Texas A&M Transportation Institute
Proving Ground

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Test Report Date: October 2019

MASH TL-3 EVALUATION OF W-BEAM GUIDERAIL OVER UNDERGROUND STRUCTURE

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16. Abstract

The purpose of the tests reported herein was to assess the performance of the W-Beam Guiderail over Underground Structure for the Pennsylvania Department of Transportation according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO), *Manual for Assessing Safety Hardware* (*MASH*). Six posts were attached to steel reinforced concrete slabs, 60 inches square by 8-inches thick, with their tops located 6 inches below grade. The crash tests were performed in accordance with *MASH* Test Level 3 (TL-3) for longitudinal barriers, which involves two crash tests:

- *MASH* Test 3-10 involves an 1100C vehicle impacting the critical impact point (CIP) of the longitudinal barrier at a target impact speed and impact angle of 62 mi/h and 25°
- *MASH* Test 3-11 involves a 2270P vehicle impacting the CIP of the longitudinal barrier at a target impact speed and impact angle of 62 mi/h and 25°.

This report provides details of the W-Beam Guiderail over Underground Structure, detailed documentation of the crash tests and results, and an assessment of the performance for *MASH* TL-3.

The W-Beam Guiderail over Underground Structure performed acceptably for *MASH* TL-3 longitudinal barriers.

17. Key Words	18. Distribution Statement
Guardrail, Guiderail, W-Beam, Longitudinal Barriers, Metal Rail, Crash Testing, Roadside Safety, *MASH*.	

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

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Chapter 1. INTRODUCTION

The purpose of the tests reported herein was to assess the performance of the W-Beam Guiderail over Underground Structure according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO), *Manual for Assessing Safety Hardware* (*MASH*) (*1*). The crash tests were performed in accordance with *MASH* Test Level 3 (TL-3) for longitudinal barriers, which involves two crash tests:

- *MASH* Test 3-10 involves an 1100C vehicle impacting the critical impact point (CIP) of the longitudinal barrier at a target impact speed and impact angle of 62 mi/h and 25°.
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This report provides details of the W-Beam Guiderail over Underground Structure, detailed documentation of the crash tests and results, and an assessment of the performance for *MASH* TL-3.

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Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of a 31-inch tall W-beam guardrail supported by steel posts installed in compacted base (see Section 2.4), with a Texas Department of Transportation (TxDOT) downstream anchor terminal (DAT) [GF (31) DAT-14] on each end, for a total installation length of 181 ft-3 inches. Timber blockouts for steel posts (PDB-01b) were installed on posts 3 through 28 using 10-inch long guardrail bolts and recessed guardrail nuts (FBB03).

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

Posts 3 through 13 and 20 through 28 were 6-ft W6×8.5 guardrail line posts (PWE01). These posts were installed approximately 40 inches deep in drilled holes that were backfilled and compacted with soil meeting Grading B of AASHTO standard specification M147-65(2004) "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses."

Posts 14 through 19 were attached to steel reinforced concrete slabs, 60 inches square by 8-inches thick, with their tops located 6 inches below grade. Posts 14 through 19 were fabricated from 37⅛-inch long sections of W6×8.5 welded to ¾-inch thick base plates. The posts were secured to the slabs with ⅞-inch diameter × 8½-inch long bolts that were integrally cast in the slabs. The slabs were covered with the aforementioned Grading B soil to the grade level of the surrounding soil.

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

Figure 2.1 presents overall information on the W-Beam Guiderail over Underground Structure, and Figure 2.2 provides photographs of the installation. Appendix A provides further details of the W-Beam Guiderail over Underground Structure.

2.2. DESIGN MODIFICATIONS DURING TESTS

No modification was made to the installation during the testing phase.

2.3. MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the W-Beam Guiderail over Underground Structure.

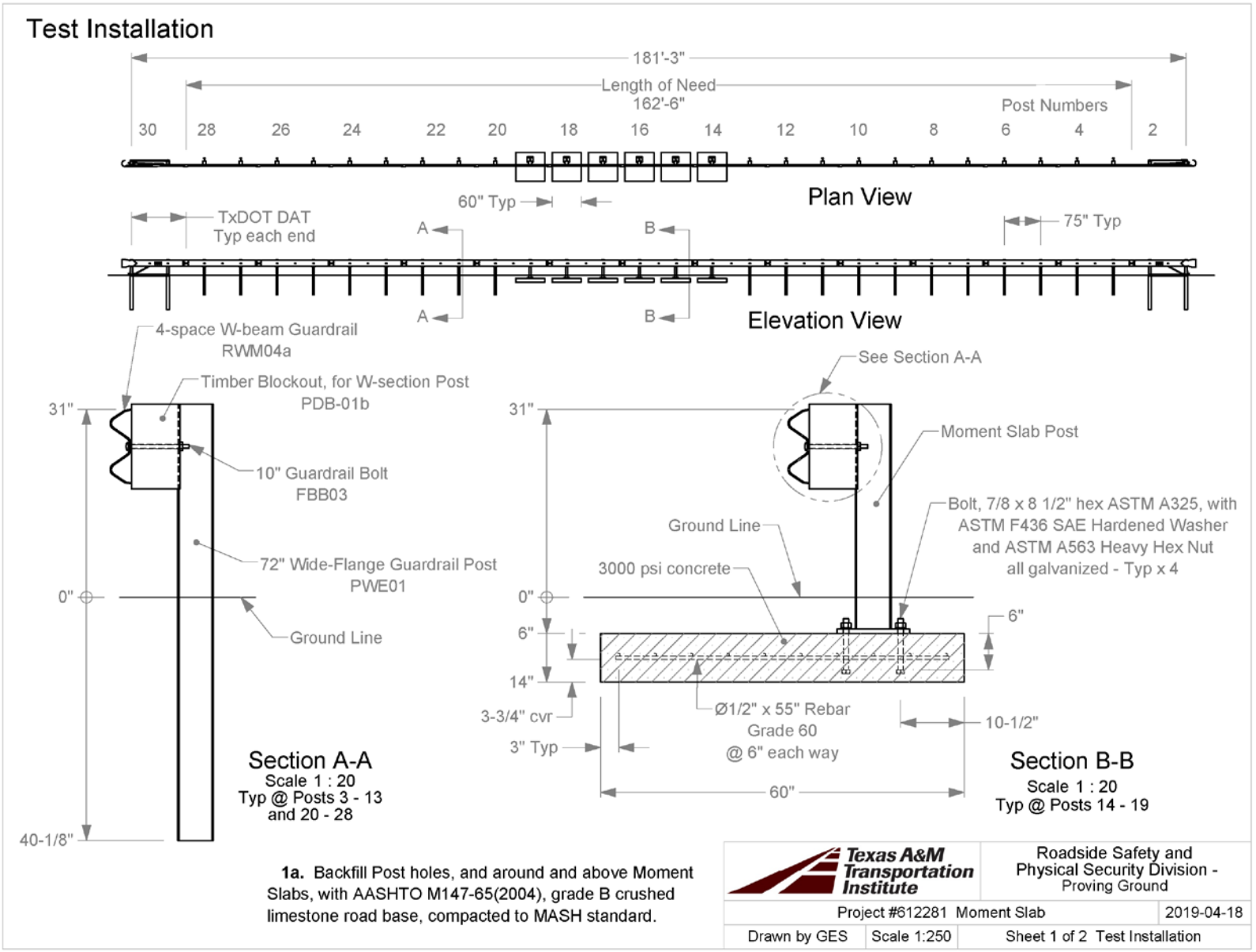

Figure 2.1. Details of W-Beam Guiderail over Underground Structure.

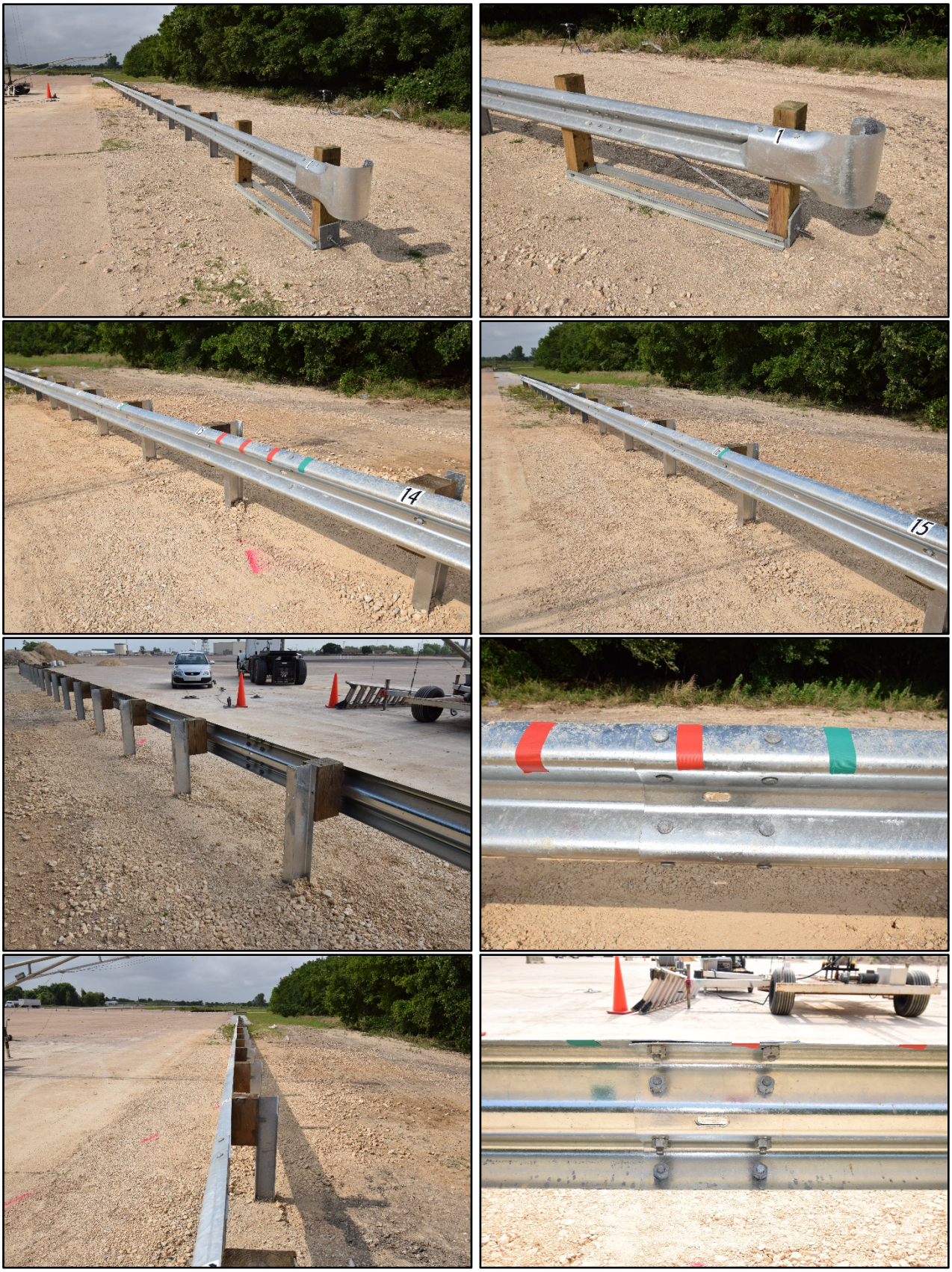

Figure 2.2. W-Beam Guiderail over Underground Structure prior to Testing.

2.4. 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 and compared to a standard dynamic test. During installation of the W-Beam Guiderail over Underground Structure for full-scale crash testing, two W6×16 ×6 ft posts were installed in the immediate vicinity of the guiderail using 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 percent of static load for the initial standard installation).

On the day of Test No. 612281-02-1 (May 20, 2019), loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 7125.5 lbf, 7180.5 lbf, and 6781 lbf, respectively. Table C.2 in Appendix C shows the strength of the backfill material in which the W-Beam Guiderail over Underground Structure was installed met minimum *MASH* requirements.

On the day of Test No. 612281-02-2 (July 8, 2019), loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 6987 lbf, 7194 lbf, and 7228 lbf, respectively. Table C.3 in Appendix C shows the strength of the backfill material in which the W-Beam Guiderail over Underground Structure was installed met minimum *MASH* requirements.

2.5 CONCRETE STRENGTH

Specified compressive strength for the slabs was 3000 psi. All twelve slabs (6 for each test) were cast from one batch of concrete on May 6, 2019. On the day of the first test (May 20, 2019) at 14 days age, the average compressive strength of the concrete was 4,185 psi.

Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST MATRIX

Table 3.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for longitudinal barriers.

Table 3.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Longitudinal Barriers.

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

The target critical impact points (CIPs) for the W-Beam Guiderail over Underground Structure were determined using the information provided in *MASH* Section 2.2.1, Section 2.3.2, and Figure 2-1. The target CIP for *MASH* Test 3-10 was 8.3 ft (99 inches) ±1 ft (12 inches) upstream of the centerline of post 16. For *MASH* Test 3-11, the target CIP was 11.8 ft (142 inches) ±1 ft (12 inches) upstream of the centerline of post 16.

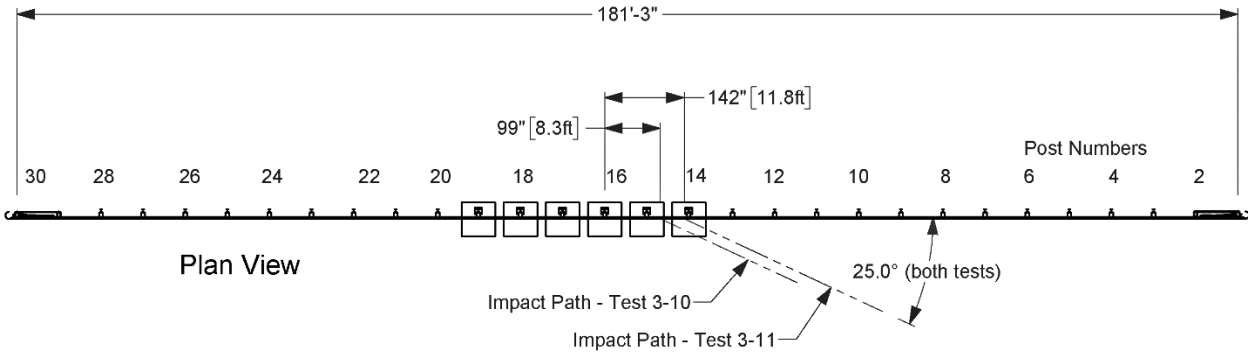

Figure 3.1. Target CIPs *MASH* Tests 3-10 and 3-11 for W-Beam Guiderail over Underground Structure.

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

3.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. The test conditions and evaluation criteria required for *MASH* TL-3 longitudinal barriers are listed in Table 3.1, and the substance of the evaluation

criteria in Table 3.2. An evaluation of the crash test results are presented in detail under the section Assessment of Test Results.

Table 3.2. Evaluation Criteria Required for *MASH* TL-3 Longitudinal Barriers.

Evaluation Factors	Evaluation Criteria	
Structural Adequacy	*A.*	*Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*
Occupant Risk	*D.*	*Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*
	F.	*The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*
	H.	*Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*
	I.	*The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*

Chapter 4. TEST CONDITIONS

4.1. TEST FACILITY

The full-scale crash tests reported herein were performed at Texas A&M Transportation Institute (TTI) Proving Ground, an International Standards Organization (ISO)/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 System 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 W-Beam Guiderail over Underground Structure 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.

4.2 VEHICLE TOW AND GUIDANCE SYSTEM

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

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems, Inc. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid state units designed for crash test service. The TDAS Pro hardware

and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 values per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark 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 all instrumentation used in the vehicle conforms to all specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO® 2901, precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the data acquisition system receive a calibration via a Genisco Rate-of-Turn table. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are also made any time data are suspect. Acceleration data are measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k=2).

TRAP uses the data from the TDAS Pro to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with 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, then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact. Rate of rotation data is measured with an expanded uncertainty of ±0.7 percent at a confidence factor of 95 percent (k=2).

4.3.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side (side opposite of impact for sign supports) 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 test.

4.3.3 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 W-Beam Guiderail over Underground Structure. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

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Chapter 5. *MASH* TEST 3-10 (CRASH TEST NO. 612281-02-1)

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-10 involves a 1100C vehicle weighing 2420 lb ±55 lb impacting the CIP of the longitudinal barrier at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The CIP for *MASH* Test 3-10 on the W-Beam Guiderail over Underground Structure was 8.3 ft (99 inches) ±1 ft (12 inches) upstream of the centerline of post 16.

The 2009 Kia Rio* used in the test weighed 2420 lb, and the actual impact speed and angle were 61.2 mi/h and 25.0°. The actual impact point was 8.3 ft (99.9 inches) upstream of the centerline of post 16. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 54 kip-ft.

5.2 WEATHER CONDITIONS

The test was performed on the morning of May 20, 2019. Weather conditions at the time of testing were as follows: wind speed: 11 mi/h; wind direction: 144° (vehicle was traveling at magnetic heading of 205°); temperature: 85°F; relative humidity: 77 percent.

5.3 TEST VEHICLE

Figures 5.1 and 5.2 show the 2009 Kia Rio used for the crash test. The vehicle's test inertia weight was 2420 lb, and its gross static weight was 2585 lb. The height to the lower edge of the vehicle front bumper was 7.75 inches, and height to the upper edge of the bumper was 21.5 inches. Table D.1 in Appendix D1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 5.1. Guiderail/Test Vehicle Geometrics for Test No. 612281-02-1.

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

Figure 5.2. Test Vehicle before Test No. 612281-02-1.

5.4 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 61.2 mi/h when it contacted the W-Beam Guiderail over Underground Structure 8.3 ft (99.9 inches) upstream of the centerline of post 16 at an impact angle of 25.0°. Table 5.1 lists events that occurred during Test No. 612281-02-1. Figure D.1 in Appendix D2 presents sequential photographs during the test.

Table 5.1. Events during Test No. 612281-02-1.

TIME (s)	EVENTS
0.0000	Vehicle contacts guiderail
0.0220	Vehicle begins to redirect
0.2270	Vehicle traveling parallel with guiderail
0.5090	Vehicle loses contact with the guiderail while traveling at 34.5 mi/h, exit trajectory of 15.6°, and heading of 15.9°

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 loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 180 ft downstream of the impact and 18 ft toward traffic lanes.

