Roadside Safety Pooled Fund

Texas A&M Transportation Institute Proving Ground

Test Report No.: 602921-1
Test Report Date: August 2014

MASH TEST 2-11 OF THE 31-INCH W-BEAM GUARDRAIL WITH 12.5-FT POST SPACING

by

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Technical Report Documentation Page

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16. Abstract

The objective of this research was to evaluate the use of a 31-inch tall, strong-post W-beam guardrail with 12 ft 6 inch post spacing and 8-inch deep wood blockouts at American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test Level 2 (TL-2) conditions. A typical strong-post W-beam guardrail uses 6 ft 3 inch post spacing. A guardrail system with fewer posts will be less expensive and therefore more cost-effective on low-speed roads.

The 31-inch W-Beam guardrail with 12 ft 6 inch post spacing contained and redirected the 2270P *MASH* test vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 36.4 inches. One of the blockouts separated from the rail element and post; however, the blockout traveled low to the ground and came to rest on the field side. It did not penetrate or show potential for penetrating the occupant compartment, or to show hazard for others in the area. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 6 degrees and 7 degrees, respectively. Occupant risk factors were within the preferred limits specified for *MASH* test 2-11. The 2270P vehicle exited within the exit box criteria.

The 31-inch W-Beam guardrail with 12 ft 6 inch post spacing performed acceptably for *MASH* test 2-11.

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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)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		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)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		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)

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1 INTRODUCTION

1.1 PROBLEM

Most strong-post W-beam guardrail systems have been tested at the Test Level 3 (TL-3) conditions specified in National Cooperative Highway Research Program (NCHRP) *Report 350* or American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*1, 2*). These systems have typically used 6 ft 3 inch post spacing. A generic strong-post W-beam guardrail system with a 27-inch rail height and using 12 ft 6 inch post spacing was tested in accordance with *NCHRP Report 350* Test Level 2 (TL-2) conditions, but did not pass due to the vehicle overriding the barrier *(3)*. However, newer systems that use a rail element at a 31-inch height may be able to contain the vehicle. Using double post spacing, TL-2 W-beam guardrail system will result in significant cost reduction to the user agencies.

1.2 BACKGROUND

It is desired to reduce the number of posts installed in the TL-2 W-beam guardrail systems, which can result in significant cost savings for user agencies. Standard strong post W-beam guardrail uses 6 ft 3 inch post spacing. Most W-beam guardrail tests have been performed at TL-3 of *MASH* or *NCHRP Report 350*, which require vehicle impact speed of 62.2 mi/h. Since many of the guardrails are installed on roads that only require TL-2 (i.e. impact speed of 44 mi/h), it needs to be evaluated if successful guardrail performance can be achieved with the larger 12 ft-6 inch post spacing. In the past, a crash test was performed with the 12 ft 6 inch post spacing under *NCHRP Report 350* TL-2 impact conditions with a 27-inch tall W-beam guardrail *(3)*. The pickup truck overrode the guardrail in this test. More recently, many user agencies have raised the height of the W-beam guardrail to 31 inches, and several successful tests have been performed at *MASH* TL-3 conditions. With the higher rail height, there is now a potential to use the larger 12 ft 6 inch post spacing for the 31-inch W-beam guardrail for TL-2 conditions.

1.3 OBJECTIVES/SCOPE OF RESEARCH

The objective of this research was to evaluate the use of a 31-inch tall, strong-post W-beam guardrail with 12 ft 6 inch post spacing and 8-inch deep wood blockouts at *MASH* TL-2 conditions.

Test 2-11 of *MASH* (5000-lb vehicle, 44 mi/h, 25 degrees) was conducted to evaluate the performance of the 31-inch tall guardrail with 12 ft 6 inch post spacing. The remainder of this report presents the description of the test article, testing criteria and procedure, and the results of the test.

2 SYSTEM DETAILS

2.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The strong-post W-Beam guardrail test installation consisted of a 31-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. The ET-PLUS end-terminals were considered to be connected to the length of need guardrail run at the splice between posts 6 and 7 on the upstream end, and at the splice between posts 14 and 15 on the downstream end. The length-of-need between the end-terminals was 100 ft. The end-terminal posts 1 through 6 and 15 through 20 were equally spaced at 6 ft 3 inches. Posts in the length-of-need (posts 6 through 15) were equally spaced at 12 ft 6 inches.

Standard 12-gauge W-beam guardrail (type RWM02a) was used in the system from posts 3 to 18. The exception was the terminal guardrail segments between posts 1 and 3 and posts 18 and 20 that had punched slots into which the anchor cable release bracket was installed.

Overlapping guardrail splices were located mid-span between posts for the guardrail between posts 6 through 15, and at every other post in the remaining terminal regions (i.e. posts 3 and 5 and posts 16 and 18).

Guardrail offset for posts 3 through 18 was accomplished by use of 8-inch deep × 14-inch tall × 6-inch wide treated routered wood offset blocks (PDB01b) attached with standard 10-inch long guardrail bolts and nuts (FBB03). Posts 2 and 19 had no offset blocks and were bolted directly to the guardrail with standard 1¼-inch bolts and nuts (FBB01).

Guardrail posts 6 through 15 were 72-inch long guardrail line posts (type PWE01) fabricated from W6×8.5 structural steel shape and complied with American Society of Testing and Materials (ASTM) A36. These posts were embedded 40 inches deep in drilled holes with compacted strong soil as per *MASH*.

Posts 2 through 5 and posts 16 through 19 were standard 72-inch Steel Yielding Terminal Posts (SYTPs) fabricated from ASTM A36, W6×8.5 structural steel shape, and embedded 40 inches in the soil per a typical ET-PLUS terminal installation.

Posts 1 and 20 were standard ET-PLUS terminal cable release anchor posts (CRPs) fabricated from W6×15 ASTM A572-50 structural steel shape, 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 20 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 19 and 20, respectively.

Figure 2.1 and Appendix A present further information on the 31-inch W-beam guardrail with 12 ft 6 inch post spacing, and Figure 2.2 provides photographs of the installation.

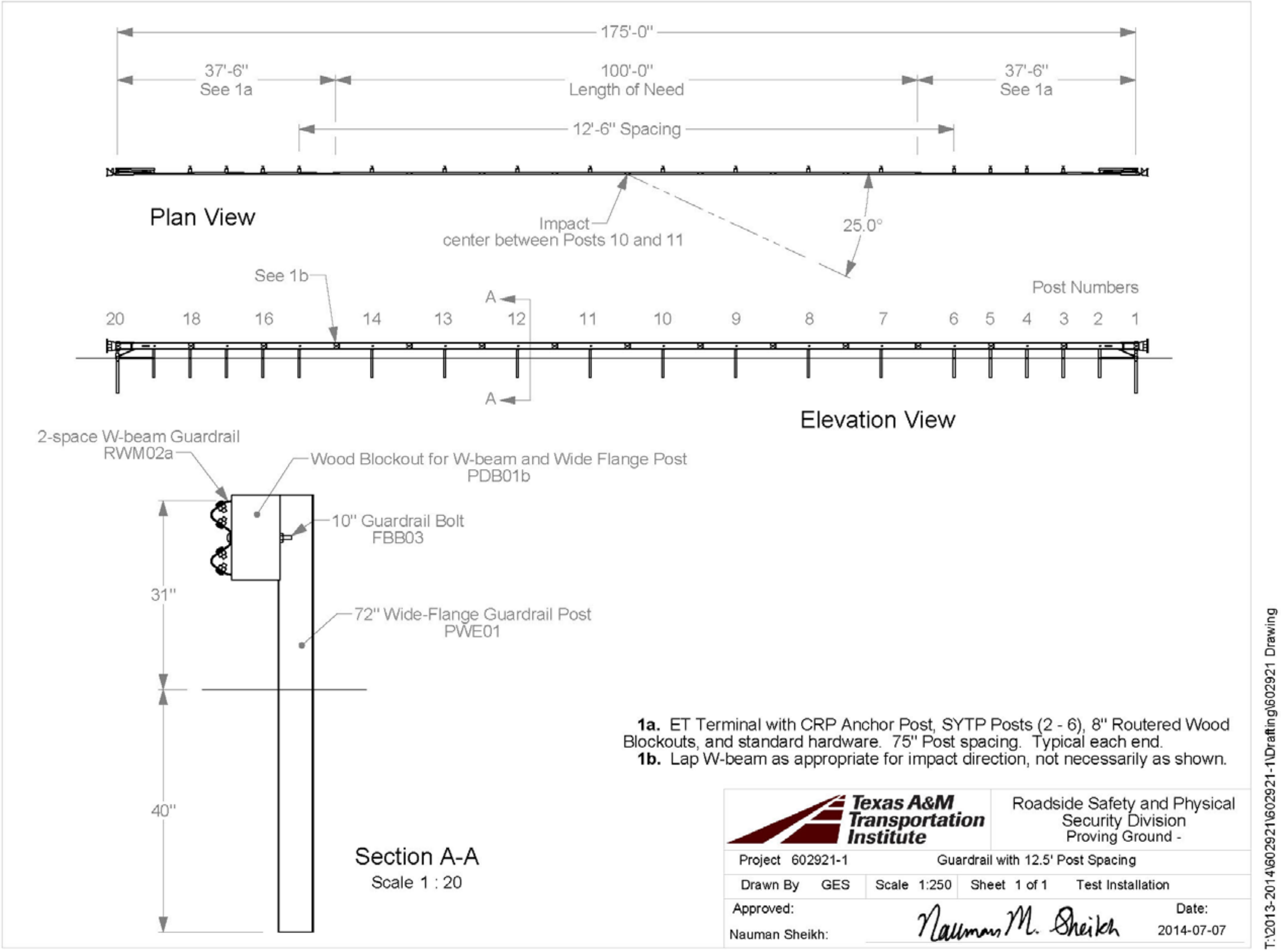


Figure 2.1. Details of the 31-inch Guardrail with 12 ft 6 inch Post Spacing.

Figure 2.2. 31-inch Guardrail with 12 ft 6 inch Post Spacing Prior to Testing.

2.2 MATERIAL SPECIFICATIONS

Certification documents are provided in Appendix B.

2.3 SOIL CONDITIONS

As stated previously, 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 C, Figure C1). During installation of the 31-inch W-beam Guardrail with 31-inch Guardrail with 12 ft 6 inch Post Spacing for full-scale crash testing, two standard W6×16 posts were installed in the immediate vicinity of the guardrail, utilizing the same fill materials and installation procedures used in the standard dynamic test (see Appendix C, Figure C2).

As determined in the tests shown in Appendix C, Figure C2, 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 percent of static load for the initial standard installation). On the day of the test, July 10, 2014, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 8695 lbf, 8415 lbf, and 7820 lbf, respectively. The strength of the backfill material met minimum requirements.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 CRASH TEST MATRIX

According to *MASH*, two tests are recommended to evaluate longitudinal barriers to 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.

