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MASH TL-3 TESTING AND EVALUATION OF FREE-STANDING PORTABLE CONCRETE BARRIER

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16. Abstract

The objective of this research was to test a 32 inch tall, F-shape profile, free-standing Portable Concrete Barrier (PCB) in accordance with the American Association of State Highway Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) testing criteria. *MASH* Tests 3-10 and 3-11 were performed on the barrier. The overall length of the barrier installation was 201 ft-3 inches. The installation was comprised of sixteen 12 ft-6 inch long precast concrete barrier segments that were connected to each other using pin-and-loop connections.

This report provides details of the free-standing PCB, documentation of the crash tests performed, the results of each crash test, and the assessment of the performance of the free-standing PCB according to *MASH* Test Level 3 (TL-3) specifications.

The free-standing PCB performed acceptably for *MASH* TL-3.

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Longitudinal barrier, Portable Concrete Barrier, PCB, portable concrete barrier, PCB, median barrier, free-standing barrier, MASH, crash testing, roadside safety	Copyrighted. Not to be copied or reprinted without consent from the Roadside Safety Research Program Pooled Fund.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSTIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSTIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Chapter 1. INTRODUCTION

1.1 INTRODUCTION

Through the Roadside Safety Pooled Fund Program TPF-5(114), Texas A&M Transportation Institute's researchers developed a Portable Concrete Barrier (PCB) system that can be anchored to concrete and asphalt pavements. The basic, freestanding barrier design used in the anchored barrier system was based on an Oregon DOT PCB system that was successfully tested under National Cooperative Highway Research Program (NCHRP) *Report 350* (*1*). A previous pooled fund project (405160-3) adapted this basic PCB design to develop a method to anchor the barrier on to concrete pavement (*2*). This anchored detail was developed and tested using *NCHRP Report 350*, which was the testing criteria at the time.

All subsequent development of the anchored barrier, which included pinning to asphalt pavement, transitions from free-standing to anchored barriers, transitions from anchored to rigid barriers, etc. (*3*-*6*) was performed using the American Association of State Highway Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) testing criteria (*7*). The pooled fund states desire to evaluate the free-standing version of the PCB used in these designs, and the anchored barrier tested on concrete, in accordance with *MASH* criteria. Successful completion of this will result in a system with all aspects tested under MASH.

1.2 OBJECTIVE

The objective of this research was to test the free-standing PCB used in the previously developed restrained PCB design, in accordance with *MASH* testing criteria. *MASH* Tests 3-10 and 3-11 were performed on the free-standing PCB, as described below.

1. *MASH* Test 3-10. This test involves the *MASH* 1100C small passenger car impacting the barrier at 62 mi/h and 25 degrees.
2. *MASH* Test 3-11. This test involves the *MASH* 2270P pickup truck impacting the barrier at 62 mi/h and 25 degrees.

This report provides details of the free-standing PCB, documentation of the crash tests performed, the results of each crash test, and the assessment of the performance of the free-standing PCB according to *MASH* Test Level 3 (TL-3) criteria.

Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The overall length of the test installation was 201 ft-3 inches. The installation was comprised of sixteen 12 ft-6 inch long precast concrete F-shape barrier segments connected end-to-end. The F-shape segments were 32 inches tall, 24 inches wide at the base, and 9½ inches wide at the top. The barrier segments were set on an unreinforced concrete apron. No pins, anchors, or adhesives were used to secure the segments to the apron. Details of the segments, including steel reinforcement, can be found in Appendix A.

Adjacent precast barrier segments were connected using a pin-and-loop type connection. The barrier connection was comprised of two sets of three loops that extended from the ends of adjacent barrier segments. A connecting pin was inserted through the loops to establish the connection. After installation, the slack in the barrier connections was removed. The distance between the end faces of adjacent barrier segments was about 1 inch. Refer to Sheet 5 of 5 in Appendix A for details of the connection.

Figure 2.1 presents overall information on the free-standing PCB, and Figure 2.2 provides photographs of the installation. Appendix A provides further details of the Free-Standing PCB.

2.2. MATERIAL SPECIFICATIONS

The minimum compressive strength of the concrete for the precast F-shape barrier segments, provided by Waskey Bridges, Inc., was specified as 5000 psi. Cores were taken from the tops of segments 4 and 8 on Test No. 607911-1. The unconfined compressive strength of the concrete cores was 9150 psi and 4930 psi, respectively.

All reinforcing steel was grade 60 material. The loops for the connecting pin were fabricated from ASTM A36 steel. The connecting pin between adjacent barrier segments was fabricated from ASTM A449 steel. The washer on each connecting pin met ASTM A572 grade 50 standards. Certification documents for the materials used are included in Appendix B.

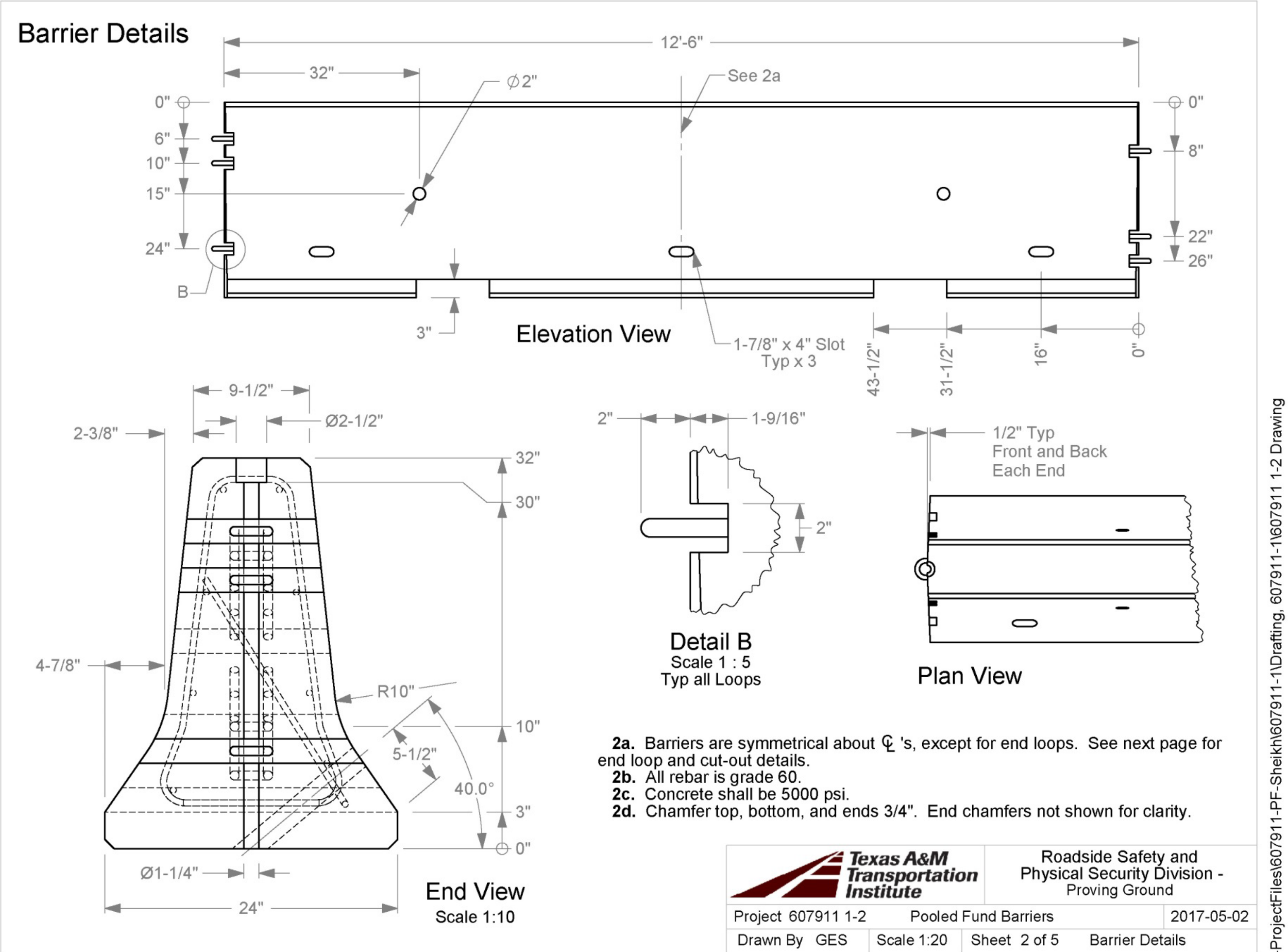


Figure 2.1. Overall Details of the Free-Standing PCB.

Figure 2.2. Free-Standing PCB prior to Testing.

Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST MATRIX

According to *MASH*, two tests are recommended to evaluate longitudinal barriers, such as PCBs, for *MASH* Test Level 3 (TL-3). Details of these tests are shown in Table 3.1

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

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

MASH Tests 3-10 and 3-11 evaluate a barrier's ability to successfully contain and redirect passenger vehicles and evaluate occupant risk. *MASH* Test 3-11 also evaluates the structural adequacy of the barrier.

Both crash tests were performed on the free-standing PCB. The target critical impact point (CIP) selected for each test was determined according to guidance provided in *MASH (Section 2.3.2.1 and Table 2-7)*. The target CIP for *MASH* Test 3-10 on the free-standing PCB was 3.6 ft upstream of the joint between segments 6 and 7, and for *MASH* Test 3-11 was 4.3 ft upstream of the joint between segments 6 and 7. Figures 3.1 and 3.2 show the impact points on the free-standing PCB for *MASH* Tests 3-10 and 3-11, respectively.

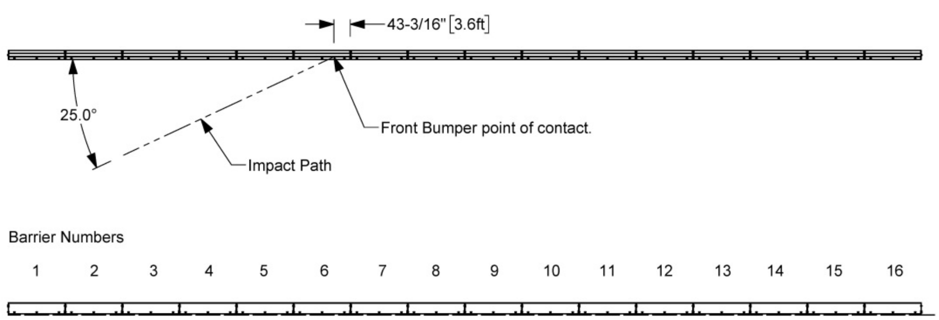


Figure 3.1. Target CIP for *MASH* Test 3-10 on the Free-Standing PCB.

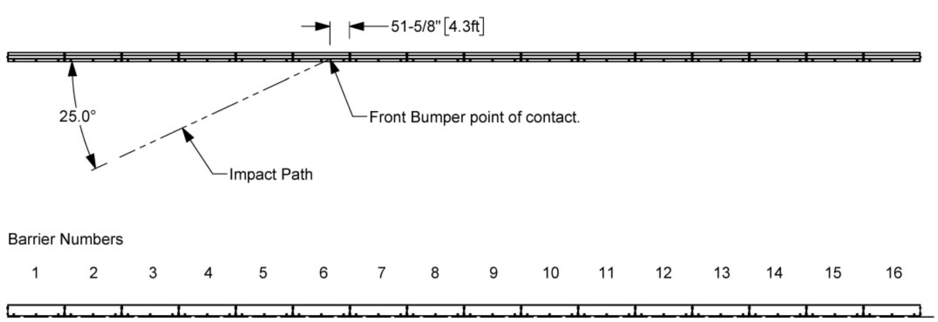


Figure 3.2. Target CIP for *MASH* Test 3-11 on the Free-Standing PCB.

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

3.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2A and 5-1A through 5-1C of *MASH* were used to evaluate the crash tests reported herein. The test conditions and evaluation criteria required for *MASH* TL-3 are listed in Table 3.1, and the substance of the evaluation criteria in Table 3.2. An evaluation of the crash test results are presented in detail under the section entitled Assessment of Test Results.

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

Structural Adequacy	*A.*	*Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*
Occupant Risk	*D.*	*Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*
		Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.
	F.	*The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*
	H.	*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.*
	I.	*Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.*

Chapter 4. TEST CONDITIONS

4.1. TEST FACILITY

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

The test facilities of the TTI Proving Ground are located on the Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 miles northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and evaluation of roadside safety hardware and perimeter protective devices. The site selected for construction and testing of the PCB was an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement, but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE SYSTEM

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

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

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

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

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

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

4.3.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side of the 1100C vehicle. The dummy was not instrumented.

According to *MASH*, use of a dummy in the 2270P vehicle is optional, and a dummy was not used in the test with the 2270P vehicle.

4.3.3 Photographic Instrumentation Data Processing

Photographic coverage of each test included three digital high-speed cameras:

- One overhead with a field of view perpendicular to the ground and directly over the impact point;
- One placed behind the installation at an angle; and
- A third placed to have a field of view parallel to and aligned with the installation at the downstream end.

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the PCB. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

Chapter 5. *MASH* TEST 3-10 (CRASH TEST NO. 607911-1)

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-10 involves an 1100C vehicle weighing 2420 lb ±55 lb impacting the CIP of the free-standing PCB at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The CIP for *MASH* Test 3-10 on the free-standing PCB was 3.6 ft ±1 ft upstream of the joint between segments 6 and 7.

The 2011 Kia Rio used in the test weighed 2428 lb, and the actual impact speed and angle were 62.8 mi/h and 25.2 degrees, respectively. The actual impact point was 3.3 ft upstream of the joint between segments 6 and 7. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 58 kip-ft.

5.2 WEATHER CONDITIONS

The test was performed on the morning of March 6, 2017. Weather conditions at the time of testing were as follows: wind speed: 16 mi/h; wind direction: 181 degrees (vehicle was traveling in a northerly direction); temperature: 77°F; relative humidity: 79 percent.

5.3 TEST VEHICLE

The 2011 Kia Rio shown in Figures 5.1 and 5.2 was used for the crash test. The vehicle's test inertia weight was 2428 lb. Its gross static weight including the dummy was 2593 lb. The height to the lower edge of the vehicle bumper was 8.0 inches, and the height to the upper edge of the bumper was 21.5 inches. Table C.1 in Appendix C1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 5.1. Free-Standing PCB/Test Vehicle Geometrics for Test No. 607911-1.

Figure 5.2. Test Vehicle before Test No. 607911-1.

5.4 TEST DESCRIPTION

The 2011 Kia Rio, traveling at an impact speed of 62.8 mi/h, contacted the Free-Standing PCB 3.3 ft upstream of the joint between segments 6 and 7 at an impact angle of 25.2 degrees. At 0.011 s after impact, the left front tire began to climb the traffic face of segment 6, and at 0.023 s, segment 6 began to displace toward the field side and rotate about the joint between segments 5 and 6. The vehicle began to redirect at 0.034 s and the downstream end of segment 7 began to displace toward the traffic side at 0.044 s. At 0.058 s, the upstream end of segment 8 began to displace toward the traffic side, and at 0.165 s, the joint between segments 7 and 8 began to displace toward the field side. The vehicle began traveling parallel to the barrier at 0.181 s, and the left rear of the vehicle contacted segment 7 at 0.262 s. At 0.276 s, concrete began to spall from the downstream field side toe of segment 7, and at 0.284 s, concrete began to spall from the upstream field side toe of segment 8. The vehicle lost contact with the barrier at 0.545 s, and was traveling at an exit speed and angle of 47.7 mi/h and 5.8 degrees. Brakes on the vehicle were not applied. Figures C.1 and C.2 in Appendix C2 present sequential photographs during the test.

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). After loss of contact with the barrier, the vehicle yawed counterclockwise and came to rest 193 ft downstream of the impact and 9 ft toward traffic lanes. The 1100C vehicle exited within the exit box criteria defined in *MASH*.

5.5 DAMAGE TO TEST INSTALLATION

Figures 5.3 and 5.4 show the damage to the free-standing PCB. Concrete broke off at the impact side toes of segments 6 and 7 at the joint. Concrete spalled from the downstream field side toe of segment 7, from the upstream field side toe of segment 8, and from the upstream field side toe of segment 9. Tire marks and scrapes were noted along the traffic side for a distance of 16.7 ft from point of impact. Working width was 60.7 inches. Maximum dynamic deflection during the test was 36.2 inches, and maximum permanent deflection was 34.0 inches.

Figure 5.3. Free-Standing PCB after Test No. 607911-1.

Figure 5.4. Field Side Free-Standing PCB after Test No. 607911-1.

