MASH TL-2 Evaluation of Strong-Post W-Beam Guardrail with Reduced Rail Heights

Test Report No.: 602361-1&2 **Test Report Date: December 2014**

U.S. Department of Transportation
Federal Highway Administration

FOREWORD

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ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
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Technical Report Documentation Page

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16. Abstract

Strong-post W-beam guardrail has been developed for high-speed roadway application using a design speed of 62 mi/h. This speed corresponds to test level 3 (TL-3) of American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) criteria. Some of the testing performed at the 62 mi/h impact speed with reduced rail height showed that 27.75-inch rail height is the minimum acceptable height to successfully contain and redirect an impacting vehicle. This prompted Federal Highway Administration to issue guidance on the use of the strong-post W-beam guardrail, setting the minimum acceptable rail height to 27.75 inches.

Other than test level 3, which is primarily used for high-speed applications, *MASH* specifies test level 2 (TL-2), which requires testing at a reduced speed of 44 mi/h for low speed applications. Due to the lower testing speed, there is a 50% reduction in impact energy between TL-3 and TL-2. While the TL-3 testing of the W-beam guardrail establishes a minimum rail height threshold of 27.75 inches, there is a possibility to reduce this threshold for lower-speed TL-2 applications.

In this research, two full-scale crash tests were performed using the *MASH* TL-2 conditions. The first test was performed with a strong-post W-beam guardrail system at a reduced rail height of 25 inches. The second test was performed at a further reduced rail height of 24 inches. Both of these tests were successful.

Although new guardrail installations would normally be installed at recommended heights for TL-3, results of these tests can be used to reduce minimum rail height threshold for existing strong-post W-beam guardrail to 24 inches for TL-2 conditions. While the guardrail is expected to perform acceptably at the 24-inch rail height, it is not recommended to install W-beam guardrail at this height. W-beam guardrail should be installed at the standard rail height and the allowance in the reduction of the rail height should only be used when evaluating existing guardrail.

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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 yard	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 1000 L 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 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	fl 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 (2000 lb)	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	lbf/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)

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

1 INTRODUCTION

1.1 BACKGROUND

Strong-post W-beam guardrail has been developed for high-speed roadway application using a design speed of 62 mi/h. This speed corresponds to test level 3 (TL-3) of American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) criteria, and of the preceding National Cooperative Highway Research Program (NCHRP) *Report 350* testing criteria *(1, 2)*. Some of the testing performed at the 62 mi/h impact speed with reduced rail height showed that 27.75-inch rail height is the minimum acceptable height to successfully contain and redirect an impacting vehicle *(3)*. Rail height lower than 27.75 inches is likely to result in the vehicle vaulting over the rail. This prompted Federal Highway Administration to issue guidance on the use of the strong-post W-beam guardrail on its website, setting the minimum acceptable rail height to 27.75 inches *(4)*.

Other than Test Level 3, which is primarily used for high-speed applications, *MASH* specifies Test Level 2 (TL-2), which requires testing at a reduced speed of 44 mi/h for low speed applications. Due to the lower testing speed, there is a 50 percent reduction in impact energy between TL-3 and TL-2. While the TL-3 testing of W-beam guardrail establishes a minimum rail height threshold of 27.75 inches, there is potential to reduce the minimum height requirement for lower-speed TL-2 applications of the W-beam guardrail.

User agencies are often faced with difficulty in maintaining appropriate guardrail height during repaving of roads. Asphalt layers used for repaving raises the roadway level, effectively reducing the height of the guardrail. There is significant usage of the W-beam guardrail on low-speed roads (such as county roads, city roads, park roads, etc.) that can benefit from the potential reduction in minimum guardrail height threshold. If existing guardrail can be allowed to remain in place for a longer period of time without resetting or raising the height, it can significantly reduce the complexity and cost of road repaving, thus reducing the cost of maintaining, resurfacing, or rehabilitating low-speed roads.

1.2 OBJECTIVES/SCOPE OF RESEARCH

The objective of this project was to determine the minimum guardrail height for strong-post W-beam guardrail that meets safety performance criteria set forth under AASHTO *MASH* TL-2 conditions.

To evaluate the performance of the guardrail, two full-scale crash tests were performed. The first test was performed at a reduced rail height of 25 inches. The second test was performed at further reduced rail height of 24 inches. Details of the testing criteria used, the guardrail systems tested, description of the crash tests, and test results are presented next.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 CRASH TEST MATRIX

According to *MASH*, two tests are recommended to evaluate longitudinal barriers to Test Level Two (TL-2).

- ***MASH* Test 2-10:** A 2420-lb vehicle impacting the critical impact point (CIP) of the length of need (LON) of the barrier at a nominal impact speed and angle of 44 mi/h and 25 degrees, respectively. This test investigates a barrier's ability to successfully contain and redirect a small passenger vehicle.

- ***MASH* Test 2-11:** A 5000-lb pickup truck impacting the CIP of the LON of the barrier at a nominal impact speed and angle of 44 mi/h and 25 degrees, respectively. This test investigates a barrier's ability to successfully contain and redirect light trucks and sport utility vehicles.

As mentioned previously, two crash tests were performed under this project. The first crash test was performed at a reduced rail height of 25 inches. The second test was performed at a further reduced rail height of 24 inches. Both of these tests corresponded to *MASH* Test 2-11 conditions. The target critical impact points for these tests are described in Section 4.2 and Section 5.2 of the report.

Test 2-10 with the small passenger car was not performed. This is because several tests have been successfully performed in the past with the small car impacting a 31-inch tall W-beam guardrail under *MASH* TL-3 impact conditions (i.e. 62 mi/h speed) *(5, 6)*. The small car test is used to judge the potential of a vehicle under-riding the barrier or resulting in additional occupant risk due to vehicle parts snagging with posts or other barrier parts. With a reduced rail height of 25 and 24 inches, and a significantly reduced speed of 44 mi/h, the small car is not expected to under-ride the barrier or cause additional snagging and occupant risk compared to the previously performed *MASH* TL-3 tests at the 31-inch rail height.

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

2.2 EVALUATION CRITERIA

The crash test was evaluated in accordance with the criteria presented in *MASH*. The performance of the strong-post W-beam guardrail is judged on the basis of three factors: structural adequacy, occupant risk, and post-impact vehicle trajectory. Structural adequacy is judged on the ability of the strong-post W-beam guardrail to contain and redirect the vehicle, or bring the vehicle to a controlled stop in a predictable manner. Occupant risk criteria evaluate the potential risk of hazard to occupants in the impacting vehicle, and, to some extent, other traffic and pedestrians or workers in construction zones, if applicable. Post impact vehicle trajectory is

assessed to determine potential for secondary impact with other vehicles or fixed objects, creating further risk of injury to occupants of the impacting vehicle and/or risk of injury to occupants in other vehicles. The appropriate safety evaluation criteria from Table 5.1 of *MASH* were used to evaluate the crash test reported herein, and are listed in further detail under the assessment of the crash test.

3 TEST CONDITIONS

3.1 TEST FACILITY

The full-scale crash test reported herein was performed at Texas A&M Transportation Institute (TTI) Proving Ground. TTI Proving Ground is 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 at the TTI Proving Ground consist of a 2000 acre complex of research and training facilities situated 10 miles northwest of the main campus of Texas A&M University. The site, formerly a United States Army Air Corps Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and evaluation of roadside safety hardware. The site selected for the installation of the TL-2 strong-post W-beam guardrail is along a wide out-of-service runway/apron. The runway/apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches thick. The apron was built in 1942, and the joints have some displacement, but are otherwise flat and level.

3.2 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 two-to-one speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained freewheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated, if needed, to bring it to a safe and controlled stop.

3.3 DATA ACQUISITION SYSTEMS

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

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

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

3.3.2 Anthropomorphic Dummy Instrumentation

Use of a dummy in the 2270P vehicle is optional according to *MASH*, and there was no dummy used in the tests with the 2270P vehicle.

3.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from the high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-digital video camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

4 *MASH* TEST 2-11 ON THE 25-INCH TALL W-BEAM GUARDRAIL

4.1 TEST ARTICLE DETAILS

4.1.1 Test Article Design and Construction

The test installation consisted of a 25-inch tall W-beam guardrail system in *MASH* compacted strong soil with a standard 37 ft 6 inch ET-PLUS end terminal on each end. The total post-to-post installation length was 175 ft 0 inch. The guardrail splices at post 7 and post 23 were considered to be the end points of the ET-PLUS end-terminals at each end of the length of need. The length of need was 100 ft 0 inch between posts 7 and 23.

All posts (1 through 29) were equally spaced at 6 ft 3 inches. Standard 12-gauge W-beam guardrail (type RWM02a) was used in the system from posts 3 to 28. The exception was the terminal guardrail pieces between posts 1 and 3 and posts 27 and 29 that had punched slots into which the anchor cable release bracket was installed.

The top of the W-beam was 25 inches above grade from post 7 through 23 (in the length of need), and guardrail splices were located at every other post (i.e. odd numbered posts). The guardrail height tapered upward from 25 inches (at post 7 and 23) to 27⅝ inches (at post 1 and 29, respectively).

Guardrail offset for posts 3 through 27 was accomplished by use of 8-inch deep × 14-inch tall × 6-inch wide treated and routed wood offset blocks (PDB01b), attached with standard 10-inch long guardrail bolts and nuts (FBB03). Posts 2 and 28 had no offset blocks and were bolted directly to the guardrail with standard 1¼-inch bolts and nuts (FBB01).

Guardrail posts 7 through 23 in the length of need were 72-inch long guardrail line posts fabricated from W6×8.5 ASTM A36 structural steel shape (type PWE01). These posts were embedded 46 inches deep in drilled holes with compacted strong soil as per *MASH*.

Posts 2 through 6 and posts 24 through 28 were standard 72-inch Steel Yielding Terminal Posts (SYTPs) fabricated from W6×8.5 ASTM A36 structural steel shape, and embedded in the soil per a typical ET-PLUS terminal installation, but with varying depths due to the aforementioned tapered height to the terminal.

Posts 1 and 29 were standard ET-PLUS terminal cable release anchor posts (CRPs), embedded in drilled holes with compacted *MASH* strong soil per a typical ET-PLUS terminal installation. A standard 78-inch long ET-PLUS anchor cable and square tube type anchor cable release bracket were used to anchor the W-beam rail to posts 1 and 29 near grade. An 81-inch long 3×3×¼-inch steel angle ground strut on the field side of the ET-PLUS terminal connected posts 1 and 2 and posts 28 and 29, respectively.

Figure 4.1 presents further information on the 25-inch TL-2 strong-post W-beam guardrail system, and Figure 4.2 provides photographs of the installation.

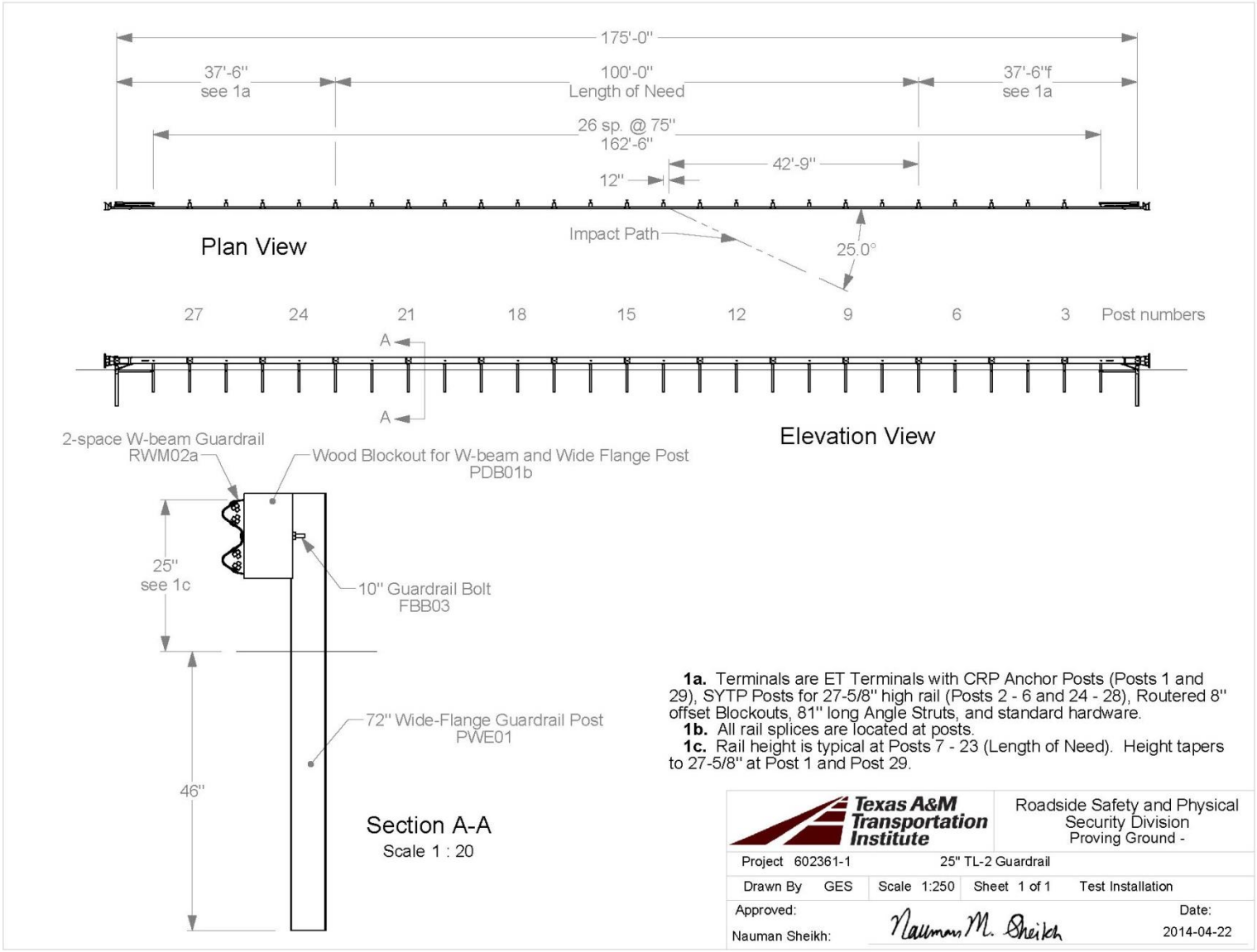


Figure 4.1. Details of the 25-inch Tall Strong-Post W-beam Guardrail.

Figure 4.2. 25-inch Tall Strong-post W-beam Guardrail Installation Prior to Testing.

4.1.2 Material Specifications

Material properties of various components are noted in the Section 4.1.1, and certification documents can be found in Appendix A.

4.1.3 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.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test (see Appendix B, Figure B.1). During installation of the 25-inch TL-2 Guardrail for full-scale crash testing, two standard W6×16 posts were installed in the immediate vicinity of the 25-inch TL-2 strong-post W-beam guardrail, utilizing the same fill materials and installation procedures used in the standard dynamic test (see Appendix B, Figure B.2).

As determined in the tests shown in Appendix B, Figure B.2, the minimum post load required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, is 3940 lb, 5500 lb, and 6540 lb, respectively (90% of static load for the initial standard installation). On the day of the test, May 2, 2014, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 7323 lb_f, 7424 lb_f, and 7373 lb_f, respectively. The strength of the backfill material met minimum requirements.

4.2 TEST DESIGNATION AND IMPACT CONDITIONS

MASH test 2-11 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the guardrail at an impact speed of 44 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The 2008 Dodge Ram 1500 pickup truck used in the test weighed 5049 lb and the actual impact speed and angle were 44.6 mi/h and 25.4 degrees, respectively. The target critical impact point (CIP) for this test was determined using *MASH* guidelines and was found to be 7 ft 3 inches upstream of post 15 of the installation (i.e., 12 inches upstream of post 14). The actual impact point was 14.0 inches upstream of post 14. Target impact severity (IS) was 57.8 kip-ft, and actual IS was 61.8 kip-ft (+6.9 percent).

4.3 TEST VEHICLE

Figures 4.3 and 4.4 show the 2008 Dodge Ram 1500 pickup truck used for this crash test. Test inertia weight of the vehicle was 5049 lb, and its gross static weight was 5049 lb. The height to the lower edge of the vehicle front bumper was 15.75 inches, and the height to the upper edge of the front bumper was 28.00 inches. The height to the center of gravity was 28.25 inches. Additional dimensions and information on the vehicle are given in Appendix C, Table C.1 and Table C.2. 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 4.3. Vehicle and Installation Geometrics for Test No. 602361-1.

Figure 4.4. Vehicle before Test No. 602361-1.

4.4 WEATHER CONDITIONS

The crash test was performed the morning of May 2, 2014. Weather conditions at the time of testing were: wind speed: 3 mi/h; wind direction: 249 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 72 ºF; relative humidity: 42 percent.

4.5 TEST DESCRIPTION

The 2008 Dodge Ram 1500 pickup truck, traveling at an impact speed of 44.6 mi/h, contacted the guardrail 14.0 inches upstream of post 14 at an impact angle of 25.4 degrees. At approximately 0.056 s after impact, the vehicle contacted post 14 which began to deflect toward the field side, and at 0.089 s, the vehicle contacted post 15 which began to deflect toward the field side. The blockout from post 15 separated from the post at 0.166 s, and the vehicle contacted post 16 at 0.222 s. At 0.293 s, the vehicle was traveling parallel with the guardrail, and at 0.328 s, the rear of the vehicle contacted the guardrail. The vehicle lost contact with the guardrail at 0.596 s, and was traveling at an exit speed and angle of 28.7 mi/h and 10.8 degrees, respectively. Brakes on the vehicle were not applied and the vehicle came to rest 115 ft downstream of impact. Appendix C2, Figure C.1 presents sequential photographs of the test.

4.6 TEST ARTICLE AND COMPONENT DAMAGE

Figures 4.5 and 4.6 show damage to the 25-inch tall W-beam guardrail installation. The soil around post 1 and post 13 was disturbed. Post 14 was slightly rotated clockwise and was pushed toward the field side 1.75 inches at ground level. Post 15 was rotated counterclockwise, separated from the rail element and the blockout, and pushed toward the field side 4.75 inches at ground level. The blockout at post 15 split along the bolt hole. Post 16 was slightly rotated counterclockwise and was pushed toward the field side 1.75 inches at ground level. The soil around post 17 was disturbed. The vehicle was in contact with the guardrail 28 ft 6 inches before losing contact with the rail. The vehicle contacted the installation a second time at post 29, which became dislodged from the ground base, but remained directly over the base. The ET head was partially pulled off the rail element. Working width was 26.3 inches. Maximum dynamic deflection during the test was 18.0 inches, and maximum permanent deformation was 13.5 inches.

