Test Report No. 608551-01-1-5
Test Report Date: April 2019

MASH TL-3 EVALUATION OF 31-INCH W-BEAM GUARDRAIL WITH WOOD AND STEEL POSTS IN CONCRETE MOW STRIP

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Contract No.: T4541-CS
Test Nos.: 608551-1 / 2 / 3 / 4 / 5
Test Dates: 2017-11-15 / 11-27 / 10-09 / 10-27 / 2019-01-18

Sponsored by
Roadside Safety Research Program Pooled Fund
Study No. TPF-5(114)

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle *MASH* TL-3 EVALUATION OF 31-INCH W-BEAM GUARDRAIL WITH WOOD AND STEEL POSTS IN CONCRETE MOW STRIP		5. Report Date April 2019 6. Performing Organization Code
7. Author(s) Nauman M. Sheikh, Wanda L. Menges, and Darrell L. Kuhn		8. Performing Organization Report No. Test Report No. 608551-1-4
9. Performing Organization Name and Address Texas A&M Transportation Institute Proving Ground 3135 TAMU College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. T4541-CS
12. Sponsoring Agency Name and Address Washington State Department of Transportation Transportation Building, MS 47372 Olympia, Washington, 98504-7372		13. Type of Report and Period Covered Technical Report: March 2017 – April 2019 14. Sponsoring Agency Code

15. Supplementary Notes
Project Title: 31" W-Beam Guardrail with Steel and Wood Posts in Concrete Mow Strip
Name of Contracting Technical Representative: Michael Elle, P.E., Minnesota Department of Transportation

16. Abstract

The objective of the tests performed in this project was to evaluate the performance of a 31-inch tall W-beam guardrail system installed in a concrete mow-strip that reduces maintenance of the guardrail system by preventing growth of vegetation around the posts. Both wood post and steel post W-beam guardrail systems were evaluated. The tests were performed in accordance with the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*). *MASH* Tests 3-10 and 3-11 were performed for both wood and steel guardrail systems.

The 31-inch W-beam guardrail system with wood posts in concrete mow strip performed acceptably for *MASH* Test 3-10. However, during *MASH* Test 3-11, the W-beam rail element ruptured, allowing the 2270P vehicle to penetrate the installation. Consequently, the wood post W-beam guardrail system in concrete mow strip did not perform acceptably for *MASH* TL-3 evaluation criteria for longitudinal barriers.

Subsequently, TTI researchers performed another *MASH* Test 3-11 on the wood post guardrail system with the posts at a reduced embedment depth of 36 inches. After loss of contact with the guardrail, the 2270P vehicle rolled and, therefore, did not perform acceptably for *MASH* TL-3.

The 31-inch W-beam guardrail system with steel posts in concrete mow strip performed acceptably for both *MASH* Tests 3-10 and 3-11. The steel post W-beam guardrail system in concrete mow strip is considered to have acceptable performance in accordance with the criteria for *MASH* TL-3 longitudinal barriers.

17. Key Words Longitudinal barriers, guardrail, W-beam, steel post, wood post, mow strip, roadside maintenance, roadside safety, crash testing		18. Distribution Statement Copyrighted. Not to be copied or reprinted without consent from the Roadside Safety Pooled Fund Program.	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 184	22. Price

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

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ACKNOWLEDGMENTS

This research project was performed under a pooled fund program between the following States and Agencies. The authors acknowledge and appreciate their guidance and assistance.

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Chapter 1. INTRODUCTION

1.1 PROBLEM STATEMENT

The Roadside Safety Pooled Fund expressed a desire to have an option to install an American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) compliant, 31-inch tall, W-beam guardrail system, with either wood or steel posts, in a concrete mow strip, which reduces maintenance of the guardrail systems by preventing growth of vegetation around the guardrail posts (*1*).

1.2 BACKGROUND

In 2004, Texas A&M Transportation Institute (TTI) designed and crash tested a 27-inch tall W-beam guardrail system that was installed in concrete mow-strip (*2*). The mow strip had leave-outs at the locations of guardrail posts. The leave-outs were back filled with low-strength grout after the posts were installed. This prevented growth of vegetation around the posts, and the low-strength grout did not hinder the deflection of the guardrail posts when impacted by a vehicle. This system was designed and crash tested under National Cooperative Highway Research Program (NCHRP) *Report 350* criteria with both round wood and steel posts (*3*). Since then, W-beam guardrail height has been increased to 31 inches, and the new *MASH* testing criteria has become a required standard for roadway safety hardware evaluation.

1.3 WORK PLAN

The objective of this research was to test a 31-inch tall W-beam guardrail system in concrete mow-strip. Both steel and wood post options were evaluated. The tests were performed using the *MASH* Test Level 3 (TL-3) criteria.

The work plan for this research was comprised of four full-scale crash tests, two for each guardrail post type (steel and wood). The following five crash tests were actually performed for the guardrail installed in leave-outs within a reinforced concrete mow strip and back filled with low-strength grout.

1. *MASH* Test 3-10 of the 31-inch tall wood post W-beam guardrail system. This test involved the *MASH* 1100C small passenger car impacting the guardrail at 62 mi/h and 25°.
2. *MASH* Test 3-11 of the 31-inch tall wood post W-beam guardrail system. This test involved the *MASH* 2270P pickup truck impacting the guardrail at 62 mi/h and 25°.
3. *MASH* Test 3-10 of the 31-inch tall steel post W-beam guardrail system. This test involved the *MASH* 1100C small passenger car impacting the guardrail at 62 mi/h and 25°.
4. *MASH* Test 3-11 of the 31-inch tall steel post W-beam guardrail system. This test involved the *MASH* 2270P pickup truck impacting the guardrail at 62 mi/h and 25°.

5 *MASH* Test 3-11 of the 31-inch tall wood post W-beam guardrail system with reduced post embedment of 36 inches. This test involved the *MASH* 2270P pickup truck impacting the guardrail at 62 mi/h and 25°.

This report provides details of the guardrail systems, detailed documentation of the crash tests, the crash test results, and an assessment of the performance of the guardrails in the concrete mow strip according to *MASH* TL-3 evaluation criteria.

Chapter 2. TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 CRASH TEST PERFORMED / MATRIX

Table 2.1 shows the test conditions and evaluation criteria for *MASH* Test Level 3 (TL-3) for longitudinal barriers. The critical impact point (CIP) for each test was determined using the information provided in *MASH* Section 2.3.2 and *MASH* Figure 2-1, and these are provided under the section Test Designation and Actual Test Conditions for each test. The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 3 presents brief descriptions of these procedures.

Table 2.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Longitudinal Barriers.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	3-10	1100C	62 mi/h	25°	A, D, F, H, I
	3-11	2270P	62 mi/h	25°	A, D, F, H, I

2.2 EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2A and 5-1A through 5-1C of *MASH* were used to evaluate the crash tests reported herein. The test conditions and evaluation criteria required for *MASH* TL-3 are listed in Table 2.1, and the substance of the evaluation criteria in Table 2.2. An evaluation of each crash test is presented in detail under the section Assessment of Test Results.

Table 2.2. Evaluation Criteria Required for *MASH* TL-3 Longitudinal Barriers.

Evaluation Factors	Evaluation Criteria
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.*
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 undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.
	H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.
	I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.

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Chapter 3. TEST CONDITIONS

3.1 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)/International Electrotechnical Commission (IEC) 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 the *MASH* guidelines and standards.

The test facilities of the TTI Proving Ground are located on the Texas A&M University RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 miles northwest of the flagship 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 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 and perimeter protective devices. The site selected for construction and testing of the guardrail in mow strip was along the edge of an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement, but are otherwise flat and level.

3.2 VEHICLE TOW AND GUIDANCE SYSTEM

Each test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2:1 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 was moving unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site (no sooner than 2 s after impact), after which the brakes were activated, if needed, to bring the test vehicle to a safe and controlled stop.

3.3 DATA ACQUISITION SYSTEMS

3.3.1 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 produced by Diversified Technical Systems, Inc. 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 as well as 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 and all instrumentation used in the vehicle conforms to all specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO® 2901, precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the data acquisition system receive a calibration via a Genisco Rate-of-Turn table. 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 is 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 low-pass 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).

3.3.2 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 vehicles. The dummy was not instrumented.

According to *MASH*, use of a dummy in the 2270P vehicle is optional, and no dummy was used in the tests with the 2270P vehicles.

3.3.3 Photographic Instrumentation Data Processing

Photographic coverage of each test included three digital 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 guardrail installation. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

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Chapter 4. 31-INCH W-BEAM GUARDRAIL SYSTEM ON WOOD POSTS IN CONCRETE MOW STRIP

4.1 SYSTEM DETAILS

4.1.1 Test Article and Installation Details

The test installation consisted of a 31-inch tall W-beam guardrail with timber posts (posts 3 through 28) installed in compacted base (see Section 4.1.3), with a Texas Department of Transportation (TxDOT) downstream anchor terminal (DAT) [GF (31) DAT-14] on each end, for a total installation length of 181 ft-3 inches. Timber blockouts for wood posts (PDB-01a) were installed on posts 3 through 28 using 18-inch long guardrail bolts and recessed guardrail nuts (FBB04).

Standard 12-gauge W-beam guardrail (type RWM04a) was used in the system. The top of the W-beam was 31 inches above grade, and the guardrail splices were located mid-span between every other post. Posts were equally spaced at 6 ft-3 inches.

Guardrail posts 3 through 28 were 6-ft timber guardrail line posts (PDE02). These 26 posts were installed 40 inches deep in drilled holes that were backfilled and compacted with soil meeting Grading B of AASHTO standard specification M147-65(2004) "*Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses*".

From post 8 through post 23, a TxDOT Class D (2000 psi) concrete mow strip measuring 100-ft long × 42-inches wide × 4-inches thick, reinforced with WWF W3×W3 mesh, was installed. A 19-inch square 'leave-out' was located at each post. The leave-outs were located 8 inches from the traffic side edge of the mow strip. The posts were installed in the 'leave-outs' with a 7-inch distance between the edge of the concrete mow-strip 'leave-out' and the back face of the post. After the posts and mow strip were installed, the 4-inch deep 'leave-outs' were filled with low-strength grout.

Each TxDOT GF (31) DAT-14 terminal was 9 ft-4½ inches long as measured from their anchor posts to the W-beam splice between posts 2 and 3 and posts 28 and 29, respectively.

Figure 4.1 presents overall information on the 31-inch W-beam guardrail with wood posts in concrete mow strip, and Figure 4.2 provides photographs of the installation. Appendix A1 provides further details of the installation.

4.1.2 Material Specifications

Appendix B provides material certification documents for the materials used to install/construct the wood post guardrail system installation in concrete mow strip.

The specified concrete strength for the mow strip was 3000 psi. Concrete strength for the first test (Test No. 608551-3 performed 2017-10-09) at 17 days of age was 3040 psi.

The low-strength grout mix used in the leave-outs was comprised of 1-part Type 1A cement, 14 parts sand, and 5 parts water, by volume. Grout compressive strength on the day of Test No. 608551-1 (7 days of age) was 120 psi, and on day of Test No. 608551-2 (18 days of age) was 180 psi.

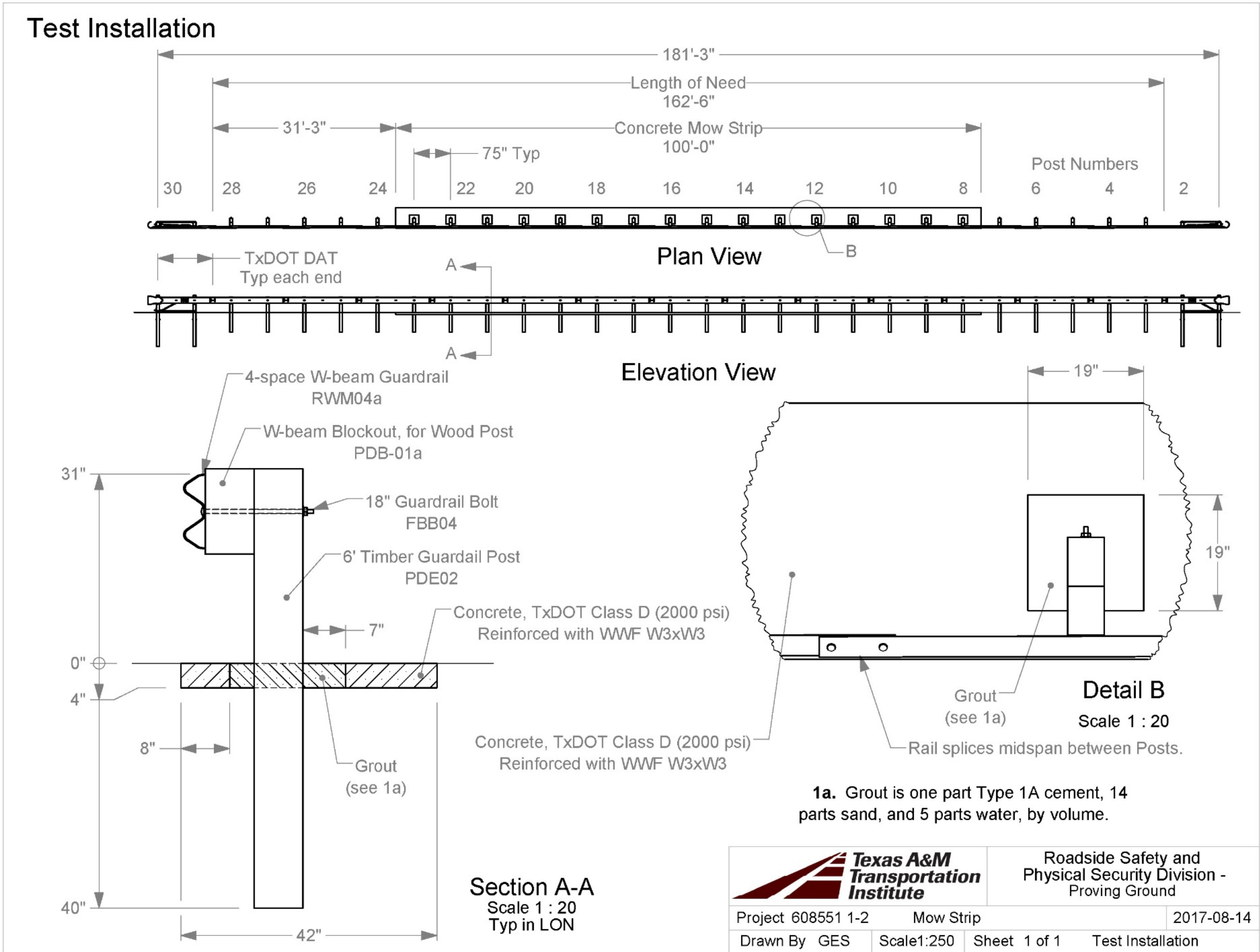


Figure 4.1. Overall Details of 31-inch W-Beam Guardrail on Wood Posts in Concrete Mow Strip.

Figure 4.2. 31-inch W-Beam Guardrail on Wood Posts in Concrete Mow Strip prior to Test Nos. 608551-1 and 2.

4.1.3 Soil Conditions

The test installation was installed in standard soil meeting grading B of AASHTO standard specification M147-65(2004) "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses."

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the guardrail system, two W6×16 posts were installed in the immediate vicinity of the guardrail utilizing the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table C.1 in Appendix C presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

As determined by the tests summarized in Appendix C, Table C.1, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 3940 lb, 5500 lb, and 6540 lb, respectively (90% of static load for the initial standard installation). On the day of Test No. 608551-1, November 15, 2017, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 8232 lbf, 8939 lbf, and 8939 lbf, respectively. On the day of Test No. 608551-2, December 5, 2017, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 8787 lbf, 8585 lbf, and 8434 lbf, respectively. Tables C.2 and C.3 in Appendix C show the strength of the backfill material in which the guardrail system was installed met minimum *MASH* requirements.

4.2 *MASH* TEST 3-10 ON THE 31-INCH W-BEAM GUARDRAIL SYSTEM ON WOOD POSTS IN CONCRETE MOW STRIP

4.2.1 Test Designation and Actual Test Conditions

MASH Test 3-10 involves an 1100C vehicle weighing 2420 lb ±55 lb impacting the CIP of the guardrail at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The target CIP for *MASH* Test 3-10 on the guardrail was 7.5 ft ±1 ft upstream of post 15. This CIP was determined using the information provided in *MASH* Section 2.3.2 and *MASH* Figure 2-1.

The 2009 Kia Rio[*] used in the test weighed 2434 lb, and the actual impact speed and angle were 62.3 mi/h and 24.7°, respectively. The actual impact point was 7.6 ft upstream of post 15. Minimum target impact severity was 51 kip-ft, and actual IS was 55 kip-ft.

4.2.2 Weather Conditions

The test was performed on the morning of November 15, 2017. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 182° (vehicle was traveling in a southwesterly direction); temperature: 71°F; relative humidity: 86%.

4.2.3 Test Vehicle

Figures 4.3 and 4.4 show the 2009 Kia Rio that was used for the crash test. The vehicle's test inertia weight was 2434 lb, and its gross static weight was 2599 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and the height to the upper edge of the bumper was 21.0 inches. Table D1 in Appendix D1 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.

[*] The 2009 model vehicle used is older than the 6-year age noted in *MASH*, and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2009 model vehicle met the *MASH* requirements.

Figure 4.3. Guardrail in Mow Strip/Test Vehicle Geometrics for Test No. 608551-1.

Figure 4.4. Test Vehicle before Test No. 608551-1.

4.2.4 Test Description

The test vehicle contacted the guardrail 7.6 ft upstream of post 15 while traveling at an impact speed of 62.3 mi/h and an impact angle of 24.7°. Table 4.1 lists events that occurred during Test No. 608551-1. Figures D.1 and D.2 in Appendix D2 present sequential photographs during the test.

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 1100C vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the guardrail, the vehicle came to rest 175 ft downstream of the impact and 25 ft toward the field side.

4.2.5 Damage to Test Installation

Figures 4.5 and 4.6 show the damage to the guardrail. Post 1 was pulled downstream 1.0 inch and post 2 was pulled downstream 0.25 inch at ground level. The rail element released from posts 3 through 19, and the blockouts remained attached to the top of fractured posts 10 and 13. Post 10 split through the bolt holes, post 13 broke off above grade, and posts 14-17 broke off at grade. Post 30 was pulled upstream 0.38 inch at ground level. Working width was 45.8

inches at a height of 31.5 inches. Maximum dynamic deflection during the test was 37.8 inches, and maximum permanent deformation was 12.0 inches.

Table 4.1. Events during Test No. 608551-1.

TIME (s)	EVENT
0.020	Post 14 begins to deflect to field side, disturbing grout
0.027	Post 15 begins to deflect to field side
0.029	Post 13 begins to deflect to field side
0.037	Vehicle begins to redirect
0.041	Blockout and bolt release from post 14
0.049	Post 14 fully fractured at grout level
0.057	Grout at post 15 disturbed as post deflects to field side
0.065	Right front tire begins to underride guardrail just before post 15
0.066	Post 16 begins to deflect to field side
0.077	Grout at post 16 disturbed as post deflects to field side
0.080	Blockout and bolt release from post 15
0.092	Right front tire impacts post 15 and rides up and over post
0.093	Post 15 fully fractured at grout level and begins to split longitudinally
0.102	Post 17 begins to deflect to field side
0.123	Blockout and bolt release from post 16
0.187	Right front tire impacts post 16; post nearly horizontal
0.194	Post 13 begins to fracture from blockout downward
0.195	Right rear of vehicle impacts rail at splice between post 14-15
0.242	Vehicle becomes parallel with rail
0.500	Vehicle loses contact with rail traveling at 38.8 mi/h and 13.4°

Figure 4.5. Guardrail in Mow Strip/Test Vehicle after Test No. 608551-1.

Figure 4.6. Guardrail in Mow Strip after Test No. 608551-1.

4.2.6 Vehicle Damage

Figure 4.7 shows the damage sustained by the vehicle. The front bumper, hood, right front fender, right front tire and rim, right front and rear doors, right rear quarter panel, and the rear bumper were damaged. Maximum exterior crush to the vehicle was 10.0 inches in the side plane at the right front corner at bumper height. No occupant compartment deformation or intrusion occurred. Figure 4.8 shows the interior of the vehicle. Tables D.2 and D.3 in Appendix D1 provide exterior crush and occupant compartment measurements.

Figure 4.7. Test Vehicle after Test No. 608551-1.

Before Test **After Test**

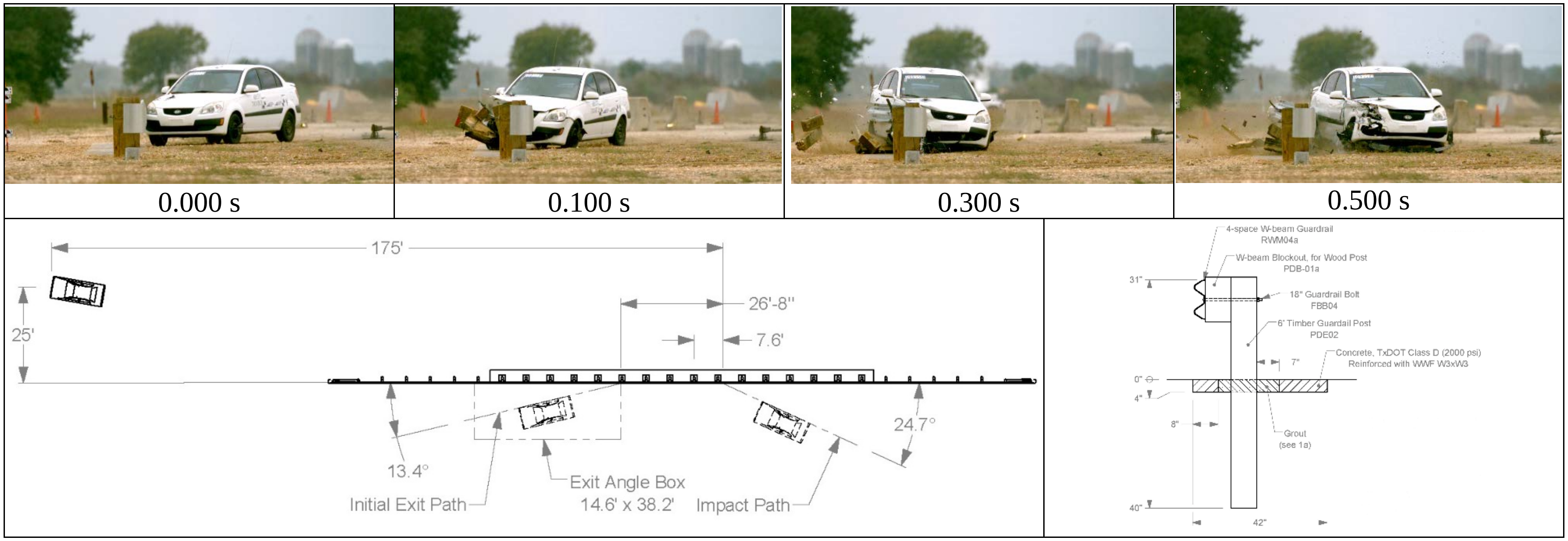
Figure 4.8. Interior of Test Vehicle for Test No. 608551-1.

4.2.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and the results are shown in Table 4.2. Figure 4.9 summarizes these data and other pertinent information from the test. Figure D.3 in Appendix D3 shows the vehicle angular displacements, and Figures D.4 through D.9 in Appendix D4 show accelerations versus time traces.

Table 4.2. Occupant Risk Factors for Test No. 608551-1.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	15.7 ft/s	at 0.1372 s on right side of interior
Lateral	16.1 ft/s	
Ridedown Accelerations		
Longitudinal	5.8 g	0.1716 - 0.1816 s
Lateral	8.1 g	0.2231 - 0.2331 s
Theoretical Head Injury Velocity (THIV)	23.4 km/h 6.5 m/s	at 0.1311 s on right side of interior
Post Head Deceleration (PHD)	9.1 g	0.1751 - 0.1851 s
Accident Severity Index (ASI)	0.83	0.1990 - 0.2490 s
Maximum 50-ms Moving Average		
Longitudinal	-5.2 g	0.0449 - 0.0949 s
Lateral	-6.7 g	0.1819 - 0.2319 s
Vertical	-2.5 g	0.1604 - 0.2104 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	11°	0.1954 s
Pitch	6°	2.0000 s
Yaw	39°	0.3999 s



General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-10
TTI Test No.	608551-1
Test Date	2017-11-15

Test Article

Type	Guardrail
Name	31-inch W-Beam Guardrail System on Wood Posts in Concrete Mow Strip
Installation Length	181 ft-3 inches
Material or Key Elements	Wood posts installed 40 inches deep in concrete mow strip measuring 100-ft long × 42-inches wide × 4-inches thick with 19-inch square × 4-inch deep ‘leave-outs’ filled with low-strength grout
Soil Type and Condition	AASHTO M147-65(2004), Grading B Soil (crushed limestone), Damp

Test Vehicle

Type/Designation	1100C
Make and Model	2009 Kia Rio
Curb	2487 lb
Test Inertial	2434 lb
Dummy	165 lb
Gross Static	2599 lb

Impact Conditions

Speed	62.3 mi/h
Angle	24.7°
Location/Orientation	7.6 ft upstream of post 15
Impact Severity	55 kip-ft

Exit Conditions

Speed	38.8 mi/h
Trajectory/Heading Angle	13.4°/13.4°

Occupant Risk Values

Longitudinal OIV	15.7 ft/s
Lateral OIV	16.1 ft/s
Longitudinal Ridedown	5.8 g
Lateral Ridedown	8.1 g
THIV	23.4 km/h
PHD	9.1 g
ASI	0.83
Max. 0.050-s Average	
Longitudinal	-5.2 g
Lateral	-6.7 g
Vertical	-2.5 g

Post-Impact Trajectory

Stopping Distance	175 ft downstream 25 ft twd field side

Vehicle Stability

Maximum Yaw Angle	39°
Maximum Pitch Angle	6°
Maximum Roll Angle	11°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	37.8 inches
Permanent	12.0 inches
Working Width	45.8 inches
Height of Working Width	31.5 inches

Vehicle Damage

VDS	01RFQ4
CDC	01FREW3
Max. Exterior Deformation	10.0 inches
OCDI	FS0000000
Max. Occupant Compartment Deformation	None

Figure 4.9. Summary of Results for *MASH* Test 3-10 on 31-inch W-Beam Guardrail on Wood Posts in Concrete Mow Strip.

4.3 *MASH* TEST 3-11 ON THE 31-INCH W-BEAM GUARDRAIL SYSTEM ON WOOD POSTS IN CONCRETE MOW STRIP

4.3.1 Test Designation and Actual Test Conditions

MASH Test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the guardrail at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The CIP for *MASH* Test 3-11 on the guardrail was 11.64 ft ±1 ft upstream of post 15. This CIP was determined using the information provided in *MASH* Section 2.3.2 and *MASH* Figure 2-1.

The 2012 Dodge RAM 1500 pickup truck used in the test weighed 5038 lb, and the actual impact speed and angle were 63.3 mi/h and 25.4°, respectively. The actual impact point was 11.58 ft upstream of post 15. Minimum target impact severity was 106 kip-ft, and actual IS was 124 kip-ft.

4.3.2 Weather Conditions

The test was performed on the morning of December 5, 2017. Weather conditions at the time of testing were as follows: wind speed: 12 mi/h; wind direction: 13 degrees (vehicle was traveling in a southwesterly direction); temperature: 57°F; relative humidity: 65 percent.

4.3.3 Test Vehicle

Figures 4.10 and 4.11 show the 2012 Dodge RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5038 lb, and its gross static weight was 5038 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and the height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 29.0 inches. Tables E.1 and E.2 in Appendix E1 give 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 4.10. Guardrail in Mow Strip/Test Vehicle Geometrics for Test No. 608551-2.

Figure 4.11. Test Vehicle before Test No. 608551-2.

4.3.4 Test Description

The test vehicle contacted the guardrail in mow strip 11.58 ft upstream of post 15 at an impact angle of 25.4° while traveling at an impact speed of 63.3 mi/h. Table 4.3 lists events that occurred during Test No. 608551-2. Figures E.1 and E.2 in Appendix E2 present sequential photographs during the test.

Table 4.3. Events during Test No. 608551-2.

TIME (s)	EVENT
0.015	Post 13 begins to deflect to field side, disturbing grout
0.019	Post 14 begins to deflect to field side
0.030	Vehicle begins to redirect
0.033	Post 13 fully fractured at grout level
0.040	Post 15 begins to deflect to field side
0.047	Post 14 fully fractured at grout level
0.051	Blockout and bolt release from post 14
0.062	Grout at post 15 disturbed as post deflects to field side
0.073	Post 16 begins to deflect to field side
0.075	Right front tire impacts post #14; Post at ~30° to horizontal
0.085	Post 12 deflects toward field side at grout level and begins to split longitudinally upward
0.097	Rail begins to tear from bottom up at downstream end of bolted joint between Posts 14 and 15
0.101	Post 14 impacts ground
0.105	Guardrail fully ruptured near bolted joint
0.112	Blockout and bolt release from post 13
0.125	Guardrail separates from post 16 and begins to form kink
0.149	Guardrail separates from post 17
0.163	Guardrail begins to bend about post 12 and separates from blockout
0.171	Guardrail separates from Post 18
0.472	Vehicle loses contact with rail after penetration while traveling at 53.5 mi/h

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 2270P vehicle did not redirect and penetrated the rail.

4.3.5 Damage to Test Installation

Figure 4.12 shows the damage to the guardrail. No movement was noted at post 1, and post 2 was pulled downstream 0.25 inch at ground level. Post 12 was partially fractured at ground level and was leaning 68° toward the field side. The rail element released from posts 12 through 25, and posts 13 through 17 fractured at ground level. The rail element ruptured at the downstream side of the joint between posts 14 and 15.

Figure 4.12. Guardrail in Mow Strip after Test No. 608551-2.

4.3.6 Vehicle Damage

Figure 4.13 shows the damage sustained by the vehicle. The front bumper, grill, radiator, left front fender, left front and rear doors, left rear exterior bed, right front fender, and right front tire were damaged. Maximum exterior crush to the vehicle was 24.0 inches in the front plane at the right front quarter point at bumper height. No occupant compartment deformation or intrusion was noted. Figure 4.14 shows the interior of the vehicle. Tables E.3 and E.4 in Appendix E1 provide exterior crush and occupant compartment measurements.

Figure 4.13. Test Vehicle after Test No. 608551-2.

Before Test **After Test**

Figure 4.14. Interior of Test Vehicle for Test No. 608551-2.

4.3.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and results are shown in Table 4.4. Figure 4.15 summarizes these data and other pertinent information from the test. Figure E.3 in Appendix E3 shows the vehicle angular displacements, and Figures E.4 through E.9 in Appendix E4 show accelerations versus time traces.

Table 4.4. Occupant Risk Factors for Test No. 608551-2.

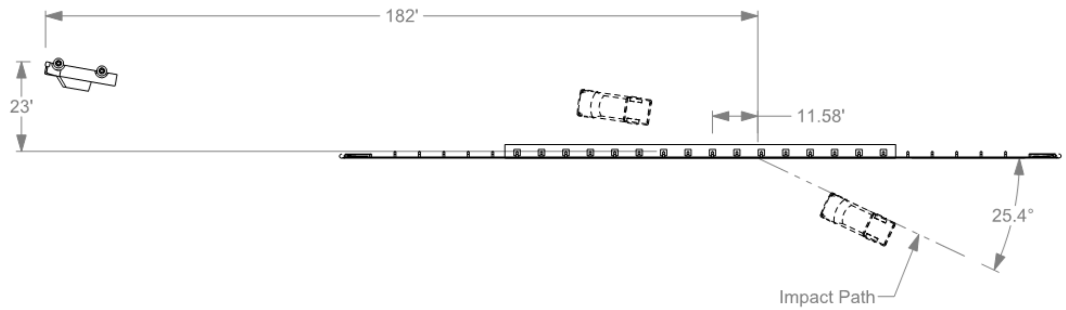
Occupant Risk Factor	Value	Time
OIV		
Longitudinal	12.8 ft/s	at 0.1779 s on right side of interior
Lateral	7.2 ft/s	
Ridedown Accelerations		
Longitudinal	4.0 g	0.3128 - 0.3228 s
Lateral	3.0 g	0.4161 - 0.4261 s
THIV	15.7 km/h 4.3 m/s	at 0.1671 s on right side of interior
PHD	4.2 g	0.3127 - 0.3227 s
ASI	0.50	0.0953 - 0.1453 s
Maximum 50-ms Moving Average		
Longitudinal	-3.7 g	0.0962 - 0.1462 s
Lateral	-3.4 g	0.0620 - 0.1120 s
Vertical	1.9 g	1.4470 - 1.4970 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	90°	1.5000 s
Pitch	1°	0.9542 s
Yaw	37°	1.2708 s

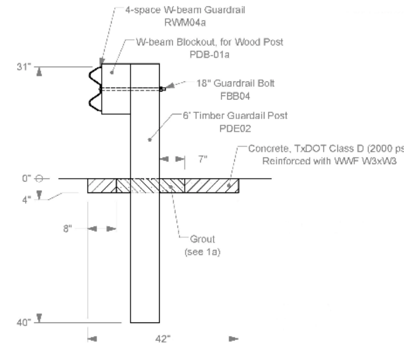
0.000 s

0.160 s

0.320 s

0.480 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-11
TTI Test No.	608551-2
Test Date	
Test Article	
Type	Guardrail
Name	31-inch W-Beam Guardrail System on Wood Posts in Concrete Mow Strip
Installation Length	181 ft-3 inches
Material or Key Elements	Wood posts embedded 40 inches deep in concrete mow strip 42 inches wide × 4 inches thick with 19-inch square × 4-inch deep 'leave-outs' filled with low-strength grout
Soil Type and Condition	AASHTO M147-65(2004), Grading B Soil (crushed limestone), Damp
Test Vehicle	
Type/Designation	2270P
Make and Model	2012 Dodge RAM 1500 Pickup
Curb	4887 lb
Test Inertial	5038 lb
Dummy	No dummy
Gross Static	5038 lb

Impact Conditions	
Speed	63.3 mi/h
Angle	25.4°
Location/Orientation	11.58 ft upstream of post 15
Impact Severity	124 kip-ft
Exit Conditions	
Speed	53.5 mi/h
Trajectory/Heading Angle	Rail ruptured
Occupant Risk Values	
Longitudinal OIV	12.8 ft/s
Lateral OIV	7.2 ft/s
Longitudinal Ridedown	4.0 g
Lateral Ridedown	3.0 g
THIV	15.7 km/h
PHD	4.2 g
ASI	0.50
Max. 0.050-s Average	
Longitudinal	-3.7 g
Lateral	-3.4 g
Vertical	1.9 g

Post-Impact Trajectory	
Stopping Distance	182 ft downstream 23 ft twd field side
Vehicle Stability	
Maximum Yaw Angle	37°
Maximum Pitch Angle	1°
Maximum Roll Angle	90°
Vehicle Snagging	No
Vehicle Pocketing	Yes
Test Article Deflections	
Dynamic	Rail Ruptured
Permanent	Rail Ruptured
Working Width	Rail Ruptured
Height of Working Width	Rail Ruptured
Vehicle Damage	
VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	24.0 inches
OCDI	None
Max. Occupant Compartment Deformation	FR0000000

Figure 4.15. Summary of Results for *MASH* Test 3-11 on 31-inch W-Beam Guardrail on Wood Posts in Concrete Mow Strip.

4.4 SUMMARY

The 31-inch W-beam Guardrail System on wood posts in concrete mow strip performed acceptably for *MASH* Test 3-10. However, during *MASH* Test 3-11, the W-beam rail element ruptured, allowing the 2270P vehicle to penetrate the installation. The 31-inch W-beam Guardrail System on wood posts in concrete mow strip did not perform acceptably for *MASH* TL-3 longitudinal barriers.

Subsequent to the failure of the W-beam Guardrail System on wood posts in concrete mow strip in *MASH* Test 3-11 as described above, a decision was made to perform *MASH* Test 3-11 on a wood post system with reduced post embedment. This installation and test are described in Chapter 5.

Chapter 5. 31-INCH W-BEAM GUARDRAIL SYSTEM ON WOOD POSTS WITH REDUCED EMBEDMENT IN CONCRETE MOW STRIP

5.1 SYSTEM DETAILS

5.1.1 Test Article and Installation Details

The test installation was the same as the previous Test No. 608551-2 with the exception that guardrail posts 3 through 28 were 68 inches long and were installed 36 inches deep.

Figure 5.1 presents overall information on the 31-inch W-beam guardrail with wood posts in concrete mow strip, and Figure 5.2 provides photographs of the installation. Appendix A2 provides further details of the installation.

5.1.2 Material Specifications

Appendix B provides material certification documents for the materials used to install/construct the wood post guardrail system installation in concrete mow strip.

The low-strength grout mix used in the leave-outs was comprised of 1-part Type 1A cement, 14 parts sand, and 5 parts water, by volume. Grout compressive strength on the day of Test No. 608551-5 (7 days of age) was 120 psi.

5.1.3 Soil Conditions

The test installation was installed in standard soil meeting grading B of AASHTO standard specification M147-65(2004) "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses."

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the guardrail system, two W6×16 posts were installed in the immediate vicinity of the guardrail utilizing the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table C.1 in Appendix C presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

As determined by the tests summarized in Appendix C, Table C.1, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 3940 lb, 5500 lb, and 6540 lb, respectively (90% of static load for the initial standard installation). On the day of Test No. 608551-5, January 18, 2019, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 6868 lbf, 7727 lbf, and 8434 lbf, respectively. Table C.4 in Appendix C shows the strength of the backfill material in which the guardrail system was installed met minimum *MASH* requirements.

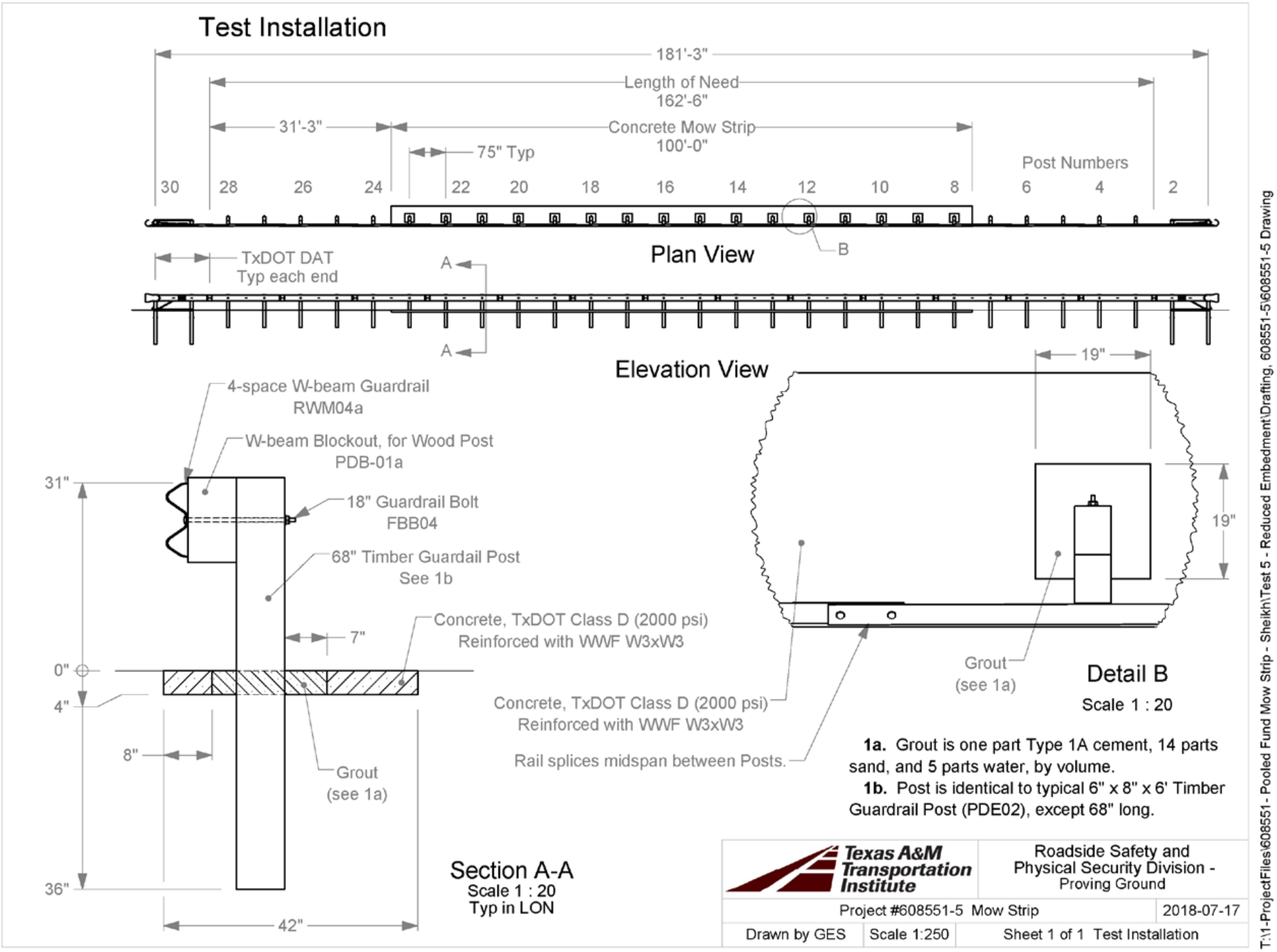


Figure 5.1. Overall Details of 31-inch W-Beam Guardrail on Wood Posts with Reduced Embedment in Concrete Mow Strip.

Figure 5.2. 31-inch W-Beam Guardrail on Wood Posts with Reduced Embedment in Concrete Mow Strip prior to Test No. 608551-5.

5.2 *MASH* TEST 3-10 ON THE 31-INCH W-BEAM GUARDRAIL SYSTEM ON WOOD POSTS WITH REDUCED EMBEDMENT IN CONCRETE MOW STRIP

5.2.1 Test Designation and Actual Test Conditions

MASH Test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the guardrail at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The CIP for *MASH* Test 3-11 on the guardrail was 12 ft ±1 ft upstream of post 14. This CIP was determined using the information provided in *MASH* Section 2.3.2 and *MASH* Figure 2-1.

The 2014 RAM 1500 pickup truck used in the test weighed 5037 lb, and the actual impact speed and angle were 63.5 mi/h and 24.6°, respectively. The actual impact point was 11.5 ft upstream of post 14. Minimum target impact severity was 106 kip-ft, and actual IS was 118 kip-ft.

5.2.2 Weather Conditions

The test was performed on the morning of January 18, 2019. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 172° (vehicle was traveling in a southwesterly direction); temperature: 57°F; relative humidity: 100%.

5.2.3 Test Vehicle

Figures 5.3 and 5.4 show the 2014 Dodge RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5037 lb, and its gross static weight was 5037 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and the height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.5 inches. Tables F.1 and F.2 in Appendix F1 give 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 5.3. Guardrail in Mow Strip/Test Vehicle Geometrics for Test No. 608551-5.

Figure 5.4. Test Vehicle before Test No. 608551-5.

5.2.4 Test Description

The test vehicle contacted the guardrail 11.5 ft upstream of post 14 while traveling at an impact speed of 63.5 mi/h and an impact angle of 24.6°. Table 5.1 lists events that occurred during Test No. 608551-5. Figures F.1 and F.2 in Appendix F2 present sequential photographs during the test.

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 2270P vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the guardrail, the vehicle rolled clockwise 369° and came to rest upright 160 ft downstream of the impact and 17 ft toward the traffic lanes.

Table 5.1. Events during Test No. 608551-5.

TIME (s)	EVENT
0.0000	Vehicle contacts guardrail
0.0170	Post 12 begins to deflect toward field side
0.0180	Vehicle begins to redirect; post 13 begins to deflect toward field side
0.0370	Post 14 begins to deflect toward field side
0.0460	Bumper reaches post 13
0.0700	Right front tire contacts and begins to ride over post 13
0.0830	Post 15 begins to deflect toward field side
0.1120	Bumper reaches post 14; post 16 begins to deflect toward field side
0.1290	Guardrail element begins to ride upward on bumper
0.1840	Lower edge of guardrail element reaches top right front tire
0.1930	Rear of vehicle contacts guardrail
0.2560	Bumper reaches post 16; post 17 begins to deflect toward field side
0.2760	Vehicle is parallel to the installation
0.3420	Bumper reaches post 17
0.6330	Vehicle lost contact with guardrail. Vehicle proceeds and is out-of-view: Exit trajectory and heading angles and speed are unobtainable

5.2.5 Damage to Test Installation

Figure 5.5 shows the damage to the guardrail. Post 1 was pulled downstream 1.0 inch. The rail element released from posts 1 through 10, 13 through 17, and 19. Post 11 split through the bolt holes. Post 12 was leaning toward the field side at 82°. Posts 13-17 broke off at grade. There were gaps of 0.25 inch on the traffic side, 0.5 inch on the downstream side, and 1.5 inch on the field side of post 18. The soil was slightly disturbed at post 30. Posts 13 to 19 came to rest 6 to 30 feet behind rail. Working width was 55.7 inches, and height of working width was 53.0 inches. Maximum dynamic deflection during the test was 49.3 inches, and maximum permanent deformation was 35.0 inches.

Figure 5.5. Guardrail in Mow Strip after Test No. 608551-5.

5.2.6 Vehicle Damage

Figure 5.6 shows the damage sustained by the vehicle. The front bumper, hood, grill, upper and lower A-arms, upper and lower ball joint mounts, right front fender, right front tire and rim, right front door and window glass, right rear door, and right rear exterior bed were damaged in the initial impact. After losing contact with the guardrail, the vehicle rolled clockwise 369°, thereby damaging the roof, windshield, left front fender, left front and rear doors, left front door window glass, left rear exterior bed, right A and B posts, and right rear door window glass. Maximum exterior crush to the vehicle was 8.0 inches in the front and side planes at the right front corner at bumper height. Maximum occupant compartment deformation was 12.0 inches in the right front passenger roof area. Figure 5.7 shows the interior of the vehicle. Tables F.2 and F.3 in Appendix F1 provide exterior crush and occupant compartment measurements.

Figure 5.6. Test Vehicle after Test No. 608551-5.

