Texas A&M Transportation Institute

DEVELOPMENT OF MODIFIED TxDOT SINGLE-POST SKID-MOUNTED SIGN SUPPORT

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-R3

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

Previous crash testing determined that the conventional Texas Department of Transportation (TxDOT) single-post skid-mounted sign support did not satisfy guidelines included in the American Association of State Highway and Transportation Officials *Manual for Assessing Safety Hardware* (*MASH*). Modifications were made to the system to improve impact performance and meet *MASH* requirements. The modifications included increasing mounting height of the sign, installing weakening holes in the wood support post at a prescribed height, and adding a wire rope loop around the weakening holes to act as a hinge mechanism when sections of the wood sign support fracture during vehicle impact.

Crash tests were performed on the modified TxDOT single-post skid-mounted sign support system in accordance with the *MASH* Test Level 3 (TL-3) matrix for work-zone traffic control devices. This report provides details of the modified TxDOT single-post skid-mounted sign support, the crash tests and results, and the performance assessment of the modified TxDOT single-post skid-mounted sign support for *MASH* TL-3 work-zone traffic control device evaluation criteria. The modified TxDOT single-post skid-mounted sign support with 90-inch sign mounting height, weakening holes, and tether cable met the performance criteria for *MASH* TL-3 work-zone traffic control devices.

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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 the project was Roger P. Bligh, P.E. TX#78550. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or 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 (TxDOT) single wood-post skid-mounted temporary sign support system uses a nominal 4-inch × 4-inch post and is designed for use with a maximum 12-sq-ft sign panel. Details can be found on TxDOT Barricade and Construction Sheet BC(5)-14. Under TxDOT Research Project 0-6946 (*1*), the system was crash tested to determine if it was compliant with the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*2*). During Test 3-72, with the sign panel oriented parallel to the path of the impacting pickup truck, the wood post fractured and the edge of the aluminum sign panel contacted and penetrated the top of the windshield, resulting in a 4-inch-long tear in its laminate. Consequently, the system did not meet *MASH* evaluation criteria.

The objective of this research effort was to modify the design of the single wood-post skid-mounted temporary sign support system to improve its impact performance and meet *MASH* requirements.

This report provides details of the modified TxDOT single skid-mounted sign support, crash tests and their results, and performance assessment of the modified TxDOT single skid-mounted sign support based on evaluation criteria for *MASH* TL-3 work-zone traffic control devices.

CHAPTER 2. TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1. CRASH TEST PERFORMED/MATRIX

Table 2.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for work-zone traffic control devices. The target critical impact angle (CIA) was determined using the information provided in *MASH* Section 2.2.4.1, Figure 2-5, and Section 3.4.2.3. *MASH* recognizes that a work-zone traffic control device may be rotated into an "out-of-service" position that places it 90 degrees to its normal "in-service" orientation. Therefore, these devices are typically tested at their CIA between 0 and 25 degrees for the in-service evaluation, and at 90 degrees for the out-of-service evaluation. Additionally, a temporary sign support might be placed at or near an intersection, which also requires evaluation at the 90-degree orientation per *MASH* Section 2.2.4.1. The CIA for the modified TxDOT single skid-mounted sign support was selected at 0 degrees. This angle was considered to provide increased opportunity for secondary contact of the sign with the windshield and roof of the impacting vehicle. A higher impact angle might induce rotation of the sign after fracture of the support, as well as a less predictable trajectory. Figure 2.1 shows the target impact angles for the *MASH* tests on the modified TxDOT single skid-mounted sign support.

Table 2.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Work-Zone Traffic Control Devices.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Work-Zone Traffic Control Device	3-70	1100C	19 mi/h	CIA	B, D, E, F, H, I, N
	3-71	1100C	62 mi/h	CIA	B, D, E, F, H, I, N
	3-72	2270P	62 mi/h	CIA	B, D, E, F, H, I, N

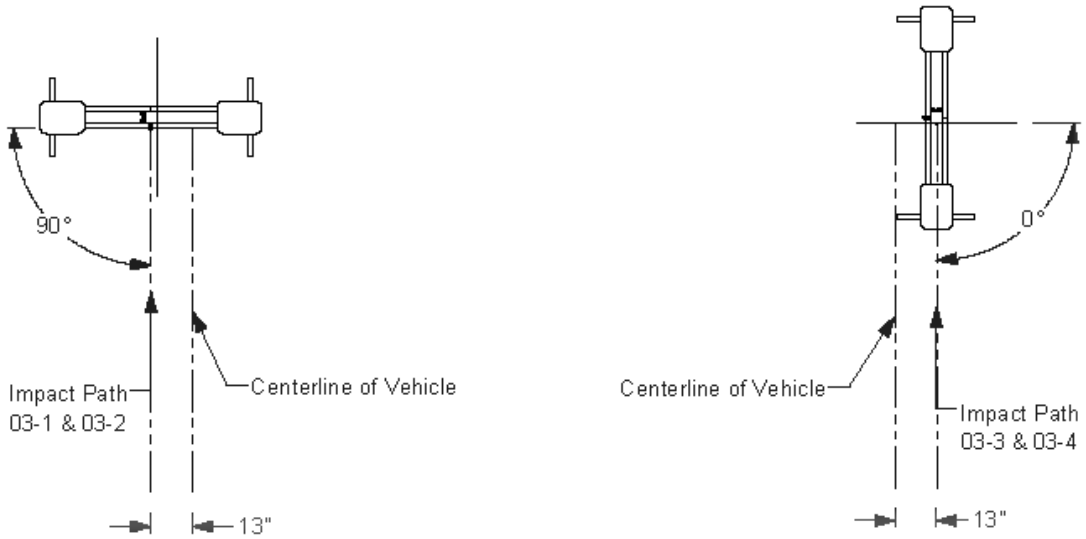


Figure 2.1. Target CIAs for *MASH* TL-3 Tests on Modified TxDOT Single Skid-Mounted Sign Support.

MASH states that Test 3-70 is considered optional for work-zone traffic control devices weighing less than 220 lb because velocity changes during low-speed impacts with freestanding, lightweight features will be within acceptable limits (see *MASH* Section 2.2.4.2 "Description of Tests"). Therefore, *MASH* Test 3-70 was not performed since the modified TxDOT single skid-mounted sign support weighed approximately 79 lb (exclusive of the two ballast sandbags).

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 3 presents brief descriptions of these procedures.

2.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-5 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. Table 2.1 lists the test conditions and evaluation criteria required for *MASH* TL-3, and Table 2.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 10.

Table 2.2. Evaluation Criteria Required for *MASH* TL-3 Work-Zone Traffic Control Devices.

Evaluation Factors	Evaluation Criteria		*MASH* Test
Structural Adequacy	*B.*	*The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.*	*71, 72*
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.*	*71, 72*
	E.	*Detached elements, fragments, or other debris from the test article, or vehicle damage, should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.*	*71, 72*
	F.	*The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	*71, 72*
	H.	*Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.*	*71, 72*
	I.	*The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	*71, 72*
Post-Impact Vehicular Response	*N.*	*Vehicle trajectory behind the test article is acceptable.*	*71, 72*

CHAPTER 3. TEST CONDITIONS

3.1. TEST FACILITY

The full-scale crash tests reported herein were performed at the Texas A&M Transportation Institute (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 modified TxDOT single skid-mounted sign support 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.

3.2. VEHICLE TOW AND GUIDANCE SYSTEM

Each 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.

3.3. DATA ACQUISITION SYSTEMS

3.3.1. 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 them 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 onto 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).

3.3.2. Anthropomorphic Dummy Instrumentation

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

According to *MASH*, use of a dummy in the 2270P vehicle is optional, and no dummy was used in the tests with the 2270P vehicle.

3.3.3. Photographic Instrumentation Data Processing

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

- One with a field of view perpendicular to and aligned with the sign support.
- One placed upstream from the installation at an oblique angle.

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the modified TxDOT single skid-mounted sign support. 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 4. *MASH* TEST 3-72 AT 90 DEGREES (CRASH TEST NO. 469680-03-2)

4.1. TEST ARTICLE DESIGN AND CONSTRUCTION

The initial test installation consisted of a 36-inch-square × 0.10-inch-thick aluminum sign mounted in a diamond orientation on a 4×4 wooden post. The bottom of the sign was 84 inches above grade. Two 2½-inch-diameter weakening holes were drilled through the post, one perpendicular to the sign panel 66 inches from grade and another parallel to the sign panel 69½ inches above grade. The weakening holes were designed to control the fracture location of the wood sign post during impact and, thus, help control both the length and trajectory of the fracture support segments. A 38-inch-long, $^{3}/_{16}$-inch-diameter, 7×19 wire rope tether was fed through ½-inch-diameter holes drilled through the post parallel to the sign panel just below and above the 2½-inch weakening holes. The tether cable was secured back to itself with four wire rope clips. The tether cable was designed to act as a hinge mechanism that prevents the lower section of the fracture support post from independently rotating toward the vehicle windshield.

The post was supported by two 60-inch-long, 2×6 wooden skids centered on the post and oriented perpendicular to the face of the sign. The free ends of the skids were separated using 5½-inch-tall, 4×4 wooden blocks. A 24-inch-long, 2×6 wooden outrigger was attached perpendicular across each end of the skids. A 40-lb sandbag was placed on each end of the skids for stability. The post was also supported in the back by a 34½-inch-long, 2×4 wooden brace that was secured to the back of the post and between the skids. The sign support assembly weighed 79 lb excluding the sandbags.

Figure 4.1 presents the overall information on the modified TxDOT single skid-mounted sign support, and Figure 4.2 provides photographs of the installation. Drawings were provided by the TTI Proving Ground, and construction was performed by TTI Proving Ground personnel.

4.2. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the work-zone traffic control device at an impact speed of 62 mi/h ± 2.5 mi/h. The impact angle for this test was 90 degrees ± 1.5 degrees. The target impact point was the centerline of the sign support post aligned 13 inches from the centerline of the vehicle toward the driver's side. Figure 2.1 and Figure 4.3 depict the target impact setup.

The 2270P vehicle weighed 5000 lb, and the actual impact speed and angle were 63.0 mi/h and 90 degrees. The vehicle impacted the sign support post 13 inches toward the driver's side from the centerline of the vehicle. Minimum target kinetic energy (KE) was 594 kip-ft, and actual KE was 664 kip-ft.

4.3. WEATHER CONDITIONS

The test was performed on the morning of July 16, 2020. Weather conditions at the time of testing were as follows: wind speed: 10 mi/h; wind direction: 211 degrees (vehicle was traveling at a heading of 350 degrees); temperature: 86°F; relative humidity: 78 percent.

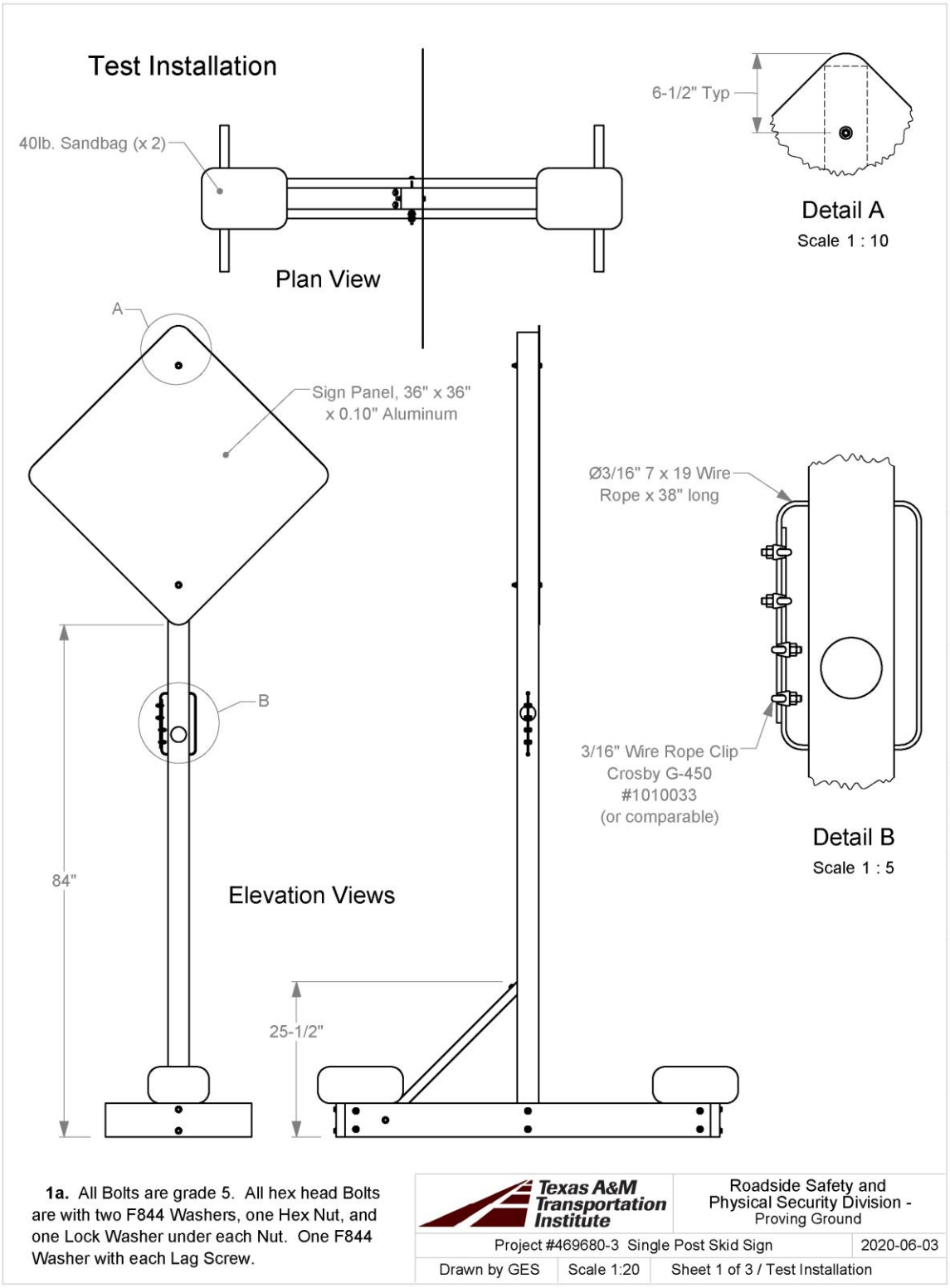


Figure 4.1. Modified TxDOT Single Skid-Mounted Sign Support Details (Original) for Crash Test 469680-03-2.

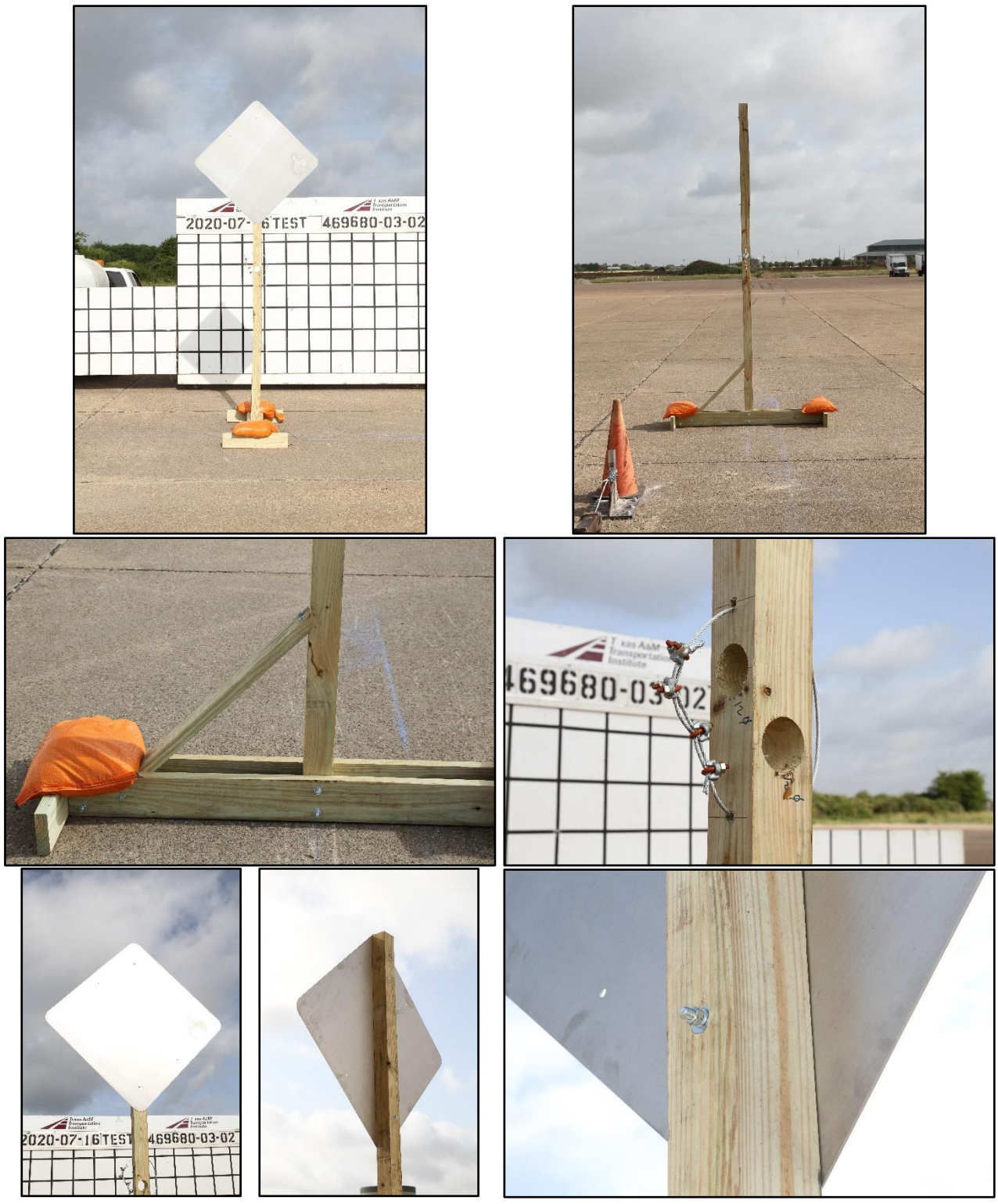


Figure 4.2. Modified TxDOT Single Skid-Mounted Sign Support (Original) prior to Crash Test No. 469680-03-2.

Figure 4.3. Sign Support/Test Vehicle Geometrics for Test No. 469680-03-2.

4.4. TEST VEHICLE

Figure 4.4 shows the 2014 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5000 lb, and its gross static weight was 5000 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 29.0 inches. Tables B.1 and B.2 in Appendix B.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 4.4. Test Vehicle before Test No. 469680-03-2.

4.5. TEST DESCRIPTION

Table 4.1 lists events that occurred during Test No. 469680-03-2. Figure B.1 in Appendix B.2 presents sequential photographs during the test.

Brakes on the vehicle were applied 1.15 s after impact. The vehicle subsequently came to rest 295 ft downstream of the point of impact and along the centerline of the vehicle impact path.

Table 4.1. Events during Test No. 469680-03-2.

Time (s)	Events
0.000	Vehicle impacts sign support
0.002	Wood post begins to fracture at impact height
0.004	Wood post begins to fracture at weakening holes
0.081	Sign panel contacts top of roof
0.166	Vehicle loses contact with sign panel while traveling at 61.4 mi/h

4.6. DAMAGE TO TEST INSTALLATION

Figure 4.5 shows the damage to the modified TxDOT single skid-mounted sign support. The debris field started 2 ft from impact and extended 30 ft downstream, 12 ft to the left, and 20 ft to the right, with smaller pieces of the base, post, and sandbags scattered throughout. There was a 4-ft-long piece of a skid 10 ft to the left and 45 ft downstream of impact. There was a 1-ft-long piece of the post 80 ft downstream and in line with the impact path. The sign panel and attached post section landed 105 ft downstream and 5 ft to the right of impact. There was also a 1-ft-long section of post located 15 ft to the right and 120 ft downstream of impact.

Figure 4.5. Modified TxDOT Single Skid-Mounted Sign Support after Test No. 469680-03-2.

4.7. DAMAGE TO TEST VEHICLE

Figure 4.6 shows the damage sustained by the vehicle. The front bumper sustained a 4-inch × 4-inch × 0.5-inch deformation 13 inches to the left of the centerline of the vehicle. There was also a 4-inch × 3-inch × 0.5-inch deformation at the front edge of the hood 13 inches to the left of the centerline of the vehicle. There was a 22-inch-long cut in the roof 13 inches to the left of the centerline and starting 1 inch rearward of the front windshield. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 0.5 inches on the bumper and hood 13 inches left of the centerline of the vehicle. The sign panel penetrated the roof of the occupant compartment over the driver's seat. Figure 4.7 shows the interior of the vehicle after the test. Tables B.3 and B.4 in Appendix B.1 provide exterior crush and occupant compartment measurements.

4.8. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 4.2. Figure B.2 in Appendix B.3 shows the vehicle angular displacements, and Figures B.3 through B.5 in Appendix B.4 show acceleration versus time traces. Figure 4.8 summarizes pertinent information from the test.

Figure 4.6. Test Vehicle after Test No. 469680-03-2.

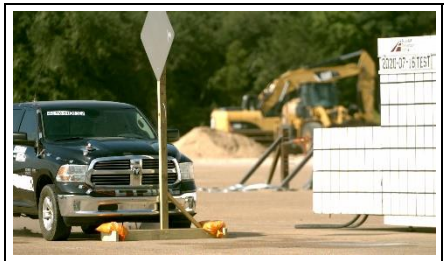
Figure 4.7. Interior of Test Vehicle after Test No. 469680-03-2.

Table 4.2. Occupant Risk Factors for Test No. 469680-03-2.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	0.0 ft/s	at 0.6845 s on right side of interior
Lateral	2.3 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	0.9 g	1.5736–1.5836 s
Lateral	0.4 g	1.8478–1.8578 s
Theoretical Head Impact Velocity (THIV)	0.8 m/s	at 0.6991 s on right side of interior
Acceleration Severity Index (ASI)	0.2	0.1510–0.2010 s
Maximum 50-ms Moving Average		
Longitudinal	−1.0 g	0.0091–0.0591 s
Lateral	−1.5 g	0.1173–0.1673 s
Vertical	−0.7 g	0.0159–0.0659 s
Maximum Yaw, Pitch, and Roll Angles		
Yaw	4°	1.7340 s
Pitch	4°	2.0000 s
Roll	3°	0.1980 s

4.9. DISCUSSION

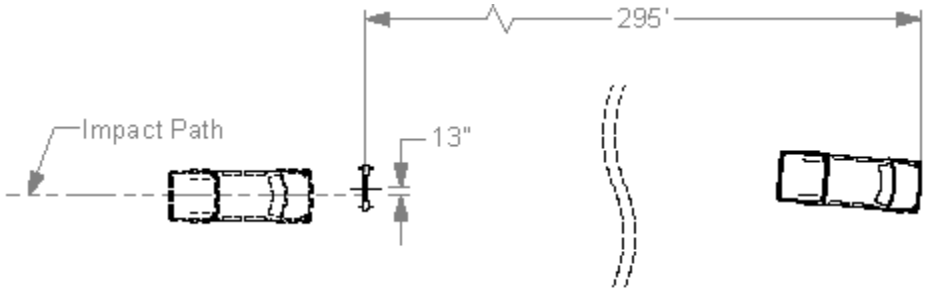
During Crash Test No. 469680-03-2, the sign panel contacted the roof of the 2270P vehicle, sliced a 22-inch-long hole in the roof, and penetrated the occupant compartment over the driver's seat. Film analysis indicated that while the tether cable prevented the fractured segments of the support post from separating, the amount of slack in the cable delayed its effectiveness in influencing the trajectory of the connected segments. A decision was made to reduce the length of the tether cable and remove the excess slack to more quickly engage the hinge mechanism provided between the two fracture segments of the support post. *MASH* Test 3-72 at 90 degrees was repeated on the redesigned single skid-mounted sign support, as described in the next chapter.

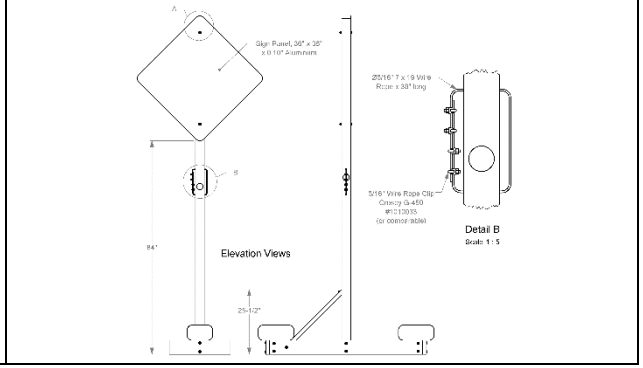

0.000 s


0.075 s


0.150 s


0.225 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 3-72 at 90°
- TTI Test No. 469680-03-2
- Test Date 2020-07-16

Test Article
- Type ..... Support Structure—Sign Support
- Name ..... TxDOT Single Skid-Mounted Sign Support
- Installation Height ..... 84-inch mounting height
- Material or Key Elements ... 36-inch-square × 0.10-inch-thick aluminum sign mounted in a diamond configuration on a 4×4 wooden post on 2×6 skid base w/ 2 sandbags

Soil Type and Condition ..... Placed on concrete surface, dry

Test Vehicle
- Type/Designation 2270P
- Make and Model ..... 2014 RAM 1500 Pickup
- Curb ..... 5039 lb
- Test Inertial ..... 5000 lb
- Dummy ..... No dummy
- Gross Static ..... 5000 lb

Impact Conditions
- Speed ..... 63.0 mi/h
- Angle ..... 90°
- Location/Orientation ..... 13 inches left of vehicle centerline

Kinetic Energy ..... 664 kip-ft

Exit Conditions
- Speed ..... 61.4 mi//h
- Trajectory/Heading Angle ... 90°

Occupant Risk Values
- Longitudinal OIV ..... 0.0 ft/s
- Lateral OIV ..... 2.3 ft/s
- Longitudinal Ridedown ..... 0.9 g
- Lateral Ridedown ..... 0.4 g
- THIV ..... 0.8 m/s
- ASI 0.2

Max. 0.050-s Average
- Longitudinal ..... −1.0 g
- Lateral ..... −1.5 g
- Vertical ..... −0.7 g

Post-Impact Trajectory
- Stopping Distance ..... 295 ft downstream Centerline

Vehicle Stability
- Maximum Yaw Angle ..... 4°
- Maximum Pitch Angle ..... 4°
- Maximum Roll Angle ..... 3°

Test Article Debris Scatter
- Longitudinal ..... 30 ft downstream
- Lateral ..... 12 ft left/20 ft right

Vehicle Damage
- VDS 12FL2
- CDC 12FLAN8
- Max. Exterior Deformation ..... 0.5 inches
- OCDI ..... Roof penetration
- Max. Occupant Compartment Deformation ..... Roof cut

Figure 4.8. Summary of Results for *MASH* Test 3-72 at 90 Degrees on Modified TxDOT Single Skid-Mounted Sign Support.

CHAPTER 5. *MASH* TEST 3-72 AT 90 DEGREES (CRASH TEST NO. 469680-03-2A)

5.1. TEST ARTICLE AND INSTALLATION DETAILS

The design of the single skid-mounted sign support remained the same as described in Section 4.1, with two exceptions. The tether cable that looped around the weakening holes in the support post was decreased in length from 38 inches to 36 inches, while the hole through which the cable passed remained spaced at 10 inches above and below the larger weakening holes. Additionally, any excess slack in the tether cable was removed before the cable clamps were tightened to secure it in place. Figure 5.1 presents overall details of the modified TxDOT single skid-mounted sign support, and Figure 5.2 provides photographs of the test installation.

5.2. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the work-zone traffic control device at an impact speed of 62 mi/h ± 2.5 mi/h. The impact angle for this test was 90 degrees ± 1.5 degrees. The target impact point was the centerline of the sign support post aligned 13 inches from the centerline of the vehicle toward the driver's side. Figure 2.1 and Figure 5.3 depict the target impact setup.

The 2270P vehicle weighed 5021 lb, and the actual impact speed and angle were 63.0 mi/h and 90 degrees. The vehicle impacted the sign support 13 inches toward the driver's side from the centerline of the vehicle. Minimum target KE was 594 kip-ft, and actual KE was 667 kip-ft.

5.3. WEATHER CONDITIONS

The test was performed on the morning of July 17, 2020. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h; wind direction: 216 degrees (vehicle was traveling at a heading of 350 degrees); temperature: 85°F; relative humidity: 80 percent.

5.4. TEST VEHICLE

Figure 5.4 shows the 2014 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5021 lb, and its gross static weight was 5021 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.75 inches. Tables C.1 and C.2 in Appendix C.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

5.5. TEST DESCRIPTION

Table 5.1 lists events that occurred during Test No. 469680-03-2A. Figure C.1 in Appendix C.2 presents sequential photographs during the test.

Brakes on the vehicle were applied at 2.0 s after impact. The vehicle subsequently came to rest 330 ft downstream of the point of impact and 7 ft left of the center of the impact path.

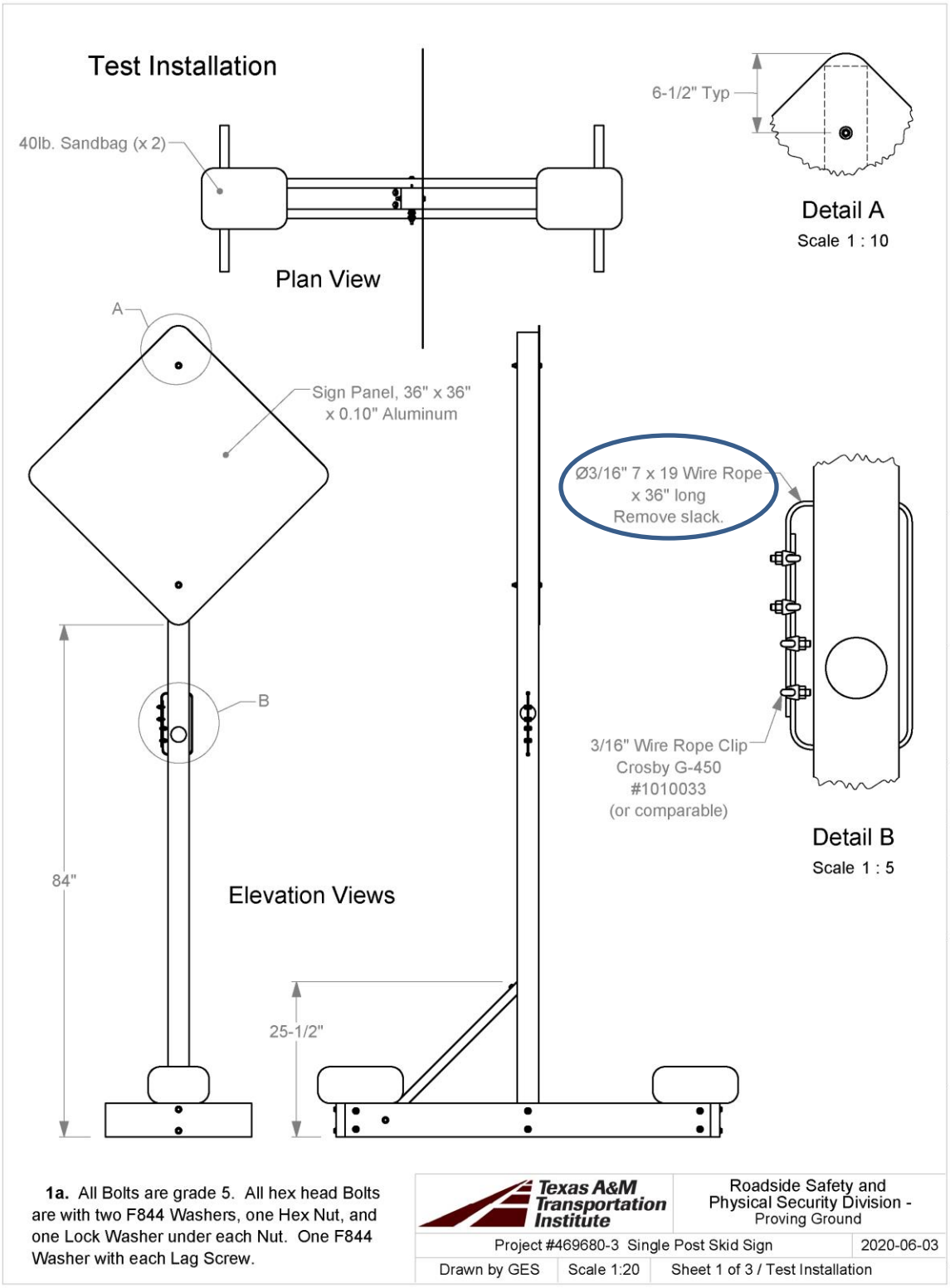


Figure 5.1. Modified TxDOT Single Skid-Mounted Sign Support Details (First Modification) for Crash Test 469680-03-2A.

