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EVALUATION OF A MODIFIED STEEL POST W-BEAM GUARDRAIL SYSTEM

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16. Abstract

In May 1993, a set of revised test procedures was published in National Cooperative Highway Research Program (NCHRP) Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features." The Federal Highway Administration (FHWA) formally adopted these new test procedures and has mandated that, after September 30, 1998, only highway safety appurtenances that have successfully met these guidelines may be used in new projects on the National Highway System (NHS).

The most significant change made in the new guidelines with regard to the evaluation of longitudinal barriers was the adoption of a 2000-kg pickup truck (2000P) as a design test vehicle. Since most existing longitudinal barriers have been tested with a large passenger sedan, it was necessary to reevaluate the performance of these barriers with the new pickup truck test vehicle. As part of this reevaluation process, the Federal Highway Administration (FHWA) sponsored the crash testing of many commonly used guardrail systems. A test of the widely used G4(1S) steel post W-beam guardrail system indicated that this system was not in compliance with the new NCHRP Report 350 guidelines.

This report presents the results of a crash test on a modified steel post, W-beam guardrail system that incorporates 152-mm × 152-mm routed wood blockouts. This modified steel post guardrail system successfully met the performance evaluation criteria of NCHRP Report 350. Although the vehicle became completely airborne during the impact sequence, it remained upright and was successfully contained and redirected.

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IMPLEMENTATION RECOMMENDATIONS

Based on the results of the crash test reported herein, the modified TxDOT steel post W-beam guardrail system with 152-mm × 152-mm routed wood blockouts is considered suitable for implementation. Should TxDOT decide to implement this system, it should be incorporated into TxDOT standards through revision of standard drawing MBGF-95A(M). This roadway standard is currently maintained by the Design Division.

DISCLAIMER

ACKNOWLEDGMENT

The TxDOT project director for this research was Mr. Mark A. Marek, P.E. from the Design Division. Mr. Marek's assistance is acknowledged and appreciated.

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SUMMARY

In May 1993, a set of revised test procedures was published in National Cooperative Highway Research Program (NCHRP) Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features." The Federal Highway Administration (FHWA) formally adopted these new test procedures and has mandated that, after September 30, 1998, only highway safety appurtenances that have successfully met these guidelines may be used in new projects on the National Highway System (NHS).

The most significant change made in the new guidelines with regard to the evaluation of longitudinal barriers was the adoption of a 2000-kg pickup truck (2000P) as a design test vehicle. Since most existing longitudinal barriers have been tested with a large passenger sedan, it was necessary to reevaluate the performance of these barriers with the new pickup truck test vehicle. As part of this reevaluation process, the Federal Highway Administration (FHWA) sponsored the crash testing of many commonly used guardrail systems. A test of the widely used G4(1S) steel post W-beam guardrail system indicated that this system was not in compliance with the new NCHRP Report 350 guidelines.

This report presents the results of a crash test on a modified steel post, W-beam guardrail system that incorporates 152-mm × 152-mm routed wood blockouts. This modified steel post guardrail system successfully met the performance evaluation criteria of NCHRP Report 350. Although the vehicle became completely airborne during the impact sequence, it remained upright and was successfully contained and redirected.

I. INTRODUCTION

The crashworthiness of roadside safety appurtenances such as guardrail, guardrail end terminals, guardrail-to-bridge rail transitions, and other traffic barriers must be demonstrated before they can be implemented on a roadway or roadside. The evaluation of these devices typically involves full-scale crash testing. In May 1993, a set of revised test procedures was published in National Cooperative Highway Research Program (NCHRP) Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features."[1] By a final rule in Federal Register Vol. 58, No. 135, dated July 16, 1993, the Federal Highway Administration (FHWA) formally adopted these new test procedures as a "Guide or Reference" document in 23 CFR part 625.5. FHWA has also mandated that, after September 30, 1998, only highway safety appurtenances that have successfully met the performance evaluation guidelines contained in NCHRP Report 350 may be used on new projects on the National Highway System (NHS).

Changes incorporated into the new NCHRP Report 350 guidelines include new design test vehicles, expanded test matrices, and revised impact conditions. The most significant change made in new guidelines with regard to the evaluation of longitudinal barriers was the adoption of a 2000-kg pickup truck (2000P) as a design test vehicle. Since most existing longitudinal barriers were tested with a large passenger sedan according to the previous guidelines contained in NCHRP Report 230,[2] it was necessary to reevaluate the performance of these barriers under the new pickup truck test vehicle.

As part of this reevaluation process, the Federal Highway Administration (FHWA) sponsored the crash testing of many commonly used guardrail systems. [3] This testing indicated that the widely used G4(1S) steel post W-beam guardrail system was not in compliance with the new guidelines. This system consists of a 12-ga. W-beam rail mounted on W150×13.5 steel posts at a height of 550 mm to the center of the rail. The posts are embedded 1118 mm in the ground and are spaced at 1905 mm. Steel W150×13.5 blockouts are used between the post and the rail element in the standard design. During the test, the 2000P test vehicle rolled 90 degrees onto its side on the traffic side of the barrier.

A subsequent test of a modified G4(1S) guardrail was successful. The modified system was identical in construction to the standard system with the exception of replacing the W150×13.5 steel blockout with a nominal 152 mm × 203 mm routed wood blockout. During this test, the 2000P test vehicle remained upright and stable, and the system was judged to have met all applicable evaluation criteria. Besides the obvious difference of blockout material type, this approved guardrail system differs from the standard TxDOT steel post guardrail system in terms of blockout depth, post length and, consequently, embedment depth. While the modified G4(1S) guardrail utilizes a 1829-mm long post with an 1118-mm embedment depth, the TxDOT steel post guardrail incorporates a 1676-mm long post with a 965-mm embedment.

In order to review these results and assess the status of TxDOT guardrail design, the department initiated a value engineering (VE) study on the topic in April 1997. The value engineering team studied the guardrail issue and generated recommendations regarding how TxDOT should comply with NCHRP Report 350 based on factors such as Report 350 approval, ability to retrofit/upgrade existing installations, ability to use current inventory, cost, and use of the system by other states. The VE team recommended that TxDOT continue to use the shorter 1676-mm long W6×9 steel post with a 152 mm × 152 mm × 356 mm long routed wood or plastic blockout provided it is shown to meet NCHRP Report 350 standards. Because the nominal 152 mm × 152 mm blockout provides the same offset distance as the standard W6×9 steel block, it should facilitate retrofit and repair of existing steel post guardrail systems. Additionally, the use of the 1676-mm long steel post should provide TxDOT and other state agencies with a more cost effective steel post guardrail, permit the upgrading of existing installations to NCHRP Report 350 standards, and allow the use of current inventory.

This report presents the results of a crash test on a modified TxDOT steel post, W-beam guardrail system with 152-mm × 152-mm routed wood blockouts. The crash test performed was NCHRP Report 350 test designation 3-11, which involves a 2000-kg pickup truck (2000P) impacting the barrier at a nominal speed and angle of 100 km/h and 25 degrees, respectively. A description of the installation, results of the full-scale crash test, and evaluation of the impact performance are presented in the sections that follow.

II. STUDY APPROACH

TEST ARTICLE

A modified TxDOT steel post W-beam guardrail system was constructed for evaluation under NCHRP Report 350 guidelines. The system consisted of 7620-mm long, 12-gauge W-beam rail elements mounted on 1676-mm long W150×13.5 steel posts at a height of 550 mm to the center of the rail. All guardrail steel was certified to meet American Association of State Highway Transportation Officials (AASHTO) M-180 specifications, and the structural steel posts were certified to meet American Standard Testing and Materials (ASTM) A-36 and AASHTO M-183 specifications. The certified analysis is attached as Appendix A.

The steel posts were spaced 1905 mm on center and embedded 965 mm using a drill and backfill procedure. A 610-mm diameter auger was used to drill the holes. The holes were backfilled with a Type A crushed limestone base material having a maximum dry density of 2066 kg/m^3 and an optimum moisture content of 9.0 percent. The backfill material was compacted in 152 mm layers using a pneumatic tamper driven by an air compressor.

The W150×13.5 steel offset blocks used in the standard TxDOT steel post guardrail system (MBGF-95A(M)) were replaced with full 152 mm × 152 mm × 356 mm long solid wood blockouts. Details of the modified TxDOT steel post W-beam guardrail system are shown in Figure 1. A 108-mm wide by 10-mm deep channel is routed into the back side of the blockout to accept the flange of the W150×13.5 steel post and prevent rotation of the blockout in field applications. A 19-mm diameter hole is drilled through the blockout and offset 30 mm from the center of the blockout to avoid the web of the steel post and permit attachment through the flange. Details of the routed wood blockout are shown in Figure 2.

The W-beam rail, routed wood blockout, and steel post are connected using a single 16-mm diameter × 203-mm long button head guardrail bolt. A standard washer was used between the hex nut and flange of the steel post, but not between the post bolt head and rail element. The W-beam splice connections consisted of eight 16-mm diameter × 32-mm long button head guardrail bolts. All guardrail bolts were certified to meet ASTM A-307 specifications and the hex nuts were certified to meet ASTM A-563 specifications. Both the bolts and nuts were galvanized to ASTM A-153. The certified analysis is attached as Appendix A.

The completed test installation consisted of a 30.5-m long section of the modified steel post W-beam guardrail with the routed 152 mm × 152 mm wood blockouts, and a 11.4-m long, Type I, ET-2000 guardrail terminal (SGT(6)-97(M)) at each end, for a total installation length of 53.3 m. The overall layout of the test installation is shown in Figure 3 and photographs of the completed installation are shown in Figure 4.

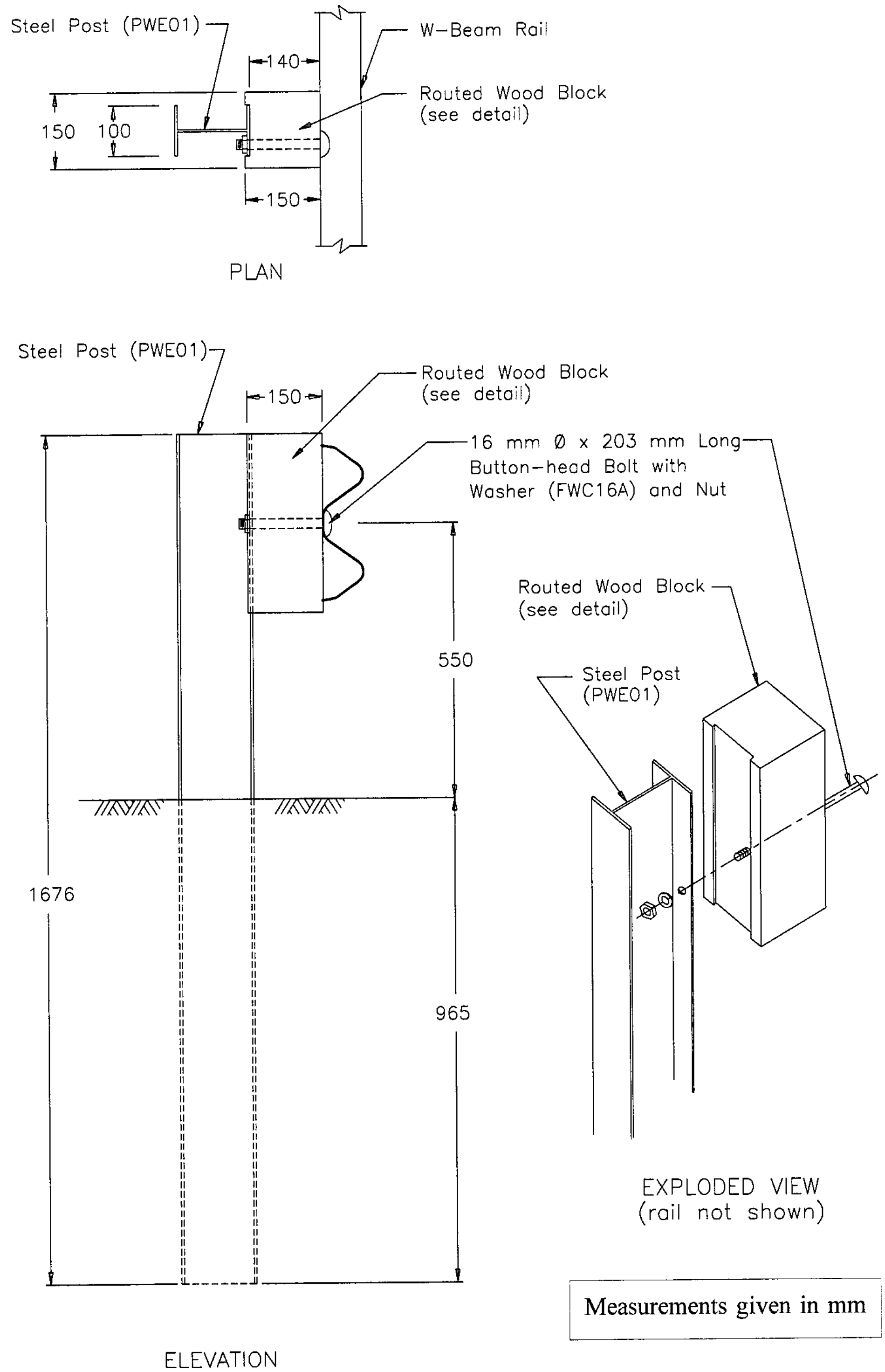


Figure 1. Details of the TxDOT guardrail on steel posts installation.

