Roadside Safety Pooled Fund

Texas A&M Transportation Institute
Proving Ground

Test Report No. 610461-01-3&4
Test Report Date: April 2021

MASH TL-3 EVALUATION OF REDESIGNED BARRIER GAP RAIL

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Contract No.: T-4541 CZ
Test Nos.: 610461-01-3 and 610461-01-4
Test Dates: 2021-04-07 and 2021-04-09

Sponsored by
Roadside Safety Research Program Pooled Fund
Study No. TPF-5(114)

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
MASH TL-3 EVALUATION OF REDESIGNED BARRIER GAP RAIL	April 2021
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
William F. Williams, Wanda L. Menges, William Schroeder, and Darrell L. Kuhn	Test Report No. 610461-01-3&4
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas A&M Transportation Institute Proving Ground 3135 TAMU College Station, Texas 77843-3135	11. Contract or Grant No. T-4541 CZ
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Washington State Department of Transportation Research Office MS 47372, Transportation Building Olympia, WA 98504-7372	Technical Report: January – April 2021
	14. Sponsoring Agency Code

15. Supplementary Notes

Project Title: Thrie/W-Beam/Tubular Barrier Gap Rail for MASH TL-3

Name of Contacting Representative: Michael Elle, P.E., Technical Representative

16. Abstract

Median barriers are needed to prevent cross-over accidents. A flexible median barrier, such as a cable barrier, can be used on roadways with ample median space. However, when median width is limited, a rigid concrete barrier is typically used. Concrete median barriers are typically cast-in-place continuous concrete barriers. In some instances, underground utilities and other structures are located in alignment with the rigid median barrier. There is a need to span across these structures/underground utilities with something other than the rigid median barrier.

The purpose of this research was to design a transition railing attachment that can span across an open space in the median barrier. This median barrier attachment was crash tested to American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test Level-3 (TL-3).

During previous testing to *MASH*, the initial barrier gap design performed acceptably for *MASH* Test 3-11. However, due to the rollover and excessive occupant compartment deformation, that barrier gap design did not perform acceptably for *MASH* Test 3-10.

The TTI researchers redesigned the barrier gap rail and performed *MASH* Tests 3-10 and 3-11. The redesigned barrier gap rail met the performance criteria for *MASH* TL-3 longitudinal barriers.

17. Key Words	18. Distribution Statement
Longitudinal barrier, thrie beam, W-beam, tubular rail, barrier gap, crash testing, roadside safety, MASH	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	94	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

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

ACKNOWLEDGMENTS

This research project was performed under a pooled fund program between the following States and Agencies. The authors acknowledge and appreciate their guidance and assistance.

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Revised January 2021

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

Chapter 1. INTRODUCTION

1.1 PROBLEM

Median barriers are needed to prevent cross-over accidents. A cable barrier can be used on roadways with ample median space. However, when median width is limited, a rigid concrete barrier is typically used. Concrete median barriers are typically cast-in-place continuous concrete barriers. In some instances, underground utilities and other structures are located in alignment with the rigid median barrier. There is a need to span across these structures/underground utilities with something other than the rigid median barrier.

The purpose of this research was to design a transition railing attachment that can span across an open space in the median barrier. This median barrier attachment would be crash tested to American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test Level-3 (TL-3) *(1)*.

A successful design tested for this project would enable the state departments of transportation (DOTs) the ability to use a *MASH* TL-3 crashworthy gap transition across an open space in a rigid concrete median barrier. A 36-inch-tall single slope median barrier was used for this project. If the results of the full-scale crash test were successful per *MASH* 2016, this barrier design would be submitted to Federal Highway Administration (FHWA) for eligibility for federal funds reimbursement.

1.2 BACKGROUND

There is a need for a crashworthy barrier structure to span across open gaps in rigid concrete median barriers. Sometimes underground utilities and other structures are located in alignment with rigid concrete barriers located in the median. TTI researchers previously tested a median barrier embedded 10 inches into soil base (TTI Project No. 405160-13) (*2*). This research presented a design to restrict lateral deflection of a concrete barrier when placed adjacent to steep slopes or on top of Mechanically Stabilized Earth (MSE) walls, without using a concrete moment slab. This design was developed through the use of full-scale finite element vehicle impact analysis and crash testing. The design incorporated precast 20-ft long single slope barrier segments with grouted rebar grid connections. The barrier segments were embedded 10 inches in soil and were placed in front of a 1.5H:1V slope. The offset of the barrier from the slope break point of the soil embankment was restricted to a minimum of 2 ft. *MASH* Test 3-11 was performed to evaluate the performance of the embedded barrier. The barrier performed acceptably. The permanent lateral deflection of the barrier was 5.5 inches. Figure 1.1 illustrates a photo of the design, and Figure 1.2 illustrates a brief cross-section detail of the design. These figures illustrate the use of a barrier used for a median application.

Oftentimes, obstructions or other features are located along the alignment for a barrier in the median. There is a need to span across these obstructions or features, which, results in open gaps in rigid concrete barriers located in the median. Manholes and drainage inlets are often obstructing the continuity and the median barrier placement. Due to access reasons, these manholes and other features do not permit the use of rigid barrier located directly on top of the structure. Therefore, a barrier structure of some type is needed to span across gaps in the median barrier.

Figure 1.1. 32-inch Barrier with Steel Grid Slot Connection Embedded 10 inches.

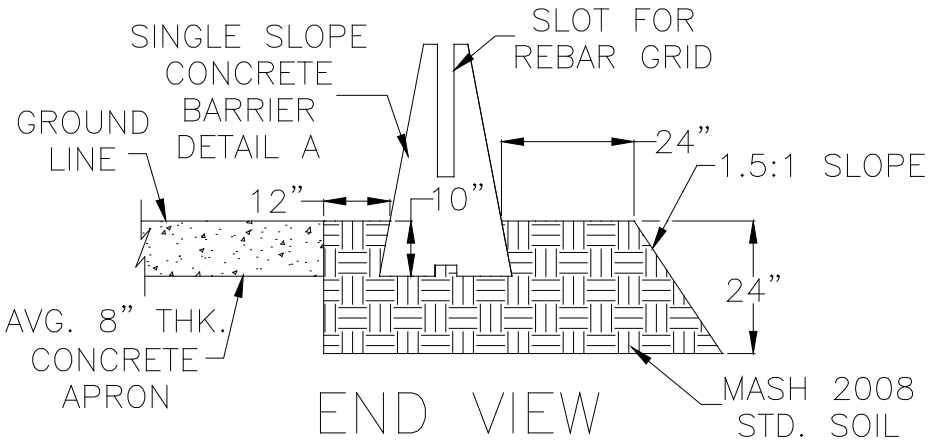

Figure 1.2. Details of 32-inch Steel Grid Slot Barrier Embedded 10 inches.

1.3 OBJECTIVE

The objective of this research was to design a tubular barrier gap rail system for use on a 36-inch-tall single slope barrier. Thrie-beam, W-beam, and tubular rail elements were considered for the barrier rail design. The maximum open gap used for this design was 8 ft. The new design was tested to *MASH* TL-3. TTI received preliminary details from Minnesota Department of Transportation (MnDOT) on the barrier details that were considered for the design. TTI researchers incorporated much of this information into the initial design concepts. Figure 1.3

illustrates these details. Figure 1.4 illustrates a preliminary concept developed for the barrier gap rail system.

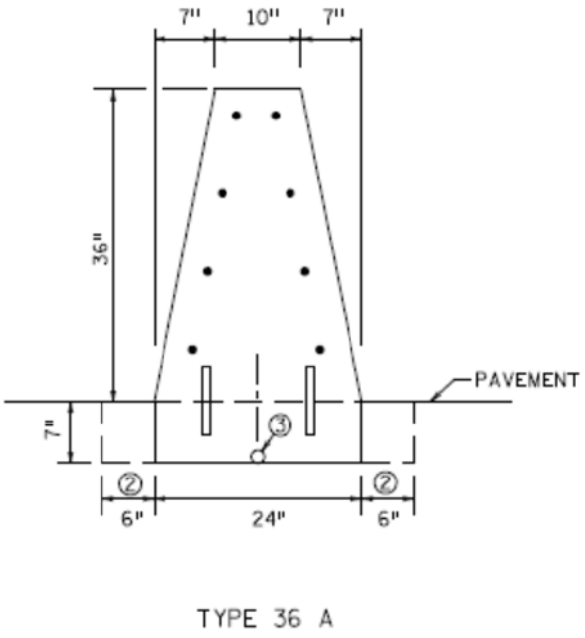

Figure 1.3. Proposed Median Barrier Gap Details from MnDOT for Type 36A Barrier.

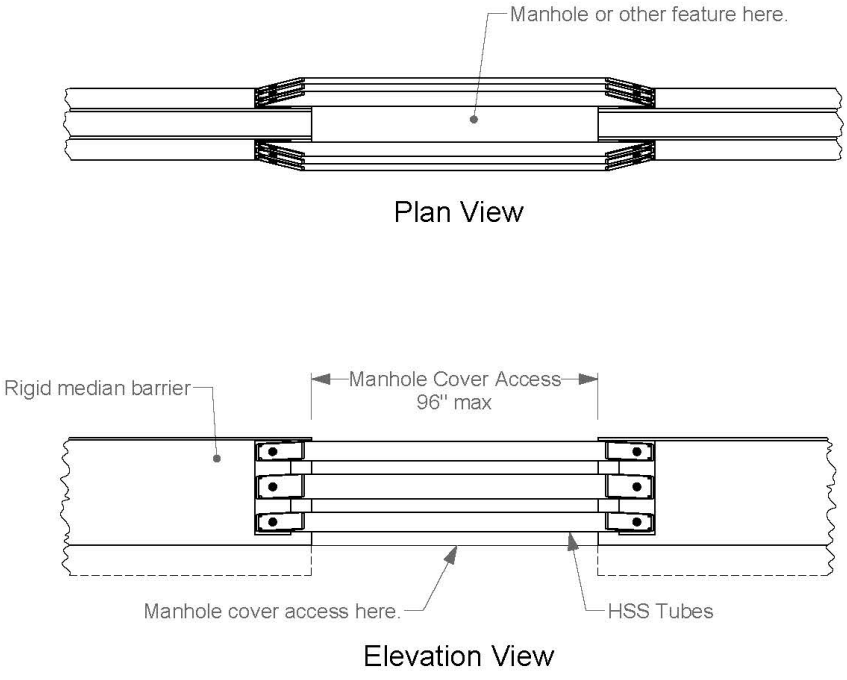

Figure 1.4. Preliminary Details for Median Barrier Gap Design.