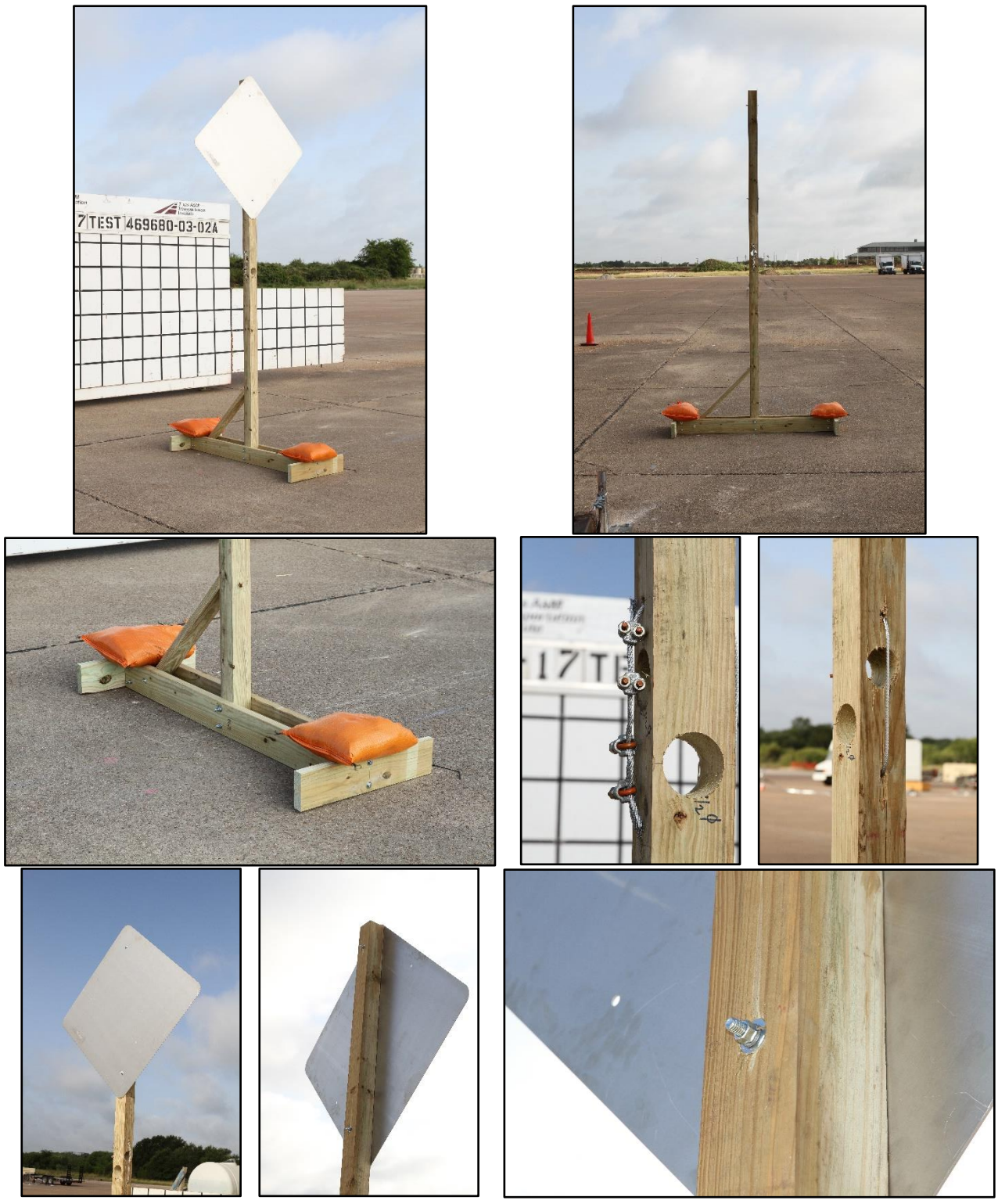


Figure 5.2. Modified TxDOT Single Skid-Mounted Sign Support (First Modification) prior to Crash Test No. 469680-03-2A.

Figure 5.3. Sign Support/Test Vehicle Geometrics for Test No. 469680-03-2A.

Figure 5.4. Test Vehicle before Test No. 469680-03-2A.

Table 5.1. Events during Test No. 469680-03-2A.

Time (s)	Events
0.000	Vehicle impacts sign support post
0.002	Wood post fractures at impact height
0.006	Wood post fractures at weakening holes
0.084	Sign contacts top of roof
0.165	Vehicle loses contact with sign panel while traveling at 61.2 mi/h

5.6. DAMAGE TO TEST INSTALLATION

Figure 5.5 shows the damage to the modified TxDOT single skid-mounted sign support. The debris field started from the point of impact and extended 12 ft to the left, 12 ft to the right, and 82 ft downstream of the point of impact. The sign panel with the attached post came to rest 82 ft downstream and 6 ft to the left of impact.

Figure 5.5. Modified TxDOT Single Skid-Mounted Sign Support after Test No. 469680-03-2A.

5.7. DAMAGE TO TEST VEHICLE

Figure 5.6 shows the damage sustained by the vehicle. The front bumper sustained a 4-inch × 6-inch × 0.75-inch deformation 13 inches to the left of the centerline of the vehicle. There was also a 4-inch × 2-inch × 0.5-inch deformation at the front edge of the hood 13 inches to the left of the centerline of the vehicle. There was a 12-inch-long cut in the roof 13 inches to the left of the centerline and starting 1 inch from the top edge of the front windshield. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 0.75 inches. The sign panel penetrated the roof of the occupant compartment over the driver's seat. Figure 5.7 shows the interior of the vehicle. Tables C.3 and C.4 in Appendix C.1 provide exterior crush and occupant compartment measurements.

5.8. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 5.2. Figure C.2 in Appendix C.3 shows the vehicle angular displacements, and Figures C.3 through C.5 in Appendix C.4 show acceleration versus time traces. Figure 5.8 summarizes pertinent information from the test.

Figure 5.6. Test Vehicle after Test No. 469680-03-2A.

Figure 5.7. Interior of Test Vehicle after Test No. 469680-03-2A.

Table 5.2. Occupant Risk Factors for Test No. 469680-03-2A.

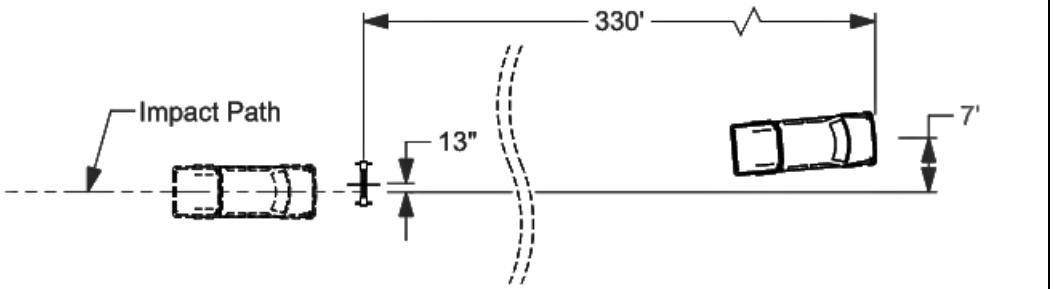
Occupant Risk Factor	Value	Time
OIV		
Longitudinal	2.6 ft/s	at 0.9647 s on right side of interior
Lateral	1.6 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	0.2 g	1.0731–1.0831 s
Lateral	0.5 g	1.1998–1.2098 s
THIV	0.9 m/s	at 0.9876 s on front of interior
ASI	0.1	0.0960–0.1460 s
Maximum 50-ms Moving Average		
Longitudinal	−1.0 g	0.0038–0.0538 s
Lateral	−1.0 g	0.1208–0.1708 s
Vertical	0.5 g	0.1325–0.1825 s
Maximum Yaw, Pitch, and Roll Angles		
Yaw	4°	1.4993 s
Pitch	4°	1.5000 s
Roll	3°	0.2008 s

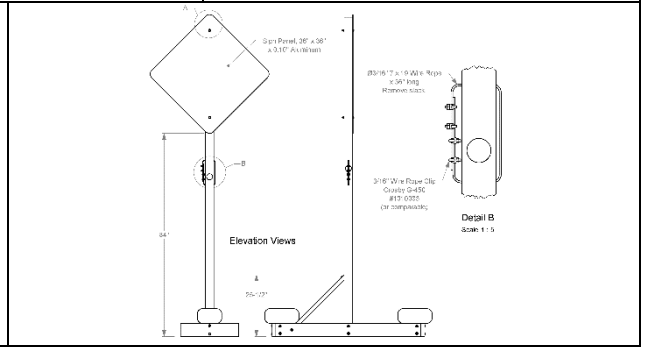

0.000 s


0.075 s


0.150 s


0.225 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 3-72 at 90°
- TTI Test No. 469680-03-2A
- Test Date 2017-07-17

Test Article
- Type ..... Support Structure—Sign Support
- Name ..... TxDOT Single Skid-Mounted Sign Support
- Installation Length ..... 84-inch mounting height
- Material or Key Elements ... 36-inch-square × 0.10-inch-thick aluminum sign mounted in a diamond configuration on a 4×4 wooden post on 2×6 skid base w/ 2 sandbags

Soil Type and Condition ..... Placed on concrete surface, dry

Test Vehicle
- Type/Designation 2270P
- Make and Model ..... 2014 RAM 1500 Pickup
- Curb ..... 5033 lb
- Test Inertial ..... 5021 lb
- Dummy ..... No dummy
- Gross Static ..... 5021 lb

Impact Conditions
- Speed ..... 63.0 mi/h
- Angle ..... 90°
- Location/Orientation ..... 13 inches left of vehicle centerline

Kinetic Energy ..... 667 kip-ft

Exit Conditions
- Speed ..... 61.2 mi/h
- Trajectory/Heading Angle ... 90°

Occupant Risk Values
- Longitudinal OIV ..... 2.6 ft/s
- Lateral OIV ..... 1.6 ft/s
- Longitudinal Ridedown ..... 0.2 g
- Lateral Ridedown ..... 0.5 g
- THIV ..... 0.9 m/s
- ASI 0.1

Max. 0.050-s Average
- Longitudinal ..... −1.0 g
- Lateral ..... −1.0 g
- Vertical ..... 0.5 g

Post-Impact Trajectory
- Stopping Distance ..... 330 ft downstream 7 ft left of center

Vehicle Stability
- Maximum Yaw Angle ..... 4°
- Maximum Pitch Angle ..... 4°
- Maximum Roll Angle ..... 3°

Test Article Debris Scatter
- Longitudinal ..... 82 ft downstream
- Lateral ..... 12 ft left/12 ft right

Vehicle Damage
- VDS 12FL2
- CDC 12FLAN8
- Max. Exterior Deformation ..... 0.75 inches
- OCDI ..... Roof penetrated
- Max. Occupant Compartment Deformation ..... Roof cut

Figure 5.8. Summary of Results for *MASH* Test 3-72 at 90 Degrees on Modified TxDOT Single Skid-Mounted Sign Support (with Shortened Wire Rope Cable).

5.9. DISCUSSION

During Crash Test No. 469680-03-2A, the sign panel contacted the roof of the 2270P vehicle, sliced a 12-inch-long hole in the roof, and penetrated the occupant compartment over the driver's seat. Design changes were made to improve impact performance. The modifications included raising both the sign mounting height and weakening holes 6 inches to reduce the interaction between the sign panel and the roof of the pickup truck. *MASH* Test 3-72 at 90 degrees was repeated on this redesigned single skid-mounted sign support, as described in the next chapter.

CHAPTER 6. *MASH* TEST 3-72 AT 90 DEGREES (CRASH TEST NO. 469680-03-2B)

6.1. TEST ARTICLE AND INSTALLATION DETAILS

The design of the single skid-mounted sign support remained the same as described in Section 5.1 with the following changes. The sign mounting height was increased by 6 inches, from 84 inches to 90 inches. The length of the vertical wood support post was correspondingly increased by 6 inches. Additionally, the height of the weakening holes in the wood support post was increased by 6 inches. The length of the tether cable remained at 36 inches with slack removed, as in Crash Test No. 469680-03-2A. Figure 6.1 presents overall details of the modified TxDOT single skid-mounted sign support, and Figure 6.2 provides photographs of the test installation. Appendix A provides further details of the final revisions on the modified TxDOT single skid-mounted sign support.

6.2. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the work-zone traffic control device at an impact speed of 62 mi/h ± 2.5 mi/h. The impact angle for this test was 90 degrees ± 1.5 degrees. The target impact point was the centerline of the sign support aligned 13 inches from the centerline of the vehicle toward the driver's side. Figure 2.1 and Figure 6.3 depict the target impact setup.

The 2270P vehicle weighed 5056 lb, and the actual impact speed and angle were 63.0 mi/h and 90 degrees. The vehicle impacted the sign support 13 inches toward the driver's side from the centerline of the vehicle. Minimum target KE was 594 kip-ft, and actual KE was 671 kip-ft.

6.3. WEATHER CONDITIONS

The test was performed on the afternoon of July 17, 2020. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 64 degrees (vehicle was traveling at a heading of 350 degrees); temperature: 95°F; relative humidity: 55 percent.

6.4. TEST VEHICLE

Figure 6.4 shows the 2014 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5056 lb, and its gross static weight was 5056 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 29.0 inches. Tables D.1 and D.2 in Appendix D.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

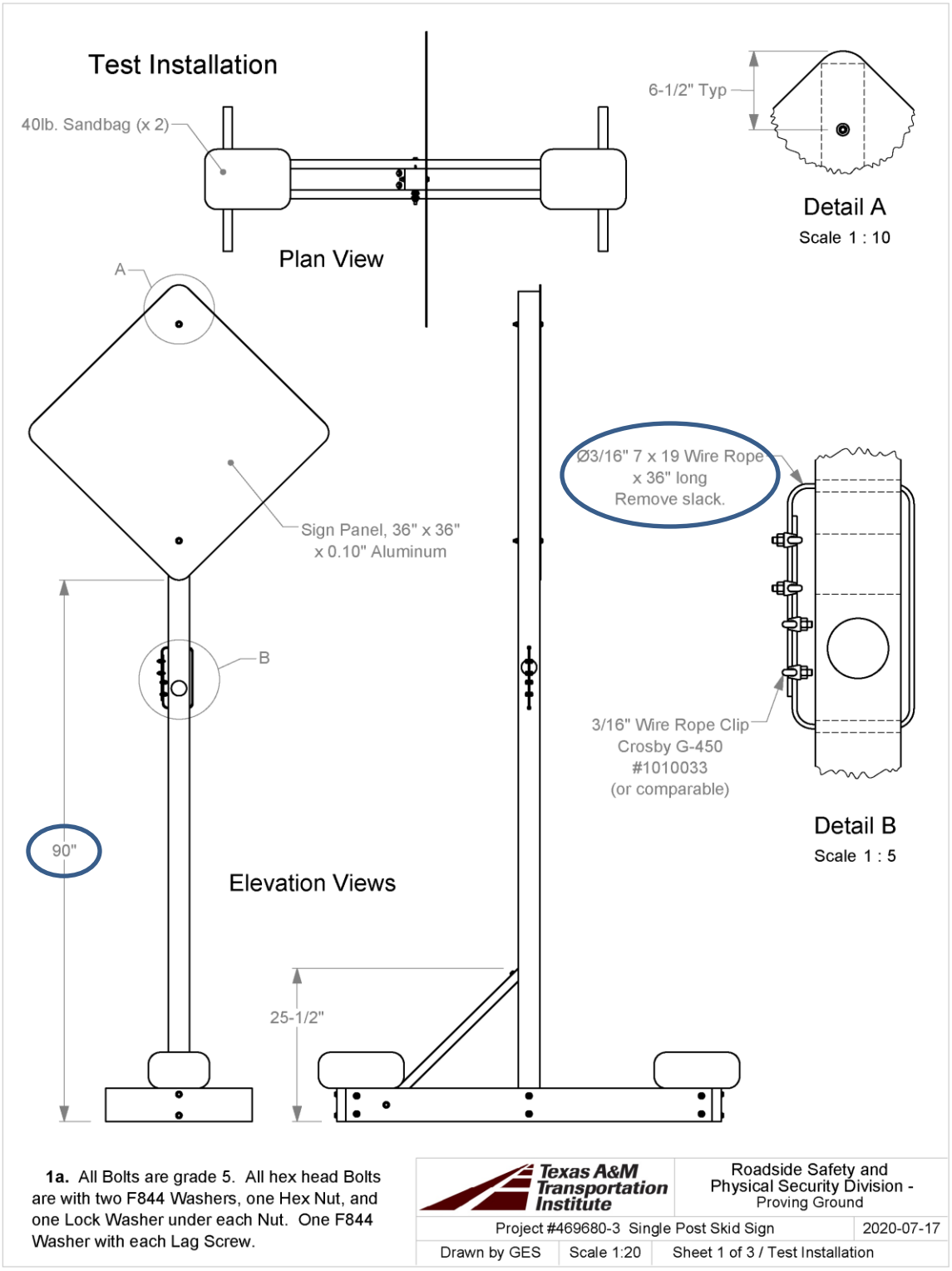


Figure 6.1. Modified TxDOT Single Skid-Mounted Sign Support Details (Final Modification) for Crash Test Nos. 469680-03-2B, 469680-03-4, 469680-03-1, and 469680-03-3.

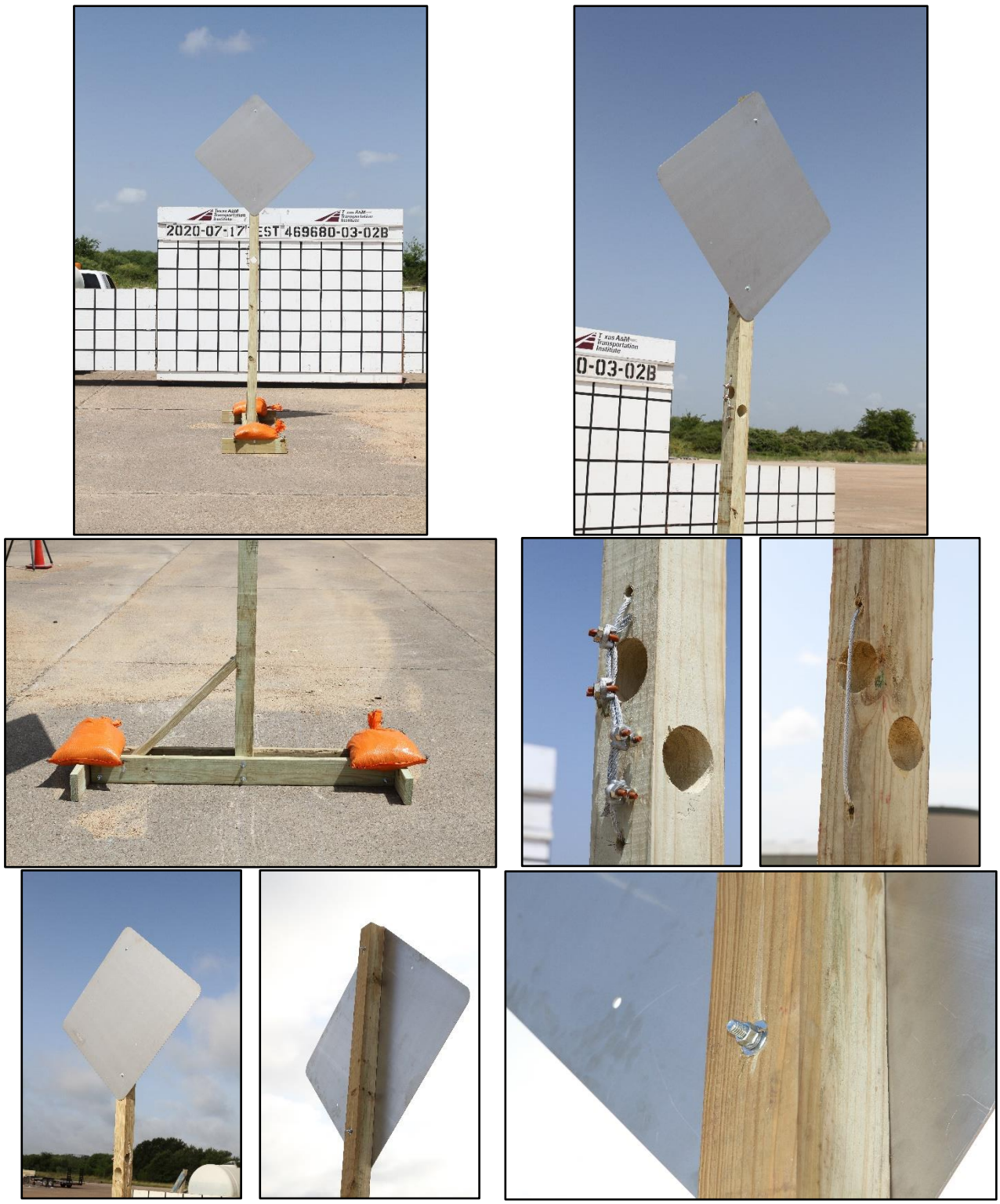


Figure 6.2. Modified TxDOT Single Skid-Mounted Sign Support (Final Modification) prior to Crash Test Nos. 469680-03-2B, 469680-03-4, 469680-03-1, and 469680-03-3 (Typical).

Figure 6.3. Sign Support/Test Vehicle Geometrics for Test No. 469680-03-2B.

Figure 6.4. Test Vehicle before Test No. 469680-03-2B.

6.5. TEST DESCRIPTION

Table 6.1 lists events that occurred during Test No. 469680-03-2B. Figure D.1 in Appendix D.2 presents sequential photographs during the test.

Table 6.1. Events during Test No. 469680-03-2B.

Time (s)	Events
0.000	Vehicle impacts sign support
0.003	Wood post fractures at impact height
0.006	Wood post fractures at holes
0.074	Wood post contacts top of windshield
0.101	Vehicle loses contact with wood post while traveling at 62.3 mi/h

Brakes on the vehicle were applied at 2.5 s after impact. The vehicle came to rest 390 ft downstream of the point of impact along the centerline of the impact path.

6.6. DAMAGE TO TEST INSTALLATION

Figure 6.5 shows the damage to the modified TxDOT single skid-mounted sign support. The debris field extended from 6 ft left, 6 ft right, and 45 ft downstream of impact, with the exception of one 20-inch-long piece of the post that landed 210 ft downstream and 32 ft to the left of impact. The sign panel and the attached segments of the fractured post came to rest 15 ft downstream and in line with the impact path.

Figure 6.5. Modified TxDOT Single Skid-Mounted Sign Support after Test No. 469680-03-2B.

6.7. DAMAGE TO TEST VEHICLE

Figure 6.6 shows the damage sustained by the vehicle. The front bumper sustained a 4-inch × 5-inch × 0.25-inch deformation 13 inches to the left of the centerline of the vehicle. There was also a 4-inch × 3-inch × 0.5-inch deformation at the front edge of the hood 13 inches to the left of the centerline of the vehicle. The windshield was shattered over an area of 12 inches × 14 inches × 1 inch near the top center at the roofline; however, there was no tear or cut in the windshield laminate. There was an 8-inch × 6-inch × 0.75-inch deformation in the roof 13 inches to the left of the centerline with no tear or cut. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 1.0 inch in the windshield. Maximum occupant compartment deformation was 1.0 inch in the windshield area. Figure 6.7 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D.1 provide exterior crush and occupant compartment measurements.

6.8. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.2. Figure D.2 in Appendix D.3 shows the vehicle angular displacements, and Figures D.3 through D.5 in Appendix D.4 show acceleration versus time traces. Figure 6.8 summarizes pertinent information from the test.

Figure 6.6. Test Vehicle after Test No. 469680-03-2B.

Figure 6.7. Interior of Test Vehicle after Test No. 469680-03-2B.

Table 6.2. Occupant Risk Factors for Test No. 469680-03-2B.

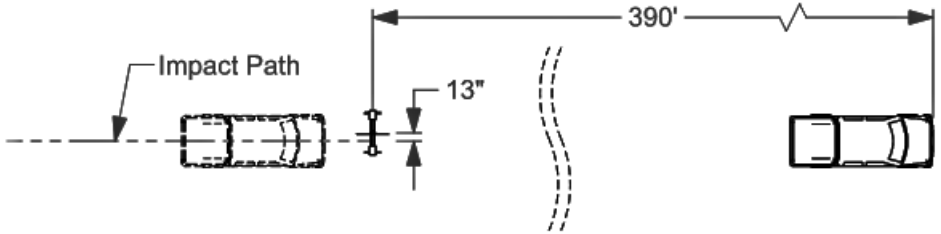
Occupant Risk Factor	Value	Time
OIV		
Longitudinal	0.0 ft/s	at 0.6845 s on right side of interior
Lateral	2.3 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	0.9 g	1.5736–1.5836 s
Lateral	0.4 g	1.8478–1.8578 s
THIV	0.8 m/s	at 0.6991 s on right side of interior
ASI	0.2	0.1510–0.2010 s
Maximum 50-ms Moving Average		
Longitudinal	−1.0 g	0.0091–0.0591 s
Lateral	−1.5 g	0.1173–0.1673 s
Vertical	−0.7 g	0.0159–0.0659 s
Maximum Yaw, Pitch, and Roll Angles		
Yaw	4°	1.7340 s
Pitch	4°	2.0000 s
Roll	3°	0.1980 s

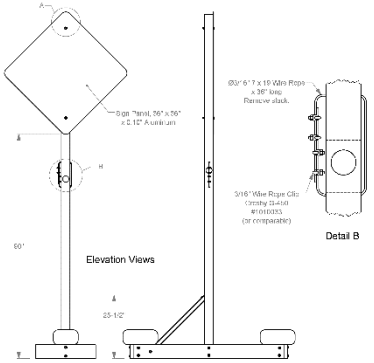
0.000 s

0.075 s

0.150 s

0.225 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 3-72 at 90°
- TTI Test No. 469680-03-2B
- Test Date 2020-07-17

Test Article
- Type ..... Support Structure—Sign Support
- Name ..... TxDOT Single Skid-Mounted Sign Support
- Installation Length ..... 90-inch mounting height
- Material or Key Elements ... 36-inch-square × 0.10-inch-thick aluminum sign mounted in a diamond configuration on a 4×4 wooden post on 2×6 skid base w/ 2 sandbags

Soil Type and Condition ..... Placed on concrete surface, dry

Test Vehicle
- Type/Designation 2270P
- Make and Model ..... 2014 RAM 1500 Pickup
- Curb ..... 5013 lb
- Test Inertial ..... 5056 lb
- Dummy ..... No dummy
- Gross Static ..... 5056 lb

Impact Conditions
- Speed ..... 63.0 mi/h
- Angle ..... 90°
- Location/Orientation ..... 13 inches to left of vehicle centerline

Kinetic Energy ..... 671 kip-ft

Exit Conditions
- Speed ..... 62.3 mi/h
- Trajectory/Heading Angle ... 90°

Occupant Risk Values
- Longitudinal OIV ..... 0.0 ft/s
- Lateral OIV ..... 2.3 ft/s
- Longitudinal Ridedown ..... 0.9 g
- Lateral Ridedown ..... 0.4 g
- THIV ..... 0.8 m/s
- ASI 0.2

Max. 0.050-s Average
- Longitudinal ..... −1.0 g
- Lateral ..... −1.5 g
- Vertical ..... −0.7 g

Post-Impact Trajectory
- Stopping Distance ..... 390 ft downstream Centerline

Vehicle Stability
- Maximum Yaw Angle ..... 4°
- Maximum Pitch Angle ..... 4°
- Maximum Roll Angle ..... 3°

Test Article Debris Scatter
- Longitudinal ..... 210 ft downstream
- Lateral ..... 32 ft left/6 ft right

Vehicle Damage
- VDS 12FL2
- CDC 12FLAN7
- Max. Exterior Deformation ..... 1.0 inch
- OCDI LF0000000
- Max. Occupant Compartment Deformation ..... 1.0 inch (windshield)

Figure 6.8. Summary of Results for *MASH* Test 3-72 at 90 Degrees on Modified TxDOT Single Skid-Mounted Sign Support (with Shortened Wire Rope Cable and Sign Mounting Height, Breakaway Holes, and Wire Rope Cable Raised 6 inches).

6.9. DISCUSSION

The redesigned TxDOT single skid-mounted sign support performed acceptably for *MASH* Test 3-72 at 90 degrees. Changes included a 36-inch tether cable with slack removed, the mounting height of the sign panel and length of the support post increased by 6 inches, and the weakening holes correspondingly raised 6 inches such that the bottom weakening/breakaway hole was 72 inches above grade. Details of this system are provided in Figure 7.1.

The remaining tests in the *MASH* matrix were performed with this same installation configuration. These tests are described in the following chapters.

CHAPTER 7. *MASH* TEST 3-72 AT 0 DEGREES (CRASH TEST NO. 469680-03-4)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the work-zone traffic control device at an impact speed of 62 mi/h ± 2.5 mi/h. The impact angle for this test was 0 degrees ± 1.5 degrees. The target impact point was the centerline of the sign support aligned 13 inches from the centerline of the vehicle toward the passenger's side. Figure 2.1 and Figure 7.1 depict the target impact setup.

Figure 7.1. Sign Support/Test Vehicle Geometrics for Test No. 469680-03-4.

The 2270P vehicle weighed 5024 lb, and the actual impact speed and angle were 62.1 mi/h and 0 degrees. The vehicle impacted the sign support 13 inches toward the passenger's side from the centerline of the vehicle. Minimum target KE was 594 kip-ft, and actual KE was 648 kip-ft.

7.2. WEATHER CONDITIONS

The test was performed on the morning of August 3, 2020. Weather conditions at the time of testing were as follows: wind speed: 1 mi/h; wind direction: 203 degrees (vehicle was traveling at a heading of 350 degrees); temperature: 88°F; relative humidity: 71 percent.

7.3. TEST VEHICLE

Figure 7.2 shows the 2014 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5024 lb, and its gross static weight was 5024 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 29.5 inches. Tables E.1 and E.2 in Appendix E.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.2. Test Vehicle before Test No. 469680-03-4.

7.4. TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 469680-03-4. Figure E.1 in Appendix E.2 presents sequential photographs during the test.

Table 7.1. Events during Test No. 469680-03-4.

Time (s)	Events
0.000	Vehicle impacts sign support
0.005	Wood post fractures at impact/bumper height
0.006	Wood post fractures at breakaway holes
0.027	Vehicle loses contact with sign support while traveling at 61.4 mi/h
0.145	Sign panel contacts top rear of roof

Brakes on the vehicle were applied at 2.56 s after impact. The vehicle came to rest 350 ft downstream of the point of impact and 6 ft to the left of the centerline of the vehicle impact path.

7.5. DAMAGE TO TEST INSTALLATION

Figure 7.3 shows the damage to the modified TxDOT single skid-mounted sign support. The base of the sign support came to rest 16 ft downstream and in line with impact. The sign and attached post segments landed 32 ft downstream and 2 ft to the right of impact. The support post fractured at several locations, including through the weakening holes, at the base, and at bumper height.

Figure 7.3. Modified TxDOT Single Skid-Mounted Sign Support after Test No. 469680-03-4.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.4 shows the damage sustained by the vehicle. The front bumper sustained a 4-inch × 8-inch × 0.25-inch deformation 13 inches to the right of the centerline of the vehicle. There was also a 4-inch × 4-inch × 0.5-inch deformation at the front edge of the hood 13 inches to the right of the centerline of the vehicle. There was a 26-inch × 24-inch area of scuff marks on the roof to the right of the centerline. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 0.5 inches in the front plane to the right of the center at bumper height. No occupant compartment deformation or intrusion was observed. Figure 7.5 shows the interior of the vehicle. Tables E.3 and E.4 in Appendix E.1 provide exterior crush and occupant compartment measurements.

7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.2. Figure E.2 in Appendix E.3 shows the vehicle angular displacements, and Figures E.3 through E.5 in Appendix E.4 show acceleration versus time traces. Figure 7.**6** summarizes pertinent information from the test.

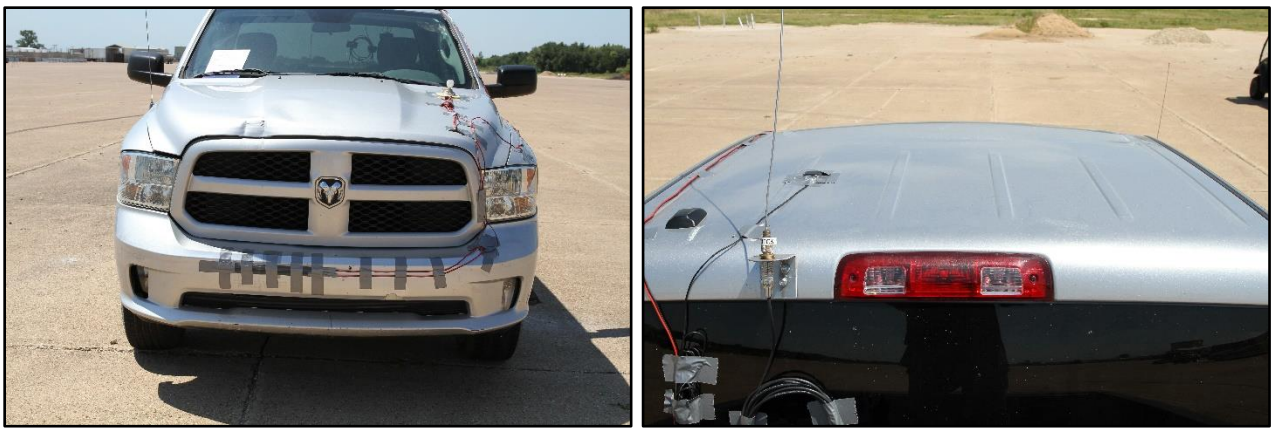


Figure 7.4. Test Vehicle after Test No. 469680-03-4.

Figure 7.5. Interior of Test Vehicle after Test No. 469680-03-4.

Table 7.2. Occupant Risk Factors for Test No. 469680-03-4.

