



**NCHRP REPORT 350 UPDATE TEST 3-11  
OF THE TXDOT TYPE T-1F BRIDGE RAIL**

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**TEXAS DEPARTMENT OF TRANSPORTATION  
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**July 2007**

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



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16. Abstract  <p style="text-align: center;">TxDOT and other state DOTs make considerable use of various non-proprietary roadside safety hardware systems. Although some barrier crash testing has been performed during the development of the update to <i>NCHRP Report 350</i>, many barrier systems and other roadside safety features have yet to be evaluated under the proposed guidelines. Also, evaluation of new roadside safety features following the updated safety-performance evaluation guidelines is needed.</p> <p style="text-align: center;">The purpose of this research project is to assess the performance of a new TxDOT Type T-1F Bridge Rail according to the safety-performance evaluation guidelines included in the update to <i>NCHRP Report 350</i>. The proposed crash test for this project was in accordance with Test Level 3 of the proposed update to <i>NCHRP Report 350</i>, which involves the new 2270P vehicle (a 5000 lb Quad Cab Pickup).</p> <p style="text-align: center;">The TxDOT Type T-1F Bridge Rail performed acceptably for <i>NCHRP Report 350</i> Update test 3-11.</p>			
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## **DISCLAIMER**

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# CHAPTER 1. INTRODUCTION

## 1.1 BACKGROUND

Since the 1940s, the United States has been committed to crash testing highway safety appurtenances. National guidelines for testing roadside appurtenances originated in 1962 with a one-page document – *Highway Research Circular 482* entitled “Proposed Full-Scale Testing Procedures for Guardrails” (1). This document included four specifications on test article installation, one test vehicle, six test conditions and three evaluation criteria. In 1974, *NCHRP Report 153*, “Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances” was published (2). This 16-page document provided the first complete test matrix for evaluating safety features. Data collection methods, evaluation criteria, and limited guidance on reporting formats were included. These procedures gained wide acceptance following their publication, but it was recognized at that time that periodic updating would be needed.

Published in 1978, Transportation Research Circular 191, “Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances” (3) provided limited interim changes to *NCHRP Report 153* to address minor changes requiring modified treatment of particular problem areas. An extensive revision and update to these procedures was made in 1981 with the publication of *NCHRP Report 230*, “Recommended Procedures for the Safety Performance Evaluation of Highway Features” (4). This 42-page document contained different service levels for evaluating longitudinal barriers whose test matrices included vehicles ranging from small passenger cars to intercity buses.

In 1993, *NCHRP Report 350*, “Recommended Procedures for the Safety Performance Evaluation of Highway Features” was published (5). This 132-page document represented a comprehensive update to crash test and evaluation procedures. It incorporated significant changes and additions to procedures for safety-performance evaluation, and updates reflecting the changing character of the highway network and the vehicles using it. Changes included the introduction of multiple test levels, inclusion of matrices for other roadside features that had not previously been addressed, adoption of a new design test vehicle, and more and different test conditions, etc.

Some of the notable differences between *NCHRP Report 350* and *NCHRP Report 230*, as excerpted from *Report 350*, were as follows:

1. It provides a wider range of test procedures to permit safety performance evaluations for a wider range of barriers, terminals, crash cushions, breakaway support structures and utility poles, truck-mounted attenuators, and work zone traffic control devices.
2. It uses a 4409-lb, 3/4-ton pickup truck as the standard design test vehicle in place of the 4500-lb passenger sedan to represent the growing population of light trucks in the vehicle fleet.

3. It defines other test vehicles such as an 18,000-lb single-unit cargo truck and 80,000-lb tractor-trailer vehicles to provide the basis for optional testing to meet higher performance levels.
4. It includes a broader range of tests for each category of safety feature to provide a uniform basis for establishing warrants for the application of roadside safety hardware that consider the levels of use of the roadway facility. Six basic test levels are defined for the various classes of roadside safety features.
5. The report includes guidelines for the selection of the critical impact point for crash tests on redirecting-type safety hardware.

The Federal Highway Administration (FHWA) formally adopted the new performance evaluation guidelines for highway safety features set forth in *NCHRP Report 350* as a “Guide or Reference” document in the Federal Register, Volume 58, Number 135, dated July 16, 1993, which added paragraph (a)(13) to 23 CFR 625.5. FHWA subsequently mandated that, starting in September 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).

Through various pooled fund studies and other research projects, FHWA, TxDOT, and state DOTs tested the most widely used safety appurtenances. Additionally, manufacturers worked toward recertification of their proprietary products. Ultimately, numerous changes and modifications to existing hardware were required to comply with the *NCHRP Report 350*. Many of these changes were attributed to the change from the 4500-lb passenger sedan to the 4400-lb (2000P) pickup truck. The pickup truck represented an SUV class of vehicle that had a higher center-of-gravity and was inherently less stable than the large passenger sedan used under *NCHRP Report 230*. In addition, the pickup truck had a shorter front overhang often resulting in snagging of the front wheel and subsequent displacement of the wheel and tire into the floor/toe pan. As a result of snagging and wheel displacement, excessive intrusion into the occupant compartment was frequently observed.

After an extended period of analyses, testing, and evaluation, hardware standards were updated to accommodate the pickup truck design test vehicle and other changes in *NCHRP Report 350*. On February 14, 2000, Dwight Horne, FHWA Director of Highway Safety Infrastructure issued a memorandum summarizing and describing all nonproprietary longitudinal roadside and median barriers that met *NCHRP Report 350* requirements at one or more test levels or were considered to be equivalent to barriers that had been tested.

However, the highway environment is continually changing and evolving and, consequently, the guidelines for testing and evaluating the impact performance of roadside safety features must be periodically updated to stay current with advancements in technology and changes in the vehicle fleet and impact conditions. In recognition of this inevitability, the foreword of *NCHRP Report 350* states the following:

“The evolution of the knowledge of roadside safety and performance evaluations is reflected in this document. Inevitably, parts of this document will need to be revised in the future, but it is the consensus opinion of the project panel and the many reviewers of these procedures that this document will effectively meet the needs for uniform safety performance evaluation procedures into the 21<sup>st</sup> century.”

In 1997, TTI researchers first evaluated the needs and relevancy of updating *NCHRP Report 350* under NCHRP Project 22-14(01) “Improvement of the Procedures for the Safety Performance Evaluation of Roadside Features.” The objectives were: 1) evaluate the relevancy and efficacy of the crash testing procedures; 2) assess the needs for updating *NCHRP Report 350*; and 3) provide recommended strategies for their implementation. Many white papers were produced outlining the various testing and evaluation areas of the document and discussing the state of the practice and observations made during the testing that followed the adoption of *NCHRP Report 350*.

Research to update *NCHRP Report 350* and take the next step in the continued advancement and evolution of roadside safety testing and evaluation was recently completed under NCHRP Project 22-14(02) (6). The results of this research effort, which was performed at the University of Nebraska, will be a new document that will be published by the American Association of State Highway and Transportation Officials (AASHTO) and will supersede *NCHRP Report 350*. Changes being proposed for incorporation into the new guidelines include new design test vehicles, revised test matrices, and revised impact conditions.

## **1.2 OBJECTIVES/SCOPE OF RESEARCH**

TxDOT and other state DOTs make considerable use of various non-proprietary roadside safety hardware systems. Although some barrier crash testing has been performed during the development of the update to *NCHRP Report 350*, many barrier systems and other roadside safety features have yet to be evaluated under the proposed guidelines. Also, evaluation of new roadside safety features following the updated safety-performance evaluation guidelines is needed.

The purpose of this research project is to assess the performance of a new TxDOT Type T-1F Bridge Rail according to the safety-performance evaluation guidelines included in the update to *NCHRP Report 350*. The proposed crash test for this project was in accordance with Test Level 3 of the update to *NCHRP Report 350*, which involves the new 2270P vehicle (a 5000 lb (1/2 ton) Quad Cab Pickup).





## CHAPTER 2. CRASH TEST PROCEDURES

### 2.1 TEST ARTICLE DESIGN AND CONSTRUCTION

For this project, Texas Transportation Institute (TTI) and Texas Department of Transportation (TxDOT) designed, constructed, and crash tested a prototype steel and aluminum aesthetic bridge rail designated as Texas Type T-1F for TxDOT. The total length of the railing installation was approximately 78 ft-1½ inches in length. The T-1F Bridge Railing system is an aluminum rail and steel post system consisting of two tubular steel rail elements mounted on 1¼-inch thick steel plate posts spaced 8 ft apart. The “bullet-shaped” rails used for this bridge rail are like the rail member used for the TxDOT T4(A) Bridge Rail. The center of the lower rail and the top of the upper rail measured 1 ft-6 inches and 2 ft-6¾ inches, respectively from the pavement surface. The rails were mechanically attached to the posts using aluminum clamp bars and stainless steel bolts. The 1¼-inch thick steel plate posts were welded to 12 inch x 12 inch x 1½ inch thick base plates. Each post was anchored to the curb using four 7/8-inch diameter A325 anchor bolts with a 6½ inch x 11 inch x ¼ inch thick anchor plate used for additional anchorage. The bridge railing system was supported by a cast-in-place concrete deck and curb. The curb was 15½ inches wide and 9 inches high. The post plates and base plates were manufactured from A572 Grade 50 material.

The railing installation was constructed using 2 ft long “bullet-shaped” aluminum bar splices that fit snug within the aluminum rail members. Rail splices were located 9 inches from the centerline of the posts.

A simulated concrete bridge deck cantilever and curb was constructed immediately adjacent to an existing concrete apron located at the TTI test facility. The total length of the concrete deck and curb installation was 76 ft-3 inches. The bridge deck cantilever was 2 ft-6 inches in width and 8 inches thick and was rigidly attached to an existing concrete foundation. A 1 ft-3½ inches wide by 9-inch high concrete curb was cast on top of the concrete deck. Transverse reinforcement in the deck consisted of #5 bars spaced 6 inches on centers in the top layer. Transverse reinforcement in the bottom layer consisted of #5 bars spaced at 18 inches on centers. Longitudinal reinforcement in the top layer of the deck consisted two #4 bars spaced 9 inches on centers. Longitudinal reinforcement in the bottom layer of the deck consisted of two #5's located 3 inches on centers closest to the field side edge with a third #5 bar located approximately 12 inches away. In addition to the deck reinforcement, #5 stirrups (“V” Bars) were closely spaced around each post. These bars were cast in the deck for reinforcement for the concrete curb. Longitudinal reinforcement in the curb consisted of three #5 bars equally spaced in the top of the “V” Bars. In addition, two #5 “Z” Bars were located within the curb. All reinforcement was bare steel (not epoxy coated) and was specified to have a minimum yield strength of 60 ksi.

Details of the TxDOT Type T-1F system are shown in figures 2.1 and 2.2 and Appendix A. Photographs of the completed installation are shown in figure 2.3.

