Midwest State's Regional Pooled Fund Research Program
Fiscal Year 1998-1999 (Year 9)
NDOR Research Project Number SPR-3(017)

DEVELOPMENT OF A 7.62-m LONG SPAN GUARDRAIL SYSTEM – PHASE II

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Submitted to

MIDWEST STATE'S REGIONAL POOLED FUND PROGRAM
Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

MwRSF Research Report No. TRP-03-88-99

August 13, 1999

Technical Report Documentation Page

1. Report No.	2.	3. Recipient's Accession No.
SPR-3(017)		

4. Title and Subtitle	5. Report Date
Development of a 7.62-m Long Span Guardrail System – Phase II	August 13, 1999
	6.
7. Author(s)	**8. Performing Organization Report No.**
Polivka, K.A., Bielenberg, B.W., Sicking, D.L., Faller, R.K., Rohde, J.R., and Keller, E.A.	TRP-03-88-99
9. Performing Organization Name and Address	**10. Project/Task/Work Unit No.**
Midwest Roadside Safety Facility (MwRSF) University of Nebraska-Lincoln 1901 Y St., Bldg. C Lincoln, NE 68588-0601	11. Contract © or Grant (G) No. SPR-3(017)
12. Sponsoring Organization Name and Address	**13. Type of Report and Period Covered**
Midwest States Regional Pooled Fund Program Nebraska Department of Roads 1500 Nebraska Highway 2 Lincoln, Nebraska 68502	Final Report 1999 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration

16. Abstract (Limit: 200 words)

A 7.62-m long span guardrail system was developed for use over low-fill culverts. The long span design was constructed with two 2.66-mm (12-gauge) thick nested W-beam rails totaling 30.48 m in length. The nested W-beam rail was supported by sixteen W150x13.5 steel posts and six standard CRT posts, each with two 150x200x360 wood blockouts. Each post measured 1,830-mm long. Post spacings were 1,905-mm on center except for the 7.62-m spacing between the two CRT posts surrounding the unsupported span.

The research study included full-scale vehicle crash testing, using a ¾-ton pickup truck. The test, impacting at a speed of 102.9 km/hr and an angle of 24.7 degrees, was conducted and reported in accordance with the requirements specified in NCHRP Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of High Features*. The safety performance of the long-span barrier system was determined to be acceptable according to Test Level 3 (TL-3) of the NCHRP Report No. 350 criteria.

17. Document Analysis/Descriptors		18. Availability Statement
Highway Safety, Guardrail, Longitudinal Barrier, Box Culvert	Roadside Appurtenances, Crash Test, Compliance Test	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	51	

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State Highway Departments participating in the Midwest State's Regional Pooled Fund Research Program, the Washington State Department of Transportation, the Federal Highway Administration, CONTECH Construction Products, Inc., nor Lane Enterprises. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the Midwest States Regional Pooled Fund Program funded by the Iowa Department of Transportation, Kansas Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Nebraska Department of Roads, Ohio Department of Transportation, South Dakota Department of Transportation, and Wisconsin Department of Transportation for sponsoring this project; (2) the Washington State Department of Transportation for sponsoring this project; (3) CONTECH Construction Products, Inc. and Lane Enterprises for sponsoring this project; (4) MwRSF personnel for constructing the barriers and conducting the crash test; (5) Center for Infrastructure Research, Engineering Research Center, and the University of Nebraska-Lincoln for matching support, and (6) Daniel Mushett, Highway Timber Products Co. - a division of Cox Industries, Inc. for donating the wood posts and blockouts.

A special thanks is also given to the following individuals who made a contribution to the completion of this research project.

Midwest Roadside Safety Facility

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1 INTRODUCTION

1.1 Problem Statement

Guardrails are often placed over box culverts to protect motorists from the hazard presented by cross-drainage culverts installed under highways. Unfortunately, the performance of these guardrails is seriously diminished when the box culvert is installed with less than 1,016 mm of fill material. In a situation where the guardrail extends across a culvert, it is usually necessary to attach the guardrail posts to the culvert surface. When the guardrail is impacted, these posts are severely deformed and often pulled loose, thereby causing significant damage to the culvert. The damage and expensive repair costs could be avoided if an unsupported guardrail segment spanned across the culvert.

The Ohio Department of Transportation's (OhDOT's) Office of Structural Engineering issued a special plan sheet which provided details on several options for spanning culverts in low-fill situations which would not require attaching the guardrail posts to the culvert. However, these options for spanning culverts permitted the use of span lengths much longer than those successfully crash tested in previous research studies. It is noted that crash tests, based on passenger cars, have been performed successfully on span lengths of 3.81 and 5.72 m according to the evaluation criteria provided by the National Cooperative Highway Research Program (NCHRP) Report No. 230, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances* (1). Since span lengths in excess of 5.72 m have not been subjected to full-scale crash testing, these designs can no longer be used on Federal-aid highways unless shown to meet impact safety standards. Therefore, if OhDOT wishes to use longer unsupported span lengths (i.e., 7.62 to 9.14

m) to extend over low-fill culvert installations, then a need exists to develop and crash test a new guardrail system according to current safety guidelines.

1.2 Objective

The objective of the research project was to develop a new guardrail system for box culverts capable of unsupported spans on the order of 7.62 m. The new guardrail system was designed to meet the Test Level 3 (TL-3) safety performance criteria set forth in the NCHRP Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (2).

1.3 Scope

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

2 LITERATURE REVIEW

When culverts span more than 6.1 m, the American Association of State Highway Transportation Officials (AASHTO) defines them as bridge lengths and thus, normally require the use of a full-strength, rigid bridge rail (3). However, the use of a rigid bridge rail can potentially create a transition problem between the rigid bridge rail and the flexible roadside guardrail commonly used upstream of the bridge rail. Therefore, roadside guardrails are often continued over low-fill culverts to reduce construction costs.

Problems arise when the guardrails must continue across the culverts because of the shallowness of the soil fill. In such cases, full embedment of the guardrail posts is not possible. Crash testing has previously demonstrated that posts with shallow embedment depths can easily be pulled out of the ground, thus resulting in vehicle snagging or vaulting and causing potentially disastrous results (4). Therefore, the guardrail posts need sufficient embedment to: (1) develop the necessary friction to prevent the posts from pulling out of the ground; (2) develop sufficient lateral soil forces to develop the bending strength of the posts; and (3) provide energy dissipation through post rotation in soil.

A design that alleviates the diminished performance of the guardrail with shallow embedded posts has been successfully developed and successfully crash tested. This design involved welding base plates to the short steel posts and bolting them to the top surface of the concrete culvert (4). However, this design required that the front face of the W-beam be placed 914 mm from the head wall of the culvert to provide space for the guardrail and posts to deflect during impact. In some instances, this design required that the culvert be extended outward away from the roadway. This alternative increases the cost of the structure, especially in rehabilitation projects where no other culvert work is needed (4).

In 1992, an alternative design was developed for the Kansas Department of Transportation (KsDOT) that provided a stiffer barrier and reduced the amount of deflection over the culvert (5). The successfully crash tested design consisted of a nested W-beam with half-post spacing. The steel posts were bolted to the top of the concrete culvert and installed adjacent to the concrete culvert head wall. Steel posts must be used for the segment over the low-fill culvert.

Previous designs for wood-post guardrail systems that eliminate the use of the steel posts in the segment over the culvert include unsupported guardrail segments which span across the culverts. Unsupported spans of 3.81 and 5.72 m have been successfully crash tested according to the NCHRP Report No. 230 criteria using "passenger-size" sedans (6-7). These successful designs utilized nested W-beam guardrail, which has twice the tensile capacity of a single rail. These designs are simpler and less expensive alternatives to the designs which require attachment of the base of the posts to the top of the culvert. These designs have been recommended for use with both wood-post and steel-post guardrail systems due to the compatible strengths of wood and steel posts (6).

Recently, the Midwest Roadside Safety Facility (MwRSF) completed the Phase I development effort for a long-span guardrail system (8). For this study, a 7.62-m long guardrail span was designed and unsuccessfully crash tested according to the NCHRP Report No. 350 criteria using ¾-ton pickup trucks. Following an analysis and redesign of the guardrail system, the system was retested. The results of this effort are reported herein.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as long-span guardrail systems traversing culverts, must satisfy the requirements provided in NCHRP Report No. 350 to be accepted for use on new construction projects or as a replacement for existing designs not meeting current safety standards. According to Test Level 3 (TL-3) of NCHRP Report No. 350, long-span guardrail systems must be subjected to two full-scale vehicle crash tests: (1) a 2,000-kg pickup truck impacting at a speed of 100.0 km/hr and at an angle of 25 degrees; and (2) an 820-kg small car impacting at a speed of 100.0 km/hr and at an angle of 20 degrees. However, W-beam barriers struck by small cars have been shown to meet safety performance standards, being essentially rigid (8-10), with no significant potential for occupant risk problems arising from vehicle pocketing or severe wheel snagging on the post at the downstream end of the long-span. Therefore, the 820-kg small car crash test was deemed unnecessary for this project.

3.2 Evaluation Criteria

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

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

Structural Adequacy	A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.
Occupant Risk	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.
	F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.
	M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test devise.

4 LONG-SPAN GUARDRAIL DESIGN (DESIGN NO. 3)

The total length of the test installation was 53.34-m long, as shown in Figure 1. Photographs of the test installation are shown in Figures 2 through 3. The test installation consisted of 30.48 m of nested 12-gauge W-beam rail supported by both CRT and steel posts, standard 12-gauge W-beam guardrail supported by steel posts, and an anchorage system replicating a BCT on both the upstream and downstream ends but installed tangent to the guardrail system.

The entire system was constructed with twenty-six guardrail posts. Post nos. 3 through 8 and 15 through 24 were galvanized ASTM A36 steel W150x13.5 sections measuring 1,830-mm long. Post nos. 9 through 14 were CRT timber posts measuring 150-mm wide x 200-mm deep x 1,830-mm long. Post nos. 1 through 2 and 25 through 26 were timber posts measuring 140-mm wide x 190-mm deep x 1,080-mm long and were placed in steel foundation tubes. The timber posts and foundation tubes were part of an anchor system, similar to a BCT but installed tangent to the system, used to develop the required tensile capacity in the guardrail.

Post nos. 1 through 11 and 12 through 26 were spaced 1,905-mm on center. The unsupported span between post nos. 11 and 12 was 7.62-m long, as shown in Figure 1. For post nos. 3 through 24, the soil embedment depth was 1,100 mm. In addition, 150-mm wide x 200-mm deep x 360-mm long routed wood spacer blockouts were used to block the rail away from post nos. 3 through 8 and 15 through 24. For CRT post nos. 9 through 14, two 150-mm wide x 200-mm deep x 360-mm long wood spacer blockouts were used at each post to block the rail away from the posts, as shown in Figures 1 and 2. This is in contrast to the Design No. 2 system (8), previously tested with single wood spacer blockouts on the six CRT posts adjacent to the long-span section of guardrail.

A standard 2.66-mm thick W-beam rail, measuring 7,620-mm long, was placed between post nos. 1 and 5. Subsequently, nested W-beam guardrail, measuring 2.66-mm thick and 30.48-m long, was used to span between post nos. 5 and 18. A standard 2.66-mm thick W-beam rail, measuring 7,620-mm long, was placed between post nos. 18 through 22 and another between post nos. 22 and 26, as shown in Figure 1. The top mounting height of the W-beam rail was 706 mm.

All lap-splice connections between the rail sections were configured to reduce vehicle snagging at the splice during the crash test. In addition, for lap-splice connections consisting of four W-beam rails, the upstream nested rails were placed in front of the downstream nested rails, as shown in Figure 2.

