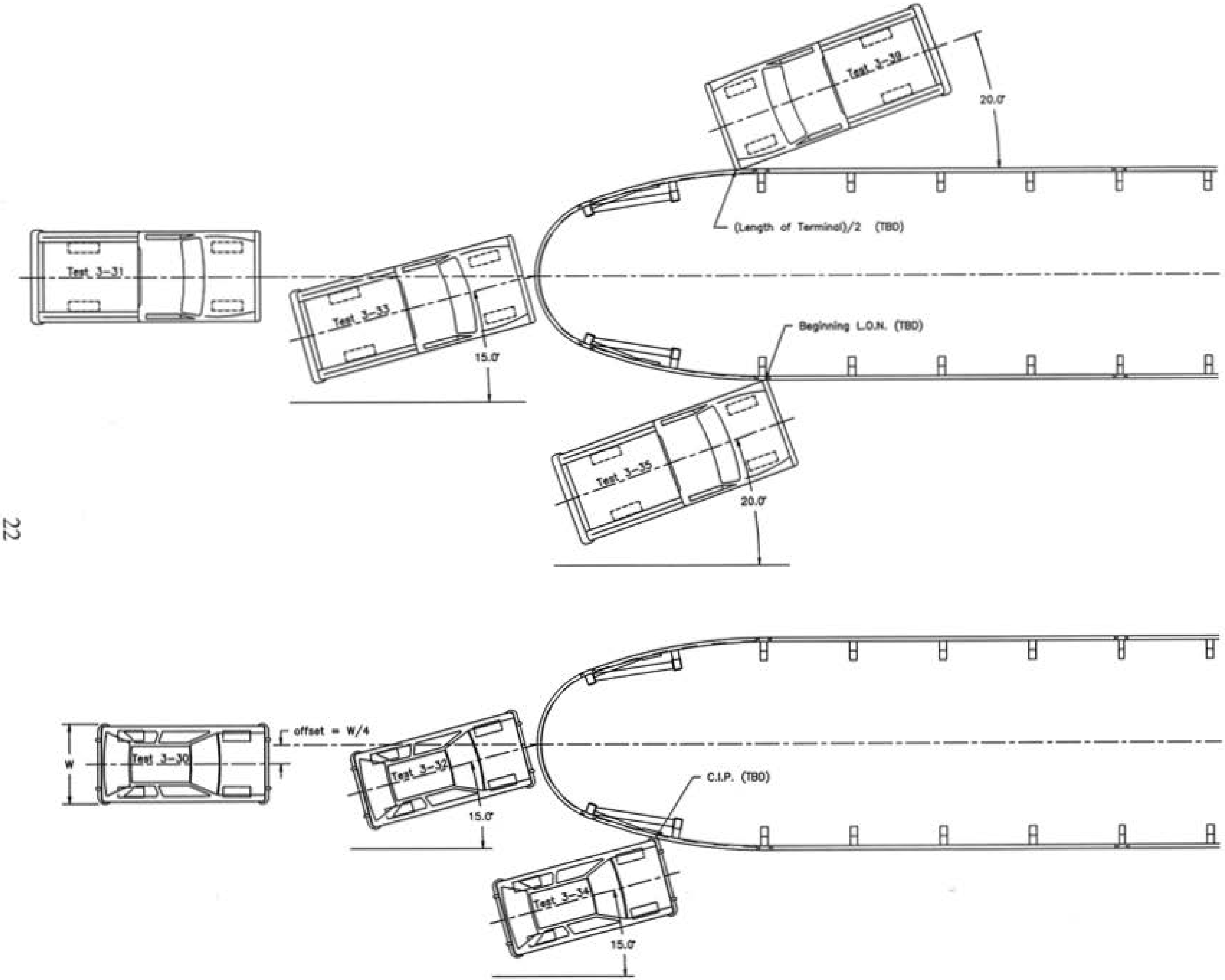


Figure 13. Proposed Full Scale Crash Tests for Bullnose Barrier Evaluation

terminal concept. The primary goal was to demonstrate that the new concept could capture both light trucks and mini-size vehicles. The results from these two tests would be used to obtain information for calibration of computer models, evaluate the feasibility of the design concept for the other required impact conditions, and obtain information for future design modifications and improvements.

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 terminal 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, thereby subjecting occupants of other vehicles to undue hazard or to subject the occupants of the impacting vehicle 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 (Test 3-31) and 820C Small Car (Test 3-30)

Structural Adequacy	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.
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.
	H. Occupant impact velocities should satisfy the following: **Occupant Impact Velocity Limits (m/s)** <u>Component</u> Preferred Maximum Longitudinal and Lateral 9 12
	I. Occupant ridedown accelerations should satisfy the following: **Occupant Ridedown Acceleration Limits (G's)** <u>Component</u> Preferred Maximum Longitudinal and Lateral 15 20
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	N. Vehicle trajectory behind the test article is acceptable.

4 TEST CONDITIONS

4.1 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 an 2.44-m high chain-link security fence.

4.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicles. The distance traveled and the speed of the tow vehicle are one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the bullnose barrier. A fifth wheel, built by the Nucleus Corporation, was located on the tow vehicle and used in conjunction with a digital speedometer to increase the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (15) was used to steer the test vehicle. A guide-flag, attached to the front-left wheel and the guide cable, was sheared off before impact. The 9.5-mm diameter guide cable was tensioned to approximately 13.3 kN, and supported laterally and vertically every 30.48 m by hinged stanchions. 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.

4.3 Test Vehicles

For test MBN-1, a 1989 Ford F-250 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 1,998 kg. The test vehicle and vehicle dimensions are shown in Figure 14.

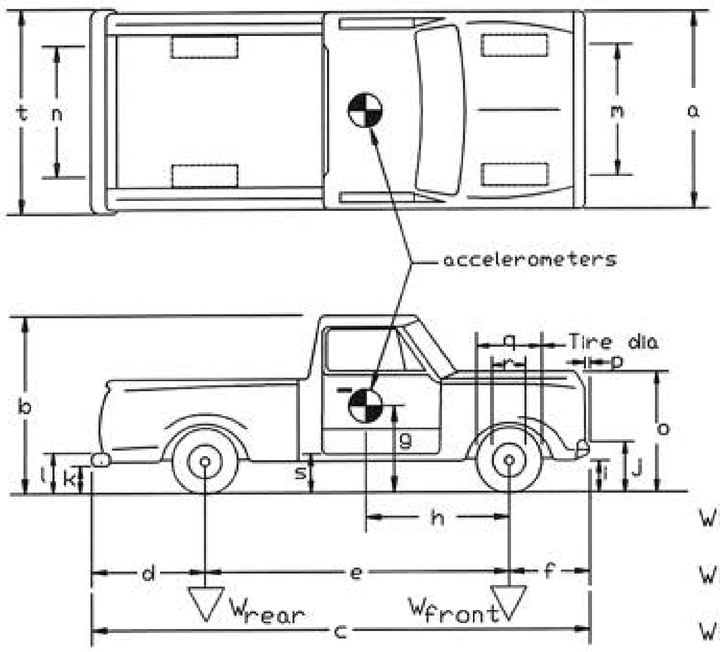
For test MBN-2, a 1988 Ford Festiva compact car was used as the test vehicle. The test

Date: 7/22/97 Test Number: MBN-1 Model: F-250

Make: FORD Vehicle I.D.#: 1FTHF25Y4KLA36481

Tire Size: 235/85 R16 Year: 1989 Odometer: 65499

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm

a	1930.4	b	1854.2
c	5334.0	d	1206.5
e	3390.9	f	736.6
g	738.4	h	1485.6
i	431.8	j	736.6
k	438.15	l	654.0
m	1670.0	n	1632.0
o	1219.2	p	44.45
q	793.75	r	444.5
s	520.7	t	1930.4

Wheel Center Height Front 368.3

Wheel Center Height Rear 381.0

Wheel Well Clearance (FR) 882.65

Wheel Well Clearance (RR) 965.2

Engine Type STRAIGHT 6 CYL

Engine Size 300 in^3

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Weights - kg	Curb	Test Inertial	Gross Static
W_{front}	1120	1123	1123
W_{rear}	862	875	875
W_{total}	1982	1998	1998

Note any damage prior to test: Minor floorboard deformation and dents on drivers side.

Figure 14. Vehicle Dimensions, Test MBN-1

inertial and gross static weights were 886 kg. The test vehicle and vehicle dimensions are shown in Figure 15.

The Suspension Method was used to determine the vertical component of the center of gravity for the test vehicles. This method is based on the principle that the center of gravity 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 center of gravity were established. The intersection of these planes pinpointed the location of the center of gravity. The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 14 through 15.

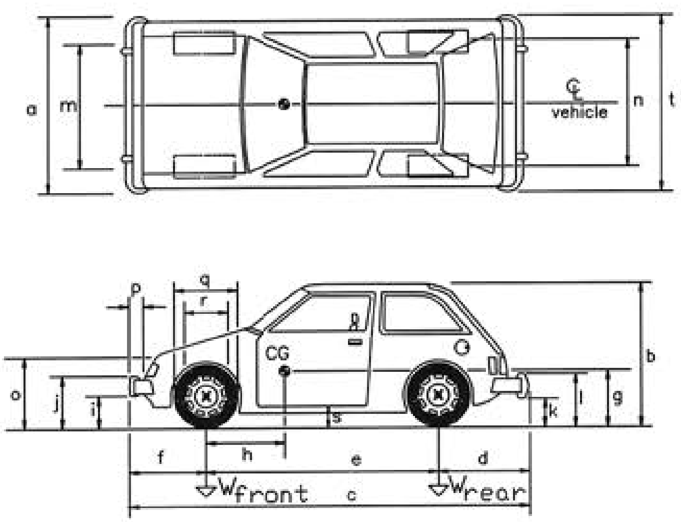
Square, black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film, as shown in Figures 16 through 17. One target was placed on the center of gravity on the driver's side door, the passenger's side door, and on the roof of the vehicle. The remaining targets 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 vehicles would track properly along the guide cable. Two 5B flash bulbs were mounted on both the hood and roof of the vehicles to pinpoint the time of impact with the bullnose barrier 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.

Date: 7/25/97 | Test Number: MBN-2 | Model: FESTIVA

Make: FORD | Vehicle I.D.#: KNJBT06K4JB125183

Tire Size: 145 R12 | Year: 1988 | Odometer: 125473



Vehicle Geometry - mm

a	1574.8	b	1422.4
c	3505.2	d	558.8
e	2298.7	f	647.7
g	546.1	h	882.65
i	381.0	j	539.75
k	355.6	l	520.7
m	1390.65	n	1384.3
o	762.0	p	76.2
q	527.0	r	330.2
s	279.4	t	1574.8

height of wheel center 247.65

Engine Type STRAIGHT 4 CYL.

Engine size 1.3 L

Transmission Type:

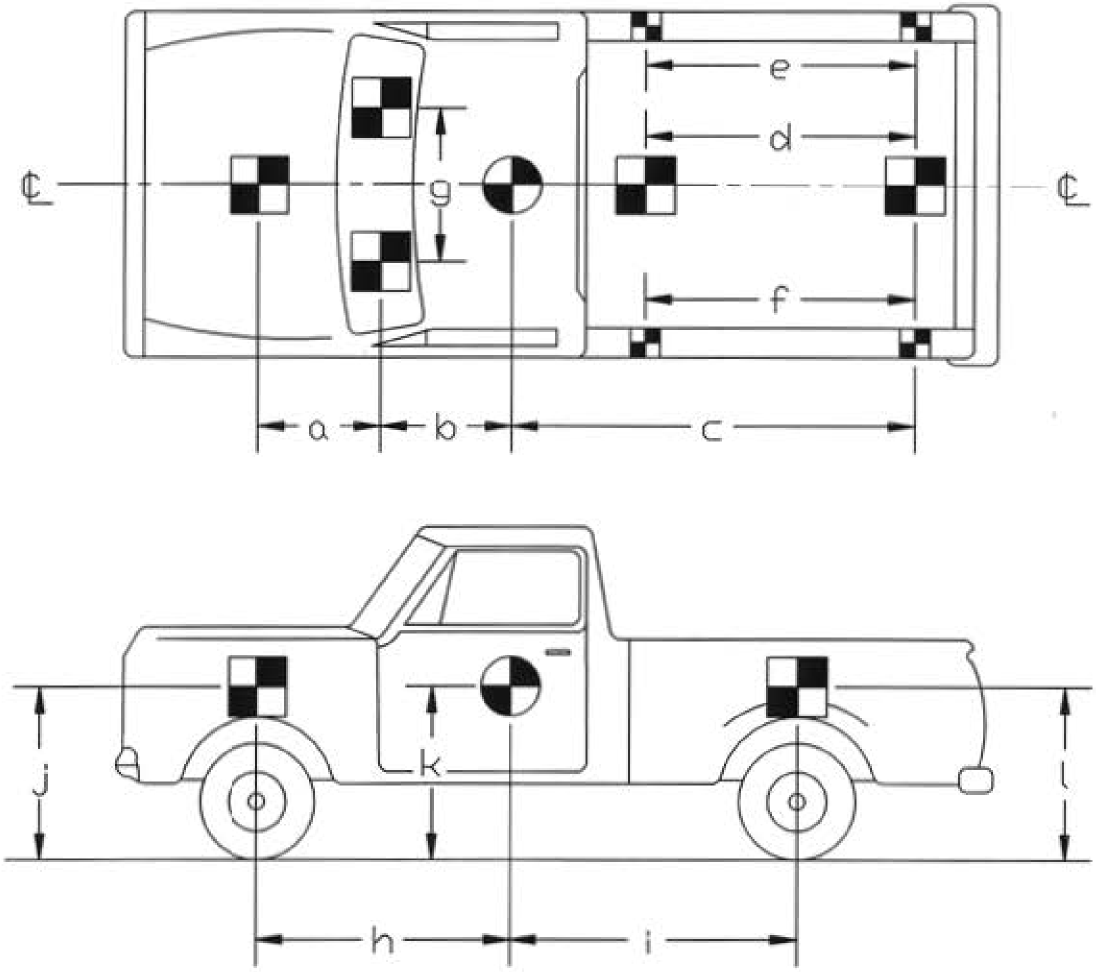
Automatic or (Manual)

(FWD) or RWD or 4WD

Weight - kg	Curb	Test Inertial	Gross Static
W_{front}	485	501	537
W_{rear}	268	310	350
W_{total}	753	811	886

Damage prior to test: Front grill broken, front bumper bent

Figure 15. Vehicle Dimensions, Test MBN-2

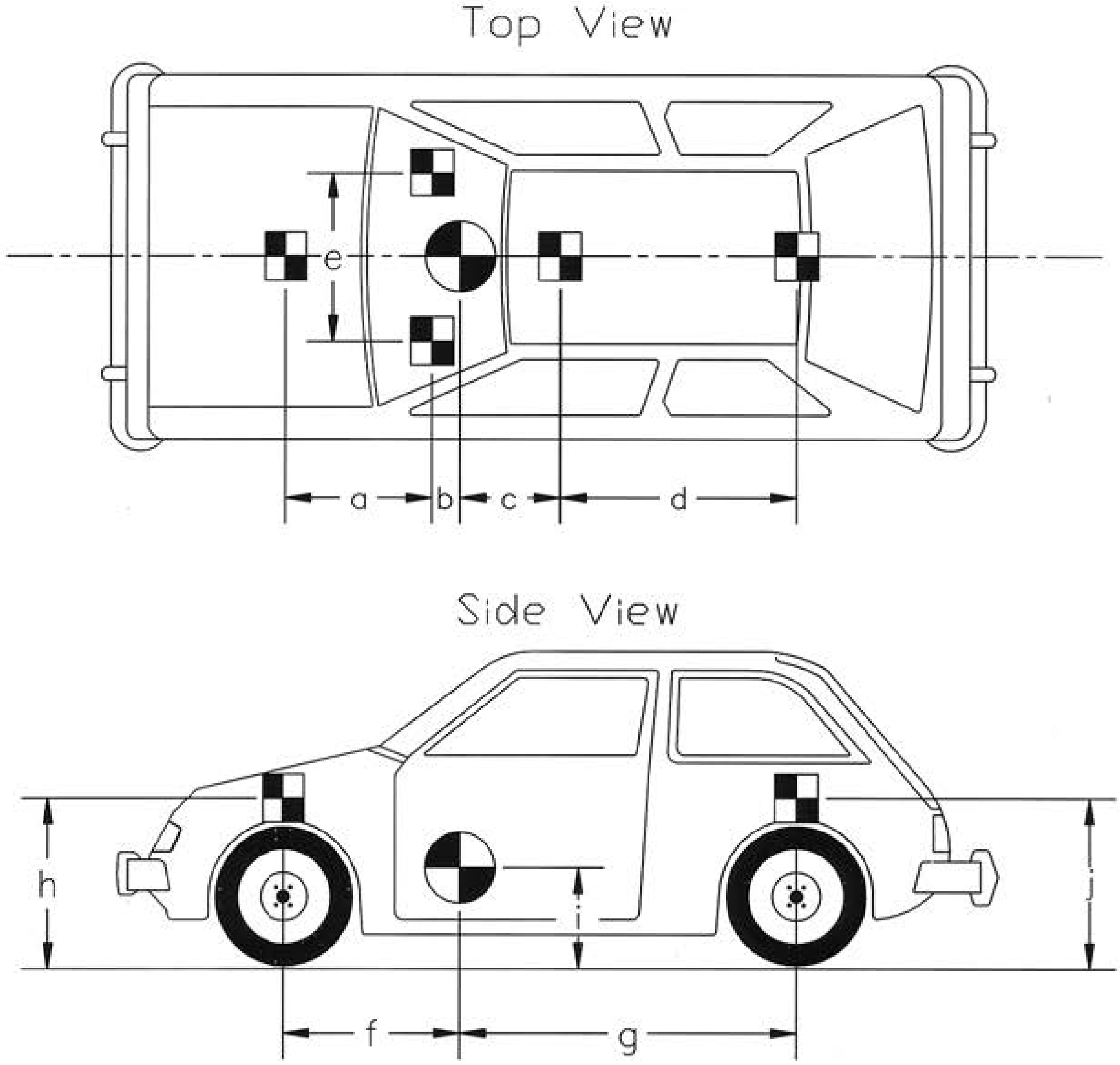


TEST #: MBN-1

TARGET GEOMETRY (mm)

a	876.3	b	635.0	c	2578.1	d	1803.4
e	1695.5	f	1695.5	g	844.5	h	1492.3
i	1905.0	j	1066.8	k	717.6	l	1130.3

Figure 16. Vehicle Target Locations, Test MBN-1



TEST #: MBN – 2

TARGET GEOMETRY (mm)

a	1130.3	b	127.0	c	273.0	d	1130.3
e	660.4	f	882.6	g	1416.0	h	698.5
		i	536.6	j	658.8		

Figure 17. Vehicle Target Locations, Test MBN-2

4.4 Data Acquisition Systems

4.4.1 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 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.

