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Proving Ground

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TECHNICAL MEMORANDUM

Contract No.: **1000090 (Award No. 61251)**
Test Report No.: **TM 479070-1**
Project Name: **Crash Testing for Hawaii DOT Typical Cement Rubble Masonry Guardrail Walls at MASH Test Levels One and Two**
Sponsor: **Hawaii Department of Transportation**

DATE: **February 6, 2013**

TO: **Dean Takiguchi**
Hawaii Department of Transportation

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SUMMARY REPORT:

DISCLAIMER:

The contents of this report reflect the views of the authors who are solely responsible for the facts and accuracy of the data, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Hawaii Department of Transportation, The Texas A&M University System, or Texas A&M Transportation Institute. This report does not constitute a standard, specification, or regulation. In addition, the above listed agencies assume no liability for its contents or use thereof. The names of specific products or manufacturers listed herein do not imply endorsement of those products or manufacturers. The results reported herein apply only to the article being tested. The test was performed according to TTI Proving Ground quality procedures and according to AASHTO *MASH*.

TEST ARTICLE DESIGN AND CONSTRUCTION

The Hawaii Masonry Wall is a cement rubble masonry wall that is intended to serve as a longitudinal barrier according to the provisions of American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test Levels One and Two. The wall is constructed using stacked limestone with mortar joints. The Hawaii Masonry Wall was installed at the TTI Proving Ground facility by R. W. Pfeffer Masonry, Inc. of Bryan, TX.

Approximate overall dimensions for the installation, above grade, were 24 inches wide at the base, 16 inches wide at the top, and 24 inches tall. The overall length of the installation was 100 ft. The limestone used to construct the wall was clean, hard, sound, and durable. The individual stones had a minimum thickness not less than 6 inches and minimum width not less than 1-1/2 times the thickness and not less than 12 inches. With the exception of header stones, the minimum length was 1-1/2 times the stone's width. The largest stones were used on the bottom course, after which the stones were graded to decrease in width from bottom to top of the wall. The fascia stones were uniformly distributed by size. The wall was finished with a 2-inch mortar cap.

The stones were fully embedded in mortar. The mortar mix contained 1 part cement and 2 parts sand and/or fine aggregate by volume. The mortar was placed within 30 minutes of water being added. A minimum overlap of 6 inches was specified where the stones overlapped. On the day of testing, the average mortar compressive strength was 6530 psi.

The wall was installed in a bed of crushed limestone, 72 inches wide by 20 inches deep. The crush limestone used was Georgetown Superflex with 100 percent compaction and a moisture content of 10.1, measured on the day of testing. The wall was keyed into the crushed limestone bedding 12 inches and was centered along the width. The approximate overall dimensions of the wall were 28 inches wide at the base, 16 inches wide at the top, and 36 inches tall. The wall side opposite impact had a positive slope of 12V:3H. The impact side had a positive slope of 12V:1H.

Photographs of the Hawaii Masonry Wall are shown in figure 1. Refer to Attachment A for further details of the test article.

TEST DESIGNATION AND ACTUAL TEST CONDITIONS

MASH test 1-11 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the Hawaii Masonry Wall at an impact speed of 31 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was the quarter point of the installation. The 2008 Dodge Ram 1500 pickup truck used in the test weighed 5039 lb and the actual impact speed and angle were 31.1 mi/h and 25.4 degrees, respectively. The actual impact point was 26 ft downstream of end of the wall.

TEST VEHICLE

A 2008 Dodge Ram 1500 pickup truck, shown in figure 2, was used for the crash test. Test inertia weight of the vehicle was 5039 lb, and its gross static weight was 5039 lb. The height to the lower edge of the vehicle front bumper was 13.75 inches, and the height to the upper edge of the front bumper was 25.375 inches. The height to the center of gravity was 28.0 inches. Additional information on the vehicle is provided in Attachment B.

Figure 1. Hawaii Masonry Wall prior to test 479070-1.

Figure 2. Test vehicle prior to test 479070-1.

SOIL AND/OR WEATHER CONDITIONS

The crash test was performed the morning of November 13, 2012. Weather conditions at the time of testing were: Wind speed: 6 mi/h; wind direction: 47 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 57ºF; relative humidity: 36 percent.

BRIEF TEST DESCRIPTION

The 2008 Dodge Ram 1500 pickup truck, traveling at an impact speed of 31.1 mi/h, impacted the Hawaii Masonry Wall 26 ft downstream of the end of the wall at an impact angle of 25.4 mi/h. At 0.040 s after impact, the vehicle began to redirect, and at 0.048 s, the mortar cap on top of the wall began to crack in the horizontal direction and the right front tire blew out. The top row of stones began to deflect toward the field side at 0.062 s, and the mortar cap began to crack longitudinally at 0.079 s. As the vehicle continued forward, the stones continued to fall off to the field side, and as the vehicle exited the film, it remained in contact with the wall. The brakes on the vehicle were not applied and the vehicle came to rest 83.5 ft downstream of impact and adjacent to the traffic face of the wall. Sequential photographs of the test period are presented in Attachment C.

TEST ARTICLE/COMPONENT DAMAGE

A portion of the mortar cap (a length of 30 ft) and a portion of the first layer of rock (a length of 10 ft) was displaced toward the field side of the installation as shown in figure 3. .

Figure 3. Hawaii Masonry Wall after test 479070-1.

TEST VEHICLE DAMAGE

The right front upper and lower ball joints, right front tie rod end, and the right front spindle, rotor and caliper were deformed. Also damaged were the front bumper, right front fender, right front door, right rear door and the right front tire and wheel rim, as shown in figure 4. Maximum exterior crush to the vehicle was 9.0 inches. The floor pan was deformed 0.75 inch in the firewall/toe pan area in the front passenger position.

Figure 4. Test vehicle after test 479070-1.

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 11.5 ft/s at 0.157 s, the highest 0.010-s occupant ridedown acceleration was 6.5 Gs from 0.262 to 0.272 s, and the maximum 0.050-s average acceleration was -5.1 Gs between 0.032 and 0.082 s. In the lateral direction, the occupant impact velocity was 10.2 ft/s at 0.157 s, the highest 0.010-s occupant ridedown acceleration was 4.5 Gs from 0.264 to 0.274 s, and the maximum 0.050-s average was -4.6 Gs between 0.032 and 0.082 s. Theoretical Head Impact Velocity (THIV) was 16.3 km/h or 4.5 m/s at 0.150 s; Post-Impact Head Decelerations (PHD) was 7.2 Gs between 0.262 and 0.272 s; and Acceleration Severity Index (ASI) was 0.68 between 0.032 and 0.082 s. These data and other pertinent information from the test are summarized in figure 5. Vehicle angular displacements and accelerations are shown graphically in Attachment D.

SUMMARY AND CONCLUSIONS

The Hawaii Masonry Wall contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was not obtainable. A portion of the mortar cap and first layer of stones in a section of the wall broke off and were lying on the field side of the installation. This debris did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area. Maximum occupant compartment deformation was 0.75 inch in the firewall/toe pan area on the front passenger side. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12 degrees and 4 degrees, respectively. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle exited within the exit box.

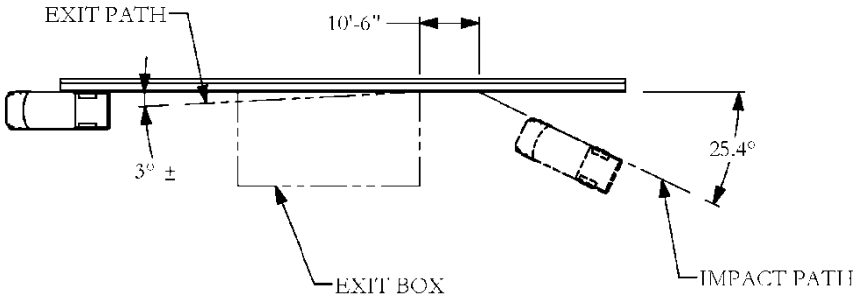
The Hawaii Masonry Wall performed acceptably for *MASH* test 1-11, as shown in table 1.