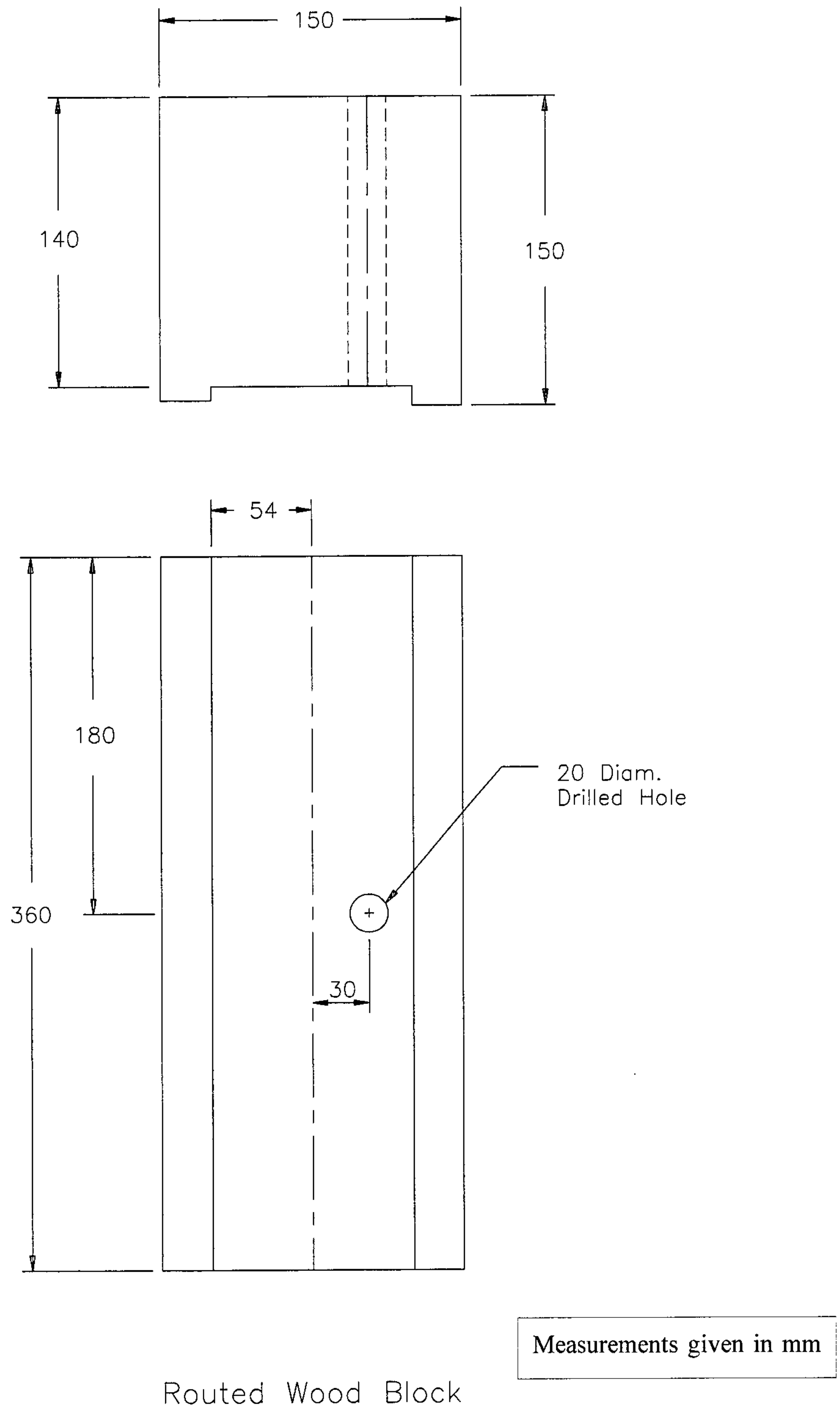


Figure 2. Details of the routed wood blockout for test 439637-1.

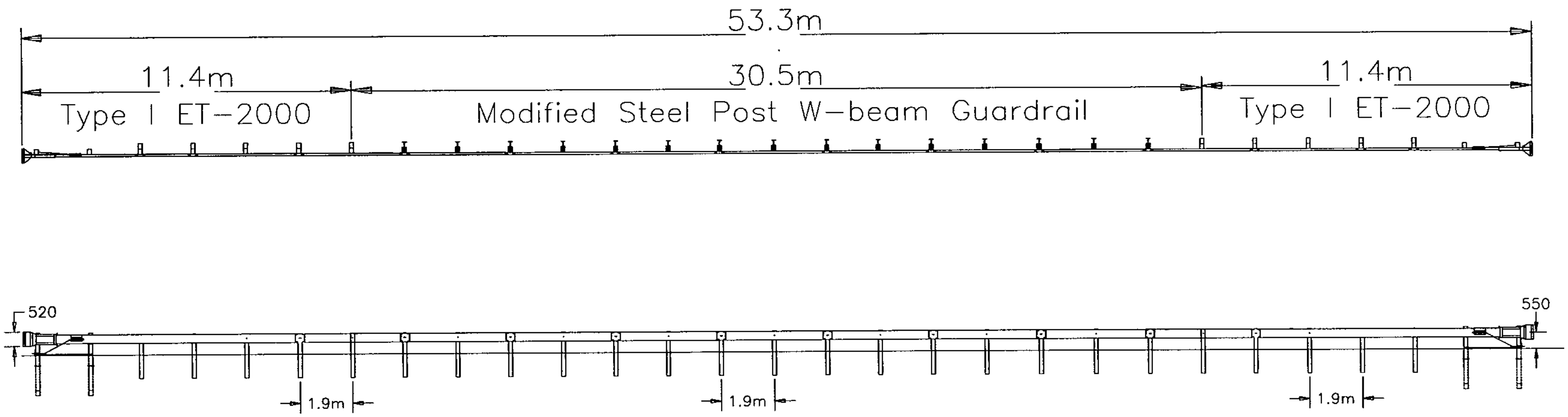


Figure 3. Layout of the TxDOT guardrail on steel posts installation before test 439637-1.

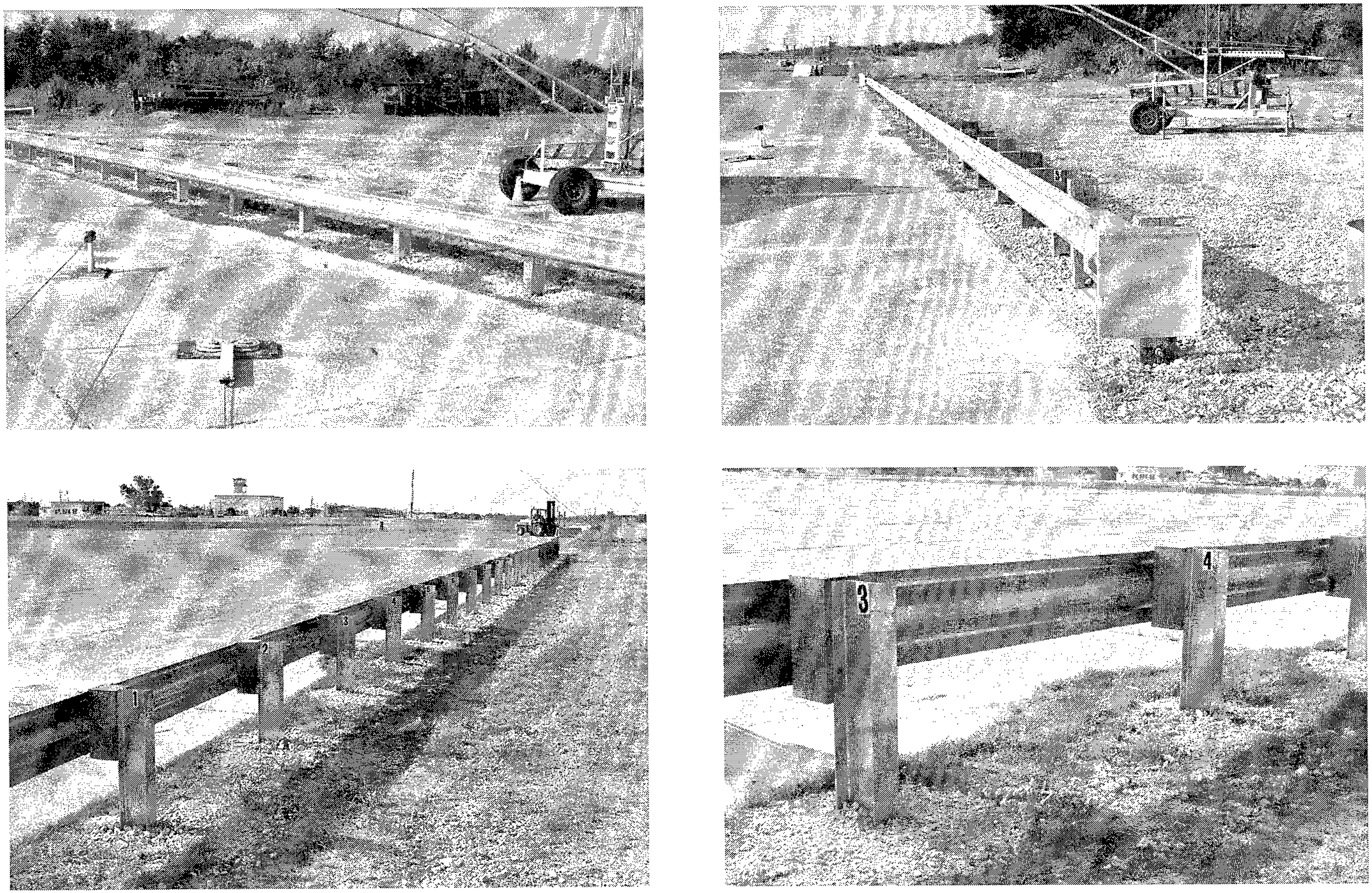


Figure 4. Photographs of completed installation before test 439637-1.

FULL-SCALE CRASH TESTING

Impact Conditions

NCHRP Report 350 presents recommended procedures for the safety performance evaluation of highway features. The test matrix for a longitudinal barrier consists of two tests:

❶ **NCHRP Report 350 test designation 3-10**: This test involves an 820-kg passenger car impacting the critical impact point (CIP) of the barrier at a nominal speed of 100 km/h and a nominal angle of 20 degrees. The purpose of this test is to evaluate the overall performance of the barrier section with specific attention given to occupant risk.