Before Test **After Test**

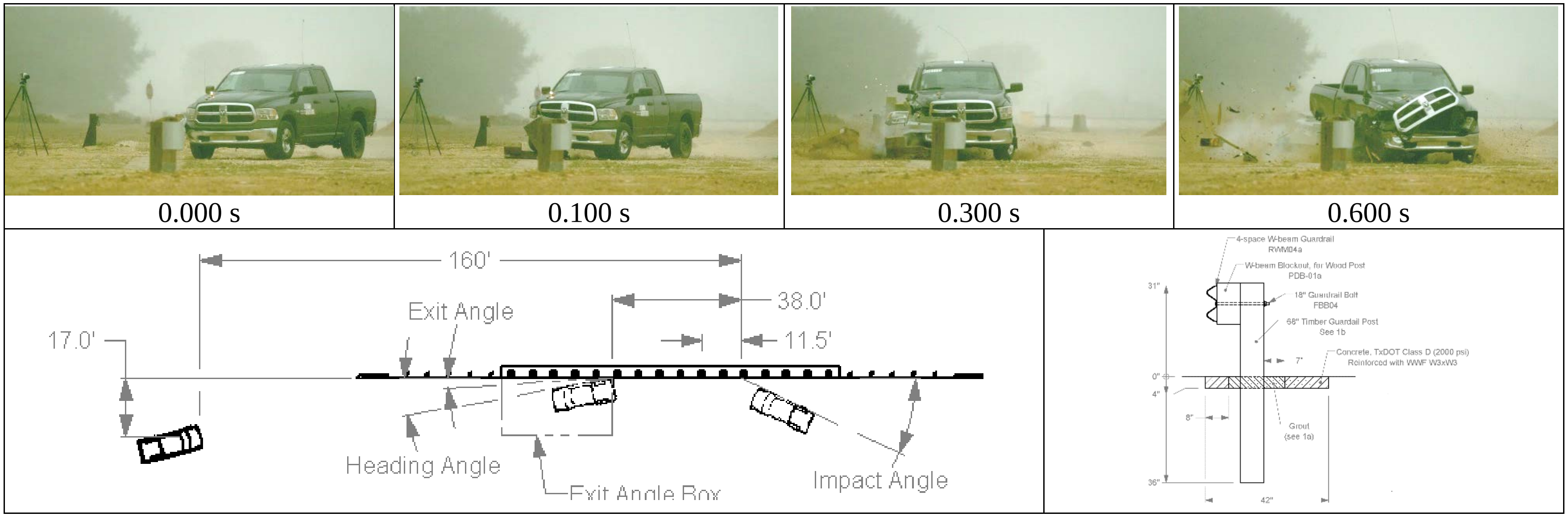
Figure 5.7. Interior of Test Vehicle for Test No. 608551-5.

5.2.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and the results are shown in Table 5.2. Figure 5.8 summarizes these data and other pertinent information from the test. Figure F.3 in Appendix F3 shows the vehicle angular displacements, and Figures F.4 through F.9 in Appendix F4 show accelerations versus time traces.

Table 5.2. Occupant Risk Factors for Test No. 608551-5.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	11.8 ft/s	at 0.1530 s on right side of interior
Lateral	15.1 ft/s	
Ridedown Accelerations		
Longitudinal	4.7 g	0.2317 - 0.2417 s
Lateral	8.6 g	0.2294 - 0.2394 s
THIV	20.3 km/h 5.6 m/s	at 0.1481 s on right side of interior
PHD	9.7 g	0.2295 - 0.2395 s
ASI	0.72	0.2355 - 0.2855 s
Maximum 50-ms Moving Average		
Longitudinal	-3.9 g	0.0696 - 0.1196 s
Lateral	-5.8 g	0.2094 - 0.2594 s
Vertical	-5.3 g	4.7189 - 4.7689 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	369°	4.0512 s
Pitch	18°	4.1589 s
Yaw	122°	5.0000 s



General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-11
TTI Test No.	608551-5
Test Date	2019-01-18

Test Article

Type	Guardrail
Name	31-inch W-Beam Guardrail System on Wood Posts with Reduced Embedment in Concrete Mow Strip
Installation Length	181 ft-3 inches
Material or Key Elements	Wood posts installed 36 inches deep in concrete mow strip measuring 100-ft long × 42-inches wide × 4-inches thick with 19-inch square × 4-inch deep ‘leave-outs’ filled with low-strength grout
Soil Type and Condition	AASHTO M147-65(2004), Grading B Soil (crushed limestone), Damp

Test Vehicle

Type/Designation	2270P
Make and Model	2014 RAM 1500 Pickup
Curb	5032 lb
Test Inertial	5037 lb
Dummy	No dummy
Gross Static	5037 lb

Impact Conditions

Speed	63.5 mi/h
Angle	24.6°
Location/Orientation	11.5 ft upstream of post 14
Impact Severity	118 kip-ft

Exit Conditions

Speed	Out of view
Trajectory/Heading Angle	Out of view

Occupant Risk Values

Longitudinal OIV	11.8 ft/s
Lateral OIV	15.1 ft/s
Longitudinal Ridedown	4.7 g
Lateral Ridedown	8.6 g
THIV	20.3 km/h
PHD	9.7 g
ASI	0.72
Max. 0.050-s Average	
Longitudinal	-3.9 g
Lateral	-5.8 g
Vertical	-5.3 g

Post-Impact Trajectory

Stopping Distance	160 ft downstream 17 ft toward traffic

Vehicle Stability

Maximum Yaw Angle	122°
Maximum Pitch Angle	18°
Maximum Roll Angle	369°
Vehicle Snagging	No
Vehicle Pocketing	Yes

Test Article Deflections

Dynamic	49.3 inches
Permanent	35.0 inches
Working Width	55.6 inches
Height of Working Width	53.0 inches

Vehicle Damage

VDS	01RFQ6
CDC	01RFEW4
Max. Exterior Deformation	8.0 inches
OCDI	RF0300010
Max. Occupant Compartment Deformation	12.0 inches (roof, due to rollover)

Figure 5.8. Summary of Results for *MASH* Test 3-11 on 31-inch W-Beam Guardrail on Wood Posts with Reduced Embedment in Concrete Mow Strip.

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Chapter 6. 31-INCH W-BEAM GUARDRAIL SYSTEM ON STEEL POSTS IN CONCRETE MOW STRIP

6.1 SYSTEM DETAILS

6.1.1 Test Article and Installation Details

The test installation consisted of a 31-inch tall W-beam guardrail with structural steel posts (posts 3 through 28) installed in compacted base, with a Texas Department of Transportation (TxDOT) downstream anchor terminal (DAT) [GF (31) DAT-14] on each end, for a total installation length of 181 ft-3 inches. Timber blockouts for W-section steel posts (PDB-01b) were installed on posts 3 through 28 using 10-inch long guardrail bolts and recessed guardrail nuts (FBB03).

Standard 12-gauge W-beam guardrail (type RWM04a) was used in the system. The top of the W-beam was 31 inches above grade, and the guardrail splices were located mid-span between every other post. Posts were equally spaced at 6 ft-3 inches.

Guardrail posts 3 through 28 were standard 6-ft long line posts fabricated from W6×8.5 ASTM A36 structural steel shape (PWE01). These 26 posts were installed 40 inches deep in drilled holes that were backfilled and compacted with soil meeting Grading B of AASHTO standard specification M147-65(2004) "*Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses*".

From post 8 through post 23, a TxDOT Class D (2000 psi) concrete mow strip measuring 100-ft long × 42-inches wide × 4-inches thick, reinforced with WWF W3xW3 mesh, was installed. A 19-inch square 'leave-out' was located at each post. The posts were installed in the 'leave-outs' with a 7-inch distance between the edge of the concrete mow-strip 'leave-out' and the back flange of the post. After the posts and mow strip were installed, the 4-inch deep 'leave-outs' were filled with low-strength grout.

Each TxDOT GF (31) DAT-14 terminal was 9 ft-4½ inches long as measured from their anchor posts to the W-beam splice between posts 2 and 3 and posts 28 and 29, respectively.

Figure 6.1 presents overall information on the 31-inch W-beam guardrail system on steel posts in concrete mow strip, and Figure 6.2 provides photographs of the installation. Appendix A3 provides further details of the guardrail in mow strip.

6.1.2 Material Specifications

Appendix B provides material certification documents for the materials used to install/construct the 31-inch W-beam guardrail system with steel posts in concrete mow strip.

The specified concrete strength for the mow strip was 3000 psi. Concrete strength for the first test (Test No. 608551-3 performed 2017-10-09) at 17 days of age was 3040 psi.

The low-strength grout mix was comprised of 1-part Type 1A cement, 14 parts sand, and 5 parts water (on a volume basis). Grout compressive strength on the day of Test No. 608551-3 (17 days of age) was 150 psi, and on day of Test No. 608551-4 (28 days of age) was 180 psi.

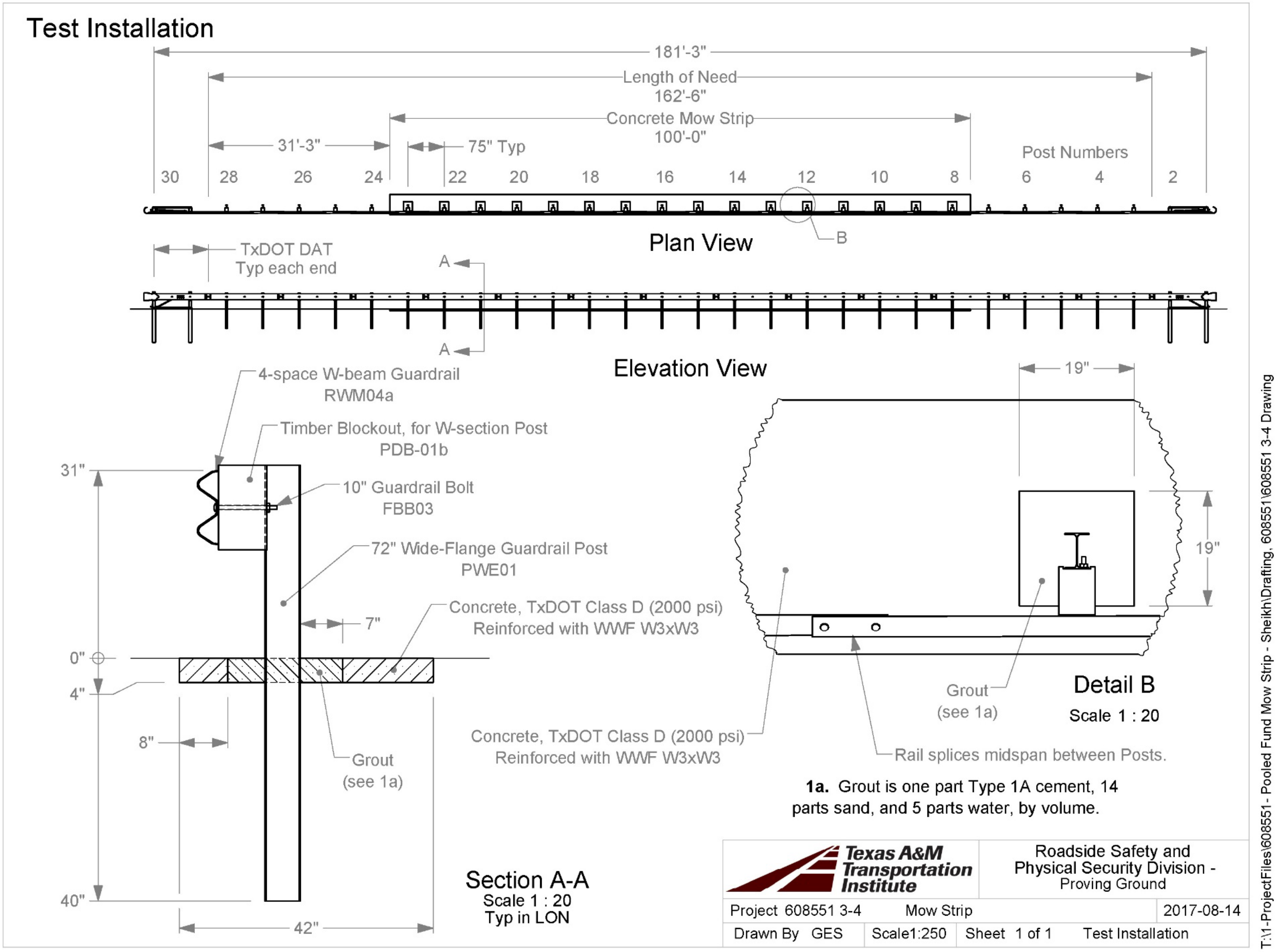

Figure 6.1. Overall Details of 31-inch W-Beam Guardrail on Steel Posts in Concrete Mow Strip.

Figure 6.2. 31-inch W-Beam Guardrail on Steel Posts in Concrete Mow Strip prior to Testing.

6.1.3 Soil Conditions

The test installation was installed in soil meeting Grading B of AASHTO standard specification M147-65(2004) "*Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses*". In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test (see Appendix C, Figure C1). During installation of the steel post guardrail system for full-scale crash testing, two standard W6×16 posts were installed in the immediate vicinity of the test installation, utilizing the same fill materials and installation procedures used in the test installation and standard dynamic test (see Appendix C, Figure C2).

As determined in the tests shown in Appendix C, Figures C5 and C6, the minimum post load required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, is 3940 lb, 5500 lb, and 6540 lb, respectively (90% of static load for the initial standard installation). On the day of Test No. 608551-3, October 9, 2017, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 6969 lbf, 8585 lbf, and 10,050 lbf, respectively. On the day of Test No. 608551-4, October 27, 2017, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 10,606 lbf, 9949 lbf, and 8181 lbf, respectively. The strength of the backfill material met minimum *MASH* requirements.

6.2 *MASH* TEST 3-10 ON THE 31-INCH W-BEAM GUARDRAIL SYSTEM ON STEEL POSTS IN CONCRETE MOW STRIP

6.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-10 involves an 1100C vehicle weighing 2420 lb ±55 lb impacting the CIP of the guardrail at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The CIP for *MASH* Test 3-10 on the guardrail was 7.75 ft ±1 ft upstream of post 15. This CIP was determined using the information provided in *MASH* Section 2.3.2 and *MASH* Figure 2-1.

The 2011 Kia Rio* used in the test weighed 2428 lb, and the actual impact speed and angle were 63.6 mi/h and 24.4°, respectively. The actual impact point was 7.6 ft upstream of post 15. Minimum target impact severity was 51 kip-ft, and actual IS was 56 kip-ft.

6.2.2 Weather Conditions

The test was performed on the morning of October 9, 2017. Weather conditions at the time of testing were as follows: wind speed: 8 mi/h; wind direction: 164 degrees (vehicle was traveling in a southwesterly direction); temperature: 84°F; relative humidity: 80%.

6.2.3 Test Vehicle

Figures 6.3 and 6.4 show the 2011 Kia Rio used for the crash test. The vehicle's test inertia weight was 2428 lb, and its gross static weight was 2593 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and the height to the upper edge of the bumper was 21.5 inches. Table G.1 in Appendix G1 give 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.

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* The 2011 model vehicle used is older than the 6-year age noted in *MASH*, and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2011 model vehicle met the *MASH* requirements.

Figure 6.3. Guardrail/Test Vehicle Geometrics for Test No. 608551-3.

Figure 6.4. Test Vehicle before Test No. 608551-3.

6.2.4 Test Description

The test vehicle contacted the guardrail 7.6 ft upstream of post 15 at an impact angle of 24.4° while traveling at an impact speed of 63.6 mi/h. Table 6.1 lists events that occurred during Test No. 608551-3. Figures G.1 and G.2 in Appendix G2 present sequential photographs during the test.

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 1100C vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the guardrail, the vehicle came to rest 98 ft downstream of the impact and 10 ft toward traffic lanes.

Table 6.1. Events during Test No. 608551-3.

TIME (s)	EVENT
0.007	Post 14 begins to deflect toward field side
0.010	Right front corner of bumper contacts post 14
0.017	Posts 13 and 15 begin to deflect downstream / Vehicle begins to redirect
0.058	Right front tire goes under rail element
0.069	Center of front bumper contacts post 15
0.074	Post 16 begins to deflect toward field side
0.085	Post 17 begins to deflect toward field side
0.105	Front bumper cover fractures near center and right side separates from vehicle
0.144	Center of front bumper contacts post 16
0.192	Rear of vehicle contacts rail element
0.246	Right front corner of vehicle contacts post 17
0.248	Vehicle traveling parallel with guardrail
0.514	Vehicle loses contact with guardrail traveling at 58.1 mi/h and 11.8°

6.2.5 Damage to Test Installation

Figures 6.5 and 6.6 show the damage to the guardrail. No damage or movement was noted for posts 1 through 11. The rail element separated from post 12 and posts 15-18. Blockouts were missing from posts 15-17, and were in pieces scattered toward the field side of the installation. Post 14 deflected through the grout 2.5 inches and was leaning 82° toward the field side. Post 15 deflected through the grout 1.5 inches and was leaning downstream at 15°. Post 16 deflected through the grout 2.0 inches and was leaning downstream at 15°. Post 17 deflected through the grout 0.7 inch and was leaning downstream at 32°. No damage or movement was noted from post 18 through to the end of the guardrail. Working width was 30.7 inches, and height of working width was 45.8 inches. Maximum dynamic deflection during the test was 27.4 inches, and maximum permanent deformation was 17.0 inches.

Figure 6.5. Guardrail after Test No. 608551-3.

Figure 6.6. Posts 15-18 after Test No. 608551-3.

6.2.6 Vehicle Damage

Figure 6.7 shows the damage sustained by the vehicle. The front bumper, hood, radiator and support, right front fender, and right front door were deformed. The right front strut, right front tire and rim, and right rear tire were also damaged. Maximum exterior crush to the vehicle was 11.0 inches in the side plane at the right front corner at bumper height. No occupant compartment deformation or intrusion occurred. Figure 6.8 shows the interior of the vehicle. Tables G.2 and G.3 in Appendix G1 provide exterior crush and occupant compartment measurements.

Figure 6.7. Test Vehicle after Test No. 608551-3.

Figure 6.8. Interior of Test Vehicle after Test No. 608551-3.

6.2.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and results are shown in Table 6.2. Figure 6.9 summarizes these data and other pertinent information from the test. Figure G.3 in Appendix G3 shows the vehicle angular displacements, and Figures G.4 through G.9 in Appendix G4 show accelerations versus time traces.

Table 6.2. Occupant Risk Factors for Test No. 608551-3.

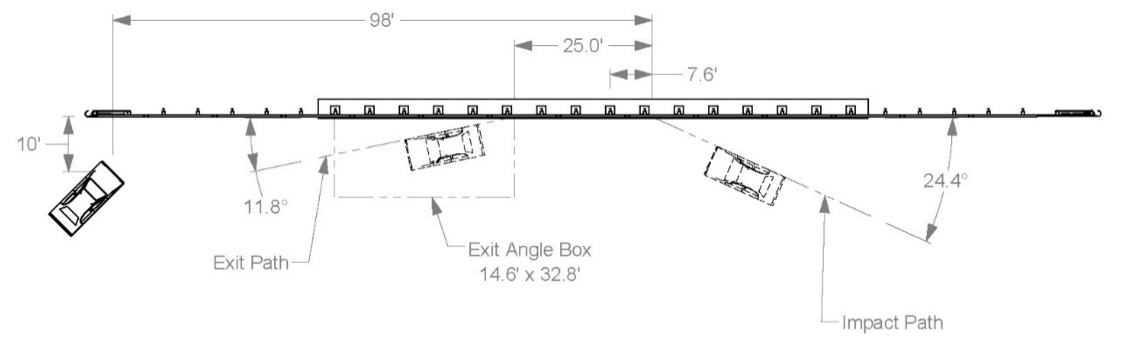
Occupant Risk Factor	Value	Time
OIV **Longitudinal** **Lateral**	 20.3 ft/s 16.1 ft/s	at 0.1203 s on right side of interior
Ridedown Accelerations **Longitudinal** **Lateral**	 9.1 g 8.7 g	 0.1576 - 0.1676 s 0.1579 - 0.1679 s
THIV	27.0 km/h 7.5 m/s	at 0.1148 s on right side of interior
PHD	12.6 g	0.1578 - 0.1678 s
ASI	0.95	0.0656 - 0.1156 s
Maximum 50-ms Moving Average **Longitudinal** **Lateral** **Vertical**	 -7.6 g -7.0 g -2.3 g	 0.0496 - 0.0996 s 0.1202 - 0.1702 s 0.0900 - 0.1400 s
Maximum Roll, Pitch, and Yaw Angles **Roll** **Pitch** **Yaw**	 9° 5° 35°	 2.0000 s 0.5512 s 0.5545 s

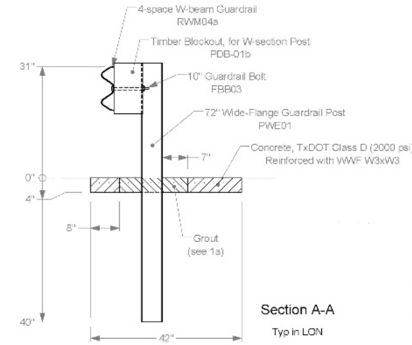
0.000 s

0.100 s

0.200 s

0.400 s





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-10
TTI Test No.	608551-3
Test Date	2017-10-09

Test Article

Type	Guardrail
Name	31-inch W-Beam Guardrail System on Steel Posts in Concrete Mow Strip
Installation Length	181 ft-3 inches
Material or Key Elements	Steel posts embedded 40 inches deep in concrete mow strip 42 inches wide × 4 inches thick with 19-inch square × 4-inch deep 'leave-outs' filled with low-strength grout

Soil Type and Condition	AASHTO M147-65(2004), grading B Soil (crushed limestone), Damp

Test Vehicle

Type/Designation	1100C
Make and Model	2011 Kia Rio
Curb	2454 lb
Test Inertial	2428 lb
Dummy	165 lb
Gross Static	2593 lb

Impact Conditions

Speed	63.6 mi/h
Angle	24.4°
Location/Orientation	7.6 ft upstream of Post 15

Impact Severity	56 kip-ft

Exit Conditions

Speed	58.1 mi/h
Trajectory/Heading Angle	11.8°/11.1°

Occupant Risk Values

Longitudinal OIV	20.3 ft/s
Lateral OIV	16.1 ft/s
Longitudinal Ridedown	9.1 g
Lateral Ridedown	8.7 g
THIV	27.0 km/h
PHD	12.6 g
ASI	0.95
Max. 0.050-s Average	
Longitudinal	-7.6 g
Lateral	-7.0 g
Vertical	-2.3 g

Post-Impact Trajectory

Stopping Distance	98 ft downstream 10 ft toward traffic

Vehicle Stability

Maximum Yaw Angle	35°
Maximum Pitch Angle	5°
Maximum Roll Angle	9°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	27.4 inches
Permanent	17.0 inches
Working Width	30.7 inches
Height of Working Width	45.8 inches

Vehicle Damage

VDS	01RFQ5
CDC	01FREW3
Max. Exterior Deformation	11.0 inches
OCDI	FS0000000
Max. Occupant Compartment Deformation	None

Figure 6.9. Summary of Results for *MASH* Test 3-10 on 31-inch W-Beam Guardrail on Steel Posts in Concrete Mow Strip.

6.3 *MASH* TEST 3-11 (CRASH TEST NO. 608551-4) ON GUARDRAIL ON STEEL POSTS IN MOW STRIP

6.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the guardrail at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The CIP for *MASH* Test 3-11 on the guardrail was 11.75 ft ±1 ft upstream of post 15. This CIP was determined using the information provided in *MASH* Section 2.3.2 and *MASH* Figure 2-1.

The 2012 Dodge RAM 1500 used in the test weighed 5011 lb, and the actual impact speed and angle were 62.8 mi/h and 25.6 degrees, respectively. The actual impact point was 12.0 ft upstream of post 15. Minimum target impact severity was 106 kip-ft, and actual IS was 123 kip-ft.

6.3.2 Weather Conditions

The test was performed on the morning of October 27, 2017. Weather conditions at the time of testing were as follows: wind speed: 15 mi/h; wind direction: 355 degrees (vehicle was traveling in a southwesterly direction); temperature: 60°F; relative humidity: 55%.

6.3.3 Test Vehicle

Figures 6.10 and 6.11 show the 2012 Dodge RAM 1500 used for the crash test. The vehicle's test inertia weight was 5011 lb, and its gross static weight was 5011 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and the height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.0 inches. Tables H.1 and H.2 in Appendix H1 give 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 6.10. Guardrail/Test Vehicle Geometrics for Test No. 608551-4.

Figure 6.11. Test Vehicle before Test No. 608551-4.

6.3.4 Test Description

The test vehicle contacted the guardrail 12.0 ft upstream of post 15 at an impact angle of 25.6° while traveling at an impact speed of 62.8 mi/h. Table 6.4 lists events that occurred during Test No. 608551-4. Figures H.1 and H.2 in Appendix H2 present sequential photographs during the test.

Table 6.3. Events during Test No. 608551-4.

TIME (s)	EVENT
0.012	Post 13 begins to deflect toward field side
0.018	Post 14 begins to deflect toward field side
0.024	Vehicle begins to redirect
0.025	Post 12 begins to deflect downstream
0.046	Post 15 begins to deflect toward field side
0.058	Right front corner of bumper contacts post 14
0.074	Right front tire begins to climb impact side flange of post 14
0.081	Blockout at post 14 fractures and releases from post
0.119	Center of front bumper contacts post 15
0.126	Post 16 begins to deflect toward field side
0.133	Blockout at post 15 fractures and releases from post
0.193	Rear of vehicle contacts rail element
0.205	Center of front bumper contacts blockout of post 16
0.290	Right front quarter point of bumper contacts blockout of post 17
0.302	Vehicle traveling parallel with guardrail
0.384	Right front corner of bumper contacts post 18
0.896	Vehicle loses contact with guardrail (out of view of overhead)

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 2270P vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 120 ft downstream of the impact and 4 ft toward field side.

6.3.5 Damage to Test Installation

Figures 6.12 through 6.14 show the damage to the guardrail. Post 1 was pulled downstream 3.0 inches, and post 2 was pulled downstream 0.5 inch at ground level. Posts 3 through 11 showed no apparent movement, and the rail element was separated from posts 2 through 12. Post 12 had rotated 10° clockwise, but the grout was not disturbed. Post 13 was displaced 1.0 inches toward field side and rotated 30° clockwise, but remained attached to the rail element. The blockouts separated from posts 14 through 18, and the posts were leaning downstream 15°. Post 19 had rotated 50° clockwise with evidence of vehicle contact on the flanges on the impact side of the post. The rail element released from posts 14-23 and 25-28. The soil around posts 29 and 30 was disturbed. Working width was 53.9 inches, and height of working width was 60.1 inches. Maximum dynamic deflection during the test was 50.6 inches, and maximum permanent deformation was 21.0 inches.

Figure 6.12. Guardrail after Test No. 608551-4.

Figure 6.13. Posts 12-18 after Test No. 608551-4.

Figure 6.14. Guardrail Downstream of Impact Area after Test No. 608551-4.

6.3.6 Vehicle Damage

Figure 6.15 shows the damage sustained by the vehicle. The front bumper, grill, right front fender, right upper and lower ball joints, right front tire and rim, right front and rear doors, right exterior bed, and rear bumper were damaged. Maximum exterior crush to the vehicle was 10.0 inches in the side plane at the right front corner just above the bumper. No occupant compartment deformation or intrusion occurred. Figure 6.16 shows the interior of the vehicle. Tables E.3 and D. in Appendix D1 provide exterior crush and occupant compartment measurements.

6.3.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and results are shown in Table 6.4. Figure 6.17 summarizes these data and other pertinent information from the test. Figure H.3 in Appendix H3 shows the vehicle angular displacements, and Figures H.4 through H.9 in Appendix H4 show accelerations versus time traces.

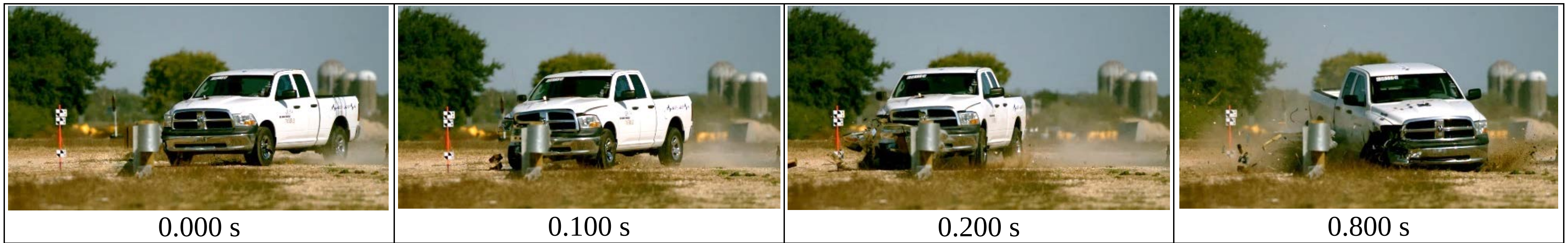
Figure 6.15. Test Vehicle after Test No. 608551-4.

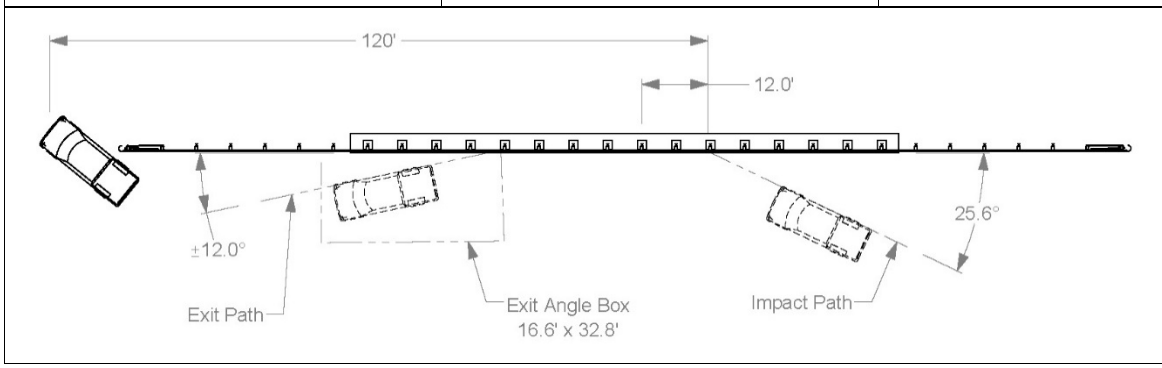
Before Test **After Test**

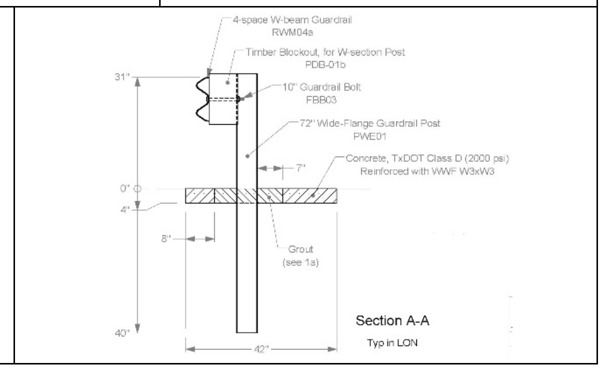
Figure 6.16. Interior of Test Vehicle for Test No. 608551-4.

Table 6.4. Occupant Risk Factors for Test No. 608551-4.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	15.4 ft/s	at 0.1531 s on right side of interior
Lateral	14.4 ft/s	
Ridedown Accelerations		
Longitudinal	7.0 g	0.4478 - 0.4578 s
Lateral	7.3 g	0.2372 - 0.2472 s
THIV	21.6 km/h 6.0 m/s	at 0.1466 s on right side of interior
PHD	7.6 g	0.2372 - 0.2472 s
ASI	0.61	0.2449 - 0.2949 s
Maximum 50-ms Moving Average		
Longitudinal	-3.9 g	0.0747 - 0.1247 s
Lateral	-5.0 g	0.2195 - 0.2695 s
Vertical	-1.2 g	0.7510 - 0.8010 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	16°	3.9541 s
Pitch	4°	2.8559 s
Yaw	40°	0.7589 s







General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-11
TTI Test No.	608551-4
Test Date	2017-10-27

Test Article

Type	Guardrail
Name	31-inch W-Beam Guardrail System on Steel Posts in Concrete Mow Strip
Installation Length	181 ft-3 inches
Material or Key Elements	Steel posts embedded 40 inches deep in concrete mow strip 42 inches wide × 4 inches thick with 19-inch square × 4-inch deep ‘leave-outs’ filled with low-strength grout

Soil Type and Condition	AASHTO M147-65(2004), grading B Soil (crushed limestone), Damp

Test Vehicle

Type/Designation	2270P
Make and Model	2012 Dodge RAM 1500 Pickup
Curb	4982 lb
Test Inertial	5011 lb
Dummy	No Dummy
Gross Static	5011 lb

Impact Conditions

Speed	62.8 mi/h
Angle	25.6°
Location/Orientation	12.0 ft upstream of Post 15

Impact Severity	123 kip-ft

Exit Conditions

Speed	Not obtainable
Trajectory/Heading Angle	~12-13°

Occupant Risk Values

Longitudinal OIV	15.4 ft/s
Lateral OIV	14.4 ft/s
Longitudinal Ridedown	7.0 g
Lateral Ridedown	7.3 g
THIV	21.6 km/h
PHD	7.6 g
ASI	0.61
Max. 0.050-s Average	
Longitudinal	-3.9 g
Lateral	-5.0 g
Vertical	-1.2 g

Post-Impact Trajectory

Stopping Distance	120 ft downstream 4 ft twd field side

Vehicle Stability

Maximum Yaw Angle	40°
Maximum Pitch Angle	4°
Maximum Roll Angle	16°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	50.6 inches
Permanent	21.0 inches
Working Width	53.9 inches
Height of Working Width	60.1 inches

Vehicle Damage

VDS	01RFQ3
CDC	01FREW3
Max. Exterior Deformation	10.0 inches
OCDI	FS0000000
Max. Occupant Compartment Deformation	None

Figure 6.17. Summary of Results for *MASH* Test 3-11 on 31-inch W-Beam Guardrail on Steel Posts in Concrete Mow Strip.

Chapter 7. SUMMARY AND CONCLUSIONS

7.1 ASSESSMENT OF TEST RESULTS

An assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-3 longitudinal barriers is provided in Tables 7.1 through 7.5.

7.2 CONCLUSIONS

7.2.1 Wood Post System

The 31-inch W-beam Guardrail System on wood posts in concrete mow strip performed acceptably for *MASH* Test 3-10. However, during *MASH* Test 3-11, the W-beam rail element ruptured, allowing the 2270P vehicle to penetrate the installation. The 31-inch W-beam Guardrail System on Wood Posts in Concrete Mow Strip did not perform acceptably for *MASH* TL-3 longitudinal barriers.

MASH Test 3-11 was then performed on the 31-inch W-beam Guardrail System on wood posts in concrete mow strip with a reduced post embedment of 36 inches. After loss of contact with the guardrail, the 2270P vehicle rolled clockwise 369° and came to rest upright. Due to rollover of the vehicle, the 31-inch W-beam Guardrail System on wood posts with reduced embedment in concrete mow strip did not perform acceptably for *MASH* TL-3 longitudinal barriers.

Table 7.6 provides an overall assessment of the tests performed on the 31-inch W-beam Guardrail System on Wood Posts in Concrete Mow Strip.

7.2.2 Steel Post System

The 31-inch W-beam Guardrail System on steel posts in concrete mow strip performed acceptably for *MASH* TL-3 longitudinal barriers.

Table 7.7 provides an overall assessment of the tests.

Table 7.1. Performance Evaluation Summary for *MASH* Test 3-10 on 31-inch W-Beam Guardrail on Wood Posts in Concrete Mow Strip.

Test Agency: Texas A&M Transportation Institute | Test No.: 608551-1 | Test Date: 2017-11-15

***MASH* Test 3-10 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 31-inch W-beam guardrail with wood posts in concrete mow strip contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 37.8 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.*	A few wood posts and blockouts detached from the rail element but did not penetrate or 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 5.2.2 and Appendix E of MASH.	No occupant compartment deformation or intrusion occurred.	
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 and pitch angles were 11° and 6°, respectively.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 15.7 ft/s, and lateral OIV was 16.1 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Maximum longitudinal occupant ridedown acceleration was 5.8 g, and maximum lateral occupant ridedown acceleration was 8.1 g.	Pass

Table 7.2. Performance Evaluation Summary for *MASH* Test 3-11 on 31-inch W-Beam Guardrail on Wood Posts in Concrete Mow Strip.

Test Agency: Texas A&M Transportation Institute | Test No.: 608551-2 | Test Date: 2017-11-27

MASH Test 3-11 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 31-inch W-beam guardrail with wood posts in concrete mow strip did not contain or redirect the 2270P vehicle. The vehicle penetrated the installation.	Fail
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.	A few wood posts and blockouts detached from the rail element but did not penetrate or 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 5.2.2 and Appendix E of MASH.	No occupant compartment deformation or intrusion occurred.	
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 penetrated the rail and rolled 90 degrees onto its left side.	Fail
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 12.8 ft/s, and lateral OIV was 7.2 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Maximum longitudinal occupant ridedown acceleration was 4.0 g, and maximum lateral occupant ridedown acceleration was 3.0 g.	Pass

Table 7.3. Performance Evaluation Summary for *MASH* Test 3-11 on 31-inch W-Beam Guardrail on Wood Posts with Reduced Embedment in Concrete Mow Strip.

Test Agency: Texas A&M Transportation Institute | Test No.: 608551-5 | Test Date: 2019-01-18

***MASH* Test 3-11 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 31-inch W-beam guardrail on wood posts with reduced embedment in concrete mow strip contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 49.3 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.*	A few wood posts and blockouts detached from the rail element but did not penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area.	Fail
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 12.0 inches in the roof area due to rollover.	
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 penetrated the rail and rolled clockwise 369°.	Fail
H. *Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*	Longitudinal OIV was 11.8 ft/s, and lateral OIV was 15.1 ft/s.	Pass
I. *The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Maximum longitudinal occupant ridedown acceleration was 4.7 g, and maximum lateral occupant ridedown acceleration was 8.6 g.	Pass

Table 7.4. Performance Evaluation Summary for *MASH* Test 3-10 on 31-inch W-Beam Guardrail on Steel Posts in Concrete Mow Strip.

Test Agency: Texas A&M Transportation Institute | Test No.: 608551-3 | Test Date: 2017-10-09

***MASH* Test 3-10 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 31-inch W-beam guardrail with steel posts in concrete mow strip contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 27.4 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.	A few wood blockouts detached from the rail element and posts but did not penetrate or 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 5.2.2 and Appendix E of MASH.	No occupant compartment deformation or intrusion occurred.	
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 and pitch angles were 9° and 5°, respectively.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 20.3 ft/s, and lateral OIV was 16.1 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Maximum longitudinal occupant ridedown acceleration was 9.1 g, and maximum lateral occupant ridedown acceleration was 8.7 g.	Pass

Table 7.5. Performance Evaluation Summary for *MASH* Test 3-11 on 31-inch W-Beam Guardrail on Steel Posts in Concrete Mow Strip.

Test Agency: Texas A&M Transportation Institute | Test No.: 608551-4 | Test Date: 2017-10-27

***MASH* Test 3-11 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 31-inch W-beam guardrail with steel posts in concrete mow strip contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 50.6 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.*	A few wood blockouts detached from the rail element and posts but did not penetrate or 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 5.2.2 and Appendix E of MASH.	No occupant compartment deformation or intrusion occurred.	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 and pitch angles were 16° and 4°, respectively.	Pass
H. *Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*	Longitudinal OIV was 15.4 ft/s, and lateral OIV was 14.4 ft/s.	Pass
I. *The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Maximum longitudinal occupant ridedown acceleration was 7.0 g, and maximum lateral occupant ridedown acceleration was 7.3 g.	Pass

Table 7.6. Assessment Summary for *MASH* TL-3 Testing on 31-inch W-Beam Guardrail on Wood Posts in Concrete Mow Strip.

Evaluation Factors	Evaluation Criteria	Test No. 608551-1	Test No. 608551-2	Test No. 608551-5 (Reduced Embedment)
Structural Adequacy	A	S	U	S
Occupant Risk	D	S	S	U
	F	S	U	U
	H	S	S	S
	I	S	S	S
***MASH* Test No.**		***MASH* Test 3-10**	***MASH* Test 3-11**	***MASH* Test 3-11**
Pass/Fail		Pass	Fail	Fail

Key: S = Satisfactory
U = Unsatisfactory

Table 7.7. Assessment Summary for *MASH* TL-3 Testing on 31-inch W-Beam Guardrail on Steel Posts in Concrete Mow Strip.

Evaluation Factors	Evaluation Criteria	Test No. 608551-3	Test No. 608551-4
Structural Adequacy	A	S	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
***MASH* Test No.**		***MASH* Test 3-10**	***MASH* Test 3-11**
Pass/Fail		Pass	Pass

Key: S = Satisfactory
U = Unsatisfactory

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REFERENCES

1. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition.* 2016, American Association of State Highway and Transportation Officials: Washington, D.C.
2. R. P. Bligh, R. N. Seckinger, A. Y. Abu-Odeh, P. N. Roschke, W. L. Menges, and R. R. Haug. "Dynamic Response of Guardrail Systems Encased in Pavement Mow Strips." Texas A&M Transportation Institute, College Station, Texas, 2004.
3. H.E. Ross, Jr., D.L. Sicking, R.A. Zimmer, and J.D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features,* National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

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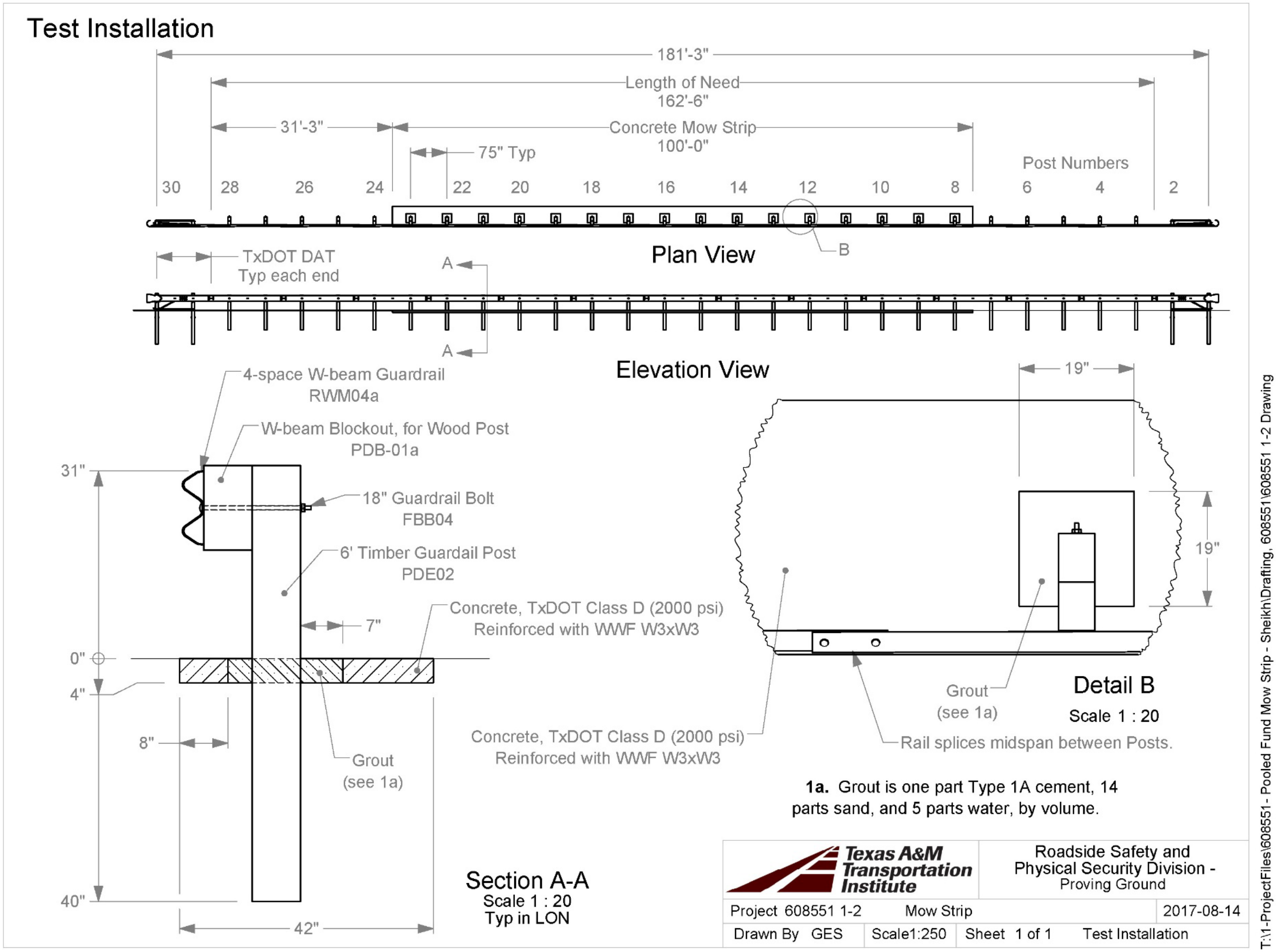
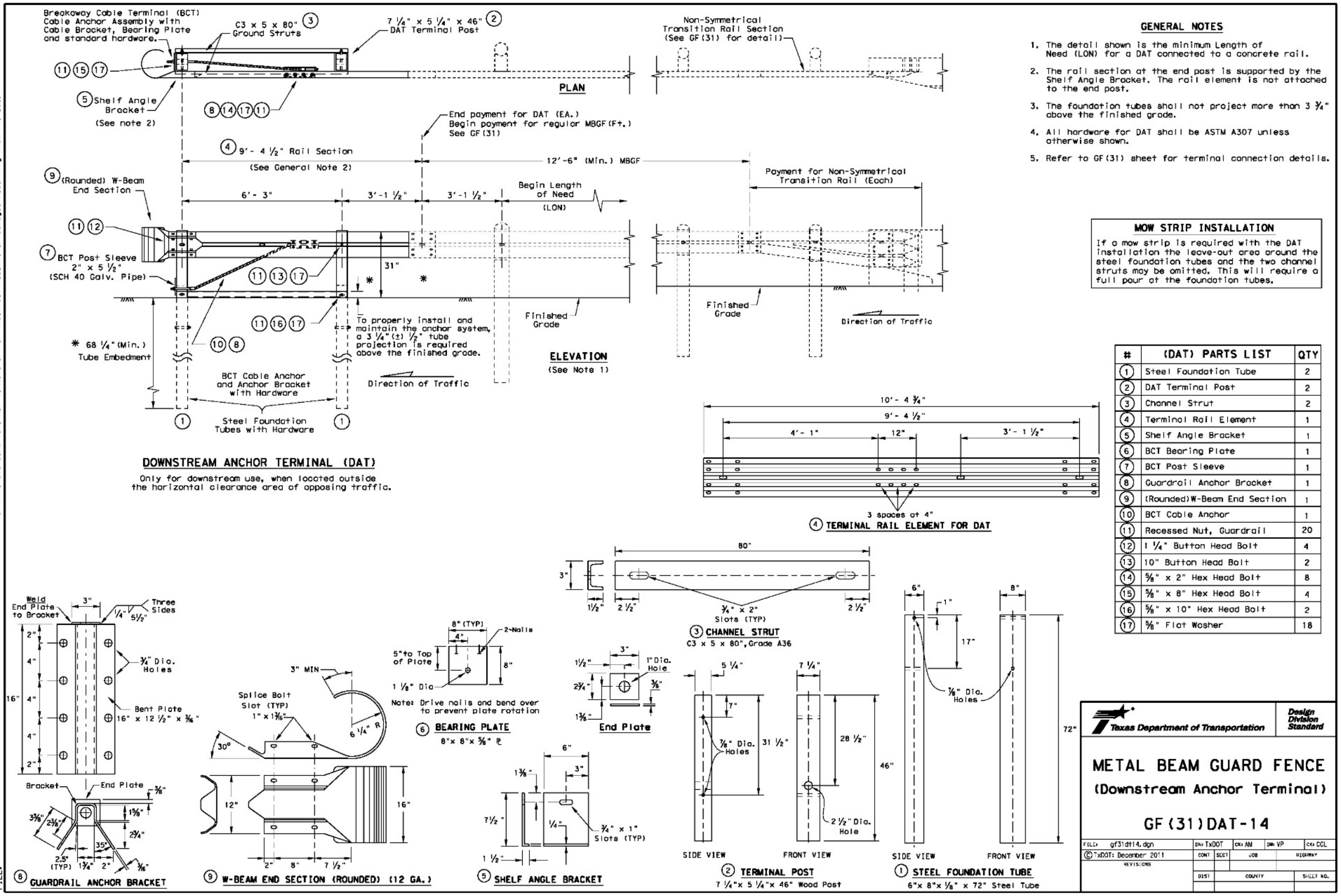
APPENDIX A. DETAILS OF THE MOW STRIP SYSTEMS

A1. MOW STRIP ON WOOD POSTS





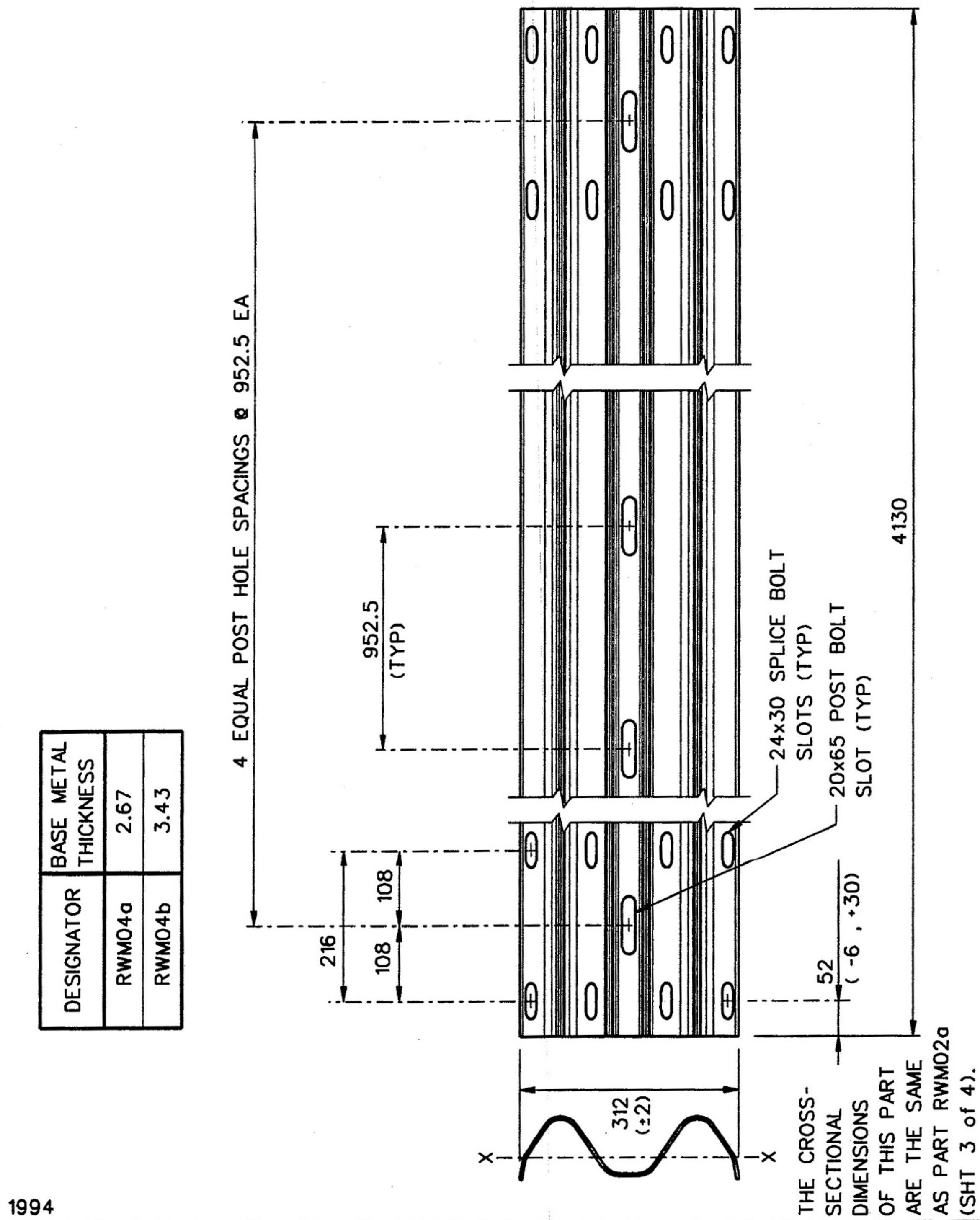
GENERAL NOTES

1. The detail shown is the minimum Length of Need (LON) for a DAT connected to a concrete rail.
2. The rail section at the end post is supported by the Shelf Angle Bracket. The rail element is not attached to the end post.
3. The foundation tubes shall not project more than 3 3/4" above the finished grade.
4. All hardware for DAT shall be ASTM A307 unless otherwise shown.
5. Refer to GF(31) sheet for terminal connection details.