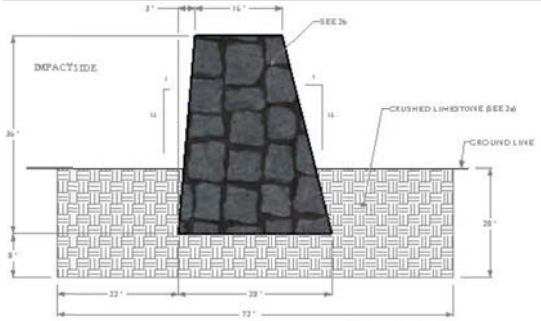

0.000 s


0.150 s


0.300 s


0.600 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. AASHTO MASH 1-11
- Test Agency Test No. 479070-1
- Test Date 2012-11-13

Test Article
- Type ..... Longitudinal Barrier
- Name ..... Hawaii Masonry Wall
- Installation Length ..... 100 ft
- Material or Key Elements .... Cement rubble masonry

Soil Type and Condition ..... Crushed Limestone, dry

Test Vehicle
- Designation 2270P
- Model ..... 2008 Dodge Ram 1500 pickup
- Mass
  - Curb ..... 4761 lb
  - Test Inertial ..... 5039 lb
  - Dummy ..... No dummy
  - Gross Static ..... 5039 lb

Impact Conditions
- Speed ..... 31.1 mi/h
- Angle ..... 25.4 degrees
- Impact Location ..... 26 ft dwnstrm from end

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

Occupant Risk Values
- Impact Velocity
  - Longitudinal ..... 11.5 ft/s
  - Lateral ..... 10.2 ft/s
- THIV ..... 16.3 km/h
- Ridedown Accelerations
  - Longitudinal ..... 6.5 G
  - Lateral ..... 4.5 G
- PHD ..... 7.2 G
- ASI 0.68
- Max. 0.050-s Average
  - Longitudinal ..... -5.1 G
  - Lateral ..... -4.6 G
  - Vertical ..... 2.8 G

Post-Impact Trajectory
- Stopping Distance ..... 83.5 ft dwnstrm
  Adjacent to wall

Vehicle Stability
- Maximum Yaw Angle ..... 22 degrees
- Maximum Pitch Angle ..... 4 degrees
- Maximum Roll Angle ..... 12 degrees
- Vehicle Snagging ..... No
- Vehicle Pocketing ..... No

Test Article Deflections
- Dynamic ..... Not Obtainable
- Permanent ..... None
- Working Width ..... 83.8 inches
- Vehicle Intrusion ..... 26.8 inches

Vehicle Damage
- VDS 01RFQ2
- CDC 01FREW2
- Max. Exterior Deformation ..... 9.0 inches
- OCDI RF0010000
- Max. Occupant Compartment Deformation ..... 0.75 inch

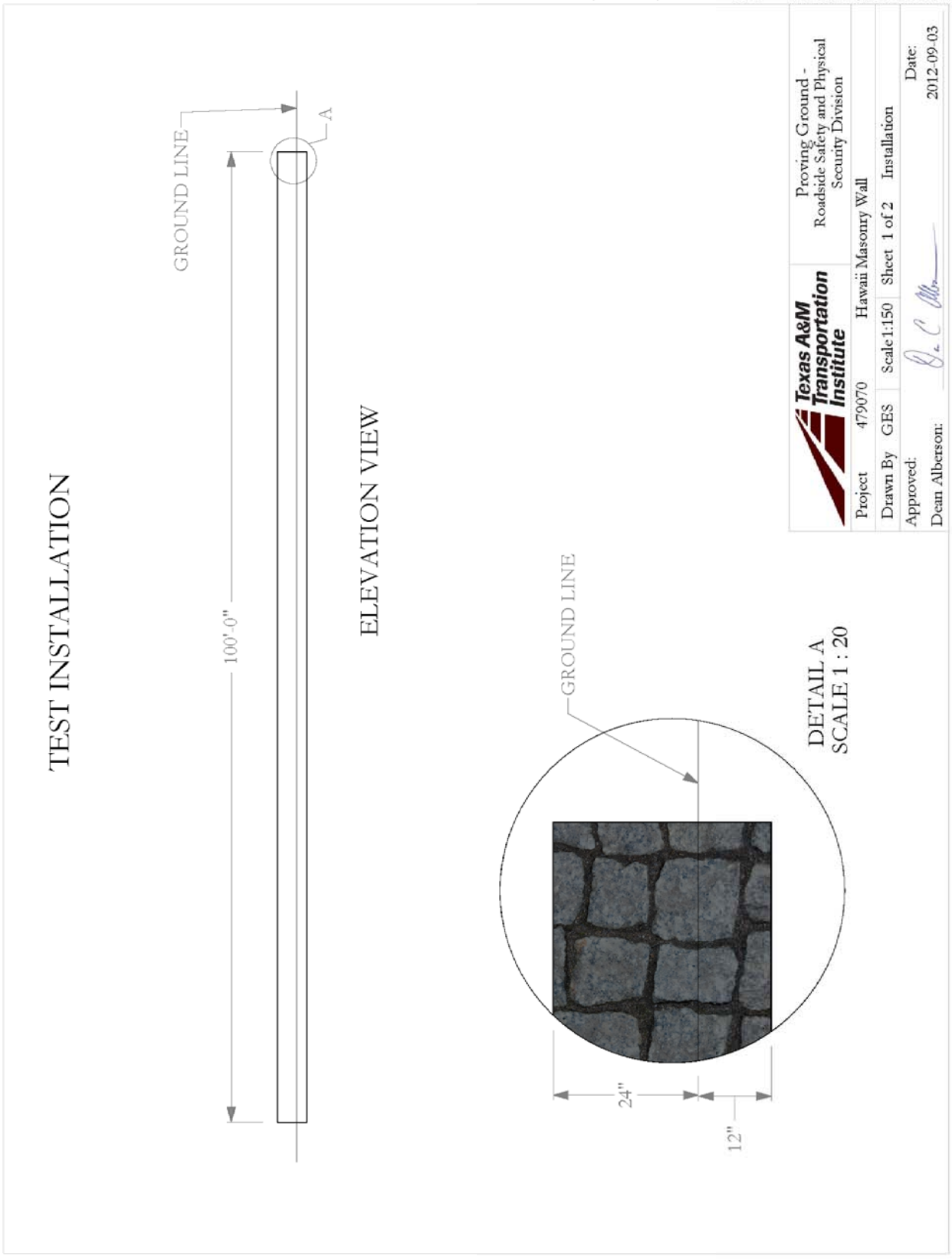
Figure 5. Summary of results for *MASH* test 1-11 on the Hawaii Masonry Wall.

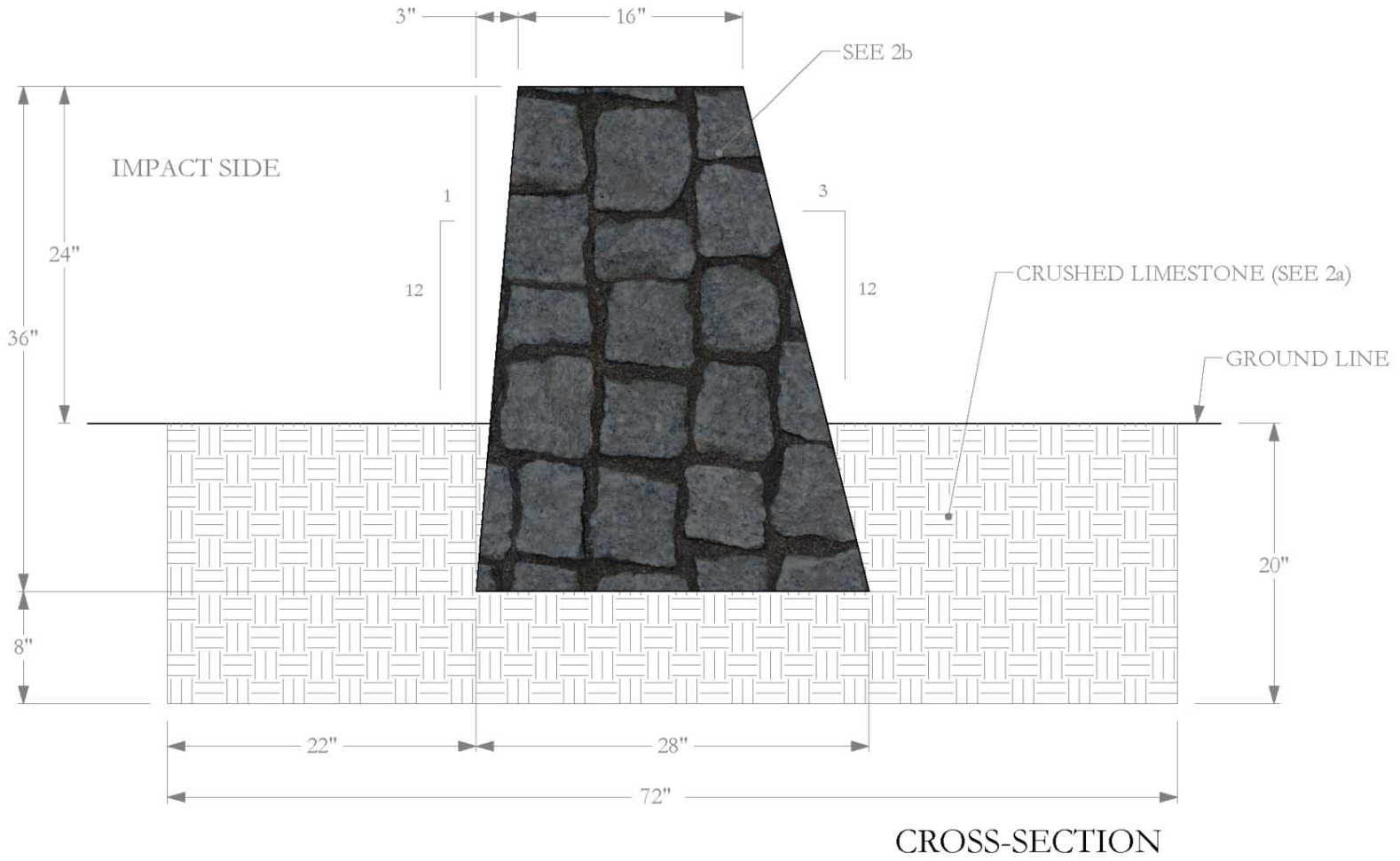
Table 1. Performance evaluation summary for MASH test 1-11 on the Hawaii Masonry Wall.