5.5 DAMAGE TO TEST INSTALLATION

Figure 5.3 shows the damage to the W-Beam Guiderail over Underground Structure. The soil was disturbed around post 1, and it was pulled downstream 0.13 inch at ground level. The W-beam rail element released from posts 16 through 18, and the blockouts released from posts 16 and 17. Post 15 was leaning toward the field side at 77°, posts 16 and 17 were leaning toward the field side at approximately 5° and downstream approximately 45°, and post 18 was leaning toward the field side at 87°. No movement or damage was observed at posts 2-14 and 19-30.

Working width† was 30.5 inches, and height of working width was 39.8 inches. Maximum dynamic deflection during the test was 27.0 inches, and maximum permanent deformation was 20.5 inches.

Figure 5.3. Guiderail after Test No. 612281-02-1.

† Working width is defined as the distance between the traffic face of the barrier before impact and the maximum lateral position of any major part of the barrier or the vehicle after impact.

5.6 VEHICLE DAMAGE

Figure 5.4 shows the damage sustained by the vehicle. The front bumper, hood, radiator and support, right front fender, right front tire and rim, right front strut and tower, right front and rear doors, right rear quarter panel, and rear bumper were damaged. Maximum exterior crush to the vehicle was 8.0 inches in the side plane at the right front corner at bumper height. No occupant compartment deformation or intrusion was observed. Figure 5.5 shows the interior of the vehicle. Tables D.2 and D.3 in Appendix D1 provide exterior crush and occupant compartment measurements.

Figure 5.4. Test Vehicle after Test No. 612281-02-1.

Figure 5.5. Interior of Test Vehicle after Test No. 612281-02-1.

5.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and results are shown in Table 5.2. Figure 5.6 summarizes these data and other pertinent information from the test. Figure D.2 in Appendix D3 shows the vehicle angular displacements, and Figures D.3 through D.5 in Appendix D4 show acceleration versus time traces.

Table 5.2. Occupant Risk Factors for Test No. 612281-02-1.

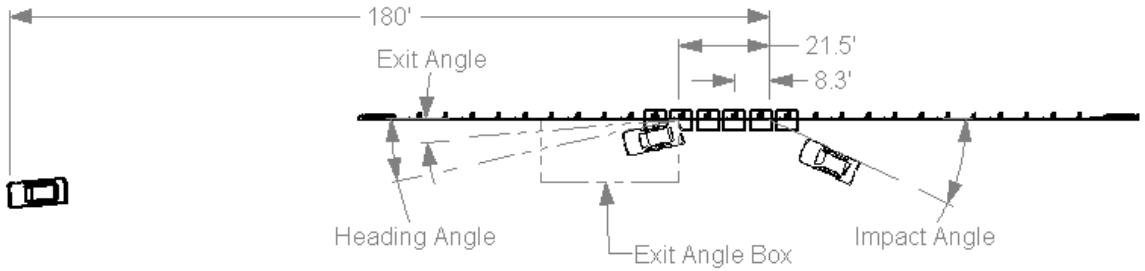
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	**18.0 ft/s**	at 0.1114 s on right side of interior
Lateral	**17.7 ft/s**	
Occupant Ridedown Accelerations		
Longitudinal	**8.0 g**	0.1445 - 0.1545 s
Lateral	**9.8 g**	0.1469 - 0.1569 s
Theoretical Head Impact Velocity (THIV)	**27.6 km/h** **7.7 m/s**	at 0.1075 s on right side of interior
Post Head Deceleration (PHD)	**12.0 g**	0.1468 - 0.1568 s
Acceleration Severity Index (ASI)	**0.95**	0.0484 - 0.0984 s
Maximum 50-ms Moving Average		
Longitudinal	**-6.5 g**	0.0451 - 0.0951 s
Lateral	**-7.6 g**	0.0417 - 0.0917 s
Vertical	**-3.0 g**	0.1287 - 0.1787 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**7°**	0.1805 s
Pitch	**6°**	0.4423 s
Yaw	**41°**	0.6541 s

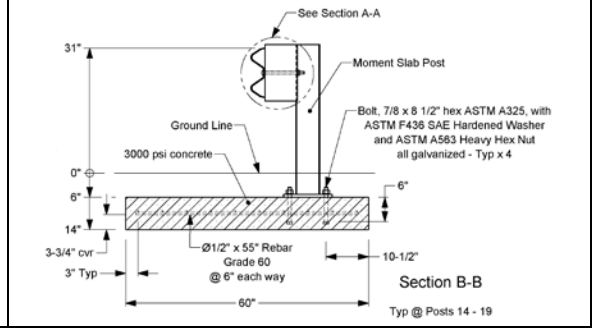
0.000 s

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 3-10
- TTI Test No. 612281-02-1
- Test Date 2019-05-20

Test Article
- Type ..... Longitudinal Barrier – Guardrail
- Name ..... W-Beam Guiderail over Underground Structure
- Installation Length ..... 181 ft-3 inches
- Material or Key Elements ... 31-inch tall W-beam guardrail with W6×8.5 posts with six 8-inch thick steel reinforced concrete slabs, 60 inches square, cast at post locations 14 through 19, with their tops 6 inches below grade
- **Soil Type and Condition** ..... AASHTO M147-65(2004), grading B Soil (crushed limestone), Damp

Test Vehicle
- Type/Designation 1100C
- Make and Model ..... 2009 Kia Rio
- Curb ..... 2475 lb
- Test Inertial ..... 2420 lb
- Dummy ..... 165 lb
- Gross Static ..... 2585 lb

Impact Conditions
- Speed ..... 61.2 mi/h
- Angle ..... 25°
- Location/Orientation ..... 99.9 inches upstream of post 16
- **Impact Severity** ..... 54 kip-ft

Exit Conditions
- Speed ..... 34.5 mi/h
- Trajectory/Heading Angle ... 15.6° / 15.9°

Occupant Risk Values
- Longitudinal OIV ..... 18.0 ft/s
- Lateral OIV ..... 17.7 ft/s
- Longitudinal Ridedown ..... 8.0 g
- Lateral Ridedown ..... 9.8 g
- THIV ..... 27.6 km/h
- PHD ..... 12.0 g
- ASI 0.95

Max. 0.050-s Average
- Longitudinal ..... -6.5 g
- Lateral ..... -7.6 g
- Vertical ..... -3.0 g

Post-Impact Trajectory
- Stopping Distance ..... 180 ft downstream 18 ft toward traffic

Vehicle Stability
- Maximum Yaw Angle ..... 41°
- Maximum Pitch Angle ..... 6°
- Maximum Roll Angle ..... 7°
- Vehicle Snagging ..... No
- Vehicle Pocketing ..... No

Test Article Deflections
- Dynamic ..... 27.0 inches
- Permanent ..... 20.5 inches
- Working Width ..... 30.5 inches
- Height of Working Width ..... 39.8 inches

Vehicle Damage
- VDS 01RFQ4
- CDC 01FREW3
- Max. Exterior Deformation ..... 8.0 inches
- OCDI RF0000000
- Max. Occupant Compartment Deformation ..... None

Figure 5.6. Summary of Results for *MASH* Test 3-10 on W-Beam Guiderail over Underground Structure.

Chapter 6. *MASH* TEST 3-11 (CRASH TEST NO. 612281-02-2)

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the longitudinal barrier at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The target CIP for *MASH* Test 3-11 on the W-Beam Guiderail over Underground Structure was 11.8 ft ±1 ft upstream of the centerline of post 16.

The 2014 RAM 1500 pickup truck used in the test weighed 5042 lb, and the actual impact speed and angle were 62.6 mi/h and 24.8°. The actual impact point was 11.1 ft upstream of the centerline of post 16. Minimum target IS was 106 kip-ft, and actual IS was 116 kip-ft.

6.2 WEATHER CONDITIONS

The test was performed on the morning of July 8, 2019. Weather conditions at the time of testing were as follows: wind speed: 8 mi/h; wind direction: 202° (vehicle was traveling at magnetic heading of 205°); temperature: 88°F; relative humidity: 72 percent.

6.3 TEST VEHICLE

Figures 6.1 and 6.2 show the 2014 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5042 lb, and its gross static weight was 5042 lb. The height to the lower edge of the vehicle front 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 29.0 inches. Tables E.1 and E.2 in Appendix E1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.1. Guiderail/Test Vehicle Geometrics for Test No. 612281-02-2.

Figure 6.2. Test Vehicle before Test No. 612281-02-2.

6.4 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 62.6 mi/h when it contacted the W-Beam Guiderail over Underground Structure 11.1 ft (133 inches) upstream of the centerline of post 16 at an impact angle of 24.8°. Table 6.1 lists events that occurred during Test No. 612281-02-2. Figures E.1 and E.2 in Appendix E2 present sequential photographs during the test.

Table 6.1. Events during Test No. 612281-02-2.

TIME (s)	EVENTS
0.0000	Vehicle contacts guiderail
0.0110	Post 14 begins to move back toward field side
0.0230	Post 14 begins to rotate clockwise and post 15 begins rotating counter-clockwise
0.0300	Post 13 begins to rotate clockwise
0.0470	Post 11 and 12 begin to rotate clockwise
0.0510	Post 16 begins rotating counter-clockwise
0.0520	Vehicle begins to redirect
0.0700	Post 17 and 18 begin to rotate counter-clockwise
0.2050	Vehicle traveling parallel with guiderail
0.6090	Vehicle loses contact with barrier while traveling at 31.6 mi/h, trajectory of 17.0° with a heading of 13.3° from guiderail

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 loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 135 ft downstream of the impact and 20 ft toward the field side. Brakes on the vehicle were not applied.

6.5 DAMAGE TO TEST INSTALLATION

Figure 6.3 shows the damage to the W-Beam Guiderail over Underground Structure. The soil was disturbed around post 1, and it was pulled downstream 1.25 inches at ground level. The rail element released from posts 1 through 27, and the blockouts released from posts 15 through 19. Post 13 rotated 30° clockwise, post 14 was rotated 90° clockwise, posts 15 through 19 were leaning downstream at approximately 5° (all about the vertical centerline), and post 20 was leaning downstream at 84° and had a 0.5-inch gap at grade on the traffic side. Post 30 had a 0.5-inch gap on the downstream side. The rail element was partially torn just downstream of post 16. Working width was 62.4 inches, and height of working width was 54.3 inches. Maximum dynamic deflection during the test was 53.1 inches, and maximum permanent deformation was 17.1 inches.

Figure 6.3. Guiderail after Test No. 612281-02-2.

6.6 VEHICLE DAMAGE

Figure 6.4 shows the damage sustained by the vehicle. The front bumper, grill, right front fender, right front tire and rim, right lower A-arm, right front and rear doors, right rear tire and rim, right rear exterior bed, and rear bumper were damaged. Maximum exterior crush to the vehicle was 11.0 inches in the side plane at the right front corner at bumper height. No occupant compartment deformation or intrusion was observed. Figure 6.5 shows the interior of the vehicle. Tables E.3 and E.4 in Appendix E1 provide exterior crush and occupant compartment measurements.

Figure 6.4. Test Vehicle after Test No. 612281-02-2.

Figure 6.5. Interior of Test Vehicle after Test No. 612281-02-2.

6.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and results are shown in Table 6.2. Figure 6.6 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.6 in Appendix E4 show acceleration versus time traces.

Table 6.2. Occupant Risk Factors for Test No. 612281-02-2.

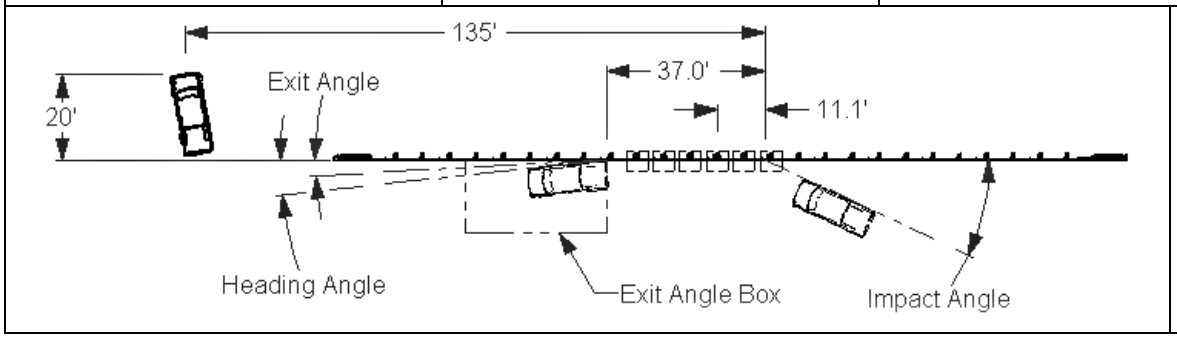
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	**16.1 ft/s**	at 0.1532 s on right side of interior
Lateral	**13.8 ft/s**	
Occupant Ridedown Accelerations		
Longitudinal	**8.1 g**	0.5473 - 0.5573 s
Lateral	**7.7 g**	0.3143 - 0.3243 s
Theoretical Head Impact Velocity (THIV)	**22.9 km/h** **6.4 m/s**	at 0.1463 s on right side of interior
Post Head Deceleration (PHD)	**10.0 g**	0.5477 - 0.5577 s
Acceleration Severity Index (ASI)	**0.66**	0.1003 - 0.1503 s
Maximum 50-ms Moving Average		
Longitudinal	**-5.0 g**	0.0692 - 0.1192 s
Lateral	**-4.8 g**	0.3084 - 0.3584 s
Vertical	**2.0 g**	0.5648 - 0.6148 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**9°**	2.0000 s
Pitch	**4°**	0.6583 s
Yaw	**41°**	0.7350 s

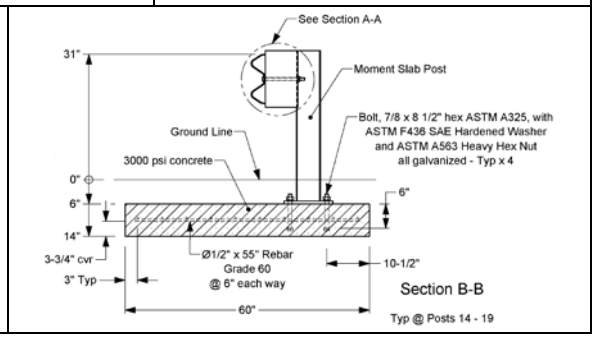
0.000 s

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. 612281-02-2
- Test Date 2019-07-08

Test Article
- Type ..... Longitudinal Barrier – Guardrail
- Name ..... W-Beam Guiderail over Underground
- Installation Length ..... Structure
- Material or Key Elements ... 181 ft-3 inches 31-inch tall W-beam guardrail with W6×8.5 posts with six 8-inch thick steel reinforced concrete slabs, 60 square, cast at post locations 14 through 19, with their tops 6 inches below grade
- **Soil Type and Condition** ..... AASHTO M147-65(2004), grading B Soil (crushed limestone), Damp

Test Vehicle
- Type/Designation 2270P
- Make and Model ..... 2014 RAM 1500 Pickup
- Curb ..... 4997 lb
- Test Inertial ..... 5042 lb
- Dummy ..... No Dummy
- Gross Static ..... 5042 lb

Impact Conditions
- Speed ..... 62.6 mi/h
- Angle ..... 24.8°
- Location/Orientation ..... 11.1 ft upstream of centerline of post 16

Impact Severity ..... 116 kip-ft

Exit Conditions
- Speed ..... 31.6 mi/h
- Trajectory/Heading Angle ... 17.0° / 13.3°

Occupant Risk Values
- Longitudinal OIV ..... 16.1 ft/s
- Lateral OIV ..... 13.8 ft/s
- Longitudinal Ridedown ..... 8.1 g
- Lateral Ridedown ..... 7.7 g
- THIV ..... 22.9 km/h
- PHD ..... 10.0 g
- ASI 0.66

Max. 0.050-s Average
- Longitudinal ..... -5.0 g
- Lateral ..... -4.8 g
- Vertical ..... 2.0 g

Post-Impact Trajectory
- Stopping Distance ..... 135 ft downstream 20 ft twd field side

Vehicle Stability
- Maximum Yaw Angle ..... 41°
- Maximum Pitch Angle ..... 4°
- Maximum Roll Angle ..... 9°
- Vehicle Snagging ..... No
- Vehicle Pocketing ..... No

Test Article Deflections
- Dynamic ..... 53.1 inches
- Permanent ..... 17.1 inches
- Working Width ..... 62.4 inches
- Height of Working Width ..... 54.3 inches

Vehicle Damage
- VDS 01RFQ6
- CDC 01FREW4
- Max. Exterior Deformation ..... 11.0 inches
- OCDI FS0000000
- Max. Occupant Compartment Deformation ..... None

Figure 6.6. Summary of Results for *MASH* Test 3-11 on W-Beam Guiderail over Underground Structure.

Chapter 7. SUMMARY AND CONCLUSIONS

7.1 ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed on the W-Beam Guiderail over Underground Structure in accordance with *MASH* TL-3, which involves two crash tests.

7.1.1 *MASH* Test 3-10 (Crash Test No. 612281-02-1)

Table 7.1 provides an assessment of *MASH* Test 3-10 on the W-Beam Guiderail over Underground Structure. The W-Beam Guiderail over Underground Structure contained and redirected the 1100C vehicle. The vehicle did not underride, override, or penetrate the installation. Maximum dynamic deflection during the test was 27.0 inches. Two blockouts released from the posts and metal rail element, however these did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area. No occupant compartment deformation or intrusion was observed. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 7° and 6°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*.

7.1.2 *MASH* Test 3-11 (Crash Test No. 612281-02-2)

Table 7.2 provides an assessment of *MASH* Test 3-11 on the W-Beam Guiderail over Underground Structure. The W-Beam Guiderail over Underground Structure contained and redirected the 2270P vehicle. The vehicle did not underride, override, or penetrate the installation. Maximum dynamic deflection during the test was 53.1 inches. Several blockouts released from the posts and metal rail element, however these did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area. No occupant compartment deformation or intrusion was observed. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 9° and 4°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*.

7.2 CONCLUSIONS

Table 7.3 shows the W-Beam Guiderail over Underground Structure, with up to six posts mounted to underground footings, performed acceptably for *MASH* TL-3 longitudinal barriers.