4.7 TEST VEHICLE DAMAGE

Figure 4.7 shows damage to the 2270P vehicle after the test. The right front upper ball joint was pulled out of the socket, the right lower ball joint broke at the mount, and the inner tie rod was pulled out of the socket. Also damaged were the front bumper, right front fender, right front and rear doors, right rear exterior bed, and the rear bumper. Maximum exterior crush to the vehicle was 10.0 inches in the side plane at the right front corner of the vehicle at bumper height. No occupant compartment deformation occurred. Figure 4.6 shows the interior of the vehicle. Exterior vehicle crush and occupant compartment measurements are shown in Appendix C1, Tables C.3 and C.4.

Figure 4.5. Vehicle and 25-inch tall W-beam Guardrail after Test No. 602361-1.

Figure 4.6. Installation after Test No. 602361-1.

Figure 4.7. Vehicle after Test No. 602361-1.

Before Test

After Test

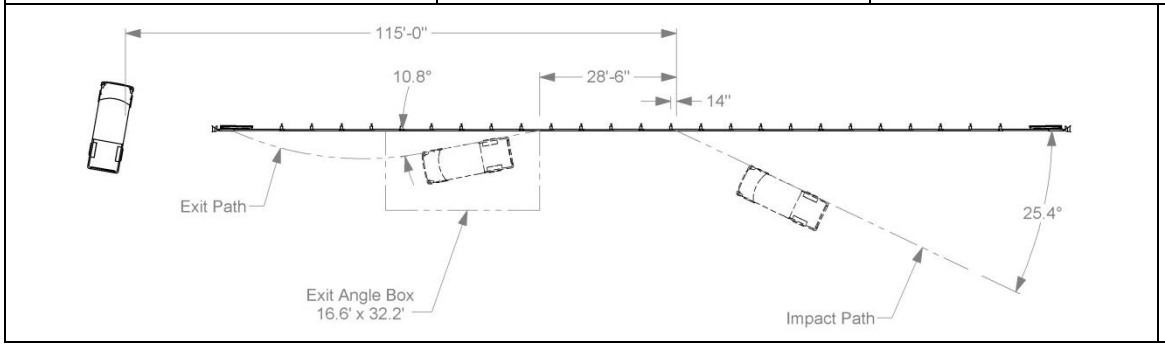
Figure 4.8. Interior of Vehicle for Test No. 602361-1.

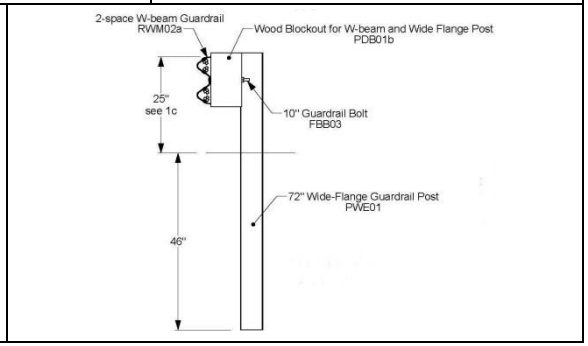
0.000 s

0.128 s

0.256 s

0.640 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 2-11
- TTI Test No. 602631-1
- Date 2014-05-02

Test Article
- Type ..... Guardrail
- Name ..... 25-inch tall strong-post W-beam guardrail
- Installation Length ..... 175.0 ft
- Material or Key Elements .... 25-inch tall 12-ga W beam guardrail w/72-inch long W6×8.5 ASTM A36 structural steel shape posts spaced at 6 ft 3 inches w/8×14×6 inch routed wood blocks
- **Soil Type and Condition**..... Standard soil, dry

Test Vehicle
- Type/Designation 2270P
- Make and Model..... 2008 Dodge Ram 1500
- Curb ..... 4925 lb
- Test Inertial ..... 5049 lb
- Dummy..... None
- Gross Static..... 5049 lb

Impact Conditions
- Speed.....44.6 mi/h
- Angle.....25.4 degrees
- Location/Orientation .....CIP-14 inches upstrm post 14 (+6.9%)

Impact Severity.....61.8 kip-ft

Exit Conditions
- Speed.....28.7 mi/h
- Angle.....10.8 degrees

Occupant Risk Values
- Impact Velocity
  - Longitudinal.....14.1 ft/s
  - Lateral.....13.8 ft/s
- Ridedown Accelerations
  - Longitudinal.....9.1 G
  - Lateral.....6.0 G
- THIV.....20.8 mi/h
- PHD .....10.4 G
- ASI 0.50
- Max. 0.050-s Average
  - Longitudinal.....−4.0 G
  - Lateral.....−4.2 G
  - Vertical.....−4.2 G

Post-Impact Trajectory
- Stopping Distance ..... 115.0 ft dwnstrm

Vehicle Stability
- Maximum Yaw Angle..... 36 degrees
- Maximum Pitch Angle..... 8 degrees
- Maximum Roll Angle..... 14 degrees
- Vehicle Snagging..... No
- Vehicle Pocketing..... No

Test Article Deflections
- Dynamic ..... 18.0 inches
- Permanent..... 13.5 inches
- Working Width..... 26.3 inches

Vehicle Damage
- VDS..... 01RFQ5
- CDC 01FREW4
- Max. Exterior Deformation ..... 10.0 inches
- OCDI RF0000000
- Max. Occupant Compartment Deformation..... None

Figure 4.9. Summary of Results for *MASH* Test 2-11 on the 25-inch Tall Strong-Post W-Beam Guardrail.

4.8 OCCUPANT RISK VALUES

Data from the accelerometer, located at the vehicle's center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 14.1 ft/s at 0.154 s, the highest 0.010-s occupant ridedown acceleration was 9.1 Gs from 0.208 to 0.218 s, and the maximum 0.050-s average acceleration was −4.0 Gs between 0.111 and 0.161 s. In the lateral direction, the occupant impact velocity was 13.8 ft/s at 0.154 s, the highest 0.010-s occupant ridedown acceleration was 6.0 Gs from 0.167 to 0.177 s, and the maximum 0.050-s average was −4.2 Gs between 0.167 and 0.217 s. Theoretical Head Impact Velocity (THIV) was 20.8 km/h or 5.8 m/s at 0.148 s; Post-Impact Head Decelerations (PHD) was 10.4 Gs between 0.208 and 0.218 s; and Acceleration Severity Index (ASI) was 0.50 between 0.086 and 0.136 s. Figure 4.9 summarizes these data and other pertinent information from the test. Vehicle angular displacements are presented in Appendix C3, Figure C.2, and accelerations versus time traces are presented in Appendix C4, Figure C.3 through Figure C.8.

4.9 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the following applicable *MASH* safety evaluation criteria is presented below.

4.9.1 Structural Adequacy

A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*

Results: The 25-inch tall strong-post W-beam guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 18.0 inches. (PASS)

4.9.2 Occupant Risk

D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).*

Results: The blockout on post 15 split and separated from the post. These fragments did not penetrate or show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. (PASS)
No occupant compartment deformation or intrusion occurred. (PASS)

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

Results: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 14 degrees and 8 degrees, respectively. (PASS)

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

Longitudinal and Lateral Occupant Impact Velocity

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

Results: Longitudinal occupant impact velocity was 14.1 ft/s, and lateral occupant impact velocity was 13.8 ft/s. (PASS)

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

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Longitudinal ridedown acceleration was 9.1 G, and lateral ridedown acceleration was 6.0 G. (PASS)

4.9.3 Vehicle Trajectory

For redirective devices, it is desirable that the vehicle be smoothly redirected and exit the barrier within the "exit box" criteria (not less than 32.8 ft), and should be documented.

Result: The 2270P vehicle exited within the exit box criteria. (PASS)

5 *MASH* TEST 2-11 ON THE 24-INCH TALL W-BEAM GUARDRAIL

5.1 TEST ARTICLE DETAILS

5.1.1 Test Article Design and Construction

Details of the test installation for this test were the same as those presented for Test No. 602361-1 under Section 4.1.1, with the following three exceptions.

1. The top of the W-beam was 24 inches above grade from post 7 through post 23 (in the length of need).
2. The guardrail height tapered upward from 24 inches (at post 7 and 23) to 27⅝ inches (at post 1 and 29, respectively).
3. Guardrail posts 7 through 23 in the length of need were embedded 47 inches deep in drilled holes with compacted strong soil as per *MASH*.

Figure 5.1 presents further information on the 24-inch tall strong-post W-beam guardrail system and Figure 5.2 provides photographs of the installation.

5.1.2 Material Specifications

Material properties of various components are noted in the Section 5.1.1, and certifications documents can be found in Appendix A.

5.1.3 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.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test (see Appendix B, Figure B.3). On the day of the test, July 7, 2014, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 9630 lb_f, 9270 lb_f, and 8845 lb_f, respectively. The strength of the backfill material met minimum requirements.

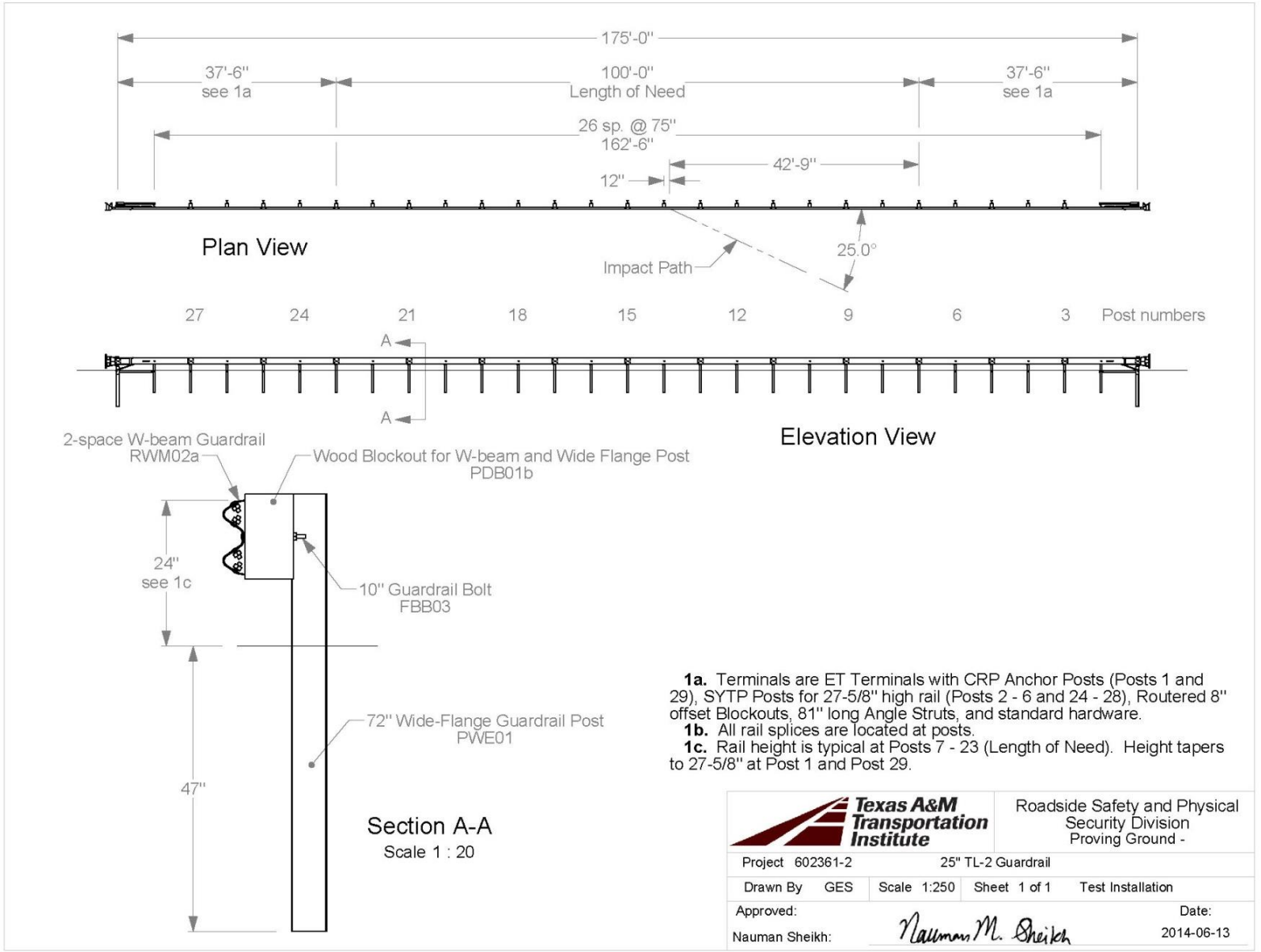


Figure 5.1. Details of the 24-inch Tall Strong-Post W-beam Guardrail.

Figure 5.2. 24-inch Tall Strong-post W-beam Guardrail prior to Testing.

5.2 TEST DESIGNATION AND IMPACT CONDITIONS

MASH test 2-11 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the guardrail at an impact speed of 44 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The 2008 Dodge Ram 1500 pickup truck used in the test weighed 5021 lb and the actual impact speed and angle were 45.2 mi/h and 24.9 degrees, respectively. The target critical impact point (CIP) for this test was determined using *MASH* guidelines and was found to be 7 ft 3 inches upstream of post 15 of the installation (i.e., 12 inches upstream of post 14). The actual impact point was 11.9 inches upstream of post 14. Target impact severity (IS) was 57.8 kip-ft, and actual IS was 60.8 kip-ft (+5.1 percent).

5.3 TEST VEHICLE

Figures 5.3 and 5.4 show the 2008 Dodge Ram 1500 pickup truck used for this crash test. Test inertia weight of the vehicle was 5021 lb, and its gross static weight was 5021 lb. The height to the lower edge of the vehicle front bumper was 15.75 inches, and the height to the upper edge of the front bumper was 27.50 inches. The height to the center of gravity was 28.00 inches. Additional dimensions and information on the vehicle are given in Appendix D1, Tables D.1 and D.2. 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.

5.4 WEATHER CONDITIONS

The crash test was performed the morning of July 7, 2014. Weather conditions at the time of testing were: wind speed: 8 mi/h; wind direction: 193 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 88°F; relative humidity: 59 percent.

5.5 TEST DESCRIPTION

The 2008 Dodge Ram 1500 pickup truck, traveling at an impact speed of 45.2 mi/h, impacted the guardrail 11.9 inches upstream of post 14 at 24.9 degrees. At approximately 0.003 s after impact, post 14 began to deflect towards the field side, and at 0.026 s, post 15 began to deflect towards the field side. The right front tire contacted the traffic face of post 14 at 0.055 s, and the vehicle began to redirect at 0.069 s. At 0.097, post 16 began to deflect towards the field side, and at 0.123 s, the right front tire contacted post 15. The right front tire contacted post 16 at 0.192 s, and the rear of the vehicle contacted the guardrail at 0.273 s. At 0.291 s, the vehicle began to travel parallel with the guardrail. At 0.634 s, the vehicle lost contact with the guardrail and was traveling at an exit speed and angle of 28.7 mi/h and 7.5 degrees, respectively. Brakes on the vehicle were applied at 3.9 s. The vehicle yawed slightly counterclockwise and came to rest 176 ft downstream of impact and 22 ft towards the field side of the guardrail. Appendix C.2, Figures C.1 and C.2 present sequential photographs of the test.

Figure 5.3. Vehicle and Installation Geometrics for Test No. 602361-2.

Figure 5.4. Vehicle before Test No. 602361-2.

5.6 TEST ARTICLE AND COMPONENT DAMAGE

Figures 5.5 and 5.6 show damage to the 24-inch tall strong-post W-beam guardrail. Post 1 was pulled downstream 0.25 inch. The guardrail bolt pulled through the rail at post 12, and the soil around post 12 and 13 was disturbed. Post 14 was leaning toward the field side 9 degrees, and there was a gap between the post and soil of 1.1 inches on the field side. Post 15 rotated clockwise 95 degrees, released from the rail, and was leaning downstream 40 degrees. Post 16 rotated clockwise 45 degrees, released from the rail, and was leaning downstream 15 degrees. The soil around post 17 was disturbed. The length of contact of the vehicle with the guardrail was 20 ft. Maximum permanent deformation of the rail element was 15.0 inches at post 15. Working width was 29.7 inches. Maximum dynamic deflection during the test was 22.4 inches.

5.7 TEST VEHICLE DAMAGE

Figure 5.7 shows damage to the vehicle after the test. The right front upper ball joint was pulled out of the socket, the right lower ball joint broke at the mount, and the inner tie rod was pulled out of the socket. The front bumper, right front tire and wheel rim, right front fender, right front door, right rear quarter panel, and rear bumper were deformed. Maximum exterior crush was 13.0 inches in the side plane at the right front corner at bumper height. No occupant compartment deformation or intrusion was evident. Figure 5.8 shows the interior of the vehicle. Exterior vehicle crush and occupant compartment measurements are shown in Appendix C.1, Table C.3 and Table C.4, respectively.

5.8 OCCUPANT RISK VALUES

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 15.7 ft/s at 0.165 s, the highest 0.010-s occupant ridedown acceleration was 10.6 Gs from 0.200 to 0.210 s, and the maximum 0.050-s average acceleration was -4.0 Gs between 0.114 and 0.164 s. In the lateral direction, the occupant impact velocity was 12.1 ft/s at 0.165 s, the highest 0.010-s occupant ridedown acceleration was 7.6 Gs from 0.181 to 0.191 s, and the maximum 0.050-s average was -4.7 Gs between 0.165 and 0.215 s. THIV was 21.0 km/h or 5.8 m/s at 0.158 s; PHD was 11.8 Gs between 0.200 and 0.210 s; and ASI was 0.69 between 0.979 and 1.029 s. Figure 5.9 summarizes these data and other pertinent information from the test. Vehicle angular displacements are presented in Appendix D.3, Figure D.3, and accelerations versus time traces are presented in Appendix D.4, Figure D.4 through D.9.

Figure 5.5. Vehicle and Installation Positions after Test No. 6012361-2.

Figure 5.6. Installation after Test No. 6012361-2.

Figure 5.7. Vehicle after Test No. 6012361-2.

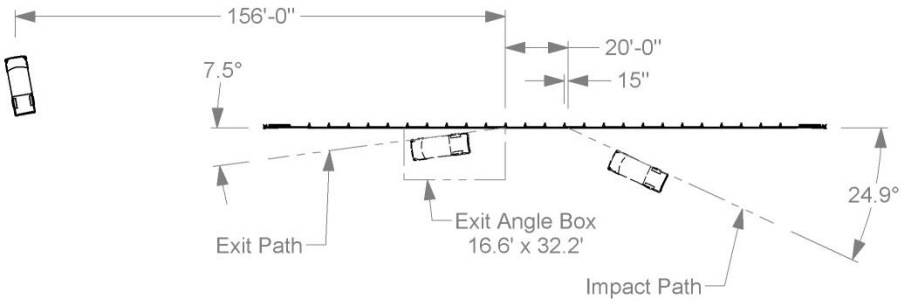
Figure 5.8. Interior of Vehicle after Test No. 6012361-2.

