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NCHRP REPORT 350 TEST 3-10 ON THE MODIFIED PennDOT TYPE 2 GUIDE RAIL - TEST 4

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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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, two 44 mm square plate washers with 10 mm diameter hole used under the head, a 6 mm round flat washer, and two nuts. Rail splices were located mid-span between posts. To support the W-beam, 14 mm (0.5 in) diameter by 40 mm (1.5 in) long shelf bolts were placed in the flange of the post just below the W-beam, with two nuts on the traffic face of the post. 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 third (5/9/00) and fourth (6/22/00) crash tests, 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. The PennDOT Type 2 guide rail contained and redirected the 2000P pickup truck (of test 3) and the 820C passenger car (test reported herein). Details of the installation and results of the fourth full-scale crash test are presented herein.

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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 mid-span between posts. Additionally, 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 test 3 (5/9/00), 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 performed acceptably with the 2000P pickup truck.(4)

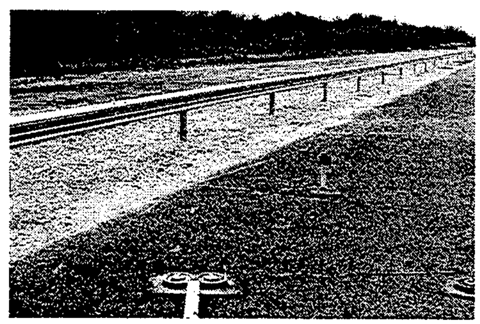
The installation used in test 3 was repaired for test 4 (6/22/00) with the small car, *NCHRP Report 350* test 3-10 (reported herein).

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

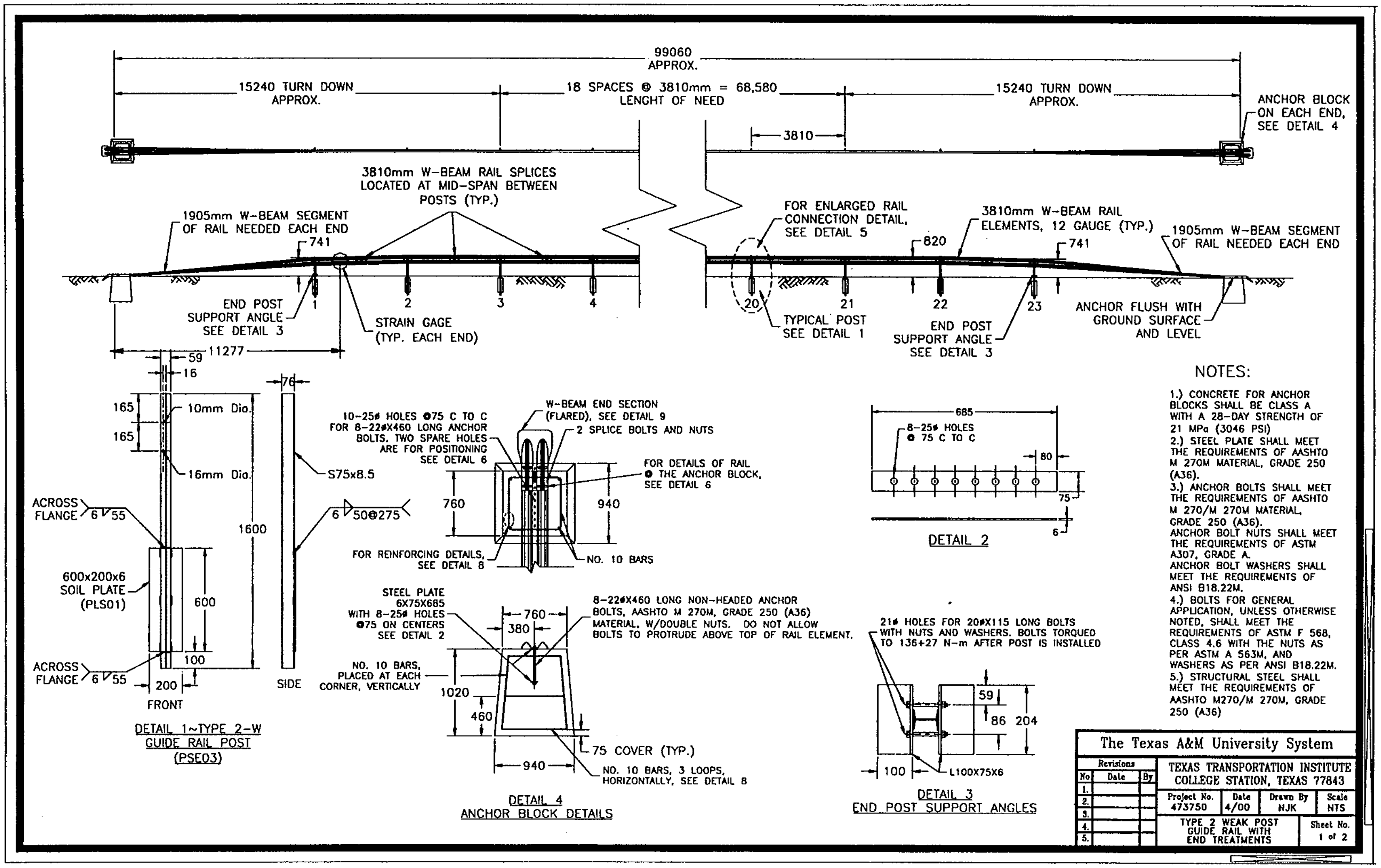


Figure 1. Details of the modified PennDOT Type 2 guide rail for test 473750-4.

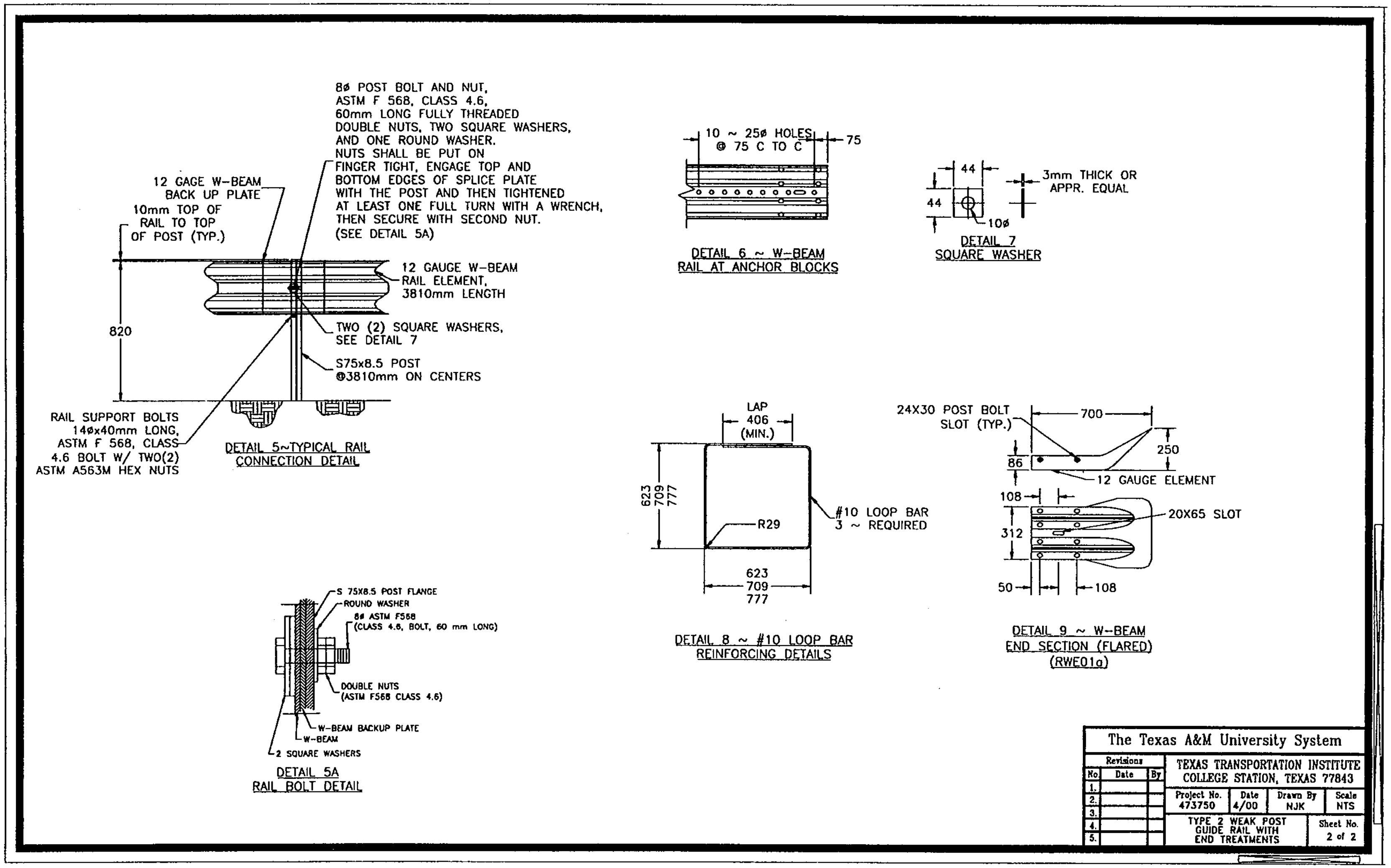


Figure 1. Details of the PennDOT Type 2 guide rail for test 473750-4 (continued).

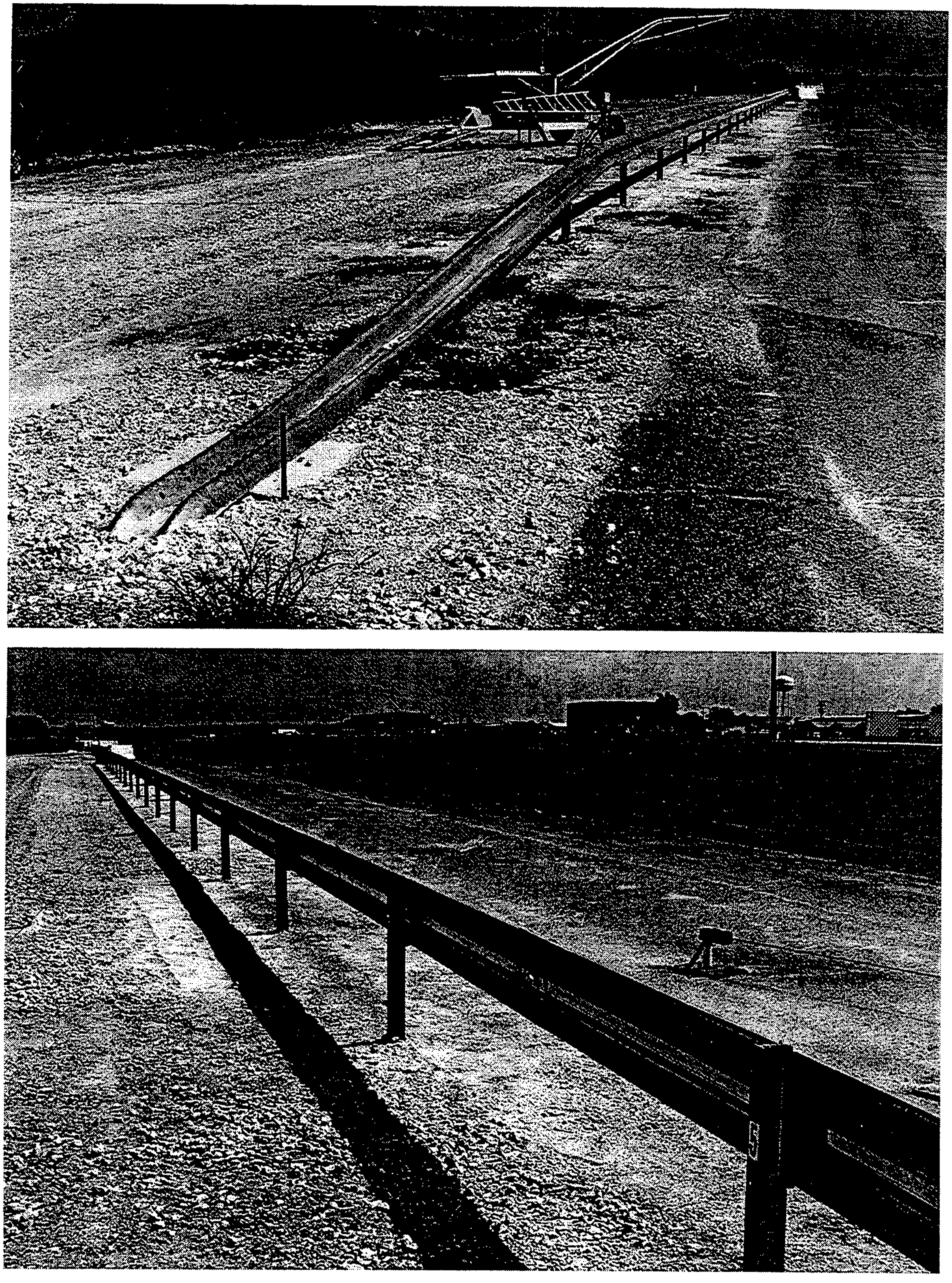


Figure 2. PennDOT Type 2 guiderail prior to test 473750-4.