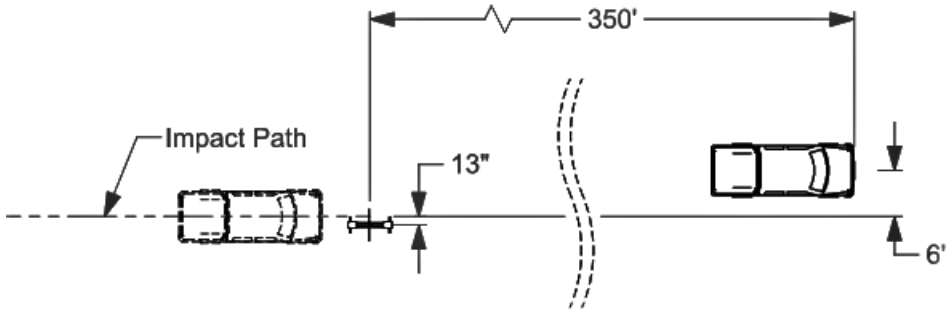
Occupant Risk Factor	Value	Time
OIV		
Longitudinal	0.3 ft/s	at 0.7944 s on right side of interior
Lateral	2.6 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	0.2 g	1.4199–1.4299 s
Lateral	0.6 g	0.8796–0.8896 s
THIV	0.8 m/s	at 0.7955 s on right side of interior
ASI	0.1	0.8849–0.9349 s
Maximum 50-ms Moving Average		
Longitudinal	−0.3 g	0.1275–0.1775 s
Lateral	−0.4 g	0.8595–0.9095 s
Vertical	−0.4 g	0.0424–0.0924 s
Maximum Yaw, Pitch, and Roll Angles		
Yaw	1°	2.0000 s
Pitch	2°	1.7252 s
Roll	2°	1.6403 s

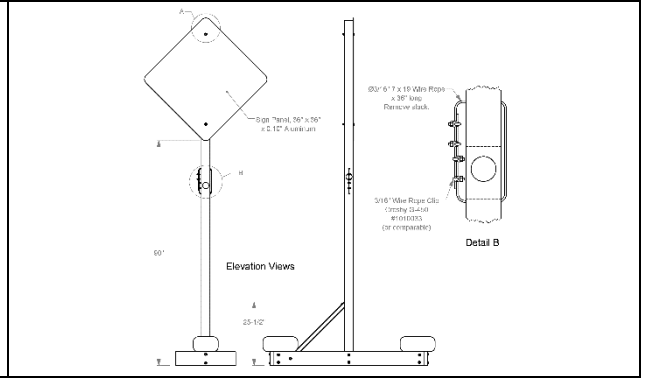

0.000 s


0.075 s


0.150 s


0.225 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 3-72 at 0°
- TTI Test No. 469680-03-4
- Test Date 2020-08-03

Test Article
- Type ..... Support Structure—Sign Support
- Name ..... TxDOT Single Skid-Mounted Sign Support
- Installation Length ..... 90-inch mounting height
- Material or Key Elements ... 36-inch-square × 0.10-inch-thick aluminum sign mounted in a diamond configuration on a 4×4 wooden post on 2×6 skid base w/ 2 sandbags

Soil Type and Condition ..... Placed on concrete surface, dry

Test Vehicle
- Type/Designation 2270P
- Make and Model ..... 2014 RAM 1500 Pickup
- Curb ..... 5072 lb
- Test Inertial ..... 5024 lb
- Dummy ..... No dummy
- Gross Static ..... 5024 lb

Impact Conditions
- Speed ..... 62.1 mi/h
- Angle ..... 0°
- Location/Orientation ..... 13 inches right of vehicle centerline

Kinetic Energy ..... 648 kip-ft

Exit Conditions
- Speed ..... 61.4 mi/h
- Trajectory/Heading Angle ... 0°

Occupant Risk Values
- Longitudinal OIV ..... 0.3 ft/s
- Lateral OIV ..... 2.6 ft/s
- Longitudinal Ridedown ..... 0.2 g
- Lateral Ridedown ..... 0.6 g
- THIV ..... 0.8 m/s
- ASI 0.1

Max. 0.050-s Average
- Longitudinal ..... −0.3 g
- Lateral ..... −0.4 g
- Vertical ..... −0.4 g

Post-Impact Trajectory
- Stopping Distance ..... 350 ft downstream 6 ft left of center

Vehicle Stability
- Maximum Yaw Angle ..... 1°
- Maximum Pitch Angle ..... 2°
- Maximum Roll Angle ..... 2°

Test Article Deflections
- Longitudinal ..... 32 ft downstream
- Lateral ..... 2 ft right

Vehicle Damage
- VDS 12FR1
- CDC 12FREN1
- Max. Exterior Deformation ..... 0.5 inches
- OCDI RF0000000
- Max. Occupant Compartment Deformation ..... None

Figure 7.6. Summary of Results for MASH Test 3-72 at 0 Degrees on Modified TxDOT Single Skid-Mounted Sign Support.

CHAPTER 8. *MASH* TEST 3-71 AT 90 DEGREES (CRASH TEST NO. 469680-03-1)

8.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-71 involves an 1100C vehicle weighing 2420 lb ± 55 lb impacting the work-zone traffic control device at an impact speed of 62 mi/h ± 2.5 mi/h. The impact angle was 90 degrees ± 1.5 degrees. The target impact point was the centerline of the sign support aligned 13 inches toward the driver's side from the centerline of the vehicle. Figure 2.1 and Figure 8.1 depict the target impact setup.

Figure 8.1. Modified TxDOT Single Skid-Mounted Sign Support/Test Vehicle Geometrics for Test No. 469680-03-1.

The 1100C vehicle weighed 2430 lb, and the actual impact speed and angle were 62.7 mi/h and 90 degrees. The vehicle impacted the sign support 13 inches toward the driver's side from the centerline of the vehicle. Minimum target KE was 288 kip-ft, and actual KE was 319 kip-ft.

8.2. WEATHER CONDITIONS

The test was performed on the afternoon of August 3, 2020. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 96 degrees (vehicle was traveling at a heading of 350 degrees); temperature: 96°F; relative humidity: 45 percent.

8.3. TEST VEHICLE

Figure 8.2 shows the 2014 Nissan Versa used for the crash test. The vehicle's test inertia weight was 2430 lb, and its gross static weight was 2595 lb. The height to the lower edge of the vehicle bumper was 7.0 inches, and the height to the upper edge of the bumper was 22.25 inches. Table F.1 in Appendix F.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 8.2. Test Vehicle before Test No. 469680-03-1.

8.4. TEST DESCRIPTION

Table 8.1 lists events that occurred during Test No. 469680-03-1. Figure F.1 in Appendix F.2 presents sequential photographs during the test.

Table 8.1. Events during Test No. 469680-03-1.

Time (s)	Events
0.000	Vehicle impacts sign support
0.006	Wood post fractures at impact height
0.011	Wood post fractures at breakaway holes
0.022	Vehicle loses contact with sign while traveling at 61.9 mi/h

Brakes on the vehicle were applied at 3.5 s after impact. The vehicle came to rest 431 ft downstream of the point of impact and 4 ft to the right of the centerline of the vehicle impact path.

8.5. DAMAGE TO TEST INSTALLATION

Figure 8.3 shows the damage to the modified TxDOT single skid-mounted sign support. The sign support broke apart into multiple pieces, and the debris field was 19 feet to the left, 12.5 feet to the right, and 142 feet downstream of impact. The section of post attached to the sign landed 22 feet downstream and 5 feet left of impact.

Figure 8.3. Modified TxDOT Single Skid-Mounted Sign Support after Test No. 469680-03-1.

8.6. DAMAGE TO TEST VEHICLE

Figure 8.4 shows the damage sustained by the vehicle. The front bumper sustained a 4-inch × 4-inch × 0.25-inch deformation 13 inches to the left of the centerline of the vehicle. There was also a small deformation in the hood and grill, and the lower radiator support was deflected 2.0 inches toward the rear of the vehicle. A small dent was noted in the oil pan; however, no fuel tank damage was observed. Maximum exterior crush to the vehicle was 0.25 inches in the front plane to the left of the center at bumper height. No occupant compartment deformation was observed. Figure 8.5 shows the interior of the vehicle. Tables F.2 and F.3 in Appendix F.1 provide exterior crush and occupant compartment measurements.

8.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 8.2. Figure F.2 in Appendix F.3 shows the vehicle angular displacements, and Figures F.3 through F.5 in Appendix F.4 show acceleration versus time traces. Figure 8.6 summarizes pertinent information from the test.

Figure 8.4. Test Vehicle after Test No. 469680-03-1.

Figure 8.5. Interior of Test Vehicle after Test No. 469680-03-1.

Table 8.2. Occupant Risk Factors for Test No. 469680-03-1.

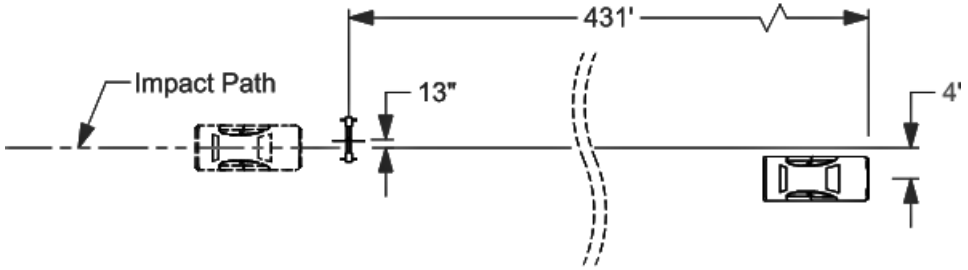
Occupant Risk Factor	Value	Time
OIV		
Longitudinal	3.9 ft/s	at 0.5844 s on front of interior
Lateral	2.0 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	1.1 g	1.0208–1.0308 s
Lateral	0.6 g	1.0498–1.0598 s
THIV	1.3 m/s	at 0.5834 s on front of interior
ASI	0.3	0.0361–0.0861 s
Maximum 50-ms Moving Average		
Longitudinal	−2.0 g	0.0020–0.0520 s
Lateral	0.5 g	0.0740–0.1240 s
Vertical	−3.2 g	0.0092–0.0592 s
Maximum Yaw, Pitch, and Roll Angles		
Yaw	2°	0.5018 s
Pitch	3°	0.1933 s
Roll	4°	2.0000 s

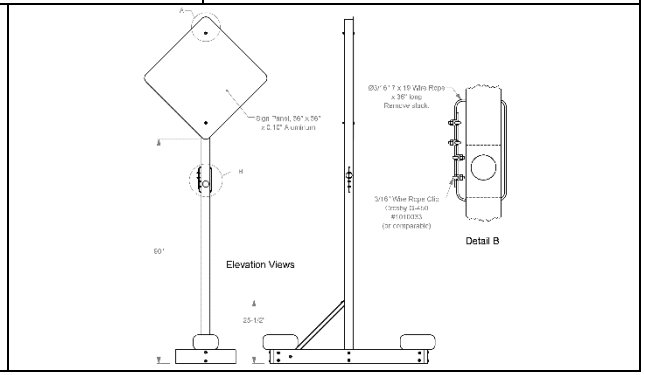

0.000 s


0.075 s


0.150 s


0.225 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 3-71 at 90°
- TTI Test No. 469680-03-1
- Test Date 2020-08-03

Test Article
- Type ..... Support Structure—Sign Support
- Name ..... TxDOT Single Skid-Mounted Sign Support
- Installation Length ..... 90-inch mounting height
- Material or Key Elements ... 36-inch-square × 0.10-inch-thick aluminum sign mounted in a diamond configuration on a 4×4 wooden post on 2×6 skid base w/ 2 sandbags

Soil Type and Condition ..... Placed on concrete surface, dry

Test Vehicle
- Type/Designation 1100C
- Make and Model ..... 2014 Nissan Versa
- Curb ..... 2446 lb
- Test Inertial ..... 2430 lb
- Dummy ..... 165 lb
- Gross Static ..... 2595 lb

Impact Conditions
- Speed ..... 62.7 mi/h
- Angle ..... 90°
- Location/Orientation ..... 13 inches to left of vehicle centerline

Kinetic Energy ..... 319 kip-ft

Exit Conditions
- Speed ..... 61.9 mi/h
- Trajectory/Heading Angle ... 90°

Occupant Risk Values
- Longitudinal OIV ..... 3.9 ft/s
- Lateral OIV ..... 2.0 ft/s
- Longitudinal Ridedown ..... 1.1 g
- Lateral Ridedown ..... 0.6 g
- THIV ..... 1.3 m/s
- ASI 0.3

Max. 0.050-s Average
- Longitudinal ..... −2.0 g
- Lateral ..... 0.5 g
- Vertical ..... −3.2 g

Post-Impact Trajectory
- Stopping Distance ..... 431 ft downstream
4 ft to right of center

Vehicle Stability
- Maximum Yaw Angle ..... 2°
- Maximum Pitch Angle ..... 3°
- Maximum Roll Angle ..... 4°

Test Article Debris Scatter
- Longitudinal ..... 142 ft downstream
- Lateral ..... 19 ft left/12½ ft right

Vehicle Damage
- VDS 12FL1
- CDC 12FLEN1
- Max. Exterior Deformation ..... 0.25 inches
- OCDI LF0000000
- Max. Occupant Compartment Deformation ..... None

Figure 8.6. Summary of Results for *MASH* Test 3-71 at 90 Degrees on Modified TxDOT Single Skid-Mounted Sign Support.

CHAPTER 9. *MASH* TEST 3-71 AT 0 DEGREES (CRASH TEST NO. 469680-03-3)

9.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-71 involves an 1100C vehicle weighing 2420 lb ± 55 lb impacting the work-zone traffic control device at an impact speed of 62 mi/h ± 2.5 mi/h. The impact angle for this test was 0 degrees ± 1.5 degrees. The target impact point was the centerline of the sign support aligned at a 13-inch offset toward the passenger's side from the centerline of the vehicle. Figure 2.1 and Figure 9.1 depict the target impact setup.

Figure 9.1. Sign Support/Test Vehicle Geometrics for Test No. 469680-03-3.

The 1100C vehicle weighed 2430 lb, and the actual impact speed and angle were 62.9 mi/h and 0 degrees. The vehicle impacted the centerline of the sign support 13 inches toward the passenger's side from the centerline of the vehicle. Minimum target KE was 288 kip-ft, and actual KE was 321 kip-ft.

9.2. WEATHER CONDITIONS

The test was performed on the afternoon of August 3, 2020. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 206 degrees (vehicle was traveling at a heading of 350 degrees); temperature: 97°F; relative humidity: 46 percent.

9.3. TEST VEHICLE

Figure 9.2 shows the 2014 Nissan Versa used for the crash test. The vehicle's test inertia weight was 2430 lb, and its gross static weight was 2595 lb. The height to the lower edge of the vehicle bumper was 7.0 inches, and height to the upper edge of the bumper was 22.25 inches. Table G.1 in Appendix G.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.

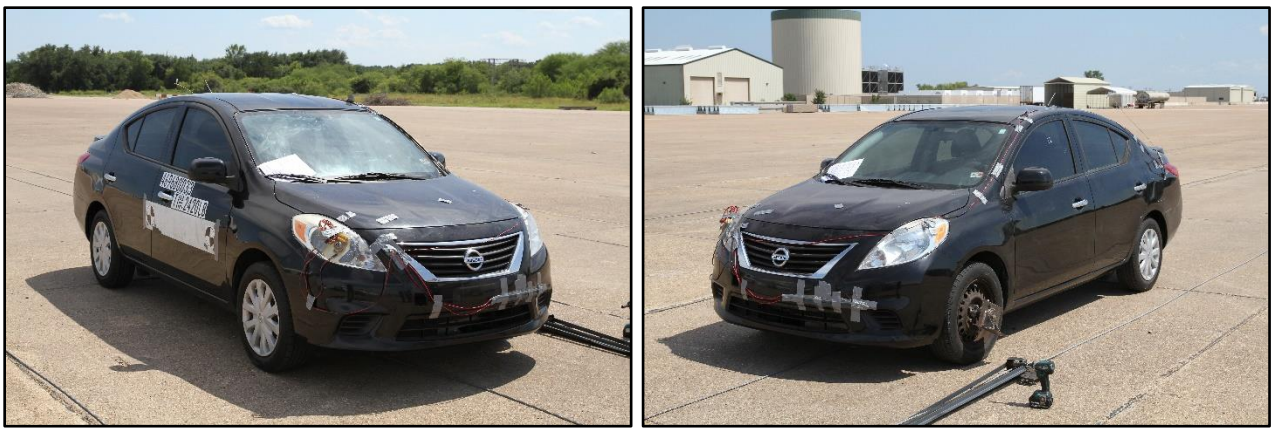


Figure 9.2. Test Vehicle before Test No. 469680-03-3.

9.4. TEST DESCRIPTION

Table 9.1 lists events that occurred during Test No. 469680-03-3. Figure H.1 in Appendix H.2 presents sequential photographs during the test.

Table 9.1. Events during Test No. 469680-03-3.

Time (s)	Events
0.000	Vehicle impacts sign support
0.006	Wood post fractures at impact height
0.009	Wood post fractures at breakaway holes
0.063	Vehicle loses contact with sign support while traveling at 59.9 mi/h

Brakes on the vehicle were applied at 3.5 s after impact. The vehicle came to rest 435 ft downstream of the point of impact and along the centerline of the vehicle impact path.

9.5. DAMAGE TO TEST INSTALLATION

Figure 9.3 shows the damage to the modified TxDOT single skid-mounted sign support. The sign panel and attached post segments landed 10 ft downstream and 3 ft to the left of impact. The base came to rest 65 ft downstream and 5 ft to the left of impact, and a 32-inch-long section of the wood brace landed 167 ft downstream and 6 ft to the left of the vehicle impact path.

Figure 9.3. Modified TxDOT Single Skid-Mounted Sign Support after Test No. 469680-03-3.

9.6. DAMAGE TO TEST VEHICLE

Figure 9.4 shows the damage sustained by the vehicle. The front bumper and grill sustained a 24-inch × 4-inch × 1.0-inch deformation 13 inches to the right of the centerline of the vehicle. There was also a 4-inch × 4-inch deformation in the hood, which was also pushed rearward 2.0 inches. The lower radiator support was deformed. A small dent was noted in the oil pan; however, no fuel tank damage was observed. Maximum exterior crush to the vehicle was 1.0 inch in the front plane to the right of the centerline at bumper height. No occupant compartment deformation or intrusion was noted. Figure 9.5 shows the interior of the vehicle. Tables G.2 and G.3 in Appendix G.1 provide exterior crush and occupant compartment measurements.

9.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 9.2. Figure G.2 in Appendix G.3 shows the vehicle angular displacements, and Figures G.3 through G.5 in Appendix G.4 show acceleration versus time traces. Figure 9.6 summarizes pertinent information from the test.

Figure 9.4. Test Vehicle after Test No. 469680-03-3.

Figure 9.5. Interior of Test Vehicle after Test No. 469680-03-3.

Table 9.2. Occupant Risk Factors for Test No. 469680-03-3.

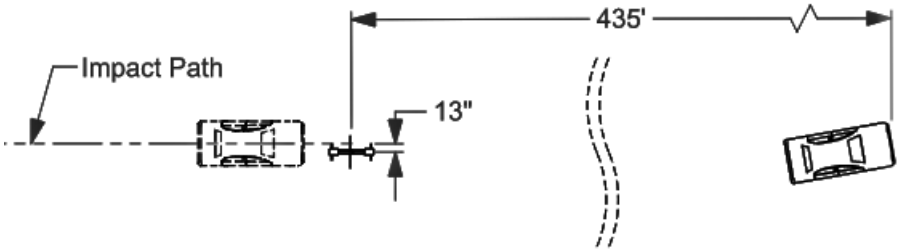
Occupant Risk Factor	Value	Time
OIV		
Longitudinal	3.6 ft/s	at 0.5369 s on left side of interior
Lateral	3.9 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	0.3 g	1.9070–1.9170 s
Lateral	0.6 g	1.2227–1.2327 s
THIV	1.6 m/s	at 0.5469 s on left side of interior
ASI	0.1	0.0451–0.0951 s
Maximum 50-ms Moving Average		
Longitudinal	−1.5 g	0.0358–0.0858 s
Lateral	0.7 g	0.2730–0.3230 s
Vertical	−2.4 g	0.0611–0.1111 s
Maximum Yaw, Pitch, and Roll Angles		
Yaw	2°	0.4579 s
Pitch	3°	1.9969 s
Roll	2°	0.3934 s

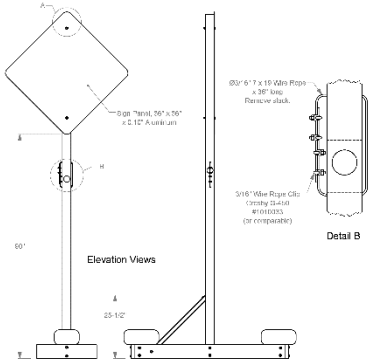

0.000 s


0.075 s


0.150 s


0.225 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 3-71 at 0°
- TTI Test No. 469680-03-3
- Test Date 2020-08-03

Test Article
- Type ..... Support Structure—Sign Support
- Name ..... TxDOT Single Skid-Mounted Sign Support
- Installation Length ..... 90-inch mounting height
- Material or Key Elements ... 36-inch-square × 0.10-inch-thick aluminum sign mounted in a diamond configuration on a 4×4 wooden post on a 2×6 skid base w/ 2 sandbags

Soil Type and Condition ..... Placed on concrete surface, dry

Test Vehicle
- Type/Designation 1100C
- Make and Model ..... 2014 Nissan Versa
- Curb ..... 2446 lb
- Test Inertial ..... 2430 lb
- Dummy ..... 165 lb
- Gross Static ..... 2595 lb

Impact Conditions
- Speed ..... 62.9 mi/h
- Angle ..... 0°
- Location/Orientation ..... 13 inches to right of vehicle centerline

Kinetic Energy ..... 321 kip-ft

Exit Conditions
- Speed ..... 59.9 mi/h
- Trajectory/Heading Angle ... 0°

Occupant Risk Values
- Longitudinal OIV ..... 3.6 ft/s
- Lateral OIV ..... 3.9 ft/s
- Longitudinal Ridedown ..... 0.3 g
- Lateral Ridedown ..... 0.6 g
- THIV ..... 1.6 m/s
- ASI 0.1

Max. 0.050-s Average
- Longitudinal ..... −1.5 g
- Lateral ..... 0.7 g
- Vertical ..... −2.4 g

Post-Impact Trajectory
- Stopping Distance ..... 435 ft downstream Centerline

Vehicle Stability
- Maximum Yaw Angle ..... 2°
- Maximum Pitch Angle ..... 3°
- Maximum Roll Angle ..... 2°

Test Article Debris Scatter
- Longitudinal ..... 167 ft downstream
- Lateral ..... 6 ft left

Vehicle Damage
- VDS 12FR1
- CDC 12FREN1
- Max. Exterior Deformation ..... 1.0 inch
- OCDI RF0000000
- Max. Occupant Compartment Deformation ..... None

Figure 9.6. Summary of Results for *MASH* Test 3-71 at 0 Degrees on Modified TxDOT Single Skid-Mounted Sign Support.

CHAPTER 10. SUMMARY AND CONCLUSIONS

10.1. ASSESSMENT OF TEST RESULTS

During the first test, *MASH* Test 3-72 at 90 degrees (Crash Test No. 469680-03-2), the sign panel contacted the roof of the 2270P vehicle, sliced a 22-inch-long hole in the roof, and penetrated into the occupant compartment over the driver's seat. Table 10.1 provides a performance assessment of this test based on the applicable evaluation criteria for *MASH* Test 3-72.

The TxDOT single skid-mounted sign support was modified by shortening the length of the tether cable from 38 inches to 36 inches and removing excess slack in the tether cable prior to tightening the cable clamps. *MASH* Test 3-72 at 90 degrees was repeated as Crash Test No. 469680-03-2A. During this test, the sign panel contacted the roof of the vehicle, sliced a 12-inch hole in the roof, and penetrated the occupant compartment over the driver's seat. Table 10.2 provides a performance assessment of this test based on the applicable evaluation criteria for *MASH* Test 3-72.

Additional changes were made to the design of the TxDOT single skid-mounted sign support. The sign mounting height was increased 6 inches to 90 inches above grade, and the vertical support post was lengthened a corresponding 6 inches. The weakening holes and tether cable were also raised 6 inches, such that the bottom weakening hole was 72 inches above grade. The full *MASH* test matrix was performed on this revised design. Table 10.3 through Table 10.6 provide an assessment of each of the successful tests based on the applicable safety evaluation criteria for *MASH* TL-3 work-zone traffic control devices.

10.2. CONCLUSIONS

Table 10.7 shows that the final design of the TxDOT single skid-mounted sign support met the performance criteria for *MASH* TL-3 work-zone traffic control devices. Details of this design are shown in Figure 6.1.

Table 10.1. Performance Evaluation Summary for *MASH* Test 3-72 at 90 Degrees on Modified TxDOT Single Skid-Mounted Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 469680-03-2 Test Date: 2020-07-16

MASH Test 3-72 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The modified TxDOT single skid-mounted sign support readily activated to the 2270P vehicle by fracturing at bumper height and at the breakaway holes.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	The sign panel elevated and rotated upon impact. One corner of the sign panel contacted the roof, sliced a 22-inch-long hole in the roof, and penetrated into the occupant compartment over the driver's seat.	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.	The sign panel penetrated the occupant compartment over the driver's seat.	
E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	None of the debris from the test article blocked the view of the driver or otherwise caused the driver to lose control.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 3° and 4°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.	Longitudinal OIV was 0.0 ft/s, and lateral OIV was 2.3 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Longitudinal occupant ridedown acceleration was 0.9 g, and lateral occupant ridedown acceleration was 0.4 g.	Pass
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 2270P vehicle came to rest 295 ft behind the installation.	Pass

Table 10.2. Performance Evaluation Summary for *MASH* Test 3-72 at 90 Degrees on Modified TxDOT Single Skid-Mounted Sign Support (with Shortened Wire Rope Cable).

Test Agency: Texas A&M Transportation Institute Test No.: 469680-03-2A Test Date: 2020-07-17

MASH Test 3-72 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The modified TxDOT single skid-mounted sign support readily activated to the 2270P vehicle by fracturing at bumper height and at the breakaway holes.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	The sign panel elevated and rotated upon impact. One corner of the sign panel contacted the roof, sliced a 12-inch-long hole in the roof, and penetrated into the occupant compartment over the driver's seat.	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.	The sign panel penetrated the occupant compartment over the driver's seat.	
E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	None of the debris from the test article blocked the view of the driver or otherwise caused the driver to lose control.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 3° and 4°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.	Longitudinal OIV was 2.6 ft/s, and lateral OIV was 1.6 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Longitudinal occupant ridedown acceleration was 0.2 g, and lateral occupant ridedown acceleration was 0.5 g.	Pass
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 2270P vehicle came to rest 330 ft behind the installation.	Pass

Table 10.3. Performance Evaluation Summary for *MASH* Test 3-72 at 90 Degrees on Modified TxDOT Single Skid-Mounted Sign Support (with Shortened Wire Rope Cable and Mounting Height, Breakaway Holes, and Wire Rope Cable Raised 6 inches).

Test Agency: Texas A&M Transportation Institute Test No.: 469680-03-2B Test Date: 2020-07-17

MASH Test 3-72 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The modified TxDOT single skid-mounted sign support readily activated to the 2270P vehicle by fracturing at bumper height and at the breakaway holes.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	The sign panel and attached post segments contacted the windshield and then went over the vehicle, and did not penetrate or show potential for penetrating the occupant compartment or presenting 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 1.0 inch in the windshield area. There were no holes or tears in the windshield.	
E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	None of the debris from the test article blocked the view of the driver or otherwise caused the driver to lose control.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 3° and 4°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.	Longitudinal OIV was 0.0 ft/s, and lateral OIV was 2.3 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Longitudinal occupant ridedown acceleration was 0.9 g, and lateral occupant ridedown acceleration was 0.4 g.	Pass
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 2270P vehicle came to rest 390 ft behind the installation.	Pass

Table 10.4. Performance Evaluation Summary for *MASH* Test 3-72 at 0 Degrees on Modified TxDOT Single Skid-Mounted Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 469680-03-4 Test Date: 2020-08-03

MASH Test 3-72 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The modified TxDOT single skid-mounted sign support readily activated to the 2270P vehicle by fracturing at bumper height and at the breakaway holes.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	The sign panel and attached post segments traveled up over the vehicle, briefly contacting the roof, and did not penetrate or show potential for penetrating the occupant compartment or presenting 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.	No occupant compartment deformation or intrusion occurred.	
E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	None of the debris from the test article blocked the view of the driver or otherwise caused the driver to lose control.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 2° and 2°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.	Longitudinal OIV was 0.3 ft/s, and lateral OIV was 2.6 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Longitudinal occupant ridedown acceleration was 0.2 g, and lateral occupant ridedown acceleration was 0.6 g.	Pass
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 2270P vehicle came to rest 350 ft behind the installation.	Pass

Table 10.5. Performance Evaluation Summary for *MASH* Test 3-71 at 90 Degrees on Modified TxDOT Single Skid-Mounted Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 469680-03-1 Test Date: 2020-08-03

MASH Test 3-71 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The modified TxDOT single skid-mounted sign support readily activated to the 1100C vehicle by fracturing at bumper height and at the breakaway holes.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	The sign panel and attached post segments traveled up over the vehicle, briefly contacting the roof, and did not penetrate or show potential for penetrating the occupant compartment or presenting 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.	No occupant compartment deformation or intrusion was observed.	
E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	None of the debris from the test article blocked the view of the driver or otherwise caused the driver to lose control.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 4° and 3°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.	Longitudinal OIV was 3.9 ft/s, and lateral OIV was 2.0 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Longitudinal occupant ridedown acceleration was 1.1 g, and lateral occupant ridedown acceleration was 0.6 g.	Pass
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 1100C vehicle came to rest 431 ft behind the installation.	Pass

Table 10.6. Performance Evaluation Summary for *MASH* Test 3-71 at 0 Degrees on Modified TxDOT Single Skid-Mounted Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 469680-03-3 Test Date: 2020-08-03

MASH Test 3-71 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The modified TxDOT single skid-mounted sign support readily activated to the 1100C vehicle by fracturing at bumper height and at the breakaway holes.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	The sign panel and attached post segments traveled up over the vehicle and did not penetrate or show potential for penetrating the occupant compartment or presenting 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.	No occupant compartment deformation or intrusion was observed.	
E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	None of the debris from the test article blocked the view of the driver or otherwise caused the driver to lose control.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 2° and 3°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.	Longitudinal OIV was 3.6 ft/s, and lateral OIV was 3.9 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Longitudinal occupant ridedown acceleration was 0.3 g, and lateral occupant ridedown acceleration was 0.6 g.	Pass
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 1100C vehicle came to rest 435 ft behind the installation.	Pass

Table 10.7. Assessment Summary for *MASH* TL-3 Tests on Final Design of Modified TxDOT Single Skid-Mounted Sign Support.

Evaluation Factors	Evaluation Criteria	Not Performed	Test No. 469680-03-1	Test No. 469680-03-2B	Test No. 469680-03-3	Test No. 469680-03-4
Structural Adequacy	B	NA	S	S	S	S
Occupant Risk	D	NA	S	S	S	S
	E	NA	S	S	S	S
	F	NA	S	S	S	S
	H	NA	S	S	S	S
	I	NA	S	S	S	S
Vehicle Trajectory	N	NA	S	S	S	S
Test No.		***MASH* Test 3-70 @ 0° & 90°**	***MASH* Test 3-71 @ 90°**	***MASH* Test 3-72 @ 90°**	***MASH* Test 3-71 @ 0°**	***MASH* Test 3-72 @ 0°**
Pass/Fail		NA	Pass	Pass	Pass	Pass

Note: S = Satisfactory; NA = Not Applicable. Two unsuccessful developmental tests (469680-03-2 and 469680-03-2A) are not included in the table.

CHAPTER 11. IMPLEMENTATION STATEMENT*

Under TxDOT Research Project 0-6946 (*1*), the TxDOT single wood-post skid-mounted temporary sign support system was tested in accordance with *MASH*. During Test 3-72, with the sign panel oriented parallel to the path of the impacting pickup truck, the wood post fractured and the edge of the aluminum sign panel contacted and penetrated the top of the windshield, resulting in a 4-inch-long tear in its laminate. Consequently, the system did not satisfy *MASH* evaluation criteria.

The objective of this research effort was to modify the design of the single wood-post skid-mounted temporary sign support system to improve its impact performance and meet *MASH* requirements. The final design of the modified single wood-post skid-mounted temporary sign support system incorporates two weakening holes, a cable tether looped around the weakening holes to serve as a hinge mechanism for the fractured support segments, and an increased sign mounting height of 90 inches from grade to the bottom of the sign panel. Details of this system are shown in Appendix A.

This revised single wood-post skid-mounted temporary sign support system was subjected to the full *MASH* test matrix for work-zone traffic control devices and found to be *MASH* TL-3 compliant. Implementation of the revised system can be accomplished through appropriate revision of TxDOT Barricade and Construction Sheet BC(5)-14. Because it was tested at impact angles of both 0 and 90 degrees, the system is considered suitable for implementation both along the roadside and at or near an intersection.

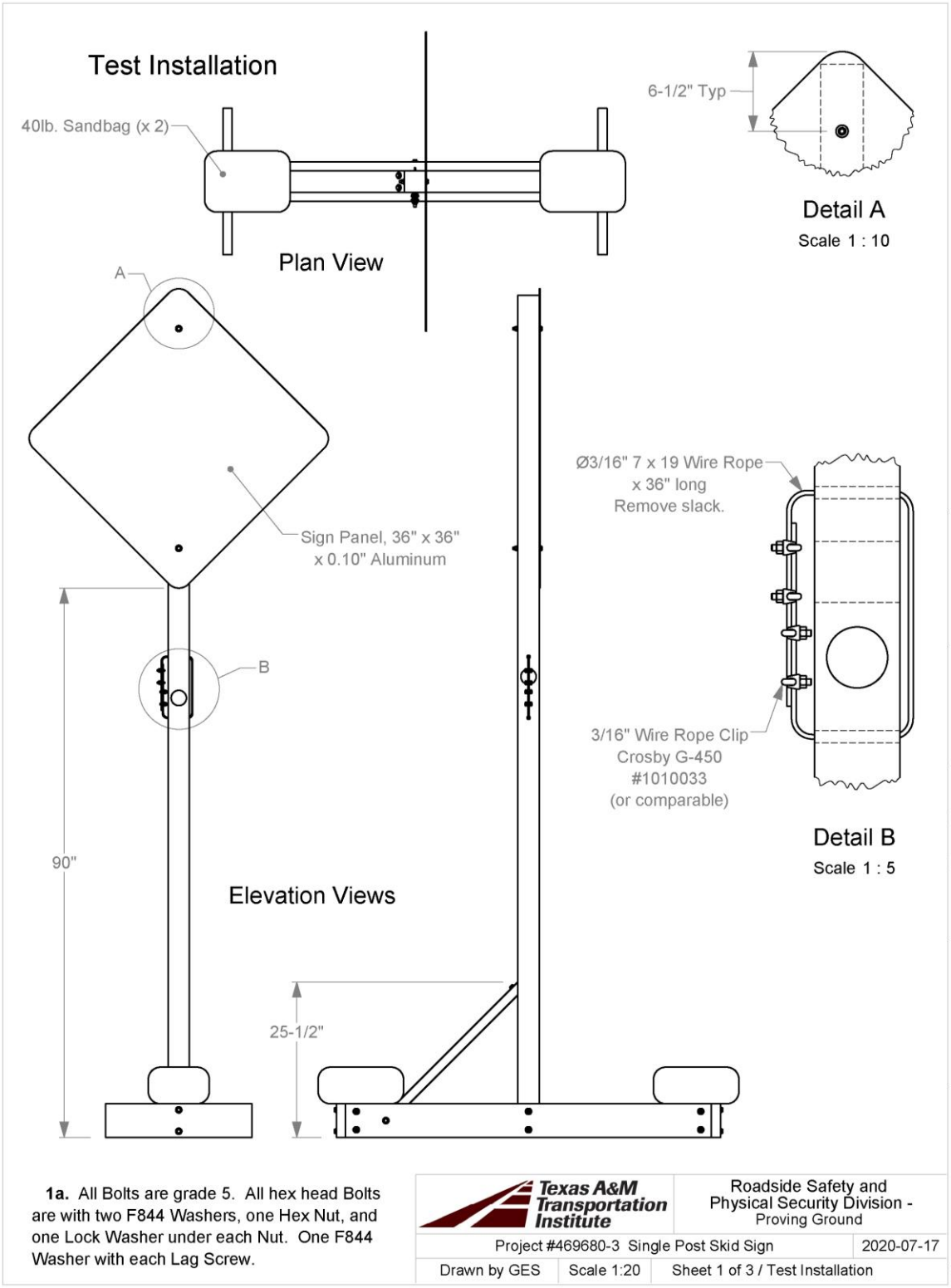
* The opinions/interpretations identified/expressed in Chapter 11 are outside the scope of TTI Proving Ground's A2LA Accreditation.