5.6 VEHICLE DAMAGE

Figure 5.5 shows the damage sustained by the vehicle. The front bumper, hood, left strut and tower, left front tire and rim, left front fender, left front and rear doors, left rear quarter panel, and rear bumper were damaged. The left side floor pan sustained light damage, and the left front door was deformed at the top near the roof/door frame, leaving a small gap. Maximum exterior crush to the vehicle was 9.5 inches in the left side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 0.5 inches in the left firewall and floor pan area. Figure 5.6 shows the interior of the vehicle. Tables C.2 and C.3 in Appendix C1 provides exterior crush and occupant compartment measurements.

5.7 OCCUPANT RISK FACTORS

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 (OIV) was 18.4 ft/s at 0.084 s, the highest 0.010-s occupant ridedown acceleration was 4.7 g from 0.142 to 0.152 s, and the maximum 0.050-s average acceleration was –10.4 g between 0.018 and 0.068 s. In the lateral direction, the OIV was 22.6 ft/s at 0.084 s, the highest 0.010-s occupant ridedown acceleration was 9.2 g from 0.240 to 0.250 s, and the maximum 0.050-s average was 13.3 g between 0.006 and 0.056 s. Theoretical Head Impact Velocity (THIV) was 31.5 km/h or

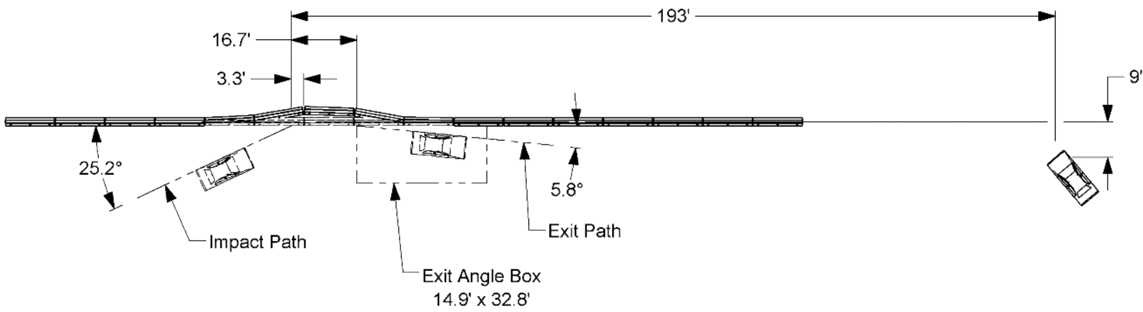
8.7 m/s at 0.081 s; Post-Impact Head Decelerations (PHD) was 9.3 g between 0.240 and 0.250 s; and Acceleration Severity Index (ASI) was 1.93 between 0.040 and 0.090 s. Figure 5.7 summarizes these data and other pertinent information from the test. Figure C.3 in Appendix C3 shows the vehicle angular displacements, and Figures C.4 through C.9 in Appendix C4 show acceleration versus time traces.

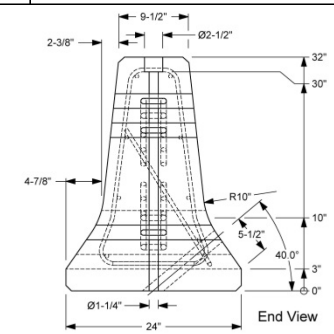
Figure 5.5. Test Vehicle after Test No. 607911-1.

Before Test   After Test

Figure 5.6. Interior of Test Vehicle for Test No. 607911-1.

0.000 s | 0.160 s | 0.320 s | 0.480 s





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-10
TTI Test No.	607911-1
Test Date	2017-03-06

Test Article

Type	Portable Concrete Barrier
Name	Free-Standing PCB
Installation Length	201 ft-3 inches
Material or Key Elements	F-shape segments 32 inches tall, 24 inches wide at the base, 9½ inches wide at the top with pin and loop type connection

Soil Type and Condition	Concrete Pavement, Damp

Test Vehicle

Type/Designation	1100C
Make and Model	2011 Kia Rio
Curb	2470 lb
Test Inertial	2428 lb
Dummy	165 lb
Gross Static	2593 lb

Impact Conditions

Speed	62.8 mi/h
Angle	25.2 degrees
Location/Orientation	3.3 ft upstream of joint 6-7

Impact Severity	58 kip-ft

Exit Conditions

Speed	47.7 mi/h
Angle	5.8 degrees

Occupant Risk Values

Longitudinal OIV	18.4 ft/s
Lateral OIV	22.6 ft/s
Longitudinal Ridedown	4.7 g
Lateral Ridedown	9.2 g
THIV	31.5 km/h
PHD	9.3 g
ASI	1.93
Max. 0.050-s Average	
Longitudinal	−10.4 g
Lateral	13.3 g
Vertical	−4.1 g

Post-Impact Trajectory

Stopping Distance	193 ft dwnstrm 9 ft twd traffic

Vehicle Stability

Maximum Yaw Angle	62 degrees
Maximum Pitch Angle	6 degrees
Maximum Roll Angle	20 degrees
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	36.2 inches
Permanent	34.0 inches
Working Width	60.7 inches

Vehicle Damage

VDS	11LFQ5
CDC	141FLEW4
Max. Exterior Deformation	9.5 inches
OCDI	LF0000000
Max. Occupant Compartment Deformation	0.5 inches

Figure 5.7. Summary of Results for *MASH* Test 3-10 on the Free-Standing PCB.

5.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable safety evaluation criteria from Table 3.2 for *MASH* Test 3-10 is provided below.

5.8.1 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 free-standing PCB contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 36.2 inches. (PASS)

5.8.2 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 $\leq$4.0 inches; windshield = $\leq$3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan $\leq$9.0 inches; forward of A-pillar $\leq$12.0 inches; front side door area above seat $\leq$9.0 inches; front side door below seat $\leq$12.0 inches; floor pan/transmission tunnel area $\leq$12.0 inches).

Results: Small pieces of concrete broke off in several places, however, these fragments did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area. (PASS)

Maximum occupant compartment deformation was 0.5 inch in the left side firewall and floor pan area. (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 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 20 degrees and 6 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 18.4 ft/s, and lateral occupant impact velocity was 22.6 ft/s. (PASS)

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

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 g	*20.49 g*

Results: Maximum longitudinal ridedown acceleration was 4.7 g, and maximum lateral ridedown acceleration was 9.2 g. (PASS)

Chapter 6. *MASH* TEST 3-11 (CRASH TEST NO. 607911-2)

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb, impacting the CIP of the free-standing PCB at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The CIP for *MASH* Test 3-11 on the free-standing PCB was 4.3 ft ±1 ft upstream of the joint between segments 6 and 7.

The 2012 Dodge RAM 1500 pickup truck used in the test weighed 5014 lb, and the actual impact speed and angle were 62.2 mi/h and 25.3 degrees, respectively. The actual impact point was 4.4 ft upstream of the joint between segments 6 and 7. Minimum target impact severity was 106 kip-ft, and actual IS was 118 kip-ft.

6.2 WEATHER CONDITIONS

The test was performed on the morning of March 9, 2017. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 165 degrees (vehicle was traveling in a northwesterly direction); temperature: 72°F; relative humidity: 81 percent.

6.3 TEST VEHICLE

The 2012 Dodge RAM 1500 pickup truck shown in Figures 6.1 and 6.2 was used for the crash test. The vehicle's test inertia weight was 5014 lb, and its gross static weight was 5014 lb. The height to the lower edge of the vehicle bumper was 12.0 inches, and height to the upper edge of the bumper was 27.5 inches. The height to the vehicle's center of gravity was 28.38 inches. Tables D.1 and D.2 in Appendix D1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.1. Free-Standing PCB/Test Vehicle Geometrics for Test No. 690900-2.

Figure 6.2. Test Vehicle before Test No. 607911-2.

6.4 TEST DESCRIPTION

The 2012 Dodge RAM 1500 pickup truck, traveling at an impact speed of 62.2 mi/h, contacted the free-standing PCB 4.4 ft upstream of the joint between segments 6 and 7 at an impact angle of 25.3 degrees. At 0.014 s after impact, the left front tire began to climb the traffic face of the barrier, and at 0.020 s, the downstream end of segment 6 began to displace toward the field side and the barrier at the joint between segments 5 and 6 began to rotate. Segment 7 began to displace toward traffic lanes at 0.044 s, and the vehicle began to redirect at 0.051 s. At 0.065 s, segment 8 began to displace toward the traffic lanes. Segment 7 began to crack at the one-third point at 0.095 s, and at 0.135 s, segment 7 began to crack at the mid-point. A small piece of concrete spalled from the upstream field side toe of segment 8 at 0.142 s, and the barrier began to displace toward the field side at the joint between segments 7 and 8 at 0.151 s. At 0.196 s, the vehicle began traveling parallel with the barrier, and at 0.254 s, the left rear of the cargo bed contacted segment 7. The B-pillar between the left doors contacted the upstream end of segment 9 at 0.453 s. At 0.732 s, the vehicle lost contact with the barrier and was traveling at an exit speed and angle of 56.3 mi/h and 7.3 degrees. Figures D.1 and D.2 in Appendix D2 present sequential photographs during the test.

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). After loss of contact with the barrier, the vehicle yawed clockwise and came to rest 255 ft downstream of the impact and 100 ft toward traffic. The 2270P vehicle exited within the exit box criteria defined in *MASH*.

6.5 DAMAGE TO TEST INSTALLATION

Figure 5.3 shows the damage to the free-standing PCB. The field side of segment 7 was cracked near the midpoint and at the upstream quarter point. The field and impact side downstream ends of the toe of segment 4 were chipped, and both field side toes of segment 5 were chipped. Figure 5.3 shows the damage to the impact side toes of segments 6 and 7. For segments 8 and 9, the upstream non-impact and impact side toes and the downstream field side toes were chipped. The upstream field side toe of segment 10 was also chipped. Working width was 87.5 inches. Maximum dynamic deflection during the test was 63.4 inches, and maximum permanent deflection was 61.5 inches.

Figure 6.3. Free-Standing PCB after Test No. 607911-2.

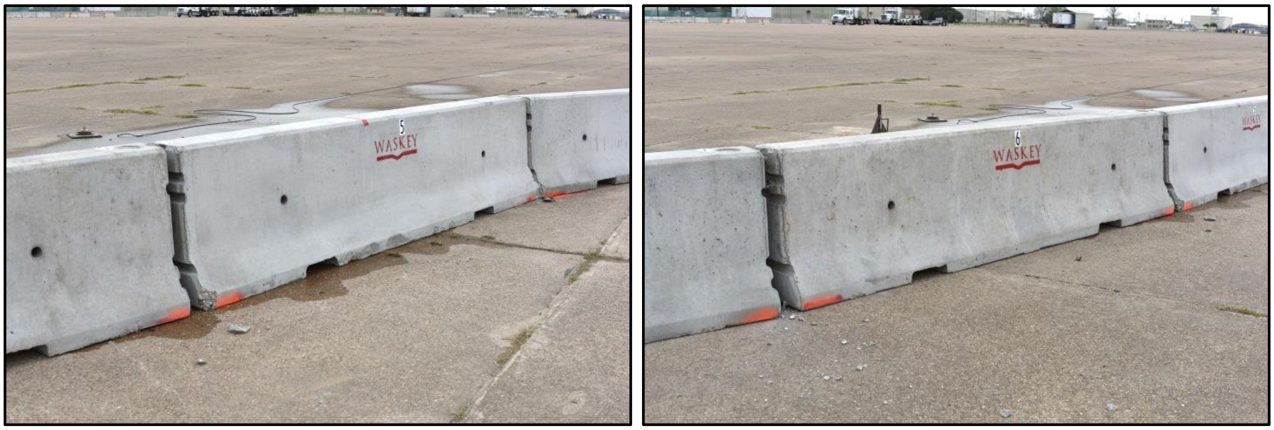


Figure 6.4. Field Side of Segments 5 and 6 after Test No. 607911-2.

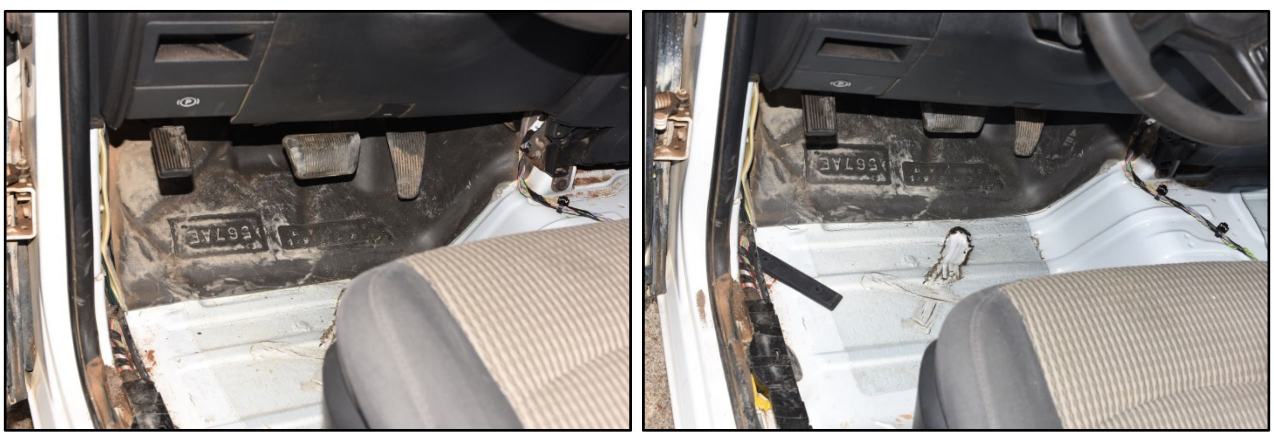
Figure 6.5. Field Side of Segment 7 after Test No. 607911-2.

Figure 6.6. Field Side of Segments 8 and 9 after Test No. 607911-2.

6.6 VEHICLE DAMAGE

Figure 6.7 shows the damage sustained by the vehicle. The front bumper, radiator and support, grill, left front fender, left front tire and rim, left front and rear doors, left lower corner of the cab, left exterior bed, left rear rim, and rear bumper were damaged. The right frame rail was deformed. The left front and rear doors were deformed at the top near the roof/door frame leaving a small opening. Maximum exterior crush to the vehicle was 14.0 inches in the side plane at the left front corner at bumper height. No occupant compartment deformation or intrusion occurred that reduced the size of the occupant compartment. Figure 6.8 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D1 provide exterior crush and occupant compartment measurements.

Figure 6.7. Test Vehicle after Test No. 607911-2.



Before Test After Test

Figure 6.8. Interior of Test Vehicle for Test No. 607911-2.

6.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the OIV was 12.1 ft/s at 0.103 s, the highest 0.010-s occupant ridedown acceleration was 3.7 g from 0.148 to 0.158 s, and the maximum 0.050-s average acceleration was –5.8 g between 0.029 and 0.079 s. In the lateral direction, the OIV was 18.4 ft/s at 0.103 s, the highest 0.010-s occupant ridedown acceleration was 14.4 g from 0.279 to 0.289 s, and the maximum 0.050-s average was 10.5 g between 0.027 and 0.077 s. THIV was 24.2 km/h or 6.7 m/s at 0.100 s; PHD was 14.6 g between 0.279 and 0.289 s; and ASI was 1.34 between 0.052 and 0.102 s. Figure 6.9 summarizes these data and other pertinent information from the test. Figures D.3 in Appendix D3 shows the vehicle angular displacements, and Figures D.4 through D.9 in Appendix D4 show acceleration versus time traces.

6.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable safety evaluation criteria from Table 3.2 for *MASH* Test 3-11 is provided below.

6.8.1 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 free-standing PCB contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 63.4 inches. (PASS)

6.8.2 Occupant Risk

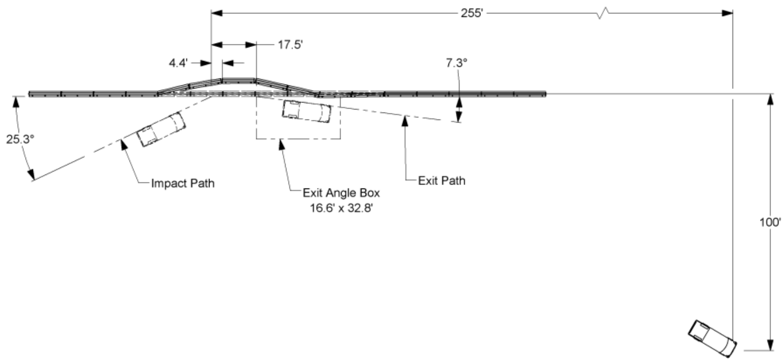
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.

