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NCHRP REPORT 350 TESTING OF THE ET-PLUS FOR 31-INCH-HIGH W-BEAM GUARDRAIL	July 2005
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7. Author(s) C. Eugene Buth, Dean C. Alberson, Roger P. Bligh, and D. Lance Bullard, Jr.	8. Performing Organization Report No. 220601-1&2
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12. Sponsoring Agency Name and Address Trinity Industries, Inc. 2525 Stemmons Freeway Dallas, TX 75207	13. Type of Report and Period Covered Test Report: April 2005 – June 2005 14. Sponsoring Agency Code

15. Supplementary Notes

Research Study Title: Recommended NCHRP Report 350 Tests for ET-PLUS System with Midwest Guardrail System

Name of Contacting Representative: Brian Smith, Trinity Industries, Inc.

16. Abstract

The Midwest Guardrail System is a 787 mm (31-inch) high W-beam guardrail system consisting of standard W-beam sections, blocked out 305 mm (12 inches) from the support posts. It is anticipated that this system will soon be adopted as a standard by several states. There is a need to modify and test an ET-PLUS system that will meet National Cooperative Highway Research Program (NCHRP) *Report 350* test requirements for use with the 787 mm (31-inch) high W-beam guardrail.

At a minimum, two full-scale crash tests will be necessary to satisfy Texas Transportation Institute (TTI) and Federal Highway Administration (FHWA) that the 787 mm (31-inch) high ET-PLUS system meets *NCHRP Report 350* requirements for a Test Level 3 terminal. These are: 1) Test 3-30 – Small car, end-on, at quarter-point offset; and 2) Test 3-35 – Pickup truck redirection at beginning of length of need (3.8 m (12.5 ft) from terminal beginning).

Several modifications were made to the standard ET-PLUS to accommodate the 787 mm (31-inch) high W-beam guardrail This report presents the details of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail, the details and descriptions of the two full-scale crash tests performed, and the results and assessment of the two tests. The ET-PLUS for 787 mm (31-inch) high W-beam guardrail met the required criteria for *NCHRP Report 350* tests 3-35 and 3-30.

17. Key Words	18. Distribution Statement
Terminal, end treatment, guardrail, crash testing, roadside safety	Copyrighted. Not to be copied or reprinted without consent from Trinity Industries.

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INTRODUCTION

PROBLEM

The Midwest Guardrail System is a 787 mm (31-inch) high W-beam guardrail system consisting of standard W-beam sections, blocked out 305 mm (12 inches) from the support posts. It is anticipated that this system will soon be adopted as a standard by several states. There is a need to modify and test an ET-PLUS system that will meet National Cooperative Highway Research Program (NCHRP) *Report 350* test requirements for use with the 787 mm (31-inch) high W-beam guardrail.(1)

OBJECTIVES/SCOPE OF RESEARCH

At a minimum, two full-scale crash tests will be necessary to satisfy Texas Transportation Institute (TTI) and Federal Highway Administration (FHWA) that the 787 mm (31-inch) ET-PLUS system meets *NCHRP Report 350* requirements for a Test Level 3 (TL-3) terminal. These are:

1. Test 3-30 – Small car, end-on, at quarter-point offset.
2. Test 3-35 – Pickup truck redirection at beginning of length of need (3.8 m (12.5 ft) from terminal beginning).

This report presents the details of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail installation, the details and descriptions of the two full-scale crash tests performed, and the results and assessment of the two tests.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of a 809-hectare complex of research and training facilities situated 16 km 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 the installation of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail was along the edge of a wide out-of-service runway apron. The runway apron consists of an unreinforced jointed concrete pavement in 3.8 m by 4.6 m (12.5 ft by 15 ft) blocks nominally 203-305 mm (8-12 inches) 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 standard ET-PLUS guardrail terminal was modified for attachment to a 787 mm (31-inch) guardrail system. Features o the modified design are as follows:

1. Raise the guardrail height to 787 mm (31 inches) throughout the terminal length.
2. Increase blockout depth to 305 mm (12 inches), beginning at post 3.
3. Use longer post bolts to accommodate increased blockout depth.
4. Modify upper part of the Hinged Breakaway Anchor (HBA) post to accommodate 787 mm (31-inch) high guardrail, at post 1.
5. Use 3.8 m (12.5 ft) W-beam, with anchor bracket holes, between posts 1 and 3. Use special 2.86 m (9.375 ft) W-beam section at post 3. This will create mid-span splices between posts 4 and 5, and beyond. Use standard 3.8 m (12.5 ft) W-beam section with holes punched on 0.95 m (3.125 ft) centers between mid-span of posts 4 and 5 and posts 6 and 7. Terminal length will end between posts 6 and 7, with a terminal length of 10.5 m (34.375 ft).
6. Punch weakening holes in SYTP at 810 mm (31.875 inches) from top of post. Raise SYTP 102 mm (4 inches) above current embedment.
7. Use modified SYTP at post positions 2 through 6.
8. Use standard W6x8.5 line posts at positions 7 and beyond.

The terminal was installed in the tangent configuration on a 787 mm (31-inch) high W-beam guardrail. Details of the modified ET-PLUS and the test installation are shown in figures 1 through 7. Photos of the installation are shown in figure 8.

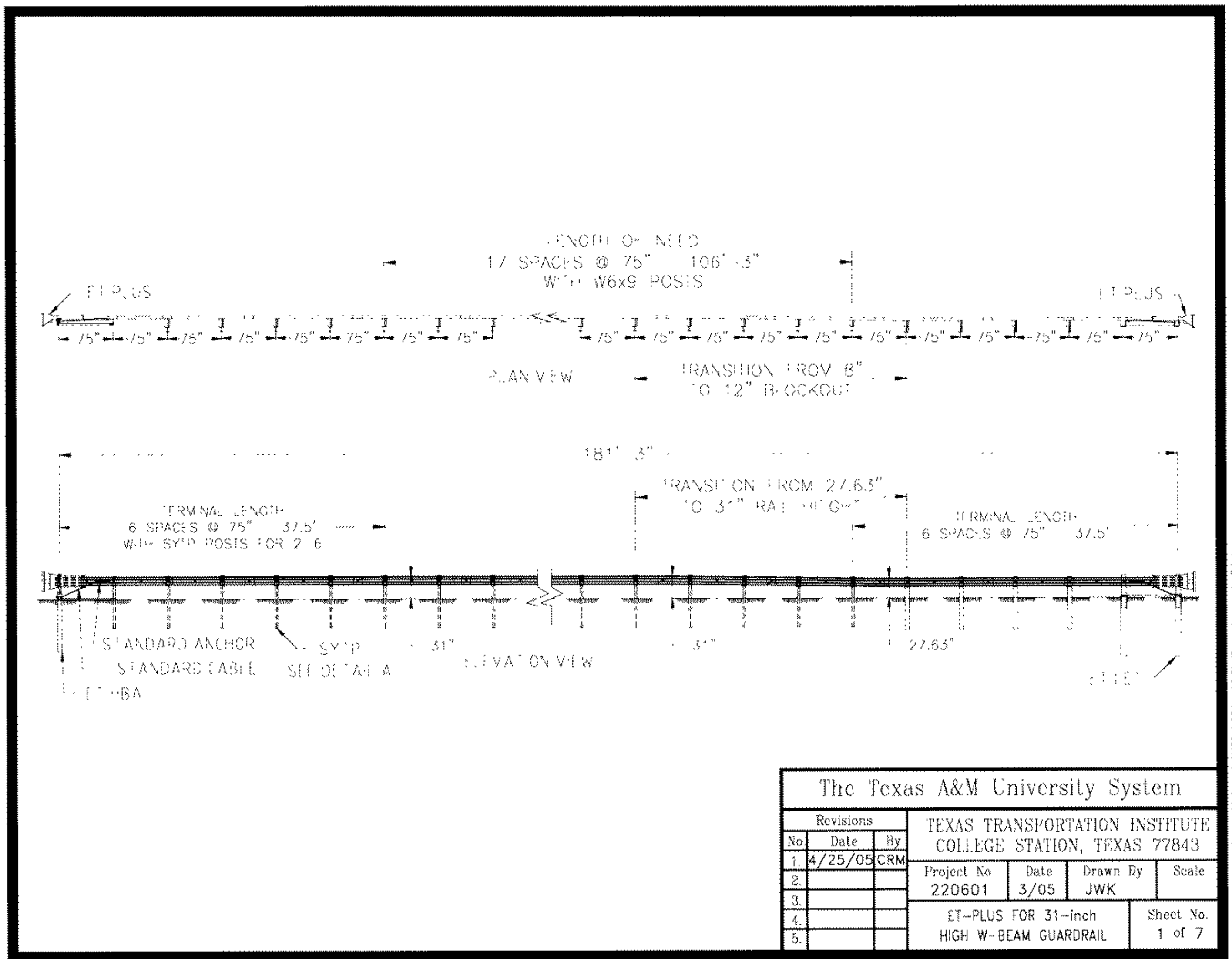


Figure 1. Details of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail (layout).

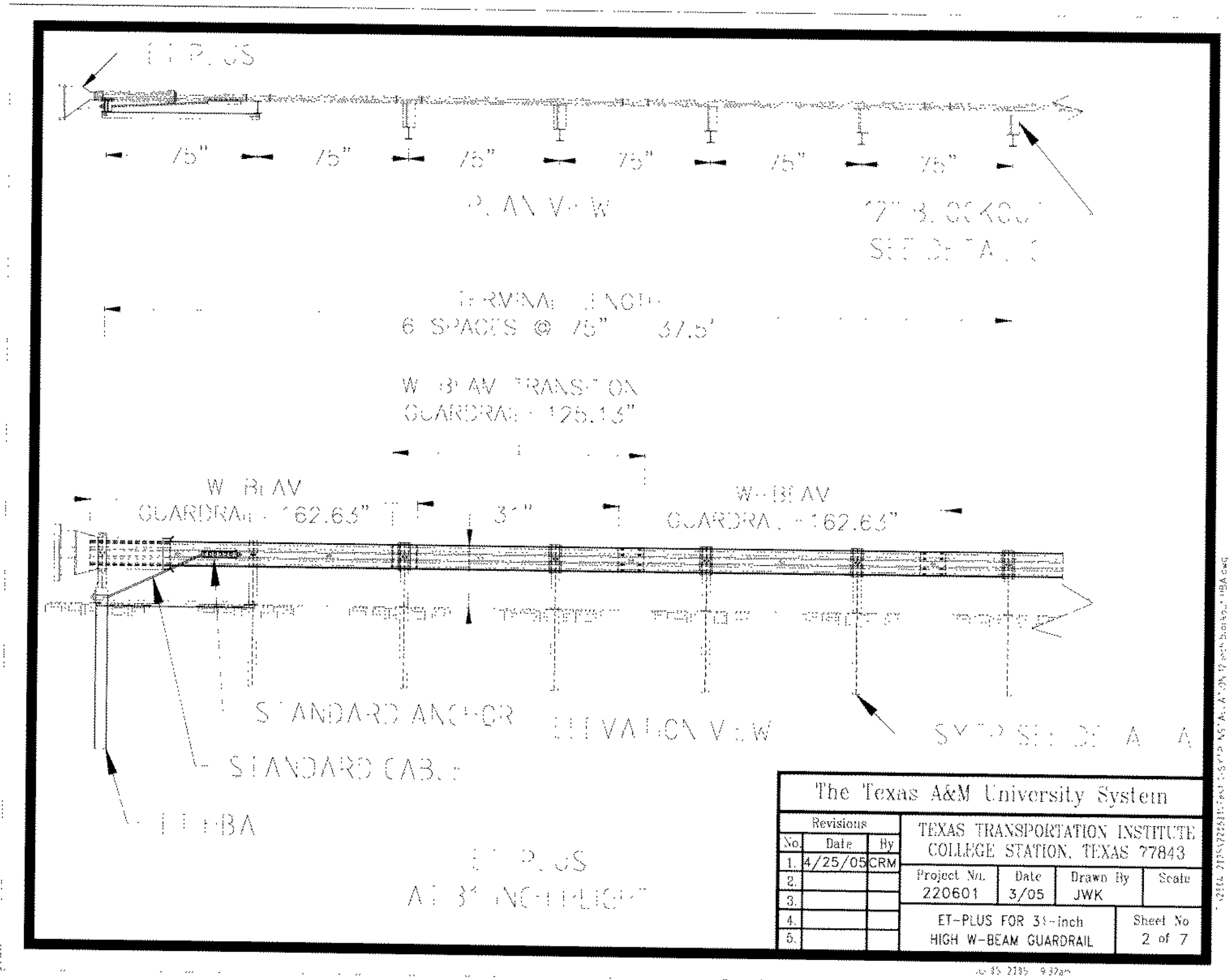


Figure 2. Details of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail (upstream terminal).

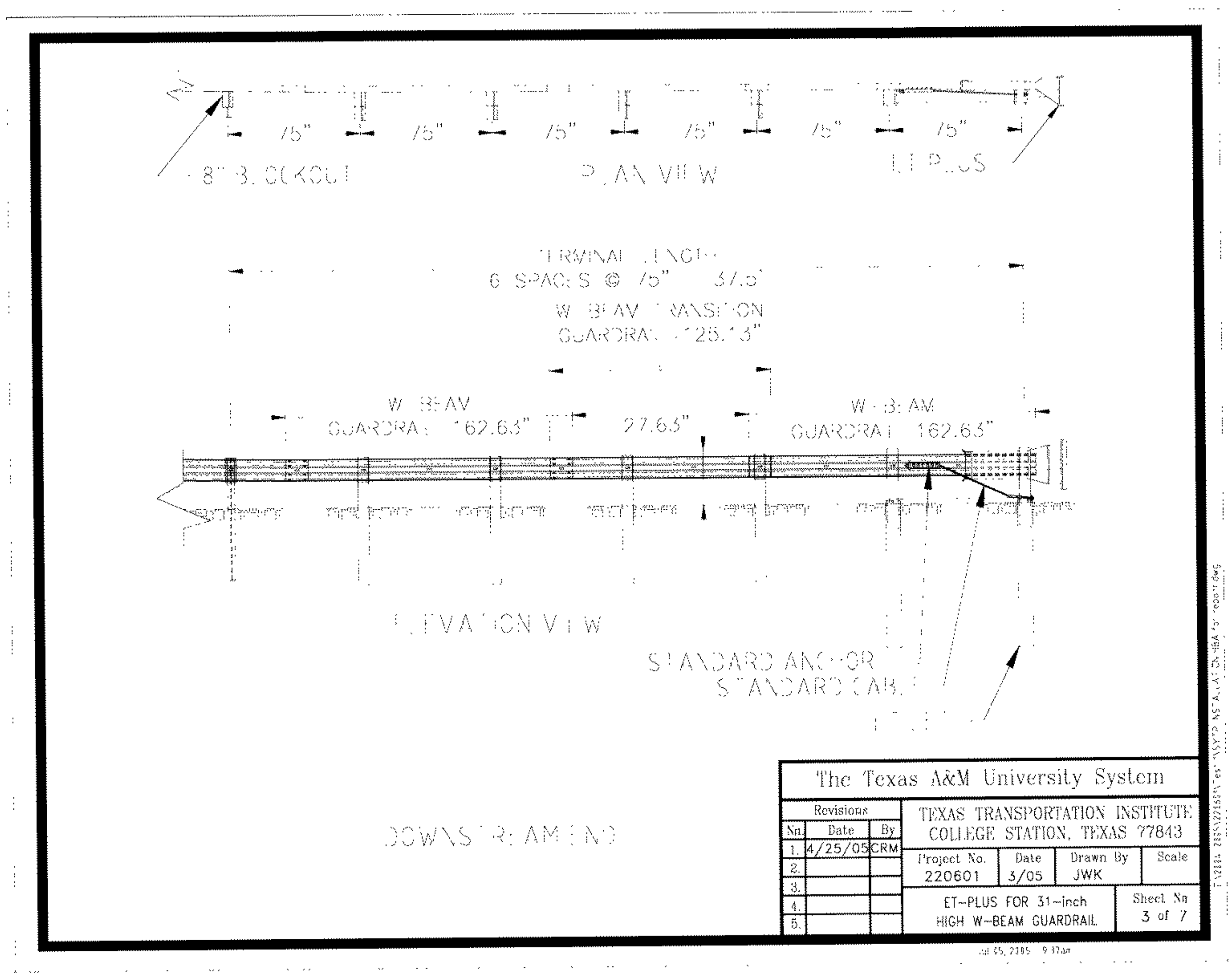


Figure 3. Details of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail (downstream terminal).

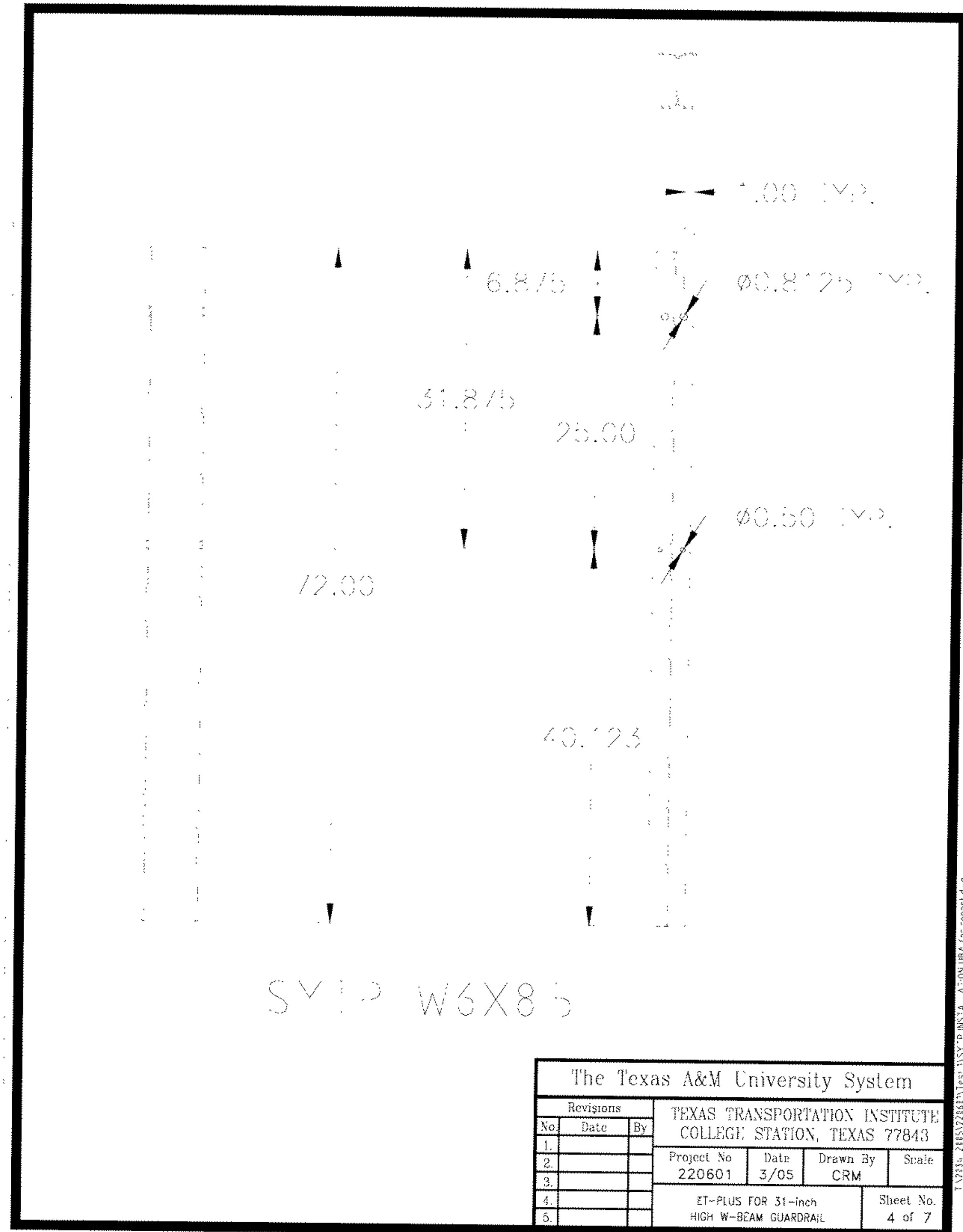


Figure 4. Details of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail (SYTP post).

