Texas Transportation Institute

NCHRP REPORT 350 TEST 3-11 ON THE MODIFIED PennDOT TYPE 2 GUIDE RAIL - TEST 3

by

C. Eugene Buth, P.E.
Senior Research Engineer

Wanda L. Menges
Associate Research Specialist

William F. Williams, P.E.
Assistant Research Engineer

and

Sandra K. Schoeneman
Research Associate

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THE TEXAS A & M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

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16. Abstract

The purpose of this project was to perform full-scale crash tests on a modified PennDOT Type 2 guide rail in accordance with National Cooperative Highway Research Program *(NCHRP) Report 350* to evaluate performance of the guide rail at test level three (TL-3). The rail was constructed in accordance with PennDOT standard drawings with modifications specified by PennDOT.

For the first test performed under this contract (11/23/99), the W-beam rail elements were attached to the posts with 6 mm (0.25 in) diameter bolts threaded full length with a 6 mm round flat washer and two 44 mm square plate washers with 10 mm diameter hole used under the head and a 6 mm round flat washer and two nuts. Rail splices were located at mid-span between posts. Also, 14 mm (0.5 in) diameter by 40 mm (1.5 in) long shelf bolts were placed in the flange of the post and just below the W-beam with two nuts on the traffic face of the post to support the W-beam. During the first test, the rail element ruptured and the 2000P pickup truck penetrated the installation.

For the installation used in the second test (1/6/00), the shelf bolts were eliminated on all but the last post near each end (the first post of the turned down). Back-up plates were added and the mounting bolt length was increased. The PennDOT Type 2 guide rail initially contained and redirected the 2000P pickup truck; however, as the vehicle continued along the guide rail, the rail dropped and allowed the vehicle to override the installation.

For the installation used in the test reported herein, the installation was constructed similar to Test 2 with the following exceptions. The height of the rail was elevated to 820 mm (32.3 in) and 8 mm (0.3 in) diameter bolts threaded the full length with an 8 mm (0.3 in) round flat washer was used instead of the 6 mm (0.25 in) diameter bolts used in Test 2. In addition, 14 mm (0.55 in) diameter by 40 mm (1.5 in) long shelf bolts were placed in the flange of each post to support the W-beam rail. Details of the installation and results of this third full-scale crash test are presented herein. The PennDOT Type 2 guide rail contained and redirected the 2000P pickup truck.

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KEY WORDS

Guide Rail, Crash Testing, Roadside Safety

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INTRODUCTION

PROBLEM

The primary purpose of all longitudinal barriers, such as guide rails, is to prevent a vehicle from leaving the roadway and striking a fixed object or terrain feature that is considered more hazardous than the barrier itself. The barrier should safely contain and redirect the errant vehicle away from the hazard. Performance of the barrier should be assessed through full-scale crash tests in accordance with the guidelines presented in National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features.*[1]

On July 25, 1997, the Federal Highway Administration (FHWA) further mandated that new construction on the National Highway System (NHS) must use *NCHRP Report 350* approved barriers by October 1998. However, on August 28, 1998, FHWA extended the deadline for several categories of roadside appurtenances. This extension included the weak-post W-beam (G2) guide rail system (herein called the PennDOT Type 2 guide rail), which allowed time for Pennsylvania Department of Transportation (PennDOT) to complete a joint effort by Bucknell University and Penn-State University to retest/redesign this barrier to meet a higher test level.

BACKGROUND

The PennDOT Type 2 guide rail has not demonstrated acceptable performance in previous crash testing according to *NCHRP Report 350* guidelines for test level 3 (TL-3). When tested to TL-2 criteria of *NCHRP Report 350*, this barrier performed acceptably. PennDOT and researchers from Bucknell University and Worcester Polytechnic Institute (WPI) analyzed and reviewed design details of the guide rail to determine modifications that could be made to improve performance to TL-3 of *NCHRP Report 350.*

OBJECTIVES/SCOPE OF RESEARCH

The purpose of this project is to perform full-scale crash tests on a modified PennDOT Type 2 guide rail in accordance with *NCHRP Report 350* to evaluate performance of the guide rail at test level 3.

A 99.0 m (325.0 ft) long test installation of modified type 2 guide rail was constructed at Texas Transportation Institute's (TTI) Proving Ground. The installation includes 68.5 m (225.0 ft) of length-of-need and 15.2 m (50.0 ft) of turned down terminal on each end. The height of the guardrail to the top of the W-beam rail element was 820 mm (32.3 in). The rail was constructed in accordance with PennDOT standard drawings with modifications specified by PennDOT. Posts were installed in drilled holes and backfilled with *NCHRP Report 350* standard soil. Strain gages were installed on one cross section of W-beam rail element near each end of the installation to measure tensile strains in the rail during the test.

On November 23, 1999, *NCHRP Report 350* test 3-11 (test no. 473750-1) was performed on a modified PennDOT Type 2 guide rail.[2] The test involved a 2000 kg (4409 lb) pickup truck impacting the critical impact point (CIP) of the length-of-need at a nominal speed and angle of 100 km/h (62.2 mi/h) and 25 degrees. The CIP for this test was determined using information contained *NCHRP Report 350* and accordingly, was determined to be the midpoint of the span between the fourth and fifth posts after the terminal section (last post of the terminal is the first post of the system).

For the installation constructed for test no. 473750-1, the W-beam rail elements were attached to the posts with 6 mm (0.25 in) diameter bolts threaded full length with a 6 mm (0.25 in) round flat washer and two 44 mm (1.7 in) square plate washers, and a 6 mm (0.25 in) round flat washer and two nuts. Rail splices were located at mid-span between posts. Also, 14 mm (0.5 in) diameter by 40 mm (1.5 in) long shelf bolts were placed in the flange of the post with two nuts on the traffic face of the post to support the W-beam. The purpose of the shelf bolts is to reduce the loading on the 6 mm (0.25 in) diameter post mounting bolts from the weight of the W-beam rail elements and other dead load, such as snow and ice on the rail elements.

During the first test, the rail element ruptured and the 2000P pickup truck penetrated the installation. In reviewing the high speed film, it was determined that a small crease at the bottom of the rail element occurred at post 8 which was apparently made by the flange of the post as the rail element moved upward on the post. The crease continued to move upward on the post and snagged on the top of post 8 which caused a small tear. As the vehicle continued traveling forward along the guide rail, the rail element wrapped around the left front corner of the vehicle creating a tensile load on the rail element. As the tensile load increased, the rail element ruptured at the small tear. The vehicle then penetrated the installation as the rail element ruptured.

For the installation used in the second test (1/6/00), the shelf bolts were eliminated on all but the last post near each end (the first post of the turned down). Back-up plates were added and the mounting bolt length was increased. *NCHRP Report 350* test 3-11 was performed on this modified Type 2 guide rail using the same CIP as in the previous test. The PennDOT Type 2 guide rail initially contained and redirected the 2000P pickup truck; however, as the vehicle continued along the guide rail, the rail dropped and allowed the vehicle to override the installation.[3]

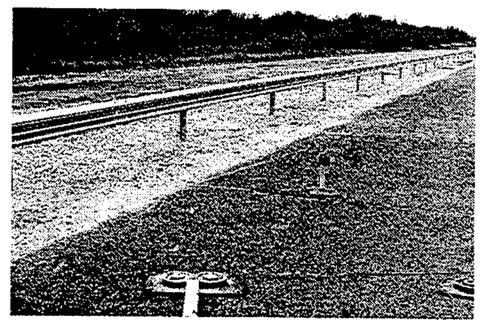
For the installation used in test 3 (5/9/00, reported herein), the rail was elevated to a height of 820 mm (32.3 in), and the diameter of the rail bolts was increased from 6 mm (0.25 in) to 8 mm (0.3 in) with a single 8 mm (0.3 in) diameter round flat washer. In addition, 14 mm (0.5 in) diameter shelf bolts were used at all post locations to support the guide rail. The modified PennDOT Type 2 guide rail was then tested and evaluated with the 2000P pickup truck.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of an 809-hectare (2000 acre) complex of research and training facilities situated 16 km (10 mi) northwest of the main campus of Texas A&M University. The site, formerly an Air Force Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for placing of the PennDOT Type 2 Guide Rail is along the edge of a wide expanse of concrete aprons which were originally used as parking aprons for military aircraft. These aprons consist of unreinforced jointed concrete pavement in 3.8 m by 4.6 m (12.5 ft by 15.1 ft) blocks (as shown in the adjacent photo) nominally 203-305 mm (8.0-12.0 in) deep. The aprons and runways are about 50 years old and the joints have some displacement, but are otherwise flat and level.



Test Article – Design and Construction

A 99.0 m (325.0 ft) long test installation of modified type 2 guide rail was constructed at TTI's Proving Ground. The installation includes 68.6 m (225.0 ft) of length-of-need and 15.2 m (50.0 ft) of turned down terminal on each end. The rail was constructed in accordance with PennDOT standard drawings with modifications specified by PennDOT. Detail drawings and layout of the test installation are shown in figure 1. Photographs of the installation are shown in figures 2 and 3.

The PennDOT Type 2 guide rail system consisted of 1.6 m (5.25 ft) long S75x8 posts with 200 mm x 600 mm x 6 mm (8.0 in x 24.0 in x 0.25 in) soil plates, spaced 3810 mm (12.5 ft) apart, and 3.8 m (12.5 ft) long 12 gauge W-beam rail elements. For this test installation, the posts were installed in drilled holes and backfilled with *NCHRP Report 350* standard soil. The height of the guardrail to the top of the W-beam rail element was 820 mm (32.3 in). The W-beam rail elements were attached to the posts with 8 mm (0.315 in) diameter ASTM F 568, Class 4.6, 60 mm (2.38 in) long, fully threaded bolts, with a round flat washer, two 44 mm (1.7 in) square plate washers, and two nuts. Rail splices were located at mid-span between posts. In addition, a 14 mm (0.5 in) diameter ASTM F 568 Class 4.6, 40 mm (1.5 in) long shelf bolt was placed in the flange

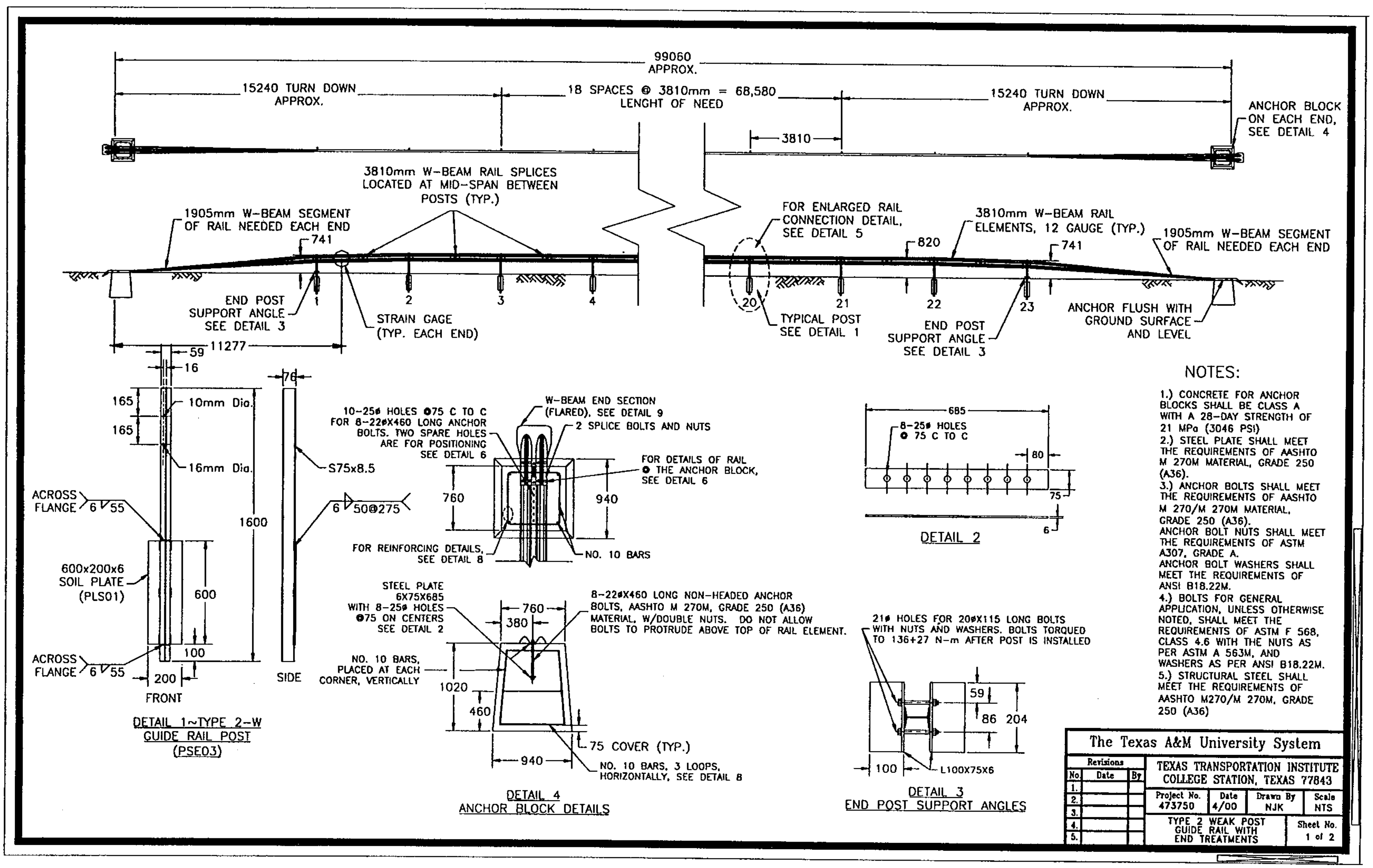


Figure 1. Details of the modified PennDOT Type 2 guide rail for test 473750-4.

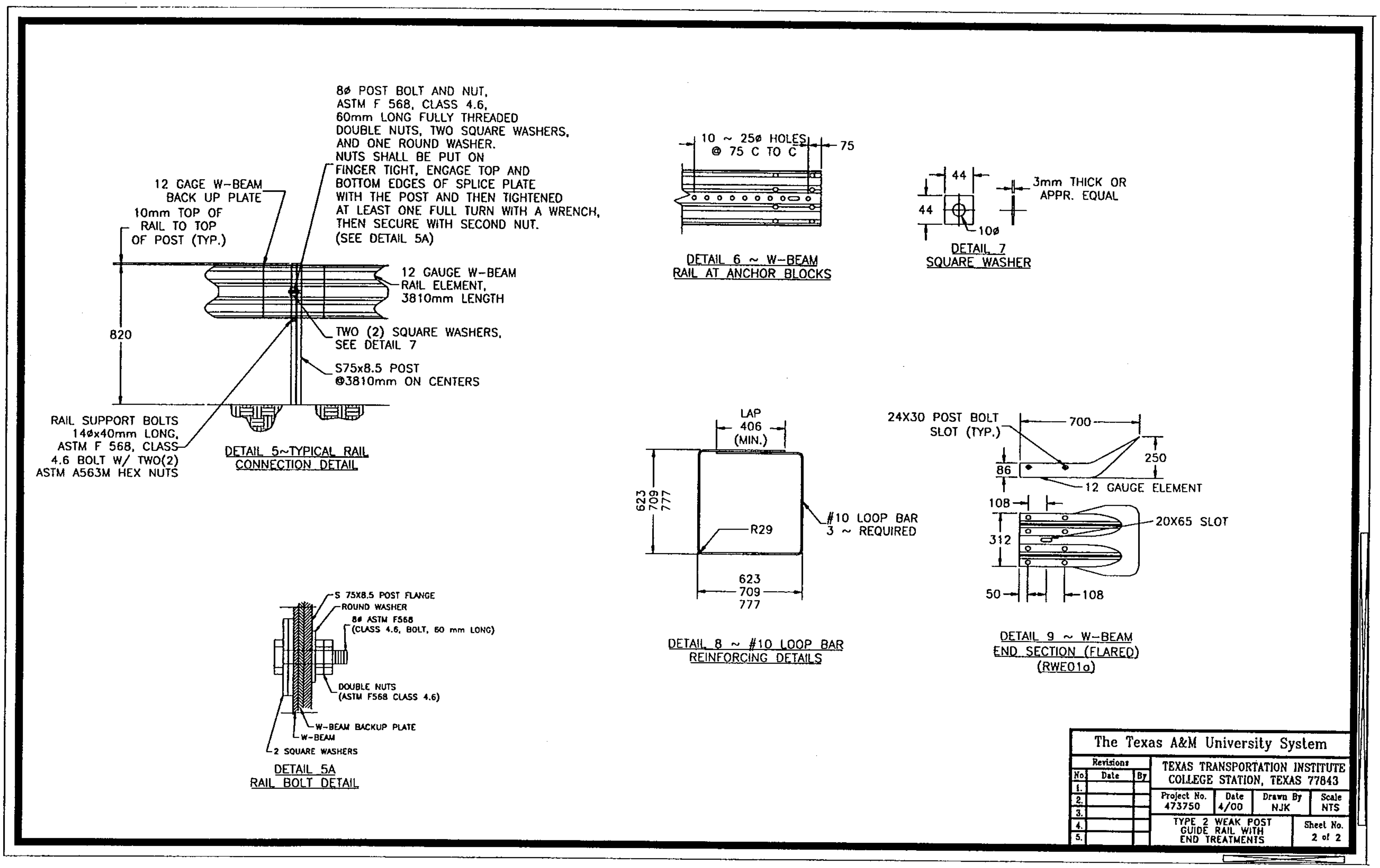


Figure 1. Details of the PennDOT Type 2 guide rail for test 473750-4 (continued).