4.4.2 Rate Transducers

A Humphrey 3-axis rate transducer with a range of 250 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 vehicles 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 plotting. Computer software, "DynaMax 1

(DM-1)" and "DADiSP" were used to digitize, analyze, and plot the rate transducer data.

4.4.3 High Speed Photography

For test MBN-1, seven 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 zoom lens, was placed downstream from the impact point and had a field of view parallel to the barrier. Two Locams, with zoom lenses, were placed on both sides of the barrier at the nose and had a field of view perpendicular to the barrier. A Locam was placed 9.14 m upstream and offset 19.81 m to the east for a view of the front of the barrier. The two remaining Locams were placed 6.4 m and 37.8 m downstream and offset 12.19 m and 21.34 m to the left, respectively, to provide additional viewing angles of the crash test. A schematic of all seven camera locations for test MBN-1 is shown in Figure 18. For test MBN-2, the exact same high-speed camera setup was used as test MBN-1. A schematic of the seven high speed camera locations for test MBN-2 is shown in Figure 19. 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.

4.4.4 Pressure Tape Switches

For tests MBN-1 and MBN-2, four 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 speeds were determined from electronic timing mark data recorded on "EGAA" software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.

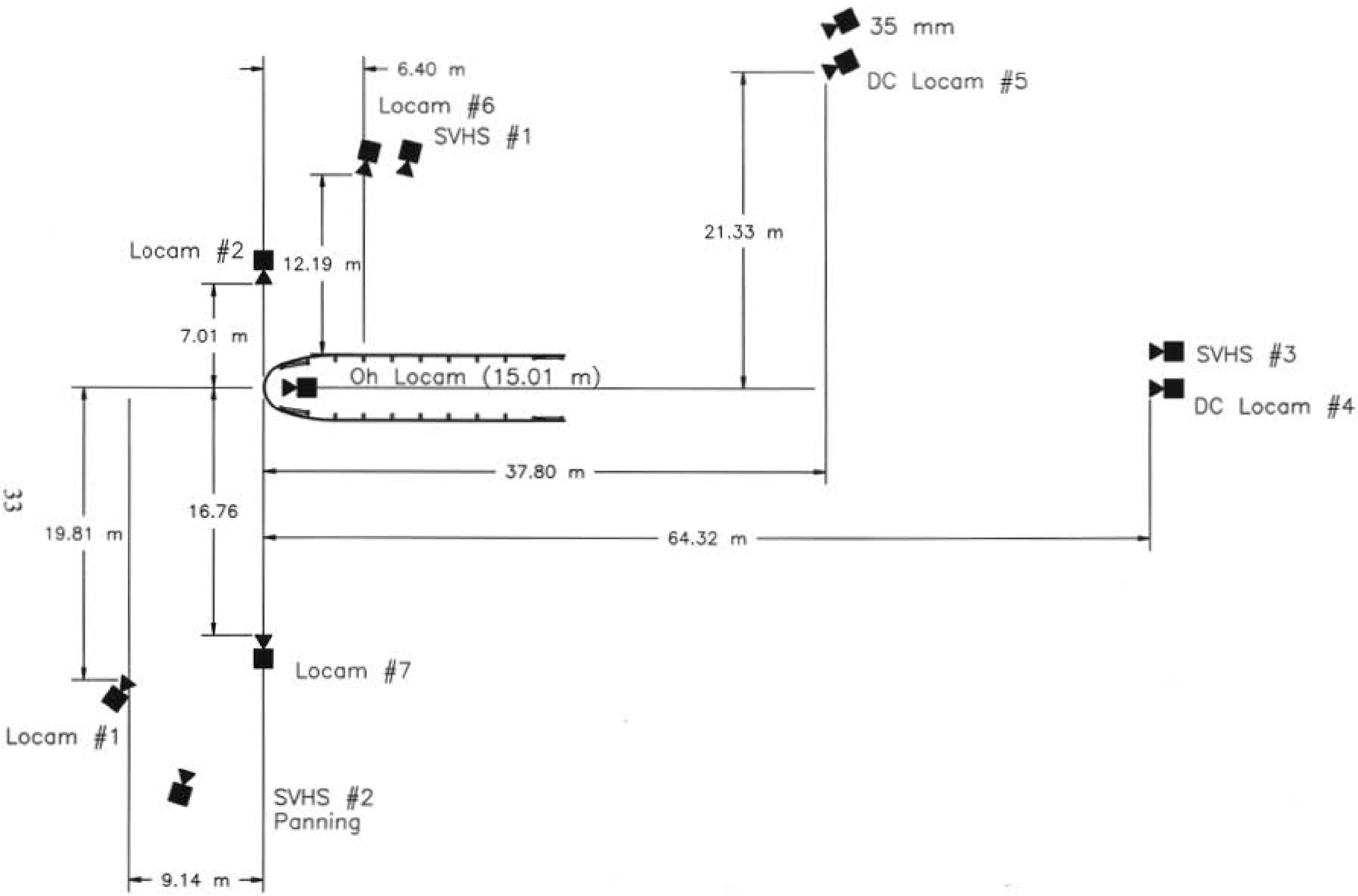


Figure 18. Location of High-Speed Cameras, Test MBN-1

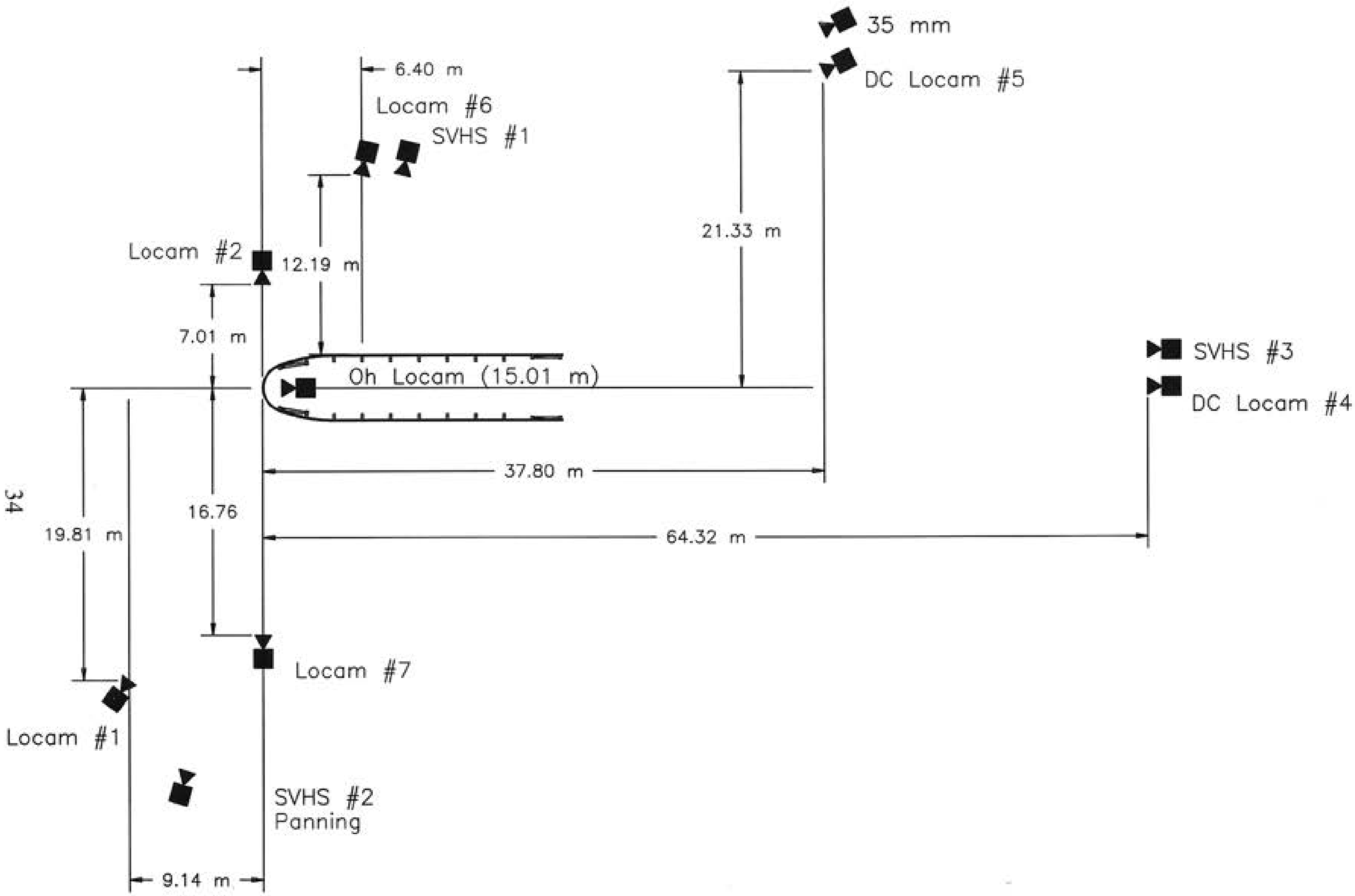


Figure 19. Location of High-Speed Cameras, Test MBN-2

4.4.5 Strain Gauges

For test MBN-1, four strain gauges were installed on the thrie beam guardrail, consisting of four gauges located on the back side of the thrie beam rail. The strain gauge positions and a photograph showing the gauges on the bullnose barrier terminal are shown in Figure 20. Strain gauges were not used in the instrumentation for the small car test, MBN-2.

For the tests, weldable strain gauges were used and consisted of gauge type LWK-06-W250B-350. The nominal resistance of the gauges was 350.0 ± 1.4 ohms with a gauge factor equal to 2.02. The operating temperature limits of the gauges was -195 to +260 degrees Celsius. The strain limits of the gauges were 0.5% in tension or compression (5000 $\mu\varepsilon$). The strain gauges were manufactured by the Micro-Measurements Division of Measurements Group, Inc. of Raleigh, North Carolina. The installation procedure required that the metal surface be clean and free from debris and oxidation. Once the surface was prepared, the gauges were spot welded to the test surface.

A Measurements Group Vishay Model 2310 signal conditioning amplifier was used to condition and amplify the low-level signals to high-level outputs for multichannel, simultaneous dynamic recording on "Test Point" software. After each signal was amplified, it was sent to a Keithly Metrabyte DAS-1802HC data acquisition board, and then stored permanently on the portable computer. The sample rate for all gauges was 5,000 samples per second (5,000 Hz), and the duration of sampling was 6 seconds.

Table 2. Strain Gauge Locations

STRAIN GAUGE INSTRUMENTATION		
Gauge Location	**Position**	**Distance**
1	Top - Middle Hump-Neutral Axis - Back Side	4" Upstream of Post # 1 Edge 7" Upstream Post # 1 CL
2	Bottom - Middle Hump-Neutral Axis - Back Side	4" Upstream of Post # 1 Edge 7" Upstream Post # 1 CL
3	Top - Middle Hump-Neutral Axis - Back Side	Midspan Between Posts #4 and #5
4	Bottom - Middle Hump-Neutral Axis - Back Side	Midspan Between Posts #4 and #5

Figure 20. Strain Gauge Locations, Test MBN-1

5 CRASH TEST MBN - 1

5.1 Test MBN-1

The 1998-kg pickup truck impacted the bullnose barrier terminal at a speed of 101.4 km/h and an angle of 0.1 degrees, as shown in Figure 21. A summary of the test results and the sequential photographs are shown in Figure 22. Additional sequential photographs are shown in Figure 23.

5.2 Test Description

Following the initial impact with the pickup truck, the thrie beam rail immediately began to deform inward. At 0.064 sec after impact, post no. 1 on both sides of the barrier fractured and the front quarter of the truck penetrated into the bullnose. The slotted thrie beam flattened across the front of the truck capturing the bumper and grill of the truck. A large "knee" or kink formed in the rail on the left side of the barrier between post nos. 1 and 2 at 0.11 sec after impact. As the truck continued to penetrate the barrier, post no. 2 on both sides of the barrier failed at 0.18 sec after impact. At this point, the front of the truck was even with post no. 3. The thrie beam snagged at post no. 3 on the right side of the barrier at a time of 0.31 sec after impact causing the thrie beam to rupture. At this time, the velocity of the pickup truck was 75.7 km/hr. This allowed the truck to continue traveling forward in the middle region of the barrier. At time 1.20 sec after impact, the truck impacted and fractured post no. 7 on the left side of the barrier as it exited the system. Figure 24 shows the trajectory of the pickup during the crash test.

5.3 Vehicle Damage

Vehicle damage was moderate, as shown in Figure 25. The front bumper and front end of the truck were crushed inward. The right-front fender of the pickup truck was crushed outward due to the barrier impact. The lower section of the right door was slightly crushed inward. The left-front fender of the truck showed some damage but there was no damage to the left-side door. There was no crushing of the pickup truck's occupant compartment. The front tire on the right side was detached from the rim during impact. Finally, the bolt mounts on the transmission were sheared off.

5.4 Barrier Damage

Barrier damage was extensive, as is shown in Figures 26 through 27. All four of the BCT posts used in the barrier fractured at the hole near the base of the post. Post no. 3 on both sides of the barrier was also broken. Post no. 11 on the left side of the barrier was contacted and broken as the truck exited through the middle of the barrier. The thrie beam buckled and bent at post no. 3 on both sides of the barrier. The thrie beam also buckled at post no. 4 on the left side of the barrier.

The thrie beam tore at two locations during the impact. The first tear occurred 229-mm upstream of post no. 1 on the left side. The tear reached from the top of the beam to the slot in the lowest valley of the beam. The second tear in the thrie beam occurred 762-mm upstream of post no. 1 on the right side. The tear was located between the valleys of the beam.

5.5 Occupant Risk Values

The normalized longitudinal occupant impact velocity (OIV) was determined to be 4.83 m/s. The maximum 0.010-sec average occupant ridedown deceleration (ORD) in the longitudinal direction was 9.95 g's. The lateral OIV and ORD limits were not determined due to the absence of contact between a hypothetical occupant and the side of the vehicle. It is noted that the occupant impact velocities and occupant ridedown decelerations were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk data are summarized in Figure 22. Results are shown graphically in Appendix A.

5.6 Discussion

Following test MBN-1, a safety performance evaluation was conducted, and the bullnose barrier design was determined to be unacceptable according to NCHRP Report No. 350 criteria. The bullnose barrier did not contain or stop the test vehicle in a controlled manner due to the fracture of the thrie beam during the impact. However, it should be noted that the pickup truck did not override the thrie beam during the impact prior to the thrie beam fracture. Detached elements and debris from the test article did not penetrate or show potential for penetrating the occupant compartment. There was no deformation of, or intrusion into, the occupant compartment that could have caused serious injury. The vehicle remained upright during and after collision and the vehicle's trajectory did not intrude into adjacent traffic lanes. Vehicle trajectory behind the test article was unacceptable as the test vehicle penetrated through the barrier and into the median area behind the bullnose. The occupant impact velocities and ridedown accelerations were within the suggested limits imposed by NCHRP Report No. 350.

The failure of the system to meet all of the safety performance criteria was directly attributed to the fracture of the thrie beam. The causes of the thrie beam fracture were investigated for correction in future designs. The thrie beam fracture occurred when the rail wrapped around post no. 3 on the right side of the barrier. When the post did not fracture, the thrie beam was pulled tight while bending, thus creating large stresses in the thrie beam at high strain rates ultimately causing the thrie beam to fracture. The use of weaker posts at post nos. 3 and 4 would allow the beam to continue to deform without snagging on the posts, preventing the large stresses and ensuing beam failure that occurred in test MBN-1.

5.7 Barrier Instrumentation Results

For test MBN-1, strain gauges were located on the thrie beam rail. The results of the strain gauge analysis are provided in Table 3. The data for strain gauges no. 1 and 2 was not used due to evidence of yielding in the rail. The strain gauges were deformed and the data would have been invalid. Graphs of the data taken from gauges no. 3 and 4 are located in the Appendix B (Figures B-1 and B-2).

