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MASH CRASH TESTING AND EVALUATION OF THE MGS WITH REDUCED POST SPACING

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16. Abstract

The objective of this research project was to evaluate reduced post spacing versions of the Midwest Guardrail System (MGS) for *MASH* compliance. In pursuit of this object, the research team performed full-scale crash tests and computer simulation efforts. The full-scale crash tests include *MASH* Tests 3-11 and 3-10 on the quarter post spacing system, *MASH* test 3-11 on the half post spacing system, and *MASH* test 3-21 on the transition from full to quarter post spacing.

This report provides details of the test installations, detailed documentation of the crash test results, and an assessment of the performance of the guardrail systems for *MASH* TL-3 evaluation criteria.

In conclusion, the research team demonstrated the *MASH* compliance of MGS variations with quarter post spacing, half post spacing, a transition between full and quarter post spacing.

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Chapter 1. INTRODUCTION

1.1 PROBLEM STATEMENT

When hazards are located near the roadside, State Departments of Transportation (DOTs) use barriers such as the Midwest Guardrail System (MGS) to provide protection for motorists. When the hazards are located close to the roadside, enhanced protection beyond what the standard MGS can provide may be required. In these cases, the typical deflection of the MGS may be too excessive for close-by hazards. Therefore, DOTs often use guardrail systems which provide reduced deflections in these situations. One method to reduce the guardrail system's deflections is to decrease the system's post spacing.

The reduced post spacing MGS has been used by DOTs for quite some time. With the publication of the *Manual for Assessing Safety Hardware (MASH)*, DOTs are updating their standards and plans to meet the *MASH* criteria (*1*). Therefore, it was desired that these reduced post spacing systems be evaluated for *MASH* compliance.

1.2 OBJECTIVE

The primary objective of this research project was to evaluate reduced post spacing guardrail systems for *MASH* compliance. This involves engineering analysis, computer simulation, and full-scale crash testing.

The purpose of the tests reported herein was to assess the performance of the MGS with reduced post spacing according to the safety-performance evaluation guidelines included in AASHTO *MASH.* Two tests were performed on the MGS with quarter post spacing (*MASH* Tests 3-10 and 3-11), two tests on the MGS with half post spacing (*MASH* Test 3-11), and two tests on the MGS transition to quarter post spacing (*MASH* Test 3-21).

This report provides details of the MGS with reduced post spacing, detailed documentation of the crash test results, and an assessment of the performance of the MGS with reduced post spacing for *MASH* TL-3 evaluation criteria.

Chapter 2. TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 CRASH TEST MATRIX FOR LONGITUDINAL BARRIERS

Table 2.1 shows the test conditions and evaluation criteria for *MASH* TL-3 longitudinal barriers. *MASH* Test 3-10 involves an 1100C vehicle weighing 2420 lb ±55 lb impacting the critical impact point (CIP) of the length of need (LON) of the guardrail system at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. *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 degrees ±1.5 degrees. *MASH* Tests 3-10 and 3-11 were performed on the MGS with quarter post spacing, and *MASH* Test 3-11 was performed on the MGS with half post spacing.

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 degrees	A, D, F, H, I
	3-11	2270P	62 mi/h	25 degrees	A, D, F, H, I

The target CIP for each test on the LON of the MGS with reduced post spacing was determined using the information provided in *MASH* Section 2.2.1 and Section 2.3.2. The target CIPs for *MASH* Tests 3-10 and 3-11 on the MGS with quarter post spacing are shown in Figure 2.1.

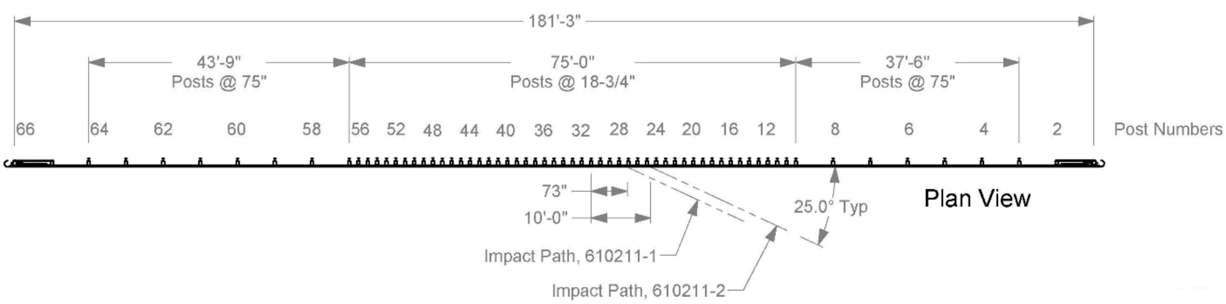


Figure 2.1. Target CIPs for *MASH* Tests 3-10 (610211-1) and 3-11 (610211-2) on MGS with Quarter Post Spacing.

The target CIP for *MASH* Test 3-11 on the MGS with half post spacing is shown in Figure 2.2.

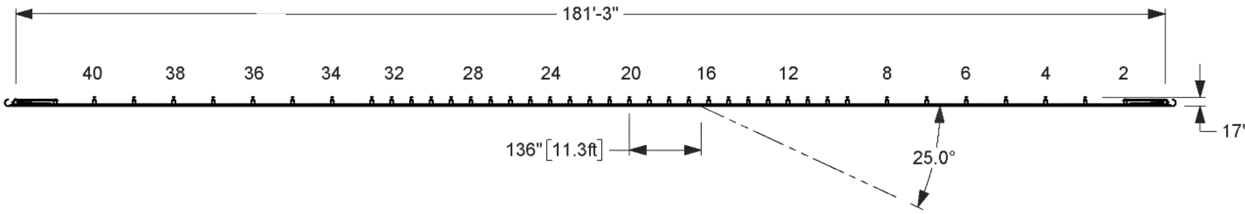


Figure 2.2. Target CIP for *MASH* 3-11 (610211-3) on MGS with Half Post Spacing.

2.2 CRASH TEST MATRIX FOR TRANSITIONS

Table 2.2 shows the test conditions and evaluation criteria for *MASH* TL-3 for transitions. *MASH* Test 3-20 involves an 1100C vehicle weighing 2420 lb ±55 lb impacting the CIP of the transition from standard post spacing to quarter post spacing at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. *MASH* Test 3-21 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the transition from full post spacing to quarter post spacing at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. *MASH* Test 3-20 is optional and was not performed on the transition.

Table 2.2. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Transitions.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	3-20	1100C	62 mi/h	25 degrees	A, D, F, H, I
	3-21	2270P	62 mi/h	25 degrees	A, D, F, H, I

The target CIP for each test on the transition from full post spacing to quarter post spacing was determined using the information provided in *MASH* Section 2.2.1 and Section 2.3.2. The target CIP for the first *MASH* Test 3-21 on the transition from full post spacing to quarter post spacing is shown in Figure 2.4, and the target CIP for the second *MASH* Test 3-21 on the transition from full post spacing to quarter post spacing is shown in Figure 2.5.

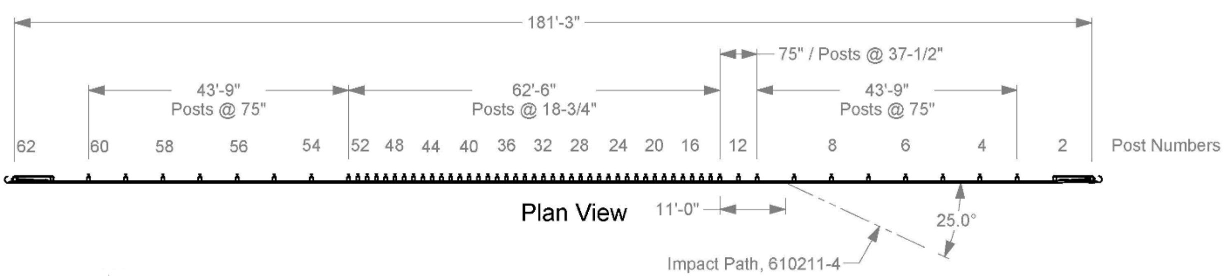


Figure 2.4. Target CIP for *MASH* 3-21 (610211-4) on Transition from Full Post Spacing to Quarter Post Spacing.

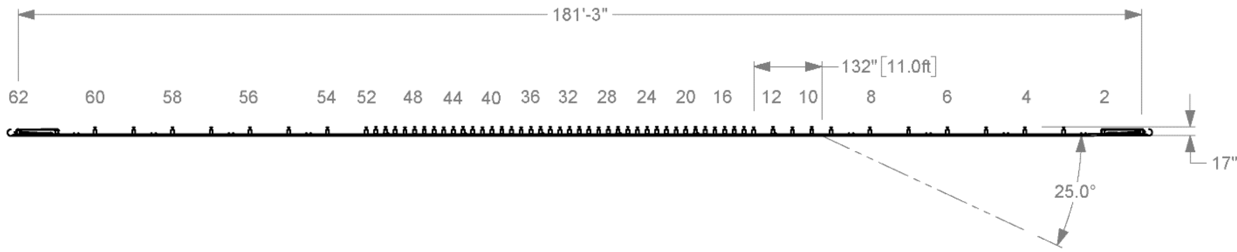


Figure 2.5. Target CIP for *MASH* 3-21 (610211-5) on Transition from Full Post Spacing to Quarter Post Spacing.

2.3 EVALUATION CRITERIA

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 3 presents brief descriptions of these procedures.

The appropriate safety evaluation criteria from Tables 2-2A and 5-1 of *MASH* were used to evaluate the crash tests reported herein. The test conditions and evaluation criteria required for *MASH* Tests 3-10 and 3-11 are listed in Table 2.1, and for *MASH* 3-21 in Table 2.2. The substance of the evaluation criteria is presented in Table 2.3. An evaluation of the crash test results for each test is presented in detail under the section Assessment of Test Results.

Table 2.1. Evaluation Criteria Required for *MASH* TL-3 Longitudinal Barriers and Transitions.

Evaluation Factors	Evaluation Criteria	*MASH* Test
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.*	*3-10, 3-11, 3-20, and 3-21*
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.*	*3-10, 3-11, 3-20, and 3-21*
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	*3-10, 3-11, 3-20, and 3-21*
	H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	*3-10, 3-11, 3-20, and 3-21*
	I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	*3-10, 3-11, 3-20, and 3-21*

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 MGS with reduced post spacing 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 and through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site.

3.3 DATA ACQUISITION SYSTEMS

3.3.1 Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained onboard 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 samples per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit in case the primary battery cable is severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units is returned to the factory annually for complete recalibration and to ensure that all instrumentation used in the vehicle conforms to the 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 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 anytime data are suspect. Acceleration data are measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k = 2).

TRAP uses the data from the TDAS Pro to compute the occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and 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 an SAE Class 180-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, and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation 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 vehicle. 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 vehicle.

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 test 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.

Chapter 4. MGS WITH QUARTER POST SPACING

4.1 SYSTEM DETAILS OF MGS WITH QUARTER POST SPACING

4.1.1 Test Installation Details

The 181 ft-3-inch-long test installation was comprised of a 31-inch high, 12-gauge, 4-space, W-beam guardrail system. The W-beam rail was supported by wide-flange posts with 14-inch-tall wood blockouts. A TxDOT DAT terminated each end of the guardrail system. Beginning with the upstream DAT, there were three distinct sections of the installation:

1. a 37 ft-6-inch-long section (posts 3 through 9) with post spacing at 75 inches;
2. a 75 ft-0-inch-long section (posts 9 through 57) with quarter post spacing at 18¾ inches; and
3. a 43 ft-9-inch-long section (posts 57 through 64) with post spacing at 75 inches.

In the full post spacing sections, a 10-inch button-head guardrail bolt secured each blockout to a post. In the quarter post spacing section, the bolts secured the rail only at half post spacing. Therefore, no additional slots were cut in the W-beam rail. Additionally, the quarter post spacing section did not have posts bolted to the rail at splice locations. In the full-post spacing sections, the W-beam rails were spliced at midspan between the posts.

The wide-flange posts were embedded 40 inches deep in drilled holes that were backfilled with crushed limestone base and compacted to meet *MASH* strength requirements.

Figure 4.1 presents overall information on the MGS with quarter post spacing, and Figure 4.2 provides photographs of the installation. Appendix A provides further details of the MGS with quarter post spacing.

4.1.2 Design Modifications

No modification was made to the MGS with quarter post spacing during this part of the testing phase.

4.1.3 Material Specifications

Appendix B provides material certification documents for the materials used to construct the MGS with quarter post spacing.

4.1.4 Soil Conditions

The test installation was installed in standard soil meeting grading A 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 MGS with quarter post spacing for full-scale crash testing, two W6×16 posts were installed in the immediate vicinity of MGS with quarter post spacing 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.

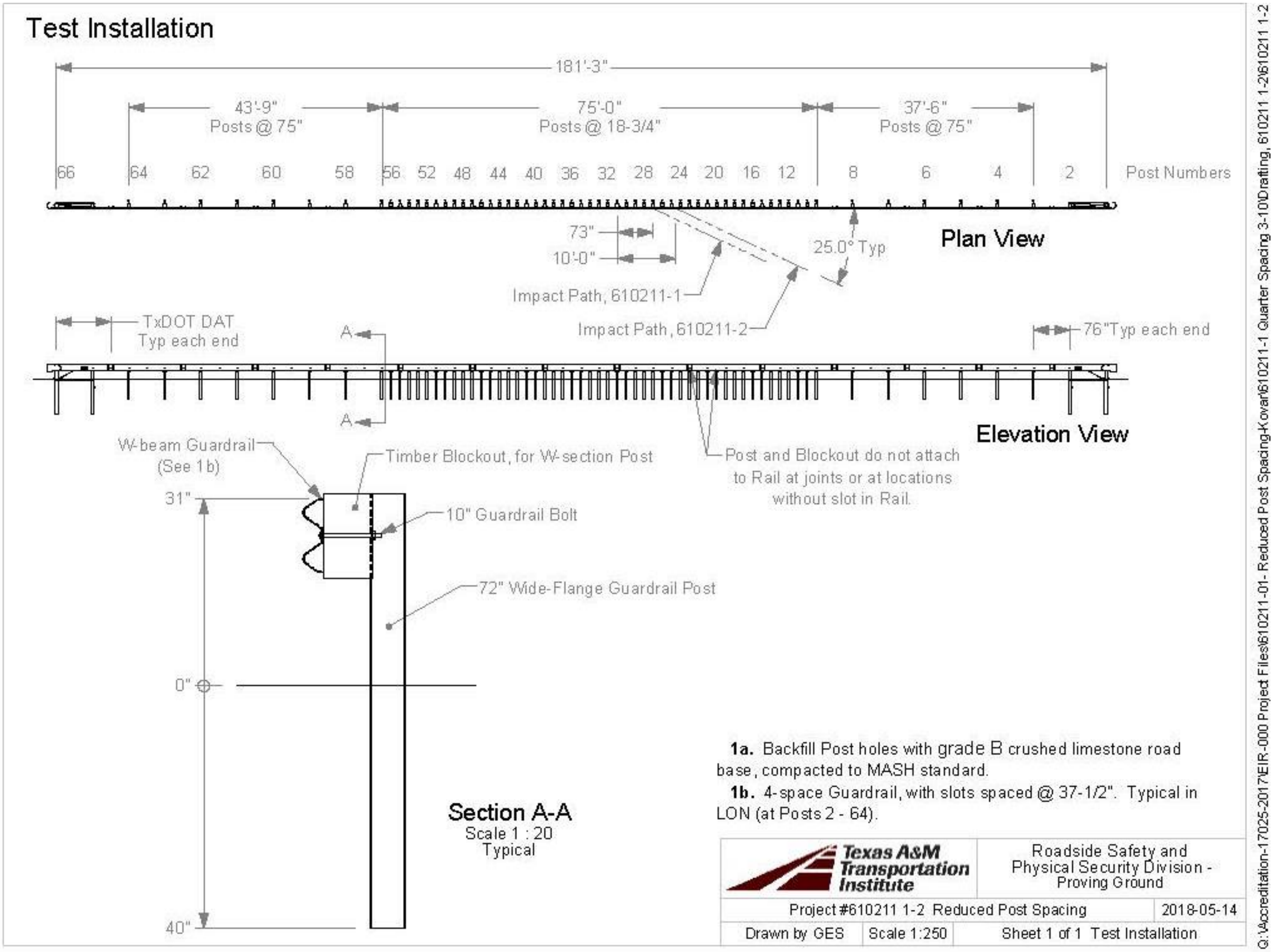


Figure 4.1. Details of the MGS with Quarter-Post Spacing.

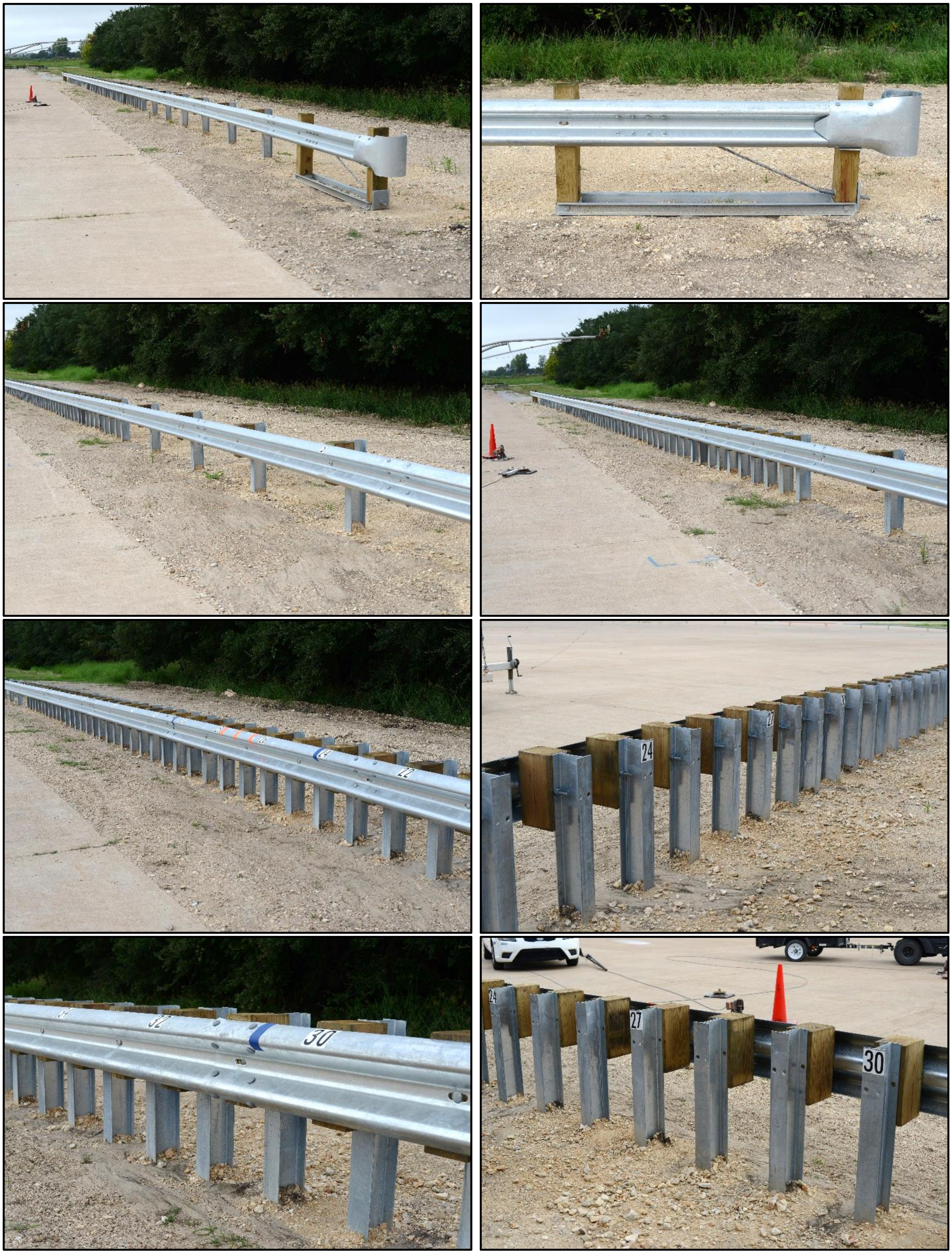


Figure 4.2. MGS with Quarter Post Spacing prior to Testing.

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. 610211-01-1, October 4, 2018, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 7979 lbf, 8333 lbf, and 8282 lbf, respectively. On the day of Test No. 610211-01-2, October 22, 2018, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 6515 lbf, 7222 lbf, and 7373 lbf, respectively. Tables C.2 and C.3 in Appendix C show the strength of the backfill material in which the MGS with quarter post spacing was installed met minimum *MASH* requirements for both tests.

4.2 *MASH* TEST 3-10 (CRASH TEST NO. 610211-01-1) ON MGS WITH QUARTER POST SPACING

4.2.1 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 degrees ±1.5 degrees. The CIP for *MASH* Test 3-10 on the MGS with quarter post spacing was 73 inches ±12 inches upstream of post 31 (see Figure 2.1 and Figure 4.3).

Figure 4.3. Guardrail/Test Vehicle Geometrics for Test No. 610211-01-1.

The 1100C vehicle used in the test weighed 2453 lb, and the actual impact speed and angle were 63.7 mi/h and 25.5 degrees, respectively. The actual impact point was 74.8 inches upstream of post 31. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 62 kip-ft.

4.2.2 Weather Conditions

The test was performed on the morning of October 4, 2018. Weather conditions at the time of testing were as follows: wind speed: 5 mi/h; wind direction: 125 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 81°F; relative humidity: 84 percent.

4.2.3 Test Vehicle

Figures 4.3 and 4.4 show the 2010 Kia Rio* used for the crash test. The vehicle's test inertia weight was 2453 lb, and its gross static weight was 2618 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 D.1 in Appendix D gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system. It was released to be freewheeling and unrestrained just prior to impact.

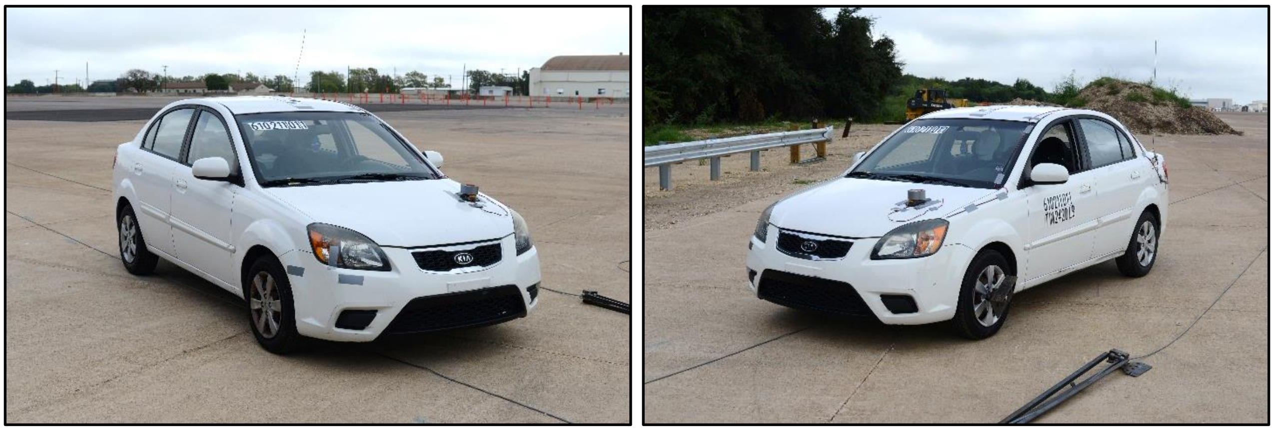


Figure 4.4. Test Vehicle before Test No. 610211-01-1.

4.2.4 Test Description

Table 4.1 lists events that occurred during Test No. 610211-01-1. Figures D.1 and D.2 in Appendix D2 present sequential photographs during the test.

Table 4.1. Events during Test No. 610211-01-1.

TIME (s)	EVENT
0.0000	Vehicle contacted guardrail
0.0360	Vehicle began to redirect
0.1390	Vehicle began to yaw back toward the guardrail
0.1830	Left rear tire left the pavement
0.3780	Vehicle lost contact with barrier while traveling at 10.0 mi/h, at a trajectory of 53.3 degrees, and a heading of 62.5 degrees
0.5020	Vehicle was perpendicular to the guardrail, with front facing the barrier
0.7840	Right rear tire made contact with pavement
0.8260	Left rear tire made contact with pavement
1.0100	Vehicle traveling parallel to guardrail with front facing upstream
	Vehicle continued to yaw clockwise as it lost contact with the guardrail

* The 2010 model vehicle used is older than the 6-year age noted in *MASH*, and was selected based upon availability. An older model vehicle was permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2010 model vehicle met the *MASH* requirements.

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 test vehicle exited in the exit box criteria defined in *MASH*. Brakes on the vehicle were applied after the vehicle exited the test site, and the vehicle subsequently came to rest 8 ft downstream of the impact and 24 ft toward traffic lanes.

4.2.5 Damage to Test Installation

Figure 4.5 shows the damage to the MGS with quarter post spacing. No visible movement was noted at posts 1 through 24. Posts 29-34 were all deformed and leaning downstream. The soil around post 37 was disturbed, and there was no movement noted at posts 38 to the end. Table 4.2 provides additional measurements regarding the posts movement through the soil. Working width was 16.4 inches, and height of working width was 29.0 inches. Maximum dynamic deflection during the test was 16.4 inches, and maximum permanent deformation of the W-beam rail was 7.5 inches.

4.2.6 Damage to Test Vehicle

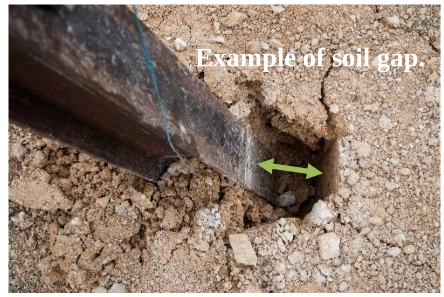
Figure 4.6 shows the damage sustained by the vehicle. The front bumper, hood, radiator and support, right front fender, right front strut and tower, right front tire and rim, right front door, and right front floor pan were damaged. The windshield sustained a stress crack from the right lower A-pillar. No damage to the fuel tank was observed. Maximum exterior crush to the vehicle was 15.5 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation was 0.75 inch in the right front firewall area. Figure 4.7 shows the interior of the vehicle. Tables D.2 and D.3 in Appendix D1 provide exterior crush and occupant compartment measurements.

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 are shown in Table 4.3. Figure 4.8 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.6 in Appendix D4 show accelerations versus time traces.

Figure 4.5. MGS with Quarter Post Spacing after Test No. 610211-01-1.

Table 4.2. Post Measurements for Test No. 610211-01-1.

Post #	Field Side Soil Gap (inches)	Post Lean from Vertical	
25	½	-	
26	¾	-	
27	1½	-	
28	2	5°	
29	Not Measurable	51°	
30		60°	
31		61°	
32		48°	
33		38°	
34		22°	
35	1¼	2°	
36	¾	1°	

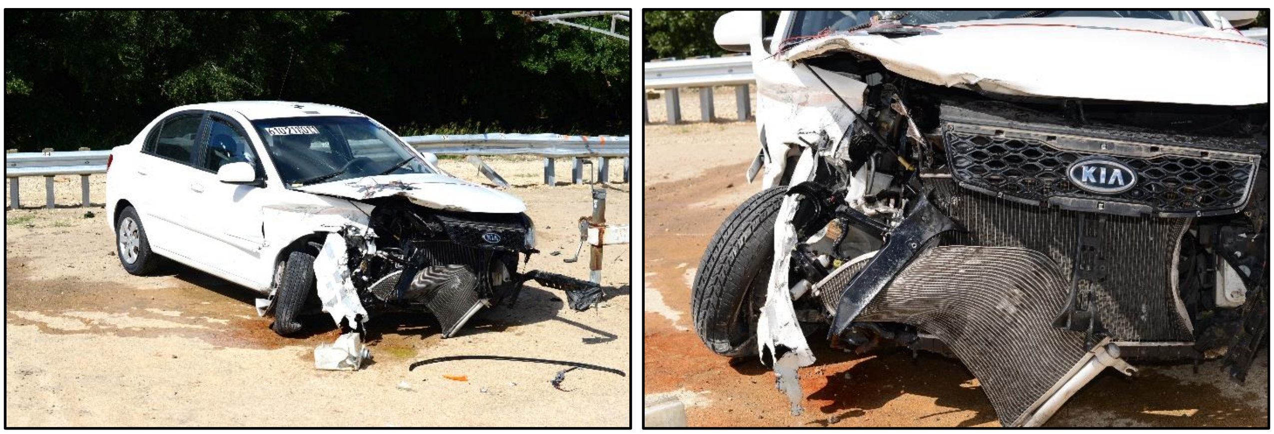


Figure 4.6. Test Vehicle after Test No. 610211-01-1.

Before Test After Test

Figure 4.7. Interior of Test Vehicle for Test No. 610211-01-1.

Table 4.3. Occupant Risk Factors for Test No. 610211-01-1.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	**33.1 ft/s**	at 0.0989 s on right side of interior
Lateral	**22.0 ft/s**	
Occupant Ridedown Accelerations		
Longitudinal	**17.9 g**	0.1068 - 0.1168 s
Lateral	**18.6 g**	0.1103 - 0.1203 s
Theoretical Head Impact Velocity (THIV)	**11.5 m/s**	at 0.0959 s on right side of interior
Acceleration Severity Index (ASI)	**1.6**	0.0698 - 0.1198 s
Maximum 50-ms Moving Average		
Longitudinal	**-16.6 g**	0.0662 - 0.1162 s
Lateral	**-9.7 g**	0.0299 - 0.0799 s
Vertical	**-3.4 g**	0.8539 - 0.9039 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**14°**	0.1791 s
Pitch	**16°**	0.4366 s
Yaw	**222°**	2.0000 s

General Information

Test Agency .... Texas A&M Transportation Institute (TTI)
Test Standard Test No. ...... MASH Test 3-10
TTI Test No. 610211-01-1
Test Date 2018-10-04

Test Article

Type .... Longitudinal Barrier – Guardrail
Name .... MGS with Quarter Post Spacing
Installation Length .... 181 ft 3 inches
Material or Key Elements ... 31-inch tall MGS W-Beam Guardrail with 18¾-inch post spacing for the LON

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

Test Vehicle

Type/Designation 1100C
Make and Model .... 2010 Kia Rio
Curb .... 2462 lb
Test Inertial .... 2453 lb
Dummy .... 165 lb
Gross Static .... 2618 lb

Impact Conditions

Speed .... 63.7 mi/h
Angle .... 25.5°
Location/Orientation .... 74.8 inches upstream of post 31

Impact Severity .... 62 kip-ft

Exit Conditions

Speed .... 10.0 mi/h
Exit Trajectory/Heading ...... 53.3°/62.5°

Occupant Risk Values

Longitudinal OIV .... 33.1 ft/s
Lateral OIV .... 22.0 ft/s
Longitudinal Ridedown .... 17.9 g
Lateral Ridedown .... 18.6 g
THIV .... 11.5 m/s
ASI 1.6
Max. 0.050-s Average
Longitudinal .... -16.6 g
Lateral .... -9.7 g
Vertical .... -3.4 g

Post-Impact Trajectory

Stopping Distance .... 8 ft downstream 24 ft toward traffic

Vehicle Stability

Maximum Roll Angle .... 14°
Maximum Pitch Angle .... 16°
Maximum Yaw Angle .... 222°

Test Article Deflections

Dynamic .... 16.4 inches
Permanent .... 7.5 inches
Working Width .... 16.4 inches
Height of Working Width .... 29.0 inches

Vehicle Damage

VDS 01RFQ5
CDC 01FREW5
Max. Exterior Deformation .... 15.5 inches
OCDI RF0010000
Max. Occupant Compartment Deformation .... 0.75 inch

Figure 4.8. Summary of Results for *MASH* Test 3-10 on MGS with Quarter Post Spacing.

4.3 *MASH* TEST 3-11 (CRASH TEST NO. 610211-01-2) ON MGS WITH QUARTER POST SPACING

4.3.1 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 degrees ±1.5 degrees. The CIP for *MASH* Test 3-11 on the MGS with quarter post spacing was 120 inches ±12 inches upstream of post 31 (see Figure 2.1 and Figure 4.9).

Figure 4.9. Guardrail/Test Vehicle Geometrics for Test No. 610211-01-2.

The 2270P vehicle used in the test weighed 5007 lb, and the actual impact speed and angle were 63.1 mi/h and 26.1 degrees, respectively. The actual impact point was 123.4 inches upstream of post 31. Minimum target IS was 106 kip-ft, and actual IS was 129 kip-ft.

4.3.2 Weather Conditions

The test was performed on the morning of October 22, 2018. Weather conditions at the time of testing were as follows: wind speed: 1 mi/h; wind direction: 71 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 58°F; relative humidity: 76 percent.

4.3.3 Test Vehicle

Figures 4.9 and 4.10 show the 2014 RAM 1500 pickup truck used for the crash test. The vehicle’s test inertia weight was 5007 lb, and its gross static weight was 5007 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 inches. The height to the center of gravity of the vehicle was 28.3 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 the cable reverse tow and guidance system. It was released to be freewheeling and unrestrained just prior to impact.

Figure 4.10. Test Vehicle before Test No. 610211-01-2.

4.3.4 Test Description

Table 4.4 lists events that occurred during Test No. 610211-01-2. Figures E.1 and E.2 in Appendix E2 present sequential photographs during the test.

Table 4.4. Events during Test No. 610211-01-2.

TIME (s)	EVENT
0.0000	Vehicle contacted guardrail
0.0300	Vehicle began to redirect
0.2010	Right rear bumper of vehicle contacted guardrail
0.2220	Vehicle was parallel with guardrail
0.4440	Vehicle lost contact with guardrail while traveling at 41.4 mi/h, at a trajectory of 16.5 degrees, and a heading of 15.9 degrees
0.8840	Vehicles right rear tire made contact with pavement

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 test vehicle exited in the exit box criteria defined in *MASH*. Brakes on the vehicle were applied after the vehicle exited the test site, and the vehicle subsequently came to rest 154 ft downstream of the impact and 35 ft toward the field side.

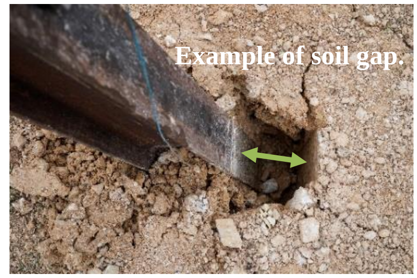
4.3.5 Damage to Test Installation

Figure 4.11 shows the damage to the MGS with quarter post spacing. The soil around post 1 was disturbed, and the rail released from the blockouts at posts 27, 29, and 31. The soil around posts 21 and 22 was disturbed, and posts 26 through 31 were pushed downstream and toward the field side. Table 4.5 provides additional measurements. Working width was 37.1 inches, and height of working width was 27.9 inches. Maximum dynamic deflection during the test was 19.5 inches, and maximum permanent deformation of the W-beam rail was 11.0 inches.

Figure 4.11. MGS System with Quarter Post Spacing after Test No. 610211-01-2.

Table 4.5. Post Measurements for Test No. 610211-01-2.

Post #	Field Side Soil Gap (inches)	Post Lean from Vertical	
		F/S	D/S
23	½	1°	-
24	1	3°	-
25	2¼	4°	-
26	Not Measurable	7°	-
27		10°	30°
28		14°	-
29		17°	14°
30		13°	-
31		14°	-
32	2½	10°	-
33	2½	5°	-
34	¾	2°	-



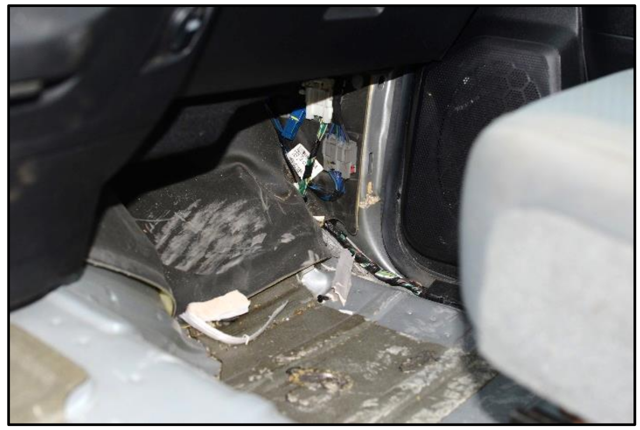
F/S=field side; D/S=downstream

4.3.6 Damage to Test Vehicle

Figure 4.12 shows the damage sustained by the vehicle. The front bumper, radiator and support, grill, right head light, right front fender, right front upper and lower A arms, right front tire and rim, right frame rail, right front door (4-inch gap at top of door), right front floor pan, right rear door, right rear fender, right rear rim, and right bumper were damaged. No damage to the fuel tank was observed. Maximum exterior crush to the vehicle was 15 inches in the front plane on the right side above the front bumper. Maximum occupant compartment deformation was 2 inches in the right front firewall area. Figure 4.13 shows the interior of the vehicle. Tables E.3 and E.4 in Appendix E1 provide exterior crush and occupant compartment measurements.

Figure 4.12. Test Vehicle after Test No. 610211-01-2.

Before Test



After Test

Figure 4.13. Interior of Test Vehicle for Test No. 610211-01-2.

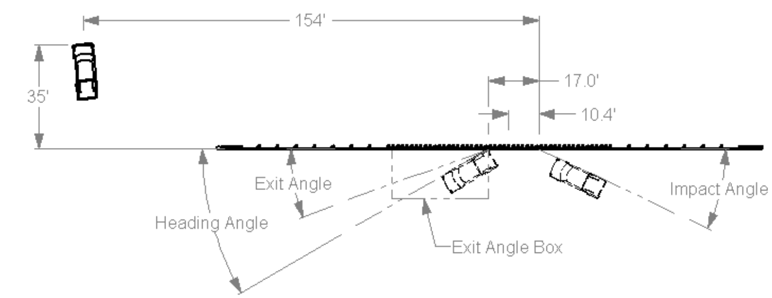
4.3.7 Occupant Risk Factors

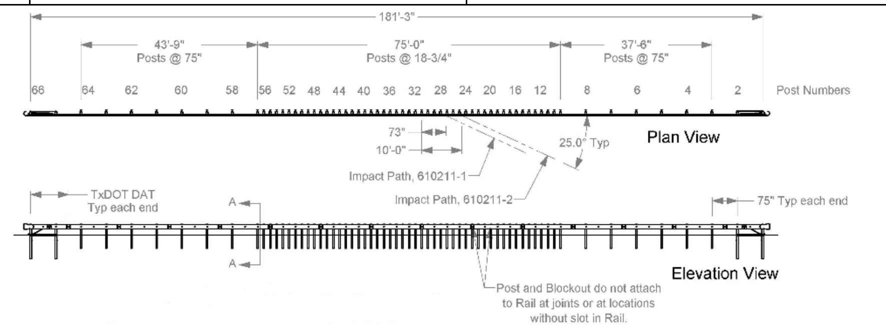
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 4.6. Figure 4.14 summarizes these data and other pertinent information from the test. Figure E.3 in Appendix E3 shows the vehicle angular displacements, and Figures E.4 through E.9 in Appendix E4 show accelerations versus time traces.

Table 4.6. Occupant Risk Factors for Test No. 610211-01-2.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	**21.0 ft/s**	at 0.1200 s on right side of interior
Lateral	**21.1 ft/s**	
Occupant Ridedown Accelerations		
Longitudinal	**14.5 g**	0.1229 - 0.1329 s
Lateral	**8.3 g**	0.1226 - 0.1326 s
THIV	**8.8 m/s**	at 0.1157 s on right side of interior
ASI	**1.1**	0.0624 - 0.1124 s
Maximum 50-ms Moving Average		
Longitudinal	**-8.9 g**	0.0858 - 0.1358 s
Lateral	**-7.9 g**	0.0527 - 0.1027 s
Vertical	**3.2 g**	0.1846 - 0.2346 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**16°**	0.4591 s
Pitch	**11°**	0.6415 s
Yaw	**48°**	0.9671 s

0.000 s | 0.200 s | 0.400 s | 0.600 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-11
TTI Test No.	610211-01-2
Test Date	2018-10-22
Test Article	
Type	Longitudinal Barrier – Guardrail
Name	MGS with Quarter Post Spacing
Installation Length	181 ft-3 inches
Material or Key Elements	31-inch-tall MGS W-Beam Guardrail with 18¾-inch post spacing for the LON
Soil Type and Condition	Drilled and backfilled in AASHTO M147-65(2004), grading B Soil (crushed limestone), Damp
Test Vehicle	
Type/Designation	2270P
Make and Model	2014 Ram 1500
Curb	5019 lb
Test Inertial	5007 lb
Dummy	No Dummy
Gross Static	5007 lb

Impact Conditions	
Speed	63.1 mi/h
Angle	26.1°
Location/Orientation	123.4 inches upstream of post 31
Impact Severity	129 kip-ft
Exit Conditions	
Speed	41.4 mi/h
Exit Trajectory/Heading	16.5°/15.9°
Occupant Risk Values	
Longitudinal OIV	21.0 ft/s
Lateral OIV	21.1 ft/s
Longitudinal Ridedown	14.5 g
Lateral Ridedown	8.3 g
THIV	8.8 m/s
ASI	1.1
Max. 0.050-s Average	
Longitudinal	-8.9 g
Lateral	-7.9 g
Vertical	3.2 g

Post-Impact Trajectory	
Stopping Distance	154 ft downstream 35 ft twd field side
Vehicle Stability	
Maximum Roll Angle	16°
Maximum Pitch Angle	11°
Maximum Yaw Angle	48°
Test Article Deflections	
Dynamic	19.5 inches
Permanent	11.0 inches
Working Width	37.1 inches
Height of Working Width	27.9 inches
Vehicle Damage	
VDS	01RFQ4
CDC	01FREW3
Max. Exterior Deformation	15 inches
OCDI	RF0011000
Max. Occupant Compartment Deformation	2.0 inch

Figure 4.14. Summary of Results for *MASH* Test 3-11 on MGS with Quarter Post Spacing.

Chapter 5. MGS WITH HALF POST SPACING

5.1 SYSTEM DETAILS OF MGS WITH HALF POST SPACING

5.1.1 Test Installation Details

The 181 ft-3-inch-long test installation was comprised of a 31-inch high, 12-gauge, 4-space, W-beam guardrail system. The W-beam rail was supported by 72-inch wide-flange posts with 14-inch-tall wood blockouts. TxDOT DATs terminated each end of the guardrail system. Beginning with the upstream DAT, there were three distinct sections of the installation:

1. a 37 ft-6-inch-long section (posts 3 through 9) with full post spacing at 75 inches.
2. a 75 ft-0-inch-long section (posts 9 through 33) with half post spacing at 37½-inches; and
3. a 43 ft-9-inch-long section (posts 33 through 40) with full post spacing at 75 inches.

A 10-inch button-head guardrail bolt secured each blockout to a post except where a post was located at a rail splice. In the full-post spacing sections, the W-beam rails were spliced at midspan between the posts.

The wide-flange posts were embedded 40 inches deep in drilled holes that were backfilled with crushed limestone base and compacted to meet *MASH* strength requirements.

Figure 5.1 presents overall information on the MGS with half post spacing, and Figure 5.2 provides photographs of the installation. Appendix F provides further details of the MGS with half post spacing.

5.1.2 Design Modifications

No modification was made to the MGS with half post spacing prior to this crash test.

5.1.3 Material Specifications

Appendix B provides material certification documents for the materials used to construct the MGS with half post spacing.

5.1.4 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 MGS with half post spacing for full-scale crash testing, two W6×16 posts were installed in the immediate vicinity of MGS with half post spacing 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.

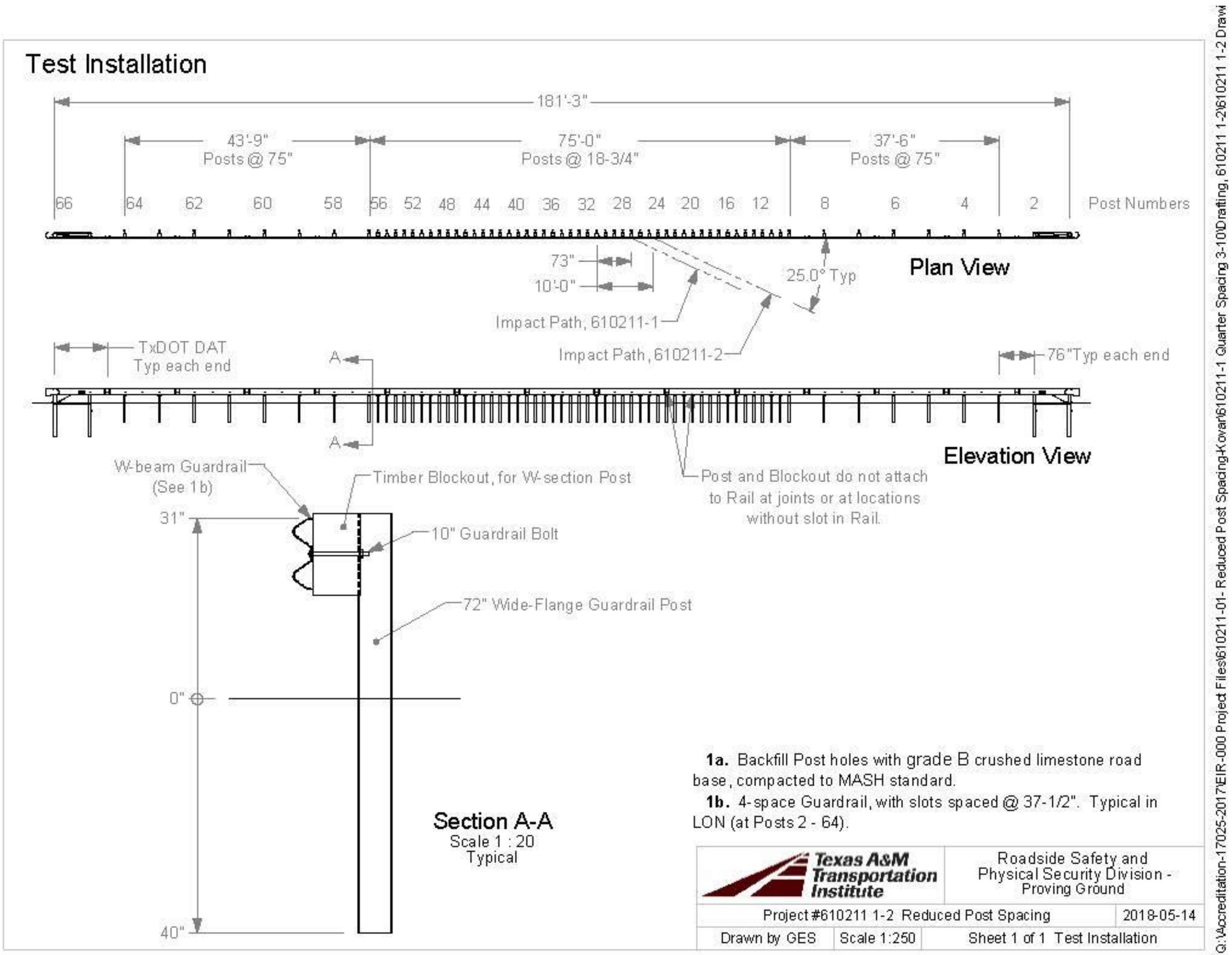


Figure 5.1. Details of the MGS with Half Post Spacing.

Figure 5.2. MGS with Half Post Spacing prior to Testing.

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. 610211-01-3, February 18, 2019, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 5808 lbf, 6515 lbf, and 6919 lbf, respectively. Table C.4 in Appendix C shows the strength of the backfill material in which the MGS with half post spacing was installed met minimum *MASH* requirements.

5.2 *MASH* TEST 3-11 (CRASH TEST NO. 610211-01-3) ON MGS WITH HALF POST SPACING

5.2.1 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 degrees ±1.5 degrees. The CIP for *MASH* Test 3-11 on the MGS with half post spacing was 136 inches ±12 inches upstream of post 20 (see Figure 2.2 and Figure 5.3).

Figure 5.3. MGS with Half Post Spacing/Test Vehicle Geometrics for Test No. 610211-01-3.

The 2270P vehicle used in the test weighed 5018 lb, and the actual impact speed and angle were 62.2 mi/h and 24.9 degrees. The actual impact point was 138 inches upstream of post 20. Minimum target IS was 106 kip-ft, and actual IS was 115 kip-ft.

5.2.2 Weather Conditions

The test was performed on the morning of February 18, 2019. Weather conditions at the time of testing were as follows: wind speed: 11 mi/h; wind direction: 82 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 54°F; relative humidity: 52 percent.

5.2.3 Test Vehicle

Figures 5.3 and 5.4 shows the 2013 RAM 1500 pickup truck used for the crash test. The vehicle’s test inertia weight was 5018 lb, and its gross static weight was 5018 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 G.1 and G.2 in Appendix G1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system. It was released to be freewheeling and unrestrained just prior to impact.

Figure 5.4. Test Vehicle before Test No. 610211-01-3.

5.2.4 Test Description

Table 5.1 lists events that occurred during Test No. 610211-01-3. Figures G.1 and G.2 in Appendix I2 present sequential photographs during the test.

Table 5.1. Events during Test No. 610211-01-3.

TIME (s)	EVENTS
0.0000	Vehicle contacted guardrail
0.0380	Vehicle began to redirect
0.1450	Guardrail ruptured and vehicle began to pass to field side
0.5630	Vehicle began traveling parallel with guardrail on the field side

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 test vehicle penetrated the guardrail. Brakes on the vehicle were applied after the vehicle exited the test site, and the vehicle subsequently came to rest 48 ft downstream of the impact and 1 ft toward the field side.

5.2.5 Damage to Test Installation

Figure 5.5 shows the damage to the MGS with half post spacing. The W-beam guardrail ruptured at post 20 and released from post 16 through post 39. The soil was disturbed at post 1. Table 5.2 provides additional measurements.

Figure 5.5. MGS with Half Post Spacing after Test No. 610211-01-3.

Table 5.2. Post Lean for Test No. 610211-01-3.

<table>
<tr><th rowspan="2">Post #</th><th colspan="2">Soil Gap (inches)</th><th rowspan="2">Post Lean
from Vertical</th><td rowspan="8">
</td></tr>
<tr><th>T/S</th><th>F/S</th></tr>
<tr><td>16</td><td>½</td><td>-</td><td>2°</td></tr>
<tr><td>17</td><td>-</td><td>1</td><td>6°</td></tr>
<tr><td>18-25</td><td colspan="2" rowspan="4">Not Measurable</td><td>90°</td></tr>
<tr><td>26</td><td>55°</td></tr>
<tr><td>27</td><td>55°</td></tr>
<tr><td>28-30</td><td>40°</td></tr>
</table>

T/S=traffic side; F/S=field side

5.2.6 Damage to Test Vehicle

Figure 5.6 shows the damage sustained by the vehicle. The front bumper, hood, grill, radiator and support, right and left front fenders, right front and rear doors, rear exterior bed, rear bumper, right front and rear tires and rims, and left front tire were damaged. No damage to the fuel tank was observed. Maximum exterior crush to the vehicle was 22.0 inches in the front plane at the center at bumper height. Maximum occupant compartment deformation was 0.5 inch in the right floorpan. Figure 5.7 shows the interior of the vehicle. Tables G.3 and G.4 in Appendix G1 provide exterior crush and occupant compartment measurements.

Figure 5.6. Test Vehicle after Test No. 610211-01-3.

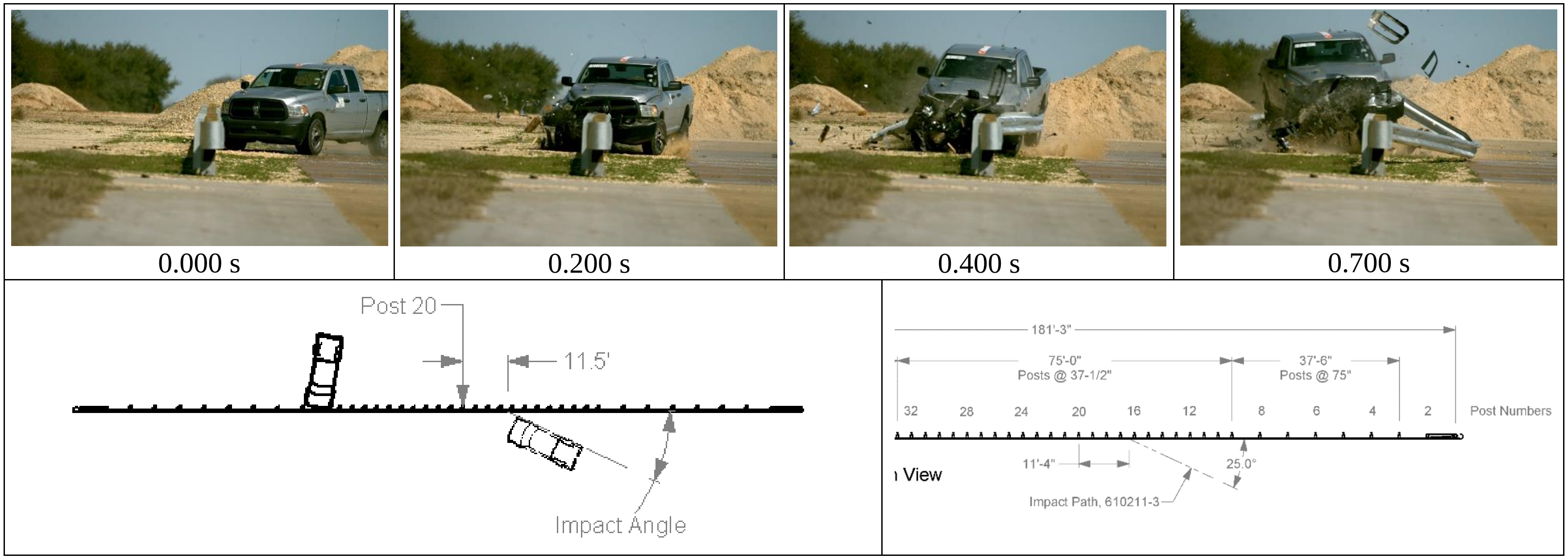
Figure 5.7. Interior of Test Vehicle after Test No. 610211-01-3.

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 are shown in Table 5.3. Figure 5.8 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.6 in Appendix G4 show accelerations versus time traces.

Table 5.3. Occupant Risk Factors for Test No. 610211-01-3.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	**17.4 ft/s**	at 0.1285 s on right side of interior
Lateral	**17.1 ft/s**	
Occupant Ridedown Accelerations		
Longitudinal	**11.0 g**	0.2159 – 0.2259 s
Lateral	**3.5 g**	0.9923 – 1.0023 s
THIV	**7.0 m/s**	at 0.1238 s on right side of interior
ASI	**0.9**	0.0640 – 0.1140 s
Maximum 50-ms Moving Average		
Longitudinal	**-6.5 g**	0.2758 – 0.3258 s
Lateral	**-6.6 g**	0.0511 – 0.1011 s
Vertical	**2.9 g**	0.1758 – 0.2258 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**31°**	1.2106 s
Pitch	**7°**	1.5709 s
Yaw	**95°**	1.9623 s



General Information
- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: MASH Test 3-11
- TTI Test No.: 610211-01-3
- Test Date: 2019-02-18

Test Article
- Type: Longitudinal Barrier – Guardrail
- Name: MGS with Half Post Spacing
- Installation Length: 181 ft-3 inches
- Material or Key Elements: 31-inch-tall MGS W-Beam Guardrail with 37½-inch post spacing for the LON

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

Test Vehicle
- Type/Designation: 2270P
- Make and Model: 2013 RAM 1500 Pickup
- Curb: 5038 lb
- Test Inertial: 5018 lb
- Dummy: No dummy
- Gross Static: 5018 LB

Impact Conditions
- Speed: 62.2 mi/h
- Angle: 24.9°
- Location/Orientation: 138 inches upstream of post 20

Impact Severity: 115 kip-ft

Exit Conditions
- Speed: NA
- Angle: NA

Occupant Risk Values
- Longitudinal OIV: 17.4 ft/s
- Lateral OIV: 17.1 ft/s
- Longitudinal Ridedown: 11.0 g
- Lateral Ridedown: 3.5 g
- THIV: 7.0 m/s
- ASI: 0.9
- Max. 0.050-s Average
  - Longitudinal: -6.5 g
  - Lateral: -6.6 g
  - Vertical: 2.9 g

Post-Impact Trajectory
- Stopping Distance: 48 ft downstream, 1 ft twd field side

Vehicle Stability
- Maximum Roll Angle: 31°
- Maximum Pitch Angle: 7°
- Maximum Yaw Angle: 95°

Test Article Deflections
- Dynamic: Ruptured
- Permanent: Ruptured
- Working Width: Ruptured
- Height of Working Width: NA

Vehicle Damage
- VDS: 12FC6
- CDC: 12FNEW4
- Max. Exterior Deformation: 22.0 inches
- OCDI: FS0000000
- Max. Occupant Compartment Deformation: 0.5 inch

Figure 5.8. Summary of Results for *MASH* Test 3-11 on MGS with Half Post Spacing.

5.3 COMPUTER SIMULATION OF MGS WITH HALF POST SPACING

5.3.1 Failure Investigation

Following the failed *MASH* test 3-11, the research team investigated the cause of the rail rupture. After a thorough analysis of the damaged installation and the crash test video, the research team determined the rail rupture was caused by a localized interaction between the W-beam rail and the wood blockout. Figure 5.9 shows a rear view of the test installation at the approximate time of rail rupture. As the rail deflected laterally rearward and flattened with the impact of the test vehicle, the edge of the W-beam became intertwined with the wood blockout. As the wood blockout deflected and twisted, the edge of the rail deformed. This deformation caused a tear to initiate in the rail, and the continuing impact event propagated the tear through the rest of the rail cross-section.

Figure 5.9. Rear View of Rail Rupture.

5.3.2 Design Improvement

With the discovery of the rail rupture cause, the research team began developing improvements to the system. The simplest and most cost-effective improvement developed was the shortened blockout. This modified blockout is 10-inches tall compared to the standard 14-inch tall blockout. The short vertical dimension minimizes interaction of the blockout with the bottom edge of the W-beam rail. Therefore, the tear initiation which was seen in the failed crash test would be prevented. Figure 5.10 below shows a comparison of the two blockouts and their relationship to the W-beam rail.

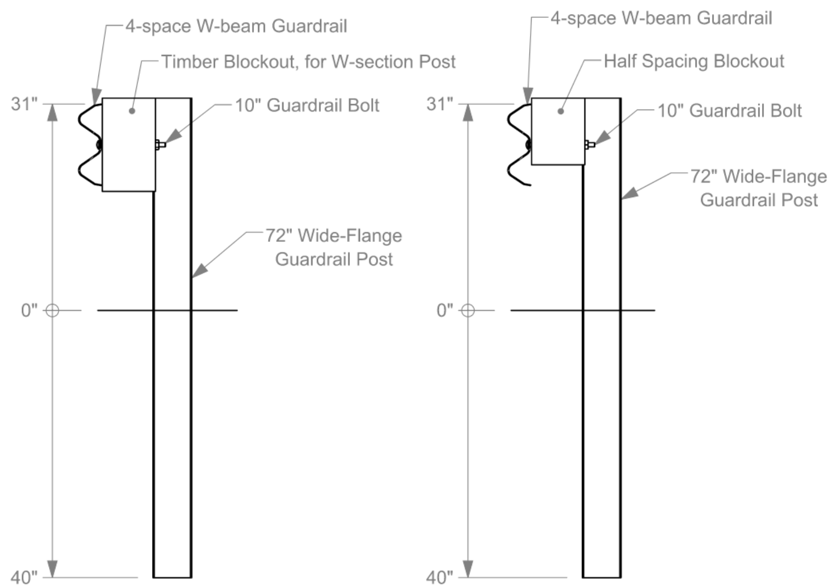


Figure 5.10. Blockout Comparison.

5.3.3 Computer Simulation

The research team then evaluated the crashworthiness of the half post spacing system with the shortened blockout using computer simulation. To perform the computer simulation, the research team used LS-DYNA, a commercially available non-linear finite element analysis code.

5.3.3.1 Model Development

The research team first developed the model of the original half post spacing system with 14-inch tall blockouts. The research team had a level of confidence with this model because it was developed with components from previous projects whose models were confirmed to be accurately predicting impact behavior. To further gain confidence in the model, the research team compared the results of the failed crash test and the corresponding computer simulation. Because the model lacked the ability to replicate the rail rupture, the research team confirmed the behavior of the model until the time of rail rupture in the failed test. Figure 5.11 through Figure 5.13 show the comparison between the failed test and the simulation. After comparing the simulation to the failed test, the research team accepted the validity of the model and proceeded with further computer simulation.

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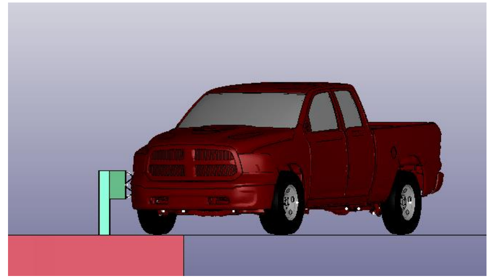

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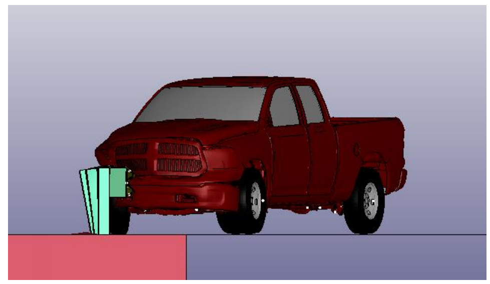

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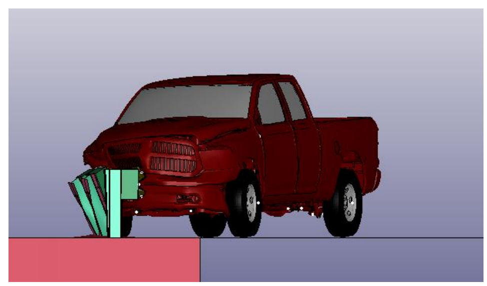

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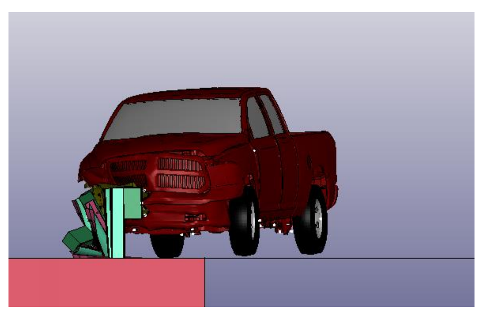

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Figure 5.11. Gut View Comparison of Failed *MASH* Test 3-11 Simulation.

