TTI: 9-1002-15

CRASH TEST AND EVALUATION OF THE TxDOT T224 BRIDGE RAIL

ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
TTI Proving Ground
3100 SH 47, Building 7091
Bryan, TX 77807

Test Report 9-1002-15-5

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
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16. Abstract

The objective of this research was to evaluate the impact performance of the TxDOT T224 Bridge Rail according to the safety-performance evaluation guidelines included in AASHTO *MASH* for Test Level Five (TL-5). This report describes the TxDOT T224 Bridge Rail, documents the impact performance of the rail system according to *MASH* TL-5 evaluation criteria, and presents recommendations regarding implementation.

The TxDOT T224 Bridge Rail as tested herein met all the safety evaluation criteria and performance requirements of *MASH* TL-5. Based on the successful results from all three full-scale crash tests, the TxDOT T224 Bridge Rail as tested and reported herein is recommended for implementation on new bridges requiring *MASH* TL-5 performance requirements.

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CRASH TEST AND EVALUATION OF THE TxDOT T224 BRIDGE RAIL

by

William F. Williams, P.E.
Associate Research Engineer
Texas A&M Transportation Institute

Roger P. Bligh, Ph.D., P.E.
Senior Research Engineer
Texas A&M Transportation Institute

Wanda L. Menges
Research Specialist
Texas A&M Transportation Institute

and

Darrell L. Kuhn, P.E.
Research Specialist
Texas A&M Transportation Institute

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation, and its contents are not intended for construction, bidding, or permit purposes. In addition, the above listed agencies assume no liability for its contents or use thereof. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report. The engineer in charge of the project was Roger P. Bligh, P.E. (Texas, #78550).

TTI PROVING GROUND DISCLAIMER

The results of the crash testing reported herein apply only to the article being tested.

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

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3100 SH 47, Building 7091
Bryan, TX 77807

Wanda L. Menges, Research Specialist
Deputy Quality Manager

Richard A. Zimmer, Senior Research Specialist
Proving Ground Director
Quality Manager

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CHAPTER 1: INTRODUCTION

1.1 PROBLEM

The current research was conducted under a project that sought to provide the Texas Department of Transportation (TxDOT) with a mechanism to quickly and effectively evaluate high-priority issues related to roadside safety devices. Such safety devices help shield motorists from roadside hazards such as non-traversable terrain and fixed objects. To maintain the desired level of safety for the motoring public, these safety devices must be designed to accommodate a variety of site conditions, placement locations, and a changing vehicle fleet. Periodically, there is a need to assess the compliance of existing safety devices with current vehicle testing criteria and develop new devices that address identified needs.

Under this project, TxDOT identified roadside safety issues and prioritized these for investigation. Each roadside safety issue is addressed with a separate work plan and test report.

1.2 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. In the continued advancement and evolution of roadside safety testing and evaluation, a research effort completed in 2009 resulted in a document published by the American Association of State Highway and Transportation Officials (AASHTO), entitled *Manual for Assessing Safety Hardware* (*MASH*), which supersedes the previous crash test and evaluation guidelines (*1*). Changes incorporated into the guidelines include new design test vehicles, revised test matrices, and revised impact conditions.

1.3 OBJECTIVE/SCOPE OF RESEARCH

The objective of this research was to evaluate the impact performance of the TxDOT T224 Bridge Rail according to the safety-performance evaluation guidelines included in AASHTO *MASH* for Test Level Five (TL-5).

This report describes the TxDOT T224 Bridge Rail, documents the impact performance of the rail system according to *MASH* TL-5 evaluation criteria, and presents recommendations regarding implementation.

CHAPTER 2:
SYSTEM DETAILS

2.1 TEST ARTICLE AND INSTALLATION DETAILS

2.1.1 Overall Details

The test installation was a 160 ft-2 inch long concrete beam on concrete posts and curb. The concrete bridge rail measured 42 inches in overall height above the bridge deck, with the bottom of the beam located 21 inches above the bridge deck. The width of the rail was 16½ inches, and it was supported on integral posts every 15 ft with 10 ft of clear opening between adjacent posts. The beam and posts were integral with a 9-inch tall steel reinforced concrete curb. Additionally, the deck, curb, posts, and beam had a 2-inch wide expansion joint located 65 ft from the upstream end of the installation.

2.1.2 Rail

The beam was 21 inches tall × 16½ inches wide with the traffic side face flush with the posts and the curb. The beam was continuous for the length of the installation except for the 2-inch wide expansion joint. The beam and posts were cast as a monolithic concrete unit atop the curb.

Reinforcing steel in the beam consisted of ten ¾-inch diameter longitudinal reinforcing bars (#6 rebar); five each on the traffic side and the field side spaced, on approximately 4-inch vertical centers. Longitudinal bar overlap was 25 inches minimum. These 10 longitudinal bars were contained within 320 transverse 17-inch × 12½-inch rectangular reinforcing hoop 'S'-bars of ⅝-inch diameter bars (#5 rebar), longitudinally spaced at 6 inches with 2 inches of concrete coverage at top and sides. Junctions were wire-tied as necessary (see Sheets 4, 5, and 6 of 7 for details in Appendix A).

At the expansion joint, three horizontal 1-inch diameter joint bars (#8 rebar), 60 inches long, were embedded 29 inches into each adjacent end of the rail. They were located 9¾ inches from the field side face and at vertical depths of 4½, 10½, and 16½ inches from the top. The downstream end of each joint bar was sleeved with 1¼-inch diameter schedule 80 PVC pipe (see Appendix A Sheet 4 of 7 for details).

2.1.3 Posts and Curb

The parapet had two configurations of posts: intermediate posts and end posts. The posts were 5-ft long and spaced 15 ft center-to-center with 10 ft long windows between the posts. End posts were located at each end and adjacent to the 2-inch wide expansion joint. The traffic side of the posts, rail, and curb were flush with one another in a vertical plane.

The posts were 60 inches long × 12 inches tall × 15 inches wide. The exposed ends of the posts were tapered 7 inches toward the field side over a distance of 14 inches. Intermediate post reinforcement in the longitudinal direction consisted of one 32-inch long ⅝-inch diameter bar (#5 rebar) on the traffic side and two 56-inch long ⅝-inch diameter bars (#5 rebar) on the field side. Vertical reinforcement consisted of six VP-1 bars that were 40-inch long, ⅝-inch diameter (#5 rebar), and equally spaced at 6 inches on the traffic side, and five VP-2 bars that were 40-inch long, ⅝-inch diameter (#5 rebar), and equally spaced at 12 inches on the field side. These bars extended from the top of the bridge deck, through the post, and to within 2 inches of the top of the beam (see Appendix A Sheet 5 of 7 for details).

End post reinforcement in the longitudinal direction consisted of one 46-inch long ⅝-inch diameter bar (#5 rebar) on the traffic side and two 56-inch long ⅝-inch diameter bars (#5 rebar) on the field side. Vertical reinforcement consisted of 12 VP-1 bars that were 40-inch long, ⅝-inch diameter (#5 rebar), and equally spaced at 4 inches on the traffic side, and 15 VP-2 bars that were 40-inch long, ⅝-inch diameter (#5 rebar), and equally spaced at 4 inches on the field side. These bars extended from the top of the bridge deck, through the post, and to within 2 inches of the top of the beam (see Appendix A Sheet 4 of 7 for details).

The curb was 16½ inches wide × 9 inches tall. The field side face of the curb was set back 1½ inches from the outer edge of the deck (see Appendix A Sheets 1 and 2 of 7 for details). Curb reinforcement consisted of two longitudinal ⅝-inch diameter bars (#5 rebar) located approximately 6 inches above the bridge deck and transversely located on 10⅝-inch centers with 21-inch minimum lap joints. The curb was anchored to the deck with 214 ⅝-inch diameter (#5 rebar) V bars measuring 12½ inches wide × 14¼ inches tall and spaced on 9-inch centers along the length of the curb. The top of the V bars extended 7 inches into the curb above the deck (see Appendix A Sheets 2 and 7 of 7 for details).

2.1.4 Bridge Deck

The constructed bridge deck was 52 inches wide × 8½ inches thick and extended for the entire 160 ft-2 inches of the test installation and included the aforementioned 2-inch wide expansion joint. The concrete deck cantilever width was 40 inches. There were two reinforcing steel mats in the deck. Rebar clearance was 1¼ inches at the bottom of the deck for the lower mat, and 2½ inches at the top of the deck for the upper mat. Longitudinal reinforcement in each mat consisted of five ½-inch diameter longitudinal reinforcing bars (#4 rebar) spaced on 9-inch transverse centers. Minimum overlap for longitudinal bar splices was 17 inches.

Transverse reinforcement in the lower mat consisted of ⅝-inch diameter reinforcing bars (#5 rebar), each with a 40½-inch horizontal leg in the deck and a 36½-inch vertical leg in the support wall, spaced longitudinally at 18 inches.

Transverse reinforcement in the upper mat consisted of ⅝-inch diameter reinforcing bars (#5 rebar), each with a 48-inch horizontal leg in the deck and a 39½-inch vertical leg in the support wall, spaced longitudinally at 4½ inches.

Where the bridge deck was attached to the existing moment slab, 43 L-shaped, ⅝-inch diameter reinforcing bars (#5 rebar) with a 7-inch horizontal leg in the deck and a 25-inch vertical leg in the support wall, were welded to existing rebar stubs that protruded from the slab every 18 inches. Where no rebar stubs existed, the tie bars were epoxied into holes drilled in the exposed face or the existing moment slab.

2.1.5 Support Wall

The bridge deck support wall was 12 inches thick × 35½ inches tall and extended for the length of the installation. Reinforcement was comprised of ½-inch diameter longitudinal reinforcing bars (#4 rebar) spaced on 15-inch vertical centers. Vertical reinforcement was the continuation of the top and bottom transverse bars from the bridge deck. The top transverse bars ran outside the longitudinal reinforcement on the outer earth face of the wall, and the bottom transverse bars ran outside the longitudinal reinforcement on the inner field side face of the wall. The clear cover to these vertical bars was 2 inches. The wall was constructed on top of a 5-inch thick working slab and secured with 16-inch long, ⅝-inch diameter reinforcing tie bars (#5 rebar) bars longitudinally spaced at 12-inches for the length of the installation (see Sheet 2 of 7 for details).

2.1.6 Moment Slab

For this test, approximately 30 ft of new moment slab was added on the downstream end of the existing 130-ft long × 9-ft wide slab. This yielded a 160 ft-2 inches long moment slab for constructing the deck, curb, posts, and beam. The 8-inch thick × 9-ft wide × 30-ft long moment slab extension had one center mat of steel reinforcement. The mat consisted of eight ½-inch diameter longitudinal reinforcing bars (#4 rebar) spaced on 12-inch lateral centers. Longitudinal overlap at bar splices was 17 inches minimum. Transverse reinforcement for the moment slab mat consisted of extended transverse bars from the upper mat of the bridge deck overhang. These eighty ⅝-inch diameter reinforcing bars (#5 rebar) bars were longitudinally spaced at 4½ inches. Junctions of the longitudinal and transverse bars were wire-tied on site as necessary.

The existing moment slab, which was constructed circa 1994, has been added to and extended over the years, and has been used for several previous tests. Also, it is integrally supported by a couple of longitudinal subterranean walls of unknown dimensions and reinforcement.

2.1.7 Area Paving Work Slab

To assist in workmanship and construction of the installation, an area paving work slab was poured at the bottom of the excavated trench on the field side of the deck and rail for the length of the installation. The 5±-inch thick × 9 ft-6 inch wide slab was reinforced with ½-inch diameter reinforcing bars (#4 rebar) spaced on a 12-inch grid. The top surface of the work slab was 44 inches below the top side of the bridge deck/moment slab (see Sheet 2 of 7 for details).

2.1.8 Construction Sequence

In constructing the test installation, concrete pours were performed in the following sequence: 1-area paving work slab; 2-support wall (up to 36 inches high); 3-moment slab and bridge deck; 4-curb; and finally 5-posts and beam. Polystyrene foam blocks were used as removable leave-outs to create the windows between the posts.

Figure 2.1 presents overall information on the TxDOT T224 Bridge Rail, and Figure 2.2 provides photographs of the installation. Appendix A provides further details of the TxDOT T224 Bridge Rail.

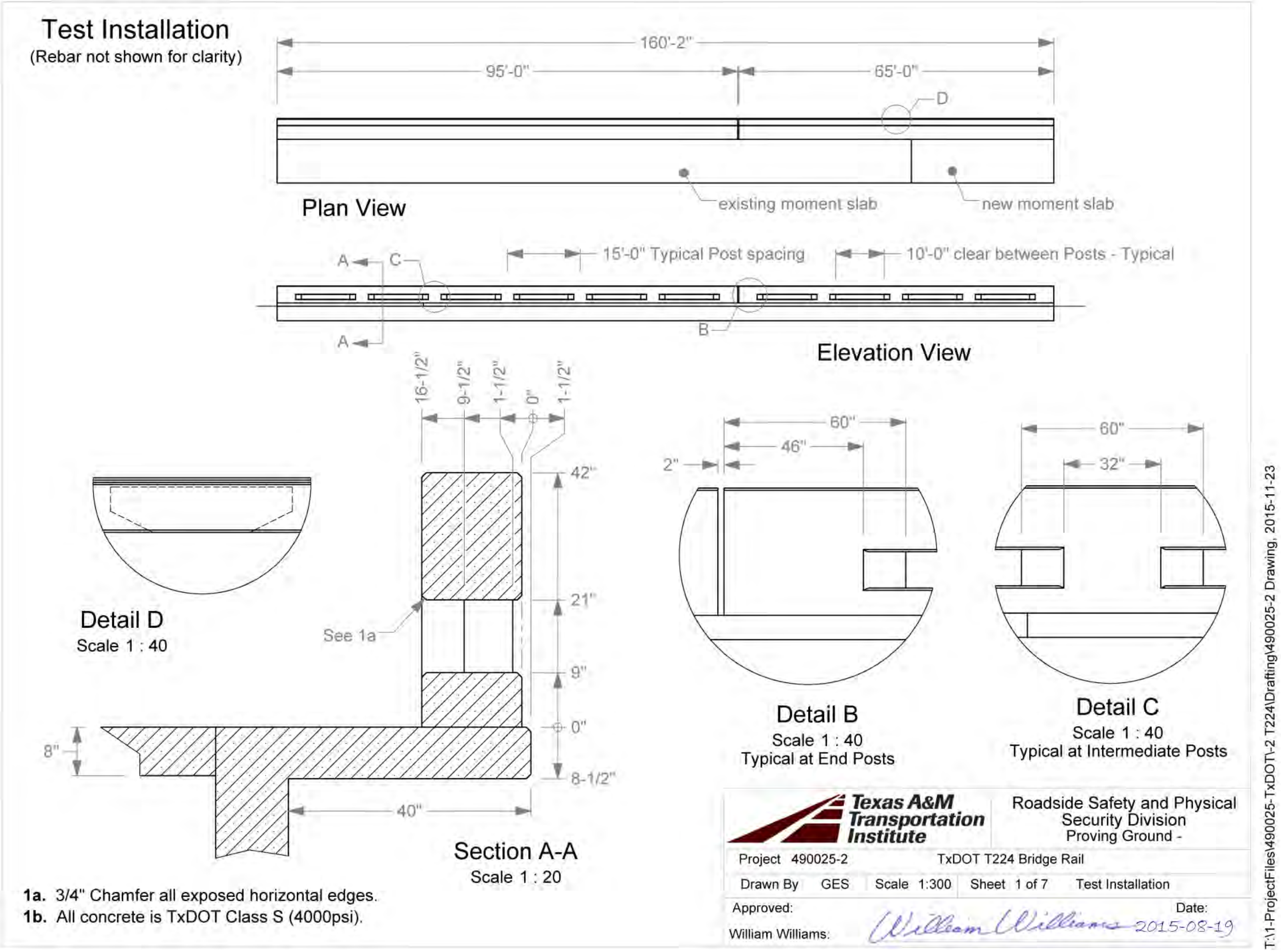


Figure 2.1. Overall Details of the TxDOT T224 Bridge Rail.

Figure 2.2. TxDOT T224 Bridge Rail prior to Testing.

2.2 MATERIAL SPECIFICATIONS

The specified minimum unconfined compressive strength of the concrete for the bridge deck, curb, and parapet was 4000 psi TxDOT Class S. The compressive strengths of the six batches of concrete used in the construction measured an average of 3830 psi.

Steel reinforcement was ASTM A615 grade 60 rebar with specified minimum yield strength of 60 ksi. Epoxied connections were installed with Hilti RE500 epoxy anchoring system according to Hilti instructions.

Appendix B provides material certification documents for the materials used to install/construct the TxDOT T224 Bridge Rail.

CHAPTER 3: TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 CRASH TEST MATRIX

According to *MASH*, three tests are recommended to evaluate longitudinal barriers to TL-5:

- ***MASH* Test 5-10**: A 2420-lb vehicle impacting the critical impact point (CIP) of the length of need (LON) of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively.
- ***MASH* Test 5-11**: A 5000-lb pickup truck impacting the CIP of the LON of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively.
- ***MASH* Test 5-12**: A 79,366-lb tractor van-trailer impacting the CIP of the LON of the bridge rail at a nominal impact speed and angle of 50 mi/h and 15 degrees, respectively.

MASH Tests 5-10 and 5-11 evaluate a barrier's ability to successfully contain and redirect passenger vehicles and evaluate occupant risk. *MASH* Test 5-12 evaluates the structural adequacy of the bridge rail. All three tests were performed on the TxDOT T224 Bridge Rail. The target CIP for each test was determined according to the information provided in *MASH* and is summarized in Figure 3.1.

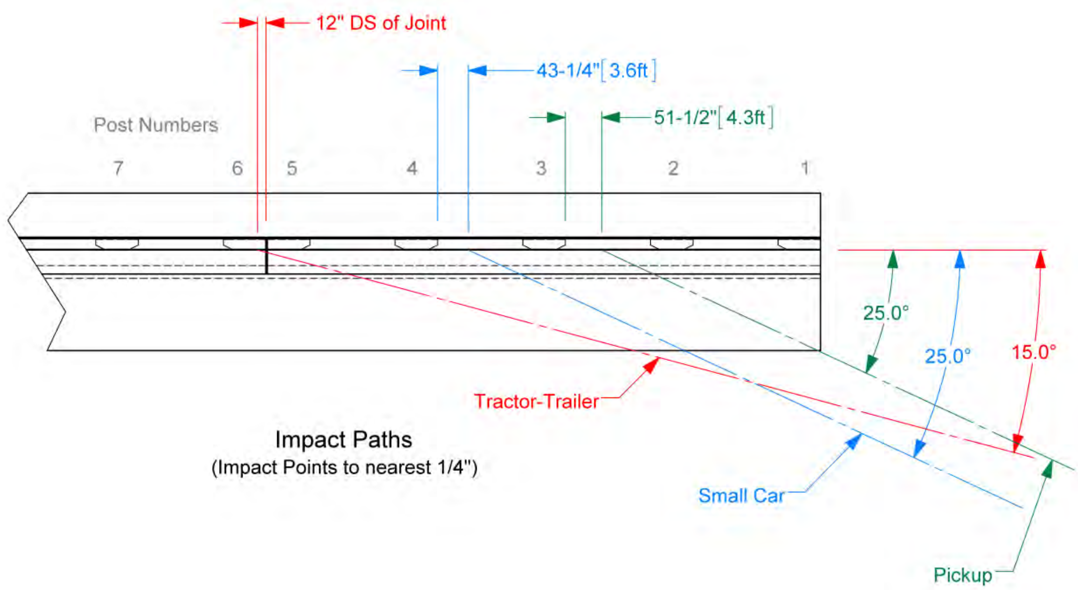


Figure 3.1. Target CIPs for TL-5 Tests on the TxDOT T224 Bridge Rail.

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 4 presents brief descriptions of these procedures.

3.2 EVALUATION CRITERIA

The crash test results were evaluated accordance with the criteria presented in *MASH*. The impact performance of the TxDOT T224 Bridge Rail was judged based on three factors:

- Structural adequacy, which is judged on the ability of the TxDOT T224 Bridge Rail to contain and redirect the vehicle.
- Occupant risk, which evaluates the potential risk of hazard to occupants in the 1100C and 2270P vehicles, and to some extent, other traffic, pedestrians, or workers in construction zones, if applicable.
- Post-impact vehicle trajectory, which considers 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 *MASH* were used to evaluate the crash tests reported herein. These criteria are listed in further detail under the assessment of each crash test.

CHAPTER 4: TEST CONDITIONS

4.1 TEST FACILITY

The full-scale crash tests reported herein were performed at Texas A&M Transportation Institute (TTI) Proving Ground, an International Standards Organization (ISO) 17025-accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing certificate 2821.01. The full-scale crash tests were performed according to TTI Proving Ground quality procedures and according to *MASH* guidelines and standards.

The TTI Proving Ground is a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons that are 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 evaluation of roadside safety hardware. The site selected for construction and testing of the TxDOT T224 Bridge Rail was the end of an out-of-service runway. The runway consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The runway was built in 1942, and the joints have some displacement but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE SYSTEM

The 1100C passenger car and 2270P pickup truck were 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 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site, after which brakes were activated, if needed, to bring the test vehicle to a safe and controlled stop.

The 36000V tractor-trailer was self-powered and was guided into the test installation via a cable guidance system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs).

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro that Diversified Technical Systems, Inc. produced. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid state units designed for crash test service. The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 values per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units is returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology. All accelerometers are calibrated annually according to SAE J211 *4.6.1* by means of an ENDEVCO® 2901, precision primary vibration standard. This device and its support instruments are returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are also made any time data are suspect. Acceleration data are measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k=2).

TRAP uses the data from the TDAS Pro to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. TRAP 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, 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. Rate of rotation data is measured with an expanded uncertainty of ±0.7 percent at a confidence factor of 95 percent (k=2).

4.3.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side of the 1100C vehicle. The dummy was not instrumented.

According to *MASH*, use of a dummy in the 2270P vehicle is optional. However, it is recommended a dummy be used when testing "any longitudinal barrier with a height greater than or equal to 33 inches." Use of the dummy in the 2270P vehicle is recommended for tall rails to evaluate the "potential for an occupant to extend out of the vehicle and come into direct contact with the test article." Although this information is reported, it is not part of the impact performance evaluation. Since the rail height of the TxDOT T224 Bridge Rail was 42 inches, a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

MASH does not recommend or require use of a dummy in the 36000V vehicle. However, for informational purposes, an H3 instrumented dummy provided by the National Highway Traffic Safety Association (NHTSA) was positioned in the driver's seat and restrained with lap and shoulder belts. Measurements and photographs were taken per NHTSA protocol for use in studying dummy interaction with large vehicles.

4.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of each 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 on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the TxDOT T224 Bridge Rail. The flashbulb was visible from each camera. The videos from these high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-digital video camera and still cameras recorded and documented conditions of each test vehicle and the installation before and after the test.

CHAPTER 5: CRASH TEST NO. 490025-2-2 (*MASH* TEST 5-10)

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 5-10 involves an 1100C vehicle weighing 2420 lb ±55 lb impacting the CIP of the TxDOT T224 Bridge Rail at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The CIP for *MASH* Test 5-10 on the TxDOT T224 Bridge Rail was determined to be 3.6 ft upstream of a post. The 2009 Kia Rio used in the test weighed 2422 lb, and the actual impact speed and angle were 62.6 mi/h and 25.1 degrees, respectively. The actual impact point was 4.2 ft upstream of post 4. Target impact severity (IS) was ≥51 kip-ft, and actual IS was 57 kip-ft.

5.2 WEATHER CONDITIONS

The test was performed on the morning of August 18, 2015. Weather conditions at the time of testing were as follows: wind speed: 5 mi/h; wind direction: 204 degrees with respect to the vehicle (vehicle was traveling in a northeasterly direction); temperature: 89°F; relative humidity: 58 percent.

5.3 TEST VEHICLE

A 2009 Kia Rio, shown in Figures 5.1 and 5.2, was used for the crash test. The vehicle's test inertia weight was 2422 lb, and its gross static weight was 2587 lb. The height to the lower edge of the vehicle bumper was 9.5 inches, and the height to the upper edge of the bumper was 21.5 inches. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

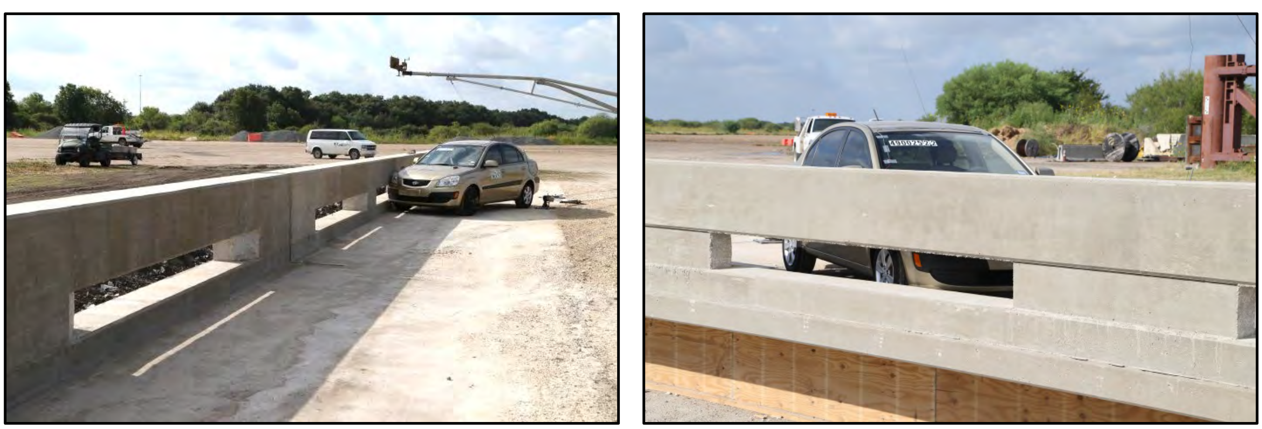


Figure 5.1. TxDOT T224 Bridge Rail/1100C Vehicle Geometrics for Test No. 490025-2-2.

Figure 5.2. 1100C Test Vehicle before Test No. 490025-2-2.

5.4 TEST DESCRIPTION

The 2009 Kia Rio, traveling at an impact speed of 62.6 mi/h, contacted the TxDOT T224 Bridge Rail 4.2 ft upstream of post 4 at an impact angle of 25.1 degrees. At 0.015 s after impact, the vehicle began to redirect, and at 0.027 s, the roof began to deform. The right front corner of the bumper contacted post 4 at 0.031 s, and the windshield began to crack at the right lower corner at 0.037 s. At 0.070 s, the glass in the right front passenger door shattered, and at 0.205 s, the vehicle began to travel parallel with the bridge rail. The right rear of the vehicle contacted the bridge rail at 0.277 s. At 0.430 s, the vehicle lost contact with the bridge rail while traveling at an exit speed and angle of 41.7 mi/h and 7.1 degrees, respectively. Brakes on the vehicle were not applied, and the vehicle came to rest 190 ft downstream of impact and 28 ft toward the field side. In Appendix C.2, Figures C.1 and C.2 present sequential photographs of the test.

5.5 DAMAGE TO TEST INSTALLATION

Figure 5.3 shows the damage to the TxDOT T224 Bridge Rail after *MASH* Test 5-10. The traffic face of the bridge rail sustained mostly cosmetic damage in the form of scrapes and tire marks. Some concrete was scraped off the traffic side edge of the curb, and there were tire marks and gouges caused by the wheel rim on the upstream side of post 4. The 1100C vehicle was in contact with the bridge rail a total distance of 17.5 ft. Working width was 16.5 inches. Maximum dynamic deflection during the test was not obtained due to view being blocked by the vehicle and dust, and no maximum permanent deformation after the test occurred.