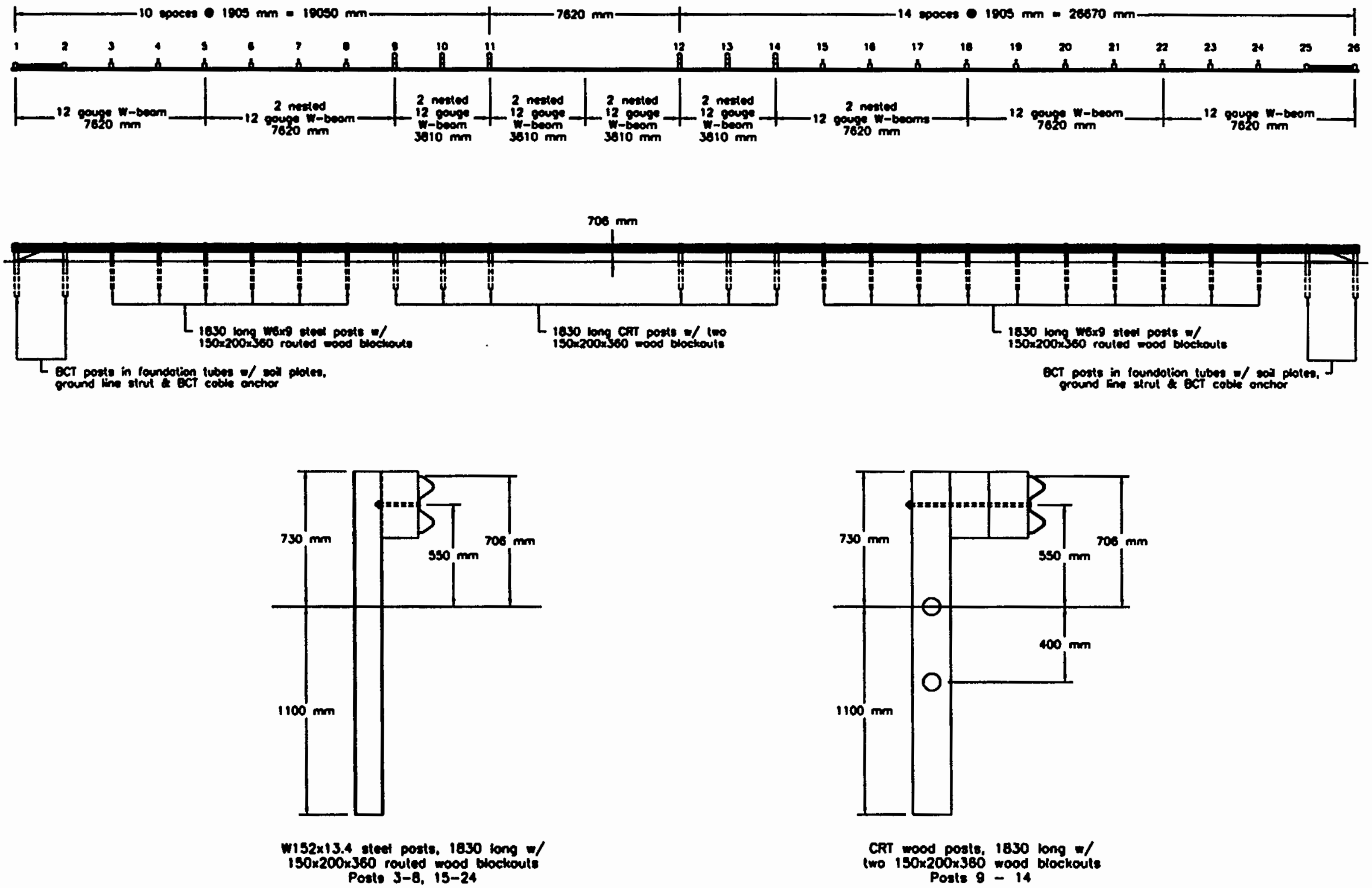


Figure 1. Modified Long-Span Guardrail System, Design No. 3

Figure 2. Long-Span Guardrail Element, Design No. 3

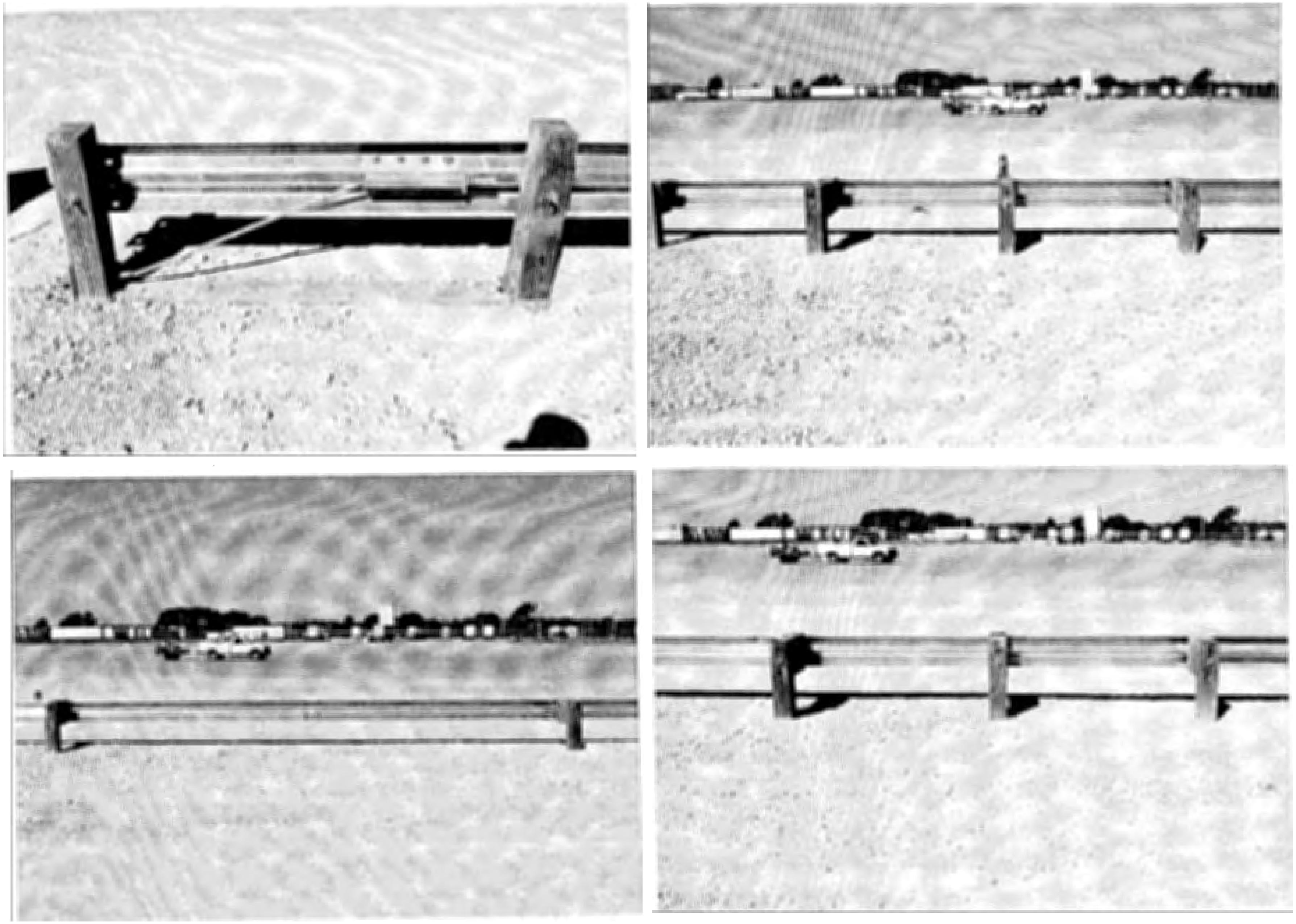


Figure 3. Long-Span Guardrail Element, Design No. 3

5 TEST CONDITIONS

5.1 Test Facility

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

5.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch (12) was used to steer the test vehicle. A guide-flag, attached to the front-left wheel and the guide cable, was sheared off before impacting the guardrail. The 9.5-mm diameter guide cable was tensioned to approximately 13.3 kN, and supported by hinged stanchions in the lateral and vertical directions and spaced at 30.48 m initially and at 15.24 m toward the end of the guidance system. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. The vehicle guidance system was approximately 457.2-m long.

5.3 Test Vehicle

For test OLS-3, a 1992 Chevrolet C-2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 1,994 kg. The test vehicle is shown in Figure 4, and vehicle dimensions are shown in Figure 5.

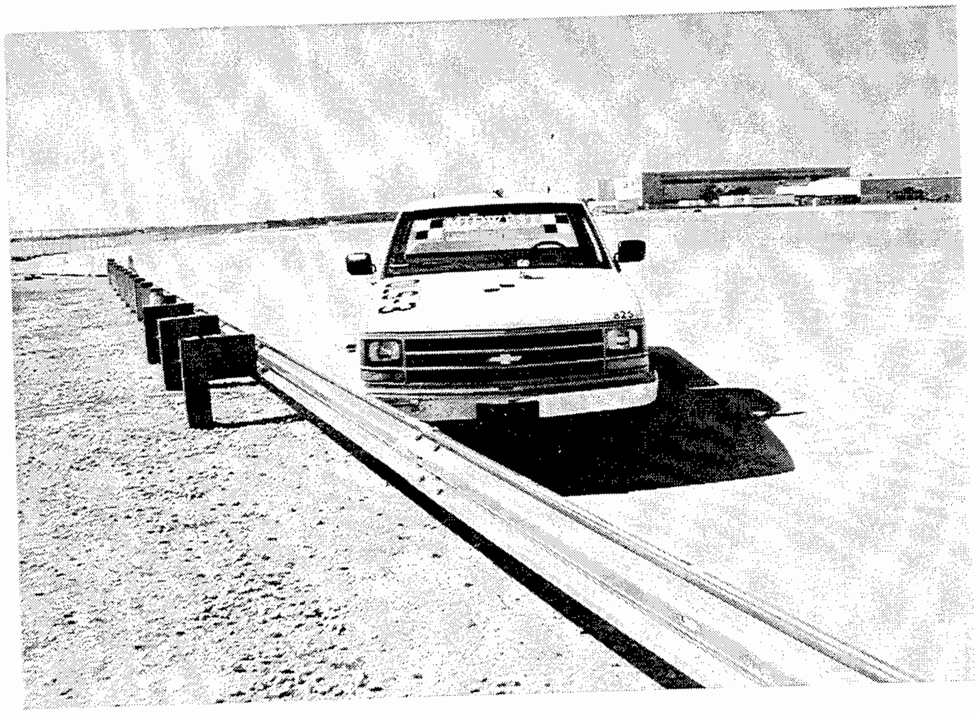


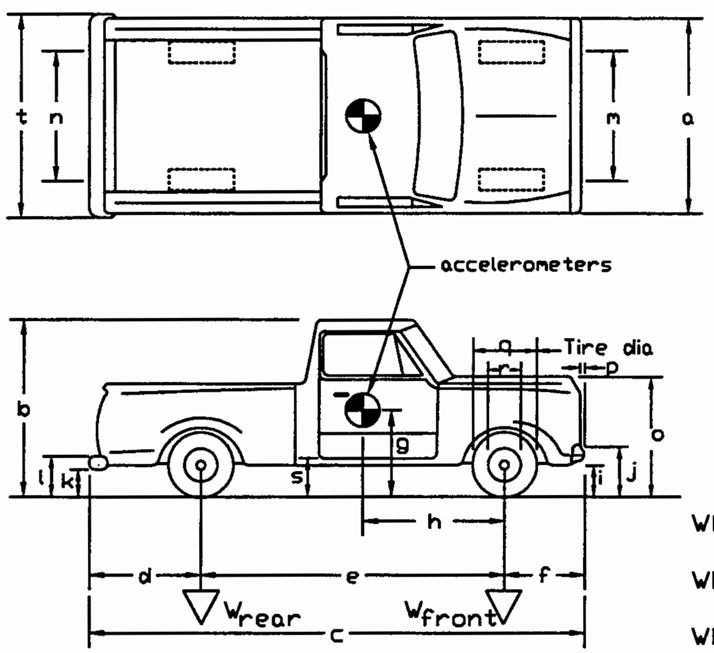
Figure 4. Test Vehicle, Test OLS-3

Date: 5/26/99 Test Number: OLS-3 Model: 2500

Make: CHEVROLET Vehicle I.D.#: 1GCFC24Z6MZ179474

Tire Size: LT245/75R16 Year: 1992 Odometer: 114,281

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm

a	1892	b	1784
c	5556	d	1302
e	3327	f	889
g	738	h	1480
i	406	j	610
k	603	l	787
m	1581	n	1613
o	972	p	89
q	749	r	445
s	432	t	1835

Wheel Center Height Front 365

Wheel Center Height Rear 371

Wheel Well Clearance (FR) 914

Wheel Well Clearance (RR) 851

Engine Type 6 cyl. gas

Engine Size 4.3L 262 ci

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Weights - kg	Curb	Test Inertial	Gross Static
W_{front}	1050	1107	1107
W_{rear}	832	887	887
W_{total}	1882	1994	1994

Note any damage prior to test: NONE

Figure 5. Vehicle Dimensions, Test OLS-3

The Suspension Method (13) was used to determine the vertical component of the center of gravity for the test vehicle. 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 center of gravity is shown in Figure 6.

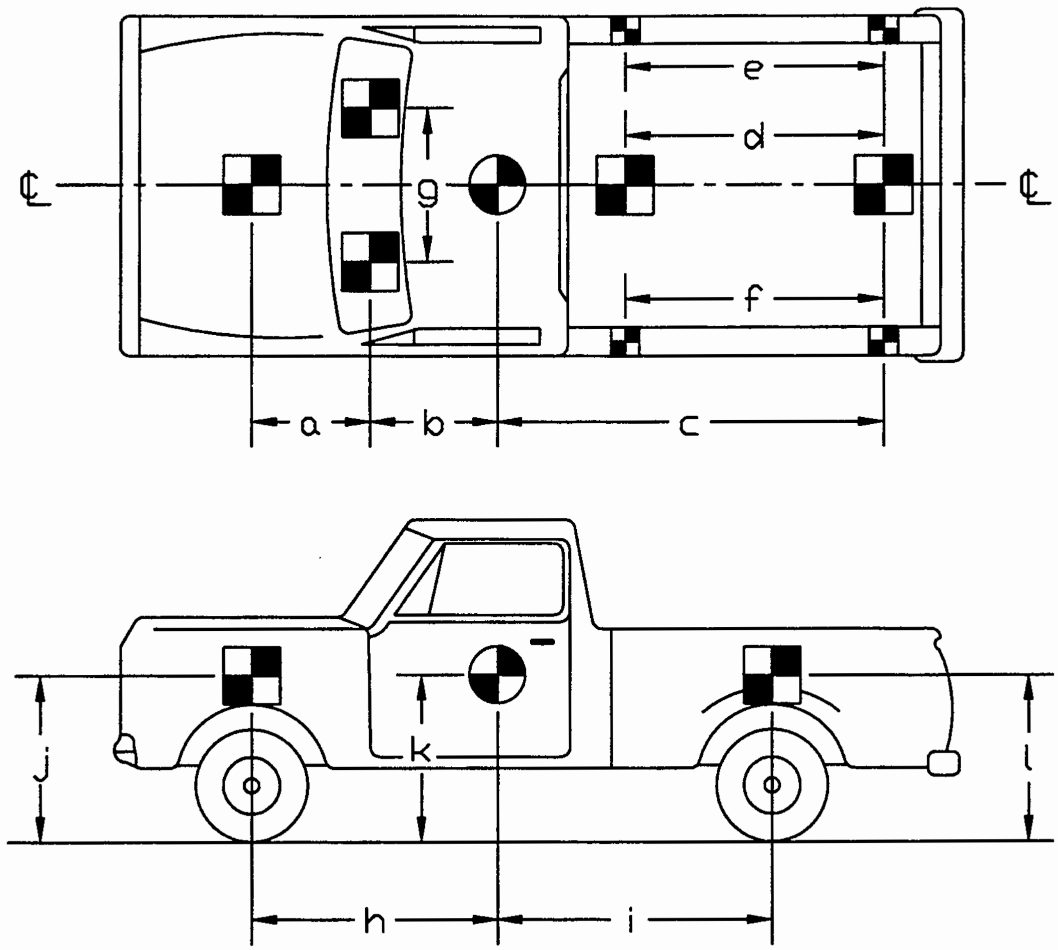
Square, black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film, as shown in Figure 6. One target was placed on the center of gravity on the driver's side door, the passenger's side door, and on the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for film analysis.