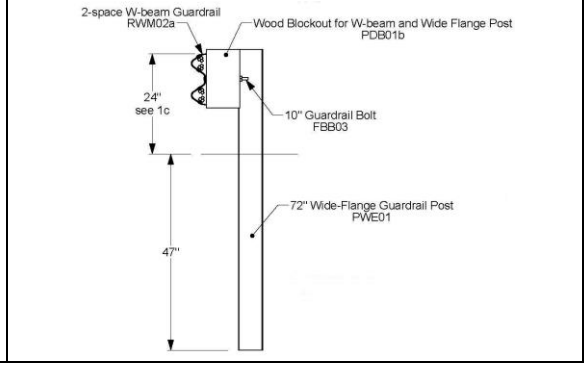
0.000 s

0.224 s

0.448 s

0.672 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 2-11
- TTI Test No. 602361-2
- Date 2014-07-07

Test Article
- Type ..... Guardrail
- Name ..... 24-inch Tall Strong-post W-Beam Guardrail
- Installation Length ..... 175 ft
- Material or Key Elements .... 24-inch tall 12-ga W beam guardrail w/72-inch long W6×8.5 ASTM A36 structural steel shape posts spaced at 6 ft 3 inches w/8×14×6 inch routed wood blocks

Soil Type and Condition..... Standard Soil, Dry

Test Vehicle
- Type/Designation 2270P
- Make and Model..... 2008 Dodge Ram 1500
- Curb ..... 5102 lb
- Test Inertial ..... 5021 lb
- Dummy..... No dummy
- Gross Static..... 5021 lb

Impact Conditions
- Speed.....45.2 mi/h
- Angle.....24.9 degrees
- Location/Orientation .....

Impact Severity.....60.8 kip-ft (+5%)

Exit Conditions
- Speed.....28.7 mi/h
- Angle.....7.5 degrees

Occupant Risk Values
- Impact Velocity
  - Longitudinal.....15.7 ft/s
  - Lateral.....12.1 ft/s
- Ridedown Accelerations
  - Longitudinal.....10.6 G
  - Lateral.....7.5 G
- THIV.....21.0 km/h
- PHD .....11.8 G
- ASI .....0.69 G
- Max. 0.050-s Average
  - Longitudinal.....-4.0 G
  - Lateral.....-4.7 G
  - Vertical.....-6.0 G

Post-Impact Trajectory
- Stopping Distance ..... 176 ft dwnstrm
  22 ft twd field side

Vehicle Stability
- Maximum Yaw Angle..... 33 degrees
- Maximum Pitch Angle..... 10 degrees
- Maximum Roll Angle..... 13 degrees
- Vehicle Snagging..... No
- Vehicle Pocketing..... No

Test Article Deflections
- Dynamic ..... 22.4 inches
- Permanent..... 15.0 inches
- Working Width ..... 29.7 inches

Vehicle Damage
- VDS..... 01RFQ4
- CDC 01RFEW4
- Max. Exterior Deformation ..... 13.0 inches
- OCDI RF0000000
- Max. Occupant Compartment Deformation..... None

Figure 5.9. Summary of Results for *MASH* Test 2-11 on the 24-inch Tall Strong-Post W-Beam Guardrail.

5.9 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the following applicable *MASH* safety evaluation criteria is presented below.

5.9.1 Structural Adequacy

A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*

Results: The 24-inch tall strong-post W-beam guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 22.4 inches. (PASS)

5.9.2 Occupant Risk

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

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

Results: Although three posts separated from the rail element, the posts remained in the ground. These detached elements did not penetrate or show potential for penetrating the occupant compartment, or to present hazard to others. (PASS)

No deformation or intrusion of the occupant compartment occurred. (PASS)

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

Results: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13 degrees and 10 degrees, respectively. (PASS)

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

Longitudinal and Lateral Occupant Impact Velocity

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

Results: Longitudinal occupant impact velocity was 15.7 ft/s, and lateral occupant impact velocity was 12.1 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Maximum longitudinal occupant ridedown acceleration was 10.6 G, and maximum lateral occupant ridedown acceleration was 7.6 G. (PASS)

5.9.3 Vehicle Trajectory

For redirective devices, it is desirable that the vehicle be smoothly redirected and exit the barrier within the "exit box" criteria (not less than 32.8 ft), and should be documented.

Result: The 2270P vehicle exited within the exit box criteria. (PASS)

6 SUMMARY AND CONCLUSIONS

6.1 SUMMARY OF RESULTS

6.1.1 *MASH* Test 2-11 on the 25-inch Tall Strong-Post W-Beam Guardrail

The 25-inch tall strong-post W-beam guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 18.0 inches. The blockout on post 15 split into two pieces at the bolt hole and separated from the post. These fragments did not penetrate or show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No occupant compartment deformation or intrusion occurred. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 14 degrees and 8 degrees, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria.

6.1.2 *MASH* Test 2-11 on the 24-inch Tall Strong-Post W-Beam Guardrail

The 24-inch tall strong-post W-beam guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 22.4 inches. Although the rail element separated from three posts (12, 15, and 16), the posts remained in the ground. The detached element did not penetrate or show potential for penetrating the occupant compartment, or to present hazard to others. No deformation or intrusion of the occupant compartment occurred. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13 degrees and 10 degrees, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria.

6.2 CONCLUSIONS

Table 6.1 shows that the 25-inch tall strong-post W-beam guardrail performed acceptably. Table 6.2 shows that the 24-inch tall strong-post W-beam guardrail also performed acceptably.

6.3 RECOMMENDATIONS[*]

Successful performance of the 25-inch and 24-inch tall strong-post W-beam guardrail under MASH TL-2 conditions shows that lower minimum rail height threshold can be allowed for the low-speed applications. It is recommended to reduce minimum acceptable rail height to 24 inches. While the guardrail is expected to perform acceptably at the 24-inch rail height, it is

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

not recommended to install W-beam guardrail at this height. Doing so will leave no negative tolerance in the rail height; making it problematic for field installations and routine maintenance requiring pavement overlays. The guardrail should be installed at the standard rail height and the allowance in the reduction of the rail height should only be used when evaluating existing guardrail.

While the strong-post guardrail system in the tests described herein used steel posts, the results of these tests can be considered applicable to guardrails with wood posts. These posts have slightly greater post strength compared to steel posts and are considered equivalent in performance. Steel posts have exposed flanges, which can interact with the guardrail during impact to result in a localized tear in the rail, potentially leading to a rail rupture. These flanges are also installed parallel to the rail, which exposes them to various vehicle parts during impact, thus increasing the snagging potential for the vehicle. This is not the case for the wood posts as they have a uniform cross-section without flanges, making them less critical in comparison to the steel posts. Additionally, steel posts tend to twist around their axis, increasing possibility of contacting the rail to cause a tear. This is also not likely in the case of wood posts, which maintain their cross-section and don't have flanges. Thus, generally speaking, a guardrail system that performs acceptably with steel posts is expected to perform equivalently or better with wood posts.

Guardrail installations in the tests reported herein had overlapping rail splices located at the posts. Some newer guardrail systems offset the splices mid-span between posts. This offsetting helps eliminate potential localized stress concentrations in the rail that can arise due to the guardrail's interaction with the post and the blockout. The 24-inch rail height should also be acceptable for the guardrail systems with offset splices. This offsetting is not expected to negatively influence the performance of the rail.

Table 6.1. Performance Evaluation Summary for *MASH* Test 2-11 on the 25-inch TL-2 Strong-Post W-Beam Guardrail.

Test Agency: Texas A&M Transportation Institute Test No.: 602361-1 Test Date: 2014-05-02

***MASH* Test 2-11 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 25-inch TL-2 Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 18.0 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.	The blockout on post 15 split and separated from the post. These fragments did not penetrate or show potential for penetrating the occupant compartment, or to 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 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion occurred.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 14 degrees and 8 degrees, respectively.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.	Longitudinal occupant impact velocity was 14.1 ft/s, and lateral occupant impact velocity was 13.8 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.	Longitudinal ridedown acceleration was 9.1 G, and lateral ridedown acceleration was 6.0 G.	Pass
Vehicle Trajectory		
For redirective devices, it is desirable that the vehicle be smoothly redirected and exit the barrier within the "exit box" criteria (not less than 32.8 ft), and should be documented.	The 2270P vehicle exited within the exit box criteria.	Pass*

* Desirable, but not required.

Table 6.2. Performance Evaluation Summary for *MASH* Test 2-11 on the 24-inch TL-2 Strong-Post W-Beam Guardrail.

Test Agency: Texas A&M Transportation Institute Test No.: 602361-2 Test Date: 2014-07-07

***MASH* Test 2-11 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 24-inch TL-2 Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 22.4 inches.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	Although the rail element separated from three posts (12, 15, and 16), the posts remained in the ground. The detached elements did not penetrate or show potential for penetrating the occupant compartment, or to present hazard to others.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion occurred.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 13 degrees and maximum pitch was 10 degrees.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.	Longitudinal occupant impact velocity was 15.7 ft/s, and lateral occupant impact velocity was 12.1 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.	Maximum longitudinal occupant ridedown acceleration was 10.6 G, and maximum lateral occupant ridedown acceleration was 7.6 G.	Pass
Vehicle Trajectory		
For redirective devices, it is desirable that the vehicle be smoothly redirected and exit the barrier within the "exit box" criteria (not less than 32.8 ft), and should be documented.	The 2270P vehicle exited within the exit box criteria.	Pass*

* Desirable, but not required.

7 REFERENCES

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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. K.A. Polivka, D.L. Sicking, J.R. Rohde, R.K. Faller, and J.C. Holloway, *Crash Testing of Michigan's Type B (W-beam) Guardrail System – Phase II*, Report TRP-03-104-00, Midwest Roadside Safety Facility, Lincoln, Nebraska, 2000.
4. FHWA website URL: http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/ctrmeasures/wbeam/, Retrieved July 30, 2014.
5. R.P. Bligh, A.Y. Abu-Odeh, and W.L. Menges, *MASH Test 3-10 on 31-inch W-Beam Guardrail With Standard Offset Blocks*, Report 9-1002-4, Texas A&M Transportation Institute, College Station, Texas, 2010.
6. A.Y. Abu-Odeh, K. Ha, I. Liu, and W.L. Menges, *MASH TL-3 Testing and Evaluation of the W-beam Guardrail on Slope*, Report 405160-20, Texas A&M Transportation Institute, College Station, Texas, 2012.

APPENDIX A MATERIAL CERTIFICATION DOCUMENTS

A1 MATERIALS FOR TEST NO. 602361-1

MATERIAL USED

TEST NUMBER	602361
TEST NAME	TL-2 W-beam Rail
DATE	2014-05-02

#	DATE RECEIVED	DESCRIPTION	GRADE	YIELD	TENSILE	SUPPLIER
		W-beam		see file		Trinity
	2013-07-08	guardrail parts		see file		Trinity

#33 Po 147201 Pc 200012B

NUCOR STEEL
SHEET MILL GROUP

A Division of Nucor Corp
Hickman, AR 870/762-2100

METALLURGICAL TEST

Date Printed: 2/24/12 Page 1 of 1

Sold To: TRINITY HIGHWAY PRODUCTS, LLC
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ATTN: MAILDROP 7115
DALLAS, TX 75356 6028

Ship To: TRINITY HIGHWAY PRODUCTS, LLC
C/O PACO

ARMOREL, AR 72310

Order/Line	H290779-1	Product	HOT BAND	B/L #	692926	Ship Date	2/24/12
P/O Number	147201 M	Dimensions	.0960 MIN x 57.5000 MIN (INCHES)			Vehicle #	NSA74
Description	A1011-10 SS GR50						

PASSED & CERTIFIED
FEB 27 2012
Trinity Highway Products, LLC
Dallas, Texas Plant 99

With the following modifications:

Customer Part Number 200012B

Heat	221642	Coil ID	746087.0000	746088.0000
Heat	221644	Coil ID	746101.0000	746103.0000

Heat	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Nb	N	Ti	B	Ca	Sb
221642	.21	.79	.008	.001	.03	.16	.05	.05	.01	.006	.03	.003	.000	.009	.001	.000	.002	.001
221644	.20	.76	.007	.002	.03	.13	.04	.04	.01	.005	.04	.002	.000	.008	.001	.000	.002	.001

Coil ID	Dir	Test	Val.	UOM	Test	Val.	UOM	Test	Val.	UOM
746087.0000	L	Long Yield	59.9	KSI	Long Tensile	82.0	KSI	Long Elong	19	%
746088.0000	L	Long Yield	59.9	KSI	Long Tensile	82.0	KSI	Long Elong	19	%
746101.0000	L	Long Yield	58.9	KSI	Long Tensile	81.4	KSI	Long Elong	24	%
746103.0000	L	Long Yield	58.9	KSI	Long Tensile	81.4	KSI	Long Elong	24	%

All goods are sold subject to the description, specifications and terms and conditions set forth on the face and reverse side, or otherwise provided with, Nucor Steel's order acknowledgement.
Tensile specimens are tested in accordance with ASTM A-370 specification: standard rectangular test configuration (Figure 3) with 2 inch gauge length and a 2% offset yield method. Steel is aluminum killed and produced to a fine grain practice.
This material has been produced in compliance with the chemistry and established rolling practices of the ordered specification. If material is ordered to a chemistry only, testing is not performed by producer.
Materials certified to most current revision of ASTM specifications.
We hereby certify the above is correct as contained in the records of the corporation.

100% MELTED AND MANUFACTURED IN THE USA

Chad Gentry

Chad Gentry

METC1100

Rev. 12/18/08 FRM-014-HM

TR No. 602361-1-2

45

2014-12-04

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207
Project: DOWN STREAM ANCHOR TXDOT

Order Number: 1200715 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 47971 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 7/8/13

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
4	907G	12/BUFFER/ROLLED	M-180	A	2	4114810	52,300	69,600	32.0	0.190	0.390	0.008	0.003	0.020	0.020	0.001	0.030	0.004	4
4	3000G	CBL 3/4X6'6/DBL	HW			95825													
8	4140B	WD 4'0.25 POST 5.5X7.5	HW			16259													
8	19481G	C3X5#X6'-8" RUBRAIL	A-36			V918386	53,150	71,910	29.0	0.130	0.700	0.013	0.046	0.220	0.240	0.001	0.060	0.021	4
4	20207G	12/9'4.5/8-HOLE ANCH/S	RHC			L12013													4
			M-180	A		166224	58,340	74,860	32.3	0.190	0.730	0.011	0.004	0.010	0.130	0.000	0.090	0.001	4
			M-180	A		166282	58,270	74,990	26.7	0.190	0.720	0.011	0.002	0.020	0.120	0.000	0.070	0.001	4
			M-180	A		166767	56,550	73,470	27.8	0.190	0.730	0.009	0.004	0.010	0.070	0.000	0.040	0.001	4
			M-180	A		166768	59,620	75,820	26.8	0.200	0.740	0.009	0.004	0.020	0.080	0.001	0.050	0.000	4
						166769													4
			M-180	A		167156	57,160	74,250	30.1	0.190	0.710	0.008	0.004	0.020	0.090	0.000	0.040	0.000	4
			M-180	A		41315760	67,000	87,600	27.0	0.200	0.870	0.007	0.002	0.030	0.080	0.000	0.030	0.001	4
4	36120A	DAT-31-TX-HDW-CAN	A-500			A64076	62,082	63,261	50.0	0.050	0.410	0.014	0.003	0.030	0.110	0.003	0.070	0.001	4
4	105310G	CBL 3/4X6'6/DBL SWG/12"T	HW			96034													

TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

TR No. 602361-1-2

Certified Analysis

Trinity Highway Products, LLC

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Project: DOWN STREAM ANCHOR TXDOT

Order Number: 1200715 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 47971 Ship Date:
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Shipped To: TX
Use State: TX

As of: 7/8/13

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 8th day of July, 2013

Notary Public:
Commission Expires:

JOMARY LUGINSLAND
MY COMMISSION EXPIRES
May 24, 2015

Jomary Luginsland

Trinity Highway Products, LLC
Certified By:
Quality Assurance

46

2014-12-04

TR No. 602361-1-2

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207
Project: SAMPLES FOR TXDOT CRASH TESTING

Order Number: 1200385 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 47972 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 7/8/13

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
8	9G	12/12'6/6'3 /S				F11713													
			M-180		A	B302626	63,900	83,400	26.0	0.200	0.700	0.010	0.005	0.020	0.090	0.001	0.050	0.003	4
			M-180		A	B302628	63,900	83,400	26.0	0.200	0.700	0.010	0.005	0.020	0.090	0.001	0.050	0.003	4
			M-180		A	B302630	60,100	80,300	27.0	0.200	0.730	0.010	0.003	0.030	0.100	0.001	0.050	0.004	4
31	11G	12/12'6/3'1.5/S				F11713													
			M-180		A	B302626	63,900	83,400	26.0	0.200	0.700	0.010	0.005	0.020	0.090	0.001	0.050	0.003	4
			M-180		A	B302628	63,900	83,400	26.0	0.200	0.700	0.010	0.005	0.020	0.090	0.001	0.050	0.003	4
			M-180		A	B302630	60,100	80,300	27.0	0.200	0.730	0.010	0.003	0.030	0.100	0.001	0.050	0.004	4
2	30G	12/12'6/S SRT-1	M-180	A		515667	63,400	72,700	27.0	0.063	0.740	0.012	0.008	0.008	0.019	0.036	0.026	0.000	4
8	32G	12/12'6/6'3/S ET2000 ANC				F12313													
			M-180		A	233242	58,800	80,200	26.0	0.190	0.790	0.011	0.003	0.020	0.140	0.001	0.060	0.002	4
			M-180		A	B303680	60,800	81,300	25.0	0.210	0.720	0.018	0.003	0.030	0.100	0.001	0.060	0.003	4
290	533G	6'0 POST/8.5/DDR	A-36			58013721	62,600	78,300	26.6	0.080	1.020	0.016	0.020	0.230	0.290	0.015	0.160	0.003	4
	533G		A-36			59054825	60,100	76,100	25.1	0.080	0.830	0.009	0.022	0.240	0.330	0.013	0.130	0.002	4
	533G		A-36			59054828	61,400	77,000	26.4	0.090	0.900	0.011	0.014	0.200	0.300	0.012	0.150	0.001	4
2	701A	.25X11.75X16 CAB ANC	A-36			3039454	54,900	78,100	28.0	0.180	0.870	0.027	0.038	0.200	0.350	0.001	0.160	0.012	4
8	704A	CABLE ANCHOR BRKT	A-500			E46000	68,425	78,404	25.0	0.200	0.810	0.013	0.008	0.013	0.030	0.006	0.030	0.001	4
2	907G	12/BUFFER/ROLLED	M-180	A	2	4114810	52,300	69,600	32.0	0.190	0.390	0.008	0.003	0.020	0.020	0.001	0.030	0.004	4
8	3000G	CBL 3/4X6'6/DBL	HW			95825													

47

2014-12-04

TR No. 602361-1-2

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207
Project: SAMPLES FOR TXDOT CRASH TESTING

Order Number: 1200385 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 47972 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 7/8/13