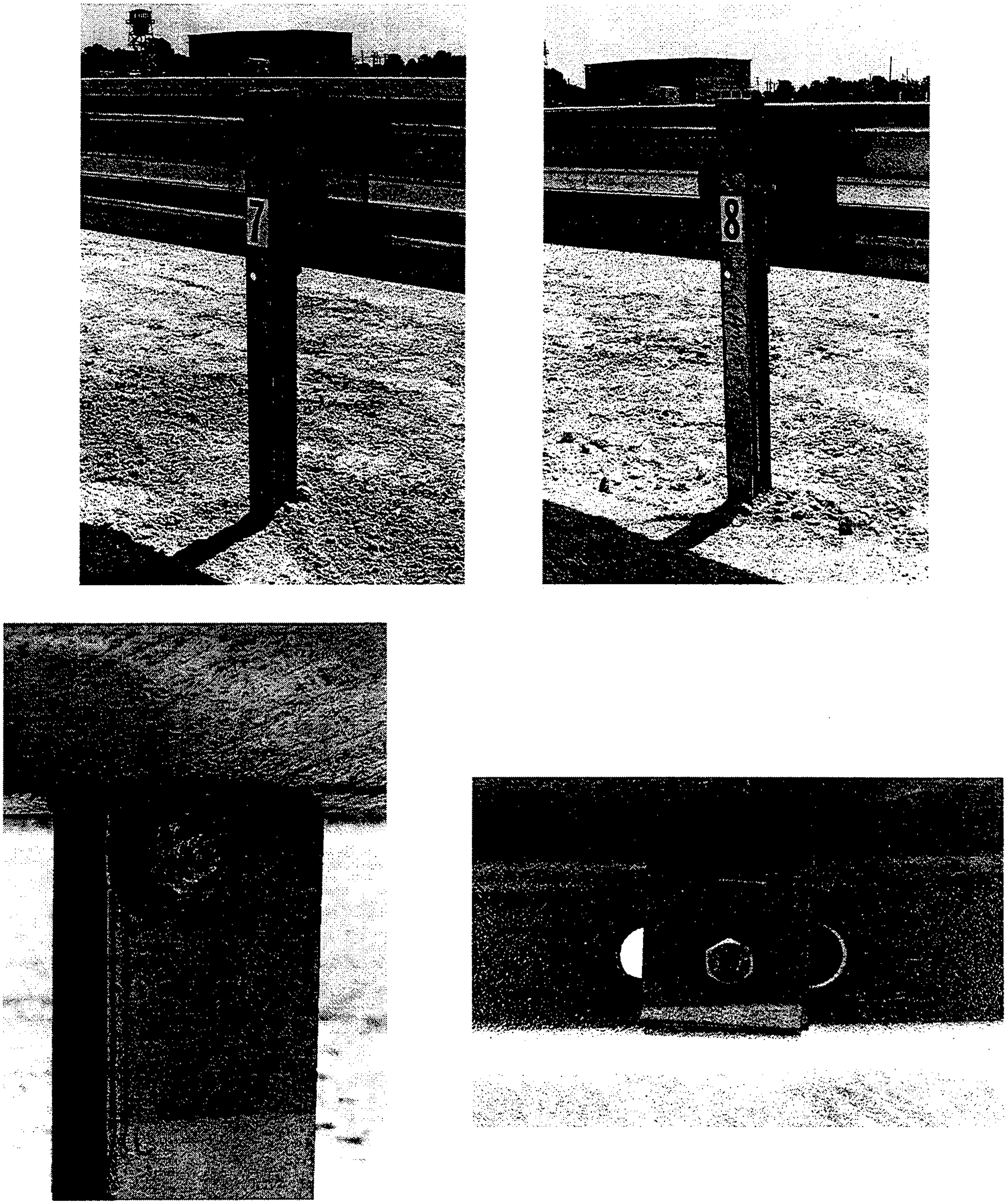


Figure 3. PennDOT Type 2 guiderail posts and connectors prior to testing.

flange 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 the 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 3-10. 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.*

  H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity - m/s	
Preferred	*Maximum*
9	*12*

  I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations - g's	
Preferred	*Maximum*
15	*20*

- **Vehicle Trajectory**

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

  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

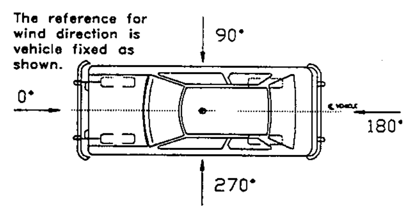
CRASH TEST 473750-4 (*NCHRP REPORT 350* TEST NO. 3-10)

Test Vehicle

A 1997 Geo Metro, shown in figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 820 kg (1806 lb), and its gross static weight was 896 kg (1974 lb). The height to the lower edge of the vehicle front bumper was 395 mm (15.6 in) and to the upper edge of the front bumper was 500 mm (19.7 in). Additional dimensions and information on the vehicle are given in appendix B, figure 12. 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 June 22, 2000. Five days before the test 20 mm (0.8 in) of rainfall was recorded and three days before 8 mm (0.3 in) of rainfall was recorded. No other rainfall was recorded for the remaining ten days prior to the test. Moisture content was 6.5 percent, 6.7 percent, and 7.0 percent at posts 7, 8, and 9, respectively. Weather conditions at the time of testing were as follows: wind speed: 8 km/h; wind direction: 190 degrees with respect to the vehicle (vehicle was traveling northerly direction); temperature: 34°C; relative humidity: 41 percent.



Impact Description

The 820C vehicle, traveling at a speed of 100.5 km/h (62.4 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 21.1 degrees. Shortly after impact, the W-beam rail element moved. Posts 6 and 7 moved away from traffic at 0.017 s, and at 0.047 s the vehicle began to redirect. At 0.059 s post 7 detached from the rail element. By 0.069 s post 8 moved away from traffic. At 0.143 s post 8 detached from the rail element. By 0.166 s post 9 moved away from traffic. The left front bumper of the vehicle contacted post 8 at 0.215 s. At 0.234 s the left rear side of the vehicle contacted the rail element. The vehicle became parallel with the system at 0.256 s and was traveling at a speed of 85.2 km/h (52.9 mi/h). At 0.386 s the left front bumper of the vehicle contacted post 9. At 0.409 s the left front tire contacted post 9. By 0.412 s, post 9 detached from the rail element, and by 0.473 s, post 9 touched the ground. The vehicle lost contact with the rail element at 0.531 s and was traveling 78.4 km/h (48.7 mi/h) and an exit angle of 1.0 degree. The vehicle traveled parallel with the system yawing toward the rail element at 0.540 s. At 1.478 s the vehicle was still traveling parallel with the system but yawed away from the rail element. Brakes on the

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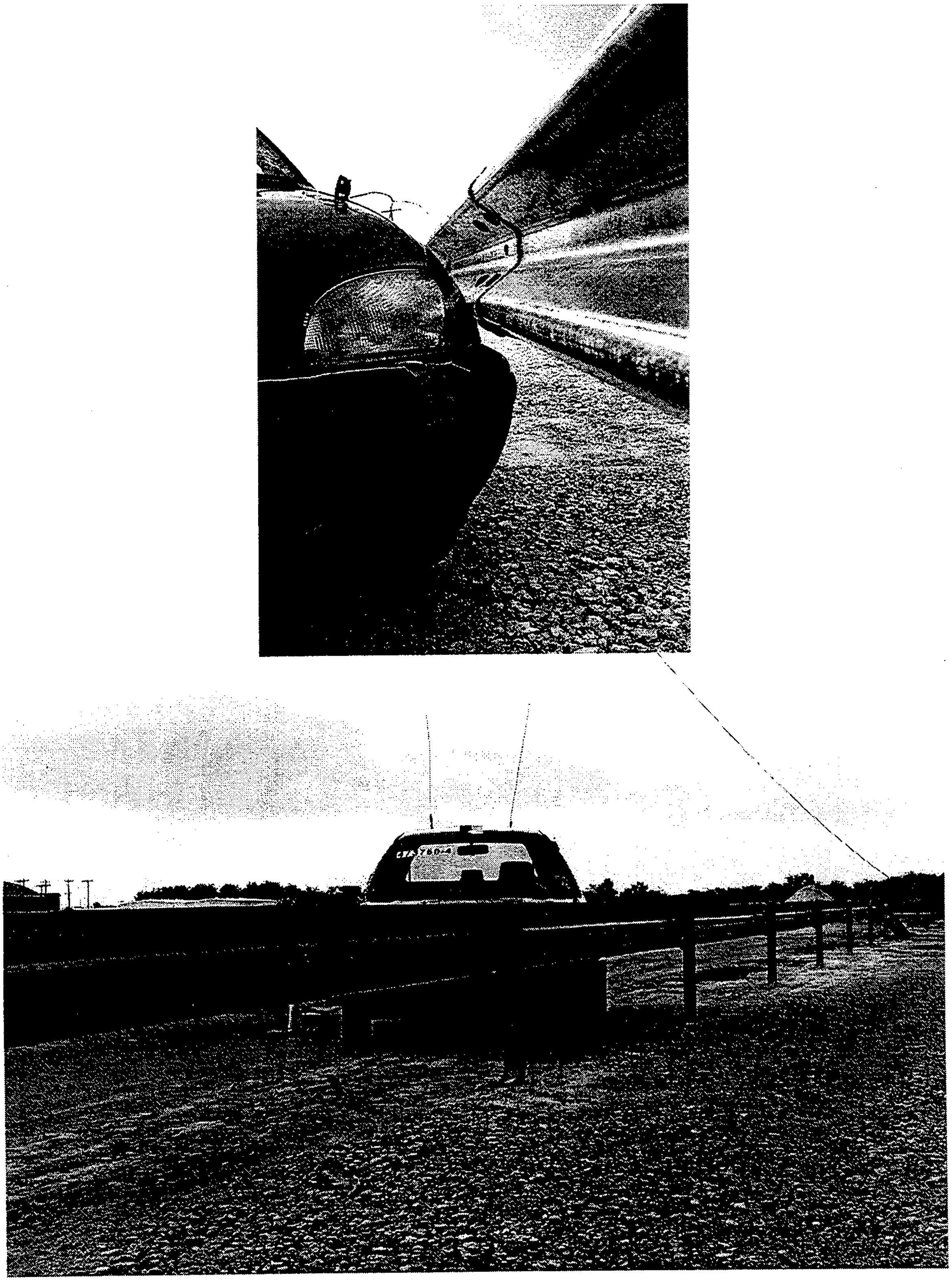


Figure 4. Vehicle/installation geometrics for test 473750-4.

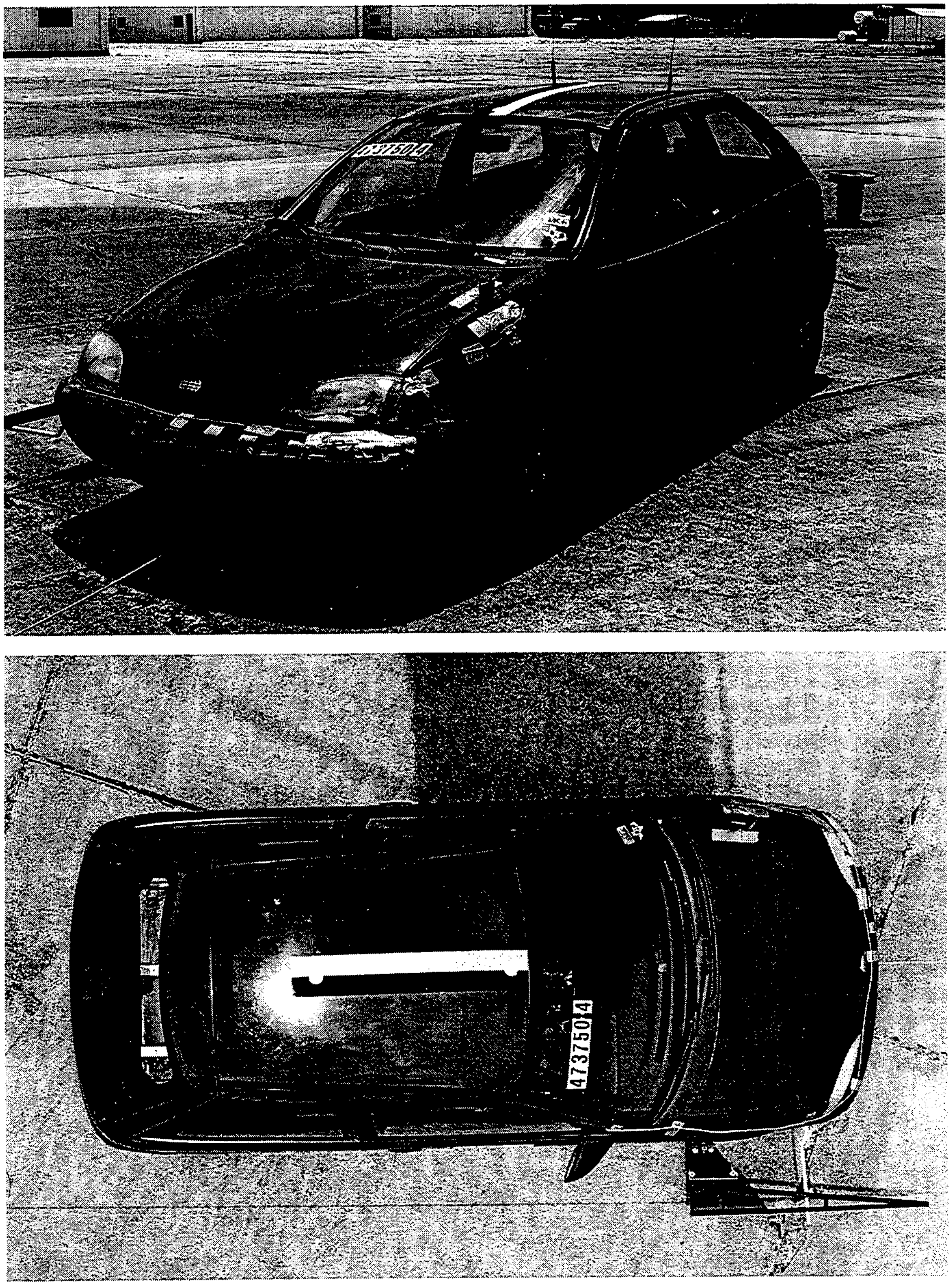


Figure 5. Vehicle before test 473750-4.

vehicle were applied at 5.0 s after impact and the vehicle subsequently came to rest 73.2 m (240.2 ft) down from impact and 7.6 m (24.9 ft) toward traffic lanes. Sequential photographs of the test period are shown in appendix C, figures 13 and 14.

