Roadside Safety Pooled Fund

Texas A&M Transportation Institute Proving Ground

Test Report No. 608421-1
Test Report Date: September 2017

MASH TEST 3-11 OF 28-INCH W-BEAM GUARDRAIL SYSTEM WITH 8-INCH COMPOSITE BLOCKOUTS RAISED 4 INCHES ON STEEL POSTS

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16. Abstract

The purpose of this research is to test and evaluate the performance of a 28-inch W-beam rail system with 8-inch composite blockouts raised on steel posts as a means of adjusting rail height. The outcome of this study will complement any existing guideline regarding the procedure of raising blockout mounting height on steel posts to achieve recommended rail height for a W-beam guardrail.

The purpose of the test reported herein was to assess the performance of the 28-inch W-beam guardrail system with 8-inch composite blockouts raised on steel posts 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).* The crash test was performed in accordance with *MASH* Test 3-11, which involves a 2270P vehicle impacting the 28-inch W-beam guardrail system with raised composite blockouts at a target impact speed and impact angle of 62 mi/h and 25 degrees, respectively.

This report provides details of the 28-inch W-beam guardrail system with raised composite blockouts, documentation of the crash test performed, results of the crash test, and assessment of the performance of the tested system according to *MASH* Test 3-11 evaluation criteria.

The 28-inch W-beam guardrail system with raised composite blockouts contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 52.6 inches. Detached blockouts did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to others in the area. No reduction or intrusion of the occupant compartment occurred. The 2270P vehicle remained upright during and after the collision period. Maximum roll and pitch angles were 32 degrees and 12 degrees, respectively. Occupant risk factors were within the preferred limits specified in *MASH*.

The 28-inch W-beam guardrail system with composite blockouts raised 4 inches performed acceptably for *MASH* Test 3-11.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSTIONS 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
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSTIONS 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
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		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. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Chapter 1. INTRODUCTION

1.1 PROBLEM STATEMENT

With recent changes/clarifications about appropriate height for W-beam guardrails, existing locations have been identified where rail height is lower than recommended. Pavement overlays can create locations where this occurs. Raising the blockout on the post is a simple, low-cost mean to adjust the rail height. However, it is unknown how the rail will perform with raised composite blockouts.

The purpose of this research is to test and evaluate the performance of a 28-inch W-beam rail system with 8-inch composite blockouts raised on steel posts as a means of adjusting rail height. The outcome of this study will complement any existing guidelines regarding the procedure of raising blockout mounting height on steel posts to achieve the recommended rail height for a W-beam guardrail.

The information compiled from this research will enable the Departments of Transportation to decide whether raising blockouts on the posts can be used as a low-cost mean to adjust rail height.

1.2 BACKGROUND

On May 17, 2010, FHWA issued a technical memorandum to provide guidance to State DOTs and FHWA Division Offices on height of guardrail for new installations on the National Highway System (NHS) *(1)*. The technical memorandum details the minimum mounting heights of systems successfully crash tested per the National Cooperative Highway Research Program (NCHRP) Report 350 "Recommended Procedures for the Safety Performance Evaluation of Highway Features" and the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) *(2, 3)*. In regard to *MASH*, the memorandum recognized performance issues with modified G4(1S) guardrail, and recommended adoption of 31-inch high guardrail designs for new installations.

The FHWA Office of Safety Design and the FHWA Resource Center give suggestions on how to adjust rail height when pavement work is needed. When the barrier does not need to be moved it is a common practice to raise the blockout on the post up to three inches as a cost-effective means to adjust rail height. This requires field drilling or punching of a new hole in the guardrail post.

Raising the blockouts above the post can induce flexural stresses into the blockout in addition to the compressive stresses that are normally present during an impact. Thus, since the stresses in the blockouts are altered compared to intended design conditions, the impact performance of the guardrail with raised blockouts needs to be investigated. The information compiled from this research will enable the Departments of Transportation to decide whether raising blockouts on the posts can be chosen as a cost-effective means to adjust rail height when below recommended value, without compromising the rail system performance.

A recently completed research study funded by the Roadside Safety Pooled Fund group investigated behavior of wood and composite blockouts raised 4 inches on steel posts (*4*). Pendulum tests were conducted to determine the dynamic impact performance of wood and composite blockouts raised on a steel guardrail post. From the comparison of the energy plots, it appears that the system with wood blockouts was able to absorb more energy during the impact event in comparison to the systems which used proprietary composite blockouts. Also, the wood blockouts remained attached to the post and were not fractured as a consequence of the first impact from the pendulum nose. In each test, however, the composite blockout had sufficient strength to develop the capacity of the steel guardrail post. If the raised composite blockout fractured or detached, this behavior occurred after the post had twisted more than 90 degrees out of plane with the guardrail and in some cases was related to a secondary impact from the pendulum as it swung back after the initial impact event. If a guardrail post is laterally loaded to the point it twists 90 degrees or more as it bends and deflects, it is likely that the guardrail has detached from the blockout and the effective offset distance has been reduced. Researchers concluded that fracture of the blockout at this time is not likely to affect the outcome of the impact event.

1.3 OBJECTIVE

The purpose of the test reported herein was to assess the performance of a 28-inch W-beam guardrail system with 8-inch wide composite blockouts raised on steel posts according to the safety-performance evaluation guidelines included in the AASHTO *MASH*. The crash test was performed in accordance with *MASH* Test 3-11, which involves a 2270P vehicle impacting the 28-inch W-beam guardrail system with raised composite blockouts at a target impact speed and impact angle of 62 mi/h and 25 degrees, respectively.

This report provides details of the 28-inch W-beam guardrail system with raised composite blockouts, documentation of the crash test performed, results of the crash test, and assessment of the performance of the tested system according to *MASH* Test 3-11 evaluation criteria.

Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of a 28-inch tall W-beam with structural steel posts (posts 3-27) guardrail system with a TxDOT GF (31) DAT-14 terminal on the each end, for a total installation length of 175 ft-0 inches. Mondo Polymer Blockouts (Model #GB14SH1) were installed on posts 3 through 27.

Standard 12-gauge W-beam guardrail (type RWM04a) was used in the system. The top of the W-beam was 28 inches above grade, with the top of the post 25 inches above grade. The top of the Mondo Polymer Blockouts were 1-inch above the guardrail and 4-inches above the posts. Guardrail splices were located at every other post, and the posts were equally spaced at 6 ft-3 inches.

Guardrail posts 3 through 27 were modified PWE01 line posts fabricated from W6×8.5 ASTM A36 structural steel shape, with an additional $^{13}/_{16}$-inch diameter hole centered 3 inches below the post's top and 1⅛ inches from the centerline of the web. The two existing $^{13}/_{16}$-inch diameter holes (centered 7 inches below the top and 2¼ inches straddling the web) were not used. These 25 posts were installed 47-inch deep in drilled holes. Guardrail offset for posts 3 to 27 was accomplished by use of 7½-inch deep Mondo Polymer Blockouts (Model #GB14SH1) attached with standard 10-inch long guardrail bolts and recessed nuts (FBB03) in the aforementioned hole centered 3 inches from the top.

Each TxDOT GF (31) DAT-14 terminal was 9 ft-4½ inches long as measured from the anchor posts to the W-beam splice between posts 2 and 3 and posts 27 and 28, respectively.

Figure 2.1 presents overall information on the 28-inch W-beam guardrail system with raised composite blockouts, and Figure 2.2 provides photographs of the installation. Appendix A provides further details of the 28-inch W-beam guardrail system with raised composite blockouts, Mondo Blockout, and TxDOT GF (31) DAT-14 terminal system.

2.2. MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the 28-inch W-beam guardrail system with raised composite blockouts.

