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MASH TL-4 EVALUATION OF FLARED CAST-IN-PLACE CONCRETE BARRIER

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16. Abstract

The purpose of this research was to investigate the crashworthiness of a flared concrete median barrier. The structural capacity and the occupant risk factors of such proposed barrier system was evaluated with respect to *MASH* Test Level 4 (TL-4) criteria through computer simulations and full-scale crash testing.

The information compiled from this research provides FHWA and State Departments of Transportation with an acceptable flare for rigid cast-in-place concrete barrier systems under the 2016 *MASH* TL-4 conditions. A successfully crash-tested flared concrete barrier system can be applied in situations where flaring a concrete barrier is needed to shield errant vehicles from fixed objects. A crashworthy flared concrete barrier would result in a reduction in system length for locations where space is limited. A successfully crash-tested system reduces the risks of injury or fatality for impacting errant vehicles.

The flared concrete barrier system reported herein met the performance criteria for *MASH* TL-4 longitudinal barriers.

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APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square 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
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	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
		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

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Chapter 1. INTRODUCTION

1.1 PROBLEM STATEMENT

Concrete median barriers are used by State Departments of Transportation (DOTs) as permanent and temporary barriers for providing separation of traffic. Typically, the crashworthiness of these barriers is tested and evaluated through full-scale crash testing conducted per current roadside safety device standards. Occasionally, DOTs have the need to flare the concrete barrier length of need (LON) around fixed objects such as bridge piers. No current recommendations are available to guide barrier flare rate around such fixed objects, while still maintaining barrier crashworthiness. Although the current practice is to flare the cast-in-place concrete barrier at a maximum 20:1 flare rate, no full-scale crash testing has been conducted to determine the crashworthiness of the system at this condition, or at a flare rate that might be considered more critical. Flaring a concrete barrier directly affects the impact angle of run-off-the-road errant vehicles, increasing the impact severity of such vehicles, and creating opportunities for pocketing, vehicle instability, and /or occupant interaction with the shielded fixed object.

The purpose of this research was to investigate the crashworthiness of a flared rigid concrete median barrier. The structural capacity and the occupant risk factors of the proposed concrete system was evaluated according to the American Association of State Highway and Transportation Officials (AASHTO) updated 2016 edition of the *Manual for Assessing Safety Hardware* (*MASH)* Test Level 4 (TL-4) criteria through computer simulations and full-scale crash testing.

The information compiled from this research provides the Federal Highway Administration (FHWA) and State Departments of Transportation with an acceptable flare for a cast-in-place concrete barrier system under *MASH* 2016 TL-4 conditions. A successfully crash-tested flared concrete barrier system can be applied in situations where flaring a concrete barrier is needed to shield errant vehicles from fixed objects. A crashworthy flared concrete barrier would result in a reduction in system length for locations where space is limited. A successfully crash-tested system reduces the risks of injury or fatality for impacting errant vehicles.

1.2 BACKGROUND

The 2016 *MASH* edition is the latest in a series of documents that provided guidance on testing and evaluation of roadside safety features. The original *MASH* document was published in 2009 and represents a comprehensive update to crash test and evaluation procedures that reflect changes in the vehicle fleet, operating conditions, and roadside safety knowledge and technology (*3*). The *MASH* documents supersede the *NCHRP Report 350* standards.

The structural adequacy *MASH* 2016 test for TL-4 conditions consists of a 22,000-lb single unit truck (SUT) (denoted 10000S) impacting the barrier at 56 mi/h and 15 degrees with respect to the roadway (Test 4-12). The severity *MASH* 2016 test consists of a 5000-lb pickup truck (denoted 2270P) (Test 4-11), and a 2420-lb passenger car (denoted 1100C) (Test 4-10) impacting the barrier at 62 mi/h and 25 degrees with respect to the roadway.

MASH was developed to incorporate significant changes and additions to procedures for safety-performance evaluation, and updates reflecting the changing character of the highway network and the vehicles using it. For example, *MASH* increased the weight of the pickup truck design test vehicle from 4409 lb to 5000 lb, changed the body style from a ¾-ton, standard cab to a ½-ton, 4-door, and imposed a minimum height for the vertical center of gravity (CG) of 28 inches. The increase in vehicle mass represents an increase in impact severity of approximately 13 percent for Test 4-11 with the pickup truck design test vehicle compared to the impact conditions of *NCHRP Report 350*. The increased impact severity may, therefore, result in increased impact forces and larger lateral barrier deflections compared to *NCHRP Report 350*.

The impact conditions for the small car test have also changed. The weight of the small passenger design test vehicle increased from 1800 lb to 2420 lb, and the impact angle increased from 20 degrees to 25 degrees with respect to the roadway. These changes represent an increase in impact severity of 188 percent for Test 4-10 with the small car design test vehicle compared to the impact conditions of *NCHRP Report 350*. This increase in impact severity might result in increased vehicle deformation and could possibly aggravate vehicle stability.

MASH also adopted more quantitative and stringent evaluation criteria for occupant compartment deformation than *NCHRP Report 350*. An increase in impact severity might result in increased vehicle deformation and could possibly result in failure to meet the latest *MASH* evaluation criteria. For example, *NCHRP Report 350* established a 6-inch threshold for occupant compartment deformation or intrusion. *MASH*, by comparison, limited the extent of roof crush to no more than 3.9 inches. In addition, *MASH* requires that the vehicle windshield not sustain a deformation greater than 3 inches, and not have holes or tears in the safety lining as a result of the test impact.

1.3 OBJECTIVE

The purpose of this research was to investigate the crashworthiness of a flared concrete median barrier. The structural capacity and the occupant risk factors of the proposed system were evaluated with respect to *MASH* TL-4 criteria through computer simulations and full-scale crash testing.

Chapter 2. FINITE ELEMENT ANALYSIS

2.1. BACKGROUND

According to AASHTO Roadside Design Guide (RDG), a roadside barrier is considered flared when it is not parallel to the edge of the roadway. One concern with flaring a barrier away from the roadway is that it would result in a higher impact angle from a potential errant vehicle. As the effective vehicle impact angle increases, the severity of the impact increases. For rigid barrier systems, the RDG recommends a maximum flare rate of 26:1 for a design speed of 60 mi/h (*4*).

2.2 MEMBERS SURVEY

The researchers polled the Roadside Safety Pooled Fund Member States to identify the most used flare rate and other design characteristics of cast-in-place (CIP) concrete barriers. The survey results indicated that a maximum flare rate of 20:1 appears to be the most common among the respondent States. Additionally, the minimum installed flare length was 5 ft. Table 2.1 shows the summary of the survey results on CIP flared concrete barriers. The researchers utilized finite element computer simulation to identify the critical impact point on a CIP flared concrete barrier.

Table 2.1. Survey Results on CIP Flare Rates Information.

Member State	Minimum Flared Length (ft)	Fixed Object Minimum Distance (inches)	Maximum Flare Rate (for high-speed roads)	Minimum Fixed Object Offset (inches)
Alabama	5	Not specified	20:1	4
Alaska	Not specified	Determined by designers	20:1	Not specified
Florida	15	Not specified	20:1	Depends on Barrier Height
Illinois	No standard	No standard	No standard	No standard
Iowa	Not specified	Determined by designers	20:1	15
Louisiana	Based on RDG	No standard	Based on RDG	6
Michigan	Not specified	Not specified	24:1	11
Ontario	Depends on speed	Depends on length of object	32:1	6.5
Texas	5	Not specified	20:1	4
Utah	Not specified	No minimum	30:1	2
Washington	9.25	No standard	25:1	8
West Virginia	No standard	No standard	20:1	No standard
Wisconsin	Based on RDG	No minimum	Based on RDG	5

2.3 FINITE ELEMENT MODEL SIMULATIONS

2.3.1 Introduction

The researchers conducted finite element modeling on the initial design. The simulations were performed using LS-DYNA, which is a commercially available general-purpose finite element analysis software. The following summarizes the simulation effort for this task.

2.3.2 Detailed Modeling

An explicit finite element model of the CIP flared concrete barrier was modeled using rigid material representation. Figure 2.1 illustrates the system with inclusion of a section with a 20:1 flare rate. The vehicle model used in the simulations was originally developed by the National Crash Analysis Center. Figure 2.2 shows the *MASH* passenger car (1100C), pickup truck (2270P), and single unit truck (10000S) models.

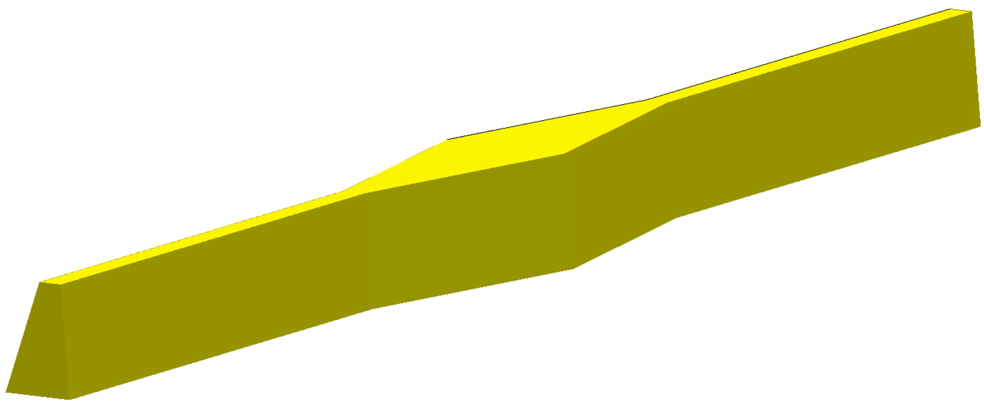


Figure 2.1. Single Slope Barrier with 20:1 Flare.

(a) (b) (c)

Figure 2.2. *MASH* Test Vehicle Models; (a) 1100C, (b) 2270P, and (c) 10000S.

2.3.3 Simulation

All impact simulations were performed under *MASH* TL-4 impact conditions. The researchers conducted a parametric analysis to investigate the system and the impacting vehicles performance at various impact locations, with 1-ft increments. The objective was to identify the critical impact point(s) for recommendation for full-scale crash testing. The simulations included locations upstream of the beginning of the flare and at the flare breakpoint . Furthermore, the researchers investigated the potential for tire disengagement and its influence on the stability of the pickup truck. Simulation results indicated that tire disengagement did not appear to cause aggravated vehicular instability during and after the impact event. Considering the higher center of gravity of the pickup truck compared to the small car, it was concluded that tire disengagement investigation for the small car was not necessary.

Additionally, the researchers investigated additional barrier design variables such as barrier height, length, and flare rates. A barrier height of 36 inches indicated significant instability of the single unit truck (SUT) during the impact event. Simulations also indicated that a barrier height of 40 inches would be deemed acceptable for CIP barriers with a flare rate of 20:1. Furthermore, a flare rate higher than 20:1 showed a higher probability of vehicular instability when impacted at TL-4 test criteria. The researchers concluded that flare length was not a critical variable based on computer simulation results.

The parametric analysis indicated that the vehicle impact on the flare seems to cause higher occupant risk factors. This result would be expected given the higher impact severity due to higher vehicle effective impact angle. The sequential images of the simulations are presented in Figure 2.3 to Figure 2.5.

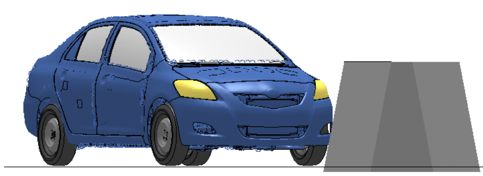
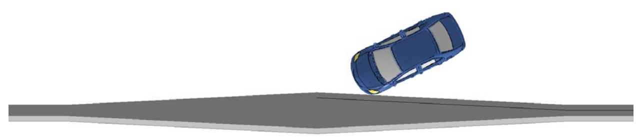
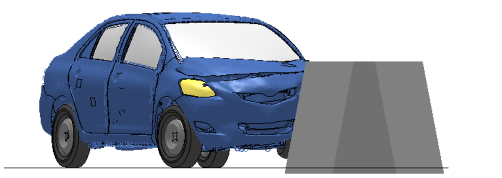
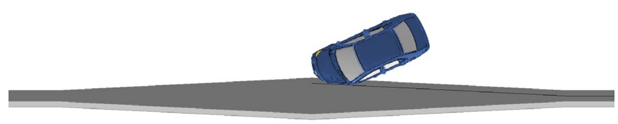
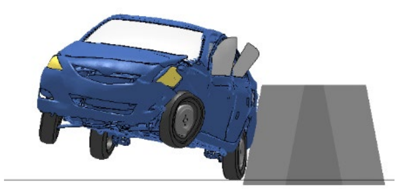
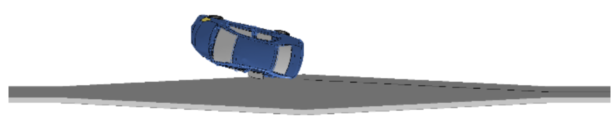
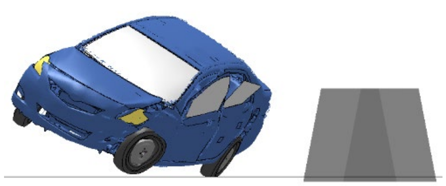
Frontal View	**Top View**	**Time (s)**
		0.00
		0.05
		0.25
		0.50

Figure 2.3. Sequential Simulation Images of *MASH* Test 4-10 on CIP Flared Barrier.

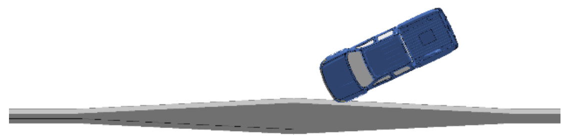
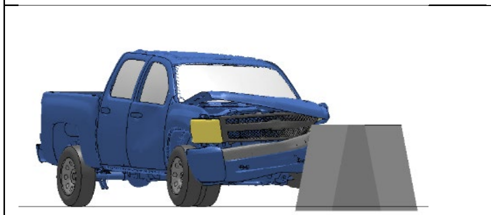
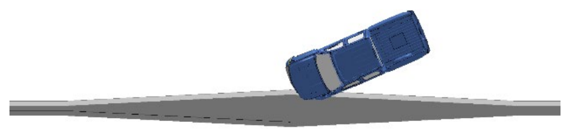
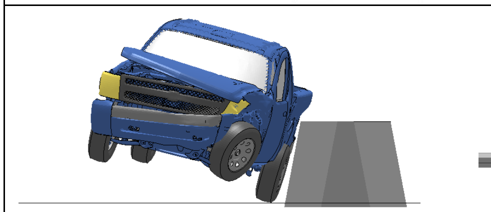
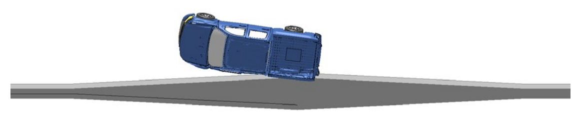
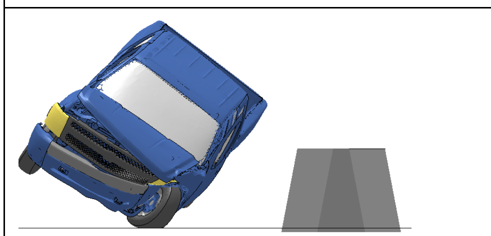
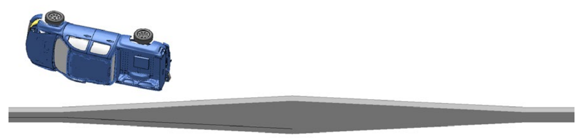
Frontal View	Top View	Time (s)
		0.00
		0.05
		0.25
		0.50

Figure 2.4. Sequential Simulation Images of *MASH* Test 4-11 on CIP Flared Barrier.

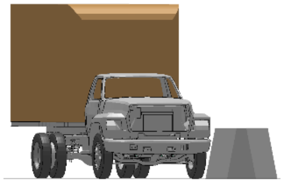
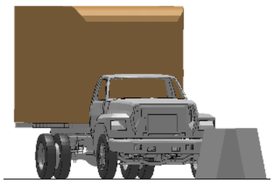
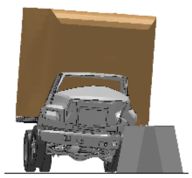
Frontal View	Top View	Time (s)
		0.00
		0.05
		0.25
		0.50

Figure 2.5. Sequential Simulation Images of *MASH* Test 4-12 on CIP Flared Barrier.

All three vehicles seemed to indicate a more critical behavior when their impact event was contained on the flared section of the barrier, and not upstream of the flare breakpoint. Also, in order to maximize the potential for vehicle instability during the impact event, the impact points were selected to be at a specific distance upstream of the end of the 20:1 flare.

2.4 CONCLUSIONS

Based on the computer simulations, the researchers decided to impact the small car and pickup truck at 5 ft upstream of the end of the 20:1 flare. According to the conducted computer simulation and previous crash testing, it was decided for critical impact point of 10 ft upstream of the end of the 20:1 flare for the SUT impact, to provide enough barrier length to develop a full interaction between the SUT and the flare *(5)*. Figure 2.6 illustrates the critical impact points proposed for the full-scale crash tests' conduction.

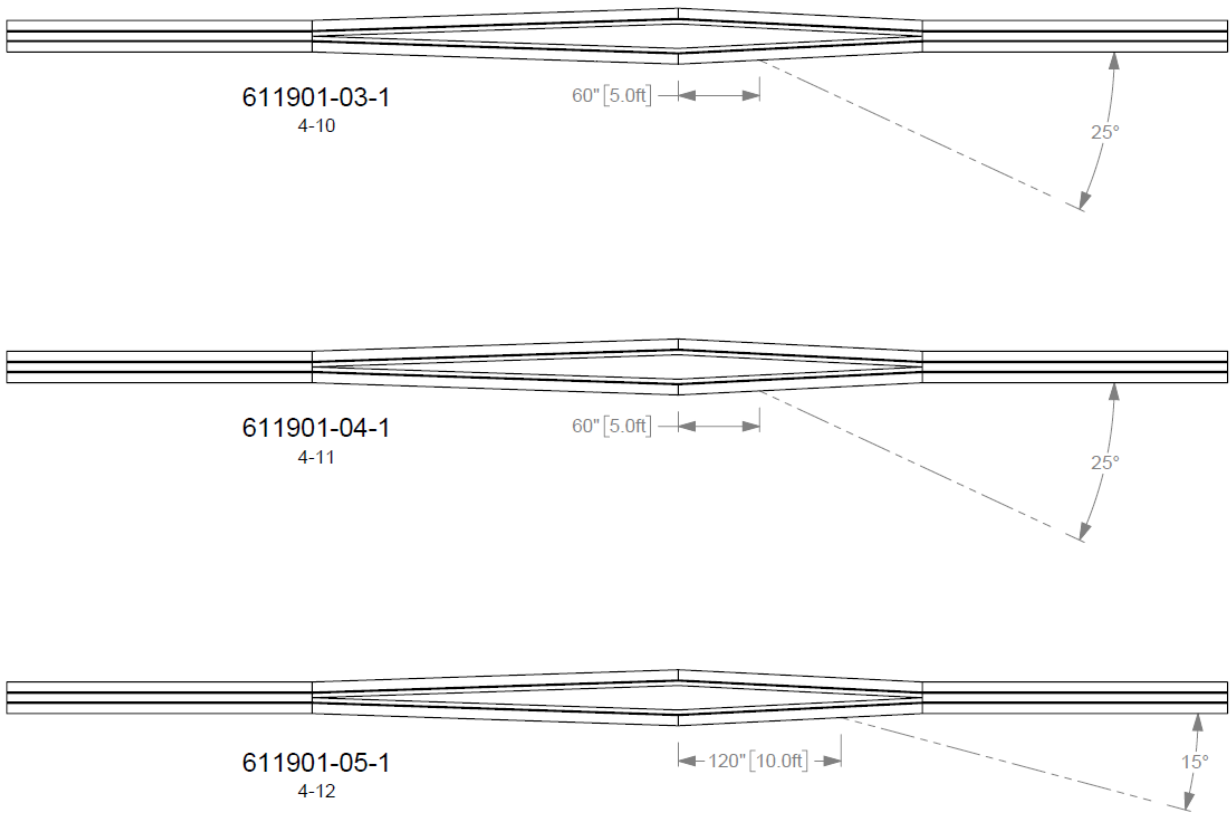


Figure 2.6. Selected CIPs for Each *MASH* TL-4 Tests Based on Simulation.

Chapter 3. SYSTEM DETAILS

3.1 TEST ARTICLE AND INSTALLATION DETAILS

The installation consisted of a 75 ft long, 40-inch tall reinforced concrete single slope median barrier that flared 18 inches wider in its intermediate segment. Each upstream and downstream segment was 18 ft 9 inches long, 23¼ inches wide at bottom, and sloped up on both sides to 8 inches wide at the top . The intermediate flared section maintained the same single slope and each measured 4 inches wide at top. The upstream segment flared outward at a 20:1 ratio for 15 ft in length. The downstream segment flared back inward at a 30:1 ratio over a length of 23 ft.

The flared sections were connected to each other with ½-inch diameter galvanized rods, and the void between them was filled with uncompacted coarse aggregate. Multiple ¾-inch diameter rebar anchor rods embedded 6 inches deep and secured with epoxy were used to anchor the barrier sections to the existing concrete apron.

Figure 3.1 presents the overall information on the critical flare concrete barrier system, and Figure 3.2 provides photographs of the installation. Appendix A provides further details on the critical flare concrete barrier system. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by Tucker Construction supervised by TTI Proving Ground personnel.