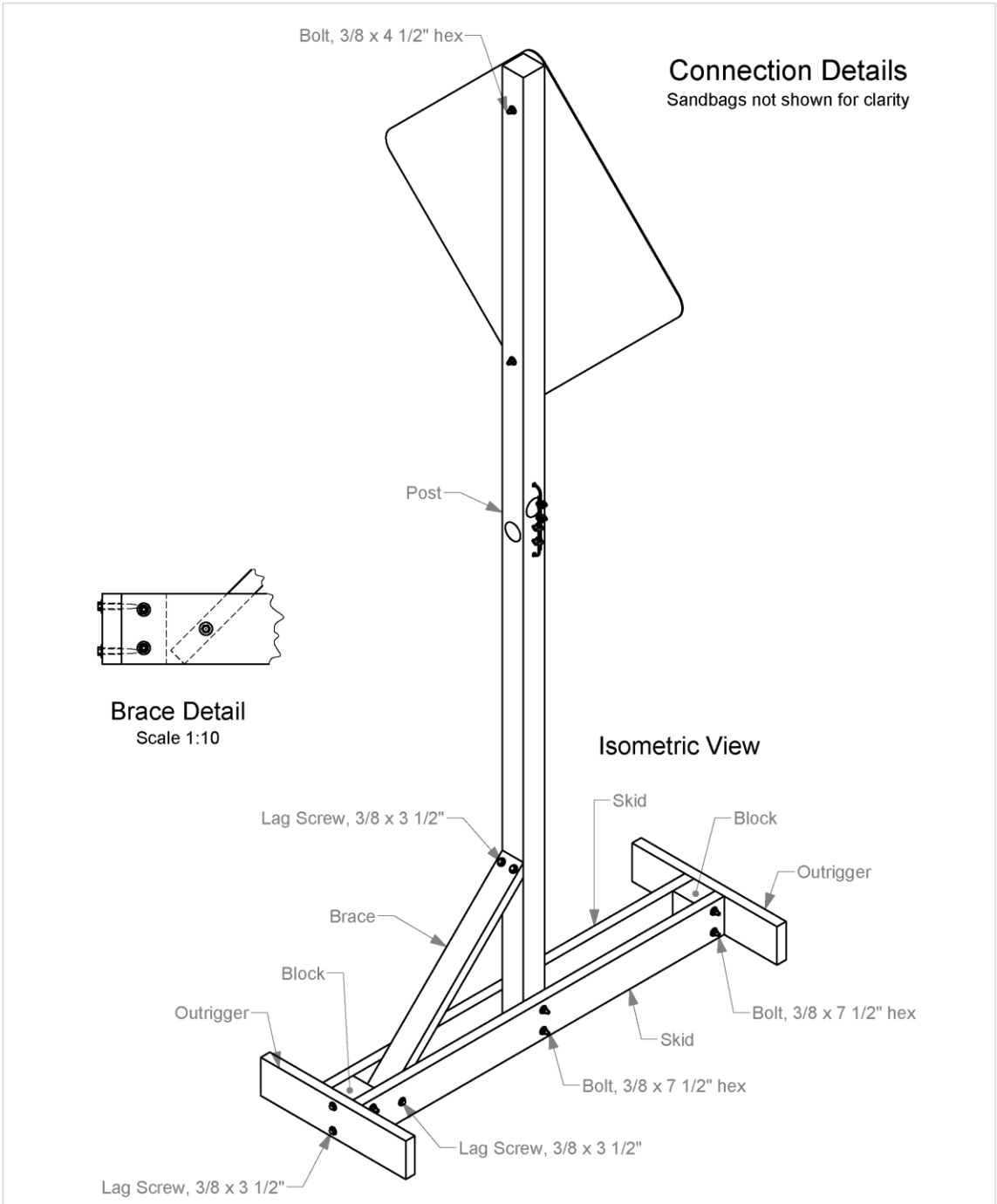
REFERENCES

1. Roger P. Bligh, Wanda L. Menges, Bill L. Griffith, Glenn E. Schroeder, and Darrell L. Kuhn. *MASH Evaluation of TxDOT Roadside Safety Features—Phase III*, Research Report FHWA/TX-20/0-6946-R3, Texas A&M Transportation Institute, College Station, TX, May 2020.

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

APPENDIX A. DETAILS OF MODIFIED TXDOT SINGLE SKID-MOUNTED SIGN SUPPORT





2a. All Bolts are grade 5. All hex head Bolts are with two USS Flat Washers, one Hex Nut, and one Lock Washer under each Nut. One USS Flat Washer with each Lag Screw.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469680-3 Single Post Skid Sign		2020-07-17
Drawn by GES	Scale 1:15	Sheet 2 of 3 / Connection Details

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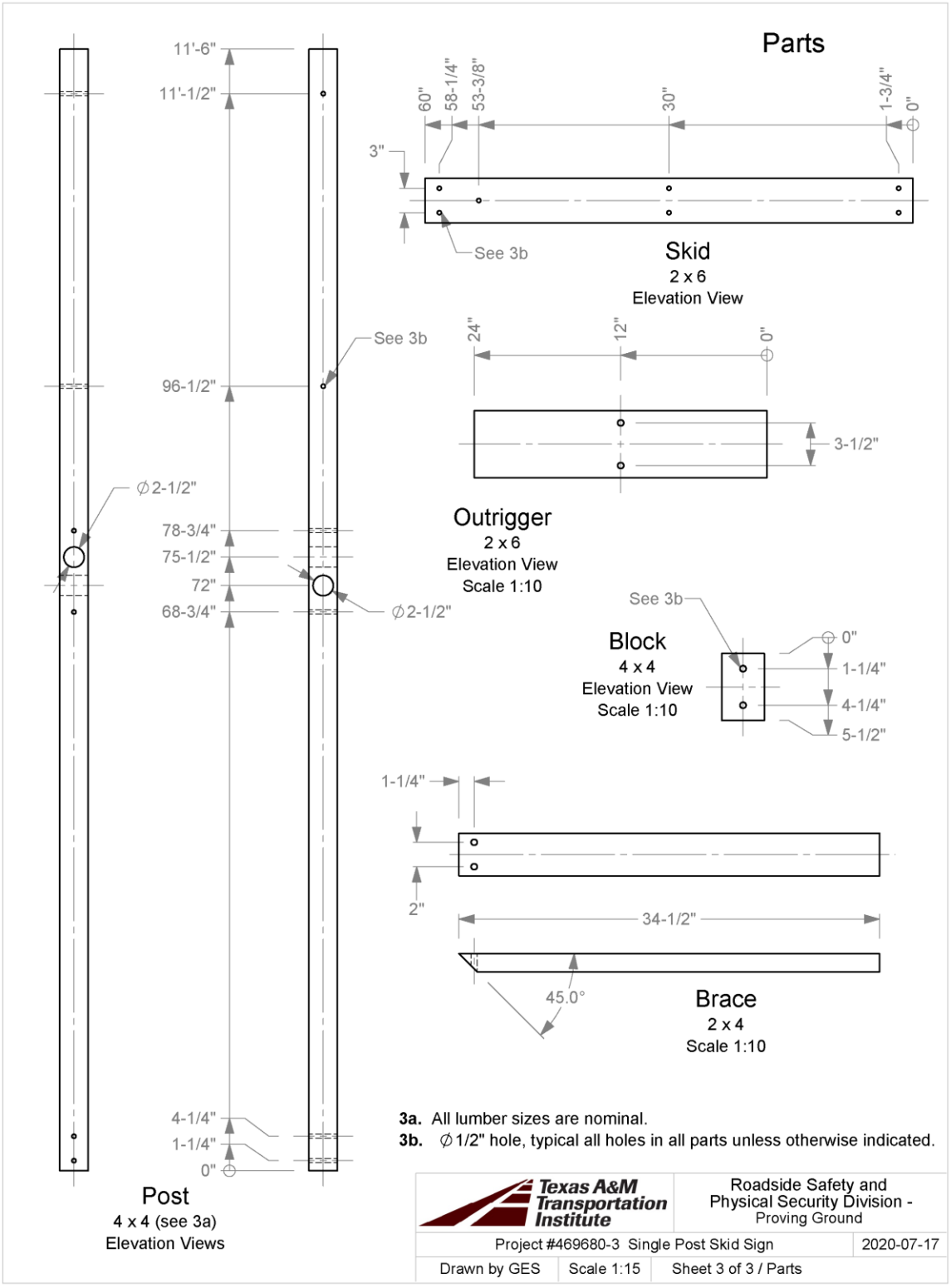
Parts
11'-6"
11'-1/2"
96-1/2"
78-3/4"
75-1/2"
72"
68-3/4"
4-1/4"
1-1/4"
0"
See 3b
∅2-1/2"
∅2-1/2"
Post
4 x 4 (see 3a)
Elevation Views
60"
58-1/4"
53-3/8"
30"
1-3/4"
0"
3"
See 3b
Skid
2 x 6
Elevation View
24"
12"
0"
3-1/2"
Outrigger
2 x 6
Elevation View
Scale 1:10
See 3b
Block
4 x 4
Elevation View
Scale 1:10
0"
1-1/4"
4-1/4"
5-1/2"
1-1/4"
2"
34-1/2"
45.0°
Brace
2 x 4
Scale 1:10
3a. All lumber sizes are nominal.
3b. ∅1/2" hole, typical all holes in all parts unless otherwise indicated.
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #469680-3 Single Post Skid Sign
2020-07-17
Drawn by GES
Scale 1:15
Sheet 3 of 3 / Parts
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APPENDIX B. *MASH* TEST 3-72 AT 90 DEGREES (CRASH TEST NO. 469680-03-2)

B.1. VEHICLE PROPERTIES AND INFORMATION

Table B.1. Vehicle Properties for Test No. 469680-03-2.

Date: 2020-7-16 Test No.: 469680-03-2 VIN No.: 1C6RR6GTXES149423

Year: 2014 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 176493

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

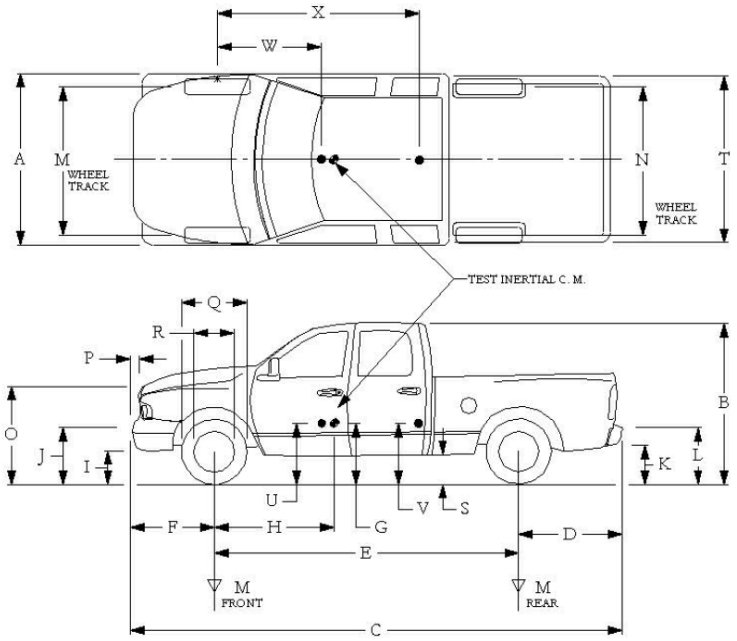
NOTES: None

Engine Type: V-8
Engine CID: 5.7 L

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

Optional Equipment:
None

Dummy Data:
Type: No dummy
Mass: 0 lb
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	29.00	L	30.00	Q	30.50	V	30.25
C	227.50	H	59.99	M	68.50	R	18.00	W	60.00
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2954	2865	2865
Back	3900	M_{rear}	2085	2135	2135
Total	6700	M_{Total}	5039	5000	5000

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

Mass Distribution:
lb LF: 1445 RF: 1420 LR: 1067 RR: 1068

Table B.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 469680-03-2.

Date: 2020-7-16 Test No.: 469680-03-2 VIN: 1C6RR6GTXES149423

Year: 2014 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 176493

Engine: 5.7 L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 100 (440 lb max)

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

Measured Vehicle Weights: (lb)

LF:	1445	RF:	1420	Front Axle:	2865
LR:	1067	RR:	1068	Rear Axle:	2135
Left:	2512	Right:	2488	Total:	5000
					5000 ±110 lb allowed

Wheel Base: 140.50 inches (148 ±12 inches allowed)

Track: F: 68.50 inches R: 68.00 inches

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

Center of Gravity, SAE J874 Suspension Method

X:	59.99 inches	Rear of Front Axle	(63 ±4 inches allowed)
Y:	-0.16 inches	Left - Right +	of Vehicle Centerline
Z:	29.00 inches	Above Ground	(minumum 28.0 inches allowed)

Hood Height: 46.00 inches (43 ±4 inches allowed)

Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches (39 ±3 inches allowed)

Rear Bumper Height: 30.00 inches

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

Table B.3. Exterior Crush Measurements for Test No. 469680-03-2.

Date: 2020-7-16 Test No.: 469680-03-2 VIN No.: 1C6RR6GTXES149423

Year: 2014 Make: RAM Model: _____

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L***	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max**** Crush								
	Bumper and Hood		0.5	-							
	Measurements recorded										
	☑ inches or ☐ mm										

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

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

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

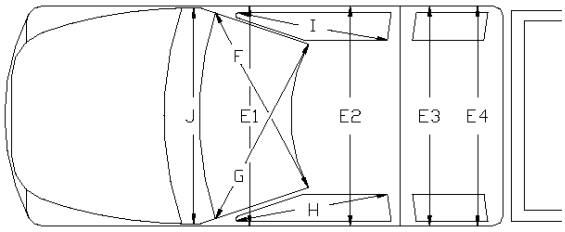
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

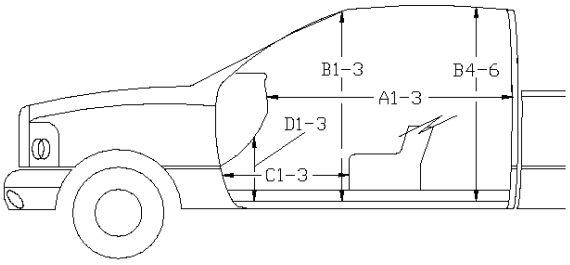
***Measure and document on the vehicle diagram the location of the maximum crush.

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

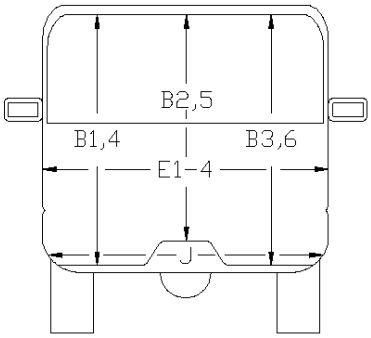
Table B.4. Occupant Compartment Measurements for Test No. 469680-03-2.

Date:	2020-7-16	Test No.:	469680-03-2	VIN No.:	1C6RR6GTXES149423
Year:	2014	Make:	RAM	Model:	1500





Vehicle Roof Penetrated over Driver Seat



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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

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

B.2. SEQUENTIAL PHOTOGRAPHS

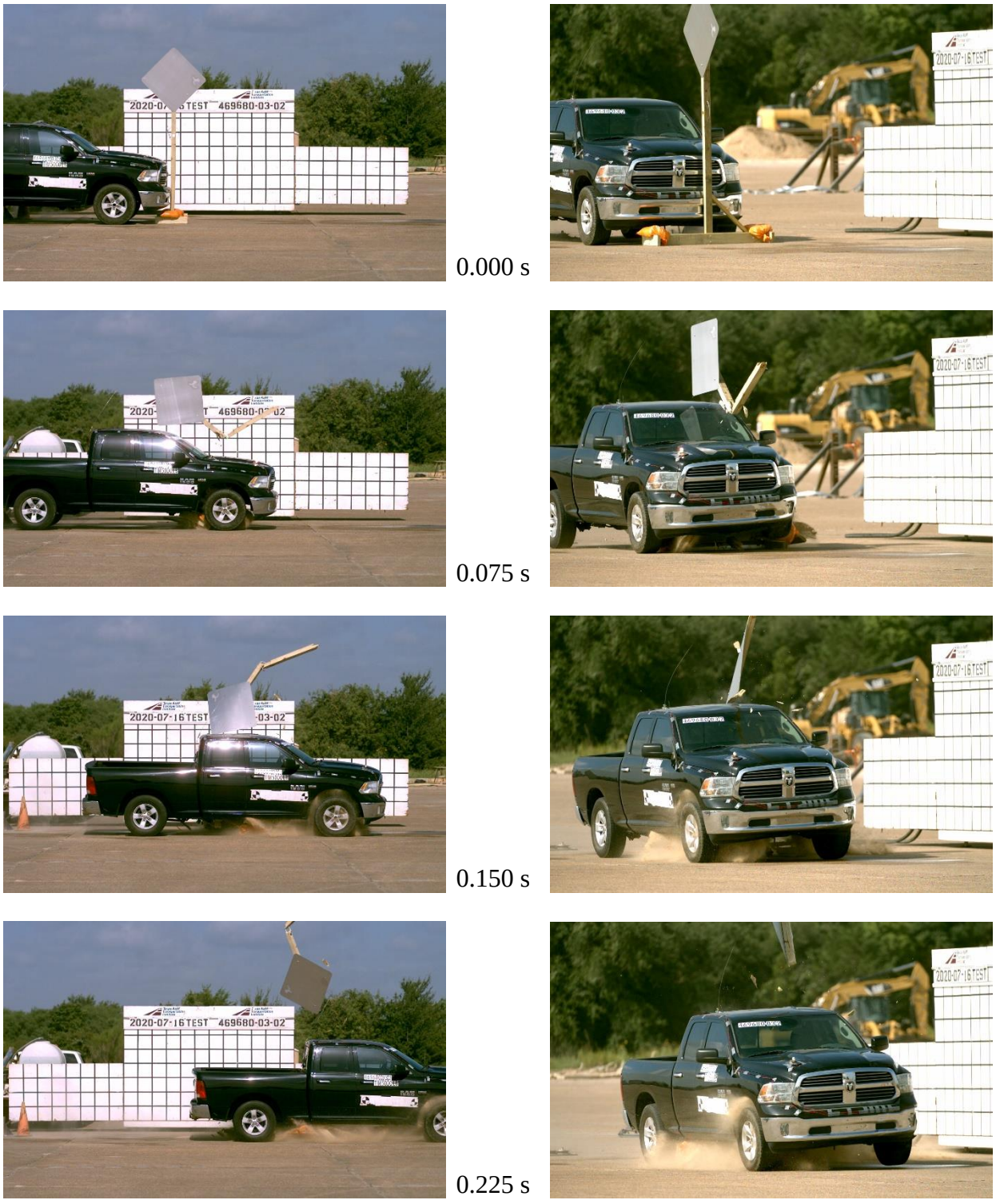
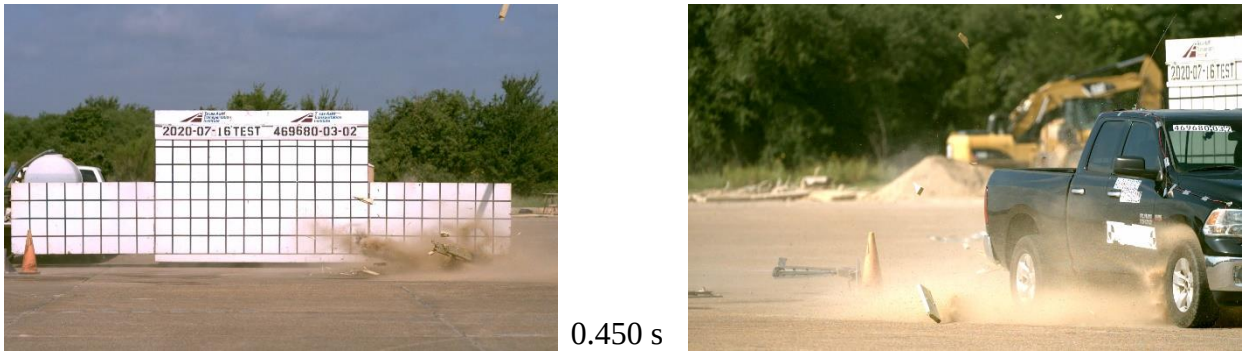


Figure B.1. Sequential Photographs for Test No. 469680-03-2 (Perpendicular and Oblique Views).



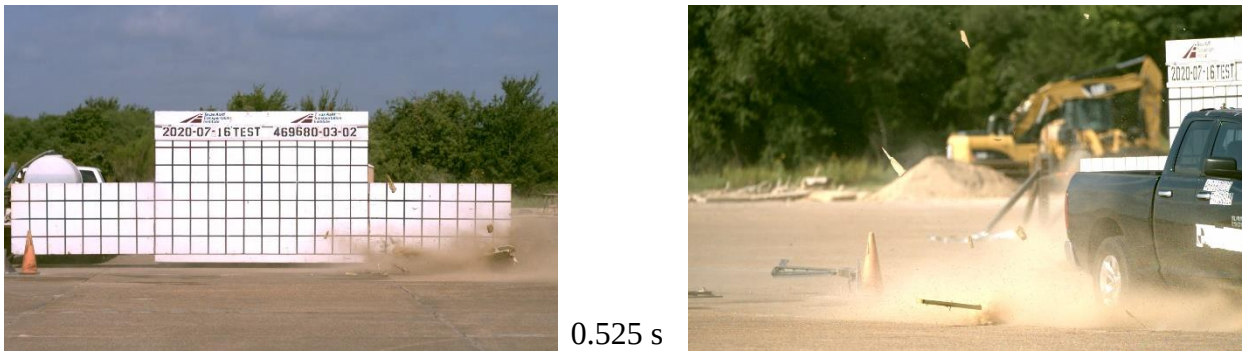
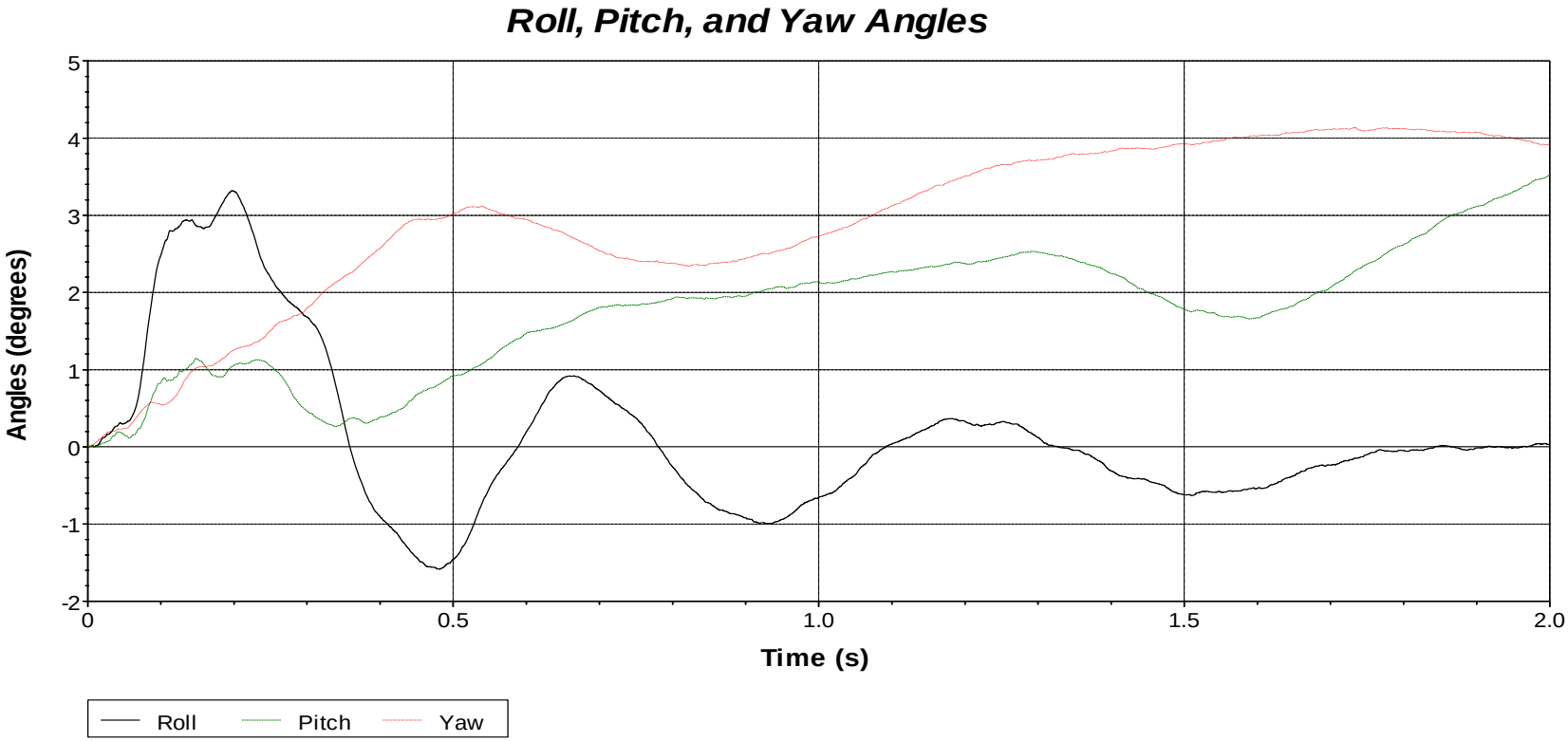
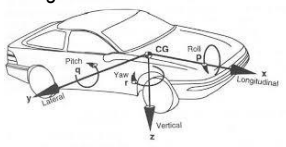


Figure B.1. Sequential Photographs for Test No. 469680-03-2 (Perpendicular and Oblique Views) (Continued).



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 469680-03-2
Test Standard Test Number: MASH Test 3-72 at 90°
Test Article: TxDOT Single Skid-Mounted Sign Support
Test Vehicle: 2014 RAM 1500 Pickup Truck
Inertial Mass: 5000 lb
Gross Mass: 5000 lb
Impact Speed: 63.0 mi/h
Impact Angle: 90°

Figure B.2. Vehicle Angular Displacements for Test No. 469680-03-2.

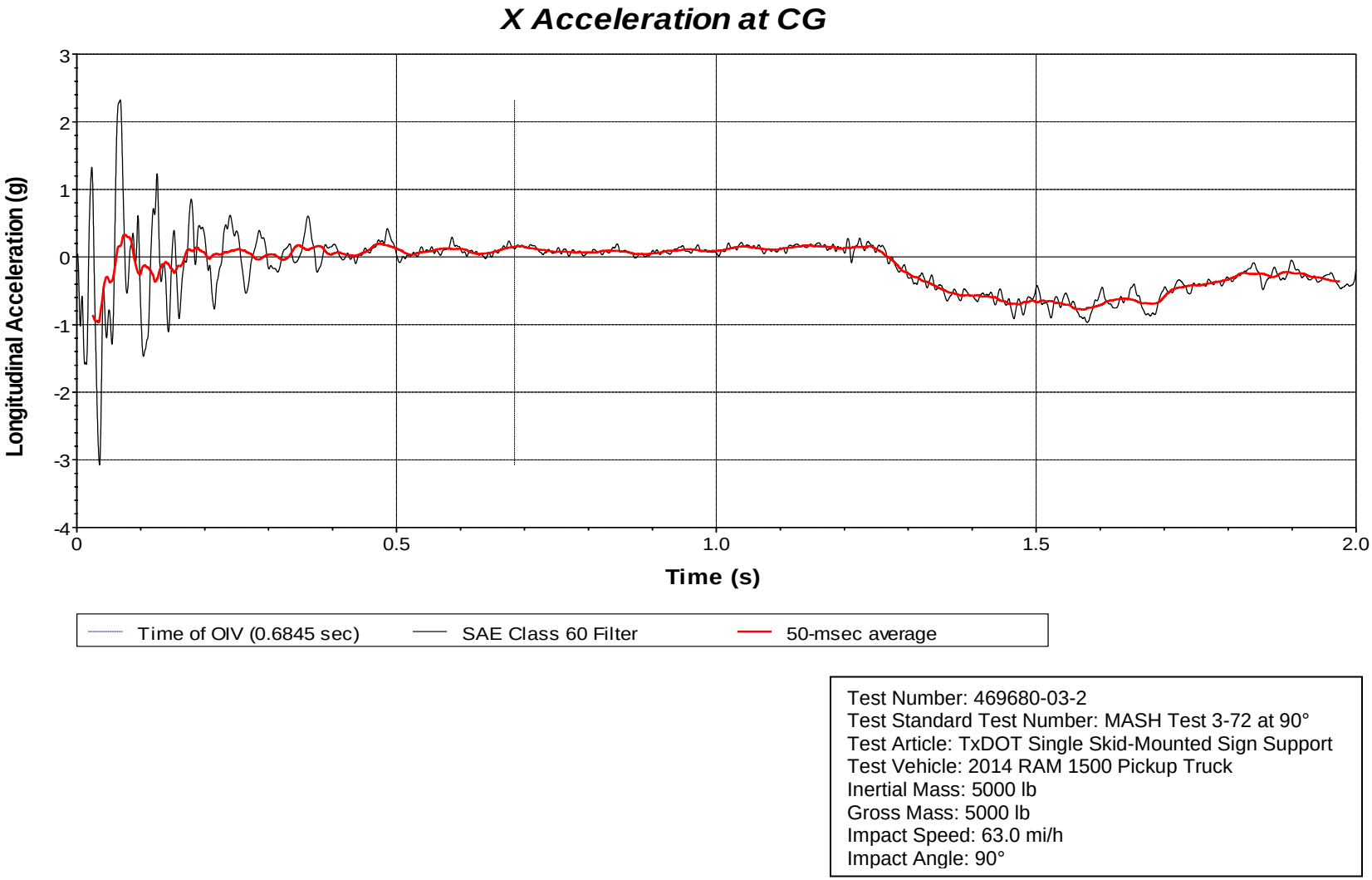
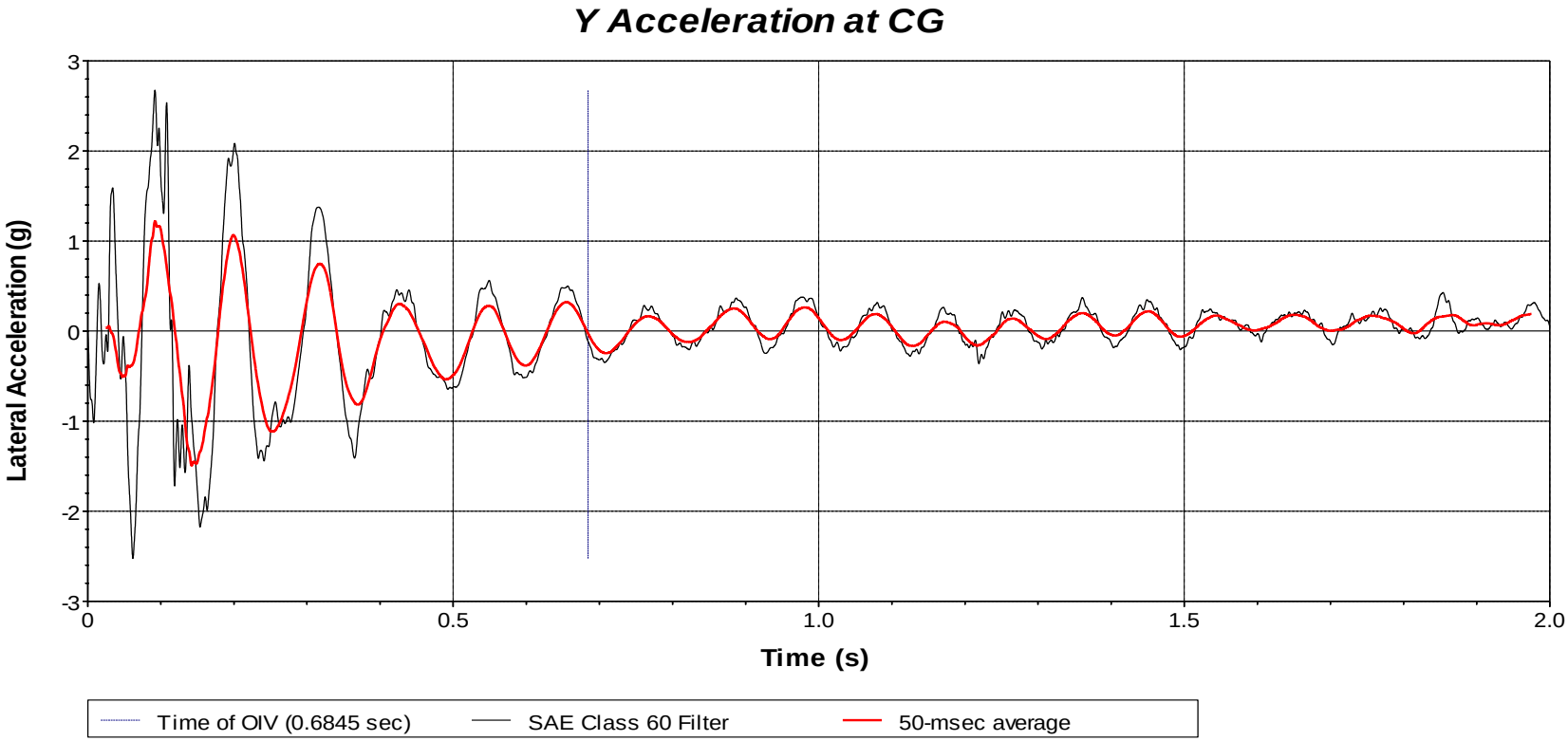


Figure B.3. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-03-2 (Accelerometer Located at Center of Gravity).