Damage to Test Article

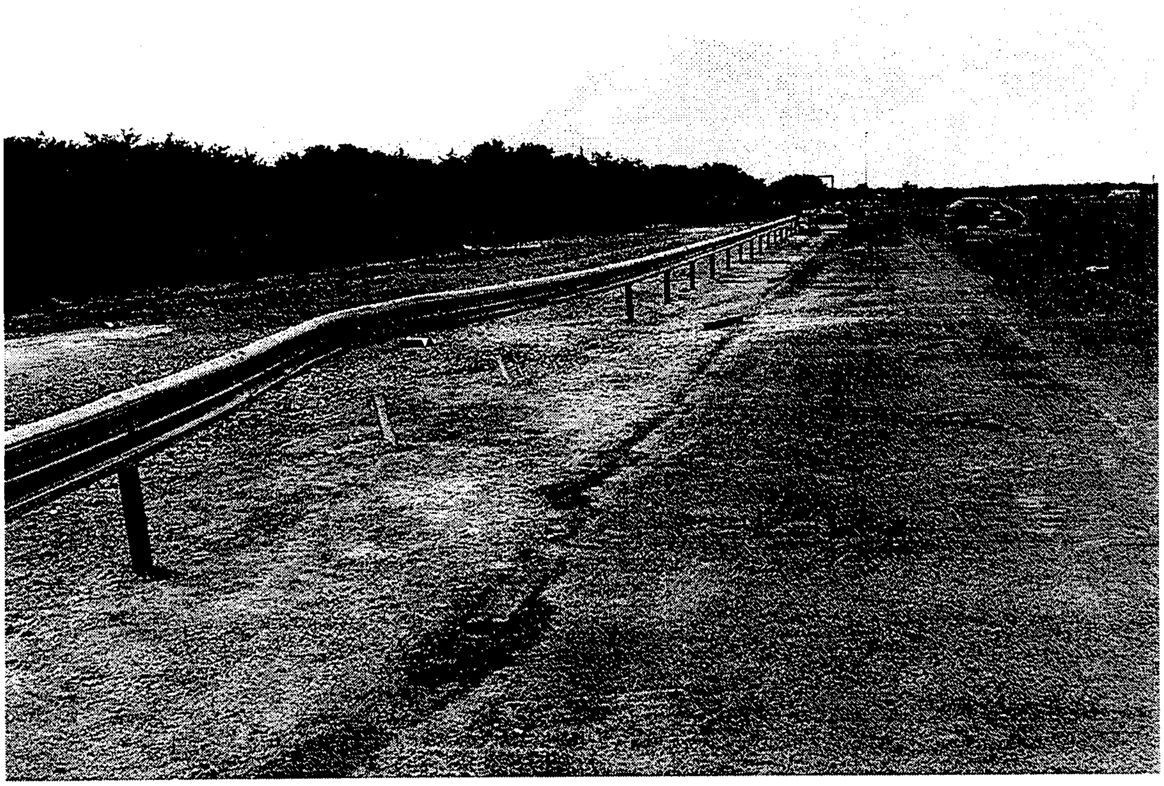
Damage to the modified Type 2 PennDOT guide rail installation is shown in figures 6 and 7. The upstream terminal anchor was disturbed and the rail element was attached to posts 1 through 6. Post 6 moved rearward 63 mm (2.5 in), post 7 moved rearward 60 mm (2.4 in), and post 8 - 80 mm (3.1 in). Post 9 was pulled out of the ground and was resting 1.5 m (5.0 ft) in front of post 10. Post 10 moved rearward 38 mm (1.5 in) and posts 11 through the downstream terminal anchor were disturbed. The rail was detached from posts 7 through 9. Length of contact of the vehicle with the rail element was 10.4 m (34.1 ft). Maximum dynamic deflection of the rail element during the test was 1.025 m (3.4 ft). Maximum permanent deformation of the rail element was 0.94 m (3.0 ft) between posts 7 and 8.

Vehicle Damage

The vehicle sustained relatively minor damage as shown in figure 8. Structural damage included damage to the left strut and C.V. joint. Also damaged were the front bumper, radiator, fan, radiator support, hood, left door, and left front and rear quarter panels. The windshield sustained some stress cracking and the gas tank was torn as shown in figure 8. Maximum crush to the exterior of the vehicle was 200 mm (7.9 in) at the left front corner. Maximum occupant compartment deformation was 6 mm (0.25 in) in the left front floor pan area. The interior of the vehicle is shown in figure 9. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 2 and 3.

Occupant Risk Factors

Data from the accelerometer located at the vehicle c.g. were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 3.3 m/s (10.8 ft/s) at 0.168 s, the highest 0.010-s occupant ridedown acceleration was -6.0 g's from 0.408 to 0.418 s, and the maximum 0.050-s average acceleration was -2.8 g's between 0.016 and 0.066 s. In the lateral direction, the occupant impact velocity was 4.5 m/s (14.8 ft/s) at 0.168 s, the highest 0.010-s occupant ridedown acceleration was 5.0 g's from 0.175 to 0.185 s, and the maximum 0.050-s average was 4.6 g's between 0.123 and 0.173 s. These data and other pertinent information from the test are summarized in figure 10. Vehicle angular displacements and accelerations versus time traces are presented in appendix D, figures 15 through 21.



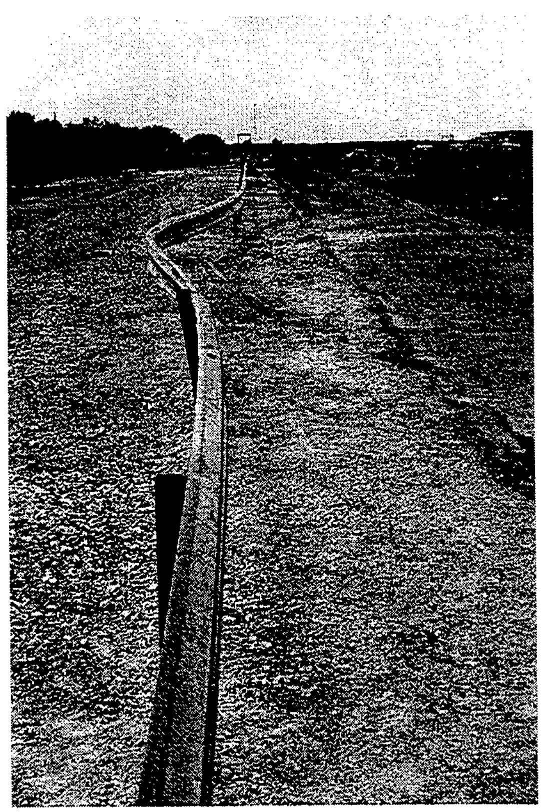


Figure 6. Vehicle trajectory after test 473750-4.

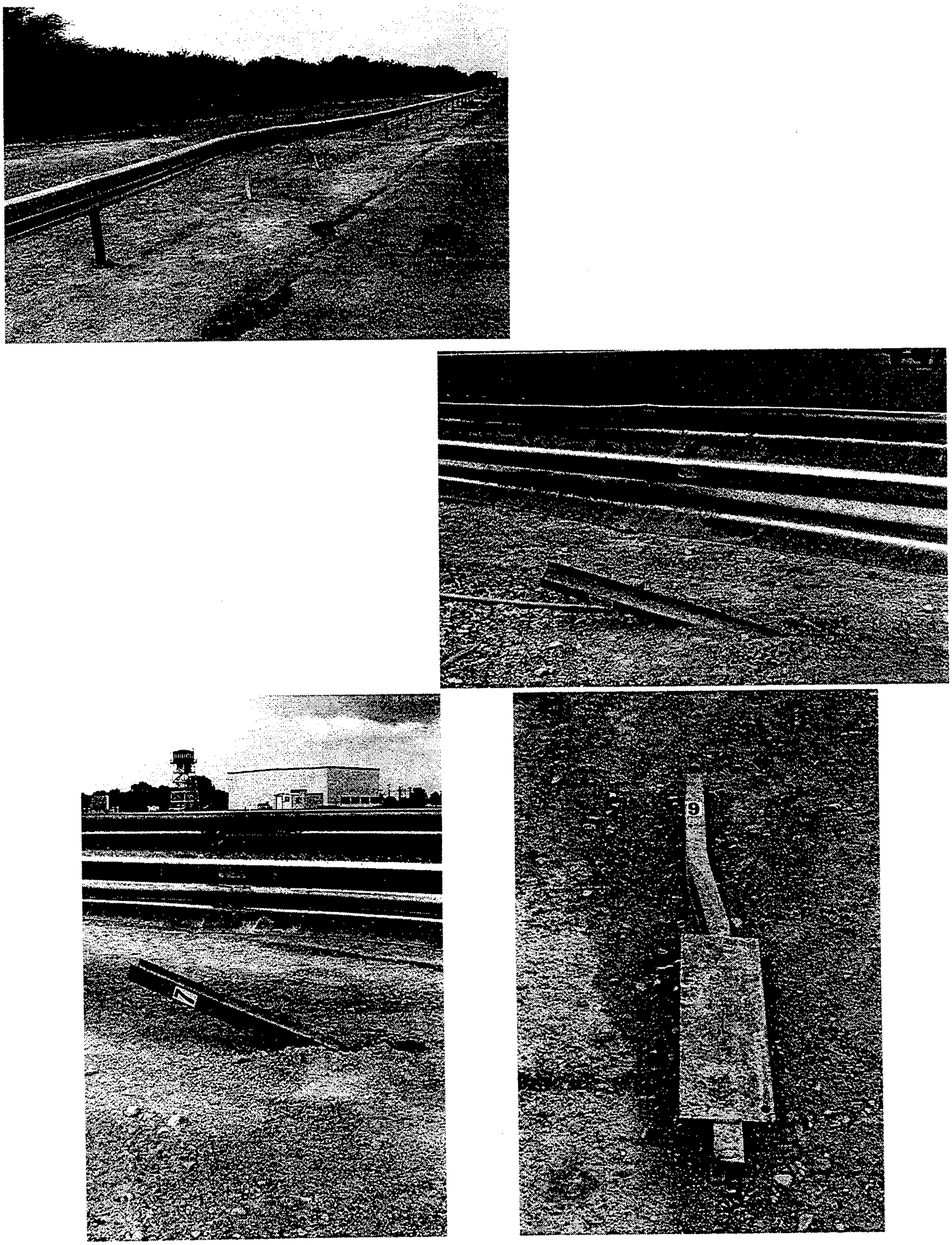


Figure 7. Installation after test 473750-4.

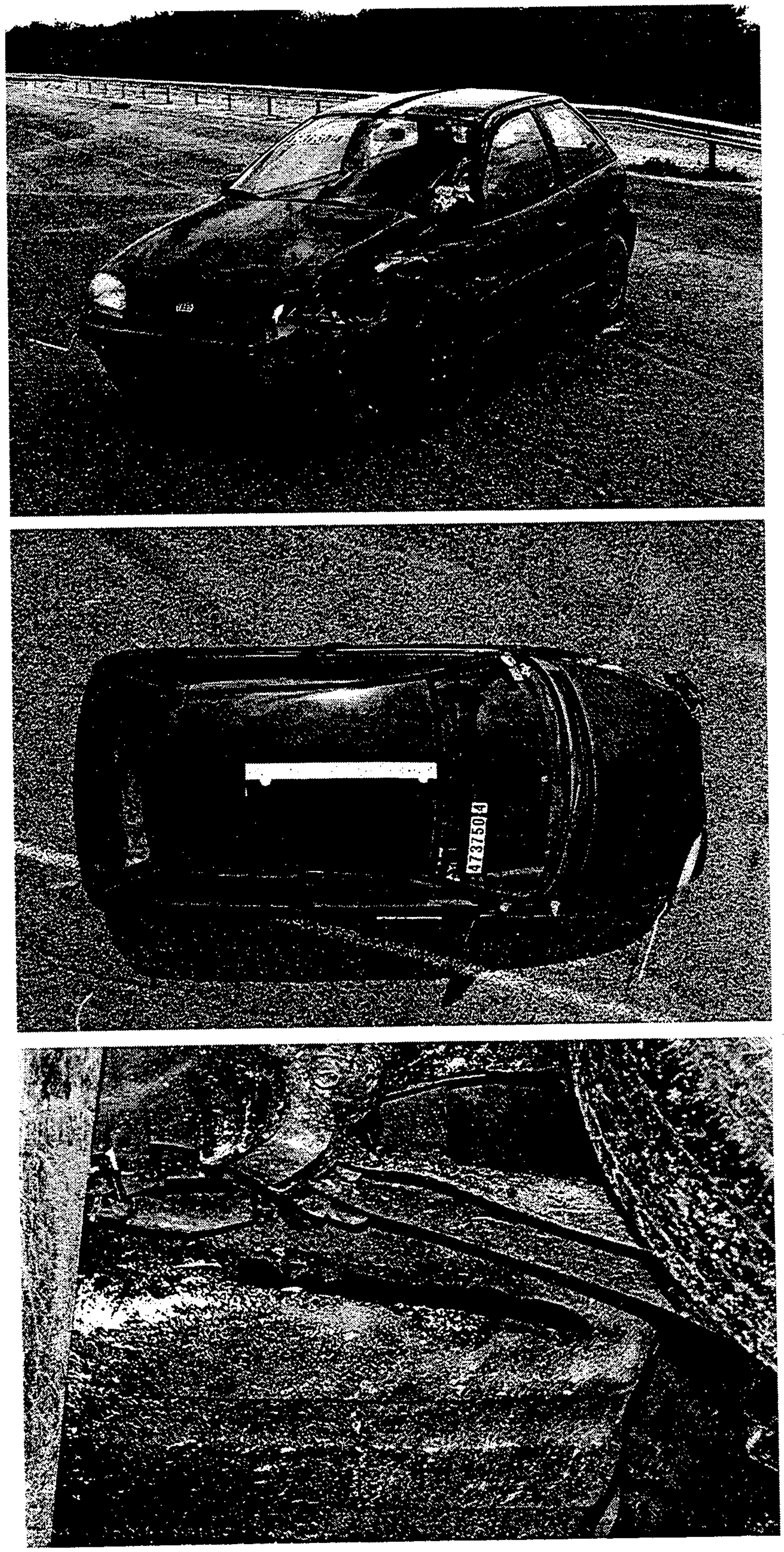
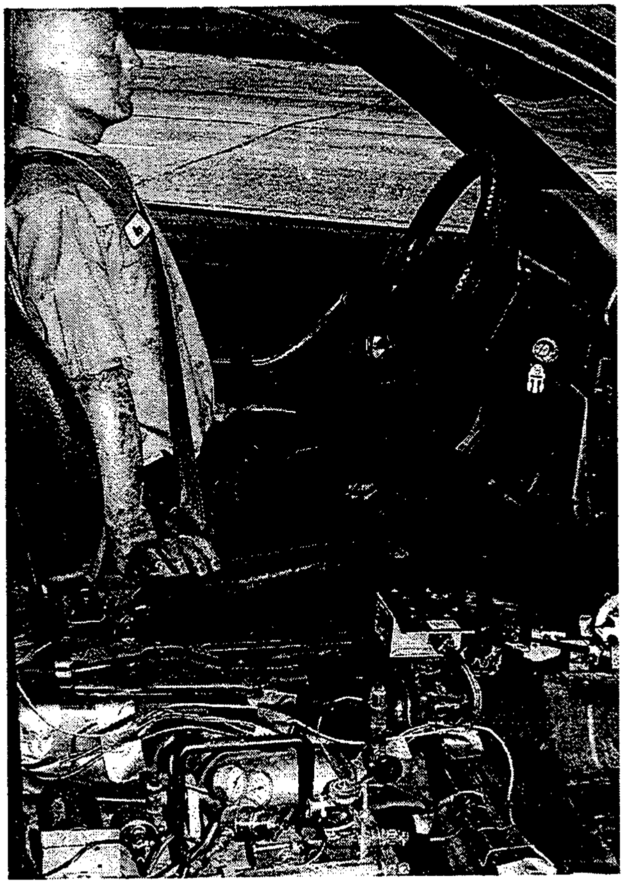


Figure 8. Vehicle after test 473750-4.



