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16. Abstract

The Texas Type T4(A) Bridge Rail is the fourth bridge rail selected for NCHRP Report 350 evaluation under this project. The Texas Type T4(A) Bridge Rail is a combination vertical wall and aluminum post which was approved for use (through comparative strength analysis to the North Carolina One-Bar Bridge Rail) under NCHRP Report 230 guidelines. With the adoption of NCHRP Report 350, the performance of the bridge rail needed to be evaluated using the 2000 kg pickup truck.

This report presents the details and results of the NCHRP Report 350 test 3-11 of the Texas Type T4(A) Bridge Rail. The bridge rail successfully contained and redirected the 2000 kg pickup truck, which remained upright during and after the collision. However, the maximum deformation of the occupant was 158 mm, which was considered marginal as to whether or not serious injuries would be incurred by occupants of the vehicle. Therefore, the Texas Type T4(A) Bridge Rail was considered marginally acceptable according to specifications for NCHRP Report 350 test designation 3-11.

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TEST 7: NCHRP REPORT 350 TEST 3-11
OF THE TEXAS TYPE T4(A) BRIDGE RAIL

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and Transitions to NCHRP Report 350 Criteria

Sponsored by the
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I. INTRODUCTION

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

Changes incorporated into the new NCHRP Report 350 guidelines include new design test vehicles, expanded test matrices, and revised impact conditions. Of most significance was the adoption of a 2000 kg pickup truck as the design test vehicle for structural adequacy tests. This change has necessitated the retesting and reevaluation of the impact performance of many existing roadside safety features. Through various pool-funded studies and research projects, FHWA tests some of the most widely used safety appurtenances, including several bridge rails and transitions. However, this testing has not been all-inclusive and some bridge rails unique to the Texas Department of Transportation (TxDOT) have not been crash tested to the new NCHRP Report 350 guidelines. Therefore, there is a need for assessing the safety performance of these railings and, if necessary, modifying the designs to meet the requirements of NCHRP Report 350 in order to permit their continued use beyond the October 1998 deadline.

Throughout the years, the Texas Transportation Institute (TTI) and TxDOT have worked jointly on the development, evaluation, and testing of many TxDOT standard bridge rail designs. This cooperative research has resulted in many satisfactory designs with demonstrated impact performance that have been successfully implemented by the department. This project is an extension of this previous work under which the performance of selected railing and transition designs is being evaluated both analytically and experimentally through full-scale crash testing to assess compliance with the new NCHRP Report 350 performance criteria.

In the first task, TTI researchers identified all bridge rails and transitions similar to those used in Texas that have already been tested or were scheduled to be tested. The researchers reviewed all previous testing on current TxDOT railing designs and any related tests on other similar designs to document any existing test results that demonstrate acceptability of the railing designs by NCHRP Report 350 standards.

In the second task, TTI researchers presented TxDOT with a list of untested bridge rails and transitions, along with needed testing for these designs. The untested bridge rails and transitions believed to have long-term usage potential to TxDOT were selected and prioritized for full-scale testing.

During task three, the first step of evaluation was a simple analysis of strength and geometry in accordance with railing provisions of the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) code, supplemented by other information available to the researchers *(3)*.

The Texas Type T4(A) Bridge Rail is the fourth bridge rail selected for NCHRP Report 350 evaluation under this project. The Texas Type T4(A) Bridge Rail is a combination vertical wall and aluminum post and railing guardrail system which was approved for use (through comparative strength analysis to the North Carolina One-Bar Bridge Rail) under NCHRP Report 230 guidelines *(4)*. With the adoption of NCHRP Report 350, the performance of the bridge rail needed to be evaluated using the 2000 kg pickup truck.

This report presents the details and results of the NCHRP Report 350 test 3-11 of the Texas Type T4(A) Bridge Rail. The bridge rail successfully contained and redirected the 2000 kg pickup truck which remained upright during and after the collision. However, the maximum deformation of the occupant was 158 mm which was considered marginal as to whether or not serious injuries would be incurred by occupants of the vehicle. Therefore, the Texas Type T4(A) Bridge Rail is considered marginally acceptable according to specifications for NCHRP Report 350 test designation 3-11.

II. STUDY APPROACH

TEST ARTICLE

The Texas Type T4(A) Bridge Rail is a combination vertical wall and aluminum post and railing guardrail system. TTI received two drawings from the Texas Department of Transportation (TxDOT) entitled “Traffic Rail (Aluminum), Type T4(A) (M),” dated January 1996. These drawings provided details for construction of the concrete deck installation and installation details for the guardrail system. All post, rail, and necessary hardware used to construct the aluminum railing were acquired from the manufacturer of the system and from a regional TxDOT maintenance facility.

For this project, TTI constructed a 23.0 m simulated concrete bridge deck cantilever. The bridge deck cantilever was 750 mm in width and 200 mm thick. The bridge deck was constructed immediately adjacent to an existing concrete runway located at the TTI test facility. The concrete deck was anchored into the existing runway with L-shaped #16 dowels spaced every 300 mm. The transverse reinforcement in the top and bottom of the deck consisted of #16 bars spaced every 150 mm. The longitudinal reinforcement in the top of the deck consisted of #13 bars spaced every 225 mm. The longitudinal reinforcement in the bottom of the deck consisted of two #16 bars on field side of the deck spaced 75 mm apart with the next adjacent bar spaced 300 mm towards the traffic face. All reinforcement used to construct the deck, with the exception of the L-shaped dowels, was epoxy coated. The 28-day compressive strength of the concrete specified to construct the deck was 28 MPa.

The Texas TypeT4(A) Bridge Rail utilizes a 460 mm vertical wall as part of the guardrail system. This wall was 254 mm in width. Reinforcement used to construct the vertical wall consisted of casting #16 U-shaped dowels into the construction pour for the deck. These bars were spaced every 260 mm. Two #16 bars were placed longitudinally inside the U-shaped bars. All reinforcement used in the construction of the vertical wall was also epoxy coated. Each aluminum post used for the railing was anchored to the vertical wall using four 19 mm A325 bolts anchored within the vertical wall. The 28-day compressive strength of the concrete specified to construct the vertical wall was 25 MPa. Please refer to Figures 1 through 3 for additional details concerning the test installation.

CRASH TEST CONDITIONS

NCHRP Report 350 requires two tests for test level 3 evaluation of longitudinal barriers:

***NCHRP Report 350* test designation 3-10**: This test involves an 820 kg passenger vehicle (820C) impacting the length-of-need (LON) of the barrier at a nominal speed and angle of 100 km/h and 20 degrees. The purpose of this test is

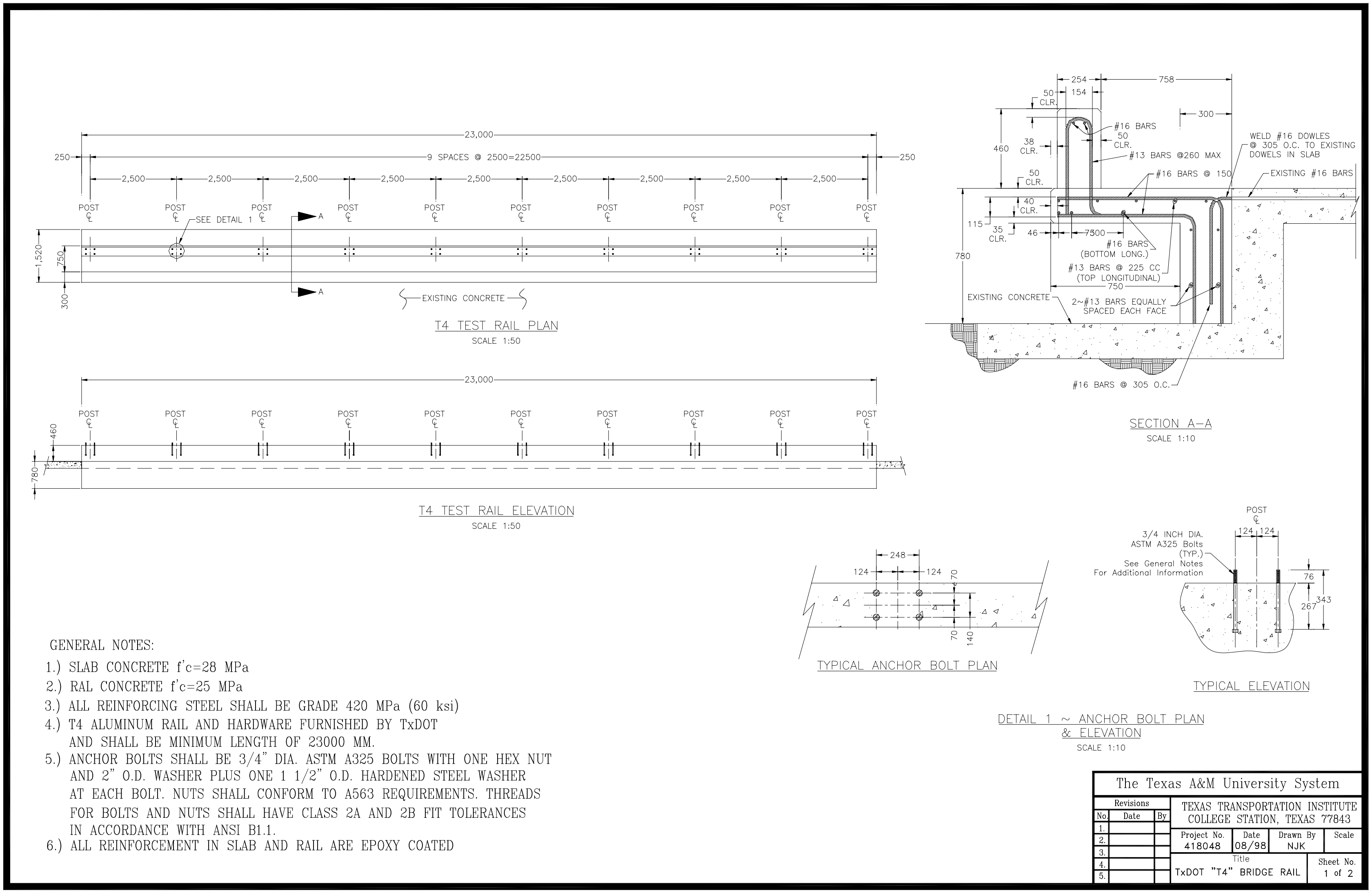


Figure 1. Details of the Texas Type T4(A) Bridge Rail – Concrete Deck and Wall.