2.3. SOIL CONDITIONS

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

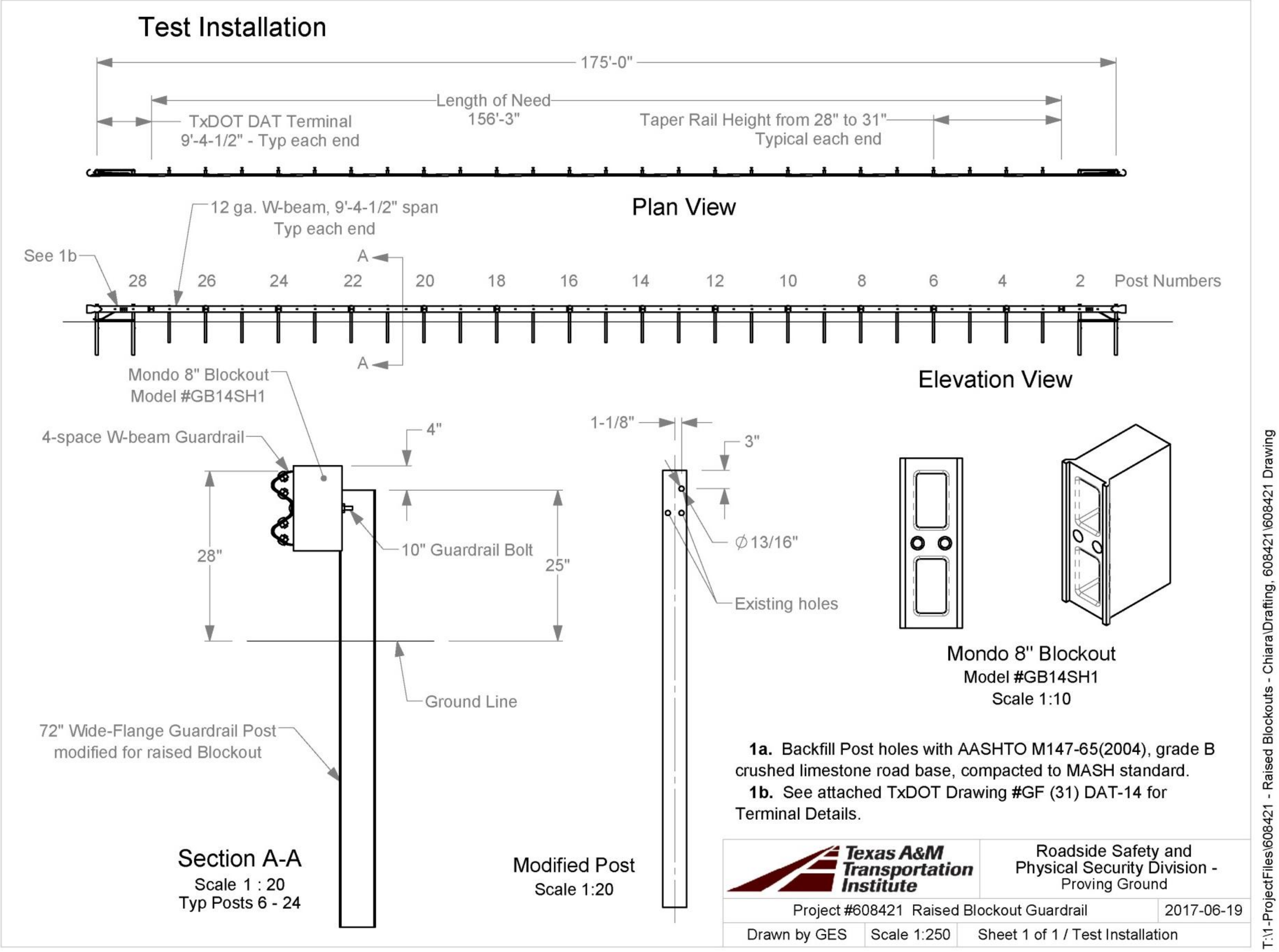


Figure 2.1. Details of the 28-inch W-Beam Guardrail System with Raised Composite Blockouts.

Figure 2.2. 28-inch W-Beam Guardrail System with Raised Composite Blockouts prior to Testing.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the 28-inch W-beam guardrail system with raised composite blockouts for full-scale crash testing, two W6×16 posts were installed in the immediate vicinity of the 28-inch W-beam guardrail system with raised composite blockouts, utilizing the same fill materials and installation procedures used in the test installation and standard dynamic test (see Table C.1 in Appendix C for establishment minimum soil strength properties in the dynamic test performed in accordance with *MASH* Appendix B).

As determined in the tests shown in Appendix C, Table C.1, the minimum post load required at deflections of 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, is 3940 lb, 5500 lb, and 6540 lb, respectively (90% of static load for the initial standard installation). On the day of the test, June 30, 2017, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 5757 lbf, 6313 lbf, and 6767 lbf, respectively. In Appendix C, Table C.2 shows that the strength of the backfill material, in which the 28-inch W-beam guardrail system with raised composite blockouts was installed, met minimum soil strength requirements.

Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST PERFORMED / MATRIX

Table 3.1 shows the test conditions and evaluation criteria for longitudinal barriers for *MASH* Test Level 3 (TL-3). *MASH* Test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the critical impact point (CIP) of the 28-inch W-beam guardrail system with raised composite blockouts at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target CIP selected for the test was determined according to the information provided in *MASH* Section 2.3.2.1 and *MASH* Appendix A2.3, and was 0.7 ft ±1 ft downstream of the centerline of post 12, as shown in Figure 3.1.

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

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

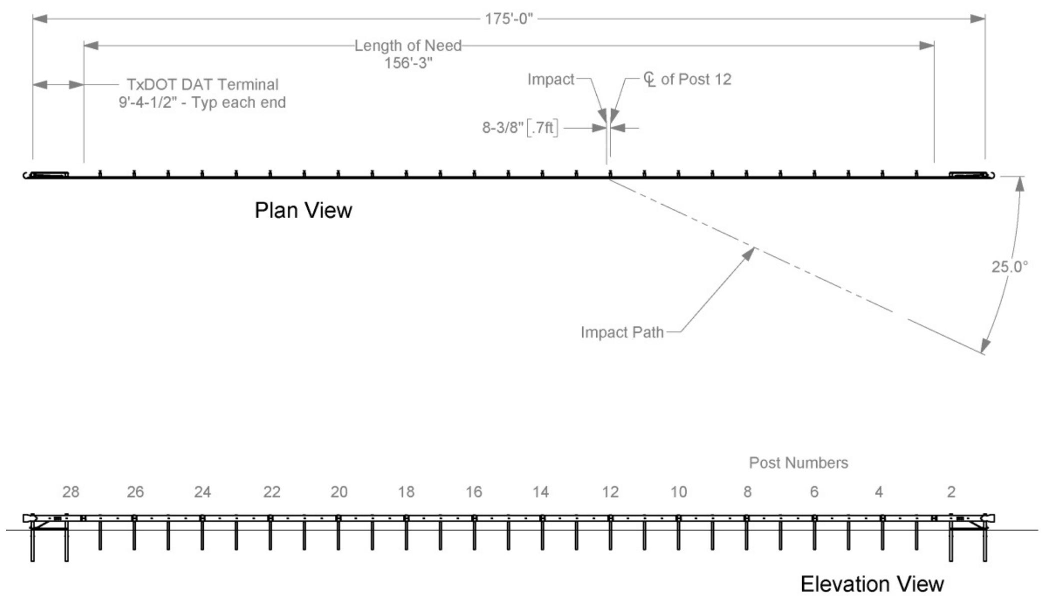


Figure 3.1. Target CIP for *MASH* Test 3-11 on the 28-inch W-beam Guardrail System with Raised Composite Blockouts.

The crash test(s) 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 2-2A and 5-1A through 5-1C of *MASH* were used to evaluate the crash test reported herein. The test conditions and evaluation criteria required for *MASH* Test 3-11 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* Test 3-11.

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

The test facilities of the TTI Proving Ground are located on the Texas A&M University RELLIS Campus which consists of a 2000-acre complex of research and training facilities situated 10 miles northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and evaluation of roadside safety hardware and perimeter protective devices. The site selected for construction and testing of the 28-inch W-beam guardrail system with raised composite blockouts 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

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 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

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

Each of the TDAS Pro units is returned to the factory annually for complete recalibration and all instrumentation used in the vehicle conforms to all specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO® 2901, precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the data acquisition system receive a calibration via a Genisco Rate-of-Turn table. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are also made any time data are suspect. Acceleration data is measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k=2).

TRAP uses the data from the TDAS Pro to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals, then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact. Rate of rotation data is measured with an expanded uncertainty of ±0.7 percent at a confidence factor of 95 percent (k=2).

4.3.2 Anthropomorphic Dummy Instrumentation

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 the/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 28-inch W-beam guardrail system with raised composite blockouts. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

Chapter 5. *MASH* TEST 3-11 (CRASH TEST NO. 608421-1)

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-11 involves a 2270P vehicle weighing 5000lb ±110 lb impacting the CIP of the 28-inch W-beam guardrail system with raised composite blockouts at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The CIP for *MASH* Test 3-11 on the 28-inch W-beam guardrail system with raised composite blockouts was 0.7 ft ±1 ft downstream of the centerline of post 12.

The 2011 Dodge RAM 1500 pickup truck used in the test weighed 5017 lb, and the actual impact speed and angle were 64.1 mi/h and 24.4 degrees, respectively. The actual impact point was 1 ft downstream of post 12. Minimum target impact severity (IS) was 106 kip-ft, and actual IS was 118 kip-ft.

5.2 WEATHER CONDITIONS

The test was performed on the morning of June 30, 2017. Weather conditions at the time of testing were as follows: wind speed: 15 mi/h; wind direction: 183 degrees (vehicle was traveling in a southwesterly direction); temperature: 90°F; relative humidity: 71 percent.

5.3 TEST VEHICLE

The 2011 Dodge RAM 1500 pickup truck, shown in Figure 5.1 and Figure 5.2, was used for the crash test. The vehicle's test inertia weight was 5017 lb, and its gross static weight was 5017 lb. The height to the lower edge of the vehicle bumper was 11.5 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.375 inches. Tables D.1 and D.2 in Appendix D1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 5.1. 28-inch W-Beam Guardrail System with Raised Composite Blockouts/Test Vehicle Geometrics for Test No. 608421-1.

Figure 5.2. Test Vehicle before Test No. 608421-1.

5.4 TEST DESCRIPTION

The test vehicle, traveling at an impact speed of 64.1 mi/h, contacted the 28-inch W-beam guardrail system with raised composite blockouts 12 inches downstream of post 12 at an impact angle of 24.4 degrees. Table 5.1 lists events that occurred during Test No. 608421-1. Figures D.1 and D.2 in Appendix D2 present sequential photographs during the test.

Table 5.1. Events during Test No. 608421-1.

TIME	EVENT
0.017	Post #12 begins to deflect to field side
0.020	Post #13 begins to deflect to field side
0.022	Guardrail begins to deform between Posts #12 and #13
0.037	Post #14 begins to deflect to field side
0.060	Vehicle begins to redirect
0.070	Blockout begins to separate from post #13
0.072	Right front tire contacts Post #13 and rides up and over post
0.077	Post #15 begins to deflect to field side
0.105	Right front tire begins to deflate
0.105	Blockout begins to separate from post #14
0.116	Blockout releases from Post #14
0.127	Post #16 begins to deflect to field side
0.130	Right front tire impacts Post #14 and rides up and over post
0.140	Passenger door begins to open at top window frame
0.178	Blockout begins to separate from post #15
0.205	Vehicle rear bumper impacts rail near Post #12
0.268	Vehicle begins traveling parallel with the installation
0.700	Vehicle lost contact with installation traveling at 43.4 mi/h and 10.0 degrees

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for 1100C and 2270P vehicles). The 2270P vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 175 ft downstream of the impact and 40 ft toward the field side.