Table 7.1. Performance Evaluation Summary for *MASH* Test 3-10 on W-Beam Guiderail over Underground Structure.

Test Agency: Texas A&M Transportation Institute Test No.: 612281-02-1 Test Date: 2019-05-20

MASH Test 3-10 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The W-Beam Guiderail over Underground Structure contained and redirected the 1100C vehicle. The vehicle did not underride, override, or penetrate the installation. Maximum dynamic deflection during the test was 27.0 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.	Two blockouts released from the posts and metal rail element, however these did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	No occupant compartment deformation or intrusion was observed.	
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 7° and 6°, respectively.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 18.0 ft/s, and lateral OIV was 17.7 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 8.0 g, and lateral occupant ridedown acceleration was 9.8 g.	Pass
Vehicle Trajectory		
For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the "exit box" criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.	The 1100C vehicle exited within the exit box criteria.	Documentation only

Table 7.2. Performance Evaluation Summary for *MASH* Test 3-11 on W-Beam Guiderail over Underground Structure.

Test Agency: Texas A&M Transportation Institute Test No.: 612281-02-2 Test Date: 2019-07-08

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 W-Beam Guiderail over Underground Structure contained and redirected the 2270P vehicle. The vehicle did not underride, override, or penetrate the installation. Maximum dynamic deflection during the test was 53.1 inches.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	Several blockouts released from the posts and metal rail element, however these did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	No occupant compartment deformation or intrusion was observed.	
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 9° and 4°, respectively.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 16.1 ft/s, and lateral OIV was 13.8 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 8.1 g, and lateral occupant ridedown acceleration was 7.7 g.	Pass
Vehicle Trajectory		
For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the "exit box" criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.	The 2270P vehicle exited within the exit box criteria.	Documentation only

Table 7.3. Assessment Summary for *MASH* TL-3 Tests on W-Beam Guiderail over Underground Structure.

Evaluation Factors	Evaluation Criteria	Test No. 612281-02-1	Test No. 612281-02-2
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

REFERENCES

1. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition.* 2016, American Association of State Highway and Transportation Officials: Washington, D.C.

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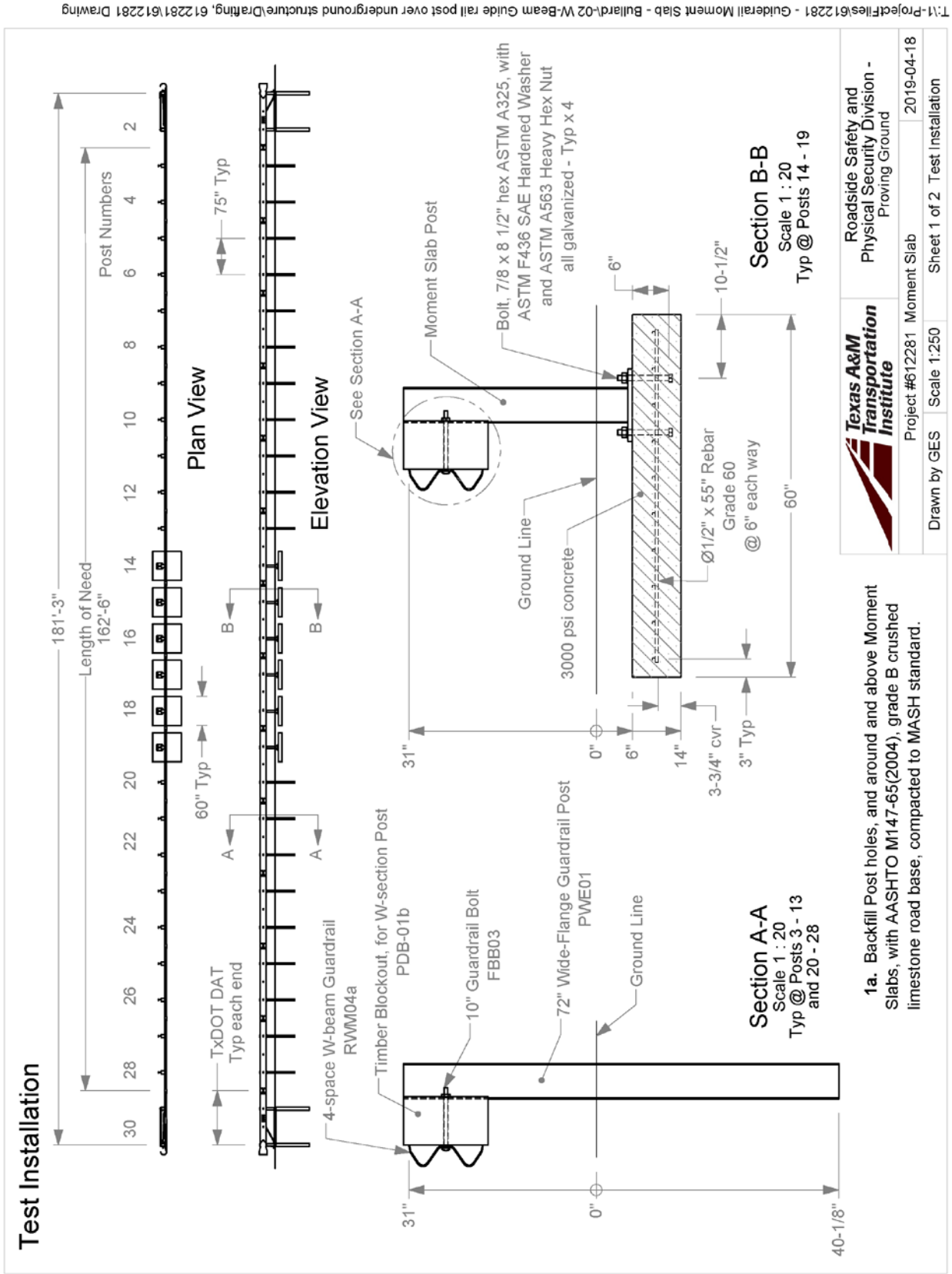
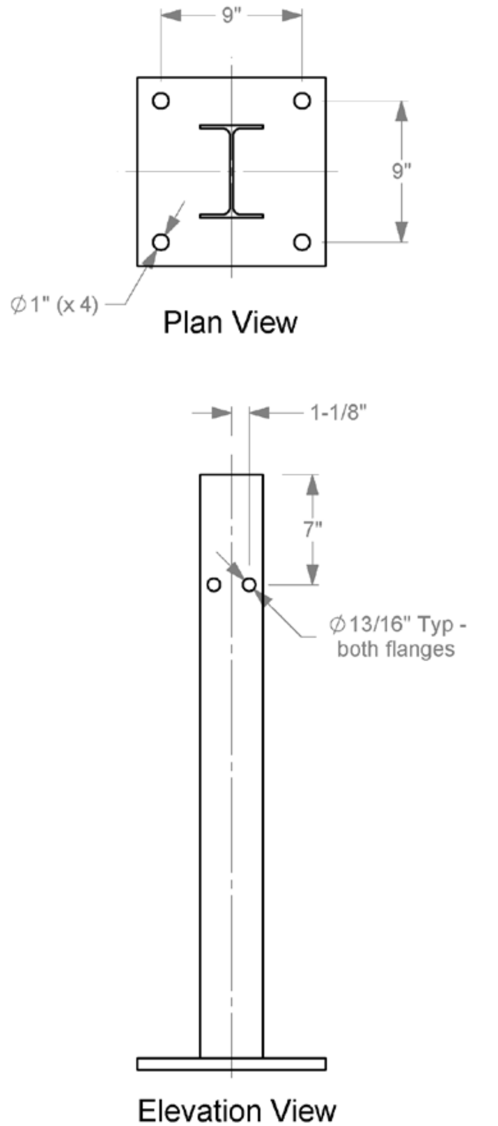
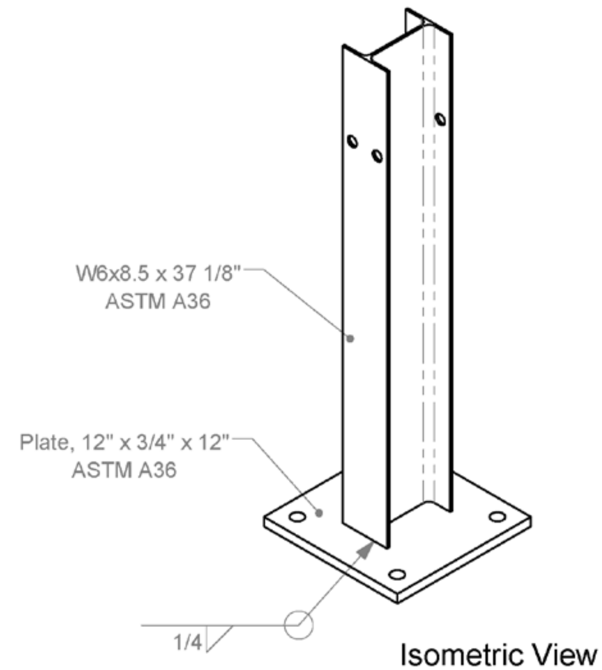
APPENDIX A. DETAILS OF THE W-BEAM GUIDERAIL OVER UNDERGROUND STRUCTURE



Post Details





2a. All welding must be performed by certified welders using industry standard practices.

2b. Galvanize all components after fabrication is complete.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #612281 Moment Slab		2019-04-18
Drawn by GES	Scale 1:10	Sheet 2 of 2 Post Details

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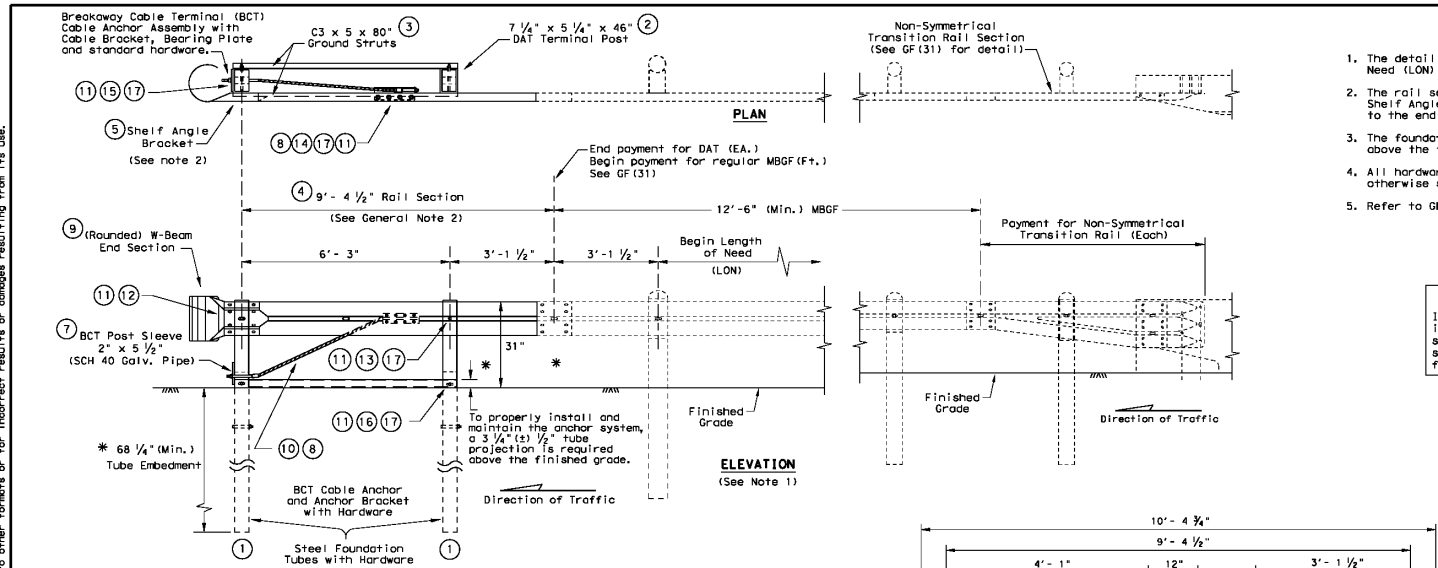


DOWNSTREAM ANCHOR TERMINAL (DAT)

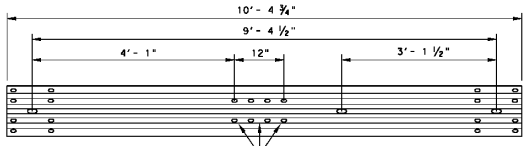
Only for downstream use, when located outside the horizontal clearance area of opposing traffic.

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.

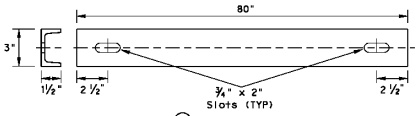
MOW STRIP INSTALLATION

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.

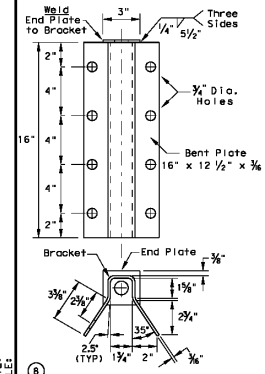


(4) TERMINAL RAIL ELEMENT FOR DAT

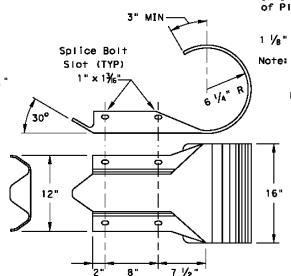
#	(DAT) PARTS LIST	QTY
(1)	Steel Foundation Tube	2
(2)	DAT Terminal Post	2
(3)	Channel Strut	2
(4)	Terminal Rail Element	1
(5)	Shelf Angle Bracket	1
(6)	BCT Bearing Plate	1
(7)	BCT Post Sleeve	1
(8)	Guardrail Anchor Bracket	1
(9)	(Rounded)W-Beam End Section	1
(10)	BCT Cable Anchor	1
(11)	Recessed Nut, 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



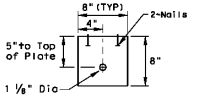
(3) CHANNEL STRUT
C3 x 5 x 80", Grade A36



(8) GUARDRAIL ANCHOR BRACKET

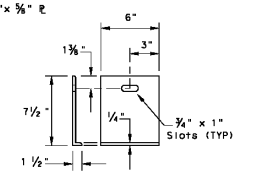


(9) W-BEAM END SECTION (ROUNDED) (12 GA.)

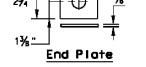


Note: Drive nails and bend over to prevent plate rotation

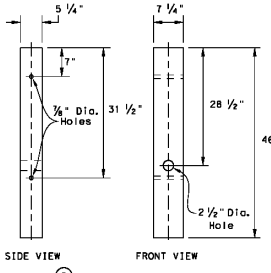
(6) BEARING PLATE
8"x 8"x 5/8" ₵



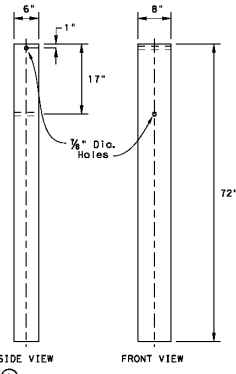
(5) SHELF ANGLE BRACKET



End Plate



(2) TERMINAL POST
7 1/4"x 5 1/4"x 46" Wood Post



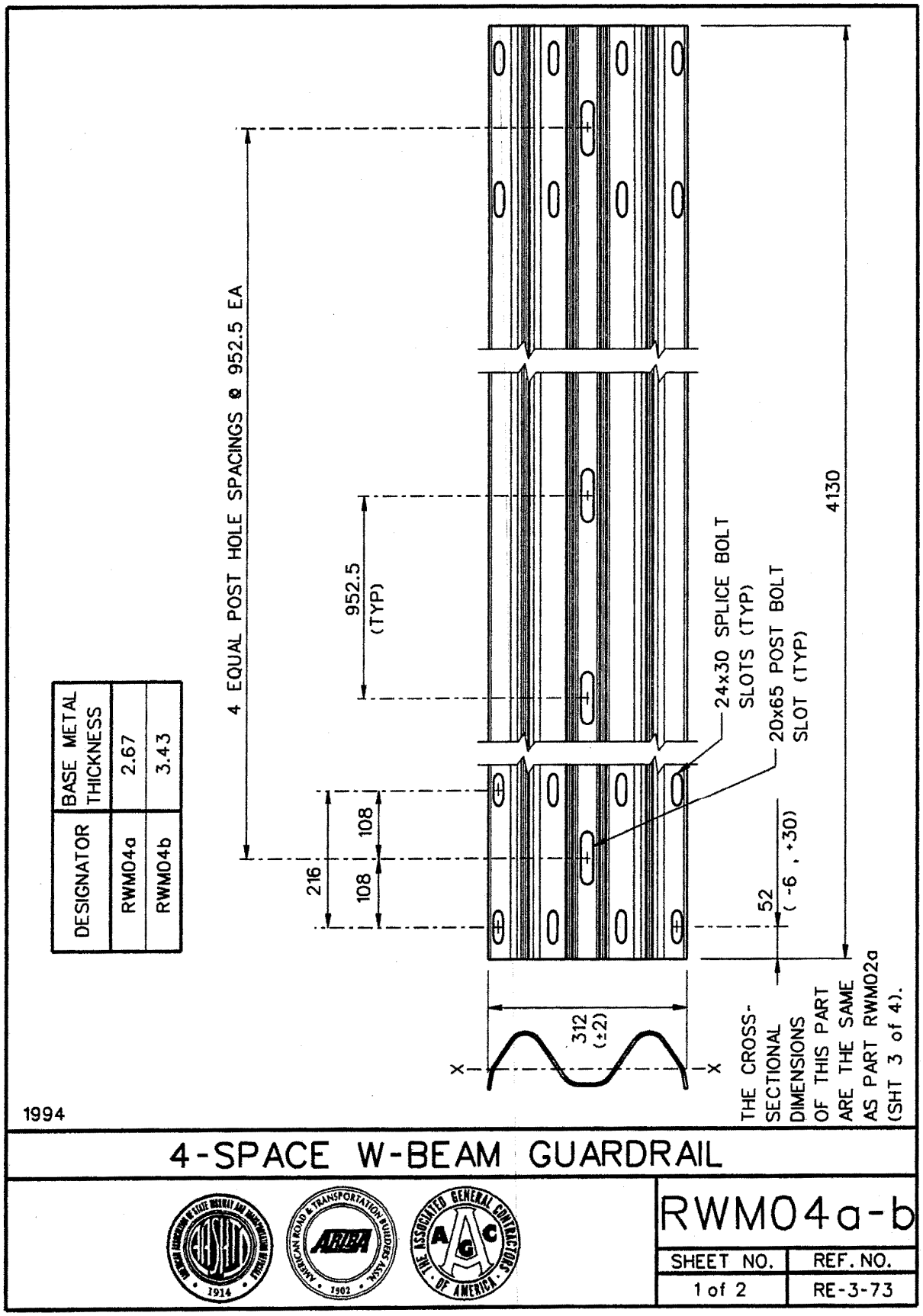
(1) STEEL FOUNDATION TUBE
6"x 8"x 1/8" x 72" Steel Tube

Texas Department of Transportation — Design Division Standard

METAL BEAM GUARD FENCE
(Downstream Anchor Terminal)

GF(31)DAT-14

FILE: gf31dt14.dgn	DN: TxDOT	CK: AM	DW: VP	CK: CGL
©TxDOT: December 2011	CONT	SECT	JOB	HIGHWAY
REVISIONS				
	DIST	COUNTY		SHEET NO.