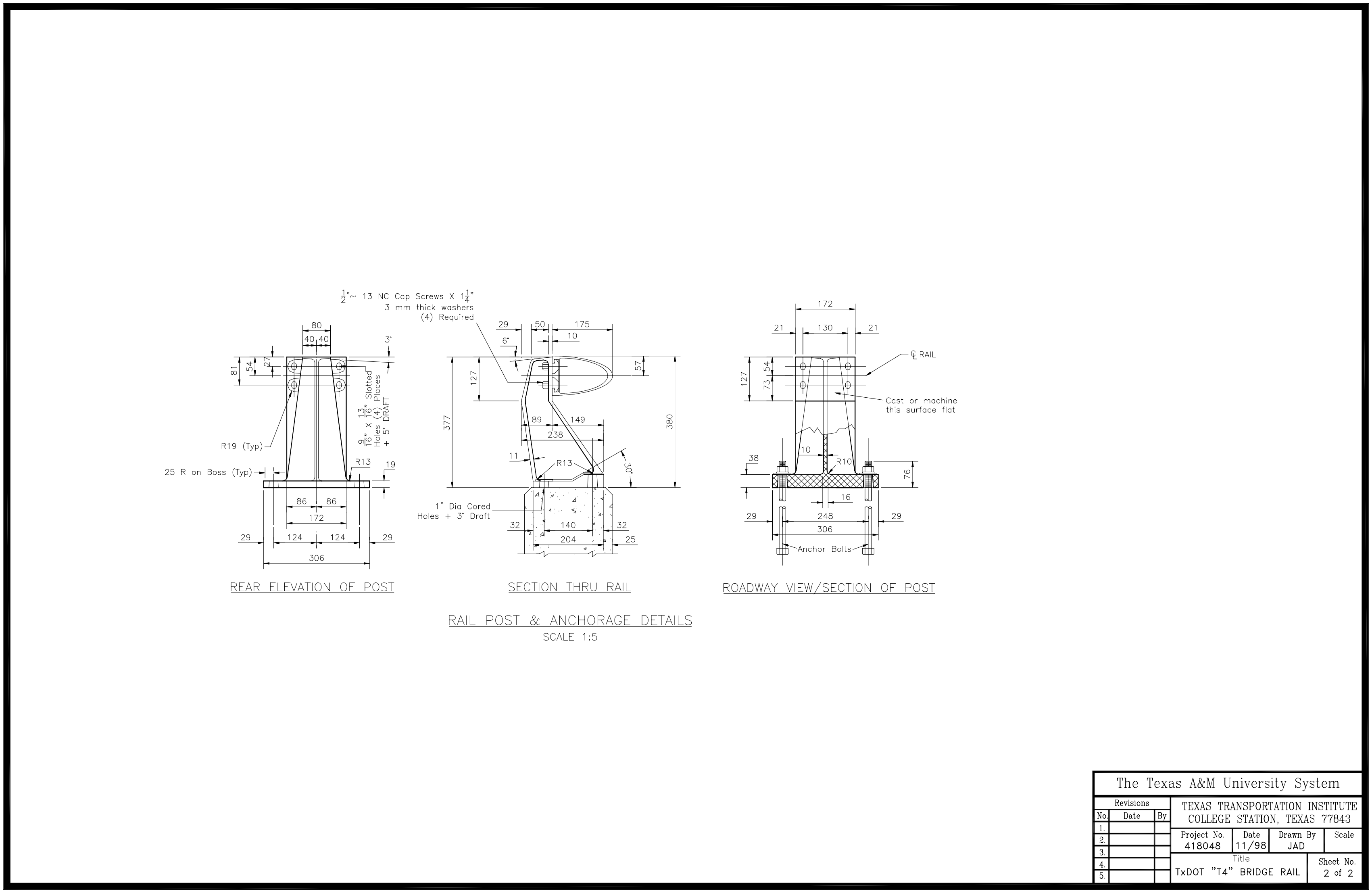


Figure 2. Details of the Texas Type T4(A) Bridge Rail – Metal Rail.

Figure 3. Test Article/Installation before Test 418049-7.

to evaluate the overall performance of the LON section, in general, and occupant risk, in particular.

***NCHRP Report 350* test designation 3-11**: The test involves a 2000 kg pickup truck (2000P) impacting 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.

The results of test 418049-7, which correspond to *NCHRP Report 350* test designation 3-11, are reported herein. The CIP was chosen according to criteria specified in *NCHRP Report 350*. The CIP was determined to be 1.3 m upstream of post 4.

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

EVALUATION CRITERIA

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

- **Structural Adequacy**

  A. *Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*

- **Occupant Risk**

  D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*

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

- **Vehicle Trajectory**

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

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

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

III. CRASH TEST RESULTS

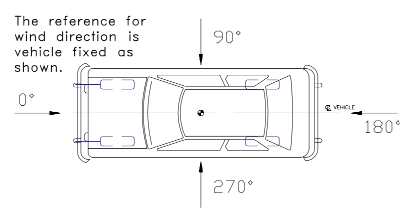
TEST NO. 418049-7 (*NCHRP Report 350* TEST NO. 3-11)

Test Vehicle

A 1995 Chevrolet 2500 pickup, shown in Figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 2000 kg and its gross static weight was 2000 kg. The height to the lower edge of the vehicle bumper was 440 mm and it was 665 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix B, Figure 11. 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 February 1, 1999. Three days before the test, 13 mm of rain fell and 10 days before, 10 mm of rain was recorded. No other rainfall occurred for the 10 days prior to the test. Weather conditions at the time of testing were as follows: wind speed: 11 km/h; wind direction: 25 degrees with respect to the vehicle (vehicle was traveling in a southerly direction); temperature: 16EC; relative humidity: 59 percent.



Test Description

The vehicle, traveling at101.4 km/h, impacted the Texas T4(A) bridge rail at a 24.8 degree angle 1.24 m upstream of post 4. Shortly after impact, the right front tire contacted the bridge rail. At 0.013 s, the right front tire steered away from the bridge rail, and at 0.028, the right front tire was traveling parallel with the bridge rail. Redirection began at 0.031 s. The left front tire steered toward the bridge rail at 0.063 s. By 0.078 s, the front windshield shattered, and by 0.093 s, the left front tire lost contact with the ground. The left and right rear tires lost contact with the ground at 0.154 s and 0.157 s, respectively. At 0.236 s, the right rear side of the vehicle contacted the bridge railing. The vehicle was traveling parallel to the installation at 0.237 s at a speed of 75.6 km/h. The vehicle lost contact with the bridge railing at 0.534 s traveling at 71.7 km/h and an exit angle of 11.3 degrees. The left front, right rear, and left rear tires returned to the ground at 0.835 s, 0.865 s, and 0.911 s, respectively. Brakes on the vehicle were applied 1.8 s after impact. The vehicle yawed almost 180 degrees and subsequently came to rest 51.8 m down from impact and 6.1 m toward traffic lanes. Sequential photographs of the test period are shown in Appendix C, Figures 13 and 14.

Figure 4. Vehicle/Installation Geometrics for Test 418049-7.

Figure 5. Vehicle before Test 418049-7.

Damage to Test Installation

Damage to the Texas T4(A) bridge rail is shown in Figures 6 through 8. The flange on the impact side of post 4 was marred and chipped as were the base plate and front bolts. Both the top and bottom of the rail element were scarred to a distance of 190 mm from the impact face of the rail. Structural cracks in the concrete portion of the rail occurred 400 mm from the center of post 4. One extended 85 mm down the field side of the concrete parapet and another radiated from the right rear bolt and extended 95 mm down the rear. A section of concrete (200 mm x 390 mm) broke out of the rear of the concrete beam deck under the bolt on the upstream field side and exposed the bolt. Maximum dynamic deflection of the rail during the test was not attainable and maximum permanent deformation of the metal rail element was 5 mm. Total length of contact of the vehicle with the bridge rail was 4.3 m.

Vehicle Damage

The vehicle sustained extensive damage to the front and right side as shown in Figure 9. Structural damage occurred to the stabilizer bar, right tie rods, right upper and lower A-arms, right front frame, and front cross member. The right A-pillar was deformed and the windshield was shattered. Also damaged were the front bumper, hood, grill, fan, radiator, right front quarter panel, right door, and right front and rear tires and rims. Maximum crush to the exterior of the vehicle was 600 mm at the front right corner near bumper height. Maximum occupant compartment deformation was 158 mm (49.7 percent reduction of space) in the right floor pan to instrument panel location and 130 mm (7.2 percent reduction of space) in the right side floor pan to roof area. The interior of the vehicle is shown in Figure 10. Exterior vehicle crush and occupant compartment deformation is shown in Appendix B, Tables 2 and 3.

Assessment of Test Results

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

- **Structural Adequacy**

  A. *Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*

  The Texas T4(A) bridge rail contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum permanent deflection of the rail during the test was 5 mm.

- **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.*

No detached elements, fragments, or other debris were present to penetrate the occupant compartment, or to show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. Maximum occupant compartment deformation was 158 mm (49.7 percent reduction of space) in the right floor pan to instrument panel location and 130 mm (7.2 percent reduction of space) in the right side floor pan to roof area. This deformation was considered marginal as to whether or not serious injury would be incurred by the occupants.

