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# NCHRP REPORT 350 EVALUATION OF THE T501 BRIDGE RAIL WITH SOUNDWALL

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Report No. 408460-F
Project No.  120-xxA1004

Sponsored by
**Texas Department of Transportation**

**January 2001**

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A & M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS   77843

Technical Report Documentation Page

1. Report No.
FHWA/TX-01/408460-F

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
NCHRP REPORT 350 EVALUATION OF THE T501 BRIDGE RAIL WITH SOUNDWALL

5. Report Date
January 2001

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.
Report 408460-F

9. Performing Organization Name and Address
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
Project No. 120-xxA1004

12. Sponsoring Agency Name and Address
Texas Department of Transportation
Construction Division
Research and Technology Transfer Section
P. O. Box 5080
Austin, Texas 78763-5080

13. Type of Report and Period Covered
Research:
July 2000 - December 2000

14. Sponsoring Agency Code

15. Supplementary Notes
Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Project Title: Crash Testing and Evaluation of a Special T501 Railing with Soundwall

16. Abstract

The Texas Department of Transportation (TxDOT) developed a new detail for a special type of T501 bridge railing with a soundwall attached atop the railing. The overall height of the bridge railing with a soundwall is 6 ft (1.8 m). The Houston District of TxDOT anticipates the new T501 railing with soundwall will be extensively implemented. The first installation site for this bridge railing/soundwall combination is on US Highway 59 from Mandell to Smith Street. In a cooperative research effort between TxDOT and the Florida Department of Transportation (FDOT), the height of the bridge railing with a soundwall was increased for FDOT and worst-case testing purposes to 8 ft (2.4 m).

The standard T501 bridge railing has been crash tested previously and demonstrated acceptable performance for both structural adequacy and occupant risk. However, with the addition of the soundwall atop the barrier, TxDOT wanted to 1.) evaluate and confirm the structural adequacy of the soundwall portion of the railing when impacted by an errant vehicle and 2.) evaluate the effect the soundwall may have on the stability of the National Cooperative Highway Research Program *(NCHRP) Report 350* 4,405 lb (2000 kg) test vehicle and 17,616 lb (8000 kg) box van. The primary performance characteristic of interest in this project is the strength of the addition of the soundwall to the top of the T501 bridge railing. Therefore, researchers recommended omitting the small car test (4-10) and performing *NCHRP Report 350* test designations 4-11 and 4-12.

This report presents the details of the two *NCHRP Report 350* tests (4-11 and 4-12). During the performance of both of these tests, the T501 bridge railing with the addition of the soundwall satisfied the performance guidelines presented in *NCHRP Report 350*.

17. Key Words
Bridge Rail, Soundwall, Longitudinal Barriers, Crash Testing, Roadside Safety Features

18. Distribution Statement
No restrictions. This document is available to the public through NTIS:
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

19. Security Classif.(of this report)
Unclassified

20. Security Classif.(of this page)
Unclassified

21. No. of Pages
80

22. Price

**Form DOT F 1700.7** **(8-72)** **Reproduction of completed page authorized**

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# ACKNOWLEDGMENTS

This research project was conducted under a cooperative program between the Texas Transportation Institute, the Texas Department of Transportation, the U.S. Department of Transportation, and Federal Highway Administration. We acknowledge and appreciate the assistance of Mr. John Vogel and Mr. Mark Bloschock of TxDOT as well as the personnel from the Florida Department of Transportation.

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# I. INTRODUCTION

## BACKGROUND

On July 16, 1993, the Federal Highway Administration (FHWA) formally adopted the performance evaluation guidelines for highway safety features set forth in National Cooperative Highway Research Program (NCHRP) *Report 350,* "Recommended Procedures for the Safety Performance of Highway Features" (1) as a "guide or reference" document in the *Federal Register*, Volume 58, Number 135 (1, 2). FHWA has also mandated that, on projects let after October 1998, only highway safety appurtenances that have successfully met the performance evaluation guidelines set for in *NCHRP Report 350* may be used on new construction projects on the National Highway System (NHS).

## PROBLEM

The Texas Department of Transportation (TxDOT) developed a new detail for a special type of T501 bridge railing with a soundwall attached atop the railing. The Houston District of TxDOT anticipates the new T501 railing with soundwall will be extensively implemented. The first installation site for this bridge railing/soundwall combination is on US Highway 59 from Mandell to Smith Street. In addition, in a cooperative research effort between TxDOT and the Florida Department of Transportation (FDOT), the height of the bridge railing with a soundwall was increased for FDOT and worst-case testing purposes to 8 ft (2.4 m).

The standard T501 bridge railing has been crash tested previously and demonstrated acceptable performance for both structural adequacy and occupant risk. However, with the addition of the soundwall atop the barrier, TxDOT wanted to 1.) evaluate and confirm the structural adequacy of the soundwall portion of the railing when impacted by an errant vehicle and 2.) evaluate the effect the soundwall may have on the stability of the *NCHRP Report 350* 4,405 lb (2000 kg) test vehicle and 17,616 lb (8000 kg) box van.

## OBJECTIVES/SCOPE OF RESEARCH

TxDOT initiated a testing program to evaluate the impact performance of the modified T501 bridge railing with a soundwall. The modified T501 bridge railing was crash tested and evaluated in accordance with guidelines presented in *NCHRP Report 350.*

To evaluate the crashworthiness of a longitudinal barrier, such as the T501 bridge railing with soundwall, *NCHRP Report 350* has multiple service levels at which an appurtenance may be evaluated. Test level three is referred to as the "basic level." The *NCHRP Report 350* TL-3 requirements for longitudinal barriers are test designations 3-10 and 3-11. Test designation 3-10 involves a 1,806-lb (820-kg) passenger vehicle (820C) impacting the critical impact point (CIP) of the length-of-need (LON) of the barrier at a nominal speed and angle of 62.2 mi/h (100 km/h) and 20 degrees. The purpose of this test is to evaluate the overall performance of the LON section, in general, and occupant risk, in particular. Test designation 3-11 involves a 4,405-lb (2000-kg) pickup truck (2000P) impacting the CIP of the LON of the barrier at a nominal speed and angle of 62.2 mi/h (100 km/h) and 25 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 2000P vehicle.

Researchers at TTI recommended that a minimum TL-3 service level be met. In addition, after consultation with TxDOT engineers and discussions about possible use of the wall on elevated structures, TTI and TxDOT decided to test and evaluate the barrier installation in accordance with *NCHRP Report 350* test level four (TL-4). The evaluation of the railing to TL-4 requires one additional test, test designation 4-12, which involves a 17,621-lb (8000-kg) single unit truck (8000S) impacting the CIP of the LON of the barrier at a nominal speed and angle of 49.7 mi/h (80 km/h) and 15 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 8000S vehicle. The impact severity of the *NCHRP Report 350* 4-12 test is approximately the same magnitude as the NCHRP Report 350 4-11 test. However, the height of load application is higher on the barrier wall, thus increasing the applied moment on the soundwall. The vertical center of gravity for the 2000 kg vehicle is approximately 27.6 in. ± 2 in. (700 ± 50 mm). The vertical center of gravity for the 8000 kg vehicle is approximately 49.2 in. ± 2 in. (1250 ± 50 mm). Additionally it should be noted, *NCHRP Report 350* tests 3-10 and 3-11 change designations to 4-10 and 4-11 without changing testing requirements when test level 4 is addressed.

Highway safety appurtenances are typically evaluated based on three criteria: occupant risk, structural adequacy, and post-impact vehicle trajectory. Many crash tests have been performed on rigid concrete barriers, including the T501 bridge railing without a soundwall. Historically, the 820 kg passenger vehicle performs well in crash tests with respect to occupant risk values and vehicle trajectory. The primary performance characteristic of interest in this project is the strength of the additional soundwall atop the T501 bridge railing. Therefore, researchers recommended omitting the small car test (4-10) and performing *NCHRP Report 350* test designations 4-11 and 4-12.

This report presents the details of the two *NCHRP Report 350* tests (4-11 and 4-12). Details of the T501 Bridge Railing with Soundwall are provided in Chapter II. Chapter III contains the details and descriptions of each of the tests, and Chapter IV presents the assessment of each test, the conclusions and a brief implementation statement.

# II. STUDY APPROACH

## TEST FACILITY

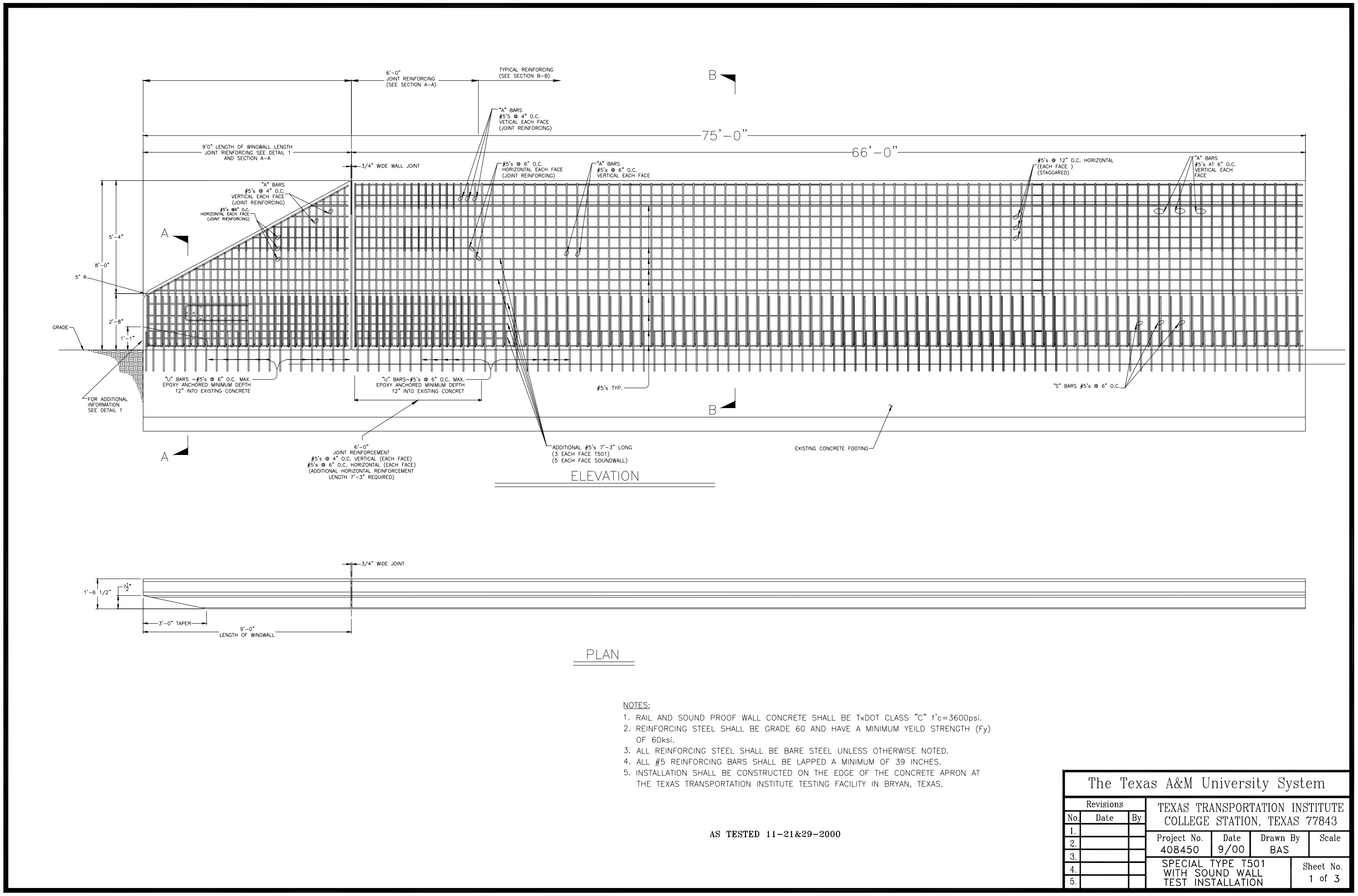
The test facilities at the Texas Transportation Institute's Proving Ground consist of an 809-hectare complex of research and training facilities situated 16 km northwest of the main campus of Texas A&M University. The site, formerly an Air Force Base, has large expanses of concrete runways and parking 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 placing of the T501 bridge railing with soundwall is along a wide out-of-service apron. The aprons consist of an unreinforced jointed concrete pavement in 12.5 ft by 15 ft (3.8 m by 4.6 m) blocks nominally 8-12 in. (203-305 mm) deep. The aprons and runways are about 50 years old and the joints have some displacement, but are otherwise flat and level.

## TEST ARTICLE

The T501 with soundwall consists of a modified T501 bridge railing with a cast-in-place 5 ft-4 in. (1.6 m) tall concrete soundwall cast on top of the bridge rail. On April 17, 2000, TTI received a drawing from TxDOT entitled "Special Type T501 With Soundwall" dated January 2000. This drawing provided details for construction of a concrete soundwall that measured 3 ft-4 in. (1.0 m) constructed on top of the standard T501 bridge rail. As part of a joint agreement between TxDOT and the Florida Department of Transportation, the height of the soundwall was increased to 5 ft-4 in. (1.6 m), which resulted in a total barrier height of 8 ft-0 in (2.4 m).

Researchers at TTI performed engineering calculations on the 8.0 ft (2.4 m) barrier in accordance with the latest 1998 American Association of State Highway Transportation Officials (AASHTO) LRFD Bridge Design Specifications. These calculations and drawings were submitted to TxDOT for review on August 17, 2000. The details as shown on the drawings provided in this report were approved by TxDOT for construction on September 15, 2000. Additional details are provided on the drawings shown as Figure 1. Photographs of the installations as tested are shown in Figures 2 and 3.

For this project, 66 ft (20.1 m) of T501 bridge rail with 5 ft-4 in (1.6 m) of cast-in-place concrete soundwall was constructed. The total height of the barrier was 8.0 ft (2.4 m). In addition, an additional 9.0 ft (2.7 m) of wall that tapered to the standard T501 height of 32 in. (813 mm) was constructed. A construction joint approximately ¾ in. (19 mm) wide was located between the standard 8-ft (2.4 m) tall section and the point of taper. The total length of the installation was 75 ft (22.9 m). For design and ease of construction, the width of the soundwall was 7½ in. (190 mm) with two layers of reinforcing steel. The standard T501 bridge rail was modified by increasing the overall width of the section by 1½ in. (38 mm) to support the 7½ in. (190 mm) wide soundwall. The total base width of the T501 section was 1 ft-6½ in. (0.47 m).



NOTES:

1. RAIL AND SOUND PROOF WALL CONCRETE SHALL BE TxDOT CLASS "C" f'c=3600psi.
2. REINFORCING STEEL SHALL BE GRADE 60 AND HAVE A MINIMUM YEILD STRENGTH (Fy) OF 60ksi.
3. ALL REINFORCING STEEL SHALL BE BARE STEEL UNLESS OTHERWISE NOTED.
4. ALL #5 REINFORCING BARS SHALL BE LAPPED A MINIMUM OF 39 INCHES.
5. INSTALLATION SHALL BE CONSTRUCTED ON THE EDGE OF THE CONCRETE APRON AT THE TEXAS TRANSPORTATION INSTITUTE TESTING FACILITY IN BRYAN, TEXAS.

AS TESTED 11-21&29-2000

The Texas A&M University System

| Revisions | | |
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COLLEGE STATION, TEXAS 77843

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SPECIAL TYPE T501
WITH SOUND WALL
TEST INSTALLATION

Sheet No.
1 of 3

Figure 1. Details of the T501 Bridge Rail with Soundwall.

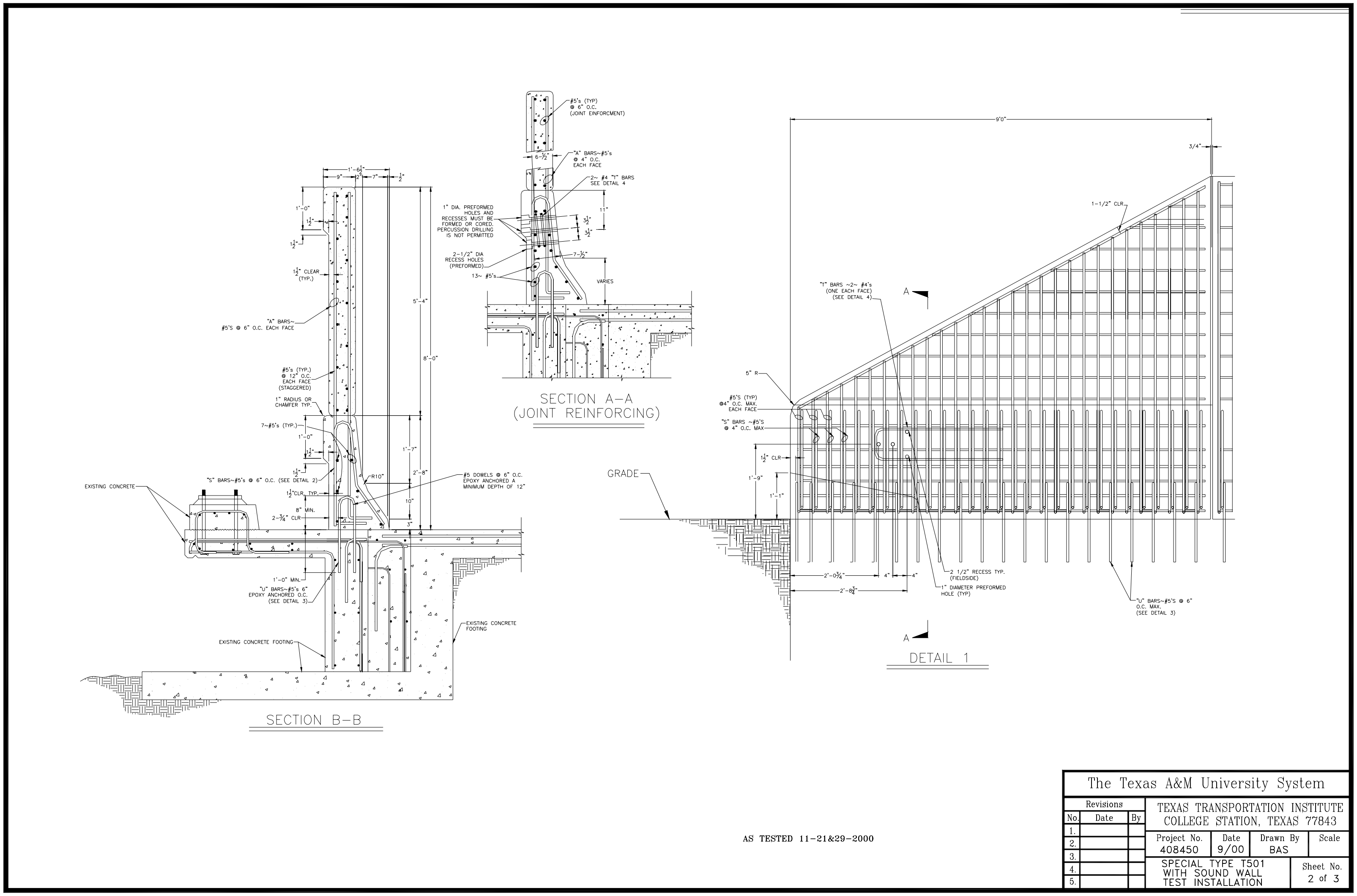

Figure 1. Details of the T501 Bridge Rail with Soundwall (continued).