Before test

After test

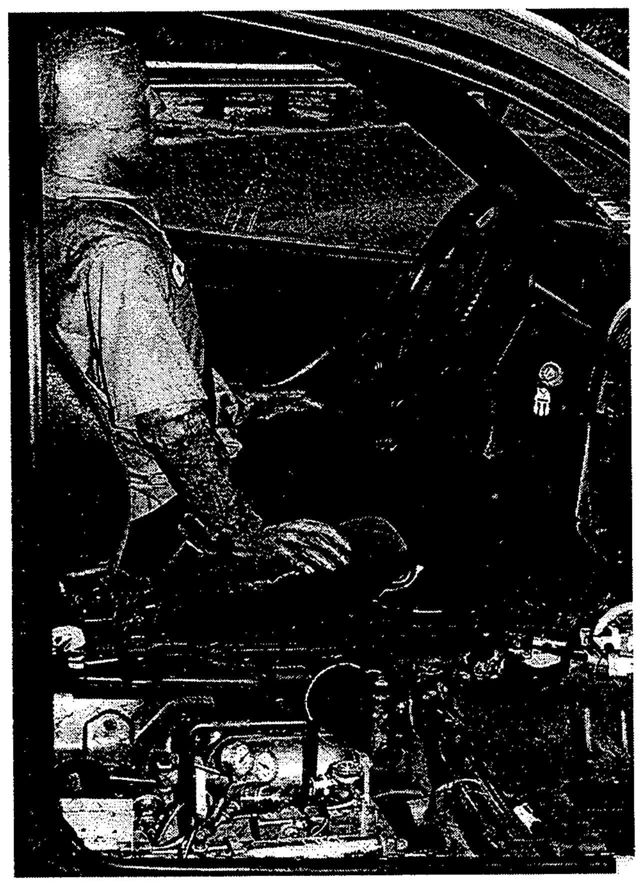
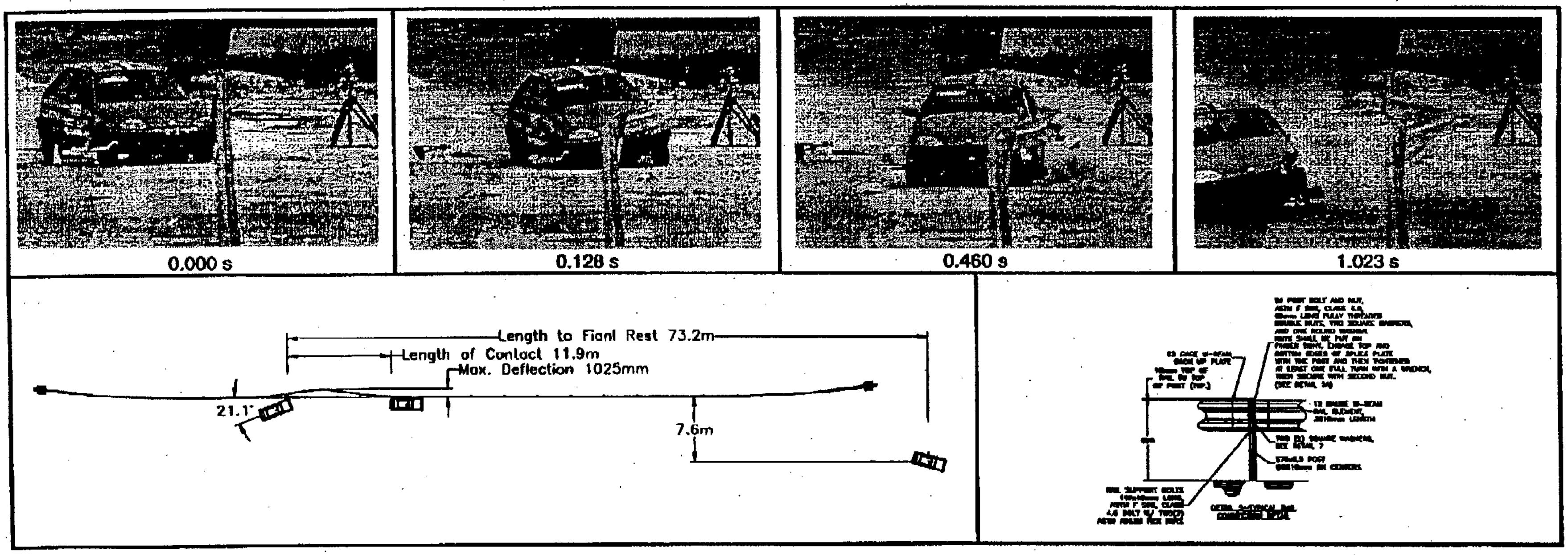


Figure 9. Interior of vehicle for test 473750-4.



General Information	
Test Agency	Texas Transportation Institute
Test No.	473750-4
Date	06/22/00
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	820C
Model	1997 Geo Metro
Mass (kg)	
Curb	827
Test Inertial	820 (1806 lb)
Dummy	76 (168 lb)
Gross Static	896 (1974 lb)

Impact Conditions	
Speed (km/h)	100.5 (62.4 mi/h)
Angle (deg)	21.1
Exit Conditions	
Speed (km/h)	78.4 (48.7 mi/h)
Angle (deg)	1.0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.3 (10.8 ft/s)
y-direction	4.5 (14.8 ft/s
THIV (km/h)	18.3 (1.1 mi/h)
Ridedown Accelerations (g's)	
x-direction	-6.0
y-direction	5.0
PHD (g's)	12.3
ASI	0.56
Max. 0.050-s Average (g's)	
x-direction	-2.8
y-direction	4.6
z-direction	-2.5

Test Article Deflections (m)	
Dynamic	1.025 (3.4 ft)
Permanent	0.940 (3.0 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ2
CDC	11FLEK2 & 11IDEW2
Maximum Exterior Vehicle Crush (mm)	200 (7.9 in)
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	6 (0.25 in)
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	43
Max. Pitch Angle (deg)	4
Max. Roll Angle (deg)	-11

Figure 10. Summary of Results for test 473750-4, *NCHRP Report 350* test 3-10.

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 22 and 23 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 25.3 kips, and the maximum on the downstream end was 16.4 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 820C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 1.025 m (3.4 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.*

  One post was pulled out of the ground and resting in front of the rail (distance of 1.5 m (5.0 ft)). No other detached elements, fragments or other debris penetrated or showed potential for penetrating the occupant compartment; nor did they present undue hazard to others in the area. Maximum deformation into the occupant compartment was 6 mm (0.25 in) in the left front floor pan area.

  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 period.

H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity - m/s	
Preferred	*Maximum*
9	*12*

Longitudinal occupant impact velocity was 3.3 m/s (10.8 ft/s) and lateral occupant impact velocity was 4.5 m/s (14.8 ft/s).

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations - g's	
Preferred	*Maximum*
15	*20*

Longitudinal occupant ridedown acceleration was -6.0 g's and lateral occupant ridedown acceleration was 5.0 g's.

- **Vehicle Trajectory**

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

The 820C vehicle would intrude into adjacent traffic lanes as it came to rest 73.2 m (240.2 ft) down from impact and 7.6 m (24.9 ft) forward of the traffic face of the barrier.

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 barrier was 1.0 degree which was 5 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
    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

- **LOSS OF VEHICLE CONTROL**

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

Vehicle may have been kept in control and not threaten other vehicles.

- **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**

One post pulled out of the ground and was resting in front of the installation (distance 1.5 m (5.0 ft)). 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 seen in table 1, the modified PennDOT Type 2 guide rail system performed acceptably during *NCHRP Report 350* test 3-10.

Note that one post pulled out of the ground and was resting in front of the installation (distance 1.5 m (5.0 ft)). No other debris of significance that would harm others in the area was present.

Table 1. Performance evaluation summary for test 473750-4, *NCHRP Report 350* test 3-10.

Test Agency: Texas Transportation Institute — Test No.: 473750-4 — Test Date: 06/22/2000

***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 820C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 1.025 m (3.4 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.	One post was pulled out of the ground and resting in front of the rail (distance of 1.5 m (4.9 ft)). No other detached elements, fragments or other debris penetrated or showed potential for penetrating the occupant compartment; nor did they present undue hazard to others in the area. Maximum deformation into the occupant compartment was 6 mm (0.25 in) in the left front floor pan area.	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 period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component: Longitudinal and lateral — Preferred: 9 — Maximum: 12	Longitudinal occupant impact velocity was 3.3 m/s (10.8 ft/s) and lateral occupant impact velocity was 4.5 m/s (14.8 ft/s).	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component: Longitudinal and lateral — Preferred: 15 — Maximum: 20	Longitudinal occupant ridedown acceleration was -6.0 g's and lateral occupant ridedown acceleration was 5.0 g's.	Pass
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The 820C vehicle would intrude into adjacent traffic lanes as it came to rest 73.2 m (240.2 ft) down from impact and 7.6 m (24.9 ft) forward of the traffic face of the barrier.	Fail*
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 barrier was 1.0 degree which was 5 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 11. 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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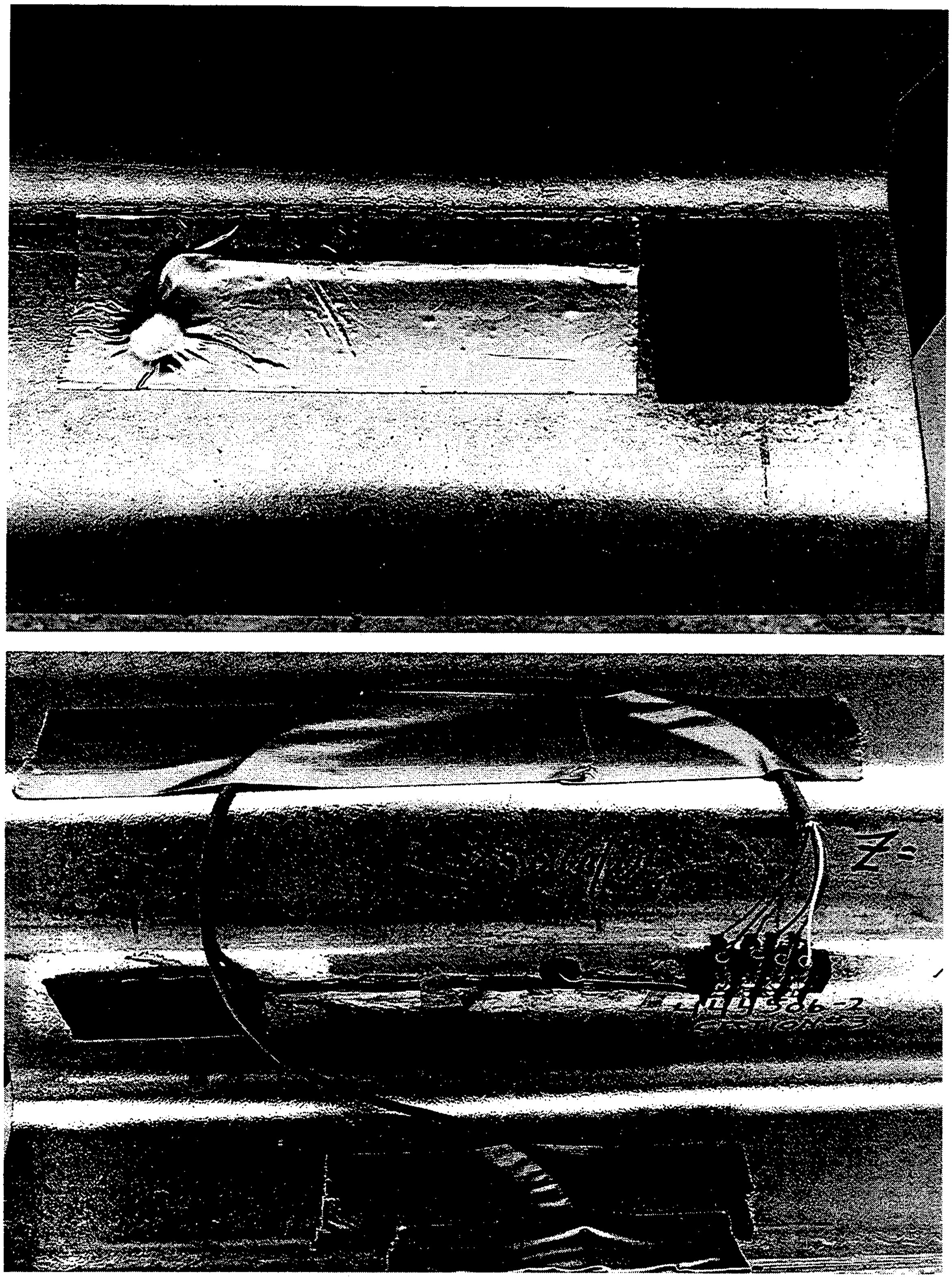


Figure 11. Strain gage installation on W-beam rail for test 473750-4.