Test Number: 469680-03-2
Test Standard Test Number: MASH Test 3-72 at 90°
Test Article: TxDOT Single Skid-Mounted Sign Support
Test Vehicle: 2014 RAM 1500 Pickup Truck
Inertial Mass: 5000 lb
Gross Mass: 5000 lb
Impact Speed: 63.0 mi/h
Impact Angle: 90°

Figure B.4. Vehicle Lateral Accelerometer Trace for Test No. 469680-03-2 (Accelerometer Located at Center of Gravity).

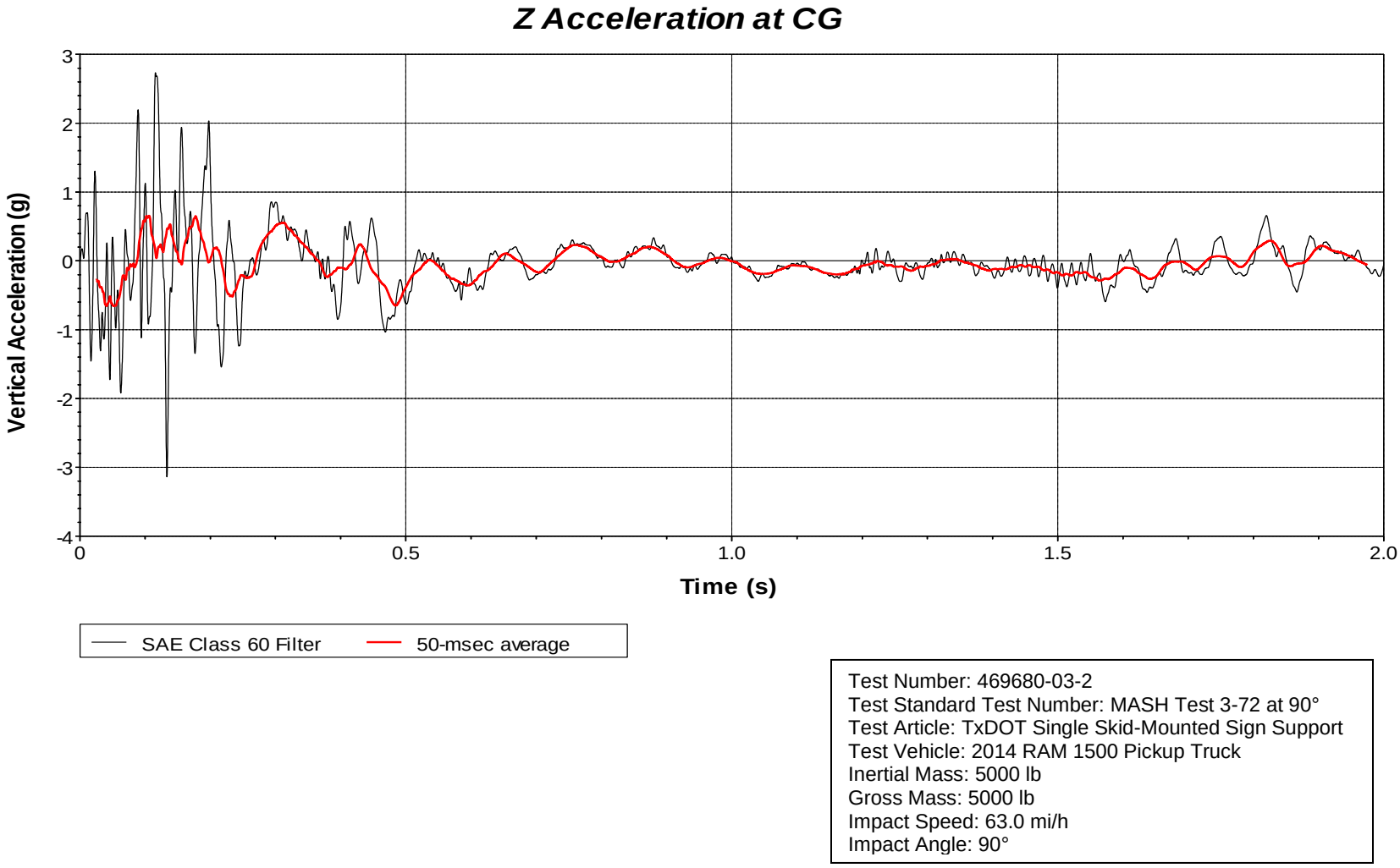


Figure B.5. Vehicle Vertical Accelerometer Trace for Test No. 469680-03-2 (Accelerometer Located at Center of Gravity).

APPENDIX C. *MASH* TEST 3-72 AT 90 DEGREES (CRASH TEST NO. 469680-03-2A)

C.1. VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 469680-03-2A.

Date: 2020-7-17 Test No.: 469680-03-2A VIN No.: 1C6RR6FT9ES243178

Year: 2014 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 131685

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

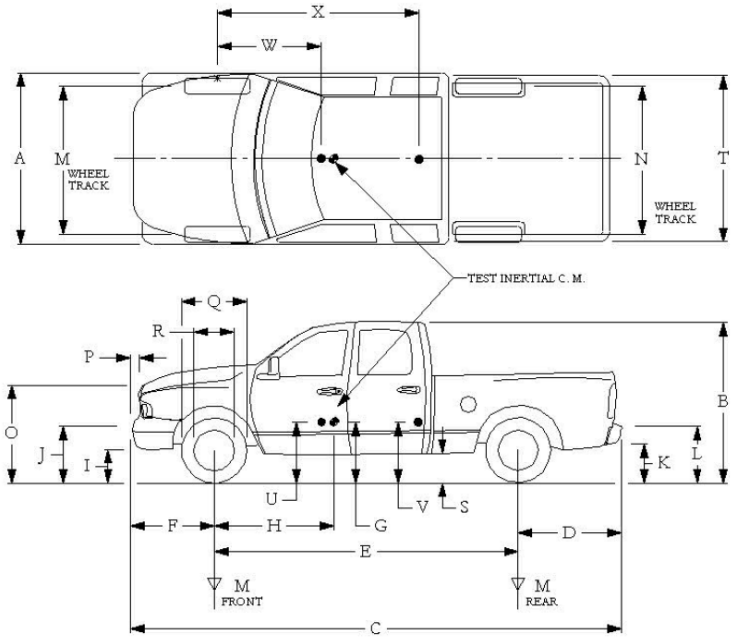
NOTES: None

Engine Type: V-8
Engine CID: 5.7 L

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

Optional Equipment:
None

Dummy Data:
Type: No dummy
Mass: 0 lb
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.75	L	30.00	Q	30.50	V	30.25
C	227.50	H	62.90	M	68.50	R	18.00	W	62.90
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2903	2773	2773
Back	3900	M_{rear}	2130	2248	2248
Total	6700	M_{Total}	5033	5021	5021

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

Mass Distribution:
lb LF: 1369 RF: 1404 LR: 1137 RR: 1111

Table C.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 469680-03-2A.

Date: 2020-7-17 Test No.: 469680-03-2A VIN: 1C6RR6FT9ES243178

Year: 2014 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 131685

Engine: 5.7 L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 200 (440 lb max)

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

Measured Vehicle Weights: (lb)									
LF:	1369		RF:	1404		Front Axle:	2773		
LR:	1137		RR:	1111		Rear Axle:	2248		
Left:	2506		Right:	2515		Total:	5021		
							5000 ±110 lb allowed		
Wheel Base:	140.50	inches	Track: F:	68.50	inches	R:	68.00	inches	
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed					
Center of Gravity, SAE J874 Suspension Method									
X:	62.90	inches	Rear of Front Axle	(63 ±4 inches allowed)					
Y:	0.06	inches	Left -	Right +	of Vehicle Centerline				
Z:	28.75	inches	Above Ground	(minumum 28.0 inches allowed)					

Hood Height: 46.00 inches
43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches
39 ±3 inches allowed

Rear Bumper Height: 30.00 inches

Overall Length: 227.50 inches
237 ±13 inches allowed

Table C.3. Exterior Crush Measurements for Test No. 469680-03-2A.

Date:	2020-7-17	Test No.:	469680-03-2A	VIN No.:	1C6RR6FT9ES243178
Year:	2014	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L***	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max**** Crush								
	Bumper		0.75	-							
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

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

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

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

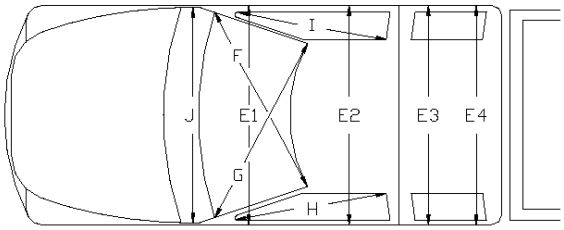
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

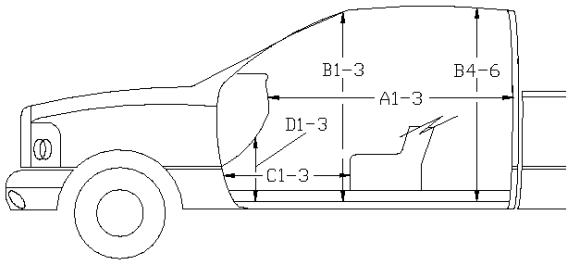
***Measure and document on the vehicle diagram the location of the maximum crush.

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

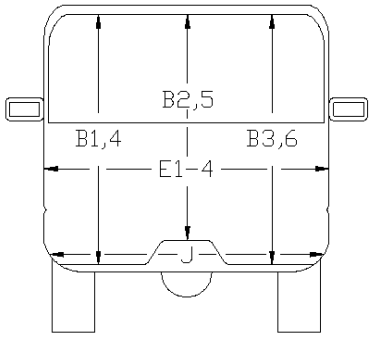
Table C.4. Occupant Compartment Measurements for Test No. 469680-03-2A.

Date:	2020-7-17	Test No.:	469680-03-2A	VIN No.:	1C6RR6FT9ES243178
Year:	2014	Make:	RAM	Model:	1500





Vehicle Roof Penetrated over Driver Seat



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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

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

C.2. SEQUENTIAL PHOTOGRAPHS

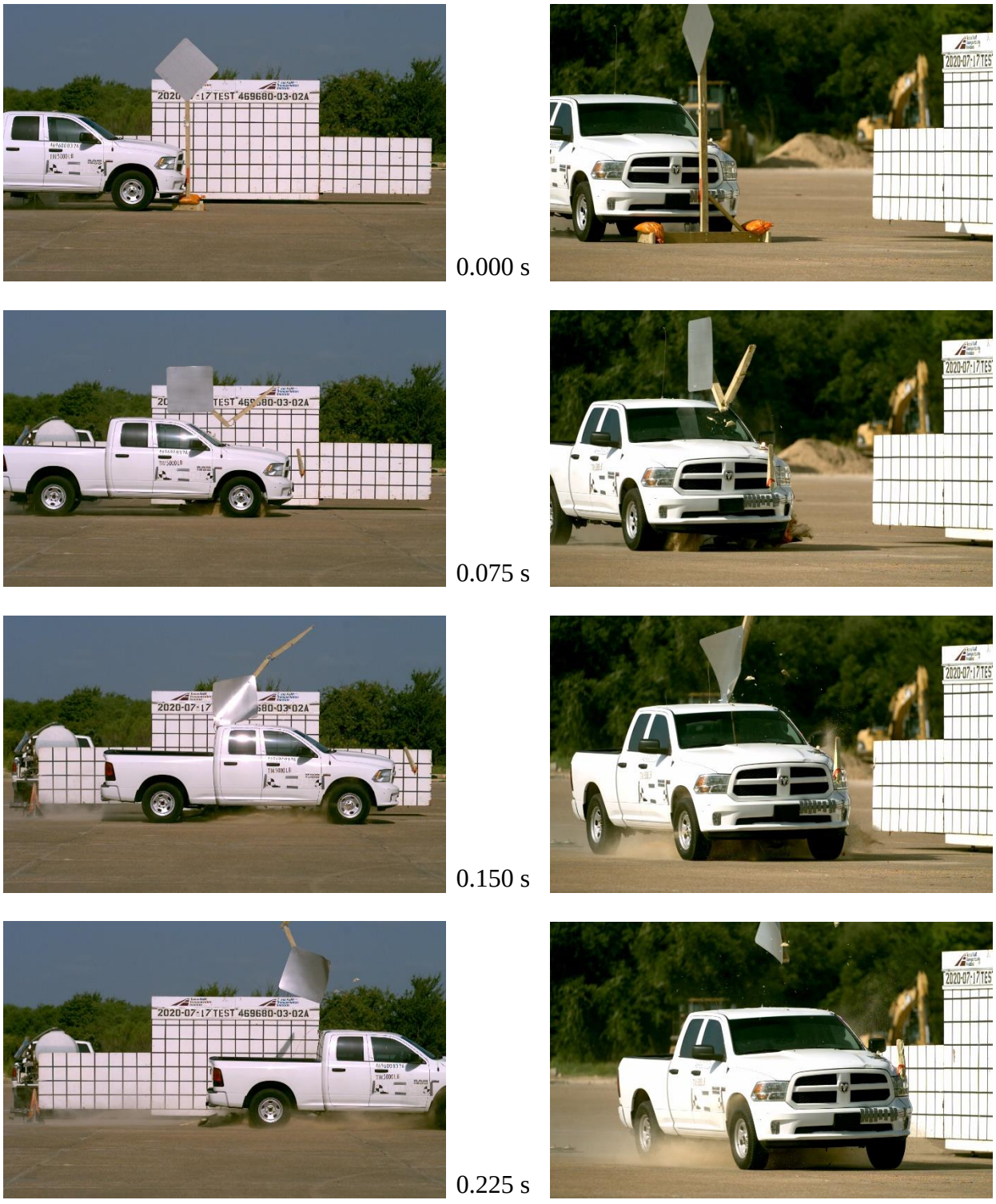


Figure C.1. Sequential Photographs for Test No. 469680-03-2A (Perpendicular and Oblique Views).

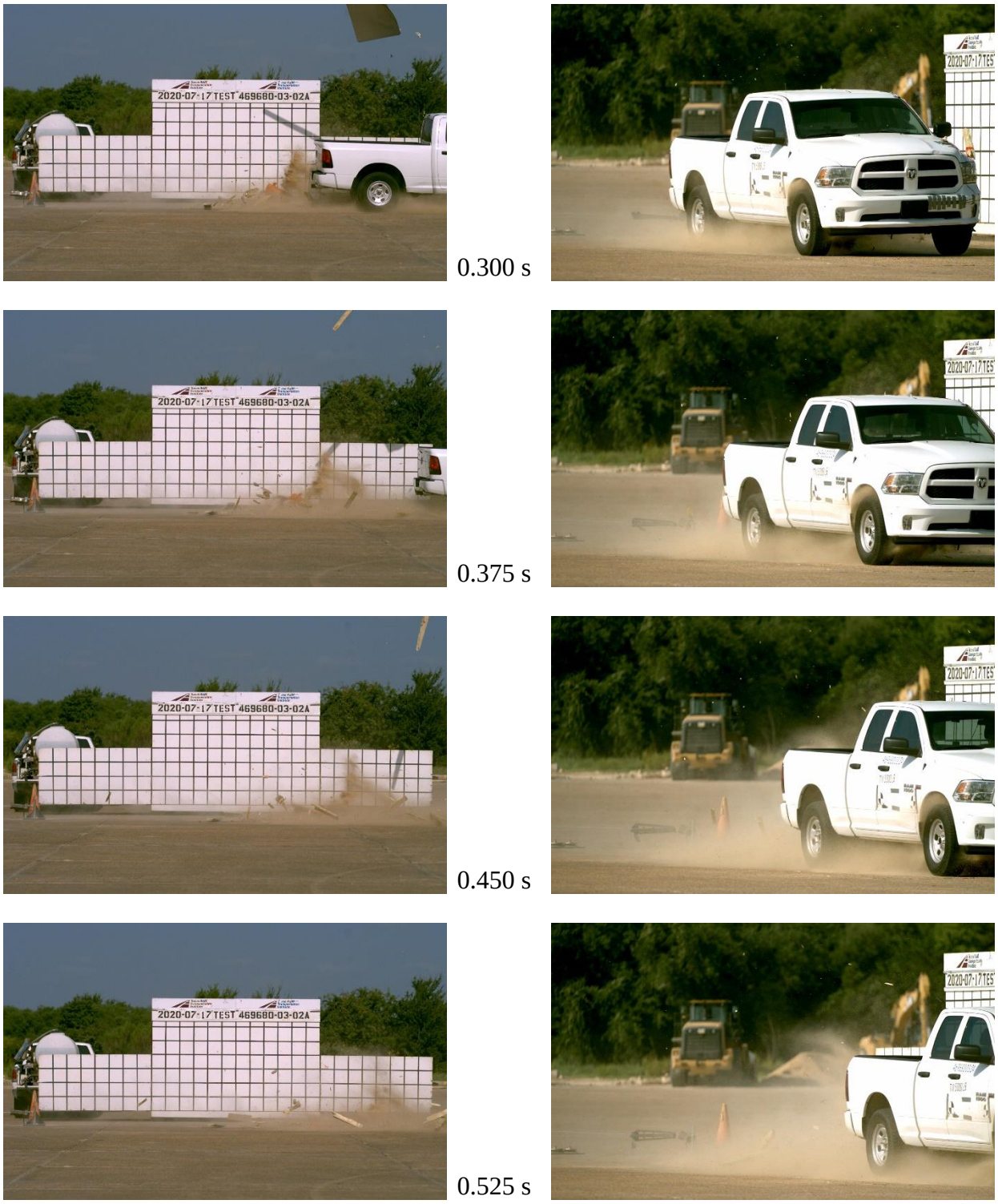
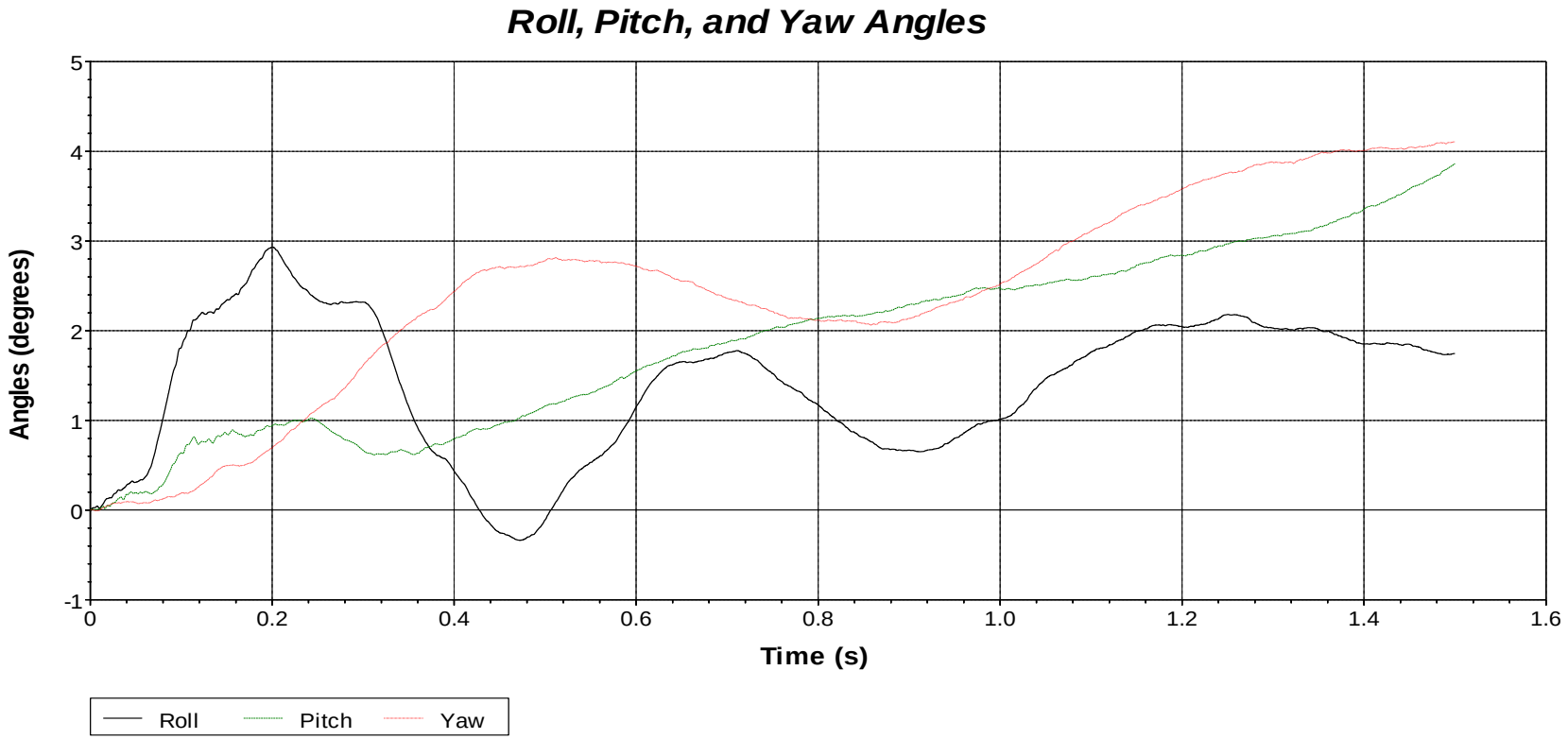
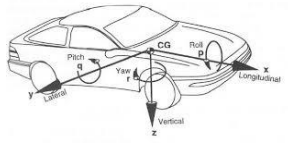


Figure C.1. Sequential Photographs for Test No. 469680-03-2A (Perpendicular and Oblique Views) (Continued).



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 469680-03-2A
Test Standard Test Number: MASH Test 2-72 at 90°
Test Article: TxDOT Single Skid-Mounted Sign Support
Test Vehicle: 2014 RAM 1500 Pickup
Inertial Mass: 5021 lb
Gross Mass: 5021 lb
Impact Speed: 63.0 mi/h
Impact Angle: 90°

Figure C.2. Vehicle Angular Displacements for Test No. 469680-03-2A.

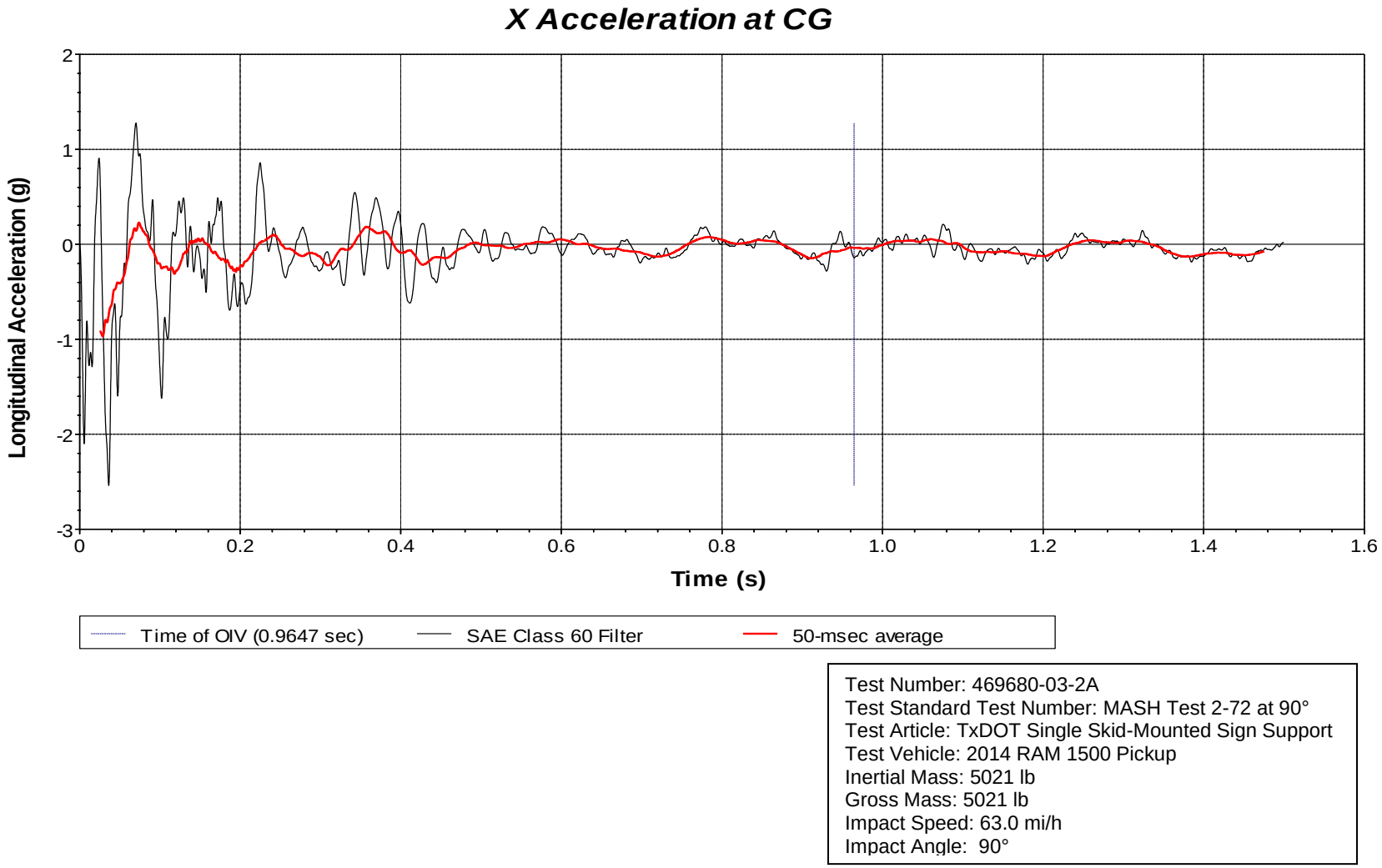
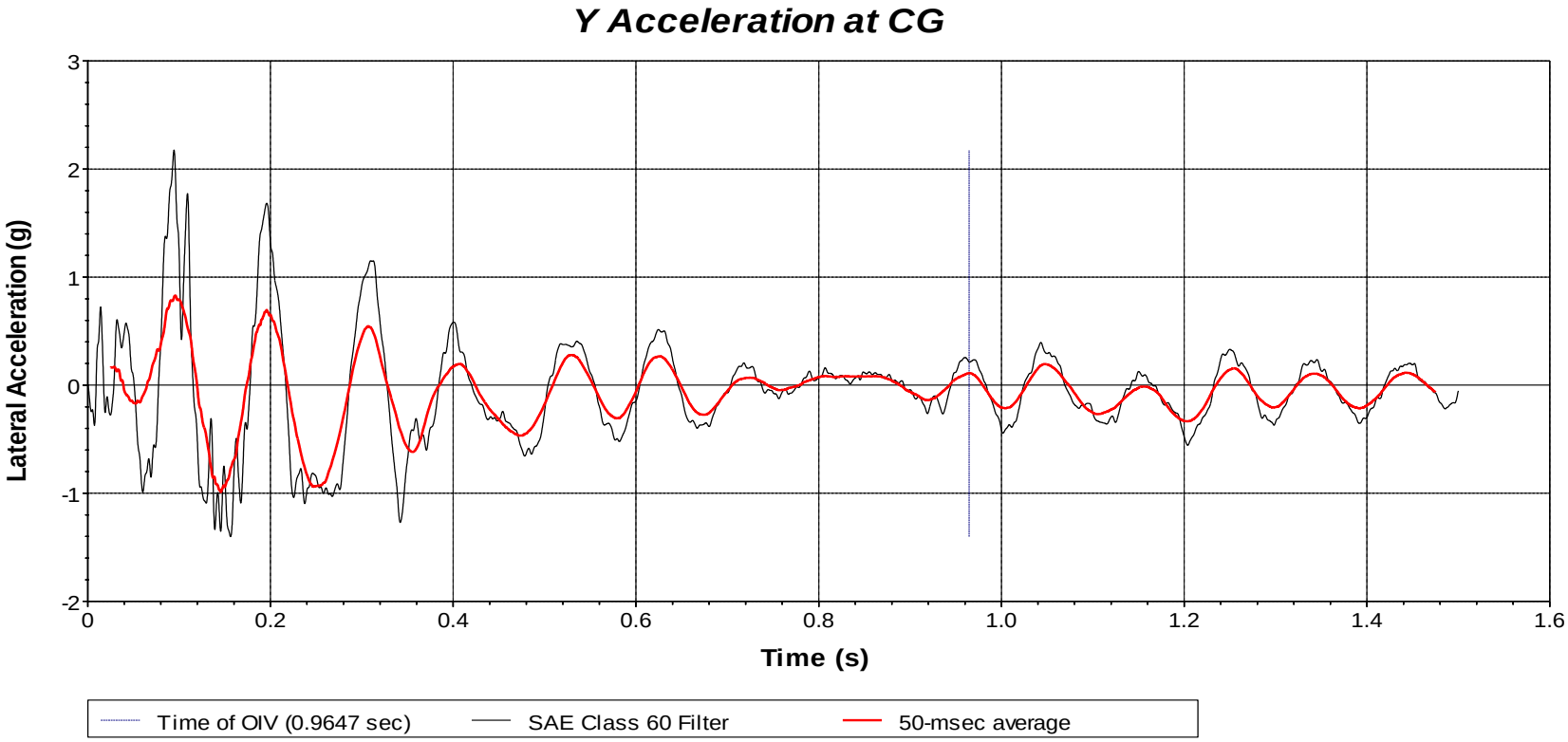


Figure C.3. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-03-2A (Accelerometer Located at Center of Gravity).



Test Number: 469680-03-2A
Test Standard Test Number: MASH Test 2-72 at 90°
Test Article: TxDOT Single Skid-Mounted Sign Support
Test Vehicle: 2014 RAM 1500 Pickup
Inertial Mass: 5021 lb
Gross Mass: 5021 lb
Impact Speed: 63.0 mi/h
Impact Angle: 90°

Figure C.4. Vehicle Lateral Accelerometer Trace for Test No. 469680-03-2A (Accelerometer Located at Center of Gravity).

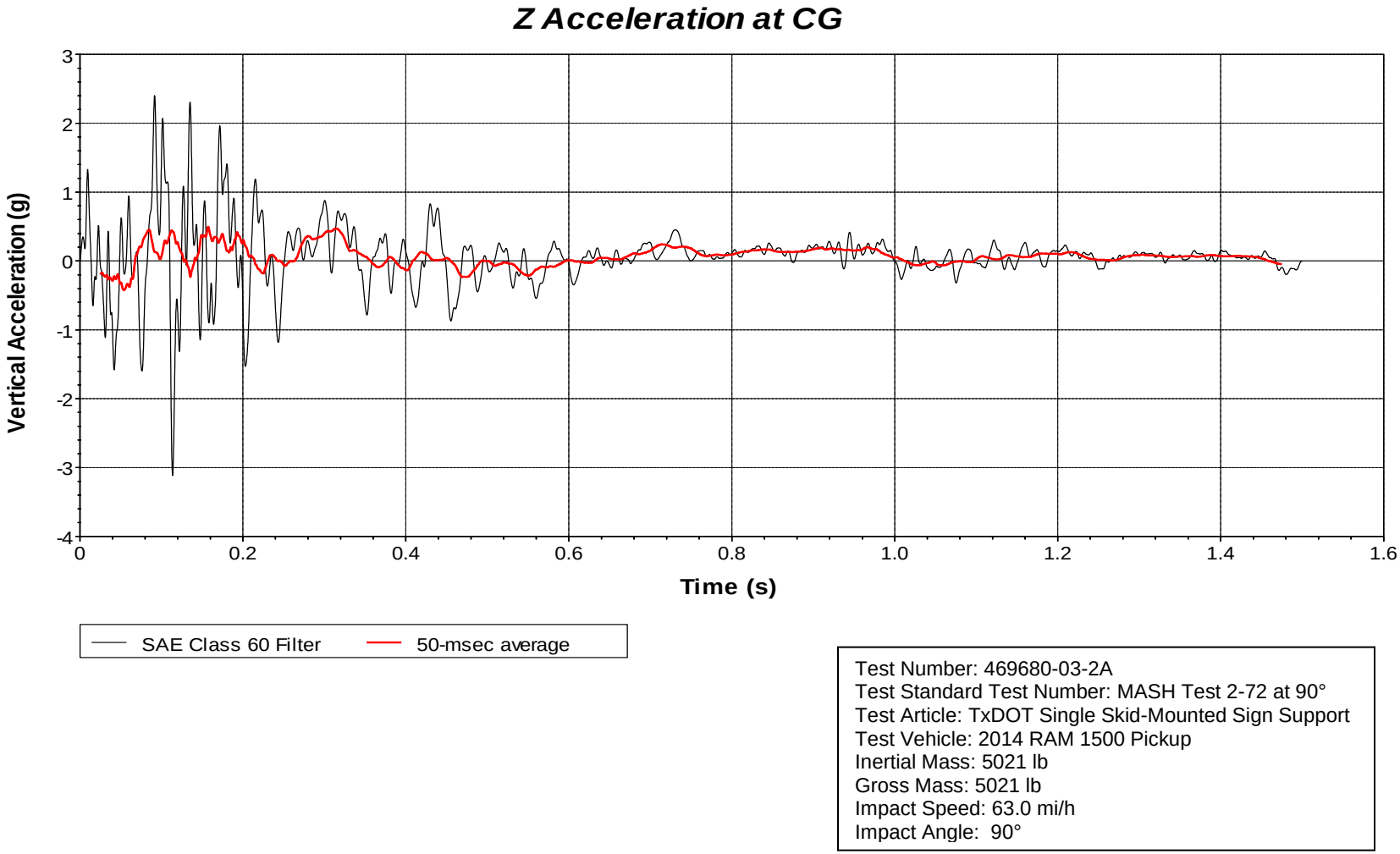


Figure C.5. Vehicle Vertical Accelerometer Trace for Test No. 469680-03-2A (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 3-72 AT 90 DEGREES (CRASH TEST NO. 469680-03-2B)

D.1. VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 469680-03-2B.

Date: 2020-7-17 Test No.: 469680-03-2B VIN No.: 1C6RR6FT1ES148937

Year: 2014 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 211424

Note any damage to the vehicle prior to test: None

• Denotes accelerometer location.