The test reported herein corresponds to *MASH* Test 2-11. The target CIP for *MASH* Test 2-11, determined using finite element analyses, was centered between posts 10 and 11, as shown in Figure 3.1.

Several tests have been performed in the past using the 2420-lb small passenger car with the 31-inch tall W-beam guardrail at the higher 62 mi/h impact speed of *MASH* Test 3-10 *(4, 5)*. These tests have passed successfully and it is therefore expected that the small car test at a much lower 44 mi/h speed will also meet *MASH* criteria. Similarly, due to the lower impact speed of 44 mi/h, the small car is not expected to under-ride the guardrail. For these reasons, full-scale crash tests were performed with the pickup truck only, i.e. Test 2-11 of *MASH*.

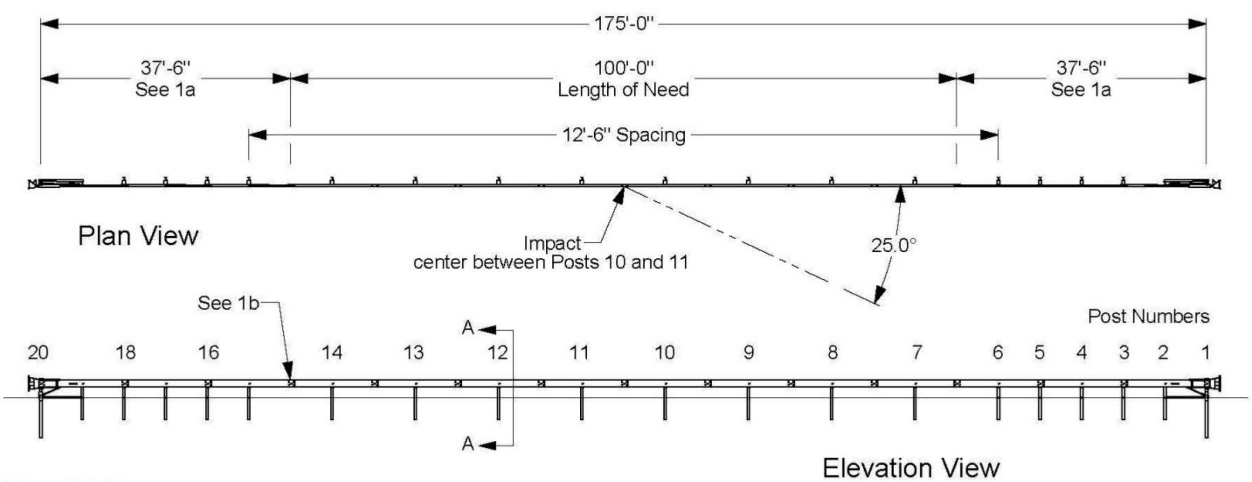


Figure 3.1. Impact Point for *MASH* Test 2-11 on the 31-inch W-Beam Guardrail with 12 ft 6 inch Post Spacing.

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

3.2 EVALUATION CRITERIA

The crash test was evaluated in accordance with the criteria presented in *MASH*. The performance of the 31-inch W-beam guardrail with 12 ft 6 inch post spacing 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 guardrail to contain and redirect the vehicle, or bring the vehicle to a controlled stop in a predictable manner. Occupant risk criteria evaluates 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.

4 TEST CONDITIONS

4.1 TEST FACILITY

The full-scale crash test reported herein was performed at Texas A&M Transportation Institute (TTI) Proving Ground. 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 Corp 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 31-inch W-beam guardrail with 12 ft 6 inch post spacing is along a wide out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches thick. The apron was constructed in 1942, and the joints have some displacement, but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE SYSTEM

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

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro manufactured 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 available channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 values per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units is returned to the factory annually for complete recalibration. 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).

4.3.2 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.

4.3.3 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 these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

5 CRASH TEST 602921-1 (*MASH* TEST NO. 2-11)

5.1 TEST DESIGNATION AND ACTUAL 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 target impact point was centered between posts 10 and 11. The 2008 Dodge Ram 1500 quad cab pickup truck used in the test weighed 5004 lb and the actual impact speed and angle were 45.7 mi/h and 25.0 degrees, respectively. The actual impact point was centered between posts 10 and 11. Target impact severity (IS) was 57.8 kip-ft, and actual IS was 62.4 kip-ft (+8 percent).

5.2 TEST VEHICLE

Figure 5.1 and 5.2 show the 2008 Dodge Ram 1500 pickup truck used for this crash test. Test inertia weight of the vehicle was 5004 lb, and its gross static weight was 5004 lb. The height to the lower edge of the vehicle front bumper was 15.0 inches, and the height to the upper edge of the front bumper was 26.5 inches. The height to the center of gravity was 28.75 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.

5.3 WEATHER CONDITIONS

The crash test was performed the morning of July 10, 2014. Weather conditions at the time of testing were: wind speed: 10 mi/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 87°F; relative humidity: 63 percent.

5.4 TEST DESCRIPTION

The 2008 Dodge Ram 1500 quad cab pickup truck, traveling at an impact speed of 45.7 mi/h, impacted the guardrail mid-span between posts 10 and 11 at an impact angle of 25.0 degrees. At approximately 0.072 s after impact, the vehicle began to redirect, and at 0.085 s, the right front corner of the vehicle bumper contacted post 11. The right front tire contacted post 11 at 0.124 s, and the right front corner of the vehicle bumper contacted post 12 at 0.319 s. At 0.324 s, the vehicle began traveling parallel with the guardrail, and at 0.338 s, the right front tire contacted post 12. The vehicle continued to ride along the traffic face of the guardrail and out of view of the high-speed cameras. Brakes on the vehicle were applied at 2.6 s after impact, and the vehicle subsequently yawed clockwise and came to rest 218.3 ft downstream of the point of impact and 7 ft toward traffic lanes. Appendix D2, Figure D.1 presents sequential photographs of the test.

Figure 5.1. Vehicle and Installation Geometrics for Test No. 602921-1.

Figure 5.2. Vehicle before Test No. 602921-1.

5.5 TEST ARTICLE AND COMPONENT DAMAGE

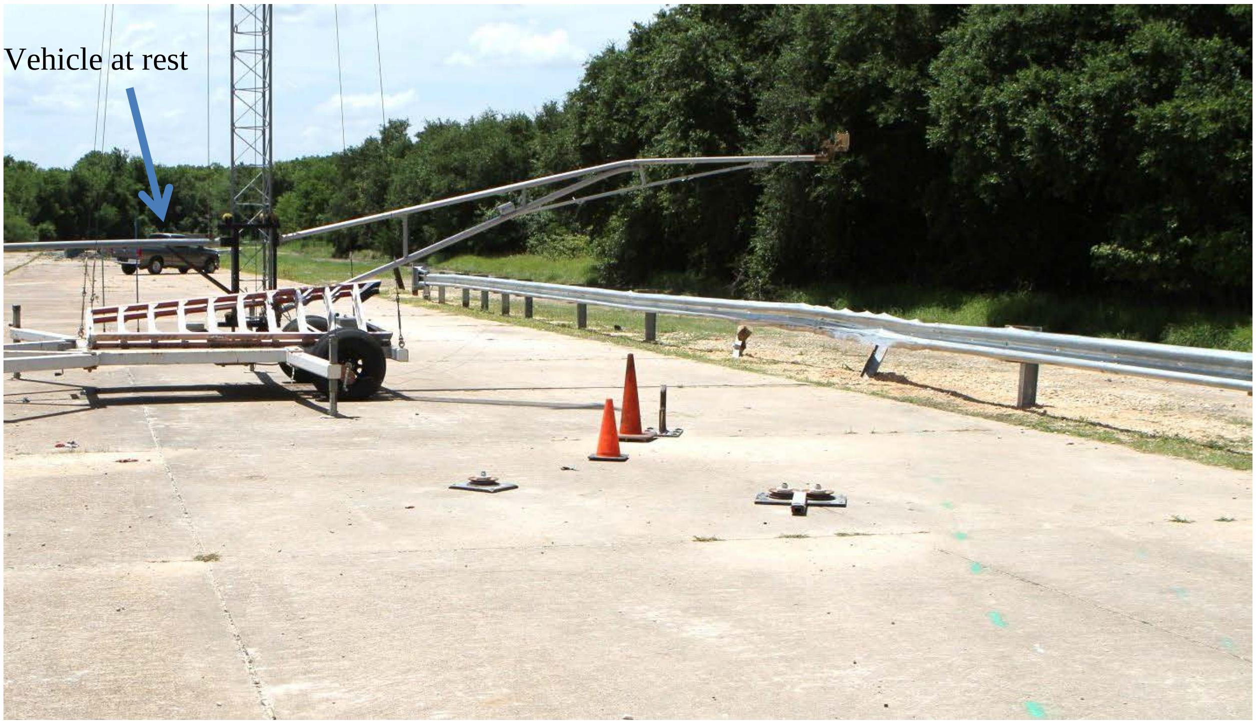
Figures 5.3 and 5.4 show damage to the 31-inch W-beam guardrail with 12 ft 6 inch post spacing. Post 1 was pulled downstream 1 inch. Post 10 moved 1.1 inches toward the field side and was leaning 5 degrees toward field side. Post 11 was leaning 45 degrees downstream and toward the field side, and the blockout separated from the rail element and post 11 and was resting 23 ft toward the field side of post 12. Post 12 separated from the rail element, rotated 90 degrees counterclockwise, and was leaning 45 degrees downstream. Post 13 separated from the rail element, moved through the soil 0.5 inch, and was leaning 3 degrees toward the field side. The post bolt pulled through the bolt opening in the rail element at post 19, but the blockout remained attached to the post. Post 20 was pulled upstream 0.4 inch. Length of contact of the vehicle with the guardrail was 33.3 ft. Working width was 44.3 inches, and vehicle intrusion was 41.1 inches. Maximum dynamic deflection of the rail element during the test was 36.4 inches, and maximum permanent deformation of the rail element was 27.2 inches.

5.6 TEST VEHICLE DAMAGE

Figure 5.5 shows damage to the vehicle after the test. The front bumper, right front tire and wheel rim, right front fender, right front and rear doors, right rear exterior bed, and rear bumper were scratched and deformed. Maximum exterior crush was 9.0 inches in the side plane at the right front corner at bumper height. No occupant compartment deformation or intrusion occurred. Figure 5.6 shows the interior of the vehicle. Exterior vehicle crush and occupant compartment measurements are shown in Appendix D2, Tables D.3 and D.4.

