TTI: 0-6968

MASH TEST 4-12 OF SHALLOW ANCHORAGE SINGLE SLOPE TRAFFIC RAIL (SSTR)

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
TTI Proving Ground
1254 Avenue A, Building 7091
Bryan, TX 77807

Test Report 0-6968-R10

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
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16. Abstract

The purpose of the tests reported herein was to assess the performance of the Texas Department of Transportation's (TxDOT's) shallow anchorage single slope traffic rail (SSTR) according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*). *MASH* Test 4-12 was performed on the TxDOT shallow anchorage SSTR to determine the structural adequacy of the anchorage.

Two different barrier configurations were evaluated: with and without dowel bars between barrier segments across expansion joints. This report provides details of the TxDOT shallow anchorage SSTR, the crash tests and results, and the performance assessment of the TxDOT shallow anchorage SSTR as a *MASH* Test Level 4 (TL-4) longitudinal barrier.

Both variations of the TxDOT shallow anchorage SSTR (with and without dowel bars between barrier segments across expansion joints) were determined to be *MASH* TL-4 compliant. No delamination or damage to the deck was observed in the test installation after impact.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of this project was Roger P. Bligh, P.E. Texas #78550. The United States Government and the State of Texas do not endorse products or manufacturers. Trade of manufacturers' names appear herein solely because they are considered essential to the object of this report.

TTI PROVING GROUND DISCLAIMER

The results of the crash testing reported herein apply only to the article tested.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square 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

CHAPTER 1. INTRODUCTION

The Texas Department of Transportation's (TxDOT's) single slope traffic rail (SSTR) has performed acceptably according to the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test Level 4 (TL-4) longitudinal barriers (*1*). Different configurations of the SSTR have been tested and shown to satisfy *MASH* TL-4 criteria (*2*). However, it is further desired to be able to anchor an SSTR into a 4½-inch-thick cast-in-place deck slab that is constructed over a prestressed box beam, slab beam, or prestressed panel. The main concern with this application is the strength of the anchoring system.

The purpose of the tests reported herein was to assess the performance of the TxDOT shallow anchorage SSTR according to the safety-performance evaluation guidelines included in the AASHTO *MASH*. *MASH* Test 4-12 was performed on the TxDOT shallow anchorage SSTR to determine the structural adequacy of the anchorage.

This report provides details of the TxDOT shallow anchorage SSTR, the crash tests and results, and the performance assessment of the TxDOT shallow anchorage SSTR as a *MASH* TL-4 longitudinal barrier.

CHAPTER 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The installation consisted of three sections of 36-inch-tall concrete SSTR. Two of the sections were 25 ft. in length, and the third section, placed on the left end when viewing from the traffic side, was 74 ft. 9¾ inches long. There was a 2-inch joint between each barrier section, which resulted in a total length of 125 ft. 1¾ inches. The SSTR was anchored in place using No. 4 rebar anchors embedded in a cast-in-place concrete slab measuring 4½ inches thick. The rebar anchors rested on the top surface of precast concrete panels that were 8 ft. 4 inches long, 10 ft. wide, and 4 inches thick. The upper concrete slab was then cast in place over the precast concrete panels to simulate field construction.

Figure 2.1 presents overall information on the TxDOT shallow anchorage SSTR, and Figure 2.2 provides photographs of the test installation. Appendix A provides further details on the TxDOT shallow anchorage SSTR. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by Tucker Construction and supervised by TTI Proving Ground personnel.

2.2. DESIGN MODIFICATIONS

For Test No. 469680-02-2, the dowel bars between barrier segments across the expansion joints were cut through so the barrier segments were not connected. After only minor barrier movement and damage in Test No. 469680-02-1, this was done to see if acceptable impact performance could be achieved without the need for dowel bars across adjacent joints. Prior to the third test (Test No. 469680-02-3), the concrete apron was extended downstream of the barrier to replace the soil beyond the end of the barrier to provide a more uniform and representative runout area.

2.3. MATERIAL SPECIFICATIONS

The specified compressive strength of the concrete used in the panels, deck, and parapet was 5000 psi, 4000 psi, and 3600 psi, respectively. On the day of the first test, June 16, 2020, the average compressive strength of the concrete was as follows:

- Average concrete strength for the panels: 5360 psi at 42 days of age.
- Average concrete strength for the deck: 5121 psi at 33 days of age.
- Average concrete strength for the parapet: 4255 psi at 25 days of age.

Appendix B provides material certification documents for the materials used to install/construct the TxDOT shallow anchorage SSTR.

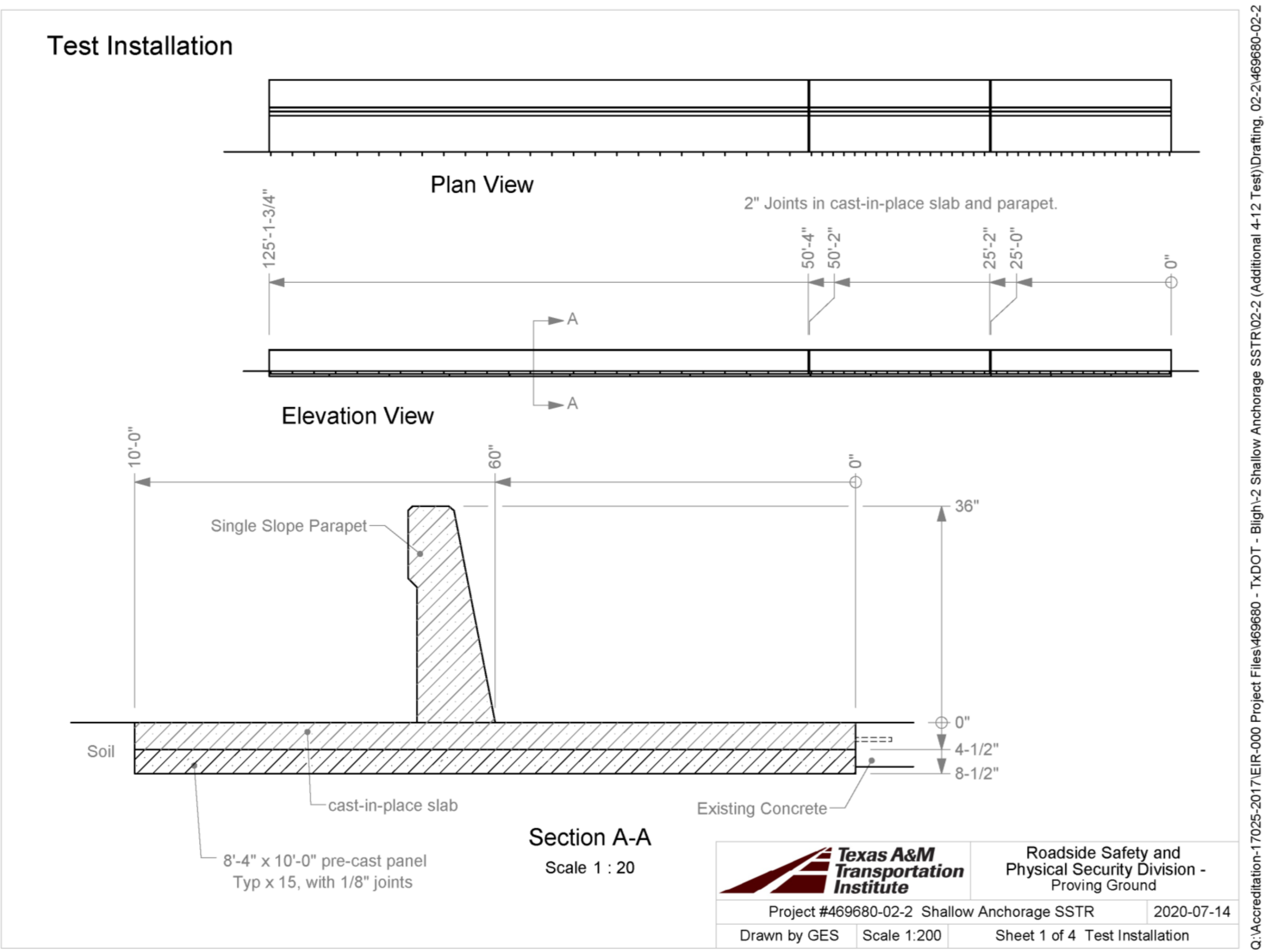

Figure 2.1. TxDOT Shallow Anchorage SSTR Details.

Figure 2.2. TxDOT Shallow Anchorage SSTR prior to Testing.

CHAPTER 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST PERFORMED/MATRIX

Table 3.1 shows the recommended test conditions and evaluation criteria for *MASH* TL-4 longitudinal barriers.

Table 3.1. 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

MASH Test 4-12 was performed on the TxDOT shallow anchorage SSTR. Test 4-12 was the critical test for evaluating the strength of the anchorage system. Tests 4-10 and 4-11 were not considered necessary to assess *MASH* compliance of the anchorage system. Previous tests that have been performed on single slope barriers indicate the profile is *MASH* compliant for the 1100C passenger car and 2270P pickup truck (*3, 4*).

The target critical impact point (CIP) for the test was determined using the information provided in *MASH* Section 2.2.1, Section 2.3.2, and Table 2-8. Figure 3.1 shows the target CIP for *MASH* Test 4-12 on the TxDOT shallow anchorage SSTR, which is 5 ft. upstream of an expansion joint.

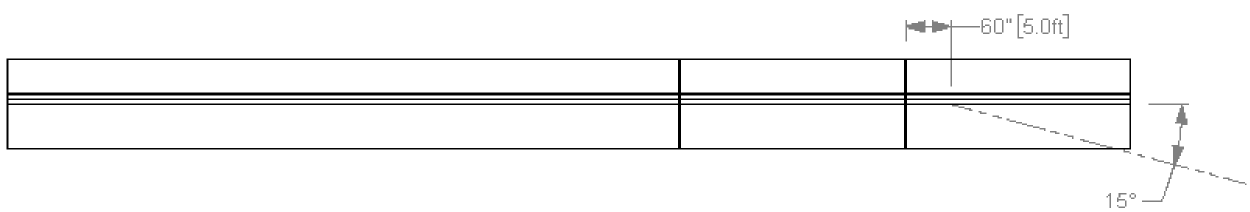

Figure 3.1. Target CIP for First and Third *MASH* Test 4-12 on TxDOT Shallow Anchorage SSTR (Test No. 469680-02-1 and 3).

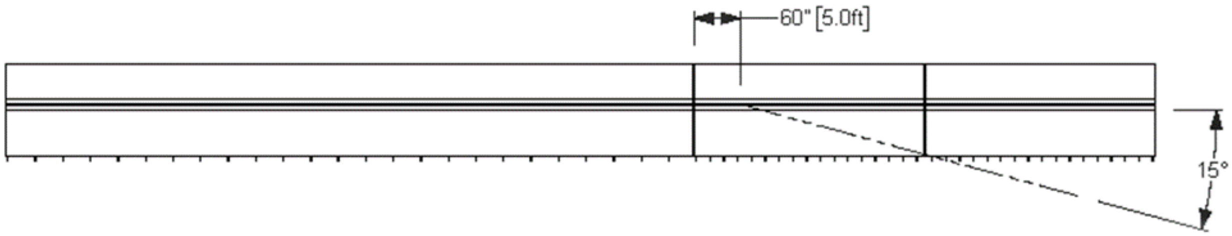

Figure 3.2. Target CIP for Second *MASH* Test 4-12 on TxDOT Shallow Anchorage SSTR (Test No. 469680-02-2)

In Test No. 469680-02-2, the dowels bars across the expansion joints were cut such that the barrier segments were not connected. For this test, the impact point was shifted to an undamaged barrier section with the CIP as shown in Figure 3.1 In this test, the vehicle rolled onto its roof, causing excessive occupant compartment deformation. The rollover was partially attributed to an uneven runout area (part soil and part concrete) beyond the barrier installation. Therefore, *MASH* Test 4-12 was repeated on the system without dowel bars (Test No. 469680-02-3) with a more uniform and representative runout area. Since both barrier segments had been previously impacted, the impact point was shifted back to the first barrier segment as shown in Figure 3.1.

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

3.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. Table 3.1 lists the test conditions and evaluation criteria required for *MASH* Test 4-12, and Table 3.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 7.

Table 3.2. Evaluation Criteria Required for *MASH* Test 4-12.

Evaluation Factors	Evaluation Criteria
Structural Adequacy	*A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*
Occupant Risk	*D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present 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.*
	G. It is preferable, although not essential, that the vehicle remain upright during and after the collision.

CHAPTER 4. TEST CONDITIONS

4.1. 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 TxDOT shallow anchorage SSTR 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.

4.2. VEHICLE TOW AND GUIDANCE SYSTEM

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

4.3. DATA ACQUISITION SYSTEMS

4.3.1. 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 axes 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).

4.3.2. Anthropomorphic Dummy Instrumentation

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

4.3.3. Photographic Instrumentation Data Processing

Photographic coverage of the 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 TxDOT shallow anchorage SSTR. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

CHAPTER 5. *MASH* TEST 4-12 (CRASH TEST NO. 469680-02-1)

5.1. 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 TxDOT shallow anchorage SSTR was 5 ft ± 1 ft upstream of the centerline of the joint between Segments 1 and 2. Figure 3.1 and Figure 5.1 depict the target impact setup.

Figure 5.1. TxDOT Shallow Anchorage SSTR/Test Vehicle Geometrics for Test No. 469680-02-1.

The 10000S vehicle weighed 22,340 lb, and the actual impact speed and angle were 56.9 mi/h and 14.6 degrees. Minimum target impact severity (IS) was 142 kip-ft, and actual IS was 153 kip-ft. The actual impact point was 3.4 ft upstream of the centerline of the joint between Segments 1 and 2, which is 1.6 ft downstream of the target impact point and 0.6 ft outside the recommended *MASH* tolerance for impact point, and thus is out of specifications for *MASH*. When speaking about the impact point for large trucks, *MASH* Section 2.3.2.2 states that "the critical impact point for these vehicles should be chosen to maximize loading on critical barrier elements such as joints and splices." Section A2.3.2.2 further elaborates that "impact point selection guidelines presented in Section 2.3.2.2 are based on the distance from initial contact to the location of maximum lateral force." The objective of *MASH* Test 4-12 on the TxDOT shallow anchorage SSTR was to evaluate the effectiveness of the shallow anchorage system at a critical area near a barrier end/joint. Film analysis of this test showed that both the initial frontal impact and the subsequent rear impact of the truck occurred on the downstream end of the impacted barrier segment in advance of the joint. In fact, the lateral impact forces were applied to the barrier at a point closer to the segment end than initially planned, making it even more critical for evaluation of both the barrier and anchorage system. Thus, the outcome of the test was considered valid despite the actual impact point falling 0.6 ft downstream of the recommended *MASH* tolerance for CIP.

5.2. WEATHER CONDITIONS

The test was performed on the afternoon of June 16, 2020. Weather conditions at the time of testing were as follows: wind speed: 10 mi/h; wind direction: 203 degrees (vehicle was traveling at a heading of 185 degrees); temperature: 89°F; relative humidity: 48 percent.

5.3. TEST VEHICLE

Figure 5.2 shows the 2011 International 4300 single-unit truck (SUT) used for the crash test. The vehicle's test inertia weight was 22,340 lb, and its gross static weight was 22,340 lb. The height to the lower edge of the vehicle bumper was 18.5 inches, and height to the upper edge of the bumper was 33.5 inches. The height to the center of gravity of the vehicle's ballast was 61.75 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 5.2. Test Vehicle before Test No. 469680-02-1.

5.4. TEST DESCRIPTION

Table 5.1 lists events that occurred during Test No. 469680-02-1. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 5.1. Events during Test No. 469680-02-1.

Time (s)	Events
0.000	Vehicle bumper impacts barrier
0.006	Right front tire leaves pavement
0.035	Vehicle begins to redirect
0.143	Left front tire leaves pavement
0.207	Left rear tires leave pavement
0.244	Vehicle travels parallel with barrier
0.251	Right lower rear corner of box contacts top of barrier
1.105	Left front tire contacts 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. After loss of contact with the barrier, the vehicle came to rest 279 ft downstream of the point of impact and 70 ft toward the field side of the barrier.

5.5. DAMAGE TO TEST INSTALLATION

Figure 5.3 shows the damage to the TxDOT shallow anchorage SSTR. Before the test, any cracks in the deck and barrier were noted with a black paint marker. No additional cracks or enlarging of existing cracks were evident after the test. The deck was tested for delamination at the interface between the two concrete slabs, and none were detected. There was gouging and scuffing present on the traffic face of the barrier at the impacted joint. Rebar was exposed on the downstream end of Segment 1 at the joint between Segments 1 and 2. There was also gouging at the top of the field side corner of Segments 1 and 2 from contact with the bottom frame of the box of the truck. Working width[*] was 78.4 inches, and height of working width was 152.2 inches. No dynamic deflection during the test or permanent deformation after the test was observed.

5.6. DAMAGE TO TEST VEHICLE

Figure 5.4 shows the damage sustained by the vehicle. The front bumper, hood, right front tire and rim, right front spring assembly and U-bolts, right fuel tank and side steps, right door, right floor pan, right lower edge of box, right rear outer tire and rim, and right rear U-bolts were damaged. Maximum exterior crush to the vehicle was 18.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 2.5 inches in the right front floor pan/firewall. Figure 5.5 shows the interior of the vehicle.

5.7. VEHICLE INSTRUMENTATION

Data from the accelerometers were digitized for informational purposes only and are reported in Figure 5.6. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.9 in Appendix C.4 show acceleration versus time traces. Figure 5.6 summarizes pertinent information from the test.

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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 5.3. TxDOT Shallow Anchorage SSTR after Test No. 469680-02-1.

Figure 5.4. Test Vehicle after Test No. 469680-02-1.

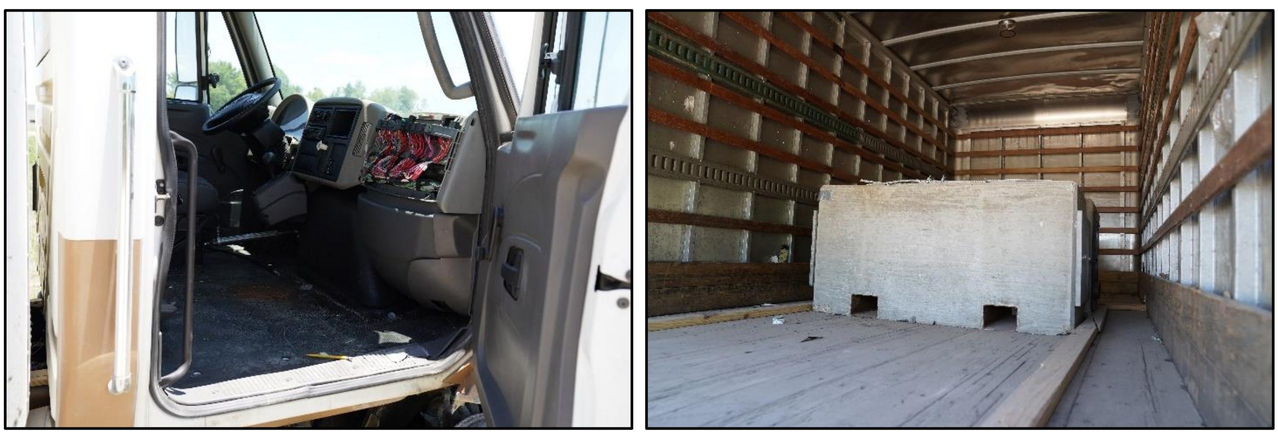
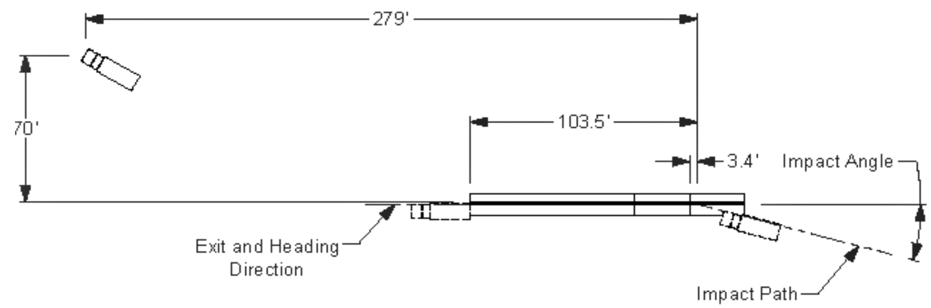
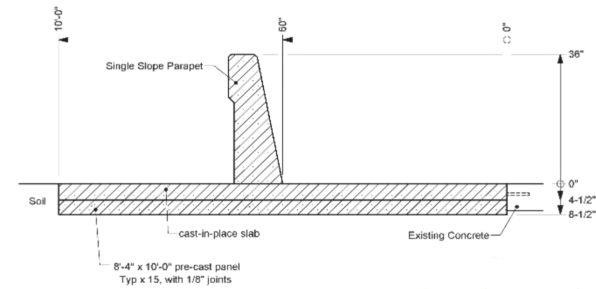


Figure 5.5. Interior of Test Vehicle after Test No. 469680-02-1.





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 4-12
TTI Test No.	469680-02-1
Test Date	2020-06-16
Test Article	
Type	Longitudinal Barrier—Bridge Rail
Name	TxDOT Shallow Anchorage SSTR
Installation Length	125 ft 1¾ inches
Material or Key Elements	36-inch-tall single sloped barrier anchored to a 4½-inch-thick concrete slab cast in place on top of precast panels measuring 8 ft 4 inches long x 10 ft wide x 4 inches thick
Soil Type and Condition	Concrete slab, damp
Test Vehicle	
Type/Designation	10000S
Make and Model	2011 International 4300 SUT
Curb	13,640 lb
Test Inertial	22,340 lb
Dummy	No dummy
Gross Static	22,340 lb

Impact Conditions	
Speed	56.9 mi/h
Angle	14.6°
Location/Orientation	3.4 ft upstream of joint 1–2
Impact Severity	153 kip-ft
Exit Conditions	
Speed	Out of view
Trajectory/Heading Angle	Along barrier
Occupant Risk Values	
Longitudinal OIV	6.2 ft/s
Lateral OIV	13.5 ft/s
Longitudinal Ridedown	4.3 g
Lateral Ridedown	6.9 g
THIV	4.5 m/s
ASI	0.6
Max. 0.050-s Average	
Longitudinal	−2.2 g
Lateral	−4.6 g
Vertical	−3.6 g

Post-Impact Trajectory	
Stopping Distance	279 ft downstream 70 ft twd field side
Vehicle Stability	
Maximum Yaw Angle	15°
Maximum Pitch Angle	27°
Maximum Roll Angle	12°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	None measurable
Permanent	None measurable
Working Width	78.4 inches
Height of Working Width	152.2 inches
Vehicle Damage	
VDS	NA
CDC	01FREW3
Max. Exterior Deformation	18.0 inches
OCDI	NA
Max. Occupant Compartment Deformation	2.5 inches

Note: OIV = Occupant Impact Velocity; THIV = Theoretical Head Impact Velocity; ASI = Acceleration Severity Index; NA = Not Applicable.

Figure 5.6. Summary of Results for *MASH* Test 4-12 on TxDOT Shallow Anchorage SSTR.

CHAPTER 6. *MASH* TEST 4-12 WITHOUT DOWEL BARS (CRASH TEST NO. 469680-02-2)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

In the original test installation, dowel bars were included between barrier segments across the expansion joints to provide load transfer and continuity between barrier segments and limit barrier movement and possible deck damage. Based on the results of the first test (i.e., no barrier movement and no deck damage or delamination), TxDOT requested an additional *MASH* Test 4-12 without the dowel bars. If successful, this configuration would reduce construction complexity of the barrier in the field.

For Test No. 469680-02-2, the dowel bars between barrier segments across the expansion joints were cut through such that the barrier segments were not connected. The CIP for *MASH* Test 4-12 on the TxDOT shallow anchorage SSTR without dowel bars was 5 ft ± 1 ft upstream of the centerline of the joint between Segments 2 and 3. This downstream joint was selected to avoid the need for barrier repair at the previously impacted joint.

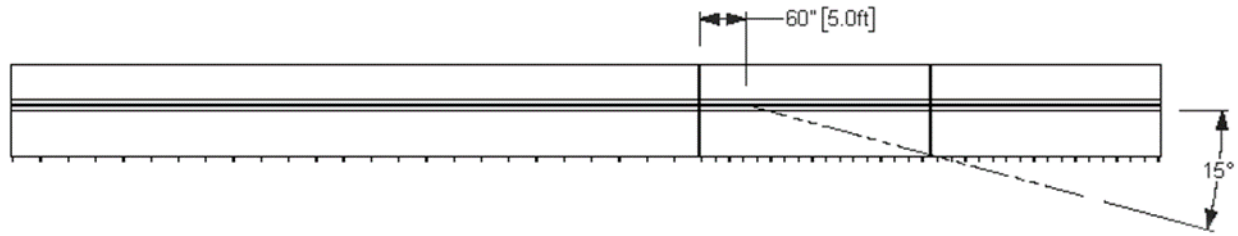


Figure 3.2 and Figure 6.1 depict the target impact setup. The remaining target impact conditions for *MASH* Test 4-12 are stated in Section 5.1.

Figure 6.1. TxDOT Shallow Anchorage SSTR without Dowel Bars/Test Vehicle Geometrics for Test No. 469680-02-2.

The 10000S vehicle weighed 22,190 lb, and the actual impact speed and angle were 56.7 mi/h and 14.2 degrees. The actual impact point was 4.5 ft upstream of the centerline of the joint between Segments 2 and 3. Minimum target IS was 142 kip-ft, and actual IS was 144 kip-ft.

6.2. WEATHER CONDITIONS

The test was performed on the morning of August 10, 2020. Weather conditions at the time of testing were as follows: wind speed: 9 mi/h; wind direction: 190 degrees (vehicle was traveling at a heading of 185 degrees); temperature: 89°F; relative humidity: 58 percent.

6.3. TEST VEHICLE

Figure 6.2 shows the 2011 International 4300 SUT used for the crash test. The vehicle's test inertia weight was 22,190 lb, and its gross static weight was 22,190 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 63.4 inches. Table D.1 in Appendix D.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. 469680-02-2.

6.4. TEST DESCRIPTION

Table 6.1 lists events that occurred during Test No. 469680-02-2. Figure D.1 in Appendix D.2 presents sequential photographs during the test.

Table 6.1. Events during Test No. 469680-02-2.

Time (s)	Events
0.0000	Vehicle bumper impacts barrier
0.0150	Right front tire leaves pavement
0.0360	Vehicle begins to redirect
0.1050	Left front tire leaves pavement
0.2450	Left rear tires leave pavement
0.2890	Vehicle travels parallel with barrier
0.8370	Left front tire returns to 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 not applied. After loss of contact with the barrier, the vehicle rolled 192 degrees and came to rest on its roof 229 ft downstream of the point of impact and 43 ft toward the field side of the barrier.