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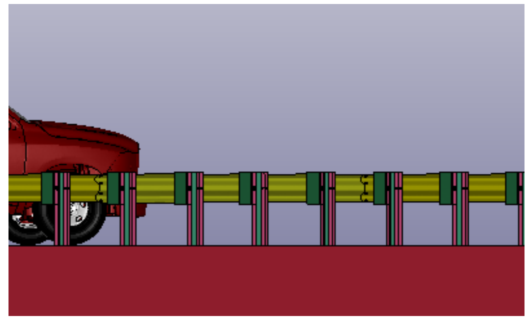

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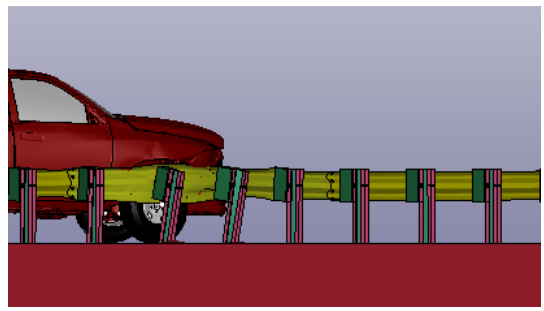

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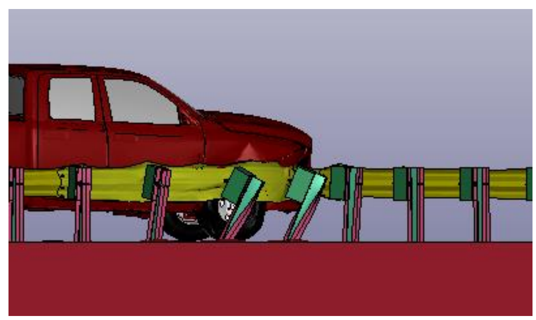

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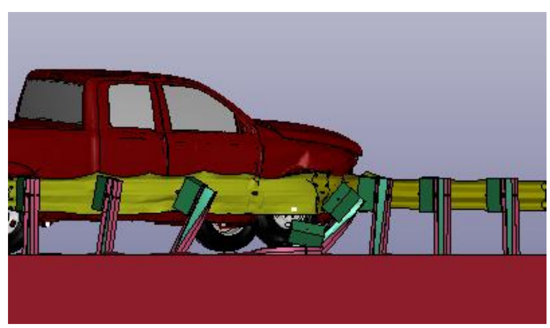

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Figure 5.12. Rear View Comparison of Failed *MASH* Test 3-11 Simulation.

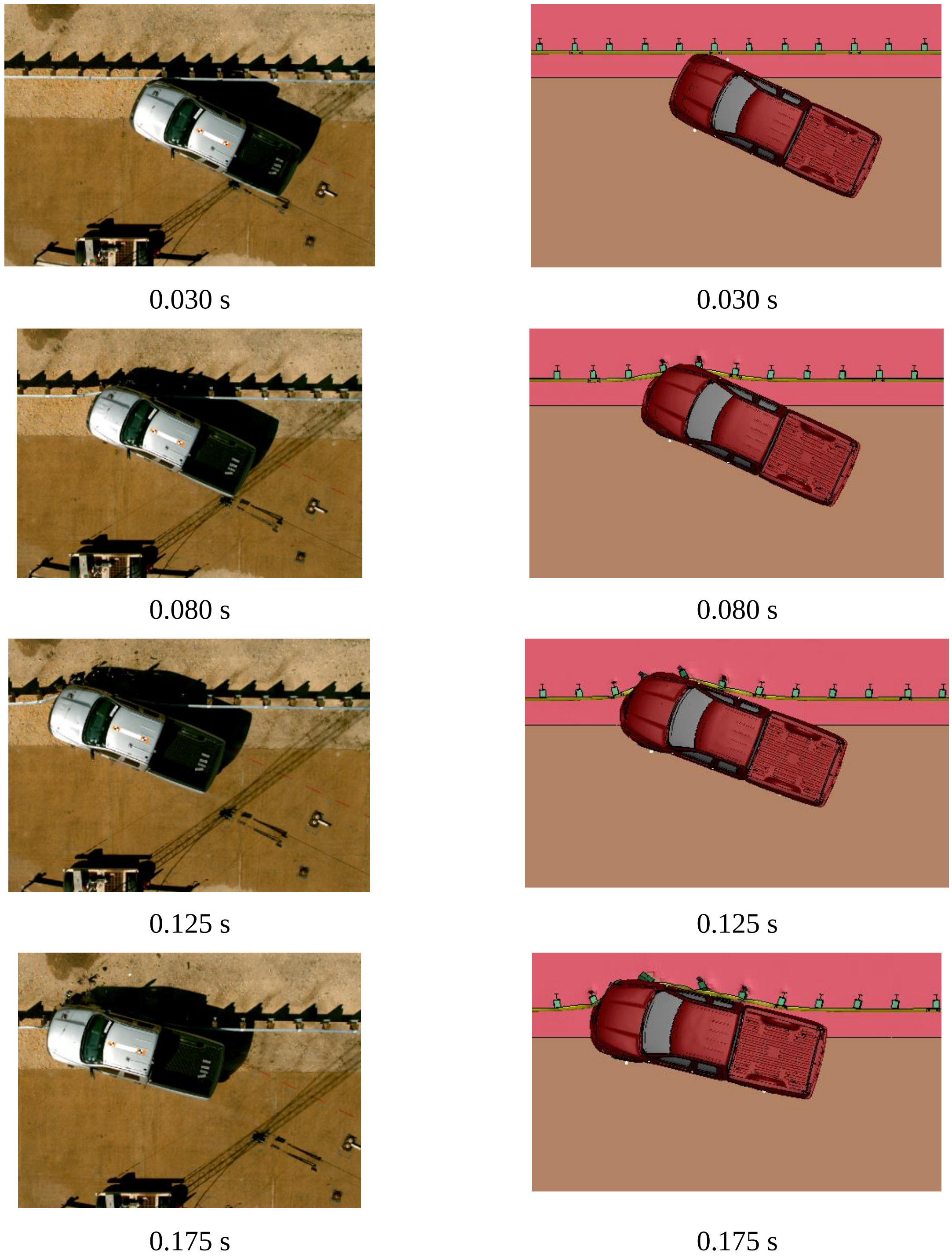
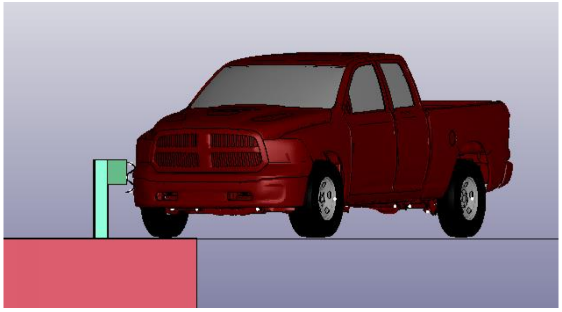


Figure 5.13. Top View Comparison of Failed *MASH* Test 3-11 Simulation.

5.3.3.2 Computer Simulation of *MASH* Test 3-11 with Shortened Blockout

The research team then performed computer simulations to predict the crashworthiness of the half post spacing system with the shortened blockouts. The blockouts were 10-inches tall in the half post spacing section and 14-inches tall in the full post spacing sections of the model. The impact point was selected to be the same as the failed crash test. Figure 5.14 through Figure 5.18 show the sequential images of the simulation. The research team concluded the computer simulations predicted the half post spacing system with shortened blockouts would be crashworthy. The system successfully contained and redirected the test vehicle. The test vehicle remained stable and did not roll. The occupant impact velocity and ridedown acceleration were 24.4 ft/s and -13.8 g, both within preferred *MASH* limits. The maximum dynamic deflection was 31.5 inches. Lastly, the bottom edge of the W-beam did not show potential for interacting with the blockouts, which caused the failure in the first crash test. Because of these computer simulation results, the research team recommend the half post spacing system with shortened blockouts be full-scale tested to *MASH*.



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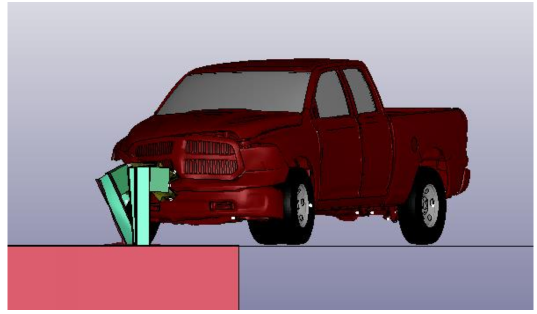

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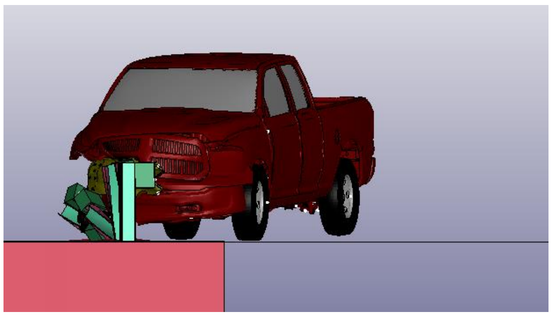

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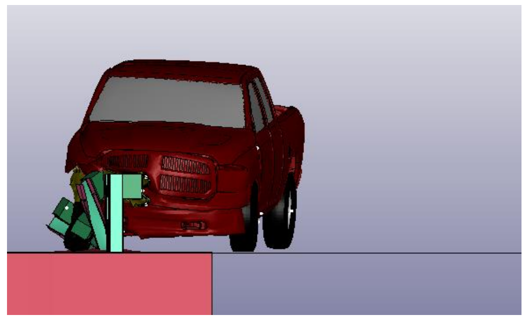

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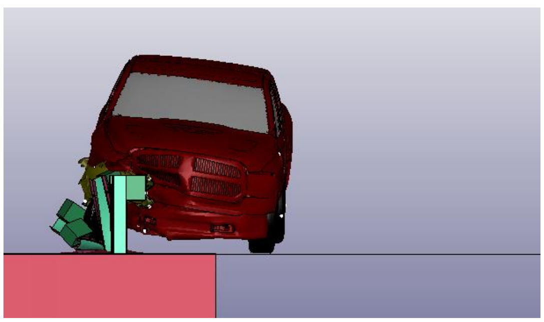

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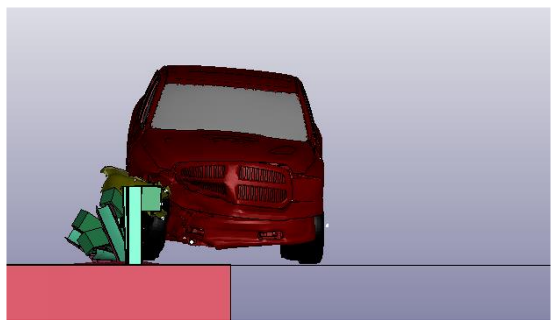

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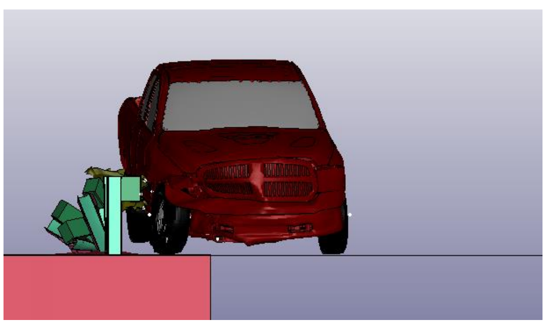

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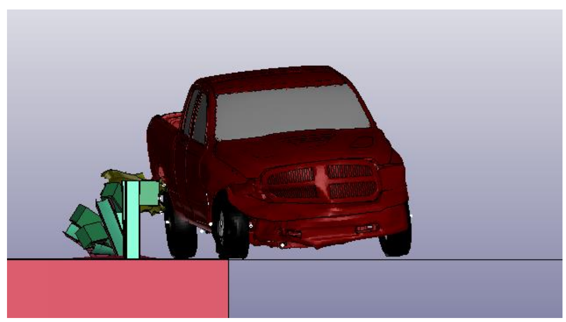

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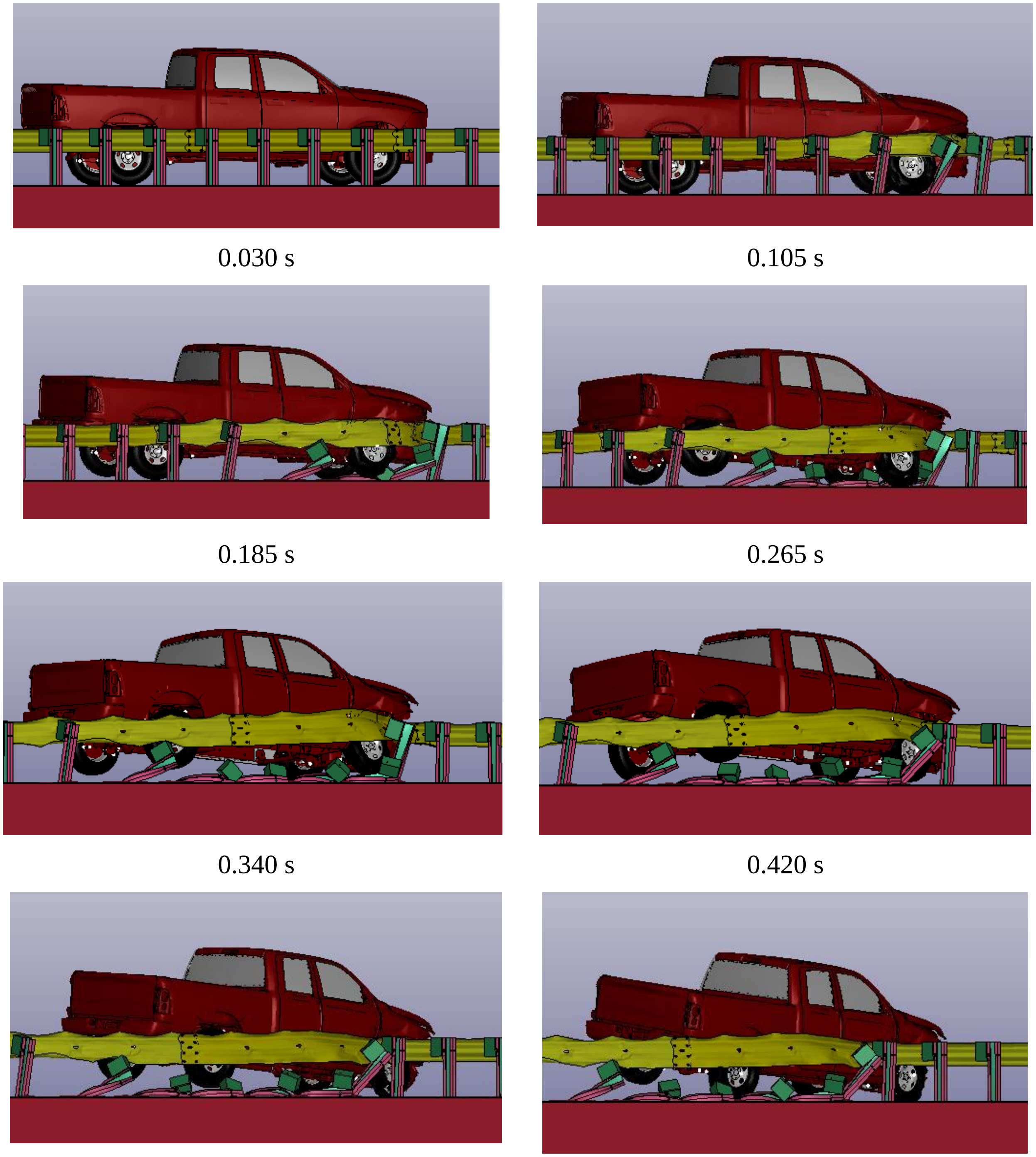
Figure 5.14. Gut View Sequential for Half Post Spacing System with Shortened Blockouts



0.030 s 0.105 s
0.185 s 0.265 s
0.340 s 0.420 s
0.500 s 0.575 s

Figure 5.15. Rear View Sequential for Half Post Spacing System with Shortened Blockouts.

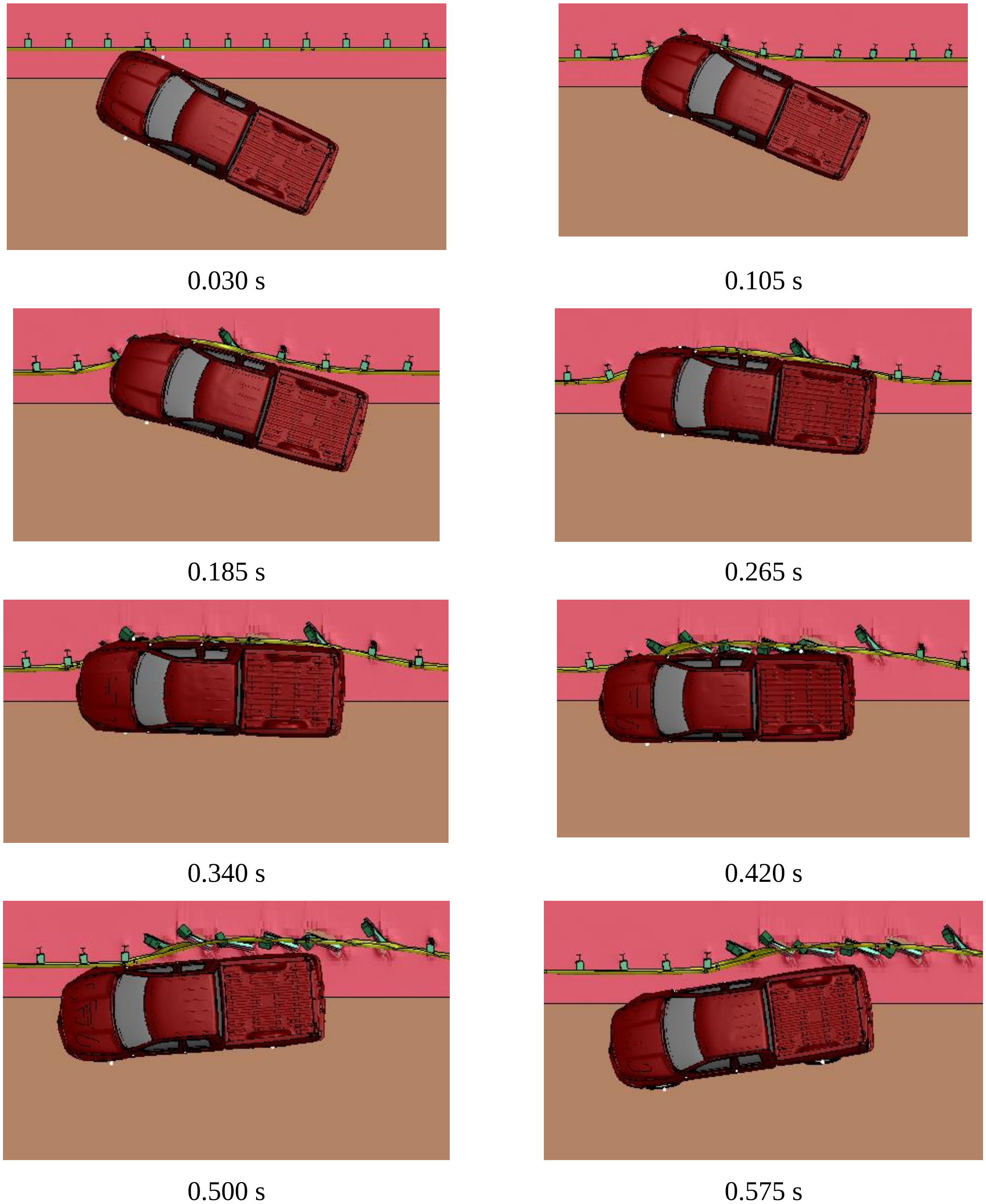


Figure 5.16. Top View Sequential for Half Post Spacing System with Shortened Blockouts.

5.4 SYSTEM DETAILS OF MGS WITH HALF POST SPACING AND SHORTENED BLOCKOUTS

5.4.1 Test Installation Details

The 181 ft-3-inch-long test installation was comprised of a 31-inch high, 12-gauge, 4-space, W-beam guardrail system. The W-beam rail was supported by 72-inch wide-flange posts with timber blockouts. TxDOT DATs terminated each end of the guardrail system. Beginning with the upstream DAT, there were three distinct sections of the installation:

1. a 37 ft-6-inch-long section (posts 3 through 9) with post spacing at 75 inches;
2. a 75 ft-0-inch-long section (posts 9 through 33) with half post spacing at 37½-inches; and
3. a 43 ft-9-inch-long section (posts 33 through 40) with post spacing at 75 inches.

A 10-inch button-head guardrail bolt secured each blockout to a post except where a post was located at a rail splices. Standard 14-inch-tall wood blockouts were installed on posts 3 through 8 and 34 through 40 (full post spacing sections). Shortened 10-inch-tall wood blockouts were installed on posts 9 through 33 (half post spacing section). In the full-post spacing sections, the W-beam rails were spliced at midspan between the posts.

The wide-flange posts were embedded 40 inches deep in drilled holes that were backfilled with crushed limestone base and compacted to meet *MASH* strength requirements.

Figure 5.17 presents overall information on the MGS with half post spacing and shortened blockouts, and Figure 5.18 provides photographs of the installation. Appendix H provides further details of the MGS with half post spacing and shortened blockouts.

5.4.2 Design Modifications

Following the failed *MASH* test 3-11 on the half post spacing system, the research team modified the blockouts within the half post spacing section to be 10-inches tall instead of the original 14-inches. This was intended to minimize interaction between the bottom edge of the W-beam rail and the blockouts, which was attributed to the original test failure. The research team evaluated this change through computer simulation. Further discussion on this modification can be found in Section 5.3.

5.4.3 Material Specifications

Appendix B provides material certification documents for the materials used to construct the MGS with half post spacing and shortened blockouts.

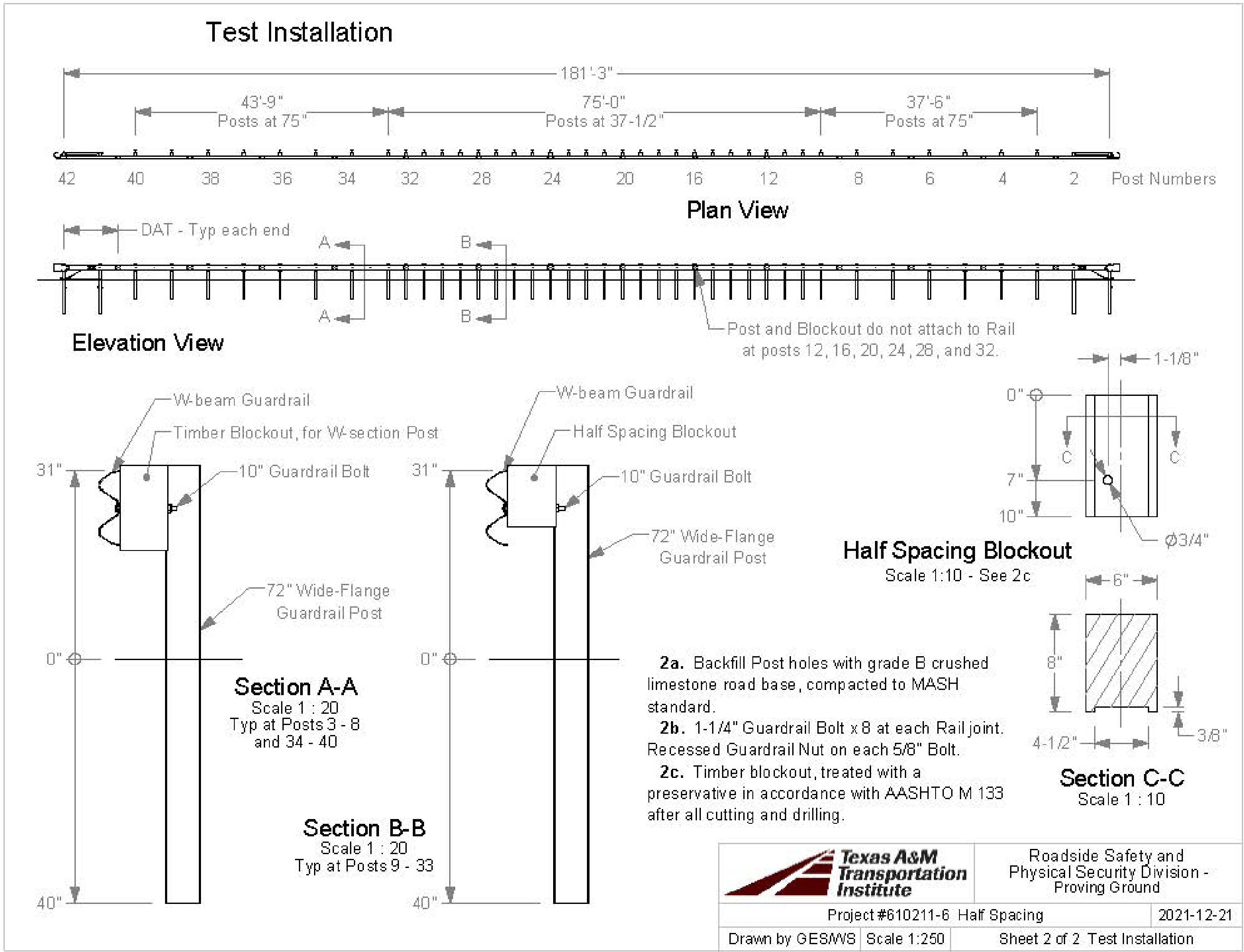


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Figure 5.17. Details of the MGS with Half Post Spacing and Shortened Blockouts.

Figure 5.18. MGS with Half Post Spacing and Shortened Blockouts prior to Testing.

5.4.4 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 MGS with half post spacing and shortened blockouts for full-scale crash testing, two W6×16 posts were installed in the immediate vicinity of MGS with half post spacing and shortened blockouts 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. 610211-01-6, March 5, 2021, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 10,555 lbf, 10,858 lbf, and 10,050 lbf, respectively. Table C.5 in Appendix C shows the strength of the backfill material in which the MGS with half post spacing and shortened blockouts was installed met minimum *MASH* requirements.

5.5 *MASH* TEST 3-11 (CRASH TEST NO. 610211-01-6) ON MGS WITH HALF POST SPACING AND SHORTENED BLOCKOUTS

5.5.1 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 degrees ±1.5 degrees. The CIP for *MASH* Test 3-11 on the MGS with half post spacing and shortened blockouts was 136 inches ±12 inches upstream of post 20 (see Figure 2.3 and Figure 5.19).

Figure 5.19. Guardrail/Test Vehicle Geometrics for Test No. 610211-01-6.

The 2270P vehicle used in the test weighed 5039 lb, and the actual impact speed and angle were 63.3 mi/h and 25.0 degrees. The actual impact point was 137.2 inches upstream of post 20. Minimum target IS was 106 kip-ft, and actual IS was 121 kip-ft.

5.5.2 Weather Conditions

The test was performed on the morning of March 5, 2021. Weather conditions at the time of testing were as follows: wind speed: 7 mi/h; wind direction: 221 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 66°F; relative humidity: 81 percent.

5.5.3 Test Vehicle

Figure 5.20 shows the 2016 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5039 lb, and its gross static weight was 5039 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 28.6 inches. Tables I.1 and I.2 in Appendix I1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system. It was released to be freewheeling and unrestrained just prior to impact.

Figure 5.20. Test Vehicle before Test No. 610211-01-6.

5.5.4 Test Description

Table 5.4 lists events that occurred during Test No. 610211-01-6. Figures I.1 and I.2 in Appendix H2 present sequential photographs during the test.

Table 5.4. Events during Test No. 610211-01-6.

TIME (s)	EVENTS
0.0000	Vehicle impacted guardrail
0.0175	Post 17 began to deflect toward the field side
0.0460	Vehicle began to redirect
0.1980	Rear bumper contacted the guardrail
0.2230	Left front tire lifted off of the pavement
0.2700	Vehicle was traveling parallel with guardrail
0.3100	Left front tire touched the pavement
0.6760	Vehicle lost contact with guardrail while traveling at 51.6 mi/h, at a trajectory of 12.5 degrees, and a heading of 11.8 degrees

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 test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied after the vehicle exited the test site, and the vehicle subsequently came to rest 138 ft downstream of the impact and 35 ft toward the field side.

5.5.5 Damage to Test Installation

Figure 5.21 shows the damage to the MGS with half post spacing and shortened blockouts. The soil was disturbed at posts 3-11, 13-14, 24-37, and 40. Starting at post 5 and continuing until post 15, the posts had a slight clockwise twist, with the exception of post 12, which was not connected to the rail due the splice location. Posts 18-22 were laid over nearly horizontal, and posts 19-22 were missing their blockouts. Those blockouts were behind the installation in a debris field that was 39 ft towards the field side, and 101 ft downstream from impact. There was a secondary contact from the vehicle redirecting back into the installation at the joint in the rail between posts 38 and 39. Table 5.5 provides additional measurements. Working width was 43.1 inches, and height of working width was 10.1 inches. Maximum dynamic deflection during the test was 25.6 inches, and maximum permanent deformation was 21.2 inches.

5.5.6 Damage to Test Vehicle

Figure 5.22 shows the damage sustained by the vehicle. The front bumper, hood, grill, right front fender, right frame rail, right upper and lower control arms, right front tire and rim, right front and rear doors, right cab corner, right rear exterior bed, and rear bumper were damaged. No damage to the fuel take was observed. Maximum exterior crush to the vehicle was 14.0 inches in the front plane at the right front corner at bumper height. No occupant compartment deformation or intrusion occurred. Figure 5.23 shows the interior of the vehicle. Tables I.3 and I.4 in Appendix I1 provide exterior crush and occupant compartment measurements.

5.5.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 5.6. Figure 5.24 summarizes these data and other pertinent information from the test. Figure I.3 in Appendix I3 shows the vehicle angular displacements, and Figures I.4 through I.6 in Appendix H4 show accelerations versus time traces.

Figure 5.21. MGS with half Post Spacing and Shortened Blockouts after Test No. 610211-01-6.

Table 5.5. Post Measurements for Test No. 610211-01-6.

Post #	Soil Gap (inches)			Post Lean from Vertical
	D/S	T/S	F/S	
1	⅛	-	-	-
2	⅛	-	-	-
15	-	⅛	-	-
16	-	⅝	¼	1°
17	-	-	1¼	3°
23	-	⅞	-	37°
38	-	⅛	-	-
39	-	½	-	-

D/S=downstream; T/S=traffic side; F/S=field side

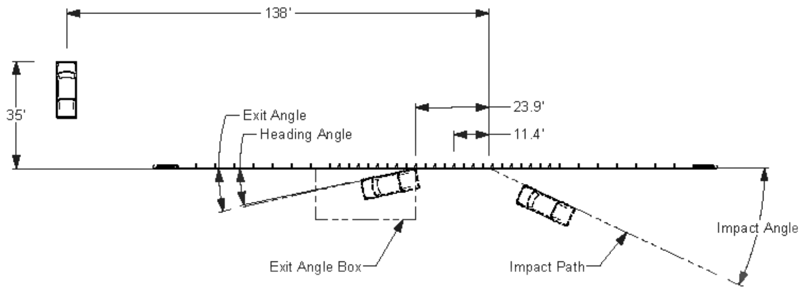
Figure 5.22. Test Vehicle after Test No. 610211-01-6.

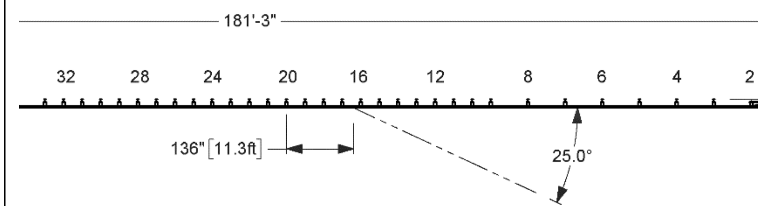
Figure 5.23. Interior of Test Vehicle after Test No. 610211-01-6.

Table 5.6. Occupant Risk Factors for Test No. 610211-01-6.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	**19.5 ft/s**	at 0.1381 s on right side of interior
Lateral	**16.3 ft/s**	
Occupant Ridedown Accelerations		
Longitudinal	**10.3 g**	0.3275 - 0.3375 s
Lateral	**8.1 g**	0.2447 - 0.2547 s
THIV	**7.8 m/s**	at 0.1320 s on right side of interior
ASI	**0.9**	0.0612 - 0.1112 s
Maximum 50-ms Moving Average		
Longitudinal	**-6.3 g**	0.0712 - 0.1212 s
Lateral	**-6.1 g**	0.2164 - 0.2664 s
Vertical	**2.5 g**	0.1290 - 0.1790 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**7°**	2.4441 s
Pitch	**8°**	0.5481 s
Yaw	**38°**	0.5991 s

0.000 s | 0.200 s | 0.400 s | 0.600 s





General Information
- Test Agency....................... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ...... MASH Test 3-11
- TTI Test No. 610211-01-6
- Test Date 2021-03-05

Test Article
- Type .... Longitudinal Barrier – Guardrail
- Name................................ MGS with half Post Spacing and Shortened Blockouts
- Installation Length............. 181 ft-3 inches
- Material or Key Elements... 31-inch tall MGS W-Beam Guardrail with 37½-inch post spacing for the LON and shortened blockouts

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

Test Vehicle
- Type/Designation 2270P
- Make and Model .... 2016 RAM 1500 Pickup
- Curb.................................. 5071 lb
- Test Inertial .... 5039 lb
- Dummy .... No dummy
- Gross Static .... 5039 lb

Impact Conditions
- Speed .... 63.3 mi/h
- Angle .... 25.0°
- Location/Orientation .... 137.2 inches upstream of post 20

Impact Severity.................... 121 kip-ft

Exit Conditions
- Speed .... 51.6 mi/h
- Trajectory/Heading Angle... 12.5°/11.8°

Occupant Risk Values
- Longitudinal OIV .... 19.5 ft/s
- Lateral OIV......................... 16.3 ft/s
- Longitudinal Ridedown .... 10.3 g
- Lateral Ridedown .... 8.1 g
- THIV .... 7.8 m/s
- ASI.................................... 0.9

Max. 0.050-s Average
- Longitudinal .... -6.3 g
- Lateral............................ -6.1 g
- Vertical........................... 2.5 g

Post-Impact Trajectory
- Stopping Distance.................... 138 ft downstream 35 ft twd field side

Vehicle Stability
- Maximum Roll Angle .... 7°
- Maximum Pitch Angle .... 8°
- Maximum Yaw Angle .... 38°

Test Article Deflections
- Dynamic.................................. 25.6 inches
- Permanent .... 21.2 inches
- Working Width.......................... 43.1 inches
- Height of Working Width .... 10.1 inches

Vehicle Damage
- VDS 01RFQ4
- CDC.. 01RLEW3
- Max. Exterior Deformation......... 14.0 inches
- OCDI....................................... LF0000000
- Max. Occupant Compartment Deformation .... None

Figure 5.24. Summary of Results for *MASH* Test 3-11 on MGS with half Post Spacing and Shortened Blockouts.

Chapter 6. TRANSITION FROM FULL TO QUARTER POST SPACING

6.1 SYSTEM DETAILS OF TRANSITION FROM FULL TO QUARTER POST SPACING

6.1.1 Test Installation Details

The 181 ft-3-inch-long test installation was comprised of a 31-inch high, 12-gauge, 4-space, W-beam guardrail system. The W-beam rail was supported by 72-inch wide-flange posts with 14-inch-tall wood blockouts. TxDOT DATs terminated each end of the guardrail system. Beginning with the upstream DAT, there were four distinct sections of the installation:

1. a 49 ft-3-inch-long section (posts 3 through 10) with full post spacing at 75 inches;
2. a 75-inch-long transition section (posts 10-11-12) with half post spacing at 37½ inches;
3. a 62 ft-6-inch-long section (posts 12 through 52) with quarter post spacing at 18¾-inches; and
4. a 43 ft-9-inch-long section (posts 52 through 60) with post spacing at 75 inches.

In the full post spacing sections, a 10-inch button-head guardrail bolt secured each blockout to a post. In the quarter and half post spacing sections, the bolts secured the rail only at half post spacing. Therefore, no additional slots were cut in the W-beam rail. Additionally, the quarter and half post spacing sections did not have posts bolted to the rail at splice locations. In the full-post spacing sections, the W-beam rails were spliced at midspan between the posts.

The wide-flange posts were embedded 40 inches deep in drilled holes that were backfilled with crushed limestone base and compacted to meet *MASH* strength requirements.

Figure 6.1 presents overall information on the transition from full to quarter post spacing, and Figure 6.2 provides photographs of the installation. Appendix J provides further details of the transition from full to quarter post spacing.

6.1.2 Design Modifications

No modification was made to the transition from full to quarter post spacing prior to this crash test.

6.1.3 Material Specifications

Appendix B provides material certification documents for the materials used to construct the transition from full to quarter post spacing.

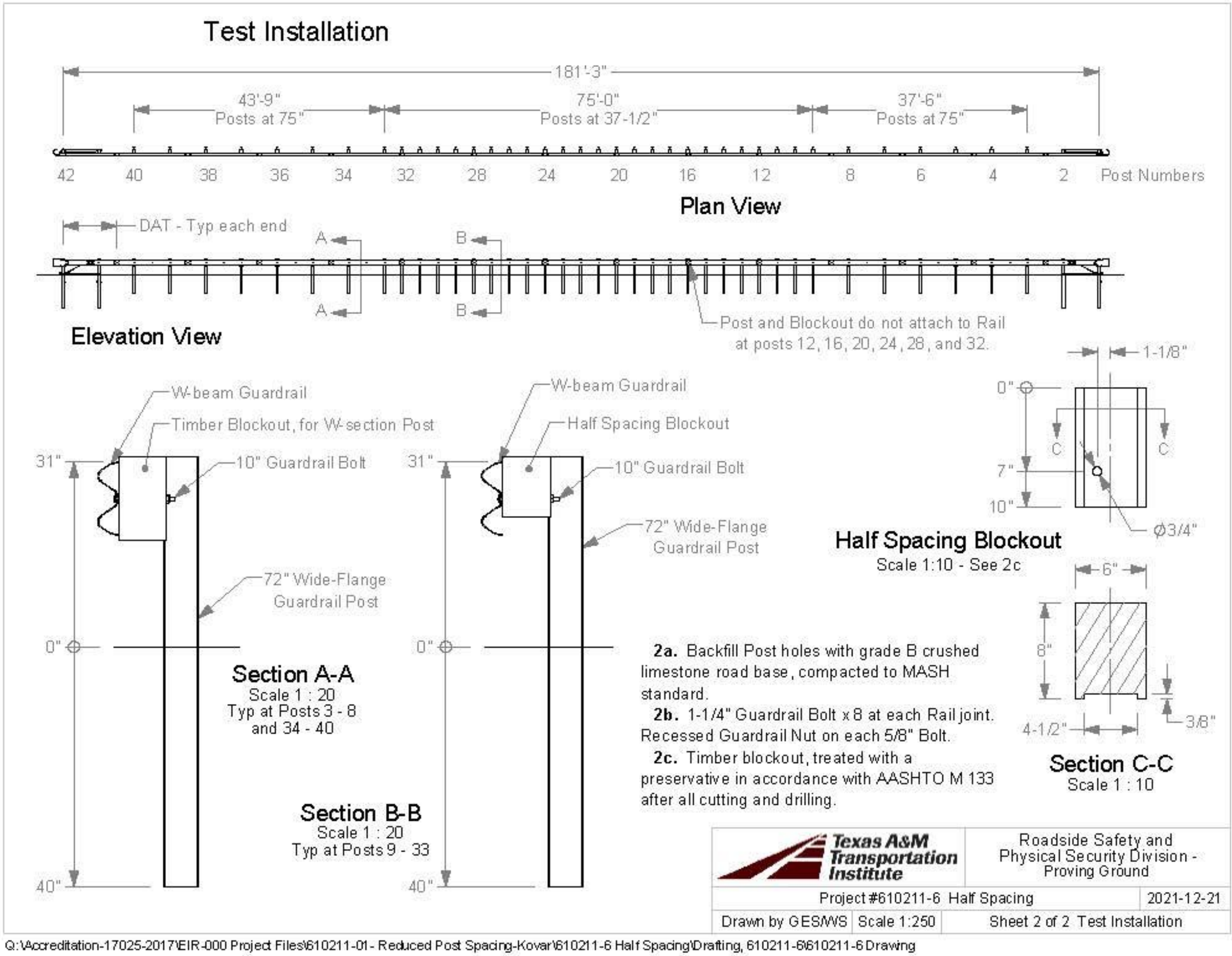


Figure 6.1. Details of the Transition from Full to Quarter-Post Spacing.

Figure 6.2. Transition from Full to Quarter Post Spacing prior to Testing.

6.1.4 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 transition from full to quarter post spacing for full-scale crash testing, two W6×16 posts were installed in the immediate vicinity of transition from full to quarter post spacing 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. 610211-01-4, November 27, 2018, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 6414 lbf, 6919 lbf, and 6717 lbf, respectively. Table C.6 in Appendix C shows the strength of the backfill material in which the transition from full to quarter post spacing was installed met minimum *MASH* requirements.

6.2 *MASH* TEST 3-21 (CRASH TEST NO. 610211-01-4) ON TRANSITION FROM FULL TO QUARTER POST SPACING

6.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-21 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the transition at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The CIP for *MASH* Test 3-21 on the standard transition from full to quarter post spacing was 132 inches ±12 inches upstream of post 13 (see Figure 2.4 and Figure 6.3).

Figure 6.3. Transition/Test Vehicle Geometrics for Test No. 610211-01-4.

The 2270P vehicle used in the test weighed 5060 lb, and the actual impact speed and angle were 64.1 mi/h and 25.1 degrees. The actual impact point was 133.2 inches upstream of post 12. Minimum target IS was 106 kip-ft, and actual IS was 125 kip-ft.

6.2.2 Weather Conditions

The test was performed on the morning of November 27, 2018. Weather conditions at the time of testing were as follows: wind speed: 8 mi/h; wind direction: 192 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 55°F; relative humidity: 43 percent.

6.2.3 Test Vehicle

Figure 6.4 shows the 2013 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5060 lb, and its gross static weight was 5060 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and 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 K.1 and K.2 in Appendix K1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system. It was released to be freewheeling and unrestrained just prior to impact.

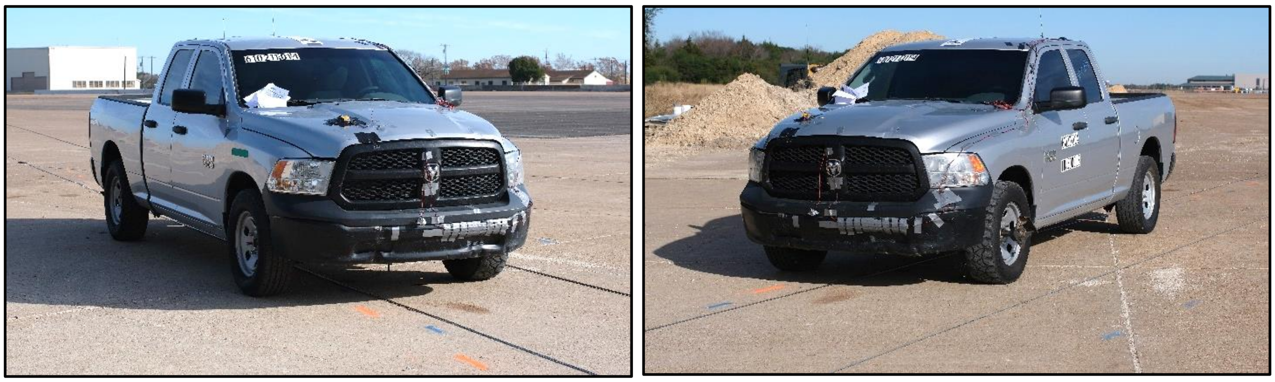


Figure 6.4. Test Vehicle before Test No. 610211-01-4.

6.2.4 Test Description

Table 6.1 lists events that occurred during Test No. 610211-01-4. Figures K.1 and K.2 in Appendix G2 present sequential photographs during the test.

Table 6.1. Events during Test No. 610211-01-4.

TIME (s)	EVENTS
0.0000	Vehicle contacted transition
0.0570	Vehicle began to redirect
0.1170	Rail element began to tear
0.1240	Rail element has fully torn
0.3420	Vehicle is fully airborne
0.3550	Vehicle is traveling parallel with transition
0.7480	Right rear tire contacted ground on field side of guardrail
0.9080	Right front tire contacted ground on field side of guardrail
1.6260	Vehicle passed through guardrail to field side and rolled on its side

After loss of contact with the transition, the vehicle rolled onto its right side and came to rest 30 ft downstream of the impact and 3 ft toward the field side.

6.2.5 Damage to Test Installation

Figure 6.5 shows the damage to the installation. The rail element detached from all posts/blockouts except post 61, which sheared at ground level. Posts 3-8 and 23 until the end showed no movement. The blockouts separated from posts 11-16, and the rail element ruptured at the splice at post 11. Table 6.2 provides additional measurements.

Figure 6.5. Transition from Full to Quarter Post Spacing after Test No. 610211-01-4.

Table 6.2. Post Measurements for Test No. 610211-01-4.

Post #	Soil Gap (inches)		Post Lean from Vertical
	D/S	F/S	
1-2	½	-	-
9	-	1½	4°
10	-	-	53°
11	-	-	62°
12	-	-	65°
13	-	-	68°
14-17	-	-	59°
18	-	-	53°
19-20	-	-	45°
21	-	-	15°
22	-	-	10°

D/S=downstream; F/S=field side

6.2.6 Damage to Test Vehicle

Figure 6.6 shows the damage sustained by the vehicle. The front bumper, grill, hood, radiator and support, right front fender, right front tire and rim, right front and rear doors, right rear exterior bed, and right rear tire and rim were damaged. No damage to the fuel tank was observed. Maximum exterior crush to the vehicle was 18.0 inches in the front plane near the center at bumper height. No occupant compartment deformation or intrusion occurred. Figure 6.7 shows the interior of the vehicle. Tables K.3 and K.4 in Appendix K1 provide exterior crush and occupant compartment measurements.

Figure 6.6. Test Vehicle after Test No. 610211-01-4.

Figure 6.7. Interior of Test Vehicle for Test No. 610211-01-4.

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 are shown in Table 6.3. Figure 6.8 summarizes these data and other pertinent information from the test. Figure K.3 in Appendix K3 shows the vehicle angular displacements, and Figures K.4 through K.6 in Appendix K4 show accelerations versus time traces.

Table 6.3. Occupant Risk Factors for Test No. 610211-01-4.

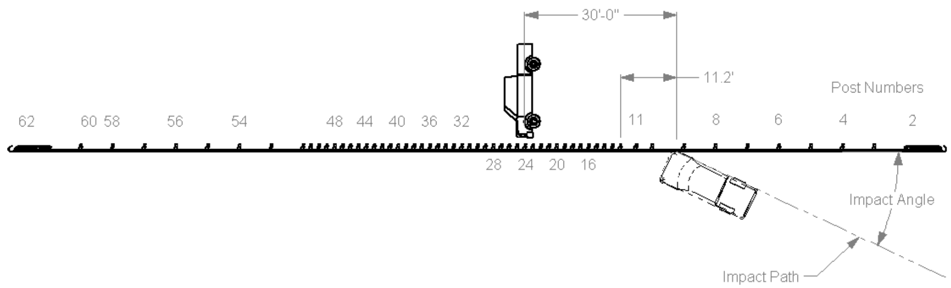
Occupant Risk Factor	Value	Time
OIV		
Longitudinal	**19.7 ft/s**	at 0.1405 s on right side of interior
Lateral	**16.1 ft/s**	
Occupant Ridedown Accelerations		
Longitudinal	**15.9 g**	0.1942 - 0.2042 s
Lateral	**4.7 g**	0.1828 - 0.1928 s
THIV	**7.5 m/s**	at 0.1351 s on right side of interior
ASI	**0.9**	0.2152 - 0.2652 s
Maximum 50-ms Moving Average		
Longitudinal	**-10.9 g**	0.1940 - 0.2440
Lateral	**-5.6 g**	0.0788 - 0.1288 s
Vertical	**-4.1 g**	0.2033 - 0.2533 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**89°**	2.0142 s
Pitch	**5°**	1.3551 s
Yaw	**115°**	2.3055 s

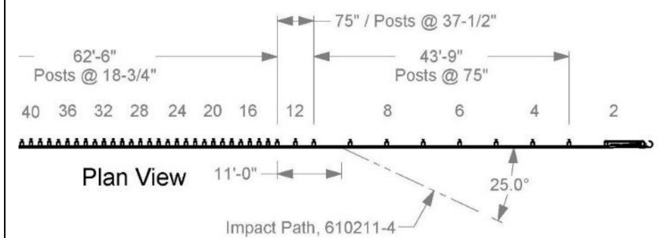
0.000 s

0.200 s

0.400 s

0.700 s





General Information
- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: MASH Test 3-21
- TTI Test No.: 610211-01-4
- Test Date: 2018-11-27

Test Article
- Type: Transition
- Name: Transition from Full to Quarter-Post Spacing
- Installation Length: 181 ft-3 inches
- Material or Key Elements: 31-inch-tall Transition from Full to Quarter Post Spacing

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

Test Vehicle
- Type/Designation: 2270P
- Make and Model: 2013 RAM 1500 Pickup
- Curb: 5030 lb
- Test Inertial: 5060 lb
- Dummy: No dummy
- Gross Static: 5060 lb

Impact Conditions
- Speed: 64.1 mi/h
- Angle: 25.1°
- Location/Orientation: 133.2 inches upstream of post 11

Impact Severity: 125 kip-ft

Exit Conditions
- Speed: NA
- Angle: NA

Occupant Risk Values
- Longitudinal OIV: 19.7 ft/s
- Lateral OIV: 16.1 ft/s
- Longitudinal Ridedown: 15.9 g
- Lateral Ridedown: 4.7 g
- THIV: 7.5 m/s
- ASI: 0.9

Max. 0.050-s Average
- Longitudinal: -10.9 g
- Lateral: -5.6 g
- Vertical: -4.1 g

Post-Impact Trajectory
- Stopping Distance: 30 ft downstream 3 ft twd field side

Vehicle Stability
- Maximum Roll Angle: 89°
- Maximum Pitch Angle: 5°
- Maximum Yaw Angle: 115°

Test Article Deflections
- Dynamic: Rail Ruptured
- Permanent: Rail Ruptured
- Working Width: Rail Ruptured
- Height of Working Width: NA

Vehicle Damage
- VDS: 01FD6
- CDC: 01FDEW4
- Max. Exterior Deformation: 18.0 inches
- OCDI: FS0000000
- Max. Occupant Compartment Deformation: None

Figure 6.8. Summary of Results for *MASH* Test 3-21 on Transition from Full to Quarter Post Spacing.

6.3 SIMULATION ON TRANSITION FROM FULL TO QUARTER POST SPACING

6.3 FAILURE INVESTIGATION

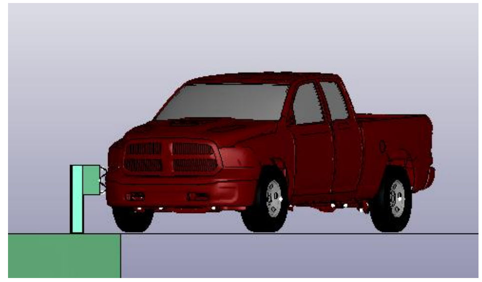
Following the failed *MASH* test 3-21, the research team investigated the cause of the rail rupture. After a thorough analysis of the crash test video, the research team determined the rail rupture was caused by rail pocketing in the transition. This rail pocketing was attributed to a short transition between differing stiffnesses. The difference in stiffness between the full post spacing section and the quarter post spacing section was too large for such a short transition. This pocketing caused excessive loading in the rail element, which resulted in rupture at a critical splice location.

6.3.1 Design Improvement

With the discovery of the rail rupture cause, the research team began developing improvements to the system. The research team explored lengthening the transition zone between full and quarter post spacing. To lengthen the transition, the research team recommended additional posts spaced at 37½-inches. To evaluate the effect of the additional posts, the research team used computer simulation to determine the reduction in pocketing potential. To perform the computer simulation, the research team used LS-DYNA to perform the finite element analysis.

6.3.1.1 Model Development

The research team first developed the model of the original transition from full to half post spacing. The research team had a level of confidence with this model because it was developed with components from previous projects whose models were confirmed to be accurately predicting impact behavior. To further gain confidence in the model, the research team compared the results of the failed crash test and the corresponding computer simulation. Because the model lacked the ability to replicate the rail rupture, the research team confirmed the behavior of the model until the time of rail rupture in the failed test. Figure 6.9 through Figure 6.11 show the comparison between the failed test and the simulation. After comparing the simulation to the failed test, the research team accepted the validity of the model and proceeded with further computer simulation.

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 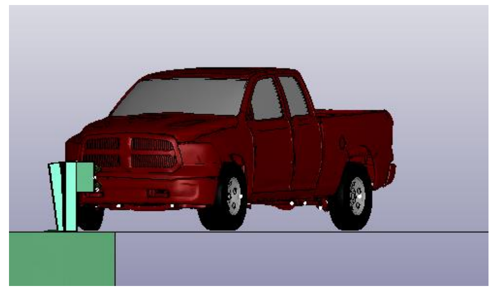

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 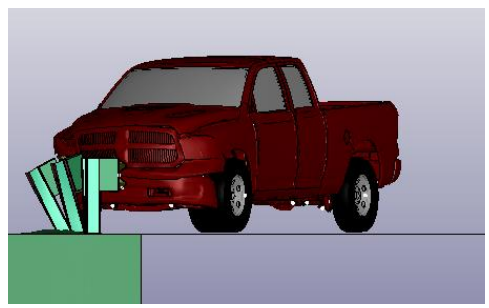

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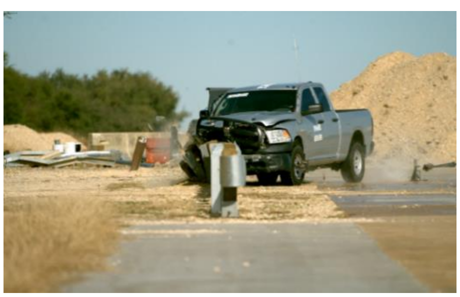
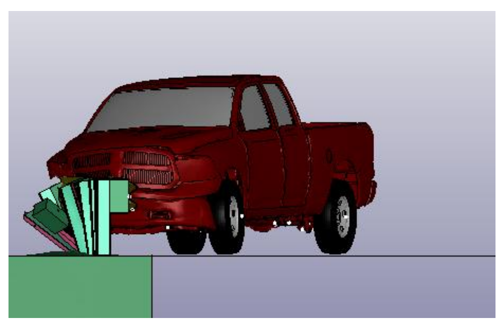
 

0.145 s 0.145 s

Figure 6.9. Gut View Comparison of Failed *MASH* Test 3-21 Simulation.

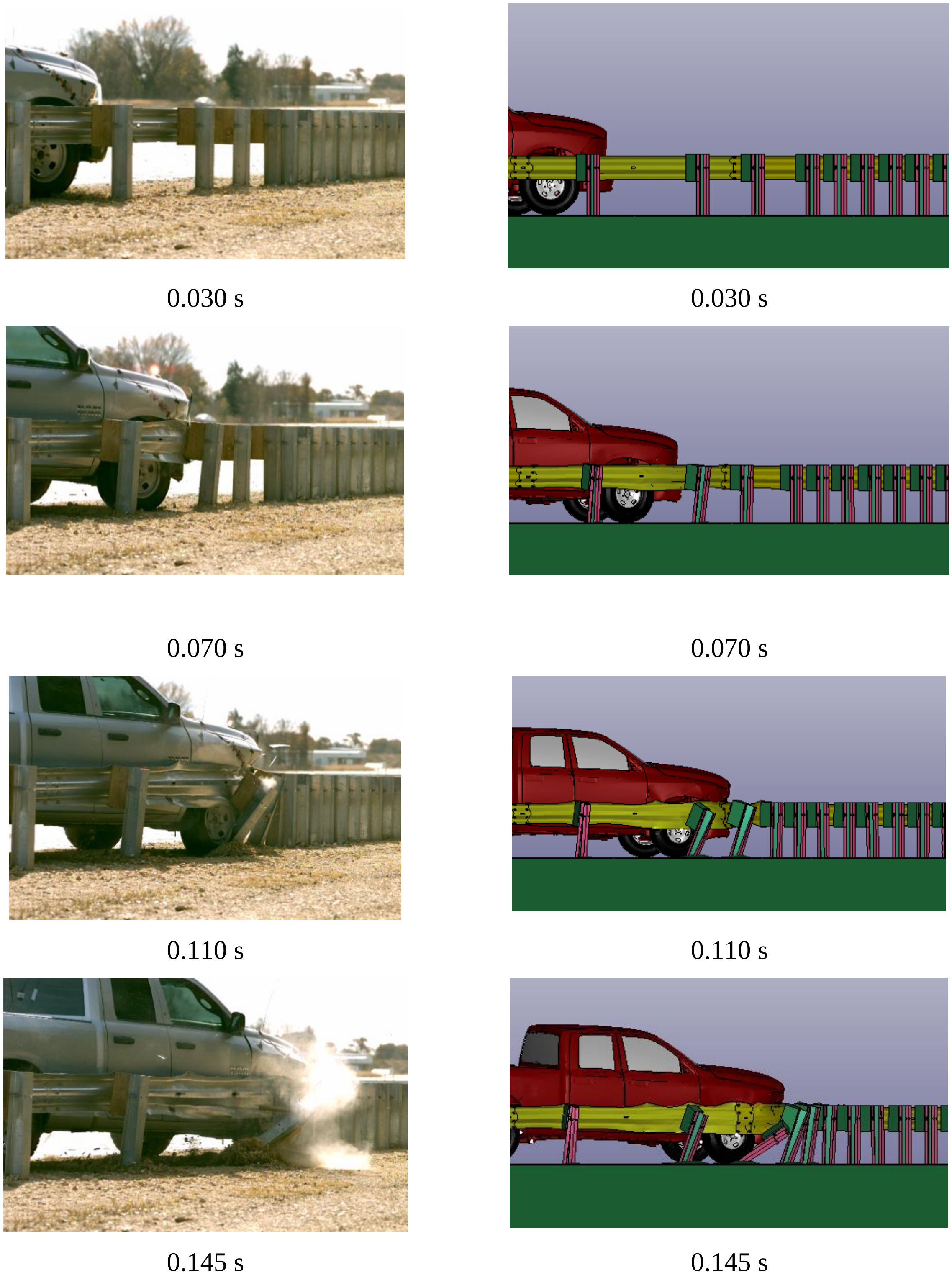


Figure 6.10. Rear View Comparison of Failed *MASH* Test 3-21 Simulation.

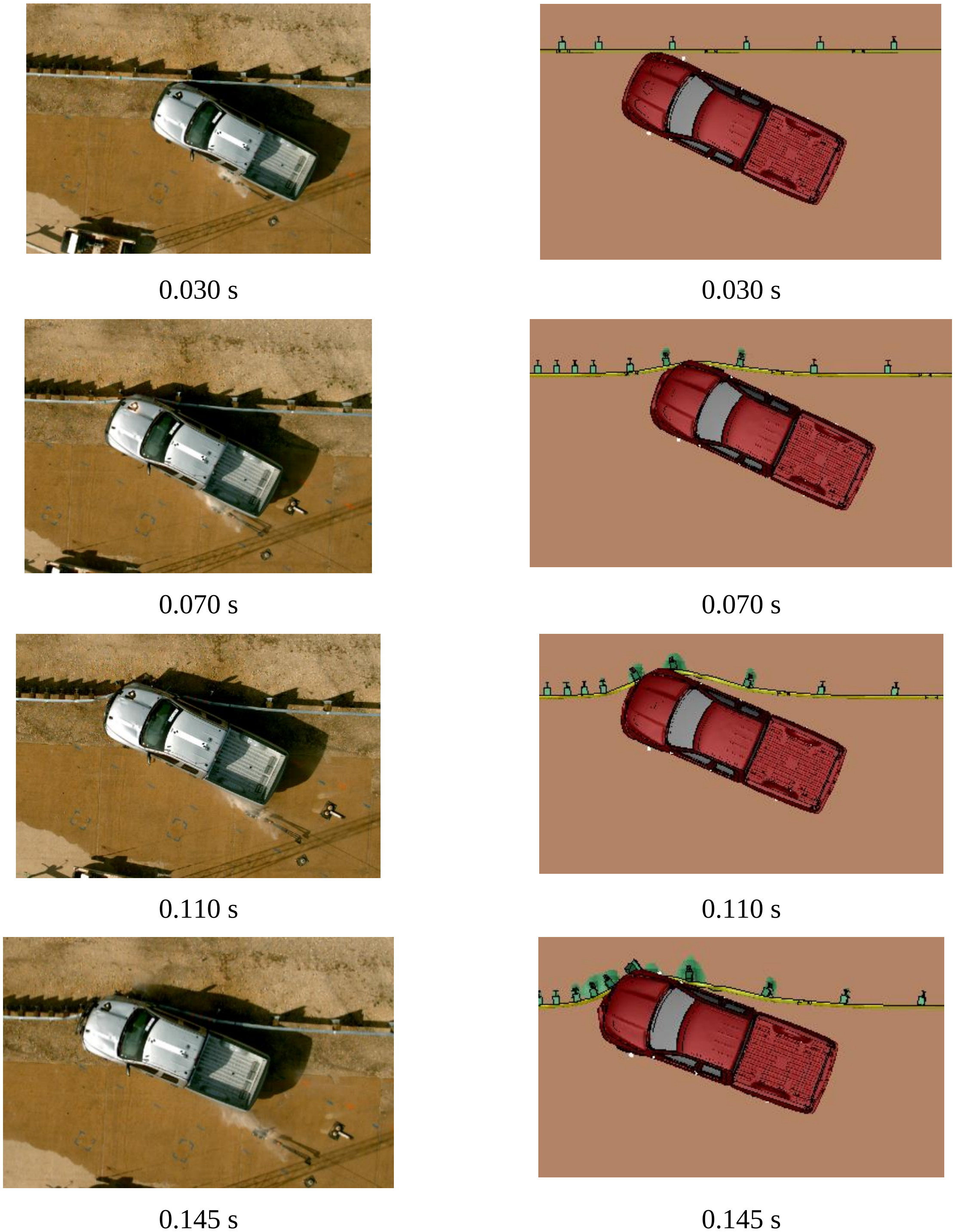


Figure 6.11. Overhead View Comparison of Failed *MASH* Test 3-21 Simulation.

6.3.1.2 Computer Simulation of *MASH* Test 3-21 with Longer Transition

The research team then performed computer simulations to determine the additional length needed to minimize the pocketing behavior. After several iterations, the research team chose to add one additional post to the transition. Figure 6.12 shows a comparison of the transition length used in the original failed crash test and the longer length recommended by the research team. It is important to note the blockouts located at the posts spaced at 37 ½-inches are the original 14-inch vertical height and not the shortened 10-inch vertical height used in the second half post spacing test. The research team did not recommend using the shortened blockouts in the transition to simplify the installation and minimize potential errors in construction.

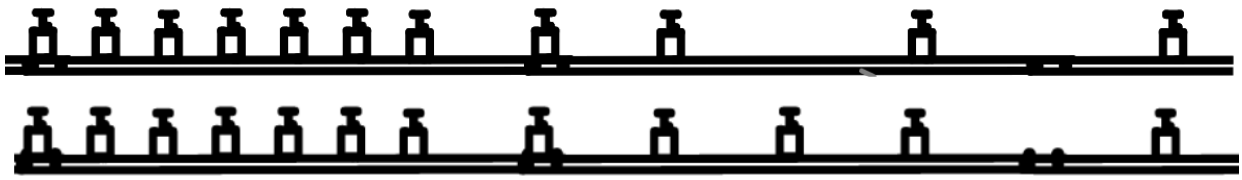
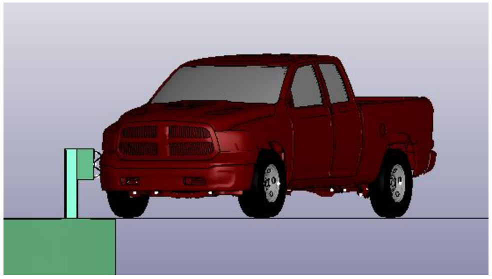


Figure 6.12. Comparison of Transition Lengths.