5.6 DAMAGE TO TEST VEHICLE

Figure 5.4 shows the damage that the 1100C vehicle sustained. The right front strut and tower were deformed The front bumper, hood, radiator, right front tire and rim, right front fender, right front door and door glass, roof, right rear door, and right rear quarter panel were damaged. The A-pillar was deformed and caused the windshield to fracture. Maximum exterior crush to the vehicle was 13.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 4.0 inches in the right side instrument panel.

Figure 5.5 shows the interior of the vehicle. Tables C.2 and C.3 in Appendix C.1 provides exterior crush and occupant compartment measurements.

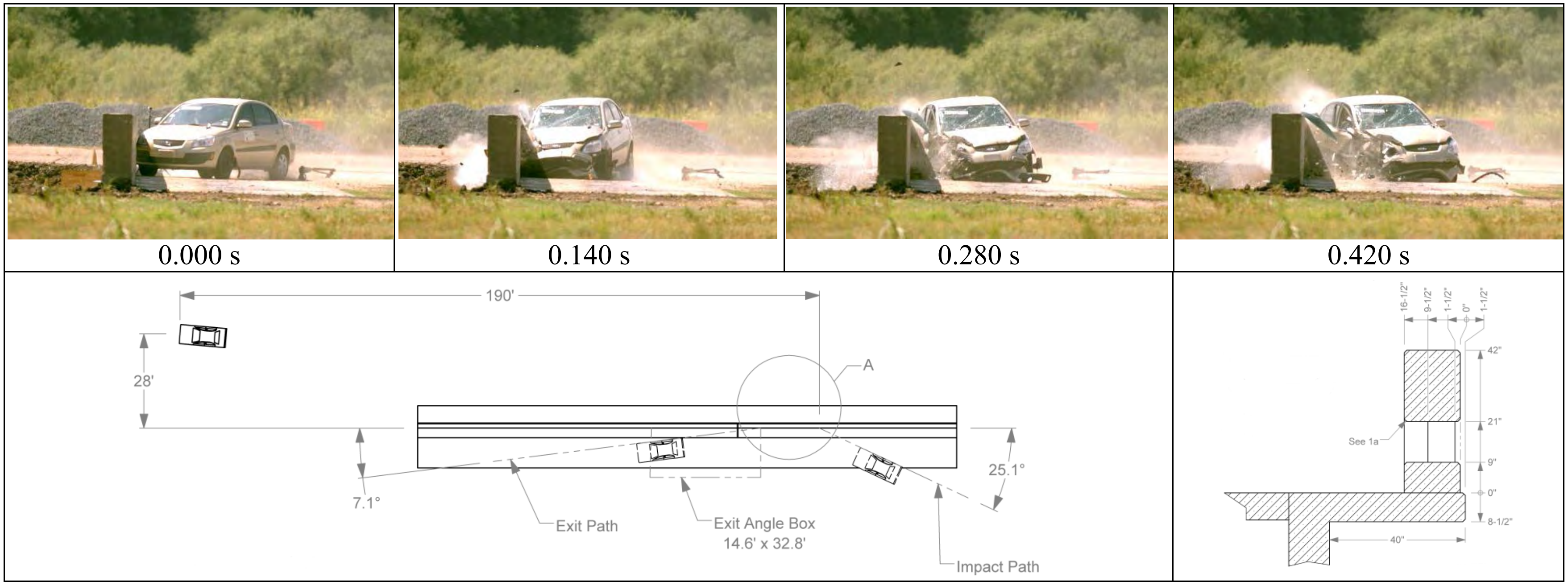
Figure 5.3. TxDOT T224 Bridge Rail after Test No. 490025-2-2.

Figure 5.4. Test Vehicle after Test No. 490025-2-2.

Figure 5.5. Interior of Test Vehicle for Test No. 490025-2-2.

5.7 OCCUPANT RISK FACTORS

Data from the accelerometers, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity (OIV) was 31.5 ft/s at 0.076 s, the highest 0.010-s occupant ridedown acceleration (RDA) was 14.1 g from 0.076 to 0.086 s, and the maximum 0.050-s average acceleration was –17.8 g between 0.018 and 0.068 s. In the lateral direction, the OIV was 30.2 ft/s at 0.076 s, the highest 0.010-s occupant RDA was 10.1 g from 0.079 to 0.089 s, and the maximum 0.050-s average was −17.2 g between 0.023 and 0.073 s. Theoretical Head Impact Velocity (THIV) was 47.8 km/h or 13.3 m/s at 0.074 s; Post-Impact Head Decelerations (PHD) was 15.5 g between 0.077 and 0.087 s; and Acceleration Severity Index (ASI) was 2.68 between 0.048 and 0.098 s. Figure 5.6 summarizes these data and other pertinent information from the test. In Appendix C.3, Figure C.3 shows the vehicle angular displacements, and Figures C.4 through C.9 in Appendix C.4 shows acceleration versus time traces.



General Information
Test Agency: Texas Transportation Institute (TTI)
Test Standard Test No.: MASH Test 5-10
TTI Test No.: 490025-2-2
Test Date: 2015-08-18

Test Article
Type: Bridge Rail
Name: TxDOT T224 Bridge Rail
Installation Length: 160 ft 2 inches
Material or Key Elements: 42-inch high16½ inch wide reinforced concrete rail with integral reinforced concrete posts every 15 ft with 10 ft clear window between adjacent posts

Soil Type and Condition: Concrete Bridge Deck, Dry

Test Vehicle
Type/Designation: 1100C
Make and Model: 2009 Kia Rio
Curb: 2448 lb
Test Inertial: 2422 lb
Dummy: 165 lb
Gross Static: 2587 lb

Impact Conditions
Speed: 62.6 mi/h
Angle: 25.1 degrees
Location/Orientation: 4.2 ft upstream of post 4

Impact Severity: 57 kip-ft

Exit Conditions
Speed: 41.7 mi/h
Angle: 7.1 degrees

Occupant Risk Values
Longitudinal OIV: 31.5 ft/s
Lateral OIV: 30.2 ft/s
Longitudinal Ridedown: 14.1 g
Lateral Ridedown: 10.1 g
THIV: 47.8 km/h
PHD: 15.5 g
ASI: 2.68
Max. 0.050-s Average
Longitudinal: –17.8 g
Lateral: –17.2 g
Vertical: –2.4 g

Post-Impact Trajectory
Stopping Distance: 190 ft dwnstrm 28 twd field side

Vehicle Stability
Maximum Yaw Angle: 52 degrees
Maximum Pitch Angle: 3 degrees
Maximum Roll Angle: 7 degrees
Vehicle Snagging: No
Vehicle Pocketing: No

Test Article Deflections
Dynamic: None measureable
Permanent: None
Working Width: 16.5 inches

Vehicle Damage
VDS: 01RFQ5
CDC: 01RFEW4
Max. Exterior Deformation: 13.0 inches
OCDI: RF0014000
Max. Occupant Compartment Deformation: 4.0 inches

Figure 5.6. Summary of Results for *MASH* Test 5-10 on the TxDOT T224 Bridge Rail.

5.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 5-10 is provided below.

5.8.1 Structural Adequacy

A. 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.

Results: The TxDOT T224 Bridge Rail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Dynamic deflection was not obtained due to vehicle and dust obscuring the view; however, there was no permanent deformation present. (PASS)

5.8.2 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 MASH (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/ transmission tunnel area ≤12.0 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 4.0 inches in the right front instrument panel area. (PASS)

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

Results: The 1100C vehicle remained upright during and after the collision event. Maximum roll was 7 degrees, and maximum pitch was 3 degrees. (PASS)

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

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal OIV was 31.5 ft/s, and lateral OIV was 30.2 ft/s. (PASS)

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

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 g	*20.49 g*

Results: Maximum longitudinal RDA was 14.1 , and maximum lateral RDA was 10.1 . (PASS)

CHAPTER 6:
CRASH TEST NO. 490025-2-3 (*MASH* TEST 5-11)

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 5-11 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the TxDOT T224 Bridge Rail at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The CIP for *MASH* Test 5-11 on the TxDOT T224 Bridge Rail was determined to be 4.3 ft upstream of a post. The 2009 Dodge Ram 1500 pickup used in the test weighed 5042 lb, and the actual impact speed and angle were 64.3 mi/h and 24.8 degrees, respectively. The actual impact point was 3.9 ft upstream of post 3. Target IS was ≥106 kip-ft, and actual IS was 123 kip-ft.

6.2 WEATHER CONDITIONS

The test was performed on the morning of August 19, 2015. Weather conditions at the time of testing were as follows: wind speed: 8 mi/h; wind direction: 179 degrees with respect to the vehicle (vehicle was traveling in a northeasterly direction); temperature: 90°F; relative humidity: 64 percent.

6.3 TEST VEHICLE

The 2009 Dodge Ram 1500 pickup, shown in Figures 6.1 and 6.2, was used for the crash test. The vehicle's test inertia weight was 5042 lb, and its gross static weight was 5207 lb. The height to the lower edge of the vehicle bumper was 10.50 inches, and the height to the upper edge of the bumper was 25.25 inches. The height to the vehicle's center of gravity was 28.12 inches. Tables D.1 and D.2 in Appendix D.1 give additional dimensions of and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.1. TxDOT T224 Bridge Rail/Test Vehicle Geometrics for Test No. 490025-2-3.

Figure 6.2. Test Vehicle before Test No. 490025-2-3.

6.4 TEST DESCRIPTION

The 2009 Dodge Ram 1500 pickup, traveling at an impact speed of 64.3 mi/h, contacted the TxDOT T224 Bridge Rail 3.9 ft upstream of post 3 at an impact angle of 24.8 degrees. At 0.010 s after impact, the right front tire contacted the bridge rail and the vehicle began to redirect. The right front tire blew out at 0.020 s, and the top of the right front door began to open at 0.031 s. At 0.054 s, the dummy began to move toward the right front door, and at 0.078 s, the glass in the right front door shattered. The dummy's head extended 12.8 inches outside the door/window frame at 0.122 s, and the dummy's head contacted the bottom of the window frame at 0.134 s and began to return to the interior of the vehicle. The vehicle began traveling parallel with the bridge rail at 0.199 s. At 0.316 s, the vehicle lost contact with the bridge rail while traveling at an exit speed and angle of 41.2 mi/h and 7.0 degrees, respectively. Brakes on the vehicle were not applied, and the vehicle came to rest 205 ft downstream of impact and 6 ft toward the field side. In Appendix D.2, Figures D.1 and D.2 present sequential photographs during the test.

6.5 DAMAGE TO TEST INSTALLATION

Figure 6.3 shows the damage to the TxDOT T224 Bridge Rail. The traffic face of the bridge rail sustained mostly cosmetic damage in the form of scrapes and tire marks. Some concrete was scraped off the traffic side edge of the curb, and there were tire marks and gouges caused by the wheel rim on the upstream side of post 3. The 2270P vehicle was in contact with the bridge rail a distance of 14.2 ft. Working width was 16.5 inches. Maximum dynamic deflection during the test was negligible. No measureable permanent deformation was noted.

Figure 6.3. TxDOT T224 Bridge Rail after Test No. 490025-2-3.

6.6 DAMAGE TO TEST VEHICLE

Figure 6.4 shows the damage that the 2270P vehicle sustained. The right front rail, the right front upper and lower A-arms, and the right upper and lower ball joints were deformed. Also damaged were the front bumper, grill, hood, right front fender, right front tire and rim, right front door and door glass, right rear exterior bed, right rear tire and rim, and rear bumper. The A-pillar was deformed causing the windshield to fracture. Maximum exterior crush to the vehicle was 18.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 5.0 inches in the right firewall area. Figure 6.5 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 6.4. Test Vehicle after Test No. 490025-2-3.

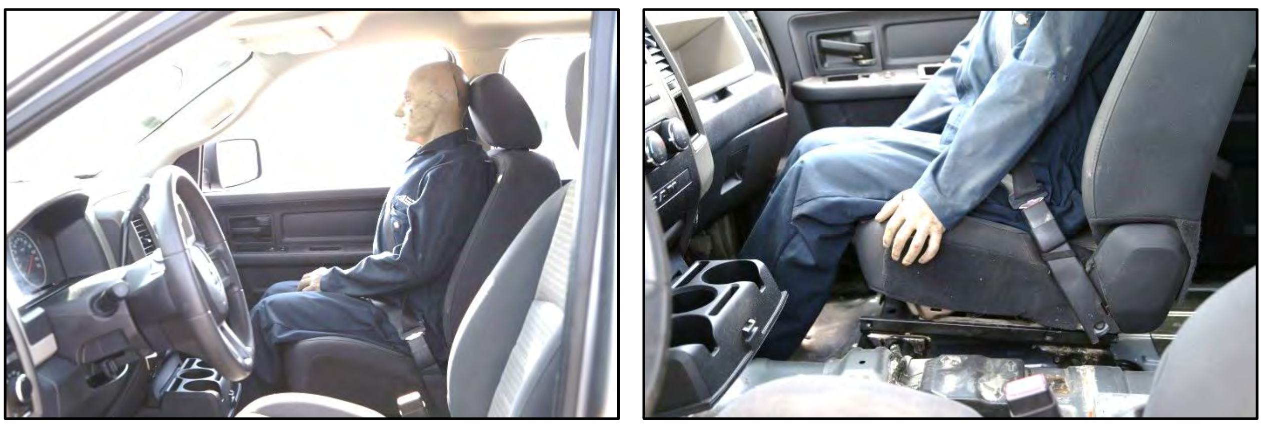
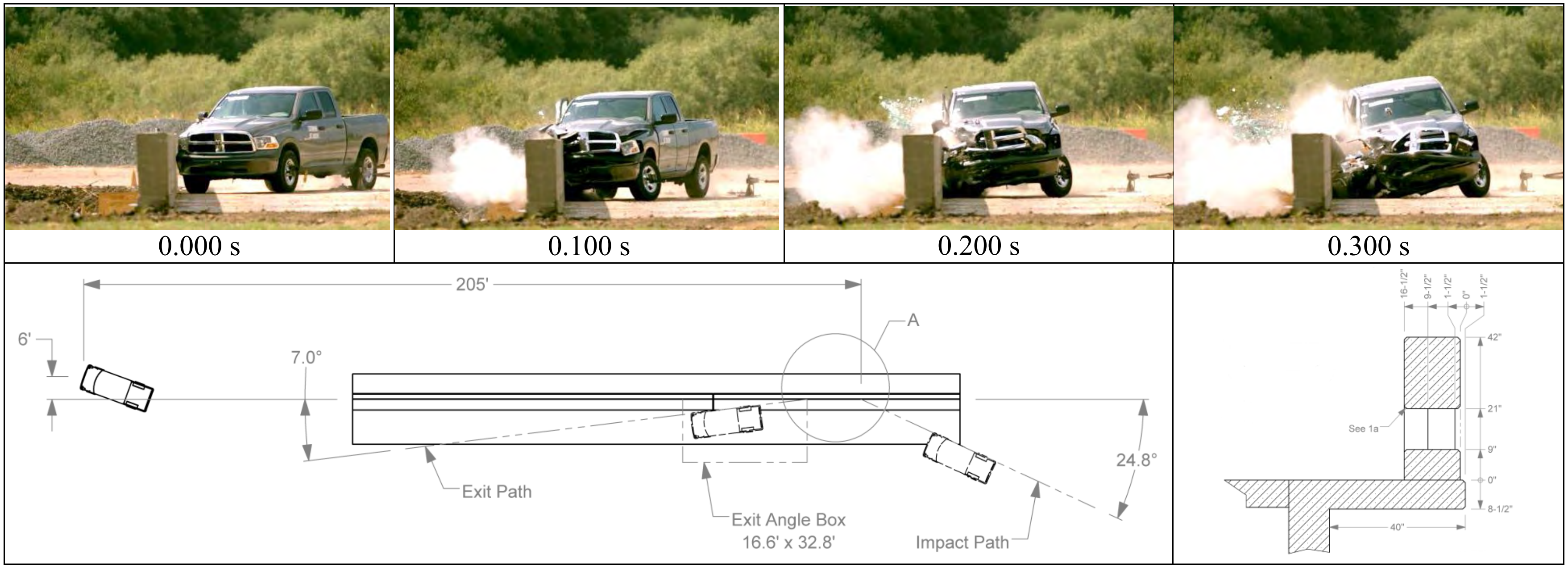


Figure 6.5. Interior of Test Vehicle for Test No. 490025-2-3.

6.7 OCCUPANT RISK FACTORS

Data from the accelerometers, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the OIV was 21.6 ft/s at 0.093 s, the highest 0.010-s occupant RDA was 7.5 g from 0.093 to 0.103 s, and the maximum 0.050-s average acceleration was –9.6 g between 0.046 and 0.096 s. In the lateral direction, the OIV was 28.9 ft/s at 0.093 s, the highest 0.010-s occupant RDA was 12.2 g from 0.222 to 0.232 s, and the maximum 0.050-s average was –14.9 g between 0.042 and 0.092 s. THIV was 38.1 km/h or 10.6 m/s at 0.091 s; PHD was 17.0 g between 0.091 and 0.101 s; and ASI was 1.82 between 0.058 and 0.108 s. Figure 6.6 summarizes these data and other pertinent information from the test. In Appendix D.3, Figure D.3 shows the vehicle angular displacements, and Figures D.4 through D.9 in Appendix D.4 shows acceleration versus time traces.



General Information

Test Agency	Texas Transportation Institute (TTI)
Test Standard Test No.	MASH Test 5-11
TTI Test No.	490025-2-3
Test Date	2015-08-19
Test Article	
Type	Bridge Rail
Name	TxDOT T224 Bridge Rail
Installation Length	160 ft 2 inches
Material or Key Elements	42-inch high16½ inch wide reinforced concrete rail with integral reinforced concrete posts every 15 ft with 10 ft clear window between adjacent posts
Soil Type and Condition	Concrete Bridge Deck, Dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2009 Dodge Ram 1500 Pickup
Curb	5035 lb
Test Inertial	5042 lb
Dummy	165 lb
Gross Static	5207 lb

Impact Conditions

Speed	64.3 mi/h
Angle	24.8 degrees
Location/Orientation	3.9 ft dwnstrm of post 3
Impact Severity	123 kip-ft
Exit Conditions	
Speed	41.2 mi/h
Angle	7.0 degrees
Occupant Risk Values	
Longitudinal OIV	21.6 ft/s
Lateral OIV	28.9 ft/s
Longitudinal Ridedown	7.5 g
Lateral Ridedown	12.2 g
THIV	38.1 km/h
PHD	17.0 g
ASI	1.82
Max. 0.050-s Average	
Longitudinal	−9.6 g
Lateral	−14.9 g
Vertical	−3.2 g

Post-Impact Trajectory

Stopping Distance	205 ft dwnstrm 6 ft twd field side
Vehicle Stability	
Maximum Yaw Angle	36 degrees
Maximum Pitch Angle	5 degrees
Maximum Roll Angle	6 degrees
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	Negligible
Permanent	None
Working Width	16.5 inches
Vehicle Damage	
VDS	01RFQ5
CDC	01FREW5
Max. Exterior Deformation	18.0 inches
OCDI	RF1032000
Max. Occupant Compartment Deformation	5.0 inches

Figure 6.6. Summary of Results for *MASH* Test 5-11 on the TxDOT T224 Bridge Rail.

6.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 5-11 is provided below.

6.8.1 Structural Adequacy

A. 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.

Results: The TxDOT T224 Bridge Rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. No measureable dynamic deflection was noted. (PASS)

6.8.2 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 MASH (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 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 5.0 inches in the right firewall area. (PASS)

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. Maximum roll was 6 degrees, and maximum pitch was 5 degrees. (PASS)

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

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal OIV was 21.6 ft/s, and lateral OIV was 28.9 ft/s. (PASS)

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

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 g	*20.49 g*

Results: Maximum longitudinal RDA was 7.5 g, and maximum lateral RDA was 12.2 g. (PASS)

CHAPTER 7:
CRASH TEST NO. 490025-2-1 (*MASH* TEST 5-12)

7.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 5-12 involves a 36000V vehicle weighing 79,300 lb ±1100 lb impacting the CIP of the TxDOT T224 Bridge Rail at an impact speed of 50 mi/h ±2.5 mi/h and an angle of 15 degrees ±1.5 degrees. The CIP for *MASH* Test 5-12 on the TxDOT T224 Bridge Rail was determined to be 1 ft downstream of the joint between posts 5 and 6. The ballasted weight of the 2003 Volvo VE tractor and 1995 Dorsey DTV van-type trailer used in the test was 79,760 lb, and the actual impact speed and angle were 50.5 mi/h and 14.1 degrees, respectively. The actual impact point was 2.0 ft downstream of the joint between posts 5 and 6. Target IS was ≥404 kip-ft, and actual IS was 404 kip-ft.

7.2 WEATHER CONDITIONS

The test was performed the morning of August 21, 2015. Weather conditions at the time of testing were as follows: wind speed: 5 mi/h; wind direction: 142 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 85°F; relative humidity: 71 percent.

7.3 TEST VEHICLE

A 2003 Volvo VE tractor with 1995 Dorsey DTV van-type trailer, shown in Figures 7.1 and 7.2, was used for the crash test. The vehicle's test inertia weight was 79,760 lb, and its gross static weight was 79,945 lb. The height to the lower edge of the vehicle bumper was 17.75 inches, and the height to the upper edge of the bumper was 30.0 inches. The height of center of gravity of the ballast was 72.0 inches. Table E.1 in Appendix E.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation under its own power using a cable guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.1. TxDOT T224 Bridge Rail/Test Vehicle Geometrics for Test No. 490025-2-1.

Figure 7.2. Test Vehicle before Test No. 490025-2-1.

7.4 TEST DESCRIPTION

The 2003 Volvo VE tractor with 1995 Dorsey DTV van-type trailer, traveling at an impact speed of 50.5 mi/h, contacted the TxDOT T224 Bridge Rail 2.0 ft downstream of the joint between posts 5 and 6 at an impact angle of 14.0 degrees. At 0.028 s after impact, the right front tire contacted the bridge rail, and at 0.064 s, the cab of the vehicle began to redirect. The trailer began to redirect at 0.069 s, and the left front tire began to rotate inward at 0.102 s. At 0.224 s, the right rear forward outer tire of the rear tandem of the tractor blew out, and at 0.261 s, the right rear rearward outer tire of the rear tandem blew out. The cab became parallel to the bridge rail at 0.304 s, and the right front corner of the trailer contacted the top of the bridge rail at 0.325 s. The right rear of the trailer contacted the bridge rail at 0.751 s, and the trailer became parallel to the bridge rail at 0.756 s. At 1.164 s, the vehicle lost contact with the bridge rail while traveling at an exit speed and angle of 41.3 mi/h and 0.4 degrees, respectively. Brakes on the vehicle were applied at 3.13 s, and the vehicle subsequently came to rest 295 ft downstream of impact and 62 ft toward the field side. In Appendix E.2, Figures E.1 and E.2 present sequential photographs of the test.

7.5 DAMAGE TO TEST INSTALLATION

Figure 7.3 shows the damage to the TxDOT T224 Bridge Rail. The curb was fractured at its connection with the deck 3.5 ft both upstream and downstream from the joint. The curb was also cracked over a length ranging from 6 ft upstream to 17 ft downstream of the joint. The upper rail was cracked from the joint extending downstream for 18 ft, and two cracks in the rail were noted from the joint extending upstream 12.5 ft (primary crack) and 17 ft 8 inches (secondary crack). The field side of the deck was cracked upstream of post 5. Working width was 38.5 inches from the traffic side of the bridge rail to the farthest extent of the vehicle. Maximum dynamic deflection during the test was 2.1 inches, and maximum permanent deformation as 1.4 inches.

Figure 7.3. TxDOT T224 Bridge Rail after Test No. 490025-2-1.

7.6 DAMAGE TO TEST VEHICLE

Figure 7.4 shows the damage that the vehicle sustained. The front axle was pushed rearward 36 inches, and the right tie rod, right U-bolts, and right front shock and mount were deformed. Also damaged were the front bumper, hood, right front tire and rim, right front fender, right fuel tank, right side steps, and right rear outer tires and wheel rims of the tractor tandem. The right side lower edge of the trailer was also deformed and scraped. Maximum exterior crush to the vehicle was 12.0 inches in the front plane at the right front corner at bumper height. No occupant compartment deformation occurred. Figure 7.5 shows the interior of the vehicle.

Figure 7.4. Test Vehicle after Test No. 490025-2-1.

Before Test After Test

Figure 7.5. Interior of Test Vehicle for Test No. 490025-2-1.

7.7 OCCUPANT RISK FACTORS

Data from the accelerometers, located near the vehicle center of gravity, were digitized for informational purposes only. In the longitudinal direction, the OIV was 4.3 ft/s at 0.241 s, the highest 0.010-s occupant RDA was 8.9 g from 0.252 to 0.262 s, and the maximum 0.050-s average acceleration was –3.3 g between 0.225 and 0.275 s. In the lateral direction, the OIV was 14.8 ft/s at 0.241 s, the highest 0.010-s occupant RDA was 15.1 g from 0.250 to 0.260 s, and the maximum 0.050-s average was –6.2 g between 0.234 and 0.284 s. THIV was 17.7 km/h or 4.9 m/s at 0.242 s; PHD was 17.3 g between 0.252 and 0.262 s; and ASI was 0.58 between 0.204 and 0.254 s. Figure 7.6 summarizes these data and other pertinent information from the test. In Appendix E.3, Figure E.3 shows the vehicle angular displacements, and Figures E.4 through E.9 in Appendix E.4 shows acceleration versus time traces.

7.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 5-12 is provided below.

7.8.1 Structural Adequacy

A. 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.

Results: The TxDOT T224 Bridge Rail contained and redirected the 36000V vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 2.1 inches. (PASS)

7.8.2 Occupant Risk

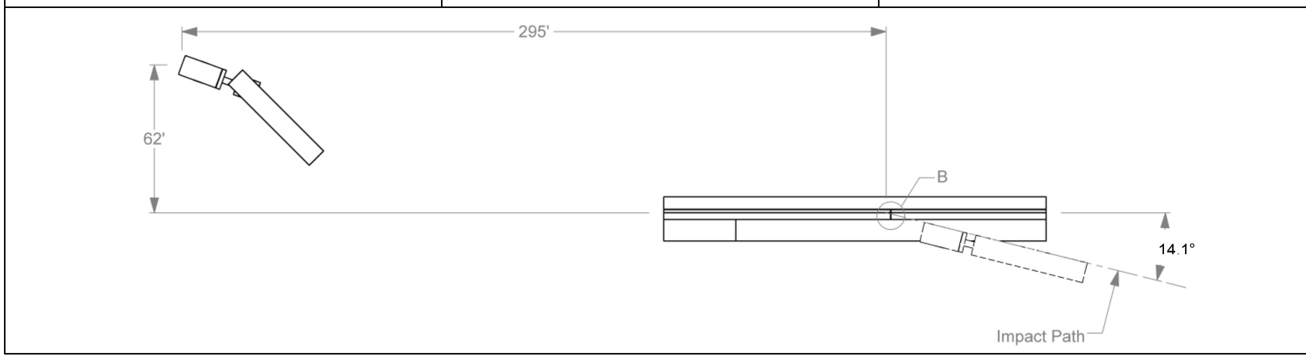
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.