3.2 DESIGN MODIFICATIONS DURING TESTS

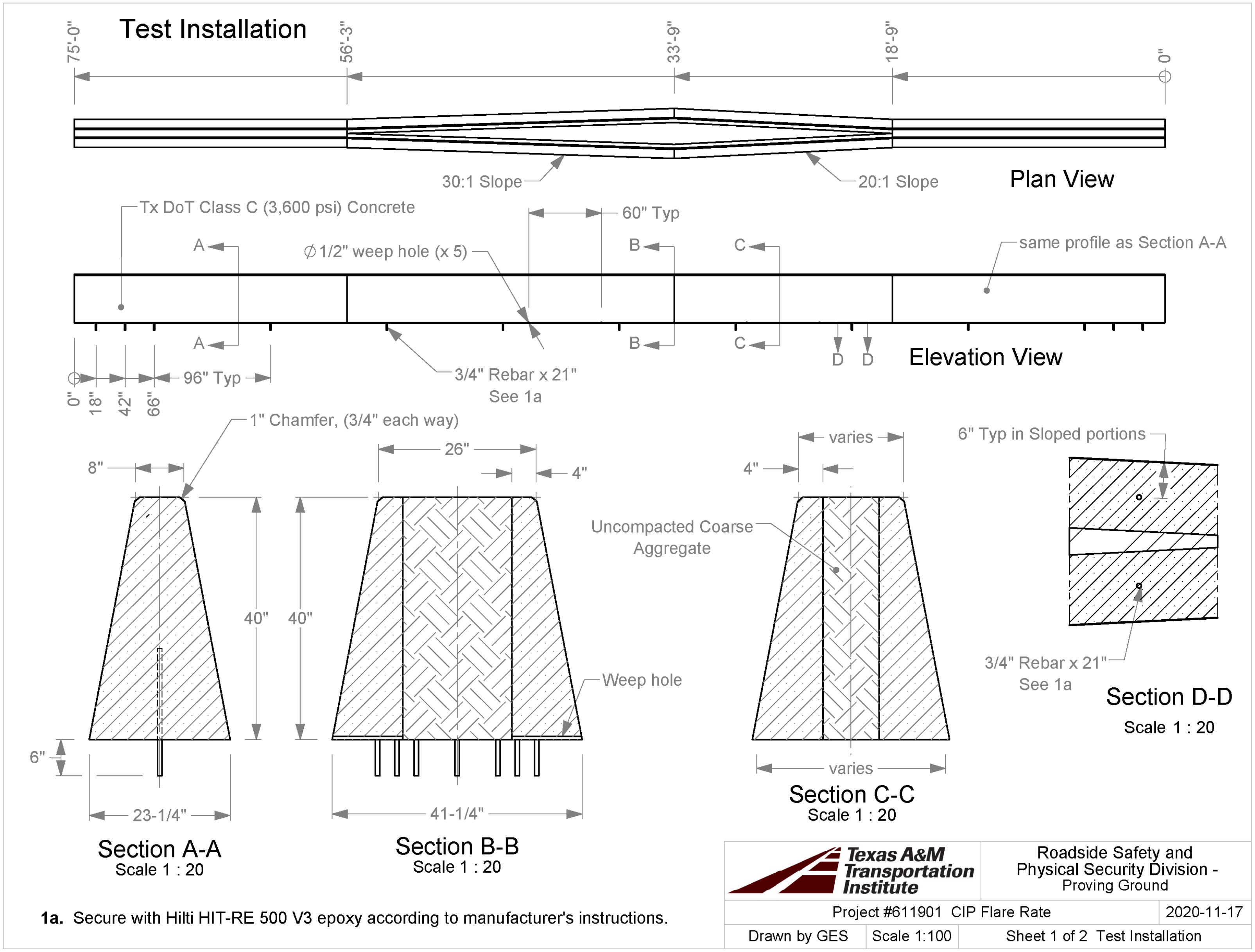
No modification was made to the installation during the testing phase.

3.3 MATERIAL SPECIFICATIONS

The specified compressive strength of the concrete used in the barrier was 3600 psi. On March 24, 2021, one day before the first test, the average compressive strengths of the concrete were as follows:

- Average concrete strength for the traffic side flared barrier and north and south median barriers: 4863 psi at 29 days of age.
- Average concrete strength for the field side of the flared barrier: 3490 psi at 22 days of age.

Appendix B provides material certification documents for the materials used to install/construct the critical flare concrete barrier system.



Q:\Accreditation-17025-2017\EIR-000 Project Files\611901 - CIP Critical Flare Rates - Chiara\Drafting, 611901\611901 Drawing

Figure 3.1. Details of Critical Flare Concrete Barrier System.

Figure 3.2. Critical Flare Concrete Barrier System prior to Testing.

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Chapter 4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 CRASH TEST PERFORMED/MATRIX

Table 4.1. shows the test conditions and evaluation criteria for *MASH* TL-4 for longitudinal barriers. The target critical impact points (CIPs) for each test were determined using the information obtained through computer simulation. Figure 4.1 shows the target CIP for the *MASH* TL-4 tests on the critical flare concrete barrier system.

Table 4.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-4 Longitudinal Barriers.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	4-10	1100C	62 mi/h	25°	A, D, F, H, I
	4-11	2270P	62 mi/h	25°	A, D, F, H, I
	4-12	10000S	56 mi/h	15°	A, D, G

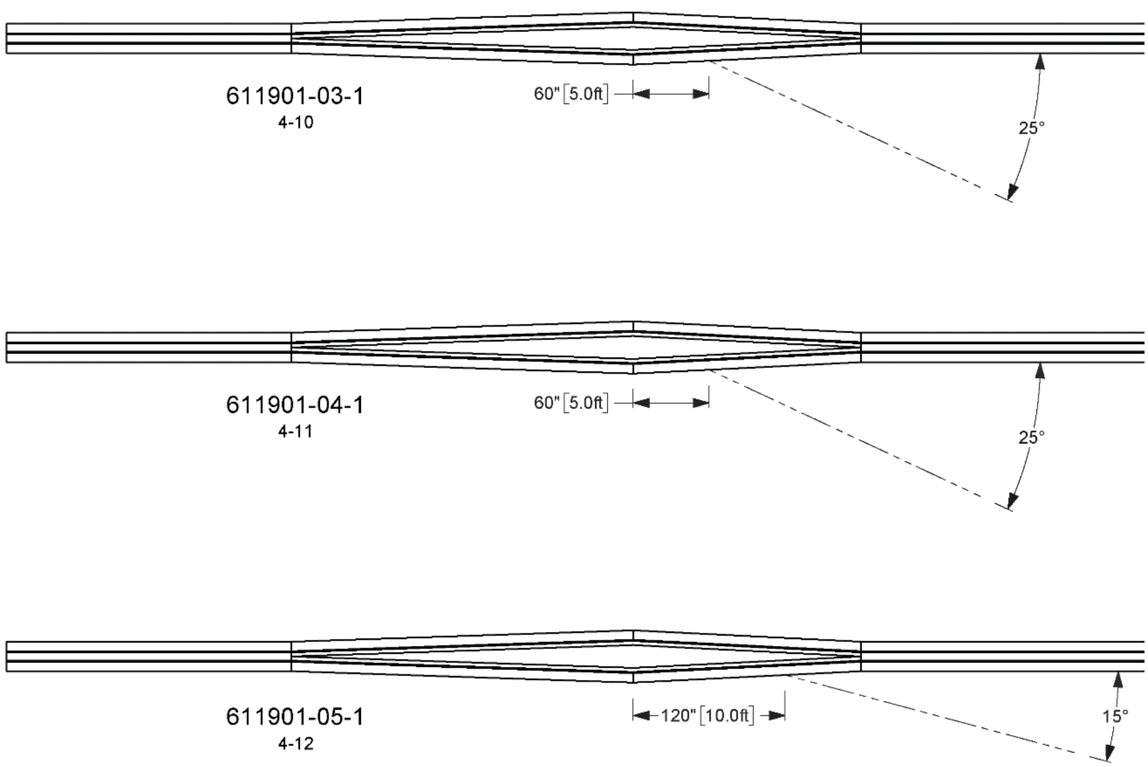


Figure 4.1. Target CIPs for *MASH* TL-4 Tests on Critical Flare Concrete Barrier System.

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 5 presents brief descriptions of these procedures.

4.2 EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. Table 4.1. lists the test conditions and evaluation criteria required for *MASH* TL-4, and Table 4.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 9.

Table 4.2. Evaluation Criteria Required for *MASH* TL-4 Longitudinal Barriers.

Evaluation Factors	Evaluation Criteria	*MASH* Test
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.*	*4-10, 4-11, and 4-12*
Occupant Risk	*D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*	*4-10, 4-11, and 4-12*
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	*4-10 and 4-11*
	G. It is preferable, although not essential, that the vehicle remain upright during and after the collision.	*4-12*
	H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	*4-10 and 4-11*
	I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	*4-10 and 4-11*

Chapter 5. TEST CONDITIONS

5.1 TEST FACILITY

The full-scale crash tests reported herein were performed at the TTI Proving Ground, an International Standards Organization (ISO)/International Electrotechnical Commission (IEC) 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, as well as *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 mi 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, highway pavement durability and efficacy, and roadside safety hardware and perimeter protective device evaluation. The site selected for construction and testing of the critical flare concrete barrier system was along the edge of an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement but are otherwise flat and level.

5.2. 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 and through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site.

5.3. DATA ACQUISITION SYSTEMS

5.3.1. Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained onboard 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 samples per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit in case the primary battery cable is severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units is returned to the factory annually for complete recalibration and to ensure that all instrumentation used in the vehicle conforms to the 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 calibration via a Genisco Rate-of-Turn table. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel per SAE J211. Calibrations and evaluations are also made anytime data are suspect. Acceleration data are 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 the occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and 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 an SAE Class 180-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, and 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 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).

5.3.2. 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. However, *MASH* recommends that a dummy be used when testing "any longitudinal barrier with a height greater than or equal to 33 inches." More specifically, use of the dummy in the 2270P vehicle is recommended for tall rails to evaluate the "potential for an occupant to extend out of the vehicle and come into direct contact with the test article." Although this information is reported, it is not part of the impact performance evaluation. Since the rail height of the critical flare concrete barrier system was 40 inches, a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

MASH does not recommend or require use of a dummy in the 10000S vehicle, and no dummy was placed in the 10000S vehicle.

5.3.3. 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 upstream from the installation at an angle to have a field of view of the interaction of the rear of the vehicle with the installation.
- A third placed with 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 critical flare concrete barrier system. 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 6. *MASH* TEST 4-10 (CRASH TEST NO. 611901-03-1)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-10 involves a 1100C vehicle weighing 2420 lb ± 55 lb impacting the CIP of the longitudinal barrier 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 4-10 on the barrier system was 5.0 ft ± 1 ft upstream of the centerline of the maximum width of the flare. Figure 4.1 and Figure 6.1 depict the target impact setup.

Figure 6.1. Barrier System/Test Vehicle Geometrics for Test No. 611901-03-1.

The 1100C vehicle weighed 2432 lb, and the actual impact speed and angle were 62.7 mi/h and 24.7 degrees. The actual impact point was 4.6 ft upstream of the centerline of the maximum width of the flare. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 56 kip-ft.

6.2. WEATHER CONDITIONS

The test was performed on the morning of March 30, 2021. Weather conditions at the time of testing were as follows: wind speed: 18 mi/h; wind direction: 180 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 73°F; relative humidity: 79 percent.

6.3. TEST VEHICLE

Figure 6.2 shows the 2016 Nissan Versa used for the crash test. The vehicle's test inertia weight was 2432 lb, and its gross static weight was 2597 lb. The height to the lower edge of the vehicle bumper was 7.00 inches, and the height to the upper edge of the bumper was 22.3 inches. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.2. Test Vehicle before Test No. 611901-03-1.

6.4. TEST DESCRIPTION

Table 6.1 lists events that occurred during Test No. 611901-03-1. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 6.1. Events during Test No. 611901-03-1.

Time (s)	Events
0.0000	Vehicle impacts the barrier system
0.0320	Vehicle begins to redirect
0.0900	Left front tire lifts off of the pavement
0.1440	Left rear tire lifts off of the pavement
0.1520	Vehicle traveling parallel with the barrier system
0.1720	Right rear bumper contacts the barrier system
0.2200	Vehicle loses contact with the barrier system while traveling at 50.8 mi/h, trajectory of 3.6 degrees, and heading of 7.3 degrees

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied after the vehicle exited the test site. The vehicle subsequently came to rest 158 ft downstream of the point of impact and 95 ft toward traffic lanes.

6.5. DAMAGE TO TEST INSTALLATION

Figure 6.3 shows the damage to the barrier system. There was minor gouging and scuffing on the concrete at impact. Working width* was 41.25 inches, and height of working

* Per *MASH*, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.

width was at the toe of the barrier. No measurable dynamic deflection during the test or permanent deformation after the test was observed.

Figure 6.3. Barrier System after Test No. 611901-03-1.

6.6. DAMAGE TO TEST VEHICLE

Figure 6.4 shows the damage sustained by the vehicle. The front bumper, hood, grill, radiator and support, right front fender, right front strut and tower, right front tire and rim, right A-pillar, right front floor pan, right front corner of the roof, right front door and window glass, right rear door, right rear quarter panel, and rear bumper were damaged. The windshield sustained stress cracks radiating upward and inward from the lower right corner. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 10.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 3.5 inches in the kick panel/toe pan area and 3.0 inches in the right front firewall area. Figure 6.5 shows the interior of the vehicle. Tables C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

Figure 6.4. Test Vehicle after Test No. 611901-03-1.

Figure 6.5. Interior of Test Vehicle after Test No. 611901-03-1.

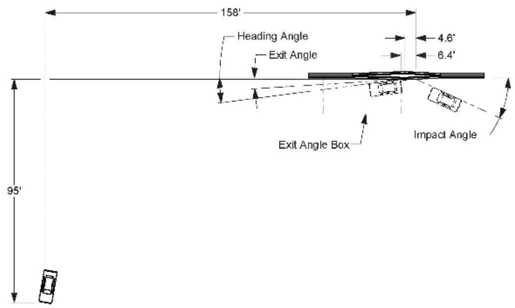
6.7. OCCUPANT RISK FACTORS

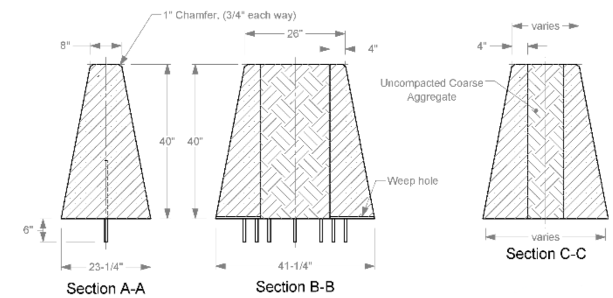
Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.2. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.6 in Appendix C.4 show acceleration versus time traces. Figure 6.6 summarizes pertinent information from the test.

Table 6.2. Occupant Risk Factors for Test No. 611901-03-1.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	21.3 ft/s	at 0.0753 s on right side of interior
Lateral	33.1 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	4.0 g	0.0815 - 0.0915 s
Lateral	13.3 g	0.1622 - 0.1722 s
Theoretical Head Impact Velocity (THIV)	12.0 m/s	at 0.0737 s on right side of interior
Acceleration Severity Index (ASI)	2.7	0.0477 - 0.0977 s
Maximum 50-ms Moving Average		
Longitudinal	−12.2 g	0.0201 - 0.0701 s
Lateral	−19.5 g	0.0205 - 0.0705 s
Vertical	−5.7 g	0.0475 - 0.0975 s
Maximum Yaw, Pitch, and Roll Angles		
Roll	16°	0.5085 s
Pitch	10°	2.5890 s
Yaw	111°	5.0000 s

0.000 s | 0.100 s | 0.200 s | 0.400 s





General Information

- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: *MASH* Test 4-10
- TTI Test No.: 611901-03-1
- Test Date: 2021-03-30

Test Article

- Type: Longitudinal Barrier—Concrete Barrier
- Name: Flared Concrete Barrier System
- Installation Length: 75 ft
- Material or Key Elements: 20:1 Flare for 15 ft Upstream 40-inch tall single slope CIP

Soil Type and Condition: Concrete pavement, damp

Test Vehicle

- Type/Designation: 1100C
- Make and Model: 2016 Nissan Versa
- Curb: 2349 lb
- Test Inertial: 2432 lb
- Dummy: 165 lb
- Gross Static: 2597 lb

Impact Conditions

- Speed: 62.7 mi/h
- Angle: 24.7°
- Location/Orientation: 4.6 ft upstream of maximum flare

Impact Severity: 56 kip-ft

Exit Conditions

- Speed: 50.8 mi/h
- Trajectory/Heading Angle: 3.6°/7.3°

Occupant Risk Values

- Longitudinal OIV: 21.3 ft/s
- Lateral OIV: 33.1 ft/s
- Longitudinal Ridedown: 4.0 g
- Lateral Ridedown: 13.3 g
- THIV: 12.0 m/s
- ASI: 2.7

Max. 0.050-s Average

- Longitudinal: −12.2 g
- Lateral: −19.5 g
- Vertical: −5.7 g

Post-Impact Trajectory

- Stopping Distance: 158 ft downstream 95 ft twd traffic lanes

Vehicle Stability

- Maximum Roll Angle: 16°
- Maximum Pitch Angle: 10°
- Maximum Yaw Angle: 111°
- Vehicle Snagging: No
- Vehicle Pocketing: No

Test Article Deflections

- Dynamic: None
- Permanent: None
- Working Width: 41.25
- Height of Working Width: At toe of barrier

Vehicle Damage

- VDS: 01RFQ6
- CDC: 01FREW5
- Max. Exterior Deformation: 10.0 inches
- OCDI: RF0020000
- Max. Occupant Compartment Deformation: 3.5 inches

Figure 6.6. Summary of Results for *MASH* Test 4-10 on Critical Flare Concrete Barrier System.

Chapter 7. *MASH* TEST 4-11 (CRASH TEST NO. 611901-04-1)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-11 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the CIP of the longitudinal barrier 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 4-11 on the barrier system was 5.0 ft ± 1 ft upstream of the centerline of the maximum width of the flare. Figure 4.1 and Figure 7.1 depict the target impact setup.

Figure 7.1. Barrier System/Test Vehicle Geometrics for Test No. 611901-04-1.

The 2270P vehicle weighed 5020 lb, and the actual impact speed and angle were 63.2 mi/h and 24.9 degrees. The actual impact point was 4.9 ft upstream of the centerline of the maximum width of the flare. Minimum target IS was 106 kip-ft, and actual IS was 119 kip-ft.

7.2. WEATHER CONDITIONS

The test was performed on the morning of March 25, 2021. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 355 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 64°F; relative humidity: 73 percent.

7.3. TEST VEHICLE

Figure 7.2 shows the 2015 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5020 lb, and its gross static weight was 5185 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.75 inches. Tables D.1 and D.2 in Appendix D.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.2. Test Vehicle before Test No. 611901-04-1.

7.4. TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 611901-04-1. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 611901-04-1.

Time (s)	Events
0.0000	Vehicle impacts the barrier system
0.0440	Vehicle begins to redirect
0.0920	Left front tire lifts off of the pavement
0.1730	Left rear tire lifts off of the pavement
0.1870	Vehicle traveling parallel with the barrier system
0.1930	Right rear bumper contacts the barrier system
0.2900	Vehicle loses contact with the barrier system while traveling at 51.1 mi/h, trajectory of 2.4 degrees, and heading of 4.3 degrees

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 2.0 s after impact. After loss of contact with the barrier, the vehicle came to rest 262 ft downstream of the point of impact and 4 ft toward traffic lanes.

7.5. DAMAGE TO TEST INSTALLATION

Figure 7.3 shows the damage to the barrier system. There was minor gouging of the barrier face at impact from the wheel lugs, and the face of the concrete was scuffed at impact and downstream of it. There were some cracks on the field side at 8.0 inches downstream of impact.

Working width* was 41.25 inches, and height of working width was at the toe of the barrier. No measurable dynamic deflection during the test nor permanent deformation after the test was observed.

Figure 7.3. Barrier System after Test No. 611901-04-1.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.4 shows the damage sustained by the vehicle. The front bumper, hood, grill, radiator and support, right frame, right front tire and rim, right front fender, right front door and door glass, right front floor pan, right rear door, right rear cab corner, right rear exterior bed, right rear tire and rim, and rear bumper were damaged. The windshield sustained stress cracks radiating upward and inward from the right lower corner. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 9.0 inches in the side plane at the right front corner just above bumper height. Maximum occupant compartment deformation was 5.0 inches in the right front firewall area. Figure 7.5 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D.1 provide exterior crush and occupant compartment measurements.

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* Per *MASH*, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.

Figure 7.4. Test Vehicle after Test No. 611901-04-1.