5.5 DAMAGE TO TEST INSTALLATION

Figure 5.4 shows the damage to the 28-inch W-beam guardrail system with raised composite blockouts. Post 1 was pulled downstream 1.25 inches at ground level, and post 2 was pulled downstream 0.625 inch at ground level. The rail element separated from the shelf bracket at post 1 and released from posts 2 and 3. The rail element was pulled downstream 3.0 inches from post 1 toward impact. Post 11 had gaps between the post and the soil of 0.75 inch on the traffic side and 0.25 inch on the field side, and the post was leaning toward the field side at 88 degrees. Post 12 had gaps between the post and the soil of 2.5 inch on the traffic side and 0.75 inch on the field side, and the post was leaning toward the field side at 88 degrees. The blockouts separated from the posts and rail element from posts 14 through 16, and the rail element released from posts 13 through 17. Post 17 was leaning downstream at 79 degrees and toward the field side 76 degrees. Post 18 had gaps between the post and the soil of 0.125 inch on the traffic side and 0.5 inch on the field side. No movement in the rail or posts was noted beyond post 18. Working width was 69.6 inches at a height of 53.0 inches. Maximum dynamic deflection during the test was 52.6 inches, and maximum permanent deformation was 36.0 inches.

Figure 5.3. Test Vehicle and Guardrail System after Test No. 608421-1.

Figure 5.4. Upstream Terminal after Test No. 608421-1.

Figure 5.5. Posts 11 through 14 after Test No. 608421-1.

Figure 5.6. Posts 15 through 18 after Test No. 608421-1.

Figure 5.7. Field Side of Guardrail and Released Blockouts after Test No. 608421-1.

5.6 VEHICLE DAMAGE

Figure 5.8 shows the damage sustained by the vehicle. The front bumper, right front fender, right front upper and lower A-arms, right front upper ball joint, right front tire and rim, sway bar, right front tie rod, right front and rear doors, right rear exterior bed, right rear rim, and rear bumper were damaged. Maximum exterior crush to the vehicle was 10.0 inches in the front plane at the right front corner at bumper height. No reduction or intrusion of the occupant compartment occurred. Figure 5.9 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D1 provide exterior crush and occupant compartment measurements.

Figure 5.8. Test Vehicle after Test No. 608421-1.

Before Test After Test

Figure 5.9. Interior of Test Vehicle for Test No. 608421-1.

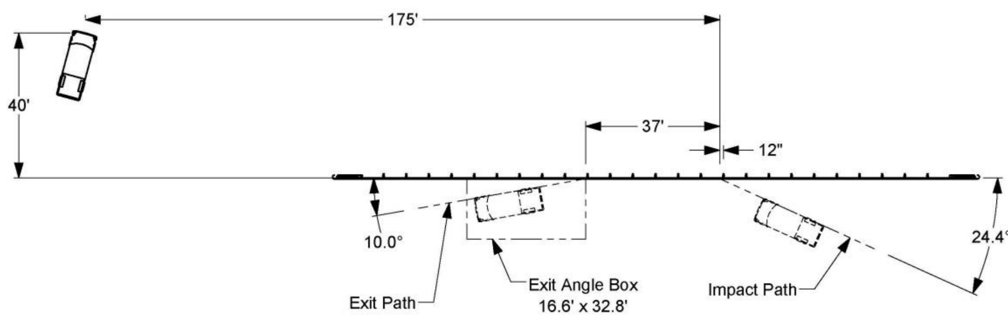
5.7 OCCUPANT RISK FACTORS

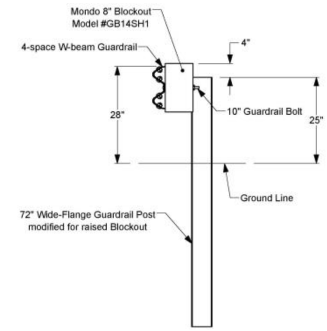
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 5.2. Figure 5.10 summarizes these data and other pertinent information from the test. Figure D.3 in Appendix D3 shows the vehicle angular displacements, and Figures D.4 through D.9 in Appendix D4 show accelerations versus time traces.

Table 5.2. Occupant Risk Factors for Test No. 608421-1.

Occupant Risk Factor	Value	Time
Impact Velocity		
Longitudinal	**15.7 ft/s**	at 0.1587 s on right side of interior
Lateral	**14.4 ft/s**	
Ridedown Accelerations		
Longitudinal	**5.8 g**	0.2811 - 0.2911 s
Lateral	**6.5 g**	0.2861 - 0.2961 s
THIV	**22.0 km/h** **6.1 m/s**	at 0.1513 s on right side of interior
PHD	**8.1 g**	0.2817 - 0.2917 s
ASI	**0.57**	0.3864 - 0.4364 s
Maximum 50-ms Moving Average		
Longitudinal	**-4.5 g**	0.0661 - 0.1161 s
Lateral	**-4.8 g**	0.3589 - 0.4089 s
Vertical	**-2.2 g**	1.3655 - 1.4155 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**31.6°**	0.7862 s
Pitch	**-12.3°**	0.9569 s
Yaw	**-43.7°**	0.7853 s

0.000 s | 0.200 s | 0.400 s | 0.700 s





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-11
TTI Test No.	608421-1
Test Date	2017-06-30

Test Article

Type	Longitudinal Barrier - Guardrail
Name	28-inch W-Beam with Raised Blockouts
Installation Length	175 ft
Material or Key Elements	28-inch tall W-beam with structural steel posts guardrail system with Mondo Polymer Blockouts (Model #GB14SH1) with rail and blockouts raised 4 inches
Soil Type and Condition	AASHTO M147-65(2004), grading B Soil (crushed limestone), dry

Test Vehicle

Type/Designation	2270P
Make and Model	2011 Dodge RAM 1500 Pickup
Curb	4882 lb
Test Inertial	5017 lb
Dummy	No dummy
Gross Static	5017 lb

Impact Conditions

Speed	64.1 mi/h
Angle	24.4 degrees
Location/Orientation	12 inches d/s of Post 12
Impact Severity	118 kip-ft

Exit Conditions

Speed	43.4 mi/h
Angle	10.0 degrees

Occupant Risk Values

Longitudinal OIV	15.7 ft/s
Lateral OIV	14.4 ft/s
Longitudinal Ridedown	5.8 g
Lateral Ridedown	6.5 g
THIV	22.0 km/h
PHD	8.1 g
ASI	0.57
Max. 0.050-s Average	
Longitudinal	-4.5 g
Lateral	-4.8 g
Vertical	-2.2 g

Post-Impact Trajectory

Stopping Distance	175 ft downstream 40 ft twd field side

Vehicle Stability

Maximum Yaw Angle	44 degrees
Maximum Pitch Angle	12 degrees
Maximum Roll Angle	32 degrees
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	52.6 inches
Permanent	36.0 inches
Working Width	69.6 inches
Height of Working Width	53.0 inches

Vehicle Damage

VDS	01RFQ4
CDC	01FREW4
Max. Exterior Deformation	10.0 inches
OCDI	RF0000000
Max. Occupant Compartment Deformation	None

Figure 5.10. Summary of Results for *MASH* Test 3-11 on 28-inch W-Beam Guardrail System with Raised Composite Blockouts.

Chapter 6. SUMMARY AND CONCLUSIONS

6.1. ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-11 is provided in Table 6.1.

6.2 CONCLUSIONS

The 28-inch W-beam guardrail system with raised composite blockouts contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 52.6 inches. Detached blockouts did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to others in the area. No reduction or intrusion of the occupant compartment occurred. The 2270P vehicle remained upright during and after the collision period. Maximum roll and pitch angles were 32 degrees and 12 degrees, respectively. Occupant risk factors were within the preferred limits specified in *MASH*.

The 28-inch W-beam guardrail system with composite blockouts raised 4 inches performed acceptably for *MASH* Test 3-11.

6.3 IMPLEMENTATION*

For the test conducted in this study, a guardrail height of 28 inches was chosen, and rail splices were positioned on posts. These selections represent the worst case condition for testing. Taller rail heights, offset rail splices, and raising of the blockout less than 4 inches are considered acceptable based on the results of this more critical test. The practice can be used to raise the height of a deficient guardrail to an acceptable height (i.e., 28 inches or greater), or could be used to raise the height of existing guardrail to improve performance (e.g., 31-inch rail height).

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

Table 6.1. Performance Evaluation Summary for *MASH* Test 3-11 on 28-inch W-Beam Guardrail System with Raised Composite Blockouts.