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

The vehicle remained upright during the collision and after loss of contact with the installation.

- **Vehicle Trajectory**

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

The vehicle trajectory may intrude into adjacent traffic lanes as it came to rest 6.1 m toward 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.*

Data from the tri-axial 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 for evaluation of criterion L of *NCHRP Report 350*. In the longitudinal direction, occupant impact velocity was 8.5 m/s at 0.137 s, maximum 0.010-s ridedown acceleration was -9.7 g's from 0.101 to 0.111 s, and the maximum 0.050-s average was -11.0 g's between 0.046 and 0.096 s. These data and other information pertinent to the test are presented in Figure 11. Vehicle angular displacements and accelerations versus time traces are shown in Appendix D, Figures 15 through 21.

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

Exit angle at loss of contact was 11.3 degrees which was 46 percent of the impact angle.

Figure 6. After Impact Trajectory for Test 418049-7.

Figure 7. Installation after Test 418049-7.

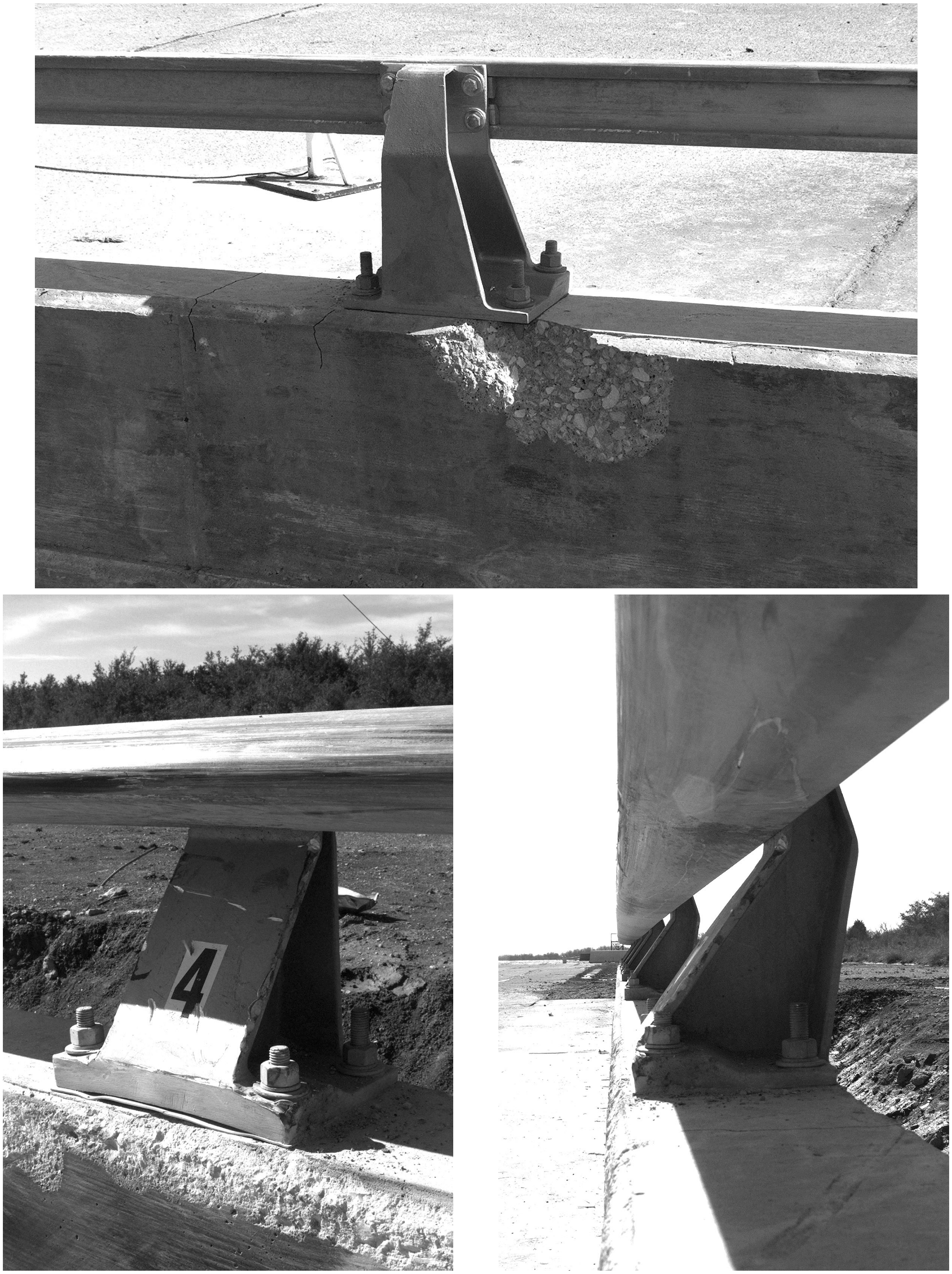


Figure 8. Damage at Post 4 after Test 418049-7.

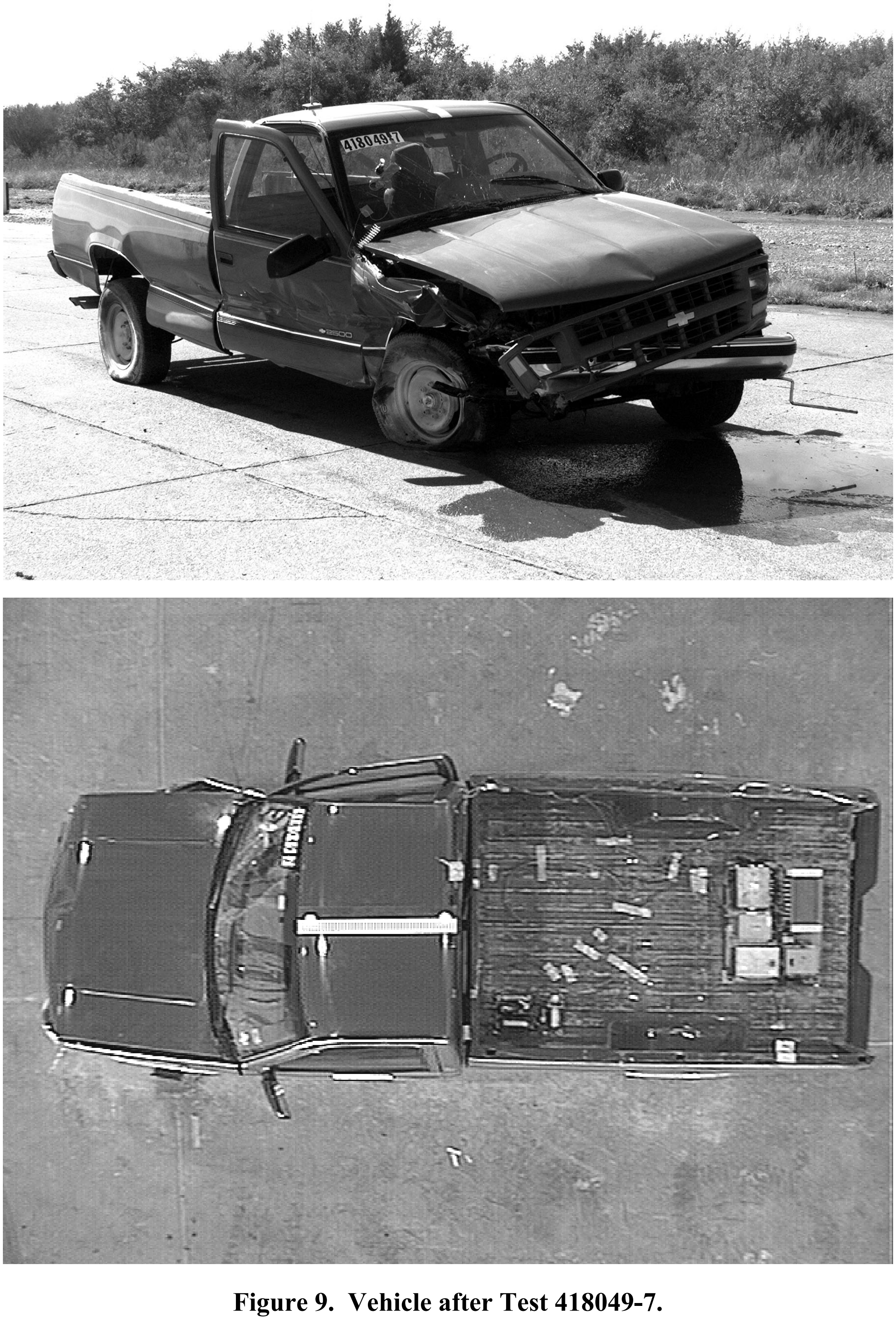
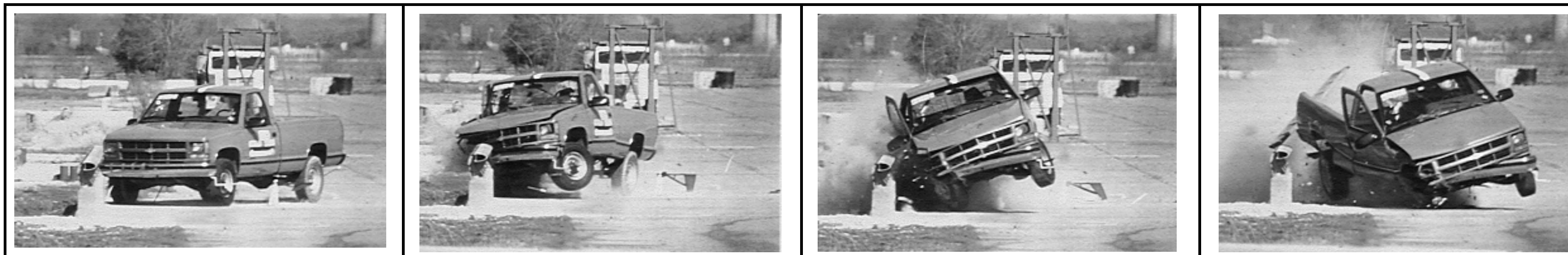


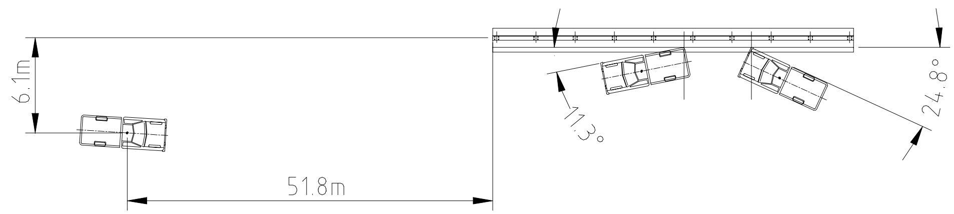
Figure 9. Vehicle after Test 418049-7.