6.5. DAMAGE TO TEST INSTALLATION

Figure 6.3 and Figure 6.4 show the damage to the TxDOT shallow anchorage SSTR without dowel bars. No cracks were observed in the barrier or deck slab. No delaminations were detected at the interface between the two concrete slabs. Some gouging occurred on the traffic face of the barrier in the impact region, and contact and scuff marks were evident from the point of impact to the end of the barrier. Working width* was 60.6 inches, and height of working width was 150.9 inches. No dynamic deflection during the test nor permanent deformation after the test was observed.

6.6. DAMAGE TO TEST VEHICLE

Figure 6.5 and Figure 6.6 show the damage sustained by the vehicle. After loss of contact with the barrier, the vehicle rolled 192 degrees and came to rest on its roof. Before the vehicle rolled over, the front bumper, hood, front axle, right and left front spring assembly and U-bolts, right front tire and rim, right front door, right fuel tank and side steps, rear of cab, lower edge of the box, and right rear outer rim were damaged. Maximum exterior crush to the vehicle before rollover was 16.0 inches in the side plane at the right front corner at bumper height. Due to rollover, the occupant compartment deformation was unable to be measured.

6.7. VEHICLE INSTRUMENTATION

Data from the accelerometers were digitized for informational purposes only and are reported in Figure 6.2. Figure D.2 in Appendix D.3 shows the vehicle angular displacements, and Figures D.3 through D.8 in Appendix D.4 show acceleration versus time traces. Figure 6.7 summarizes pertinent information from the test.

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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 6.3. TxDOT Shallow Anchorage SSTR without Dowel Bars after Test No. 469680-02-2.

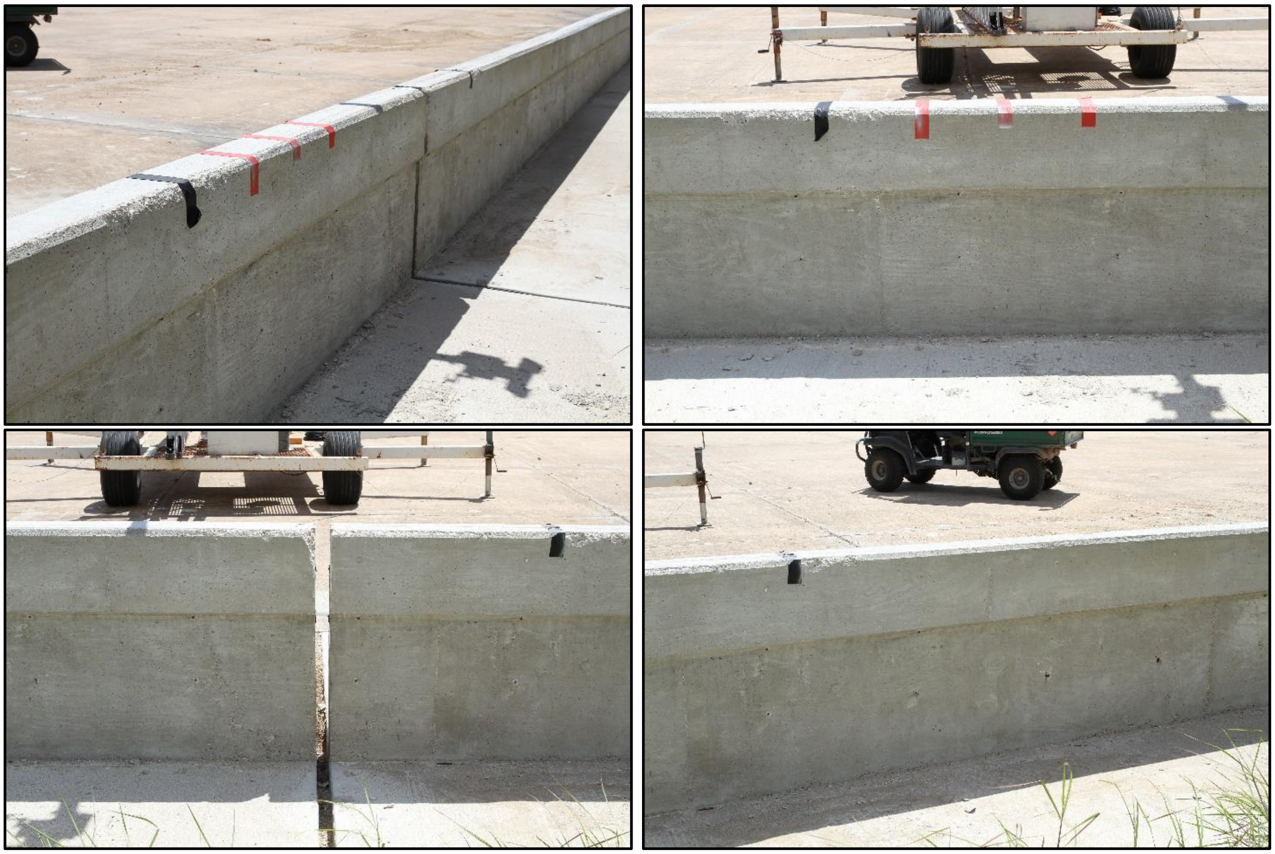
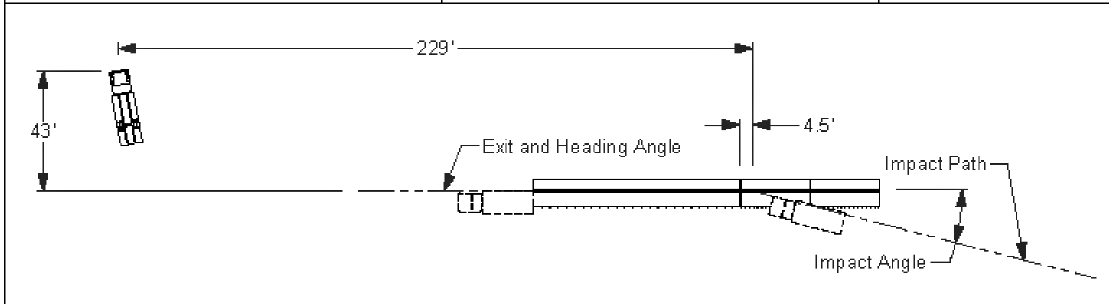


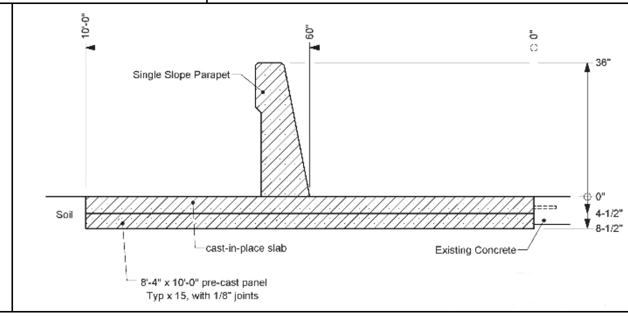
Figure 6.4. Field Side of SSTR without dowel bars after Test No. 469680-02-2.

Figure 6.5. Test Vehicle after Test No. 469680-02-2.

Figure 6.6. Test Vehicle (Uprighted) after Test No. 469680-02-2.

0.000 s | 0.200 s | 0.400 s | 0.700 s





General Information
- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: MASH Test 4-12
- TTI Test No.: 469680-02-2
- Test Date: 2020-08-10

Test Article
- Type: Longitudinal Barrier—Bridge Rail
- Name: TxDOT Shallow Anchorage SSTR
- Installation Length: 125 ft 1¾ inches
- Material or Key Elements: 36-inch-tall single sloped barrier anchored to a 4½-inch-thick concrete slab cast in place on top of precast panels measuring 8 ft 4 inches long x 10 ft wide x 4 inches thick

Soil Type and Condition: Concrete slab, damp

Test Vehicle
- Type/Designation: 10000S
- Make and Model: 2011 International 4300 SUT
- Curb: 13,020 lb
- Test Inertial: 22,190 lb
- Dummy: No dummy
- Gross Static: 22,190 lb

Impact Conditions
- Speed: 56.7 mi/h
- Angle: 14.2°
- Location/Orientation: 4.5 ft upstream of joint 2–3

Impact Severity: 144 kip-ft

Exit Conditions
- Speed: Out of view
- Trajectory/Heading Angle: Along barrier

Occupant Risk Values
- Longitudinal OIV: 5.6 ft/s
- Lateral OIV: 9.8 ft/s
- Longitudinal Ridedown: 2.9 g
- Lateral Ridedown: 10.5 g
- THIV: 3.4 m/s
- ASI: 0.5

Max. 0.050-s Average
- Longitudinal: −1.6 g
- Lateral: 3.9 g
- Vertical: 17.3 g

Post-Impact Trajectory
- Stopping Distance: 229 ft downstream 43 ft twd field side

Vehicle Stability
- Maximum Yaw Angle: 17°
- Maximum Pitch Angle: 35°
- Maximum Roll Angle: 192°
- Vehicle Snagging: No
- Vehicle Pocketing: No

Test Article Deflections
- Dynamic: None measurable
- Permanent: None measurable
- Working Width: 60.6 inches
- Height of Working Width: 150.9 inches

Vehicle Damage
- VDS: NA
- CDC: NA
- Max. Exterior Deformation: Vehicle rolled 192°
- OCDI: NA
- Max. Occupant Compartment Deformation: Vehicle rolled 192°

Figure 6.7. Summary of Results for *MASH* Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars.

CHAPTER 7. *MASH* TEST 4-12 WITHOUT DOWEL BARS AND WITH CONCRETE APRON EXTENDED DOWNSTREAM OF THE BARRIER (CRASH TEST NO. 469680-02-3)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

In the previous *MASH* Test 4-12 (469680-02-2), the vehicle rolled onto its roof, causing excessive occupant compartment deformation. Analysis indicated that soil in the runout area immediately downstream of the test installation contributed to the roll of the SUT after it exited the barrier system. The impact side tires and wheels furrowed into the soil, while the tires on the opposite side of the truck were on concrete pavement. *MASH* Section 3.2 states that "a flat surface, preferably paved, should be used when accelerating the test vehicle to the desired speed and to provide for unrestricted trajectory of the vehicle following impact. The surface should be free of curbs, swales, ditches, or other irregularities that could influence impact or post-impact behavior of the vehicle except when test conditions require such features."

Consequently, *MASH* Test 4-12 was repeated with a modification to the runout area. Figure 7.1 shows how the concrete apron was extended downstream of the test installation to replace the existing soil immediately beyond the end of the barrier. The extension of the concrete downstream of the barrier is considered more representative of the field applications for this system on high-speed bridge structures. The CIP for *MASH* Test 4-12 on the TxDOT shallow anchorage SSTR without dowel bars was 5 ft ± 1 ft upstream of the centerline of the joint between Segments 1 and 2. Damage to the barrier at this location from Test No. 469680-02-1 was repaired using a non-shrink grout. Figure 3.1 and Figure 7.2 depict the target impact setup. The remaining target impact conditions for *MASH* Test 4-12 are described in Section 5.1.

The 10000S vehicle weighed 22,500 lb, and the actual impact speed and angle were 57.4 mi/h and 14.7 degrees. The actual impact point was 5.0 ft upstream of the centerline of the joint between Segments 1 and 2. Minimum target IS was 142 kip-ft, and actual IS was 160 kip-ft.

Figure 7.1. Runout Area Extended for Test No. 469680-02-3.

Figure 7.2. TxDOT Shallow Anchorage SSTR without Dowel Bars and with Concrete Apron Extended Downstream of Barrier/Test Vehicle Geometrics for Test No. 469680-02-3.

7.2. WEATHER CONDITIONS

The test was performed on the afternoon of August 19, 2020. Weather conditions at the time of testing were as follows: wind speed: 8 mi/h; wind direction: 72 degrees (vehicle was traveling at a heading of 185 degrees); temperature: 96°F; relative humidity: 23 percent.

7.3. TEST VEHICLE

Figure 7.3 shows the 2009 International 4300 SUT used for the crash test. The vehicle's test inertia weight was 22,500 lb, and its gross static weight was 22,500 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 61.25 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 7.3. Test Vehicle before Test No. 469680-02-3.

7.4. TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 469680-02-3. Figures E.1 and E.2 in Appendix E.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 469680-02-3.

Time (s)	Events
0.000	Vehicle bumper impacts barrier
0.012	Right front tire leaves pavement
0.037	Vehicle begins to redirect
0.185	Left front tire leaves pavement
0.226	Left rear tires leave pavement
0.234	Lower right rear corner of box frame contacts barrier
0.294	Vehicle travels parallel with barrier
0.650	Left front tire returns to 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 2.75 s after impact. After loss of contact with the barrier, the vehicle came to rest 263 ft downstream of the point of impact and 99 ft toward the field side of the barrier.

7.5. DAMAGE TO TEST INSTALLATION

Figure 7.4 and Figure 7.5 show the damage to the TxDOT shallow anchorage SSTR without dowel bars. No cracks were observed in the barrier or deck slab. No delamination was detected at the interface between the two concrete slabs. There was some gouging on the face of the concrete barrier in the impact region and on Segment 2, with scuffing running along the length of the barrier. A section of rebar was exposed on the traffic side of Segment 1 at the joint between Segments 1 and 2. Working width* was 81.5 inches, and height of working width was 142.5 inches. No dynamic deflection during the test nor permanent deformation after the test was observed.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.6 and Figure 7.7 show the damage sustained by the vehicle. The front bumper, hood, right floor pan, front axle, U-bolts, spring assembly, right front tire and rim, right fuel tank and side steps, right front corner of the box, and right rear outer tire and rim were damaged due to contact with the barrier. After loss of contact with the barrier, the vehicle rolled onto its left side, which caused damage to the left front door, windshield, left side steps and battery box, and left air tanks. Maximum exterior crush to the vehicle was 16.0 inches in the side plane at the

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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.

right front corner at bumper height. Maximum occupant compartment deformation was 9.75 inches in the right floor pan area at the seam with the right door. Figure 7.8 shows the interior of the vehicle after the test.

Figure 7.4. TxDOT Shallow Anchorage SSTR without Dowel Bars and with Concrete Apron Extended Downstream of Barrier after Test No. 469680-02-3.

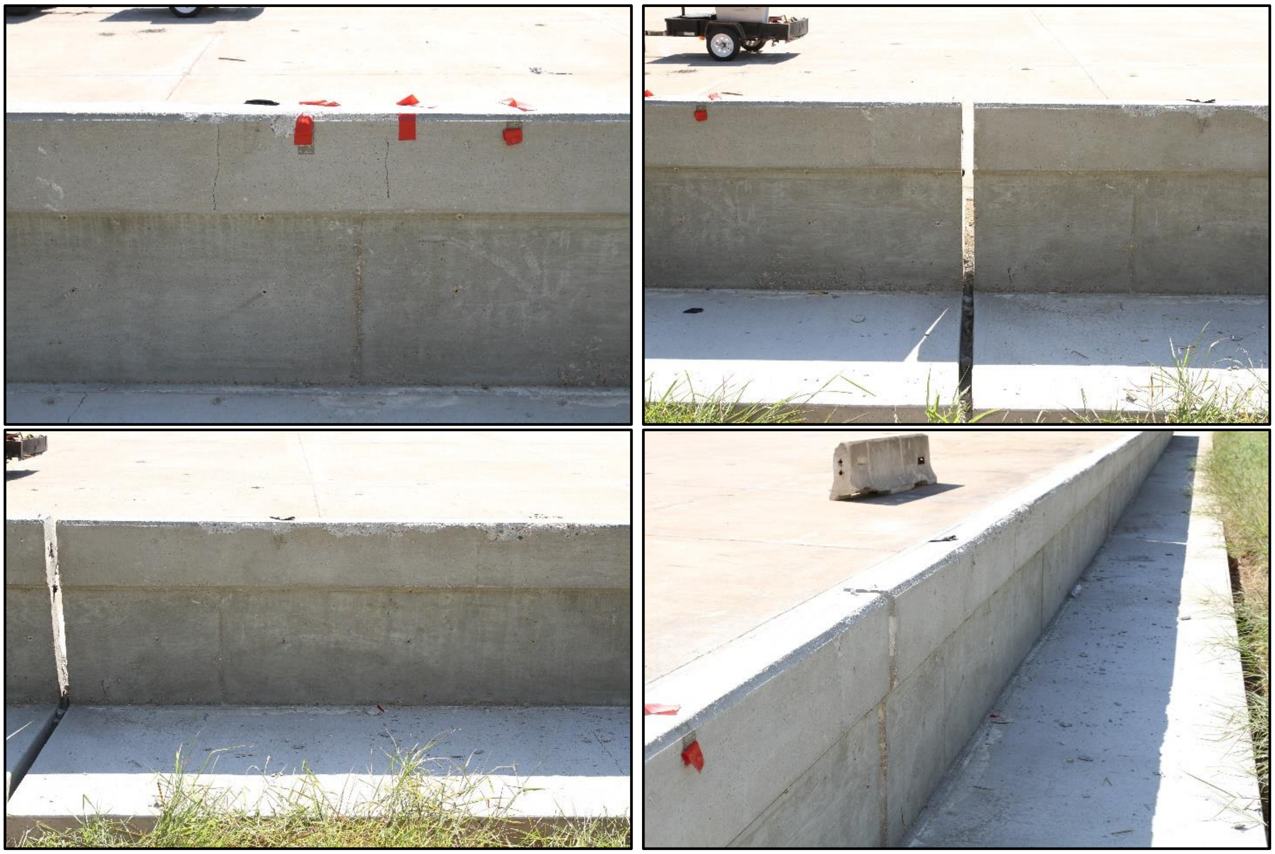


Figure 7.5. Field Side of SSTR without Dowel Bars and with Concrete Apron Extended Downstream of Barrier after Test No. 469680-02-3.

Figure 7.6. Test Vehicle after Test No. 469680-02-3.

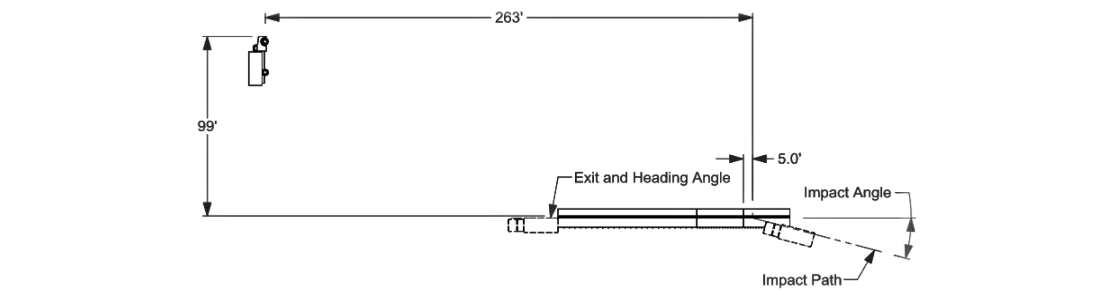
Figure 7.7. Test Vehicle (Uprighted) after Test No. 469680-02-3.

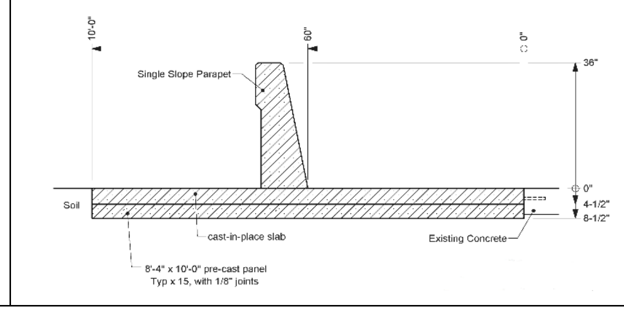
Figure 7.8. Interior of Test Vehicle after Test No. 469680-02-3.

7.7. VEHICLE INSTRUMENTATION

Data from the accelerometers were digitized for informational purposes only and are reported in Figure 7.9. Figure E.3 in Appendix E.3 shows the vehicle angular displacements, and Figures E.4 through E.9 in Appendix E.4 show acceleration versus time traces. Figure 7.9 summarizes pertinent information from the test.

0.000 s	0.200 s	0.400 s	0.700 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 4-12
TTI Test No.	469680-02-3
Test Date	2020-08-19
Test Article	
Type	Longitudinal Barrier—Bridge Rail
Name	TxDOT Shallow Anchorage SSTR
Installation Length	125 ft 1¾ inches
Material or Key Elements	36-inch-tall single sloped barrier anchored to a 4½-inch-thick concrete slab cast in place on top of precast panels measuring 8 ft 4 inches long x 10 ft wide x 4 inches thick
Soil Type and Condition	Concrete slab, damp
Test Vehicle	
Type/Designation	10000S
Make and Model	2009 International 4300 SUT
Curb	13,770
Test Inertial	22,500 lb
Dummy	No dummy
Gross Static	22,500 lb

Impact Conditions	
Speed	57.4 mi/h
Angle	14.7°
Location/Orientation	5 ft upstream of joint 1–2
Impact Severity	160 kip-ft
Exit Conditions	
Speed	Out of view
Trajectory/Heading Angle	Along barrier
Occupant Risk Values	
Longitudinal OIV	6.2 ft/s
Lateral OIV	11.2 ft/s
Longitudinal Ridedown	3.3 g
Lateral Ridedown	4.9 g
THIV	4.0 m/s
ASI	0.4
Max. 0.050-s Average	
Longitudinal	−1.6 g
Lateral	−2.9 g
Vertical	−3.2 g

Post-Impact Trajectory	
Stopping Distance	263 ft downstream 99 ft twd field side
Vehicle Stability	
Maximum Yaw Angle	38°
Maximum Pitch Angle	16°
Maximum Roll Angle	44°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	None measurable
Permanent	None measurable
Working Width	81.5 inches
Height of Working Width	142.5 inches
Vehicle Damage	
VDS	NA
CDC	01FREW3
Max. Exterior Deformation	16.0 inches
OCDI	NA
Max. Occupant Compartment Deformation	9.75 inches

Figure 7.9. Summary of Results for *MASH* Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars and with Concrete Apron Extended Downstream of the Barrier.

CHAPTER 8. SUMMARY AND CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* Test 4-12 on the TxDOT shallow anchorage SSTR. During the first test (469680-02-1), the impact point was out of the ± 1 ft specification per *MASH*, but the outcome of the test was considered valid since the vehicle impacted the barrier at a location more critical for evaluation of both the barrier and anchorage system. Table 8.1 provides an assessment of this test based on the applicable safety evaluation criteria for *MASH* Test 4-12 for longitudinal barriers.

For both the second and third tests (469680-02-2 and 3), the dowel bars between barrier segments across the expansion joints were cut through such that the barrier segments were not connected. In the second test (469680-02-2), the vehicle rolled over onto its roof. Table 8.2 provides an assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 4-12 for longitudinal barriers. The third test was a repeat of the second test. It was determined that soil in the runout area at the end of the test installation contributed to the rollover of the truck in the second test. Therefore, prior to the third test (469680-02-3), the concrete apron was extended downstream of the barrier to replace the soil immediately beyond the end of the barrier to provide a runout area that was more uniform and consistent with anticipated field implementation. Table 8.3 provides an assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 4-12 for longitudinal barriers.

8.2. CONCLUSIONS

Table 8.1 and Table 8.3 show that the TxDOT shallow anchorage SSTR (with and without dowel bars between barrier segments across expansion joints) meets the performance criteria for *MASH* Test 4-12 for longitudinal barriers.

Table 8.1. Performance Evaluation Summary for *MASH* Test 4-12 on TxDOT Shallow Anchorage SSTR.

Test Agency: Texas A&M Transportation Institute | Test No.: 469680-02-1 | Test Date: 2020-06-16

***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 TxDOT shallow anchorage SSTR contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. No measurable dynamic deflection or permanent deformation 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 from the test article were present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 2.5 inches in the right front floor pan/firewall area.	
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 12° and 27°.	Pass

Table 8.2. Performance Evaluation Summary for *MASH* Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars.

Test Agency: Texas A&M Transportation Institute　　Test No.: 469680-02-2　　Test Date: 2020-08-10

***MASH* Test 4-12 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 TxDOT shallow anchorage SSTR without dowel bars contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. No measurable dynamic deflection or permanent deformation 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 from the test article were present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Fail
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Rolled over onto roof.	
G. *It is preferable, although not essential, that the vehicle remain upright during and after collision.*	The 10000S vehicle rolled 192° and came to rest on its roof. *MASH* Section A2.2.1 permits only a ¼ roll of the vehicle.	Fail

Table 8.3. Performance Evaluation Summary for *MASH* Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars and with Concrete Apron Extended Downstream of the Barrier.

Test Agency: Texas A&M Transportation Institute | Test No.: 469680-02-3 | Test Date: 2020-08-19

***MASH* Test 4-12 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 TxDOT shallow anchorage SSTR without dowel bars contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. No measurable dynamic deflection or permanent deformation 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 from the test article were present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 9.75 inches in the right floor pan at a seam location with the door.	
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The 10000S vehicle rolled counterclockwise and came to rest on its left side.	Pass

CHAPTER 9. IMPLEMENTATION*

The TxDOT shallow anchorage SSTR attached to a 4.5-inch-thick cast-in-place deck performed acceptably for *MASH* Test 4-12 both with and without No. 8 rebar dowels between adjacent barrier segments across expansion joints. There was no structural damage to the deck, and only minor damage to the SSTR.

MASH Test 4-10 with the 1100C passenger car and Test 4-11 with the 2270P pickup truck were considered unnecessary. When impacted by the SUT, the shallow anchorage SSTR had no dynamic or permanent movement and behaved as a rigid barrier. The SSTR has previously been successfully crash tested with the passenger vehicles, demonstrating the impact performance of the single slope profile (*3*, *4*). Thus, the TxDOT shallow anchorage SSTR attached to a 4.5-inch-thick cast-in-place deck is considered *MASH* compliant.

The shallow anchorage applications of interest to TxDOT include anchorage over a prestressed concrete panel inset from the deck edge, and on the edge of a deck over a prestressed box or slab beam. The application over a panel would have a minimum cast-in-place deck thickness of 4.5 inches, and the deck over a box or slab beam would have a thickness of at least 5 inches. The shallow anchorage over a panel was considered to be the critical case for evaluation due to the shallower anchor embedment and opportunity for concrete fracture or delamination around or beneath the anchor bars. Based on the successful *MASH* testing of this application, the less critical application of a shallow anchorage SSTR attached to the edge of a 5-inch-thick deck cast in place over a prestressed box beam or slab beam is also considered *MASH* compliant and suitable for implementation.

The 25-ft barrier segments evaluated in the tests represent a minimum segment length for field implementation. Implementation can be accomplished through revision of bridge rail standard detail sheets.