When evaluating the crashworthiness of the longer transition, the research team selected the same impact point as the failed crash test. Figure 6.13 through Figure 6.15 show the sequential images of the simulation. The research team concluded the computer simulations predicted the longer transition would be crashworthy. The system successfully contained and redirected the test vehicle. The test vehicle remained stable and did not roll. The occupant impact velocity and ridedown acceleration were 18.7 ft/s and -16.0 g, both within acceptable *MASH* limits. The maximum dynamic deflection was 30.5-inches. Lastly, simulations showed a reduction in the pocketing behavior seen in the failed crash test. Because of these computer simulation results; the research team recommend the longer transition be full-scale tested to *MASH*.



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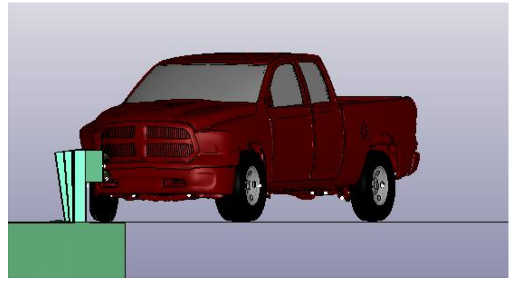
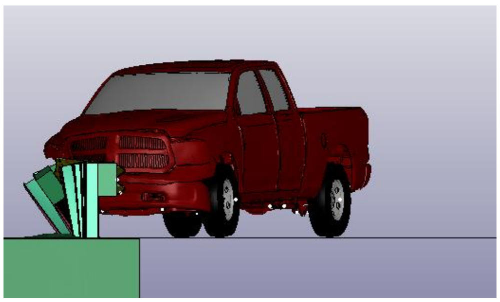


0.065 s



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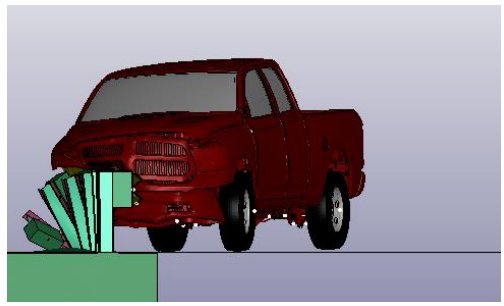

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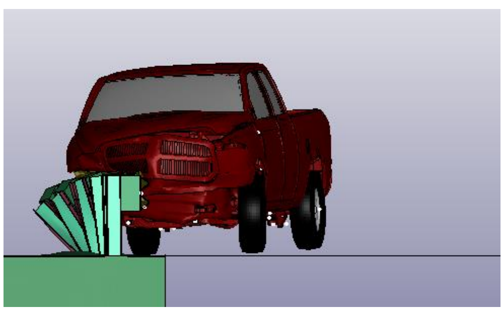

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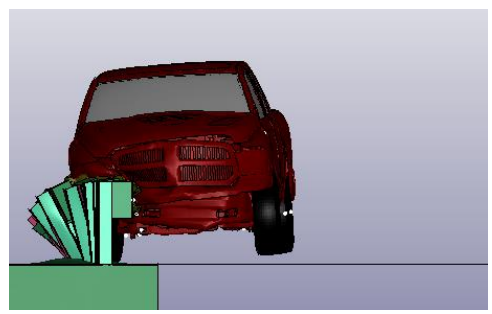

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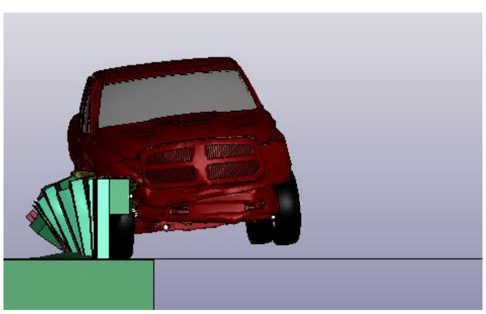

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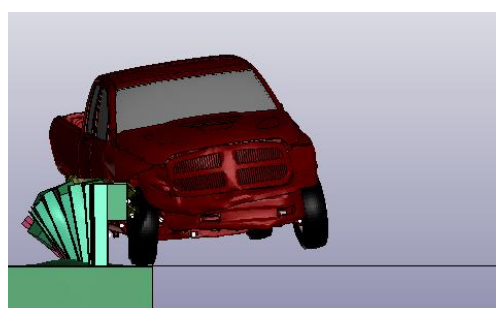

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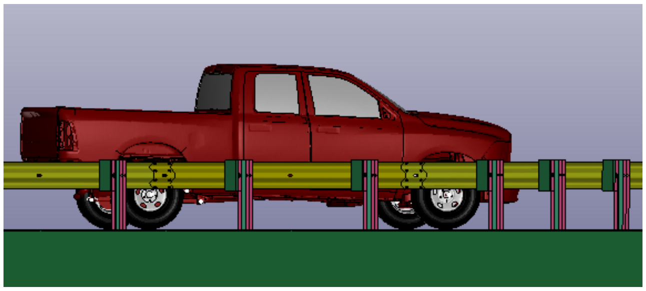
Figure 6.13. Gut View Sequential for Longer Transition Simulation.



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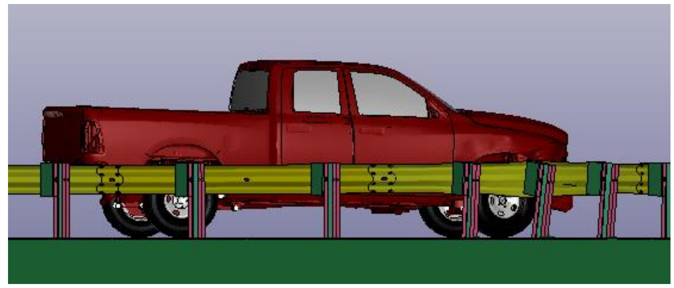

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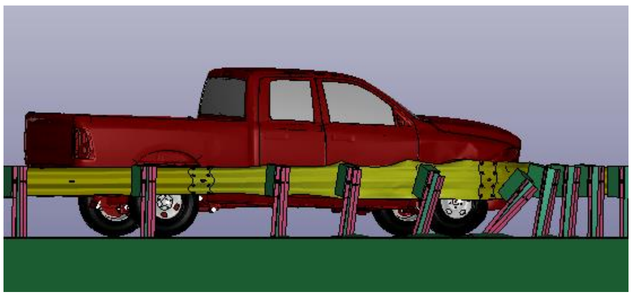

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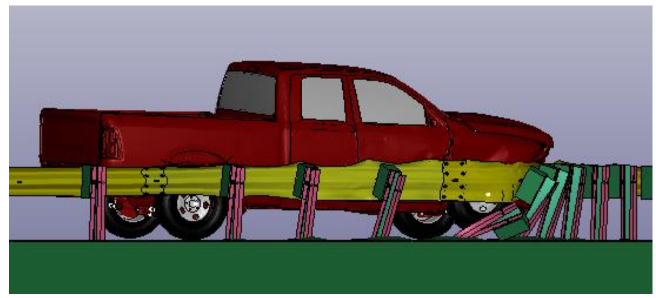

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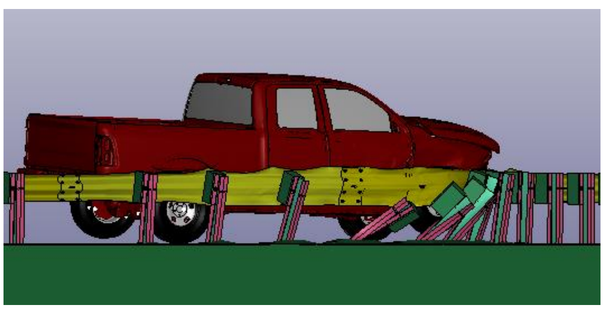

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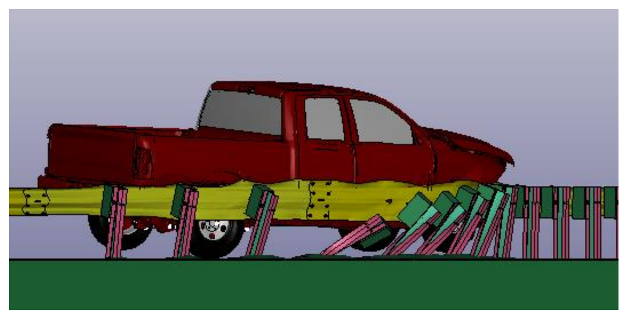

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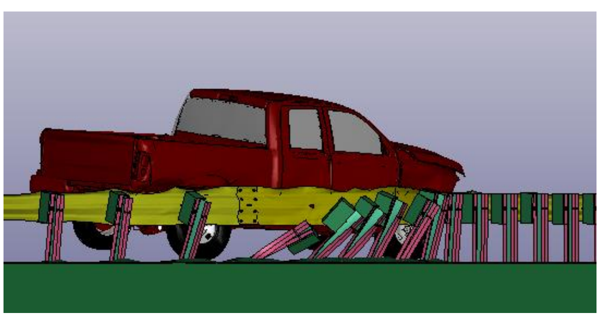

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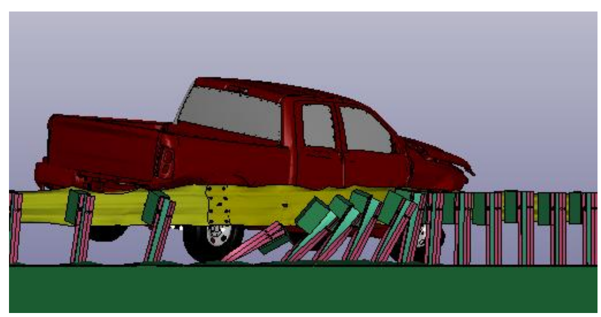

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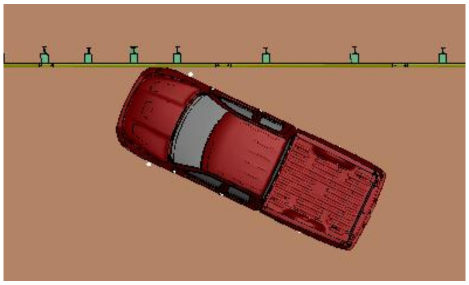
Figure 6.14. Rear View Sequential for Longer Transition Simulation.



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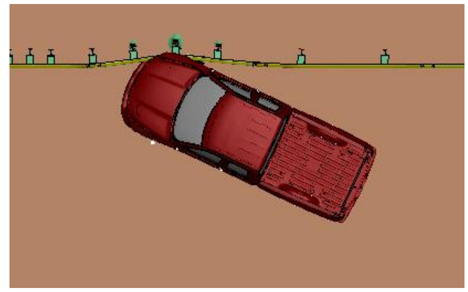

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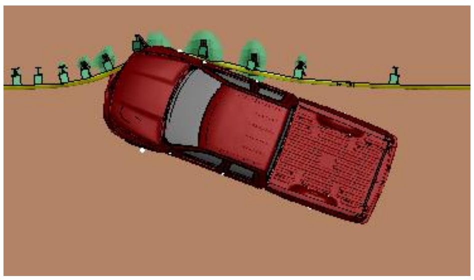

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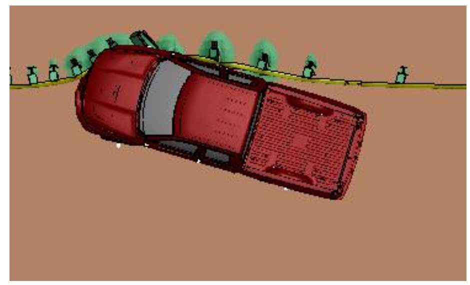

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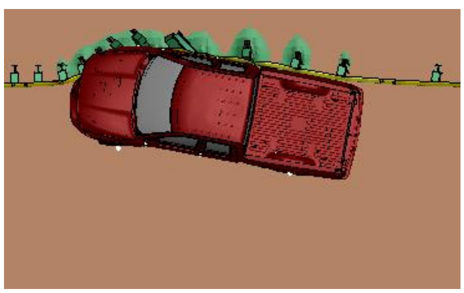

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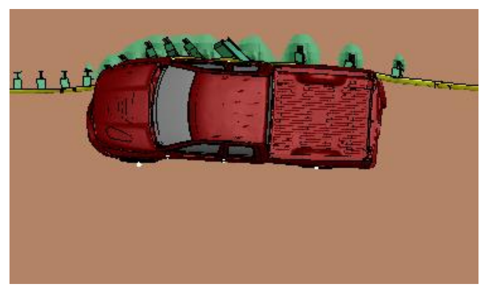

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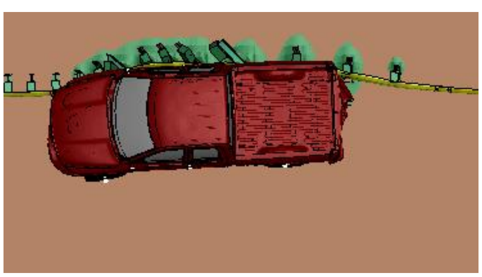

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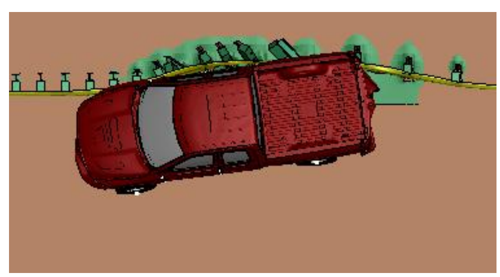

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Figure 6.15. Overhead View Sequential for Longer Transition Simulation.

6.4 SYSTEM DETAILS OF LONGER TRANSITION FROM FULL TO QUARTER POST SPACING

6.4.1 Test Installation Details

The 181 ft-3-inch-long test installation was comprised of a 31-inch high, 12-gauge, 4-space, W-beam guardrail system. The W-beam rail was supported by 72-inch wide-flange posts with 14-inch-tall wood blockouts. TxDOT DATs terminated each end of the guardrail system. Beginning with the upstream DAT, there were four distinct sections of the installation:

1. a 37 ft-6-inch-long section (posts 3 through 9) with full post spacing at 75 inches.
2. a 12 ft-6-inch-long transition section (posts 9 through 13) with half post spacing at 37½ inches.
3. a 62 ft-6-inch-long section (posts 13 through 53) with quarter post spacing at 18¾-inches; and
4. a 43 ft-9-inch-long section (posts 53 through 60) with full post spacing at 75 inches.

In the full post spacing sections, a 10-inch button-head guardrail bolt secured each blockout to a post. In the quarter and half post spacing sections, the bolts secured the rail only at half post spacing. Therefore, no additional slots were cut in the W-beam rail. Additionally, the quarter and half post spacing sections did not have posts bolted to the rail at splice locations. In the full-post spacing sections, the W-beam rails were spliced at midspan between the posts.

The wide-flange posts were embedded 40 inches deep in drilled holes that were backfilled with crushed limestone base and compacted to meet *MASH* strength requirements.

Figure 6.16 presents overall information on the longer transition from full to quarter post spacing, and Figure 6.17 provides photographs of the installation. Appendix L provides further details of the longer transition from full to quarter post spacing.

6.4.2 Design Modifications

Following the failed *MASH* test 3-21 on the transition from full to quarter post spacing, the research team modified the transition with the addition of a post. This was intended to lengthen the transition and minimize the pocketing behavior seen in the failed crash test. The research team evaluated this change through computer simulation. Further discussion on this modification can be found in Section 6.3.

6.4.3 Material Specifications

Appendix B provides material certification documents for the materials used to construct the longer transition from full to quarter post spacing.

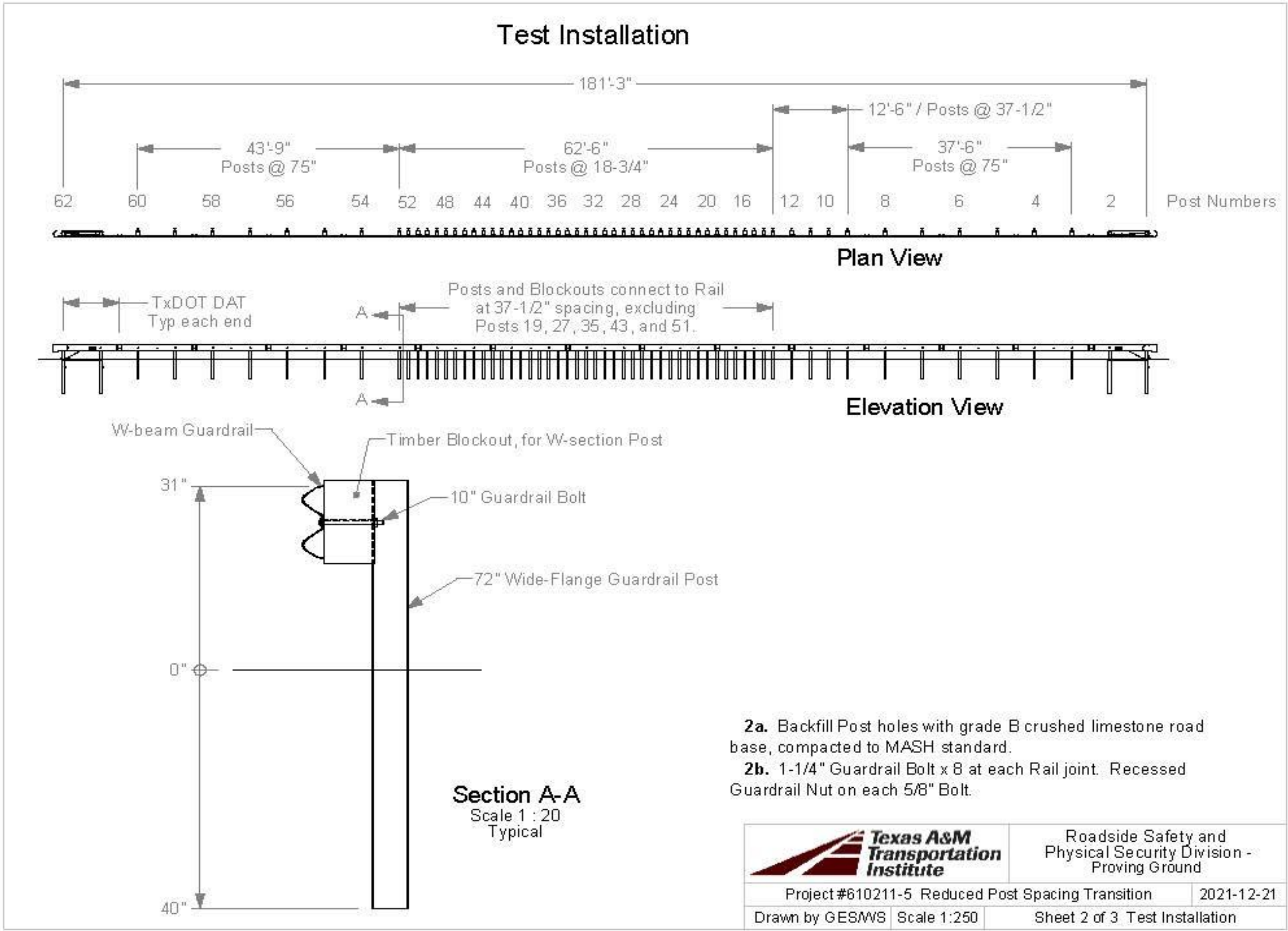

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Figure 6.16. Details of the Longer Transition from Full to Quarter-Post Spacing.

Figure 6.17. MGS with Longer Transition from Full to Quarter Post Spacing prior to Testing.

6.4.4 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 longer transition from full to quarter post spacing for full-scale crash testing, two W6×16 posts were installed in the immediate vicinity of longer transition from full to quarter post spacing 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. 610211-01-5, March 12, 2021, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 7929 lbf, 8787 lbf, and 8484 lbf, respectively. Table C.7 in Appendix C shows the strength of the backfill material in which the longer transition from full to quarter post spacing was installed met minimum *MASH* requirements.

6.5 *MASH* TEST 3-21 (CRASH TEST NO. 610211-01-5) ON LONGER TRANSITION FROM FULL TO QUARTER POST SPACING

6.5.1 Test Designation and Actual Test Conditions

MASH Test 3-21 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the transition at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The CIP for *MASH* Test 3-21 on the longer transition from full to quarter post spacing was 132 inches ±12 inches upstream of post 13 (see Figure 2.5 and Figure 6.18).

Figure 6.18. Transition/Test Vehicle Geometrics for Test No. 610211-01-5.

The 2270P vehicle used in the test weighed 5021 lb, and the actual impact speed and angle were 61.5 mi/h and 25.1 degrees. The actual impact point was 133.5 inches upstream of post 13. Minimum target IS was 106 kip-ft, and actual IS was 114 kip-ft.

6.5.2 Weather Conditions

The test was performed on the morning of March 12, 2021. Weather conditions at the time of testing were as follows: wind speed: 10 mi/h; wind direction: 169 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 74°F; relative humidity: 86 percent.

6.5.3 Test Vehicle

Figures 6.18 and 6.19 show the 2016 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5021 lb, and its gross static weight was 5021 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 28.6 inches. Tables M.1 and M.2 in Appendix M1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system. It was released to be freewheeling and unrestrained just prior to impact.

Figure 6.19. Test Vehicle before Test No. 610211-01-5.

6.5.4 Test Description

Table 6.4 lists events that occurred during Test No. 610211-01-5. Figures M.1 and M.2 in Appendix M2 present sequential photographs during the test.

Table 6.4. Events during Test No. 610211-01-5.

TIME (s)	EVENTS
0.0000	Vehicle impacted the transition
0.0163	Post 10 began to deflect towards the field side
0.0230	Vehicle began to redirect
0.1250	Left front tire lifted off of the pavement
0.1980	Rear bumper contacted the transition
0.2780	Vehicle traveling parallel with transition
0.5820	Vehicle lost contact with transition while traveling at 29.03mi/h, at a trajectory of 19.0 degrees, and a heading of 12.5 degrees
0.7850	Left front tire returned to pavement

For transitions, 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 test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied after the vehicle exited the test site, and the vehicle subsequently came to rest 245 ft downstream of the impact point and in-line with the installation.

6.5.5 Damage to Test Installation

Figure 6.19 through Figure 6.21 show the damage to the installation. The rail released from posts 1 through 8, 11 through 16, and post 18. Post 2 was split in half vertically. Posts 11 through 13 and post 15 were missing their blockouts, and post 16 had only a partial blockout remaining. The debris field of the blockouts extended 58 ft downstream and 35 ft towards the field side. The soil was disturbed at posts 2 through 8 and 19 through 21. Table 6.5 provides additional measurements. Working width was 36.9 inches, and height of working width was 60.7 inches. Maximum dynamic deflection during the test was 23.9 inches, and maximum permanent deformation was 15.0 inches.

6.2.6 Damage to Test Vehicle

Figure 6.22 shows the damage sustained by the vehicle. The front bumper, grill, radiator and support, right front fender, right front tire and rim, right frame rail, right upper and lower control arms, right front and rear doors, right rear exterior bed, and rear bumper were damaged. No damage to the fuel tank was observed. Maximum exterior crush to the vehicle was 16.0 inches in the front plane at the right front corner at bumper height. No occupant compartment deformation or intrusion occurred. Figure 6.23 shows the interior of the vehicle. Tables M.3 and M.4 in Appendix M1 provide exterior crush and occupant compartment measurements.

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 are shown in Table 6.6. Figure 6.24 summarizes these data and other pertinent information from the test. Figure M.3 in Appendix M3 shows the vehicle angular displacements, and Figures M.4 through M.6 in Appendix M4 show accelerations versus time traces.

Figure 6.20. Longer Transition from Full to Quarter Post Spacing after Test No. 610211-01-5.

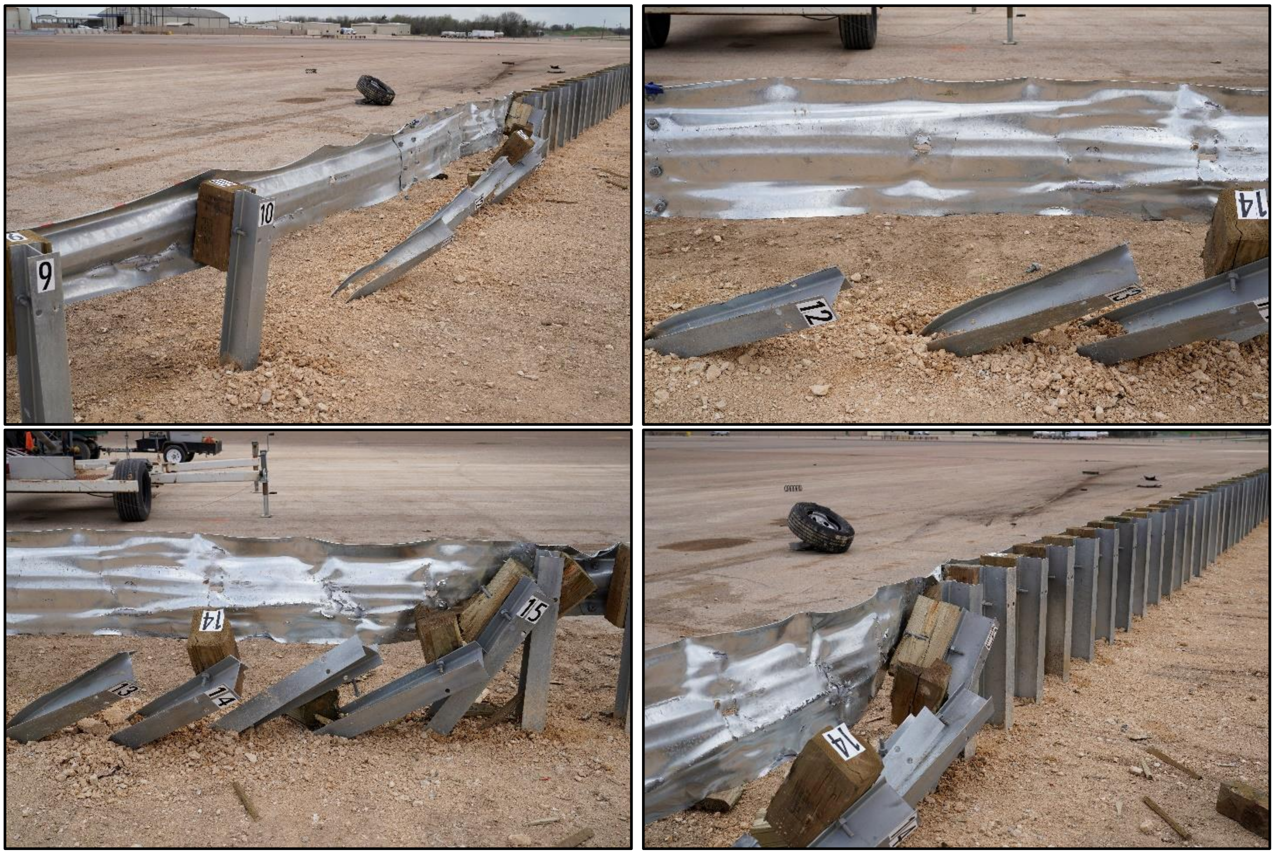


Figure 6.21. Field Side of Longer Transition from Full to Quarter Post Spacing after Test No. 610211-01-5.

Table 6.5. Post Measurements for Test No. 610211-01-5.

	Soil Gap (inches)			Post Lean (from Vertical)		Twist	
Post #	**U/S**	**T/S**	**F/S**	**D/S**	**F/S**	**CW**	**CCW**
1	¾	-	-	5°	-	-	-
9	-	⅛	¼	-	-	-	X
10	-	1¾	1¼	-	6°	-	-
11-16	-	-	-	56°	-	-	-
17	-	-	-	28°	-	-	-
18	-	¼	¼	-	-	X	-

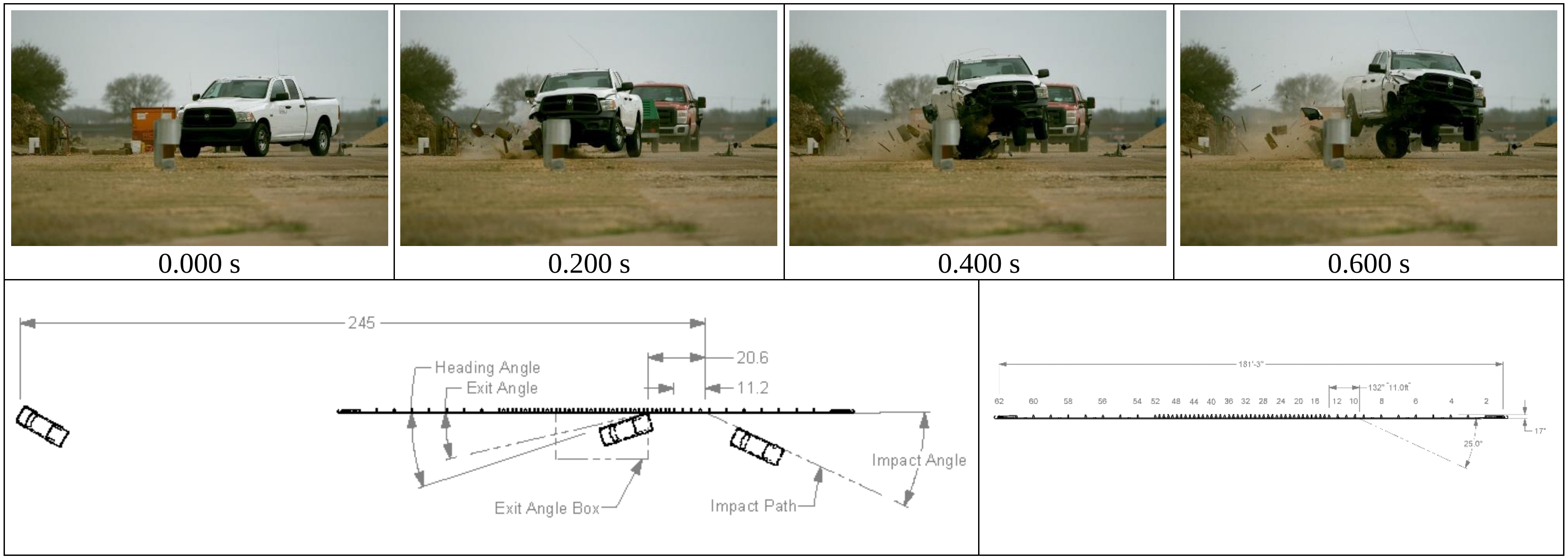
U/S=upstream; T/S= traffic side; F/S=field side; CW=clockwise; CCW=counterclockwise

Figure 6.22. Test Vehicle after Test No. 610211-01-5.

Figure 6.23. Interior of Test Vehicle for Test No. 610211-01-5.

Table 6.6. Occupant Risk Factors for Test No. 610211-01-5.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	**18.0 ft/s**	at 0.1353 s on right side of interior
Lateral	**16.4 ft/s**	
Occupant Ridedown Accelerations		
Longitudinal	**11.1 g**	0.3110 - 0.3210 s
Lateral	**11.1 g**	0.2422 - 0.2522 s
THIV	**7.1 m/s**	at 0.1301 s on right side of interior
ASI	**0.8**	0.0675 - 0.1175 s
Maximum 50-ms Moving Average		
Longitudinal	**-6.4 g**	0.0655 - 0.1155 s
Lateral	**-6.1 g**	0.0410 - 0.0910 s
Vertical	**-2.5 g**	0.9988 - 1.0488 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**13°**	1.1649 s
Pitch	**11°**	1.3871 s
Yaw	**41°**	0.9718 s



General Information
- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: MASH Test 3-21
- TTI Test No.: 610211-01-5
- Test Date: 2021-03-12

Test Article
- Type: Transition
- Name: Longer Transition from Full to Quarter-Post Spacing
- Installation Length: 181 ft-3 inches
- Material or Key Elements: 31-inch-tall Transition from Full to Quarter Post Spacing

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

Test Vehicle
- Type/Designation: 2270P
- Make and Model: 2016 RAM 1500 Pickup
- Curb: 4932 lb
- Test Inertial: 5021 lb
- Dummy: No dummy
- Gross Static: 5021 lb

Impact Conditions
- Speed: 61.5 mi/h
- Angle: 25.1°
- Location/Orientation: 133.5 inches upstream of post 13

Impact Severity: 114 kip-ft

Exit Conditions
- Speed: 29.0 mi/h
- Trajectory/Heading Angle: 19.0°/12.5°

Occupant Risk Values
- Longitudinal OIV: 18.0 ft/s
- Lateral OIV: 16.4 ft/s
- Longitudinal Ridedown: 11.1 g
- Lateral Ridedown: 11.1 g
- THIV: 7.1 m/s
- ASI: 0.8
- Max. 0.050-s Average
  - Longitudinal: -6.4 g
  - Lateral: -6.1 g
  - Vertical: -2.5 g

Post-Impact Trajectory
- Stopping Distance: 245 ft downstream In-line

Vehicle Stability
- Maximum Yaw Angle: 13°
- Maximum Pitch Angle: 11°
- Maximum Roll Angle: 41°

Test Article Deflections
- Dynamic: 23.9 inches
- Permanent: 15.0 inches
- Working Width: 36.9 inches
- Height of Working Width: 60.7 inches

Vehicle Damage
- VDS: 01RFQ5
- CDC: 01FREW4
- Max. Exterior Deformation: 16.0 inches
- OCDI: RF0000000
- Max. Occupant Compartment Deformation: None

Figure 6.24. Summary of Results for *MASH* Test 3-21 on Longer Transition from Full to Quarter Post Spacing.

Chapter 7. SUMMARY OF TEST RESULTS

7.1 ASSESSMENT OF TEST RESULTS

7.1.1 MGS with Quarter Post Spacing

7.1.1.1 MASH Test 3-10 (Crash Test No. 610211-01-1)

The 1100C vehicle was contained and redirected. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 16.4 inches. There were a few detached fragments, however, they did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard for others on the barrier. Maximum occupant compartment deformation was 0.75 inches in the right firewall area. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 14 degrees and 16 degrees, respectively. Occupant risk factors were within the allowable limits specified in *MASH*. The vehicle exited within the exit box. Table 7.1 provides an assessment of these results.

7.1.1.2 MASH Test 3-11 (Crash Test No. 610211-01-2)

The 2270P vehicle was contained and redirected. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 19.5 inches. There were a few detached fragments, however, they did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard for others on the barrier. Maximum occupant compartment deformation was 2.0 inches in the right firewall area. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 16 degrees and 11 degrees, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The vehicle exited within the exit box. Table 7.2 provides an assessment of these results.

7.1.2 MGS with Half Post Spacing

7.1.2.1 Crash Test No. 610211-01-3

The 2270P vehicle penetrated the installation. The guardrail ruptured and the deformed end caused 22.0 inches of deformation to the front center of the vehicle but did not penetrate the occupant compartment. Maximum occupant compartment deformation was 0.5 inch in the right floor pan area. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 31 degrees and 7 degrees, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle penetrated the installation and came to rest on the field side of the installation. Table 7.3 provides an assessment of these results.

7.1.2.2 Crash Test No. 610211-01-6

The 2270P vehicle was contained and redirected. The vehicle did not penetrate, override, or underride the installation. Maximum dynamic deflection of the installation was 25.6 inches. No occupant compartment deformation or intrusion occurred. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 7 degrees and 8 degrees. Occupant risk factors were within the preferred limits specified in *MASH*. The vehicle exited within the exit box. Table 7.4 provides an assessment of these results.

7.1.3 MGS Transition to Quarter Post Spacing

7.1.3.1 Crash Test No. 610211-01-4

The 2270P vehicle penetrated the installation. There were a few detached fragments, however they did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard for others in the area. No deformation or intrusion into the occupant compartment occurred. The 2270P vehicle rolled 90 degrees onto its right side. Occupant risk factors were within the allowable limits specified in *MASH*. The 2270P vehicle penetrated the installation and came to rest on the field side of the guardrail. Table 7.5 provides an assessment of these results.

7.1.3.2 Crash Test No. 610211-01-5

The 2270P vehicle was contained and redirected. The vehicle did not penetrate, override, or underride the installation. Maximum dynamic deflection of the installation was 23.9 inches. No occupant compartment deformation or intrusion occurred. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13 degrees and 11 degrees. Occupant risk factors were within the preferred limits specified in *MASH*. The vehicle exited within the exit box. Table 7.6 provides an assessment of these results.

Table 7.1. Performance Evaluation Summary for *MASH* Test 3-10 on MGS with Quarter Post Spacing.

Test Agency: Texas A&M Transportation Institute | Test No.: 610211-01-1 | Test Date: 2018-10-04

MASH Test 3-10 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> *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 MGS with quarter post spacing contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 16.4 inches.	Pass
<u>Occupant Risk</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	There were a few detached fragments, however, they did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard for 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.	Maximum occupant compartment deformation was 0.75 inches in the right firewall area.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 14 degrees and 16 degrees, 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 33.1 ft/s, and lateral OIV was 22.0 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 was 17.9 g, and maximum lateral occupant ridedown was 18.6 g.	Pass

Table 7.2. Performance Evaluation Summary for *MASH* Test 3-11 on MGS with Quarter Post Spacing.

Test Agency: Texas A&M Transportation Institute | Test No.: 610211-01-2 | Test Date: 2018-10-22

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 MGS with quarter post spacing contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 19.5 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.*	There were a few detached fragments, however they did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard for 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.	Maximum occupant compartment deformation was 2.0 inches in the right firewall area.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 16 degrees and 11 degrees, 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 21.0 ft/s, and lateral OIV was 21.1 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 was 14.5 g, and maximum lateral occupant ridedown was 8.3 g.	Pass

Table 7.3. Performance Evaluation Summary for *MASH* Test 3-11 on MGS with Half Post Spacing.

Test Agency: Texas A&M Transportation Institute | Test No.: 610211-01-3 | Test Date: 2019-02-18

***MASH* Test 3-11 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> *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 MGS with half post spacing did not contain the 2270P vehicle. The vehicle penetrated the installation.	Fail
<u>Occupant Risk</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	The guardrail ruptured and the ruptured end caused 22.0 inches of deformation to the front center of the vehicle, but did not penetrate or deform the occupant compartment.	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.	Maximum occupant compartment deformation was 0.5 inch in the right floor pan.	
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 31 degrees and 7 degrees, 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 17.4 ft/s, and lateral OIV was 17.1 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.	Longitudinal occupant ridedown acceleration was 11.0 g, and lateral occupant ridedown acceleration was 3.5 g.	Pass

Table 7.4. Performance Evaluation Summary for *MASH* Test 3-11 on MGS with Half Post Spacing and Shortened Blockouts.

Test Agency: Texas A&M Transportation Institute	Test No.: 610211-01-6	Test Date: 2021-03-05
***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 MGS with half post spacing and shortened blockouts contained and redirected the 2270P vehicle. The vehicle did not penetrate, override, or underride the installation. Maximum dynamic deflection of the installation was 25.6 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.	There were a few detached fragments, however, they did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard for 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 remained upright during and after the collision event. Maximum roll and pitch angles were 7 degrees and 8 degrees.	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.	Maximum longitudinal OIV was 19.5 ft/s, and lateral OIV was 16.3 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.	Longitudinal occupant ridedown acceleration was 10.3 g, and lateral occupant ridedown acceleration was 8.1 g.	Pass

Table 7.5. Performance Evaluation Summary for *MASH* Test 3-21 on Transition to Quarter Post Spacing.

Test Agency: Texas A&M Transportation Institute — Test No.: 610211-01-4 — Test Date: 2018-11-27

***MASH* Test 3-21 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> *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 MGS with Transition to Quarter Post Spacing did not contain the 2270P vehicle. The vehicle penetrated the installation.	Fail
<u>Occupant Risk</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	There were a few detached fragments, but they did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard for 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 deformation or intrusion into the occupant compartment 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 rolled 90 degrees onto its right 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 19.7 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 was 15.9 g, and maximum lateral occupant ridedown was 4.7 g.	Pass

Table 7.6. Performance Evaluation Summary for *MASH* Test 3-21 on Longer Transition from Full to Quarter Post Spacing.

Test Agency: Texas A&M Transportation Institute | Test No.: 610211-01-5 | Test Date: 2021-03-12

MASH Test 3-21 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 longer transition to quarter post spacing contained and redirected the 2270P vehicle. The vehicle did not penetrate, override, or underride the installation. Maximum dynamic deflection of the installation was 23.9 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.*	There were a few detached fragments, however, they did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard for 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 remained upright during and after the collision event. Maximum roll and pitch angles were 13 degrees and 11 degrees.	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.*	Maximum longitudinal OIV was 18.0 ft/s, and lateral OIV was 16.4 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.*	Longitudinal occupant ridedown acceleration was 11.1 g, and lateral occupant ridedown acceleration was 11.1 g.	Pass

7.2 CONCLUSIONS

7.2.1 MGS with Quarter Post Spacing

Table 7.6 shows the MGS with quarter post spacing performed acceptably according to specifications for *MASH* TL-3 longitudinal barriers.

Table 7.6. Assessment Summary for *MASH* TL-3 Tests on MGS with Quarter Post Spacing.

Evaluation Factors	Evaluation Criteria	Test No. 610211-01-1	Test No. 610211-01-2
Structural Adequacy	A	S	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
	Test No.	***MASH* Test 3-10**	***MASH* Test 3-11**
	Pass/Fail	Pass	Pass

S = Satisfactory
U = Unsatisfactory
N/A = Not Applicable

7.2.2 MGS with Half-Post Spacing

Table 7.7 shows the MGS with half -post spacing did not perform successfully for *MASH* Test 3-11 (Test No. 610211-01-3). However, after modification to the system, the MGS with half-post spacing and shortened blockouts performed acceptably according to specifications for *MASH* Test 3-11 (Test No. 610211-01-6) for longitudinal barriers.

Table 7.7. Assessment Summary for *MASH* TL-3 Tests on MGS with Half-Post Spacing.

Evaluation Factors	Evaluation Criteria	Test No. 610211-01-3	Test No. 610211-01-6 (Shortened Blockouts)
Structural Adequacy	A	U	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
	Test No.	***MASH* Test 3-11**	***MASH* Test 3-11**
	Pass/Fail	Fail	Pass

S = Satisfactory
U = Unsatisfactory
N/A = Not Applicable

7.2.3 Transition from Full to Quarter Post Spacing

Table 7.7 shows the transition from full to quarter post spacing did not perform successfully for *MASH* Test 3-21 (Test No. 610211-01-4). However, after modification to the system, the longer transition from full to quarter post spacing performed acceptably according to specifications for *MASH* Test 3-21 (Test No. 610211-01-5) for longitudinal barriers.

Table 7.8. Assessment Summary for *MASH* TL-3 Tests on MGS with Transition to Quarter Post Spacing.

Evaluation Factors	Evaluation Criteria	Test No. 610211-01-4	Test No. 610211-01-5 (Longer Transition)
Structural Adequacy	A	U	S
Occupant Risk	D	S	S
	F	U	S
	H	S	S
	I	S	S
	Test No.	***MASH* Test 3-21**	***MASH* Test 3-21**
	Pass/Fail	Fail	Pass

S = Satisfactory
U = Unsatisfactory
N/A = Not Applicable

Chapter 8. CONCLUSIONS AND IMPLEMENTATION *

8.1 MGS WITH QUARTER POST SPACING

To evaluate the crashworthiness of longitudinal barriers, *MASH* specifies test 3-11 with a 5000 lb pickup truck and test 3-10 with a 2420 lb small passenger car. In this project, the research team evaluated the MGS with quarter (18¾-inch) post spacing with both *MASH* test 3-11 and 3-10. The MGS with quarter post spacing successfully met the requirements set forth in *MASH* for both tests. Therefore, the research team concluded the MGS with quarter (18¾-inch) post spacing is suitable for implementation as a *MASH* compliant hardware system.

The research team reviewed installation damage and high-speed video to determine recommended installation lengths when shielding hazards with stiffened guardrail. Figure 8.1 shows an overhead view of the post-test installation. The red line designates the length of installation that had noticeable damage after the test. The length of this damaged zone measured approximately 24 ft. The maximum dynamic deflection was 19½ inches measured from pre-impact traffic face of rail to impacted traffic face of rail. This maximum dynamic deflection was located approximately 12 ft downstream of the start of the damaged section shown in Figure 8.1. To accommodate standard guardrail lengths, the 24 ft distance was adjusted to 25 ft. Consequently, the research team recommends installing a minimum of 25 ft of quarter post spacing with the hazard located in the center of this length. This recommendation considers both the primary direction of traffic as well as situations where the shielded hazard is within the clear zone of opposing traffic. The working width was 37.1-inches measured from pre-impact traffic face of rail to furthest extent of a deformed post, and the height of the working width was 27.9 inches above grade. On both the upstream and downstream sides of the quarter post spacing, the research team recommends transitioning to full post spacing using the transition discussed below in Section 8.3 and terminating the system with a *MASH* compliant terminal or downstream anchor terminal as appropriate.

Figure 8.1. Width of Noticeable Damaged Section of Quarter Post Spacing System

* The opinions/interpretations identified/expressed in this section of the report are outside the scope of TTI Proving Ground's A2LA Accreditation.

8.2 MGS WITH HALF POST SPACING

In this project, the research team modified the half (37½-inch) post spacing system to include shortened 10-inch tall blockouts. For crashworthiness evaluation, the research team performed *MASH* test 3-11 on the half post spacing system with shortened blockouts. This system successfully met the requirements set forth in *MASH* test 3-11. Based on previous crash testing, *MASH* test 3-10 was considered less critical and unnecessary. The successful containment and redirection of the 5000 lb pickup truck in *MASH* test 3-11 demonstrated this system would have the structural capacity to contain and redirect the 2420 lb small car under *MASH* test 3-10 impact conditions. Furthermore, both full (75-inch) and quarter (18¾-inch) post spacing guardrail systems have successfully passed *MASH* test 3-10. The full post spacing test was performed by TTI in 2010 (*3*), and the quarter post spacing system test is reported herein and discussed above in Section 8.1. Since these two tests bracket the stiffness of the half post spacing system, it is expected that a small car impact on the half post spacing system would also be successful. These two *MASH* tests 3-10 were performed with installations utilizing a standard 14-inch vertical height wood blockouts, instead of the newly evaluated 10-inch vertical height used for the half post spacing system. However, the research team concluded this would not negatively influence the outcome of a small car impact. This shortened height was utilized to minimize potential for rail rupture during the pickup truck impact. The small car impact imparts significantly less load to the rail because of the decreased mass, so the potential for rail rupture is even further reduced. Additionally, the research team concluded the shortened blockout would not cause snagging concerns during an impact. The MGS system successfully met *MASH* test 3-10 criteria without blockouts (*4*), with quarter post spacing (reported herein), and with full post spacing with 8-inch deep blockouts (*3*). These systems resulted in different degrees of wheel overlap and wheel snagging that either bracket or are more critical and severe than the wheel overlap and snagging expected for the half post spacing system with shortened blockouts. Consequently, the research team concluded the MGS with half (37½-inch) post spacing is suitable for implementation as a *MASH* compliant hardware system.

The research team reviewed installation damage and high-speed video to determine recommended installation length when shielding hazards with stiffened guardrail. Figure 8.2 shows an overhead view of the post-test installation. The red line designates the length of installation that had noticeable damage after the test. The length of this damage zone measured approximately 35 ft. The maximum dynamic deflection was 25.6 inches measured from pre-impact traffic face of rail to impacted traffic face of rail. The maximum dynamic deflection was located approximately 17 ft downstream of the start of the damaged section shown in Figure 8.2. To accommodate standard guardrail lengths, the 35-feet distance was adjusted to 37½-ft. Consequently, the research team recommends installing a minimum of 37½-ft of half post spacing with the hazard located in the center of this length. This recommendation considers both the primary direction of traffic as well as situations where the shielded hazard is within the clear zone of opposing traffic. The working width was 43.1 inches measured from pre-impact traffic face of rail to furthest extent of a damaged post, and the height of the working width was at a height of 10.1 inches above grade. On both the upstream and downstream sides of the half post spacing, the research team recommends transitioning to full post spacing using the transition discussed below in Section 8.4 and terminating the system with a *MASH* compliant terminal or downstream anchor terminal as appropriate.

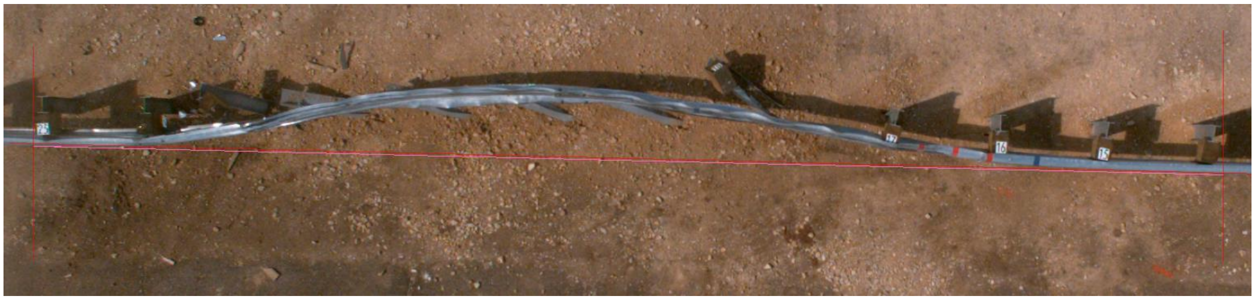


Figure 8.2. Width of Noticeable Damaged Section of Half Post Spacing System

8.3 TRANSITION FROM FULL TO QUARTER POST SPACING

In this project, the research team evaluated a transition from full post spacing to quarter post spacing with four spaces of 37½ inches. This transition utilizes the standard 14-inch vertical height blockout instead of the 10-inch vertical height blockout used in the half post spacing test.

To evaluate this system, the research team performed *MASH* test 3-21 on the transition from full to quarter post spacing with an additional post. This system successfully met the requirements set forth in *MASH* test 3-21. *MASH* indicates that test 3-20 is optional unless there is "reasonable uncertainty regarding the impact performance of the system for impacts with small passenger vehicles" (*1*). Tests performed with the small passenger car are intended to evaluate snagging and other occupant risk metrics. With the successful small car test on the quarter post spacing system (discussed above in Section 8.1), the research team evaluated a system that was stiffer and had higher potential for snagging during a small car impact. Furthermore, a successful *MASH* test 3-10 was completed on a MGS without blockouts by the Midwest Roadside Safety Facility (MwRSF) in 2013 (*4*). Despite different test numbers, the impact conditions for *MASH* tests 3-10 and 3-20 are the same, a 2420 lb passenger car impacting the test article at a speed of 62 mi/h and 25 degrees. These systems provide more critical conditions based upon snagging concerns with a small car impact. Therefore, the research team concluded this transition would also perform successfully under *MASH* test 3-10 impact conditions. Consequently, the research team concluded the transition with the additional post is suitable for implementation as a *MASH* compliant hardware system.

8.4 TRANSITION FROM FULL TO HALF POST SPACING

The research team recommends transitioning between full and half post spacing by simply ending the full post spacing section and beginning the half post spacing section. No further transition is necessary. Transitions are implemented because crashworthiness issues may arise when barrier installations have changes in stiffness. If the change in stiffness is too abrupt, "pocketing" of the impacting vehicle can result, which can subsequently lead to rail rupture or vehicle instability. The larger the difference in stiffness, the higher the concern for pocketing. When comparing the change in stiffness between a full to quarter post spacing system and a full to half post spacing system, the full to quarter post spacing system has a larger change in stiffness. This leads to a higher concern for pocketing of an impacting vehicle. Because of this concern, the research team concluded the more critical transition to evaluate through full-scale testing was the transition from full to quarter post spacing, rather than the transition from full to half post spacing.

In *MASH* test 3-21 of the transition from full to quarter post spacing discussed above in Section 8.3, the pickup truck impacted the test installation in the half post spacing section and headed downstream into the quarter post spacing section. This test successfully met *MASH* criteria. The change in stiffness between the quarter and half post spacing section is the same as the change in stiffness between a full and half post spacing section. In both cases, you are reducing the post spacing in half or doubling the number of posts. Because the pickup truck was successfully redirected by a transition with the same relative change in stiffness as would be seen in a full to half post spacing transition, the research team concluded this full to half post spacing transition would successfully meet *MASH* criteria.

The research team also concluded *MASH* test 3-20 was not necessary. *MASH* indicates that test 3-20 is optional unless there is "reasonable uncertainty regarding the impact performance of the system for impacts with small passenger vehicles" (*1*). Tests performed with the small passenger car are intended to evaluate snagging and other occupant risk metrics. With the successful small car test on the quarter post spacing system (discussed above in Section 8.1), the research team evaluated a system that was stiffer and had higher potential for snagging during a small car impact. Furthermore, a successful *MASH* test 3-10 was completed on a MGS without blockouts by MwRSF in 2013 (*4*). Despite different test numbers, the impact conditions for *MASH* tests 3-10 and 3-20 are the same, a 2,420 lb passenger car impacting the test article at a speed of 62 mi/h and 25 degrees. These systems provide more critical conditions based upon snagging concerns with a small car impact. Therefore, the research team concluded this transition would also perform successfully under *MASH* test 3-10 impact conditions. Based on this analysis, the research team concluded the transition between full and half post spacing is suitable for implementation as a *MASH* compliant hardware system.

REFERENCES

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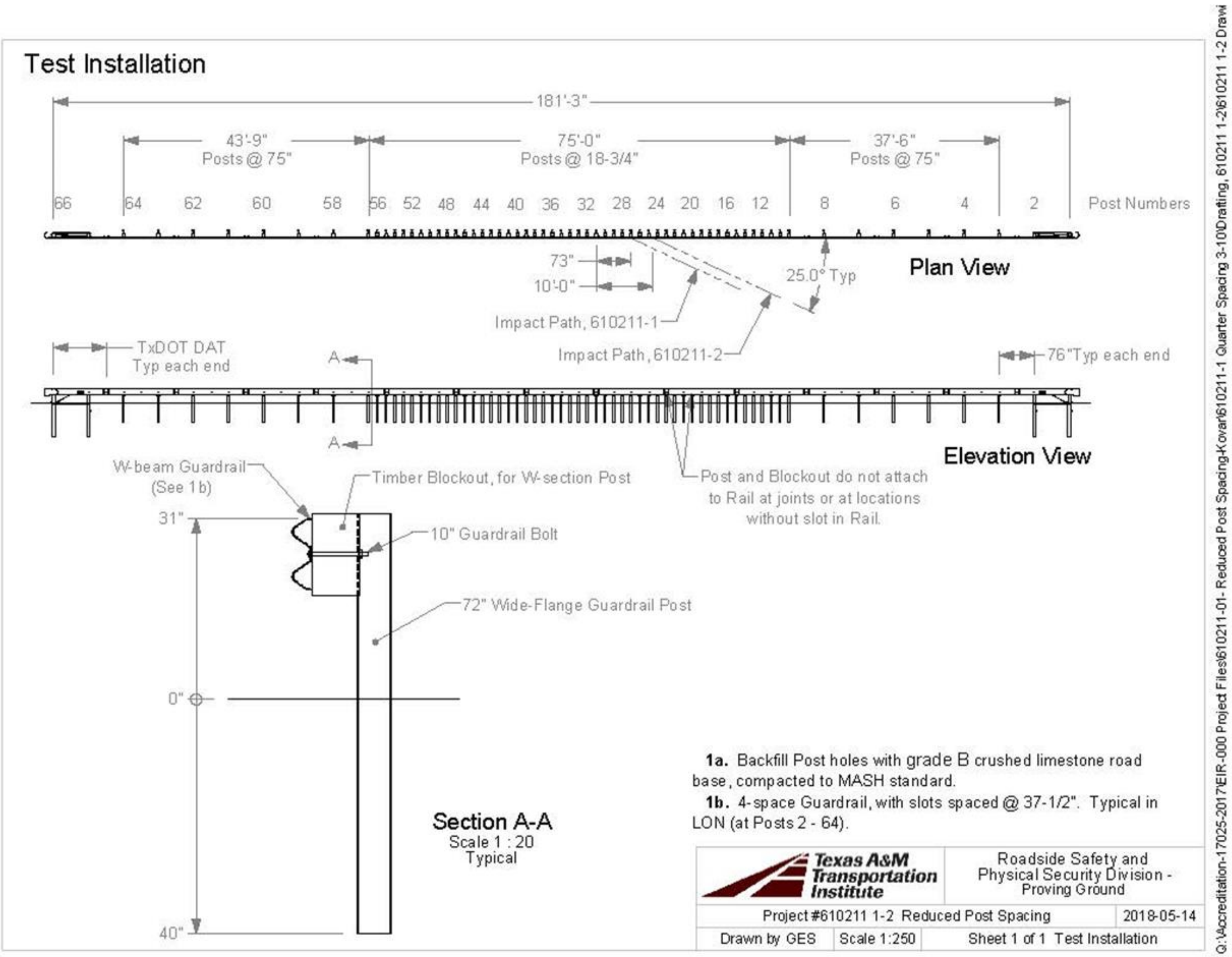
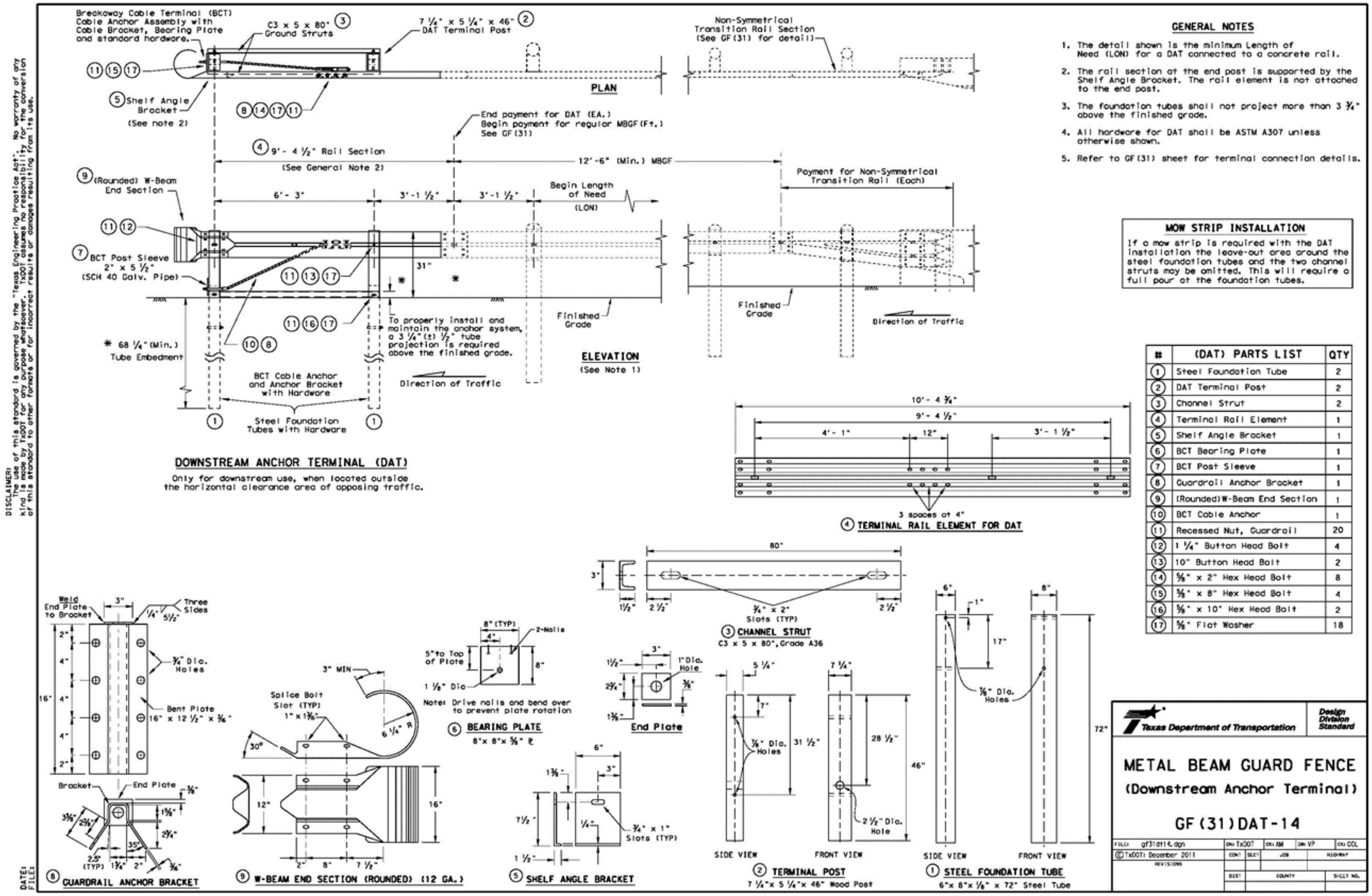
2. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, B.W., and Reid, J.D. *Performance Evaluation of the Midwest Guardrail System– Update to NCHRP 350 Test No. 3-11 with 28" C.G. Height (2214MG-2).* Midwest Roadside Safety Facility, Lincoln, Nebraska, 2006. https://mwrsf.unl.edu/researchhub/files/Report149/TRP-03-171-06.pdf

3. Bligh, R.P., Abu-Odeh, A.Y., and Menges, W.L. *MASH Test 3-11 on the 31-inch W-Beam Guardrail with Standard Offset Blocks.* Texas A&M Transportation Institute, College Station, Texas, 2010. https://www.roadsidepooledfund.org/wp-content/uploads/2016/10/420020-5_Report.pdf.

4. Schrum, K.D., Lechtenberg, K.A., Bielenberg, R.W., Rosenbaugh, S.K., Faller, R.K., Reid, J.D., and Sicking, D.L. *Safety Performance Evaluation of the Non-Blocked Midwest Guardrail System (MGS)* Midwest Roadside Safety Facility, Lincoln, Nebraska, 2013. https://www.roadsidepooledfund.org/wp-content/uploads/2016/10/TRP-03-262-12.pdf.


Test Installation
181'-3"
43'-9"
Posts @ 75"
75'-0"
Posts @ 18-3/4"
37'-6"
Posts @ 75"
66 64 62 60 58 56 52 48 44 40 36 32 28 24 20 16 12 8 6 4 2
Post Numbers
73"
10'-0"
25.0° Typ
Plan View
Impact Path, 610211-1
Impact Path, 610211-2
TxDOT DAT
Typ each end
A
76"Typ each end
A
Elevation View
W-beam Guardrail
(See 1b)
Timber Blockout, for W-section Post
Post and Blockout do not attach
to Rail at joints or at locations
without slot in Rail.
31"
10" Guardrail Bolt
72" Wide-Flange Guardrail Post
0"
1a. Backfill Post holes with grade B crushed limestone road base, compacted to MASH standard.
1b. 4-space Guardrail, with slots spaced @ 37-1/2". Typical in LON (at Posts 2 - 64).
Section A-A
Scale 1 : 20
Typical
Texas A&M Transportation Institute
Roadside Safety and
Physical Security Division -
Proving Ground
Project #610211 1-2 Reduced Post Spacing
2018-05-14
40"
Drawn by GES
Scale 1:250
Sheet 1 of 1 Test Installation
Q:\Accreditation-17025-2017\EIR-000 Project Files\610211-01- Reduced Post Spacing-Kovar\610211-1 Quarter Spacing 3-10\Drafting, 610211 1-2\610211 1-2 Drawi



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 of 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

Texas Department of Transportation — Design Division Standard

METAL BEAM GUARD FENCE

(Downstream Anchor Terminal)

GF(31)DAT-14

FILE: gf31dt14.dgn · ©TxDOT: December 2011

SPECIFICATIONS

W-beam and thrie-beam guardrail posts shall be manufactured using AASHTO M 270 / M 270M (ASTM A 709 / A 709M) Grade 36 [250] steel unless corrosion-resistant steel is required, in which case the post shall be manufactured from AASHTO M 270 / M 270M (ASTM A 709 / A 709M) Grade 50W [345W] steel. The dimensions of the cross-section shall conform to a W6x9 [W150x13.5] section as defined in AASHTO M 160 / M 160M (ASTM A 6 / A 6M). [W150x12.6] wide flange posts are an acceptable alternative that is considered equivalent to the [W150x13.5].