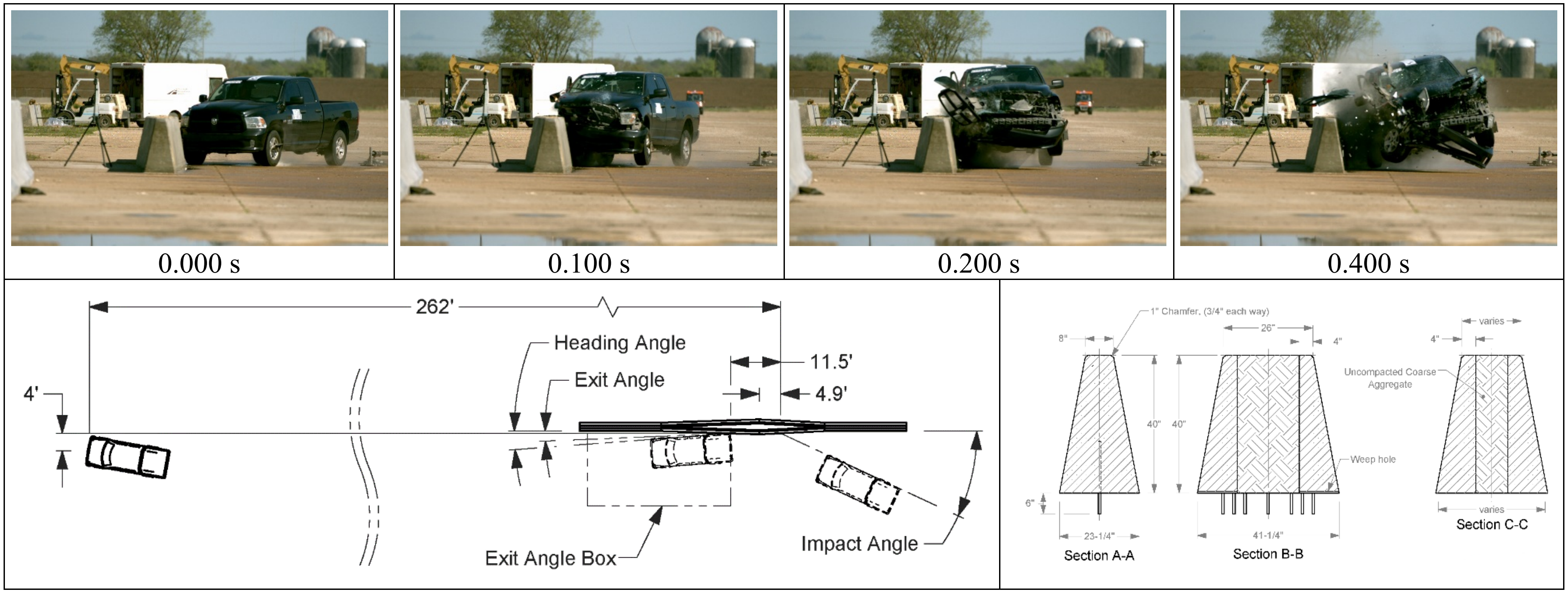
Figure 7.5. Interior of Test Vehicle after Test No. 611901-04-1.

7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.2. Figure D.3 in Appendix D.3 shows the vehicle angular displacements, and Figures D.4 through D.6 in Appendix D.4 show acceleration versus time traces. Figure 7.6 summarizes pertinent information from the test.

Table 7.2. Occupant Risk Factors for Test No. 611901-04-1.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	18.7 ft/s	at 0.0930 s on right side of interior
Lateral	28.9 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	3.3 g	0.1991 - 0.2091 s
Lateral	10.8 g	0.2222 - 0.2322 s
THIV	10.7 m/s	at 0.0907 s on right side of interior
ASI	1.95	0.0584 - 0.1084 s
Maximum 50-ms Moving Average		
Longitudinal	−9.4 g	0.0164 - 0.0664 s
Lateral	−15.5 g	0.0353 - 0.0853 s
Vertical	−3.4 g	0.6282 - 0.6782 s
Maximum Yaw, Pitch, and Roll Angles		
Roll	22°	0.6126 s
Pitch	6°	0.6702 s
Yaw	41°	0.9930 s



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 4-11
TTI Test No.	611901-04-1
Test Date	2021-03-25
Test Article	
Type	Longitudinal Barrier—Concrete Barrier
Name	Critical Flare Concrete Barrier System
Installation Length	75 ft
Material or Key Elements	20:1 Flare for 15 ft Upstream 30:1 Flare for 23 ft Downstream
Soil Type and Condition	Concrete pavement, damp
Test Vehicle	
Type/Designation	2270P
Make and Model	2015 RAM 1500 Pickup
Curb	4903 lb
Test Inertial	5020 lb
Dummy	165 lb
Gross Static	5185 lb

Impact Conditions	
Speed	63.2 mi/h
Angle	24.9°
Location/Orientation	4.9 ft upstream of flare
Impact Severity	119 kip-ft
Exit Conditions	
Speed	51.1 mi/h
Trajectory/Heading Angle	2.4°/4.3°
Occupant Risk Values	
Longitudinal OIV	18.7 ft/s
Lateral OIV	28.9 ft/s
Longitudinal Ridedown	3.3 g
Lateral Ridedown	10.8 g
THIV	10.7 m/s
ASI	2.0
Max. 0.050-s Average	
Longitudinal	−9.4 g
Lateral	−15.5 g
Vertical	−3.4 g

Post-Impact Trajectory	
Stopping Distance	262 ft downstream 4 ft twd traffic lanes
Vehicle Stability	
Maximum Roll Angle	22°
Maximum Pitch Angle	6°
Maximum Yaw Angle	41°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	None
Permanent	None
Working Width	41.25 inches
Height of Working Width	At toe of barrier
Vehicle Damage	
VDS	01RFQ5
CDC	01FREW5
Max. Exterior Deformation	9.0 inches
OCDI	RF0030000
Max. Occupant Compartment Deformation	5.0 inches

Figure 7.6. Summary of Results for *MASH* Test 4-11 on Critical Flare Concrete Barrier System.

Chapter 8. *MASH* TEST 4-12 (CRASH TEST NO. 611901-05-1)

8.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-12 involves a 10000S vehicle weighing 22,000 lb ± 660 lb impacting the CIP of the longitudinal barrier at an impact speed of 56 mi/h ± 2.5 mi/h and an angle of 15 degrees ± 1.5 degrees. The CIP for *MASH* Test 4-12 on the barrier system was 10.0 ft ± 1 ft upstream of the centerline of the maximum width of the flare. Figure 4.1 and Figure 8.1 depict the target impact setup.

Figure 8.1. Barrier System/Test Vehicle Geometrics for Test No. 611901-05-1.

The 10000S vehicle weighed 22,140 lb, and the actual impact speed and angle were 58.5 mi/h and 15.3 degrees. The actual impact point was 10.1 ft upstream of the centerline of the maximum width of the flare. Minimum target IS was 142 kip-ft, and actual IS was 176 kip-ft.

8.2. WEATHER CONDITIONS

The test was performed on the morning of April 1, 2021. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 85 degrees (vehicle was traveling at a heading of 185 degrees); temperature: 61°F; relative humidity: 31 percent.

8.3. TEST VEHICLE

Figure 8.2 shows the 2009 International 4300 single-unit truck used for the crash test. The vehicle's test inertia weight was 22,140 lb, and its gross static weight was 22,140 lb. The height to the lower edge of the vehicle bumper was 18.25 inches, and height to the upper edge of the bumper was 33.25 inches. The height to the center of gravity of the vehicle's ballast was 63.5 inches. Table E.1 in Appendix E.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 8.2. Test Vehicle before Test No. 611901-05-1.

8.4. TEST DESCRIPTION

Table 8.1 lists events that occurred during Test No. 611901-05-1. Figures E.1 and E.2 in Appendix E.2 present sequential photographs during the test.

Table 8.1. Events during Test No. 611901-05-1.

Time (s)	Events
0.0000	Vehicle impacts the barrier system
0.0600	Vehicle begins to redirect
0.1340	Left front tire lifts off of the pavement
0.2210	Left rear tire lifts off of the pavement
0.2420	Vehicle traveling parallel with barrier system
0.2450	Right rear side of the box contacts the installation
0.5460	Vehicle loses contact with the barrier system while traveling at 52.5 mi/h along the traffic face of the barrier system
0.7060	Left front tire returns to the pavement

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 65.6 ft for heavy vehicles). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 2.5 s after impact, and the vehicle subsequently came to rest 271 ft downstream of the point of impact and 1 ft toward the traffic lanes.

8.5. DAMAGE TO TEST INSTALLATION

Figure 8.3 and Figure 8.4 show the damage to the barrier system. Damage at impact consisted of spalling on top of the concrete, exposing rebar, and scuffing and gouging on the concrete face. There was a secondary impact downstream of impact, which resulted in further spalling and exposed rebar. Working width* was 54.9 inches, and height of working width was 123.7 inches. No measurable dynamic deflection during the test or permanent deformation after the test was observed.

Figure 8.3. Barrier System after Test No. 611901-05-1.

* Per *MASH*, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.

Figure 8.4. Field Side of Barrier System after Test No. 611901-05-1.

8.6. DAMAGE TO TEST VEHICLE

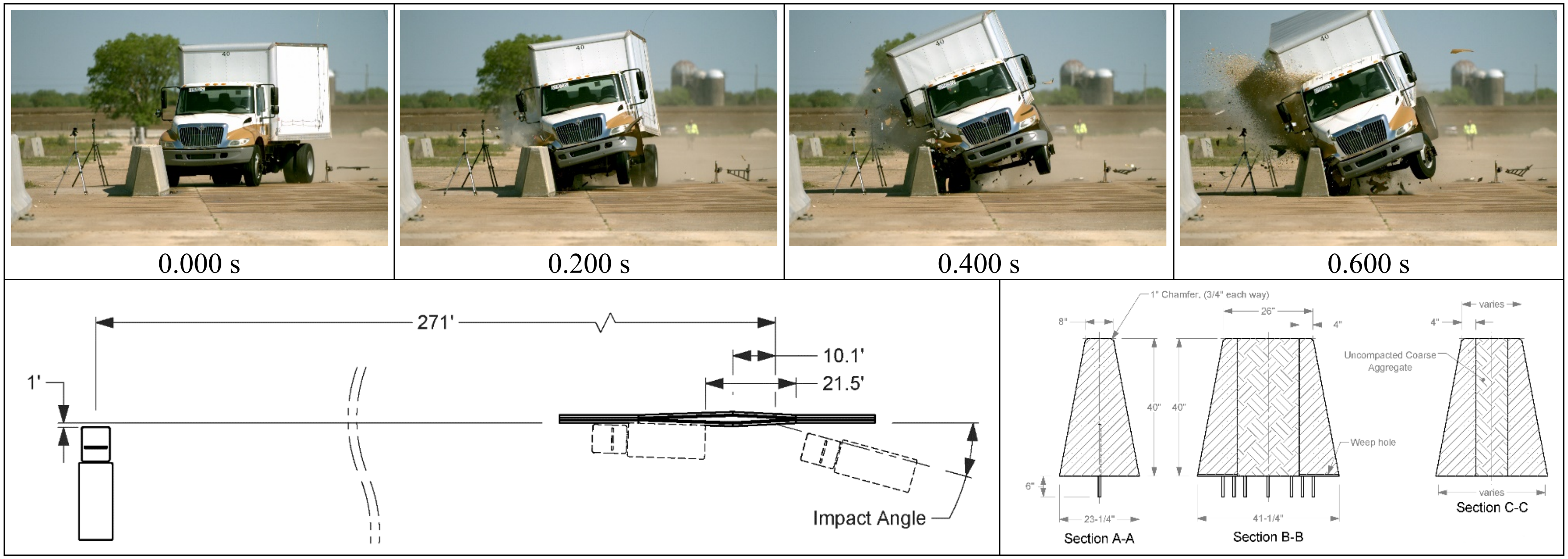
Figure 8.5 shows the damage sustained by the vehicle. The front bumper, hood, right front tire and rim, front axle and spring assembly, right side step, right door, right lower corner of the box, and right rear outer tire and rim were damaged. The fuel tank was dislodged and separated from the truck. Maximum exterior crush to the vehicle was 10.0 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation was 4.0 inches in the right front floor pan and firewall. Figure 8.6 shows the interior of the vehicle.

Figure 8.5. Test Vehicle after Test No. 611901-05-1.

Figure 8.6. Interior of Test Vehicle after Test No. 611901-05-1.

8.7. VEHICLE INSTRUMENTATION

Data from the accelerometers were digitized for informational purposes only and are reported in Figure 8.7. Figure E.3 in Appendix E.3 shows the vehicle angular displacements, and Figures E.4 through E.9 in Appendix C.4 show acceleration versus time traces. Figure 8.7 summarizes pertinent information from the test.



General Information
- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: *MASH* Test 4-12
- TTI Test No.: 611901-05-1
- Test Date: 2021-04-01

Test Article
- Type: Longitudinal Barrier—Concrete Barrier
- Name: Critical Flare Concrete Barrier System
- Installation Length: 75 ft
- Material or Key Elements: 20:1 Flare for 15 ft Upstream; 30:1 Flare for 23 ft Downstream

Soil Type and Condition: Concrete pavement, damp

Test Vehicle
- Type/Designation: 10000S
- Make and Model: 2009 International 4300 Truck
- Curb: 13,280 lb
- Test Inertial: 22,140 lb
- Dummy: No dummy
- Gross Static: 22,140 lb

Impact Conditions
- Speed: 58.5 mi/h
- Angle: 15.3°
- Location/Orientation: 10.1 ft upstream of maximum flare

Impact Severity: 176 kip-ft

Exit Conditions
- Speed: 52.5 mi/h
- Trajectory/Heading Angle: Along barrier

Occupant Risk Values
- Longitudinal OIV: 6.8 ft/s
- Lateral OIV: 14.6 ft/s
- Longitudinal Ridedown: 4.4 g
- Lateral Ridedown: 7.3 g
- THIV: 5.0 m/s
- ASI: 0.5
- Max. 0.050-s Average
  - Longitudinal: −2.3 g
  - Lateral: −4.6 g
  - Vertical: −2.1 g

Post-Impact Trajectory
- Stopping Distance: 271 ft downstream; 1 ft twd traffic lanes

Vehicle Stability
- Maximum Roll Angle: 21°
- Maximum Pitch Angle: 10°
- Maximum Yaw Angle: 23°
- Vehicle Snagging: No
- Vehicle Pocketing: No

Test Article Deflections
- Dynamic: None
- Permanent: None
- Working Width: 54.9 inches
- Height of Working Width: 123.7 inches

Vehicle Damage
- VDS: NA
- CDC: 01FREW4
- Max. Exterior Deformation: 10.0 inches
- OCDI: NA
- Max. Occupant Compartment Deformation: 4.0 inches

Figure 8.7. Summary of Results for *MASH* Test 4-12 on Critical Flare Concrete Barrier System.

Chapter 9. SUMMARY AND CONCLUSIONS

9.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-4, which involves three tests, on the critical flare concrete barrier system. Table 9.1 through Table 9.3 provide an assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-4 longitudinal barriers.

9.2. CONCLUSIONS

Table 9.4 shows that the critical flare concrete barrier system met the performance criteria for *MASH* TL-4 longitudinal barriers.

Table 9.1. Performance Evaluation Summary for *MASH* Test 4-10 on Critical Flare Concrete Barrier System.

Test Agency: Texas A&M Transportation Institute | Test No.: 611901-03-1 | Test Date: 2021-03-30

***MASH* Test 4-10 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 critical flare concrete barrier system contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. No measurable dynamic deflection during the test was observed.	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.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 3.5 inches in the kick panel/toe pan area and 3.0 inches in the right front firewall 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 16° and 10°.	Pass
H. *Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*	Longitudinal OIV was 21.3 ft/s, and lateral OIV was 33.1 ft/s.	Pass
I. *The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Maximum longitudinal ridedown acceleration was 4.0 g, and maximum lateral ridedown acceleration was 13.3 g.	Pass

Table 9.2. Performance Evaluation Summary for *MASH* Test 4-11 on Critical Flare Concrete Barrier System.

Test Agency: Texas A&M Transportation Institute | Test No.: 611901-04-1 | Test Date: 2021-03-25

MASH Test 4-11 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 critical flare concrete barrier system contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. No measurable dynamic deflection during the test was observed.	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.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 5.0 inches in the right front firewall area.	
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 22° and 6°.	Pass
H. *Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*	Longitudinal OIV was 18.7 ft/s, and lateral OIV was 28.9 ft/s.	Pass
I. *The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Maximum longitudinal ridedown acceleration was 3.3 g, and maximum lateral ridedown acceleration was 10.8 g.	Pass

Table 9.3. Performance Evaluation Summary for *MASH* Test 4-12 on Critical Flare Concrete Barrier System.

Test Agency: Texas A&M Transportation Institute　　Test No.: 611901-05-1　　Test Date: 2021-04-01

MASH Test 4-12 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The critical flare concrete barrier system contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. No measurable dynamic deflection during the test was observed.	Pass
<u>Occupant Risk</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 4.0 inches in the right front floor pan and firewall.	
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The 10000S vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 21° and 10°.	Pass

Table 9.4. Assessment Summary for *MASH* TL-4 Tests on Critical Flare Concrete Barrier System.

Evaluation Factors	Evaluation Criteria	Test No. 611901-03-1	Test No. 611901-04-1	Test No. 611901-05-1
Structural Adequacy	A	S	S	S
Occupant Risk	D	S	S	S
	F	S	S	N/A
	G	N/A	N/A	S
	H	S	S	N/A
	I	S	S	N/A
	Test No.	***MASH* Test 4-10**	***MASH* Test 4-11**	***MASH* Test 4-12**
	Pass/Fail	Pass	Pass	Pass

Note: S = Satisfactory; N/A = Not Applicable.

REFERENCES

1. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition.* American Association of State Highway and Transportation Officials: Washington, DC, 2016.

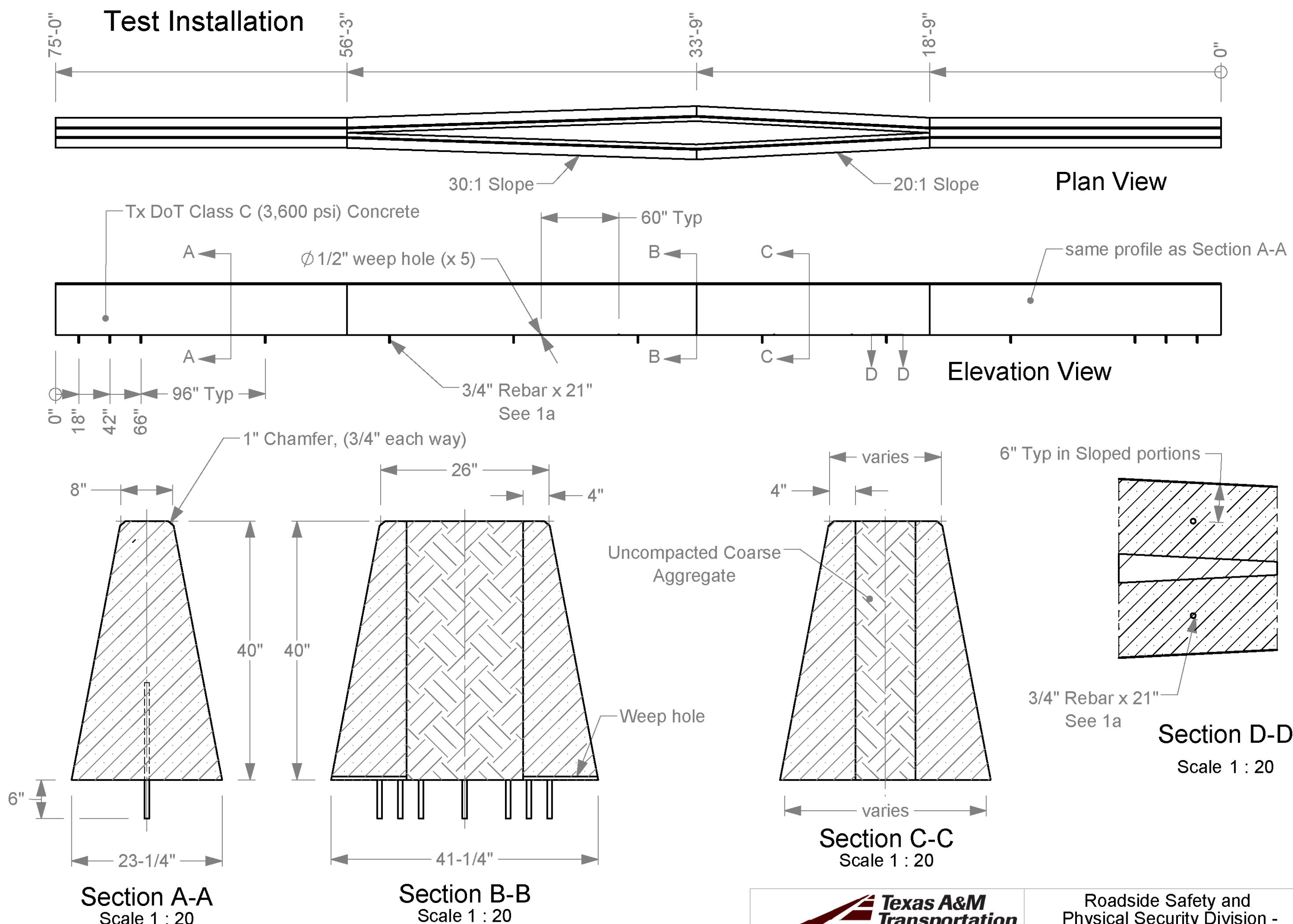
2. H. E. Ross, D. L. Sicking, R. A. Zimmer, and J. D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

3. American Association of State Highway and Transportation Officials, *Manual for Assessing Safety Hardware*, AASHTO Subcommittee on Bridges and Structures, Washington, DC, 2009.

4. American Association of State Highway and Transportation Officials. *Roadside Design Guide*, 4th Ed., American Association of State Highway and Transportation Officials, Washington, DC, 2011.