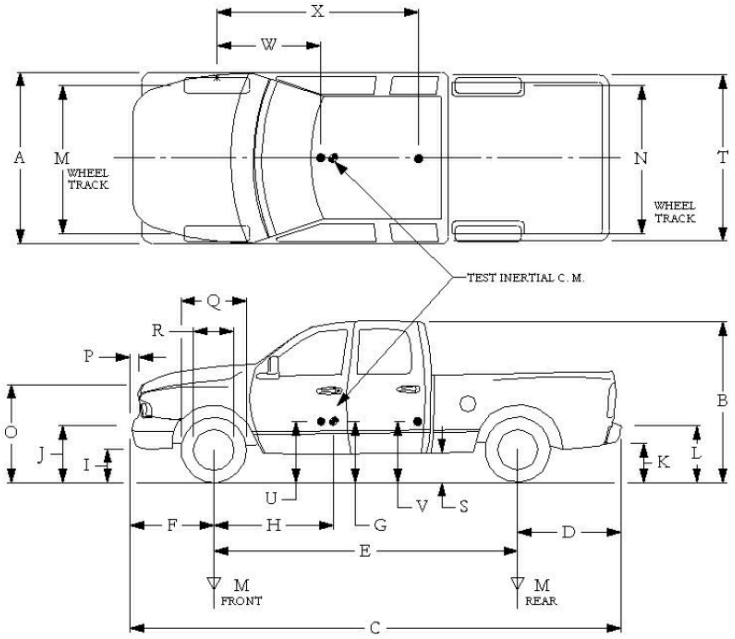
NOTES: None

Engine Type: V-8
Engine CID:

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

Optional Equipment:
None

Dummy Data:
Type: No dummy
Mass: 0 lb
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	29.00	L	30.00	Q	30.50	V	30.25
C	227.50	H	62.41	M	68.50	R	18.00	W	62.5
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2899	2810	2810
Back	3900	M_{rear}	2114	2246	2246
Total	6700	M_{Total}	5013	5056	5056

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

Mass Distribution:
lb LF: 1400 RF: 1410 LR: 1142 RR: 1104

Table D.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 469680-03-2B.

Date: 2020-7-17 Test No.: 469680-03-2B VIN: 1C6RR6FT1ES148937

Year: 2014 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 211424

Engine: V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 160 (440 lb max)

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

Measured Vehicle Weights: (lb)					
LF:	1400	RF:	1410	Front Axle:	2810
LR:	1142	RR:	1104	Rear Axle:	2246
Left:	2542	Right:	2514	Total:	5056
					5000 ±110 lb allowed

Wheel Base:	140.50 inches	Track: F:	68.50 inches	R:	68.00 inches
148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed		

Center of Gravity, SAE J874 Suspension Method				
X:	62.41 inches	Rear of Front Axle	(63 ±4 inches allowed)	
Y:	-0.19 inches	Left - Right +	of Vehicle Centerline	
Z:	29.00 inches	Above Ground	(minumum 28.0 inches allowed)	

Hood Height: 46.00 inches
43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches
39 ±3 inches allowed

Rear Bumper Height: 30.00 inches

Overall Length: 227.50 inches
237 ±13 inches allowed

Table D.3. Exterior Crush Measurements for Test No. 469680-03-2B.

Date:	2020-7-17	Test No.:	469680-03-2B	VIN No.:	1C6RR6FT1ES148937
Year:	2014	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L***	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max**** Crush								
	Windshield		1.0	-							
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

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

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

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

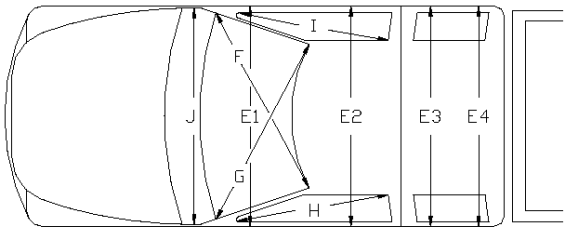
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

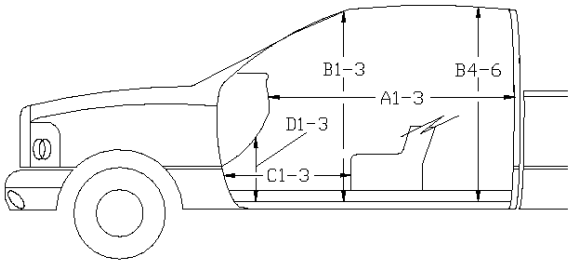
***Measure and document on the vehicle diagram the location of the maximum crush.

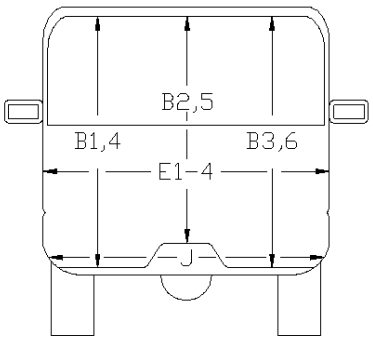
Note: Use as many lines/columns as necessary to describe each damage profile.

Table D.4. Occupant Compartment Measurements for Test No. 469680-03-2B.

Date:	2020-7-17	Test No.:	469680-03-2B	VIN No.:	1C6RR6FT1ES148937
Year:	2014	Make:	RAM	Model:	1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

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

D.2. SEQUENTIAL PHOTOGRAPHS

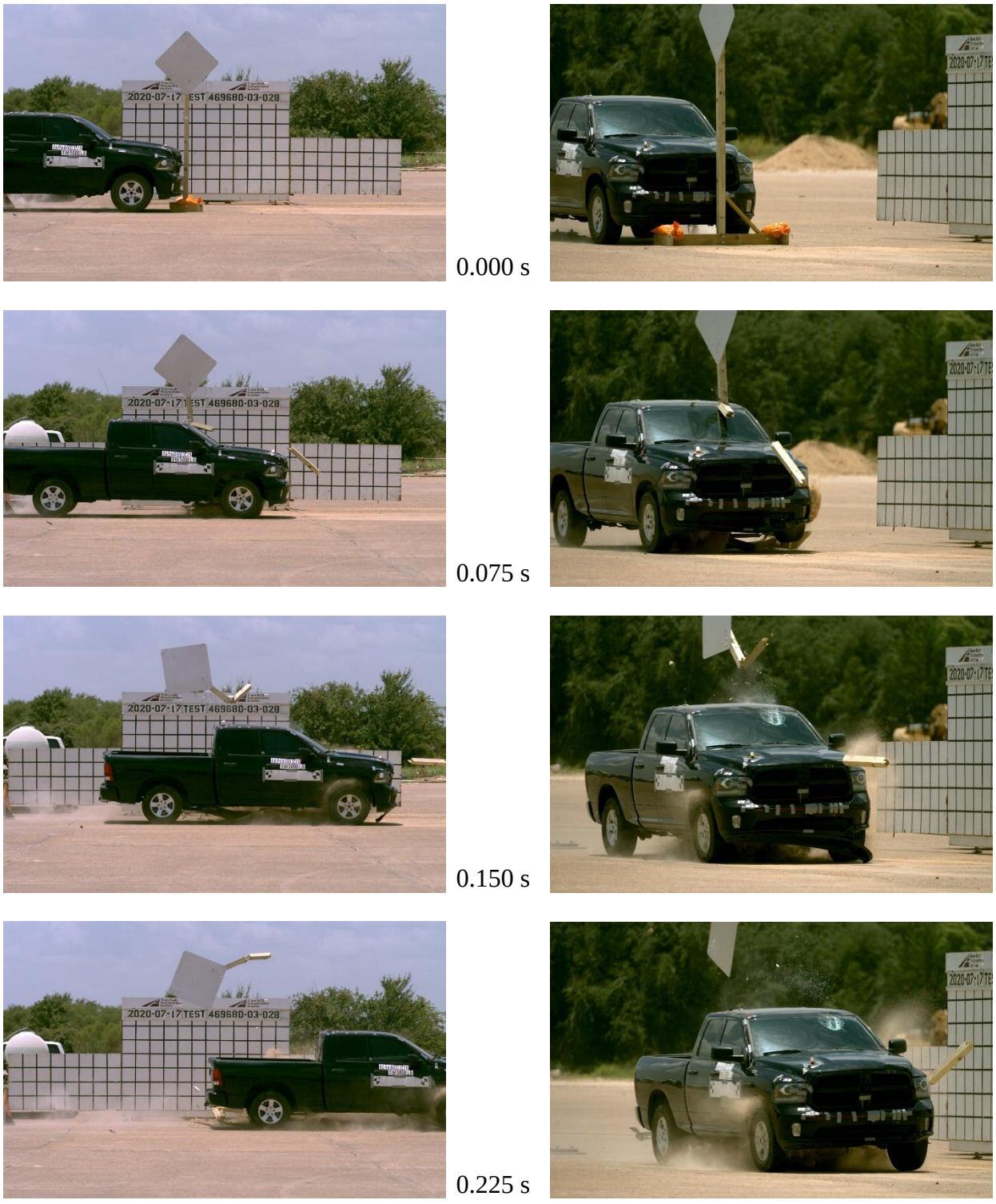


Figure D.1. Sequential Photographs for Test No. 469680-03-2B (Perpendicular and Oblique Views).

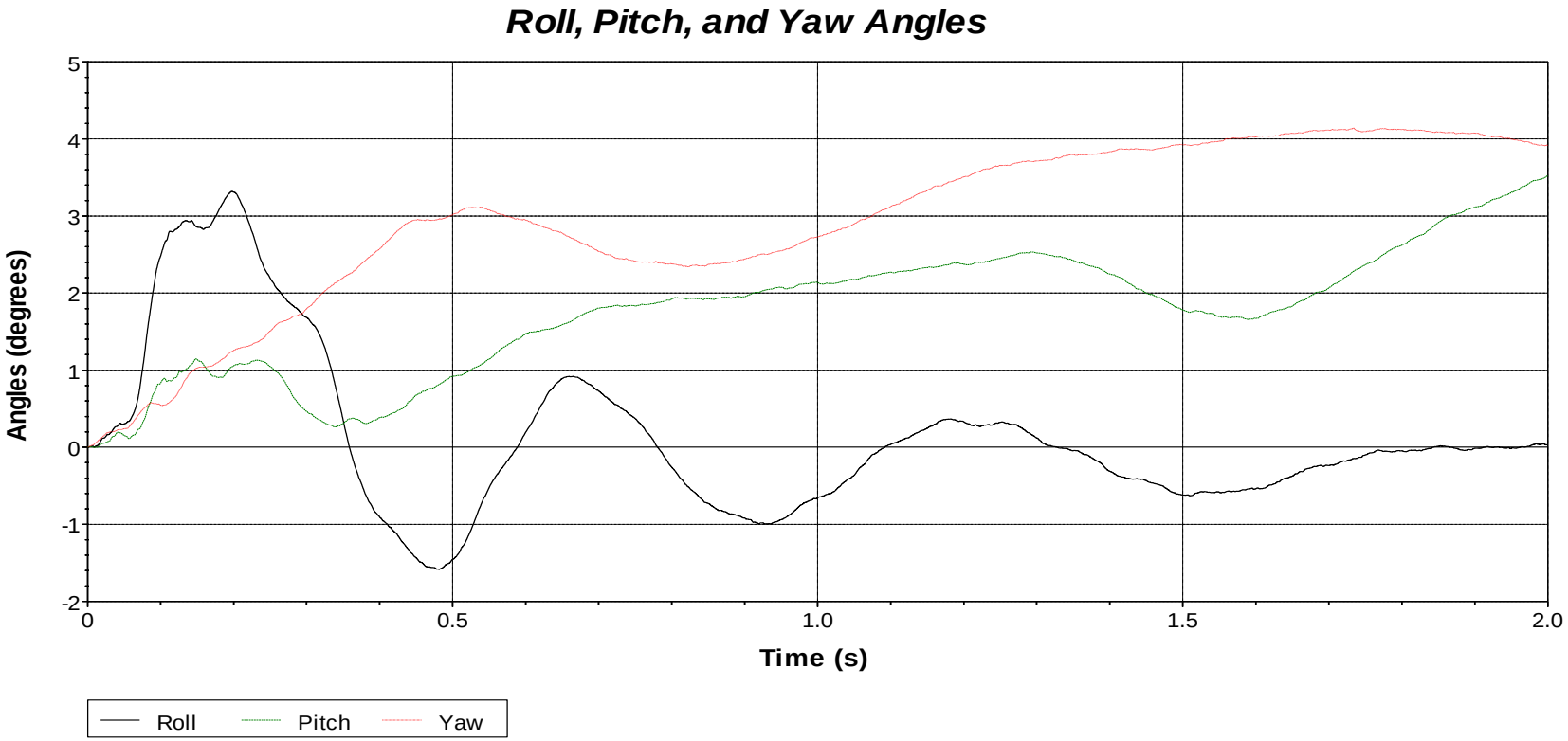
0.300 s


0.375 s


0.450 s

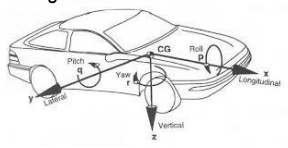

0.525 s


Figure D.1. Sequential Photographs for Test No. 469680-03-2B (Perpendicular and Oblique Views) (Continued).



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 469680-03-2B
Test Standard Test Number: MASH Test 2-72 at 90°
Test Article: TxDOT Single Skid-Mounted Sign Support
Test Vehicle: 2014 RAM 1500 Pickup
Inertial Mass: 5056 lb
Gross Mass: 5056 lb
Impact Speed: 63.0 mi/h
Impact Angle: 90°

Figure D.2. Vehicle Angular Displacements for Test No. 469680-03-2B.

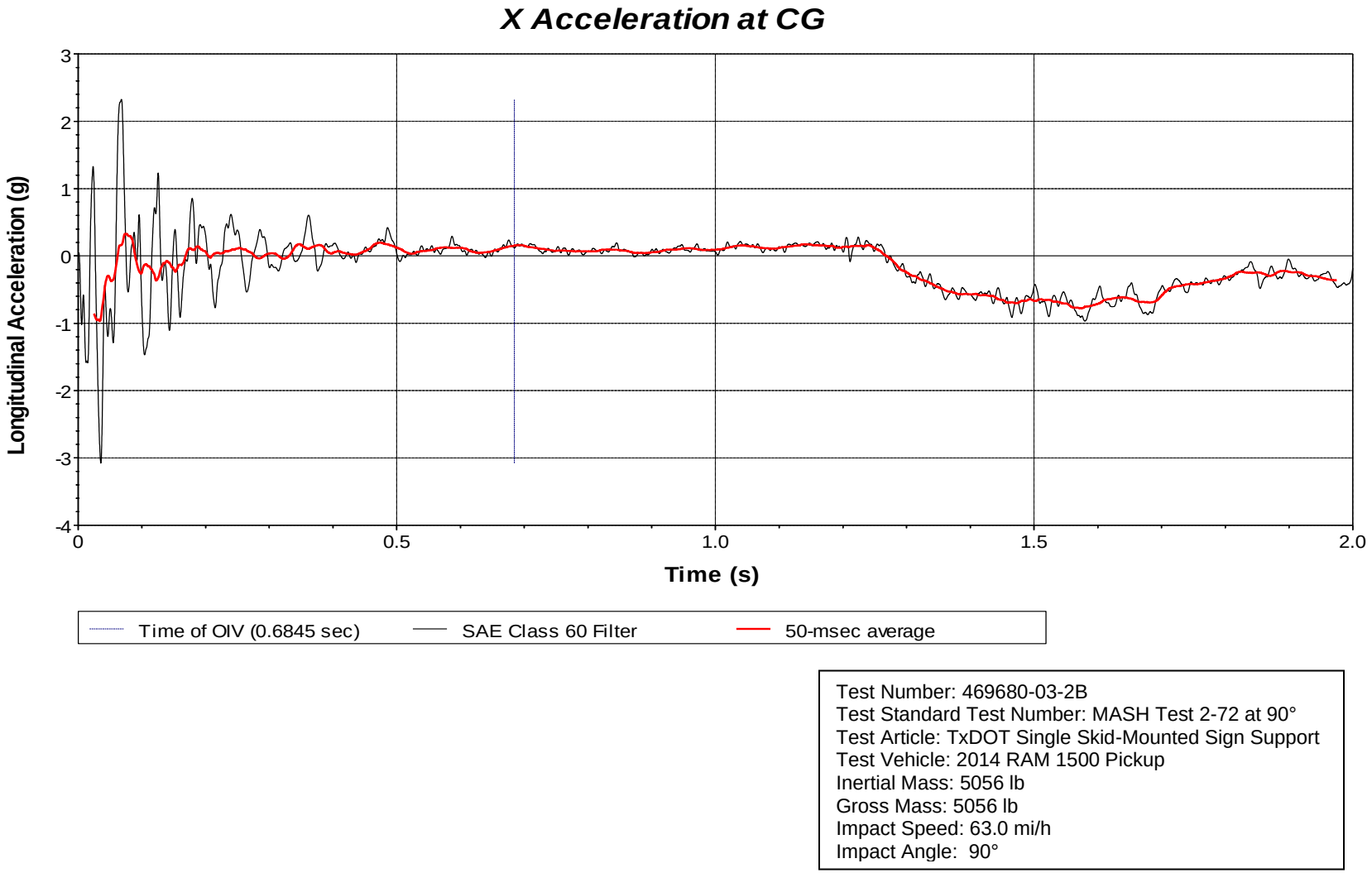


Figure D.3. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-03-2B (Accelerometer Located at Center of Gravity).

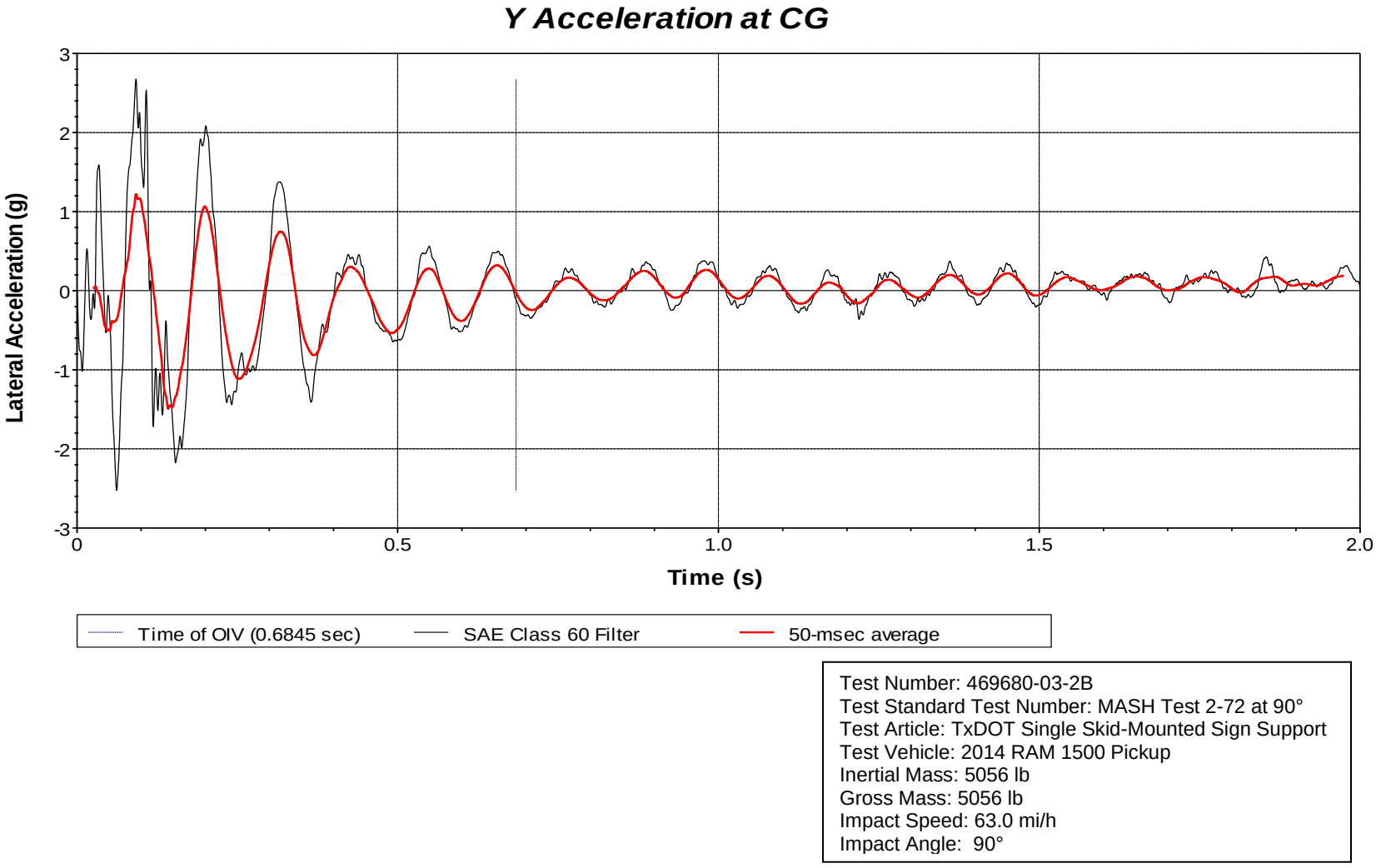


Figure D.4. Vehicle Lateral Accelerometer Trace for Test No. 469680-03-2B (Accelerometer Located at Center of Gravity).

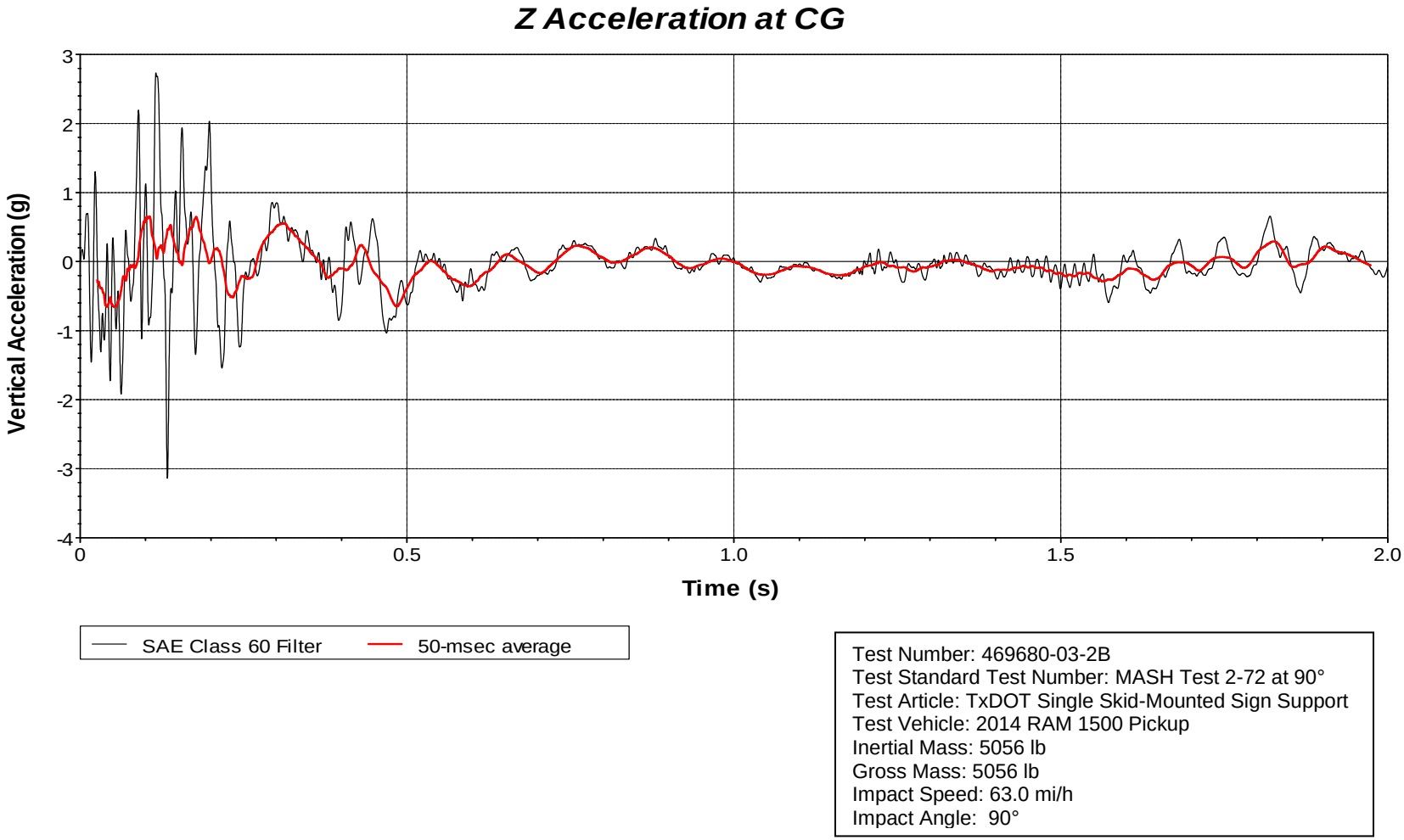


Figure D.5. Vehicle Vertical Accelerometer Trace for Test No. 469680-03-2B (Accelerometer Located at Center of Gravity).

APPENDIX E. *MASH* TEST 3-72 AT 0 DEGREES (CRASH TEST NO. 469680-03-4)

E.1. VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 469680-03-4.

Date: 2020-8-3 Test No.: 469680-03-4 VIN No.: 1C6RR6FT8ES149339

Year: 2014 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 138970

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

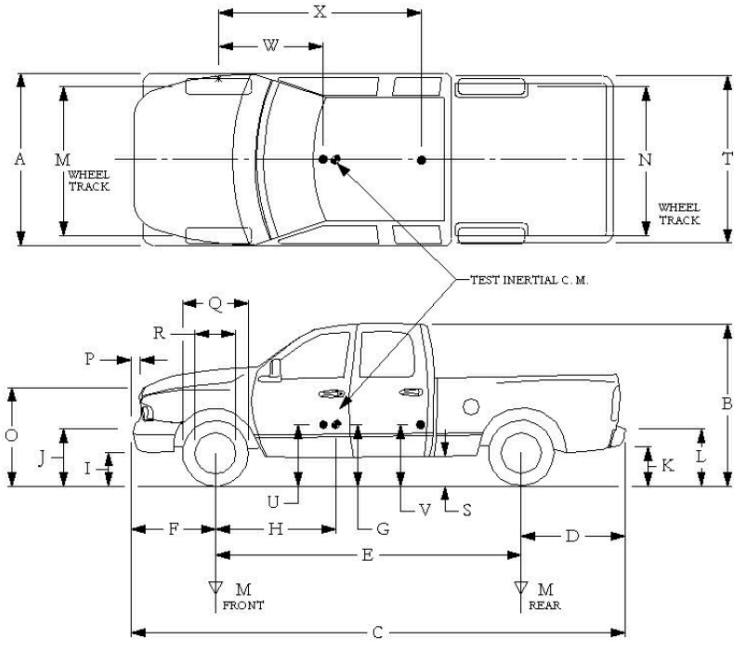
NOTES: None

Engine Type: V-8
Engine CID: 5.7 L

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

Optional Equipment:
None

Dummy Data:
Type:
Mass: 0 lb
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	29.50	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.48	M	68.50	R	18.00	W	60.5
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2913	2861	2861
Back	3900	M_{rear}	2159	2163	2163
Total	6700	M_{Total}	5072	5024	5024

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

Mass Distribution:
lb LF: 1406 RF: 1455 LR: 1124 RR: 1039

Table E.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 469680-03-4.

Date: 2020-8-3 Test No.: 469680-03-4 VIN: 1C6RR6FT8ES149339

Year: 2014 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 138970

Engine: 5.7 L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 105 (440 lb max)

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

Measured Vehicle Weights: (lb)									
LF:	1406		RF:	1455		Front Axle:	2861		
LR:	1124		RR:	1039		Rear Axle:	2163		
Left:	2530		Right:	2494		Total:	5024		
							5000 ±110 lb allowed		
Wheel Base:	140.50	inches	Track: F:	68.50	inches	R:	68.00	inches	
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed					
Center of Gravity, SAE J874 Suspension Method									
X:	60.49	inches	Rear of Front Axle		(63 ±4 inches allowed)				
Y:	-0.24	inches	Left -	Right +	of Vehicle Centerline				
Z:	29.50	inches	Above Ground		(minumum 28.0 inches allowed)				

Hood Height: 46.00 inches Front Bumper Height: 27.00 inches

43 ±4 inches allowed

Front Overhang: 40.00 inches Rear Bumper Height: 30.00 inches

39 ±3 inches allowed

Overall Length: 227.50 inches

237 ±13 inches allowed

Table E.3. Exterior Crush Measurements for Test No. 469680-03-4.

Date:	2020-8-3	Test No.:	469680-03-4	VIN No.:	1C6RR6FT8ES149339
Year:	2014	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L***	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max**** Crush								
	Front plane at bmpr ht		0.5	-							
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

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

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

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

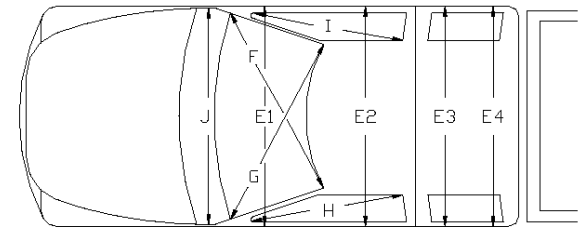
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

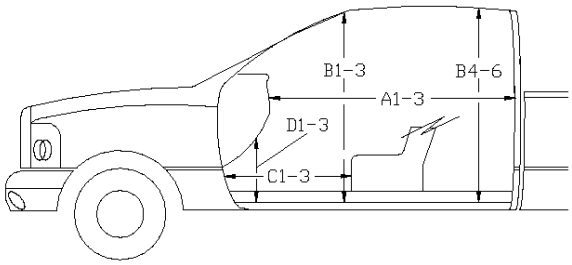
***Measure and document on the vehicle diagram the location of the maximum crush.

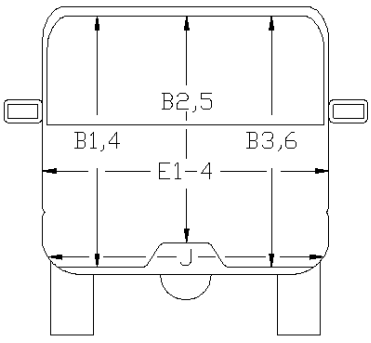
Note: Use as many lines/columns as necessary to describe each damage profile.

Table E.4. Occupant Compartment Measurements for Test No. 469680-03-4.

Date:	2020-8-3	Test No.:	469680-03-4	VIN No.:	1C6RR6FT8ES149339
Year:	2014	Make:	RAM	Model:	1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

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

E.2. SEQUENTIAL PHOTOGRAPHS

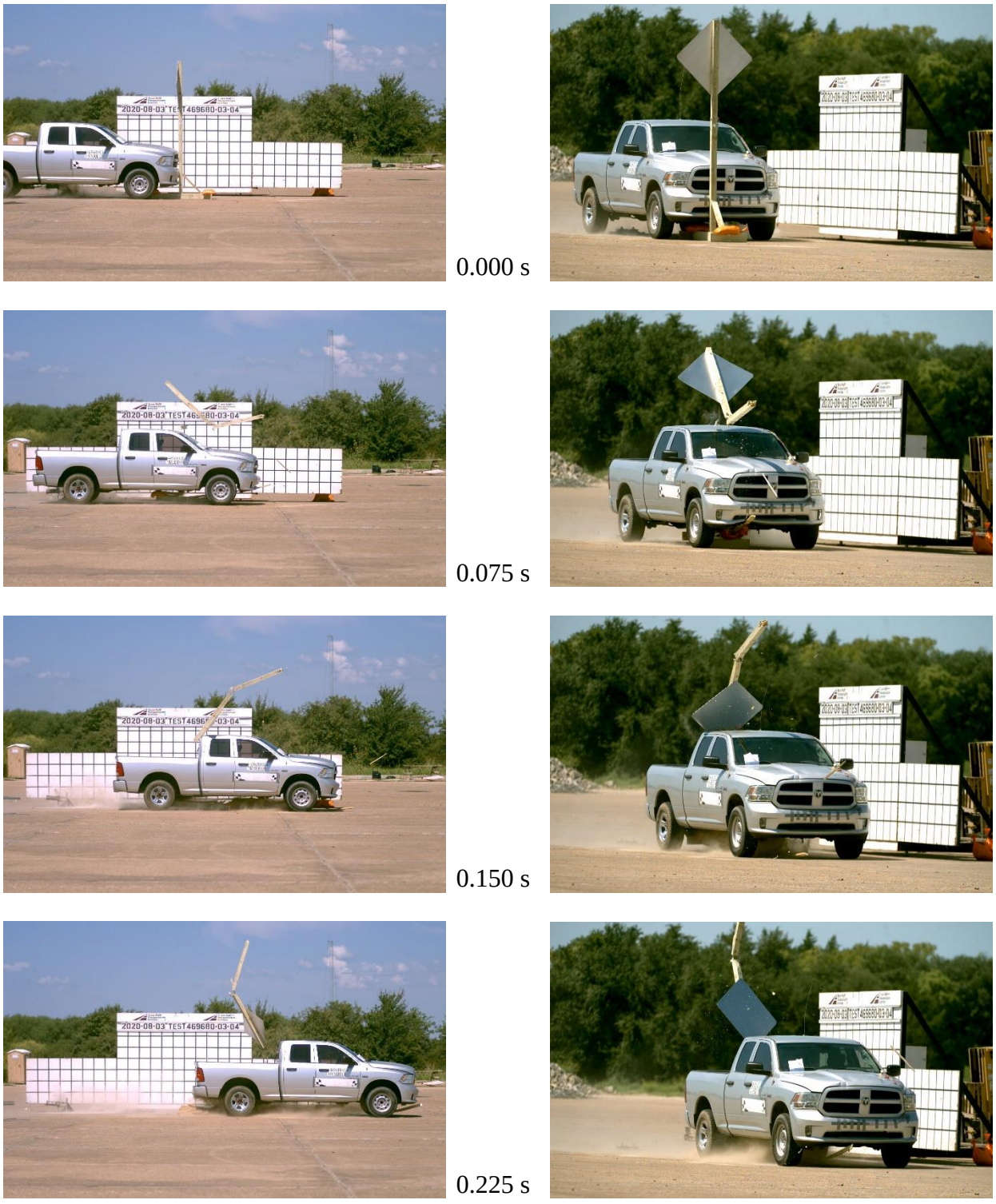


Figure E.1. Sequential Photographs for Test No. 469680-03-4 (Perpendicular and Oblique Views).