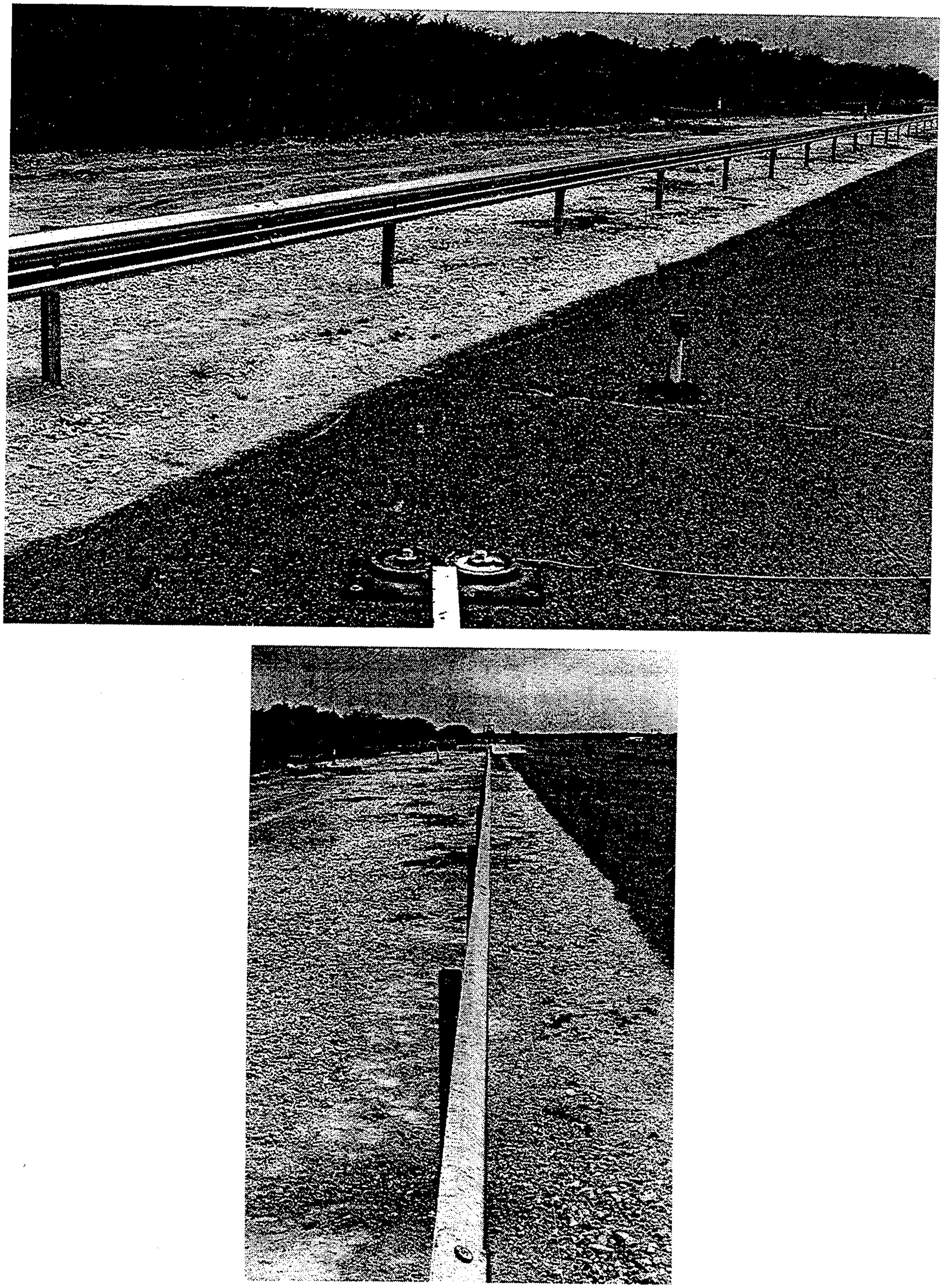


Figure 2. PennDOT Type 2 guide rail prior to testing.

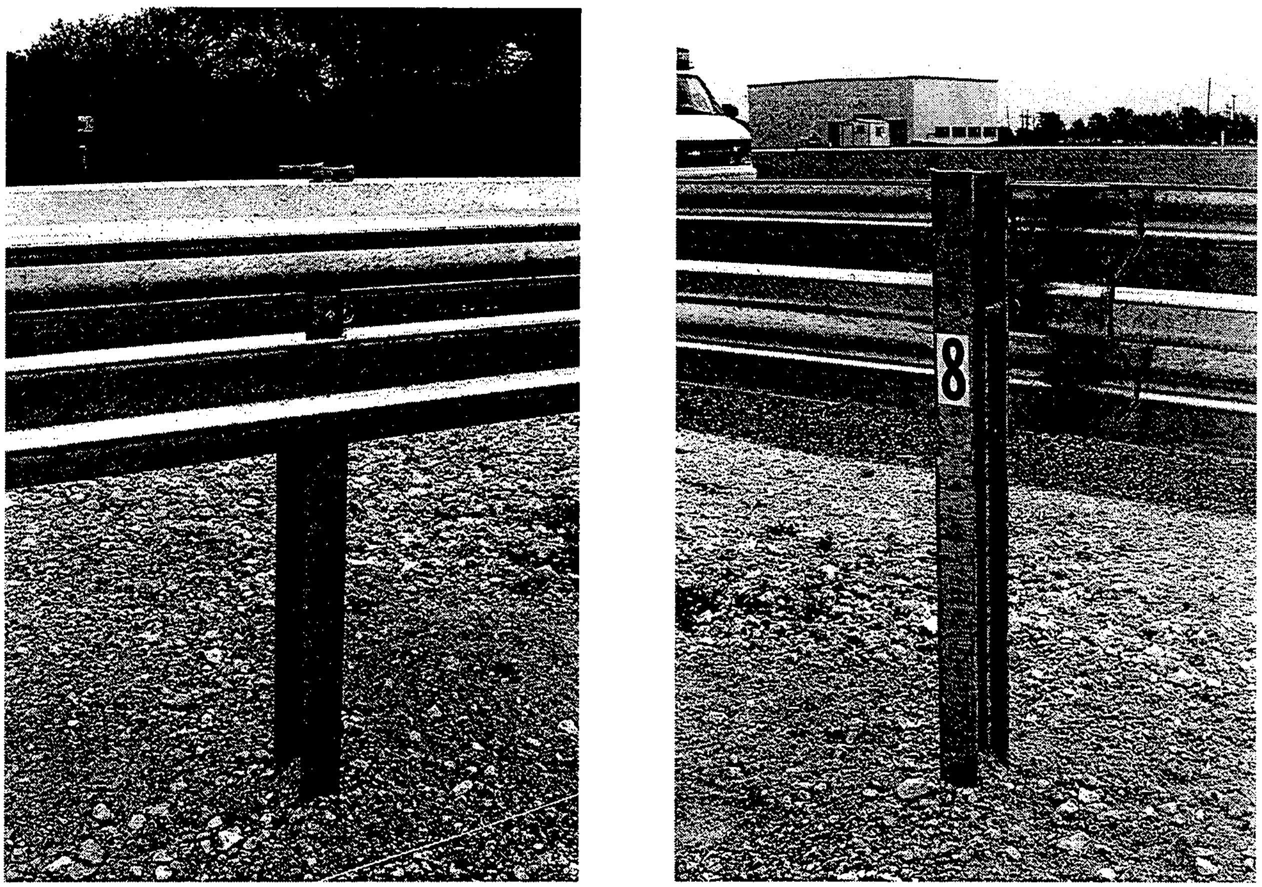


Figure 3. PennDOT Type 2 guide rail posts prior to testing.

of each post with two nuts on the traffic face to support the W-beam at each post location. The purpose of the shelf bolts is to reduce the loading on the 8 mm (0.25 in) diameter post bolts from the weight of the W-beam rail elements and other dead load, such as snow and ice on the rail elements. In addition, 12 gage W-Beam Back-up Plates were installed between each post and the W-Beam Guardrail. Strain gages were installed on one cross section of W-beam rail element near each end of the installation to measure tensile strains in the rail during the test.

Each end of the guide rail was anchored to an approximate 1 meter (39.4 in) tall concrete anchor block measuring 940 mm x 940 mm (37 in x 37 in) at the base and 760 mm x 760 mm (30 in x 30 in) at the top. The block was installed flush with the grade. The ends of the guide rail attached to eight 22 mm diameter x 460 mm long (7/8 in x 18 in) American Association of State Highway Traffic Officials (AASHTO) M 270 M, Grade 250 anchor bolts connected to a 75 mm x 685 mm x 6 mm (3 in x 27 in) anchor plate embedded into each anchor block. For additional information concerning the test installation please refer to figure 1 of this report.

Test Conditions

According to NCHRP Report 350, two crash tests are required for evaluation of longitudinal barriers to test level three (TL-3):

> ***NCHRP Report 350* test designation 3-10**: An 820-kg (1806 lb) passenger car impacting the critical impact point (CIP) in the length of need (LON) of the longitudinal barrier at a nominal speed and angle of 100 km/h (62.2 mi/h) and 20 degrees. The purpose of this test is to evaluate the overall performance of the LON section in general, and occupant risks in particular.

> ***NCHRP Report 350* test designation 3-11**: A 2000-kg (4409 lb) pickup truck impacting the CIP in the LON of the longitudinal barrier at a nominal speed and angle of 100 km/h (62.2 mi/h) and 25 degrees. The test is intended to evaluate the strength of section in containing and redirecting the pickup truck.

The test reported herein corresponds to *NCHRP Report 350* test designation 3-11. The CIP for this test was determined using information contained *NCHRP Report 350* and accordingly was determined to be the midpoint of the span between the fourth and fifth posts after the terminal section (last post of the terminal is the first post of the system).

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented in appendix A.

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, the following safety evaluation criteria from table 5.1 of *NCHRP Report 350* were used to evaluate the crash test reported herein:

- **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 (39.4 ft/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.*

In a memo entitled: *Action: Identifying Acceptable Highway Safety Features*, FHWA suggests the following supplemental evaluation factors and terminology be used for visual assessment of test results:

- **PASSENGER COMPARTMENT INTRUSION**

  1. **Windshield Intrusion**

     a. No windshield contact
     b. Windshield contact, no damage
     c. Windshield contact, no intrusion
     d. Device embedded in windshield, no significant intrusion
     e. Complete intrusion into passenger compartment
     f. Partial intrusion into passenger compartment

  2. **Body Panel Intrusion**

- **LOSS OF VEHICLE CONTROL**

  1. **Physical loss of control**
  2. **Loss of windshield visibility**
  3. **Perceived threat to other vehicles**
  4. **Debris on pavement**

- **PHYSICAL THREAT TO WORKERS OR OTHER VEHICLES**

  1. **Harmful debris that could injure workers or others in the area**
  2. **Harmful debris that could injure occupants in other vehicles**

- **VEHICLE AND DEVICE CONDITION**

  1. **Vehicle Damage**

     a. None
     b. Minor scrapes, scratches or dents
     c. Significant cosmetic dents
     d. Major dents to grill and body panels
     e. Major structural damage

  2. **Windshield Damage**

     a. None
     b. Minor chip or crack
     c. Broken, no interference with visibility
     d. Broken and shattered, visibility restricted but remained intact
     e. Shattered, remained intact but partially dislodged
     f. Large portion removed
     g. Completely removed

  3. **Device Damage**

     a. None
     b. Superficial
     c. Substantial, but can be straightened
     d. Substantial, replacement parts needed for repair
     e. Cannot be repaired

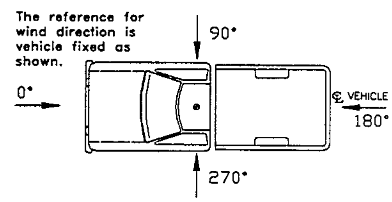
CRASH TEST 473750-3 (*NCHRP REPORT 350* TEST 3-11)

Test Vehicle

A 1995 Chevrolet 2500 pickup truck, shown in figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 2000 kg (4409 lb), and its gross static weight was 2000 kg (4409 lb). The height to the lower edge of the vehicle front bumper was 435 mm (17.1 in) and to the upper edge of the front bumper was 655 mm (25.8 in). Additional dimensions and information on the vehicle are given in appendix B, figure 13. 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.

Soil and Weather Conditions

The crash test was performed the morning of May 9, 2000. Nine days before the test 114 mm (4.5 in) of rainfall was recorded and four days before 18 mm (0.7 in) was recorded. Moisture content of the *NCHRP Report 350* standard soil in which the PennDOT system was installed was 8.4 percent, 8.5 percent, and 9.4 percent at posts 7, 8, and 9, respectively. Weather conditions at the time of testing were as follows: wind speed: 8 km/h (5 mi/h); wind direction: 195 degrees (vehicle was traveling in a northeasterly direction); temperature: 28°C (82°F); relative humidity: 37 percent.



Impact Description

The 2000P vehicle, traveling at a speed of 102.4 km/h (63.6 mi/h), impacted the PennDOT Type 2 guide rail between posts 6 and 7 (1.72 m (5.65 ft) upstream of post 7) at an angle of 26.5 degrees. Shortly after impact, post 7 moved rearward and by 0.049 s the vehicle began to redirect. Post 8 moved at 0.063 s and the left front tire contacted post 7 at 0.082 s. The top of post 7 touched ground at 0.102 s and post 9 moved at 0.104 s. At 0.107 s the left front tire lost contact with the ground surface. At 0.126 s the rail-to-post connection at post 8 released and the rail element began to ride up and over the top of the post. Post 10 moved at 0.155 s and the front bumper of the vehicle contacted post 8 at 0.192 s. Posts 11 and 12 moved at 0.223 s and 0.252 s, respectively. The vehicle became parallel with the system at 0.371 s and was traveling at a speed of 77.8 km/h (48.4 mi/h). The left front tire contacted post 9 at 0.383 s and the rail-to-post connection at post 9 released at 0.398 s. At 0.589 s the left front tire contacted post 10 and at 0.592 s the rail-to-post connection at post 10 released. The left front tire contacted post 11 at 0.822 s and the rail-to-post connection released at 0.824 s. At 1.067 s the left front tire contacted post 12 and at 1.069 s the rail-to-post connection released. The vehicle lost contact with the rail element at 1.418 s and was traveling 59.3 km/h (36.9 mi/h). The exit angle was not obtainable,

Figure 4. Vehicle/installation geometrics for test 473750-3.