On October 9, 2019, *MASH* Test 3-10 was performed on the barrier gap design shown in Figure 1.5. The barrier gap design contained and redirected the 1100C vehicle, and it did not penetrate, underride, or override the installation. No dynamic deflection was observed during the test, and there was no measurable permanent deformation after the test. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 5.5 inches in the windshield/roof area, which exceeds the limit specified in *MASH*. The 1100C vehicle rolled over after loss of contact with the rail. Occupant risk factors were within the limits specified in *MASH*.

Due to the rollover and excessive occupant compartment deformation of the 1100C vehicle, the barrier gap design did not perform acceptably for *MASH* Test 3-10.

The TTI researchers redesigned the barrier gap rail and performed *MASH* Tests 3-10 and 3-11.

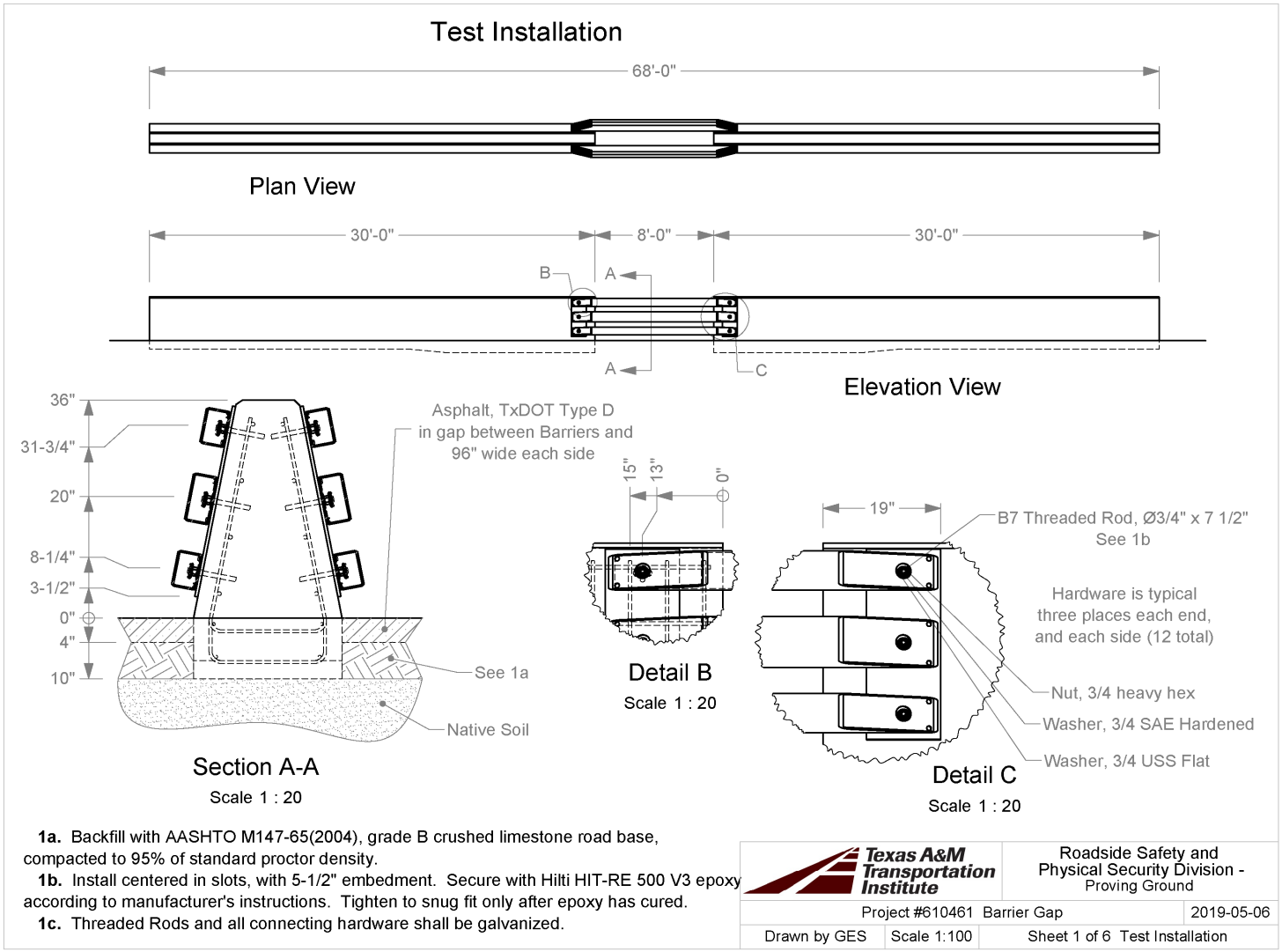

Figure 1.5. Details for Median Barrier Gap Design used in MASH Test 3-10 (Crash Test No. 610461-2).

***Asphalt Type D Mix Specification** https://ftp.txdot.gov/pub/txdot-info/cmd/cserve/specs/2014/standard/s340.pdf **

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Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of two 30-ft long single slope reinforced concrete median barriers, with an 8-ft gap between them. This gap was spanned with six rectangular HSS 8×4×⅜ steel tube rails, three each on the traffic and field sides, which were attached to steel plate assemblies at each end. These steel plate assemblies were secured to the opposing faces of the barriers and constructed so that the exterior faces of the rails were flush with the faces of the barriers. The center and lower two pair of tubes were further reinforced with braces at their center points. These braces were fabricated of steel plates and rectangular tubes.

The top of the parapet sections and rails were located 36 inches above grade. The concrete barriers measured 10 inches wide at the top, and 24 inches wide at the bottom at grade and below. The barriers were embedded 10 inches deep in 4 inches of TxDOT Type D asphalt placed on top of 6 inches of compacted crushed limestone road base.

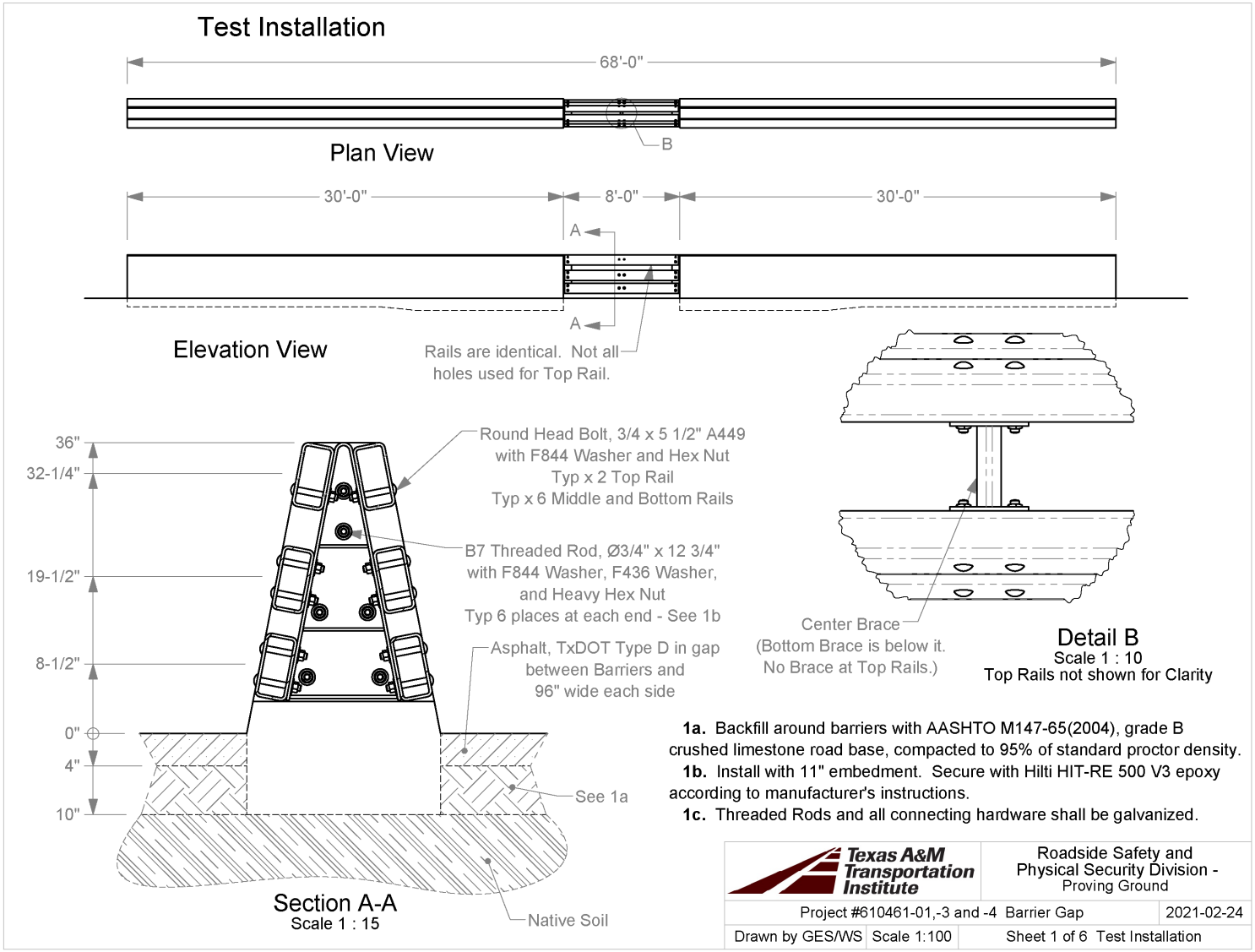
Figure 2.1 presents the overall information on the redesigned barrier gap rail, and Figure 2.2 provides photographs of the installation. Appendix A provides further details on the redesigned barrier gap rail. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by TTI Proving Ground personnel.

2.2. DESIGN MODIFICATIONS DURING TESTS

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

2.3. MATERIAL SPECIFICATIONS

The specified compressive strength of the concrete used in the barrier was 5000 psi. On the day of Test No. 610461-2 (October 9, 2019), the compressive concrete strength for the downstream and upstream barriers averaged 6137 psi at 57 days age and 5912 psi at 47 days age, respectively. Appendix B provides material certification documents for the materials used to install/construct the redesigned barrier gap rail.



***Asphalt Type D Mix Specification** https://ftp.txdot.gov/pub/txdot-info/cmd/cserve/specs/2014/standard/s340.pdf **

Figure 2.1. Details of Redesigned Barrier Gap Rail.

Figure 2.2. Redesigned Barrier Gap Rail prior to Testing.