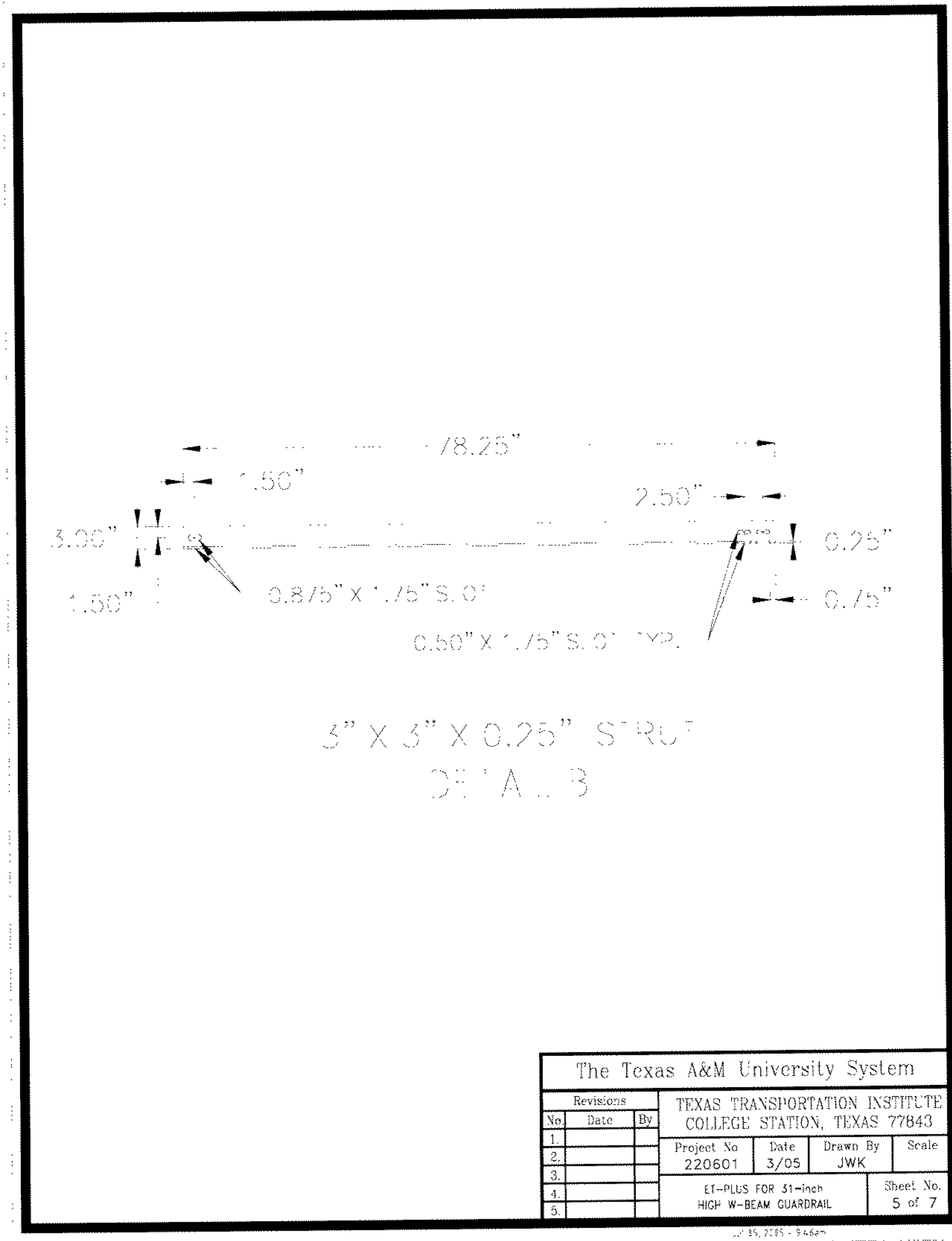


Figure 5. Details of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail (strut).

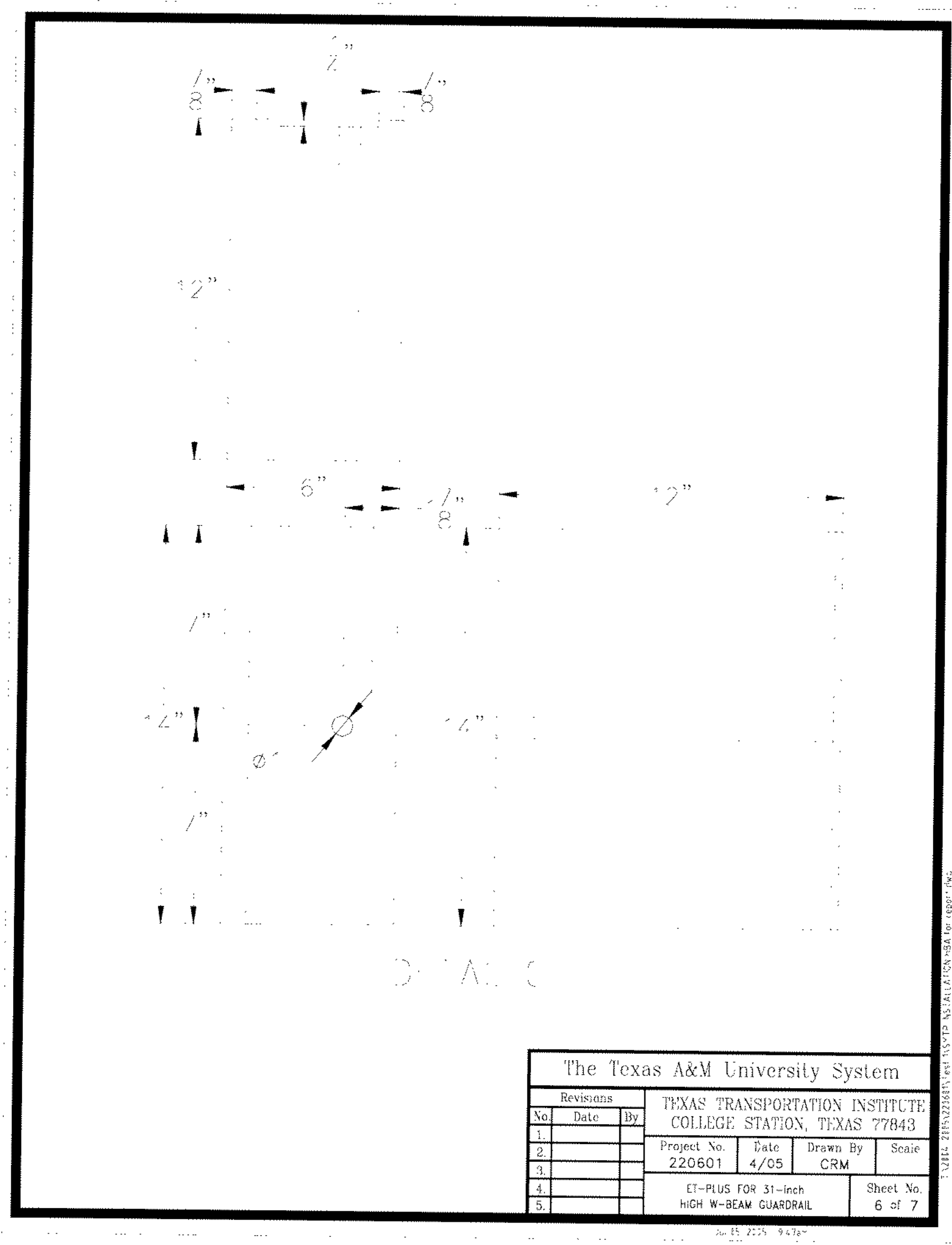


Figure 6. Details of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail (blockout).

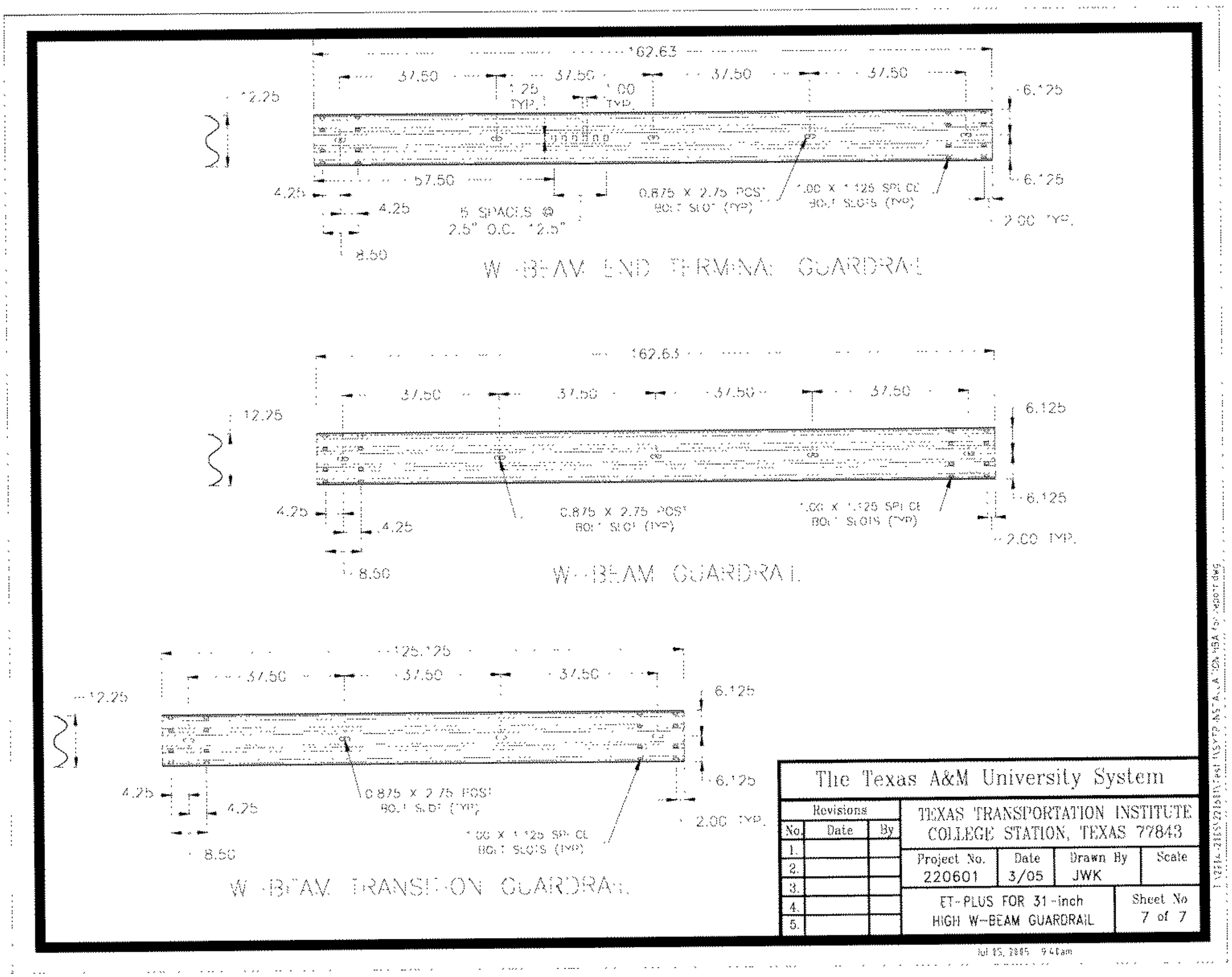


Figure 7. Details of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail (W-beam).

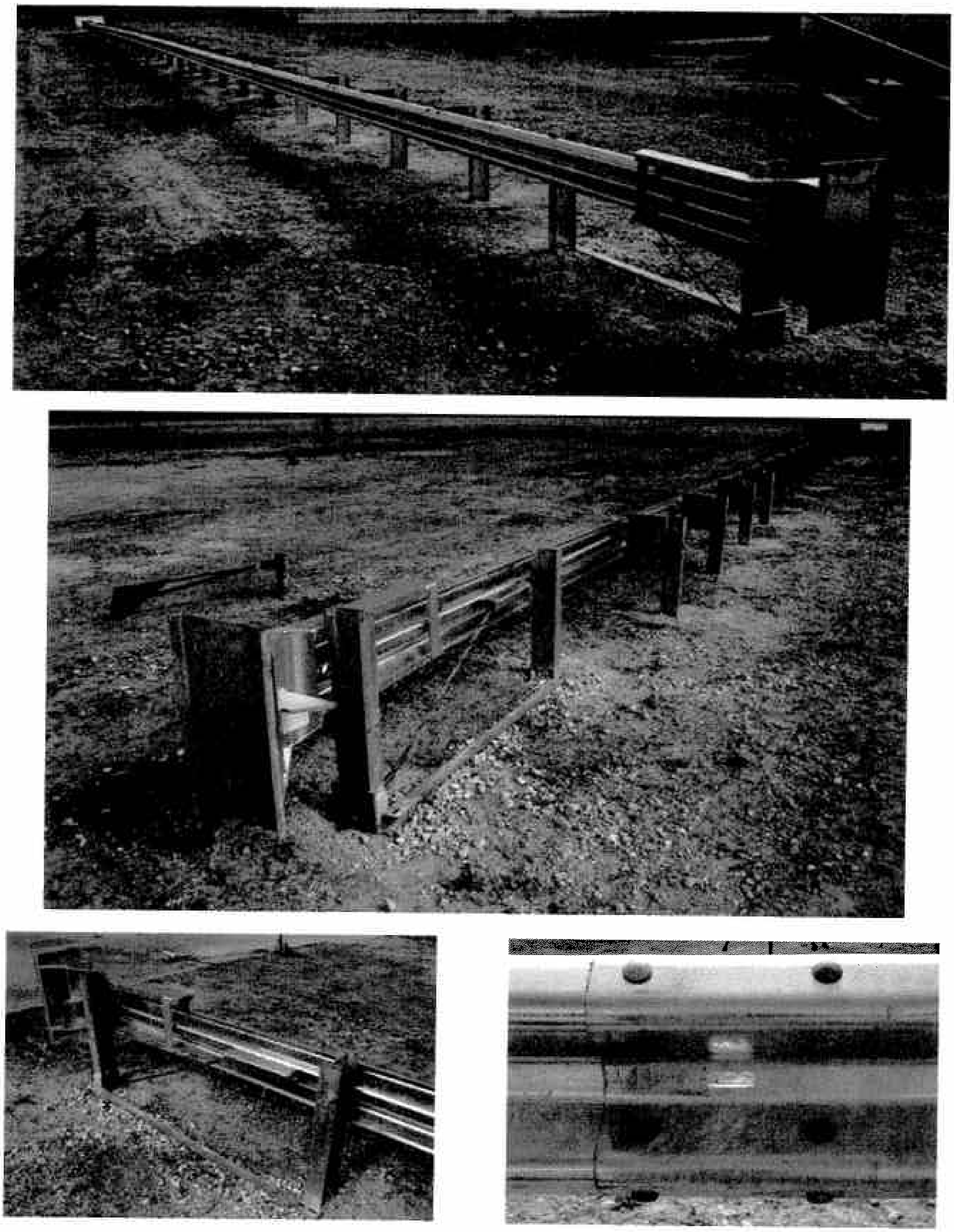


Figure 8. ET-PLUS for 787 mm (31-inch) high W-beam guardrail prior to testing.

Test Conditions

According to *NCHRP Report 350*, up to seven crash tests are recommended to evaluate the impact performance of a gating terminal at test level 3 (TL-3):

> ***NCHRP Report 350* test designation 3-30**: An 820 kg passenger car impacting the terminal end-on at a nominal speed and angle of 100 km/h and 0 degree. The centerline of the terminal is aligned with the front quarter point of the vehicle. The test is intended to evaluate occupant risk and vehicle trajectory criteria.
>
> ***NCHRP Report 350* test designation 3-31**: A 2000 kg pickup truck impacting the terminal end-on at a nominal speed and angle of 100 km/h and 0 degree. The centerline of the terminal is aligned with the centerline of the vehicle. The test is intended to evaluate the capacity of the device to absorb the kinetic energy of the 2000 kg vehicle in a safe manner.
>
> ***NCHRP Report 350* test designation 3-32**: An 820 kg passenger car impacting the terminal end-on at a nominal speed and angle of 100 km/h and 15 degrees. The centerline of the nose of the terminal is aligned with the centerline of the vehicle. The test is intended to evaluate occupant risk and vehicle trajectory criteria.
>
> ***NCHRP Report 350* test designation 3-33**: A 2000 kg pickup truck impacting the terminal end-on at a nominal speed and angle of 100 km/h and 15 degrees. The centerline of the nose of the terminal is aligned with the centerline of the vehicle. The test is intended to evaluate occupant risk and vehicle trajectory criteria.
>
> ***NCHRP Report 350* test designation 3-34**: An 820 kg passenger car impacting the side of the terminal at a critical impact point (CIP) between the end of the terminal and the beginning of the length of need (LON) at a nominal speed and angle of 100 km/h and 15 degrees. The test is intended to evaluate occupant risk and vehicle trajectory criteria.
>
> ***NCHRP Report 350* test designation 3-35**: A 2000 kg pickup truck impacting the side of the terminal at the beginning of the LON at a nominal speed and angle of 100 km/h and 20 degrees. The test is intended to evaluate the ability of the device to contain and redirect the 2000 kg pickup within vehicle trajectory criteria.
>
> ***NCHRP Report 350* test designation 3-39**: A 2000 kg pickup truck impacting the side of the terminal at the midpoint of the LON in the reverse direction at a nominal speed and angle of 100 km/h and 20 degrees. The test is intended to evaluate the performance of the terminal for a "reverse" direction hit.

At a minimum, two full-scale crash tests were deemed necessary to satisfy TTI and FHWA that the 31 inch ET-PLUS system meets *NCHRP Report 350* requirements for a Test

Level 3 terminal. *NCHRP Report 350* tests 3-30 and 3-35 were performed on the ET-PLUS for 787 mm (31-inch) high W-beam guardrail.

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Appendix A presents brief descriptions of these procedures.

Evaluation Criteria

The crash test 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." Safety evaluation criteria from table 5.1 of *NCHRP Report 350* were used to evaluate the crash test reported herein.

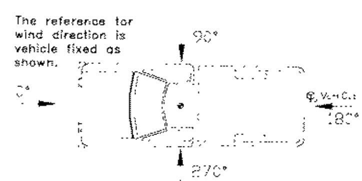
CRASH TEST 220601-1 (*NCHRP REPORT 350* TEST NO. 3-35)

Test Vehicle

A 1992 Chevrolet 2500 pickup truck, shown in figures 9 and 10, was used for the crash test. Test inertia weight of the vehicle was 2031 kg, and its gross static weight was 2031 kg. The height to the lower edge of the vehicle front bumper was 378 mm, and the height to the upper edge of the front bumper was 595 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 23. 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 5, 2005. No rainfall was recorded for the ten days prior to the test. Moisture content of the *NCHRP Report 350* standard soil in which the test article was installed was 6.0 percent. Weather conditions at the time of testing were: Wind speed: 3 km/h; wind direction: 195 degrees with respect to the vehicle (vehicle was traveling in a northeasterly direction); temperature: 23°C; relative humidity: 45 percent.



Impact Description

The pickup truck, traveling at an impact speed of 100.5 km/h, impacted the ET-PLUS for 787 mm (31-inch) high W-beam guardrail at post 3 at an impact angle of 19.2 degrees. At approximately 0.044 s after impact, the vehicle began to redirect. The front of the vehicle reached post 4 at 0.068 s, and the tire/wheel assembly contacted the post at the base at 0.079 s. At 0.144 s, the front of the vehicle reached post 5, and at 0.160 s, the tire contacted post 5 and rode over it. The vehicle reached post 6 at 0.222 s, and the tire contacted post 6 at 0.246 s and rode over the post. At 0.305 s, the vehicle reached post 7, and at 0.344 s, the tire contacted post 7 and rode over the post. The vehicle reached post 8 at 0.400 s, and post 9 at 0.523 s, at which time the vehicle began to yaw clockwise. The vehicle continued out of view of the overhead camera while still in contact with the rail. At 0.791 s, the vehicle lost contact with the rail, and at 1.668 s, the vehicle contacted the rail a second time at post 15, and came to rest between posts 15 and 16. Sequential photographs of the test period are shown in appendix C, figures 25 and 26.

Figure 9. Vehicle/installation geometrics for test 220601-1.

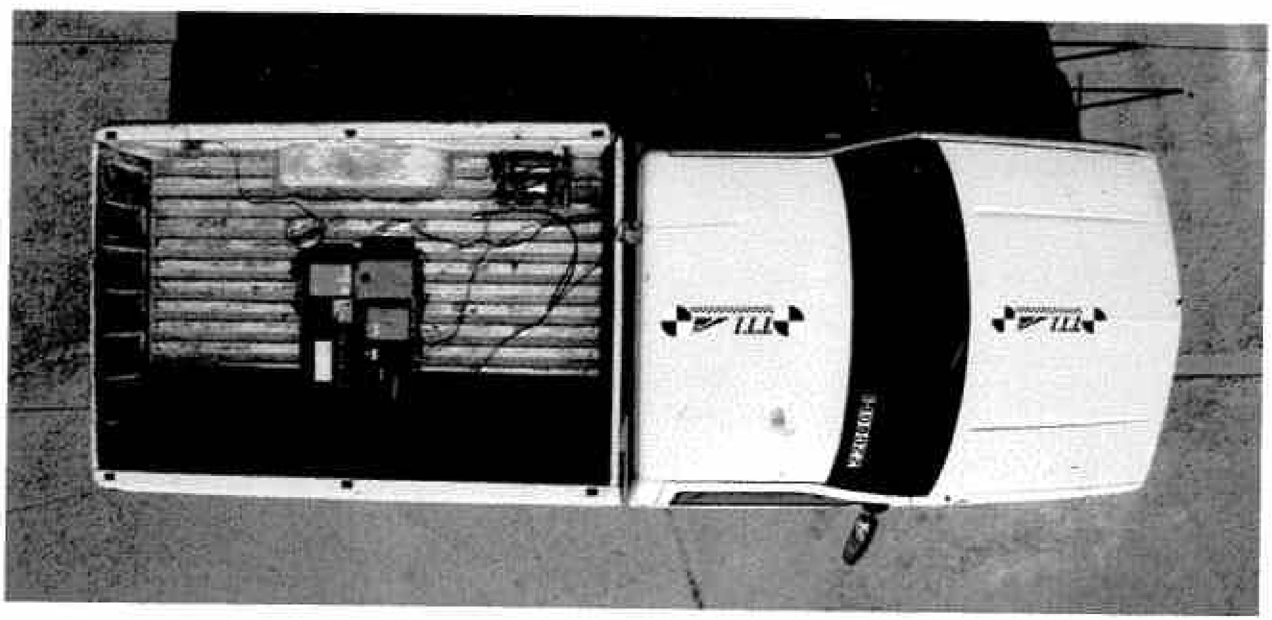


Figure 10. Vehicle before test 220601-1.