5. N. M. Sheikh, R. P. Bligh, W. L. Menges. *Determination of Minimum Height and Lateral Design Load For Mash Test Level 4 Bridge Rails*, Report No. FHWA/TX-12/9-1002-5, Texas A&M Transportation Institute, College Station, TX, 2011.

APPENDIX A. DETAILS OF CRITICAL FLARE CONCRETE BARRIER SYSTEM

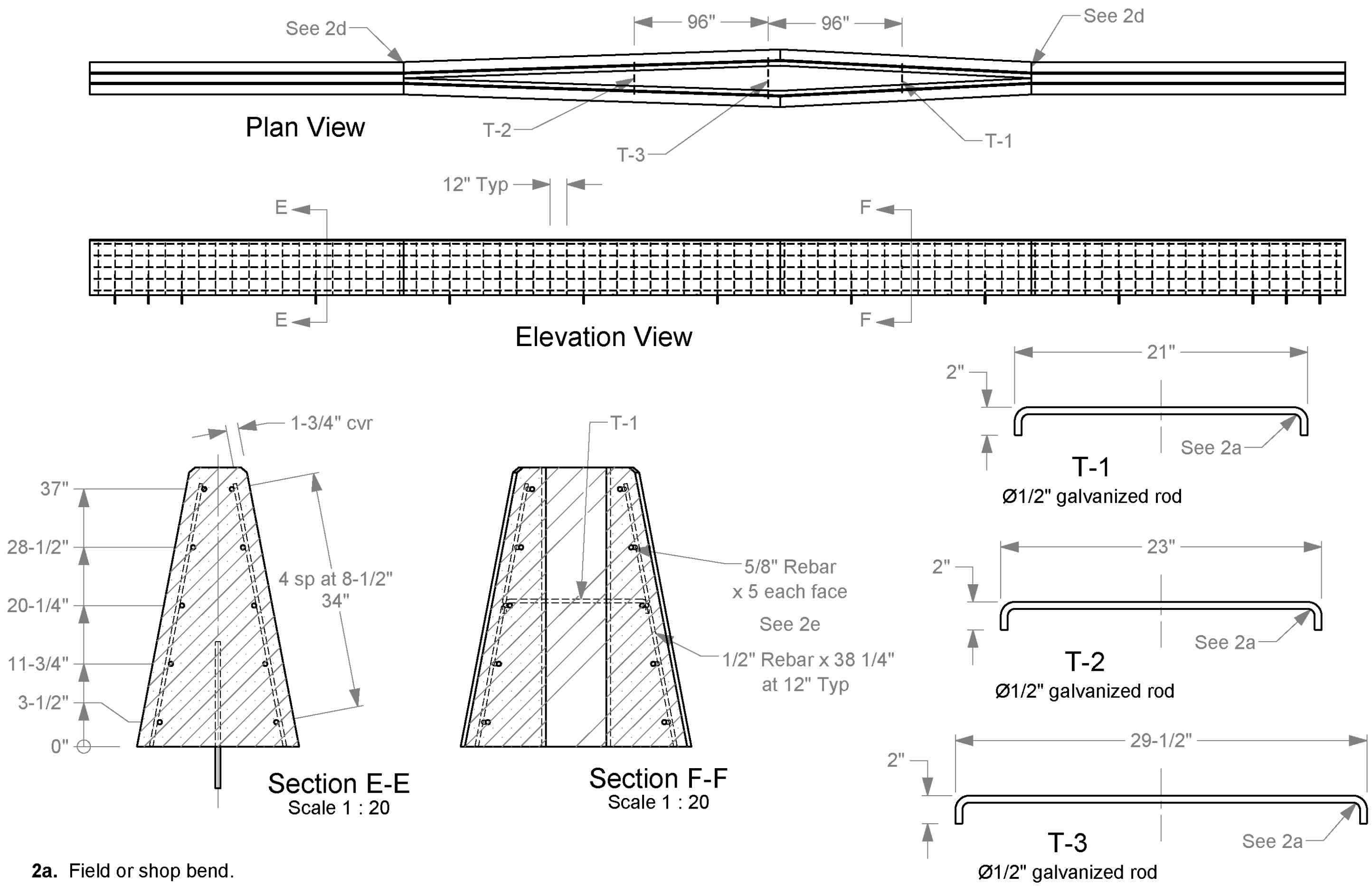


1a. Secure with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #611901 CIP Flare Rate		2020-11-17
Drawn by GES	Scale 1:100	Sheet 1 of 2 Test Installation

Q:\Accreditation-17025-2017\EIR-000 Project Files\611901 - CIP Critical Flare Rates - Chiara\Drafting, 611901\611901 Drawing

Rebar Details



2a. Field or shop bend.
2b. Minimum rebar lap is 24" for #5 bars. All rebar is grade 60.
2c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).
2d. Construction joint is permissible, but rebar laps may not be within 24" each side.
2e. Welded Wire is permissible, with D14 for vertical bars and D20 for horizontal bars, spaced as shown. Welded Wire shall conform to ASTM A497.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #611901 CIP Flare Rate		2020-11-17
Drawn by GES	Scale 1:100	Sheet 2 of 2 Rebar Details

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APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

Texas A&M Transportation Institute	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Revision Date: 2020-07-29
Quality Form	Revised by: B.L. Griffith Approved by: D. L. Kuhn	Revision: 7	Page: 1 of 1

Project No: 611901 **Casting Date:** 3/2/2021 **Mix Design (psi):** B1400

Name of Technician Taking Sample: Terracon

Name of Technician Breaking Sample: Terracon

Signature of Technician Taking Sample: Terracon

Signature of Technician Breaking Sample: Terracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	tucker #4	527	back side flare barrier

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average

TUCKER_concrete
979-777-6749
TRUCK_#4
TUCKER_CONSTRUCTION
TTI

TICKET # 527

START DATE: 2021-03-02 TIME: 09:53:09
STOP DATE: 2021-03-02 TIME: 10:32:16

MIX DESIGN: B1400

RAW CEMENT COUNTS: 2251
RAW CONVEYOR COUNTS: 76585
CONVEYOR SPEED: 50
TOTAL YARDS 3.569

MATERIAL	RATE SETTING	TOTAL
CEMENT	9.343309LBS	1845.37L
SAND	5.397386 GA	4864.736
ADJUSTED:		
STONE	7.101724 GA	6718.48L
ADJUSTED:		
WATER	28.01423GAL	90.66679
ADMIX #1	0.0OZ/MIN	0.0OZ
ADMIX #2	0.0OZ/MIN	0.0OZ
ADMIX #3	0.0OZ/MIN	0.0OZ

TOTAL SAND MOISTURE: 0.0
TOTAL STONE MOISTURE: 0.0

ame_____
OTES:

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0168
Service Date: 03/02/21
Report Date: 03/24/21
Task: PO# 611901

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: 4,000 psi @ 28 days

Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1000 **Plant:**
Truck No.: 4 **Ticket No.:** 527

Field Test Data

Test	Result	Specification
Slump (in):	9	
Air Content (%):	1.7	
Concrete Temp. (F):	49	
Ambient Temp. (F):	51	
Plastic Unit Wt. (pcf):	152.6	
Yield (Cu. Yds.):		

Sample Information

Sample Date: 03/02/21 **Sample Time:** 1000
Sampled By: Ethan Boultinghouse
Weather Conditions: Clear, Moderate wind
Accumulative Yards: 4 **Batch Size (cy):** 4
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: Critical flare concrete wall filling on north side of air field
Placement Location: Critical flare concrete wall filling on north side of air field

Laboratory Test Data

Set No.	Specimen ID	Avg Diam. (in)	Area (sq in)	Date Received	Date Tested	Age at Test (days)	Maximum Load (lbs)	Compressive Strength (psi)	Fracture Type	Tested By
1	A	6.01	28.37		03/24/21	22 F	103,500	3,650	3	SLS
1	B	6.01	28.37		03/24/21	22 F	94,650	3,340	1	SLS
1	C	6.01	28.37		03/24/21	22 F	98,710	3,480	5	AWD
1	D					Hold				

Initial Cure: Outside **Final Cure:** Field Cured

Comments: **F = Field Cured**

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).
Terracon Rep.: Ethan Boultinghouse **Start/Stop:** 0930-1100
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke
(1) Terracon Consultants, Inc., Alex Dunigan, P.E.
(1) Texas Transportation Institute, Bill Griffith

Reviewed By:
Alexander Dunigan
Project Manager

Test Methods: ASTM C 31, ASTM C143, ASTM C231, ASTM C1064

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

Page 1 of 1

CR0001, 11-16-12, Rev.6

Texas A&M Transportation Institute	**QF 7.3-01 Concrete Sampling**	Doc. No. QF 7.3-01	Revision Date: 2020-07-29
Quality Form	Revised by: B.L. Griffith Approved by: D. L. Kuhn	Revision: 7	Page: 1 of 1

Project No: 611901 **Casting Date:** 2/23/2021 **Mix Design (psi):** 3600

Name of Technician Taking Sample: Terracon

Name of Technician Breaking Sample: Terracon

Signature of Technician Taking Sample: Terracon

Signature of Technician Breaking Sample: Terracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	tucker	511	100% of barrier, traffic side flare

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average

TUCKER_concrete
979-777-6749
TRUCK_#4
TUCKER_CONSTRUCTION
TTI

TICKET # 511

START DATE: 2021-02-23 TIME: 09:34:14
STOP DATE: 2021-02-23 TIME: 10:40:20

MIX DESIGN: B1400

RAW CEMENT COUNTS: 6053
RAW CONVEYOR COUNTS: 205800
CONVEYOR SPEED: 50
TOTAL YARDS 9.598

MATERIAL	RATE SETTING	TOTAL
CEMENT	9.343309LBS	4962.25L
SAND	5.397386 GA	13072.56
ADJUSTED:		
STONE	7.101724 GA	18053.97
ADJUSTED:		
WATER	23.01422GAL	214.1636
ADMIX #1	0.0OZ/MIN	0.0OZ
ADMIX #2	0.0OZ/MIN	0.0OZ
ADMIX #3	0.0OZ/MIN	0.0OZ

TOTAL SAND MOISTURE: 0.0
TOTAL STONE MOISTURE: 0.0

Name_____ _________
NOTES:

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0166
Service Date: 02/23/21
Report Date: 03/25/21 Revision 1 -
Task: PO# 611901

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: 4,000 psi @ 28 days

Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 0930 **Plant:**
Truck No.: 4 **Ticket No.:** 511

Sample Information

Sample Date: 02/23/21 **Sample Time:** 1030
Sampled By: Mohammed Mobeen
Weather Conditions: Clear, Light Wind
Accumulative Yards: 9.6/9.6 **Batch Size (cy):** 9.6
Placement Method:
Water Added Before (gal):
Water Added After (gal):
Sample Location: PO 611901
Placement Location: PO 611901

Field Test Data

Test	Result	Specification
Slump (in):	5	Not Specified
Air Content (%):	2.8	Not Specified
Concrete Temp. (F):	62	40 - 95
Ambient Temp. (F):	57	40 - 95
Plastic Unit Wt. (pcf):	147.2	Not Specified
Yield (Cu. Yds.):		

Laboratory Test Data

Set No.	Specimen ID	Avg Diam. (in)	Area (sq in)	Date Received	Date Tested	Age at Test (days)	Maximum Load (lbs)	Compressive Strength (psi)	Fracture Type	Tested By
1	A	6.01	28.37		03/24/21	29 F	124,040	4,370	1	SLS
1	B	6.01	28.37		03/24/21	29 F	140,000	4,940	1	SLS
1	C	6.01	28.37		03/24/21	29 F	149,880	5,280	3	AWD
1	D					Hold				

Initial Cure: Outside **Final Cure:** Field Cured

Comments: **F = Field Cured**

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).
Terracon Rep.: Mohammed Mobeen **Start/Stop:**
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Alex Dunigan, P.E.
(1) Texas Transportation Institute, Bill Griffith

Reviewed By:
Alexander Dunigan
Project Manager

Test Methods: ASTM C 31, ASTM C143, ASTM C231, ASTM C1064

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

APPENDIX C. *MASH* TEST 4-10 (CRASH TEST NO. 611901-03-1)

C.1. VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 611901-03-1.

Date: 2021-03-30 Test No.: 611901-03-1 VIN No.: 3N1CN7AP4GL838776

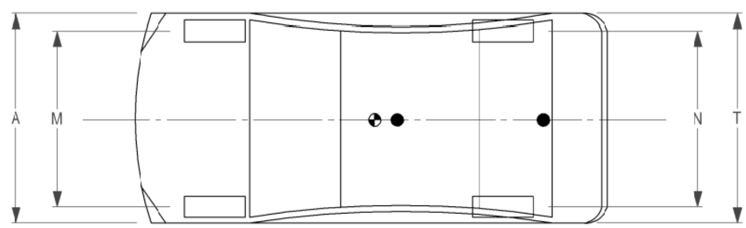
Year: 2016 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 91587 Tire Size: P185/65R15

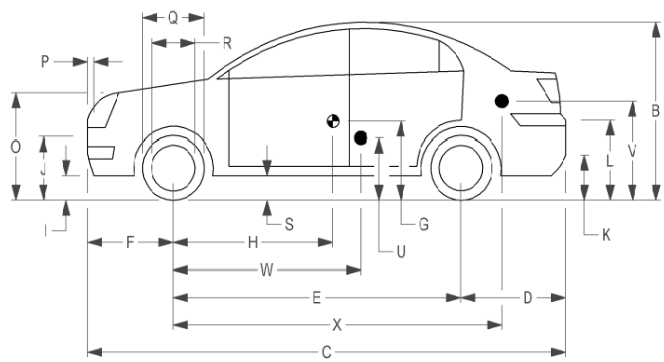
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None



Engine Type: 4 CYL
Engine CID: 1.6 L
Transmission Type:
☑ Auto or ☐ Manual
☑ FWD ☐ RWD ☐ 4WD
Optional Equipment:
None



Dummy Data:
Type: 50th Percentile Male
Mass: 165 lb
Seat Position: IMPACT SIDE

Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	41.64	M	58.30	R	16.25	W	41.60
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.25	O	30.50	T	64.50		

Wheel Center Ht Front 11.50 Wheel Center Ht Rear 11.50 W-H -0.04

RANGE LIMIT: A = 65 ±3 inches; C = 169 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; H = 39 ±4 inches; O (Top of Radiator Support) = 28 ±4 inches
(M+N)/2 = 59 ±2 inches; W-H < 2 inches or use MASH Paragraph A4.3.2

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1750	M_{front}	1410	1443	1528
Back	1687	M_{rear}	939	989	1069
Total	3389	M_{Total}	2349	2432	2597

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

Mass Distribution:
lb LF: 757 RF: 686 LR: 494 RR: 495

Table C.2. Exterior Crush Measurements for Test No. 611901-03-1.

Date:	2021-3-30	Test No.:	611901-03-1	VIN No.:	3N1CN7AP4GL838776
Year:	2016	Make:	NISSAN	Model:	VERSA

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 bmp ht	14	10	38	-	-	-	-	-	-	6
2	Side plane above bmp	14	8.5	42	-	-	-	-	-	-	60
	Measurements recorded										
	☑ **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.

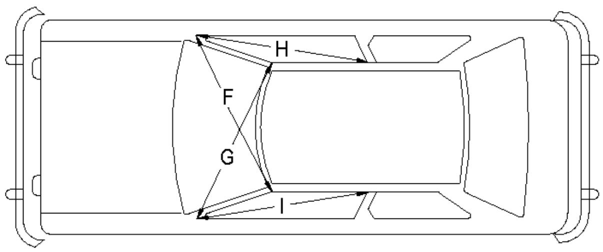
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

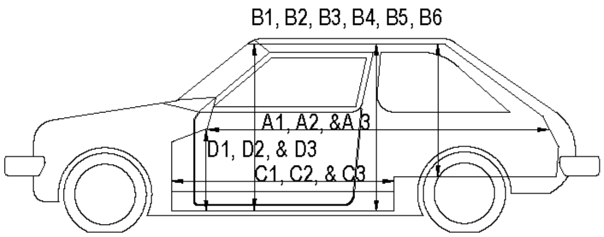
***Measure and document on the vehicle diagram the location of the maximum crush.

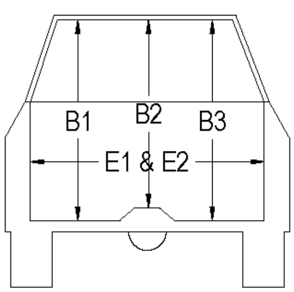
Note: Use as many lines/columns as necessary to describe each damage profile.

Table C.3. Occupant Compartment Measurements for Test No. 611901-03-1.

Date:	2021-03-30	Test No.:	611901-03-1	VIN No.:	3N1CN7AP4GL838776
Year:	2016	Make:	NISSAN	Model:	VERSA







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	75.00	75.00	0.00
A2	74.00	74.00	0.00
A3	74.00	74.00	0.00
B1	43.00	43.00	0.00
B2	37.00	37.00	0.00
B3	43.00	42.00	-1.00
B4	46.50	46.50	0.00
B5	42.50	42.50	0.00
B6	46.50	46.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	23.00	-3.00
D1	12.50	12.50	0.00
D2	0.00	0.00	0.00
D3	10.00	10.00	0.00
E1	45.00	45.00	0.00
E2	48.75	54.75	6.00
F	47.50	47.50	0.00
G	47.50	47.50	0.00
H	39.00	39.00	0.00
I	39.00	38.00	0.00
J*	48.50	45.00	-3.50

C.2. SEQUENTIAL PHOTOGRAPHS

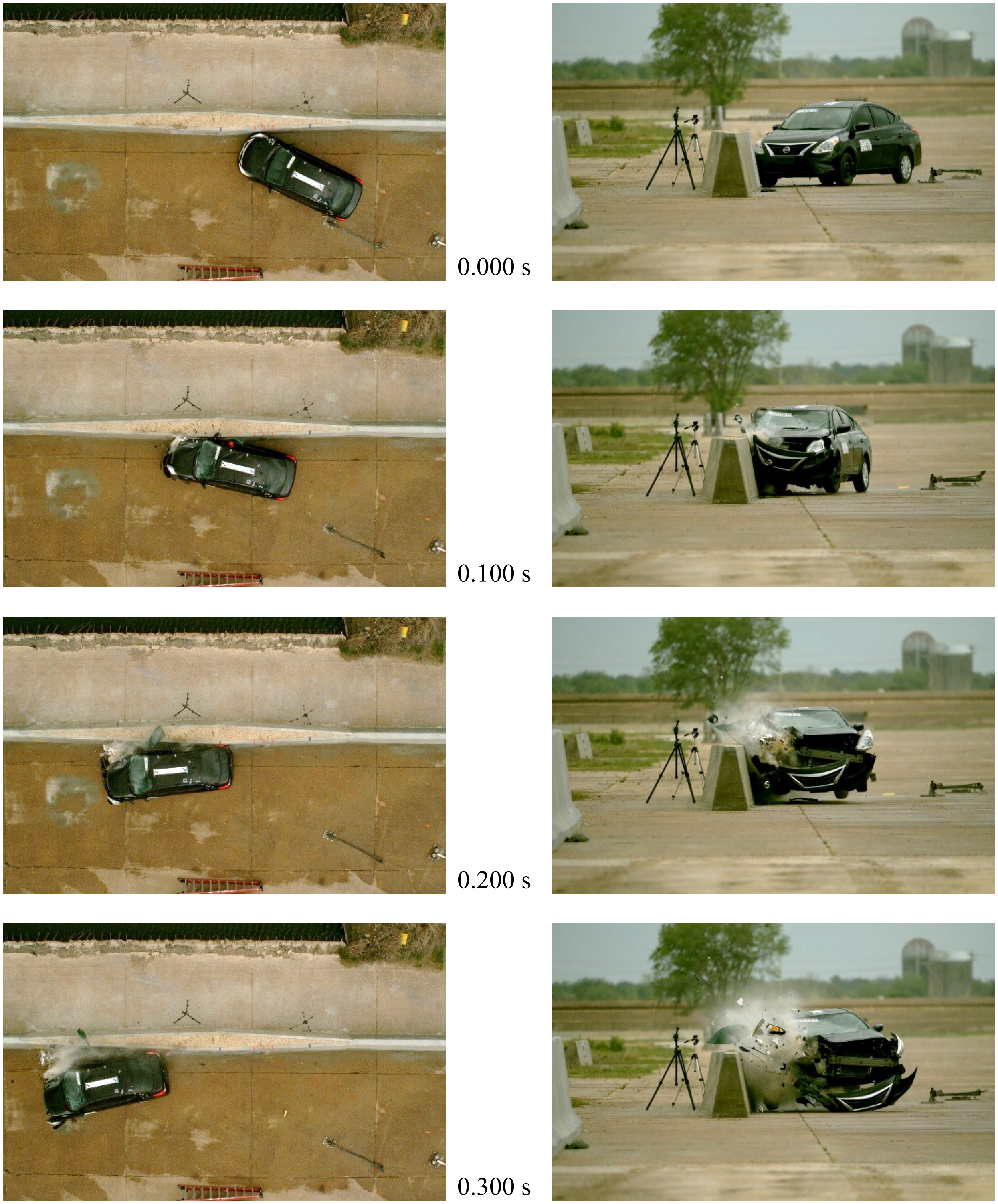


Figure C.1. Sequential Photographs for Test No. 611901-03-1 (Overhead and Frontal Views).