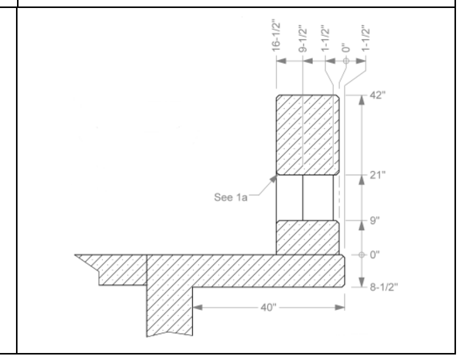
Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 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)

No occupant compartment deformation occurred. (PASS)

0.000 s	0.390 s	0.780 s	1.170 s





General Information	
Test Agency	Texas Transportation Institute (TTI)
Test Standard Test No.	MASH Test 5-12
TTI Test No.	490025-2-1
Test Date	2015-08-21
Test Article	
Type	Bridge Rail
Name	TxDOT T224 Bridge Rail
Installation Length	160 ft 2 inches
Material or Key Elements	42-inch high16½ inch wide reinforced concrete rail with integral reinforced concrete posts every 15 ft with 10 ft clear window between adjacent posts
Soil Type and Condition	Concrete Bridge Deck, Dry
Test Vehicle	
Type/Designation	36000V
Make and Model	2003 Volvo VE w/1995 Dorsey Trailer
Curb	30,240 lb
Test Inertial	79,760 lb
Dummy	185 lb
Gross Static	79,945 lb

Impact Conditions	
Speed	50.5 mi/h
Angle	14.1 degrees
Location/Orientation	2.0 ft dwnstrm of joint
Impact Severity	404 kip-ft
Exit Conditions	
Speed	41.3 mi/h
Angle	0.4 degree
Occupant Risk Values	
Longitudinal OIV	4.3 ft/s
Lateral OIV	14.8 ft/s
Longitudinal Ridedown	8.9 g
Lateral Ridedown	15.1 g
THIV	17.7 km/h
PHD	17.3 g
ASI	0.58
Max. 0.050-s Average	
Longitudinal	−3.3 g
Lateral	−6.2 g
Vertical	−4.7 g

Post-Impact Trajectory	
Stopping Distance	295 ft dwnstrm 62 ft twd field side
Vehicle Stability	
Maximum Yaw Angle	34 degrees
Maximum Pitch Angle	8 degrees
Maximum Roll Angle	18 degrees
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	2.1 inches
Permanent	1.2 inches
Working Width	38.5 inches
Vehicle Damage	
VDS	NA
CDC	01FREW3
Max. Exterior Deformation	12.0 inches
Max. Occupant Compartment Deformation	None

Figure 7.6. Summary of Results for *MASH* Test 5-12 on the TxDOT T224 Bridge Rail.

CHAPTER 8:
SUMMARY AND CONCLUSIONS

8.1 SUMMARY OF RESULTS

8.1.1 *MASH* Test 5-10 (Crash Test No. 490025-2-2)

The TxDOT T224 Bridge Rail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. No measureable dynamic deflection was noted. 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 4.0 inches in the right front instrument panel area. The 1100C vehicle remained upright during and after the collision event. Maximum roll was 7 degrees, and maximum pitch was 3 degrees. Occupant risk factors were within the required limits specified in *MASH*.

8.1.2 *MASH* Test 5-11 (Crash Test No. 490025-2-3)

The TxDOT T224 Bridge Rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. No measureable dynamic deflection was noted. 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 5.0 inches in the right firewall area. The 2270P vehicle remained upright during and after the collision event. Maximum roll was 6 degrees, and maximum pitch was 5 degrees. Occupant risk factors were within the preferred limits specified in *MASH*.

8.1.3 *MASH* Test 5-12 (Crash Test No. 490025-2-1)

The TxDOT T224 Bridge Rail contained and redirected the 36000V vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 2.1 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. No occupant compartment deformation occurred. The 36000V vehicle remained upright during and after the collision event. Maximum roll angle was 18 degrees at 0.402 s.

8.2 CONCLUSIONS

Tables 8.1 through 8.3 summarize the evaluation criteria for each *MASH* test. As shown in these tables, the TxDOT T224 Bridge Rail meets all criteria for *MASH* TL-5.

Table 8.1. Performance Evaluation Summary for *MASH* Test 5-10 on the TxDOT T224 Bridge Rail.

Test Agency: Texas A&M Transportation Institute — Test No.: 490025-2-2 — Test Date: 2015-08-18

MASH Test 5-10 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. *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.*	The TxDOT T224 Bridge Rail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. No measureable dynamic deflection was noted.	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.*	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
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 4.0 inches in the right front instrument panel area.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 1100C vehicle remained upright during and after the collision event. Maximum roll was 7 degrees and maximum pitch was 3 degrees.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.*	Longitudinal OIV was 31.5 ft/s, and lateral OIV was 30.2 ft/s.	Pass
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 20.49 Gs.*	Maximum longitudinal RDA was 14.1 , and maximum lateral RDA was 10.1 .	Pass

Table 8.2. Performance Evaluation Summary for *MASH* Test 5-11 on the TxDOT T224 Bridge Rail.

Test Agency: Texas A&M Transportation Institute | Test No.: 490025-2-3 | Test Date: 2015-08-19

***MASH* Test 5-11 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy *A. 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.*	The TxDOT T224 Bridge Rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. No measureable dynamic deflection was noted.	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.*	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
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 5.0 inches in the right firewall area.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 6 degrees, and maximum pitch was 5 degrees.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.	Longitudinal OIV was 21.6 ft/s, and lateral OIV was 28.9 ft/s.	Pass
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 20.49 Gs.	Maximum longitudinal RDA was 7.5 g, and maximum lateral RDA was 12.2 g.	Pass

Table 8.3. Performance Evaluation Summary for *MASH* Test 5-12 on the TxDOT T224 Bridge Rail.

Test Agency: Texas A&M Transportation Institute | Test No.: 490025-2-1 | Test Date: 2015-08-21

MASH Test 5-12 Evaluation Criteria	Test Results	Assessment
Structural Adequacy *A. 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*	The TxDOT T224 Bridge Rail contained and redirected the 36000V vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 2.1 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.*	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
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation occurred.	Pass
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The 36000V vehicle remained upright during and after the collision event. Maximum roll angle was 18 degrees at 0.402 s.	Pass

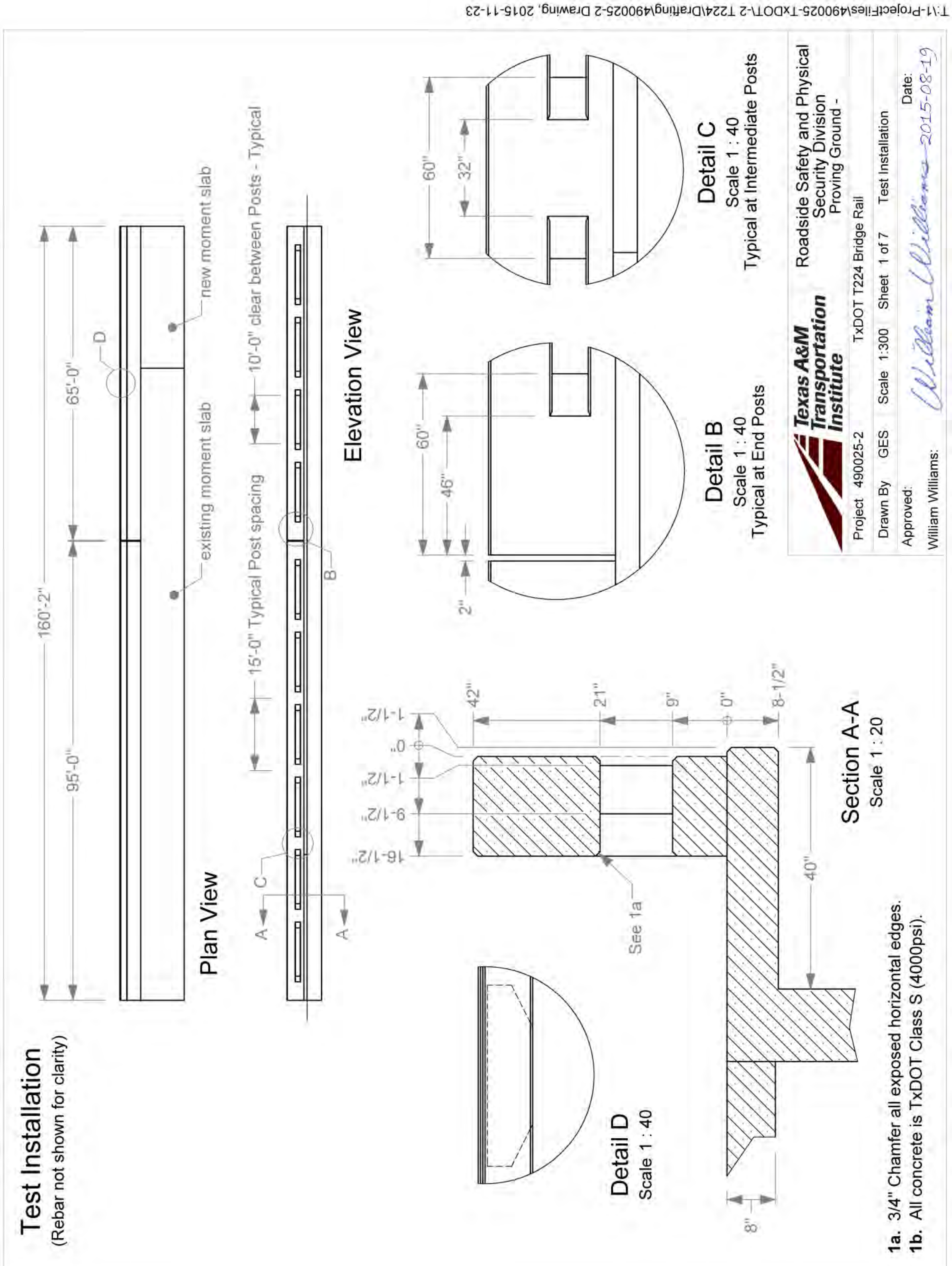
CHAPTER 9:
IMPLEMENTATION STATEMENT

The TxDOT T224 Bridge Rail as tested herein met all the safety evaluation criteria and performance requirements of *MASH* TL-5. Based on the successful results from all three full-scale crash tests, the TxDOT T224 Bridge Rail as tested and reported herein is recommended for implementation on new bridges requiring *MASH* TL-5 performance requirements.

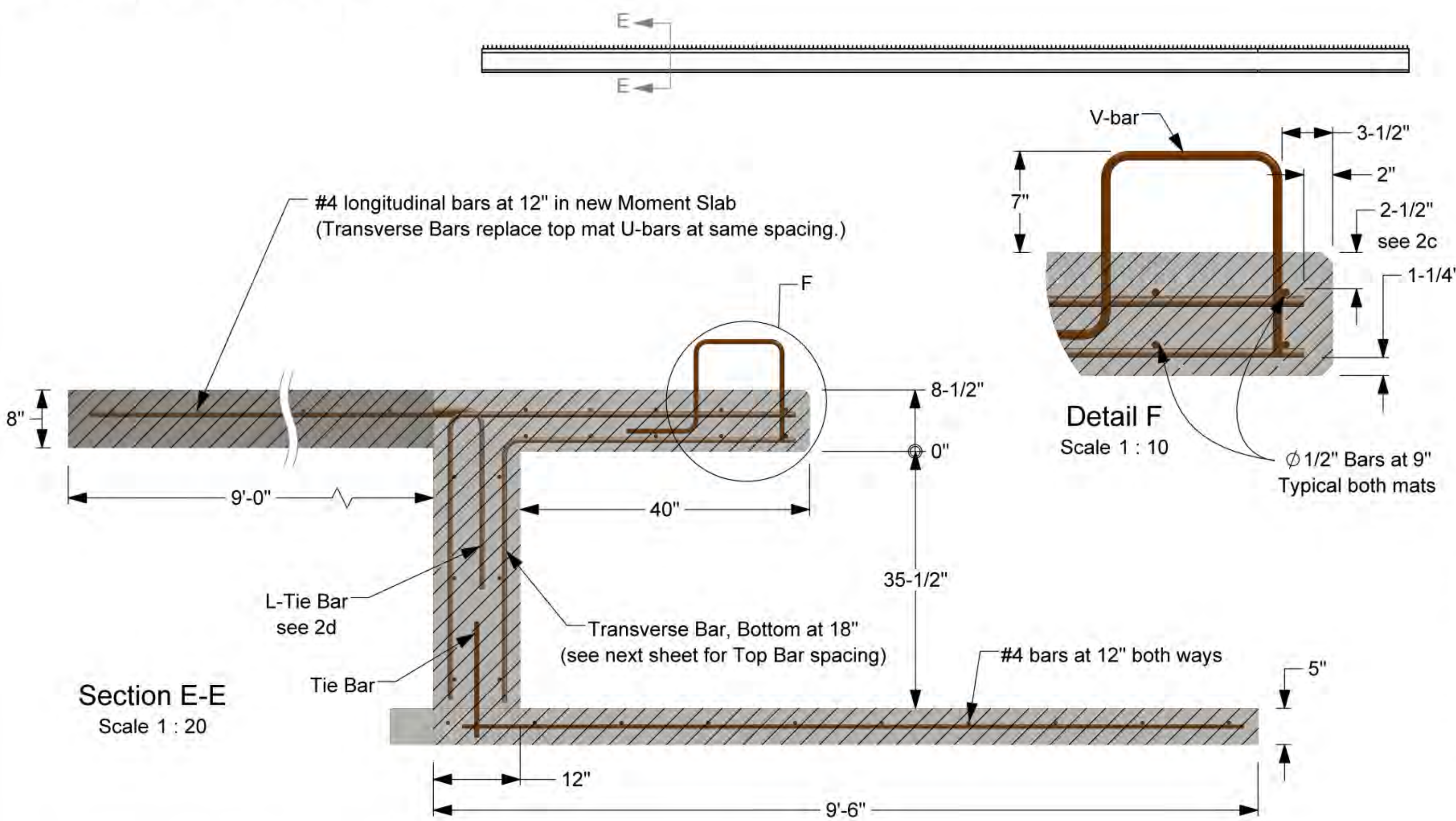
REFERENCES

1. AASHTO. *Manual for Assessing Roadside Safety Hardware.* 2009, American Association of State Highway and Transportation Officials: Washington, D.C.

APPENDIX A. DETAILS OF THE TXDOT T224 BRIDGE RAIL



Moment Slab and Deck Details



2a. Minimum rebar laps are 25" for #6 (Ø3/4") bars, 21" for #5 (Ø5/8") bars, and 17" for #4 (Ø1/2") bars.

2b. Bar spacing may be adjusted ±5/8" to avoid conflict with other bars.

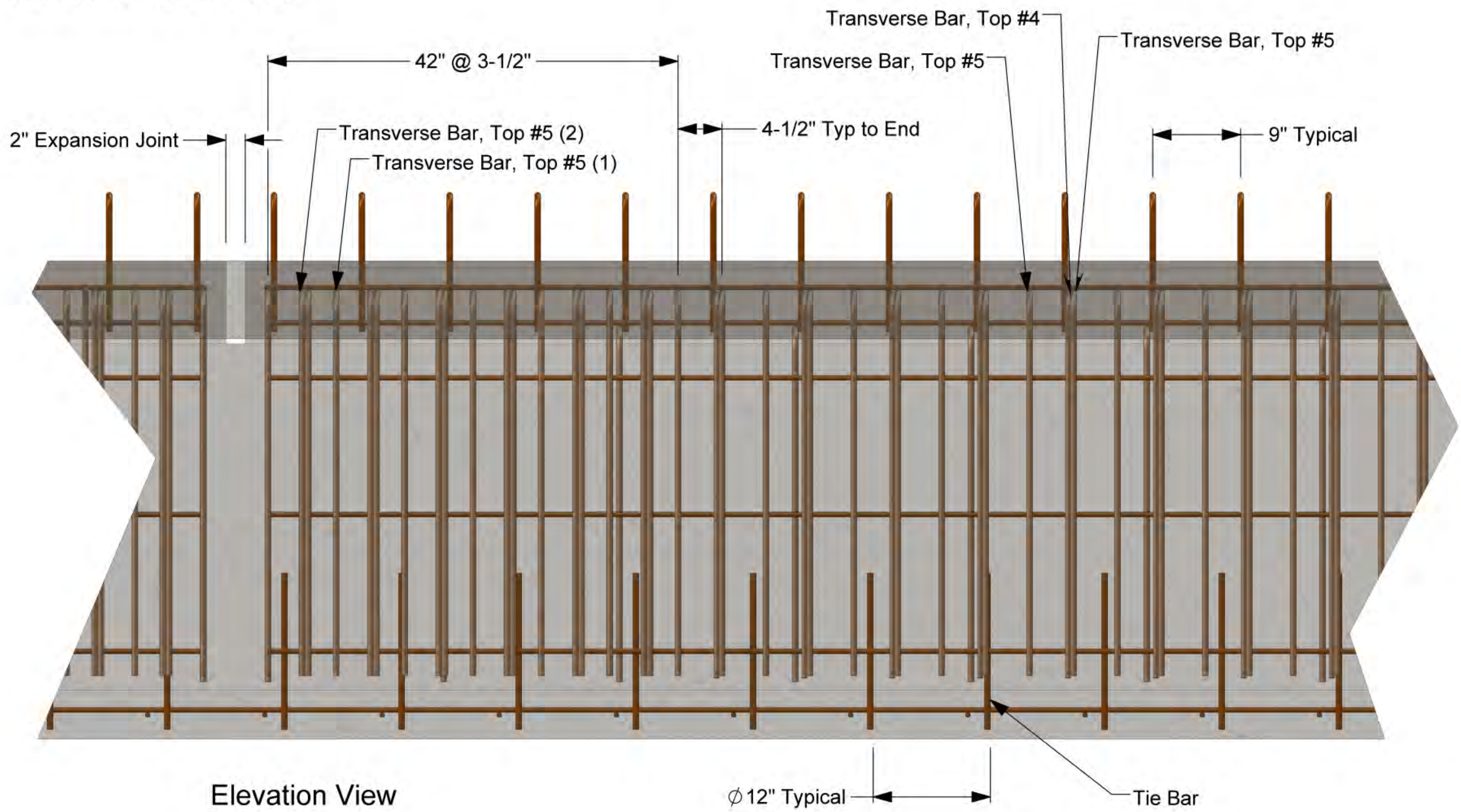
2c. Rebar clearance is 1-1/4" at bottom of Deck and 2-1/2" at top. 2" at all other locations unless otherwise indicated.

2d. L-Tie Bars weld to rebar protruding from existing Moment Slab at 18". Epoxy bars into Moment Slab as needed (not shown here).

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project 490025-2	TxDOT T224 Bridge Rail	2015-08-19
Drawn By GES	Scale1:300 Sheet 2 of 7	Moment Slab, Deck, etc.

T:\1-ProjectFiles\490025-TxDOT-2 T224\Drafting\490025-2 Drawing, 2015-11-23

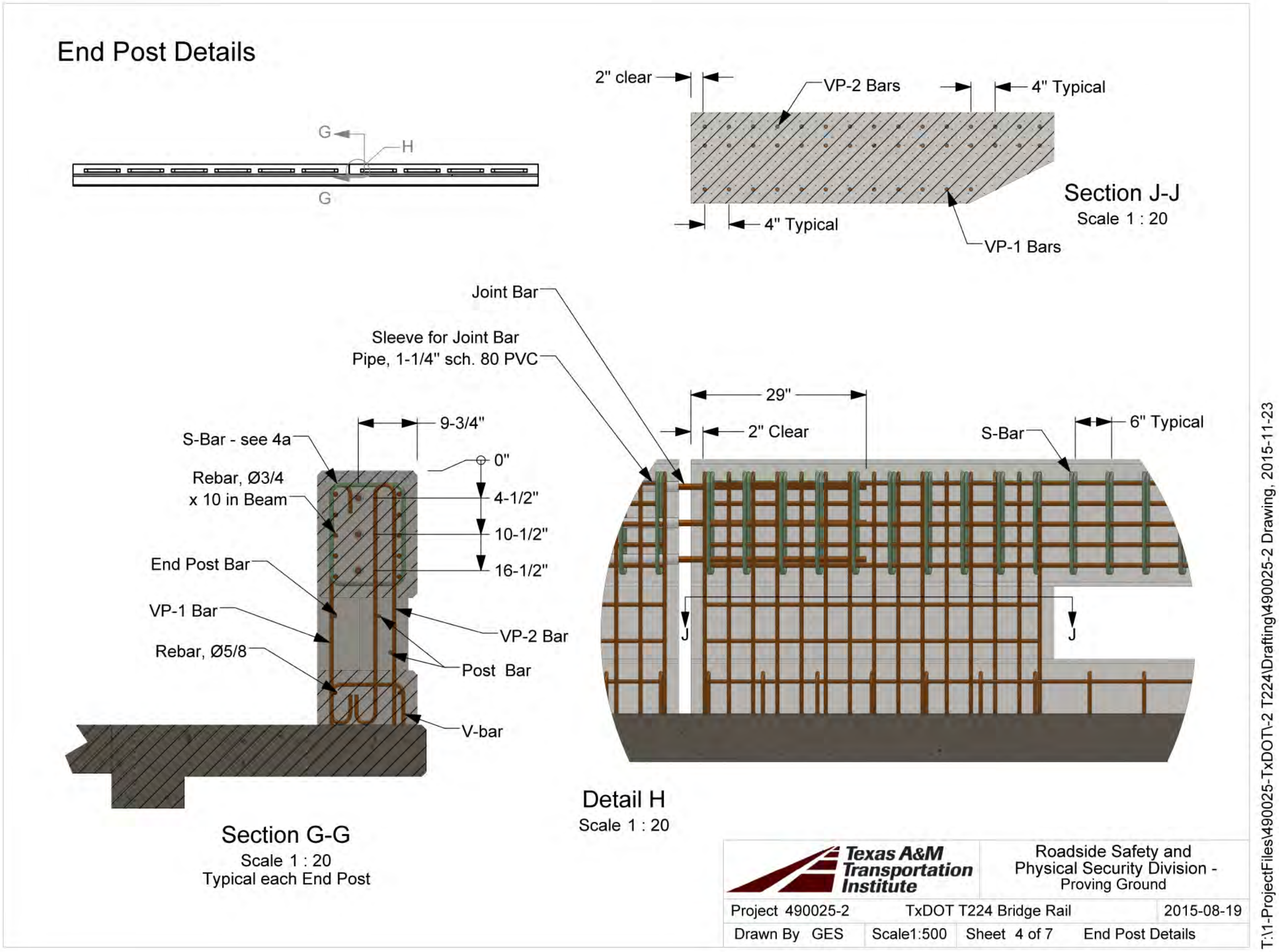
Moment Slab, etc.-2

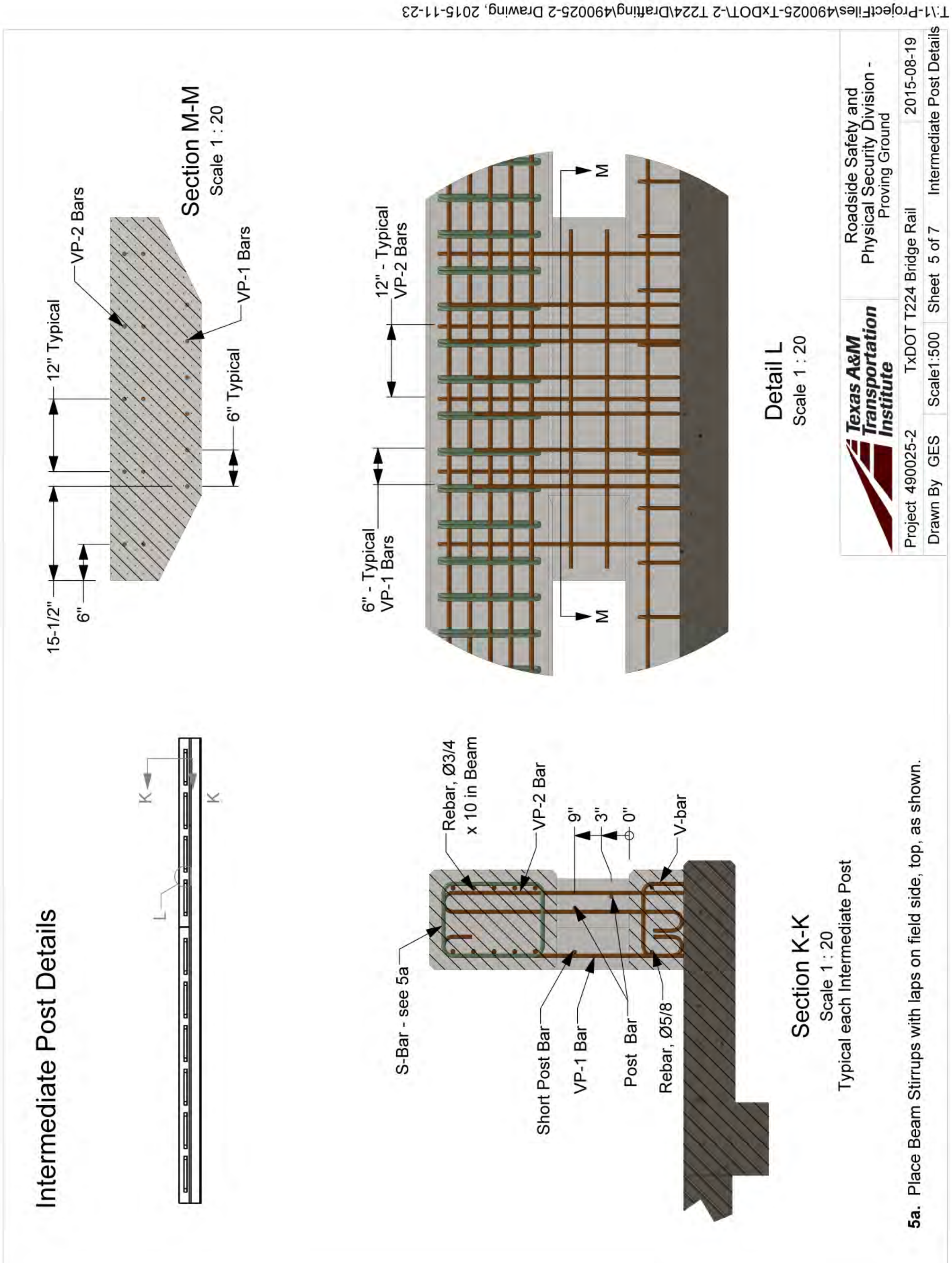


3a. Rebar spacing is typical for each side of Expansion Joint. Top Transverse Bars are #5's alternating single and double at 3-1/2" for 42", followed by #5's at 4-1/2" with #4 bars beside alternating #5's to end of Rail. (Top Deck L-bars will be replaced with straight bars, same size and spacing, in new Moment Slab.)

