DRAFT REPORT

Top-Mounted W-Beam Bridge Railing for Longitudinal Glulam Timber Decks Located on Low-Volume Roads

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ABSTRACT

A semi-rigid, top-mounted W-beam bridge railing was developed for use on longitudinal timber deck bridges located on low-volume roads. The bridge rail consisted of a 12-gauge (2.66-mm) W-beam rail supported by W6x9 (W150x13.5) steel posts spaced 6-ft 3-in. (1,905-mm) on center. The posts were bolted to a steel plate which attached to the bridge deck surface.

The research study included one full-scale vehicle crash test with a ¾-ton pickup truck impacting the bridge rail at a speed of 31.8 mph (51.2 km/hr) and at an angle of 25.2 degrees. The safety performance of the bridge railing was acceptable according to the Test Level 1 (TL-1) evaluation criteria described in the National Cooperative Highway Research Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*.

TABLE OF CONTENTS

Page

DISCLAIMER STATEMENT i

ACKNOWLEDGMENTS ii

ABSTRACT iii

TABLE OF CONTENTS iv
List of Figures vi
List of Tables vii

1 INTRODUCTION 1
1.1 Problem Statement 1
1.2 Objective 1
1.3 Scope 2

2 LITERATURE REVIEW 3
2.1 Bridge Railings for Timber Deck Bridges 3
2.2 Other W-Beam Bridge Railings Systems 4

3 TEST REQUIREMENTS AND EVALUATION CRITERIA 5
3.1 Test Requirements 5
3.2 Evaluation Criteria 8

4 DESIGN DETAILS 10
4.1 Timber Deck and Substructure 10
4.2 W-Beam Bridge Railing System 10

5 TEST CONDITIONS 16
5.1 Test Facility 16
5.2 Vehicle Tow and Guidance System 16
5.3 Test Vehicle 16
5.4 Data Acquisition Systems 19
5.4.1 Accelerometers 19
5.4.2 Rate Transducer 21
5.4.3 High-Speed Photography 21
5.4.4 Pressure Tape Switches 22

6 FULL-SCALE CRASH TEST 24
6.1 TEST LVBR-3 (4,412 lbs (2,001 kg), 31.8 mph (51.2 km/hr), 25.2 degrees) 24
6.2 Test Description 24
6.3 Vehicle Damage 25

6.4 Barrier Damage 25
6.5 Occupant Risk Values 26

7 DISCUSSION AND CONCLUSIONS 35

8 RECOMMENDATIONS 37

9 REFERENCES 38

10 APPENDICES 41
APPENDIX A - ACCELEROMETER DATA ANALYSIS 41

List of Figures

Page

1. W-Beam Bridge Railing System 12
2. Layout of W-Beam Bridge Railing System 13
3. Bridge Rail Design Details 14
4. Post-To-Deck Attachment 15
5. Test Vehicle, Test LVBR-3 17
6. Vehicle Dimensions, Test LVBR-3 18
7. Vehicle Target Locations, Test LVBR-3 20
8. Location of High-Speed Cameras, Test LVBR-3 23
9. Impact Location, Test LVBR-3 27
10. Summary of Test Results and Sequential Photographs, Test LVBR-3 28
11. Additional Sequential Photographs, Test LVBR-3 29
12. Vehicle Position at Rest, Test LVBR-3 30
13. Vehicle Damage, Test LVBR-3 31
14. Bridge Rail Damage, Test LVBR-3 32
15. Post Damage (Post Nos. 7 and 8), Test LVBR-3 33
16. Post Damage (Post No. 9), Test LVBR-3 34

A-1. Graph of Longitudinal Deceleration, Test LVBR-3 42

A-2. Graph of Longitudinal Occupant Impact Velocity, Test LVBR-3 43

A-3. Graph of Longitudinal Occupant Displacement, Test LVBR-3 44

A-4. Graph of Lateral Deceleration, Test LVBR-3 45

A-5. Graph of Lateral Occupant Impact Velocity, Test LVBR-3 46

A-6. Graph of Lateral Occupant Displacement, Test LVBR-3 47

List of Tables

Page

1. AASHTO Crash Test Conditions for Bridge Railings (2) and NCHRP 350 Crash Test Conditions for Longitudinal Barriers (1) 7
2. NCHRP Report 350 Evaluation Criteria for 2000P Pickup Truck Crash Test (1) 9
3. Summary of Safety Performance Evaluation 35

1 INTRODUCTION

1.1 Problem Statement

Historically, bridge railing systems have been not been developed for use on low-speed, low-volume roads; however, many U.S. Forest Service and National Forest utility and service roads often carry very low traffic volumes at operating speeds of 20 mph (32.2 km/hr) or less. These roads are often narrow, generally incorporating one- or two-lane timber bridges, with span lengths between 15 and 35 ft (4.6 to 10.7 m). The bridge rails that have been designed for high-speed facilities can be unnecessarily expensive for low-volume road applications. In recognition of the need to develop bridge railings for this low service level, the United States Department of Agriculture (USDA) Forest Service, Forest Product Laboratory (FPL), in cooperation with the Midwest Roadside Safety Facility (MwRSF), undertook the task of developing four low-service level bridge railing systems. This report provides a detailed discussion of the research methods used during the development effort for one of the four bridge railings as well as the test results used to evaluate its safety performance.

1.2 Objective

The objective of this research was to develop a semi-rigid, top-mounted W-beam bridge railing system for use on longitudinal timber decks with low traffic volumes and speeds. Several design factors were considered, such as concerns for aesthetics, economy, material availability, ease of construction, and reasonable margin of structural adequacy. The bridge railing was developed to meet the Test Level 1 (TL-1) evaluation criteria described in the National Cooperative Highway Research Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1). A longitudinal glulam timber deck was selected for use in the development of the bridge railing because it is the weakest type of longitudinal timber deck currently in use for resisting transverse railing loads. Thus, any bridge railing not damaging the longitudinal glulam deck could easily be adapted to other, stronger, timber deck systems.

1.3 Scope

The research objective was achieved by performing several tasks. First, a literature review was performed on existing low performance level railings and other bridge railings developed for timber deck bridges. Second, an analysis and design phase was performed on all structural members and connections. Third, a full-scale vehicle crash test was performed using a 3/4-ton pickup truck, weighing approximately 4,409 lbs (2,000 kg), with a target impact speed and angle of 31.1 mph (50 km/h) and 25 degrees, respectively. Finally, the test results were analyzed, evaluated and documented, with conclusions and recommendations that pertain to the safety performance of the new bridge railing.

2 LITERATURE REVIEW

2.1 Bridge Railings for Timber Deck Bridges

Over the past seven years, MwRSF and FPL engineers have designed and developed several bridge railings and transitions for use on longitudinal glulam timber bridge decks. Eight bridge railings have been developed for several design impact conditions, including AASHTO Performance Levels 1 and 2 (2), NCHRP 350 Test Levels 1 and 4 (1), as well as for very low-speed, low-volume roadways (3-8). The bridge railing systems developed for timber decks include: (1) an AASHTO PL-1 Glulam Rail with Curb bridge railing (3-6); (2) an AASHTO PL-1 Glulam Rail without Curb bridge railing (3-6); (3) an AASHTO PL-1 Steel Thrie-Beam Rail bridge railing (3-6); (4) an AASHTO PL-2 Steel Thrie-Beam with top-mounted Channel Rail bridge railing (4-7); (5) a NCHRP 350 TL-4 Glulam Rail with Curb bridge railing (4-7); (6) a NCHRP 350 TL-1 low-cost Breakaway W-Beam bridge railing (8); (7) a Low-Height Curb-Type Sawn Timber bridge railing for low-speed, low-volume roads (8); and (8) a NCHRP 350 TL-1 Curb-Type Glulam Rail bridge railing (9).

Two other research programs conducted in the United States provide information on the crashworthiness of bridge railings for use on timber deck bridges. The first program was performed at Southwest Research Institute (SwRI) in the late 1980's in which crash tests were conducted according to AASHTO Performance Level 1 conditions on a glulam rail with a curb bridge railing system attached to a spike-laminated longitudinal timber bridge deck (10). In 1993, a second research project was conducted by the Constructed Facilities Center (CFC) at West Virginia University with crash testing performed by the Texas Transportation Institute (TTI). Crash tests were performed according to AASHTO Performance Level 1 conditions on three bridge railing systems and one transition system attached to a transverse glulam timber deck (11-14).

2.2 Other W-Beam Bridge Railing Systems

In 1959, researchers at the California Department of Transportation (CALTRANS) crash tested a 12-gauge W-beam bridge railing supported by W6x15.5 steel posts spaced on 6-ft 3-in. (1905-mm) centers (15). The test was performed with a 4,000-lb (1,814-kg) vehicle impacting at 55 mph (89 km/hr) and 30 degrees, resulting in "excessive" rail deflection of approximately 5 ft.

In 1978, the TTI researchers crash tested a 12-gauge W-beam bridge railing supported by W6x8.5 steel posts spaced on 6-ft 3-in. (1905-mm) centers (16). The test was performed with a 4,500-lb (2,041-kg) sedan impacting at 60 mph (97 km/hr) and 26.2 degrees and was unsuccessful. The dynamic and permanent set rail deflections were 6 and 5 ft, respectively. These large rail deflections allowed the vehicle to wedge between the rail and bridge slab and fracture the bridge posts.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Until recently, bridge railings were typically designed to satisfy the requirements provided in the American Association of State Highway and Transportation Official's (AASHTO's) *Guide Specifications for Bridge Railings* (2). More specifically, bridge railings were designed according to the appropriate performance level of the roadway, based upon a number of factors such as design speed, average daily traffic (ADT), percentage of trucks, bridge rail offset, and number of lanes. These guide specifications included three performance levels, as shown in Table 1, which provided criteria for evaluating the safety performance of bridge railings.

The recently published NCHRP Report No. 350 (1) provides for six test levels, as shown in Table 1, for evaluating longitudinal barriers. Although this document does not contain objective criteria for the conditions under which each test level is to be used, safety hardware developed to meet the lower test levels are generally intended for use on lower service level roadways while higher test level hardware is intended for use on higher service level roadways. The lowest performance level, Test Level 1 (TL-1), is suitable for applications on low-volume, low-speed facilities such as residential streets. Thus, test impact conditions from Test Level 1 were chosen for this top-mounted bridge railing. Test Level 1 requires that the bridge railing meet two full-scale vehicle crash tests: (1) an 1,808-lb (820-kg) small car impacting at 31.1 mph (50 km/hr) and 20 degrees; and (2) a 4,409-lb (2,000-kg) pickup truck impacting at a speed of 31.1 mph (50 km/hr) and 25 degrees. However, the 1,808-lb (820-kg) small car crash test was considered unnecessary, since W-beam strong-post barrier systems, such as the G4(1S), have been shown to meet safety performance standards when impacted by small cars at impact speeds up to 60 mph (96.6 km/hr) (17-18). In addition, the new top-mounted bridge rail essentially provides the same structural adequacy as W-beam strong-post barrier systems.

Table 1. AASHTO Crash Test Conditions for Bridge Railings (2) and NCHRP 350 Crash Test Conditions for Longitudinal Barriers (1)

AASHTO Performance Level (2)	Impact Conditions				
	Small Car (816 kg)	Pickup Truck (2,449 kg)	Medium Single-Unit Truck (8,165 kg)	Van-Type Tractor-Trailer (22,680 kg)	
1	80.5 km/h and 20 deg	72.4 km/h and 20 deg			
2	96.6 km/h and 20 deg	96.6 km/h and 20 deg	80.5 km/h and 15 deg		
3	96.6 km/h and 20 deg	96.6 km/h and 20 deg		80.5 km/h and 15 deg	
NCHRP 350 Test Level (1)	**Impact Conditions**				
	Small Car (820 kg)	Pickup Truck (2,000 kg)	Single-Unit Van Truck (8,000 kg)	Tractor/Van Trailer (36,000 kg)	Tractor/Tank Trailer (36,000 kg)
1	50 km/h & 20 deg	50 km/h & 25 deg			
2	70 km/h & 20 deg	70 km/h & 25 deg			
3 (Basic Level)	100 km/h & 20 deg	100 km/h & 25 deg			
4	100 km/h & 20 deg	100 km/h & 25 deg	80 km/h & 15 deg		
5	100 km/h & 20 deg	100 km/h & 25 deg		80 km/h & 15 deg	
6	100 km/h & 20 deg	100 km/h & 25 deg			80 km/h & 15 deg

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 railing 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 2.

Table 2. NCHRP Report 350 Evaluation Criteria for 2000P Pickup Truck Crash Test (1).

Structural Adequacy	A.	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.
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 DESIGN DETAILS

4.1 Timber Deck and Substructure

A full-size simulated timber bridge system was constructed at the MwRSF outdoor test site. In order to simulate an actual timber bridge installation, the longitudinal glulam timber bridge deck was mounted on six reinforced-concrete bridge supports. The inner three concrete bridge supports had center-to-center spacings of 18 ft 9 in. (5.72 m) whereas the outer two spacings were 18 ft 3 in. (5.56 m).