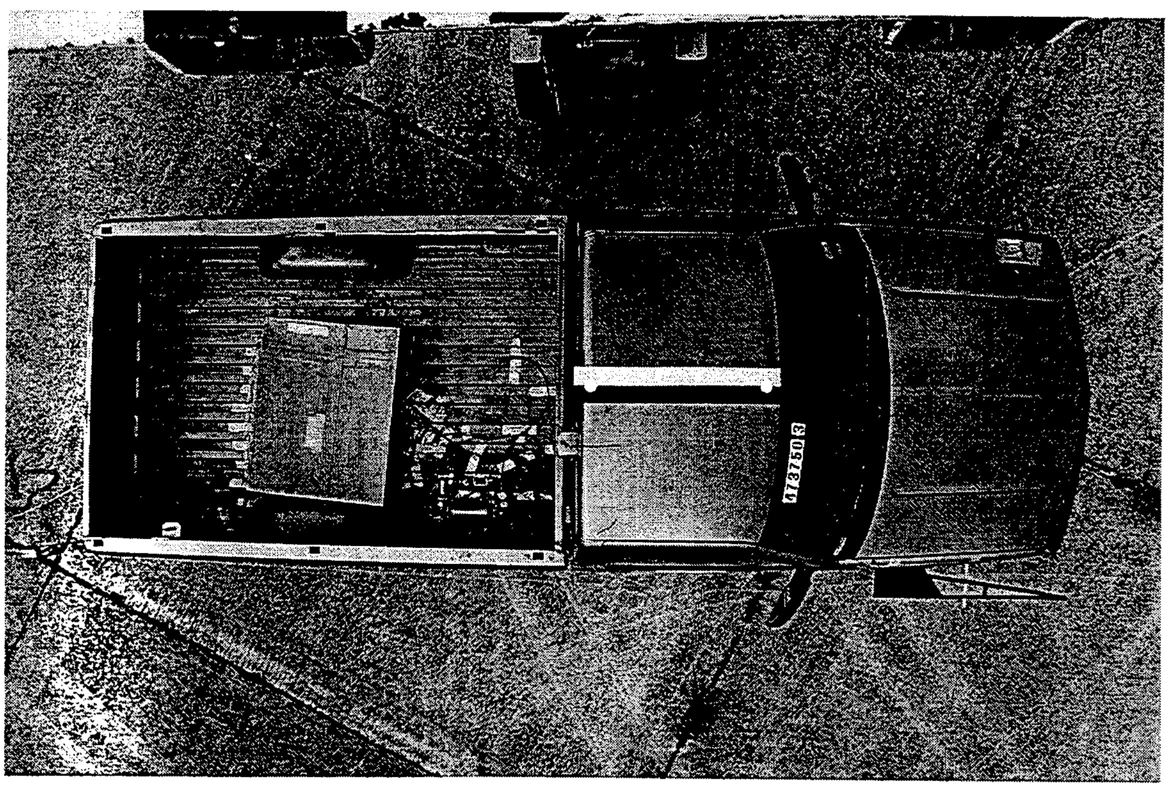


Figure 5. Vehicle before test 473750-3.

from the overhead camera view; however, the exit angle was approximated from tire marks after the test at less than 2 degrees. At 2.160 s the vehicle contacted the rail element a second time and at 2.209 s the frame member of the vehicle contacted the rail. The vehicle contacted the rail again near post 17, remained in contact with the rail element, and rode off the end of the terminal at 5.492 s. Brakes on the vehicle were not applied and the vehicle subsequently came to rest 68.6 m (225.1 ft) down from the impact point and in line with the traffic face of the rail. Sequential photographs of the test period are shown in appendix C, figures 14 and 15.

Damage to Test Article

Damage to the modified Type 2 PennDOT guide rail installation is shown in figures 6 through 8. The upstream end terminal through post 2 were disturbed. Post 3 moved rearward 13 mm (0.5 in), post 4 moved rearward 63 mm (2.5 in), post 5 - 150 mm (5.9 in), post 6 - 610 mm (24.0 in), post 7 - 580 mm (22.8 in) and post 8 - 490 mm (19.3 in). Posts 9, 10, and 11 were pulled out of the ground and resting 4.6 m (15.1 ft), 3.0 m (9.8 ft) respectively, near the rail. Post 12 was pulled up but the end remained in the ground. Post 13 was pulled rearward 40 mm (1.6 in) and posts 14 through the end were disturbed. The downstream end terminal was pulled longitudinally 10 mm (0.4 in). The rail was separated from posts 7 through 13. Length of contact of the vehicle with the rail element was 25.6 m (84.0 ft). Maximum dynamic deflection of the rail element during the test was 2.12 m (6.94 ft). Maximum permanent deformation of the rail element was 1.64 mm (5.40 ft) between posts 8 and 9.

Vehicle Damage

The vehicle sustained minor damage as shown in figure 9. No structural damage was imparted to the vehicle; however, the bumper, grill, left front and rear quarter panels, left door and left rear tire were damaged. Maximum exterior crush to the vehicle was 230 mm (9.1 in) at the left front corner. No deformation or intrusion into the occupant compartment occurred from the impact with the guardrail. The interior of the vehicle is shown in figure 10. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 2 and 3.

Occupant Risk Factors

Data from the tri-axial accelerometer, located at the vehicle center of gravity, were digitized to compute occupant impact velocity and ridedown accelerations. The occupant impact velocity and ridedown accelerations in the longitudinal axis only are required from these data for evaluation of criterion L of *NCHRP Report 350*. In the longitudinal direction, the occupant impact velocity was 3.9 m/s (12.8 ft/s) at 0.200 s, the highest 0.010-s occupant ridedown acceleration was -5.9 g's from 0.405 to 0.415 s, and the maximum 0.050-s average acceleration was -3.4 g's between 0.221 and 0.271 s. In the lateral direction, the occupant impact velocity was 4.2 m/s (13.8 ft/s) at 0.200 s, the highest 0.010-s occupant ridedown acceleration was 6.4 g's

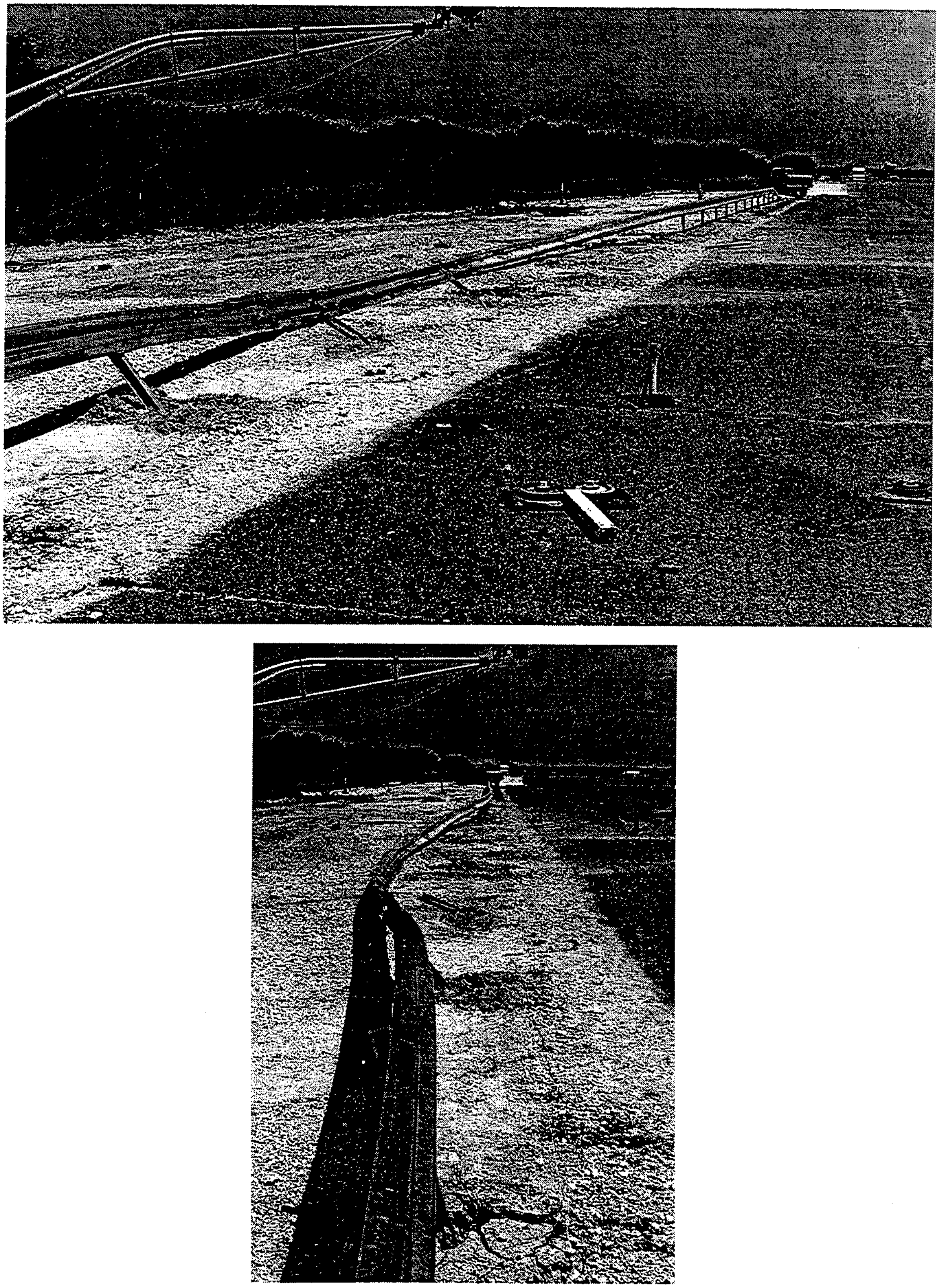


Figure 6. Vehicle trajectory after test 473750-3.

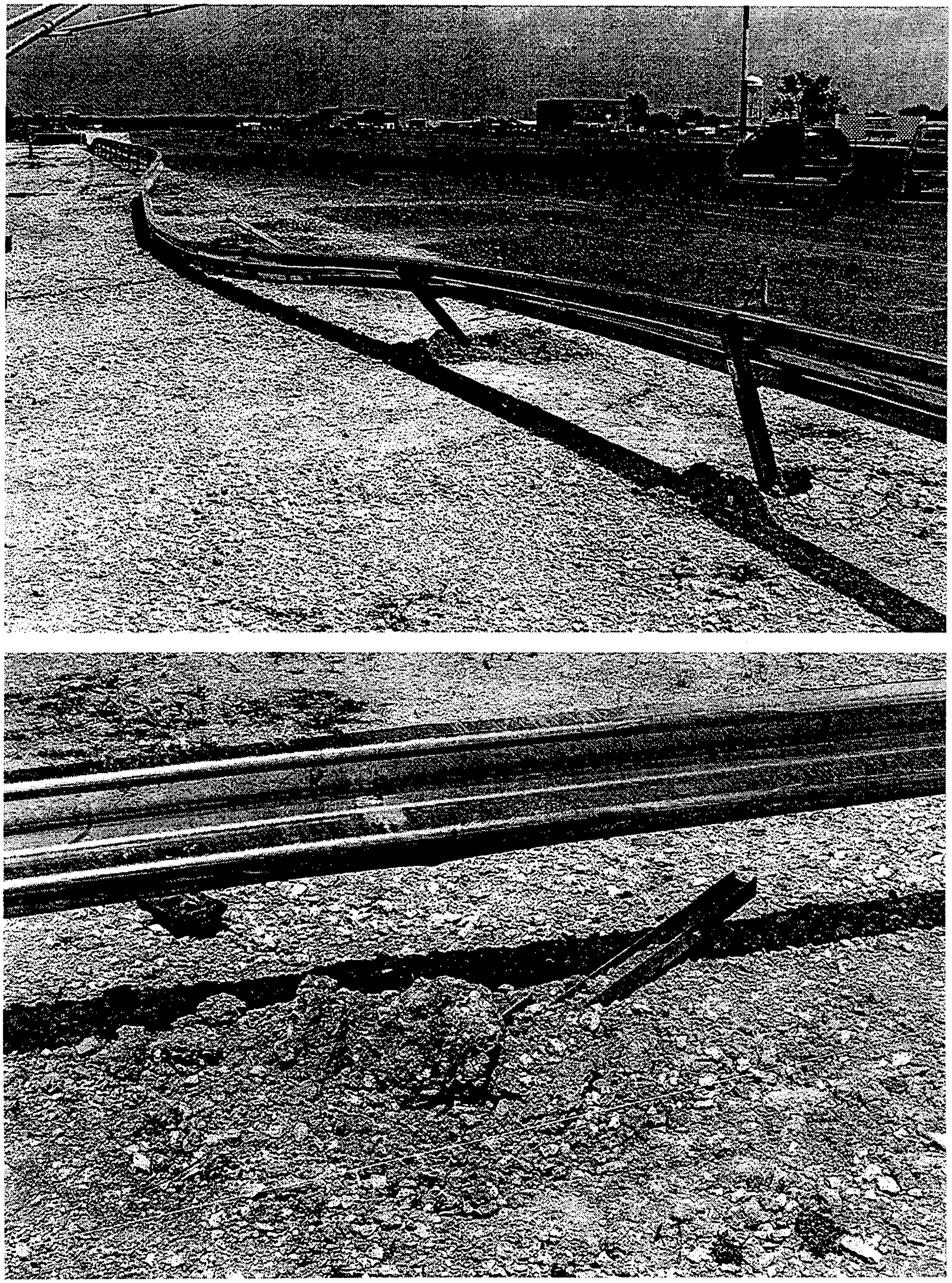


Figure 7. Rail damage after test 473750-3.

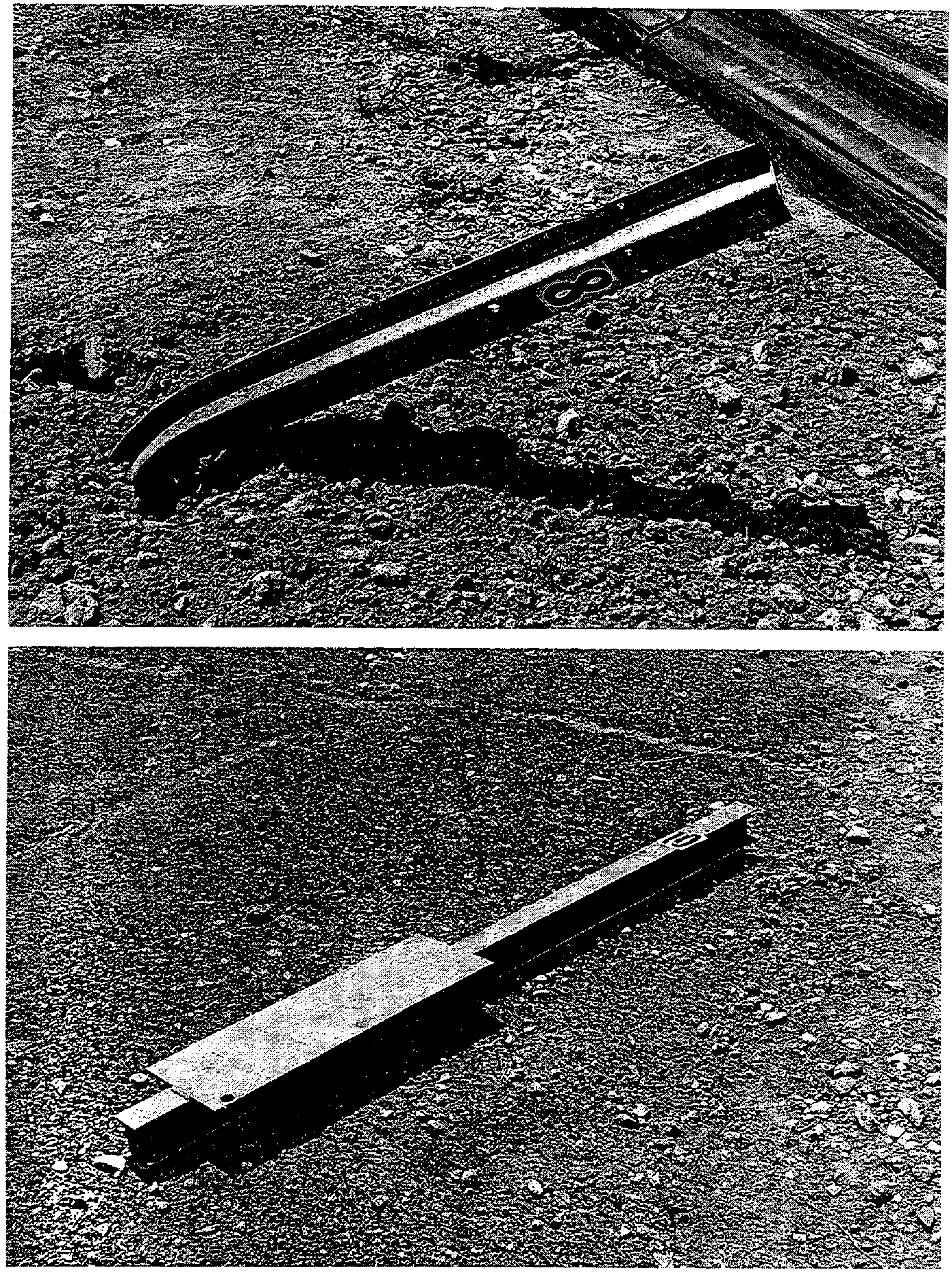


Figure 8. Post damage after test 473750-3.