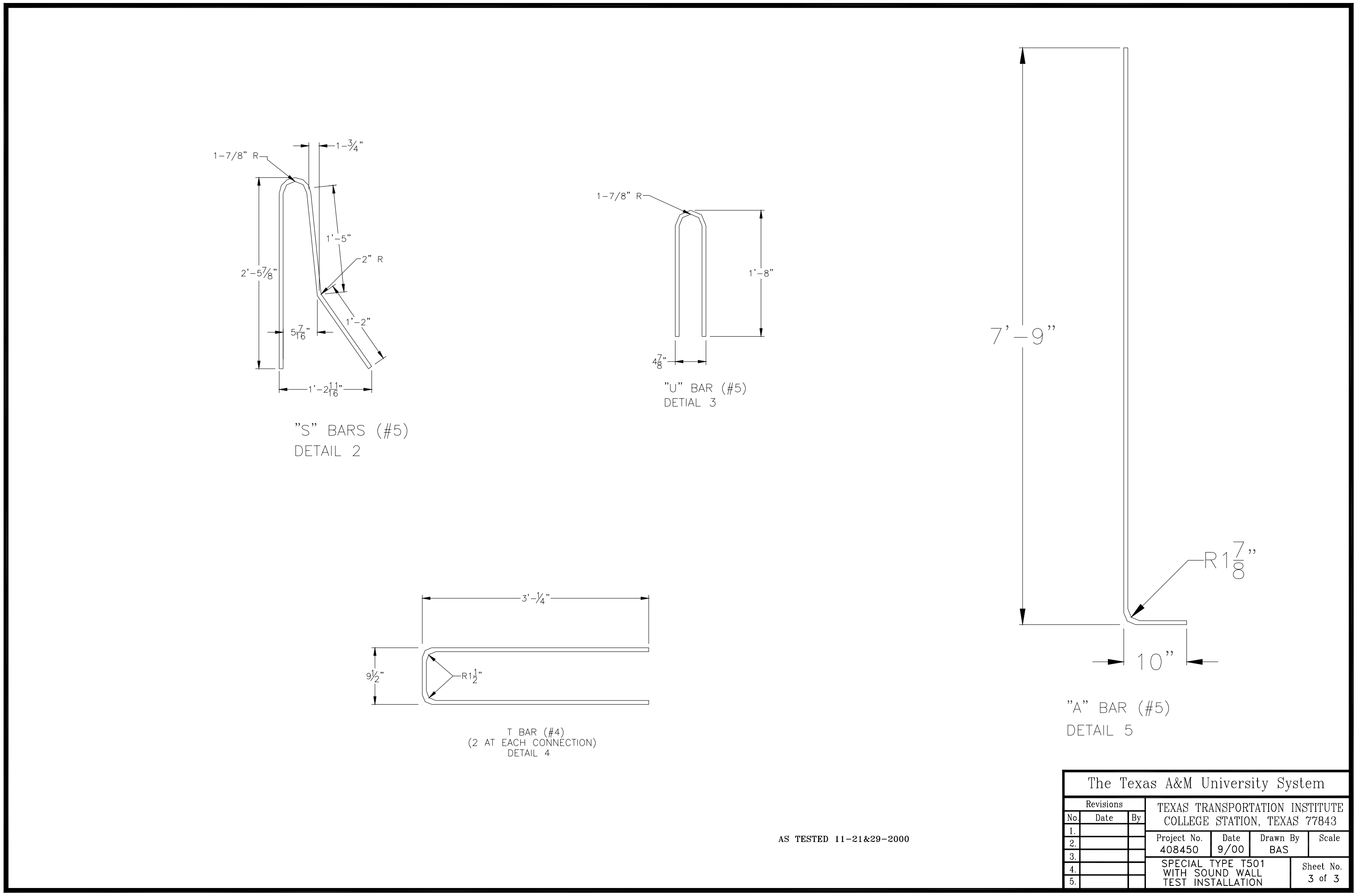

Figure 1.  Details of the T501 Bridge Rail with Soundwall (continued).

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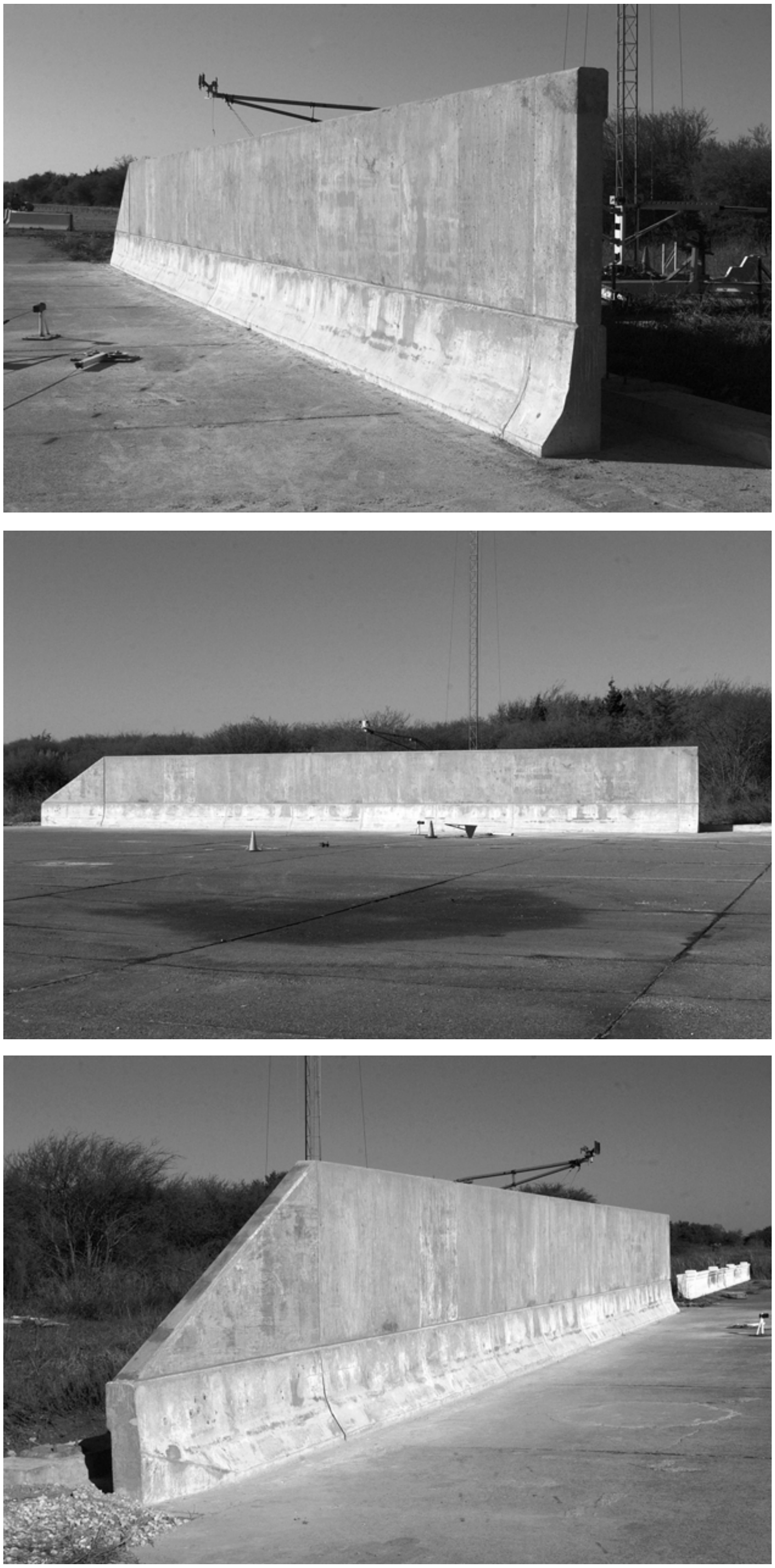


**Figure 2. T501 Bridge Rail with Soundwall before Test 408460-1.**

**Figure 3. T501 Bridge Rail with Soundwall before Test 408460-2.**

The soundwall was anchored to an existing concrete footing at the TTI Proving Ground using #5 “U” shaped bars located approximately 6 in. (152 mm) apart. These bars were epoxy anchored into an existing footing.

In the standard length of barrier section, the vertical reinforcing in the T501 Bridge Rail consisted of #5 “V” shaped and “L” bars located approximately 6 in. (152 mm) apart. The “L” shaped bars were located on both the traffic and field sides (two layers) of the barrier. The “L” shaped dowels extended from the T501 bridge rail to the top of the soundwall and were used to support the soundwall. However, approximately 6.0 ft (1.8 m) from each side of the construction joint and 6.0 ft (1.8 m) from the end of the barrier, these bars were located approximately 4 in. (102 mm) apart. A closer spacing was required in these areas to satisfy the AASHTO LRFD requirements.

In the standard length of need barrier section, the horizontal reinforcing in the T501 bridge rail consisted of six evenly spaced #5 bars similar to the details shown on the TxDOT standard “Type T501” drawing. However, the top longitudinal bar in the T501 section was not added to ease in construction. Horizontal reinforcing in the standard length of need section for the soundwall consisted of #5 bars located approximately 12 in. (305 mm) apart on both the traffic and field side faces (two layers). These bars were staggered between the layers to facilitate construction. However, approximately 6.0 ft (1.8 m) from each side of the construction joint and 6.0 ft (1.8 m) from the end of the barrier, the horizontal reinforcing spacing was reduced to approximately 6 in. (152 mm) in both the T501 and the soundwall sections. A reduced spacing was required in these areas to satisfy the AASHTO LRFD requirements. All reinforcing steel used for this project was bare steel (not epoxy coated) and had a minimum yield strength of 60 ksi (413.7 kPa). TxDOT Class “C” Concrete was used in both the T501 bridge rail and soundwall cross sections. Compressive strength tests performed on the day of Test 1 on concrete used to construct the T501 bridge rail revealed an average compressive strength of 5046 psi (34,791 kPa) (age 20 days). Compressive strength tests performed on the day of Test 1 on concrete used to construct the soundwall revealed an average compressive strength of 4330 psi (29,854 kPa) (age 11 days).

## CRASH TEST CONDITIONS

TxDOT determined that the T501 bridge rail with soundwall should be evaluated according to requirements for test level 4 (TL-4) of *NCHRP Report 350*. Three tests are required for TL-4 evaluation of longitudinal barriers:

> ***NCHRP Report 350*** **test designation 4-10**: This test involves an 820-kg passenger vehicle (820C) impacting critical impact point of the length-of-need of the barrier at a nominal speed and angle of 100 km/h and 20 degrees. The purpose of this test is to evaluate the overall performance of the LON section, in general, and occupant risk, in particular.

> ***NCHRP Report 350* test designation 4-11**: The test involves a 2000-kg pickup truck (2000P) impacting the CIP of the LON of the barrier at a nominal speed and angle of 100 km/h and 25 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 2000P vehicle.
>
> ***NCHRP Report 350* test designation 4-12**: The test involves an 8000-kg single unit truck (8000S) impacting the CIP of the LON of the barrier at a nominal speed and angle of 80 km/h and 15 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 8000S vehicle.

Researchers concluded that only tests 4-11 and 4-12 were needed to evaluate the T501 bridge rail with soundwall. The T501 bridge rail had performed acceptably with the small vehicle and the soundwall would not affect the performance with this small vehicle. *NCHRP Report 350* tests 4-11 and 4-12 were performed and are reported herein.

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 performed was evaluated in accordance with *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, researchers used the safety evaluation criteria from Table 5.1 of *NCHRP Report 350* to evaluate the crash test reported herein.

# III. CRASH TEST RESULTS

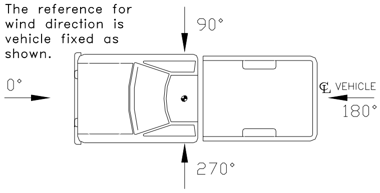
## TEST NO. 408460-1 (*NCHRP Report 350* TEST NO. 4-11)

### Test Vehicle

A 1996 Chevrolet 2500 pickup, shown in Figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 4,405 lb (2000 kg), and its gross static weight was 4,405 lb (2000 kg). The height to the lower edge of the vehicle bumper was 17.5 in. (445 mm), and it was 26.2 in. (665 mm) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix B, Figure 18. 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 test was performed the morning of November 21, 2000. Nine days before the test, 0.5 in. (12 mm) of rain was recorded; five days before, 0.3 in (7 mm); and three days before, 1.3 in. (33 mm). No other rainfall was recorded for the remainder of the 10 days prior to the test. Weather conditions at the time of testing were as follows: wind speed: 5 mi/h (8 km/h); wind direction: 290 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 55 °F (13 °C); relative humidity: 39 percent.



### Test Description

The vehicle, traveling at 63.1 mi/h (101.6 km/h), impacted the T501 bridge rail with soundwall 26.2 ft (8.0 m) from the end at an impact angle of 25.5 degrees. Shortly after impact the right front tire began to climb the face of the bridge rail, and at 0.053 s the windshield cracked. At 0.183 s the vehicle was traveling parallel with the bridge rail at a speed of 47.4 mi/h (76.3 km/h). The rear of the vehicle contacted the bridge rail at 0.204 s. The vehicle lost contact with the bridge rail at 0.266 s and was traveling at a speed of 51.9 mi/h (83.5 km/h) and an exit angle of 4.1 degrees. The vehicle remained upright, brakes were applied at 3.5 s after impact, and the vehicle subsequently came to rest 237.5 ft (72.4 m) downstream of impact and 15.1 ft (4.6 m) forward of the face of the bridge rail. Sequential photographs of the test period are shown in Appendix C, Figures 20 and 21.

Figure 4.  Vehicle/Installation Geometrics for Test 408460-1.

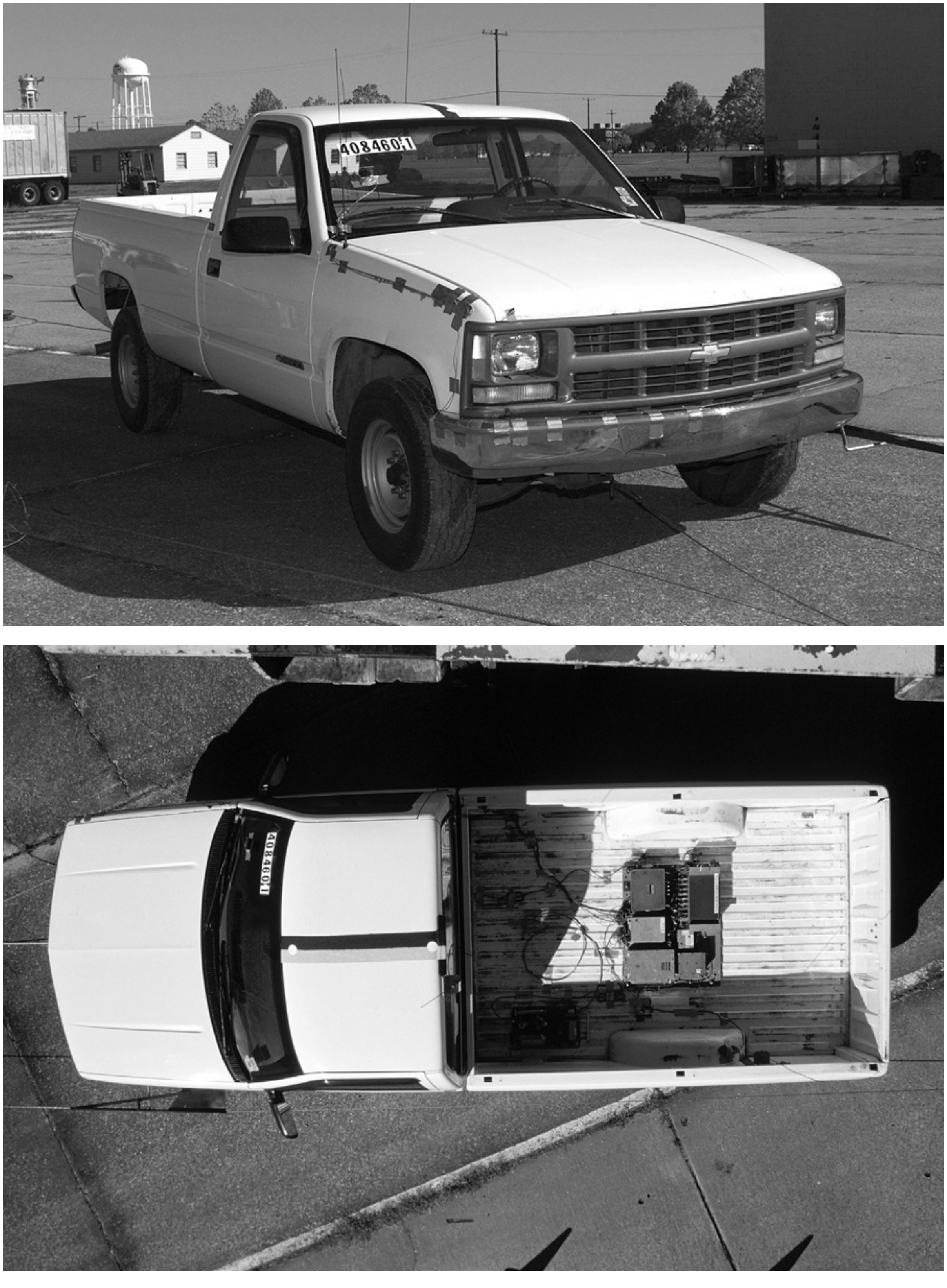


**Figure 5. Vehicle before Test 408460-1.**

## Damage to Test Installation

The T501 bridge rail with soundwall sustained only cosmetic damage as shown in Figures 6 and 7. Tire marks on the face of the bridge rail started at 26.2 ft (8.0 m) from the end and extended 15.2 ft (4.6 m) downstream of impact.

## Vehicle Damage

The vehicle sustained structural damage to the right side, including the right lower A-arm, right outer tie rod end, and right side frame rail. As can be seen in Figure 8, the hood, front bumper, right front quarter panel, right front tire and rim, right door, right rear of the bed, and the right rear tire and rim were also damaged. The windshield was cracked, the right A-pillar was deformed, the right door glass was shattered, and the roof was deformed. Maximum exterior crush to the vehicle was 18.1 in. (460 mm) on the right front corner at bumper height. Maximum occupant compartment deformation was 6.3 in. (160 mm) to the right side of the firewall; however, this deformation was not considered to be a probable cause of serious injury. Photographs of the interior of the vehicle are shown in Figure 9. Exterior vehicle crush and occupant compartment measurements are shown in Appendix B, Tables 3 and 4.

## Occupant Risk Factors

Data from the tri-axial accelerometer, located at the vehicle center of gravity, were digitized to compute occupant impact velocity and ridedown accelerations. The occupant impact velocity and ridedown accelerations in the longitudinal axis only are required from these data for evaluation of criterion L of *NCHRP Report 350*. In the longitudinal direction, occupant impact velocity was 21.7 ft/s (6.6 m/s) at 0.086 s, maximum 0.010-s ridedown acceleration was -6.5 g’s from 0.090 to 0.100 s, and the maximum 0.050-s average was -9.9 g’s between 0.009 and 0.059 s. The values in the lateral direction are given for information purposes only. In the lateral direction, the occupant impact velocity was 27.2 ft/s (8.3 m/s) at 0.086 s, the highest 0.010-s occupant ridedown acceleration was -7.6 g’s from 0.223 to 0.233 s, and the maximum 0.050-s average was -14.5 g’s between 0.185 and 0.235 s. These data and other information pertinent to the test are presented in Figure 10. Vehicle angular displacements are plotted in Appendix D, Figure 24, and accelerations versus time traces are shown in Appendix E, Figures 26 through 31.

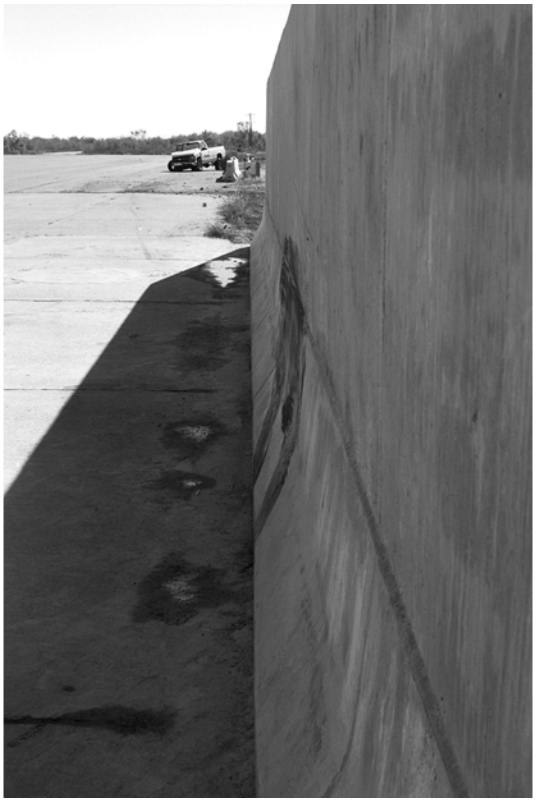


Figure 6. After Impact Trajectory for Test 408460-1.