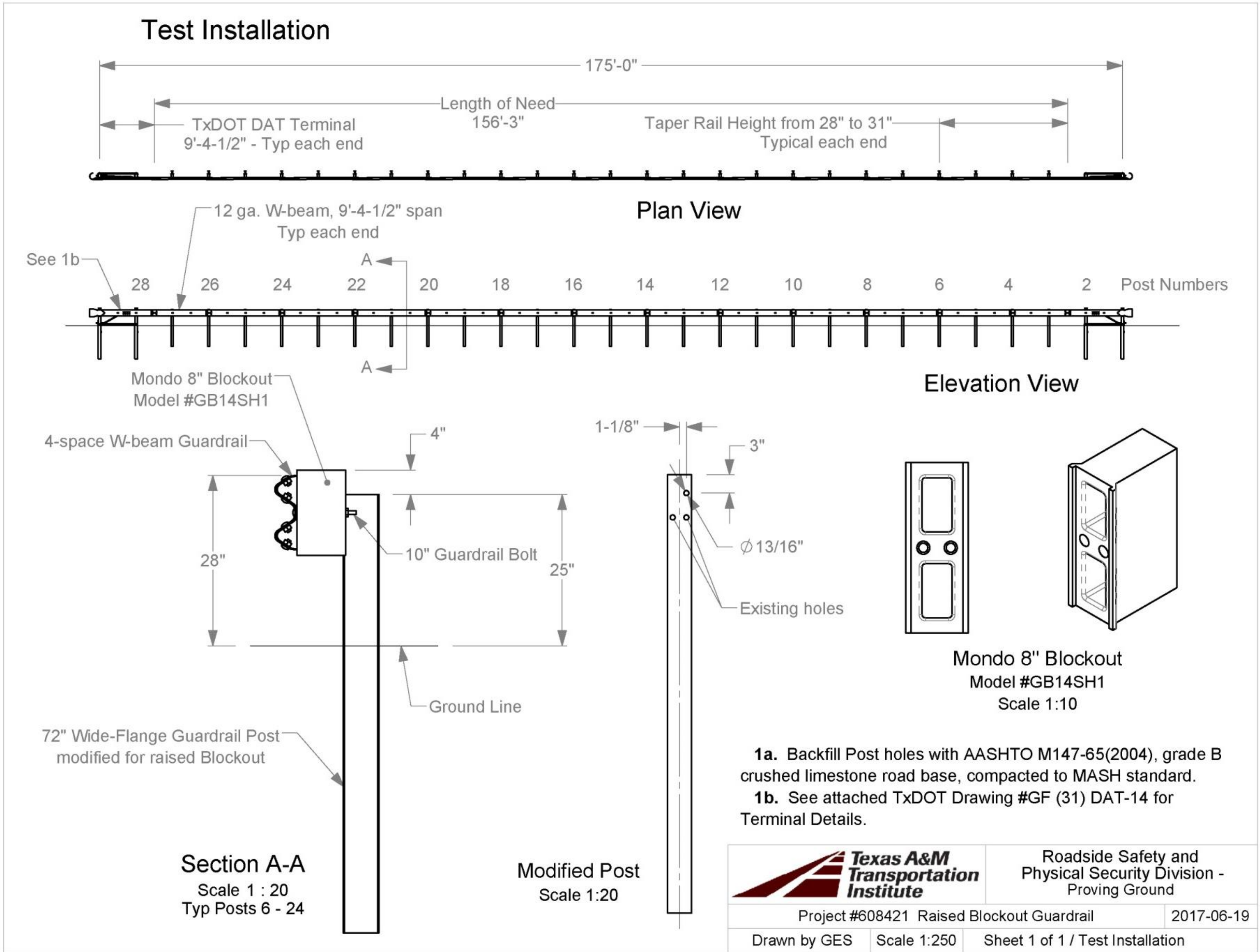
Test Agency: Texas A&M Transportation Institute | Test No.: 608421-1 | Test Date: 2017-06-30

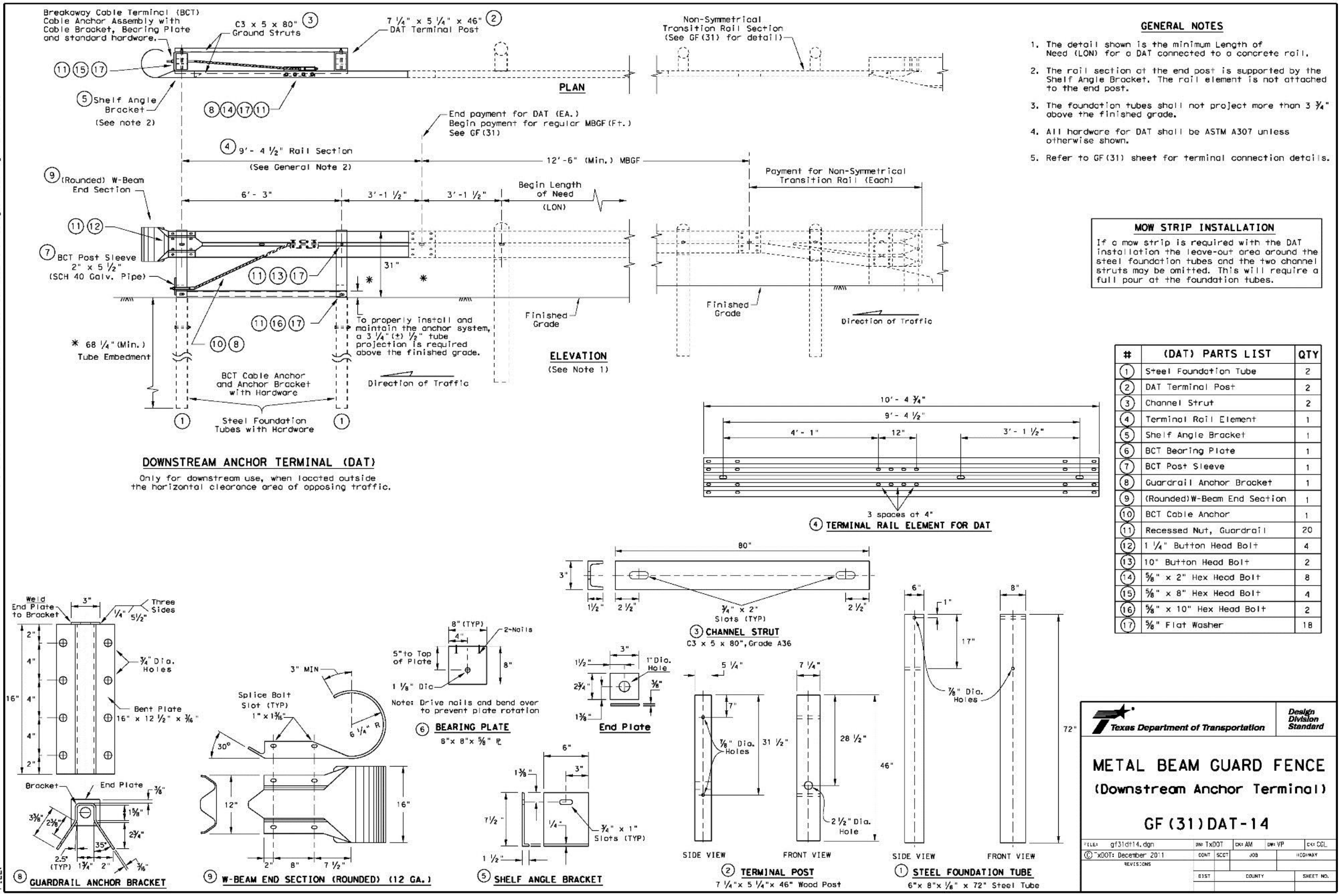
***MASH* Test 3-11 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The 28-inch W-beam guardrail system with raised composite blockouts contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 52.6 inches.	Pass
<u>Occupant Risk</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	Detached blockouts did not penetrate or show potential for penetrating the occupant compartment, or present undue 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 reduction or intrusion of the occupant compartment occurred.	
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision period. Maximum roll and pitch angles were 32 degrees and 12 degrees, respectively.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 15.7 ft/s, and lateral OIV was 14.4 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Maximum longitudinal ridedown acceleration was 5.8 g, and maximum lateral ridedown acceleration was 6.5 g.	Pass

REFERENCES

1. *Roadside Design: Steel Strong-Post W-beam Guardrail*, May 17, 2010, Memorandum, Office of Safety Design, Federal Highway Administration, U.S. Department of Transportation.
2. H.E. Ross, Jr., D.L. Sicking, R.A. Zimmer and J.D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.
3. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition.* 2016, American Association of State Highway and Transportation Officials: Washington, D.C.
4. C. Silvestri Dobrovolny, W. L. Menges, and D. L. Kuhn. *Pendulum Testing on Composite Blockouts Raised on Steel Posts*. Technical Memo 605311, Texas A&M Transportation Institute, College Station, TX, February 15, 2017.

APPENDIX A. DETAILS OF THE 28-INCH W-BEAM GUARDRAIL SYSTEM WITH RAISED COMPOSITE BLOCKOUTS





GENERAL NOTES

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

MOW STRIP INSTALLATION

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

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

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

Mondo Polymer Technologies, Inc.
P.O. Box 250 / 27620 State Rt. 7 North
Reno, OH 45773
Phone: (888) 607-4790
Plastics from Today for Tomorrow……

Material Specification

Product ID: **GB14SH2**

Description: **Composite Recycled Guardrail Block 14" x 8" x 5 1/8" for Steel Post w/hanger (see attached drawing for dimensions and tolerances)**

Lot #: **16-04-22-1**

Composition: [1] **≥ 85% Thermoplastic Polyolefins**
≤ 13% Fillers and/or Trace Plastics
Minimum of 2 % UV Stabilizers

Density: **0.90 – 0.98 g/cm^3**

Specific Gravity: **< 1**

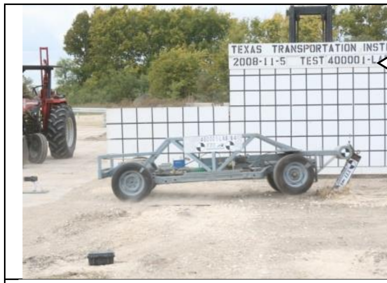
Hardness: **Shore D 45-70**

Melt Temperature: **≥ 244° F (118° C)**

Water Absorption: **<0.01**

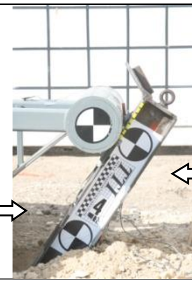
[1] **Manufactured from no less than 75% recycled content material**

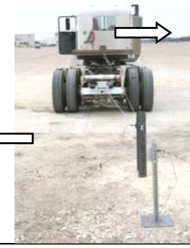
Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.