## **2.2 MATERIAL SPECIFICATIONS**

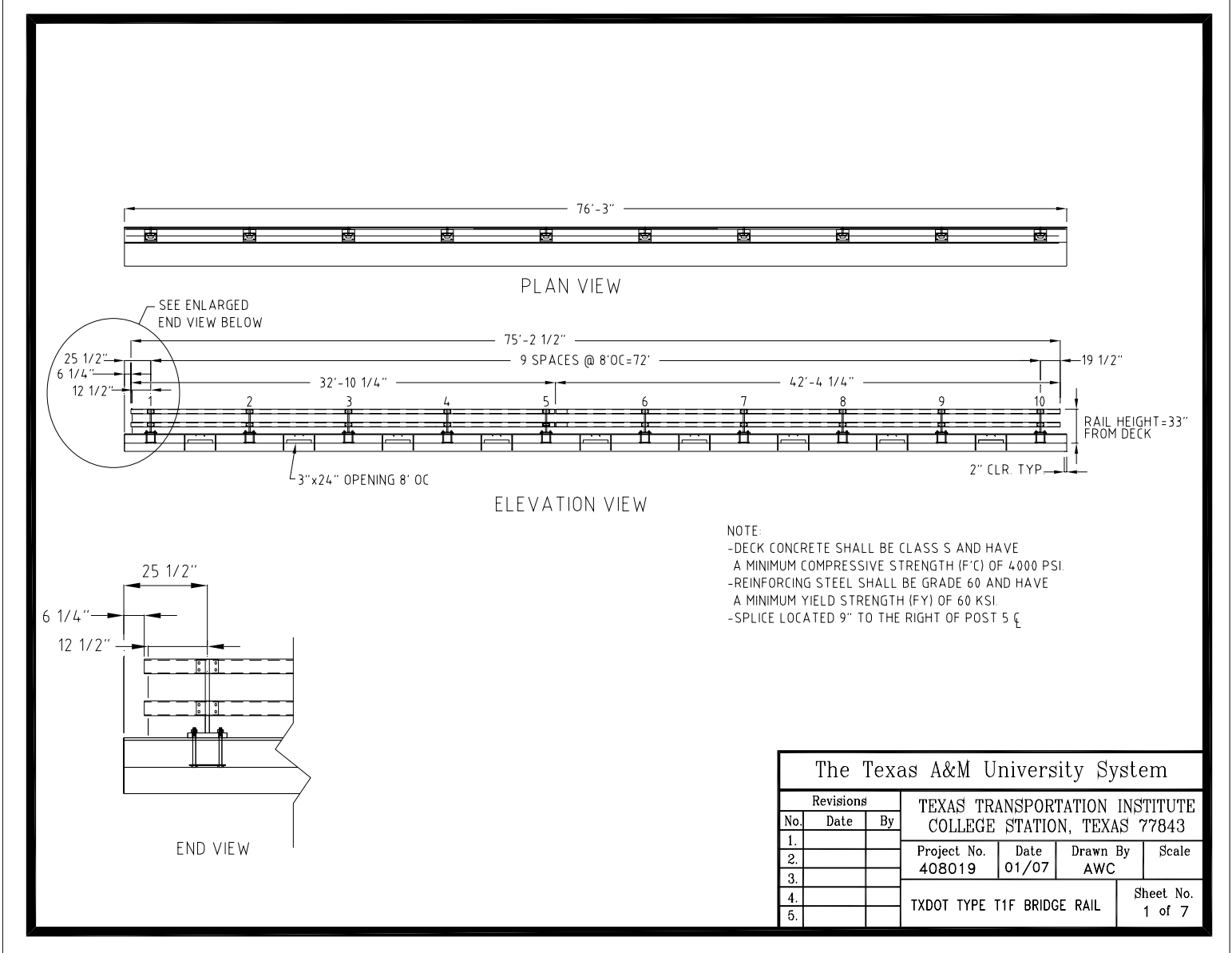
All reinforcement was bare steel (not epoxy coated) and was specified to have a minimum yield strength of 60 ksi.

Standard concrete compressive strength cylinders were cast for both the concrete deck and curb. For the concrete deck, strength tests performed at 34 days age resulted in an average compressive strength of 4943 psi. For the concrete curb, strength tests performed at 27 days age resulted in an average compressive strength of 4395 psi. The post plates and base plates were manufactured from A572 Grade 50 material.

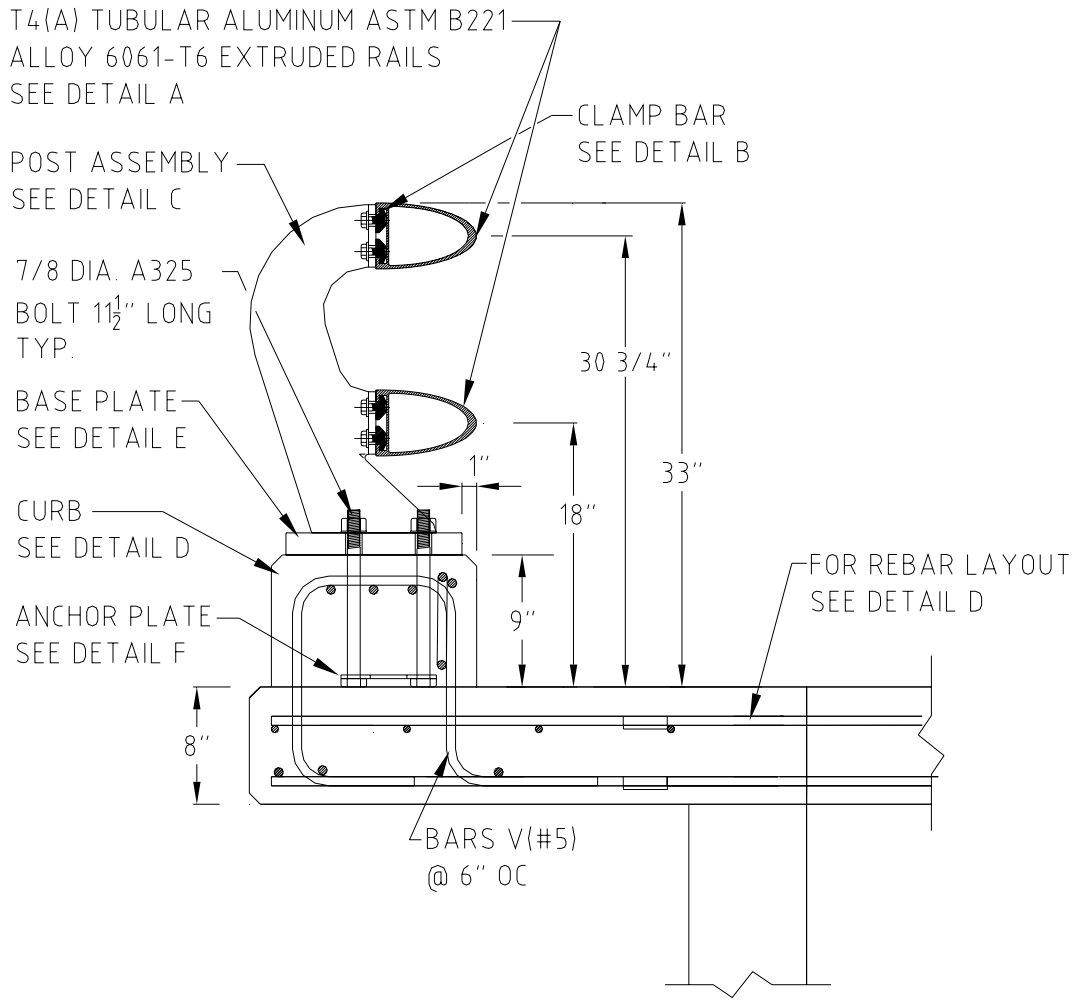
## **2.3 SOIL/FOUNDATION CONDITIONS**

The simulated concrete bridge deck cantilever and curb was constructed immediately adjacent to an existing out-of-service concrete apron located at the TTI test facility. The apron consists of an unreinforced jointed-concrete pavement in 12.5 ft by 15 ft blocks nominally 8 to 12 inches deep. The apron is over 60 years old, and the joints have some displacement, but are otherwise flat and level.

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**Figure 2.1. Details of the TxDOT T-1F Bridge Rail Installation.**



**Figure 2.2. Cross Section of the TxDOT T-1F Bridge Rail Installation.**



**Figure 2.3. TxDOT T-1F Bridge Rail Installation Before Test 408019-1.**



## CHAPTER 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

### 3.1 CRASH TEST MATRIX

The underlying philosophy behind the test conditions recommended in the update to *NCHRP Report 350* continues to be one of “worst practical conditions.” When selecting test parameters such as test vehicle type and weight, impact speed and angle, and point of impact, the update recommends what are considered to be worst, or most critical, conditions with consideration given to available technology, relevancy in terms of the incremental increase in the level of safety provided, and associated costs of new features compared to existing features. For example, the weights of the selected small passenger car and pickup truck test vehicles represent 2<sup>nd</sup> and 94<sup>th</sup> percentile of passenger vehicles based on sales data, and the selected impact speed and angle combination represents the 92.5<sup>th</sup> percentile as determined from the reconstruction of real-world crashes. When the combined effects of all testing parameters are considered, the tests prescribed in the update to *NCHRP Report 350* (Update) are believed to reasonably represent the extremes of impact conditions expected to be encountered in real-world crashes.

Major revisions proposed for incorporation into the new guidelines include new design test vehicles, revised test matrices and impact conditions, changes to the evaluation criteria, inclusion of tests for additional features, and increased emphasis on in-service performance evaluation. Some proposed changes include:

- It has been recommended to change the large design test vehicle from a standard cab, ¾-ton pickup truck with a center-of-gravity (C.G.) height of approximately 27-inches to a ½-ton, four-door, crew-cab pickup truck with a minimum C.G. height of 28-inches. It is still the intent to have this design test vehicle represent the light truck segment of the vehicle fleet. The weight of the test vehicle will increase approximately 13% from 4400 lb to 5000 lb, which represents the 94<sup>th</sup> percentile heaviest passenger vehicle in terms of sales (i.e., only six percent of new passenger type vehicles sold weigh more than the specified test weight). The increase in weight will place more structural demand (i.e., increased impact forces) on existing appurtenances, and the increase in C.G. height may aggravate stability issues associated with some barrier systems.
- The weight of the small car test vehicle will increase 35% from 1800 lb to 2425 lb. This reflects the fact that 1800-lb vehicles are virtually nonexistent in terms of new car sales. The weight specified for the newly recommended small passenger car represents the 2<sup>nd</sup> percentile lightest passenger vehicle in terms of sales (i.e., only two percent of new vehicles sold weigh less than the specified test weight).
- It has been recommended that the impact angle for all redirection tests be adjusted to 25 degrees. This means an increase from the current 20 degree impact angle for small car tests and for pickup truck redirection tests on terminals and crash cushions. Considering both the increase in weight and impact angle, the impact severities of the small car redirection test (Test 3-10) and the pickup truck redirection tests on terminals and crash cushions (e.g., Test 3-35) increase by 206% and 73%, respectively. The revised small car

redirection test will not pose a problem in terms of structural adequacy compared to the pickup truck test. However, the effect of the increase in angle and impact severity on vehicle stability and occupant risk may need to be evaluated for some devices.

- With the increase in weight to 5000 lb, the impact severity of the Test Level 3 (TL-3) pickup truck redirection test (Test 3-11) has an impact severity that is 16% greater than the current TL-4 single-unit truck test (Test 4-12). Consequently, it has been proposed to modify the conditions of the single-unit truck (SUT) impact in the Update to make it a more discerning test. The weight of the SUT will increase 23% from 18,000 lb to 22,045 lb, and the impact speed will increase 12% from 50 mph to 56 mph. The resulting increase in impact severity is 54%. This may affect the status of some barriers currently classified as TL-4 barriers under *NCHRP Report 350*.

TxDOT contracted with TTI to perform a full-scale crash test using the 2270P test vehicle (5000-lb Dodge Quad Cab pickup truck) impacting the TxDOT T-1F Bridge Rail at the critical impact point of the length-of-need at an impact speed and angle of 62.2 mi/h and 25 degrees, respectively.

All crash test, data analysis, and evaluation and reporting procedures followed under this project were in accordance with guidelines presented in the update to *NCHRP Report 350*. Appendix A presents brief descriptions of these procedures.

### **3.2 EVALUATION CRITERIA**

The crash test was evaluated in accordance with the criteria presented in the update to *NCHRP Report 350*. The performance of the TxDOT Type T-1F Bridge Rail is judged on the basis of three factors: structural adequacy, occupant risk, and post impact vehicle trajectory. Structural adequacy is judged based on the TxDOT Type T-1F Bridge Rail's ability to contain and redirect the vehicle, or bring the vehicle to a controlled stop in a predictable manner. Occupant risk criteria evaluates the potential risk of hazard to occupants in the impacting vehicle, and to some extent other traffic, pedestrians, or workers in construction zones, if applicable. Post impact vehicle trajectory is assessed to determine potential for secondary impact with other vehicles or fixed objects, creating further risk of injury to occupants of the impacting vehicle and/or risk of injury to occupants in other vehicles. The appropriate safety evaluation criteria from table 5.1 of the update to *NCHRP Report 350* were used to evaluate the crash test reported herein, and are listed in further detail under the assessment of the crash test.



## **CHAPTER 4. TEST CONDITIONS**

### **4.1 TEST FACILITY**

The Texas Transportation Institute Proving Ground is a 2000-acre complex of research and training facilities located 10 mi northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for construction and testing of the bridge rail evaluated under this project is along an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5 ft by 15 ft blocks nominally 8 to 12 inches deep. The apron is over 60 years old, and the joints have some displacement, but are otherwise flat and level.

### **4.2 VEHICLE TOW AND GUIDANCE SYSTEM**

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.