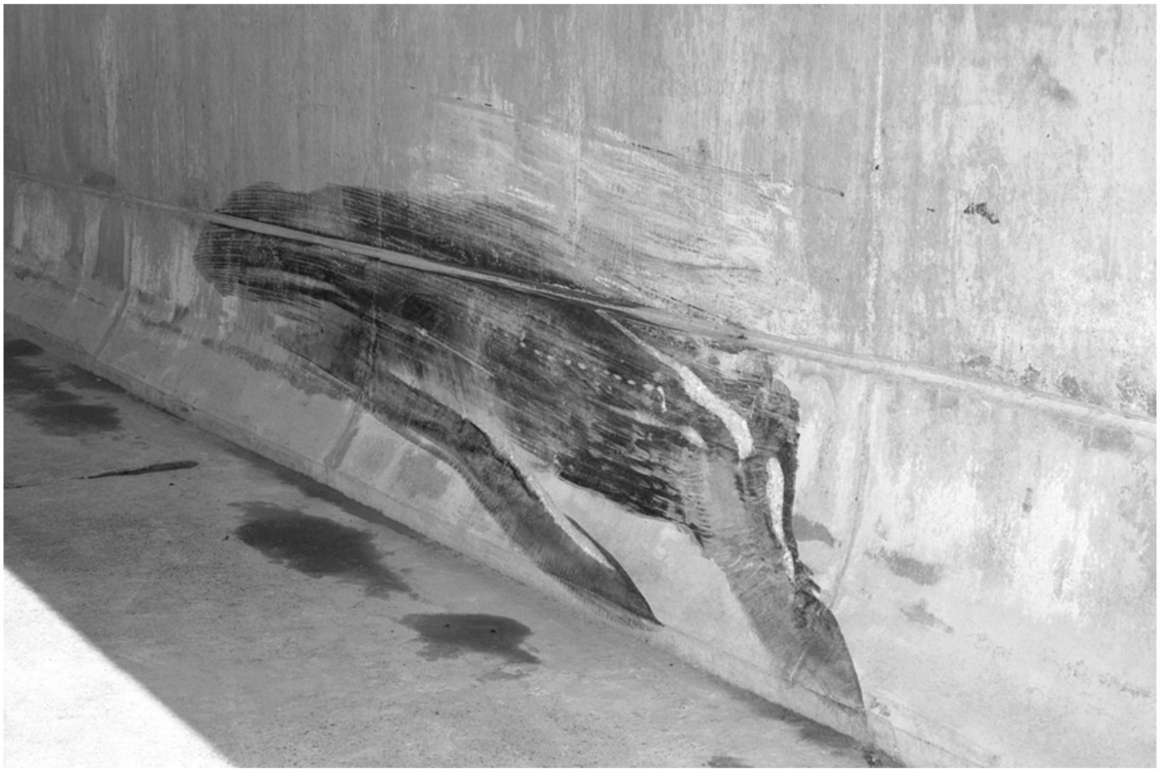


**Figure 7. Installation after Test 408460-1.**

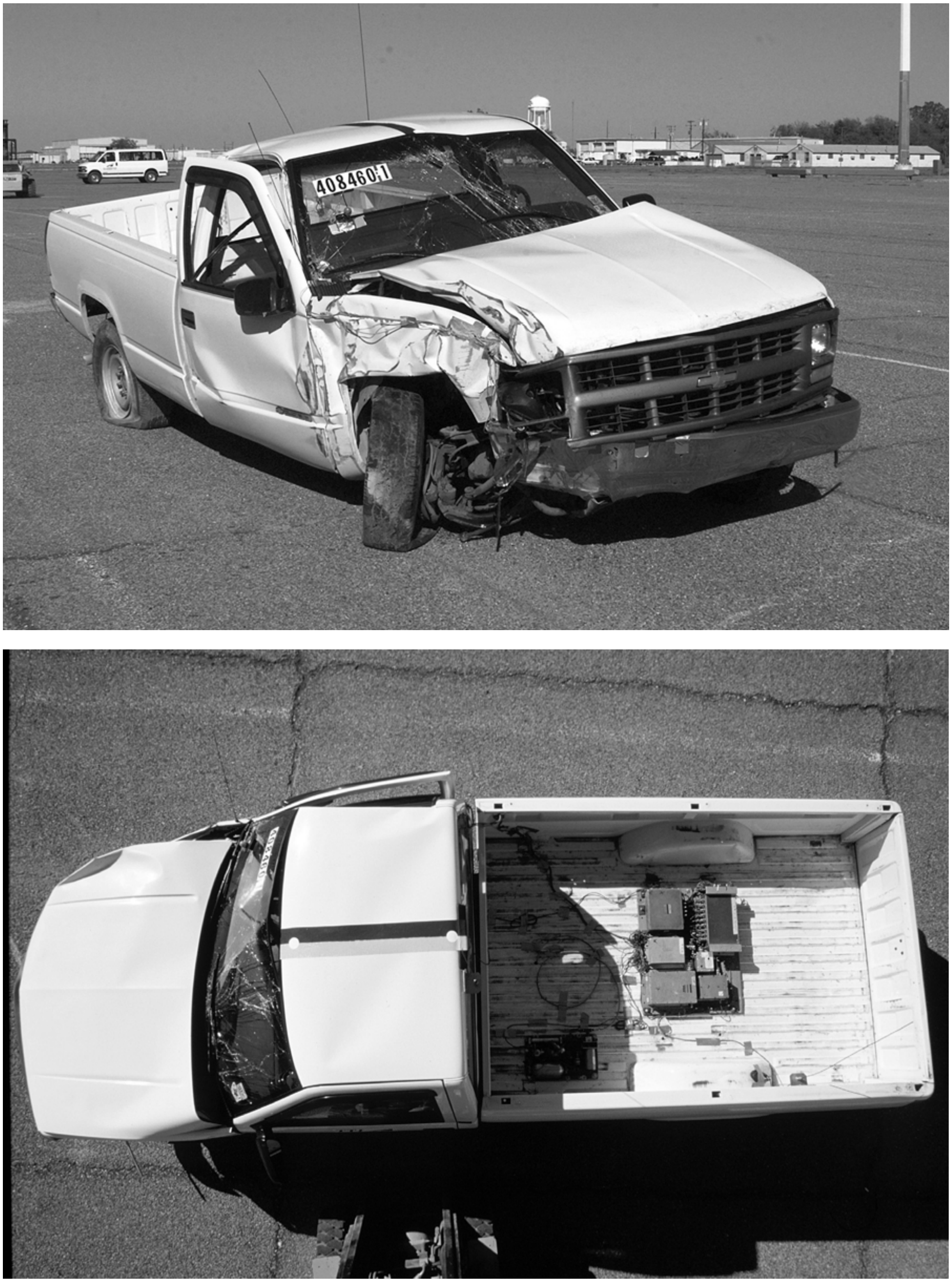
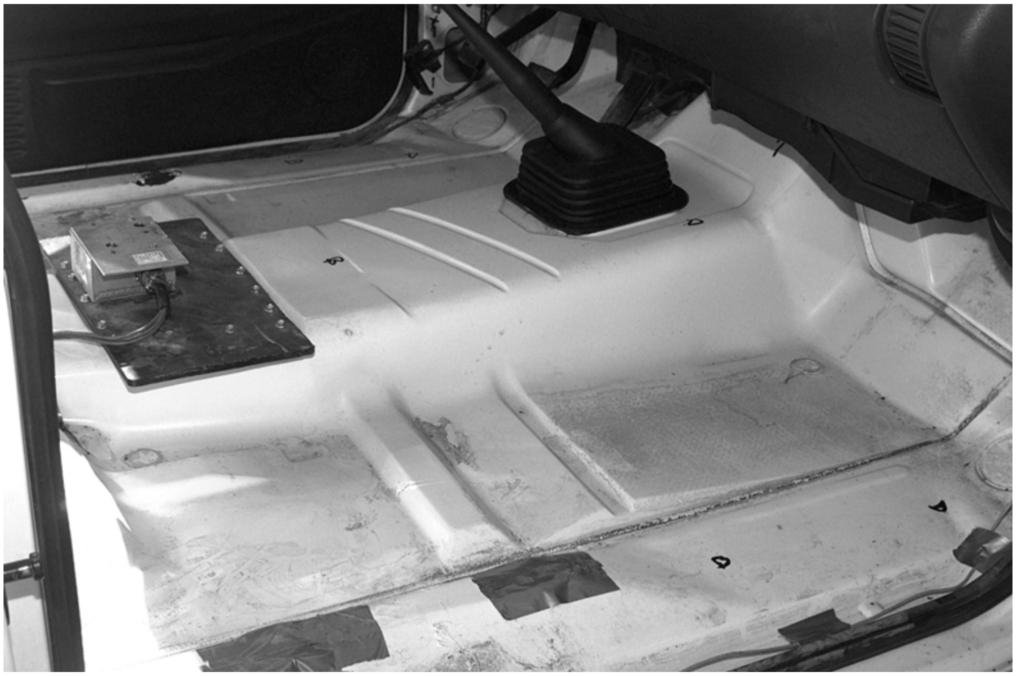


**Figure 8. Vehicle after Test 408460-1**.


Before test

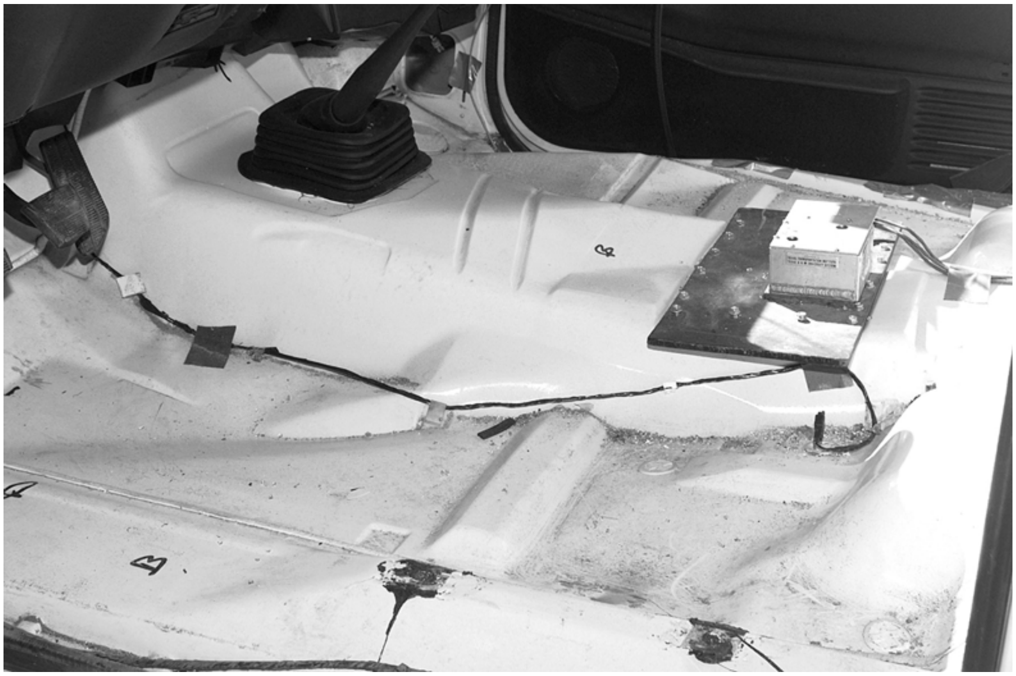
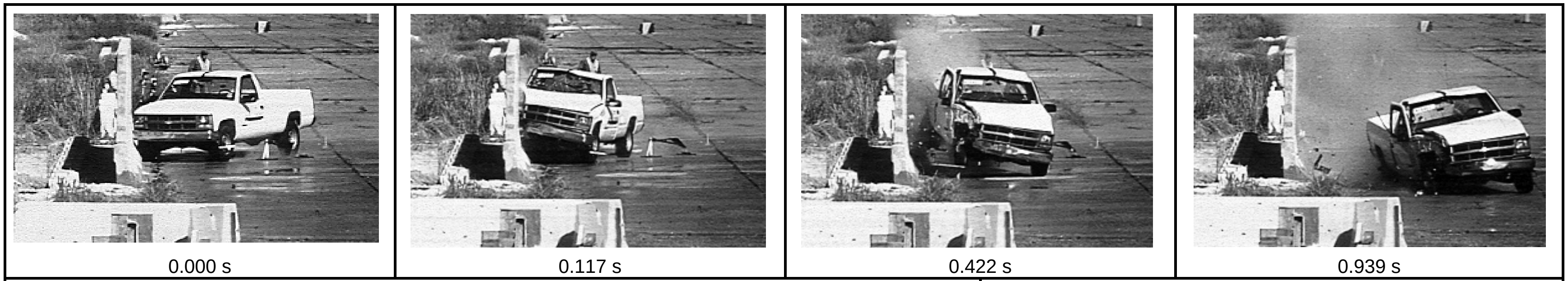
After test


**Figure 9. Interior of Vehicle for Test 408460-1**.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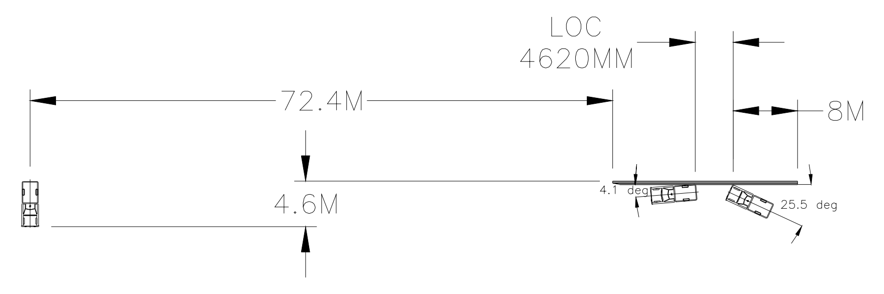
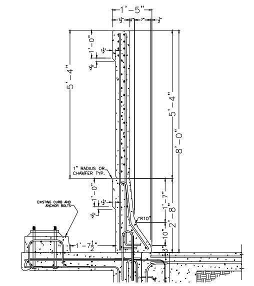




| | |
|---|---|
| **General Information** | |
| Test Agency | Texas Transportation Institute |
| Test No. | 408460-1 |
| Date | 11/21/00 |
| **Test Article** | |
| Type | Bridge Rail |
| Name | T501 bridge rail with concrete soundwall |
| Installation Length (ft) | 75.0 (22.9 m) |
| Material or Key Elements | T501 bridge rail with a cast-in-place 5ft-4" (1.6 m) tall concrete soundwall |
| **Soil Type and Condition** | Concrete pavement, dry |
| **Test Vehicle** | |
| Type | Production |
| Designation | 2000P |
| Model | 1996 Chevrolet 2500 pickup truck |
| Mass (lb) | |
| Curb | 4634 (2102 kg) |
| Test Inertial | 4405 (2000 kg) |
| Dummy | No dummy |
| Gross Static | 4405 (2000 kg) |

| | |
|---|---|
| **Impact Conditions** | |
| Speed (mi/h) | 63.1 (101.6 km/h) |
| Angle (deg) | 25.5 |
| **Exit Conditions** | |
| Speed (mi/h) | 51.9 (83.5 km/h) |
| Angle (deg) | 4.1 |
| **Occupant Risk Values** | |
| Impact Velocity (ft/s) | |
| x-direction | 21.7 (6.6 m/s) |
| y-direction | 27.2 (8.3 m/s) |
| THIV (mi/h) | 23.4 (37.6 km/h) |
| Ridedown Accelerations (g's) | |
| x-direction | -6.5 |
| y-direction | -7.6 |
| PHD (g's) | 7.7 |
| ASI | 1.78 |
| Max. 0.050-s Average (g's) | |
| x-direction | -9.9 |
| y-direction | -14.5 |
| z-direction | -5.0 |

| | |
|---|---|
| **Test Article Deflections** (ft) | |
| Dynamic | N/A |
| Permanent | N/A |
| Working Width | N/A |
| **Vehicle Damage** | |
| Exterior | |
| VDS | 01RFQ3 |
| CDC | 01FREK3<br>& 01RYEW3 |
| Maximum Exterior Vehicle Crush (in.) | 18.1 (460 mm) |
| Interior | |
| OCDI | FS1023000 |
| Max. Occ. Compart. Deformation (in.) | 6.3 (160 mm) |
| **Post-Impact Behavior** | |
| (during 1.0 s after impact) | |
| Max. Yaw Angle (deg) | -35 |
| Max. Pitch Angle (deg) | -11 |
| Max. Roll Angle (deg) | 16 |

**Figure 10. Summary of Results for Test 408460-1, *NCHRP Report 350* Test 4-11.**

## TEST NO. 408460-2 (*NCHRP Report 350* TEST NO. 4-12)

### Test Vehicle

A 1988 GMC 7000 single-unit truck, shown in Figures 11 and 12, was used for the crash test. Test inertia weight of the vehicle was 17,621 lb (8000 kg), and its gross static weight was 17,621 lb (8000 kg). The height to the lower edge of the vehicle bumper was 22.0 in. (560 mm), and it was 33.9 in. (860 mm) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix B, Figure 19. 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 test was performed the morning of November 29, 2000. Ten days before the test, 1.3 in. (33 mm) of rain was recorded and five days before, 0.3 in. (8 mm). No other rainfall was recorded for the remaining 10 days prior to the test. Weather conditions at the time of testing were as follows: wind speed: 9 mi/h (14 km/h); wind direction: 15 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 59 °F (15 °C); relative humidity: 90 percent.

### Test Description

The vehicle, traveling at a speed of 54.8 mi/h (83.4 km/h), impacted the T501 bridge rail with soundwall 25.4 ft (7.75 m) from the end of the bridge rail at an impact angle of 14.9 degrees. Shortly after impact the left front tire began to ride up the face of the bridge rail. At 0.042 s after impact the left front wheel steered toward the bridge rail and at 0.077 s the right front wheel steered toward the bridge rail. The front of the box van contacted the soundwall at 0.092 s. At 0.234 s the vehicle was traveling parallel with the bridge rail at a speed of 47.3 mi/h (76.1 km/h). The rear of the vehicle contacted the soundwall at 0.240 s. At 0.509 s the vehicle lost contact with the bridge rail and was traveling at a speed of 46.7 mi/h (75.2 km/h) and an exit angle of 2.1 degrees. Brakes on the vehicle were applied at 1.425 s after impact and the vehicle subsequently came to rest 300.0 ft (91.4 m) downstream of impact and 112.5 ft (34.3 m) forward of the face of the bridge rail. Sequential photographs of the test period are shown in Appendix C, Figures 22 and 23.

### Damage to Test Installation

Damage to the T501 bridge rail with soundwall was only cosmetic as shown in Figures 13 and 14. Tire marks were on the face of the bridge rail and scuff marks were on the face of the soundwall. Length of contact of the vehicle with the T501 bridge rail with soundwall began at 25.4 ft (7.75 m) from the end and extended 36.8 ft (11.23 m) downstream of impact.

Figure 11. Vehicle/Installation Geometrics for Test 408460-2.

Figure 12. Vehicle before Test 408460-2.

Figure 13.  After Impact Trajectory for Test 408460-2.

Figure 14.  Installation after Test 408460-2.