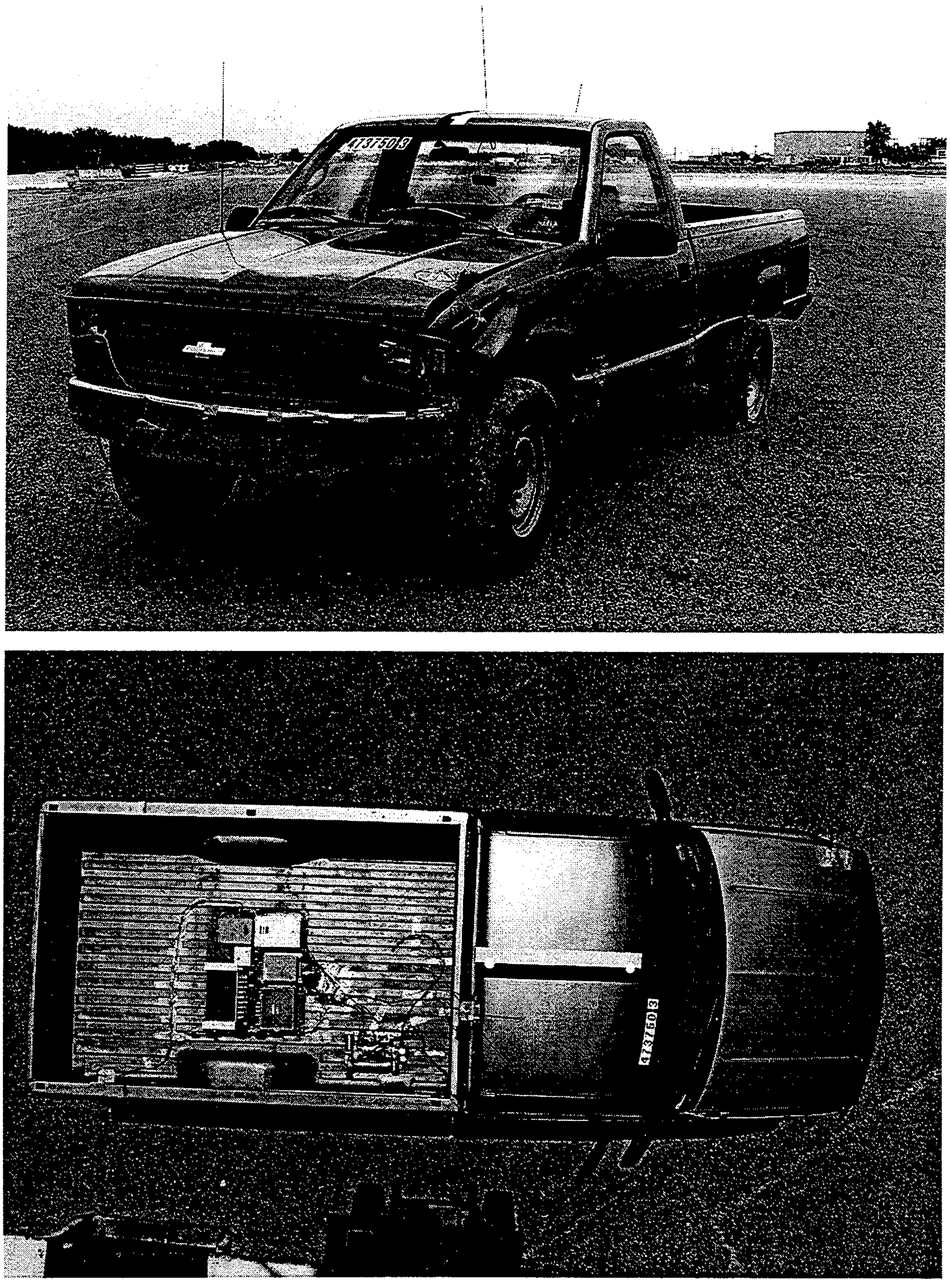
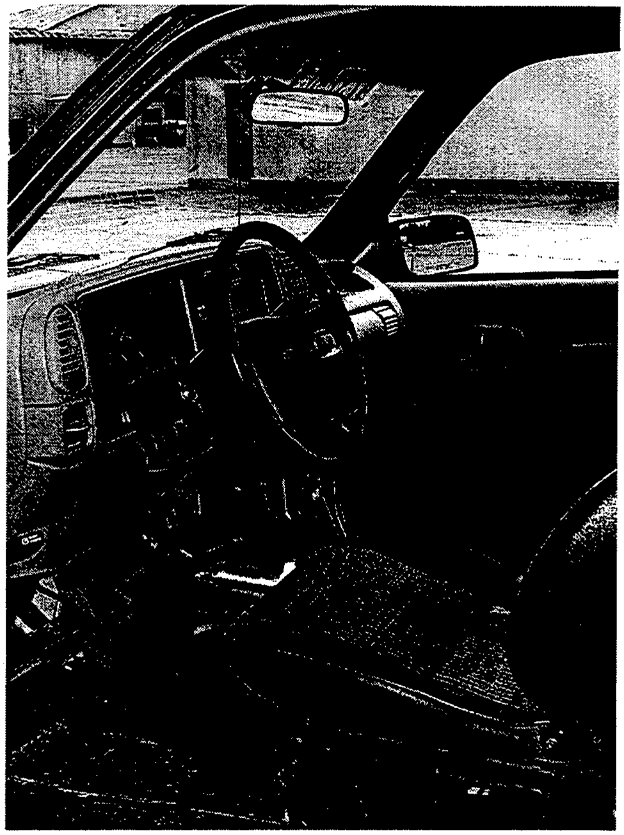
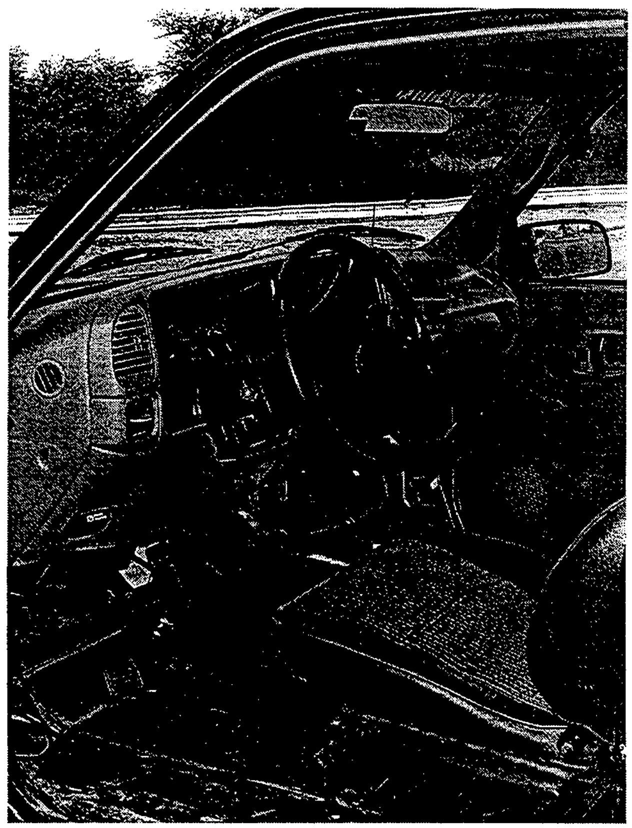


Figure 9. Vehicle after test 473750-3.

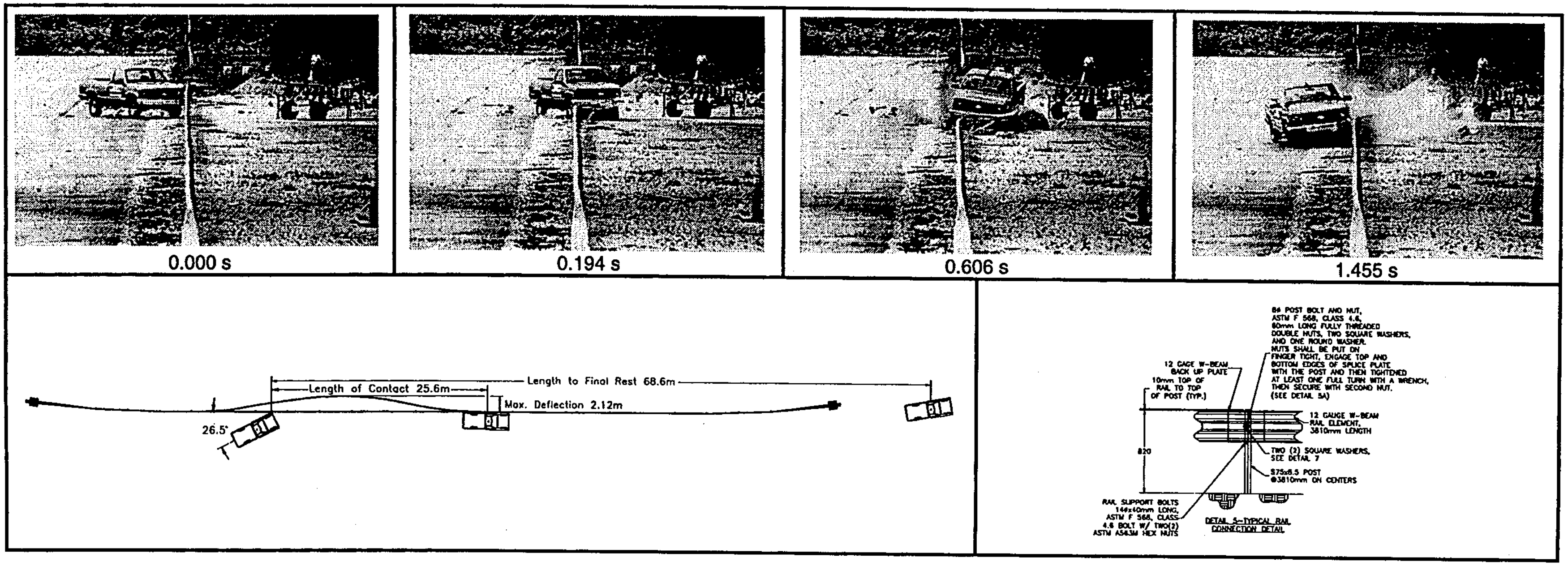


Before test



After test

Figure 10. Interior of vehicle for test 473750-3.



General Information	
Test Agency	Texas Transportation Institute
Test No.	473750-3
Date	05/09/00
Test Article	
Type	Guide Rail
Name or Manufacturer	Modified Penn DOT Type 2 Guide Rail
Installation Length (m)	99.0
Material or Key Elements	W-beam Guide Rail w S3x5.7 Posts & Backup Plates
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1995 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	2104
Test Inertial	2000
Dummy	No Dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	102.4
Angle (deg)	26.5
Exit Conditions	
Speed (km/h)	59.3
Angle (deg)	~2
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.9
y-direction	4.2
THIV (km/h)	18.5
Ridedown Accelerations (g's)	
x-direction	-5.9
y-direction	6.4
PHD (g's)	8.8
ASI	0.53
Max. 0.050-s Average (g's)	
x-direction	-3.4
y-direction	4.0
z-direction	-1.9

Test Article Deflections (m)	
Dynamic	2.12
Permanent	1.64
Vehicle Damage	
Exterior	
VDS	11LFQ2
CDC	11FLEK2 & 11IDEW2
Maximum Exterior Vehicle Crush (mm)	230
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	nil
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	36
Max. Pitch Angle (deg)	-5
Max. Roll Angle (deg)	-12

Figure 11. Summary of results for test 473750-3, *NCHRP Report 350* test 3-11.

from 0.402 to 0.412 s, and the maximum 0.050-s average was 4.0 g's between 0.226 and 0.276 s. These data and other pertinent information from the test are summarized in figure 11. Vehicle angular displacements and accelerations versus time traces are presented in appendix D, figures 16 through 22.

Rail Instrumentation Results

Strain gages were installed on the neutral axis of the W-beam rail element near each end of the installation to measure tensile strains in the rail during the test. Graphs of data from the strain gauges installed on the railing are shown in figures 23 and 24 at the end of appendix D. These data were collected to provide information for use in computer simulation. The data serve no purpose in determining acceptability of performance of the guide rail.

The strain gages were located 11 277 mm (444.0 in) from each end anchor. This location was chosen because it was out of any foreseen impact area and was also not in any area of the rail that was distorted or twisted. The maximum tensile rail force on the upstream end of the guide rail was 52.0 kips, and the maximum on the downstream end was 37.0 kips.

SUMMARY AND CONCLUSIONS

ASSESSMENT OF TEST RESULTS

As stated previously, the following *NCHRP Report 350* safety evaluation criteria were used to evaluate this 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.*

  The modified PennDOT Type 2 guide rail contained and redirected the 2000P vehicle. Maximum dynamic deflection of the rail element was 2.12 m (6.94 ft).

- **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.*

  Three posts were pulled out of the ground and resting in front of the rail (maximum distance 4.6 m (15.1 ft)) and another was pulled up but remained at its original location. No other detached elements, fragments or other debris penetrated nor showed potential for penetrating the occupant compartment; nor presented undue hazard to others in the area. No deformation or intrusion into the occupant compartment occurred.

  F. *The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.*

  The vehicle remained upright and stable during and after the collision period.

- **Vehicle Trajectory**

K. *After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*

The vehicle did not intrude into adjacent traffic lanes as the vehicle came to rest 68.6 m (225 ft) down from impact and in line with the face of the rail.

L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s (39.4 ft/s) and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.*

The longitudinal occupant impact velocity was 3.9 m/s (12.8 ft/s) and ridedown acceleration was -5.9 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.*

Exit angle at loss of contact with the guide rail was less than 2 degrees, which was 8 percent of the impact angle.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

◆ **PASSENGER COMPARTMENT INTRUSION**

1. Windshield Intrusion

a. No windshield contact (circled)
b. Windshield contact, no damage
c. Windshield contact, no intrusion
d. Device embedded in windshield, no significant intrusion
e. Complete intrusion into passenger compartment
f. Partial intrusion into passenger compartment

2. Body Panel Intrusion yes or no (circled)

◆ **LOSS OF VEHICLE CONTROL**

1. Physical loss of control

2. Loss of windshield visibility

3. Perceived threat to other vehicles

4. Debris on pavement

The vehicle could have been kept in control.

◆ **PHYSICAL THREAT TO WORKERS OR OTHER VEHICLES**

1. Harmful debris that could injure workers or others in the area

2. Harmful debris that could injure occupants in other vehicles

Three posts pulled out of the ground and were resting in front of the installation (maximum distance 4.6 m (15.1 ft)) and another was pulled up but lying near its original location. No other debris of significance that would harm others in the area was present.