Figure 21. Impact Location MBN-1

0.00 sec | 0.06 sec | 0.115 sec | 0.180 sec | 0.305 sec

0.00 sec | 0.06 sec | 0.115 sec | 0.180 sec | 0.305 sec

- Test Number MBN-1
- Date 7/22/97
- Appurtenance .... Bullnose Median Barrier
- Total Length .... 20,144 mm
- Steel Thrie Beam (Nested)
  - Thickness .... 12 gauge (2.66 mm)
  - Top Mounting Height .... 804 mm
- Wood Posts
  - Post Nos. 1 - 2, 10 - 11 (BCT) .... 140 mm x 190.5 mm x 1,080-mm long
  - Post Nos. 3 - 9 .... 150 mm x 200 mm x 1,980-mm long
- Wood Spacer Blocks
  - Post Nos. 1 - 8 .... 150 mm x 200 mm x 554-mm long
- Soil Type .... Grading B - AASHTO M 147-65 (1990)
- Vehicle Model .... 1989 Ford 250 2WD
  - Curb .... 1,982 kg
  - Test Inertial .... 1,998 kg
  - Gross Static .... 1,998 kg
- Vehicle Speed
  - Impact .... 101.4 km/hr
  - Exit .... NA
- Vehicle Angle
  - Impact .... 0.1 deg
  - Exit .... NA deg
- Vehicle Snagging .... None
- Vehicle Stability .... Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal .... 9.95 g's
  - Lateral (not required) .... NA
- Occupant Impact Velocity (Normalized)
  - Longitudinal .... 4.83 m/s
  - Lateral (not required) .... NA
- Vehicle Damage .... Moderate
  - TAD 12-FD-4
  - SAE 12FDEW5
- Vehicle Stopping Distance .... 24.69 m downstream, 8.38 m left of centerline
- Barrier Damage .... Extensive rail damage and five fractured posts
- Maximum Deflections
  - Permanent Set .... NA
  - Dynamic .... NA

Figure 22. Summary and Sequential Photos, Test MBN-1

0.00 sec

0.063 sec

0.185 sec

0.389 sec

1.204 sec

Figure 23. Additional Sequential Photographs, Test MBN-1

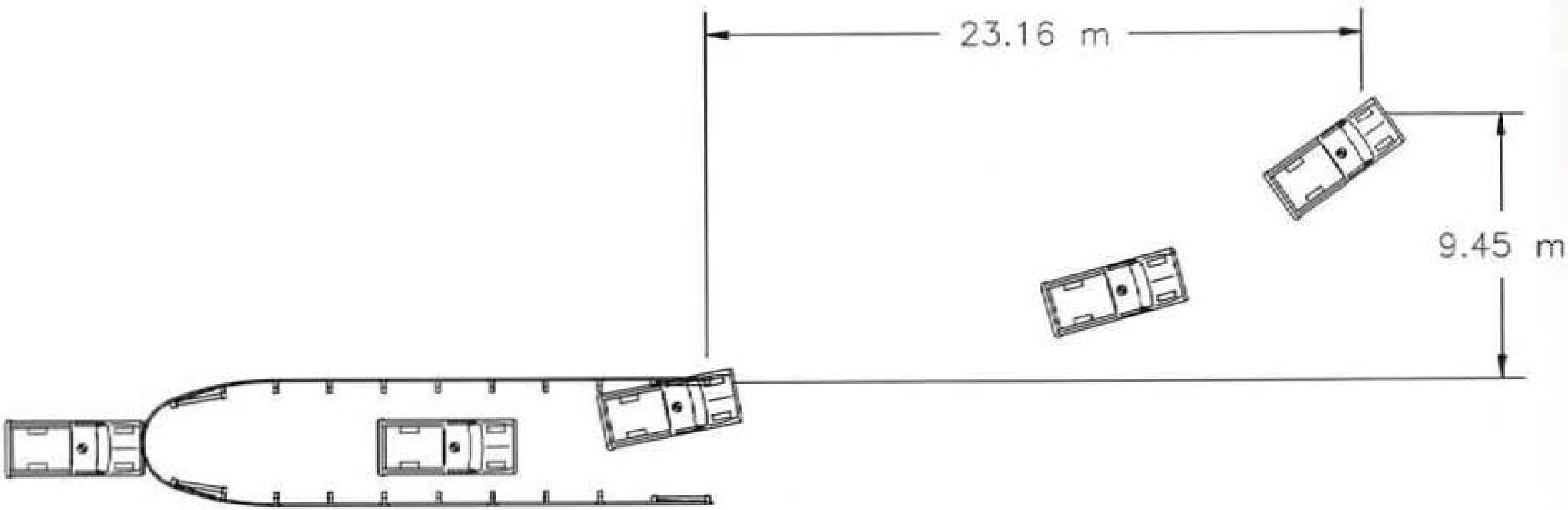


Figure 24. Vehicle Trajectory, MBN-1

Figure 25. Vehicle Damage, Test MBN-1

Figure 26. Barrier Damage, Test MBN-1

Figure 27. Barrier Damage, Test MBN-1

Table 3. Strain Gauge Data, Test MBN-1

Hardware type	Strain Gauge No.	Maximum μ Strain[1] (in./in.)	Maximum Stress[2] (ksi)	Comments
Thrie Beam	1	NA	NA	Data was not taken because of yield of the rail at the gauge location
	2	NA	NA	Data was not taken because of yield of the rail at the gauge location
	3	260	7806	None
	4	421	12625	None

1. All strain values are shown as the absolute value only
2. All elastic stress values are shown as the absolute value only and calculated by multiplying the strain by the modulus of elasticity equal to 30,000 ksi. Minimum yield stress for the thrie beam is 50 ksi.

NA- Not Available

6 BARRIER MODIFICATIONS (DESIGN FOR MBN - 2)

The bullnose barrier terminal system was modified prior to conducting the second full-scale crash test, test MBN-2. An analysis of the test MBN-1 results revealed problems or flaws that needed to be remedied prior to performing additional crash tests.

As previously described, the bullnose configuration used for test MBN-1 was constructed with standard 150-mm wide by 200-mm deep timber guardrail posts for post nos. 3 through 9 on each side. Also, the thrie beam rail sections on either side of the system did not contain any horizontal slots between post nos. 3 through 11. Therefore, the relative strength of the guardrail system was much higher downstream of post no. 3 versus the region upstream of post no. 3.

During test MBN-1, the first two posts on each side of the system fractured as planned, and the first two thrie beam segments buckled and deformed easily with the inclusion of the horizontal slots. However, when the thrie beam rail deformed around post no. 3 on the right side of the system, the post did not fracture, resulting in high stresses and strains being induced into the thrie beam rail. This high impulse loading led to the rupture of the thrie beam rail on the right side of the guardrail system without stopping the vehicle. In addition, even though post no. 3 on the left side of the system fractured, another potential problem was revealed as the stiff segment of thrie beam between post nos. 3 and 4 was deformed toward the left side of the vehicle as the vehicle penetrated the bullnose system. Since the thrie beam did not contain slots for weakening the rail in this region, the thrie beam kinked at post no. 4 and formed a knee at post no. 3. This knee revealed the potential for penetrating or snagging on an impacting vehicle although no actual vehicle contact occurred on the left side of the system.

Although the thrie beam fractured during test MBN-1 and did not capture the pickup truck, the slotted thrie beam rail prevented the pickup truck from overriding the nose section of the system. Therefore, the researchers believed that the system could be significantly improved by weakening the buckling and bending strength of the thrie beam rail after post no. 3 as well as replacing post nos. 3 and 4 with posts that would fracture more easily. Following the failure of test MBN-1, modifications were made to the guardrail system. These modifications to the bullnose guardrail system consisted of changing of post nos. 3 and 4 to breakaway posts and incorporating slots in another section of the thrie beam rail. A schematic of the modified design is shown in Figure 28, and photographs are provided in Figures 29 through 30.

For the first modification, post no. 3 on each side of the system was replaced by a 140-mm by 190.5-mm BCT post set in a foundation tube without a bearing plate, while post no. 4 on each side was replaced by a CRT post. These post changes were made to accelerate the fracture of the posts in those areas, prevent high loads being imparted into the thrie beam rail, and reduce the high rail stresses from occurring at concentrated locations. These changes would also allow for a more gradual dissipation of the vehicle's kinetic energy.

The slot pattern for rail section no. 2 on both sides of the bullnose barrier terminal was also modified slightly from the original design. The new slot pattern for rail no. 2 is shown in Figure 32. The slot pattern was changed to form eighteen 290-mm long slots, 9 in each valley. Each of the slots is separated by a 100-mm gap. The slot width remained 25 mm. The final major modification to the bullnose system was the addition of slots to rail section no. 3 on both sides of the system. The slot pattern of rail section no. 3 is shown in Figure 33. Twelve 300-mm slots were cut out of the valleys, six in each valley, with 250-mm spaces between them. The modification of the slots in section no. 2 and the addition of slots to section no. 3 serve to reduce the strength of the beam. Reducing the

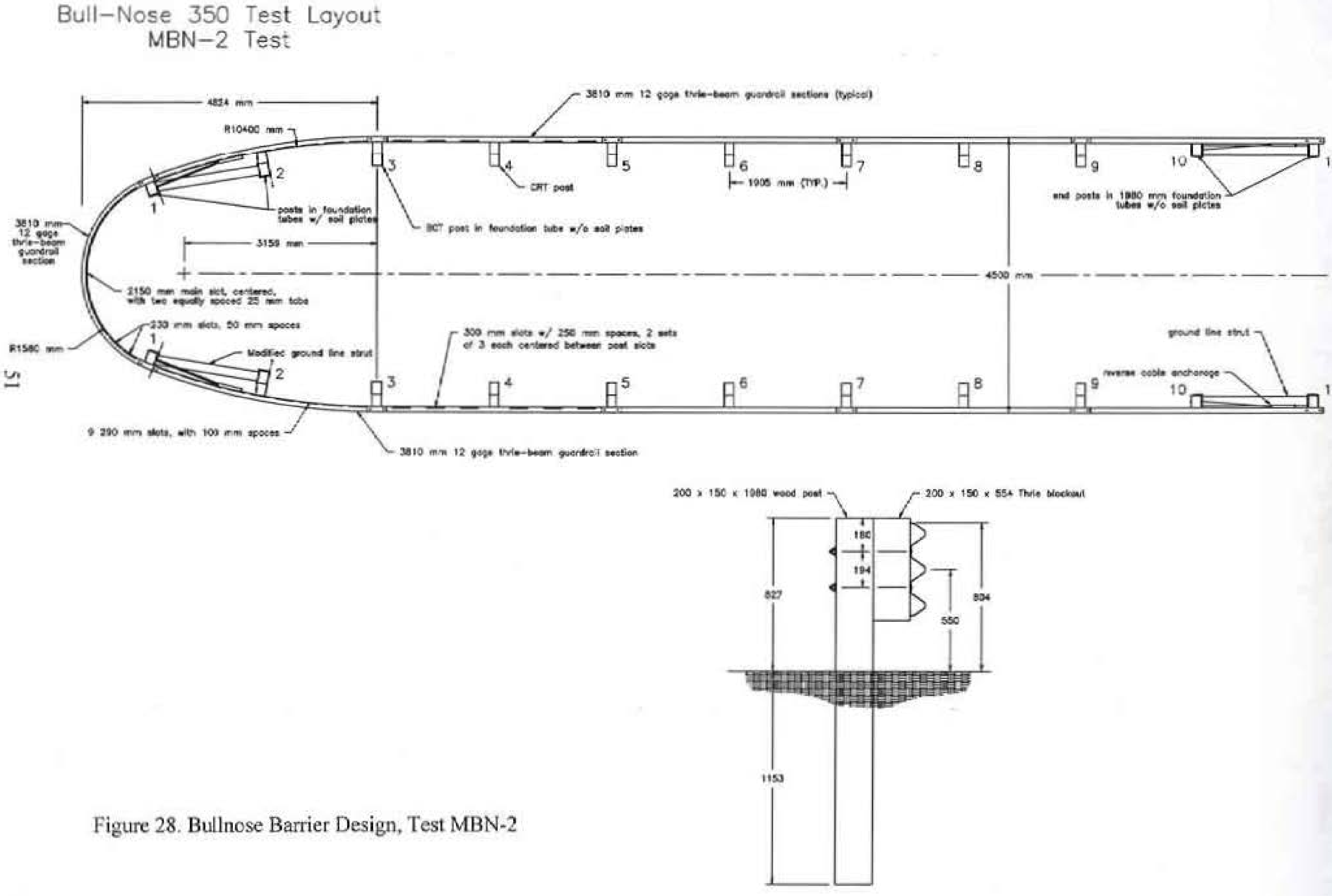


Figure 28. Bullnose Barrier Design, Test MBN-2

Figure 29. Bullnose Design for Test MBN-2

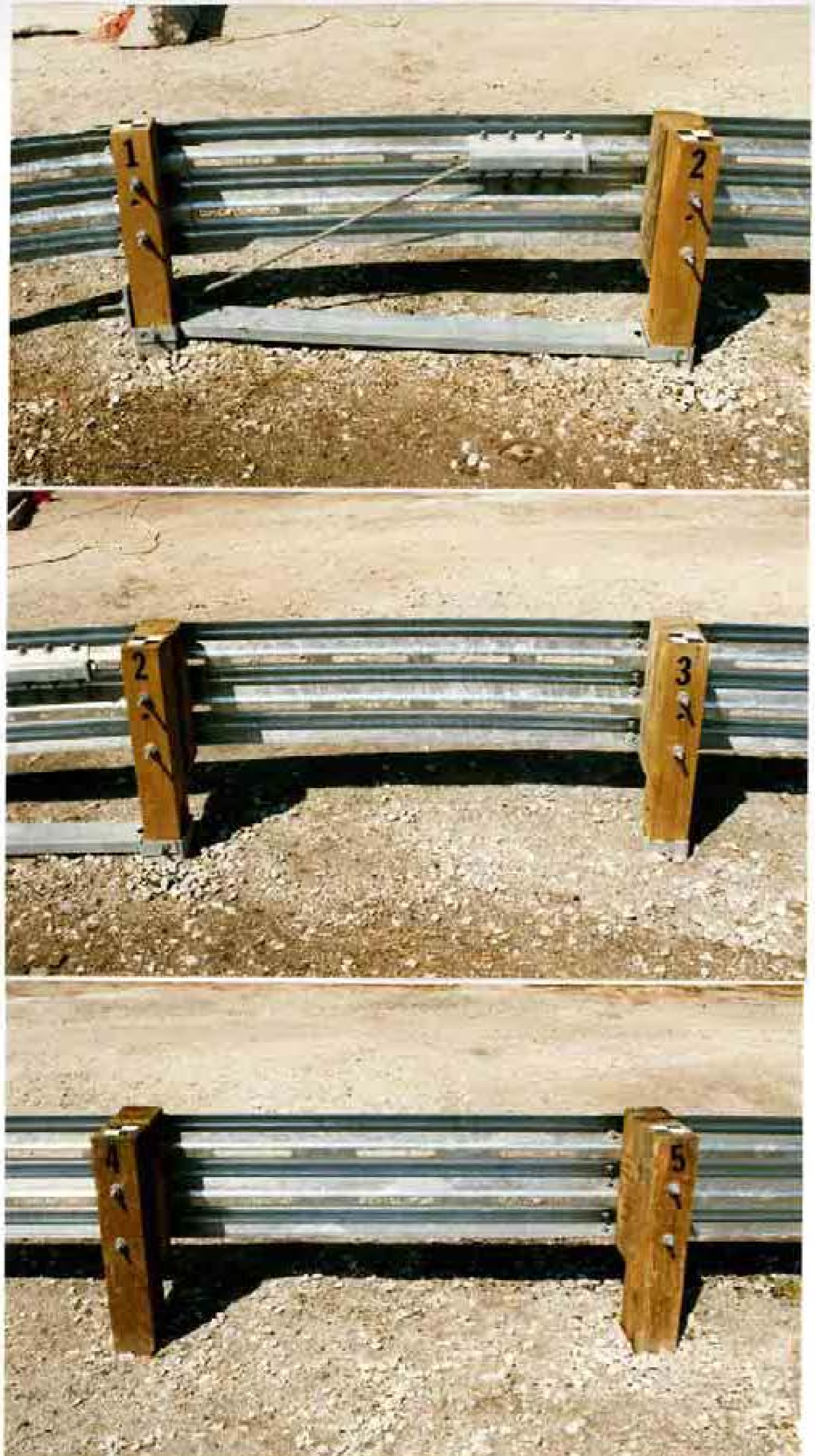
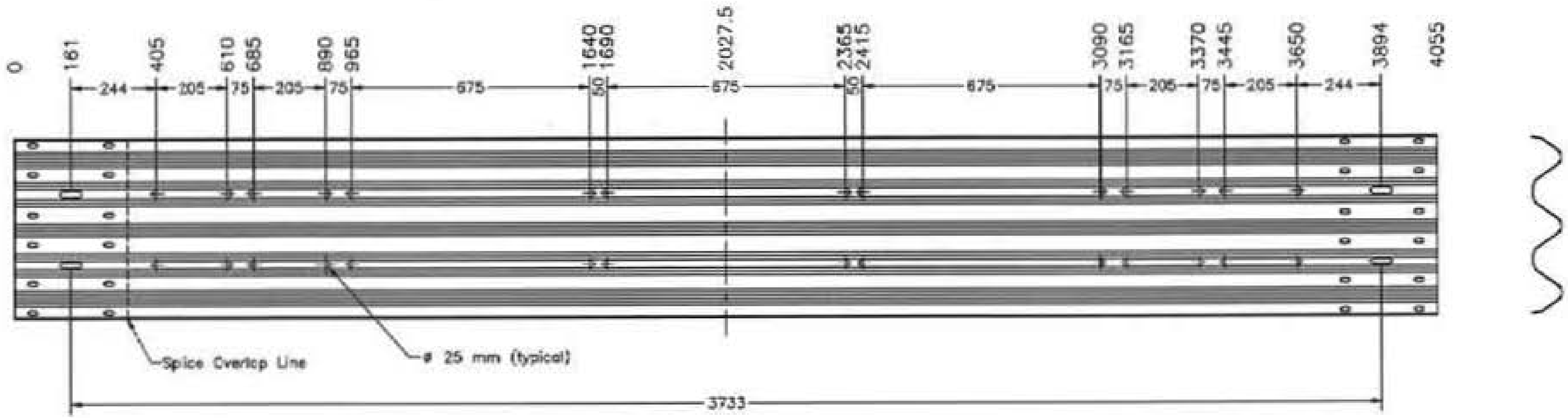
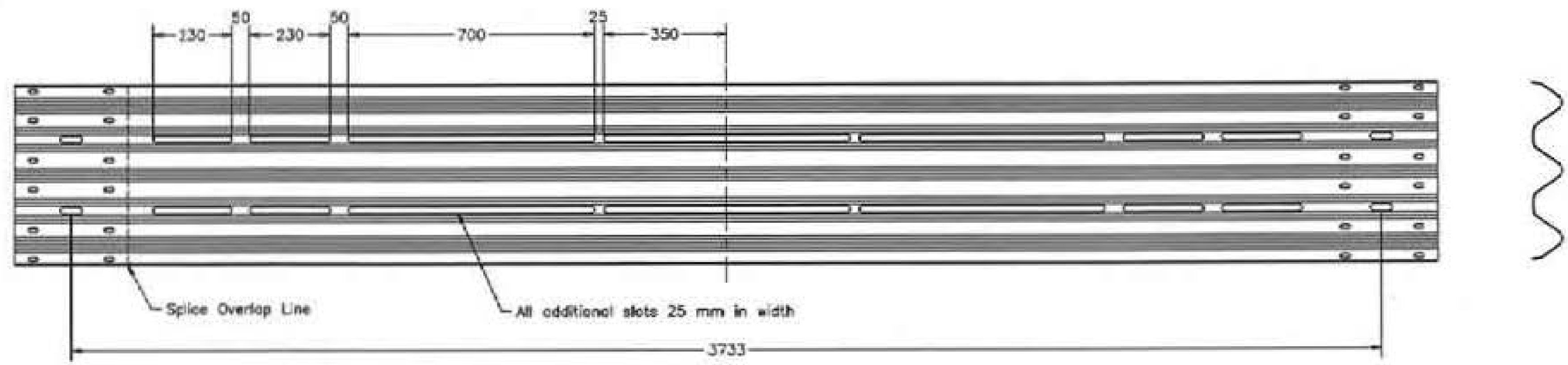