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Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST PERFORMED/MATRIX

Table 3.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for longitudinal barriers. The target critical impact points (CIPs) for each test were determined using the information provided in *MASH* Section 2.2.1 and Section 2.3.2. Figure 3.1 shows the target CIP for *MASH* Tests 3-10 and 3-11on the redesigned barrier gap rail.

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

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

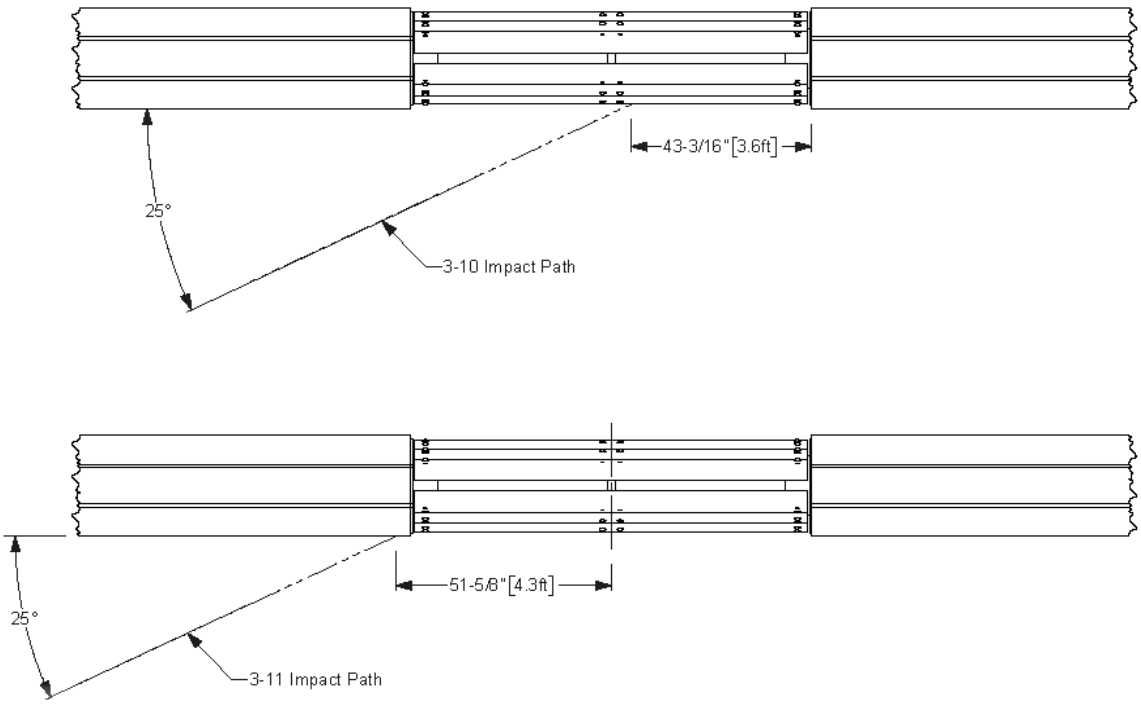

Figure 3.1. Target CIPs for *MASH* TL-3 Tests on Redesigned Barrier Gap Rail.

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

3.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. Table 3.1. lists the test conditions and evaluation criteria required for *MASH* TL-3, and Table 3.2. provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 7.

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

Evaluation Factors	Evaluation Criteria		*MASH* Test
Structural Adequacy	*A.*	*Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	*3-10 and 3- 11*
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.*	*3-10 and 3- 11*
	F.	*The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	*3-10 and 3- 11*
	H.	*Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*	*3-10 and 3- 11*
	I.	*The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	*3-10 and 3- 11*

Chapter 4. TEST CONDITIONS

4.1. TEST FACILITY

The full-scale crash tests reported herein were performed at the TTI Proving Ground, an International Standards Organization (ISO)/International Electrotechnical Commission (IEC) 17025-accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing Certificate 2821.01. The full-scale crash tests were performed according to TTI Proving Ground quality procedures, as well as *MASH* guidelines and standards.

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

4.2. VEHICLE TOW AND GUIDANCE SYSTEM

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

4.3. DATA ACQUISITION SYSTEMS

4.3.1. Vehicle Instrumentation and Data Processing

The/Each test vehicle was instrumented with a self-contained onboard data acquisition system. The signal conditioning and acquisition system is a 16-channel Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems Inc. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid-state units designed for crash test service. The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling, and filtering based on

transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 samples per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit in case the primary battery cable is severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

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

TRAP uses the data from the TDAS Pro to compute the occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with an SAE Class 180-Hz low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

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

4.3.2. Anthropomorphic Dummy Instrumentation

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

According to *MASH*, use of a dummy in the 2270P vehicle is optional. However, *MASH* recommends that a dummy be used when testing "any longitudinal barrier with a height greater than or equal to 33 inches." More specifically, use of the dummy in the 2270P vehicle is recommended for tall rails to evaluate the "potential for an occupant to extend out of the vehicle and come into direct contact with the test article." Although this information is reported, it is not part of the impact performance evaluation. Since the rail height of the barrier was 36 inches, a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

4.3.3. Photographic Instrumentation Data Processing

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

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

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the redesigned barrier gap rail. 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.

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Chapter 5. *MASH* TEST 3-10 (CRASH TEST NO. 610461-01-3)

5.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-10 involves a 1100C vehicle weighing 2420 lb ± 55 lb impacting the CIP of the longitudinal barrier at an impact speed of 62 mi/h ± 2.5 mi/h and an angle of 25 degrees ± 1.5 degrees. The CIP for *MASH* Test 3-10 on the redesigned barrier gap rail was 3.6 ft ± 1 ft upstream of the downstream barrier end. Figure 3.1 and Figure 5.1 depict the target impact setup.

Figure 5.1. Redesigned Barrier Gap Rail/Test Vehicle Geometrics for Test No. 610461-01-3.

The 1100C vehicle weighed 2425 lb, and the actual impact speed and angle were 62.5 mi/h and 24.5 degrees. The actual impact point was 3.0 ft upstream of the downstream barrier end. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 55 kip-ft.

5.2. WEATHER CONDITIONS

The test was performed on the morning of April 7, 2021. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 232 degrees (vehicle was traveling at a heading of 325 degrees); temperature: 72°F; relative humidity: 93 percent.

5.3. TEST VEHICLE

Figure 5.2 shows the 2015 Nissan Versa used for the crash test. The vehicle's test inertia weight was 2425 lb, and its gross static weight was 2590 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 C.1 in Appendix C.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 5.2. Test Vehicle before Test No. 610461-01-3.

5.4. TEST DESCRIPTION

Table 5.1 lists events that occurred during Test No. 610461-01-3. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 5.1. Events during Test No. 610461-01-3.

Time (s)	Events
0.000	Vehicle impacted the barrier
0.020	Left front tire lifts off the pavement
0.036	Vehicle begins to redirect
0.156	Vehicle traveling parallel with barrier
0.169	Left rear bumper contacts the installation
0.276	Vehicle lost contact with the barrier while traveling at 50.7 mi/h, a trajectory of 1.8 degrees, and a heading of 7.4 degrees

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 3.0 s after impact, and the vehicle subsequently came to rest 198 ft downstream of the point of impact and 16 ft toward the field side of the barrier.

5.5. DAMAGE TO TEST INSTALLATION

Figure 5.3 shows the damage to the redesigned barrier gap rail. There was some scuffing downstream of the rails on the concrete barrier, and some small gouging on the downstream barrier at the middle rail connection. Working width* was 24.0 inches, and height of working

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

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

Figure 5.3. Redesigned Barrier Gap Rail after Test No. 610461-01-3.

5.6. DAMAGE TO TEST VEHICLE

Figure 5.4 shows the damage sustained by the vehicle. The front bumper, hood, grill, radiator and support, left front fender, left front strut and tower, left front tire and rim, left front A-pillar, left front corner of floor pan, left front and rear doors, left rear quarter panel, and rear bumper were damaged. The windshield sustained stress cracks radiating upward and inward from the left lower corner. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 10.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 3.0 inches in the left front firewall area. Figure 5.5 shows the interior of the vehicle. Tables C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

Figure 5.4. Test Vehicle after Test No. 610461-01-3.

Figure 5.5. Interior of Test Vehicle after Test No. 610461-01-3.

5.7. 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.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.6 in Appendix C.4 show acceleration versus time traces. Figure 5.6 summarizes pertinent information from the test.

Table 5.2. Occupant Risk Factors for Test No. 610461-01-3.

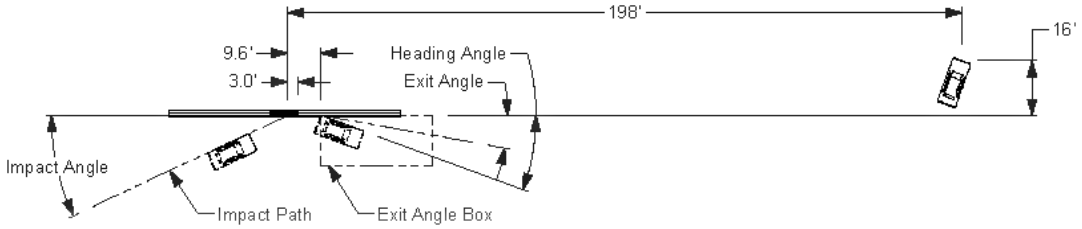
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	20.8 ft/s	at 0.0775 s on left side of interior
Lateral	29.6 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	4.4 g	0.1670 - 0.1770 s
Lateral	11.2 g	0.1681 - 0.1781 s
Theoretical Head Impact Velocity (THIV)	10.9 m/s	at 0.0759 s on left side of interior
Acceleration Severity Index (ASI)	2.5	0.0464 - 0.0964 s
Maximum 50-ms Moving Average		
Longitudinal	−11.7 g	0.0240 - 0.0740 s
Lateral	19.0 g	0.0233 - 0.0733 s
Vertical	−5.8 g	0.0550 - 0.1050 s
Maximum Yaw, Pitch, and Roll Angles		
Roll	17°	0.5219 s
Pitch	6°	0.6117 s
Yaw	56°	1.0332 s

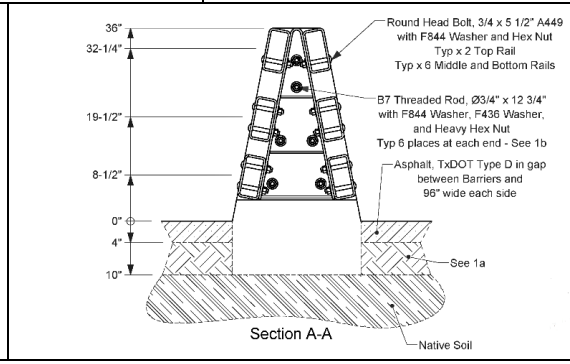

0.000 s


0.100 s


0.200 s


0.400 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... *MASH* Test 3-10
- TTI Test No. 610461-01-3
- Test Date 2021-04-07