MOW STRIP INSTALLATION

If a mow strip is required with the DAT installation the leave-out area around the steel foundation tubes and the two channel struts may be omitted. This will require a full pour at the foundation tubes.

#	(DAT) PARTS LIST	QTY
1	Steel Foundation Tube	2
2	DAT Terminal Post	2
3	Channel Strut	2
4	Terminal Rail Element	1
5	Shelf Angle Bracket	1
6	BCT Bearing Plate	1
7	BCT Post Sleeve	1
8	Guardrail Anchor Bracket	1
9	(Rounded)W-Beam End Section	1
10	BCT Cable Anchor	1
11	Recessed Nut, Guardrail	20
12	1 1/4" Button Head Bolt	4
13	10" Button Head Bolt	2
14	5/8" x 2" Hex Head Bolt	8
15	5/8" x 8" Hex Head Bolt	4
16	5/8" x 10" Hex Head Bolt	2
17	5/8" Flat Washer	18



DESIGNATOR	BASE METAL THICKNESS
RWM04a	2.67
RWM04b	3.43

4-SPACE W-BEAM GUARDRAIL

RWM04a-b

SHEET NO.	REF. NO.
1 of 2	RE-3-73

SPECIFICATIONS

Corrugated sheet steel beams shall conform to the current requirements of AASHTO M180. The section shall be manufactured from sheets with a nominal width of 483 mm. Guardrail RWM04a shall conform to AASHTO M180 Class A and RWM04b shall conform to Class B. Corrosion protection may be either Type II (zinc-coated) or Type IV (corrosion resistant steel). Corrosion resistant steel should conform to ASTM A606 for Type IV material and shall not be zinc-coated, painted or otherwise treated. Inertial properties are calculated for the whole cross-section without a reduction for the splice bolt holes.

Designator	Area (10^3 mm^2)	I_x (10^6 mm^4)	I_y (10^6 mm^4)	S_x (10^3 mm^3)	S_y (10^3 mm^3)
RWM04a-b	1.3	1.0	--	23	--

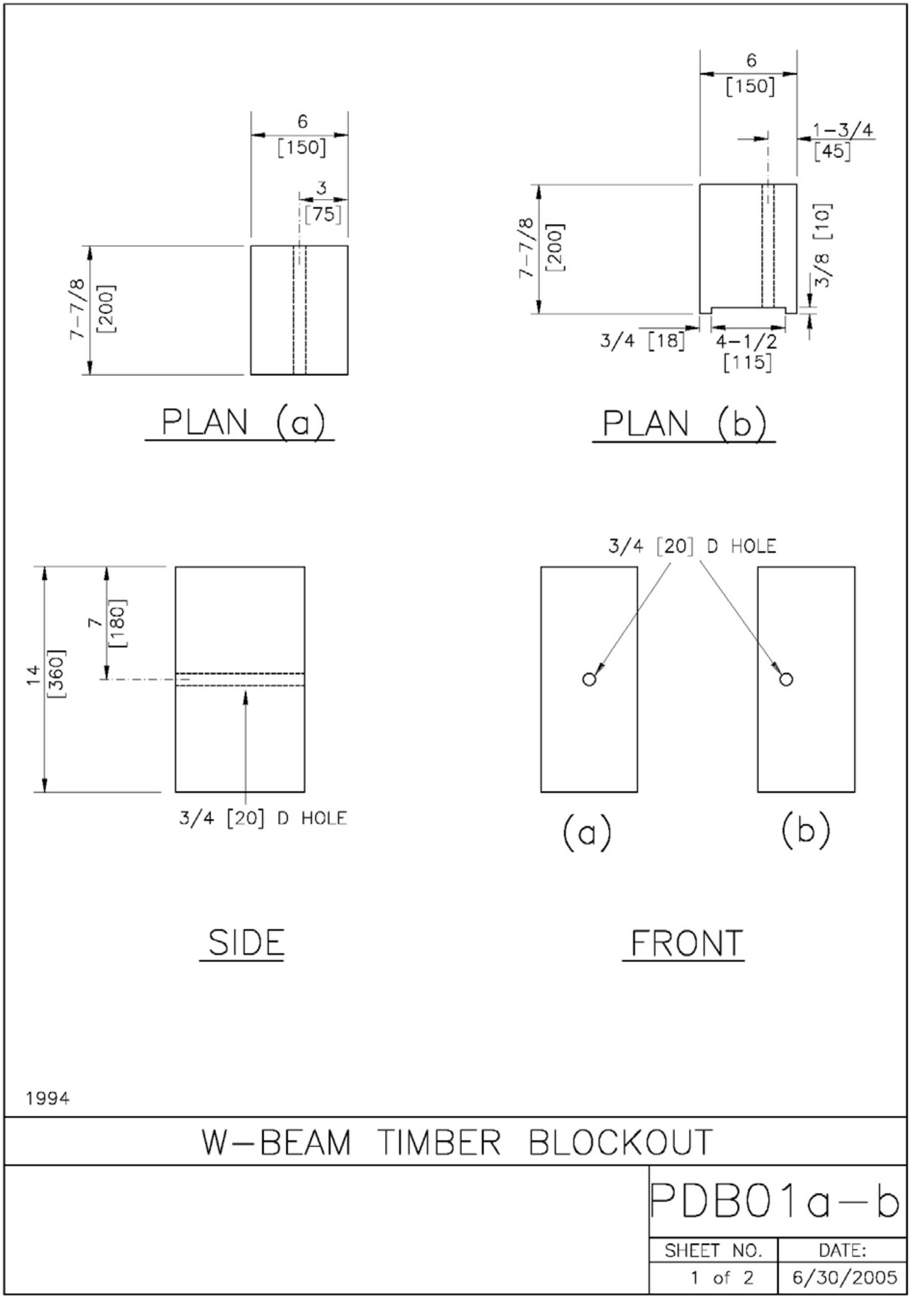
Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

This corrugated sheet steel beam is used as a rail element in transition systems STB02 and STB03 or when a reduced post spacing is desired in the SGR02, SGR04a-b, SGM02, and SGM04a-b.

4-SPACE W-BEAM GUARDRAIL

RWM04a-b	
SHEET NO.	DATE
2 of 2	04-01-95


6
[150]
3
[75]
7-7/8
[200]
PLAN (a)
6
[150]
1-3/4
[45]
7-7/8
[200]
[10]
3/8
3/4 [18]
4-1/2
[115]
PLAN (b)
14
[360]
7
[180]
3/4 [20] D HOLE
SIDE
3/4 [20] D HOLE
(a)
(b)
FRONT
1994
W-BEAM TIMBER BLOCKOUT
PDB01a-b
SHEET NO.
1 of 2
DATE:
6/30/2005

SPECIFICATIONS

Blockouts shall be made of timber with a stress grade of at least 1160 psi [8 MPa]. Grading shall be in accordance with the rules of the West Coast Lumber Inspection Bureau, Southern Pine Inspection Bureau, or other appropriate timber association. Timber for blockouts shall be either rough-sawn (unplaned) or S4S (surfaced four sides) with nominal dimensions indicated. The variation in size of blockouts in the direction parallel to the axis of the bolt holes shall not be more than ± ¼ inch [6 mm]. Only one type of surface finish shall be used for posts and blockouts in any one continuous length of guardrail.

All timber shall receive a preservation treatment in accordance with AASHTO M 133 after all end cuts are made and holes are drilled.

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

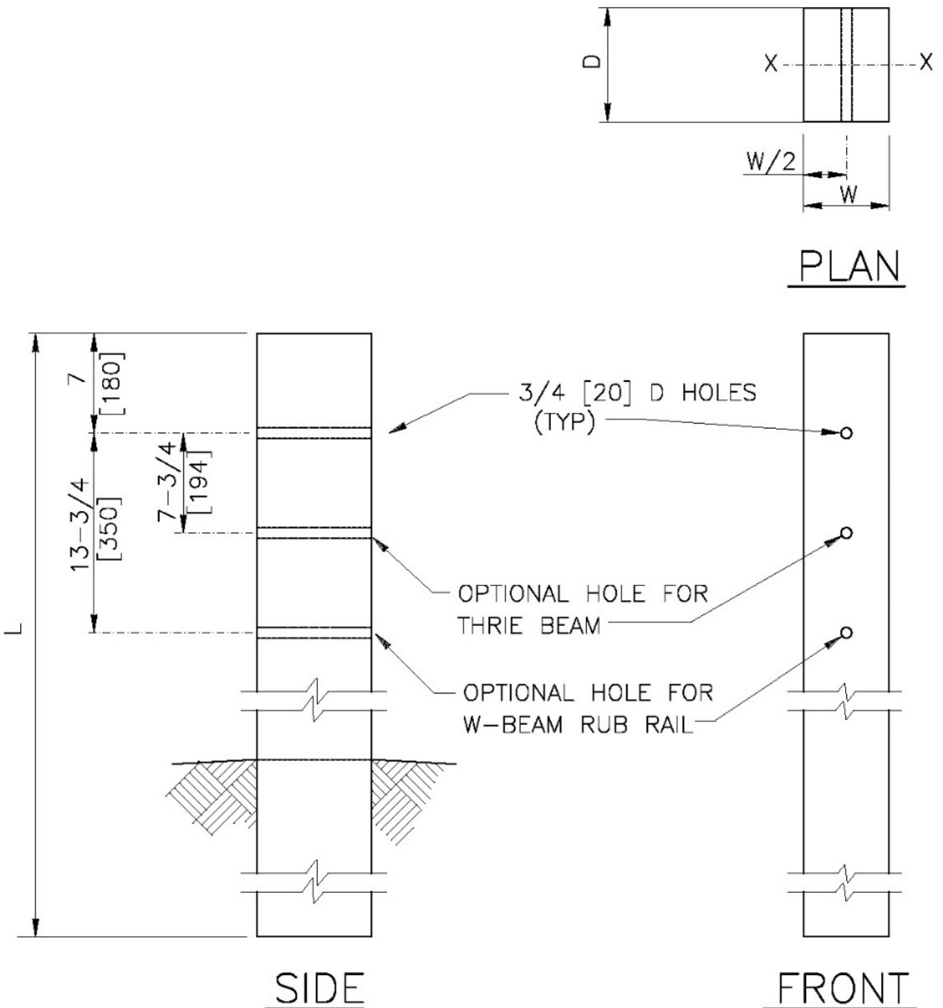
INTENDED USE

Blockout PDB01a is used with wood post PDE01 or PDE02 in the SGR04b strong-post W-beam guardrail and the SGM04b median barrier. Blockout PDB01b is routed to be used with steel post PWE01 or PWE02 in the SGR04c guardrail and the SGM04a median barrier.

W-BEAM TIMBER BLOCKOUT

PDB01a-b

SHEET NO.	DATE
2 of 2	7/06/2005



DESIGNATOR	L	W	D
PDE01	64 [1625]	6 [150]	7-7/8 [200]
PDE02	72 [1830]	6 [150]	7-7/8 [200]
PDE03	78 [1980]	6 [150]	7-7/8 [200]
PDE04	81 [2060]	6 [150]	7-7/8 [200]
PDE05	72 [1830]	7-7/8 [200]	7-7/8 [200]
PDE06	78 [1980]	7-7/8 [200]	7-7/8 [200]
PDE07	72 [1830]	9-7/8 [250]	9-7/8 [250]
PDE08	78 [1980]	9-7/8 [250]	9-7/8 [250]

1994

TIMBER GUARDRAIL POST

PDE01-08

SHEET NO.	DATE:
1 of 2	6/28/2005

SPECIFICATIONS

Posts shall be made of timber with a stress grade of at least 1160 psi [8 MPa]. Stress grading shall be in accordance with the rules of the West Coast Lumber Inspection Bureau, Southern Pine Inspection Bureau, or other appropriate timber association. Timber for posts shall be either rough-sawn (unplaned) or S4S (surfaced four sides) with nominal dimensions indicated. The size tolerance of posts in the direction parallel to the axis of the bolt holes shall not be more than ± ¼ inch [6 mm]. Only one type of surface finish shall be used for posts and blockouts in any one continuous length of guardrail.

All timber shall receive a preservation treatment in accordance with AASHTO M 133 after all end cuts are made and holes are drilled.

Inertial properties shown below are based on the nominal dimensions shown.

Designator	Area in^2 [10^3 mm^2]	I_x in^4 [10^6 mm^4]	I_y in^4 [10^6 mm^4]	S_x in^3 [10^3 mm^3]	S_y in^3 [10^3 mm^3]
PDE01-02	46.5 [30]	240.2 [100]	134.5 [56]	61.0 [1000]	45.8 [750]
PDE03-04	62.0 [40]	319.5 [133]	319.5 [133]	81.3 [1333]	81.3 [1333]
PDE05-06	77.5 [50]	624.6 [260]	401.2 [167]	127.1 [2083]	101.7 [1667]
PDE07-08	97.6 [63]	783.2 [326]	783.2 [326]	158.9 [2604]	158.9 [2604]

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

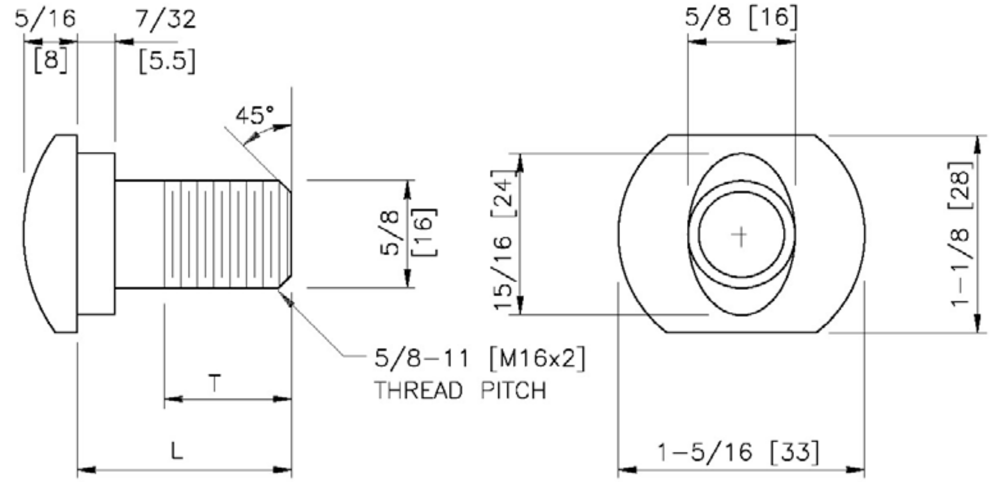
INTENDED USE

These posts are used in a variety of strong-post W-beam and thrie-beam systems, including the SGR04b, SGR04c, and SGR09c guardrails and the SGM04b and SGM09c median barriers.

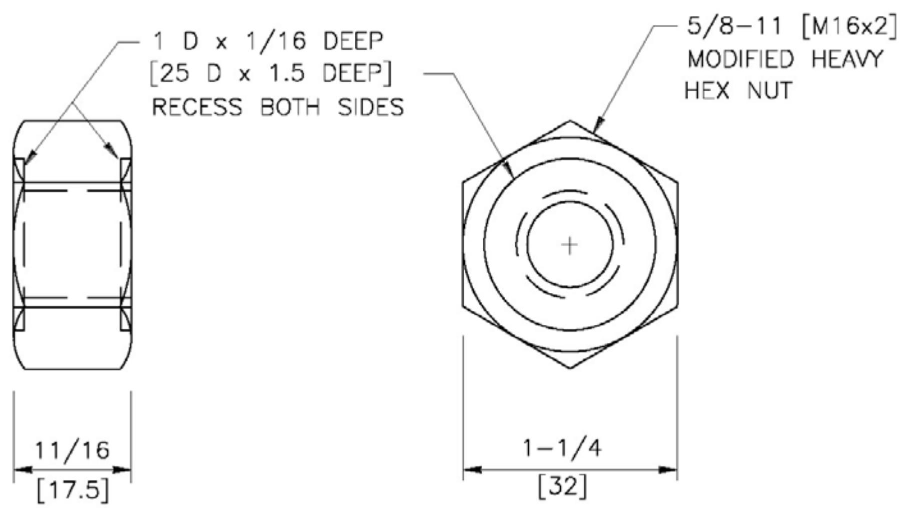
TIMBER GUARDRAIL POST

PDE01-08	
SHEET NO.	DATE
2 of 2	7/06/2005

NOTES: 1. ALL FILLETS SHALL HAVE A MINIMUM RADIUS OF 1/16 [2].
2. IF THE BOLT EXTENDS MORE THAN 1/4 [6] FROM THE NUT THE BOLT SHOULD BE TRIMMED BACK.



DESIGNATOR	L	T (MIN)
FBB01	1-1/4 [35]	1-1/8 [30]
FBB02	2 [50]	1-3/4 [45]
FBB03	10 [255]	4 [100]
FBB04	18 [460]	4 [100]
FBB05	25 [640]	4 [100]



1976

GUARDRAIL BOLT AND RECESSED NUT

FBB01-05

SHEET NO.	DATE:
1 of 2	6/30/2005

SPECIFICATIONS

The geometry and material specifications for this oval shoulder button-headed bolt and hex nut are found in AASHTO M 180. The bolt shall have 5/8-11 [M16x2] threads as defined in ANSI B1.1 [ANSI B1.13M] for Class 2A [6g] tolerances. Bolt material shall conform to ASTM A307 Grade A [ASTM F 568M Class 4.6], with a tensile strength of 60 ksi [400 MPa] and yield strength of 36 ksi [240 MPa]. Material for corrosion-resistant bolts shall conform to ASTM A325 Type 3 [ASTM F 568M Class 8.8.3], with tensile strength of 120 ksi [830 MPa] and yield strength of 92 ksi [660 MPa]. This bolt material has corrosion resistance comparable to ASTM A588 steels. Metric zinc-coated bolt heads shall be marked as specified in ASTM F 568 Section 9 with the symbol "4.6."

Nuts shall have ANSI B1.1 Class 2B [ANSI B1.13M Class 6h] 5/8-11 [M16x2] threads. The geometry of the nuts, with the exception of the recess shown in the drawing, shall conform to ANSI B18.2.2 [ANSI B18.2.4.1M Style 1] for zinc-coated hex nuts (shown in drawing) and ANSI B18.2.2 [ANSI B18.2.4.6M] for heavy hex corrosion-resistant nuts (not shown in drawing). Material for zinc-coated nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade A [AASHTO M 291M (ASTM A 563M) Class 5], and material for corrosion-resistant nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade C3 [AASHTO M 291M (ASTM A 563M) Class 8S3].

When zinc-coated bolts and nuts are required, the coating shall conform to either AASHTO M 232 (ASTM A 153/A 153M) for Class C or AASHTO M 298 (ASTM B 695) for Class 50. Zinc-coated nuts shall be tapped over-size as specified in AASHTO M 291 (ASTM A 563) [AASHTO M 291M (ASTM A 563M)], except that a diametrical allowance of 0.020 inch [0.510 mm] shall be used instead of 0.016 inches [0.420 mm].

Designator	Stress Area of Threaded Bolt Shank (in^2 [mm^2])	Min. Bolt Tensile Strength (kips [kN])
FBB01-05	0.226 [157.0]	13.6 [62.8]

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

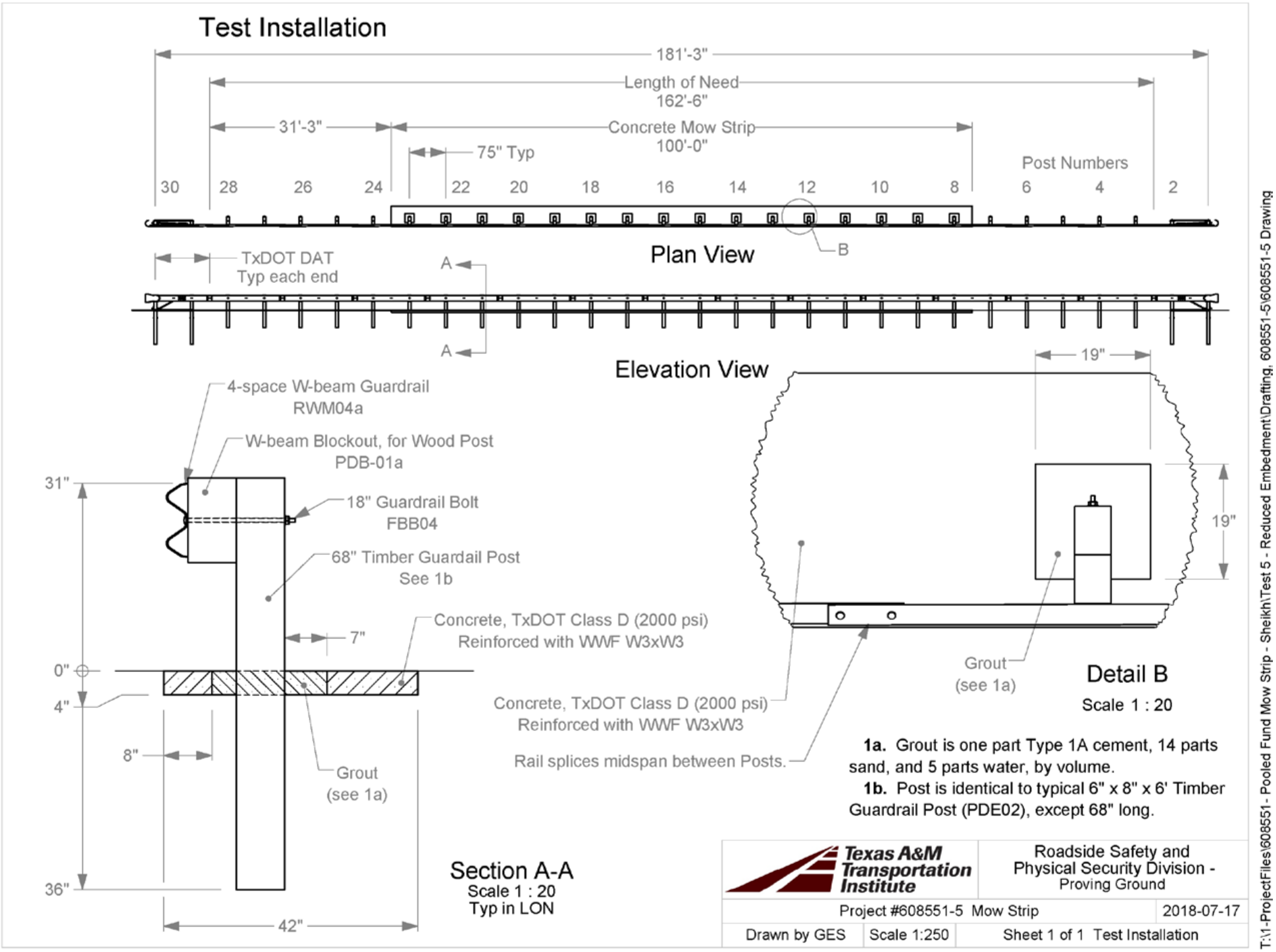
INTENDED USE

These bolts and nuts are used in numerous guardrail and median barrier designs.

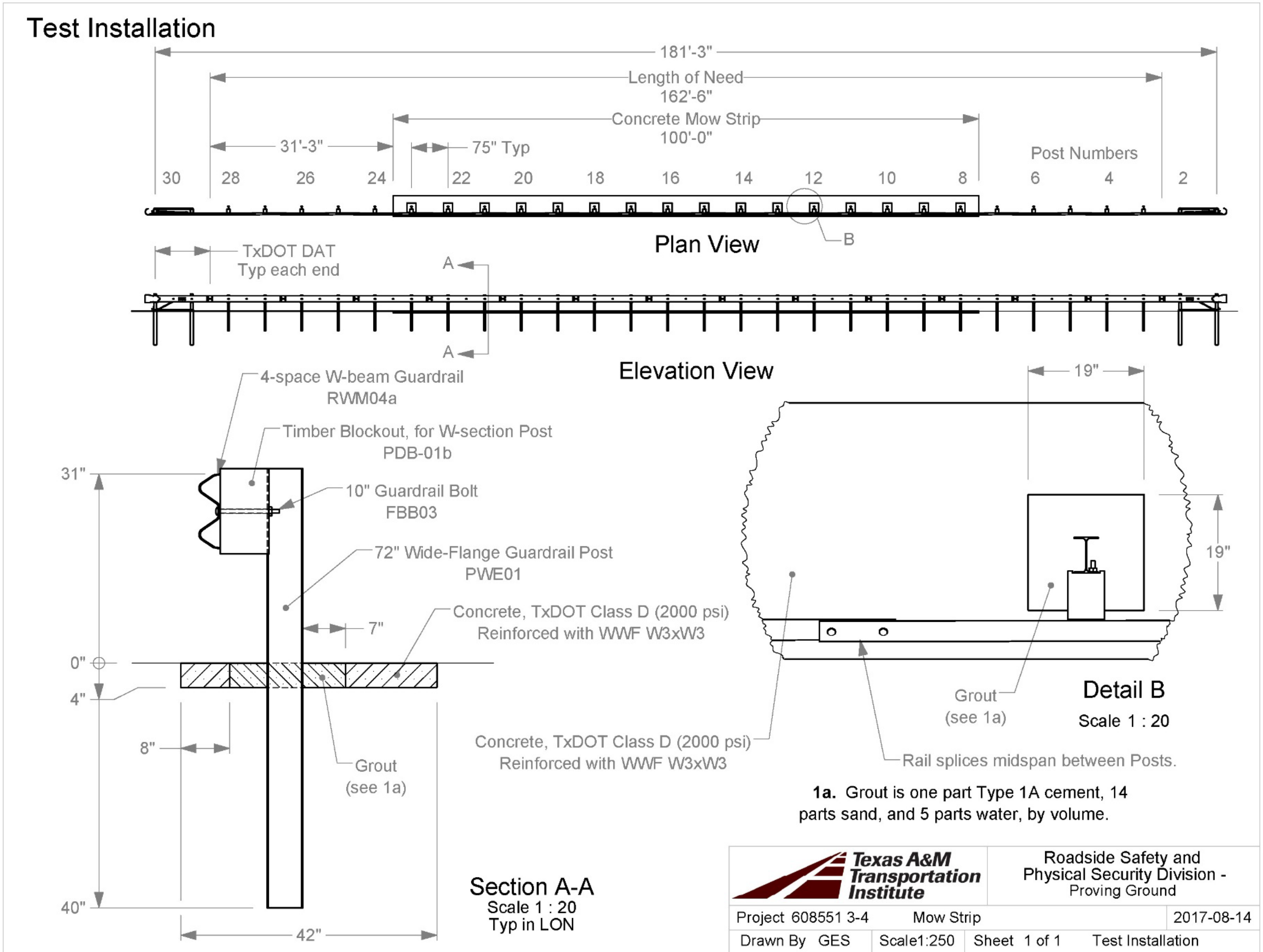
GUARDRAIL BOLT AND RECESSED NUT

FBB01-05	
SHEET NO.	DATE
2 of 2	6/30/2005

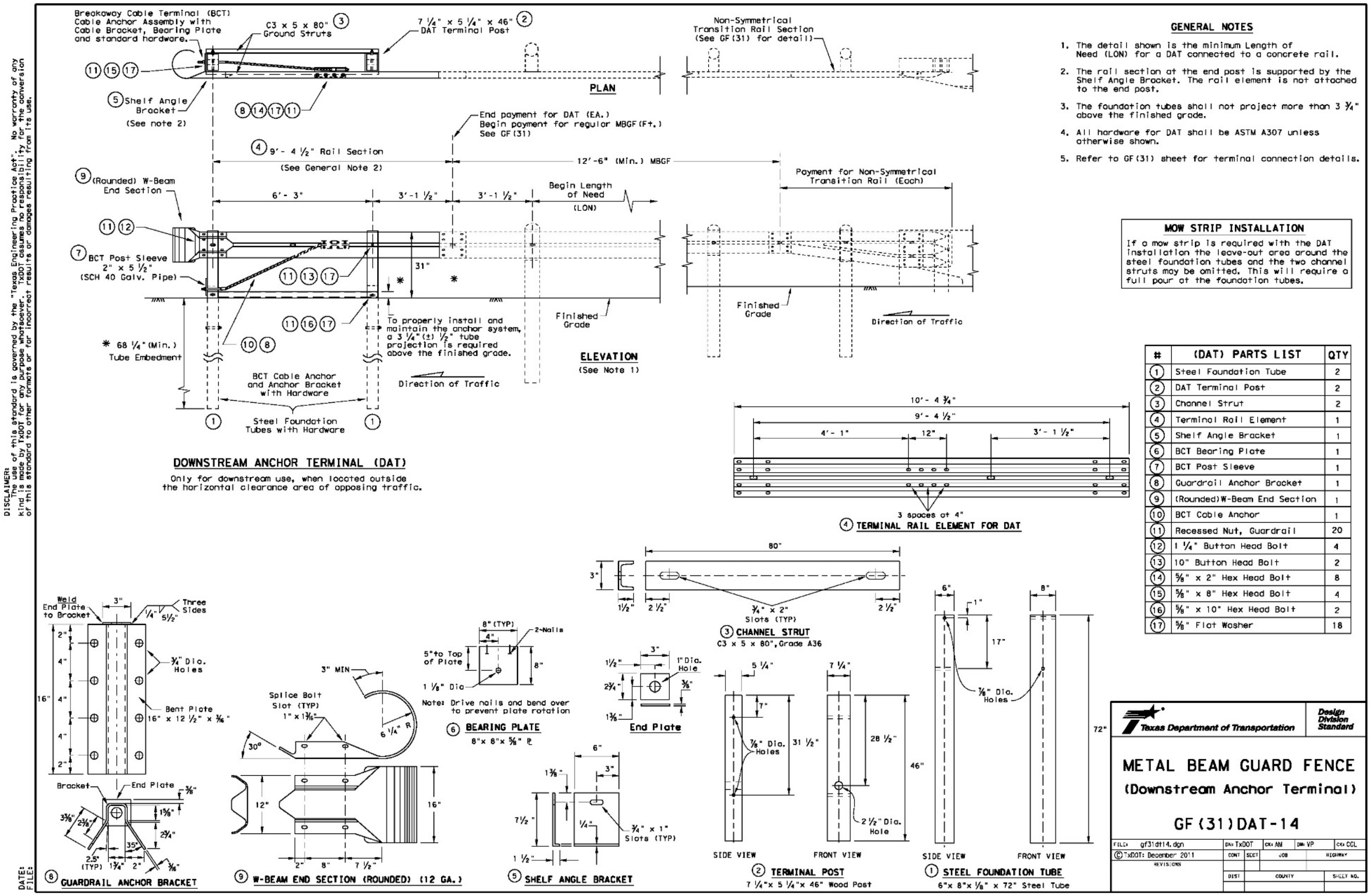
A2. MOW STRIP ON WOOD POSTS WITH REDUCED EMBEDMENT



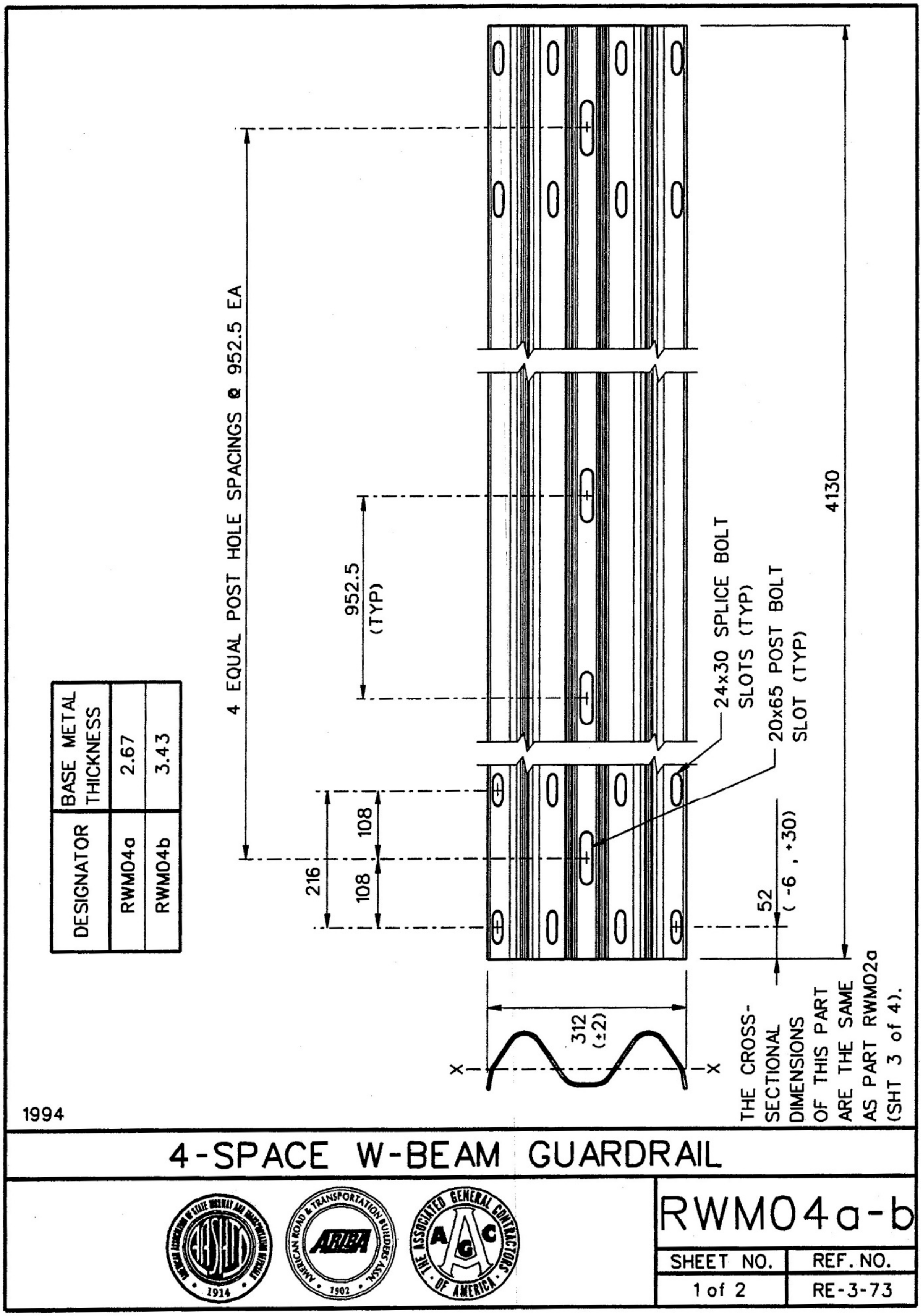
A3. MOW STRIP ON STEEL POSTS



T:\1-ProjectFiles\608551- Pooled Fund Mow Strip - Sheikh\Drafting, 608551\608551 3-4 Drawing



#	(DAT) PARTS LIST	QTY
1	Steel Foundation Tube	2
2	DAT Terminal Post	2
3	Channel Strut	2
4	Terminal Rail Element	1
5	Shelf Angle Bracket	1
6	BCT Bearing Plate	1
7	BCT Post Sleeve	1
8	Guardrail Anchor Bracket	1
9	(Rounded) W-Beam End Section	1
10	BCT Cable Anchor	1
11	Recessed Nut, Guardrail	20
12	1 ¼" Button Head Bolt	4
13	10" Button Head Bolt	2
14	⅝" x 2" Hex Head Bolt	8
15	⅝" x 8" Hex Head Bolt	4
16	⅝" x 10" Hex Head Bolt	2
17	⅝" Flat Washer	18


4-SPACE W-BEAM GUARDRAIL
RWM04a-b
SHEET NO.
1 of 2
REF. NO.
RE-3-73
1994
DESIGNATOR
BASE METAL THICKNESS
RWM04a
2.67
RWM04b
3.43
4 EQUAL POST HOLE SPACINGS @ 952.5 EA
952.5 (TYP)
216
108
108
24x30 SPLICE BOLT SLOTS (TYP)
20x65 POST BOLT SLOT (TYP)
52 (-6 , +30)
4130
312 (±2)
X
X
THE CROSS-SECTIONAL DIMENSIONS OF THIS PART ARE THE SAME AS PART RWM02a (SHT 3 of 4).

SPECIFICATIONS

Corrugated sheet steel beams shall conform to the current requirements of AASHTO M180. The section shall be manufactured from sheets with a nominal width of 483 mm. Guardrail RWM04a shall conform to AASHTO M180 Class A and RWM04b shall conform to Class B. Corrosion protection may be either Type II (zinc-coated) or Type IV (corrosion resistant steel). Corrosion resistant steel should conform to ASTM A606 for Type IV material and shall not be zinc-coated, painted or otherwise treated. Inertial properties are calculated for the whole cross-section without a reduction for the splice bolt holes.

Designator	Area (10^3 mm^2)	I_x (10^6 mm^4)	I_y (10^6 mm^4)	S_x (10^3 mm^3)	S_y (10^3 mm^3)
RWM04a-b	1.3	1.0	--	23	--

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

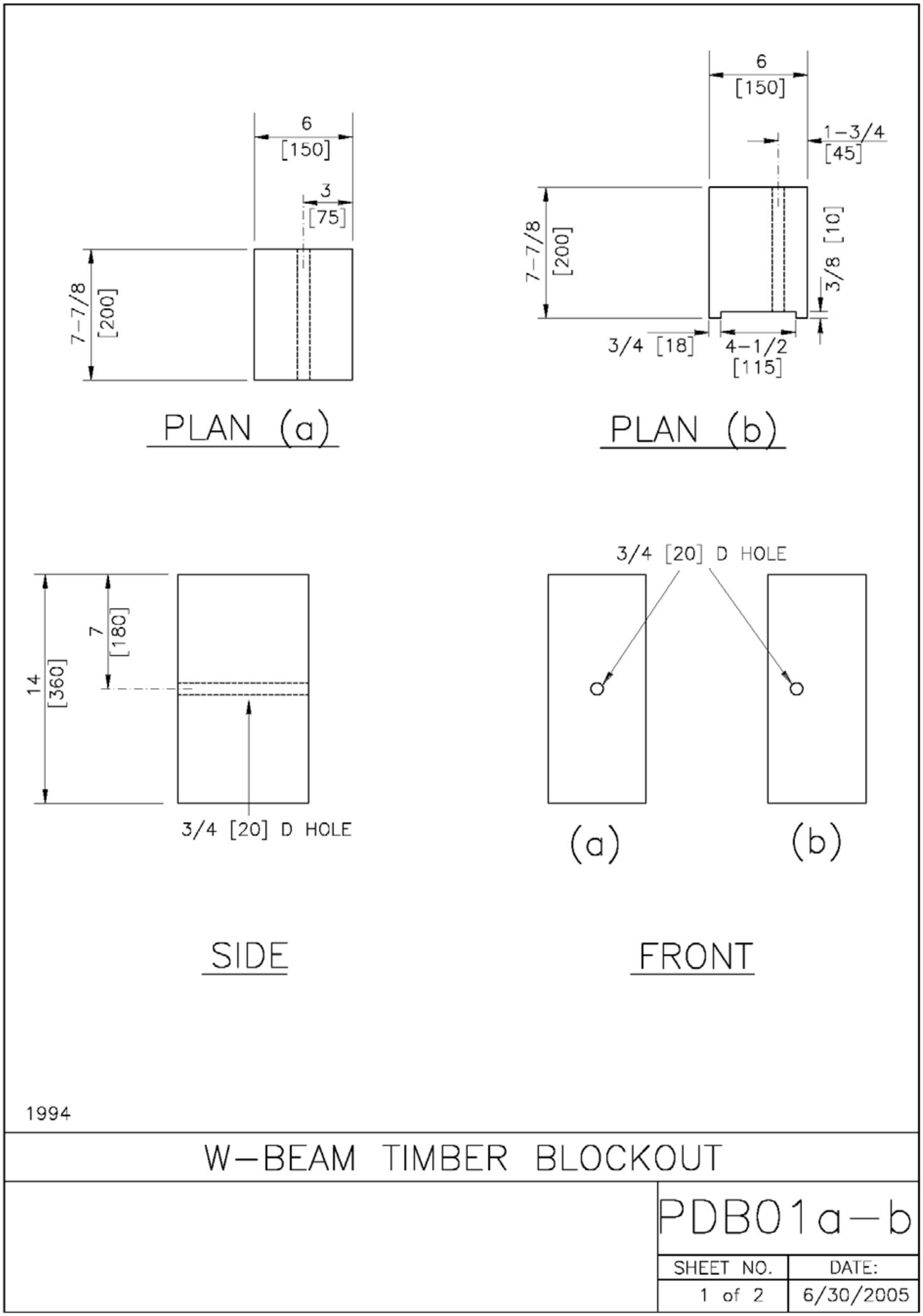
INTENDED USE

This corrugated sheet steel beam is used as a rail element in transition systems STB02 and STB03 or when a reduced post spacing is desired in the SGR02, SGR04a-b, SGM02, and SGM04a-b.

4-SPACE W-BEAM GUARDRAIL

RWM04a-b

SHEET NO.	DATE
2 of 2	04-01-95


6
[150]
3
[75]
7-7/8
[200]
PLAN (a)
6
[150]
1-3/4
[45]
7-7/8
[200]
[10]
3/8
3/4 [18]
4-1/2
[115]
PLAN (b)
14
[360]
7
[180]
3/4 [20] D HOLE
SIDE
3/4 [20] D HOLE
(a)
(b)
FRONT
1994
W-BEAM TIMBER BLOCKOUT
PDB01a-b
SHEET NO.
1 of 2
DATE:
6/30/2005

SPECIFICATIONS

Blockouts shall be made of timber with a stress grade of at least 1160 psi [8 MPa]. Grading shall be in accordance with the rules of the West Coast Lumber Inspection Bureau, Southern Pine Inspection Bureau, or other appropriate timber association. Timber for blockouts shall be either rough-sawn (unplaned) or S4S (surfaced four sides) with nominal dimensions indicated. The variation in size of blockouts in the direction parallel to the axis of the bolt holes shall not be more than ± ¼ inch [6 mm]. Only one type of surface finish shall be used for posts and blockouts in any one continuous length of guardrail.

All timber shall receive a preservation treatment in accordance with AASHTO M 133 after all end cuts are made and holes are drilled.