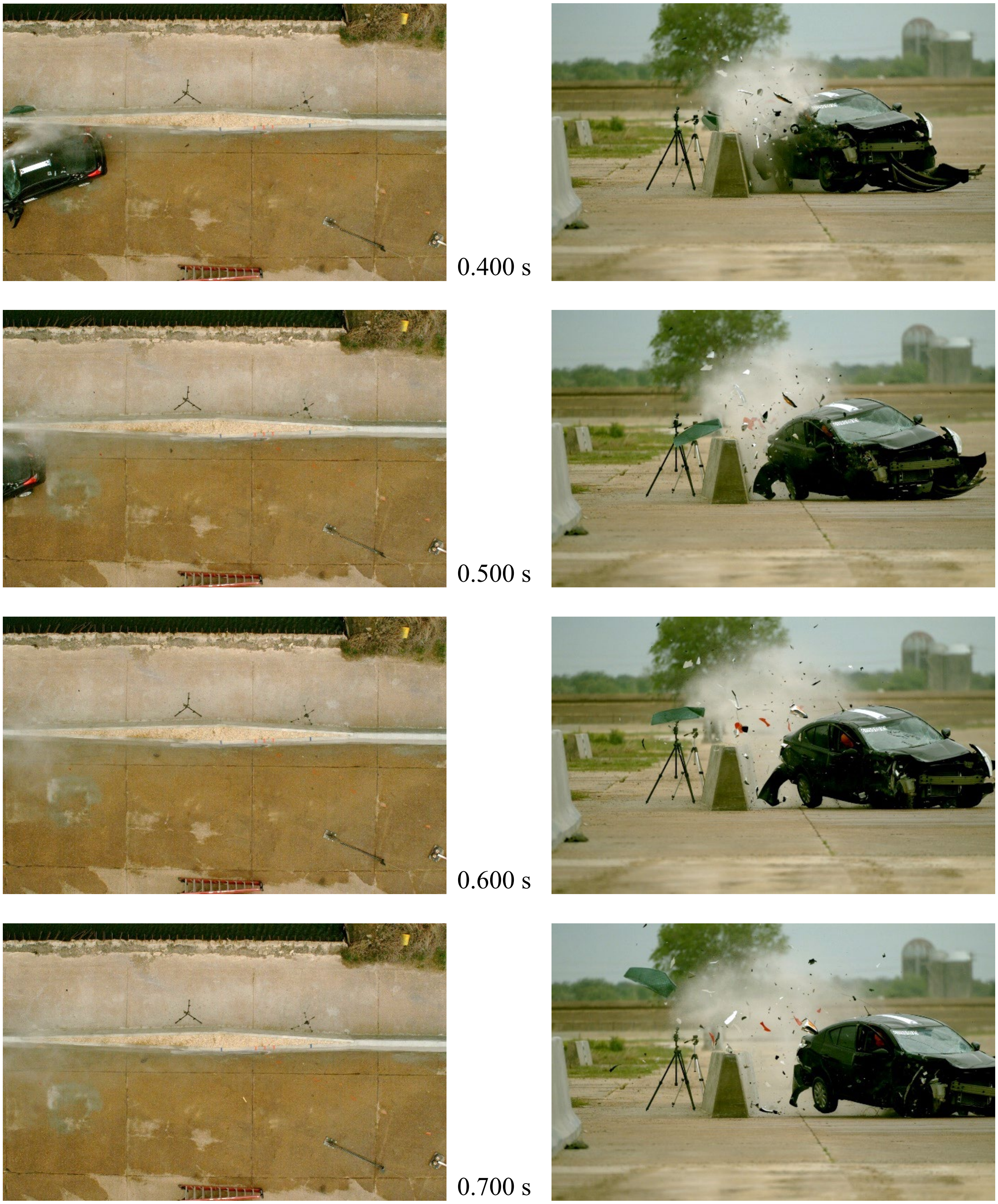


Figure C.1. Sequential Photographs for Test No. 611901-03-1 (Overhead and Frontal Views) (Continued).


0.000 s


0.100 s


0.200 s


0.300 s

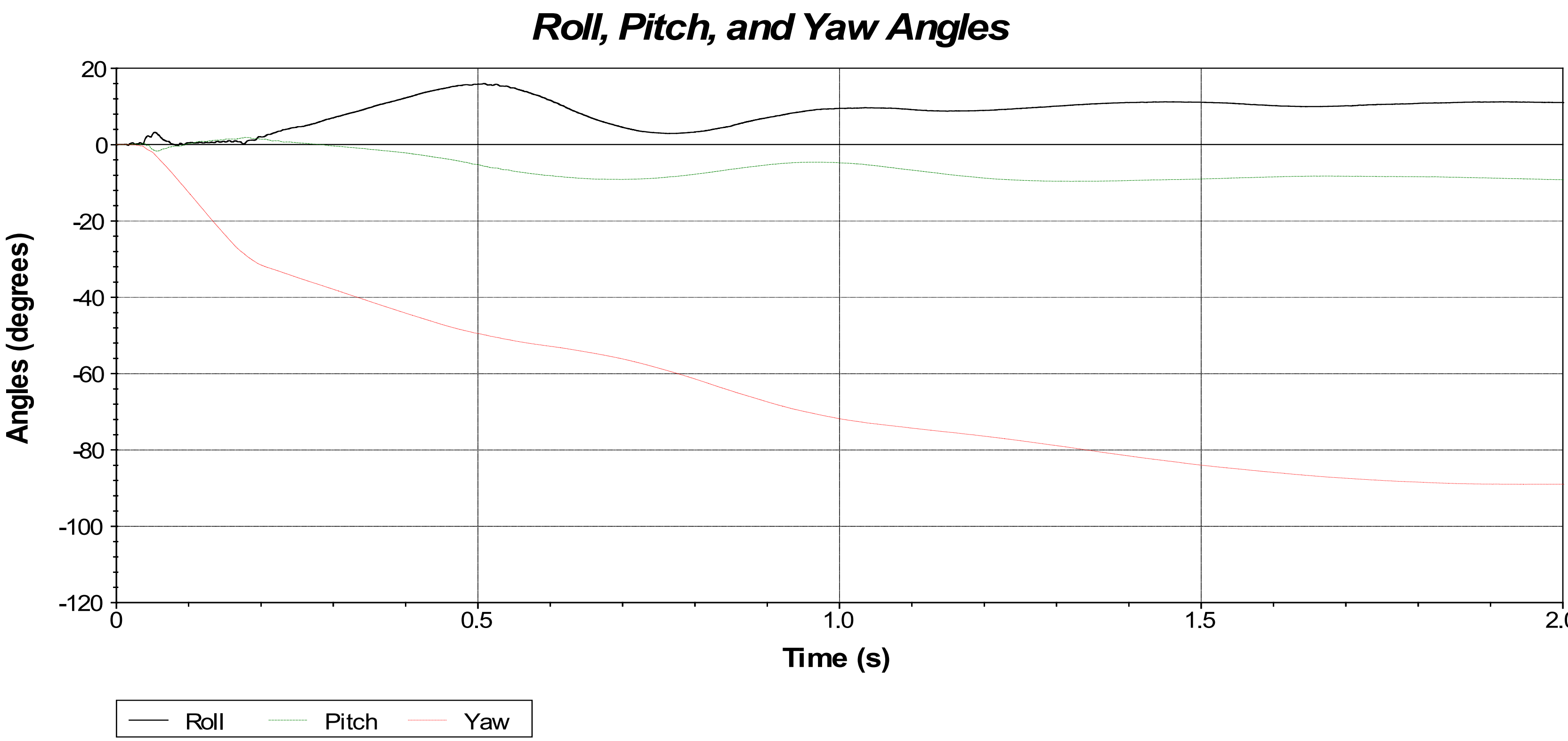

0.400 s


0.500 s


0.600 s

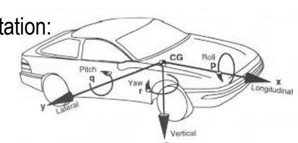

0.700 s

Figure C.2. Sequential Photographs for Test No. 611901-03-1 (Rear View).



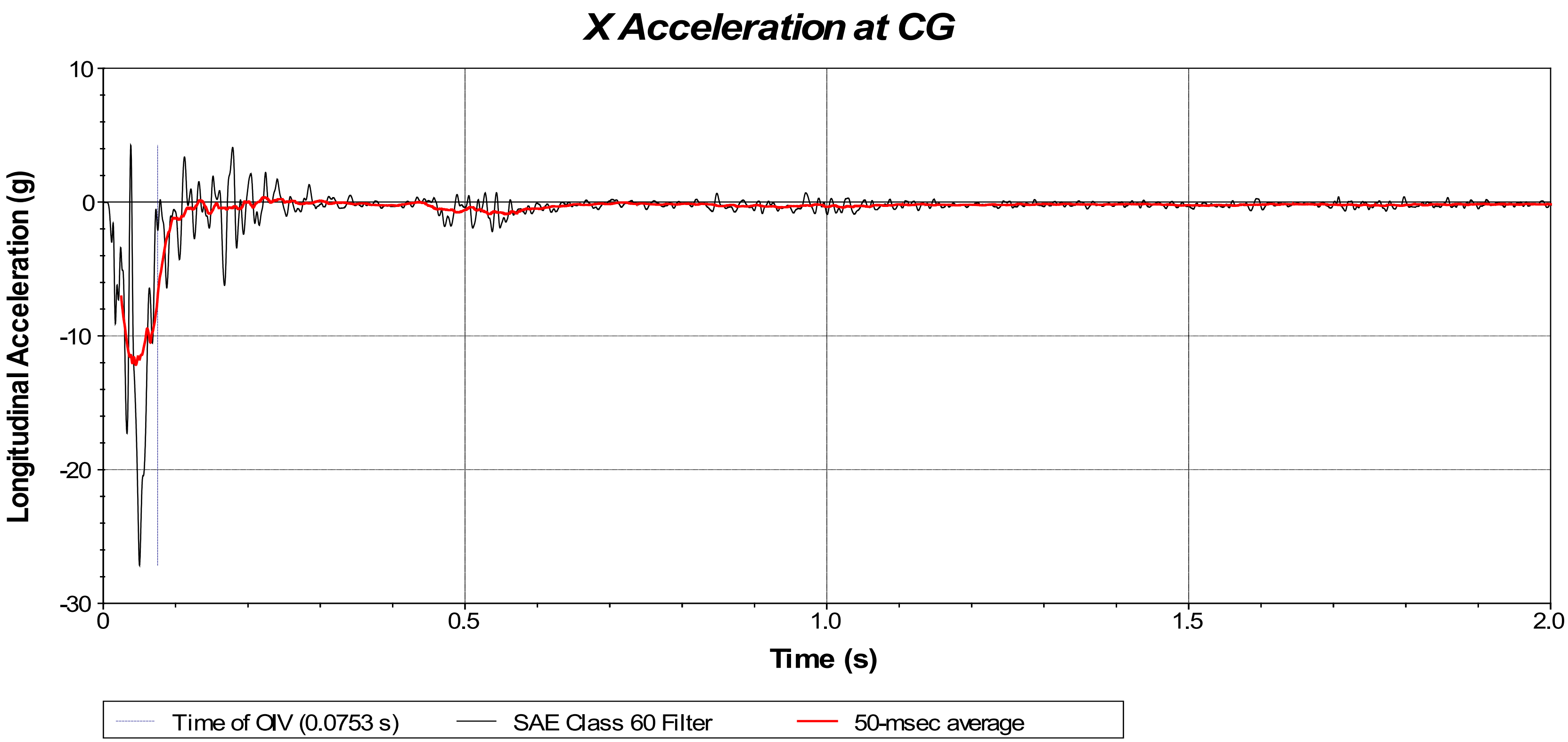
Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 611901-03-1
Test Standard Test Number: *MASH* Test 4-10
Test Article: Critical Flare Concrete Barrier System
Test Vehicle: 2016 Nissan Versa
Inertial Mass: 2432 lb
Gross Mass: 2597 lb
Impact Speed: 62.7 mi/h
Impact Angle: 24.7°

Figure C.3. Vehicle Angular Displacements for Test No. 611901-03-1.



Test Number: 611901-03-1
Test Standard Test Number: *MASH* Test 4-10
Test Article: Critical Flare Concrete Barrier System
Test Vehicle: 2016 Nissan Versa
Inertial Mass: 2432 lb
Gross Mass: 2597 lb
Impact Speed: 62.7 mi/h
Impact Angle: 24.7°

Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 611901-03-1 (Accelerometer Located at Center of Gravity).

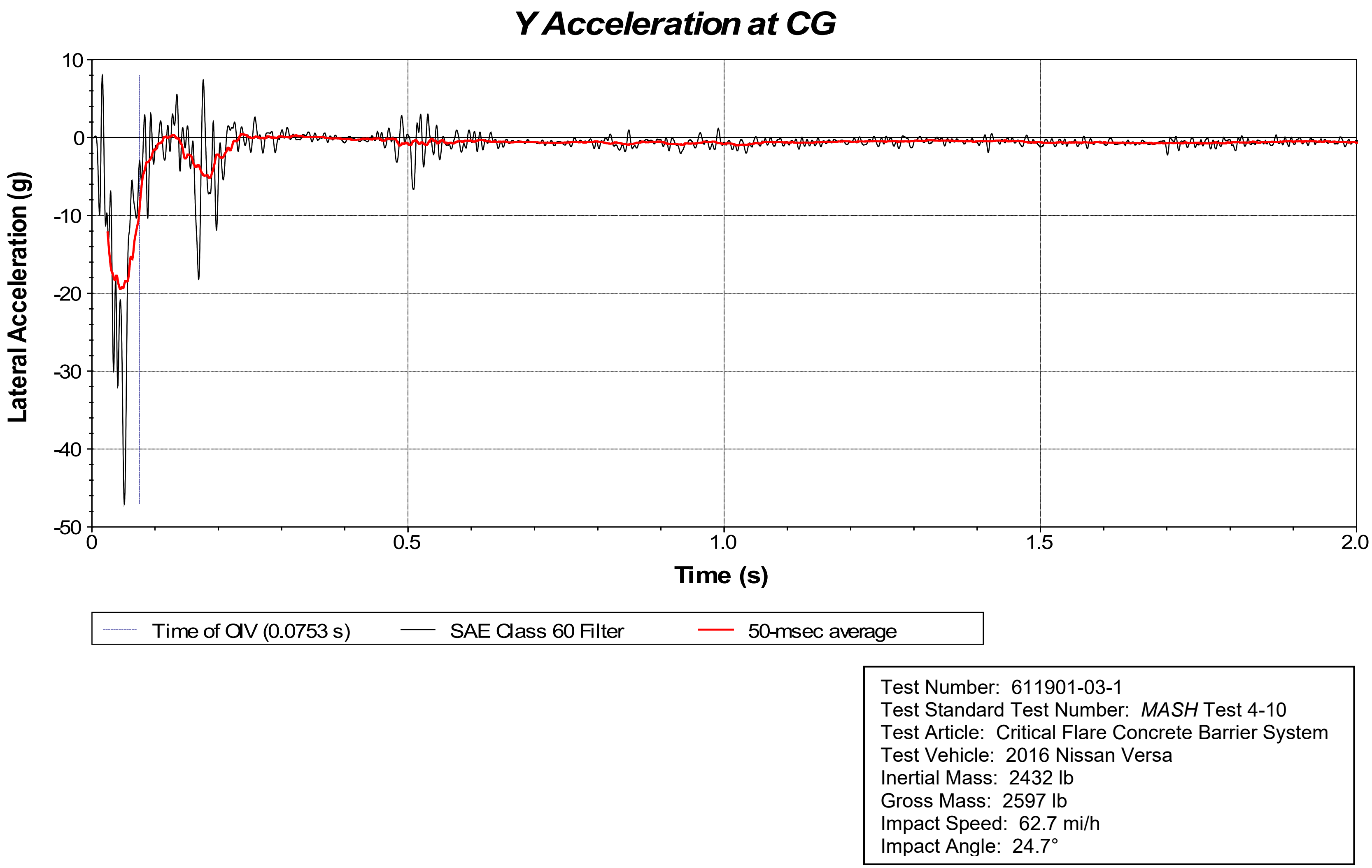


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 611901-03-1 (Accelerometer Located at Center of Gravity).

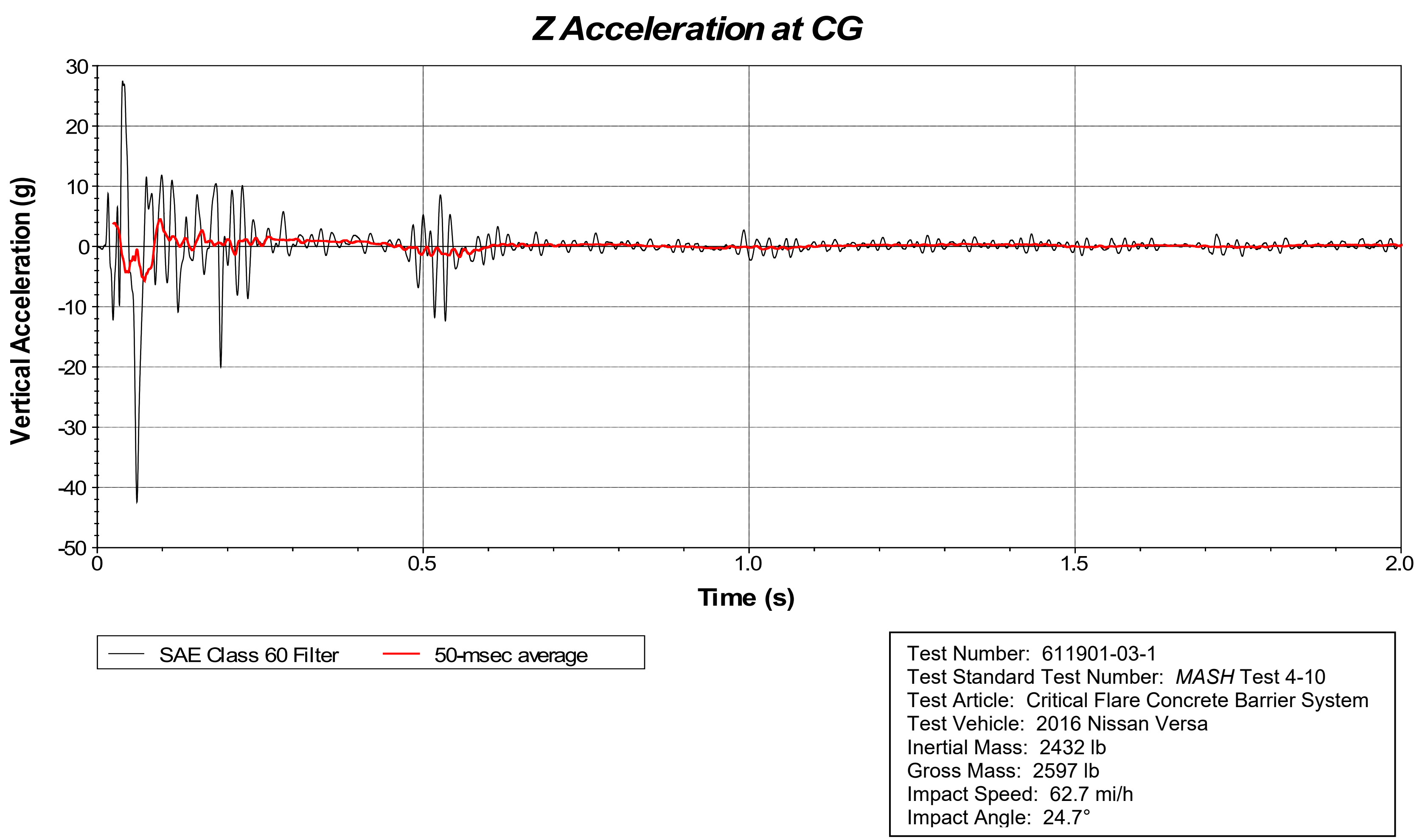


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 611901-03-1 (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 4-11 (CRASH TEST NO. 611901-04-1)

D.1. VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 611901-04-1.

Date: 2021 Test No.: 611901-04-1 VIN No.: 1C6RR6FT5FS654532

Year: 2015 Make: RAM Model: 1500

Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 185010

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

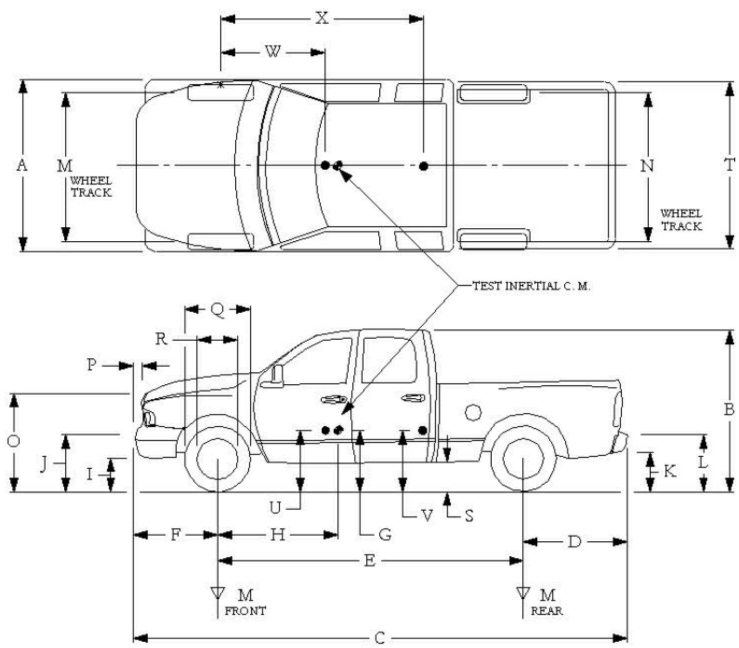
NOTES: None

Engine Type: V-8
Engine CID: 5.7 L

Transmission Type:
☑ Auto or ☐ Manual
☐ FWD ☑ RWD ☐ 4WD

Optional Equipment:
None

Dummy Data:
Type: 50th Percentile Male
Mass: 165 lb
Seat Position: IMPACT SIDE



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.75	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.99	M	68.50	R	18.00	W	62
D	44.00	I	11.75	N	68.00	S	13.00	X	79
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50

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}	2887	2805	2890
Back	3900	M_{rear}	2016	2215	2295
Total	6700	M_{Total}	4903	5020	5185

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

Mass Distribution:
lb LF: 1398 RF: 1407 LR: 1148 RR: 1067

Table D.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 611901-04-1.