Test Article
- Type ..... Longitudinal Barrier—Barrier Gap
- Name ..... Redesigned Barrier Gap Rail
- Installation Length ..... 68 ft with 8 ft gap; 36 inches tall
- Material or Key Elements ... HSS 8×4×⅜ inch rails

Soil Type and Condition ..... Keyed in 10 inches of asphalt / road base

Test Vehicle
- Type/Designation 1100C
- Make and Model ..... 2015 Nissan Versa
- Curb ..... 2434 lb
- Test Inertial ..... 2425 lb
- Dummy ..... 165 lb
- Gross Static ..... 2590 lb

Impact Conditions
- Speed ..... 62.5 mi/h
- Angle ..... 24.5°
- Location/Orientation ..... 3.0 ft upstream of downstream end

Impact Severity ..... 55 kip-ft

Exit Conditions
- Speed ..... 50.7 mi/h
- Trajectory/Heading Angle ... 1.8° / 7.4°

Occupant Risk Values
- Longitudinal OIV ..... 20.8 ft/s
- Lateral OIV ..... 29.6 ft/s
- Longitudinal Ridedown ..... 4.4 g
- Lateral Ridedown ..... 11.2 g
- THIV ..... 10.9 m/s
- ASI 2.5

Max. 0.050-s Average
- Longitudinal ..... −11.7 g
- Lateral ..... 19.0 g
- Vertical ..... −5.8 g

Post-Impact Trajectory
- Stopping Distance ..... 198 ft downstream
  16 ft twd field side

Vehicle Stability
- Maximum Roll Angle ..... 17°
- Maximum Pitch Angle ..... 6°
- Maximum Yaw Angle ..... 56°
- Vehicle Snagging ..... No
- Vehicle Pocketing ..... No

Test Article Deflections
- Dynamic ..... None
- Permanent ..... None
- Working Width ..... 24.0 inches
- Height of Working Width ..... At the toe

Vehicle Damage
- VDS 11LFQ5
- CDC 11FLEW4
- Max. Exterior Deformation ..... 10.0 inches
- OCDI LF0020000
- Max. Occupant Compartment Deformation ..... 3.0 inches

Figure 5.6. Summary of Results for *MASH* Test 3-10 on Redesigned Barrier Gap Rail.

Chapter 6. *MASH* TEST 3-11 (CRASH TEST NO. 610461-01-4)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-11 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the CIP of the longitudinal barrier at an impact speed of 62 mi/h ± 2.5 mi/h and an angle of 25 degrees ± 1.5 degrees. The CIP for *MASH* Test 3-11 on the redesigned barrier gap rail was 4.3 ft ± 1 ft upstream of the centerline of the metal rail. Figure 3.1 and Figure 6.1 depict the target impact setup.

Figure 6.1. Redesigned Barrier Gap Rail/Test Vehicle Geometrics for Test No. 610461-01-4.

The 2270P vehicle weighed 5071 lb, and the actual impact speed and angle were 62.5 mi/h and 25.3 degrees. The actual impact point was 4.1 ft upstream of the centerline of the metal rail. Minimum target IS was 106 kip-ft, and actual IS was 121 kip-ft.

6.2. WEATHER CONDITIONS

The test was performed on the morning of April 9, 2021. Weather conditions at the time of testing were as follows: wind speed: 15 mi/h; wind direction: 178 degrees (vehicle was traveling at a heading of 325 degrees); temperature: 76°F; relative humidity: 85 percent.

6.3. TEST VEHICLE

Figure 6.2 shows the 2016 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5071 lb, and its gross static weight was 5236 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 28.25 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 6.2. Test Vehicle before Test No. 610461-01-4.

6.4. TEST DESCRIPTION

Table 6.1 lists events that occurred during Test No. 610461-01-4. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 6.1. Events during Test No. 610461-01-4.

Time (s)	Events
0.000	Vehicle impacts the barrier
0.032	Vehicle begins to redirect
0.081	Right front tire lifts off the pavement
0.174	Vehicle traveling parallel with barrier
0.185	Left rear bumper contacts barrier
0.345	Vehicle loses contact with barrier while traveling at 52.8 mi/h, a trajectory of 2.7 degrees, and a heading of 10.0 degrees

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 4.5 s after impact, and the vehicle subsequently came to rest 282 ft downstream of the point of impact and 49 ft toward traffic lanes.

6.5. DAMAGE TO TEST INSTALLATION

Figure 6.3 shows the damage to the redesigned barrier gap rail. There was some scuffing of the barrier at impact, and along the rails until loss of contact at the second barrier. Working width* was 24.0 inches, and height of working width was at the toe of the barrier. Maximum

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

dynamic deflection during the test was 1.0 inches in the metal rail, and no permanent deformation was after the test was observed.

Figure 6.3. Redesigned Barrier Gap Rail after Test No. 610461-01-4.

6.6. DAMAGE TO TEST VEHICLE

Figure 6.4 shows the damage sustained by the vehicle. The front bumper, hood, grill, left front fender, left front tire and rim, left front and rear doors, left front floor pan, left rear cab corner, left rear exterior bed, and left rim were damaged. The windshield sustained stress cracks radiating upward and inward from the left lower corner. No fuel tank damage was observed.

Maximum exterior crush to the vehicle was 10.0 inches in the front plane at the left front corner at bumper height. Maximum occupant compartment deformation was 3.5 inches in the left front firewall area. Figure 6.5 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 6.4. Test Vehicle after Test No. 610461-01-4.

Figure 6.5. Interior of Test Vehicle after Test No. 610461-01-4.

6.7. OCCUPANT RISK FACTORS

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

Table 6.2. Occupant Risk Factors for Test No. 610461-01-4.

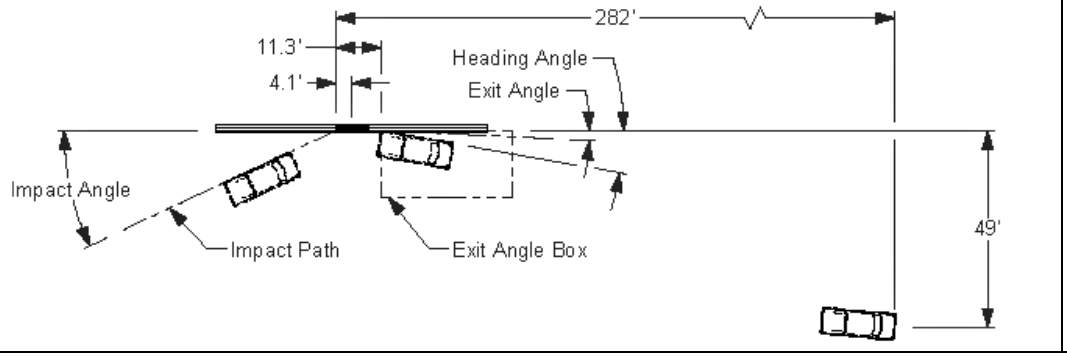
Occupant Risk Factor	Value	Time
OIV		
Longitudinal	18.9 ft/s	at 0.0917 s on left side of interior
Lateral	28.0 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	6.2 g	0.0917 - 0.1017 s
Lateral	14.7 g	0.2116 - 0.2216 s
THIV	10.3 m/s	at 0.0895 s on left side of interior
ASI	1.9	0.0561 - 0.1061 s
Maximum 50-ms Moving Average		
Longitudinal	−9.3 g	0.0284 - 0.0784 s
Lateral	15.1 g	0.0303 - 0.0803 s
Vertical	−4.6 g	0.0097 - 0.0597 s
Maximum Yaw, Pitch, and Roll Angles		
Roll	32°	0.6057 s
Pitch	11°	1.7362 s
Yaw	53°	1.3699 s

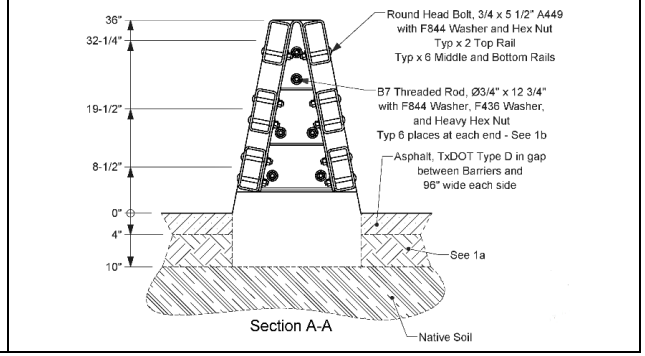
0.000 s

0.100 s

0.200 s

0.400 s





General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... *MASH* Test 3-11
- TTI Test No. 610461-01-4
- Test Date 2021-04-09

Test Article
- Type ..... Longitudinal Barrier—Barrier Gap
- Name ..... Redesigned Barrier Gap Rail
- Installation Length ..... 68 ft with 8 ft gap; 36 inches tall
- Material or Key Elements ... HSS 8×4×⅜ inch rails

Soil Type and Condition ..... Keyed in 10 inches of asphalt / road base

Test Vehicle
- Type/Designation 2270P
- Make and Model ..... 2016 RAM 1500 Pickup
- Curb ..... 5091 lb
- Test Inertial ..... 5071 lb
- Dummy ..... 165 lb
- Gross Static ..... 5236 lb

Impact Conditions
- Speed ..... 62.5 mi/h
- Angle ..... 25.3°
- Location/Orientation ..... 4.1 ft upstream of centerline of rail

Impact Severity ..... 121 kip-ft

Exit Conditions
- Speed ..... 52.8 mi/h
- Trajectory/Heading Angle ... 2.7° / 10.0°

Occupant Risk Values
- Longitudinal OIV ..... 18.9 ft/s
- Lateral OIV ..... 28.0 ft/s
- Longitudinal Ridedown ..... 6.2 g
- Lateral Ridedown ..... 14.7 g
- THIV ..... 10.3 g
- ASI 1.9

Max. 0.050-s Average
- Longitudinal ..... −9.3 g
- Lateral ..... 15.1 g
- Vertical ..... −4.6 g

Post-Impact Trajectory
- Stopping Distance ..... 282 ft downstream
  49 ft twd traffic lanes

Vehicle Stability
- Maximum Roll Angle ..... 32°
- Maximum Pitch Angle ..... 11°
- Maximum Yaw Angle ..... 53°
- Vehicle Snagging ..... No
- Vehicle Pocketing ..... No

Test Article Deflections
- Dynamic ..... 1.0 inch
- Permanent ..... None
- Working Width ..... 24.0 inches
- Height of Working Width ..... At the toe

Vehicle Damage
- VDS 11LFQ4
- CDC 11FLEW4
- Max. Exterior Deformation ..... 10.0 inches
- OCDI LF0020000
- Max. Occupant Compartment Deformation ..... 3.5 inches

Figure 6.6. Summary of Results for *MASH* Test 3-11 on Redesigned Barrier Gap Rail.