### **4.2 DATA ACQUISITION SYSTEMS**

#### **4.2.1 Vehicle Instrumentation and Data Processing**

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center of gravity (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a backup biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO<sup>®</sup> Model 2262CA, piezoresistive accelerometers with a  $\pm 100$  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  $\pm 2.5$  volt maximum level. The signal conditioners also provide the capability of an R-cal

(resistive calibration) or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15-channel, constant-bandwidth, Inter-Range Instrumentation Group (IRIG), FM/FM telemetry link for recording and for display. Calibration signals from the test vehicle are recorded before the test and immediately afterwards. A crystal-controlled time reference signal is simultaneously recorded with the data. Wooden dowels actuate pressure-sensitive switches on the bumper of the impacting vehicle prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an “event” mark on the data record to establish the instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto TEAC<sup>®</sup> instrumentation data recorder. After the test, the data are played back from the TEAC<sup>®</sup> recorder and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer into engineering units using the R-cal and pre-zero values at 10,000 samples per second, per channel. WinDigit also provides Society of Automotive Engineers (SAE) J211 class 180 phaseless digital filtering and vehicle impact velocity.

All accelerometers are calibrated annually according to the (SAE) J211 4.6.1 by means of an ENDEVCO<sup>®</sup> 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/compartiment impact velocities, time of occupant/compartiment impact after vehicle impact, and the highest 10-milliseconds (ms) average ridedown acceleration. WinDigit calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact.

#### **4.2.2 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 test with the 2000P vehicle.

### **4.2.3 Photographic Instrumentation and Data Processing**

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.



## **CHAPTER 5. CRASH TEST 408019-1** **(NCHRP REPORT 350 UPDATE TEST NO. 3-11)**

### **5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS**

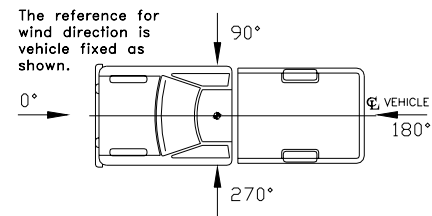
*NCHRP Report 350* Update test 3-11 involves a 2270P vehicle weighing 5000 lb  $\pm$  100 lb and impacting the bridge rail at an impact speed of 62.2 mi/h  $\pm$  2.5 mi/h and an angle of 25 degrees  $\pm$  1.5 degrees. The target impact point was 51.2 inches upstream of the centerline of the splice located near post 6. The 2003 Dodge Ram 1500 pickup truck used in the test weighed 4947 lb and the actual impact speed and angle were 62.0 mi/h and 23.8 degrees, respectively. The actual impact point was 66.25 inches upstream of the splice.

### **5.2 TEST VEHICLE**

A 2003 Dodge 1500 pickup truck, shown in Figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 4947 lb, and its gross static weight was 4947 lb. The height to the lower edge of the vehicle bumper was 13.75 inches, and it was 26.0 inches to the upper edge of the bumper. Figure B1 in Appendix B1 gives additional dimensions and information on the vehicle. 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.

### **5.3 WEATHER CONDITIONS**

The test was performed on the morning of May 22, 2007. Weather conditions at the time of testing were as follows: Wind speed: 11 mi/h; Wind direction: 330 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); Temperature: 76°F, Relative humidity: 80 percent.



### **5.4 TEST DESCRIPTION**

The 2003 Dodge 1500 pickup truck, traveling at an impact speed of 62.0 mi/h, impacted the bridge rail 66.25 inches upstream of the splice located near post 6 at an impact angle of 23.8 degrees. At approximately 0.022 s, the right front wheel rim contacted the curb and began to ride up the traffic face of the curb. At 0.045 s, the vehicle began to redirect. The left front tire became airborne at 0.084 s, and the left rear tire at 0.126 s. At 0.151 s, the front of the exterior bed of the vehicle contacted the top rail element, and at 0.158 s, the rear of the bed contacted the rail element. The vehicle was parallel with the bridge rail at 0.174 s, traveling at a speed of 32.1 mi/h. The rear bumper contacted the lower rail element at 0.179 s. At 0.329 s, the vehicle lost contact with the bridge rail and was traveling at an exit speed of 31.7 mi/h and an exit angle of 9.5 degrees. Brakes on the vehicle were applied at 1.25 s, and the vehicle came to rest 247 ft downstream of impact and 21 ft forward of the traffic face of the bridge rail. Figures B2 and B3 in Appendix B2 show sequential photographs of the test period.



**Figure 5.1. Vehicle/Installation Geometrics for Test 408019-1.**



**Figure 5.2. Vehicle Before Test 408019-1.**

## **5.5 TEST ARTICLE AND COMPONENT DAMAGE**

Damage to the TxDOT Type T-1F Bridge Rail is shown in figures 5.3 and 5.4. The concrete was gouged out of the traffic face of the curb. The curb also had cracks radiating out from the right front and rear and left rear anchor bolts at post 5 and both front anchors bolts at post 6. The rail splice at the top did not change, but the bottom splice opened up 0.24 inch. Length of contact of the vehicle with the top rail element, bottom rail element and curb was 142 inches, 146 inches, and 121 inches, respectively. Maximum permanent deformation of the top rail element was 0.7 inch and the bottom rail element was 3.2 inches. Working width was 15.0 inches. Maximum dynamic deformation of the top rail element during the test was not obtainable.

## **5.6 TEST VEHICLE DAMAGE**

Damage to the 2270P is shown in figure 5.5. Structural damage was imparted to the right front upper and lower ball joints and A-arms, the right tie rod end and the right frame rail. Also damaged were the front bumper, hood, grill, radiator and radiator support, right front quarter panel, right front and rear doors and right rear exterior bed. The right front tire and rim separated from the vehicle and the right rear rim was deformed but the tire was not deflated. Maximum exterior crush to the vehicle was 15.0 inches in the frontal plane at the right front corner at bumper height. The floor pan, firewall, toe pan and kickpanel on the right side were deformed. Maximum occupant compartment deformation was 1.3 inches in the right firewall/toe pan area. Photographs of the interior of the vehicle are shown in figure 5.6. Exterior crush and occupant compartment deformations are shown in tables B1 and B2.

## **5.7 OCCUPANT RISK VALUES**

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 17.4 ft/s at 0.088 s, the highest 0.010-s occupant ridedown acceleration was -8.9 Gs from 0.092 to 0.102 s, and the maximum 0.050-s average acceleration was -8.6 Gs between 0.029 and 0.079 s. In the lateral direction, the occupant impact velocity was 30.8 ft/s at 0.088 s, the highest 0.010-s occupant ridedown acceleration was -12.0 Gs from 0.202 to 0.212 s, and the maximum 0.050-s average was -15.9 Gs between 0.040 and 0.090 s. Figure 5.7 presents these data and other pertinent information from the test. Figures B4 through B10 in Appendix B3 presents vehicle angular displacements and accelerations versus time traces.





**Figure 5.3. After Impact Trajectory Path for Test 408019-1.**



**Figure 5.4. Installation After Test 408019-1.**



**Figure 5.5. Vehicle After Test 408019-1.**

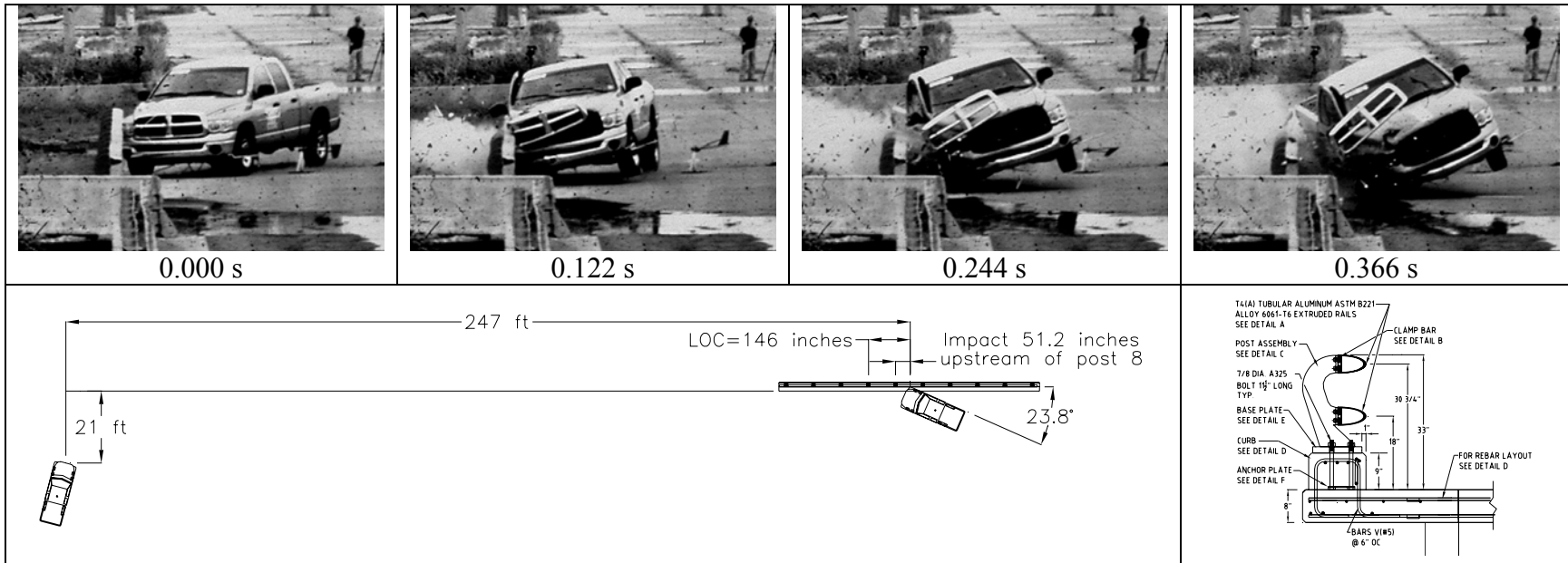


Before Test



After Test

**Figure 5.6. Interior of Vehicle for Test 408019-1.**



25

General Information		Impact Conditions		Test Article Deflections (inch)	
Test Agency.....	Texas Transportation Institute	Speed (mi/h).....	62.0	Dynamic .....	Not Obtainable
Test No. ....	408019-1	Angle (deg).....	23.8	Permanent.....	3.2
Date .....	05-22-2007	<b>Exit Conditions</b>		Working Width.....	15.0
<b>Test Article</b>		Speed (mi/h).....	31.7	<b>Vehicle Damage</b>	
Type.....	Bridge Rail	Angle (deg).....	9.5	Exterior	
Name .....	TxDOT Type T-1F	<b>Occupant Risk Values</b>		VDS.....	01RFQ2
Installation Length (ft).....	76.25	Impact Velocity (ft/s)		CDC .....	01FREW3
Material or Key Elements .....	Steel post system with 2 tubular aluminum rail elements on steel plate posts on bridge deck 8 inches thick with 9-inch high concrete curb	Longitudinal.....	17.4	Maximum Exterior	
<b>Soil Type and Condition</b> .....		Lateral .....	30.8	Vehicle Crush (inch) .....	15.0
Concrete Deck, Dry		THIV (km/h).....	37.5	Interior	
<b>Test Vehicle</b>		Ridedown Accelerations (Gs)		OCDI .....	RF0000000
Type.....	Production	Longitudinal.....	-8.9	Maximum Occupant Compartment	
Designation.....	2270P	Lateral .....	-12.0	Deformation (inch) .....	1.26
Model.....	2003 Dodge 1500 Quad Cab Pickup	PHD (g's).....	12.1	<b>Post-Impact Behavior</b>	
Mass (lb)		ASI .....	1.90	(during 1.0 sec after impact)	
Curb.....	4863	Max. 0.050-s Average (Gs)		Max. Yaw Angle (deg).....	-34
Test Inertial.....	4947	Longitudinal.....	-8.6	Max. Pitch Angle (deg).....	-9
Dummy .....	No dummy	Lateral .....	-15.9	Max. Roll Angle (deg) .....	19
Gross Static.....	4947	Vertical .....	2.8		

Figure 5.7. Summary of Results for NCHRP Report 350 Update Test 3-11 on the TxDOT Type T-1F Bridge Rail.