After the section is cut and all holes are drilled or punched, the component should be zinc-coated according to AASHTO M 111 (ASTM A 123) unless corrosion-resistant steel is used. When corrosion-resistant steel is used, the portion of the post to be embedded in soil shall be zinc-coated according to AASHTO M 111 (ASTM A 123) and the portion above the soil shall not be zinc-coated, painted or otherwise treated.

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]
PWE01-04	2.63 [1.7]	16.43 [6.84]	2.19 [0.91]	5.57 [91.2]	1.11 [18.2]

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

Posts PWE01 and PWE02 are used with the SGR04a and SGR04c guardrails and the SGM04a median barrier. Blockouts like PWB01 (steel) or PDB01 (wood) are attached to each post.

Post PWE03 is used with the SGR09a guardrail and the SGM09a median barrier. Wood or plastic blockouts like the PWB02 are attached to each post with FBB03 bolts and FWC16a washers under the nuts.

Post PWE04 is used with the SGR09b guardrail and the SGM09b median barrier. A modified steel blockout PWB03 is attached to each post with at least two 1.5-inch [40 mm] long FBX16a bolts and nuts.

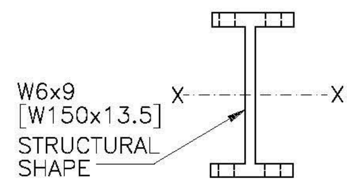
WIDE-FLANGE GUARDRAIL POST

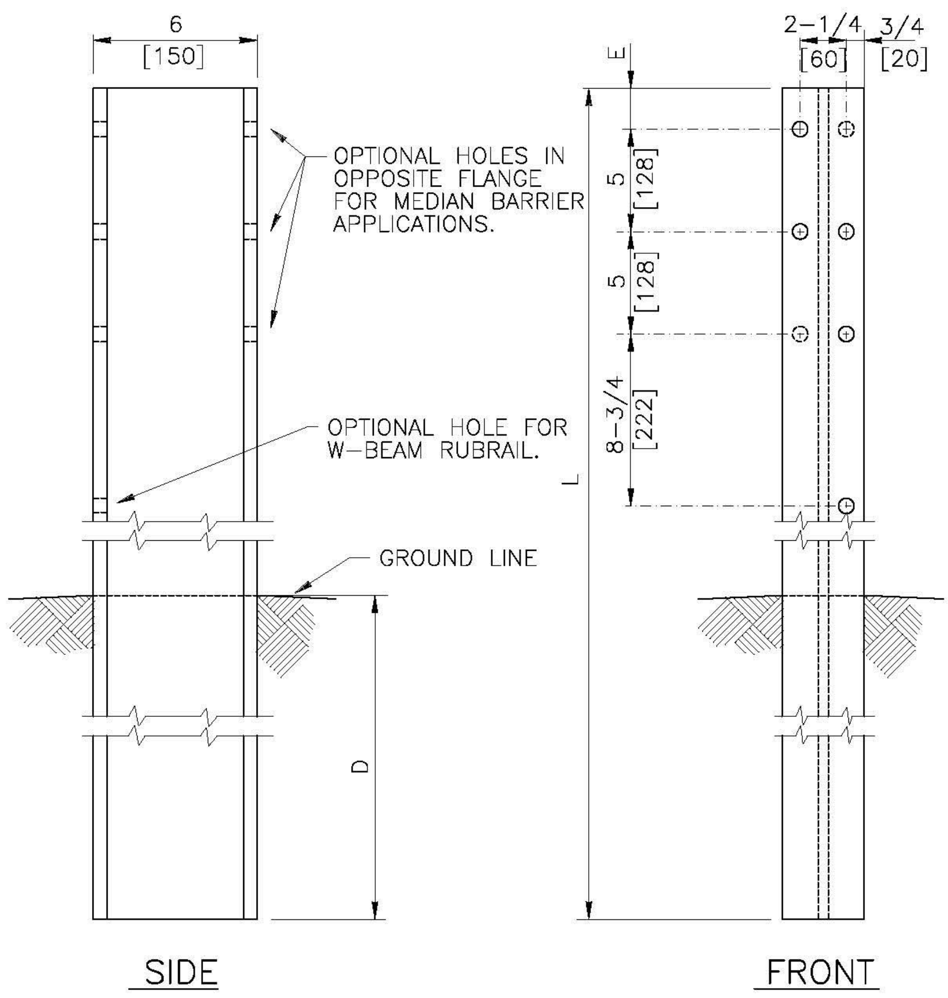
PWE01-04

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

DESIGNATOR	L	D	E
PWE01	72 [1830]	43-1/4 [1100]	2 [52]
PWE02	78 [1980]	49-1/4 [1250]	2 [52]
PWE03	78 [1980]	45-3/8 [1153]	5-7/8 [149]
PWE04	81 [2060]	46-1/8 [1173]	5-7/8 [149]

NOTE: ALL HOLES ARE 3/4 [20] D.





1994

WIDE-FLANGE GUARDRAIL POST

PWE01-04	
SHEET NO.	DATE:
1 of 2	7/27/2005

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.

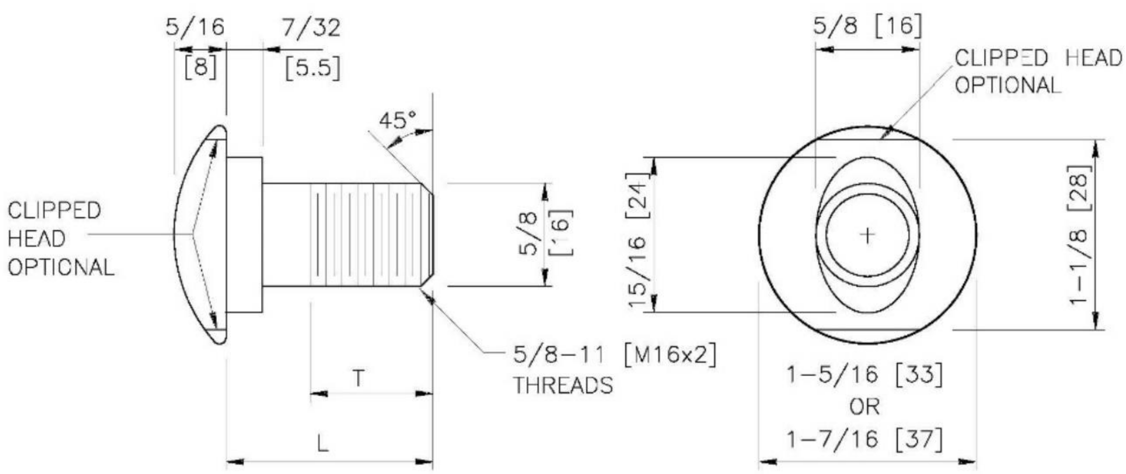
INTENDED USE

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

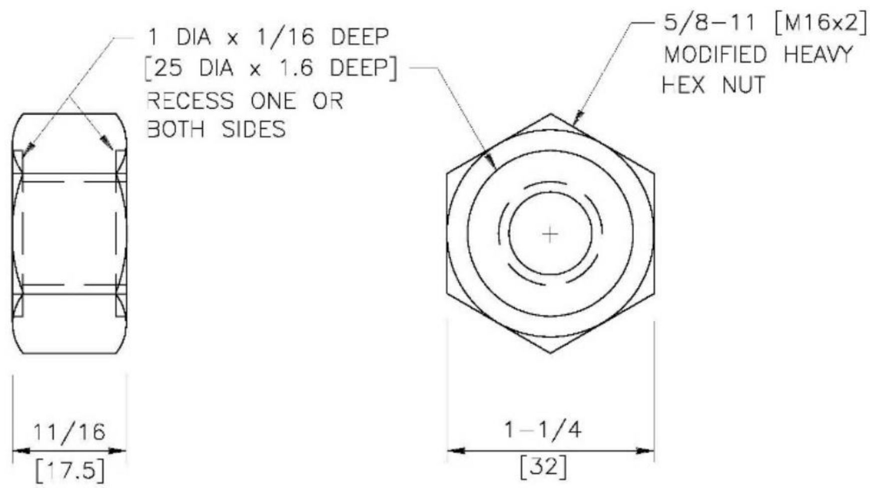
GUARDRAIL BOLT AND RECESSED NUT

FBB01-05	
SHEET NO.	DATE
2 of 2	5/2/2018

NOTES: 1. ALL FILLETS SHALL HAVE A VINIMUM 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 [32]	1-1/8 [28]
FBB02	2 [51]	1-3/4 [44]
FBB03	10 [254]	4 [102]
FBB04	18 [457]	4 [102]
FBB05	25 [635]	4 [102]



GUARDRAIL BOLT AND RECESSED NUT

FBB01-05

SHEET NO.	DATE:
1 of 2	5/2/2018

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.

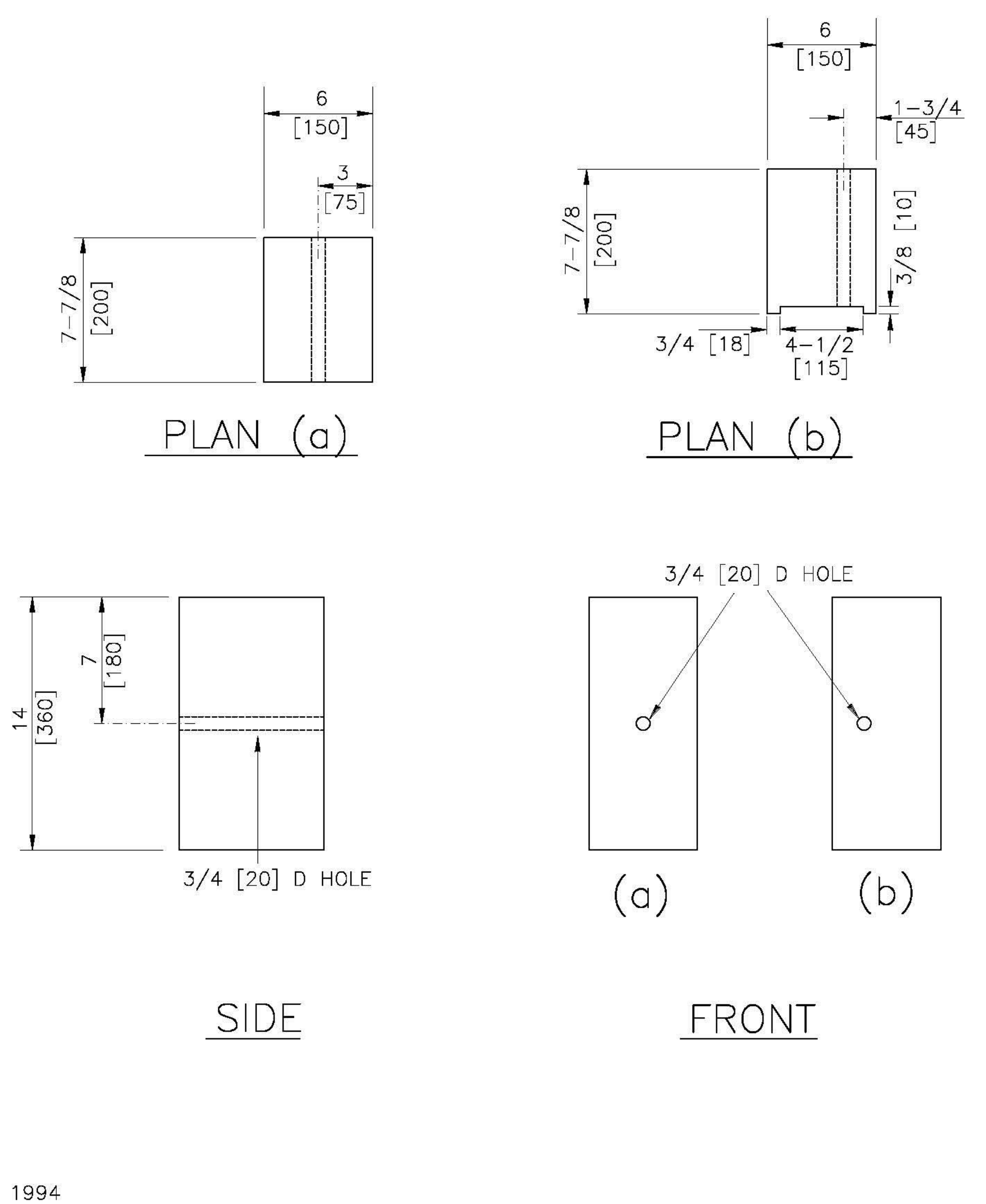
INTENDED USE

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



W-BEAM TIMBER BLOCKOUT

PDB01a-b		
SHEET NO.	DATE:	
1 of 2	6/30/2005	

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.

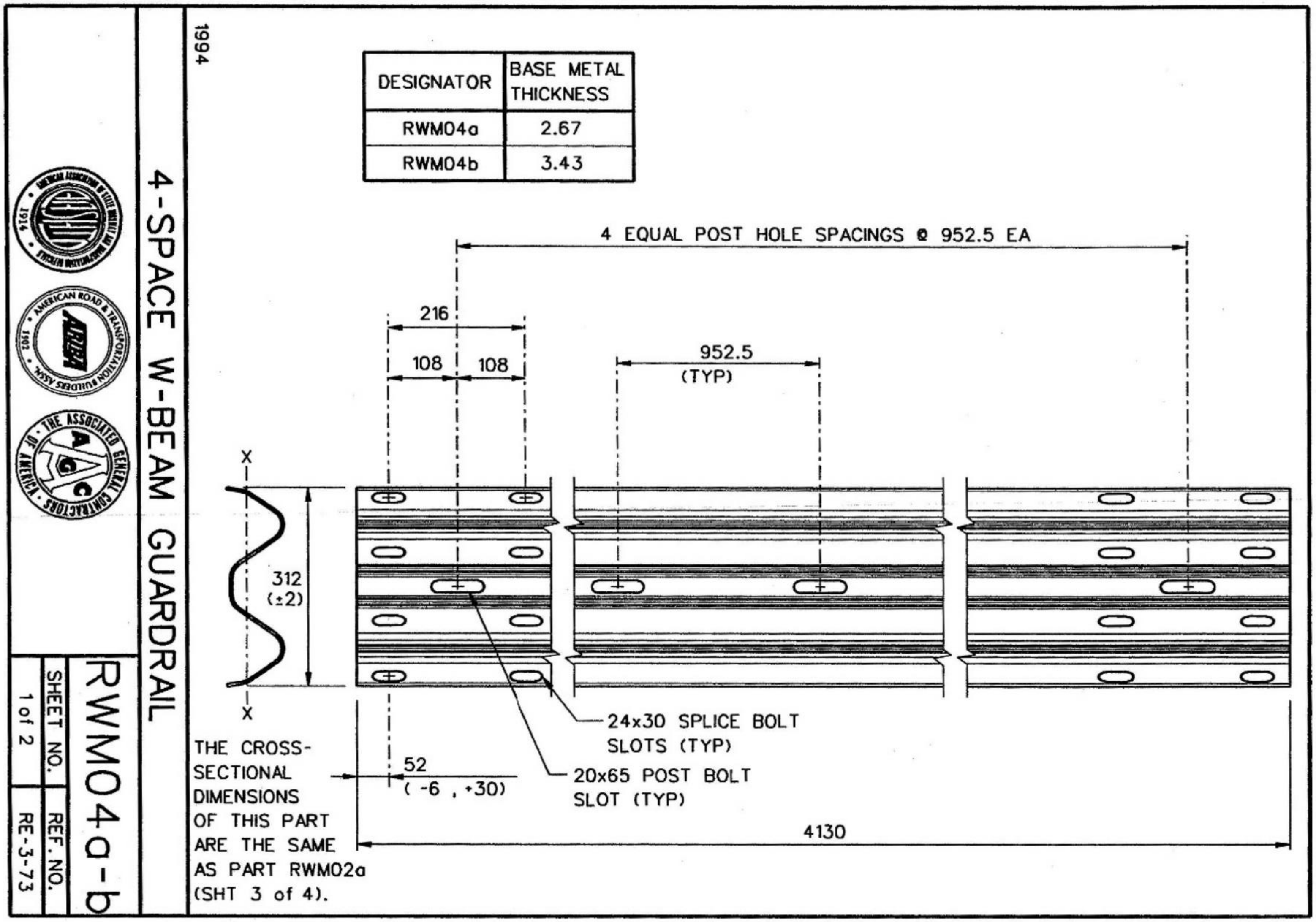
INTENDED USE

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


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

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: TEXAS A&M TRANSPORTATION INSTI
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Project: TEXAS DOT ROUND POST TEST

Order Number: 1299315 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TX DOT RD PST
BOL Number: 73117 Ship Date: 8/29/2018
Document #: 1
Shipped To: TX
Use State: TX

As of: 9/10/18

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
55	11G	12/12'6/3'1.5/S	RHC		2	L10518													4
			M-180	A	2	221964	62,660	81,850	26.0	0.200	0.720	0.011	0.004	0.020	0.130	0.000	0.070	0.000	4
			M-180	A	2	221967	60,810	79,990	26.5	0.180	0.760	0.012	0.004	0.020	0.120	0.000	0.070	0.002	4
			M-180	A	2	222039	61,590	79,770	24.0	0.190	0.720	0.011	0.003	0.020	0.110	0.000	0.060	0.002	4
			M-180	A	2	222040	63,720	83,580	23.6	0.200	0.740	0.013	0.005	0.020	0.100	0.001	0.060	0.000	4
			M-180	A	2	222041	61,320	80,430	22.8	0.190	0.720	0.011	0.006	0.010	0.120	0.000	0.060	0.000	4
	11G				2	F13018													
			M-180	A	2	1183716	53,400	76,400	24.0	0.200	0.770	0.007	0.000	0.030	0.120	0.004	0.050	0.004	4
			M-180	A	2	1282848	57,200	78,000	21.0	0.190	0.770	0.005	0.003	0.020	0.060	0.002	0.040	0.003	4
			M-180	A	2	1283649	57,400	83,100	22.0	0.190	0.770	0.006	0.001	0.030	0.110	0.004	0.040	0.004	4
			M-180	A	2	1283650	50,400	75,100	25.0	0.200	0.770	0.007	0.001	0.020	0.110	0.004	0.040	0.004	4
	11G				2	F13418													
			M-180	A	2	1183716	53,400	76,400	24.0	0.200	0.770	0.007	0.000	0.030	0.120	0.004	0.050	0.004	4
			M-180	A	2	1184166	60,900	84,200	25.0	0.220	0.760	0.006	0.001	0.030	0.070	0.000	0.030	0.004	4
			M-180	A	2	1283649	57,400	83,100	22.0	0.190	0.770	0.006	0.001	0.030	0.110	0.004	0.040	0.004	4
			M-180	A	2	1283650	50,400	75,100	25.0	0.200	0.770	0.007	0.001	0.020	0.110	0.004	0.040	0.004	4
			M-180	A	2	1283651	58,400	79,200	25.0	0.190	0.770	0.006	0.002	0.020	0.110	0.005	0.040	0.004	4
			M-180	A	2	1284097	51,500	73,600	26.0	0.220	0.780	0.006	0.003	0.020	0.080	0.001	0.050	0.004	4
			M-180	A	2	1183716	53,400	76,400	24.0	0.200	0.770	0.007	0.000	0.030	0.120	0.004	0.050	0.004	4
			M-180	A	2	1184166	60,900	84,200	25.0	0.220	0.760	0.006	0.001	0.030	0.070	0.000	0.030	0.004	4
			M-180	A	2	1283649	57,400	83,100	22.0	0.190	0.770	0.006	0.001	0.030	0.110	0.004	0.040	0.004	4
			M-180	A	2	1283650	50,400	75,100	25.0	0.200	0.770	0.007	0.001	0.020	0.110	0.004	0.040	0.004	4
			M-180	A	2	1283651	58,400	79,200	25.0	0.190	0.770	0.006	0.002	0.020	0.110	0.005	0.040	0.004	4
			M-180	A	2	1284097	51,500	73,600	26.0	0.220	0.780	0.006	0.003	0.020	0.080	0.001	0.050	0.004	4
1	119013B	CUSTOM161"MFTGR.PALL	HW			10909													

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: TEXAS A&M TRANSPORTATION INSTI
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Project: TEXAS DOT ROUND POST TEST

Order Number: 1299315 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TX DOT RD PST T
BOL Number: 73117 Ship Date: 8/29/2018
Document #: 1
Shipped To: TX
Use State: TX

As of: 9/10/18

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)
FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 10th day of September, 2018 .

Notary Public:
Commission Expires:

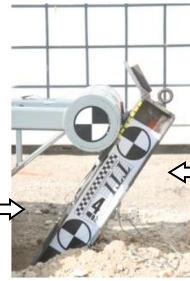
JOMARY LUGINSLAND
Notary Public, State of Texas
My Commission Expires
May 28, 2019

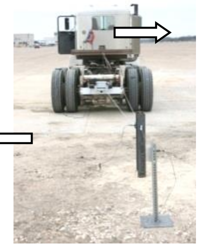
Certified By: Trinity Highway Products, LLC
Quality Assurance

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

Dynamic Setup

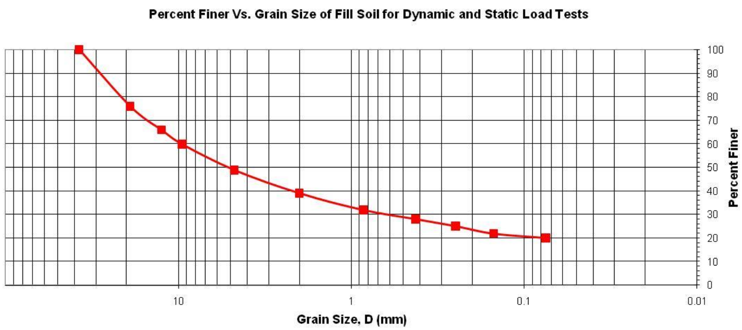
Post-Test Photo of post



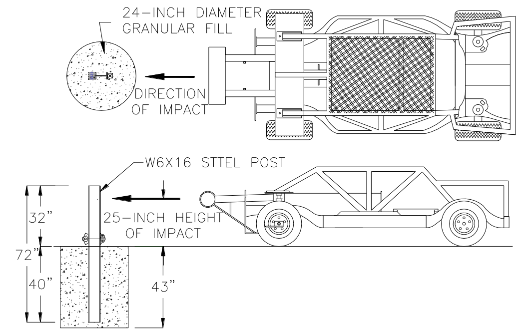


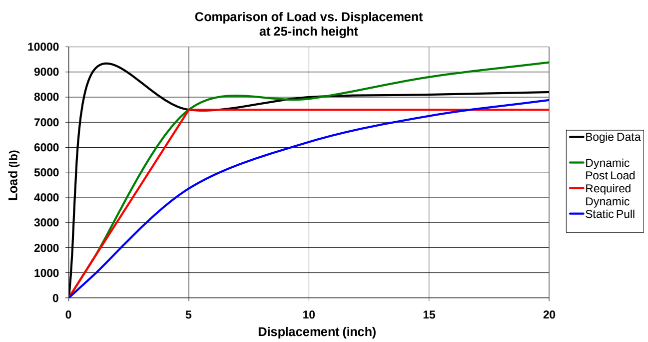
Post-Test Photo

Static Load Test

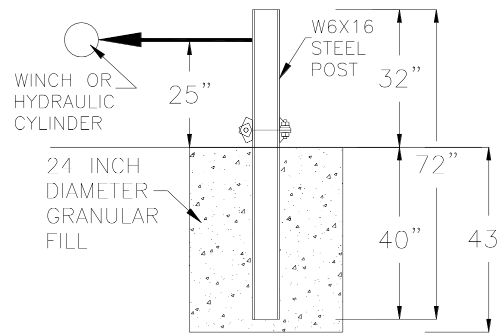


Dynamic Test Installation Details



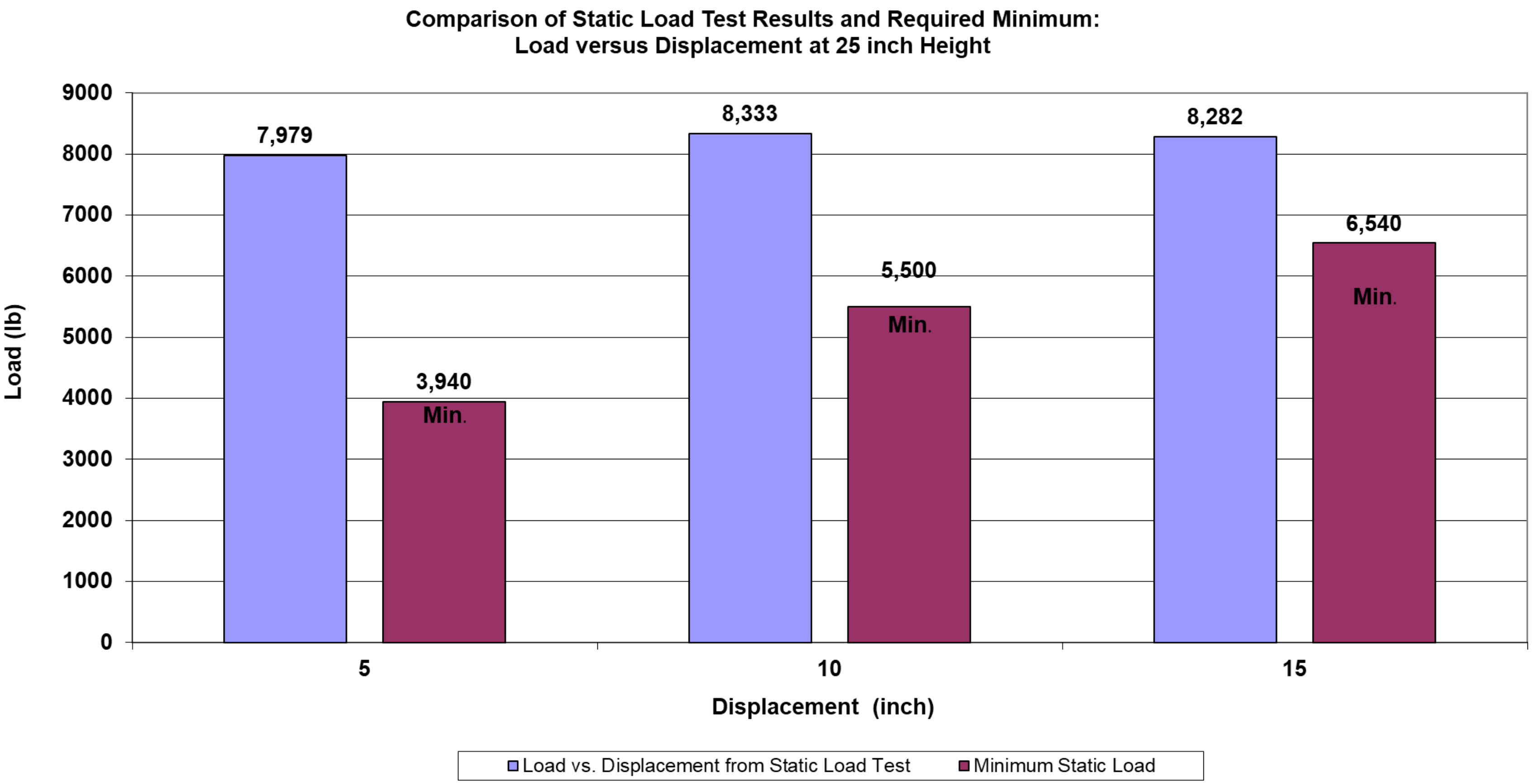


Static Load Test Installation Details



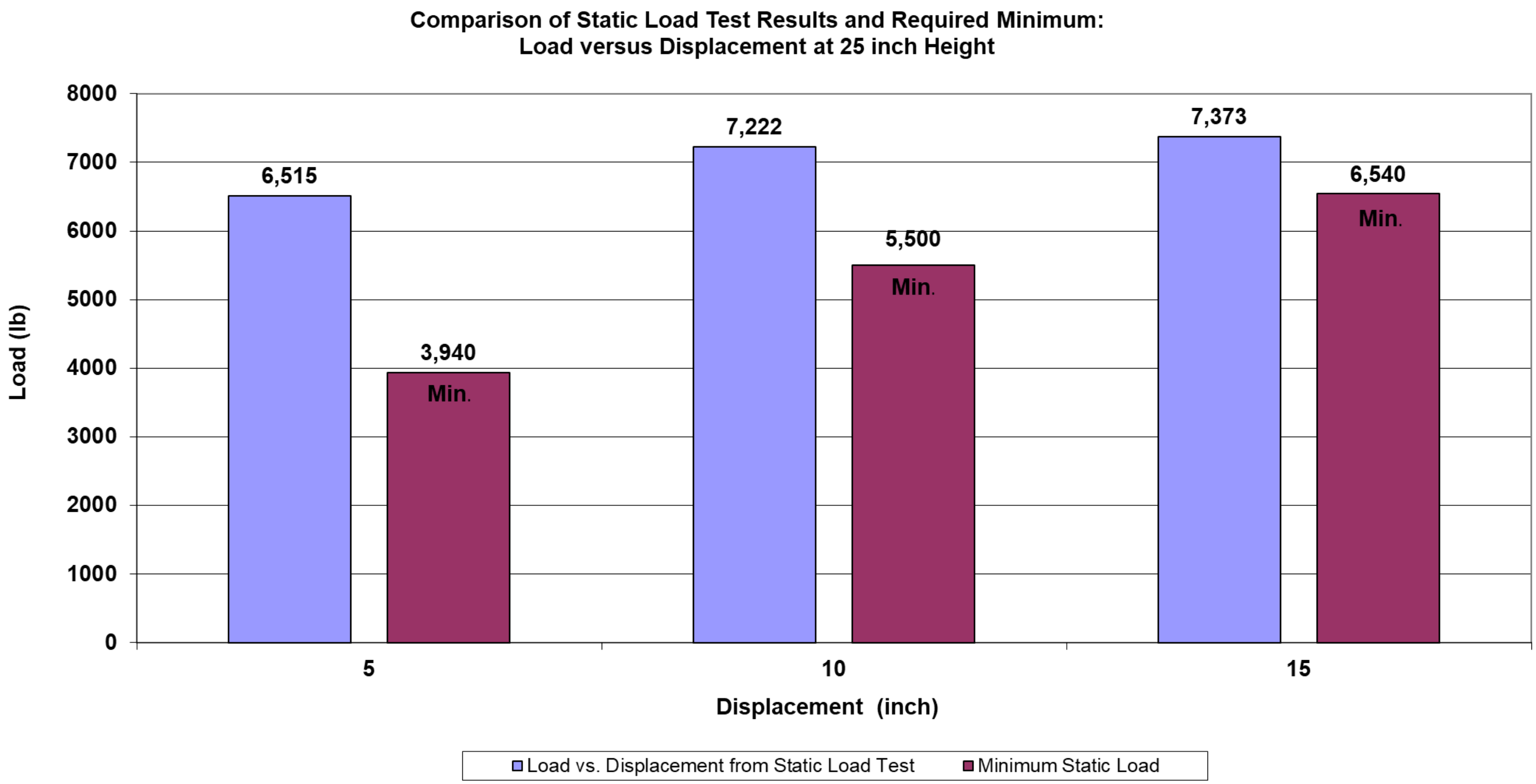
Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement 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. 610211-01-1.



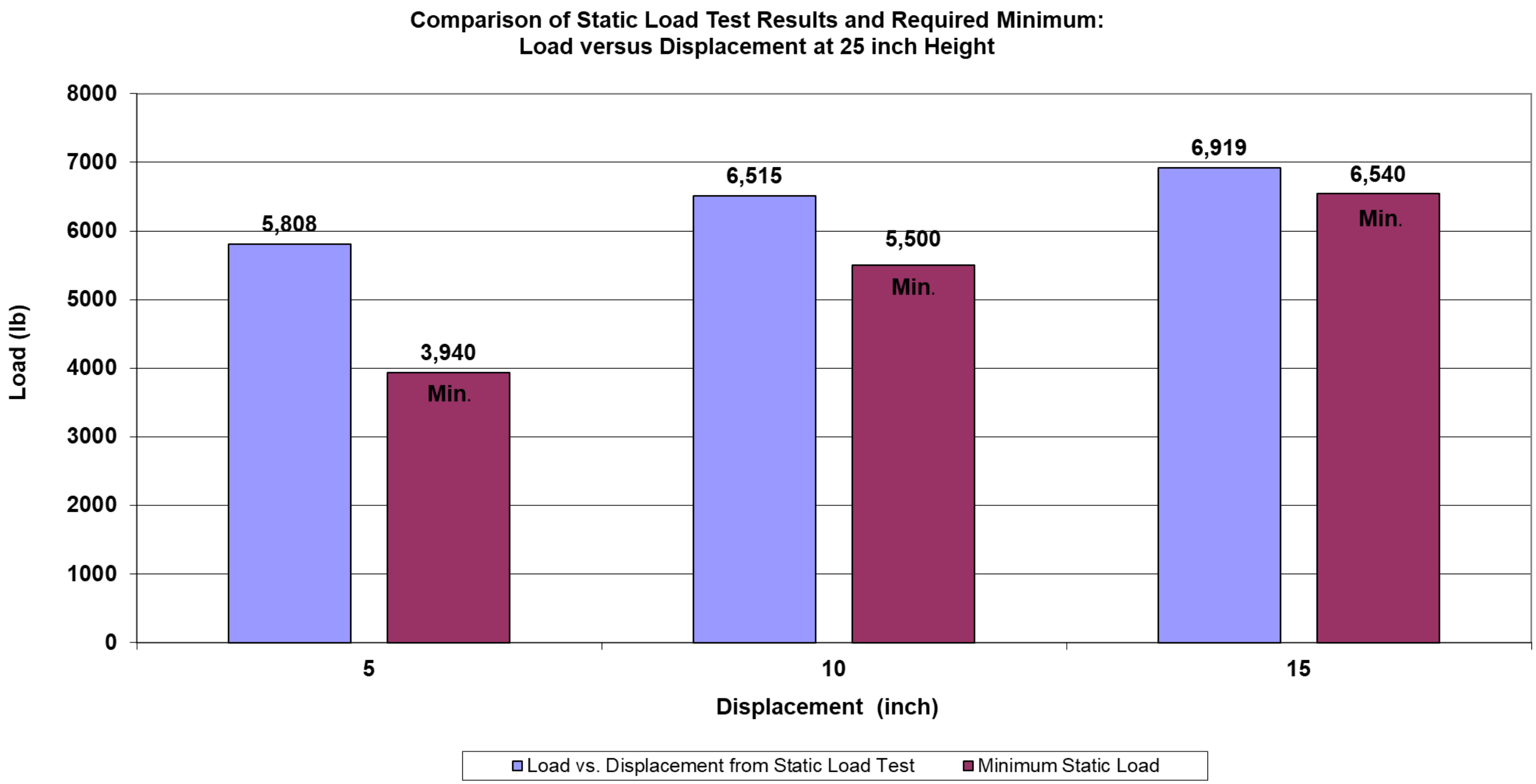
Date	2018-10-04 – Test No. 610211-01-1
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.3. Test Day Static Soil Strength Documentation for Test No. 610211-01-2.



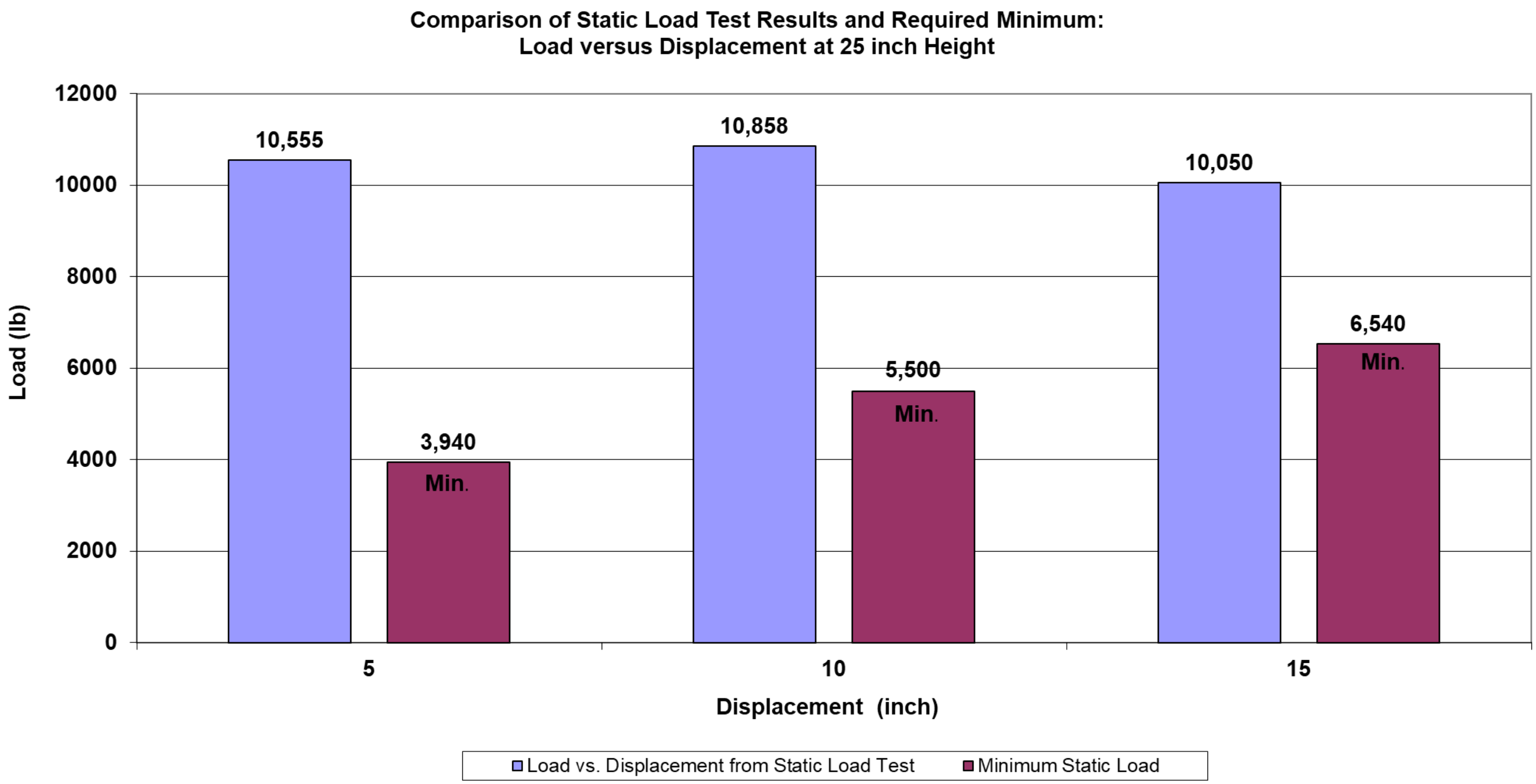
Date	2018-10-22 – Test No. 610211-01-2
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.4. Test Day Static Soil Strength Documentation for Test No. 610211-01-3.



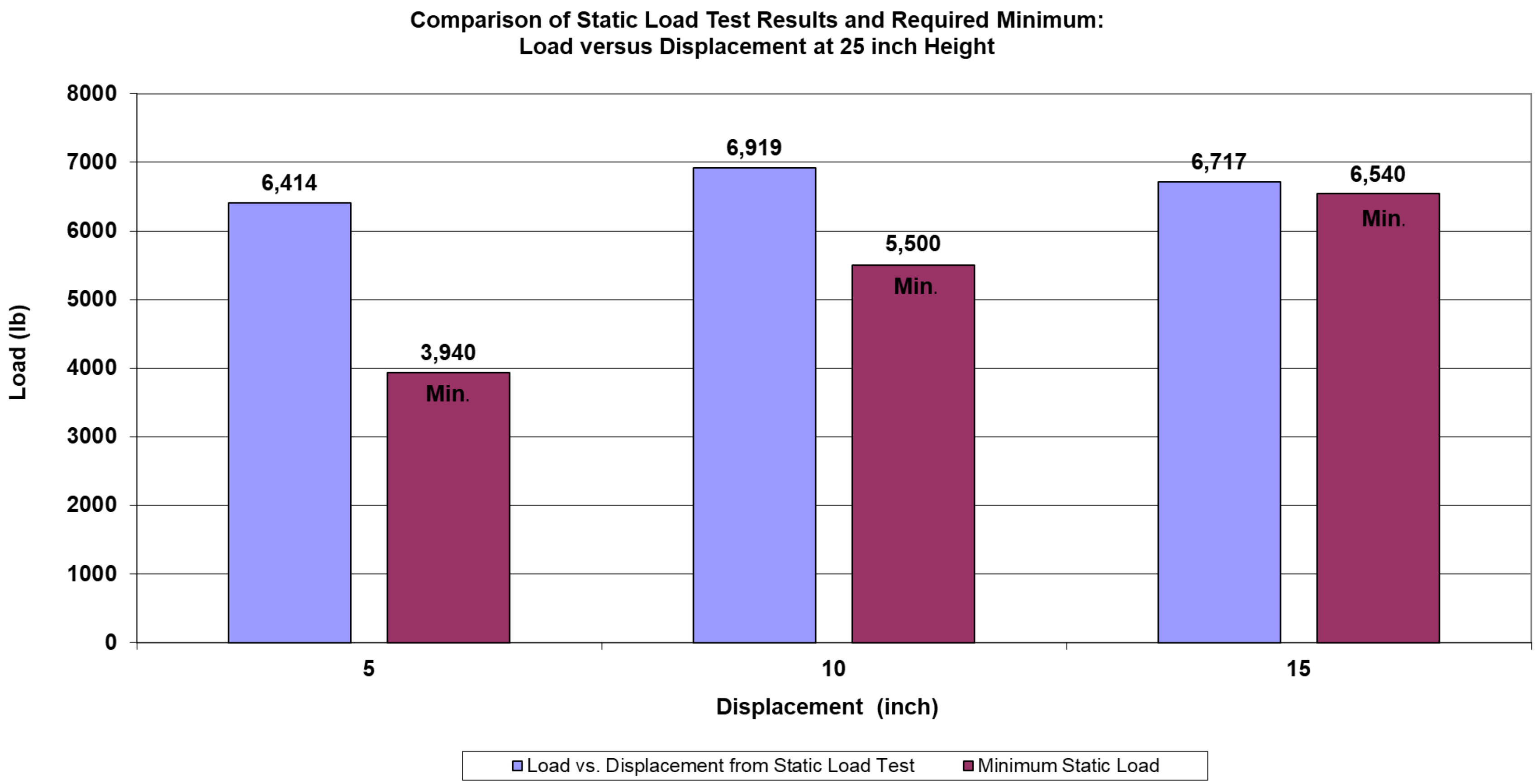
Date	2019-02-18 – Test No. 610211-01-3
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.5. Test Day Static Soil Strength Documentation for Test No. 610211-01-6.



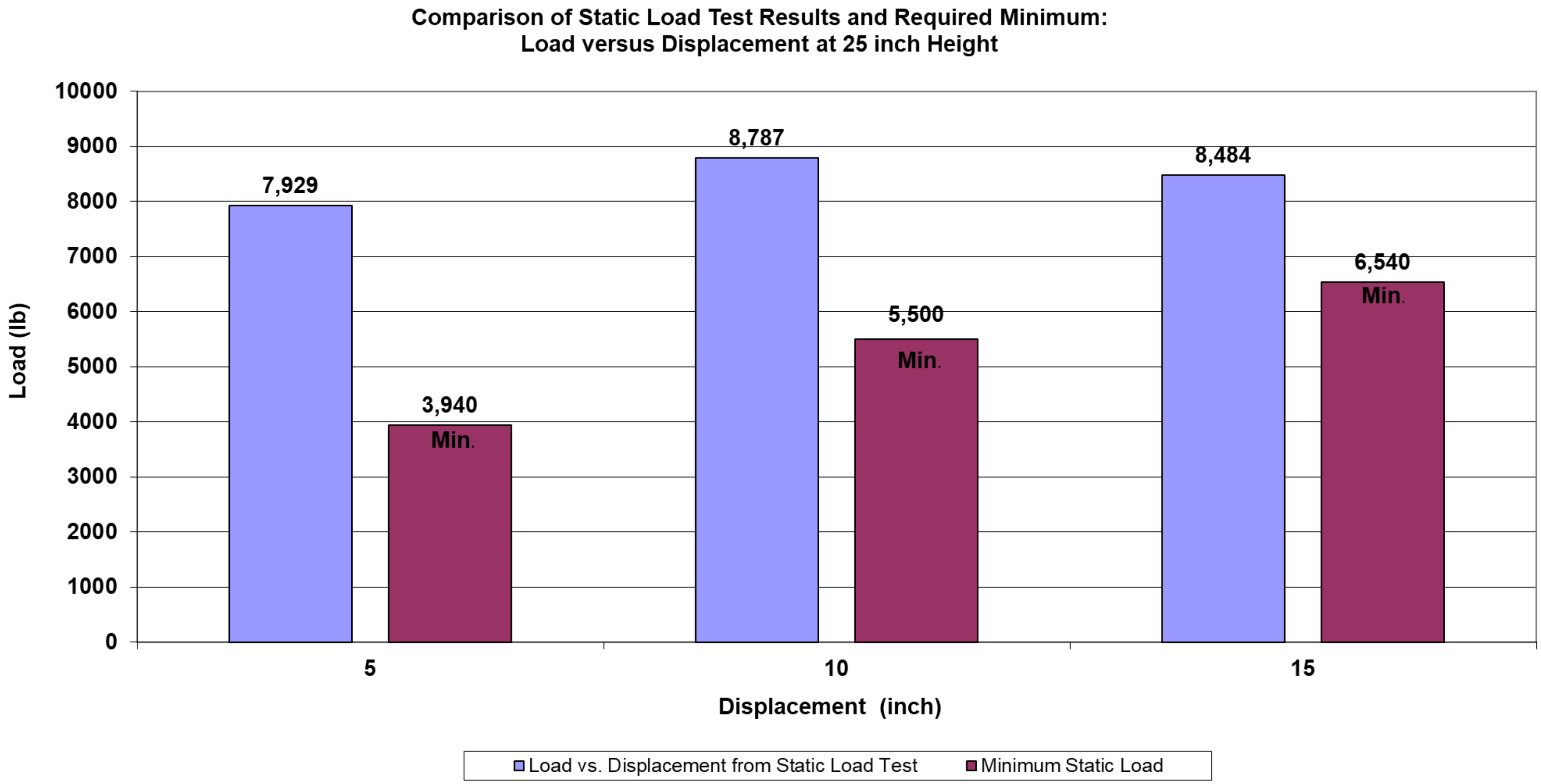
Date	2021-03-05 – Test No. 610211-01-6
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.6. Test Day Static Soil Strength Documentation for Test No. 610211-01-4.



Date	2018-11-27– Test No. 610211-01-4
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.7. Test Day Static Soil Strength Documentation for Test No. 610211-01-5.



Date	2021-03-12 – Test No. 610211-01-5
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. 610211-01-1)

D1 VEHICLE PROPERTIES AND INFORMATION

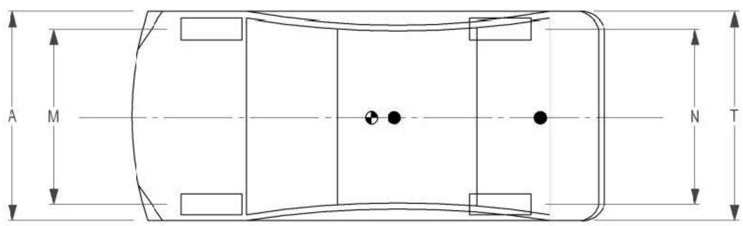
Table D.1. Vehicle Properties for Test No. 610211-01-1.

Date:	2018-10-04	Test No.:	610211-01-1	VIN No.:	KNADH4A38A6622688
Year:	2010	Make:	Kia	Model:	Rio
Tire Inflation Pressure:	32 psi	Odometer:	141706	Tire Size:	185/65R14

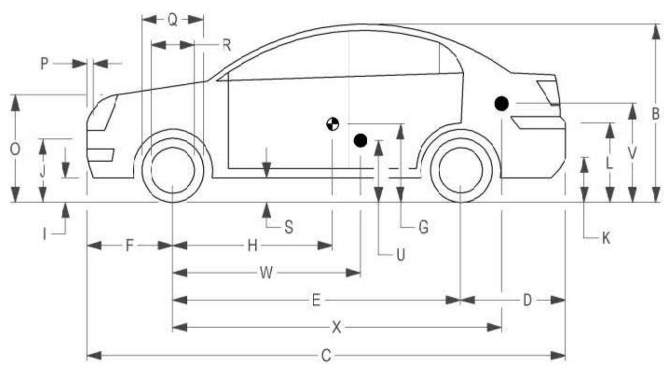
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None



Engine Type: 4 cylinder
Engine CID: 1.6 L
Transmission Type:
☑ Auto or ☐ Manual
☑ FWD ☐ RWD ☐ 4WD
Optional Equipment:



Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Impact Side

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	20.25
C	165.75	H	35.75	M	57.75	R	15.50	W	35.75
D	34.00	I	7.75	N	57.70	S	8.25	X	101.50
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 0.00

RANGE LIMIT: A = 65 ±3 inches; C = 168 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; G = 39 ±4 inches; O = TOP OF RADIATOR SUPPORT ~~(24 ±4 inches)~~; M+N/2 = 56 ±2 inches; W-H < 2 inches or use MASH Paragraph A4.3.2

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1718	M_{front}	1597	1565	1650
Back	1874	M_{rear}	865	888	968
Total	3638	M_{Total}	2462	2453	2618

Allowable TIM = 2420 lb ±55 lb | Allowable GSM = 2585 lb ± 55 lb

Mass Distribution:

lb	LF:	778	RF:	787	LR:	423	RR:	465

Table D.2. Exterior Crush Measurements for Test No. 610211-01-1.

Date:	2018-10-04	Test No.:	610211-01-1	VIN No.:	KNADH4A38A6622688
Year:	2010	Make:	Kia	Model:	Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FT BUMPER	12	11	16	--	--	--	--	--	--	-22
2	ABOVE FT BUMPER	12	15.5	34	2	8	11	12.5	14	15.5	+60
	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.

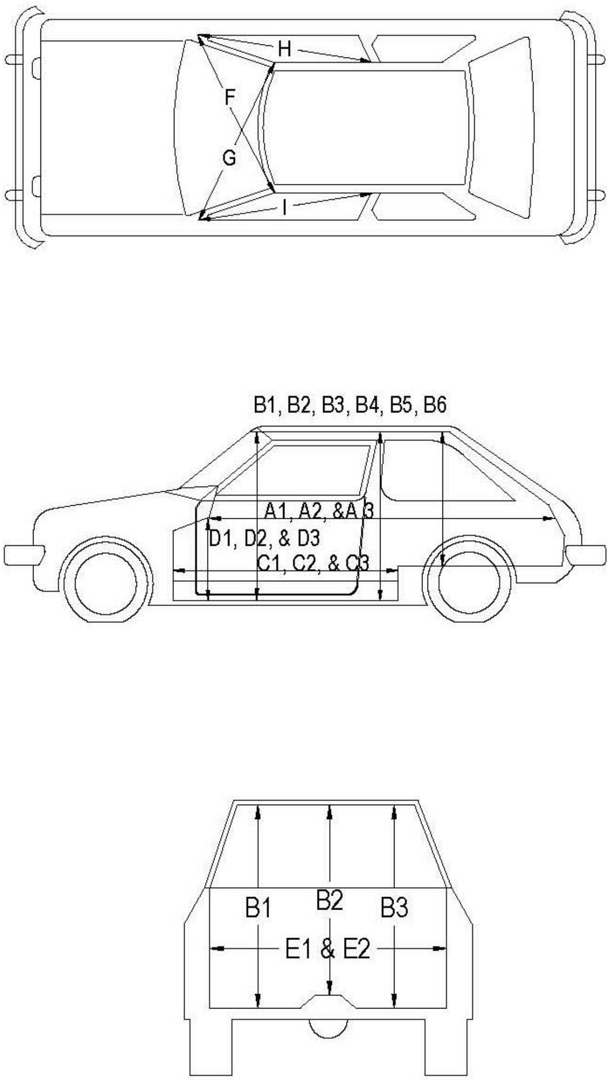
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 D.3. Occupant Compartment Measurements for Test No. 610211-01-1.

Date:	2018-10-04	Test No.:	610211-01-1	VIN No.:	KNADH4A38A6622688
Year:	2010	Make:	Kia	Model:	Rio

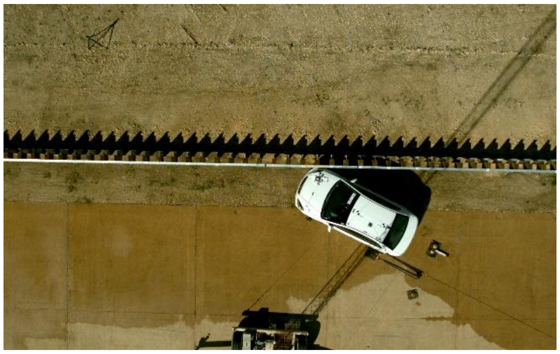


OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

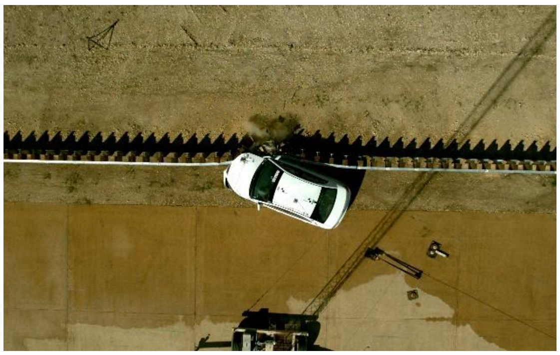
	Before	After (inches)	Differ.
A1	67.50	67.50	0.00
A2	67.25	67.25	0.00
A3	67.75	67.75	0.00
B1	40.50	40.50	0.00
B2	39.00	39.00	0.00
B3	40.50	40.25	-0.25
B4	36.25	36.25	0.00
B5	36.00	36.00	0.00
B6	36.25	36.25	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	25.25	-0.75
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	9.25	-0.25
E1	51.50	51.50	0.00
E2	51.00	51.25	0.25
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	51.00	51.00	0.00

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

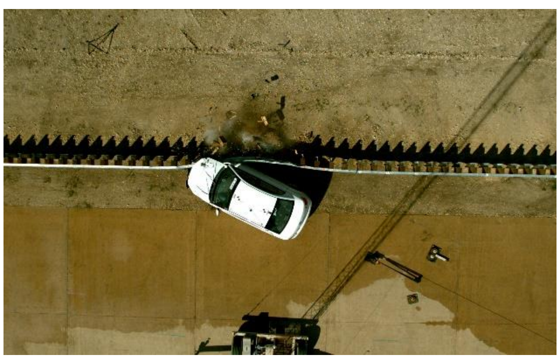
D2 SEQUENTIAL PHOTOGRAPHS



0.000 s



0.100 s



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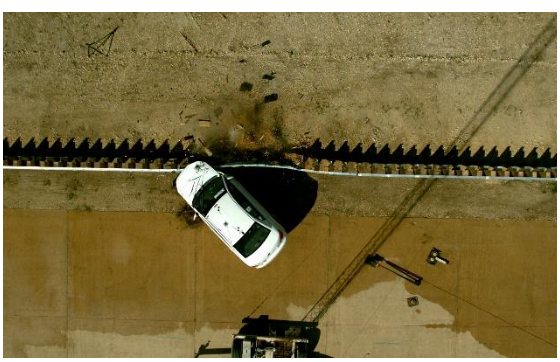
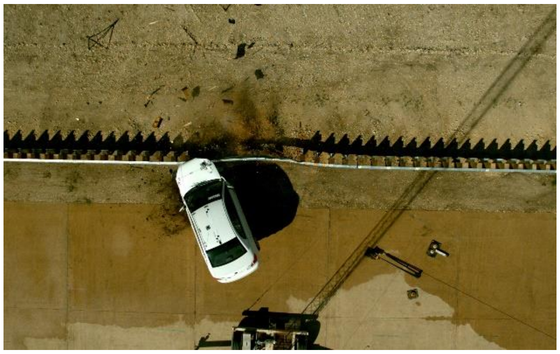
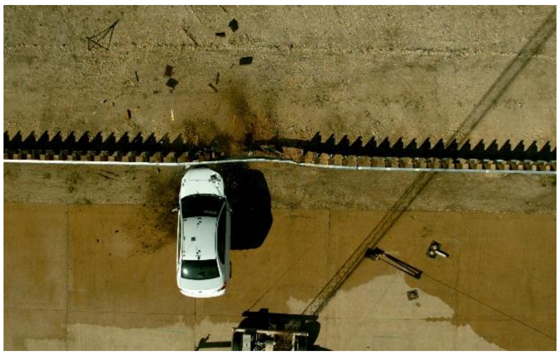


0.300 s

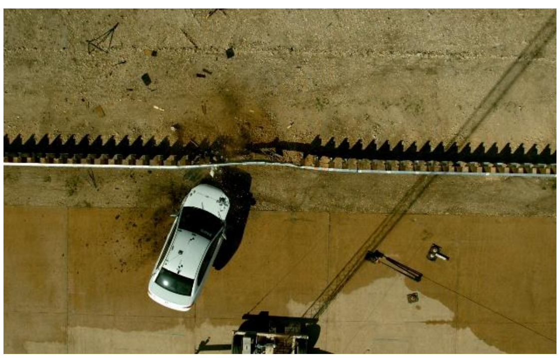
Figure D.1. Sequential Photographs for Test No. 610211-01-1 (Overhead and Frontal Views).



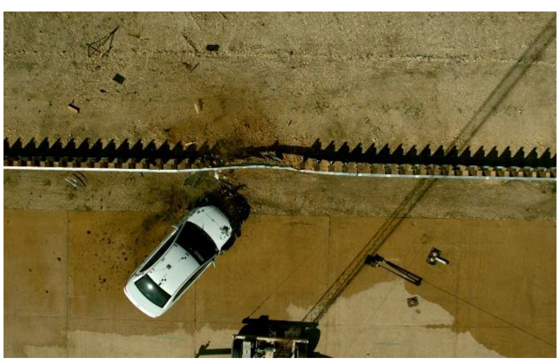
0.400 s



0.500 s



0.600 s

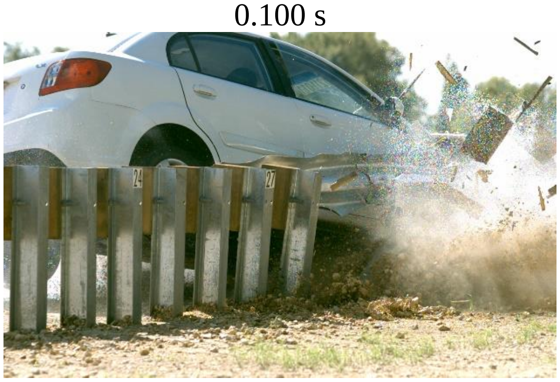


0.700 s

Figure D.1. Sequential Photographs for Test No. 610211-01-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s



0.200 s

0.300 s

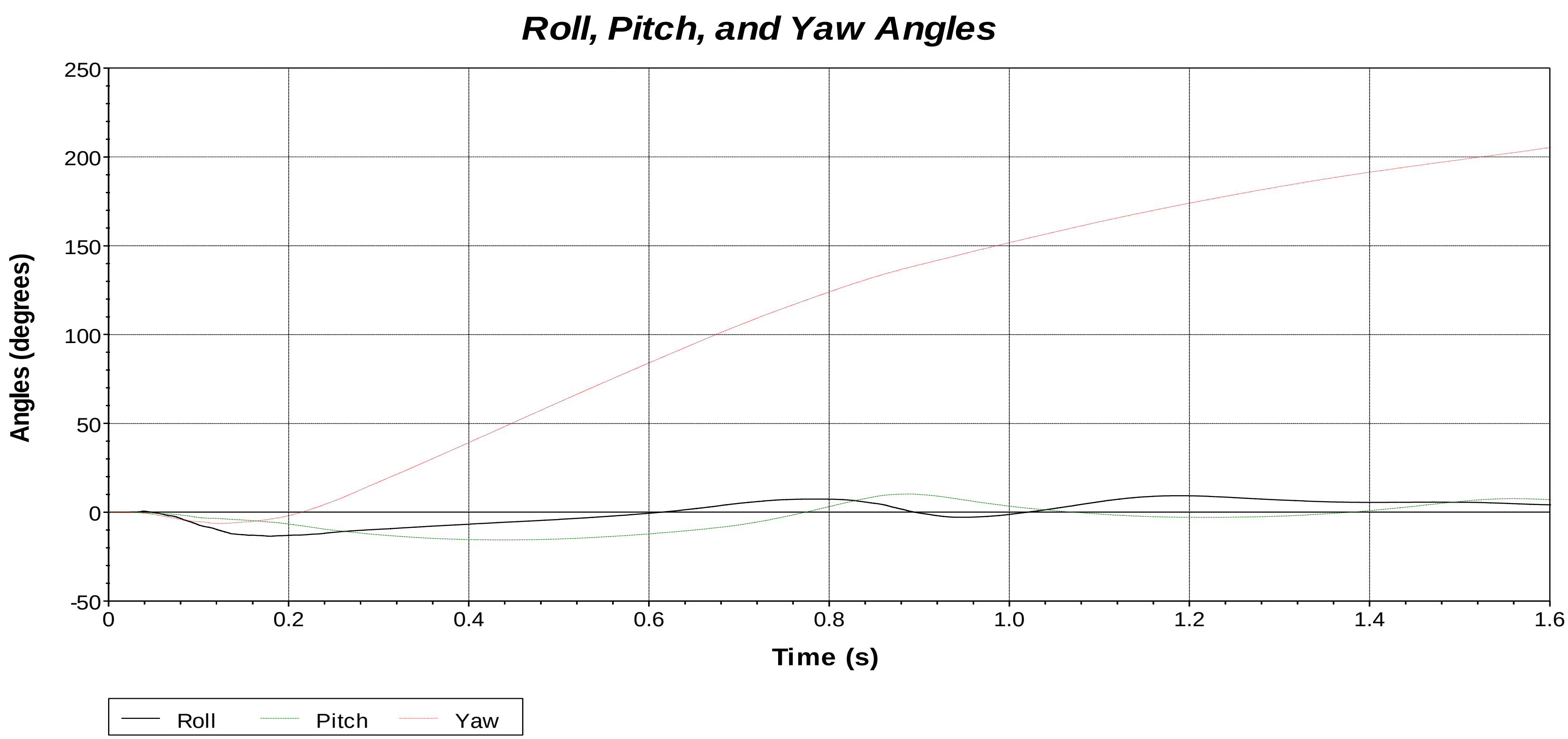
0.400 s

0.500 s

0.600 s

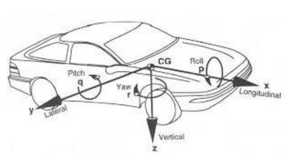
0.700 s

Figure D.2. Sequential Photographs for Test No. 610211-01-1 (Rear View).