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 490025-2	TxDOT T224 Bridge Rail		2015-08-19
Drawn By GES	Scale 1:15	Sheet 3 of 7	Moment Slab, etc.-2

T:\2014-2015\490025 - TxDOT-2 T224\Drafting\490025-2 Drawing


End Post Details
G
H
G
2" clear
VP-2 Bars
4" Typical
4" Typical
VP-1 Bars
Section J-J
Scale 1 : 20
Joint Bar
Sleeve for Joint Bar
Pipe, 1-1/4" sch. 80 PVC
29"
2" Clear
S-Bar
6" Typical
J
J
S-Bar - see 4a
Rebar, Ø3/4
x 10 in Beam
End Post Bar
VP-1 Bar
Rebar, Ø5/8
9-3/4"
0"
4-1/2"
10-1/2"
16-1/2"
VP-2 Bar
Post Bar
V-bar
Section G-G
Scale 1 : 20
Typical each End Post
Detail H
Scale 1 : 20
Texas A&M Transportation Institute
Roadside Safety and
Physical Security Division -
Proving Ground
Project 490025-2
TxDOT T224 Bridge Rail
2015-08-19
Drawn By GES
Scale1:500
Sheet 4 of 7
End Post Details
T:\1-ProjectFiles\490025-TxDOT-2 T224\Drafting\490025-2 Drawing, 2015-11-23


T:\1-ProjectFiles\490025-TxDOT-2 T224\Drafting\490025-2 Drawing, 2015-11-23
Intermediate Post Details
K
K
L
Section M-M
Scale 1 : 20
15-1/2"
6"
12" Typical
6" Typical
VP-2 Bars
VP-1 Bars
6" - Typical
VP-1 Bars
12" - Typical
VP-2 Bars
M
M
Detail L
Scale 1 : 20
S-Bar - see 5a
Rebar, Ø3/4
x 10 in Beam
VP-2 Bar
9"
3"
0"
V-bar
Short Post Bar
VP-1 Bar
Post Bar
Rebar, Ø5/8
Section K-K
Scale 1 : 20
Typical each Intermediate Post
5a. Place Beam Stirrups with laps on field side, top, as shown.
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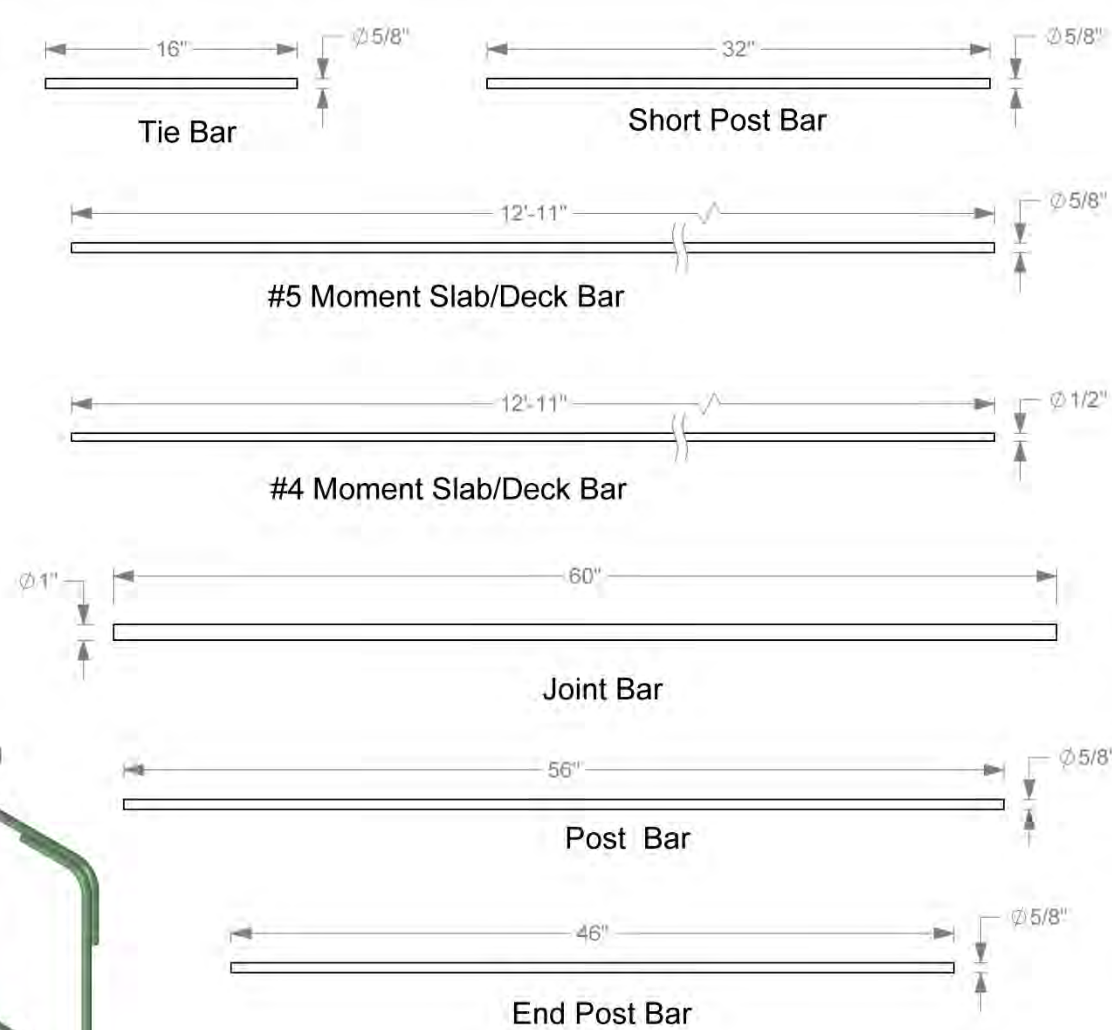
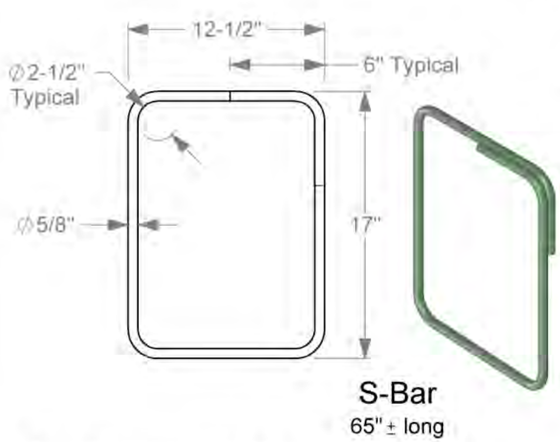
Project 490025-2
TxDOT T224 Bridge Rail
2015-08-19
Drawn By GES
Scale1:500
Sheet 5 of 7
Intermediate Post Details

Part Name	Qty.
S-Bar	320
VP-1 Bar	96
VP-2 Bar	100
V-bar	214
L-Tie Bar	43
Transverse Bar, Bottom	108
Transverse Bar, Top #4	164
Transverse Bar, Top #5	364
Short Post Bar	8
Post Bar	24
End Post Bar	4
Tie Bar	160
Joint Bar	3
#5 Moment Slab/Deck Bar	80
#4 Moment Slab/Deck Bar	40





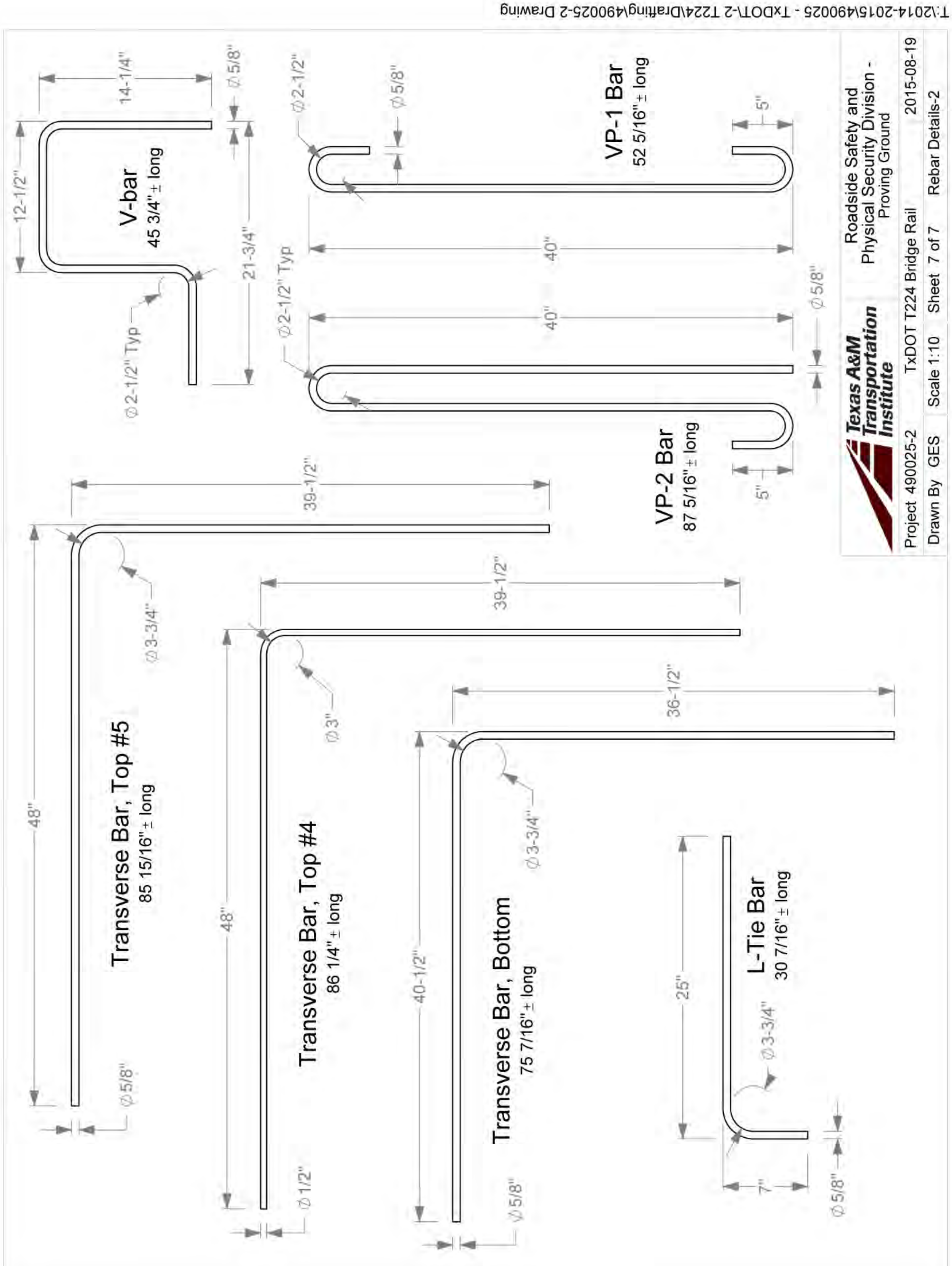
6a. All rebar is grade 60.

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project 490025-2	TxDOT T224 Bridge Rail		2015-08-19
Drawn By GES	Scale 1:10	Sheet 6 of 7	Rebar Details-1

T:\2014-2015\490025 - TxDOT-2 T224\Drafting\490025-2 Drawing


T:\2014-2015\490025 - TxDOT-2 T224\Drafting\490025-2 Drawing
V-bar
45 3/4"± long
12-1/2"
14-1/4"
21-3/4"
Ø 5/8"
Ø 2-1/2" Typ
VP-1 Bar
52 5/16"± long
Ø 2-1/2"
Ø 5/8"
40"
5"
VP-2 Bar
87 5/16"± long
Ø 2-1/2" Typ
40"
Ø 5/8"
5"
Transverse Bar, Top #5
85 15/16"± long
48"
39-1/2"
Ø 3-3/4"
Ø 5/8"
Transverse Bar, Top #4
86 1/4"± long
48"
39-1/2"
Ø 3"
Ø 1/2"
Transverse Bar, Bottom
75 7/16"± long
40-1/2"
36-1/2"
Ø 3-3/4"
Ø 5/8"
L-Tie Bar
30 7/16"± long
25"
7"
Ø 3-3/4"
Ø 5/8"
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 490025-2
TxDOT T224 Bridge Rail
2015-08-19
Drawn By GES
Scale 1:10
Sheet 7 of 7
Rebar Details-2

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

MATERIAL USED

TEST NUMBER 490025-2

TEST NAME T224 Bridge Rail

#	DATE RECEIVED	DESCRIPTION	GRADE	YIELD	TENSILE	SUPPLIER
14-068	2015-05-19	Rebar, #4	Grade 60	73.3	106.3	CMC Steel
14-069	2015-05-19	Rebar, #5	Grade 60	64.9	101.4	CMC Steel
14-070	2015-05-19	Rebar, #6	Grade 60	63.5	99.8	CMC Steel
14-071	2015-05-19	Rebar, #8	Grade 60	63.5	103.5	CMC Steel
14-072	2015-05-28	Rebar, #4	Grade 60	73.6	110.9	CMC Steel
14-073	2015-05-28	Rebar, #5	Grade 60	65.2	101.2	CMC Steel

14-068

CMC

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

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William VanderWaal
Quality Assurance/Reliability Manager

HEAT NO.:3055319 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-14 Gr 420/60 ROLL DATE: 04/19/2015 MELT DATE: 04/12/2015	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900

Delivery#: 81512082	
BOL#: 70546775	
CUST PO#: 676800	
CUST P/N: 552420D	
DLVRY LBS / HEAT: 8764.000 LB	
DLVRY PCS / HEAT: 656 EA	

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.40%				
Mn	0.78%				
P	0.013%				
S	0.039%				
Si	0.18%				
Cu	0.43%				
Cr	0.20%				
Ni	0.26%				
Mo	0.094%				
V	0.001%				
Cb	0.003%				
Sn	0.013%				
Al	0.001%				
Yield Strength test 1	73.3ksi				
Tensile Strength test 1	106.3ksi				
Elongation test 1	15%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	1.750IN				
Bend Test 1	Passed				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

05/06/2015 03:45:07
Page 1 OF 1

14-069

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HEAT NO.:3053254 SECTION: REBAR 16MM (#5) 40'0" 420/60 GRADE: ASTM A615-14 Gr 420/60 ROLL DATE: 01/16/2015 MELT DATE: 01/12/2015	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 81497845 BOL#: 70542262 CUST PO#: 674744 CUST P/N: 552540D DLVRY LBS / HEAT: 32040.000 LB DLVRY PCS / HEAT: 768 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.41%				
Mn	0.93%				
P	0.012%				
S	0.041%				
Si	0.22%				
Cu	0.28%				
Cr	0.14%				
Ni	0.16%				
Mo	0.073%				
V	0.000%				
Cb	0.002%				
Sn	0.011%				
Al	0.001%				
Yield Strength test 1	64.9ksi				
Tensile Strength test 1	101.4ksi				
Elongation test 1	13%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	2.188IN				
Bend Test 1	Passed				

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REMARKS :

PB

04/20/2015 11:40:09
Page 1 OF 1

14-070

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HEAT NO.:3054394 SECTION: REBAR 19MM (#6) 40'0" 420/60 GRADE: ASTM A615-14 Gr 420/60 ROLL DATE: 03/07/2015 MELT DATE: 03/02/2015	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900

Delivery#: 81474344
BOL#: 70534286
CUST PO#: 671414
CUST P/N: 552640D
DLVRY LBS / HEAT: 47586.000 LB
DLVRY PCS / HEAT: 792 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.44%				
Mn	0.73%				
P	0.017%				
S	0.037%				
Si	0.20%				
Cu	0.29%				
Cr	0.21%				
Ni	0.14%				
Mo	0.047%				
V	0.001%				
Cb	0.002%				
Sn	0.012%				
Al	0.002%				
Yield Strength test 1	63.5ksi				
Tensile Strength test 1	99.8ksi				
Elongation test 1	15%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	3.750IN				
Bend Test 1	Passed				

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REMARKS :

03/19/2015 14:24:44
Page 1 OF 1

14-071

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HEAT NO.:3055477 SECTION: REBAR 25MM (#8) 20'0" 420/60 GRADE: ASTM A615-14 Gr 420/60 ROLL DATE: 04/29/2015 MELT DATE: 04/19/2015	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 81512069 BOL#: 70546716 CUST PO#: 676800 CUST P/N: 552820D DLVRY LBS / HEAT: 23496.000 LB DLVRY PCS / HEAT: 440 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.39%				
Mn	1.16%				
P	0.013%				
S	0.043%				
Si	0.22%				
Cu	0.30%				
Cr	0.11%				
Ni	0.16%				
Mo	0.051%				
V	0.001%				
Cb	0.003%				
Sn	0.013%				
Al	0.001%				
Yield Strength test 1	63.4ksi				
Tensile Strength test 1	103.5ksi				
Elongation test 1	17%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	5.000IN				
Bend Test 1	Passed				

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REMARKS :

05/05/2015 14:36:05
Page 1 OF 1

14-072

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William VanderWaal
Quality Assurance/Reliability Manager

HEAT NO.:3053909 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-14 Gr 420/60 ROLL DATE: 03/21/2015 MELT DATE: 02/08/2015	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 81487998 BOL#: 70538609 CUST PO#: 673425 CUST P/N: 552420D DLVRY LBS / HEAT: 46011.000 LB DLVRY PCS / HEAT: 3444 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.44%				
Mn	0.86%				
P	0.013%				
S	0.047%				
Si	0.21%				
Cu	0.32%				
Cr	0.21%				
Ni	0.17%				
Mo	0.087%				
V	0.001%				
Cb	0.002%				
Sn	0.012%				
Al	0.002%				
Yield Strength test 1	73.6ksi				
Tensile Strength test 1	110.9ksi				
Elongation test 1	13%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	1.750IN				
Bend Test 1	Passed				

THIS MATERIAL IS FULLY KILLED. 100% MELTED AND MANUFACTURED IN THE USA. WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

04/08/2015 01:26:46
Page 1 OF 1

14-073

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William VanderWaal
Quality Assurance/Reliability Manager

HEAT NO.:3052444 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-14 Gr 420/60 ROLL DATE: 01/19/2015 MELT DATE: 12/05/2014	SOLD TO		SHIP TO		Delivery#: BOL#: CUST PO#: CUST P/N: DLVRY LBS / HEAT: DLVRY PCS / HEAT:

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.41%				
Mn	0.83%				
P	0.015%				
S	0.034%				
Si	0.19%				
Cu	0.34%				
Cr	0.19%				
Ni	0.19%				
Mo	0.068%				
V	0.001%				
Cb	0.003%				
Sn	0.013%				
Al	0.002%				
Yield Strength test 1	65.2ksi				
Tensile Strength test 1	101.2ksi				
Elongation test 1	11%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	2.188IN				
Bend Test 1	Passed				

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REMARKS :

05/27/2015 17:22:19
Page 1 OF 1

APPENDIX C. CRASH TEST NO. 490025-2-2 (*MASH* TEST 5-10)

C.1 VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 490025-2-2.

Date: 2015-08-18 Test No.: 490025-2-2 VIN No.: KNADA223696557458

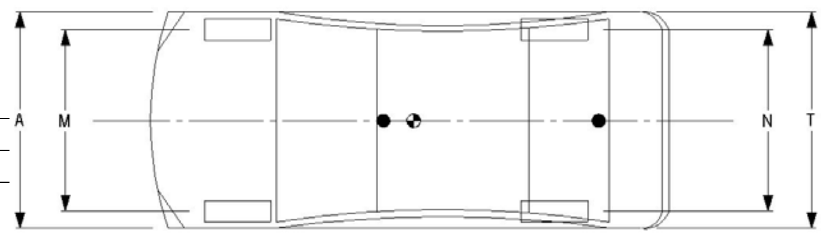
Year: 2009 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 100802 Tire Size: 185/65R14

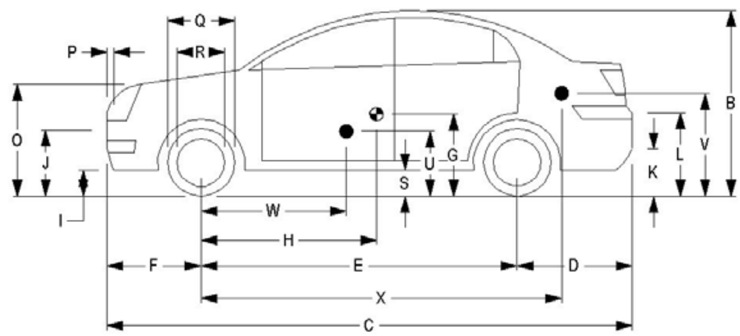
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: NA



Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
___ Auto or x Manual
x FWD ___ RWD ___ 4WD
Optional Equipment:
NA



Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Front passenger

Geometry: inches

A	66.38	F	33.00	K	12.75	P	4.12	U	14.50
B	58.25	G	-----	L	25.00	Q	22.19	V	21.50
C	165.75	H	36.57	M	52.75	R	15.38	W	44.00
D	34.00	I	9.50	N	57.12	S	9.00	X	109.00
E	98.75	J	21.50	O	31.50	T	66.12		
	Wheel Center Ht Front		11.00		Wheel Center Ht Rear		11.00		

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1918	M_{front}	1533	1525	1616
Back	1874	M_{rear}	915	897	971
Total	3638	M_{Total}	2448	2422	2587

Mass Distribution:
lb LF: 779 RF: 746 LR: 439 RR: 458

Table C.2. Exterior Crush Measurements of Vehicle for Test No. 490025-2-2.

Date: 2015-08-18 Test No.: 490025-2-2 VIN No.: KNADA223696557458

Year: 2009 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	24	13	26	1	2.5	4	6.5	8	13	+19
2	Side plane at bumper ht	24	11	44	2	3.25	6.5	8.5	10	11	+50
	Measurements recorded										
	in inches										

[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.

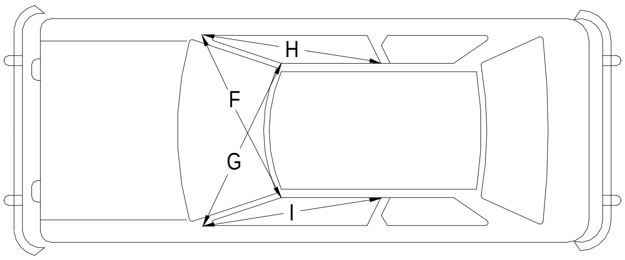
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

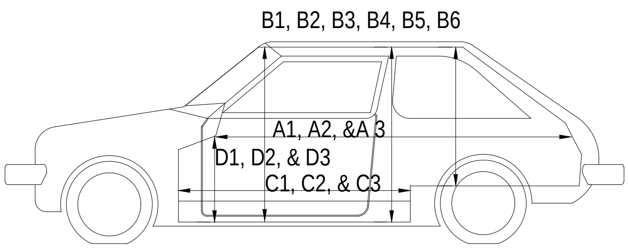
***Measure and document on the vehicle diagram the location of the maximum crush.

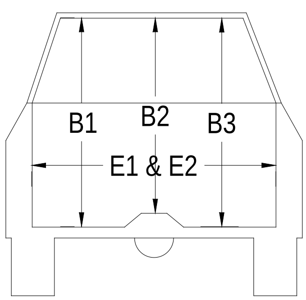
Note: Use as many lines/columns as necessary to describe each damage profile.

Table C.3. Occupant Compartment Measurements of Vehicle for Test No. 490025-2-2.

Date:	2015-08-18	Test No.:	490025-2-2	VIN No.:	KNADA223696557458
Year:	2009	Make:	Kia	Model:	Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	67.75	67.75
A2	67.00	67.00
A3	67.75	66.25
B1	40.25	40.25
B2	35.75	35.75
B3	40.25	38.25
B4	36.00	36.00
B5	35.75	35.75
B6	36.00	36.00
C1	27.00	27.00
C2	-----	-----
C3	27.00	24.50
D1	9.50	9.50
D2	-----	-----
D3	9.50	5.50
E1	46.00	49.00
E2	51.00	53.50
F	50.50	48.50
G	50.50	50.50
H	36.50	36.50
I	36.50	35.50
J*	50.50	49.50

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

C.2 SEQUENTIAL PHOTOGRAPHS

Figure C.1. Sequential Photographs for Test No. 490025-2-2 (Overhead and Frontal Views).

0.280 s

0.350 s

0.420 s

0.490 s

Figure C.1. Sequential Photographs for Test No. 490025-2-2 (Overhead and Frontal Views) (Continued).

0.000 s

0.070 s

0.140 s

0.210 s

0.280 s

0.350 s

0.420 s

0.490 s

Figure C.2. Sequential Photographs for Test No. 490025-2-2 (Rear View).

C.3 VEHICLE ANGULAR DISPLACEMENT

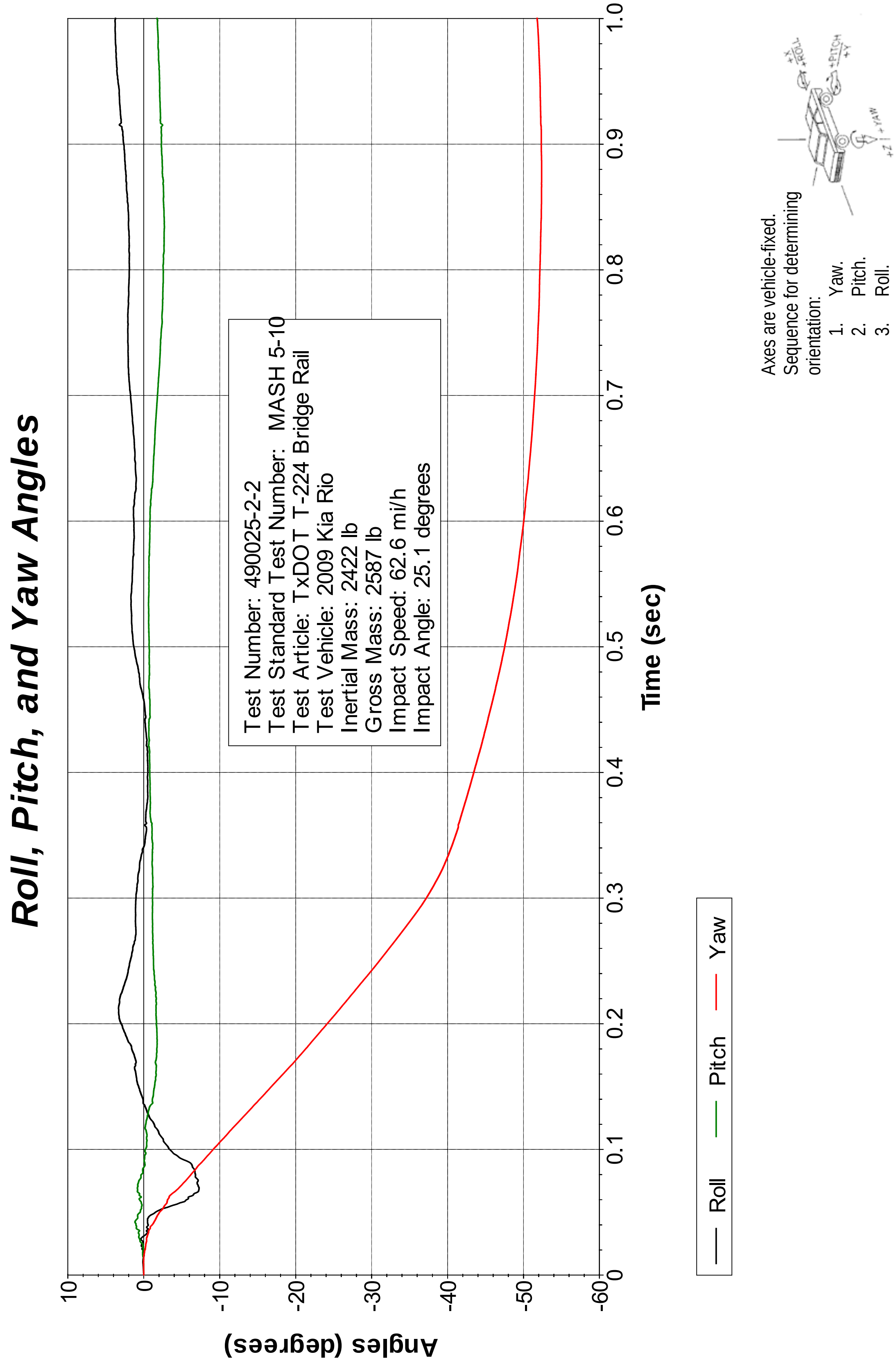


Figure C.3. Vehicle Angular Displacements for Test No. 490025-2-2.