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
1,216	3340G	5/8" GR HEX NUT	HW			130517N													
816	3360G	5/8"X1.25" GR BOLT	HW			130531B													
130	3500G	5/8"X10" GR BOLT A307	A-307			20060370	0	0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
80	3540G	5/8"X14" GR BOLT A307	HW			24228													
16	3900G	1" ROUND WASHER F844	HW			060119													
16	3910G	1" HEX NUT A563	HW			1244010													
20	15000G	6'0 SYT PST/8.5/31" GR HT	A-36			11553	49,000	71,000	25.5	0.120	0.700	0.022	0.024	0.250	0.300	0.002	0.260	0.005	4
8	19258A	HBA-BRG PL/WELDED	A-36			1024916	55,200	76,900	25.0	0.170	0.760	0.018	0.025	0.170	0.320	0.001	0.150	0.032	4

TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

48

2014-12-04

Certified Analysis

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WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 8th day of July, 2013

Notary Public:
Commission Expires:

JOMARY LUGINSLAND
MY COMMISSION EXPIRES
May 24, 2015

Jomary Luginsland

Trinity Highway Products, LLC

Certified By: Luis Ortiz
Quality Assurance

MATERIAL USED

TEST NUMBER 602361-2

TEST NAME TL-2 W-beam Rail

DATE 2014-07-07

#	DATE RECEIVED	DESCRIPTION	GRADE	YIELD	TENSILE	SUPPLIER
		W-beam		see file		Trinity
	2013-07-08	guardrail parts		see file		Trinity

#33 Po 147201 Pc 200012B

NUCOR STEEL
SHEET MILL GROUP

A Division of Nucor Corp
Hickman, AR 870/762-2100

METALLURGICAL TEST

Date Printed: 2/24/12 Page 1 of 1

Sold To: TRINITY HIGHWAY PRODUCTS, LLC
P.O. BOX 566028
ATTN: MAILDROP 7115
DALLAS, TX 75356 6028

Ship To: TRINITY HIGHWAY PRODUCTS, LLC
C/O PACO

ARMOREL, AR 72310

Order/Line	H290779-1	Product	HOT BAND	B/L #	692926	Ship Date	2/24/12
P/O Number	147201 M	Dimensions	.0960 MIN x 57.5000 MIN (INCHES)			Vehicle #	NSA74
Description	A1011-10 SS GR50						

With the following modifications:

Customer Part Number 200012B

PASSED & CERTIFIED
FEB 27 2012
Trinity Highway Products, LLC
Dallas, Texas Plant 99

Heat 221642 Coil ID 746087.0000 746088.0000
Heat 221644 Coil ID 746101.0000 746103.0000

Heat	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Nb	N	Ti	B	Ca	Sb
221642	.21	.79	.008	.001	.03	.16	.05	.05	.01	.006	.03	.003	.000	.009	.001	.000	.002	.001
221644	.20	.76	.007	.002	.03	.13	.04	.04	.01	.005	.04	.002	.000	.008	.001	.000	.002	.001

Coil ID	Dir	Test	Val.	UOM	Test	Val.	UOM	Test	Val.	UOM
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This material has been produced in compliance with the chemistry and established rolling practices of the ordered specification. If material is ordered to a chemistry only, testing is not performed by producer.
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We hereby certify the above is correct as contained in the records of the corporation.

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Chad Gentry

METC1100

Rev. 12/18/08 FRM-014-HM

TR No. 602361-1-2

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
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2525 STEMMONS FRWY

DALLAS, TX 75207
Project: DOWN STREAM ANCHOR TXDOT

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4	3000G	CBL 3/4X6'6/DBL	HW			95825													
8	4140B	WD 4'0.25 POST 5.5X7.5	HW			16259													
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4	20207G	12/9'4.5/8-HOLE ANCH/S	RHC			L12013													4
			M-180	A		166224	58,340	74,860	32.3	0.190	0.730	0.011	0.004	0.010	0.130	0.000	0.090	0.001	4
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4	36120A	DAT-31-TX-HDW-CAN	A-500			A64076	62,082	63,261	50.0	0.050	0.410	0.014	0.003	0.030	0.110	0.003	0.070	0.001	4
4	105310G	CBL 3/4X6'6/DBL SWG/12"T	HW			96034													

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ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

52

2014-12-04

TR No. 602361-1-2

Certified Analysis

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2548 N.E. 28th St.
Ft Worth, TX 76111
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2525 STEMMONS FRWY

DALLAS, TX 75207
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			M-180	A		167156	57,160	74,250	30.1	0.190	0.710	0.008	0.004	0.020	0.090	0.000	0.040	0.000	4
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4	36120A	DAT-31-TX-HDW-CAN	A-500			A64076	62,082	63,261	50.0	0.050	0.410	0.014	0.003	0.030	0.110	0.003	0.070	0.001	4
4	105310G	CBL 3/4X6'6/DBL SWG/12"T	HW			96034													

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DALLAS, TX 75207
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Use State: TX

As of: 7/8/13

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
8	9G	12/12'6/6'3 /S				F11713													
			M-180		A	B302626	63,900	83,400	26.0	0.200	0.700	0.010	0.005	0.020	0.090	0.001	0.050	0.003	4
			M-180		A	B302628	63,900	83,400	26.0	0.200	0.700	0.010	0.005	0.020	0.090	0.001	0.050	0.003	4
			M-180		A	B302630	60,100	80,300	27.0	0.200	0.730	0.010	0.003	0.030	0.100	0.001	0.050	0.004	4
31	11G	12/12'6/3'1.5/S				F11713													
			M-180		A	B302626	63,900	83,400	26.0	0.200	0.700	0.010	0.005	0.020	0.090	0.001	0.050	0.003	4
			M-180		A	B302628	63,900	83,400	26.0	0.200	0.700	0.010	0.005	0.020	0.090	0.001	0.050	0.003	4
			M-180		A	B302630	60,100	80,300	27.0	0.200	0.730	0.010	0.003	0.030	0.100	0.001	0.050	0.004	4
2	30G	12/12'6/S SRT-1	M-180	A		515667	63,400	72,700	27.0	0.063	0.740	0.012	0.008	0.008	0.019	0.036	0.026	0.000	4
8	32G	12/12'6/6'3/S ET2000 ANC				F12313													
			M-180		A	233242	58,800	80,200	26.0	0.190	0.790	0.011	0.003	0.020	0.140	0.001	0.060	0.002	4
			M-180		A	B303680	60,800	81,300	25.0	0.210	0.720	0.018	0.003	0.030	0.100	0.001	0.060	0.003	4
290	533G	6'0 POST/8.5/DDR	A-36			58013721	62,600	78,300	26.6	0.080	1.020	0.016	0.020	0.230	0.290	0.015	0.160	0.003	4
	533G		A-36			59054825	60,100	76,100	25.1	0.080	0.830	0.009	0.022	0.240	0.330	0.013	0.130	0.002	4
	533G		A-36			59054828	61,400	77,000	26.4	0.090	0.900	0.011	0.014	0.200	0.300	0.012	0.150	0.001	4
2	701A	.25X11.75X16 CAB ANC	A-36			3039454	54,900	78,100	28.0	0.180	0.870	0.027	0.038	0.200	0.350	0.001	0.160	0.012	4
8	704A	CABLE ANCHOR BRKT	A-500			E46000	68,425	78,404	25.0	0.200	0.810	0.013	0.008	0.013	0.030	0.006	0.030	0.001	4
2	907G	12/BUFFER/ROLLED	M-180	A	2	4114810	52,300	69,600	32.0	0.190	0.390	0.008	0.003	0.020	0.020	0.001	0.030	0.004	4
8	3000G	CBL 3/4X6'6/DBL	HW			95825													

54

2014-12-04

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207
Project: SAMPLES FOR TXDOT CRASH TESTING

Order Number: 1200385 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 47972 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 7/8/13

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
1,216	3340G	5/8" GR HEX NUT	HW			130517N													
816	3360G	5/8"X1.25" GR BOLT	HW			130531B													
130	3500G	5/8"X10" GR BOLT A307	A-307			20060370	0	0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4
80	3540G	5/8"X14" GR BOLT A307	HW			24228													
16	3900G	1" ROUND WASHER F844	HW			060119													
16	3910G	1" HEX NUT A563	HW			1244010													
20	15000G	6'0 SYT PST/8.5/31" GR HT	A-36			11553	49,000	71,000	25.5	0.120	0.700	0.022	0.024	0.250	0.300	0.002	0.260	0.005	4
8	19258A	HBA-BRG PL/WELDED	A-36			1024916	55,200	76,900	25.0	0.170	0.760	0.018	0.025	0.170	0.320	0.001	0.150	0.032	4

TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

Certified Analysis

Trinity Highway Products, LLC

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207
Project: SAMPLES FOR TXDOT CRASH TESTING

Order Number: 1200385 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 47972 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 7/8/13

BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 8th day of July, 2013

Notary Public:
Commission Expires:

JOMARY LUGINSLAND
MY COMMISSION EXPIRES
May 24, 2015

Jomary Luginsland

Trinity Highway Products, LLC
Certified By:
Quality Assurance

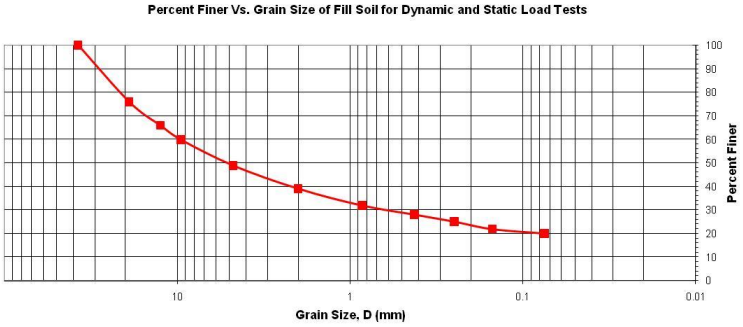
Table B.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.

Dynamic Setup

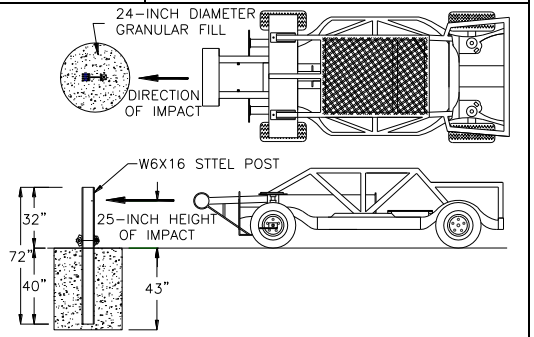
Post-Test Photo of post

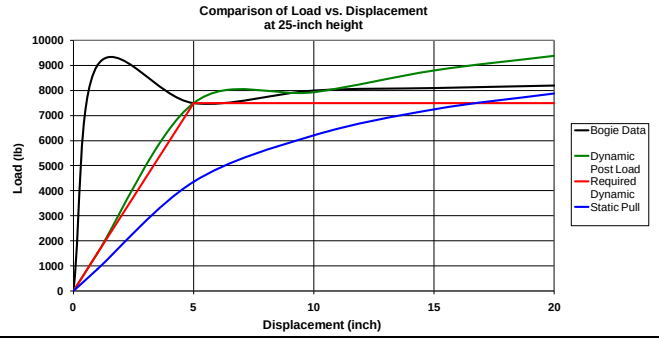
Post-Test Photo

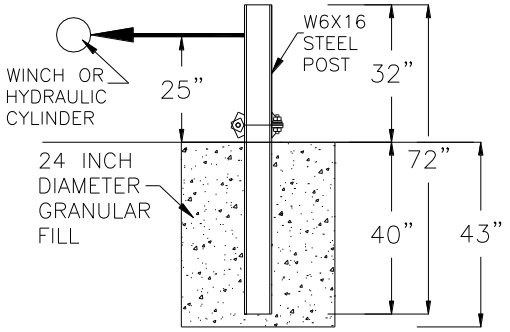
Static Load Test



Dynamic Test Installation Details



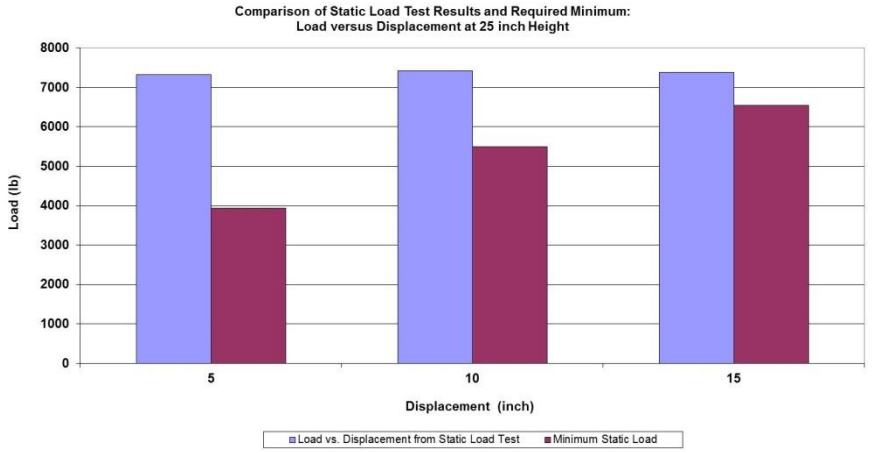




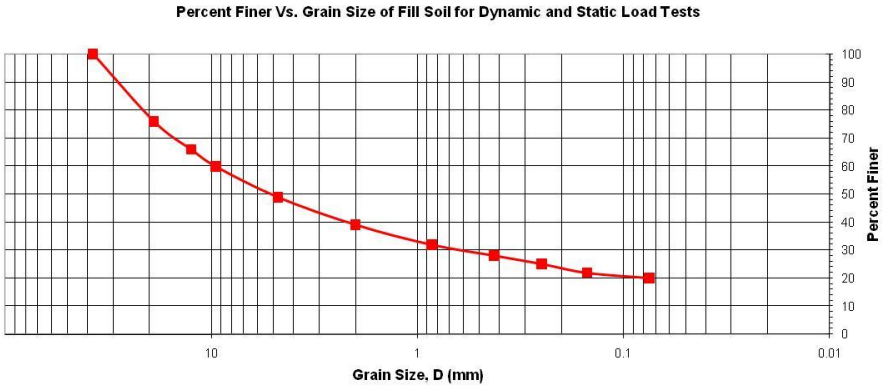
Static Load Test Installation Details

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)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor
Bogie Weight	5009 lb
Impact Velocity	20.5 mph

Table B.2. Test Day Static Soil Strength Documentation for Test No. 602631-1.



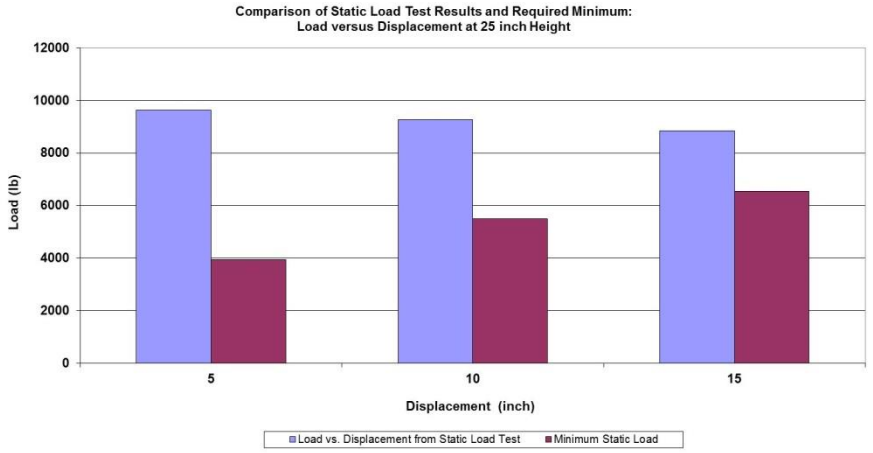
Static Load Setup



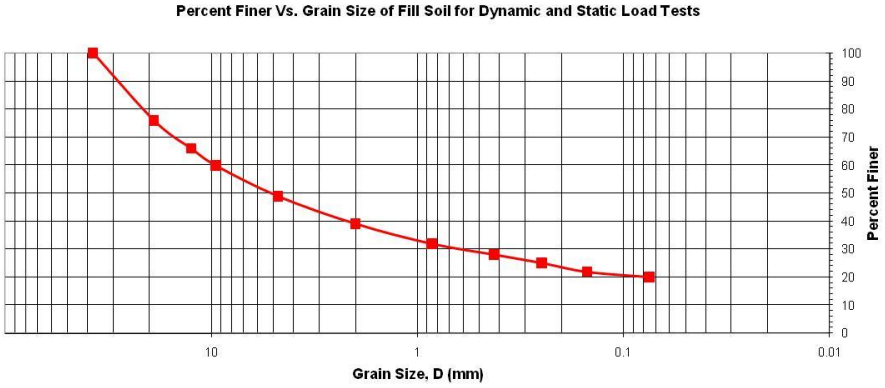
Post-Test Photo of Post

Date	2014-05-02
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 B.3. Test Day Static Soil Strength Documentation for Test No. 602631-2.



Static Load Setup



Post-Test Photo of Post

Date	2014-07-10
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

APPENDIX C CRASH TEST NO. 602361-1

C1 VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 602361-1.

Date: 2014-05-02 Test No.: 602361-1 VIN No.: 1D7HA18N58J176527

Year: 2008 Make: Dodge Model: Ram 1500

Tire Size: P265/70R17 Tire Inflation Pressure: 35 PSI

Tread Type: Highway Odometer: 201909

Note any damage to the vehicle prior to test: NONE

● Denotes accelerometer location.

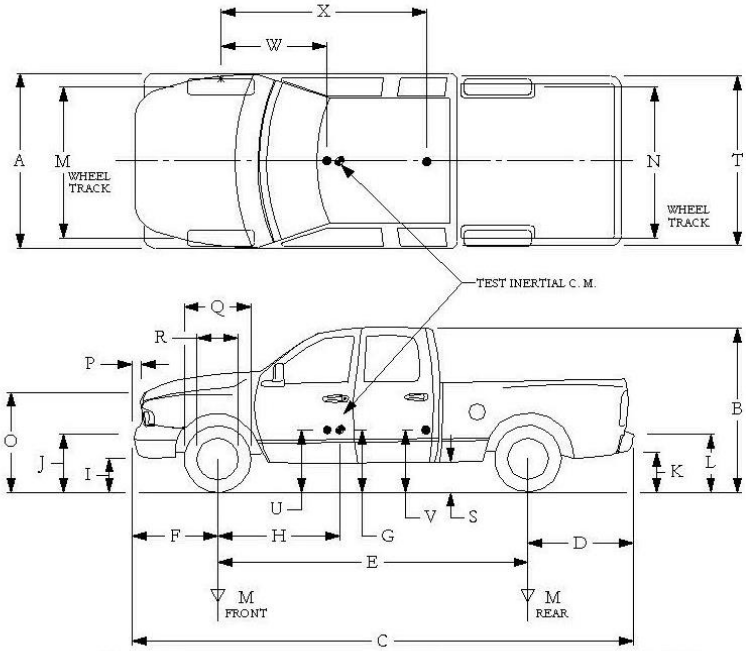
NOTES: NONE

Engine Type: V-8
Engine CID: 4.7 L

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

Optional Equipment:
NONE

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



Geometry: inches

A	78.250	F	36.000	K	20.000	P	2.875	U	28.500
B	75.000	G	28.250	L	28.50	Q	30.500	V	31.000
C	224.000	H	62.361	M	68.50	R	16.000	W	62.300
D	47.500	I	15.750	N	68.000	S	15.000	X	78.50
E	140.500	J	28.000	O	46.500	T	77.500		

Wheel Center Height Front	14.750	Wheel Well Clearance (Front)	6.000	Bottom Frame Height - Front	18.750
Wheel Center Height Rear	14.750	Wheel Well Clearance (Rear)	11.000	Bottom Frame Height - Rear	24.500

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: lb		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2856	2808	
Back	3900	M_{rear}	2069	2241	
Total	6700	M_{Total}	4925	5049	0

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

Mass Distribution:
lb LF: 1421 RF: 1387 LR: 1122 RR: 1119

Table C.2. Measurements of Vehicle Vertical CG for Test No. 602361-1.