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

SPECIFICATIONS

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

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

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

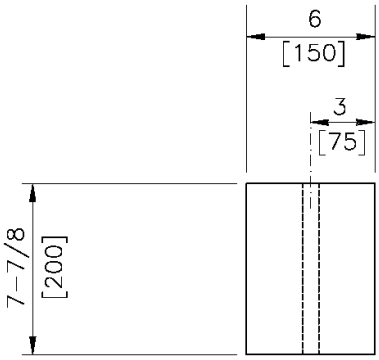
INTENDED USE

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

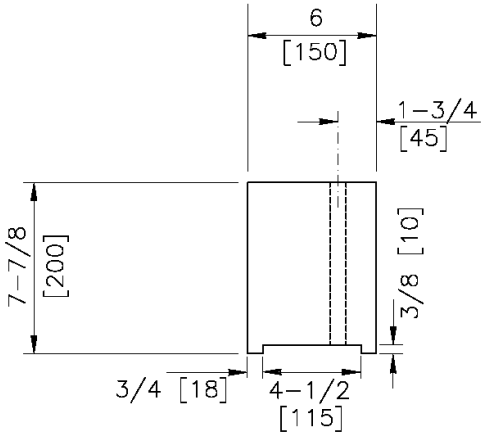
4-SPACE W-BEAM GUARDRAIL

RWM04a-b

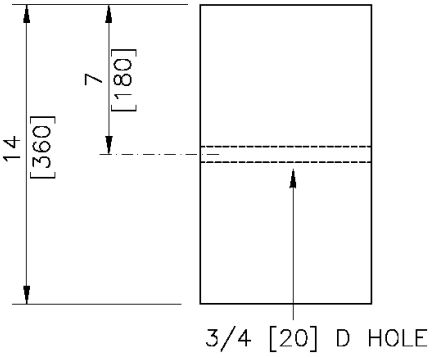
SHEET NO.	DATE
2 of 2	04-01-95



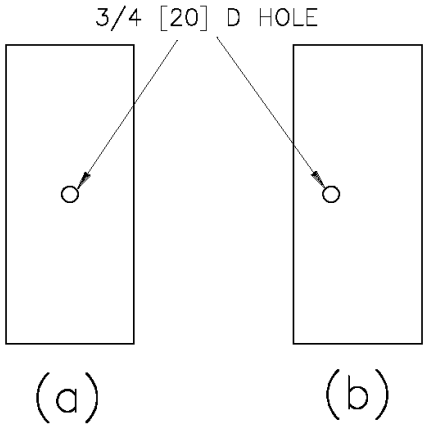
PLAN (a)



PLAN (b)



SIDE



FRONT

1994

W-BEAM TIMBER BLOCKOUT

PDB01a-b

SHEET NO.	DATE:
1 of 2	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.

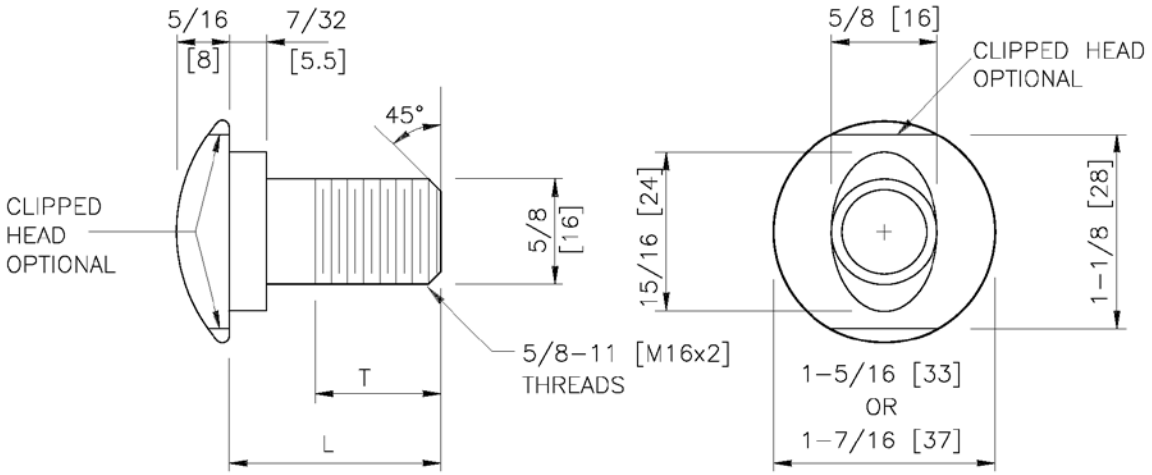
INTENDED USE

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.

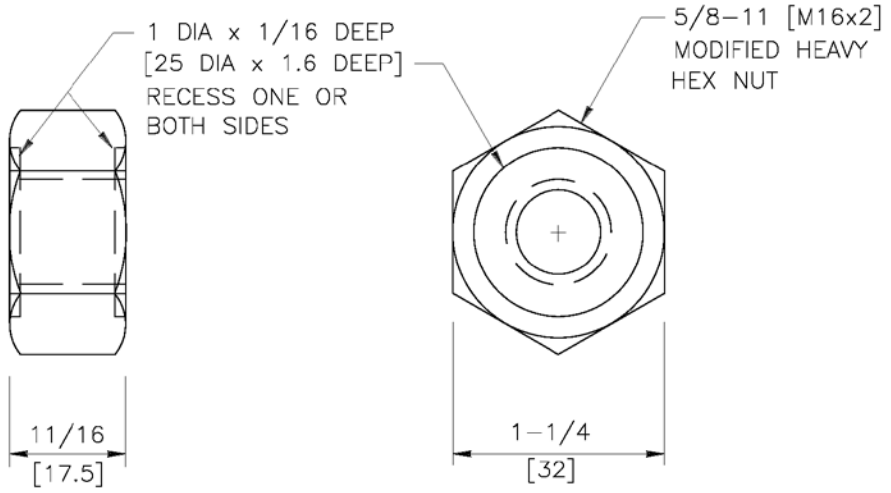
W-BEAM TIMBER BLOCKOUT

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

TF 13

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.

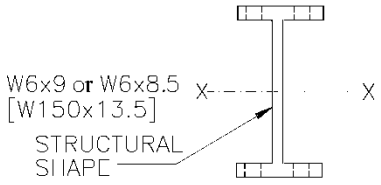
GUARDRAIL BOLT AND RECESSED NUT

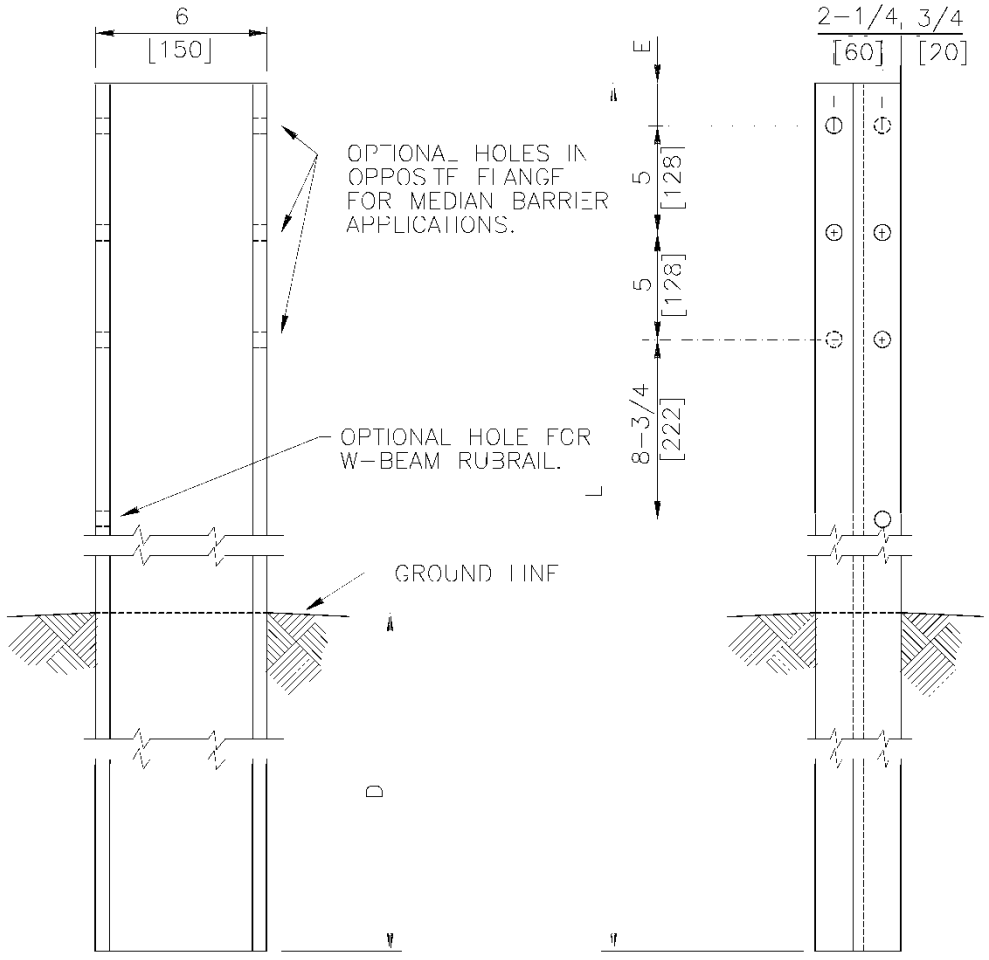
FBB01-05

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

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]
PWF04	81 [2060]	46-1/8 [1173]	5-7/8 [149]

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





SIDE

FRONT

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

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APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

NUCOR
NUCOR CORPORATION
NUCOR STEEL TEXAS

Mill Certification
3/1/2019

MTR #: J1-443217
8812 Hwy 79 W
Jewett, TX 75846
(903) 626-4461
Fax: (903) 626-6290

Sold To: TRIPLE S STEEL SUPPLY CO
PO BOX 21119
HOUSTON, TX 77226-1119
(713) 697-7105
Fax: (713) 697-5945

Ship To: TRIPLE S STEEL SUPPLY (JENSEN)
6000 JENSEN DR
HOUSTON, TX 77026-1113
(713) 354-4113

Customer P.O.	HOU-184257	Sales Order	290250.14
Product Group	Merchant Bar Quality	Part Number	53750C0024010W0
Grade	NUCOR MULTIGRADE	Lot #	JW1910154352
Size	3/4x12" Flat	Heat #	JW19101543
Product	3/4x12" Flat 20' NUCOR MULTIGRADE	B.L. Number	J1-858791
Description	NUCOR MULTIGRADE	Load Number	J1-443217
Customer Spec		Customer Part #	

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Roll Date: 2/22/2019 **Melt Date: 2/16/2019** **Qty Shipped LBS: 4,900** **Qty Shipped Pcs: 8**

ASTM A36/A36M-12, A709/709M-13 GR36, ASME SA36-10 Ed '11 Ad.
ASME SA36-2010 EDITION-2011 ADDENDA
ASTM A709/A709M-13 GR 36 [250]

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.14%	0.87%	0.011%	0.026%	0.24%	0.30%	0.15%	0.16%	0.040%	0.0564%	0.000%	0.010%

CE4020	CEA529
0.37%	0.41%

CE4020: C. E. CSA G4020, AASHTO M270
CEA529: A529 CARBON EQUIVALENT

Yield 1: 56,300psi Tensile 1: 72,000psi Elongation: 21% in 8"(% in 203.3mm)

Yield 2: 55,300psi Tensile 2: 71,300psi Elongation 21% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/A36M-14; A529/529M-05(2009) GR50(345), A572/572M-07 GR50(345); A709/709M-10 GR36(250) & GR50(345); CSA G40.21-04 GR44W(300W)& GR50W(350W); ASME SA36/SA36M-07; MEETS REPORTING REQUIREMENTS OF EN10204 SEC 3.1

Comments: E-mail: websales@nstexas.com

1. All manufacturing processes of the steel, including melting, casting & hot rolling, have been performed in U.S.A
2. Mercury in any form has not been used in the production or testing of this product.
3. Welding or weld repair was not perfomed on this material.
4. This material conforms to the specifications described on this document and may not be reproduced, except in full, without written approval of Nucor Corporation.
5. Results reported for ASTM E45 (Inclusion content) and ASTM E381 (Macro-etch) are provided as interpretation of ASTM procedures.

Bhargava R Vantari

Bhargava R Vantari
Division Metallurgist

NBMG-10 October 1, 2017

NUCOR
FASTENER DIVISION

LOT NO.
356910A

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

TEST REPORT SERIAL# FB452470
TEST REPORT ISSUE DATE 2/23/15
MANUFACTURE DATE 2/10/15
NAME OF LAB SAMPLER: DEANN MORENO, LAB TECHNICIAN

**********CERTIFIED MATERIAL TEST REPORT**********

PART NO.	LOT NO.	DESCRIPTION
161660	356910A	7/8-9 X 8 1/2 A325 HVY HX STRUC SCREW PLAIN

--CHEMISTRY MATERIAL GRADE -1037ML

MATERIAL NUMBER	HEAT NUMBER	**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER C	MN	P	S	SI	CR	
RM029534	NF14204186	.39	.78	.006	.021	.22	.36	NUCOR STEEL - NEBRASKA

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A325-10

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 39300 LBS	TENSILE STRENGTH 10 DEG-WEDGE (LBS)	STRESS (PSI)
N/A	30.8	PASS	68840	149004
N/A	31.0	PASS	68780	148874
N/A	30.1	PASS	68920	149177
N/A	31.7			
AVERAGE VALUES FROM TESTS				
	30.9		68847	149018
PRODUCTION LOT SIZE		4600 PCS		

--VISUAL INSPECTION IN ACCORDANCE WITH ASTH A325-10 4 PCS. SAMPLED LOT PASSED
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2012

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	4	1.6220	1.6330
Grip Length	4	6.9490	7.0000
Head Height	4	0.5390	0.5500
Threads	4	PASS	PASS

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO HEATS TO WHICH BISMUTH, SELENIUM, TELLURIUM, OR LEAD WAS INTENTIONALLY ADDED HAVE BEEN USED TO PRODUCE THE BOLTS.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A.
PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

A2LA ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/15

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson

JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Raw Material Cert for Lot 356910A

29534

NUCOR
NUCOR CORPORATION
NUCOR STEEL NEBRASKA

Mill Certification
11/3/2014

MTR #: 0000062246
2911 East Nucor Road
NORFOLK, NE 68701
(402) 644-0200
Fax: (402) 644-0329

Sold To: NUCOR FASTENER INDIANA
PO BOX 6100
6730 COUNTY RD 60
ST JOE, IN 46785-0000
(260) 337-1600
Fax: (435) 734-4581

Ship To: NUCOR FASTENER INDIANA
COUNTY RD 60
ST JOE, IN 46785-0000

Customer P.O.	148156	Sales Order	137668.9
Product Group	Special Bar Quality	Part Number	31000890000V000
Grade	1037ML	Lot #	NF1420418611
Size	57/64" (.8906) Round Coil	Heat #	NF14204186
Product	57/64" (.8906) Round Coil 1037ML	B.L. Number	N1-292499
Description	1037ML	Load Number	N1-236004
Customer Spec		Customer Part #	005014

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Roll Date: 11/1/2014 **Melt Date: 10/12/2014** **Qty Shipped LBS: 203,200** **Qty Shipped Pcs: 38**

Melt Date: 10/12/2014

C	Mn	V	Si	S	P	Cu	Cr	Ni	Mo	Al	Cb
0.39%	0.78%	0.003%	0.22%	0.021%	0.006%	0.09%	0.36%	0.04%	0.02%	0.001%	0.001%
Pb	**Sn**	**Ca**	**B**	**Tl**	**NICUMO**						
0.000%	0.005%	0.0000%	0.0001%	0.000%	0.15						

NICUMO: Cu+Ni+Mo

Roll Date: 11/1/2014

Reduction Ratio 70 :1

Specification Comments: Coarse Grain Practice

Sellenium,Tellurium,Lead,Bismuth or Boron were not intentionally added to this heat.

1. All manufacturing processes of the steel materials in this product, including melting, have been performed in the United States.
2. All products produced are weld free.
3. Mercury, in any form, has not been used in the production or testing of this material.
4. Test conform to ASTM A29-12, ASTM E415 and ASTM E1019-resulphurized grades or applicable customer requirements.
5. All material melted at Nucor Steel Nebraska is produced in an Electric Arc Furnace
6. Strand Cast
7. ISO-17025 LAB accreditation cert available upon request
8. Exporting Country-USA
9. Sales@nucorne.com

Chemistry Verification Checks

Part# 5014 **RM#** 29534

	Checked By	Date
Receiving OK:	297	12-1-14
Certifications OK:	375	12-1-14

Jim Hill
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 1

Stelfast Inc.