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

REFERENCES

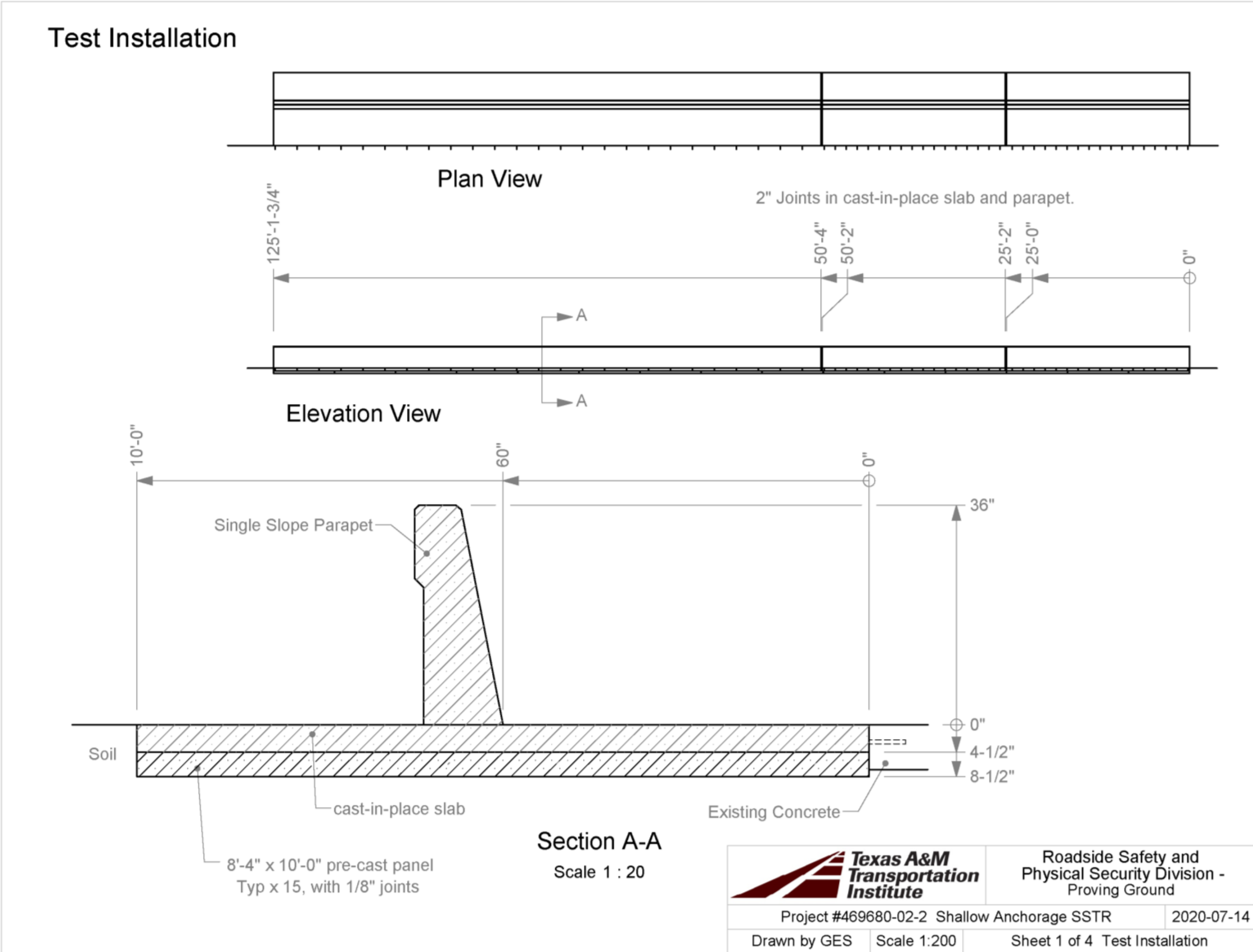
1. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition.* American Association of State Highway and Transportation Officials, Washington, DC, 2016.

2. Nauman M. Sheikh, Roger P. Bligh, and Wanda L. Menges. *Determination of Minimum Height and Lateral Design Load for MASH Test Level 4 Bridge Rails*. Report No. 9-1002-5, Texas A&M Transportation Institute, College Station, TX, December 2011.

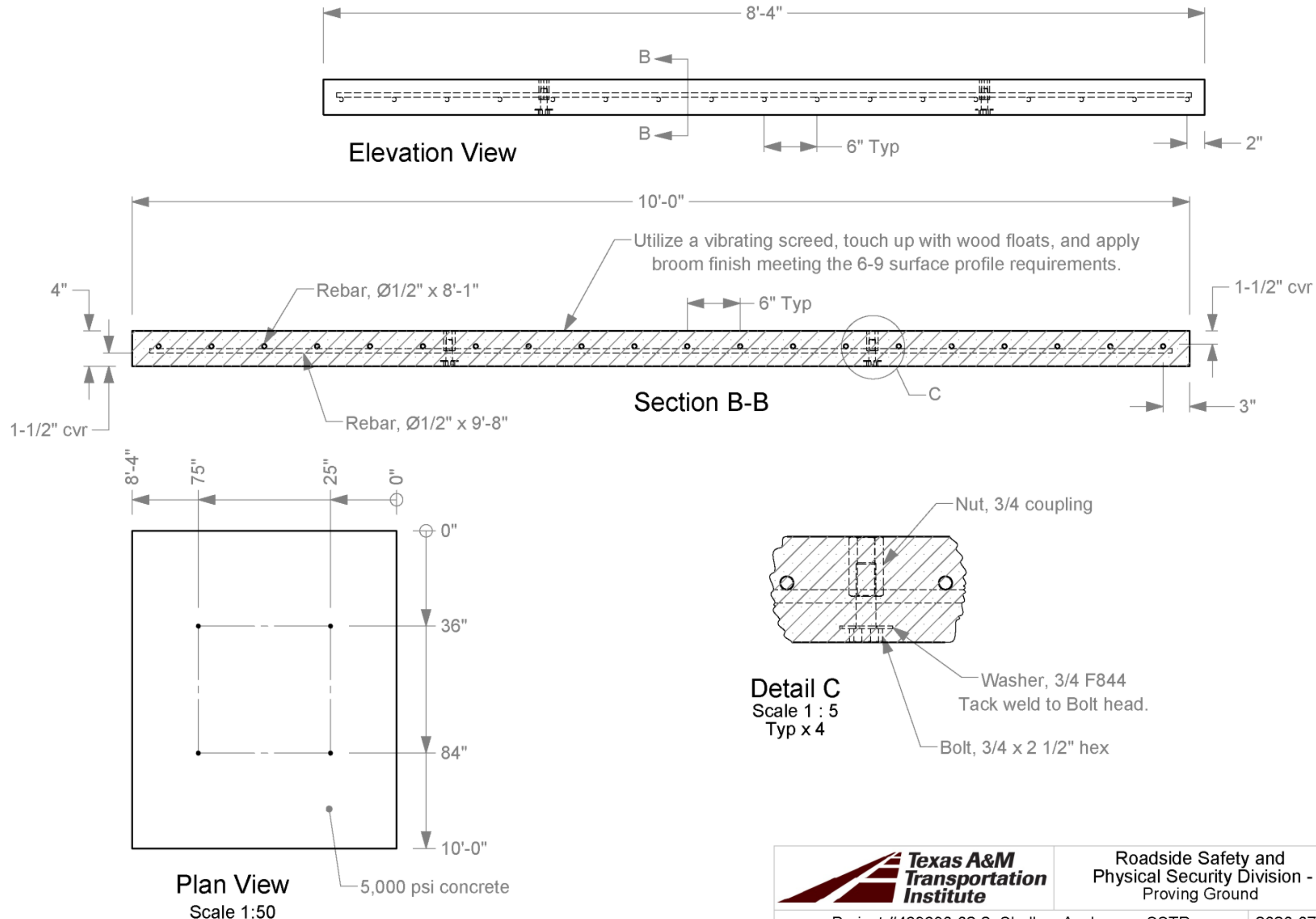
3. William F. Williams, Roger P. Bligh, and Wanda L. Menges. *MASH Test 3-11 of the TxDOT Single Slope Bridge Rail (Type SSTR) on Pan-Formed Bridge Deck*. Report No. 9-1002-3, Texas A&M Transportation Institute, College Station, TX, March 2011.

4. Akram Y. Abu-Odeh, D. Lance Bullard, Jr., P.E., Wanda L. Menges, Glenn E. Schroeder, and Darrell L. Kuhn, P.E. *MASH TL-5 Evaluation of 6-ft Tall Illinois Tollway Constant Slope Barrier on Cantilevered Bridge Deck with Noise Abatement Panels.* Report No. 690900-ITG4-6, Texas A&M Transportation Institute, College Station, TX, December 2019.

APPENDIX A. DETAILS OF SHALLOW ANCHORAGE SSTR



Panel Details



Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project #469680-02-2 Shallow Anchorage SSTR	2020-07-14

Drawn by GES	Scale 1:15	Sheet 2 of 4 Panel Details

Q:\Accreditation-17025-2017\EIR-000 Project Files\469680 - TxDOT - Bligh\-2 Shallow Anchorage SSTR\02-2 (Additional 4-12 Test)\Drafting, 02-2\469680-02-2 Draw

Deck and Parapet

Pre-cast Panels not shown for clarity

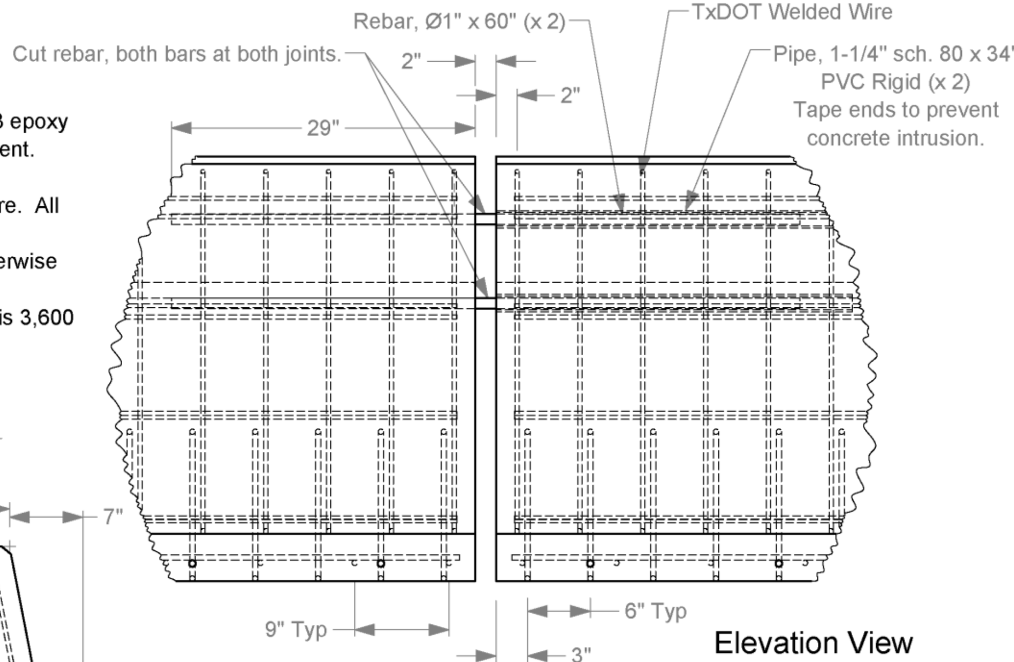
3a. Secure in existing concrete with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 6" embedment. Space @ 18" in 25' sections and @ 36" in long section.

3b. Minimum rebar lap is 19" for #4 bars and welded wire. All rebar is grade 60.

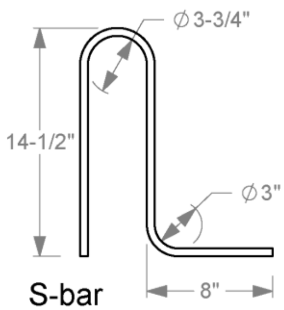
3c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).

3d. Cast-in-place Deck is 4,000 psi Concrete. Parapet is 3,600 psi Concrete.

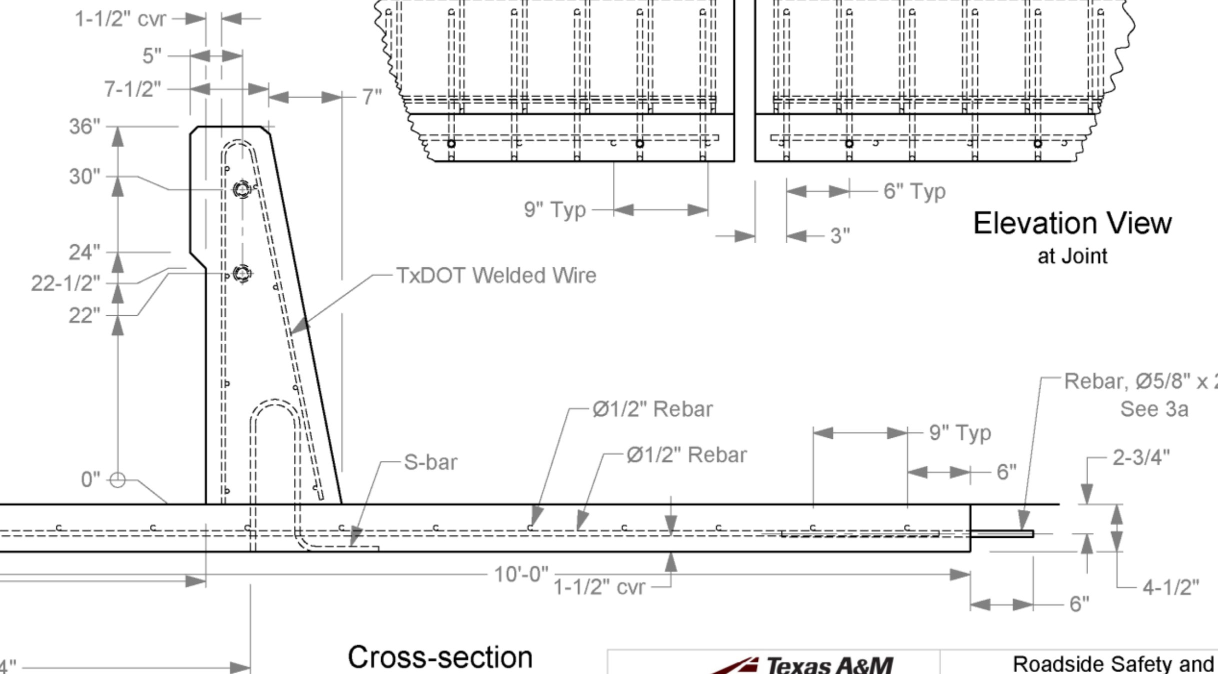
3e. Chamfer top edges of Parapet 1" (3/4" each way).



Elevation View
at Joint



S-bar
Ø1/2" Rebar
Scale 1:10



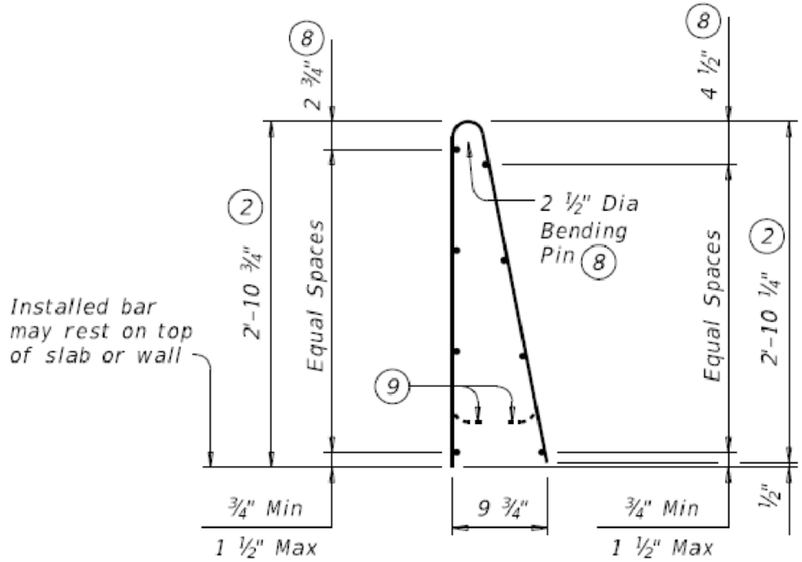
Cross-section

3f. Thoroughly wet all precast concrete panels before placing concrete on them. Remove free water from the surface before placing concrete. Provide surfaces that are in a moist, saturated surface-dry condition when placing concrete.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469680-02-2 Shallow Anchorage SSTR		2020-07-14
Drawn by GES	Scale 1:15	Sheet 3 of 4 Deck and Parapet

Q:\Accreditation-17025-2017\EIR-000 Project Files\469680 - TxDOT - Bligh\-2 Shallow Anchorage SSTR\02-2 (Additional 4-12 Test)\Drafting, 02-2\469680-02-2 Draw

Welded Wire



OPTIONAL WELDED WIRE
REINFORCEMENT (WWR)

DESCRIPTION	LONGITUDINAL WIRES	VERTICAL WIRES
Minimum (Cumulative Total) Wire Area	1.067 Sq In.	0.267 Sq In. per Ft
	No. of Wires	Spacing
Minimum	8	4"
Maximum	10	8"
Maximum Wire Size Differential	The smaller wire must have an area of 40% or more of the larger wire.	

4a. This excerpt from the TxDOT Type SSTR Drawing (rlstd014) shows the allowable options for the welded wire. The contractor shall supply the fabrication drawing and material specifications for the welded wire used for the installation.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469680-02-2 Shallow Anchorage SSTR		2020-07-14
Drawn by GES	Scale 1:200	Sheet 4 of 4 Welded Wire

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

Texas A&M Transportation Institute Proving Ground 3100 SH 47, Bldg 7091 Bryan, TX 77807 Texas A&M University College Station, TX 77843 Phone 979-845-6375	**QF 7.3-01 Concrete Sampling**	Doc. No. *QF 7.3-01*	Issue Date: 2018-06-18
Quality Form	Prepared by: Wanda L. Menges Approved by: Darrell L. Kuhn	Revision: 6	Page: 1 of 1

The information contained in this document is confidential to TTI Proving Ground.

Project No: 469680-2 **Casting Date:** 5/4/2020 **Mix Design (psi):** 4000 psi

Name of Technician Taking Sample: Teracon

Name of Technician Breaking Sample: Teracon

Signature of Technician Taking Sample: Teracon

Signature of Technician Breaking Sample: Teracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	Tucker	449	First 10 Blocks starting from the south
T2	Tucker	858	Last 5 blocks in the north

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
See attached Reports from Terracon					

TUCKER_concrete
9797776749
1904
TUCKER_CONST
TTI_LOWER_ANCHORAGE

TICKET # 858

START DATE: 2020-05-04 TIME: 10:37:31
STOP DATE: 2020-05-04 TIME: 11:07:14

MIX DESIGN: B1500

RAW CEMENT COUNTS: 3943
RAW CONVEYOR COUNTS: 134158
CONVEYOR SPEED: 45
TOTAL YARDS 5.5

MATERIAL	RATE SETTING	TOTAL
CEMENT	8.45924LBS/	3251.792
SAND	4.37853 GAT	7030.18L
ADJUSTED:		
STONE	5.701853 GA	9709.104
ADJUSTED:		
WATER	21.48222GAL	138.1016
ADMIX #1	0.0OZ/MIN	0.0OZ
ADMIX #2	124.60419OZ	805.0812
ADMIX #3	0.0OZ/MIN	0.0OZ

ASTM DATA AVAILABLE UPON REQ

Name________________________
NOTES:

TUCKER CONCRETE
8930 LACY WELL RD CS
979-777-6749 VM1802

Job # TUCKER
TTI ANCHRIDGE
TICKET # 449
START DATE: 05/04/2020 TIME: 08:49:4
STOP DATE: 05/04/2020 TIME: 09:37:2

MIX DESIGN B1500
RAW CEMENT COUNTS____________ 8076
RAW CONVEYOR COUNTS__________ 5998

TOTAL YARDS 10.50

MATERIAL	RATE SETTING	TOTAL
CAPTYPE1	__ 487.4LBPM__	6415.4LBS
LRMSAND	__ 5.2 GATE_	13851.2LBS
RGBLEND	__ 5.9 GATE_	19129.3LBS
WATER	__ 25.5GPM__	0.0GAL
SIKA686	__ 1.0GPM__	12.6GAL

MAX GPM 23.4 MAX GPY 22.53

NAME________________________
NOTES:

1/19680-2

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0114
Service Date: 05/04/20
Report Date: 05/04/20
Task: PO #469680-02

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: 5,000 psi @ 28 days

Mix ID: B1500
Supplier: Tucker
Batch Time: 0949 **Plant:**
Truck No.: **Ticket No.:** 449

Sample Information

Sample Date: 05/04/20 **Sample Time:** 1007
Sampled By: Cullen Turney
Weather Conditions: Cloudy, light wind
Accumulative Yards: 10.5/16 **Batch Size (cy):** 10.5
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: 3rd Panel
Placement Location: Panels

Field Test Data

Test	Result	Specification
Slump (in):	4	Not Specified
Air Content (%):	2.4	Not Specified
Concrete Temp. (F):	76	40 - 95
Ambient Temp. (F):	79	40 - 95
Plastic Unit Wt. (pcf):	146.0	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	6.00	28.27	05/05/20	06/15/20	42 F	136,970	4,840	1	SLS
1	B	6.00	28.27	05/05/20	06/15/20	42 F	141,110	4,990	2	SLS
1	C	6.00	28.27	05/05/20	06/15/20	42 F	149,090	5,270	1	SLS
1	D			05/05/20		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.: Cullen Turney **Start/Stop:** 0930-1200
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

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

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0114
Service Date: 05/04/20
Report Date: 05/04/20
Task: PO #469680-02

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: 5,000 psi @ 28 days

Mix ID: B1500
Supplier: Tucker
Batch Time: 1037 **Plant:**
Truck No.: **Ticket No.:** 858

Field Test Data

Test	Result	Specification
Slump (in):	4 3/4	Not Specified
Air Content (%):	2.1	Not Specified
Concrete Temp. (F):	83	40 - 95
Ambient Temp. (F):	81	40 - 95
Plastic Unit Wt. (pcf):	146.8	Not Specified
Yield (Cu. Yds.):		

Sample Information

Sample Date: 05/04/20 **Sample Time:** 1045
Sampled By: Cullen Turney
Weather Conditions: Cloudy, light wind
Accumulative Yards: 16/16 **Batch Size (cy):** 5.5
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: 12th Panel
Placement Location: Panels

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
2	A	6.00	28.27	05/05/20	06/15/20	42 F	160,640	5,680	1	SLS
2	B	6.00	28.27	05/05/20	06/15/20	42 F	161,570	5,710	1	SLS
2	C	6.00	28.27	05/05/20	06/15/20	42 F	160,280	5,670	2	SLS
2	D			05/05/20		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.: Cullen Turney **Start/Stop:** 0930-1200
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 2 of 2

CR0001, 11-16-12, Rev.6

Texas A&M Transportation Institute Proving Ground 3100 SH 47, Bldg 7091 Bryan, TX 77807 Texas A&M University College Station, TX 77843 Phone 979-845-6375	**QF 7.3-01 Concrete Sampling**	Doc. No. *QF 7.3-01*	Issue Date: 2018-06-18
Quality Form	Prepared by: Wanda L. Menges Approved by: Darrell L. Kuhn	Revision: 6	Page: 1 of 1

The information contained in this document is confidential to TTI Proving Ground.

Project No: 469680-2 **Casting Date:** 5/13/2020 **Mix Design (psi):** 4000 psi

Name of Technician Taking Sample: Teracon

Name of Technician Breaking Sample: Teracon

Signature of Technician Taking Sample: Teracon

Signature of Technician Breaking Sample: Teracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	Tucker	1407	30' of northern portion of deck
T2	Tucker	102	Remaining deck up to 6 feet in the south
T3	Tucker	481	Remaining 6 foot section of deck in the south

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
See attached Reports from Terracon					

TUCKER Concrete
8930 LACY WELL RD
77845 979 777 6749

Job # TUCKER CONSTRUCTION
TTI

2

TICKET # 102
START DATE: 05/13/2020 TIME: 11:15:05
STOP DATE: 05/13/2020 TIME: 12:17:23

MIX DESIGN B1400
RAW CEMENT COUNTS 14704
RAW CONVEYOR COUNTS 5480

TOTAL YARDS 10.64

MATERIAL	RATE SETTING	TOTAL
CAPTYPE1	448.3LBPM	5500.8LBS
LRMSAND	5.6 GATE	14511.9LBS
RGBLND	6.8 GATE	20041.8LBS
WATER	26.9GPM	275.0GAL
SIKA686	0.9GPM	10.6GAL

WATER / CEMENT RATIO 0.42
REQUEST ASTM INFORMATION

NAME
NOTES:

CONTINUED FROM 101

465680-2

TUCKER concrete
8930 LACY WELL RD, 77845
979 777 6749 VM1803

1

Job # TUCKER CONST
SHALLOW ABCHORAG
TICKET # 1407
START DATE: 05/13/2020 TIME: 11:00:06
STOP DATE: 05/13/2020 TIME: 11:30:45

MIX DESIGN B1400
RAW CEMENT COUNTS 5223
RAW CONVEYOR COUNTS 3320

TOTAL YARDS 7.96

MATERIAL	RATE SETTING	TOTAL
CAPTYPE1	474.7LBPM	4116.2LBS
LRMSAND	5.5 GATE	9206.9LBS
RGBLEND	7.1 GATE	12715.2LBS
WATER	28.5gpm	184.7gal
SIKA686	0.9GPM	8.0GAL

MAX GPY 22.53 MAX GPM 22.7

NAME
NOTES:

CONTINUED FROM 1406

465680-2

TUCKER CONCRETE
8930 LACY WELL RD CS
979-777-6749 VM1802

3

Job # TUCKER
TTI
TICKET # 481
START DATE: 05/13/2020 TIME: 11:16:35
STOP DATE: 05/13/2020 TIME: 11:35:24

MIX DESIGN B1400
RAW CEMENT COUNTS 984
RAW CONVEYOR COUNTS 732

TOTAL YARDS 1.51

MATERIAL	RATE SETTING	TOTAL
CAPTYPE1	487.4LBPM	781.7LBS
LRMSAND	6.0 GATE	2061.3LBS
RGBLEND	7.1 GATE	2846.8LBS
SIKA686	1.1GPM	1.8GAL

MAX GPM 23.4 MAX GPY 22.53

NAME
NOTES:

469688-2

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0115
Service Date: 05/13/20
Report Date: 05/14/20
Task: PO #469680-02

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: 3,000 psi @ 28 days

Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1100 **Plant:**
Truck No.: **Ticket No.:** 1406

Sample Information

Sample Date: 05/13/20 **Sample Time:** 1100
Sampled By: Mohammed Mobeen
Weather Conditions: Partly cloudy, light wind
Accumulative Yards: 7.96/20 **Batch Size (cy):** 7.96
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: Northside
Placement Location: Colorado deck

Field Test Data

Test	Result	Specification
Slump (in):	7 1/2	Not Specified
Air Content (%):	1.4	Not Specified
Concrete Temp. (F):	86	40 - 95
Ambient Temp. (F):	75	40 - 95
Plastic Unit Wt. (pcf):		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	6.00	28.27	05/14/20	06/15/20	33 F	149,520	5,290	2	SLS
1	B	6.00	28.27	05/14/20	06/15/20	33 F	144,480	5,110	1	SLS
1	C	6.00	28.27	05/14/20	06/15/20	33 F	146,360	5,180	1	SLS
1	D			05/14/20		Hold				

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

Comments: Not tested for plastic unit weight. 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:** 0930-1400
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

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.