Figure 30. Bullnose Design for Test MBN-2

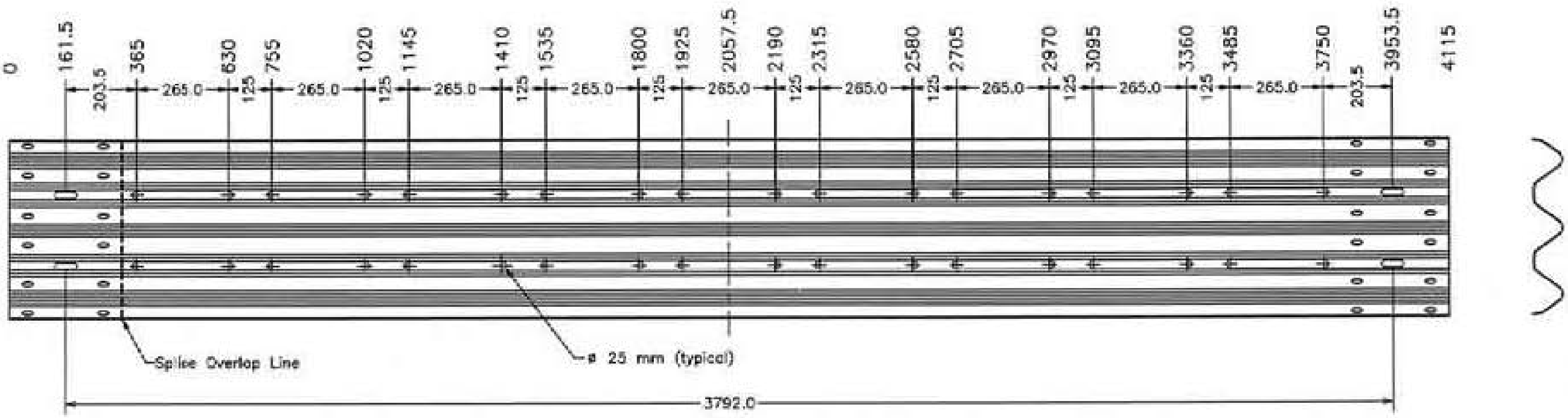


Rail Section 1 ("Nose" Section, MBN-2)

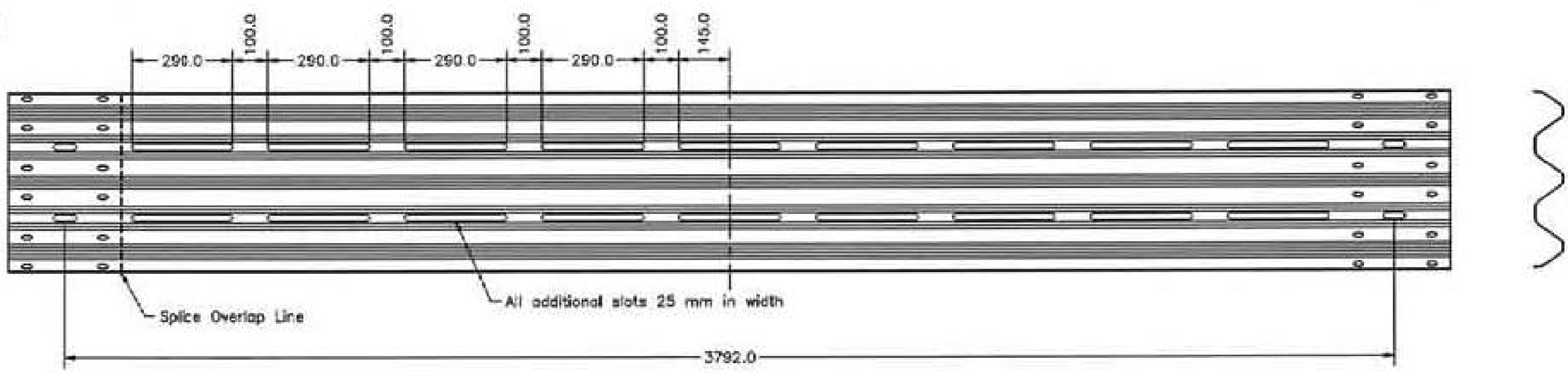


Rail Section 1 ("Nose" Section, MBN-2)

Figure 31. Rail No. 1 Detail Test, MBN-2

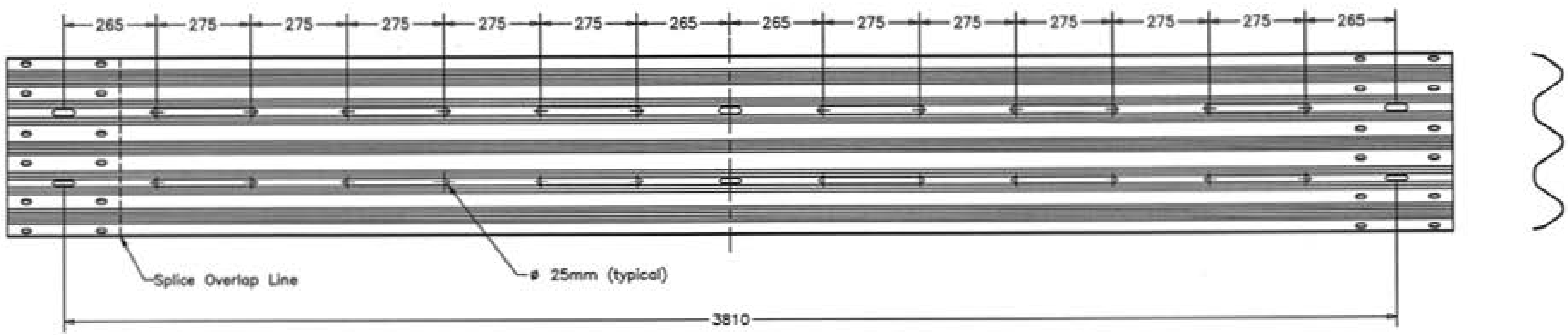


Rail Section 2 (MBN-2)

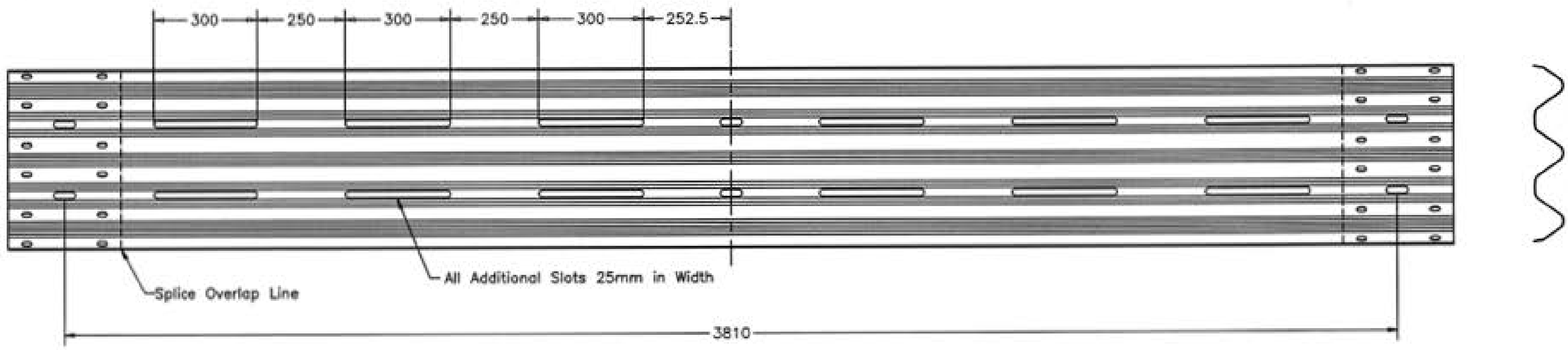


Rail Section 2 (MBN-2)

Figure 32. Rail No. 2 Detail Test, MBN-2



Rail Section 3 (MBN-2)



Rail Section 3 (MBN-2)

Figure 33. Rail No. 3 Detail Test, MBN-2

strength of the beam will also allow the beam to deform more easily during impact, thereby decreasing the high stresses created by the kinking action in the beam. The slots also aid in the capture of the vehicle by allowing the beam to wrap around the vehicle during impact to prevent overriding or under riding of the beam.

It was decided that the second test should be the 820-kg small car test as planned and not a rerun of the failed 2000-kg truck test. The project team wanted data for both a truck and a small car because one of the major purposes of these initial tests was to verify that the slotted thrie beam could capture mini-size vehicles as well as light trucks and provide data for computer simulation modeling of the bullnose system. A rerun of the truck test would have limited the available data to the behavior of the barrier in a truck impact only.

7 CRASH TEST MBN - 2

7.1 Test MBN-2

The 886-kg small car impacted the bullnose barrier terminal at a speed of 103.3 km/h and an angle of -3.4 degrees with a 1/4-point offset. A summary of the test results and the sequential photographs are shown in Figure 35. Additional sequential photographs are shown in Figure 36. Full-scale crash documentary photographs are shown in Figure 37 through Figure 38.

7.2 Test Description

The nose section of the bullnose barrier began to deform immediately after the initial impact of the 886-kg small car. At 0.107 sec after impact, post no. 1 on both sides of the barrier failed and approximately one half of the small car had penetrated the bullnose barrier. The slotted nose sections of thrie beam rail wrapped around the front of the vehicle capturing the vehicle's bumper and grill. After the failure of post no. 1, the back of the vehicle began to rotate counterclockwise towards the right side of the barrier. Post no. 2 on the right side of the barrier failed at 0.196 sec after impact. A rail "knee" or kink formed in the thrie beam on the right side of the barrier as the vehicle continued to penetrate and deform the barrier. The knee impacted the right-rear quarter panel of the small car at 0.282 sec after initial impact, deforming the right-side of the vehicle and shattering the rear window. At 0.542 sec, the vehicle was brought to a complete stop. The vehicle trajectory is shown in Figure 39.

7.3 Vehicle Damage

Vehicle damage was extensive, as shown in Figure 40. The front end of the small car was crushed, including the bumper, engine compartment, hood, and front quarter panels. The front windshield was also fractured during the impact. The right-side sheet metal behind the door was deformed inward approximately 12.7 cm due to "knees" forming in the thrie beam rail and impacting the side of the vehicle. The right-side door was damaged along its entire length, and the right-side window glass was shattered. The left-side door was deformed and wedged shut at the front hinge. Only minor floorboard deformation was found in the occupant compartment.

7.4 Barrier Damage

Barrier damage was extensive, as shown in Figure 41 through Figure 42. Post nos. 1 and 2 on each side of the system were completely fractured. The rail buckled during impact at post no. 2 on the left side of the system and slightly upstream of post no. 3 on the right side of the system. Significant tearing of the thrie beam occurred where the rail wrapped around the front end of the small car. Tearing of the horizontal slots in the thrie beam occurred at several posts and where the rail buckled near the posts nos. 2 and 3. In addition, tearing of the slots occurred at some midspan locations. Deformations to the thrie beam occurred to the nose piece as well as rail section no. 2 on both sides of the system. The deformed shape and deflection of the barrier is shown in Figure 43. The maximum permanent rail deflection was 7.11 m.

7.5 Occupant Risk Values

The normalized longitudinal and lateral occupant impact velocities (OIV) were determined to be 9.60 m/s and 3.27 m/s respectively. The maximum 0.010-sec average occupant ridedown decelerations (ORD) in the longitudinal and lateral directions were 11.37 g's and -9.98 g's respectively. It is noted that the occupant impact velocities and occupant ridedown decelerations were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer, are summarized in Figure 35. Results are shown graphically in Appendix A.

7.6 Discussion

Following test MBN-2, a safety performance evaluation was conducted, and the bullnose barrier design was determined to be acceptable for Test 3-30 according to NCHRP Report No. 350 criteria. The bullnose barrier contained and stopped the test vehicle in a controlled manner. It should be noted that the thrie beam captured the small car with no overriding or under riding of the rail. Detached elements and debris from the test article did not penetrate or show potential for penetrating the occupant compartment. There was no deformation of, or intrusion into, the occupant compartment that could have caused serious injury. The vehicle remained upright during and after collision and the vehicle's trajectory did not intrude into adjacent traffic lanes. Vehicle trajectory behind the test article was acceptable as the test vehicle did not penetrate through the barrier and into the median area behind the bullnose. The occupant impact velocities and ridedown accelerations were within the suggested limits imposed by NCHRP Report No. 350.

It is noted that the actual impact angle of -3.4 deg was not within the allowable angle tolerance of ±1.5 deg on a target impact angle of 0 deg, as provided in NCHRP Report 350. However, the authors believe that this error accentuated the vehicular yaw motion induced by the 1/4-point offset, thus making the crash test a more stringent impact condition by increasing the potential for rail penetration in the side of the car.

Figure 34. Impact Location Test MBN-2

0.00 sec | 0.107 sec | 0.200 sec | 0.280 sec | 0.495 sec

0.00 sec | 0.107 sec | 0.200 sec | 0.280 sec | 0.495 sec

• Test Number	MBN-2
• Date	7/25/97
• Appurtenance	Bullnose Median Barrier
• Total Length	20,144 m
• Steel Thrie Beam (Nested)	
Thickness	12 gauge (2.66 mm)
Top Mounting Height	804 mm
• Wood Posts	
Post Nos. 1 - 3, 10 - 11 (BCT)	140 mm x 190.5 mm x 1,080-mm long
Post No. 4 (CRT)	150 mm x 200 mm x 1,980-mm long
Post Nos. 3 - 9	150 mm x 200 mm x 1,980-mm long
• Wood Spacer Blocks	
Post Nos. 1 - 8	150 mm x 200 mm x 554-mm long
• Soil Type	Grading B - AASHTO M 147-65 (1990)
• Vehicle Model	1988 Ford Festiva
Curb	753 kg
Test Inertial	811 kg
Gross Static	886 kg
• Vehicle Speed	
Impact	103.3 km/hr
Exit	0.0 km/hr

• Vehicle Angle	
Impact	-3.4 deg
Exit	NA
• Vehicle Snagging	None
• Vehicle Stability	Satisfactory
• Occupant Ridedown Deceleration (10 msec avg.)	
Longitudinal	11.37 g's
Lateral (not required)	9.09/-9.98 g's
• Occupant Impact Velocity (Normalized)	
Longitudinal	9.60 m/s
Lateral (not required)	3.27 m/s
• Vehicle Damage	Moderate
TAD	12-FD-5 // 3-RBQ-4
SAE	12FDEW5 // 03RBEK9
• Vehicle Stopping Distance	6.55 m downstream 1.58 m west of centerline
• Barrier Damage	Extensive rail damage and four fractured posts
• Maximum Deflections	
Permanent Set	7.11 m downstream 0.97 m west of centerline
Dynamic	NA