◆ **VEHICLE AND DEVICE CONDITION**

1. Vehicle Damage

a. None
b. Minor scrapes, scratches or dents
c. Significant cosmetic dents
(d.) Major dents to grill and body panels
e. Major structural damage

2. Windshield Damage

(a.) None
b. Minor chip or crack
c. Broken, no interference with visibility
d. Broken and shattered, visibility restricted but remained intact
e. Shattered, remained intact but partially dislodged
f. Large portion removed
g. Completely removed

3. Device Damage

a. None
b. Superficial
c. Substantial, but can be straightened
(d.) Substantial, replacement parts needed for repair
e. Cannot be repaired

CONCLUSIONS

As shown in table 1, the PennDOT Type 2 guide rail performed acceptably for *NCHRP Report 350* test 3-11.

Note that three posts were pulled out of the ground. Post 9 was resting 4.6 m (15.1 ft) in front of the rail, post 10 was 3.0 m (9.8 ft) in front of the rail and post 11 was near the rail. Post 12 was pulled up but the end remained in the ground.

Table 1. Performance evaluation summary for test 473750-3, *NCHRP Report 350* test 3-11.

Test Agency: Texas Transportation Institute | Test No.: 473750-3 | Test Date: 05/09/2000

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 modified PennDOT Type 2 guide rail contained and redirected the 2000P vehicle. Maximum dynamic deflection of the rail element was 2.12 m (6.94 ft).	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.	Three posts were pulled out of the ground and resting in front of the rail (maximum distance 4.6 m (15.1 ft)) and another was pulled up but remained at its original location. No other detached elements, fragments or other debris penetrated nor showed potential for penetrating the occupant compartment; nor presented undue hazard to others in the area. No deformation or intrusion into the occupant compartment occurred.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable during and after the collision period.	Pass
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass*
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s (40 ft/s) and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	The longitudinal occupant impact velocity was 3.9 m/s (12.8 ft/s) and ridedown acceleration was -5.9 g's.	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.	Exit angle at loss of contact with the guide rail was less than 2 degrees, which was 8 percent of the impact angle.	Pass*

*Criterion K and M are preferable, not required.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING FOR THE TEST INSTALLATION

Strain gages were installed on one cross section of the W-beam rail element near each end of the installation to measure tensile strains in the rail during the test. The tensile strains were converted to axial force, by constants derived during physical calibrations, and reported as such, every 0.0005 seconds during the impact.

Each of the two instrumented W-beam rail elements was transformed into a force transducer by the use of two bondable strain gage rosettes. Each rosette consisted of two individual strain gages, oriented 90 degrees to each other. These were then connected as a full bridge strain gage circuit using two rosettes at each location. One rosette was placed on the front of the rail element, at the neutral bending axis and the other was placed on the backside of the rail, exactly opposite the first as shown in figure 12. This arrangement provided for cancellation of bending by being on the neutral axis and by placing one of the two tension gages in compression and the other in tension during a lateral bending event, producing a resultant output of zero. The two gages that were 90 degrees to the rail axis provided temperature compensation of the bridge and increased the bridge output due to Poisson's ratio of approximately 0.3.

Strain gage bridges were located 1524 mm (60.0 in) from the end of each instrumented rail element so as to avoid any end or hole effects in the strain patterns produced by axial loading. At this location, each side of the rail section was prepared by first grinding away the galvanized coating from a 60 by 60 mm (2.4 by 2.4 in) area, sanding the steel to a mirror finish, chemically cleaning, and bonding the rosette. A small 9 mm (0.4 in) hole was drilled in the rail section to allow the bridge completion wires to pass. This hole was located approximately 150 mm (6.0 in) from the gages to avoid strain distortion under the gages.

Once wired and tested, each strain gage bridge was physically calibrated to produce a curve of axial force vs. micro strain. This was accomplished by anchoring one end of the rail section and pulling on the other through a precision load cell. The resulting curve was then used to produce a force calibration step when a precision resistor was placed across one leg of the bridge, which is referred to as an R-cal or shunt cal.

The strain gages were located 11 277 mm (444.0 in) from each end anchor. This location was chosen because it was out of any foreseen impact area and was also not in any area of the rail that was distorted or twisted as would be the case closer to the end anchors.

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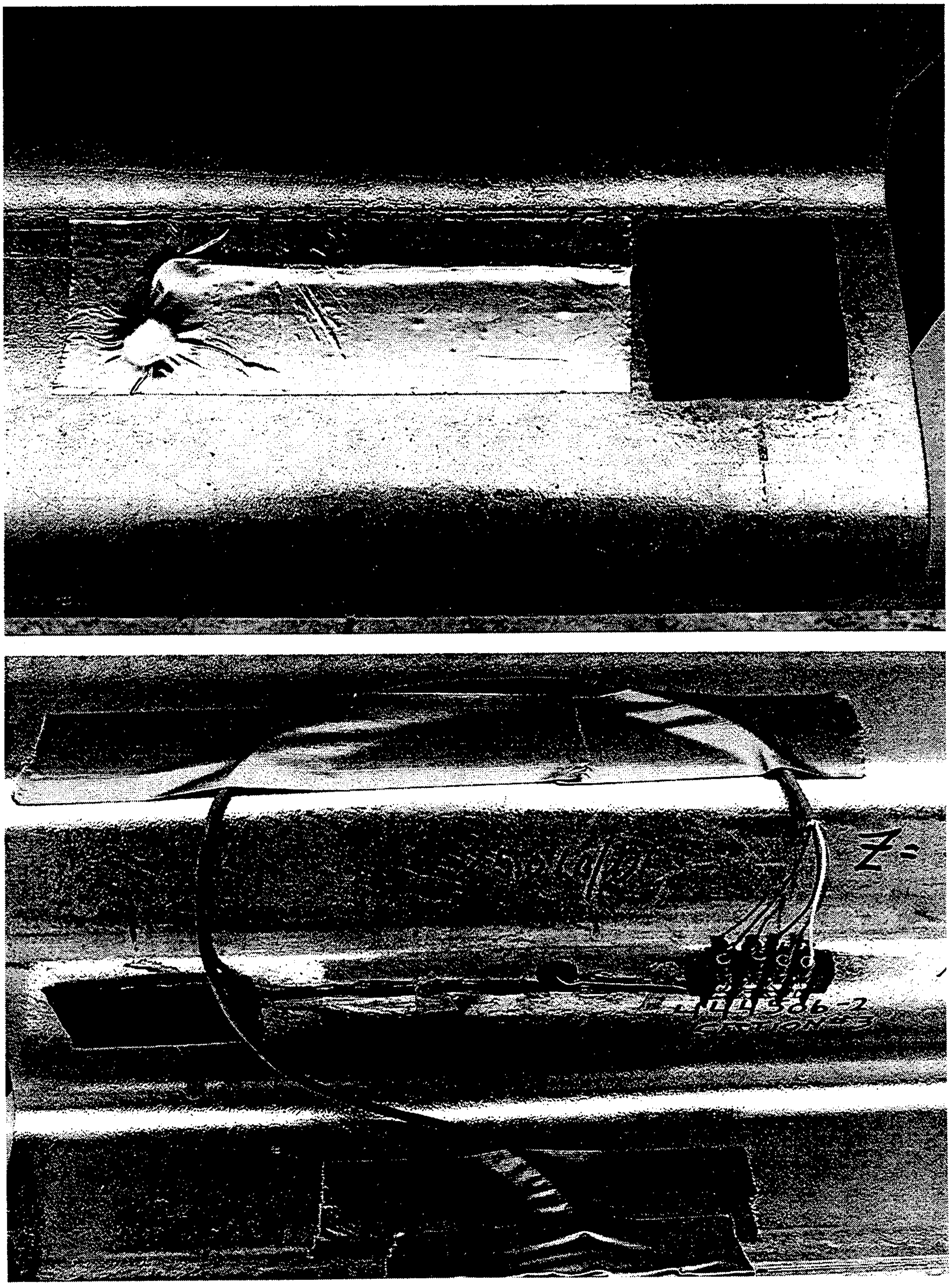


Figure 12. Strain gage installation on w-beam rail for test 473750-3.

Approximately 100 meters (328.1 ft) of cable connected the strain gages to the strain gage amplifiers located in a vehicle behind the installation with appropriate compensation calculations made for cable lengths. The output of the strain gage amplifiers fed a P-band telemetry transmitter in the instrumentation vehicle. Just prior to the impact the R-cal data was sent over the telemetry link to provide subsequent correction values to the data. In the base station, these calibration and impact data signals were recorded simultaneously, on a 28 track instrumentation tape recorder, with all of the vehicle data. These analog data were then later digitized at 2000 samples per second to produce force data in engineering units.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING FOR THE TEST VEHICLE

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. These accelerometers were ENDEVCO Model 2262CA, piezoresistive accelerometers with a ±100 g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Angular rate transducers are solid state, gas flow units designed for high g service. Signal conditioners and amplifiers in the test vehicle increase the low level signals to a ±2.5 volt maximum level. The signal conditioners also provide the capability of an R-Cal or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15 channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals, from the test vehicle, are recorded before the test and immediately afterwards. A crystal controlled time reference signal is simultaneously recorded with the data. Pressure sensitive switches on the bumper of the impacting vehicle are actuated 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 produces an "event" mark on the data record to establish the instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, is received at the data acquisition station, and demultiplexed onto separate tracks of a 28 track, (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine, filtered with Society of Automotive Engineers (SAE J211) filters, and digitized using a microcomputer, at 2000 samples per second per channel, for analysis and evaluation of impact performance.

All accelerometers are calibrated annually according to SAE J211 *4.6.1* by means of an ENDEVCO 2901, precision primary vibration standard. This device and its support instruments are returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are evaluated annually, using instruments with current NIST traceability, and the results factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are made any time data is suspect.

The digitized data are then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these 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 calculates 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 are filtered with a 60 Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using a commercially available software package (Excel).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0005-s intervals and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

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

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; and 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 is positioned on the impacting vehicle to indicate the instant of contact with the installation and is visible from each camera. The films from these high-speed cameras are analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain event times, displacement and angular data. A BetaCam, a VHS video camera, and still cameras are used to document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle is towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle is 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 is 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 moves away from the test site. A two to one speed ratio between the test and tow vehicle exists with this system. Just prior to impact with the installation, the test vehicle is released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle clears the immediate area of the test site, at which time brakes on the vehicle are activated, bringing it to a safe and controlled stop.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

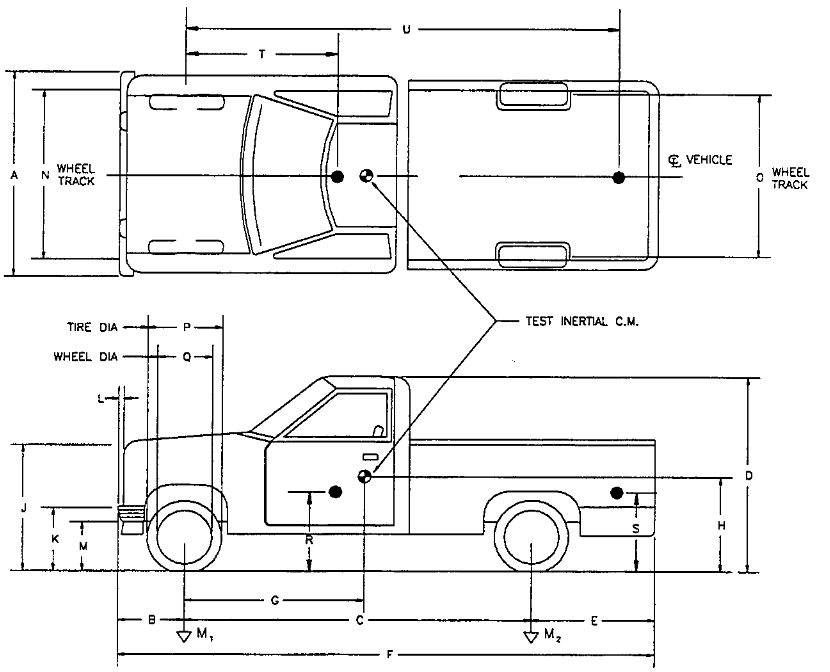
DATE: 05/09/00 TEST NO.: 473750-3 VIN NO.: 1GCGC24K2SE193349

YEAR: 1995 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ________ ODOMETER: 144042 TIRE SIZE: LT 225 75R16

MASS DISTRIBUTION (kg) LF 560 RF 551 LR 442 RR 447

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ________

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

8 LUGS

DUMMY DATA:

TYPE: ________

MASS: ________

SEAT POSITION: ________

GEOMETRY – (mm)

A	1865	E	1310	J	1095	N	1600	R	715
B	810	F	5470	K	655	O	1620	S	905
C	3350	G	1489.1	L	70	P	760	T	1480
D	1855	H		M	435	Q	445	U	3960

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1171	1111	
M_2	933	889	
M_T	2104	2000	

Figure 13. Vehicle properties for test 473750-3.

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Table 2. Exterior crush measurements for test 473750-3.

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 Width ** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front bumper	800	230	500	230	180	100	80	30	0	-570
2	750 mm above ground	800	220	1080	0	50	N/A	N/A	N/A	400	+800
							Wheel well			220	+1520

[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.

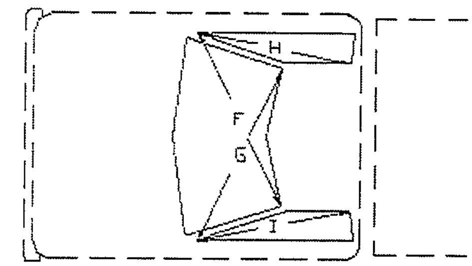
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

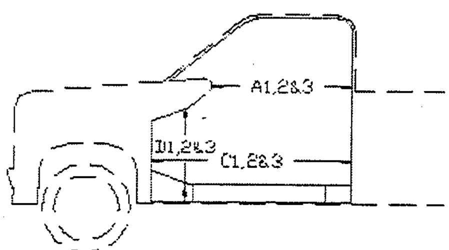
***Measure and document on the vehicle diagram the location of the maximum crush.
Note: Use as many lines/columns as necessary to describe each damage profile.

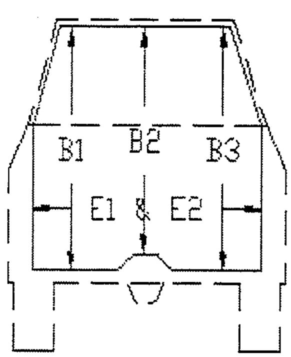
Table 3. Occupant compartment measurements for test 473750-3.