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

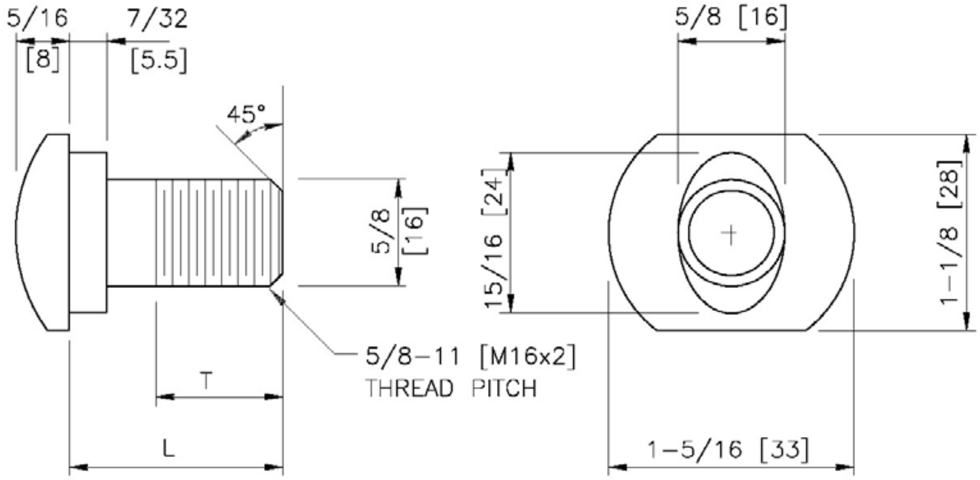
INTENDED USE

Blockout PDB01a is used with wood post PDE01 or PDE02 in the SGR04b strong-post W-beam guardrail and the SGM04b median barrier. Blockout PDB01b is routed to be used with steel post PWE01 or PWE02 in the SGR04c guardrail and the SGM04a median barrier.

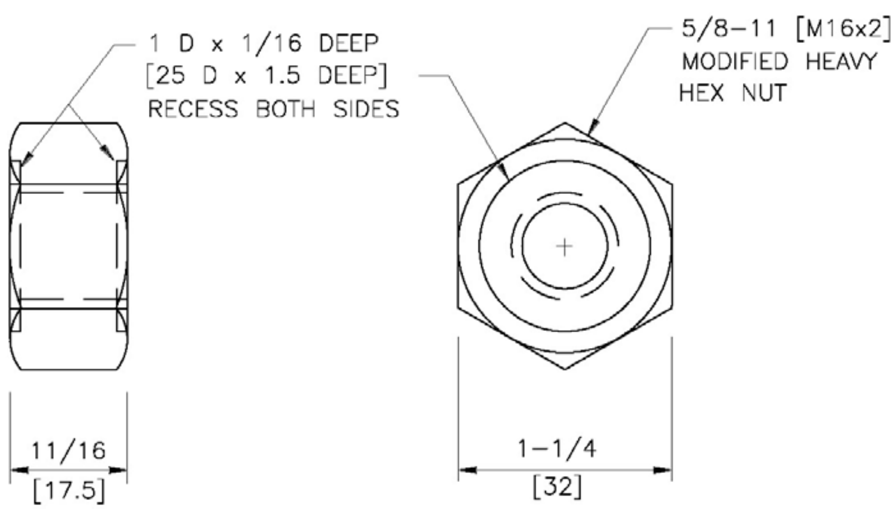
W-BEAM TIMBER BLOCKOUT

PDB01a-b	
SHEET NO.	DATE
2 of 2	7/06/2005

NOTES: 1. ALL FILLETS SHALL HAVE A MINIMUM RADIUS OF 1/16 [2].
2. IF THE BOLT EXTENDS MORE THAN 1/4 [6] FROM THE NUT THE BOLT SHOULD BE TRIMMED BACK.



DESIGNATOR	L	T (MIN)
FBB01	1-1/4 [35]	1-1/8 [30]
FBB02	2 [50]	1-3/4 [45]
FBB03	10 [255]	4 [100]
FBB04	18 [460]	4 [100]
FBB05	25 [640]	4 [100]



1976

GUARDRAIL BOLT AND RECESSED NUT

FBB01-05

SHEET NO.	DATE:
1 of 2	6/30/2005

SPECIFICATIONS

The geometry and material specifications for this oval shoulder button-headed bolt and hex nut are found in AASHTO M 180. The bolt shall have 5/8-11 [M16x2] threads as defined in ANSI B1.1 [ANSI B1.13M] for Class 2A [6g] tolerances. Bolt material shall conform to ASTM A307 Grade A [ASTM F 568M Class 4.6], with a tensile strength of 60 ksi [400 MPa] and yield strength of 36 ksi [240 MPa]. Material for corrosion-resistant bolts shall conform to ASTM A325 Type 3 [ASTM F 568M Class 8.8.3], with tensile strength of 120 ksi [830 MPa] and yield strength of 92 ksi [660 MPa]. This bolt material has corrosion resistance comparable to ASTM A588 steels. Metric zinc-coated bolt heads shall be marked as specified in ASTM F 568 Section 9 with the symbol "4.6."

Nuts shall have ANSI B1.1 Class 2B [ANSI B1.13M Class 6h] 5/8-11 [M16x2] threads. The geometry of the nuts, with the exception of the recess shown in the drawing, shall conform to ANSI B18.2.2 [ANSI B18.2.4.1M Style 1] for zinc-coated hex nuts (shown in drawing) and ANSI B18.2.2 [ANSI B18.2.4.6M] for heavy hex corrosion-resistant nuts (not shown in drawing). Material for zinc-coated nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade A [AASHTO M 291M (ASTM A 563M) Class 5], and material for corrosion-resistant nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade C3 [AASHTO M 291M (ASTM A 563M) Class 8S3].

When zinc-coated bolts and nuts are required, the coating shall conform to either AASHTO M 232 (ASTM A 153/A 153M) for Class C or AASHTO M 298 (ASTM B 695) for Class 50. Zinc-coated nuts shall be tapped over-size as specified in AASHTO M 291 (ASTM A 563) [AASHTO M 291M (ASTM A 563M)], except that a diametrical allowance of 0.020 inch [0.510 mm] shall be used instead of 0.016 inches [0.420 mm].

Designator	Stress Area of Threaded Bolt Shank (in^2 [mm^2])	Min. Bolt Tensile Strength (kips [kN])
FBB01-05	0.226 [157.0]	13.6 [62.8]

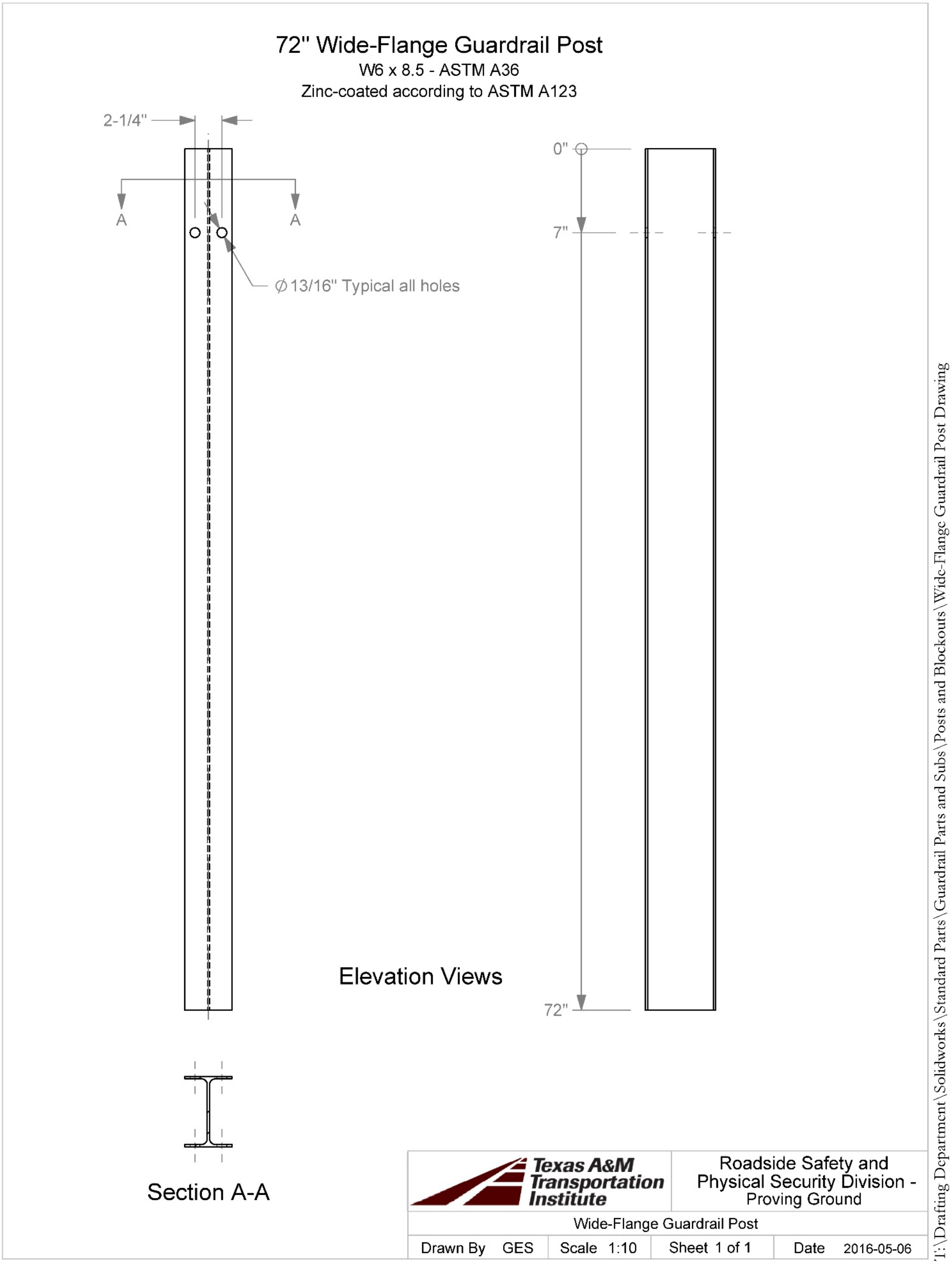
Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

These bolts and nuts are used in numerous guardrail and median barrier designs.

GUARDRAIL BOLT AND RECESSED NUT

FBB01-05	
SHEET NO.	DATE
2 of 2	6/30/2005


72" Wide-Flange Guardrail Post
W6 x 8.5 - ASTM A36
Zinc-coated according to ASTM A123
2-1/4"
A
A
∅13/16" Typical all holes
0"
7"
72"
Elevation Views
Section A-A
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Wide-Flange Guardrail Post
Drawn By GES
Scale 1:10
Sheet 1 of 1
Date 2016-05-06
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Posts and Blockouts\Wide-Flange Guardrail Post Drawing

First Test: 608551-3

Texas A&M Transportation Institute Proving Ground 3100 SH 47, Bldg 7091 Bryan, TX 77807 Texas A&M University College Station, TX 77843 Phone 979-845-6375	5.7.2 Concrete Break	Doc. No. QPF 5.7.2	Revision Date: 2012-09-17
Quality Policy Form	Revised by: G. E. Schroeder Approved by: C. E. Buth	Revision: 5	Page: 1 of 1

Project No.: 608551-3

Placement: SLAB / STRIP

Casting Date: 2017-9-18

Mix Design P.S.I.: 3000

Truck No.	Batch Ticket	Yards

Printed name of Technician taking sample: GREG FRITZ

Signature of Technician taking sample: [signature]

Printed name of Technician breaking sample: GREG FRITZ

Signature of Technician breaking sample: [signature]

Break Date	Cylinder Age	Truck No.	Total Load (Pounds)	PSI Break	Average
2017-9-22	4 DAYS	1	53000	1875	
2017-9-22	4 DAYS	1	50000	1765	1820
2017-10-9	17 DAYS	1	87000	3075	
2017-10-9	17 DAYS	1	85000	3005	3040

Test No. 608551-1 Grout Strength

GROUT COMPRESSIVE STRENGTH TEST REPORT

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Report Number: A1171057.0017
Service Date: 11/03/17
Report Date: 11/11/17 Revision 2 - 7-day results
Task: PO #608551 - Grout

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength: 150 psi @ 28 days

Mix ID: Flow fill
Supplier: Martin Marietta Materials
Batch Time: 1009 **Plant:** 617
Truck No.: 8109 **Ticket No.:** 4325823

Sample Information

Sample Date: 11/03/17 **Sample Time:** 1130
Sampled By: Mohammed Mobeen
Weather Conditions: Cloudy, light wind
Accumulative Yards: 3/3 **Batch Size:** 3
Sample Size:
Sample Location: PO #608551
Placement Location: PO #608551
Form Material: Cardboard Form **No. Units:**
Samples Plumb: Yes
Temperature Range:

Field Test Data

Test	Result	Specification
Slump (in):	9 1/2	
Grout Temp. (F):	88	
Ambient Temp. (F):	78	

Laboratory Test Data

Set No.	Specimen ID	Date Received	Date Tested	Age (days)	Area (sq in)	Maximum Load (lbs)	Compressive Strength (psi)	Fracture Type
1	A	11/06/17	11/10/17	7	10.89	1,203	110	
1	B	11/06/17	11/10/17	7	10.89	1,421	130	
1	C	11/06/17	11/10/17	7	10.89	1,203	110	
						Average (7 days)	**120**	
1	D	11/06/17	11/12/17	9				
1	E	11/06/17	11/12/17	9				
1	F	11/06/17	11/12/17	9				
1	G	11/06/17	12/01/17	28				
1	H	11/06/17	12/01/17	28				
1	I	11/06/17	12/01/17	28				

Initial Cure: Outside Plastic Lids **Final Cure:** Water Storage Tank
Comments:

Samples Made By: Terracon
Services: Obtain sample of grout at the placement location and cast specimens for compressive strength determination.

Terracon Rep.: Mohammed Mobeen **Start/Stop:** 0930-1130
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Nicole Farabee

Reviewed By:
Mark E.Dornak, P.E.
Project Manager

Test Methods: ASTM C109, ASTM C1019
The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0009, 11-16-12, Rev.6 Page 1 of 1

Test No. 608551-2 Grout Strength

GROUT COMPRESSIVE STRENGTH TEST REPORT

Terracon

Report Number: A1171057.0022
Service Date: 11/17/17
Report Date: 12/06/17 Revision 2 - Break dates
Task: PO #608551 - Grout

6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength:

Mix ID: EFLOW15
Supplier: Martin Marietta Materials
Batch Time: 1308 **Plant:** 617
Truck No.: 7130 **Ticket No.:** 4356258

Sample Information

Sample Date: 11/17/17 **Sample Time:** 1400
Sampled By: Matcek, James
Weather Conditions: Partly cloudy
Accumulative Yards: 3/3 **Batch Size:** 3
Sample Size: 1 cubic foot
Sample Location: Guard rail post
Placement Location: Guard rail post embed
Form Material: Cardboard Form **No. Units:**
Samples Plumb: Yes
Temperature Range:

Field Test Data

Test	Result	Specification
Slump (in):	11 1/2	
Grout Temp. (F):	84	
Ambient Temp. (F):	81	

Laboratory Test Data

Set No.	Specimen ID	Date Received	Date Tested	Age (days)	Area (sq in)	Maximum Load (lbs)	Compressive Strength (psi)	Fracture Type
1	A	11/18/17	11/27/17	10	10.73	1,585	150	
1	B	11/18/17	11/27/17	10	10.73	2,569	240	
1	C	11/18/17	11/27/17	10	10.73	2,350	220	
						Average (10 days)	**200**	
1	D	11/18/17	12/05/17	18	10.73	2,077	190	
1	E	11/18/17	12/05/17	18	10.73	2,296	210	
1	F	11/18/17	12/05/17	18	10.73	1,476	140	
						Average (18 days)	**180**	

Initial Cure: Outside Plastic Lids **Final Cure:** Water Storage Tank
Comments:

Samples Made By: Terracon
Services: Obtain sample of grout at the placement location and cast specimens for compressive strength determination.

Terracon Rep.: Matcek, James
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Nicole Farabee

Start/Stop: 1300-1430

Reviewed By:
Shane Sullivan
Project Manager

Test Methods: ASTM C109, ASTM C1019
The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0009, 11-16-12, Rev.6

Page 1 of 1

Test No. 608551-5 Grout Strength

GROUT COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0052
Service Date: 01/04/19
Report Date: 02/06/19 Revision 1 - break data
Task: PO #608551 - Grout

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength:

Mix ID: EFLOW 15
Supplier: Martin Marietta
Batch Time: 0842 **Plant:** 617
Truck No.: 8123 **Ticket No.:** 5146817

Field Test Data

Test	Result	Specification
Slump (in):	7 1/2	Not Specified
Grout Temp. (F):	50	40 - 95
Ambient Temp. (F):	51	40 - 95

Sample Information

Sample Date: 01/04/19 **Sample Time:** 1000
Sampled By: Mohammed Mobeen
Weather Conditions: Clear, light wind
Accumulative Yards: 5/5 **Batch Size:** 5
Sample Size:
Sample Location: job #608551
Placement Location: job #608551
Form Material: Cardboard Form **No. Units:** 8
Samples Plumb: Yes
Temperature Range:

Laboratory Test Data

Set No.	Specimen ID	Date Received	Date Tested	Age (days)	Area (sq in)	Maximum Load (lbs)	Compressive Strength (psi)	Tested By
1	A	01/04/19	01/17/19	13	10.24	1,413	140	BJA
1	B	01/04/19	01/17/19	13	10.24	1,695	170	BJA
1	C	01/04/19	01/17/19	13	10.24	1,582	150	BJA
						Average (13 days)	**150**	
1	D	01/04/19	02/04/19	31	10.89	1,582	150	BJA
1	E	01/04/19	02/04/19	31	10.89	1,808	170	BJA
1	F	01/04/19	02/04/19	31	10.89	2,034	190	BJA
						Average (31 days)	**170**	
1	al	01/04/19		Hold				
1	H	01/04/19		Hold				

Initial Cure: Onsite Cooler **Final Cure:** Cure Box

Comments:

Samples Made By: Terracon
Services: Obtain sample of grout at the placement location and cast specimens for compressive strength determination.

Terracon Rep.: Mohammed Mobeen **Start/Stop:** 0830-1030
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Andrea Gieser

Reviewed By: Shane Sullivan
Shane Sullivan
Project Manager

Test Methods: ASTM C109, ASTM C1019
The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

Page 1 of 1

CR0009, 11-16-12, Rev.6

Test No. 608551-3 Grout Strength

GROUT COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0010
Service Date: 09/22/17
Report Date: 10/10/17 Revision 4 - 21-day results
Task: PO #608551 - Grout

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength: 100 psi @ 28 days

Mix ID:
Supplier: Martin Marrietta
Batch Time: **Plant:** On site
Truck No.: **Ticket No.:**

Field Test Data

Test	Result	Specification
Slump (in):	8	
Grout Temp. (F):	93	
Ambient Temp. (F):		

Sample Information

Sample Date: 09/22/17 **Sample Time:** 1500
Sampled By: Mohammed Mobeen
Weather Conditions: Partly cloudy, light wind
Accumulative Yards: 20 **Batch Size:**
Sample Size:
Sample Location: PO #608551
Placement Location: N/A
Form Material: Cardboard Form **No. Units:** 18
Samples Plumb: Yes
Temperature Range:

Laboratory Test Data

Set No.	Specimen ID	Measured Slump (in)	Measured Flow (sec)	Date Received	Date Tested	Age (days)	Area (sq in)	Maximum Load (lbs)	Compressive Strength (psi)
1	A	8		09/25/17	10/02/17	10	10.24	1,148	110
1	B	8		09/25/17	10/02/17	10	10.24	875	90
1	C	8		09/25/17	10/02/17	10	10.24	1,203	120
1	D	8		09/25/17	10/02/17	10	10.24	984	100
1	E	8		09/25/17	10/02/17	10	10.24	1,040	100
							Average (10 days)		**100**
1	F	8		09/25/17	10/09/17	17	10.56	1,312	120
1	G	8		09/25/17	10/09/17	17	10.56	1,640	160
1	H	8		09/25/17	10/09/17	17	10.56	1,858	180
							Average (17 days)		**150**
1	I	8		09/25/17	10/13/17	21			
1	J	8		09/25/17	10/13/17	21			
1	K	8		09/25/17	10/13/17	21			
1	L	8		09/25/17	10/20/17	28			
1	M	8		09/25/17	10/20/17	28			
1	N	8		09/25/17	10/20/17	28			
1	O	8		09/25/17		Hold			
1	P	8		09/25/17		Hold			
1	Q	8		09/25/17		Hold			
1	R	8		09/25/17		Hold			
1	S	8		09/25/17		Hold			
1	T	8		09/25/17		Hold			

Initial Cure: Outside Plastic Lids **Final Cure:** Cure Box
Comments:

CR0009, 11-16-12, Rev.6

Test No. 608551-4 Grout Strength

GROUT COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0010
Service Date: 09/22/17
Report Date: 10/25/17 Revision 6 - Break data
Task: PO #608551 - Grout

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength: 100 psi @ 28 days

Mix ID:
Supplier: Martin Marrietta
Batch Time: **Plant:** On site
Truck No.: **Ticket No.:**

Field Test Data

Test	Result	Specification
Slump (in):	8	
Grout Temp. (F):	93	
Ambient Temp. (F):		

Sample Information

Sample Date: 09/22/17 **Sample Time:** 1500
Sampled By: Mohammed Mobeen
Weather Conditions: Partly cloudy, light wind
Accumulative Yards: 20 **Batch Size:**
Sample Size:
Sample Location: PO #608551
Placement Location: N/A
Form Material: Cardboard Form **No. Units:** 18
Samples Plumb: Yes
Temperature Range:

Laboratory Test Data

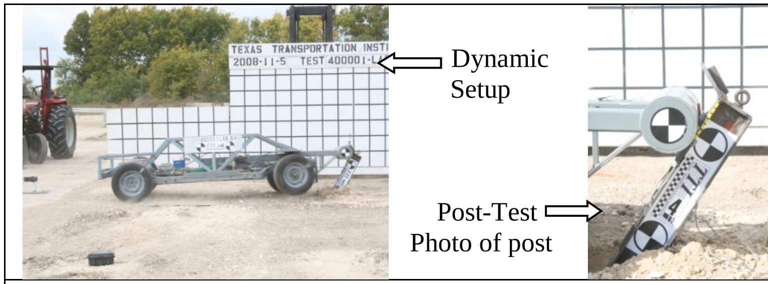
Set No.	Specimen ID	Measured Slump (in)	Measured Flow (sec)	Date Received	Date Tested	Age (days)	Area (sq in)	Maximum Load (lbs)	Compressive Strength (psi)
1	A	8		09/25/17	10/02/17	10	10.24	1,148	110
1	B	8		09/25/17	10/02/17	10	10.24	875	90
1	C	8		09/25/17	10/02/17	10	10.24	1,203	120
1	D	8		09/25/17	10/02/17	10	10.24	984	100
1	E	8		09/25/17	10/02/17	10	10.24	1,040	100
							Average (10 days)		**100**
1	F	8		09/25/17	10/09/17	17	10.56	1,312	120
1	G	8		09/25/17	10/09/17	17	10.56	1,640	160
1	H	8		09/25/17	10/09/17	17	10.56	1,858	180
							Average (17 days)		**150**
1	I	8		09/25/17	10/13/17	21	10.40	1,858	180
1	J	8		09/25/17	10/13/17	21	10.40	1,749	170
1	K	8		09/25/17	10/13/17	21	10.40	1,968	190
							Average (21 days)		**180**
1	L	8		09/25/17	10/20/17	28	10.56	1,913	180
1	M	8		09/25/17	10/20/17	28	10.56	1,640	160
1	N	8		09/25/17	10/20/17	28	10.56	2,205	210
							Average (28 days)		**180**
1	O	8		09/25/17		Hold			
1	P	8		09/25/17		Hold			
1	Q	8		09/25/17		Hold			
1	R	8		09/25/17		Hold			
1	S	8		09/25/17		Hold			
1	T	8		09/25/17		Hold			

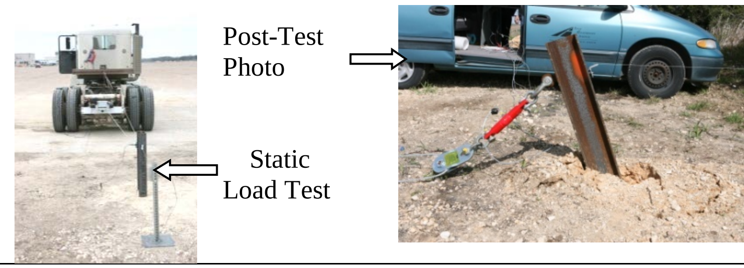
Initial Cure: Outside Plastic Lids **Final Cure:** Cure Box

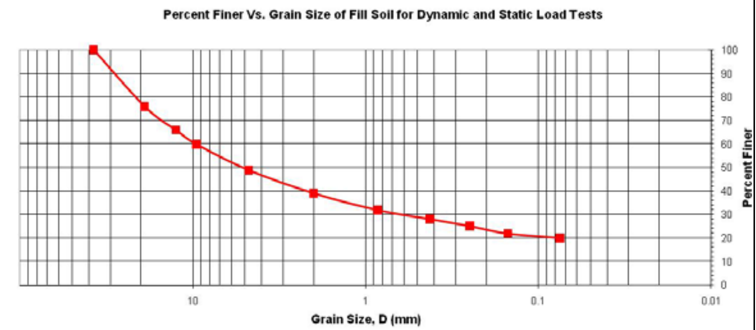
Comments: **Average compressive strength of 28 day Prism complies with the specified strength.**

CR0009, 11-16-12, Rev.6

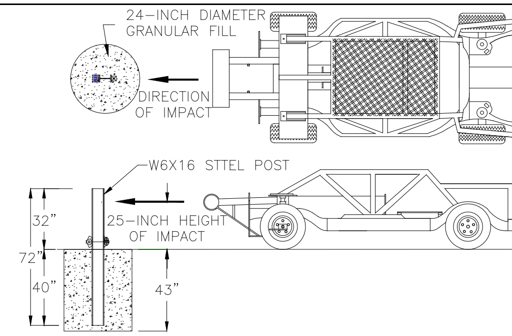
Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.

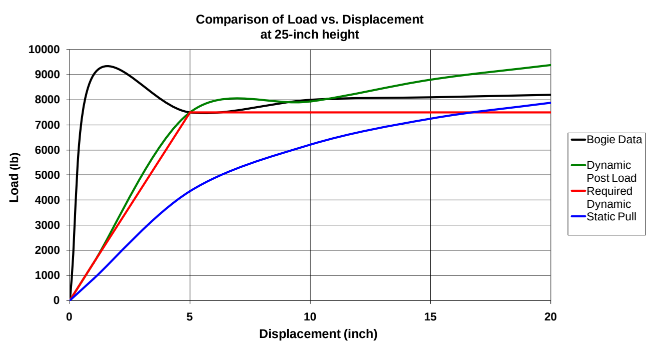




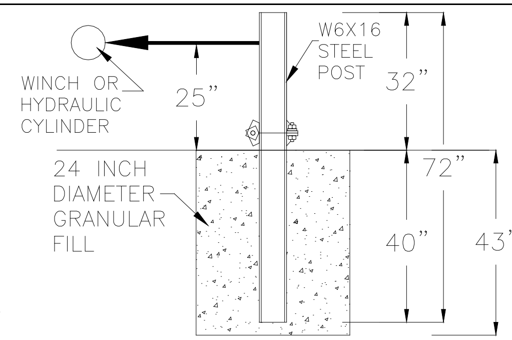


Dynamic Test Installation Details



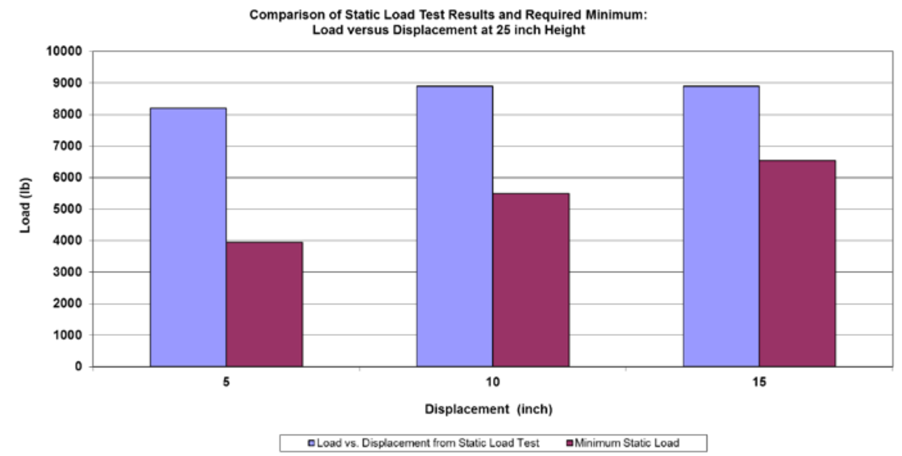


Static Load Test Installation Details

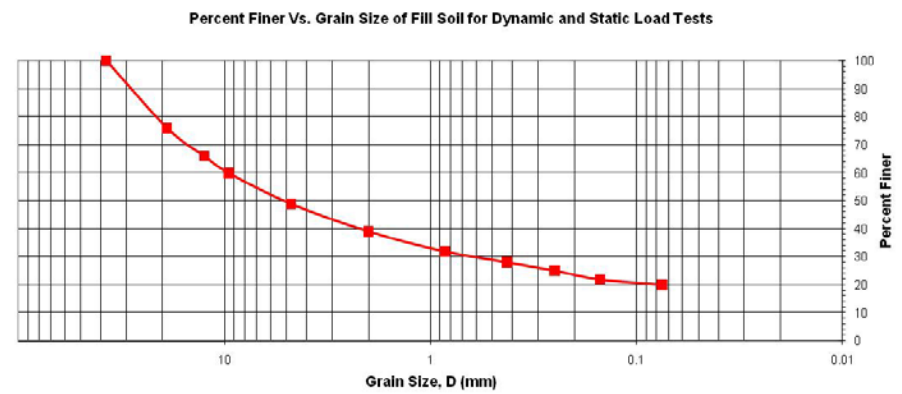


Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor
Bogie Weight	5009 lb
Impact Velocity	20.5 mph

Table C.2. Test Day Static Soil Strength Documentation for Test No. 608551-1.



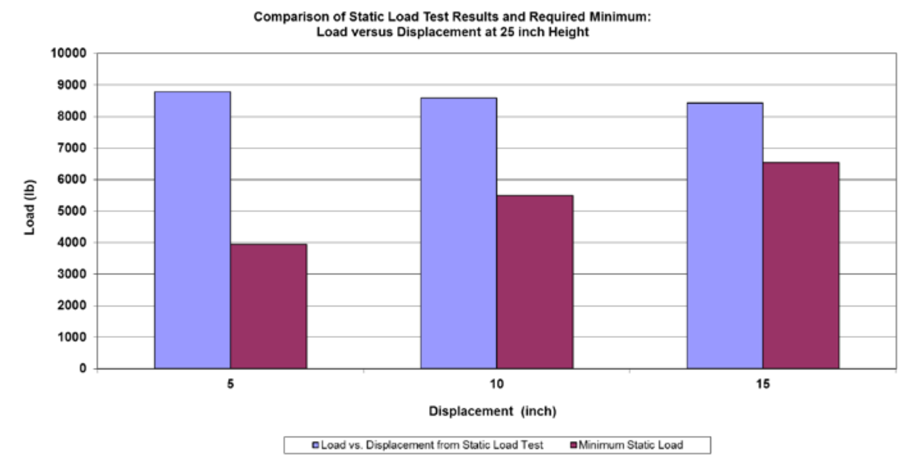
Static Load Setup



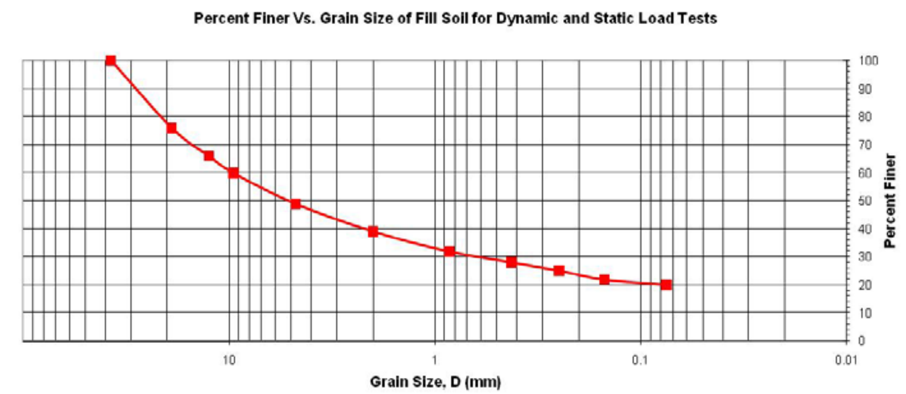
Post-Test Photo of Post

Date	2017-11-15
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.3. Test Day Static Soil Strength Documentation for Test No. 608551-2.



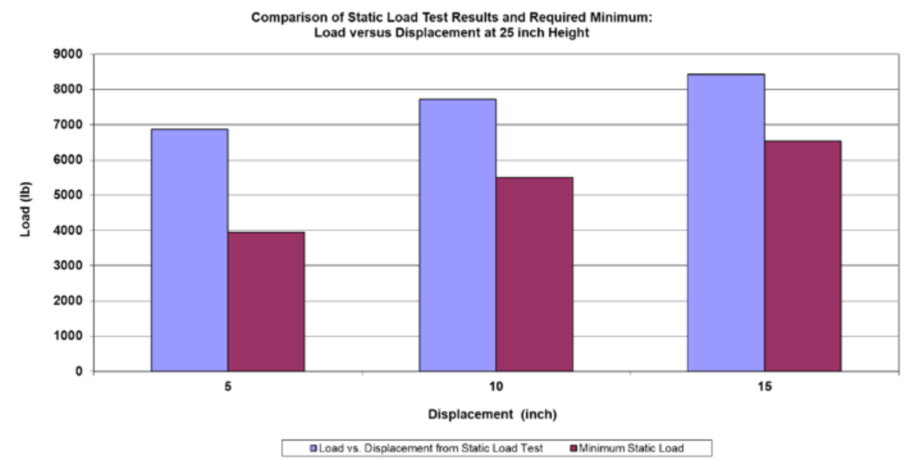
Static Load Setup



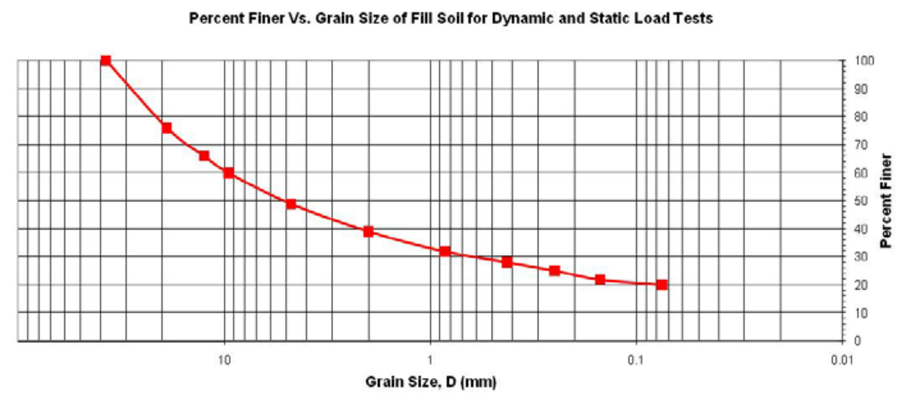
Post-Test Photo of Post

Date	2017-11-27
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.4. Test Day Static Soil Strength Documentation for Test No. 608551-5.



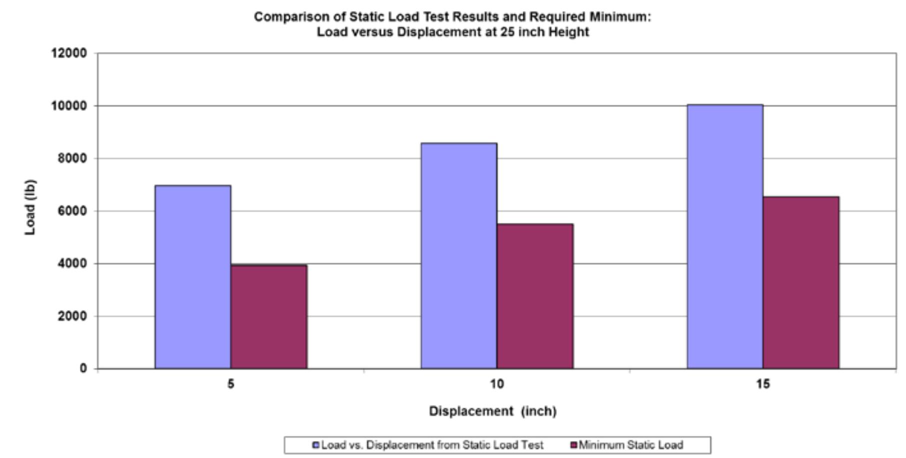
Static Load Setup



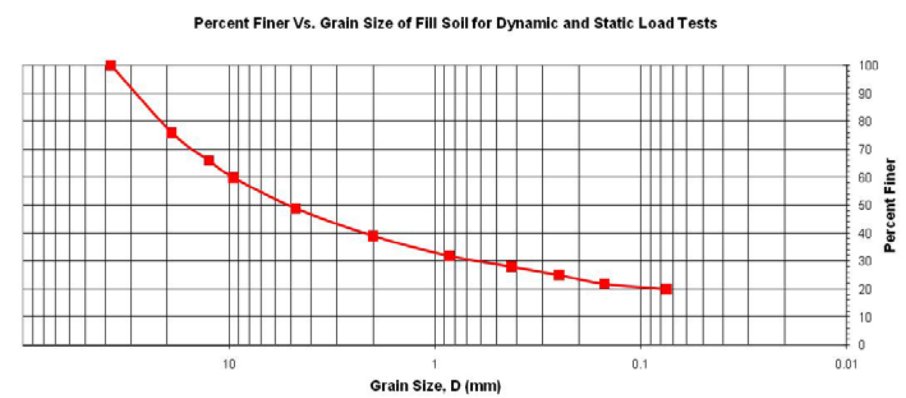
Post-Test Photo of Post

Date	2019-01-18
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.5. Test Day Static Soil Strength Documentation for Test No. 608551-3.



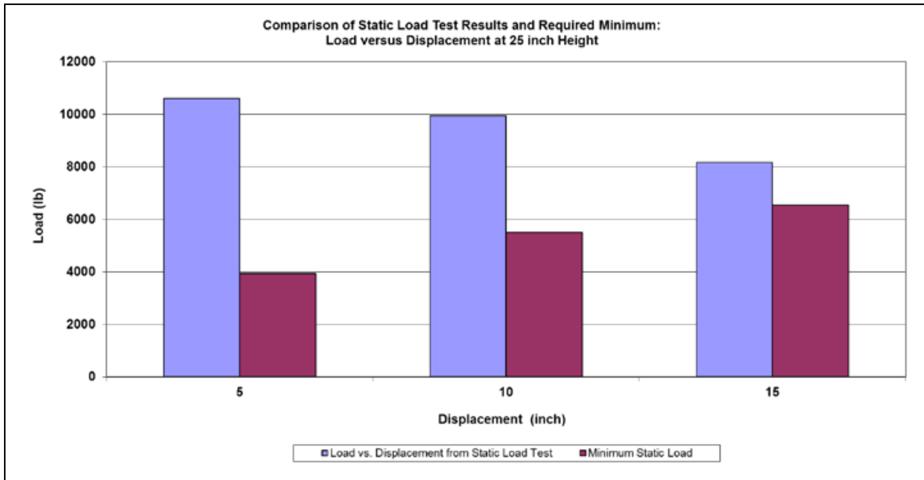
Static Load Setup



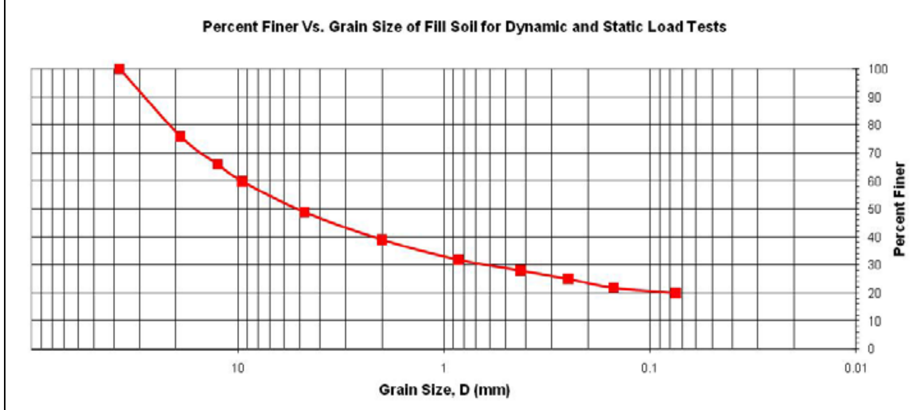
Post-Test Photo of Post

Date	2017-10-09
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.6. Test Day Static Soil Strength Documentation for Test No. 608551-4.



Static Load Setup



Post-Test Photo of Post

Date	2017-10-27
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

APPENIDX D. *MASH* TEST 3-10 (CRASH TEST NO. 608551-1)

D1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 608551-1.

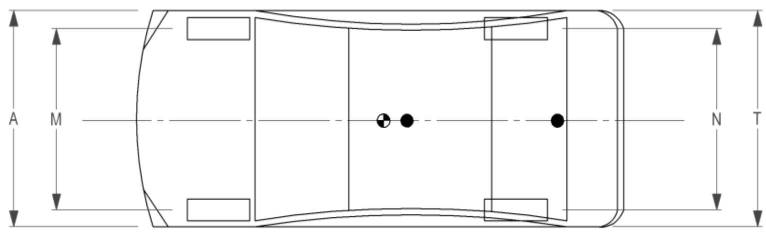
Date: 2017-11-15 Test No.: 608551-1 VIN No.: KNADE22359G453401

Year: 2009 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 117658 Tire Size: 185/65R14

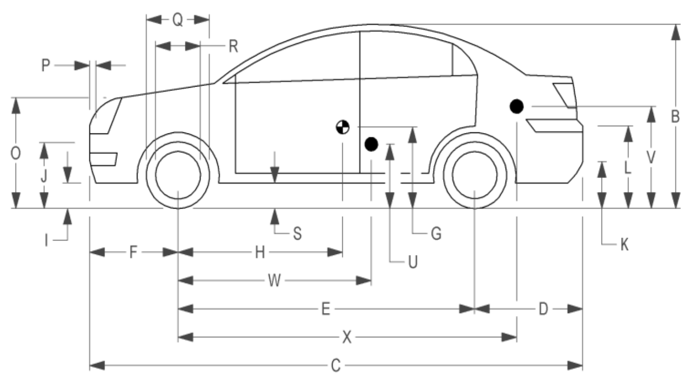
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.



NOTES: None

Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:
None



Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Right Front (Impact)

Geometry: inches

A	66.35	F	33.00	K	10.50	P	4.12	U	14.75
B	58.00	G	-----	L	24.50	Q	22.50	V	19.75
C	165.75	H	35.80	M	57.75	R	15.50	W	35.80
D	34.00	I	7.75	N	57.70	S	9.00	X	105.25
E	98.75	J	21.00	O	28.00	T	66.20		

Wheel Center Ht Front 11.00 Wheel Center Ht Rear 11.00 W-H 0

GVWR Ratings:		Mass: lb	Curb	Test Inertial	Gross Static
Front	1718	M_{front}	1579	1551	1636
Back	1874	M_{rear}	908	883	963
Total	3638	M_{Total}	2487	2434	2599

Mass Distribution:
lb LF: 772 RF: 779 LR: 435 RR: 448

Table D.2. Exterior Crush Measurements for Test No. 608551-1.

Date:	2017-11-15	Test No.:	608551-1	VIN No.:	KNADE22359G453401
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 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	24	6	24	1	1	2	3	4	6	+22
2	Side plane at bumper ht	24	10	36	0.5	2	5	8	9.5	10	+56
	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).

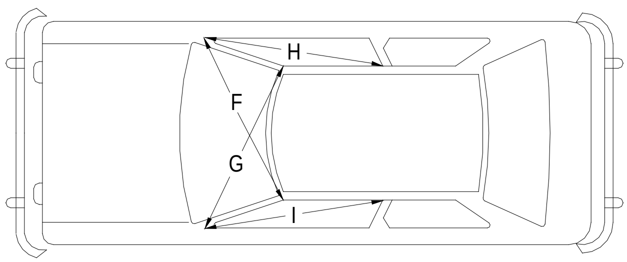
***Measure and document on the vehicle diagram the location of the maximum crush.

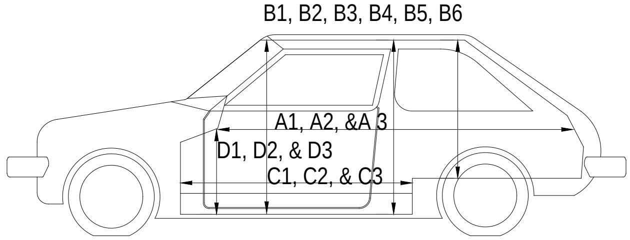
Note: Use as many lines/columns as necessary to describe each damage profile.

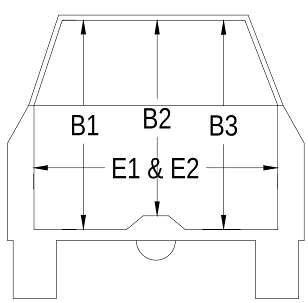
Table D.3. Occupant Compartment Measurements for Test No. 608551-1.

Date: 2017-11-15 Test No.: 608551-1 VIN No.: KNADE22359G453401

Year: 2009 Make: Kia Model: Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	**After** (inches)	**Differ.**
A1	67.50	67.50	0
A2	67.00	67.00	0
A3	67.50	67.50	0
B1	40.50	40.50	0
B2	37.00	37.00	0
B3	40.50	40.50	0
B4	36.00	36.00	0
B5	35.50	35.50	0
B6	36.00	36.00	0
C1	26.00	26.00	0
C2	-----	-----	--
C3	26.00	26.00	0
D1	9.50	9.50	0
D2	-----	-----	--
D3	9.50	9.50	0
E1	51.50	51.50	0
E2	51.00	51.00	0
F	51.00	51.00	0
G	51.00	51.00	0
H	37.00	37.00	0
I	37.00	37.00	0
J*	51.00	51.00	0

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

D2 SEQUENTIAL PHOTOGRAPHS


0.000 s



0.100 s



0.200 s

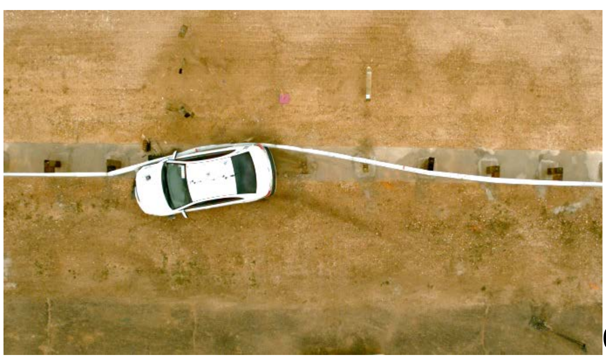
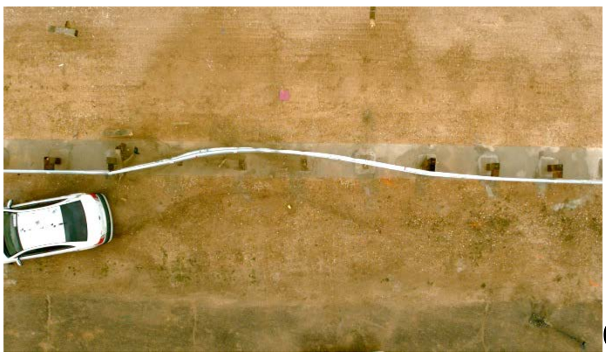


0.300 s


Figure D.1. Sequential Photographs for Test No. 608551-1 (Overhead and Frontal Views).