C.4 VEHICLE ACCELERATIONS

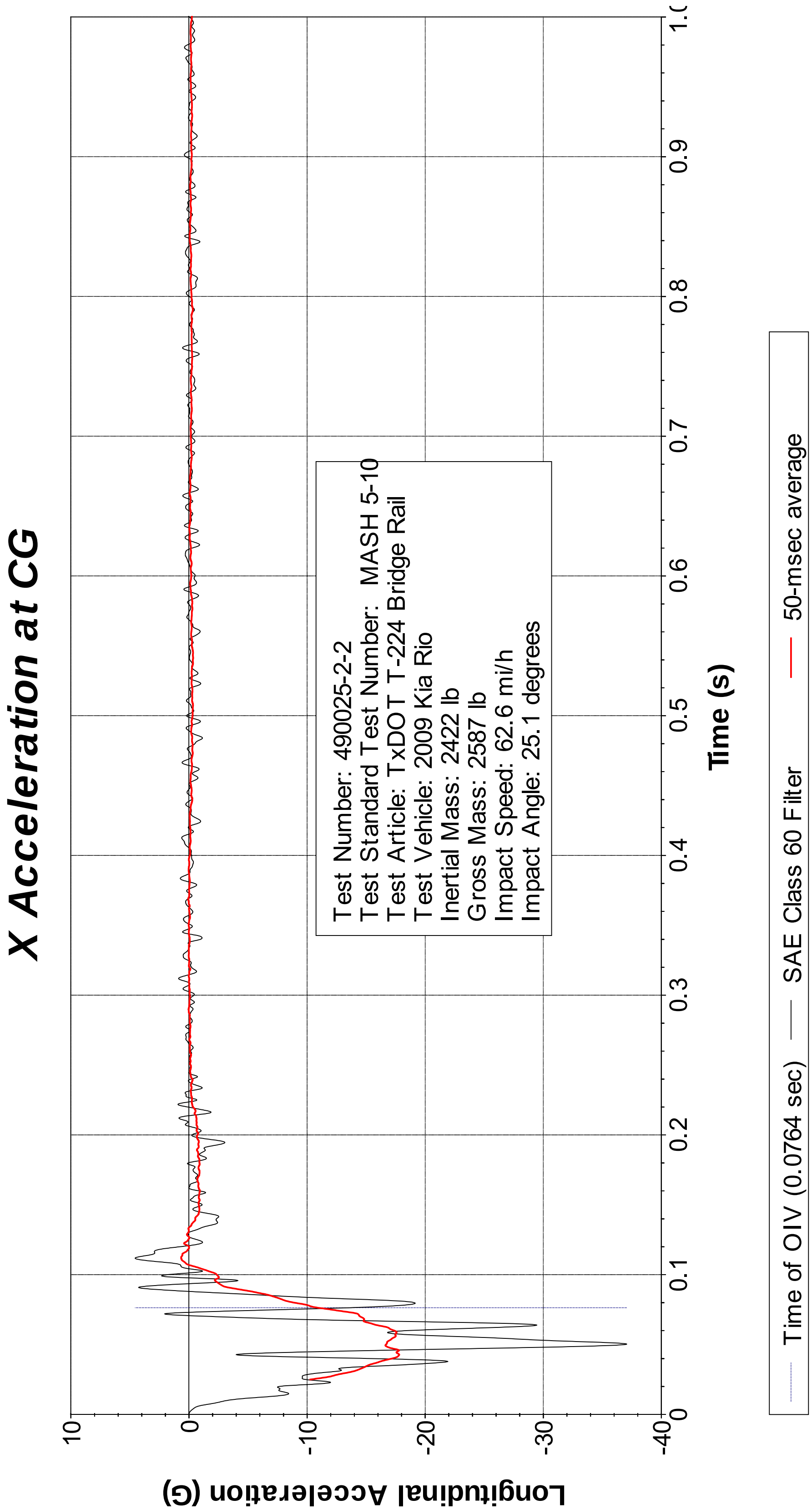


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-2-2 (Accelerometer Located at Center of Gravity).

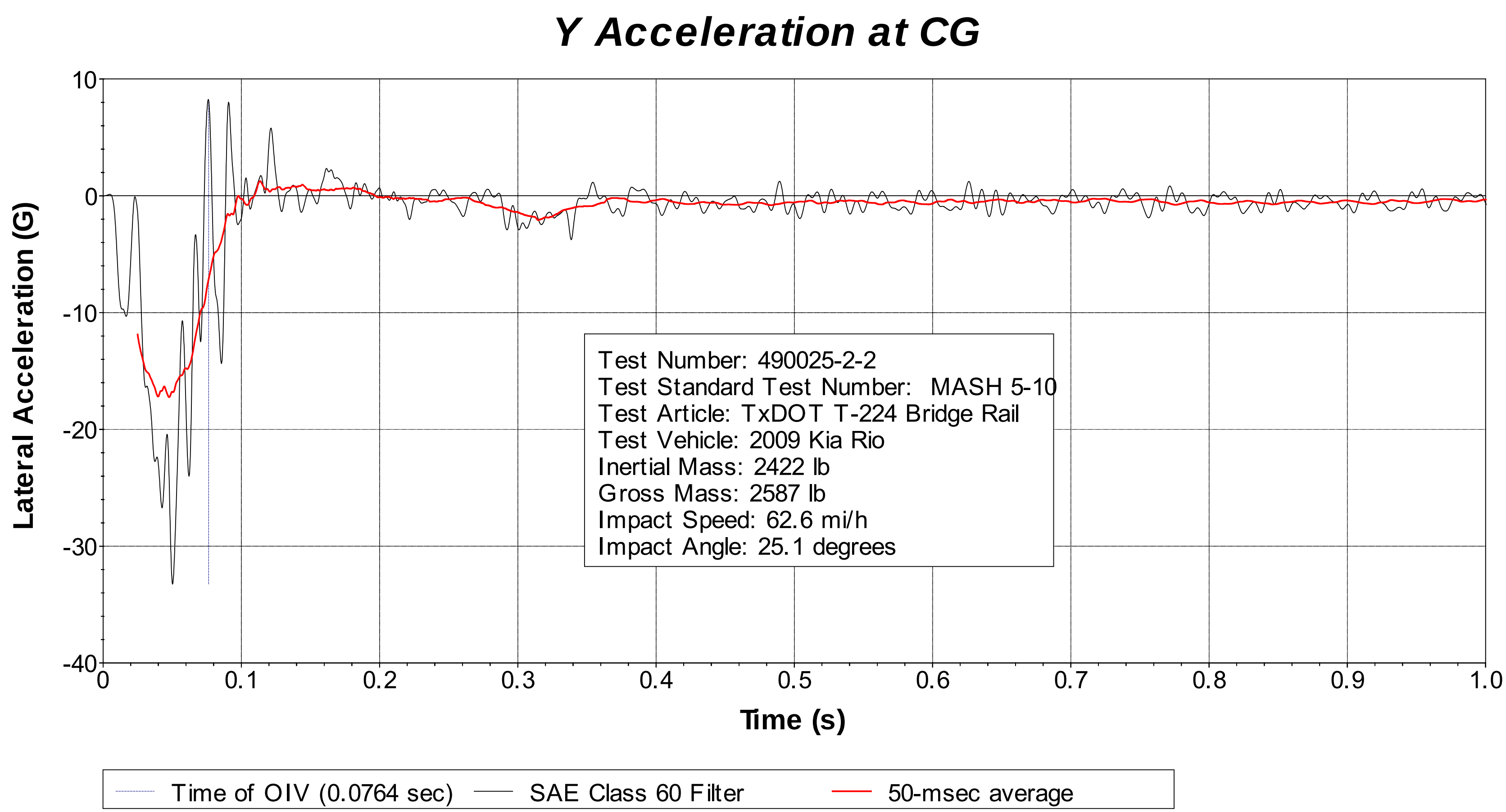


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 490025-2-2 (Accelerometer Located at Center of Gravity).

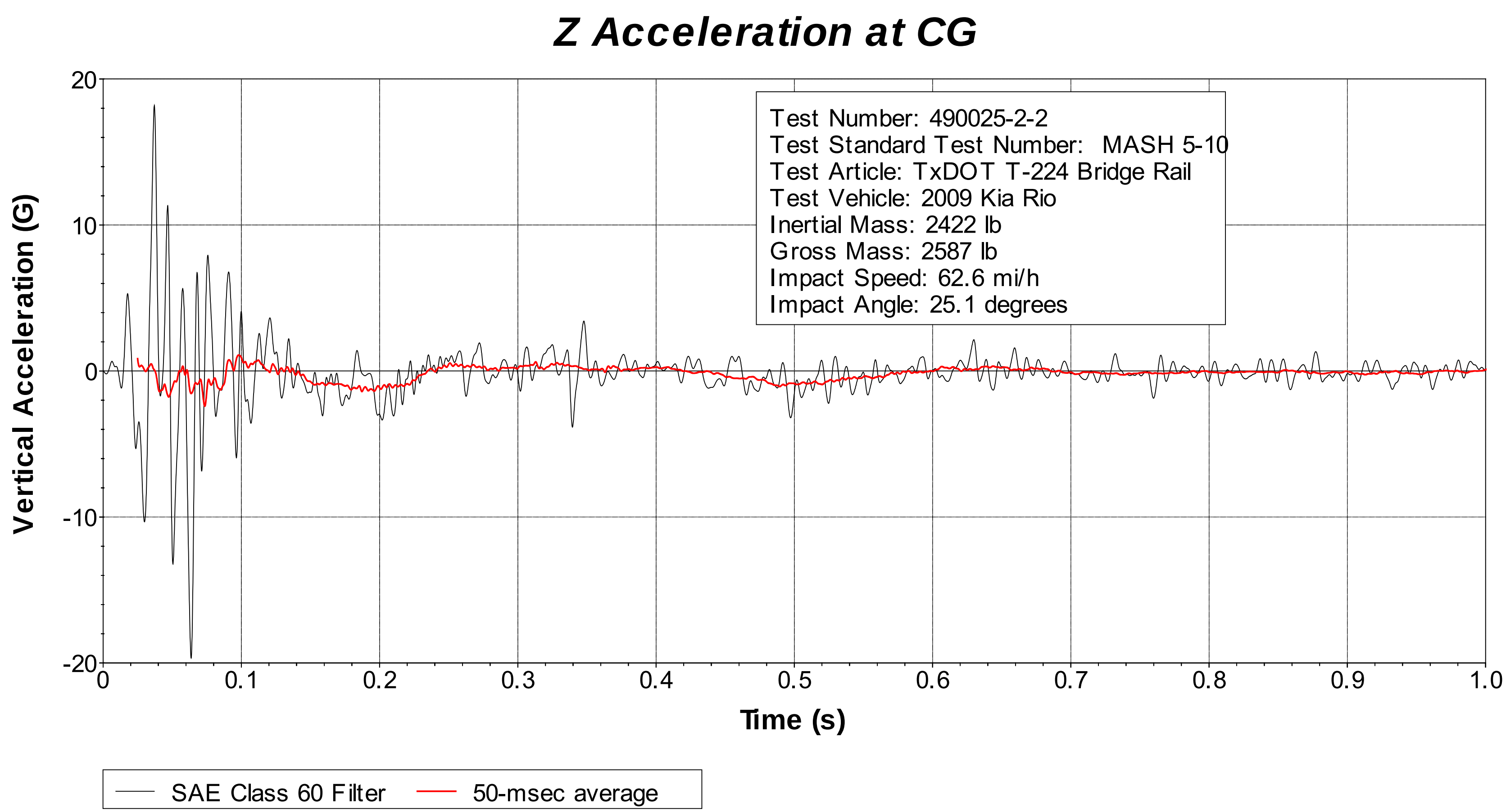


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 490025-2-2 (Accelerometer Located at Center of Gravity).

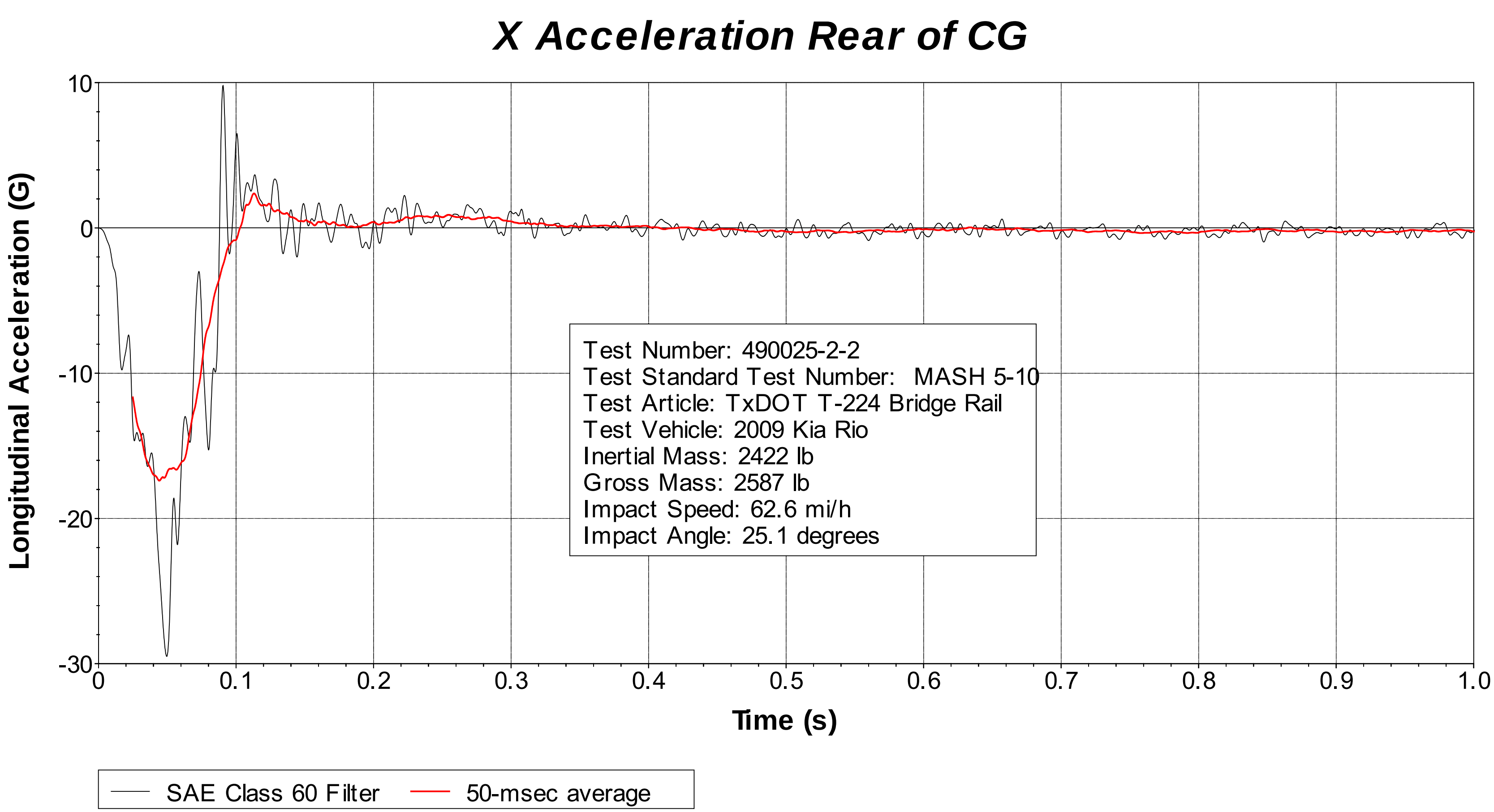


Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-2-2 (Accelerometer Located Rear of Center of Gravity).

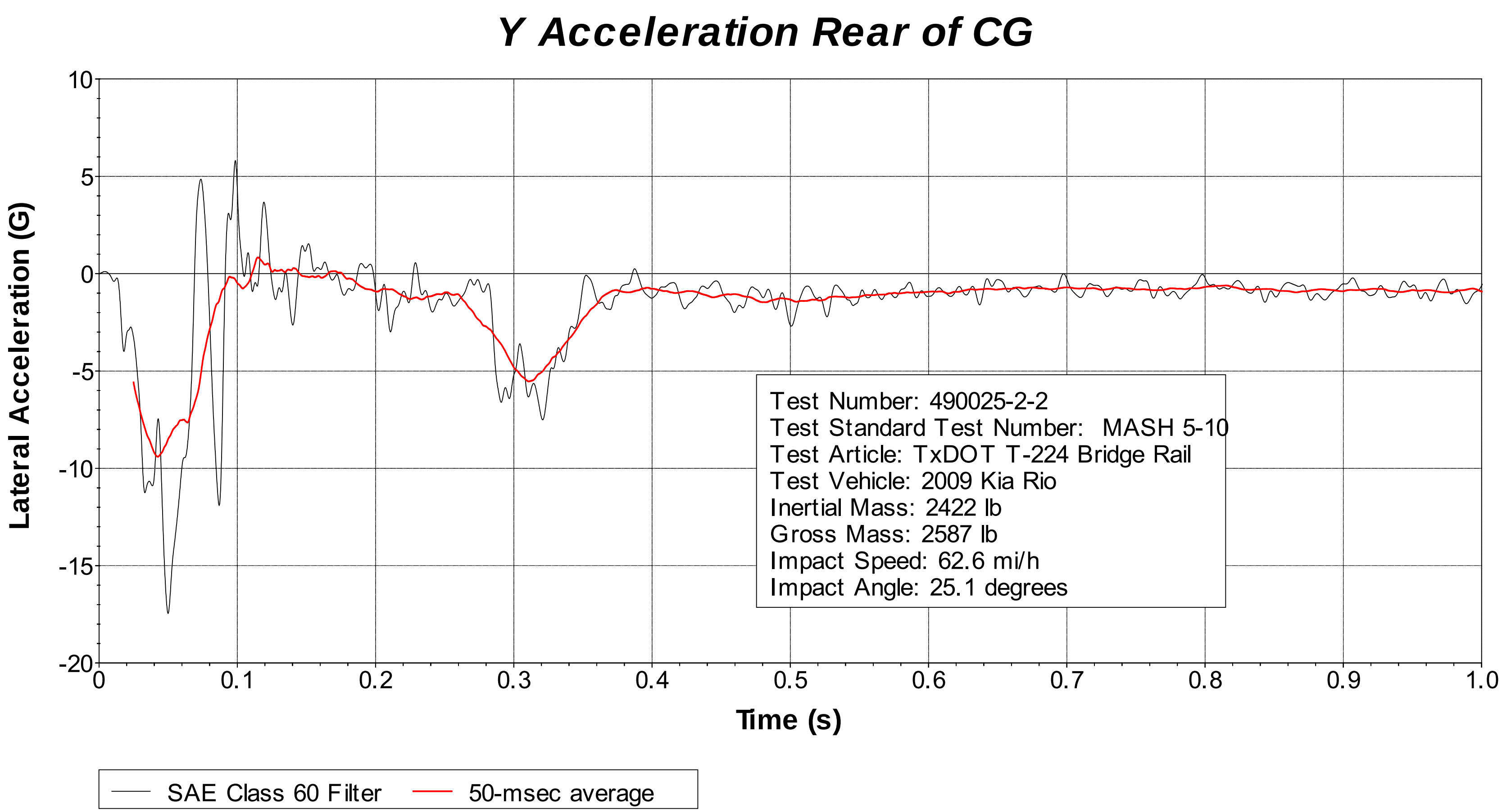


Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 490025-2-2 (Accelerometer Located Rear of Center of Gravity).

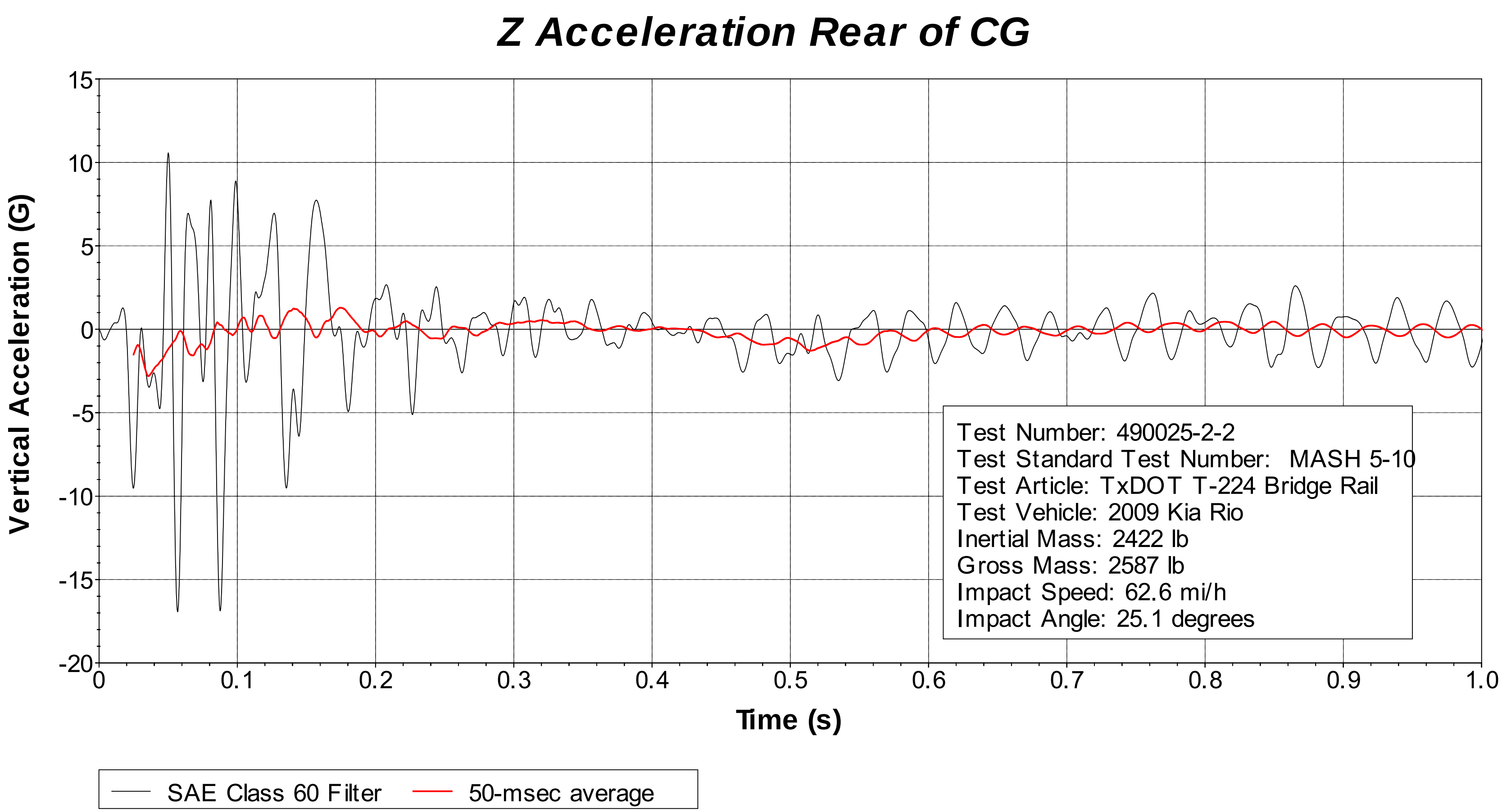


Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 490025-2-2 (Accelerometer Located Rear of Center of Gravity).

APPENDIX D. CRASH TEST NO. 490025-2-3 (*MASH* TEST 5-11)

D.1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 490025-2-3.

Date: 2015-08-19 Test No.: 490025-2-3 VIN No.: 1D3HB18739S779243

Year: 2009 Make: Dodge Model: Ram 1500

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 163126

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

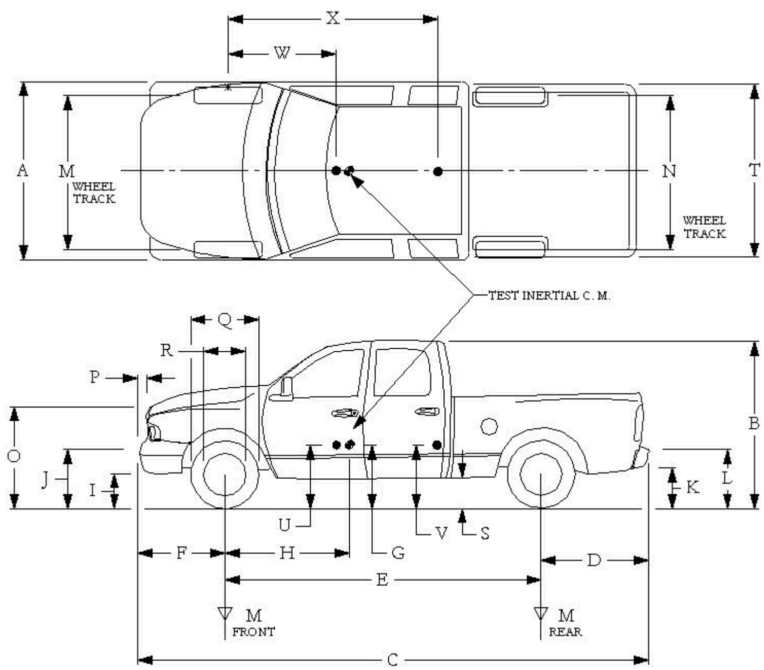
NOTES: NA

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type:
x Auto or ___ Manual
___ FWD x RWD ___ 4WD

Optional Equipment:
None

Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Right front



Geometry: inches

A	78.50	F	40.00	K	20.25	P	3.00	U	28.50
B	73.50	G	28.12	L	29.50	Q	30.50	V	29.50
C	227.50	H	61.25	M	68.50	R	18.00	W	61.20
D	47.00	I	10.50	N	68.00	S	12.25	X	77.00
E	140.50	J	25.25	O	44.50	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	17.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	25.50

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2889	2844	2929
Back	3900	M_{rear}	2146	2198	2278
Total	6700	M_{Total}	5035	5042	5207

Mass Distribution:
lb LF: 1452 RF: 1392 LR: 1110 RR: 1088

Table D.2. Measurements of Vehicle Vertical CG for Test No. 490025-2-3.

Date: 2015-08-19 Test No.: 490025-2-3 VIN: 1D3HB18739S779243

Year: 2009 Make: Dodge Model: 1500

Body Style: Quad Cab Mileage: 163126

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 162 lb (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)									
LF:	1452		RF:	1392			Front Axle:	2844	
LR:	1110		RR:	1088			Rear Axle:	2198	
Left:	2562		Right:	2480			Total:	5042	
							5000 ±110 lb allowed		
Wheel Base:		140.5	inches	Track: F:	68.5	inches	R:	68	inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed					
Center of Gravity, SAE J874 Suspension Method									
X:	61.25	inches	Rear of Front Axle		(63 ±4 inches allowed)				
Y:	-0.56	inches	Left -	Right +	of Vehicle Centerline				
Z:	28.125	inches	Above Ground		(minumum 28.0 inches allowed)				

Hood Height: 44.50 inches Front Bumper Height: 25.25 inches

Front Overhang: 40.00 inches Rear Bumper Height: 29.50 inches

Overall Length: 227.50 inches

Table D.3. Exterior Crush Measurements of Vehicle for Test No. 490025-2-3.

Date: 2015-08-19 Test No.: 490025-2-3 VIN No.: 1D3HB18739S779243

Year: 2009 Make: Dodge Model: Ram 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	32	18	36	2	4.5	7	10	12	18	+18
2	Side plane at bumper ht	32	14	57	4	5	9.5	11	12	14	+72
	Measurements recorded										
	in inches										

[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).

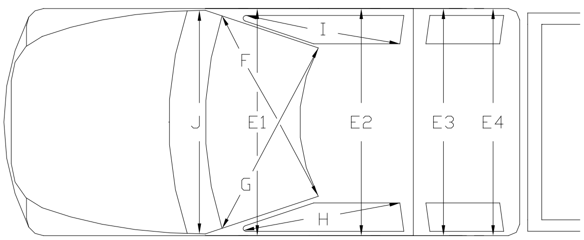
***Measure and document on the vehicle diagram the location of the maximum crush.

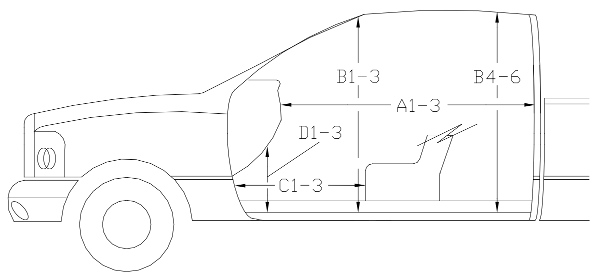
Note: Use as many lines/columns as necessary to describe each damage profile.

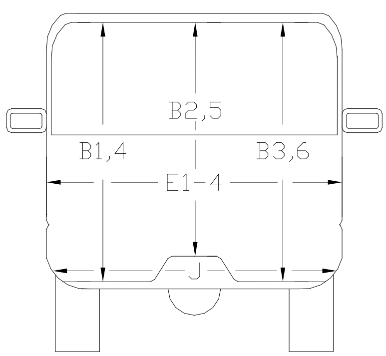
Table D.4. Occupant Compartment Measurements of Vehicle for Test No. 490025-2-3.