5.7 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 12.1 ft/s at 0.203 s, the highest 0.010-s occupant ridedown acceleration was 5.9 Gs from 0.351 to 0.361 s, and the maximum 0.050-s average acceleration was −2.8 Gs between 0.133 and 0.183 s. In the lateral direction, the occupant impact velocity was 12.5 ft/s at 0.203 s, the highest 0.010-s occupant ridedown acceleration was 5.2 Gs from 0.393 to 0.403 s, and the maximum 0.050-s average was −3.7 Gs between 0.372 and 0.422 s. Theoretical Head Impact Velocity (THIV) was 18.2 km/h or 5.1 m/s at 0.195 s; Post-Impact Head Decelerations (PHD) was 6.3 Gs between 0.351 and 0.361 s; and Acceleration Severity Index (ASI) was 0.43 between 0.392 and 0.442 s. Figure 5.7 summarize these data and other pertinent information from the test. Vehicle angular displacements are presented in Appendix D3, Figure D.2, and accelerations versus time traces are presented in Appendix D4, Figures D.3 through D.8.



Vehicle at rest

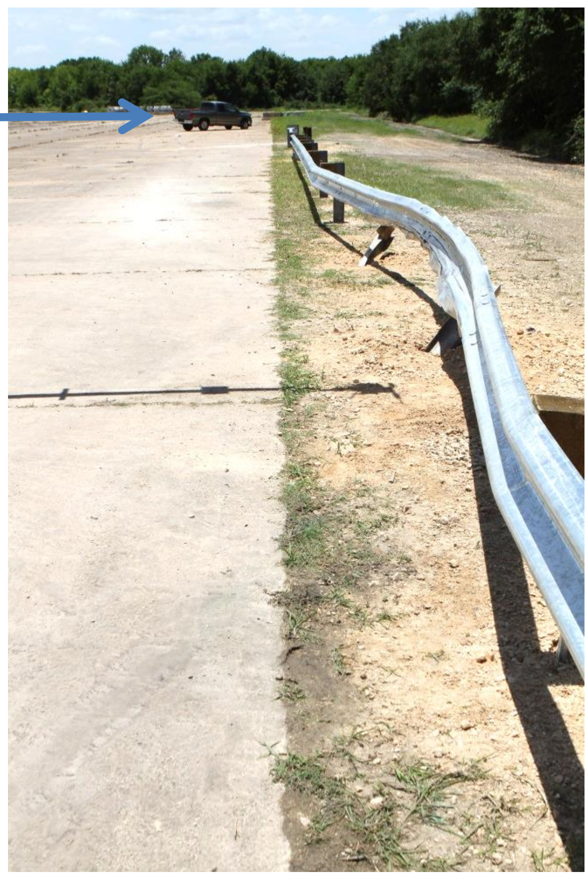


Figure 5.3. Vehicle/Guardrail Positions after Test No. 602921-1.

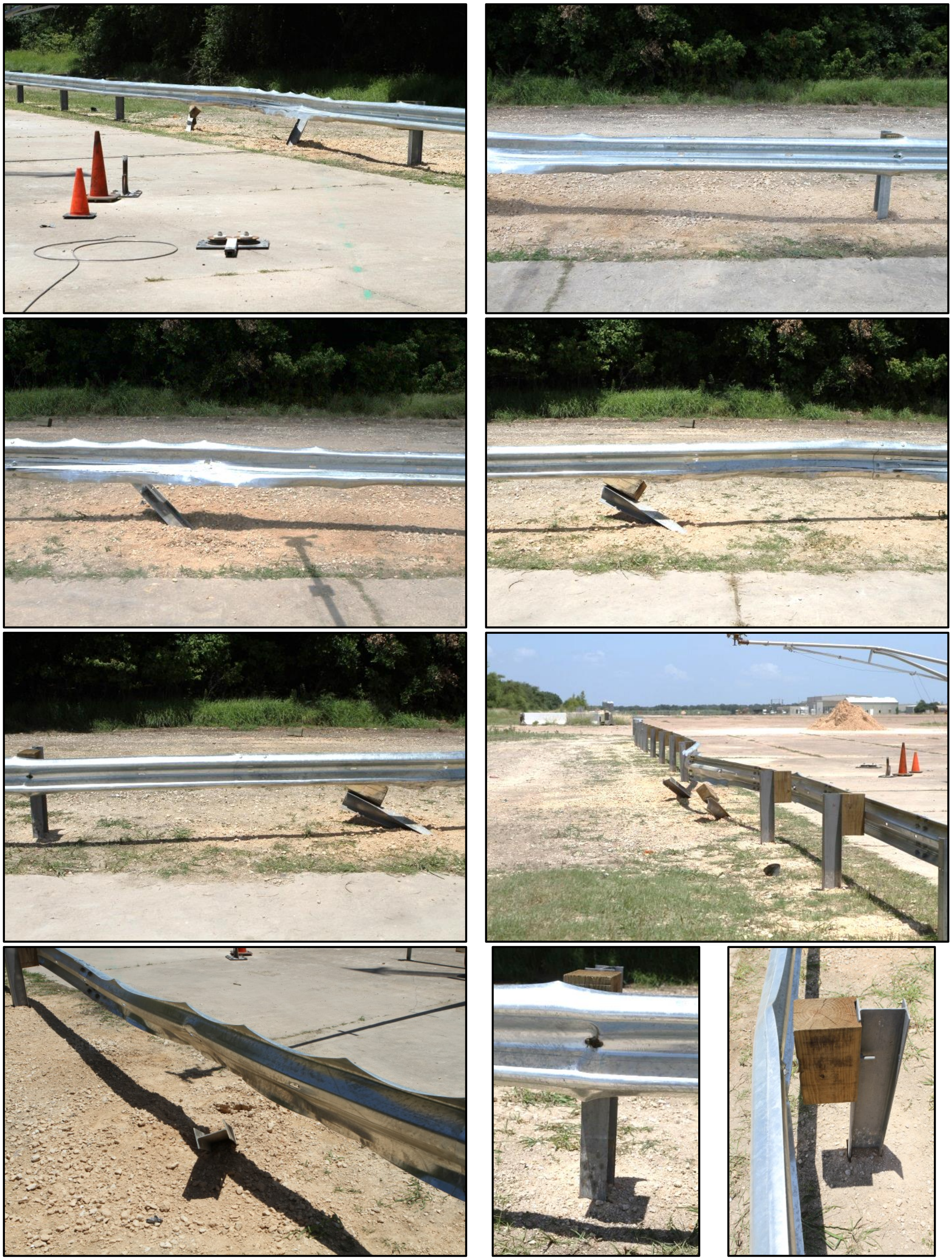


Figure 5.4. Installation after Test No. 602921-1.

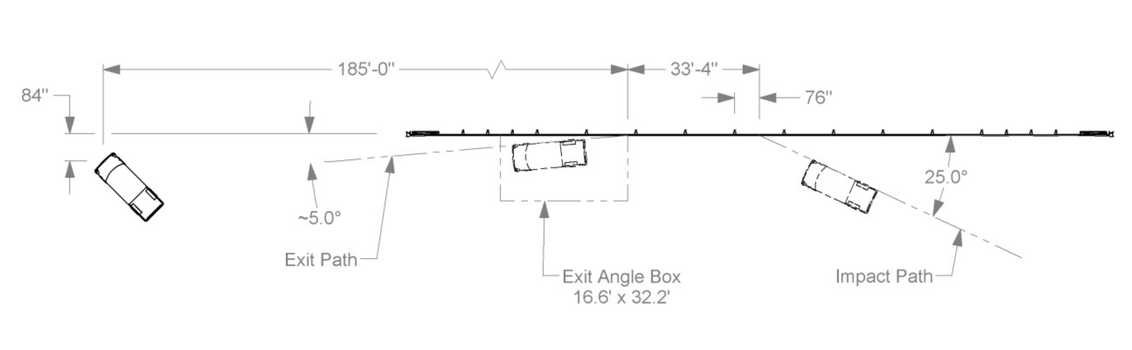
Figure 5.5. Vehicle after Test No. 602921-1.

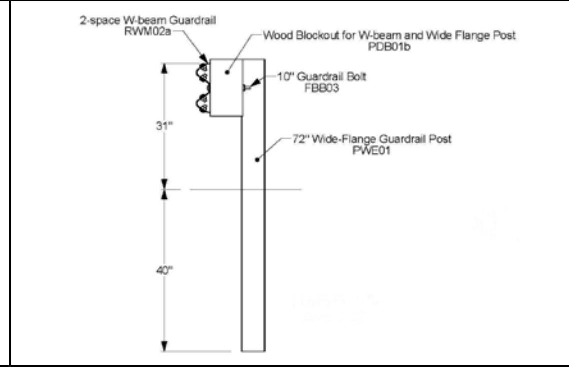
Before Test

After Test

Figure 5.6. Interior of Vehicle for Test No. 602921-1.

0.000 s | 0.196 s | 0.392 s | 0.588 s





General Information
- Test Agency .... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. .... *MASH* 2-11
- TTI Test No. 602921-1
- Date 2014-07-10

Test Article
- Type.................................. Guardrail
- Name .... 31-inch W-Beam Guardrail with 12 ft 6 inch post spacing
- Installation Length .... 175 ft
- Material or Key Elements .... 12 gauge W-beam on W6x9 steel posts and 8-inch wood blockouts at 12 ft 6 inch post spacing

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

Test Vehicle
- Type/Designation 2270P
- Make and Model................. 2008 Dodge Ram 1500 Quad Cab
- Curb .... 4887 lb
- Test Inertial .... 5004 lb
- Dummy............................... No Dummy
- Gross Static........................ 5004 lb

Impact Conditions
- Speed................................45.7 mi/h
- Angle..................................25.0 degrees
- Location/Orientation ....Midspan btw Post 10-11

Impact Severity.....................

Exit Conditions
- Speed................................Out of view
- Angle..................................Out of view

Occupant Risk Values
- Impact Velocity
  - Longitudinal......................12.1 ft/s
  - Lateral..............................12.5 ft/s
- Ridedown Accelerations
  - Longitudinal......................5.9 G
  - Lateral..............................5.2 G
- THIV...................................18.2 km/h
- PHD ....6.3 G
- ASI 0.43

Max. 0.050-s Average
- Longitudinal......................−2.8 G
- Lateral..............................−3.7 G
- Vertical ....1.8 G

Post-Impact Trajectory
- Stopping Distance .... 218.3 ft dwnstrm 7 ft toward traffic

Vehicle Stability
- Maximum Yaw Angle................. 33 degrees
- Maximum Pitch Angle................ 7 degrees
- Maximum Roll Angle.................. 6 degrees
- Vehicle Snagging....................... No
- Vehicle Pocketing...................... No

Test Article Deflections
- Dynamic .... 36.4 inches
- Permanent................................. 27.2 inches
- Working Width .... 44.3 inches
- Vehicle Intrusion........................ 41.1 inches

Vehicle Damage
- VDS... 01RFQ2
- CDC 01FREW2
- Max. Exterior Deformation .... 9.0 inches
- OCDI RF0000000
- Max. Occupant Compartment Deformation......................... None

Figure 5.7. Summary of Results for *MASH* Test 2-11 on 31-inch W-Beam Guardrail with 12 ft 6 inch Post Spacing.