0.400 s



0.500 s



0.600 s

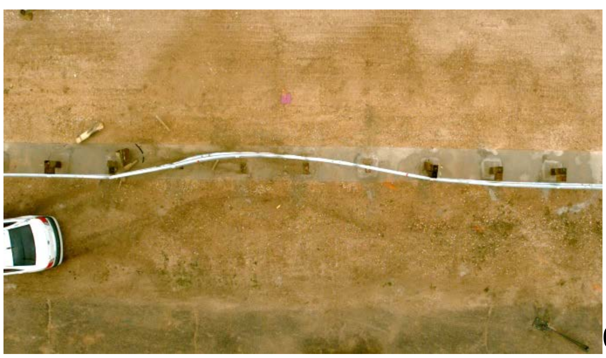
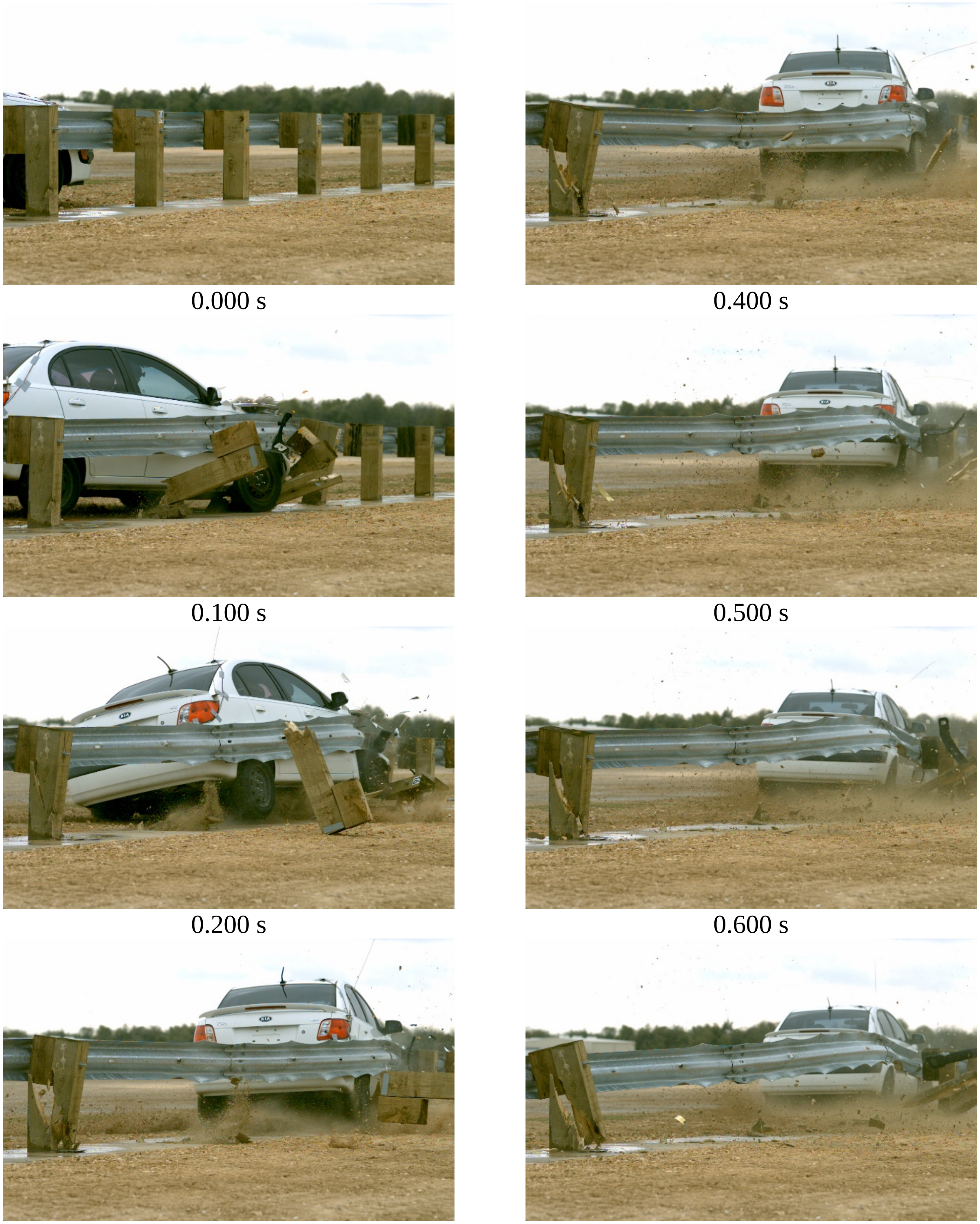
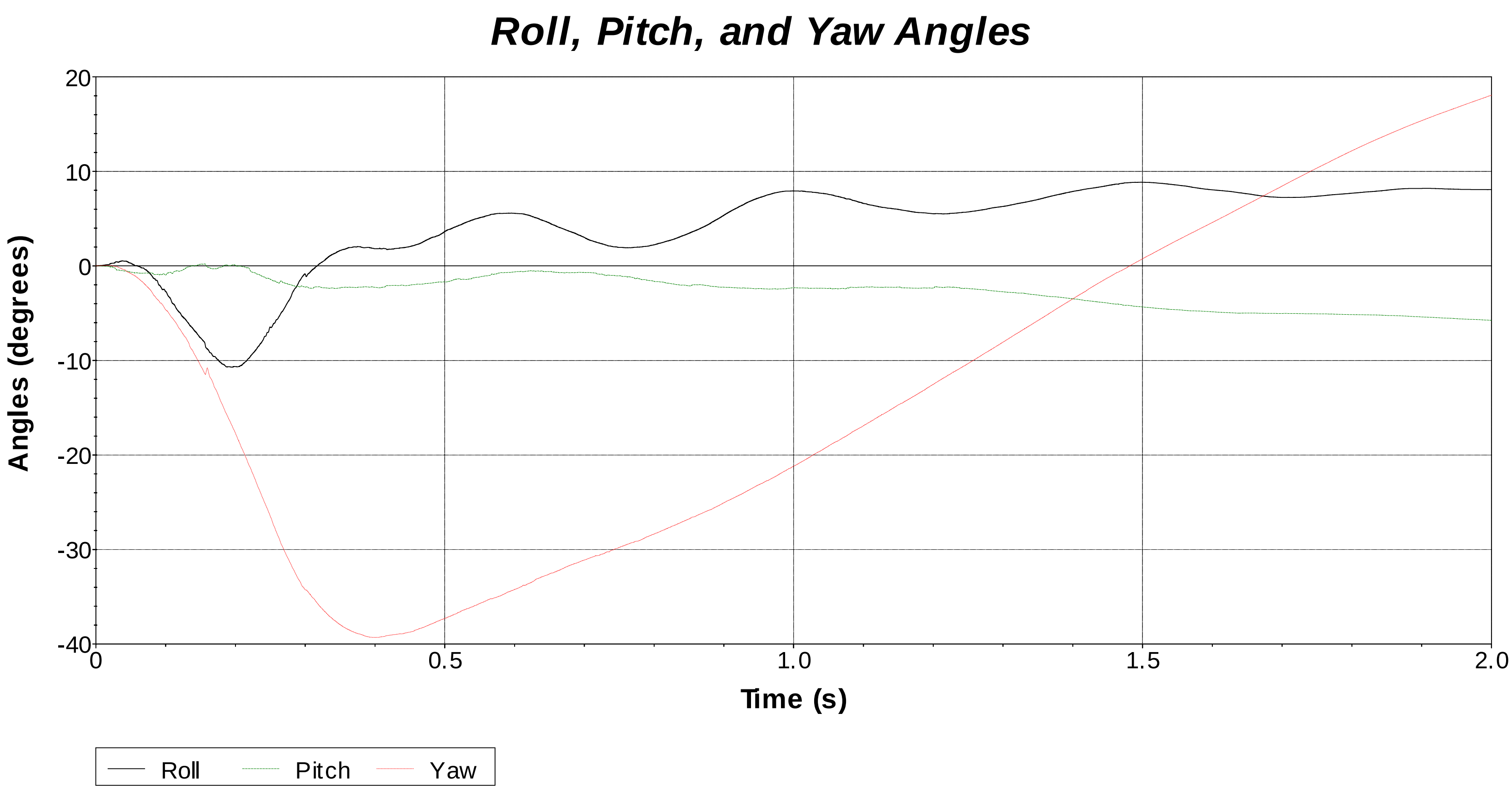


0.700 s


Figure D.1. Sequential Photographs for Test No. 608551-1 (Overhead and Frontal Views) (Continued).



0.000 s
0.100 s
0.200 s
0.300 s
0.400 s
0.500 s
0.600 s
0.700 s

Figure D.2. Sequential Photographs for Test No. 608551-1 (Rear View).



Test Number: 608551-1
Test Standard Test Number: MASH Test 3-10
Test Article: 31-inch W-Beam Guardrail on Wood Posts in Concrete Mow Strip
Test Vehicle: 2009 Kia Rio
Inertial Mass: 2434 lb
Gross Mass: 2599 lb
Impact Speed: 62.3 mi/h
Impact Angle: 24.7°

Axes are vehicle-fixed.
Sequence for determining orientation:

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

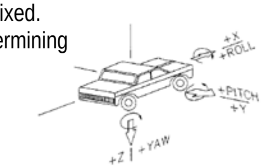


Figure D.3. Vehicle Angular Displacements for Test No. 608551-1.

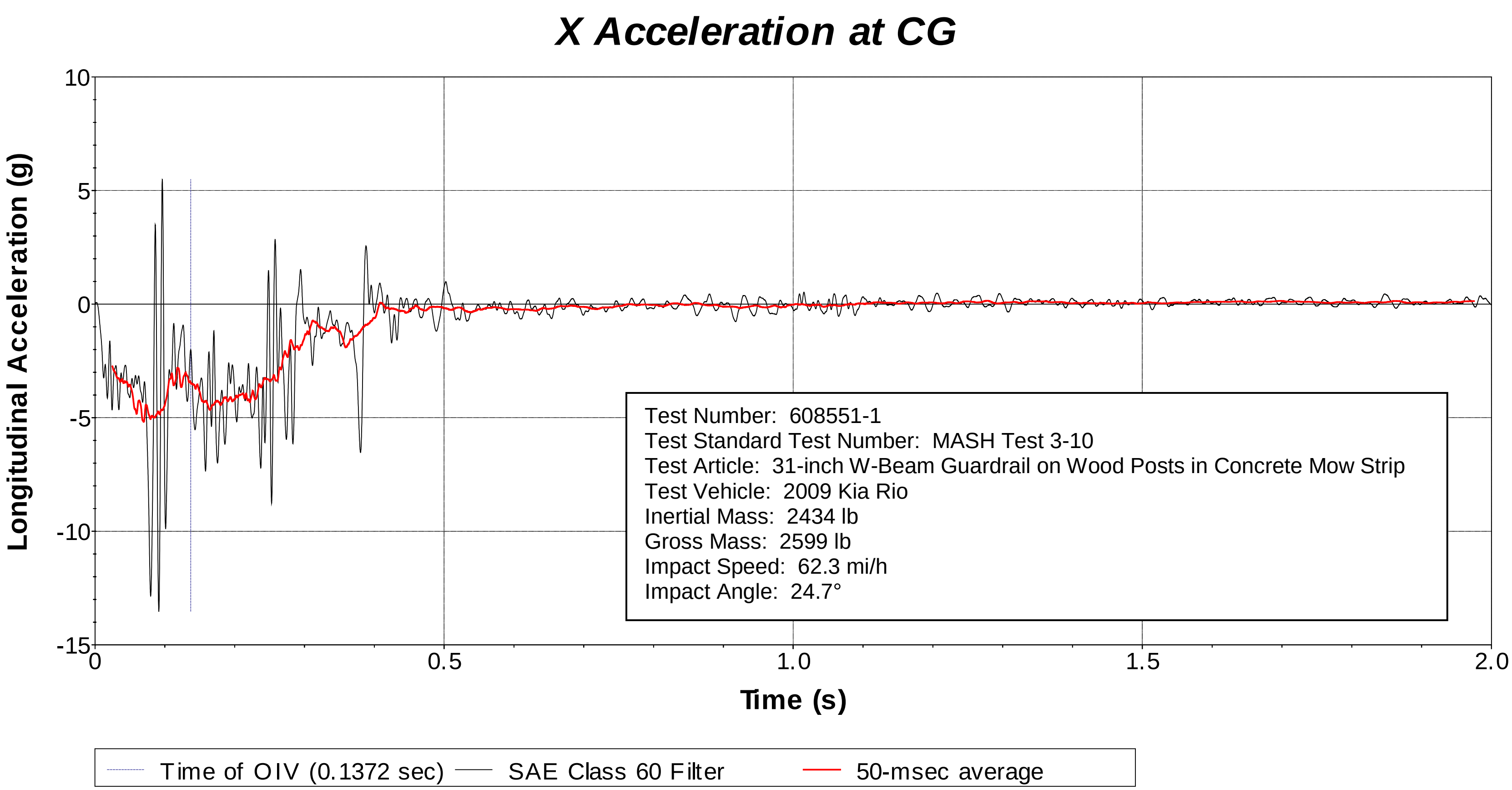


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608551-1 (Accelerometer Located at Center of Gravity).

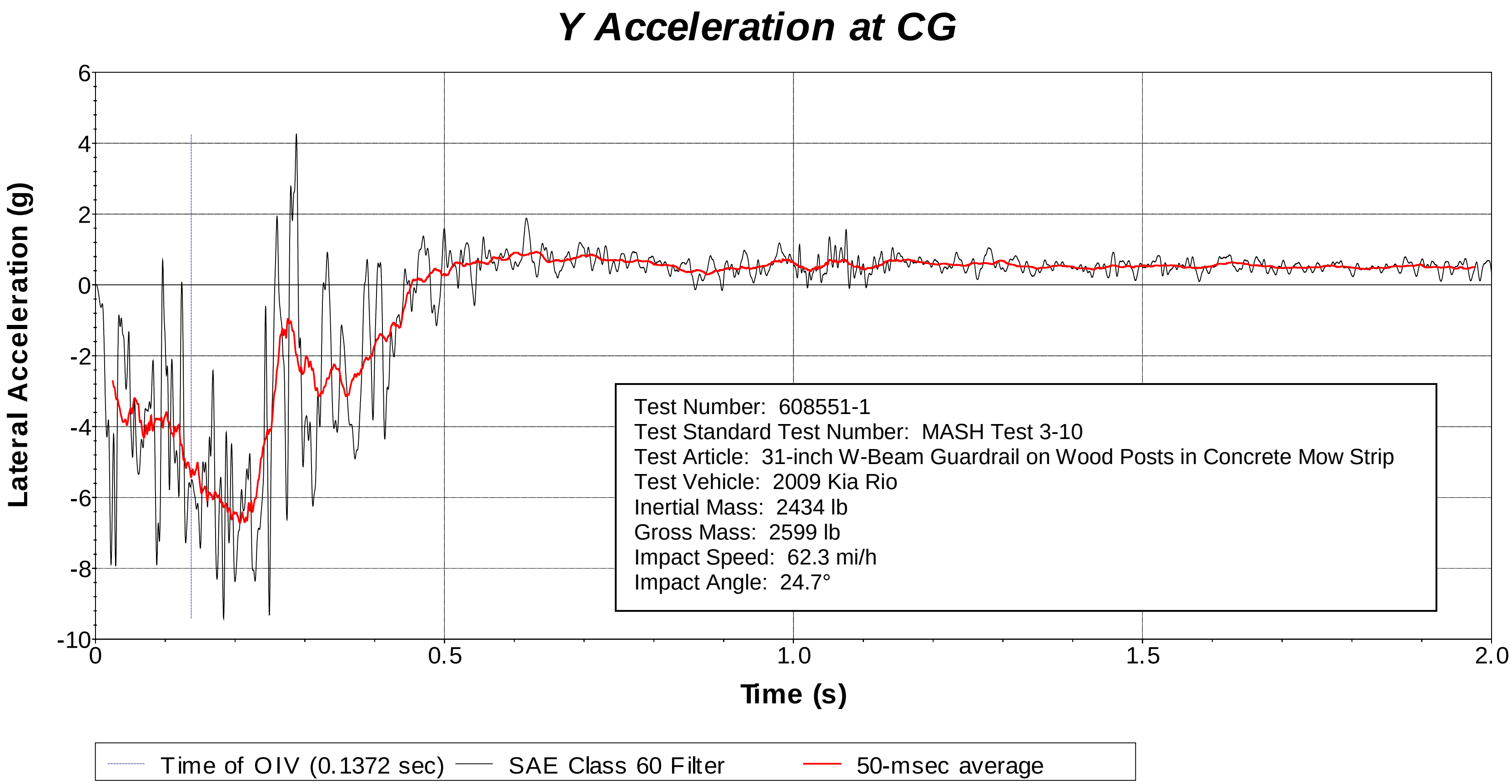


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 608551-1 (Accelerometer Located at Center of Gravity).

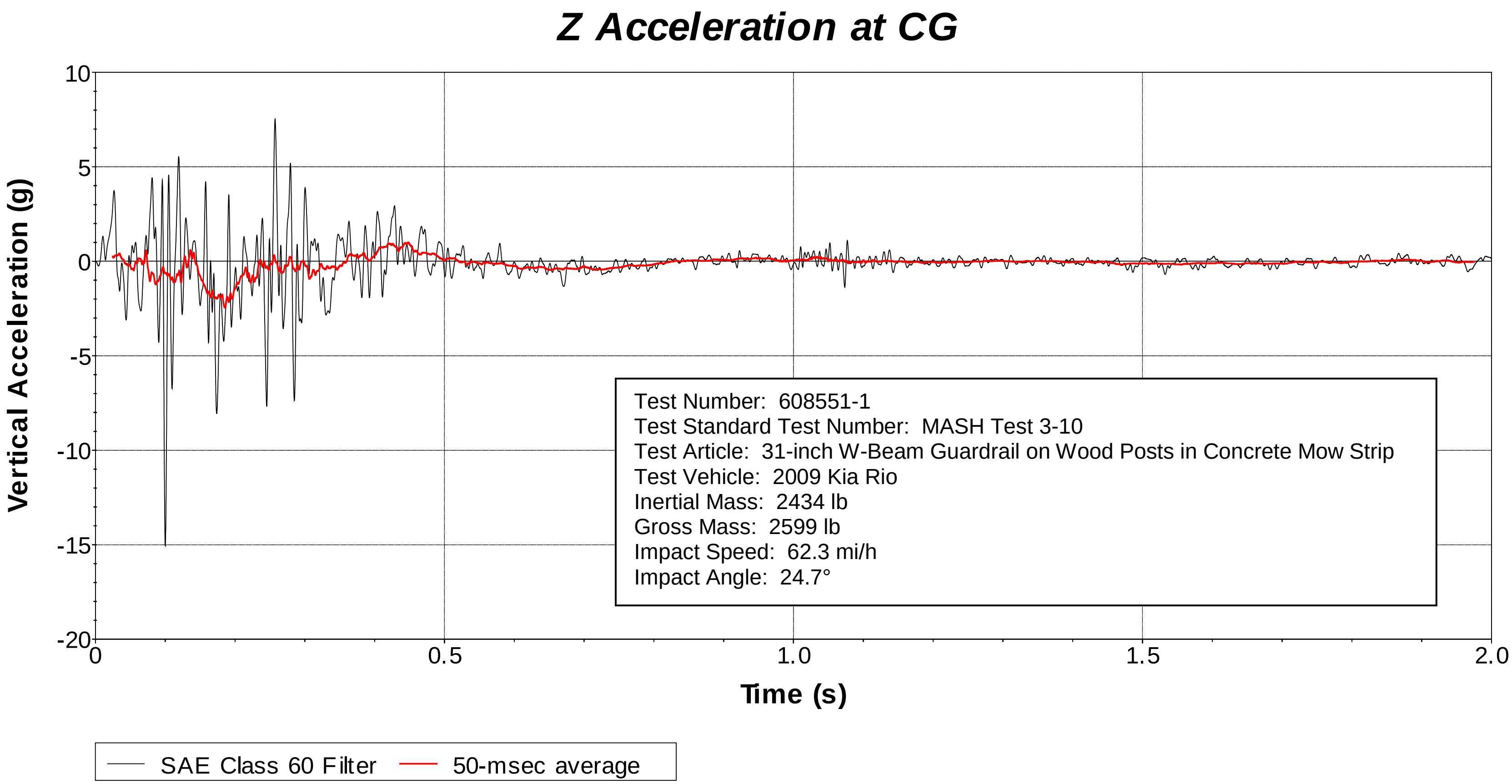


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 608551-1 (Accelerometer Located at Center of Gravity).

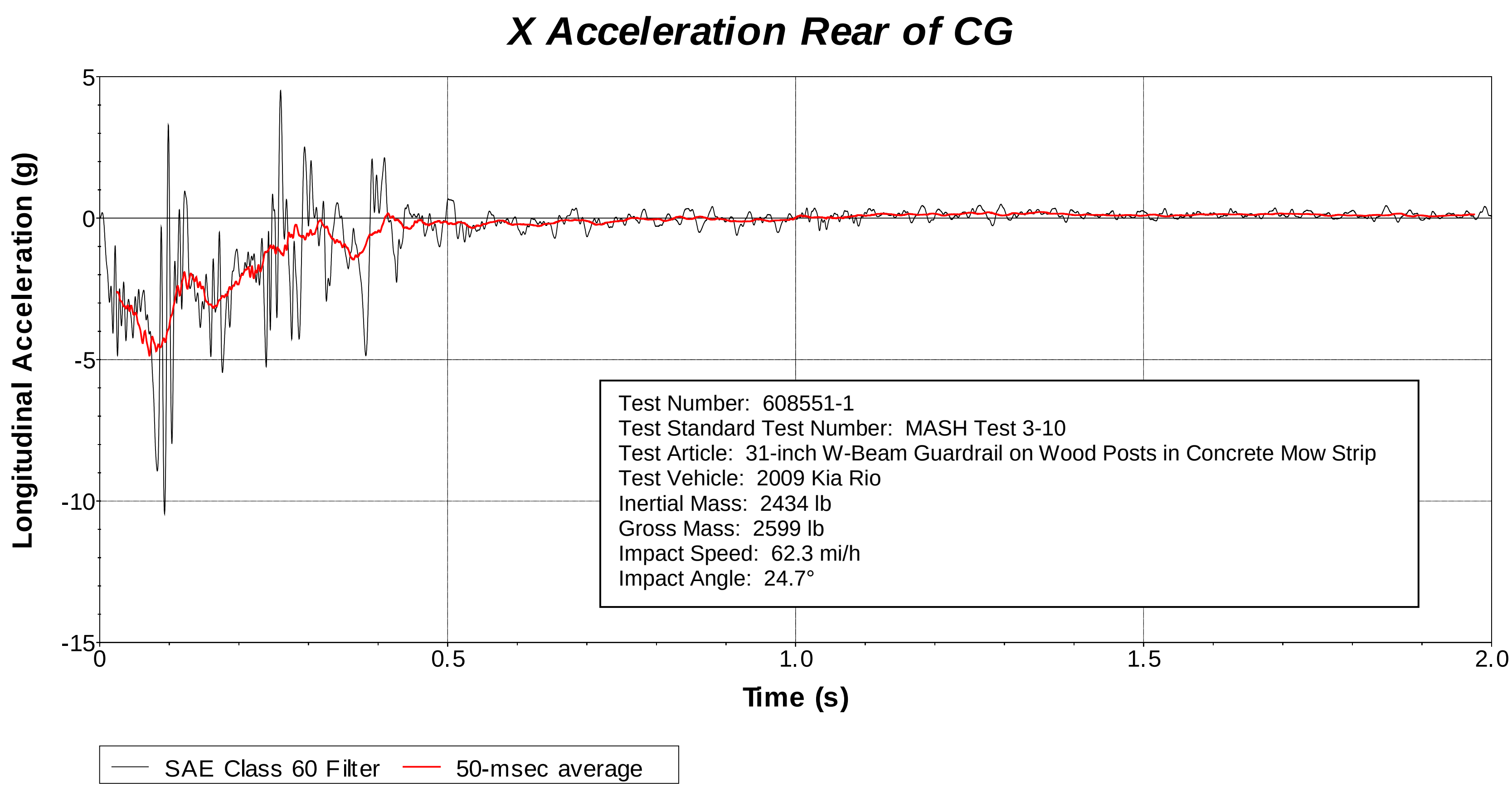


Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 608551-1 (Accelerometer Located Rear of Center of Gravity).

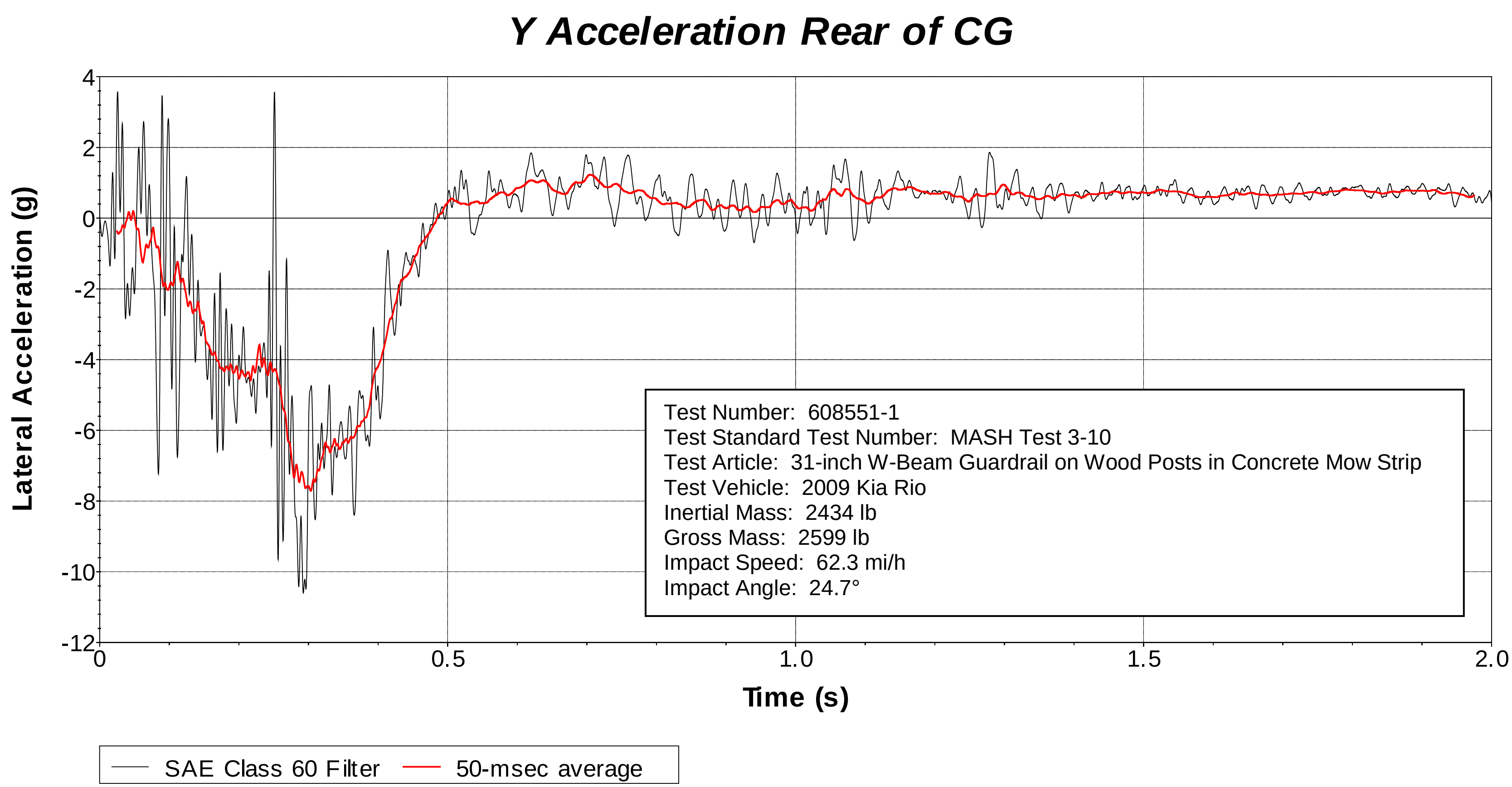


Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 608551-1 (Accelerometer Located Rear of Center of Gravity).

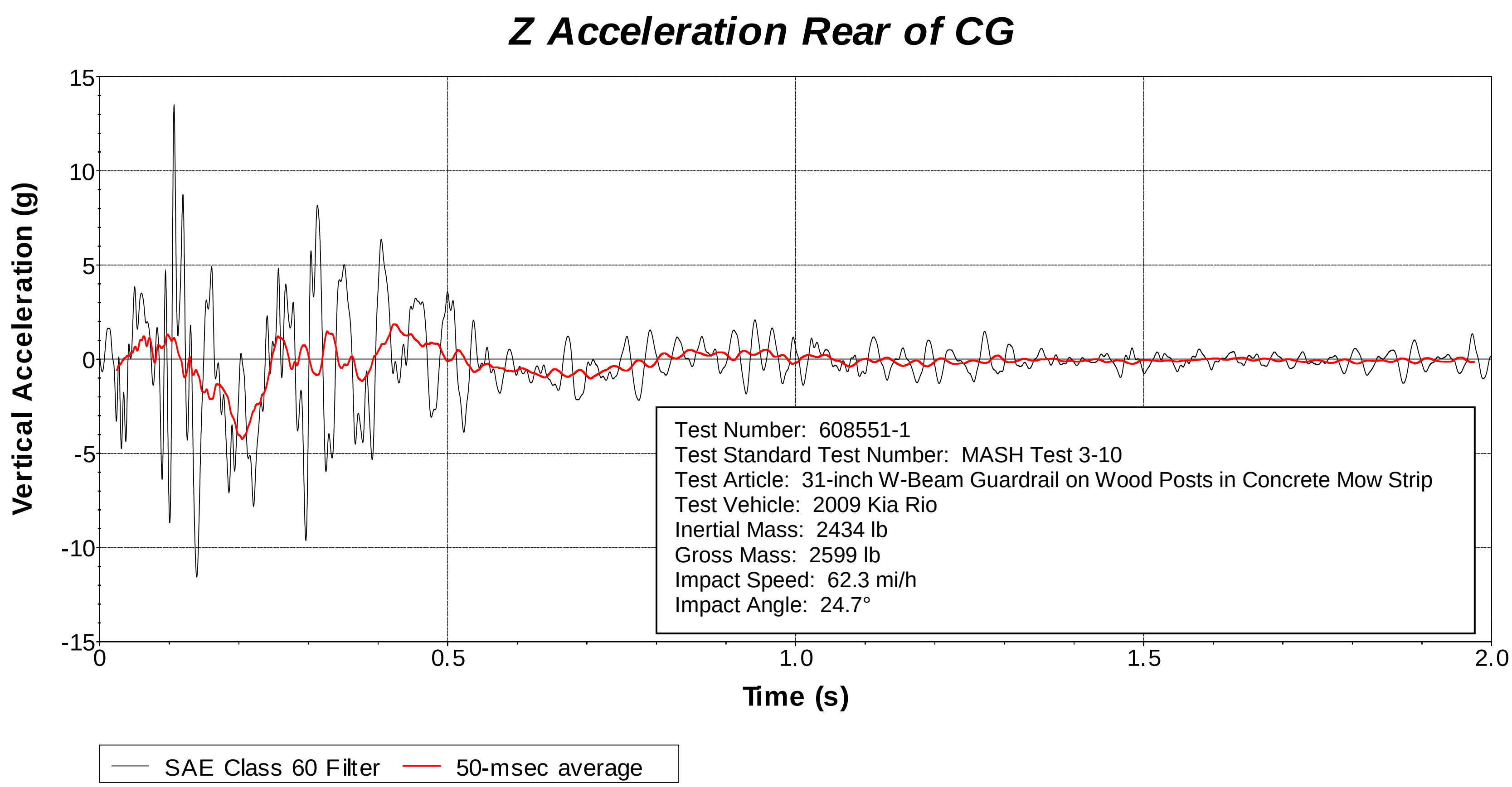


Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 608551-1 (Accelerometer Located Rear of Center of Gravity).

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APPENIDX E. *MASH* TEST 3-11 (CRASH TEST NO. 608551-2)

E1 VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 608551-2.

Date: 2017-12-04 Test No.: 608551-2 VIN No.: 1CRD6GP7CS219541

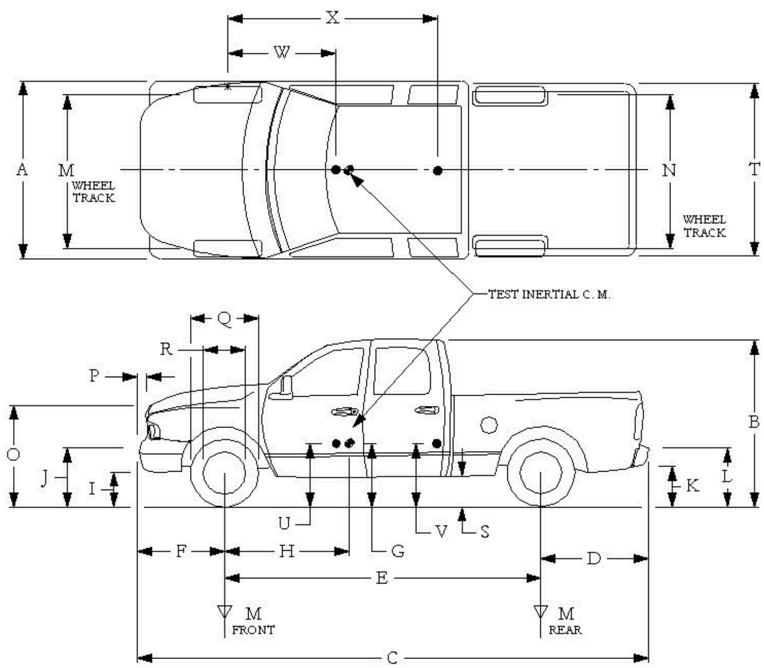
Year: 2012 Make: Dodge Model: RAM 1500

Tire Size: 265/70R17 Tire Inflation Pressure: 44 psi

Tread Type: Highway Odometer: 207403

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.



NOTES: None

Engine Type: V-8 gas
Engine CID: 4.7 liter

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

Optional Equipment:
None

Dummy Data:
Type: None
Mass: NA
Seat Position: NA

Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	28.50
B	74.00	G	29.00	L	30.00	Q	30.50	V	31.00
C	227.50	H	62.52	M	68.50	R	18.00	W	62.50
D	44.00	I	11.75	N	68.00	S	12.75	X	78.25
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.00
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}	2859	2796	----
Back	3900	M_{rear}	2028	2242	----
Total	6700	M_{Total}	4887	5038	----

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1388 RF: 1408 LR: 1118 RR: 1124

Table E.2. Measurements of Vehicle Vertical CG for Test No. 608551-2.

Date: 2017-12-04 Test No.: 608551-2 VIN: 1CRD6GP7CS219541

Year: 2012 Make: Dodge Model: RAM 1500

Body Style: Quad Cab Mileage: 207403

Engine: 5.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 200 lb (440 lb max)

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

Measured Vehicle Weights: (lb)					
LF:	1388	RF:	1408	Front Axle:	2796
LR:	1118	RR:	1124	Rear Axle:	2242
Left:	2506	Right:	2532	Total:	5038
					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:	62.53 inches	Rear of Front Axle	(63 ±4 inches allowed)		
Y:	0.18 inches	Left - Right +	of Vehicle Centerline		
Z:	29 inches	Above Ground	(minumum 28.0 inches allowed)		

Hood Height: 46.00 inches Front Bumper Height: 27.00 inches

43 ±4 inches allowed

Front Overhang: 40.00 inches Rear Bumper Height: 30.00 inches

39 ±3 inches allowed

Overall Length: 227.50 inches

237 ±13 inches allowed

Table E.3. Exterior Crush Measurements for Test No. 608551-2.

Date: 2017-12-04 Test No.: 608551-2 VIN No.: 1CRD6GP7CS219541

Year: 2012 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	18	20.5	71	10	7	9.5	20.5	7.5	19.5	0
2	Side plane at bot bumper	13	24	71	16	15.5	15.5	24	12	22.5	0
	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).

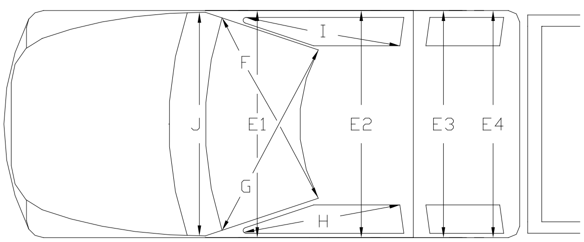
***Measure and document on the vehicle diagram the location of the maximum crush.

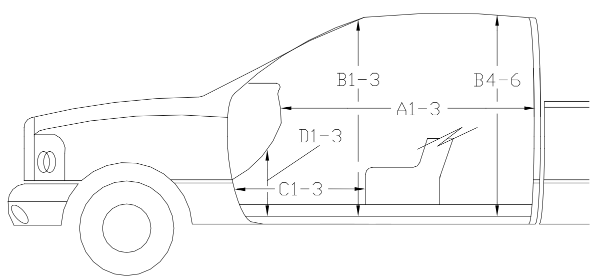
Note: Use as many lines/columns as necessary to describe each damage profile.

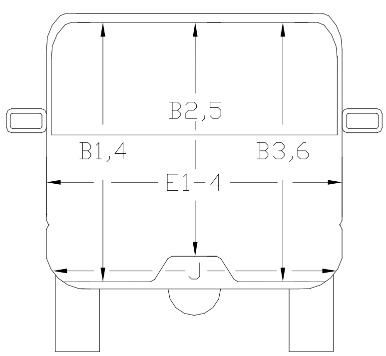
Table E.4. Occupant Compartment Measurements for Test No. 608551-2.

Date: 2017-12-04 Test No.: 608551-2 VIN No.: 1CRD6GP7CS219541

Year: 2012 Make: Dodge Model: RAM 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	62.50	62.50	0
A2	62.00	62.00	0
A3	62.00	62.00	0
B1	45.00	45.00	0
B2	38.00	38.00	0
B3	45.00	45.00	0
B4	39.50	39.50	0
B5	43.00	43.00	0
B6	39.50	39.50	0
C1	26.00	26.00	0
C2	-----	-----	--
C3	26.00	26.00	0
D1	11.00	11.00	0
D2	-----	-----	--
D3	11.25	11.25	0
E1	58.00	58.00	0
E2	63.50	63.50	0
E3	63.50	63.50	0
E4	63.50	63.50	0
F	59.00	59.00	0
G	59.00	59.00	0
H	37.50	37.50	0
I	37.50	37.50	0
J*	23.25	23.25	0

E2 SEQUENTIAL PHOTOGRAPHS

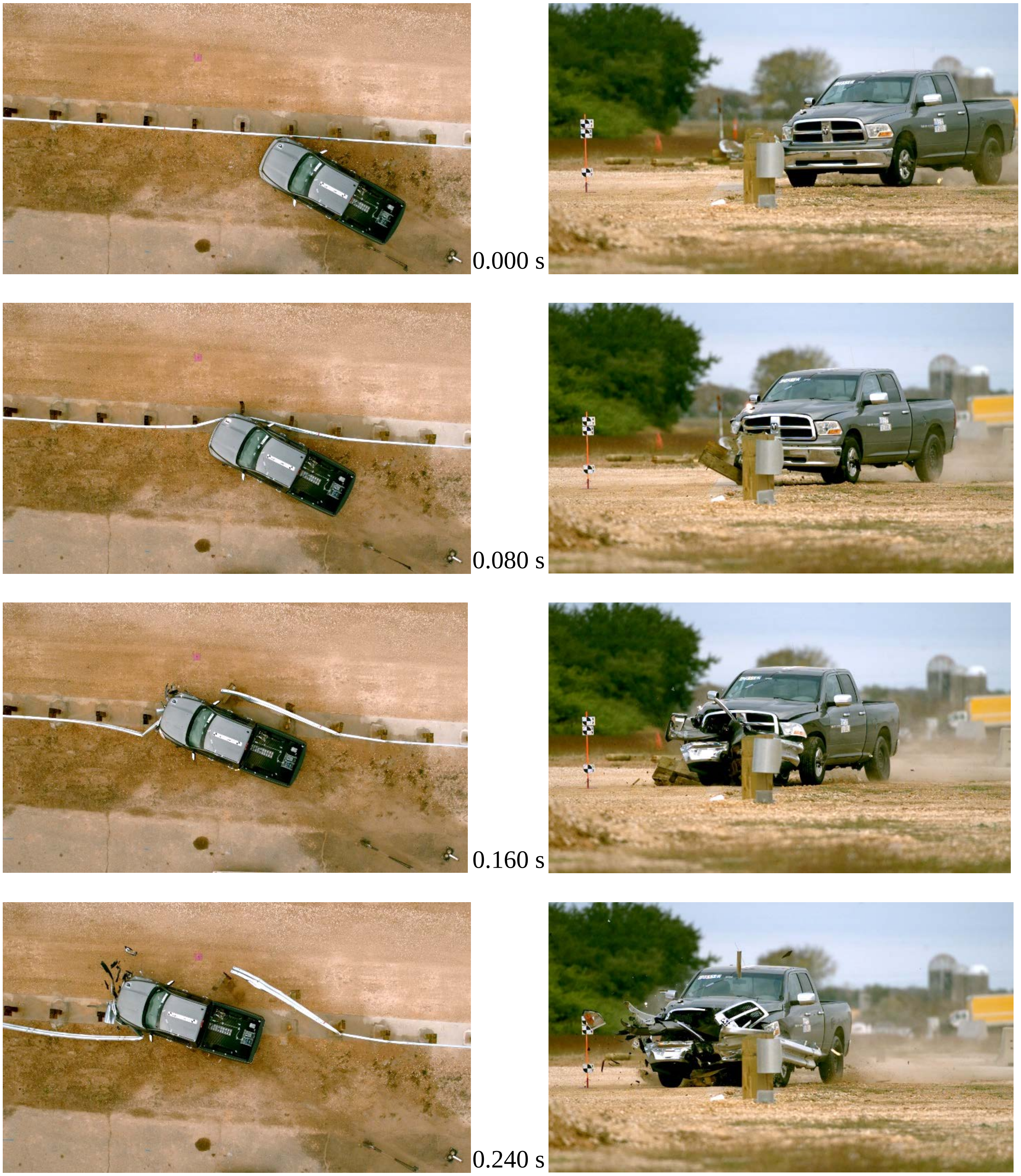


Figure E.1. Sequential Photographs for Test No. 608551-2 (Overhead and Frontal Views).


0.320 s



0.400 s



0.480 s



0.560 s


Figure E.1. Sequential Photographs for Test No. 608551-2 (Overhead and Frontal Views) (Continued).

0.000 s

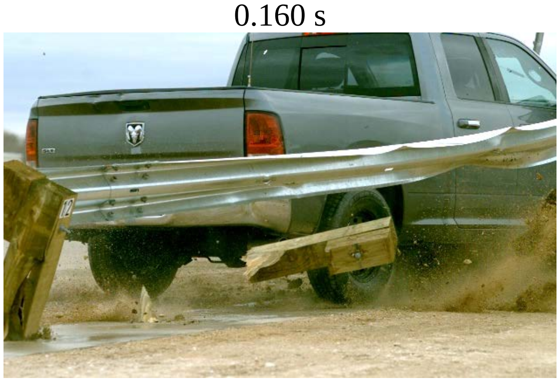
0.320 s

0.080 s

0.400 s

0.160 s

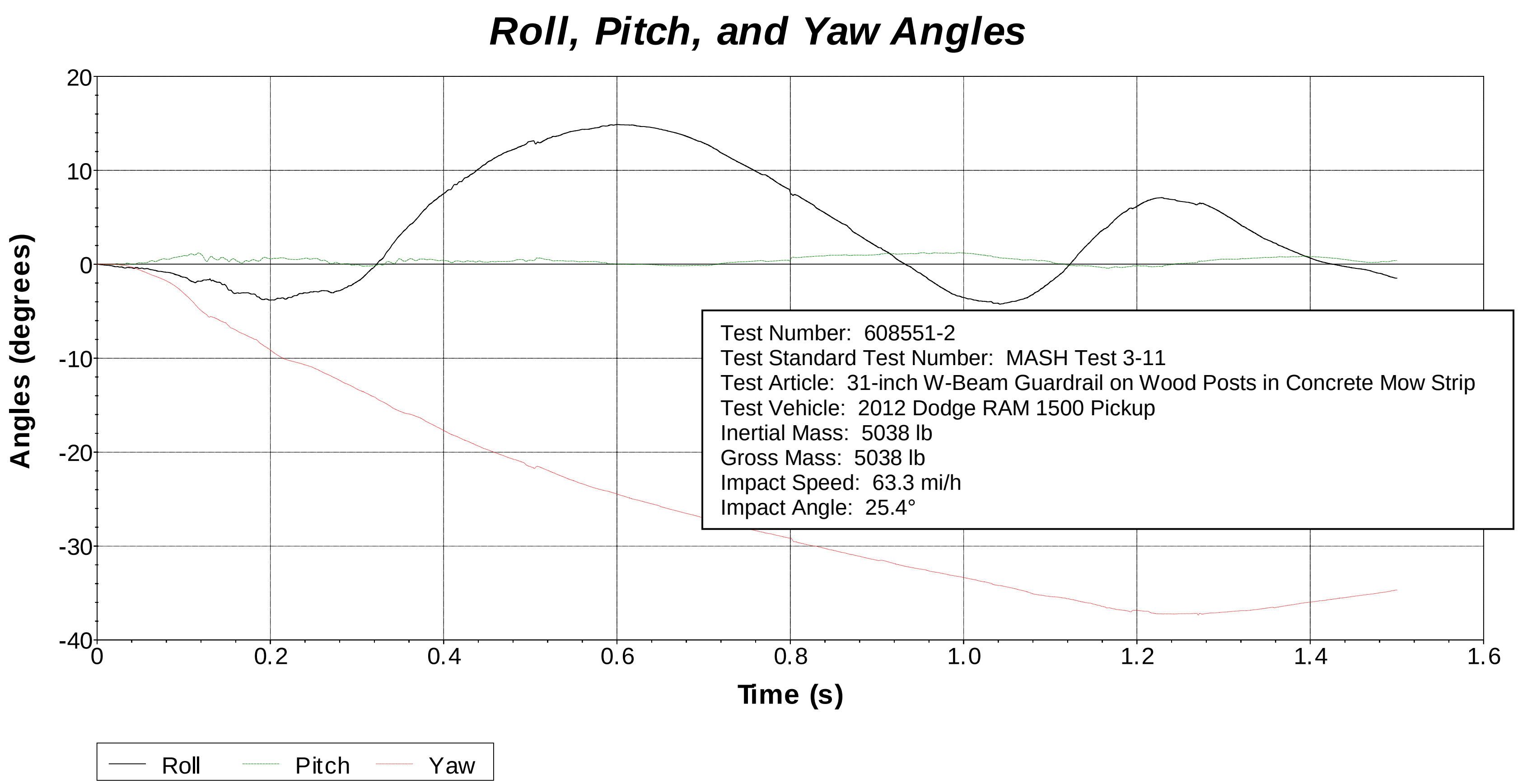
0.480 s



0.240 s

0.560 s

Figure E.2. Sequential Photographs for Test No. 608551-2 (Rear View).