## Vehicle Damage

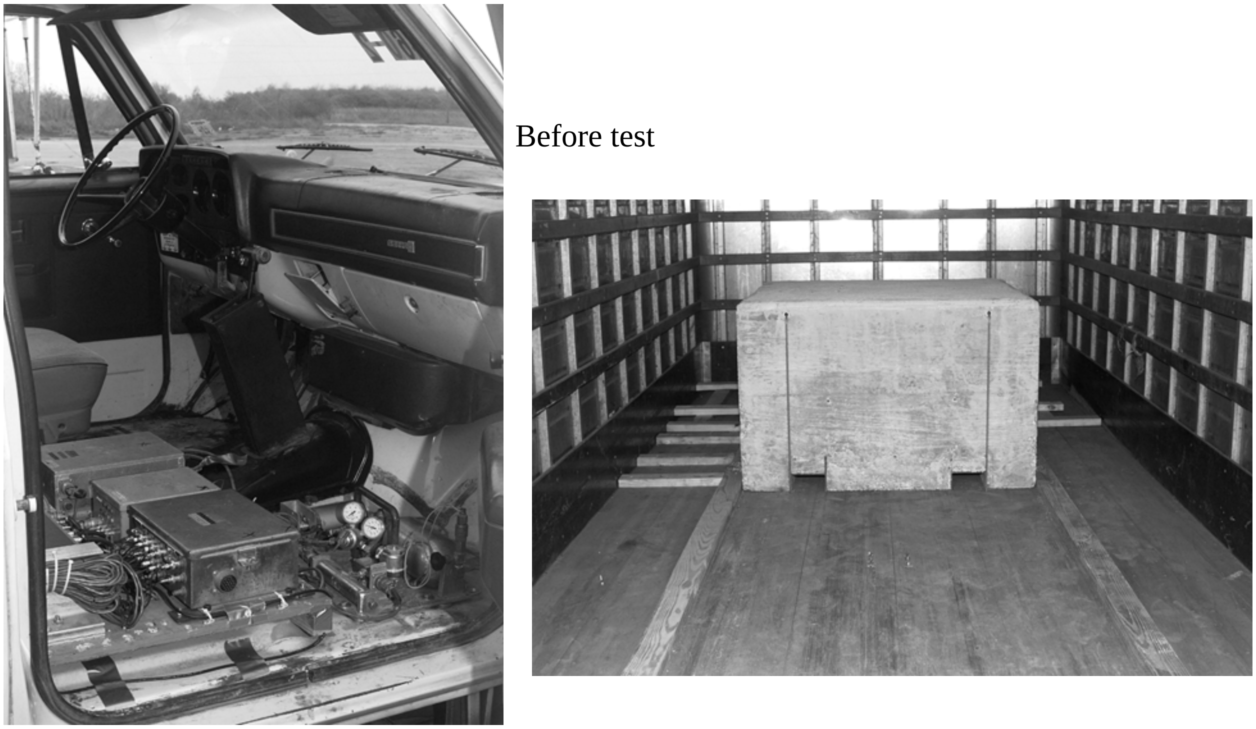
The 8000S sustained structural damage which included the left and right U-bolts that restrain the front steering axle, hood, left springs and shocks, steering arm, and gear box. As can be seen in Figure 15, the front bumper, left quarter panel, left door step, left door, left side of the box and the left rear outside rim were deformed. No deformation into the occupant compartment occurred. Photographs of the interior of the vehicle are shown in Figure 16.

## Occupant Risk Factors

Occupant risk factors are not required for the test with the 8000S vehicle; however, these factors were computed and are reported for information purposes only. Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 7.9 ft/s (2.4 m/s) at 0.176 s, the highest 0.010-s occupant ridedown acceleration was -2.8 g’s from 0.254 to 0.264 s, and the maximum 0.050-s average acceleration was -2.6 g’s between 0.066 and 0.116 s. In the lateral direction, the occupant impact velocity was 13.8 ft/s (4.2 m/s) at 0.176 s, the highest 0.010-s occupant ridedown acceleration was 10.2 g’s from 0.254 to 0.264 s and the maximum 0.050-s average was 6.2 g’s between 0.073 and 0.123 s. These data and other pertinent information from the test are summarized in Figure 17. Vehicle angular displacements are plotted in Appendix D, Figure 25, and accelerations versus time traces are presented in Appendix E, Figures 32 through 38.

Figure 15. Vehicle after Test 408460-2.

Before test



After test

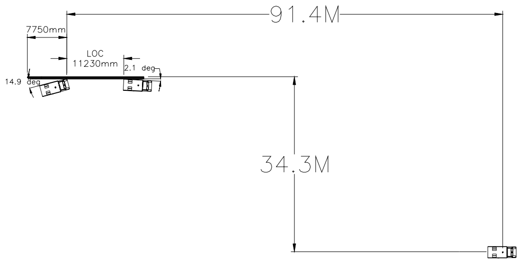
**Figure 16. Interior of Vehicle for Test 408460-2.**

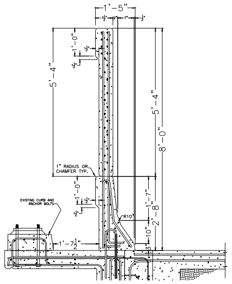
0.000 s

0.188 s

0.469 s

1.174 s





| | |
|---|---|
| **General Information** | |
| Test Agency | Texas Transportation Institute |
| Test No. | 408460-2 |
| Date | 11/29/00 |
| **Test Article** | |
| Type | Bridge Rail |
| Name | T501 bridge rail with concrete soundwall |
| Installation Length (ft) | 75.0 (22.9 m) |
| Material or Key Elements | T501 bridge rail with a cast-in-place 5ft-4" (1.6 m) tall concrete soundwall |
| **Soil Type and Condition** | Concrete pavement, dry |
| **Test Vehicle** | |
| Type | Production |
| Designation | 8000S |
| Model | 1988 GMC 7000 Single-unit truck |
| Mass (lb) | |
| Curb | 11,122 (5045 kg) |
| Test Inertial | 17,621 (8000 kg) |
| Dummy | No dummy |
| Gross Static | 17,621 (8000 kg) |

| | |
|---|---|
| **Impact Conditions** | |
| Speed (mi/h) | 54.8 (83.4 km/h) |
| Angle (deg) | 14.9 |
| **Exit Conditions** | |
| Speed (mi/h) | 46.7 (75.2 km/h) |
| Angle (deg) | 2.1 |
| **Occupant Risk Values** | |
| Impact Velocity (ft/s) | |
| x-direction | 7.9 (2.4 m/s) |
| y-direction | 13.8 (4.2 m/s) |
| THIV (mi/h) | 10.4 (16.8 km/h) |
| Ridedown Accelerations (g's) | |
| x-direction | -2.8 |
| y-direction | 10.2 |
| PHD (g's) | 10.6 |
| ASI | 0.72 |
| Max. 0.050-s Average (g's) | |
| x-direction | -2.6 |
| y-direction | 6.2 |
| z-direction | -1.8 |

| | |
|---|---|
| **Test Article Deflections** (ft) | |
| Dynamic | N/A |
| Permanent | N/A |
| Working Width | 1.1 (0.326 m) |
| **Vehicle Damage** | |
| Exterior | |
| VDS | N/A |
| CDC | N/A |
| Maximum Exterior Vehicle Crush (in.) | nil |
| Interior | |
| OCDI | FS0000000 |
| Max. Occ. Compart. Deformation (in.) | nil |
| **Post-Impact Behavior** | |
| (during 1.0 s after impact) | |
| Max. Yaw Angle (deg) | 28 |
| Max. Pitch Angle (deg) | 6 |
| Max. Roll Angle (deg) | 11 |

**Figure 17. Summary of Results for Test 408460-2, *NCHRP Report 350* Test 4-12.**

# IV. SUMMARY AND CONCLUSIONS

## ASSESSMENT OF TEST RESULTS

An assessment of each test based on the applicable *NCHRP Report 350* safety evaluation criteria is provided below.

### Test 408460-1 (*NCHRP Report 350* Test 4-11)

- **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 T501 bridge rail with soundwall contained and redirected the 2000P vehicle. The vehicle did not penetrate, underride, or override the bridge rail. No lateral deflection occurred.

- **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: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 160 mm in the right side firewall area and was not considered to be a probable cause of serious injury.

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

  Results: The vehicle remained upright during and after the collision.

- **Vehicle Trajectory**

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

Results: The vehicle came to rest 15.1 ft (4.6 m) forward of the face of the bridge rail, which would intrude into adjacent traffic lanes.

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

Results: Longitudinal occupant impact velocity was 21.7 ft/s (6.6 m/s) and ridedown acceleration was -6.5 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Results: Exit angle at loss of contact was 4.1 degrees, which was 16 percent of the impact angle.

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:

— **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

*Damage to windshield was from stress.

— **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 came to rest 15.1 ft (4.6 m) forward of the face of the bridge rail.

### — 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**

No debris were 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

*Damage to windshield was from stress.

## Test 408460-2 (*NCHRP Report 350* Test 4-12)

- **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 T501 bridge rail with soundwall contained and redirected the vehicle. The 8000S vehicle did not penetrate, underride, or override the bridge rail. No lateral deflection was noted.

- **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: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No deformation of the occupant compartment occurred.

G. *It is preferable, although not essential, that the vehicle remain upright during and after the collision.*

Results: The 8000S vehicle remained upright during and after the collision period.

- **Vehicle Trajectory**

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

Results: The vehicle came to rest 112.5 ft (34.3 m) forward of the face of the bridge rail, which would 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.*

Results: Exit angle at loss of contact was 2.1 degrees, which was 14 percent of the impact angle.

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:

— **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**
  No debris 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

The T501 bridge rail modified with a soundwall, constructed as previously described, performed well and satisfied the evaluation criteria presented in *NCHRP Report 350* for a Test Level 4 safety appurtenance. In addition, the 8 ft (2.4 m) height is considered by the researchers to be the critical or worst case of the two design heights under evaluation [6 ft (1.8 m) and 8 ft (2.4 m)] and expect the shorter installation to perform equally as well as the 8 ft (2.4m) installation.

## Table 1. Performance Evaluation Summary for Test 408460-1, *NCHRP Report 350* Test 4-11.

Test Agency: Texas Transportation Institute Test No.: 408460-1 Test Date: 11/21/2000

| ***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 T501 bridge rail with soundwall contained and redirected the 2000P vehicle. The vehicle did not penetrate, underride, or override the bridge rail. No lateral deflection occurred. | 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. | No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 6.3 in. (160 mm) in the right side firewall area and was not considered to be a probable cause of serious injury. | Pass |
| F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable. | The 2000P vehicle remained upright during and after the collision period. | Pass |
| Vehicle Trajectory | | |
| K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes. | The vehicle came to rest 15.1 ft (4.6 m) forward of the face of the bridge rail which would intrude into adjacent traffic lanes. | Fail* |
| 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 21.7 ft/s (6.6 m/s) and ridedown acceleration was -6.5 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 4.1 degrees which was 16 percent of the impact angle. | Pass* |

*Criterion K and M are preferable, not required.

### Table 2. Performance Evaluation Summary for Test 408460-2, *NCHRP Report 350* Test 4-12.

Test Agency: Texas Transportation Institute | Test No.: 408460-2 | Test Date: 11/29/2000

| ***NCHRP Report 350* Evaluation Criteria** | **Test Results** | **Assessment** |
|---|---|---|
| Structural Adequacy<br>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 T501 bridge rail with soundwall contained and redirected the vehicle. The 8000S vehicle did not penetrate, underride, or override the bridge rail. No lateral deflection was noted. | Pass |
| Occupant Risk<br>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. | No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No deformation of the occupant compartment occurred. | Pass |
| G. It is preferable, although not essential, that the vehicle remain upright during and after collision. | The 8000S vehicle remained upright during and after the collision period. | Pass* |
| Vehicle Trajectory<br>K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes. | The vehicle came to rest 112.5 ft (34.3 m) forward of the face of the bridge rail which would intrude into adjacent traffic lanes. | 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 was 2.1 degrees which was 14 percent of the impact angle. | Pass* |

*Criterion G, K, and M are 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. Dwight A. Horne, *Crash Testing of Bridge Railings*, FHWA Memorandum, May 30, 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 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. 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 separate tracks of a 28 track, (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine 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 SAE J211 class 180 phaseless digital filtering and vehicle impact velocity.

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 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-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, Low Pass 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 system being initial impact.

## ANTHROPOMORPHIC DUMMY INSTRUMENTATION

Use of a dummy in tests the 2000P and 8000S vehicles is optional according to *NCHRP Report 350* and there was no dummy used in these tests.

## 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 to have a field of view parallel to and aligned with the installation at the upstream end; 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 was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A BetaCam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

## TEST VEHICLE PROPULSION AND GUIDANCE

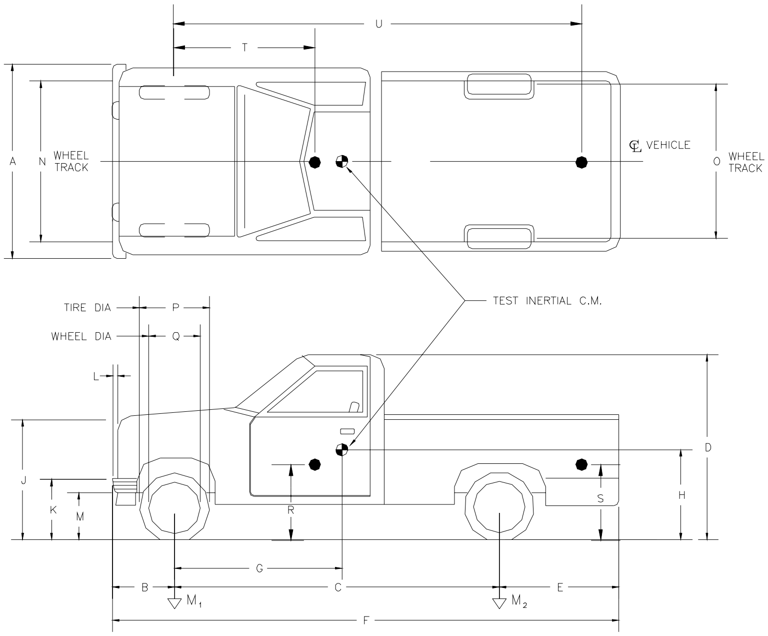
The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 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: 11/21/00
TEST NO.: 408460-1
VIN NO.: 1GCGC24RXTE169394
YEAR: 1996
MAKE: Chevrolet
MODEL: Cheyenne 2500 Pickup Truck
TIRE INFLATION PRESSURE: ________
ODOMETER: 159535
TIRE SIZE: LT 245 75R16

MASS DISTRIBUTION (kg) LF 578 RF 549 LR 430 RR 443

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ________

ENGINE TYPE: 8 CYL
ENGINE CID: 5.7L
TRANSMISSION TYPE:
__ AUTO
X MANUAL
OPTIONAL EQUIPMENT:

DUMMY DATA:
TYPE: ________
MASS: ________
SEAT POSITION: ________

GEOMETRY – (mm)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| A | 1820 | E | 1310 | J | 1090 | N | 1605 | R | 730 |
| B | 840 | F | | K | 665 | O | 1620 | S | 900 |
| C | 3350 | G | 1428.28 | L | 63 | P | 750 | T | 1440 |
| D | 1820 | H | | M | 445 | Q | 445 | U | 3370 |

| MASS – (kg) | CURB | TEST INERTIAL | GROSS STATIC |
|---|---|---|---|
| $M_1$ | 1233 | 1127 | |
| $M_2$ | 869 | 873 | |
| $M_T$ | 2102 | 2000 | |

Figure 18. Vehicle Properties for Test 408460-1.

## Table 3. Exterior Crush Measurements for Test 408460-1.

### 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)<br>(check one)<br>< 4 inches ________<br>$ 4 inches ________ | Bowing constant<br>$\frac{X1 + X2}{2}$ = ____ |

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 | At front bumper | 1140 | 450 | 1470 | -100 | -20 | -10 | 40 | 140 | 450 | 0 |
| 2 | 880 mm above ground | 1140 | 460 | 1080 | 30 | 190 | 250 | 320 | 340 | 460 | +1570 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

[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.

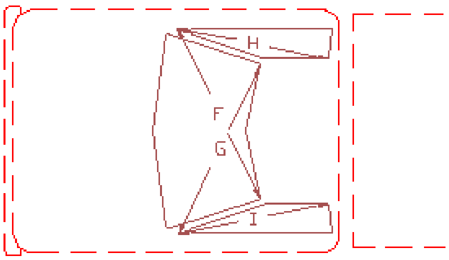
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

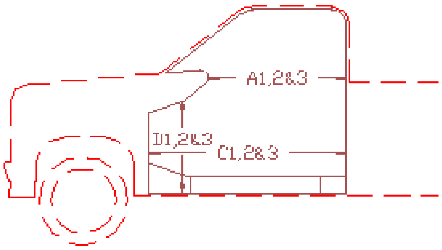
***Measure and document on the vehicle diagram the location of the maximum crush.
Note: Use as many lines/columns as necessary to describe each damage profile.

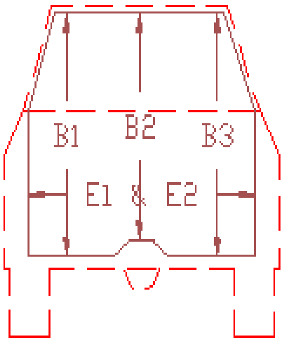
### Table 4. Occupant Compartment Measurements for Test 408460-1.

# Truck

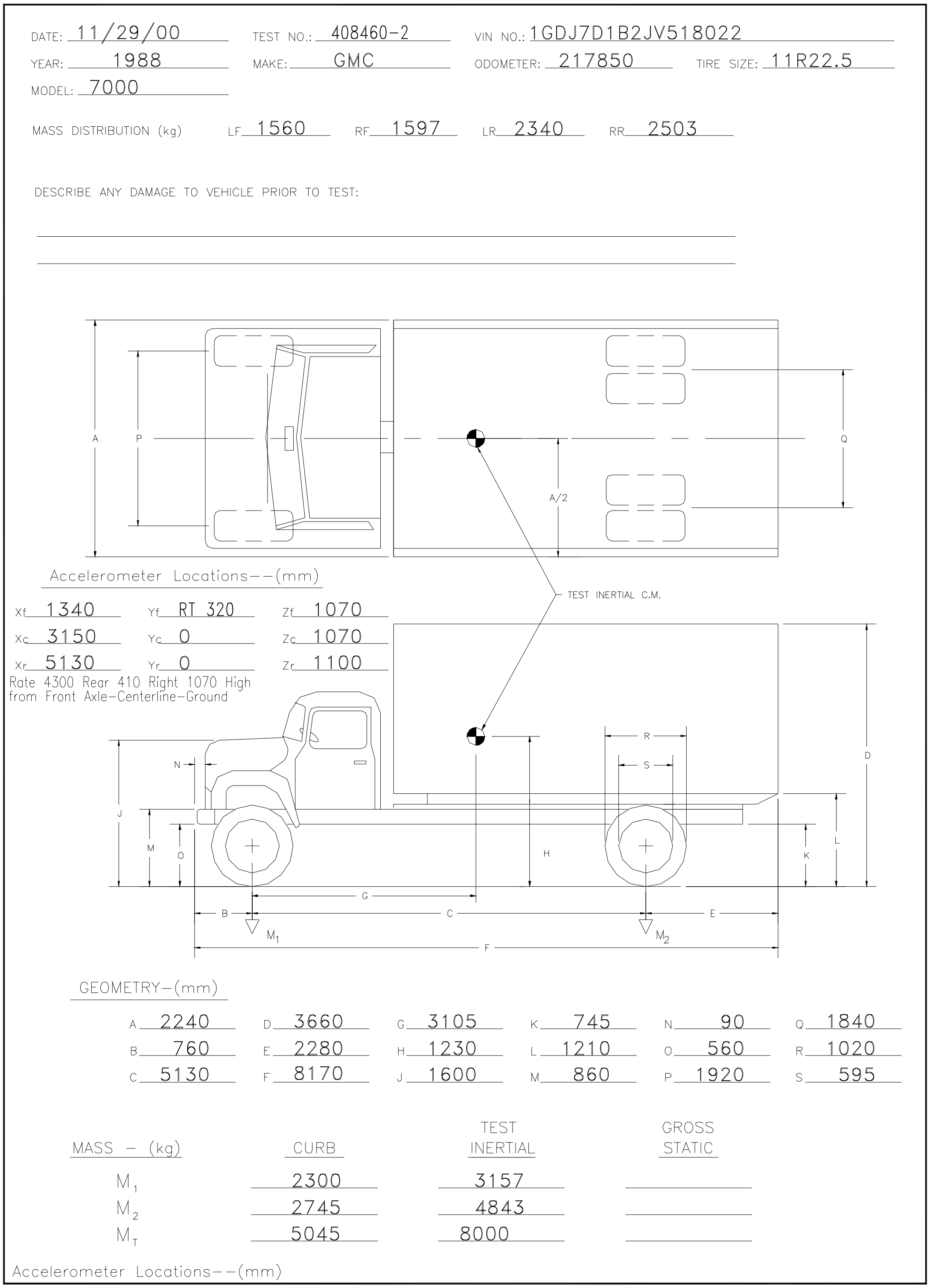
## Occupant Compartment Deformation







| | BEFORE | AFTER |
|---|---|---|
| A1 | 902 | 919 |
| A2 | 895 | 875 |
| A3 | 911 | 851 |
| B1 | 1082 | 1077 |
| B2 | 1053 | 1033 |
| B3 | 1074 | 1058 |
| C1 | 1372 | 1372 |
| C2 | 1354 | 1325 |
| C3 | 1371 | 1211 |
| D1 | 313 | 327 |
| D2 | 159 | 182 |
| D3 | 317 | 250 |
| E1 | 1591 | 1607 |
| E2 | 1595 | 1641 |
| F | 1463 | 1442 |
| G | 1463 | 1454 |
| H | 1245 | 1245 |
| I | 1245 | 1179 |
| J | 1525 | 1475 |