## 5.8 ASSESSMENT OF TEST RESULTS

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

### 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.*

Result: The TxDOT T-1F Bridge Rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the bridge rail. Maximum dynamic deflection of the bridge rail was not obtainable, but the maximum permanent deformation was 3.2 inches. (PASS)

### Occupant Risk

- D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*

*Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of the Update to NCHRP Report 350. (roof  $\leq 3.9$  inches; windshield =  $\leq 3.0$  inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan  $\leq 8.9$  inches; forward of A-pillar  $\leq 11.8$  inches; front side door area above seat  $\leq 8.9$  inches; front side door below seat  $\leq 11.8$  inches; floor pan/transmission tunnel area  $\leq 11.8$  inches)*

<u>Rating</u>	<u>Extent of Intrusion</u>
Good	<5.9 inches
Acceptable	5.9-8.6 inches
Marginal	8.6-11.8 inches
Poor	>11.8 inches

Results: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. (PASS)  
Maximum occupant compartment deformation was 1.25 inches in the right firewall area. (GOOD)

- F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*

Results: The 2270P vehicle remained upright during and after the collision event. During the 1 second after impact, the maximum roll angle was 19 degrees and maximum pitch was -9 degrees. (PASS)

H. Occupant impact velocities should satisfy the following:  
*Longitudinal and Lateral Occupant Impact Velocity*

<u>Preferred</u>	<u>Maximum</u>
29.5 ft/s	39.4 ft/s

Results: Longitudinal occupant impact velocity was 17.4 ft/s, and lateral occupant impact velocity was 30.8 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:  
*Longitudinal and Lateral Occupant Ridedown Accelerations*

<u>Preferred</u>	<u>Maximum</u>
15.0 Gs	20.0 Gs

Results: Longitudinal ridedown acceleration was -8.9 Gs, and lateral occupant ridedown acceleration was -12.0 Gs. (PASS)

### **Vehicle Trajectory**

*After impact, the vehicle shall exit the barrier within the exit box.*

Result: The 2270P vehicle remained within the exit box, and subsequently came to rest 247 ft downstream of impact and 21 ft forward of the traffic face of the bridge rail. (PASS)

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled “ACTION: Identifying Acceptable Highway Safety Features,” were used for visual assessment of test results. (7) Factors underlined below pertain to the results of the crash test reported herein.

#### ***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*

2. *Windshield Damage*

- a. *None*
- b. *Minor chip or crack*
- c. *Broken, no interference with visibility*
- d. *Broken or shattered, visibility restricted but remained intact*

3. *Device Damage*

- a. *None*
- b. *Superficial*
- c. *Substantial, but can be straightened*

- d. *Major dents to grill and body panels*
- e. *Major structural damage*

- e. *Shattered, remained intact but partially dislodged*
- f. *Large portion removed*
- g. *Completely removed*

- d. *Substantial, replacement parts needed for repair*
- e. *Cannot be repaired*



## CHAPTER 6. SUMMARY AND CONCLUSIONS

### 6.1 SUMMARY OF RESULTS

The TxDOT T-1F Bridge Rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the bridge rail. Maximum dynamic deflection of the bridge rail was not obtainable, but the maximum permanent deformation was 3.2 inches. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 1.25 inches in the right firewall area. The 2270P vehicle remained upright during and after the collision event. During the 1 second after impact, the maximum roll angle was 19 degrees and maximum pitch was -9 degrees. Occupant risk factors were within the limits specified. The 2270P vehicle remained within the exit box, and subsequently came to rest 247 ft downstream of impact and 21 ft forward of the traffic face of the bridge rail.

### 6.2 CONCLUSIONS

The TxDOT Type T-1F Bridge Rail performed acceptably according to the safety performance criteria for *NCHRP Report 350* Update test 3-11, as shown in Table 6.1.

**Table 6.1. Performance Evaluation Summary for NCHRP Report 350 Update Test 3-11 on the TxDOT Type T-1F Bridge Rail.**

Test Agency: Texas Transportation Institute

Test No.: 408019-1

Test Date: 05-22-2007

<b>NCHRP Report 350 Update Test 3-11 Evaluation Criteria</b>	<b>Test Results</b>	<b>Assessment</b>
<p>➤ Structural Adequacy</p> <p>A. <i>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable</i></p>	<p>The TxDOT T-1F Bridge Rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the bridge rail. Maximum dynamic deflection of the bridge rail was not obtainable, but the maximum permanent deformation was 3.2 inches on the bottom rail.</p>	<p align="center">Pass</p>
<p>➤ Occupant Risk</p> <p>D. <i>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 should not exceed limits set forth in Section 5.3 and Appendix E of the Update to NCHRP Report 350.</i></p>	<p>No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area.</p> <p>Maximum occupant compartment deformation was 1.25 inches in the right firewall area.</p>	<p align="center">Pass</p> <p align="center"><u>Rating:</u> Good</p>
<p>F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i></p>	<p>The 2270P vehicle remained upright during and after the collision event. During the 1 second after impact, the maximum roll angle was 19 degrees and maximum pitch was -9 degrees.</p>	<p align="center">Pass</p>
<p>H. <i>Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9.0 m/s (29.5ft/s), or at least below the maximum allowable value of 12.0 m/s (39.4 ft/s).</i></p>	<p>Longitudinal occupant impact velocity was 17.4 ft/s and lateral occupant impact velocity was 30.8 ft/s.</p>	<p align="center">Pass</p>
<p>I. <i>Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.0 Gs.</i></p>	<p>Longitudinal ridedown acceleration was -8.9 Gs and lateral occupant ridedown acceleration was -12.0 Gs.</p>	<p align="center">Pass</p>
<p>➤ Vehicle Trajectory</p> <p><i>After impact, the vehicle shall exit the barrier within the exit box.</i></p>	<p>The 2270P vehicle remained within the exit box, and subsequently came to rest 247 ft downstream of impact and 21 ft forward of the traffic face of the bridge rail.</p>	<p align="center">Pass</p>

## **CHAPTER 7. IMPLEMENTATION STATEMENT**

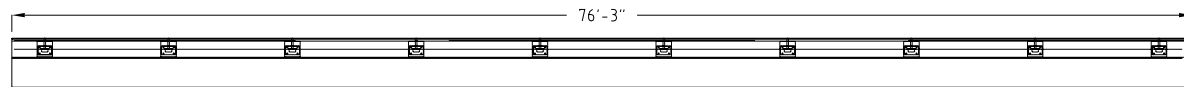
The TxDOT Type T-1F bridge rail meets the safety performance evaluation criteria of the proposed update to *NCHRP Report 350*. The TxDOT T-1F is recommended for implementation in accordance with the details and specifications provided in this report.



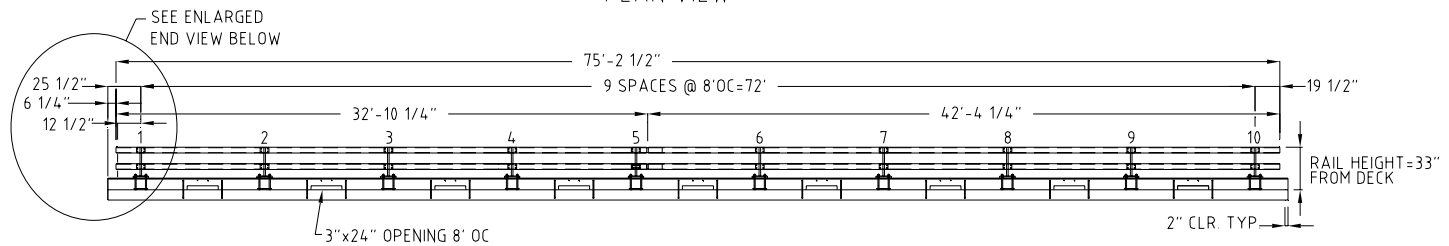
## REFERENCES

1. “Proposed Full-Scale Testing Procedures for Guardrails,” *Highway Research Circular 482*, Highway Research Board, Washington, D.C., 1962.
2. Bronstad, M.E. and Michie, J.D., “Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances,” *NCHRP Report 153*, Transportation Research Board, National Research Council, Washington, D.C., 1974.
3. “Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances,” *Transportation Research Circular 191*, Transportation Research Board, National Academy of Sciences, Washington, D.C., February 1978.
4. Michie, J.D., “Recommended Procedures for the Safety Performance Evaluation of Highway Features,” *NCHRP Report 230*, Transportation Research Board, National Research Council, Washington, D.C., March 1981.
5. Ross, Jr., H.E., Sicking, D.L., Zimmer, R.A. and Michie, J.D., “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.
6. Sicking, D.L. and Mak, K.K., *Improvement of Procedures for the Safety-Performance Evaluation of Roadside Features, Draft Guidelines – Iteration #4*, National Cooperative Highway Research Program Project No. 22-14(02), National Research Council, Washington, D.C., 2006.
7. Federal Highway Administration Memorandum from the Director, Office of Engineering, entitled: “ACTION: Identifying Acceptable Highway Safety Features,” dated July 25, 1997.

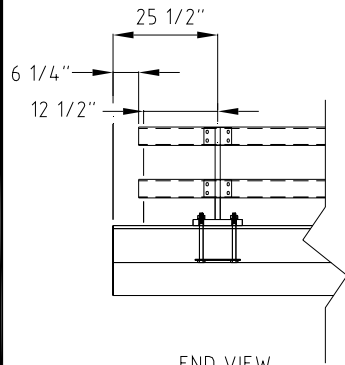




PLAN VIEW



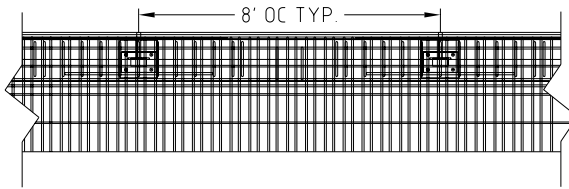
ELEVATION VIEW



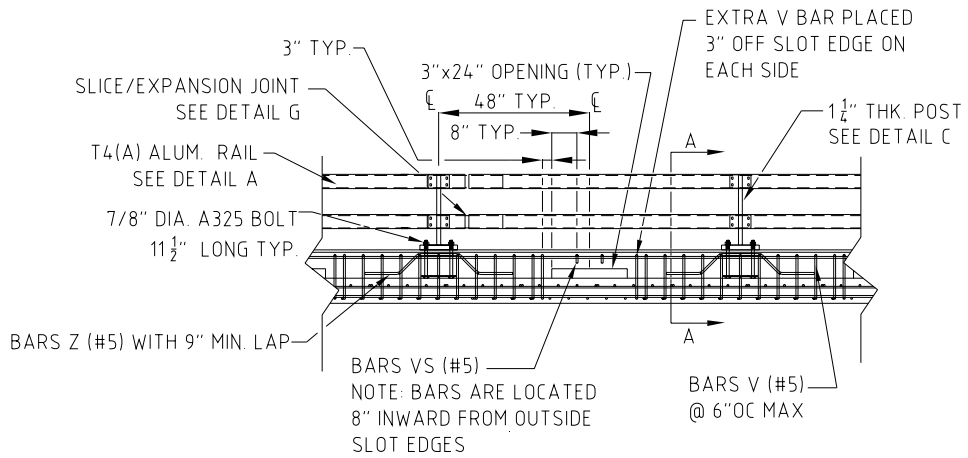
END VIEW

NOTE:  
 -DECK CONCRETE SHALL BE CLASS S AND HAVE A MINIMUM COMPRESSIVE STRENGTH (F'C) OF 4000 PSI.  
 -REINFORCING STEEL SHALL BE GRADE 60 AND HAVE A MINIMUM YIELD STRENGTH (FY) OF 60 KSI  
 -SPLICE LOCATED 9" TO THE RIGHT OF POST 5

The Texas A&M University System				
TEXAS TRANSPORTATION INSTITUTE COLLEGE STATION, TEXAS 77843				
Revisions		Project No.	Date	Drawn By
No.	Date	By	408019	AWC
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TXDOT TYPE T1F BRIDGE RAIL				Scale
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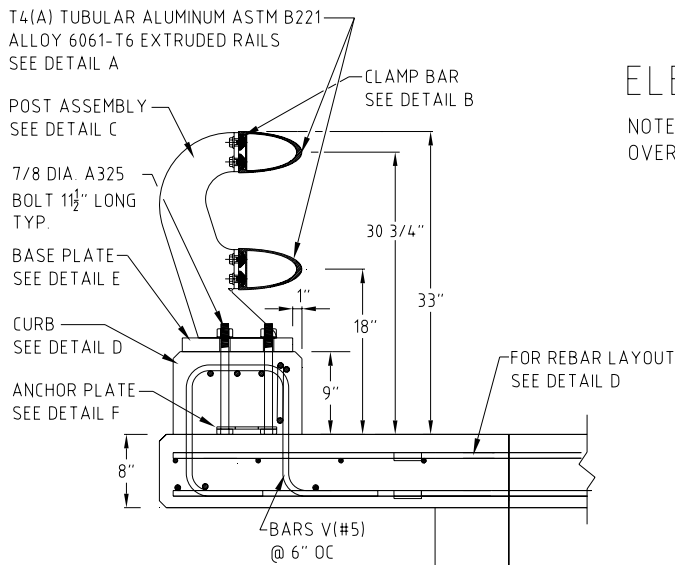