Date: 2021 Test No.: 611901-04-1 VIN: 1C6RR6FT5FS654532

Year: 2015 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 185010

Engine: 5.7 L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 140 (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70 R 17

Measured Vehicle Weights: (lb)							
LF:	1398		RF:	1407		Front Axle:	2805
LR:	1148		RR:	1067		Rear Axle:	2215
Left:	2546		Right:	2474		Total:	5020
							5000 ±110 lb allowed
Wheel Base:	140.50	inches	Track: F:	68.50	inches	R:	68.00 inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed			

Center of Gravity, SAE J874 Suspension Method				
X:	61.99	inches	Rear of Front Axle	(63 ±4 inches allowed)
Y:	-0.49	inches	Left - Right +	of Vehicle Centerline
Z:	28.75	inches	Above Ground	(minumum 28.0 inches allowed)

Hood Height: 46.00 inches (43 ±4 inches allowed) Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches (39 ±3 inches allowed) Rear Bumper Height: 30.00 inches

Overall Length: 227.50 inches (237 ±13 inches allowed)

Table D.3. Exterior Crush Measurements for Test No. 611901-04-1.

Date:	2021	Test No.:	611901-04-1	VIN No.:	1C6RR6FT5FS654532
Year:	2015	Make:	RAM	Model:	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 bmp ht	14	7	36	-	-	-	-	-	-	18
2	Side plane above bmp	14	9	54	-	-	-	-	-	-	72
	Measurements recorded										
	☑ **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.

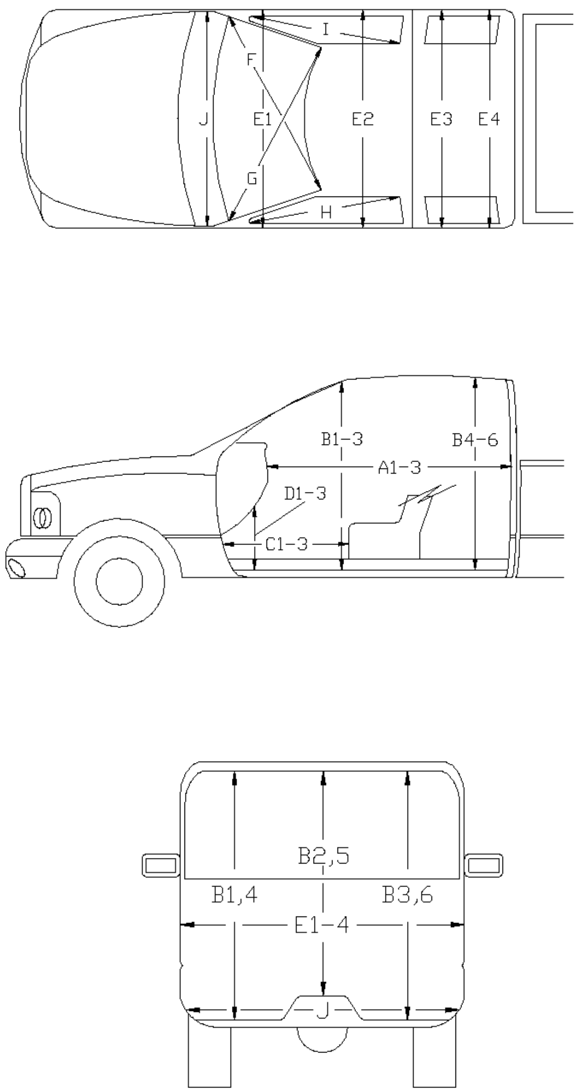
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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. 611901-04-1.

Date:	2021	Test No.:	611901-04-1	VIN No.:	1C6RR6FT5FS654532
Year:	2015	Make:	RAM	Model:	1500



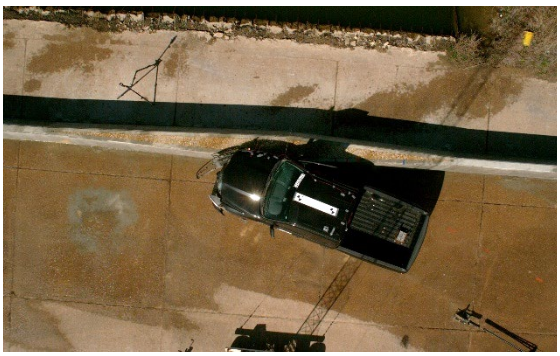
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

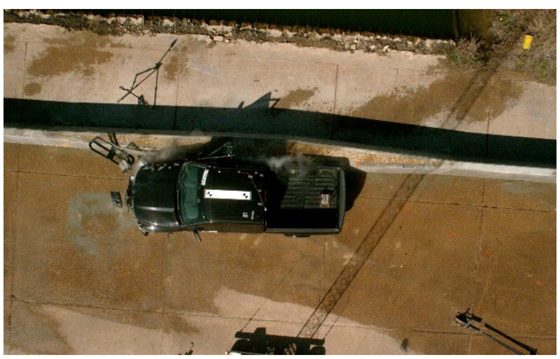
	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	21	-5.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	12.5	1.00
E1	58.50	56	-2.50
E2	63.50	67.25	3.75
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	21	-4.00

D.2. SEQUENTIAL PHOTOGRAPHS

0.000 s



0.100 s



0.200 s

0.300 s

Figure D.1. Sequential Photographs for Test No. 611901-04-1 (Overhead and Frontal Views).

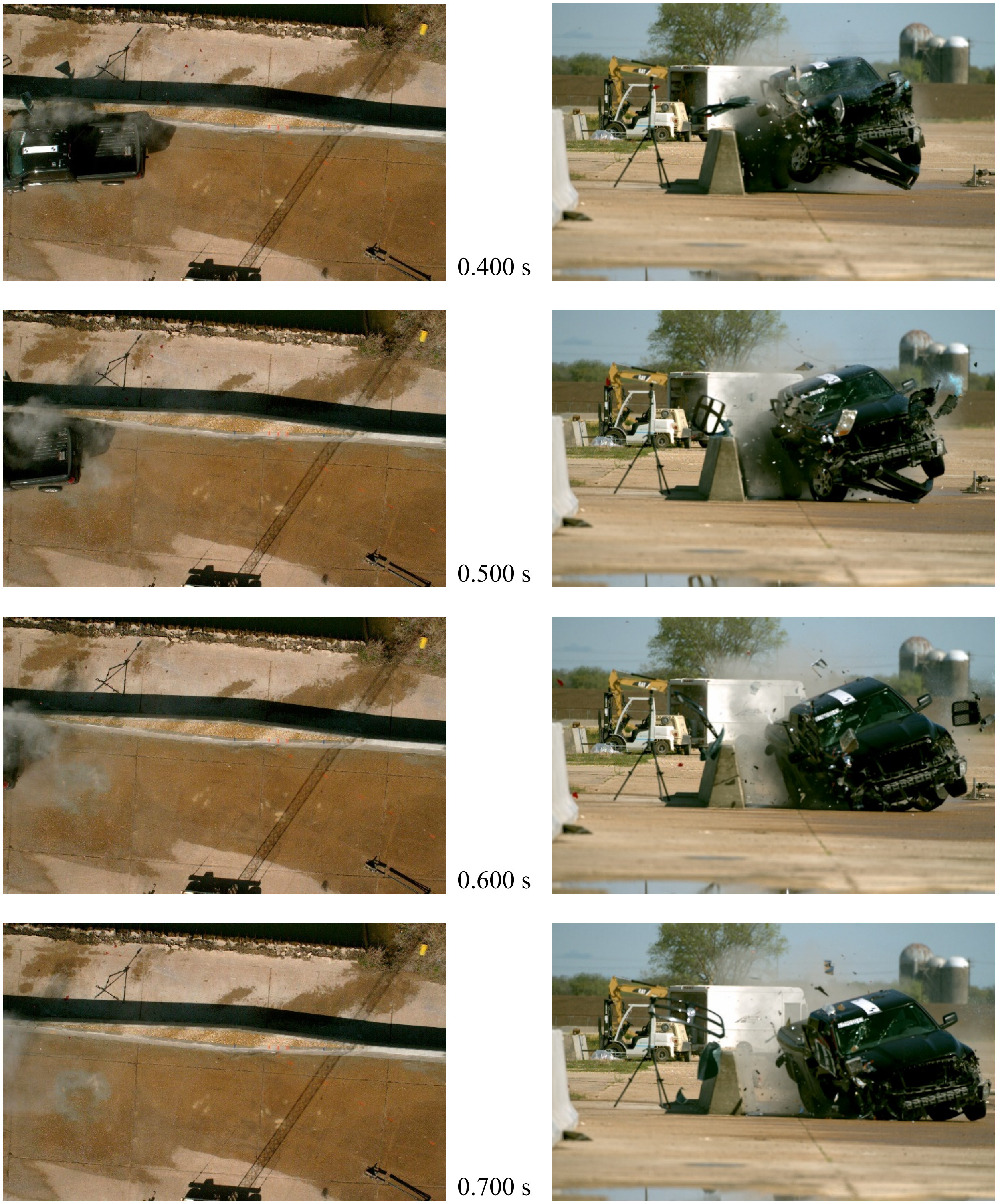


Figure D.1. Sequential Photographs for Test No. 611901-04-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

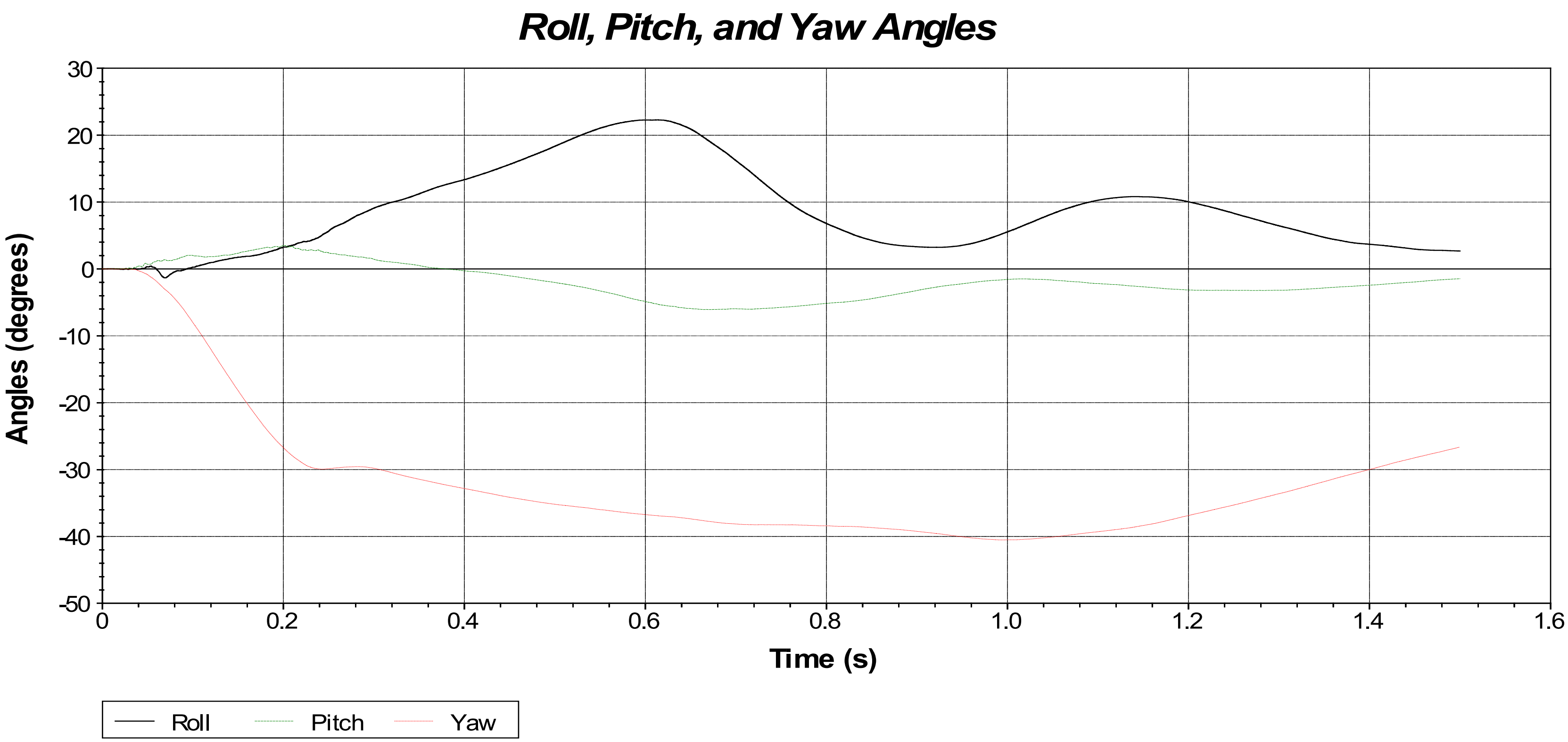
0.400 s

0.500 s

0.600 s

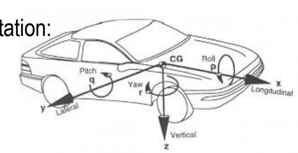
0.700 s

Figure D.2. Sequential Photographs for Test No. 611901-04-1 (Rear View).



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 611901-04-1
Test Standard Test Number: *MASH* Test 4-11
Test Article: Critical Flare Concrete Barrier System
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5020 lb
Gross Mass: 5185 lb
Impact Speed: 62.3 mi/h
Impact Angle: 24.9°

Figure D.3. Vehicle Angular Displacements for Test No. 611901-04-1.

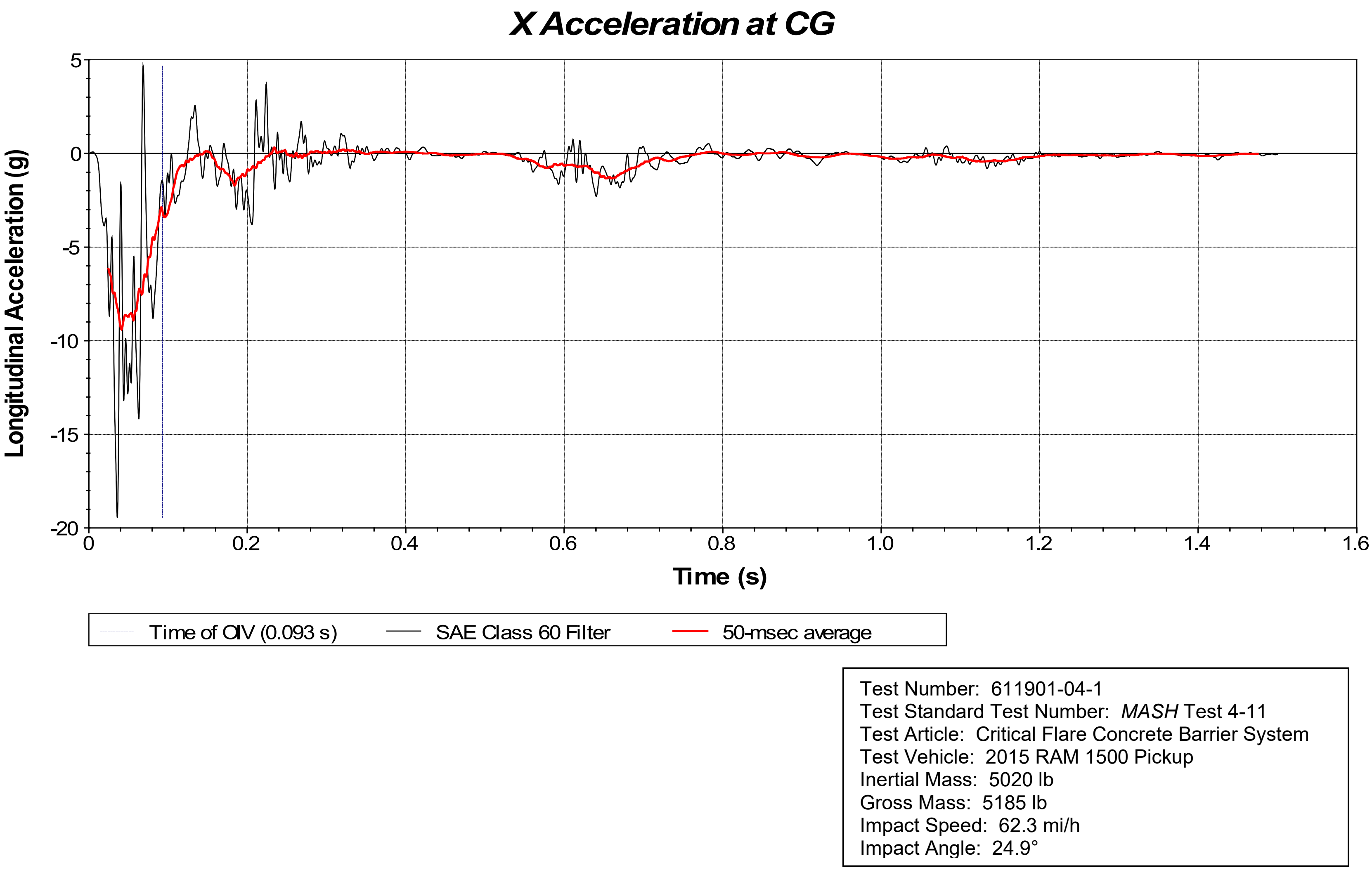
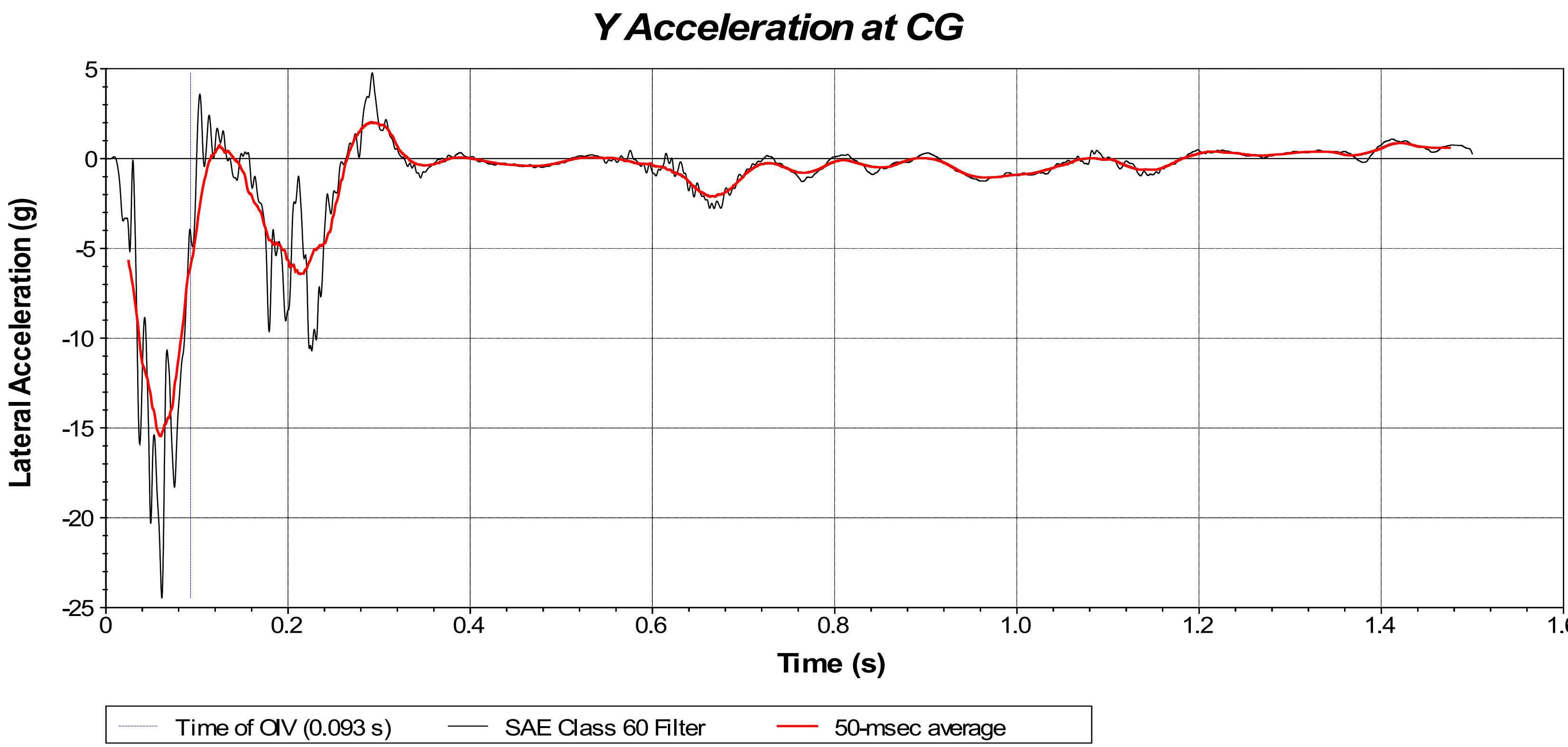


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 611901-04-1 (Accelerometer Located at Center of Gravity).