Damage to Test Article

Damage to the installation is shown in figures 11 and 12. The anchor base around post 1 moved downstream 70 mm, and post 1 was leaning toward the field side 19 mm. Post 2 was only disturbed, post 3 was pushed toward the field side 30 mm, and post 4 was pushed toward the field side 155 mm. The rail was separated from posts 5 through 9. Post 5 was pushed toward the field side 100 mm and the blockout was barely attached to the post. Post 6 was pushed toward the field side 51 mm, and the blockout was split with the biggest portion resting at post 7. Post 7 was pushed toward field side 51 mm and the blockout was barely attached to the post. Post 8 was pushed toward field side 92 mm and the blockout and side of the post were marred from contact with the vehicle. Post 9 was pushed toward field side 20 mm, and the blockout was slightly loose. The vehicle then contacted the rail again at post 15, and came to rest between posts 15 and 16. Total length of contact of the vehicle during the initial contact with the rail was 7.6 m. Maximum dynamic deflection of the rail during the test was 939 mm, and maximum residual deformation was 255 mm.

Vehicle Damage

The vehicle sustained damage to the right side, as shown in figure 13. Structural damage included a broken right outer tie rod end and deformed right frame rail. Other damage included the front bumper, hood, grill, radiator, fan, right front quarter panel, right door, right rear exterior bed, and the rear bumper. Both wheel rims on the right side were deformed and the tires deflated. Maximum exterior crush to the vehicle was 530 mm in the right side plane at the right front corner at bumper height. No measurable occupant compartment deformation occurred. Photographs of the interior of the vehicle are shown in figure 14. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 3 and 4.

Occupant Risk Factors

Data from the triaxial accelerometer, located at the vehicle center of gravity, were digitized to compute occupant impact velocity and ridedown accelerations. Only the occupant impact velocity and ridedown accelerations in the longitudinal axis are required from these data for evaluation of criterion L of *NCHRP Report 350*. In the longitudinal direction, occupant impact velocity was 8.7 m/s at 0.153 s, maximum 0.010-s ridedown acceleration was -11.5 g's from 0.222 to 0.232 s, and the maximum 0.050-s average was -7.7 g's between 0.272 and 0.322 s. In the lateral direction, the occupant impact velocity was 4.6 m/s at 0.153 s, the highest 0.010-s occupant ridedown acceleration was -6.5 g's from 0.352 to 0.362 s, and the maximum 0.050-s average was -4.6 g's between 0.066 and 0.116 s. These data and other information pertinent to the test are presented in figure 15. Vehicle angular displacements and accelerations versus time traces are shown in appendix D, figures 29 through 35.

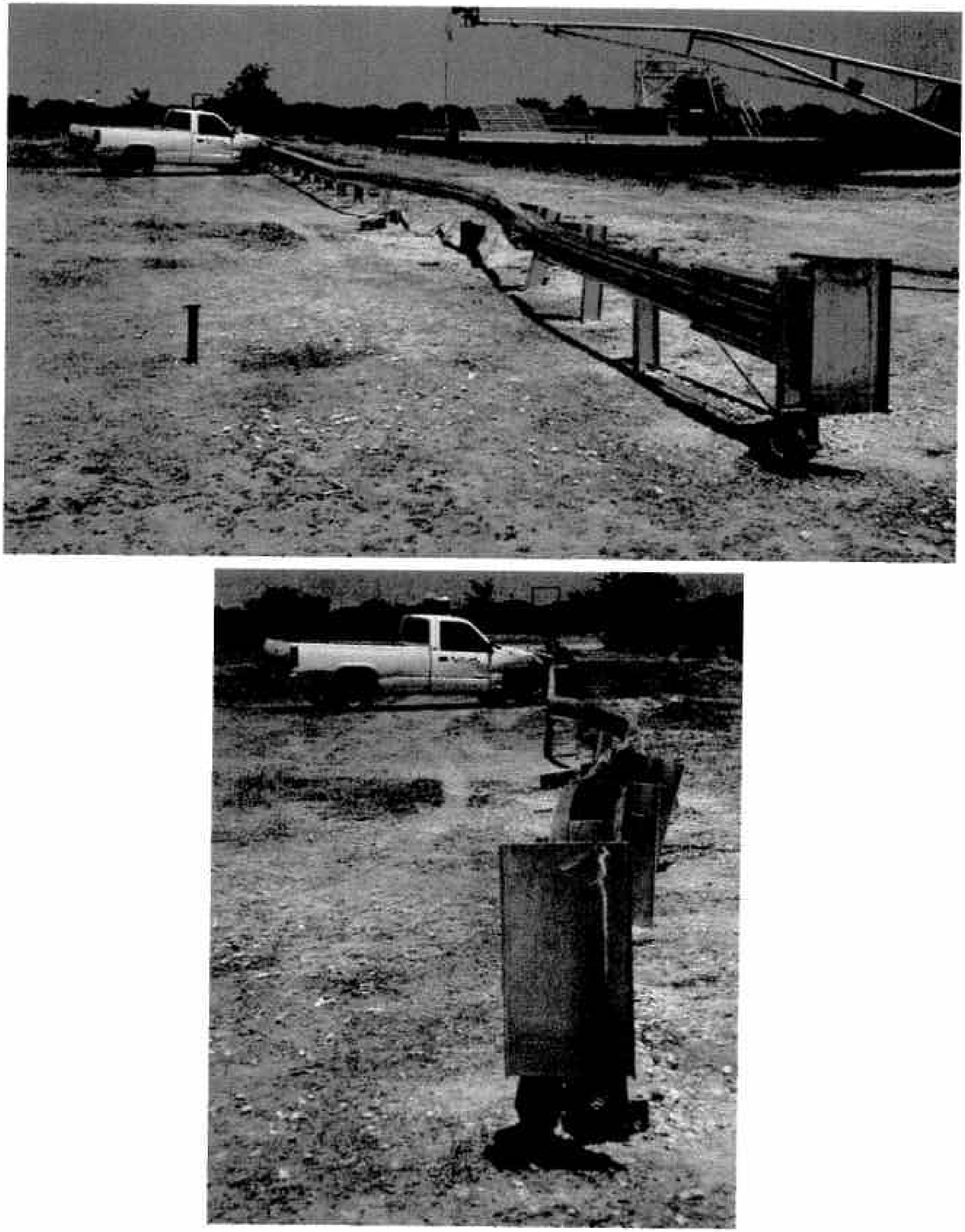


Figure 11. Vehicle trajectory path after test 220601-1.

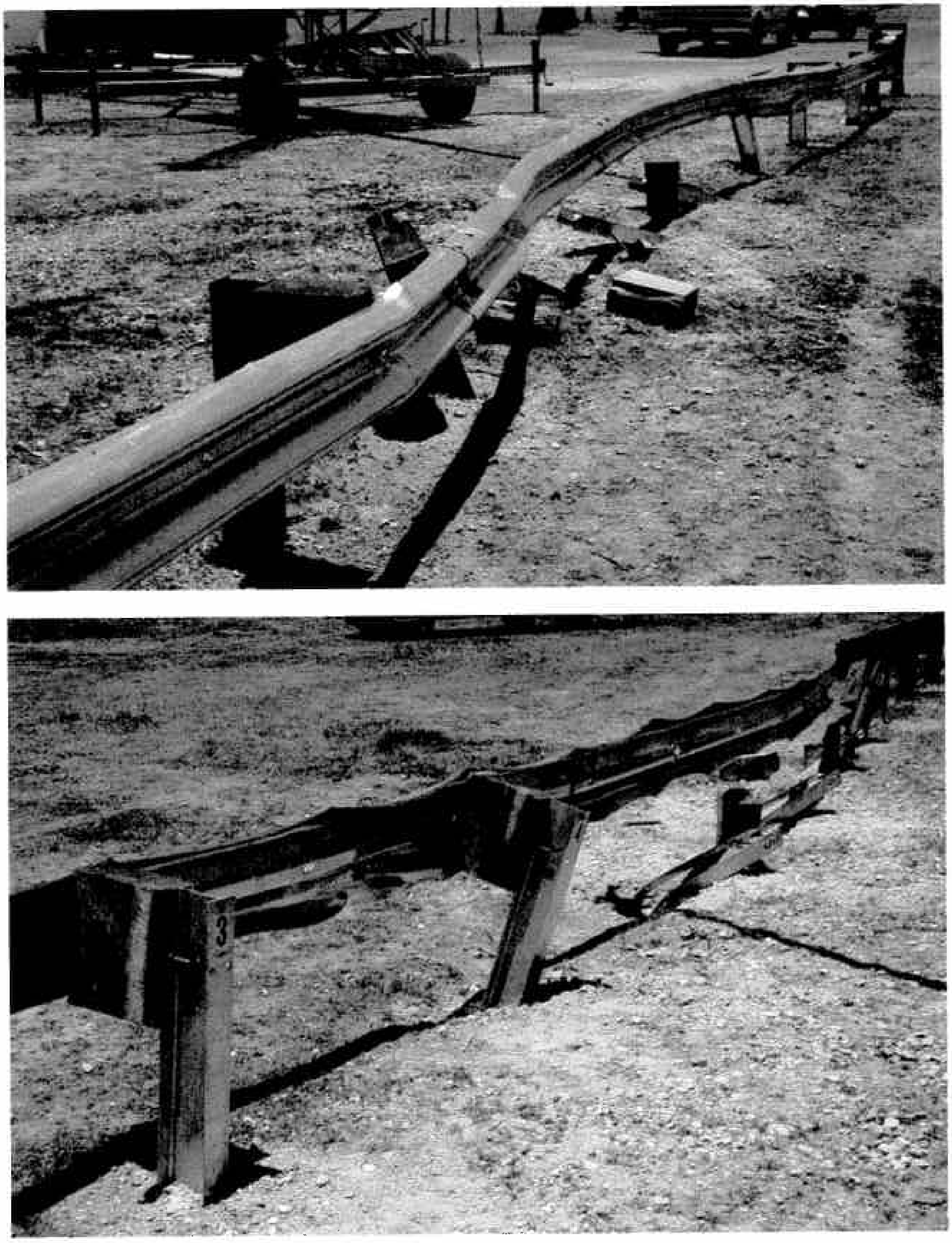


Figure 12. Installation after test 220601-1.

Figure 13. Vehicle after test 220601-1.

Before Test

After Test

Figure 14. Interior of vehicle for test 220601-1.

From: Brian Smith <Brian.Smith@trin.net>
Subject: **RE: 31" high ET**
Date: July 27, 2005 8:01:38 AM GMT-05:00
To: "Don H. Johnson" <dhj3800@mac.com>, "Buth, Gene" <G-Buth@tamu.edu>, rbligh@tamu.edu, d-alberson@tamu.edu, "Bullard, D. Lance" <l-bullard@tamu.edu>
Cc: "Menges, Wanda" <W-Menges@tamu.edu>

Don,

I cannot find the e-mail that I sent earlier, but with the X-350 having a pay length of 37'6" we need the ET-Plus with SYTP at 31" AND the ET-Plus with SYTP at 27-5/8" to be 37'6.

Since this testing was conducted with standard line posts at post locations #7 and #8, do you think you can convince Dick Powers to accept the use of standard posts at post locations #7 and #8 in the current 350 ET-Plus?

Thanks,
BS

-----Original Message-----
From: Don H. Johnson [mailto:dhj3800@mac.com]
Sent: Thursday, July 21, 2005 2:16 PM
To: Buth, Gene
Cc: Brian Smith; Menges, Wanda
Subject: Re: 31" high ET

GENE,

Please send me a cc also. I am preparing the letter to FHWA.

Thanks,

Don

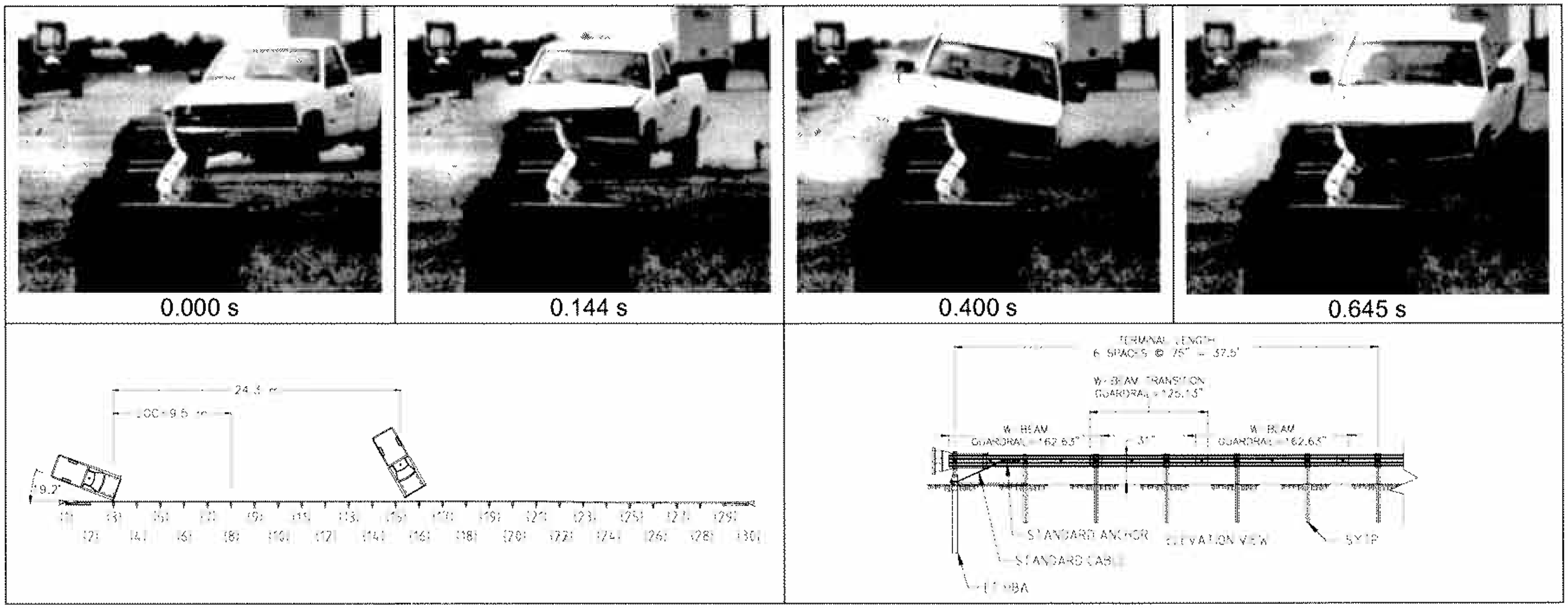
On Jul 21, 2005, at 12:55 PM, Buth, Gene wrote:

Brian,

We have finished preparing a report of testing on the 31" high ET and will be sending a pdf as well as paper copies to you.

I'm thinking that Trinity should be the one to submit the letter requesting FHWA's approval of the device.

8/10/05



General Information	
Test Agency	Texas Transportation Institute
Test No.	220601-1
Date	05-05-2005
Test Article	
Type	Terminal
Name	ET-31
Installation Length (m)	70.5
Material or Key Elements	ET-PLUS Head on HBA Posts with SYTP Posts and 787 mm high W-beam
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1992 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1912
Test Inertial	2031
Dummy	No dummy
Gross Static	2031

Impact Conditions	
Speed (km/h)	100.5
Angle (deg)	19.2
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
Longitudinal	8.7
Lateral	4.6
THIV (km/h)	31.1
Ridedown Accelerations (g's)	
Longitudinal	-11.5
Lateral	-6.5
PHD (g's)	11.9
ASI	0.83
Max. 0.050-s Average (g's)	
Longitudinal	-7.7
Lateral	-4.6
Vertical	-3.6

Test Article Deflections (m)	
Dynamic	0.94
Permanent	0.26
Working Width	0.68
Vehicle Damage	
Exterior	
VDS	01RFQ3
CDC	01RFEW3
Max. Exterior Vehicle Crush (mm)	530
Interior	
OCDI	FS0000000
Max. Occupant Compartment Deformation (mm)	0
Post-Impact Behavior	
(during 1.0 sec after impact)	
Max. Yaw Angle (deg)	-16
Max. Pitch Angle (deg)	21
Max. Roll Angle (deg)	-16

Figure 15. Summary of results for *NCHRP Report 350* test 3-35 on the ET-PLUS for 787 mm (31-inch) high W-beam guardrail.

Assessment of Test Results

An assessment of the test based on the following applicable *NCHRP Report 350* safety evaluation criteria.

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.*

Results: The ET-PLUS for 787 mm (31-inch) high W-beam guardrail contained and redirected the pickup truck. The pickup truck did not penetrate, underride, or override the installation. Maximum dynamic deflection of the rail was 939 mm. (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. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*

Results: One blockout split, and a portion separated from post 6 and came to rest next to post 7. The split blockout did not penetrate nor show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. No measurable occupant compartment deformation occurred. (PASS)

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

Results: The pickup truck remained upright during and after the collision event. (PASS)

Vehicle Trajectory

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

Result: The pickup truck did not intrude into adjacent traffic lanes. As the vehicle lost contact with the rail, it yawed clockwise and came to rest adjacent to the rail. (PASS)

L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.*

Result: Longitudinal occupant impact velocity was 8.7 m/s, and longitudinal ridedown acceleration was -11.5 g's. (PASS)

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.

Result: Exit angle at loss of contact was not attainable; however, the vehicle was yawing clockwise (toward the rail) as it lost contact. (PASS)

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features," were used for visual assessment of test results: (2)

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*

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 blockout split, but came to rest near the adjacent post, posing not threat.

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 or 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

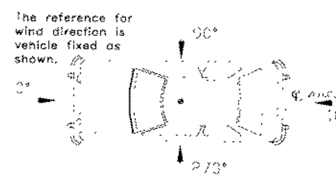
CRASH TEST 220601-2 (*NCHRP REPORT 350* TEST NO. 3-30)

Test Vehicle

A 1998 Chevrolet Metro, shown in figures 16 and 17, was used for the crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 897 kg. The height to the lower edge of the vehicle front bumper was 400 mm, and the height to the upper edge of the front bumper was 525 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 24. 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 27, 2005. No rainfall was recorded for the ten days prior to the test. Moisture content of the *NCHRP Report 350* soil in which the test article was installed was 6 percent. Weather conditions at the time of testing were: Wind speed: 0 km/h; wind direction: 0 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 28°C; relative humidity: 51 percent.



Impact Description

The small car, traveling at a speed of 101.8 km/h, impacted the end of the ET-PLUS for 787 mm (31-inch) high W-beam guardrail at an impact angle of 0.5 degrees with a quarter-point offset toward the traffic side of the rail. Upon contact with the head, the guardrail began to feed through the chute, and by 0.032 s, the front of the vehicle reached post 1. The vehicle began to yaw clockwise at 0.052 s. At 0.061 s, the end of the chute reached post 2, and at 0.118 s, the front of the vehicle reached post 2. The end of the chute reached post 3 at 0.152 s, and the front of the vehicle reached post 3 at 0.221 s. At 0.270 s, the end of the chute reached post 4, and at 0.387 s, the front of the vehicle reached post 4. The vehicle was at 90 degrees to the rail at 0.608 s, and was traveling sideways when it lost contact with the rail at 0.679 s. The small car came to rest 17.4 m downstream of impact and 8.5 m in front of the traffic face of the rail. Sequential photographs of the test period are shown in appendix C, figures 27 and 28.

Figure 16. Vehicle/installation geometrics for test 220601-2.