22979 Stelfast Parkway
Strongsville, Ohio

44149

Report of Chemical and Physical Properties

Issued To: Mack Bolt, Steel & Machine
5875 Hwy 21 East
BRYAN, TX
77808

Purchase Order: 35197
Stelfast Order: SO 217916
Certificate #: 740,479

Quantity: 300
Part #: AHHAG0875C
Description: 7/8-9 Hvy Hx Nut GrA HDG/TOS 0.022

Lot Number: 1N1840265
Heat Number: 18302532-3
Country of Origin: CN

Chemical Analysis

C	Mn	P	S	Si	Cr	Mo	V	B	Ni	Cu
0.14	0.38	0.008	0.014	0.04						

Mechanical Properties

Hardness (Core)	76- 79 HRB
Proof Load	46200 LBF MIN
Specification	ASTM A563(15)-GR.A

We hereby certify that the above data is a true copy of the data furnished to us by the producing mill or the data resulting from tests performed in approved laboratories. Stelfast does not certify to customer's part numbers.

This certificate applies to the product shown on this document, as supplied by Stelfast Inc. Alterations to the product by our customer or a third party will render this certificate void.

David Biss
Quality Manager

April 23, 2019

Stelfast Inc.
22979 Stelfast Parkway
Strongsville, Ohio
44149

Report of Chemical and Physical Properties

Mack Bolt, Steel & Machine
5875 Hwy 21 East
BRYAN TX 77808

Purchase Order: 34593
Stelfast Order: SO 212848
Certificate #: 769,688

Quantity: 600
Part #: DHWGA08750
Description: 7/8 Hardened Washer F436 HDG

Lot Number: GTR18538205A-020
Heat Number: 17400797
Country of Origin: CN

Chemical Analysis

C	Mn	P	S	Si	Cr
0.46	0.7	0.014	0.008	0.2	

Mechanical Properties

Core Hardness 29 - 34 HRC
Grade Marking ASTM F436(11) Type 1

We hereby certify that the above data is a true copy of the data furnished to us by the producing mill or the data resulting from tests performed in approved laboratories. Stelfast does not certify to customer's part numbers.
This certificate applies to the product shown on this document, as supplied by Stelfast Inc. Alterations to the product by our customer or a third party will render this certificate void.

David Biss
Quality Manager

January 30, 2019

Akzo Nobel Coatings Inc.
Powder Coatings

AkzoNobel

CERTIFICATE OF COMPLIANCE

Product Name: RB-600 (HKF30R)
Product Description: RESICOAT® GREEN REBAR COATING

To Whom It May Concern:

This is to certify that the batch number of Resicoat RB-600 fusion bonded epoxy powder coating listed below is chemically the same material as tested by Wiss Janney Elstner Associates of Northbrook Illinois to ASTM A 775. I certify that it meets the requirements of ASTM A 775. Resicoat RB-600 also meets the requirements of ASTM D 3963, ASTM A 884, AASHTO M 254 type B and AASHTO M 284.

The following batch was manufactured in the United States and qualifies as "U.S. made end products", "domestic construction materials", and "domestic manufactured goods". When applied to steel or iron in the U.S. this coating meets the Buy America provisions set forth in FHWA 23 CFR 635.410 Section 1041(a) of the ISTEA.

Batch: _VA04353NA____ Production Date: 01/24/2019____ Batch Size: _21,000_____ Kg's.

For Quality Assurance Supervisor: Kenny McFerlin
Signed

State/Commonwealth TN County of Davidson

On this the 31st (Day) of JAN (Month), 2019 (Year), before me Rebecca Hoover (Name of Notary Public)

The undersigned Notary Public, personally appeared Kenny McFerlin (Name(s) of Signer(s)) ☑ Personally known to me

To be the person(s) whose name(s) is/are subscribed to the Within instrument, and acknowledged to me that he/she/they Executed the same for the purposes therin stated.

Witness my hand and official seal

Rebecca Hoover
Signature of Notary Public

REBECCA HOOVER NOTARY PUBLIC STATE OF TENNESSEE DAVIDSON COUNTY My Commission Expires 03-10-2019

CAUTION: Special safety practices should be followed when using any powder coating. For further information, please refer to the specific product Material Safety Data Sheet (MSDS). The information contained in this COC has been determined through the application of accepted engineering practice and is believed to be reliable. Since the conditions of application and use of our products are beyond our control, no warranty is expressed or implied regarding accuracy of the information, the results to be obtained from the use of the product, or that such use will not infringe on any patent. This information is furnished with the express condition that you will make your own tests to determine the suitability of the product for your particular use. RESICOAT® is a registered trademark of Akzo Nobel.

30 Cutcart Street
USA
T +1 615 259 2490
www.interpon.us

TR No. 612281-02

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

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3087225 SECTION: REBAR 19MM (#6) 60'0" 420/60 GRADE: ASTM A615-18e1 Gr 420/60 ROLL DATE: 03/26/2019 MELT DATE: 03/11/2019 Cert. No.: 82669061 / 087225A053	SOLD TO	CMC COATING WAXAHACHIE 901 CANTRELL STREET WAXAHACHIE TX US 75165-3120 972-937-9841	SHIP TO	CMC Coatings Waxahachie 901 Cantrell St Waxahachie TX US 75165-3120 972 937 9841	Delivery#: 82669061 BOL#: 72909315 CUST PO#: CUST P/N: DLVRY LBS / HEAT: 43526.000 LB DLVRY PCS / HEAT: 483 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.43%				
Mn	0.85%				
P	0.013%				
S	0.047%				
Si	0.18%				
Cu	0.34%				
Cr	0.13%				
Ni	0.22%				
Mo	0.087%				
V	0.001%				
Cb	0.002%				
Sn	0.013%				
Al	0.000%				
Yield Strength test 1	65.5ksi				
Tensile Strength test 1	104.4ksi				
Elongation test 1	16%				
Elongation Gage Lgth test 1	8IN				
Bend Test 1	Passed				
Bend Test Diameter	3.750IN				

The Following is true of the material represented by this MTR:

**Material is fully killed*
**100% melted and rolled in the USA*
**EN10204:2004 3.1 compliant*
**Contains no weld repair*
**Contains no Mercury contamination*
**Manufactured in accordance with the latest version of the plant quality manual*
**Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661*
**Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov*

REMARKS :

2019-10-23

Texas A&M Transportation Institute Proving Ground, 3100 SH 47, Bldg 7091, Bryan, TX 77807 Texas A&M University, College Station, TX 77843, Phone 979-845-6376	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Issue Date: 2018-06-18
Quality Form	Prepared by: Wanda L. Menges Approved by: Darrell L. Kuhn	Revision: 6	Page: 1 of 1

Project No: 612281-02 Casting Date: 2019-5-9 Mix Design (psi): 4500

Name of Technician Taking Sample: GREG FRITZ

Name of Technician Breaking Sample: D. Hill

Signature of Technician Taking Sample:

Signature of Technician Breaking Sample:

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	7130	5383111	All Pads

2019-05-17

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	5-17	11 days	118000	4174	
T1	5-20	14 days	125000	4421	1
1	1	1	120000	4244	4185
1	1	1	110000	3891	1

TICKET NO. 5383111

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
12:36	13:53	14:08	14:10	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 20 GAL.
ALLOWABLE WATER (withheld from batch) 15.7 GAL.
TEST CYLINDER TAKEN ☐ YES ☒ NO BY _____
CYLINDER TAKEN ☐ BEFORE ☐ AFTER WATER

ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IN EXCESS OF SPECIFIED SLUMP IS AT CUSTOMER'S RISK.

CUSTOMER SIGNATURE
X

DELIVERY OF THESE MATERIALS IS SUBJECT TO THE TERMS AN CONDITIONS ON THE REVERSE SIDE HEREOF AS ACCEPTED B SIGNATURE ABOVE .

CUSTOMER NAME AND DELIVERY ADDRESS
TEXAS A & M UNIVERSI
TTI-Riverside Campus

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
617	7130	2020	5.0	5/6/2019	

DRIVER NAME: Billy Lomuscio
DATE: 5/6/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783659	79546	9.00	9.00

LOAD QUANTITY	PRODUCT CODE	DESCRIPTION	UNIT PRICE	AMOUNT
9.00	CYDS	R9Z50636 COM, RG, Z, 4500, RE		
1.00	ea	12987 FREIGHT CHARGE		

SPECIAL DELIVERY INSTRUCTIONS
SOUTH 2818, RIGHT ON LEONARD RIGHT ON HWY-47-LEFT INTO RELLIS CAMPUS WILL MEET YOU AT ROUND ABOUT

SALES TAX
TOTAL

DANGER! MAY CAUSE ALKALI BURNS.
SEE WARNINGS ON REVERSE SIDE.

FOR OFFICE USE ONLY **FORM:** 2608261

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
7130	943616	user	5383111	75869	12:36	5/6/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
9.00	CYDS R9Z50636				D	76889

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"RG	1365 lb	12384 lb	12360 lb	-0.19%	0.80% M	12 gl
3/8"PG	500 lb	4532 lb	4520 lb	-0.26%	0.70% M	4 gl
SAND-1	1298 lb	12232 lb	12200 lb	-0.27%	4.50% M	66 gl
CMT-I/II	435 lb	3915 lb	3930 lb	0.38%		
FLYASH-C	145 lb	1305 lb	1300 lb	-0.38%		
H20	258 lb	1430 lb	1428 lb	-0.11%		171 gl
ZY-610	17 oz	157 oz	155 oz	-1.02%		
Actual	Num Batches: 1					

Load Total: 35748 lb Design 0.445 Water/Cement 0.444 T Design 278.3 gl Actual 252.5 gl To Add: 15.7 gl
Slump: 5.00 in # Water in Truck: 10.0 gl Adjust Water: 0.0 gl / Load Trim Water: -1.7 gl/ CYD

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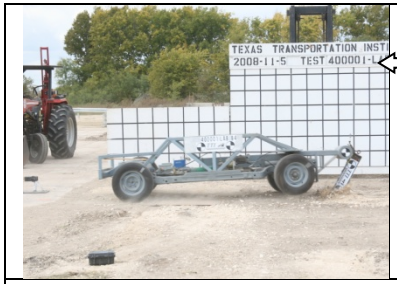
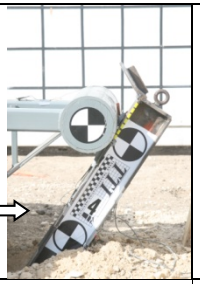
Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.



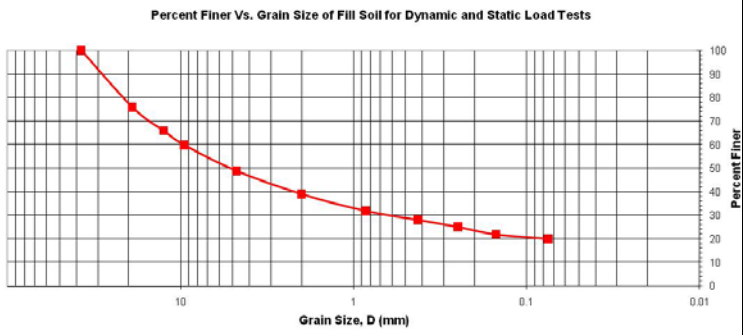
Dynamic Setup



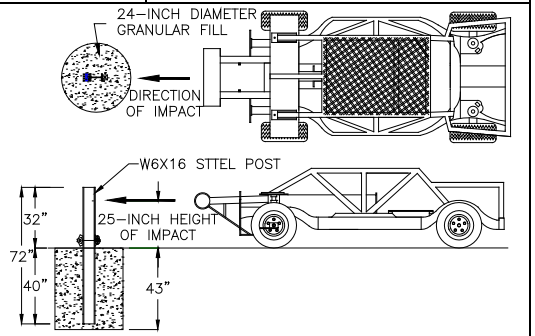
Post-Test Photo of post

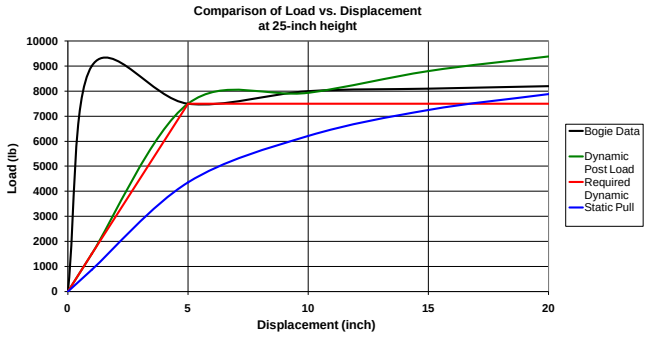
Static Load Test

Post-Test Photo

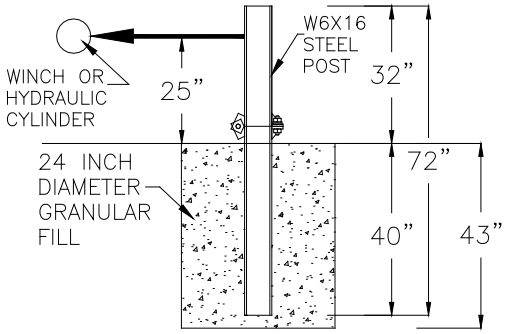


Dynamic Test Installation Details





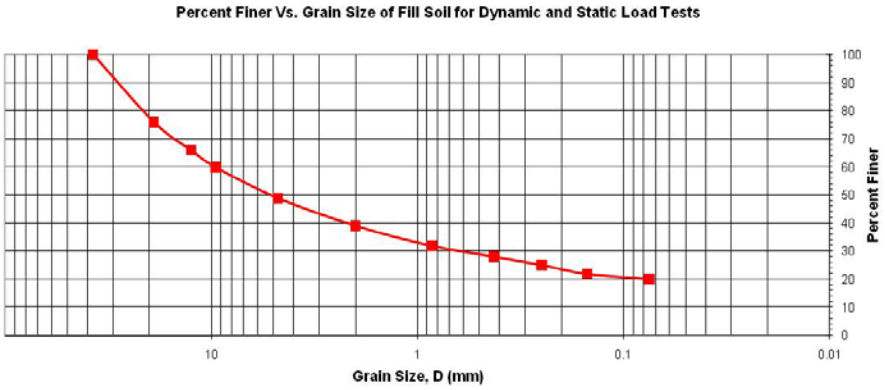
Static Load Test Installation Details



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. 612281-02-1.

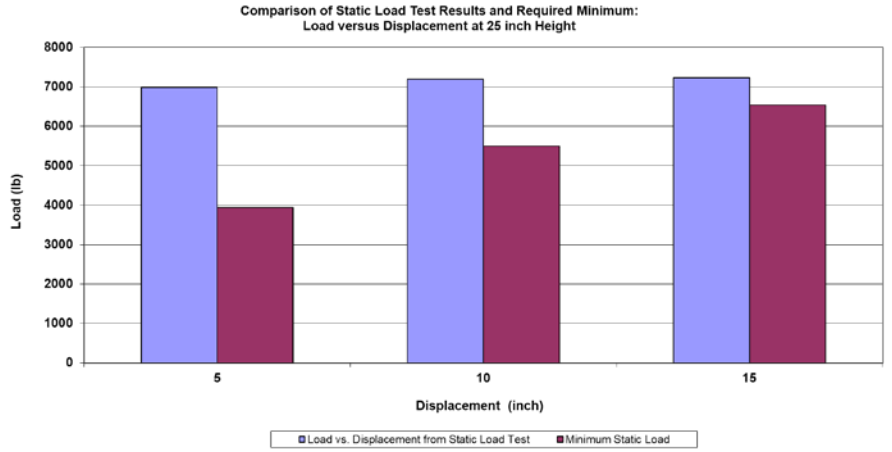
Typical Static Load Setup



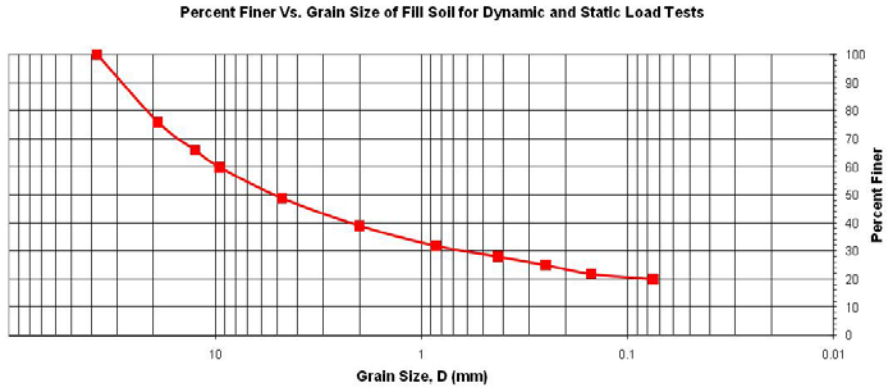
Post-Test Photo of Post

Date	2019-05-20
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. 612281-02-2.



Typical Static Load Setup



Post-Test Photo of Post

Date	2019-07-08
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

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APPENDIX D. *MASH* TEST 3-10 (CRASH TEST NO. 612281-02-1)

D1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 612281-02-1.

Date: 2019-05-20 Test No.: 612281-02-1 VIN No.: KNADE223496573559

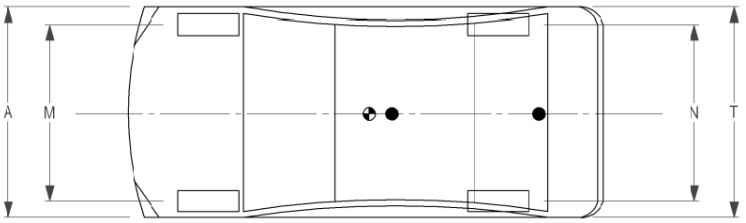
Year: 2009 Make: Kia Model: Rio

Tire Inflation Pressure: 32 PSI Odometer: 145420 Tire Size: 185/65R14

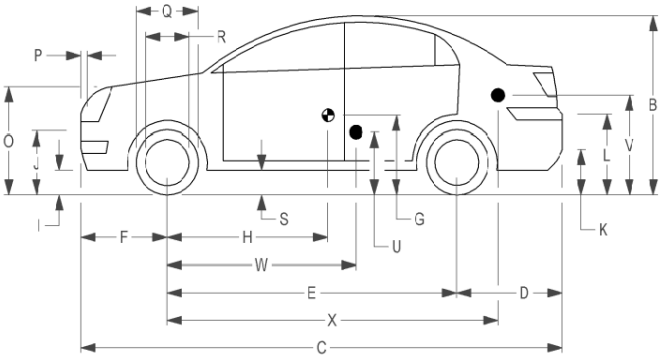
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None



Engine Type: 4 CYL
Engine CID: 1.6 L
Transmission Type:
☑ Auto or ☐ Manual
☑ FWD ☐ RWD ☐ 4WD
Optional Equipment:
None



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	14.75
B	51.50	G		L	25.25	Q	22.50	V	20.50
C	165.75	H	35.09	M	57.75	R	15.50	W	35.10
D	34.00	I	7.75	N	57.70	S	8.25	X	72.50
E	98.75	J	21.50	O	27.00	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 = 169 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; H = 39 ±4 inches; O (Bottom of Hood Lip) = 24 ±4 inches
TOP OF RADIATOR SUPPORT = 28.25 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}	1595	1560	1645
Back	1874	M_{rear}	880	860	940
Total	3638	M_{Total}	2475	2420	2585

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

Mass Distribution:
lb LF: 810 RF: 750 LR: 420 RR: 440

Table D.2. Exterior Crush Measurements for Test No. 612281-02-1.