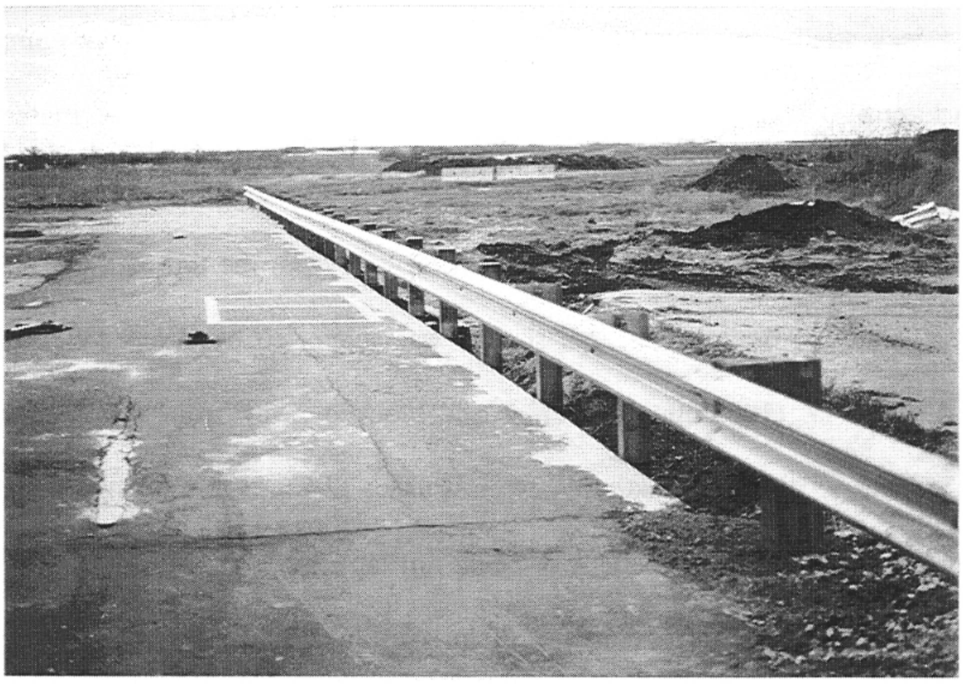
The longitudinal glulam timber deck consisted of ten rectangular panels. The panels measured 3-ft 11⅞-in. (1.22-m) wide by 18-ft 8½-in. (5.70 m) long by 10¾-in. (273-mm) thick. The timber deck was constructed so that two panels formed the width of the deck and five panels formed the length of the deck. The longitudinal glulam timber deck was fabricated with West Coast Douglas Fir and treated with pentachlorophenol in heavy oil to a minimum net retention of 0.6 lbs/ft^3 (9.61 kg/m^3) as specified in AWPA Standard C14 (19). At each longitudinal midspan location of the timber deck panels, stiffener beams were bolted transversely across the bottom side of the timber deck panels per AASHTO bridge design requirements. The stiffener beams measured 5⅛-in. (130-mm) wide by 6-in. (152-mm) thick by 8-ft (2.44-m) long. In addition, a 2-in. (51-mm) asphalt wearing surface was placed on the top of the timber deck in order to represent actual field conditions.

4.2 W-Beam Bridge Railing System

The total length of the test installation was 200 ft (60.96 m), as shown in Figures 1 through 2. The semi-rigid, top-mounted W-beam bridge railing consisted of three major structural components: (1) W-beam guardrail; (2) steel posts and spacer blocks; and (3) steel plate post-to-deck attachment hardware. Detailed drawings of the bridge rail components are provided in Figure 3. Photographs of the bridge railing system are shown in Figure 4.

A standard 12-gauge (2.66-mm) W-beam rail section was selected for the rail element with a 21.65-in. (550-mm) mounting height, as measured from the top of the asphalt wearing surface to the center of the rail. The rail section was supported by W6x9 (W150x13.5) steel posts spaced 6-ft 3-in. (1905-mm) on center and blocked away from the posts with W6x9 (W150x13.5) spacers. W-beam backup plates, measuring 12-in. (305-mm) in length, were used at post locations which did not include a W-beam rail lap-splice.

The post-to-deck attachment consisted of an ¼-in. (6.4-mm) thick, ASTM A36 steel plate attached to the deck surface with four ⅞-in. (22.2-mm) diameter by 14-in. (356-mm) long ASTM A307 hex head bolts which bolted vertically through the glulam timber deck. Two Grade 5 threaded rods, measuring ¾-in. (19.0-mm) diameter by 380-mm long, were welded to the plate using 180 mm of the rod length. The posts were rigidly attached to the deck using the threaded rods and two ½-in. (12.7-mm) diameter by 6-in. (152.4-mm) long ASTM A307 lag screws.