CR0001, 11-16-12, Rev 6 Page 1 of 3

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0115
Service Date: 05/13/20
Report Date: 05/14/20
Task: PO #469680-02

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: 3,000 psi @ 28 days

Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1115 **Plant:**
Truck No.: **Ticket No.:** 102

Sample Information

Sample Date: 05/13/20 **Sample Time:** 1230
Sampled By: Mohammed Mobeen
Weather Conditions: Partly cloudy
Accumulative Yards: 10.64/20 **Batch Size (cy):** 10.64
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: South side
Placement Location: Colorado deck

Field Test Data

Test	Result	Specification
Slump (in):	7	Not Specified
Air Content (%):	1.4	Not Specified
Concrete Temp. (F):	86	40 - 95
Ambient Temp. (F):	75	40 - 95
Plastic Unit Wt. (pcf):		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
2	A	6.00	28.27	05/14/20	06/15/20	33 F	148,500	5,250	2	SLS
2	B	6.00	28.27	05/14/20	06/15/20	33 F	141,290	5,000	2	SLS
2	C	6.00	28.27	05/14/20	06/15/20	33 F	148,510	5,250	2	SLS
2	D			05/14/20		Hold				

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

Comments: Not tested for plastic unit weight. 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:** 0930-1400
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

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.

CR0001, 11-16-12, Rev 6 Page 2 of 3

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0115
Service Date: 05/13/20
Report Date: 05/14/20
Task: PO #469680-02

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: 3,000 psi @ 28 days

Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1217 **Plant:**
Truck No.: **Ticket No.:** 481

Sample Information

Sample Date: 05/13/20 **Sample Time:** 1300
Sampled By: Mohammed Mobeen
Weather Conditions: Partly cloudy, light wind
Accumulative Yards: 1.51/20 **Batch Size (cy):** 1.51
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: South side
Placement Location: Colorado deck

Field Test Data

Test	Result	Specification
Slump (in):	7 1/2	Not Specified
Air Content (%):	1.5	Not Specified
Concrete Temp. (F):	88	40 - 95
Ambient Temp. (F):	76	40 - 95
Plastic Unit Wt. (pcf):		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
3	A	4.00	12.57	05/14/20	06/15/20	33 F	62,640	4,980	1	SLS
3	B	4.00	12.57	05/14/20	06/15/20	33 F	57,350	4,560	1	SLS
3	C	4.00	12.57	05/14/20	06/15/20	33 F	68,780	5,470	1	SLS
3	D	4.00	12.57	05/14/20	06/15/20	33 F				
3	E			05/14/20		Hold				

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

Comments: Not tested for plastic unit weight. 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:** 0930-1400
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.

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Texas A&M Transportation Institute Proving Ground, 3100 SH 47, Bldg 7091, Bryan, TX 77807 Texas A&M University, College Station, TX 77843, Phone 979-845-6375	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Issue Date: 2018-06-18
Quality Form	Prepared by: Wanda L. Menges Approved by: Darrell L. Kuhn	Revision: 6	Page: 1 of 1

The information contained in this document is confidential to TTI Proving Ground.

Project No: 469680-2 **Casting Date:** 5/21/2020 **Mix Design (psi):** 3600 psi

Name of Technician Taking Sample: Teracon
Name of Technician Breaking Sample: Teracon

Signature of Technician Taking Sample: Teracon
Signature of Technician Breaking Sample: Teracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	Tucker	134	North 3/4 of barrier
T2	Tucker	914	south 1/4 of barrier

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
See attached Reports from Terracon					

TUCKER Concrete
8930 LACY WELL RD
77845 979 777 6749

Job # TUCKER COSTRUCTION
TTI

TICKET # 134

START DATE: 05/21/2020 TIME: 14:10:04
STOP DATE: 05/21/2020 TIME: 14:52:22

MIX DESIGN B1400

RAW CEMENT COUNTS_____________ 13060
RAW CONVEYOR COUNTS__________ 4863

TOTAL YARDS 9.45

MATERIAL	RATE SETTING	TOTAL
CAPTYPE1	__ 448.3LBPM__	4885.8LBS
LRMSAND	__ 5.6 GATE_	12878.0LBS
RGBLND	__ 6.8 GATE_	17785.2LBS
WATER	__ 26.9GPM __	258.7GAL
SIKA686	__ 0.9GPM__	9.5GAL

WATER / CEMENT RATIO _ 0.44
REQUEST ASTM INFORMATION

NAME_______________________________________
NOTES:

TUCKER_concrete
9797776749
1904
TUCKER_CONST
TTI

TICKET # 914

START DATE: 2020-05-21 TIME: 14:43:35
STOP DATE: 2020-05-21 TIME: 15:05:58

MIX DESIGN: B1400

RAW CEMENT COUNTS: 1635
RAW CONVEYOR COUNTS: 55574
CONVEYOR SPEED: 45
TOTAL YARDS 2.75

MATERIAL	RATE SETTING	TOTAL
CEMENT	8.45924LBS/	1348.384
SAND	5.248304 GA	3551.202
ADJUSTED:		
STONE	6.848384 GA	4904.412
ADJUSTED:		
WATER	24.03363GAL	70.21GAL
ADMIX #1	0.0OZ/MIN	0.0OZ
ADMIX #2	127.62489OZ	339.0704
ADMIX #3	0.0OZ/MIN	0.0OZ

ASTM DATA AVAILABLE UPON REQ

Name_______________________________________
NOTES:

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0117
Service Date: 05/21/20
Report Date: 05/21/20
Task: PO #469680-02

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: 3,000 psi @

Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1410 **Plant:**
Truck No.: **Ticket No.:** 134

Sample Information

Sample Date: 05/21/20 **Sample Time:** 1415
Sampled By: Justin Maass
Weather Conditions: Cloudy, light wind
Accumulative Yards: 10/12 **Batch Size (cy):** 2
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: Southeast end
Placement Location: PO #469680-02

Field Test Data

Test	Result	Specification
Slump (in):	8 1/2	Not Specified
Air Content (%):	1.9	Not Specified
Concrete Temp. (F):	90	40 - 95
Ambient Temp. (F):	86	40 - 95
Plastic Unit Wt. (pcf):	146.4	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	6.00	28.27	05/22/20	06/15/20	25 F	121,650	4,300	1	SLS
1	B	6.00	28.27	05/22/20	06/15/20	25 F	125,180	4,430	1	SLS
1	C	6.00	28.27	05/22/20	06/15/20	25 F	119,860	4,240	1	SLS
1	D			05/22/20		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.: Justin Maass **Start/Stop:** 1315-1530
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

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.

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0117
Service Date: 05/21/20
Report Date: 05/21/20
Task: PO #469680-02

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: 3,000 psi @

Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1443 **Plant:**
Truck No.: **Ticket No.:** 914

Sample Information

Sample Date: 05/21/20 **Sample Time:** 1445
Sampled By: Justin Maass
Weather Conditions: Cloudy, light wind
Accumulative Yards: 12/12 **Batch Size (cy):** 10
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: Southeast end
Placement Location: PO #469680-02

Field Test Data

Test	Result	Specification
Slump (in):	7 1/2	Not Specified
Air Content (%):	1.9	Not Specified
Concrete Temp. (F):	90	40 - 95
Ambient Temp. (F):	87	40 - 95
Plastic Unit Wt. (pcf):	147.0	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
2	A	6.00	28.27	05/21/20	06/15/20	25 F	113,350	4,010	3	SLS
2	B	6.00	28.27	05/21/20	06/15/20	25 F	114,210	4,040	1	SLS
2	C	6.00	28.27	05/21/20	06/15/20	25 F	127,430	4,510	3	SLS
2	D			05/21/20		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.: Justin Maass **Start/Stop:** 1315-1530
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.

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CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

We hereby certify that the test results presented here
are accurate and conform to the reported grade specification

Rolando A Davila

Quality Assurance Manager

HEAT NO.:3094958 SECTION: REBAR 13MM (#4) 40'0" 420/60 GRADE: ASTM A615-18e1 Gr 420/60 ROLL DATE: 02/25/2020 MELT DATE: 02/16/2020 Cert. No.: 83003292 / 094958A371	S O L D T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	S H I P T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 83003292 BOL#: 73447157 CUST PO#: 842514 CUST P/N: DLVRY LBS / HEAT: 19881.000 LB DLVRY PCS / HEAT: 744 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.44%	Bend Test Diameter	1.750IN		
Mn	0.85%				
P	0.008%				
S	0.046%				
Si	0.17%				
Cu	0.33%				
Cr	0.10%				
Ni	0.19%				
Mo	0.074%				
V	0.000%				
Cb	0.001%				
Sn	0.020%				
Al	0.000%				
Yield Strength test 1	68.2ksi				
Tensile Strength test 1	106.1ksi				
Elongation test 1	14%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.56				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

**Material is fully killed*
**100% melted and rolled in the USA*
**EN10204:2004 3.1 compliant*
**Contains no weld repair*
**Contains no Mercury contamination*
**Manufactured in accordance with the latest version of the plant quality manual*
**Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661*
**Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov*

REMARKS :

CMC STEEL TENNESSEE
1919 Tennessee Avenue
Knoxville TN 37921-2686

CERTIFIED MILL TEST REPORT

For additional copies call

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Jim Hall
Quality Assurance Manager

HEAT NO.:7008674 SECTION: REBAR 13MM (#4) 20'0" 420/60 B150 GRADE: ASTM A615-20 Gr 420/60 ROLL DATE: MELT DATE: 03/31/2020 Cert. No.: 83060448 / 008674L771	SOLD TO: CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO: CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 83060448 BOL#: 73535610 CUST PO#: 847776 CUST P/N: DLVRY LBS / HEAT: 28056.000 LB DLVRY PCS / HEAT: 2100 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.31%	Rebar Deformation Avg. Spaci	0.330IN		
Mn	0.66%	Rebar Deformation Avg. Heigh	0.033IN		
P	0.008%	Rebar Deformation Max. Gap	0.130IN		
S	0.062%				
Si	0.19%				
Cu	0.38%				
Cr	0.10%				
Ni	0.12%				
Mo	0.015%				
V	0.003%				
Sn	0.007%				
Yield Strength test 1	93.4ksi				
Yield Strength test 1 (metri	644MPa				
Tensile Strength test 1	109.5ksi				
Tensile Strength 1 (metric)	755MPa				
Elongation test 1	11%				
Elongation Gage Lgth test 1	8IN				
Elongation Gage Lgth 1(metri	200mm				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

- *Material is fully killed*
- *100% melted and rolled in the USA*
- *EN10204:2004 3.1 compliant*
- *Contains no weld repair*
- *Contains no Mercury contamination*
- *Manufactured in accordance with the latest version of the plant quality manual*
- *Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661*
- *Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov*

REMARKS : ALSO MEETS AASHTO M31

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3094648 SECTION: REBAR 16MM (#5) 40'0" 420/60 GRADE: ASTM A615-18e1 Gr 420/60 ROLL DATE: 02/14/2020 MELT DATE: 02/04/2020 Cert. No.: 83003290 / 094648A765	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 83003290 BOL#: 73447155 CUST PO#: 842512 CUST P/N: DLVRY LBS / HEAT: 24030.000 LB DLVRY PCS / HEAT: 576 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.42%	Bend Test Diameter	2.188IN		
Mn	0.93%				
P	0.010%				
S	0.047%				
Si	0.18%				
Cu	0.28%				
Cr	0.12%				
Ni	0.20%				
Mo	0.075%				
V	0.000%				
Cb	0.001%				
Sn	0.027%				
Al	0.000%				
Yield Strength test 1	65.7ksi				
Tensile Strength test 1	104.6ksi				
Elongation test 1	14%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.59				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

**Material is fully killed*
**100% melted and rolled in the USA*
**EN10204:2004 3.1 compliant*
**Contains no weld repair*
**Contains no Mercury contamination*
**Manufactured in accordance with the latest version of the plant quality manual*
**Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661*
**Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov*

REMARKS :

National Wire L.L.C.
12262 FM 3083, Conroe, TX. 77301

Quality Control Department

Certificate of Analysis and Test

#:1
P.O:
Order #: S-6161

Customer:
CMC Construction Serv. / Houston
2001 Brittmoore Rd.
Houston, TX 77043

QTY	ITEM DESCRIPTION
6	VX6 D10.7XD13.4 68"(+1-1/2",+1") X 24'6"(6",18")

Mechanical Properties

Test Date:	3/25/2020	3/25/2020						
Wire Size	D13.4	D10.7						
Heat Number	2020598	2020150						
Diameter	0.413	0.369						
Avg. Lbs Force	12,300	10,000						
Avg. Tensile (psi)	91,600	93,000						
Avg. Yield (psi)	88,300	91,600						
Avg.Weld Shear(psi)	48,400	48,400						
Bend Test	PASS	PASS						
Reduction of Area %	N/A	N/A						

The undersigned certifies that the material tested above complies with the ASTM A1064/A1064M-18a.
The wire was melted and manufactured in the United States of America and complies with Buy America Requirements.

for Jose L. Torres
Quality Control Manager

4/29/2020
Date

MATERIAL TEST REPORT

PAGE 1

Date Printed: 02/26/2020

Mid American Steel & Wire
Madill Oklahoma

Bill to:
NATIONAL WIRE CORPORATION
12262 F.M. 3083
alejandra@nationalwirellc.com
CONROE, TX 77301

Ship to:
NATIONAL WIRE CORP.
12262 F.M. 3083

CONROE, TX 77301, TX 7730

Customer No: 000000006002
PO Number: 1480
Ship Date: 02/26/2020
Order Number: 109159
Load Number: 133572

Item Number	Description
D15321012IQM	1012IQ - 15/32 In Rod

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	N	B
2020598	0.1200	0.5000	0.0100	0.0270	0.1400	0.2000	0.1200	0.1400	0.0300	0.0080	0.0030	0.0000	0.0091	0.0002

MECHANICAL PROPERTIES

Heat Number	Yield (Psi)	Tensile (Psi)	Elongation (%)	Reduction (%)	Bend Test Pass/ Fail
2020598	47164 psi /	65513 psi /	23.44	68.79	

The melting and rolling processes used to manufacture the above described material took place in the United States of America. The material was produced and tested in accordance with ASTM A-510.

Quality Assurance: ____________________

MATERIAL TEST REPORT

PAGE 1

Date Printed: 02/17/2020

Mid American Steel & Wire
Madill, Oklahoma

Customer No:	000000006002
PO Number:	1478
Ship Date:	02/17/2020
Order Number:	108617
Load Number:	133374

Bill to:
NATIONAL WIRE CORPORATION
12262 F.M. 3083
alejandra@nationalwirellc.com
CONROE, TX 77301

Ship to:
NATIONAL WIRE CORP.
12262 F.M. 3083
CONROE, TX 77301, TX 7730

Item Number	Description
D2764101200M	27/64 1012 ROD

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	N	B
2020150	0.1200	0.5000	0.0100	0.0280	0.1700	0.2200	0.0800	0.0800	0.0200	0.0100	0.0010	0.0000	0.0077	0.0002

MECHANICAL PROPERTIES

Heat Number	Yield (Psi)	Tensile (Psi)	Elongation (%)	Reduction (%)	Bend Test Pass/ Fail
2020150	41635 psi /	62441 psi /	25.00	64.05	

The melting and rolling processes used to manufacture the above described material took place in the United States of America. The material was produced and tested in accordance with ASTM A-510.

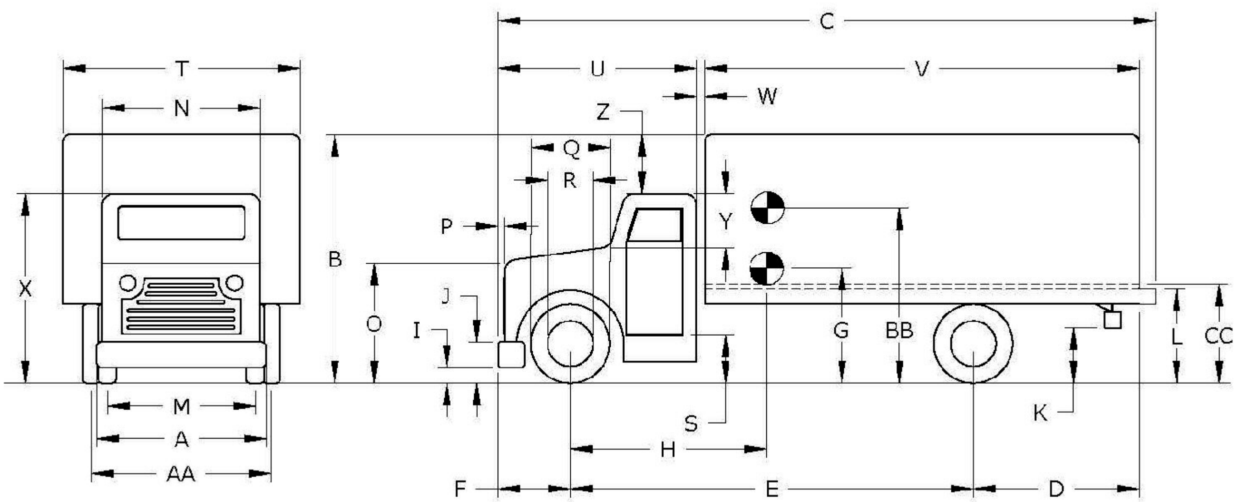
Quality Assurance: ____________

APPENDIX C. *MASH* TEST 4-12 (CRASH TEST NO. 469680-02-1)

C.1. VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 469680-02-1.

Date:	2020-6-16	Test No.:	469680-2	VIN No.:	1HTMMAAN5BH388517
Year:	2011	Make:	INTERNATIONAL	Model:	4300
Odometer:	140395	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:	138.00	L	Rear Frame Top:	37.00	V	Trailer/Box Length:	221.50
C	Overall Length:	330.75	M	Front Track Width:	80.00	W	Gap Width:	2.25
D	Rear Overhang:	86.50	N	Roof Width:	71.00	X	Overall Front Height:	98.50
E	Wheel Base:	204.75	O	Hood Height:	59.00	Y	Roof-Hood Distance:	30.00
F	Front Overhang:	39.50	P	Bumper Extension:		Z	Roof-Box Height Difference:	39.50
G	C.G. Height:		Q	Front Tire Width:	39.00	AA	Rear Track Width:	73.00
H	C.G. Horizontal Dist. w/Ballast:	129.32	R	Front Wheel Width:	23.50	BB	Ballast Center of Mass:	61.75
I	Front Bumper Bottom:	18.50	S	Bottom Door Height:	37.00	CC	Cargo Bed Height:	48.75
J	Front Bumper Top:	33.50	T	Overall Width:	96.00			

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)	2.50	Bottom Frame Height (Rear)	27.50

Table C.1. Vehicle Properties for Test No. 469680-02-1 (Continued).

Date:	2020-6-16	Test No.:	469680-2	VIN No.:	1HTMMAAN5BH388517
Year:	2011	Make:	INTERNATIONAL	Model:	4300

WEIGHTS (☑ lb or ☐ kg)

	CURB	TEST INERTIAL
$W_{front\ axle}$	7040	8230
$W_{rear\ axle}$	6600	14110
W_{TOTAL}	13640	22340

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

Ballast: 8700 (☑ lb or ☐ kg) **(as-needed)** **(See *MASH* Section 4.2.1.2 for recommended ballasting)**

Mass Distribution (☑ lb or ☐ kg): **LF:** 4170 **RF:** 4060 **LR:** 7320 **RR:** 6790

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:	129.30	0	48.25
Rear:	229.30	0	48.25

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

61.75 inches from ground to center of block

Tied down with four 5/16-inch cables

Performed by: SCD **Date:** 2020-06-16

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

C.2. SEQUENTIAL PHOTOGRAPHS

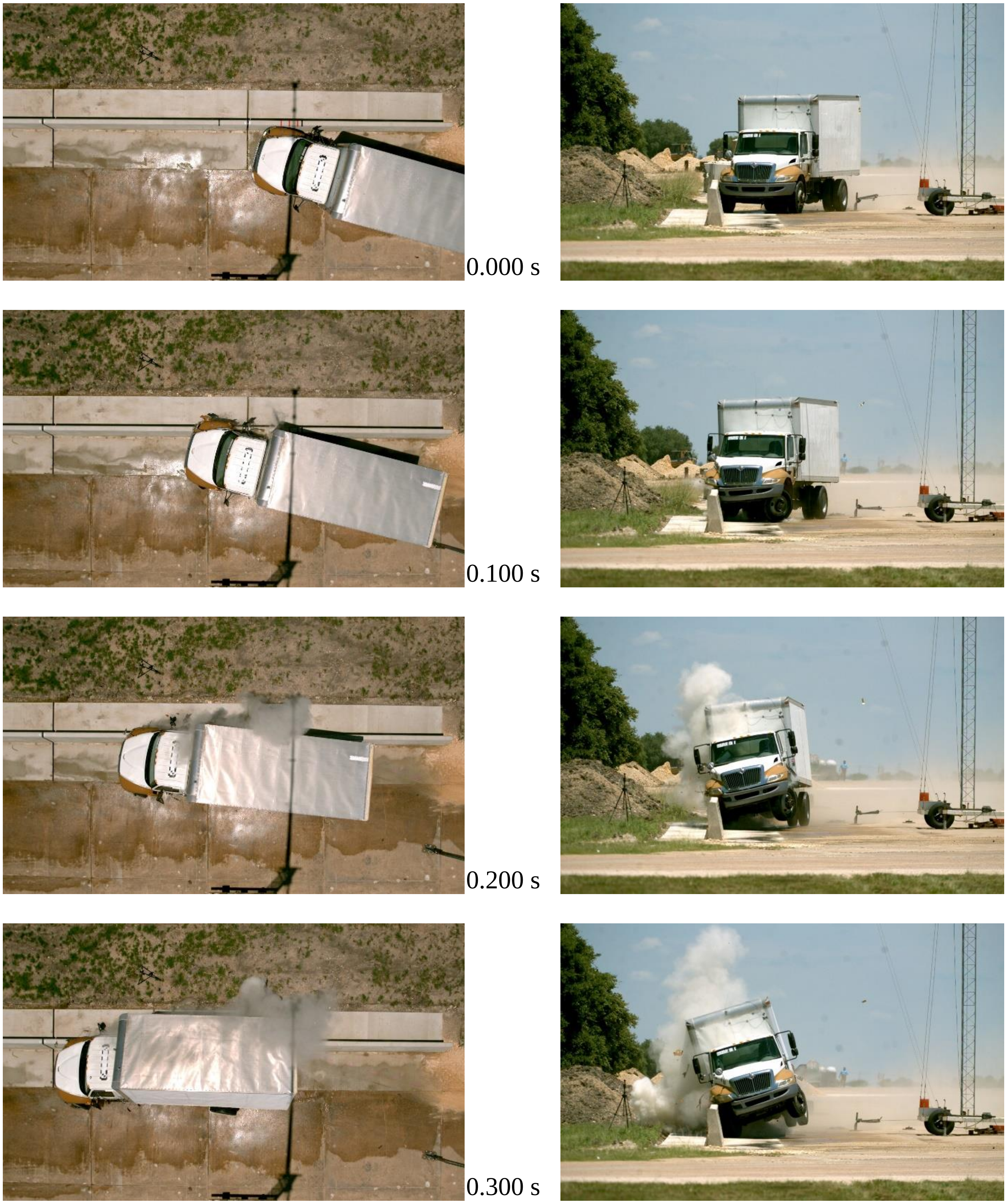


Figure C.1. Sequential Photographs for Test No. 469680-02-1 (Overhead and Frontal Views).


0.400 s



0.500 s

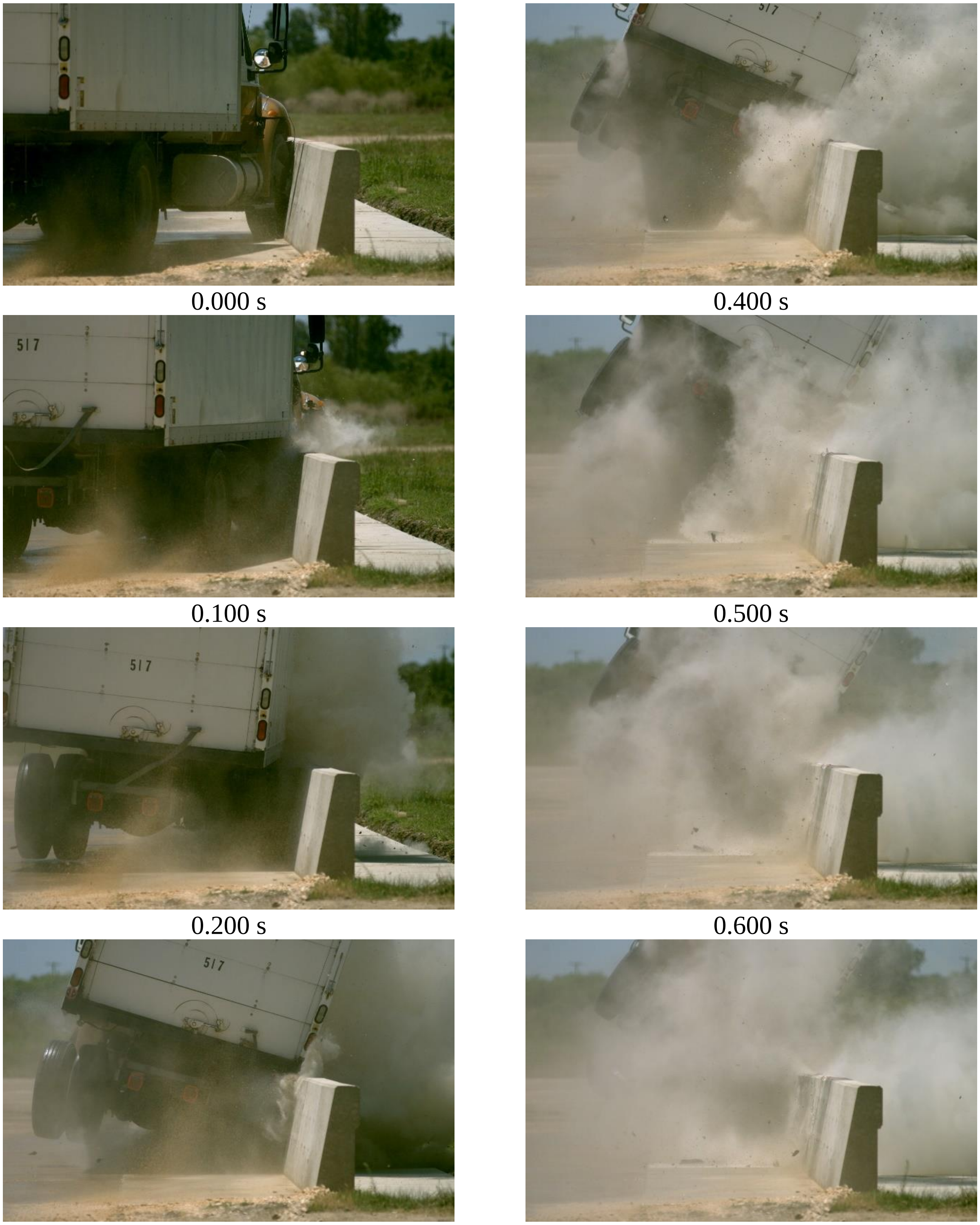


0.600 s



0.700 s


Figure C.1. Sequential Photographs for Test No. 469680-02-1 (Overhead and Frontal Views) (Continued).