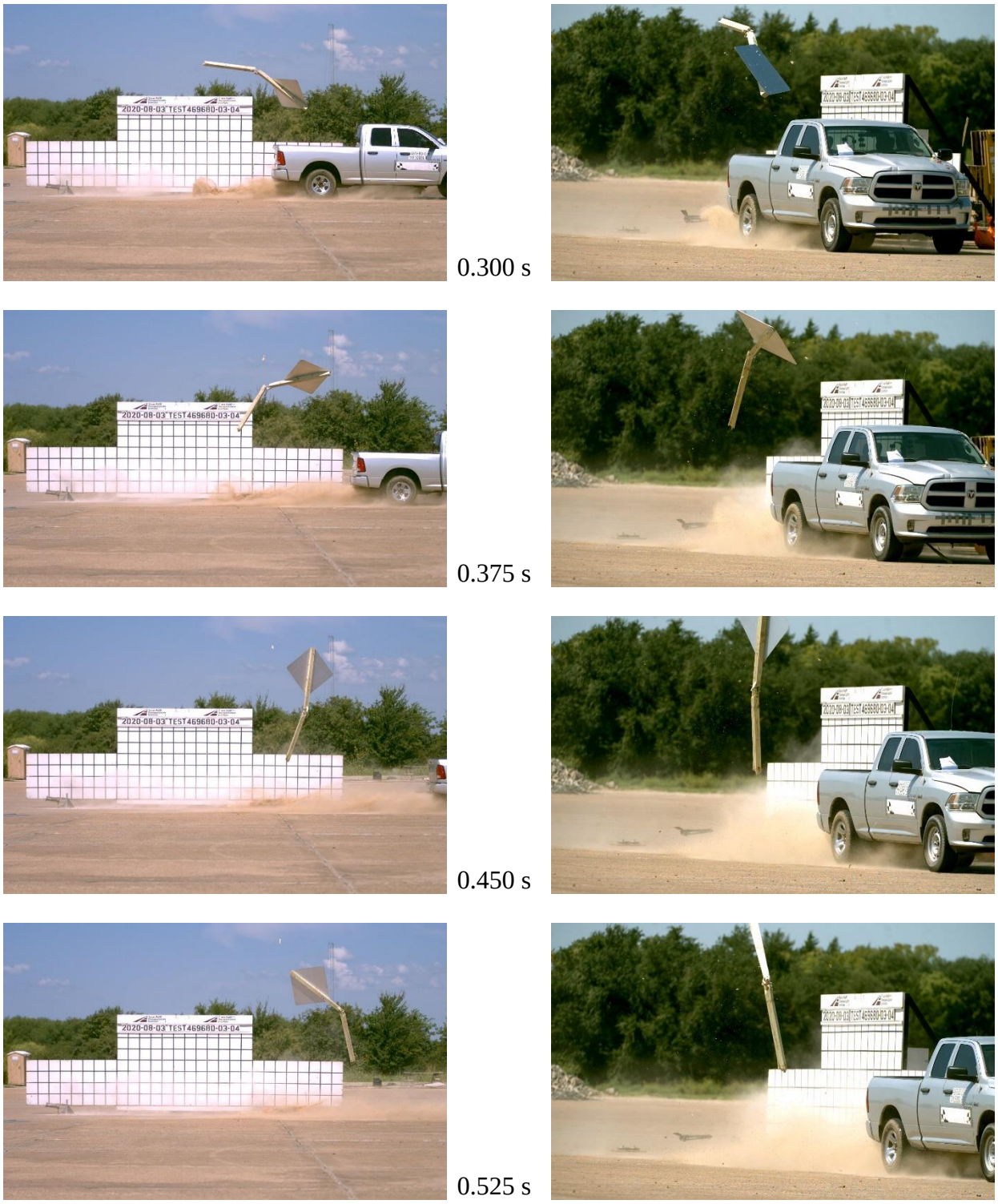
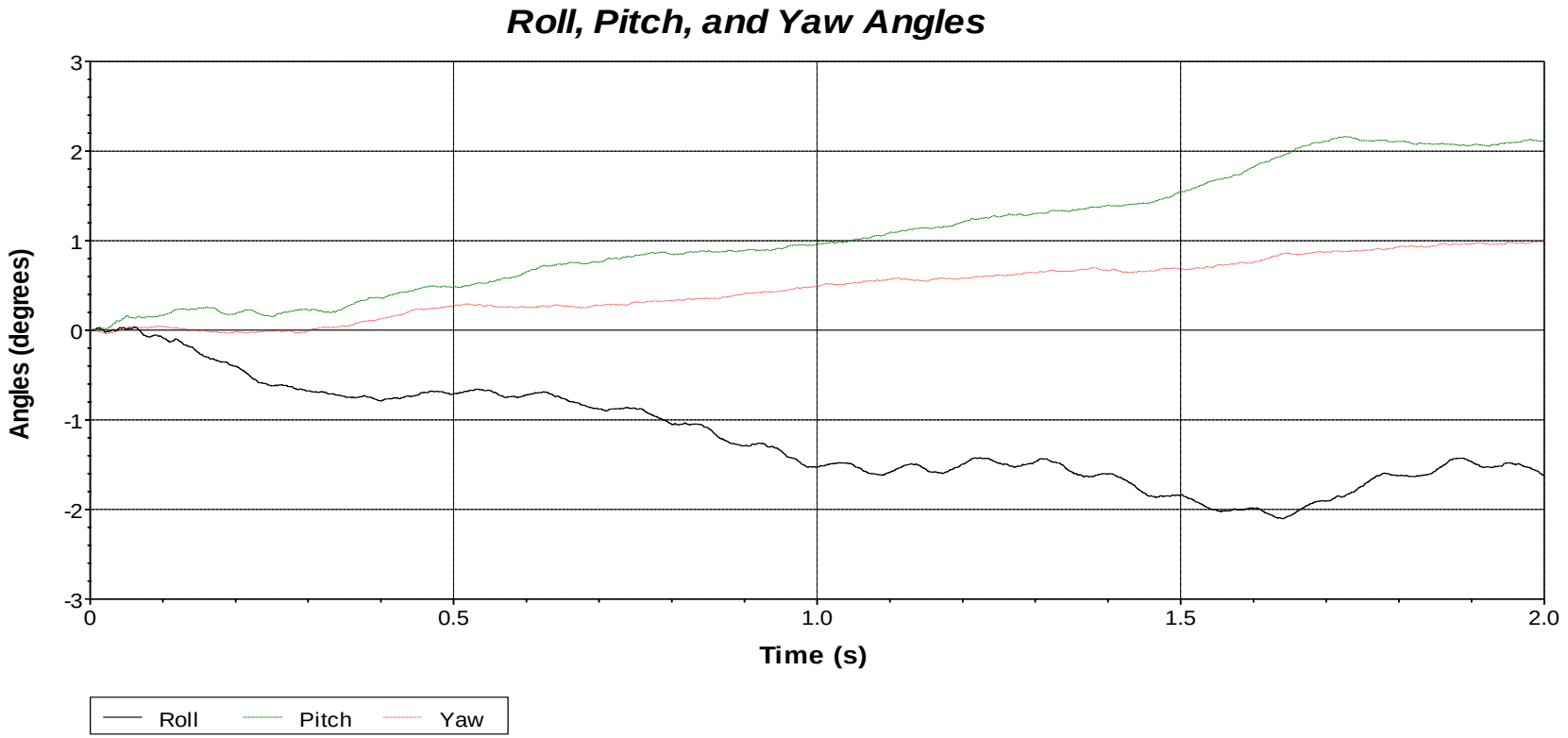
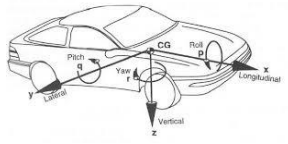


Figure E.1. Sequential Photographs for Test No. 469680-03-4 (Perpendicular and Oblique Views) (Continued).



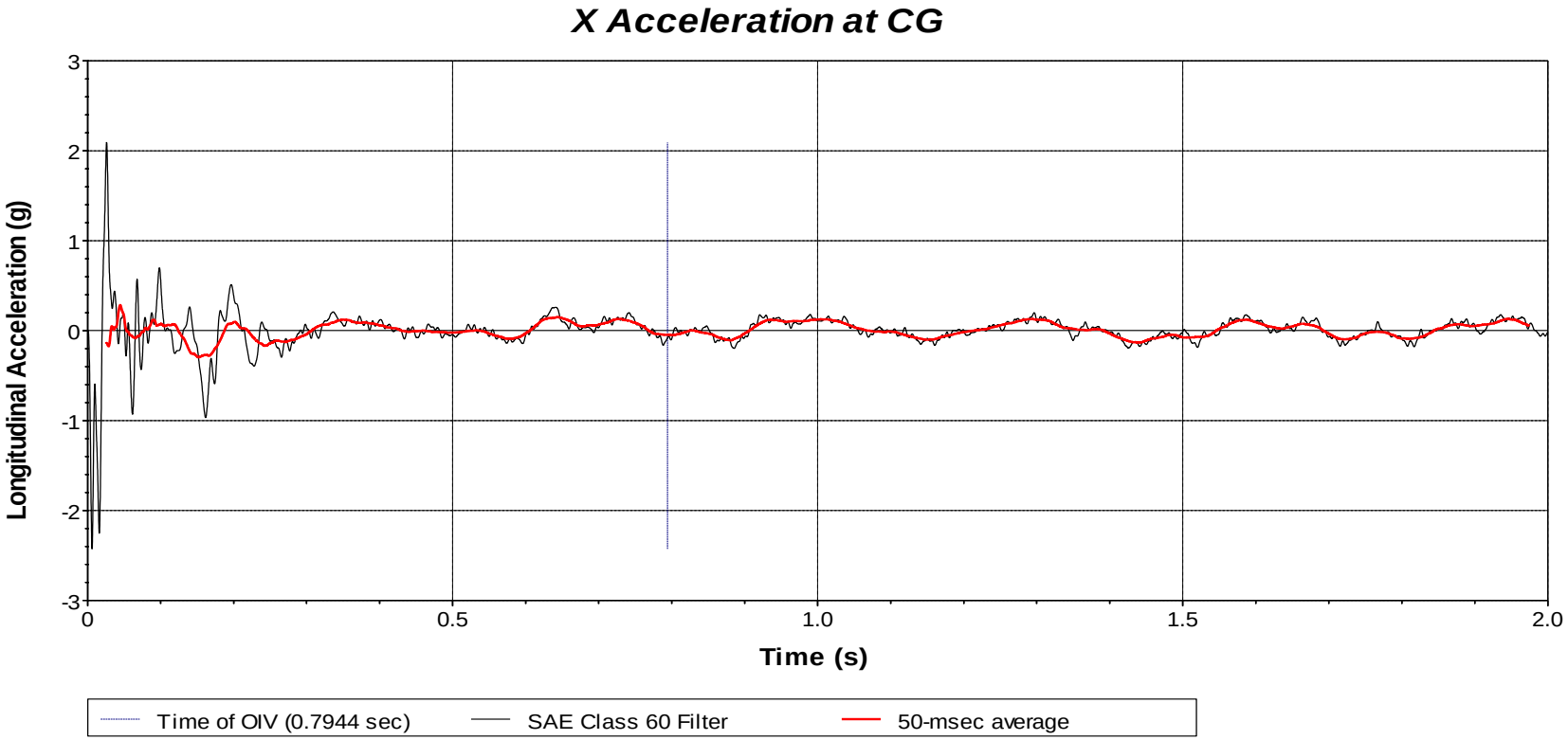
Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 469680-03-4
Test Standard Test Number: MASH Test 3-72 at 0°
Test Article: TxDOT Single Skid-Mounted Sign Support
Test Vehicle: 2014 RAM 1500 Pickup
Inertial Mass: 5024 lb
Gross Mass: 5024 lb
Impact Speed: 62.1 mi/h
Impact Angle: 0°

Figure E.2. Vehicle Angular Displacements for Test No. 469680-03-4.



Test Number: 469680-03-4
Test Standard Test Number: MASH Test 3-72 at 0°
Test Article: TxDOT Single Skid-Mounted Sign Support
Test Vehicle: 2014 RAM 1500 Pickup
Inertial Mass: 5024 lb
Gross Mass: 5024 lb
Impact Speed: 62.1 mi/h
Impact Angle: 0°

Figure E.3. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-03-4 (Accelerometer Located at Center of Gravity).

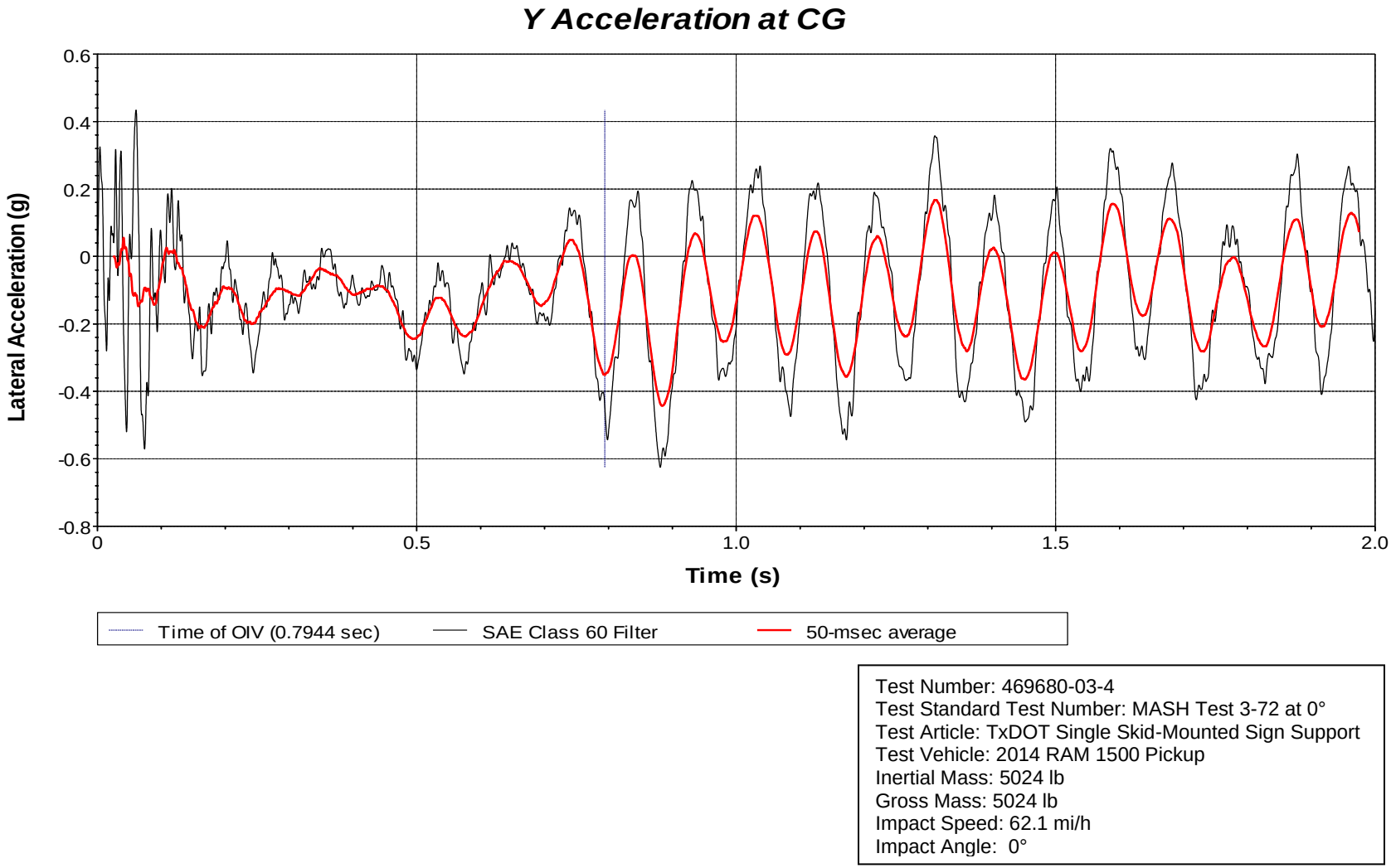


Figure E.4. Vehicle Lateral Accelerometer Trace for Test No. 469680-03-4 (Accelerometer Located at Center of Gravity).

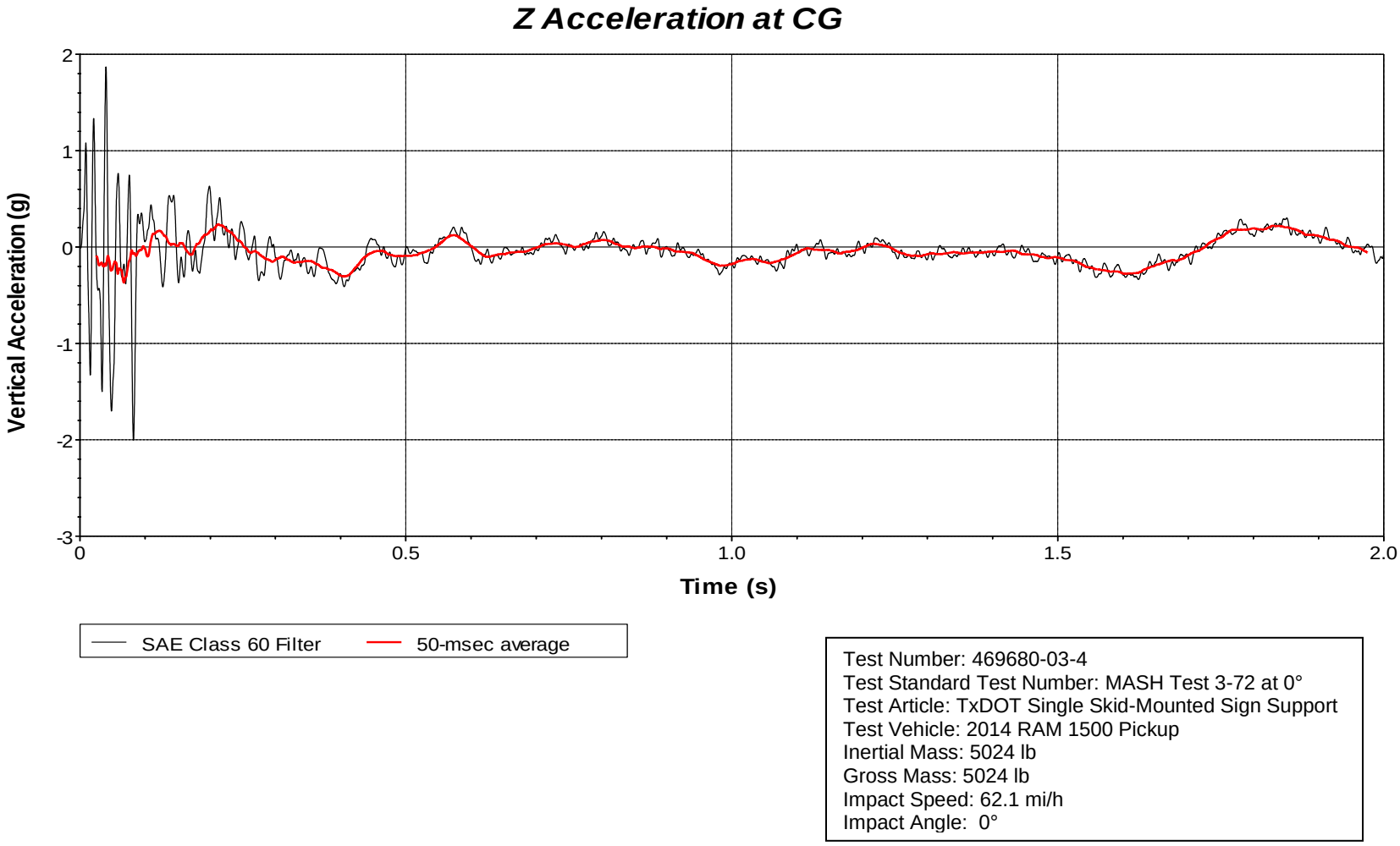


Figure E.5. Vehicle Vertical Accelerometer Trace for Test No. 469680-03-4 (Accelerometer Located at Center of Gravity).

APPENDIX F. *MASH* TEST 3-71 AT 90 DEGREES (CRASH TEST NO. 469680-03-1)

F.1. VEHICLE PROPERTIES AND INFORMATION

Table F.1. Vehicle Properties for Test No. 469680-03-1.

Date: 2020-08-03 Test No.: 469680-03-1 VIN No.: 3N1CN7AP6EL822267

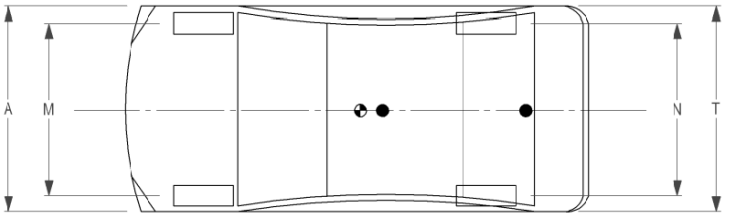
Year: 2014 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 93361 Tire Size: P185 65R 15

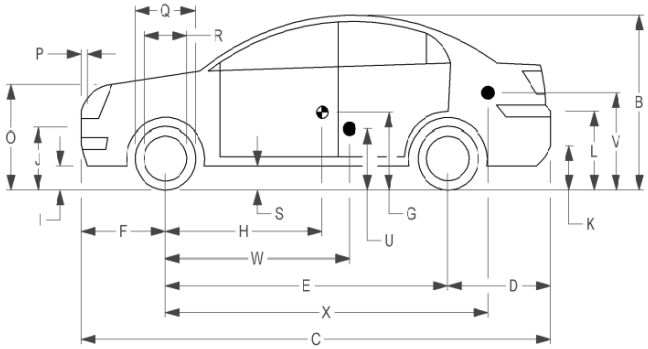
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None



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



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

Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	39.94	M	58.30	R	16.25	W	39.90
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.25	O	30.50	T	64.50		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1750	M_{front}	1472	1482	1567
Back	1687	M_{rear}	974	948	1028
Total	3389	M_{Total}	2446	2430	2595

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

Mass Distribution:
lb LF: 772 RF: 710 LR: 475 RR: 473

Table F.2. Exterior Crush Measurements for Test No. 469680-03-1.

Date:	2020-8-3	Test No.:	469680-03-1	VIN No.:	3N1CN7AP6EL822267
Year:	2014	Make:	NISSAN	Model:	VERSA

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L***	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max**** Crush								
	Front plane at bumper ht		0.25								
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

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

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

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

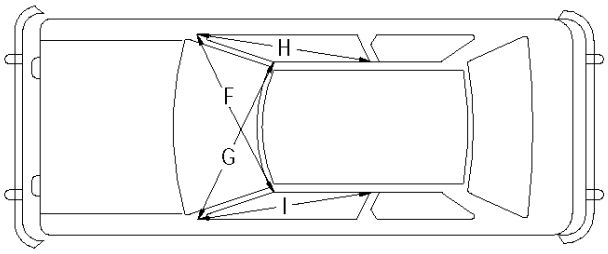
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

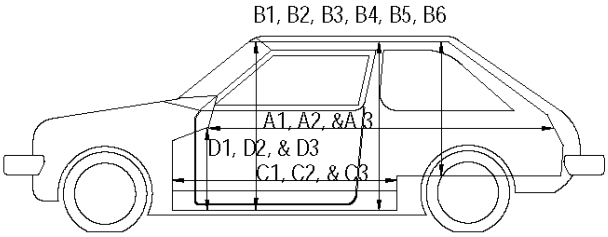
***Measure and document on the vehicle diagram the location of the maximum crush.

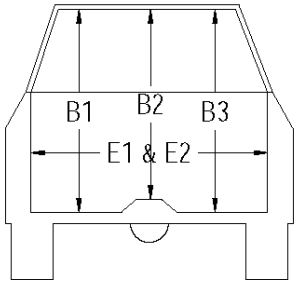
Note: Use as many lines/columns as necessary to describe each damage profile.

Table F.3. Occupant Compartment Measurements for Test No. 469680-03-1.

Date:	2020-8-3	Test No.:	469680-03-1	VIN No.:	3N1CN7AP6EL822267
Year:	2014	Make:	NISSAN	Model:	VERSA







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	75.00	75.00	0.00
A2	74.00	74.00	0.00
A3	74.00	74.00	0.00
B1	43.00	43.00	0.00
B2	37.00	37.00	0.00
B3	43.00	43.00	0.00
B4	46.50	46.50	0.00
B5	42.50	42.50	0.00
B6	46.50	46.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	12.50	12.50	0.00
D2	0.00	0.00	0.00
D3	10.00	10.00	0.00
E1	45.00	45.00	0.00
E2	48.75	48.75	0.00
F	47.5	47.5	0.00
G	47.50	47.50	0.00
H	39.00	39.00	0.00
I	39.00	39.00	0.00
J*	48.50	48.50	0.00

F.2. SEQUENTIAL PHOTOGRAPHS

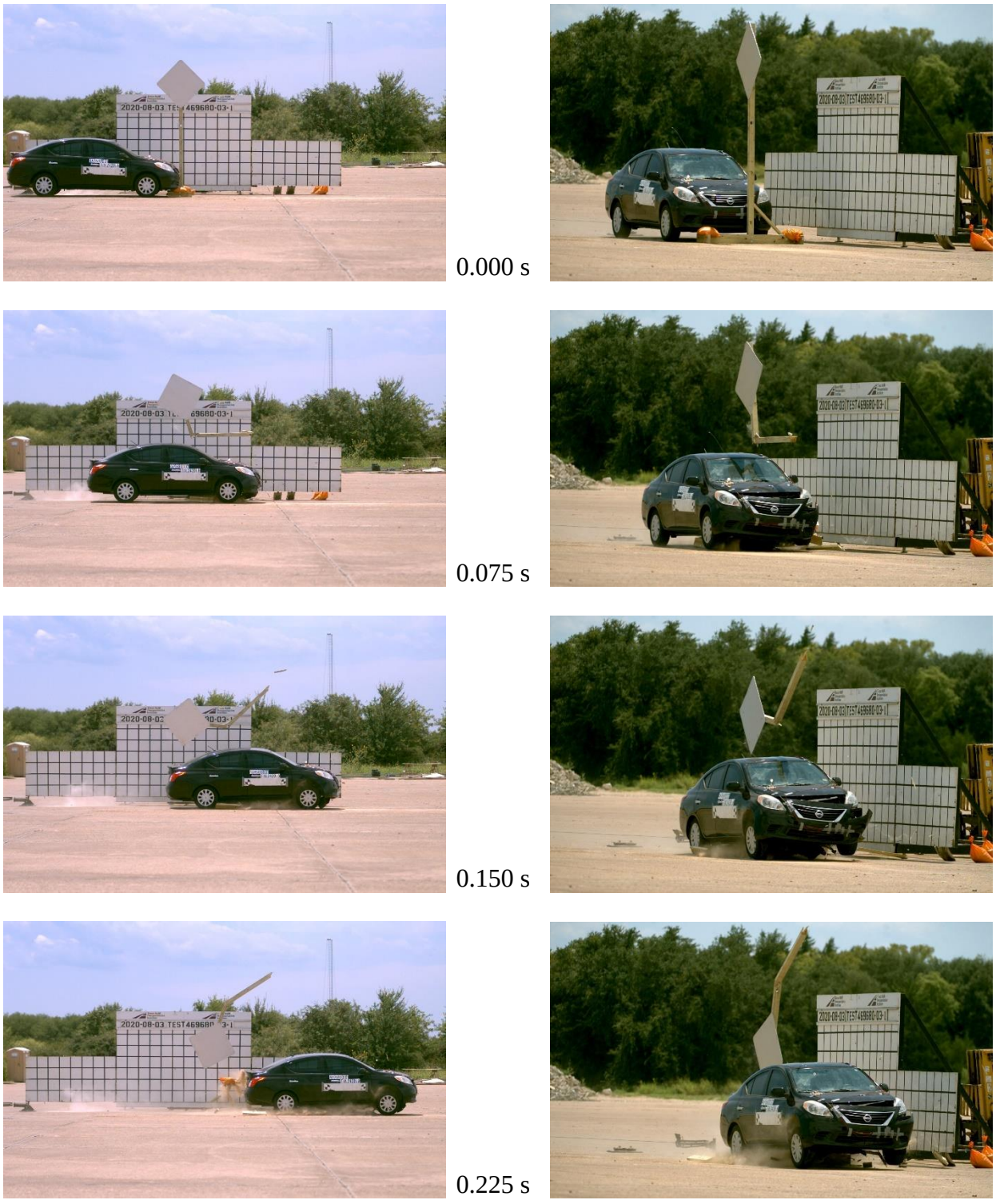
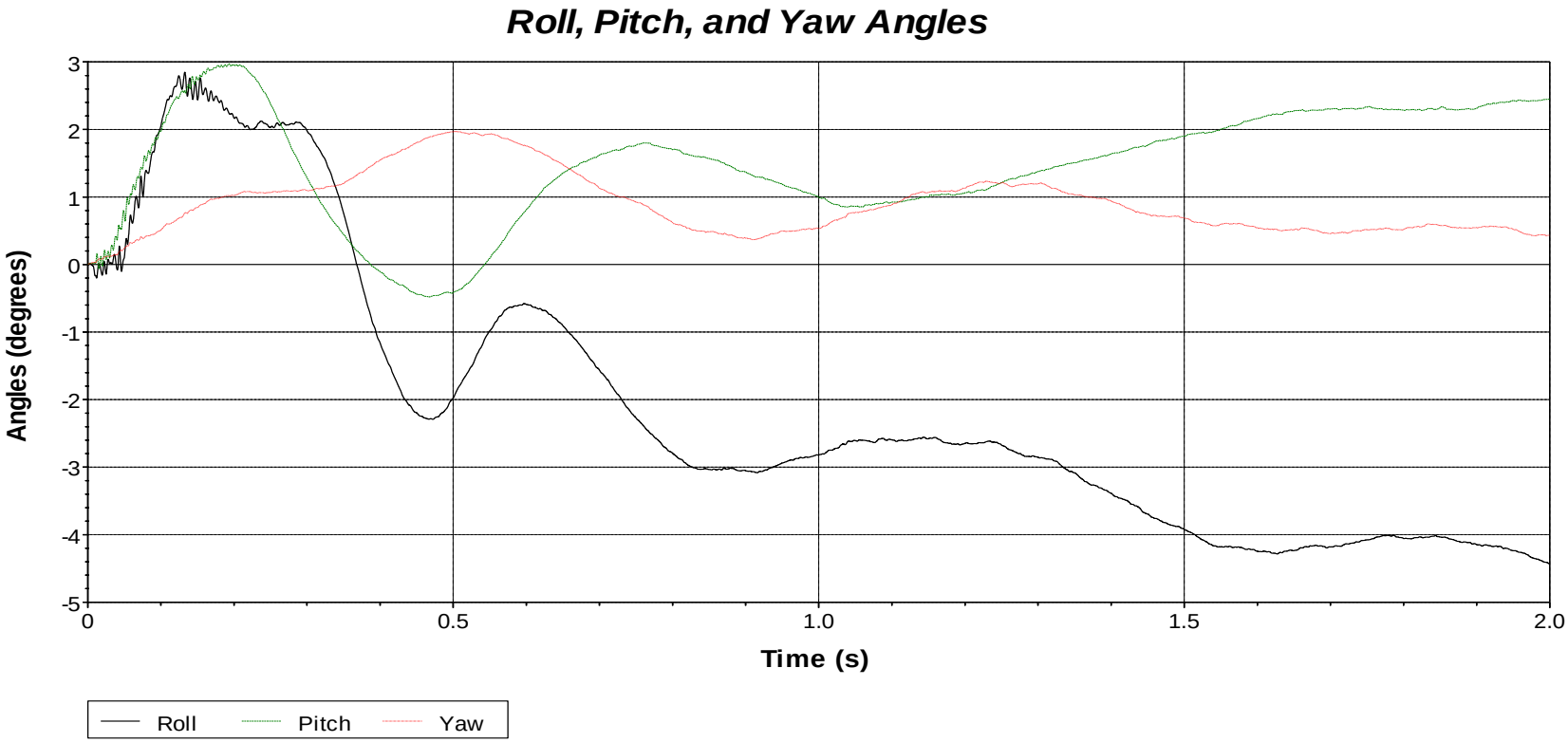


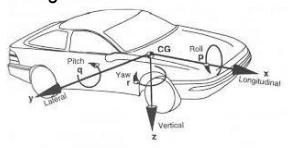
Figure F.1. Sequential Photographs for Test No. 469680-03-1 (Perpendicular and Oblique Views).

Figure F.1. Sequential Photographs for Test No. 469680-03-1 (Perpendicular and Oblique Views) (Continued).



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 469680-03-1
Test Standard Test Number: MASH Test 3-71 at 90°
Test Article: TxDOT Single Skid-Mounted Sign Support
Test Vehicle: 2014 Nissan Versa
Inertial Mass: 2430 lb
Gross Mass: 2595 lb
Impact Speed: 62.7 mi/h
Impact Angle: 90°

Figure F.2. Vehicle Angular Displacements for Test No. 469680-03-1.