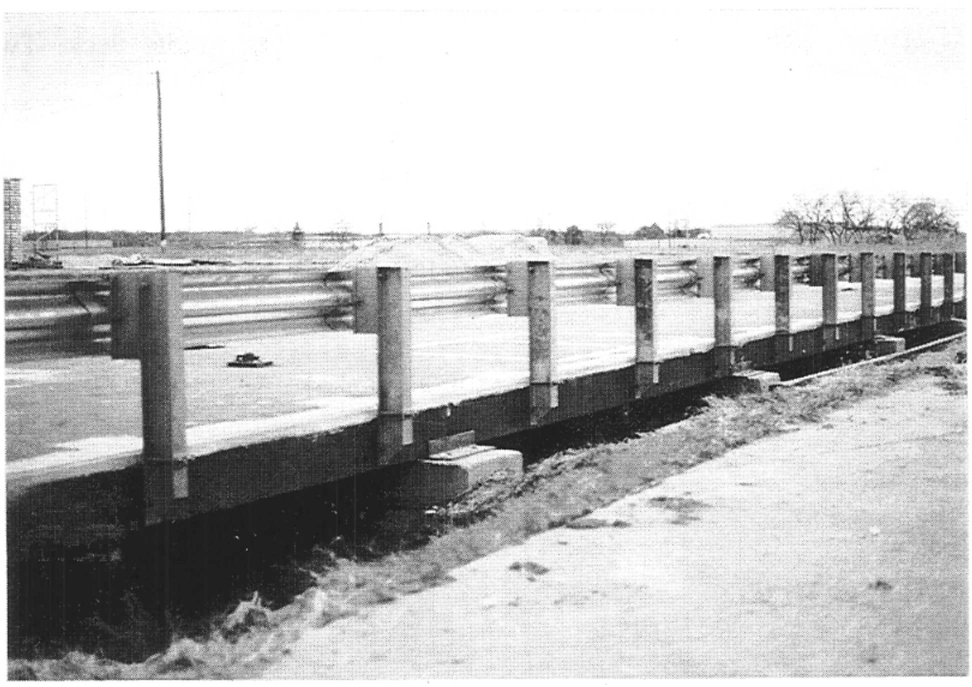


Figure 1. W-Beam Bridge Railing System

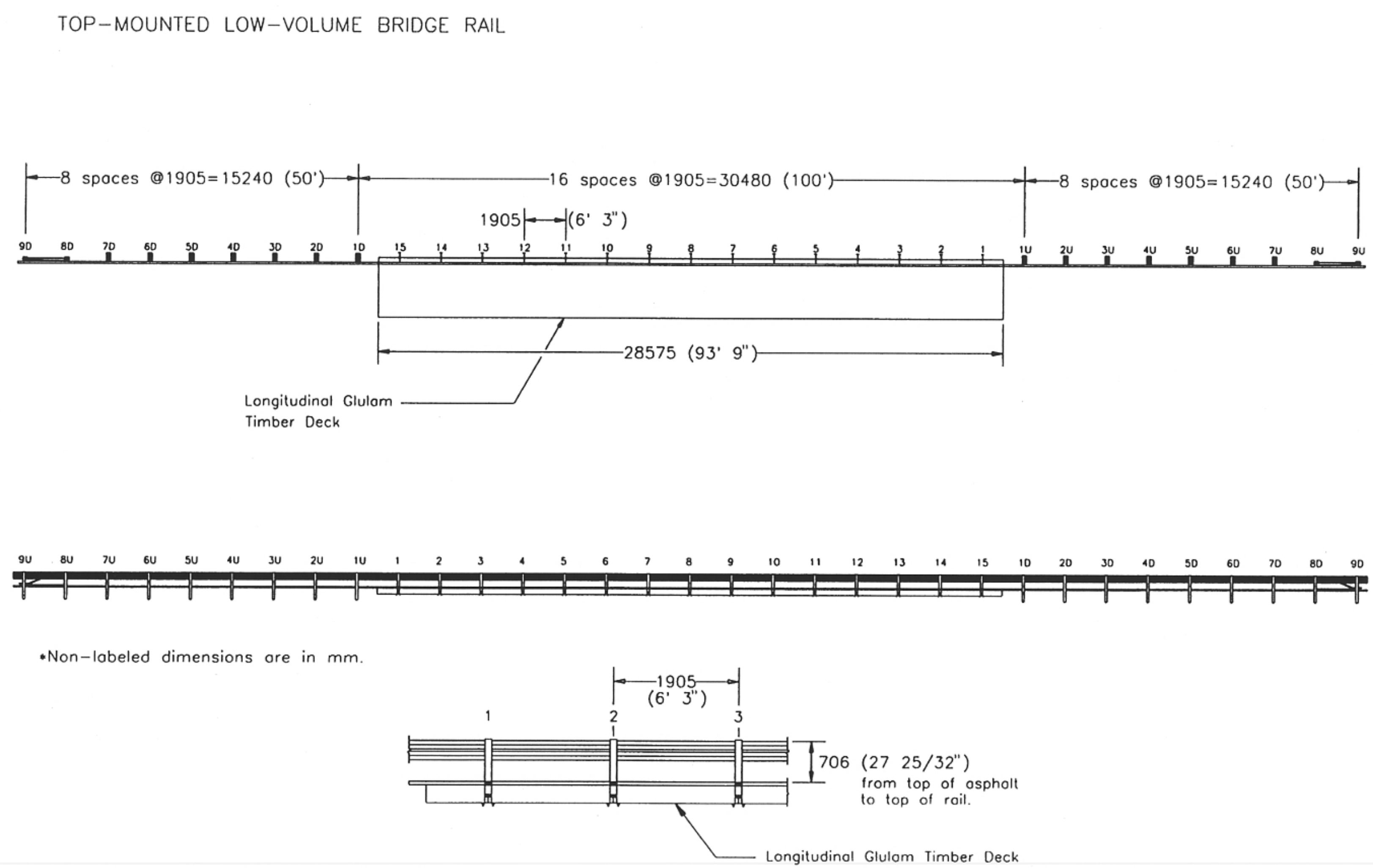


Figure 2. Layout of W-Beam Bridge Railing System

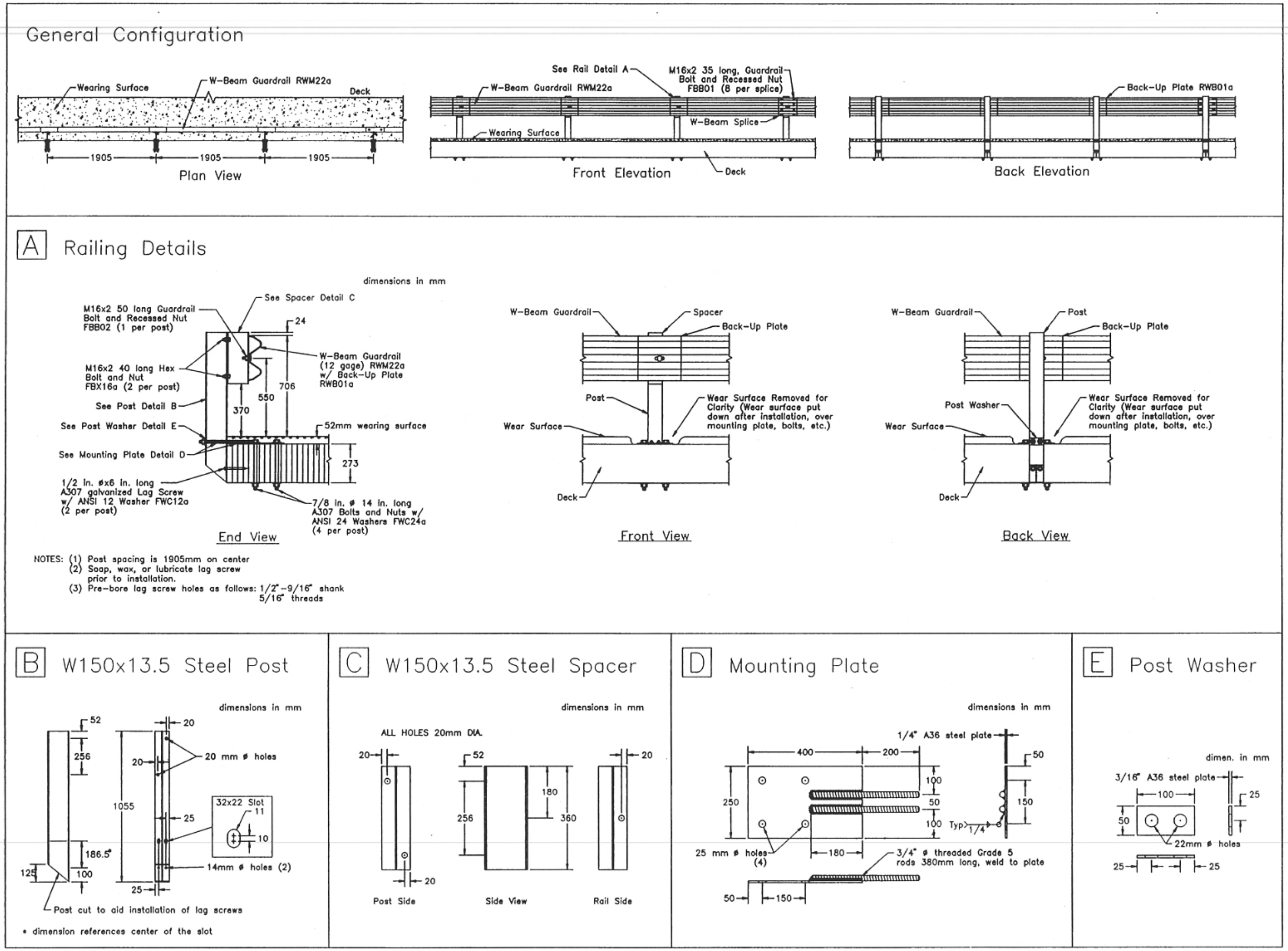


Figure 3. Bridge Rail Design Details

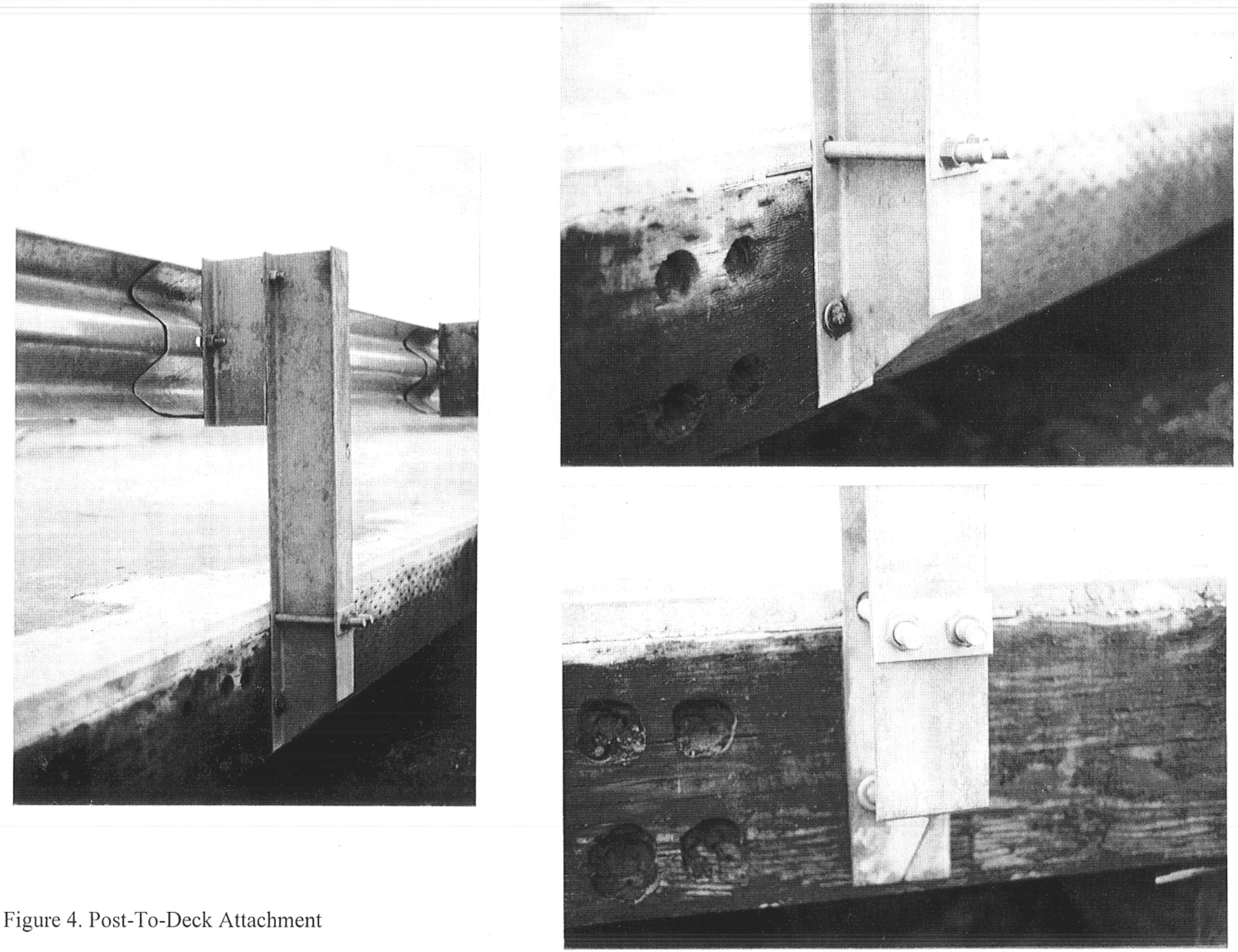


Figure 4. Post-To-Deck Attachment

5 TEST CONDITIONS

5.1 Test Facility

The testing facility is located at the Lincoln Air-Park on the NW end of the Lincoln Municipal Airport and is approximately 5 mi (8.0 km) NW of the University of Nebraska-Lincoln. The site is protected by an 8-ft (2.44-m) high chain-link security fence.

5.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test 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 bridge rail. 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 (20) 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 3/8-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,000 lbs (13.3 kN), and supported laterally and vertically every 100 ft (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 400-ft (122-m) long.

5.3 Test Vehicle

A 1988 Ford F-250 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 4,412 lbs (2,001 kg). The test vehicle is shown in Figure 5 and vehicle dimensions are shown in Figure 6.

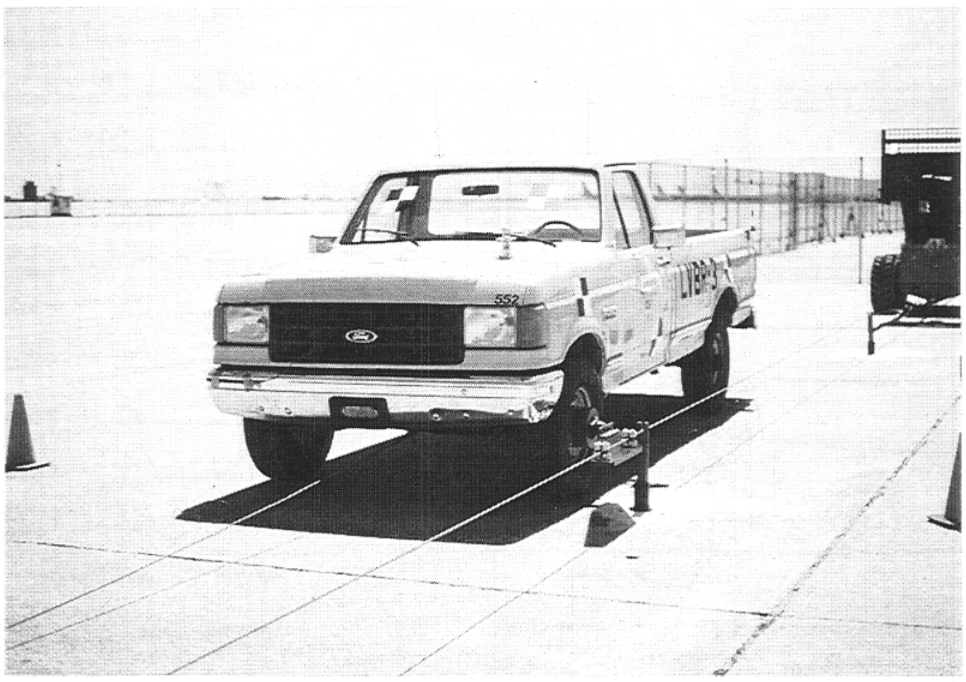
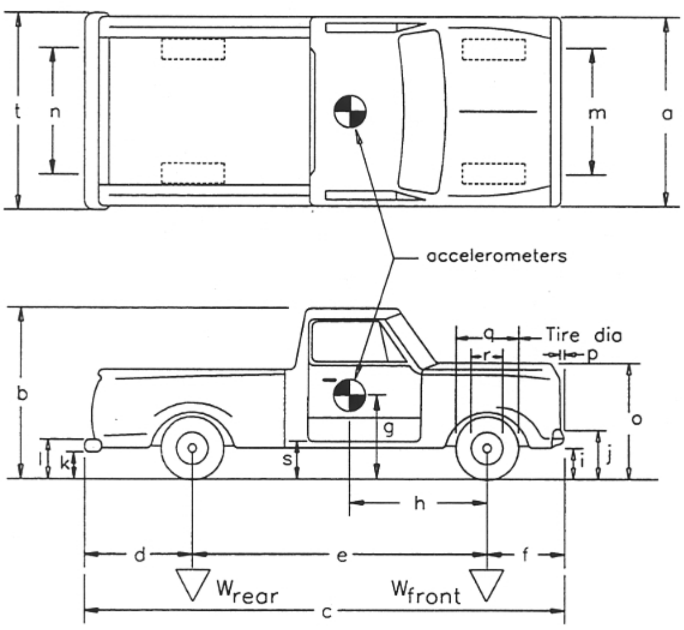


Figure 5. Test Vehicle, Test LVBR-3

Date: 4-25-96 Test Number: LVBR-3 Model: F-250

Make: FORD Vehicle I.D.#: 1FTHF25Y4JPA46516

Tire Size: LT235/85R16 Year: 1988 Odometer: 81384



Vehicle Geometry – INCHES

a 76 b 73 3/4

c 213 1/4 d 50 3/8

e 133 1/4 f 28 3/4

g 29 h 57 3/4

i R.S. 18 3/4, L.S. 19 5/16 j R.S. 28 1/4, L.S. 29 1/2

k R.S. 21, L.S. 20 3/8 l R.S. 28, L.S. 27 5/16

m 65 3/4 n 64 3/8

o 47 7/8 p 27 1/8

q 30 3/4 r 17 1/2

s 20 1/2 t 75 3/4

Wheel Center Height 15

Engine Type EFI GAS

Engine Size 6 Cyl. 300CID

Transmission Type:

Automatic or (Manual)

FWD or (RWD) or 4WD

Weight – lbs	Curb	Test Inertial	Gross Static
W_{front}	2500	2500	2500
W_{rear}	1880	1912	1912
W_{total}	4380	4412	4412

Note any damage prior to test: none

Figure 6. Vehicle Dimensions, Test LVBR-3

The Elevated Axle Method (21) was used to determine the vertical component of the center of gravity. This method converts measured wheel weights at different elevations to the location of the vertical component 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 center of gravity is shown in Figure 6. Vehicle ballast, consisting of steel plates, was rigidly attached to the floor of the pickup truck box and used to obtain the desired weight.

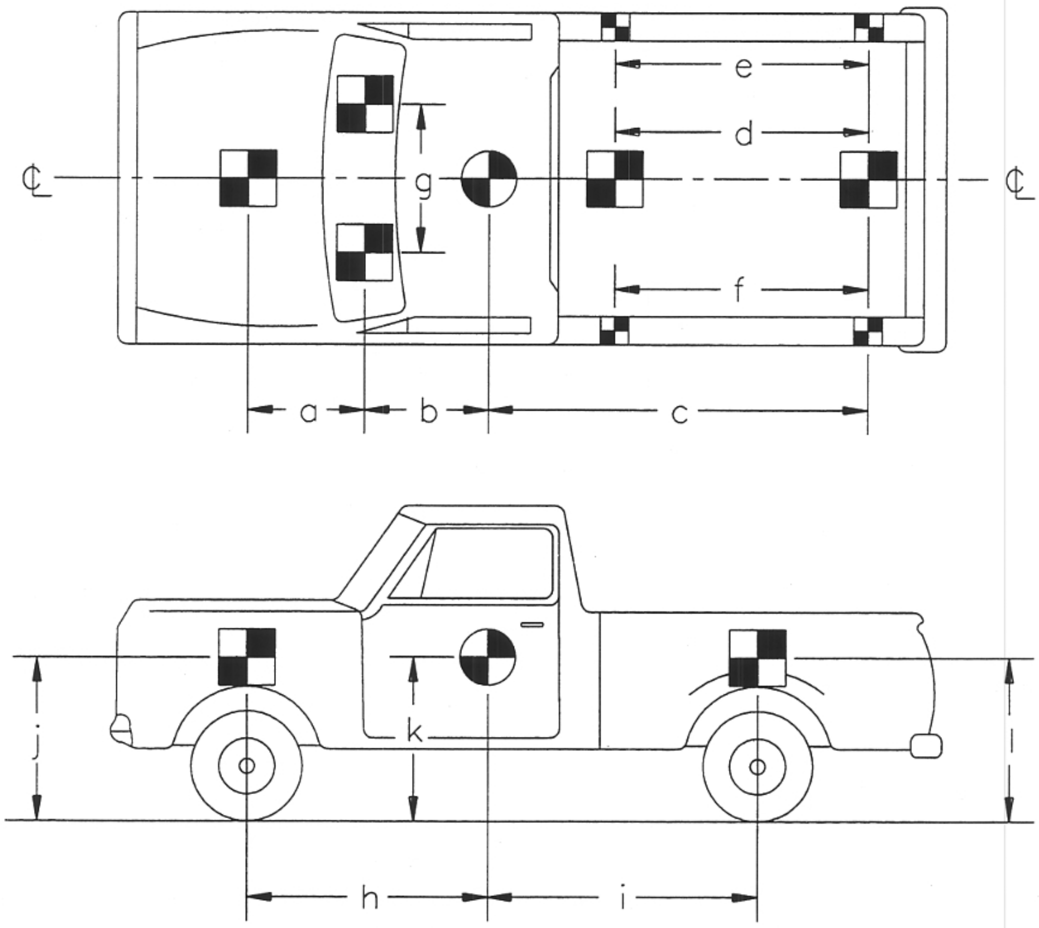
Thirteen square, black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film, as shown in Figures 5 and 7. One target was placed on the center of gravity at the driver's side of the vehicle. The remaining targets were located for reference so that they could 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 the hood of the vehicles to pinpoint the time of impact with the bridge railing 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