Date: 2014-05-02 Test No.: 602361-1 VIN: 1D7HA18N58J176527

Year: 2008 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 201909

Engine: 4.7 liter V8 Transmission: Automatic

Fuel Level: Empty Ballast: 176 lb (440 lb max)

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

Measured Vehicle Weights: (lb)

LF: 1421	RF: 1387	Front Axle: 2808
LR: 1122	RR: 1119	Rear Axle: 2241
Left: 2543	Right: 2506	Total: 5049

5000 ±110 lb allowed

Wheel Base: 140.5 inches (148 ±12 inches allowed)

Track: F: 68.5 inches R: 68 inches (Track = (F+R)/2 = 67 ±1.5 inches allowed)

Center of Gravity, SAE J874 Suspension Method

X: 62.36 in Rear of Front Axle (63 ±4 inches allowed)

Y: -0.25 in Left - Right + of Vehicle Centerline

Z: 28.25 in Above Ground (minumum 28.0 inches allowed)

Hood Height: 46.5 inches (43 ±4 inches allowed)

Front Bumper Height: 28.0 inches

Front Overhang: 36.0 inches (39 ±3 inches allowed)

Rear Bumper Height: 28.5 inches

Overall Length: 223.75 inches (237 ±13 inches allowed)

Table C.3. Exterior Crush Measurements for Test No. 602361-1.

Date: 2014-05-02 Test No.: 602361-1 VIN: 1D7HA18N58J176527

Year: 2008 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		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	8	22	0	1.5	3	4	6	8	+15
2	Side plane at bumper th	16	10	44	1.5	---	---	---	10	10	+72
	Measurements recorded										
	in inches 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).

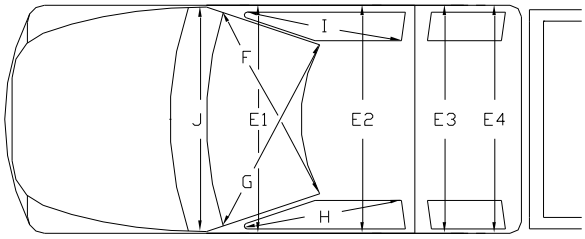
***Measure and document on the vehicle diagram the location of the maximum crush.

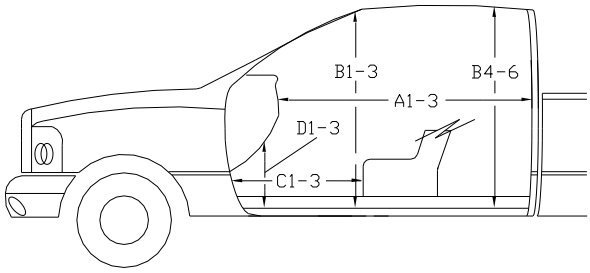
Note: Use as many lines/columns as necessary to describe each damage profile.

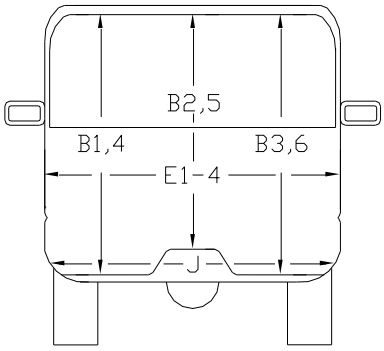
Table C.4. Occupant Compartment Measurements for Test No. 602361-1.

Date: 2014-05-02 Test No.: 602361-1 VIN: 1D7HA18N58J176527

Year: 2008 Make: Dodge Model: Ram 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	65.00	65.00
A2	64.75	64.75
A3	65.25	65.25
B1	45.25	45.25
B2	39.50	39.50
B3	45.25	45.25
B4	42.25	42.25
B5	44.75	44.75
B6	42.25	42.25
C1	27.25	27.25
C2	-----	-----
C3	27.25	27.25
D1	12.75	12.75
D2	-----	-----
D3	11.50	11.50
E1	62.75	62.75
E2	64.75	64.75
E3	64.00	64.00
E4	64.25	64.25
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.25	62.25

C2 SEQUENTIAL PHOTOGRAPHS

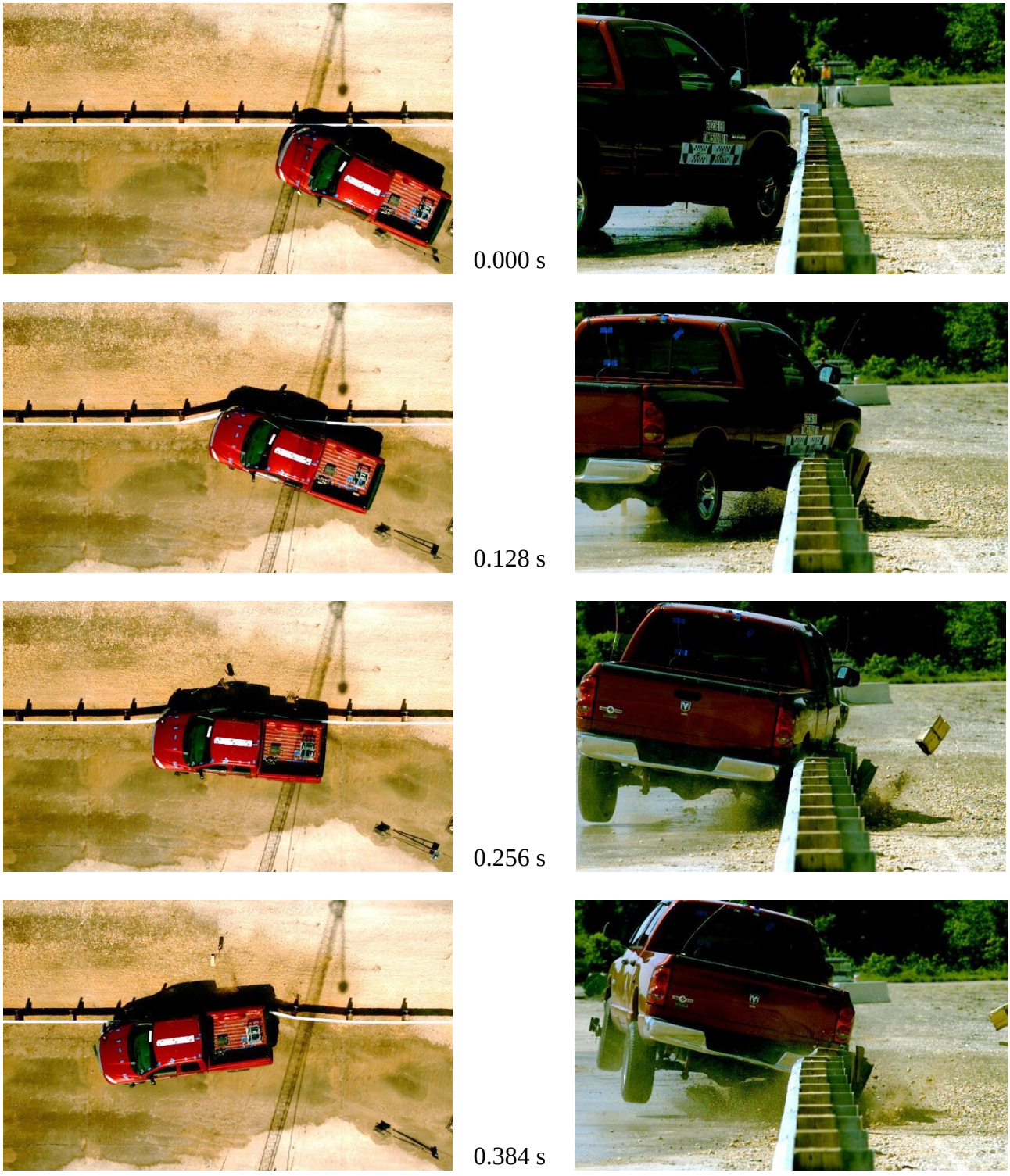
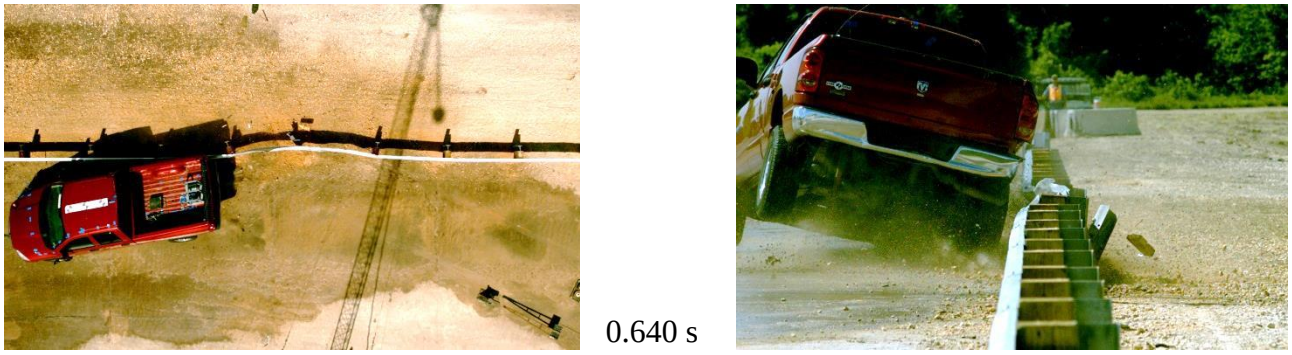


Figure C.1. Sequential Photographs for Test No. 602361-1 (Overhead and Rear Views).

0.512 s



0.640 s

0.768 s

0.896 s

Figure C.1. Sequential Photographs for Test No. 602361-1 (Overhead and Rear Views) (Continued).

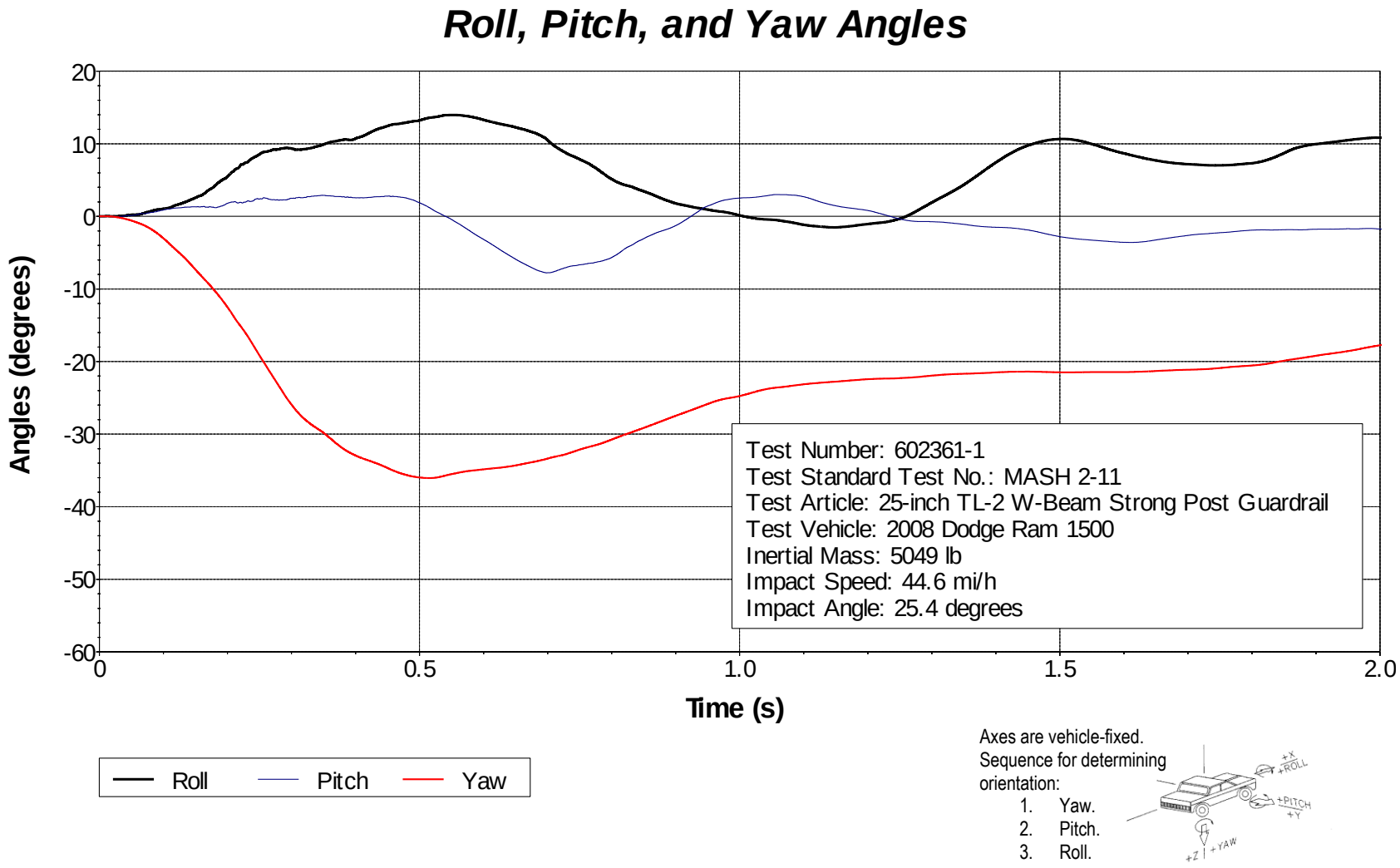


Figure C.2. Vehicle Angular Displacements for Test No. 602361-1.

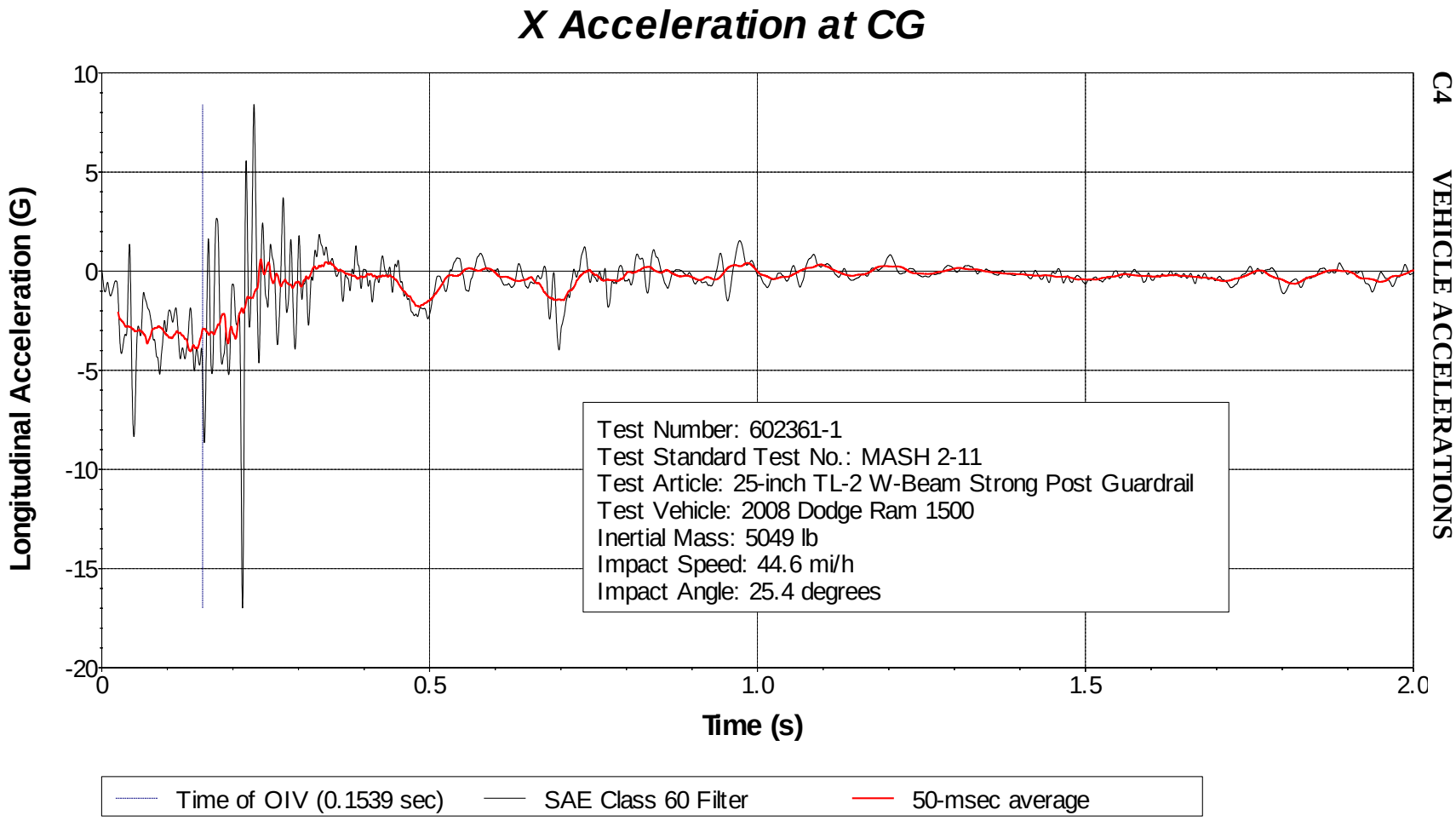


Figure C.3. Vehicle Longitudinal Accelerometer Trace for Test No. 602361-1 (Accelerometer Located at Center of Gravity).