Truck

Occupant Compartment Deformation

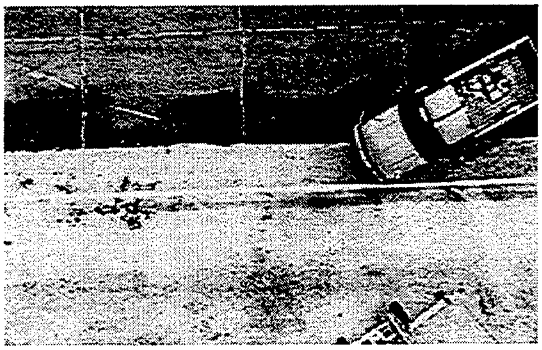






	BEFORE	AFTER
A1	875	875
A2	885	885
A3	915	915
B1	1075	1075
B2	1066	1066
B3	1075	1075
C1	1375	1375
C2	1260	1260
C3	1370	1370
D1	327	327
D2	160	160
D3	315	315
E1	1580	1580
E2	1585	1585
F	1460	1460
G	1460	1460
H	900	900
I	900	900
J	1525	1525

APPENDIX C. SEQUENTIAL PHOTOGRAPHS



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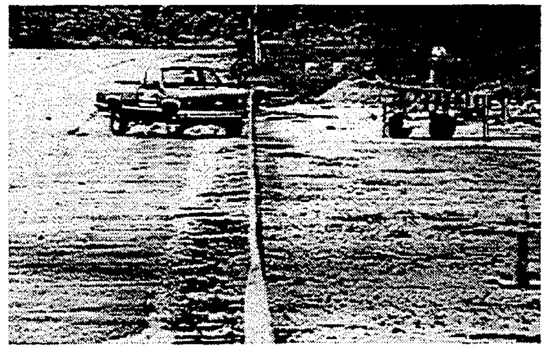

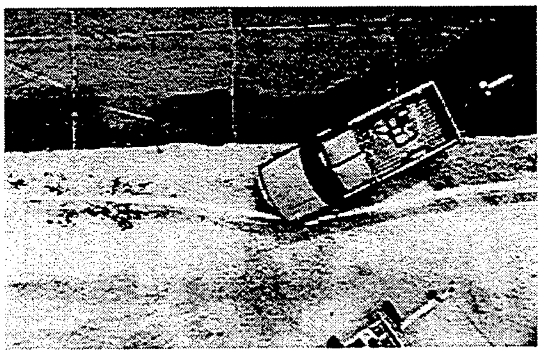

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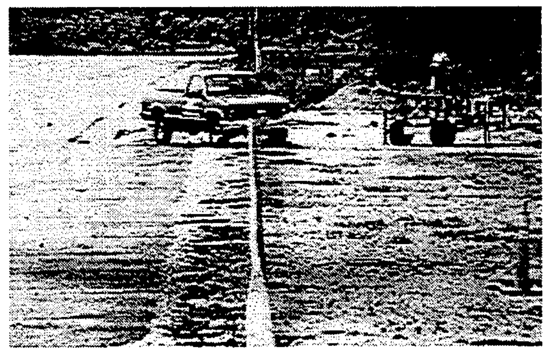

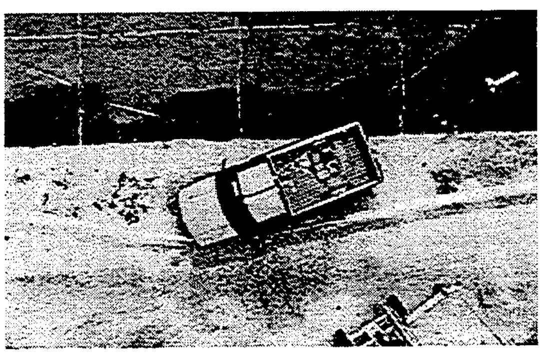

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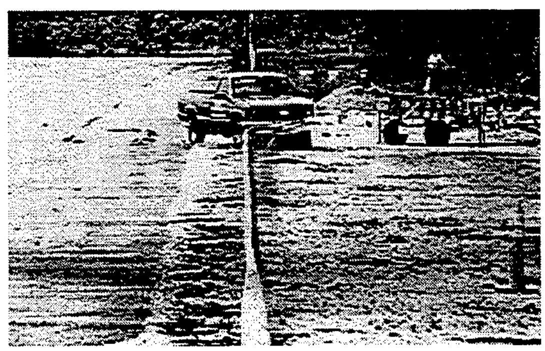

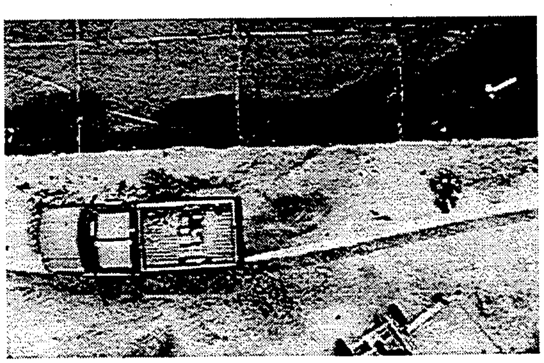

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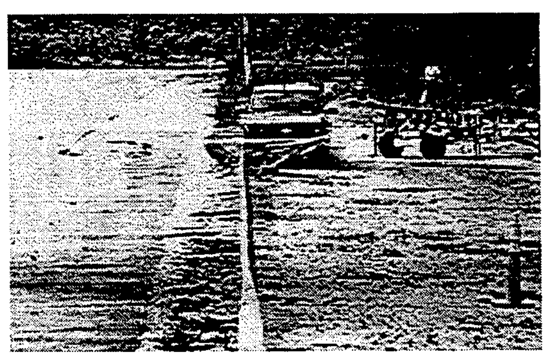

Figure 14. Sequential photographs for test 473750-3
(overhead & frontal views).

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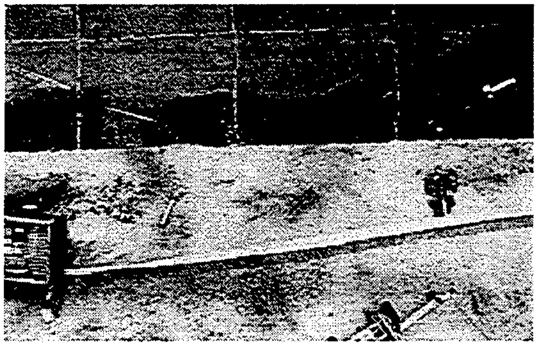
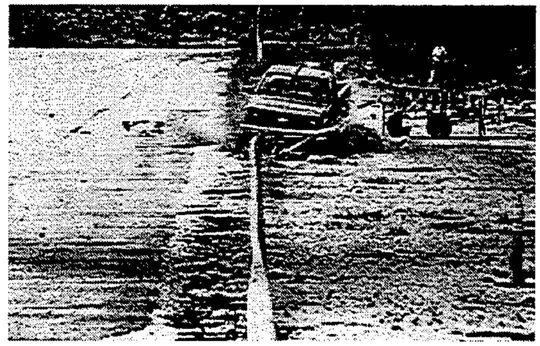

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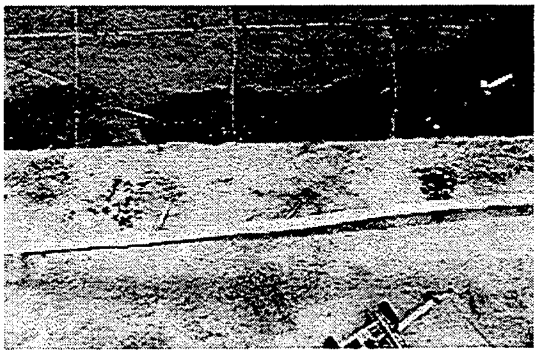


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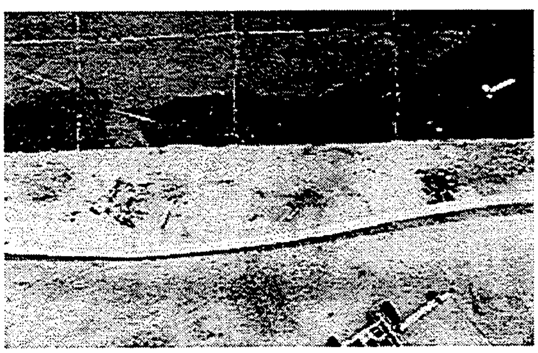


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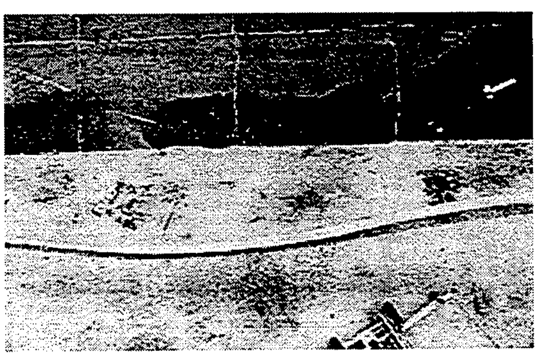


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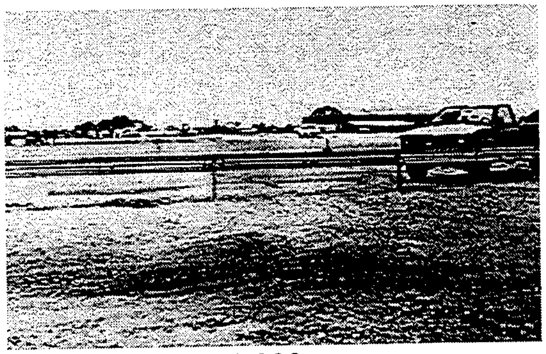
Figure 14. Sequential photographs for test 473750-3
(overhead & frontal views) (continued).



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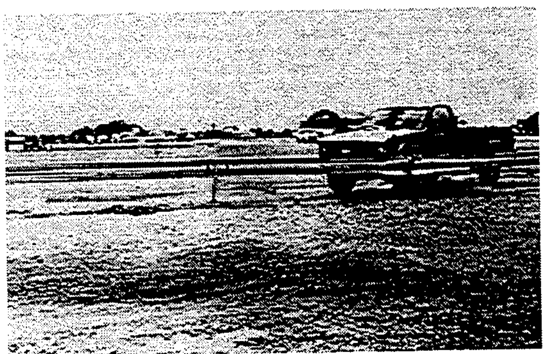

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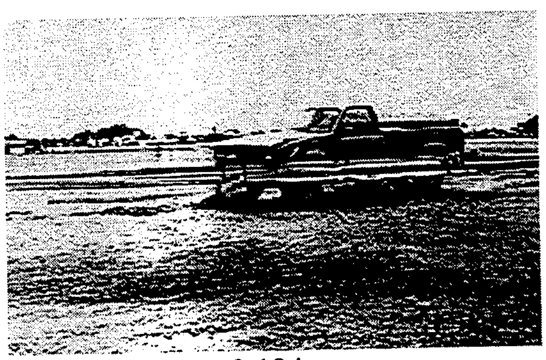

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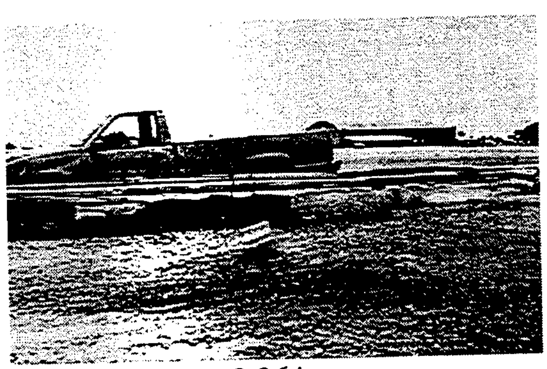

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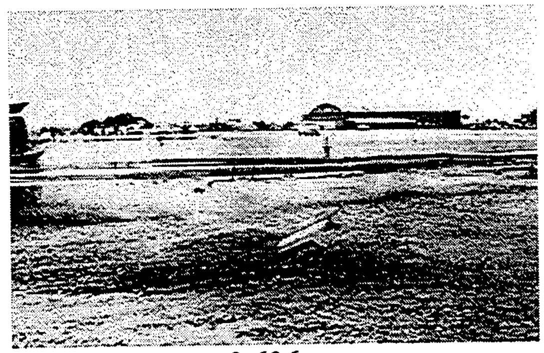

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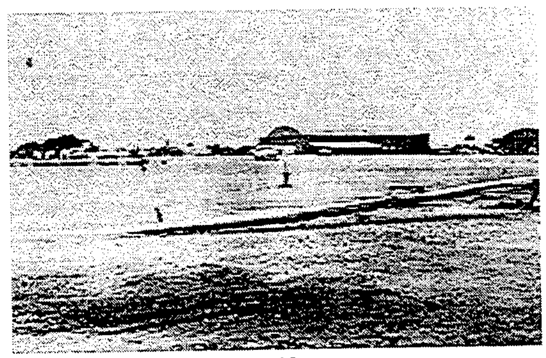
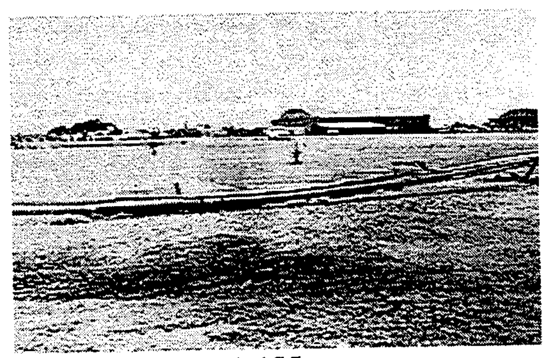


0.970 s



1.455 s

1.940 s

Figure 15. Sequential photographs for test 473750-3
(rear view).

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

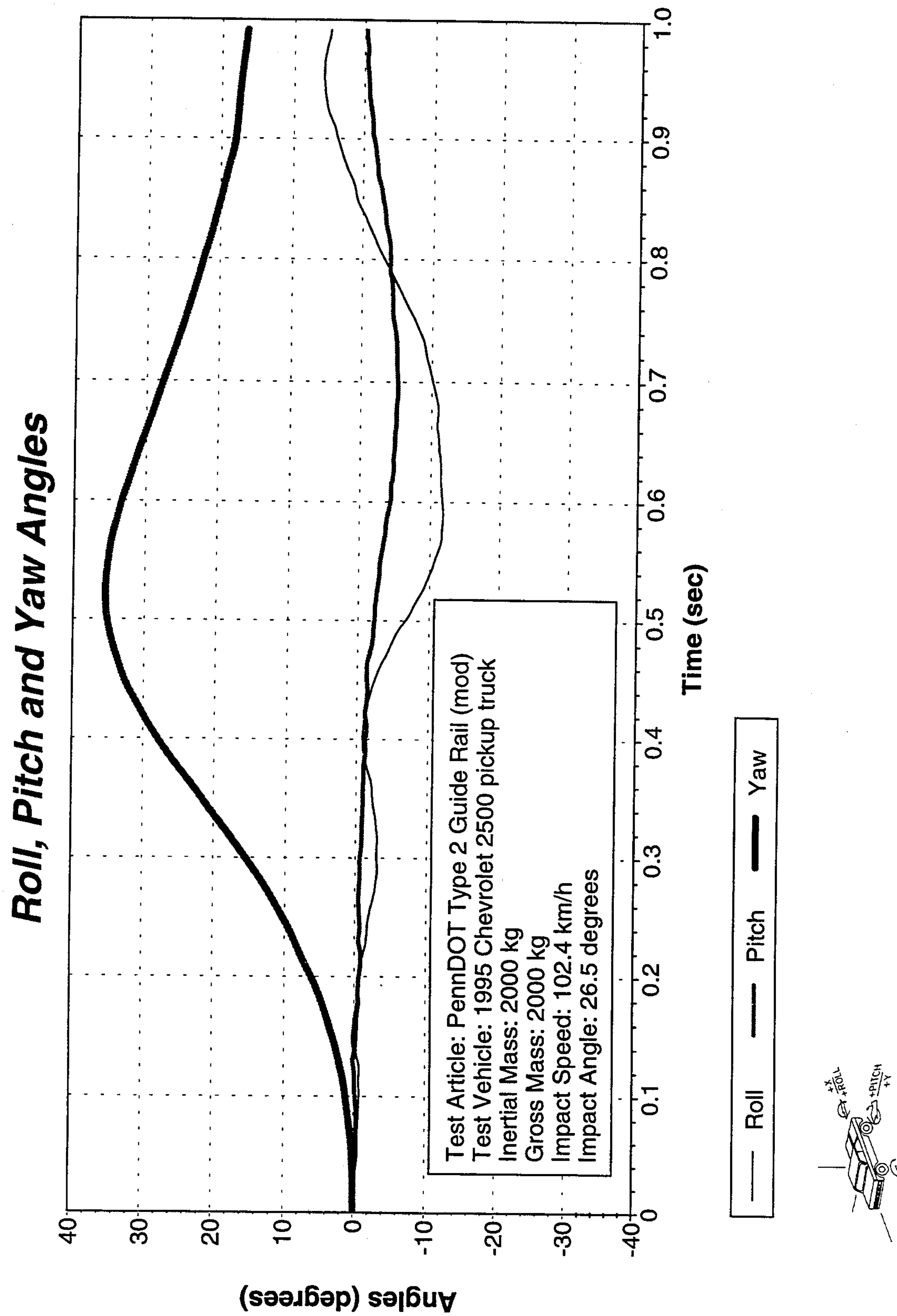


Figure 16. Vehicular angular displacements for test 473750-3.