Test Agency: Texas A&M Transportation Institute Test No.: 479070-1 Test Date: 2012-11-13

***NCHRP MASH* Test 1-11 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 Hawaii Masonry Wall contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was not measureable.	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.*	A portion of the cap and first layer of stones in a section of the wall broke off and were lying on the field side of the installation. This debris 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 0.75 inch in the firewall/toe pan area on the front passenger side.	Pass
F.	*The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12 degrees and 4 degrees, respectively.	Pass
H.	*Longitudinal and lateral occupant impact velocities should fall below the preferred value of 29.5ft/s, or at least below the maximum allowable value of 39.4 ft/s.*	Longitudinal occupant impact velocity was 11.5 ft/s, and lateral occupant impact velocity was 10.2 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 20.0 Gs.*	Longitudinal ridedown acceleration was 6.5 G, and lateral ridedown acceleration was 4.5 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.	Pass

ATTACHMENT A: TEST ARTICLE DETAILS





CROSS-SECTION

2a. Georgetown Superflex, compacted to 90% of standard proctor density. Dimensions are approximate.

2b. Limestone rock. Texture on drawing is for illustration only. See attachment for rock, mortar, and construction specifications. (Sections 5.01 - 5.03 apply for this test installation, disregard other sections regarding payment.)

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 479070	Hawaii Masonry Wall		2012-09-03
Drawn By GES	Scale 1:10	Sheet 2 of 2	Cross Section

T:\2012-2013\479070 Hawaii Masonry Wall\Drafting\Hawaii Drawing

SECTION 508 - CEMENT RUBBLE MASONRY

508.01 Description. This section describes constructing cement rubble masonry.

508.02 Materials.

Structural Concrete	601
Portland Cement	701.01
Fine Aggregate for Concrete	703.01
Water	712.01

Stones shall be clean, hard, sound, and durable. Except stones for filling voids, stones shall have thickness of not less than 6 inches and width of not less than 1-1/2 times the thickness, but not less than 12 inches. Except headers, stones shall have length of not less than 1-1/2 times its width.

Face stones shall have volume of not less than 0.75 cubic foot, and heart stones shall have volume of not less than 0.5 cubic foot.

Mortar shall consist of 1 part cement to 2 parts of fine aggregate or sand by volume. Water shall be added to make mortar easy to handle and spread with trowel. Mortar shall be prepared by mixing fine aggregate and cement in a tight container or mixing machine until mixture assumes uniform color. As mixing continues, water shall be added until proper consistency is attained. Mortar that has not been placed within 30 minutes after water has been added will be rejected. Retempering of mortar will not be allowed.

Mortar for pointing shall consist of 1 part cement to 1 part fine aggregate or sand by volume.

508.03 Construction. Excavate and backfill in accordance with Section 206 - Excavation and Backfill for Drainage Facilities.

Prepare foundation bed to be firm and normal to, or in steps normal to, face of wall. Compact foundation bed to minimum 90 percent compaction. Clean bearing surface of foundation masonry and adjust moisture to saturated, surface dry condition when mortar bed is spread. Clean and saturate stone with water before setting. Clean and moisten bed to receive mortar. Set face stones in random bond. Uniformly distribute stones by size, weathering, color, or texture. Use large stones at corners. Use large, flat stones for bottom courses. Use selected stones, roughly squared and pitched to lines at angles and ends of walls. Grade stones to decrease in size from bottom to top of work.

Bed stones fully in mortar. Overlap stones at joints at least 6 inches and form

firm bond.

Distribute headers uniformly throughout walls of structures to form at least 1/5 of exposed faces. Extend headers at least 12 inches through face wall into backing. Where wall is less than 24 inches in thickness, extend headers through wall from front face to back face.

Build interior of walls so stones are bonded without open spaces. Make horizontal joints in face not more than 1 inch in thickness and vertical joints not more than 2 inches in width. Bed face stones without spalls. Construct weep holes in wall where indicated in the contract documents. After mortar has set, loose stone and surrounding mortar shall be removed and relaid with fresh mortar.

Finish wall with 2-inch mortar capping. Mortar capping consists of 1 part cement to 2 parts fine aggregate or sand.

Use Class A concrete for copings and back walls. Make copings in sections. Extend at least full width of wall, not less than 8 inches thick, and in sections from 5 feet to 8 feet long. Cast-in-place or mold sections and set in full mortar beds.

After laying stones, clean exposed joints thoroughly of mortar to depth of 1 inch. Wet exposed joints and point with mortar for pointing. Cure pointed masonry and mortar capping for not less than 3 days after completion of wall.

508.04 Measurement. Cement rubble masonry will be paid on a lump sum basis. Measurement for payment will not apply.

508.05 Payment. The Engineer will pay for accepted cement rubble masonry on a contract lump sum basis. Payment will be full compensation for work prescribed in this section and the contract documents.

The Engineer will pay for the following pay item when included in the proposal schedule:

Pay Item	Pay Unit
Cement Rubble Masonry	Lump Sum

The Engineer will pay for excavation and backfill in accordance with and under Section 206 - Excavation and Backfill for Drainage Facilities.

END OF SECTION 508

ATTACHMENT B: TEST VEHICLE DETAILS

Table B1. Vehicle properties for test

Date: 2012-11-13 Test No.: 479070-1 VIN No.: 17DHA18N88537744

Year: 2008 Make: Dodge Model: Ram 1500

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

Tread Type: Highway Odometer: 117369

Note any damage to the vehicle prior to test:

• Denotes accelerometer location.

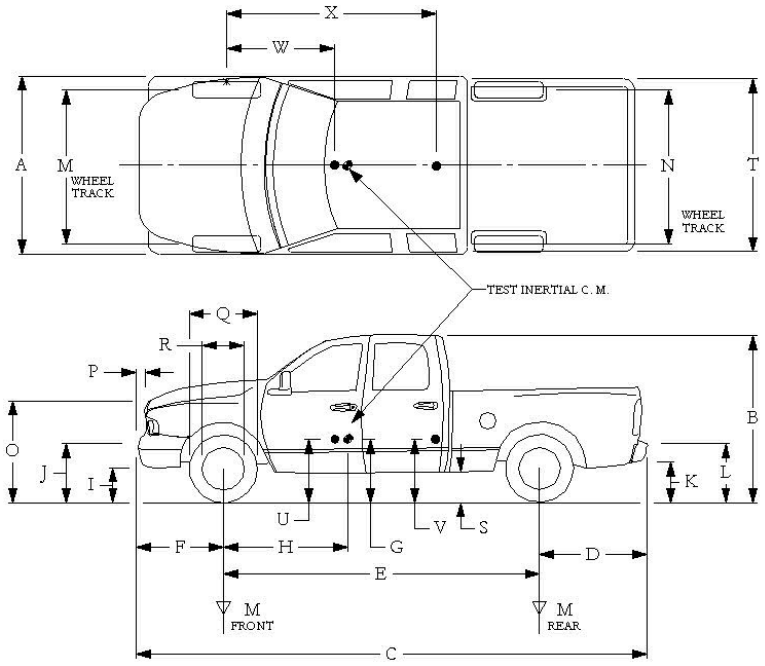
NOTES:

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment:

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



Geometry: inches

A	78.25	F	36.00	K	20.50	P	2.88	U	28.50
B	75.00	G	28.00	L	29.12	Q	31.25	V	29.50
C	223.75	H	63.10	M	68.50	R	18.38	W	61.50
D	47.25	I	13.75	N	68.00	S	12.00	X	78.00
E	140.50	J	25.38	O	44.50	T	77.50		----

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	5.00	Bottom Frame Height - Front	17.125
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	10.25	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}	2822	2776	----
Back	3900	M_{rear}	1939	2263	----
Total	6700	M_{Total}	4761	5036	----

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

Mass Distribution:

lb	LF:	RF:	LR:	RR:
	1389	1387	1110	1153

Table B2. Vehicle CG measurements for test 479070-1.