Chapter 7. SUMMARY AND CONCLUSIONS

7.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-3, which involves two tests, on the redesigned barrier gap rail. Table 7.1 and Table 7.2 provide an assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-3 longitudinal barriers.

7.2. CONCLUSIONS

Table 7.3 shows that the redesigned barrier gap rail met the performance criteria for *MASH* TL-3 longitudinal barriers.

Table 7.1. Performance Evaluation Summary for *MASH* Test 3-10 on Redesigned Barrier Gap Rail.

Test Agency: Texas A&M Transportation Institute Test No.: 610461-01-3 Test Date: 2021-04-07

MASH Test 3-10 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The redesigned barrier gap rail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the barrier. No dynamic deflection of the metal rail was observed.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 3.0 inches in the left front firewall area.	
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 17° and 6°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 20.8 ft/s, and lateral OIV was 29.6 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.	Maximum longitudinal occupant ridedown acceleration was 4.4 g, and maximum lateral occupant ridedown acceleration was 11.2 g.	Pass

Table 7.2. Performance Evaluation Summary for *MASH* Test 3-11 on Redesigned Barrier Gap Rail.

Test Agency: Texas A&M Transportation Institute Test No.: 610461-01-4 Test Date: 2021-04-09

MASH Test 3-11 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The redesigned barrier gap rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the barrier. Maximum dynamic deflection of the metal rail was 1.0 inch.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 3.5 inches in the left front firewall area.	
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 32° and 11°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 18.9 ft/s, and lateral OIV was 28.0 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.	Maximum longitudinal occupant ridedown acceleration was 6.2 g, and maximum lateral occupant ridedown acceleration was 14.7 g.	Pass

Table 7.3. Assessment Summary for *MASH* TL-3 Tests on Redesigned Barrier Gap Rail.

Evaluation Factors	Evaluation Criteria	Test No. 610461-01-3	Test No. 610461-01-4
Structural Adequacy	A	S	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
	Test No.	***MASH* Test 3-10**	***MASH* Test 3-11**
	Pass/Fail	Pass	Pass

Note: S = Satisfactory

REFERENCES

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

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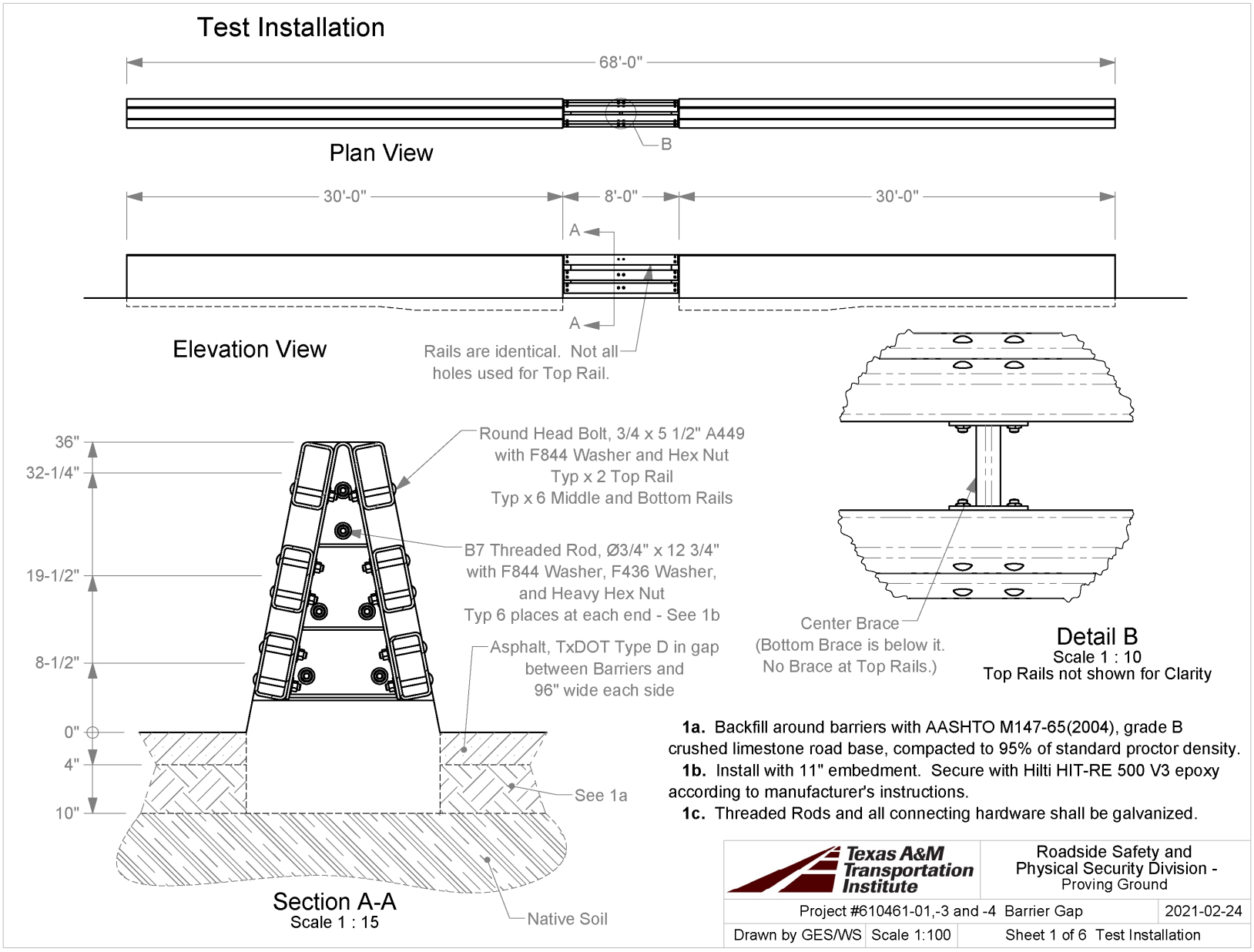

1a. Backfill around barriers with AASHTO M147-65(2004), grade B crushed limestone road base, compacted to 95% of standard proctor density.

1b. Install with 11" embedment. Secure with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions.

1c. Threaded Rods and all connecting hardware shall be galvanized.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #610461-01,-3 and -4 Barrier Gap		2021-02-24
Drawn by GES/WS	Scale 1:100	Sheet 1 of 6 Test Installation

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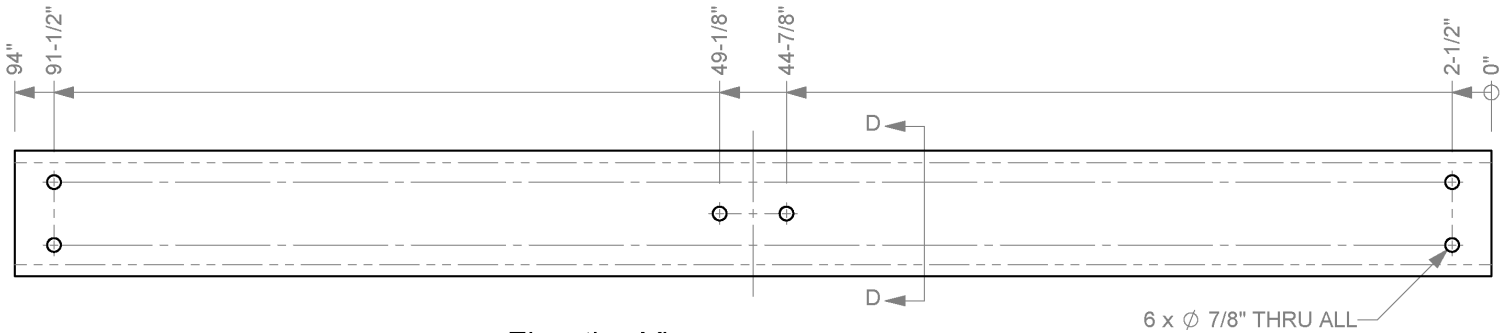
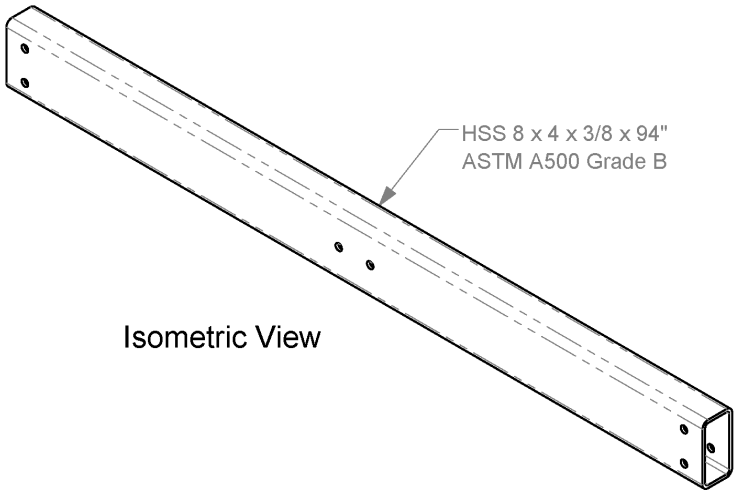
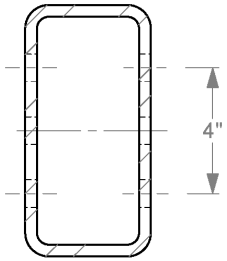
Rail Details



Elevation View



Isometric View



Section D-D

Scale 1 : 5

2a. Galvanize after fabrication is complete.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #610461-01,-3 and -4 Barrier Gap		2021-02-24
Drawn by GES/WS	Scale 1:10	Sheet 2 of 6 Rail Details