❷ **NCHRP Report 350 test designation 3-11**: This test involves a 2000-kg pickup truck impacting the CIP of the barrier at a nominal speed of 100 km/h and a nominal angle of 25 degrees. This test is intended to evaluate the strength of the barrier section in containing and redirecting the test vehicle. This test also examines vehicle stability and geometric compatibility with the barrier.

Because the strength and stiffness of the modified steel post barrier with recycled polyethylene blockouts is considered to be equivalent to the standard TxDOT steel post guardrail system (MBGF-95A(M)), the small car test (Test Designation 3-10) was considered to be unnecessary. This was based on the fact that the standard TxDOT steel post guardrail was previously approved under NCHRP Report 230 which incorporated impact conditions essentially the same as those currently contained in NCHRP Report 350. Furthermore, the impact performance with the small car should be improved over that observed with the standard TxDOT steel post guardrail based on the fact that the standard W150×13.5 steel block has a tendency to collapse during an impact which effectively reduces the offset distance between the rail and posts. The solid wood blockout maintains its shape and provides a constant offset distance throughout the impact event. This should reduce the interaction of the vehicle with the steel guardrail posts, thereby resulting in a smoother redirection.

Based on this information, researchers conducted only one crash test (test designation 3-11) for purposes of evaluating the impact performance of the modified steel post guardrail with 152-mm × 152-mm routed wood blockout. This test involved a 2000-kg pickup truck impacting at the critical impact point (CIP) of the length of need section at a nominal speed and angle of 100 km/h and 25 degrees. In accordance with the procedures and charts set forth in NCHRP Report 350, the CIP was determined to be 4.5 m upstream of a splice.

NCHRP Report 350 Evaluation Criteria

The crash test performed was evaluated in accordance with the criteria presented in NCHRP Report 350. As stated in NCHRP Report 350, "Safety performance of a highway appurtenance cannot be measured directly but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision." Accordingly, we used the following safety evaluation criteria from Table 5.1 of NCHRP Report 350 to evaluate the crash test.

- **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. Deformation 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/s 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 the test impact angle, measured at time of vehicle loss of contact with the test device.

CRASH TEST AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures adhered to guidelines presented in NCHRP Report 350. Brief descriptions of these procedures are presented as follows.

Electronic Instrumentation and Data Processing

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer near the vehicle center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels; and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals were recorded before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Pressure sensitive switches on the bumper of the impacting vehicle were actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produced an "event" mark on the data record to establish the exact instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, was received at the data acquisition station and demultiplexed into separate tracks of Inter-Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with an SAE J211 filter, and digitized using a microcomputer, for analysis and evaluation of impact performance.

The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are provided as follows.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers were then filtered with a 60 Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions were plotted using a commercially available software package (Excel 7).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.00067-s intervals and then instructed a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements referenced the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system of initial impact.

Anthropomorphic Dummy Instrumentation

Use of a dummy in the 2000P vehicle is optional according to NCHRP Report 350. There was no dummy used in the test reported herein.

Photographic Instrumentation and Data Processing

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement and angular data. A Betacam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

Test Vehicle Propulsion and Guidance

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2-to-1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring it to a safe and controlled stop.

III. CRASH TEST RESULTS

TEST 439637-1 (NCHRP REPORT 350 TEST NO. 3-11)

A 1992 Chevrolet pickup, shown in Figures 5 and 6, was used for the crash test on the TxDOT guardrail on steel posts. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2000 kg. The height to the lower edge of the vehicle bumper was 420 mm and it was 640 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Figure 7. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Test Description

The vehicle, traveling at 101.84 km/h, impacted the modified TxDOT steel post guardrail system 636 mm upstream from post 11, or 4.45 m upstream of the splice at post 13, at an angle of 24.87 degrees. Shortly after impact, lateral movement was noted in posts 10, 11, and 12 and, at 0.029 s, the vehicle began to redirect. At 0.072 s, the right front tire steered into the rail, deforming the rail between posts 11 and 12, and at 0.129 s, the right front tire contacted post 12, severely damaging the wheel and suspension assembly. Although the W-beam rail disengaged from posts 11 and 12, the presence of the rail splice at post 13 hindered the release of the rail at this location. Consequently, the rail was pulled down by the deflecting post. This allowed the vehicle to become airborne as the damaged wheel assembly rode up the deflected rail in the vicinity of post 13. However, by this time, the vehicle had already been contained and redirected, and did not proceed over the guardrail installation.

While airborne, the vehicle lost contact with the guardrail at 0.535 s, traveling at a speed of 62.35 km/h and an exit angle of 9.67 degrees. As it was exiting the system, the right rear tire briefly contacted the top of the rail. The left rear tire recontacted the ground at 1.079 s, followed shortly thereafter by the left front tire, the right front tire and, lastly, the right rear tire. The brakes on the vehicle were applied 3.05 s after impact and the vehicle subsequently came to rest 70.2 m down from the impact point and 7.3 m behind the guardrail. Sequential photographs of the test period are shown in Appendix B.

Damage to Test Installation

Damage to the guardrail is shown in Figures 8 and 9. Posts 10 through 16 were displaced laterally with maximum movement at the ground line measured to be 380 mm at post 13. Post 12 was separated from the guardrail but the rail remained attached to post 13, which was at a splice. The length of contact of the vehicle with the guardrail was 5.2 m.

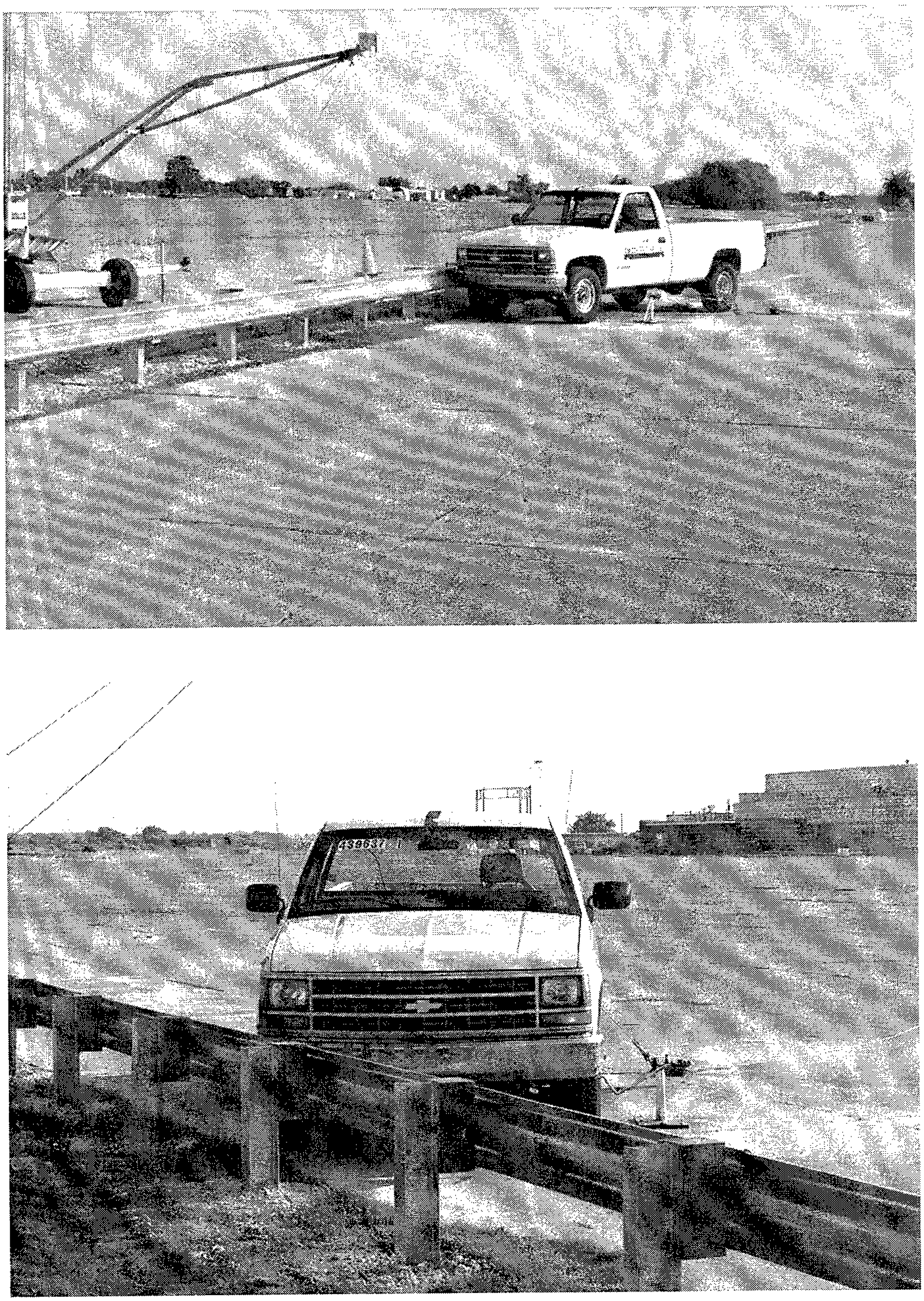


Figure 5. Vehicle/installation geometrics for test 439637-1.

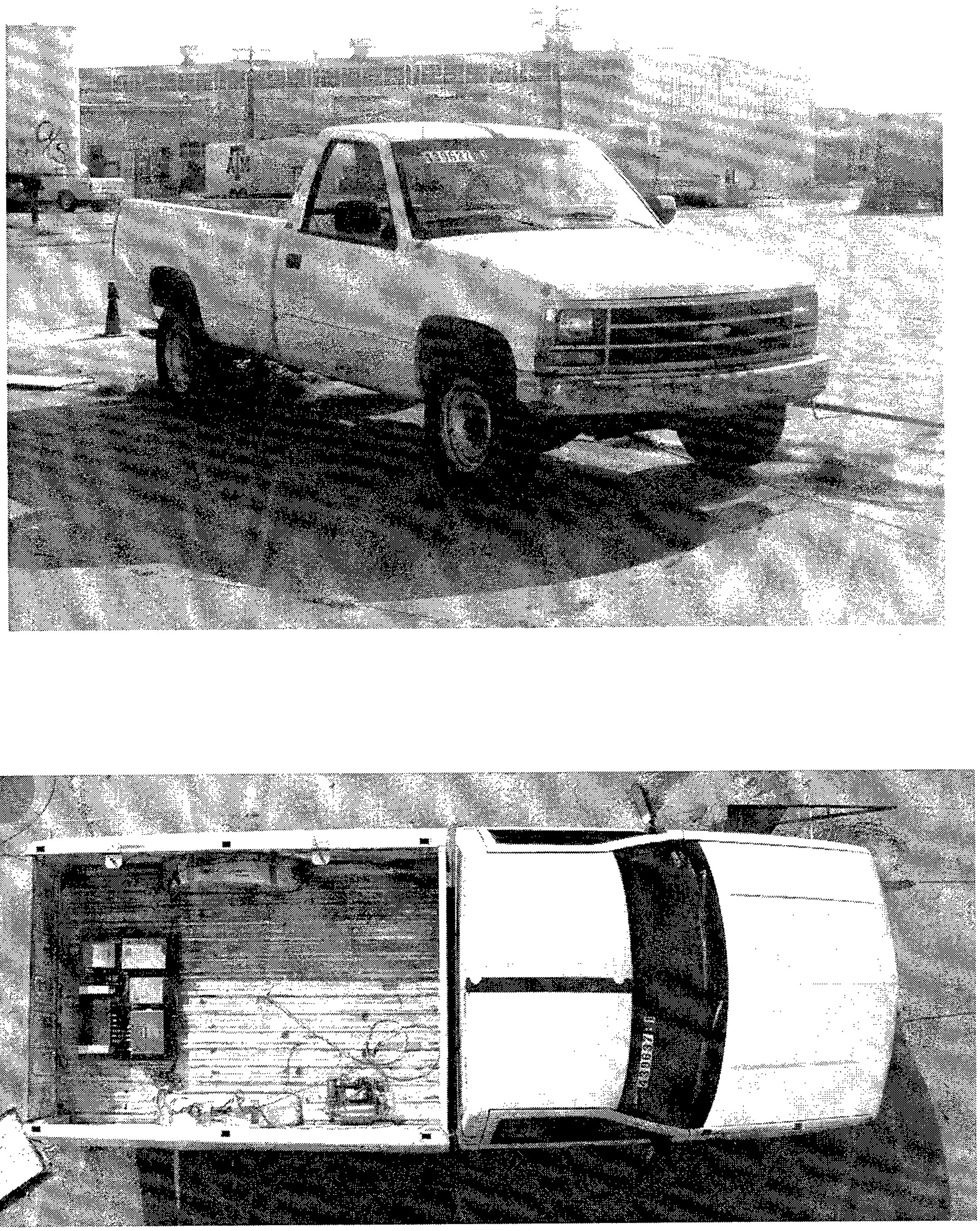


Figure 6. Vehicle before test 439637-1.