Date: 2019-05-20 Test No.: 612281-02-1 VIN No.: KNADE223496573559

Year: 2009 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width*** (CDC)	Max**** Crush								
1	Front plane at bumper ht	16	6	26	2	4	6				-16
2	Side plane at bumper ht	16	8	30	0	1	2.5	4	5	8	+52
	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.

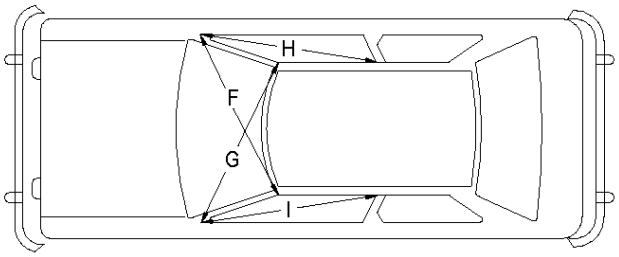
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

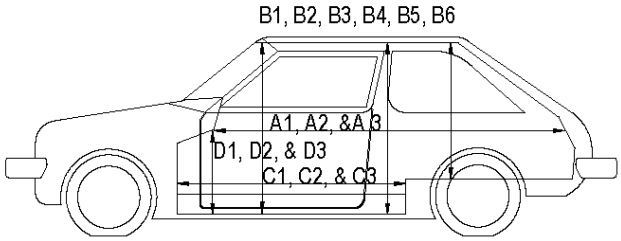
***Measure and document on the vehicle diagram the location of the maximum crush.

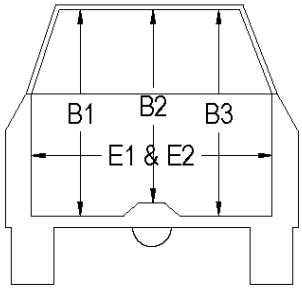
Note: Use as many lines/columns as necessary to describe each damage profile.

Table D.3. Occupant Compartment Measurements for Test No. 612281-02-1.

Date:	2019-05-20	Test No.:	612281-02-1	VIN No.:	KNADE223496573559
Year:	2009	Make:	Kia	Model:	Rio







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	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	40.50	0.00
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	26.00	0.00
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	9.50	0.00
E1	51.50	51.50	0.00
E2	51.00	51.00	0.00
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

D2 SEQUENTIAL PHOTOGRAPHS

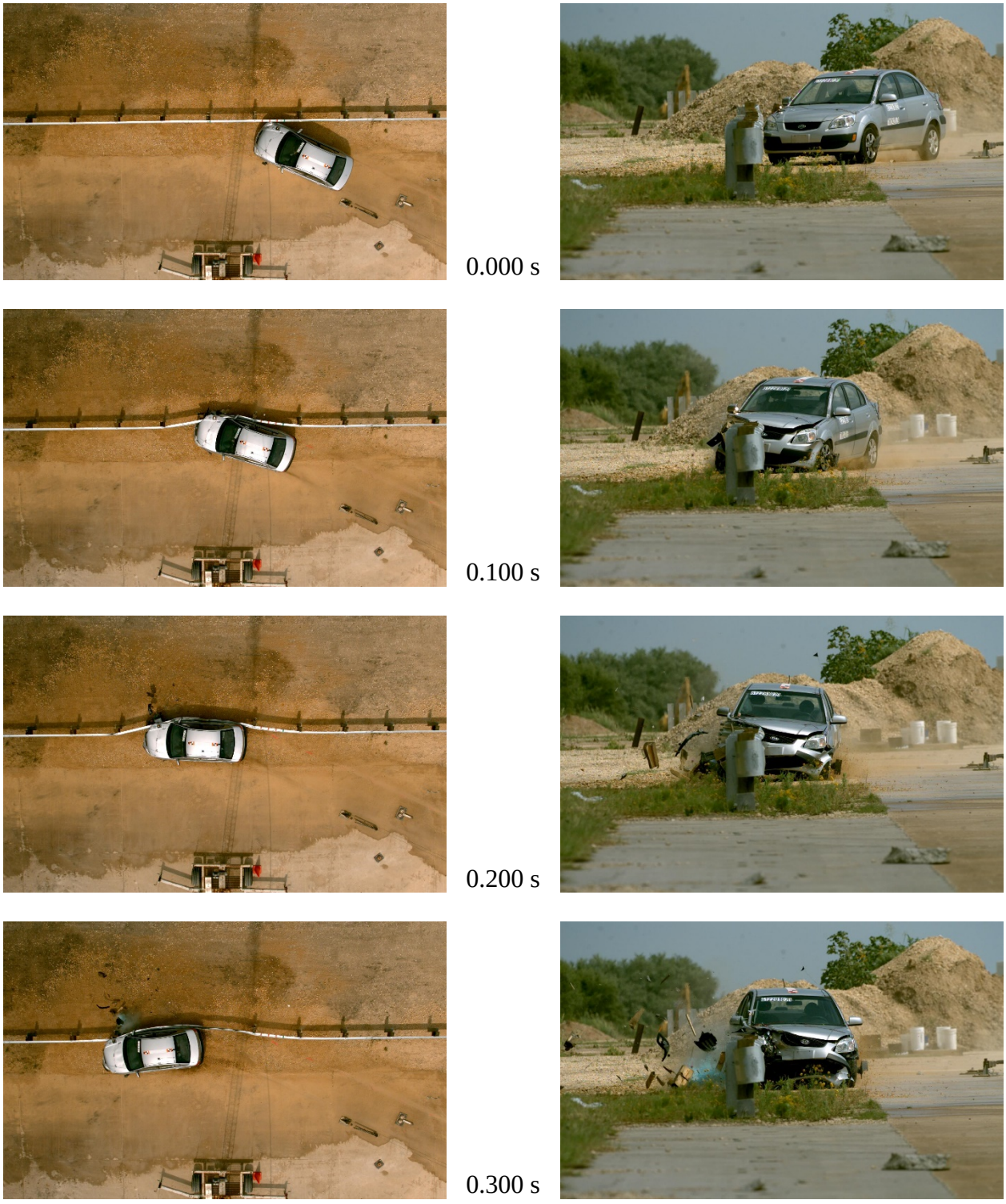
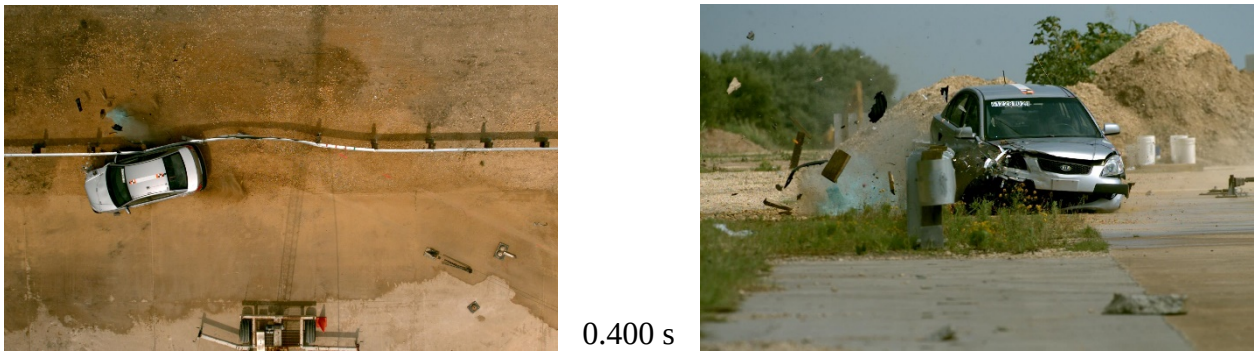
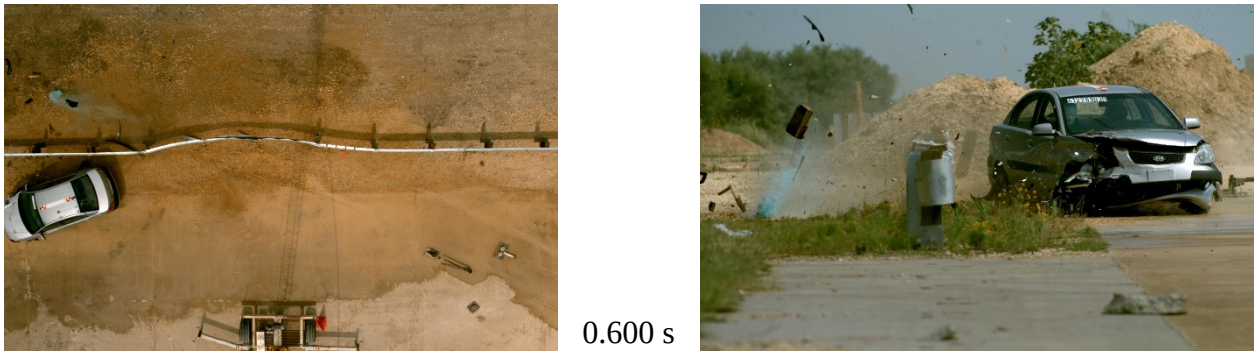


Figure D.1. Sequential Photographs for Test No. 612281-02-1 (Overhead and Frontal Views).


0.400 s


0.500 s


0.600 s


0.700 s

Figure D.1. Sequential Photographs for Test No. 612281-02-1 (Overhead and Frontal Views) (Continued).

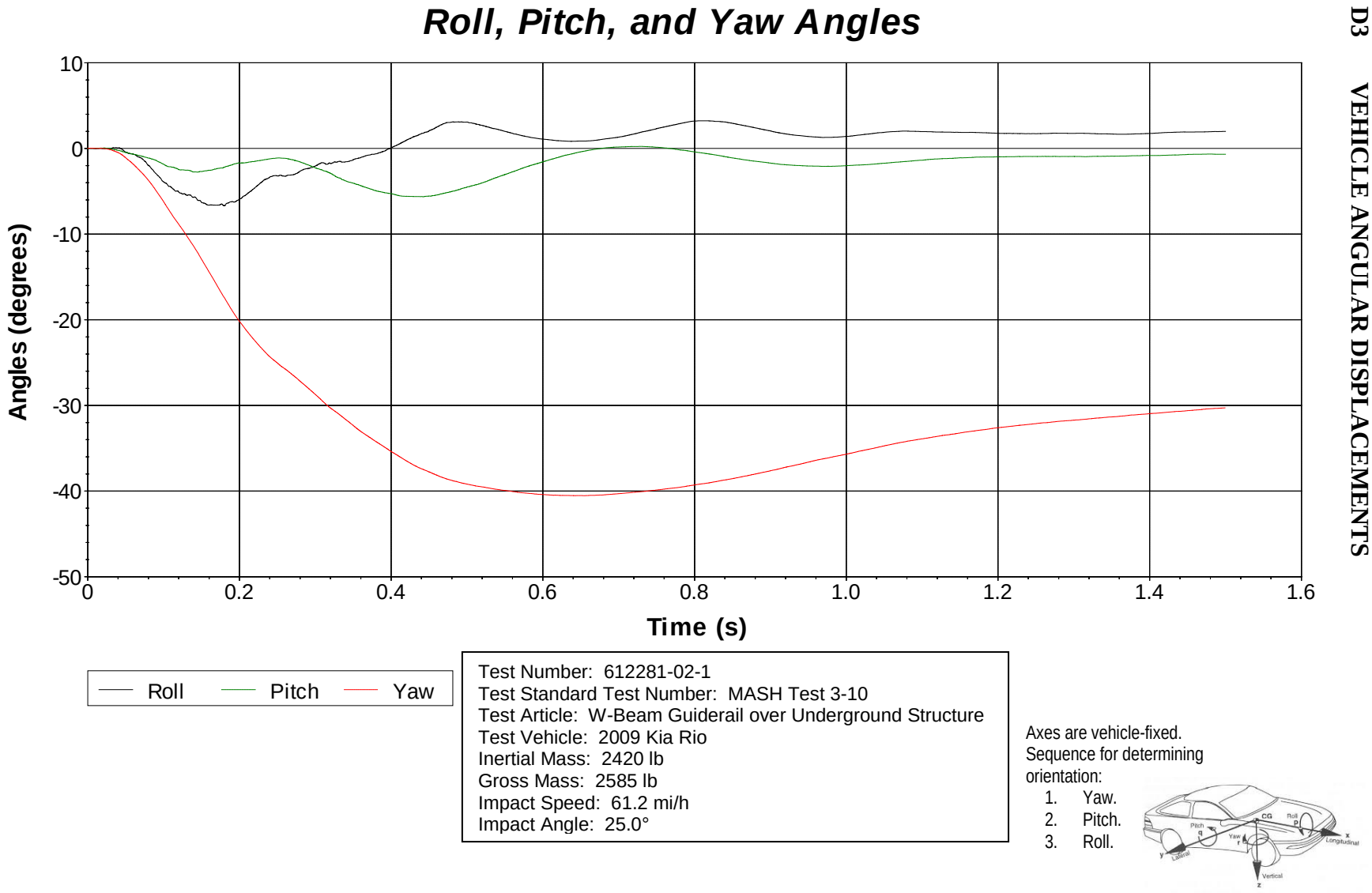


Figure D.2. Vehicle Angular Displacements for Test No. 612281-02-1.

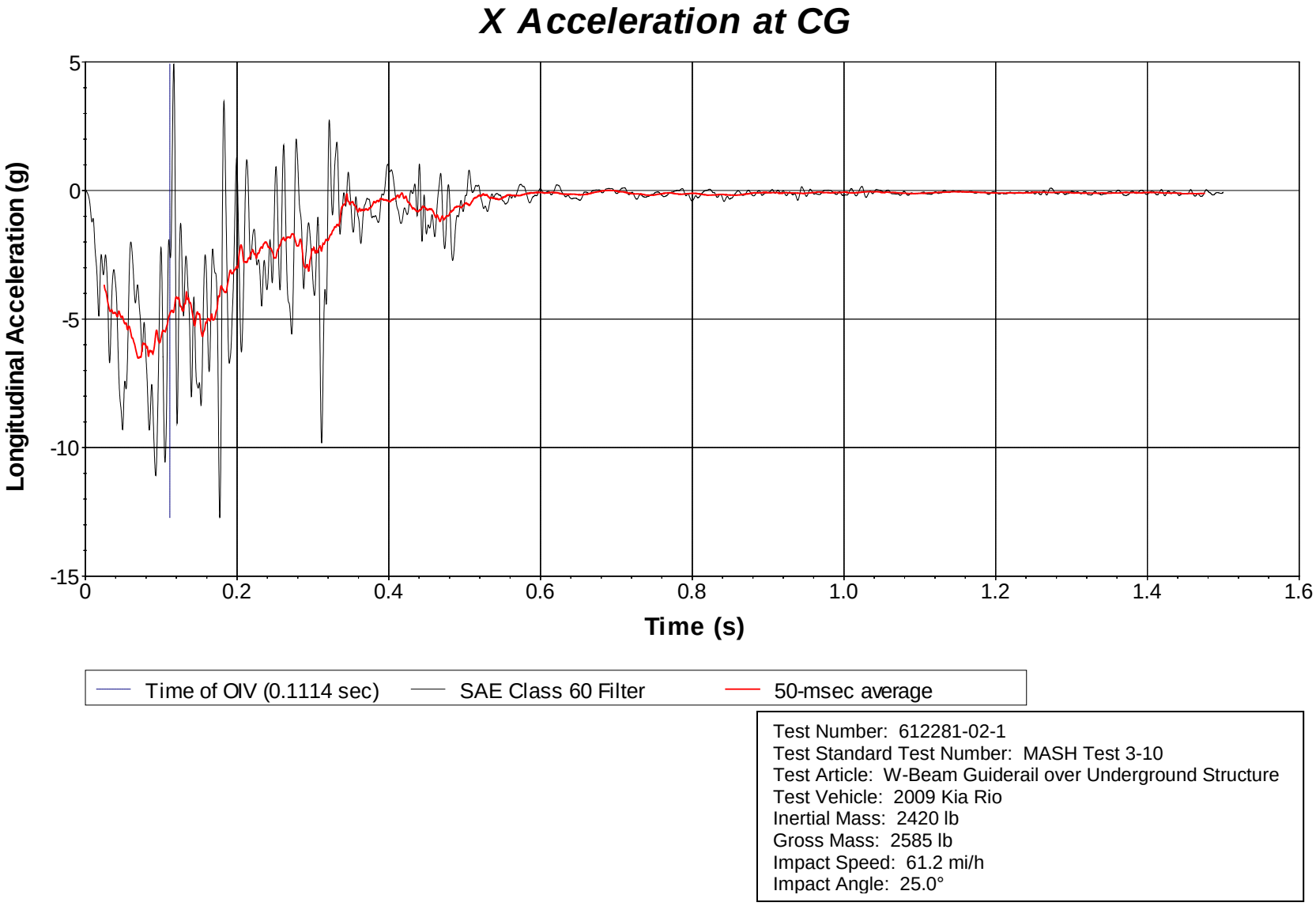


Figure D.3. Vehicle Longitudinal Accelerometer Trace for Test No. 612281-02-1 (Accelerometer Located at Center of Gravity).