Two triaxial piezoresistive accelerometer systems with a range of ±200 g's (Endevco Model 7264) were used to measure the acceleration in the longitudinal, lateral, and vertical directions. Two accelerometers were mounted in each of the three directions and were rigidly attached to a metal block mounted at the center of gravity. Accelerometer signals were received



TEST No. : LVBR-3

TARGET GEOMETRY (inches)

a —	b —	c —	d 45.5
e 76.5	f 72	g 37.75	h 57.75
i 75.5	j 42.5	k 29	l 42.5

Figure 7. Vehicle Target Locations, Test LVBR-3

and conditioned by an onboard Series 300 Multiplexed FM Data System built by Metraplex Corporation. The multiplexed signal was then transmitted to the Honeywell 101 Analog Tape Recorder. Computer software, "EGAA" 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 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 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 were received and conditioned by an onboard Series 300 Multiplexed FM Data System built by Metraplex Corporation. The multiplexed signal was then transmitted by radio telemetry to a Honeywell 101 Analog Tape Recorder. Computer software, "EGAA" and "DADiSP" were used to digitize, analyze, and plot the rate transducer data.

5.4.3 High-Speed Photography

Five high-speed 16-mm cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. A Red Lake 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 Red Lake

Locam with a 76-mm lens was placed downstream from the impact point and had a field of view parallel to the bridge rail. A Red Lake Locam with an 12.5-mm lens was placed on the traffic side of the bridge rail and had a field of view perpendicular to the bridge rail. A Red Lake Locam, with a 12.5 to 75-mm zoom lens, was placed upstream from the impact point and had a field of view parallel to the bridge rail. A Red Lake Locam, with a 12.5 to 75-mm zoom lens, was placed downstream and behind the bridge rail. A schematic of all five camera locations for test LVBR-3 is shown in Figure 8.

A 10-ft (3.05-m) long by 5-ft (1.52-m) wide, white-colored grid was painted on the asphalt surface on the traffic side of the bridge rail. This grid was incremented in 5-ft (1.52-m) divisions to provide a visible reference system for use in the analysis of the overhead high-speed film. 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

Five pressure-activated tape switches, spaced at 5-ft (1.52-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.

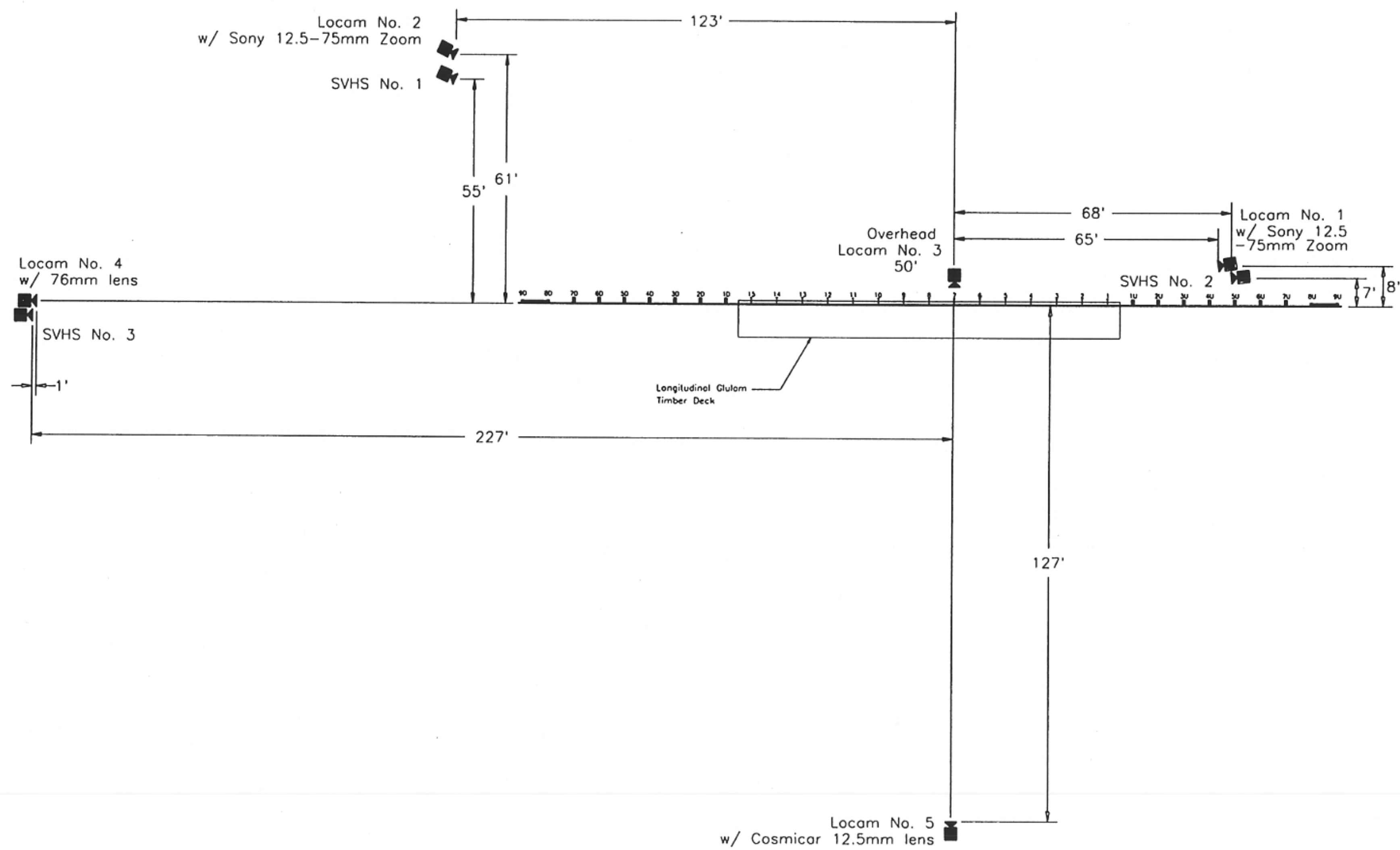


Figure 8. Location of High-Speed Cameras, Test LVBR-3

6 FULL-SCALE CRASH TEST

6.1 Test LVBR-3 (4,412 lbs (2,001 kg), 31.8 mph (51.2 km/hr), 25.2 degrees)

The pickup truck impacted the W-beam bridge railing on the upstream-side of post no. 7, as shown in Figure 9. A summary of the test results and the sequential photographs is presented in Figure 10. Additional sequential photographs are shown in Figure 11.

6.2 Test Description

Following the initial impact with the bridge rail, the right corner of the front bumper began to wedge between to the two humps of the W-beam rail section, and the left-side of the bumper began to release from the steel frame. Prior to testing, the original front bumper was removed since it contained significant deformations and replaced with a new, undamaged bumper. Round washers, instead of the standard bumper plate washers, were inadvertently used during the installation. This allowed the bolts, nuts, and round washers to pull through the holes in the steel frame during the impact. At 0.119 sec after impact, the left-side of the bumper was clearly dislodged from the vehicle frame. The front wheels began to turn towards the bridge rail at 0.131 sec. At 0.139 sec, the right-front corner of the vehicle was near post no. 8. From the overhead high-speed film, the maximum dynamic lateral deflection of 13.5 in. (343 mm) was observed at the midspan between post nos. 7 and 8 at 0.169 sec. The left-front tire was positioned approximately perpendicular to the bridge rail at 0.191 sec. At 0.322 sec, the left-rear tire became airborne, recontacting the ground at 0.433 sec. At 0.348 sec and 0.576 sec, the right-front corner of the vehicle was near post nos. 9 and 10, respectively. The vehicle temporarily lost contact with the bridge rail at 0.655 sec after impact. At 0.914 sec, the right-front corner of the vehicle was at post no. 11. The vehicle was approximately parallel with the bridge rail at 0.986 sec with a speed of 10.6 mph (17.1 km/hr). At 1.038 sec and 1.209 sec, the right-front tire and the vehicle recontacted the bridge rail, respectively. The vehicle exited the bridge rail at 1.905 sec after impact, and the vehicle came to rest approximately 25 ft (7.6 m) downstream from impact, as shown in Figure 12. The vehicle's post-test trajectory is shown in Figure 10.

6.3 Vehicle Damage

Exterior vehicle damage was relatively minor and was limited to deformations of the steel frame, right-front wheel, right-front quarter panel, grill and right-side head-lamp assembly, and front bumper, as shown in Figure 13. The steel frame was slightly shifted and twisted due to the oblique impact with the bridge rail. The right-front wheel was pushed backward and deformed due to minor snagging on the upstream side of post no. 8, and the right-front quarter panel was crushed inward. The plastic grill became dislodged and the right-side head-lamp assembly was deformed. The right-side corner of the front bumper was crushed inward while the left-side bumper attachment separated from the frame. No damage occurred to the interior occupant compartment. The vehicle damage was also assessed by the traffic accident scale (TAD) (22) and the vehicle damage index (VDI) (23), as shown in Figure 10.

6.4 Barrier Damage

The minor damage to the bridge railing system is shown in Figures 14 through 16. Vehicle contact marks were evident on the face of the W-beam rail for approximately 171 in. (4.34 m). However, plastic deformations of the rail would only require replacement of one 12-ft 6-in. (3,810-mm) long W-beam rail section. Plastic deformations to the posts, spacer blocks, plate washers, and threaded rods were basically restricted to the locations of post nos. 7 through 9 with maximum plastic deformations occurring at post no. 8, as shown in Figures 14 through 16. The upstream slotted hole, located in the flange of the traffic-side face of post no. 8, was elongated due to the post rotation resisted by the threaded rod. This stretching of the slotted hole resulted in the initiation of a horizontal crack which extended from the hole's edge toward the upstream edge of the flange. The maximum permanent set and dynamic post deflections were 9.2 in. (234 mm) and 10.8 in. (274 mm), respectively. The maximum permanent set and dynamic rail deflections were 8.0 in. (203 mm) and 13.5 in. (343 mm), respectively. No damage occurred to the deck, lag screws, anchor plates, or vertical deck bolts.

6.5 Occupant Risk Values

The normalized longitudinal and lateral occupant impact velocities were determined to be 19.3 ft/sec (5.9 m/sec) and 8.8 ft/sec (2.7 m/sec), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 6.5 g's and 4.3 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 accelerometer data, are summarized in Figure 10. Results are shown graphically in Appendix A.