0.000 s
0.400 s
0.100 s
0.500 s
0.200 s
0.600 s
0.300 s
0.700 s

Figure C.2. Sequential Photographs for Test No. 469680-02-1 (Rear View).

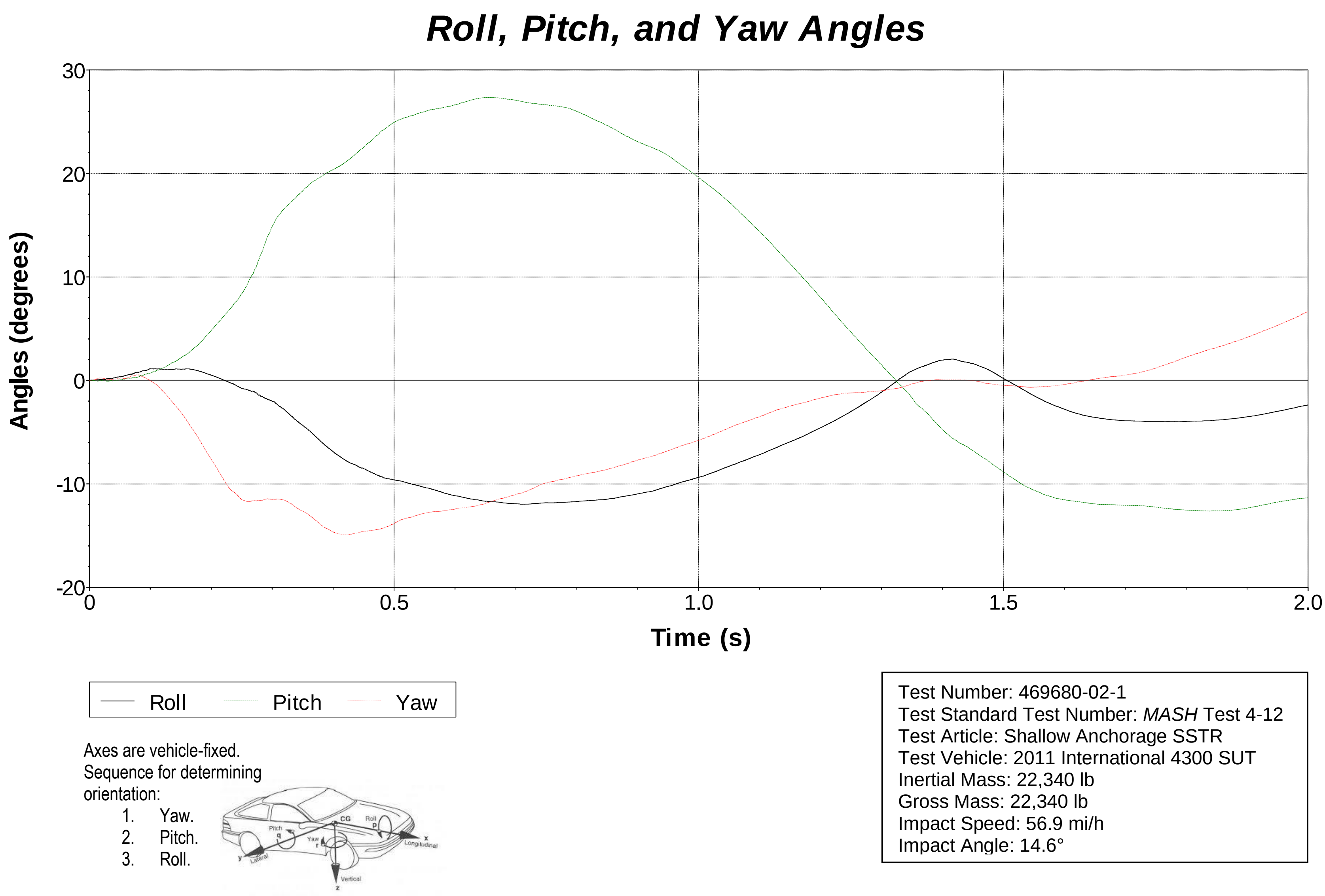


Figure C.3. Vehicle Angular Displacements for Test 469680-02-1.

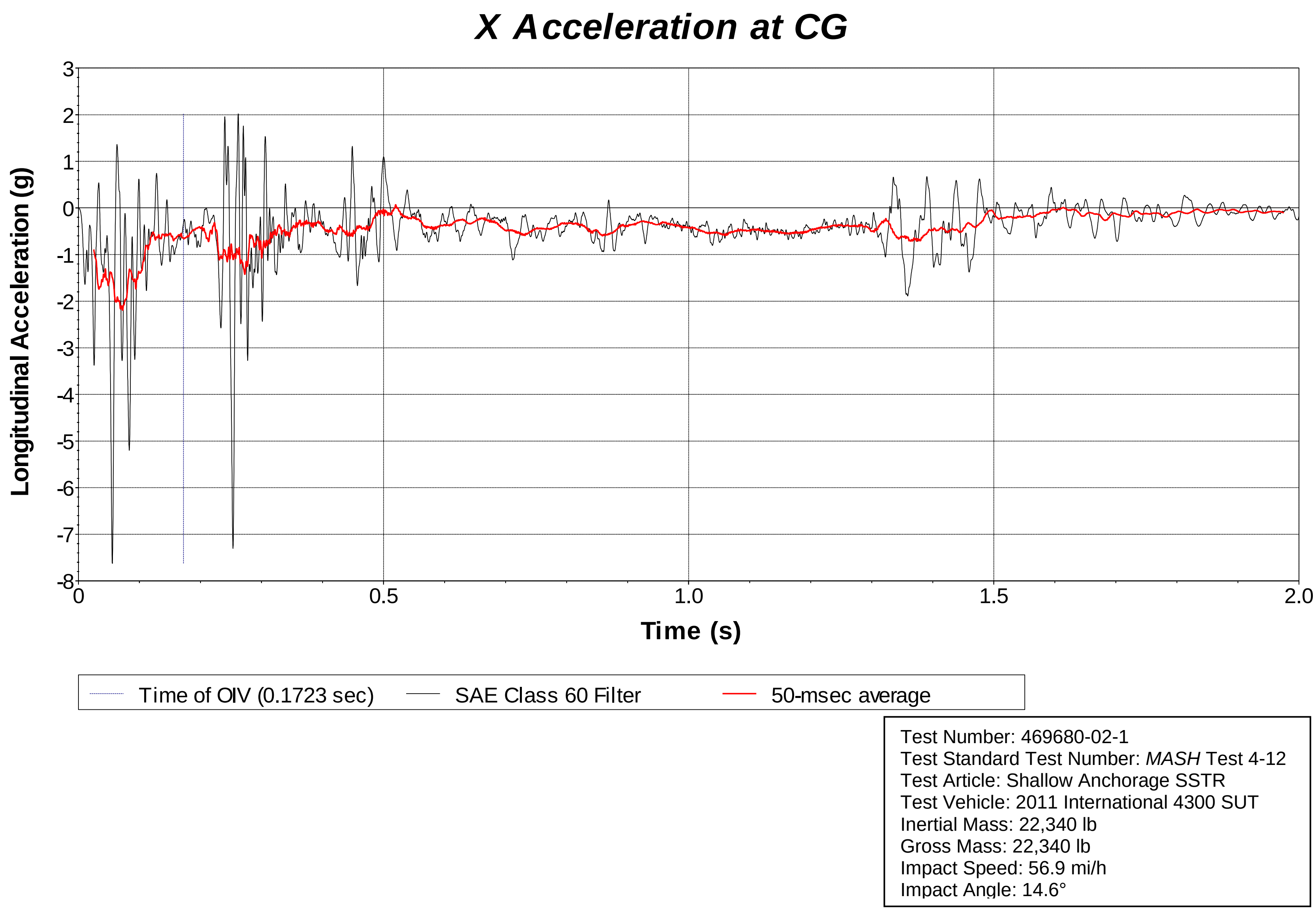


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Center of Gravity).

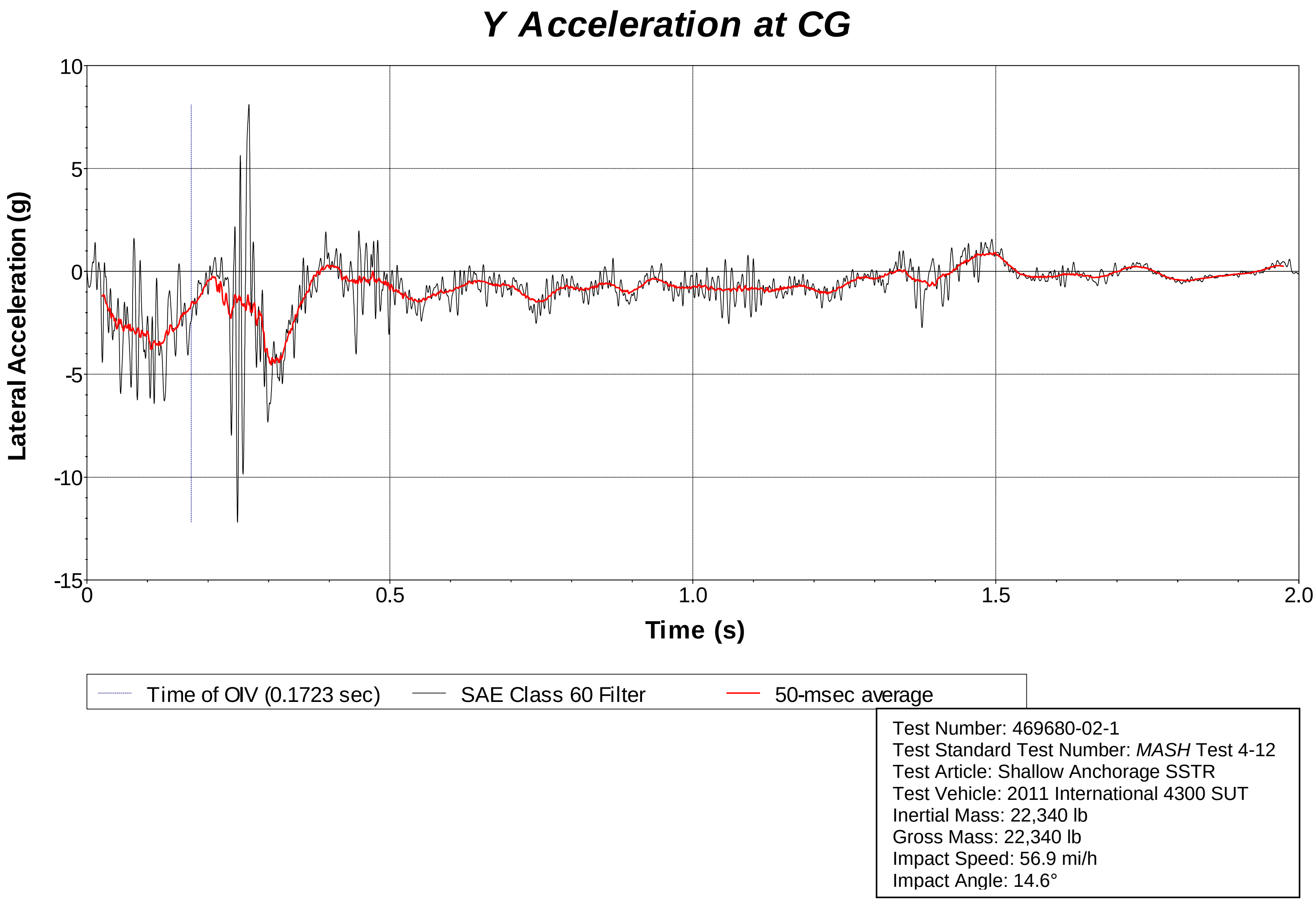


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Center of Gravity).

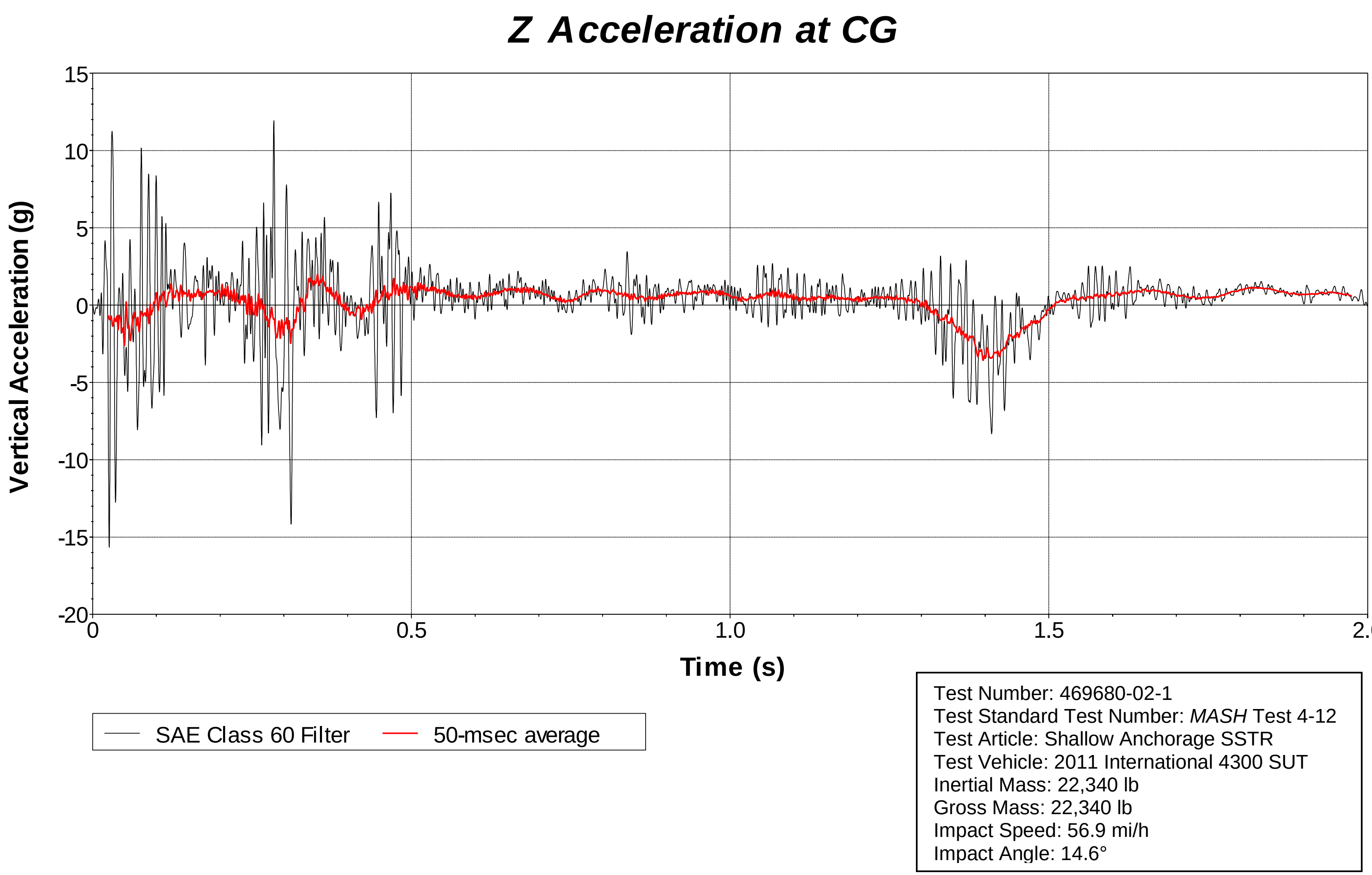


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Center of Gravity).

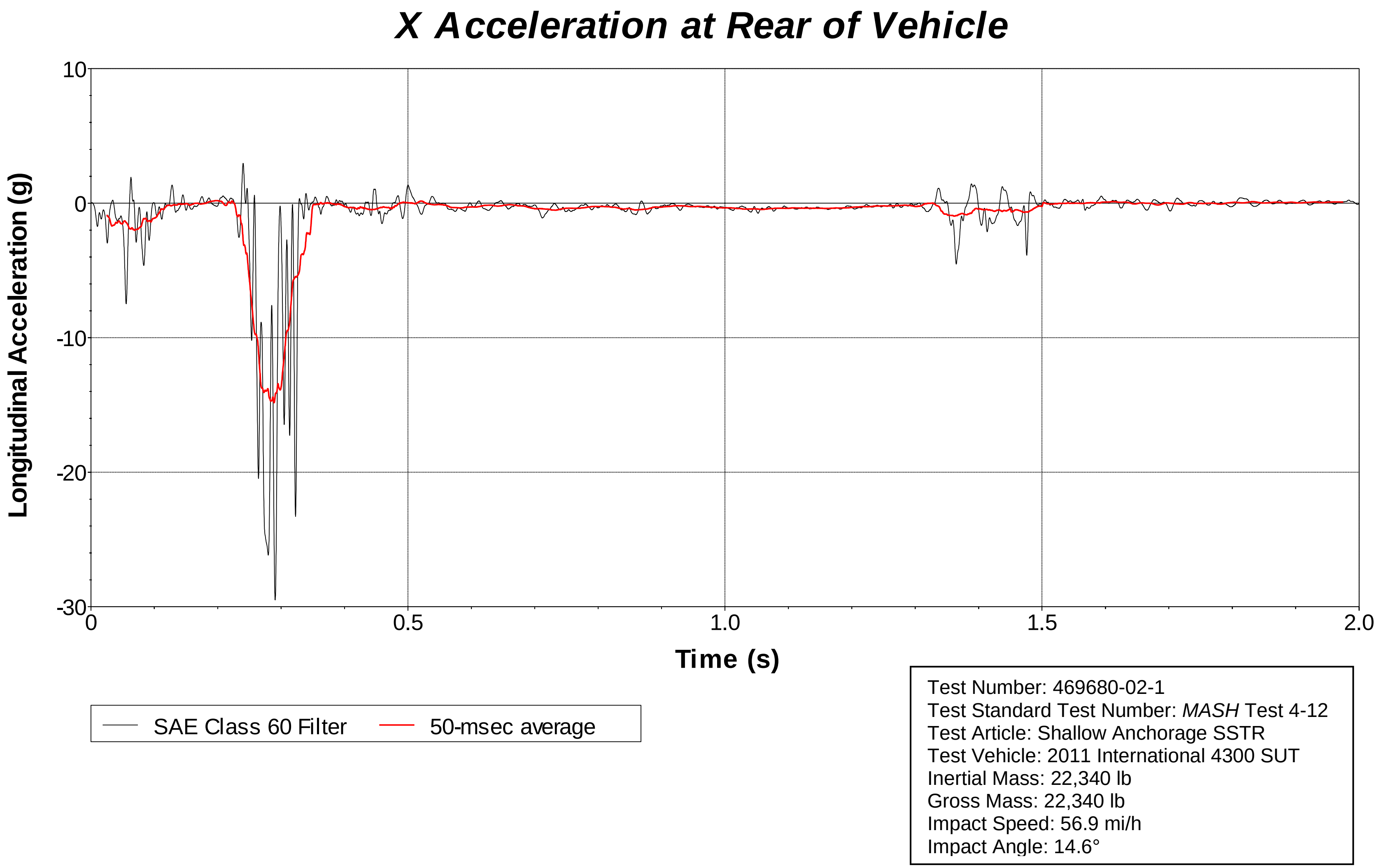


Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Rear of Vehicle).

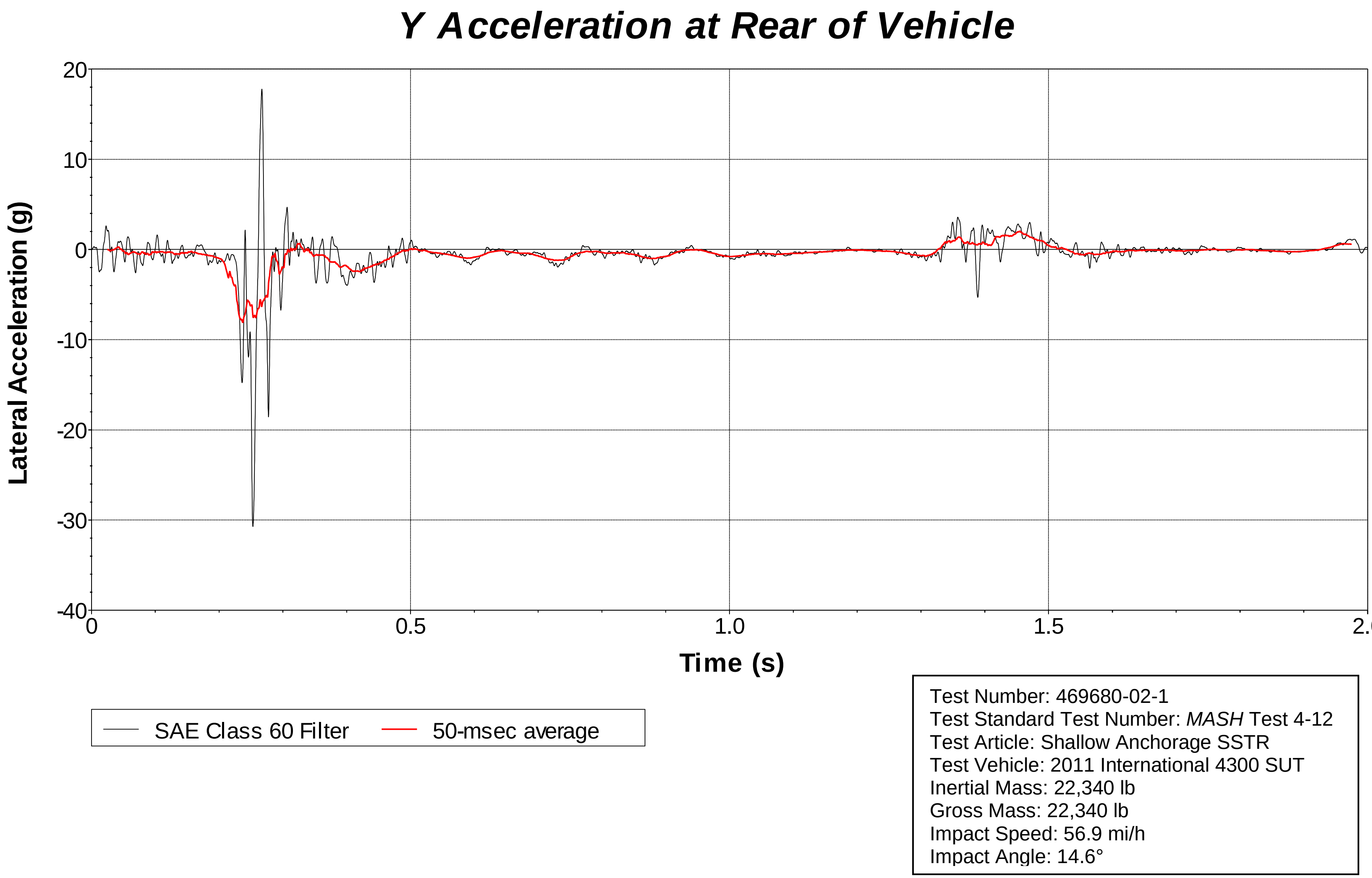


Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Rear of Vehicle).