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

5.4 Data Acquisition Systems

5.4.1 Accelerometers

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



TEST #: OLS-3

TARGET GEOMETRY (mm)

a 1073	b 718	c 1861	d 1181
e 2146	f 2153	g 953	h 1480
i 1880	j 953	k 738	l 1022

Figure 6. Vehicle Target Locations, Test OLS-3

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

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

5.4.2 Rate Transducer

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

5.4.3 High-Speed Photography

For test OLS-3, five high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. A Locam, with a wide-angle

12.5-mm lens, was placed above the test installation to provide a field of view perpendicular to the ground. A Locam with a 76 mm lens, a SVHS video camera, and a 35-mm still camera were placed downstream from the impact point and had a field of view parallel to the barrier. A Locam, with a 16 to 64-mm zoom lens, and a SVHS video camera were placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A Locam and a SVHS video camera were placed upstream and behind the barrier. Another Locam and a SVHS video camera were placed downstream and behind the barrier. A schematic of all ten camera locations for test OLS-3 is shown in Figure 7. The film was analyzed using the Vanguard Motion Analyzer. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

5.4.4 Pressure Tape Switches

For test OLS-3, five pressure-activated tape switches, spaced at 2-m intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the left-front tire of the test vehicle passed over it. Test vehicle speed was determined from electronic timing mark data recorded on "Test Point" software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

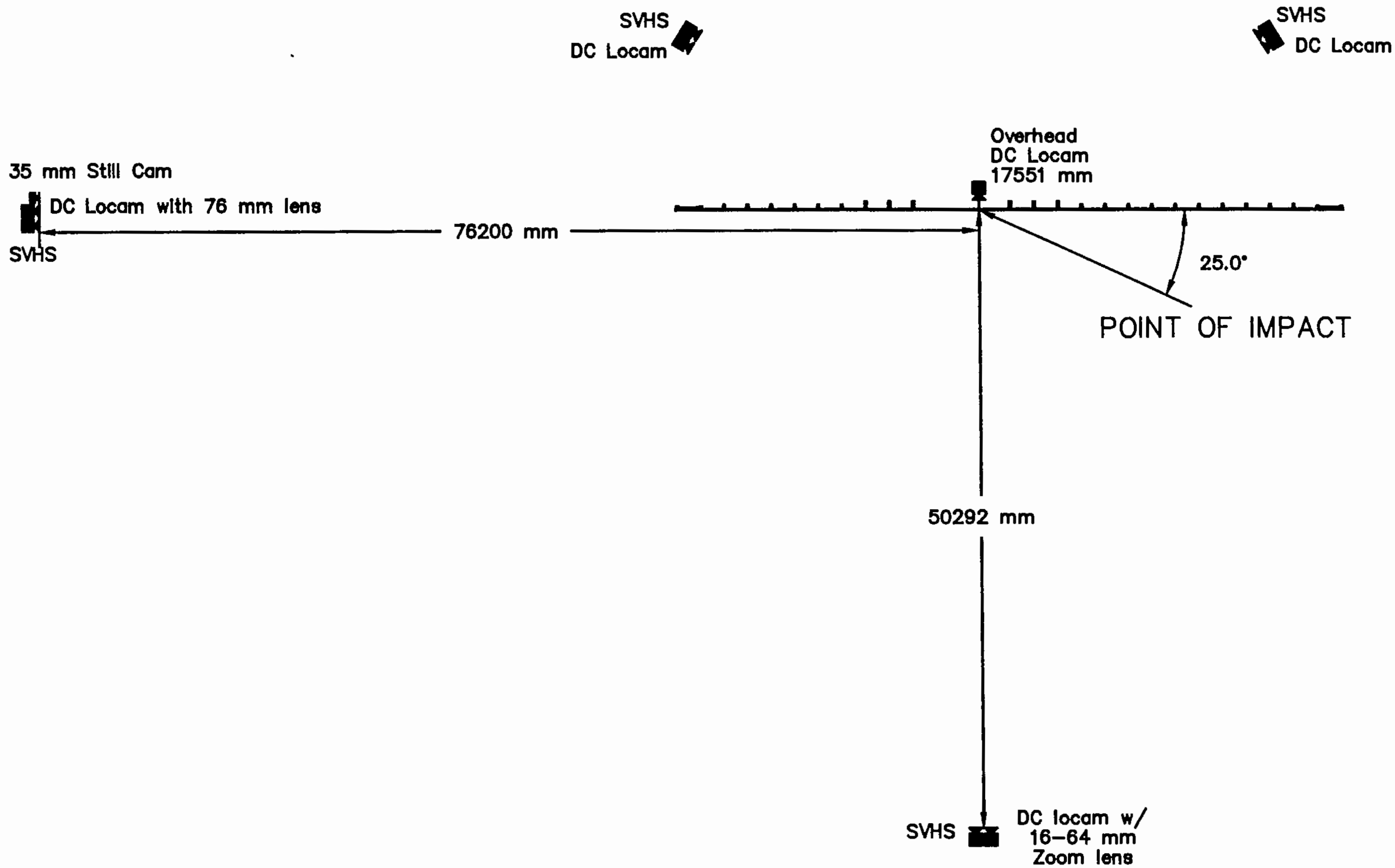


Figure 7. Location of High-Speed Cameras, Test OLS-3

6 CRASH TEST NO. 3 (DESIGN NO. 3)

6.1 Test OLS-3

The 1,994-kg pickup truck impacted the long-span guardrail system (Design No. 3) at a speed of 102.9 km/hr and an angle of 24.7 degrees. A summary of the test results and the sequential photographs are shown in Figure 8. Additional sequential photographs are shown in Figures 9 through 10. Documentary photographs of the crash test are shown in Figures 11 through 12.

6.2 Test Description

Initial impact occurred between post nos. 11 and 12 or 2.44-m downstream from the center of post no. 12, as shown in Figure 13. At 0.040 sec after impact, post no. 12 was slightly twisted in the clockwise (CW) direction. At this same time, the impacted rail flattened out while the right-front corner of the vehicle deformed inward. The right-front headlight disengaged from the vehicle at 0.064 sec. At 0.090 sec, post nos. 10 and 11 rotated backwards. At 0.132 sec, the guardrail continued to deform as post nos. 10 and 11 were rotating toward the ground. At 0.188 sec, the vehicle impacted post no. 11. At 0.212 sec, post no. 11 fractured, and the left-front tire was airborne. At 0.228 sec, post no. 9 rotated backwards. At 0.235 sec, the vehicle continued to be redirected when it yawed counter-clockwise (CCW) with the right-rear corner of the vehicle contacting the guardrail. After 0.261 sec, post no. 10 was impacted by the vehicle and subsequently fractured at 0.277 sec. The vehicle became parallel to the guardrail at 0.283 sec after impact with a velocity of 77.6 km/hr. At 0.286 sec, the left-rear tire of the vehicle was airborne. At 0.332 sec, post no. 8 rotated slightly backwards. At 0.347 sec, the right-front corner of the vehicle was at post no. 9, and the left-rear corner of the vehicle moved upward due to the twisting of the box. At 0.402 sec, the vehicle reached its maximum pitch angle of 2.3 degrees. At 0.469 sec, the vehicle exited the guardrail at a speed of 70.2 km/hr and an angle of 9.4 degrees. After 0.496 sec, the front-end of the vehicle pitched toward the ground. At 0.538 sec, the rear-end of the vehicle ascended into the air. At 0.680 sec, the vehicle reached its maximum roll angle of 10 degrees. At 1.544 sec, post no. 11 was at rest on the ground as post no. 10 descended toward the ground. At 1.722 sec, post no. 10 came to rest on the ground. The vehicle's post-impact trajectory is shown in Figure 8. The vehicle came to rest 57.37-m downstream from impact and 18.62-m laterally away from the traffic-side face of the rail, as shown in Figure 8.

6.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 14 through 18. Barrier damage consisted mostly of deformed W-beam, contact marks on a guardrail section, and deformed and fractured guardrail posts. The W-beam damage consisted of moderate deformation and flattening of the lower portion of the impacted section between post nos. 9 and 12. Contact marks were found on the guardrail between post nos. 9 and 12. The rail 533-mm downstream of post no. 11 had a major crease on the lower portion. The W-beam rail was pulled off of post nos. 3 and 4.

Two CRT posts, post nos. 10 and 11, completely fractured while CRT post nos. 9 and 12 through 14 rotated backward, as shown in Figures 16 and 17. Steel post nos. 7 through 8 and 15 through 24 were twisted slightly and pushed backward. No significant post damage occurred to post nos. 3 through 6. No significant guardrail damage occurred upstream of post no. 14 nor downstream of post no. 9.

The permanent set of the guardrail and posts is shown in Figures 14 through 18. The cable anchor ends encountered slight permanent set deformations, as shown in Figure 18. The maximum lateral permanent set rail and post deflections were approximately 1,016 mm at 953-mm upstream from the centerline of post no. 11 and 362 mm at post no. 9, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 1,450 mm at 1,905-mm upstream from the centerline of post no. 11 and 894 mm at post no. 11, respectively, as determined from the high-speed film analysis.

6.4 Vehicle Damage

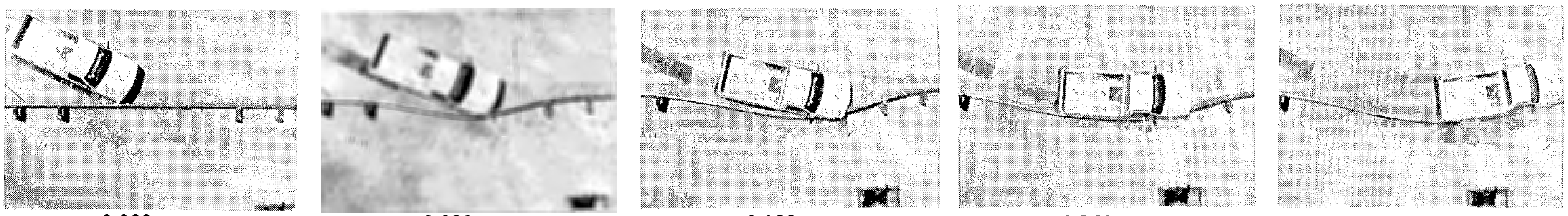
Exterior vehicle damage was minimal, as shown in Figure 19. Interior occupant compartment deformations were determined to be negligible. The right-front quarter panel was crushed inward, and the right side of the front bumper was also bent back toward the engine compartment. The right-front wheel assembly was deformed slightly, including contact marks on the rim. Small contact marks were found on the lower right side of the rear fender, the right-rear bumper, the lower right side of the truck box, and the right-side door. The right side of the box shifted downward and was twisted. No other damage to the vehicle was observed.

6.5 Occupant Risk Values

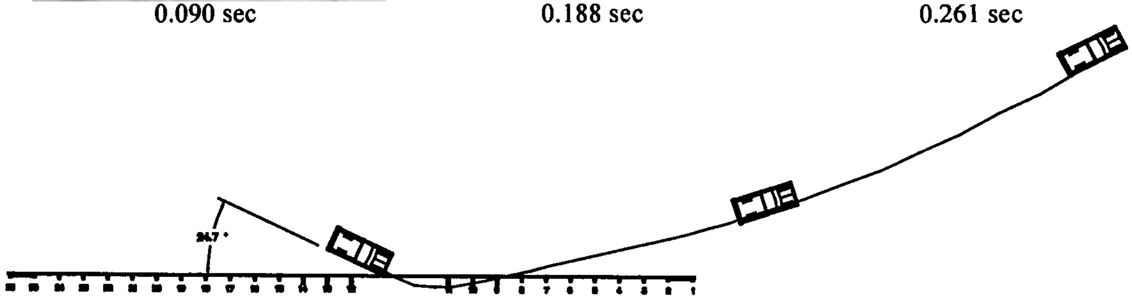
The normalized longitudinal and lateral occupant impact velocities were determined to be 3.72 m/sec and 4.96 m/sec, respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 7.28 g's and 10.10 g's, respectively. It is noted that the occupant impact velocities (OIV) and occupant ridedown decelerations (ORD) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 8. Results are shown graphically in Appendix A. The results from the rate transducer are shown graphically in Appendix B.

6.6 Discussion

The analysis of the test results for test OLS-3 showed that the long-span guardrail adequately contained and redirected the vehicle with controlled lateral displacements of the guardrail. Detached elements and debris from the test article did not penetrate or show potential for penetrating the occupant compartment. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The vehicle remained upright during and after collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle's trajectory intruded slightly into adjacent traffic lanes but was determined to be acceptable. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test OLS-3 conducted on Design No. 3 of the Ohio Long-Span Guardrail System was determined to be acceptable according to the NCHRP Report No. 350 criteria.