Date: 2015-08-19 Test No.: 490025-2-3 VIN No.: 1D3HB18739S779243

Year: 2009 Make: Dodge Model: Ram 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	66.25	66.25
A2	63.25	63.25
A3	65.75	64.50
B1	44.75	44.75
B2	38.12	38.12
B3	44.75	44.75
B4	39.50	39.50
B5	43.00	43.00
B6	39.50	39.50
C1	27.50	27.50
C2	-----	-----
C3	26.50	21.50
D1	11.25	11.25
D2	-----	-----
D3	11.25	10.00
E1	58.75	58.00
E2	63.50	65.50
E3	63.50	63.50
E4	63.25	63.25
F	59.00	59.00
G	59.00	58.75
H	37.00	37.00
I	37.00	36.75
J*	24.75	21.00

D.2 SEQUENTIAL PHOTOGRAPHS

Figure D.1. Sequential Photographs for Test No. 490025-2-3 (Overhead and Frontal Views).

0.200 s

0.250 s

0.300 s

0.350 s

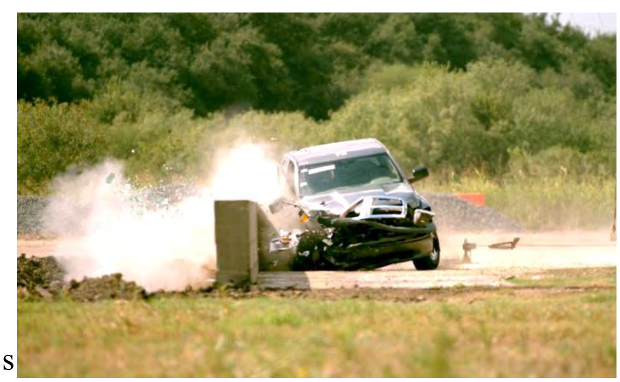


Figure D.1. Sequential Photographs for Test No. 490025-2-3 (Overhead and Frontal Views) (Continued).

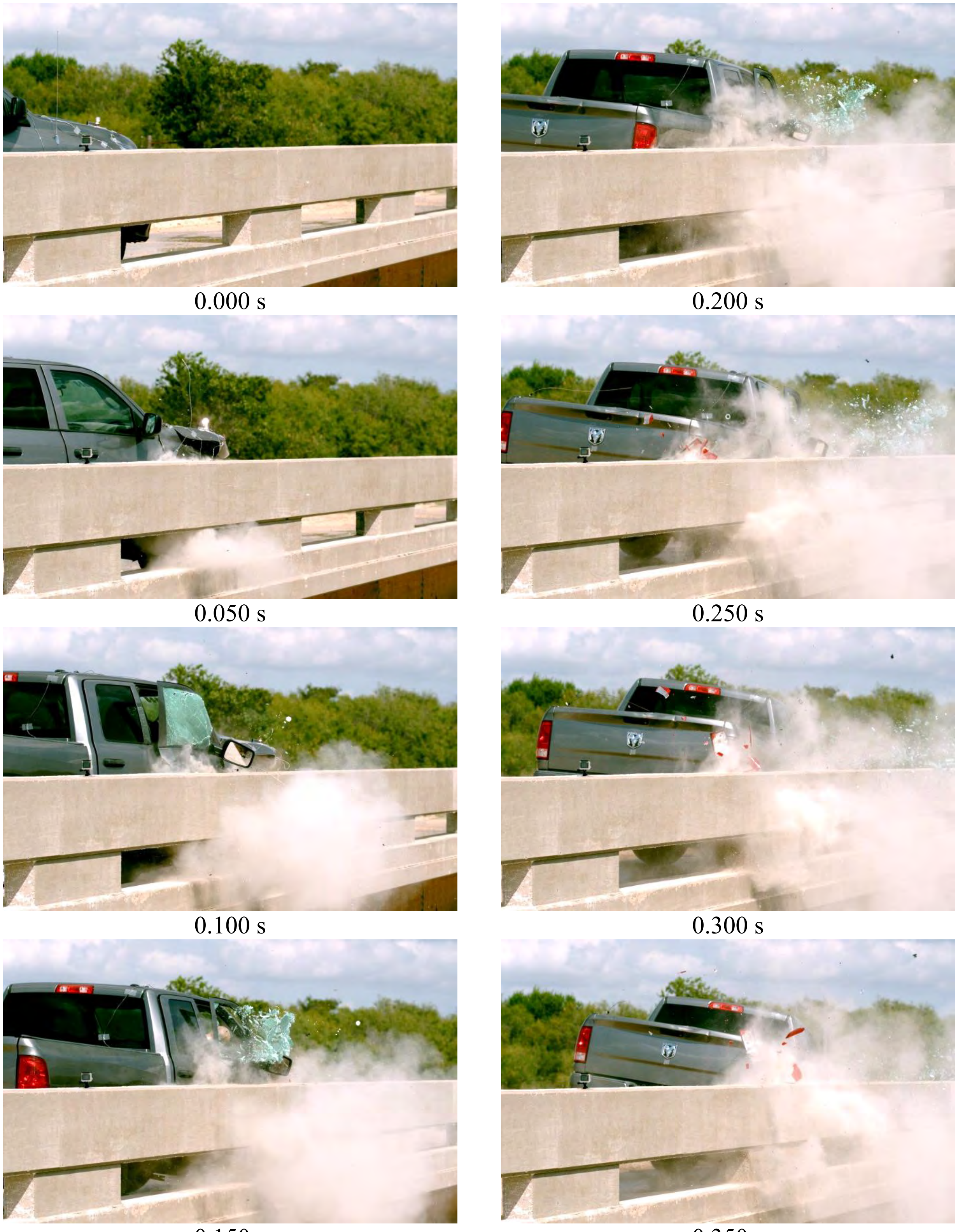


Figure D.2. Sequential Photographs for Test No. 490025-2-3 (Rear View).

D.3 VEHICLE ANGULAR DISPLACEMENT

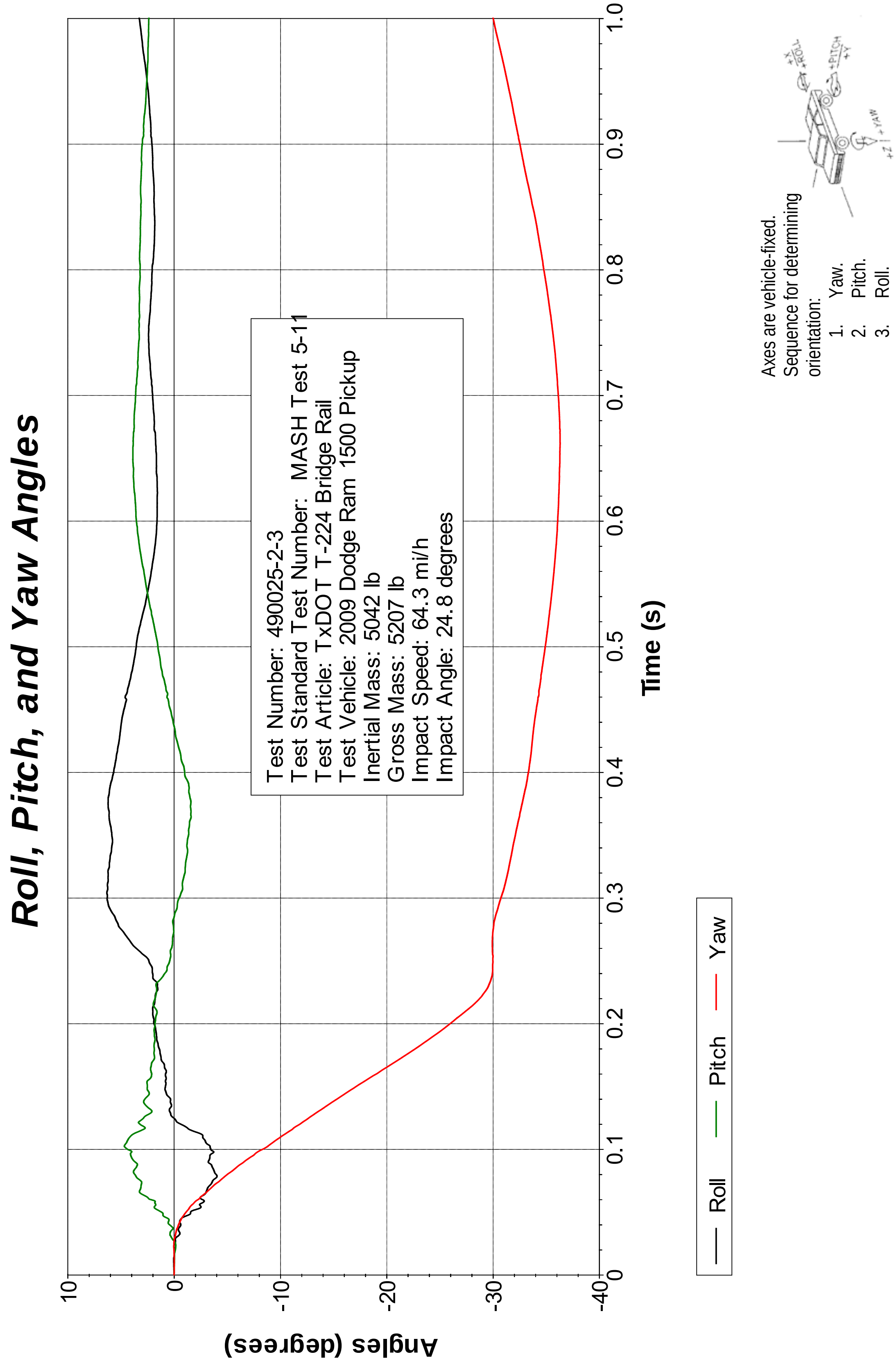


Figure D.3. Vehicle Angular Displacements for Test No. 490025-2-3.

D.4 VEHICLE ACCELERATIONS

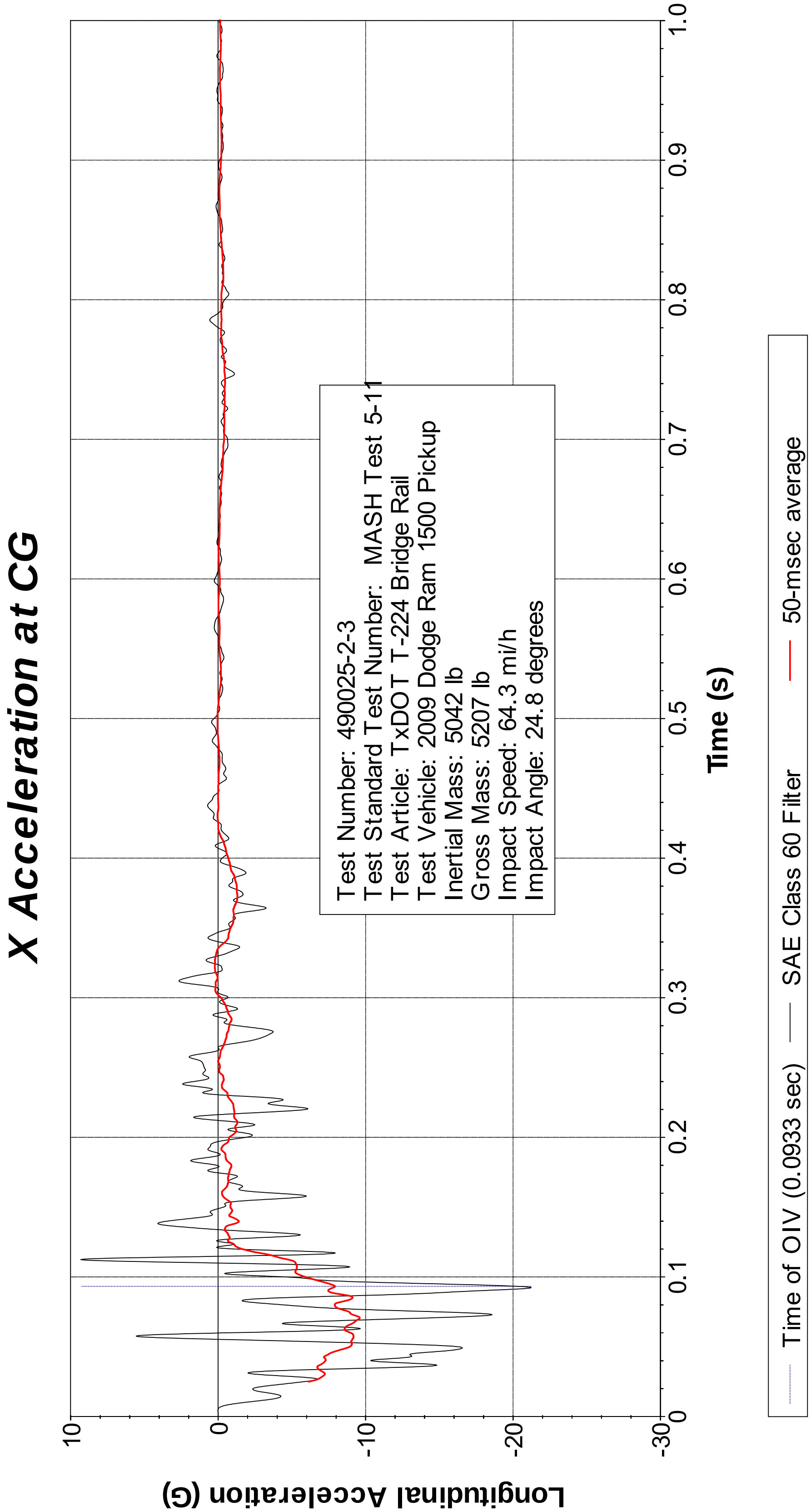


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-2-3 (Accelerometer Located at Center of Gravity).

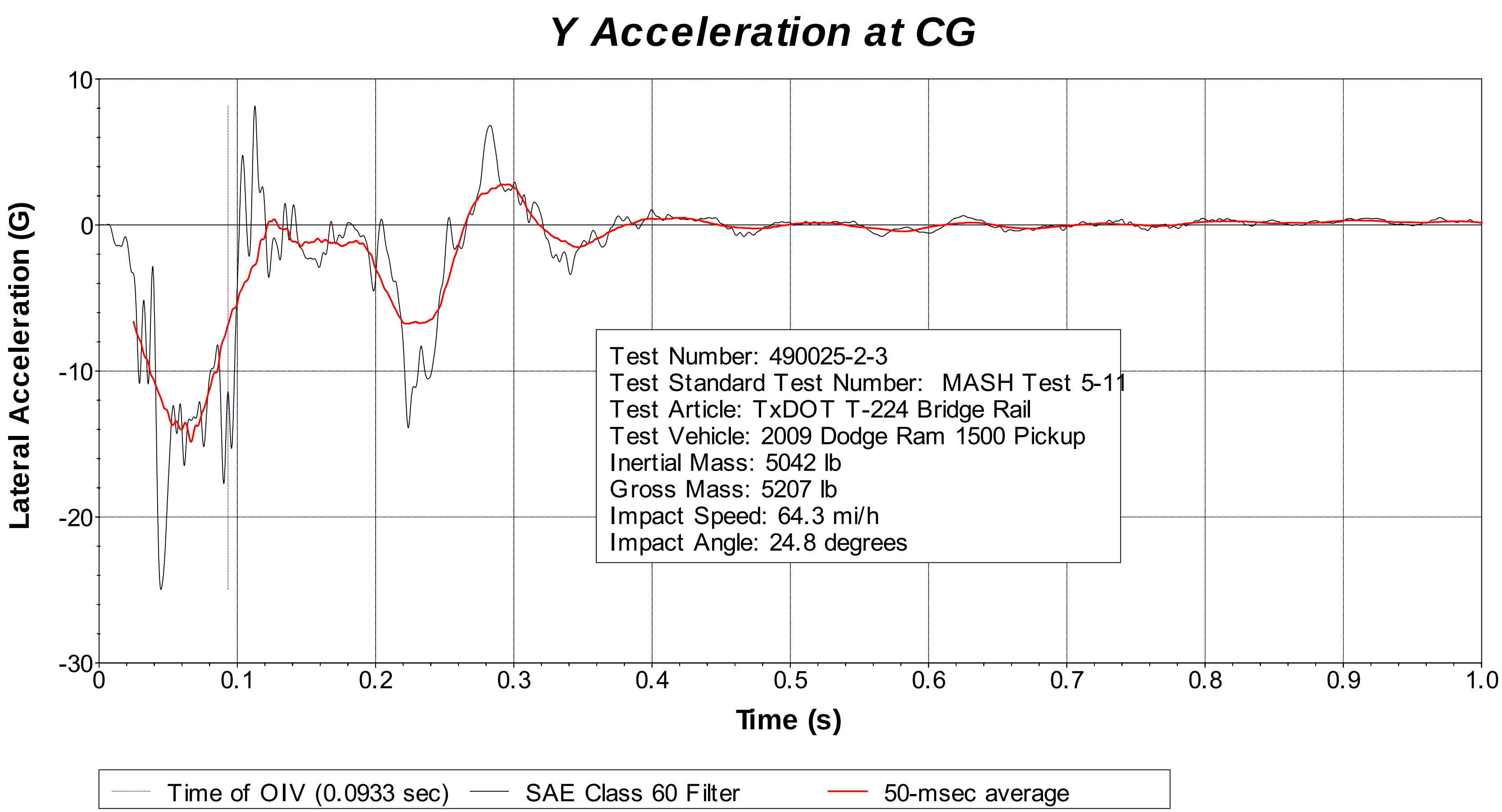


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 490025-2-3 (Accelerometer Located at Center of Gravity).

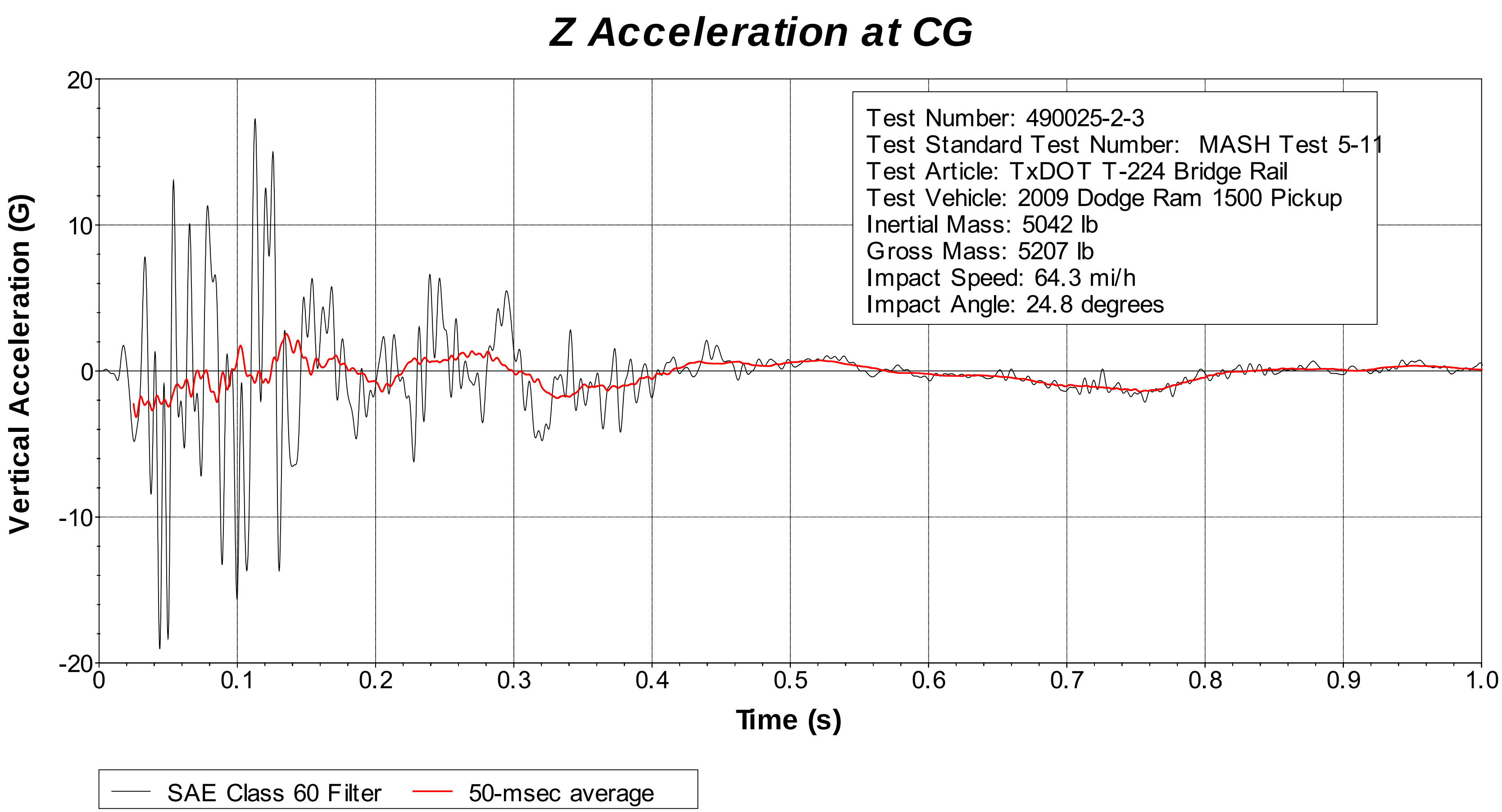


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 490025-2-3 (Accelerometer Located at Center of Gravity).

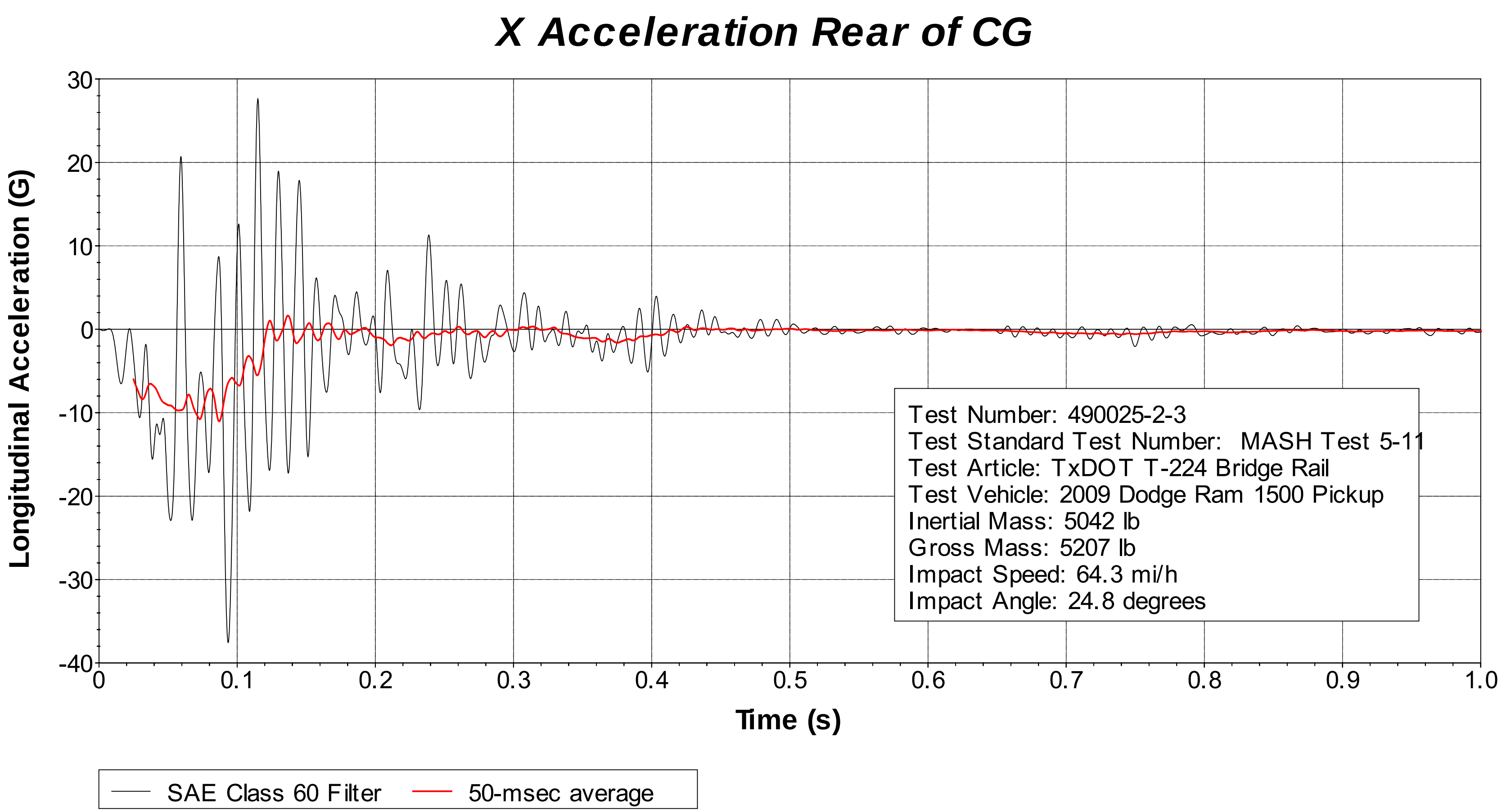


Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-2-3 (Accelerometer Located Rear of Center of Gravity).

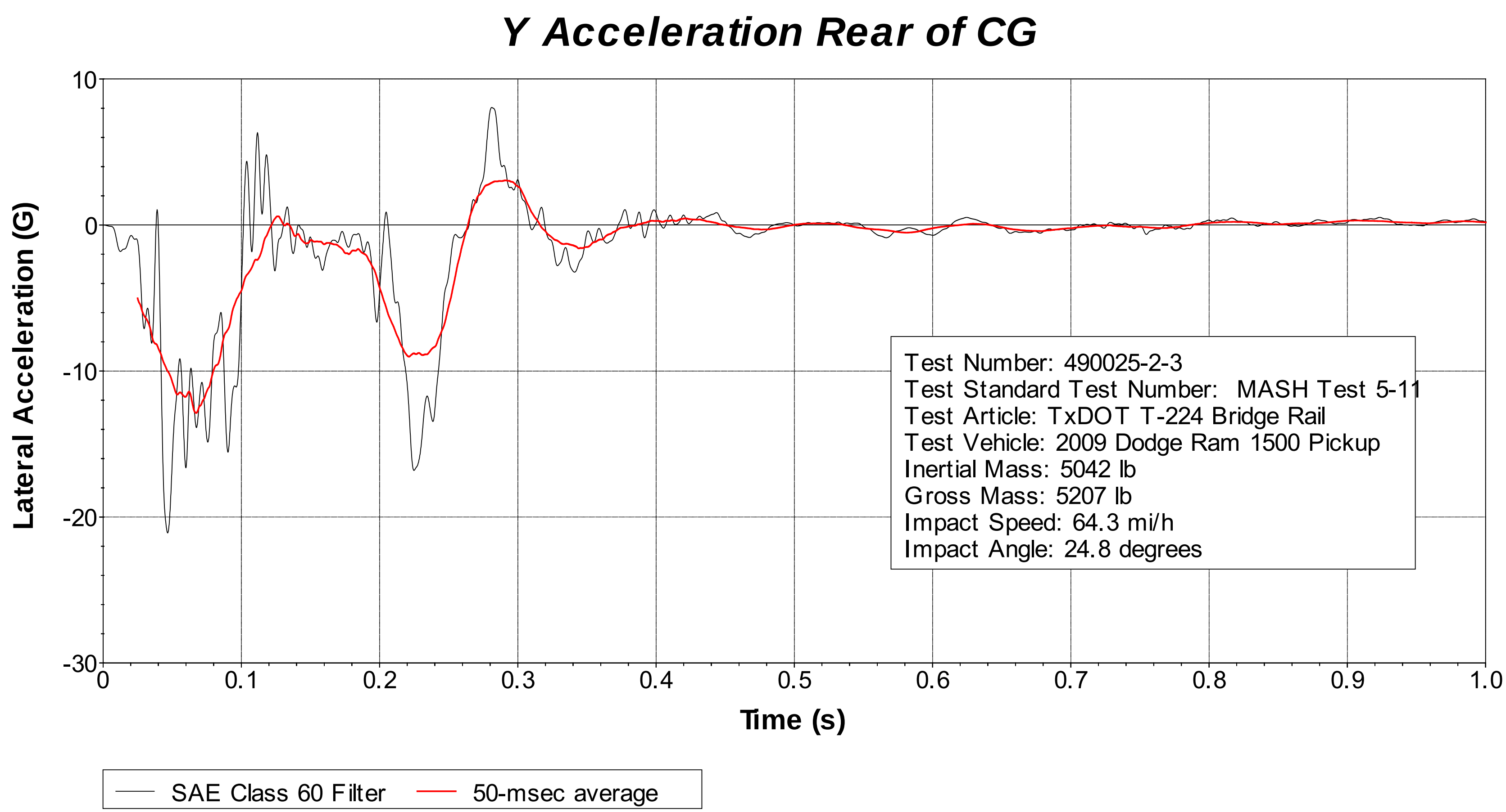


Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 490025-2-3 (Accelerometer Located Rear of Center of Gravity).