Figure 35. Summary and Sequential Photographs, Test MBN-2


0.000 sec


0.105 sec


0.209 sec


0.275 sec


0.477 sec

Figure 36. Additional Sequential Photographs, Test MBN-2

Figure 37. Full-Scale Crash Test, MBN-2

Figure 38. Full-Scale Crash Test, Test MBN-2

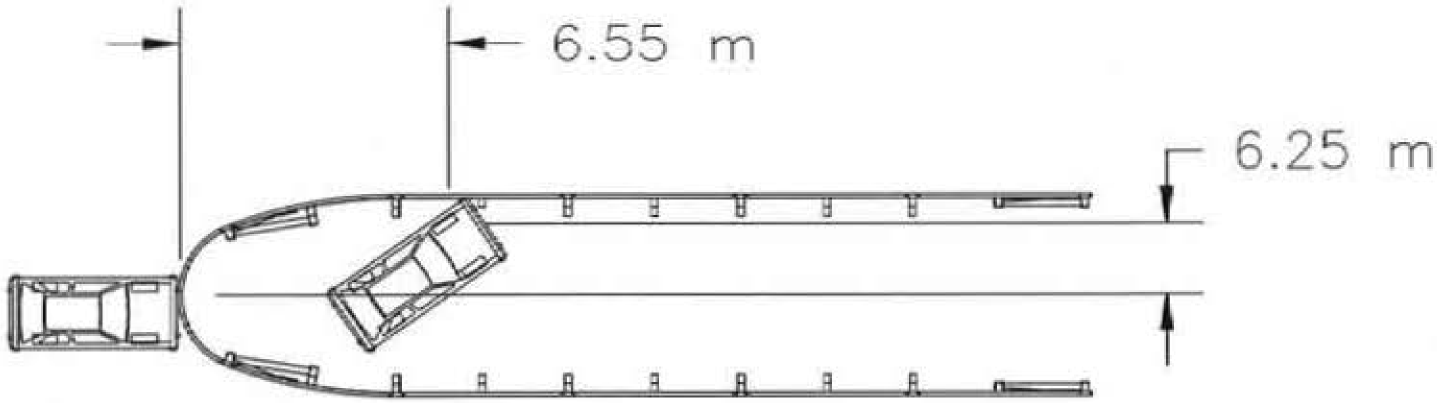


Figure 39. Vehicle Trajectory, Test MBN-2

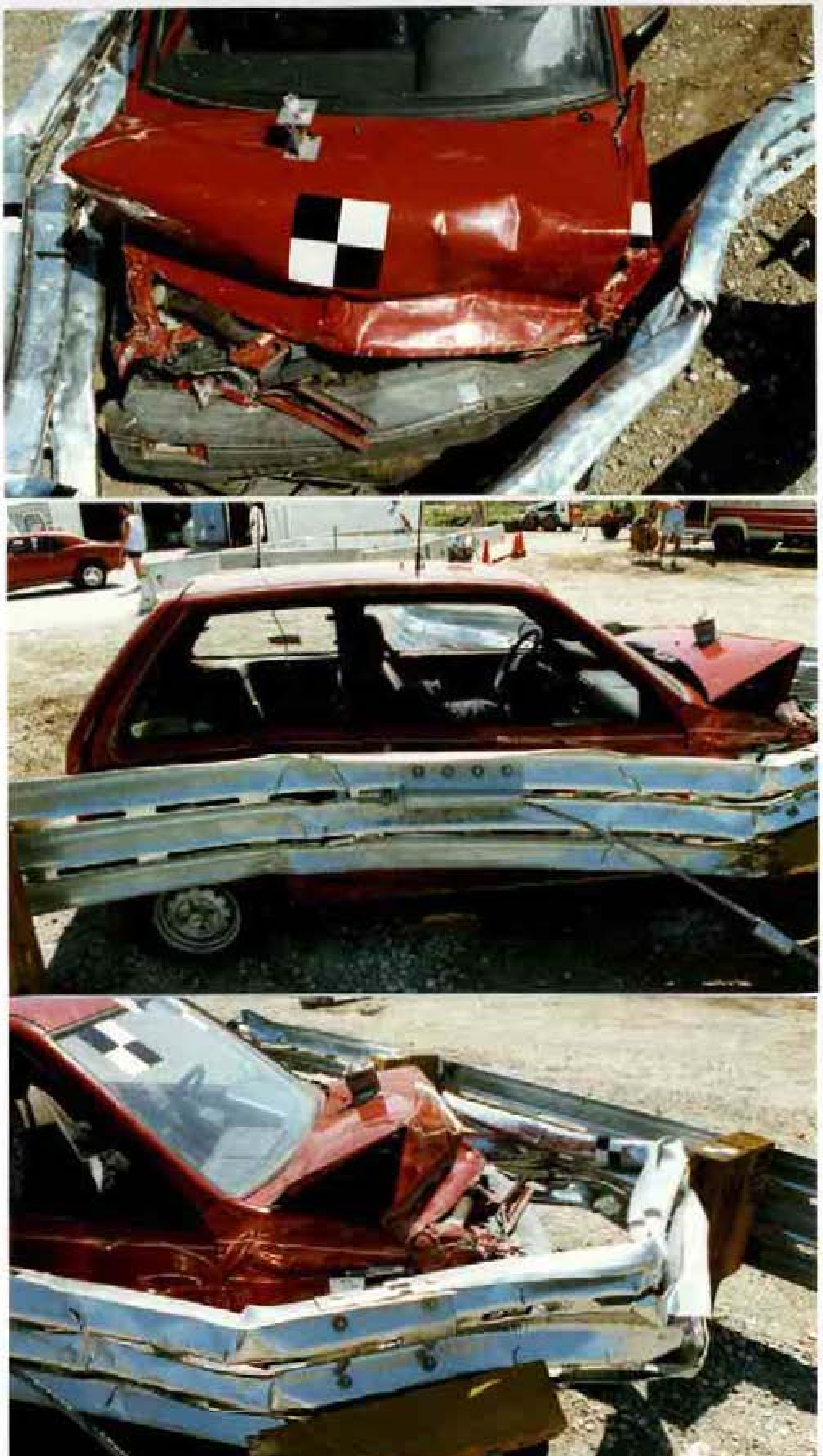


Figure 40. Vehicle Damage, Test MBN-2

Figure 41. Barrier Damage, Test MBN-2

Figure 42. Barrier Damage, Test MBN-2

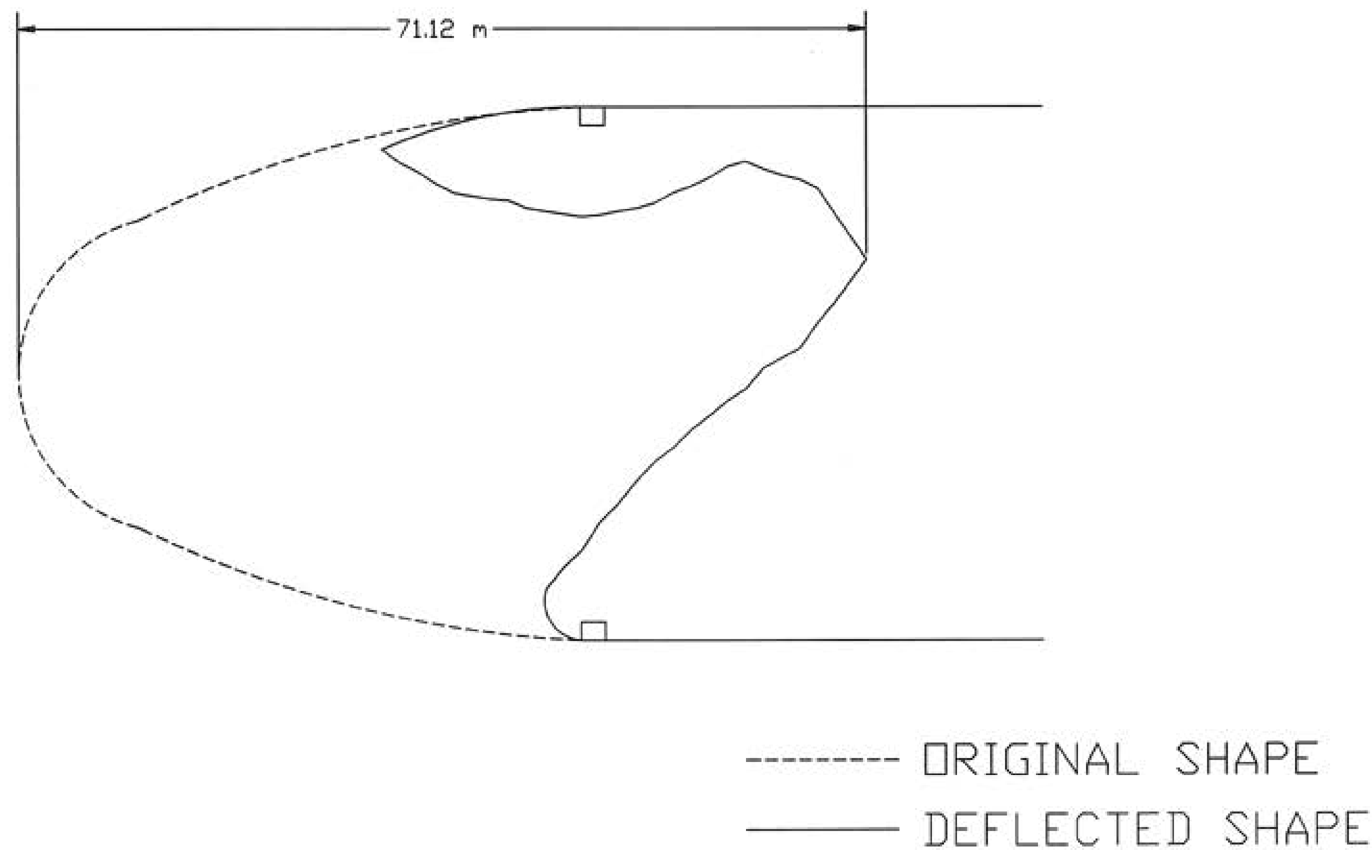


Figure 43. Permanent Rail Deflection, Test MBN-2

8 SUMMARY AND CONCLUSIONS

A bullnose median barrier terminal was developed and full-scale crash tested to evaluate the initial design concept and to provide data for future design modifications and computer simulation. Two crash tests were performed according to Test Level 3 (TL-3) of NCHRP Report No. 350. A summary of the safety performance evaluation is shown in Table 4. Test MBN-1 was conducted with a 1998-kg truck, while test MBN-2 used an 886-kg small car. The first test, test MBN-1, failed after the thrie beam fractured resulting in an uncontrolled penetration of the vehicle behind the barrier. However, the pickup truck did not show any potential for override of the thrie beam. Following this crash test, the bullnose barrier was modified to prevent the fracture of the thrie beam during impact. The bullnose was modified by the addition of BCT posts at post no. 3 on each side, CRT posts at post no. 4 on each side, and horizontal slots in the valleys of rail section no. 3. The second test, test MBN-2, was performed on the modified barrier and was determined to be acceptable according to the TL-3 crash test criteria of NCHRP Report No. 350. The small car did not show any potential for underride of the thrie beam.

The phase I development of the bullnose barrier median treatment was successfully completed. An initial design concept was developed and tested. The data gathered during the testing provided valuable information that will be used in further modification and testing of the bullnose design and in computer simulation of the bullnose barrier.

Table 4. Summary of Safety Performance Evaluation

Evaluation Factors	Evaluation Criteria	Test MBN-1	Test MBN-2
Structural Adequacy	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	U	S
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.	S	S
	F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	S	S
	H. Occupant impact velocities should satisfy the following: **Occupant Impact Velocity Limits (m/s)** Component — Preferred — Maximum Longitudinal and Lateral — 9 — 12	S	S
	I. Occupant ride down accelerations should satisfy the following: **Occupant Ride down Acceleration Limits (G's)** Component — Preferred — Maximum Longitudinal and Lateral — 15 — 20	S	S
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S	S
	N. Vehicle trajectory behind the test article is acceptable.	U	S

S - (Satisfactory)
U - (Unsatisfactory)

9 RECOMMENDATIONS

The bullnose barrier median treatment described in this report was successfully tested for a 820C small car in a head-on impact at the ¼-point of the vehicle. The results of that test demonstrate that there is significant potential for further development of the bullnose concept. Thus, it is suggested that the research described herein be further developed using the data collected from testing to modify future designs and to aid in computer simulation of future designs. In addition, with only minor modifications to the design used for test MBN-2, it may be possible to successfully capture and contain the 2000P pickup truck impacting head-on into the nose section. However, there is a potential that there still may be a need for strengthening the rail in the longitudinal direction to prevent complete fracture of the rail section.

It is further recommended that a complete set of full-scale crash tests be performed to verify and complete the compliance testing of the bullnose design.