Test Number: 611901-04-1
Test Standard Test Number: *MASH* Test 4-11
Test Article: Critical Flare Concrete Barrier System
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5020 lb
Gross Mass: 5185 lb
Impact Speed: 62.3 mi/h
Impact Angle: 24.9°

Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 611901-04-1 (Accelerometer Located at Center of Gravity).

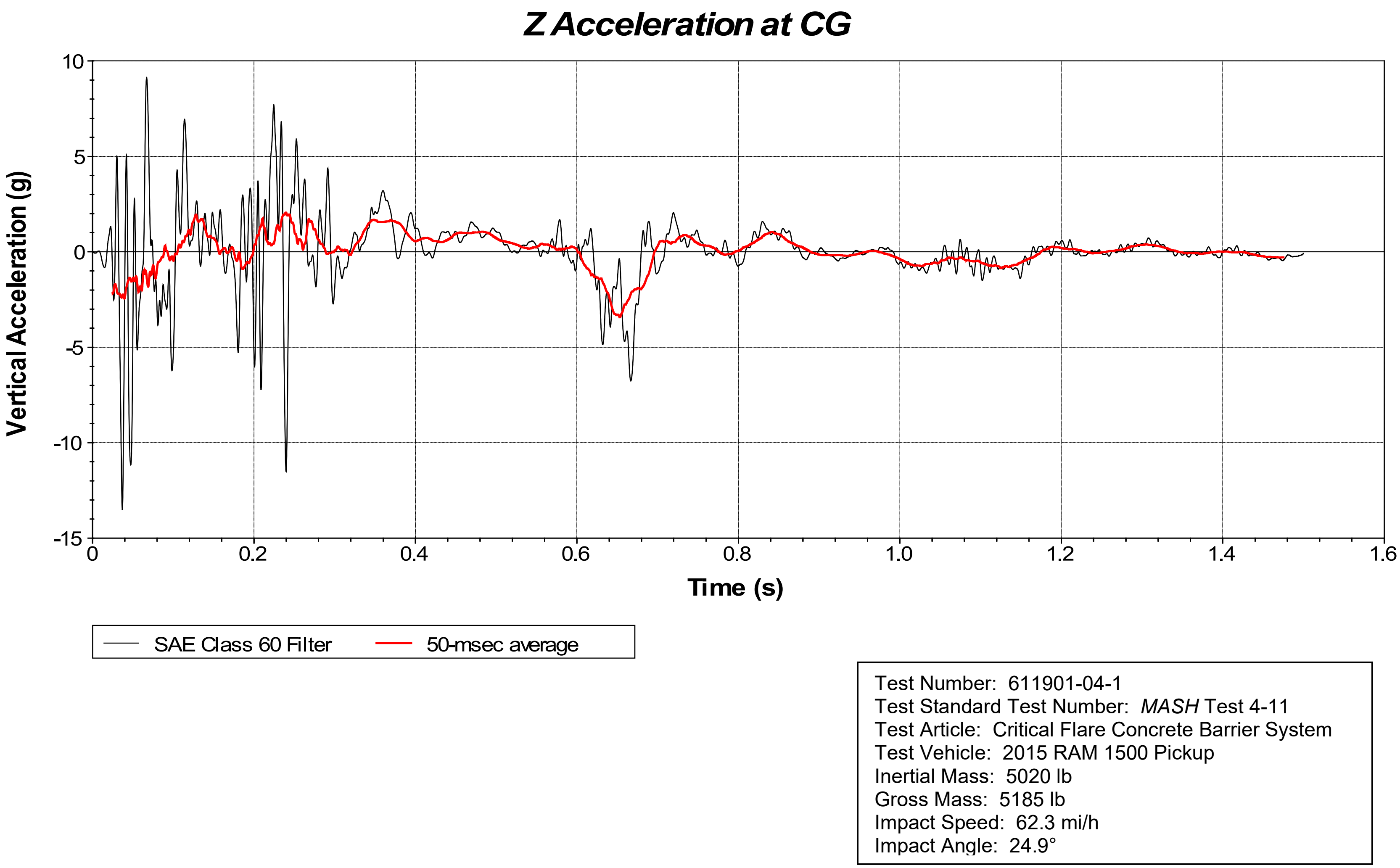


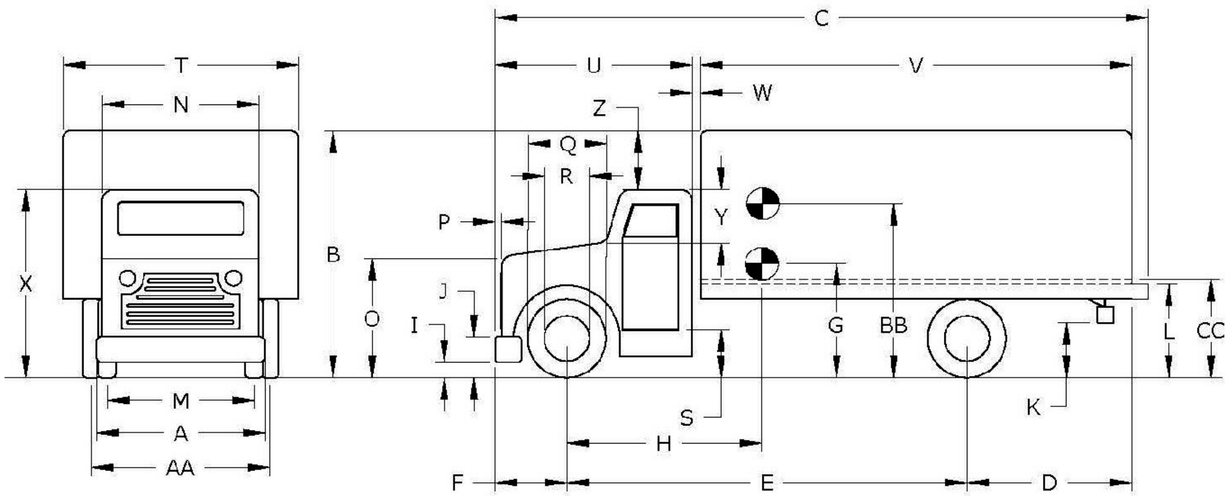
Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 611901-04-1 (Accelerometer Located at Center of Gravity).

APPENDIX E. *MASH* TEST 4-12 (CRASH TEST NO. 611901-05-1)

E.1. VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 611901-05-1.

Date:	2021-4-1	Test No.:	611901-05-1	VIN No.:	1HTMMAAN29H162218
Year:	2009	Make:	INTERNATIONAL	Model:	4300
Odometer:	198307	Tire Size Front:	275/80R22.5	Tire Size Rear:	275/80R22.5



Vehicle Geometry: ☑ inches or ☐ mm

A	Front Bumper Width:	92.50	K	Rear Bumper Bottom:		U	Cab Length:	106.00
B	Overall Height:	134.50	L	Rear Frame Top:	38.00	V	Trailer/Box Length:	223.00
C	Overall Length:	331.70	M	Front Track Width:	80.00	W	Gap Width:	3.00
D	Rear Overhang:	87.00	N	Roof Width:	71.00	X	Overall Front Height:	98.50
E	Wheel Base:	204.70	O	Hood Height:	59.00	Y	Roof-Hood Distance:	30.00
F	Front Overhang:	40.00	P	Bumper Extension:		Z	Roof-Box Height Difference:	37.00
G	C.G. Height:		Q	Front Tire Width:	39.00	AA	Rear Track Width:	73.00
H	C.G. Horizontal Dist. w/Ballast:	128.88	R	Front Wheel Width:	23.50	BB	Ballast Center of Mass:	63.50
I	Front Bumper Bottom:	18.25	S	Bottom Door Height:	37.00	CC	Cargo Bed Height:	50.50
J	Front Bumper Top:	33.25	T	Overall Width:	97.50			

Allowable Range: C = 394 inches max.; E = 240 inches max.; CC = 49 ±2 inches; BB = 63 ±2 inches above ground;

Wheel Center Height Front	19.00	Wheel Well Clearance (Front)	9.00	Bottom Frame Height (Front)	25.50
Wheel Center Height Rear	19.00	Wheel Well Clearance (Rear)	5.00	Bottom Frame Height (Rear)	27.50

More information needed on next page

Table E.1. Vehicle Properties for Test No. 611901-05-1 (Continued).

Date: 2021-4-1 Test No.: 611901-05-1 VIN No.: 1HTMMAAN29H162218

Year: 2009 Make: INTERNATIONAL Model: 4300

WEIGHTS (☑ lb or ☐ kg)	CURB	TEST INERTIAL
$W_{front\ axle}$	7060	8200
$W_{rear\ axle}$	6220	13940
W_{TOTAL}	13280	22140

Allowable Range for CURB = 13,200 ±2200 lb | Allowable Range for TIM = 22,046 ±660 lb

Ballast: 8860 (☑ lb or ☐ kg) **(as-needed)** **(See *MASH* Section 4.2.1.2 for recommended ballasting)**

Mass Distribution (☑ lb or ☐ kg): **LF:** 4010 **RF:** 4190 **LR:** 7210 **RR:** 6730

Engine Type: DT

Engine Size: 466

Transmission Type:

☐ Auto or ☐ Manual

☐ FWD ☐ RWD ☐ 4WD

Accelerometer Locations (☑ inches or ☐ mm)

	x[1]	y	z[2]
Front:			
Center:	128.00	0.00	49.50
Rear:	250.80	0.00	49.50

Describe any damage to the vehicle prior to test: NONE

Other notes to include ballast type, dimensions, mass, location, center of mass, and method of attachment:

Two blocks 30 inches high x 60 inches wide x 30 inches long

Centered in middle of bed

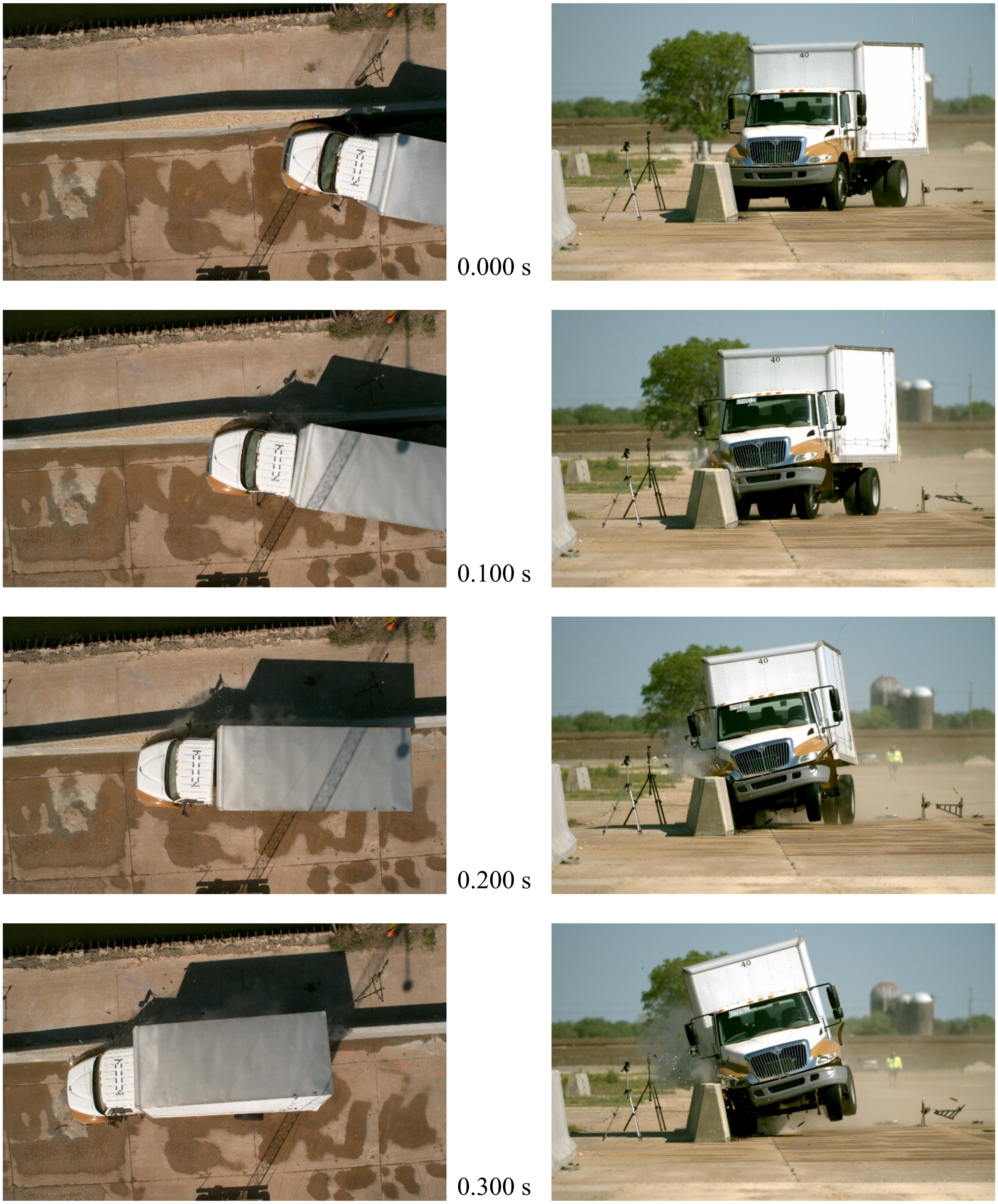
Tied down with four 3/8-inch cables per block

63.5 inches from ground to center of block

Performed by: SCD **Date:** 2021-4-1

[1] Referenced to the front axle
[2] Above ground

E.2. SEQUENTIAL PHOTOGRAPHS



0.000 s

0.100 s

0.200 s

0.300 s

Figure E.1. Sequential Photographs for Test No. 611901-05-1 (Overhead and Frontal Views).


0.400 s



0.500 s



0.600 s



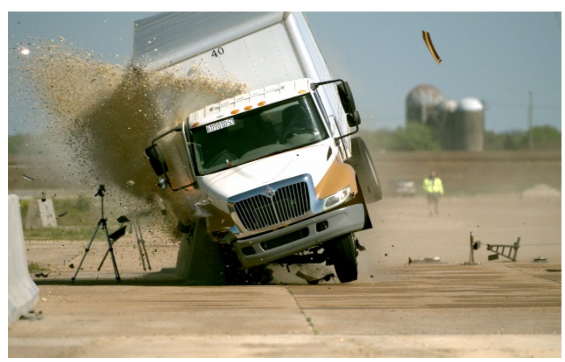
0.700 s


Figure E.1. Sequential Photographs for Test No. 611901-05-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

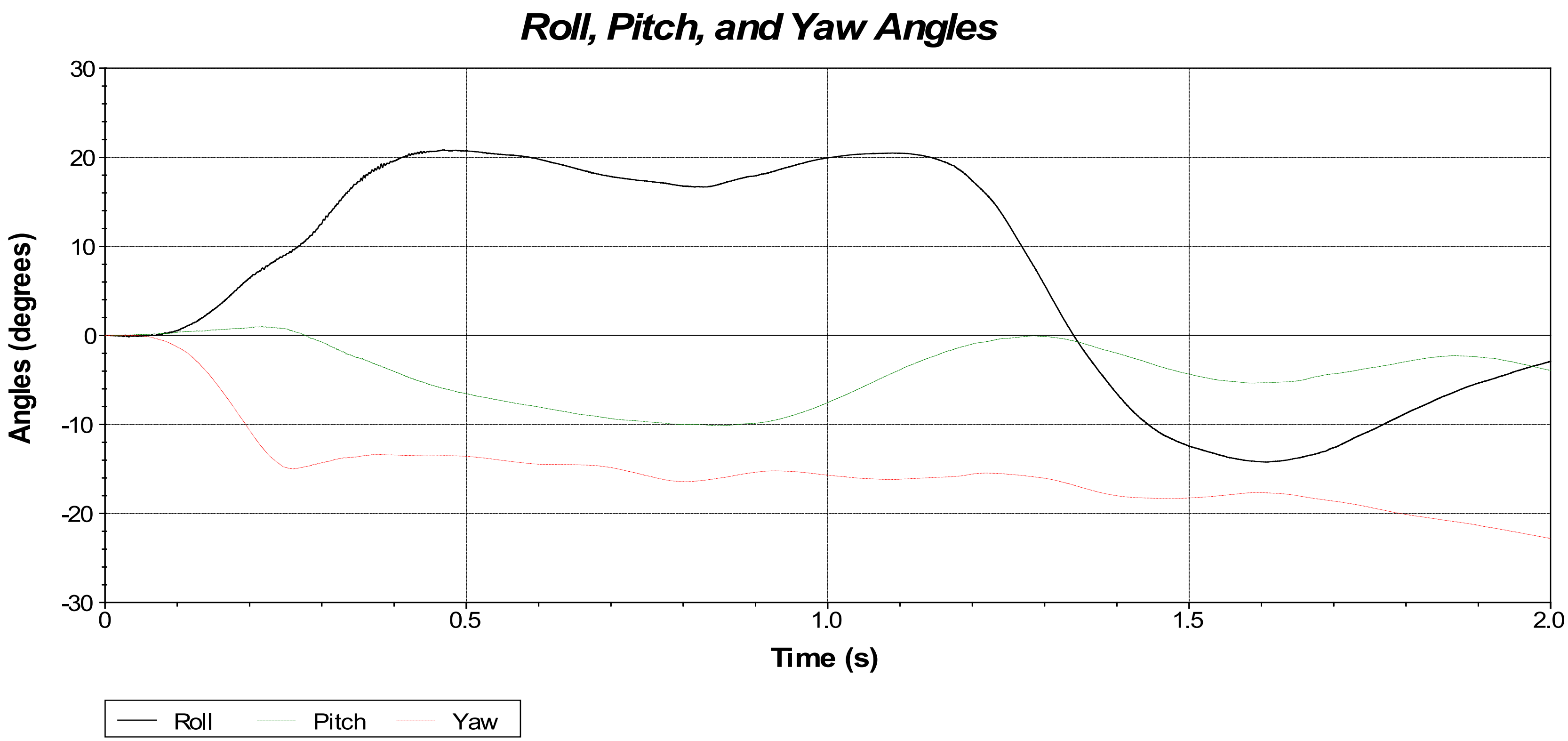
0.400 s

0.500 s

0.600 s

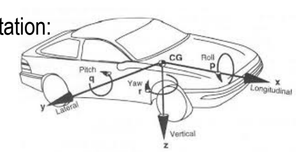
0.700 s

Figure E.2. Sequential Photographs for Test No. 611901-05-1 (Rear View).



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 611901-05-1
Test Standard Test Number: *MASH* Test 4-12
Test Article: Critical Flare Concrete Barrier System
Test Vehicle: 2009 International 4300 SUT
Inertial Mass: 22,140 lb
Gross Mass: 22,140 lb
Impact Speed: 58.5 mi/h
Impact Angle: 15.3°

Figure E.3. Vehicle Angular Displacements for Test No. 611901-05-1.