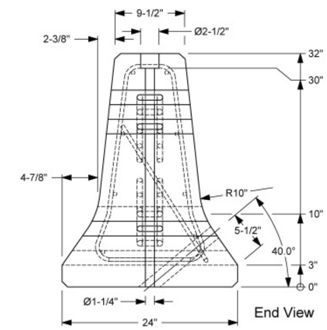
Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤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: Small pieces of concrete broke off in several places, however, these fragments did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area. (PASS)

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

0.000 s | 0.220 s | 0.440 s | 0.660 s





General Information
- Test Agency .... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. .... MASH Test 3-11
- TTI Test No. 607911-2
- Test Date 2017-03-09

Test Article
- Type .... Portable Concrete Barrier
- Name .... Free-Standing PCB
- Installation Length .... 201 ft-3 inches
- Material or Key Elements .... F-shape segments 32 inches tall, 24 inches wide at the base, 9½ inches wide at the top with pin and loop type connection

Soil Type and Condition .... Concrete Pavement, Damp

Test Vehicle
- Type/Designation 2270P
- Make and Model .... 2012 Dodge RAM 1500
- Curb .... 4858 lb
- Test Inertial .... 5014 lb
- Dummy .... No dummy
- Gross Static .... 5014 lb

Impact Conditions
- Speed .... 62.2 mi/h
- Angle .... 25.3 degrees
- Location/Orientation .... 4.4 ft upstream of joint 6-7

Impact Severity .... 118 kip-ft

Exit Conditions
- Speed .... 56.3 mi/h
- Angle .... 7.3 degrees

Occupant Risk Values
- Longitudinal OIV .... 12.1 ft/s
- Lateral OIV .... 18.4 ft/s
- Longitudinal Ridedown .... 3.7 g
- Lateral Ridedown .... 14.4 g
- THIV .... 24.2 km/h
- PHD .... 14.6 g
- ASI 1.34

Max. 0.050-s Average
- Longitudinal .... −5.8 g
- Lateral .... 10.5 g
- Vertical .... −2.2 g

Post-Impact Trajectory
- Stopping Distance .... 255 ft dwnstrm 100 ft twd traffic

Vehicle Stability
- Maximum Yaw Angle .... 51 degrees
- Maximum Pitch Angle .... 10 degrees
- Maximum Roll Angle .... 32 degrees
- Vehicle Snagging .... No
- Vehicle Pocketing .... No

Test Article Deflections
- Dynamic .... 63.4 inches
- Permanent .... 61.5 inches
- Working Width .... 87.5 inches

Vehicle Damage
- VDS 11LFQ5
- CDC 11FLEW4
- Max. Exterior Deformation .... 14.0 inches
- OCDI FS0000000
- Max. Occupant Compartment Deformation .... None

Figure 6.9. Summary of Results for *MASH* Test 3-11 on the Free-Standing PCB.

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 32 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 12.1 ft/s, and lateral occupant impact velocity was 18.4 ft/s. (PASS)

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

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 g	*20.49 g*

Results: Maximum longitudinal ridedown acceleration was 3.7 g, and maximum lateral ridedown acceleration was 14.4 g. (PASS)

Chapter 7. SUMMARY AND CONCLUSIONS

7.1 ASSESSMENT OF TEST RESULTS

An assessment of the tests based on the applicable safety evaluation criteria from Table 3.2 for *MASH* TL-3 longitudinal barriers is provided below and in Tables 7.1 and 7.2.

7.1.1 *MASH* Test 3-10 (Crash Test No. 607911-1)

The free-standing PCB contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 36.2 inches. Small pieces of concrete broke off in several places, however, these fragments did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area. Maximum occupant compartment deformation was 0.5 inch in the left side firewall and floor pan area. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 20 degrees and 6 degrees, respectively. Occupant risk factors were within the preferred limits specified in *MASH*.

7.1.2 *MASH* Test 3-11 (Crash Test No. 607911-2)

The free-standing PCB contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 63.4 inches. Small pieces of concrete broke off in several places, however, these fragments did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area. No occupant compartment deformation or intrusion occurred that reduced the size of the occupant compartment. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 32 degrees and 10 degrees, respectively. Occupant risk factors were within the preferred limits specified in *MASH*.

6.2 CONCLUSIONS

Table 7.3 shows that the Free-Standing PCB performed acceptably for *MASH* TL-3 criteria.

Table 7.1. Performance Evaluation Summary for *MASH* Test 3-10 on the Free-Standing PCB.

Test Agency: Texas A&M Transportation Institute — Test No.: 607911-1 — Test Date: 2017-03-06

***MASH* Test 3-10 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The free-standing PCB contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 36.2 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.*	Small pieces of concrete broke off in several places, however, these fragments did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 0.5 inch in the left side firewall and floor pan area.	
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 20 degrees and 6 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 18.4 ft/s, and lateral occupant impact velocity was 22.6 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.*	Maximum longitudinal ridedown acceleration was 4.7 g, and maximum lateral ridedown acceleration was 9.2 g.	Pass

Table 7.2. Performance Evaluation Summary for *MASH* Test 3-11 on the Free-Standing PCB.

Test Agency: Texas A&M Transportation Institute | Test No.: 607911-2 | Test Date: 2017-03-09

MASH Test 3-11 Evaluation Criteria	Test Results	Assessment
Structural Adequacy *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The free-standing PCB contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 63.4 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.*	Small pieces of concrete broke off in several places, however, these fragments did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion occurred that reduced the size of the occupant compartment.	
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 32 degrees and 10 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 12.1 ft/s, and lateral occupant impact velocity was 18.4 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.	Maximum longitudinal ridedown acceleration was 3.7 g, and maximum lateral ridedown acceleration was 14.4 g.	Pass

Table 7.3. Assessment Summary for *MASH* TL-3 Tests on the Free-Standing PCB.

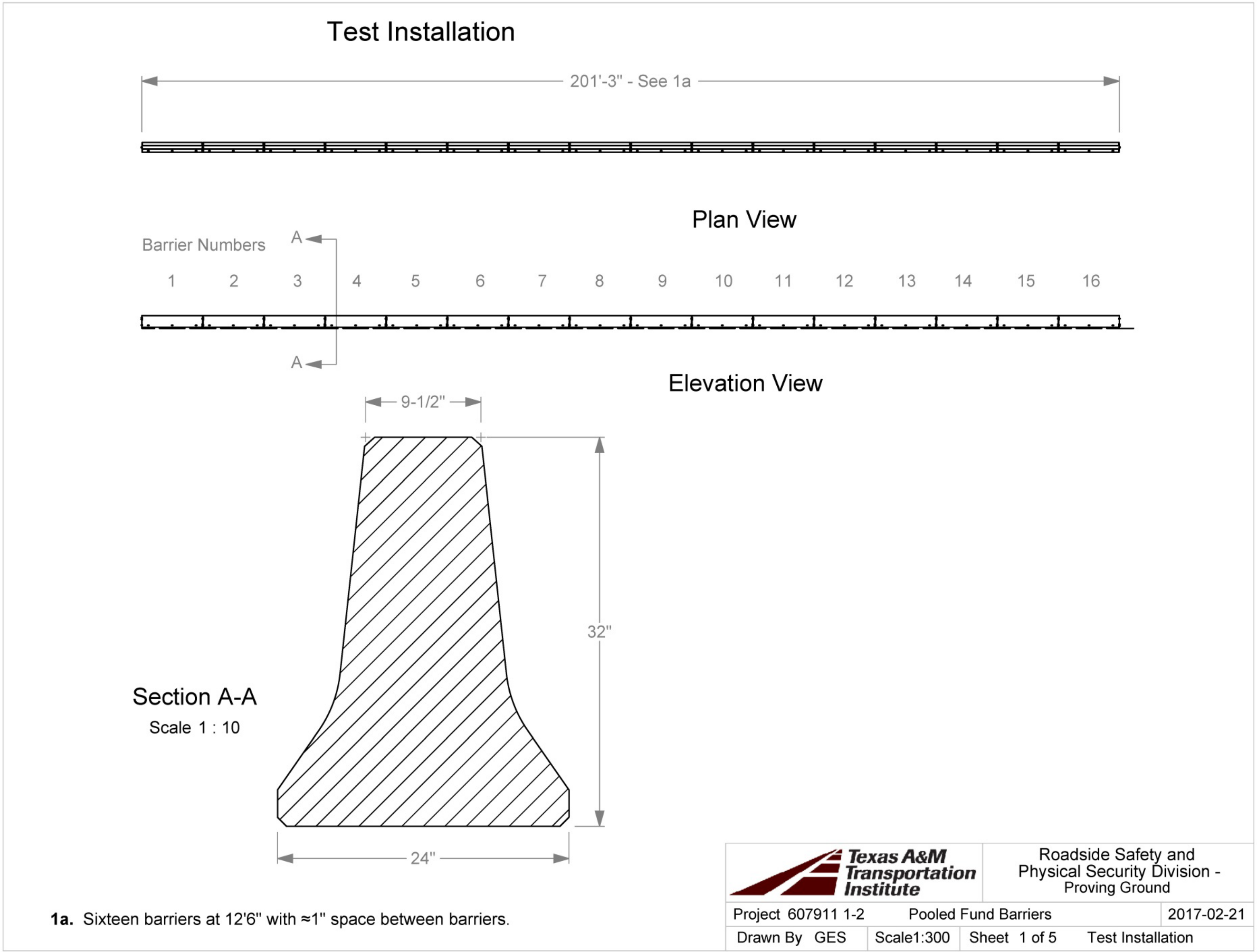
Evaluation Factors	Evaluation Criteria	Test No. 607911-1	Test No. 607911-2
Structural Adequacy	A	S	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
Test Designation		***MASH* Test 3-10**	***MASH* Test 3-11**
Pass/Fail		Pass	Pass

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

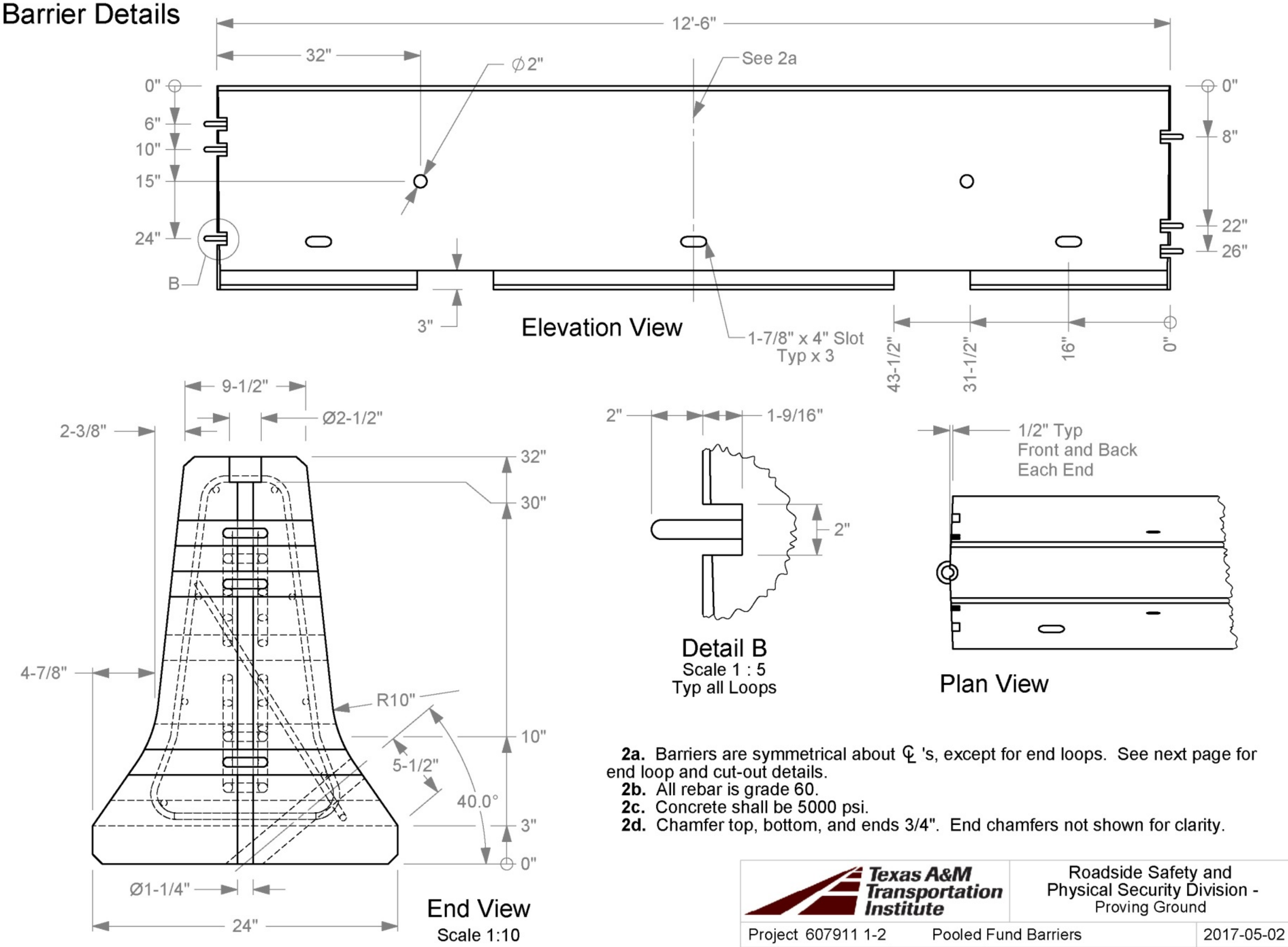
REFERENCES

1. H. E. Ross, Jr., D. L. Sicking, and R. A. Zimmer. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. Report 350, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 1993.
2. N. M. Sheikh, R.P. Bligh, and W. L. Menges. *Crash Testing and Evaluation of the 12 ft Pinned F-shape Temporary Barrier*. Test Report No. 405160-3-1/2a, Texas A&M Transportation Institute, College Station, TX, 2008.
3. N. M. Sheikh and W. L. Menges. *Development and Testing of Anchored Portable Concrete Barrier for Use on Asphalt*. Test Report No. 405160-25-1, Texas A&M Transportation Institute, College Station, TX, 2012.
4. N. M. Sheikh and W. L. Menges. *Development and Testing of a Transition From Free-Standing to Pinned Portable Concrete Barrier*. Test Report No. 405160-26, Texas A&M Transportation Institute, College Station, TX, 2013.
5. N. M. Sheikh and W. L. Menges. *Transition Design for Pinned-Down Anchored Temporary Barrier to Rigid Concrete Barrier*. Test Report No. 405160-34-1, Texas A&M Transportation Institute, College Station, TX, 2012.
6. N. M. Sheikh, W. L. Menges, and D. L. Kuhn. *MASH Transition From F-Shape Portable Concrete Barrier Pinned on Asphalt to Rigid Single-Slope Concrete Barrier*. Test Report No. 605641-1, Texas A&M Transportation Institute, College Station, TX, 2016.
7. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition.* 2016, American Association of State Highway and Transportation Officials: Washington, DC.

APPENDIX A. DETAILS OF THE TEMPORARY PCB



Barrier Details

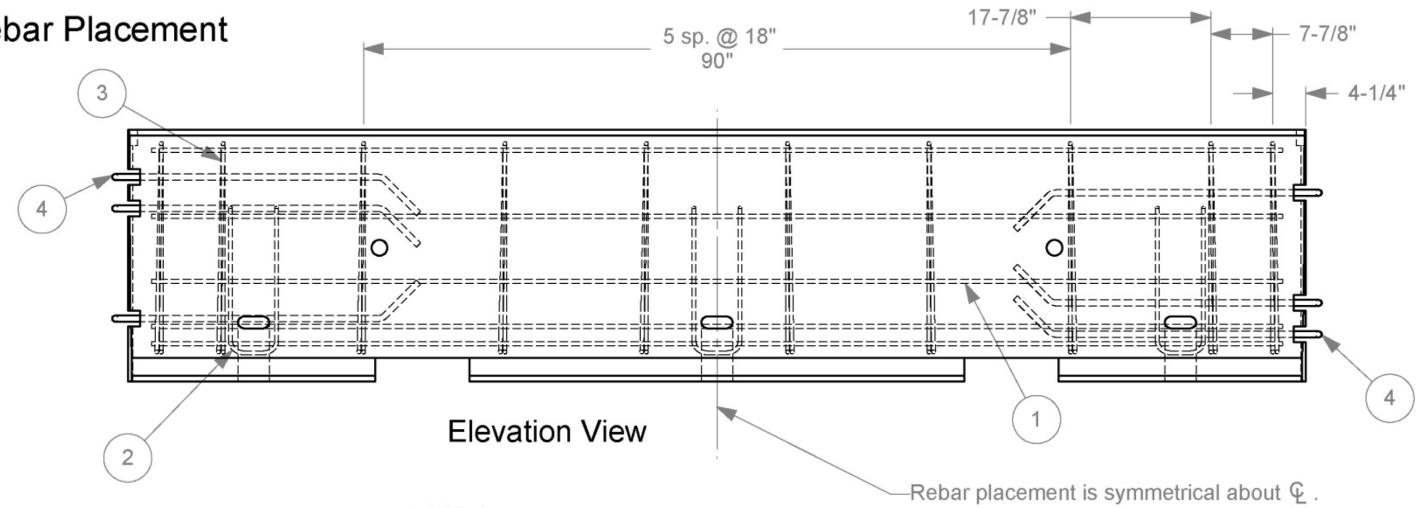


2a. Barriers are symmetrical about ℄'s, except for end loops. See next page for end loop and cut-out details.
2b. All rebar is grade 60.
2c. Concrete shall be 5000 psi.
2d. Chamfer top, bottom, and ends 3/4". End chamfers not shown for clarity.