10 REFERENCES

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APPENDICES

APPENDIX A

ACCELEROMETER DATA

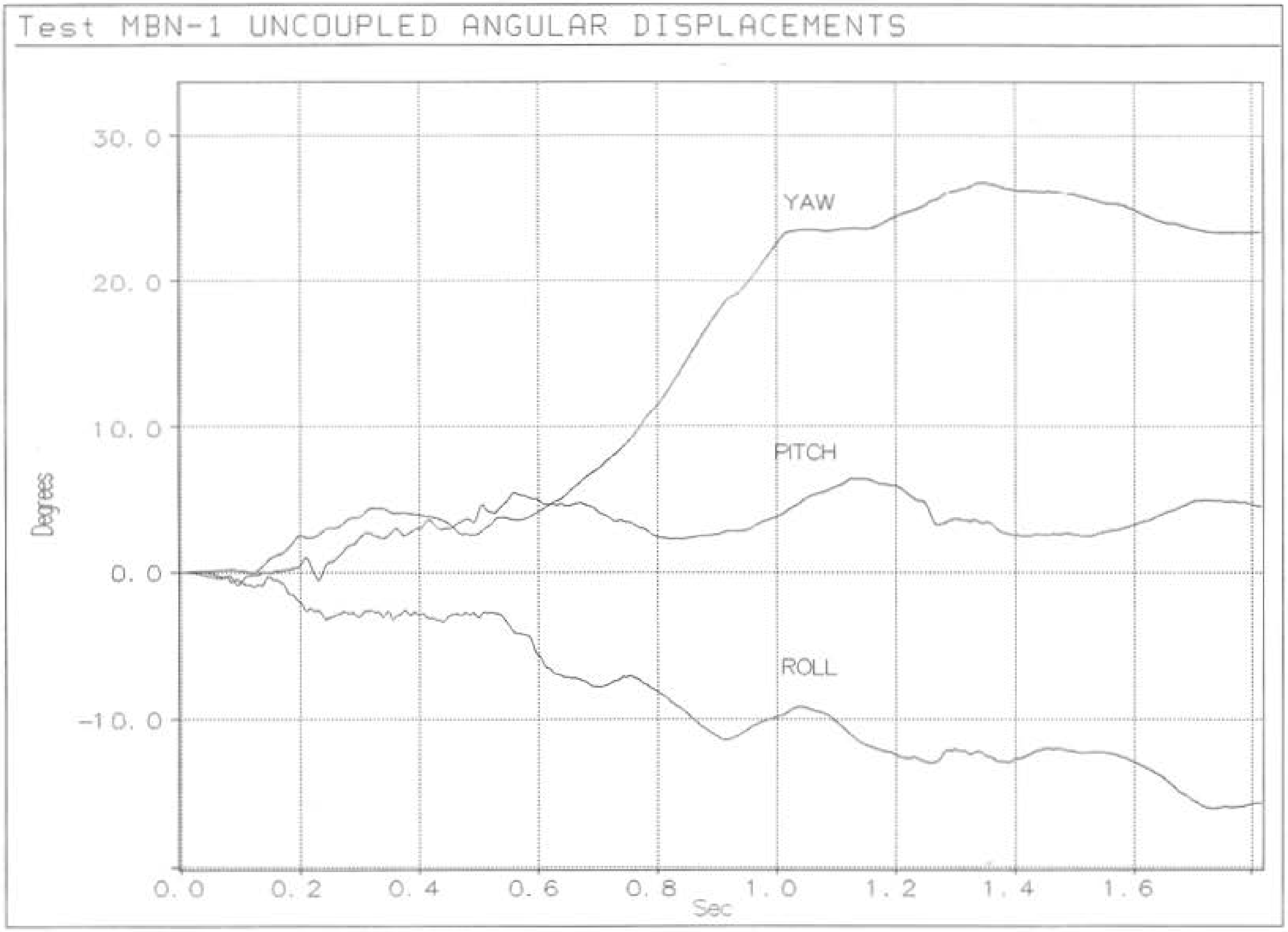

Figure A-1. Graph of Angular Displacements, Test MBN-1

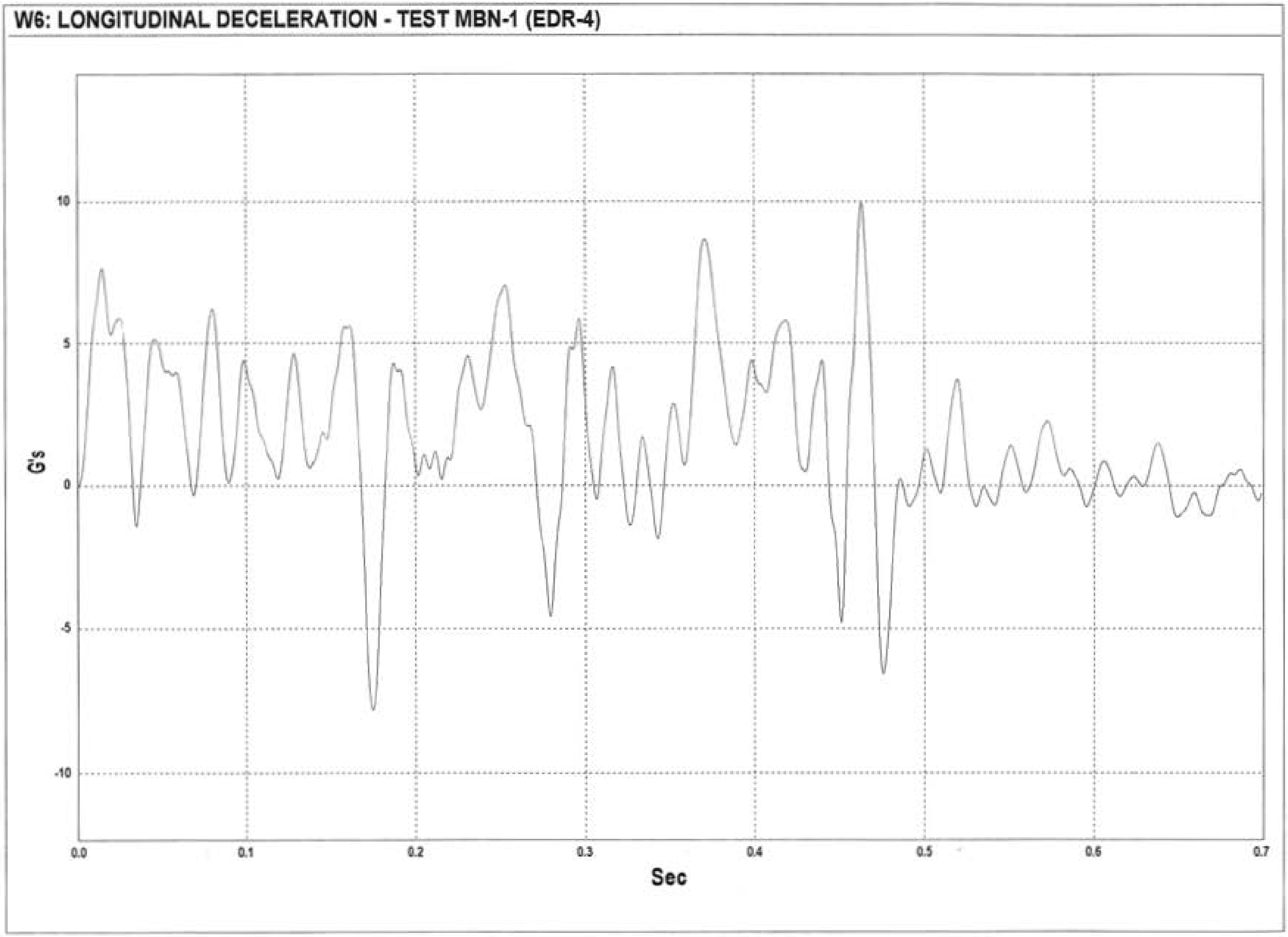

Figure A-2. Graph of Longitudinal Deceleration, Test MBN-1

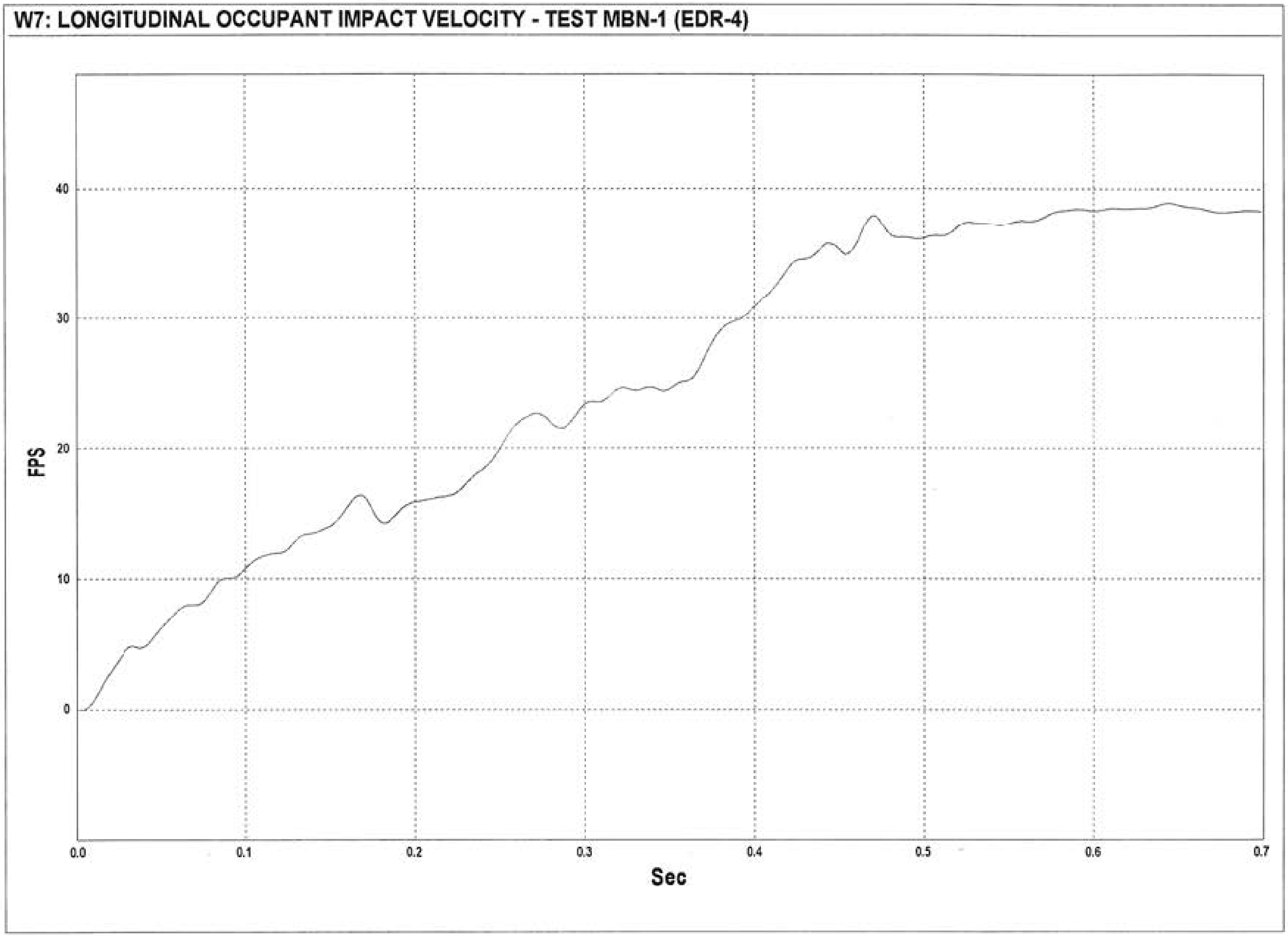

Figure A-3 Graph of Longitudinal Occupant Impact Velocity, Test MBN-1

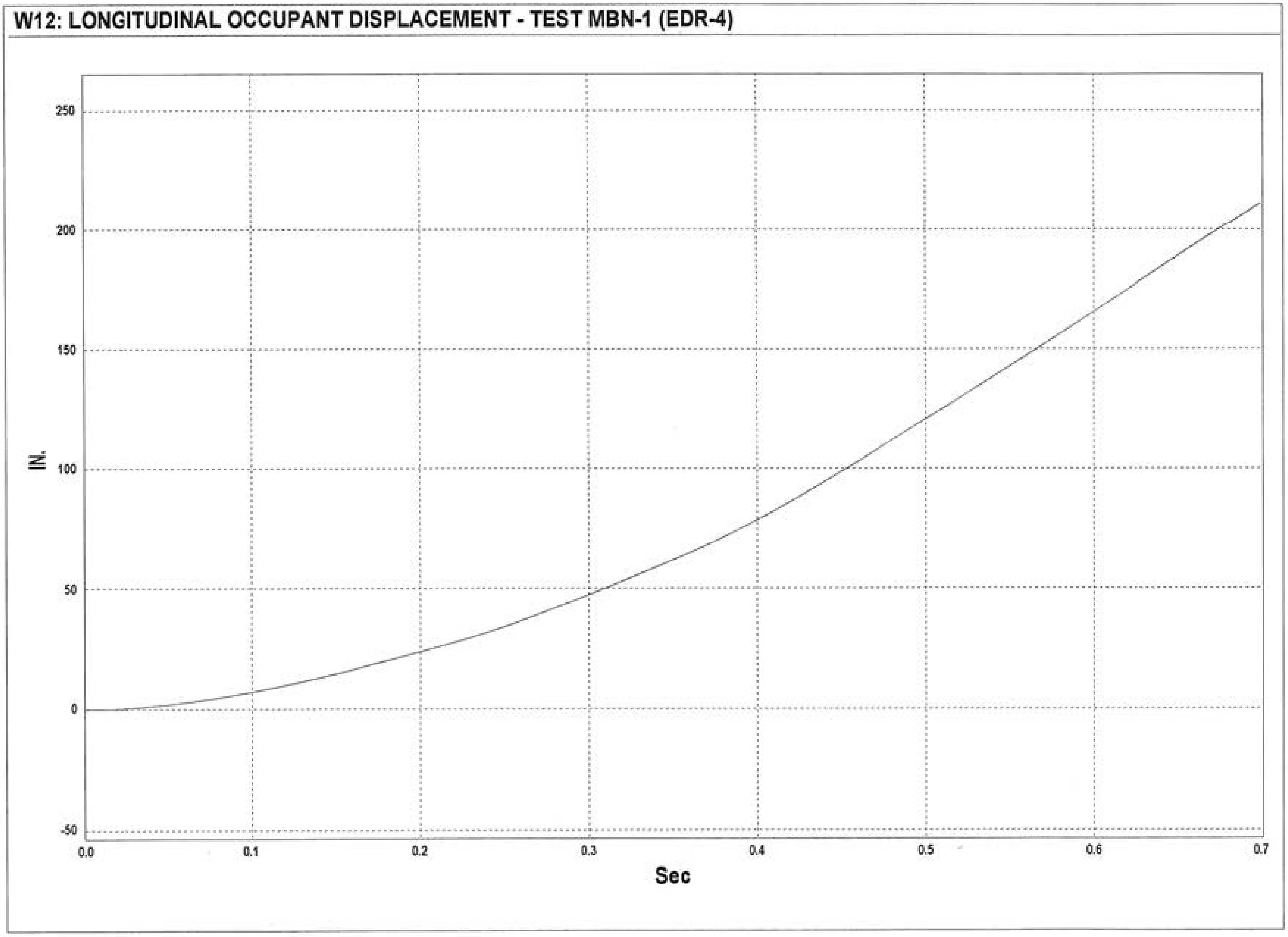

Figure A-4. Graph of Longitudinal Occupant Displacement, Test MBN-1

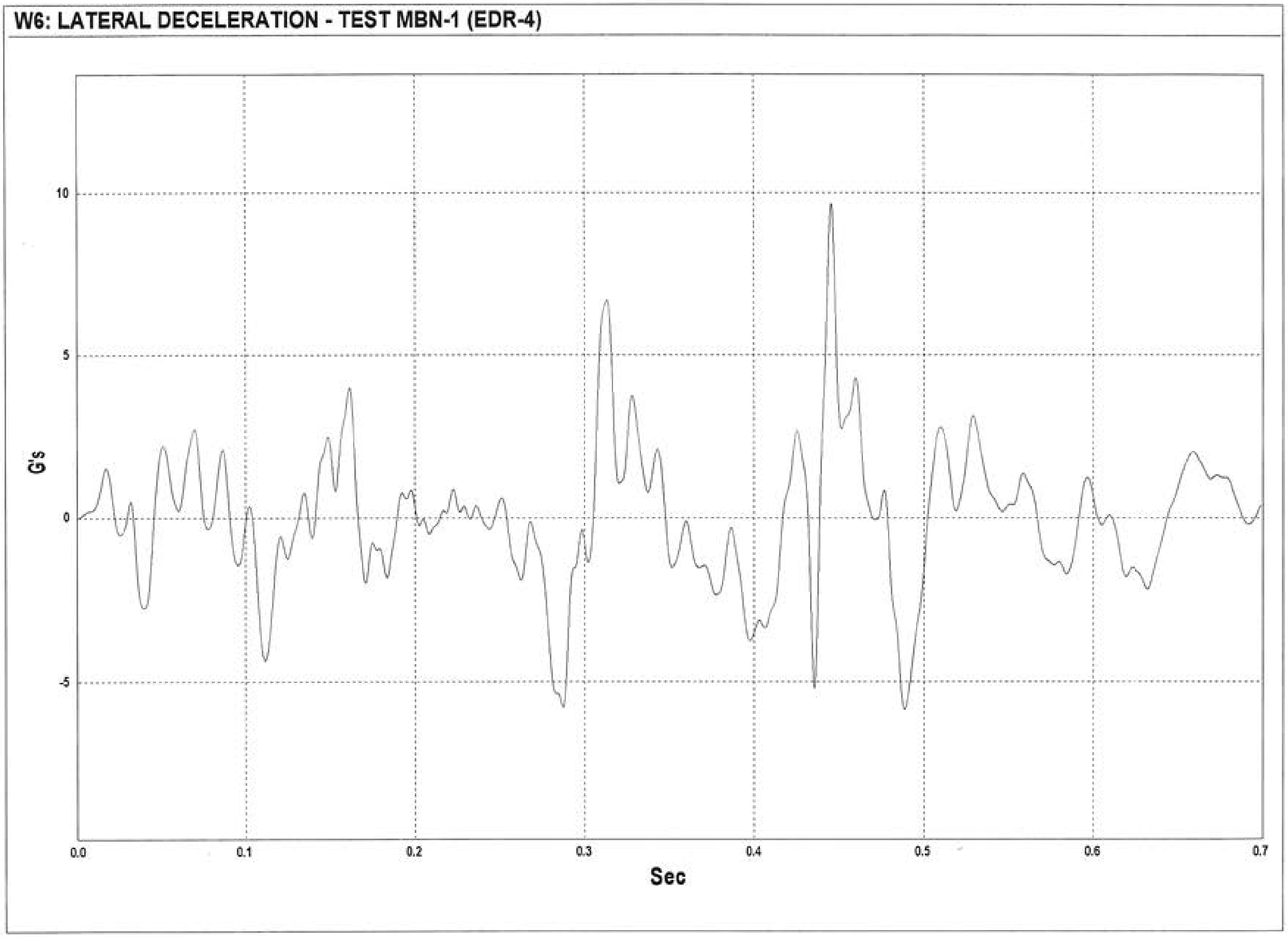