Dynamic Setup

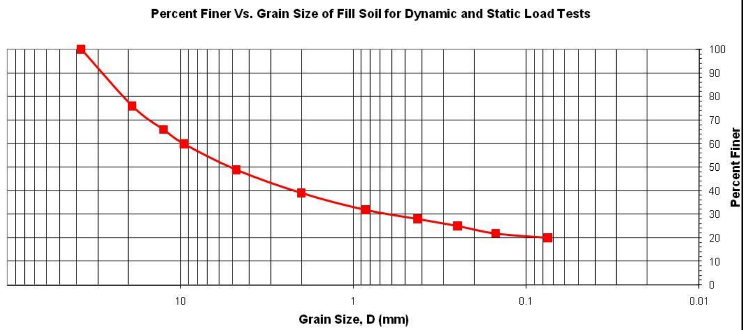
Post-Test Photo of post



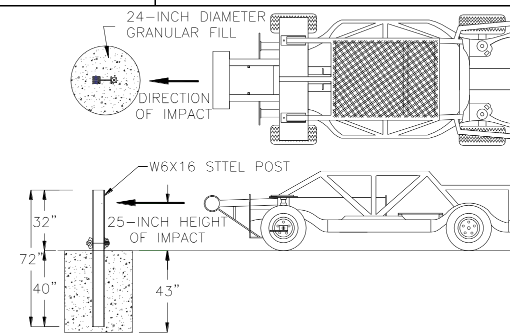


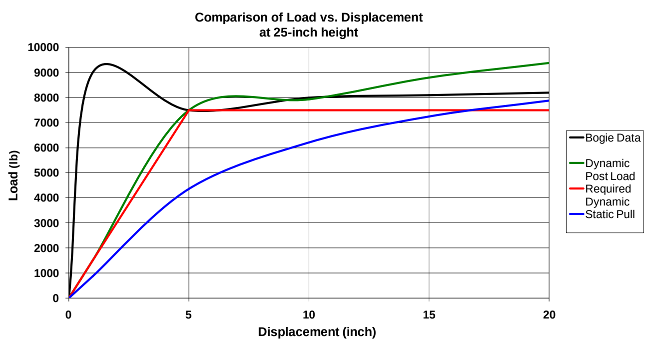
Post-Test Photo

Static Load Test

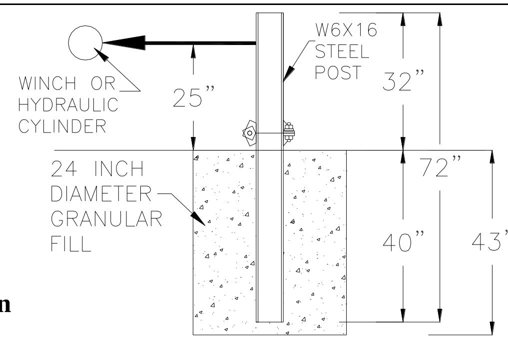


Dynamic Test Installation Details



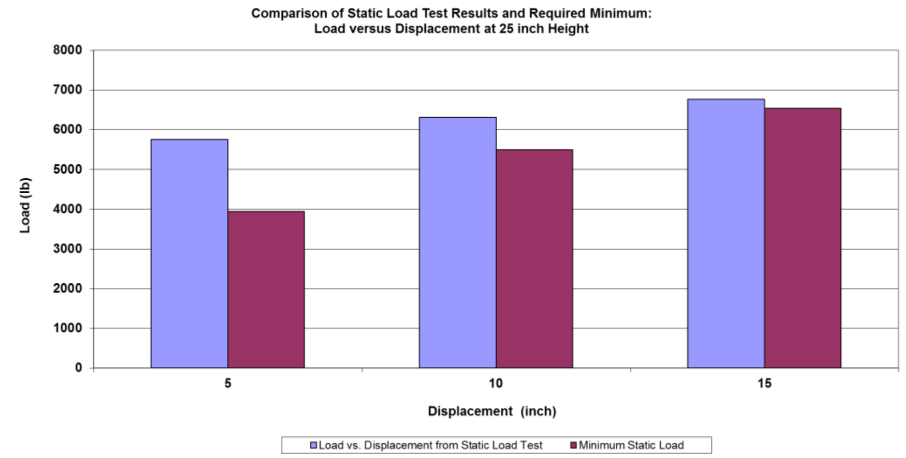


Static Load Test Installation Details

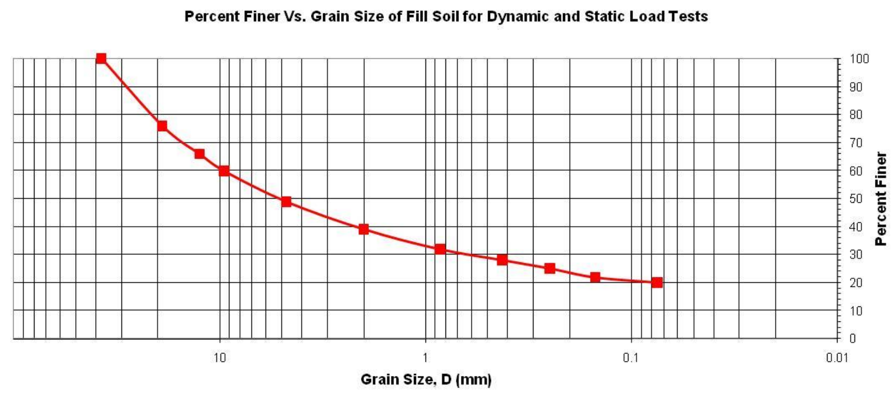


Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement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

Table C.2. Test Day Static Soil Strength Documentation for Test No. 608421-1.



Static Load Setup



Post-Test Photo of Post

Date	2017-06-30
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

APPENIDX D. *MASH* TEST 3-11 (CRASH TEST NO. 608421-1)

D1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 608421-1.

Date: 2017-06-30 Test No.: 608421-1 VIN No.: 1D7RB16P7BS547371

Year: 2011 Make: Dodge Model: RAM 1500

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

Tread Type: Highway Odometer: 146898

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

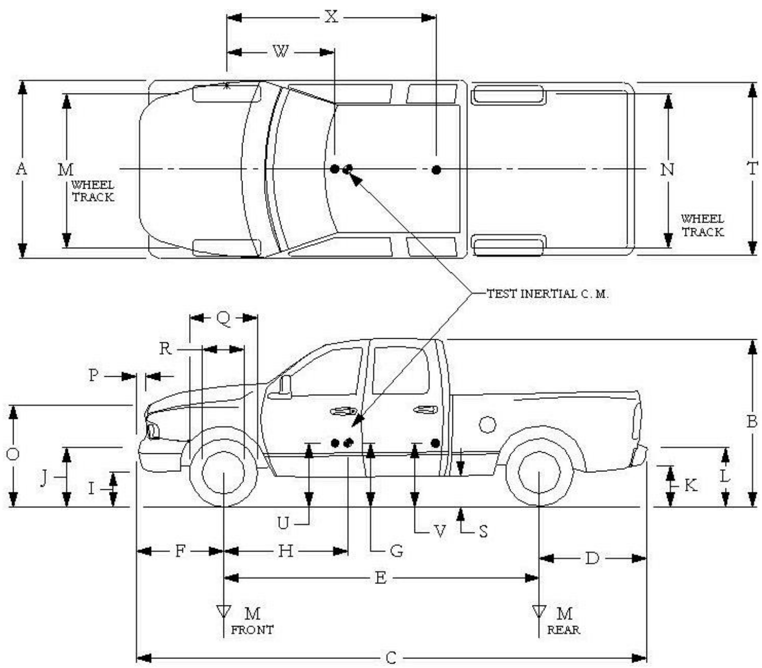
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment:
None

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



Geometry: inches

A	78.50	F	40.00	K	20.75	P	3.00	U	27.00
B	74.00	G	28.375	L	30.00	Q	30.50	V	30.00
C	227.50	H	62.50	M	68.50	R	18.00	W	62.50
D	47.00	I	11.50	N	68.00	S	13.50	X	77.75
E	140.50	J	27.00	O	45.50	T	77.00		

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2855	2785	----
Back	3900	M_{rear}	2027	2232	----
Total	6700	M_{Total}	4882	5017	----

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

Mass Distribution:
lb LF: 1391 RF: 1394 LR: 1114 RR: 1118

Table D.2. Measurements of Vehicle Vertical CG for Test No. 608421-1.

Date: 2017-06-30 Test No.: 608421-1 VIN: 1D7RB16P7BS547371

Year: 2011 Make: Dodge Model: RAM 1500

Body Style: Quad Cab Mileage: 146898

Engine: 4.7 liter V-8 Transmission: Automatic

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

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

Measured Vehicle Weights: (lb)								
LF:	1391		RF:	1394		Front Axle:	2785	
LR:	1114		RR:	1118		Rear Axle:	2232	
Left:	2505		Right:	2512		Total:	5017	
						5000 ±110 lb allowed		
Wheel Base:	140.5	inches	Track: F:	68.5	inches	R:	68	inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed				
Center of Gravity, SAE J874 Suspension Method								
X:	62.51	inches	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	0.05	inches	Left - Right +	of Vehicle Centerline				
Z:	28.375	inches	Above Ground	(minumum 28.0 inches allowed)				

Hood Height: 45.50 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 D.3. Exterior Crush Measurements for Test No. 608421-1.

Date:	2017-06-30	Test No.:	608421-1	VIN No.:	1D7RB16P7BS547371
Year:	2011	Make:	Dodge	Model:	RAM 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	20	10	28	0.5	1	1.5	3	6	10	-21
2	Side plane at bumper ht	20	9	60	1	1	--	--	9	9	+67
	Measurements recorded										
	in inches										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

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

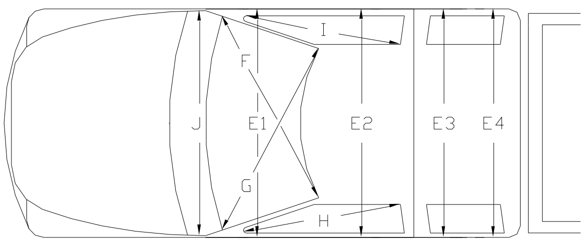
***Measure and document on the vehicle diagram the location of the maximum crush.

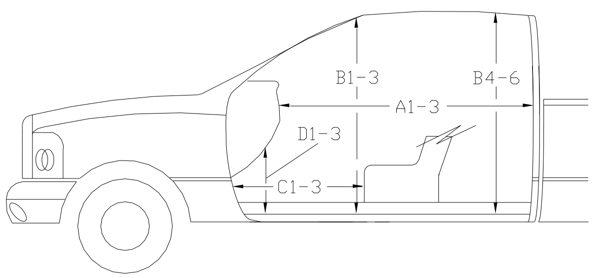
Note: Use as many lines/columns as necessary to describe each damage profile.