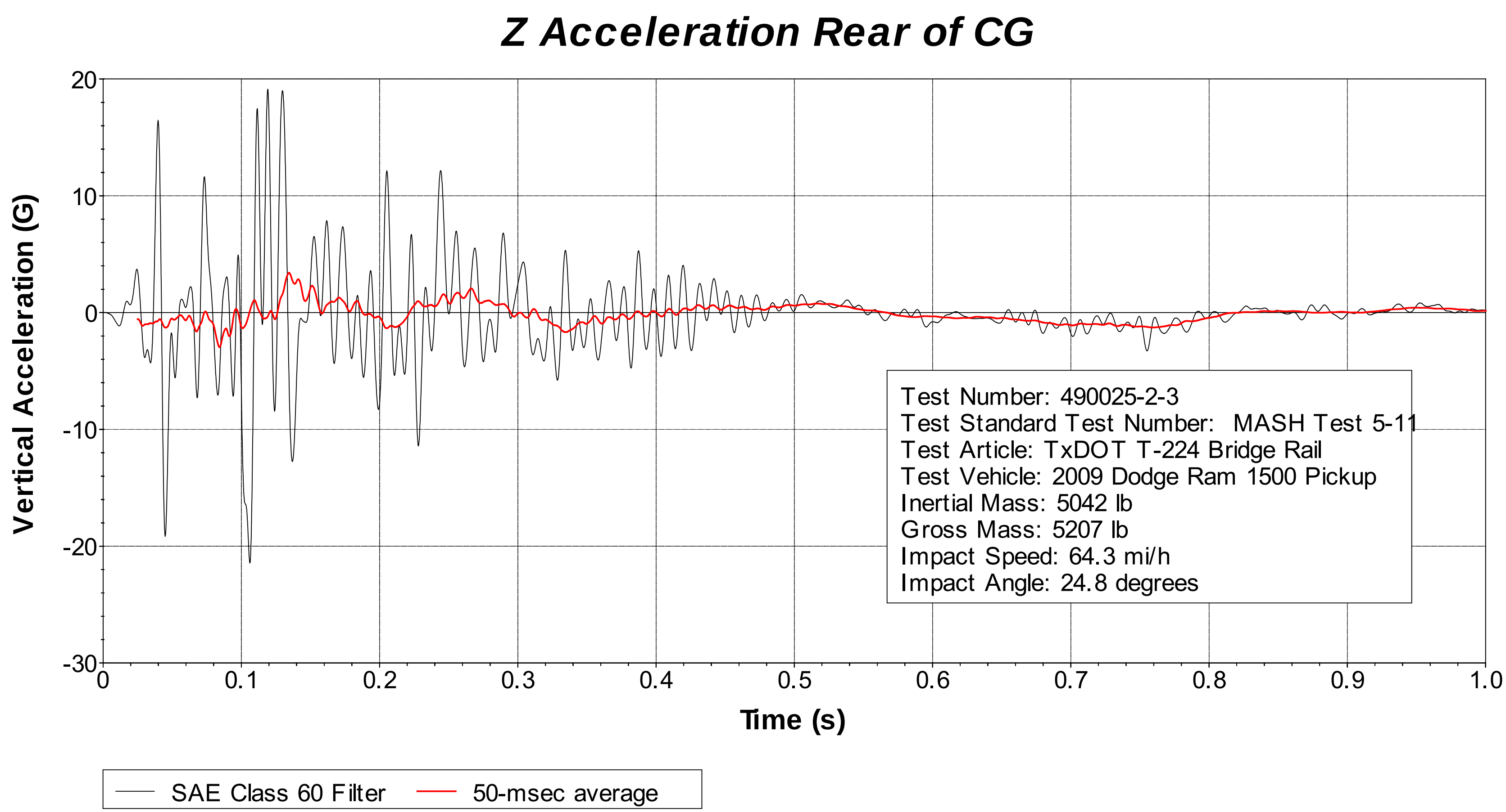


Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 490025-2-3 (Accelerometer Located Rear of Center of Gravity).

APPENDIX E. CRASH TEST NO. 490025-2-1 (*MASH* TEST 5-12)

E.1 VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 490025-2-1.

DATE: 2015-08-21 **TEST NO.:** 490025-2-1

TRACTOR

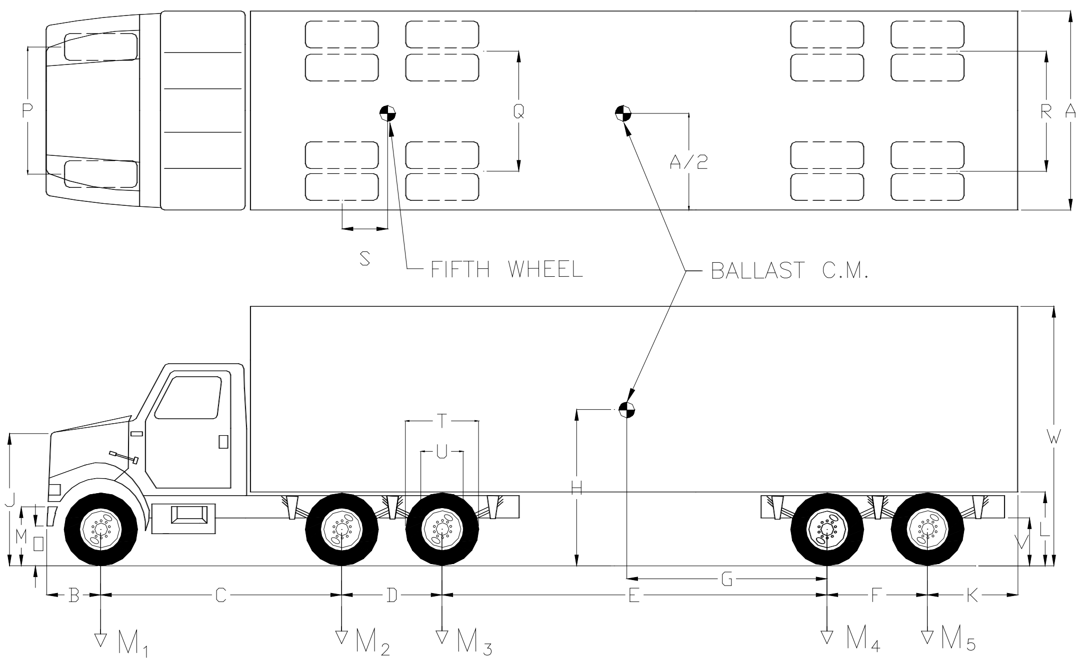
YEAR: 2003 MAKE: Volvo MODEL: VE

VIN No.: 4V4MC9GF43N350511 ODOMETER: 641346

TRAILER

YEAR: 1995 MAKE: Dorsey MODEL: DTV

VIN No.: 1DTV11529SA236630



GEOMETRY (inches)

A	102.25	D	51.50	G	245.00	K	46.00	O	17.75	R	77.50	U	25.00
B	51.50	E	476.00	H	72.00	L	50.38	P	80.00	S	23.00	V	32.00
C	138.00	F	48.00	J	65.25	M	30.00	Q	73.50	T	43.00	W	162.00

MASS (lb)	CURB		TEST INERTIAL	
M_1	8870		10000	
M_2	6070		18370	
M_3	5910		18090	
M_4	4550		16510	
M_5	4840	Allowable Range	16790	Allowable Range
M_{Total}	30240	29,000 ±3100 lb	79760	79,300 ±1100 lb

E.2 SEQUENTIAL PHOTOGRAPHS

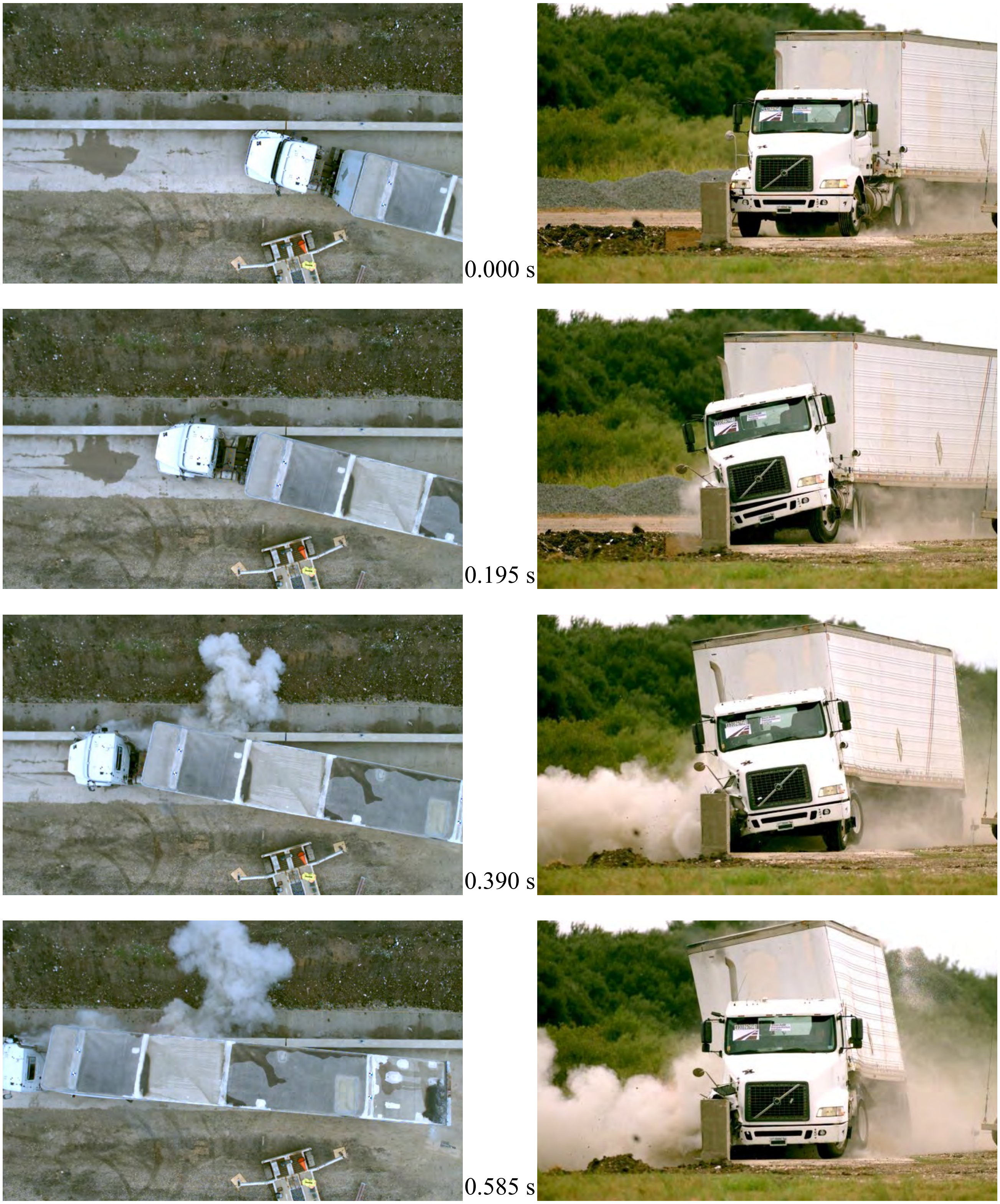


Figure E.1. Sequential Photographs for Test No. 490025-2-1 (Overhead and Frontal Views).

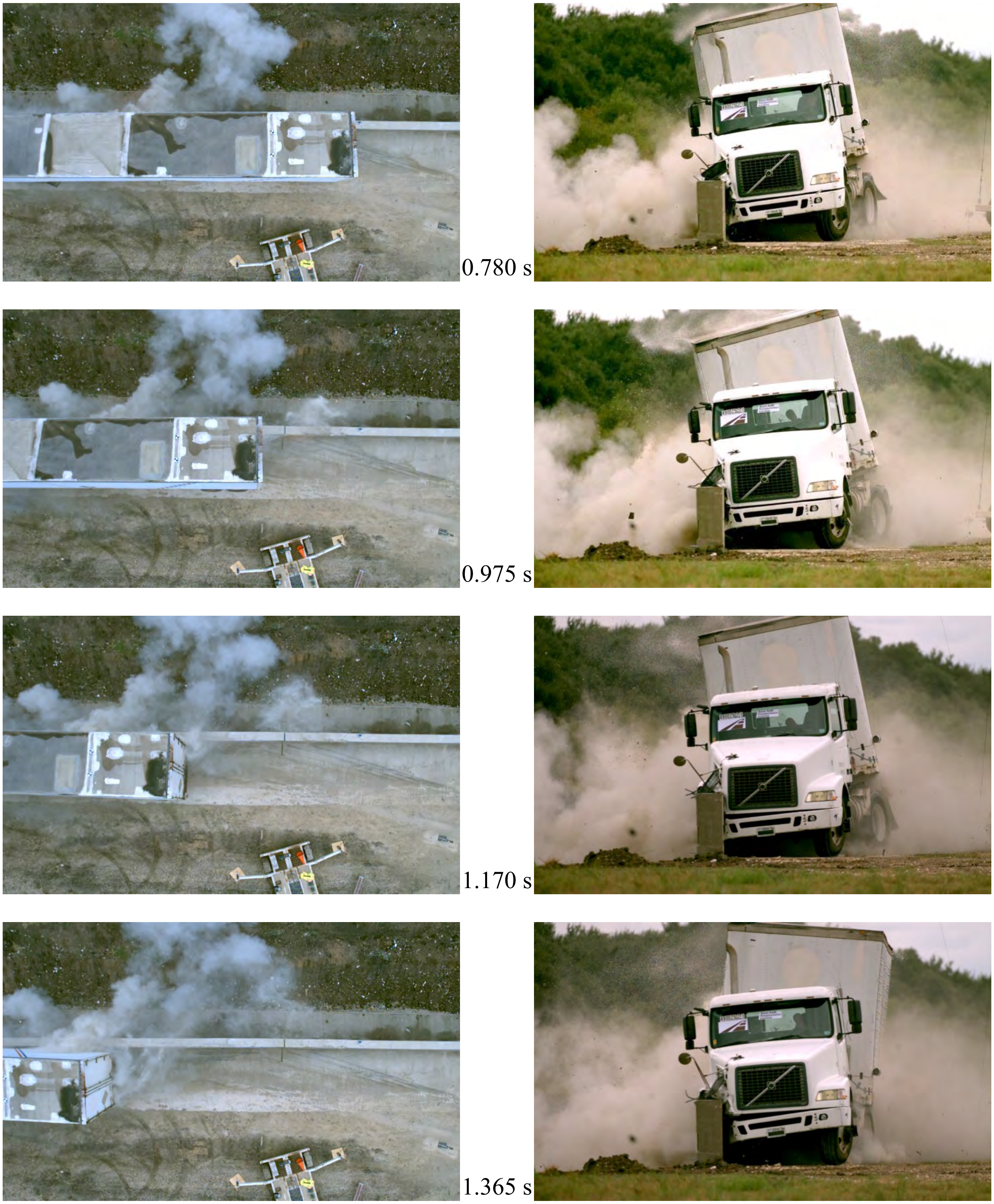


Figure E.1. Sequential Photographs for Test No. 490025-2-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.195 s

0.390 s

0.585 s

0.780 s

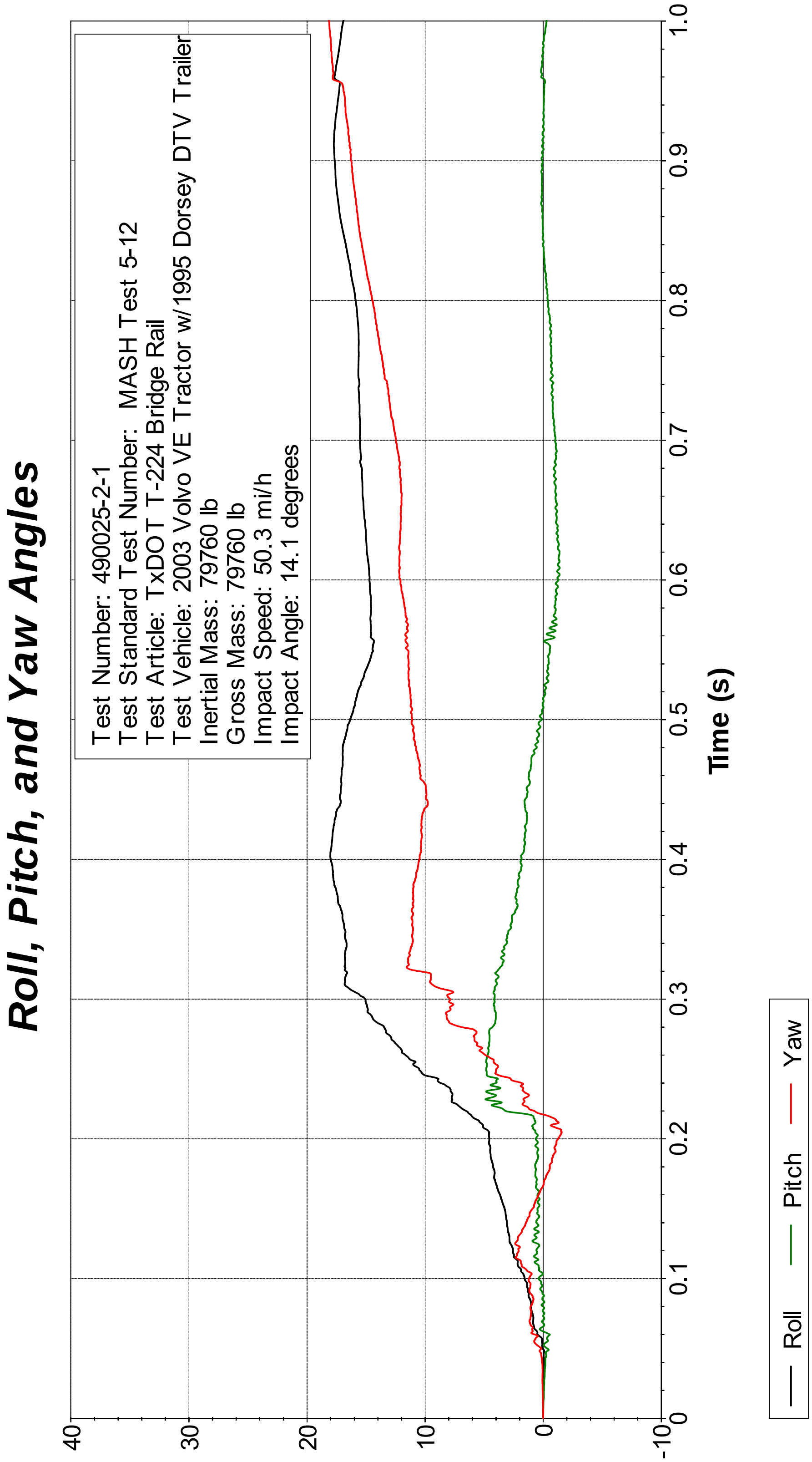
0.975 s

1.170 s

1.365 s

Figure E.2. Sequential Photographs for Test No. 490025-2-1 (Rear View).

E.3 VEHICLE ANGULAR DISPLACEMENT



Axes are vehicle-fixed.
Sequence for determining orientation:

1. Yaw.
2. Pitch.
3. Roll.

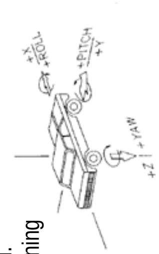


Figure E.3. Vehicle Angular Displacements for Test No. 490025-2-1.

E.4 VEHICLE ACCELERATIONS

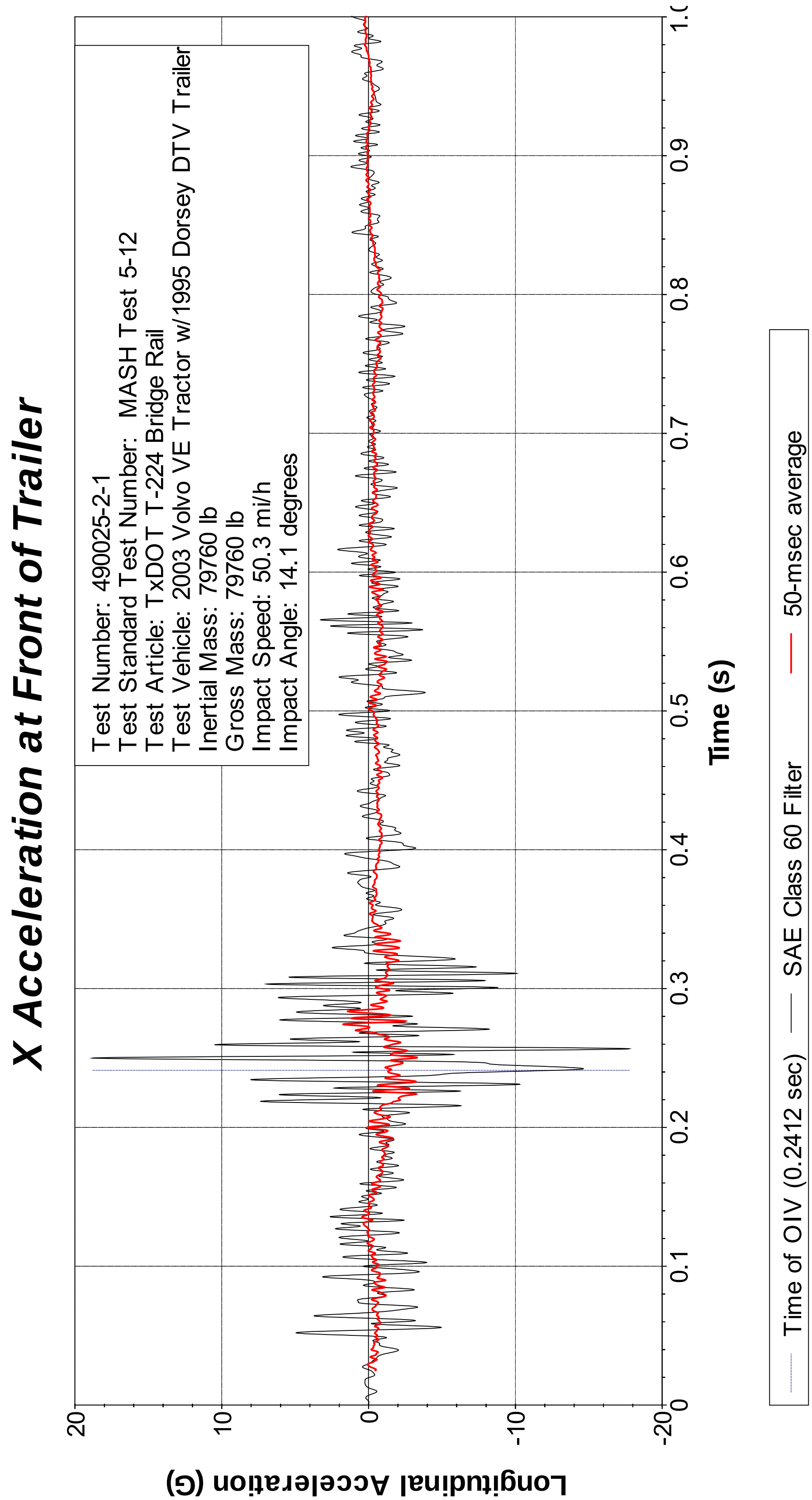


Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-2-1 (Accelerometer Located at Front of Trailer).

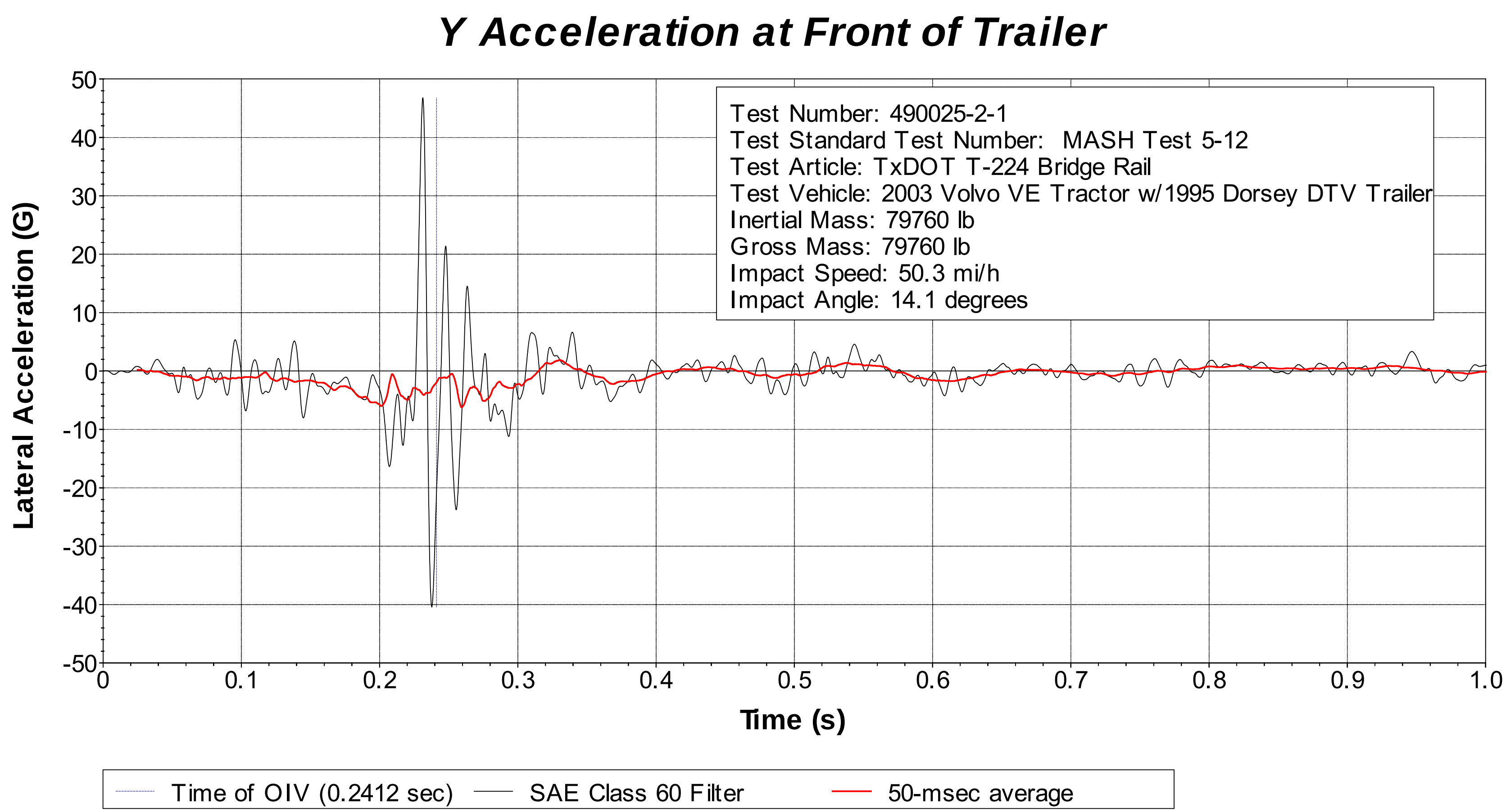


Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 490025-2-1 (Accelerometer Located at Front of Trailer).