6 SUMMARY AND CONCLUSIONS

6.1 SUMMARY OF RESULTS

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

6.1.1 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.*

<u>Results</u>: The 31-inch W-Beam Guardrail with 12 ft 6 inch post spacing contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 36.4 inches. (PASS)

6.1.2 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).

<u>Results</u>: The blockout at post 11 separated from the rail element and post; however, the blockout traveled low to the ground and came to rest on the field side of post 12. The blockout did not penetrate or show potential for penetrating the occupant compartment, or to show hazard for others in the area. (PASS)

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

<u>Results</u>: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 6 degrees and 7 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 12.1 ft/s, and lateral occupant impact velocity as 12.5 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 5.9 G, and maximum lateral occupant ridedown acceleration was 5.2 G. (PASS)

6.1.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).

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

6.2 CONCLUSIONS

As shown in Table 6.1, the 31-inch W-beam guardrail with 12 ft 6 inch post spacing performed acceptably for *MASH* test 2-11.

6.3 RECOMMENDATIONS*

Results of the crash test presented in this report show that user agencies can install the 31-inch tall W-beam guardrail with half the number of posts in the length of need by using 12 ft 6 inch post spacing. This is expected to result in nearly 50% reduction in the time and money spent in drilling holes, installing the posts, and backfilling the holes with soil. This will also significantly reduce the worker exposure in work zones that may need to maintain active traffic while installation or repair is ongoing.

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

Table 6.1. Performance Evaluation Summary for *MASH* Test 2-11 on the 31-inch Guardrail with 12 ft 6 inch Post Spacing.

Test Agency: Texas A&M Transportation Institute | Test No.: 602921-1 | Test Date: 2014-07-10

***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 31-inch W-Beam Guardrail with 12 ft 6 inch post spacing contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection was 36.4 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.*	The blockout at post 11 separated from the rail element and post; however, the blockout traveled low to the ground and came to rest on the field side of post 12. The blockout did not penetrate or show potential for penetrating the occupant compartment, or to show hazard for 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 deformation or intrusion into the occupant compartment occurred.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 6 degrees and maximum pitch was 7 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 12.1 ft/s, and lateral occupant impact velocity as 12.5 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 5.9 G, and maximum lateral occupant ridedown acceleration was 5.2 G.	Pass
Vehicle Trajectory *For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).*	The 2270P vehicle exited within the exit box criteria.	Pass

7 REFERENCES

1. Ross, H. E., D. L. Sicking, R. A. Zimmer, and J. D. Michie. *Recommended Procedures for the Safety Performance Evaluation*. NCHRP Report 350. National Academy Press, Washington, D.C., National Cooperative Highway Research Program, 1993.

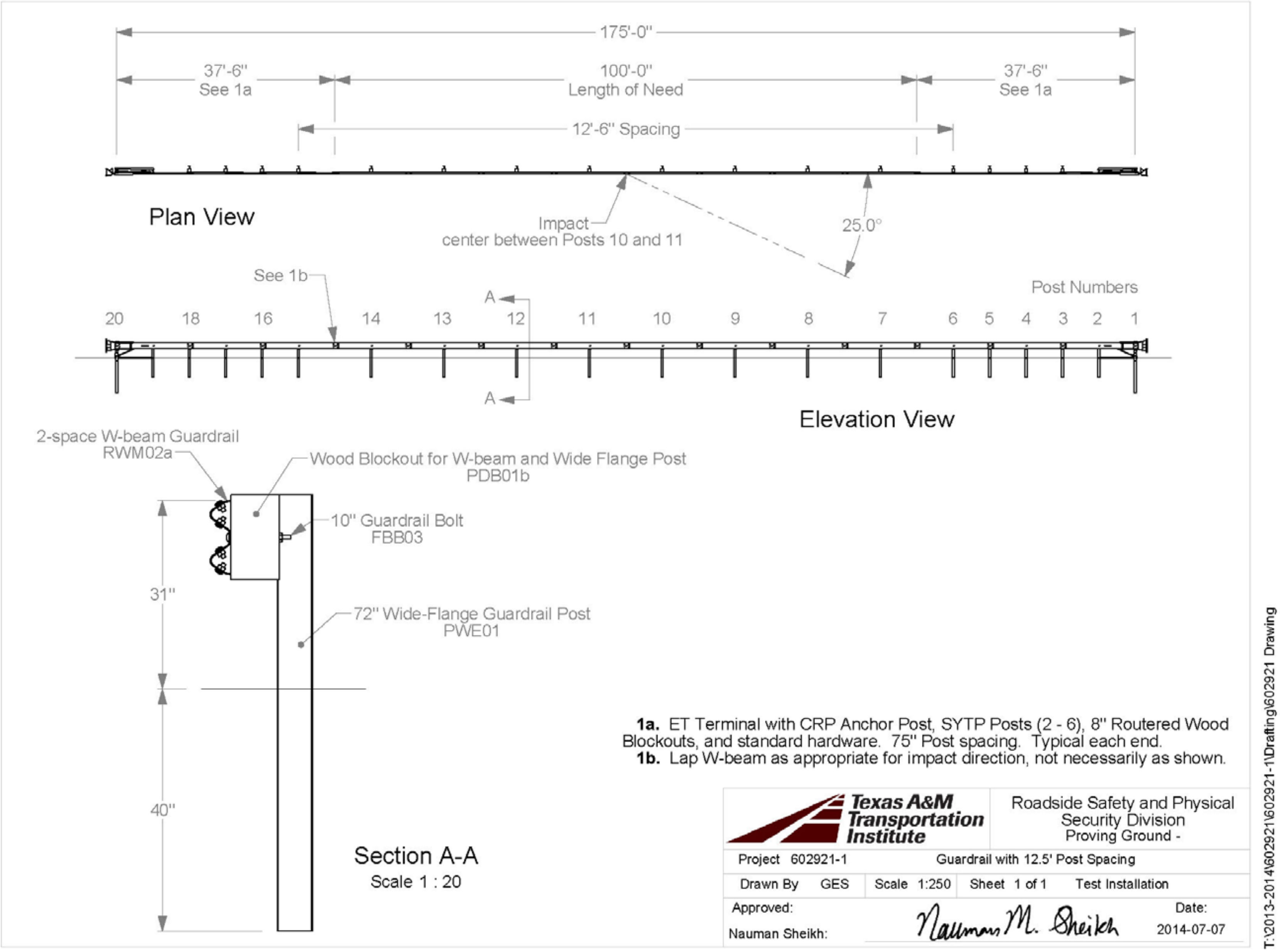
2. AASHTO. *Manual for Assessing Safety Hardware*. Washington, DC, American Association of State Highway and Transportation Officials, 2009.

3. K.K. Mak, R.P. Bligh, and D.L. Bullard, Jr., *Crash Testing and Evaluation of a Low-Speed W-beam Guardrail System,* Report WA-RD 325.1, Texas A&M Transportation Institute, College Station, Texas, 1993.

4. 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.

5. A.Y. Abu-Odeh, K. Ha, I. Liu, and W.L. Menges, *MASH TL-3Testing and Evaluation of the W-beam Guardrail on Slope*, Report 405160-20, Texas A&M Transportation Institute, College Station, Texas, 2012.

APPENDIX A. DETAILS OF TEST ARTICLE



APPENDIX B. SUPPORTING CERTIFICATION DOCMENTS

MATERIAL USED

TEST NUMBER	602921-1
TEST NAME	31" W-beam with 12.5' post spacing
DATE	2014-07-11

#	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
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 [signature]

METC1100 Rev. 12/18/08 FRM-014-HM

TR No. 602191-1

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

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

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: Luis Ortiz
Quality Assurance

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													

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

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

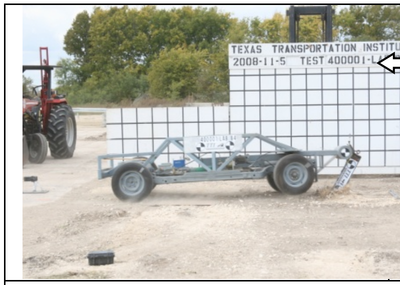
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD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

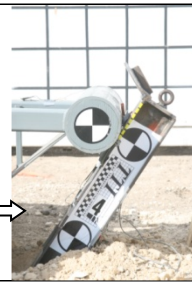
Trinity Highway Products, LLC
Certified By: Quality Assurance