DATE: 11/29/00 TEST NO.: 408460-2 VIN NO.: 1GDJ7D1B2JV518022

YEAR: 1988 MAKE: GMC ODOMETER: 217850 TIRE SIZE: 11R22.5

MODEL: 7000

MASS DISTRIBUTION (kg) LF 1560 RF 1597 LR 2340 RR 2503

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Accelerometer Locations--(mm)

| | | | | | |
|---|---|---|---|---|---|
| Xf | 1340 | Yf | RT 320 | Zf | 1070 |
| Xc | 3150 | Yc | 0 | Zc | 1070 |
| Xr | 5130 | Yr | 0 | Zr | 1100 |

Rate 4300 Rear 410 Right 1070 High from Front Axle-Centerline-Ground

GEOMETRY-(mm)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 2240 | D | 3660 | G | 3105 | K | 745 | N | 90 | Q | 1840 |
| B | 760 | E | 2280 | H | 1230 | L | 1210 | O | 560 | R | 1020 |
| C | 5130 | F | 8170 | J | 1600 | M | 860 | P | 1920 | S | 595 |

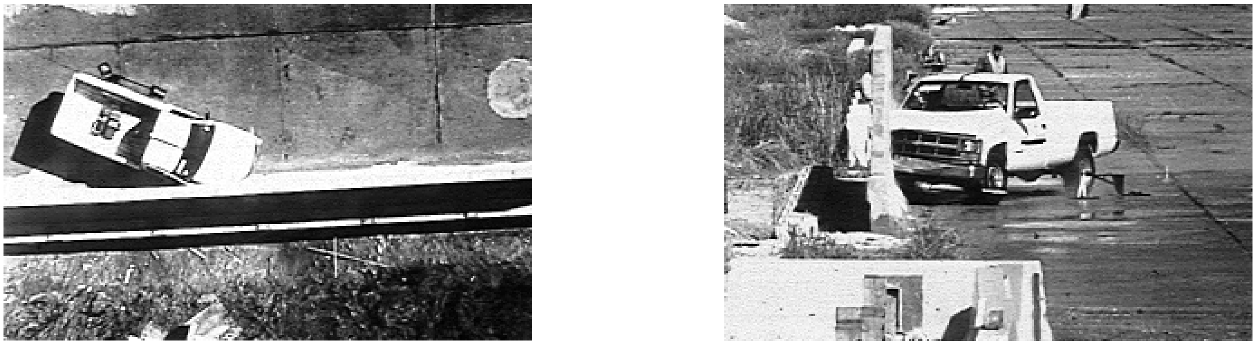
| MASS - (kg) | CURB | TEST INERTIAL | GROSS STATIC |
|---|---|---|---|
| $M_1$ | 2300 | 3157 | |
| $M_2$ | 2745 | 4843 | |
| $M_T$ | 5045 | 8000 | |

Accelerometer Locations--(mm)

Figure 19. Vehicle Properties for Test 408460-2.

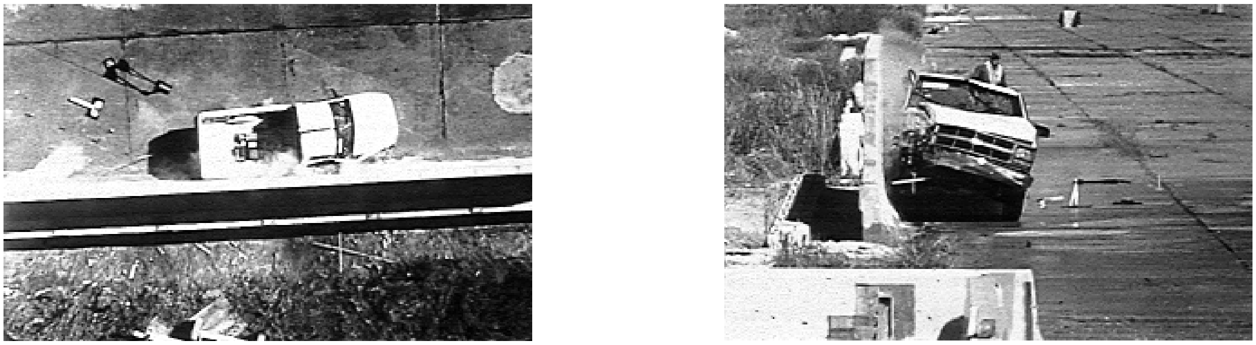
# APPENDIX C. SEQUENTIAL PHOTOGRAPHS

0.000 s



0.047 s

0.117 s



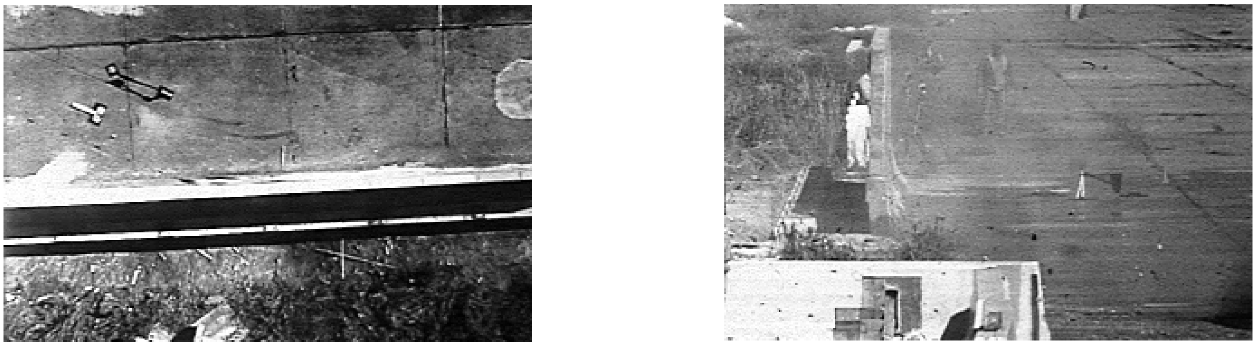
0.211 s

**Figure 20. Sequential Photographs for Test 408460-1 (Overhead and Frontal Views).**

0.422 s

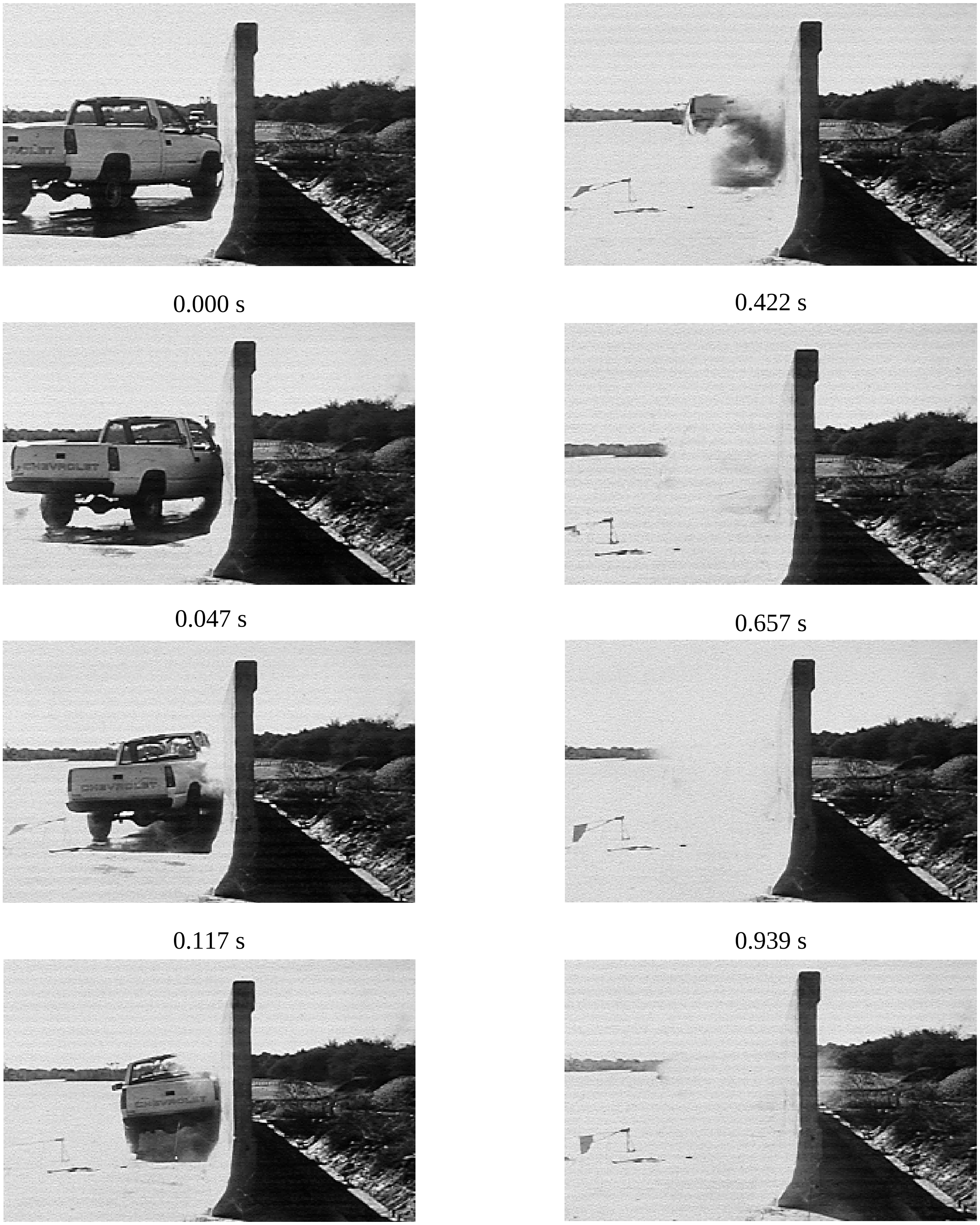
0.656 s

0.939 s



2.018 s

**Figure 20. Sequential Photographs for Test 408460-1 (Overhead and Frontal Views) (continued).**



0.000 s

0.047 s

0.117 s

0.211 s

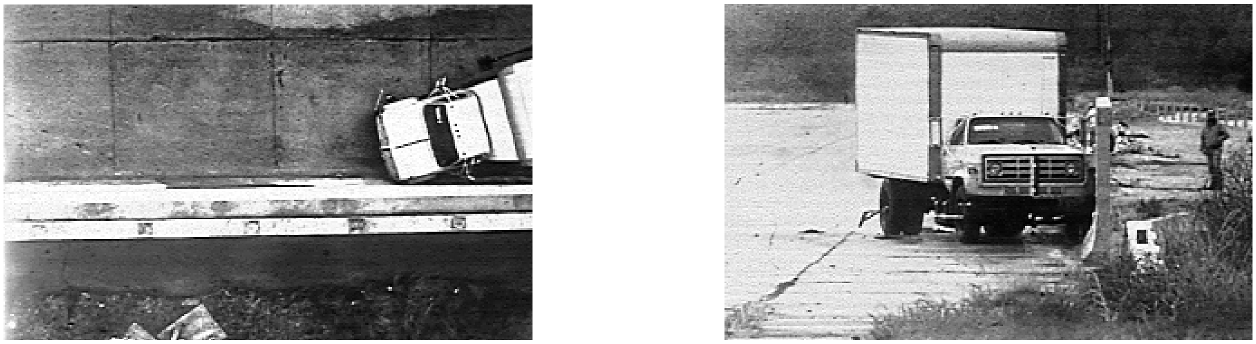
0.422 s

0.657 s

0.939 s

2.018 s

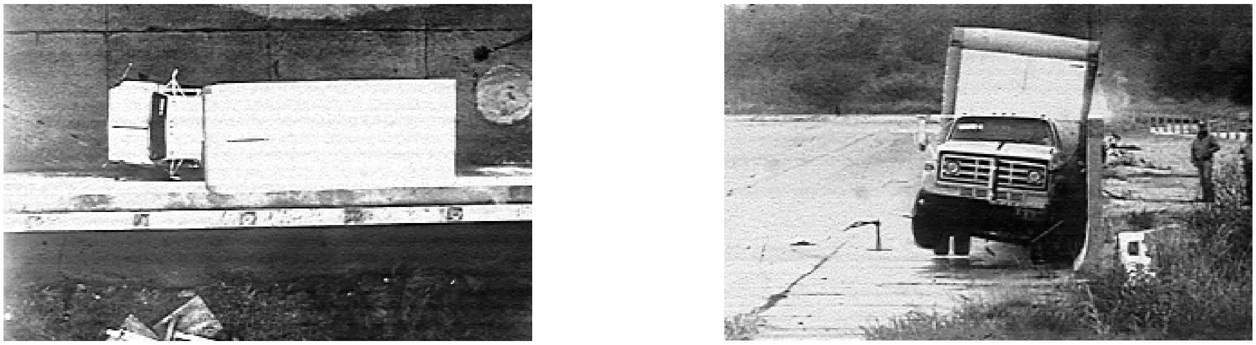
**Figure 21. Sequential Photographs for Test 408460-1 (Rear View).**



0.000 s

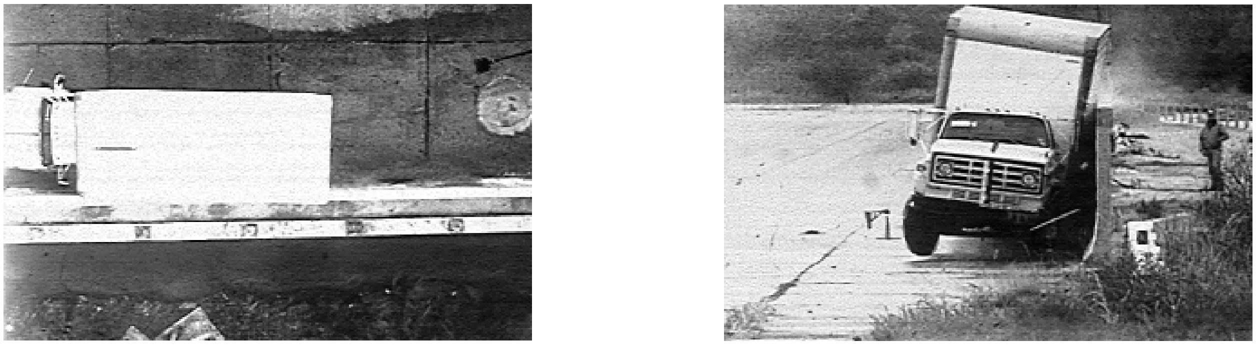
0.094 s

0.188 s

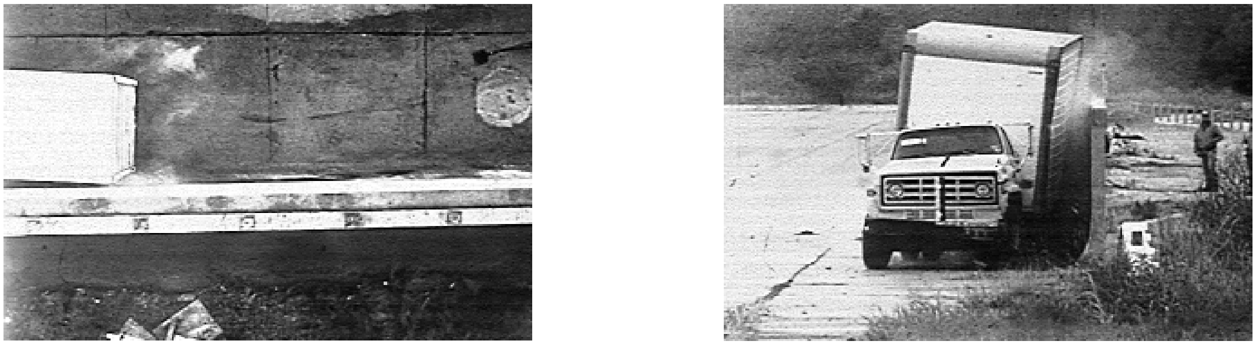


0.329 s

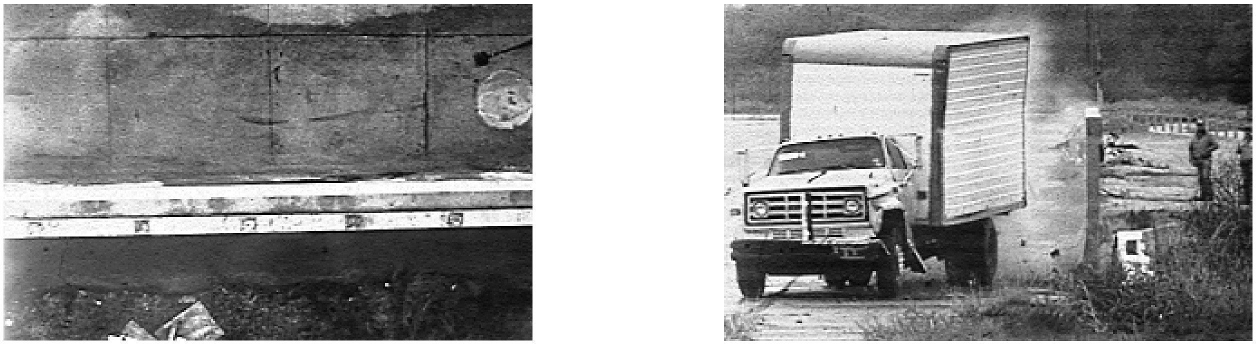
**Figure 22. Sequential Photographs for Test 408460-2 (Overhead and Frontal Views).**