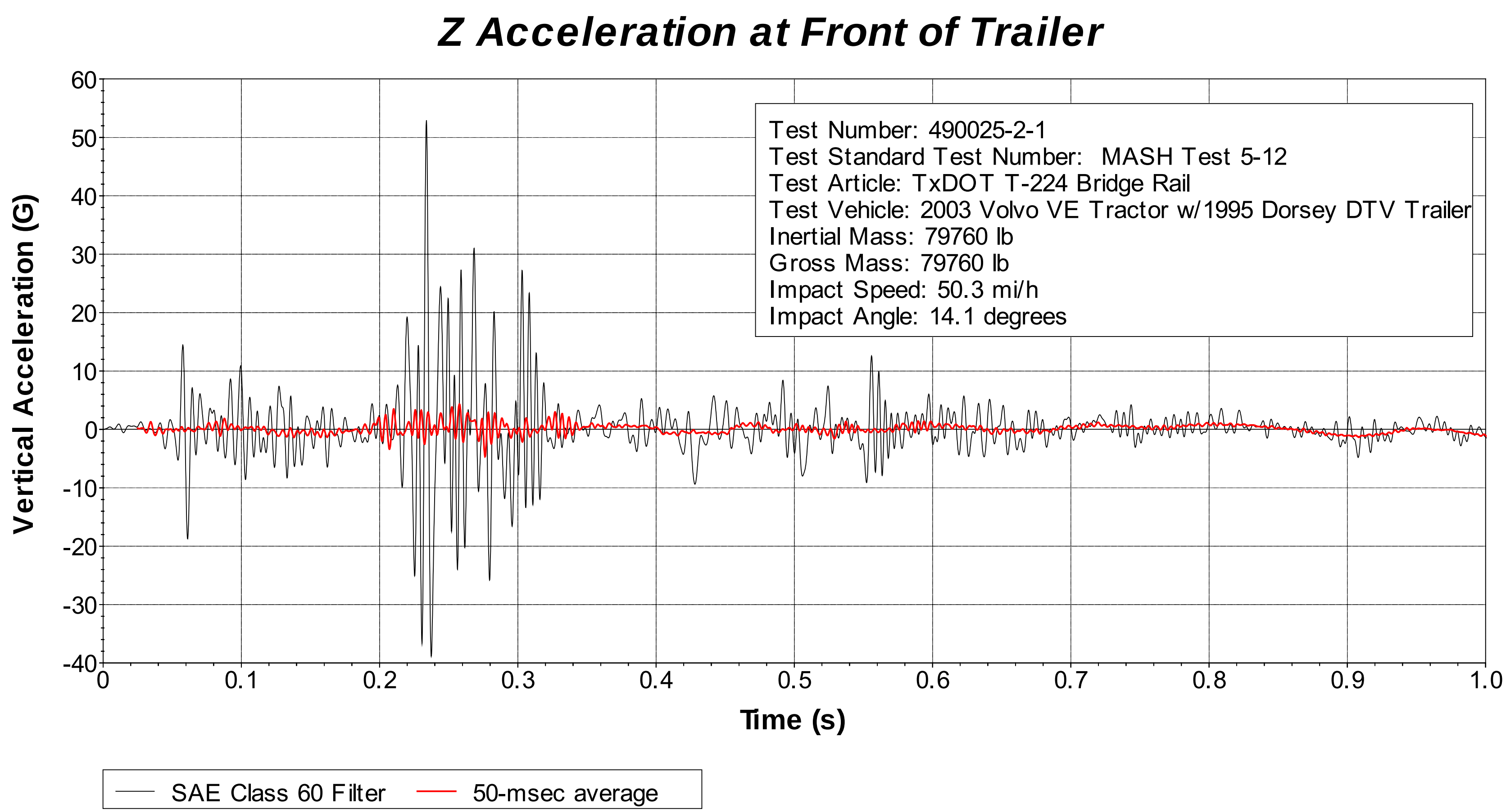


Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 490025-2-1 (Accelerometer Located at Front of Trailer).

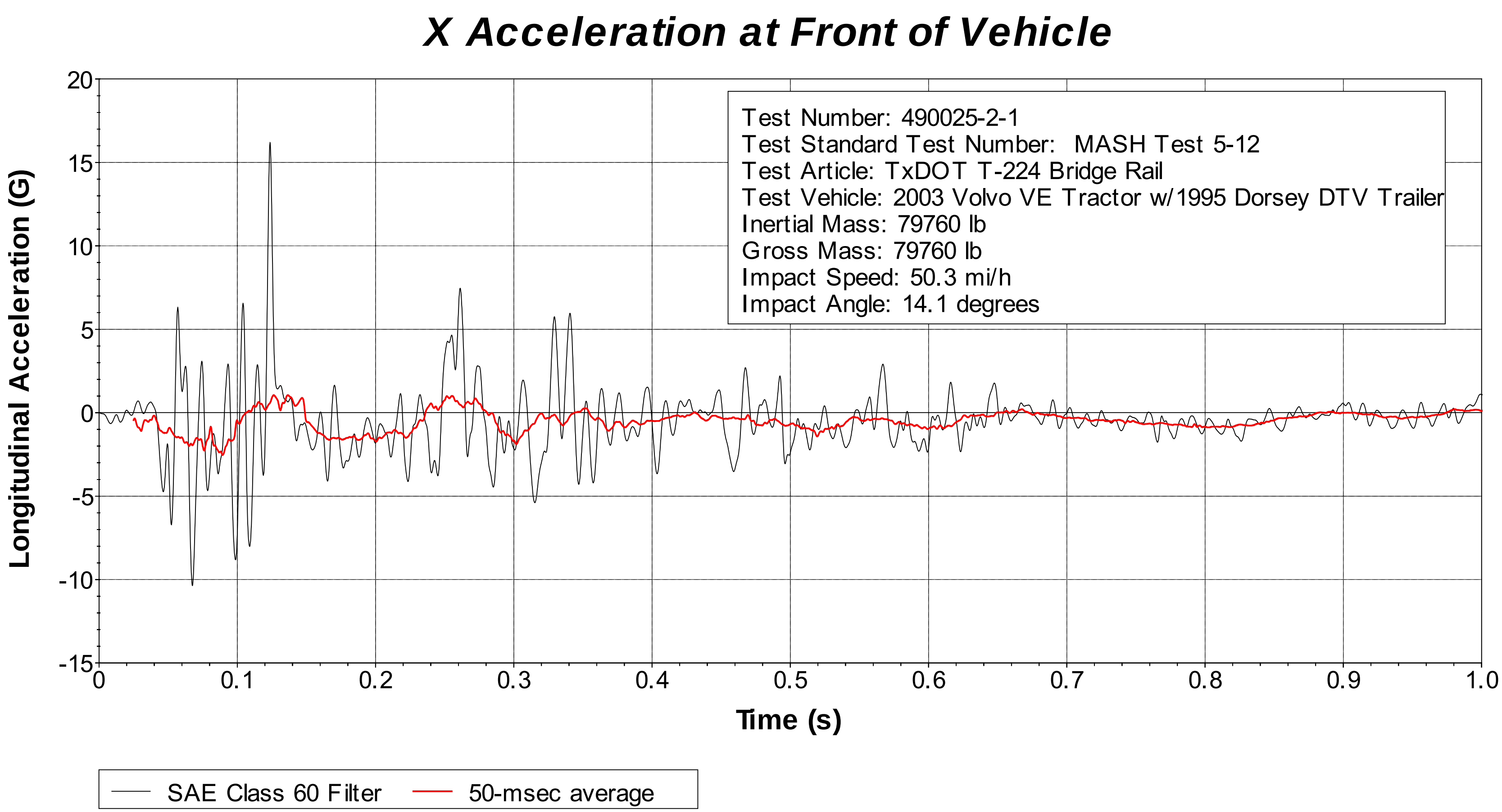


Figure E.7. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-2-1 (Accelerometer Located at Front of Vehicle).

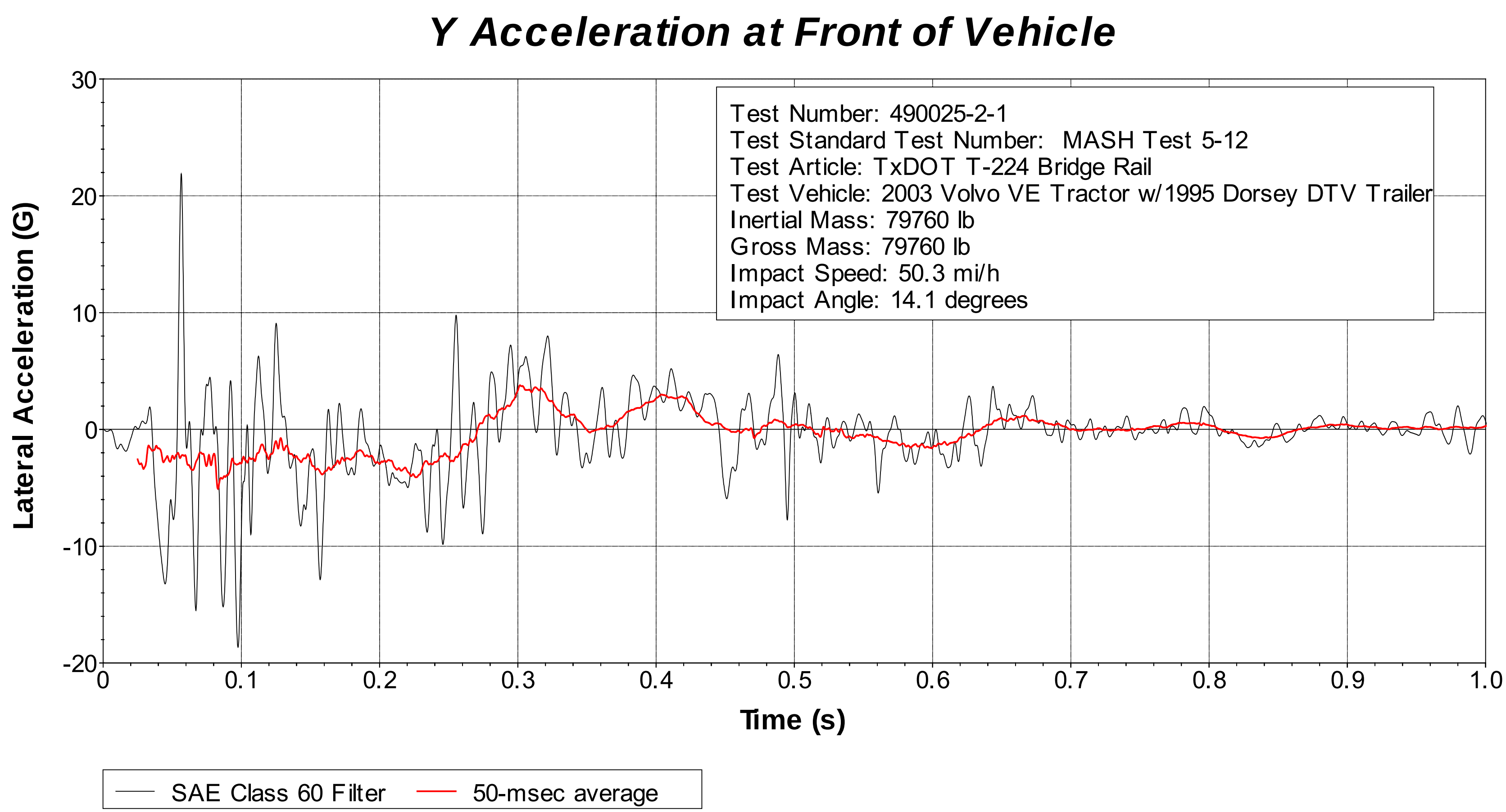


Figure E.8. Vehicle Lateral Accelerometer Trace for Test No. 490025-2-1 (Accelerometer Located at Front of Vehicle).

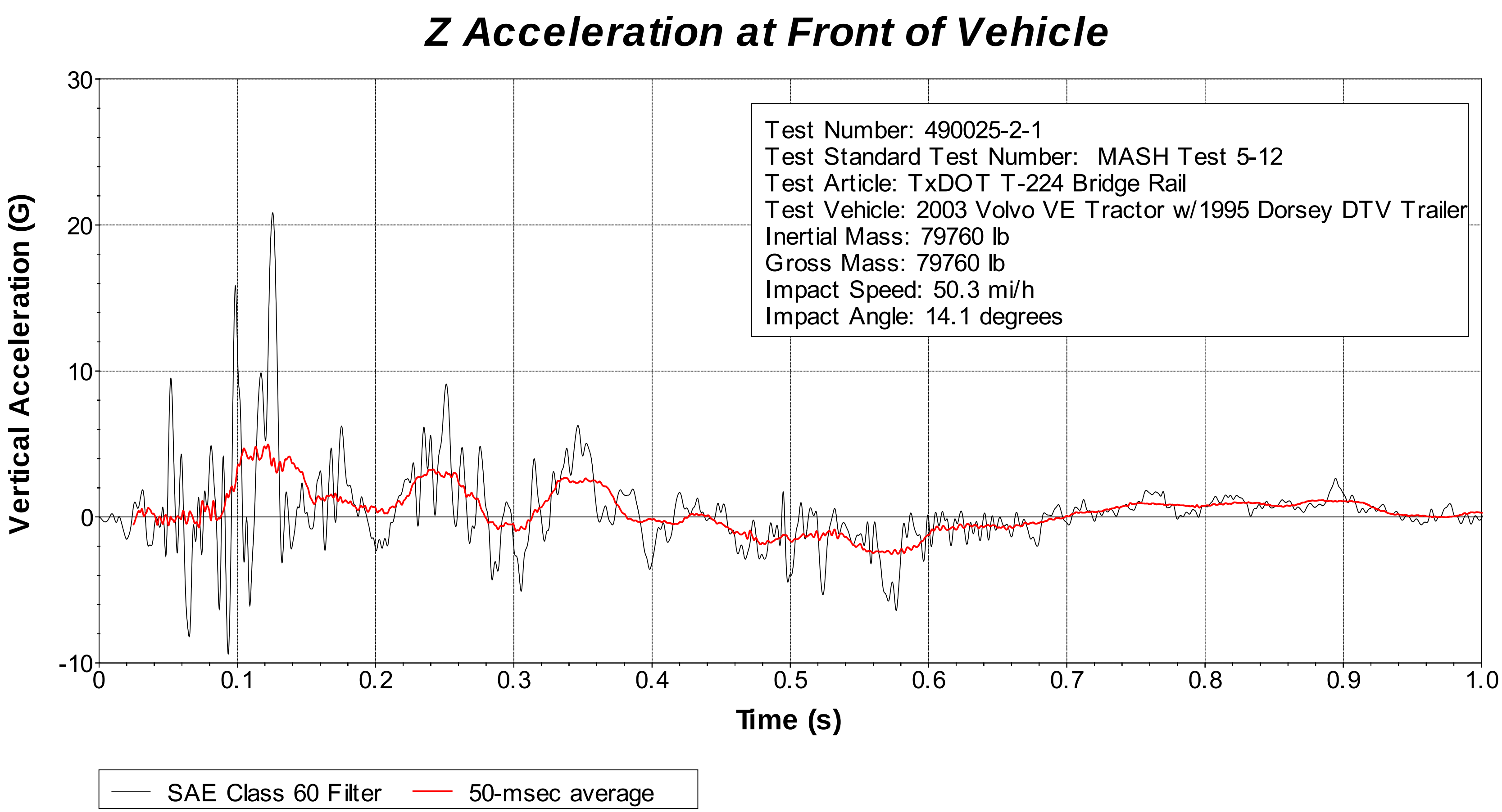


Figure E.9. Vehicle Vertical Accelerometer Trace for Test No. 490025-2-1 (Accelerometer Located at Front of Vehicle).

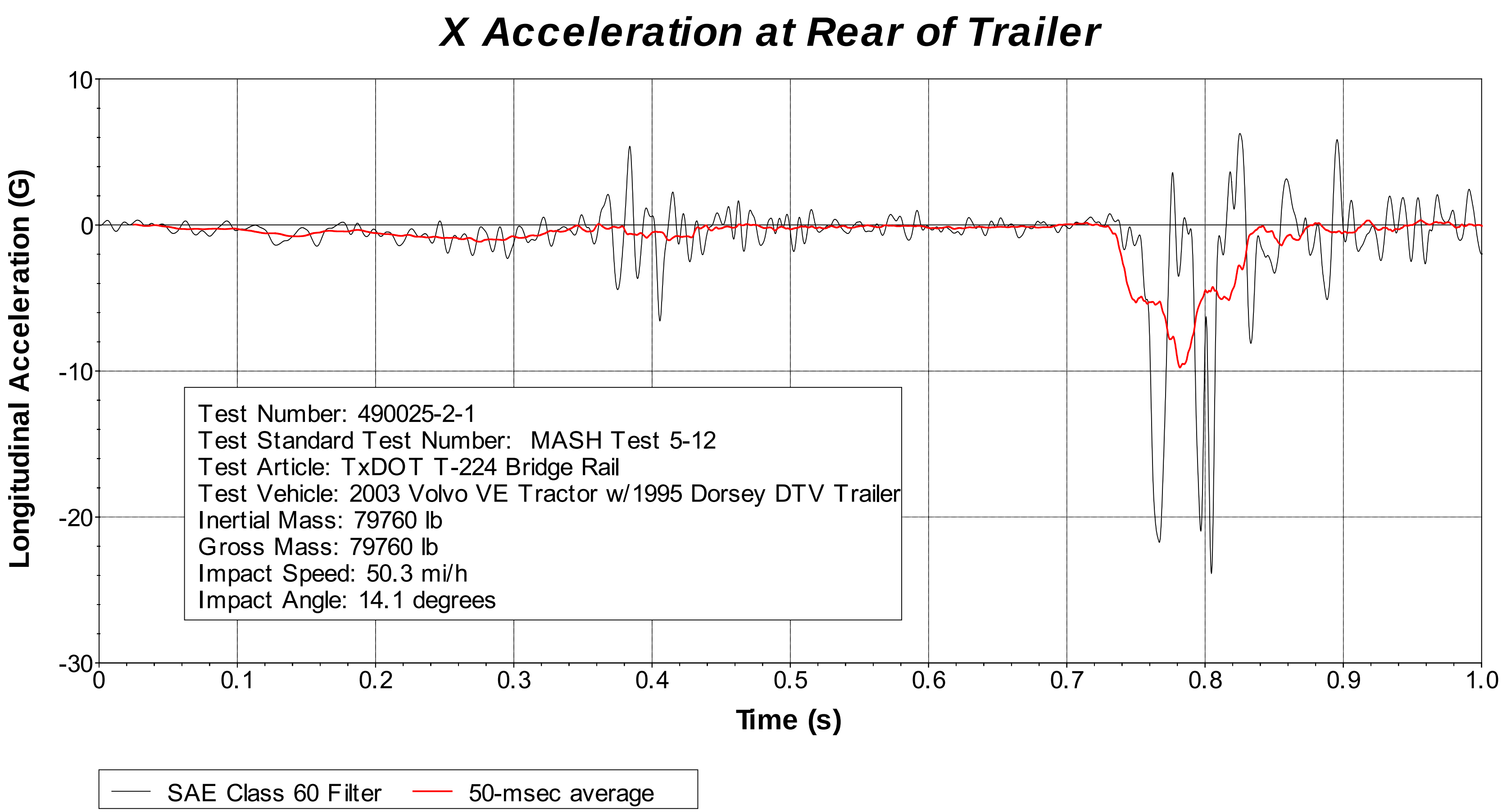


Figure E.10. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-2-1 (Accelerometer Located at Rear of Trailer).

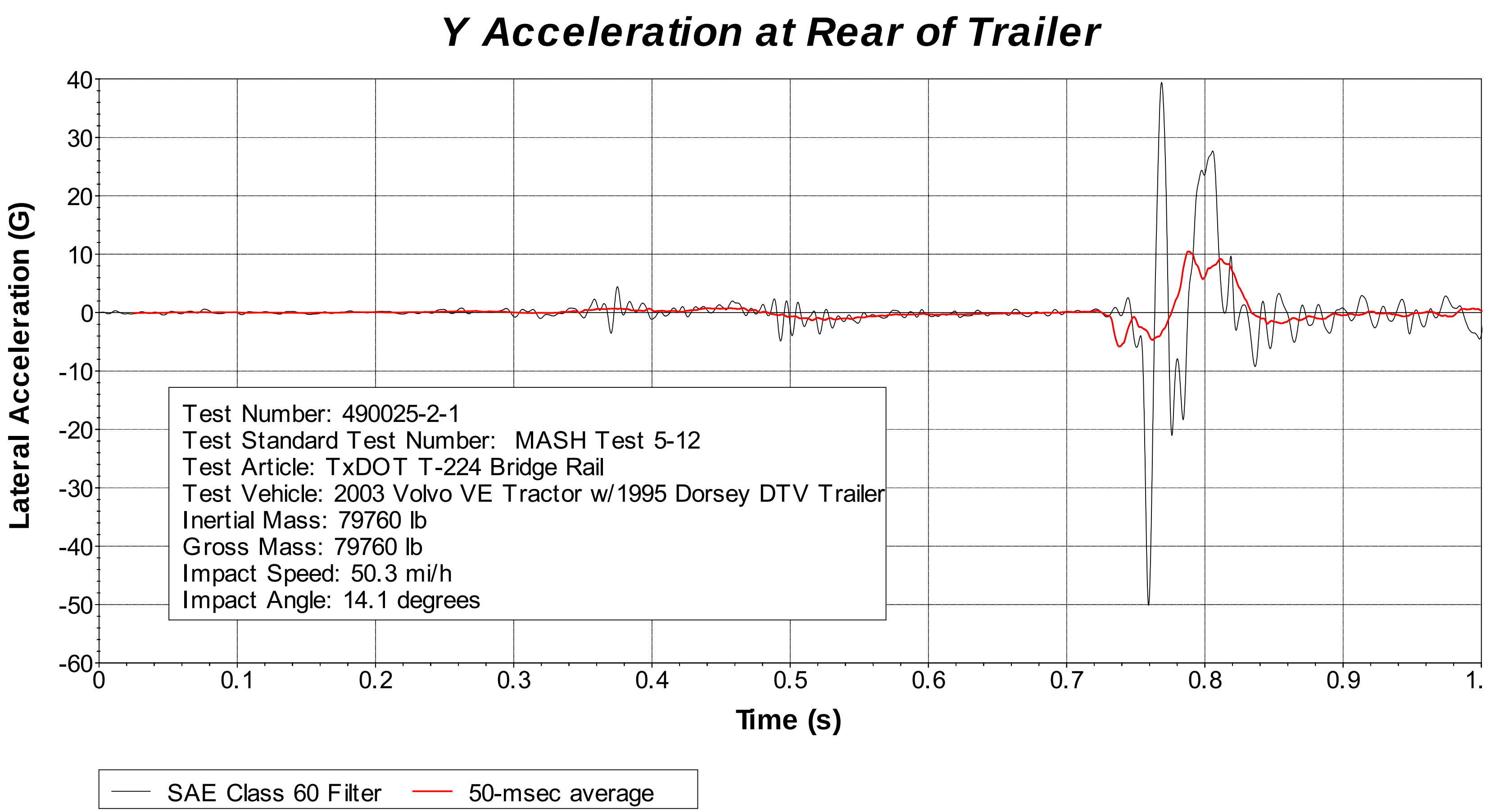


Figure E.11. Vehicle Lateral Accelerometer Trace for Test No. 490025-2-1 (Accelerometer Located at Rear of Trailer).

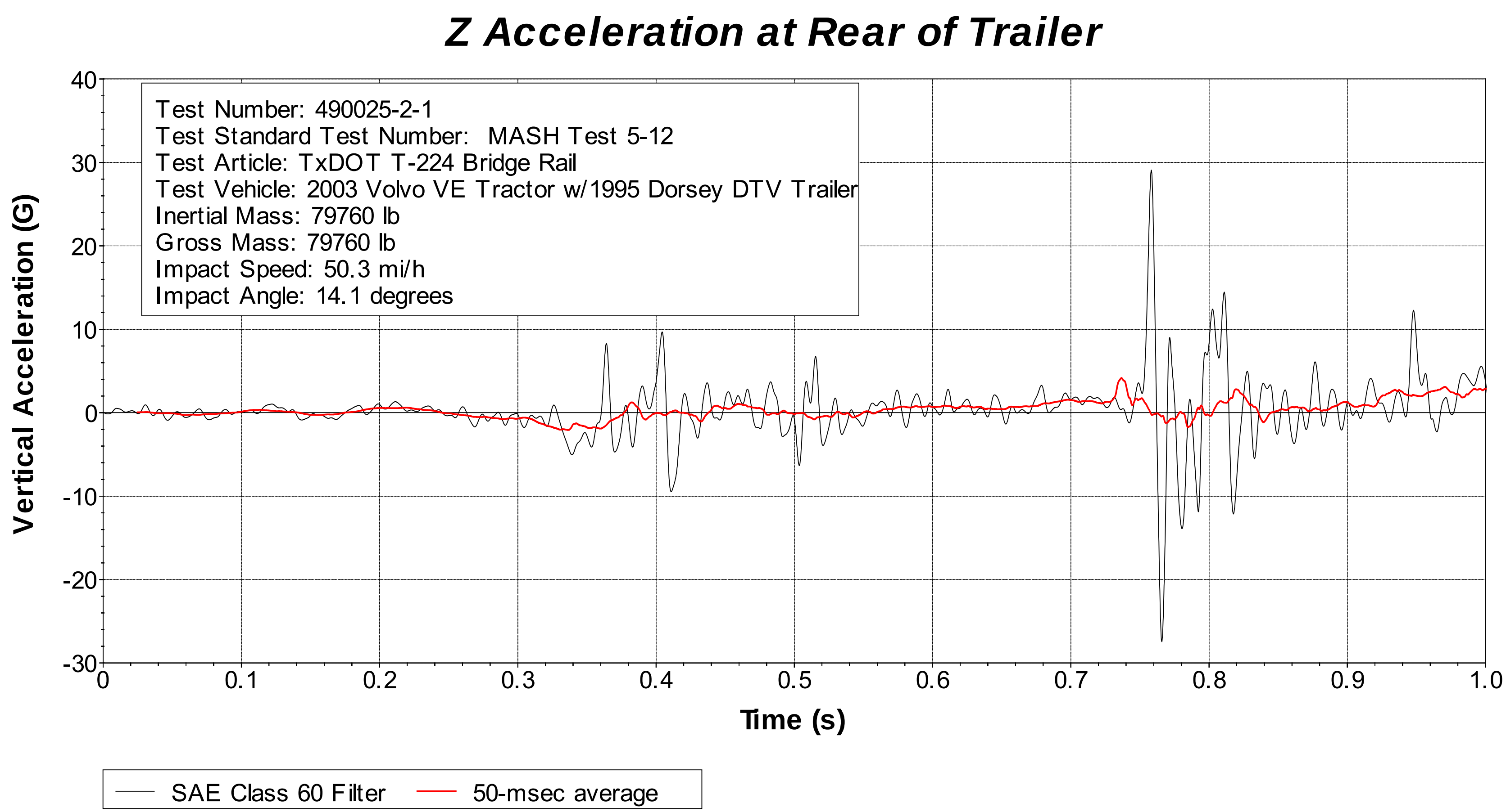


Figure E.12. Vehicle Vertical Accelerometer Trace for Test No. 490025-2-1 (Accelerometer Located at Rear of Trailer).