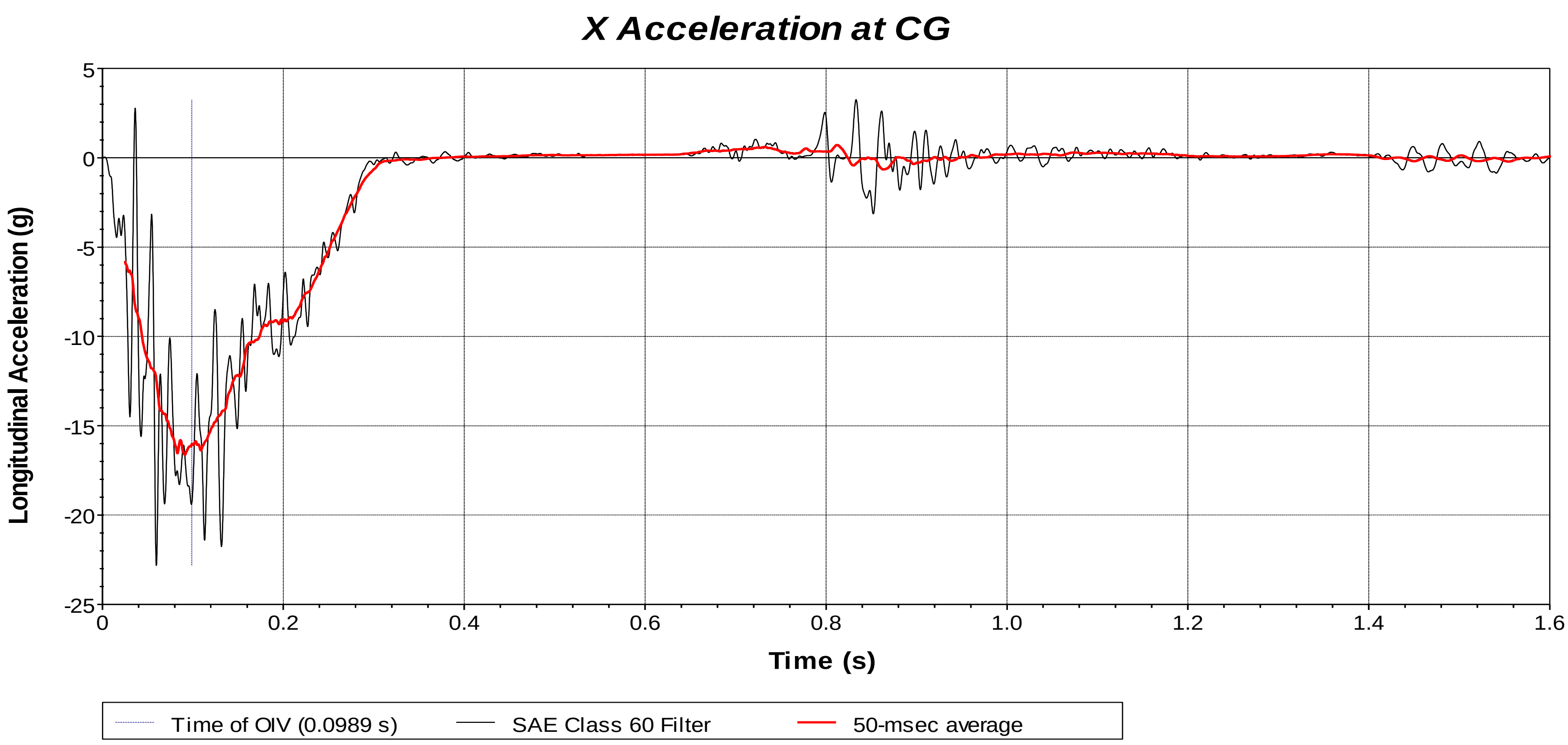
Axes are vehicle-fixed.
Sequence for determining orientation:

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



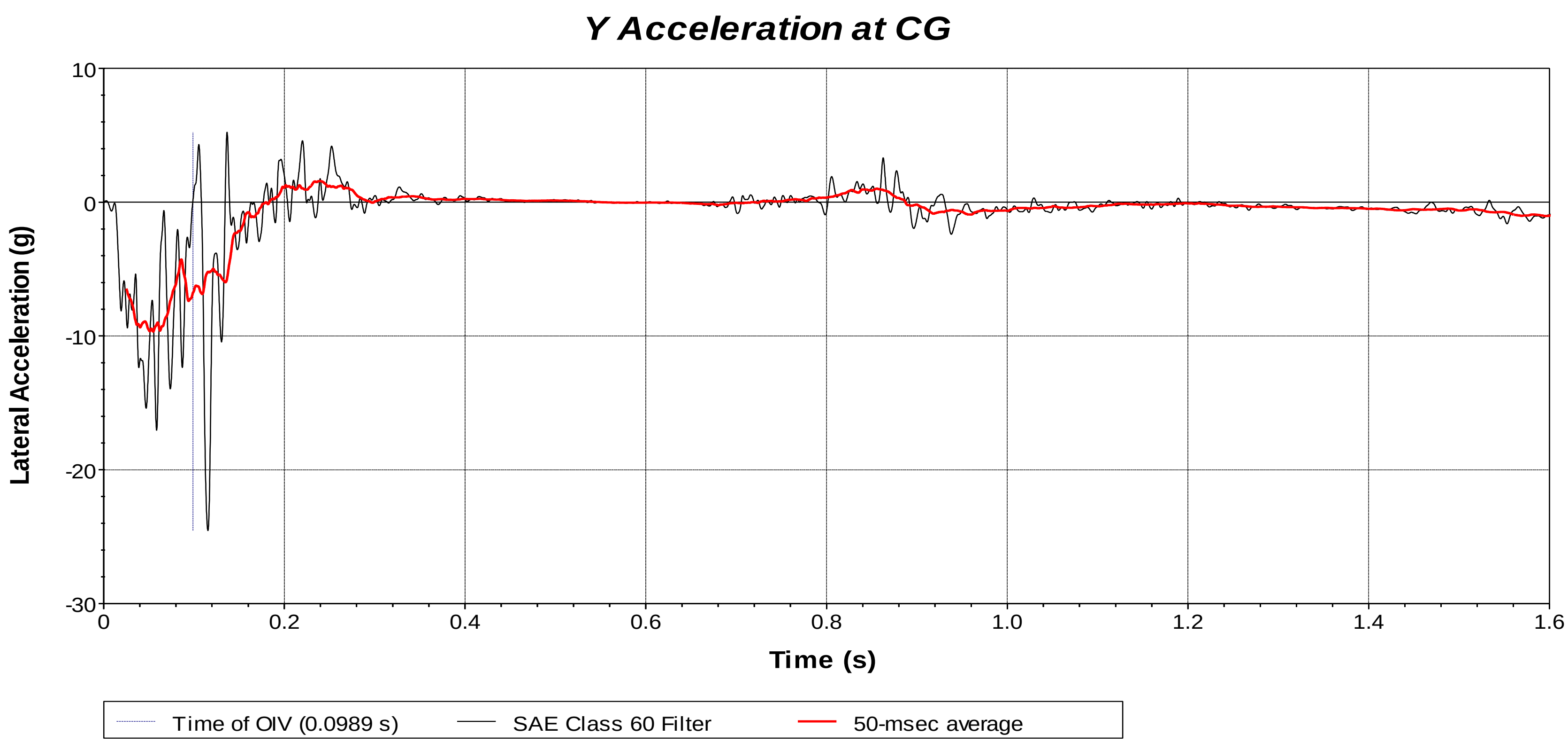
Test Number: 610211-01-1
Test Standard Test Number: MASH Test 3-10
Test Article: MGS with Quarter Post Spacing
Test Vehicle: 2010 Kia Rio
Inertial Mass: 2453 lb
Gross Mass: 2618 lb
Impact Speed: 63.7 mi/h
Impact Angle: 25.5 degrees

Figure D.3. Vehicle Angular Displacements for Test No. 610211-01-1.



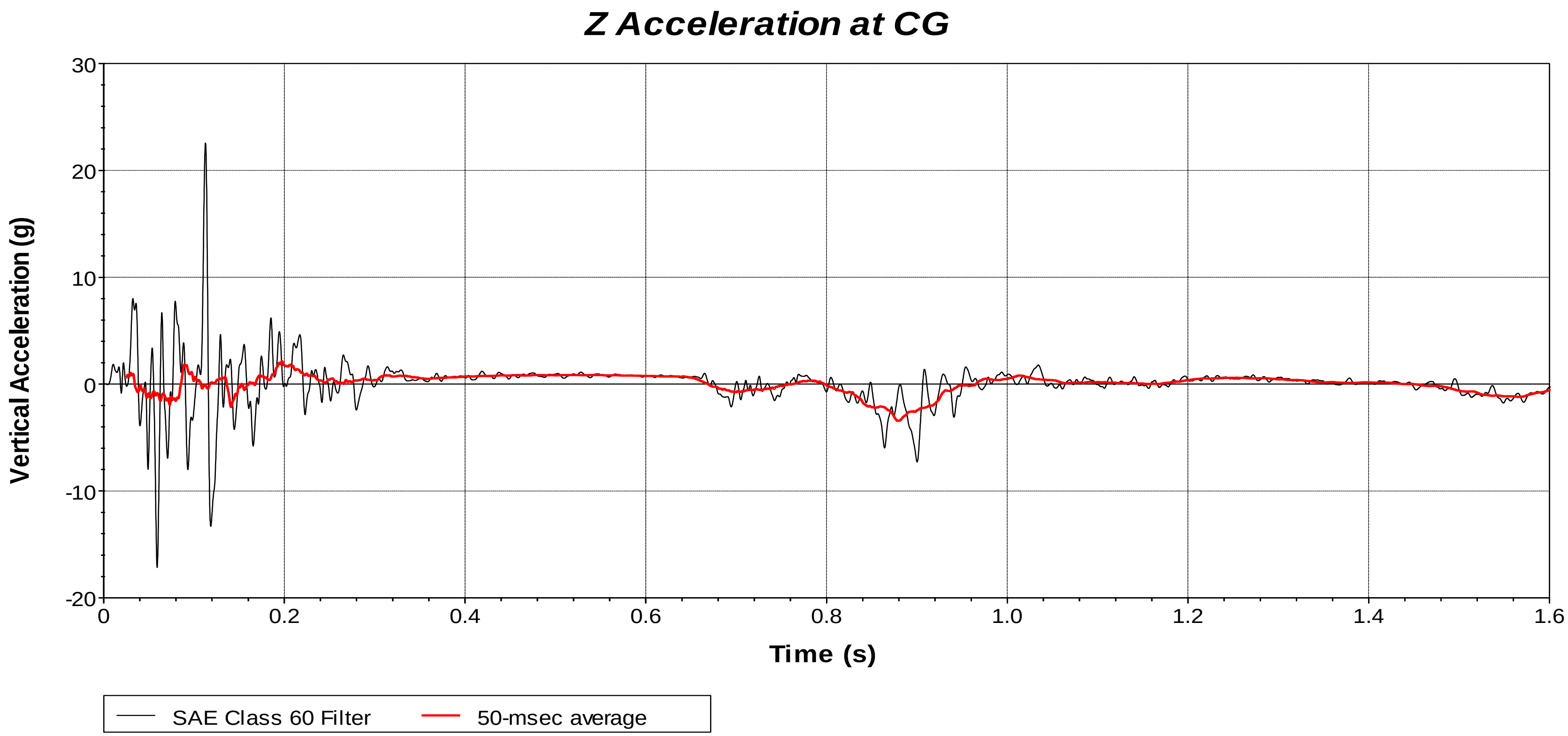
Test Number: 610211-01-1
Test Standard Test Number: MASH Test 3-10
Test Article: MGS with Quarter Post Spacing
Test Vehicle: 2010 Kia Rio
Inertial Mass: 2453 lb
Gross Mass: 2618 lb
Impact Speed: 63.7 mi/h
Impact Angle: 25.5 degrees

Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 610211-01-1 (Accelerometer Located at Center of Gravity).



Test Number: 610211-01-1
Test Standard Test Number: MASH Test 3-10
Test Article: MGS with Quarter Post Spacing
Test Vehicle: 2010 Kia Rio
Inertial Mass: 2453 lb
Gross Mass: 2618 lb
Impact Speed: 63.7 mi/h
Impact Angle: 25.5 degrees

Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 610211-01-1 (Accelerometer Located at Center of Gravity).



Test Number: 610211-01-1
Test Standard Test Number: MASH Test 3-10
Test Article: MGS with Quarter Post Spacing
Test Vehicle: 2010 Kia Rio
Inertial Mass: 2453 lb
Gross Mass: 2618 lb
Impact Speed: 63.7 mi/h
Impact Angle: 25.5 degrees

Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 610211-01-1 (Accelerometer Located at Center of Gravity).

APPENIDX E. *MASH* TEST 3-11 (CRASH TEST NO. 610211-01-2)

E1 VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 610211-01-2.

Vehicle Inventory Number: 1349

Date:	2018-10-22	Test No.:	610211-01-2	VIN No.:	1C6RR6FT9ES140231
Year:	2014	Make:	RAM	Model:	1500

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

Tread Type: Highway Odometer: 304744

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

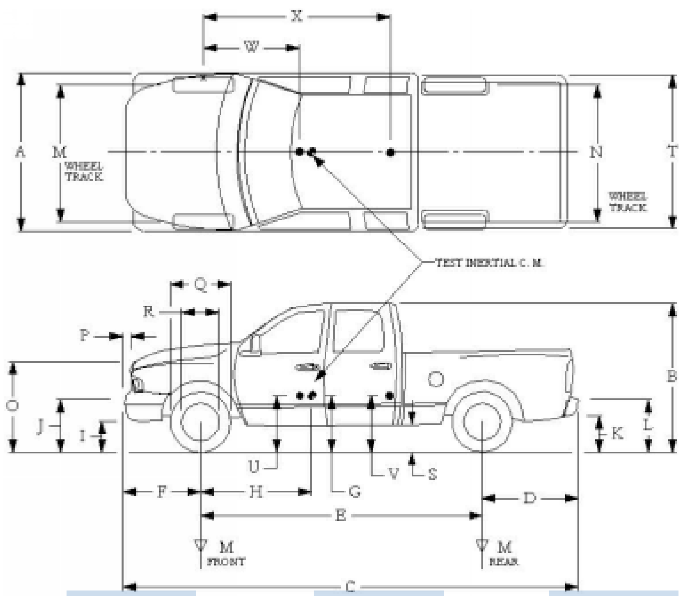
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment:
None

Dummy Data:
Type:
Mass: 0 lb
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	27.50
B	74.00	G	28.30	L	30.00	Q	30.50	V	31.25
C	227.50	H	60.75	M	68.50	R	18.00	W	60.75
D	44.00	I	11.75	N	68.00	S	13.00	X	77.00
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}	2917	2842	
Back	3900	M_{rear}	2102	2165	
Total	6700	M_{Total}	5019	5007	0

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

Mass Distribution:
lb LF: 1407 RF: 1435 LR: 1100 RR: 1065

Performed by: SCD Date: 2018-10-22

Table E.2. Measurements of Vehicle Vertical CG for Test No. 610211-01-2.

Vehicle Inventory Number: 1349

Date: 2018-10-22 Test No.: 610211-01-2 VIN: 1C6RR6FT9ES140231

Year: 2014 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 304744

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 76 (440 lb max)

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

Measured Vehicle Weights: (lb)								
LF:	1407		RF:	1435		Front Axle:	2842	
LR:	1100		RR:	1065		Rear Axle:	2165	
Left:	2507		Right:	2500		Total:	5007	
							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:	60.75	inches	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	-0.05	inches	Left -	Right +	of Vehicle Centerline			
Z:	28.30	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

Performed by: SCD Date: 2018-10-22

Table E.3. Exterior Crush Measurements for Test No. 610211-01-2.

Vehicle Inventory Number: 1349

Date:	2018-10-22	Test No.:	610211-01-2	VIN No.:	1C6RR6FT9ES140231
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	12	42	.5	1	3	5	9	12	-18
2	ABOVE FT BUMPER	18	15	65	2	4			13	15	+77
	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).

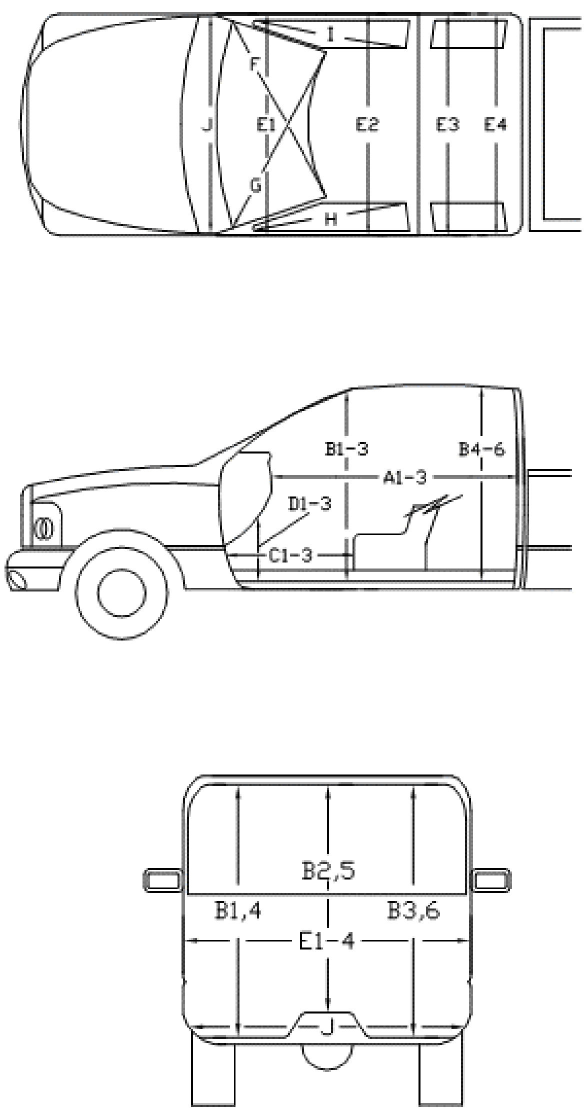
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Performed by: SCD Date: 2018-10-22

Table E.4. Occupant Compartment Measurements for Test No. 610211-01-2.

			Vehicle Inventory Number:	1349	
Date:	2018-10-22	Test No.:	610211-01-2	VIN No.:	1C6RR6FT9ES140231
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	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	24.00	-2.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	10.75	-0.75
E1	58.50	59.00	0.50
E2	63.50	62.50	-1.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	24.75	-0.25

Performed by:	SCD	Date:	2018-10-22

E2 SEQUENTIAL PHOTOGRAPHS

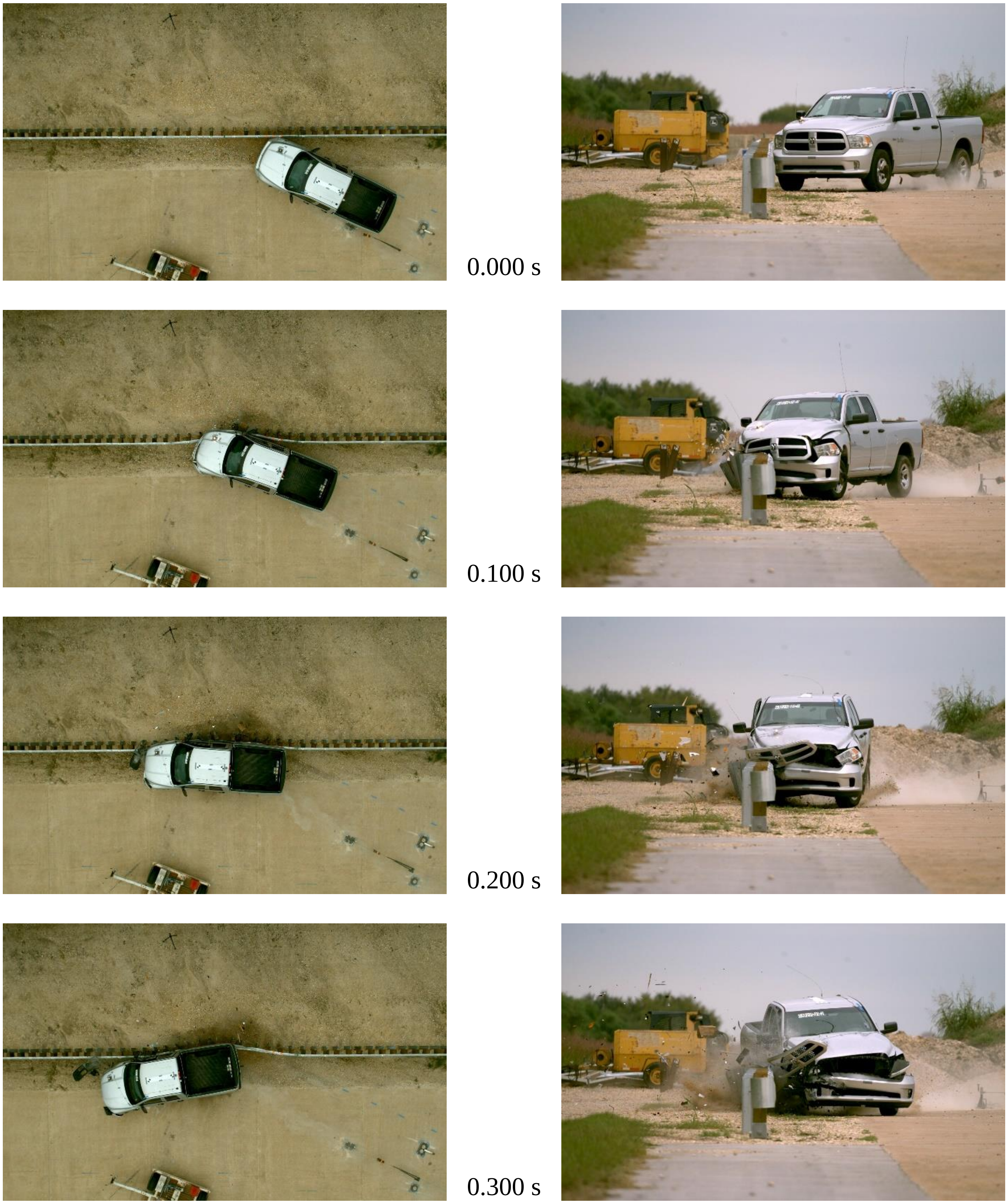
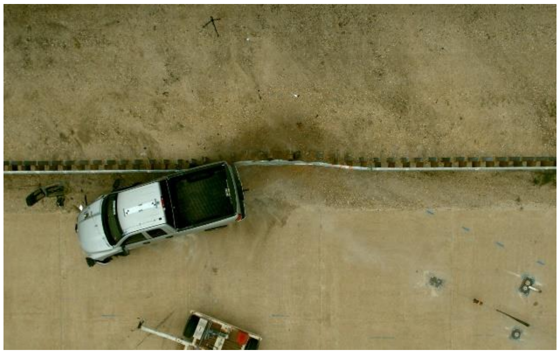


Figure E.1. Sequential Photographs for Test No. 610211-01-2 (Overhead and Frontal Views).



0.400 s

0.500 s

0.600 s

0.700 s

Figure E.1. Sequential Photographs for Test No. 610211-01-2 (Overhead and Frontal Views) (Continued).

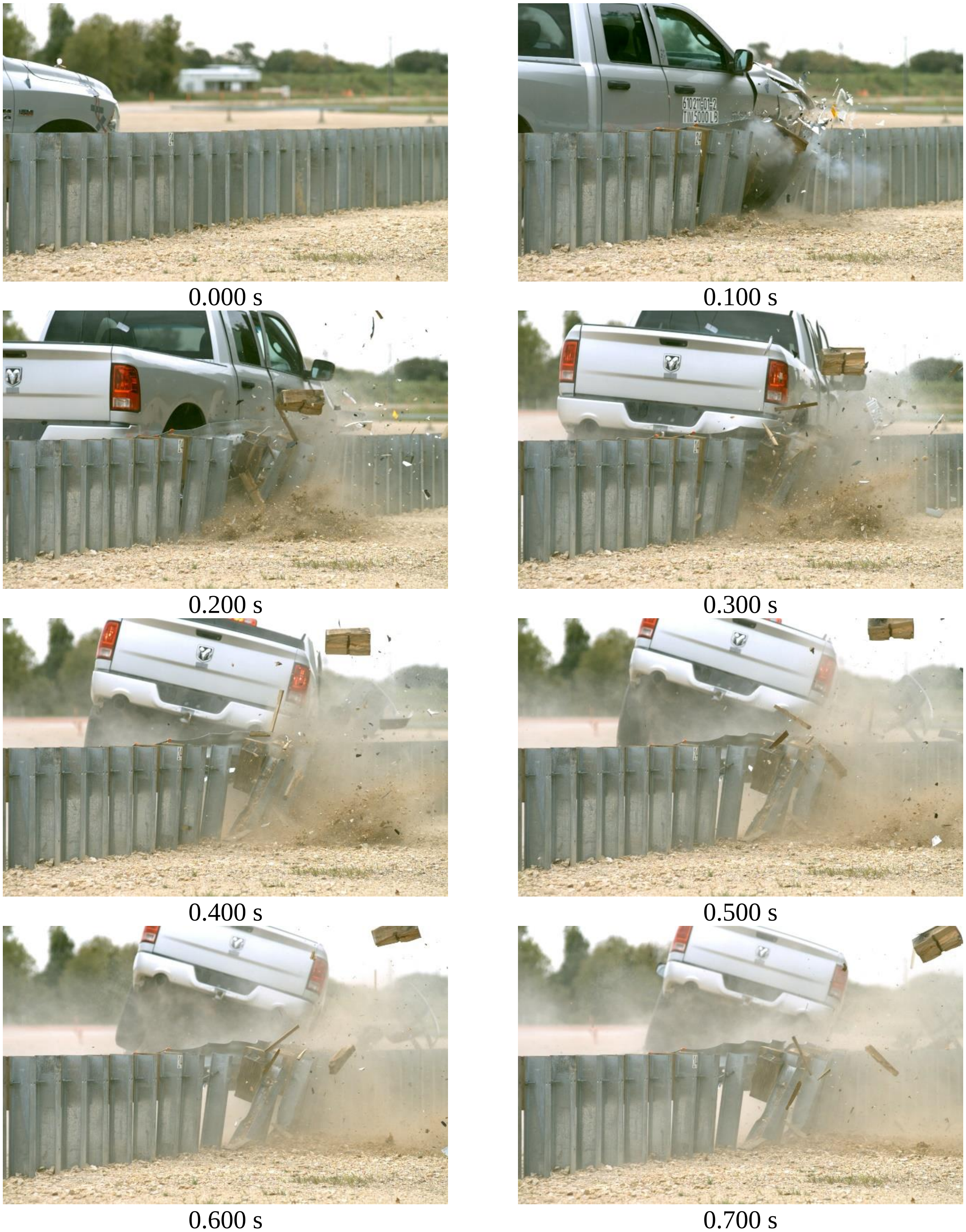
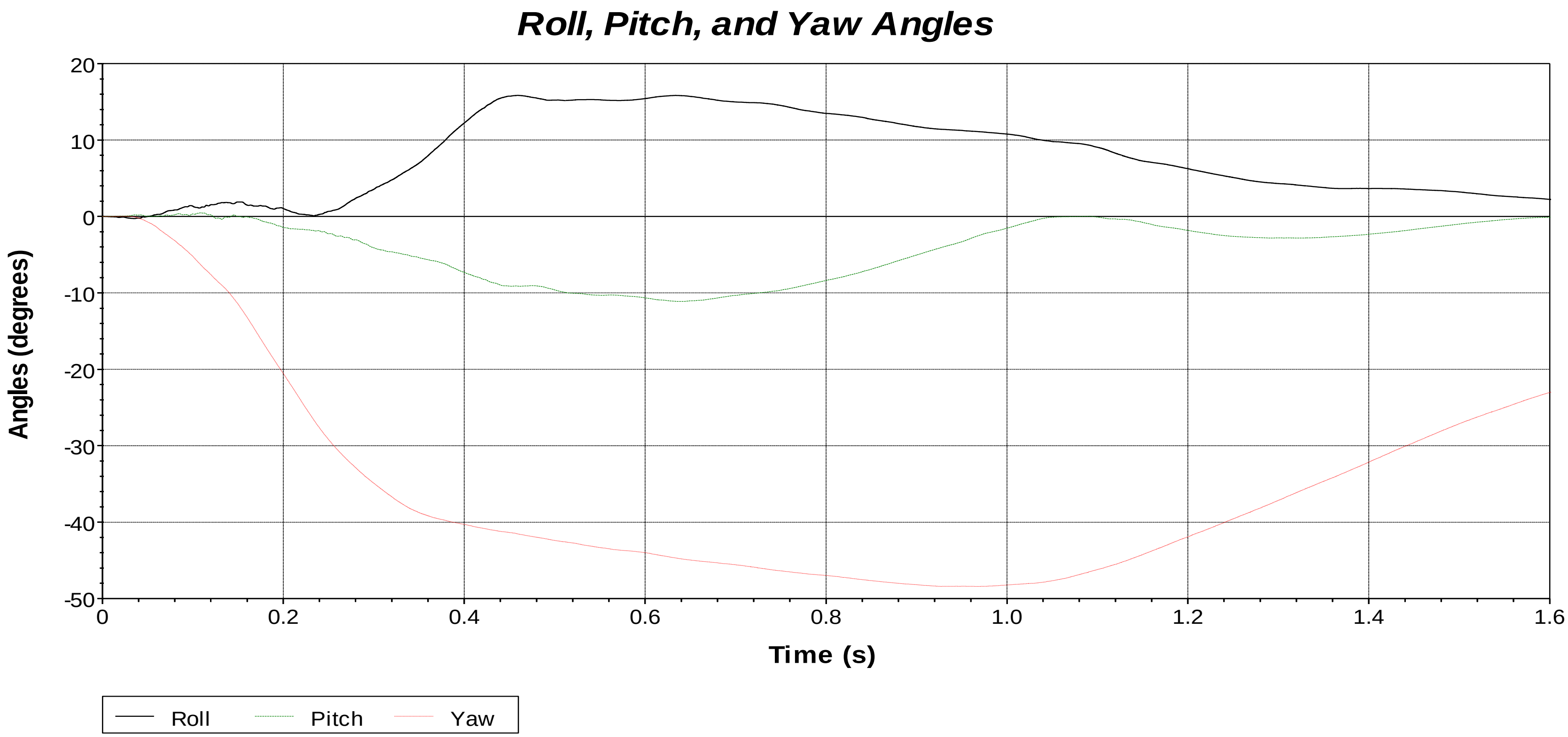
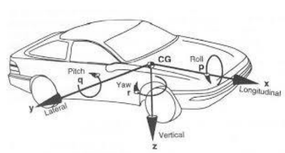


Figure E.2. Sequential Photographs for Test No. 610211-01-2 (Rear View).



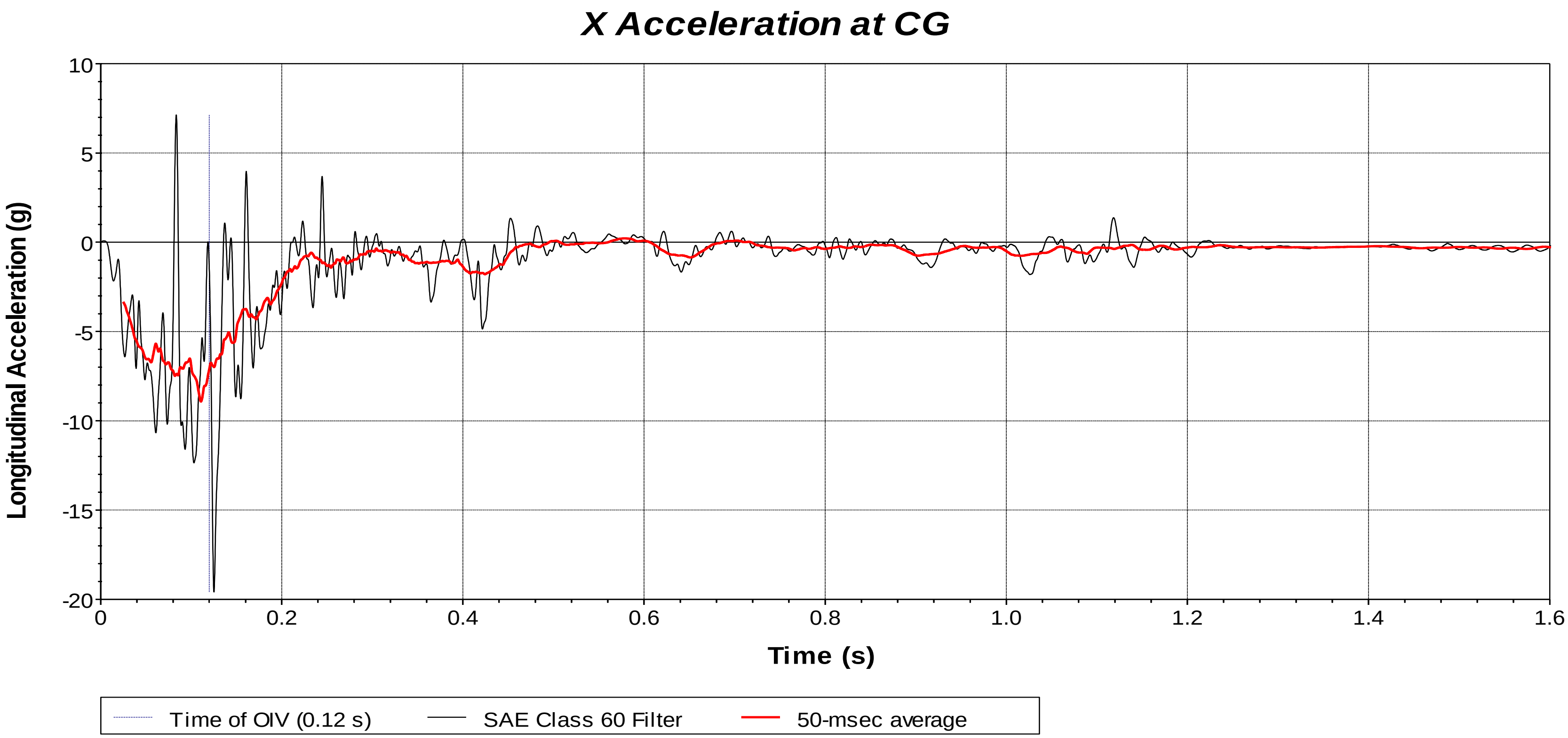
Axes are vehicle-fixed.
Sequence for determining orientation:

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



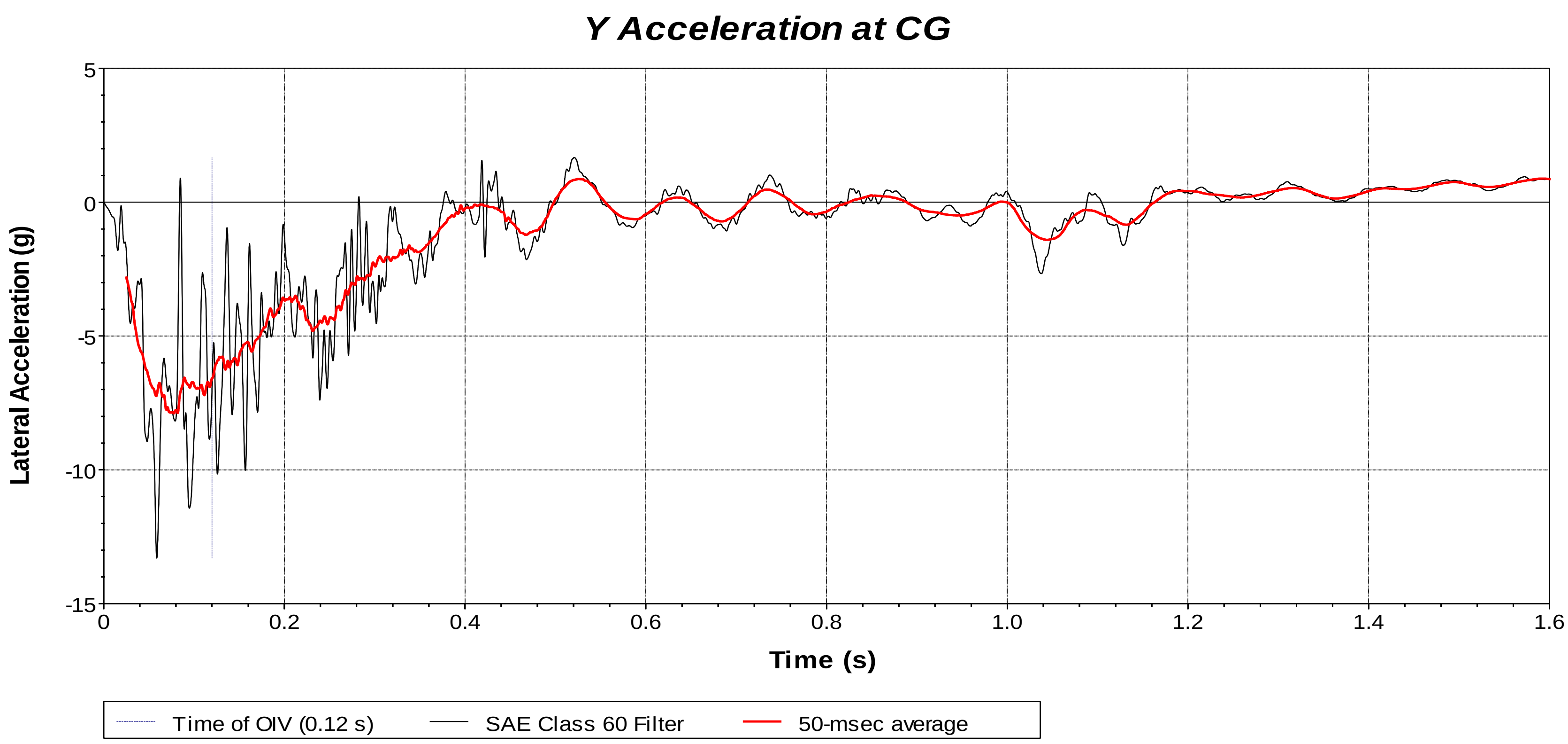
Test Number: 610211-01-2
Test Standard Test Number: MASH Test 3-11
Test Article: MGS with Quarter Post Spacing
Test Vehicle: 2014 RAM 1500
Inertial Mass: 5007 lb
Gross Mass: 5007 lb
Impact Speed: 63.1 mi/h
Impact Angle: 26.1 degrees

Figure E.3. Vehicle Angular Displacements for Test No. 610211-01-2.



Test Number: 610211-01-2
Test Standard Test Number: MASH Test 3-11
Test Article: MGS with Quarter Post Spacing
Test Vehicle: 2014 RAM 1500
Inertial Mass: 5007 lb
Gross Mass: 5007 lb
Impact Speed: 63.1 mi/h
Impact Angle: 26.1 degrees

Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 610211-01-2 (Accelerometer Located at Center of Gravity).



Test Number: 610211-01-2
Test Standard Test Number: MASH Test 3-11
Test Article: MGS with Quarter Post Spacing
Test Vehicle: 2014 RAM 1500
Inertial Mass: 5007 lb
Gross Mass: 5007 lb
Impact Speed: 63.1 mi/h
Impact Angle: 26.1 degrees

Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 610211-01-2 (Accelerometer Located at Center of Gravity).

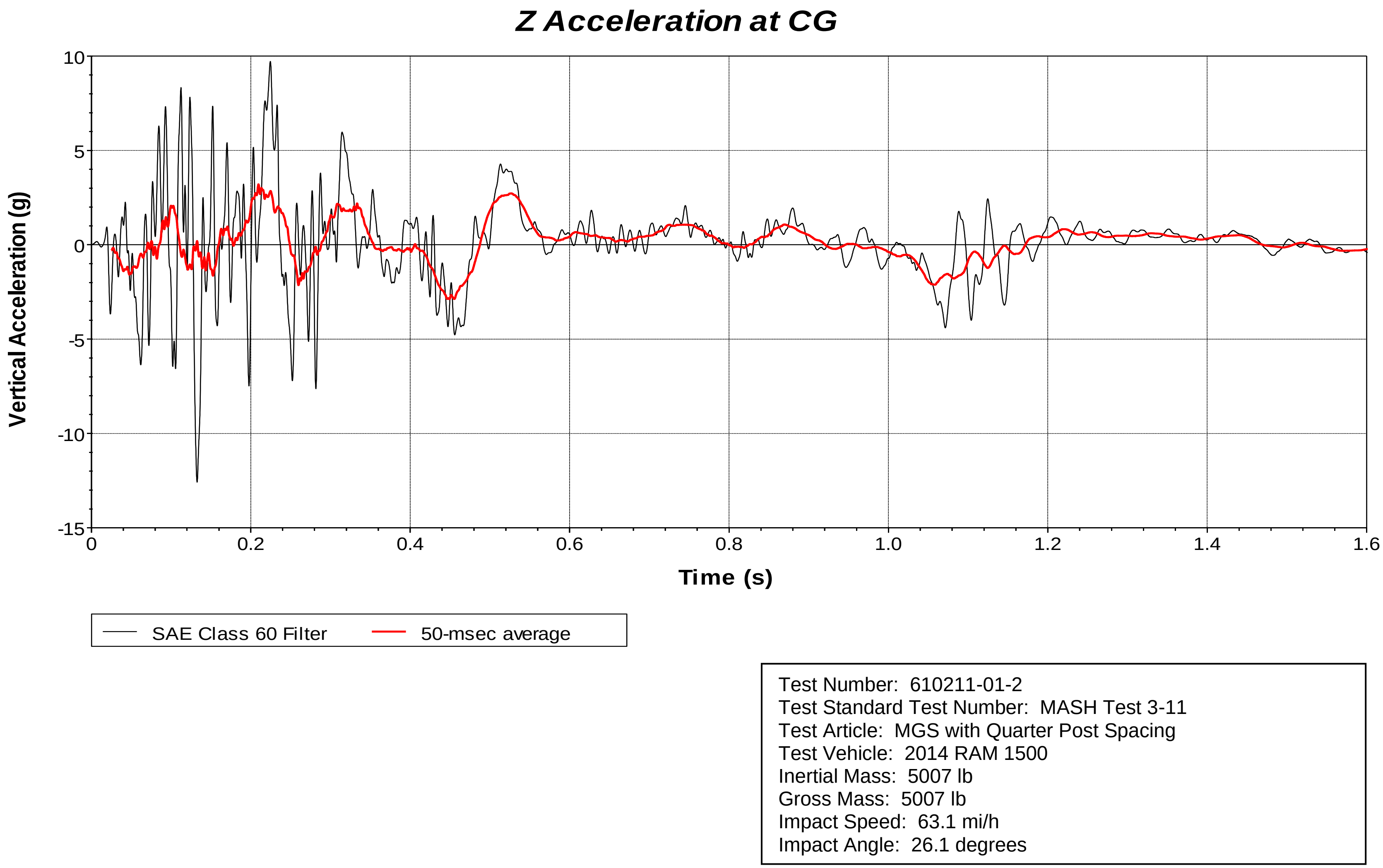
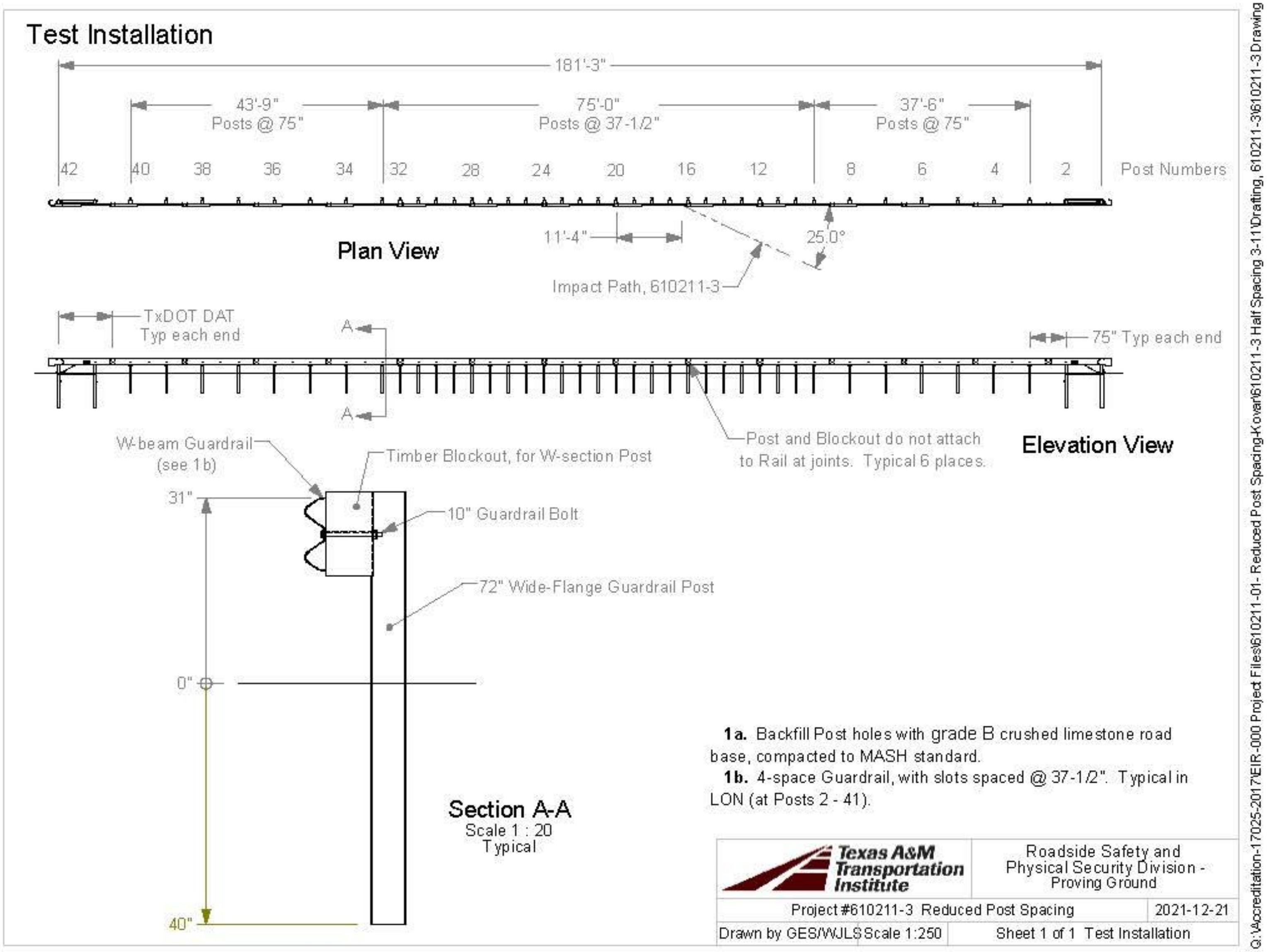
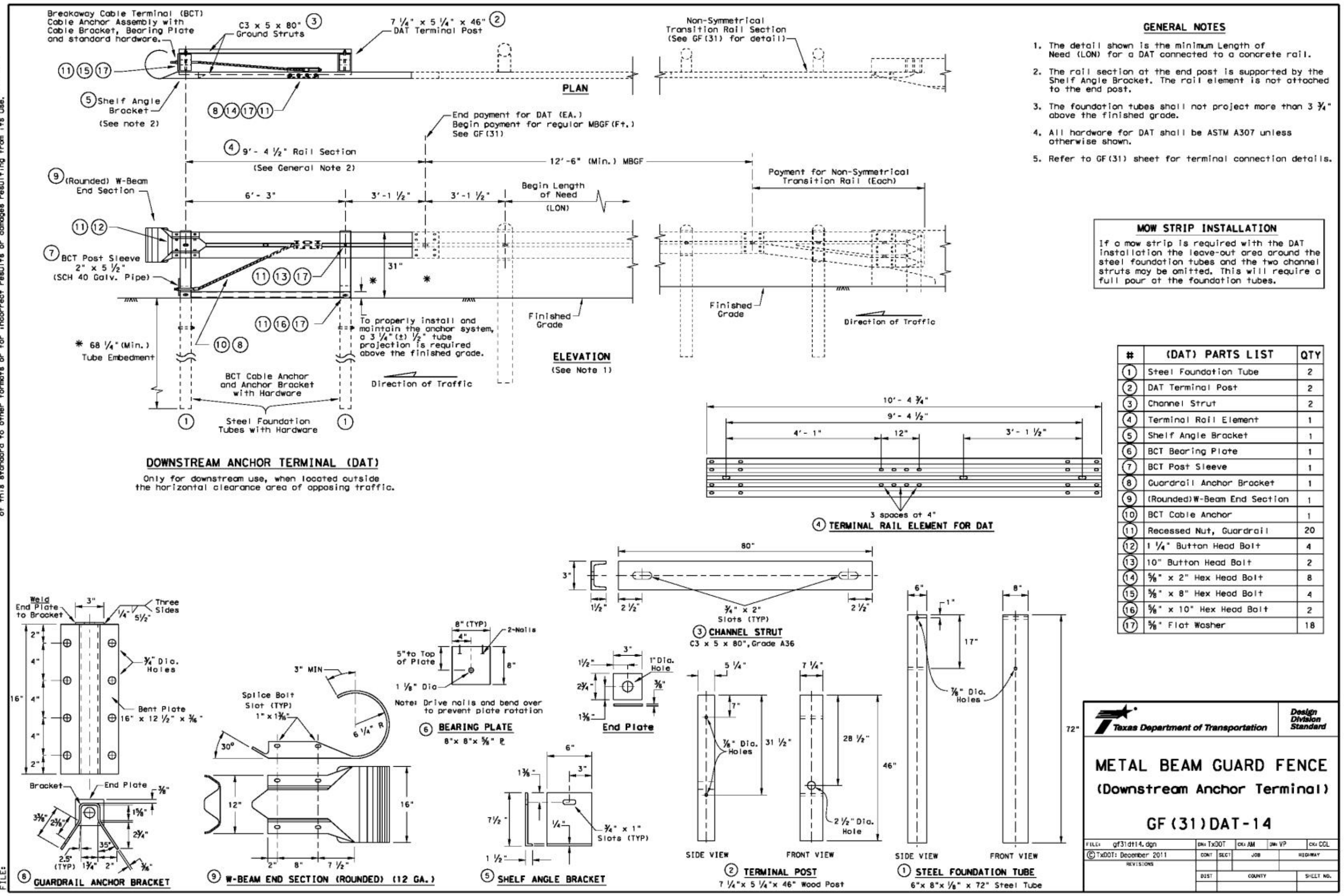


Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 610211-01-2 (Accelerometer Located at Center of Gravity).

APPENDIX F. DETAILS OF THE MGS WITH HALF POST SPACING





DISCLAIMER: The use of this standard is governed by the "Texas Engineering Practice Act". No warranty of any kind is made by TxDOT for any purpose whatsoever. TxDOT assumes no responsibility for the conversion of this standard to other formats or for incorrect results or damages resulting from its use.

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

2023-03-21

APPENIDX G. *MASH* TEST 3-11 (CRASH TEST NO. 610211-01-3)

G1 VEHICLE PROPERTIES AND INFORMATION

Table G.1. Vehicle Properties for Test No. 610211-01-3.

Date: 2019-02-18 Test No.: 610211-01-3 VIN No.: 1C6RR6FTODS707585

Year: 2013 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 187705

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

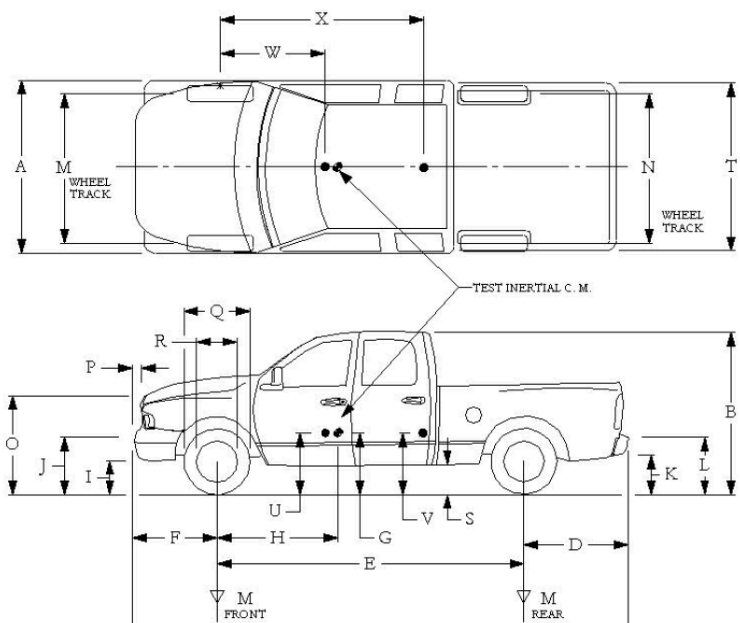
NOTES: None

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	27.00
B	74.00	G	28.00	L	30.00	Q	30.50	V	31.25
C	227.50	H	59.75	M	68.50	R	18.00	W	59.75
D	44.00	I	11.75	N	68.00	S	13.00	X	78.00
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}	2954	2884	2884
Back	3900	M_{rear}	2084	2134	2134
Total	6700	M_{Total}	5038	5018	5018

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

Mass Distribution:
lb LF: 1422 RF: 1462 LR: 1090 RR: 1044

Table G.2. Measurements of Vehicle Vertical CG for Test No. 610211-01-3.

Date: 2019-02-18 Test No.: 610211-01-3 VIN: 1C6RR6FTODS707585

Year: 2013 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 187705

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 90 (440 lb max)

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

Measured Vehicle Weights: (lb)								
LF:	1422		RF:	1462		Front Axle:	2884	
LR:	1090		RR:	1044		Rear Axle:	2134	
Left:	2512		Right:	2506		Total:	5018	
						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:	59.75	inches	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	-0.04	inches	Left -	Right +	of Vehicle Centerline			
Z:	28.00	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 G.3. Exterior Crush Measurements for Test No. 610211-01-3.

Date:	2019-02-18	Test No.:	610211-01-3	VIN No.:	1C6RR6FTODS707585
Year:	2013	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		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane-bumper ht	19	22	72	-2	1	19	19	1	3	0
	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.

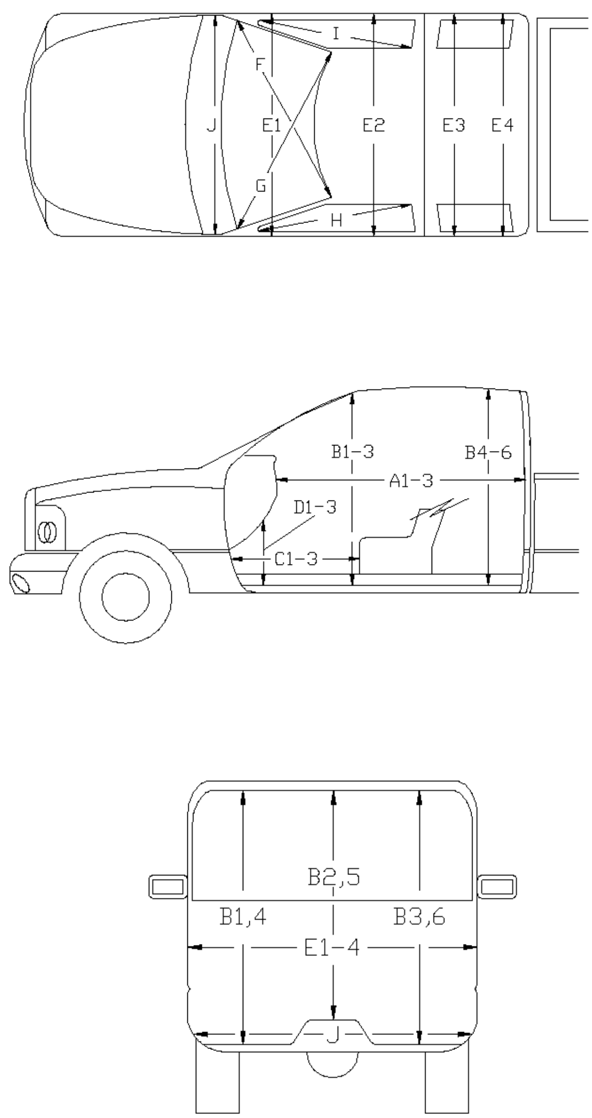
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 G.4. Occupant Compartment Measurements for Test No. 610211-01-3.

Date:	2019-02-18	Test No.:	610211-01-3	VIN No.:	1C6RR6FTODS707585
Year:	2013	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	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	44.50	-0.50
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
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	58.50	0.00
E2	63.50	63.50	0.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	25.00	0.00

G2 SEQUENTIAL PHOTOGRAPHS

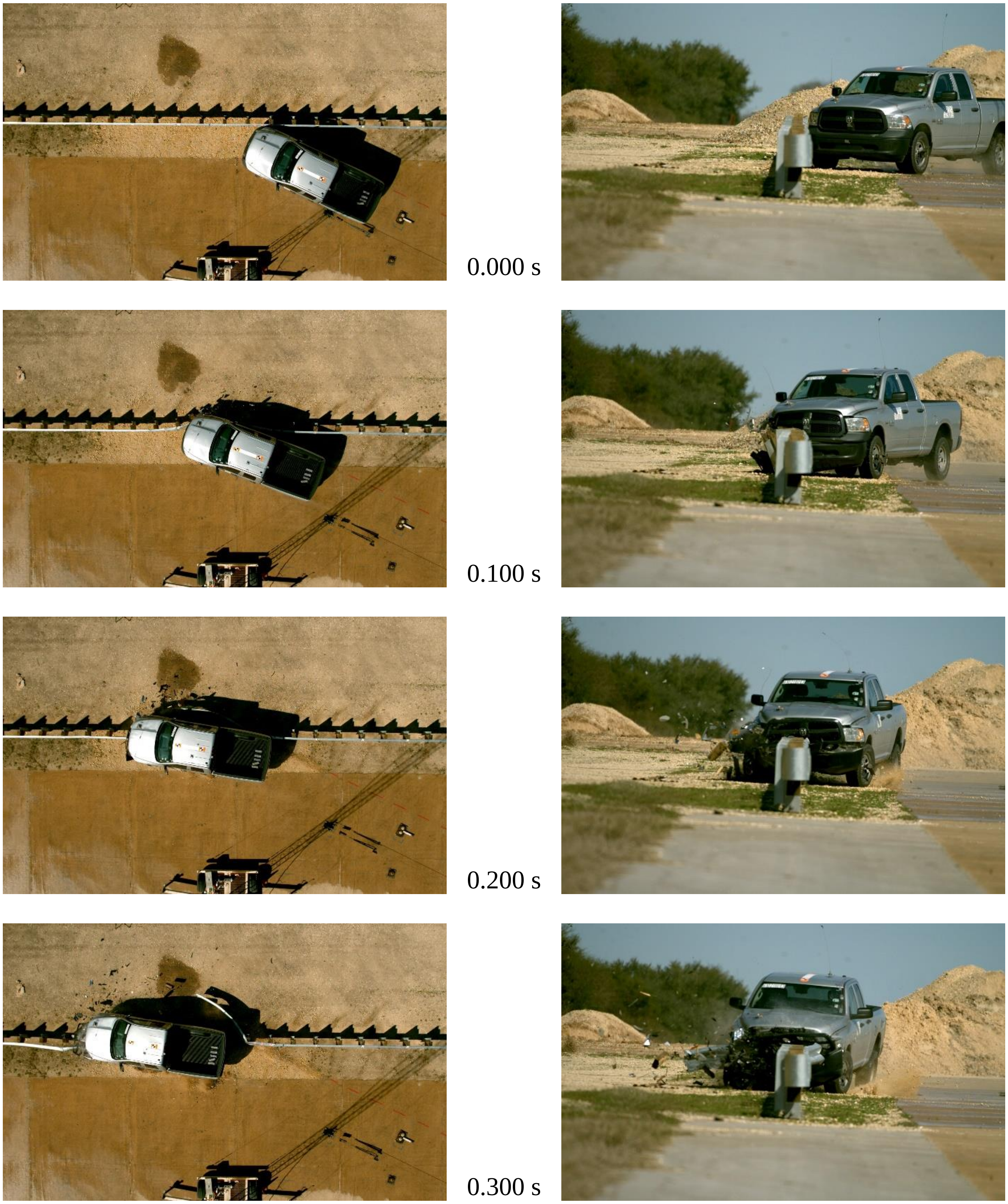


Figure G.1. Sequential Photographs for Test No. 610211-01-3 (Overhead and Frontal Views).