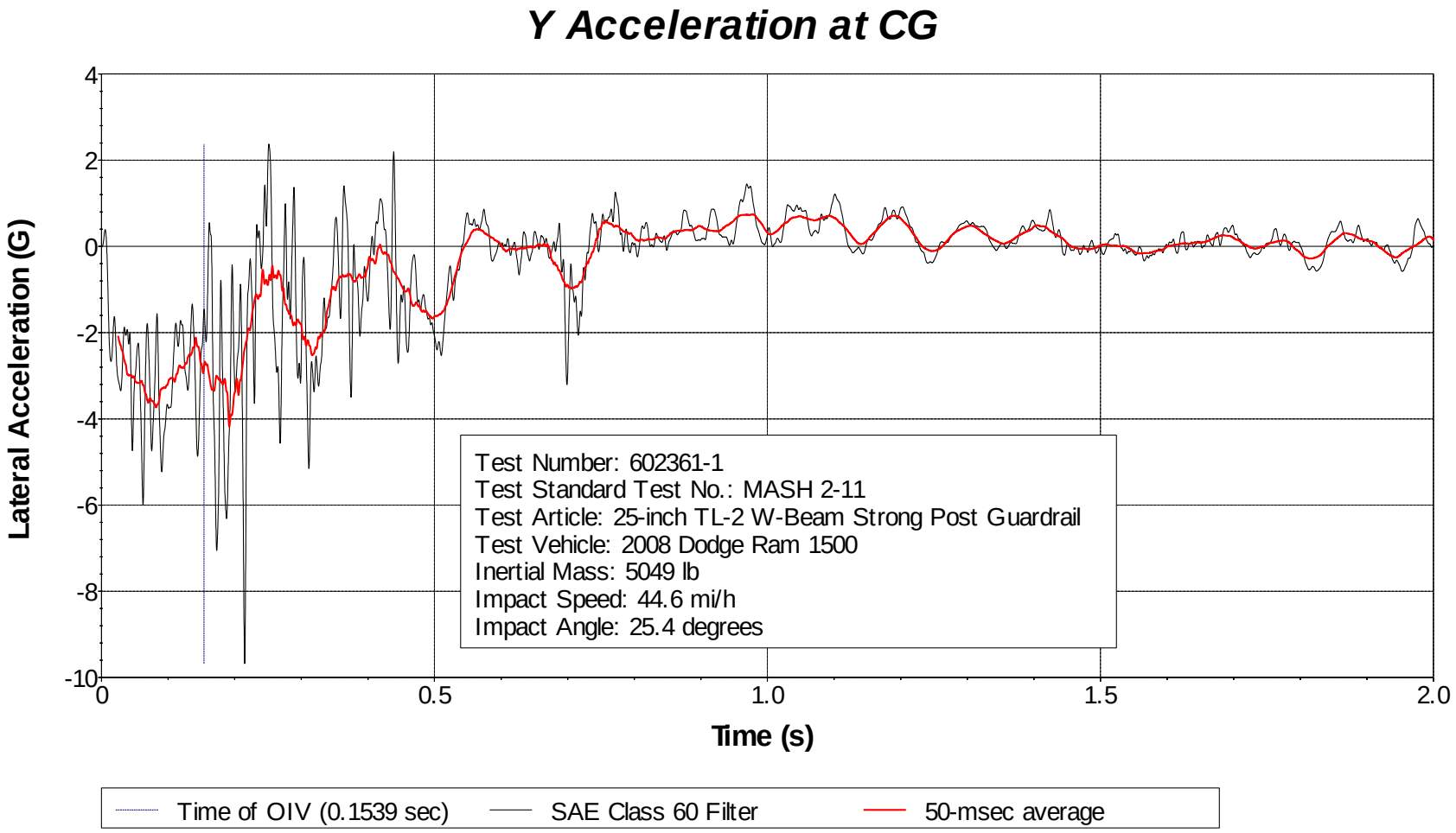


Figure C.4. Vehicle Lateral Accelerometer Trace for Test No. 602361-1 (Accelerometer Located at Center of Gravity).

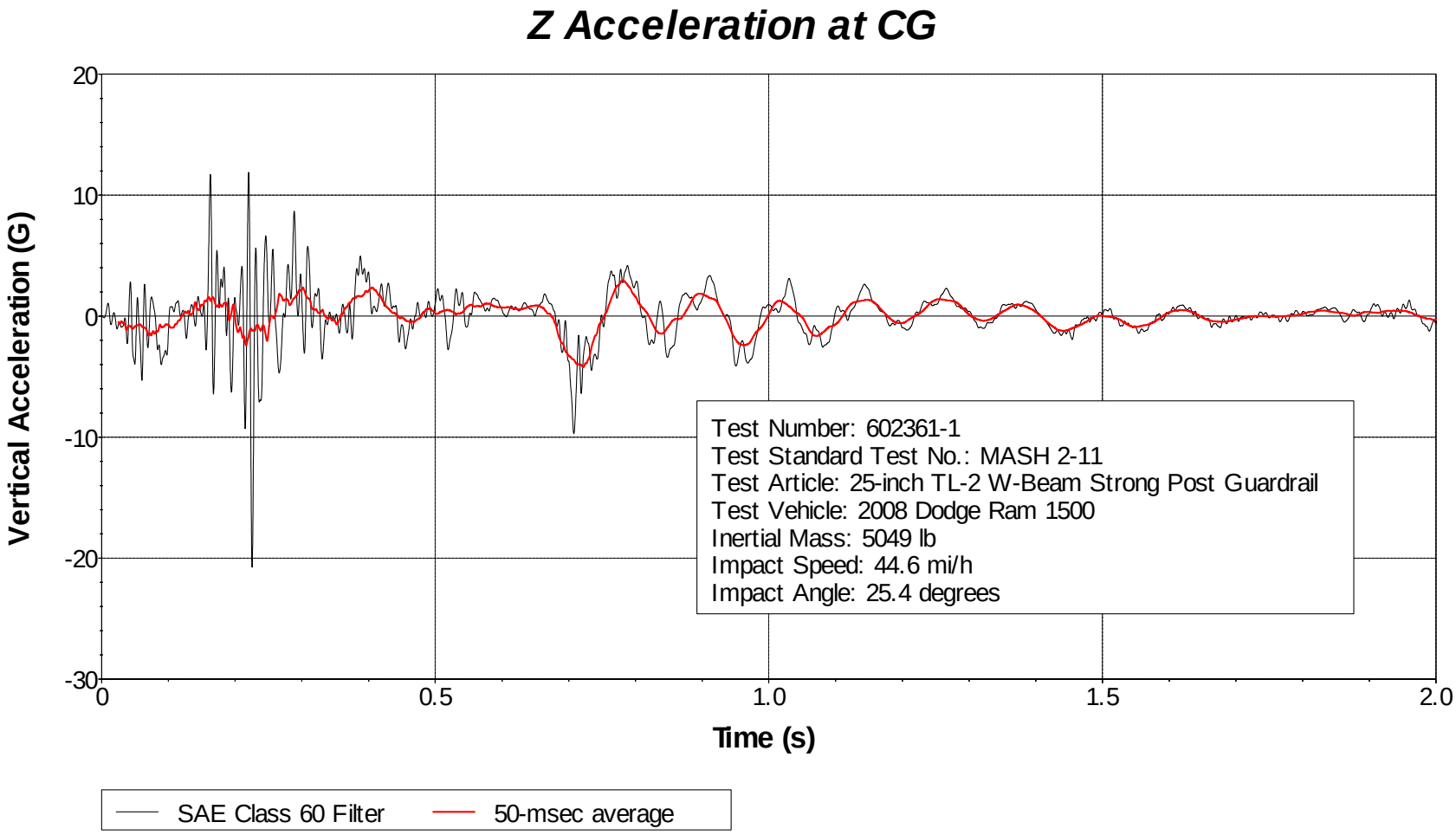


Figure C.5. Vehicle Vertical Accelerometer Trace for Test No. 602361-1 (Accelerometer Located at Center of Gravity).

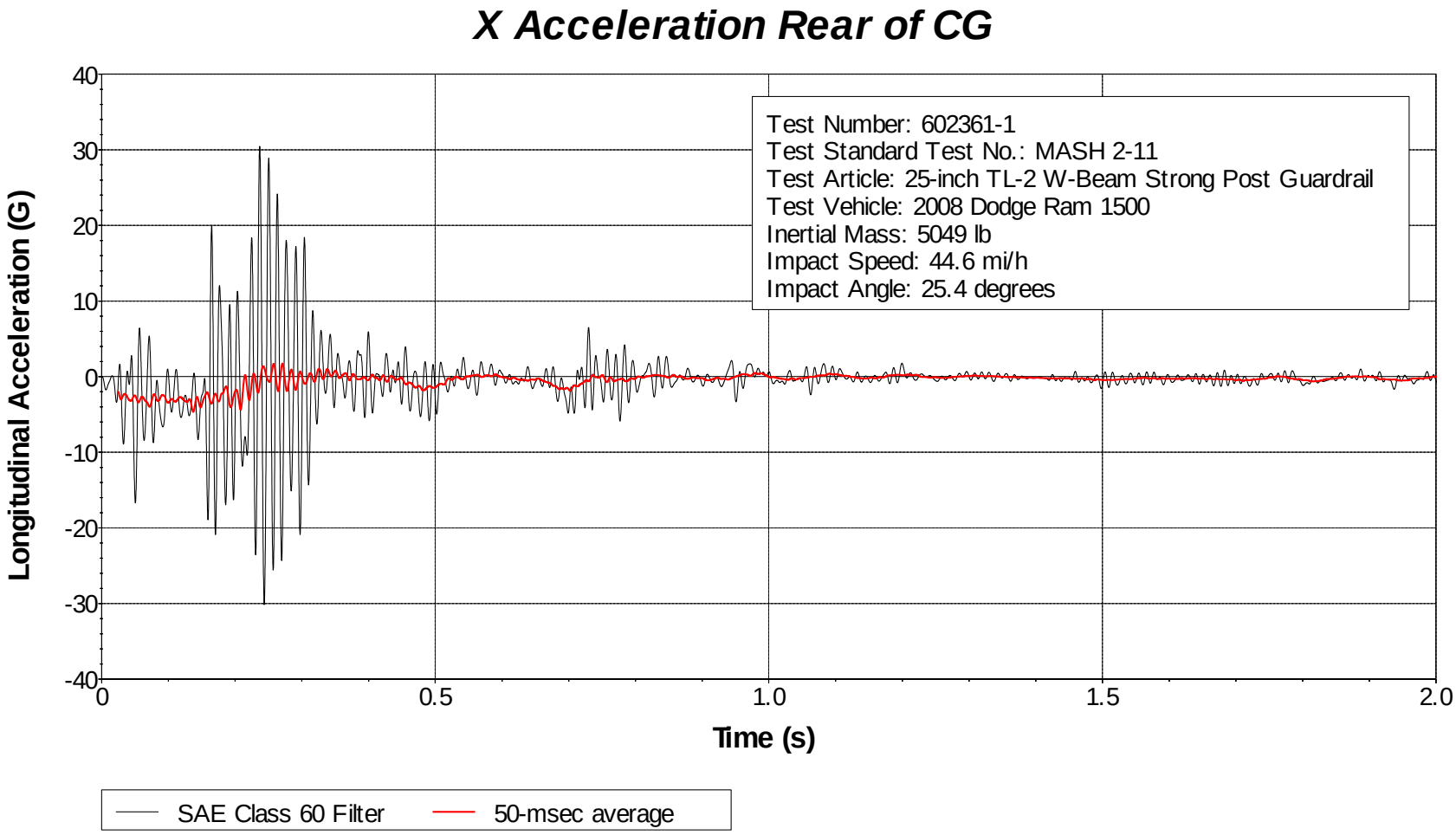


Figure C.6. Vehicle Longitudinal Accelerometer Trace for Test No. 602361-1 (Accelerometer Located Rear of Center of Gravity).

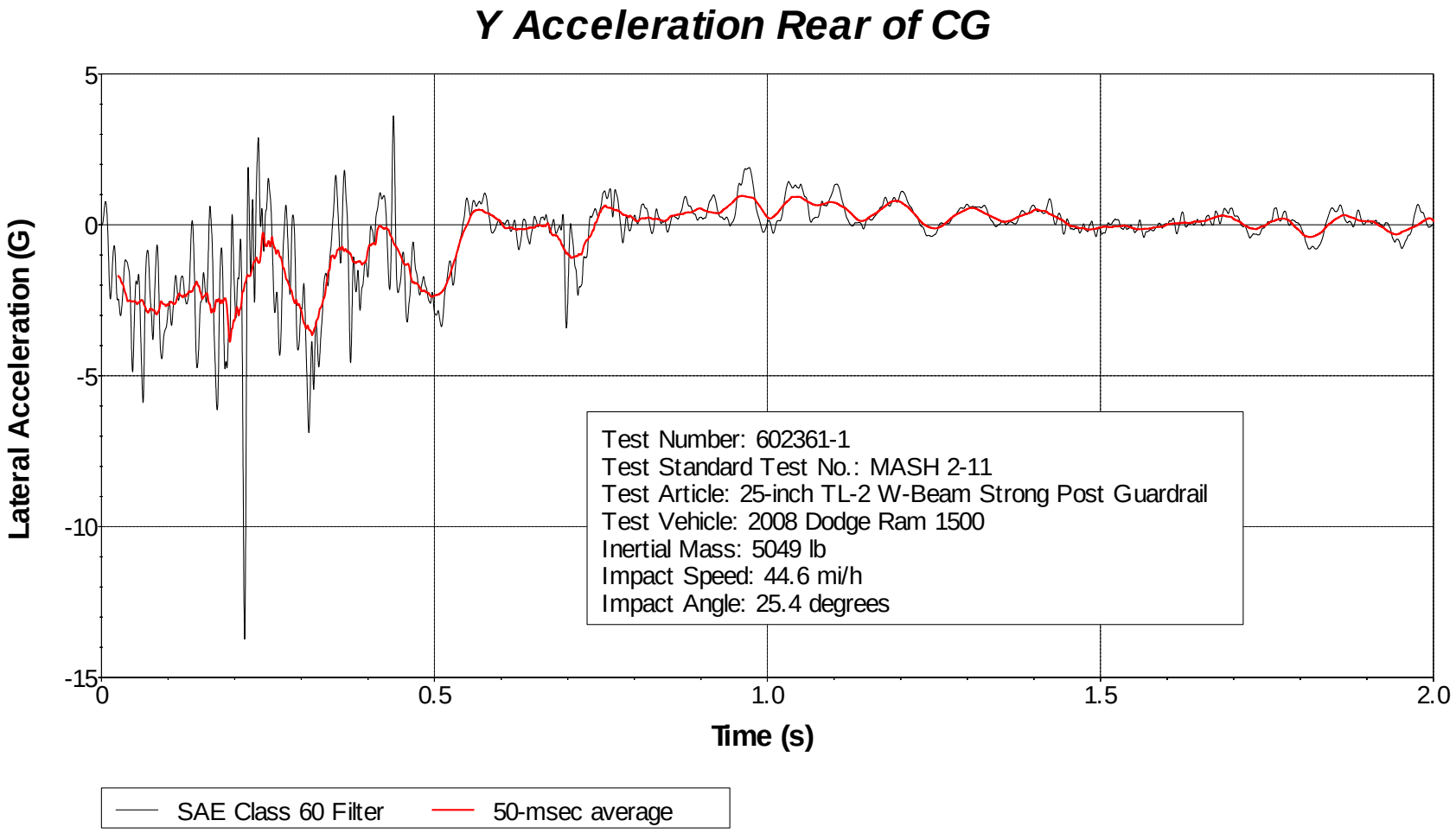


Figure C.7. Vehicle Lateral Accelerometer Trace for Test No. 602361-1 (Accelerometer Located Rear of Center of Gravity).

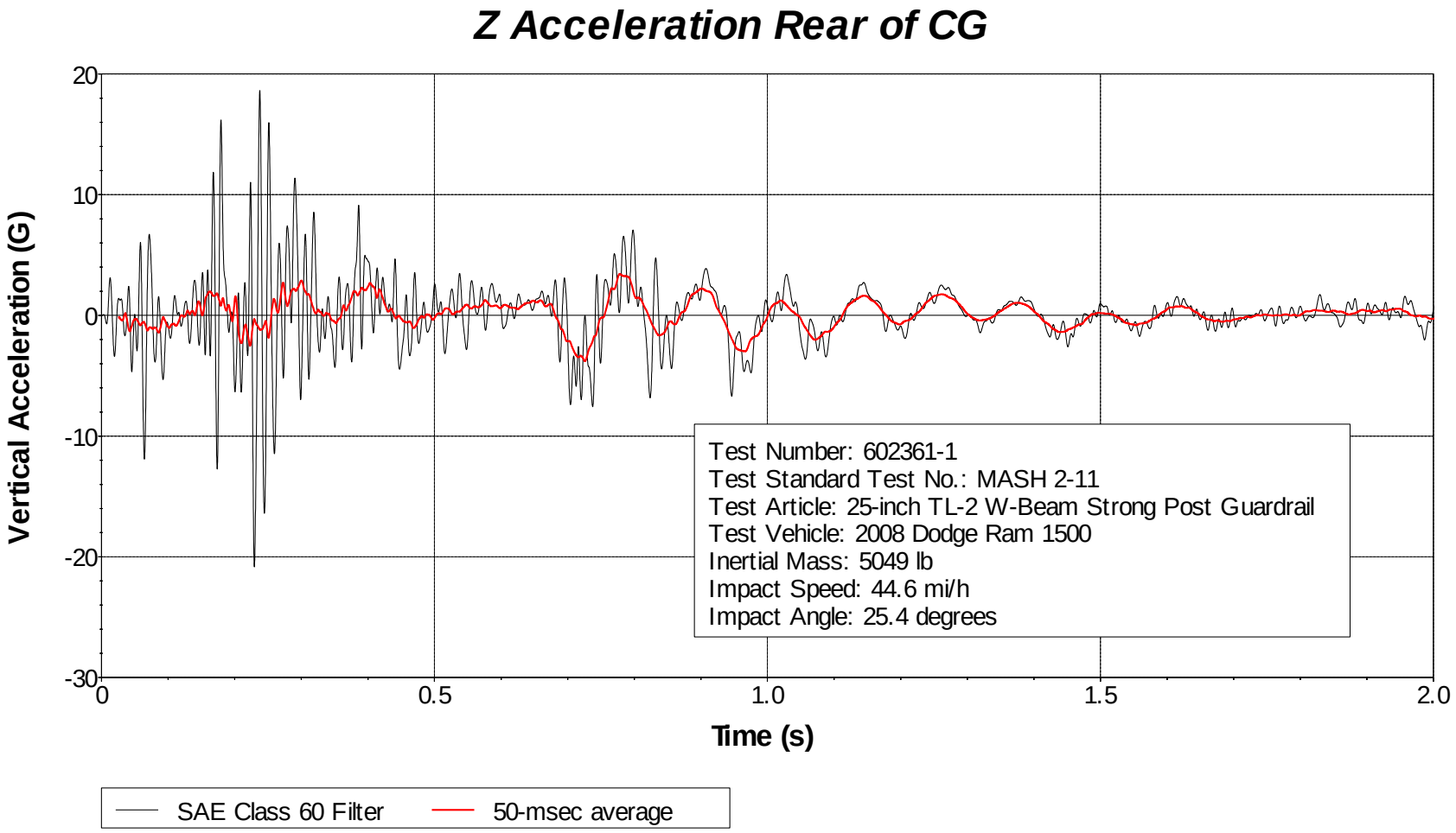


Figure C.8. Vehicle Vertical Accelerometer Trace for Test No. 602361-1 (Accelerometer Located Rear of Center of Gravity).