0.000 sec | 0.090 sec | 0.188 sec | 0.261 sec | 0.407 sec



- Test Number OLS-3
- Date 5/26/99
- Appurtenance . . . . Nested W-beam long-span guardrail system
- Total Length . . . . 53.34 m
- Steel W-Beam (Nested)
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 706 mm
- Steel Posts
  - Post Nos. 3 - 8, 15 - 24 . . . . . . W150x13.5 by 1,830-mm long
- Wood Posts
  - Post Nos. 9 - 14 (CRT) . . . . . . 150 mm x 200 mm by 1,830-mm long
  - Post Nos. 1 - 2, 25 - 26 (BCT) 140 mm x 190 mm by 1,080-mm long
- Wood Spacer Blocks
  - Post Nos. 3 - 8, 15 - 22 . . . . . . 150 mm x 200 mm by 360-mm long
  - Post Nos. 9 - 14 . . . . Two 150 mm x 200 mm by 360-mm long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1992 Chevrolet 2500 2WD
  - Curb . . . . 1,882 kg
  - Test Inertial . . . . 1,994 kg
  - Gross Static . . . . 1,994 kg
- Vehicle Speed
  - Impact . . . . 102.4 km/hr
  - Exit . . . . 70.2 km/hr
- Vehicle Angle
  - Impact . . . . 24.7 degrees
  - Exit . . . . 9.4 degrees
- Vehicle Snagging . . . . None
- Vehicle Pocketing . . . . None
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 7.28 < 20 G's
  - Lateral (not required) 10.10
- Occupant Impact Velocity (Normalized)
  - Longitudinal . . . . 3.72 < 12 m/s
  - Lateral (not required) 4.96
- Vehicle Damage . . . . Minimal
  - TAD[14] 1-RFQ-3
  - SAE[15] 1-RFEE3
- Vehicle Stopping Distance . . . . 57.37 m downstream
  18.62 m traffic-side face
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set . . . . 1,016 mm
  - Dynamic . . . . 1,450 mm

Figure 8. Summary of Test Results and Sequential Photographs, Test OLS-3 (Design No. 3)

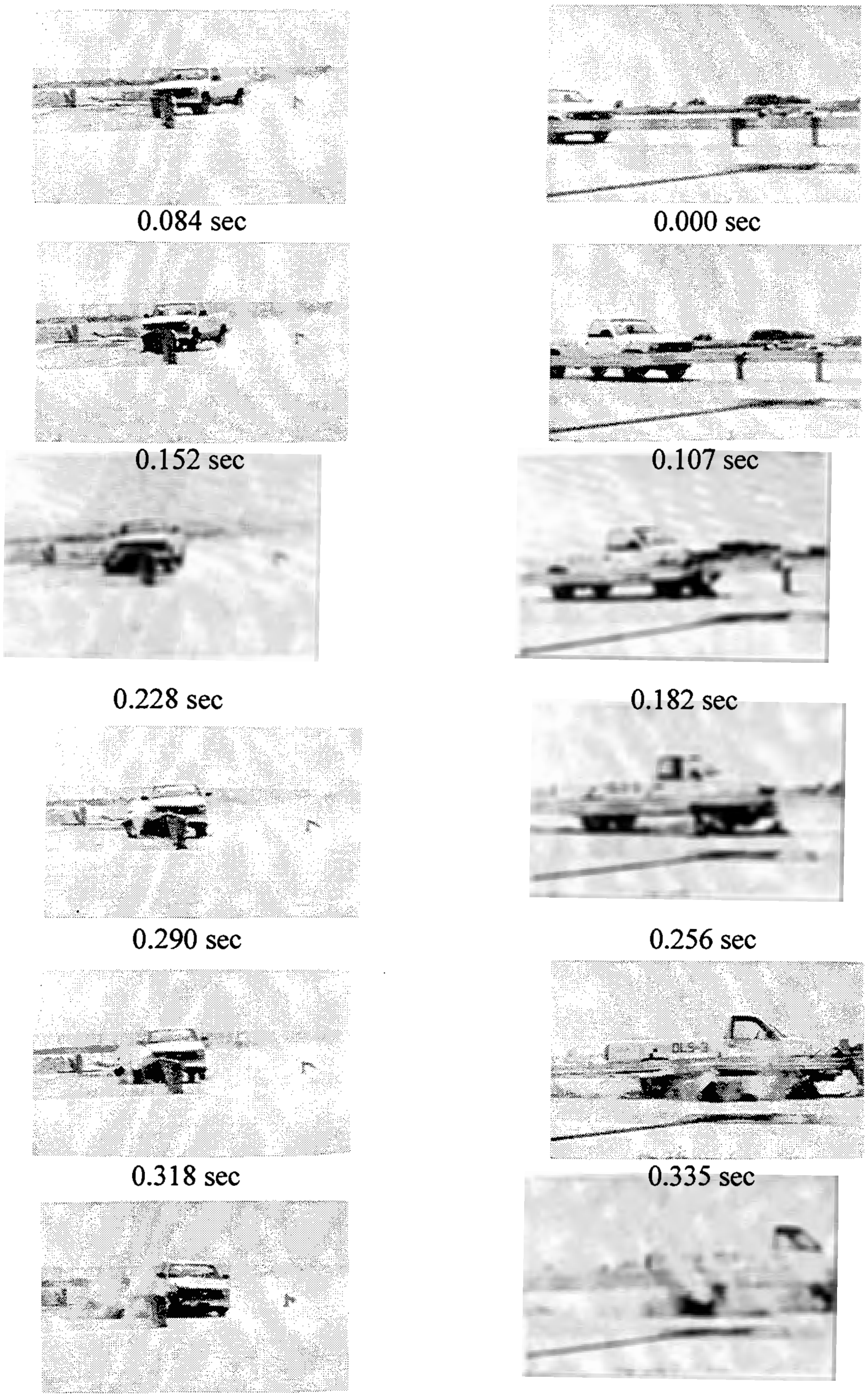


Figure 9. Additional Sequential Photographs, Test OLS-3 (Design No. 3)

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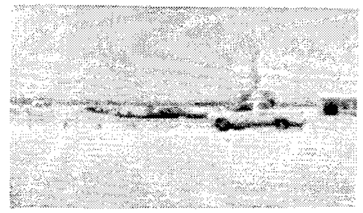

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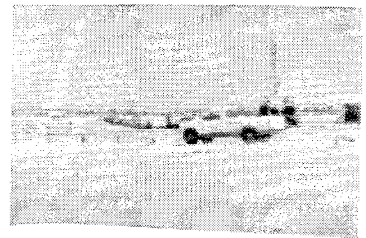
0.144 sec



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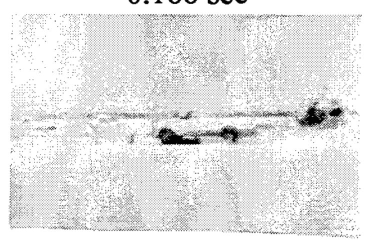
0.188 sec

0.244 sec



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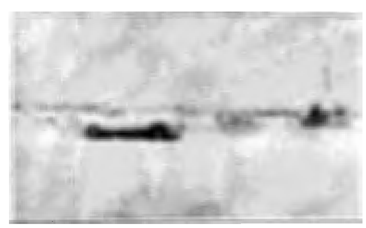

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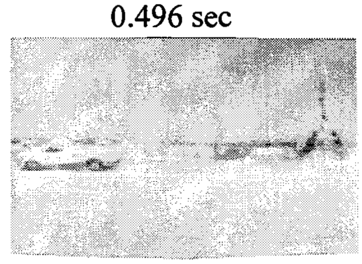
0.374 sec



0.678 sec

Figure 10. Additional Sequential Photographs, Test OLS-3 (Design No. 3)

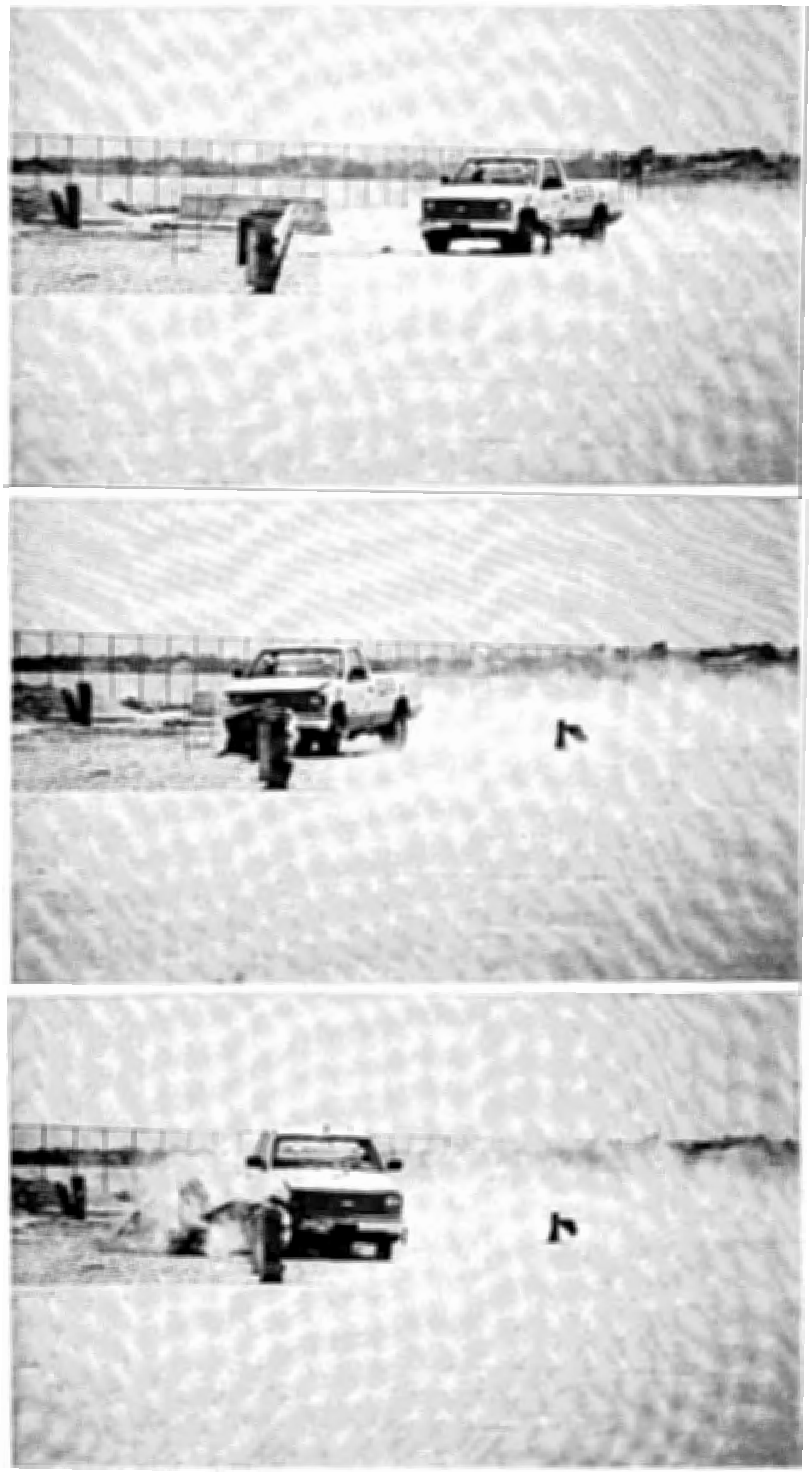


Figure 11. Documentary Photographs, Test OLS-3 (Design No. 3)

Figure 12. Documentary Photographs, Test OLS-3 (Design No. 3)

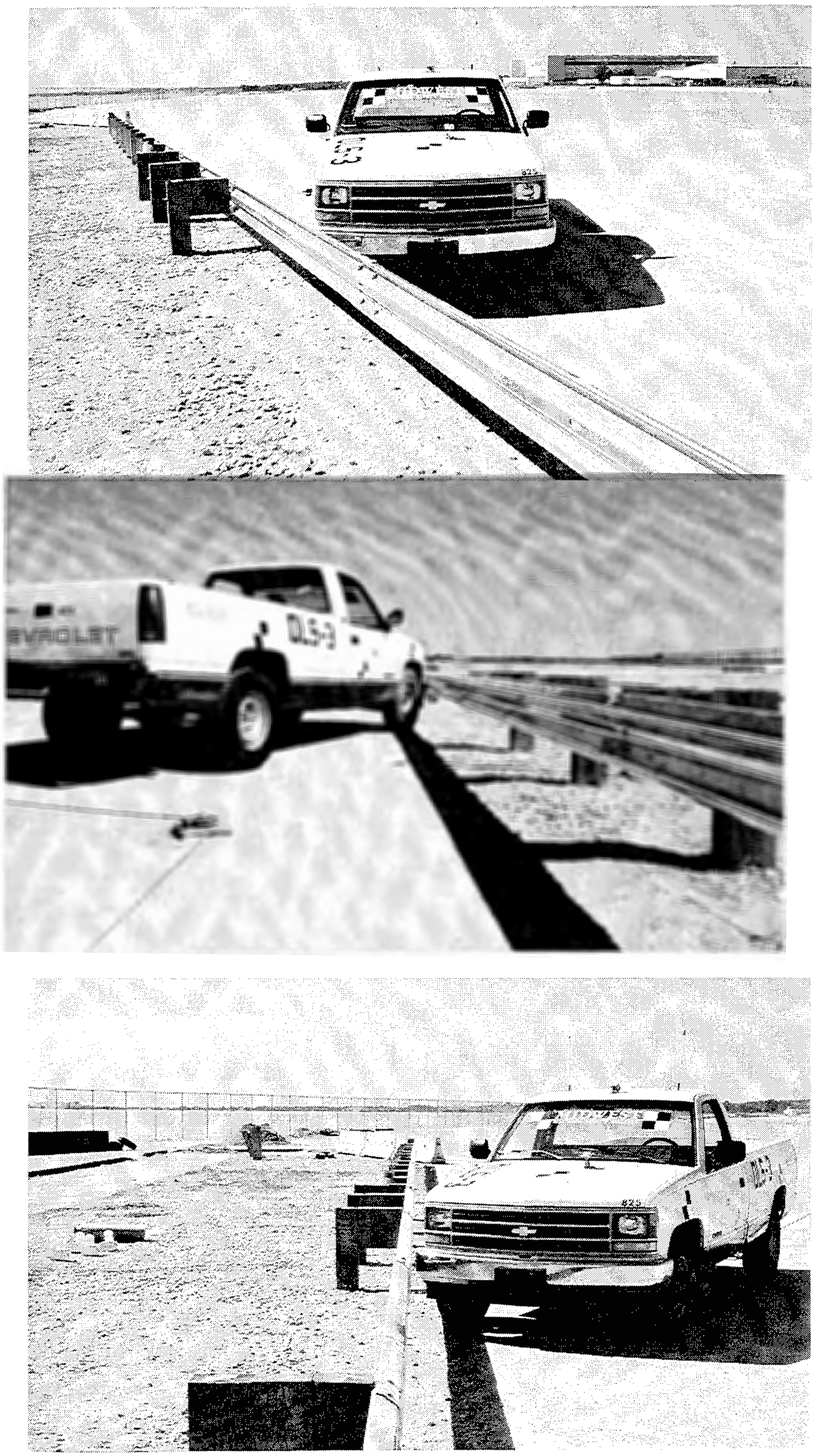


Figure 13. Impact Location, Test OLS-3 (Design No. 3)