Date: 2012-11-13 Test No.: 479070-1 VIN: 17DHA18N88537744

Year: 2008 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 117369

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 322 lb (440 lb max)

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

Measured Vehicle Weights: (lb)

LF: 1389	RF: 1387	Front Axle: 2776
LR: 1110	RR: 1153	Rear Axle: 2263
Left: 2499	Right: 2540	Total: 5039
		5000 ±110 lb allowed

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

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

Center of Gravity, SAE J874 Suspension Method

X: 63.10 in Rear of Front Axle (63 ±4 inches allowed)

Y: 0.28 in Left - Right + of Vehicle Centerline

Z: 28 in Above Ground (minumum 28.0 inches allowed)

Hood Height: 44.50 inches (43 ±4 inches allowed)

Front Bumper Height: 25.375 inches

Front Overhang: 36.00 inches (39 ±3 inches allowed)

Rear Bumper Height: 29.125 inches

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

Table B3. Vehicle crush measurements for test 479070-1.

Date: 2012-11-13 Test No.: 479070-1 VIN No.: 17DHA18N88537744

Year: 2008 Make: Dodge Model: Ram 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	18.0	9.0	16	2	6	9	---	---	---	+29
2	Side plane at bumper ht	18.0	9.0	48	5	---	---	---	7	9	+64
	Measurements recorded										
	in inches mm										

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

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

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

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

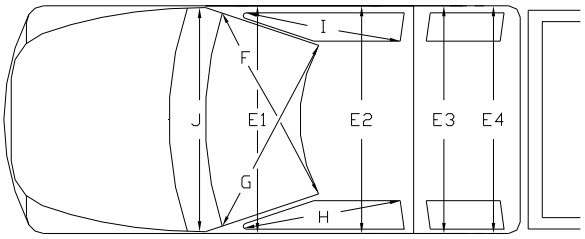
***Measure and document on the vehicle diagram the location of the maximum crush.

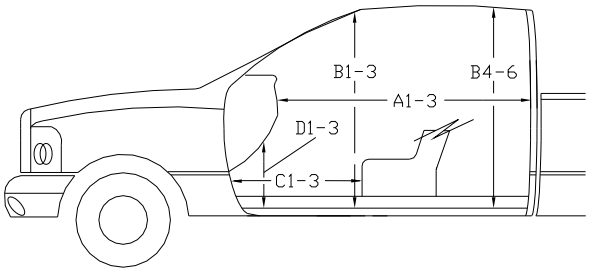
Note: Use as many lines/columns as necessary to describe each damage profile.

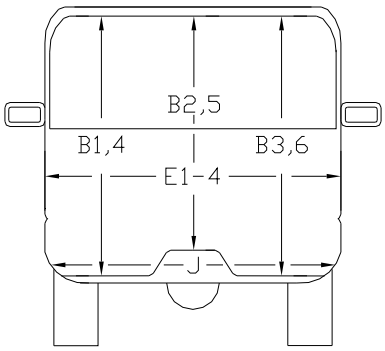
Table B4. Occupant compartment measurements for test 479070-1.

Date: 2012-11-13 Test No.: 479070-1 VIN No.: 17DHA18N88537744

Year: 2008 Make: Dodge Model: Ram 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	64.50	64.50
A2	64.25	64.25
A3	65.00	65.00
B1	45.25	45.25
B2	39.12	39.12
B3	45.25	45.25
B4	42.12	42.12
B5	45.00	45.00
B6	42.12	42.12
C1	29.50	29.50
C2	----	----
C3	27.25	26.50
D1	12.75	12.75
D2	----	----
D3	11.50	11.50
E1	62.75	62.50
E2	64.50	64.12
E3	64.00	64.00
E4	64.50	64.50
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.00	62.00

ATTACHMENT C: SEQUENTIAL PHOTOGRAPHS

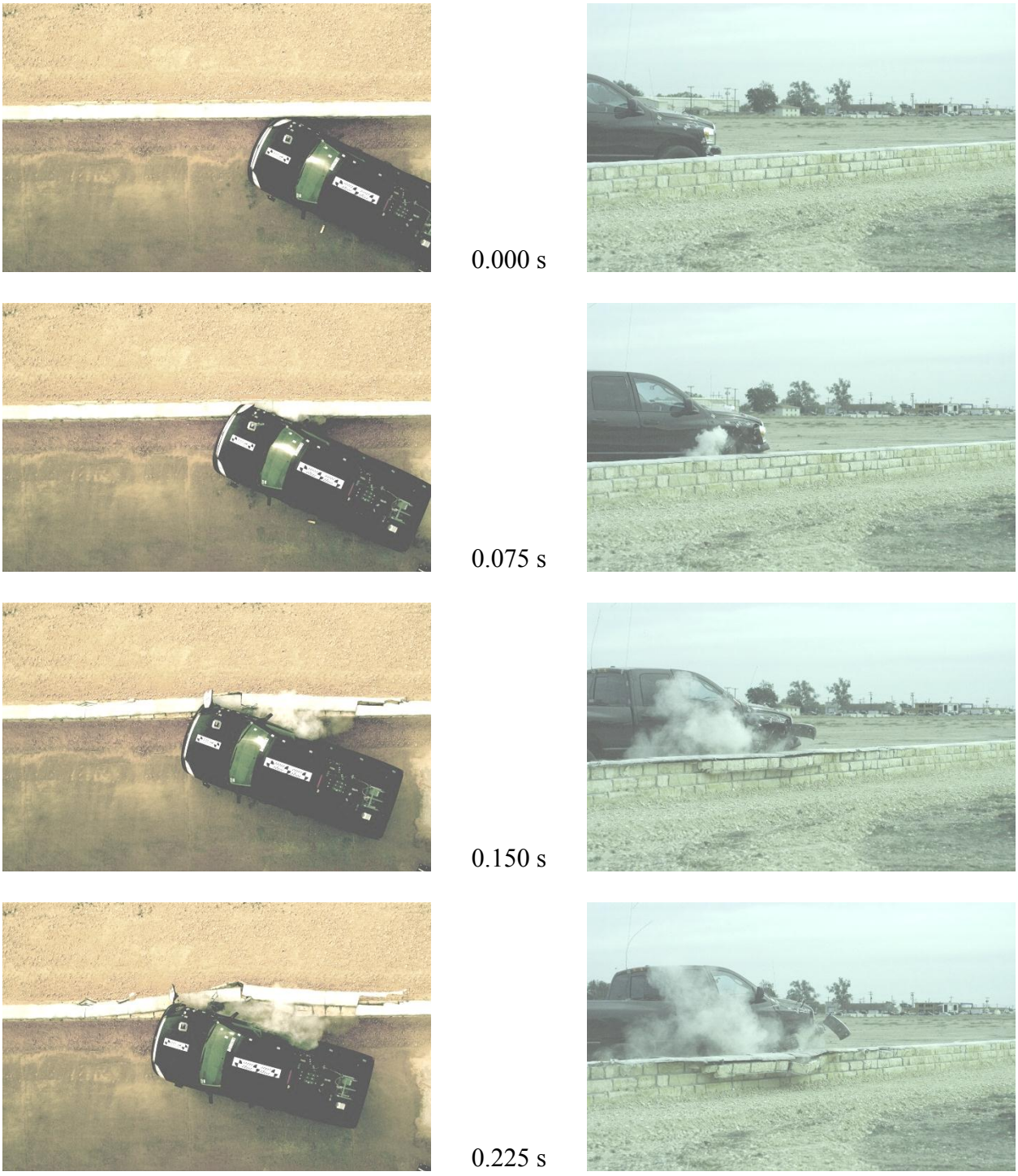
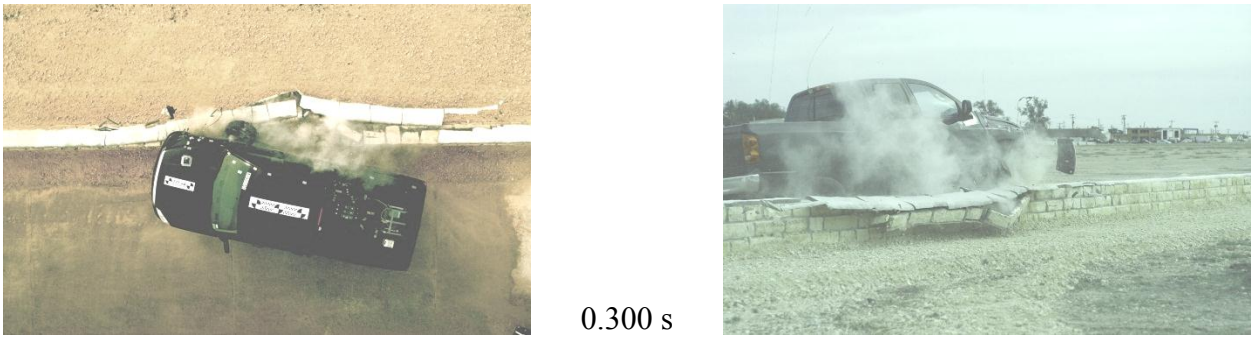