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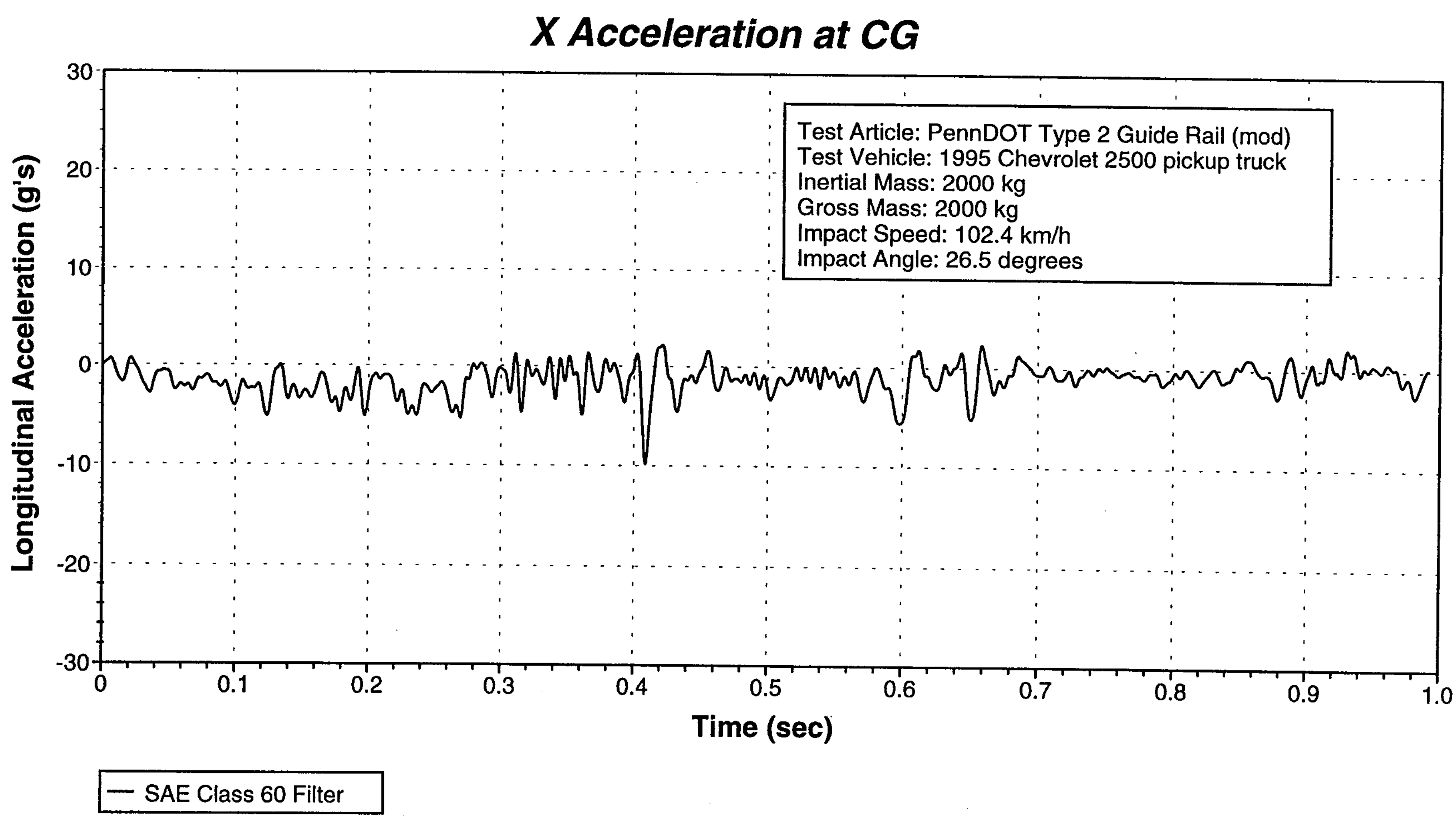

Figure 17. Vehicle longitudinal accelerometer trace for test 473750-3 (accelerometer located at center of gravity).

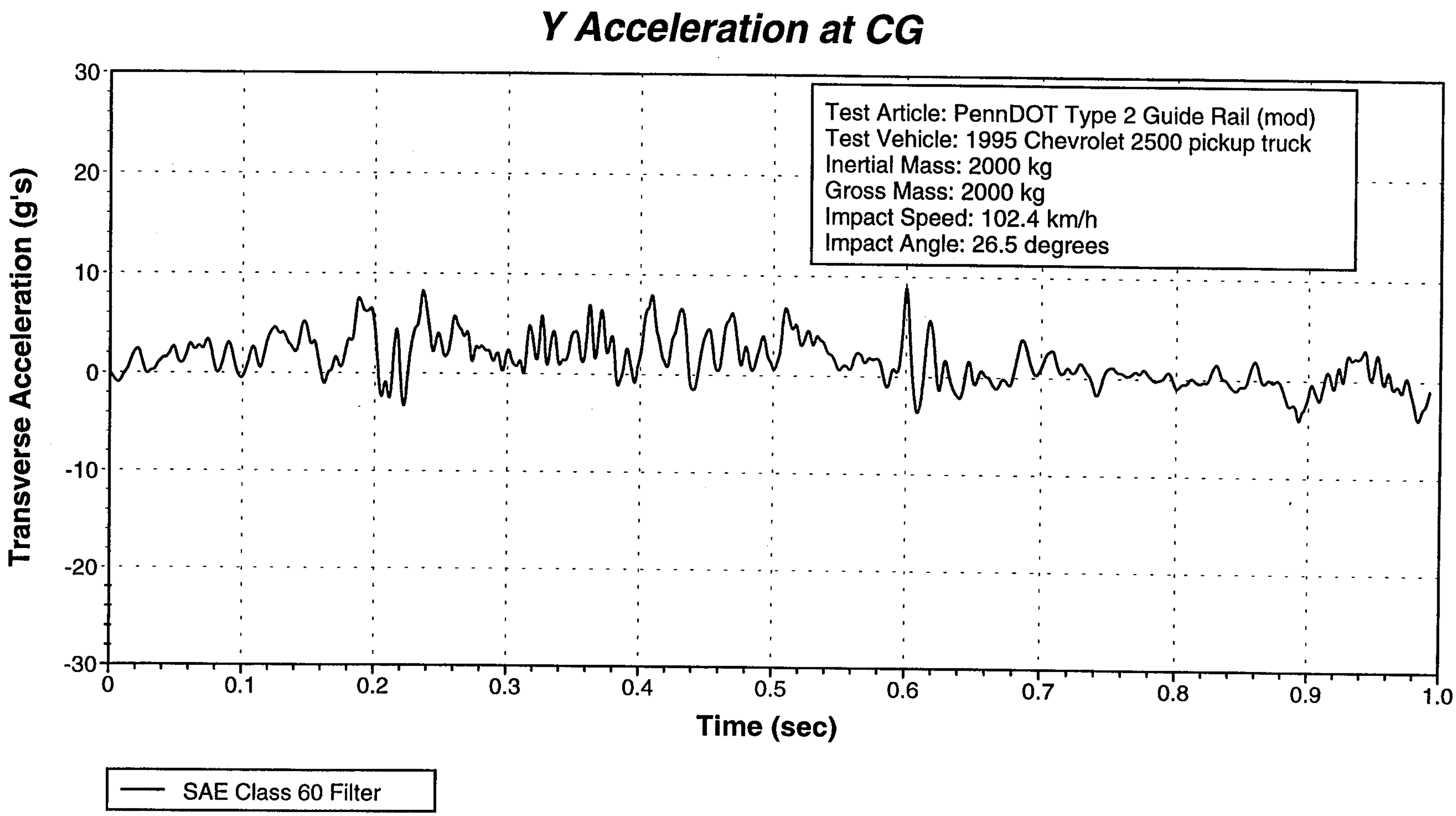

Figure 18. Vehicle lateral accelerometer trace for test 473750-3 (accelerometer located at center of gravity).

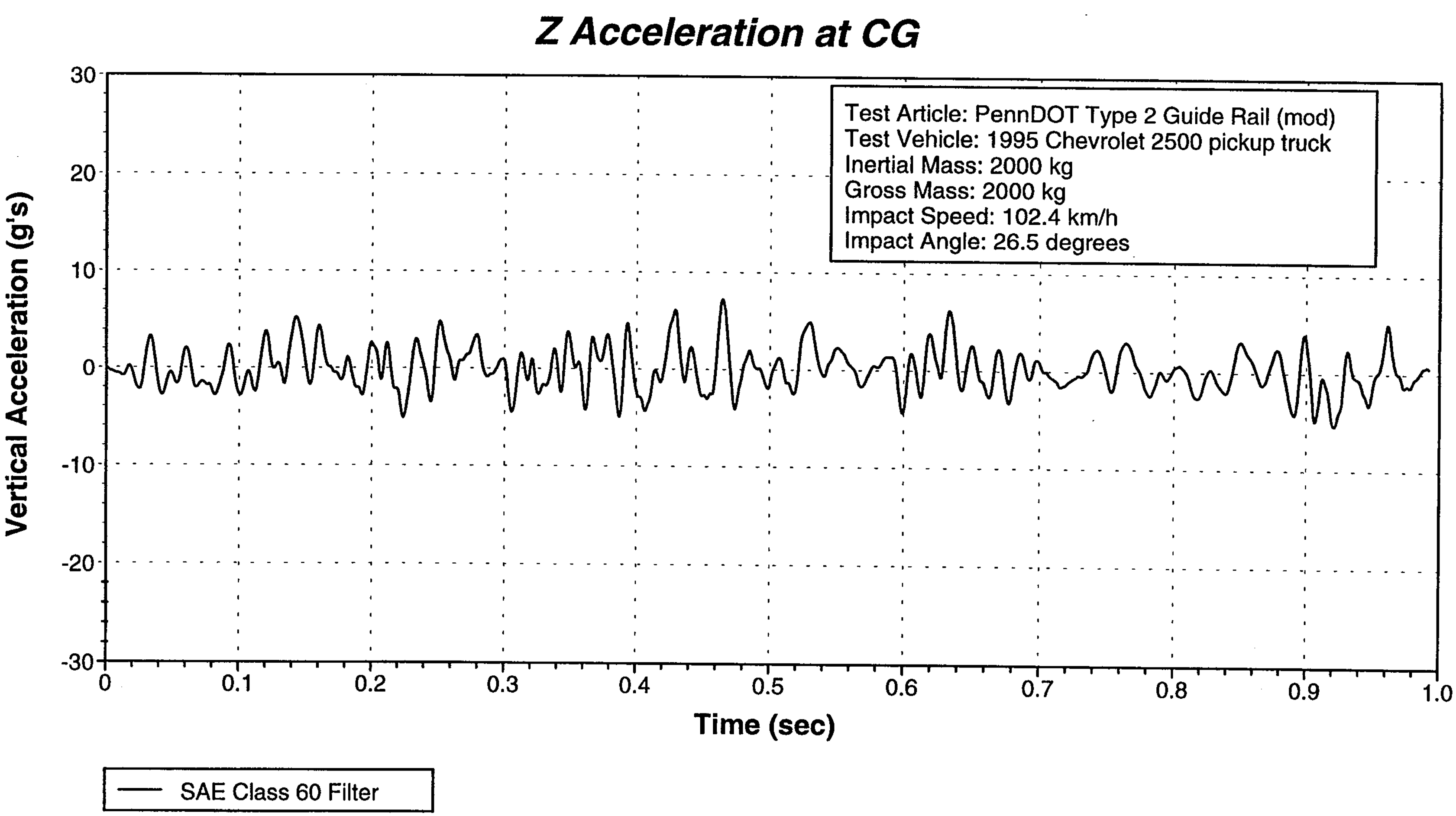

Figure 19. Vehicle vertical accelerometer trace for test 473750-3 (accelerometer located at center of gravity).

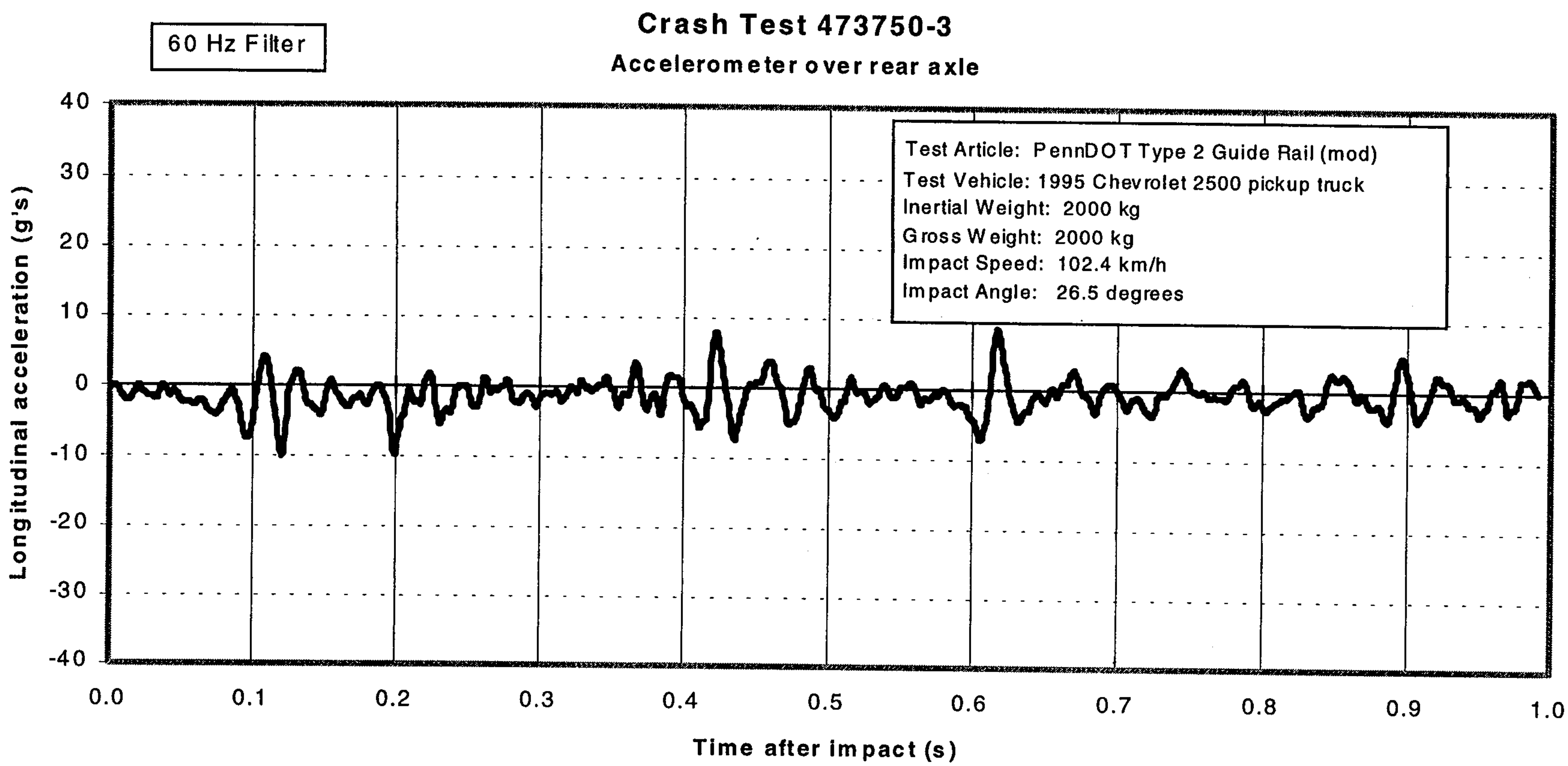

Figure 20. Vehicle longitudinal accelerometer trace for test 473750-3 (accelerometer located over rear axle).