APPENDIX C. SOIL PROPERTIES DOCUMENTAITON



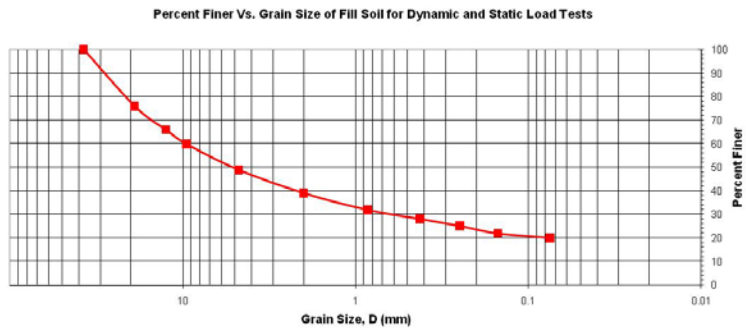
Dynamic Setup

Post-Test Photo of post

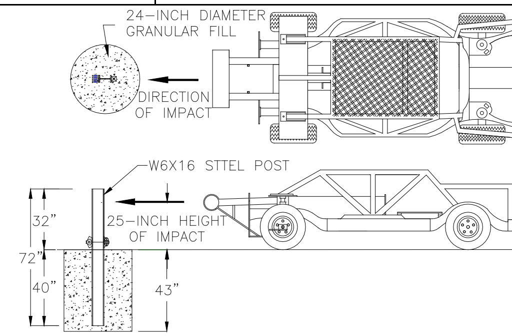


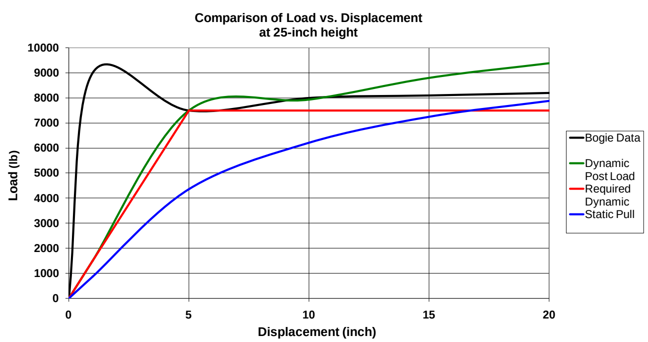
Post-Test Photo

Static Load Test

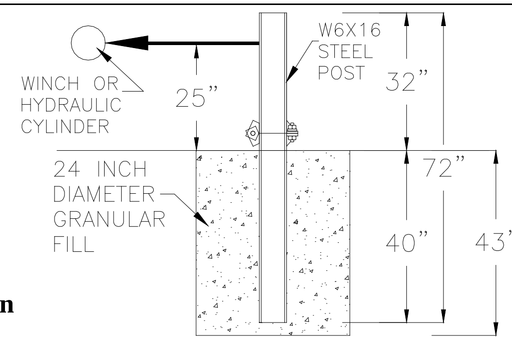


Dynamic Test Installation Details



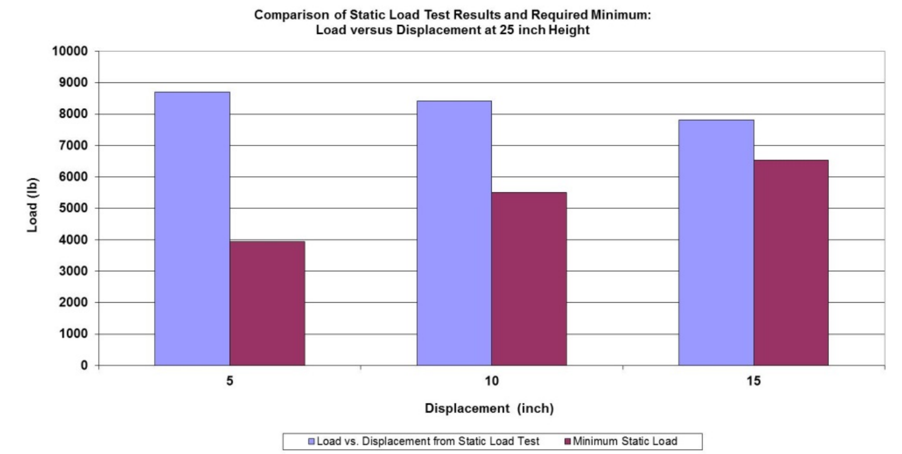


Static Load Test Installation Details

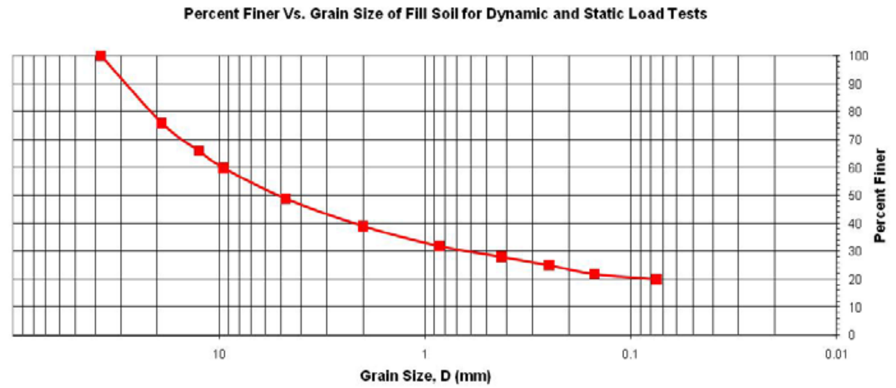


Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement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

Table A.2. Test Day Static Soil Strength Documentation for Test No. 602921-1.



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 D. CRASH TEST NO. 602921-1

D1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 602921-1.

Date: 2014-07-10 Test No.: 602921-1 VIN No.: 1D7HA18258S571453

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

Tire Size: P265/70P17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 163585

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

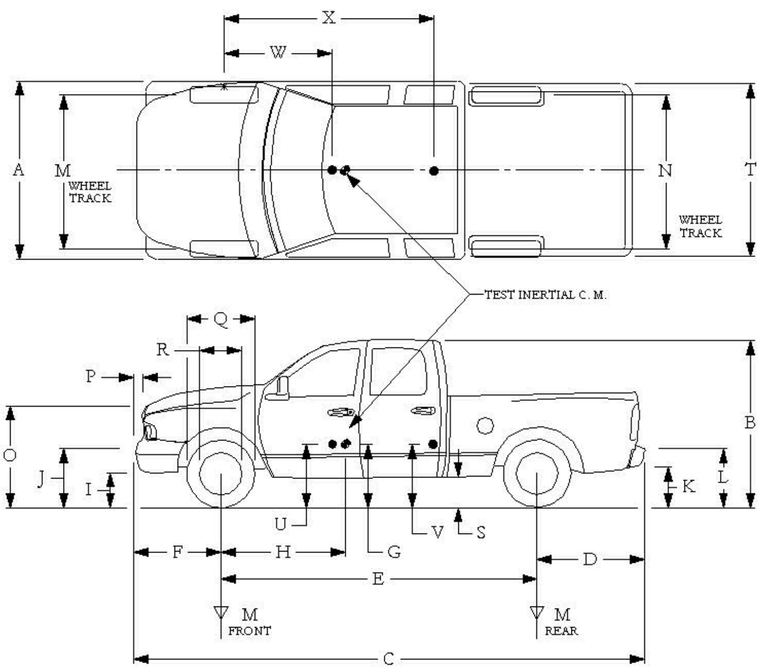
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

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



Geometry: inches

A	78.25	F	36.00	K	20.50	P	2.88	U	28.50
B	75.00	G	28.75	L	29.00	Q	30.50	V	30.50
C	223.75	H	61.24	M	68.50	R	16.00	W	61.20
D	47.25	I	15.00	N	68.00	S	14.00	X	77.10
E	140.50	J	26.50	O	46.00	T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	18.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	11.00	Bottom Frame Height - Rear	24.75

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}	2861	2823	2823
Back	3900	M_{rear}	2026	2181	2181
Total	6700	M_{Total}	4887	5004	5004

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

Mass Distribution:
lb LF: 1447 RF: 1376 LR: 1089 RR: 1092

Table D.2. Measurements of Vehicle Vertical CG for Test No. 602921-1.

Date: 2014-07-10 Test No.: 602921-1 VIN: 1D7HA18258S571453

Year: 2008 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 163585

Engine: 5.7 liter V-8 Transmission: Automatic

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

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

Measured Vehicle Weights: (lb)									
LF:	1447		RF:	1376			Front Axle:	2823	
LR:	1089		RR:	1092			Rear Axle:	2181	
Left:	2536		Right:	2468			Total:	5004	
							5000 ±110 lb allowed		
Wheel Base:		140.5	inches	Track: F:	68.5	inches	R:	68	inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed					
Center of Gravity, SAE J874 Suspension Method									
X:	61.24	in	Rear of Front Axle		(63 ±4 inches allowed)				
Y:	-0.47	in	Left -	Right +	of Vehicle Centerline				
Z:	28.75	in	Above Ground		(minumum 28.0 inches allowed)				

Hood Height: 46.00 inches Front Bumper Height: 26.50 inches

43 ±4 inches allowed

Front Overhang: 36.00 inches Rear Bumper Height: 29.00 inches

39 ±3 inches allowed

Overall Length: 223.75 inches

237 ±13 inches allowed

Table D.3. Exterior Crush Measurements for Test No. 602921-1.

Date: 2014-07-10 Test No.: 602921-1 VIN No.: 1D7HA18258S571453

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	7	20	1	2	7	---	---	---	+24
2	Side plane at bumper ht	16	9	48	1.25	---	---	---	8	9	+74
	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.

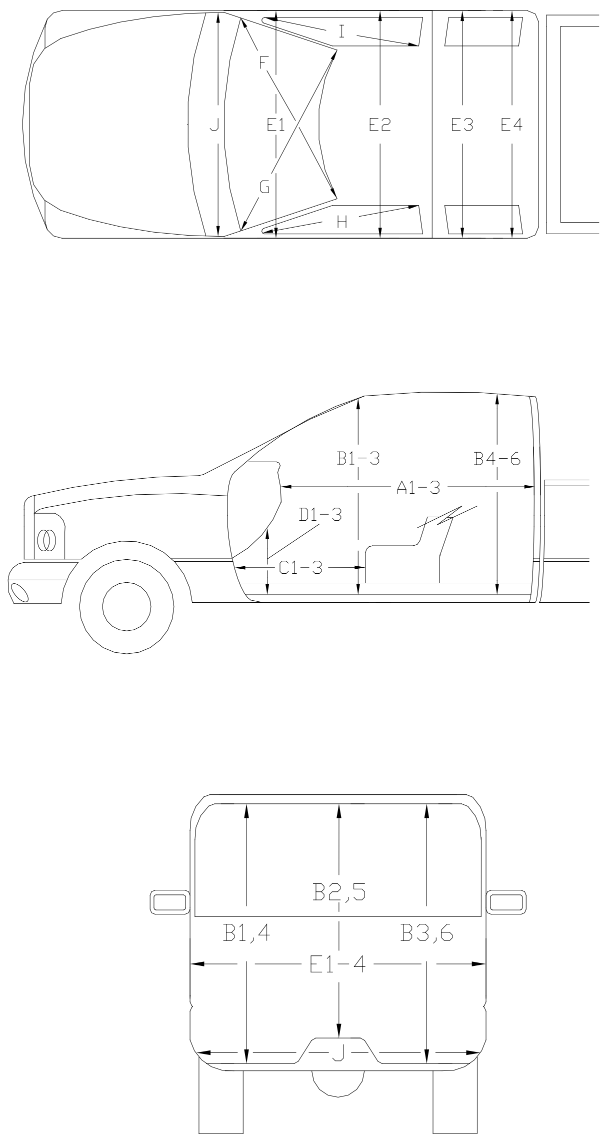
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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. 602921-1.