Axes are vehicle-fixed.
Sequence for determining orientation:
1. Yaw.
2. Pitch.
3. Roll.

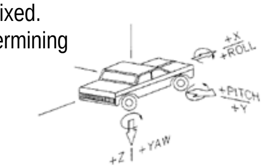


Figure E.3. Vehicle Angular Displacements for Test No. 608551-2.

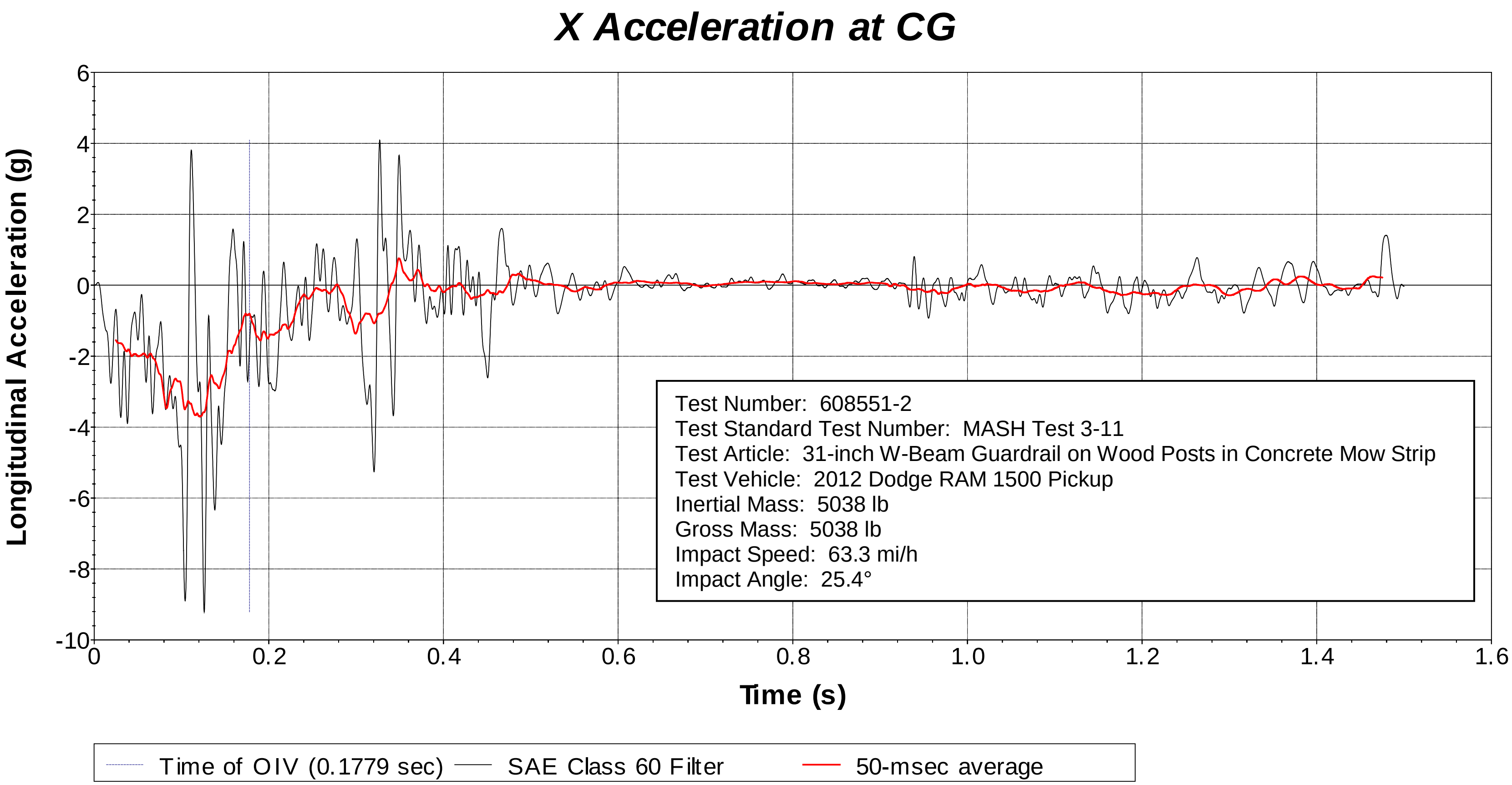


Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608551-2 (Accelerometer Located at Center of Gravity).

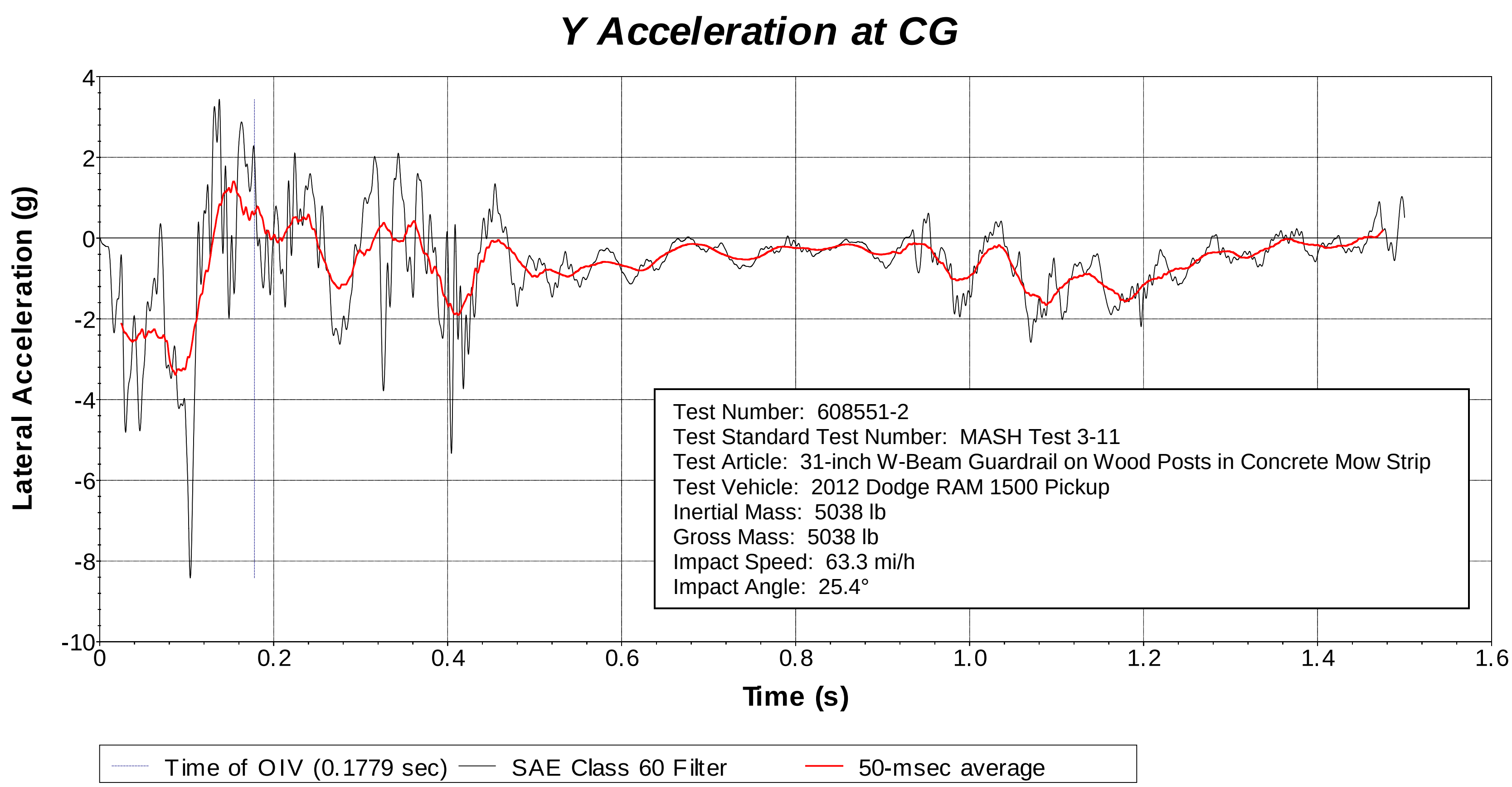


Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 608551-2 (Accelerometer Located at Center of Gravity).

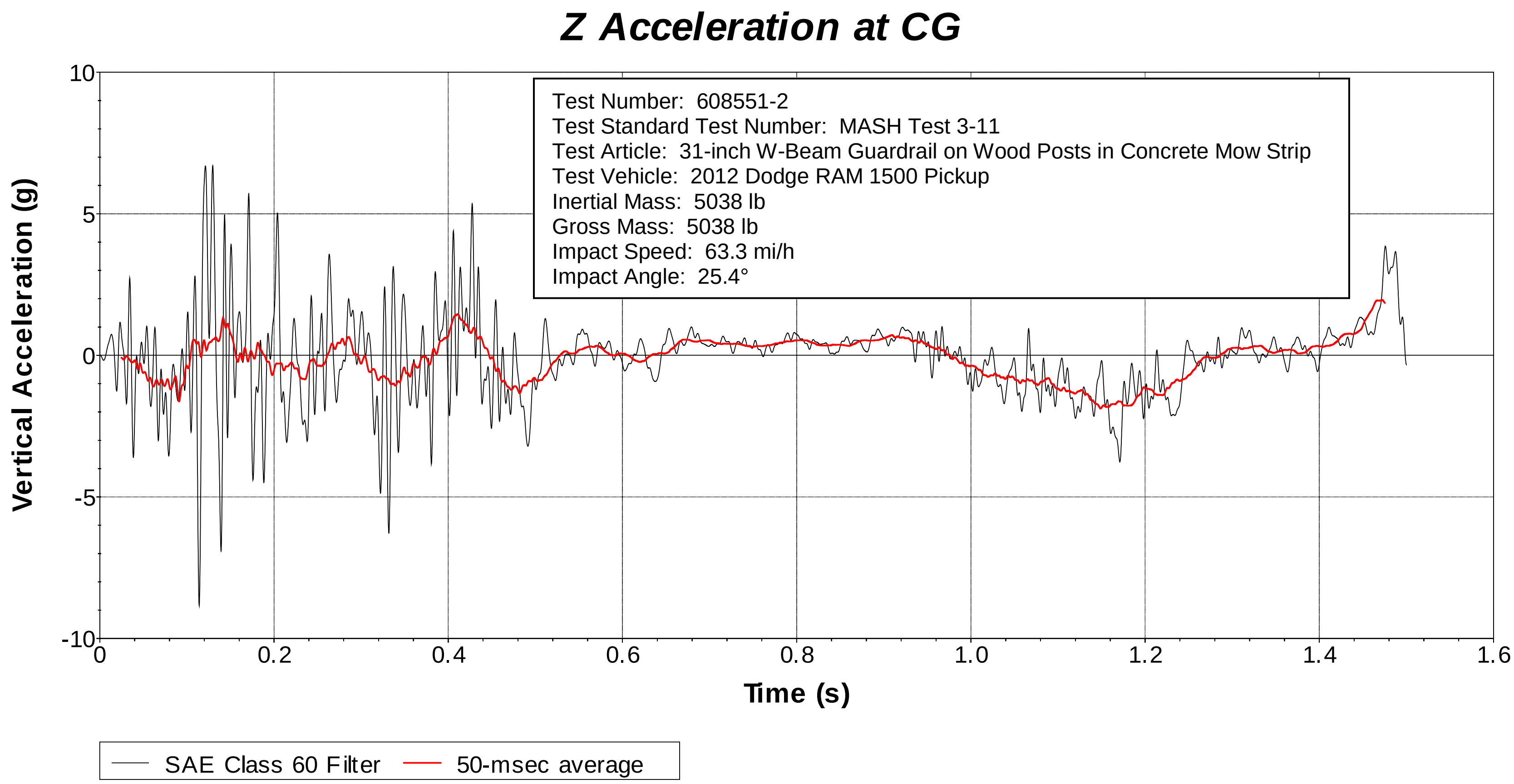


Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 608551-2 (Accelerometer Located at Center of Gravity).

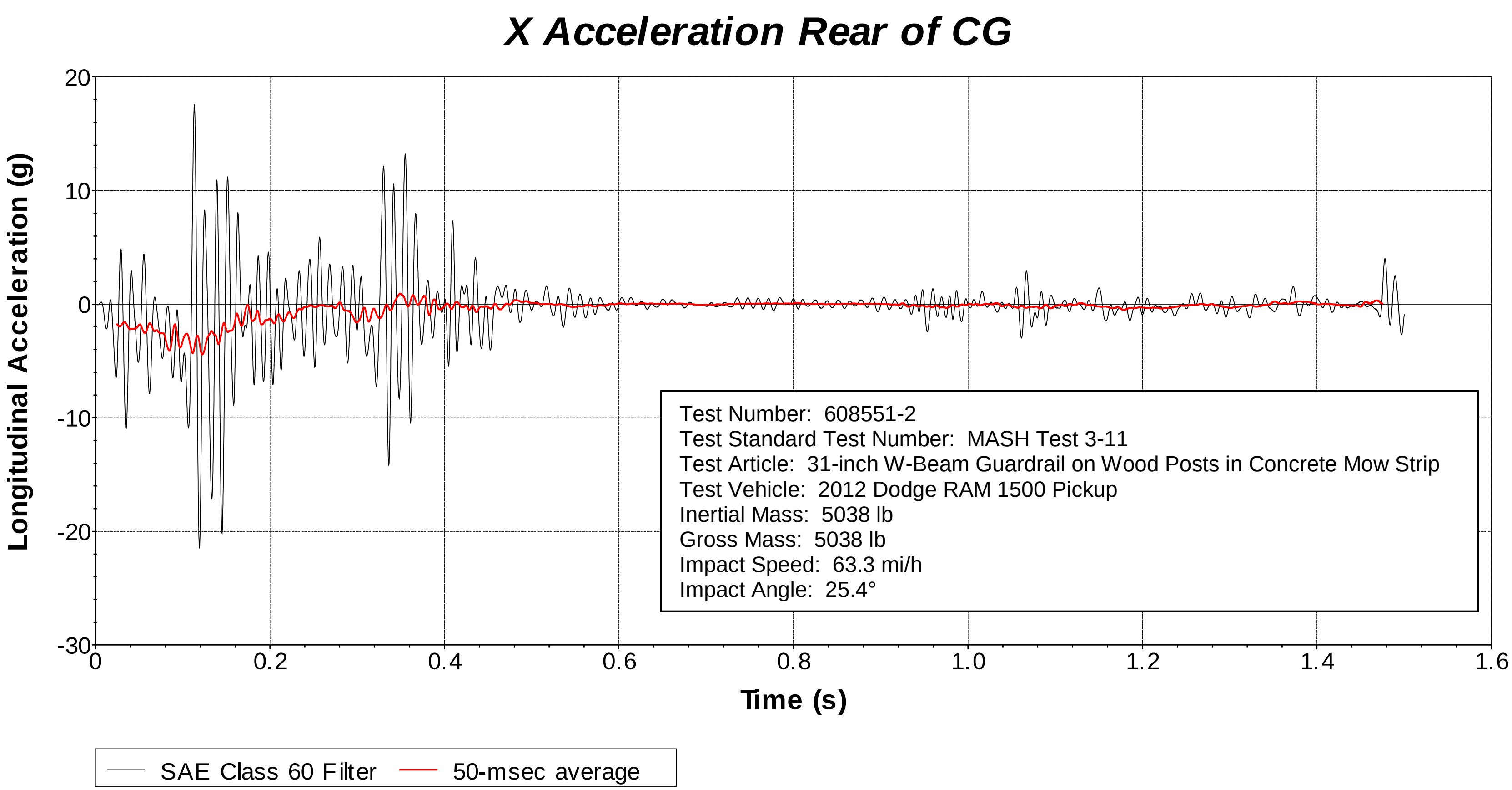


Figure E.7. Vehicle Longitudinal Accelerometer Trace for Test No. 608551-2 (Accelerometer Located Rear of Center of Gravity).

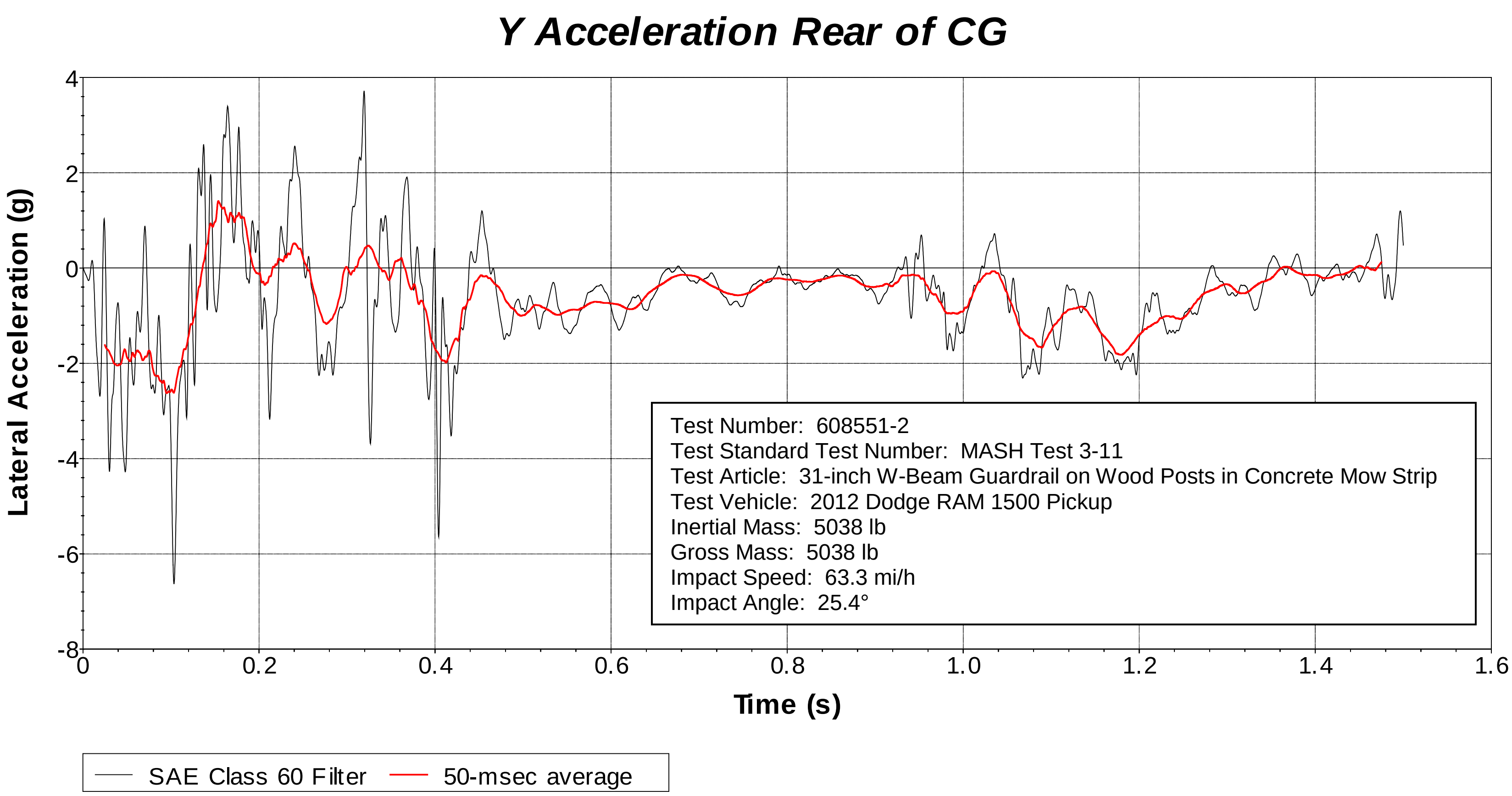


Figure E.8. Vehicle Lateral Accelerometer Trace for Test No. 608551-2 (Accelerometer Located Rear of Center of Gravity).

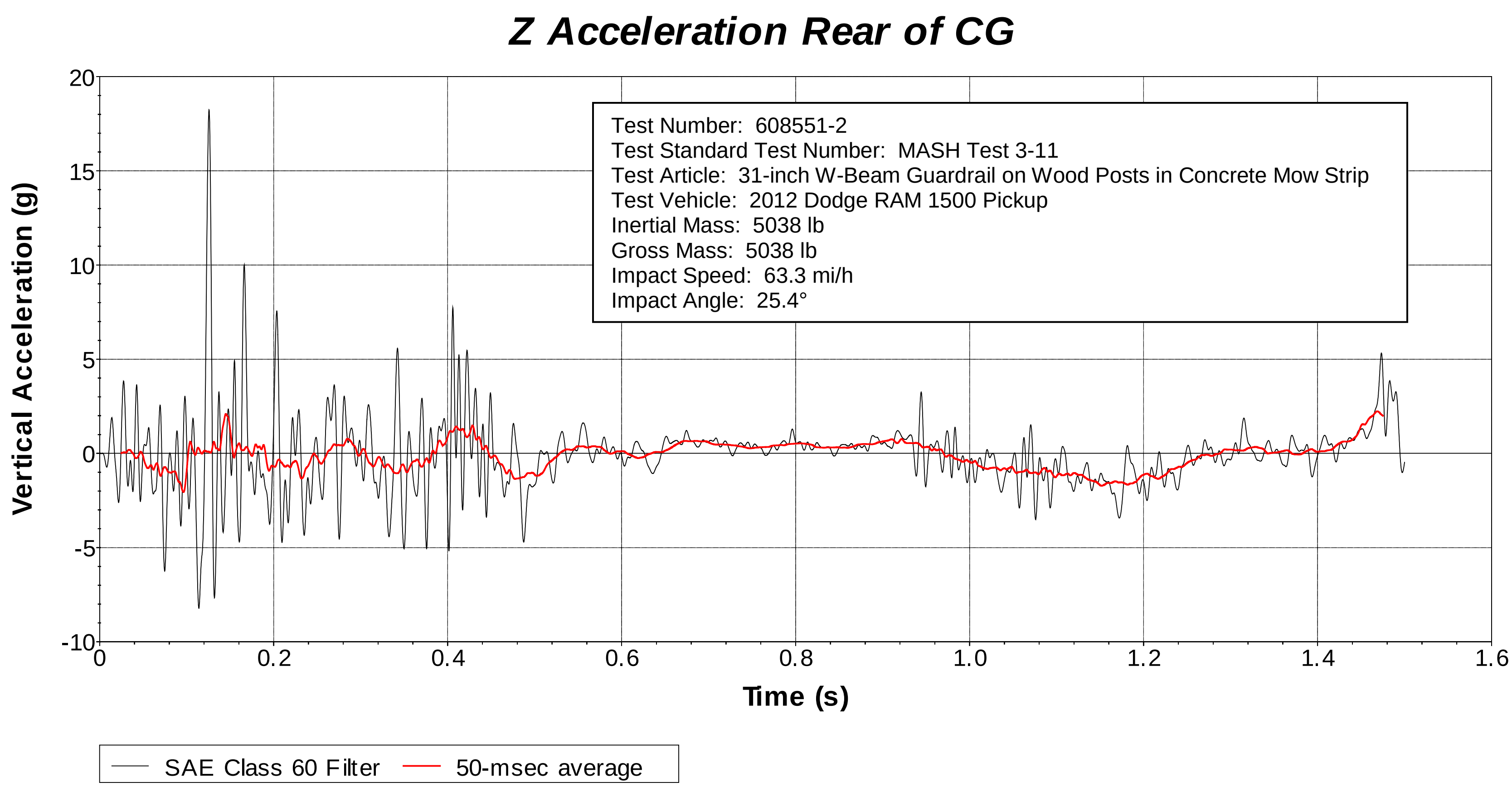


Figure E.9. Vehicle Vertical Accelerometer Trace for Test No. 608551-2 (Accelerometer Located Rear of Center of Gravity).

APPENIDX F. *MASH* TEST 3-11 (CRASH TEST NO. 608551-5)

F1 VEHICLE PROPERTIES AND INFORMATION

Table F.1. Vehicle Properties for Test No. 608551-5.

Date: 2019-01-18 Test No.: 608551-5 VIN No.: 1C6RR6FTOES149481

Year: 2014 Make: RAM Model: 1500

Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 169247

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

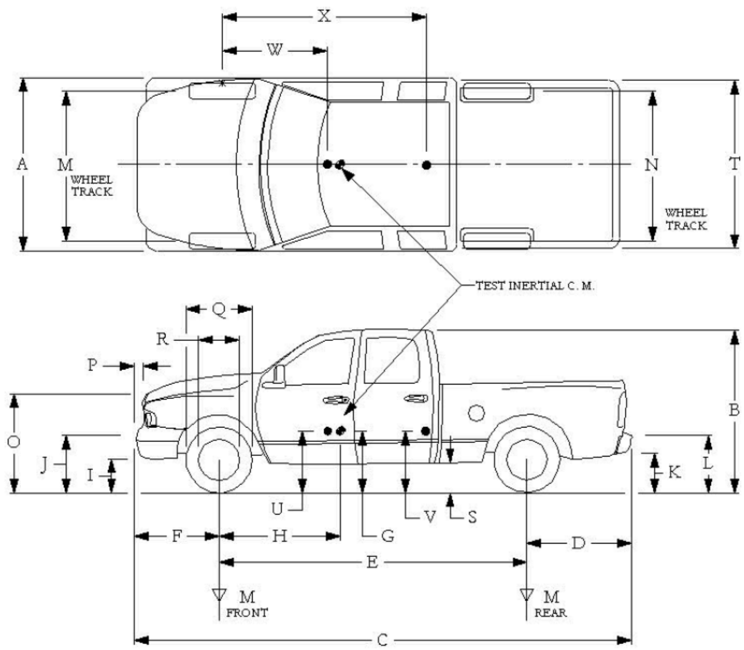
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type:
☑ Auto or ☐ Manual
☐ FWD ☑ RWD ☐ 4WD

Optional Equipment:
None

Dummy Data:
Type: None
Mass: 0 lb
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	27.50
B	74.00	G	28.50	L	30.00	Q	30.50	V	31.25
C	227.50	H	62.20	M	68.50	R	18.00	W	62.20
D	44.00	I	11.75	N	68.00	S	13.00	X	78.75
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; M+N/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2960	2807	2807
Back	3900	M_{rear}	2072	2230	2230
Total	6700	M_{Total}	5032	5037	5037

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1392 RF: 1415 LR: 1136 RR: 1094

Table F.2. Measurements of Vehicle Vertical CG for Test No. 608551-5.

Date: 2019-01-18 Test No.: 608551-5 VIN: 1C6RR6FTOES149481

Year: 2014 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 169247

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 207 (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70 R 17

Measured Vehicle Weights: (lb)							
LF:	1392		RF:	1415		Front Axle:	2807
LR:	1136		RR:	1094		Rear Axle:	2230
Left:	2528		Right:	2509		Total:	5037
							5000 ±110 lb allowed
Wheel Base:	140.50	inches	Track: F:	68.50	inches	R:	68.00 inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed			
Center of Gravity, SAE J874 Suspension Method							
X:	62.20	inches	Rear of Front Axle	(63 ±4 inches allowed)			
Y:	-0.13	inches	Left -	Right +	of Vehicle Centerline		
Z:	28.50	inches	Above Ground	(minumum 28.0 inches allowed)			

Hood Height: 46.00 inches
43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches
39 ±3 inches allowed

Rear Bumper Height: 30.00 inches

Overall Length: 227.50 inches
237 ±13 inches allowed

Table F.3. Exterior Crush Measurements for Test No. 608551-5.

Date:	2019-01-18	Test No.:	608551-5	VIN No.:	1C6RR6FTOES149481
Year:	2014	Make:	RAM	Model:	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	AT FT BUMPER	18	8	18	X	X	8	X	X	X	+32
2	SAME	18	8	40	X	X	X	X	X	8	+67
	Measurements recorded										
	☑ **inches** **or** ☐ **mm**										

[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.

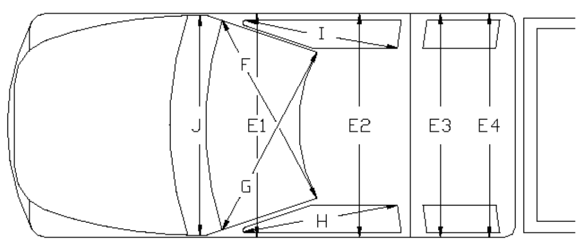
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

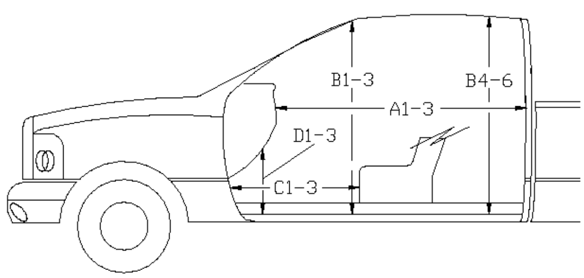
***Measure and document on the vehicle diagram the location of the maximum crush.

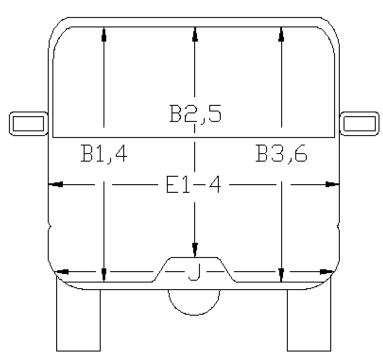
Note: Use as many lines/columns as necessary to describe each damage profile.

Table F.4. Occupant Compartment Measurements for Test No. 608551-5.

Date:	2019-01-18	Test No.:	608551-5	VIN No.:	1C6RR6FTOES149481
Year:	2014	Make:	RAM	Model:	1500







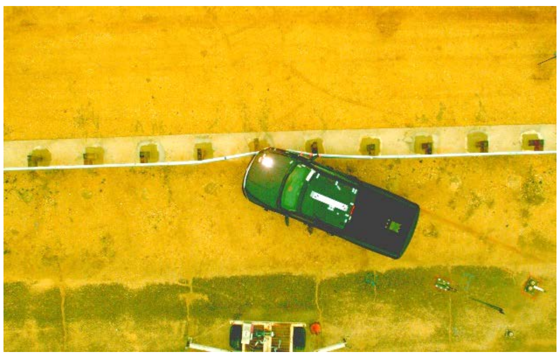
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

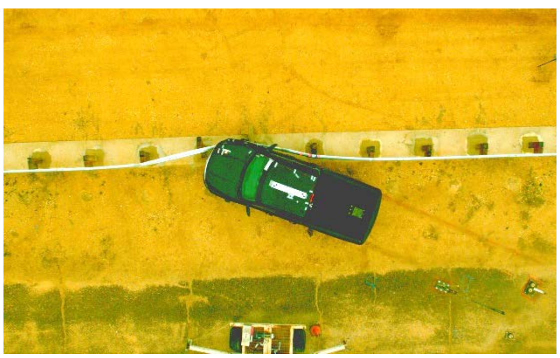
	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	44.00	-1.00
B2	38.00	34.00	-4.00
B3	45.00	33.00	-12.00
B4	39.50	36.00	-3.50
B5	43.00	41.00	-2.00
B6	39.50	44.00	4.50
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	57.50	-1.00
E2	63.50	62.50	-1.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	54.00	-5.00
G	59.00	56.00	-3.00
H	37.50	37.50	0.00
I	37.50	36.00	-1.50
J*	25.00	25.00	0.00

F2 SEQUENTIAL PHOTOGRAPHS

0.000 s



0.050 s



0.100 s

0.200 s

Figure F.1. Sequential Photographs for Test No. 608551-5 (Overhead and Frontal Views).


0.300 s



0.400 s



0.500 s



0.600 s


Figure F.1. Sequential Photographs for Test No. 608551-5 (Overhead and Frontal Views) (Continued).

0.000 s

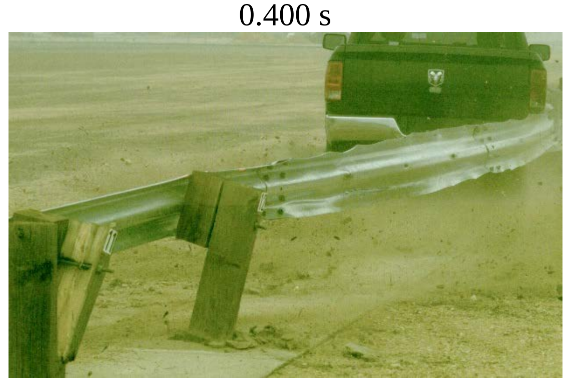
0.050 s

0.100 s

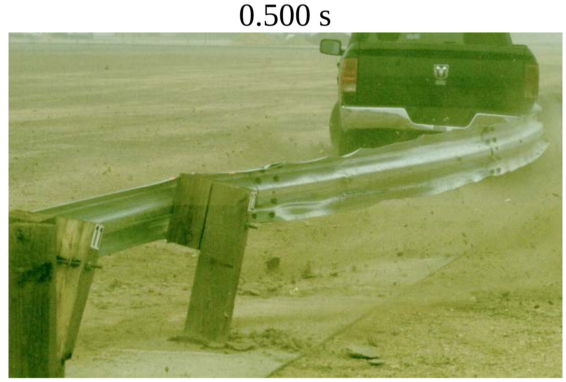
0.200 s

0.300 s

0.400 s



0.500 s



0.600 s

Figure F.2. Sequential Photographs for Test No. 608551-5 (Rear View).

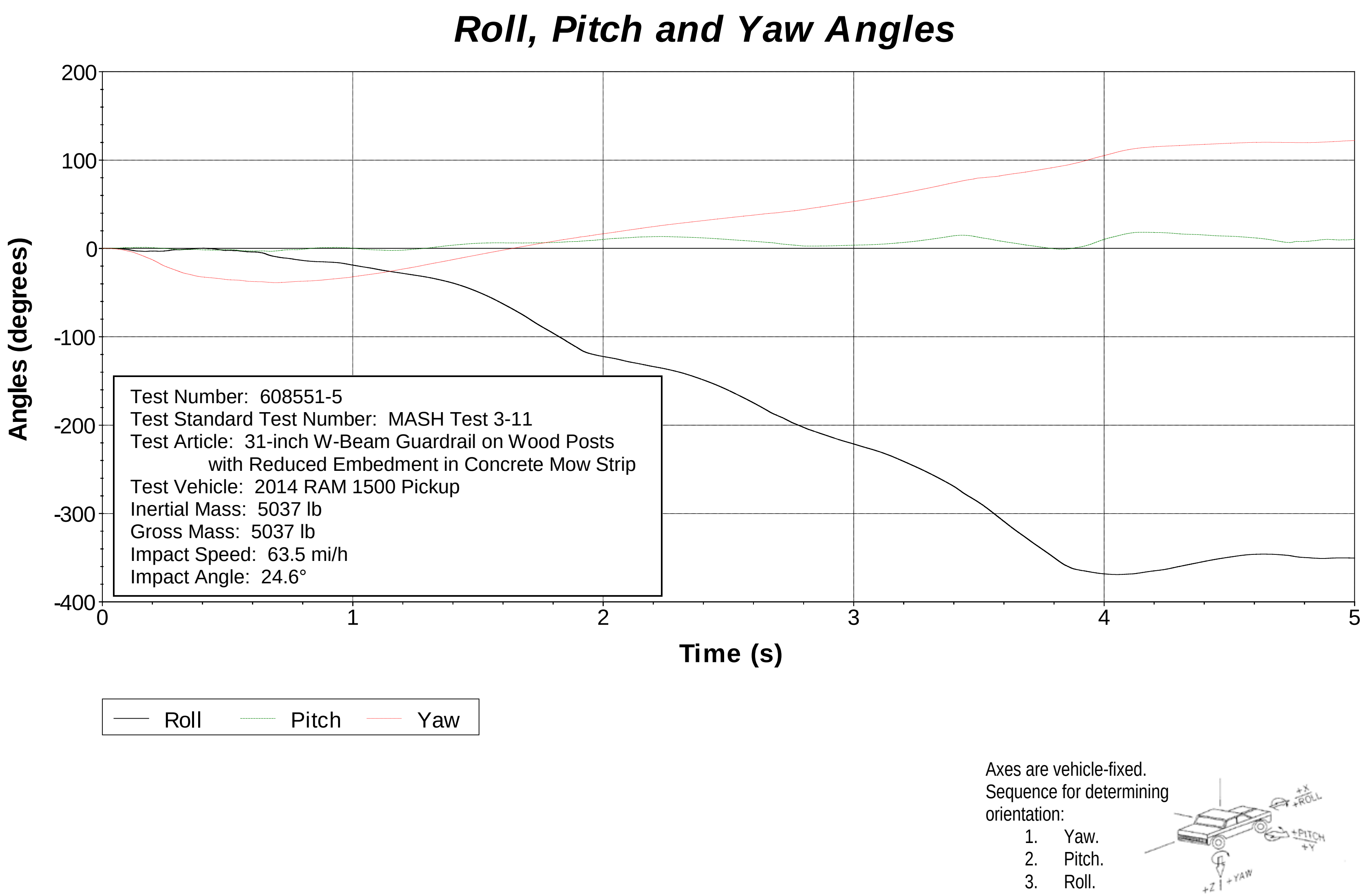


Figure F.3. Vehicle Angular Displacements for Test No. 608551-5.

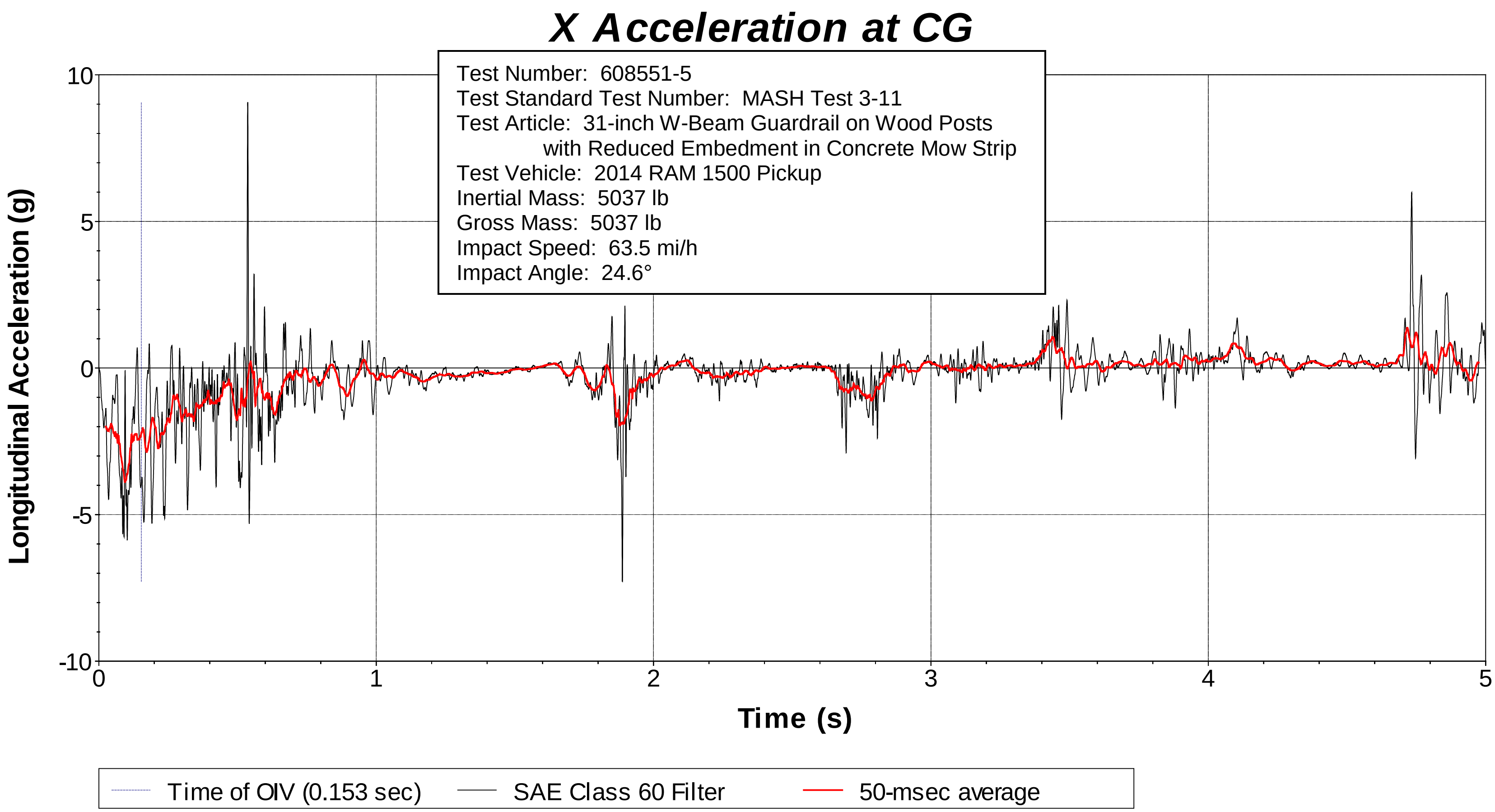


Figure F.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608551-5 (Accelerometer Located at Center of Gravity).

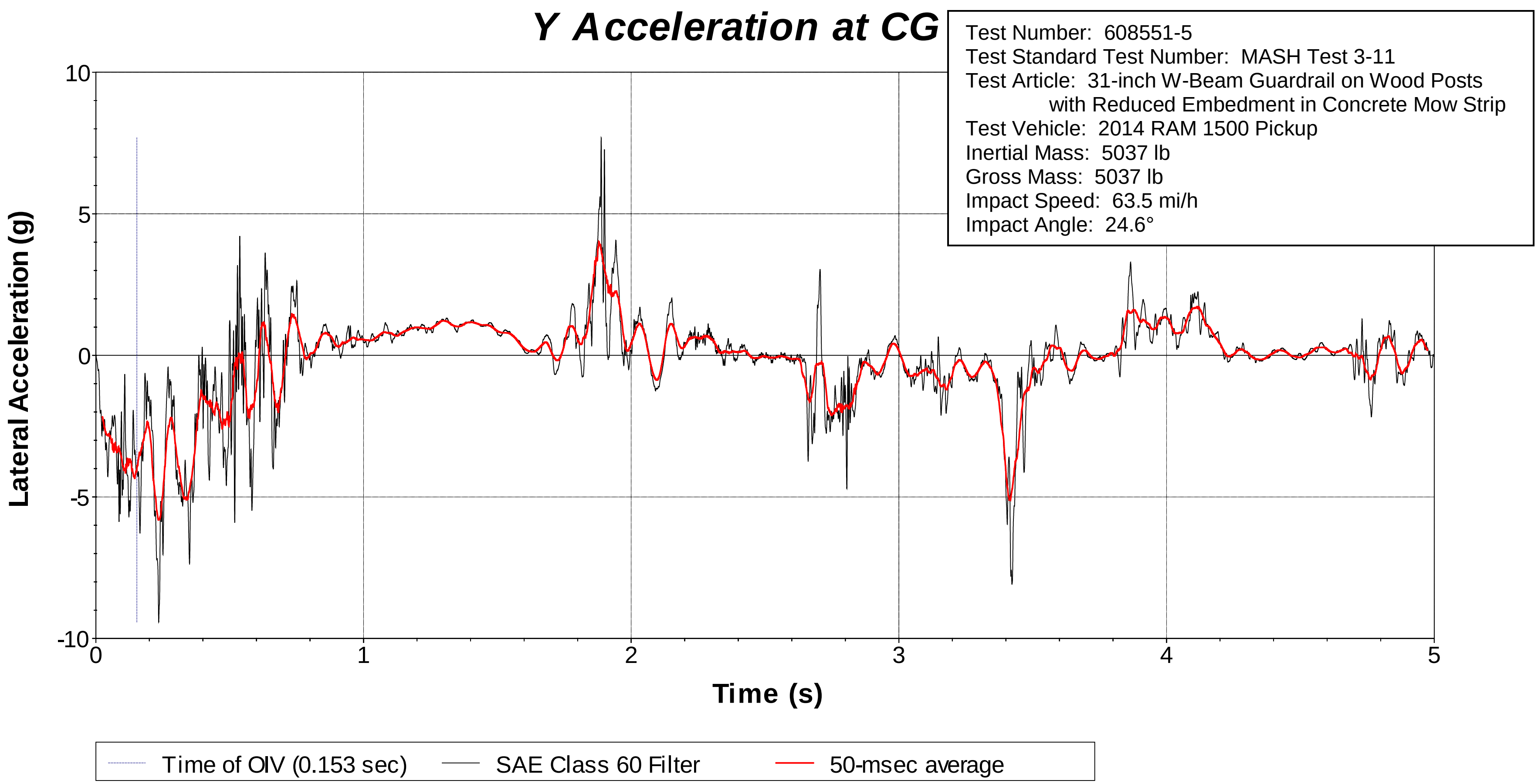
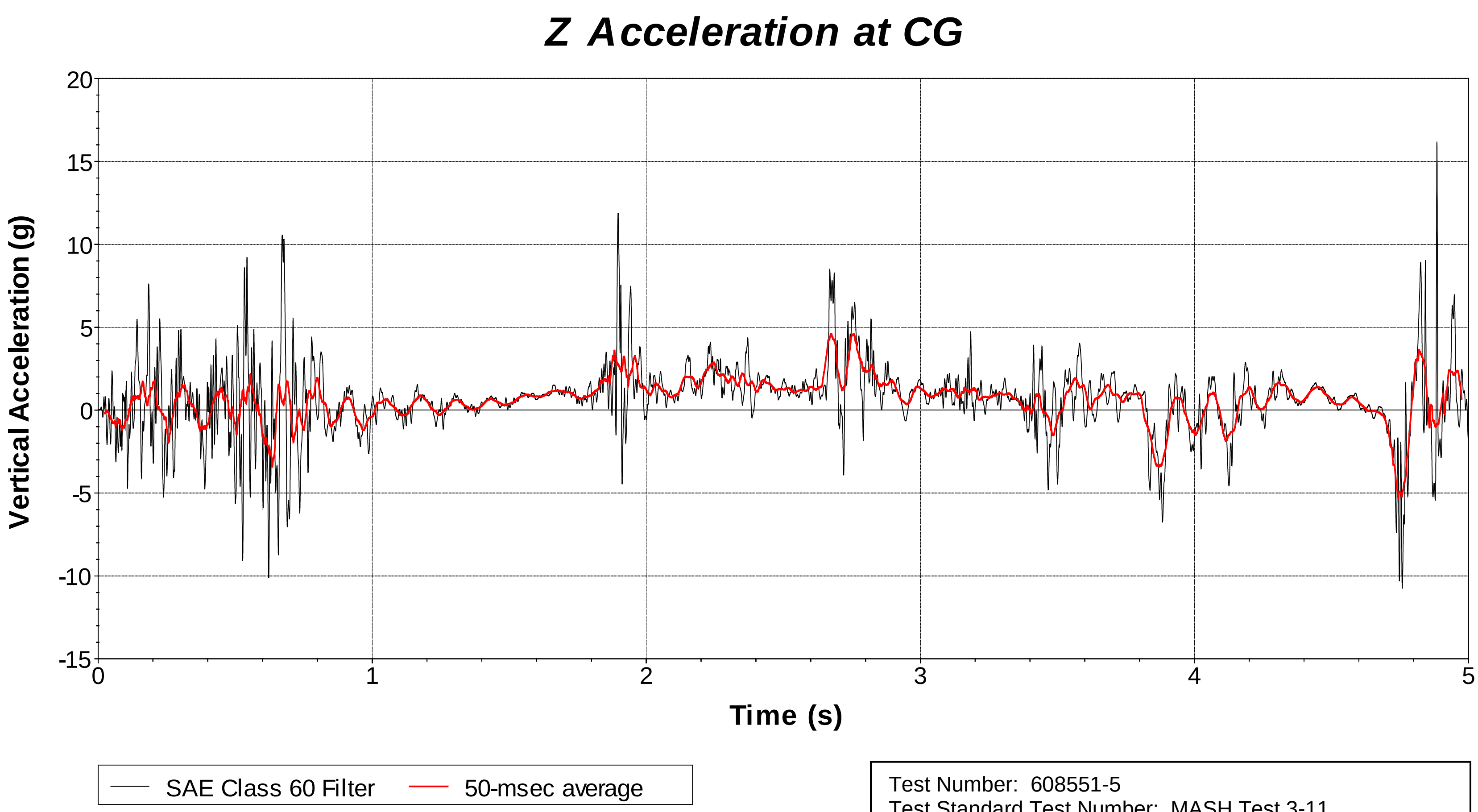
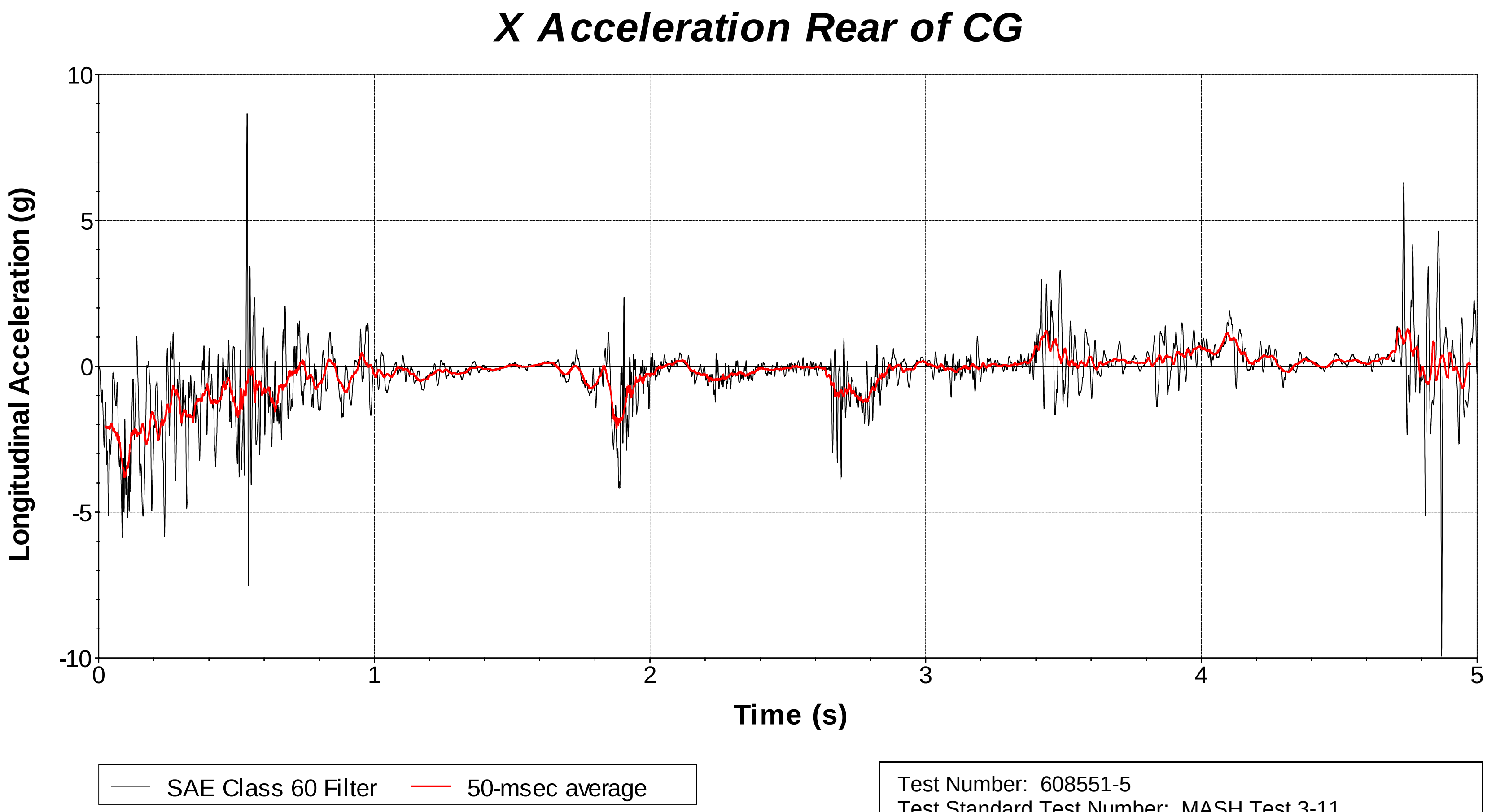


Figure F.5. Vehicle Lateral Accelerometer Trace for Test No. 608551-5 (Accelerometer Located at Center of Gravity).