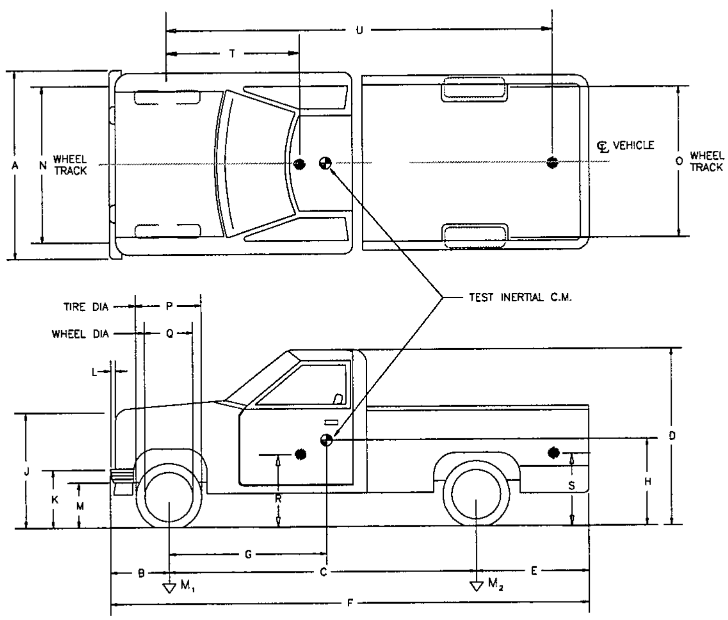
DATE: 8/5/97 TEST NO.: 439637-1 VIN NO.: 1GCGC24K9NE121164

YEAR: 1992 MAKE: CHEVY MODEL: 2500 P/U

TIRE INFLATION PRESSURE: ______ ODOMETER: 252821 TIRE SIZE: 245 75R16

MASS DISTRIBUTION (kg) LF 537 RF 553 LR 452 RR 458

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: R-80mm TO LT

ENGINE TYPE: 8 CYL.

ENGINE CID: 5.7L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A 1840	E 1270	J 1030	N 1610	R 730
B 760	F 5380	K 640	O 1620	S 740
C 3350	G 1524.25	L 70	P 740	T 1500
D 1840	H	M 420	Q 440	U 4070

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1175	1090	
M_2	904	910	
M_T	2079	2000	

Figure 7. Vehicle properties for test 439637-1.

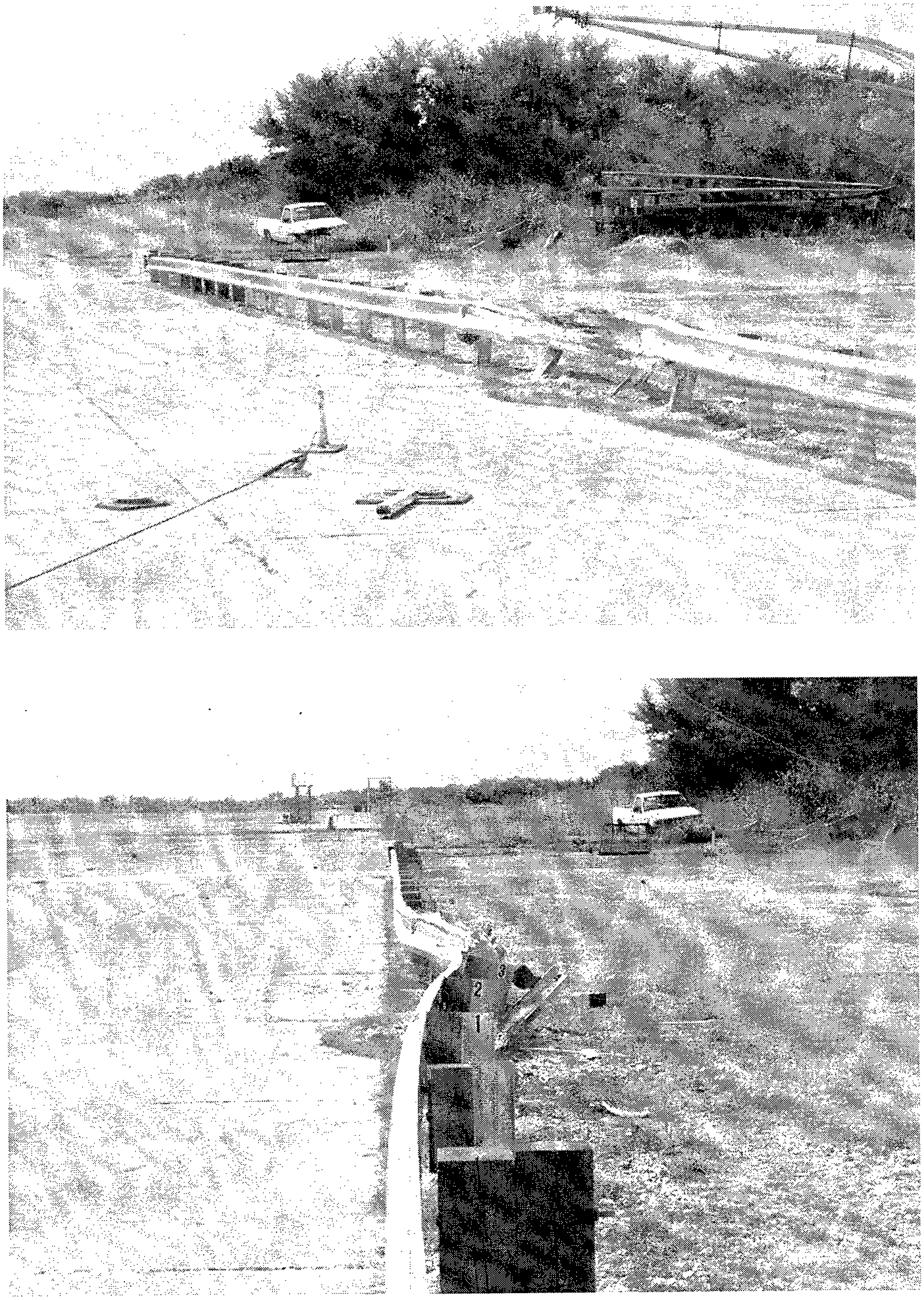


Figure 8. After impact trajectory for test 439637-1.

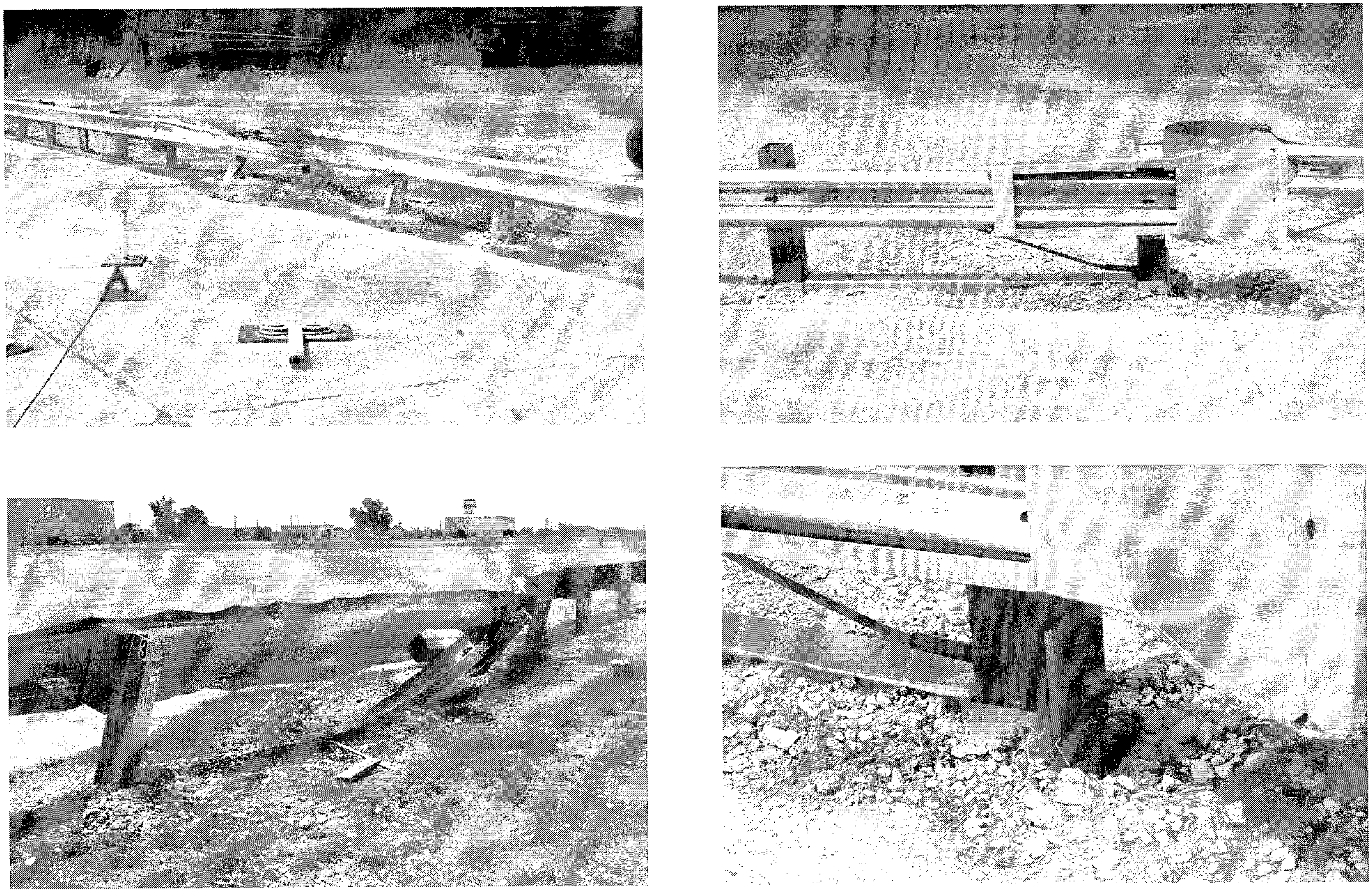


Figure 9. Installation after test 439637-1.

Maximum dynamic deflection of the rail was 0.75 m and the maximum permanent deformation was 0.45 m.

Vehicle Damage

The vehicle sustained damage to the upper and lower A-arms, stabilizer bar, right front frame, and right front tie rods. Also damaged were the fan, radiator, the right side grill, right front quarter panel, and right front tire and rim. Maximum crush to the exterior of the vehicle at bumper height was 435 mm. Maximum deformation into the occupant compartment was 23 mm in the left floorpan area. Photographs of the vehicle damage are shown in Figure 10. Additional information on vehicle damage such as exterior crush measurements and occupant compartment deformation measurements are shown in Appendix C.

Occupant Risk Values

Data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 7.38 m/s at 0.193 s, the highest 0.010-s occupant ridedown acceleration was -7.76 g from 0.214 to 0.224 s, and the maximum 0.050-s average acceleration was -7.01 g between 0.114 and 0.164 s. In the lateral direction, the occupant impact velocity was 5.21 m/s at 0.161 s, the highest 0.010-s occupant ridedown acceleration was -6.54 g from 0.209 to 0.219 s, and the maximum 0.050-s average was -6.29 g between 0.115 and 0.165 s. These data and other pertinent information from the test are summarized in Figure 11. Vehicle angular displacements are displayed in Appendix D. Vehicular accelerations versus time traces are presented in Appendix E.