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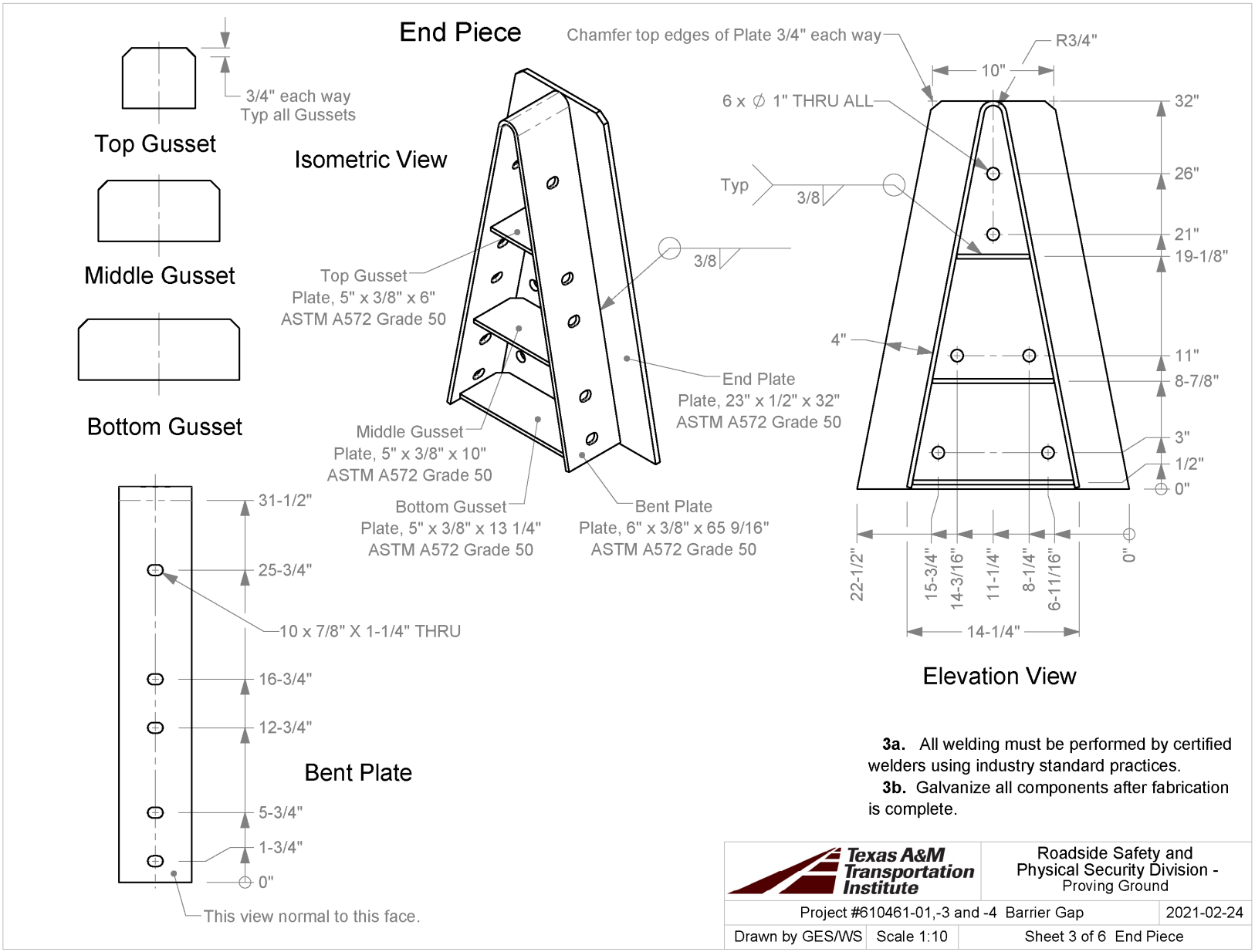

3a. All welding must be performed by certified welders using industry standard practices.

3b. Galvanize all components after fabrication is complete.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #610461-01,-3 and -4 Barrier Gap		2021-02-24
Drawn by GES/WS	Scale 1:10	Sheet 3 of 6 End Piece

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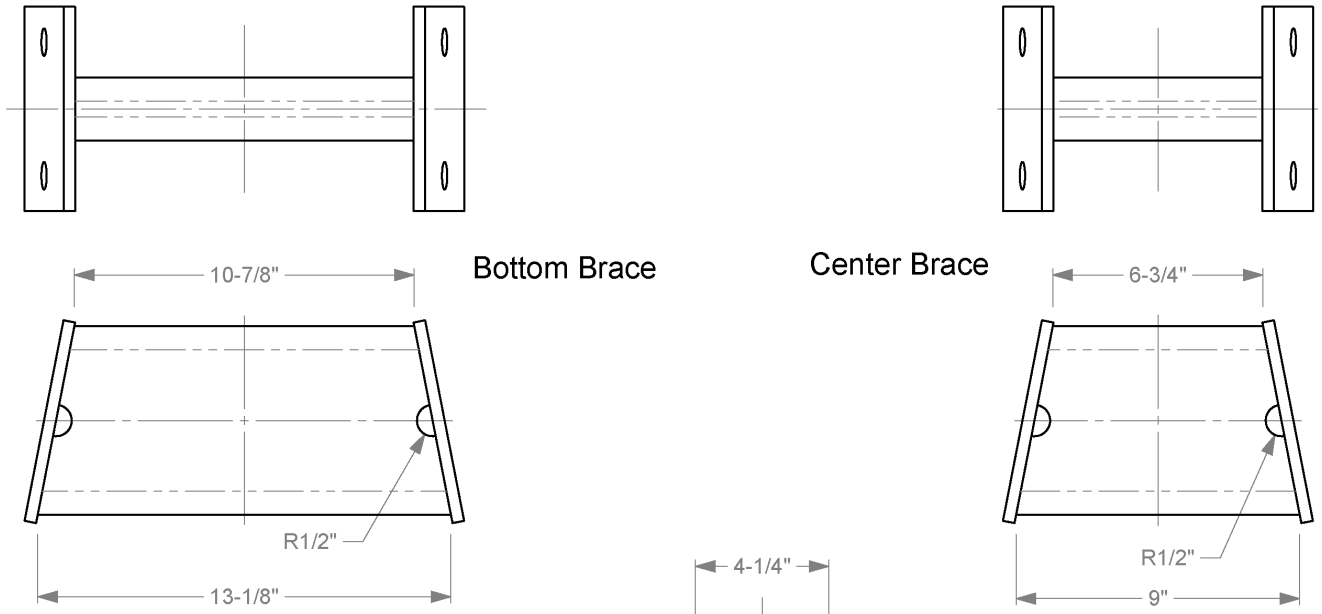
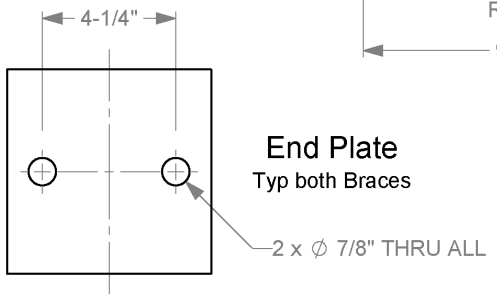
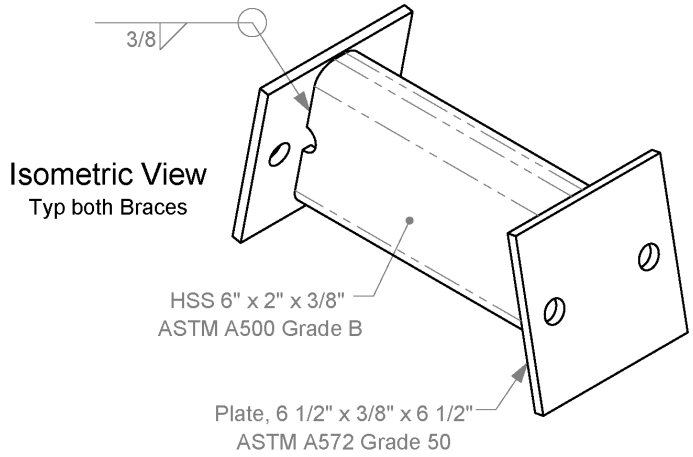
Braces







4a. All welding must be performed by certified welders using industry standard practices.

4b. Galvanize all components after fabrication is complete.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project #610461-01,-3 and -4 Barrier Gap			2021-02-24
Drawn by GES/WS	Scale 1:5	Sheet 4 of 6 Braces	

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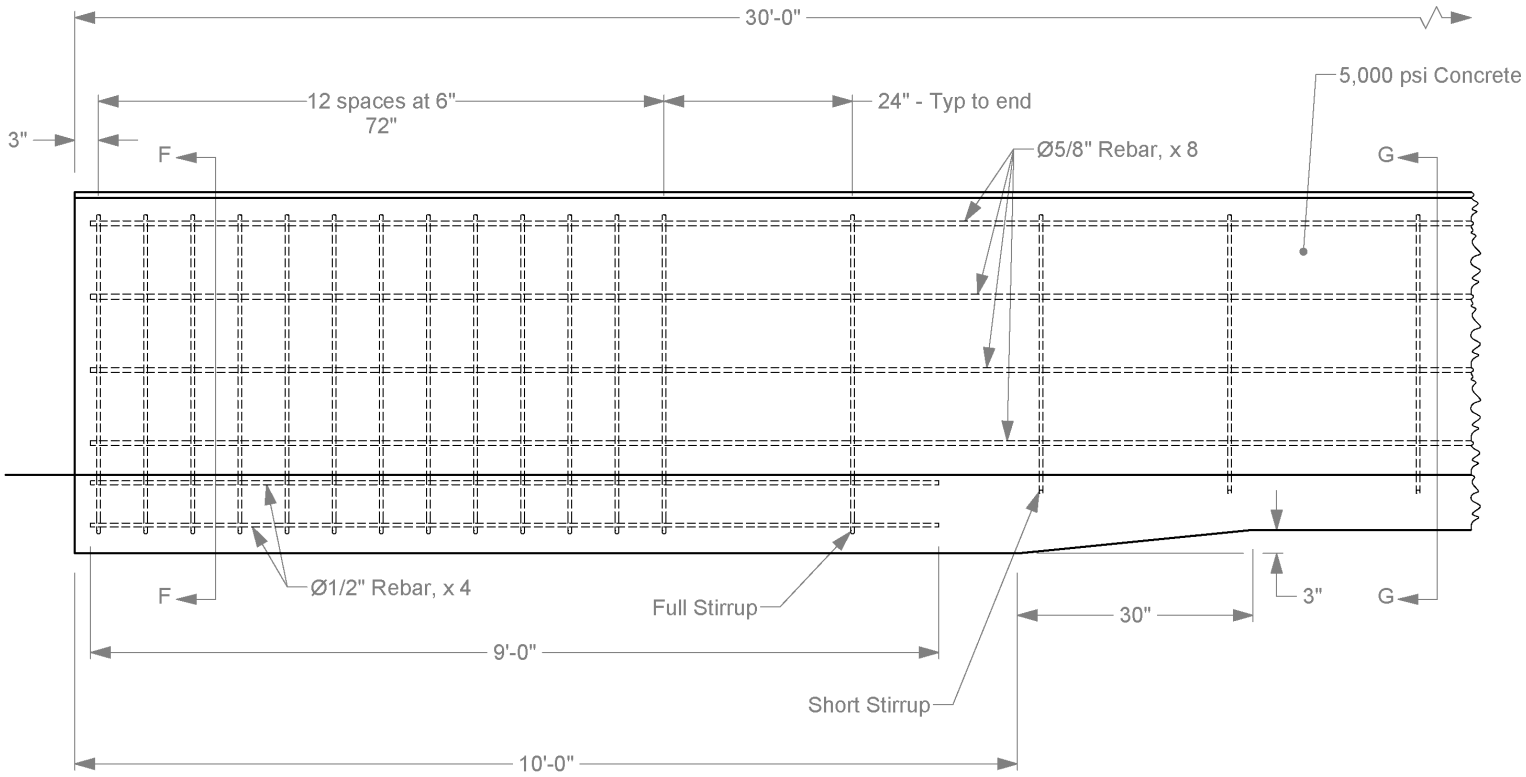
Concrete and Rebar