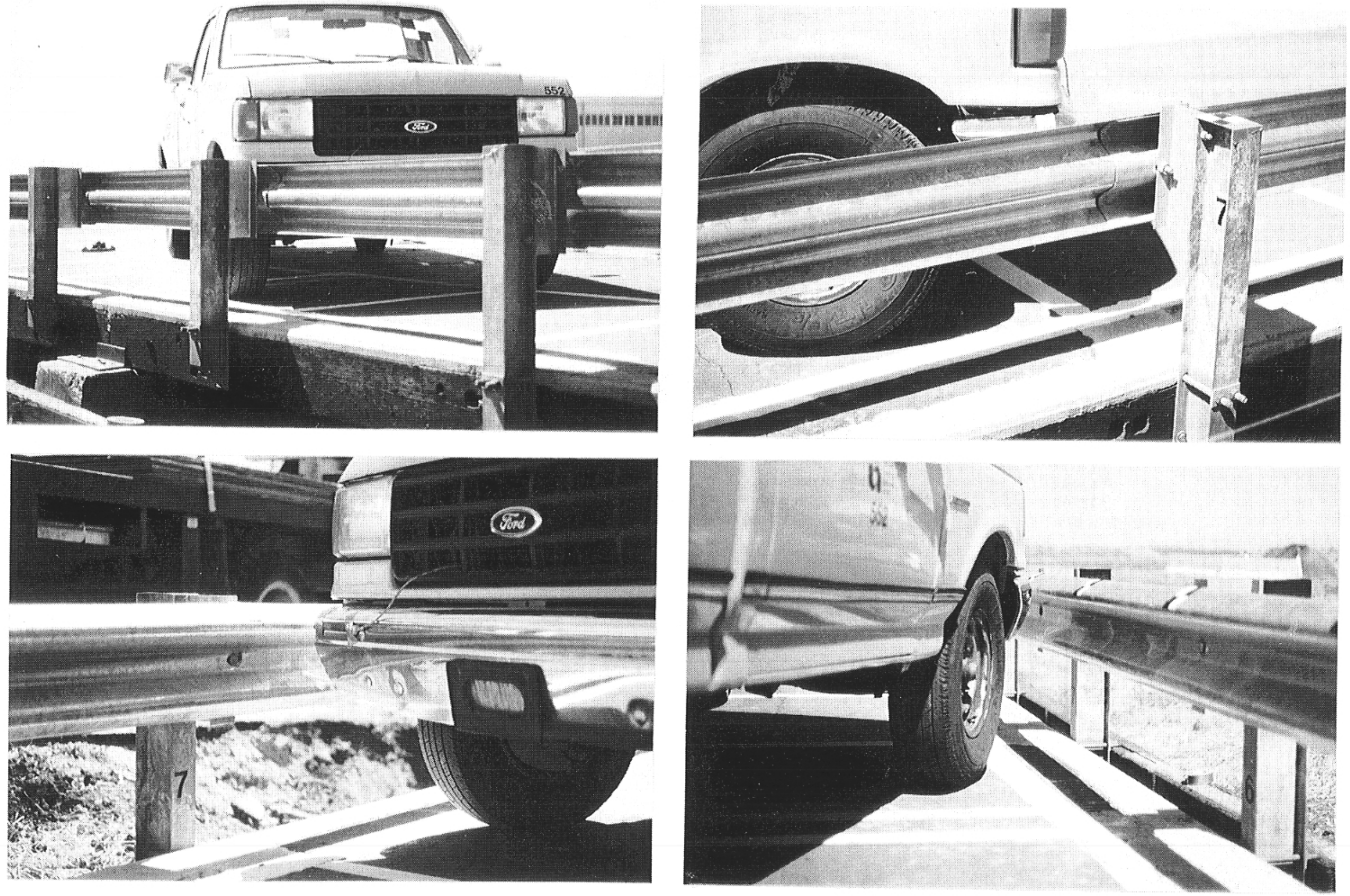
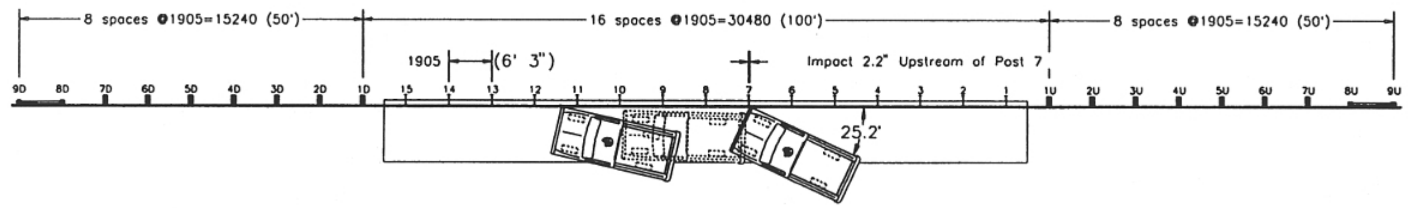
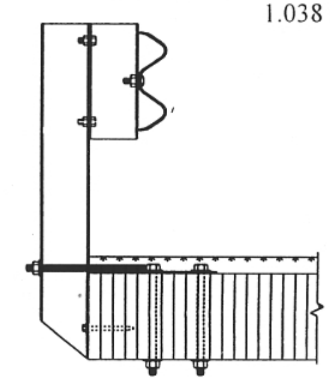


Figure 9. Impact Location, Test LVBR-3

0.000 sec | 0.131 sec | 0.202 sec | 0.433 sec | 1.038 sec



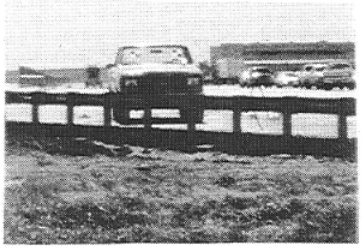


- Test Number LVBR-3
- Date 4/25/96
- Total Installation Length .... 60.96 m
- Bridge Rail Installation .... Top-Mounted W-Beam Railing System
- Bridge Rail Length .... 30.48 m
- Steel W-Beam Rail
  - Size .... 12 Gauge (2.66 mm)
  - Center Rail Mounting Height .... 550 mm
- Steel Bridge Posts (No. 1 through 15)
  - Size .... W150x13.5 by 1,055 mm long
  - Grade .... ASTM A36
  - Spacing .... 1,905 mm
- Steel Spacer Blocks
  - Size .... W150x13.5 by 360 mm long
  - Grade .... ASTM A36
- Post-To-Deck Attachment Hardware
  - Mounting Plate .... ASTM A36 6.4 mm x 250 mm x 400 mm
  - Anchor Bolts .... Four 22.2-mm φ by 356-mm long
  - Threaded Rods .... Two 19.0-mm φ per post
  - Post Washer .... ASTM A36 4.8 mm x 50 mm x 100 mm
  - Lag Screws .... Two 12.7-mm φ by 152-mm long
- Bridge Deck Installation
  - Type .... Longitudinal Glulam Timber Bridge Deck Panels
  - Panel Size .... 273 mm x 1,219 mm x 5,715 mm
  - Material .... West Coast Douglas Fir
  - Grade .... Combination No. 2

- Vehicle Model .... 1988 Ford F-250
  - Curb Weight .... 1,987 kg
  - Test Inertial Weight .... 2,001 kg
  - Gross Static Weight .... 2,001 kg
- Vehicle Speed
  - Impact .... 51.2 km/hr
  - Exit .... NA
- Vehicle Angle
  - Impact .... 25.2 degrees
  - Exit .... NA
- Vehicle Snagging .... Minor wheel snagging on post no. 8
- Vehicle Stability .... Satisfactory
- Occupant Ridedown Deceleration (0.010-sec average)
  - Longitudinal .... 6.5 G's ≤ 20 G's
  - Lateral .... 4.3 G's ≤ 20 G's
- Occupant Impact Velocity (normalized)
  - Longitudinal .... 5.9 m/s ≤ 12 m/s
  - Lateral .... 2.7 m/s ≤ 12 m/s
- Vehicle Damage .... Minor
  - TAD[22] 1-RFQ-3
  - SAE[23] 01RFEW2
- Vehicle Stopping Distance .... 7.6 m
- Barrier Damage .... Plastic deformation of posts, spacers, rail, post washers, and threaded rods
- Maximum Rail Deflections
  - Permanent Set .... 203 mm
  - Dynamic .... 343 mm

(1 in. = 25.4 mm, 1 lb = 0.454 kg, 1 mph = 1.609 kph)

Figure 10. Summary of Test Results and Sequential Photographs, Test LVBR-3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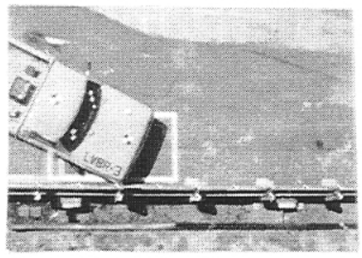
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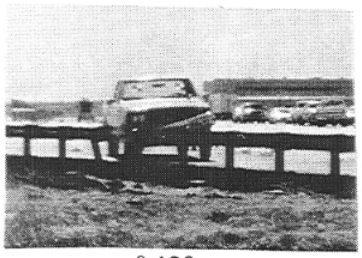
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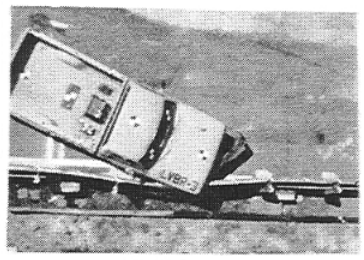
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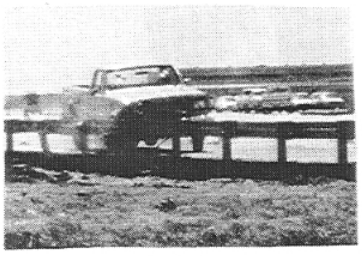
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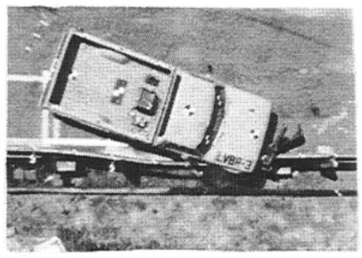
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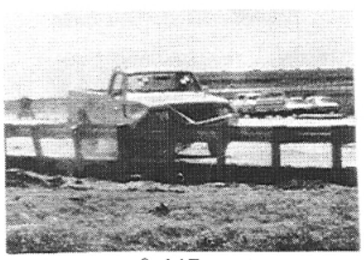
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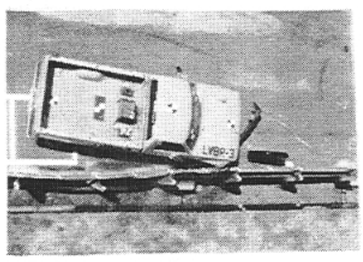
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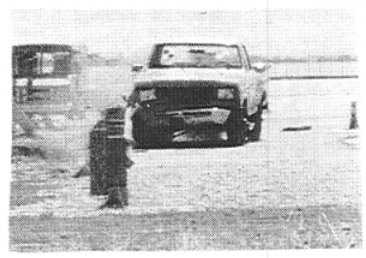
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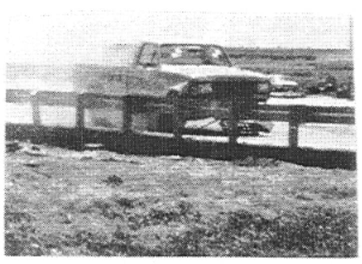
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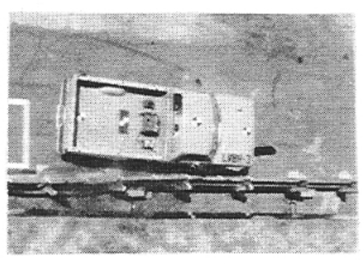
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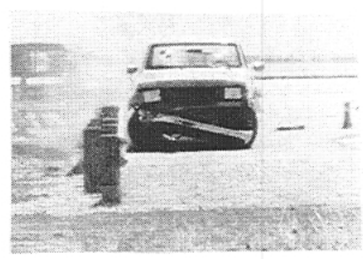
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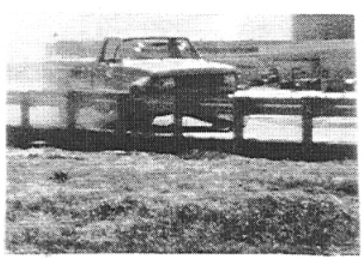
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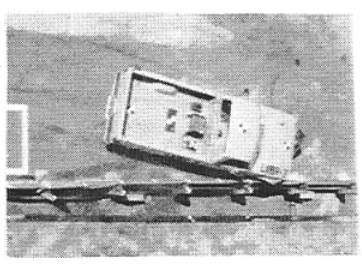
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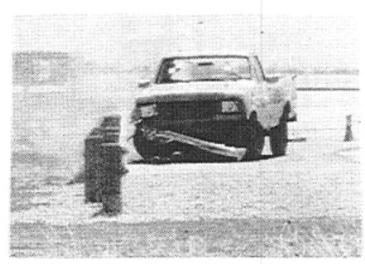
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Figure 11. Additional Sequential Photographs, Test LVBR-3