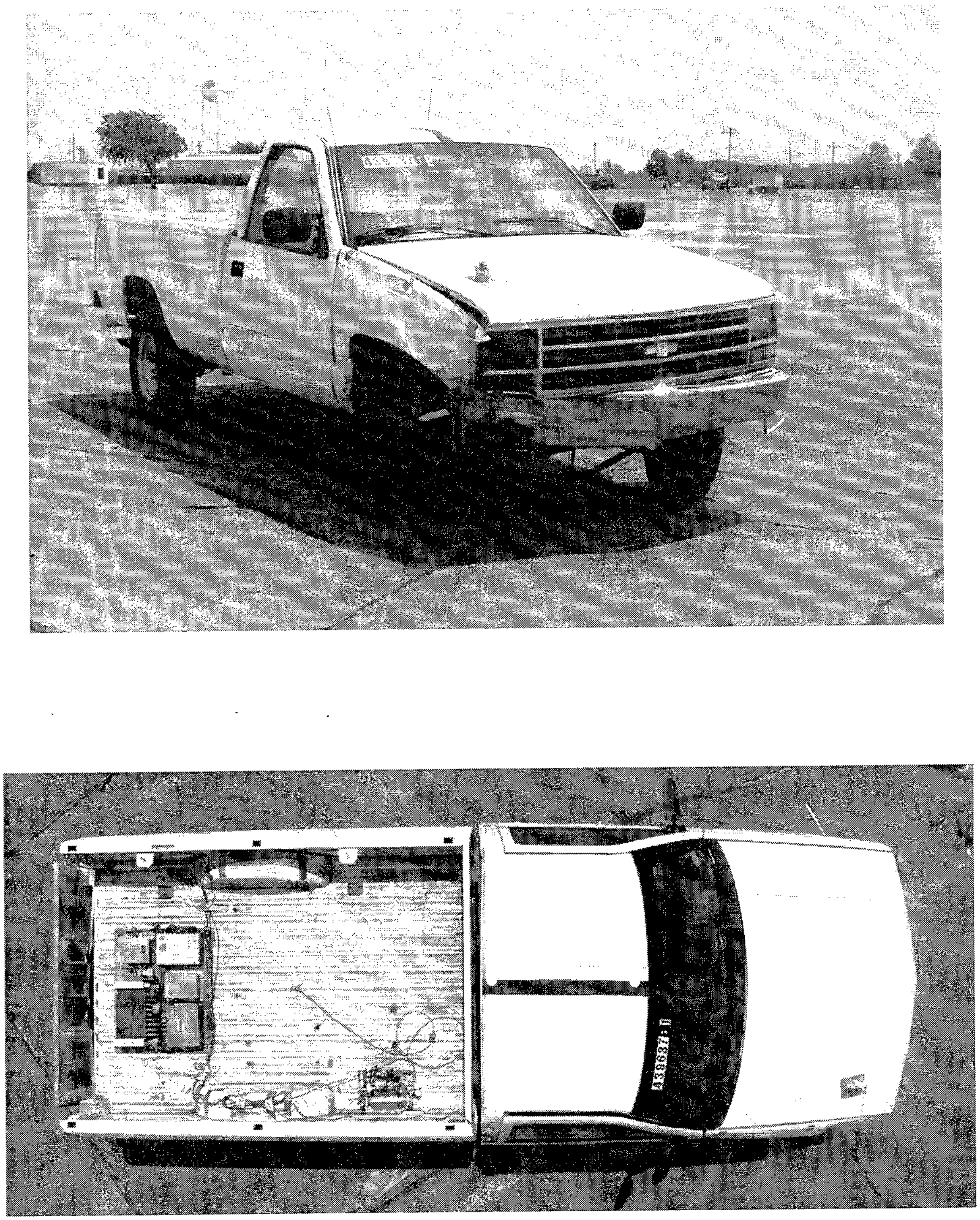
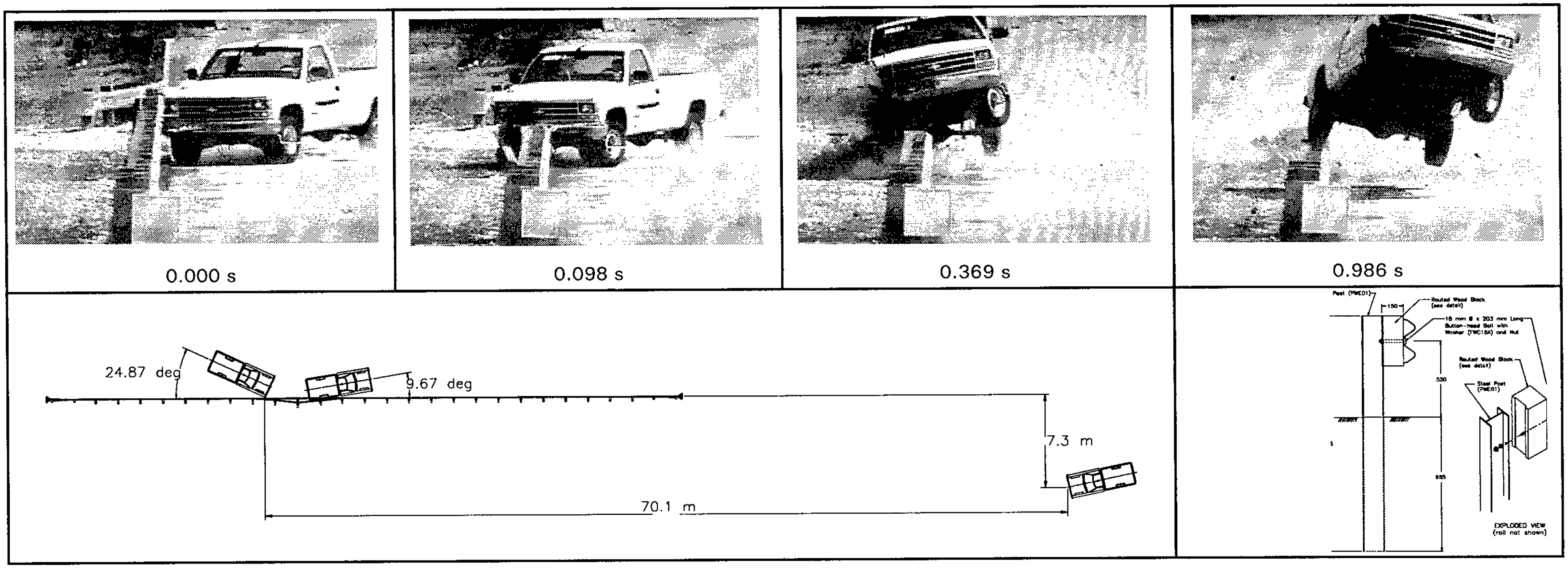


Figure 10. Vehicle after test 439637-1.



General Information	
Test Agency	Texas Transportation Institute
Test No.	439637-1
Date	08/05/97
Test Article	
Type	W-beam Guardrail
Name	Mod. Steel Post W-beam Guardrail
Installation Length (m)	53.3
Size and/or dimension and material of key elements	1676-mm long W150x13.5 steel posts and 152 mm x 152 mm routed wood block
Soil Type and Condition	Standard soil, dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1992 Chevrolet 2500 pickup
Mass (kg) Curb	2079
Test Inertial	2000
Dummy	No dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	101.84
Angle (deg)	24.87
Exit Conditions	
Speed (km/h)	62.35
Angle (deg)	9.67
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.38
y-direction	5.21
Ridedown Accelerations (g's)	
x-direction	-7.76
y-direction	-6.54
Max. 0.050-s Average (g's)	
x-direction	-7.01
y-direction	-6.29
z-direction	-4.15

Test Article Deflections (m)	
Dynamic	0.75
Permanent	0.45
Vehicle Damage	
Exterior	
VDS	01FR3
CDC	01FREW3
Maximum Exterior Vehicle Crush (mm)	435
Interior	
OCDI	FS0020000
Max. Occ. Compart. Deformation (mm)	23
Post-Impact Behavior (during 1.0 s after impact)	
Max. Roll Angle (deg)	-15
Max. Pitch Angle (deg)	13
Max. Yaw Angle (deg)	-33

Figure 11. Summary of results for test 439637-1.

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

SUMMARY OF FINDINGS

The modified TxDOT steel post guardrail with routed wood blocks successfully contained and redirected the test vehicle through controlled lateral deflection. The vehicle did not penetrate, underride, or override the guardrail installation. Although the vehicle became completely airborne during the impact sequence, it remained upright and relatively stable both during and after the collision. The detached elements from the installation did not penetrate or show potential for penetrating the occupant compartment, nor did they present undue hazard to others in the area. The minimal deformation of the occupant compartment (23 mm) was not considered to have potential to cause injury. After exiting the installation, the vehicle steered back toward the guardrail and did not intrude into adjacent traffic lanes. Occupant risk factors were within the preferable limits specified in NCHRP Report 350. Additionally, the exit angle at loss of contact with the guardrail was only 9.67 degrees, which is less than 60 percent of the impact angle as recommended.

CONCLUSIONS

The modified TxDOT steel post W-beam guardrail system with 152-mm × 152-mm routed wood blockouts is judged to have met the performance evaluation criteria of NCHRP Report 350. As shown in Table 3, the guardrail met all evaluation criteria set forth in NCHRP Report 350 for test designation 3-11.

Table 1. Performance evaluation summary for test 439637-1, NCHRP Report 350 test 3-11.

Test Agency: Texas Transportation Institute — Test No.: 439637-1 — Test Date: 8-5-97

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
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.	The TxDOT guardrail on steel posts contained and redirected the vehicle. The vehicle did not penetrate or underride the installation.	Pass
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.	The detached elements and debris did not penetrate nor show potential for penetrating the occupant compartment, nor present undue hazard to others in the area. There was minimal deformation into the occupant compartment (23 mm) and was considered to not cause serious injury.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision. The vehicle became completely airborne during the impact sequence.	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal, if any, intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal occupant impact velocity was 7.38 m/s and the occupant ridedown acceleration was -7.76 g.	Pass
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 device.	The exit angle at loss of contact with the guardrail was 9.67 degrees, which was less than 60 percent of the impact angle.	Pass

REFERENCES

1. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer, and J. D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Features," *NCHRP Report 350*, Transportation Research Board, Washington, D.C., 1993.

2. J. D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," *NCHRP Report 230*, Transportation Research Board, Washington, D.C., 1980.

3. K. K. Mak, R. P. Bligh, and W. L. Menges, "Crash Testing and Evaluation of Existing Guardrail Systems," 13 volume draft final report, FHWA Contract No. DTFH61-89-C-00089, Federal Highway Administration, Washington, D. C., December 1995.

APPENDIX A. CERTIFIED ANALYSIS OF GUARDRAIL MATERIALS

This section contains the certified analysis of guardrail materials used in the crash test performed under this study.

CERTIFIED ANALYSIS

TRINITY INDUSTRIES, INC., RF DIVISION
P.O. BOX 568887
DALLAS, TX 75356-8887

CUSTOMER: TEXAS TRANS INSTITUTE
TTI BUSINESS OFFICE
TEXAS A&M UNIVERSITY
COLLEGE STATION TX 77843-3135

ORDER NUMBER: 284843F
CUSTOMER PO: 439117
B/L NUMBER : F147944

DATE: 07/23/97 970725/3/55F/1
PROJECT: TESTING
SHIPPED TO: TEXAS

Heat No.	Yield Point	Tensile Strength	Elong. 2"/8"	C.	MN.	P.	S.	SI.	CU.	CB.	CR.	VN.	Avg Wt of Coating	Quantity	Class	Type	DESCRIPTION
7453473	66500	78200	29.0	.080	.760	.008	.020	.011	.000	.000	.000	.000	4.0	4.0 PC	A		12/25/6'3/S M-180 60G
16073	51000	78950	27.0	.130	.910	.015	.045	.250	.300	.000	.160	.000	4.0	20.0 PC			5'6 POST/8.5/SB:DR TX A-36 506G
772934	56277	65311	38.0	.060	.810	.008	.001	.030	.117	.000	.017	.003	4.0	2.0 PC			6'6 TUBE SL/.188X8X6 MET A-500 732G

ALL STEEL USED IN THE MANUFACTURE IS OF DOMESTIC ORIGIN.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS AASHTO M-183.
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
ALL BOLTS AND NUTS ARE OF DOMESTIC ORIGIN.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

State of Texas, County of Tarrant. Sworn and subscribed before me this 23rd day of July, 1997.