0.400 s

0.500 s

0.600 s

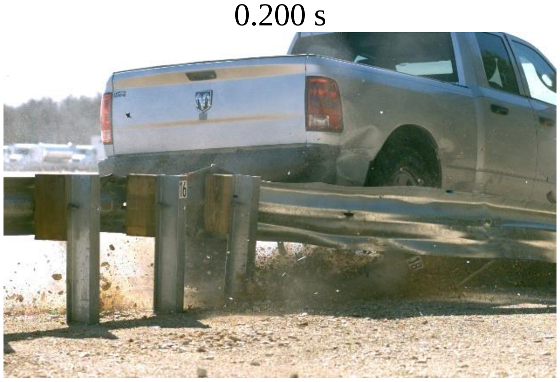
0.700 s

Figure G.1. Sequential Photographs for Test No. 610211-01-3 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

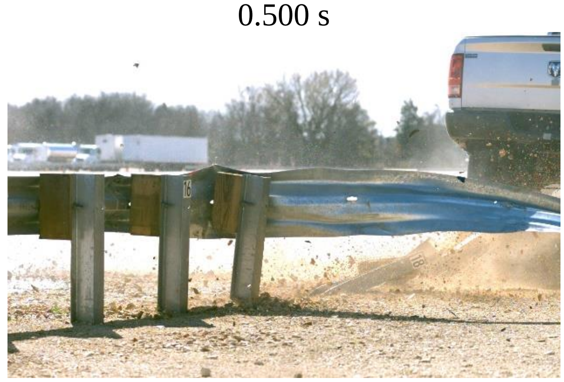
0.200 s



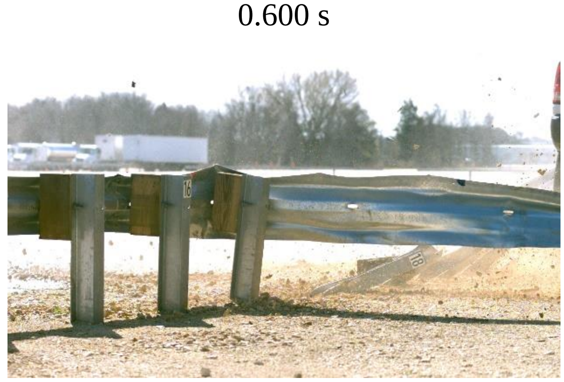
0.300 s

0.400s

0.500 s

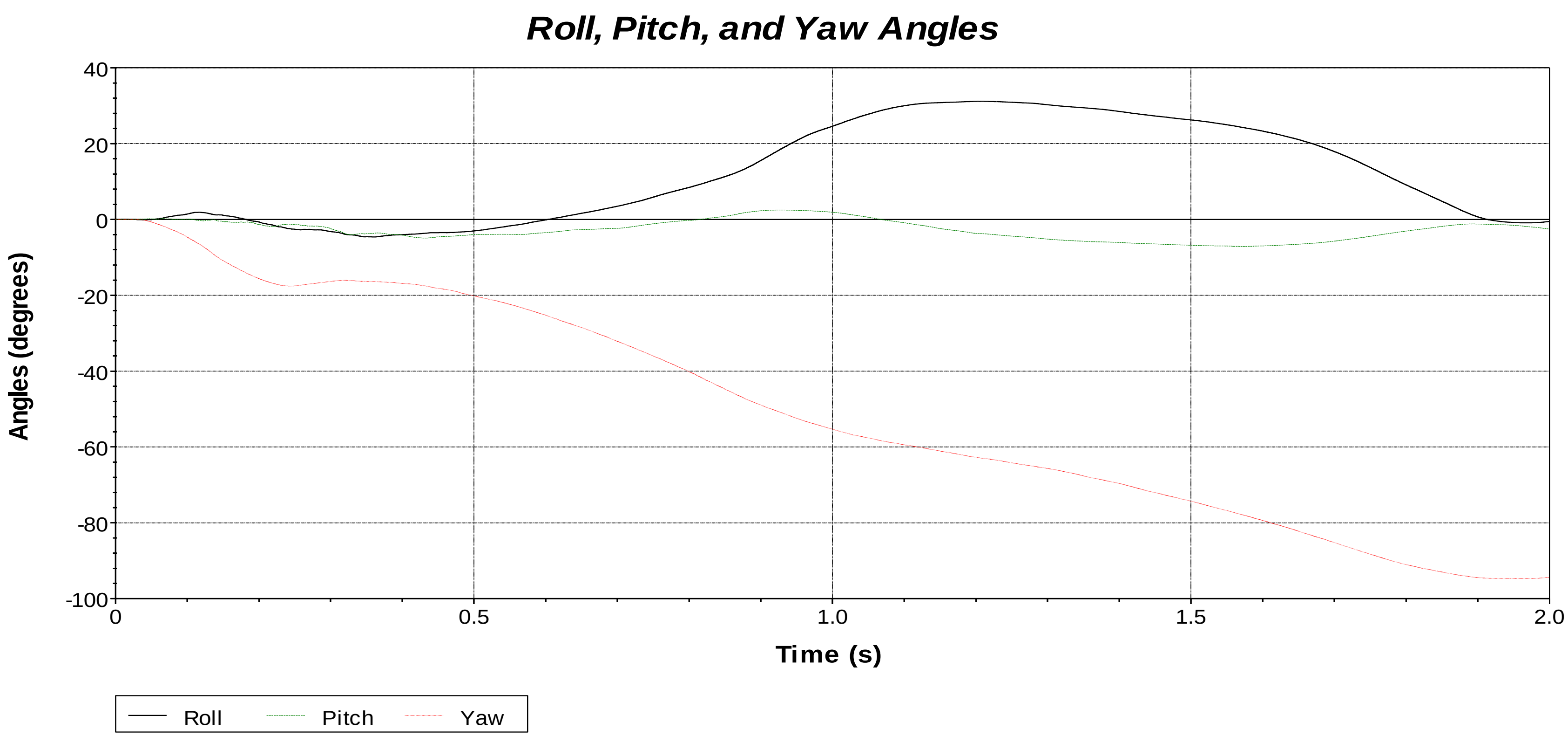


0.600 s



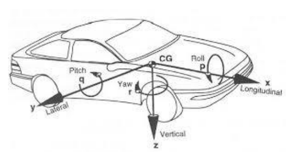
0.700 s

Figure G.2. Sequential Photographs for Test No. 610211-01-3 (Rear View).



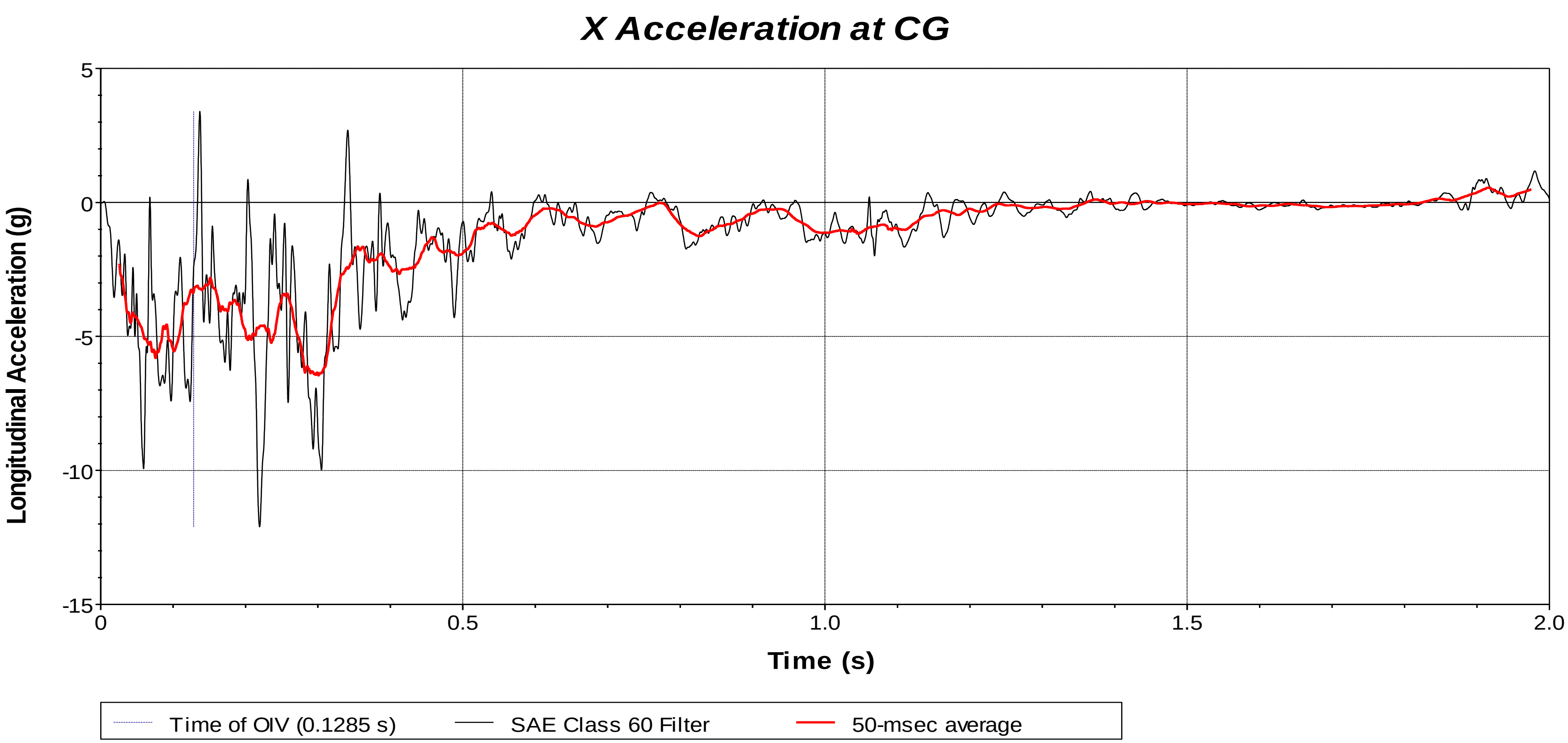
Axes are vehicle-fixed.
Sequence for determining orientation:

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



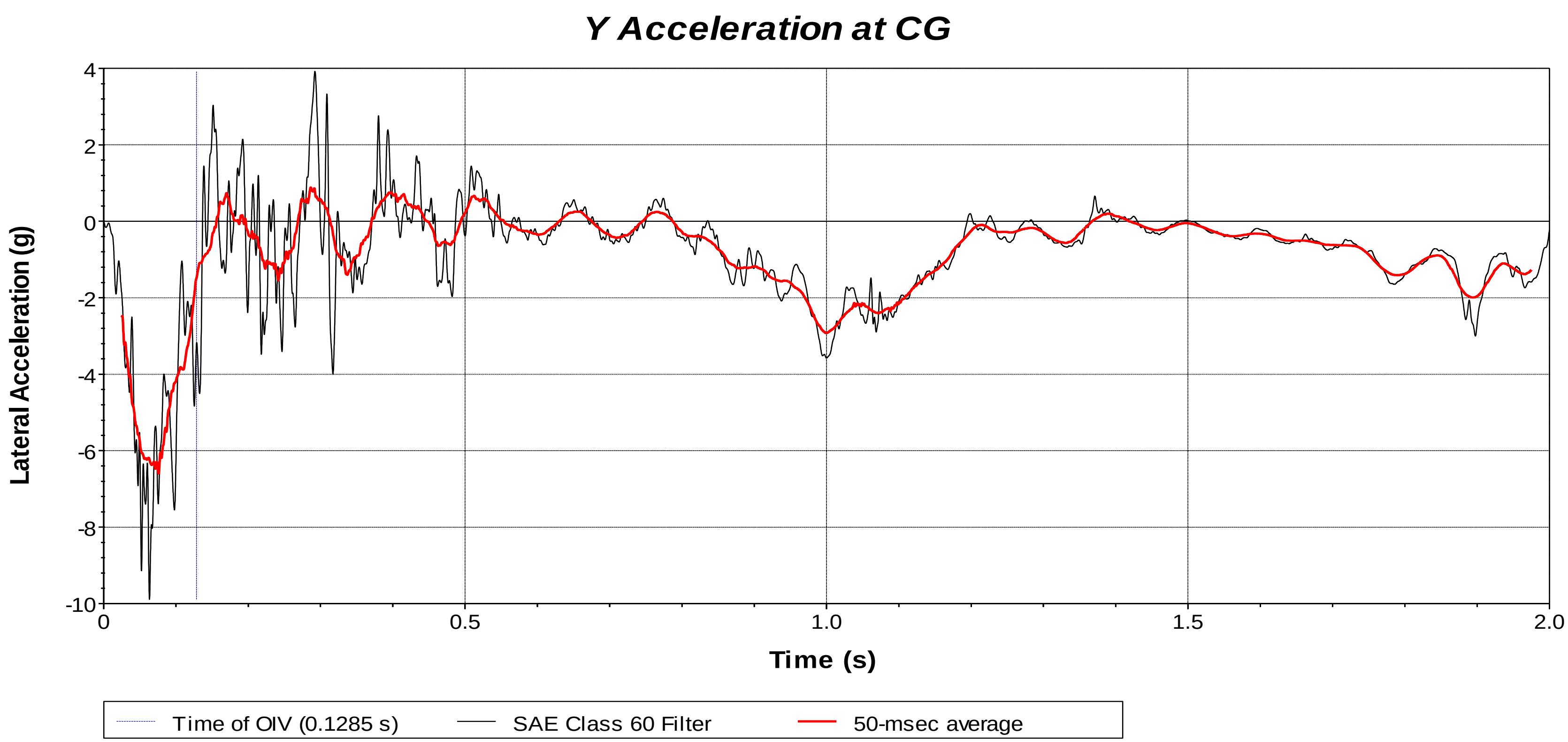
Test Number: 610211-01-3
Test Standard Test Number: MASH Test 3-11
Test Article: MGS with Half-Post Spacing
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5018 lb
Gross Mass: 5018 lb
Impact Speed: 62.2 mi/h
Impact Angle: 24.9 degrees

Figure G.3. Vehicle Angular Displacements for Test No. 610211-01-3.



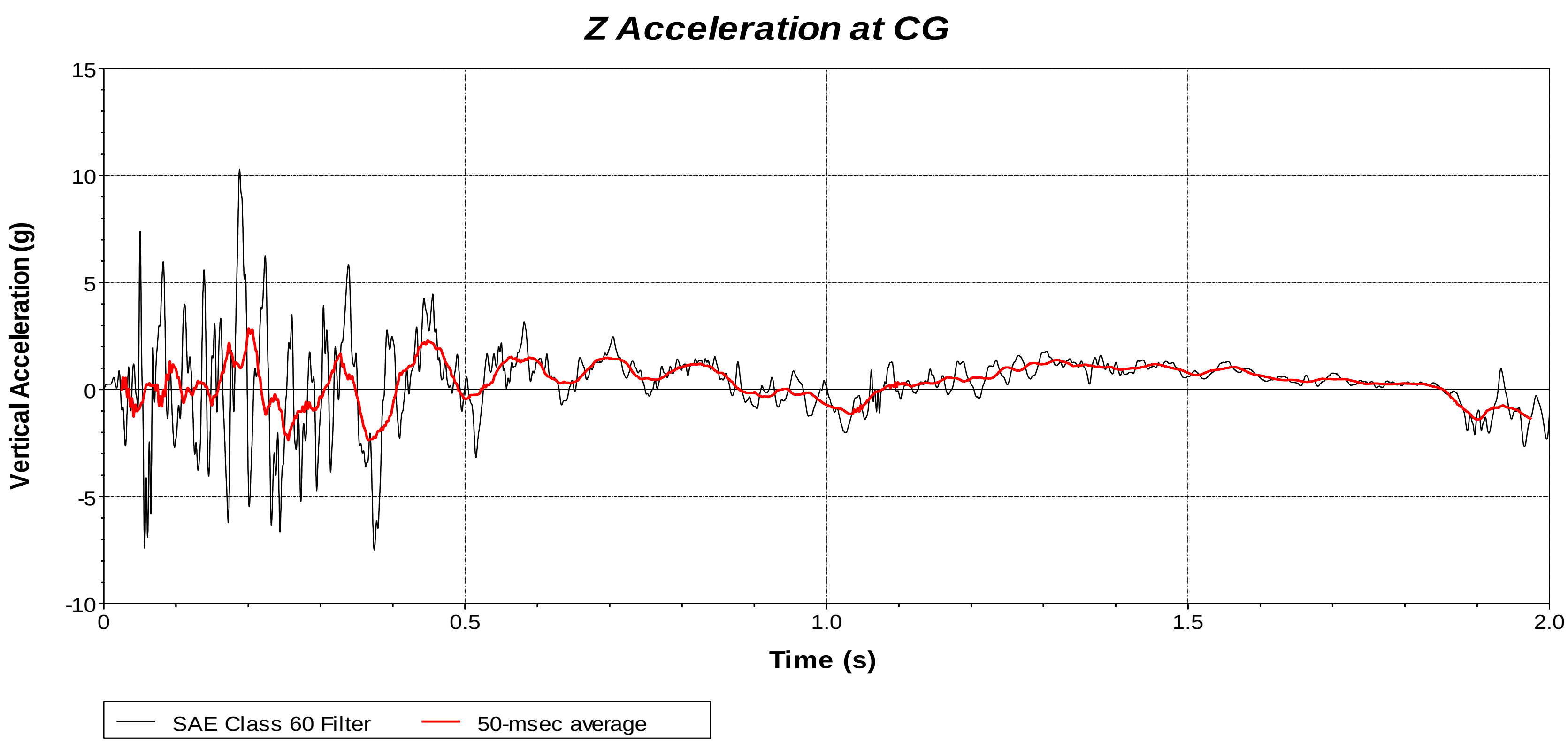
Test Number: 610211-01-3
Test Standard Test Number: MASH Test 3-11
Test Article: MGS with Half-Post Spacing
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5018 lb
Gross Mass: 5018 lb
Impact Speed: 62.2 mi/h
Impact Angle: 24.9 degrees

Figure G.4. Vehicle Longitudinal Accelerometer Trace for Test No. 610211-01-3 (Accelerometer Located at Center of Gravity).



Test Number: 610211-01-3
Test Standard Test Number: MASH Test 3-11
Test Article: MGS with Half-Post Spacing
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5018 lb
Gross Mass: 5018 lb
Impact Speed: 62.2 mi/h
Impact Angle: 24.9 degrees

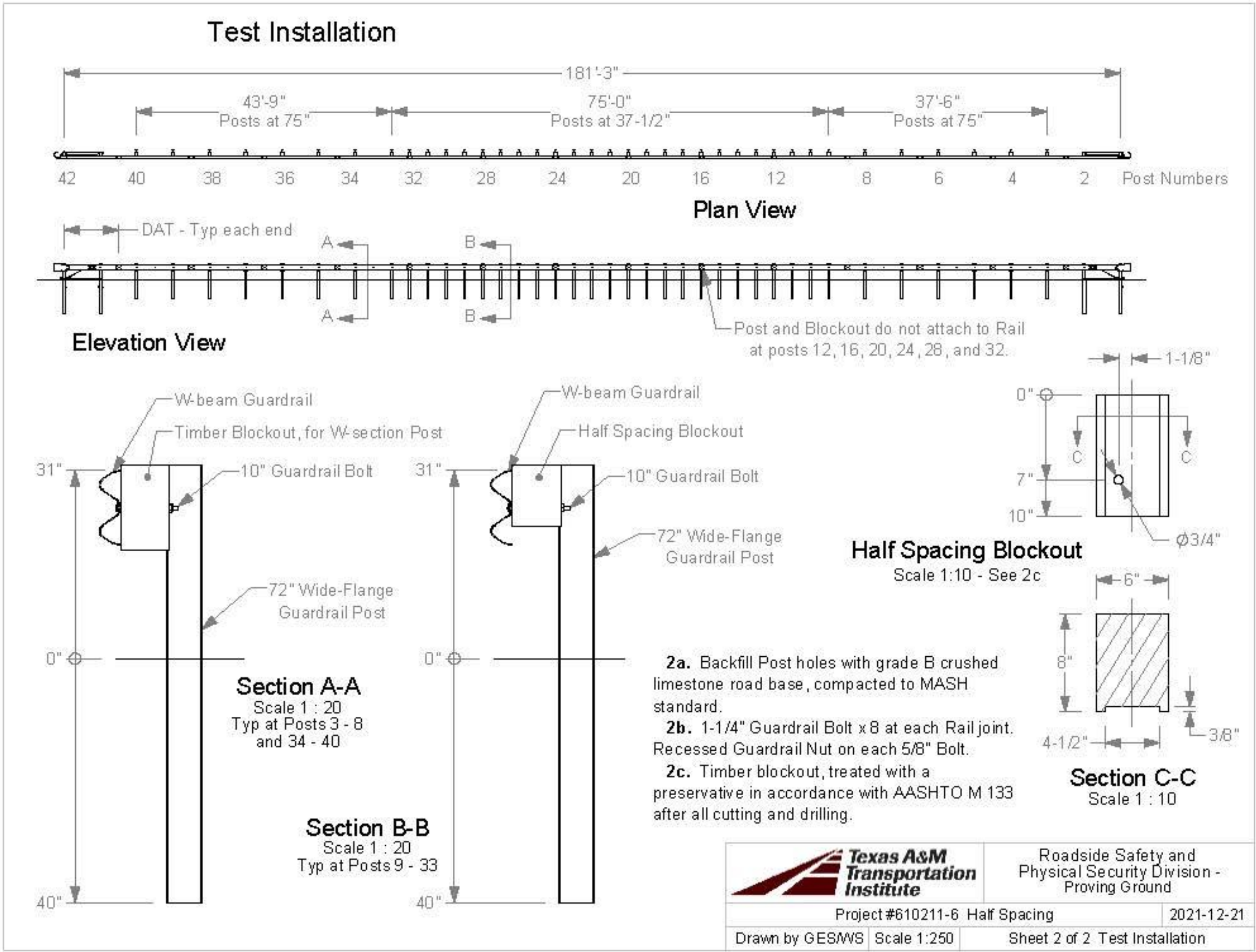
Figure G.5. Vehicle Lateral Accelerometer Trace for Test No. 610211-01-3 (Accelerometer Located at Center of Gravity).



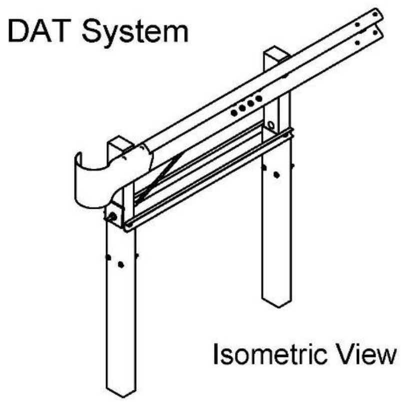
Test Number: 610211-01-3
Test Standard Test Number: MASH Test 3-11
Test Article: MGS with Half-Post Spacing
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5018 lb
Gross Mass: 5018 lb
Impact Speed: 62.2 mi/h
Impact Angle: 24.9 degrees

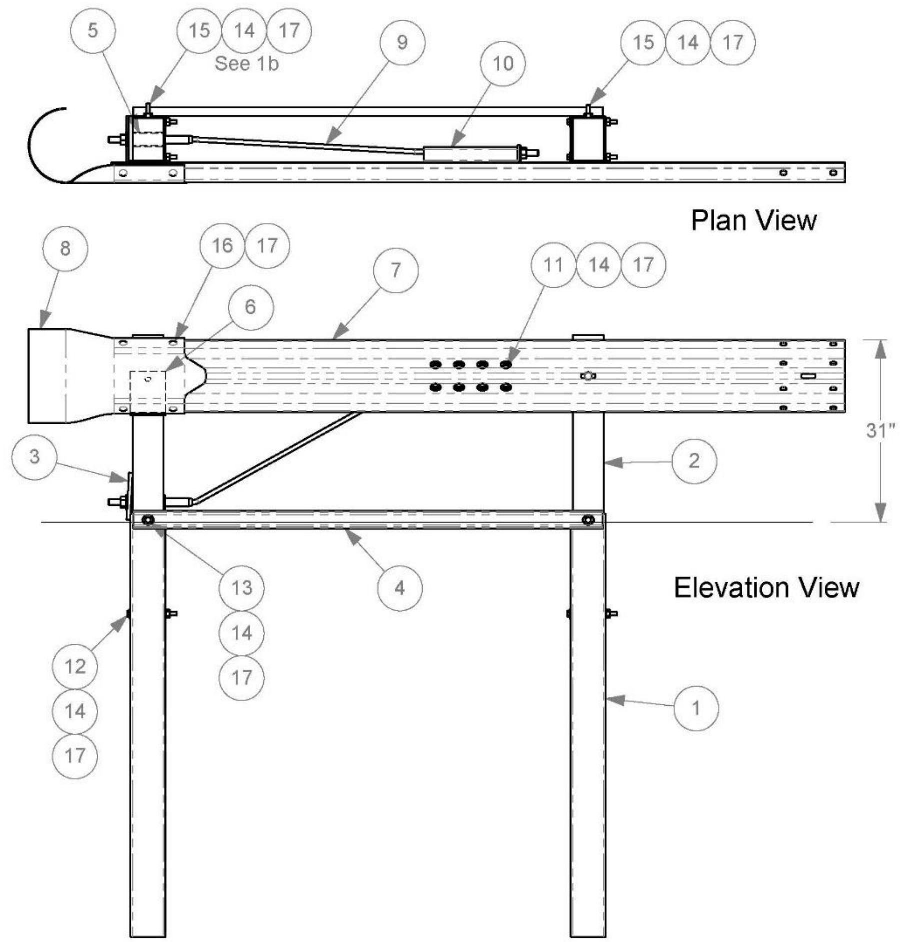
Figure G.6. Vehicle Vertical Accelerometer Trace for Test No. 610211-01-3 (Accelerometer Located at Center of Gravity).

APPENDIX H. DETAILS OF THE MGS WITH HALF POST SPACING AND SHORTENED BLOCKOUTS



Q:\Accreditation-17025-2017\EIR-000 Project Files\610211-01- Reduced Post Spacing-Kovar\610211-6 Half Spacing\Drafting, 610211-6\610211-6 Drawing





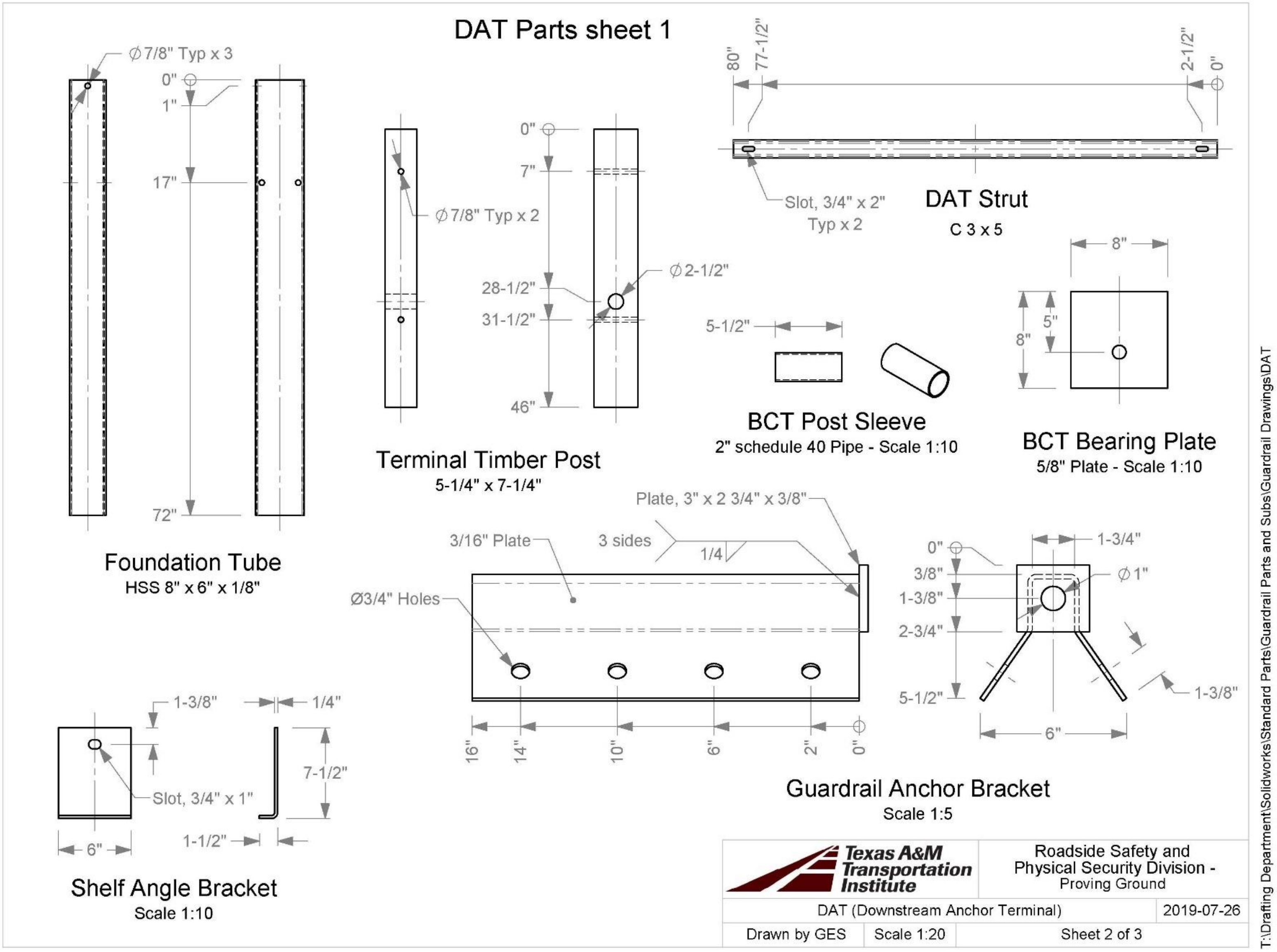
#	Part Name	Qty.
1	Foundation Tube	2
2	Terminal Timber Post	2
3	BCT Bearing Plate	1
4	DAT Strut	2
5	BCT Post Sleeve	1
6	Shelf Angle Bracket	1
7	DAT Terminal Rail	1
8	W-beam End Section	1
9	Anchor Cable Assembly	1
10	Guardrail Anchor Bracket	1
11	Bolt, 5/8 x 2" hex	8
12	Bolt, 5/8 x 8" hex	4
13	Bolt, 5/8 x 10" hex	2
14	Washer, 5/8 F844	16
15	10" Guardrail Bolt	2
16	1-1/4" Guardrail Bolt	4
17	Recessed Guardrail Nut	20

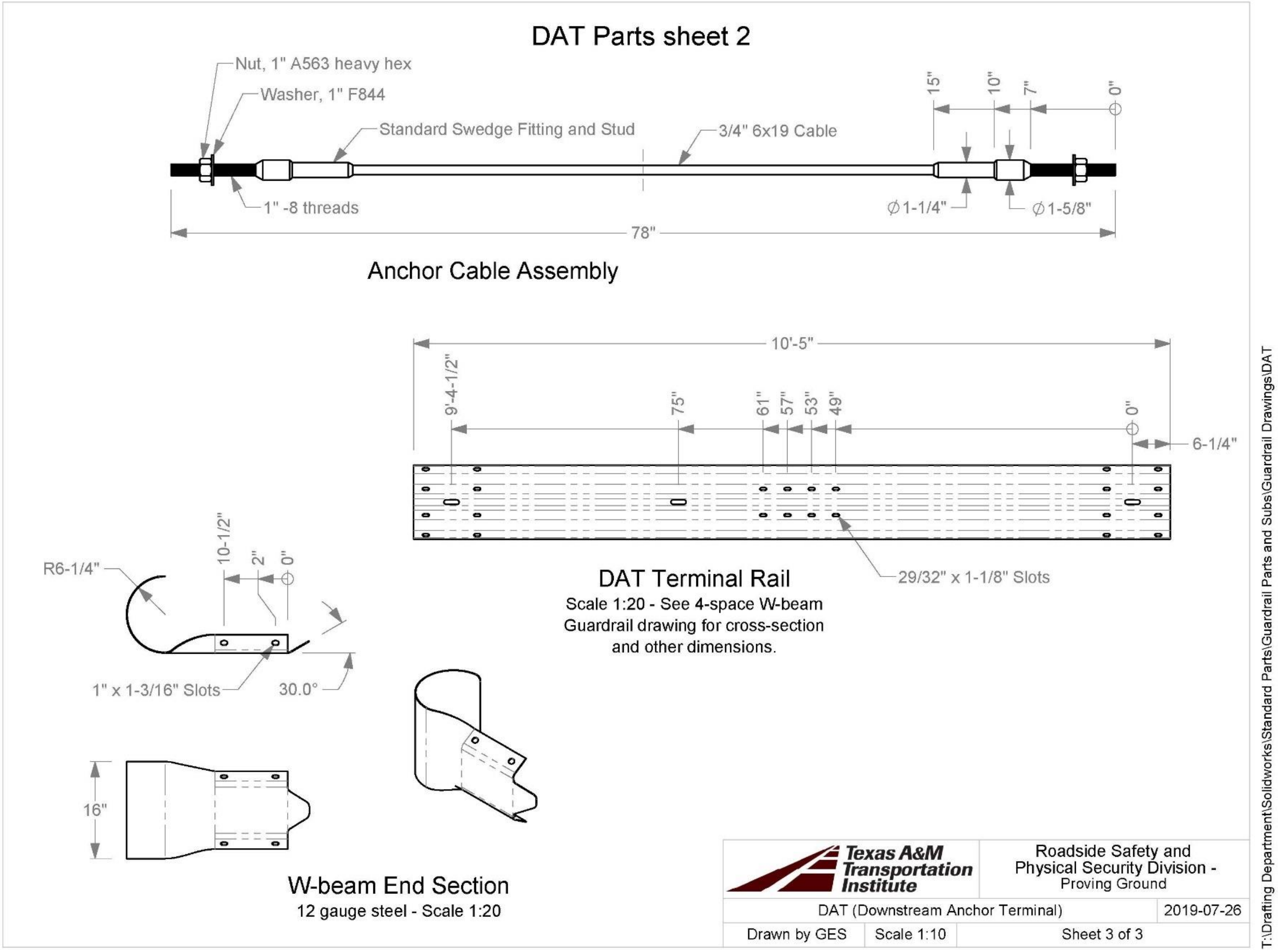
1a. All bolts are ASTM A307.

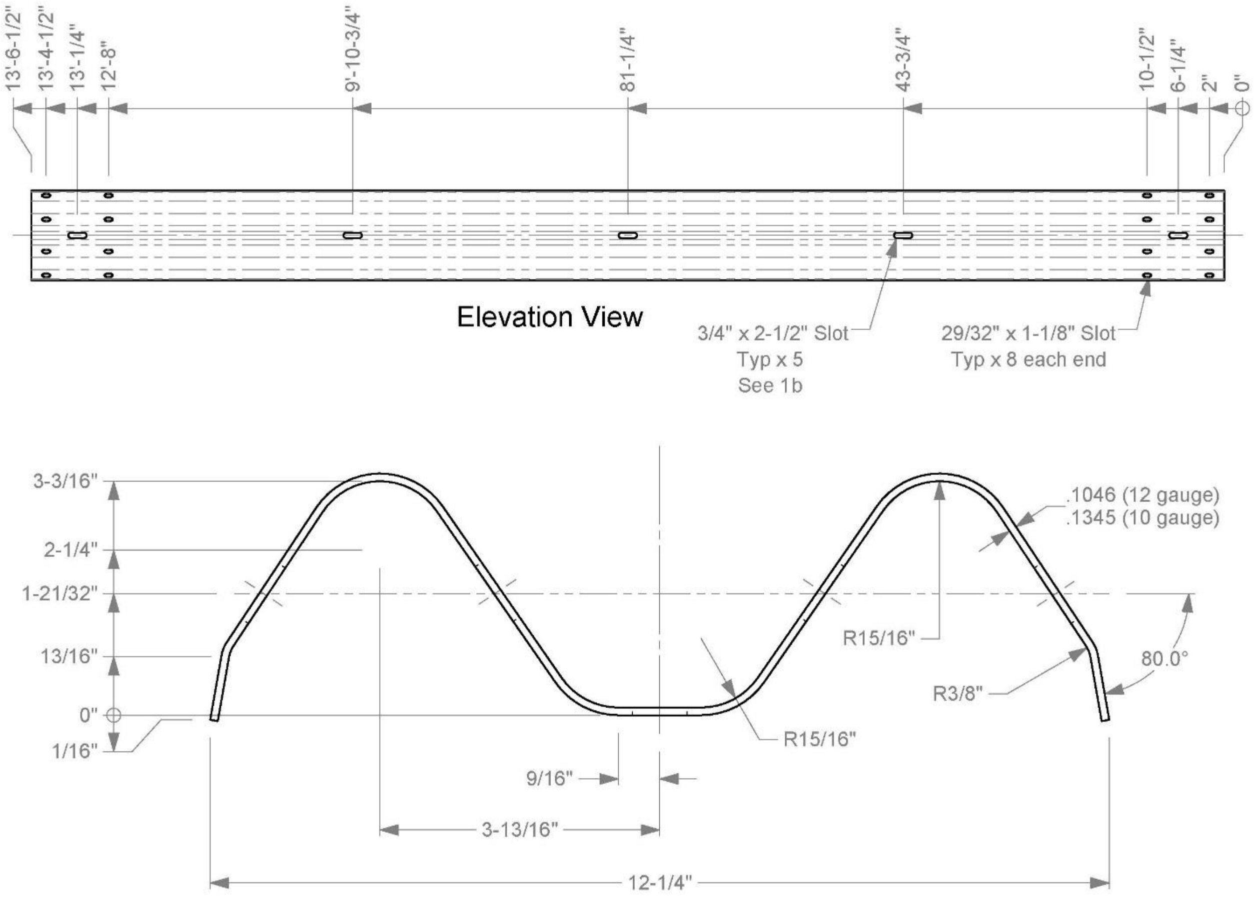
1b. Hardware secures Shelf Angle Bracket to Post. Rail is supported by Shelf Angle Bracket and does not attach directly to Post.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
DAT (Downstream Anchor Terminal)			2019-07-26
Drawn by GES	Scale 1:25	Sheet 1 of 3	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\DAT


DAT Parts sheet 1
⌀7/8" Typ x 3
0"
1"
17"
72"
Foundation Tube
HSS 8" x 6" x 1/8"
⌀7/8" Typ x 2
0"
7"
28-1/2"
31-1/2"
46"
⌀2-1/2"
Terminal Timber Post
5-1/4" x 7-1/4"
80"
77-1/2"
2-1/2"
0"
Slot, 3/4" x 2"
Typ x 2
DAT Strut
C 3 x 5
5-1/2"
BCT Post Sleeve
2" schedule 40 Pipe - Scale 1:10
8"
5"
8"
BCT Bearing Plate
5/8" Plate - Scale 1:10
Plate, 3" x 2 3/4" x 3/8"
3/16" Plate
3 sides
1/4
Ø3/4" Holes
16"
14"
10"
6"
2"
0"
0"
3/8"
1-3/8"
2-3/4"
5-1/2"
1-3/4"
⌀1"
1-3/8"
6"
Guardrail Anchor Bracket
Scale 1:5
1-3/8"
1/4"
7-1/2"
Slot, 3/4" x 1"
1-1/2"
6"
Shelf Angle Bracket
Scale 1:10
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)
2019-07-26
Drawn by GES
Scale 1:20
Sheet 2 of 3
T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts and Subs\Guardrail Drawings\DAT


DAT Parts sheet 2
Nut, 1" A563 heavy hex
Washer, 1" F844
Standard Swedge Fitting and Stud
3/4" 6x19 Cable
15"
10"
7"
0"
1" -8 threads
∅1-1/4"
∅1-5/8"
78"
Anchor Cable Assembly
10'-5"
9'-4-1/2"
75"
61"
57"
53"
49"
0"
6-1/4"
DAT Terminal Rail
Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.
29/32" x 1-1/8" Slots
R6-1/4"
10-1/2"
2"
0"
1" x 1-3/16" Slots
30.0°
16"
W-beam End Section
12 gauge steel - Scale 1:20
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)
2019-07-26
Drawn by GES
Scale 1:10
Sheet 3 of 3
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\DAT

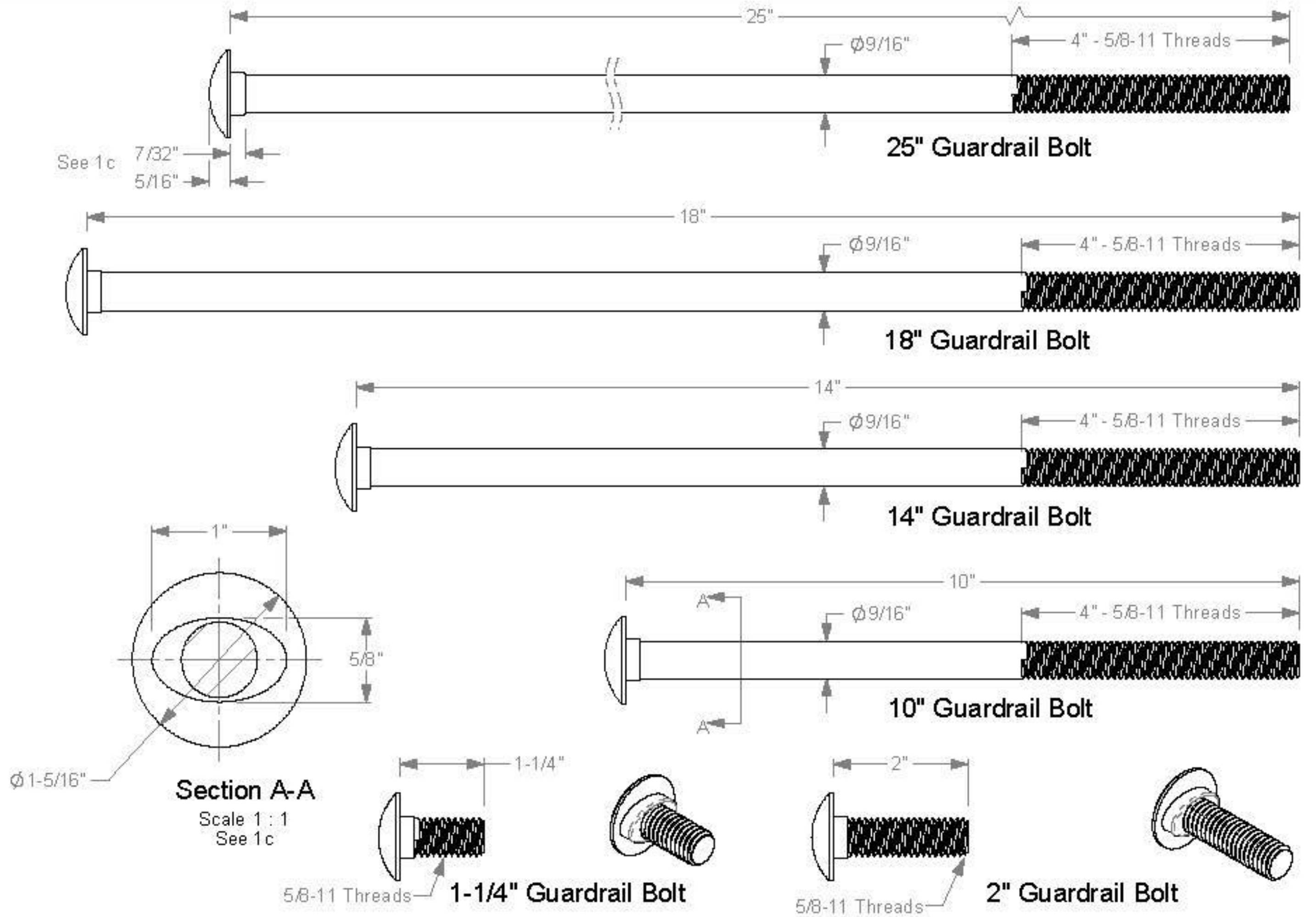


Section View

1a. Manufacture per AASHTO M180 specifications.

1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
4-space W-beam Guardrail			2020-06-05
Drawn by GES	Scale 1:20	Sheet 1 of 1	

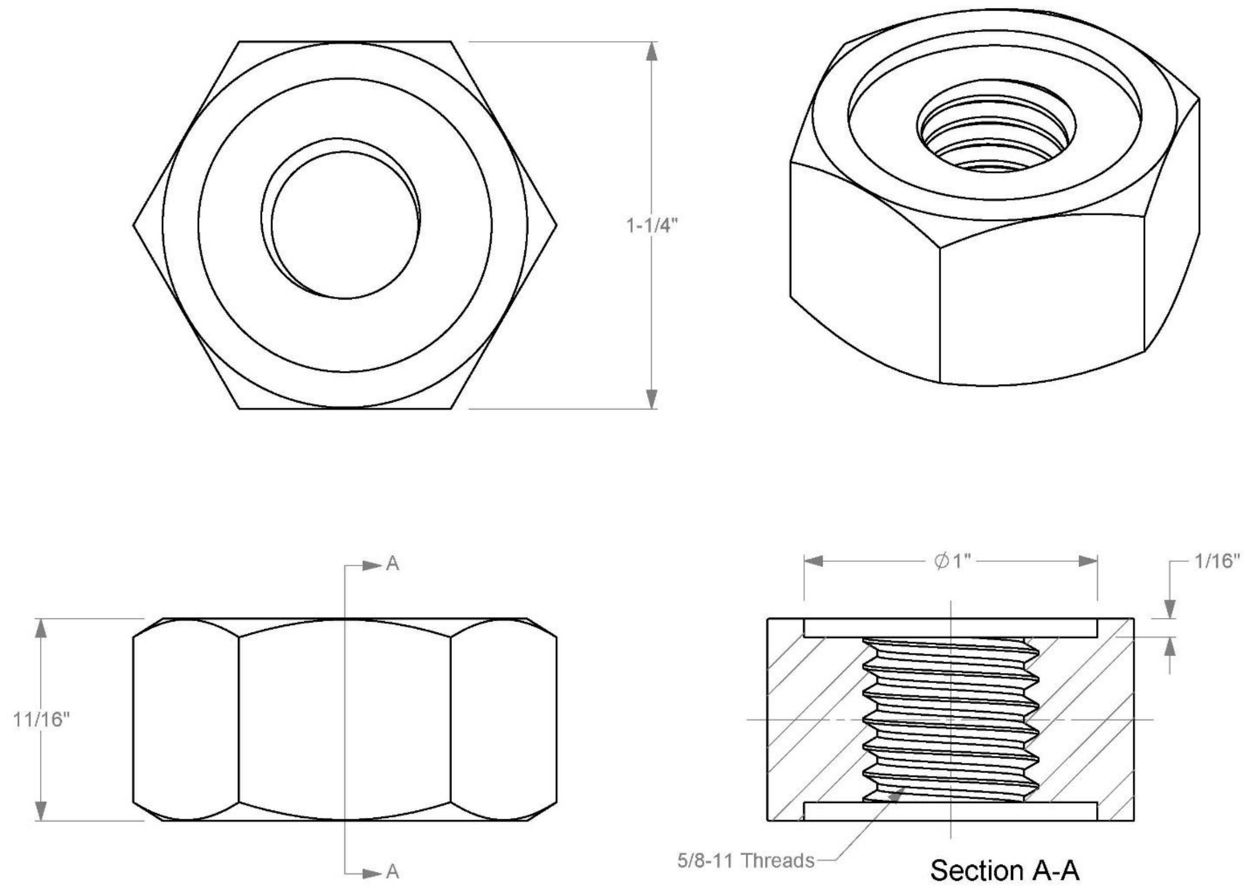


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Guardrail Bolt		2020-04-22
Drawn by GES/WS	Scale 1:2	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Guardrail Bolt

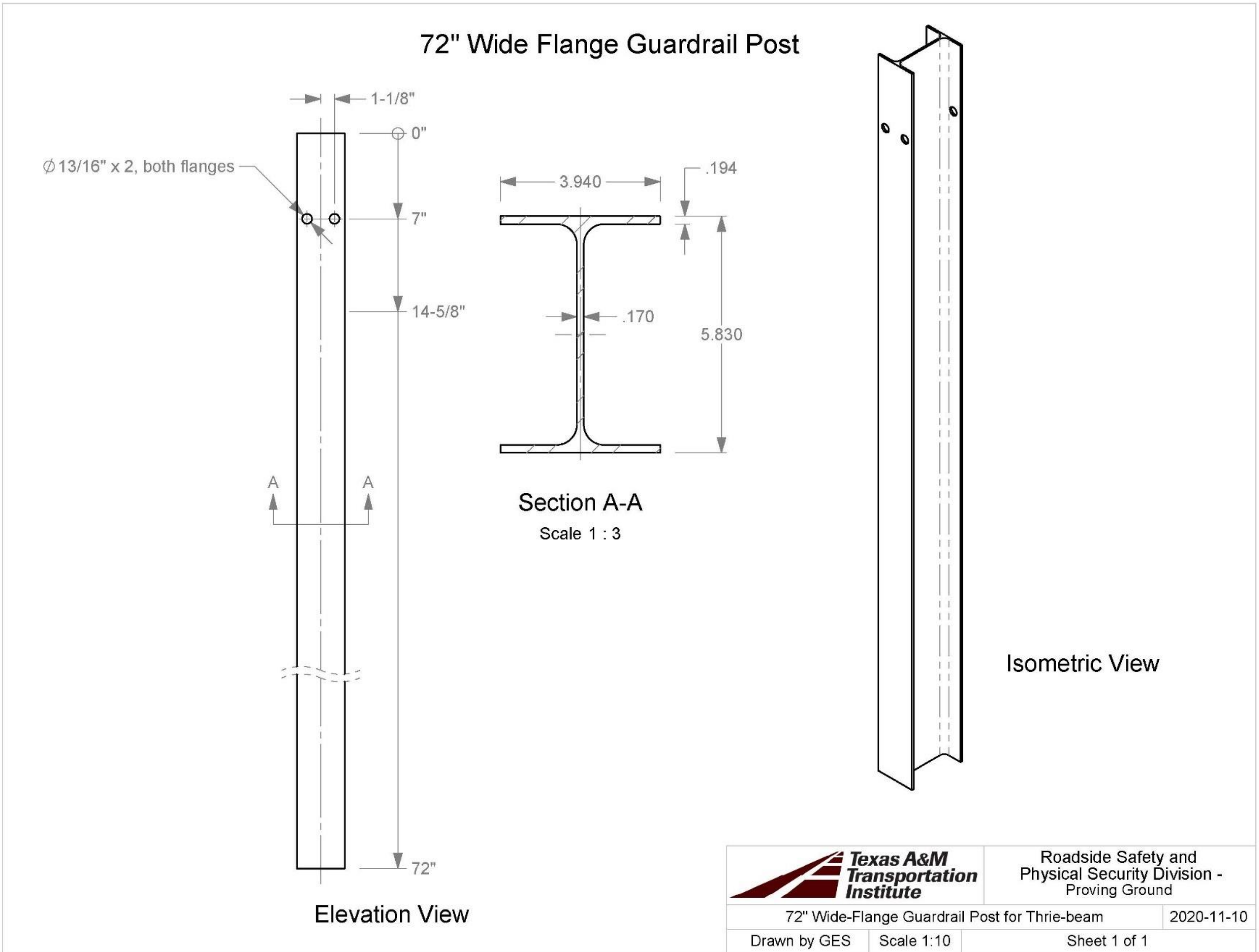
Recessed Guardrail Nut



1a. Material is ASTM A 563 Grade A.

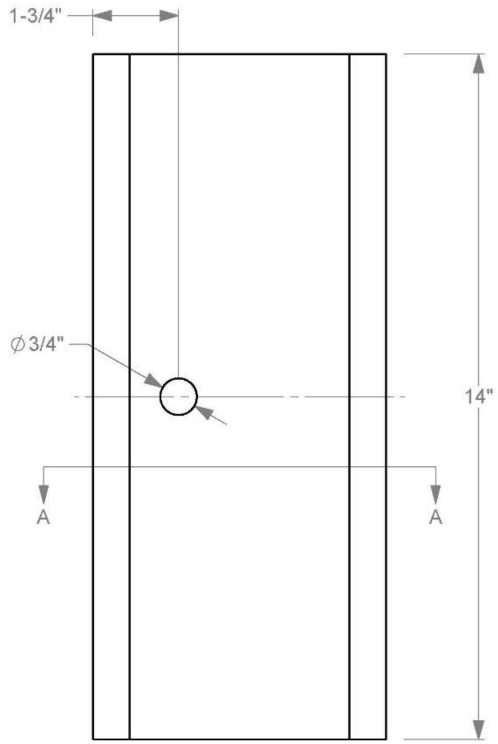
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Recessed Guardrail Nut			2019-06-27
Drawn by GES	Scale 2:1	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Nut, Recessed Guardrail

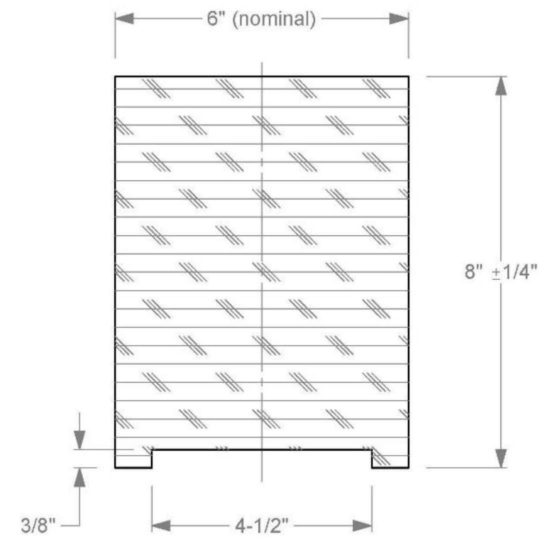


T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

Timber Blockout for W-section Post



Elevation View



Section A-A

1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Timber Blockout, for W-section Post		2019-07-03
Drawn by GES	Scale 1:3	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Timber Blockout for W-section Post

APPENIDX I. *MASH* TEST 3-11 (CRASH TEST NO. 610211-01-6)

I1 VEHICLE PROPERTIES AND INFORMATION

Table I.1. Vehicle Properties for Test No. 610211-01-6.

Date: 2021-3-6 Test No.: 610211-01-6 VIN No.: 1C6RR6FT3GS405356

Year: 2016 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 143243

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

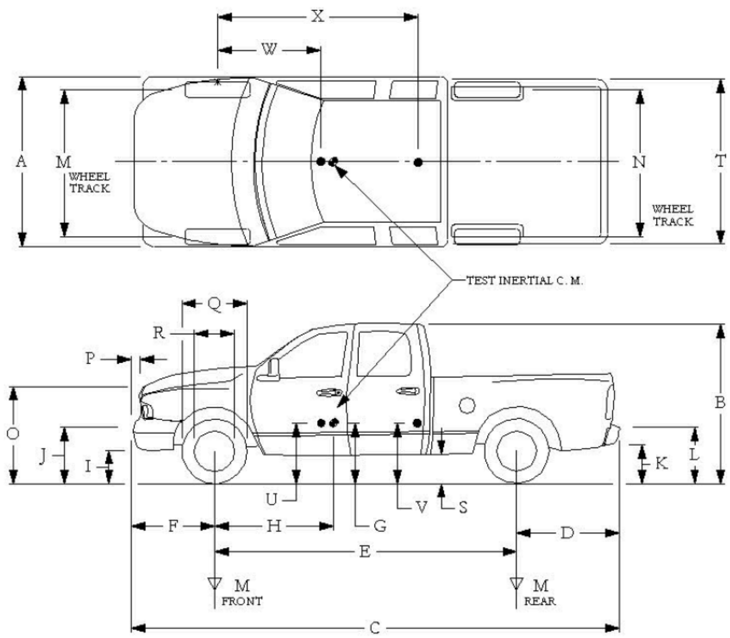
NOTES: None

Engine Type: V-8
Engine CID: 5.7L

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

Optional Equipment:
None

Dummy Data:
Type: NONE
Mass: 0 lb
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.60	L	30.00	Q	30.50	V	30.25
C	227.50	H	62.37	M	68.50	R	18.00	W	62.40
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
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}	2896	2802	2802
Back	3900	M_{rear}	2175	2237	2237
Total	6700	M_{Total}	5071	5039	5039

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

Mass Distribution:
lb LF: 1392 RF: 1410 LR: 1165 RR: 1072

Table I.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 610211-01-6.

Date: 2021-3-6 Test No.: 610211-01-6 VIN: 1C6RR6FT3GS405356

Year: 2016 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 143243

Engine: 5.7L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 130 (440 lb max)

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

Measured Vehicle Weights:		(lb)							
LF:	1392		RF:	1410			Front Axle:	2802	
LR:	1165		RR:	1072			Rear Axle:	2237	
Left:	2557		Right:	2482			Total:	5039	
							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:	62.37	inches	Rear of Front Axle		(63 ±4 inches allowed)				
Y:	-0.51	inches	Left -	Right +	of Vehicle Centerline				
Z:	28.60	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 I.3. Exterior Crush Measurements for Test No. 610211-01-6.

Date:	2021-3-6	Test No.:	610211-01-6	VIN No.:	1C6RR6FT3GS405356
Year:	2016	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	Front plane at bmp ht	14	14	24	-	-	-	-	-	-	-22
2	Side plane above bmp	14	10	60	-	-	-	-	-	-	74
	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.

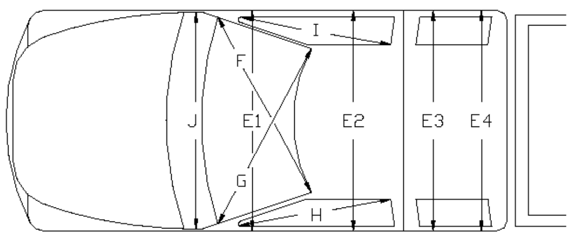
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

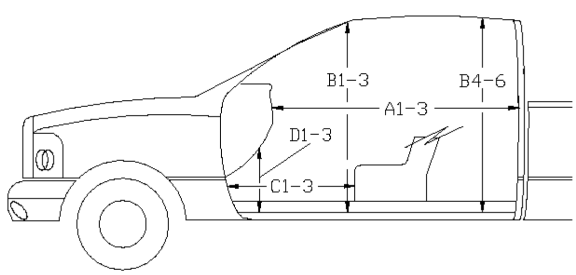
***Measure and document on the vehicle diagram the location of the maximum crush.

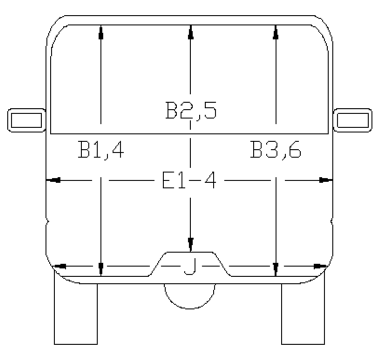
Note: Use as many lines/columns as necessary to describe each damage profile.

Table I.4. Occupant Compartment Measurements for Test No. 610211-01-6.

Date:	2021-3-6	Test No.:	610211-01-6	VIN No.:	1C6RR6FT3GS405356
Year:	2016	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	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
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	58.50	0.00
E2	63.50	63.50	0.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	25.00	0.00

I2 SEQUENTIAL PHOTOGRAPHS

0.000 s

0.100 s

0.200 s

0.300 s

Figure I.1. Sequential Photographs for Test No. 610211-01-6 (Overhead and Frontal Views).


0.400 s



0.500 s



0.600 s

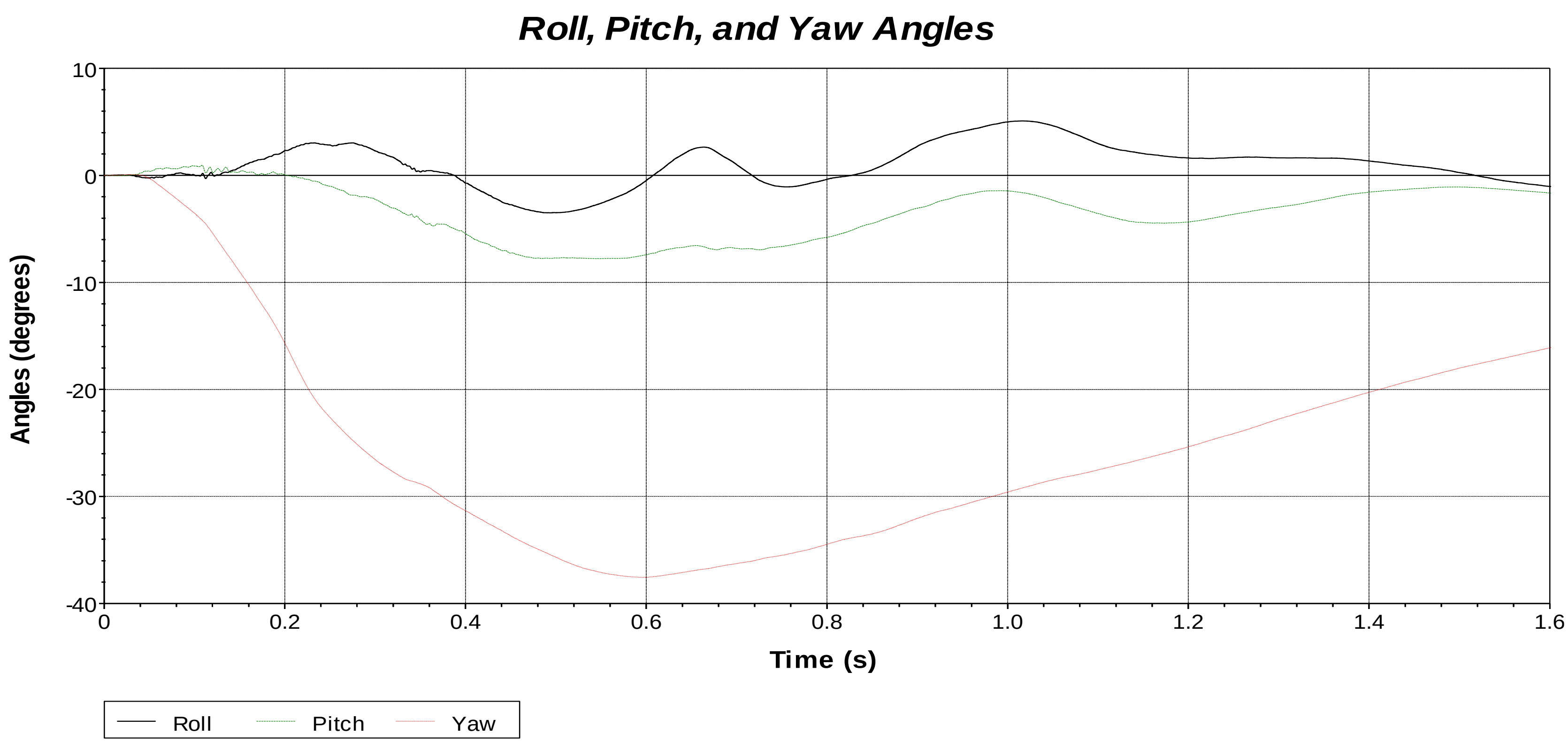


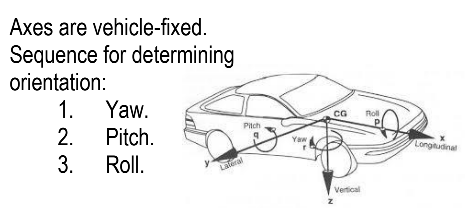
0.700 s


Figure I.1. Sequential Photographs for Test No. 610211-01-6 (Overhead and Frontal Views) (Continued).

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

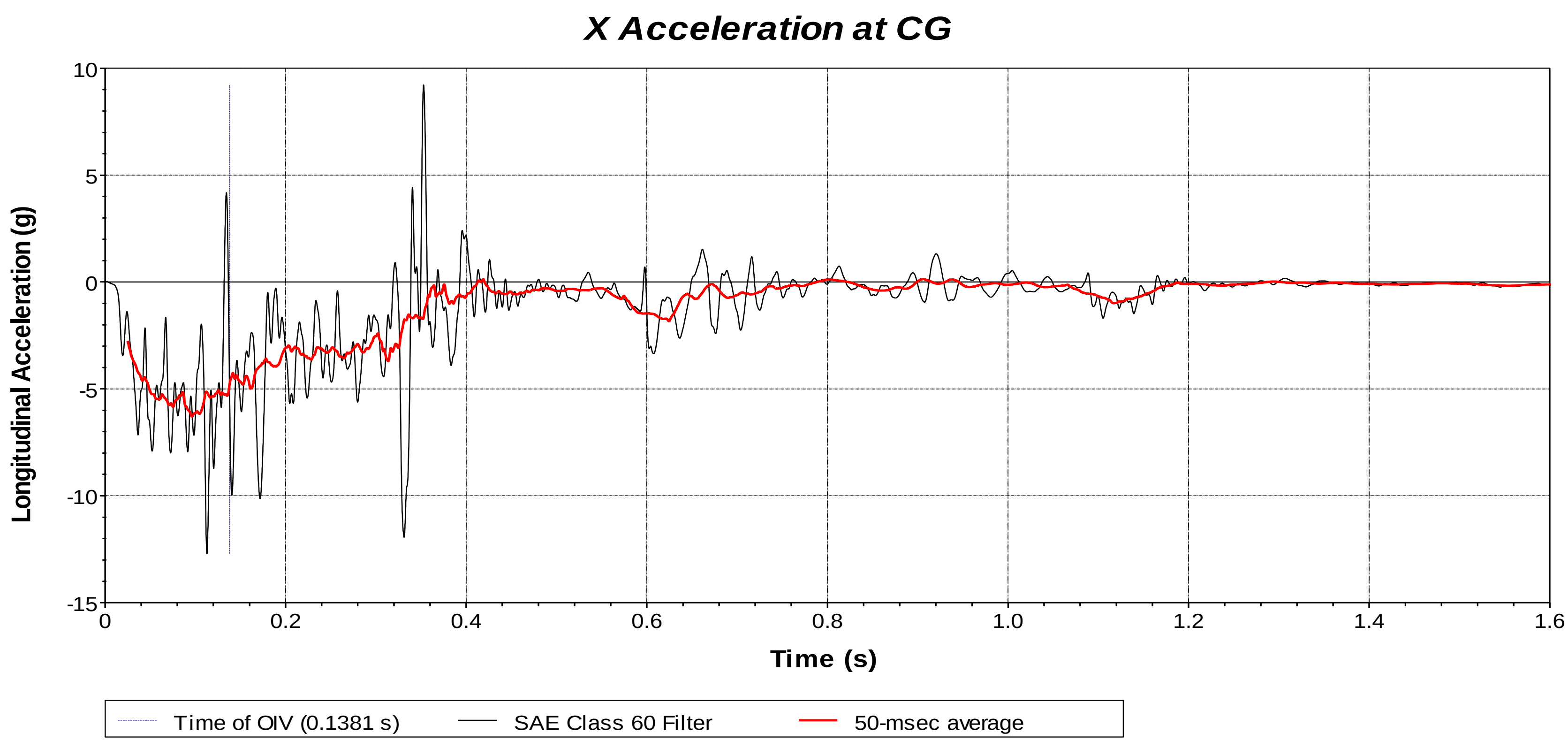
Figure I.2. Sequential Photographs for Test No. 610211-01-6 (Rear View).