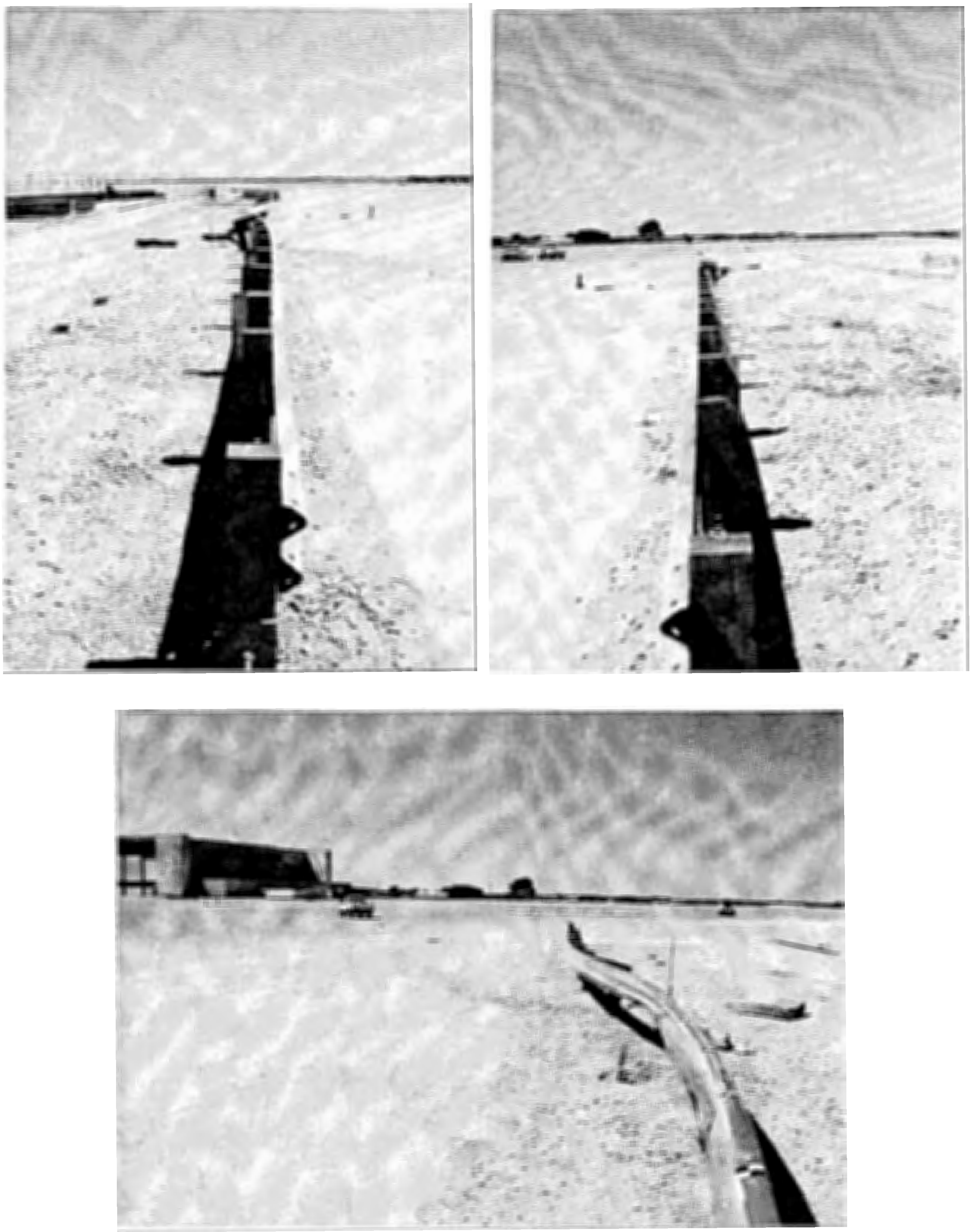
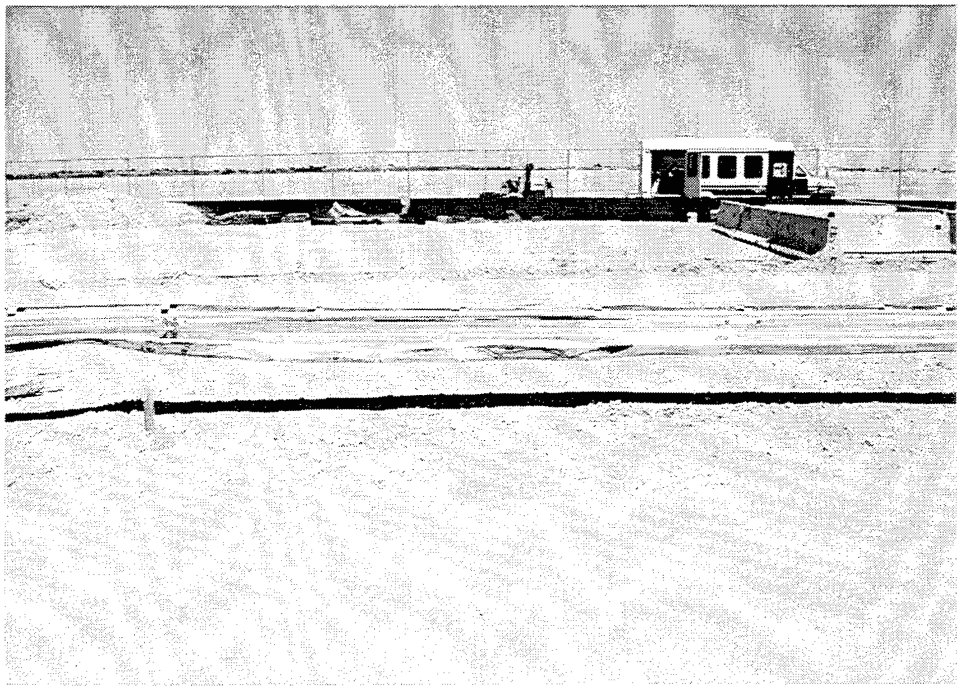


Figure 14. Long-Span Guardrail System Damage, Test OLS-3 (Design No. 3)



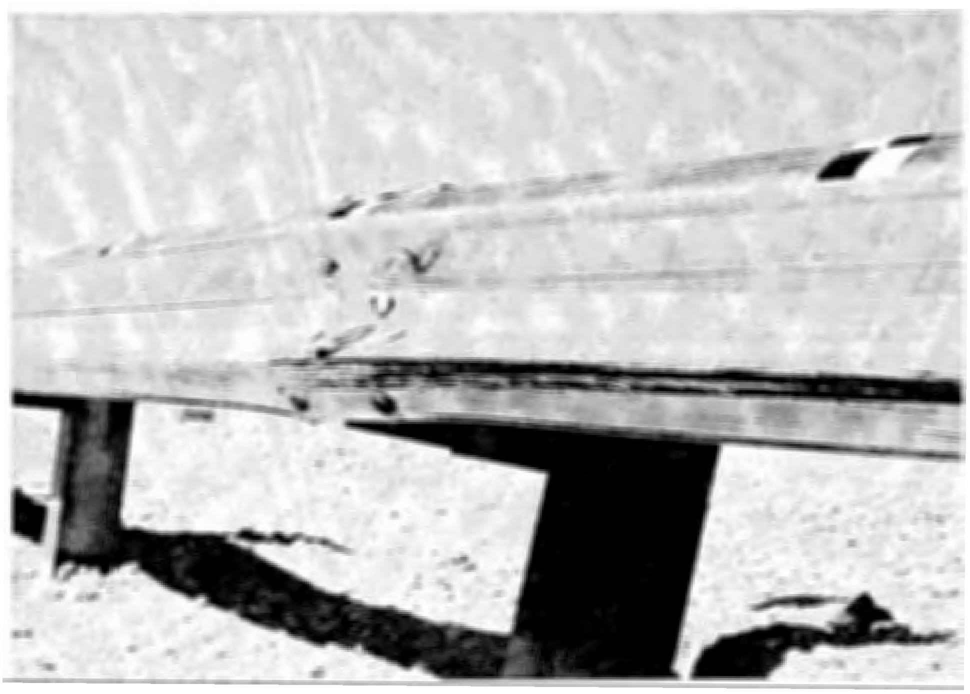


Figure 15. Long-Span Guardrail System Rail Damage, Test OLS-3 (Design No. 3)

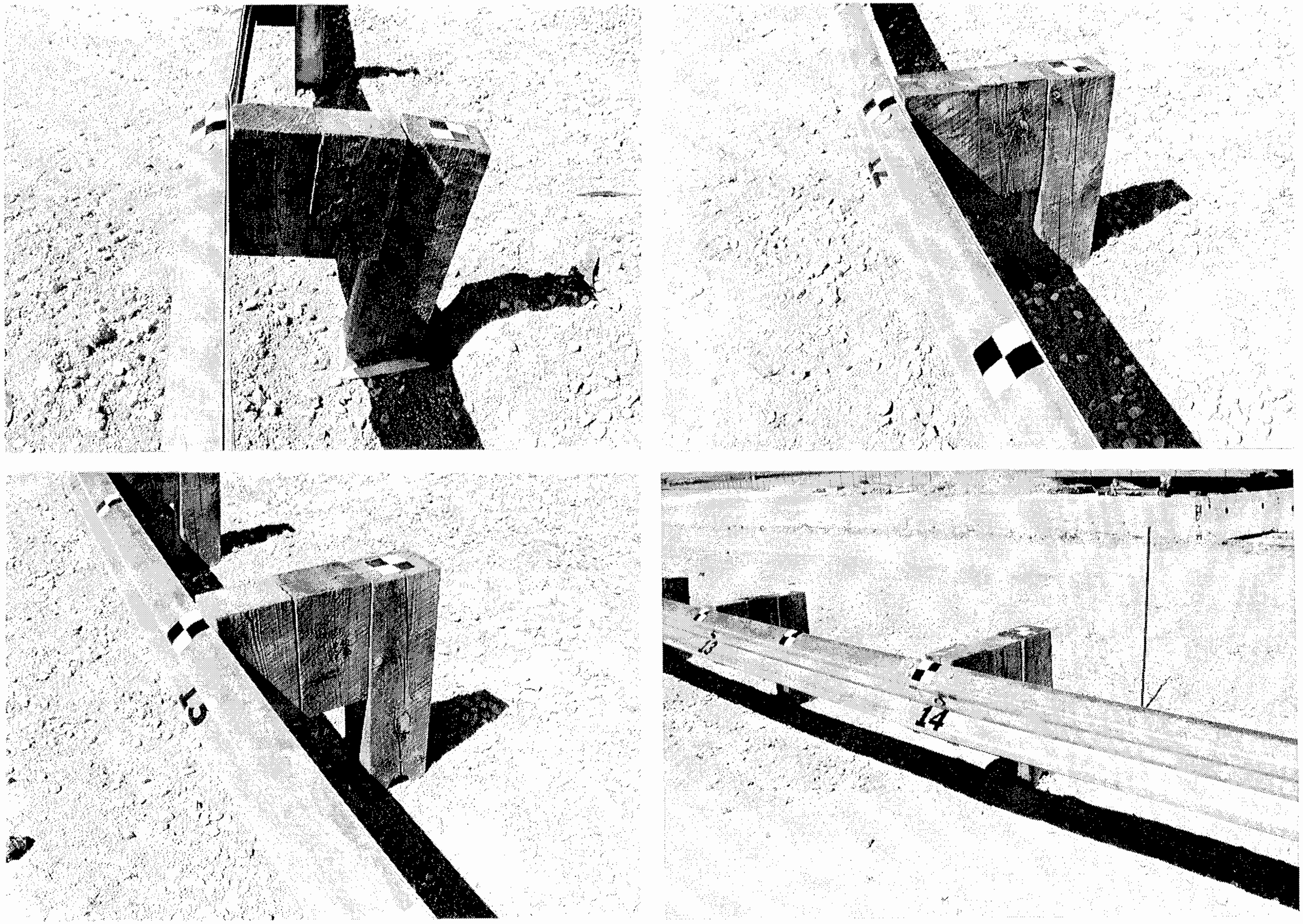


Figure 16. Final CRT Post Nos. 9, 12, 13, and 14 Positions, Test OLS-3 (Design No. 3)