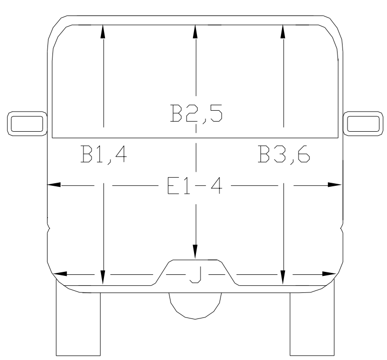
Table D.4. Occupant Compartment Measurements for Test No. 608421-1.

Date: 2017-06-30 Test No.: 608421-1 VIN No.: 1D7RB16P7BS547371

Year: 2011 Make: Dodge Model: RAM 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	**After** (inches)	**Differ.**
A1	65.00	65.00	0
A2	62.75	62.75	0
A3	65.50	65.50	0
B1	44.75	44.75	0
B2	37.75	37.75	0
B3	44.75	44.75	0
B4	39.25	39.25	0
B5	43.25	43.25	0
B6	39.25	39.25	0
C1	29.00	29.00	0
C2	-----	-----	0
C3	26.25	26.25	0
D1	11.25	11.25	0
D2	-----	-----	0
D3	11.25	11.25	0
E1	58.50	58.50	0
E2	63.50	63.75	+0.25
E3	63.50	63.50	0
E4	63.25	63.25	0
F	59.00	59.00	0
G	59.00	59.00	0
H	38.00	38.00	0
I	38.00	38.00	0
J*	23.25	23.25	0

D2 SEQUENTIAL PHOTOGRAPHS

0.000 s

0.100 s

0.200 s

0.300 s

Figure D.1. Sequential Photographs for Test No. 608421-1 (Overhead and Frontal Views).

Figure D.1. Sequential Photographs for Test No. 608421-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

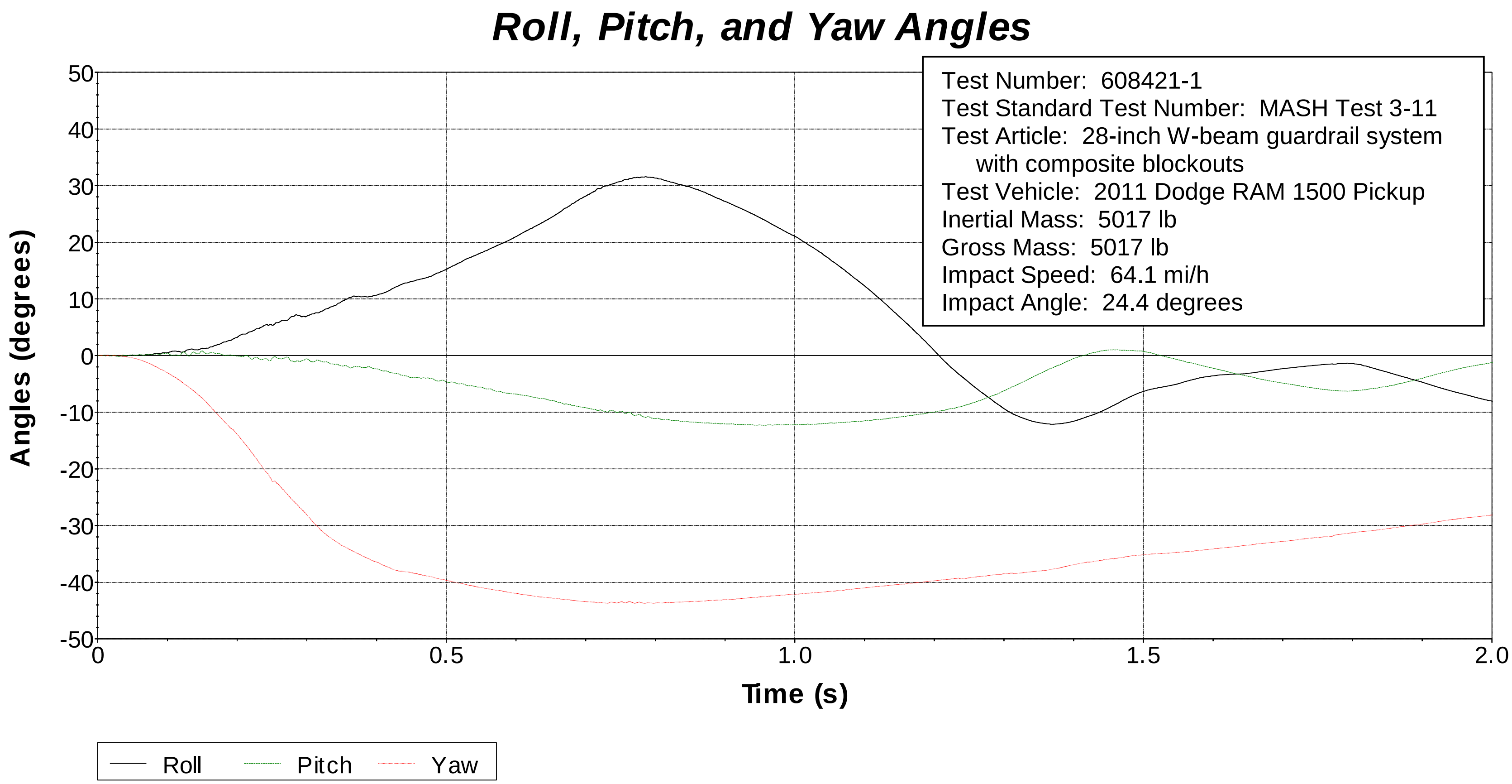
0.400 s

0.500 s

0.600 s

0.700 s

Figure D.2. Sequential Photographs for Test No. 608421-1 (Rear View).



Axes are vehicle-fixed.
Sequence for determining orientation:

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

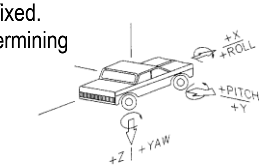


Figure D.3. Vehicle Angular Displacements for Test No. 608421-1.

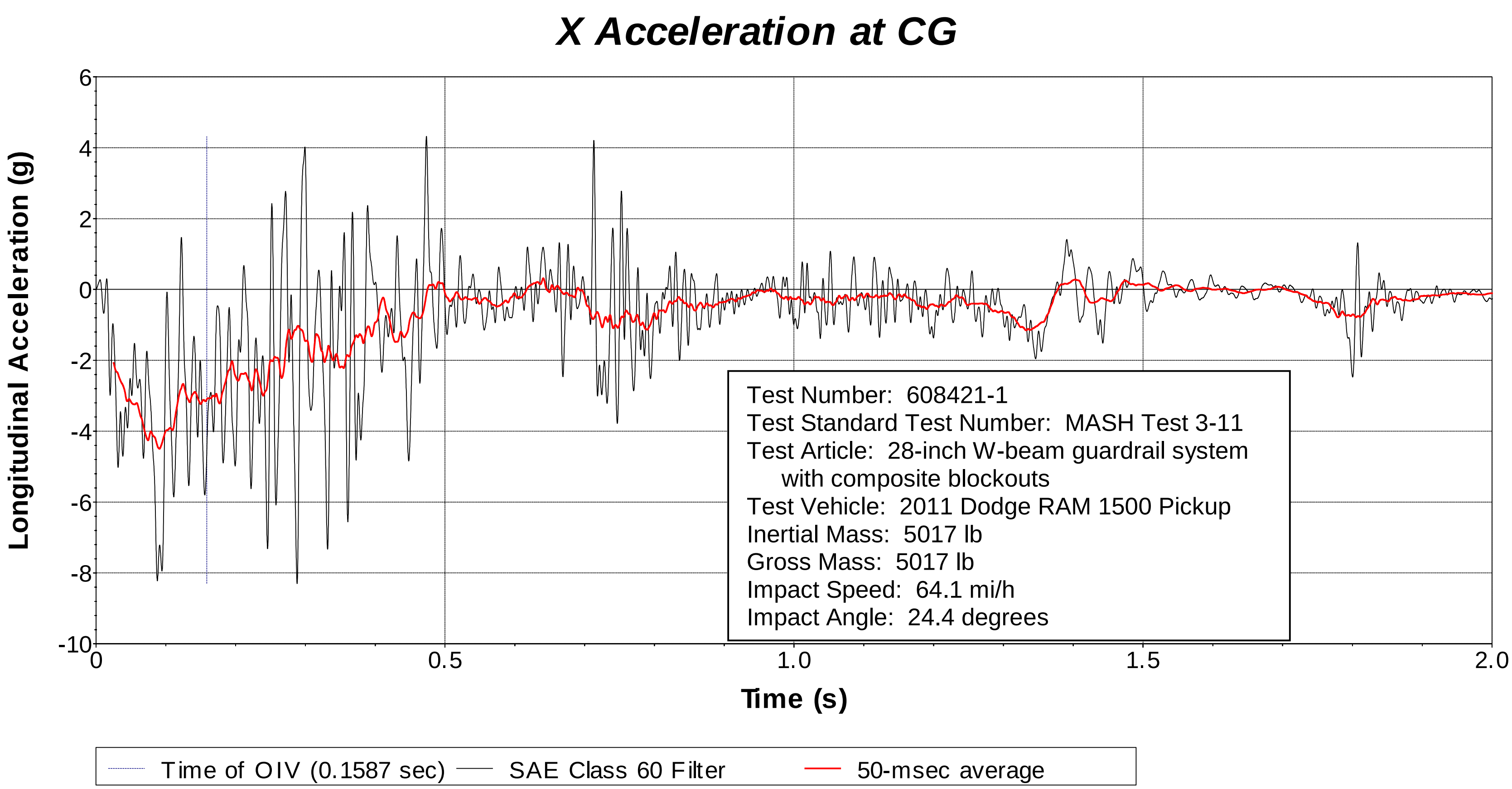


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608421-1 (Accelerometer Located at Center of Gravity).