Date:	2014-07-10	Test No.:	602921-1	VIN No.:	1D7HA18258S571453
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	65.00	65.00
A2	65.00	65.00
A3	65.25	65.25
B1	45.25	45.25
B2	39.25	39.25
B3	45.25	45.25
B4	42.00	42.00
B5	45.25	45.25
B6	42.00	42.00
C1	26.75	26.75
C2	-----	-----
C3	26.50	26.50
D1	13.00	13.00
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

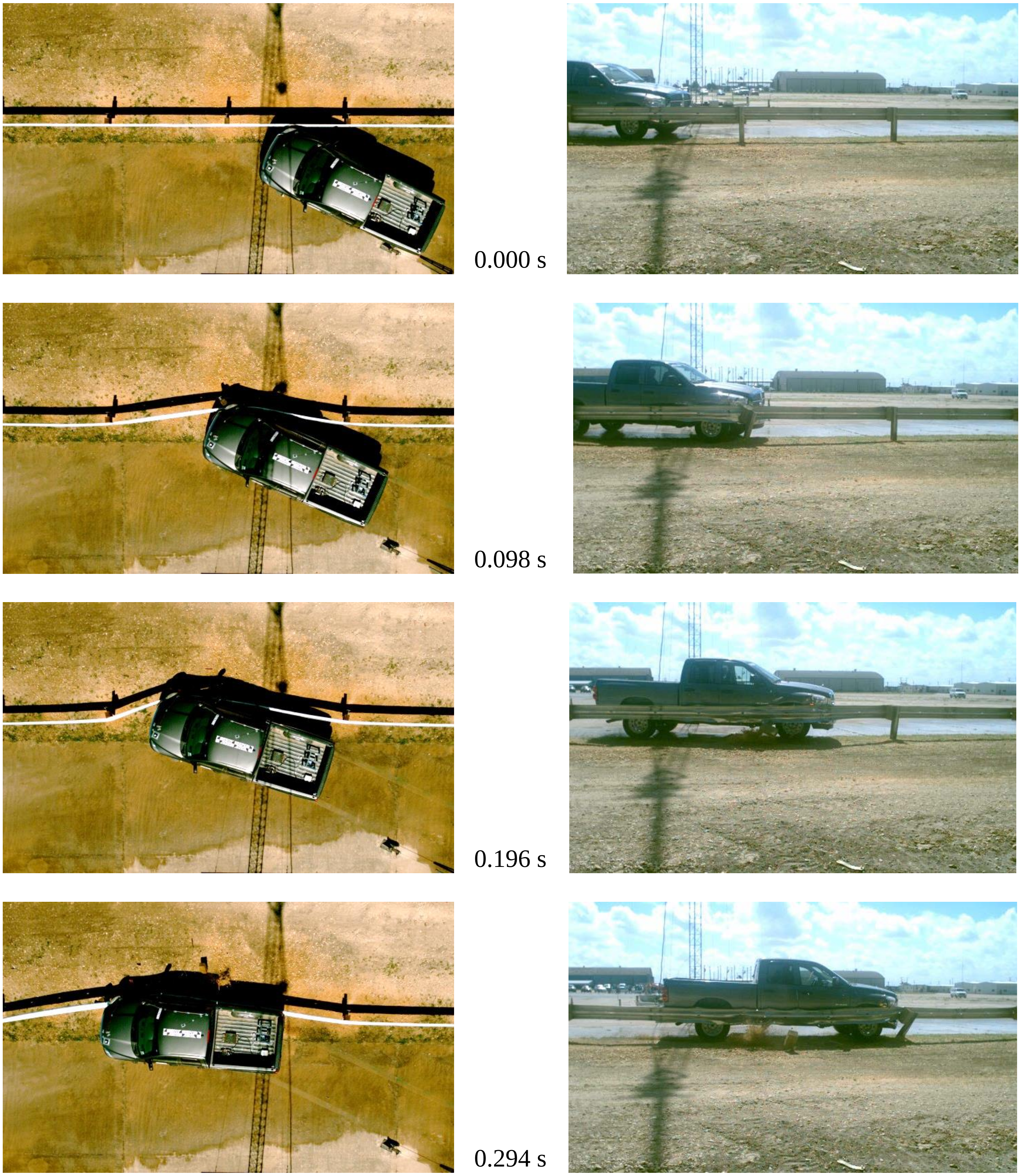


Figure D.1. Sequential Photographs for Test No. 602921-1 (Overhead and Frontal Views).


0.392 s



0.490 s

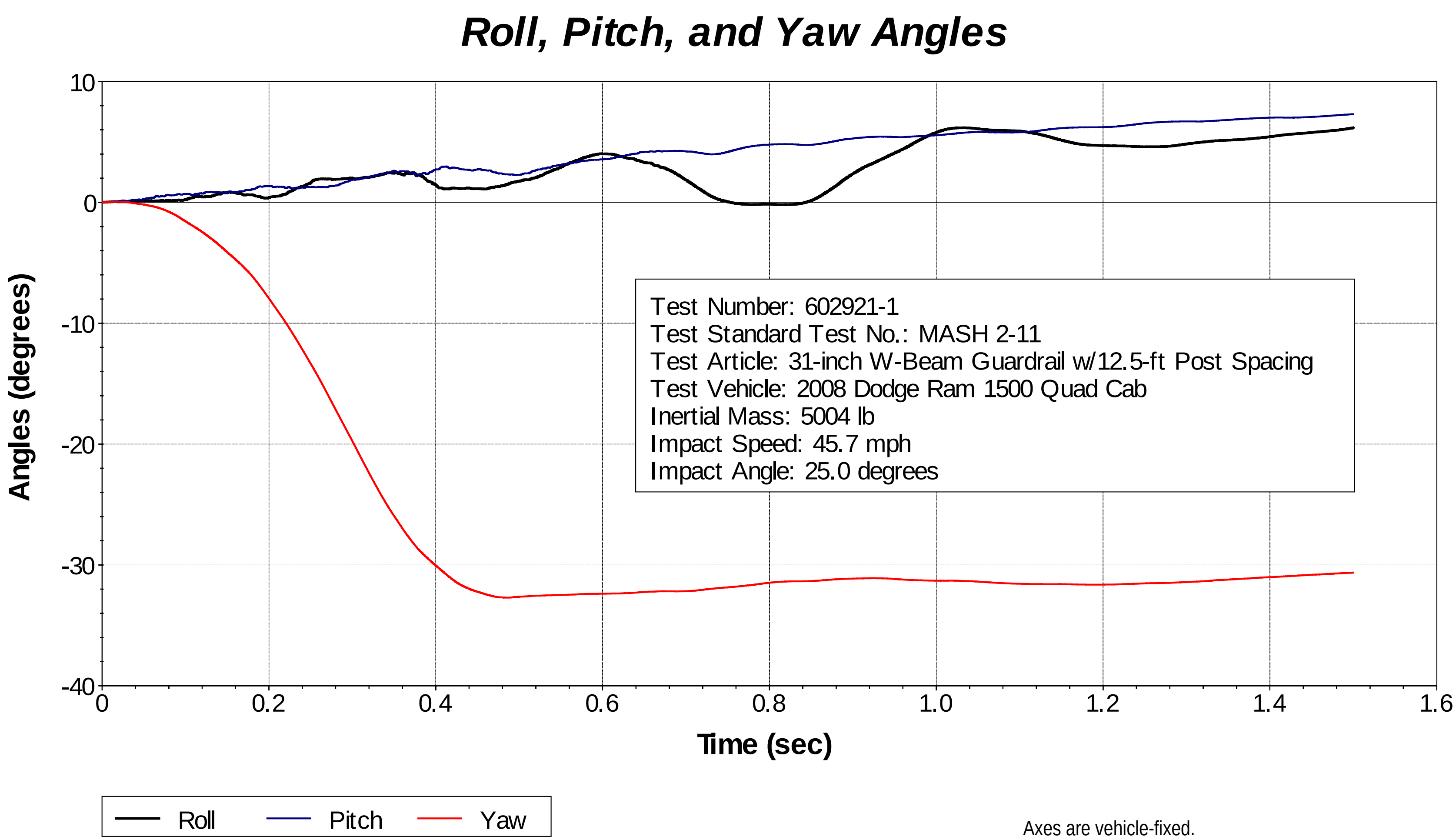


0.588 s



0.686 s


Figure D.1. Sequential Photographs for Test No. 602921-1 (Overhead and Frontal Views) (Continued).



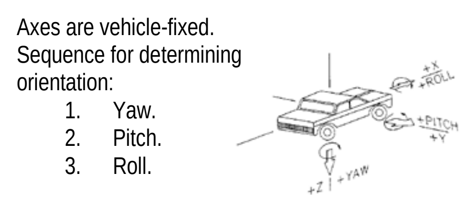


Figure D.2. Vehicle Angular Displacements for Test No. 602921-1.

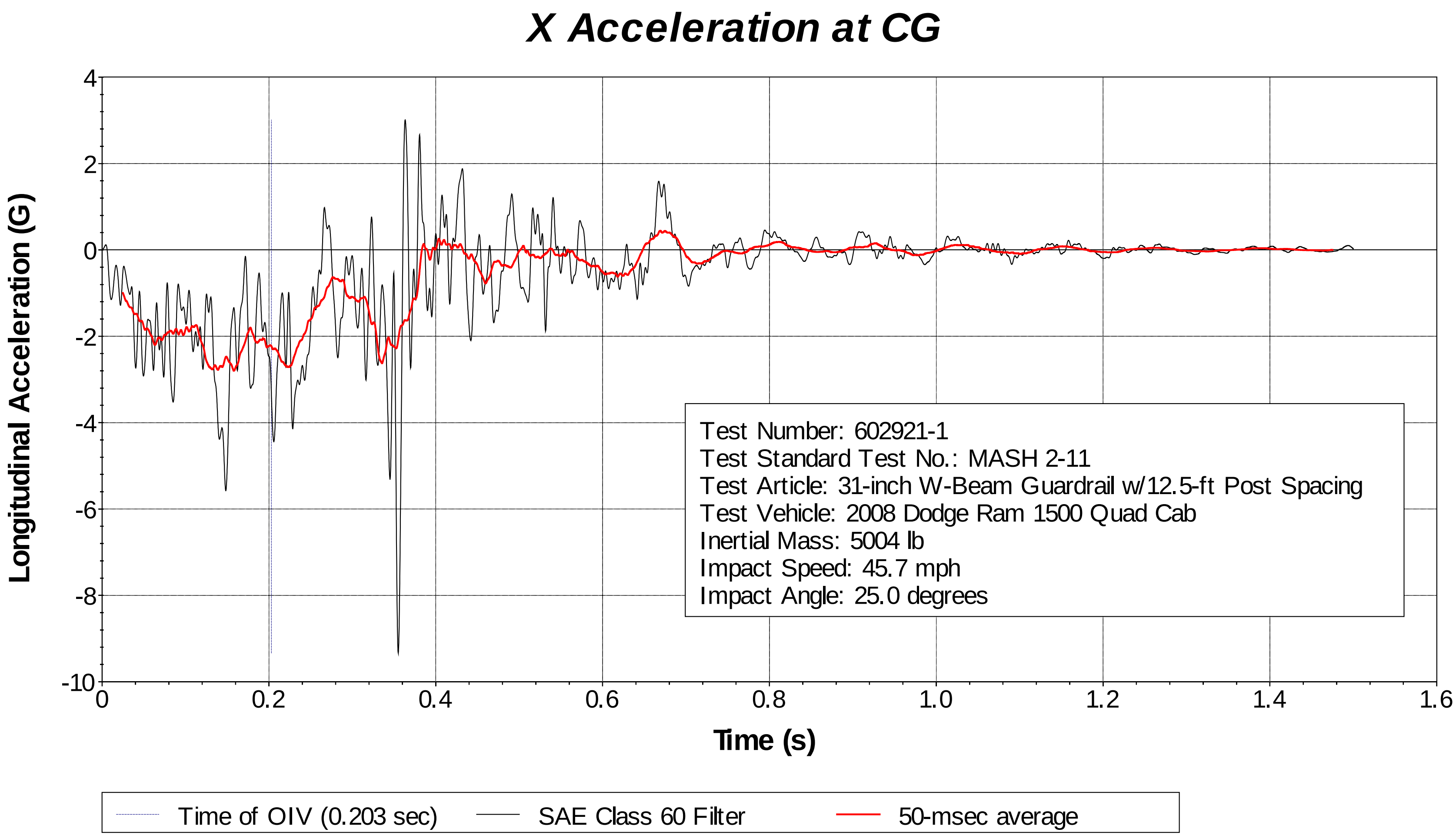


Figure D.3. Vehicle Longitudinal Accelerometer Trace for Test No. 602921-1 (Accelerometer Located at Center of Gravity).