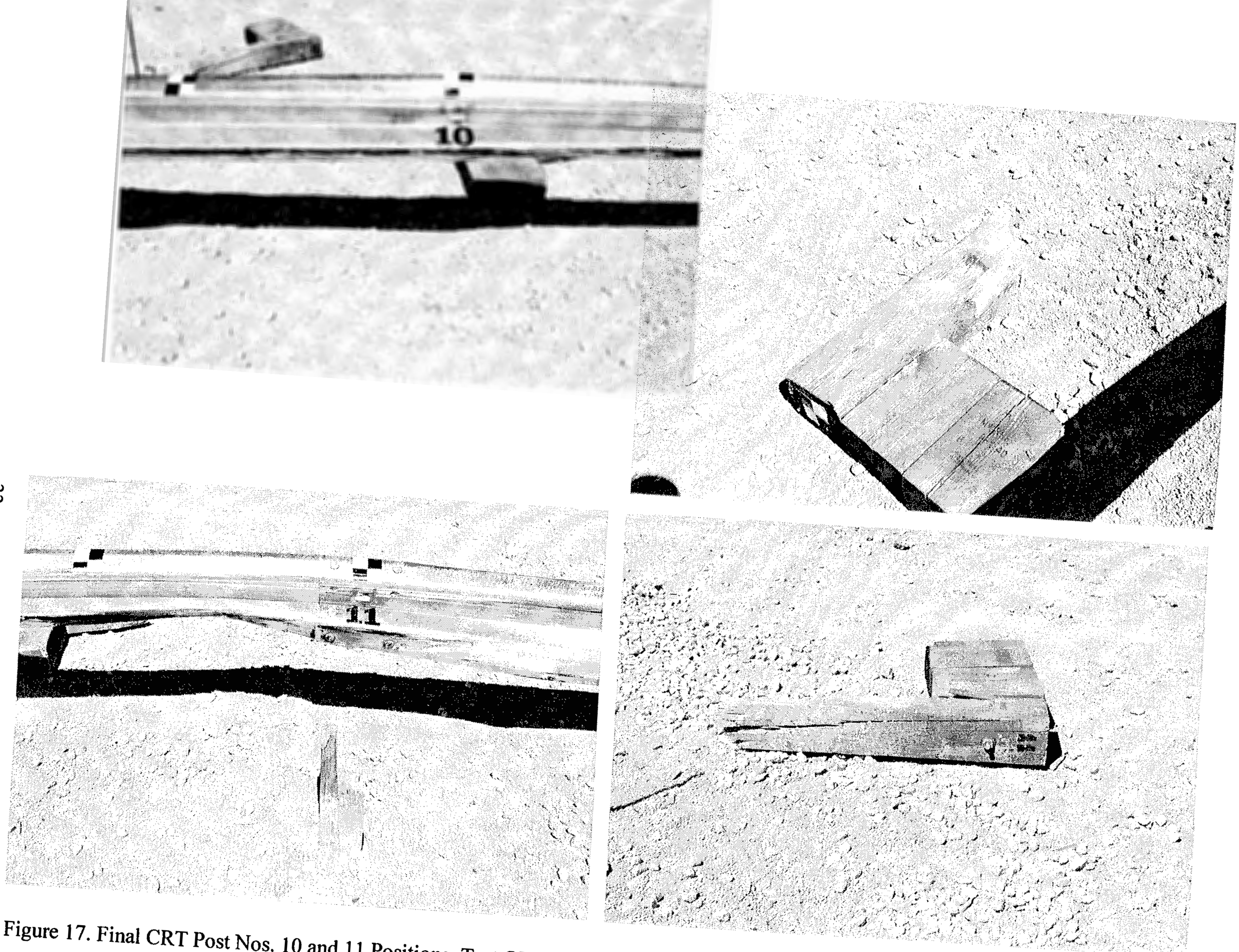


Figure 17. Final CRT Post Nos. 10 and 11 Positions, Test OLS-3 (Design No. 3)

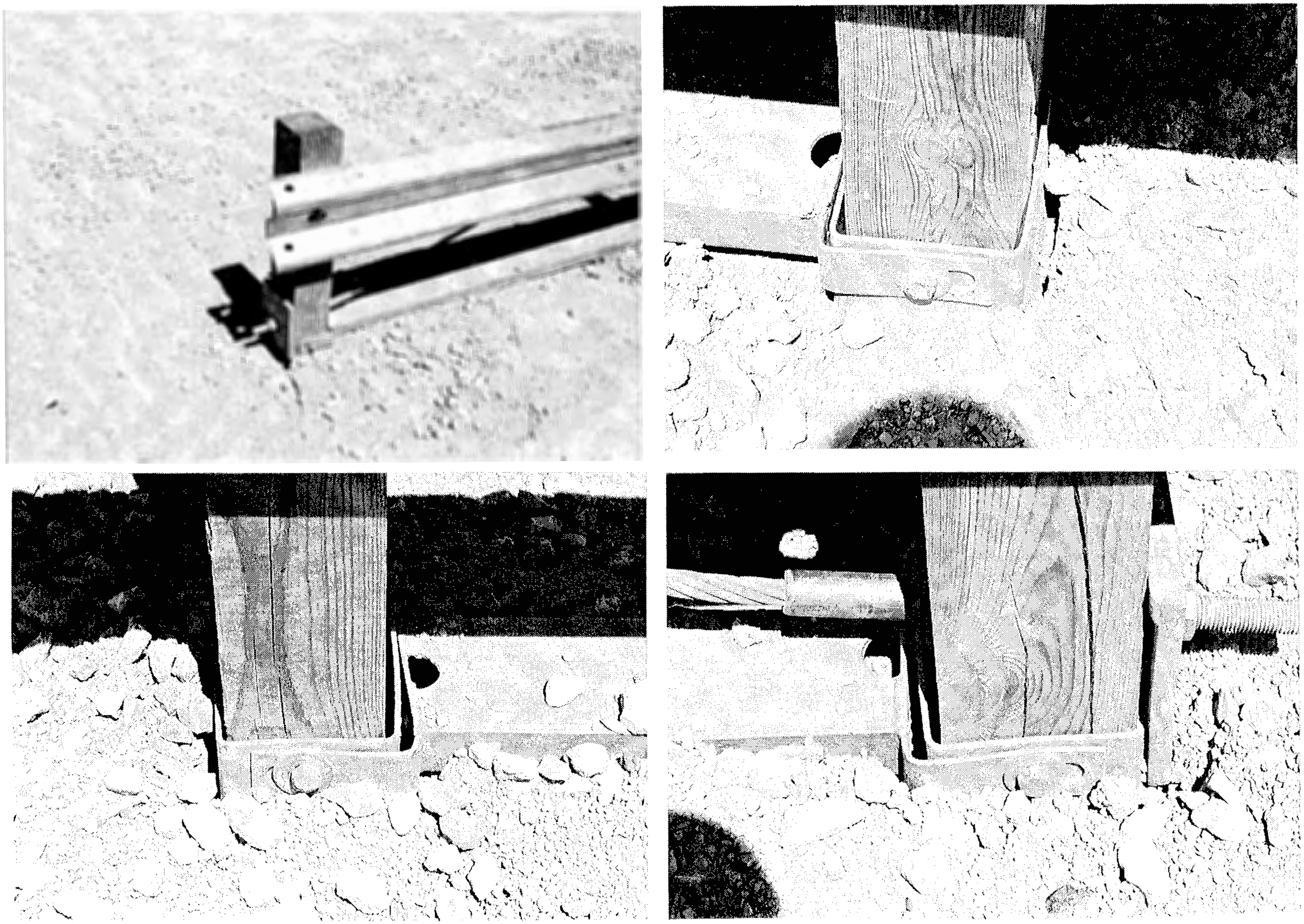


Figure 18. Permanent Set Deflections, Test OLS-3 (Design No. 3)

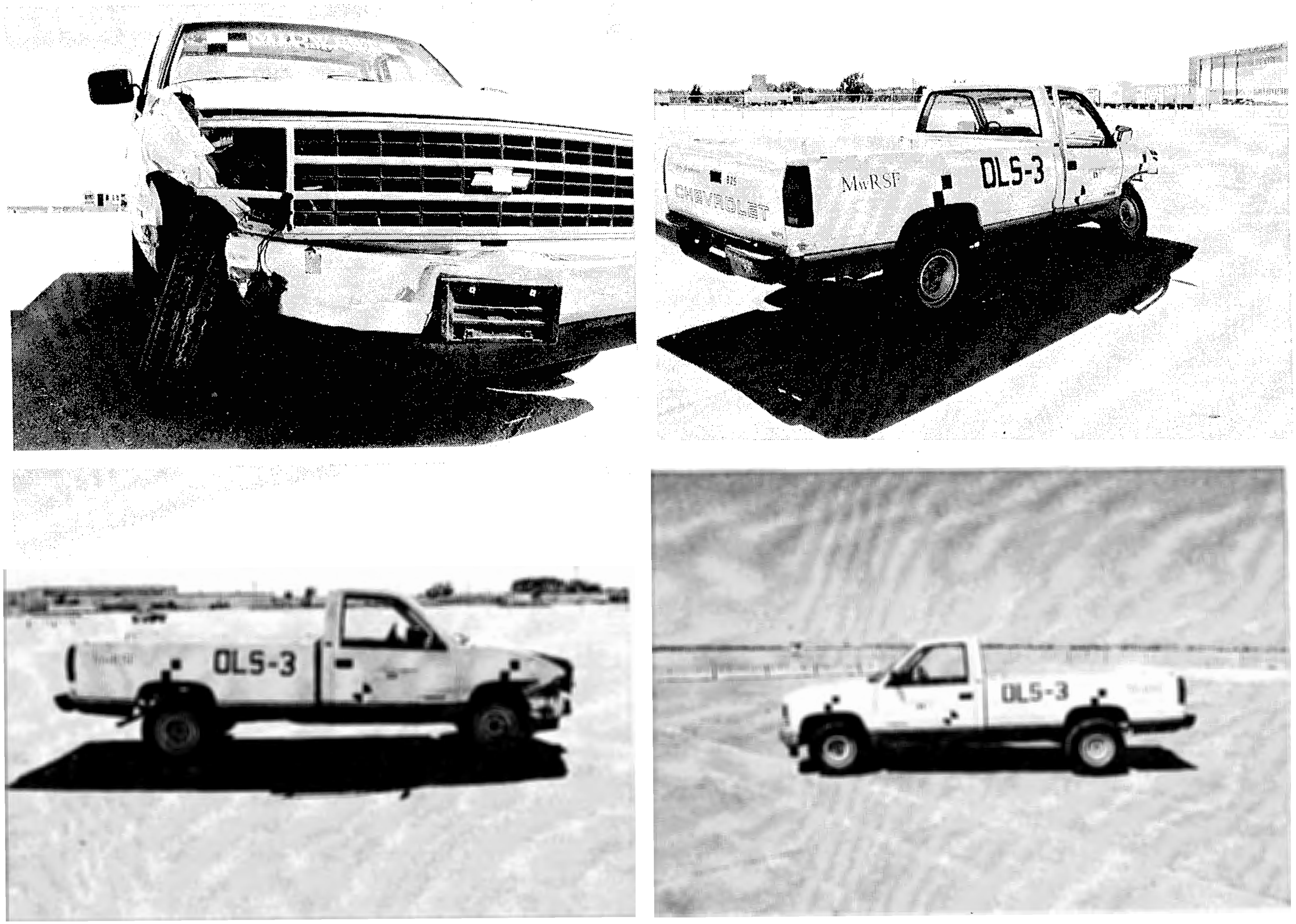


Figure 19. Vehicle Damage, Test OLS-3 (Design No. 3)

7 SUMMARY AND CONCLUSIONS

A long-span guardrail design for use over low-fill culverts was developed and full-scale vehicle crash tested. The long-span guardrail system was configured with a 30.48-m long, nested W-beam rail and incorporated an unsupported length of guardrail equal to 7.62 m. A full-scale vehicle crash test was performed with a ¾-ton pickup truck on the guardrail system and was determined to be acceptable according to the TL-3 safety performance criteria presented in NCHRP Report No. 350. A summary of the safety performance evaluation is provided in Table 2.

Table 2. Summary of Safety Performance Evaluation Results - Long-Span Guardrail System

Evaluation Factors	Evaluation Criteria	Test OLS-3 (Design No. 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)
M - (Marginal)
U - (Unsatisfactory)
NA - Not Available

8 RECOMMENDATIONS

A long-span guardrail system designed for use over low-fill culverts, as described in this report, was successfully crash tested according to the criteria found in NCHRP Report No. 350. The results of this test indicate that this design is a suitable design for use on Federal-aid highways. It is suggested that the research described herein could be further developed using the data collected from testing to modify future designs of different lengths. However, any design modifications made to the long-span guardrail system may require verification through the use of full-scale vehicle crash testing.

The long-span guardrail system (Design No. 3), as shown in Figures 1 through 3, was constructed with a rail splice at the midspan of the 7.62-m unsupported length of nested W-beam. Since crash testing has shown this design to be acceptable where a reduced cross-section exists in the steel splice, other variations in splice location would also be acceptable, such as using a 7.62-m long nested rail in the unsupported region. For Design No. 3, the length-of-need guardrail posts, post nos. 3 through 8 and 15 through 24, were configured using steel sections. However, the researchers believe that acceptable performance would also be achieved with the use of any other NCHRP Report No. 350 compliant longitudinal W-beam guardrail systems.

The crash tests described herein were performed on a test installation which did not include a concrete box culvert, headwall, and wingwall. In actual field applications, a concrete headwall would typically extend above the low-fill soil, run parallel to the roadway, and prevent the soil from eroding over the culvert end. For this situation, if the headwall is placed too close to the guardrail, a potential exists for the vehicle's wheel or fractured CRT posts to contact the headwall. If significant wheel contact occurs with the headwall or post debris striking the headwall, vehicular instabilities or rollover may result. Analysis of the OLS-3 crash test results revealed that a maximum lateral dynamic rail deflection of 1.45 m was observed. During this event, the vehicle's right-front wheel was also found to protrude under the deformed guardrail. In order to minimize or eliminate the potential for wheel contact on the culvert headwall or post debris wedged between the headwall, it is recommended that the back face of the guardrail be positioned a minimum of 1.5 m away from the front face of the headwall.

As mentioned previously, the final long-span guardrail system was constructed with 30.48-m of nested W-beam rail, as shown in Figure 1. On the crash-tested installation, two 7.62-m long, single W-beam rails or 15.24-m total were placed upstream of the nested region, while one 7.62-m long, W-beam rail was placed downstream of the nested region. This configuration provided an asymmetrical layout about the centerline of the system which was believed to be more common in actual field installations. Typically, longer guardrail runout lengths would be required on the upstream end of the obstruction. However, the system could be installed in a symmetrical manner with a standard guardrail terminal placed beyond each end of nested W-beam rail. For a standard guardrail terminal length of 11.34 m, the total installation length would be approximately 53.34 m, which was also the final length of the asymmetrical crash-tested design.