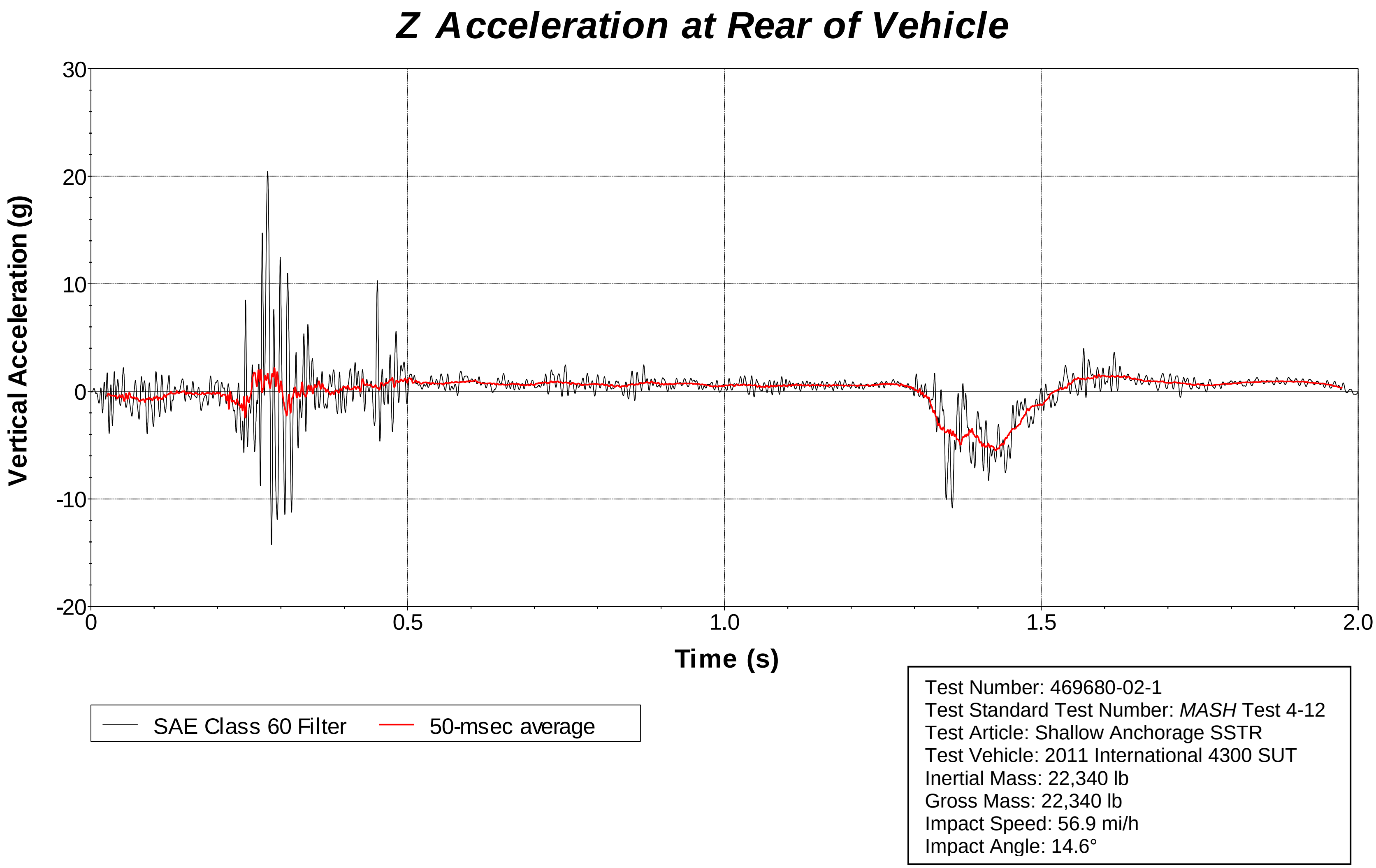


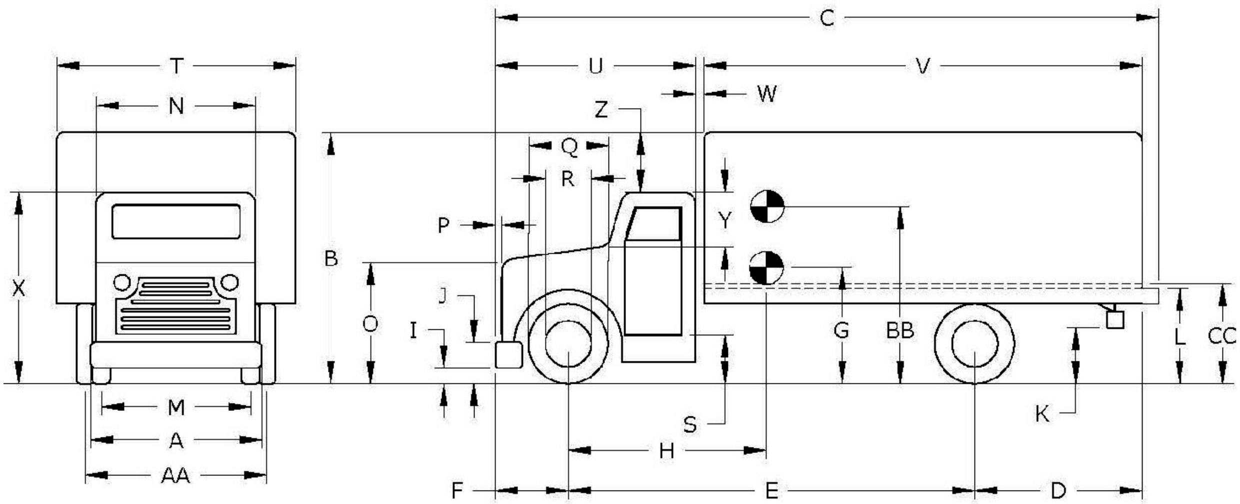
Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Rear of Vehicle).

APPENDIX D. *MASH* TEST 4-12 WITHOUT DOWEL BARS (CRASH TEST NO. 469680-02-2)

D.1. VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 469680-02-2.

Date:	2020-8-10	Test No.:	469680-02-2	VIN No.:	1HTMMAA6BH318203
Year:	2011	Make:	INTERNATIONAL	Model:	4300
Odometer:	168769	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:	135.00	L	Rear Frame Top:	38.00	V	Trailer/Box Length:	223.00
C	Overall Length:	329.75	M	Front Track Width:	80.00	W	Gap Width:	2.25
D	Rear Overhang:	85.00	N	Roof Width:	71.00	X	Overall Front Height:	98.50
E	Wheel Base:	204.75	O	Hood Height:	58.50	Y	Roof-Hood Distance:	30.00
F	Front Overhang:	40.00	P	Bumper Extension:		Z	Roof-Box Height Difference:	36.50
G	C.G. Height:		Q	Front Tire Width:	39.00	AA	Rear Track Width:	73.00
H	C.G. Horizontal Dist. w/Ballast:	130.10	R	Front Wheel Width:	23.50	BB	Ballast Center of Mass:	63.37
I	Front Bumper Bottom:	18.25	S	Bottom Door Height:	37.00	CC	Cargo Bed Height:	50.80
J	Front Bumper Top:	33.25	T	Overall Width:	97.00			

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)	4.50	Bottom Frame Height (Rear)	27.50

More information needed on next page ➡

Table D.1. Vehicle Properties for Test No. 469680-02-2 (Continued).

Date: 2020-8-10 Test No.: 469680-02-2 VIN No.: 1HTMMAA6BH318203

Year: 2011 Make: INTERNATIONAL Model: 4300

WEIGHTS (☑ lb or ☐ kg)

	CURB	TEST INERTIAL
$W_{front\ axle}$	6960	8090
$W_{rear\ axle}$	6060	14100
W_{TOTAL}	13020	22190

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

Ballast: 9170 (☑ lb or ☐ kg) **(as-needed)** **(See *MASH* Section 4.2.1.2 for recommended ballasting)**

Mass Distribution (☑ lb or ☐ kg): **LF:** 3950 **RF:** 4140 **LR:** 7260 **RR:** 6840

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:	130.1	0	50
Rear:	265	0	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

63.37 inches from ground to center of block

Tied down with four 5/16-inch cables per block

Performed by: SCD **Date:** 2020-8-10

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

D.2. SEQUENTIAL PHOTOGRAPHS

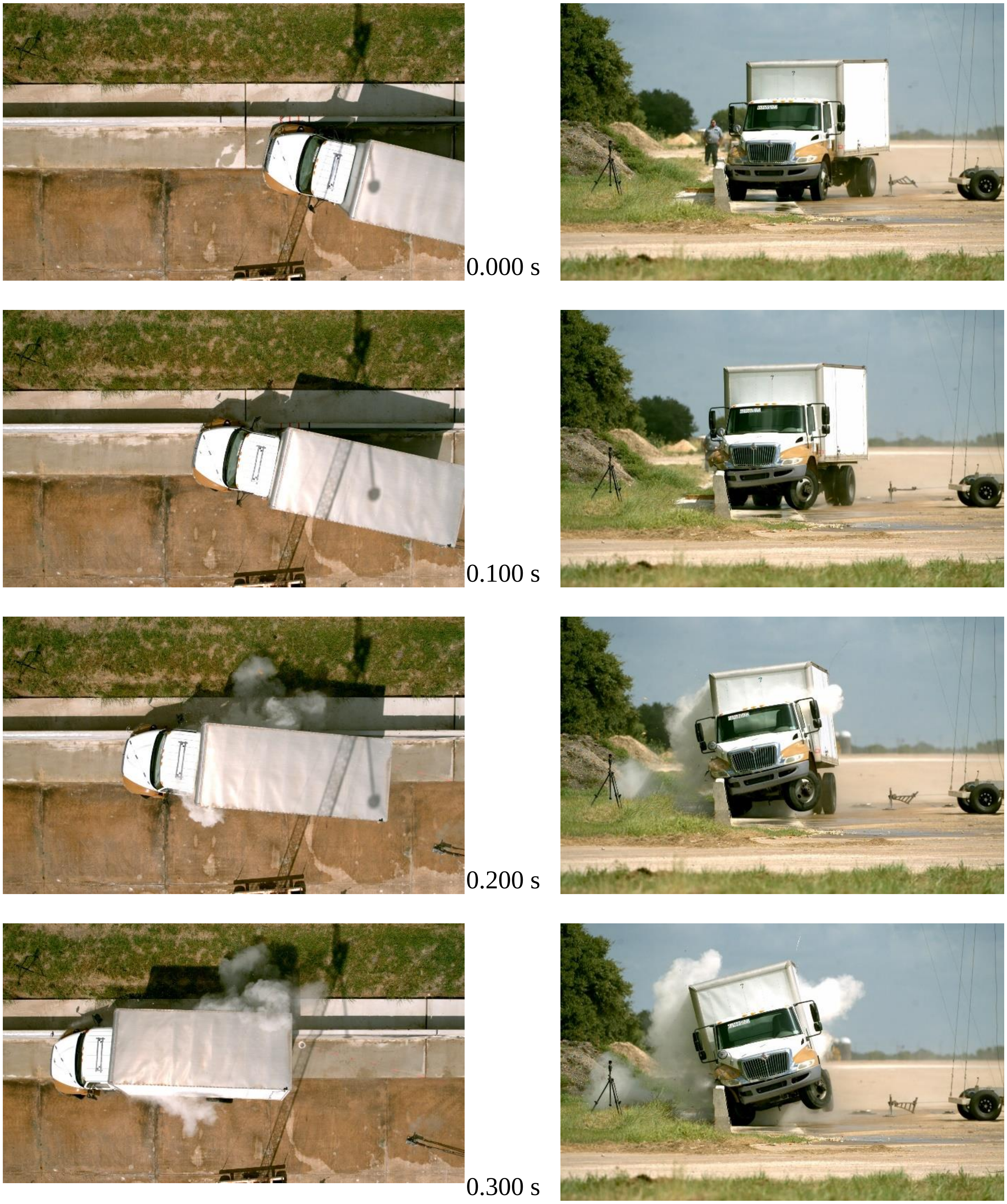


Figure D.1. Sequential Photographs for Test No. 469680-02-2 (Overhead and Frontal Views).

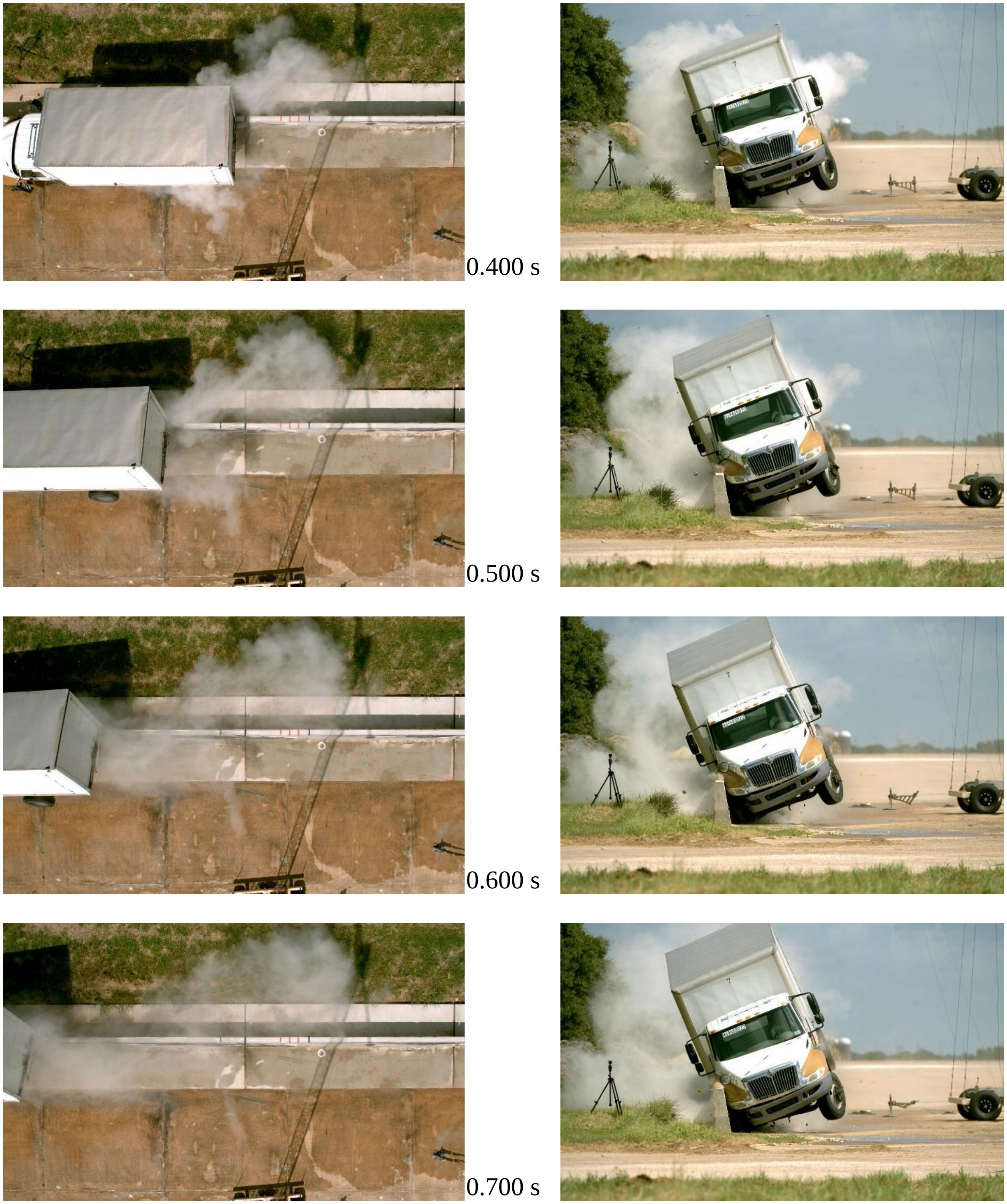
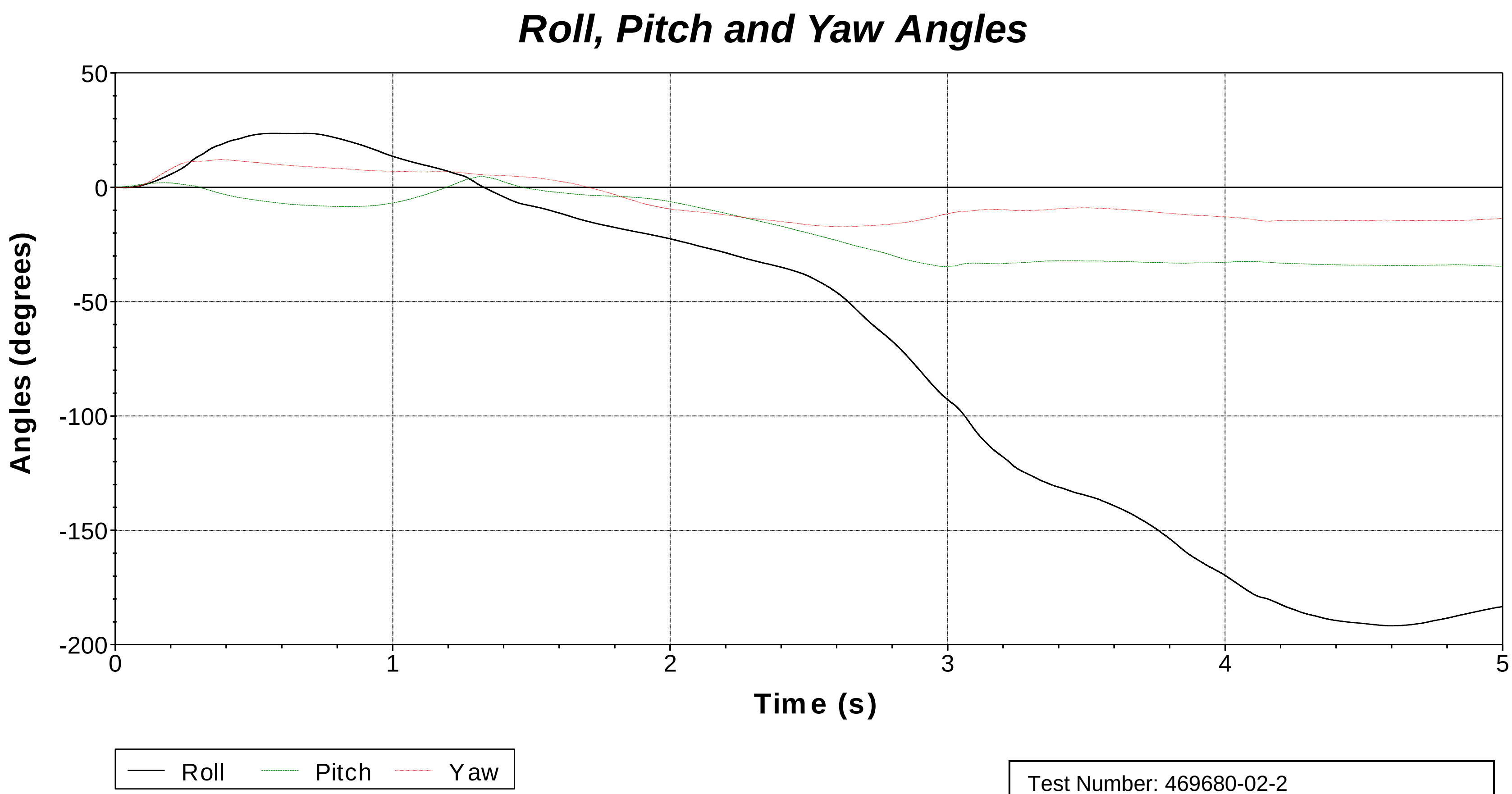
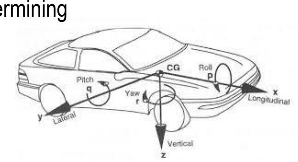


Figure D.1. Sequential Photographs for Test No. 469680-02-2 (Overhead and Frontal Views) (Continued).



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 469680-02-2
Test Standard Test Number: *MASH* Test 4-12
Test Article: Shallow Anchorage SSTR
Test Vehicle: 2011 International 4300 SUT
Inertial Mass: 22,190 lb
Gross Mass: 22,190 lb
Impact Speed: 56.7 mi/h
Impact Angle: 14.2°

Figure D.2. Vehicle Angular Displacements for Test No. 469680-02-2.

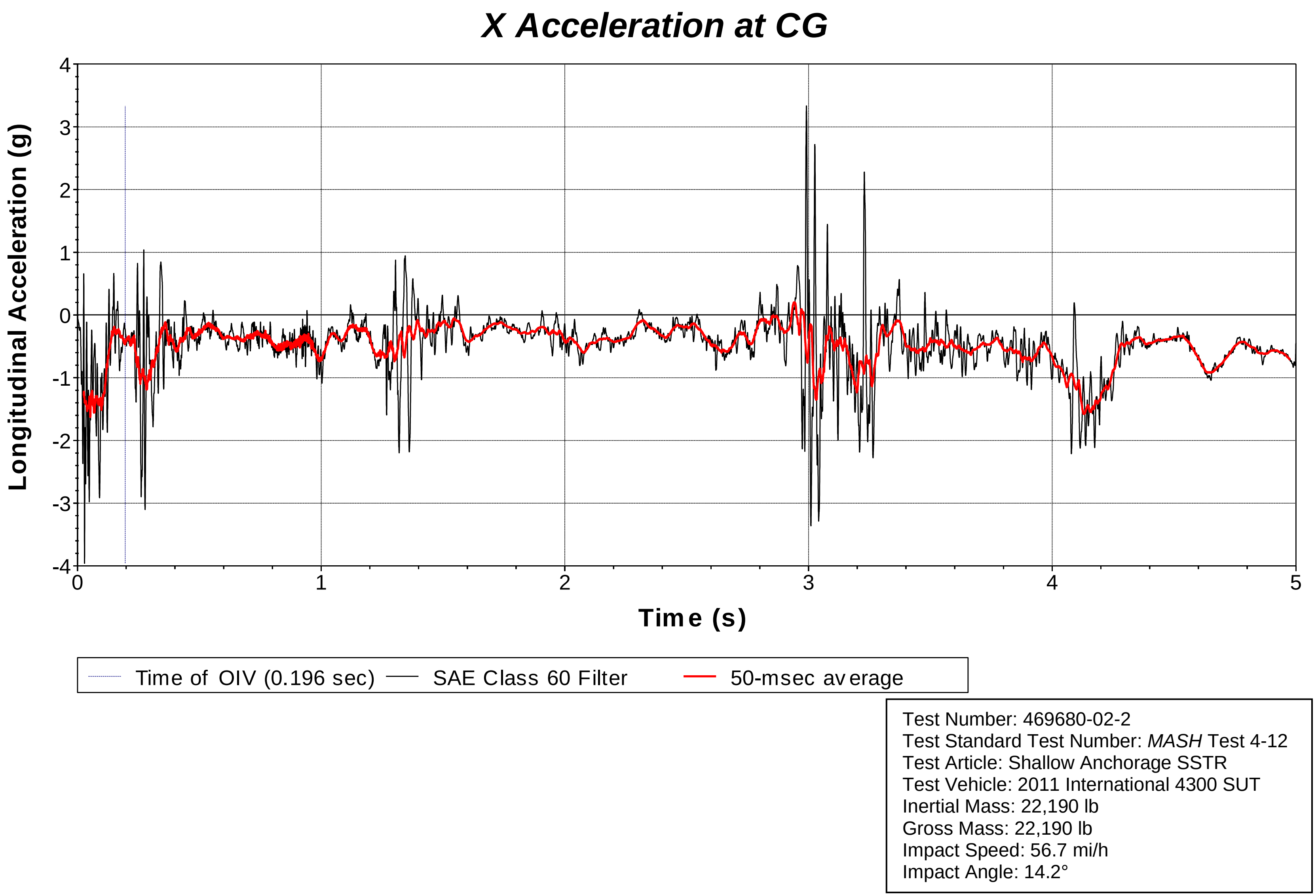


Figure D.3. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Center of Gravity).

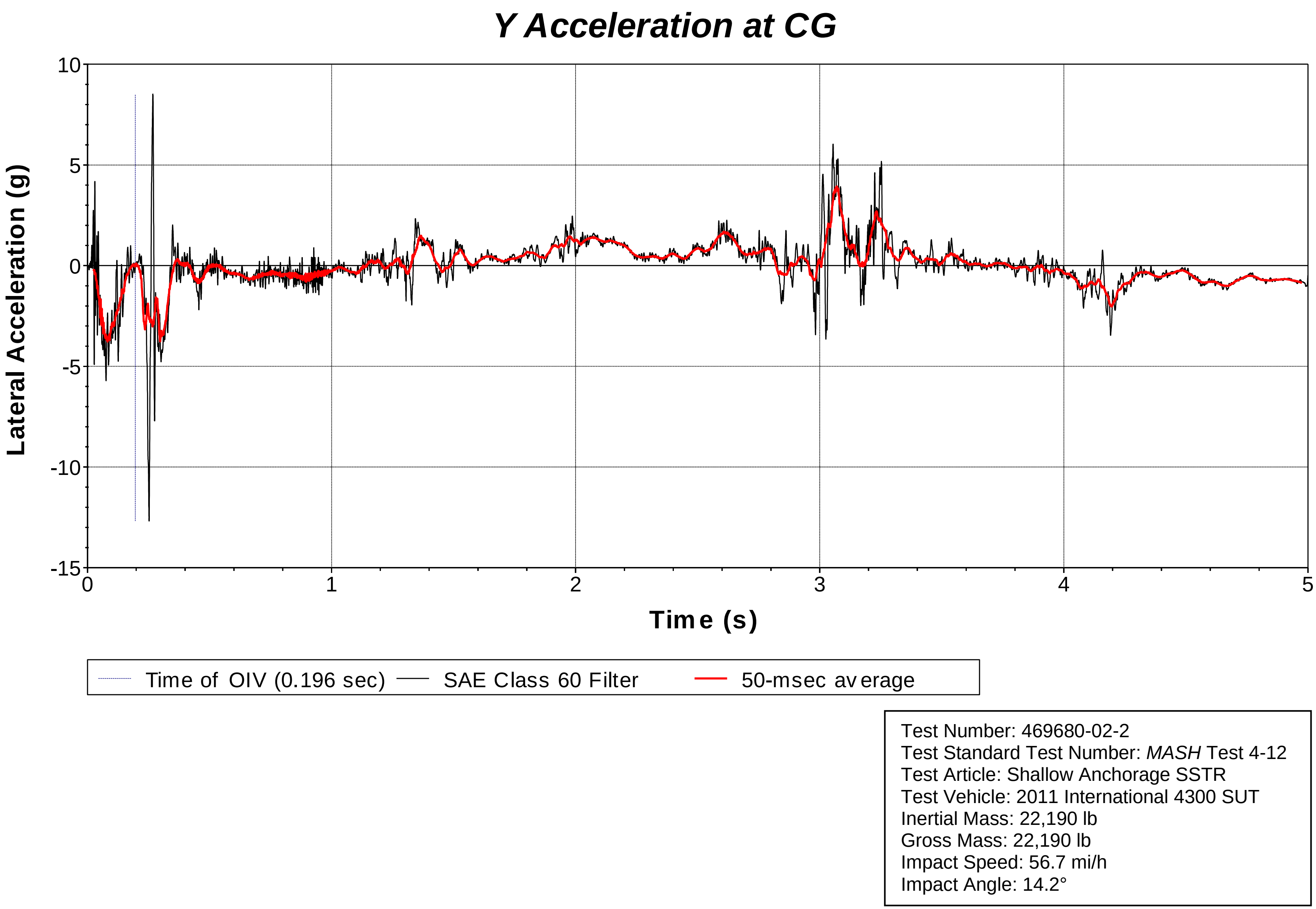


Figure D.4. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Center of Gravity).