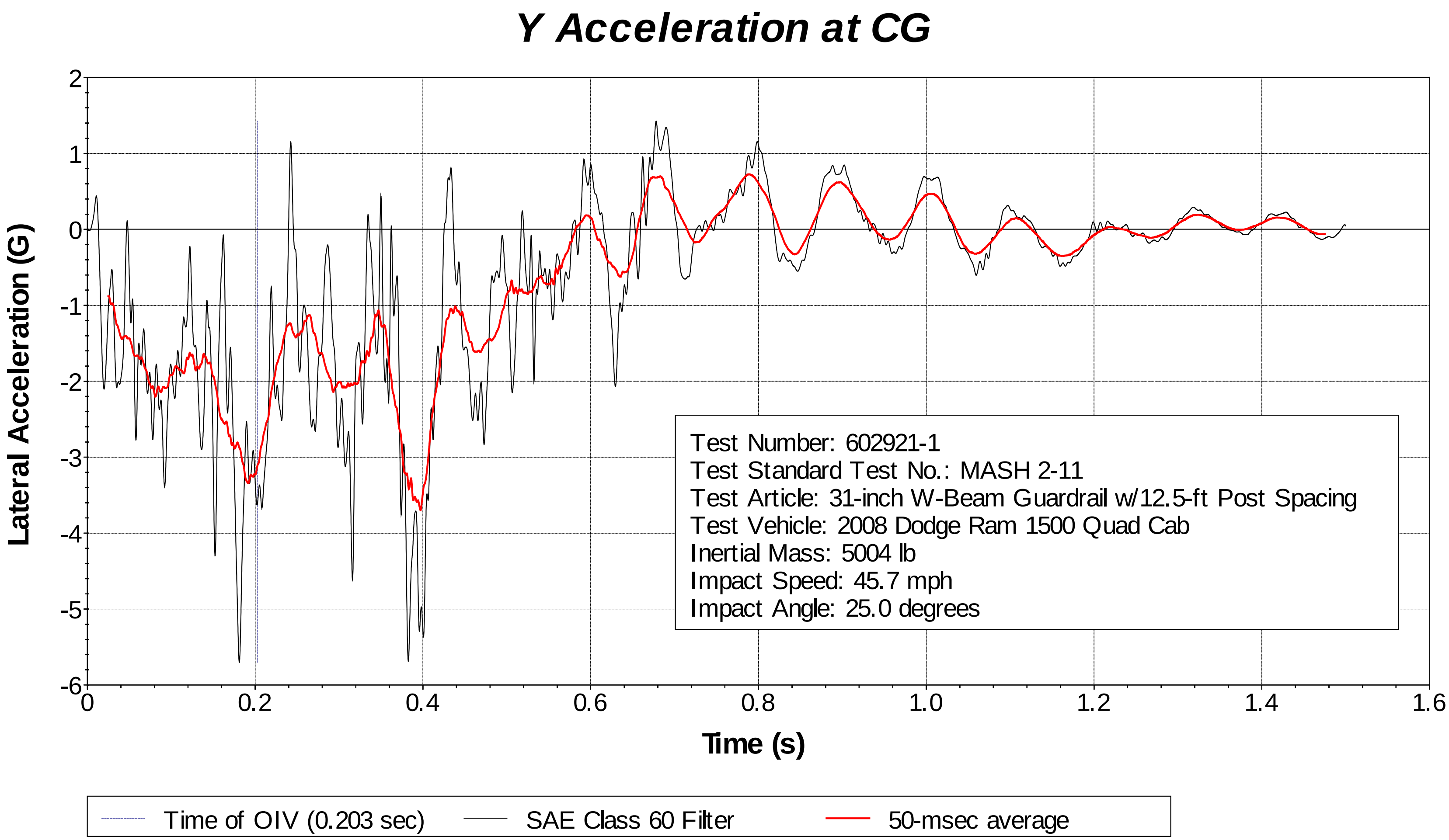


Figure D.4. Vehicle Lateral Accelerometer Trace for Test No. 602921-1 (Accelerometer Located at Center of Gravity).

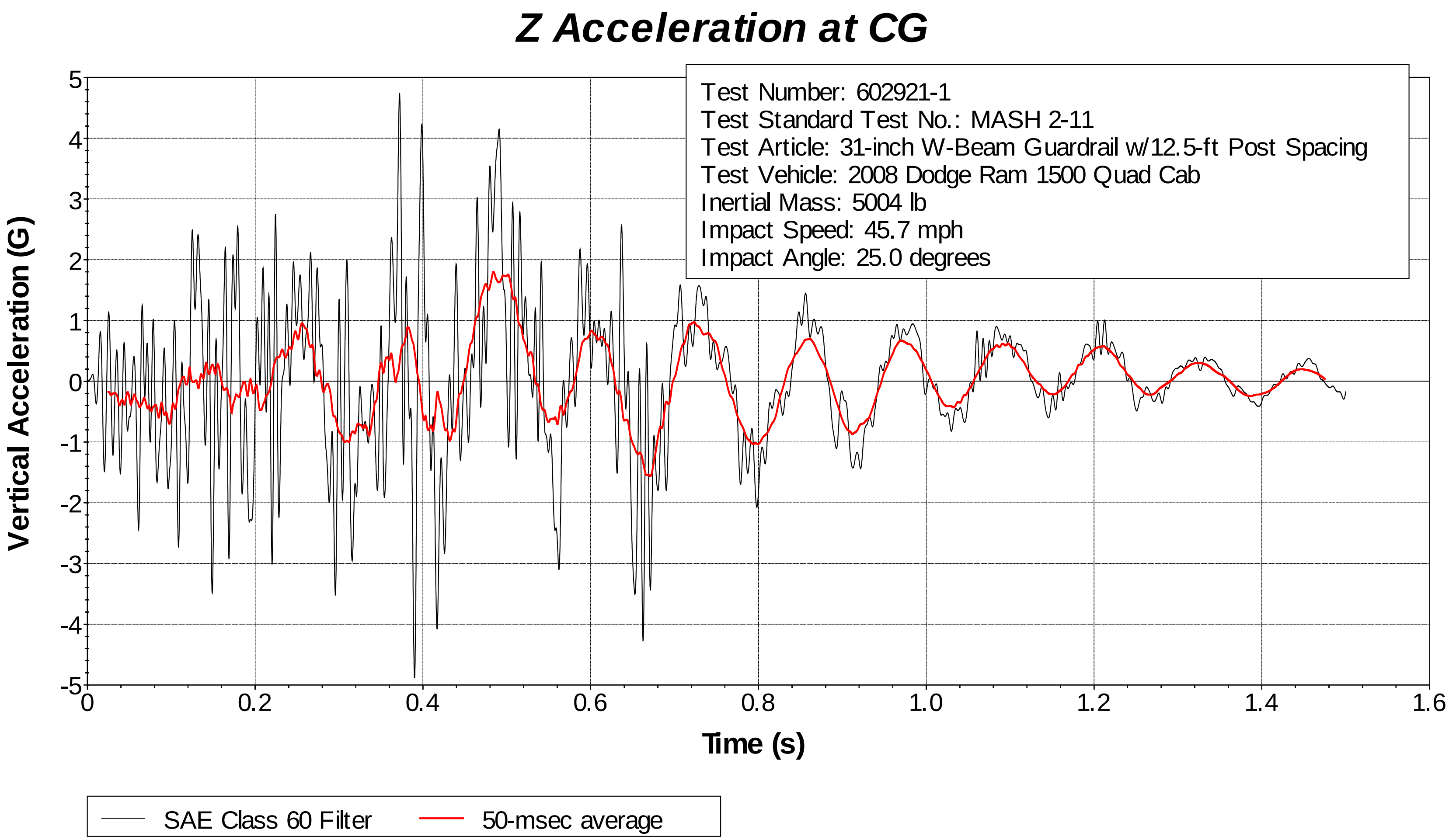


Figure D.5. Vehicle Vertical Accelerometer Trace for Test No. 602921-1 (Accelerometer Located at Center of Gravity).