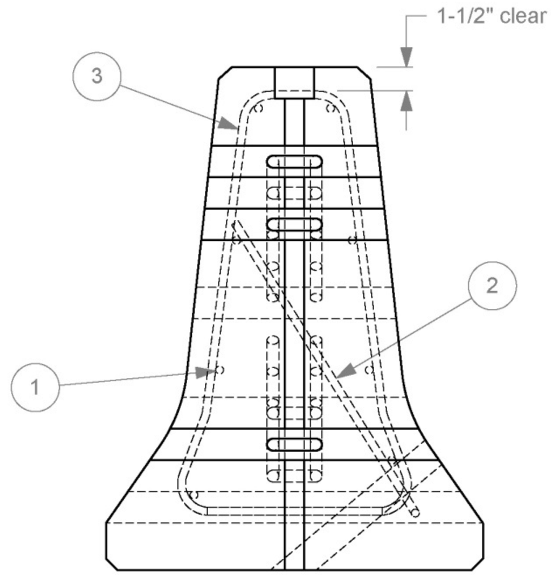
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 607911 1-2	Pooled Fund Barriers		2017-05-02
Drawn By GES	Scale 1:20	Sheet 2 of 5	Barrier Details

T:\1-ProjectFiles\607911-PF-Sheikh\607911-1\Drafting, 607911 1-2 Drawing

Rebar Placement



Elevation View



End View

Scale 1:10

#	PART NAME	QTY.
1	Rebar, #4 x 144"	8
2	403 Bar	3
3	Stirrup	10
4	End Loops	6

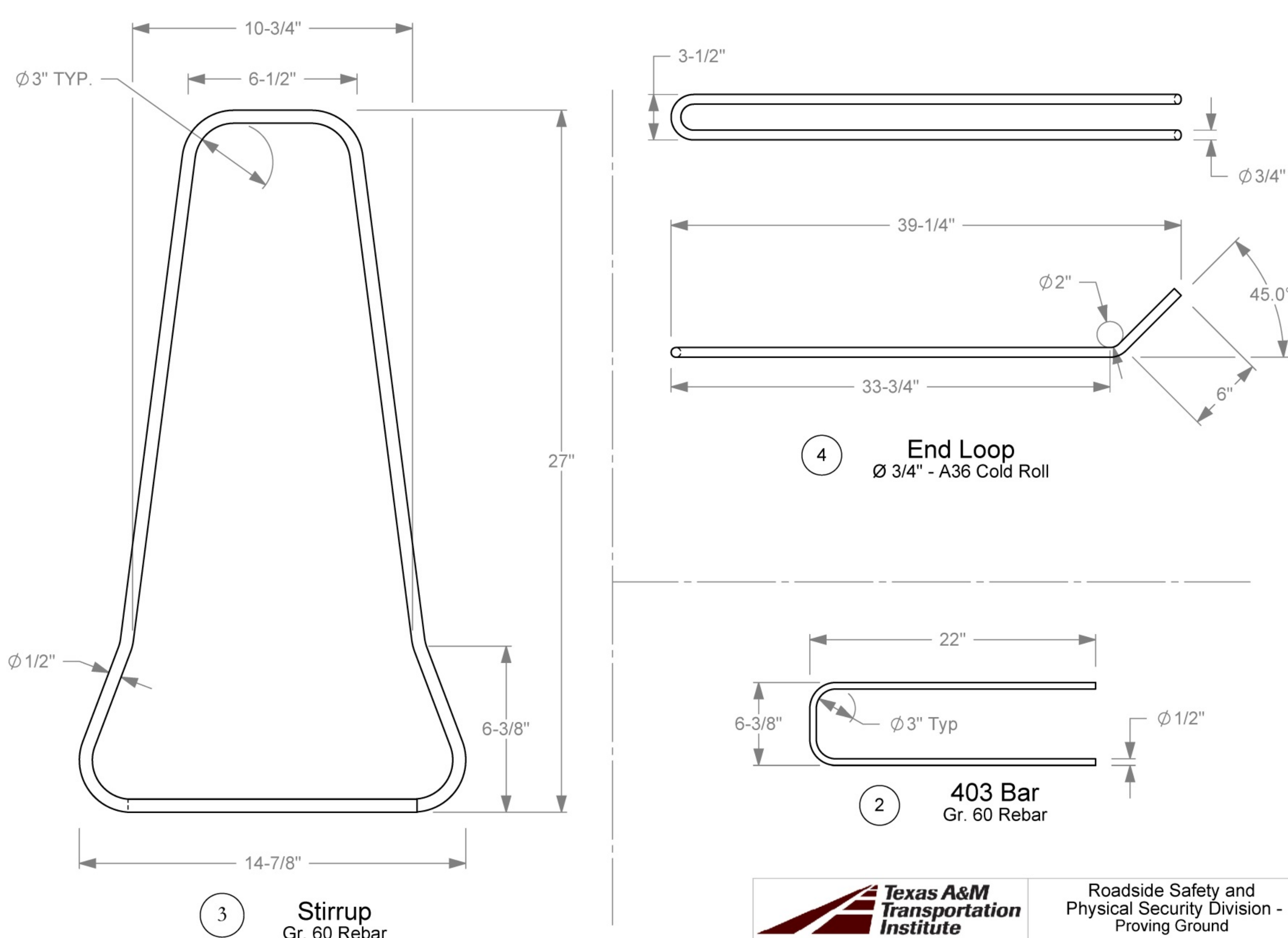
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project 607911 1-2 | Pooled Fund Barriers | 2017-05-02

Drawn By GES | Scale 1:20 | Sheet 3 of 5 | Rebar Placement

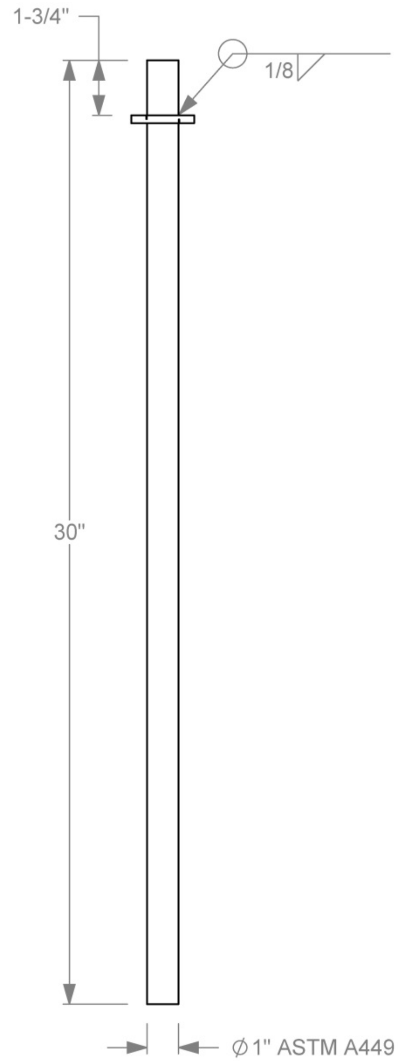
T:\1-ProjectFiles\607911-PF-Sheikh\607911-1\Drafting, 607911-1\607911 1-2 Drawing



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project 607911 1-2	Pooled Fund Barriers	2017-02-21
Drawn By GES	Scale 1:10	Sheet 4 of 5 Barrier Parts

T:\1-ProjectFiles\607911 - Sheikh\607911-1\Drafting, 607911 1-2 Drawing

Pin Details



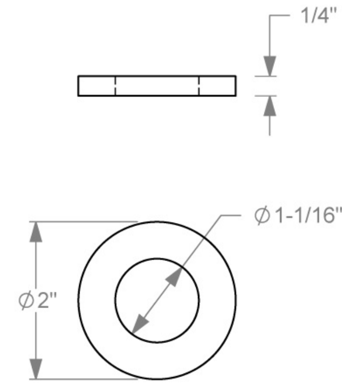


Plate Washer
for Connecting Pin
A572 grade 50
Scale 1:2

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 607911 1-2	Pooled Fund Barriers		2017-02-21
Drawn By GES	Scale 1:5	Sheet 5 of 5	Pin Details

T:\1-ProjectFiles\607911 - Sheikh\607911-1\Drafting, 607911-1\607911 1-2 Drawing

CONCRETE CORE TEST REPORT

Report Number: A1171057.0001
Service Date: 03/09/17
Report Date: 03/16/17 Revision 1 - Results
Task:

Test No. 607911-1

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength:

Specified Length: 4.00 Min
Mix ID:
Nominal Maximum Size Aggregate:

Sample Information

Placement Date: Unknown
Date Tested: 03/09/17 **Time:** 0000
Sampled By: Alexander Farabee
Drill Directions: Vertical
Date Core Obtained: 03/09/17 **Time:** 1400
Date Ends Trimmed: 03/09/17 **Time:** 0000
Moisture Conditioning History: According to ASTM C-42

Laboratory Test Data

Core ID		Location	Cored Length (in)	Trim Length (in)	Capped Length (in)	Diam. (in)	Area (sq in)	Length / Diam. Ratio	Max Load (lbs)	Corr. Factor	Comp. Strength (psi)	Fracture Type	Density (pcf)
1	A	Barrier 6	11.5	5.8	6.0	4.00	12.57	1.50	136370	0.960	10420	3	
1	B	Barrier 7	11.5	5.7	6.0	4.00	12.57	1.50	114180	0.960	8720	3	

Comments: ASTM C42 states: "Historically, it has been assumed that core strengths are generally 85 % of the corresponding standard-cured cylinder strengths, but this is not applicable to all situations. The acceptance criteria for core strength are to be established by the specifier of the tests. ACI 318 provides core strength acceptance criteria for new construction". ACI 318, 26.12.4.1c states "Concrete in an area represented by core tests shall be considered structurally adequate if the average of three cores is equal to at least 85 percent of fc' and no single core is less than 75 percent of fc'." ACI 318, 26.4.1d states: "Additional testing of cores extracted from locations represented by erratic core strength results shall be permitted."

CONCRETE CORE TEST REPORT

Report Number: A1171057.0001
Service Date: 03/09/17
Report Date: 03/16/17 Revision 1 - Results
Task:

Test No. 607911-1

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Services:
Terracon Rep.: Alexander Farabee
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Nicole Farabee

Start/Stop: 1300-1645

Reviewed By:
Mark E.Dornak, P.E.
Project Manager

Test Methods: ASTM C42

APPENIDX C. *MASH* TEST 3-10 (CRASH TEST NO. 607911-1)

C1 VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 607911-1.

Date:	2017-03-06	Test No.:	607911-1	VIN No.:	KNADH4A34B6736947
Year:	2011	Make:	Kia	Model:	Rio
Tire Inflation Pressure:	32 psi	Odometer:	144003	Tire Size:	185/65R14

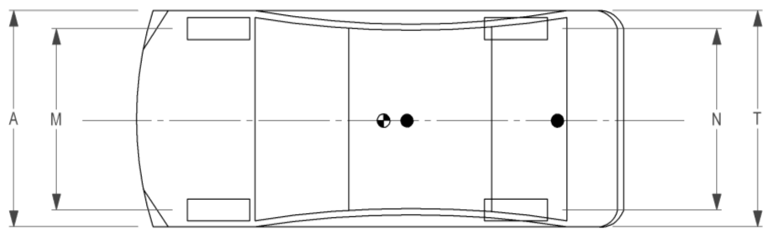
Describe any damage to the vehicle prior to test: None

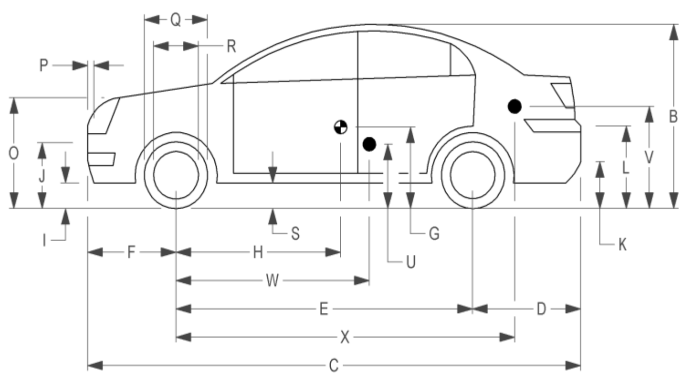
● Denotes accelerometer location.

NOTES: None

Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:
None

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





Geometry: inches

A	66.38	F	33.00	K	12.00	P	4.12	U	14.875
B	58.00	G	-----	L	24.00	Q	22.50	V	20.38
C	165.75	H	35.58	M	57.75	R	15.50	W	35.50
D	34.00	I	8.00	N	57.70	S	15.50	X	106.00
E	98.75	J	21.50	O	28.50	T	66.20		
Wheel Center Ht Front			11.00	Wheel Center Ht Rear			11.00		

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1718	M_{front}	1580	1553	1638
Back	1874	M_{rear}	890	875	955
Total	3638	M_{Total}	2470	2428	2593

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

Mass Distribution:
lb LF: 770 RF: 783 LR: 428 RR: 447

Table C.2. Exterior Crush Measurements for Test No. 607911-1.

Date:	2017-03-06	Test No.:	607911-1	VIN No.:	KNADH4A34B6736947
Year:	2011	Make:	Kia	Model:	Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	20	7	40	7	5	3	2	1	0	-15
2	Side plane at bumper ht	20	9.5	48	0	1.5	3	6.5	7.25	9.5	+60
	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.

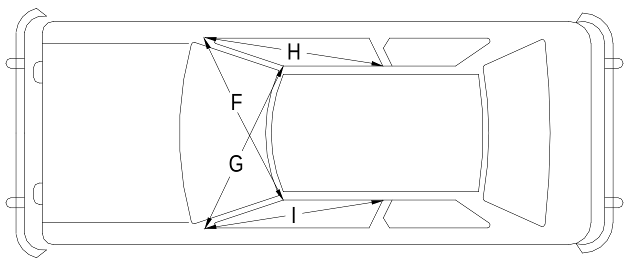
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

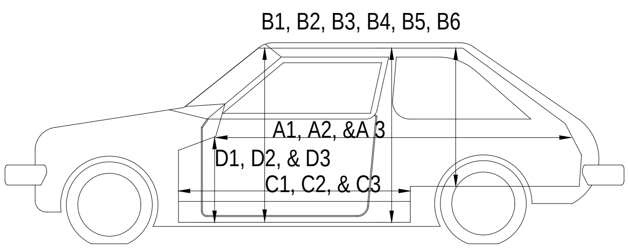
***Measure and document on the vehicle diagram the location of the maximum crush.

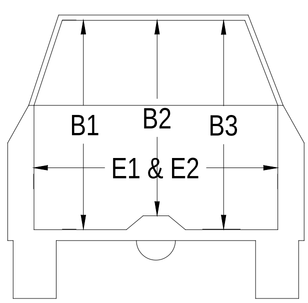
Note: Use as many lines/columns as necessary to describe each damage profile.

Table C.3. Occupant Compartment Measurements for Test No. 607911-1.

Date:	2017-03-06	Test No.:	607911-1	VIN No.:	KNADH4A34B6736947
Year:	2011	Make:	Kia	Model:	Rio







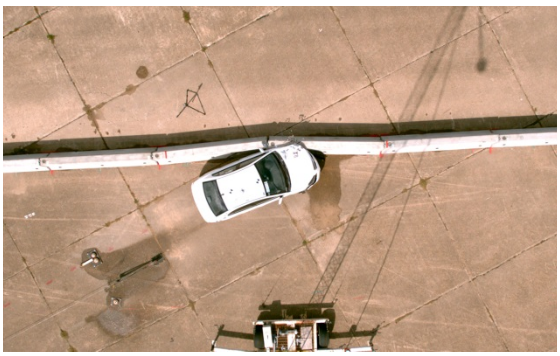
OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.75	67.75	0
A2	67.50	67.50	0
A3	67.75	67.75	0
B1	41.00	41.00	0
B2	36.25	36.25	0
B3	41.00	41.00	0
B4	36.25	36.25	0
B5	36.00	36.00	0
B6	36.25	36.25	0
C1	26.00	25.50	-0.50
C2	-----		-----
C3	26.00	26.00	0
D1	9.50	9.00	-0.50
D2	-----	-----	-----
D3	9.5	9.5	0
E1	51.50	51.75	+0.25
E2	51.25	51.50	+0.25
F	51.00	51.00	0
G	51.00	51.00	0
H	37.00	37.00	0
I	37.00	37.00	0
J*	51.00	50.75	-0.25

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

C2 SEQUENTIAL PHOTOGRAPHS


0.000 s



0.080 s



0.160 s



0.240 s


Figure C.1. Sequential Photographs for Test No. 607911-1 (Overhead and Frontal Views).