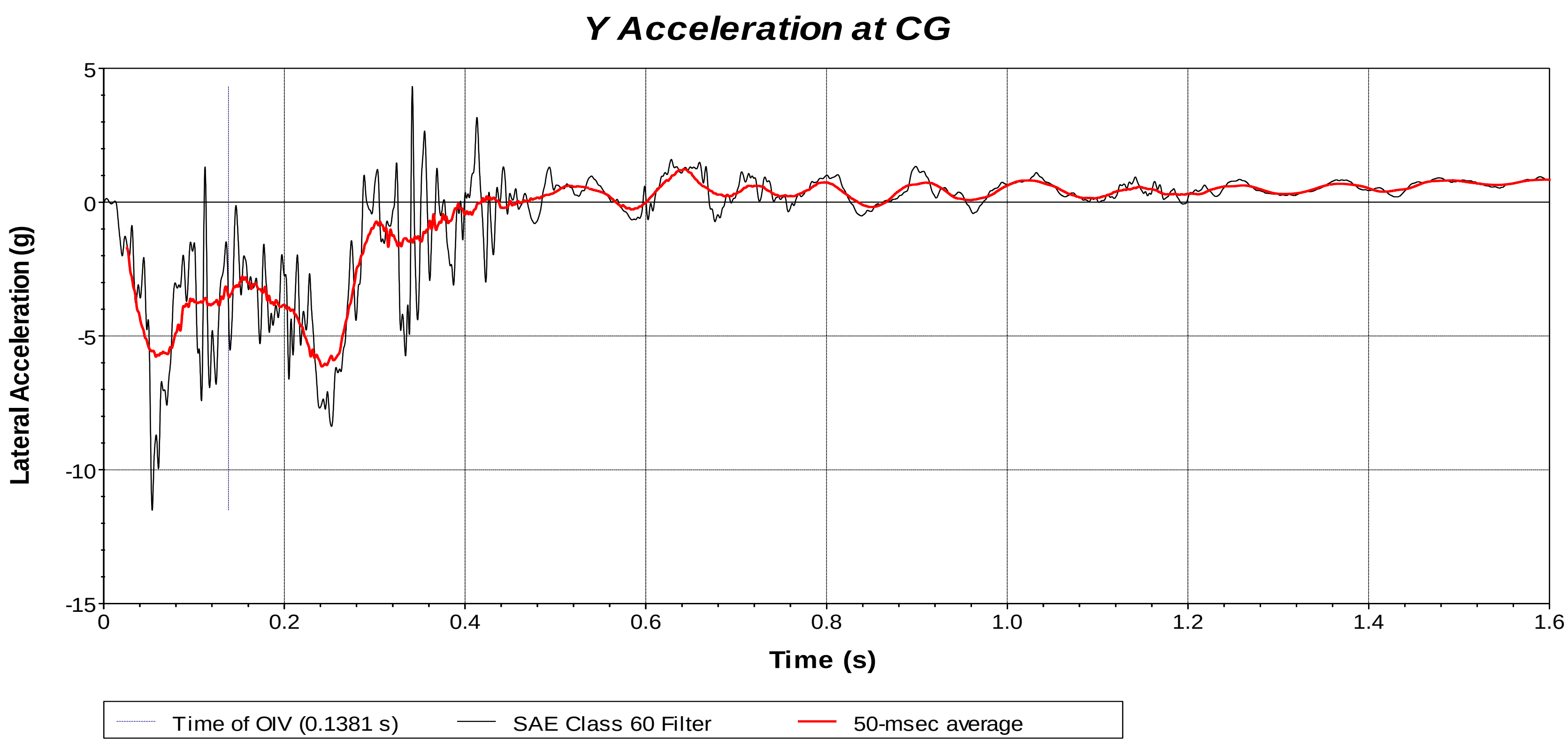
Test Number: 610211-01-6
Test Standard Test Number: *MASH* Test 3-11
Test Article: MGS with Half-Post Spacing with Shortened Blockouts
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5039 lb
Gross Mass: 5039 lb
Impact Speed: 63.3 mi/h

Figure I.3. Vehicle Angular Displacements for Test No. 610211-01-6.



Test Number: 610211-01-6
Test Standard Test Number: *MASH* Test 3-11
Test Article: MGS with Half-Post Spacing with Shortened Blockouts
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5039 lb
Gross Mass: 5039 lb
Impact Speed: 63.3 mi/h

Figure I.4. Vehicle Longitudinal Accelerometer Trace for Test No. 610211-01-6 (Accelerometer Located at Center of Gravity).



Test Number: 610211-01-6
Test Standard Test Number: *MASH* Test 3-11
Test Article: MGS with Half-Post Spacing with Shortened Blockouts
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5039 lb
Gross Mass: 5039 lb
Impact Speed: 63.3 mi/h

Figure I.5. Vehicle Lateral Accelerometer Trace for Test No. 610211-01-6 (Accelerometer Located at Center of Gravity).

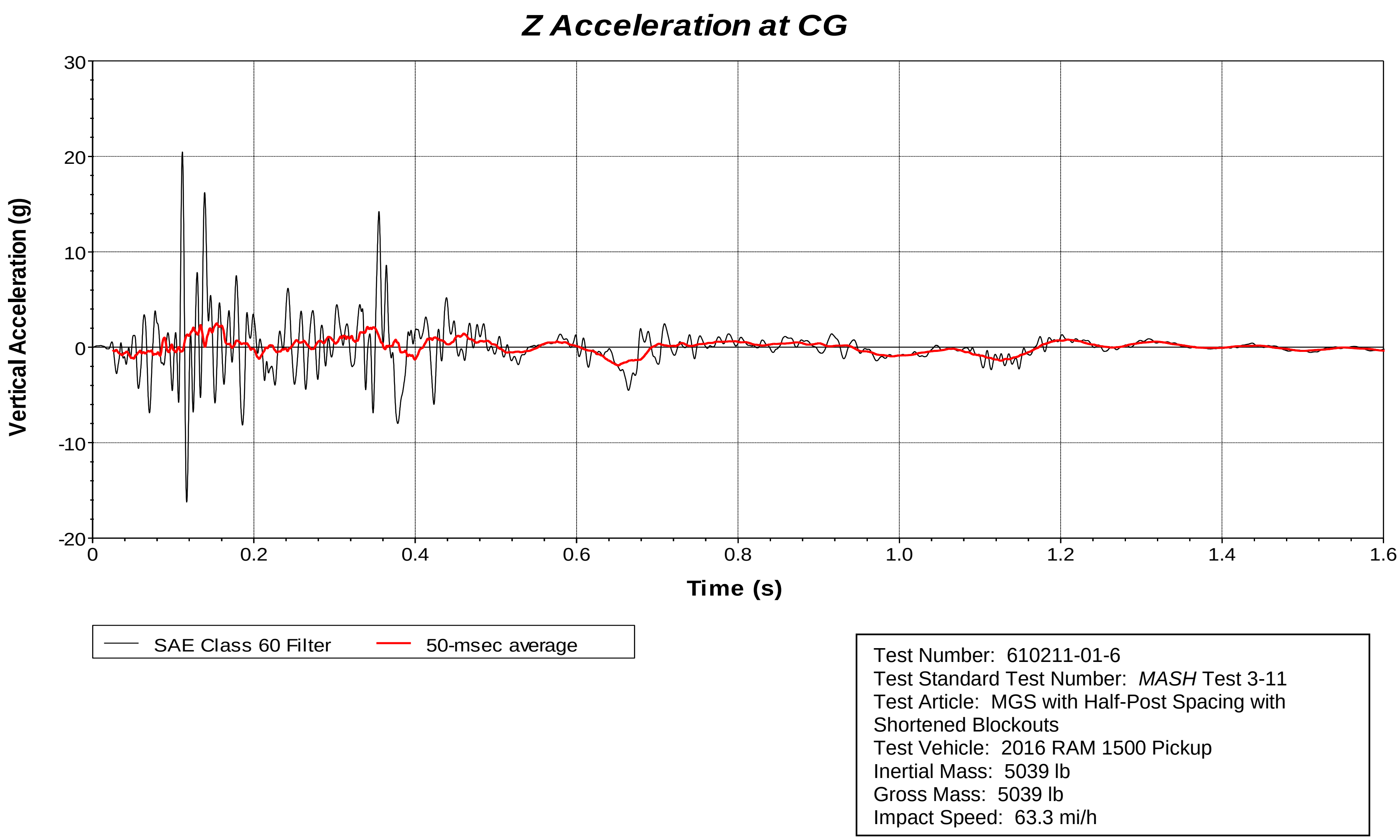
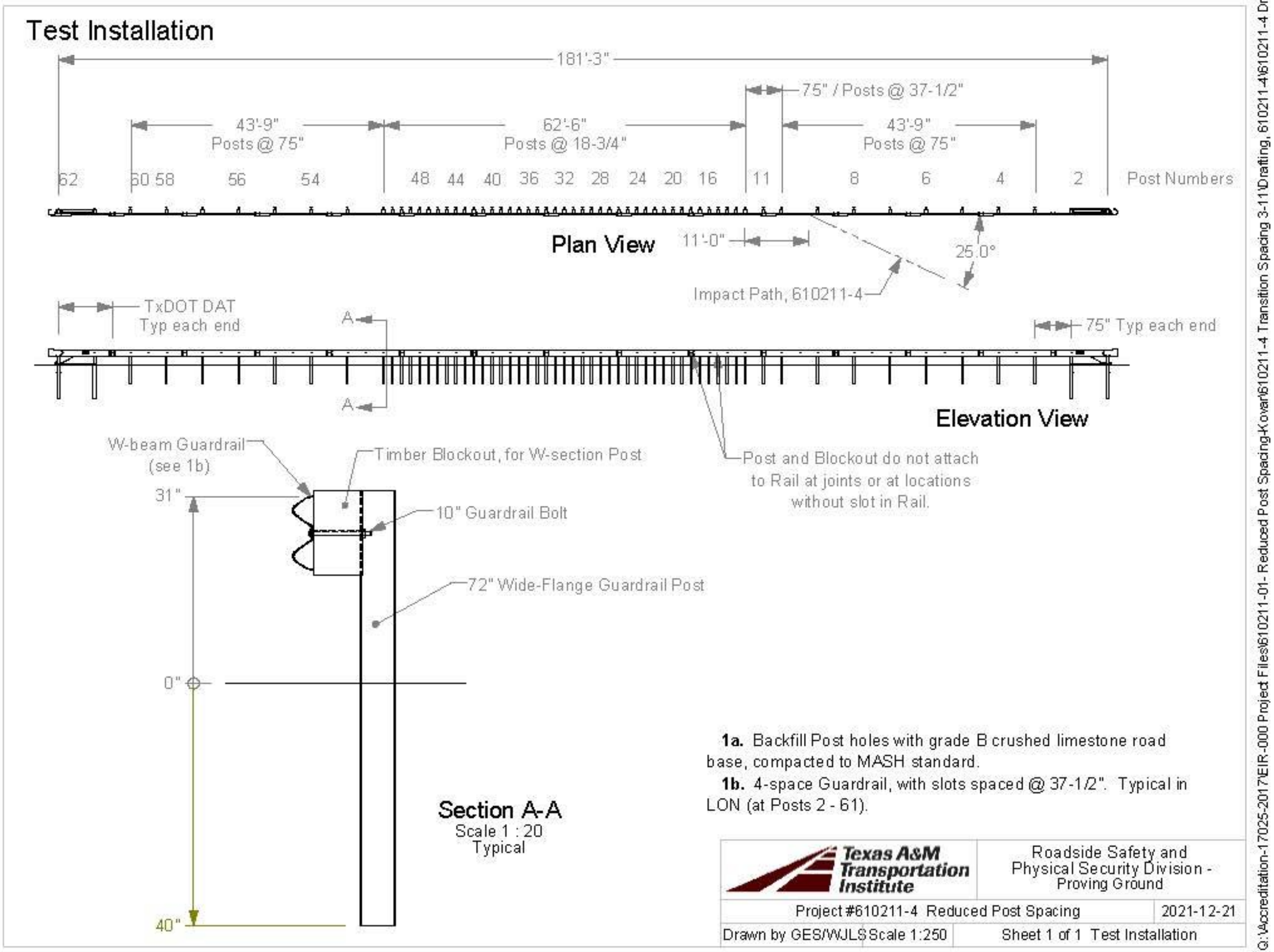
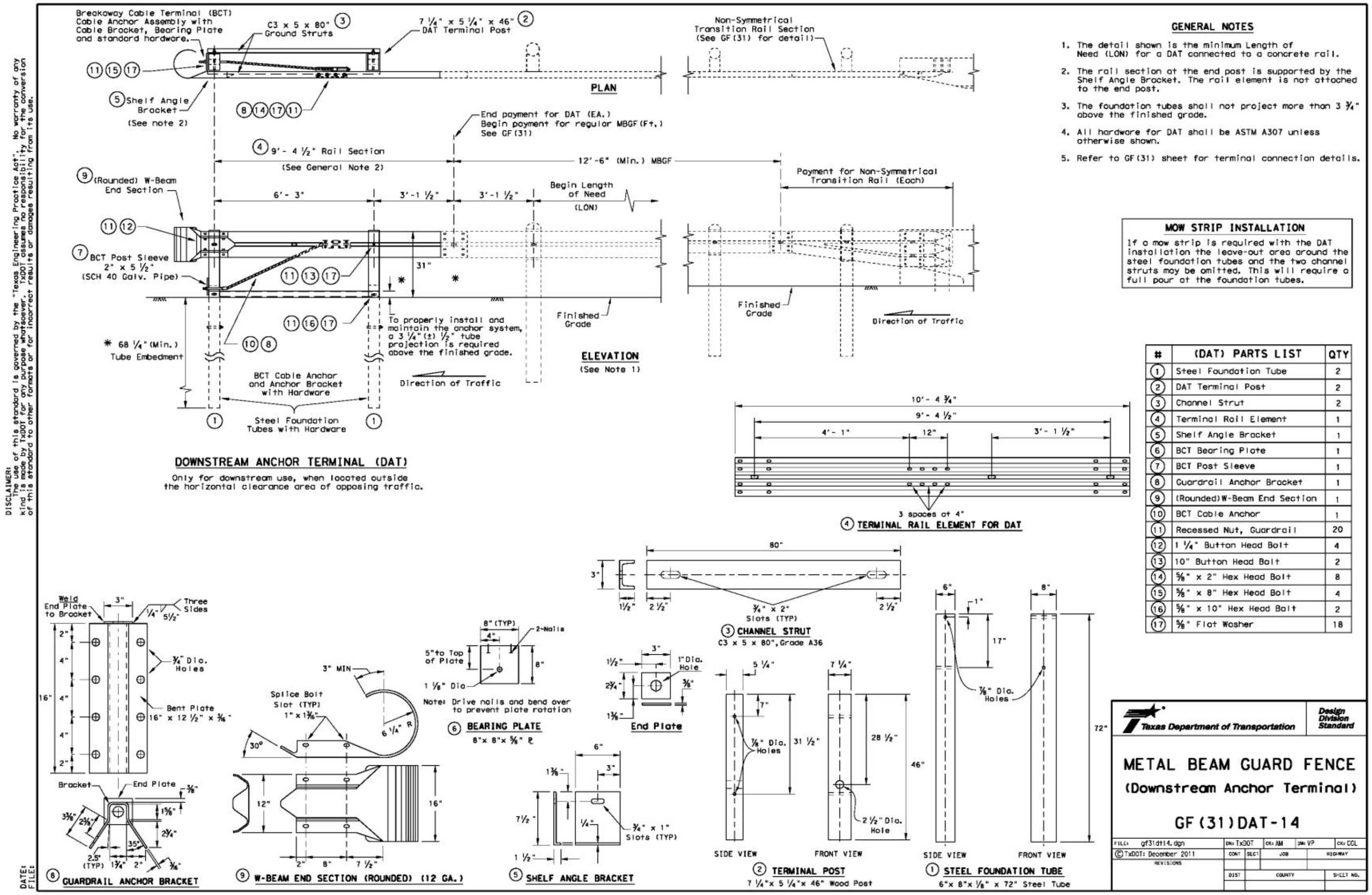


Figure I.6. Vehicle Vertical Accelerometer Trace for Test No. 610211-01-6 (Accelerometer Located at Center of Gravity).

APPENDIX J. DETAILS OF THE TRANSITION FROM FULL TO QUARTER POST SPACING





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

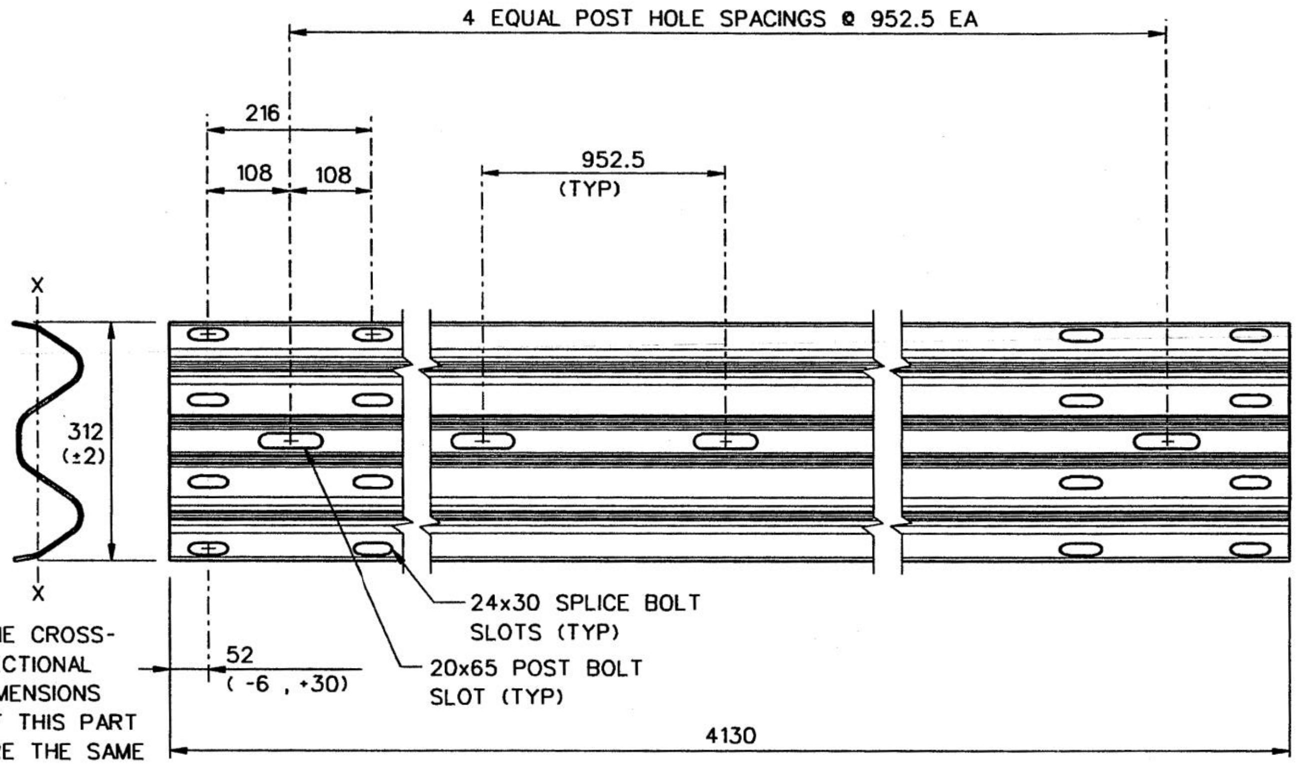
If a mow strip is required with the DAT installation the leave-out area around the steel foundation tubes and the two channel struts may be omitted. This will require a full pour at the foundation tubes.

#	(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

1994

4-SPACE W-BEAM GUARDRAIL

DESIGNATOR	BASE METAL THICKNESS
RWM04a	2.67
RWM04b	3.43



THE CROSS-SECTIONAL DIMENSIONS OF THIS PART ARE THE SAME AS PART RWM02a (SHT 3 of 4).

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

RWM04a-b

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	--

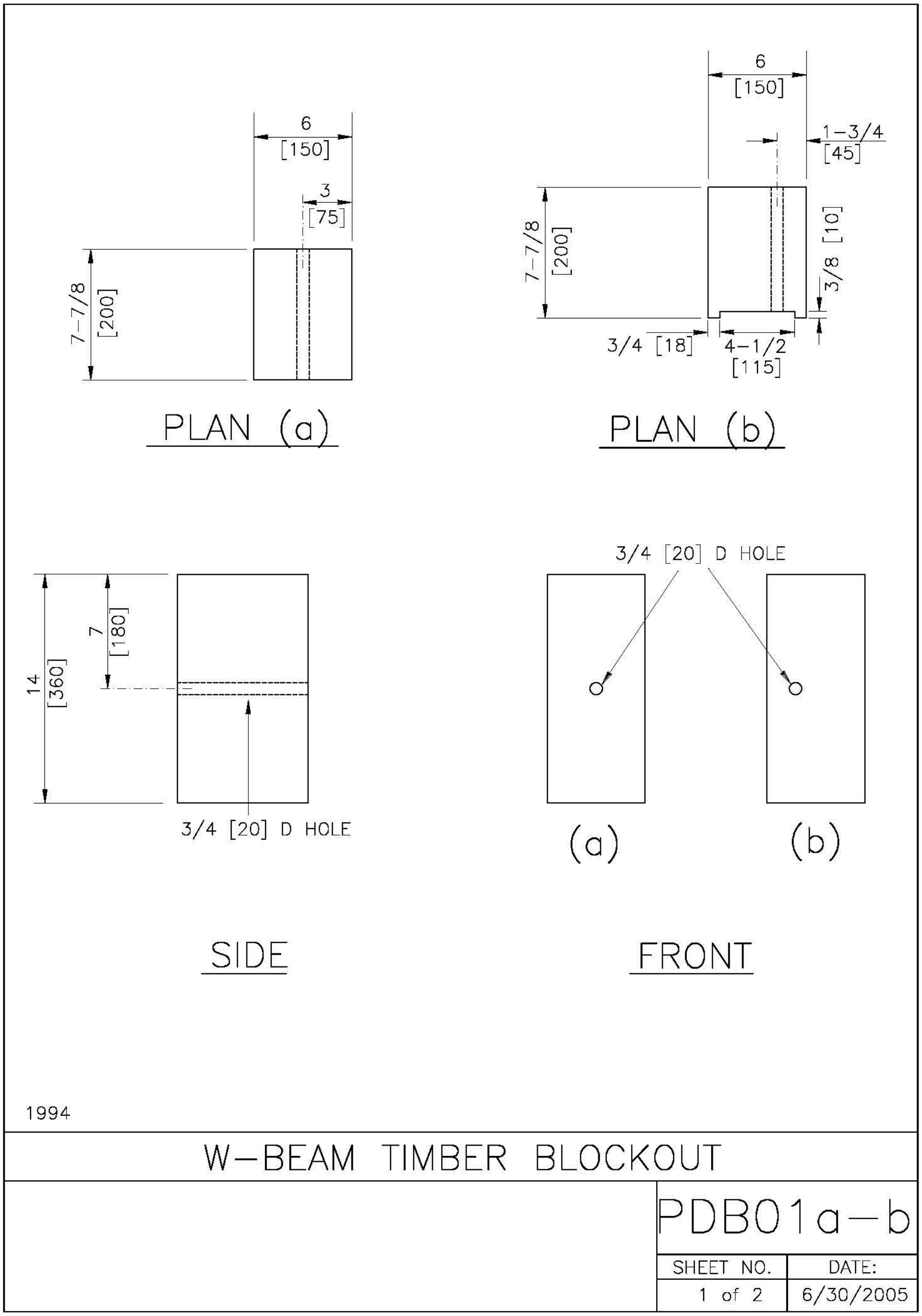
Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

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]
3/8 [10]
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.

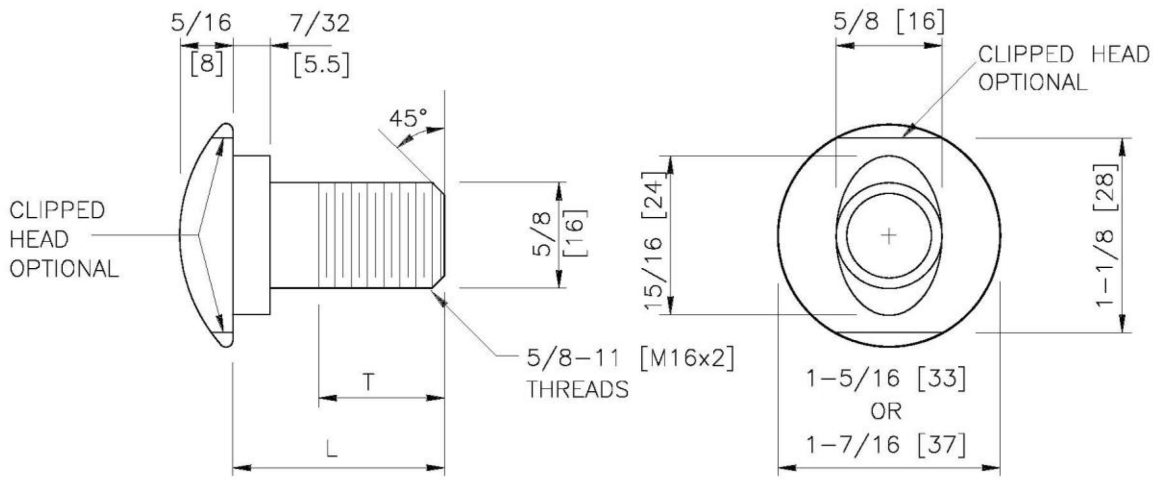
INTENDED USE

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.

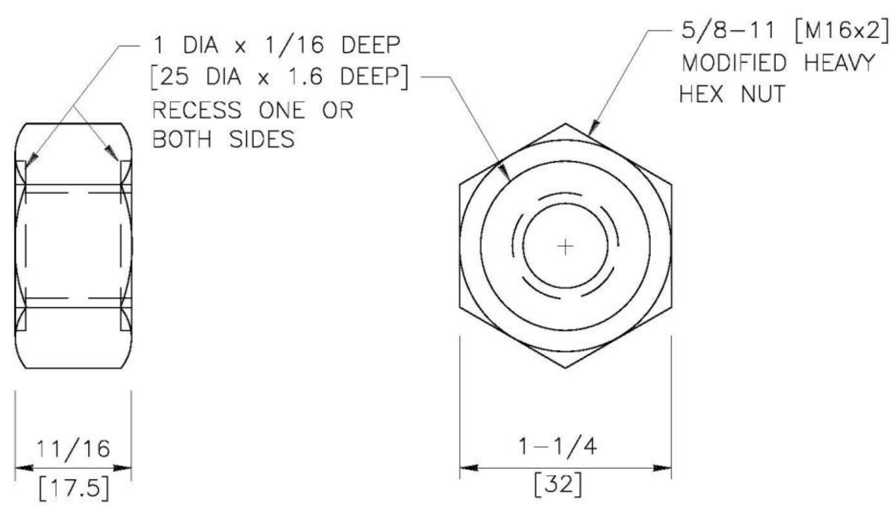
W-BEAM TIMBER BLOCKOUT

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 [32]	1–1/8 [28]
FBB02	2 [51]	1–3/4 [44]
FBB03	10 [254]	4 [102]
FBB04	18 [457]	4 [102]
FBB05	25 [635]	4 [102]



GUARDRAIL BOLT AND RECESSED NUT

TF13	FBB01–05	
	SHEET NO.	DATE:
	1 of 2	5/2/2018

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.

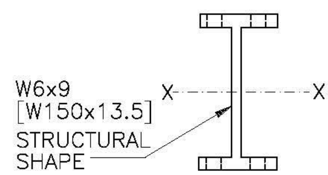
GUARDRAIL BOLT AND RECESSED NUT

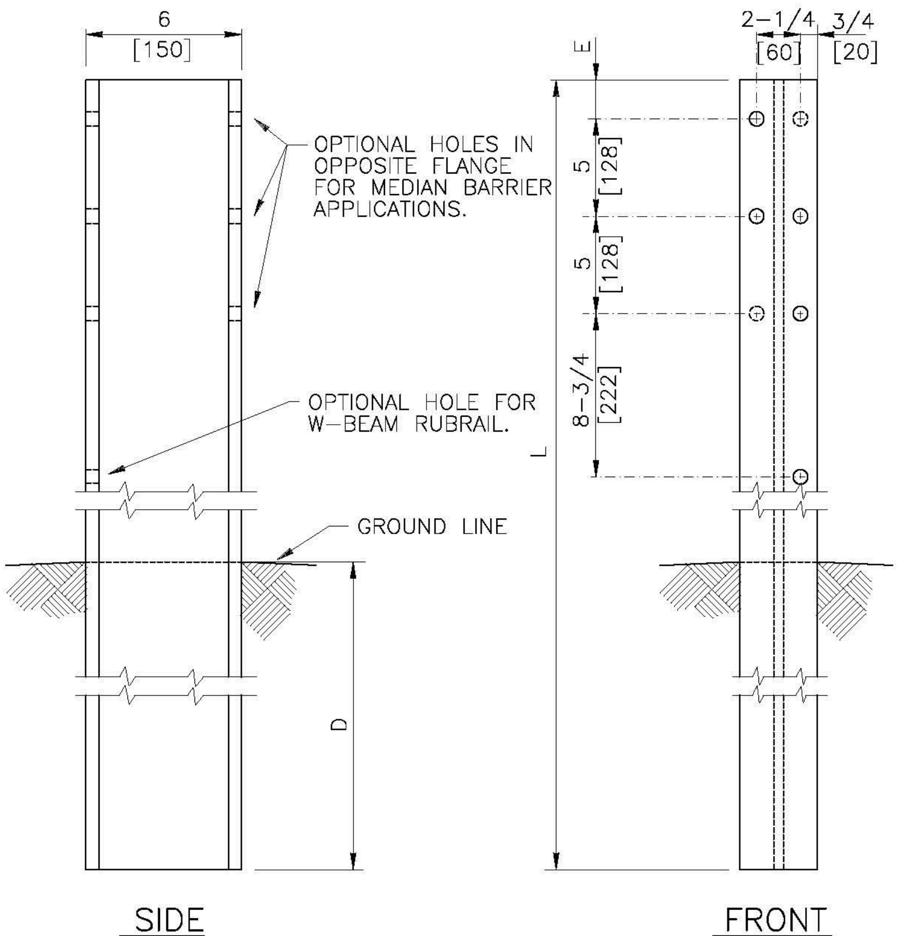
FBB01-05	
SHEET NO.	DATE
2 of 2	5/2/2018

TF 13

DESIGNATOR	L	D	E
PWE01	72 [1830]	43-1/4 [1100]	2 [52]
PWE02	78 [1980]	49-1/4 [1250]	2 [52]
PWE03	78 [1980]	45-3/8 [1153]	5-7/8 [149]
PWE04	81 [2060]	46-1/8 [1173]	5-7/8 [149]

NOTE: ALL HOLES ARE 3/4 [20] D.





1994

WIDE-FLANGE GUARDRAIL POST

PWE01-04

SHEET NO.	DATE:
1 of 2	7/27/2005

SPECIFICATIONS

W-beam and thrie-beam guardrail posts shall be manufactured using AASHTO M 270 / M 270M (ASTM A 709 / A 709M) Grade 36 [250] steel unless corrosion-resistant steel is required, in which case the post shall be manufactured from AASHTO M 270 / M 270M (ASTM A 709 / A 709M) Grade 50W [345W] steel. The dimensions of the cross-section shall conform to a W6x9 [W150x13.5] section as defined in AASHTO M 160 / M 160M (ASTM A 6 / A 6M). [W150x12.6] wide flange posts are an acceptable alternative that is considered equivalent to the [W150x13.5].

After the section is cut and all holes are drilled or punched, the component should be zinc-coated according to AASHTO M 111 (ASTM A 123) unless corrosion-resistant steel is used. When corrosion-resistant steel is used, the portion of the post to be embedded in soil shall be zinc-coated according to AASHTO M 111 (ASTM A 123) and the portion above the soil shall not be zinc-coated, painted or otherwise treated.

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]
PWE01-04	2.63 [1.7]	16.43 [6.84]	2.19 [0.91]	5.57 [91.2]	1.11 [18.2]

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

Posts PWE01 and PWE02 are used with the SGR04a and SGR04c guardrails and the SGM04a median barrier. Blockouts like PWB01 (steel) or PDB01 (wood) are attached to each post.

Post PWE03 is used with the SGR09a guardrail and the SGM09a median barrier. Wood or plastic blockouts like the PWB02 are attached to each post with FBB03 bolts and FWC16a washers under the nuts.

Post PWE04 is used with the SGR09b guardrail and the SGM09b median barrier. A modified steel blockout PWB03 is attached to each post with at least two 1.5-inch [40 mm] long FBX16a bolts and nuts.

WIDE-FLANGE GUARDRAIL POST

PWE01-04

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

APPENDIX K. *MASH* TEST 3-21 (CRASH TEST NO. 610211-01-4)

K1 VEHICLE PROPERTIES AND INFORMATION

Table K.1. Vehicle Properties for Test No. 610211-01-4.

Date: 2018-11-27 Test No.: 610211-01-4 VIN No.: 1C6RR6FP9DS523586

Year: 2013 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 233576

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

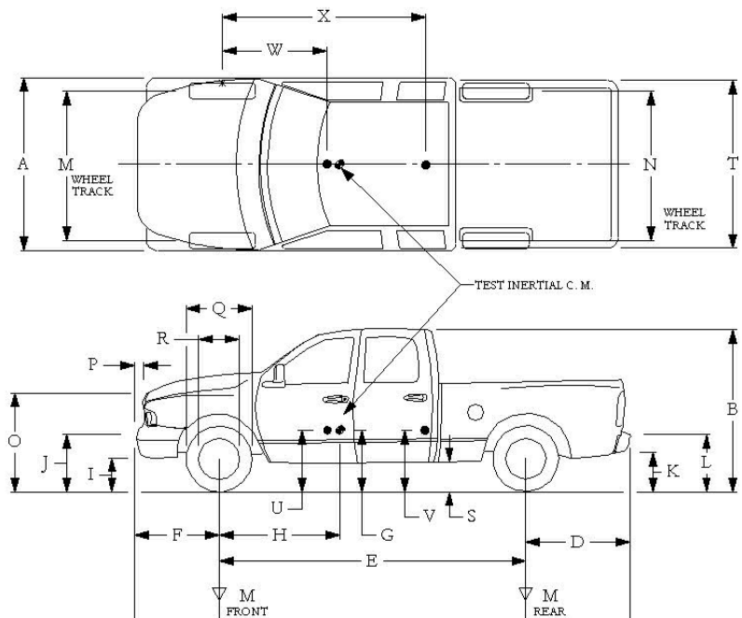
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment:
None

Dummy Data:
Type: No dummy
Mass: 0 lb
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	27.75
B	74.00	G	28.00	L	30.00	Q	30.50	V	31.00
C	227.50	H	61.90	M	68.50	R	18.00	W	61.90
D	44.00	I	11.75	N	68.00	S	13.00	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	12.50
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}	2930	2830	2830
Back	3900	M_{rear}	2100	2230	2230
Total	6700	M_{Total}	5030	5060	5060

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

Mass Distribution:
lb LF: 1440 RF: 1390 LR: 1110 RR: 1120

Table K.2. Measurements of Vehicle Vertical CG for Test No. 610211-01-4.

Date: 2018-11-27 Test No.: 610211-01-4 VIN: 1C6RR6FP9DS523586

Year: 2013 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 233576

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 152 (440 lb max)

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

Measured Vehicle Weights: (lb)									
LF:	1440		RF:	1390		Front Axle:	2830		
LR:	1110		RR:	1120		Rear Axle:	2230		
Left:	2550		Right:	2510		Total:	5060		
							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:	61.92	inches	Rear of Front Axle		(63 ±4 inches allowed)				
Y:	-0.27	inches	Left -	Right +	of Vehicle Centerline				
Z:	28.00	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 K.3. Exterior Crush Measurements for Test No. 610211-01-4.

Date:	2018-11-27	Test No.:	610211-01-4	VIN No.:	1C6RR6FP9DS523586
Year:	2013	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		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FT BUMPER	-	18	-	-	-	-	-	-	-	-
2	SAME	-	12	-	-	-	-	-	-	-	-
	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.

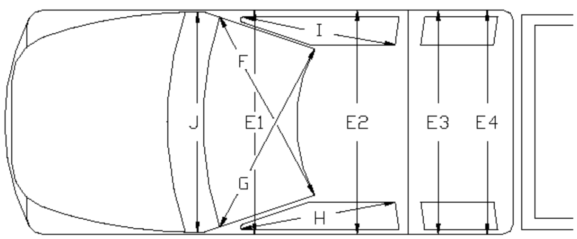
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

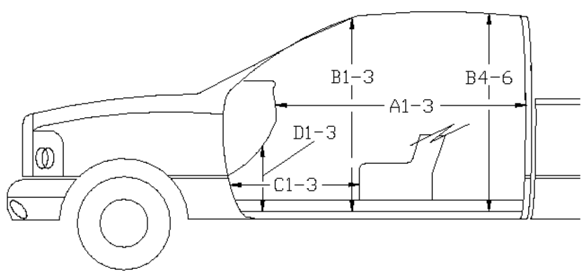
***Measure and document on the vehicle diagram the location of the maximum crush.

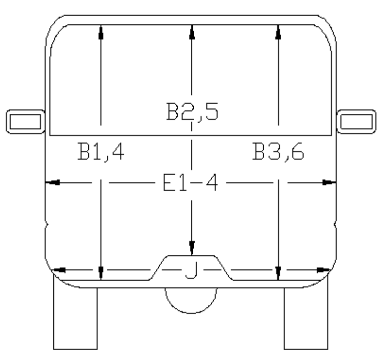
Note: Use as many lines/columns as necessary to describe each damage profile.

Table K.4. Occupant Compartment Measurements for Test No. 610211-01-4.

Date:	2018-11-27	Test No.:	610211-01-4	VIN No.:	1C6RR6FP9DS523586
Year:	2013	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	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
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	58.50	0.00
E2	63.50	63.50	0.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	25.00	0.00

K2 SEQUENTIAL PHOTOGRAPHS

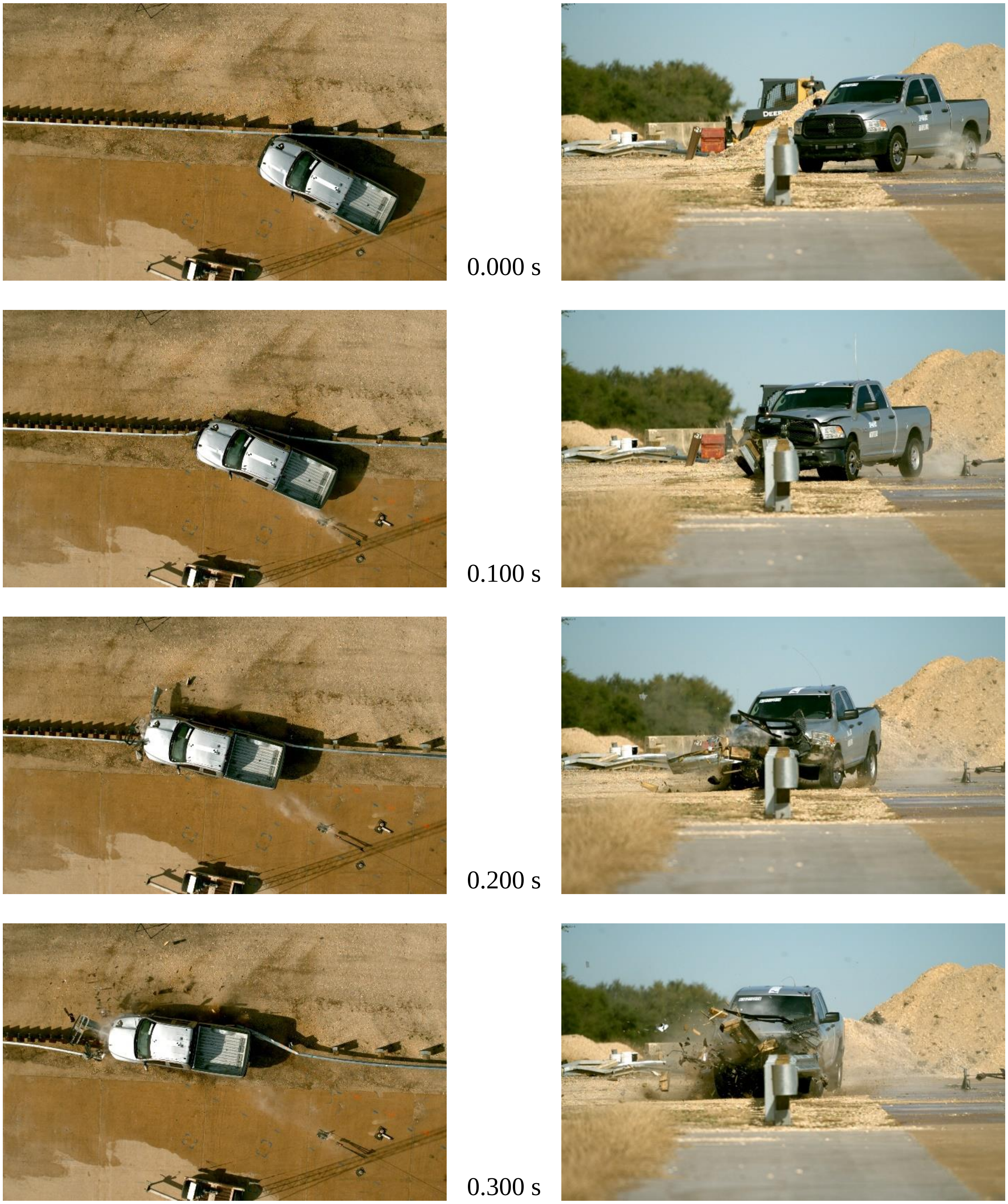
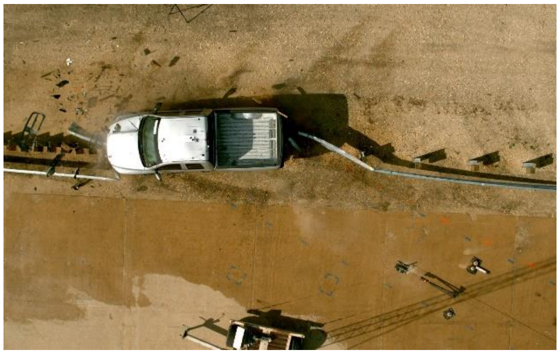
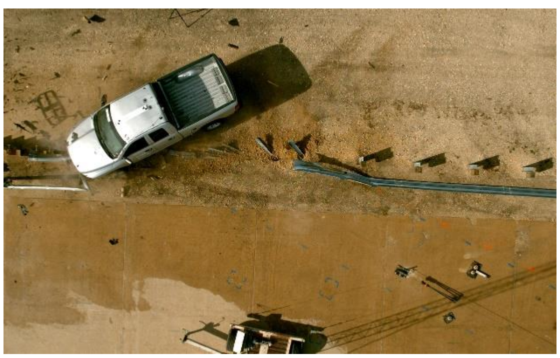


Figure K.1. Sequential Photographs for Test No. 610211-01-4 (Overhead and Frontal Views).

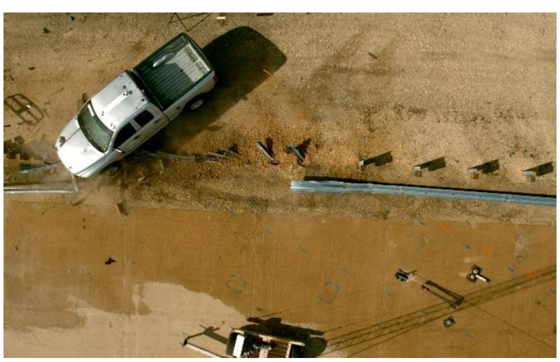


0.400 s

0.500 s



0.600 s



0.700 s

Figure K.1. Sequential Photographs for Test No. 610211-01-4 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

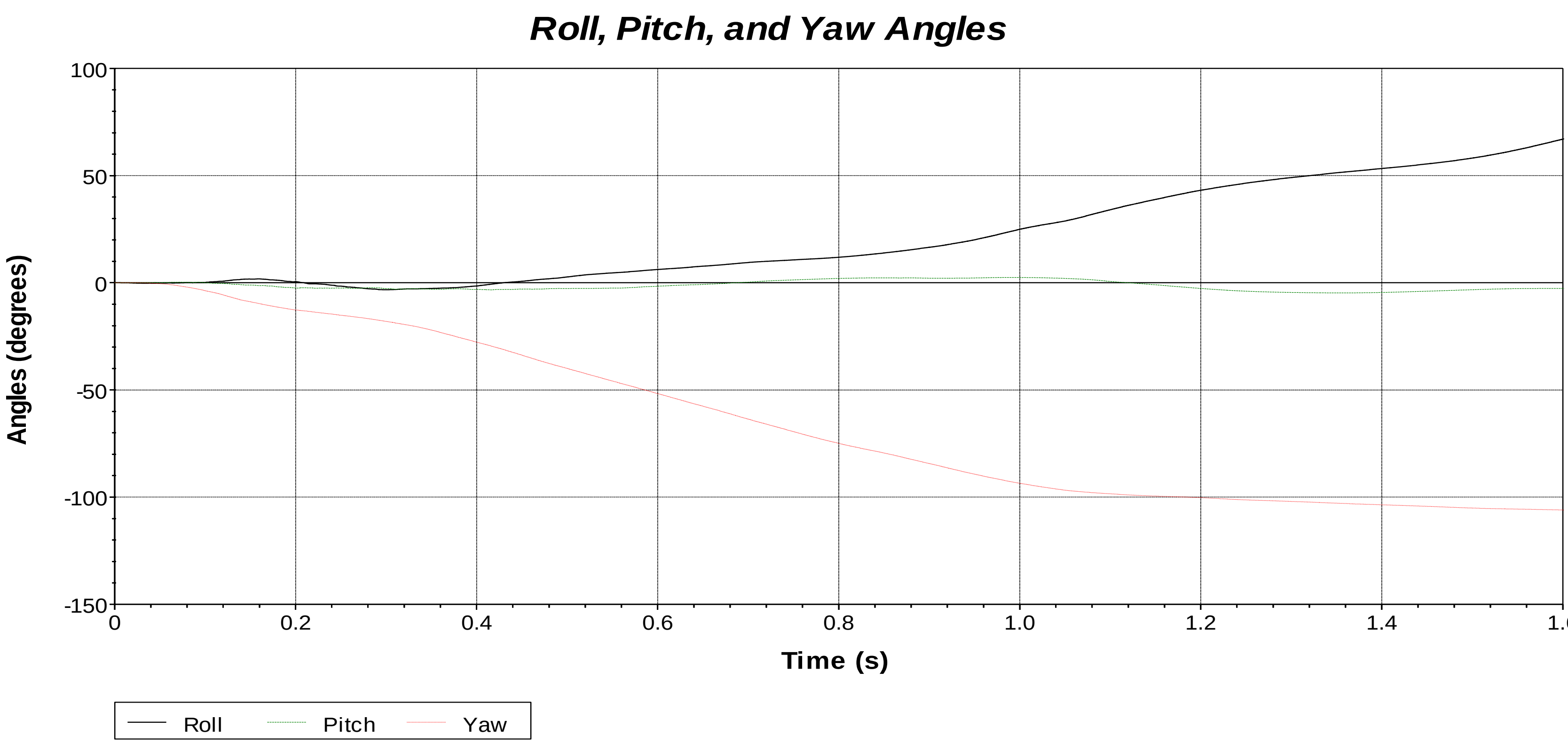
0.400 s

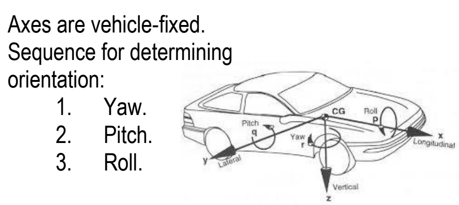
0.500 s

0.600 s

0.700 s

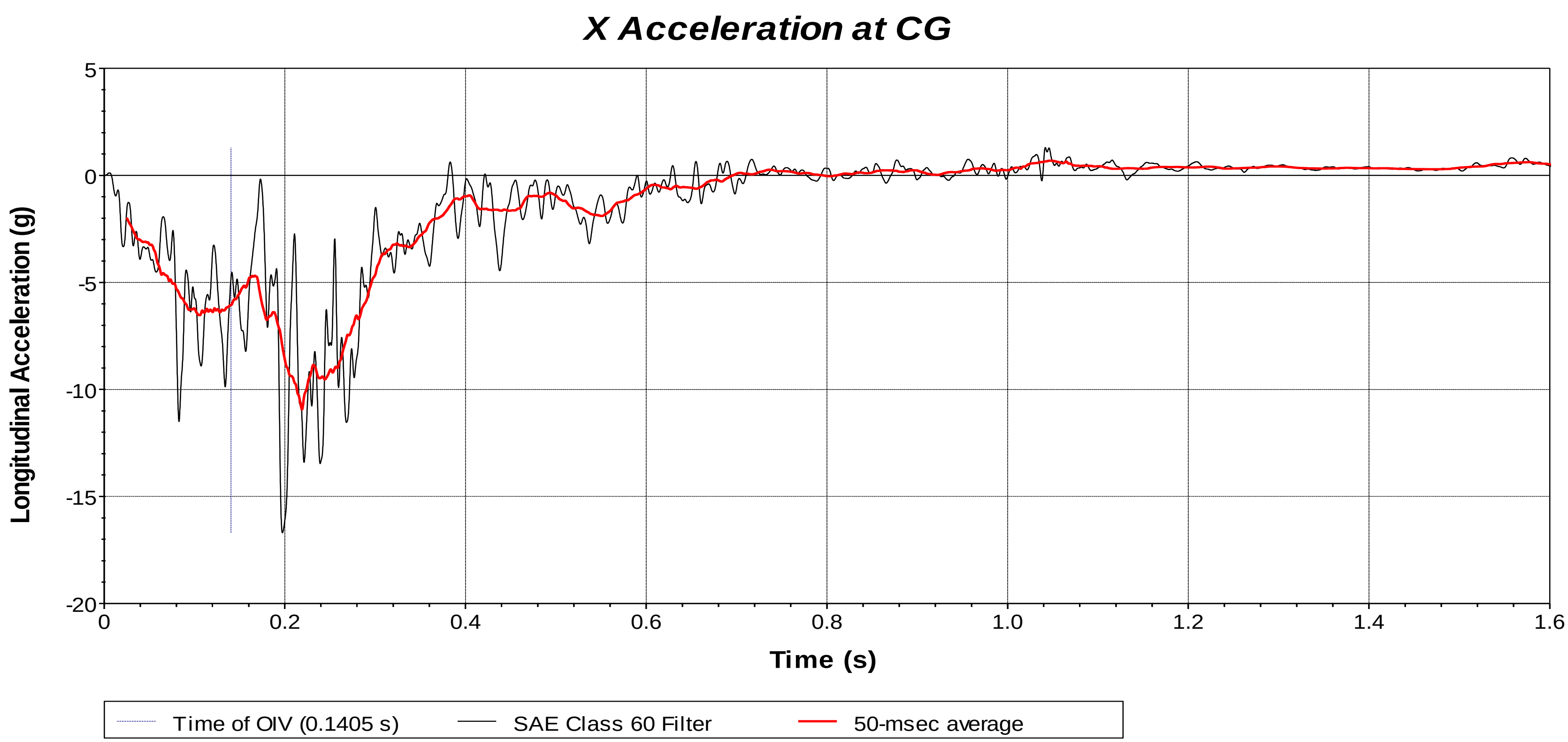
Figure K.2. Sequential Photographs for Test No. 610211-01-4 (Rear View).





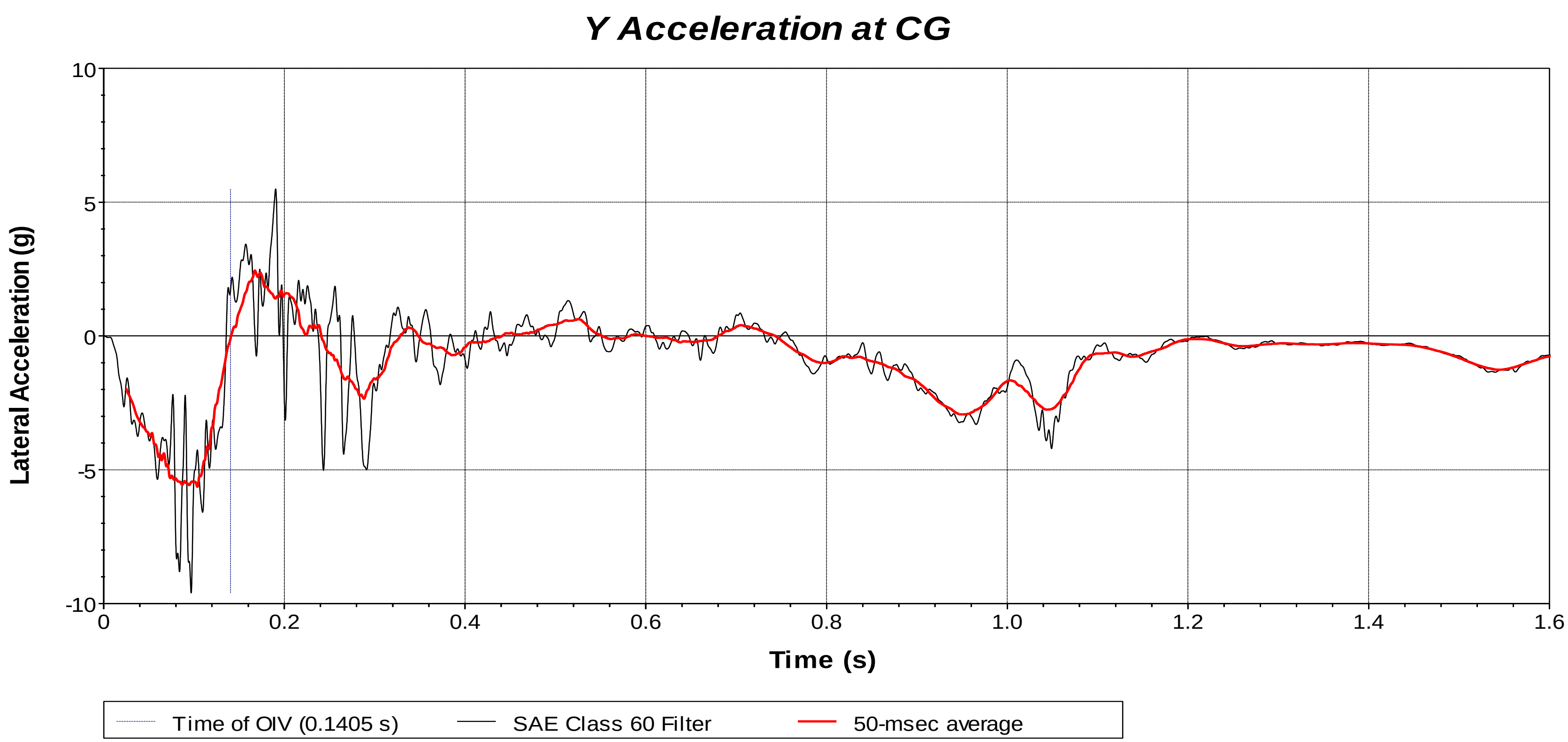
Test Number: 610211-01-4
Test Standard Test Number: MASH Test 3-21
Test Article: MGS Transition to Quarter Post Spacing
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5060 lb
Gross Mass: 5060 lb
Impact Speed: 64.1 mi/h
Impact Angle: 25.1 degrees

Figure K.3. Vehicle Angular Displacements for Test No. 610211-01-4.



Test Number: 610211-01-4
Test Standard Test Number: MASH Test 3-21
Test Article: MGS Transition to Quarter Post Spacing
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5060 lb
Gross Mass: 5060 lb
Impact Speed: 64.1 mi/h
Impact Angle: 25.1 degrees

Figure K.4. Vehicle Longitudinal Accelerometer Trace for Test No. 610211-01-4 (Accelerometer Located at Center of Gravity).



Test Number: 610211-01-4
Test Standard Test Number: MASH Test 3-21
Test Article: MGS Transition to Quarter Post Spacing
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5060 lb
Gross Mass: 5060 lb
Impact Speed: 64.1 mi/h
Impact Angle: 25.1 degrees

Figure K.5. Vehicle Lateral Accelerometer Trace for Test No. 610211-01-4 (Accelerometer Located at Center of Gravity).