Figure C1. Sequential photographs for test 479070-1
(overhead and frontal views).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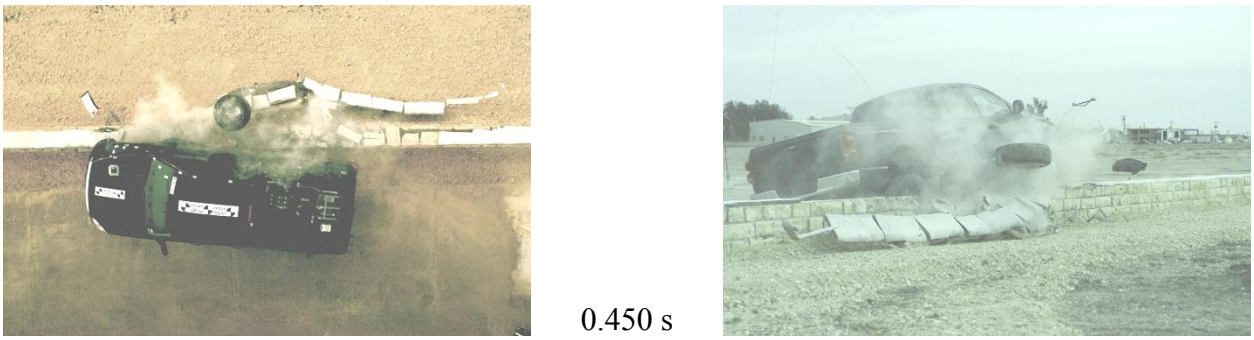
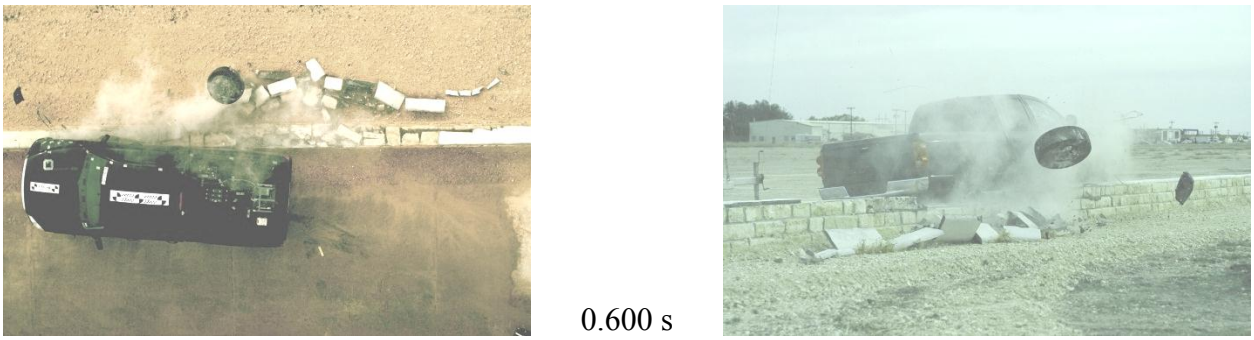

0.450 s


0.600 s

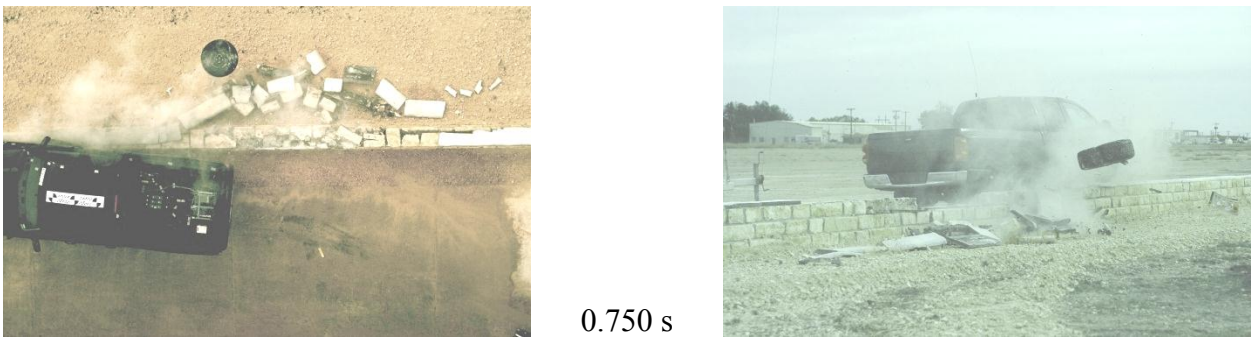

0.750 s

Figure C1. Sequential photographs for test 479070-1
(overhead and frontal views) (continued).