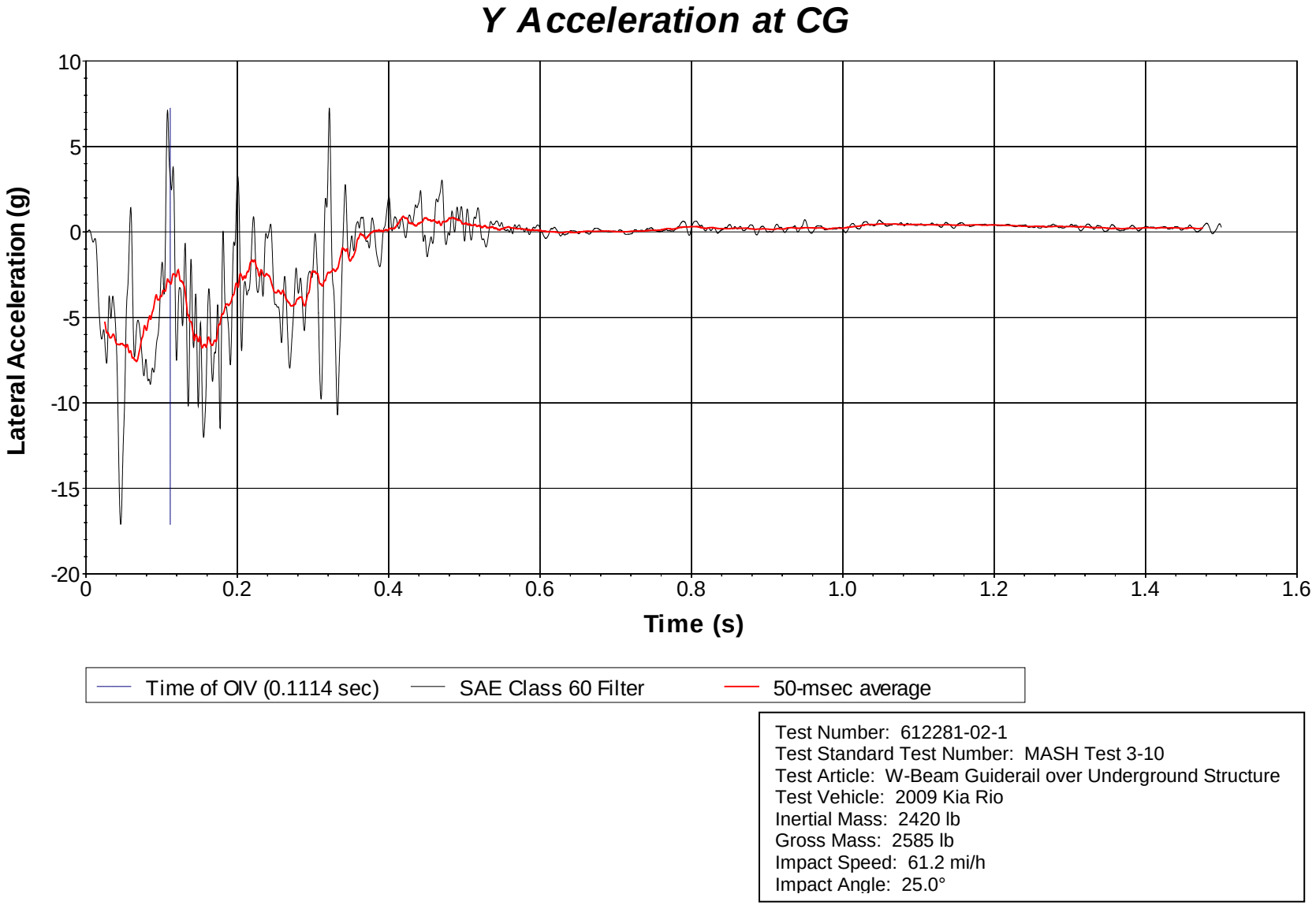


Figure D.4. Vehicle Lateral Accelerometer Trace for Test No. 612281-02-1 (Accelerometer Located at Center of Gravity).

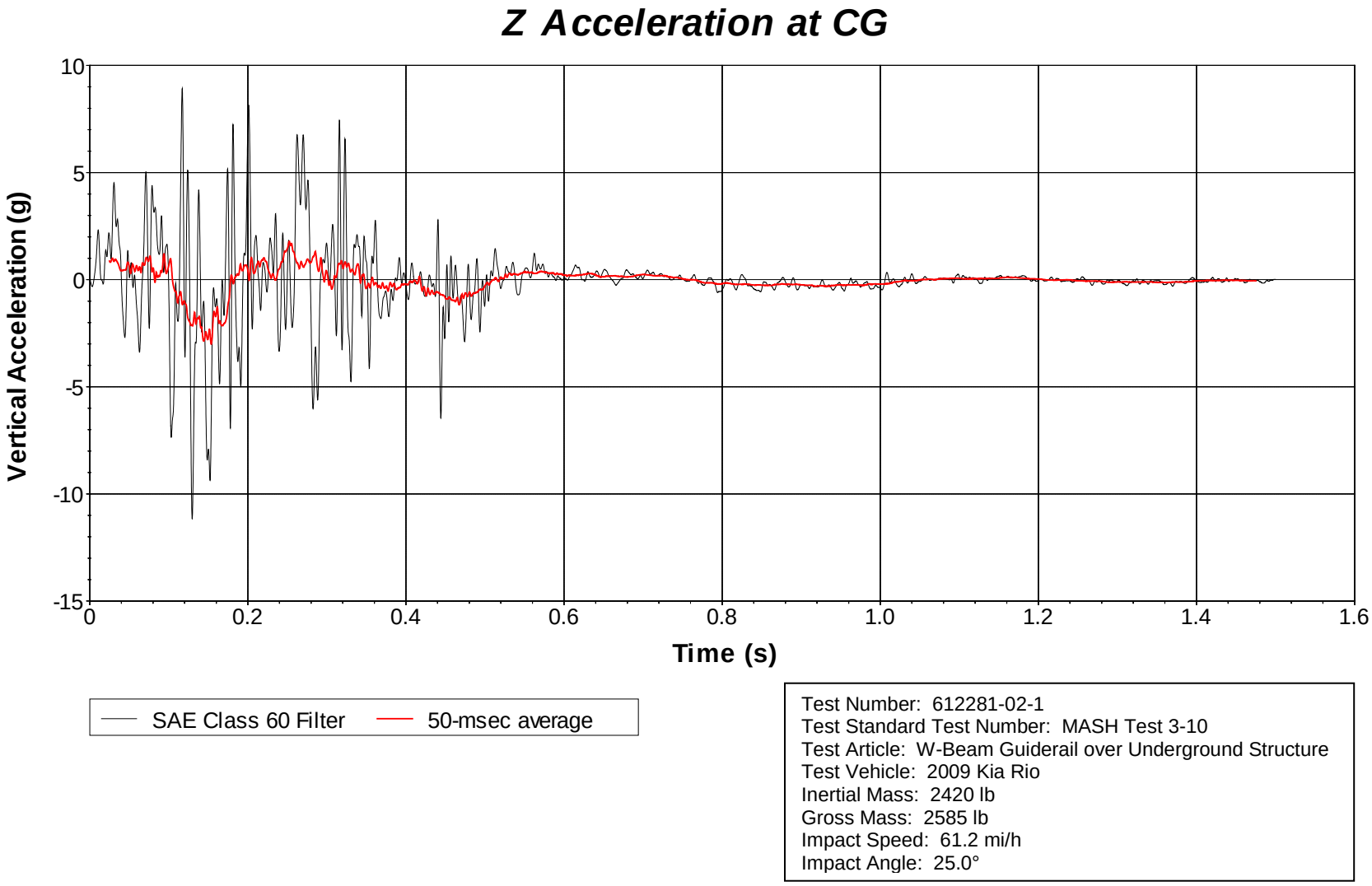


Figure D.5. Vehicle Vertical Accelerometer Trace for Test No. 612281-02-1 (Accelerometer Located at Center of Gravity).

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APPENDIX E. *MASH* TEST 3-11 (CRASH TEST NO. 612281-02-2)

E1 VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 612281-02-2.

Date: 2019-07-08 Test No.: 612281-02-2 VIN No.: 1C6RR6GT7ES264531

Year: 2014 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 158720

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

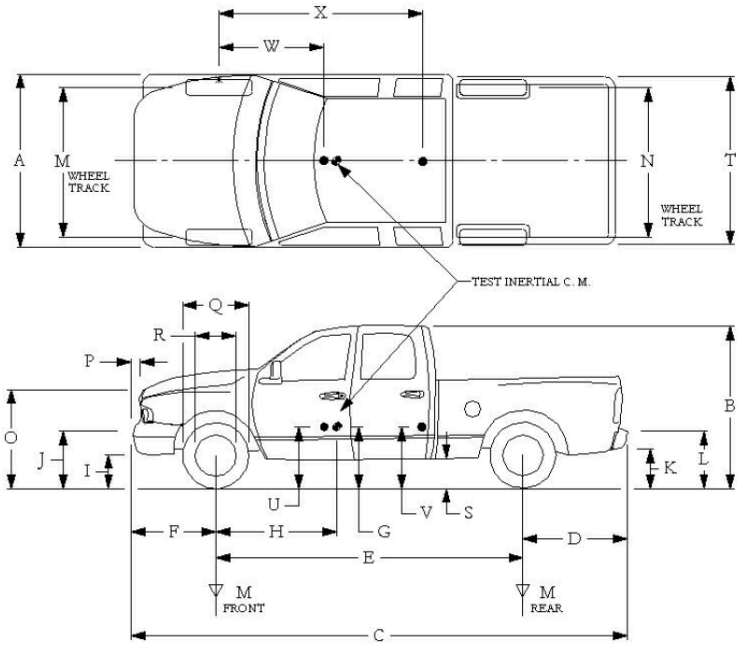
NOTES: None

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	26.75
B	74.00	G	29.00	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.71	M	68.50	R	18.00	W	60.70
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}	2912	2863	
Back	3900	M_{rear}	2085	2179	
Total	6700	M_{Total}	4997	5042	0

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

Mass Distribution:
lb LF: 1455 RF: 1408 LR: 1065 RR: 1114

Table E.2. Measurements of Vehicle Vertical CG for Test No. 612281-02-2.

Date: 2019-07-08 Test No.: 612281-02-2 VIN: 1C6RR6GT7ES264531

Year: 2014 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 158720

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 100 (440 lb max)

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

Measured Vehicle Weights: (lb)

LF:	1455	RF:	1408	Front Axle:	2863
LR:	1065	RR:	1114	Rear Axle:	2179
Left:	2520	Right:	2522	Total:	5042
					5000 ±110 lb allowed

Wheel Base: 140.50 inches (148 ±12 inches allowed) Track: F: 68.50 inches R: 68.00 inches (Track = (F+R)/2 = 67 ±1.5 inches allowed)

Center of Gravity, SAE J874 Suspension Method

X:	60.72 inches	Rear of Front Axle	(63 ±4 inches allowed)
Y:	0.01 inches	Left - Right +	of Vehicle Centerline
Z:	29.00 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 E.3. Exterior Crush Measurements for Test No. 612281-02-2.

Date:	2019-07-08	Test No.:	612281-02-2	VIN No.:	1C6RR6GT7ES264531
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		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	20	10	18	10	6	2.5	-	-	-	-27
2	Side plane at bumper ht	20	11	55	2	2.5	-	-	8	11	+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.

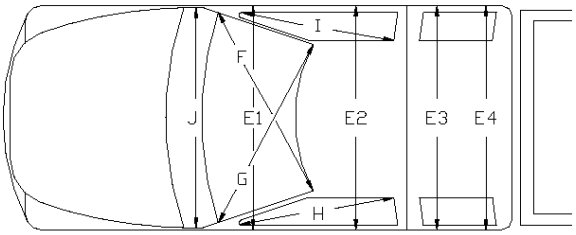
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

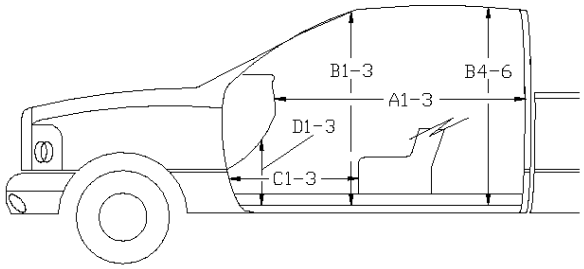
***Measure and document on the vehicle diagram the location of the maximum crush.

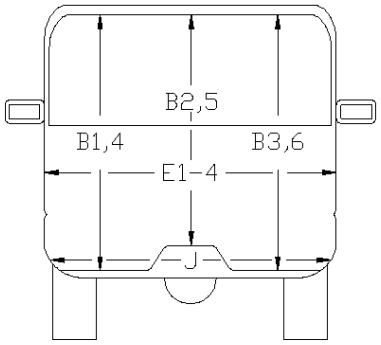
Note: Use as many lines/columns as necessary to describe each damage profile.

Table E.4. Occupant Compartment Measurements for Test No. 612281-02-2.

Date:	2019-07-08	Test No.:	612281-02-2	VIN No.:	1C6RR6GT7ES264531
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	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

E2 SEQUENTIAL PHOTOGRAPHS

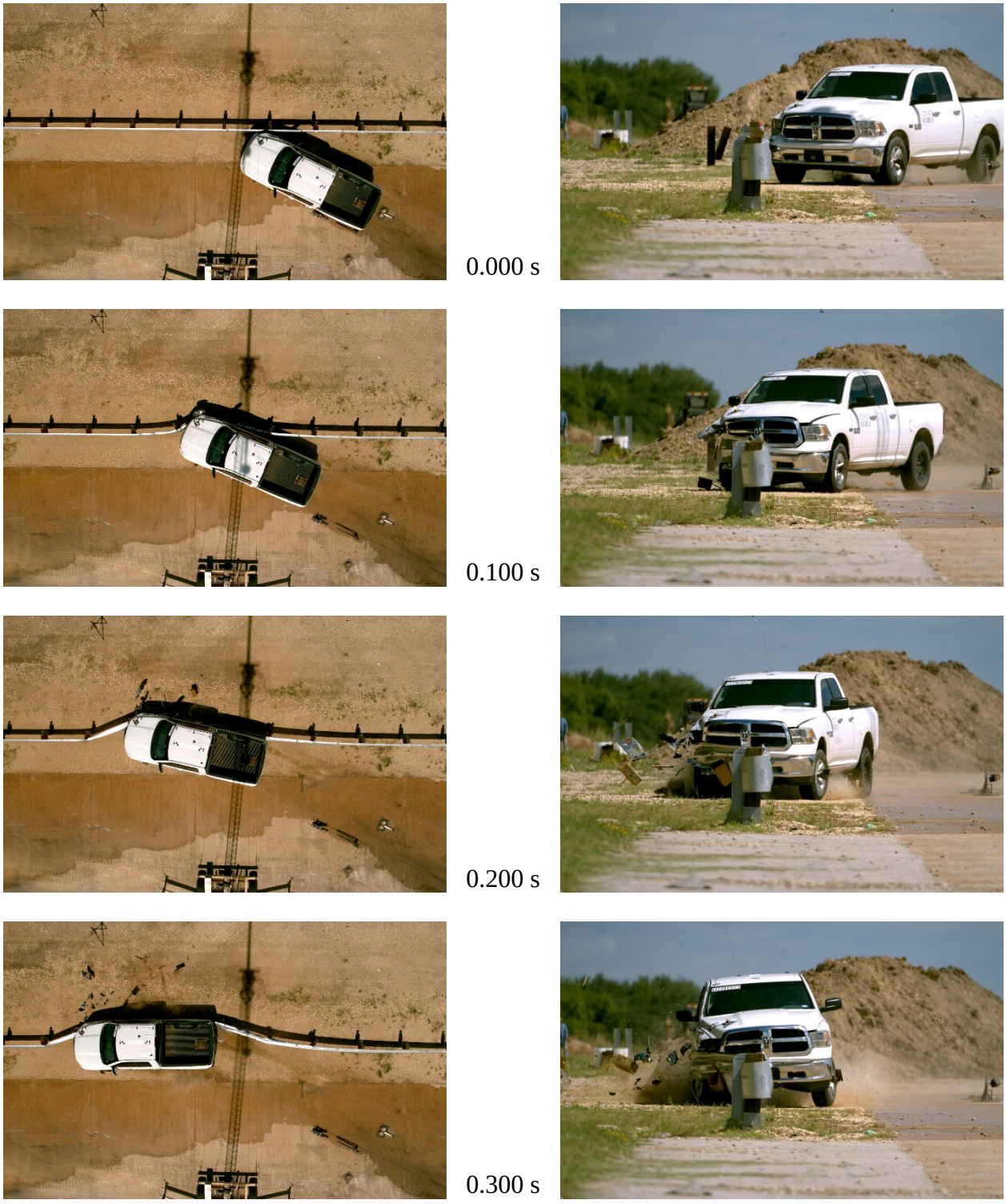


Figure E.1. Sequential Photographs for Test No. 612281-02-2 (Overhead and Frontal Views).