0.320 s

0.400 s

0.480 s

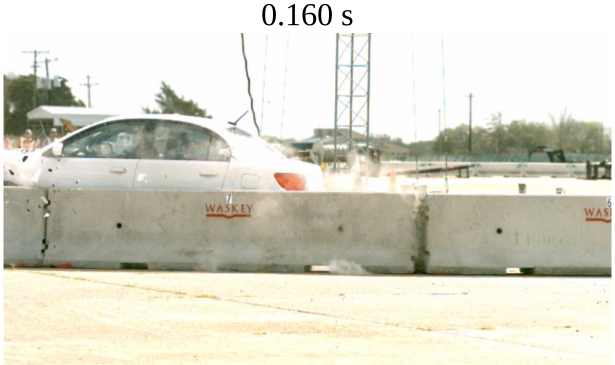
0.560 s

Figure C.1. Sequential Photographs for Test No. 607911-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.080 s

0.160 s



0.240 s

0.320 s

0.400 s

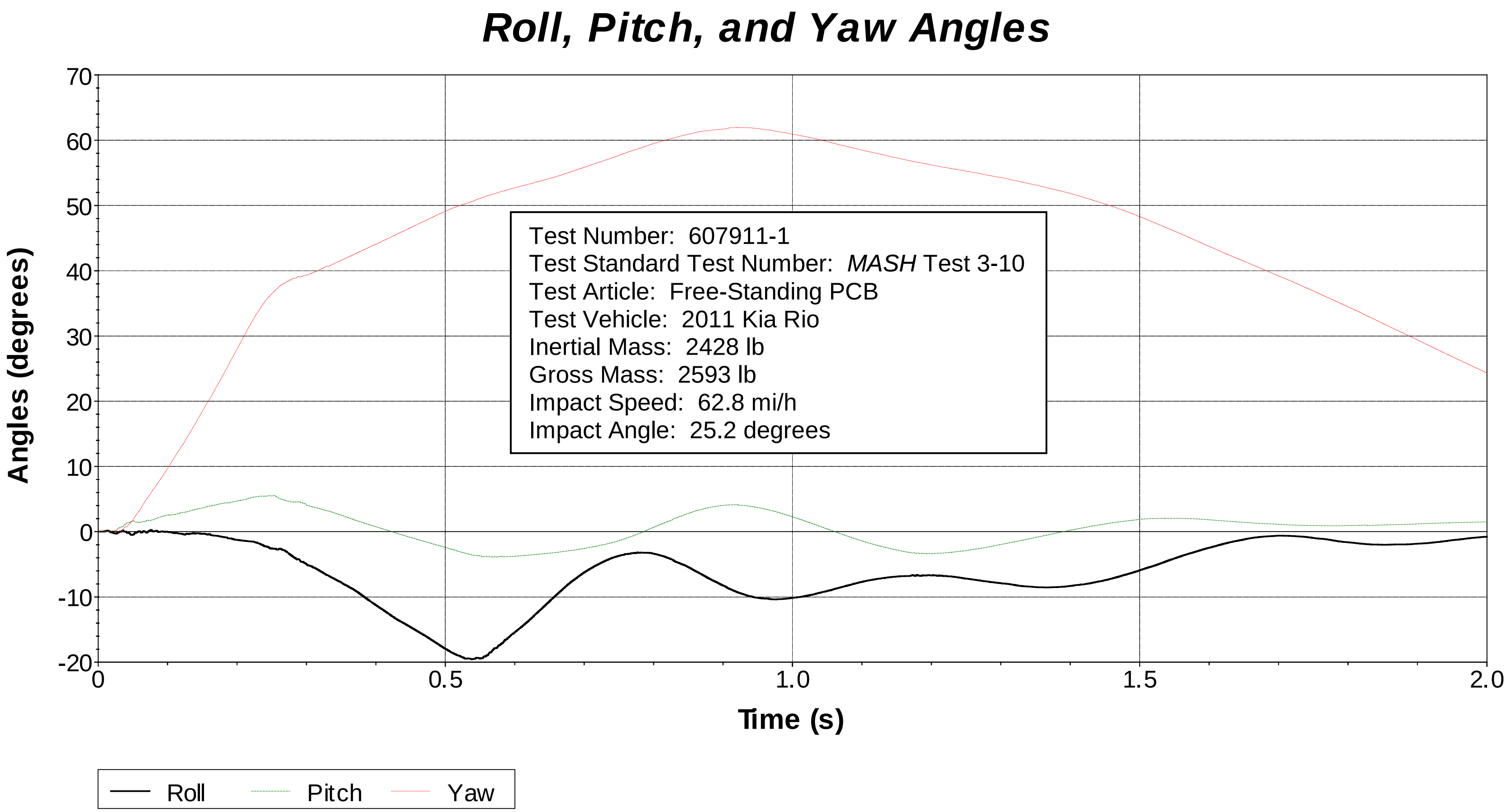
Out of view

0.480 s

Out of view

0.560 s

Figure C.2. Sequential Photographs for Test No. 607911-1 (Rear View).



Axes are vehicle-fixed.
Sequence for determining orientation:

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

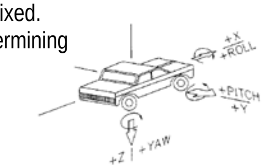


Figure C.3. Vehicle Angular Displacements for Test No. 607911-1.

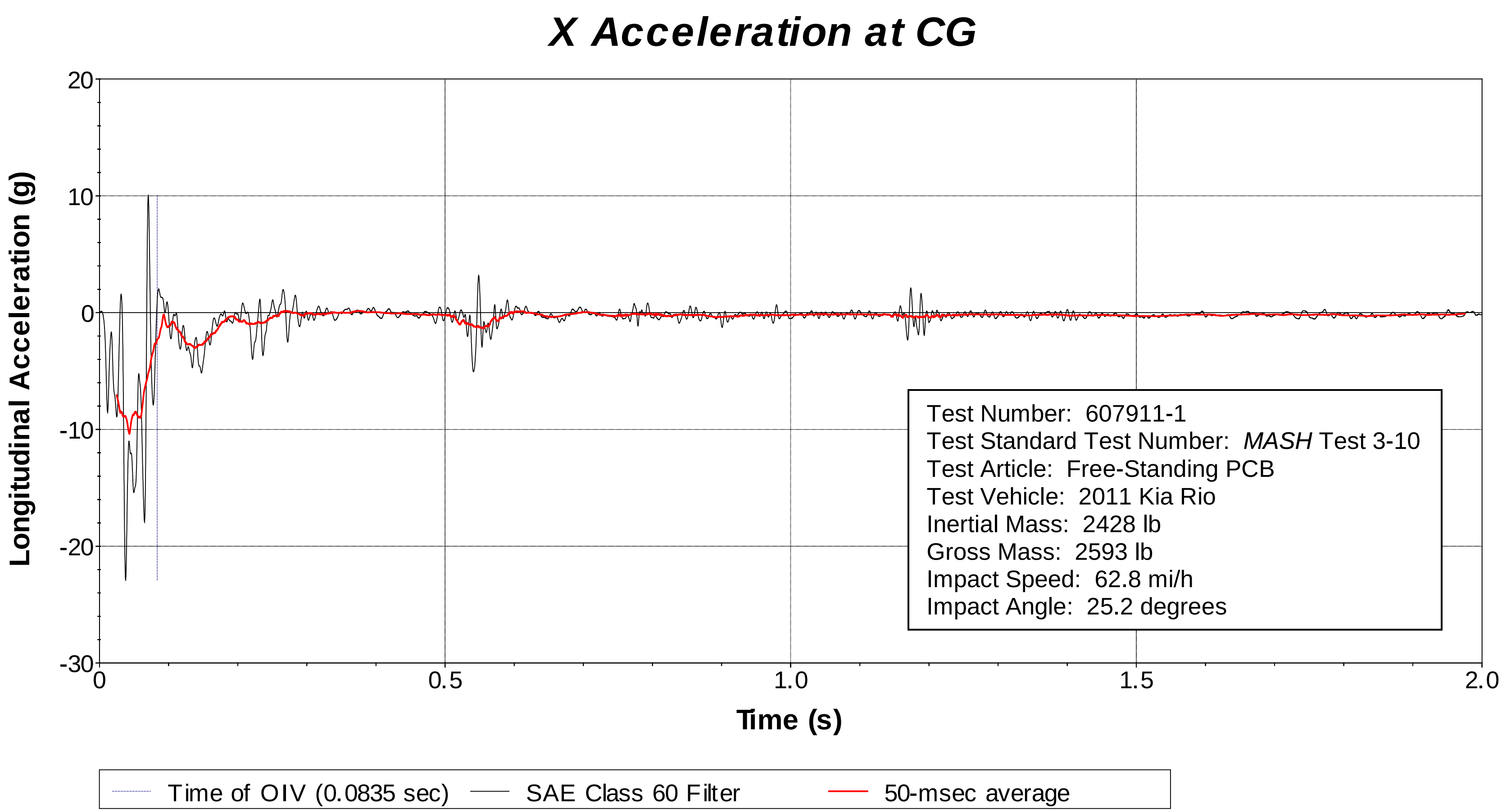


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 607911-1 (Accelerometer Located at Center of Gravity).

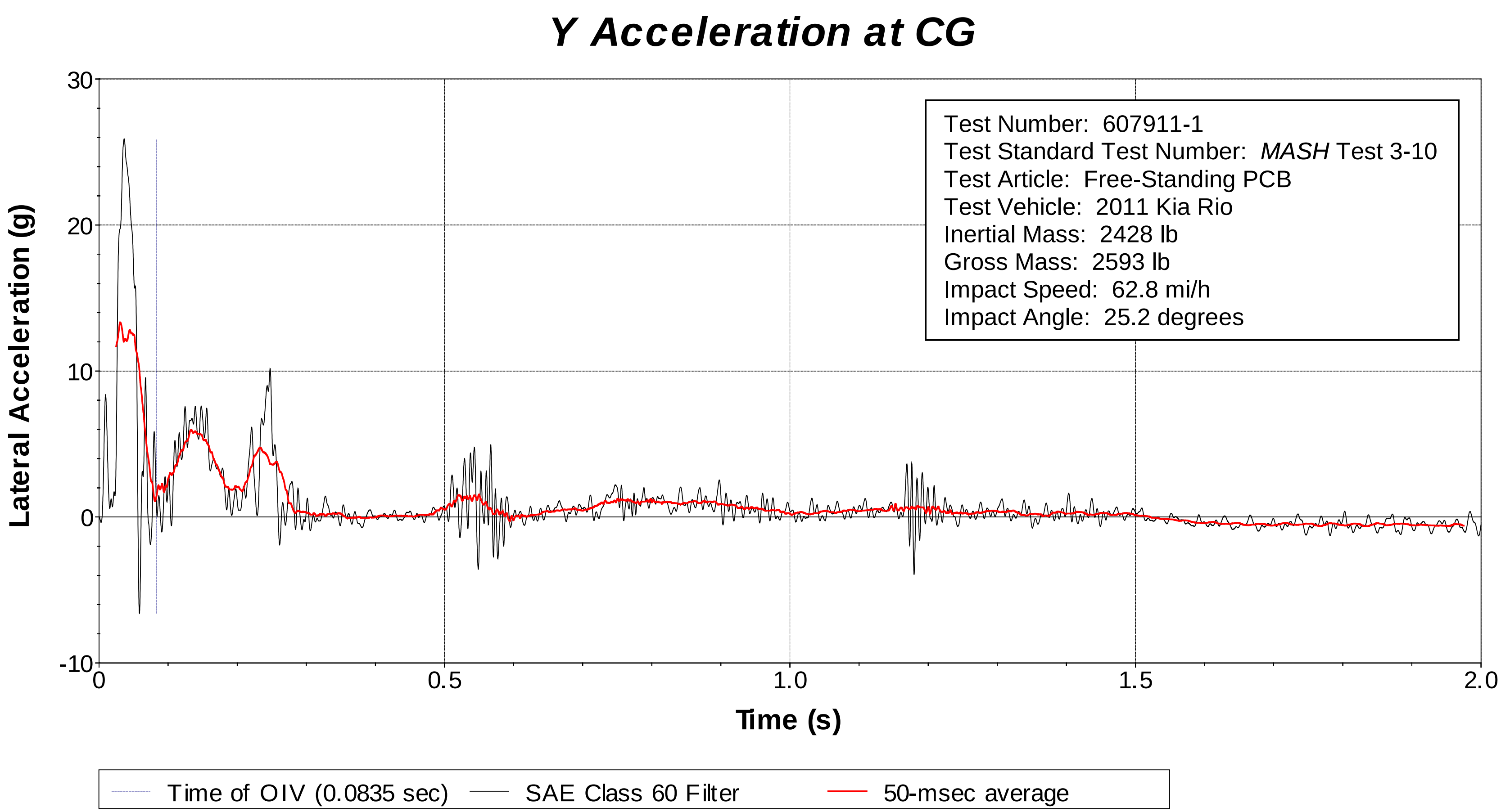


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 607911-1 (Accelerometer Located at Center of Gravity).

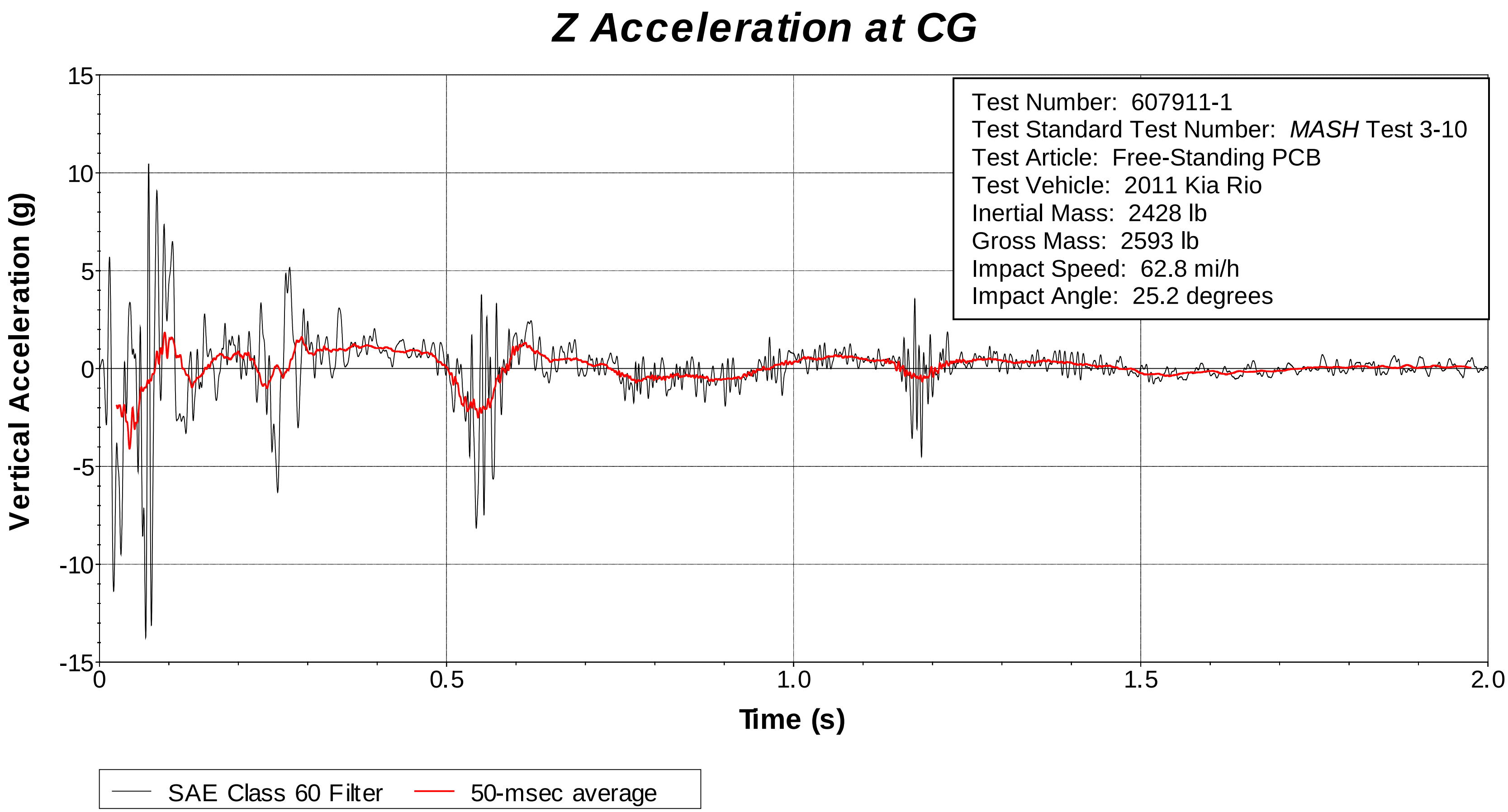


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 607911-1 (Accelerometer Located at Center of Gravity).