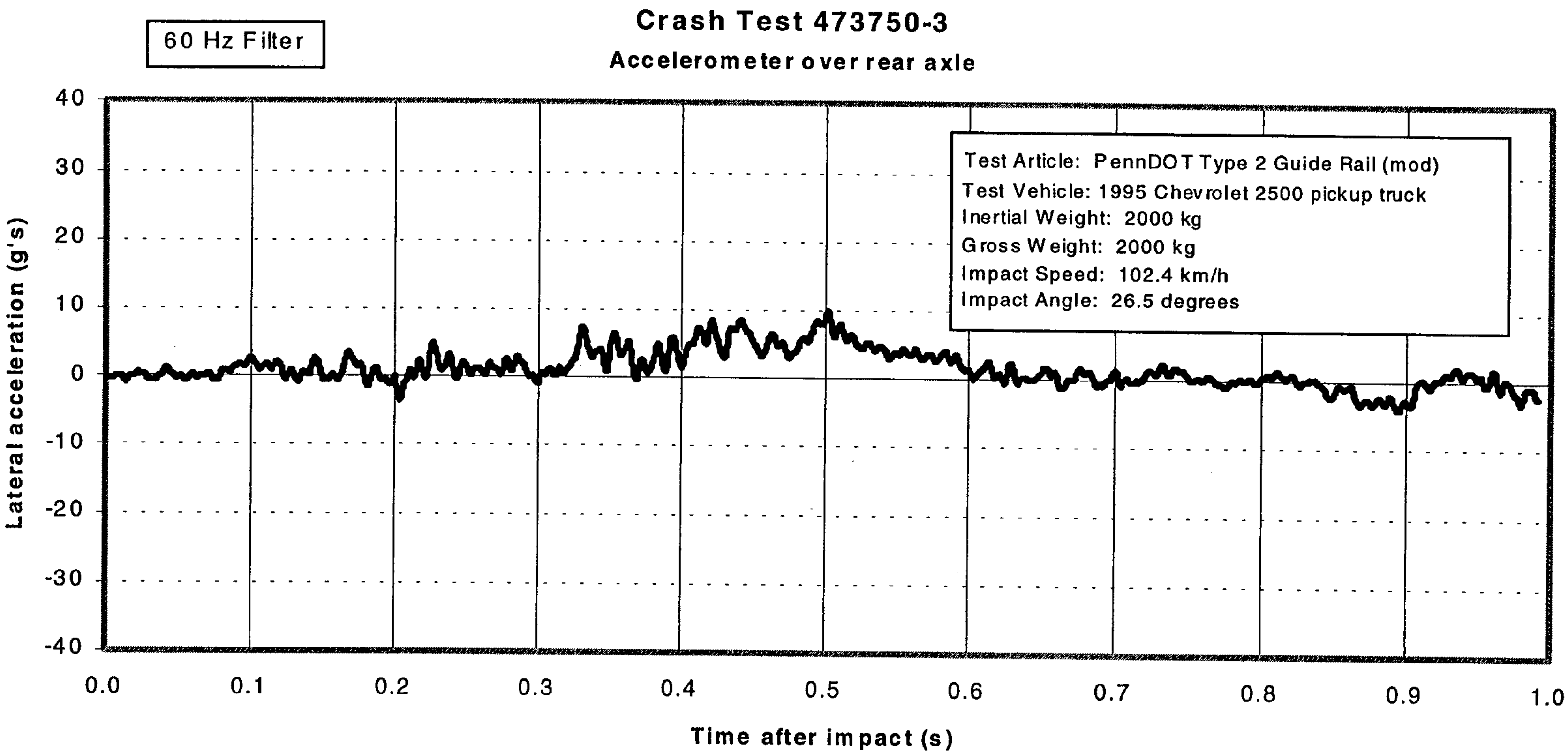

Figure 21. Vehicle lateral accelerometer trace for test 473750-3 (accelerometer located over rear axle).

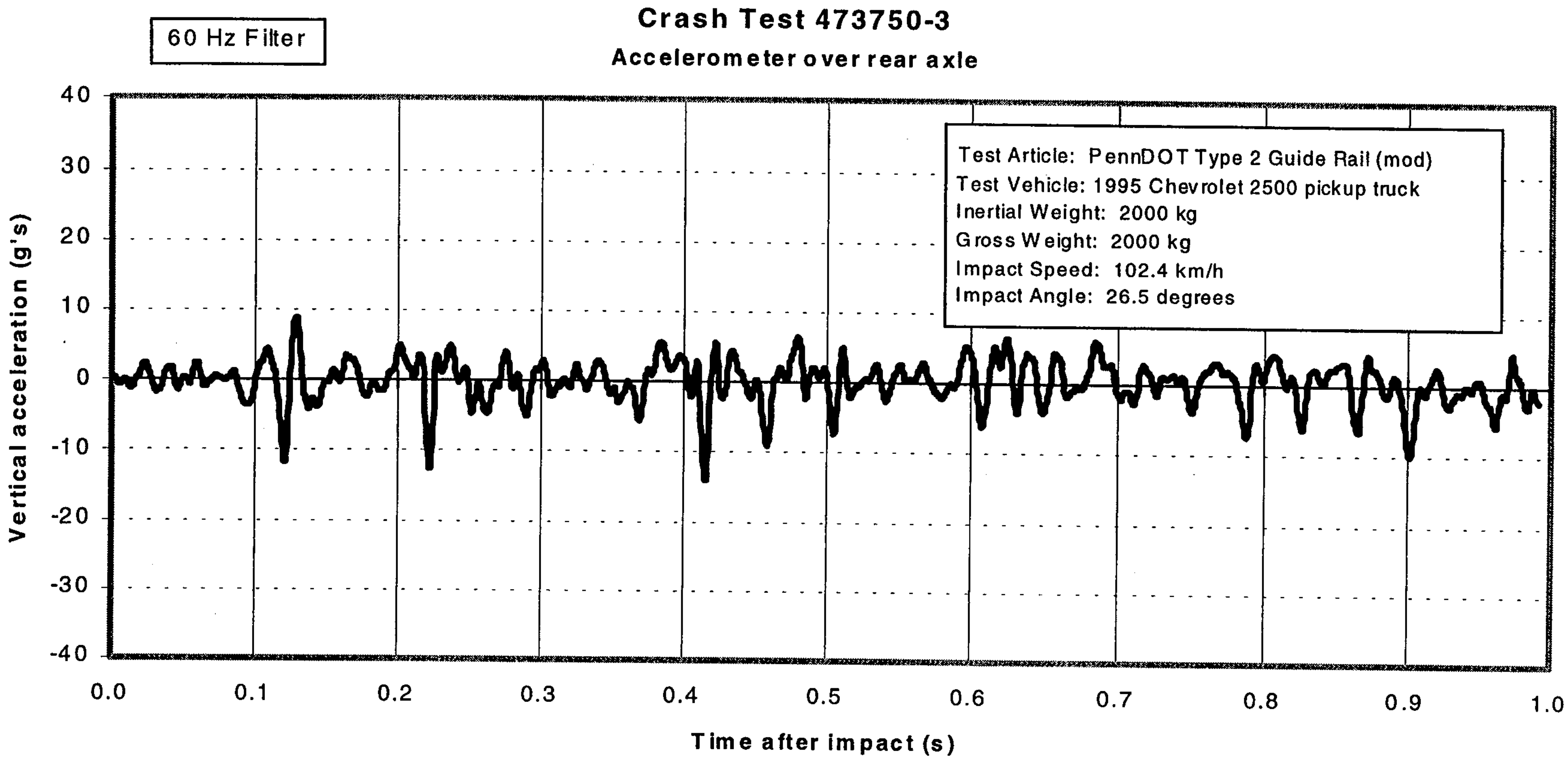

Figure 22. Vehicle vertical accelerometer trace for test 473750-3 (accelerometer located over rear axle).

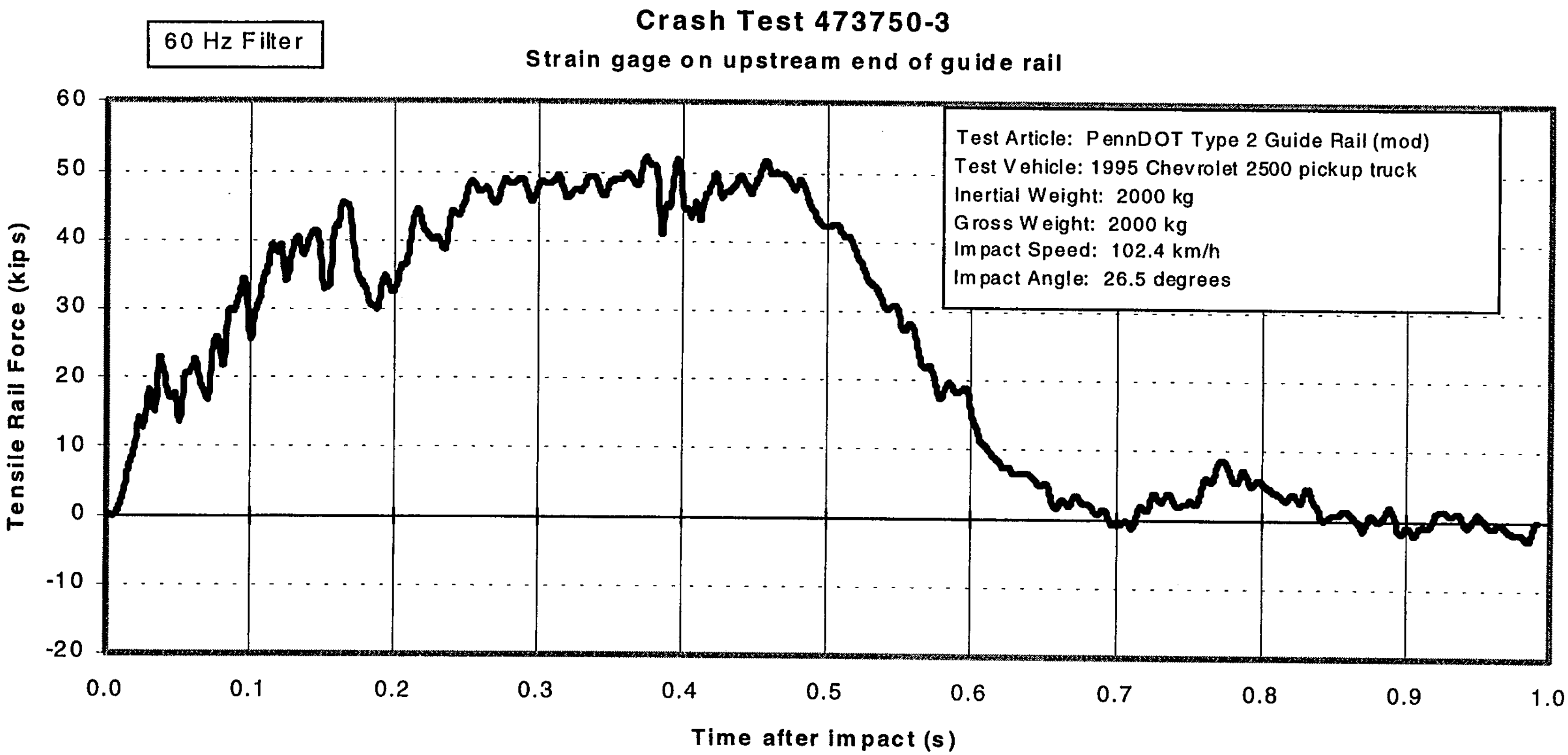

Figure 23. Tensile rail force trace for test 473750-3 (strain gage on upstream end of guide rail).

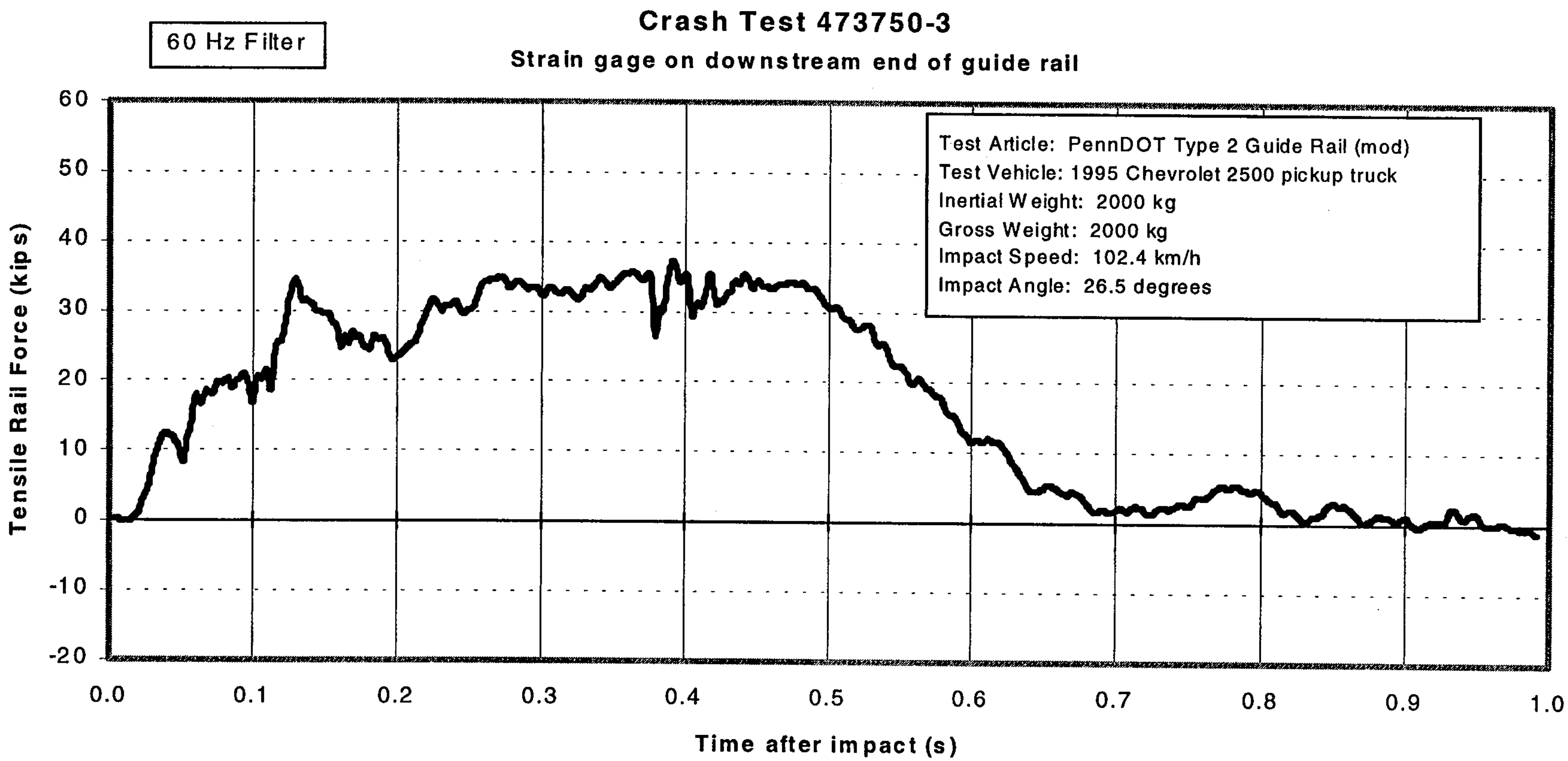

Figure 24. Tensile rail force trace for test 473750-3
(strain gage on downstream end of guide rail).

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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*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

2. C. Eugene Buth, Wanda L. Menges, and Sandra K. Schoeneman, "*NCHRP Report 350* Test 3-11 of the Modified PennDOT Type 2 Guide Rail," Report No. 473750-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, January 2000.

3. C. Eugene Buth, Wanda L. Menges, and Sandra K. Schoeneman, "*NCHRP Report 350* Test 3-11 of the Modified PennDOT Type 2 Guide Rail - Test 2," Report No. 473750-2, Texas Transportation Institute, The Texas A&M University System, College Station, TX, February 2000.

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