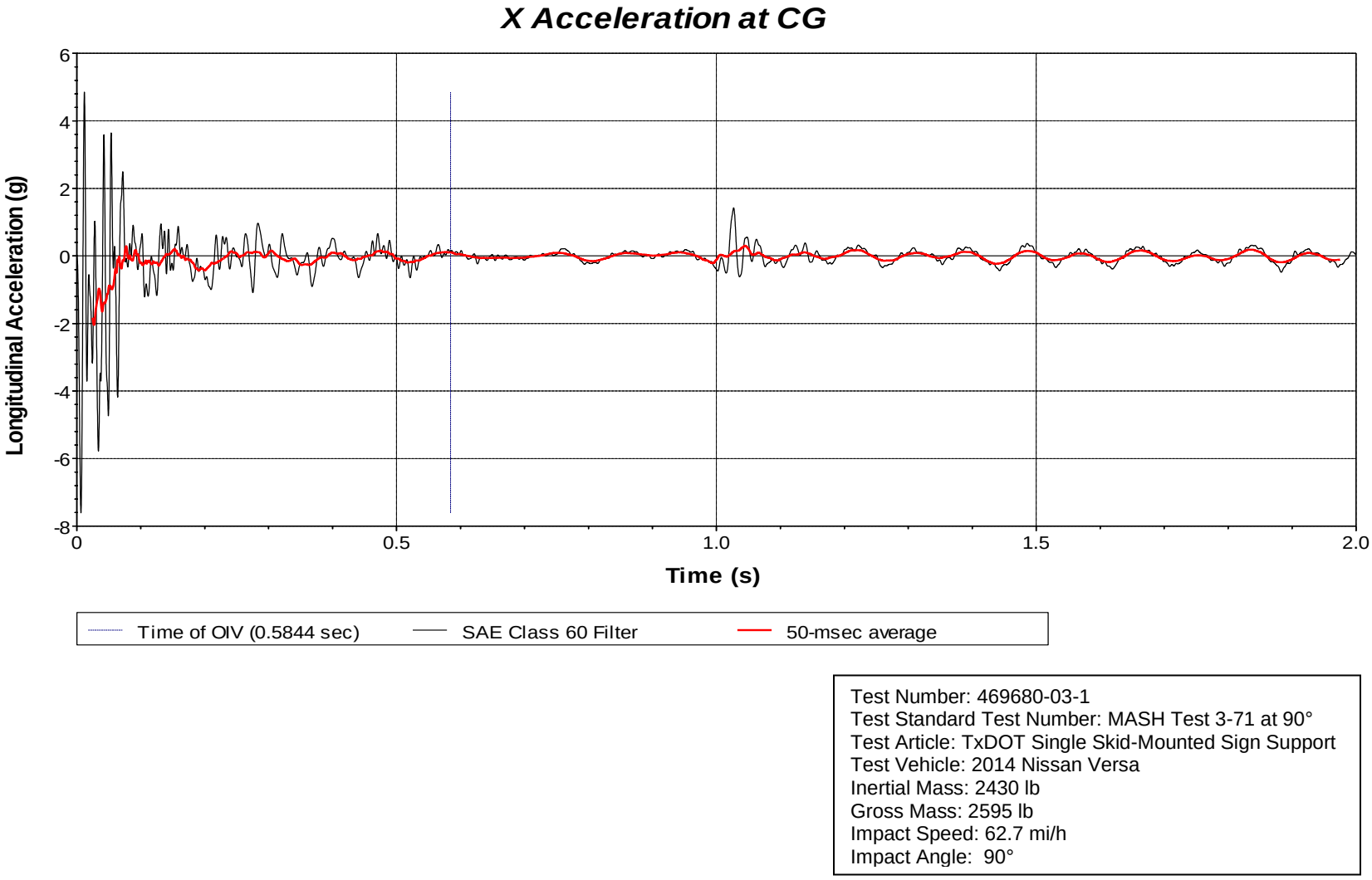


Figure F.3. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-03-1 (Accelerometer Located at Center of Gravity).

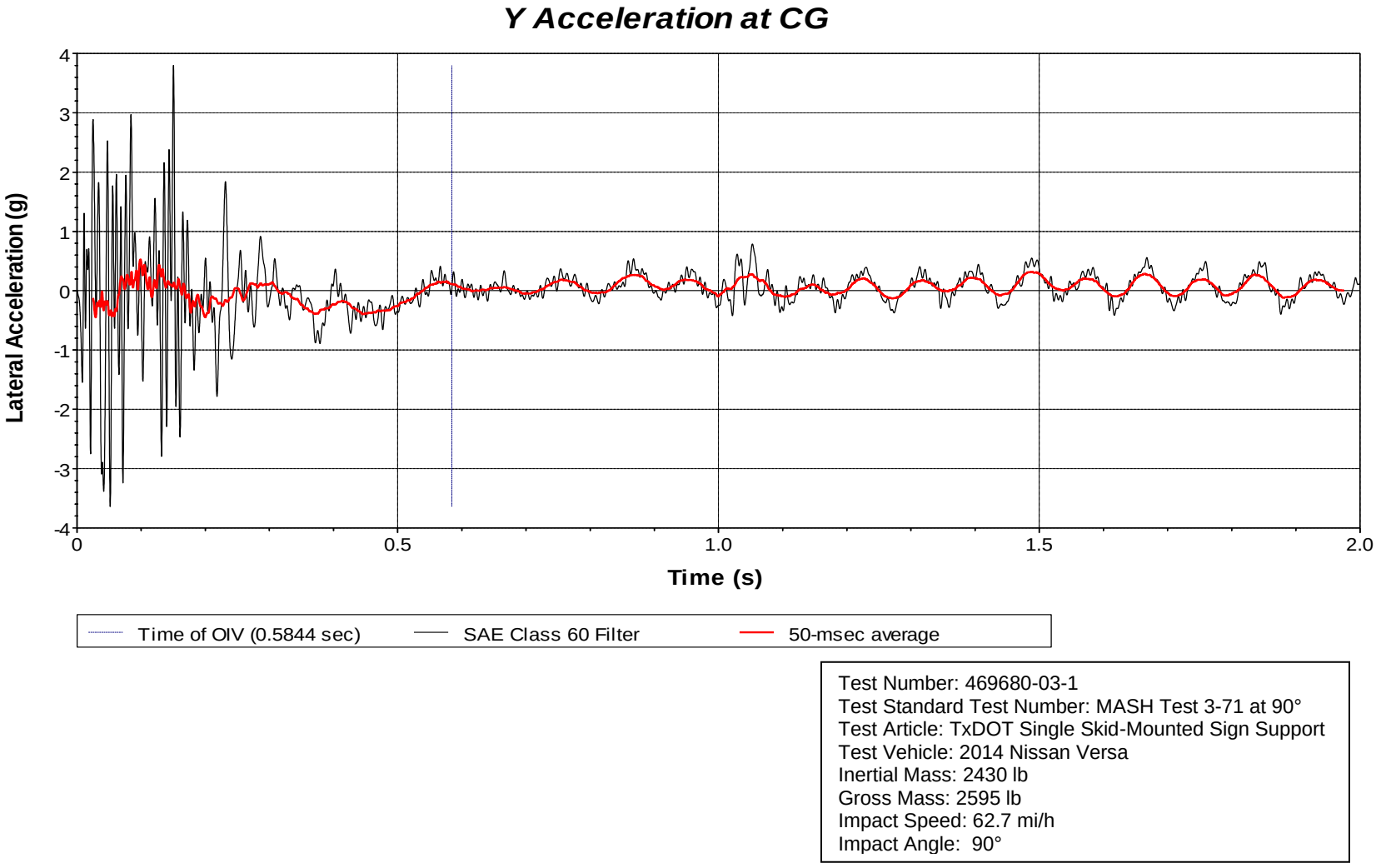


Figure F.4. Vehicle Lateral Accelerometer Trace for Test No. 469680-03-1 (Accelerometer Located at Center of Gravity).

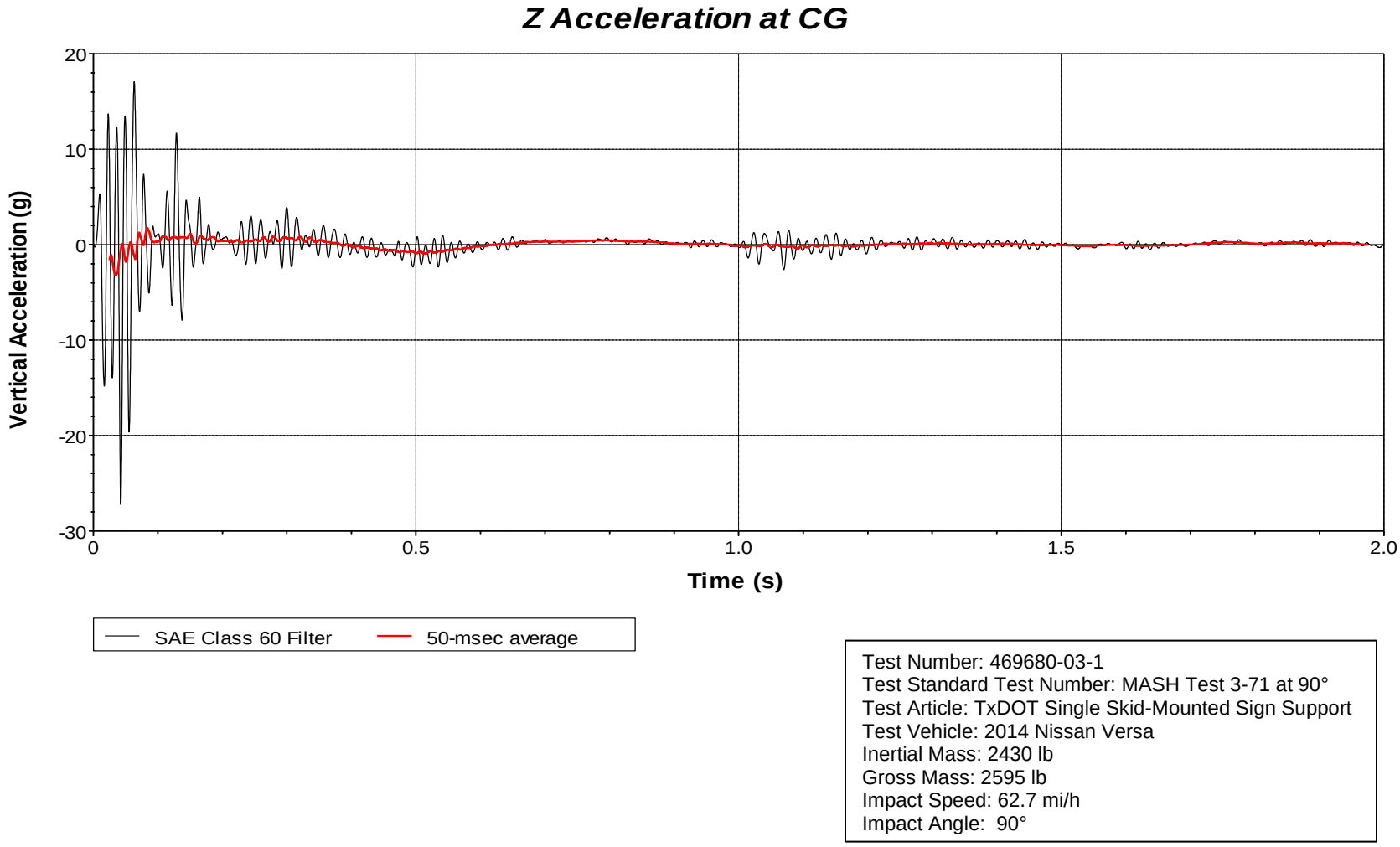


Figure F.5. Vehicle Vertical Accelerometer Trace for Test No. 469680-03-1 (Accelerometer Located at Center of Gravity).

APPENDIX G. *MASH* TEST 3-71 AT 0 DEGREES (CRASH TEST NO. 469680-03-3)

G.1. VEHICLE PROPERTIES AND INFORMATION

Table G.1. Vehicle Properties for Test No. 469680-03-3.

Date: 2020-08-03 Test No.: 469680-03-3 VIN No.: 3N1CN7AP6EL822267

Year: 2014 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 93361 Tire Size: P185 65R 15

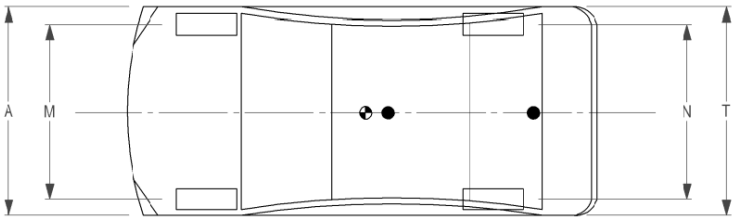
Describe any damage to the vehicle prior to test: None

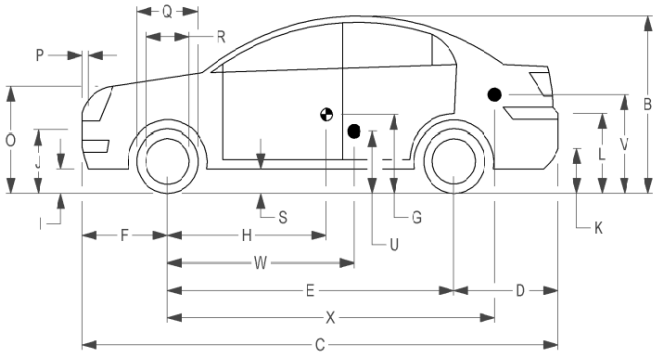
● Denotes accelerometer location.

NOTES: None

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

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





Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	39.94	M	58.30	R	16.25	W	39.90
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.25	O	30.50	T	64.50		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1750	M_{front}	1472	1482	1567
Back	1687	M_{rear}	974	948	1028
Total	3389	M_{Total}	2446	2430	2595

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

Mass Distribution:
lb LF: 772 RF: 710 LR: 475 RR: 473

Table G.2. Exterior Crush Measurements for Test No. 469680-03-3.

Date:	2020-8-3	Test No.:	469680-03-3	VIN No.:	3N1CN7AP6EL822267
Year:	2014	Make:	NISSAN	Model:	VERSA

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
	Front plane at bumper ht		1.0								
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

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

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

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

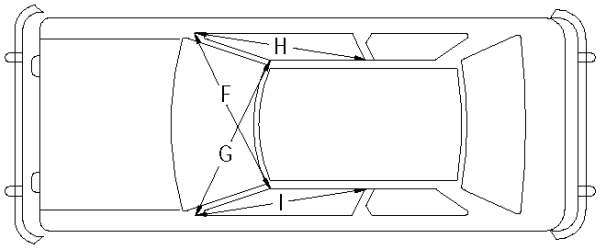
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

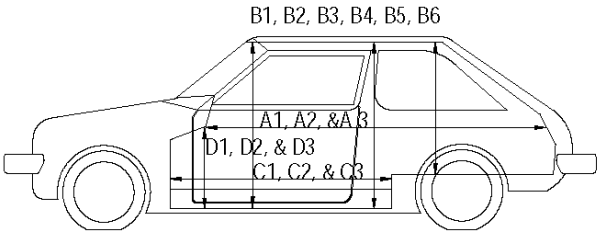
***Measure and document on the vehicle diagram the location of the maximum crush.

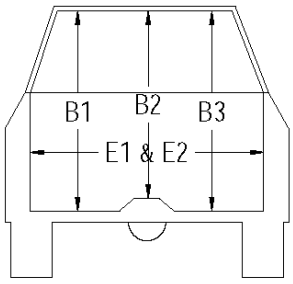
Note: Use as many lines/columns as necessary to describe each damage profile.

Table G.3. Occupant Compartment Measurements for Test No. 469680-03-3.

Date:	2020-8-3	Test No.:	469680-03-3	VIN No.:	3N1CN7AP6EL822267
Year:	2014	Make:	NISSAN	Model:	VERSA







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

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

G.2. SEQUENTIAL PHOTOGRAPHS

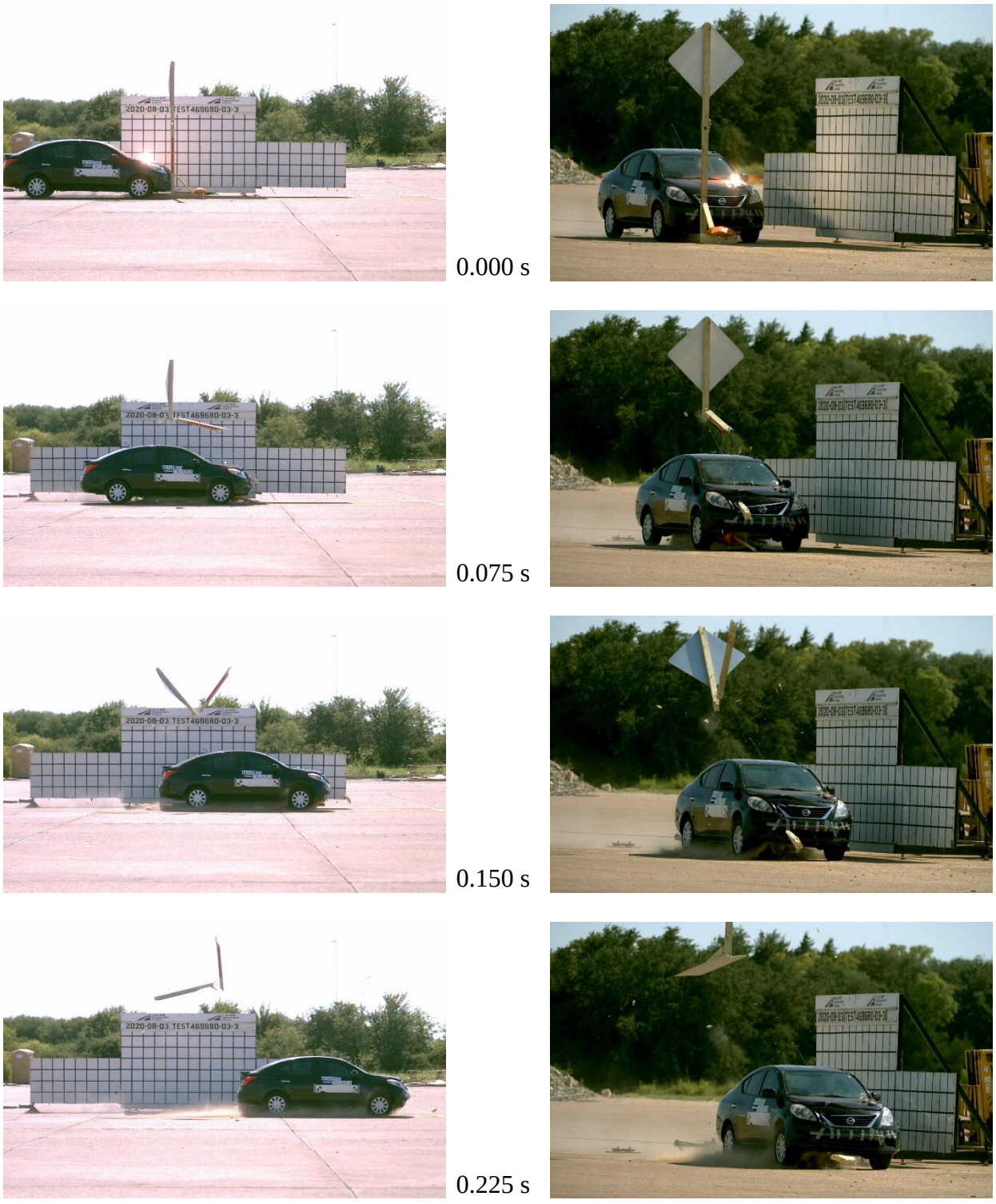


Figure G.1. Sequential Photographs for Test No. 469680-03-3 (Perpendicular and Oblique Views).

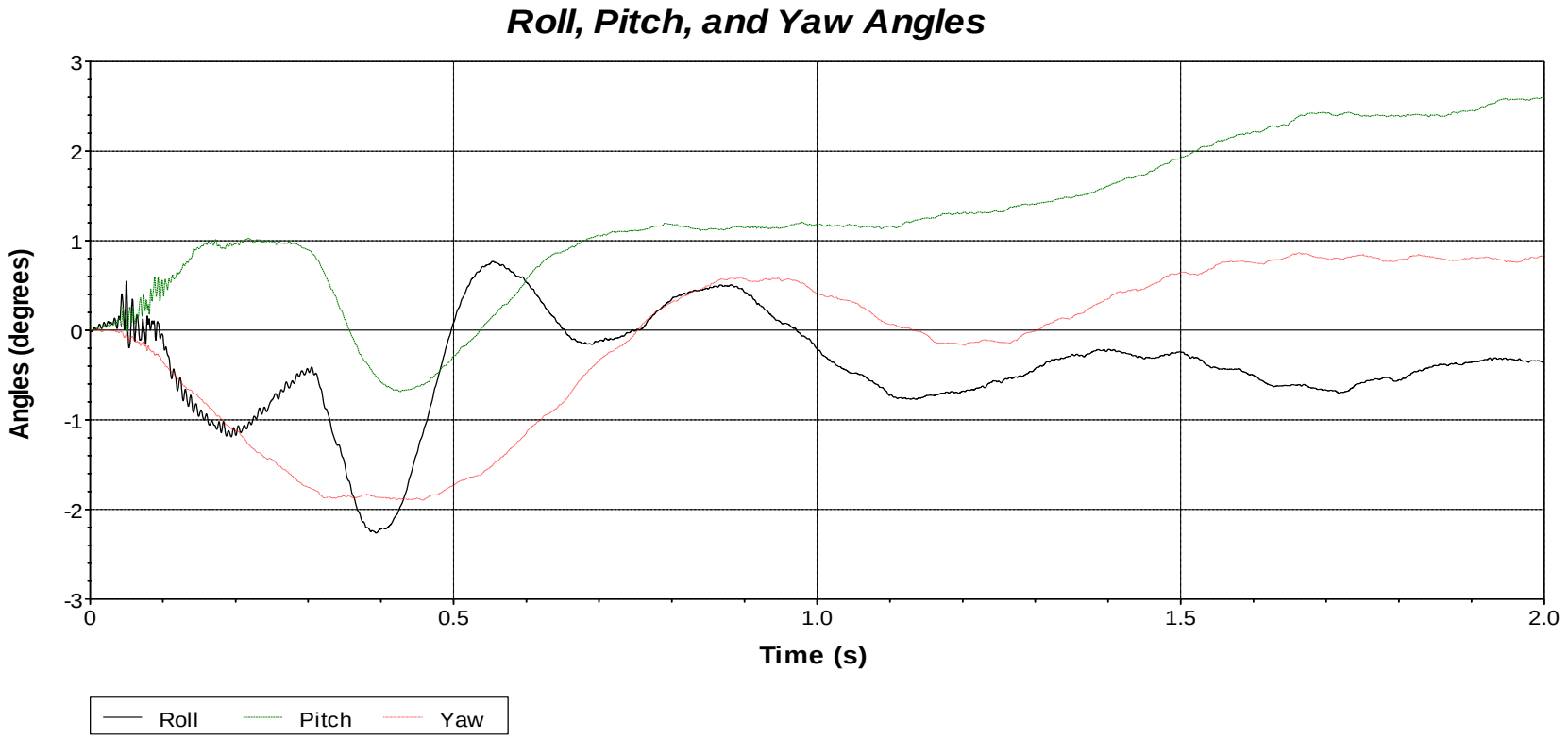
0.300 s


0.375 s


0.450 s

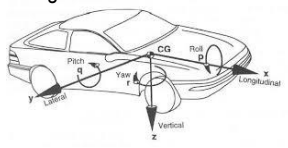

0.525 s


Figure G.1. Sequential Photographs for Test No. 469680-03-3 (Perpendicular and Oblique Views) (Continued).



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 469680-03-3
Test Standard Test Number: MASH Test 3-71 at 0°
Test Article: TxDOT Single Skid-Mounted Sign Support
Test Vehicle: 2014 Nissan Versa
Inertial Mass: 2430 lb
Gross Mass: 2595 lb
Impact Speed: 62.9 mi/h
Impact Angle: 0°

Figure G.2. Vehicle Angular Displacements for Test No. 469680-03-3.

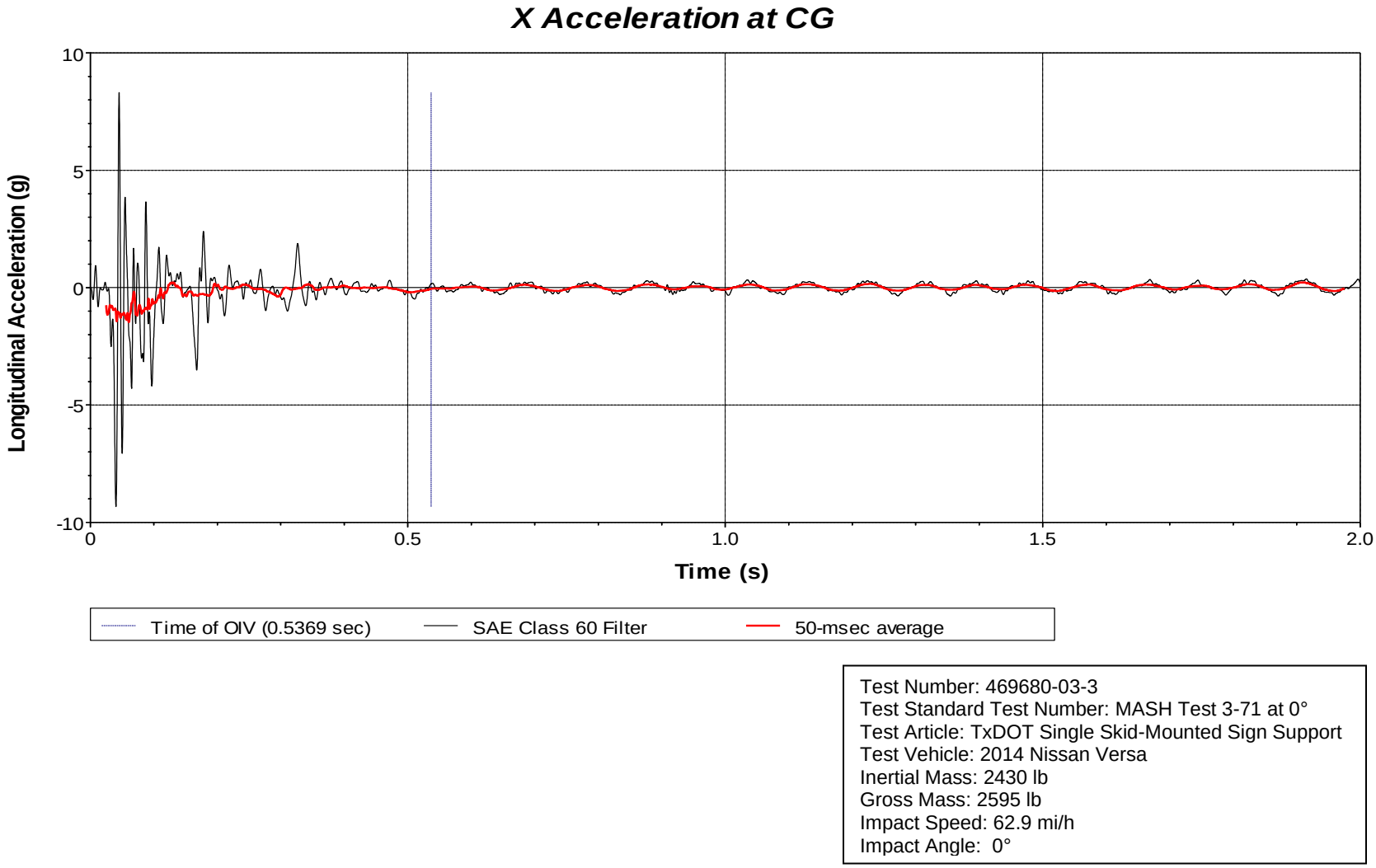


Figure G.3. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-03-3 (Accelerometer Located at Center of Gravity).

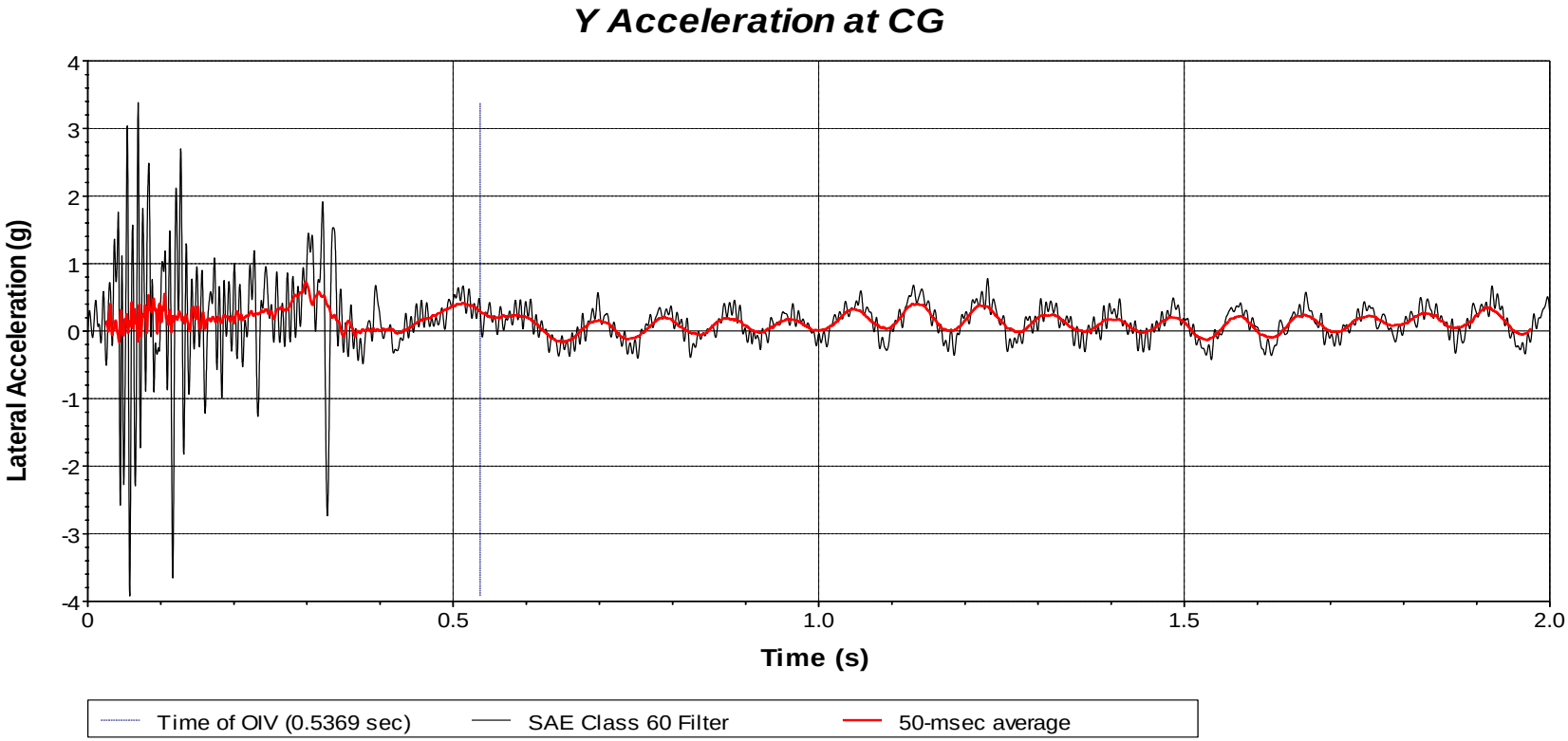


Figure G.4. Vehicle Lateral Accelerometer Trace for Test No. 469680-03-3 (Accelerometer Located at Center of Gravity).

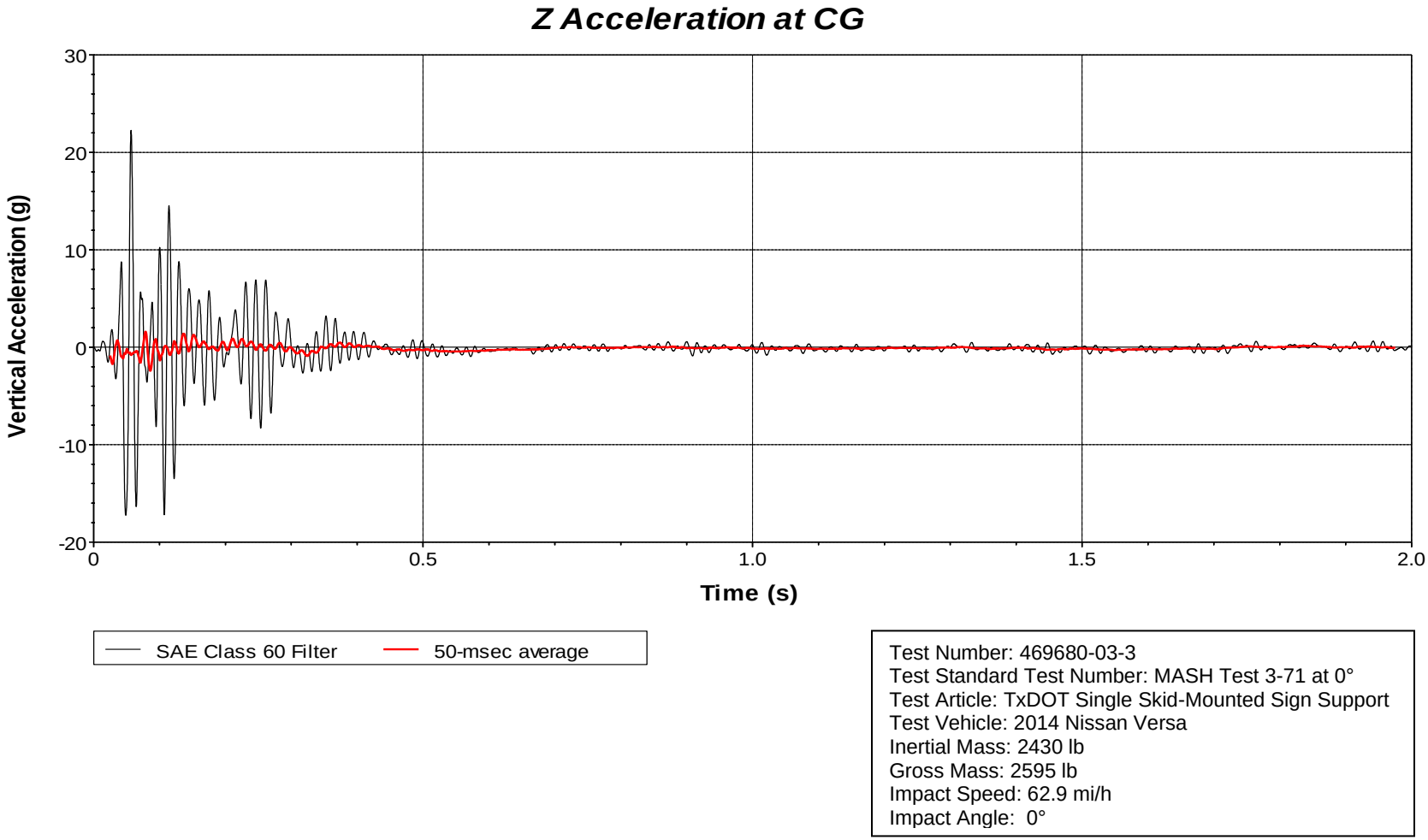


Figure G.5. Vehicle Vertical Accelerometer Trace for Test No. 469680-03-3 (Accelerometer Located at Center of Gravity).