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 10,000 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 (c.g.) 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 also 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 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, digitized and filtered with Society of Automotive Engineers (SAE J211) filters, using a microcomputer, at 10,000 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 also 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 Test Risk Assessment Program (TRAP) uses the 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. TRAP 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 are filtered with a 60-Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the 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 initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the 820C vehicle. The dummy was uninstrumented.

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 time, displacement, and angular data. A BetaCam, a VHS-format 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 was 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 so 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 was released to be free-wheeling and unrestrained. The vehicle remains 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: 06/22/00 TEST NO.: 473750-4 VIN NO.: 2C1MR2297V6701323

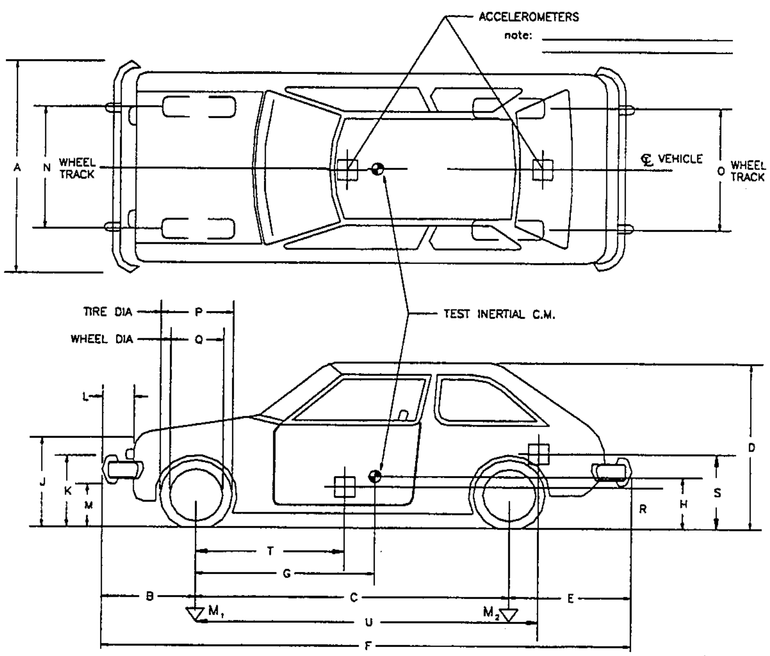
YEAR: 1997 MAKE: GEO MODEL: METRO

TIRE INFLATION PRESSURE: ______ ODOMETER: 80055 TIRE SIZE: 155 80R13

1st Use: X 2nd or More Use: ___ Minor Damage Charged to Project: ______

MASS DISTRIBUTION (kg) LF 264 RF 255 LR 152 RR 149

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 CYL

ENGINE CID: 1.3 L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1470	E	550	J	680	N	1410	R	390
B	780	F	3690	K	500	O	1370	S	570
C	2360	G	866.3	L	100	P	560	T	930
D	1410	H		M	395	Q	365	U	2460

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	539	519	553
M_2	288	301	343
M_T	827	820	896

Figure 12. Vehicle properties for test 473750-4.

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Table 2. Exterior crush measurements for test 473750-4.

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	Inner bumper	700	120	1080	120	80	50	20	10	0	0
2	610 mm above ground	700	200	900	30	50	110	130	130	200	+1120

[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).

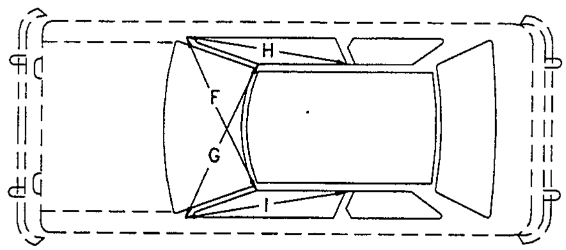
***Measure and document on the vehicle diagram the location of the maximum crush.

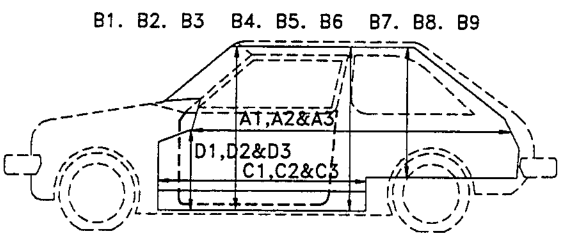
Note: Use as many lines/columns as necessary to describe each damage profile.

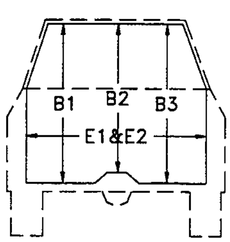
Table 3. Occupant compartment measurements for test 473750-4.

Small Car

Occupant Compartment Deformation

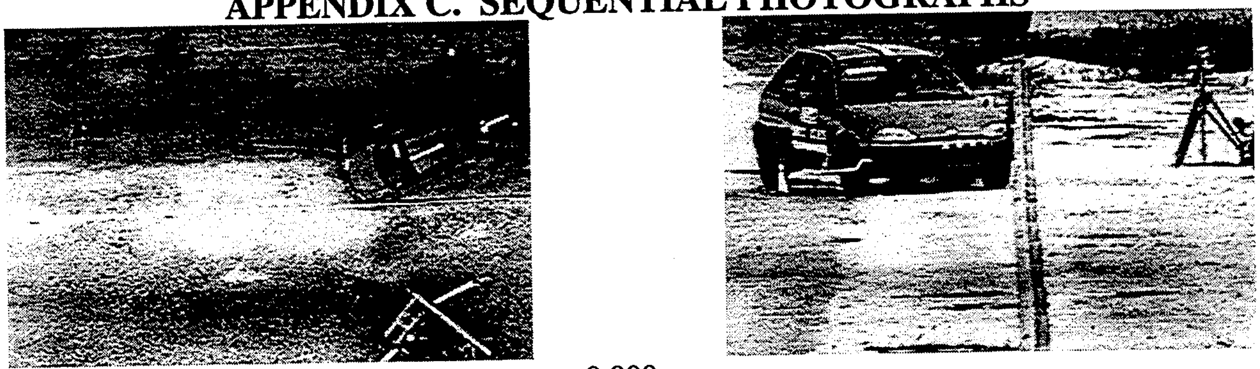






	BEFORE	AFTER
A1	1445	1442
A2	2005	2005
A3	1442	1442
B1	970	970
B2	990	990
B3	962	962
B4	932	932
B5	902	902
B6	925	925
B7	---	---
B8	---	---
B9	---	---
C1	566	560
C2	705	705
C3	562	562
D1	250	255
D2	202	202
D3	245	245
E1	1207	1210
E2	1164	1170
F	1210	1210
G	1210	1210
H	1000	1000
I	1000	1000

APPENDIX C. SEQUENTIAL PHOTOGRAPHS



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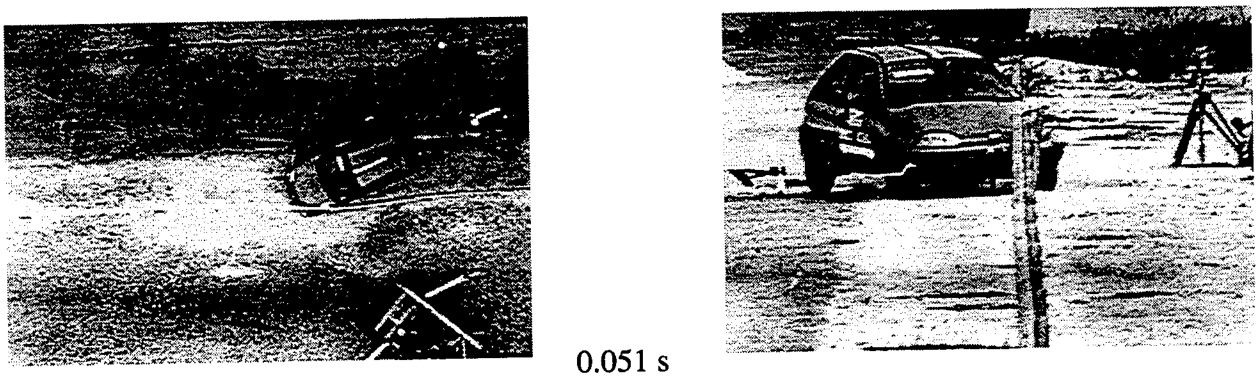

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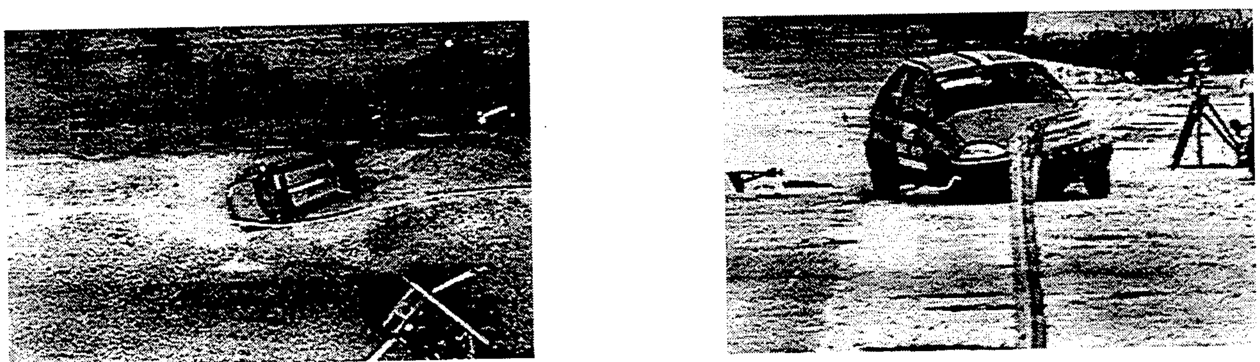

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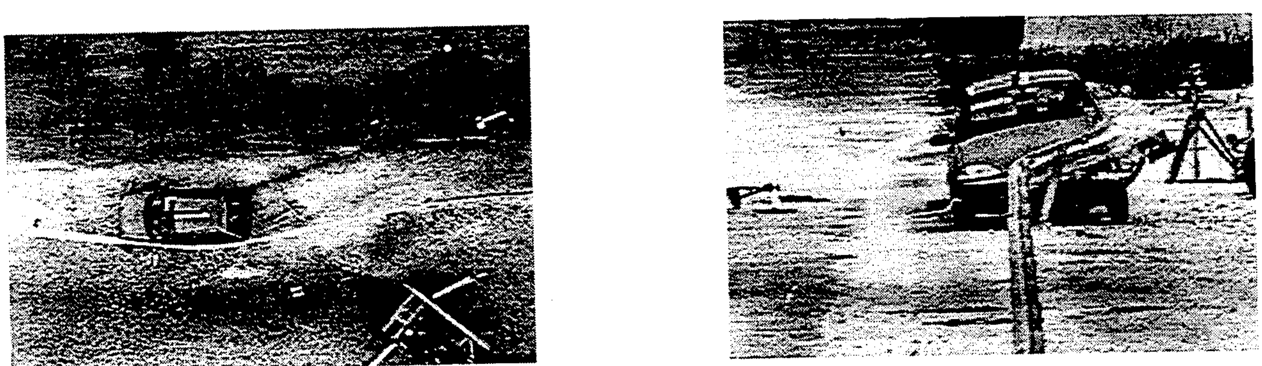
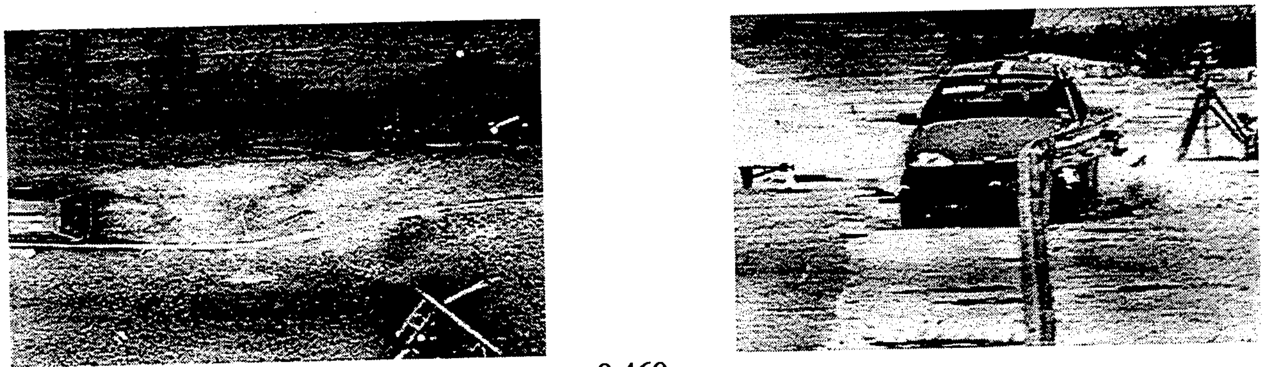


0.256 s

Figure 13. Sequential photographs for test 473750-4
(overhead & frontal views).