PLAN VIEW



ELEVATION VIEW

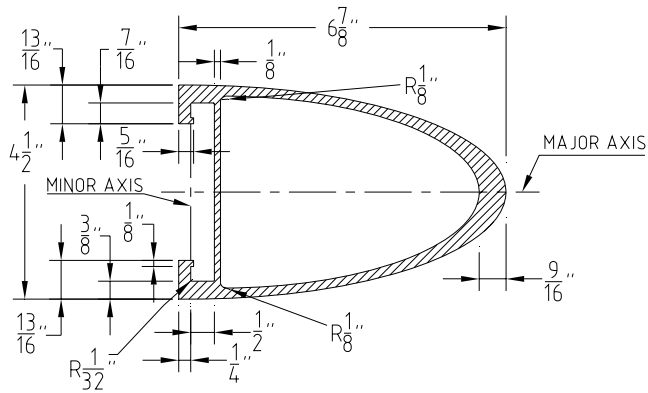
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OVER EACH SLOT, SEE DETAIL D



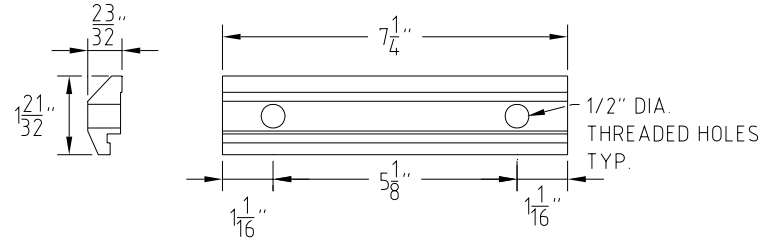
SECTION A-A

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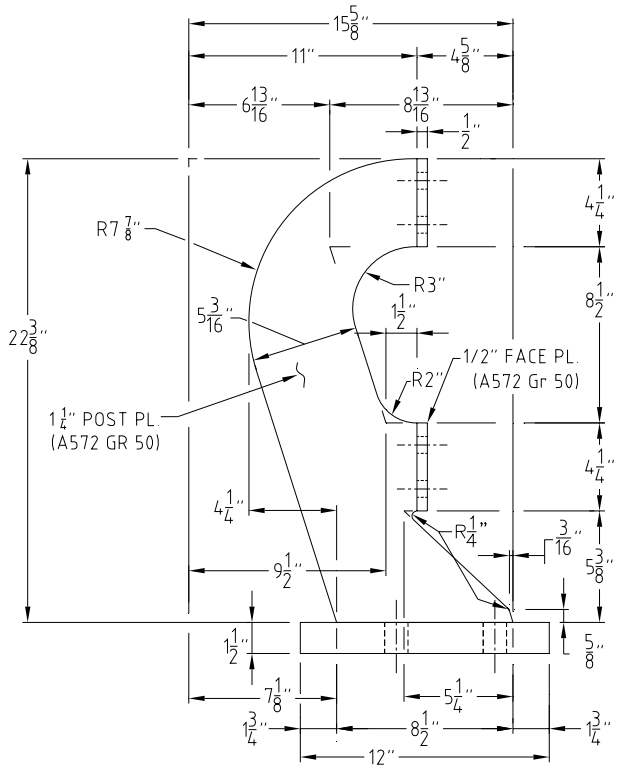
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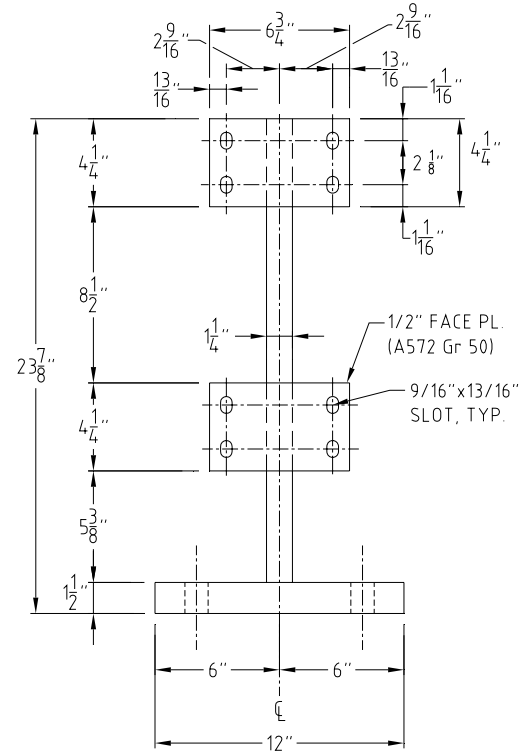
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CLAMP BAR

The Texas A&M University System

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5.						3 of 7



POST SIDE VIEW

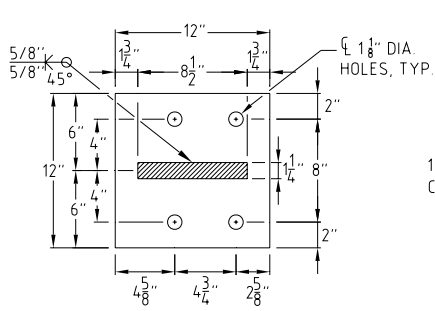


TRAFFIC SIDE VIEW

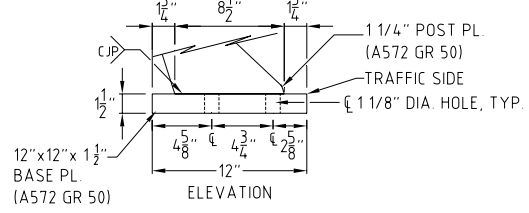
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The Texas A&M University System

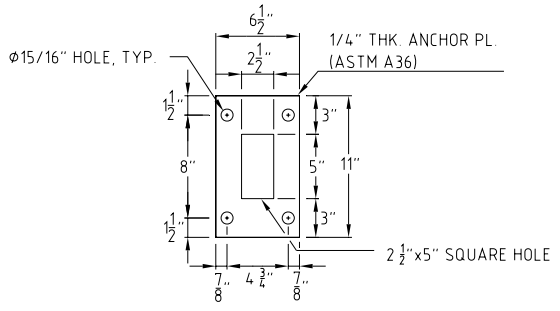
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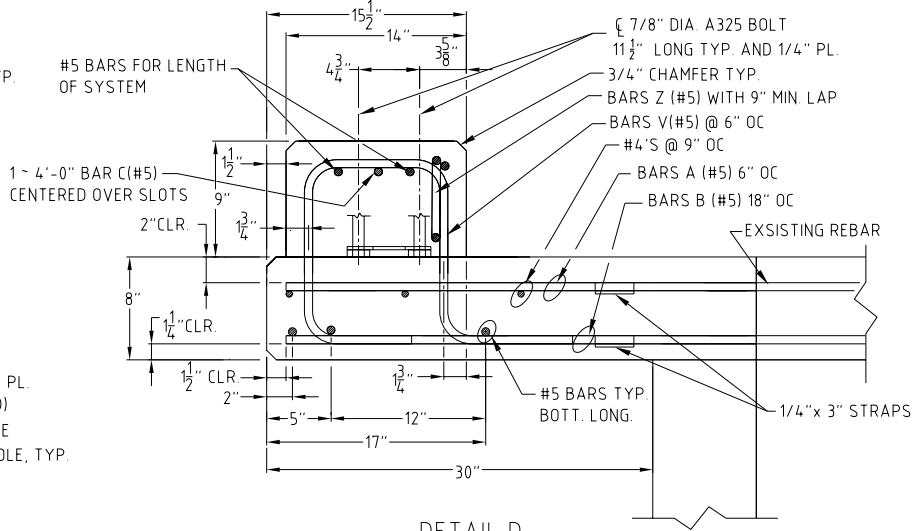
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DETAIL E  
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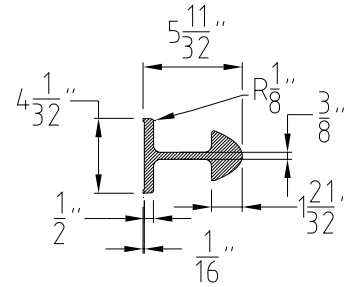
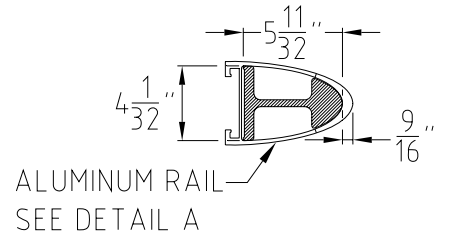
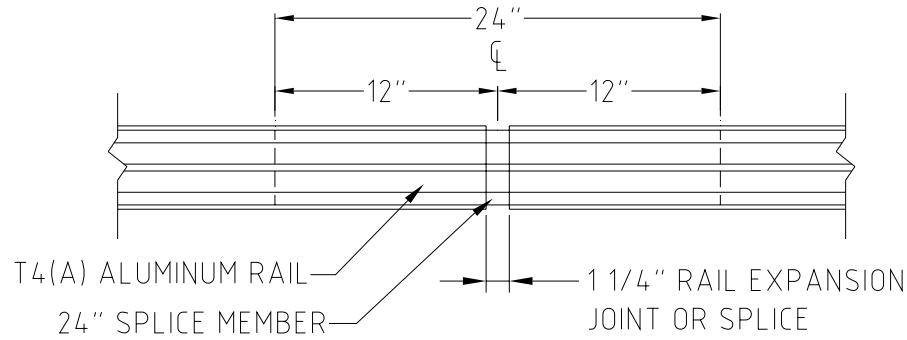


DETAIL F  
 PLAN VIEW OF ANCHOR PLATE



DETAIL D  
 REBAR DETAIL

The Texas A&M University System				
Revisions		TEXAS TRANSPORTATION INSTITUTE COLLEGE STATION, TEXAS 77843		
No.	Date	By	Project No.	Date
1.			408019	01/07
2.			Drawn By	Scale
3.			AWC	
4.			TXDOT TYPE T1F BRIDGE RAIL	Sheet No.
5.				5 of 7

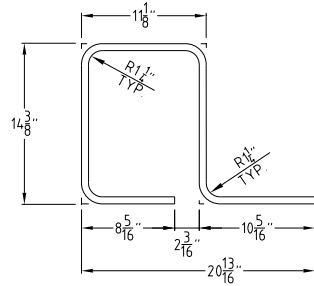


SPLICE FIT INSIDE ALUM. RAIL

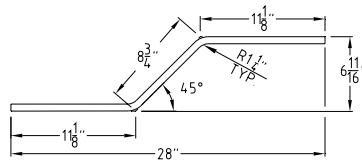
SPLICE MEMBER SECTION

DETAIL G  
TYPICAL SPLICE/EXPANSION JOINT DETAIL

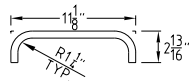
The Texas A&M University System						
Revisions			TEXAS TRANSPORTATION INSTITUTE COLLEGE STATION, TEXAS 77843			
No.	Date	By	Project No.	Date	Drawn By	Scale
1.			408019	01/07	AWC	
2.			TXDOT TYPE T1F BRIDGE RAIL			Sheet No.
3.						6 of 7
4.						
5.						



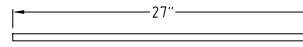
BARS V (#5)



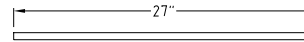
BARS Z (#5)



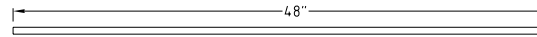
BARS VS (#5)



BARS A (#5) 6" OC



BARS B (#5) 18" OC



BARS C (#5) CENTERED OVER SLOTS

### FABRICATED REBAR PIECES

The Texas A&M University System

Revisions			TEXAS TRANSPORTATION INSTITUTE COLLEGE STATION, TEXAS 77843			
No.	Date	By	Project No.	Date	Drawn By	Scale
1.			408019	01/07	AWC	
2.						
3.						
4.			TXDOT TYPE T1F BRIDGE RAIL			Sheet No.
5.						7 of 7



## APPENDIX B. CRASH TEST NO. 408019-1

### B.1 VEHICLE PROPERTIES AND INFORMATION

Date: 05-22-2007 Test No.: 408019-1 VIN No.: 1D7HA18N935143811  
 Year: 2003 Make: Dodge Model: Ram 1500  
 Tire Size: 245 70R16 Tire Inflation Pressure: 44 psi  
 Tread Type: Highway Odometer: 186570

Note any damage to the vehicle prior to test: \_\_\_\_\_

• Denotes accelerometer location.