See next sheet for Detail Views



5a. All rebar is grade 60, and epoxy coated.
5b. Chamfer exposed edges, 3/4" each way.
5c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project #610461-01,-3 and -4 Barrier Gap			2021-02-24
Drawn by GES/WS	Scale 1:20	Sheet 5 of 6 Concrete and Rebar	

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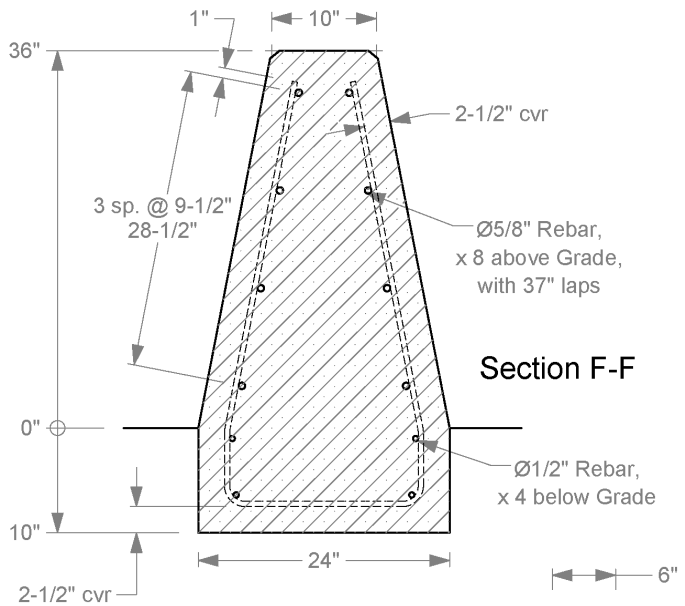
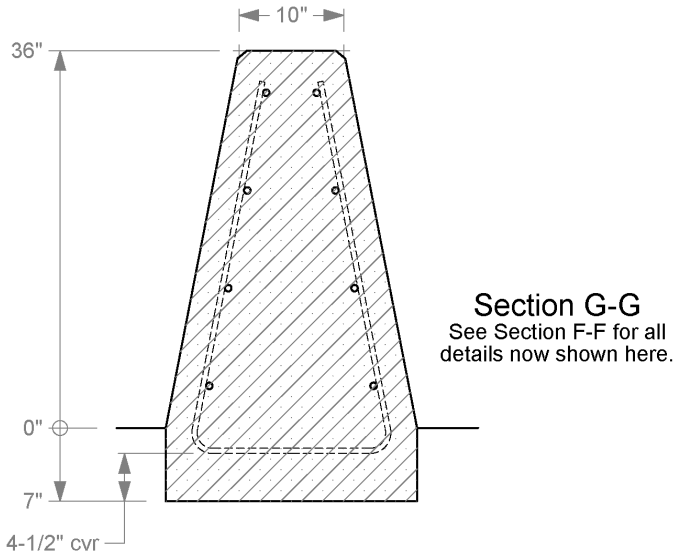
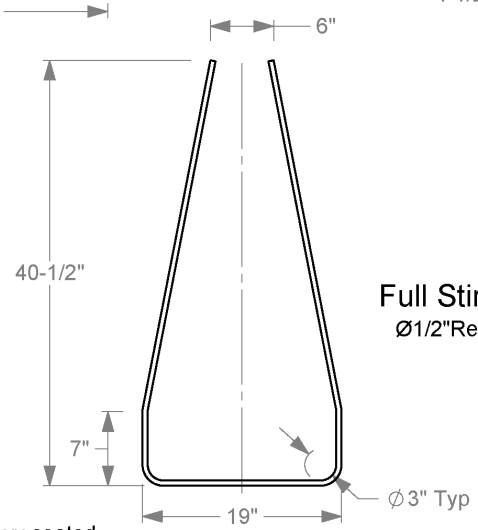


Section F-F



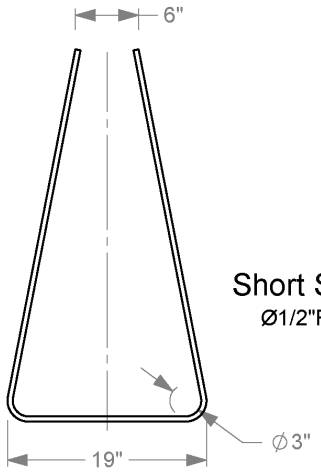
Section G-G

See Section F-F for all details now shown here.



Full Stirrup

Ø1/2"Rebar



Short Stirrup

Ø1/2"Rebar

6a. All rebar is grade 60, and epoxy coated.
6b. Chamfer exposed edges, 3/4" each way.
6c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project #610461-01,-3 and -4 Barrier Gap			2021-02-24
Drawn by GES/WS	Scale 1:15	Sheet 6 of 6 Parapet Sections & Stirrups	

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APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

610461 211055

K-T Bolt Manufacturing Company, Inc.®
1150 Katy Fort-Bend Road
Katy, Texas 77494
Ph.: 281-391-2196 Fax: 281-391-2673

Material Test Report

Customer / Company: Mack Manufacturing & Machine
Part Description: 56 pcs. ¾" (10p) x 5 ½" Dome Head Bolts
Material Specification: ASTM A449 – '14 Type 1
Coating Specification: Galvanized per ASTM F2329 / A153
Purchase Order Number: 34616
Lot Number: 62488-1
Material Heat Number: 3096596

KT
A449

Tensile Test Results

Test Specification: ASTM A449 Type 1 **Sampling: Customer Performed Sampling**

Property	Tensile	Yield	Elongation%	ROA%	Results
#1 psi	145700	135500	16.6%	59.5%	PASS
MIN	120000	92000	14%	35%	

Coating Thickness Evaluation

Sample	Average	Weight oz./ft²
1.	3.20	1.88
2.	3.80	2.24
3.	3.72	2.19
4.	3.68	2.16
5.	3.42	2.01

Hardness Testing

	Hardness-HRC
1.	32.27
2.	32.58

Chemical Analysis

C	Mn	P	S	Si	Cu	Cr
.40%	.79%	.010%	.017%	.22%	.25%	.87%
Mo	V	Cb	Sn	Al	Ni	-
.206%	.026%	.002%	.012%	.002%	.07%	-

100% Melted and Manufactured in the USA – Chemical Analysis Values taken from Certified Mill Test Report

Comments

All tests are in accordance with the latest revisions of the methods prescribed in the applicable SAE and ASTM specifications. The samples tested conform to the specifications listed above and were manufactured free of mercury contamination. No heats to which Bismuth, Selenium, Tellurium or Lead was intentionally added to produce the products. The steels were melted and manufactured in the U.S.A. and the product manufactured and tested in the U.S.A. We certify that this data is a true representation of the information provided by the material supplier and our testing laboratory. The above tested sample has been inspected for Visual Discontinuities and found Acceptable. They comply in all respects with the following ASTM A449 Type 1 and ASME B18.2.6. Threads are per ANSI B1 Class 2A.

KT Bolt Mfg., Inc.

Linda Isgett

Quality Representative

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 250990
- Part No: DUSGA07500
- Quantity (PCS): 50
- Description: 3/4 U.S.S Flat Washer HDG
- Specification: ASME B18.21.1
- Stelfast I.D. NO: 830809-O206849
- Customer PO: 36435
- Warehouse: HOU

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

This document may only be reproduced unaltered and only for certifying the same or lesser quantity of the product specified herein. Reproduction or alteration of this document for any other purpose is prohibited.

Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

January 21, 2021

Stelfast Inc.

22979 Stelfast Parkway
Strongsville, Ohio

44149

Report of Chemical and Physical Properties

Mack Bolt, Steel & Machine
5875 Hwy 21 East
BRYAN, TX
77808

Purchase Order: 34593
Stelfast Order: SO 212848
Certificate #: 746,208

Quantity: 1,000
Part #: DHWGA07500
Description: 3/4 Hardened Washer F436 HDG

Lot Number: GTR18538142A-020
Heat Number: 16606158
Country of Origin: CN

Chemical Analysis

C	Mn	P	S	Si	Cr
0.45	0.67	0.018	0.004	0.2	

Mechanical Properties

Core Hardness	29 - 34 HRC
Grade Marking	ASTM F436(11) Type 1

We hereby certify that the above data is a true copy of the data furnished to us by the producing mill or the data resulting from tests performed in approved laboratories. Stelfast does not certify to customer's part numbers.

This certificate applies to the product shown on this document, as supplied by Stelfast Inc. Alterations to the product by our customer or a third party will render this certificate void.

David Biss
Quality Manager

January 28, 2019

Stelfast Inc.