Test Number: 608551-5
Test Standard Test Number: MASH Test 3-11
Test Article: 31-inch W-Beam Guardrail on Wood Posts
with Reduced Embedment in Concrete Mow Strip
Test Vehicle: 2014 RAM 1500 Pickup
Inertial Mass: 5037 lb
Gross Mass: 5037 lb
Impact Speed: 63.5 mi/h
Impact Angle: 24.6°

Figure F.6. Vehicle Vertical Accelerometer Trace for Test No. 608551-5 (Accelerometer Located at Center of Gravity).



Test Number: 608551-5
Test Standard Test Number: MASH Test 3-11
Test Article: 31-inch W-Beam Guardrail on Wood Posts
with Reduced Embedment in Concrete Mow Strip
Test Vehicle: 2014 RAM 1500 Pickup
Inertial Mass: 5037 lb
Gross Mass: 5037 lb
Impact Speed: 63.5 mi/h
Impact Angle: 24.6°

Figure F.7. Vehicle Longitudinal Accelerometer Trace for Test No. 608551-5 (Accelerometer Located Rear of Center of Gravity).

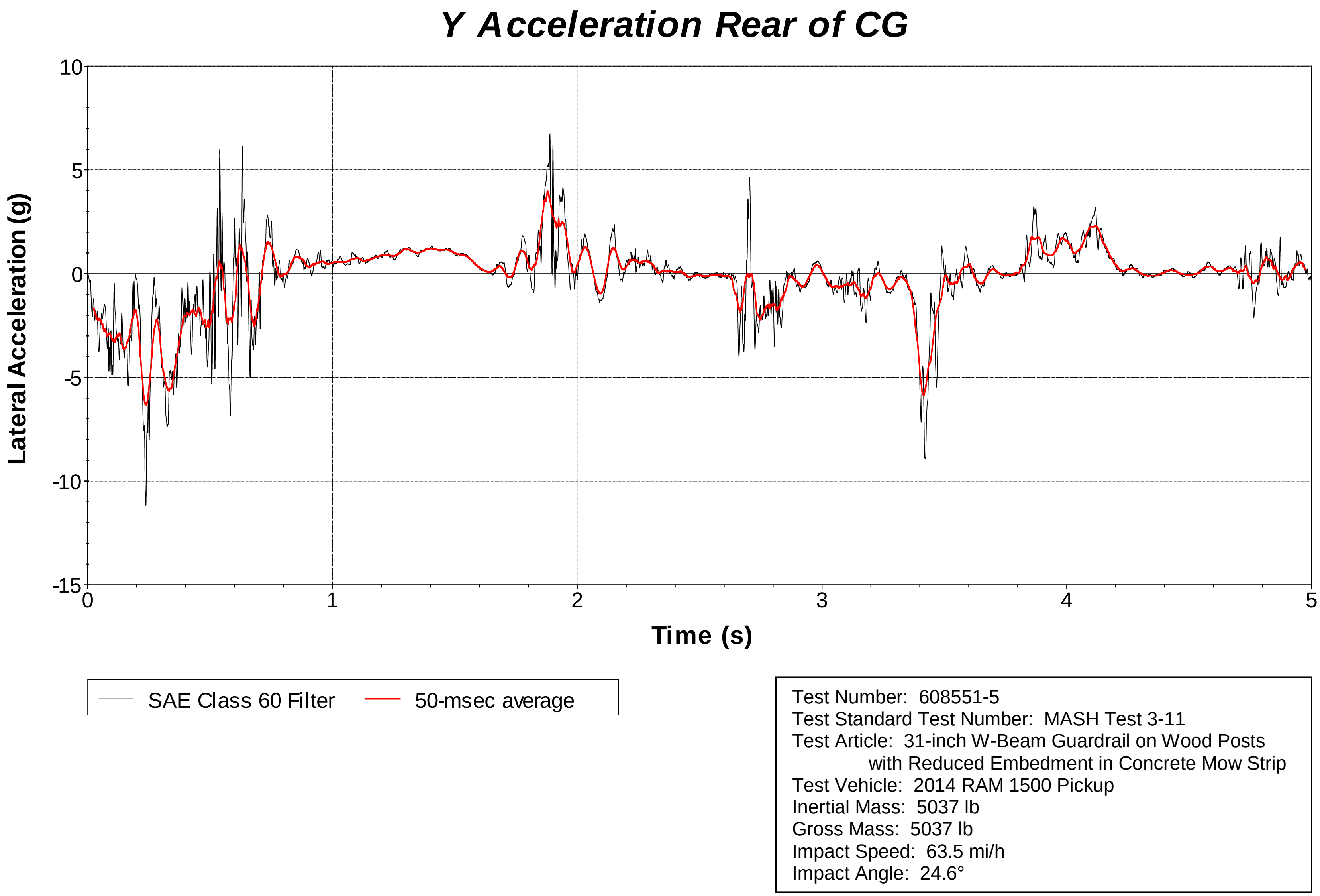


Figure F.8. Vehicle Lateral Accelerometer Trace for Test No. 608551-5 (Accelerometer Located Rear of Center of Gravity).

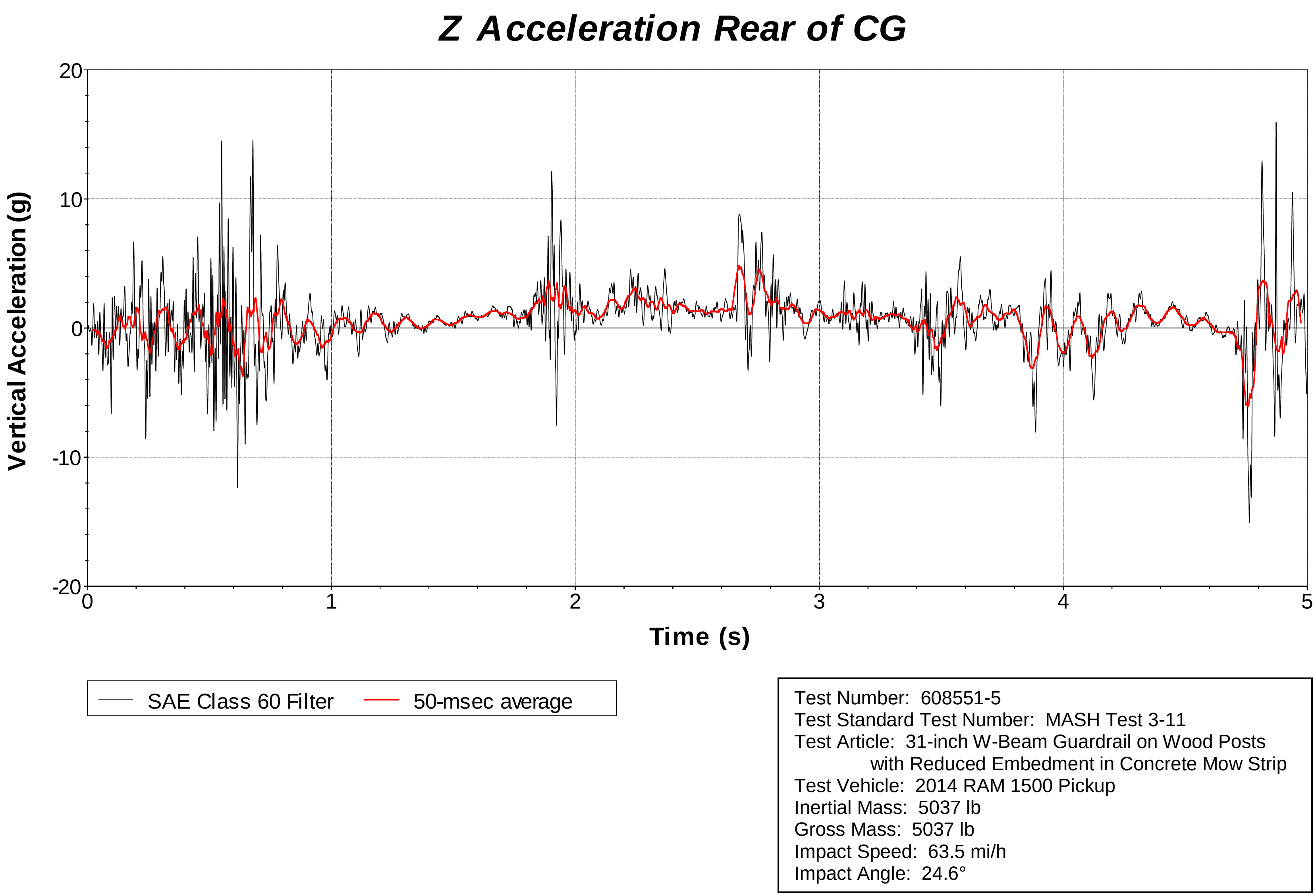


Figure F.9. Vehicle Vertical Accelerometer Trace for Test No. 608551-5 (Accelerometer Located Rear of Center of Gravity).

APPENDIX G. *MASH* TEST 3-10 (CRASH TEST NO. 608551-3)

G1 VEHICLE PROPERTIES AND INFORMATION

Table G.1. Vehicle Properties for Test No. 608551-3.

Date: 2017-10-09 Test No.: 608551-3 VIN No.: KNADH4A31B6910621

Year: 2011 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 118870 Tire Size: 185/65R14

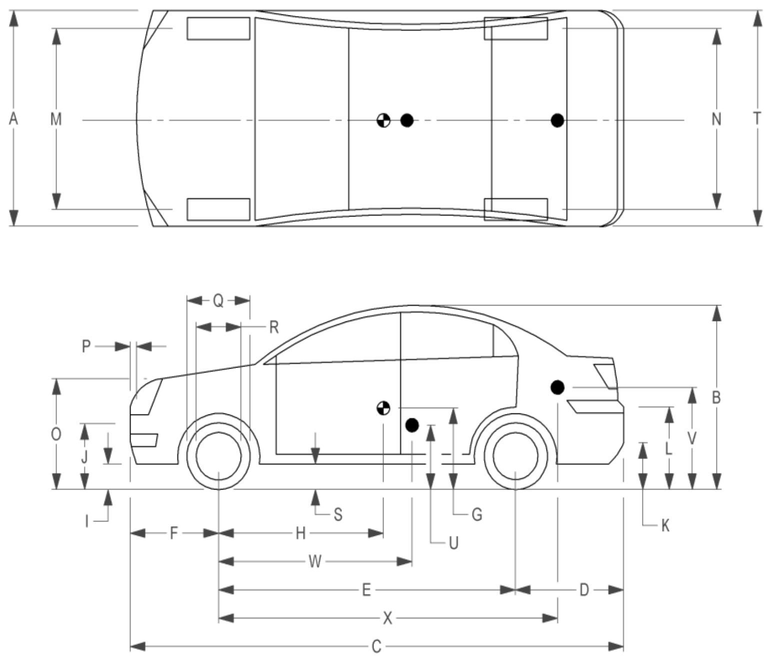
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None

Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:
None

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



Geometry: inches

A	66.38	F	33.00	K	12.25	P	4.12	U	15.00
B	51.50	G	-----	L	25.25	Q	22.50	V	20.50
C	165.75	H	35.42	M	57.75	R	15.50	W	35.40
D	34.00	I	7.75	N	57.70	S	8.25	X	106.60
E	98.75	J	21.50	O	28.25	T	66.20		
Wheel Center Ht Front			11.00	Wheel Center Ht Rear			11.00	W-H	0

GVWR Ratings:		Mass: lb	Curb	Test Inertial	Gross Static
Front	1718	M_{front}	1574	1557	1642
Back	1874	M_{rear}	880	871	951
Total	3638	M_{Total}	2454	2428	2593

Mass Distribution:
lb LF: 801 RF: 756 LR: 456 RR: 415

Table G.2. Exterior Crush Measurements for Test No. 608551-3.

Date: 2017-10-09 Test No.: 608551-3 VIN No.: KNADH4A31B6910621

Year: 2011 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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	16	9	34	0	1.5	3	4	9	7	+9
2	Side plane above bumper	16	11	40	0.5	2	4	6	9	11	+60
	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.

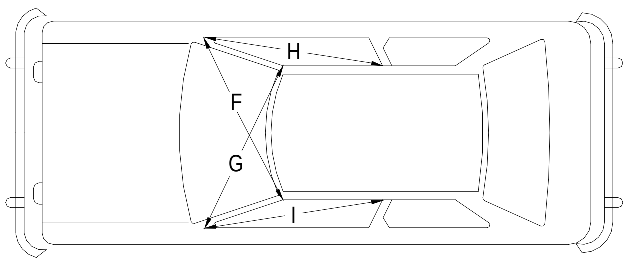
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

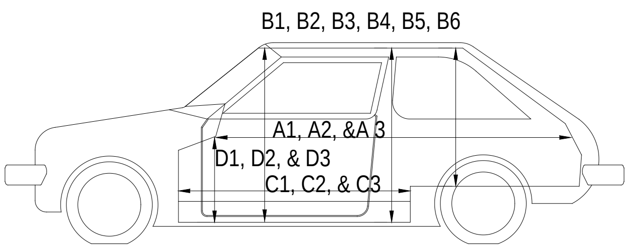
***Measure and document on the vehicle diagram the location of the maximum crush.

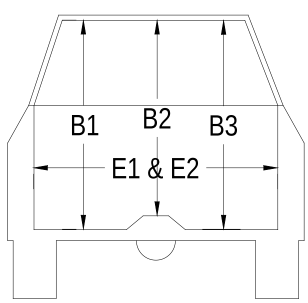
Note: Use as many lines/columns as necessary to describe each damage profile.

Table G.3. Occupant Compartment Measurements for Test No. 608551-3.

Date:	2017-10-09	Test No.:	608551-3	VIN No.:	KNADH4A31B6910621
Year:	2011	Make:	Kia	Model:	Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.50	67.50	0
A2	67.25	67.25	0
A3	67.75	67.75	0
B1	40.50	40.50	0
B2	39.00	39.00	0
B3	40.50	40.50	0
B4	36.25	36.25	0
B5	36.00	36.00	0
B6	36.25	36.25	0
C1	26.00	26.00	0
C2	-----	-----	--
C3	26.00	26.00	0
D1	9.50	9.50	0
D2	-----	-----	--
D3	9.50	9.50	0
E1	51.50	51.50	0
E2	51.00	51.00	0
F	51.00	51.00	0
G	51.00	51.00	0
H	37.50	37.50	0
I	37.50	37.50	0
J*	51.00	51.00	0

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

G2 SEQUENTIAL PHOTOGRAPHS

Figure G.1. Sequential Photographs for Test No. 608551-3 (Overhead and Frontal Views).


0.200s



0.400 s



0.600 s

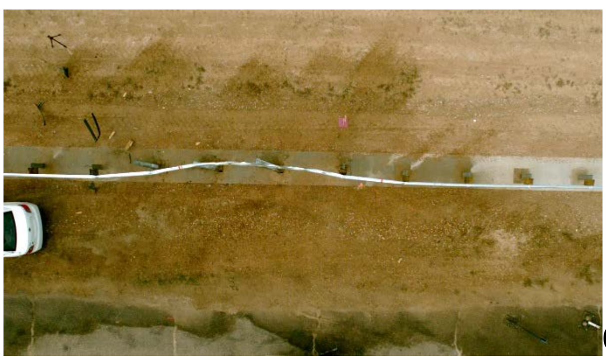


0.800 s


Figure G.1. Sequential Photographs for Test No. 608551-3 (Overhead and Frontal Views) (Continued).

0.000 s

0.050 s

0.100 s

0.150 s

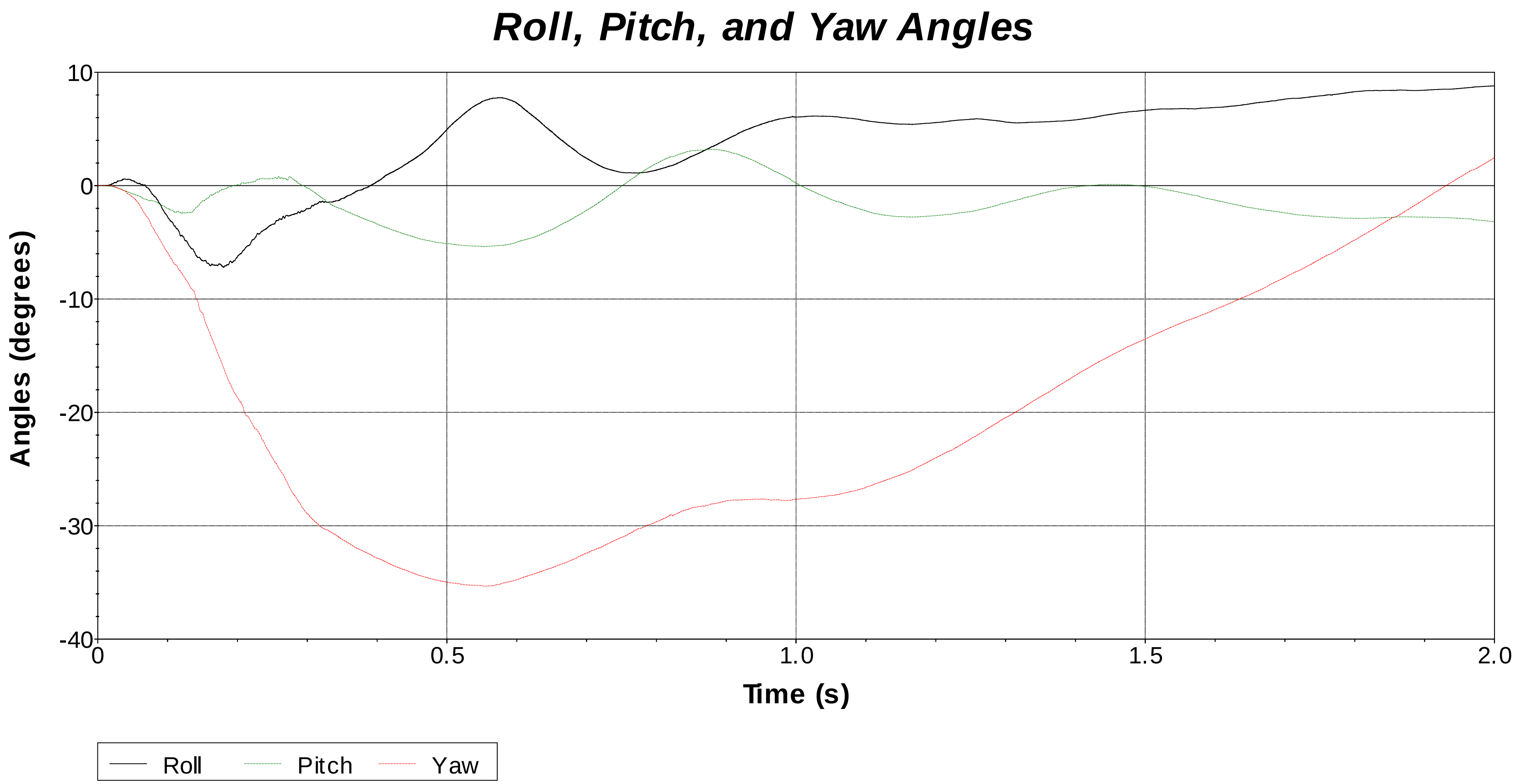
0.200 s

0.400 s

0.600 s

0.800 s

Figure G.2. Sequential Photographs for Test No. 608551-3 (Rear View).



Test Number: 608551-3
Test Standard Test Number: MASH Test 3-10
Test Article: 31-inch W-Beam Guardrail on Steel Posts in Concrete Mow Strip
Test Vehicle: 2011 Kia Rio
Inertial Mass: 2428 lb
Gross Mass: 2593 lb
Impact Speed: 63.6 mi/h
Impact Angle: 24.4°

Axes are vehicle-fixed.
Sequence for determining orientation:
1. Yaw.
2. Pitch.
3. Roll.

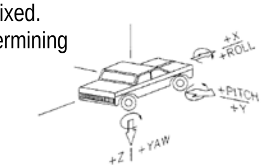


Figure G.3. Vehicle Angular Displacements for Test No. 608551-3.

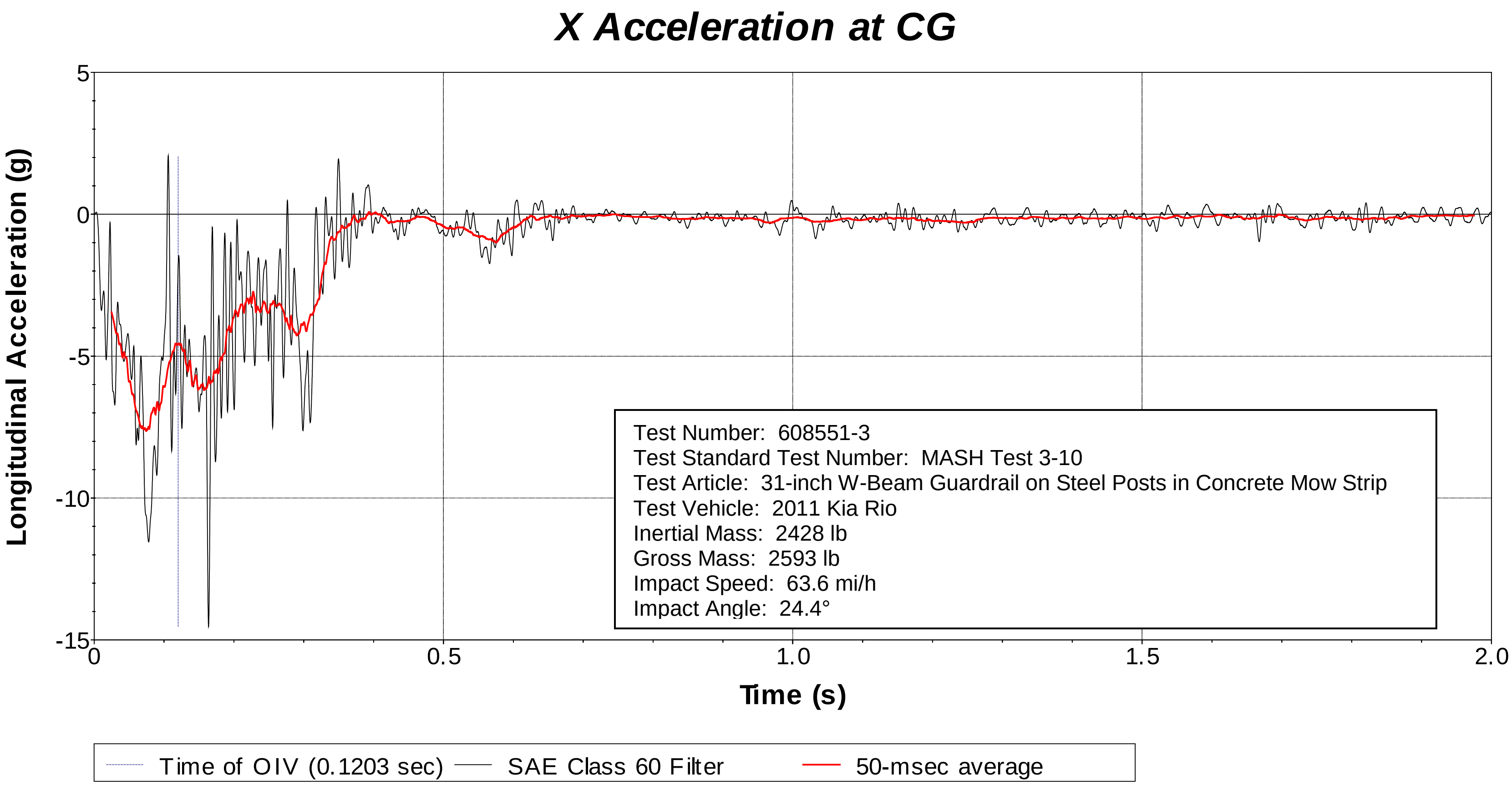


Figure G.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608551-3 (Accelerometer Located at Center of Gravity).

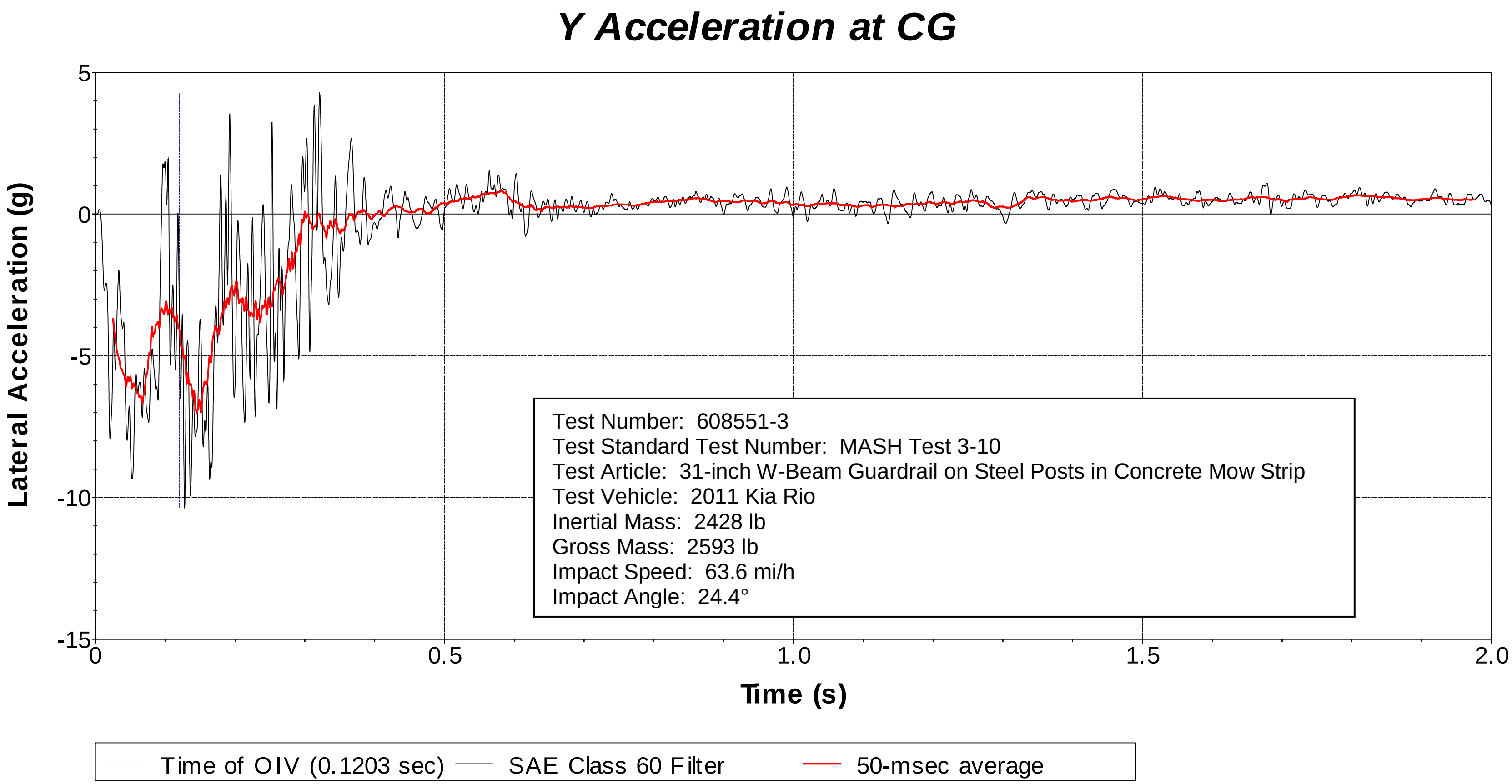


Figure G.5. Vehicle Lateral Accelerometer Trace for Test No. 608551-3 (Accelerometer Located at Center of Gravity).

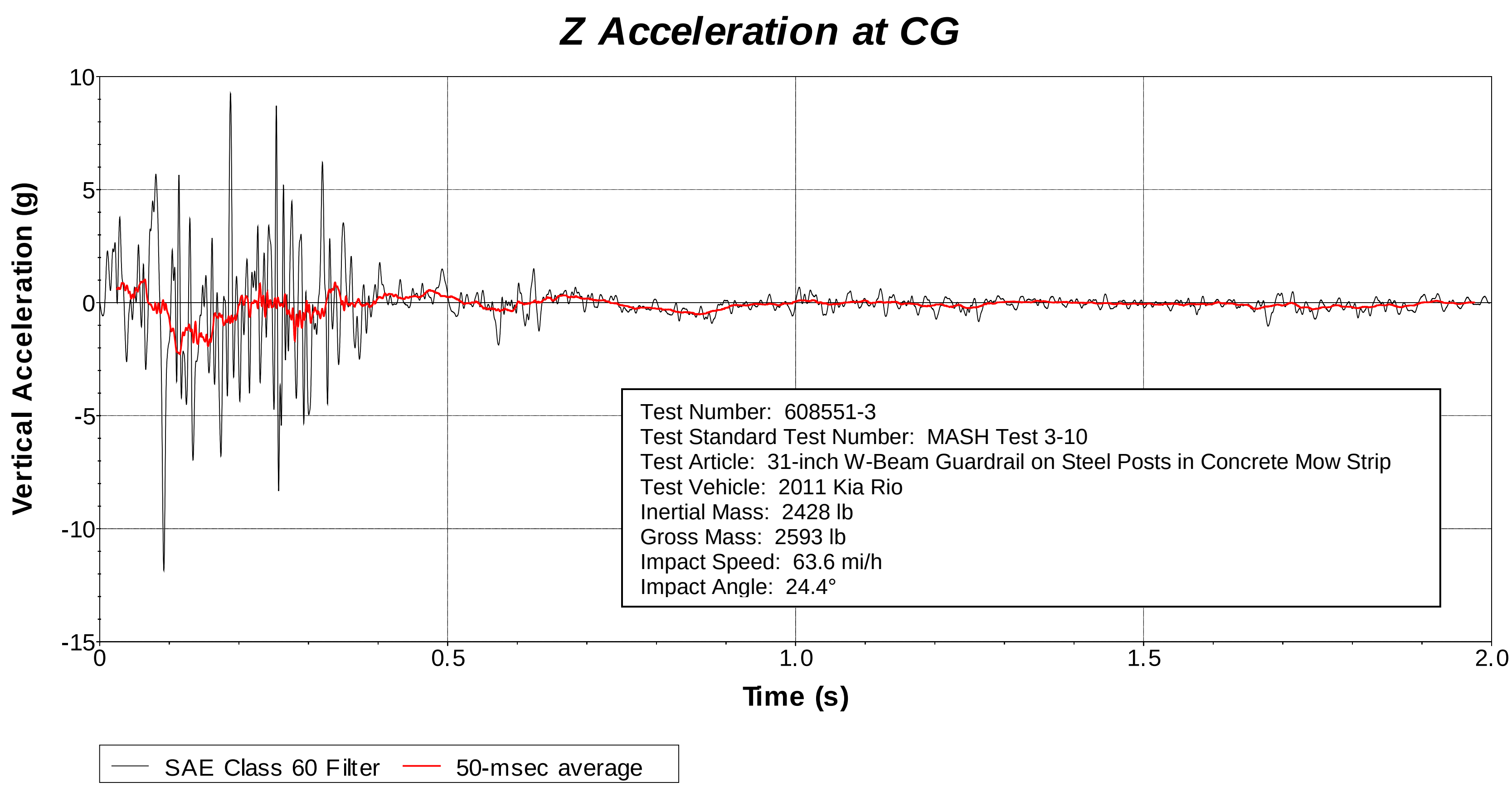


Figure G.6. Vehicle Vertical Accelerometer Trace for Test No. 608551-3 (Accelerometer Located at Center of Gravity).

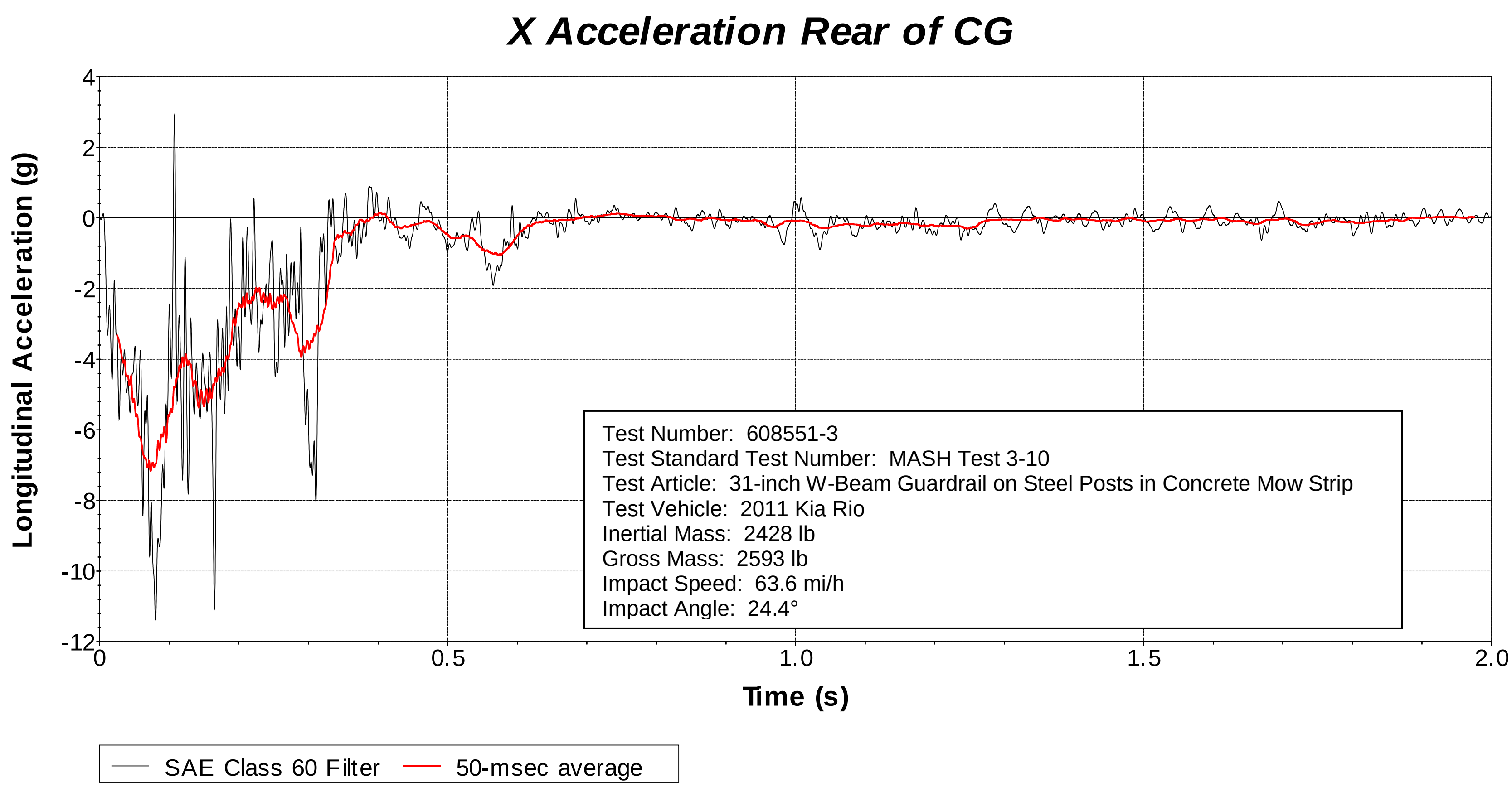


Figure G.7. Vehicle Longitudinal Accelerometer Trace for Test No. 608551-3 (Accelerometer Located Rear of Center of Gravity).

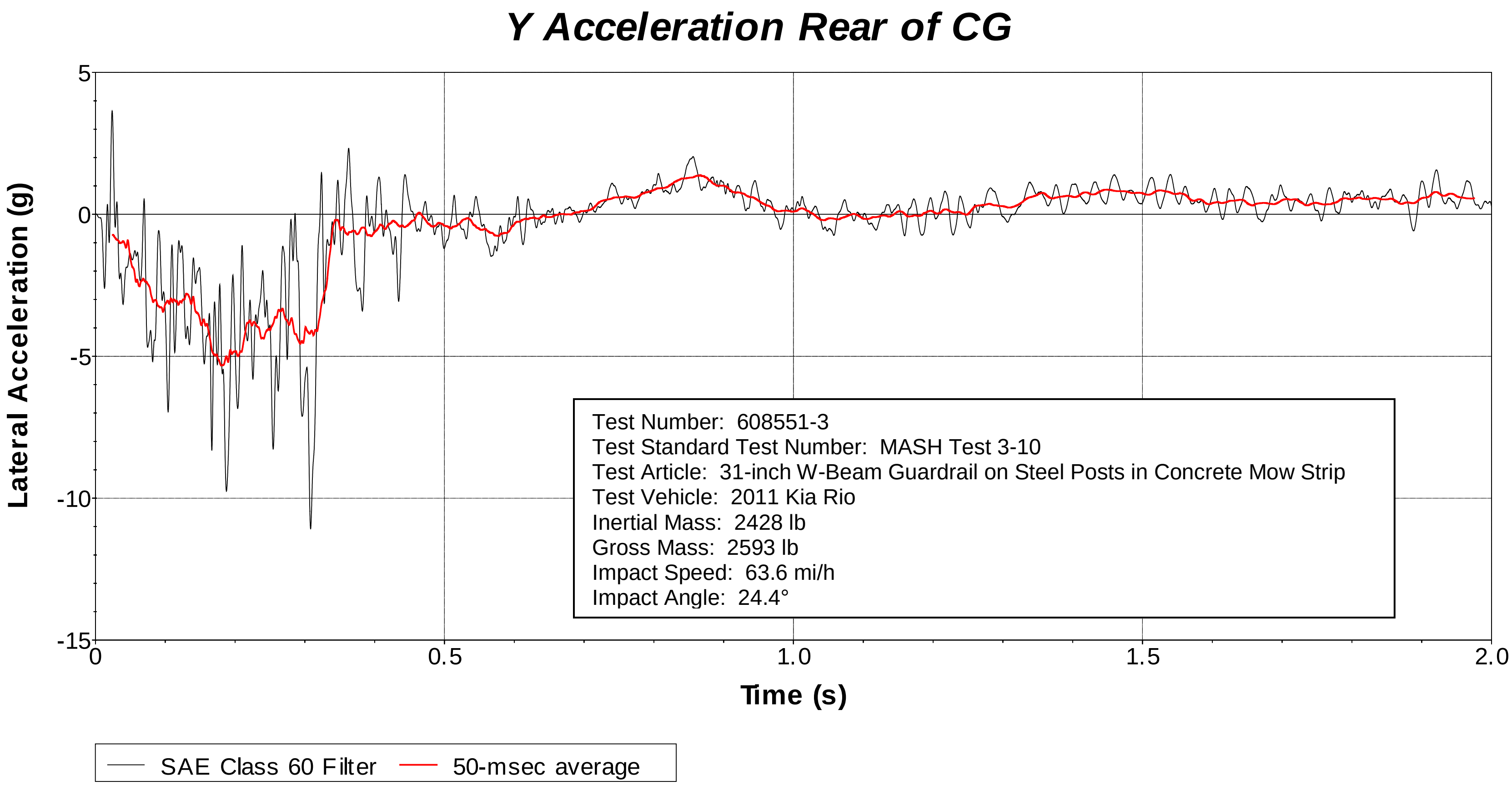


Figure G.8. Vehicle Lateral Accelerometer Trace for Test No. 608551-3 (Accelerometer Located Rear of Center of Gravity).

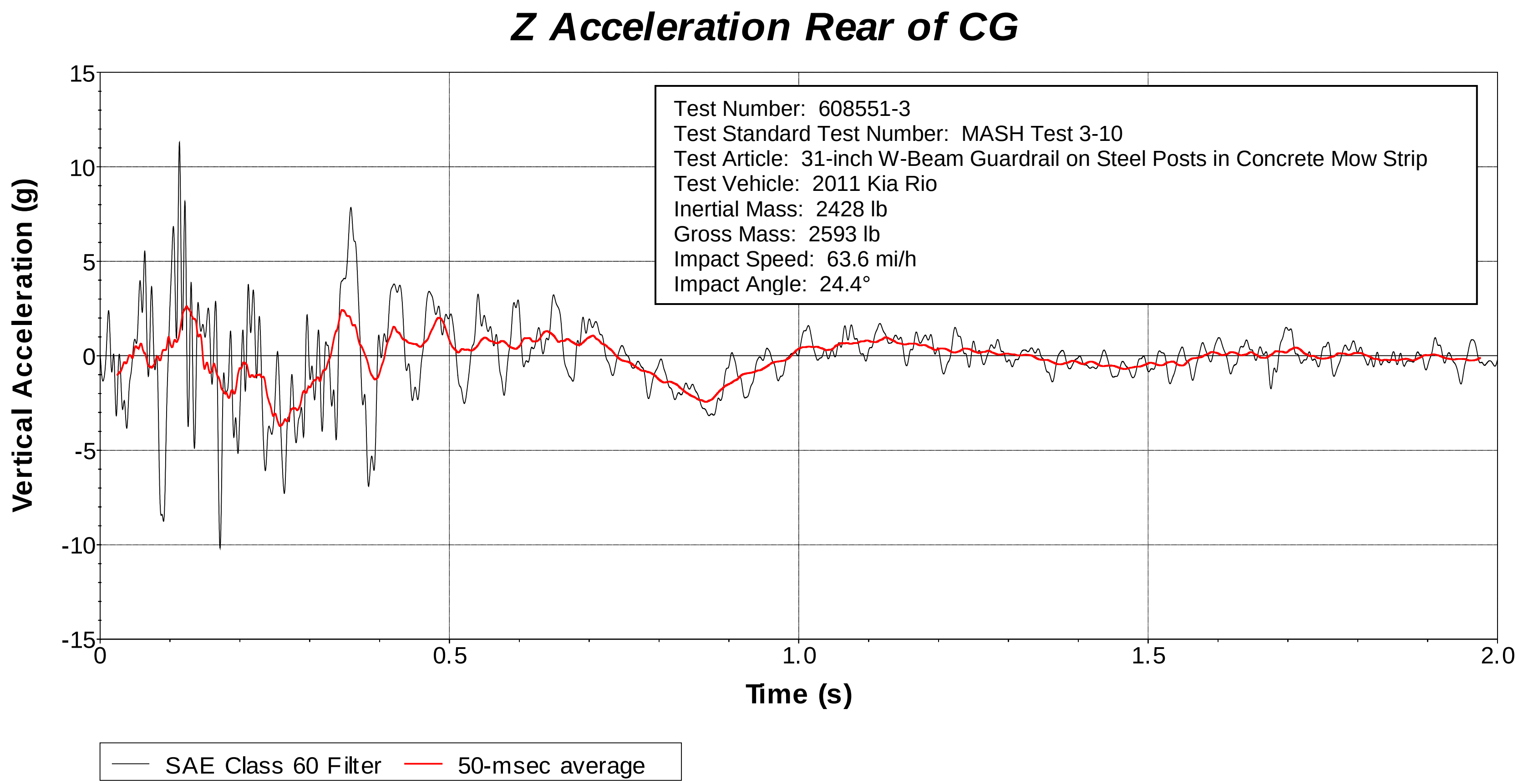


Figure G.9. Vehicle Vertical Accelerometer Trace for Test No. 608551-3 (Accelerometer Located Rear of Center of Gravity).