APPENDIX D CRASH TEST NO. 602361-2

D1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 602361-2.

Date: 2014-07-07 Test No.: 602361-2 VIN No.: 1D7HA18N88S53368

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab

Tire Size: P265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 243292

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

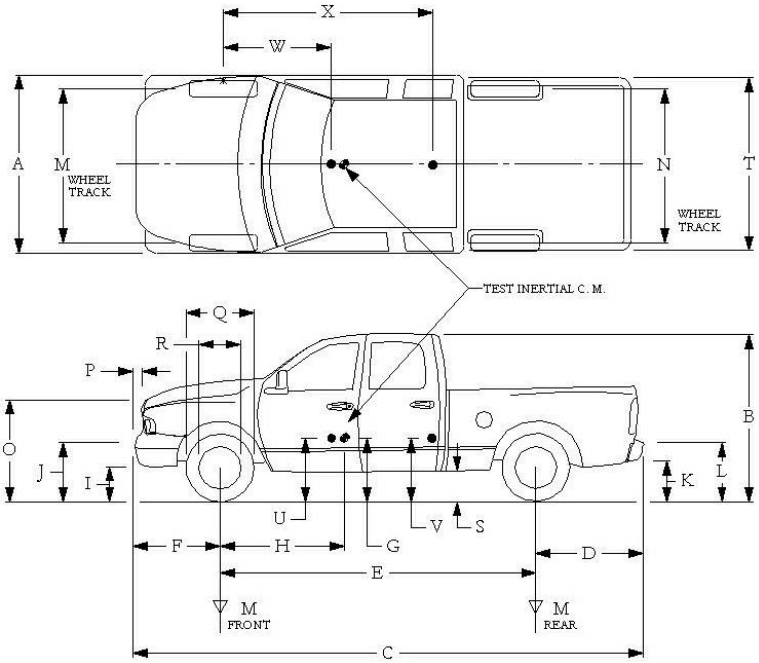
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment:

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



Geometry: inches

A	78.25	F	36.00	K	21.00	P	2.88	U	28.50
B	75.25	G	28.00	L	29.50	Q	30.50	V	30.50
C	223.75	H	60.53	M	68.50	R	16.00	W	60.50
D	47.25	I	15.75	N	68.00	S	16.00	X	77.0
E	140.50	J	27.50	O	46.25	T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	11.00	Bottom Frame Height - Rear	

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2954	2858	----
Back	3900	M_{rear}	2148	2163	----
Total	6700	M_{Total}	5102	5021	----

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

Mass Distribution:
lb LF: 1458 RF: 1400 LR: 1042 RR: 1121

Table D.2. Measurements of Vehicle Vertical CG for Test No. 602361-2.

Date: 2014-07-07 Test No.: 602361-2 VIN: 1D7HA18N88S53368

Year: 2008 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 243292

Engine: V-8 4.7 liter Transmission: Automatic

Fuel Level: Empty Ballast: 40 lb (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: P265/70R17

Measured Vehicle Weights: (lb)								
LF:	1458	RF:	1400	Front Axle:	2858			
LR:	1042	RR:	1121	Rear Axle:	2163			
Left:	2500	Right:	2521	Total:	5021			
				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:	60.53 in	Rear of Front Axle		(63 ±4 inches allowed)				
Y:	0.14 in	Left -	Right +	of Vehicle Centerline				
Z:	28 in	Above Ground		(minumum 28.0 inches allowed)				

Hood Height: 46.25 inches
43 ±4 inches allowed

Front Bumper Height: 27.50 inches

Front Overhang: 36.00 inches
39 ±3 inches allowed

Rear Bumper Height: 29.50 inches

Overall Length: 223.75 inches
237 ±13 inches allowed

Table D.3. Exterior Crush Measurements for Test No. 602361-2.

Date: 2014-07-07 Test No.: 602361-2 VIN No.: 1D7HA18N88S53368

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab

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	16.0	8.0	20.0	1	3	8	---	---	---	+23.5
2	Side plane at bumper ht	16.0	13.0	48.0	1.5	---	---	---	10	13	+72
	Measurements recorded										
	in inches										

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

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

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

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

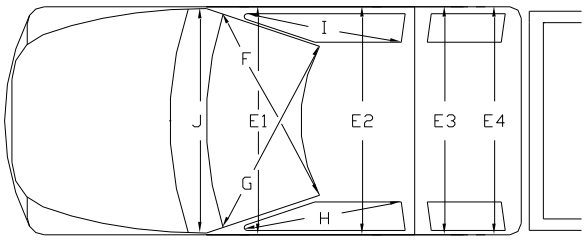
***Measure and document on the vehicle diagram the location of the maximum crush.

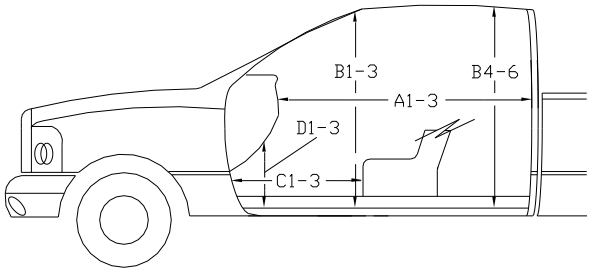
Note: Use as many lines/columns as necessary to describe each damage profile.

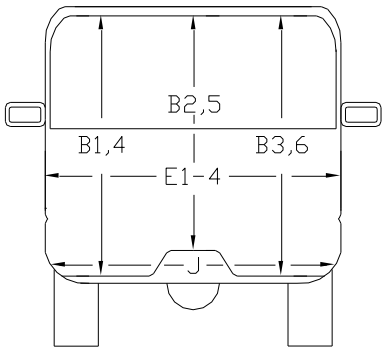
Table D.4. Occupant Compartment Measurements for Test No. 602361-2.

Date: 2014-07-07 Test No.: 602361-2 VIN No.: 1D7HA18N88S53368

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT	Before (inches)	After (inches)
A1	64.75	64.75
A2	65.00	65.00
A3	65.00	65.00
B1	45.00	45.00
B2	39.50	39.50
B3	45.00	45.00
B4	41.75	41.75
B5	44.75	44.75
B6	41.75	41.75
C1	28.75	28.75
C2	----	----
C3	26.50	26.50
D1	12.75	12.75
D2	----	----
D3	11.50	11.50
E1	62.75	62.75
E2	64.50	64.50
E3	64.00	64.00
E4	64.25	64.25
F	60.00	60.00
G	60.00	60.00
H	39.50	39.50
I	39.50	39.50
J*	62.25	62.25

D2 SEQUENTIAL PHOTOGRAPHS

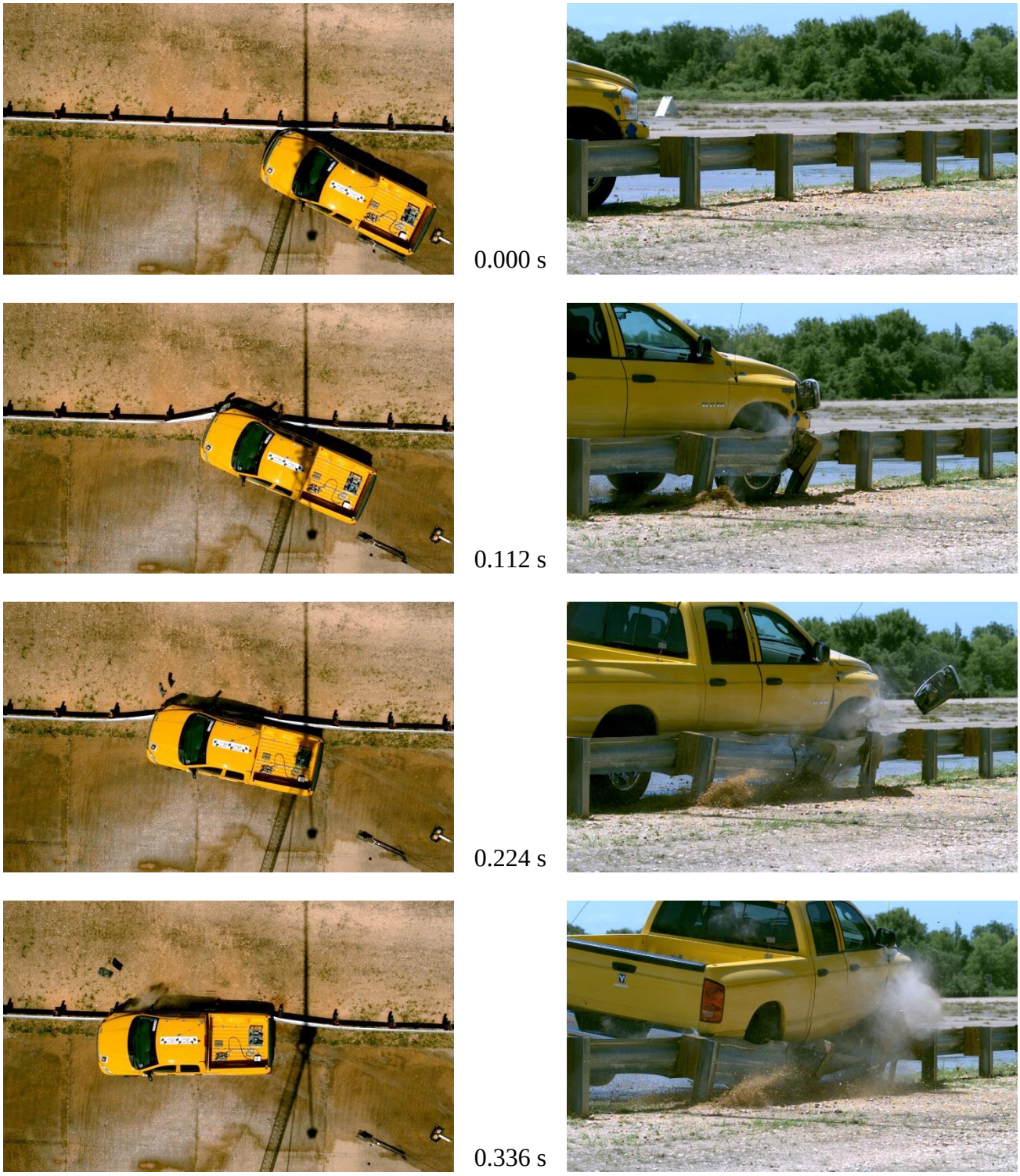


Figure D.1. Sequential Photographs for Test No. 602361-2 (Overhead and Rear Views).



0.448 s



0.560 s



0.672 s



0.784 s

Figure D.1. Sequential Photographs for Test No. 602361-2 (Overhead and Rear Views) (Continued).


0.000 s


0.368 s


0.092 s


0.460 s


0.184 s


0.552 s


0.276 s


0.644 s

Figure D.2. Sequential Photographs for Test No. 602361-2 (Rear View).

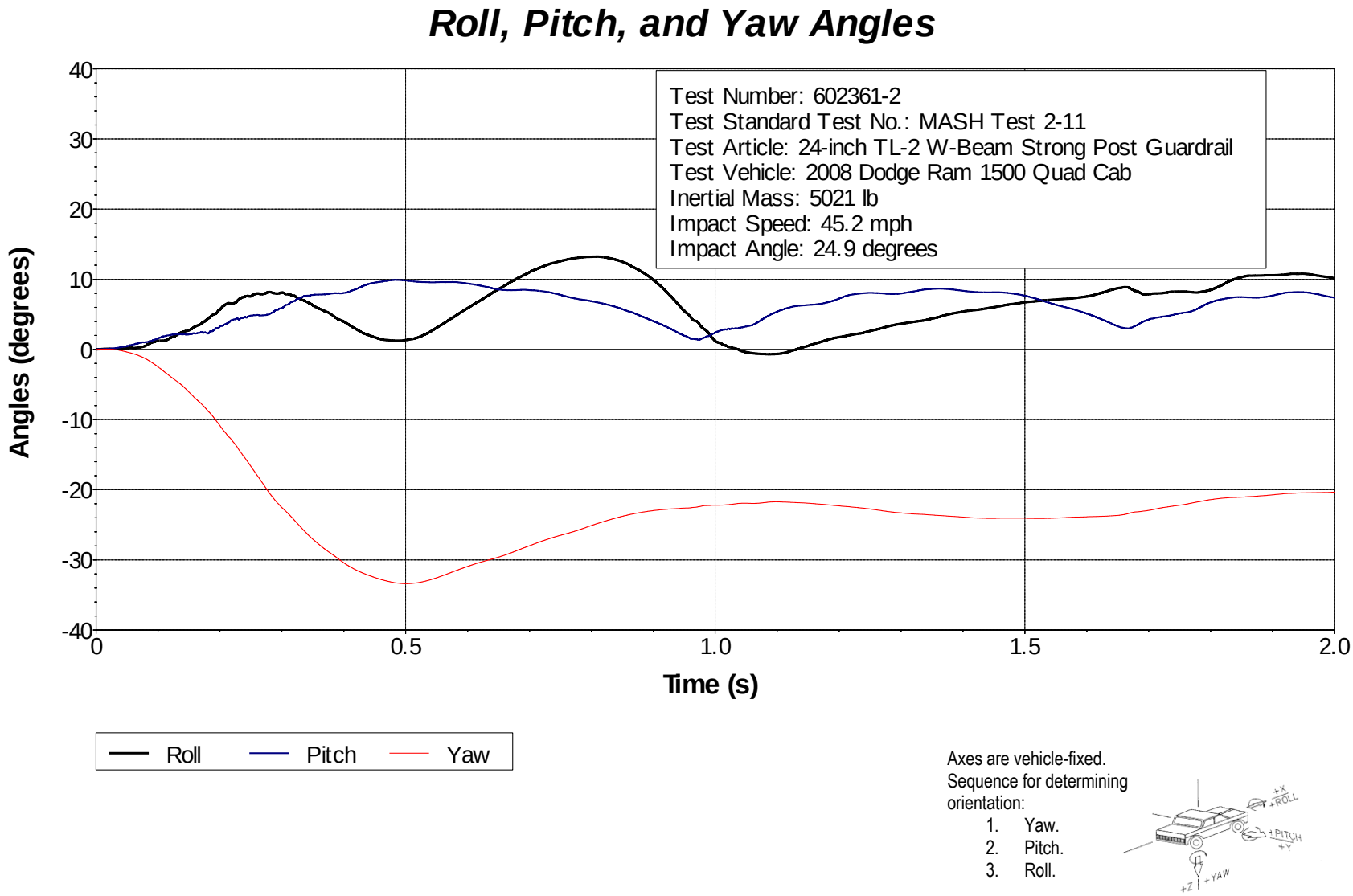


Figure D.3. Vehicle Angular Displacements for Test No. 602361-2.

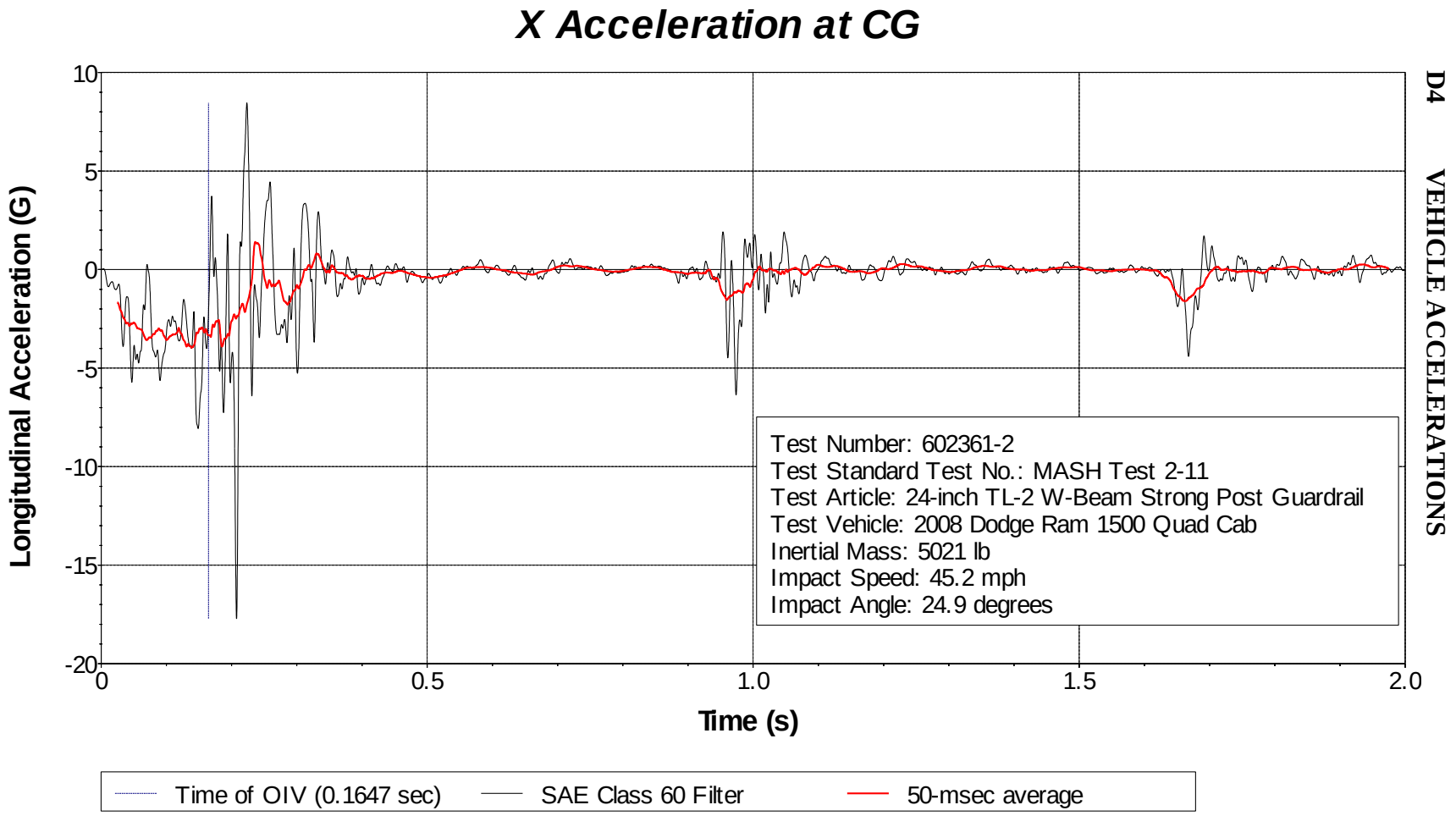


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 602361-2 (Accelerometer Located at Center of Gravity).