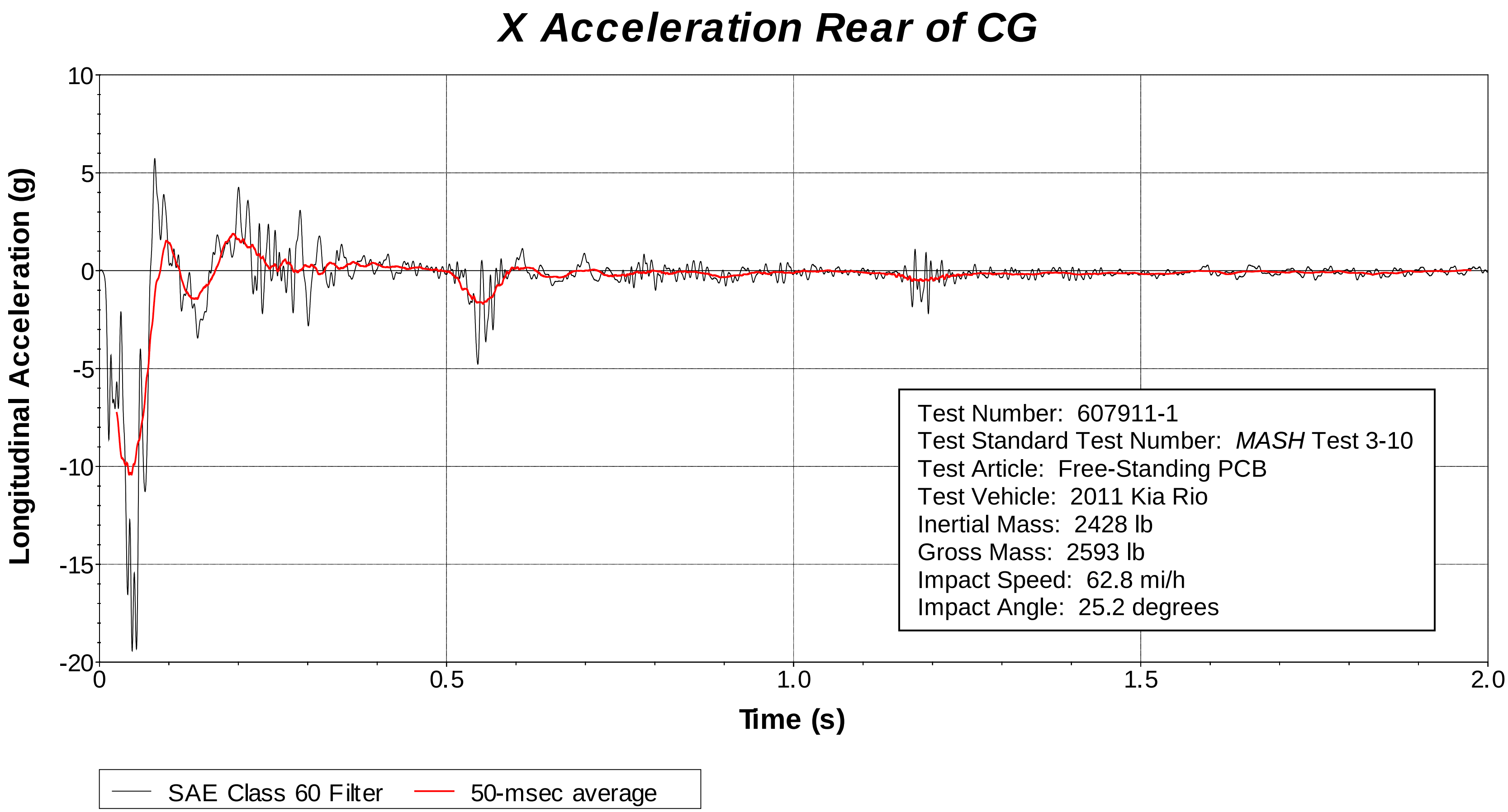


Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 607911-1 (Accelerometer Located Rear of Center of Gravity).

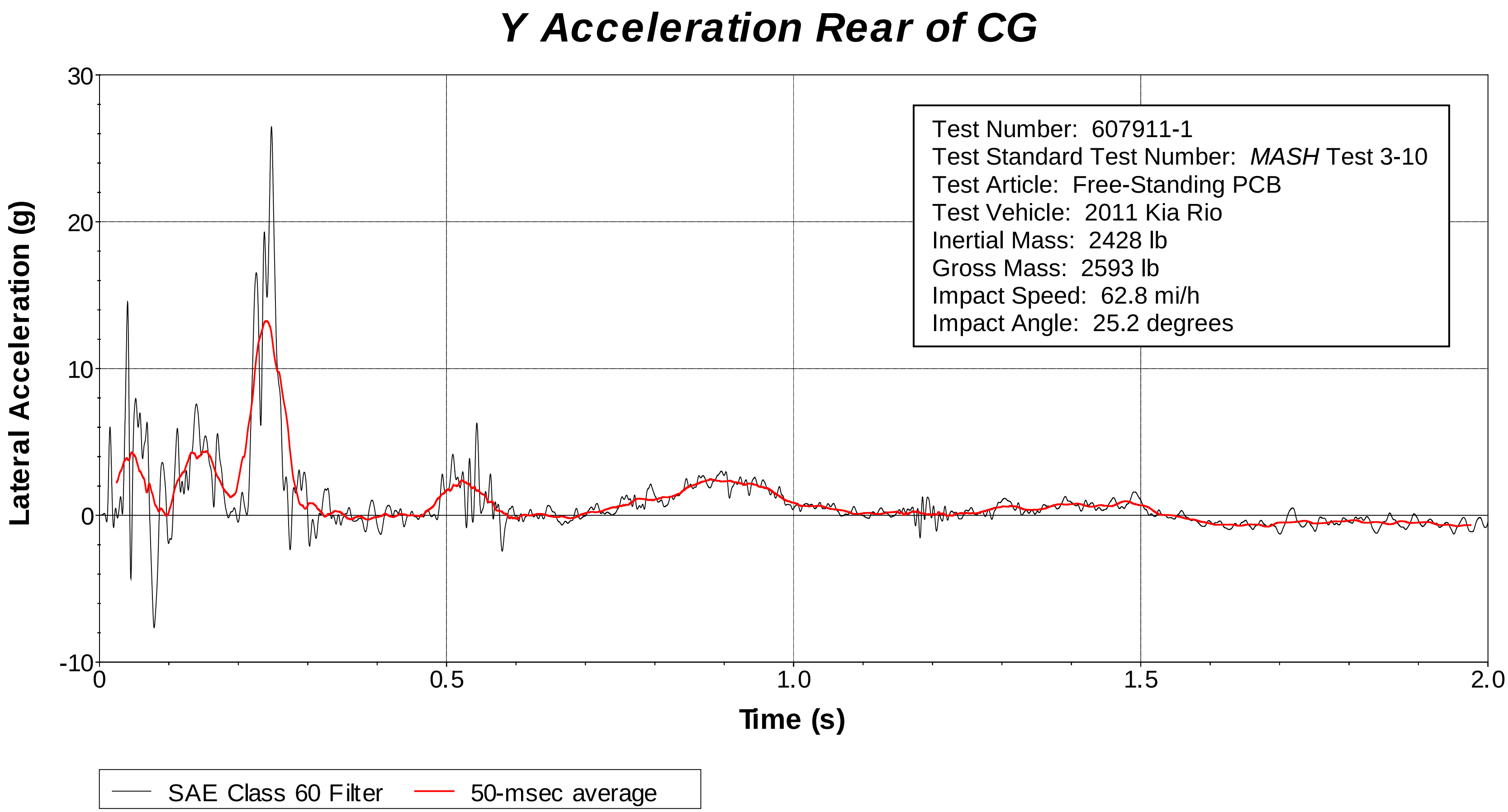


Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 607911-1 (Accelerometer Located Rear of Center of Gravity).

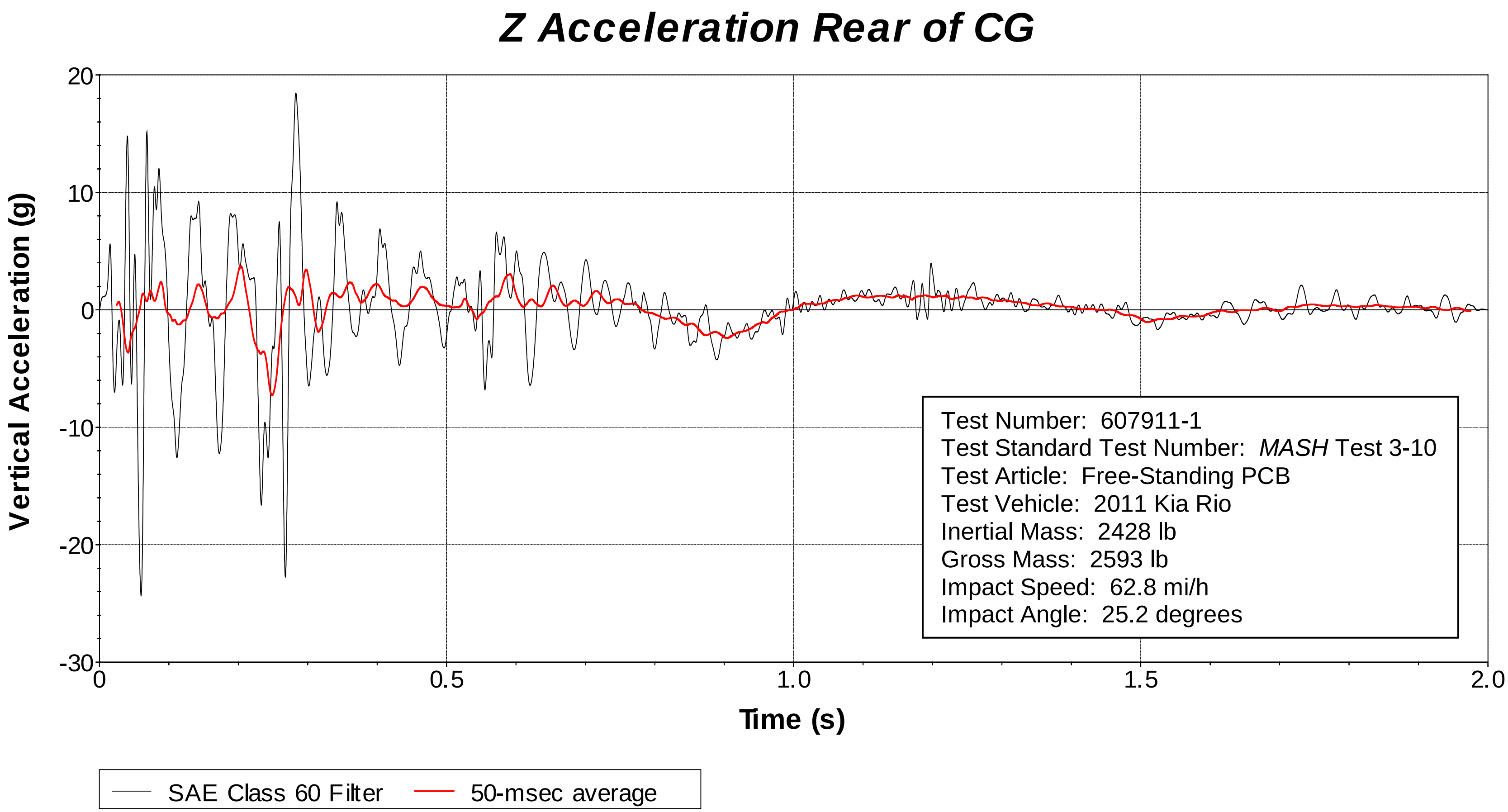


Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 607911-1 (Accelerometer Located Rear of Center of Gravity).

APPENIDX D. *MASH* TEST 3-11 (CRASH TEST NO. 607911-2)

D1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 607911-2.

Date: 2017-03-09 Test No.: 607911-2 VIN No.: 1C6RD6GP9CS255294

Year: 2012 Make: Dodge Model: RAM 1500

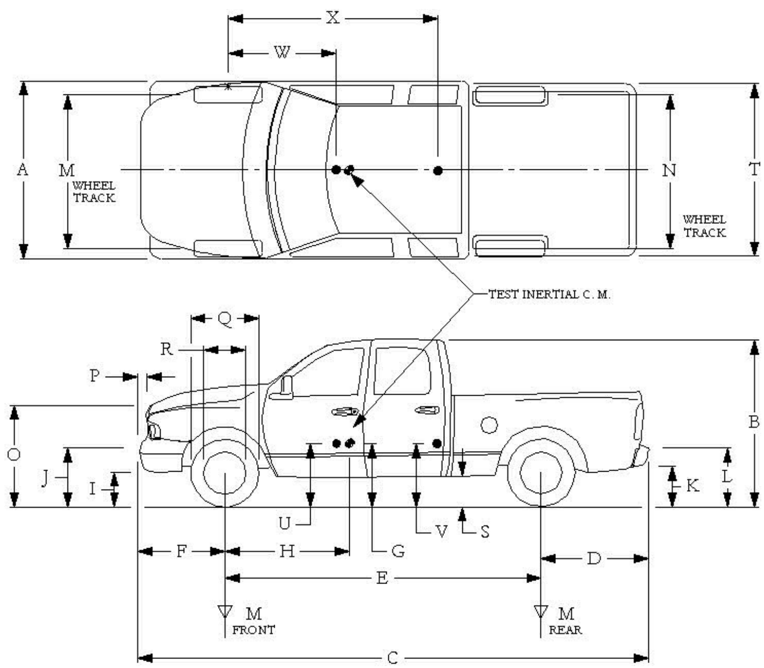
Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 172245

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None



Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment:
None

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

Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	27.50
B	75.00	G	28.38	L	29.00	Q	30.50	V	29.88
C	225.50	H	62.37	M	68.50	R	18.00	W	62.30
D	47.00	I	12.00	N	68.00	S	13.25	X	79.30
E	140.50	J	27.50	O	46.50	T	77.00		

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

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}	2825	2788	
Back	3900	M_{rear}	2033	2226	
Total	6700	M_{Total}	4858	5014	

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

Mass Distribution:
lb LF: 1383 RF: 1405 LR: 1070 RR: 1156

Table D.2. Measurements of Vehicle Vertical CG for Test No. 607911-2.

Date: 2017-03-09 Test No.: 607911-2 VIN: 1C6RD6GP9CS255294

Year: 2012 Make: Dodge Model: RAM 1500

Body Style: Quad Cab Mileage: 172245

Engine: 4.7 liter V-8 Transmission: Automatic

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

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

Measured Vehicle Weights: (lb)								
LF:	1383		RF:	1405		Front Axle:	2788	
LR:	1070		RR:	1156		Rear Axle:	2226	
Left:	2453		Right:	2561		Total:	5014	
						5000 ±110 lb allowed		
Wheel Base:	140.5	inches	Track: F:	68.5	inches	R:	68	inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed				
Center of Gravity, SAE J874 Suspension Method								
X:	62.38	inches	Rear of Front Axle		(63 ±4 inches allowed)			
Y:	0.74	inches	Left -	Right +	of Vehicle Centerline			
Z:	28.38	inches	Above Ground		(minumum 28.0 inches allowed)			

Hood Height: 46.50 inches
43 ±4 inches allowed

Front Bumper Height: 27.50 inches

Front Overhang: 40.00 inches
39 ±3 inches allowed

Rear Bumper Height: 29.00 inches

Overall Length: 225.50 inches
237 ±13 inches allowed

Table D.3. Exterior Crush Measurements for Test No. 607911-2.