0.469 s



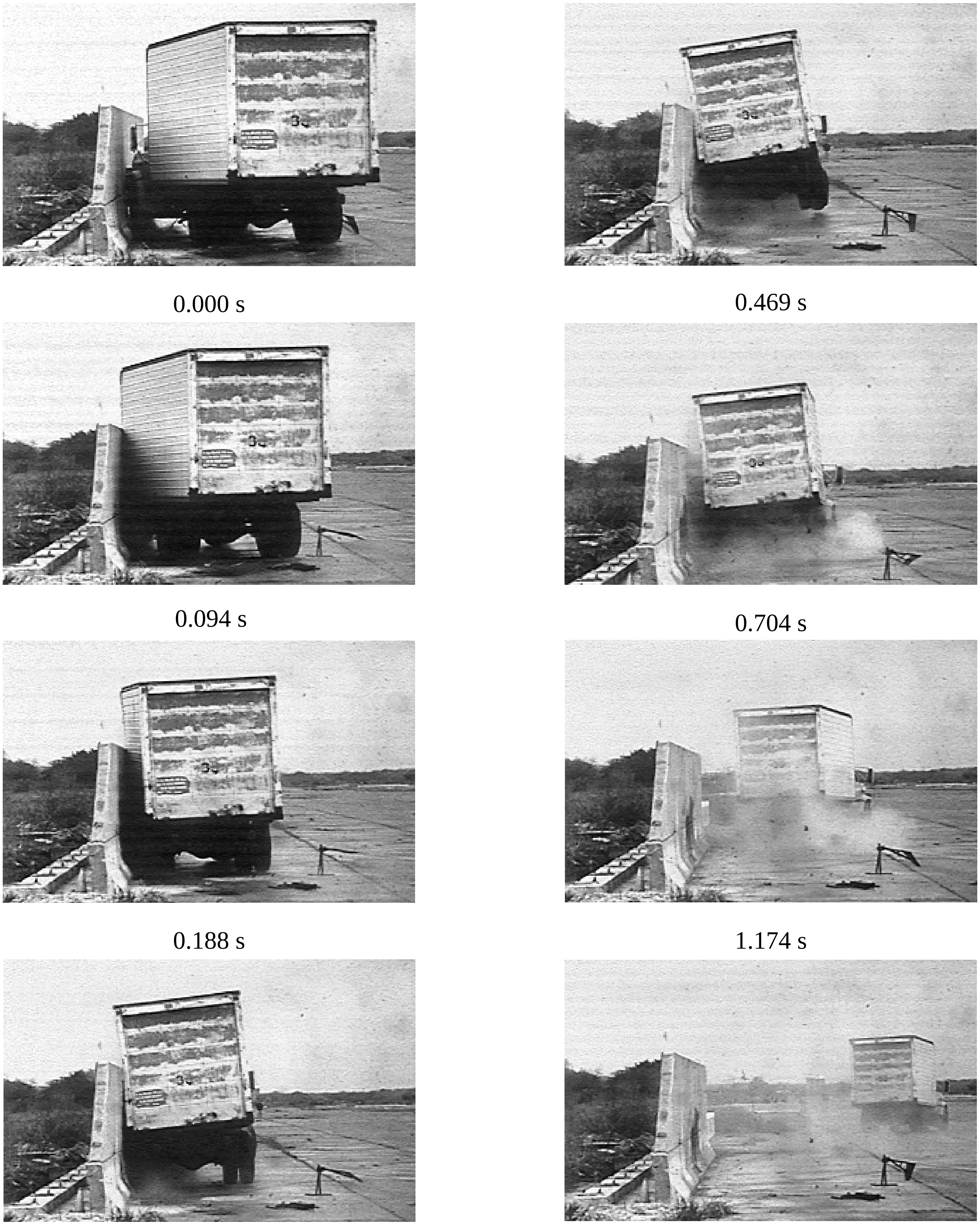
0.704 s



1.174 s

2.347 s

**Figure 22. Sequential Photographs for Test 408460-2 (Overhead and Frontal Views) (continued)**.



0.000 s

0.469 s

0.094 s

0.704 s

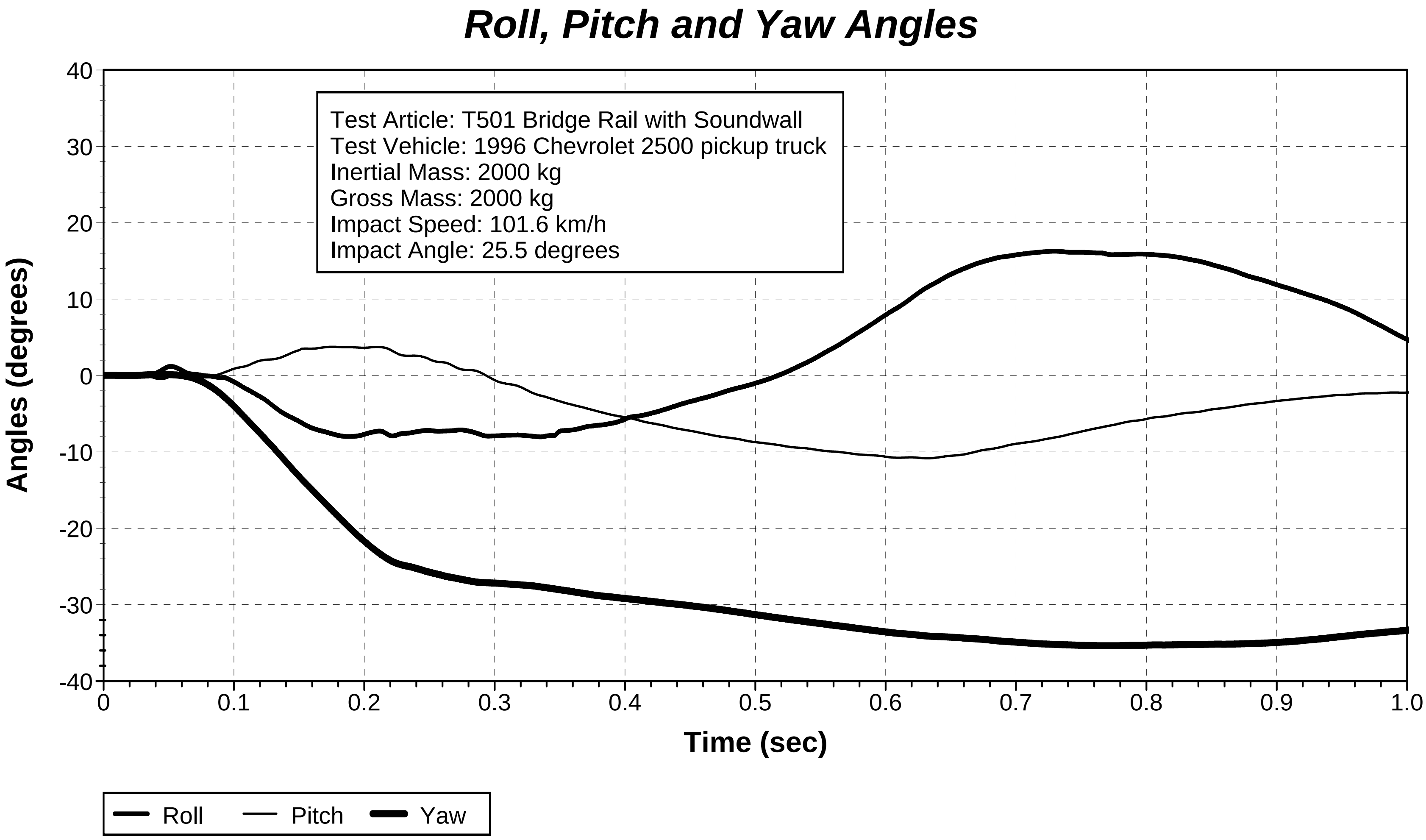
0.188 s

1.174 s

0.329 s

2.347 s

**Figure 23. Sequential Photographs for Test 408460-2 (Rear View)**.



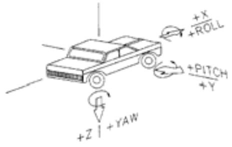
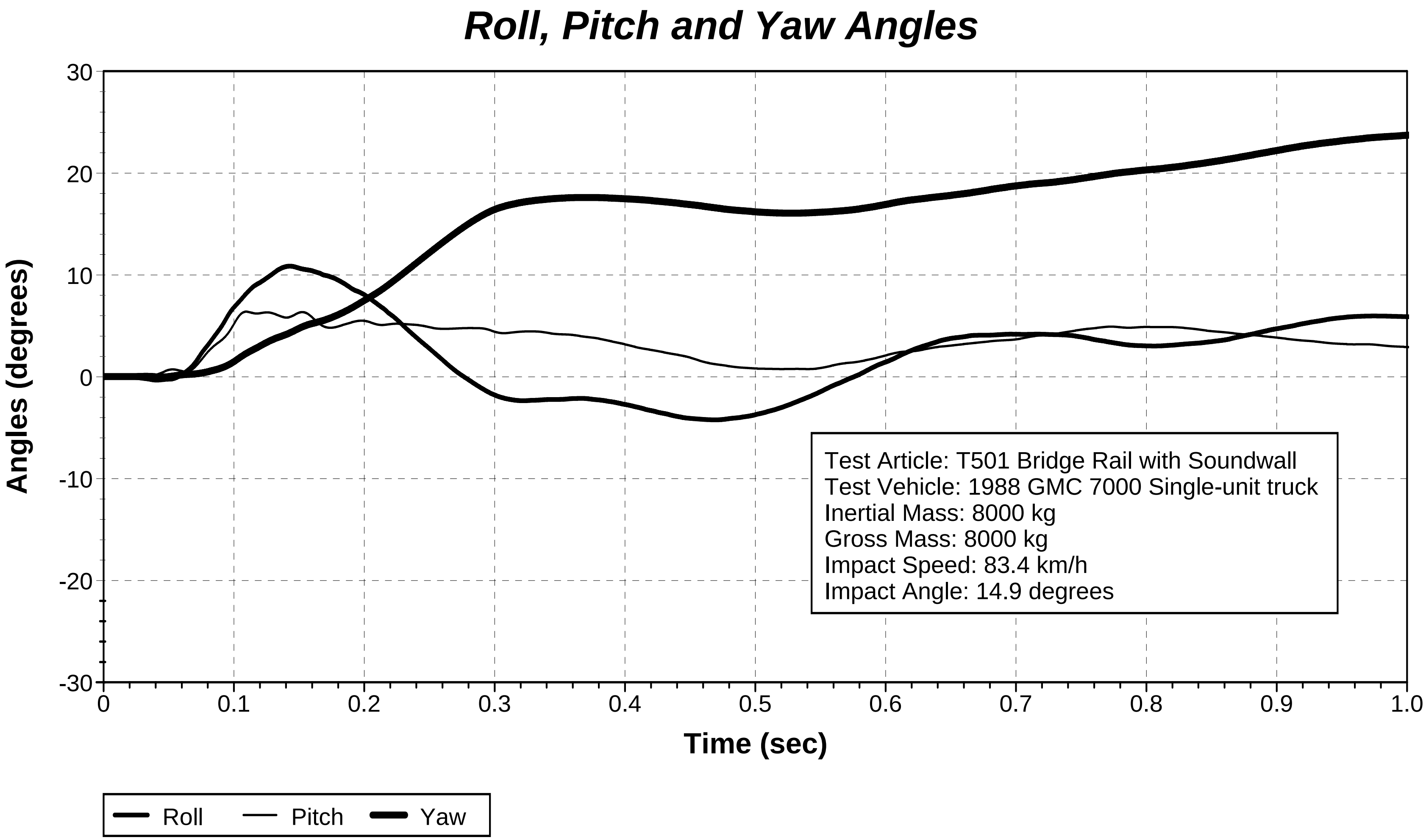


Figure 24. Vehicular Angular Displacements for Test 408460-1.



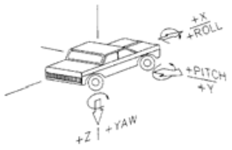
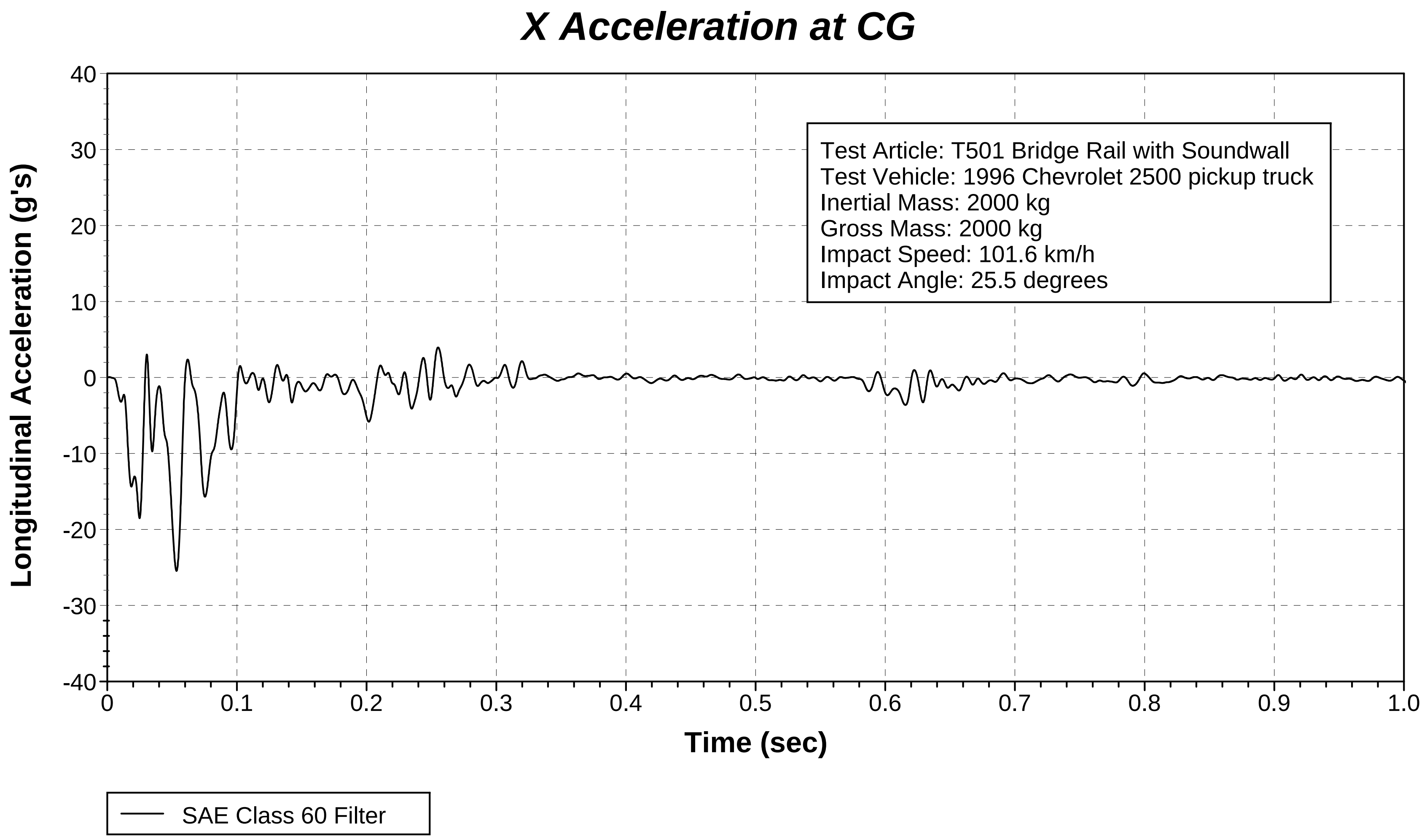


Figure 25. Vehicular Angular Displacements for Test 408460-2.



Test Article: T501 Bridge Rail with Soundwall
Test Vehicle: 1996 Chevrolet 2500 pickup truck
Inertial Mass: 2000 kg
Gross Mass: 2000 kg
Impact Speed: 101.6 km/h
Impact Angle: 25.5 degrees