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APPENIDX H. *MASH* TEST 3-11 (CRASH TEST NO. 608551-4)

H1 VEHICLE PROPERTIES AND INFORMATION

Table H.1. Vehicle Properties for Test No. 608551-4.

Date: 2017-10-27 Test No.: 608551-4 VIN No.: 1C6RD6FP06S504798

Year: 2012 Make: Dodge Model: RAM 1500

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

Tread Type: Highway Odometer: 172874

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

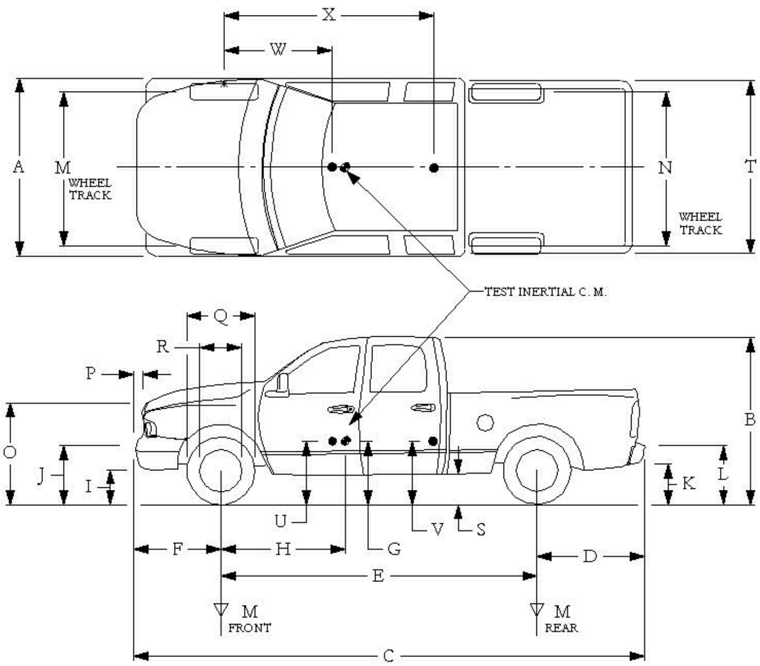
NOTES: None

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: None
Mass: NA
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	28.00
B	74.00	G	28.00	L	30.00	Q	30.50	V	30.75
C	227.50	H	61.50	M	68.50	R	18.00	W	61.50
D	44.00	I	11.75	N	68.00	S	12.75	X	78.25
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.00
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}	2912	2817	--
Back	3900	M_{rear}	2070	2194	--
Total	6700	M_{Total}	4982	5011	--

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1402 RF: 1415 LR: 1093 RR: 1101

Table H.2. Measurements of Vehicle Vertical CG for Test No. 608551-4.

Date: 2017-10-27 Test No.: 608551-4 VIN: 1C6RD6FP06S504798

Year: 2012 Make: Dodge Model: RAM 1500

Body Style: Quad Cab Mileage: 172874

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 114 lb (440 lb max)

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

Measured Vehicle Weights:		(lb)						
LF:	1402		RF:	1415		Front Axle:	2817	
LR:	1093		RR:	1101		Rear Axle:	2194	
Left:	2495		Right:	2516		Total:	5011	
						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:	61.52	inches	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	0.14	inches	Left -	Right +	of Vehicle Centerline			
Z:	28	inches	Above Ground	(minumum 28.0 inches allowed)				

Hood Height: 46.00 inches
43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches
39 ±3 inches allowed

Rear Bumper Height: 30.00 inches

Overall Length: 227.50 inches
237 ±13 inches allowed

Table H.3. Exterior Crush Measurements for Test No. 608551-4.

Date:	2017-10-27	Test No.:	608551-4	VIN No.:	1C6RD6FP06S504798
Year:	2012	Make:	Dodge	Model:	RAM 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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	20	8	24	6	1	2	4	6	8	+16
2	Side plane above bumper	20	10	60	1	2	--	--	6	10	+76
	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).

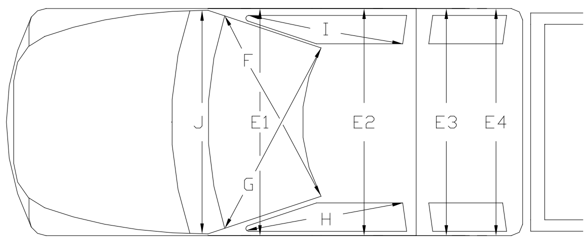
***Measure and document on the vehicle diagram the location of the maximum crush.

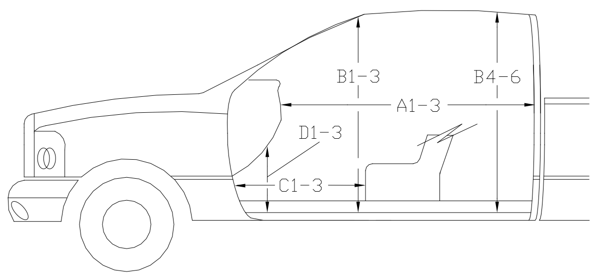
Note: Use as many lines/columns as necessary to describe each damage profile.

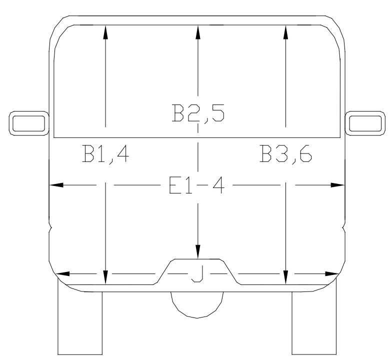
Table H.4. Occupant Compartment Measurements for Test No. 608551-4.

Date: 2017-10-27 Test No.: 608551-4 VIN No.: 1C6RD6FP06S504798

Year: 2012 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	**After** (inches)	**Differ.**
A1	65.00	65.00	0
A2	62.50	62.50	0
A3	65.50	65.50	0
B1	45.00	45.00	0
B2	38.00	38.00	0
B3	45.00	45.00	0
B4	39.50	39.50	0
B5	43.00	43.00	0
B6	39.50	39.50	0
C1	26.00	26.00	0
C2	-----	-----	--
C3	26.00	26.00	0
D1	11.00	11.00	0
D2	-----	-----	--
D3	11.25	11.25	0
E1	59.00	59.00	0
E2	63.50	63.50	0
E3	63.50	63.50	0
E4	63.50	63.50	0
F	59.00	59.00	0
G	59.00	59.00	0
H	37.50	37.50	0
I	37.50	37.50	0
J*	23.25	23.25	0

H2 SEQUENTIAL PHOTOGRAPHS

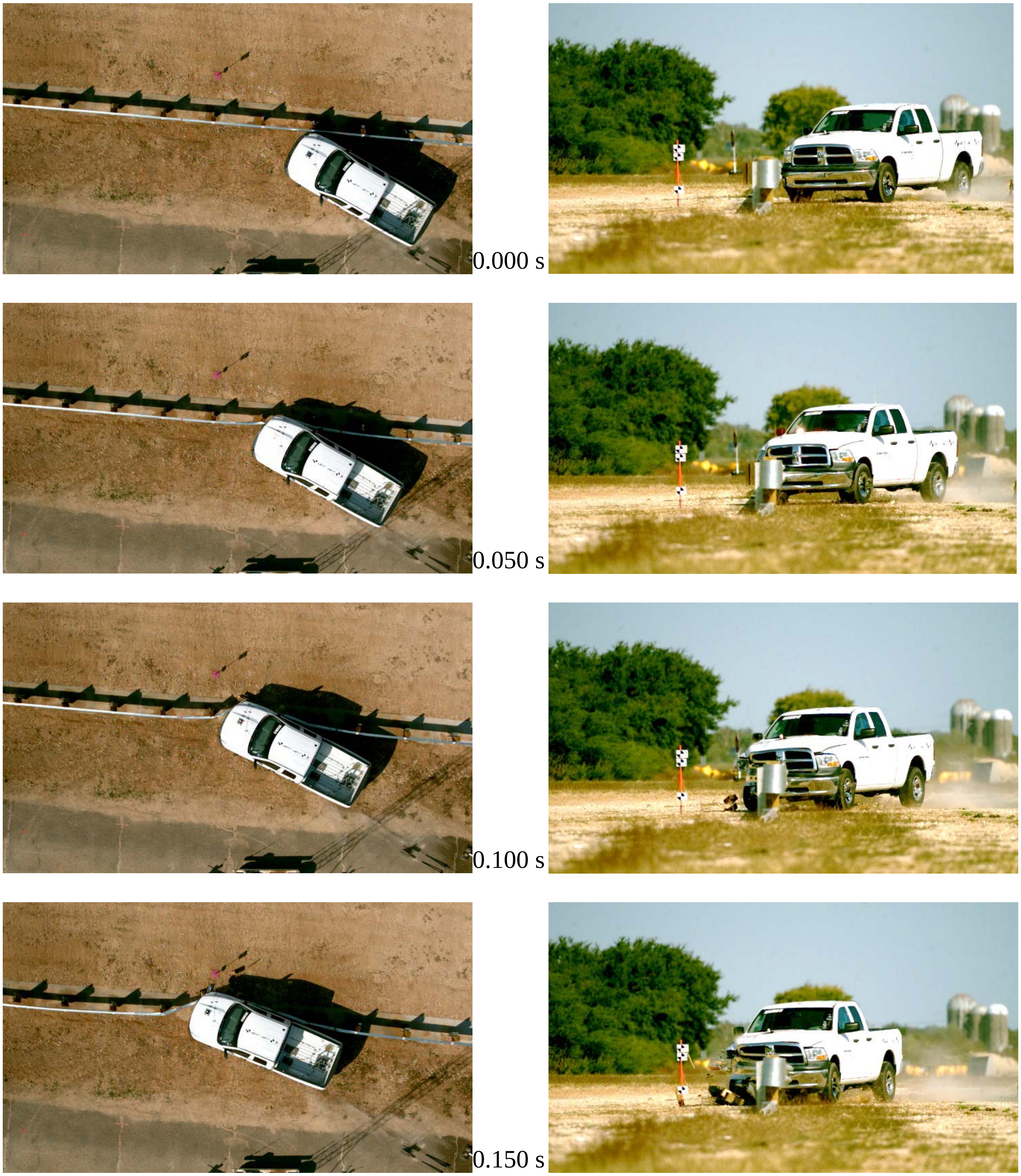


Figure H.1. Sequential Photographs for Test No. 608551-4 (Overhead and Frontal Views).

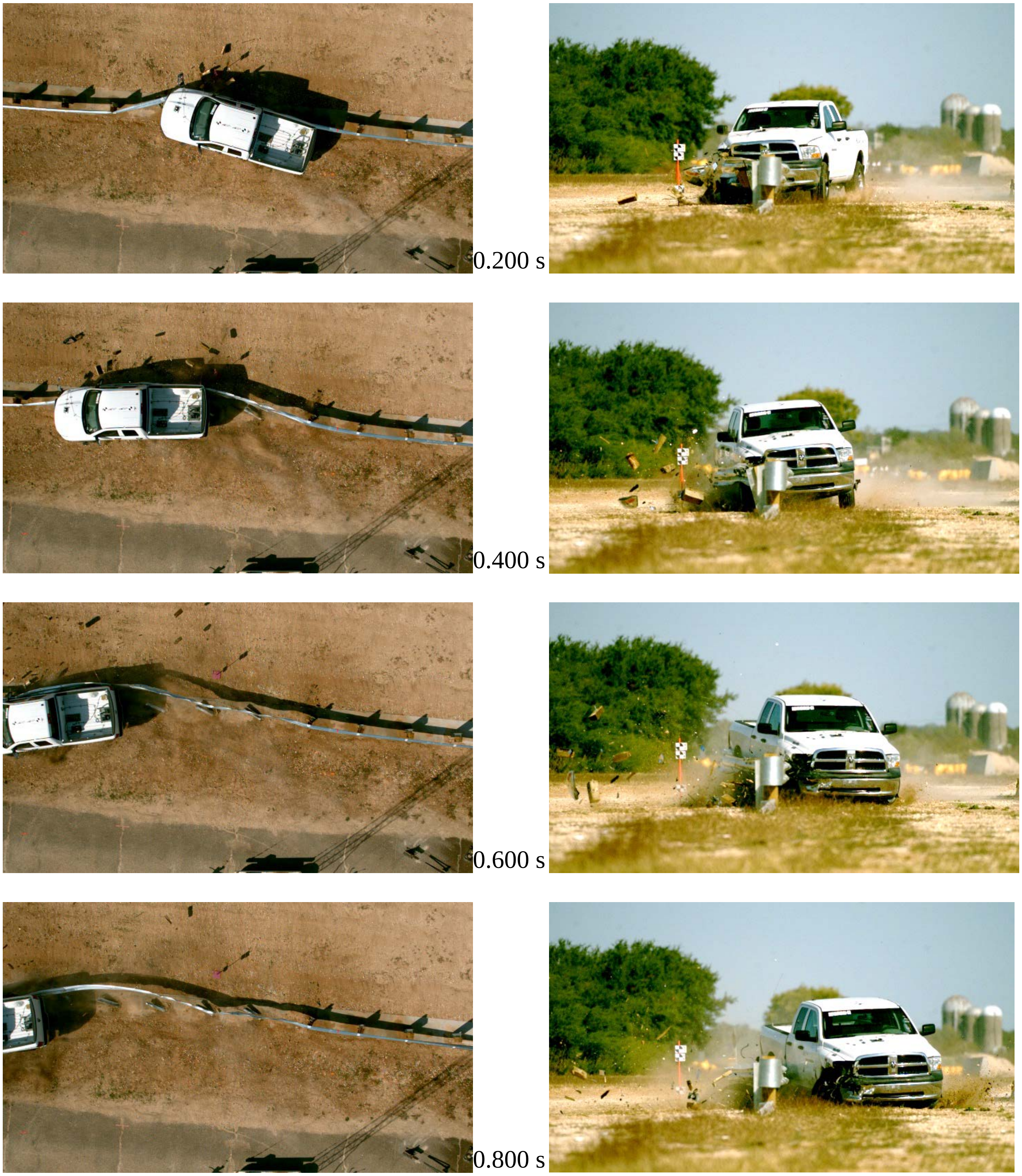
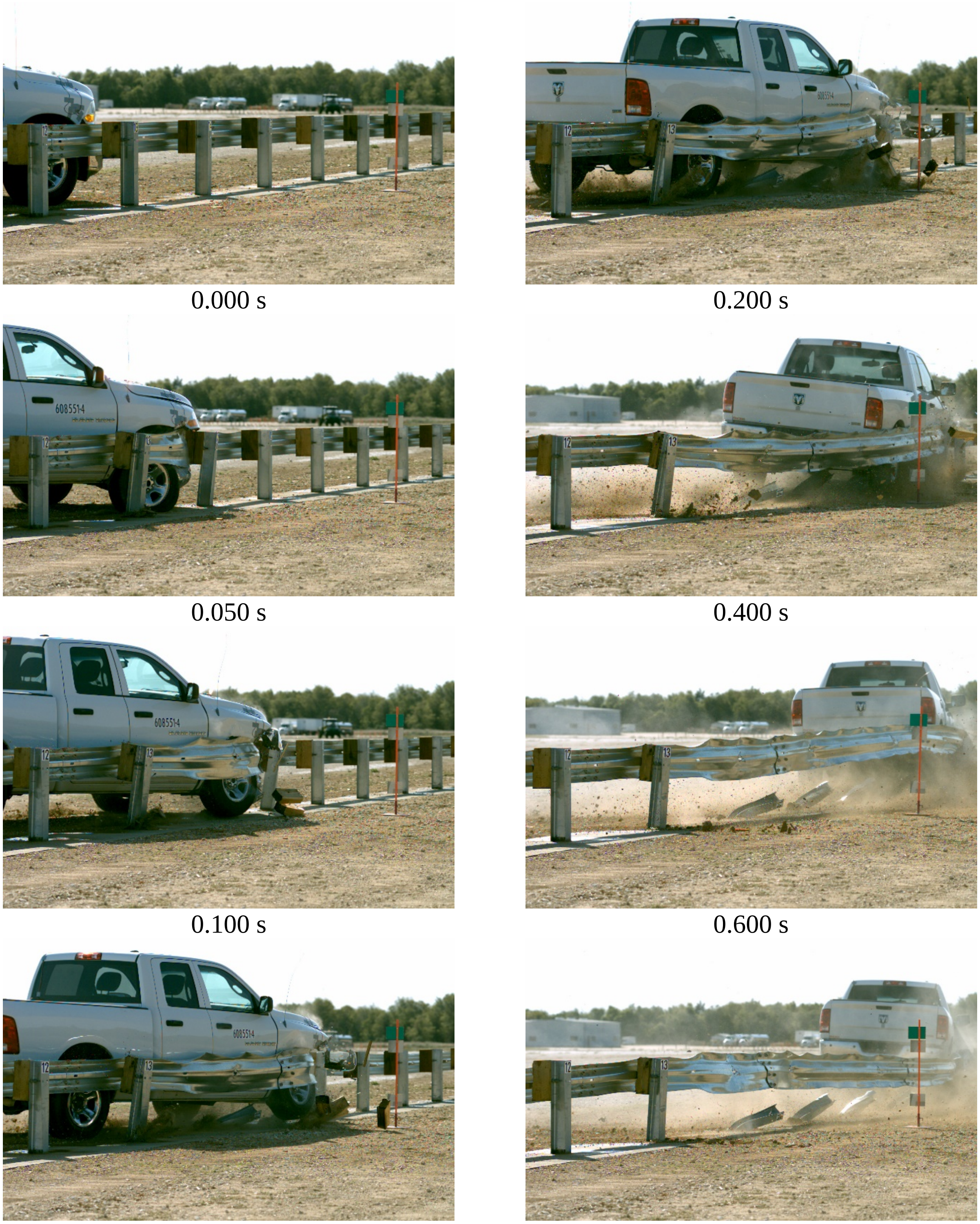


Figure H.1. Sequential Photographs for Test No. 608551-4 (Overhead and Frontal Views) (Continued).



0.000 s

0.200 s

0.050 s

0.400 s

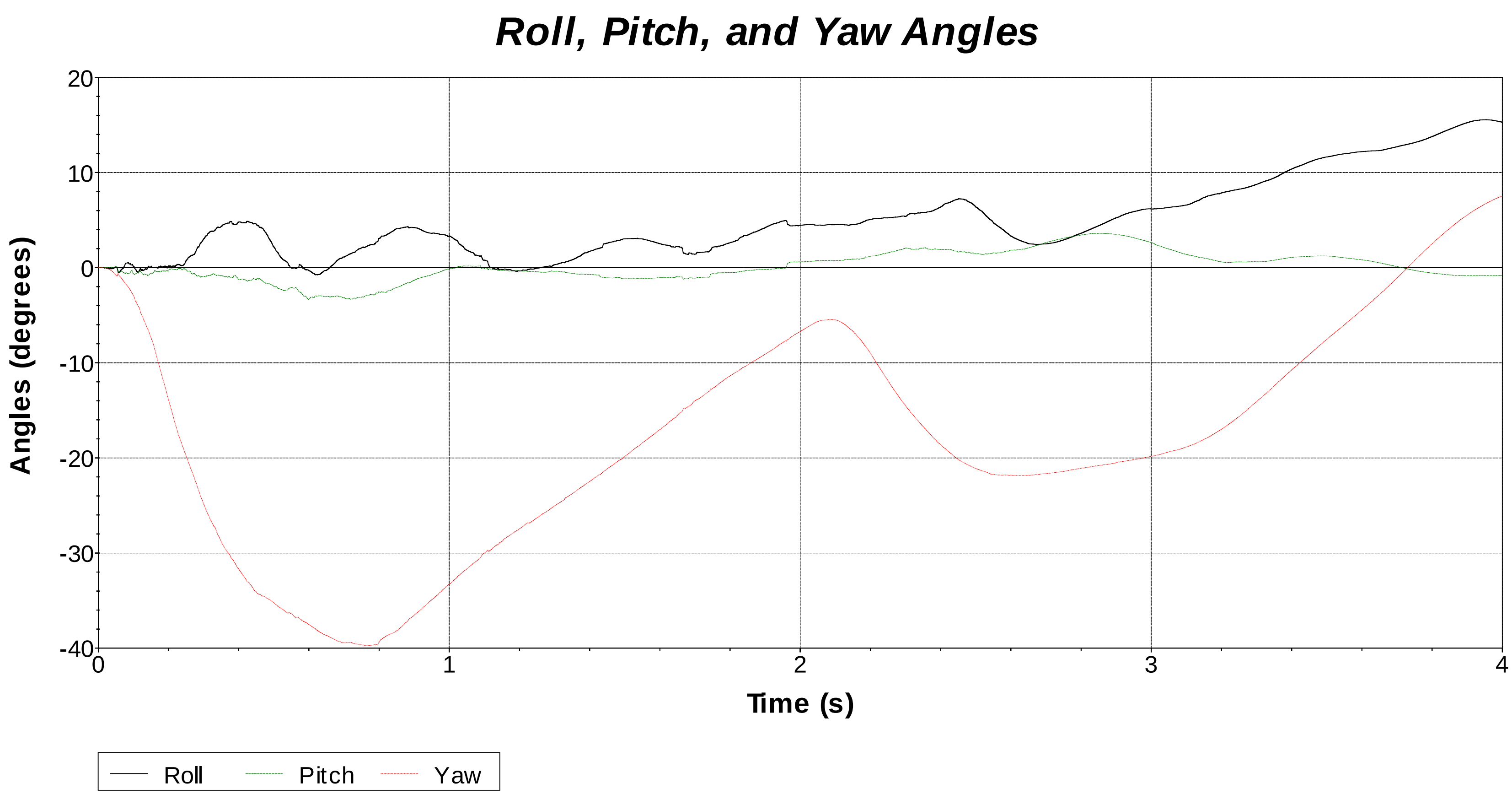
0.100 s

0.600 s

0.150 s

0.800 s

Figure H.2. Sequential Photographs for Test No. 608551-4 (Rear View).



Test Number: 608551-4
Test Standard Test Number: MASH Test 3-11
Test Article: 31-inch W-Beam Guardrail on Steel Posts in Concrete Mow Strip
Test Vehicle: 2012 Dodge RAM 1500 Pickup Truck
Inertial Mass: 5011 lb
Gross Mass: 5011 lb
Impact Speed: 62.8 mi/h
Impact Angle: 25.6°

Axes are vehicle-fixed.
Sequence for determining orientation:
1. Yaw.
2. Pitch.
3. Roll.

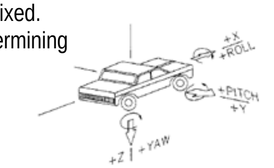


Figure H.3. Vehicle Angular Displacements for Test No. 608551-4.

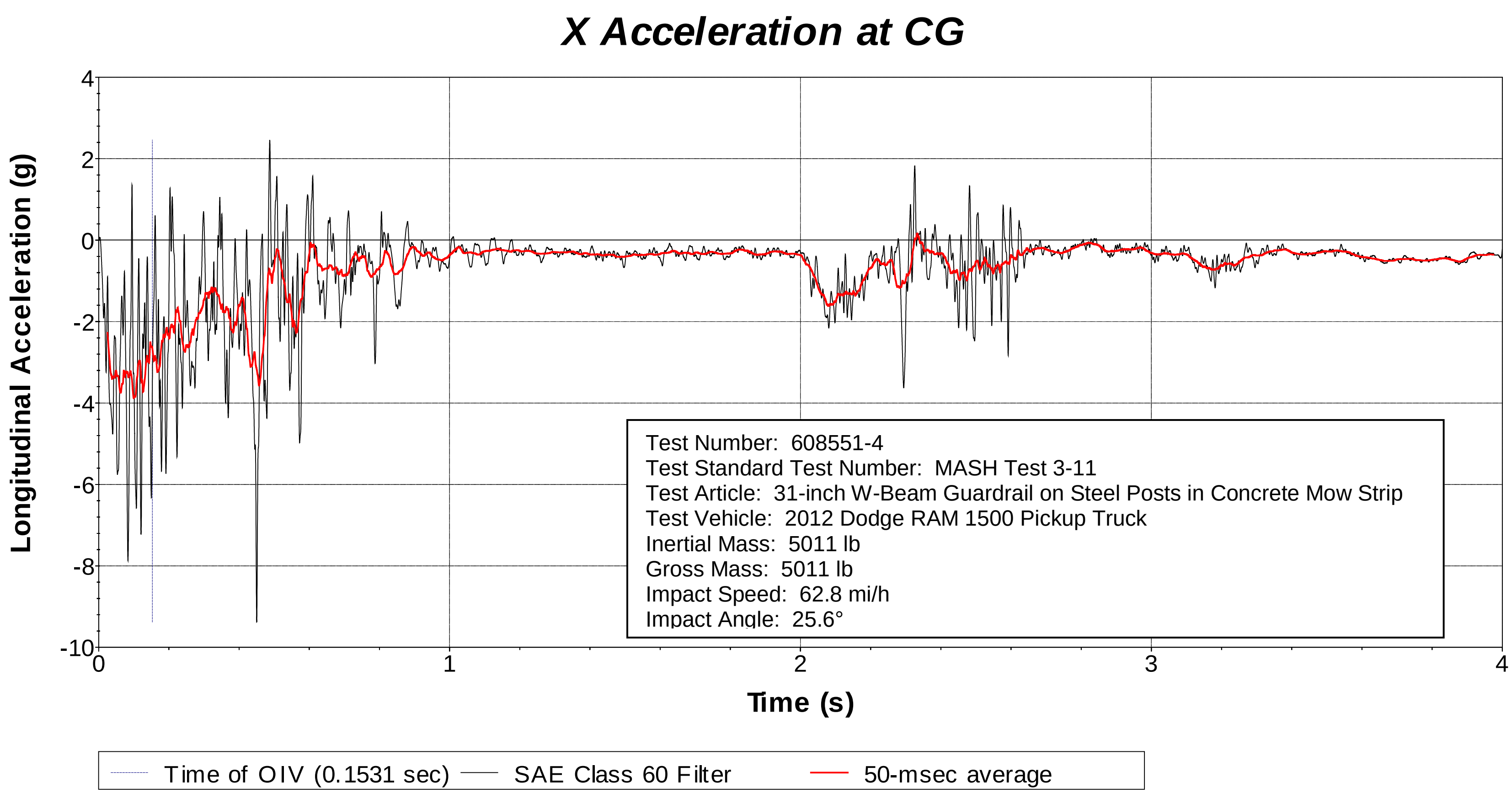


Figure H.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608551-4 (Accelerometer Located at Center of Gravity).

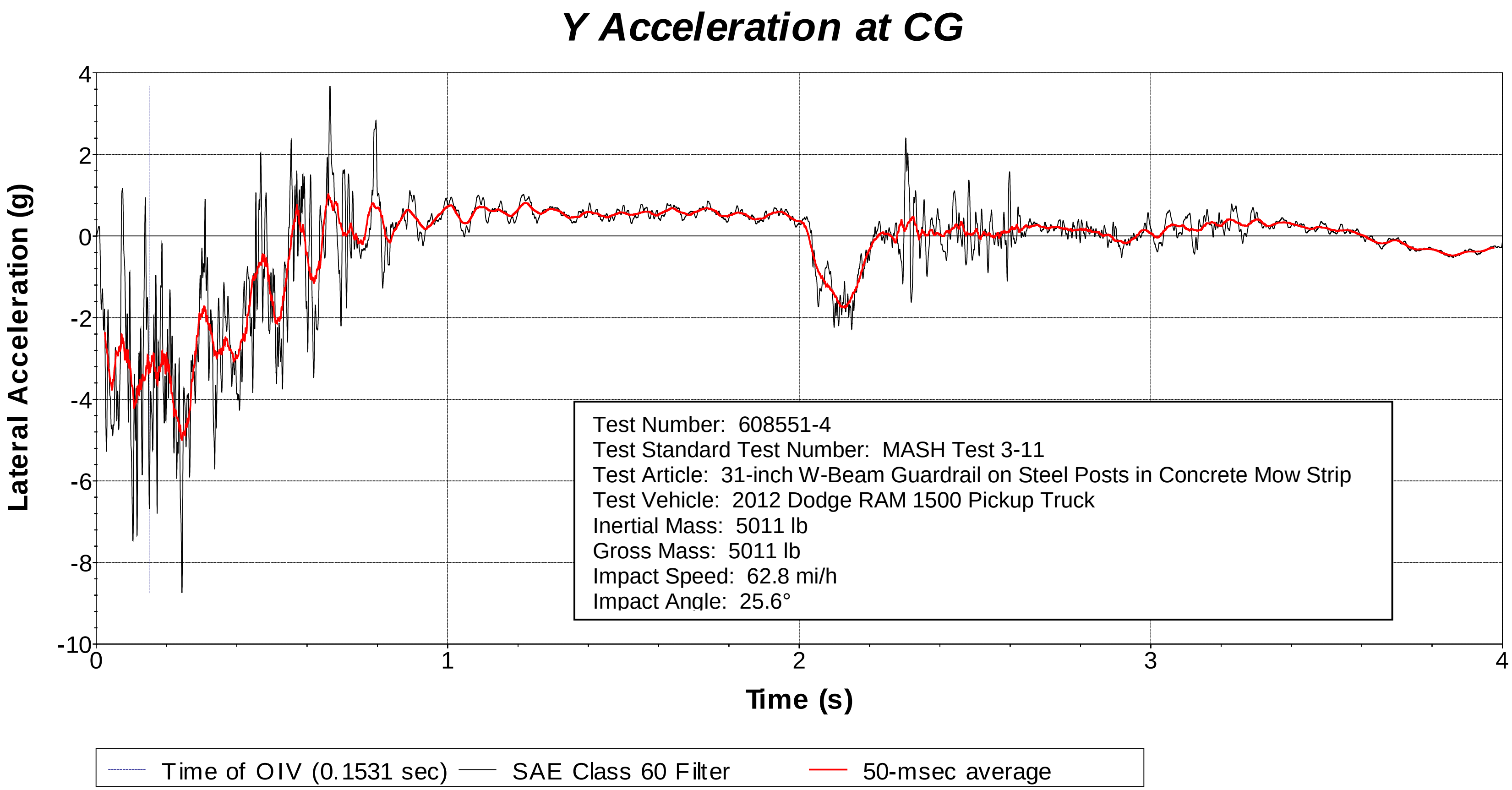
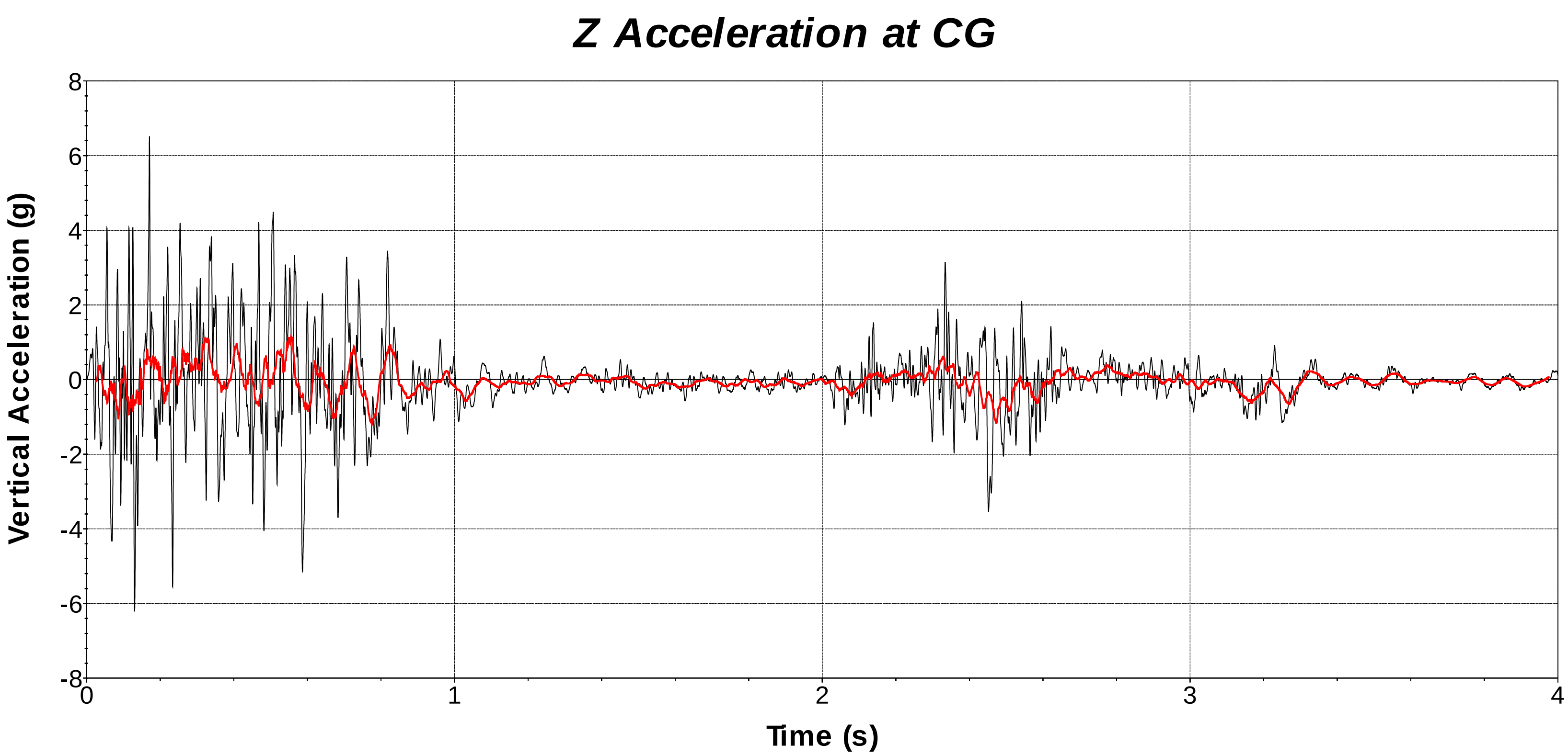


Figure H.5. Vehicle Lateral Accelerometer Trace for Test No. 608551-4 (Accelerometer Located at Center of Gravity).



SAE Class 60 Filter — 50-msec average

Test Number: 608551-4
Test Standard Test Number: MASH Test 3-11
Test Article: 31-inch W-Beam Guardrail on Steel Posts in Concrete Mow Strip
Test Vehicle: 2012 Dodge RAM 1500 Pickup Truck
Inertial Mass: 5011 lb
Gross Mass: 5011 lb
Impact Speed: 62.8 mi/h
Impact Angle: 25.6°

Figure H.6. Vehicle Vertical Accelerometer Trace for Test No. 608551-4 (Accelerometer Located at Center of Gravity).

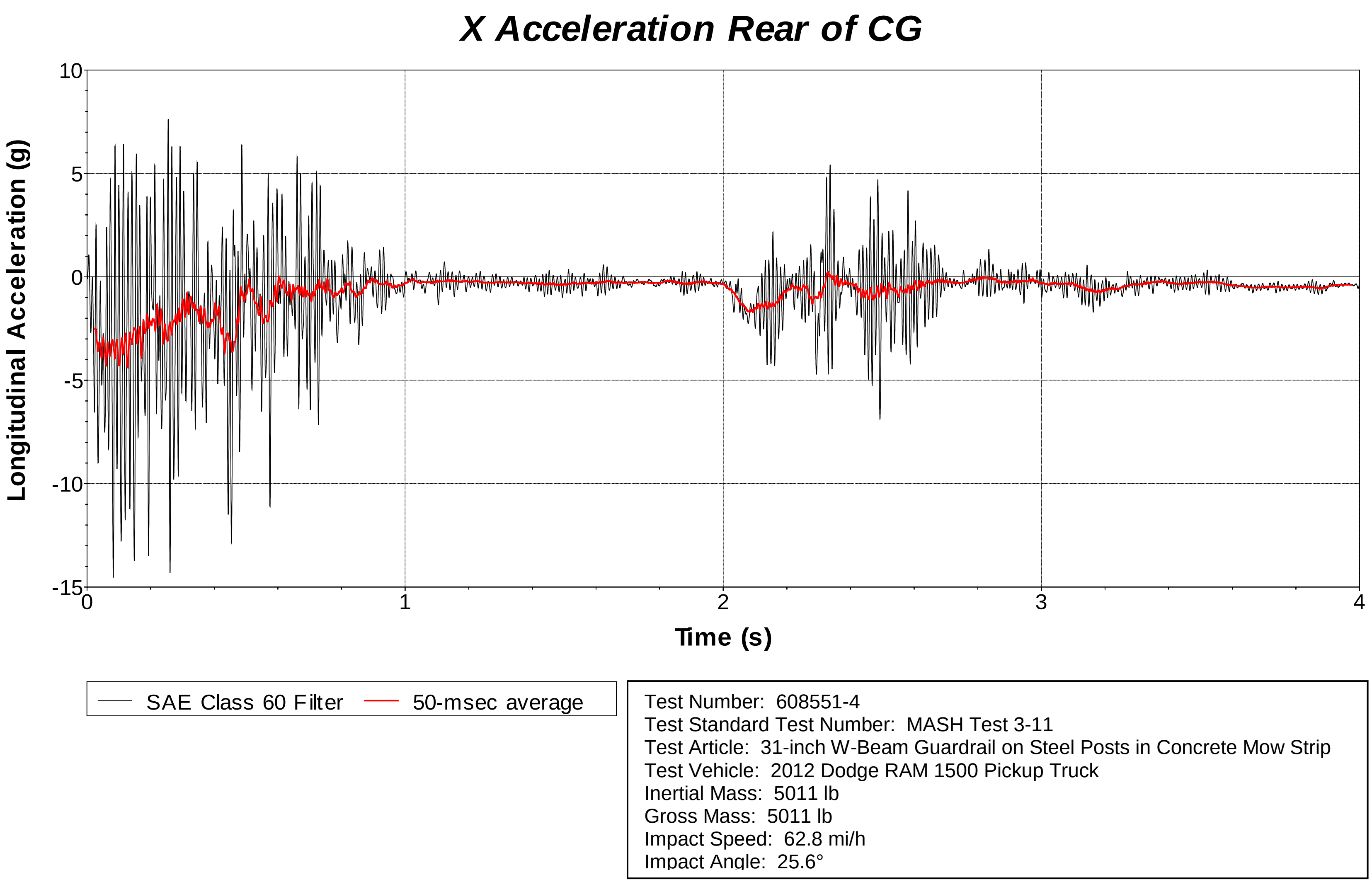


Figure H.7. Vehicle Longitudinal Accelerometer Trace for Test No. 608551-4 (Accelerometer Located Rear of Center of Gravity).

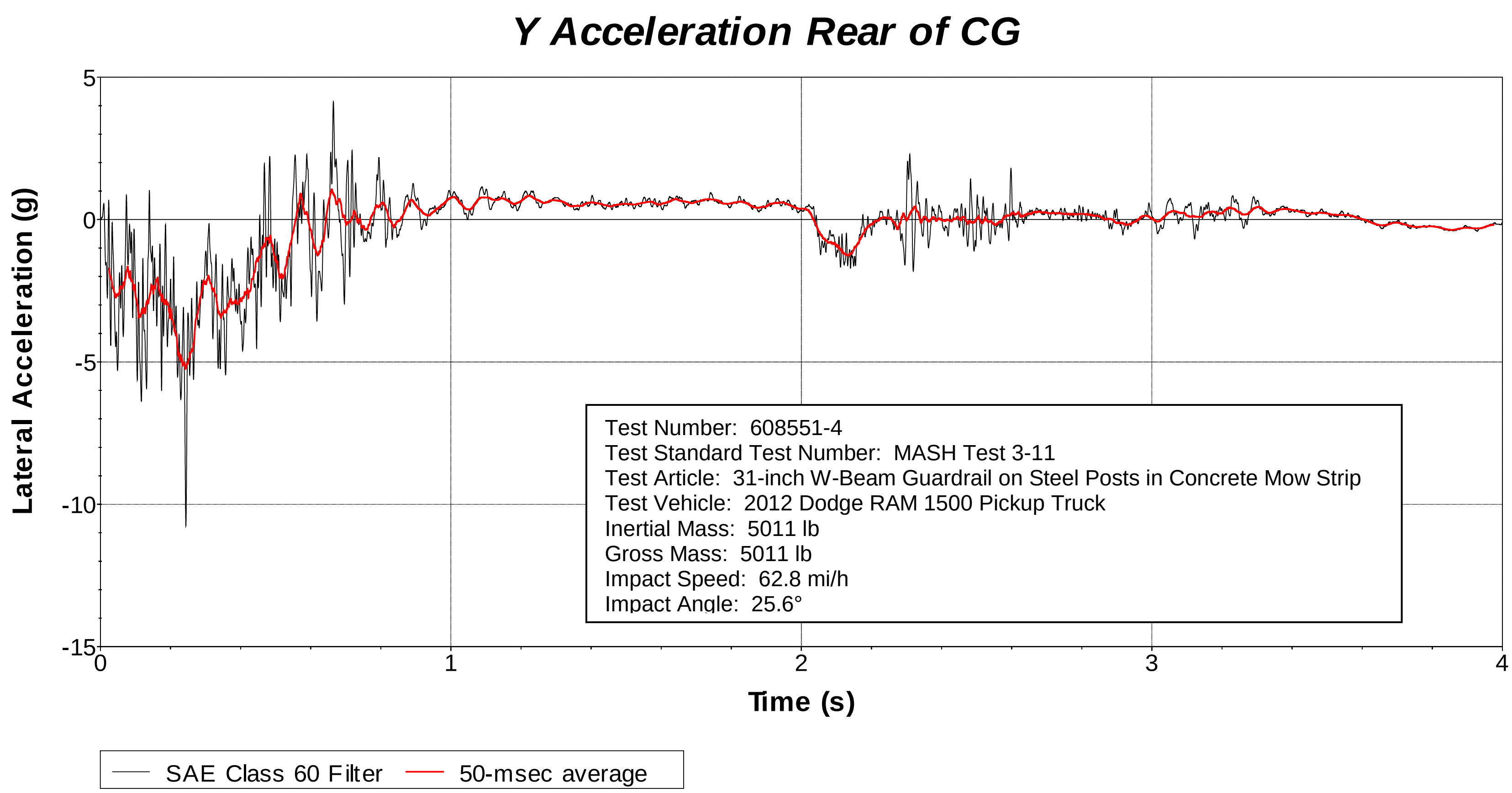


Figure H.8. Vehicle Lateral Accelerometer Trace for Test No. 608551-4 (Accelerometer Located Rear of Center of Gravity).

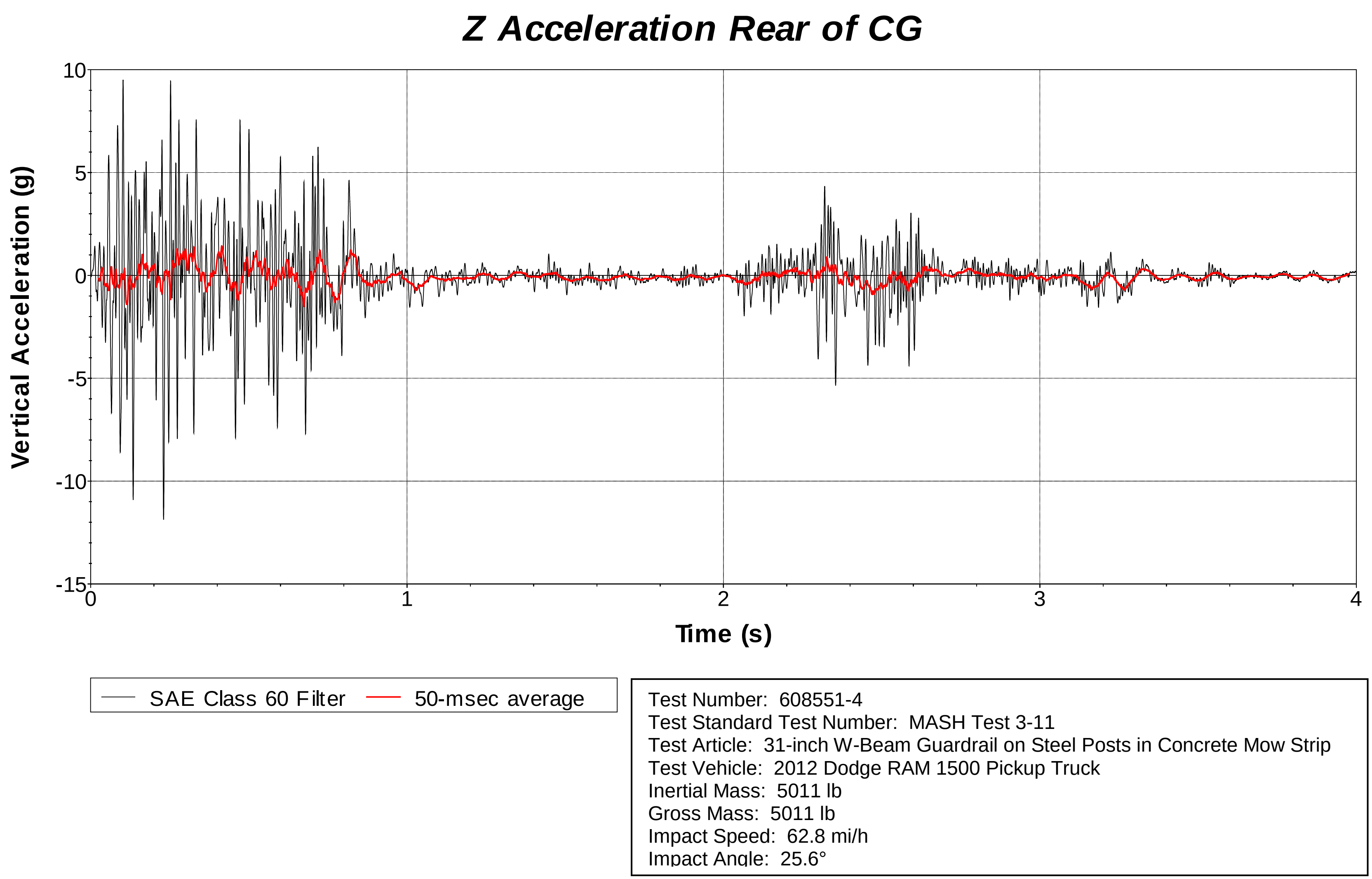


Figure H.9. Vehicle Vertical Accelerometer Trace for Test No. 608551-4 (Accelerometer Located Rear of Center of Gravity).