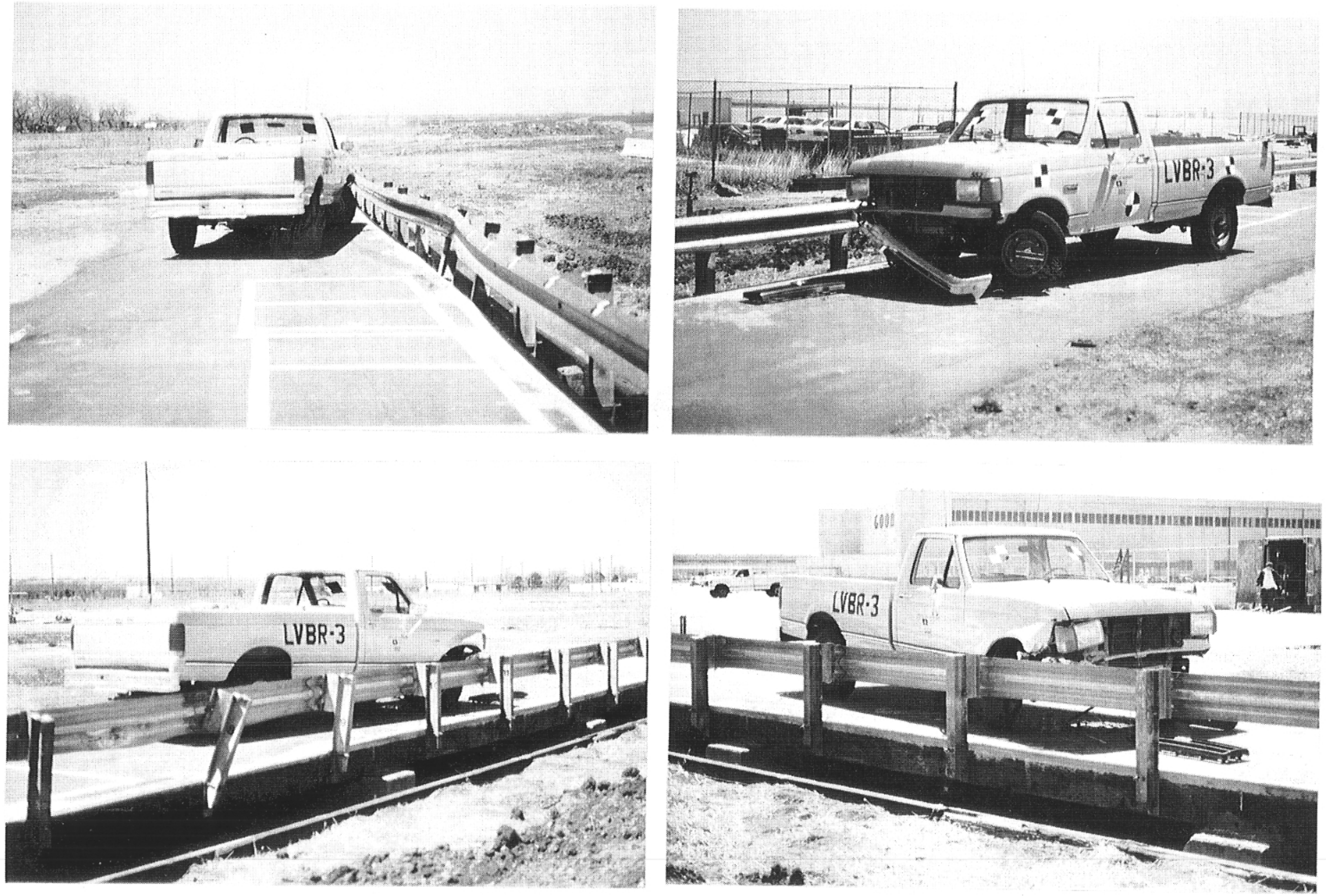

Figure 12. Vehicle Position at Rest, Test LVBR-3

Figure 13. Vehicle Damage, Test LVBR-3

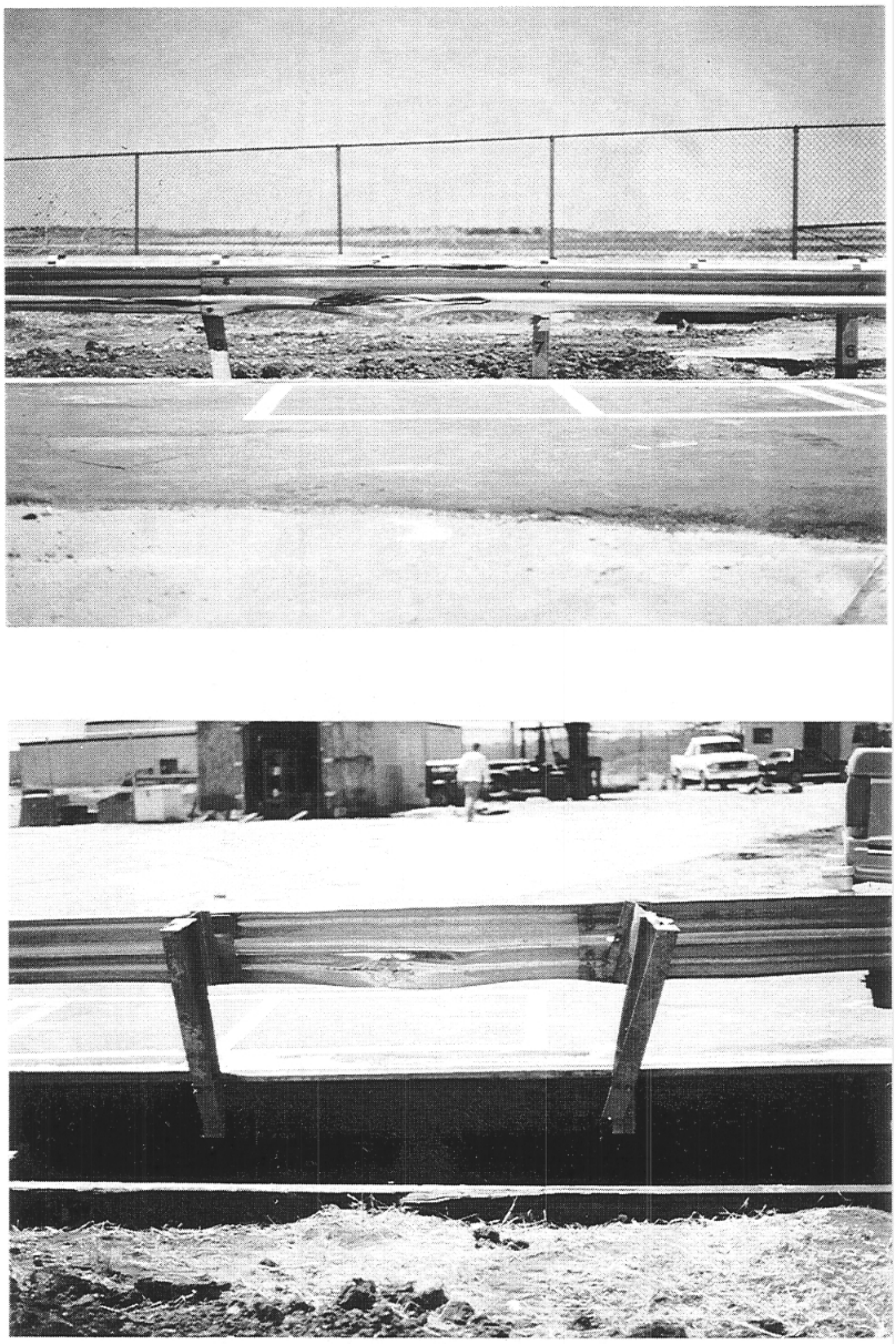

Figure 14. Bridge Rail Damage, Test LVBR-3

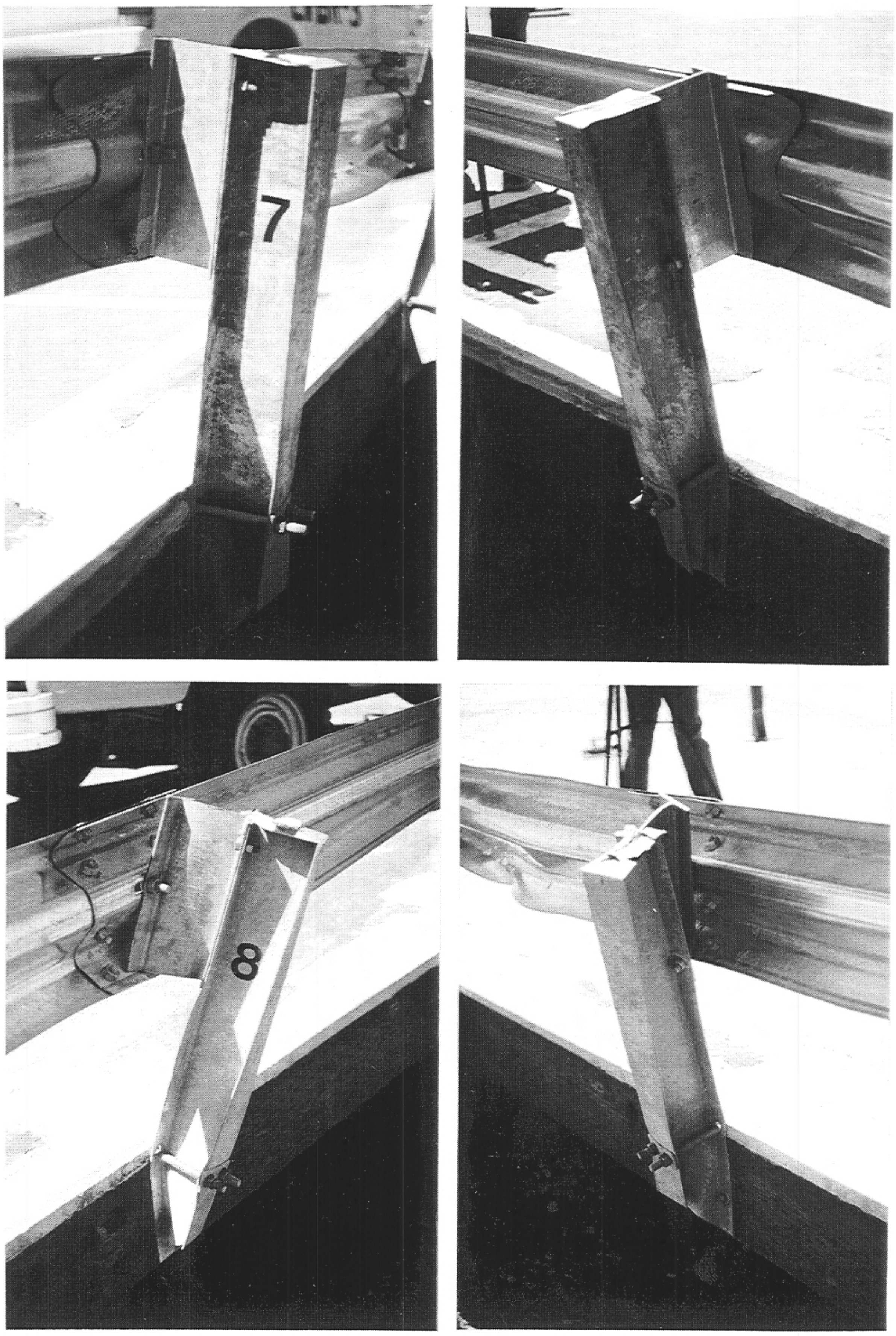

Figure 15. Post Damage (Post Nos. 7 and 8), Test LVBR-3

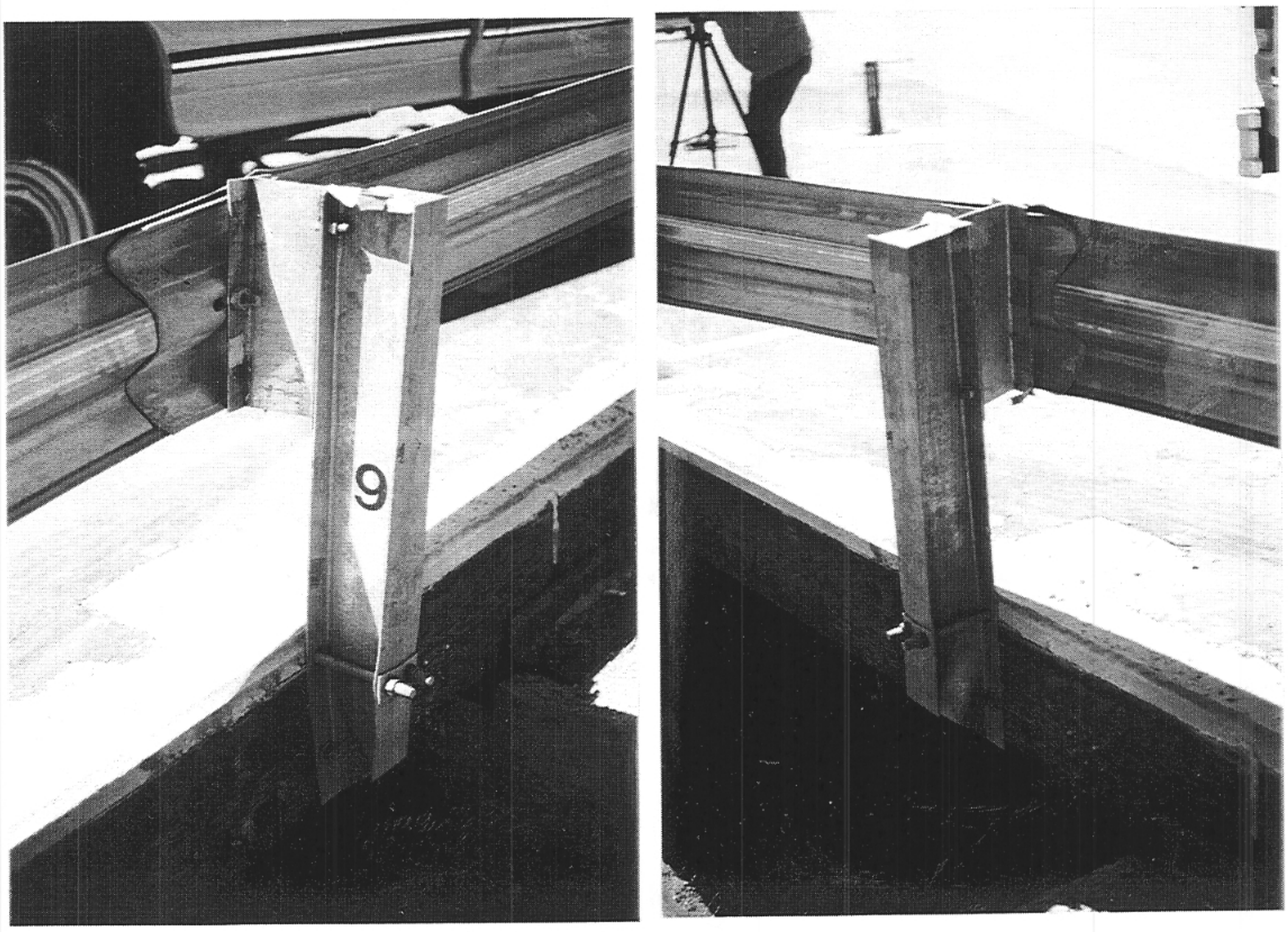

Figure 16. Post Damage (Post No. 9), Test LVBR-3

7 DISCUSSION AND CONCLUSIONS

A semi-rigid, top-mounted W-beam bridge railing was developed and crash tested for use on longitudinal glulam timber decks with low traffic volumes and speeds. One full-scale vehicle crash test, test LVBR-3, was performed and determined to have acceptable safety performance according to TL-1 of NCHRP Report No. 350 (1). A summary of the safety performance evaluation is provided in Table 3.