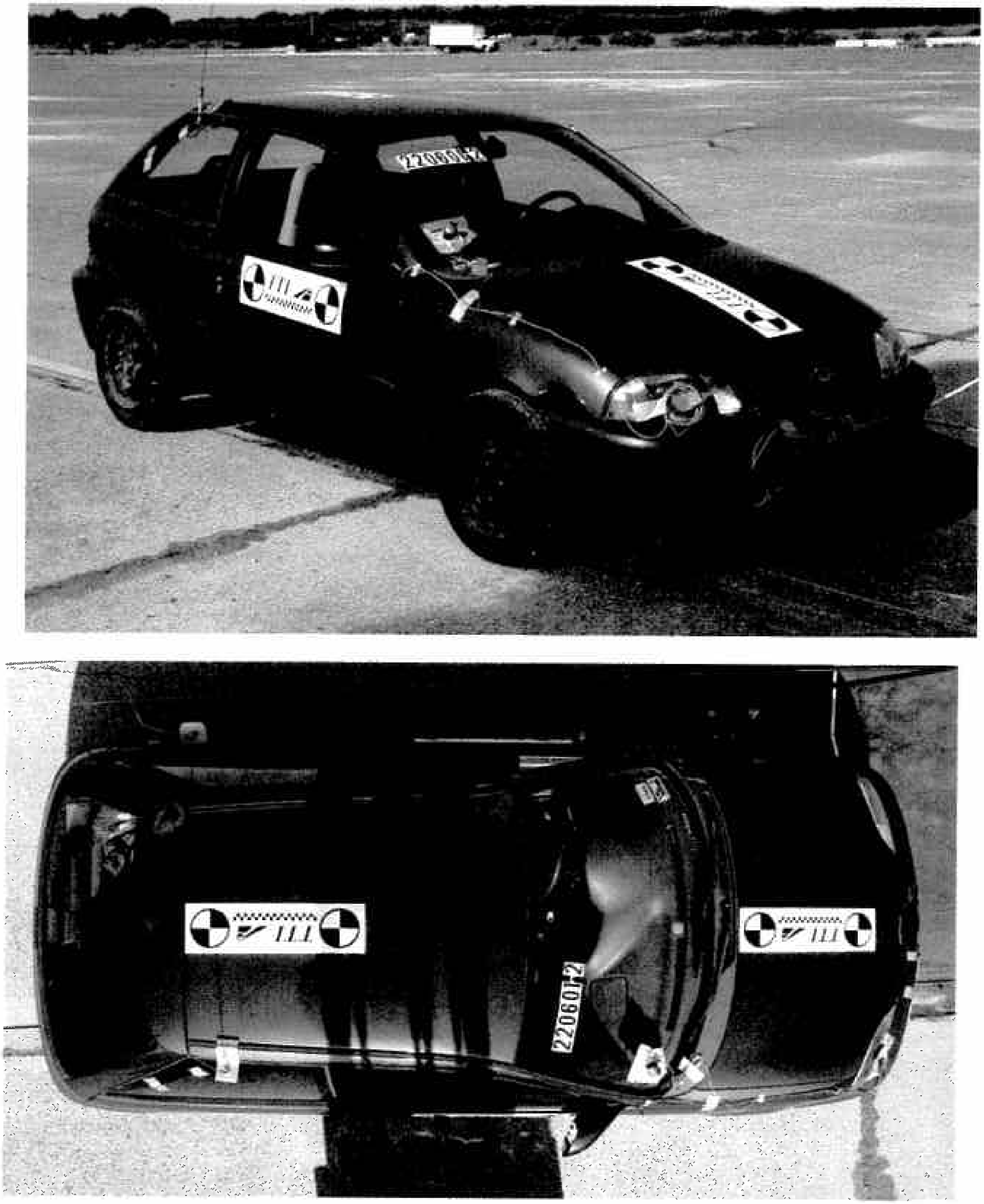


Figure 17. Vehicle before test 220601-2.

Damage to Test Article

Damage to the installation is shown in figures 18 and 19. Post 1 released with no movement at the base. The top bolt remained attached to the ET head. The anchor assembly came to rest 0.8 m in front of the traffic face of the rail between post 2 and 3. Post 2 was leaning downstream at 85 degrees, and post 3 at 80 degrees. Post 4 was rotated clockwise 45 degrees, the blockout was fractured and the slot in the rail torn. No movement was noted in post 5 and beyond. A total of 5.4 m fed through the ET head.

Vehicle Damage

The vehicle sustained damage to the front, as shown in figure 20. The only structural damage was a deformed right strut tower. Other damage included deformation of the front bumper, hood, radiator, fan, radiator support, and right and left front quarter panels. The right rear tire was deflated. Maximum exterior crush to the vehicle was 420 mm in the frontal plane at the front right corner just above the bumper. No occupant compartment deformation occurred. Photographs of the interior of the vehicle are shown in figure 21. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 5 and 6.

Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 8.3 m/s at 0.126 s, the highest 0.010-s occupant ridedown acceleration was -14.0 g's from 0.229 to 0.239 s, and the maximum 0.050-s average acceleration was -10.7 g's between 0.001 and 0.051 s. In the lateral direction, the occupant impact velocity was 0.3 m/s at 0.126 s, the highest 0.010-s occupant ridedown acceleration was 4.3 g's from 0.332 to 0.342 s, and the maximum 0.050-s average was 3.3 g's between 0.298 and 0.348 s. These data and other pertinent information from the test are summarized in figure 22. Vehicle angular displacements and accelerations versus time traces are presented in appendix D, figures 36 through 42.

Assessment of Test Results

An assessment of the test based on the following applicable *NCHRP Report 350* safety evaluation criteria.

<u>**Structural Adequacy**</u>

C. *Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.*

<u>Results</u>: The small car was brought to a controlled stop on the traffic side of the installation. (PASS)

Figure 18. Vehicle trajectory path after test 220601-2.

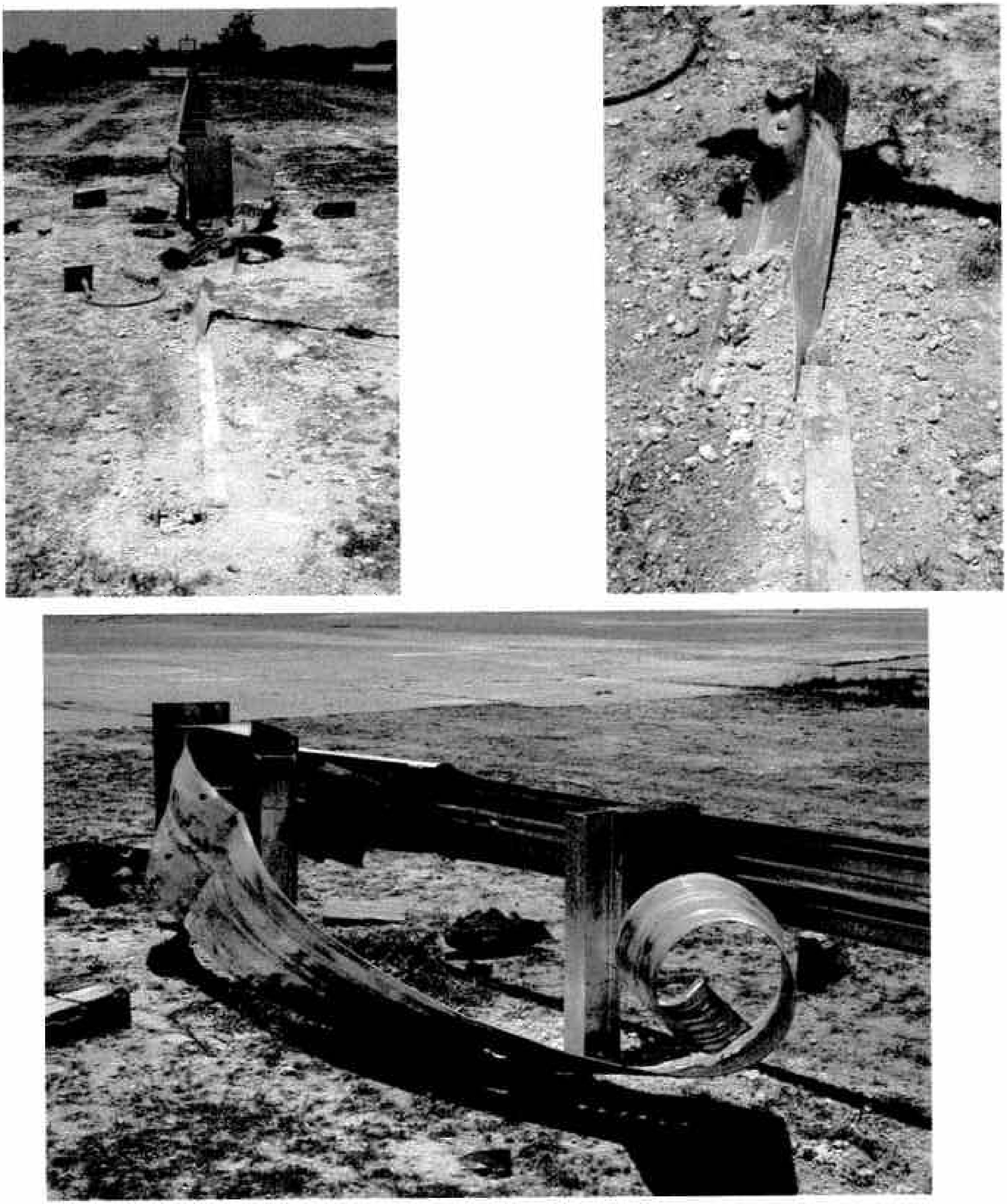


Figure 19. Installation after test 220601-2.

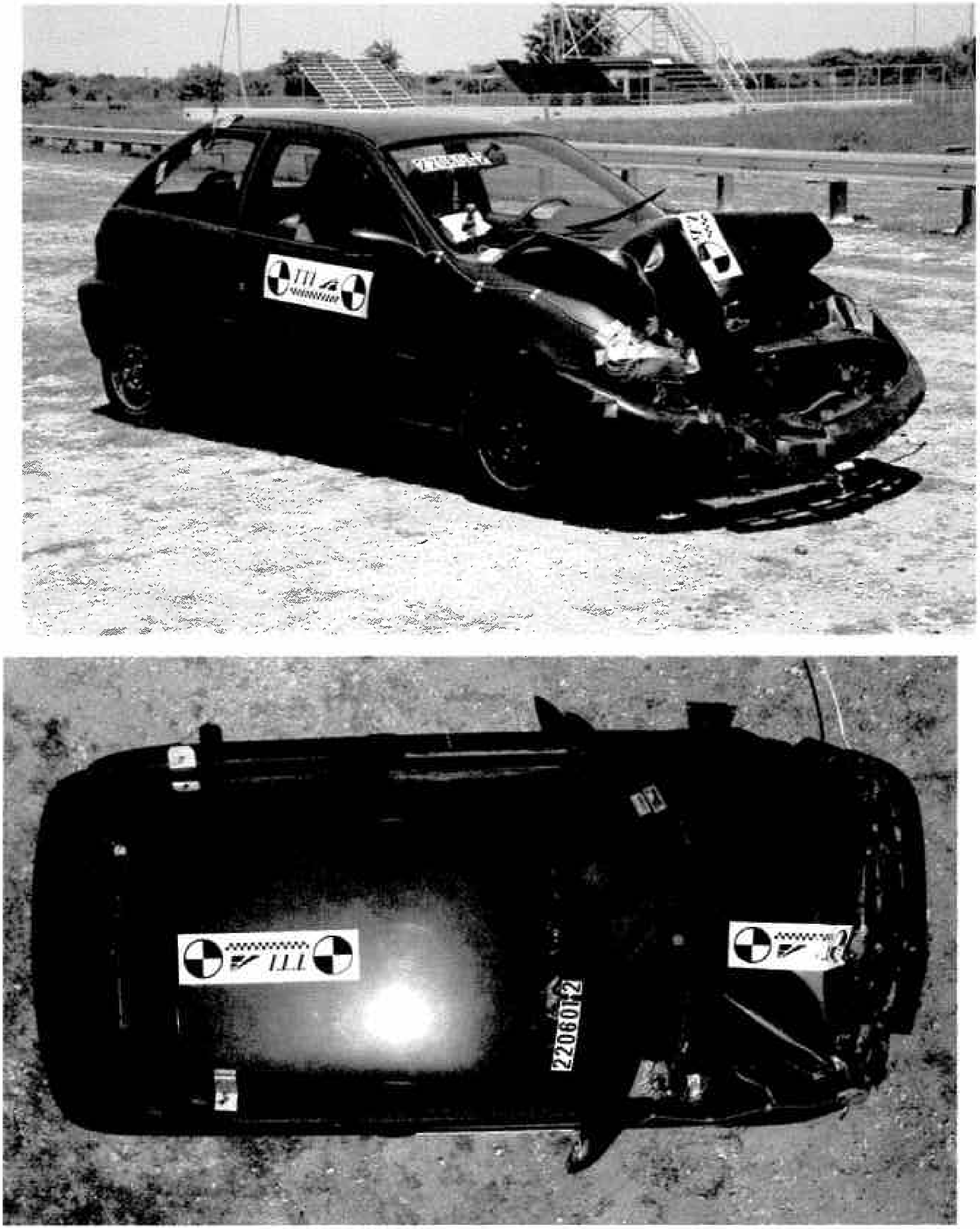
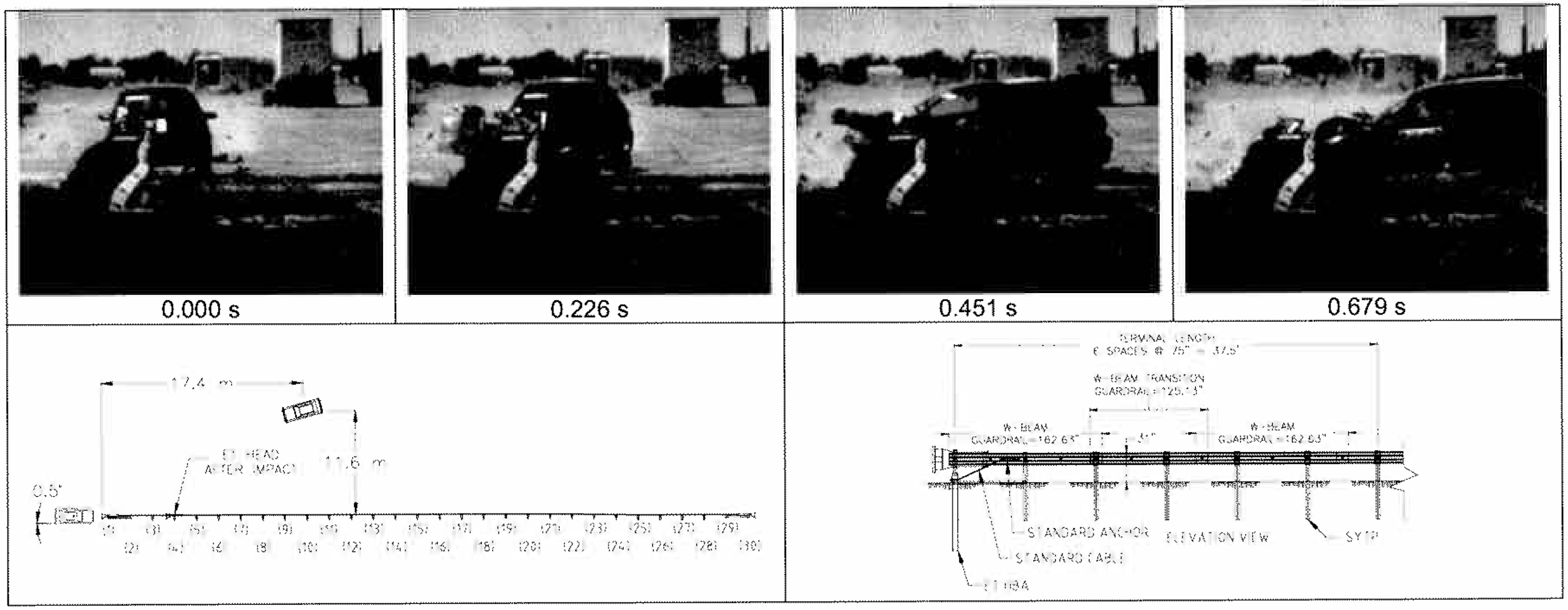


Figure 20. Vehicle after test 220601-2.

Figure 21. Interior of vehicle for test 220601-2.



General Information	
Test Agency	Texas Transportation Institute
Test No.	220601-2
Date	05-27-2005
Test Article	
Type	Terminal
Name	ET-31
Installation Length (m)	70.5
Material or Key Elements	ET-PLUS Head on HBA Posts with SYTP Posts and 787 mm high W-beam
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1998 Geo Metro
Mass (kg)	
Curb	810
Test Inertial	820
Dummy	77
Gross Static	897

Impact Conditions	
Speed (km/h)	101.8
Angle (deg)	0.5
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
Longitudinal	8.3
Lateral	0.3
THIV (km/h)	30.1
Ridedown Accelerations (g's)	
Longitudinal	-14.0
Lateral	4.3
PHD (g's)	14.3
ASI	0.92
Max. 0.050-s Average (g's)	
Longitudinal	-10.7
Lateral	3.3
Vertical	2.4

Test Article Deflections (m)	
Dynamic	5.44
Permanent	5.40
Working Width	0.36
Vehicle Damage	
Exterior	
VDS	12FD3
CDC	12FDEW3
Max. Exterior Vehicle Crush (mm)	420
Interior	
OCDI	FS0000000
Max. Occupant Compartment Deformation (mm)	0
Post-Impact Behavior	
(during 1.0 sec after impact)	
Max. Yaw Angle (deg)	140
Max. Pitch Angle (deg)	7
Max. Roll Angle (deg)	-15

Figure 22. Summary of results for *NCHRP Report 350* test 3-30 on the ET-PLUS for 787 mm (31-inch) high W-beam guardrail.

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.*

Results: Post 1 and the anchor assembly separated from the installation; however, neither of these penetrated nor showed potential to penetrate the occupant compartment, nor to present any hazard to others in the area. No occupant compartment deformation occurred. (PASS)

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

Results: The small car remained upright during and after the collision event. (PASS)

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

Longitudinal and Lateral Occupant Impact Velocity – m/s

Preferred	*Maximum*
9	*12*

Results: Longitudinal occupant impact velocity was 8.3 m/s, and lateral occupant impact velocity was 0.3 m/s. (PASS)

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

Longitudinal and Lateral Occupant Ridedown Accelerations – g's

Preferred	*Maximum*
15	*20*

Results: Longitudinal ridedown acceleration was -14.0 g's, and lateral ridedown acceleration was 4.3 g's. (PASS)

Vehicle Trajectory

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

Result: The small car intruded into traffic lanes 8.5 m. (FAIL)

N. *Vehicle trajectory behind the test article is acceptable.*

Result: The vehicle came to rest on the traffic side of the installation. (N/A)

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features," were used for visual assessment of test results: [2]

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*

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*

Post 1 and the anchor assembly separated but did not present any threat.

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 or 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*

SUMMARY AND CONCLUSIONS

SUMMARY OF RESULTS

NCHRP Report 350 Test 3-35

The ET-PLUS for 787 mm (31-inch) high W-beam guardrail contained and redirected the pickup truck with a maximum dynamic rail deflection of 939 mm. One blockout split, and a portion separated from post 6 and came to rest next to post 7. However, the split blockout did not penetrate nor show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. No measurable occupant compartment deformation occurred. The pickup truck remained upright during and after the collision event. The pickup truck did not intrude into adjacent traffic lanes. As the vehicle lost contact with the rail, it yawed clockwise and came to rest adjacent to the rail. Occupant risk factors were within the required limits. Exit angle at loss of contact was not attainable; however, the vehicle was yawing clockwise (toward the rail) as it lost contact.

NCHRP Report 350 Test 3-30

The small car was brought to a controlled stop on the traffic side of the installation. Post 1 and the anchor assembly separated from the installation; however, neither of these penetrated nor showed potential to penetrate the occupant compartment, nor to present any hazard to others in the area. No occupant compartment deformation occurred. The small car remained upright during and after the collision event. Occupant risk factors were within the specified limits. The small car intruded 8.5 m into traffic lanes as it came to rest on the traffic side of the rail.

CONCLUSIONS

As shown in tables 1 and 2, the ET-PLUS for 787 mm (31-inch) high W-beam guardrail met the required criteria for *NCHRP Report 350* tests 3-35 and 3-30, respectively.

Table 1. Performance evaluation summary for *NCHRP Report 350* test 3-35 on the ET-PLUS for 787 mm (31-inch) high W-beam guardrail.

Test Agency: Texas Transportation Institute   Test No.: 220501-1   Test Date: 05-05-2005

NCHRP Report 350 **Test 3-35 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 ET-PLUS for 787 mm (31-inch) high W-beam guardrail contained and redirected the pickup truck. The pickup truck did not penetrate, underride, or override the installation. Maximum dynamic rail deflection was 939 mm.	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 blockout split, and a portion separated from post 6 and came to rest next to post 7. The split blockout did not penetrate nor show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. No measurable occupant compartment deformation occurred.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The pickup truck remained upright during and after the collision event.	Pass
Vehicle Trajectory *K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*	The pickup truck did not intrude into adjacent traffic lanes. As the vehicle lost contact with the rail, it yawed clockwise and came to rest adjacent to the rail.	Pass *
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal occupant impact velocity was 8.7 m/s, and longitudinal ridedown acceleration was -11.5 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 was not attainable; however, the vehicle was yawing clockwise (toward the rail) as it lost contact.	Pass *

*Criterion K and M are preferable, not required.

Table 2. Performance evaluation summary for *NCHRP Report 350* test 3-30 on the ET-PLUS for 787 mm (31-inch) high W-beam guardrail.

Test Agency: Texas Transportation Institute | Test No.: 220601-2 | Test Date: 05-27-2005

***NCHRP Report 350* Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy		
C. *Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.*	The small car was brought to a controlled stop on the traffic side of the installation.	Pass
Occupant Risk		
D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*	Post 1 and the anchor assembly separated from the installation; however, neither of these penetrated nor showed potential to penetrate the occupant compartment, nor to present any hazard to others in the area. No occupant compartment deformation occurred.	Pass
F. *The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.*	The small car remained upright during and after the collision event.	Pass
H. *Occupant impact velocities should satisfy the following:* *Occupant Velocity Limits (m/s)* *Component* / *Preferred* / *Maximum* *Longitudinal and lateral* / *9* / *12*	Longitudinal occupant impact velocity was 8.3 m/s, and lateral occupant impact velocity was 0.3 m/s.	Pass
I. *Occupant ridedown accelerations should satisfy the following:* *Occupant Ridedown Acceleration Limits (g's)* *Component* / *Preferred* / *Maximum* *Longitudinal and lateral* / *15* / *20*	Longitudinal ridedown acceleration was -14.0 g's, and lateral ridedown acceleration was 4.3 g's.	Pass
Vehicle Trajectory		
K. *After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*	The small car intruded 8.5 m into traffic lanes.	Fail*
N. *Vehicle trajectory behind the test article is acceptable.*	The small car came to rest on the traffic side of the installation.	N/A

*Criterion K is preferable, not required.