ATTACHMENT D: VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

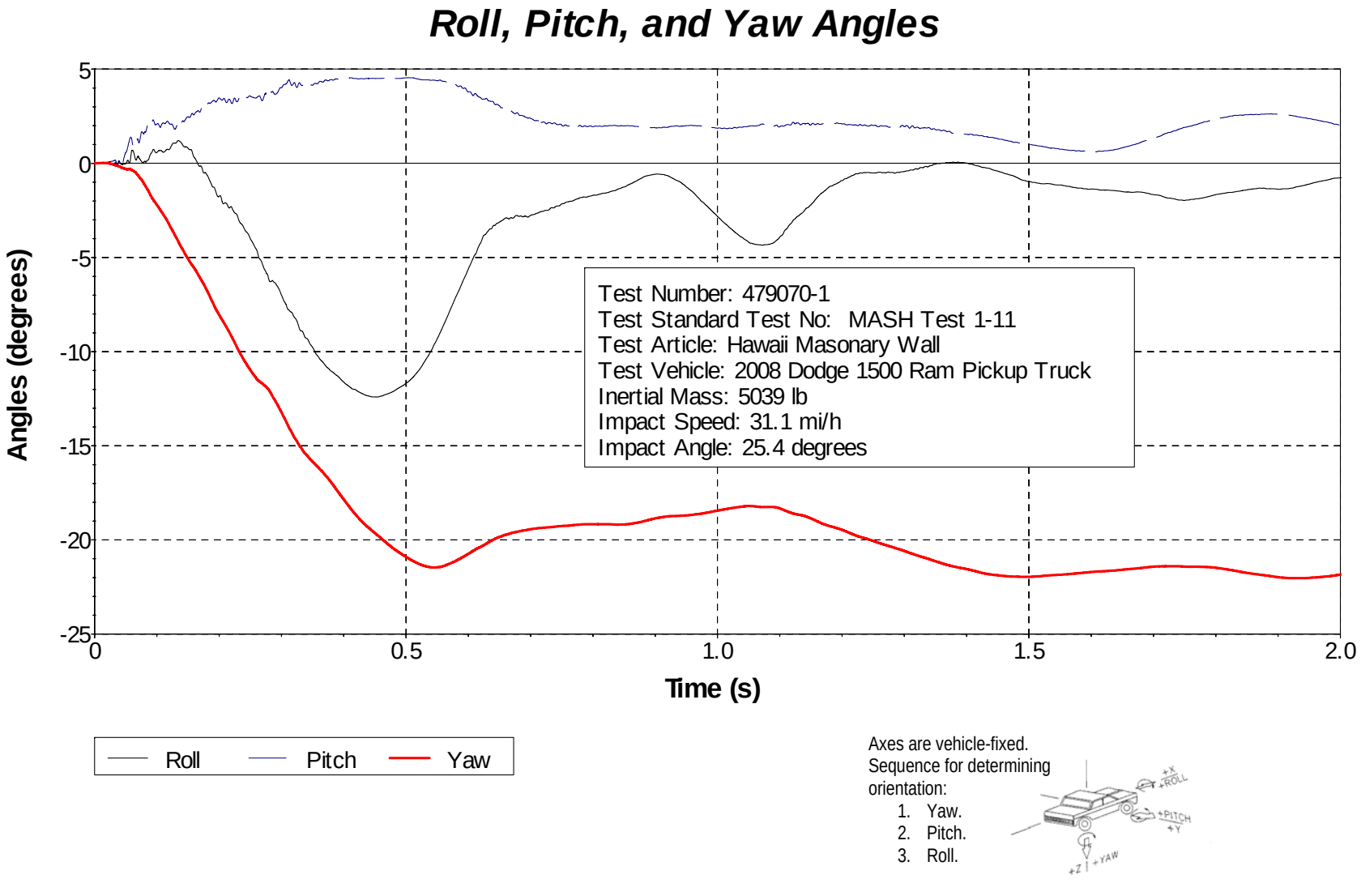


Figure D1. Vehicle angular displacements for test 479070-1.

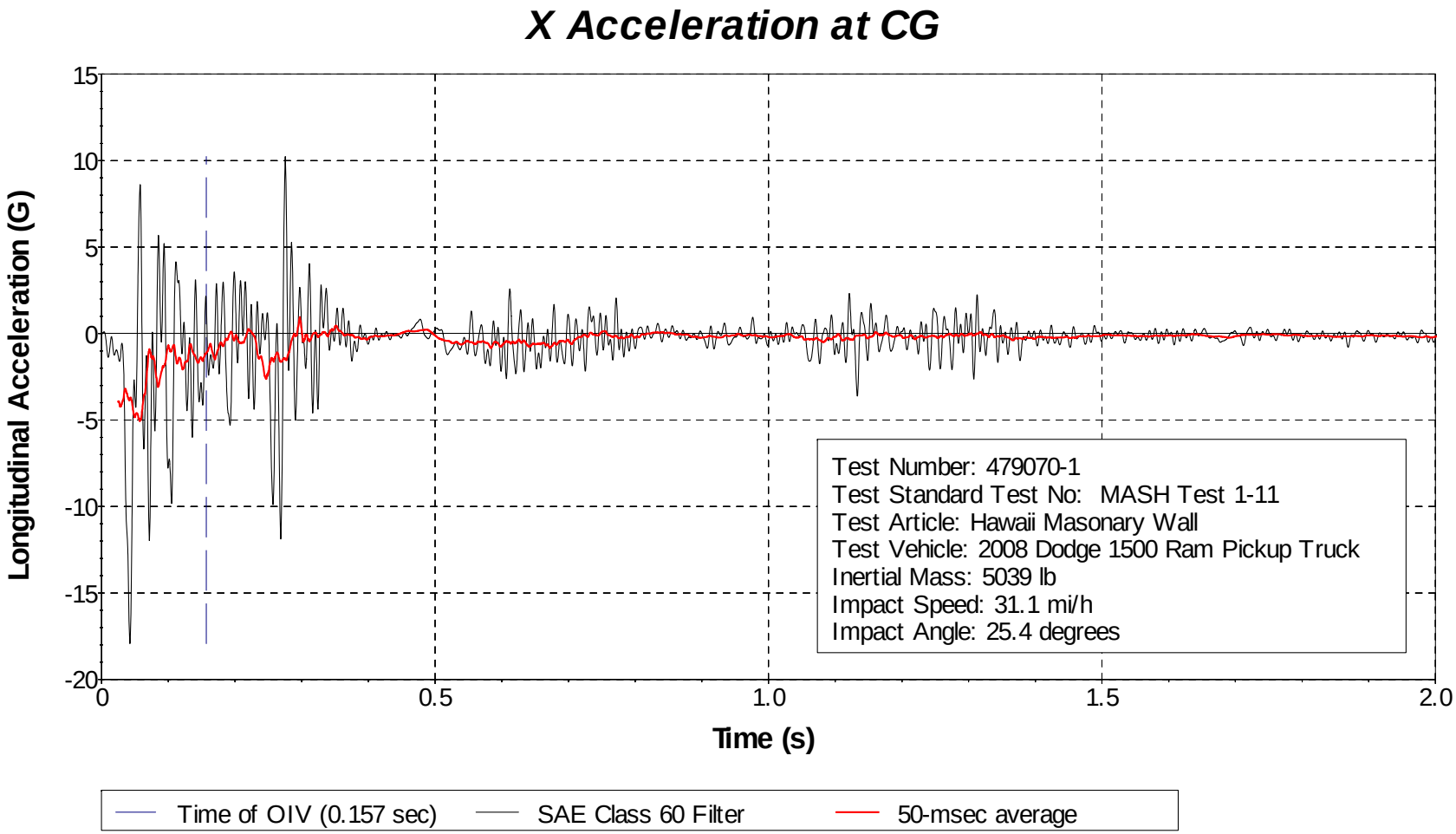


Figure D2. Longitudinal vehicle acceleration trace for test 479070-1
(accelerometer located at center of gravity).

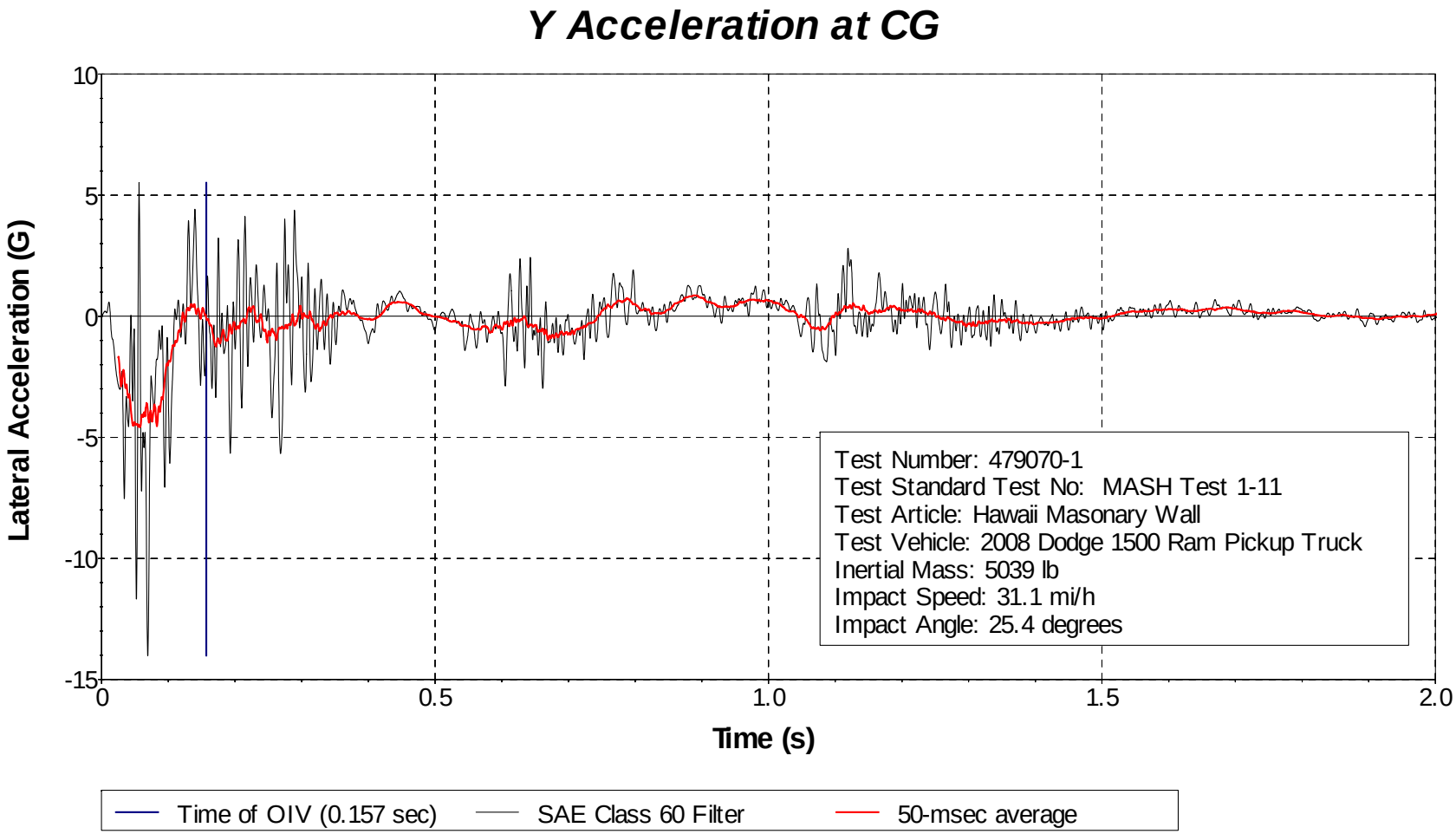


Figure D3. Lateral vehicle acceleration trace for test 479070-1
(accelerometer located at center of gravity).