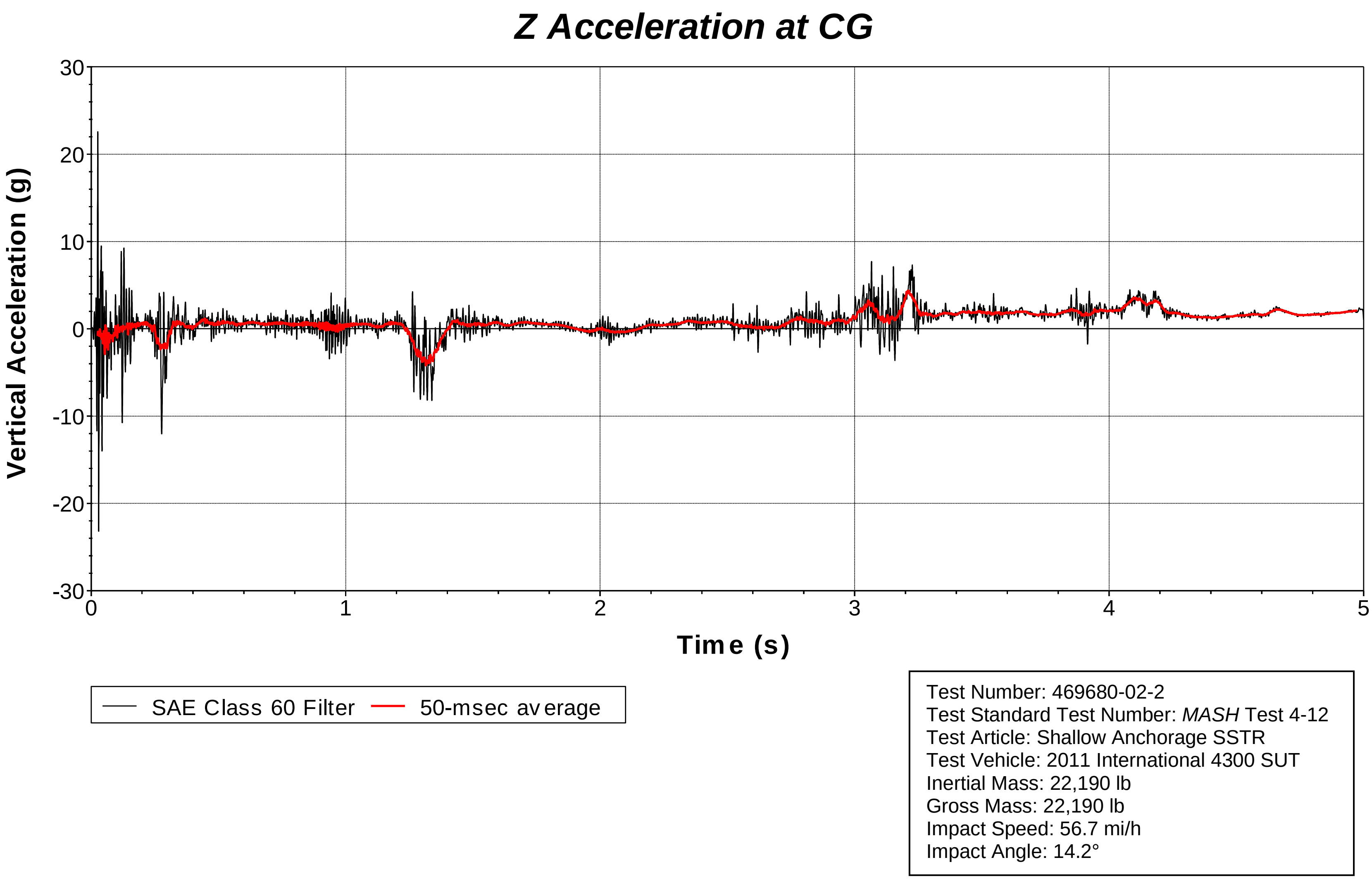


Figure D.5. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Center of Gravity).

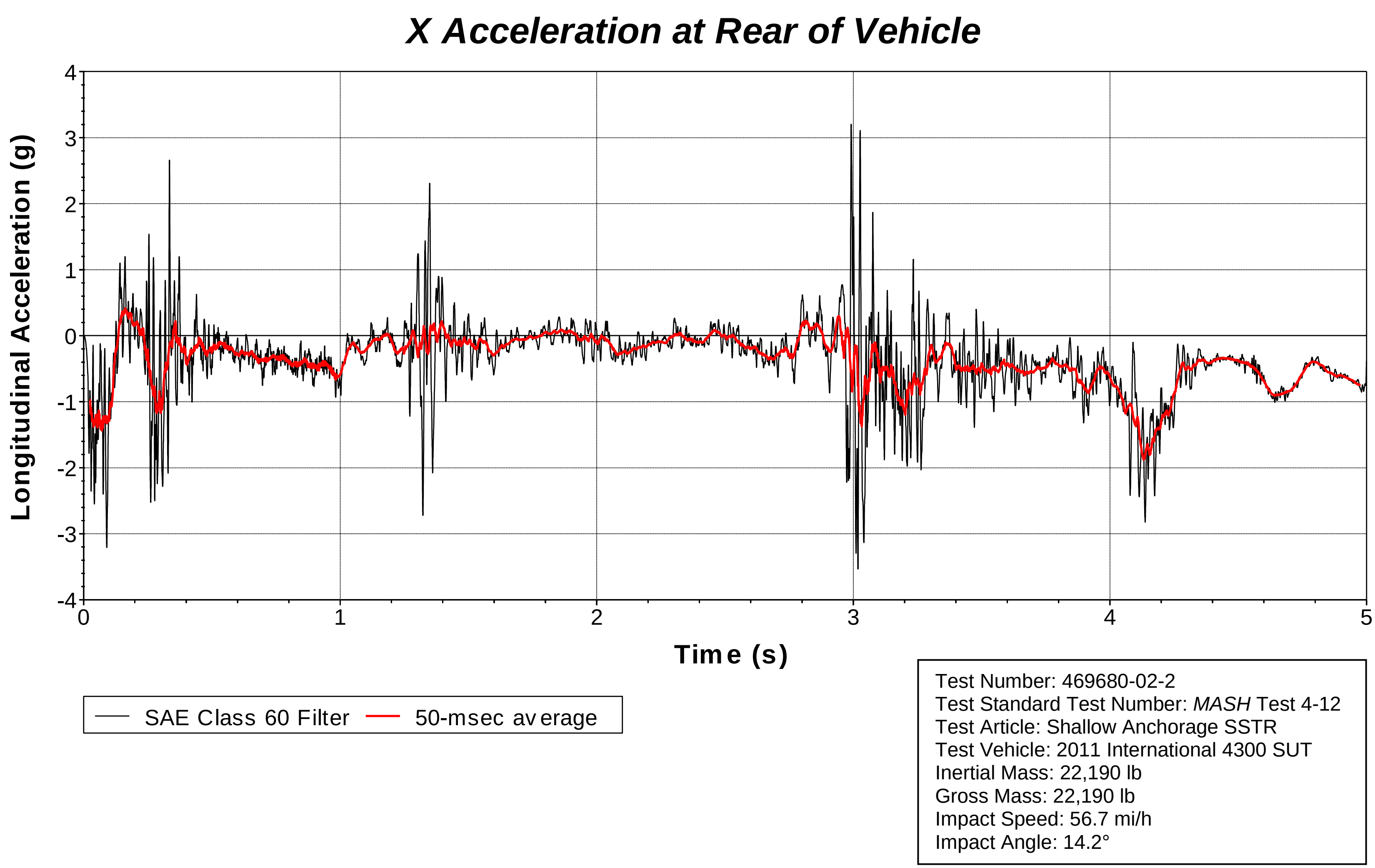


Figure D.6. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Rear of Vehicle).

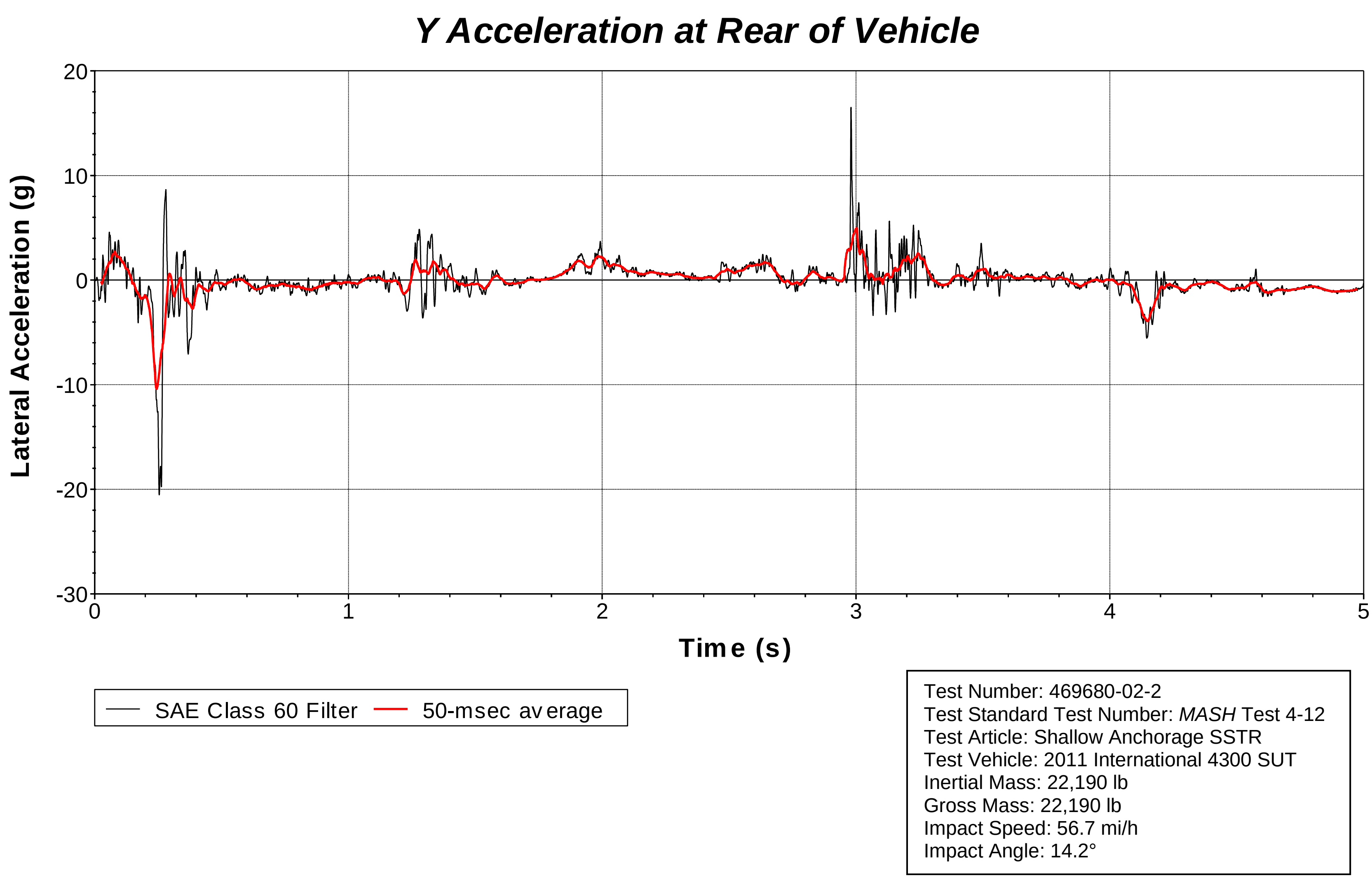


Figure D.7. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Rear of Vehicle).

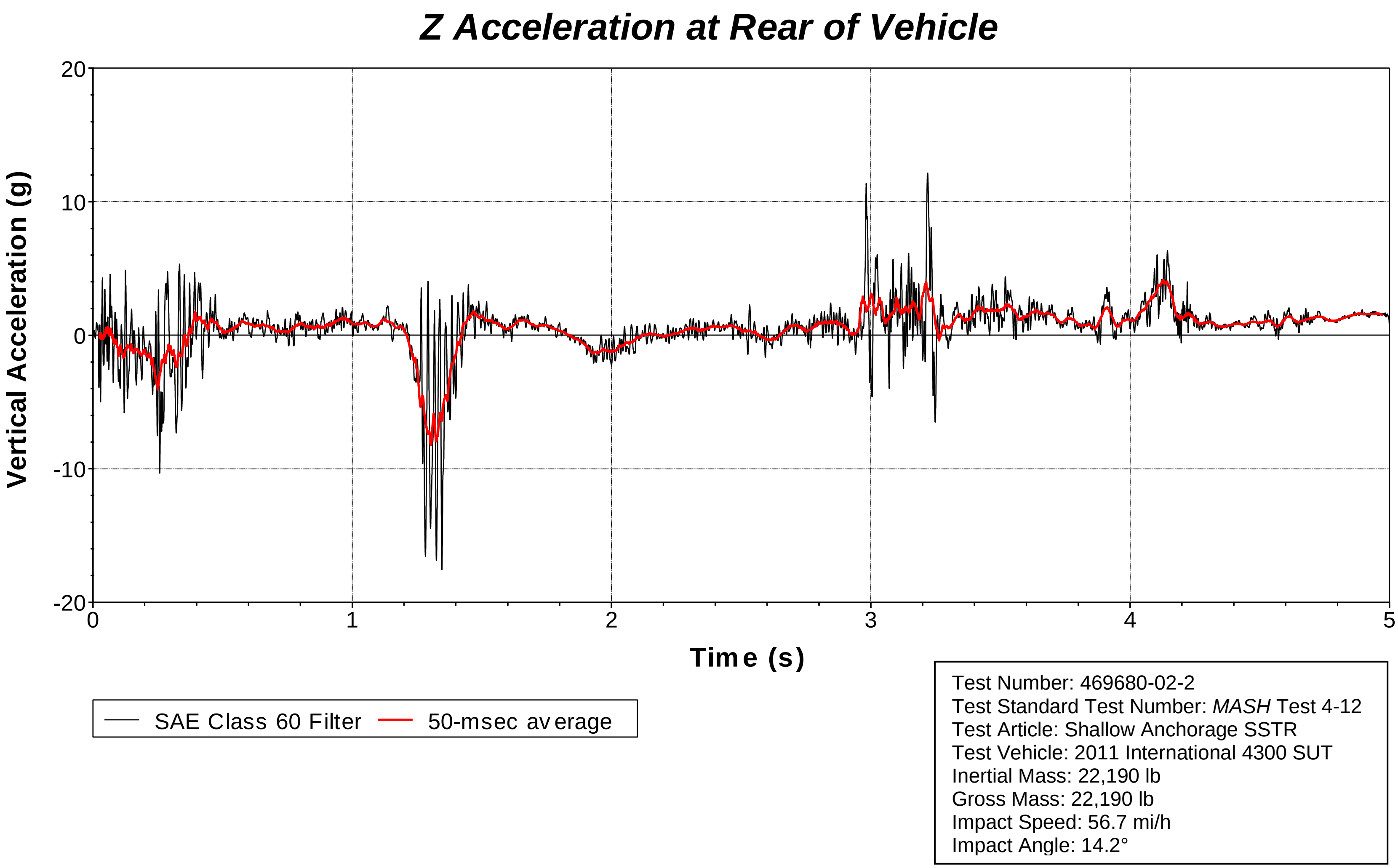


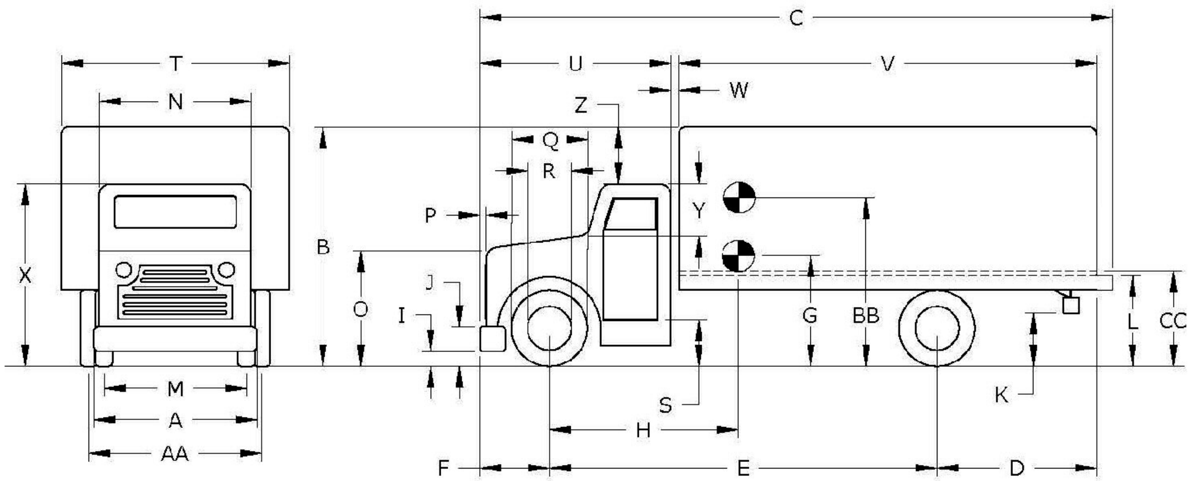
Figure D.8. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Rear of Vehicle).

APPENDIX E. *MASH* TEST 4-12 WITHOUT DOWEL BARS AND WITH CONCRETE APRON EXTENDED DOWNSTREAM OF BARRIER (CRASH TEST NO. 469680-02-3)

E.1. VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 469680-02-3.

Date:	2020-8-19	Test No.:	460680-02-3	VIN No.:	1HTMMAAN89H164197
Year:	2009	Make:	INTERNATIONAL	Model:	4300
Odometer:	235522	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:	151.50	L	Rear Frame Top:	38.00	V	Trailer/Box Length:	222.00
C	Overall Length:	329.75	M	Front Track Width:	80.00	W	Gap Width:	1.50
D	Rear Overhang:	85.00	N	Roof Width:	71.00	X	Overall Front Height:	98.50
E	Wheel Base:	204.75	O	Hood Height:	58.50	Y	Roof-Hood Distance:	30.00
F	Front Overhang:	40.00	P	Bumper Extension:		Z	Roof-Box Height Difference:	53.00
G	C.G. Height:		Q	Front Tire Width:	39.00	AA	Rear Track Width:	73.00
H	C.G. Horizontal Dist. w/Ballast:	130.13	R	Front Wheel Width:	23.50	BB	Ballast Center of Mass:	61.25
I	Front Bumper Bottom:	18.25	S	Bottom Door Height:	37.00	CC	Cargo Bed Height:	48.20
J	Front Bumper Top:	33.25	T	Overall Width:	102.00			

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)	4.50	Bottom Frame Height (Rear)	27.50

More information needed on next page ➡

Table E.1. Vehicle Properties for Test No. 469680-02-3 (Continued).

Date:	2020-8-19	Test No.:	460680-02-3	VIN No.:	1HTMMAAN89H164197
Year:	2009	Make:	INTERNATIONAL	Model:	4300

WEIGHTS
(☑ lb or ☐ kg)

	CURB	TEST INERTIAL
$W_{front\ axle}$	7040	8200
$W_{rear\ axle}$	6730	14300
W_{TOTAL}	13770	22500

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

Ballast: 8730 (☑ lb or ☐ kg) **(as-needed)**
(See *MASH* Section 4.2.1.2 for recommended ballasting)

Mass Distribution
(☑ lb or ☐ kg): **LF:** 4190 **RF:** 4010 **LR:** 7160 **RR:** 7140

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:	130.00	0.00	47.50
Rear:	238.00	0.00	47.50

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
61.25 inches from ground to center of block
Tied down with four 5/16-inch cables per block

Performed by: SCD **Date:** 2020-8-19

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

E.2. SEQUENTIAL PHOTOGRAPHS

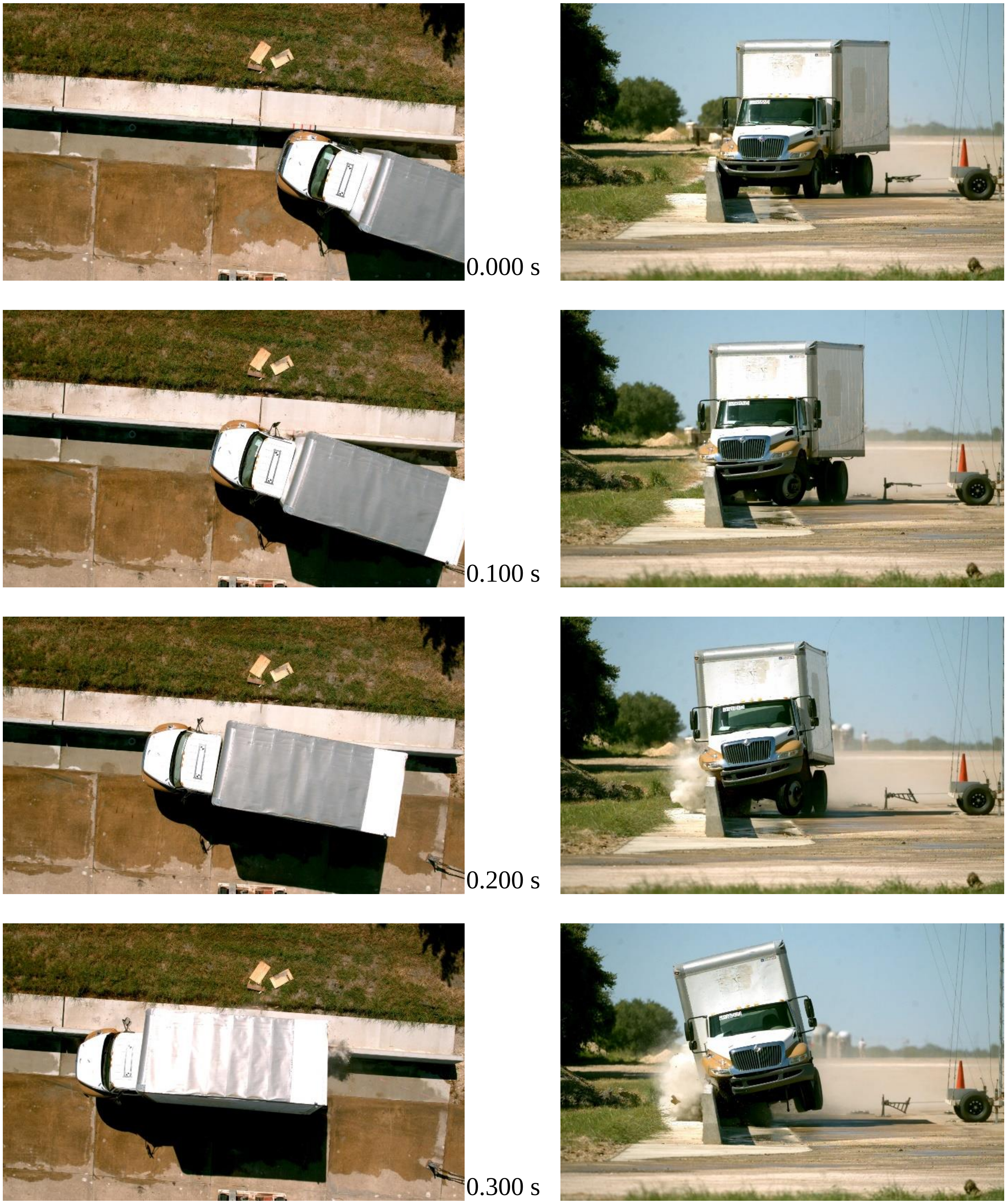


Figure E.1. Sequential Photographs for Test No. 469680-02-3 (Overhead and Frontal Views).

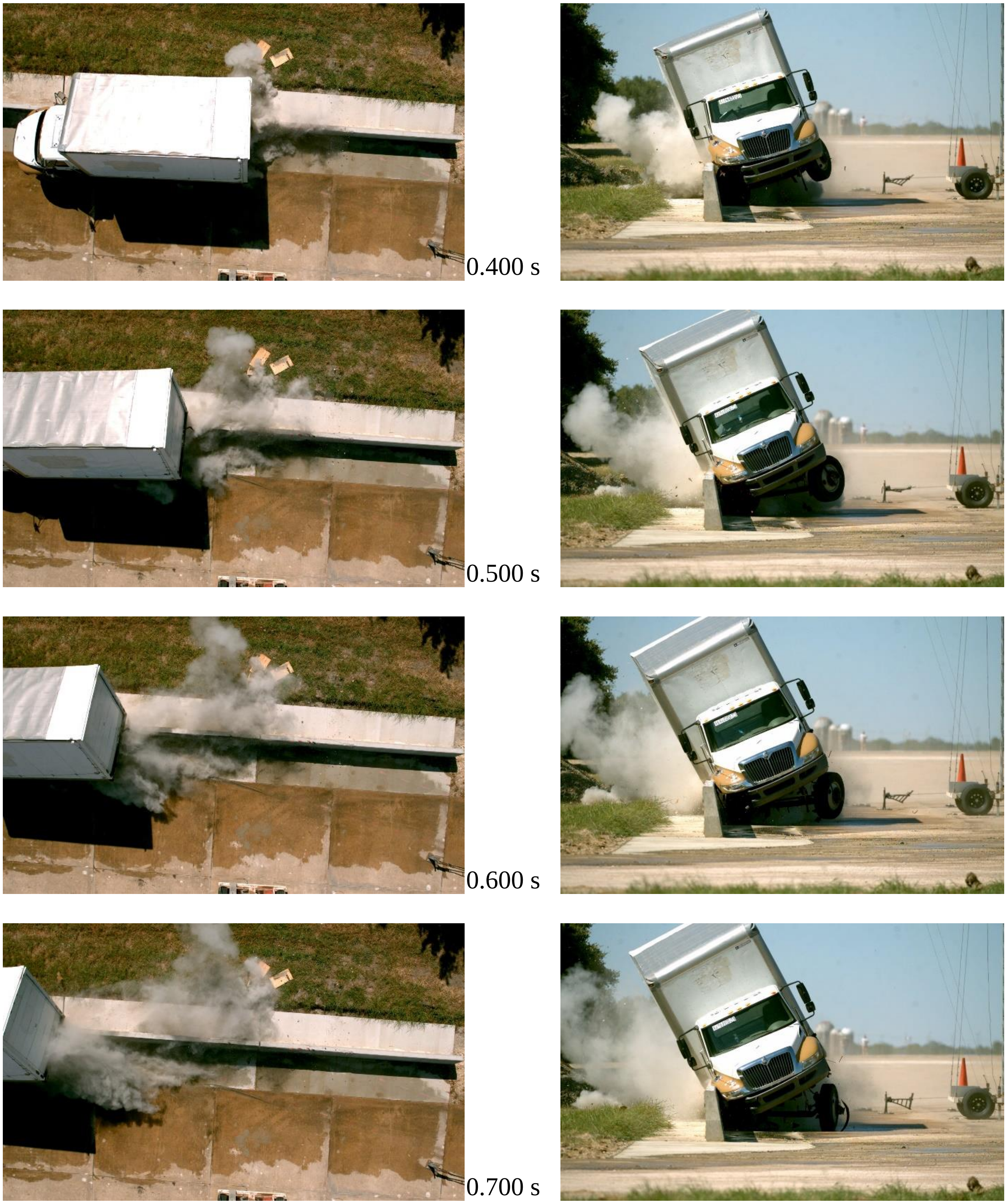
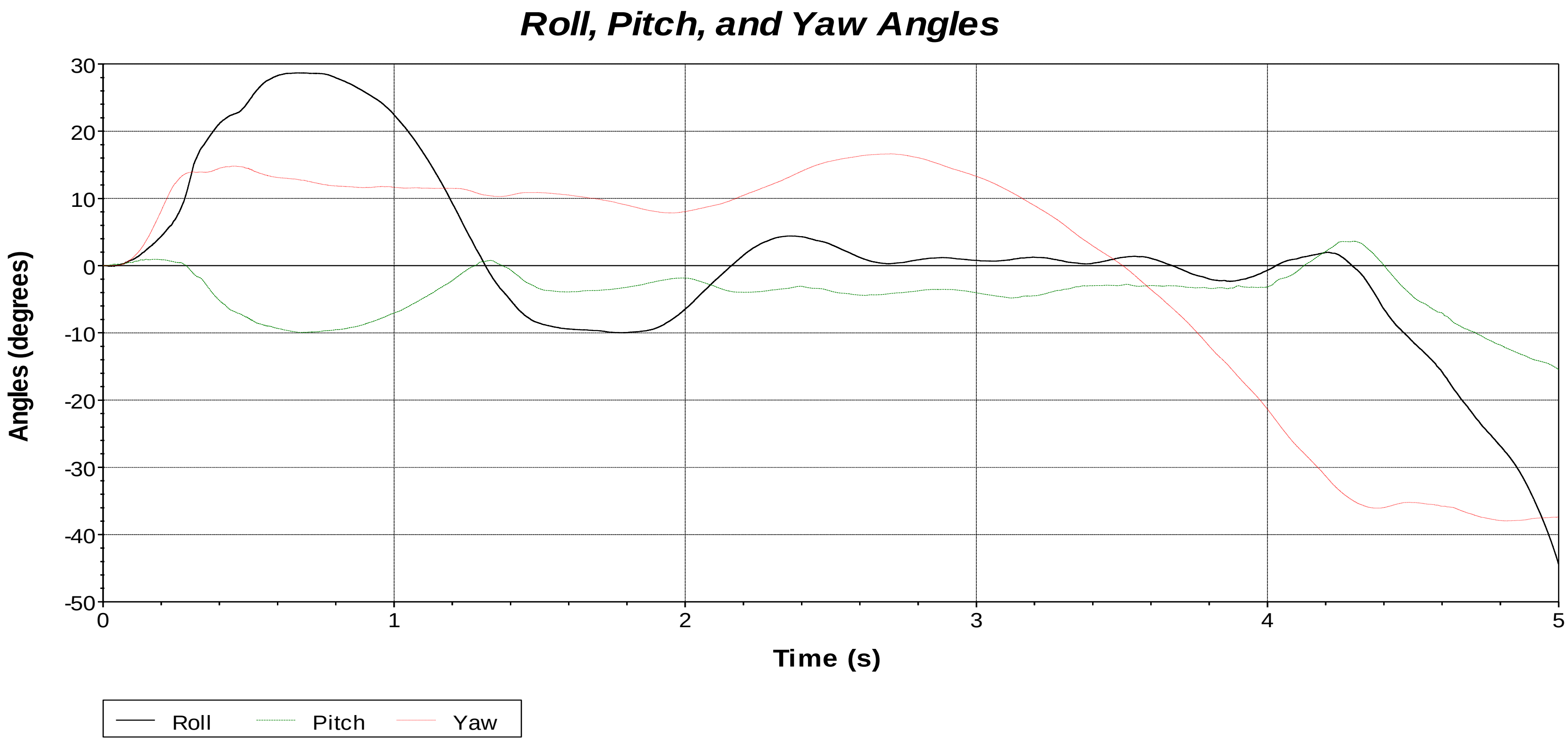


Figure E.1. Sequential Photographs for Test No. 469680-02-3 (Overhead and Frontal Views) (Continued).