Date: 2017-03-09 Test No.: 607911-2 VIN No.: 1C6RD6GP9CS255294

Year: 2012 Make: Dodge Model: RAM 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	17	8	30	8	6	4	2	1	0	-15
2	Side plane at bumper ht	17	14	27	14	12	--	--	1.5	1	+64
	Measurements recorded										
	in inches or mm										

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

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

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

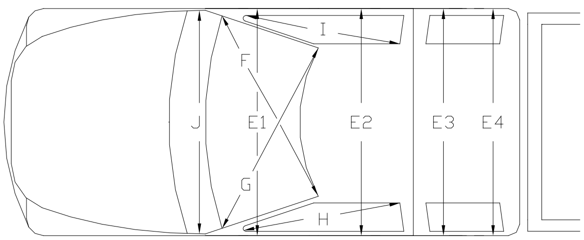
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

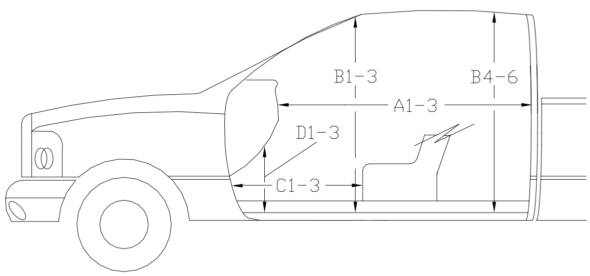
***Measure and document on the vehicle diagram the location of the maximum crush.

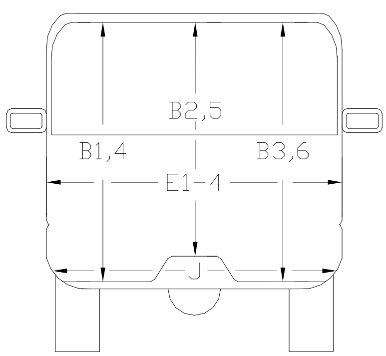
Note: Use as many lines/columns as necessary to describe each damage profile.

Table D.4. Occupant Compartment Measurements for Test No. 607911-2.

Date:	2017-03-09	Test No.:	607911-2	VIN No.:	1C6RD6GP9CS255294
Year:	2012	Make:	Dodge	Model:	RAM 1500





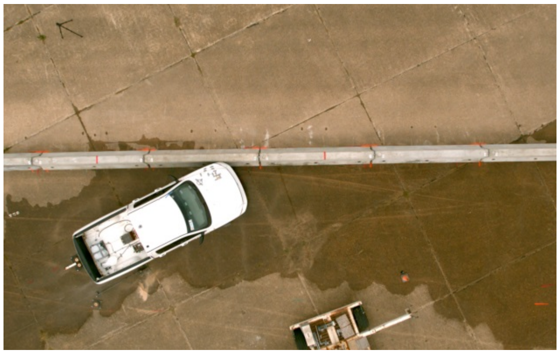


*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

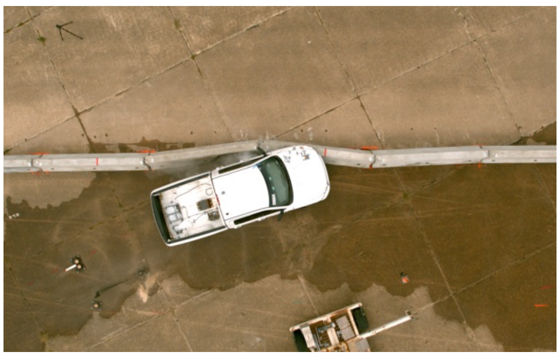
OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0
A2	63.00	63.00	0
A3	65.50	65.50	0
B1	44.00	44.00	0
B2	37.75	37.75	0
B3	44.00	44.00	0
B4	39.50	39.50	0
B5	43.25	43.25	0
B6	39.50	39.50	0
C1	27.00	27.00	0
C2	-----	-----	0
C3	26.00	26.00	0
D1	11.25	11.25	0
D2	-----	-----	0
D3	11.25	11.25	0
E1	58.50	58.50	0
E2	63.50	63.75	+0.25
E3	63.50	63.50	0
E4	63.50	63.75	+0.25
F	59.00	59.00	0
G	59.00	59.00	0
H	37.00	37.00	0
I	37.00	37.00	0
J*	23.50	23.50	0

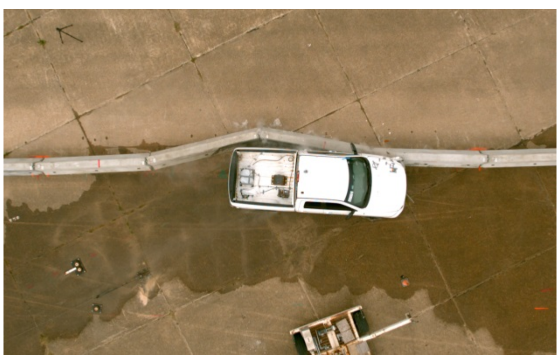
D2 SEQUENTIAL PHOTOGRAPHS



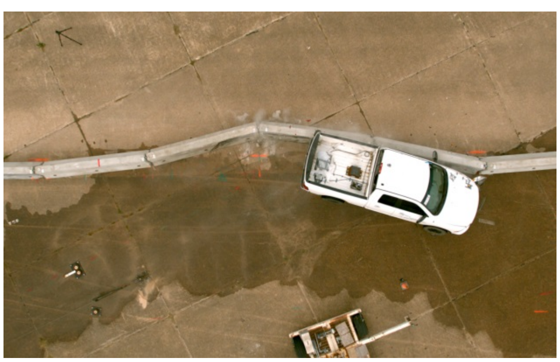
0.000 s



0.110 s



0.220 s



0.330 s

Figure D.1. Sequential Photographs for Test No. 607911-2 (Overhead and Frontal Views).


0.440 s



0.550 s



0.660 s



0.770 s


Figure D.1. Sequential Photographs for Test No. 607911-2 (Overhead and Frontal Views) (Continued).

0.000 s

0.110 s

0.220 s

0.330 s

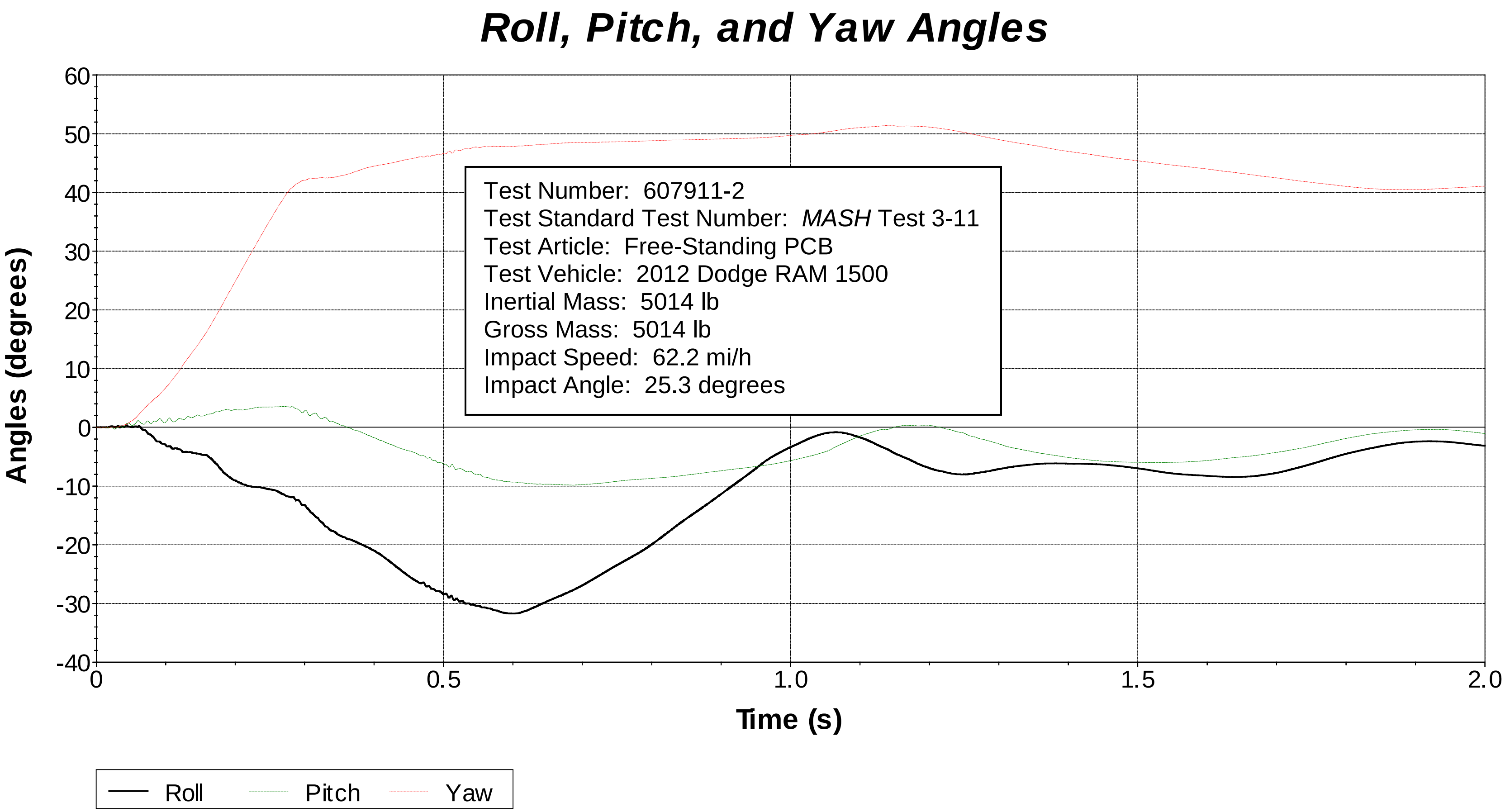
0.440 s

0.550 s

0.660 s

0.770 s

Figure D.2. Sequential Photographs for Test No. 607911-2 (Rear View).



Axes are vehicle-fixed.
Sequence for determining orientation:

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

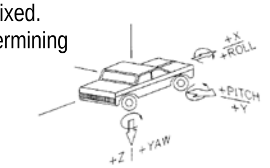


Figure D.3. Vehicle Angular Displacements for Test No. 607911-2.

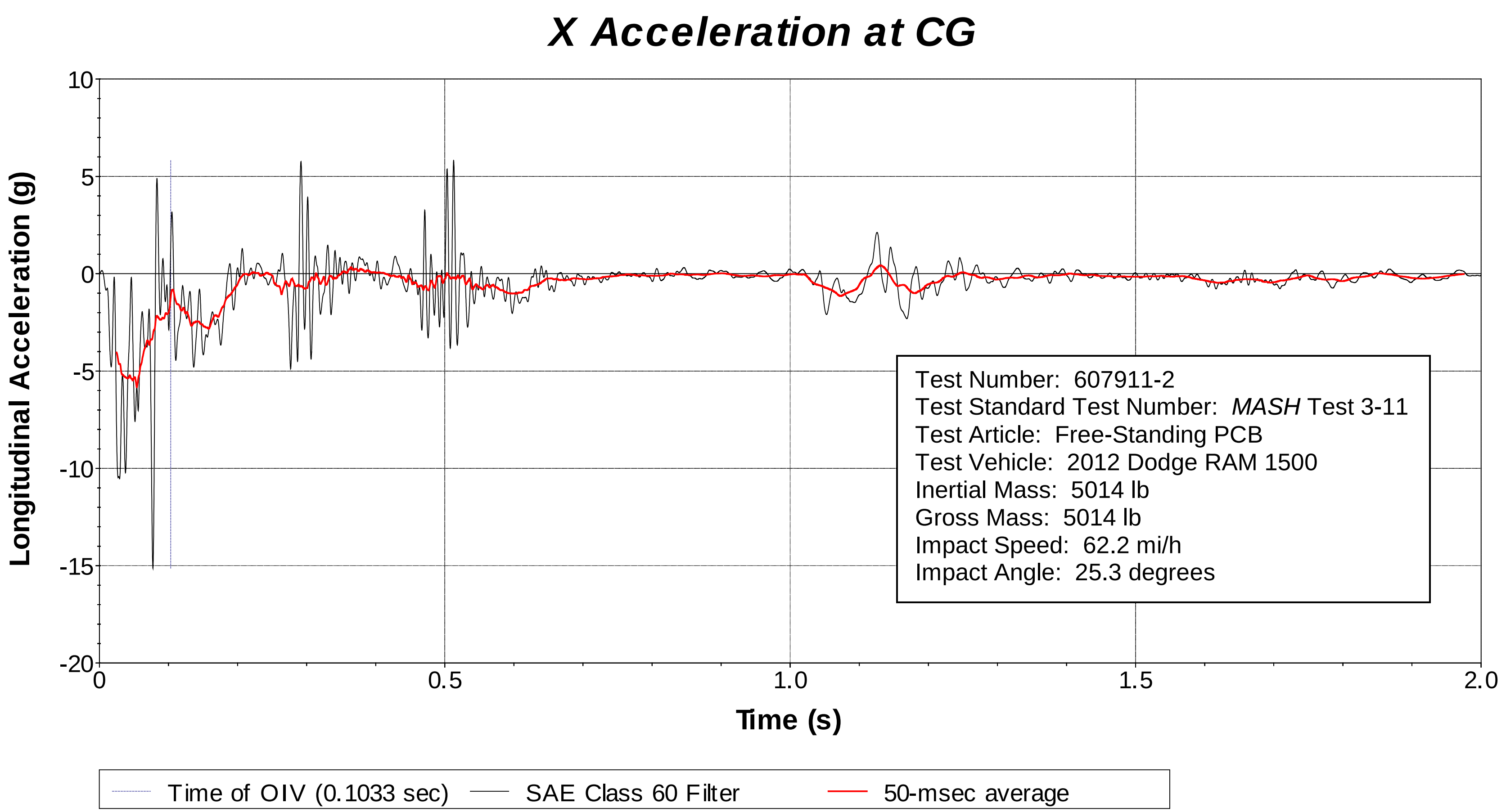


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 607911-2 (Accelerometer Located at Center of Gravity).

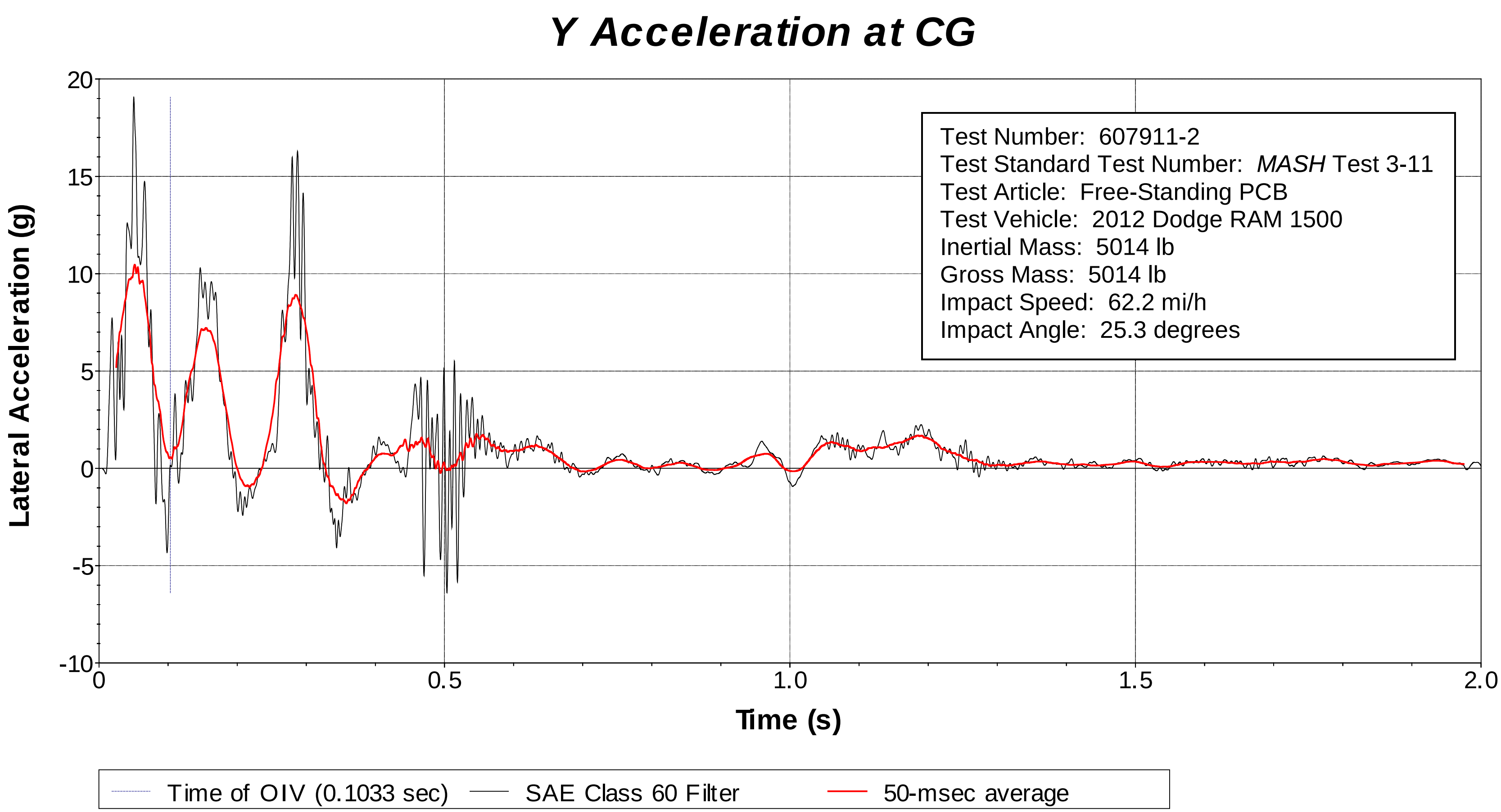


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 607911-2 (Accelerometer Located at Center of Gravity).