REFERENCES

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

2. Federal Highway Administration Memorandum, from the Director, Office of Engineering, entitled: "ACTION: Identifying Acceptable Highway Safety Features," dated July 25, 1997.

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

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 backup 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 (resistive calibration) 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 (IRIG), FM/FM telemetry link for recording and for display. 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. Wooden dowels actuate pressure-sensitive switches on the bumper of the impacting vehicle 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 TEAC® instrumentation data recorder. After the test, the data are played back from the TEAC® recorder and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer into engineering units using the R-cal and pre-zero values at 10,000 samples per second, per channel. WinDigit also provides Society of Automotive Engineers (SAE) J211 class 180 phaseless digital filtering and vehicle impact velocity.

All accelerometers are calibrated annually according to the (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 are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are made any time data are suspect.

The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-milliseconds (ms) average ridedown acceleration. WinDigit calculates 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 0.0001-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 systems being initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

An Alderson Research Laboratories Hybrid II, 50^{th} 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. Use of a dummy in the 2000P vehicle is optional according to *NCHRP Report 350*, and there was no dummy used in the tests with the 2000P vehicle.

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 flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A BetaCam, a VHS-format video camera and recorder, and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

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

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

Date: 05-05-2005 Test No.: 220601-1 VIN No.: 1GCFC24K6N2211456

Year: 1992 Make: Chevrolet Model: C2500

Tire Inflation Pressure: 60 psi Odometer: 149042 Tire Size: 225 75 R16

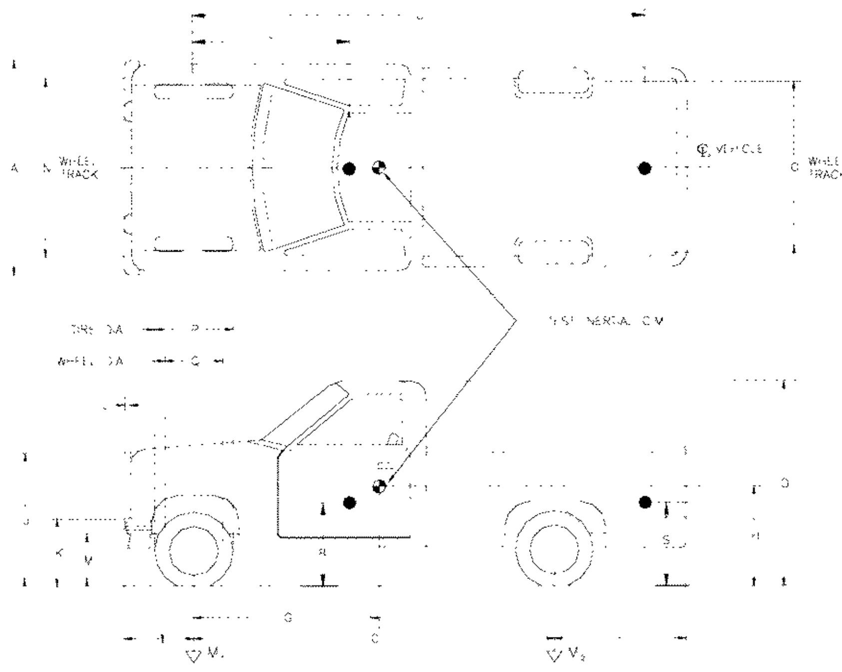
Describe any damage to the vehicle prior to test: ____________

● Denotes accelerometer location.

NOTES:
6 lug

Engine Type: V-8
Engine CID: 5.7 liter
Transmission Type:
___ Auto
x Manual
Optional Equipment:

Dummy Data:
Type: No dummy
Mass:
Seat Position:



Geometry (mm)

A	1880	E	1310	J	1038	N	1590	R	700
B	810	F	5470	K	595	O	1610	S	860
C	3350	G	1510.88	L	70	P	725	T	1460
D	1770	H		M	378	Q	440	U	3360

Mass (kg)	Curb	Test Inertial	Gross Static
M_1	1107	1115	
M_2	805	916	
M_{Total}	1912	2031	

Mass Distribution (kg): LF: 571 RF: 544 LR: 458 RR: 458

Figure 23. Vehicle properties for test 220601-1.

Table 3. Exterior crush measurements for test 220601-1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

Note: Measure C_1 to C_6 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 at bumper ht	750	300	750	50	80	135	150	200	300	-375
2	Rt Side at bmpr ht	1010	530	1400	530	240	N/A	N/A	98	0	+1700

[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).

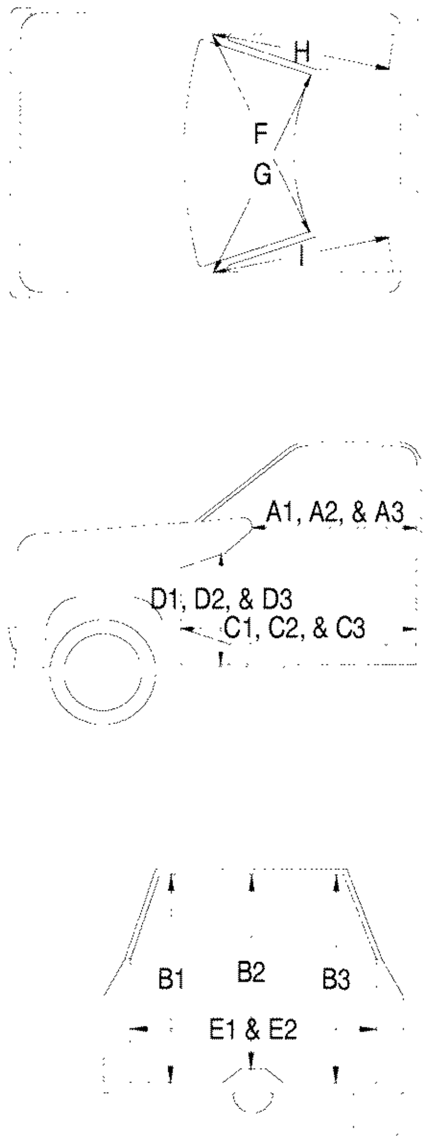
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 4. Occupant compartment measurements for test 220601-1.

Truck

Occupant Compartment Deformation



	BEFORE (mm)	AFTER (mm)
A1	898	898
A2	946	946
A3	1038	1038
B1	1097	1097
B2	981	981
B3	1079	1079
C1	1365	1365
C2	N/A	N/A
C3	1368	1368
D1	372	372
D2	167	167
D3	311	311
E1	1608	1612
E2	1610	1614
F	1475	1475
G	1475	1475
H	1111	1111
I	1121	1121
J*	1517	1517

*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

Date:	05-27-2005	Test No.:	220601-2	VIN No.:	2C1MR226rWt726669
Year:	1998	Make:	Chevrolet	Model:	Metro
Tire Inflation Pressure:	32 psi	Odometer:	144314	Tire Size:	P155 80 R13

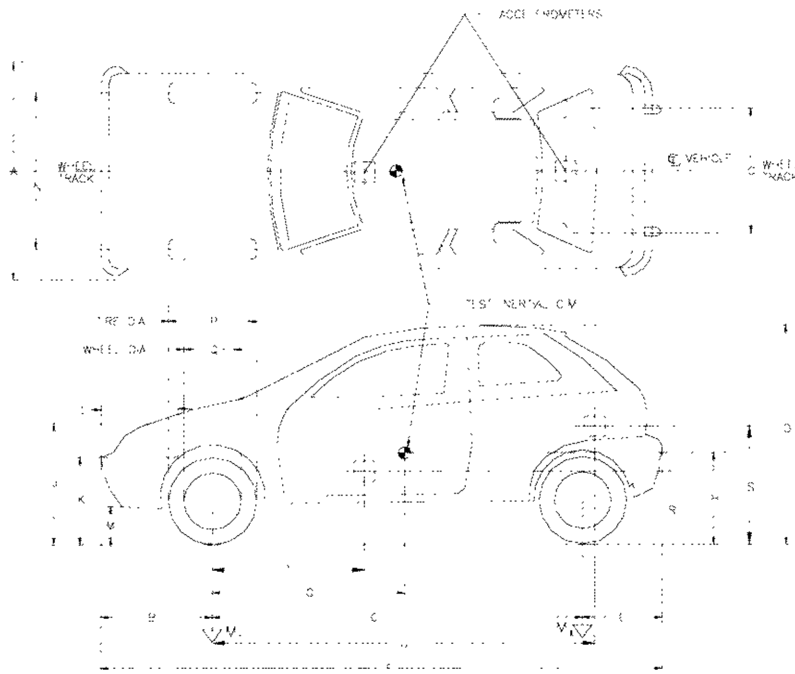
Describe any damage to the vehicle prior to test: ______

Denotes accelerometer location.

NOTES: ______

Engine Type: 3 cylinder
Engine CID: 1 liter
Transmission Type:
___ Auto
x Manual
Optional Equipment:

Dummy Data:
Type: 50th percentile male
Mass: 77 kg
Seat Position: Driver Side



Geometry (mm)

A	1450	E	560	J	610	N	1380	R	400
B	790	F	3715	K	525	O	1365	S	550
C	2365	G	931.579	L	160	P	570	T	960
D	1400	H		M	400	Q	365	U	2400

Mass (kg)	Curb	Test Inertial	Gross Static
M_1	501	497	537
M_2	309	323	360
M_{Total}	810	820	897

Mass Distribution (kg): LF: 253 RF: 244 LR: 163 RR: 160

Figure 24. Vehicle properties for test 220601-2.

Table 5. Exterior crush measurements for test 220601-2.

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

Note: Measure C_1 to C_6 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	Front above bumper	800	420	1400	230	260	315	410	410	420	0

[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).

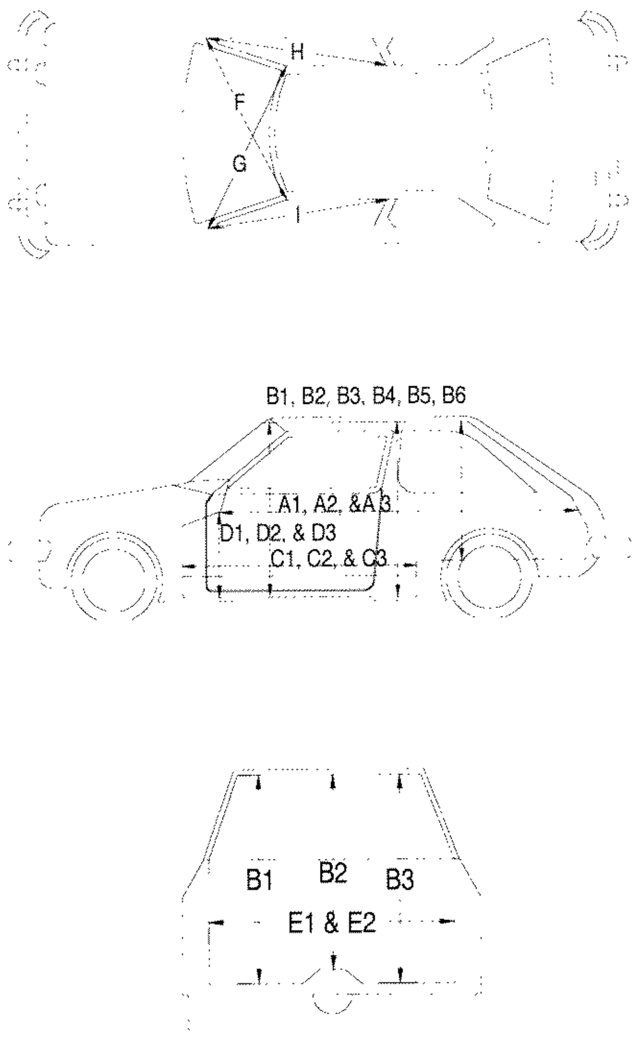
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 6. Occupant compartment measurements for test 220601-2.

Small Car

Occupant Compartment Deformation



	BEFORE (mm)	AFTER (mm)
A1	1418	1418
A2	2003	2003
A3	1407	1407
B1	955	955
B2	903	903
B3	978	978
B4	890	890
B5	898	898
B6	890	890
C1	561	561
C2	711	711
C3	561	561
D1	230	230
D2	133	133
D3	242	242
E1	1212	1212
E2	1177	1177
F	1210	1210
G	1210	1210
H	1170	1170
I	1170	1170
J*	1190	1190

*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

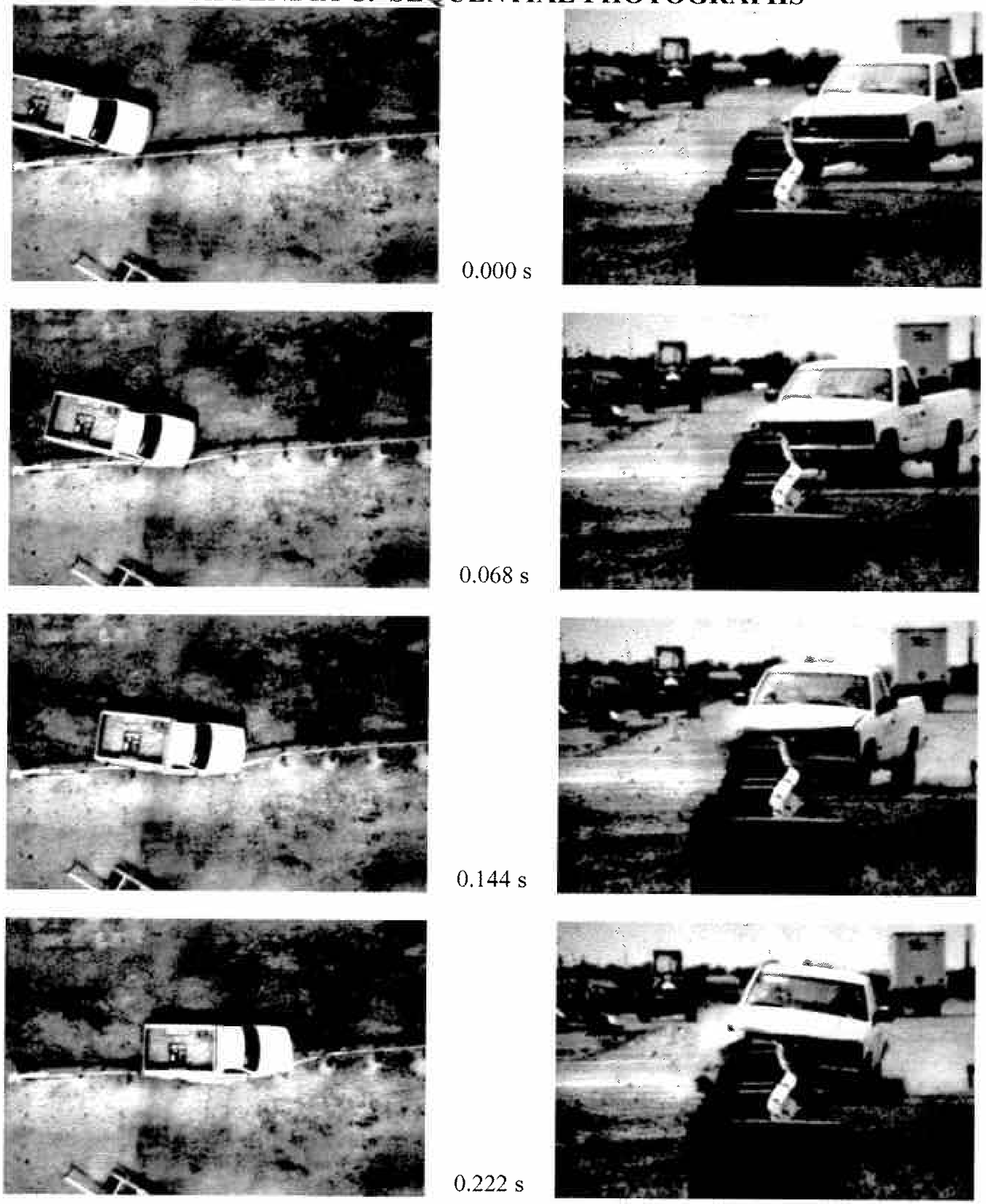


Figure 25. Sequential photographs for test 220601-1
(overhead and frontal views).

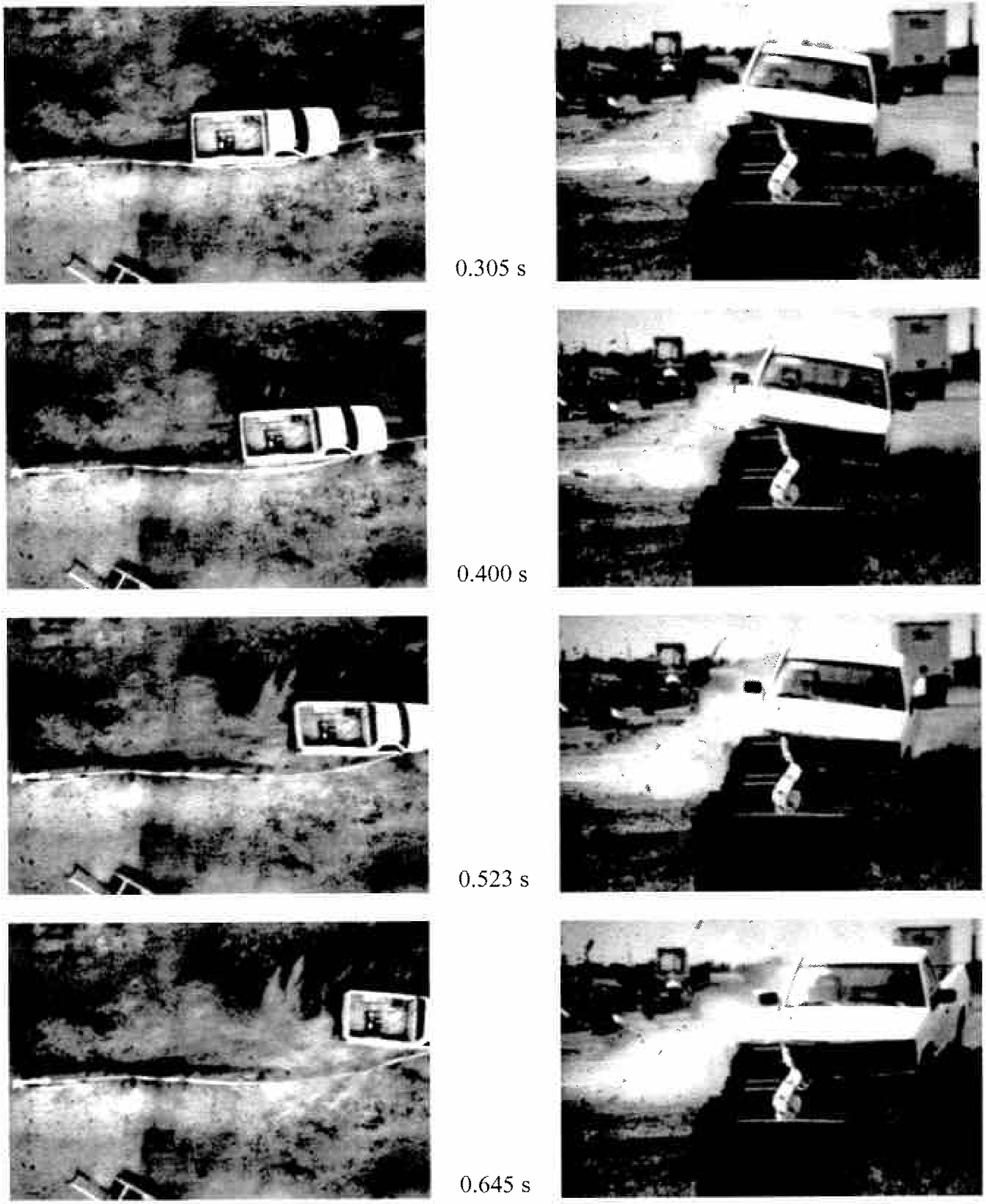


Figure 25. Sequential photographs for test 220601-1
(overhead and frontal views) (continued).

0.000 s

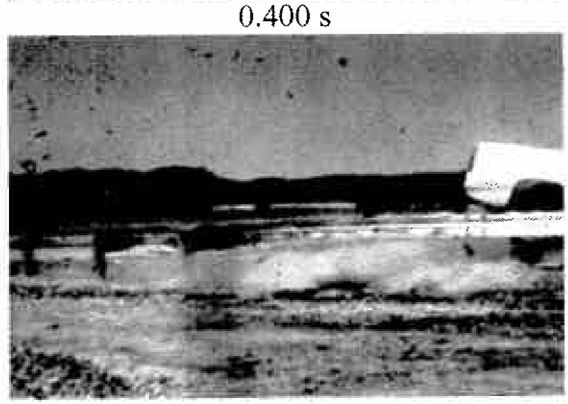
0.068 s

0.144 s

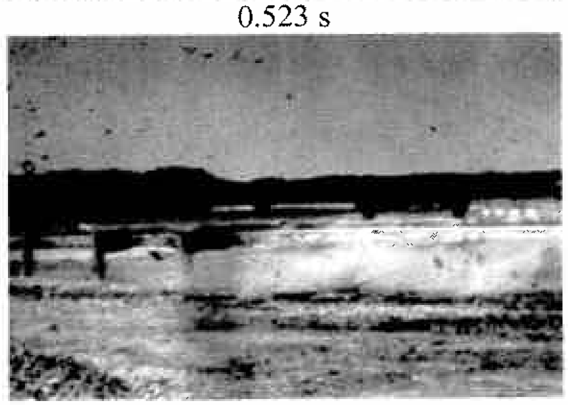
0.222 s

0.305 s

0.400 s



0.523 s



0.645 s

Figure 26. Sequential photographs for test 220601-1
(rear view).