0.000 s | 0.400 s
0.100 s | 0.500 s
0.200 s | 0.600 s
0.300 s | 0.700 s

Figure E.2. Sequential Photographs for Test No. 469680-02-3 (Rear View).



Test Number: 469680-02-3
Test Standard Test Number: *MASH* Test 4-12
Test Article: Shallow Anchorage SSTR
Test Vehicle: 2009 International 4300 SUT
Inertial Mass: 22,500 lb
Gross Mass: 22,500 lb
Impact Speed: 57.4 mi/h
Impact Angle: 14.7°

Axes are vehicle-fixed.
Sequence for determining orientation:

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

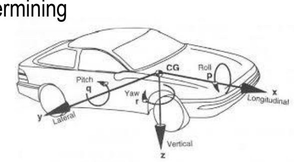
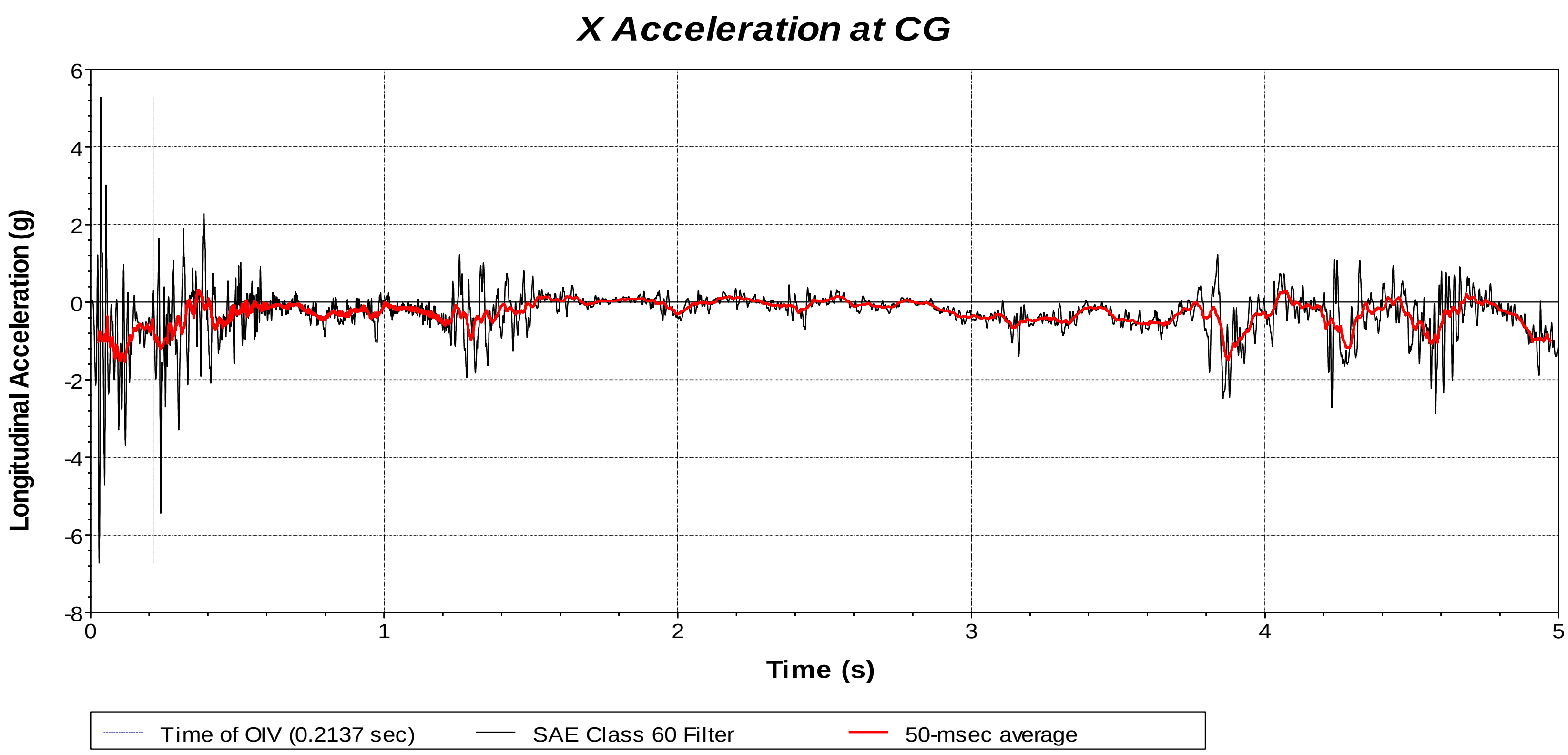


Figure E.3. Vehicle Angular Accelerations for Test No. 479680-02-3.



Test Number: 469680-02-3
Test Standard Test Number: *MASH* Test 4-12
Test Article: Shallow Anchorage SSTR
Test Vehicle: 2009 International 4300 SUT
Inertial Mass: 22,500 lb
Gross Mass: 22,500 lb
Impact Speed: 57.4 mi/h
Impact Angle: 14.7°

Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Center of Gravity).

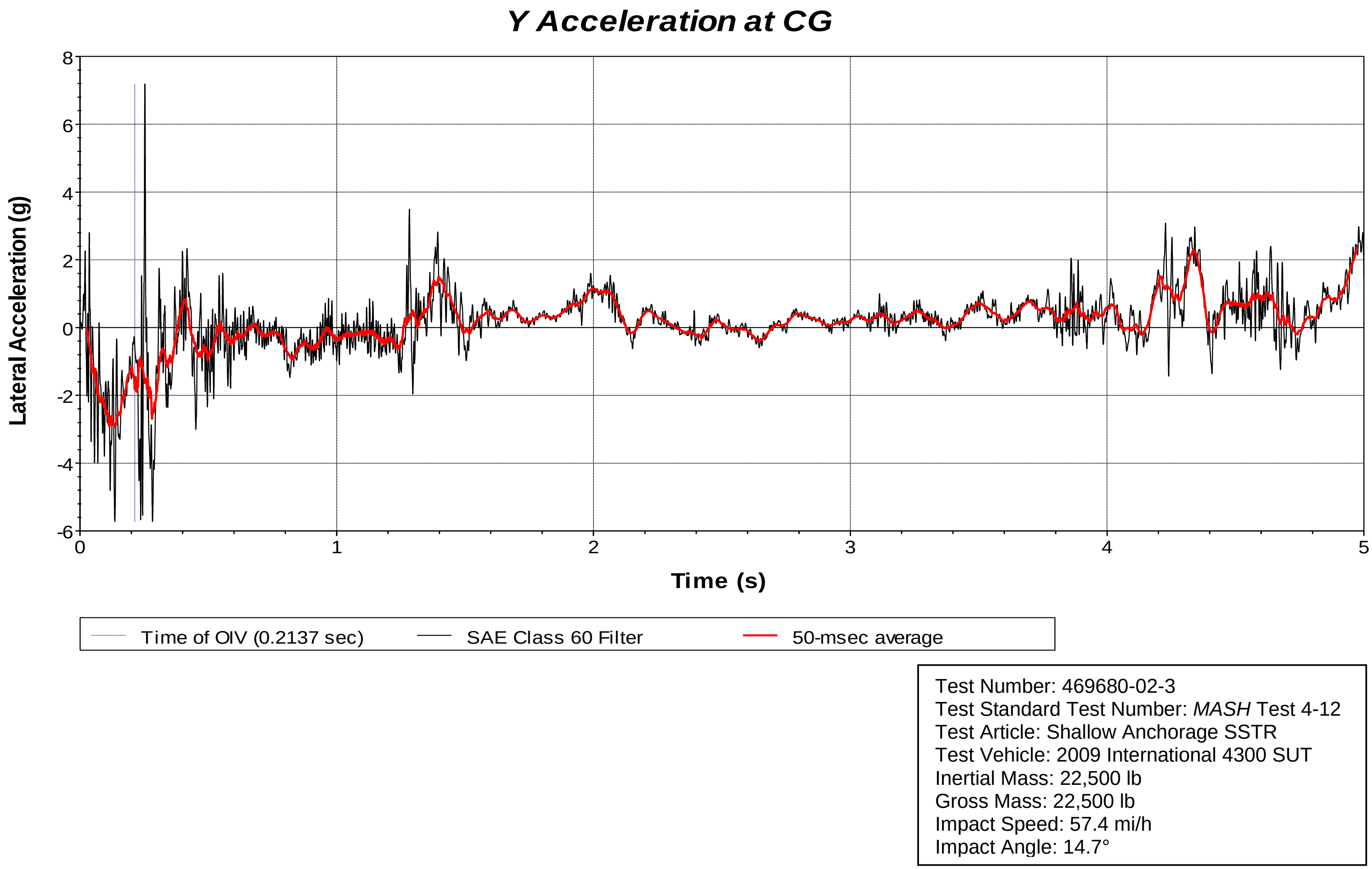
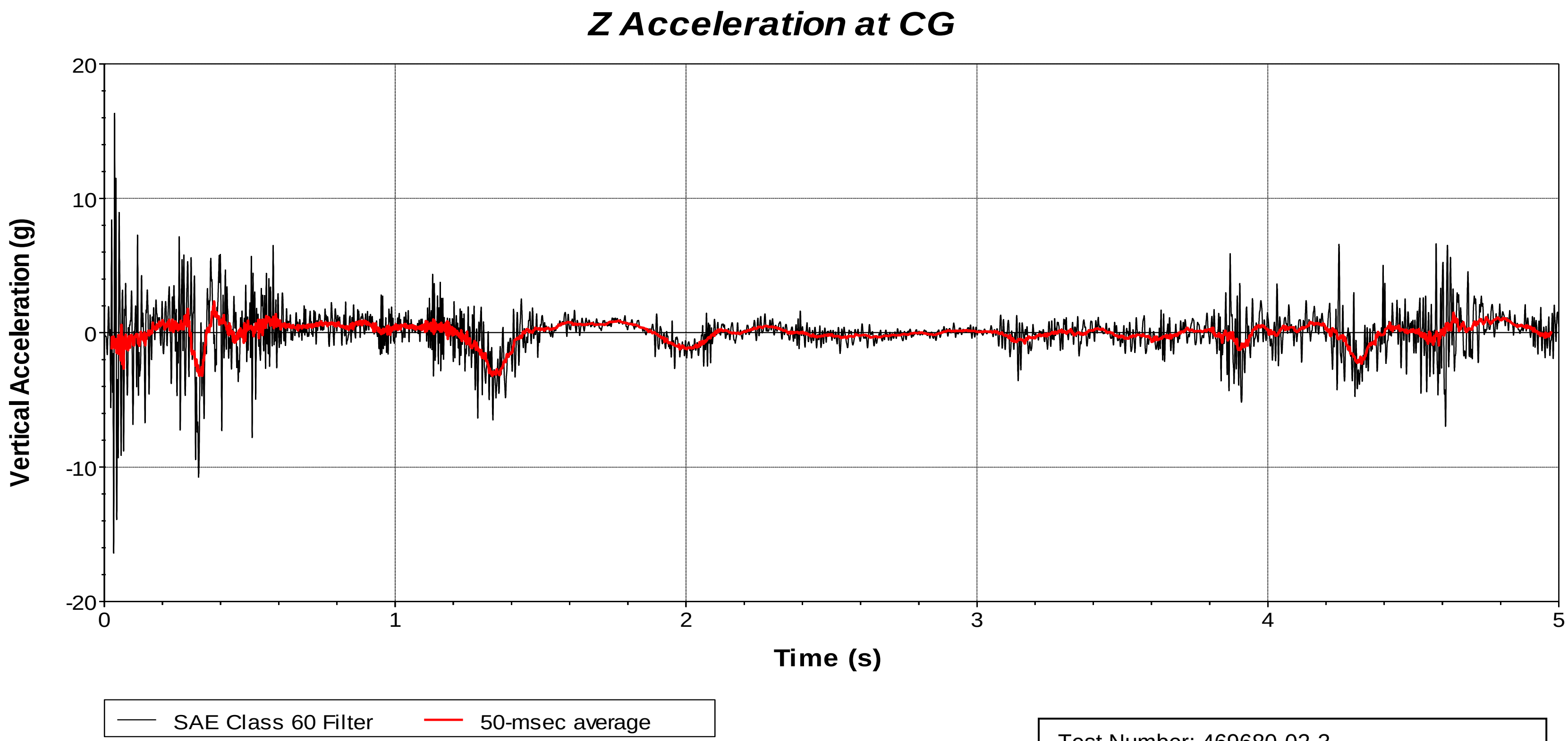


Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Center of Gravity).



Test Number: 469680-02-3
Test Standard Test Number: *MASH* Test 4-12
Test Article: Shallow Anchorage SSTR
Test Vehicle: 2009 International 4300 SUT
Inertial Mass: 22,500 lb
Gross Mass: 22,500 lb
Impact Speed: 57.4 mi/h
Impact Angle: 14.7°

Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Center of Gravity).

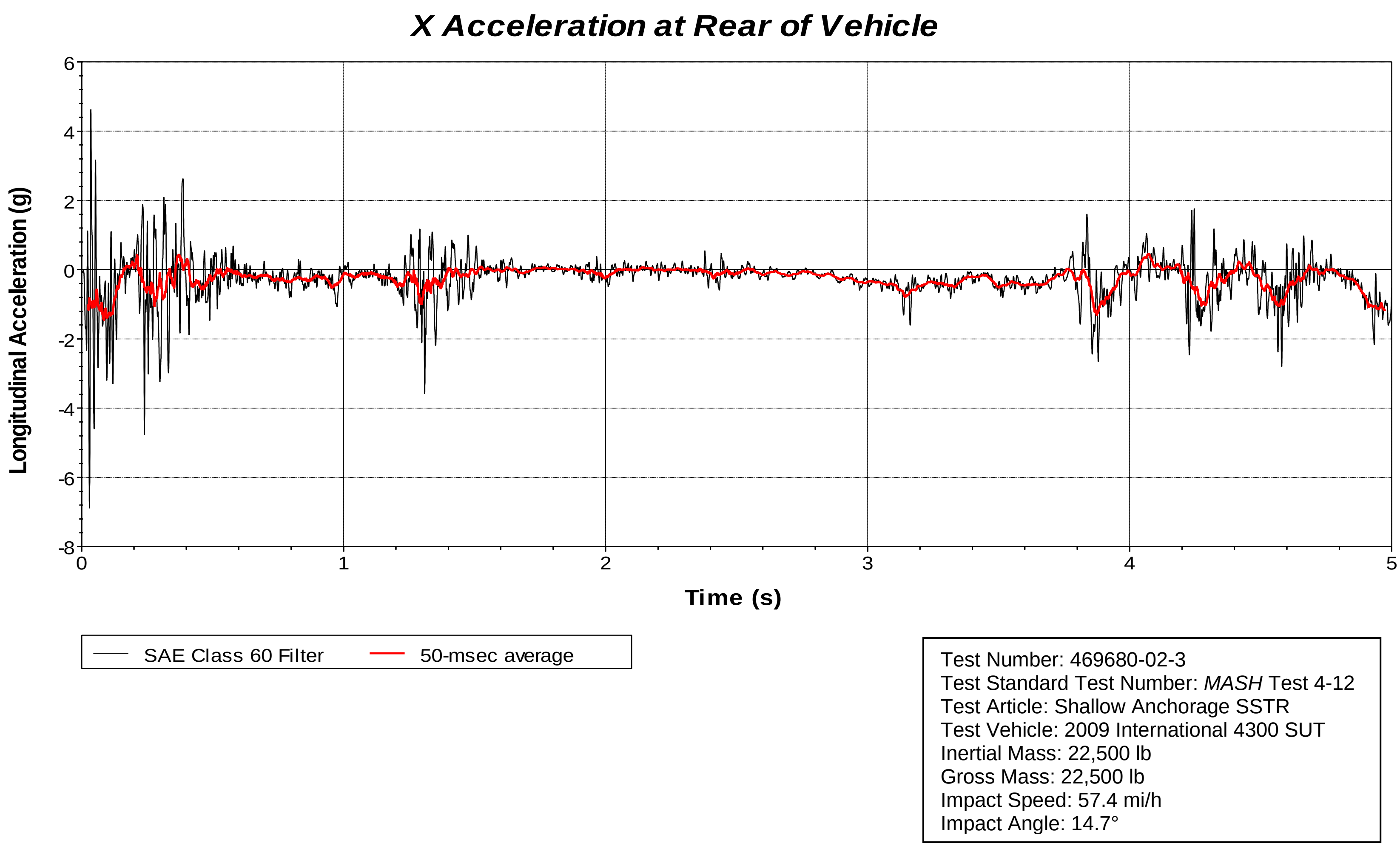


Figure E.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Rear of Vehicle).

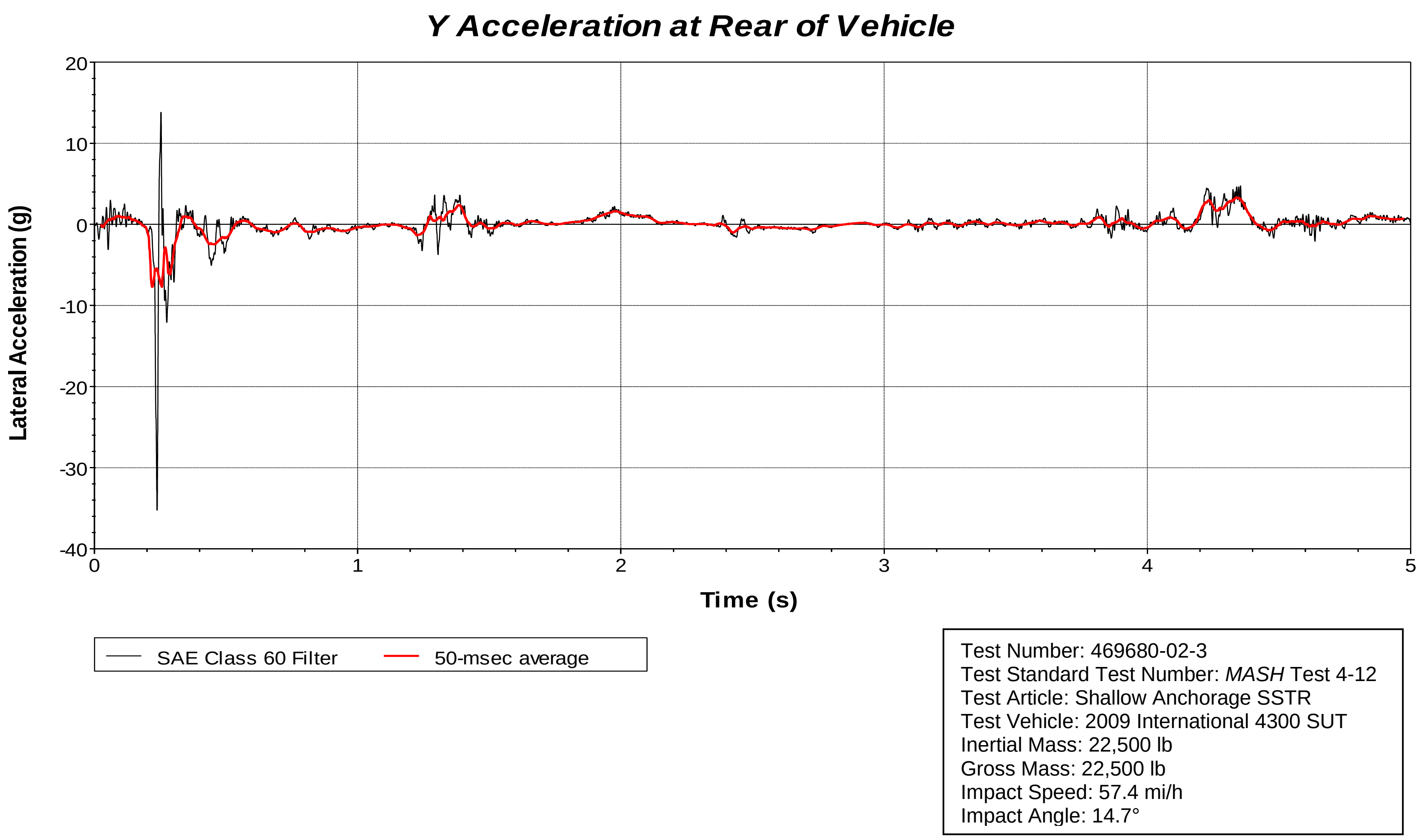


Figure E.8. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Rear of Vehicle).

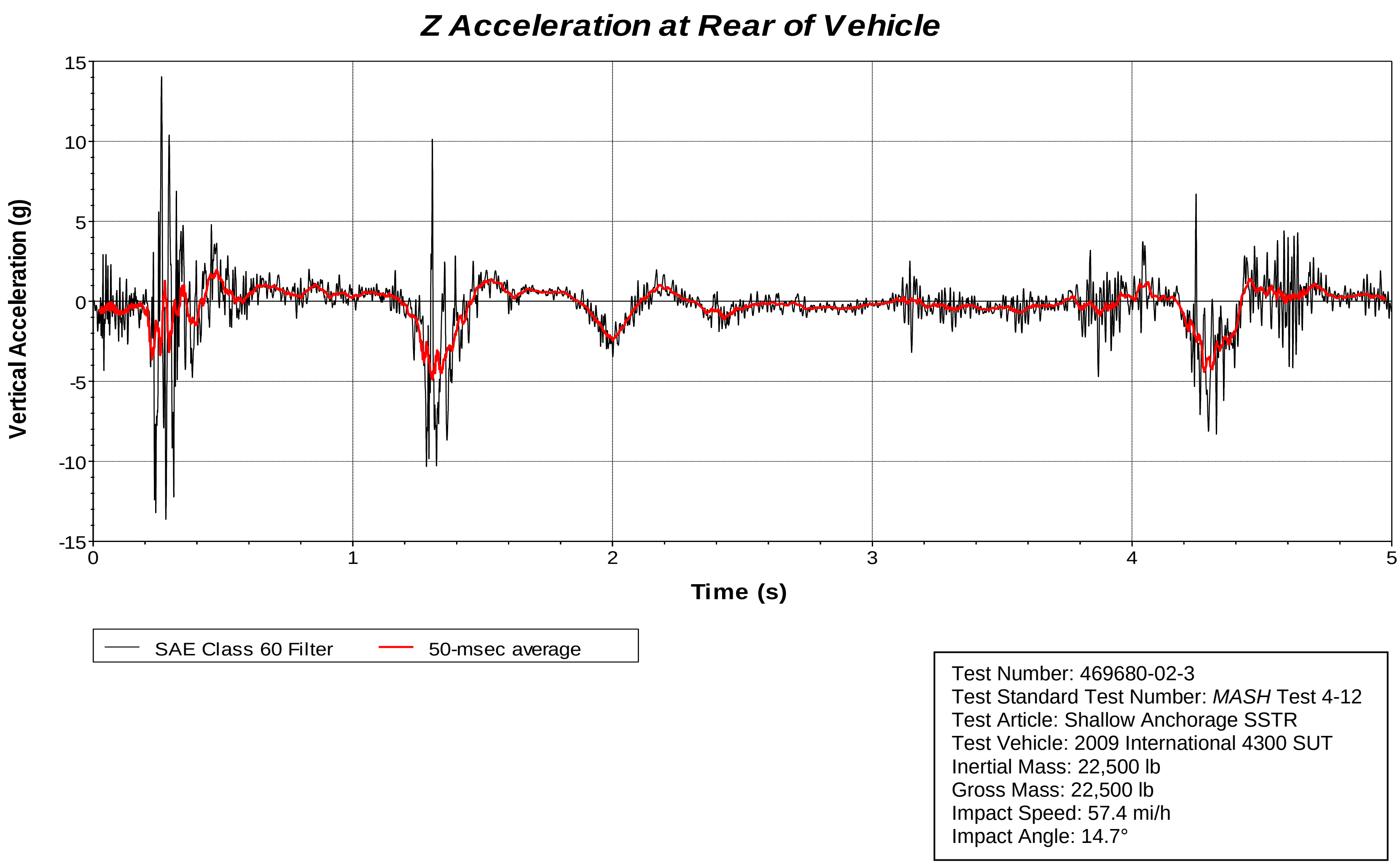


Figure E.9. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Rear of Vehicle).