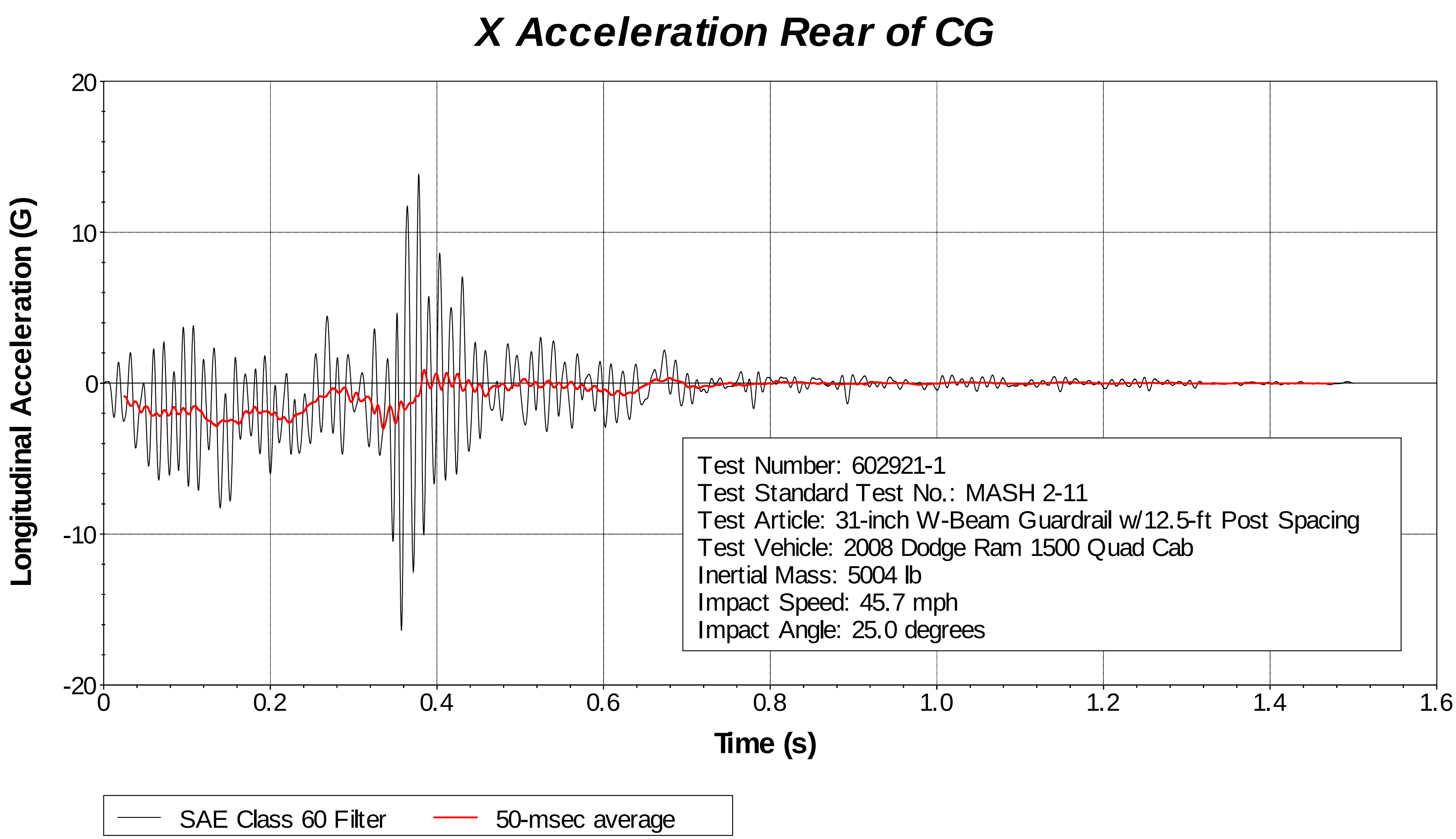


Figure D.6. Vehicle Longitudinal Accelerometer Trace for Test No. 602921-1 (Accelerometer Located Rear of Center of Gravity).

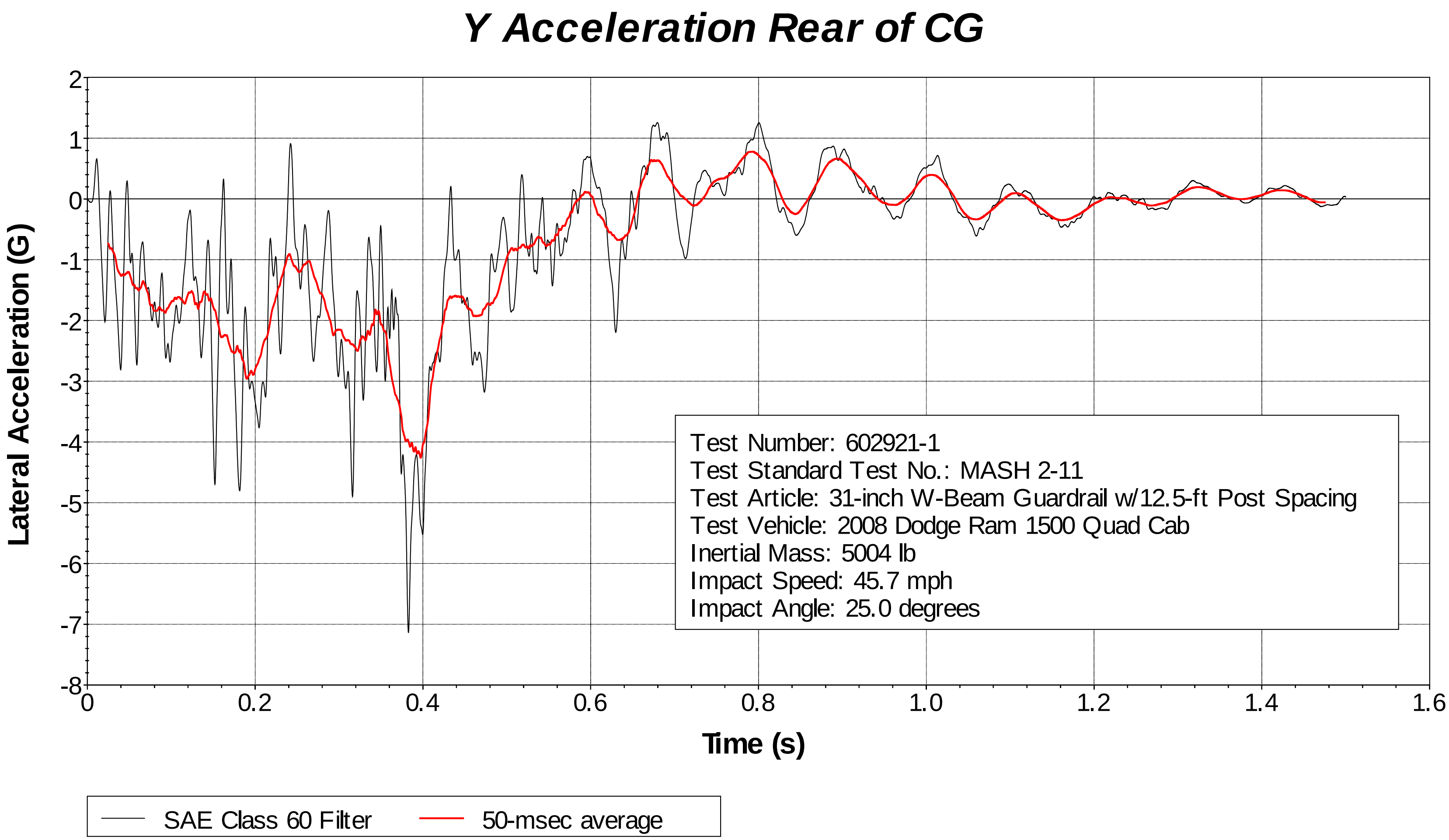


Figure D.7. Vehicle Lateral Accelerometer Trace for Test No. 602921-1 (Accelerometer Located Rear of Center of Gravity).

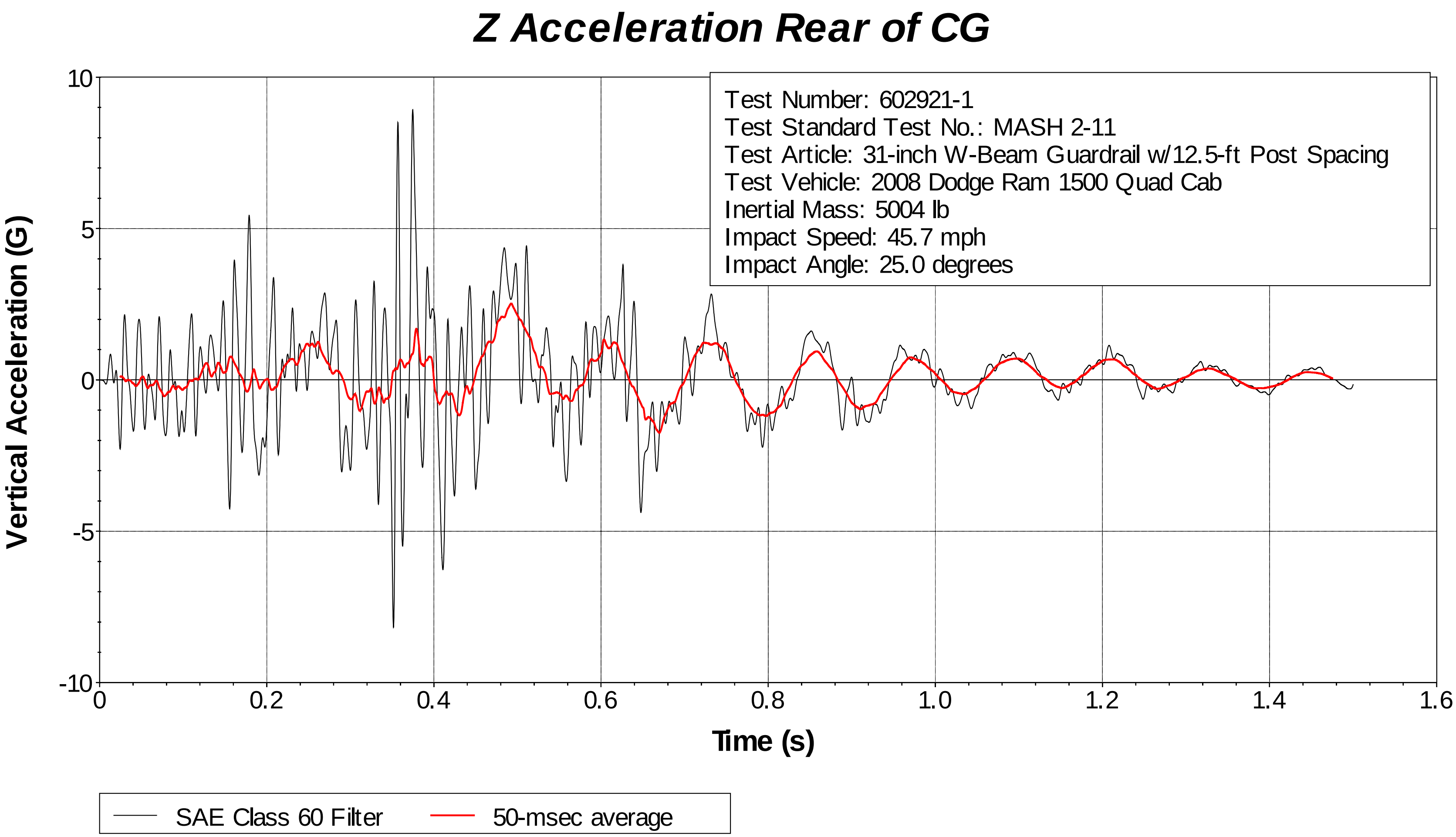


Figure D.8. Vehicle Vertical Accelerometer Trace for Test No. 602921-1 (Accelerometer Located Rear of Center of Gravity).