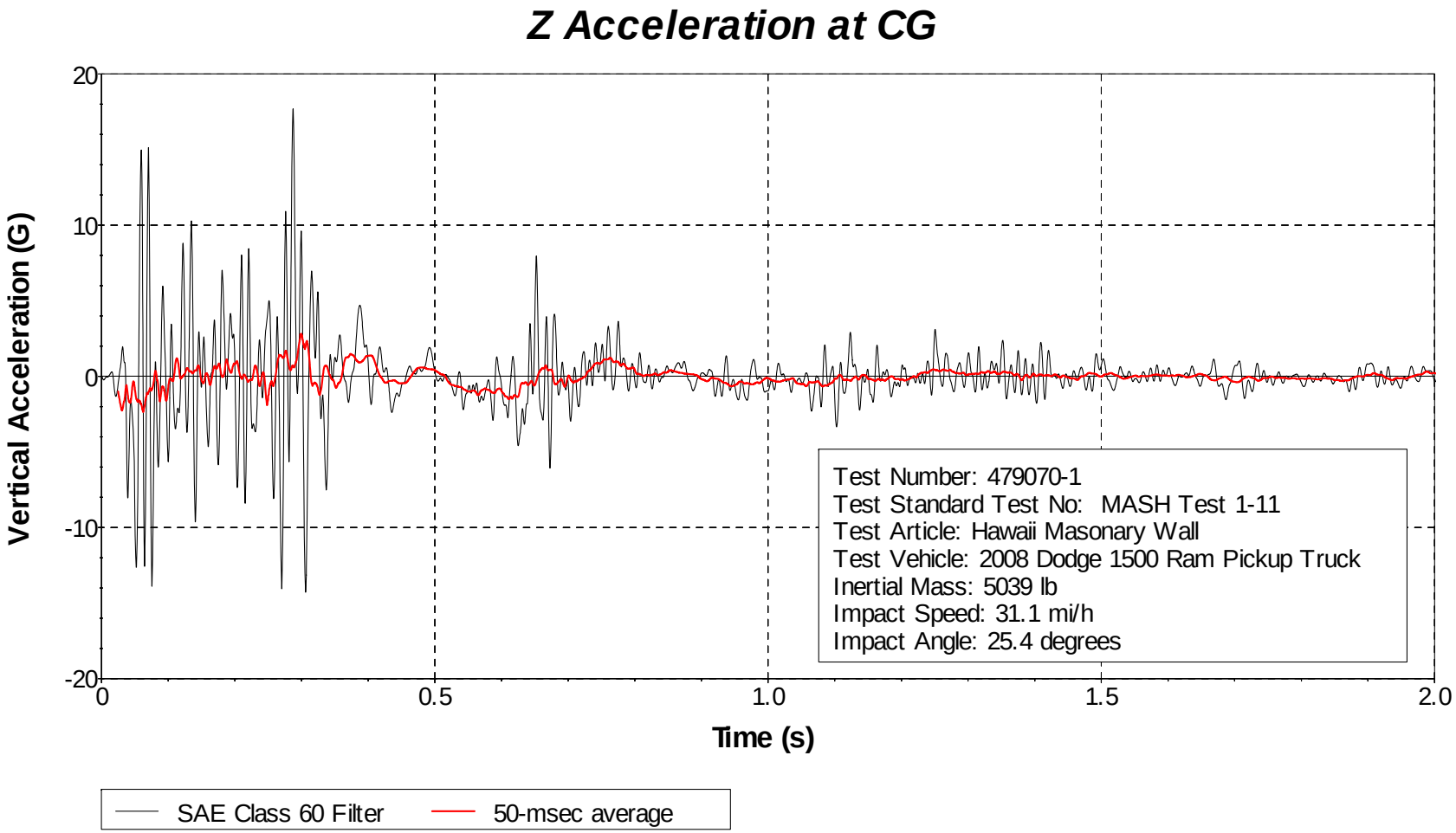


Figure D4. Vertical vehicle acceleration trace for test 479070-1
(accelerometer located at center of gravity).

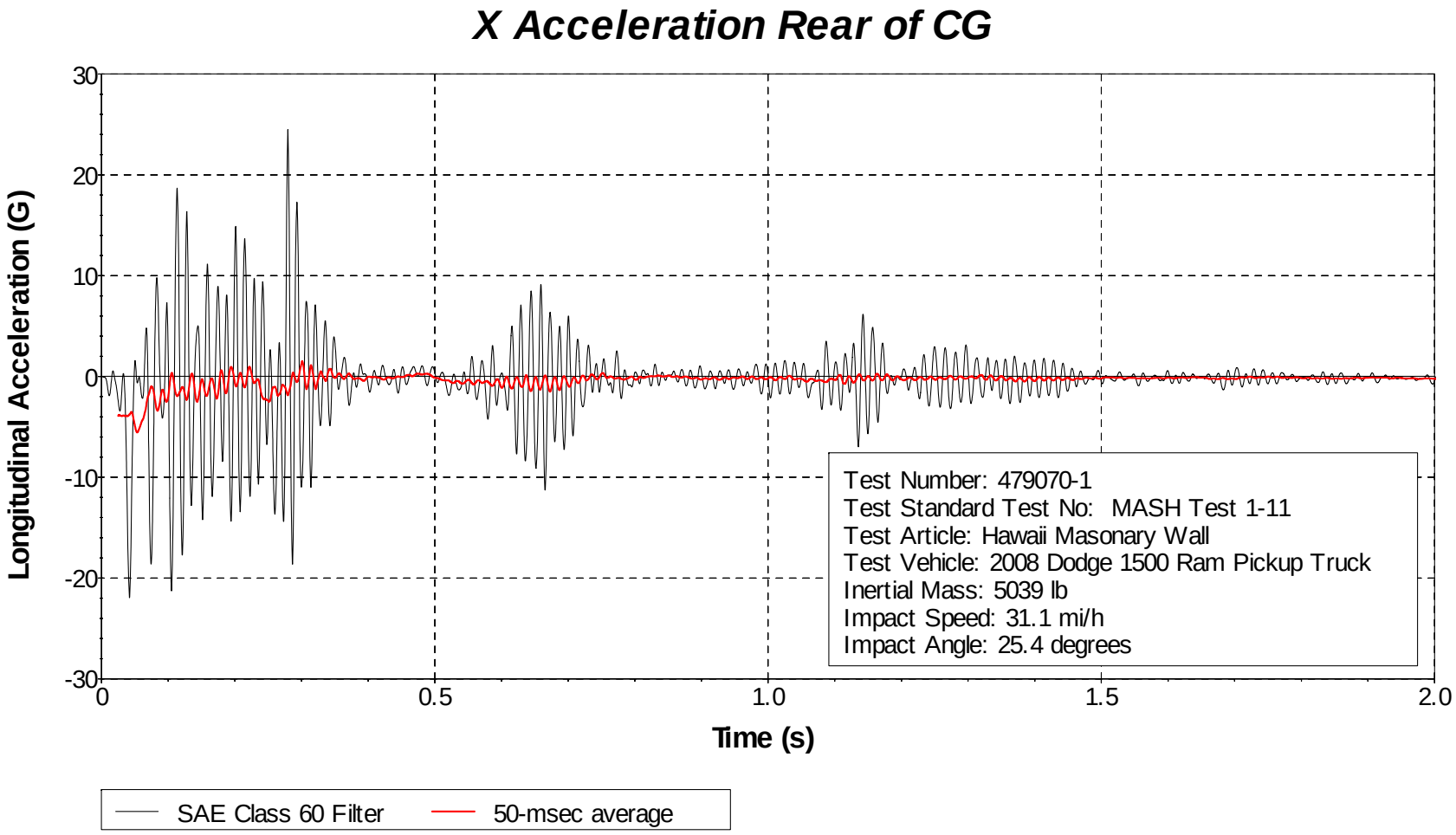


Figure D5. Longitudinal vehicle acceleration trace for test 479070-1
(accelerometer located at rear of center of gravity).