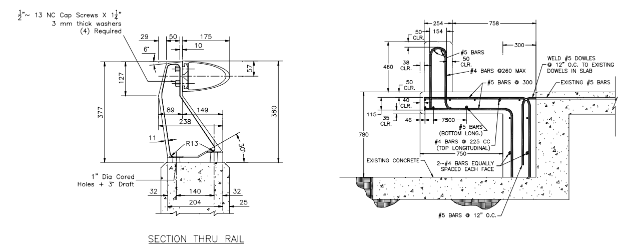
Before test

After test

Figure 10. Interior of Vehicle for Test 418049-7.







General Information
- Test Agency . . . . Texas Transportation Institute
- Test No. 418049-7
- Date 2/1/99

Test Article
- Type . . . . Bridge Rail
- Name or Manufacturer . . . . Texas T-4
- Installation Length (m) 23.0
- Material or Key Elements . . Vertical Concrete Wall with Aluminum Posts and Railing

Soil Type and Condition . . . . Concrete deck, Dry

Test Vehicle
- Type . . . . Production
- Designation 2000P
- Model . . . . 1995 Chevrolet 2500 pickup truck
- Mass (kg)
  - Curb 2071
  - Test Inertial 2000
  - Dummy . . . . No Dummy
  - Gross Static 2000

Impact Conditions
- Speed (km/h) 101.4
- Angle (deg) 24.8

Exit Conditions
- Speed (km/h) 71.7
- Angle (deg) 11.3

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 8.5
  - y-direction 7.2
- THIV (km/h) 35.3
- Ridedown Accelerations (g's)
  - x-direction . . . . -9.7
  - y-direction . . . . -6.8
- PHD (g's) 21.9
- ASI 1.50
- Max. 0.050-s Average (g's)
  - x-direction . . . . -11.0
  - y-direction . . . . -11.6
  - z-direction 4.9

Test Article Deflections (m)
- Dynamic . . . . N/A
- Permanent 0.005

Vehicle Damage
- Exterior
  - VDS 01FRQ3
  - CDC . . . . 01FREK4 & 01RDEW4
- Maximum Exterior
  - Vehicle Crush (mm) 600
- Interior
  - OCDI FS111500001
- Max. Occ. Compart.
  - Deformation (mm) 158

Post-Impact Behavior
(during 1.0 s after impact)
- Max. Yaw Angle (deg) . . . . . . -48
- Max. Pitch Angle (deg) . . . . . -5
- Max. Roll Angle (deg) 18

Figure 11. Summary of Results for Test 418049-7, *NCHRP Report 350* Test 3-11.

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

SUMMARY OF FINDINGS

The Texas Type T4(A) Bridge Rail contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum permanent deflection of the rail during the test was 5 mm. No detached elements, fragments, or other debris were present to penetrate the occupant compartment, or to show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. Maximum occupant compartment deformation was 158 mm (49.7 percent reduction of space) in the right floor pan to instrument panel location. The vehicle remained upright during the collision and after loss of contact with the installation. The vehicle trajectory may intrude into adjacent traffic lanes as it came to rest 6.1 m toward traffic lanes. Longitudinal occupant impact velocity was 8.5 m/s, and the longitudinal ridedown acceleration was -9.7 g's. Exit angle at loss of contact was 11.3 degrees which was 46 percent of the impact angle.

CONCLUSIONS

The Texas Type T4(A) Bridge Rail successfully contained and redirected the vehicle which remained upright during and after the collision. However, the maximum deformation of the occupant compartment was 158 mm which was considered marginal as to whether or not serious injury would be incurred by the occupants. Also, under criterion K (which is a preferable and not a required criterion), the vehicle may intrude into adjacent traffic lanes as it came to rest 6.1 m toward traffic lanes. Therefore, the Texas Type T4(A) Bridge Rail was considered marginally acceptable according to specifications for NCHRP Report 350 test designation 3-11. Table 1 contains a summary of the results.

Table 1. Performance Evaluation Summary for Test 418049-7, *NCHRP Report 350* Test 3-11.

Test Agency: Texas Transportation Institute | Test No.: 418049-7 | Test Date: 02/01/99

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> 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 Texas T4(A) bridge rail contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum deflection of the rail during the test was 5 mm.	Pass
<u>Occupant Risk</u> 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 the occupant compartment, or to show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. Maximum occupant compartment deformation was 158 mm (49.7 percent reduction of space) in the right floor pan to instrument panel location.	Marginal
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The vehicle remained upright during the collision and after loss of contact with the installation.	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory may intrude into adjacent traffic lanes as it came to rest 6.1 m toward 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 8.5 m/s, and ridedown acceleration was -9.7 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 11.3 degrees which was 46 percent of the impact angle.	Pass*

* Criteria K and M are preferable, not required.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

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

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels, and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO Model 2262CA, piezoresistive accelerometers with a ±100 g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Rate of turn 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 minutes before the test and also immediately afterwards. A crystal-controlled time reference signal is simultaneously recorded with the data. Pressure sensitive switches on the bumper of the impacting vehicle are actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an "event" mark on the data record to establish the exact instant of contact with the installation.

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

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

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

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

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0002-s intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

Use of a dummy in the 2000P vehicle is optional according to *NCHRP Report 350,* and 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 flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A BetaCam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

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

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

DATE: 2-1-99 TEST NO.: 418049-7 VIN NO.: 1GCGC24K3SZ192414

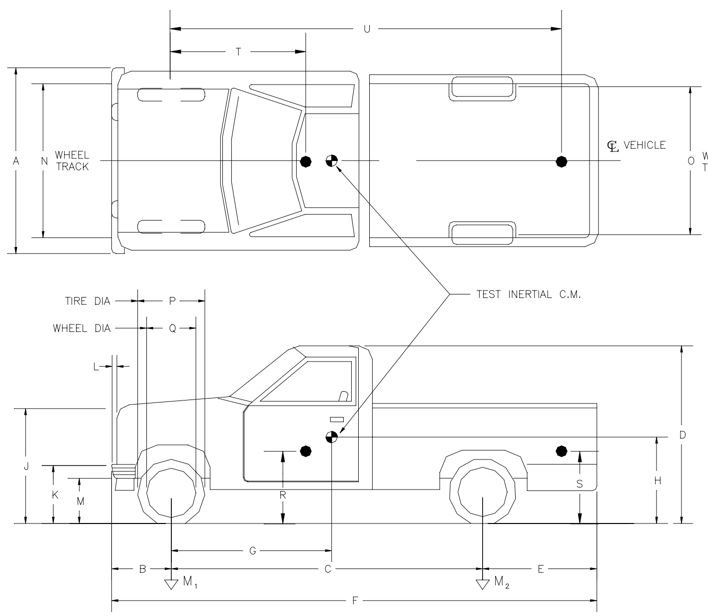
YEAR: 1995 MAKE: CHEVY MODEL: 2500P/U

TIRE INFLATION PRESSURE: ________ ODOMETER: 169961 TIRE SIZE: LT245 75R16

MASS DISTRIBUTION (kg) LF 566 RF 546 LR 439 RR 449

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

DENT IN REAR OF CAB AND INSIDE BED, CRACK IN WINDSHIELD (MARKED)



● Denotes accelerometer location.

NOTES: ____________

ENGINE TYPE: 8CYL

ENGINE CID: 5.7L

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

8 LUGS

DUMMY DATA:

TYPE: ________

MASS: ________

SEAT POSITION: ________

GEOMETRY – (mm)

A	1850	E	1350	J	1090	N	1600	R	710
B	850	F	5550	K	665	O	1620	S	890
C	3350	G	1487.4	L	100	P	760	T	1500
D	1810	H		M	440	Q	445	U	4100

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1177	1112	
M_2	894	888	
M_T	2071	2000	

Figure 12. Vehicle Properties for Test 418049-7.