Figure A-5. Graph of Lateral Deceleration, Test MBN-1

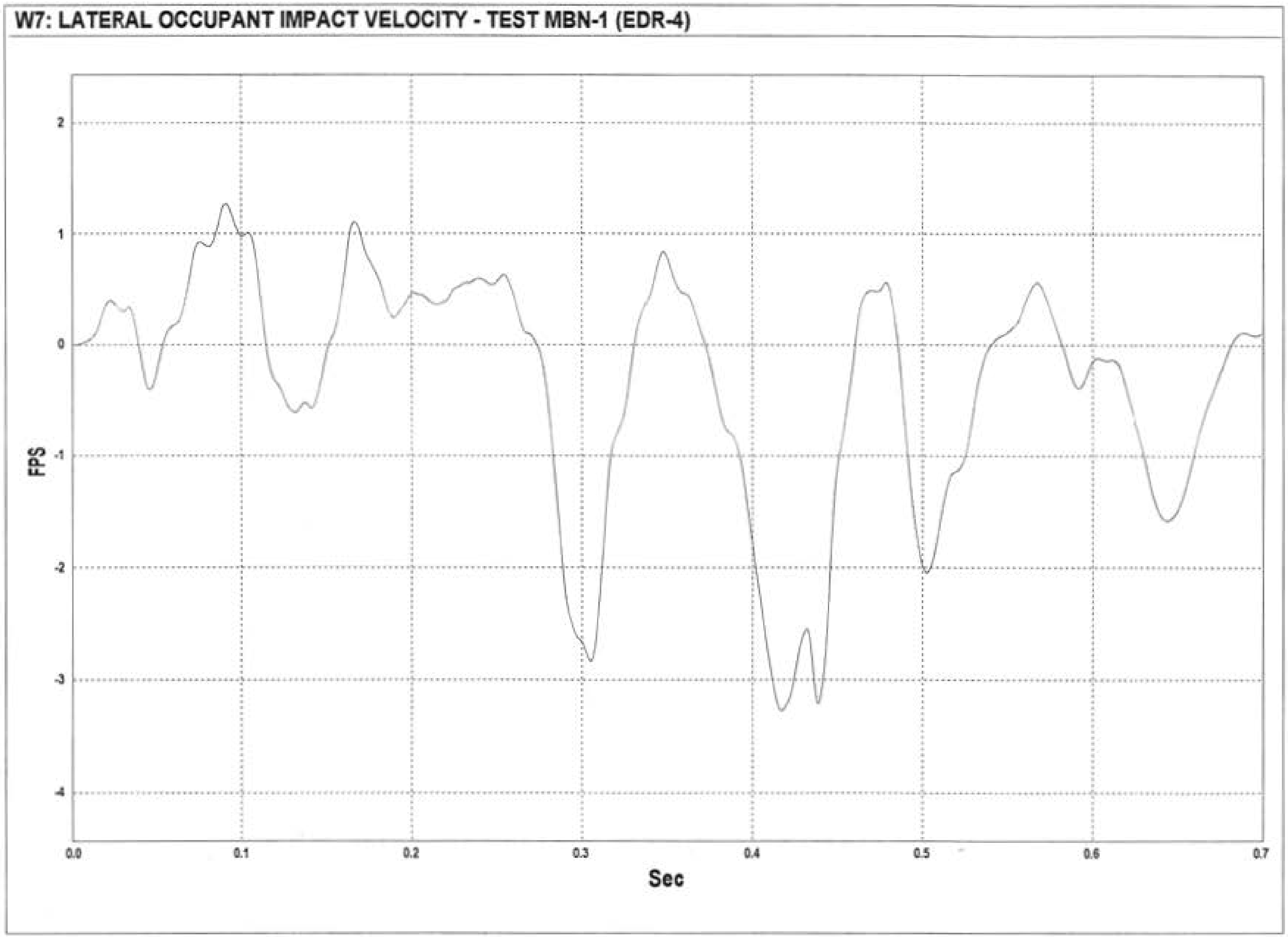

Figure A-6. Graph of Lateral Occupant Impact Velocity, Test MBN-1

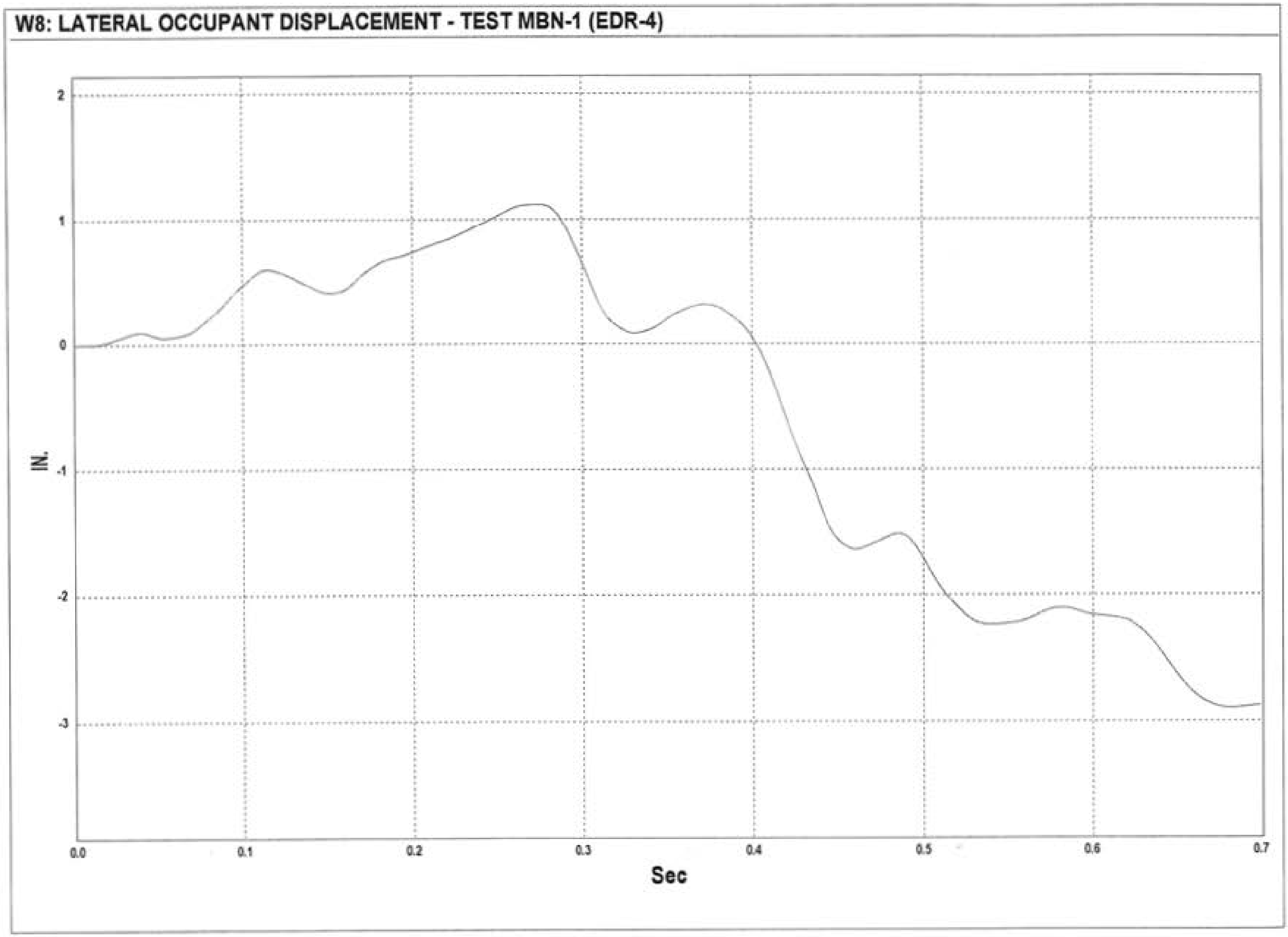

Figure A-7. Graph of Lateral Occupant Displacement, Test MBN-1

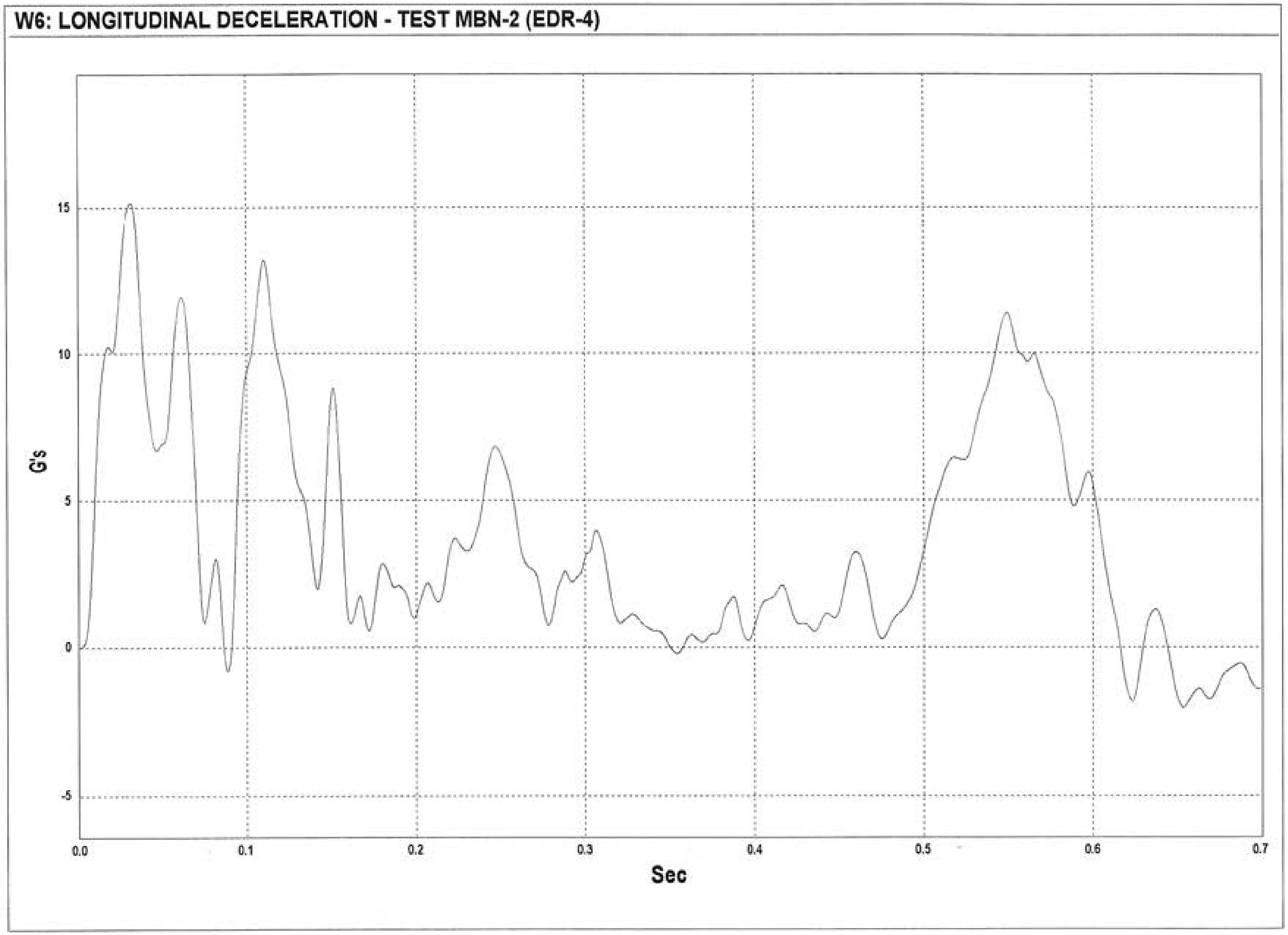

Figure A-8. Graph of Longitudinal Deceleration, Test MBN-2

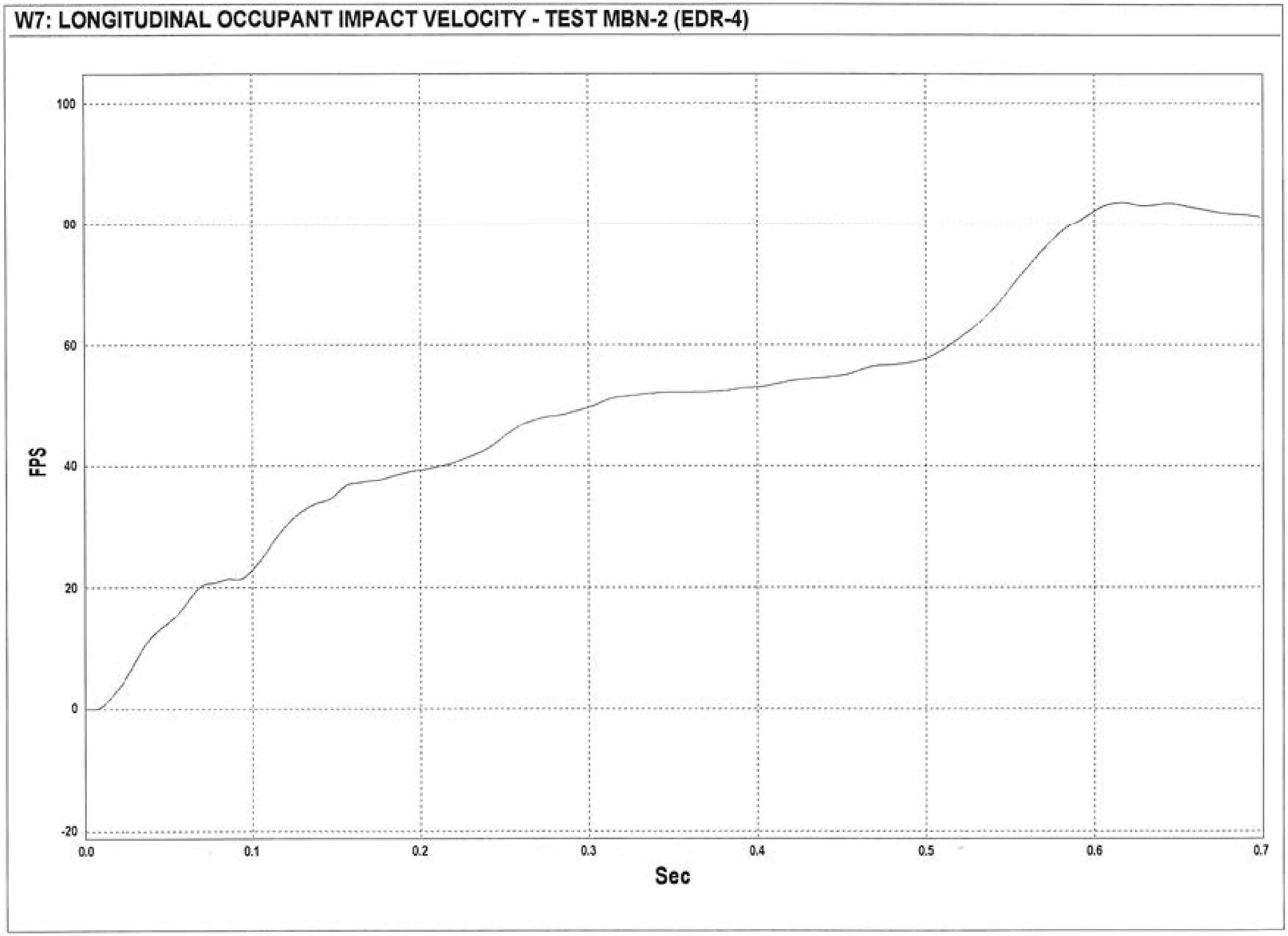

Figure A-9. Graph of Longitudinal Occupant Impact Velocity, Test MBN-2

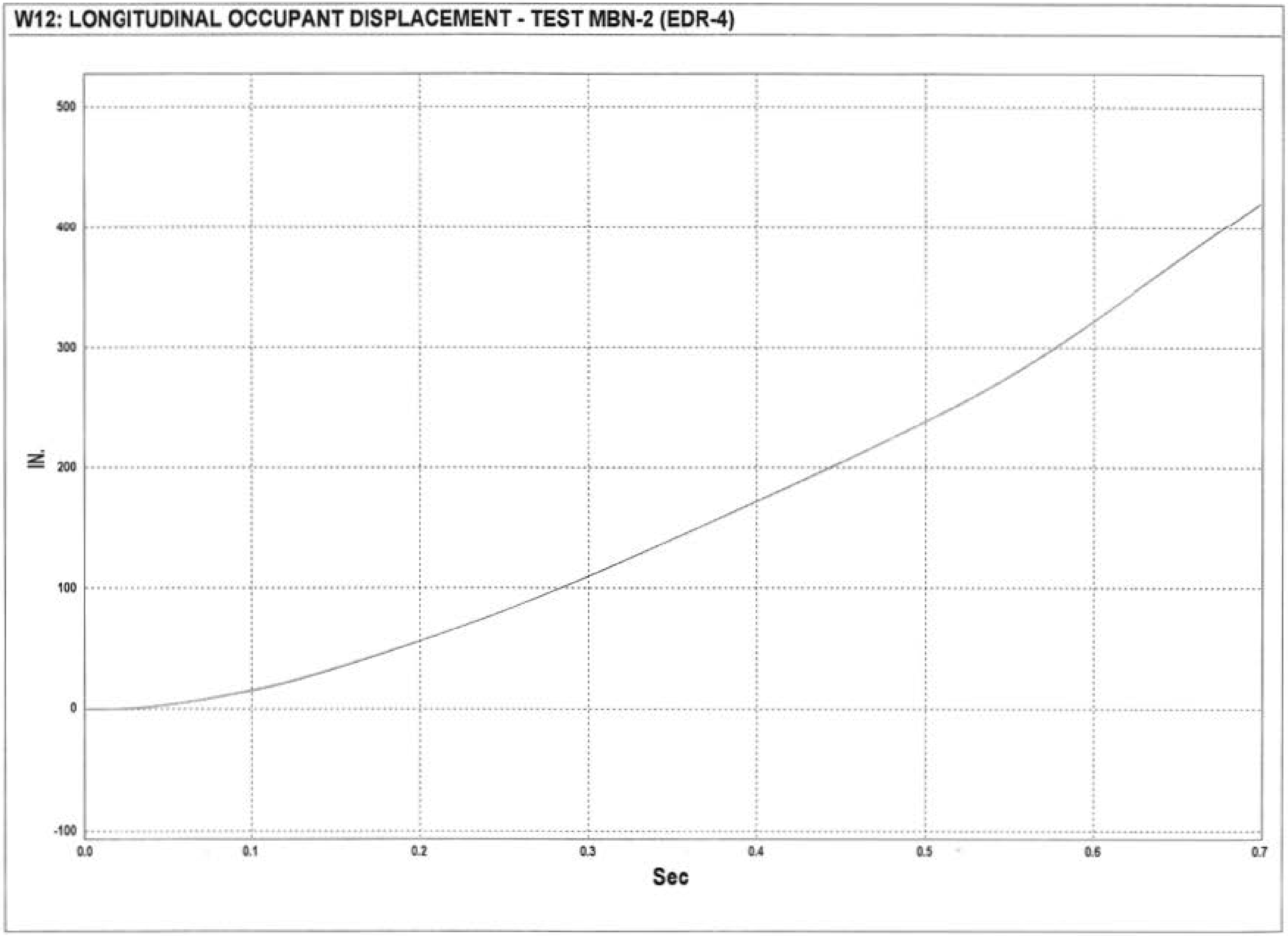