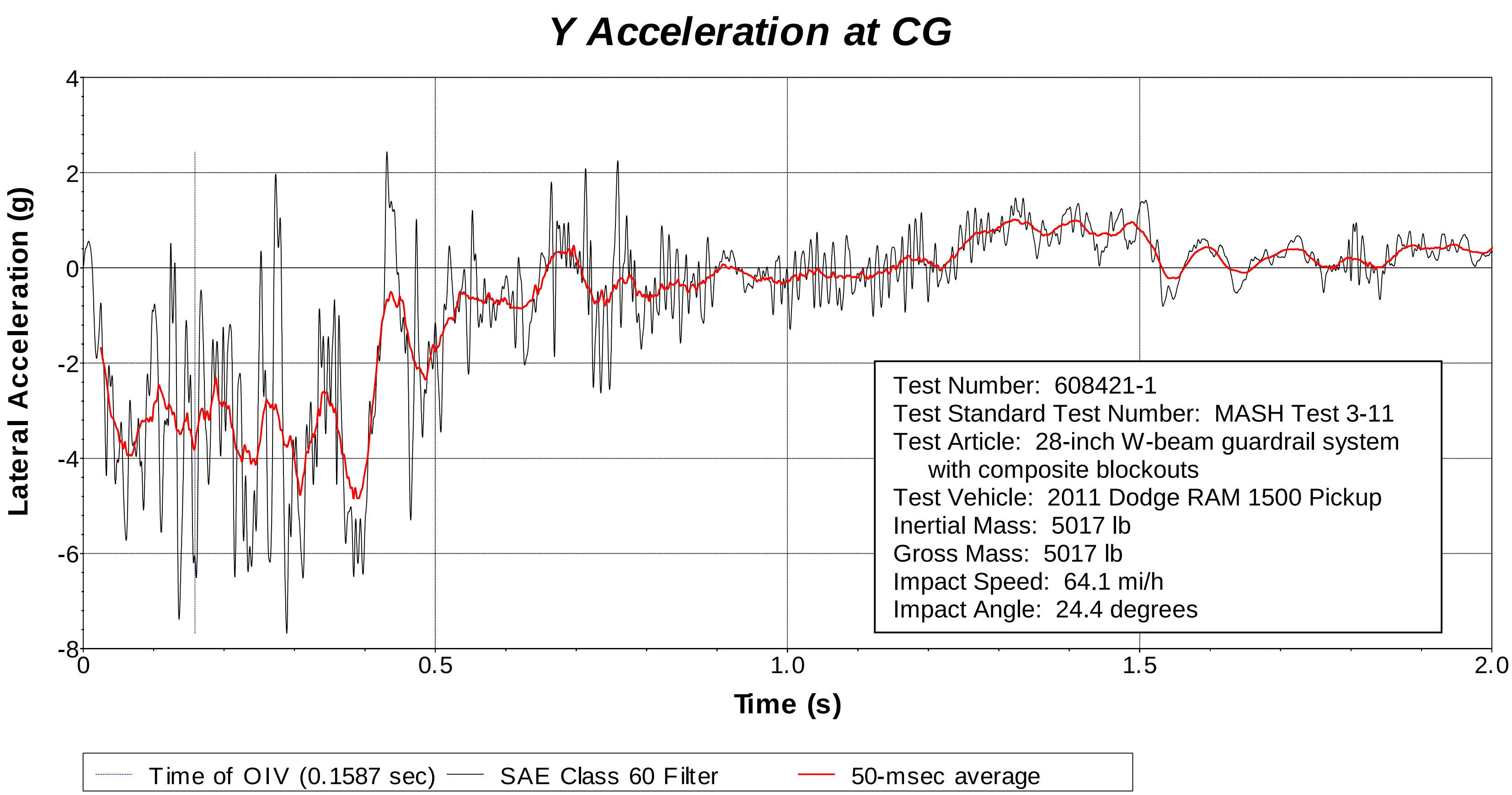


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 608421-1 (Accelerometer Located at Center of Gravity).

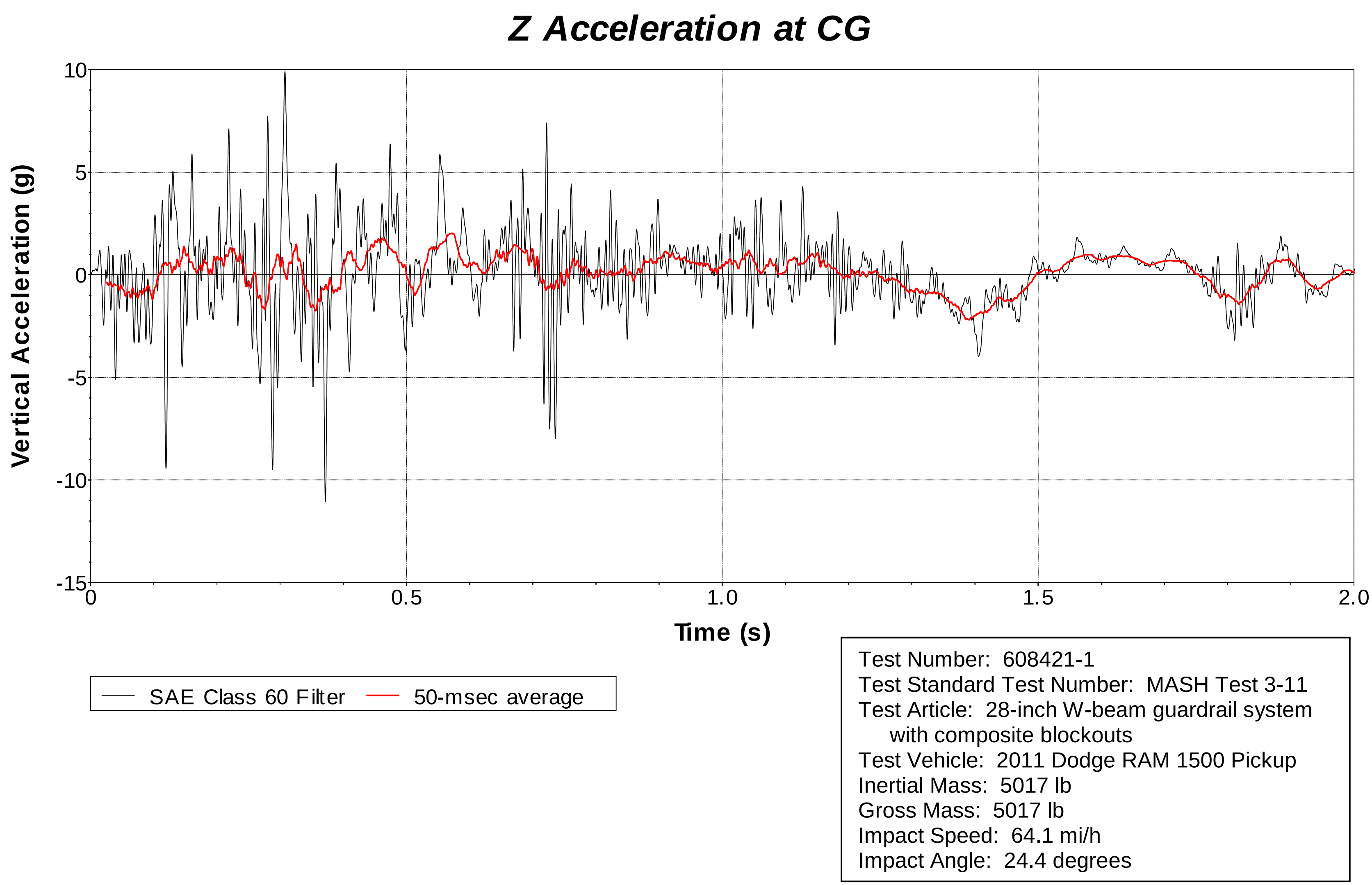


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 608421-1 (Accelerometer Located at Center of Gravity).