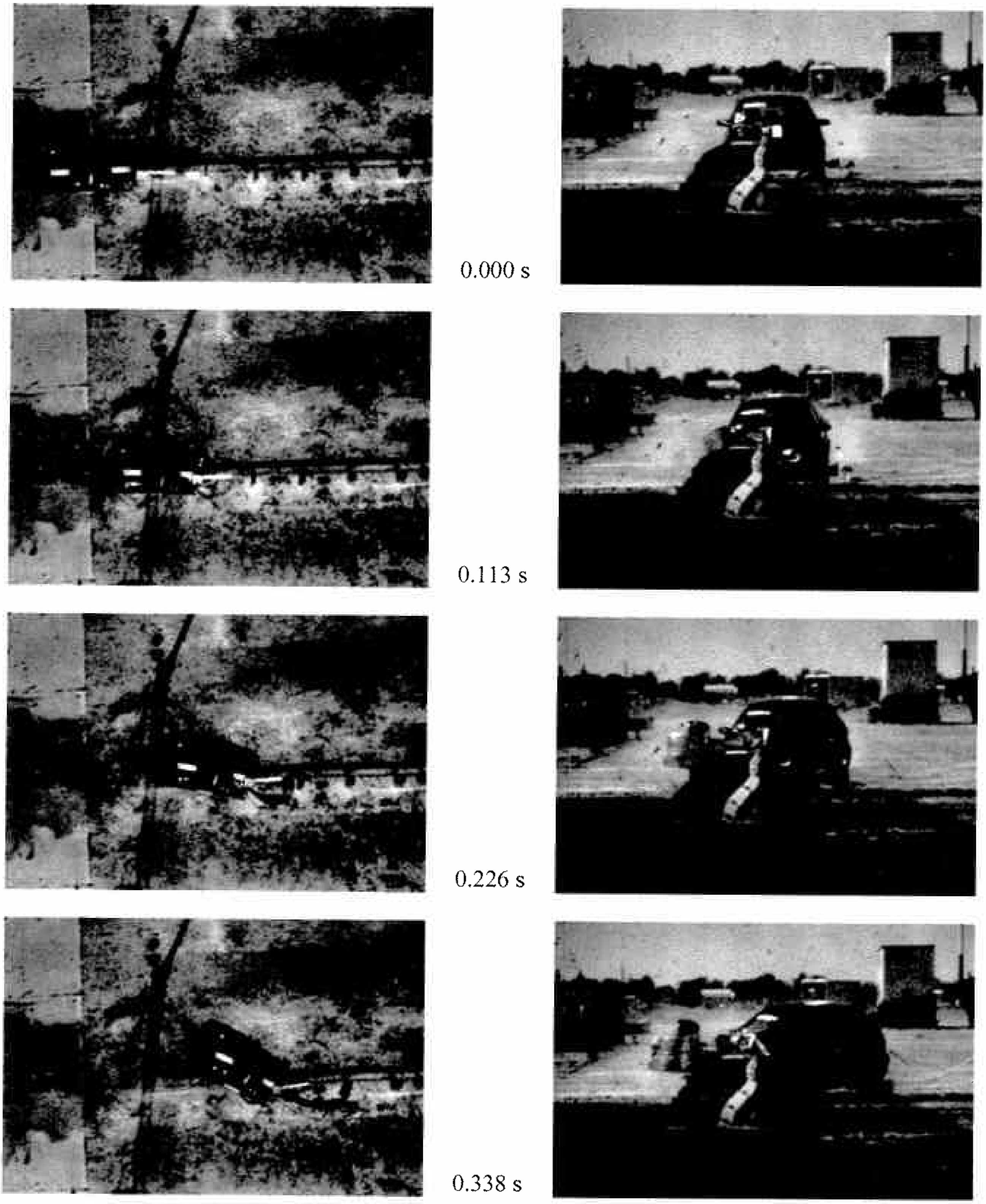
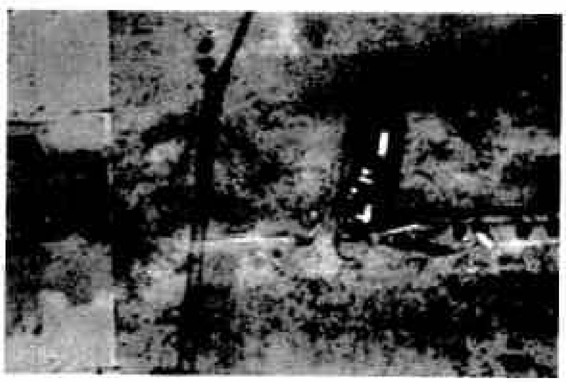


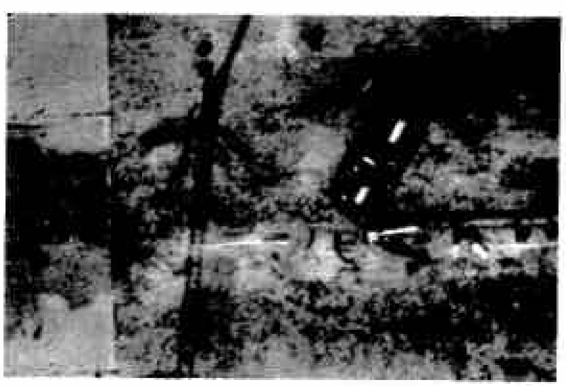
Figure 27. Sequential photographs for test 220601-2
(overhead and frontal views).


0.451 s


0.564 s

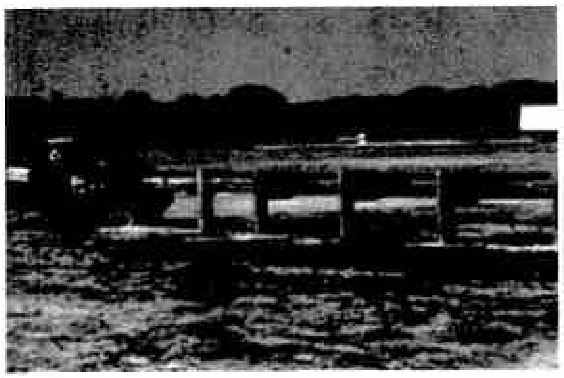



0.679 s

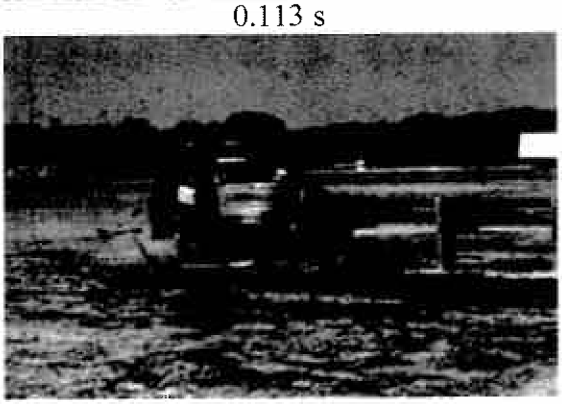


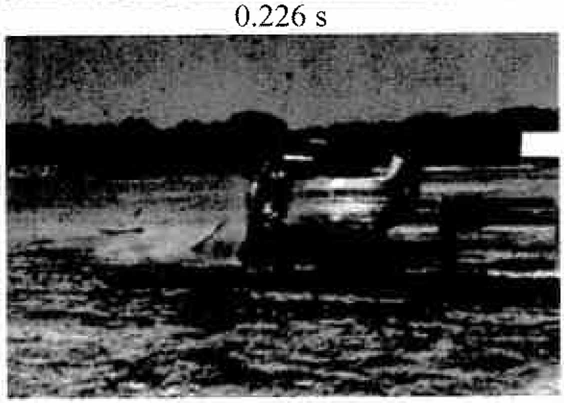

0.792 s

Figure 27. Sequential photographs for test 220601-2 (overhead and frontal views) (continued).


0.000 s

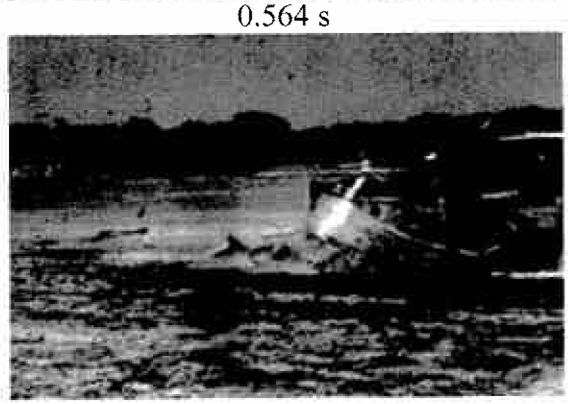

0.113 s


0.226 s


0.338 s


0.451 s


0.564 s


0.679 s

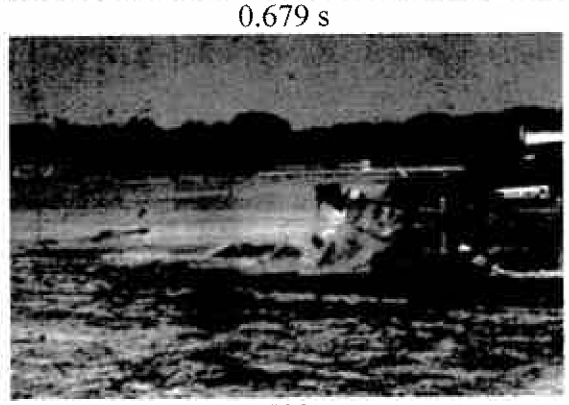

0.792 s

Figure 28. Sequential photographs for test 220601-2
(rear view).

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

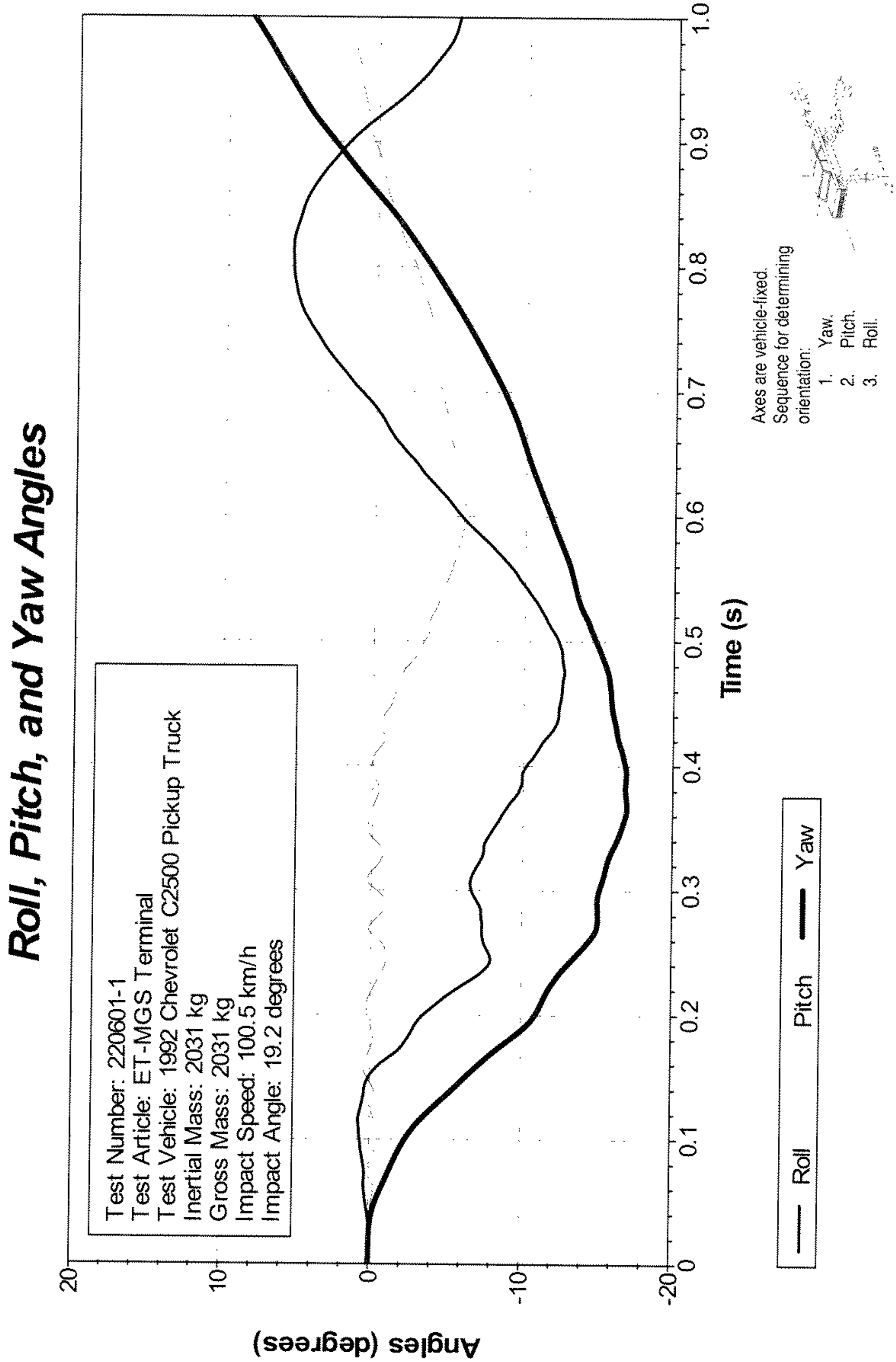


Figure 29. Vehicle angular displacements for test 220601-1.

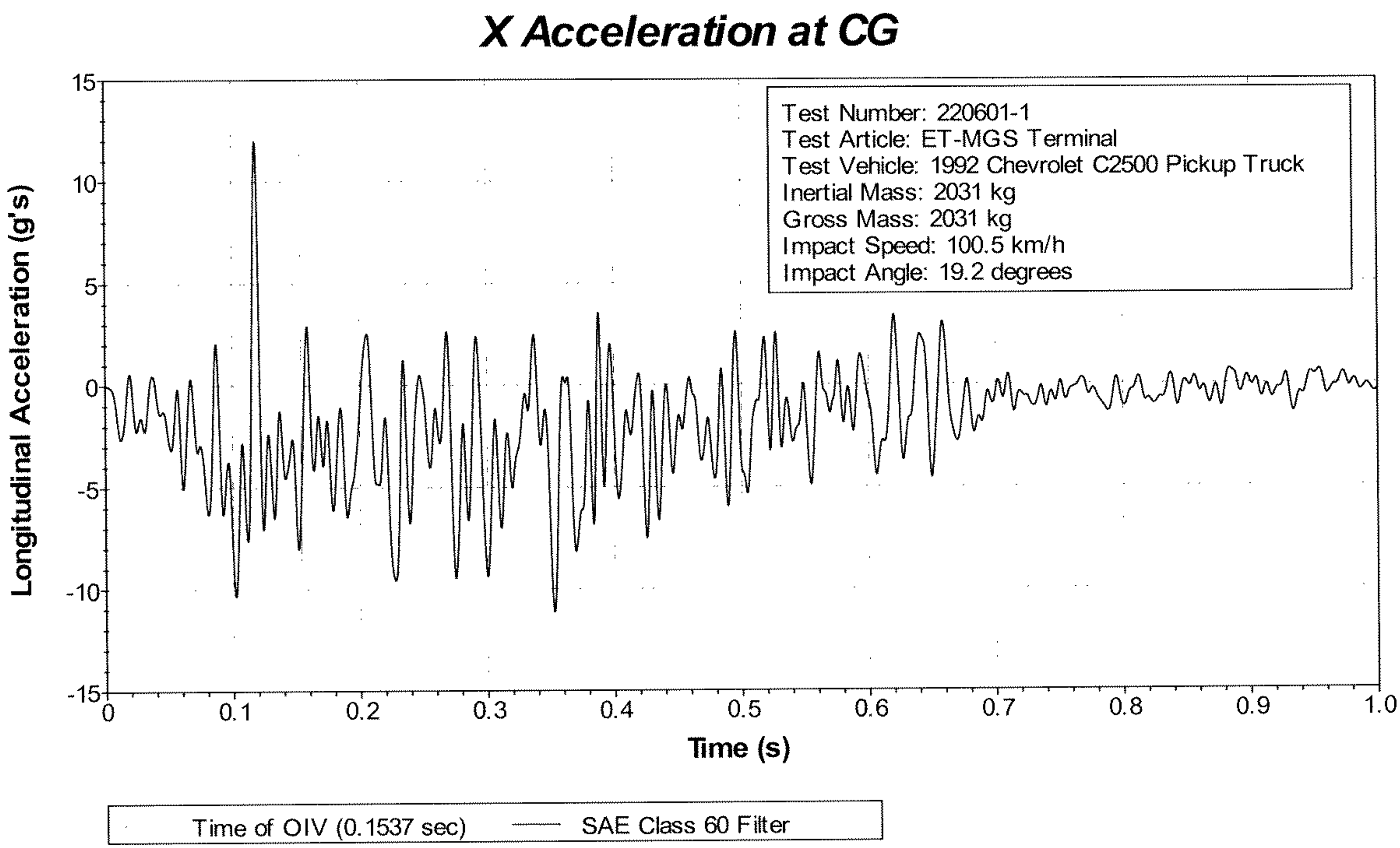


Figure 30. Vehicle longitudinal accelerometer trace for test 220601.1 (accelerometer located at center of gravity).

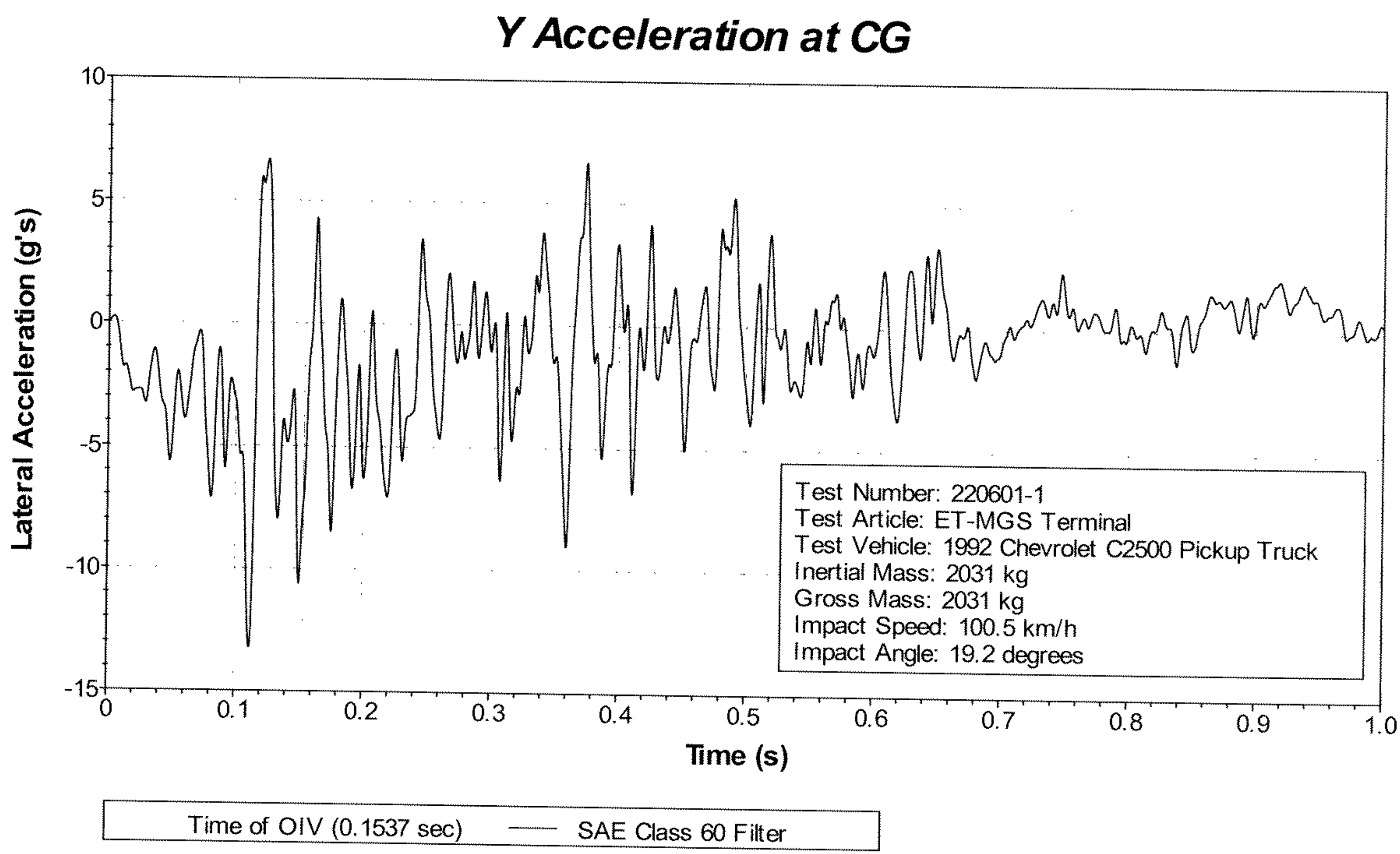


Figure 31. Vehicle lateral accelerometer trace for test 220601-1
(accelerometer located at center of gravity).