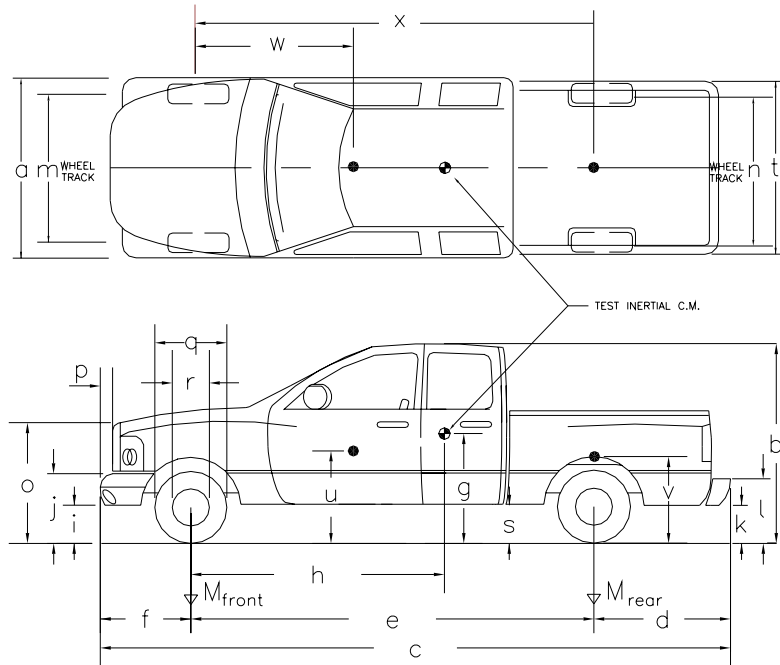
NOTES: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Engine Type: V-8  
 Engine CID: 4.7 liter

Transmission Type:  
 Auto or \_\_\_\_\_ Manual  
 FWD  RWD  4WD

Optional Equipment:  
 \_\_\_\_\_  
 \_\_\_\_\_

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



**Geometry:** inches

a	<u>77</u>	f	<u>37</u>	k	<u>21-1/4</u>	p	<u>3-1/2</u>	u	<u>28-1/2</u>
b	<u>74-1/4</u>	g	<u>28-7/16</u>	l	<u>29-1/2</u>	q	<u>30</u>	v	<u>33</u>
c	<u>224-1/2</u>	h	<u>62.03</u>	m	<u>68</u>	r	<u>18-1/4</u>	w	<u>59-1/2</u>
d	<u>47</u>	i	<u>13-3/4</u>	n	<u>67-1/2</u>	s	<u>15-1/4</u>	x	<u>140-1/2</u>
e	<u>140-1/2</u>	j	<u>26</u>	o	<u>44-1/4</u>	t	<u>75-1/2</u>		

Wheel Center Ht Front 14-1/4 Wheel Well Clearance (FR) 6 Frame Ht (FR) 16  
 Wheel Center Ht Rear 14-1/2 Wheel Well Clearance (RR) 11-1/2 Frame Ht (RR) 25-1/4

<b>GVWR Ratings:</b>	<b>Mass:</b> lb	<u>Curb</u>	<u>Test Inertial</u>	<u>Gross Static</u>
Front <u>3650</u>	$M_{front}$	<u>2789</u>	<u>2763</u>	_____
Back <u>3900</u>	$M_{rear}$	<u>2074</u>	<u>2184</u>	_____
Total <u>6650</u>	$M_{Total}$	<u>4863</u>	<u>4947</u>	_____

**Mass Distribution:**  
 lb LF: 1389 RF: 1374 LR: 1097 RR: 1087

**Figure B1. Vehicle Properties for Test 408019-1.**

**Table B1. Exterior Crush Measurements for Test 408019-1.**

**VEHICLE CRUSH MEASUREMENT SHEET<sup>1</sup>**

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

Note: Measure C<sub>1</sub> to C<sub>6</sub> 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 <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>	C <sub>6</sub>	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	14	8	28	0	1¼	3	3	3	8	+14
2	Side plane at bumper ht	59	15	74	0	3½	6⅛	--	--	15	+59
		All units in inches									

<sup>1</sup>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.

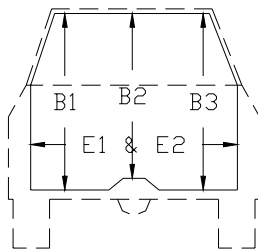
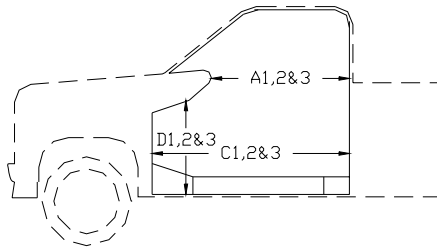
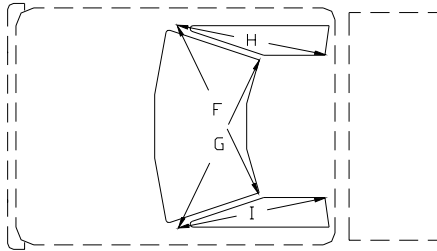
Note: Use as many lines/columns as necessary to describe each damage profile.



**Table B2. Occupant Compartment Measurements for Test 408019-1.**

# TRUCK

## Occupant Compartment Deformation



	BEFORE (inches)	AFTER (inches)
A1	65.6	65.6
A2	65.7	65.7
A3	66.3	66.3
B1	44.7	44.7
B2	39.4	39.4
B3	45.6	45.6
C1	30.1	30.1
C2	---	---
C3	28.0	26.8
D1	12.7	12.7
D2	2.5	2.5
D3	11.5	11.5
E1	64.5	65.1
E2	63.9	64.0
F	59.8	59.8
G	59.8	59.8
H	39.5	39.5
I	39.5	39.5
J*	61.8	61.2

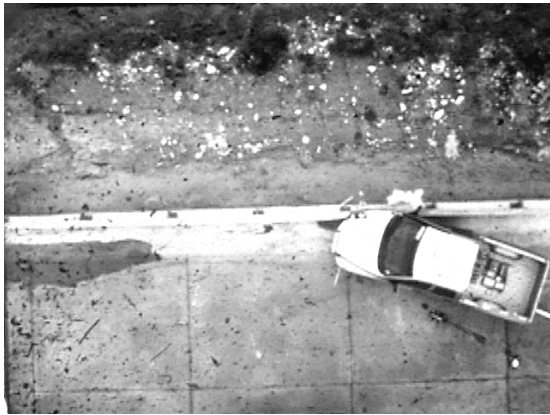
\*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.