Table 2. Exterior Crush Measurements for Test 418049-7.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	**Side Damage**
Undeformed end width _________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing: B1 ____ X1 ____ B2 ____ X2 ____ Bowing constant (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	Front bumper	900	600	1260	+200	-100	-180	-300	-460	-600	0
2	770 mm above ground	900	440	1280	185	260	N/A	N/A	380	440	+1420

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

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

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

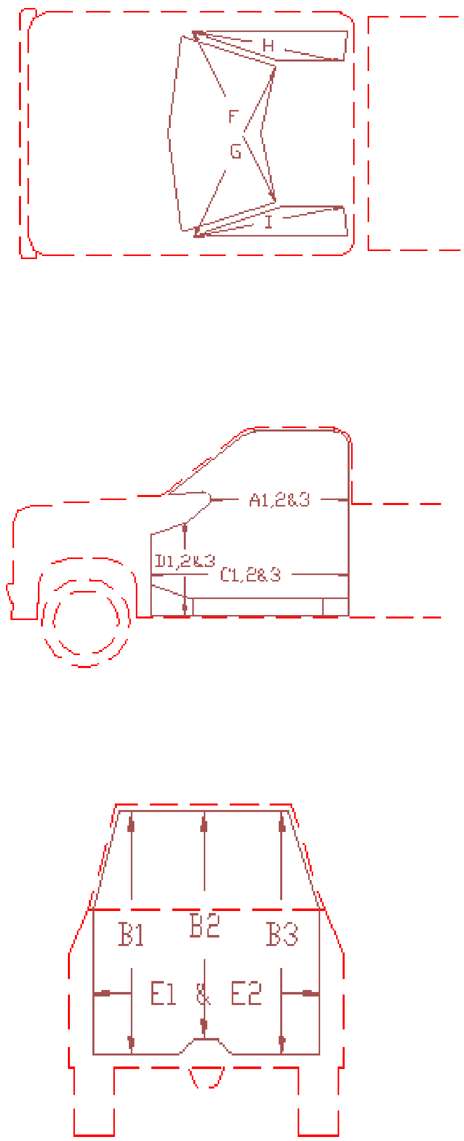
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

Table 3. Occupant Compartment Measurements for Test 418049-7.

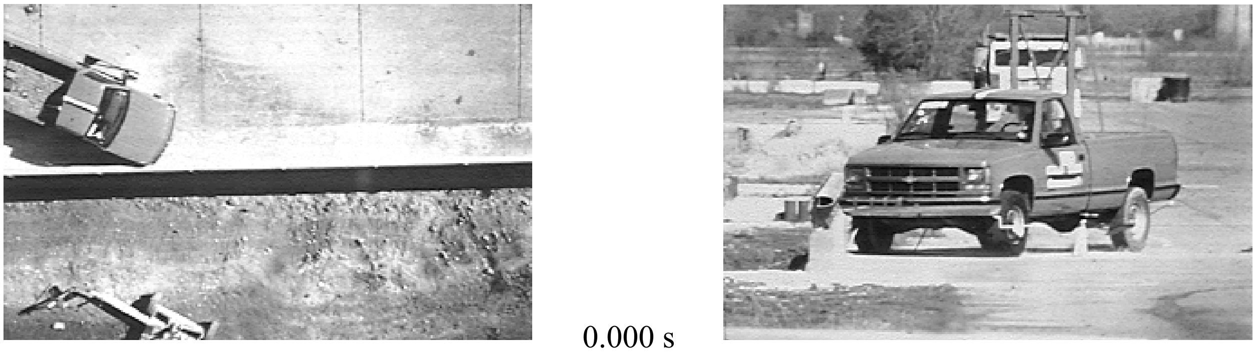
Truck

Occupant Compartment Deformation

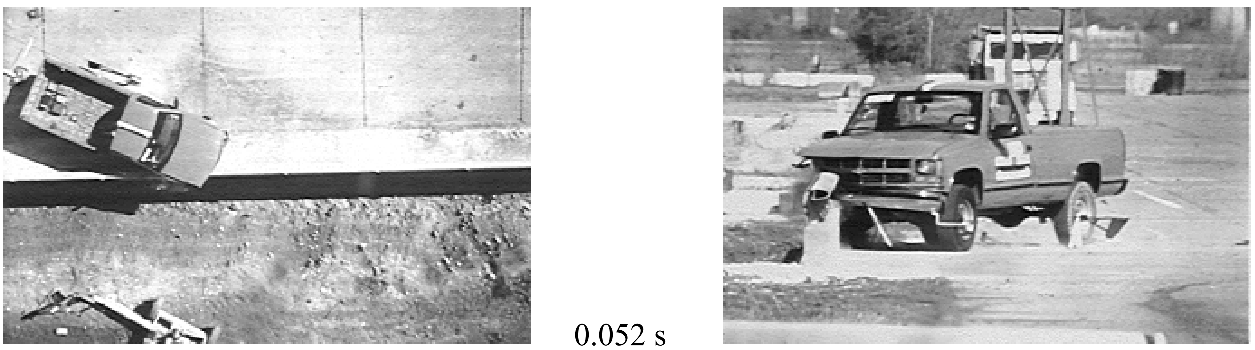


	BEFORE	AFTER
A1	869	902
A2	875	860
A3	908	866
B1	1069	1065
B2	1075	1120
B3	1080	950
C1	1377	1377
C2	1255	1175
C3	1373	1310
D1	317	340
D2	160	90
D3	318	160
E1	1585	1585
E2	1595	1635
F	1465	1435
G	1465	1465
H	800	720
I	800	800
J	1520	1425

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

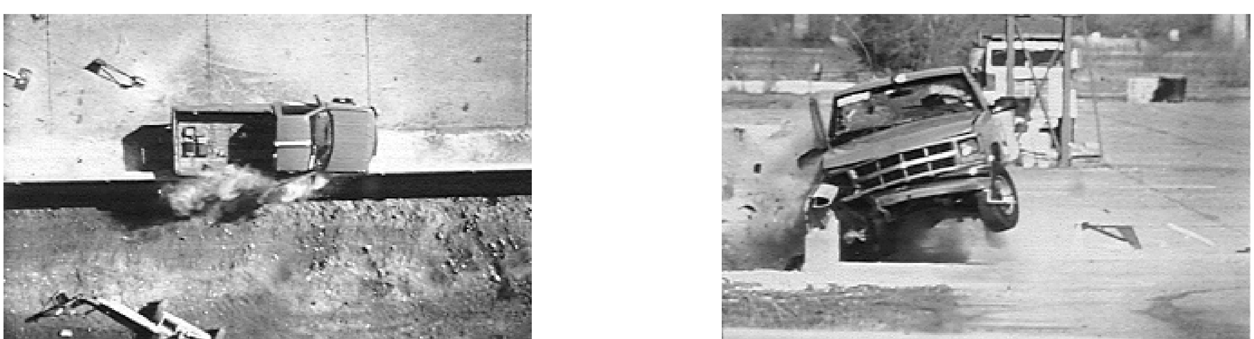


0.000 s



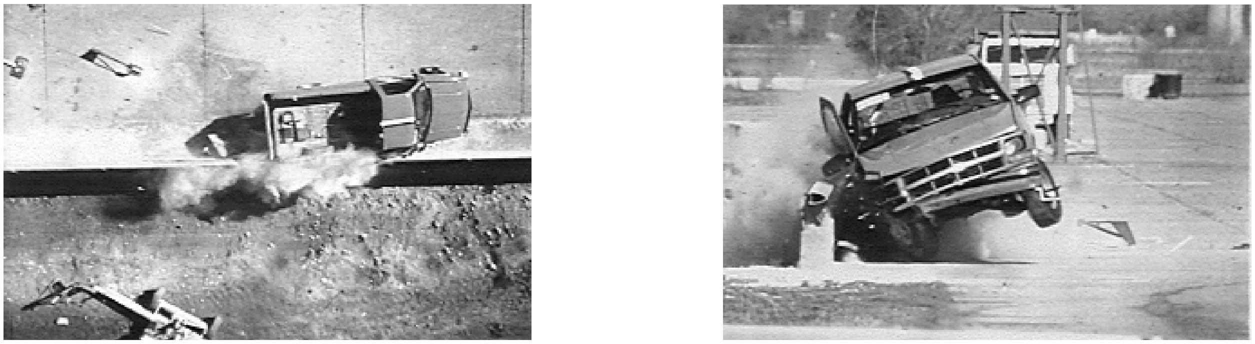
0.052 s

0.129 s

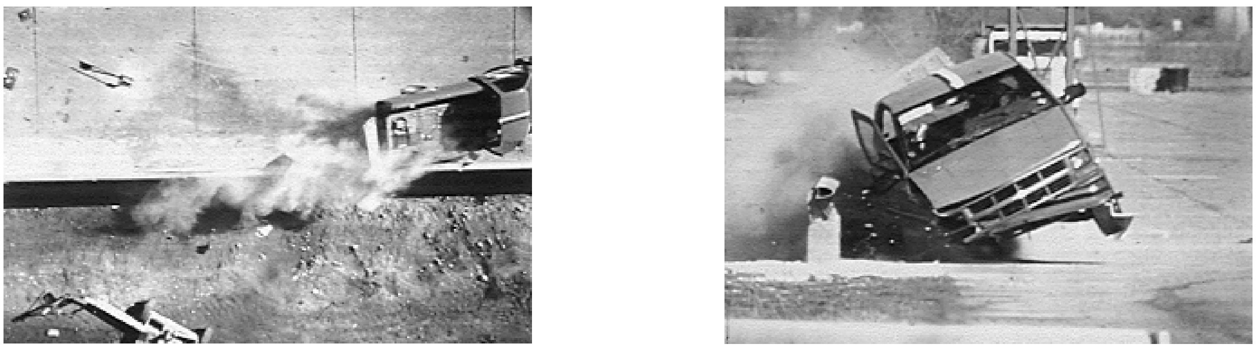


0.232 s

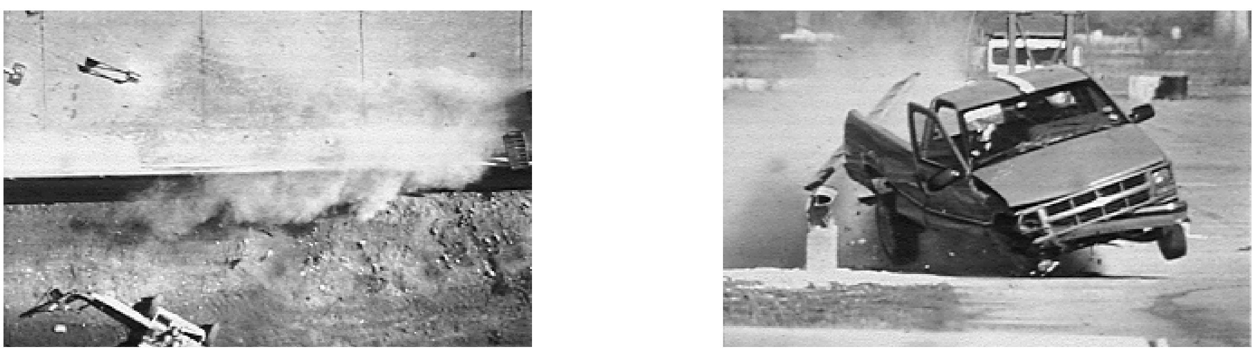
Figure 13. Sequential Photographs for Test 418049-7 (overhead & frontal views).