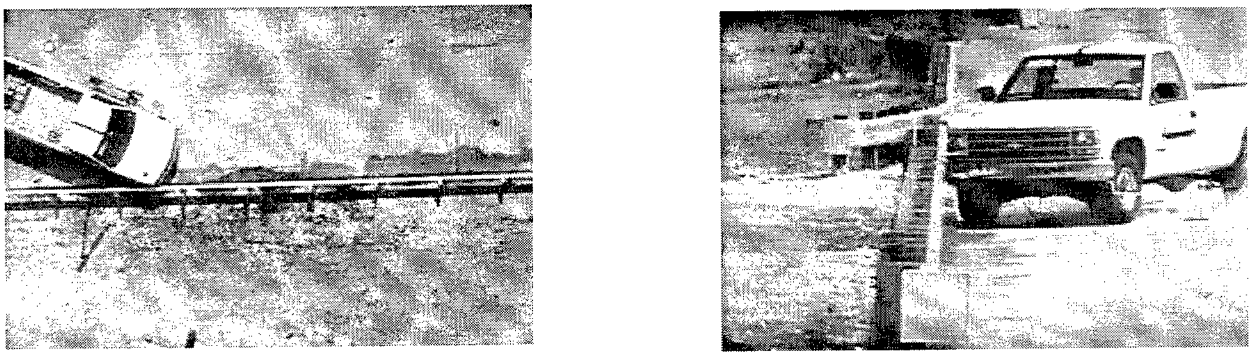
Notary Public: Gena Griesing
Commission Expires: 2/12/99

GENA L. GRIESING
NOTARY PUBLIC
STATE OF TEXAS
My Comm. Exp. 02-12-99

Trinity Industries, Inc.
Certified By: Deborah Nauton

APPENDIX B. SEQUENTIAL PHOTOGRAPHS

This section contains photographs taken from high speed film during the test sequence of the crash test performed under this study.



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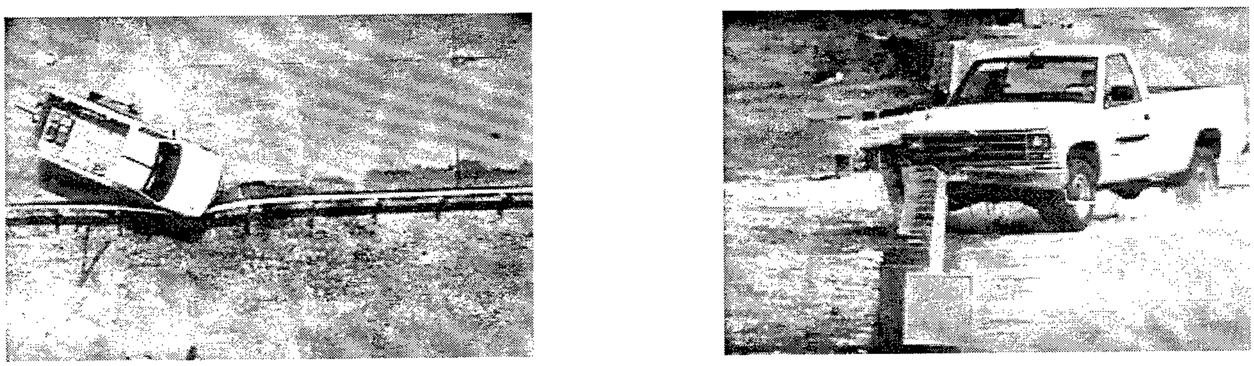
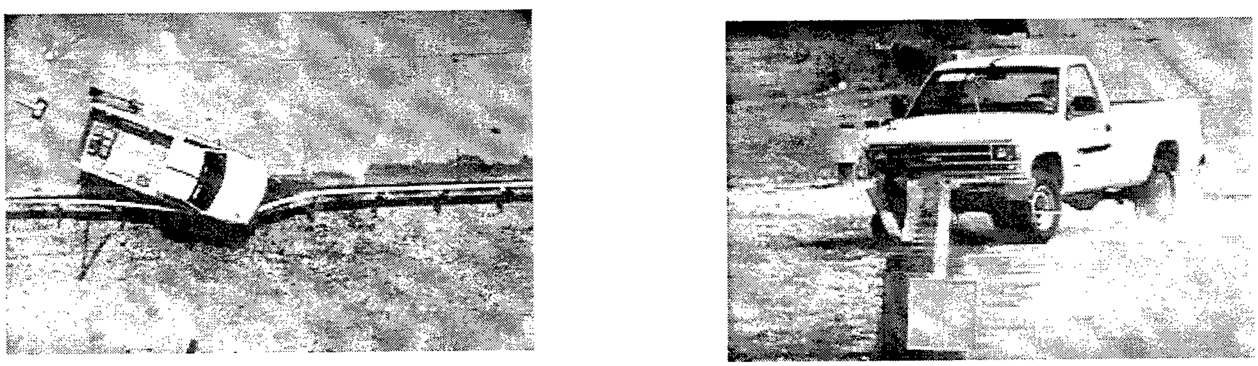


0.049 s



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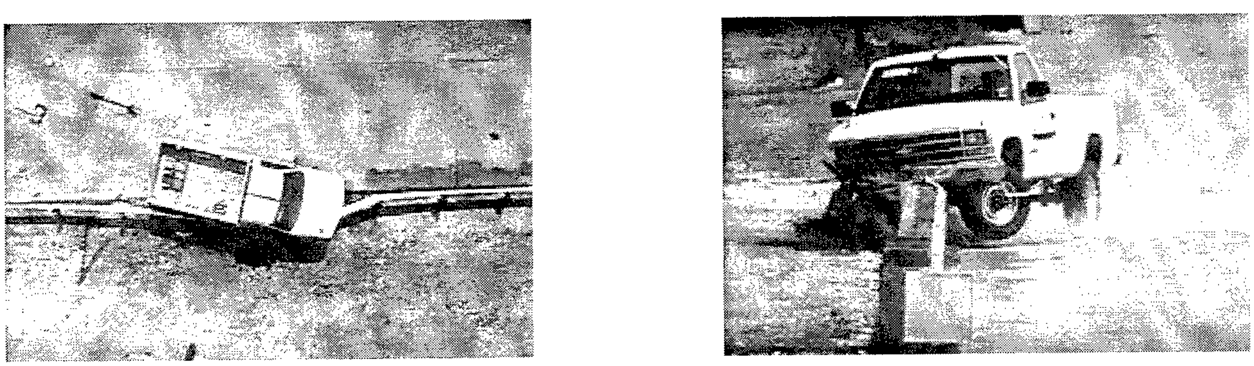
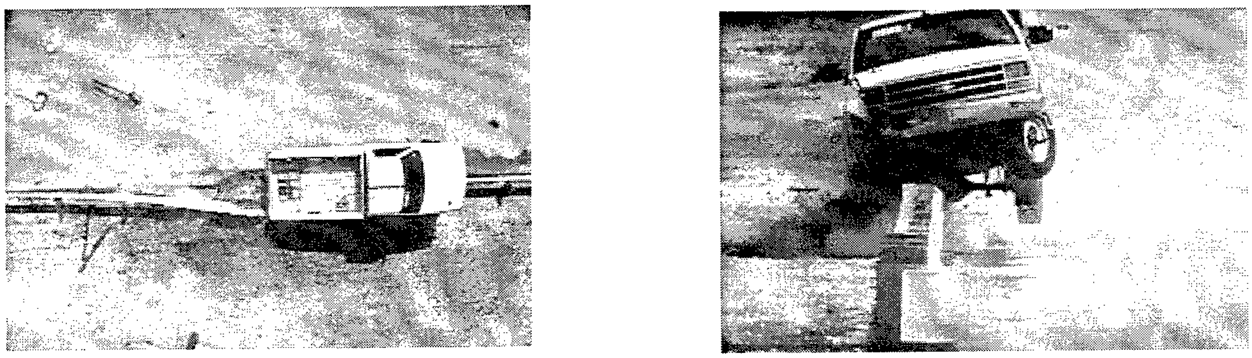
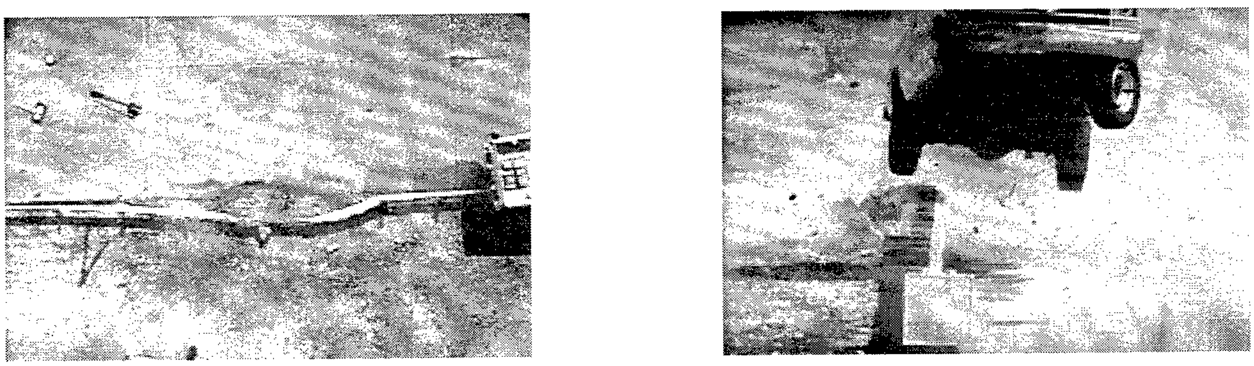


0.197 s

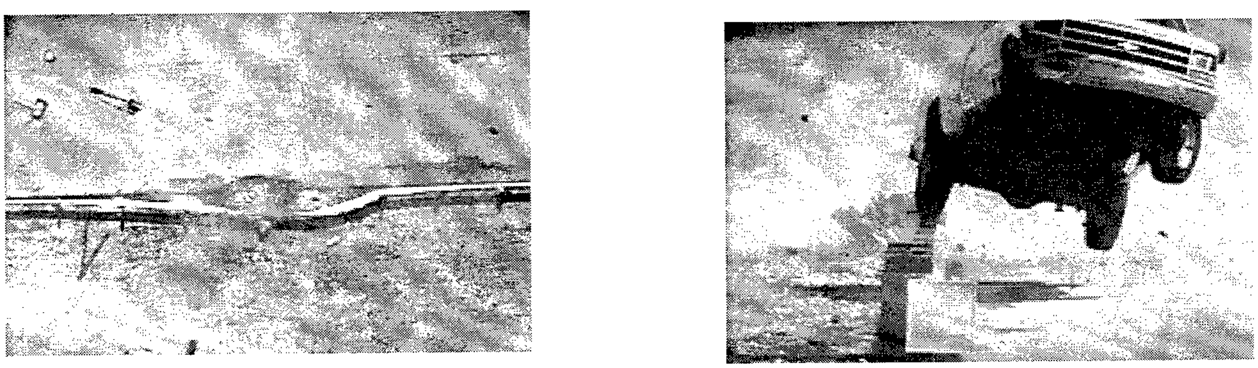
Figure 12. Sequential photographs for test 439637-1 (overhead and frontal views).