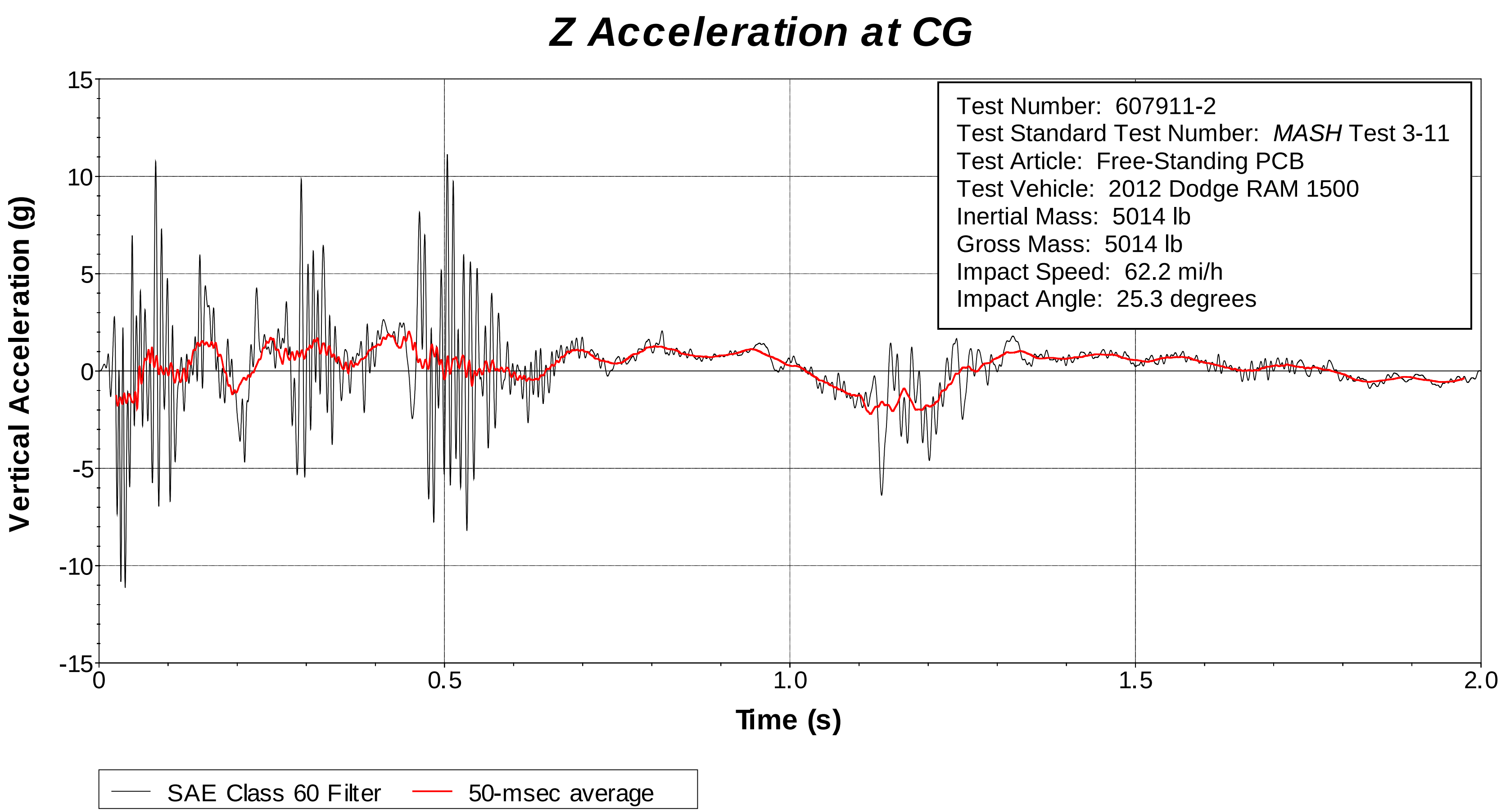


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 607911-2 (Accelerometer Located at Center of Gravity).

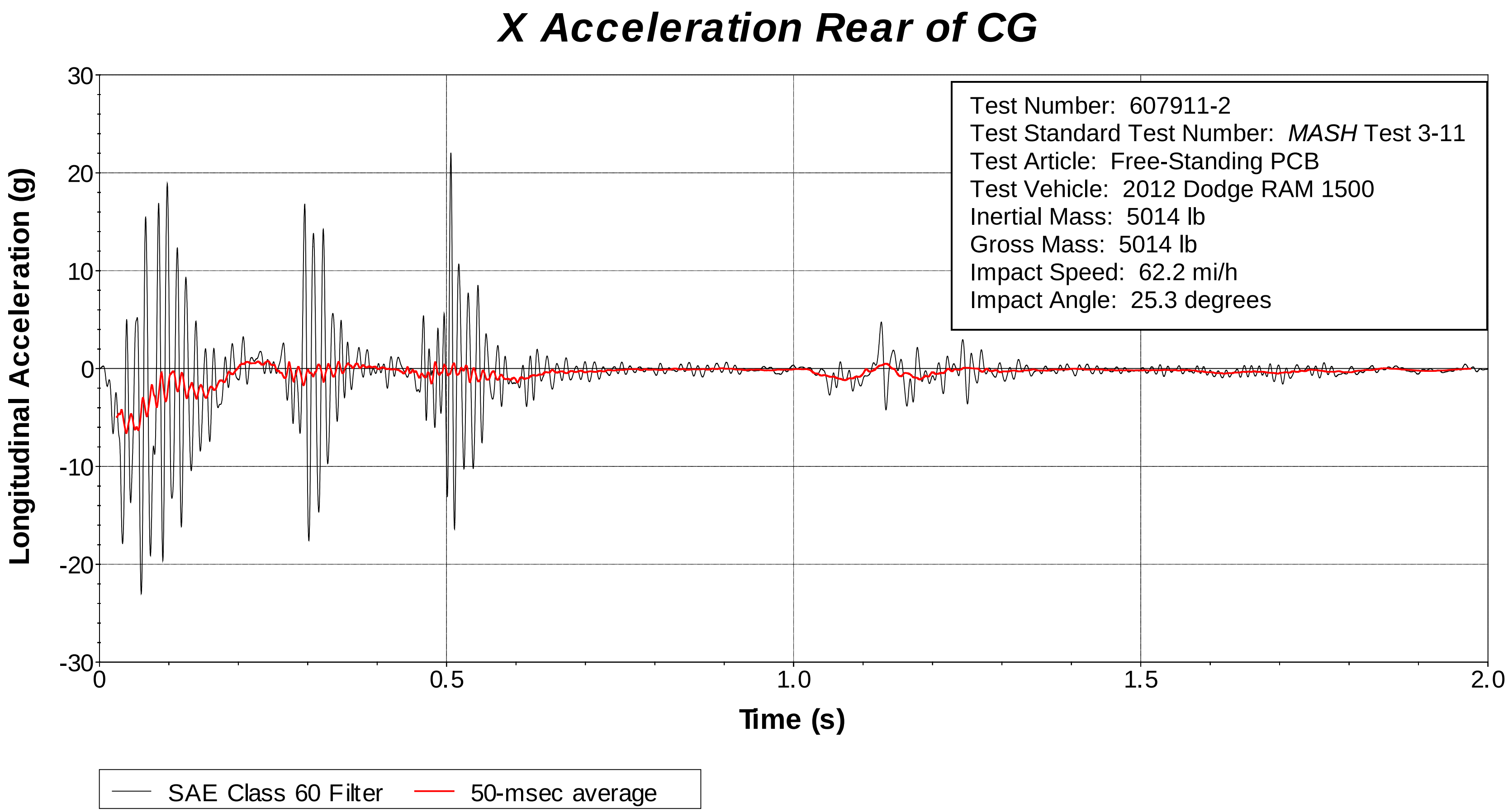


Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 607911-2 (Accelerometer Located Rear of Center of Gravity).

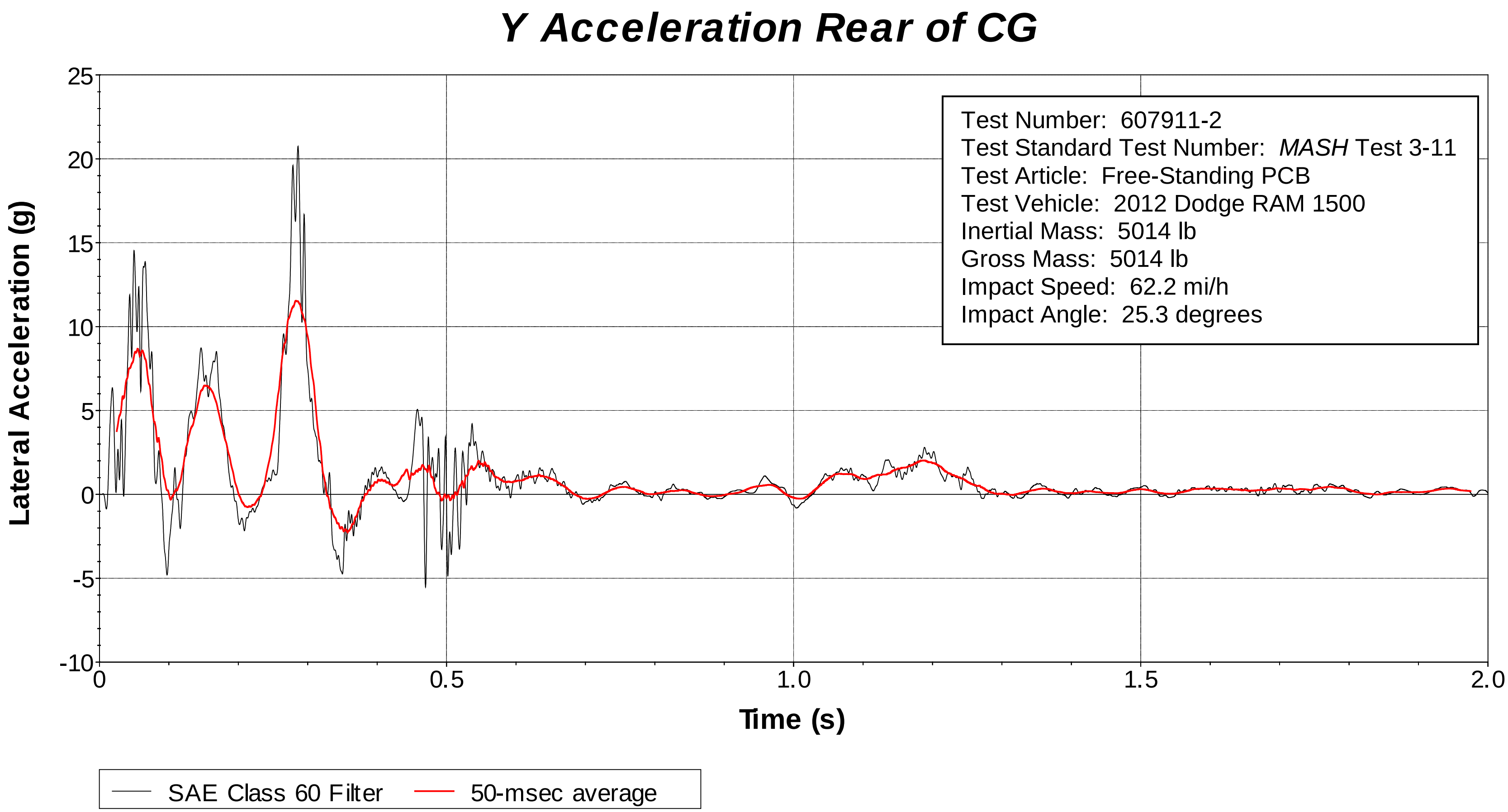


Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 607911-2 (Accelerometer Located Rear of Center of Gravity).

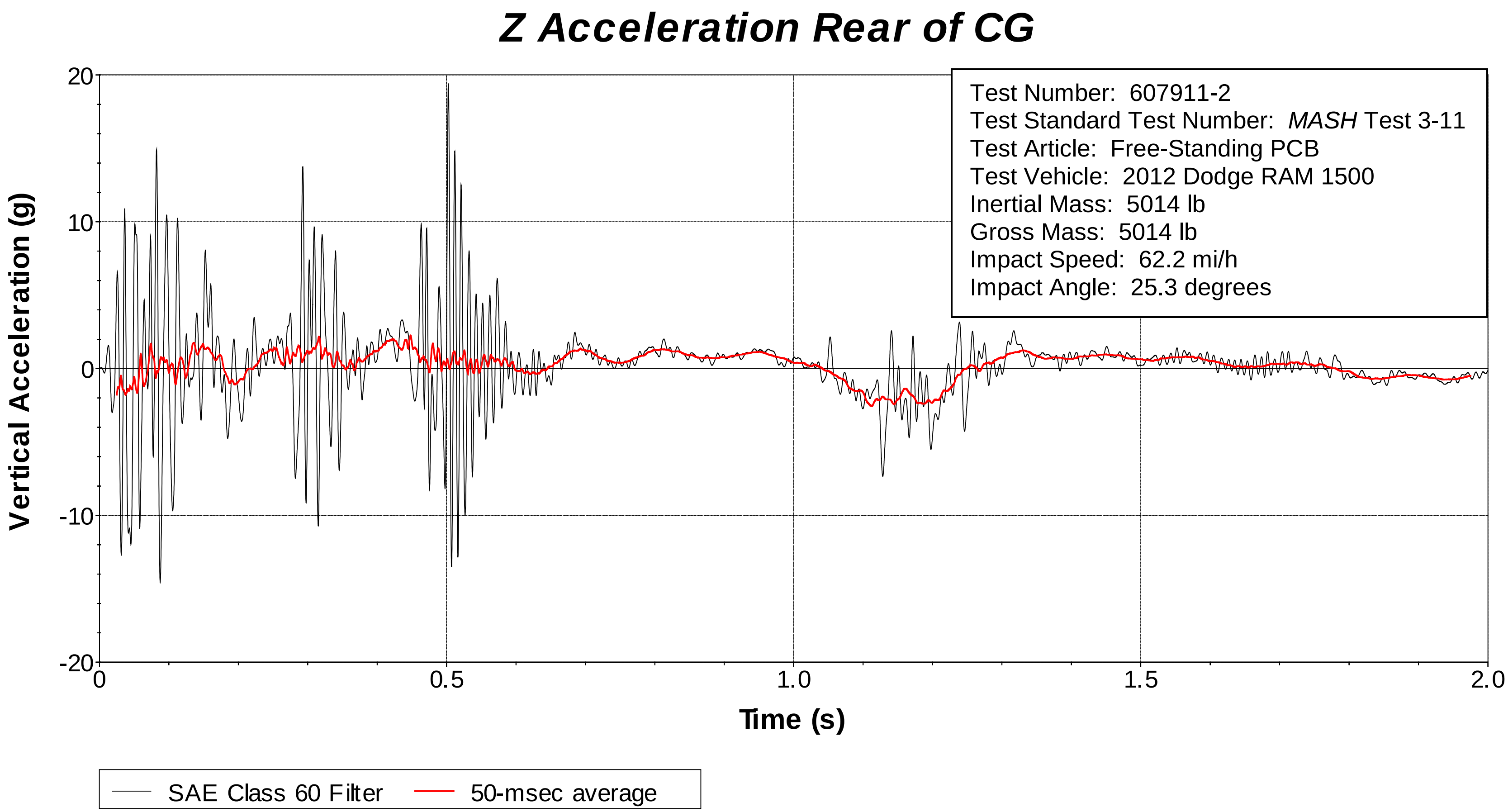


Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 607911-2 (Accelerometer Located Rear of Center of Gravity).