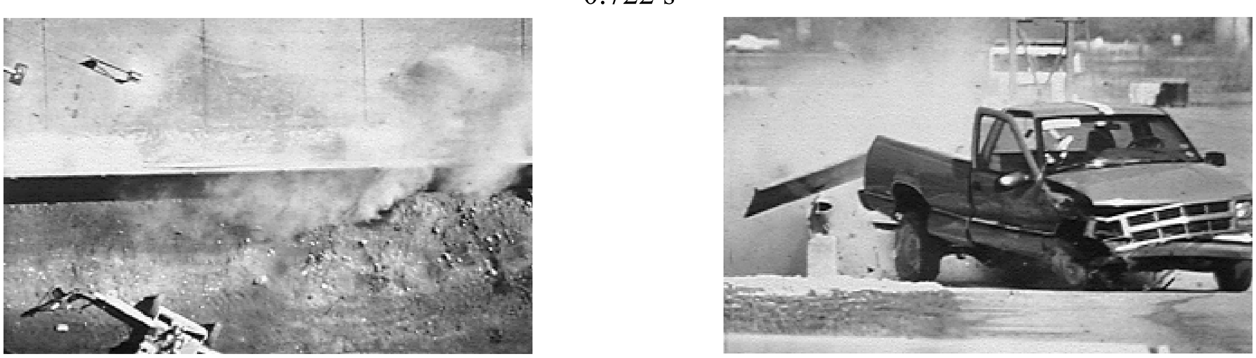
0.361 s



0.516 s



0.722 s



0.928 s

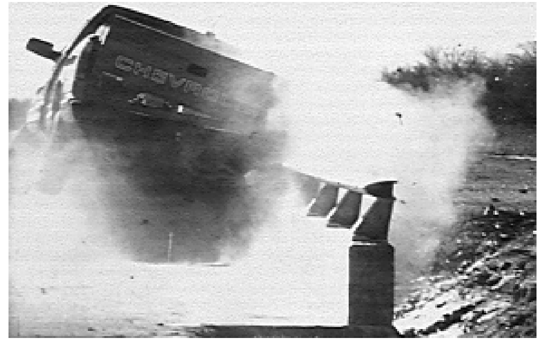
Figure 13. Sequential Photographs for Test 418049-7 (overhead & frontal views) (continued).

0.000 s

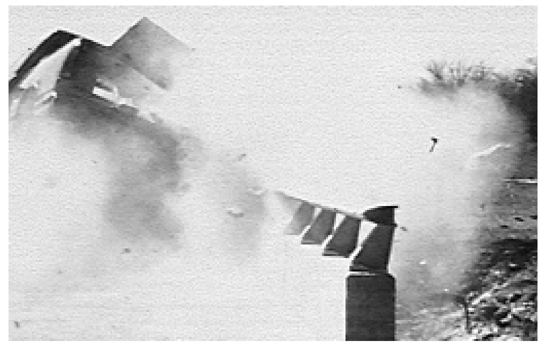
0.052 s

0.129 s

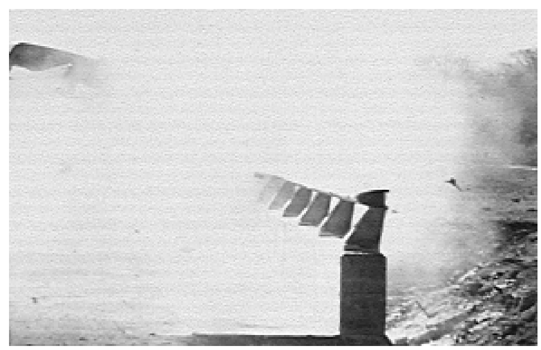
0.232 s



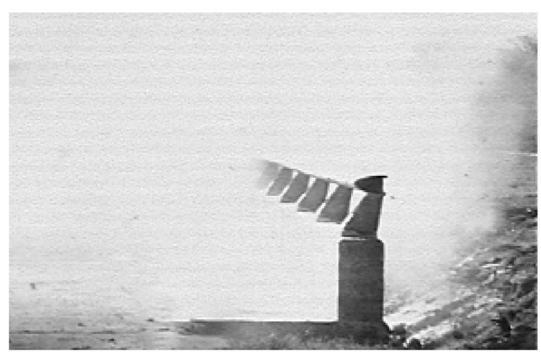
0.361 s



0.516 s



0.722 s



0.928 s

Figure 14. Sequential Photographs for Test 418049-7 (rear view).

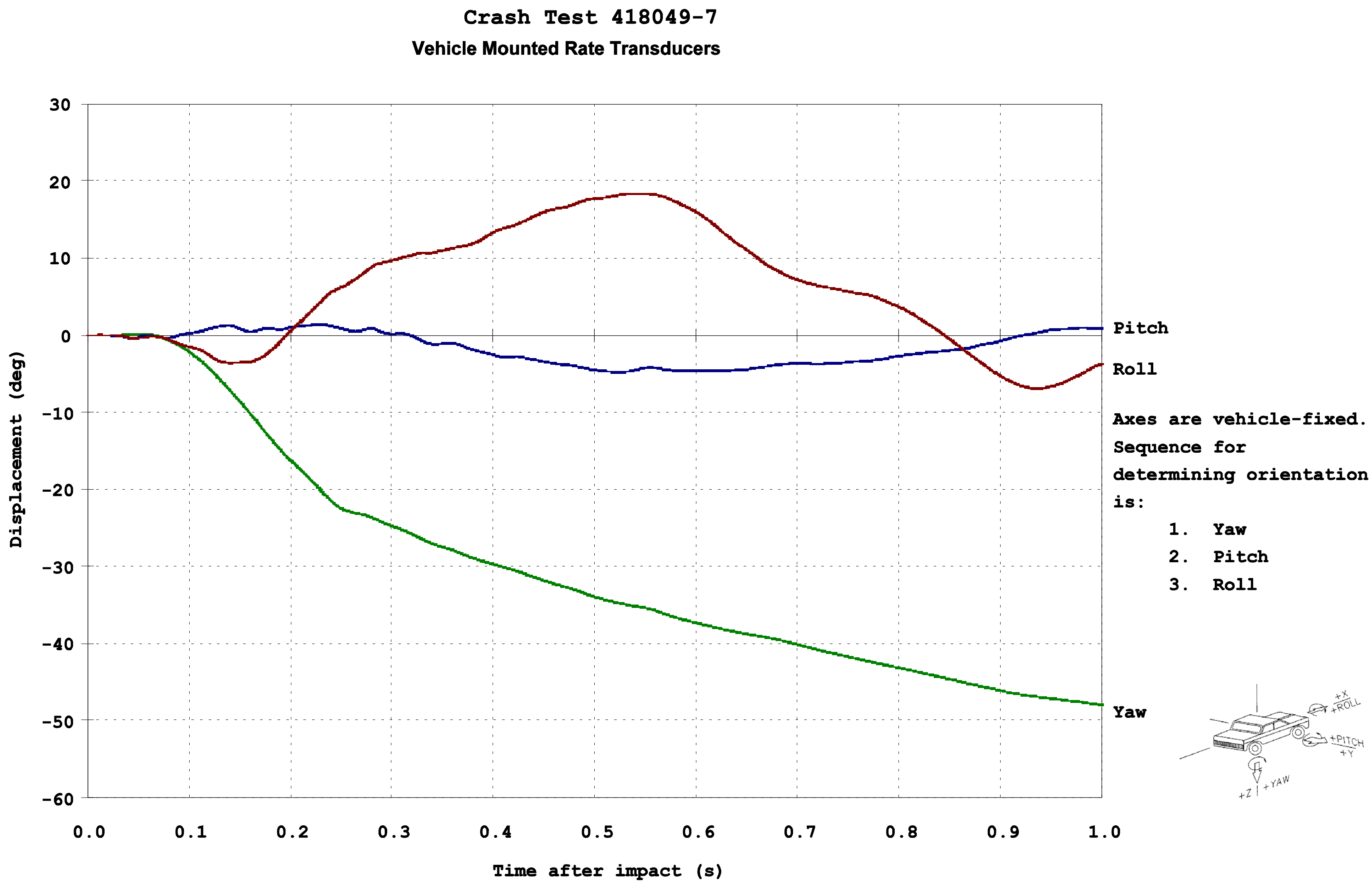


Figure 15. Vehicular Angular Displacements for Test 418049-7.