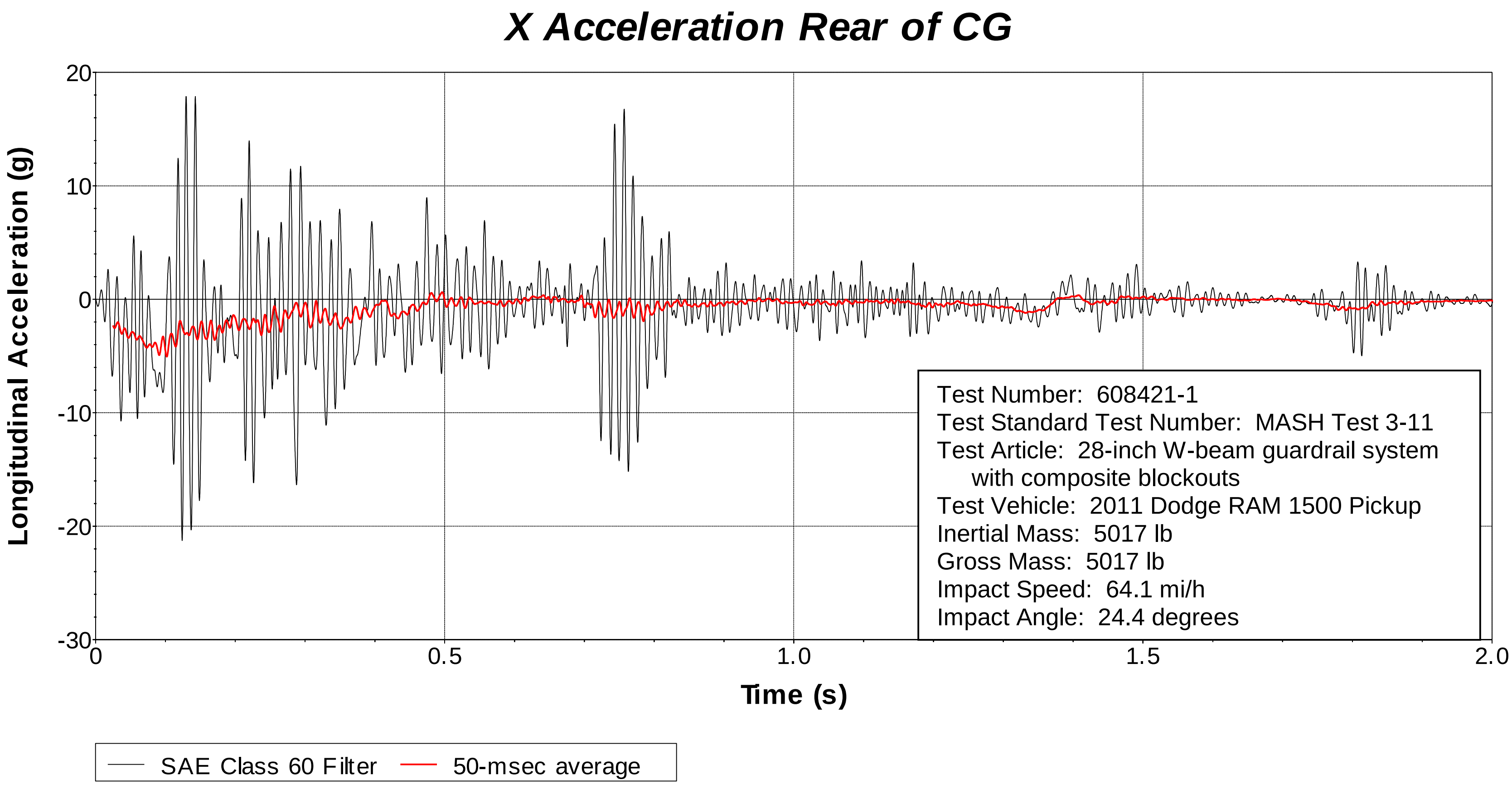


Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 608421-1 (Accelerometer Located Rear of Center of Gravity).

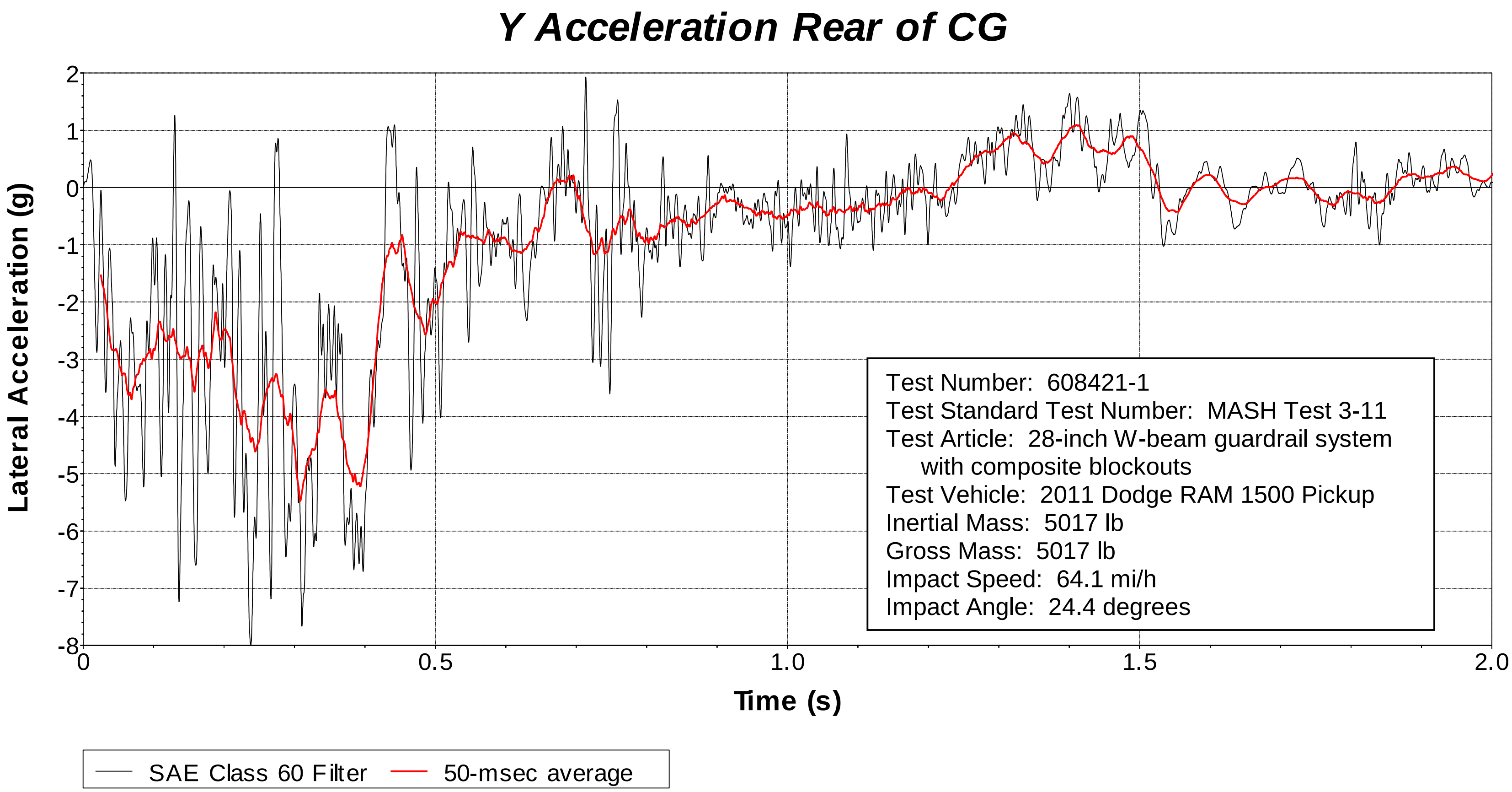


Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 608421-1 (Accelerometer Located Rear of Center of Gravity).

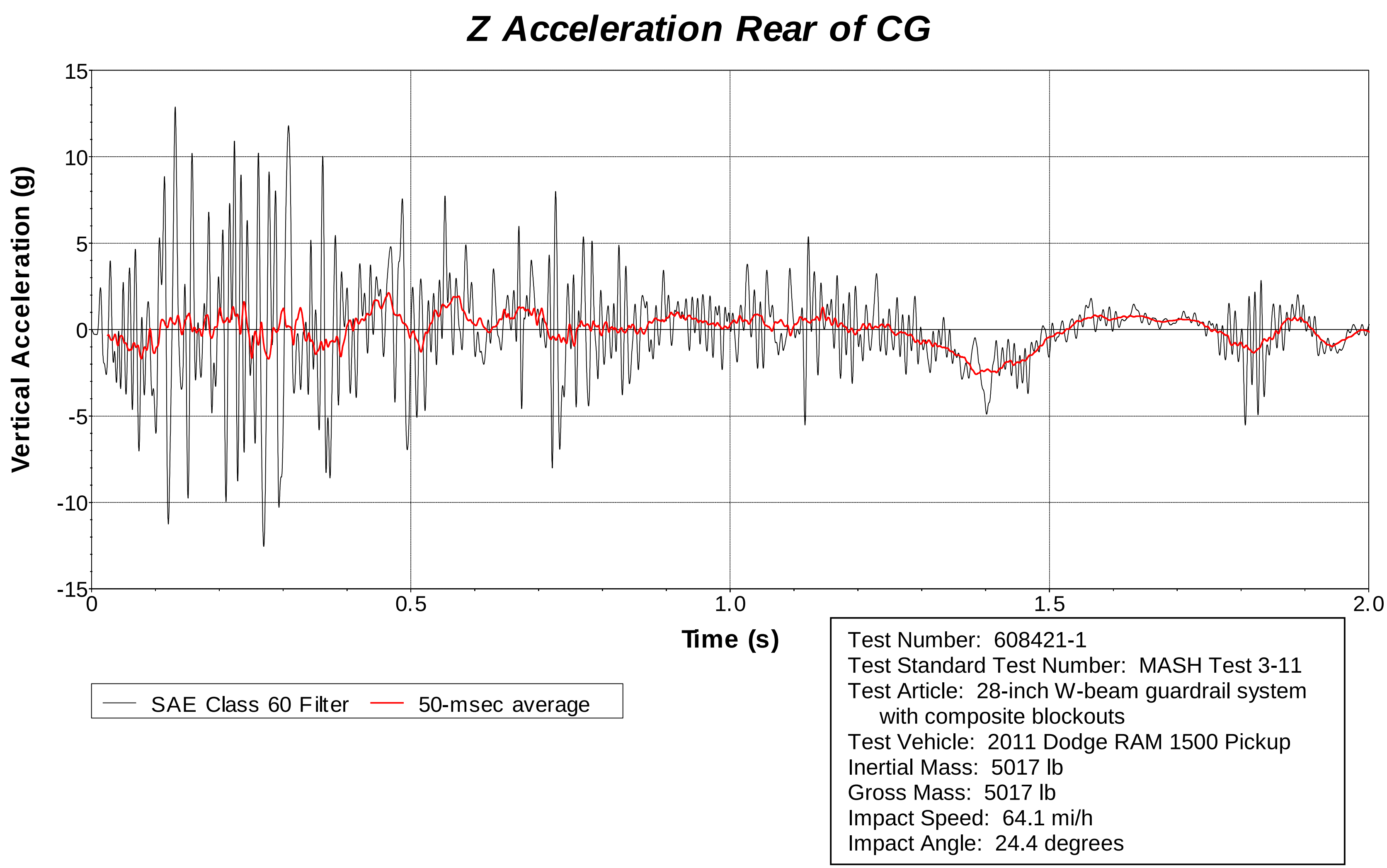


Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 608421-1 (Accelerometer Located Rear of Center of Gravity).