**Figure 26. Vehicle Longitudinal Accelerometer Trace for Test 408460-1 (Accelerometer Located at Center of Gravity).**

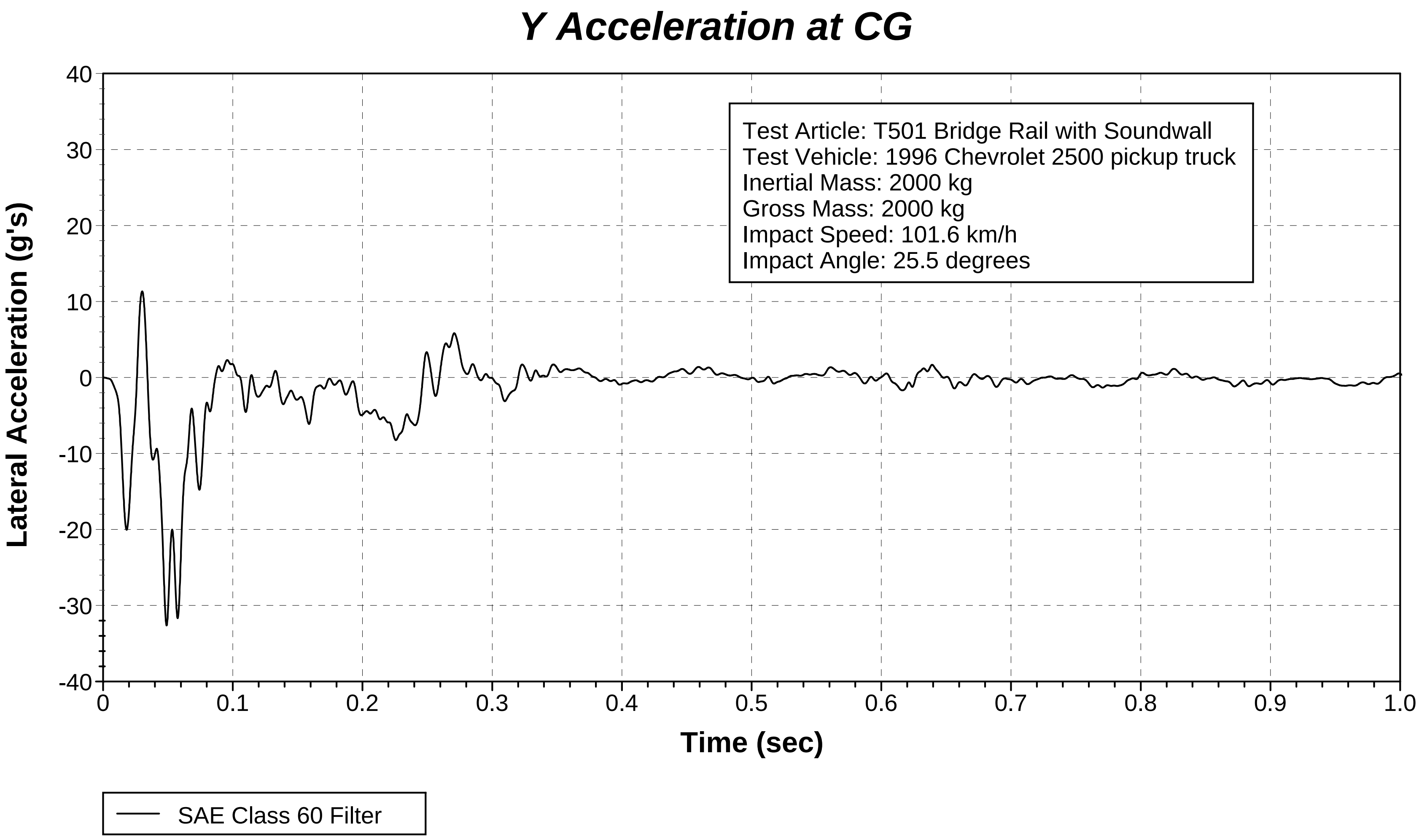


**Figure 27. Vehicle Lateral Accelerometer Trace for Test 408460-1 (Accelerometer Located at Center of Gravity).**

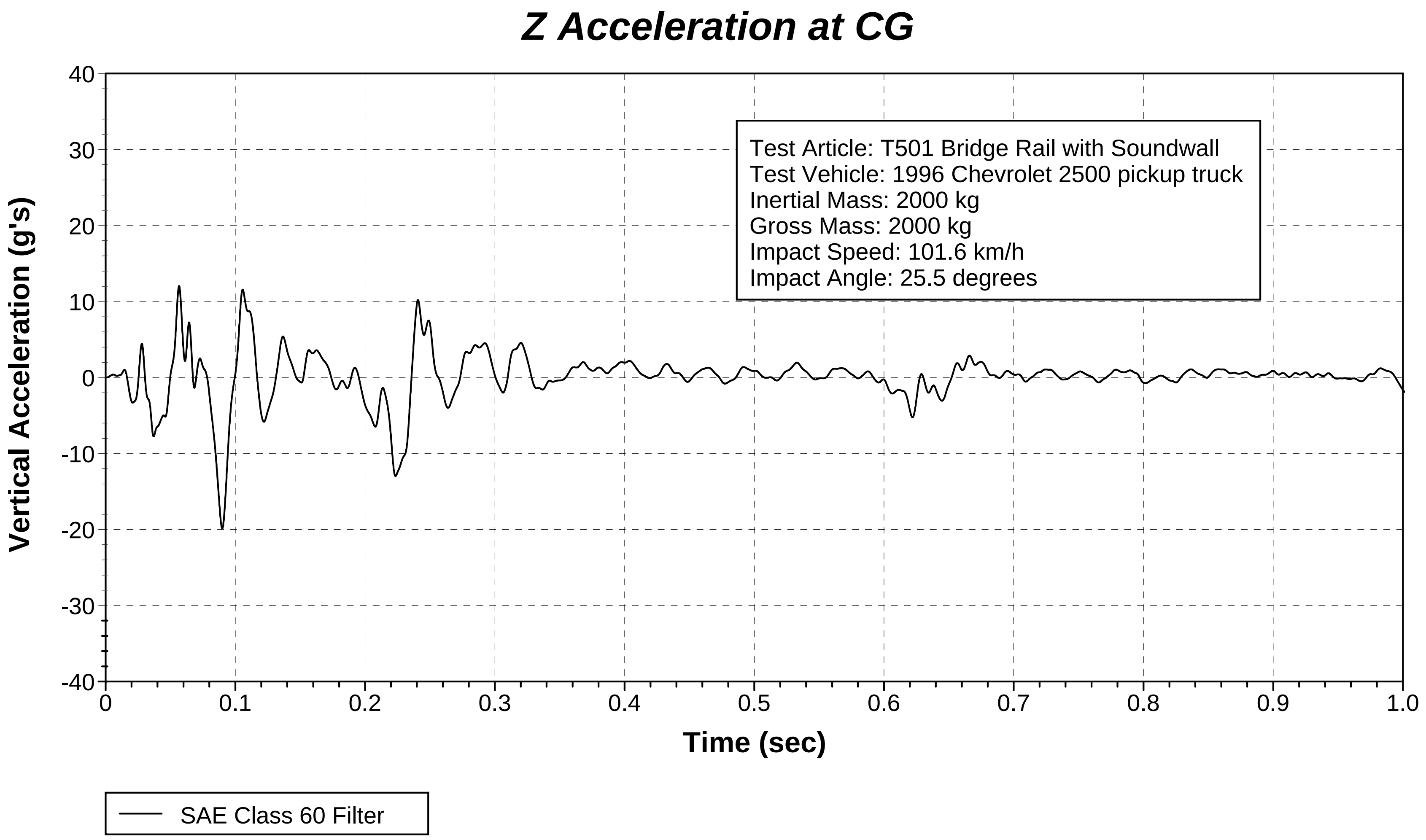


**Figure 28. Vehicle Vertical Accelerometer Trace for Test 408460-1 (Accelerometer Located at Center of Gravity).**

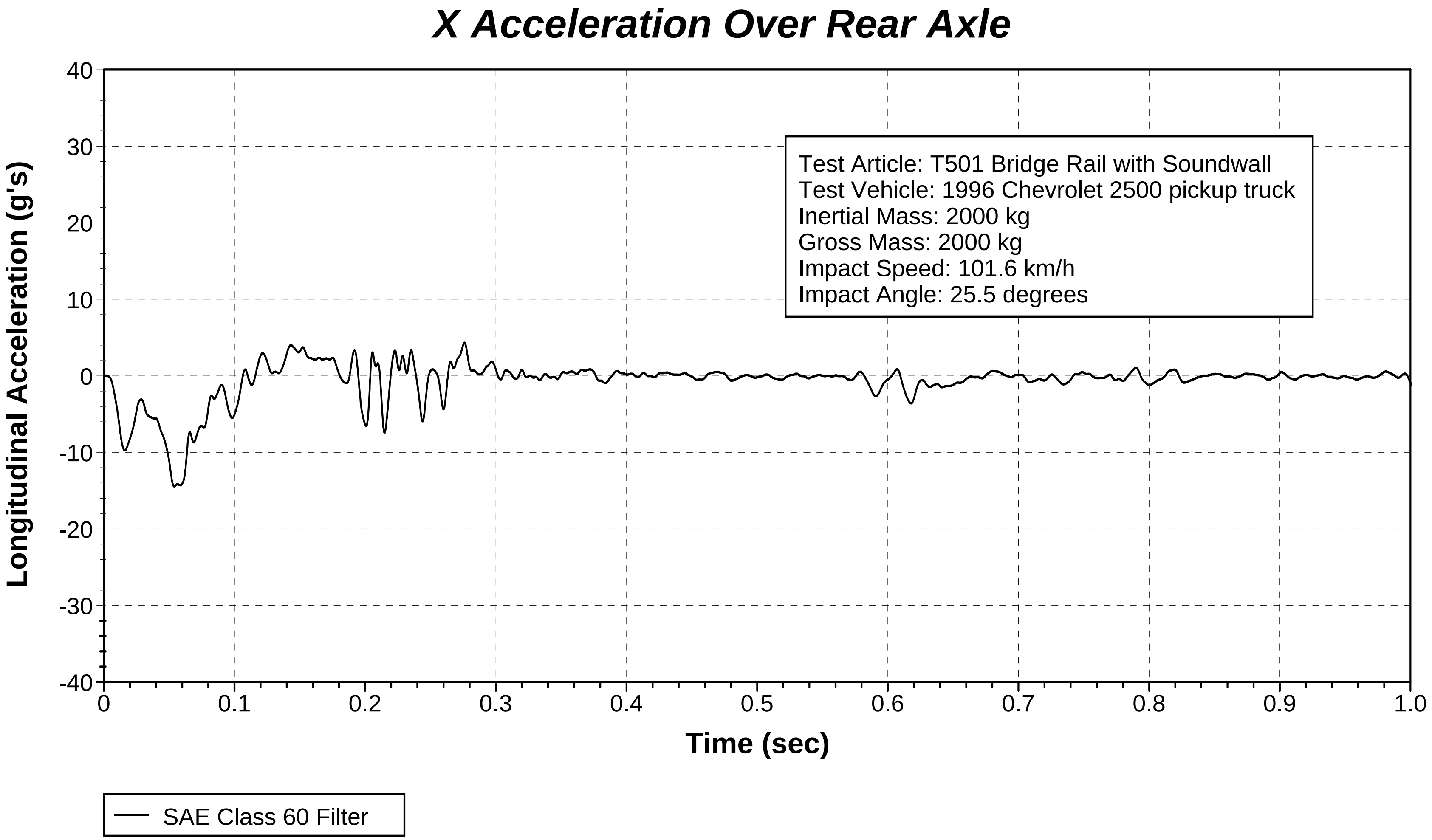
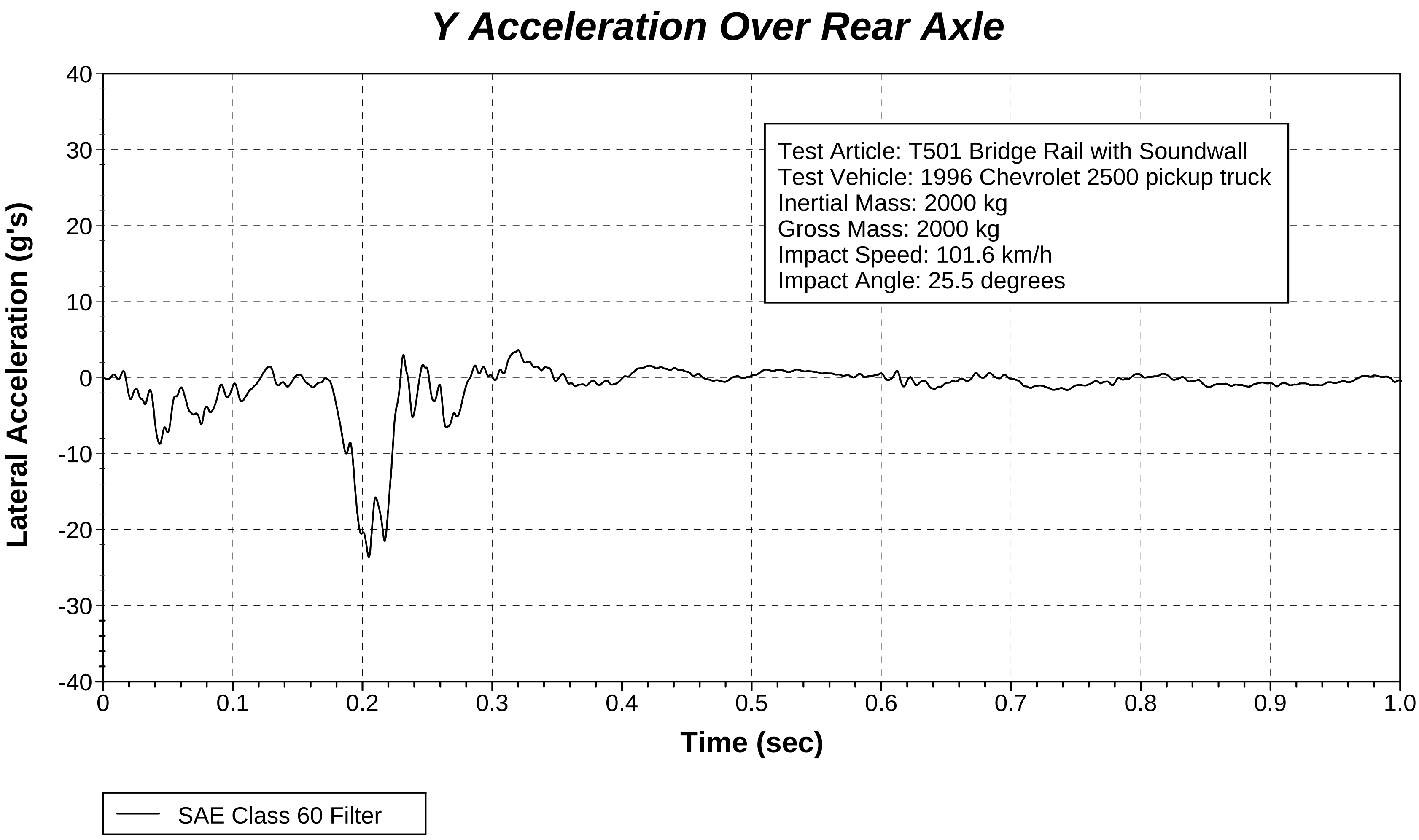


**Figure 29. Vehicle Longitudinal Accelerometer Trace for Test 408460-1 (Accelerometer Located Over Rear Axle).**



Test Article: T501 Bridge Rail with Soundwall
Test Vehicle: 1996 Chevrolet 2500 pickup truck
Inertial Mass: 2000 kg
Gross Mass: 2000 kg
Impact Speed: 101.6 km/h
Impact Angle: 25.5 degrees