Finally, the guardrail system was configured with the entire length installed tangent. However, in actual field installations, this guardrail system can be installed with either one or two ends flared away from the traveled way. For locations where a guardrail flare will be used, the minimum recommended length of tangent section adjacent to the unsupported length is 7.62 m. Flare rates should follow the recommended guidelines provided in AASHTO's *Roadside Design Guide* (16).

9 REFERENCES

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10 APPENDICES

APPENDIX A

Accelerometer Data Analysis, Test OLS-3

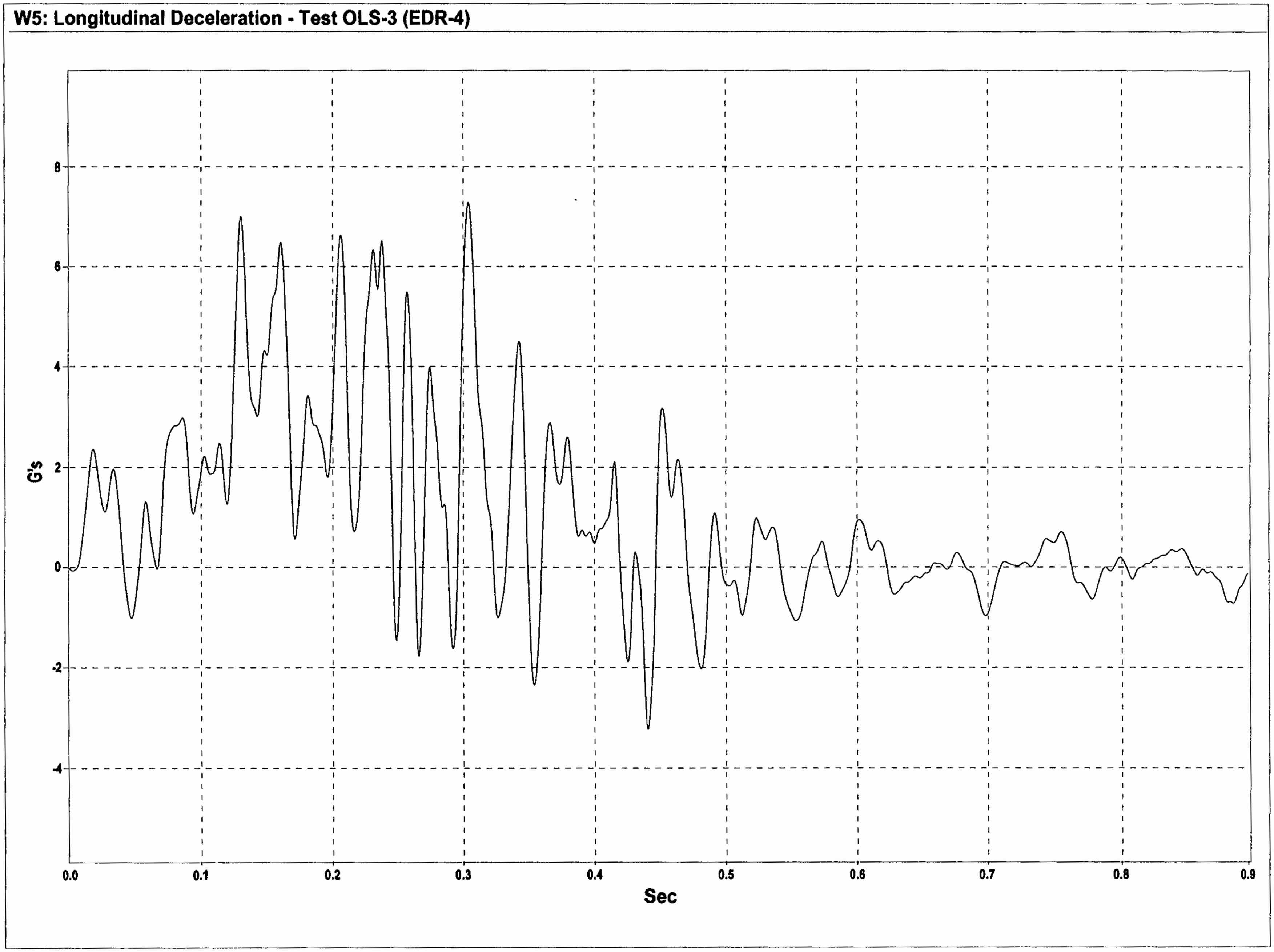

Figure A-1. Graph of Longitudinal Deceleration, Test OLS-3

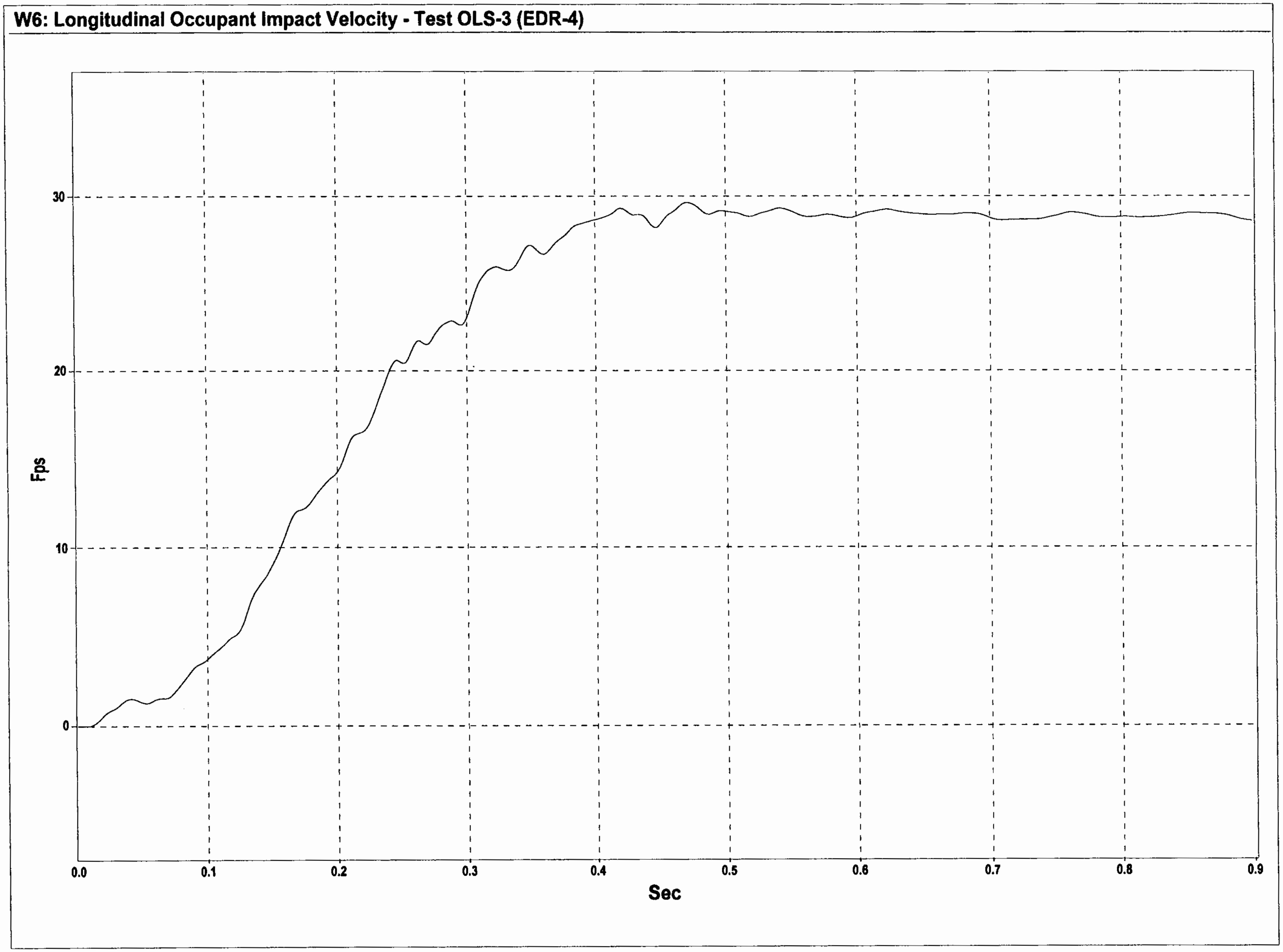