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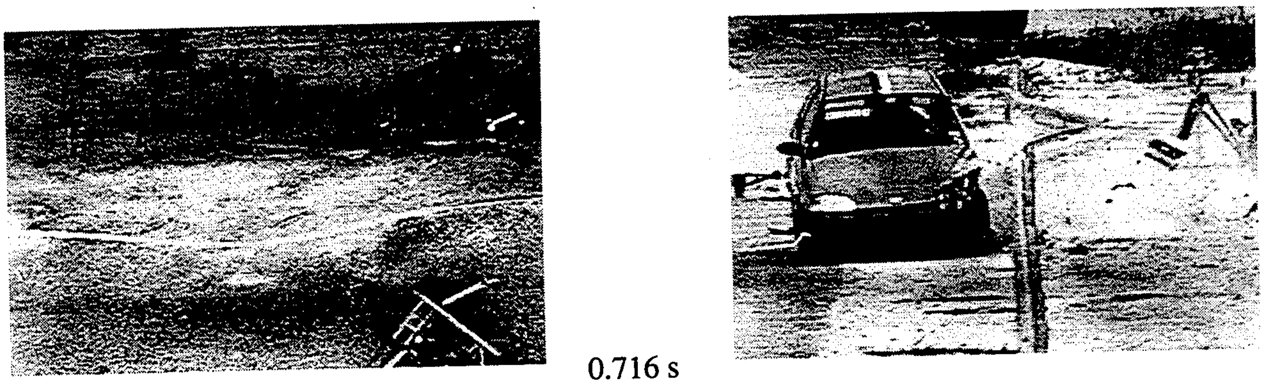

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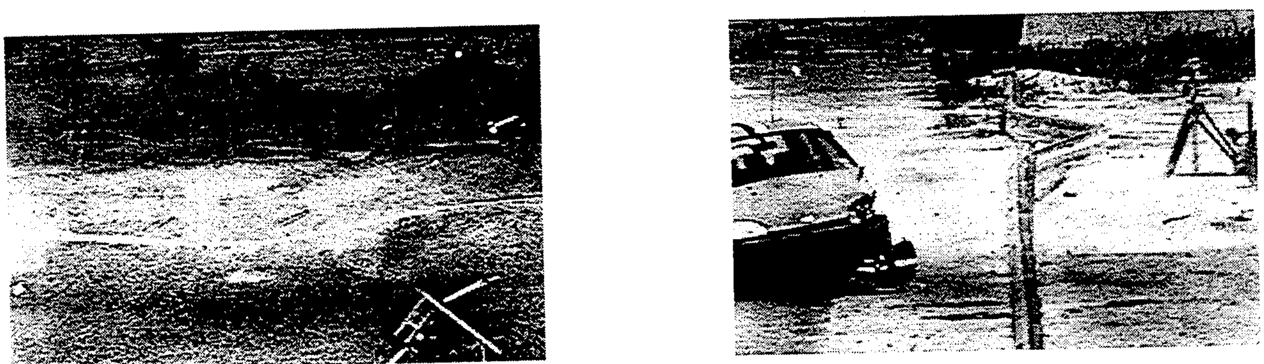
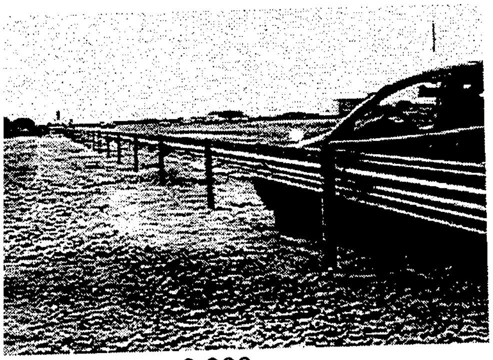


1.023 s

1.842 s

Figure 13. Sequential photographs for test 473750-4
(overhead & frontal views) (continued).



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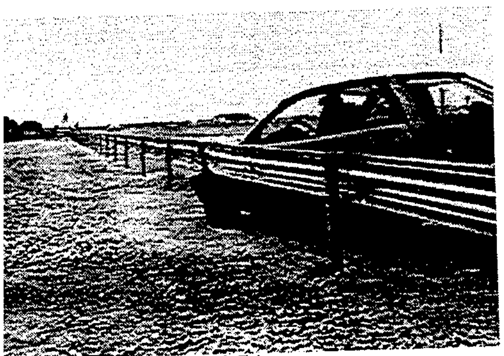
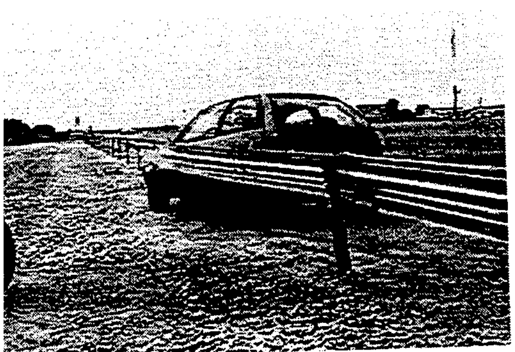


0.051 s



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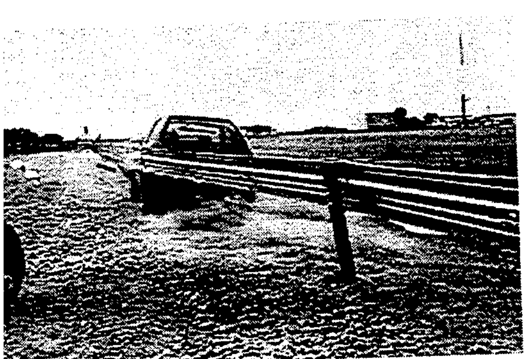

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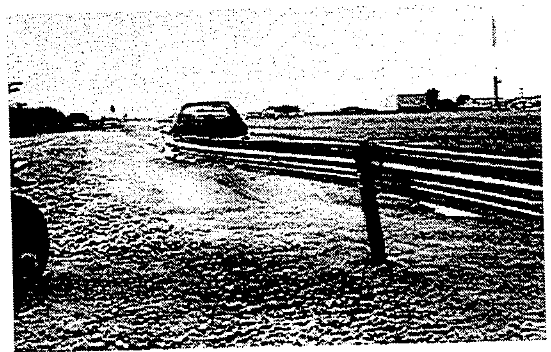

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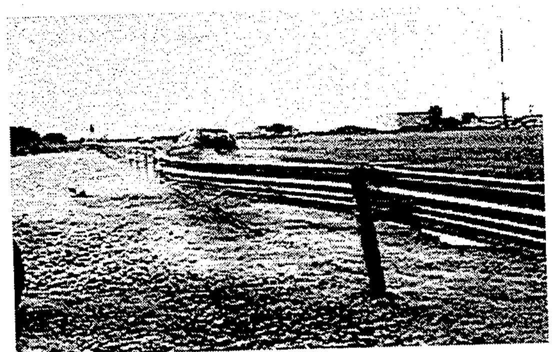

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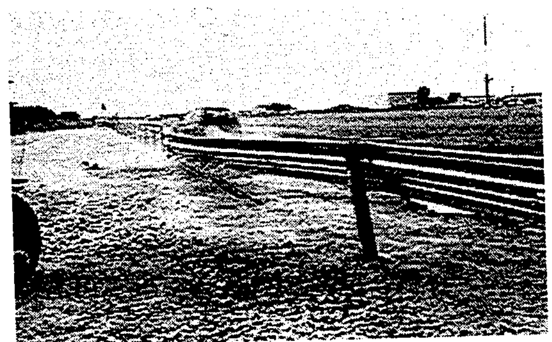
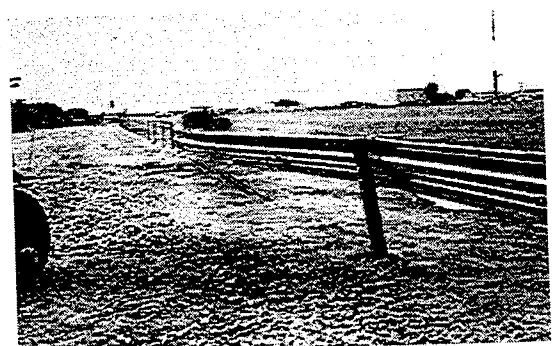


1.023 s



1.842 s

Figure 14. Sequential photographs for test 473750-4
(rear view).

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

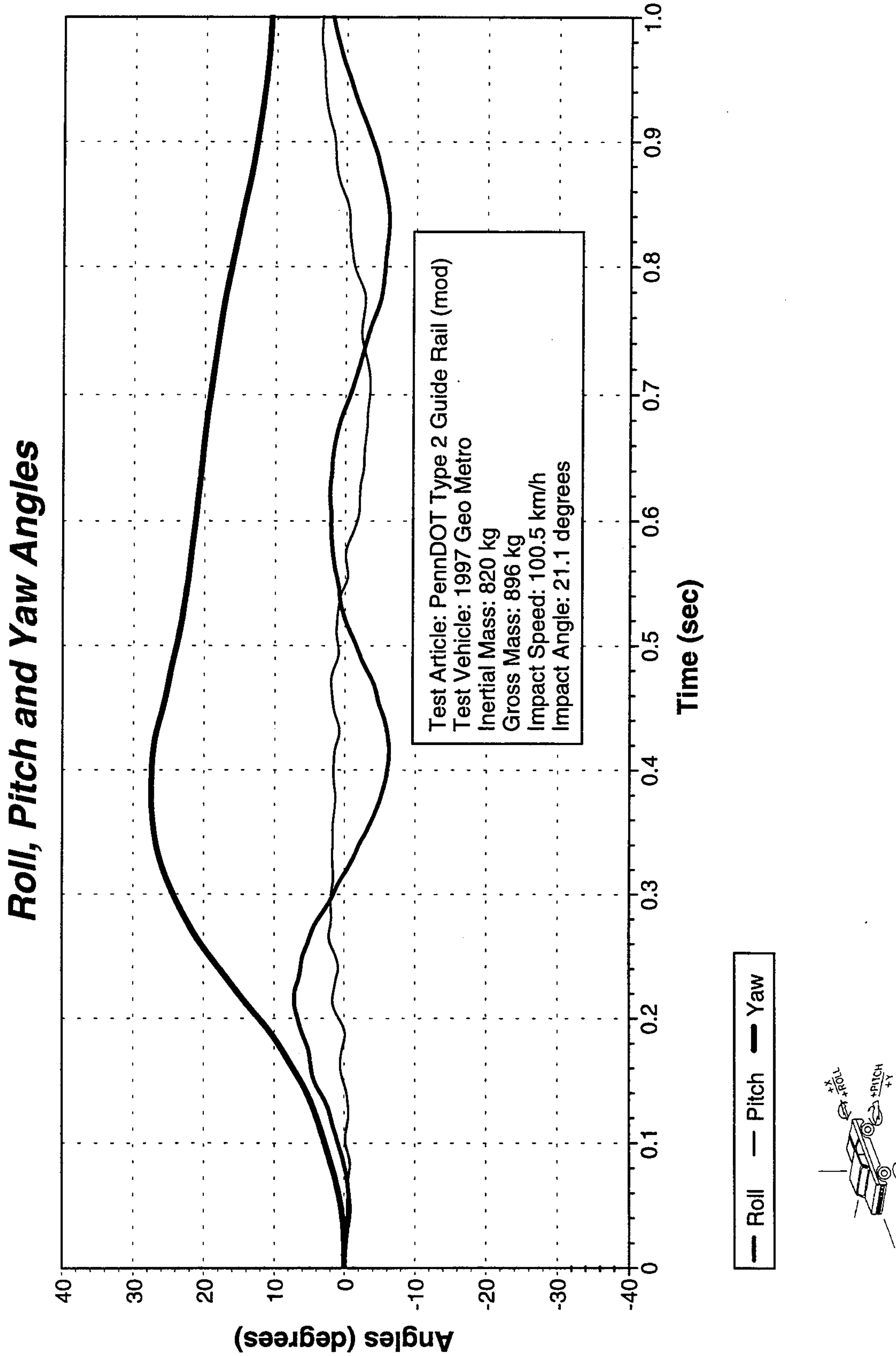


Figure 15. Vehicular angular displacements for test 473750-4.

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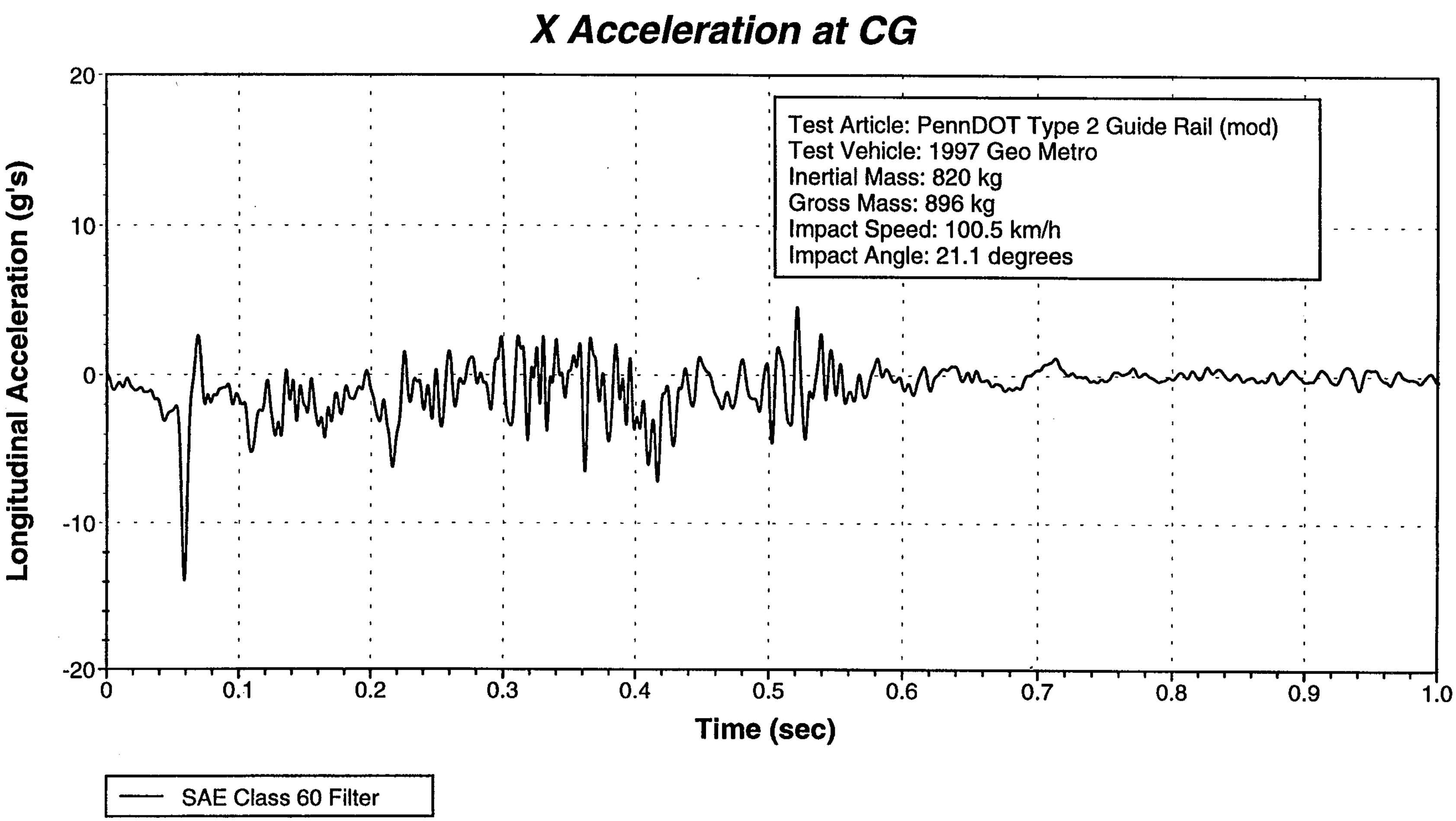

Figure 16. Vehicle longitudinal accelerometer trace for test 473750-4 (accelerometer located at center of gravity).