**Figure 30. Vehicle Lateral Accelerometer Trace for Test 408460-1 (Accelerometer Located Over Rear Axle).**

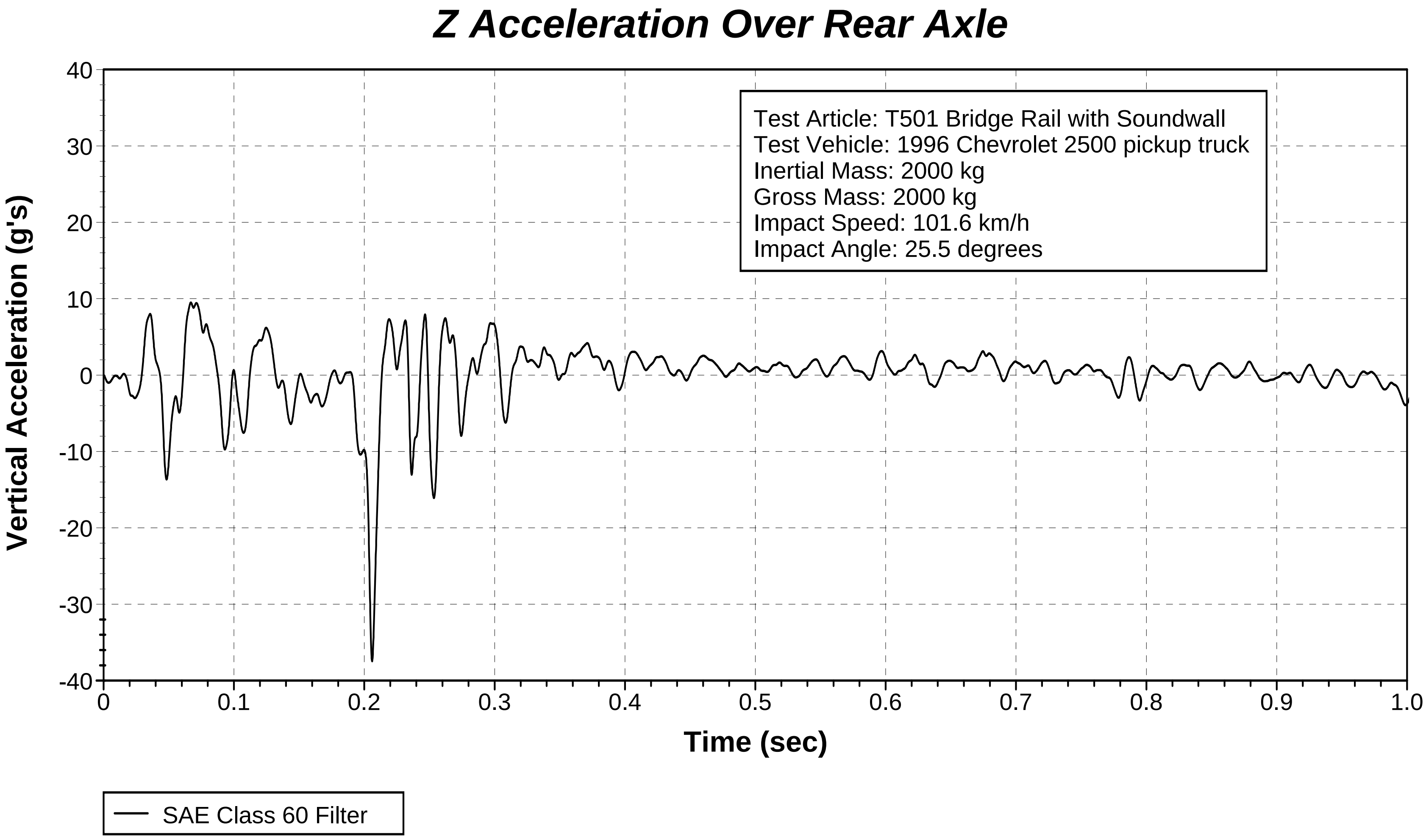


**Figure 31. Vehicle Vertical Accelerometer Trace for Test 408460-1 (Accelerometer Located Over Rear Axle).**

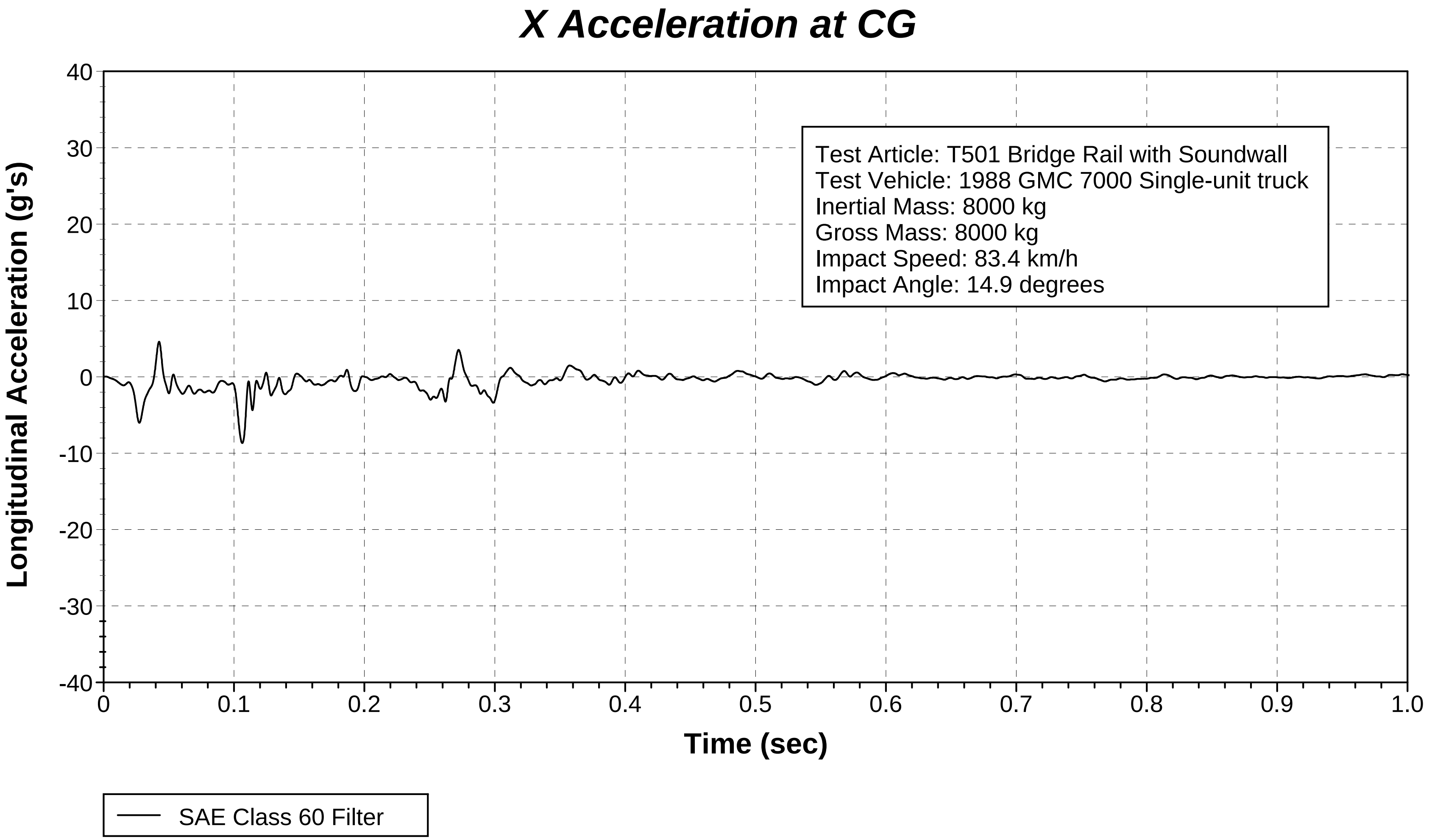


**Figure 32. Vehicle Longitudinal Accelerometer Trace for Test 408460-2 (Accelerometer Located at Center of Gravity).**

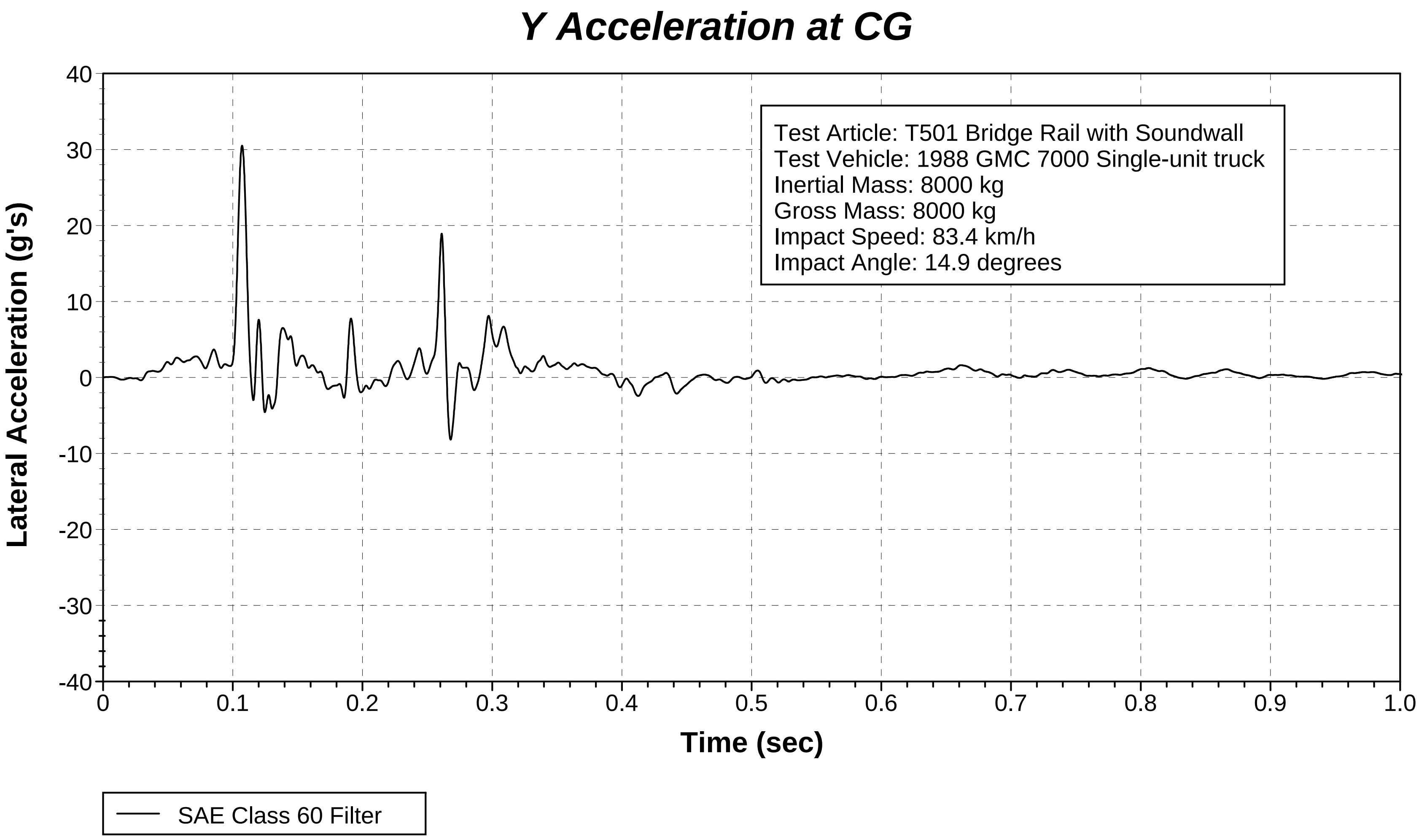


**Figure 33. Vehicle Lateral Accelerometer Trace for Test 408460-2 (Accelerometer Located at Center of Gravity).**

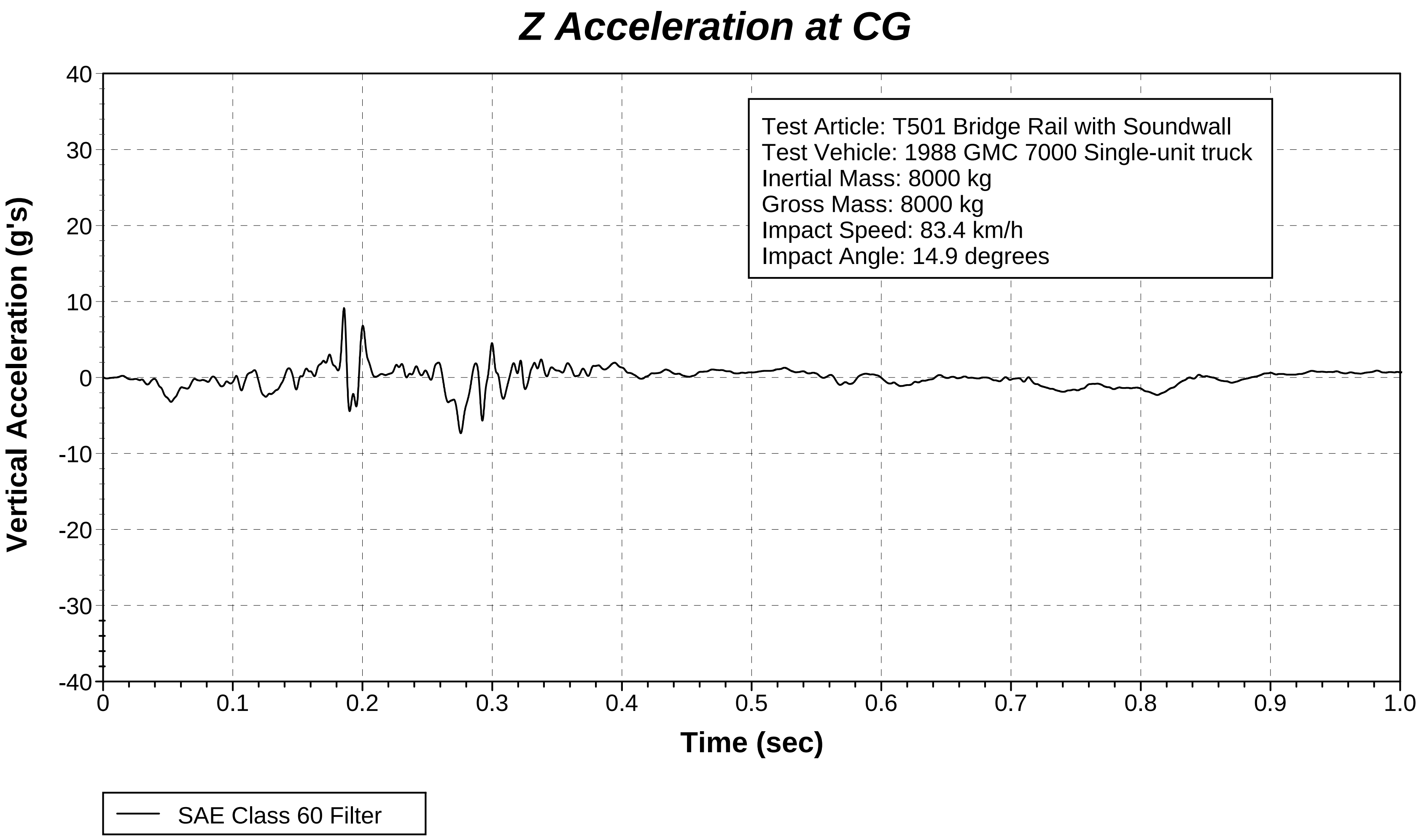


Figure 34. Vehicle Vertical Accelerometer Trace for Test 408460-2 (Accelerometer Located at Center of Gravity).

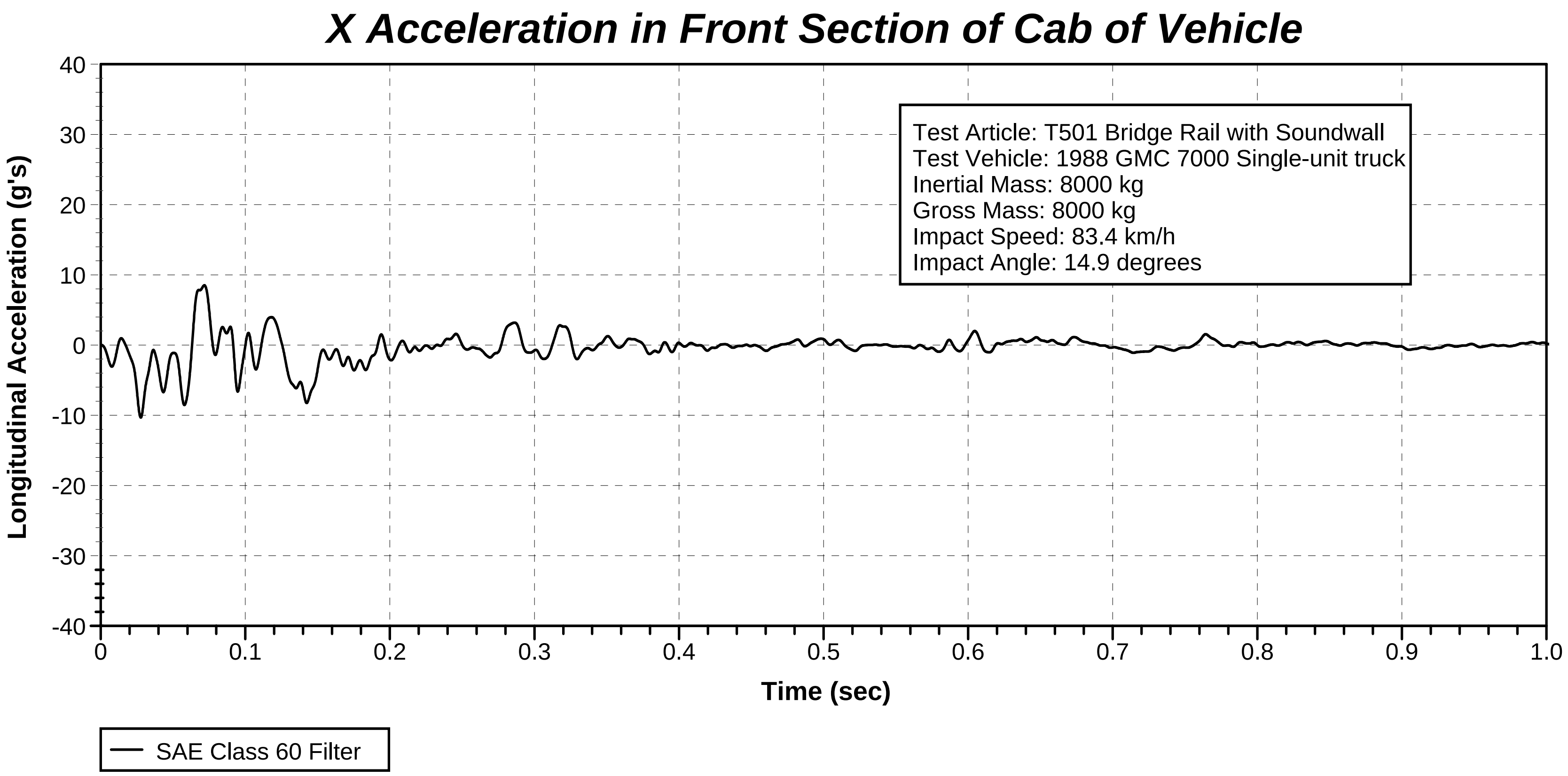


**Figure 35. Vehicle Longitudinal Accelerometer Trace for Test 408460-2 (Accelerometer Located in Cab of Vehicle).**

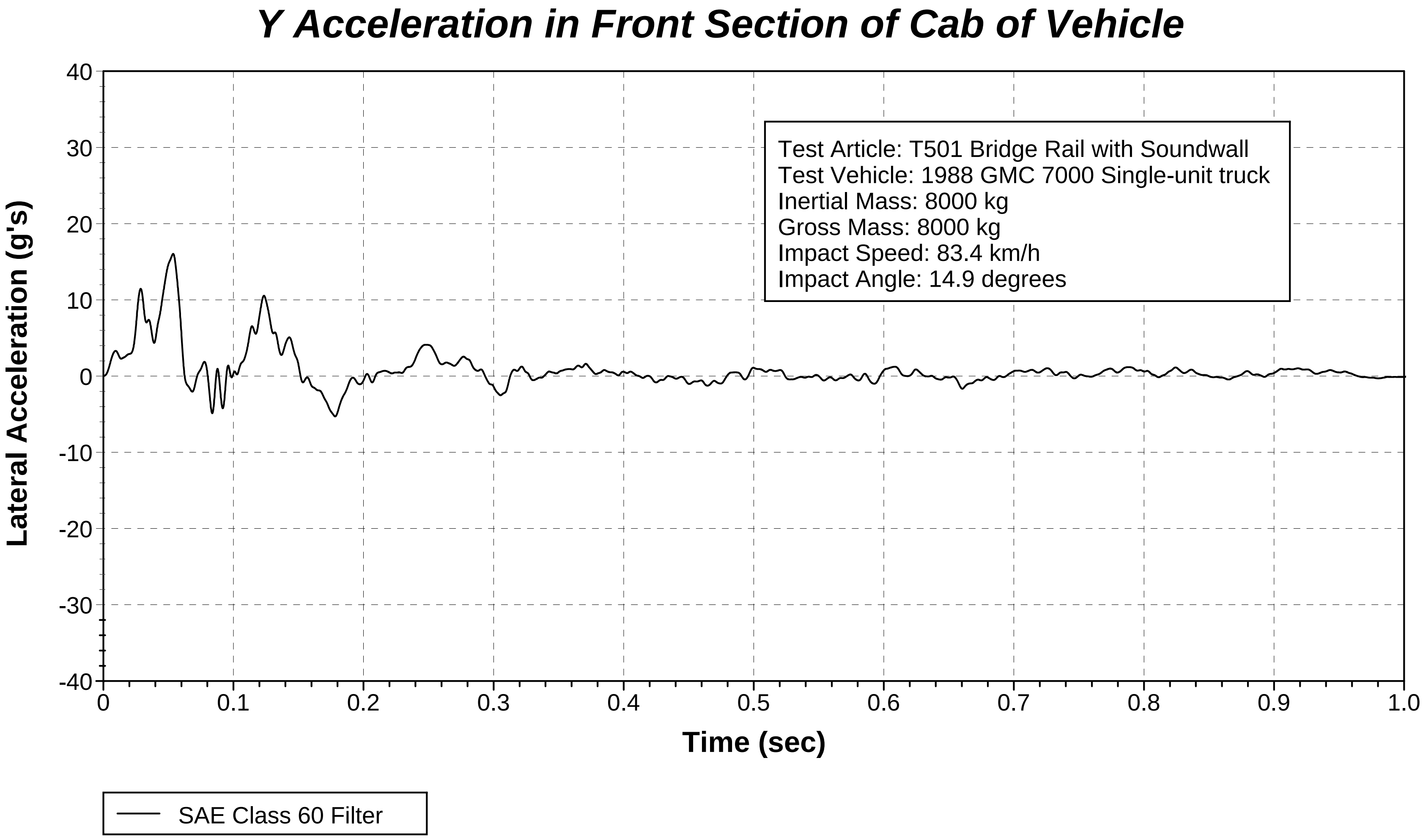


**Figure 36. Vehicle Lateral Accelerometer Trace for Test 408460-2 (Accelerometer Located in Cab of Vehicle).**

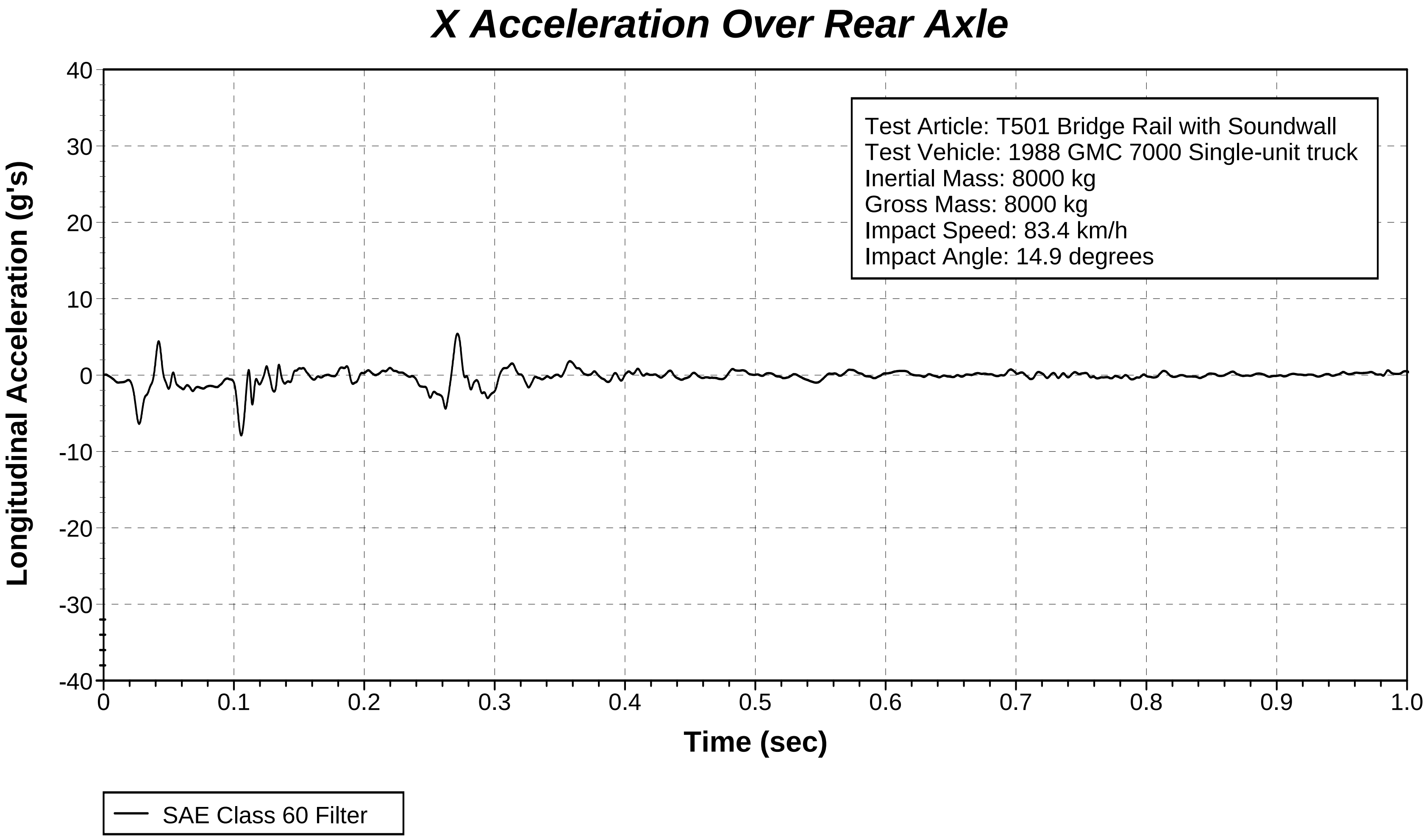


**Figure 37. Vehicle Longitudinal Accelerometer Trace for Test 408460-2 (Accelerometer Located Over Rear Axle).**

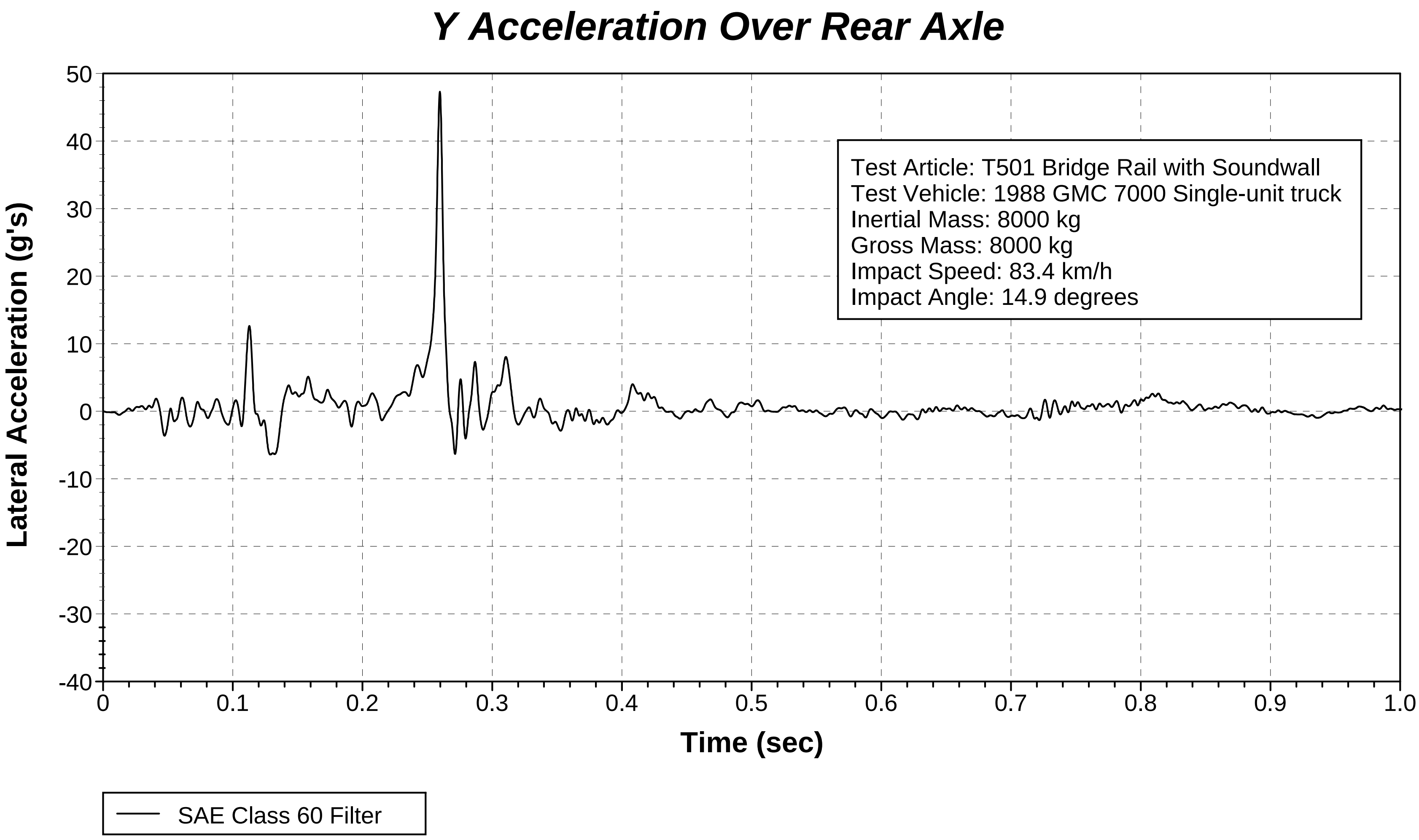


**Figure 38. Vehicle Lateral Accelerometer Trace for Test 408460-2 (Accelerometer Located Over Rear Axle).**