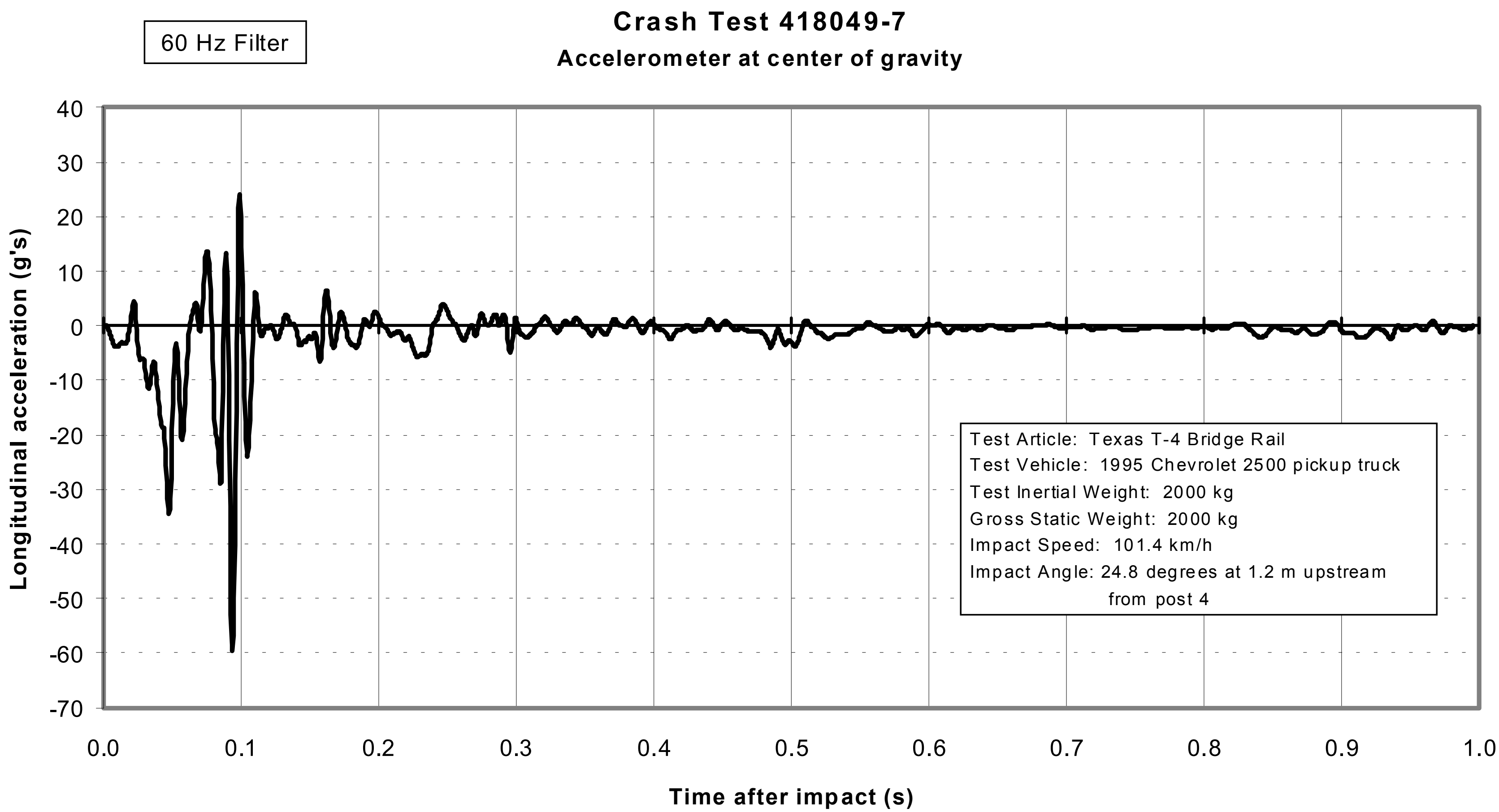


Figure 16. Vehicle Longitudinal Accelerometer Trace for Test 418049-7. (Accelerometer Located at Center of Gravity)

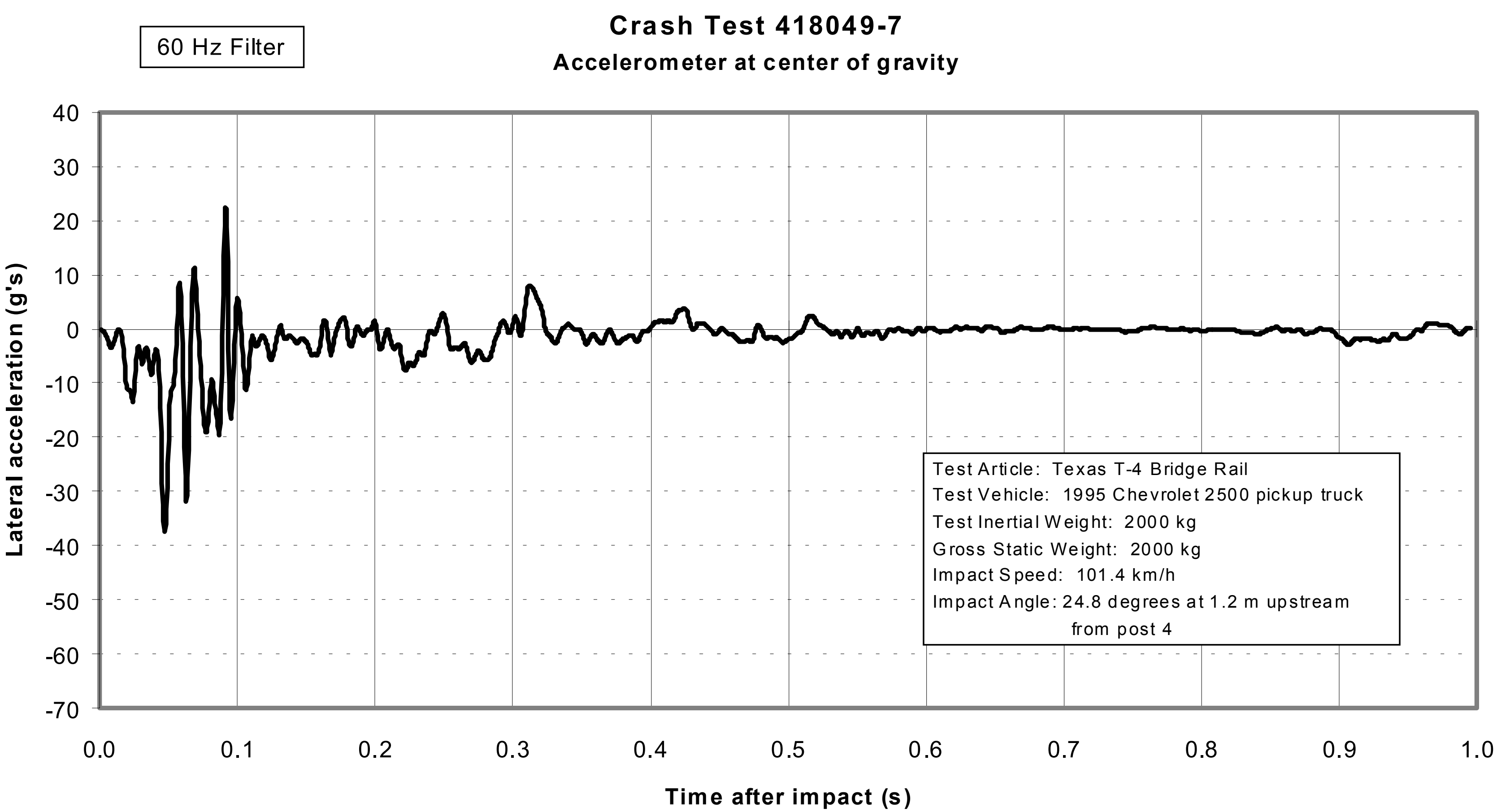


Figure 17. Vehicle Lateral Accelerometer Trace for Test 418049-7 (Accelerometer Located at Center of Gravity).