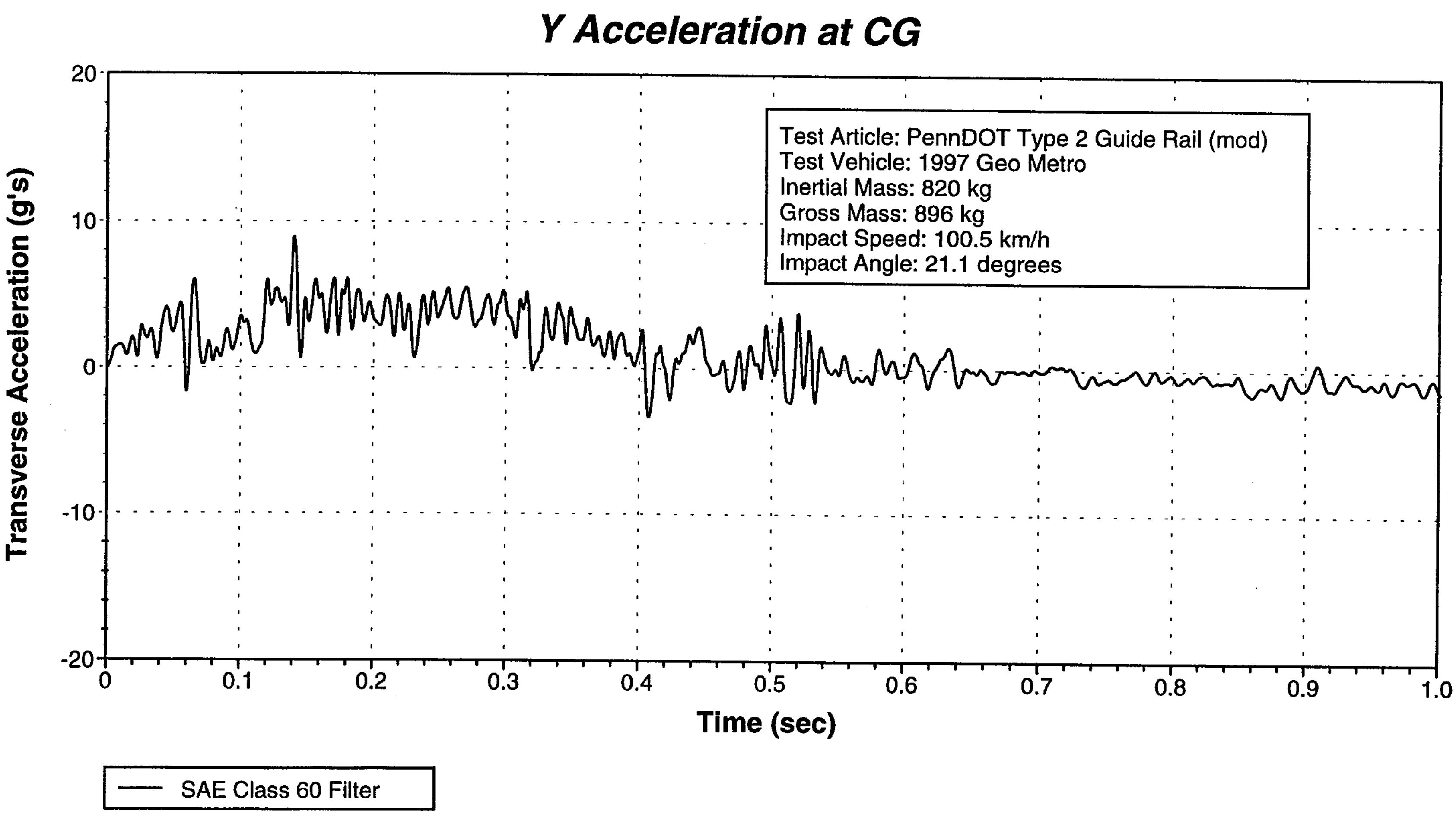

Figure 17. Vehicle lateral accelerometer trace for test 473750-4 (accelerometer located at center of gravity).

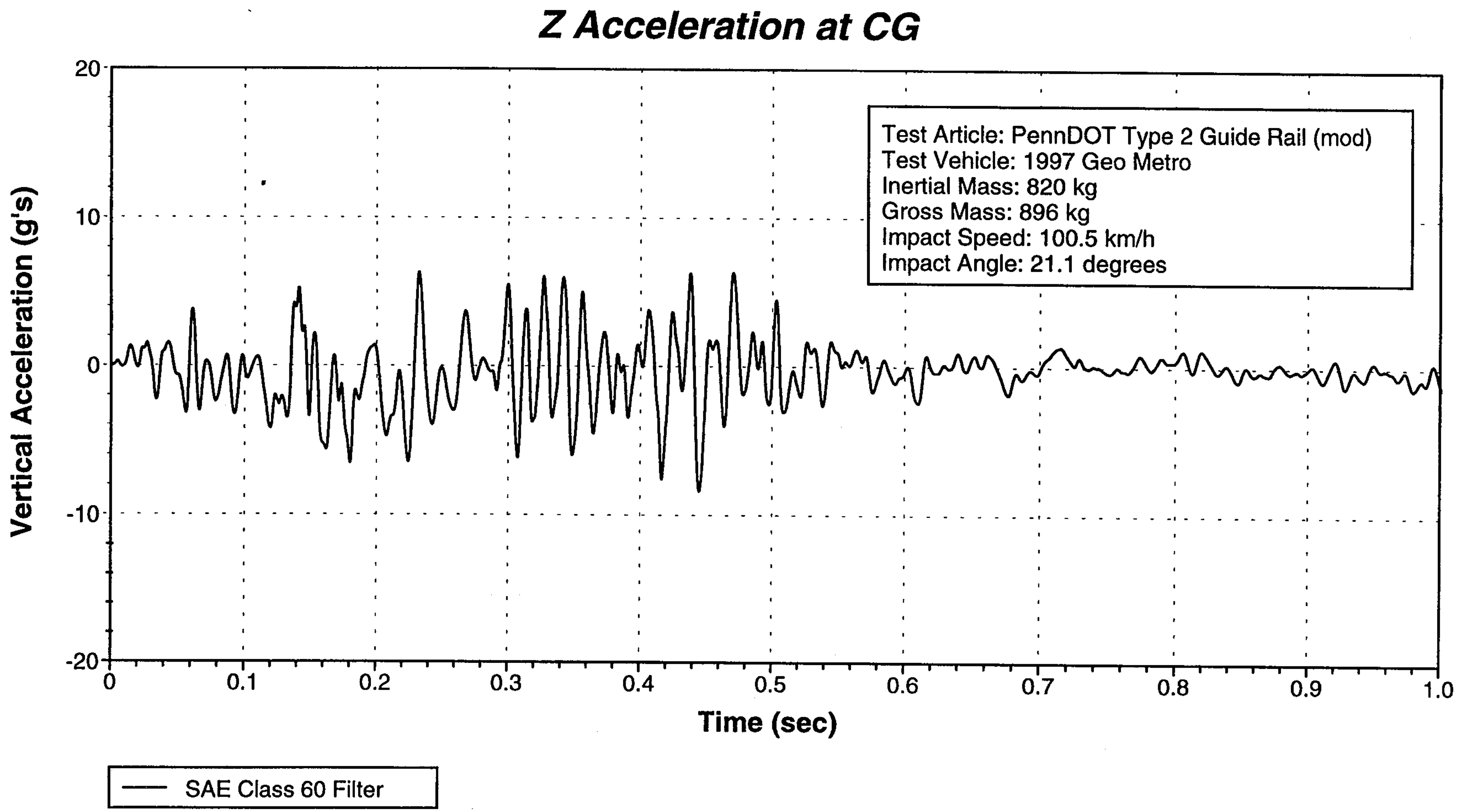

Figure 18. Vehicle vertical accelerometer trace for test 473750-4 (accelerometer located at center of gravity).

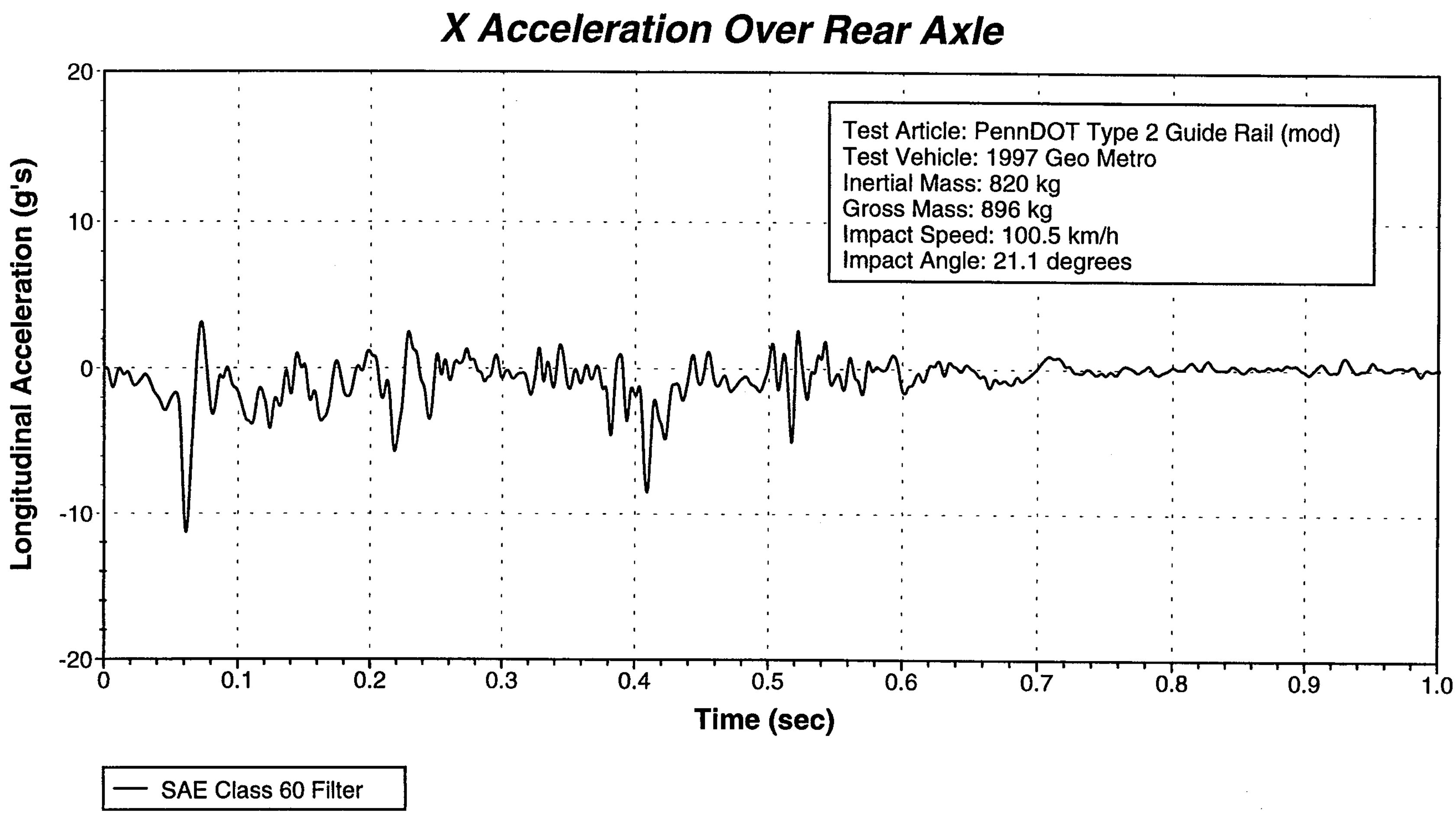

Figure 19. Vehicle longitudinal accelerometer trace for test 473750-4 (accelerometer located over rear axle).