Figure A-10. Graph of Longitudinal Occupant Displacement, Test MBN-2

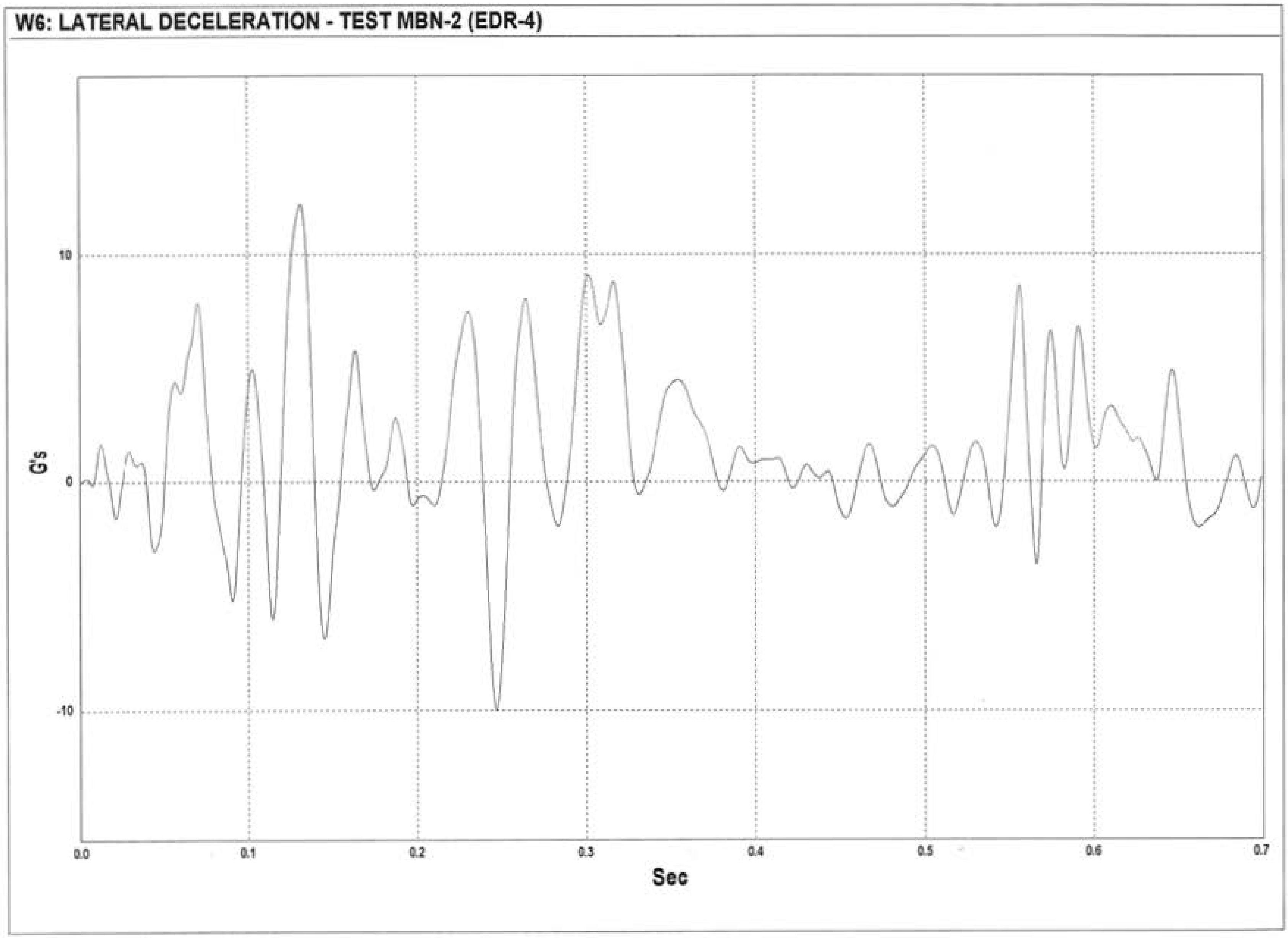

Figure A-11. Graph of Lateral Deceleration, Test MBN-2

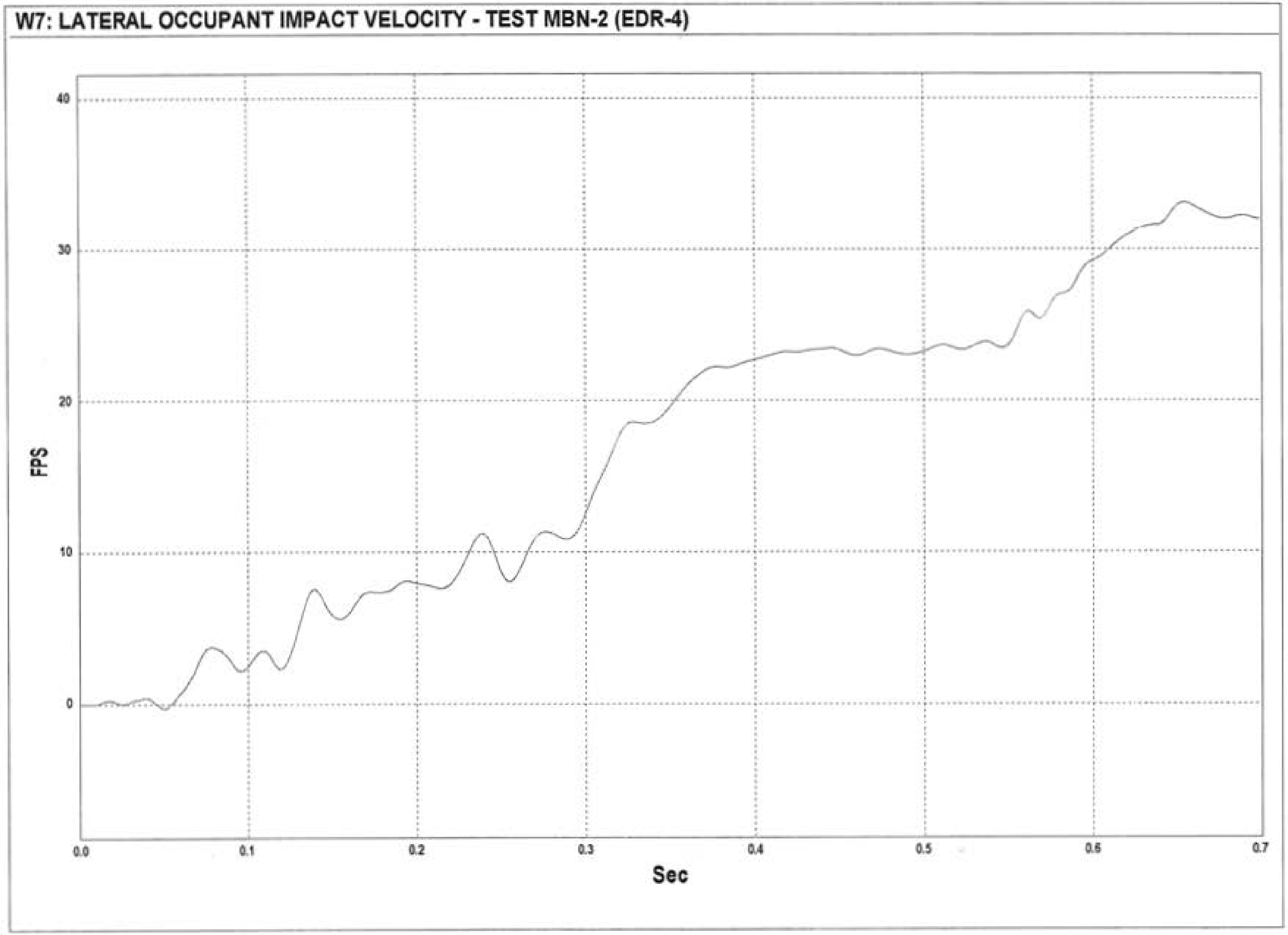

Figure A-12. Graph of Lateral Occupant Impact Velocity, Test MBN-2

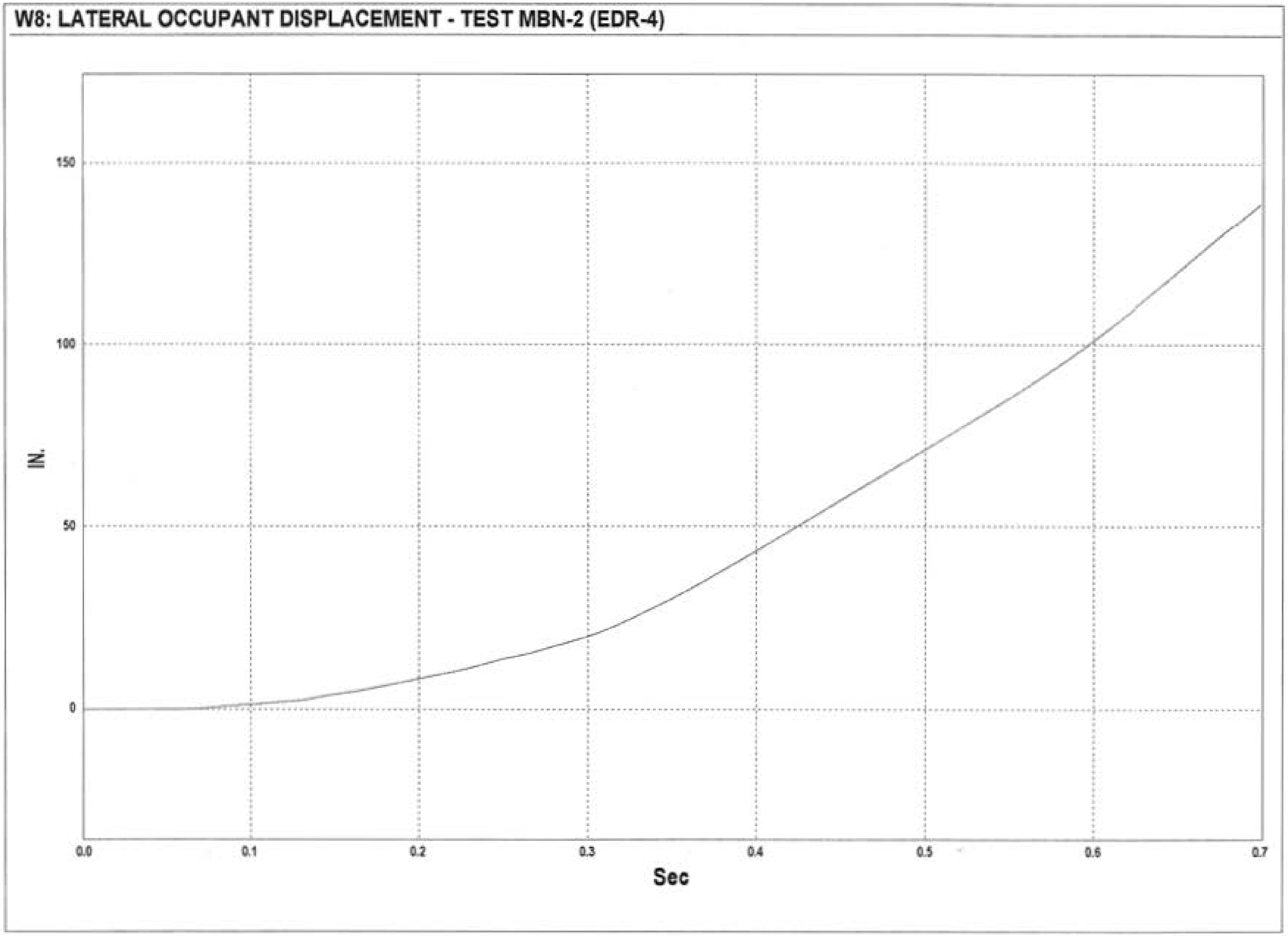

Figure A-13. Graph of Lateral Occupant Displacement, Test MBN-2

APPENDIX B

STRAIN GAUGE DATA

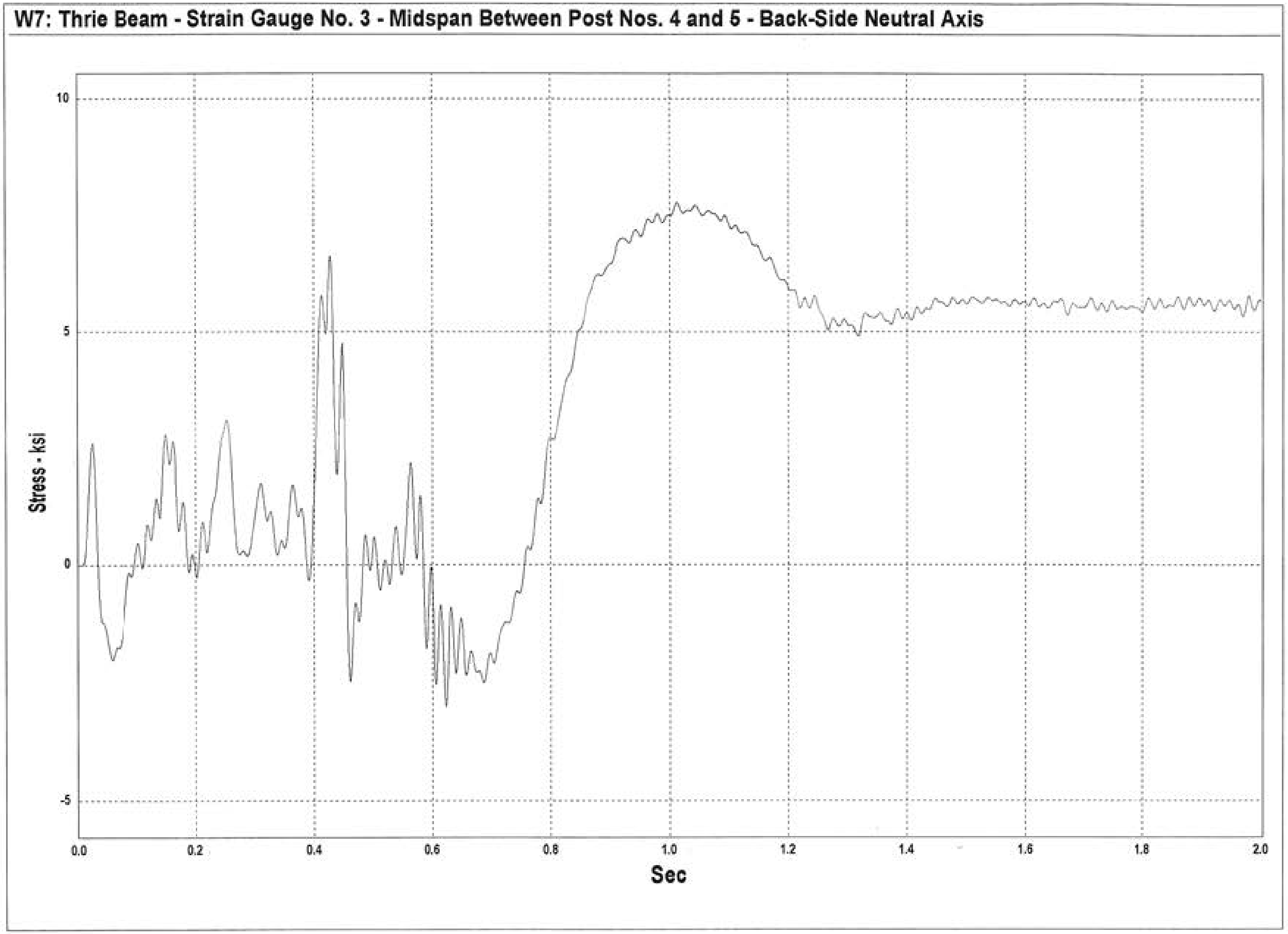

Figure B-1. Strain Gauge No. 3 Data, Test MBN-1

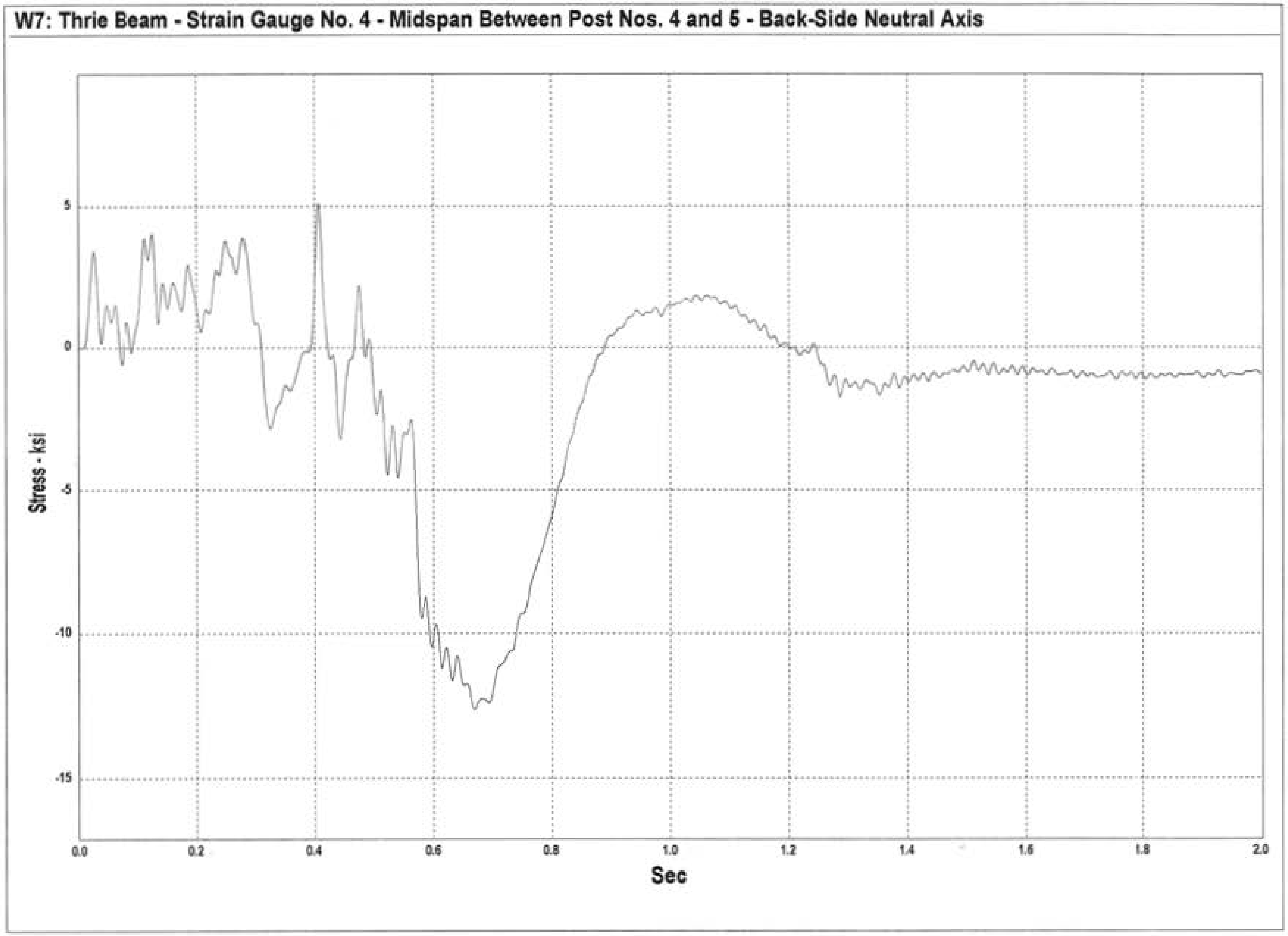

Figure B-2. Strain Gauge No. 4 Data, Test MBN-1