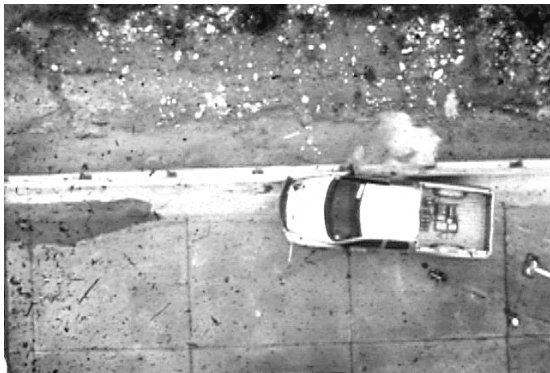
**B.1 SEQUENTIAL PHOTOGRAPHS**



0.000 s



0.061 s



0.122 s



0.183 s



**Figure B2. Sequential Photographs for Test 408019-1 (Overhead and Frontal Views).**



0.244 s



0.305 s



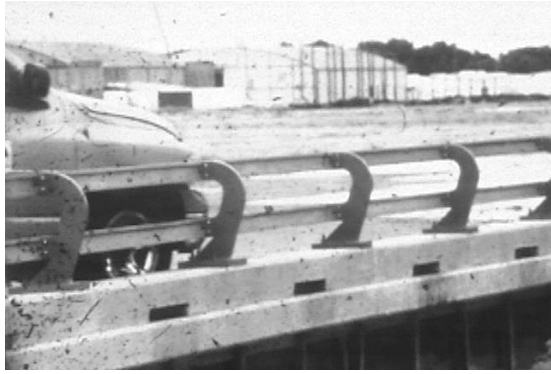
0.366 s



0.427 s



**Figure B2. Sequential Photographs for Test 408019-1  
(Overhead and Frontal Views) (continued).**



0.000 s



0.244 s



0.061 s



0.305 s



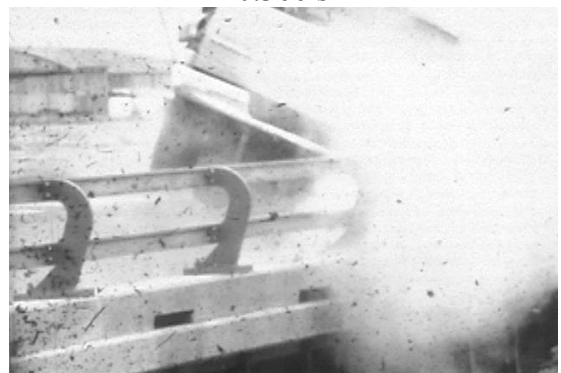
0.122 s



0.366 s



0.183 s



0.427 s

**Figure B3. Sequential Photographs for Test 408019-1 (Rear View).**



### Roll, Pitch, and Yaw Angles

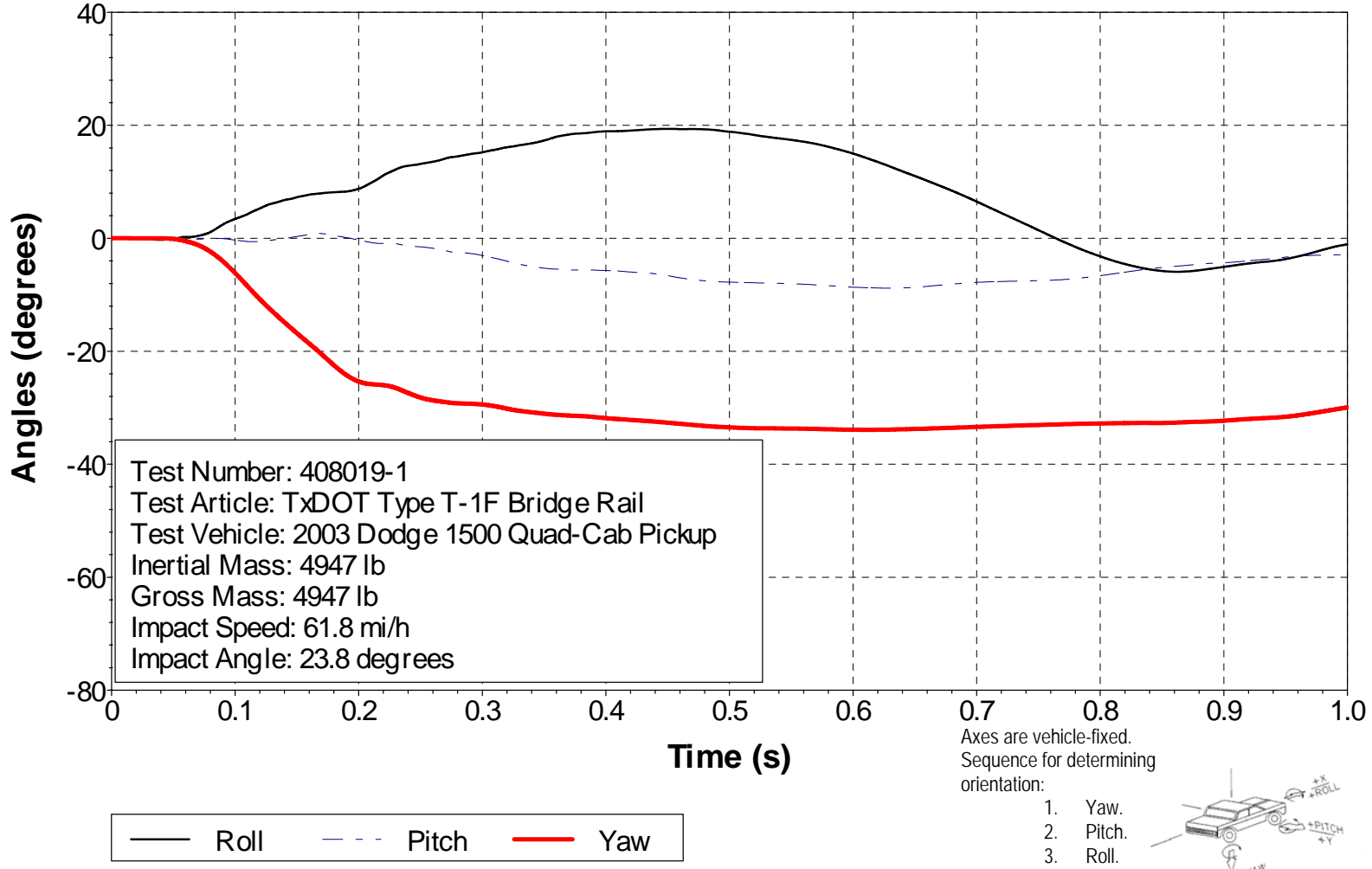
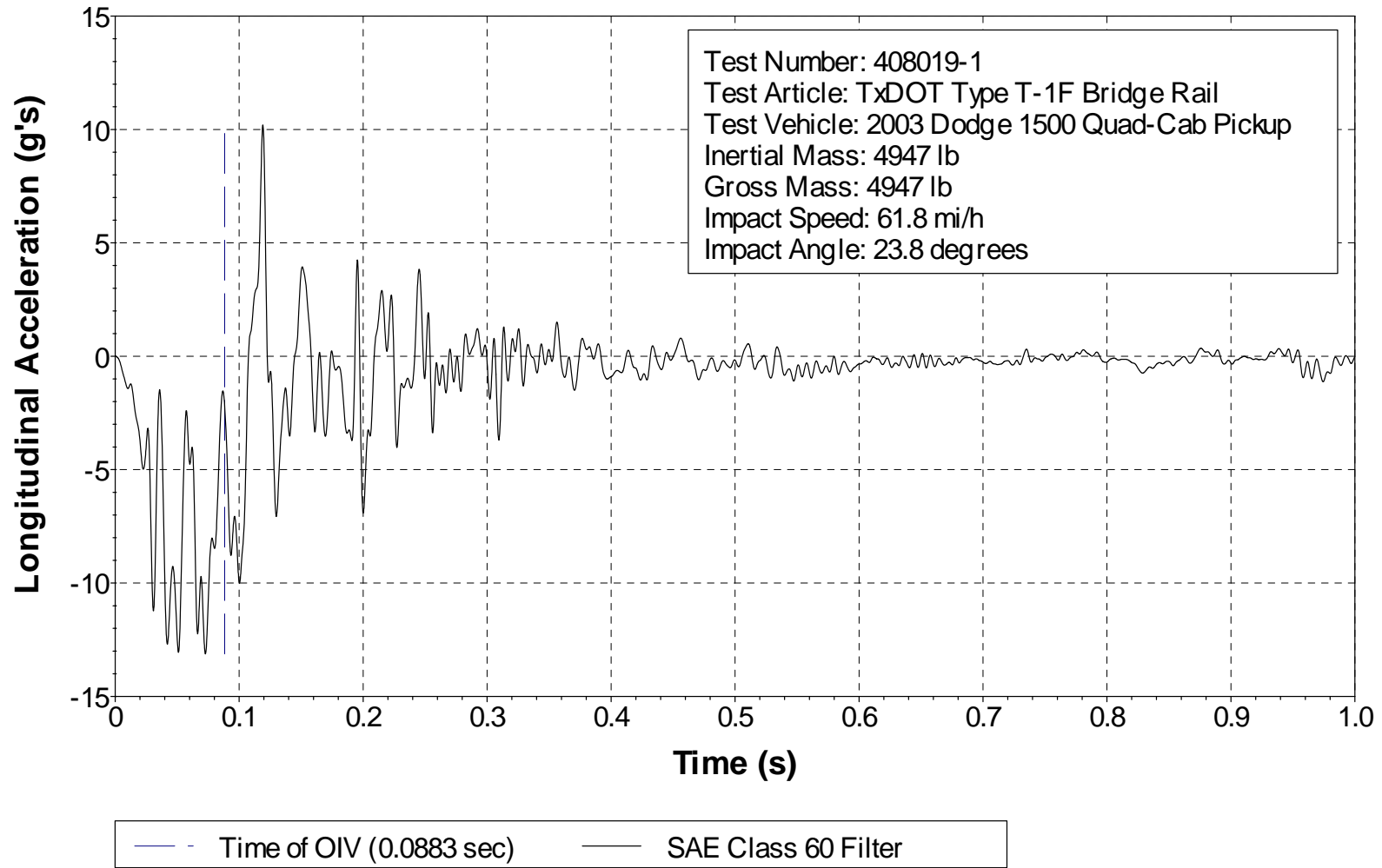


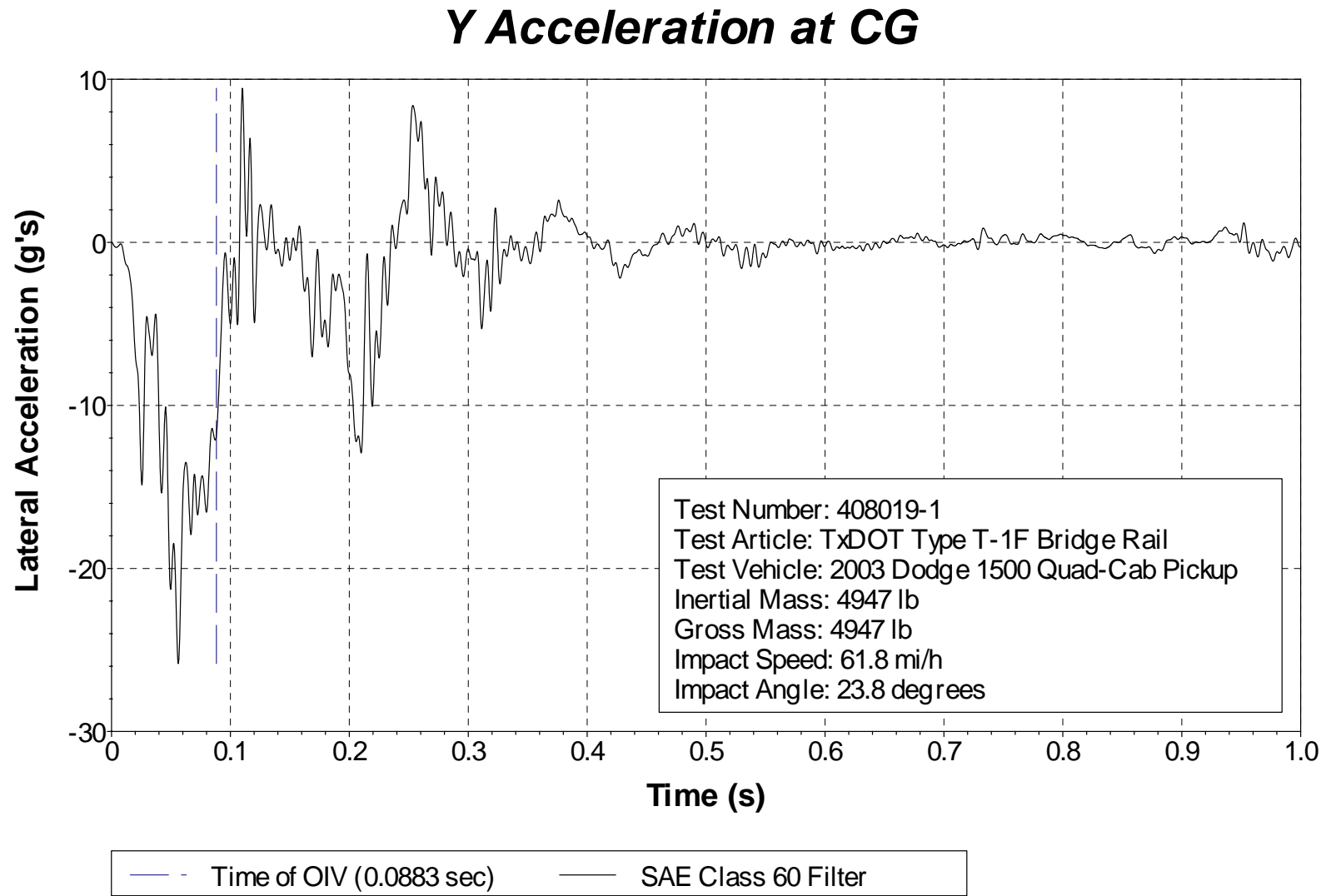
Figure B4. Vehicle Angular Displacements for Test 408019-1.

# X Acceleration at CG



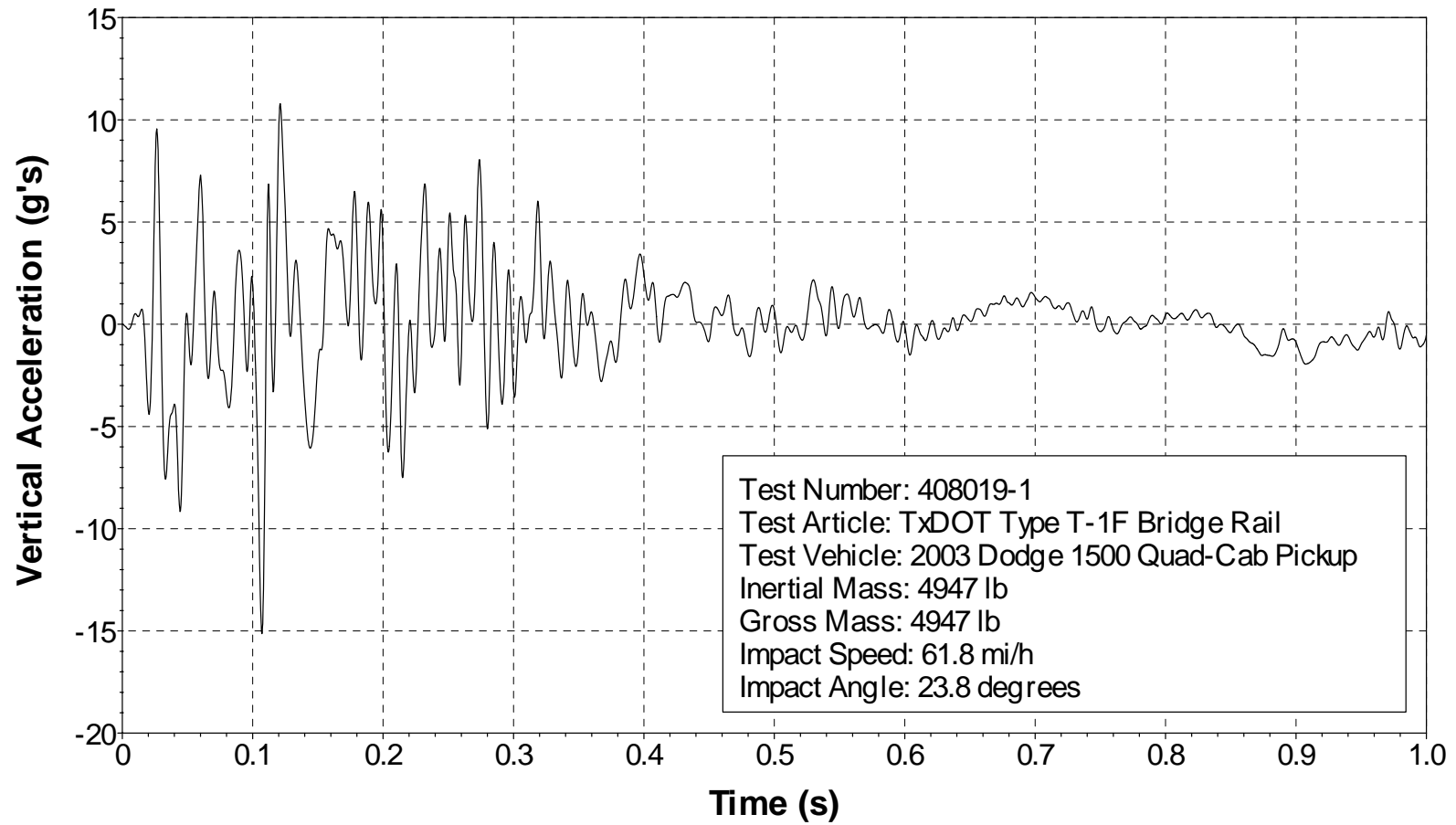
**Figure B5. Vehicle Longitudinal Accelerometer Trace for Test 408019-1  
(Accelerometer Located at Center of Gravity).**