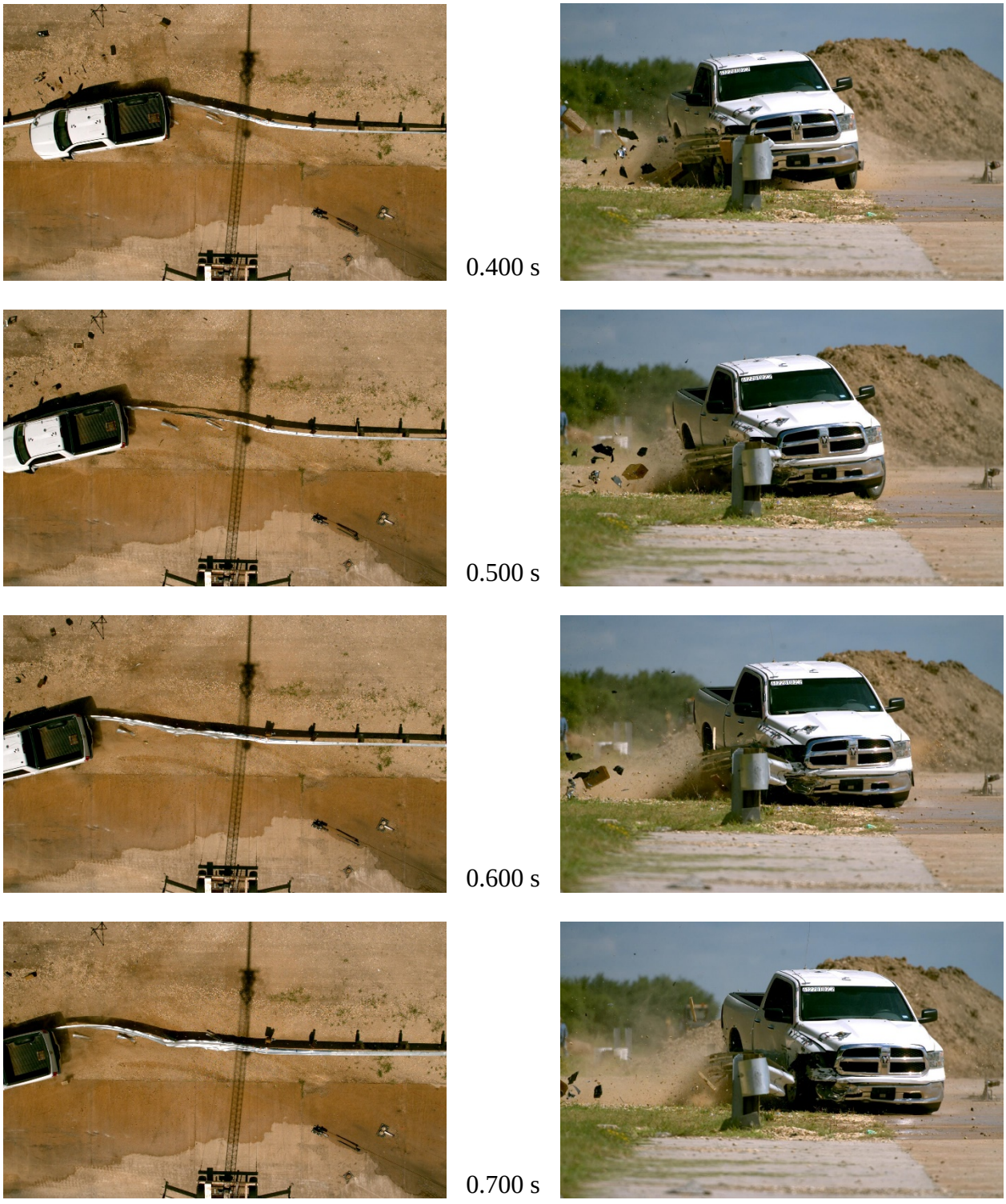


Figure E.1. Sequential Photographs for Test No. 612281-02-2 (Overhead and Frontal Views) (Continued).


0.000 s


0.400 s


0.100 s


0.500 s


0.200 s


0.600 s


300


0.700 s

Figure E.2. Sequential Photographs for Test No. 612281-02-2 (Rear View).

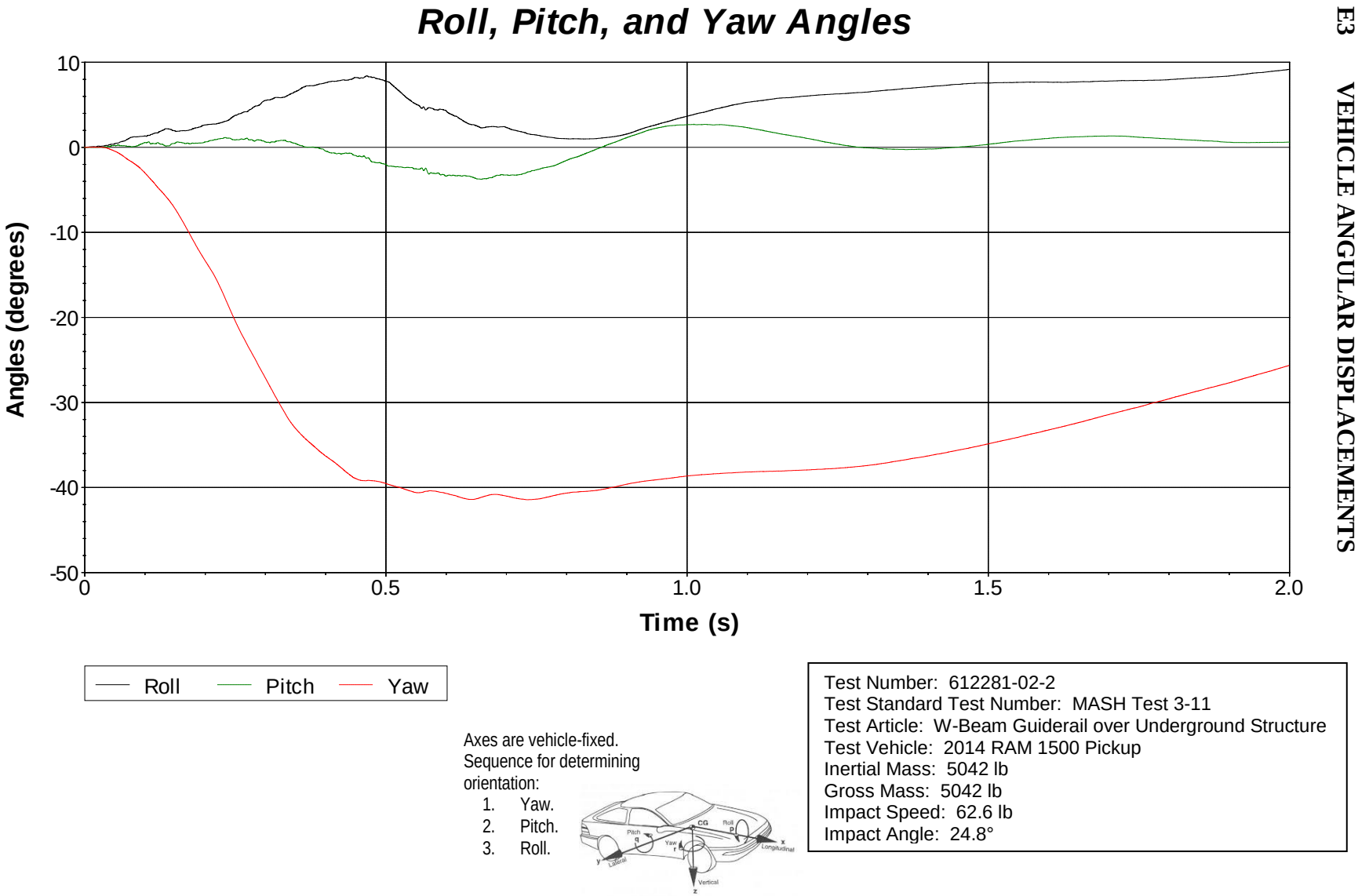


Figure E.3. Vehicle Angular Displacements for Test No. 612281-02-2.

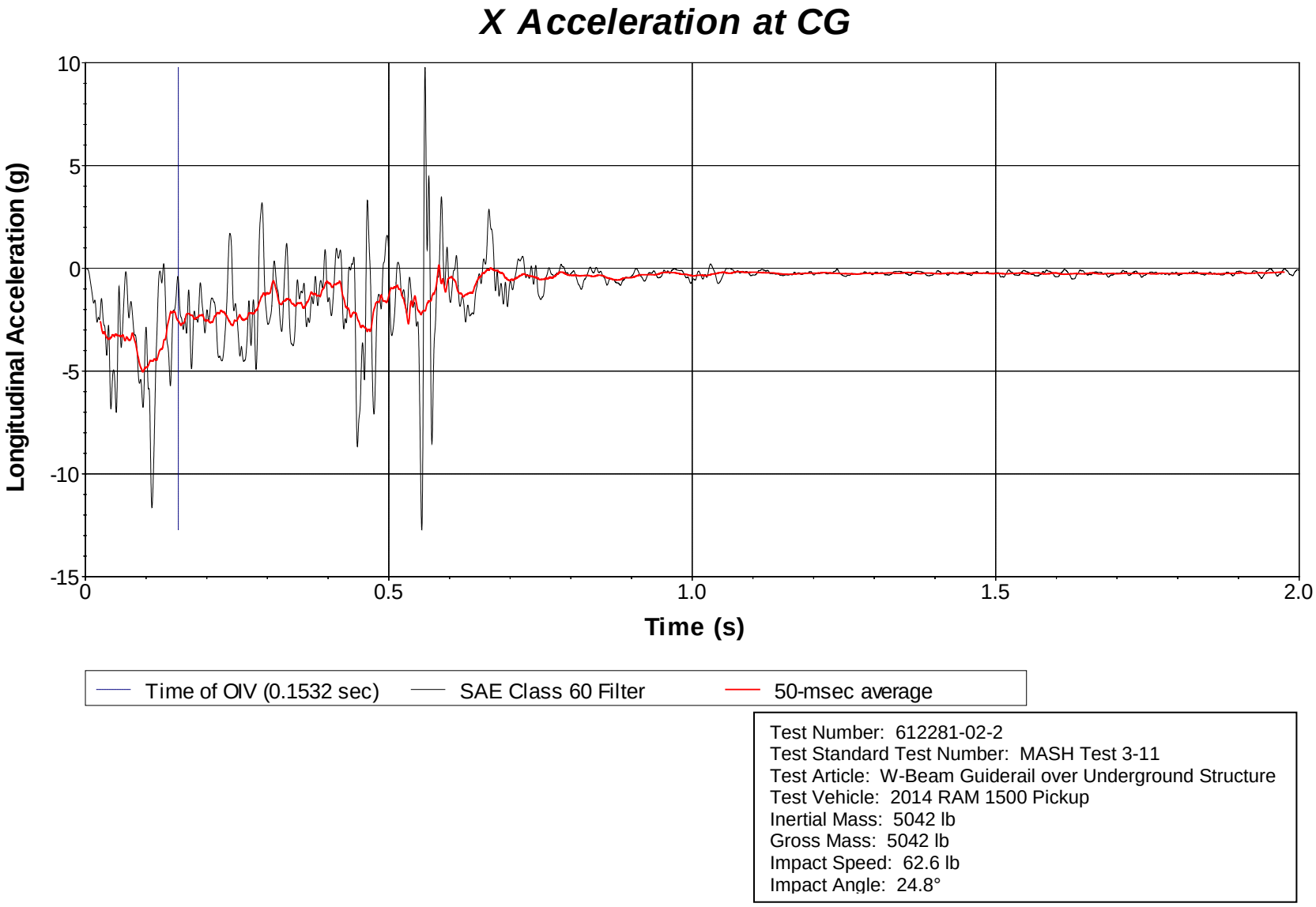


Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 612281-02-2 (Accelerometer Located at Center of Gravity).

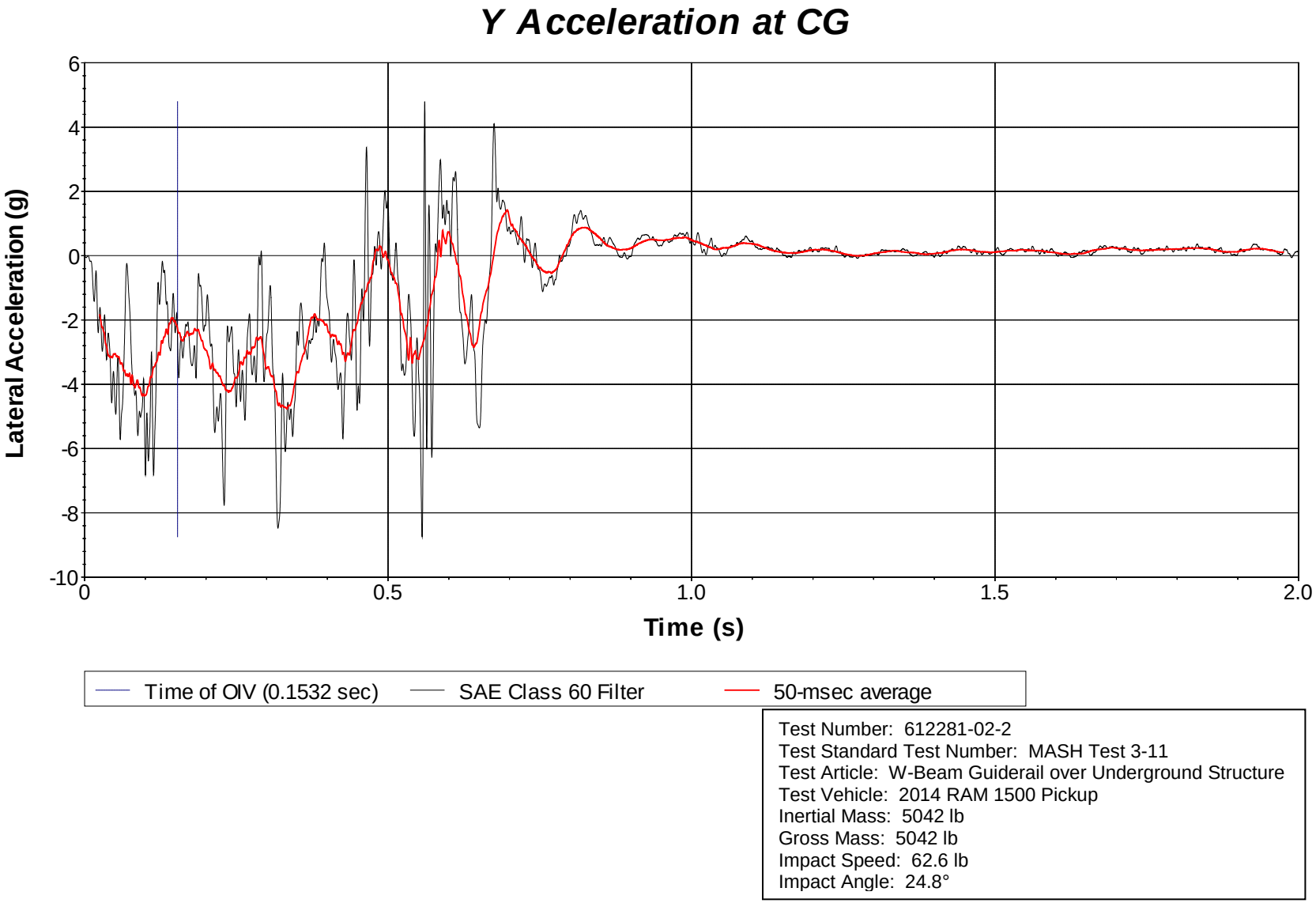


Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 612281-02-2 (Accelerometer Located at Center of Gravity).

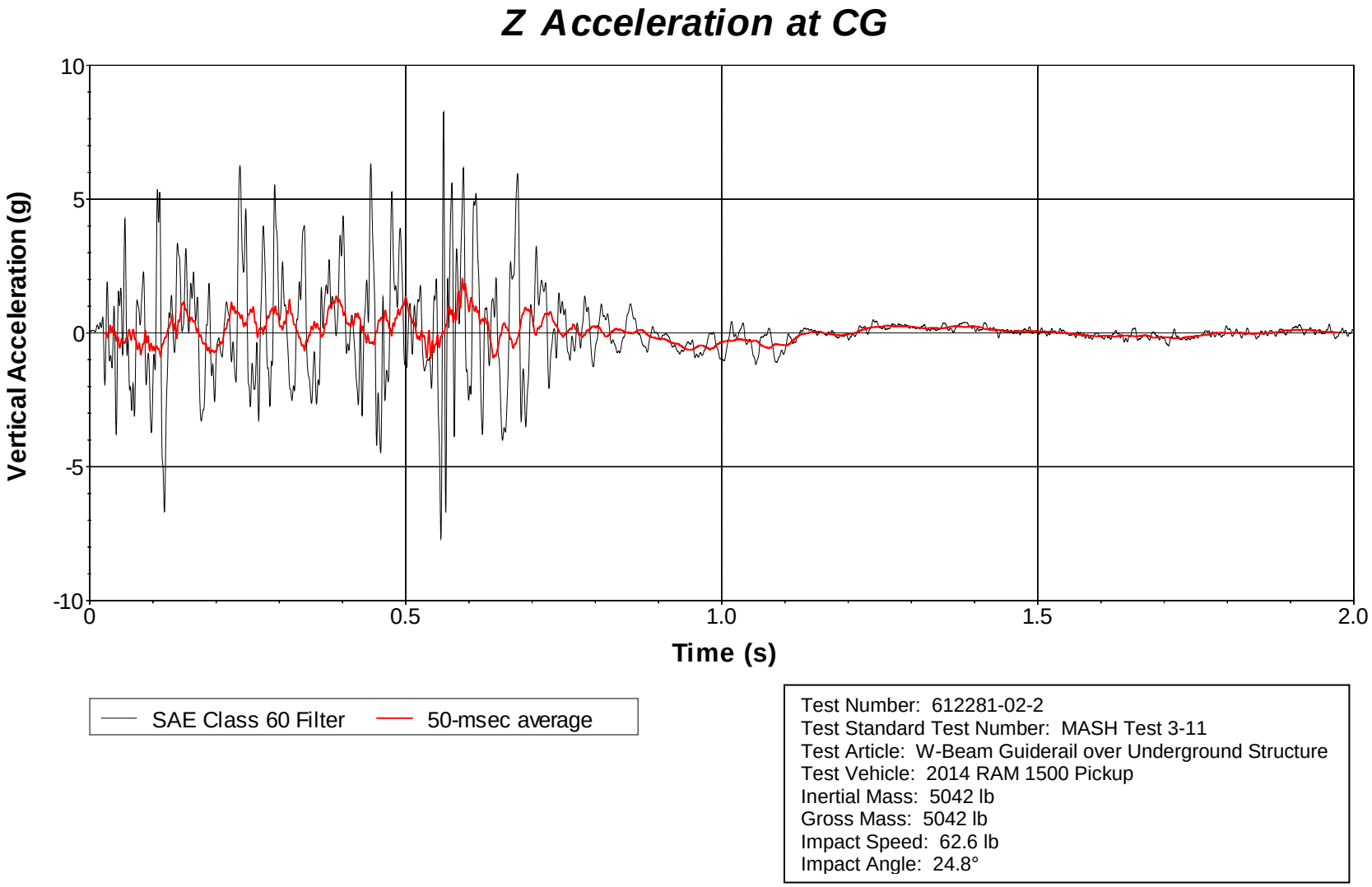


Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 612281-02-2 (Accelerometer Located at Center of Gravity).