Figure A-2. Graph of Longitudinal Occupant Impact Velocity, Test OLS-3

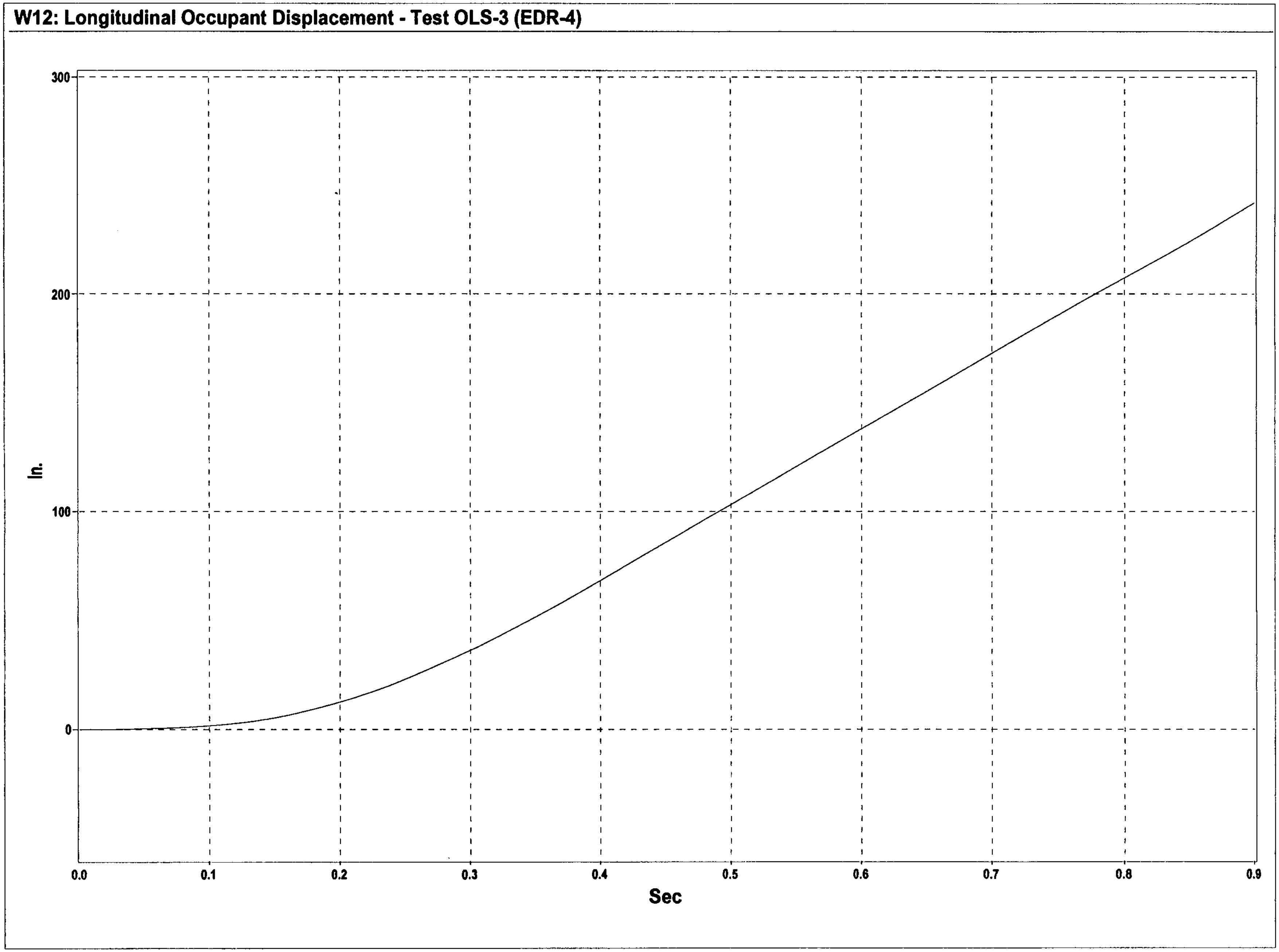

Figure A-3. Graph of Longitudinal Occupant Displacement, Test OLS-3

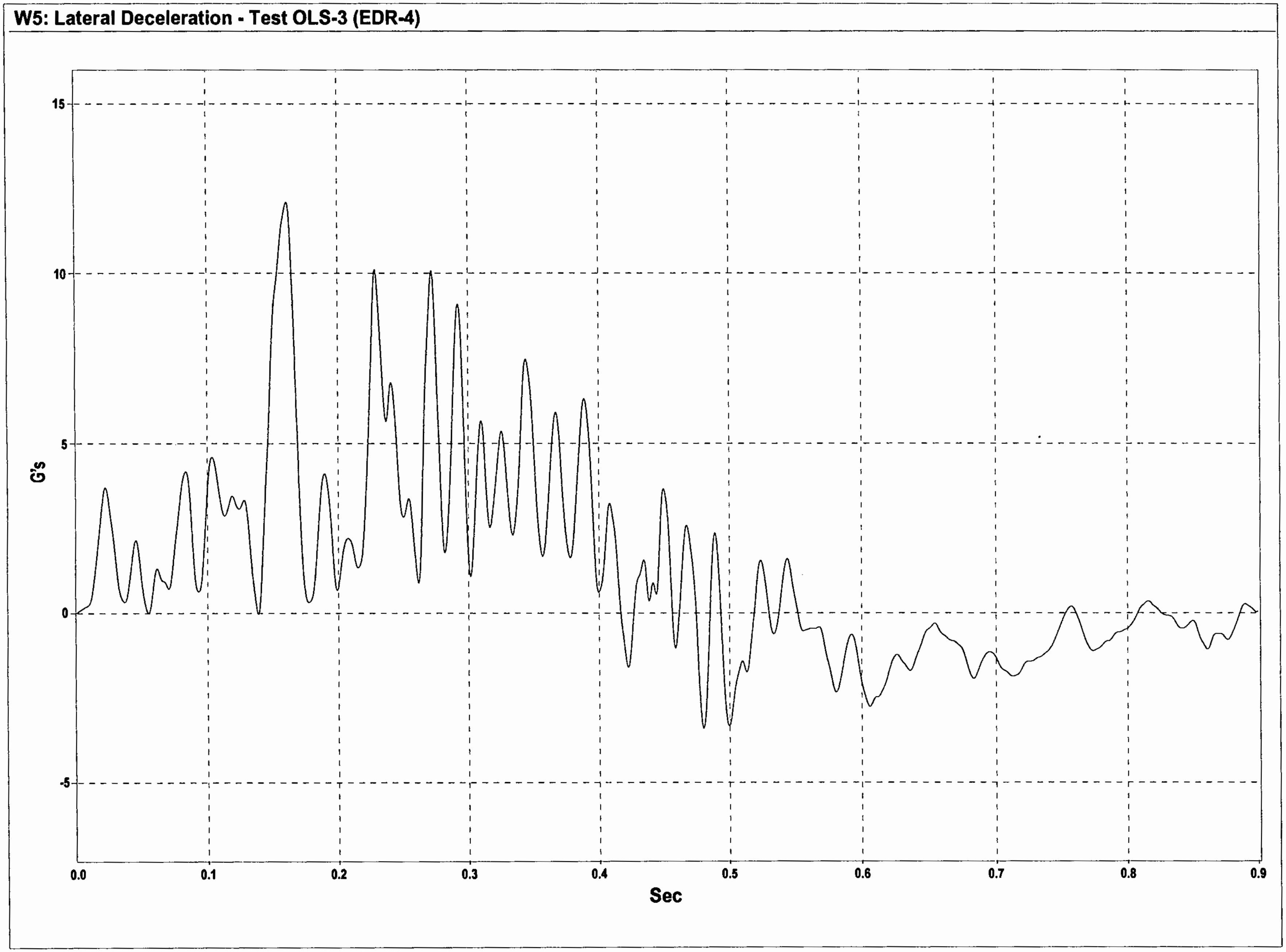

Figure A-4. Graph of Lateral Deceleration, Test OLS-3

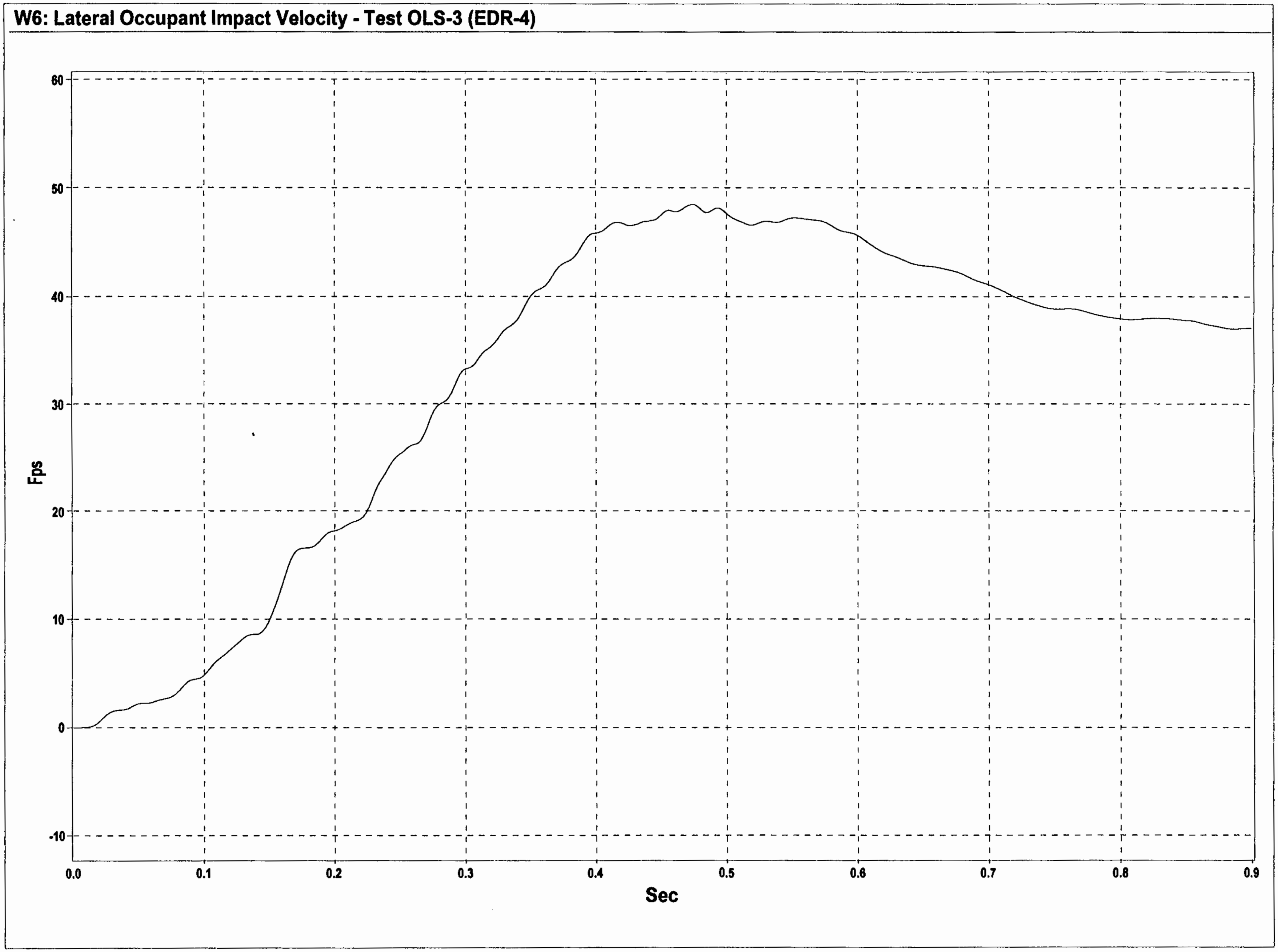

Figure A-5. Graph of Lateral Occupant Impact Velocity, Test OLS-3

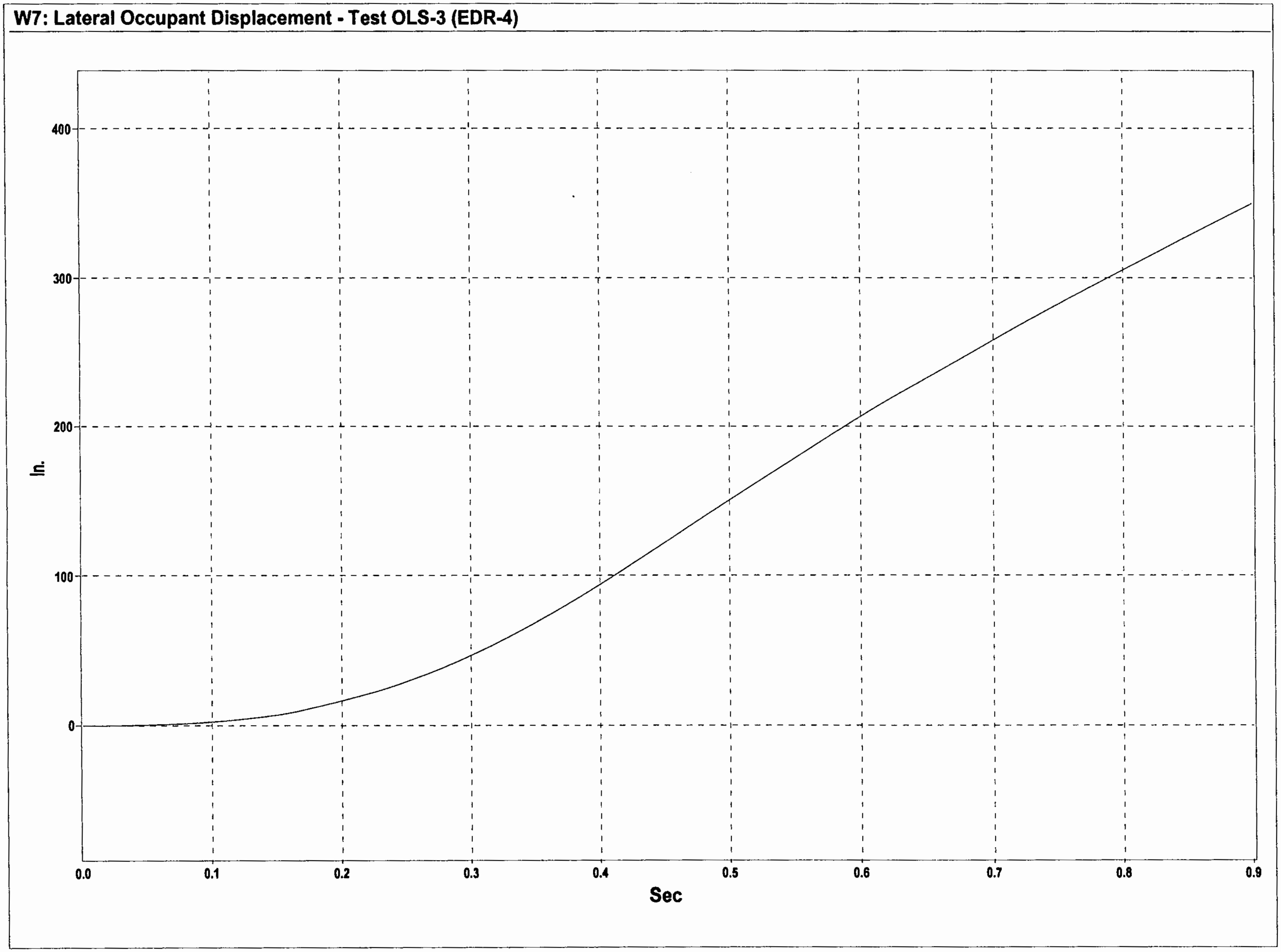

Figure A-6. Graph of Lateral Occupant Displacement, Test OLS-3

APPENDIX B

Rate Transducer Data Analysis, Test OLS-3

Figure B-1. Graph of Roll, Pitch, and Yaw Angular Displacements, Test OLS-3

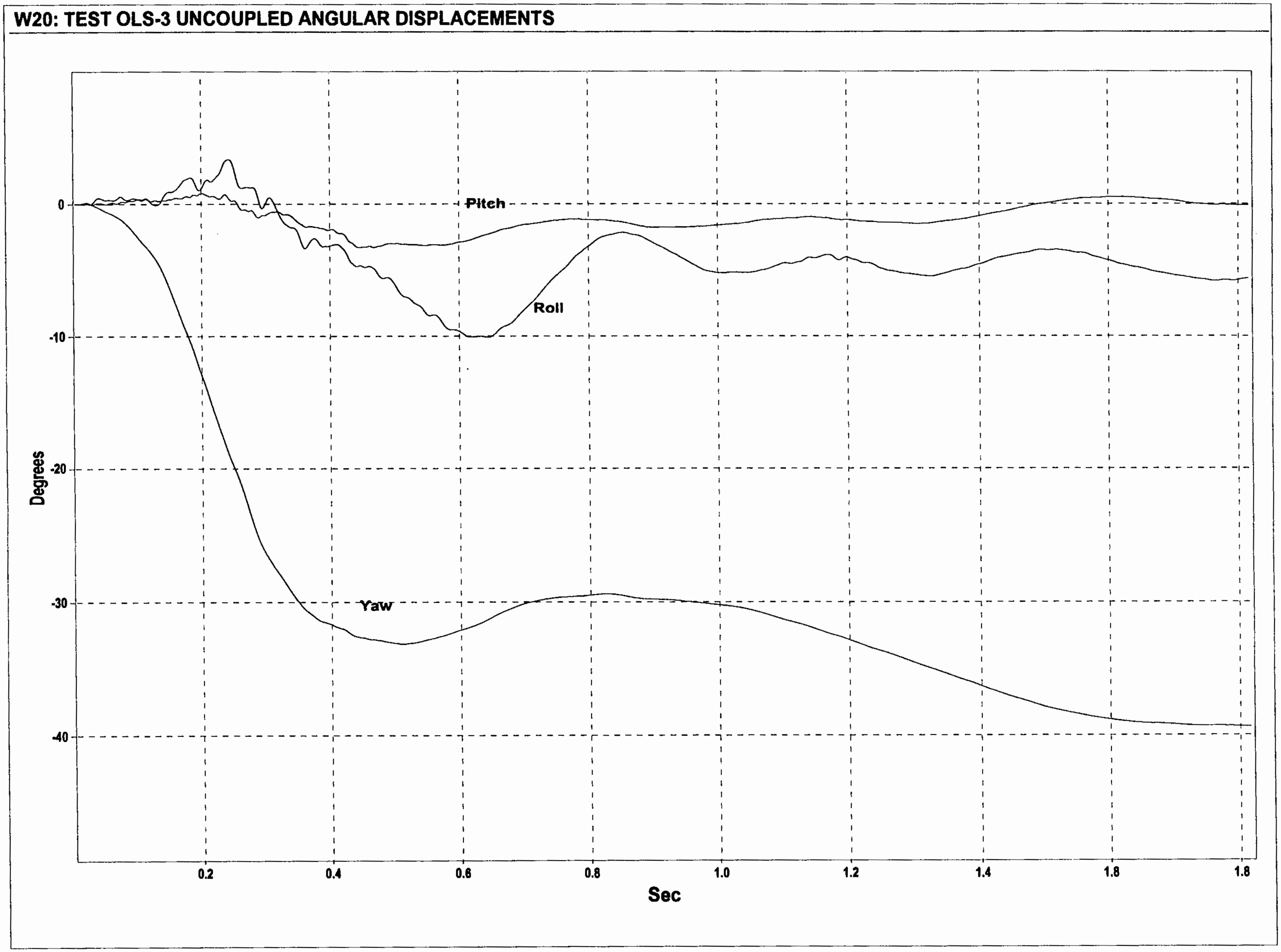

Figure B-1. Graph of Roll, Pitch, and Yaw Angular Displacements, Test OLS-3