The development of the W-beam bridge railing addressed the concerns for aesthetics, economy, material availability, ease of construction, and reasonable margin of structural adequacy. Material costs for the bridge railing can be expected to range between $18 and $22 per lineal foot ($5 and $7 per meter). In addition, the W-beam bridge railing system was relatively easy to install and should have low construction labor costs. This railing system should also be adaptable to other types of longitudinal decks with little or no modification.

During the pickup truck crash test, the left-front bumper released from the steel frame shortly after the vehicle impacted the bridge rail. Although this result is extremely rare and most likely occurred due to the placement of non-standard washers behind the bumper, the researchers believe that the satisfactory test results would not have been significantly different had the bumper remained connected to both frame supports. This is based upon the fact that the pickup truck did not show any potential for climbing up or vaulting over the railing system. In addition, the pickup truck was brought to a controlled and stable stop with the right-front corner near post no. 11.

Therefore, the successful completion of this research project resulted in a W-beam bridge railing having acceptable safety performance and meeting current crash test safety standards.

Table 3. Summary of Safety Performance Evaluation

Evaluation Factors		Evaluation Criteria	Test LVBR-3
Structural Adequacy	A.	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	S
Occupant Risk	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
	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)
U - (Unsatisfactory)

8 RECOMMENDATIONS

The semi-rigid, top-mounted W-beam bridge railing described herein was developed for use on low service-level roadways with low impact requirements (TL-1 of NCHRP 350). However, the results of this research study indicate that W-beam railing systems may be further developed for use on medium service-level roadways and work-zones with moderate impact requirements, such as TL-2 of NCHRP 350. This increase in performance level may be obtained with little or no modification, such as by (1) increasing the blockout distance between the back of the rail and the traffic-side face of the post and (2) modifying the post-to-deck attachment. However, any design modifications made to the bridge railing system can only be verified through the use of full-scale vehicle crash testing.