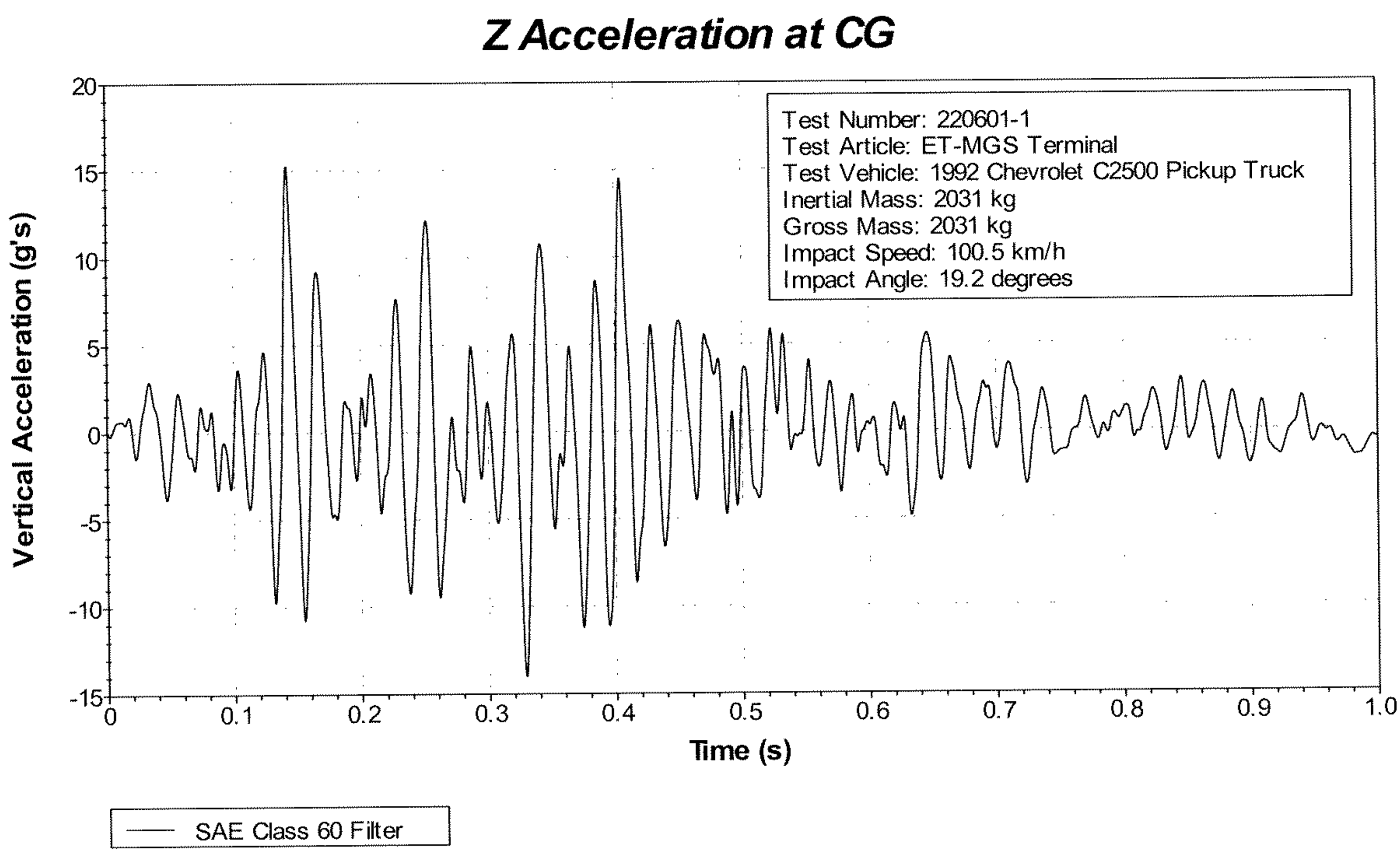


Figure 32. Vehicle vertical accelerometer trace for test 220601-1 (accelerometer located at center of gravity).

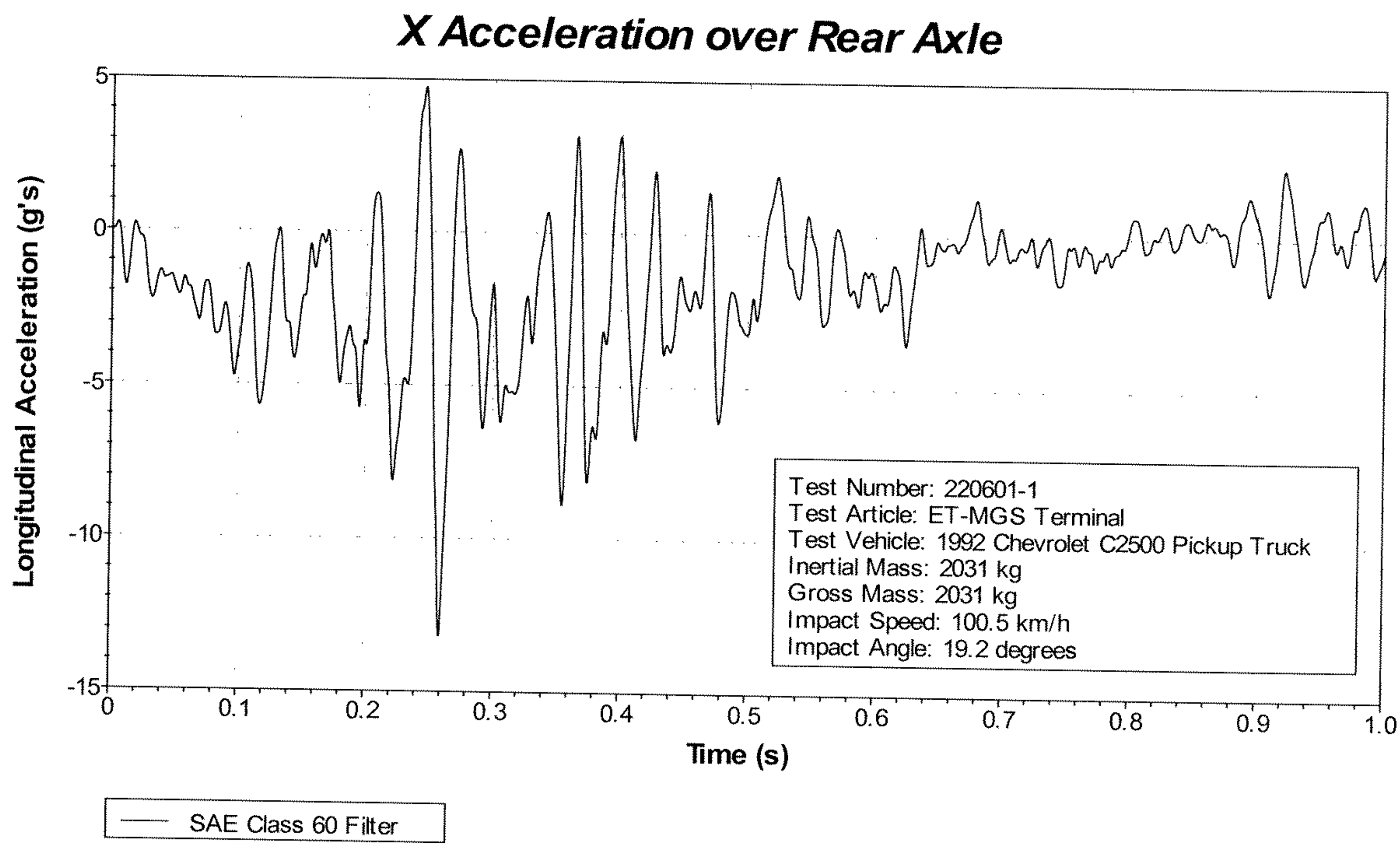


Figure 33. Vehicle longitudinal accelerometer trace for test 220601-1 (accelerometer located over rear axle).

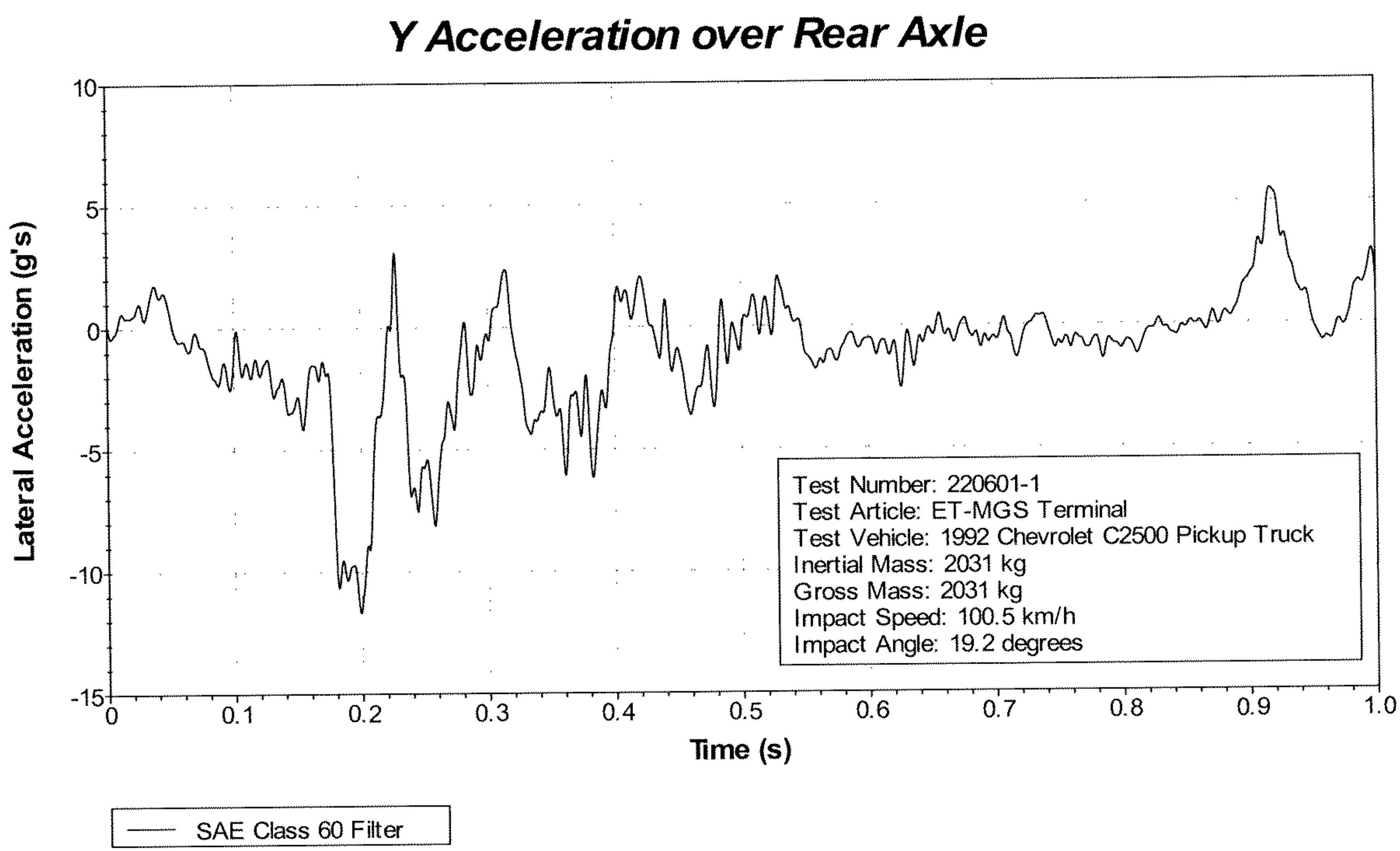


Figure 34. Vehicle lateral accelerometer trace for test 220601-1
(accelerometer located over rear axle).

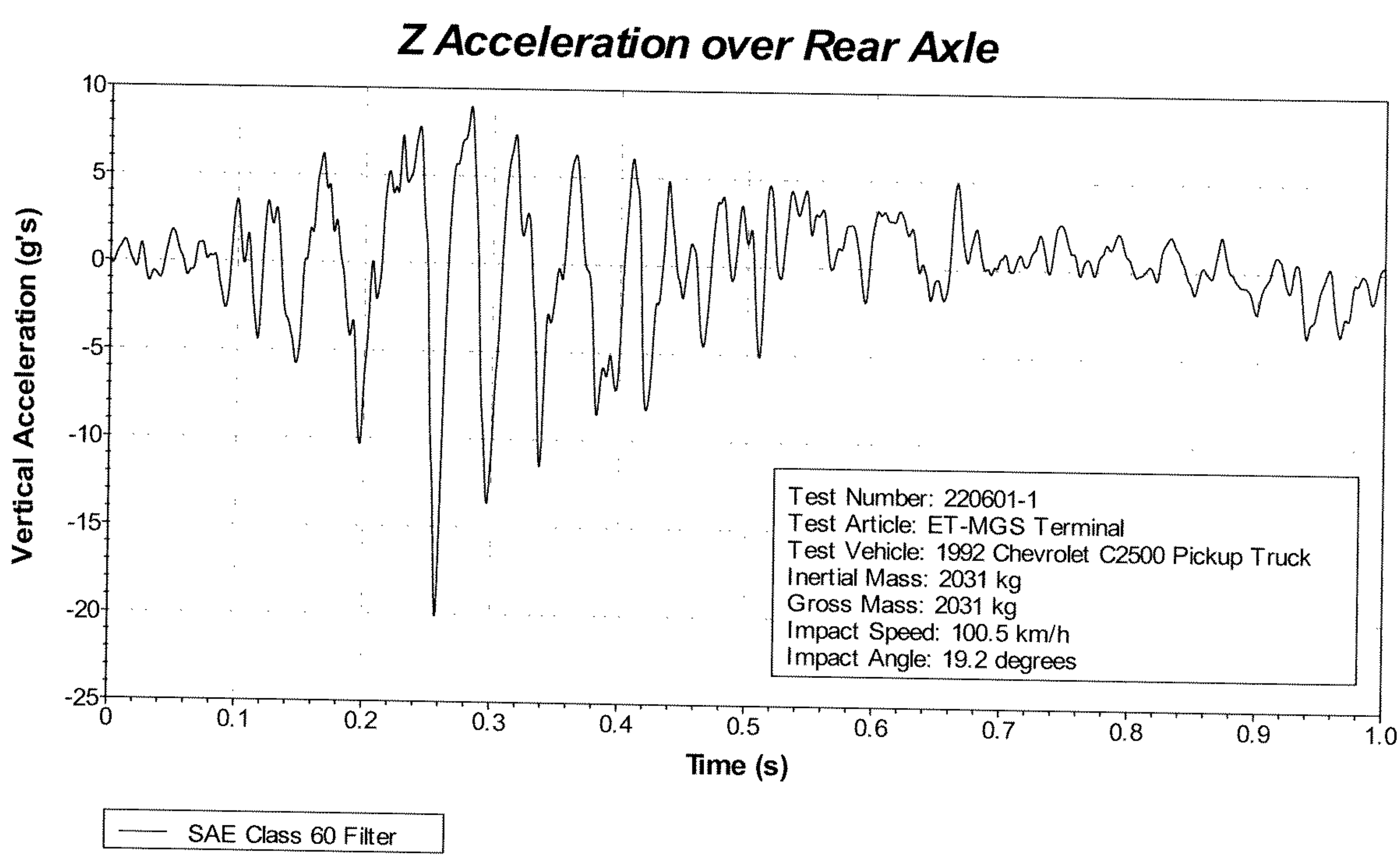


Figure 35. Vehicle vertical accelerometer trace for test 220601-1 (accelerometer located over rear axle).

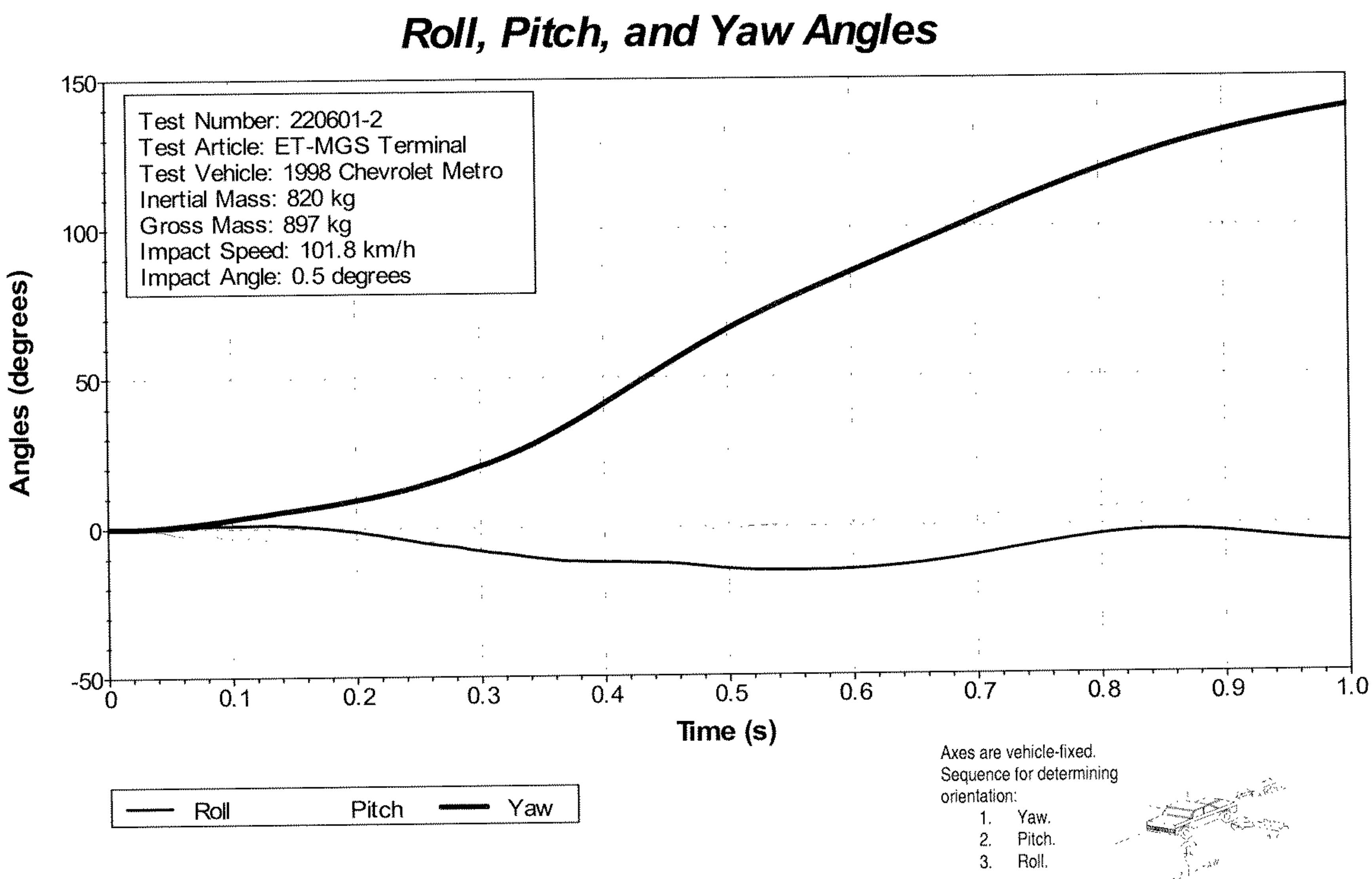


Figure 36. Vehicle angular displacements for test 220601-2.