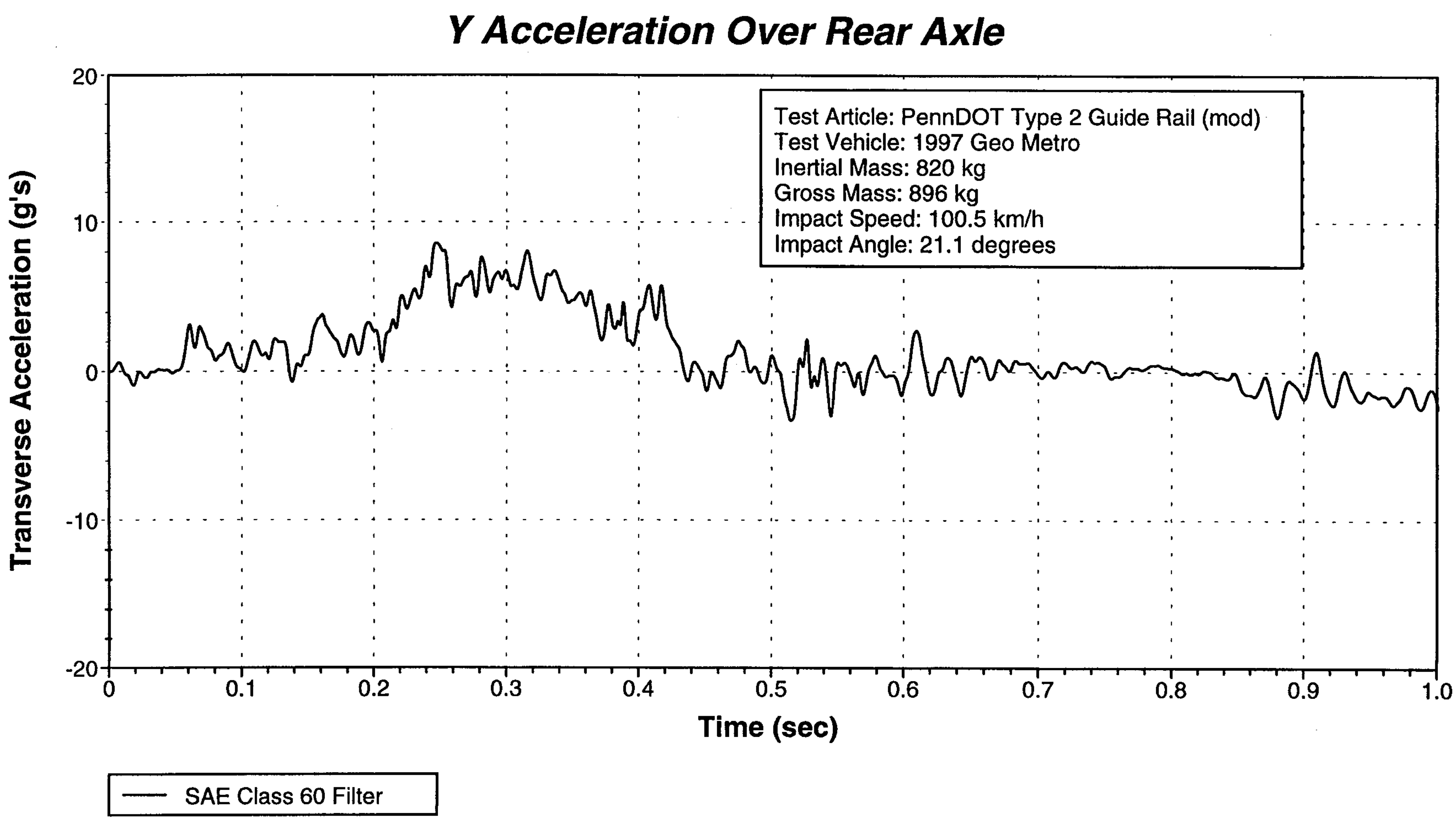

Figure 20. Vehicle lateral accelerometer trace for test 473750-4
(accelerometer located over rear axle).

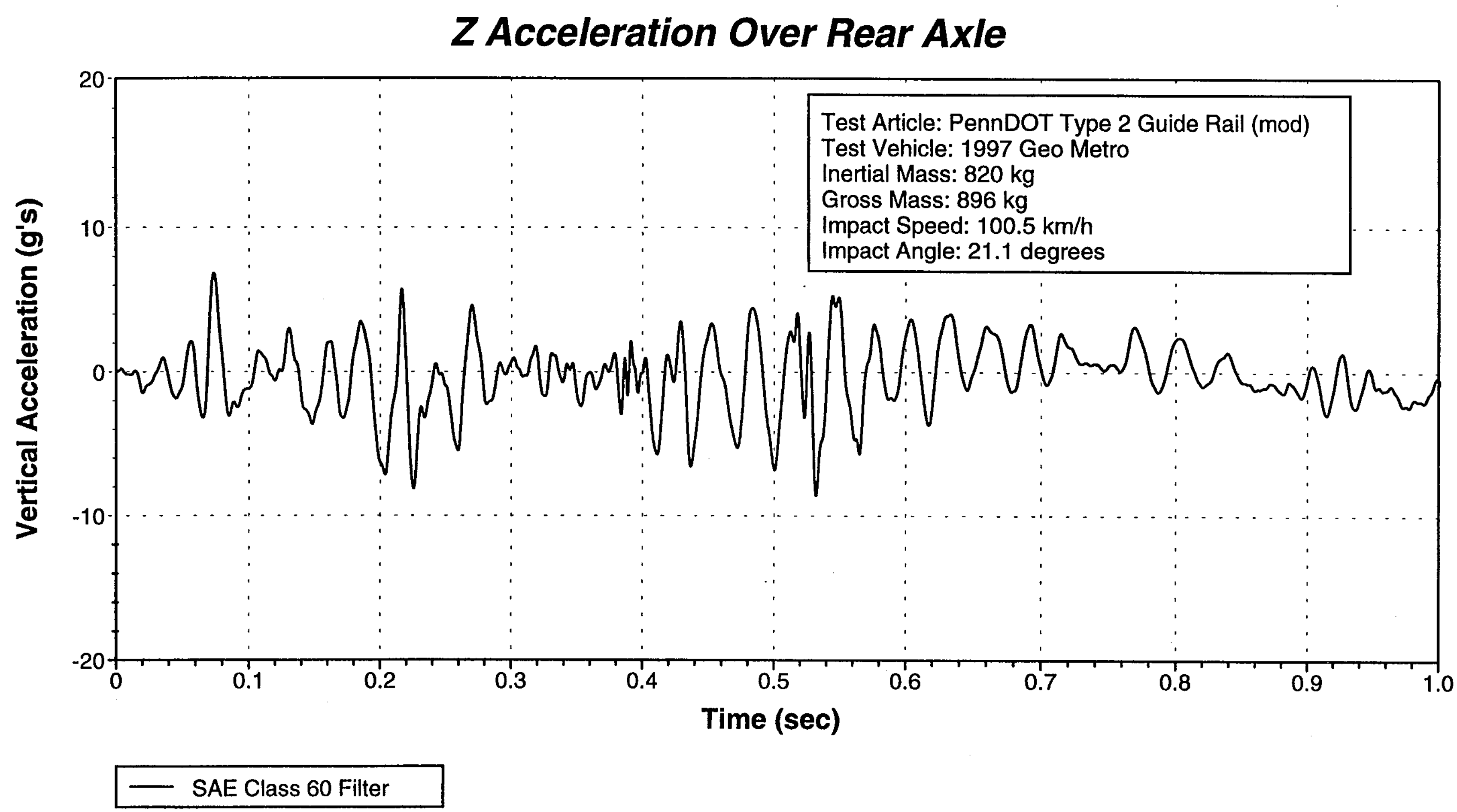

Figure 21. Vehicle vertical accelerometer trace for test 473750-4 (accelerometer located over rear axle).

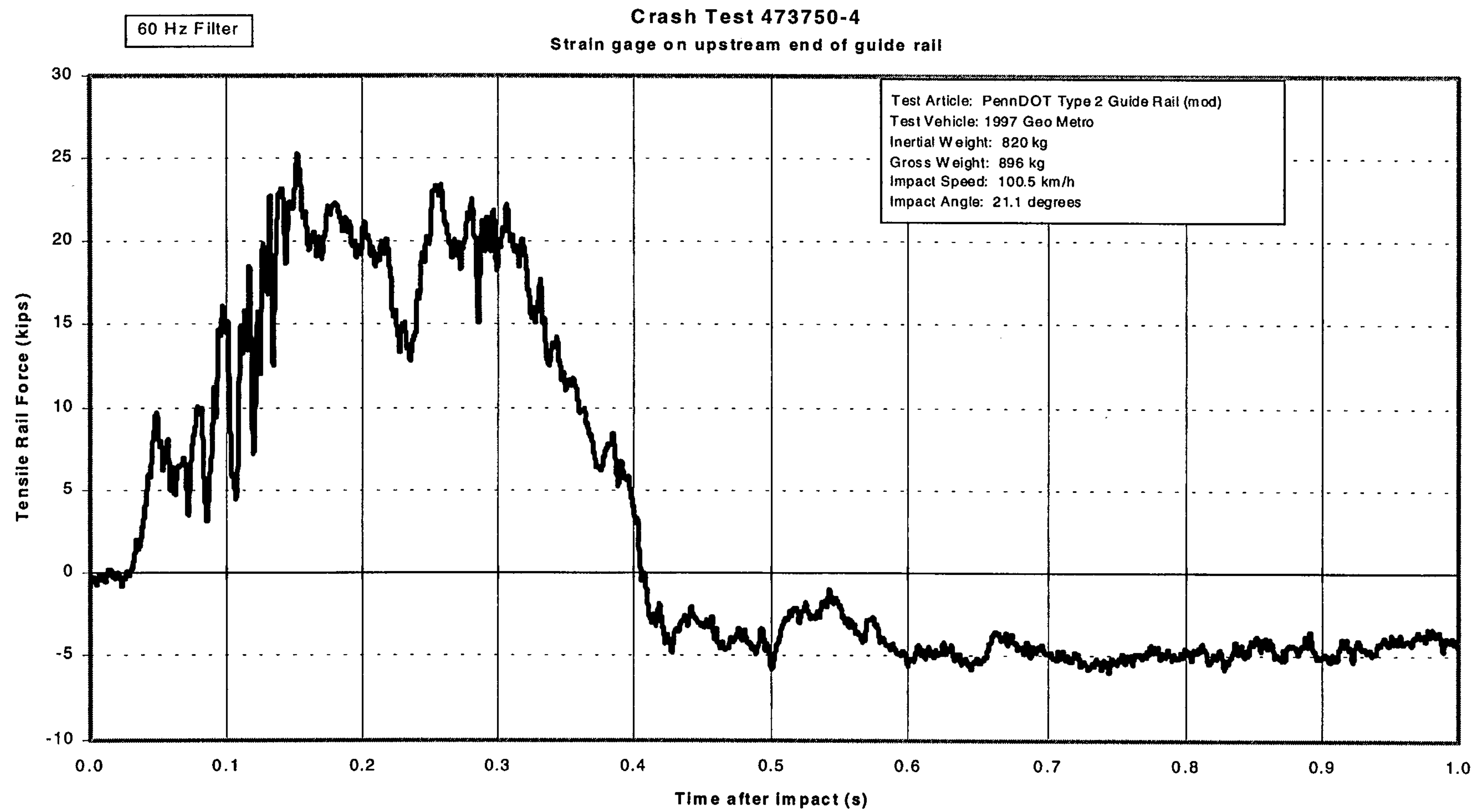

Figure 22. Tensile rail force trace for test 473750-4
(strain gage on upstream end of guide rail).

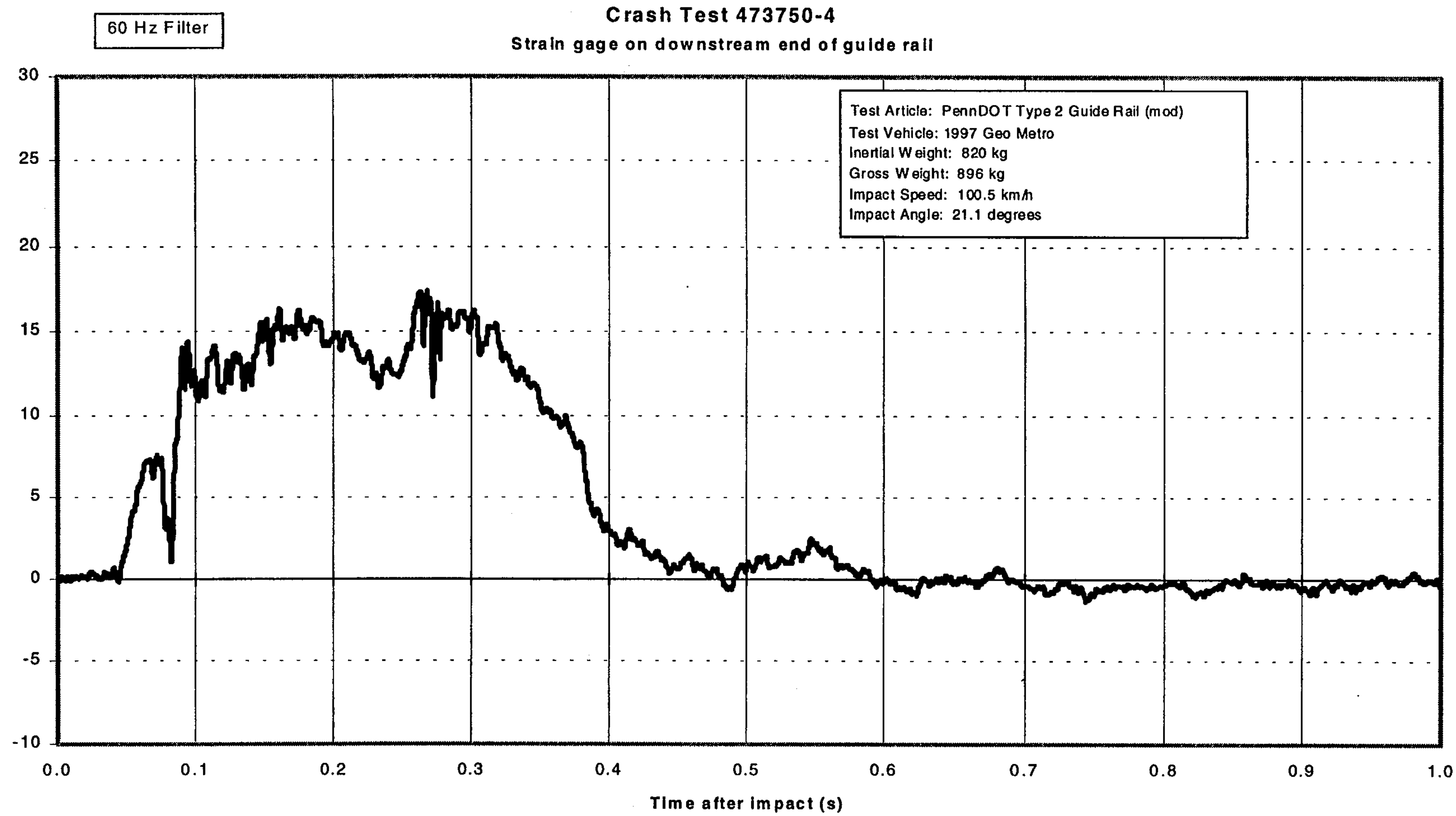

Figure 23. Tensile rail force trace for test 473750-4
(strain gage on downstream end of guide rail).

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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.

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4. 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 3," Report No. 473750-3, Texas Transportation Institute, The Texas A&M University System, College Station, TX, June 2000.

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