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10 APPENDICES

APPENDIX A - ACCELEROMETER DATA ANALYSIS

Figure A-1. Graph of Longitudinal Deceleration, Test LVBR-3

Figure A-2. Graph of Longitudinal Occupant Impact Velocity, Test LVBR-3

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

Figure A-4. Graph of Lateral Deceleration, Test LVBR-3

Figure A-5. Graph of Lateral Occupant Impact Velocity, Test LVBR-3

Figure A-6. Graph of Lateral Occupant Displacement, Test LVBR-3

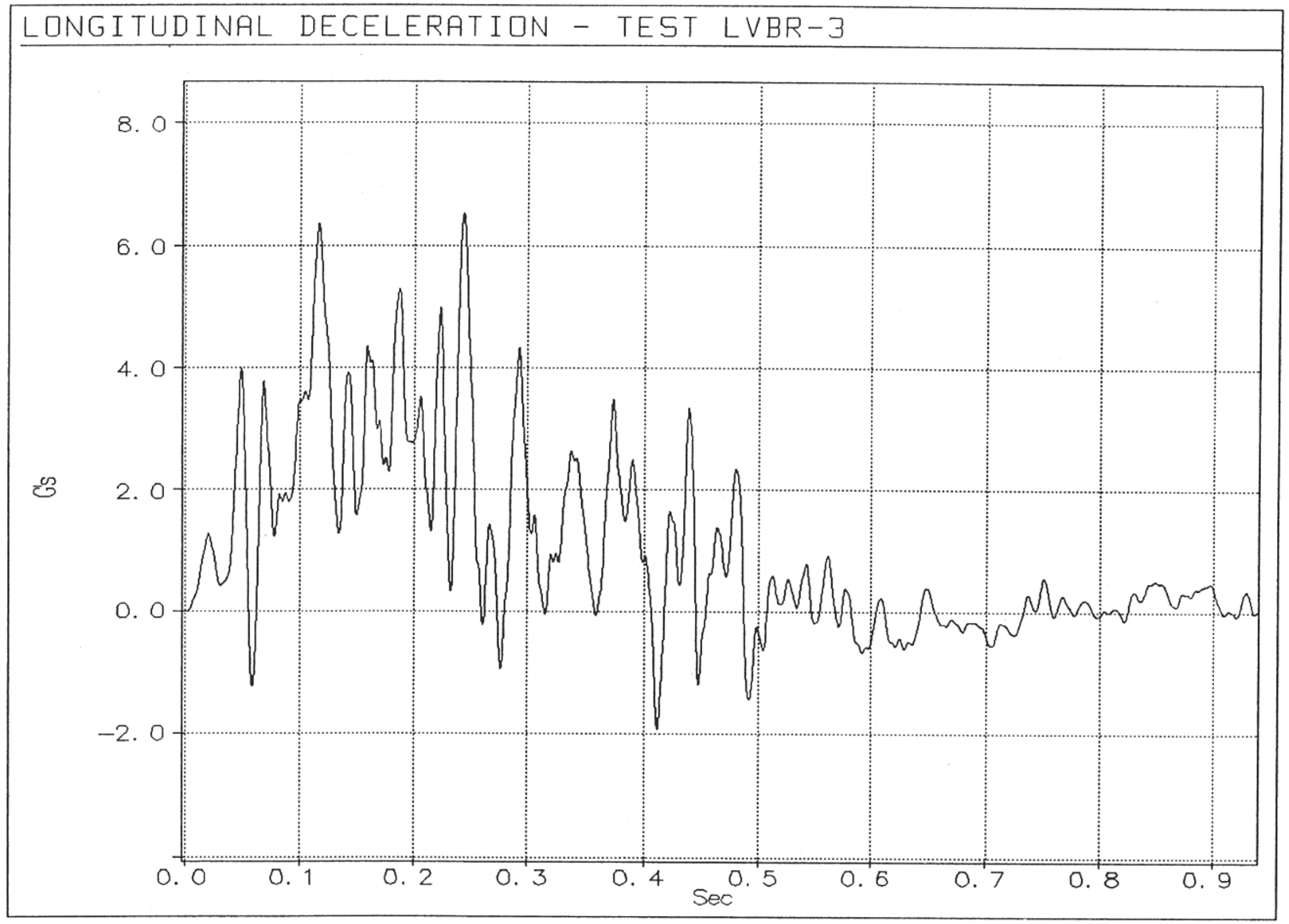

Figure A-1. Graph of Longitudinal Deceleration, Test LVBR-3

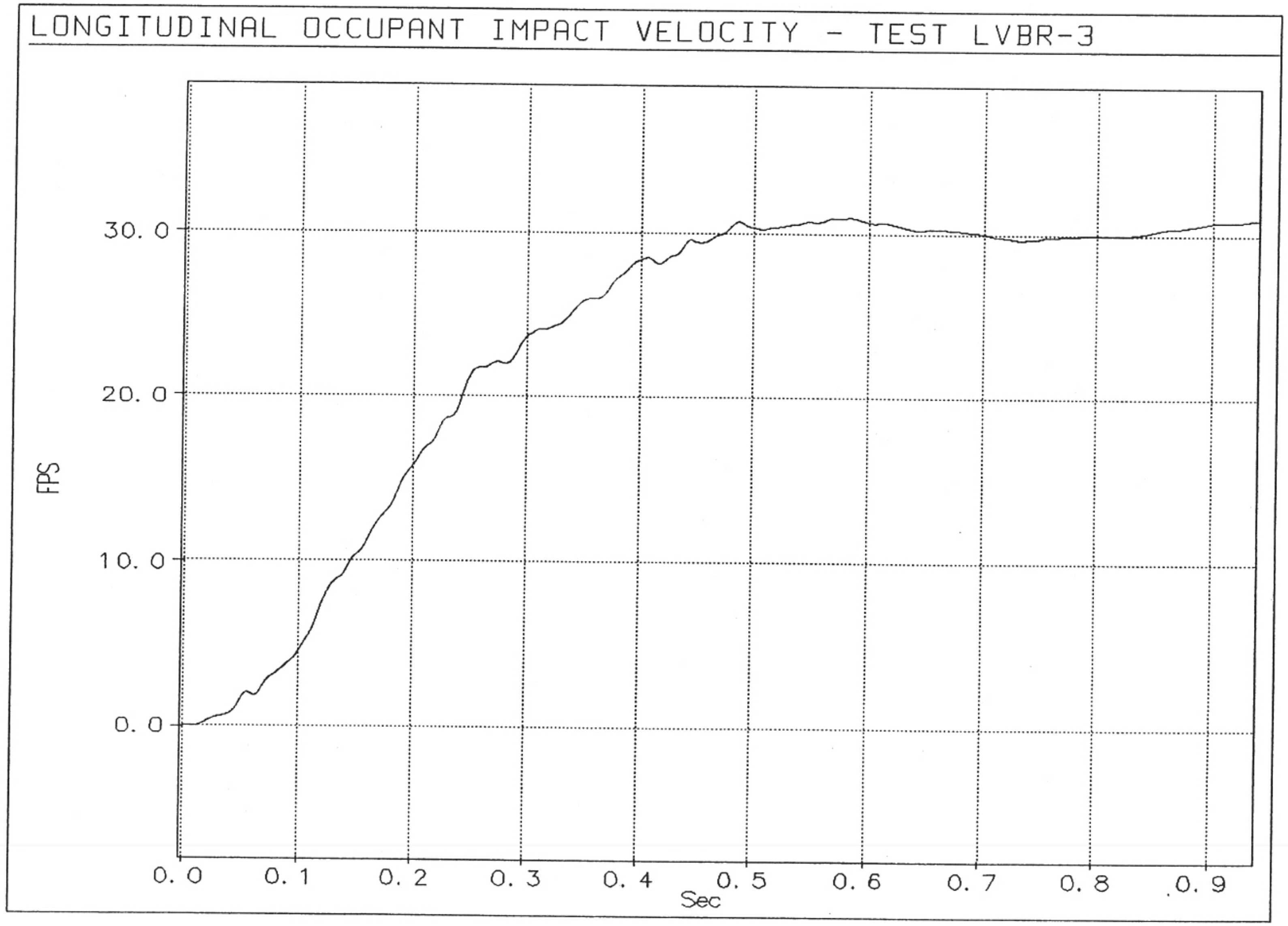

Figure A-2. Graph of Longitudinal Occupant Impact Velocity, Test LVBR-3

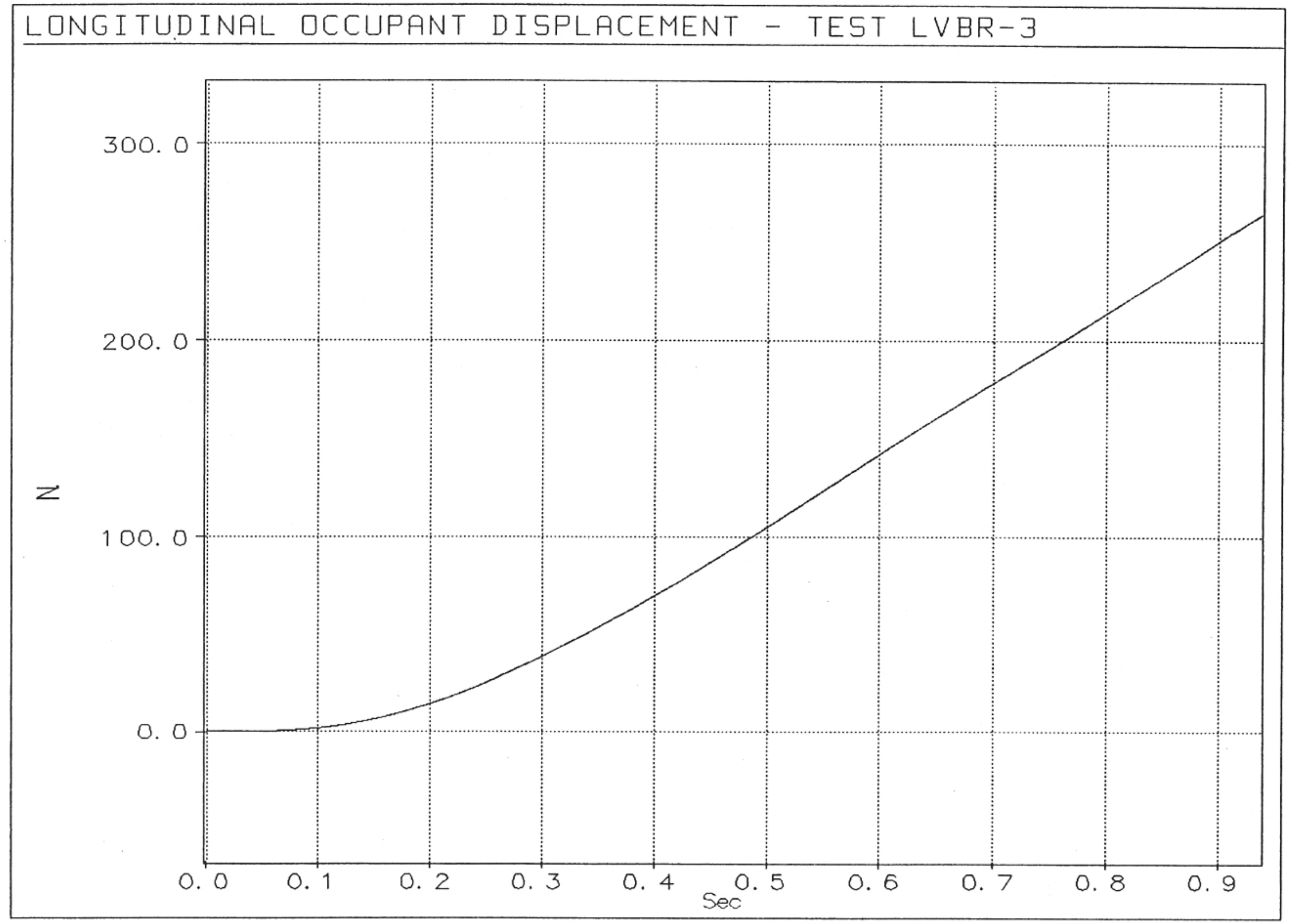

Figure A-3. Graph of Longitudinal Occupant Displacement, Test LVBR-3

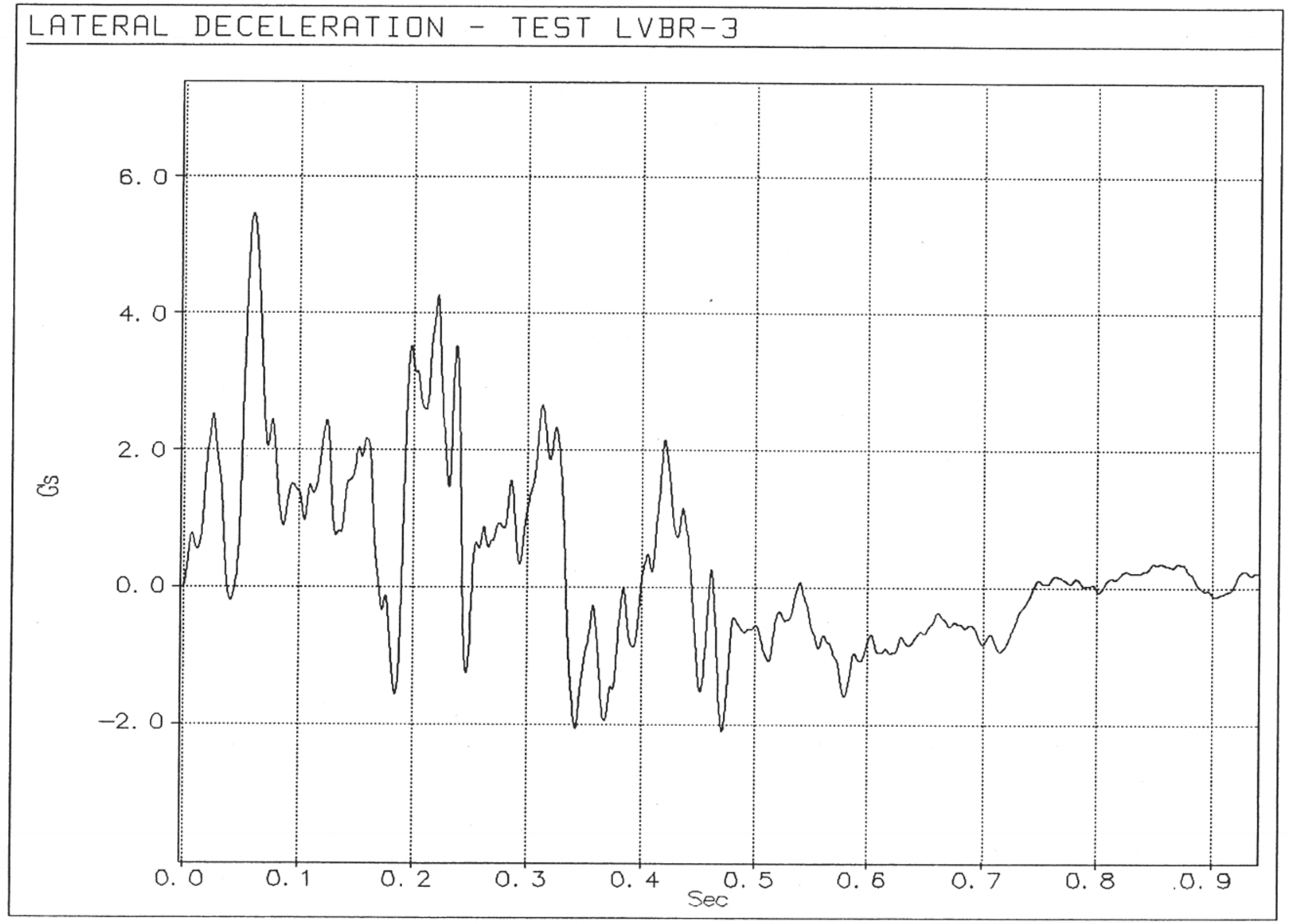

Figure A-4. Graph of Lateral Deceleration, Test LVBR-3

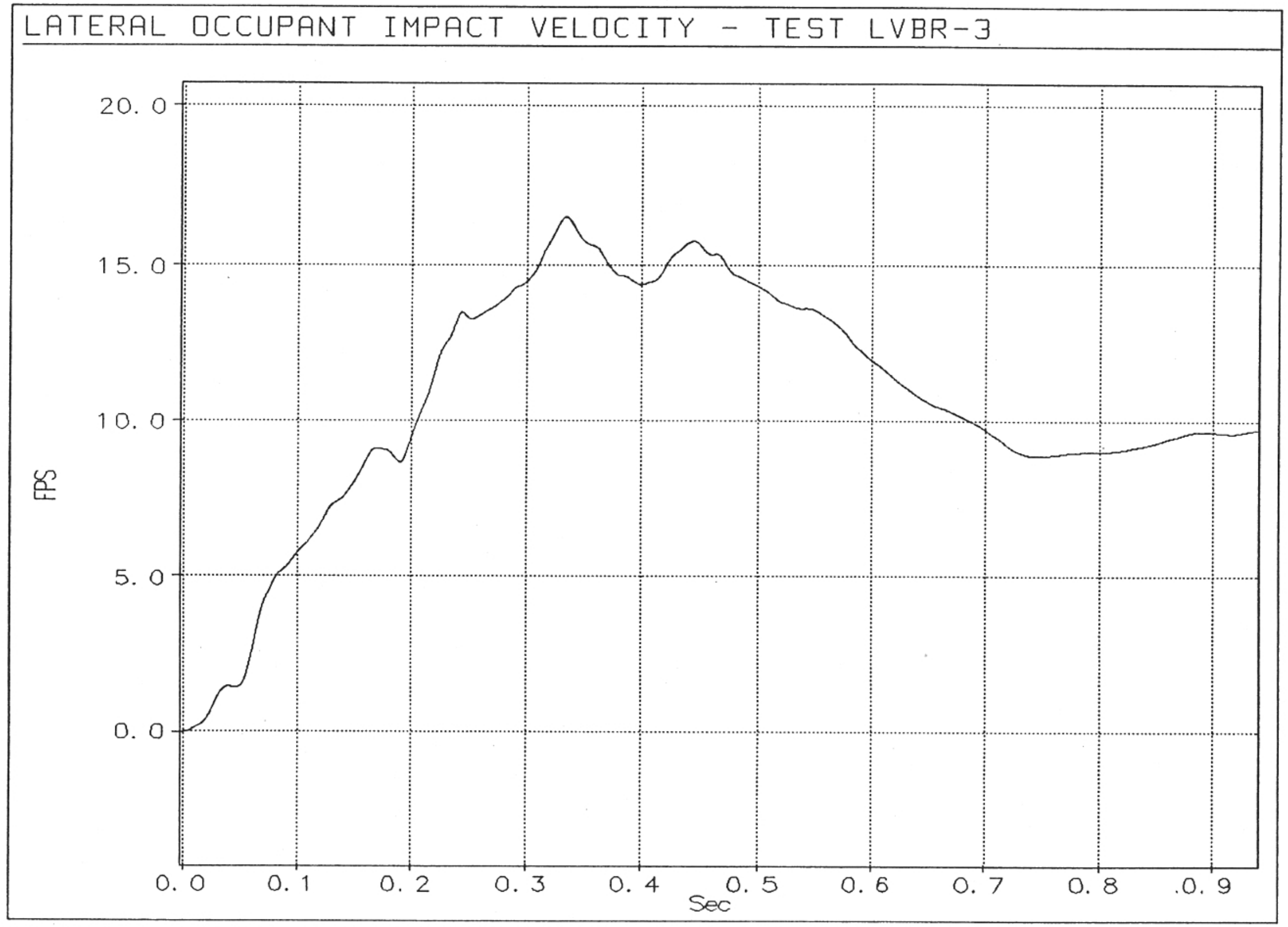

Figure A-5. Graph of Lateral Occupant Impact Velocity, Test LVBR-3

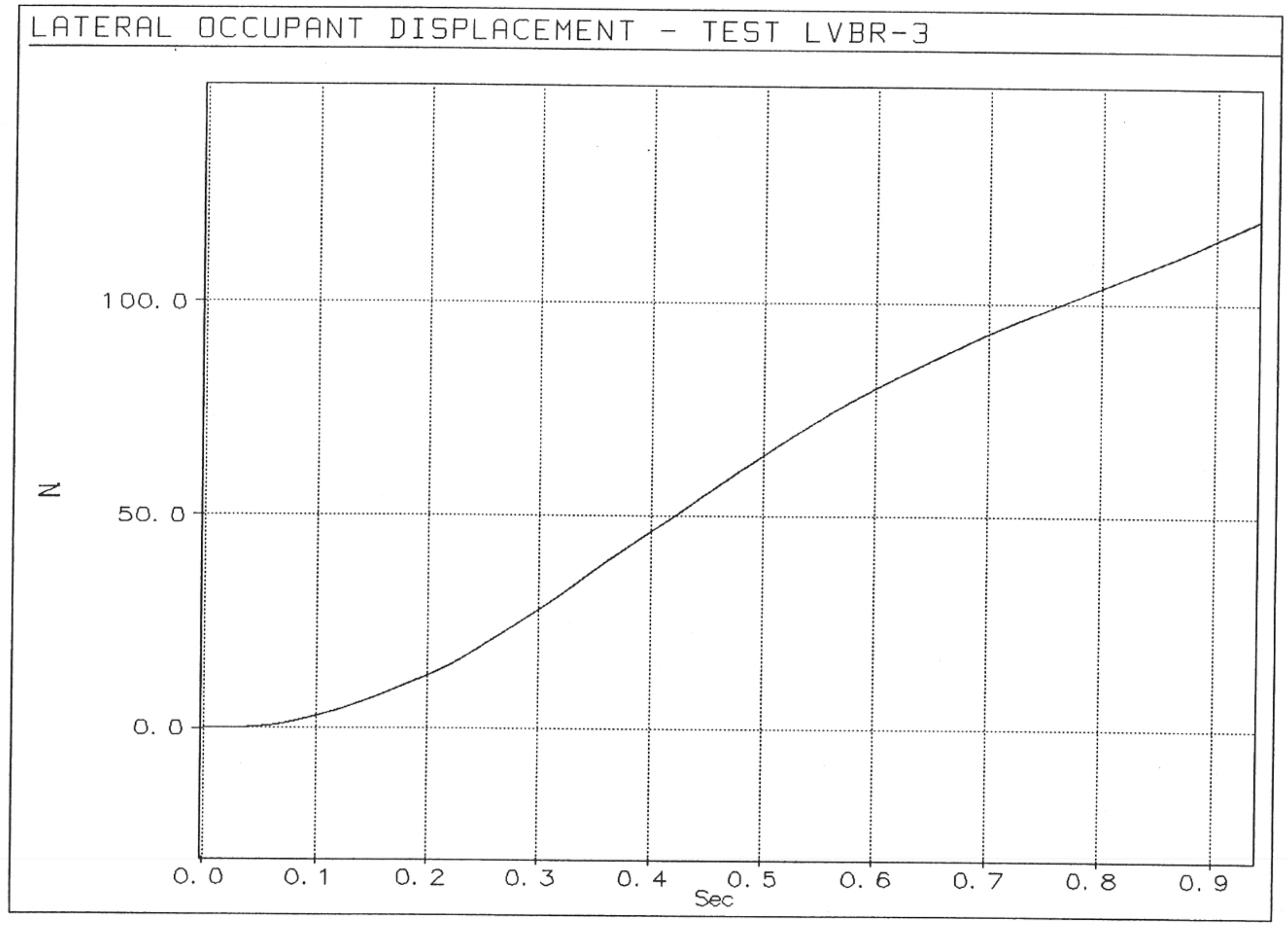

Figure A-6. Graph of Lateral Occupant Displacement, Test LVBR-3