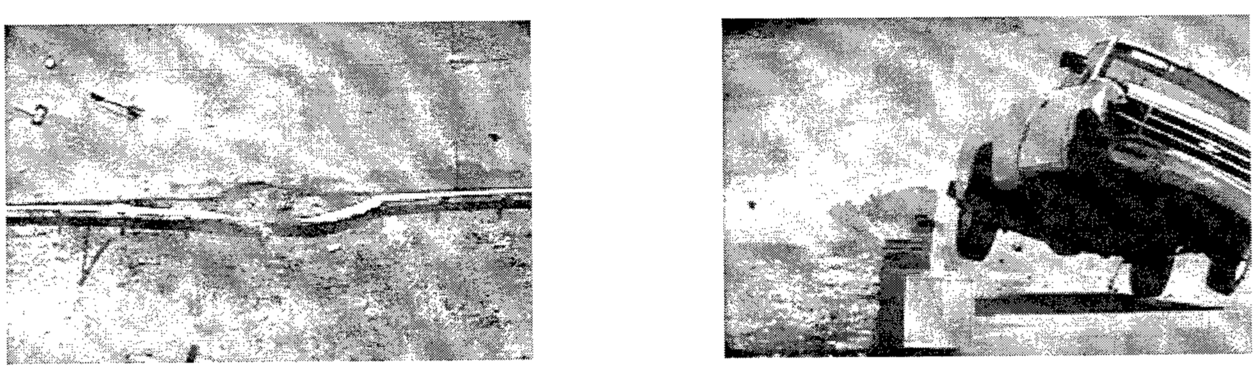
0.369 s



0.739 s

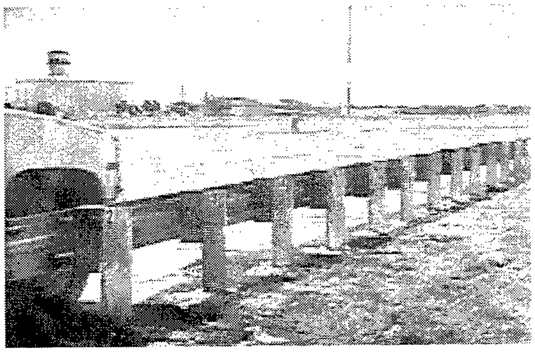


0.986 s

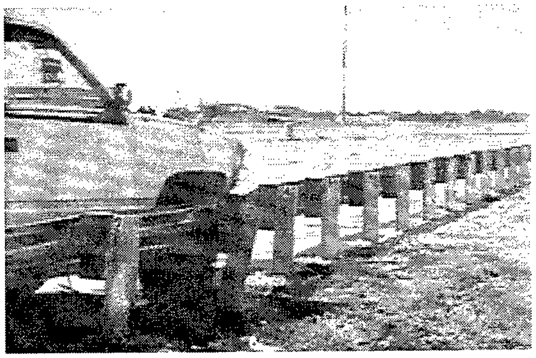


1.232 s

Figure 12. Sequential photographs for test 439637-1 (overhead and frontal views) (continued).



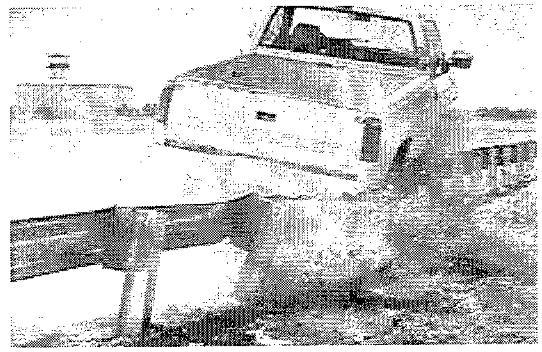
0.000 s



0.049 s

0.098 s

0.197 s



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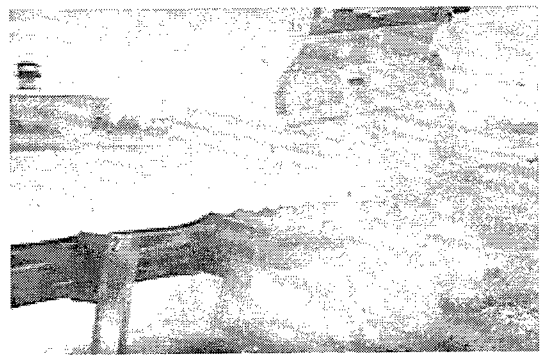

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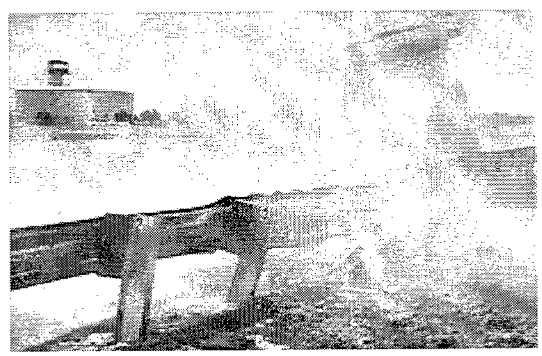
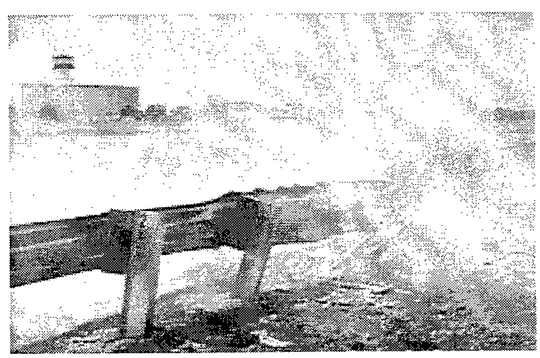


0.986 s



1.232 s

Figure 13. Sequential photographs for test 439637-1 (rear view).

APPENDIX C. ADDITIONAL VEHICLE INFORMATION

This section provides additional information on vehicles used for the crash test performed under this study.

Table 2. Exterior vehicle crush measurements for test 439637-1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	**Side Damage**
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing: B1 ____ X1 ____ B2 ____ X2 ____ Bowing constant $\frac{X1 + X2}{2}$ = ____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	Top of front bumper	700	435	750	0	50	110	180	290	435	
2	600 mm above ground	700	240	2200	0	5	10	40	--	240	

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

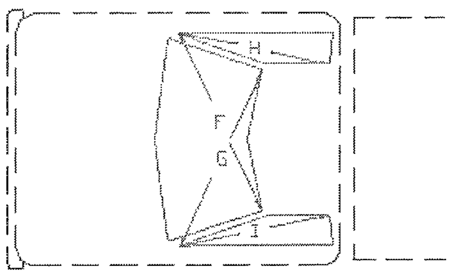
***Measure and document on the vehicle diagram the location of the maximum crush.

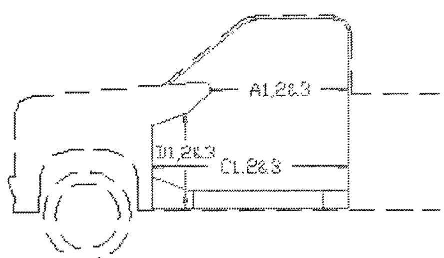
Note: Use as many lines/columns as necessary to describe each damage profile.

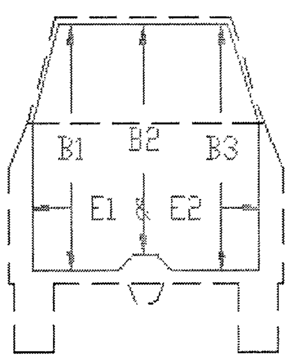
Table 3. Occupant compartment deformation for test 439637-1.

Truck

Occupant Compartment Deformation







	BEFORE	AFTER
A1	1035	1035
A2	1082	1082
A3	1045	1045
B1	1075	1075
B2	1045	1030
B3	1081	1070
C1	1368	1368
C2	1264	1257
C3	1371	1265
D1	310	310
D2	151	128
D3	311	296
E1	1590	1590
E2	1595	1595
F	1460	1450
G	1460	1460
H	900	895
I	900	900

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS

This section contains a plot of the vehicular angular displacement exhibited by the vehicle in the crash test performed under this study.

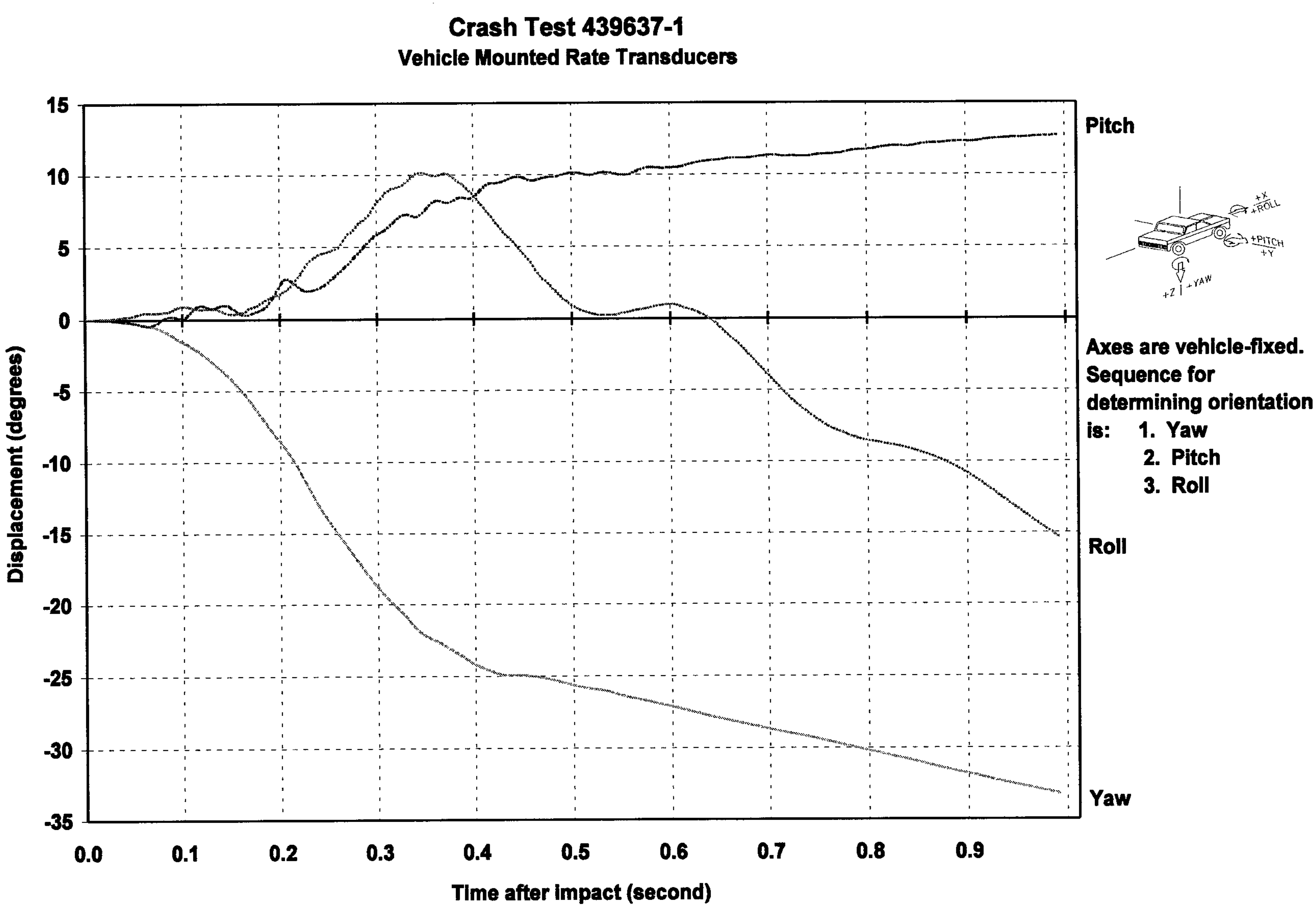


Figure 14. Vehicle angular displacements for test 439637-1.