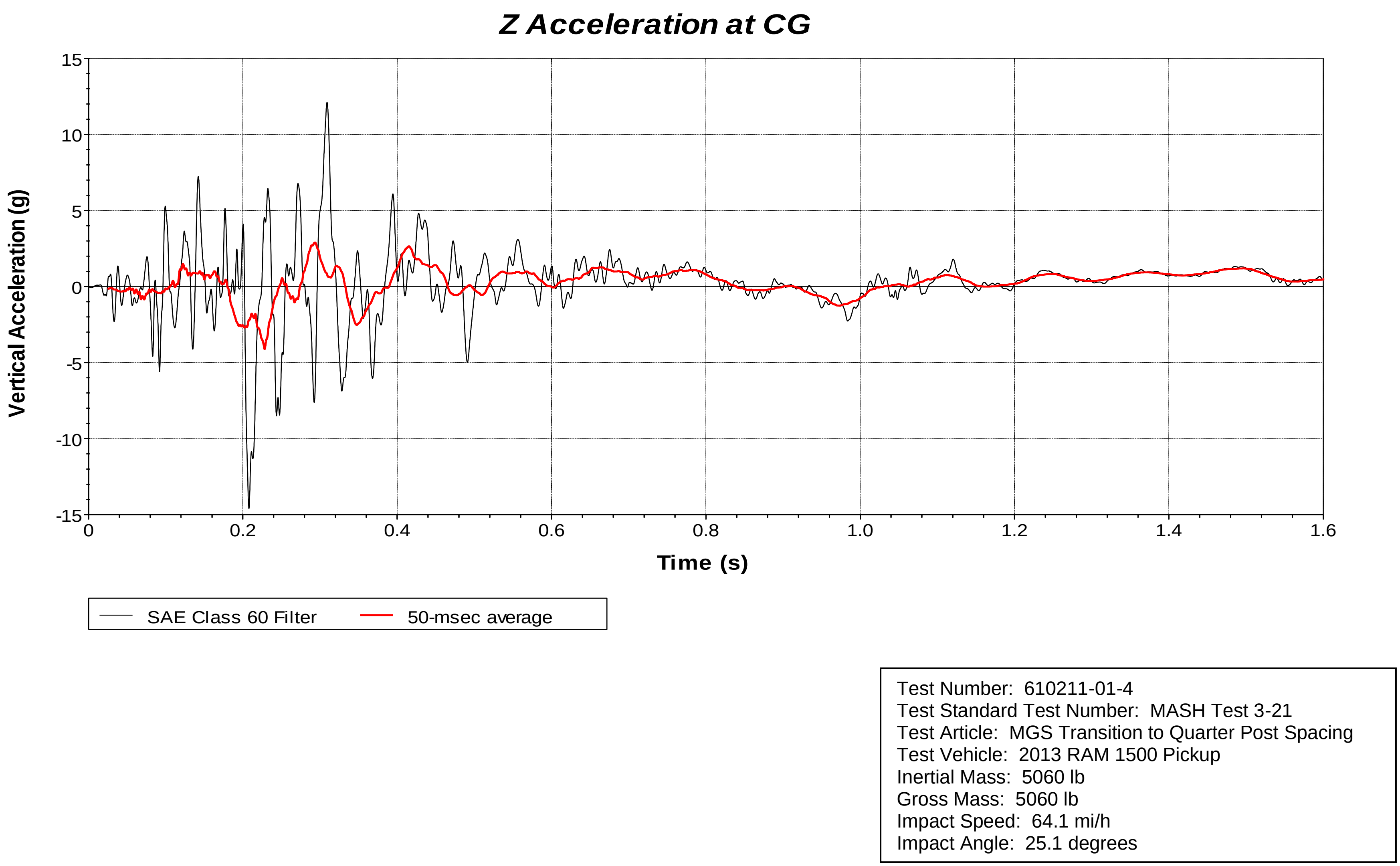
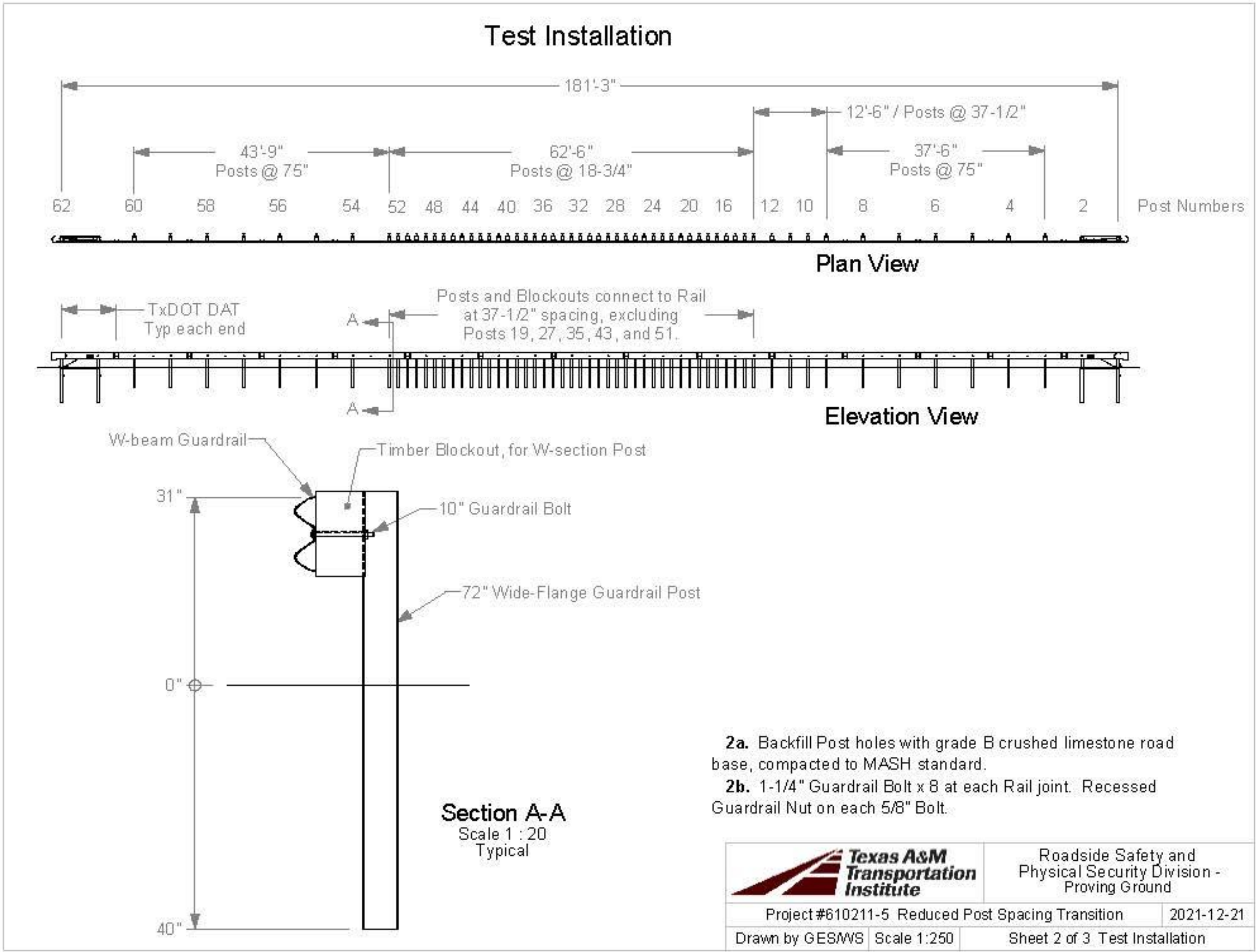


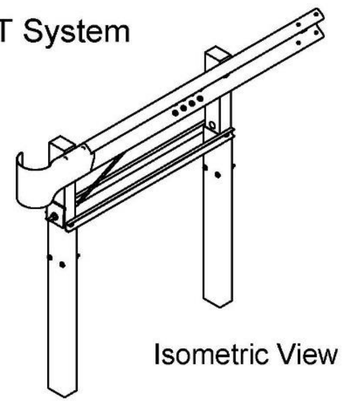
Figure K.6. Vehicle Vertical Accelerometer Trace for Test No. 610211-01-4 (Accelerometer Located at Center of Gravity

APPENDIX L. DETAILS OF THE LONGER TRANSITION FROM FULL TO QUARTER POST SPACING

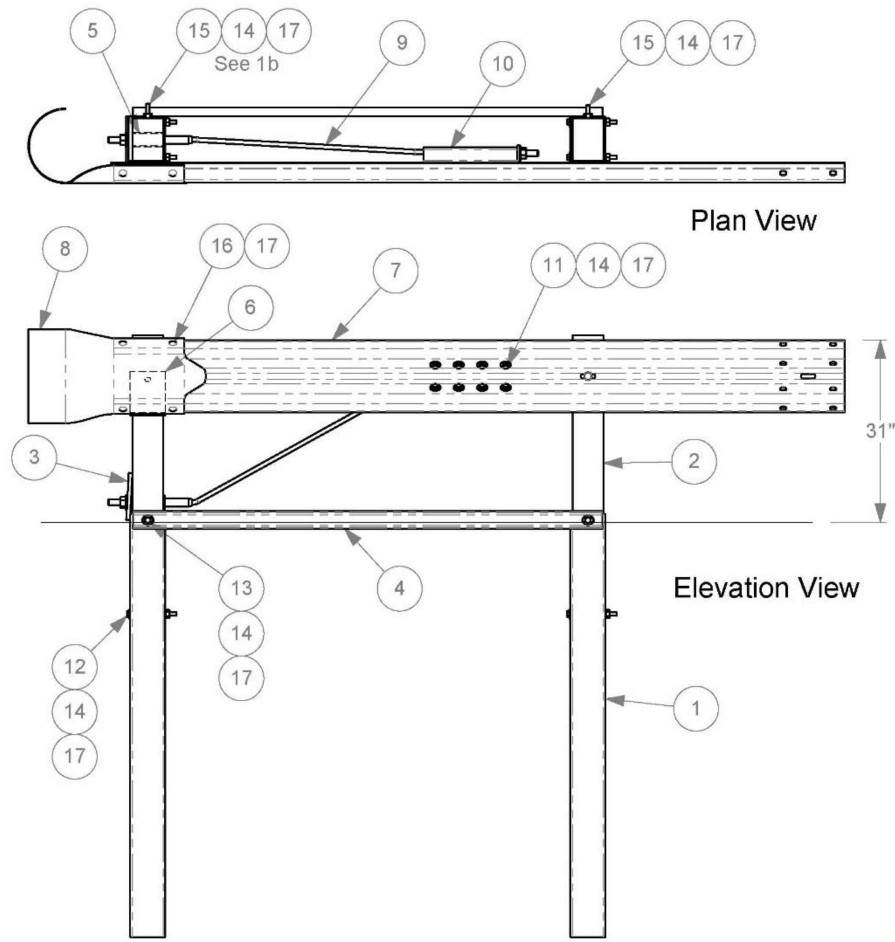


Q:\Accreditation-17025-2017\EIR-000 Project Files\610211-01- Reduced Post Spacing-Kovar\610211-5 Transition Spacing\Drafting, 610211-5\610211-5 Drawing

DAT System



Isometric View



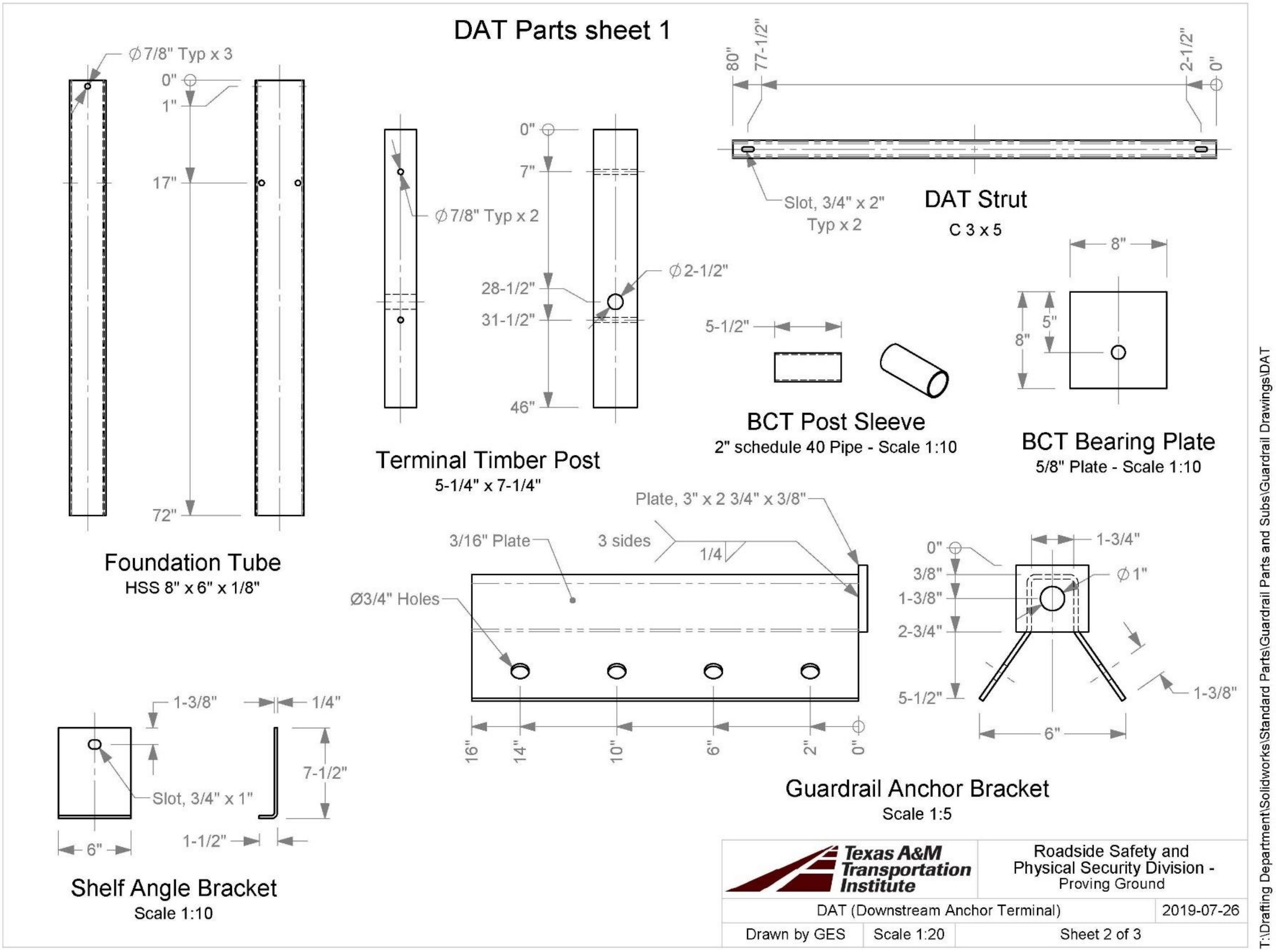
#	Part Name	Qty.
1	Foundation Tube	2
2	Terminal Timber Post	2
3	BCT Bearing Plate	1
4	DAT Strut	2
5	BCT Post Sleeve	1
6	Shelf Angle Bracket	1
7	DAT Terminal Rail	1
8	W-beam End Section	1
9	Anchor Cable Assembly	1
10	Guardrail Anchor Bracket	1
11	Bolt, 5/8 x 2" hex	8
12	Bolt, 5/8 x 8" hex	4
13	Bolt, 5/8 x 10" hex	2
14	Washer, 5/8 F844	16
15	10" Guardrail Bolt	2
16	1-1/4" Guardrail Bolt	4
17	Recessed Guardrail Nut	20

1a. All bolts are ASTM A307.

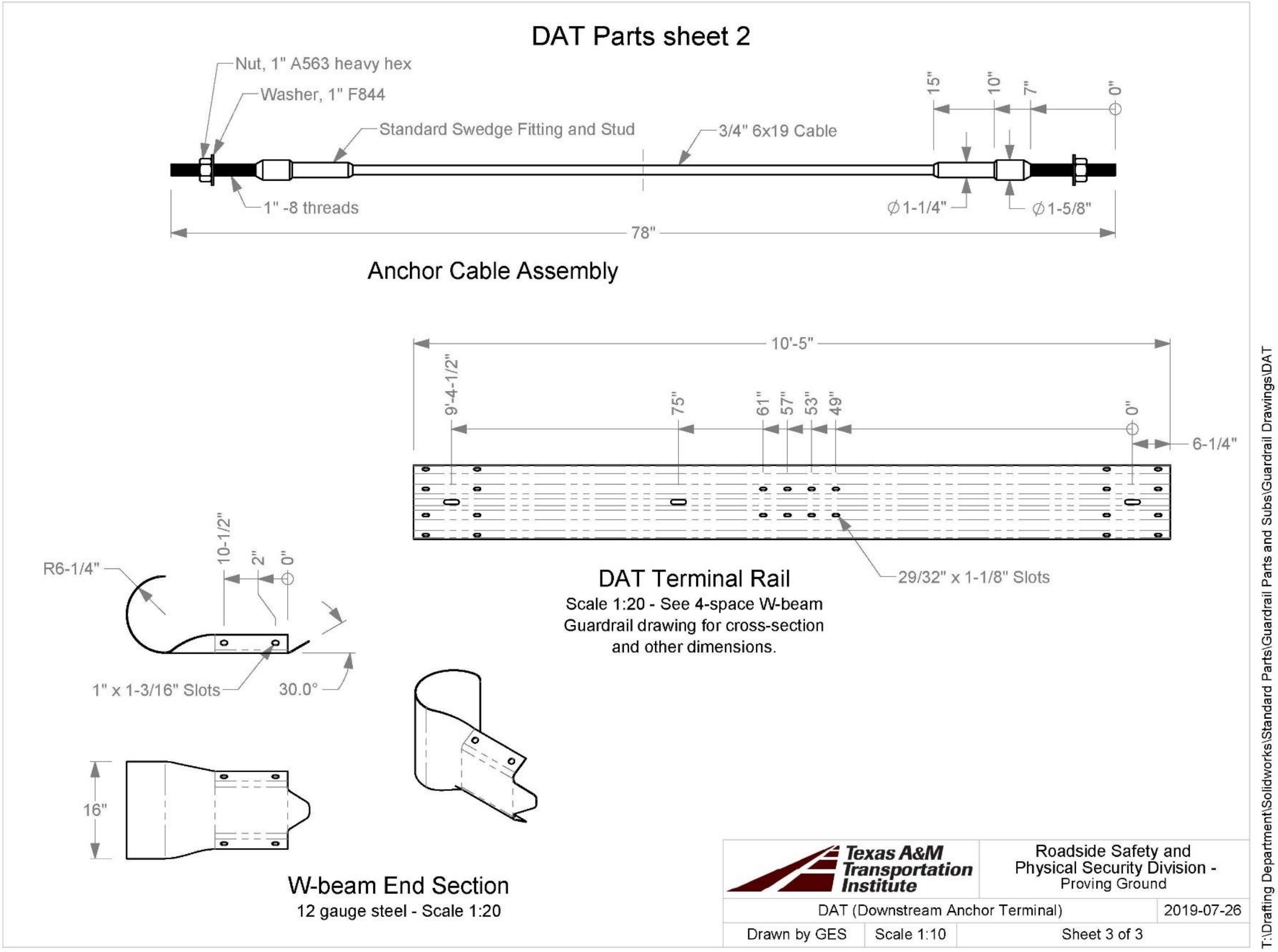
1b. Hardware secures Shelf Angle Bracket to Post. Rail is supported by Shelf Angle Bracket and does not attach directly to Post.

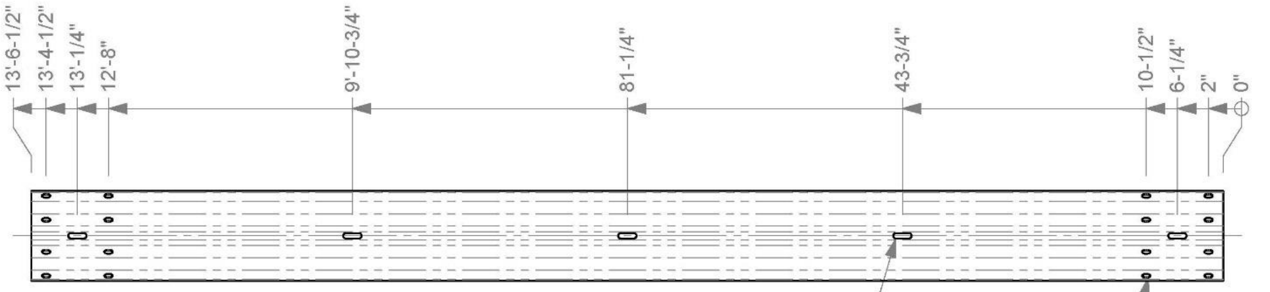
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
DAT (Downstream Anchor Terminal)		2019-07-26
Drawn by GES	Scale 1:25	Sheet 1 of 3

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\DAT

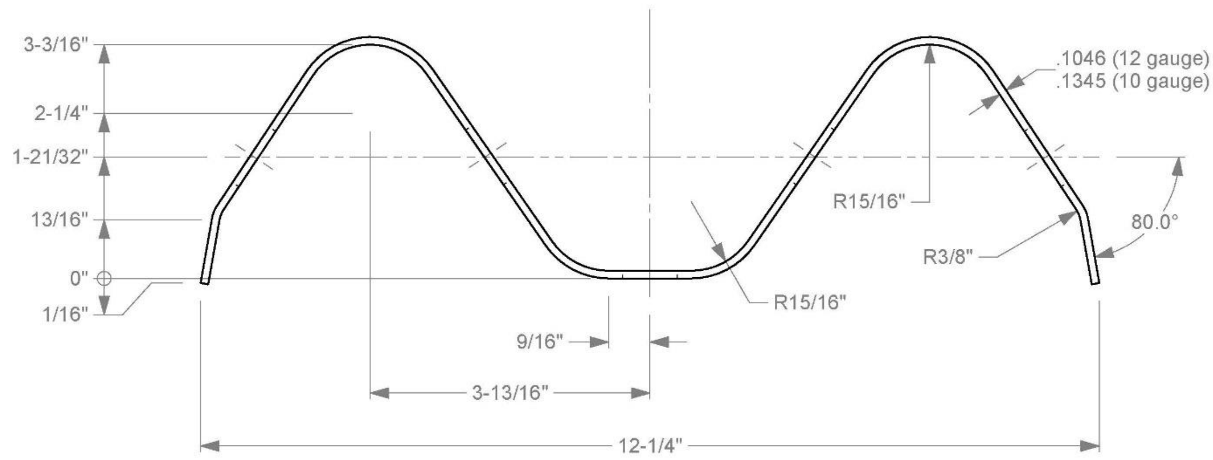


DAT Parts sheet 1
∅7/8" Typ x 3
0"
1"
17"
72"
Foundation Tube
HSS 8" x 6" x 1/8"
0"
7"
∅7/8" Typ x 2
28-1/2"
31-1/2"
∅2-1/2"
46"
Terminal Timber Post
5-1/4" x 7-1/4"
80"
77-1/2"
2-1/2"
0"
Slot, 3/4" x 2"
Typ x 2
DAT Strut
C 3 x 5
5-1/2"
BCT Post Sleeve
2" schedule 40 Pipe - Scale 1:10
8"
5"
8"
BCT Bearing Plate
5/8" Plate - Scale 1:10
Plate, 3" x 2 3/4" x 3/8"
3/16" Plate
3 sides
1/4
Ø3/4" Holes
16"
14"
10"
6"
2"
0"
0"
1-3/4"
3/8"
∅1"
1-3/8"
2-3/4"
5-1/2"
1-3/8"
6"
Guardrail Anchor Bracket
Scale 1:5
1-3/8"
1/4"
7-1/2"
Slot, 3/4" x 1"
6"
1-1/2"
Shelf Angle Bracket
Scale 1:10
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)
2019-07-26
Drawn by GES
Scale 1:20
Sheet 2 of 3
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\DAT


DAT Parts sheet 2
Nut, 1" A563 heavy hex
Washer, 1" F844
Standard Swedge Fitting and Stud
3/4" 6x19 Cable
1" -8 threads
∅1-1/4"
∅1-5/8"
15"
10"
7"
0"
78"
Anchor Cable Assembly
10'-5"
9'-4-1/2"
75"
61"
57"
53"
49"
0"
6-1/4"
29/32" x 1-1/8" Slots
DAT Terminal Rail
Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.
R6-1/4"
10-1/2"
2"
0"
1" x 1-3/16" Slots
30.0°
16"
W-beam End Section
12 gauge steel - Scale 1:20
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)
2019-07-26
Drawn by GES
Scale 1:10
Sheet 3 of 3
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\DAT



Elevation View



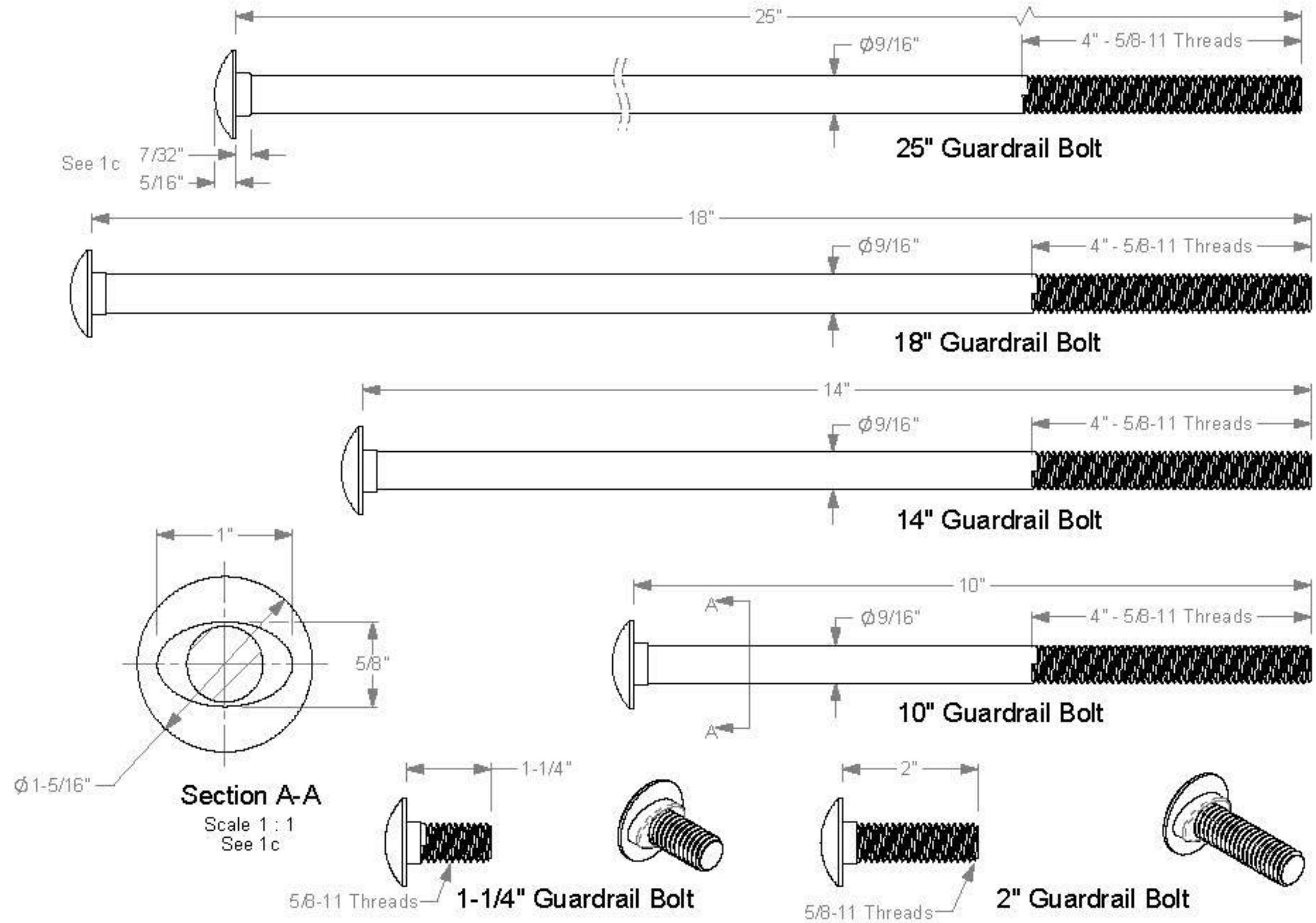
Section View

1a. Manufacture per AASHTO M180 specifications.

1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
4-space W-beam Guardrail		2020-06-05
Drawn by GES	Scale 1:20	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-Beam Guardrail

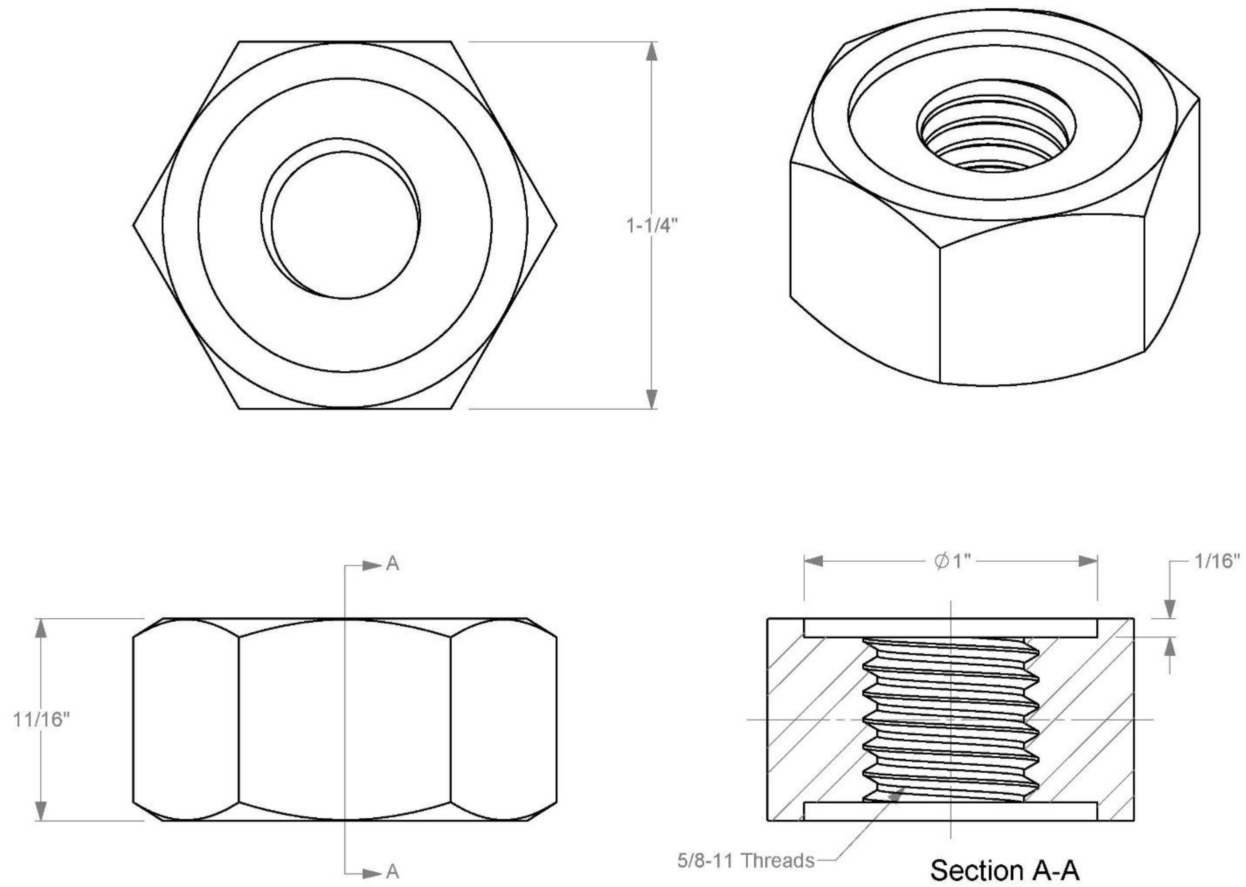


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Guardrail Bolt		2020-04-22
Drawn by GES/WS	Scale 1:2	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Guardrail Bolt

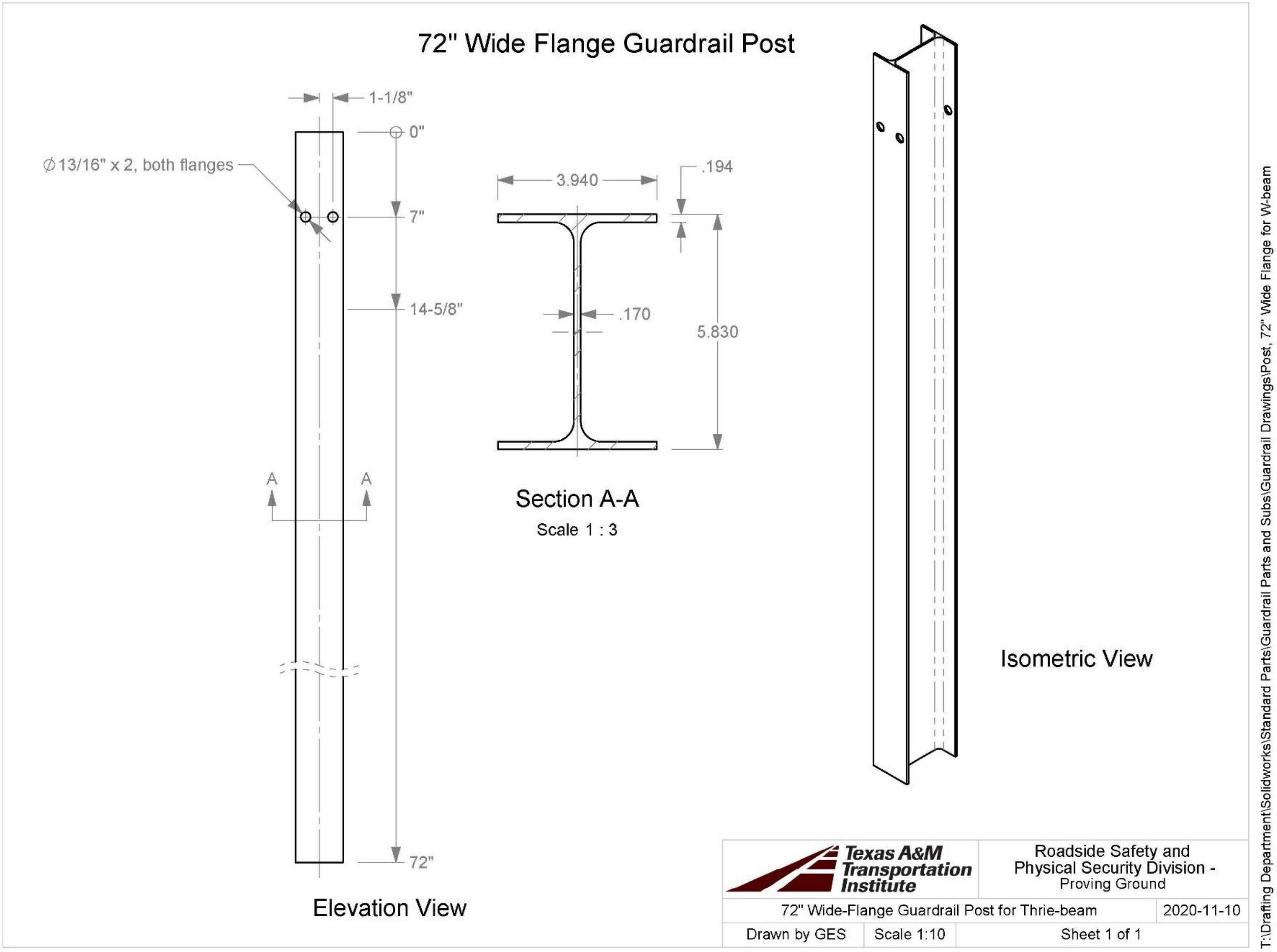
Recessed Guardrail Nut



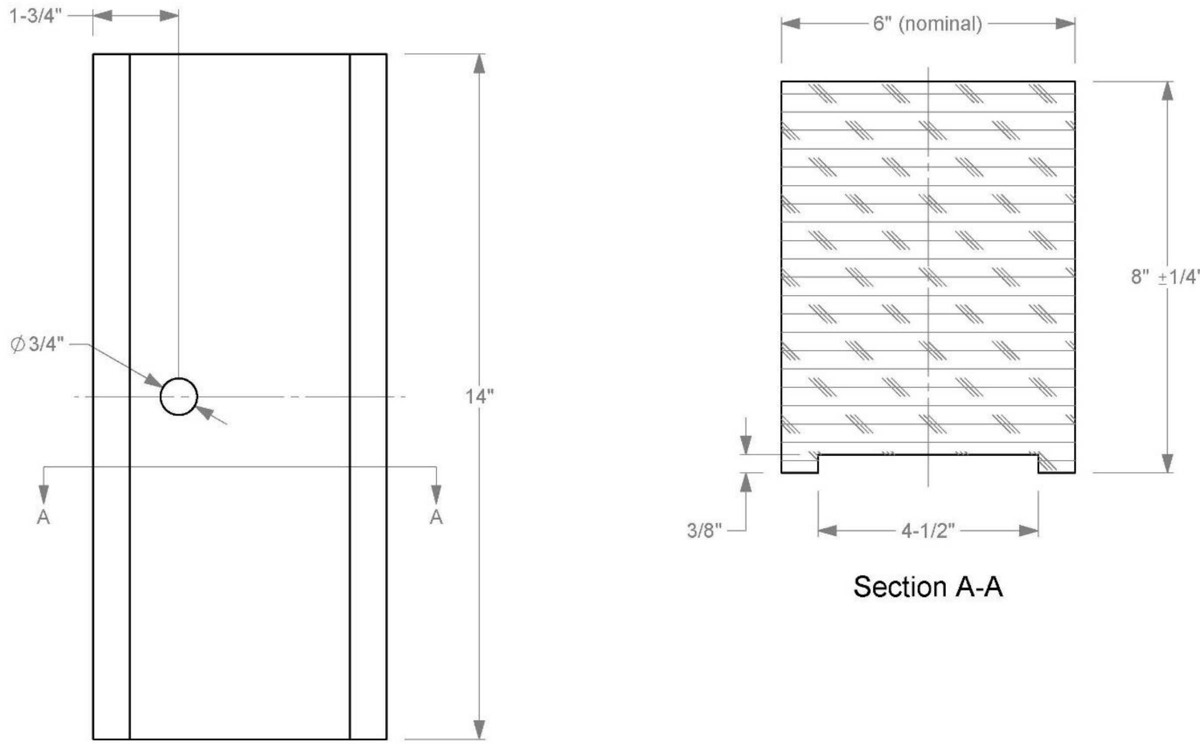
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Recessed Guardrail Nut		2019-06-27
Drawn by GES	Scale 2:1	Sheet 1 of 1

1a. Material is ASTM A 563 Grade A.

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Nut, Recessed Guardrail


72" Wide Flange Guardrail Post
1-1/8"
0"
∅13/16" x 2, both flanges
7"
14-5/8"
A
A
72"
Elevation View
3.940
.194
.170
5.830
Section A-A
Scale 1 : 3
Isometric View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
72" Wide-Flange Guardrail Post for Thrie-beam
2020-11-10
Drawn by GES
Scale 1:10
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

Timber Blockout for W-section Post



Elevation View

Section A-A

1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Timber Blockout, for W-section Post		2019-07-03
Drawn by GES	Scale 1:3	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Timber Blockout for W-section Post

APPENIDX M. *MASH* TEST 3-21 (CRASH TEST NO. 610211-01-5)

M1 VEHICLE PROPERTIES AND INFORMATION

Table M.1. Vehicle Properties for Test No. 610211-01-5.

Date: 2021-3-12 Test No.: 610211-01-5 VIN No.: 1C6RR6FT9GS312180

Year: 2016 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 127083

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

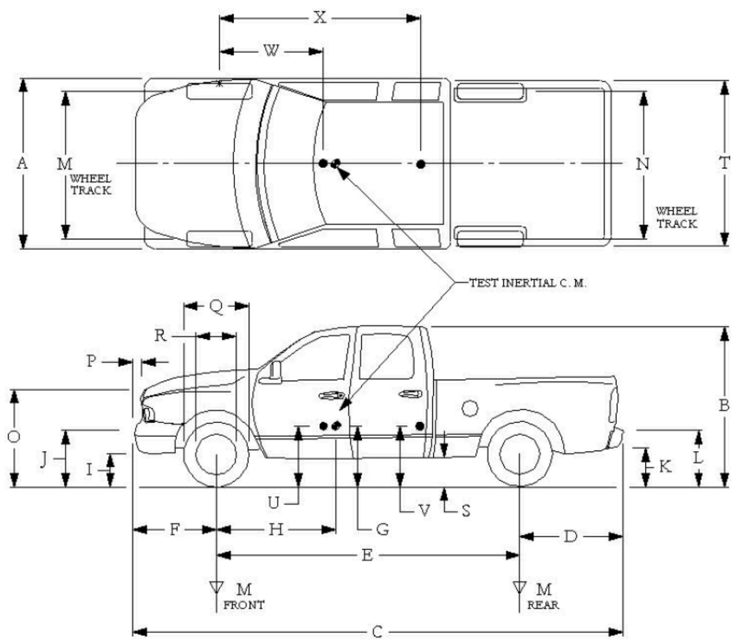
NOTES: None

Engine Type: V-8
Engine CID: 5.7L

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

Optional Equipment:
None

Dummy Data:
Type: NONE
Mass: 0 lb
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.60	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.39	M	68.50	R	18.00	W	61.40
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
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}	2901	2827	2827
Back	3900	M_{rear}	2031	2194	2194
Total	6700	M_{Total}	4932	5021	5021

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

Mass Distribution:
lb LF: 1440 RF: 1387 LR: 1104 RR: 1090

Table M.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 610211-01-5.

Date: 2021-3-12 Test No.: 610211-01-5 VIN: 1C6RR6FT9GS312180

Year: 2016 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 127083

Engine: 5.7L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 160 (440 lb max)

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

Measured Vehicle Weights: (lb)									
LF:	1440		RF:	1387			Front Axle:	2827	
LR:	1104		RR:	1090			Rear Axle:	2194	
Left:	2544		Right:	2477			Total:	5021	
							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:	61.39	inches	Rear of Front Axle		(63 ±4 inches allowed)
Y:	-0.46	inches	Left -	Right +	of Vehicle Centerline
Z:	28.60	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 M.3. Exterior Crush Measurements for Test No. 610211-01-5.

Date:	2021-3-12	Test No.:	610211-01-5	VIN No.:	1C6RR6FT9GS312180
Year:	2016	Make:	RAM	Model:	1500

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		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bmp ht	14	16	46	-	-	-	-	-	-	-9
2	Side plane at bmp ht	14	14	64	-	-	-	-	-	-	82
	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.

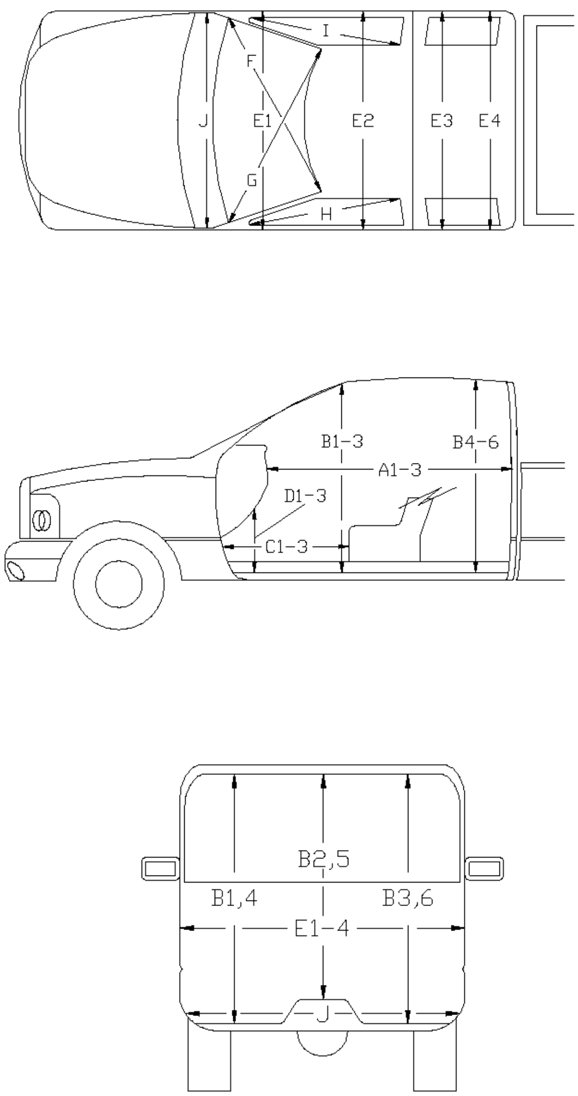
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 M.4. Occupant Compartment Measurements for Test No. 610211-01-5.

Date:	2021-3-12	Test No.:	610211-01-5	VIN No.:	1C6RR6FT9GS312180
Year:	2016	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	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
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	58.50	0.00
E2	63.50	63.50	0.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	25.00	0.00

M2 SEQUENTIAL PHOTOGRAPHS

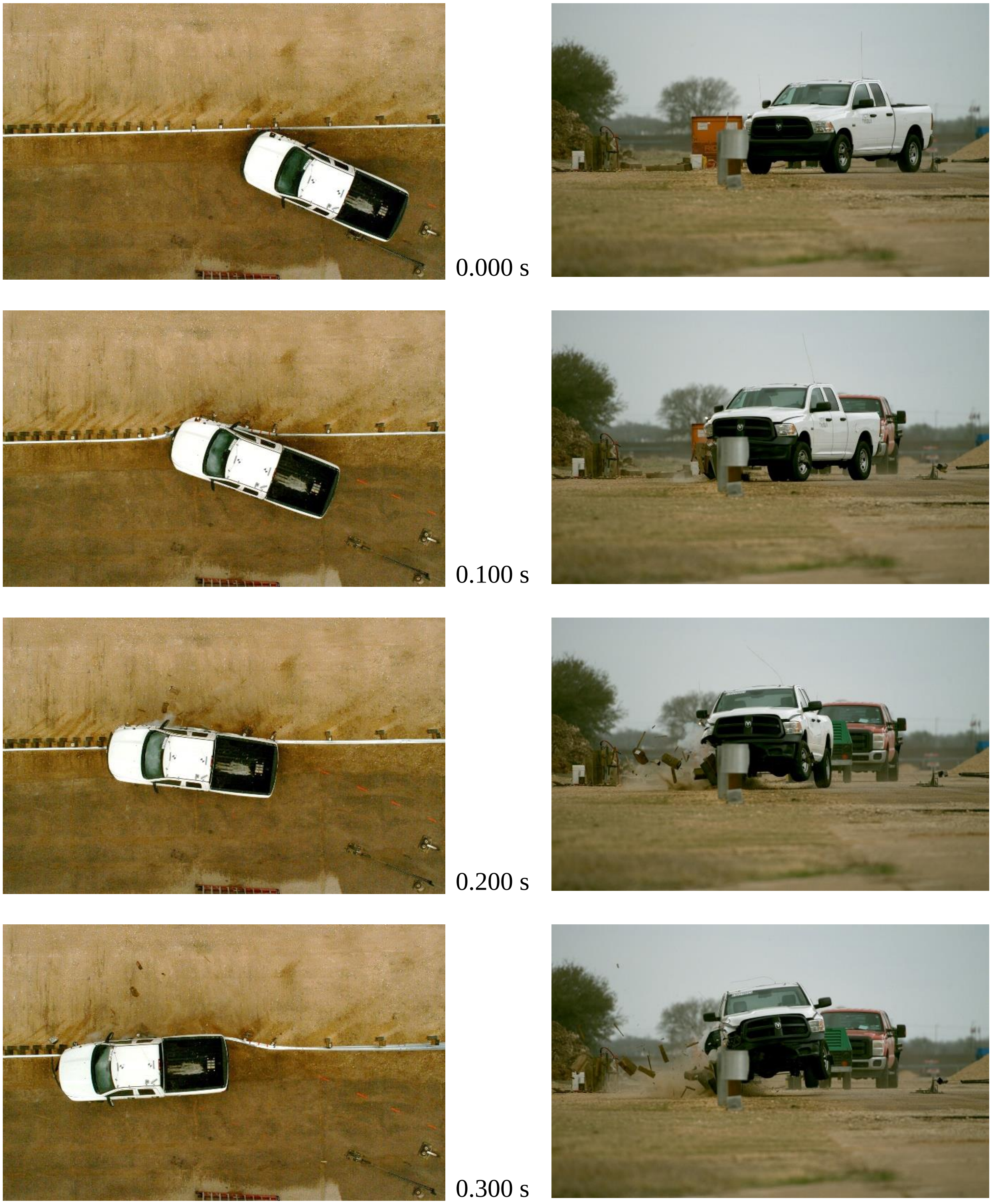


Figure M.1. Sequential Photographs for Test No. 610211-01-5 (Overhead and Frontal Views).

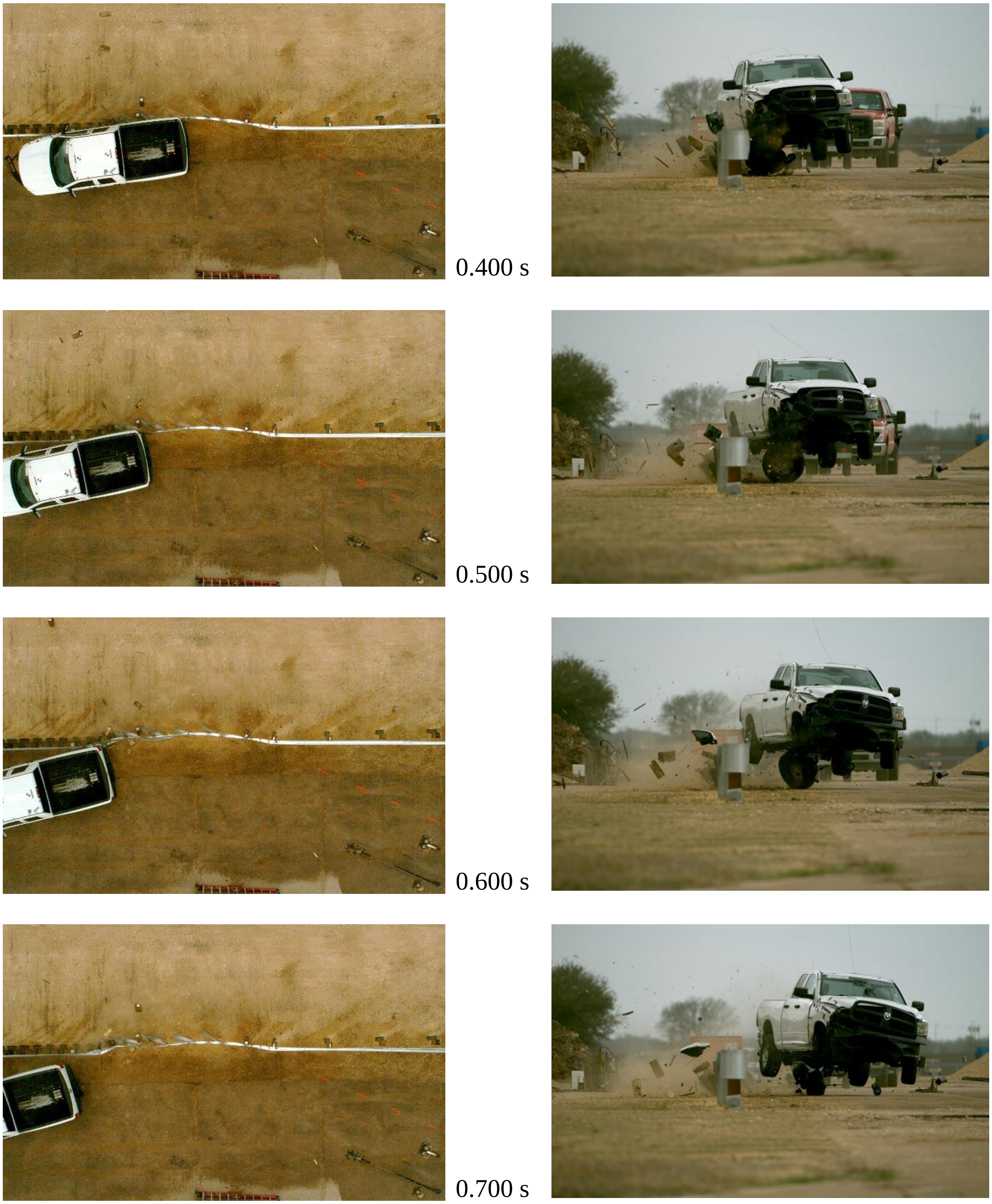


Figure M.1. Sequential Photographs for Test No. 610211-01-5 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

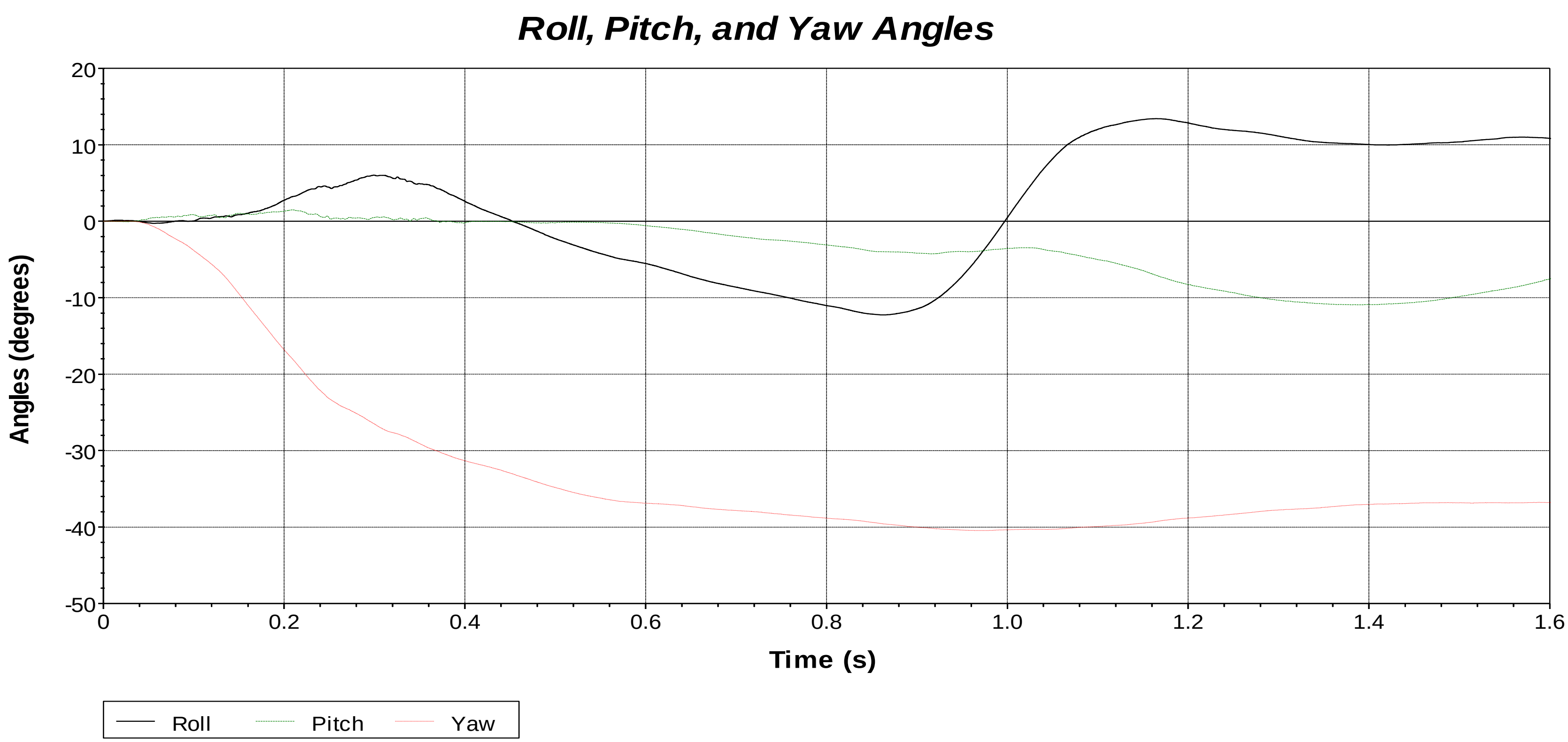
0.400 s

0.500 s

0.600 s

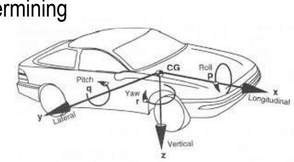
0.700 s

Figure M.2. Sequential Photographs for Test No. 610211-01-5 (Rear View).



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 610211-01-5
Test Standard Test Number: *MASH* Test 3-21
Test Article: Longer Transition from MGS to Quarter Post Spacing
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5021 lb
Gross Mass: 5021 lb
Impact Speed: 61.5 mi/h
Impact Angle: 25.1 degrees

Figure M.3. Vehicle Angular Displacements for Test No. 610211-01-5.

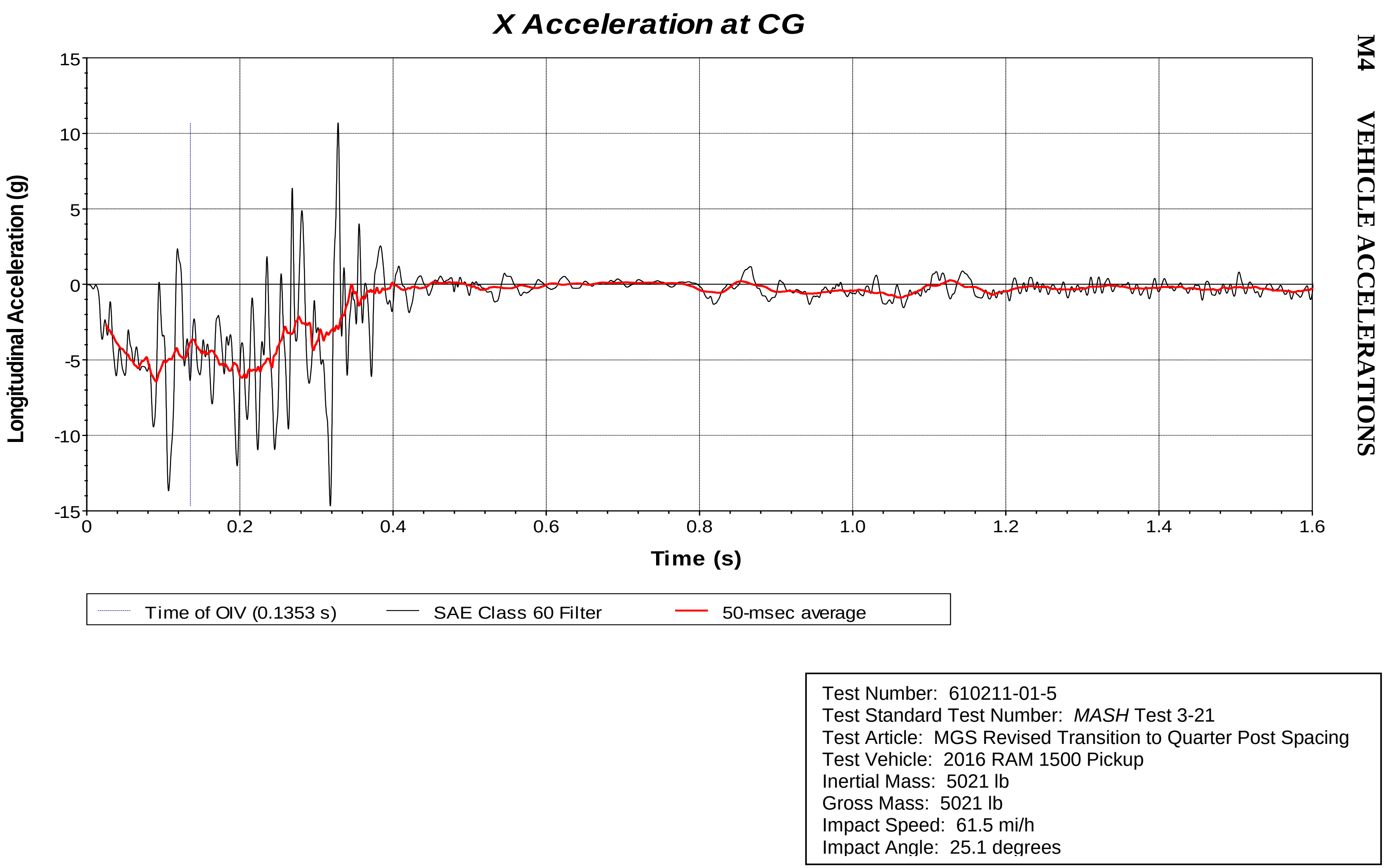
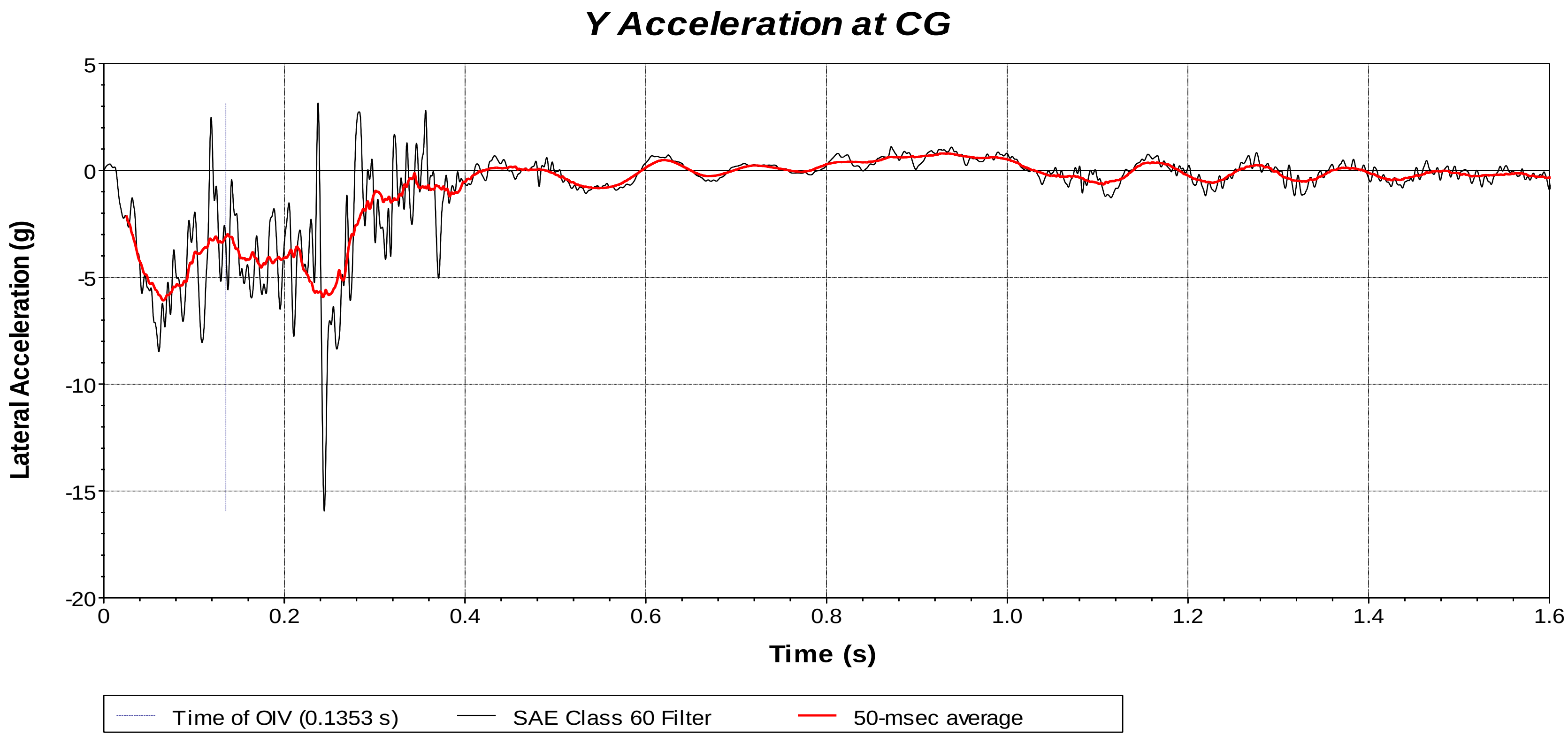
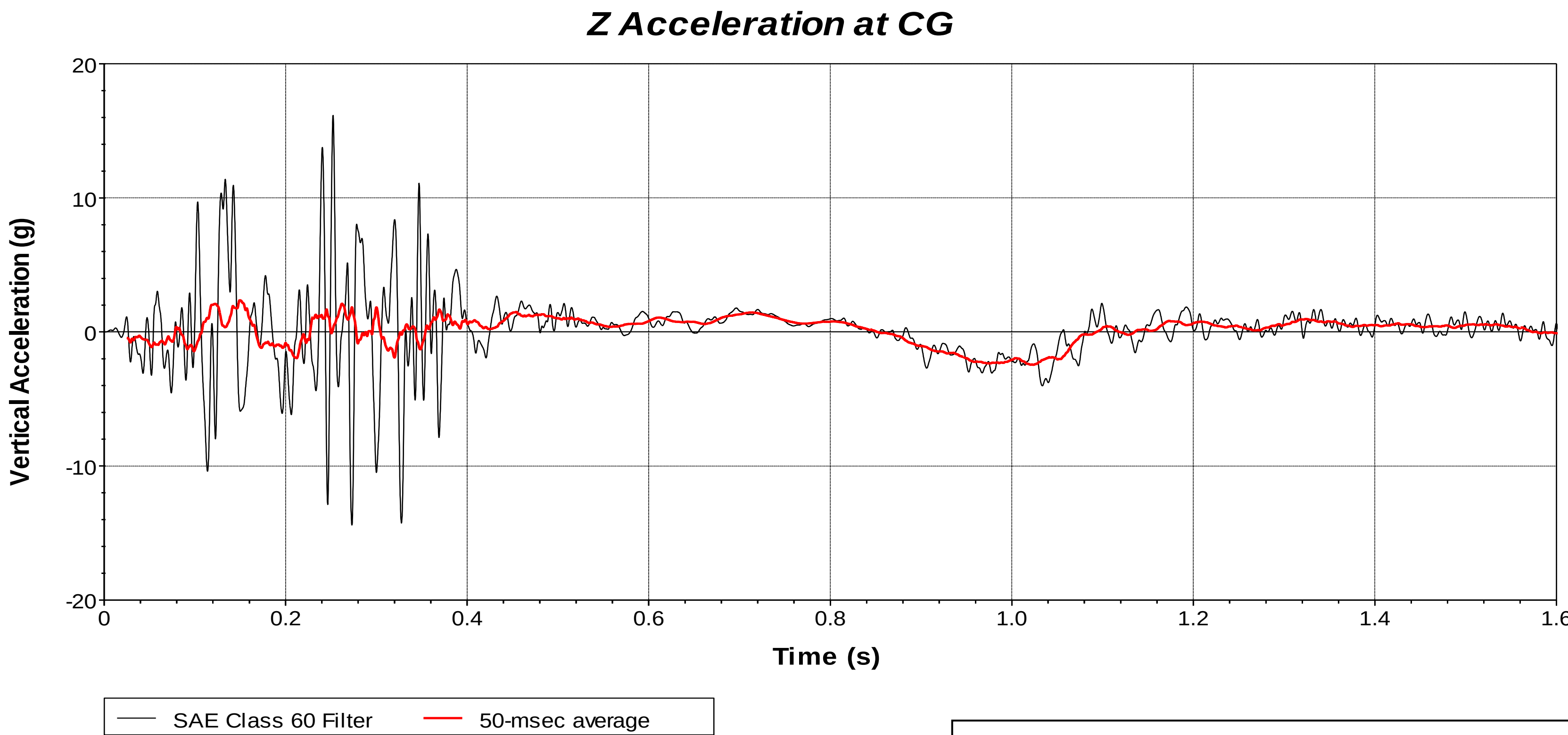


Figure M.4. Vehicle Longitudinal Accelerometer Trace for Test No. 610211-01-5 (Accelerometer Located at Center of Gravity).



Test Number: 610211-01-5
Test Standard Test Number: *MASH* Test 3-21
Test Article: MGS Revised Transition to Quarter Post Spacing
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5021 lb
Gross Mass: 5021 lb
Impact Speed: 61.5 mi/h
Impact Angle: 25.1 degrees

Figure M.5. Vehicle Lateral Accelerometer Trace for Test No. 610211-01-5 (Accelerometer Located at Center of Gravity).



Test Number: 610211-01-5
Test Standard Test Number: *MASH* Test 3-21
Test Article: MGS Revised Transition to Quarter Post Spacing
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5021 lb
Gross Mass: 5021 lb
Impact Speed: 61.5 mi/h
Impact Angle: 25.1 degrees

Figure M.6. Vehicle Vertical Accelerometer Trace for Test No. 610211-01-5 (Accelerometer Located at Center of Gravity).