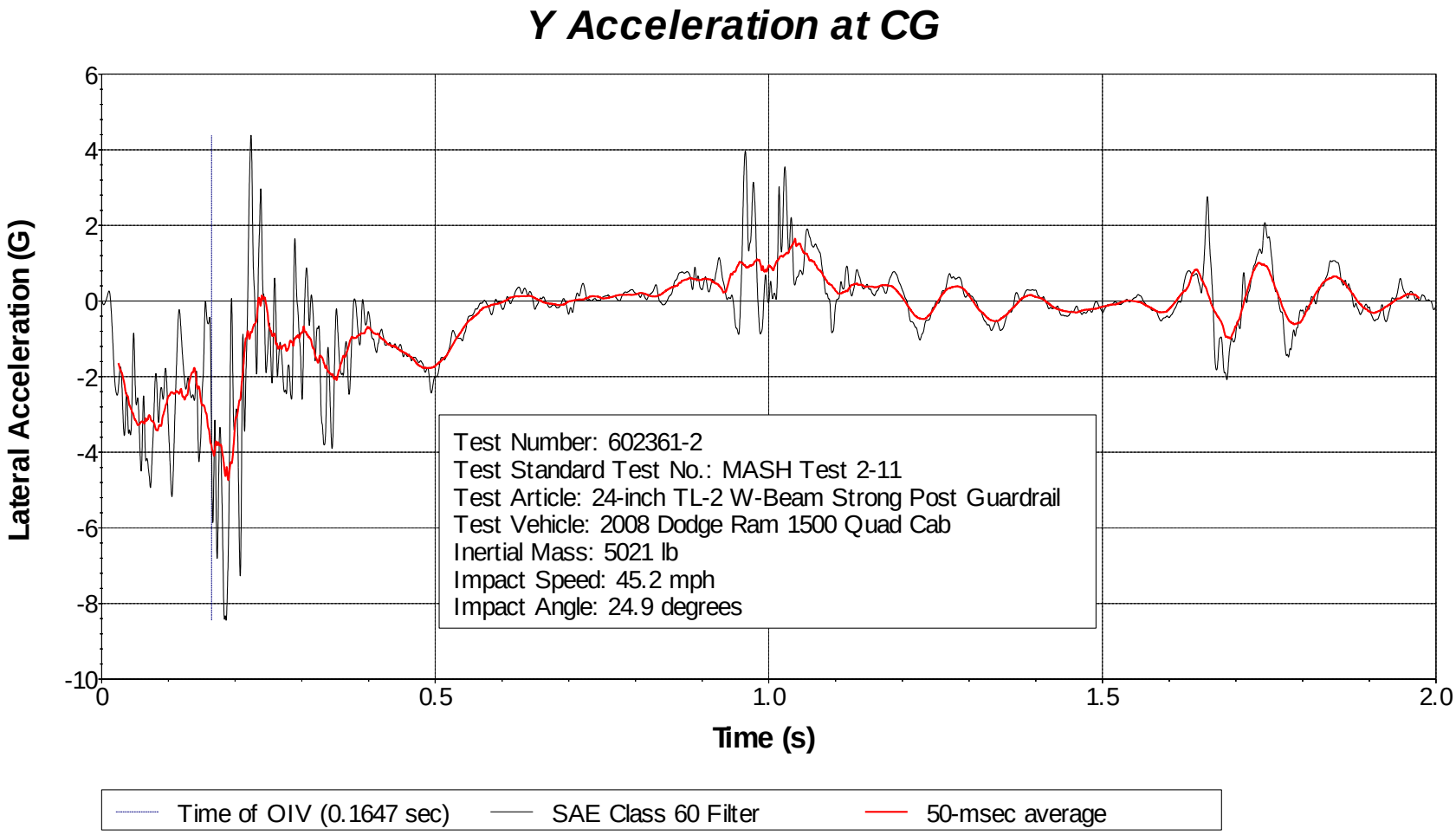


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 602361-2 (Accelerometer Located at Center of Gravity).

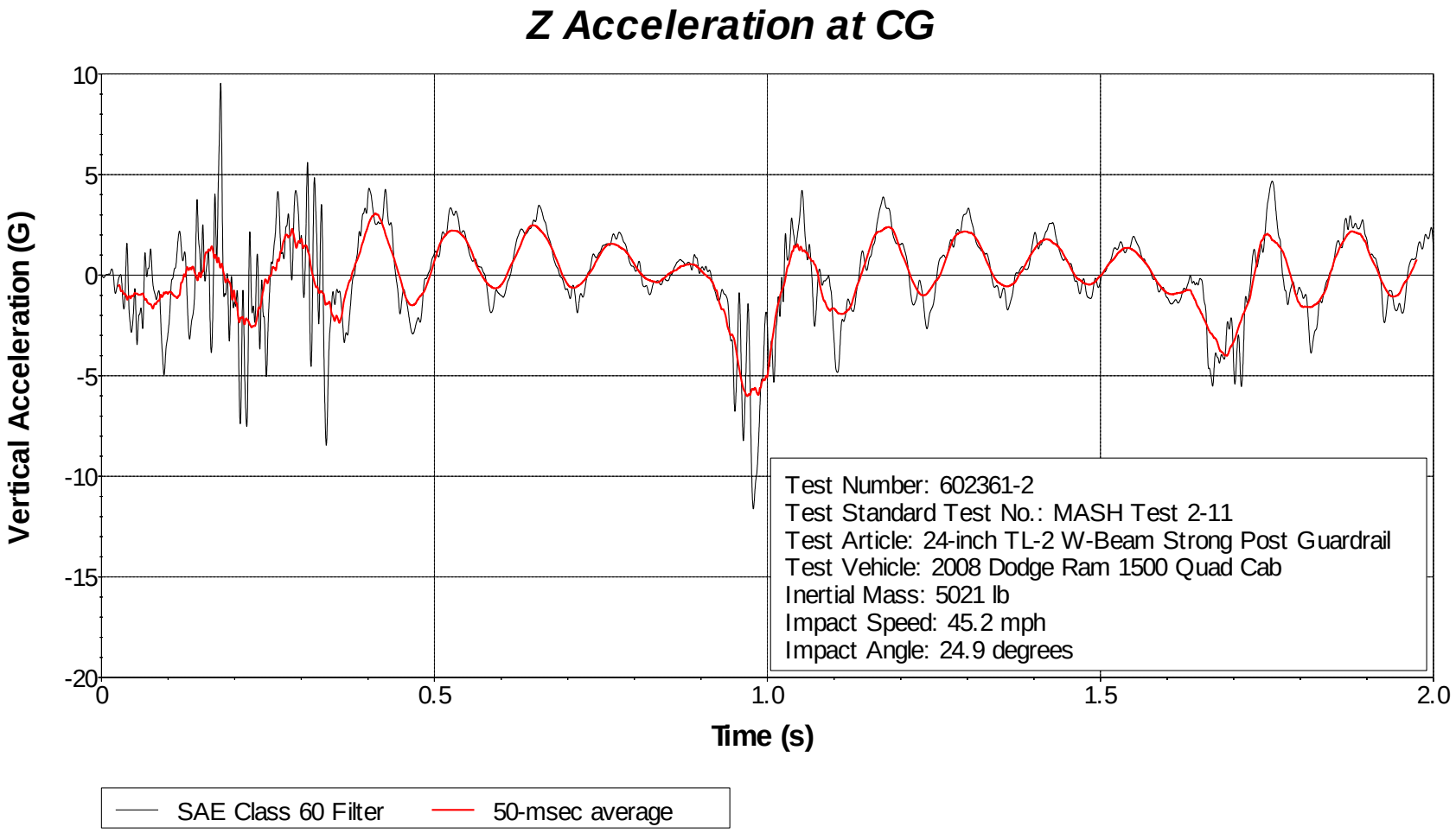


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 602361-2 (Accelerometer Located at Center of Gravity).

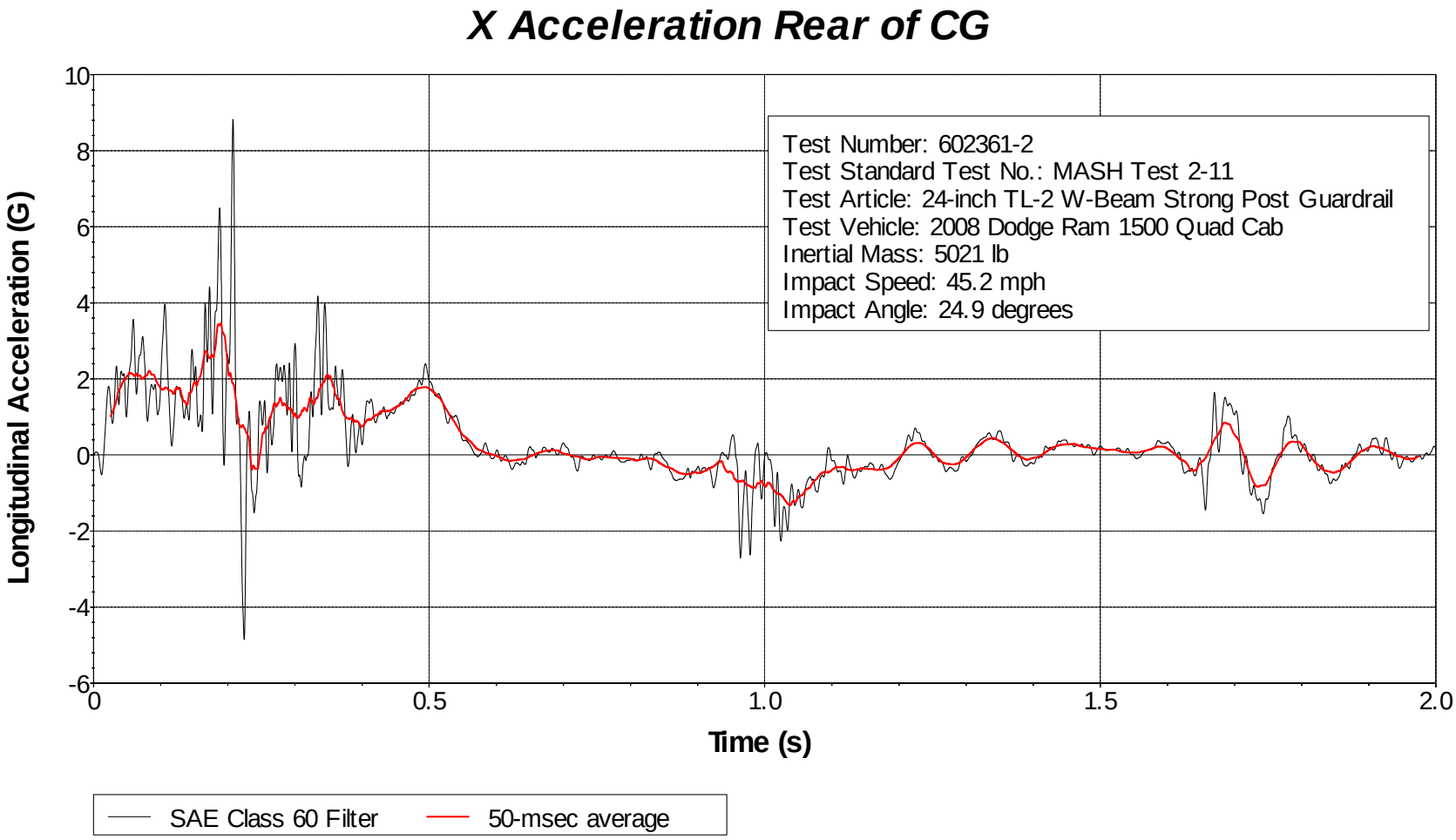


Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 602361-2 (Accelerometer Located Rear of Center of Gravity).

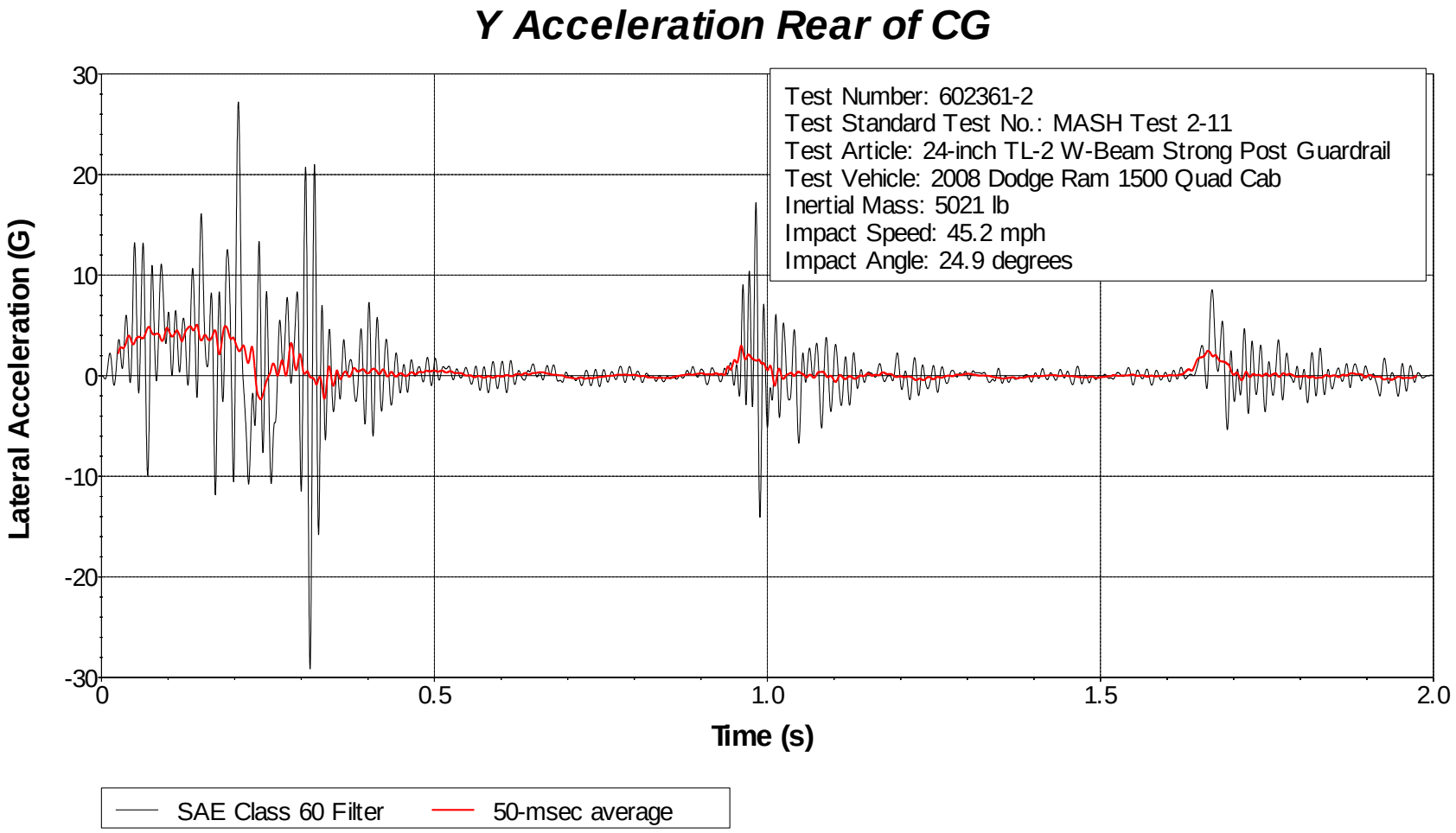


Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 602361-2 (Accelerometer Located Rear of Center of Gravity).

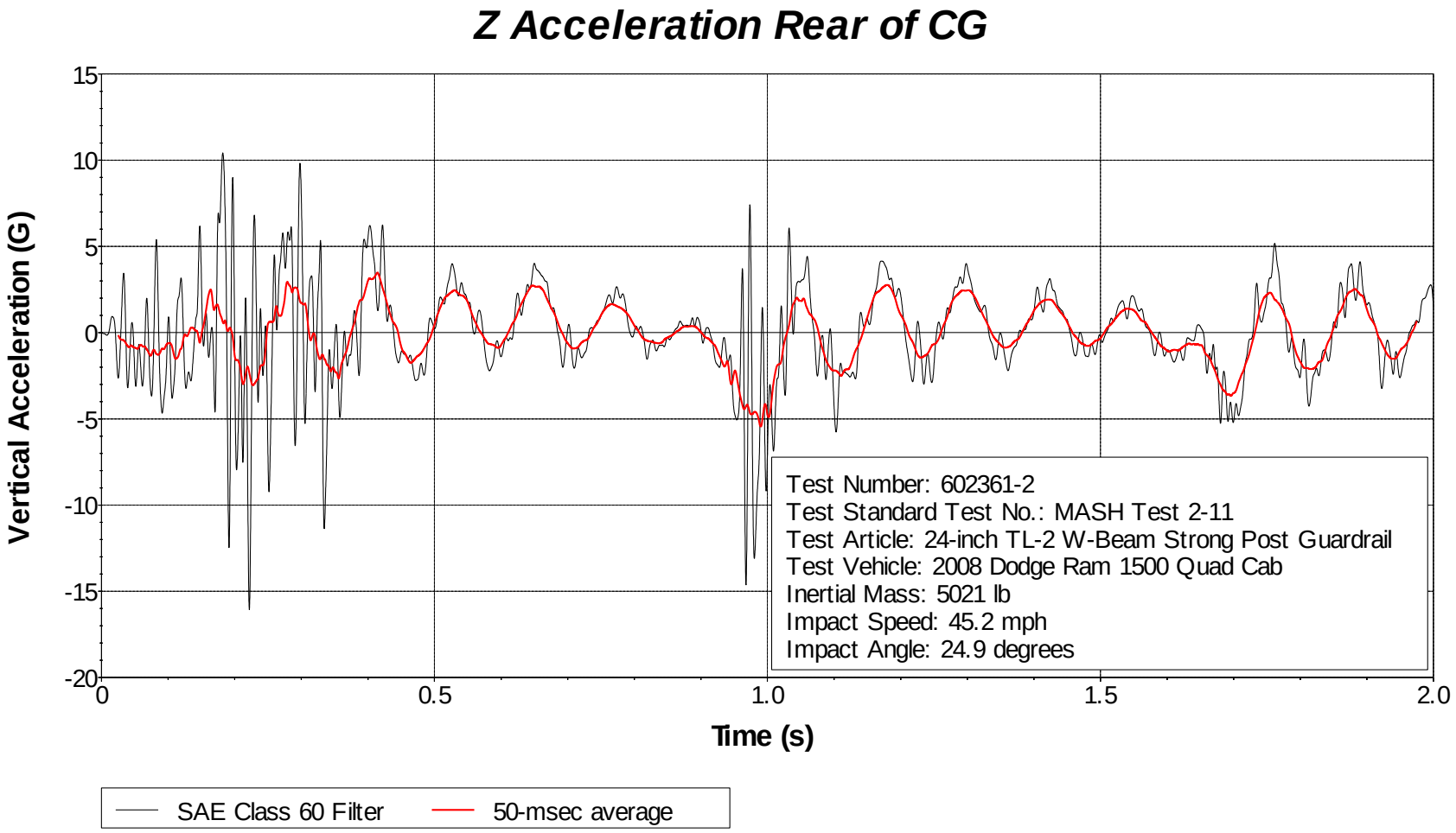


Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 602361-2 (Accelerometer Located Rear of Center of Gravity).