APPENDIX E. VEHICLE ACCELEROMETER TRACES

This section contains graphs of the vehicle accelerations experienced by the vehicle during the crash test performed under this study.

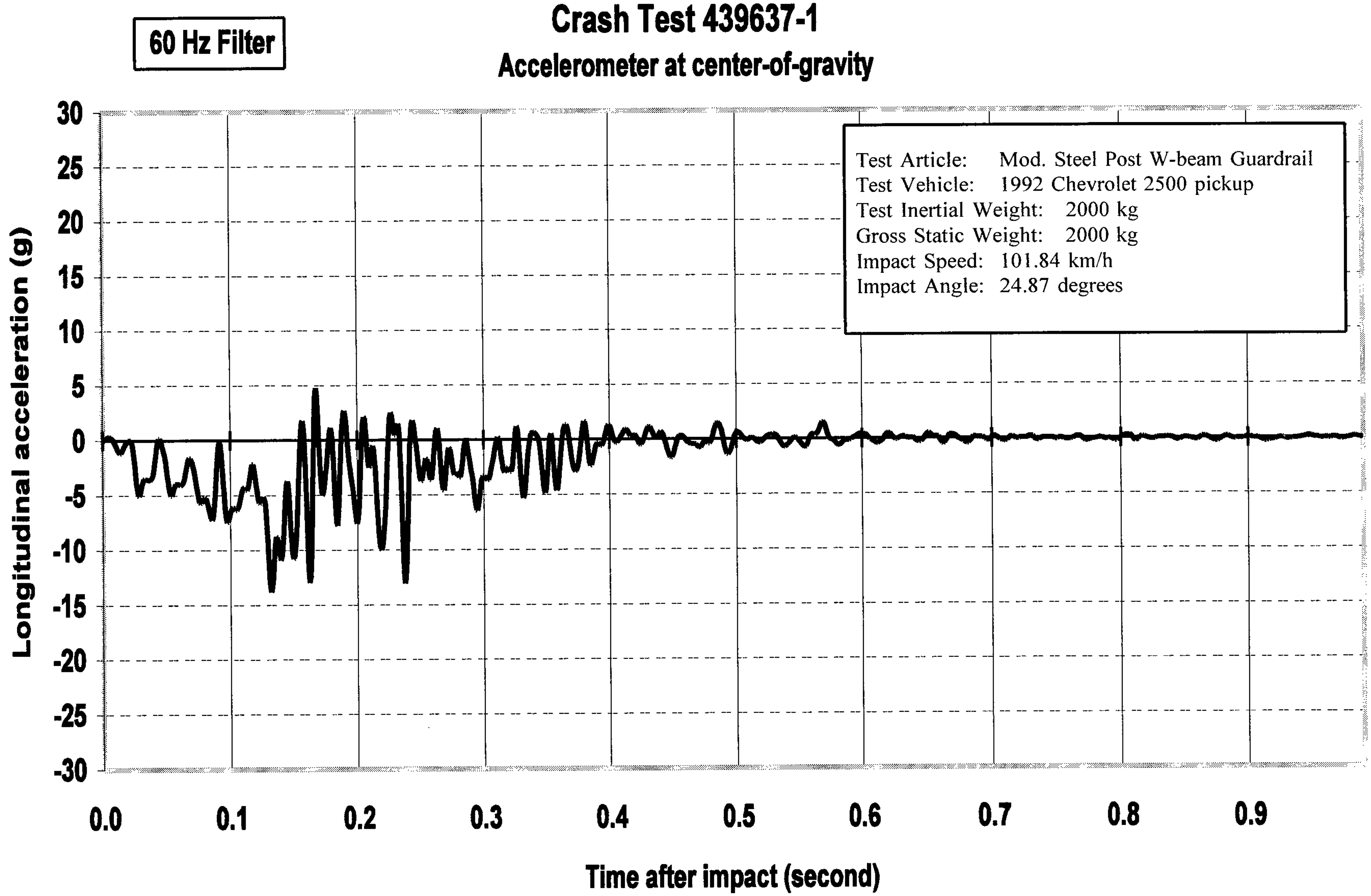


Figure 15. Vehicle longitudinal accelerometer trace for test 439637-1.

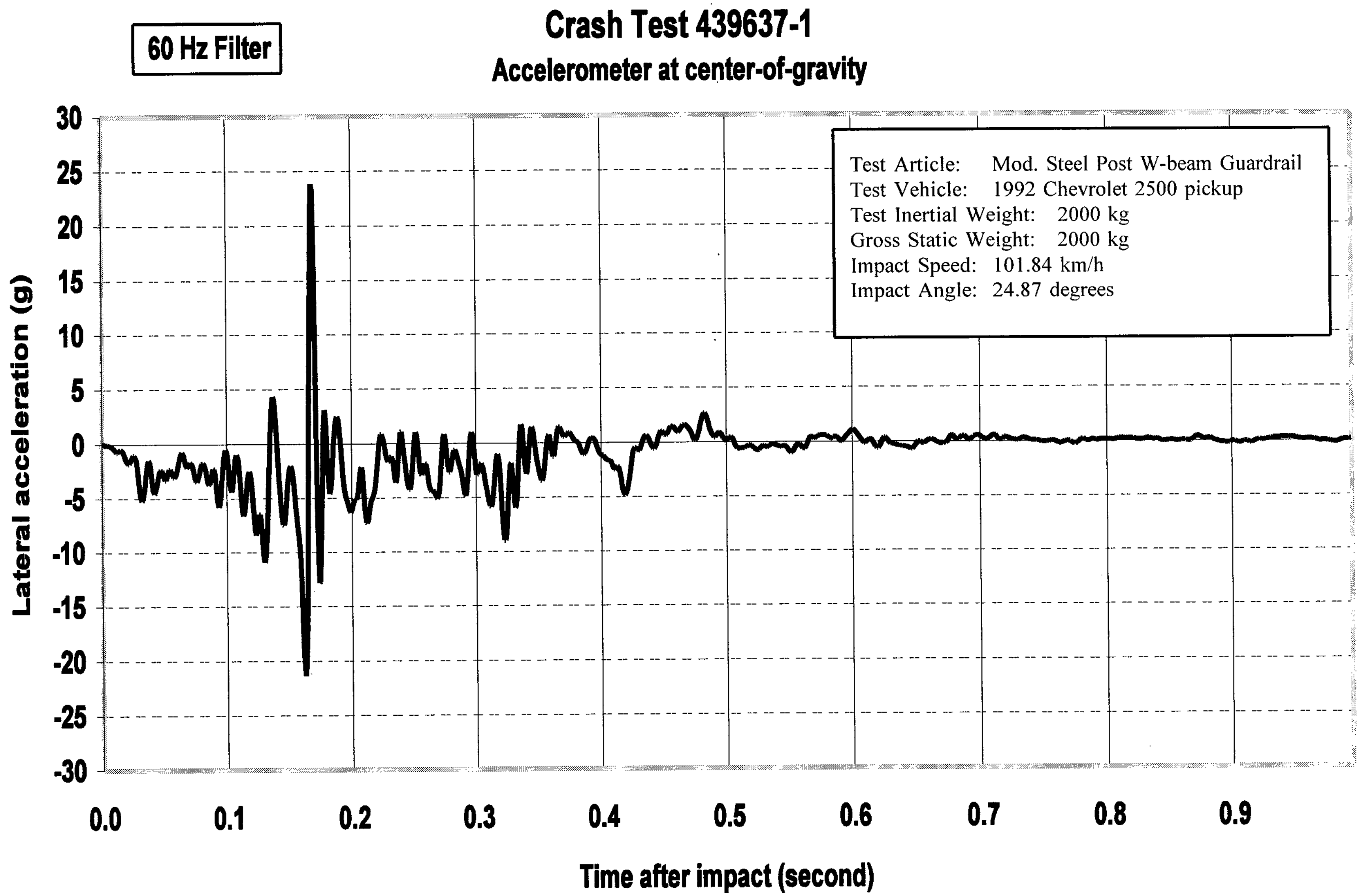


Figure 16. Vehicle lateral accelerometer traces for test 439637-1.

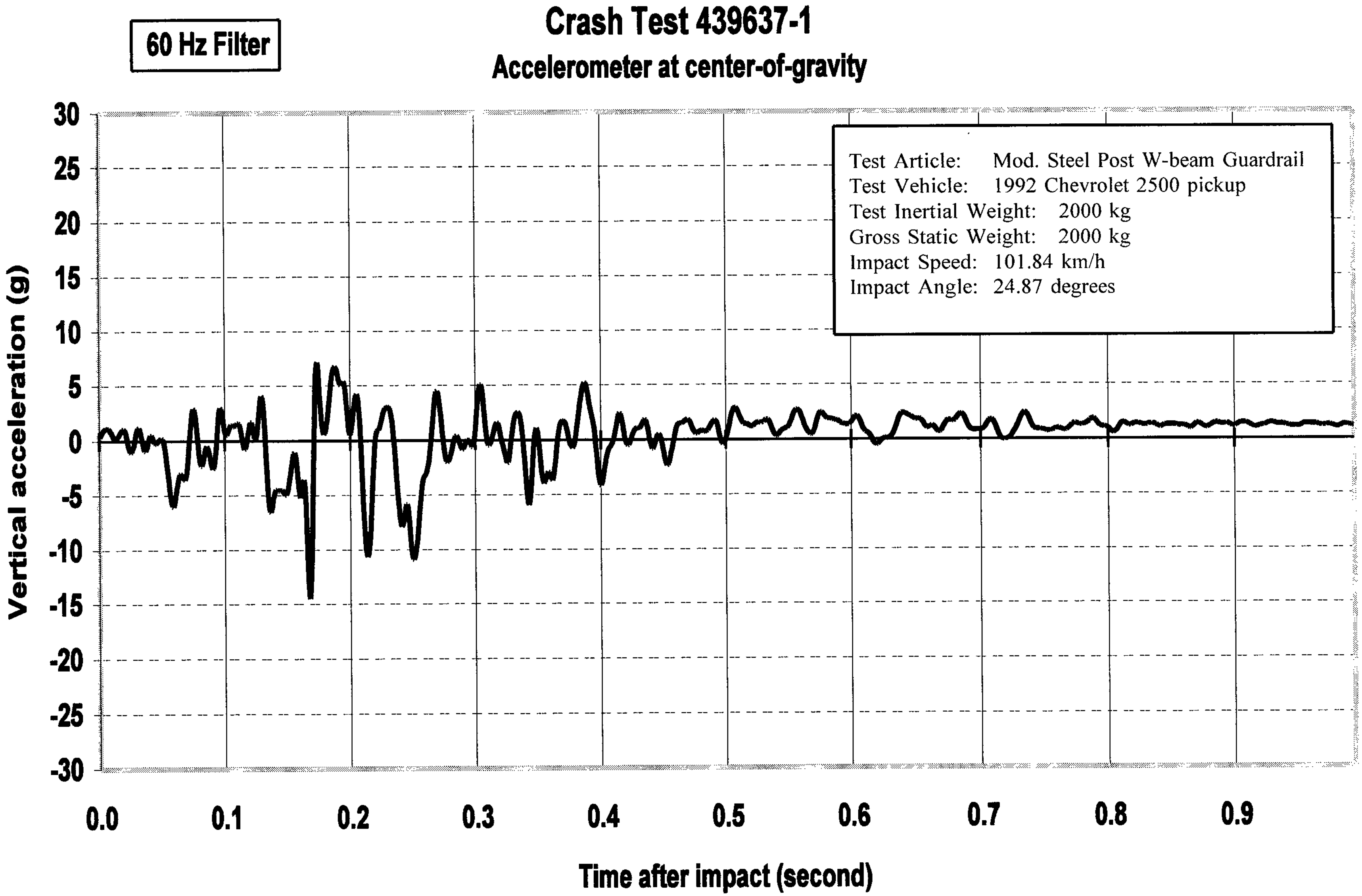


Figure 17. Vehicle vertical accelerometer trace for test 439637-1.