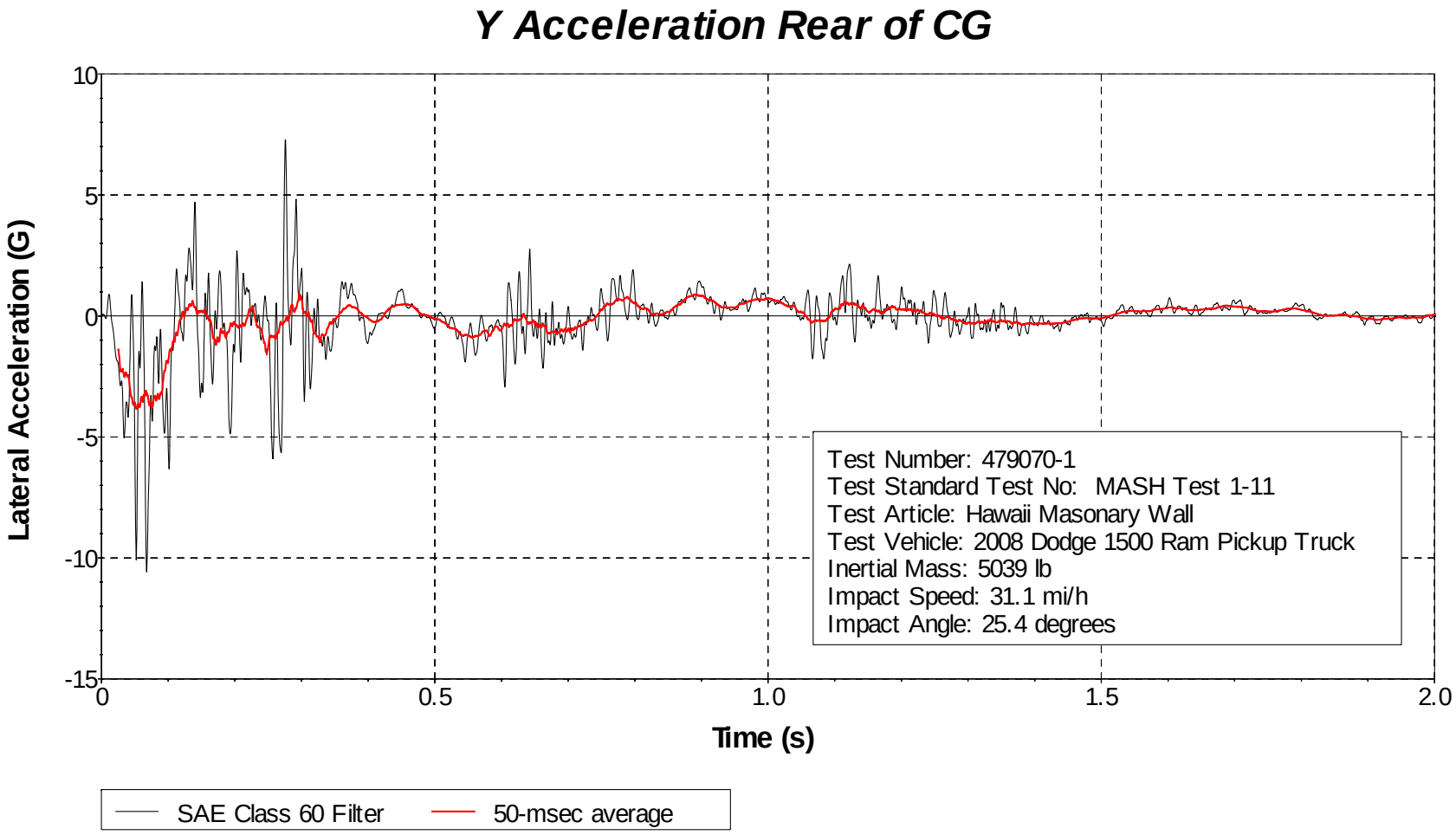


Figure D6. Lateral vehicle acceleration trace for test 479070-1
(accelerometer located at rear of center of gravity).

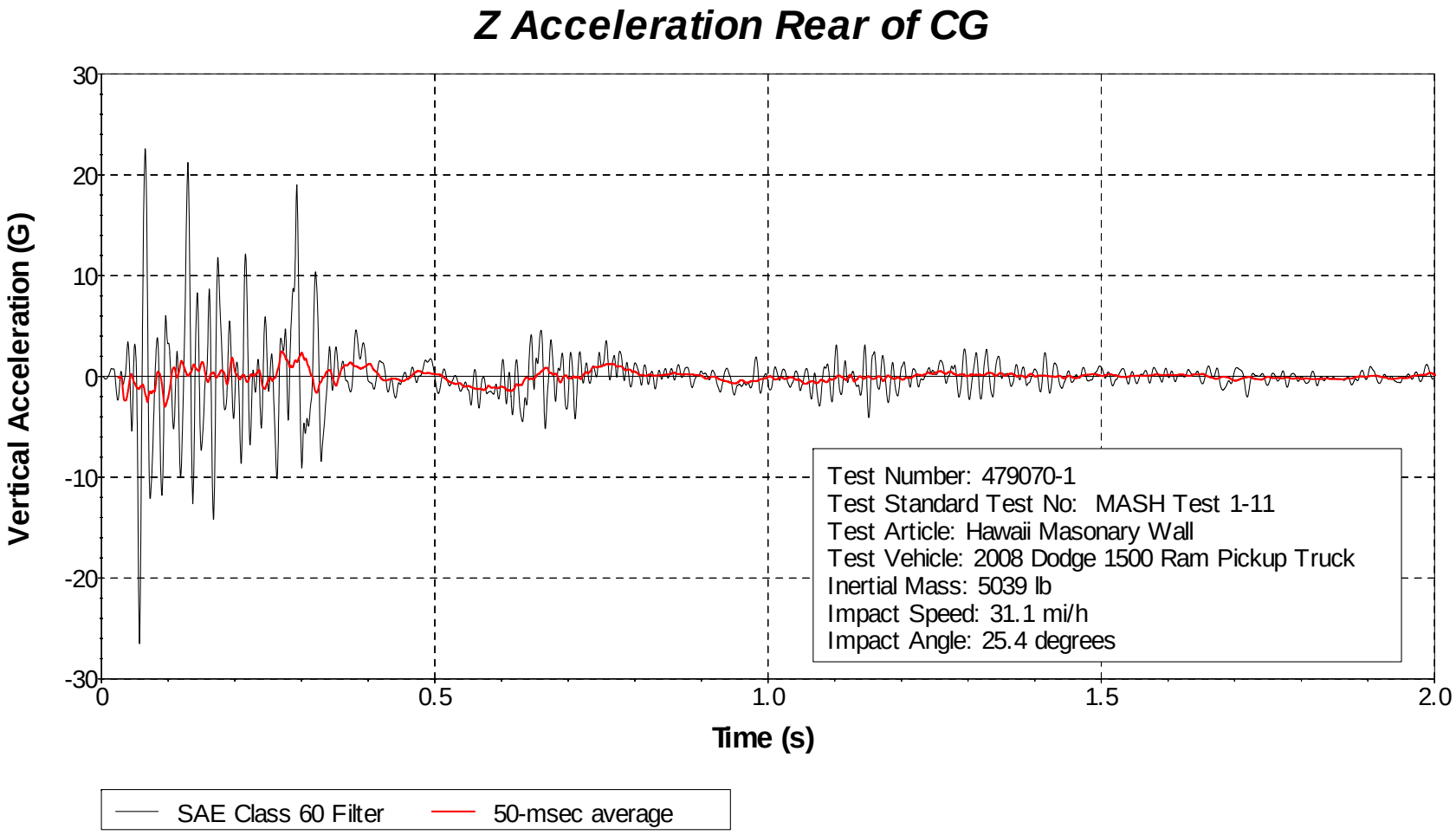


Figure D7. Vertical vehicle acceleration trace for test 479070-1
(accelerometer located at rear of center of gravity).