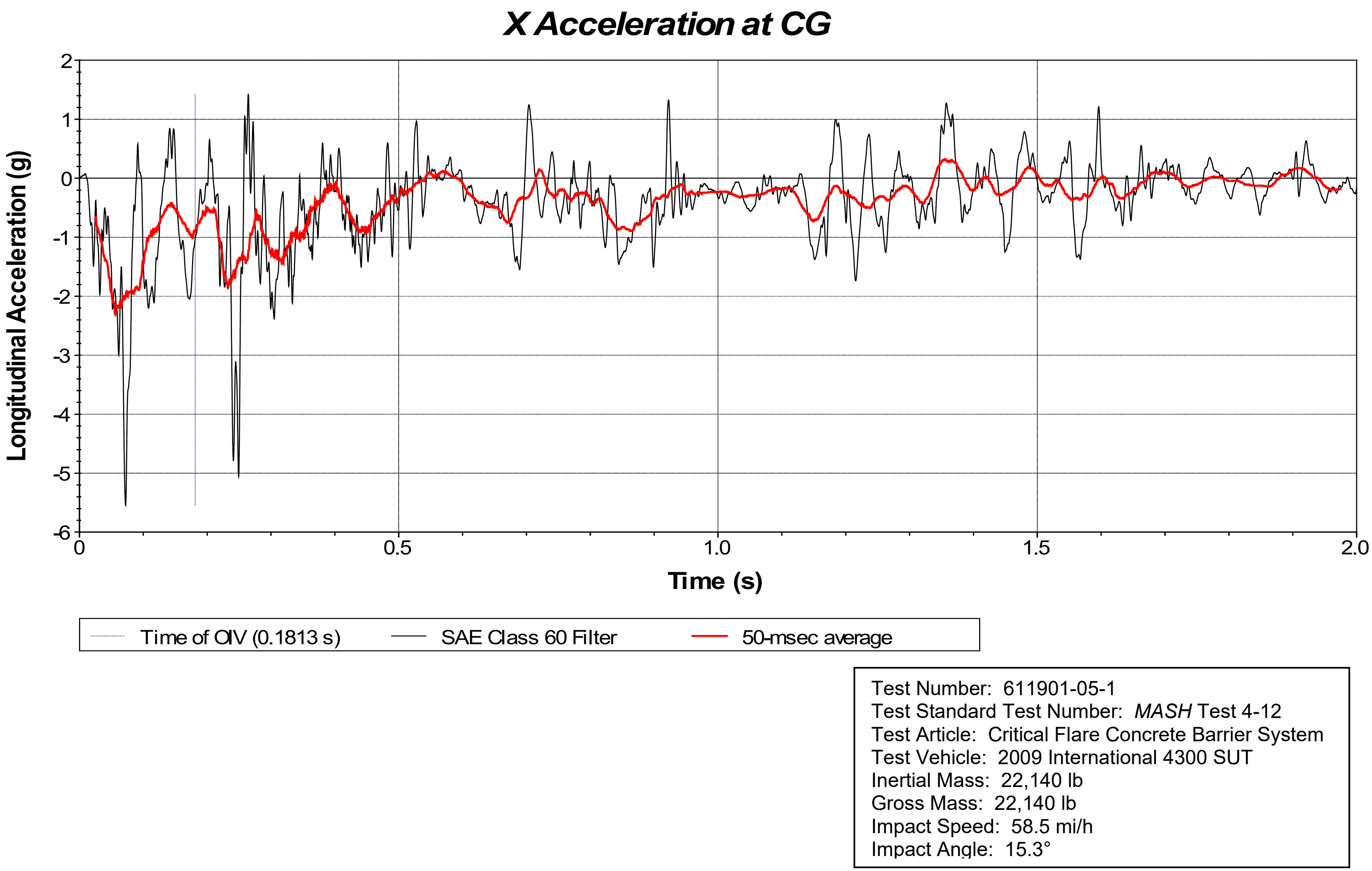
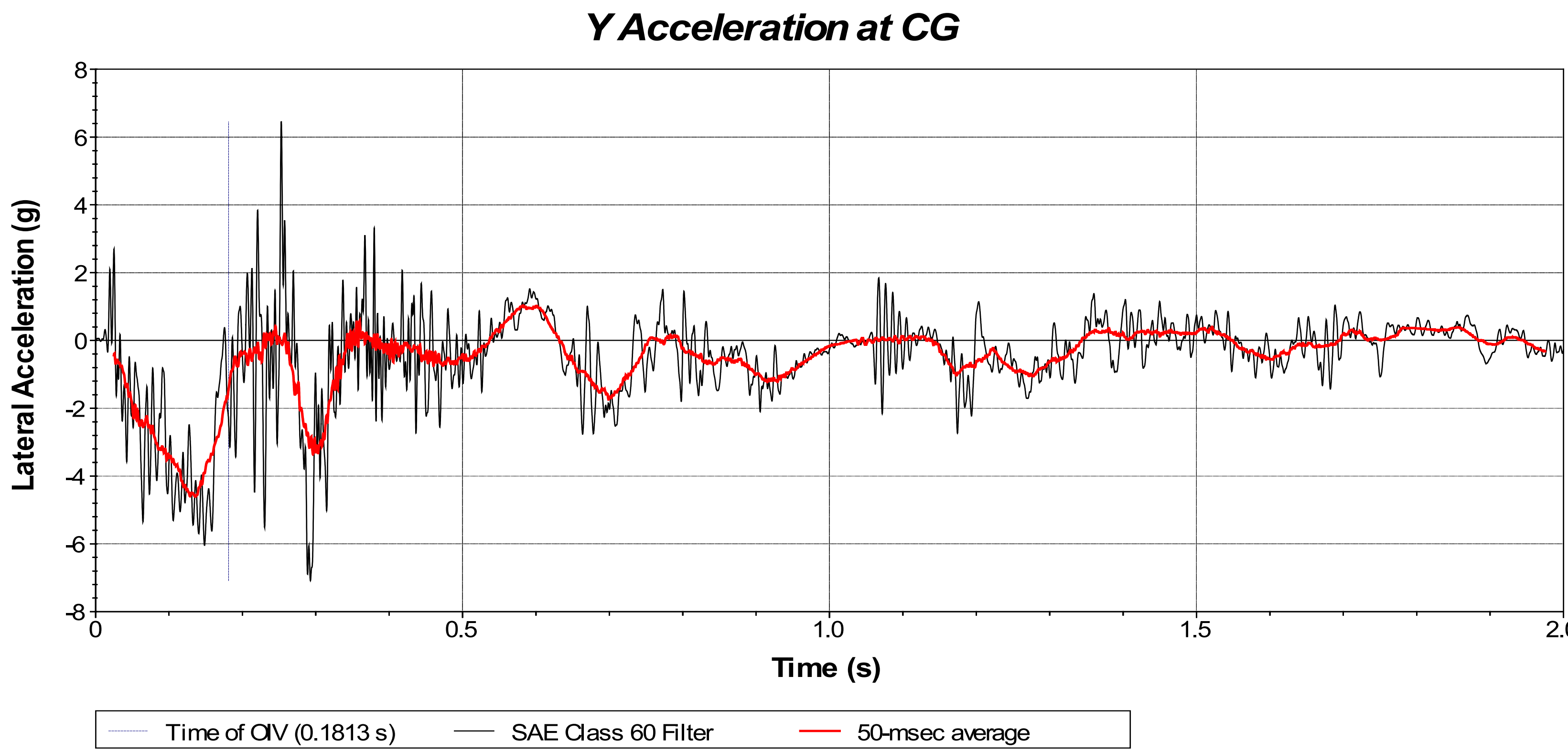


Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 611901-05-1 (Accelerometer Located at Center of Gravity).



Test Number: 611901-05-1
Test Standard Test Number: *MASH* Test 4-12
Test Article: Critical Flare Concrete Barrier System
Test Vehicle: 2009 International 4300 SUT
Inertial Mass: 22,140 lb
Gross Mass: 22,140 lb
Impact Speed: 58.5 mi/h
Impact Angle: 15.3°

Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 611901-05-1 (Accelerometer Located at Center of Gravity).

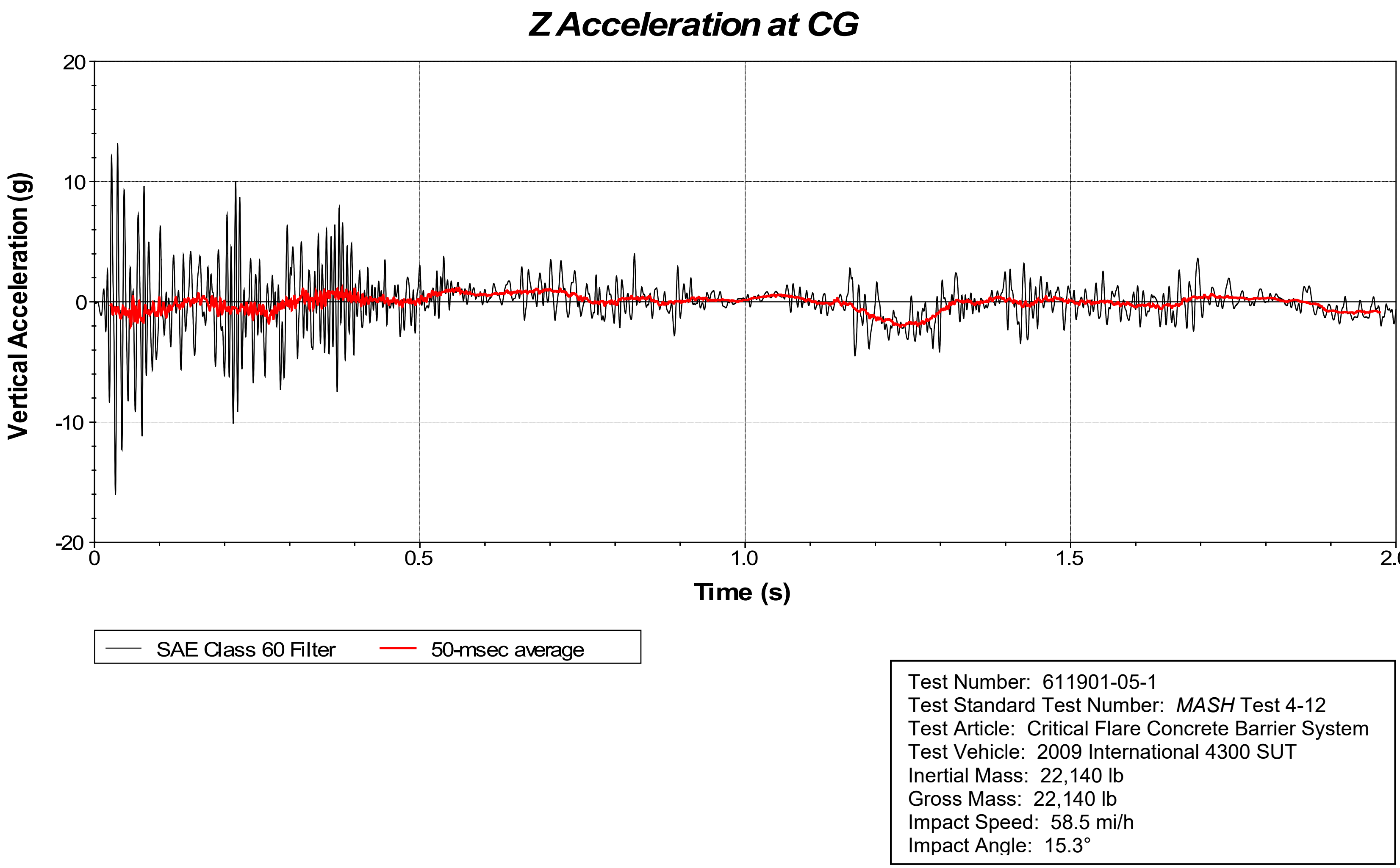


Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 611901-05-1 (Accelerometer Located at Center of Gravity).

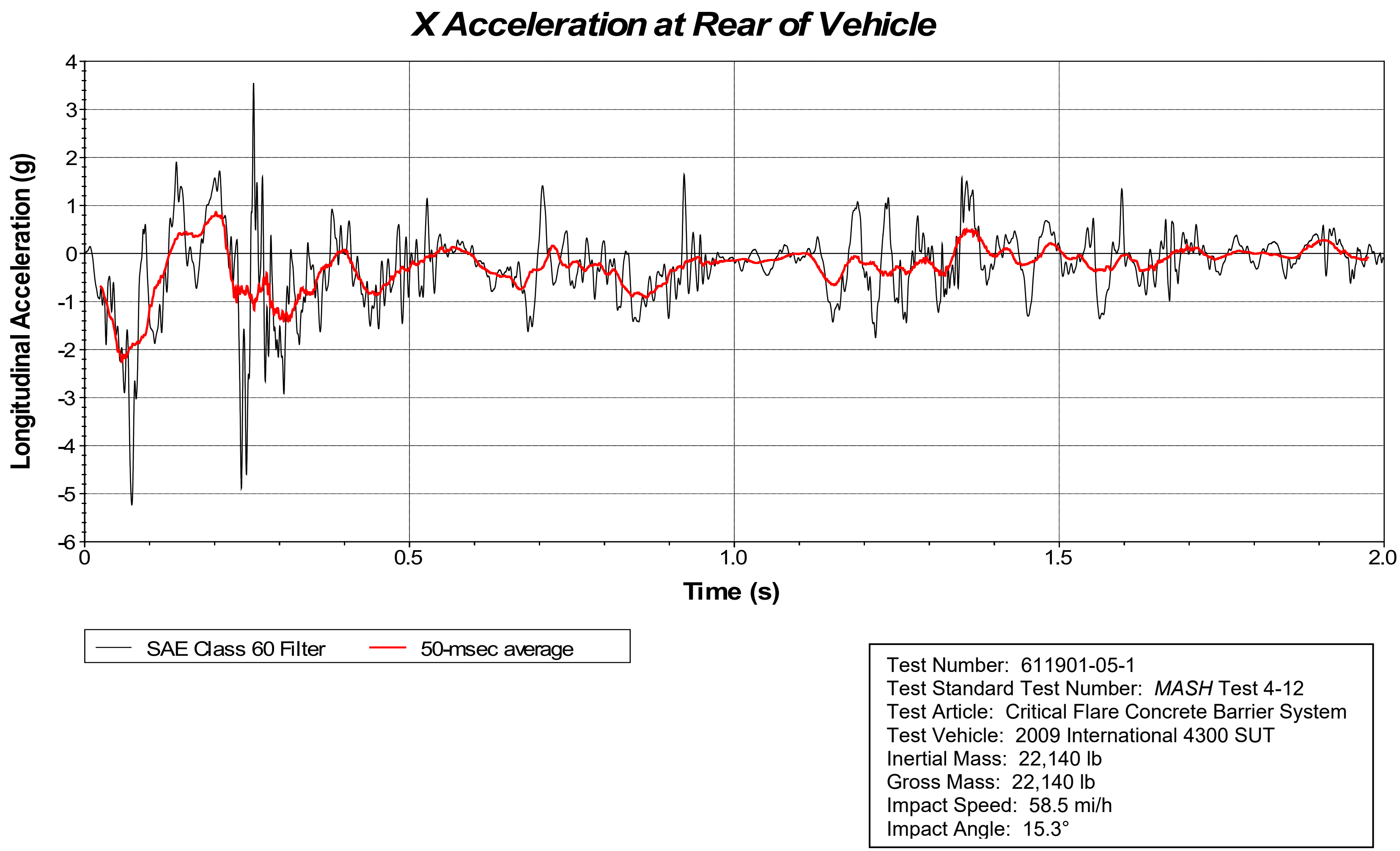
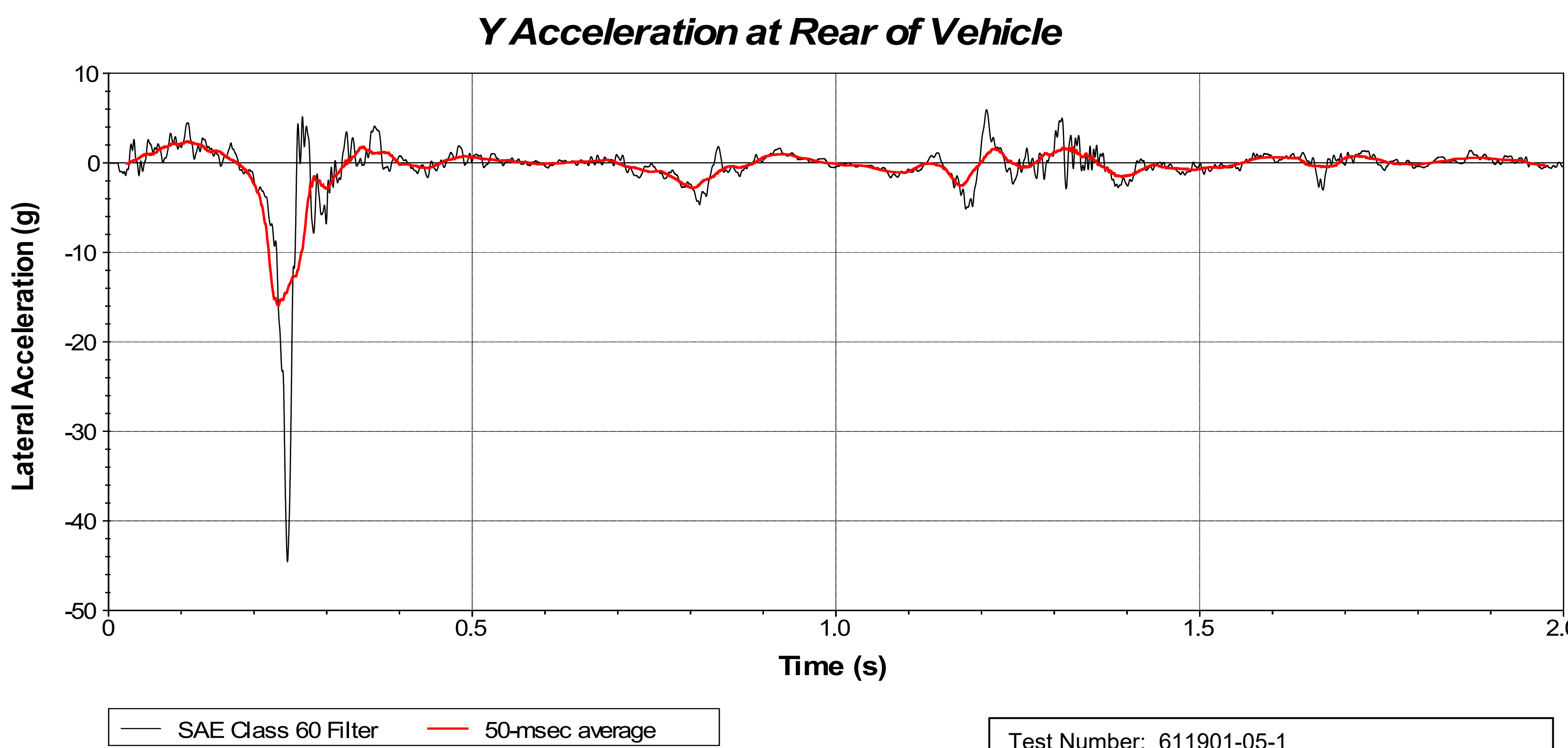


Figure E.7. Vehicle Longitudinal Accelerometer Trace for Test No. 611901-05-1 (Accelerometer Located at Rear of Vehicle).



Test Number: 611901-05-1
Test Standard Test Number: *MASH* Test 4-12
Test Article: Critical Flare Concrete Barrier System
Test Vehicle: 2009 International 4300 SUT
Inertial Mass: 22,140 lb
Gross Mass: 22,140 lb
Impact Speed: 58.5 mi/h
Impact Angle: 15.3°

Figure E.8. Vehicle Lateral Accelerometer Trace for Test No. 611901-05-1 (Accelerometer Located at Rear of Vehicle).

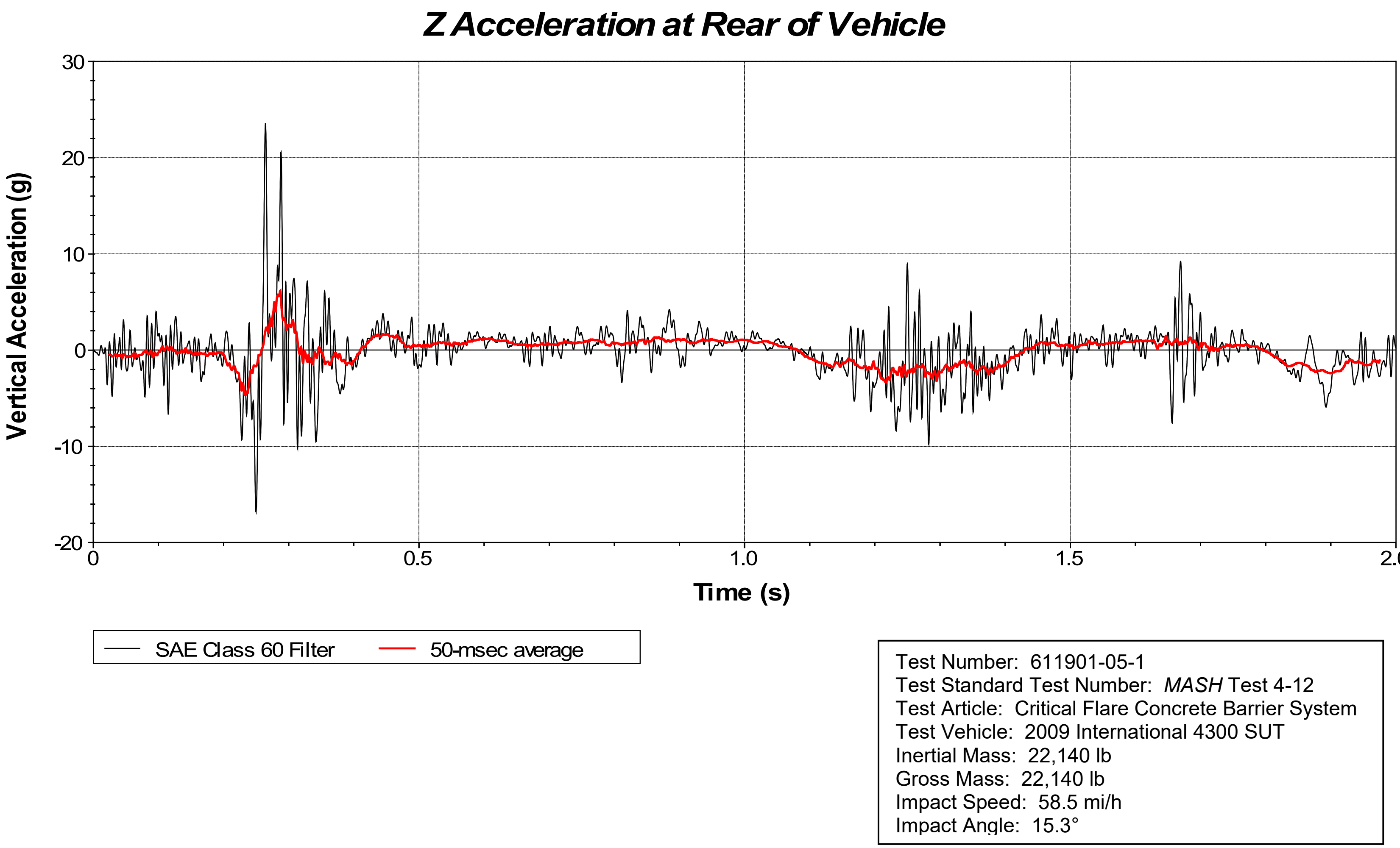


Figure E.9. Vehicle Vertical Accelerometer Trace for Test No. 611901-05-1 (Accelerometer Located at Rear of Vehicle).