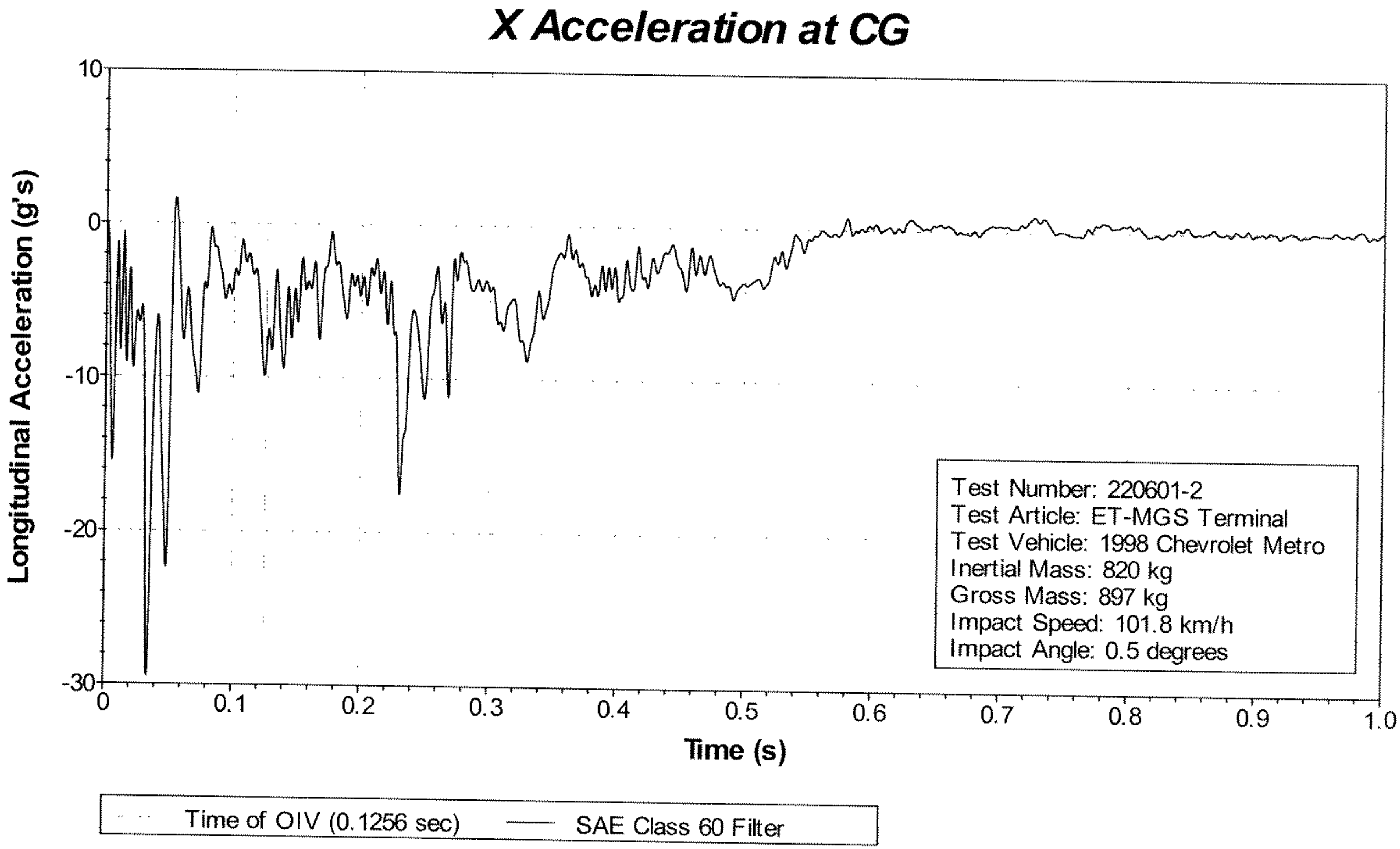


Figure 37. Vehicle longitudinal accelerometer trace for test 220601-2 (accelerometer located at center of gravity).

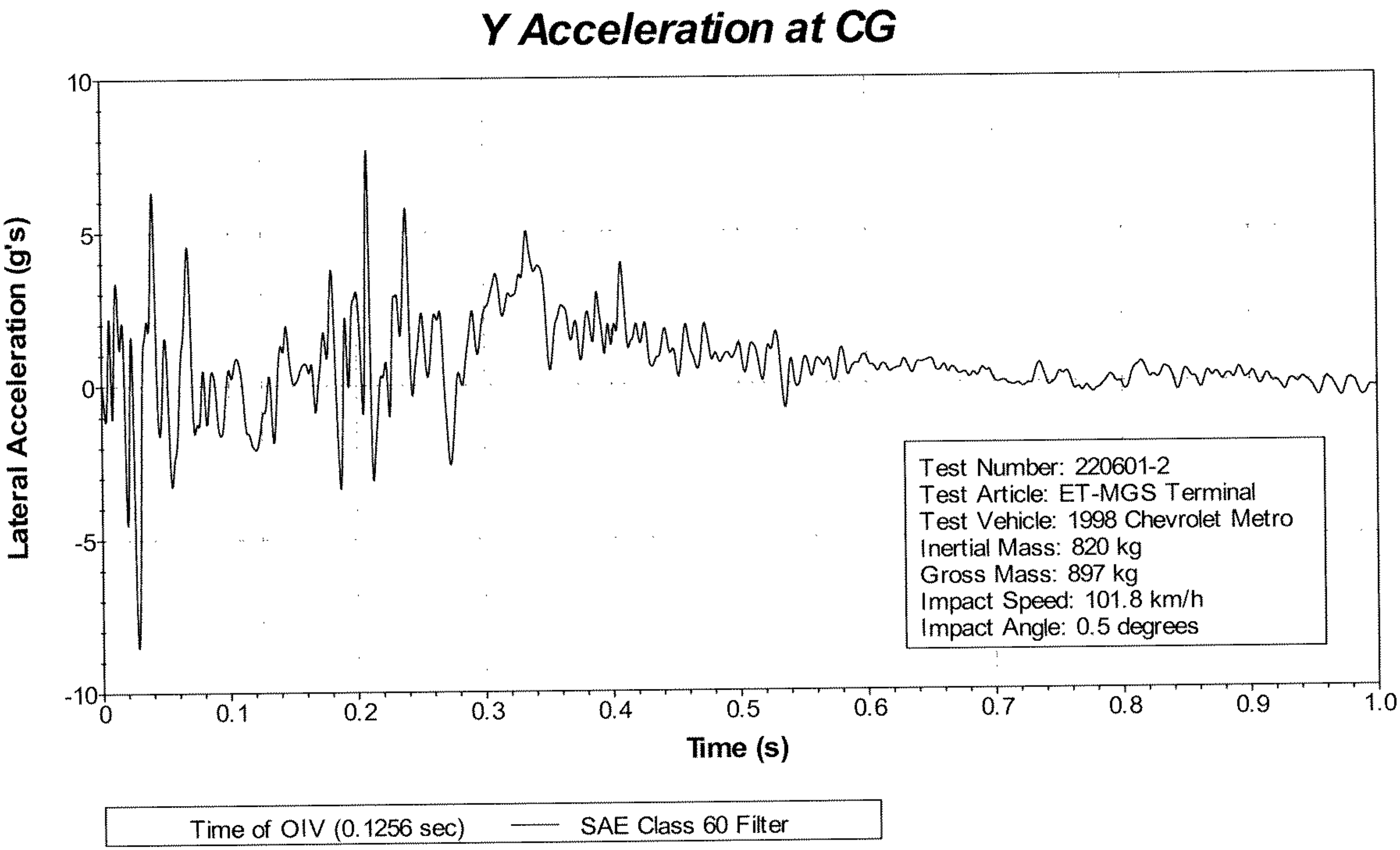


Figure 38. Vehicle lateral accelerometer trace for test 220601-2 (accelerometer located at center of gravity).

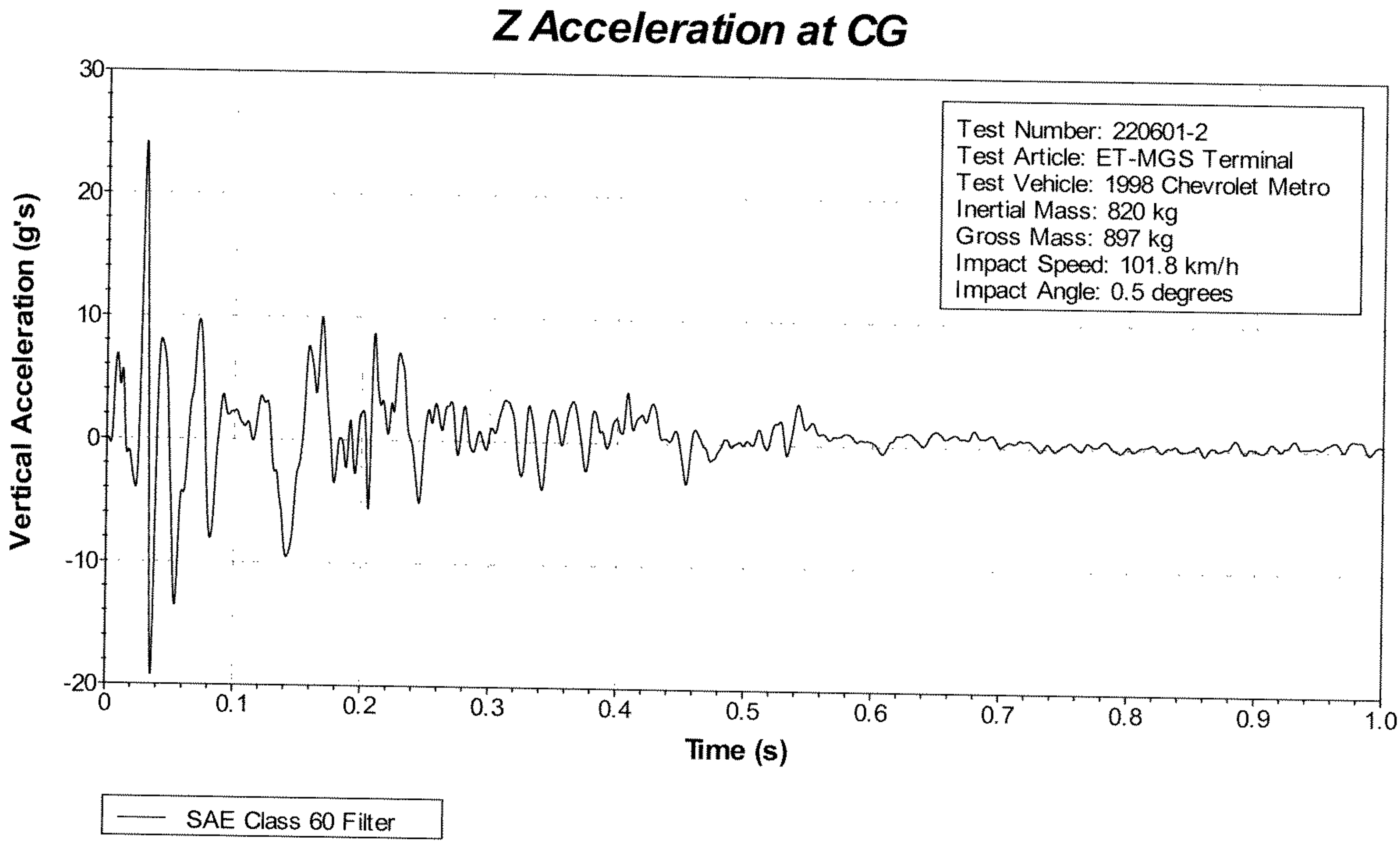


Figure 39. Vehicle vertical accelerometer trace for test 220601-2 (accelerometer located at center of gravity).

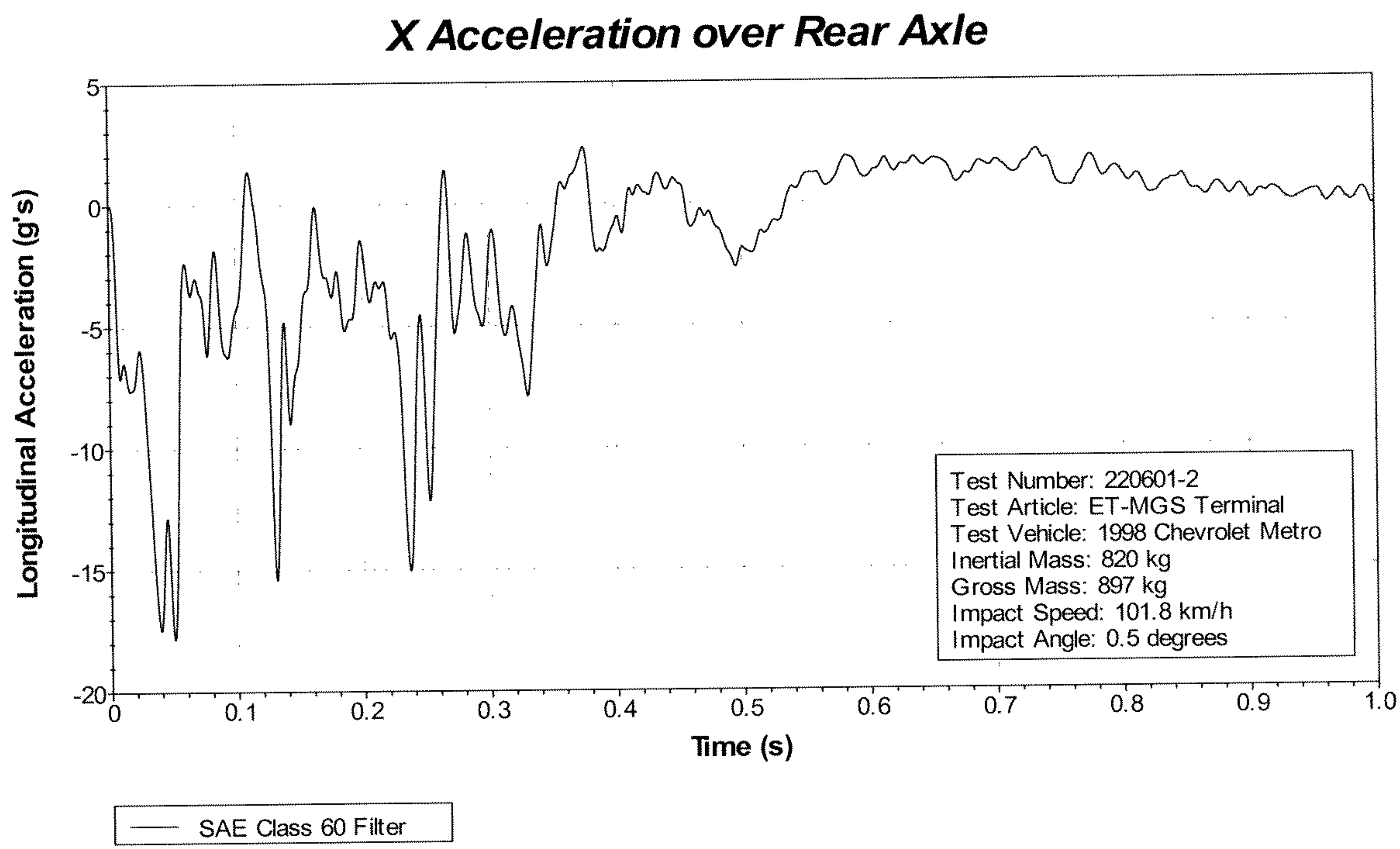


Figure 40. Vehicle longitudinal accelerometer trace for test 220601-2 (accelerometer located over rear axle).

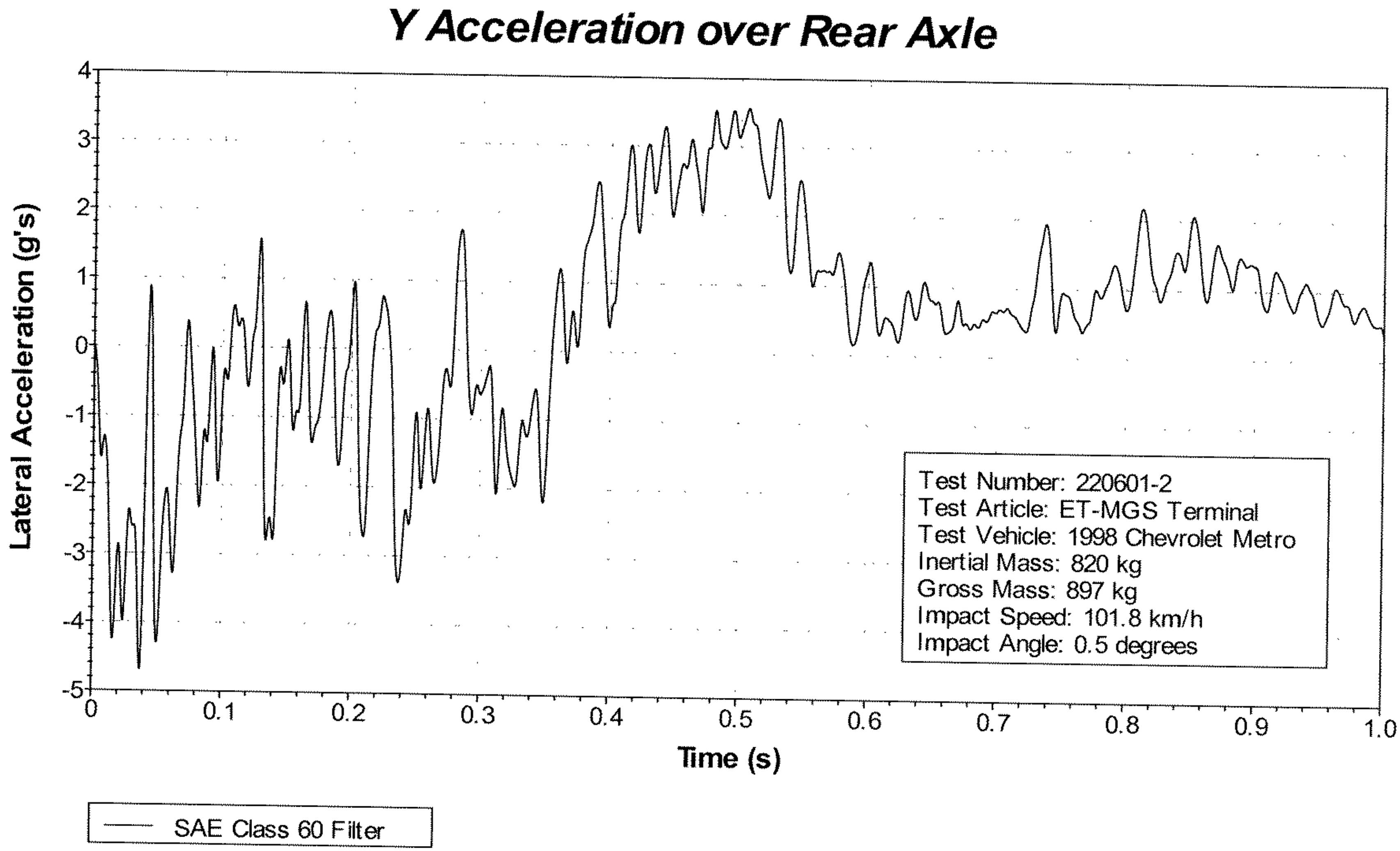


Figure 41. Vehicle lateral accelerometer trace for test 220601-2 (accelerometer located over rear axle).

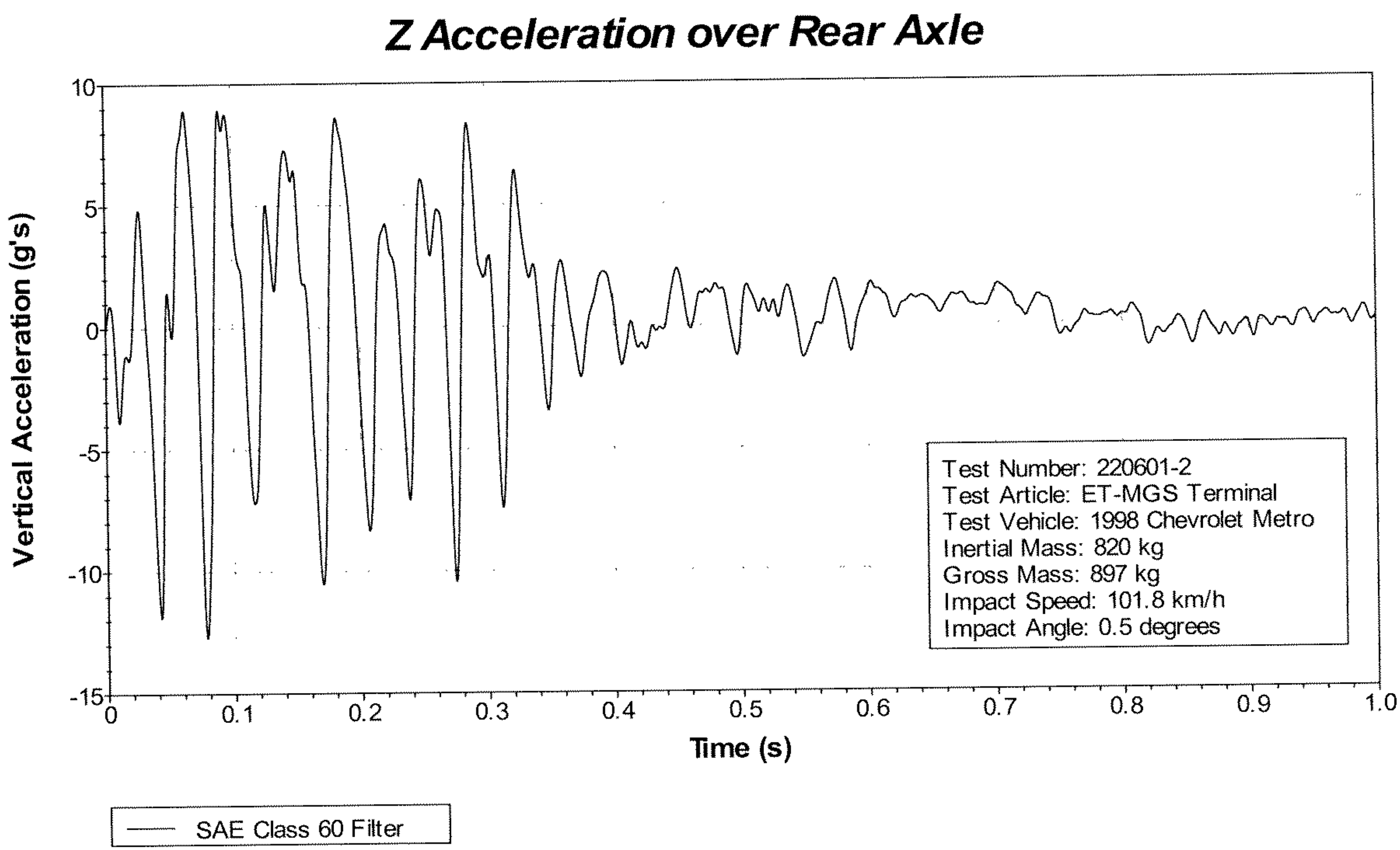


Figure 42. Vehicle vertical accelerometer trace for test 220601-2 (accelerometer located over rear axle).