**Figure B6. Vehicle Lateral Accelerometer Trace for Test 408019-1  
(Accelerometer Located at Center of Gravity).**

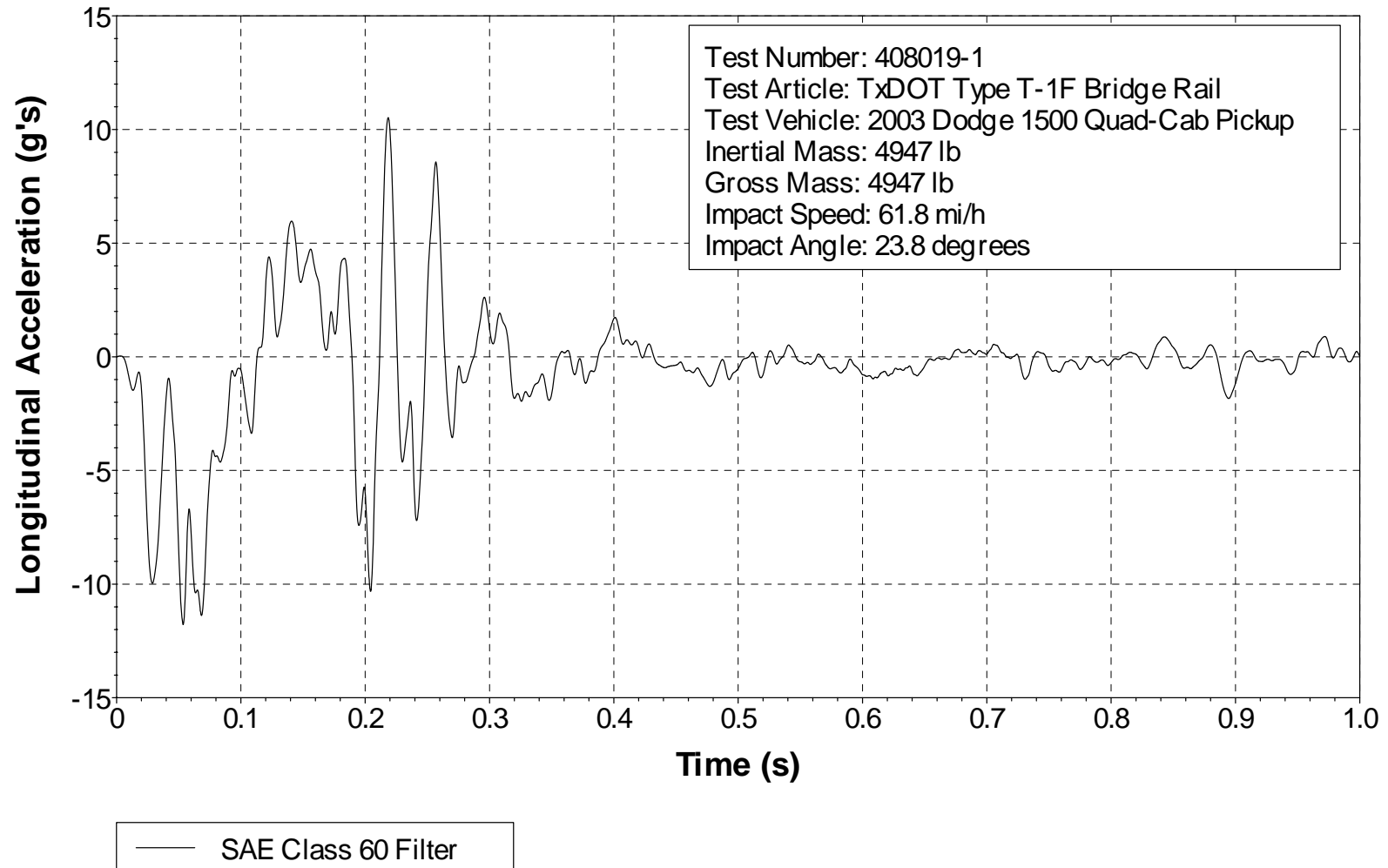
## Z Acceleration at CG



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**Figure B7. Vehicle Vertical Accelerometer Trace for Test 408019-1  
(Accelerometer Located at Center of Gravity).**

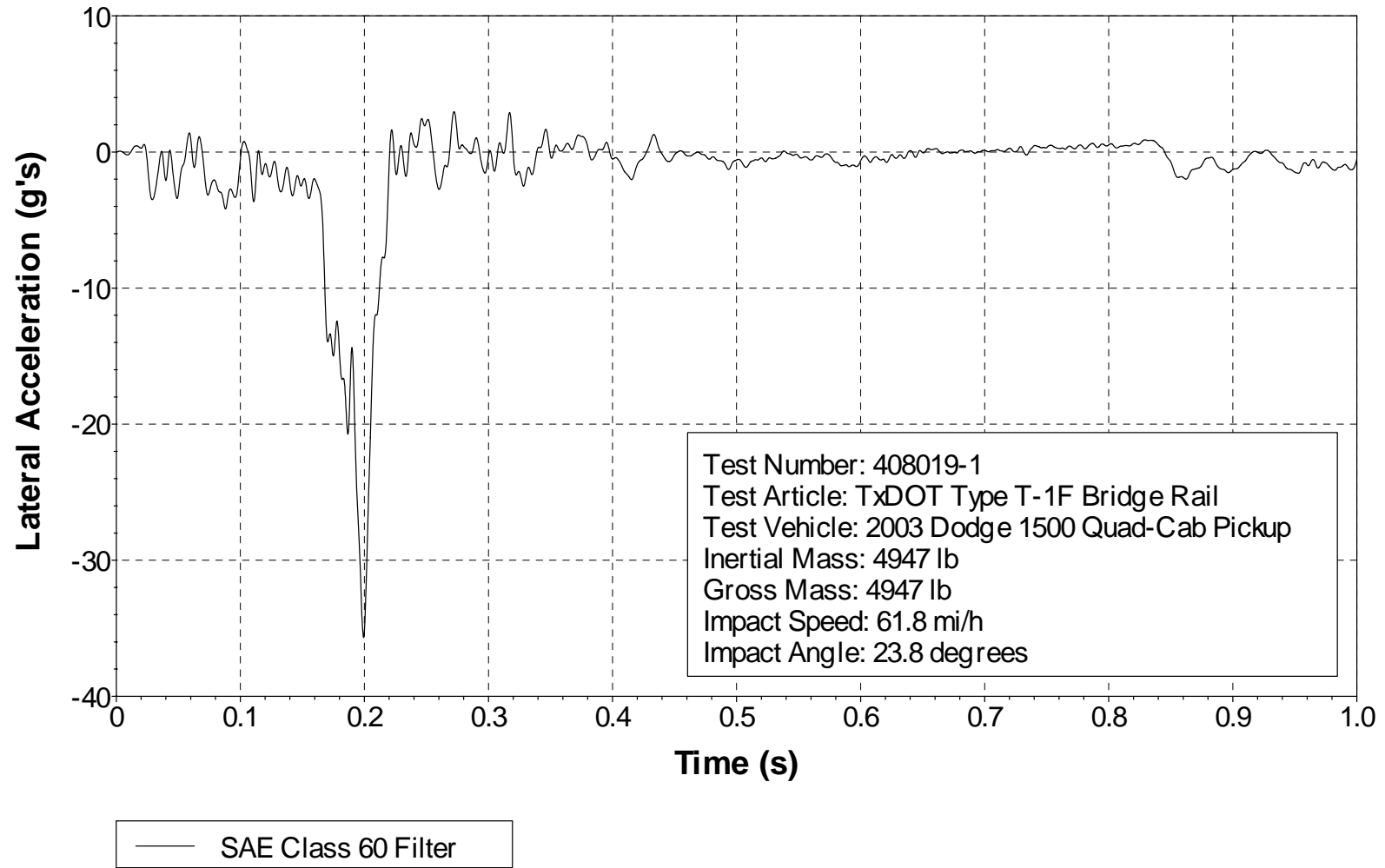
# ***X Acceleration over Rear Axle***



55

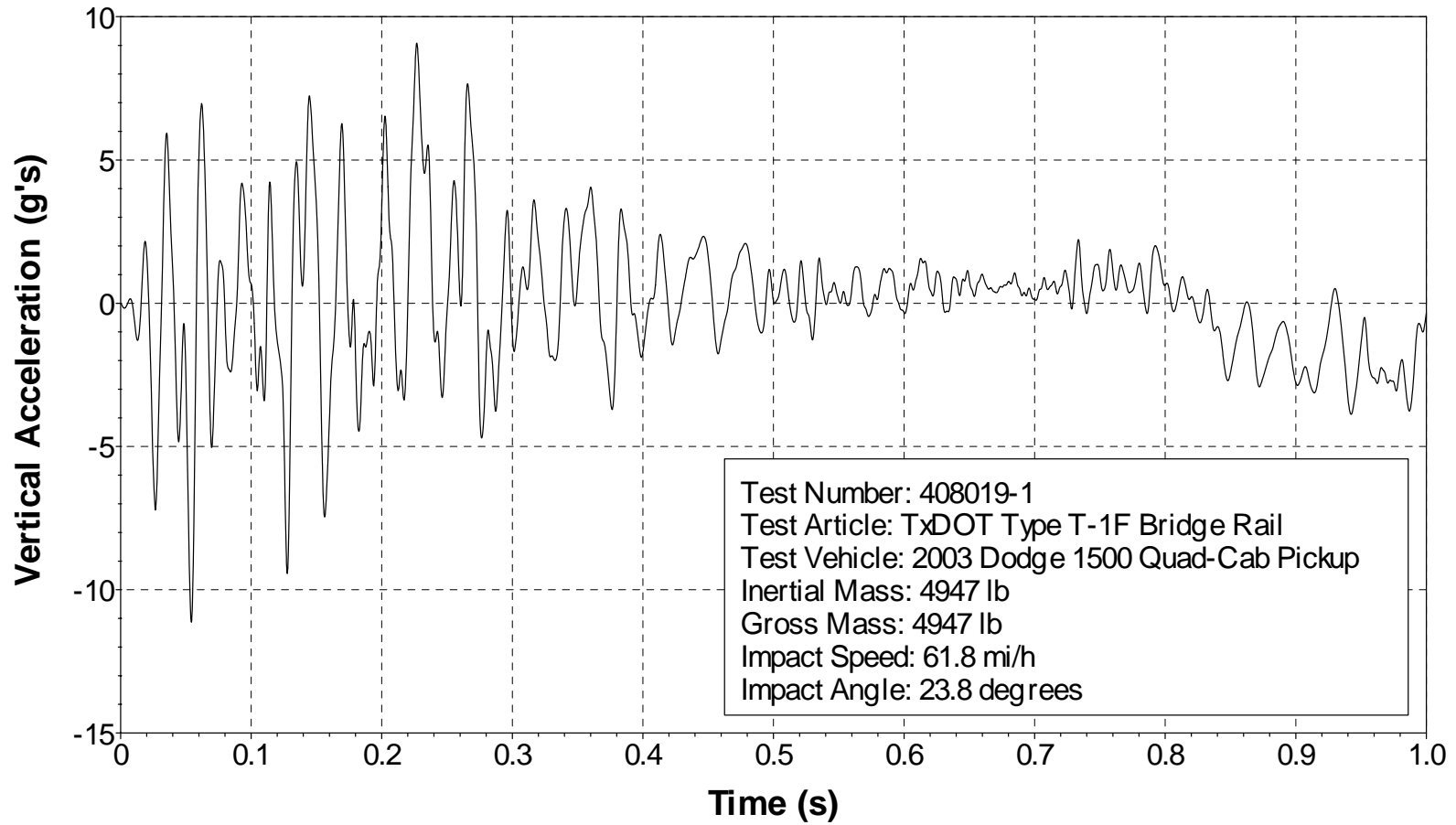
**Figure B8. Vehicle Longitudinal Accelerometer Trace for Test 408019-1  
(Accelerometer Located Over Rear Axle).**

## Y Acceleration over Rear Axle



**Figure B9. Vehicle Lateral Accelerometer Trace for Test 408019-1  
(Accelerometer Located Over Rear Axle).**

# Z Acceleration over Rear Axle



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**Figure B10. Vehicle Vertical Accelerometer Trace for Test 408019-1  
(Accelerometer Located Over Rear Axle).**