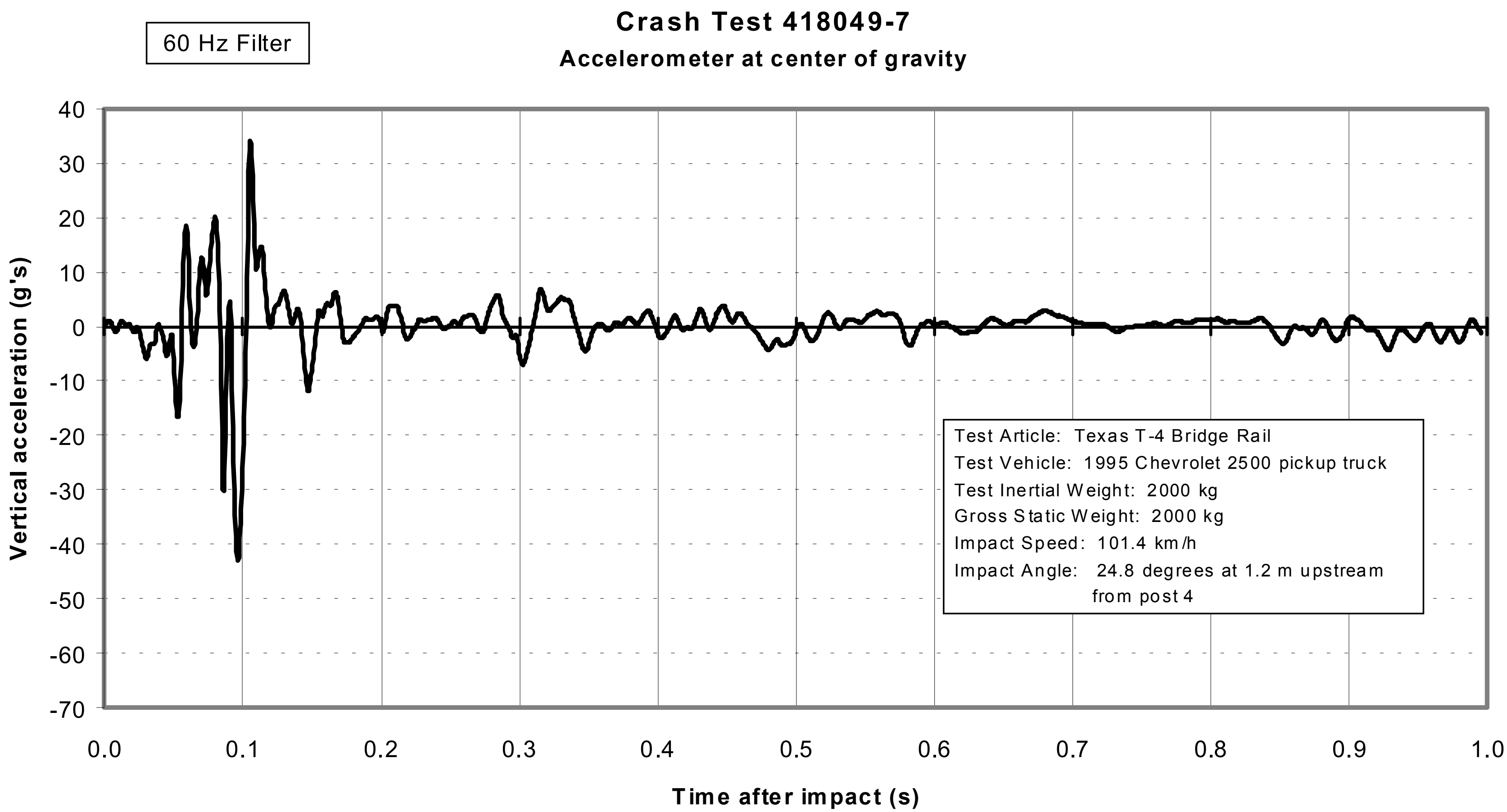


Figure 18. Vehicle Vertical Accelerometer Trace for Test 418049-7 (Accelerometer Located at Center of Gravity).

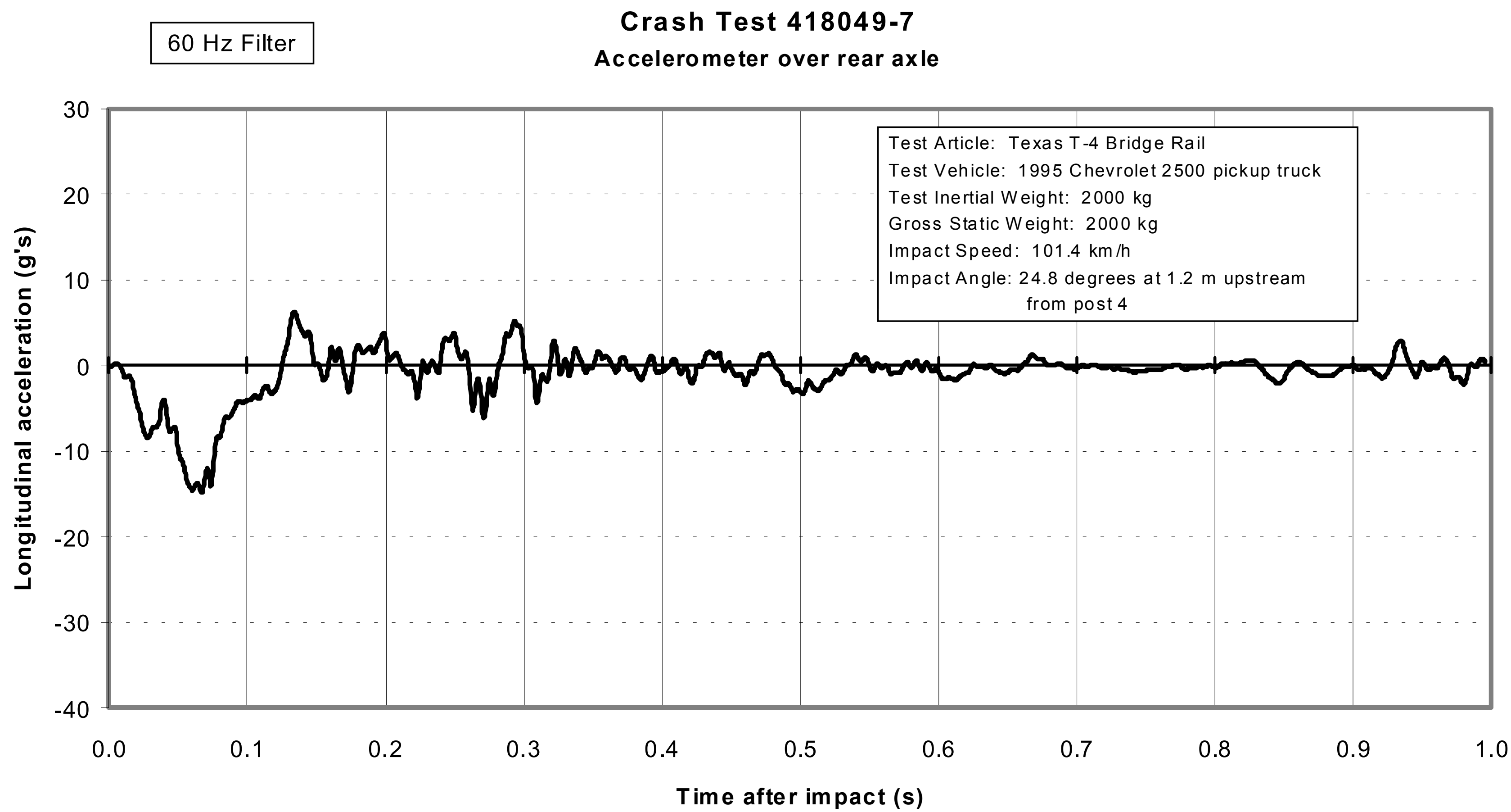


Figure 19. Vehicle Longitudinal Accelerometer Trace for Test 418049-7 (Accelerometer Located Over Rear Axle).

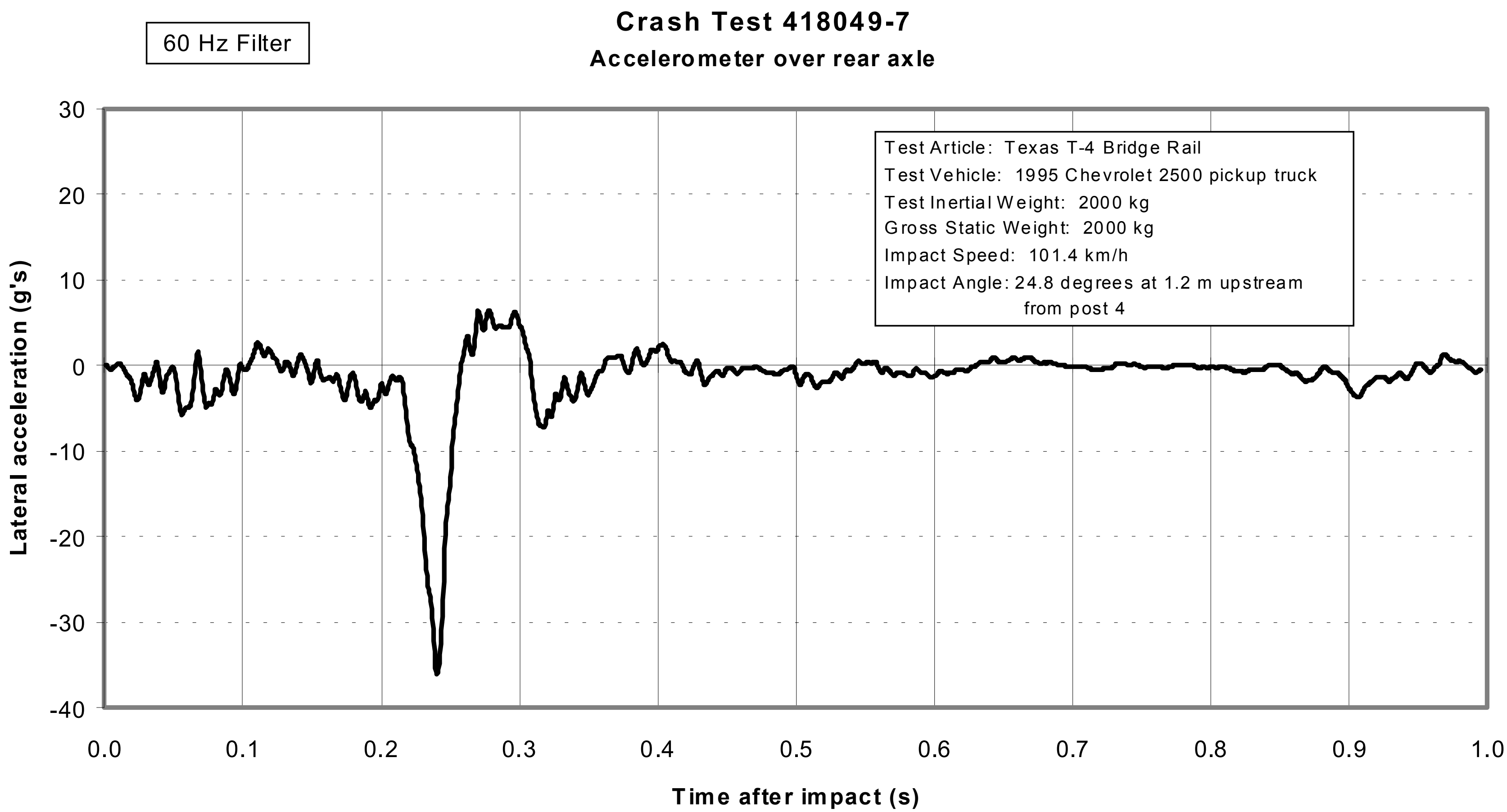


Figure 20. Vehicle Lateral Accelerometer Trace for Test 418049-7 (Accelerometer Located Over Rear Axle).

REFERENCES

1. Dwight A. Horne, *Crash Testing of Bridge Railings*, FHWA Memorandum, May 30, 1997.

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

3. *AASHTO LRFD Bridge Design Specifications*, Customary U.S. Units First Edition, American Association of State Highway and Transportation Officials, Washington, D.C., 1994.

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