22979 Stelfast Parkway
Strongsville, Ohio

44149

Report of Chemical and Physical Properties

Issued To: Mack Bolt, Steel & Machine
5875 Hwy 21 East
BRYAN, TX
77808

Purchase Order: 27901
Stelfast Order: SO 117303
Certificate #: 522,644

Quantity: 600
Part #: A2HHG0750C
Description: 3/4-10 Hvy Hx Nut 2H HDG/TOS 0.020

Lot Number: 5073290004
Heat Number: 331313534
Country of Origin: CN

Chemical Analysis

C	Mn	P	S	Si	Cr	Mo	V	B	Ni	Cu
0.45	0.75	0.018	0.006	0.19						

Mechanical Properties

Minimum Tempering Temp.	520 C
Result of 24 Hr. Temper Test	90 - 95 HRB
Hardness (Core)	31 - 32 HRC
Proof Load	58450 LBF MIN.
Macro Etch Test	S2,R2,C2
Grade Markings	ASTM A194(13a)-2H

We hereby certify that the above data is a true copy of the data furnished to us by the producing mill or the data resulting from tests performed in approved laboratories.

This certificate applies to the product shown on this document, as supplied by Stelfast Inc. Alterations to the product by our customer or a third party will render this certificate void.

ROBERT D. MEAGHER
QUALITY MANAGER

October 20, 2014

59

ZHEJIANG JUNYUE STANDARD PART CO.,LTD.
CERTIFIED MATERIAL TEST REPORT

COMMODITY: STUD SIZE: 3/4-10×144" STANDARD: ASTM A193-06

Order No: 0-206860 QTY: 1000 (PCS) INVOICE NO.: ZJJY80619

LOT NO.: JY81419-9 PART NO.: TRB70075012000C HEAD MARKS: XL B7

一、CHEMICAL ELEMENTS (%) HEAT NO: 9500923 MATERIAL: B7

CHEMICAL ELEMENT	C	Mn	Si	P	S	Cr	Mo
SPEC	0.37	0.65	0.15	max	max	0.75	0.15
	0.49	1.10	0.35	0.035	0.04	1.20	0.25
TEST REPORT	0.40	0.8	0.21	0.009	0.003	0.96	0.167

二、MACHINICAL PROPERTIES BATCH NO 2P7051901 TEST NO: A193-06 B7

ITEM	TENSILE STRENGTH min (Mpa)	YIELD STRENGTH min (Mpa)	ELONGATION min (%)	REDUCE min (%)	TEMPERING min (^{0}C)	QUENCHING (^{0}C)	HARDNESS max (HRC)
STANDARD	860	724	16	50	593	820~880	35
TEST REPORT	956	825	18	55	640	860	30

三、TESTED SIZE

ITEM		LENGTH	MAJORDIA	GO	NO	T/LENGTH	STRAIGHTNESS	ADD
STANDARD		3663.95	19.004	2A	2A		max	
		3651.25	18.677				18.29	
TEST REPORT	①	3658.00	18.85	OK	OK		OK	
	②	3660.00	18.84	OK	OK		OK	
	③	3660.00	18.82	OK	OK		OK	
PCS: 4	④	3658.00	18.85	OK	OK		OK	OK

ACID MACRO STRUCTURE					
SCATTERED POROSITY		CENTRE UNSOUNDNESS		PATTERN	MACRO ETCH TESTING
0.5	0.5	0.5	0.5	0.5	PASSED

MACRCO ETCH				
DIVISION	URFACE CONDITIO	ANDOM CONDITIO	CENTER SEGREGATION	SPEE OF TEST METHOD
SPEC	S2	R2	C3	ASTM A962-05
RESUITS	S2	R2	C3	

PARTS ARE MANUFACTURED AND TESTED IN ACCORDANCE WITH ASTM A193-06 B7
ALSO MEET THE REQUIREMENTS OF ASME SA-95 SECTION 2 IN YOUR MTR.
ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DATA IS TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIES AND OUR TESTING LABORATORY.

ZHANGGUANG
ZHEJIANG JUNYUE STANDARD PART CO.,LTD.
QUALITY DEPARTMENT

2019.12.25

53

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 224656
- Part No: DUS0007500
- Quantity (PCS): 100
- Description: 3/4 U.S.S Flat Washer
- Specification: ASME B18.21.1
- Stelfast I.D. NO: 790214-O205325
- Customer PO: 35533
- Warehouse: HOU

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

August 08, 2019

MILL TEST REPORT

Lot#: 218L136-3 Part#: 355080

BRIGHTON-BEST INTERNATIONAL INC.

www.BrightonBest.com

CERTIFICATE OF INSPECTION

COUNTRY OF ORIGIN: CHINA

Purchaser:	BRIGHTON-BEST INTERNATIONAL (TAIWAN),INC.	Date:	2018-10-26
P.O.NO:	PO B18090720/U58897	ISO NO:	15 18Q6310R31
INV NO:	218ZL211L	Expire:	21-Mar-20
Manufacturer:	ZHEJIANG GUORUI CO.,LTD.		
Address:	No.283 Chengxi North Road,Wuyuan Town,Haiyan Zhejiang,P.R.China		
Commodity:	F436 HARD ROUND STRUCTURAL FLAT WASHER WITH MFG'S I.D.&F436 ON FACE	CUSTOMER PART NO.:	355080
Size:	3/4 X 1-15/32	MANUFACTURING DATE:	2018.9.28
Lot NO.:	218L136-3	HEAT NO.:	72B370-1
Ship quantity:	36,000 MPCS	MATERIAL:	45# CARBON STEEL
Finish:	PLN		

DIMENSIONAL INSPECTION ACCORDING TO ASTM F436-11

INSPECTION ITEM	SAMPLE SIZE	SPECIFIED	ACTUAL RESULT	ACCEPT	REJECT	TEST FACILITY
Appearance	100	ASTM F436-11	OK	100	0	M
Marking	100	F436 AND JLX	OK	100	0	M
Outside Dia	8	1.500-1.436	1.464-1.467	8	0	M
Inside Dia	8	0.845-0.813	0.832-0.833	8	0	M
Thickness	8	0.177-0.122	0.154-0.164	8	0	M

CHEMICAL COMPOSITION ACCORDING TO ASTM F436-11 TEST FACILITY : S

CHEMICAL ELEMENT (%)	C	Mn	P	S	Si	Cr	Mo	Ni	Al	Ti	V
SPECIFIED			0.040 MAX	0.050 MAX							
TEST RESULT	0.46	0.66	0.020	0.007	0.29				0.029		

MECHANICAL PROPERTIES ACCORDING TO ASTM F436-11

TEST ITEM	SAMPLE SIZE	SPECIFIED	ACTUAL RESULT	ACCEPT	REJECT	TEST FACILITY
HARDNESS(HRC)	8	38-45	41-43.5	8	0	M

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY

THE REPORT IS ISSUED ACCORDING TO ISO16228 F3.1(EN10204 3.1).

SIGNATURE: GAOGUANGCHENG TITLE: QC MANAGER

Stelfast Inc.

22979 Stelfast Parkway
Strongsville, Ohio

44149

Report of Chemical and Physical Properties

Issued To: Mack Bolt, Steel & Machine
5875 Hwy 21 East
BRYAN, TX
77808

Purchase Order: 36529
Stelfast Order: SO 252426
Certificate #: 881,174

Quantity: 250
Part #: A2HHO0750C
Description: 3/4-10 Hvy Hx Nut 2H

Lot Number: N2020100938HP
Heat Number: G090002208
Country of Origin: CN

Chemical Analysis

C	Mn	P	S	Si	Cr	Mo	V	B	Ni	Cu
0.44	0.64	0.015	0.004	0.21						

Mechanical Properties

Tempering Temp.	540 C
Hardness After 24 HRS At 540 C	98 - 99 HRB
Hardness (Core)	27 - 28 HRC
Proof Load	58450 LBF
Macro Etch Test	22 - R2 - C2
Grade Markings	ASTM A194(06)-2H

We hereby certify that the above data is a true copy of the data furnished to us by the producing mill or the data resulting from tests performed in approved laboratories. Stelfast does not certify to customer's part number.

This certificate applies to the product shown on this document, as supplied by Stelfast Inc. Alterations to the product by our customer or a third party will render this certificate void.

David Biss
Quality Manager

February 24, 2021

Metals 2 Go

MATERIAL TEST REPORT COVER SHEET

224 N HEWITT DR
HEWITT TX 76643
254-235-7700
FAX 254-235-7703
MTR@METALS2GO.COM

MACK BOLT & STEEL				
PO #	36527		EXPECTED DELIVERY	02/25/21
TICKET #	218705			

TR No. 610461-01-3&4

50

2021-08-16

Atlas Tube
A DIVISION OF ZEKELMAN INDUSTRIES

REF.B/L: 80993402
Date: 01/18/2021
Customer: 179

MATERIAL TEST REPORT

Material: 8.0x4.0x375x20'0"0(2x5). **Material No:** 800403752000 **Made in:** Canada
Melted and Poured in: Canada
Sales Order: 1591048 **Purchase Order:** 4500357901 **Cust Material#:** 6680040037520

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N	Ca
799073	0.190	0.800	0.009	0.009	0.019	0.035	0.046	0.006	0.005	0.017	0.032	0.002	0.002	0.0002	0.0040	0.0002

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M102054134	10	064992 Psi	070431 Psi	33.3 %	ASTM A500-20 GRADE B&C	

Heat	MILL	Mill Location	Method	Recycled_Content	Post_Consumer	Pre-Consumer (Post Industrial)	% Harvested	Within Miles of Location
799073	STELCO	Nanticoke, ON	BOF	36.90%	19.80%	14.40%	100%	1000

Material Note:
Sales Or. Note:

Authorized by Quality Assurance: Jason Richard

The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method. This document is in compliance with the requirements of EN 10204 type 3.1

Steel Tube Institute OF NORTH AMERICA

Metals Service Center Institute

NUCOR

Mill Certification

11/30/2020

MTR#:549517-2
Lot #:110001667061

Customer PO	4500356935	Sales Order #	11024790 - 1.1
Product Group	Hot Roll - Merchant Bar Quality	Product #	3016860
Grade	Nucor Multigrade	Lot #	110001667061
Size	0.375" x 6"	Heat #	1100016670
BOL #	BOL-632808	Load #	549517
Description	Hot Roll - Merchant Bar Quality Flat 3/8" x 6" Nucor Multigrade 20' 0" [240"] 2001-6000 lbs	Customer Part #	
Production Date	10/21/2020	Qty Shipped LBS	24500
Product Country Of Origin	United States	Qty Shipped EA	160
Original Item Description		Original Item Number	

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Melt Country of Origin : United States — Melting Date: 10/14/2020

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	Ti (%)	V (%)	Sn (%)
0.14	0.88	0.019	0.019	0.217	0.14	0.23	0.05	0.30	0.001	0.051	0.011

ASTM A529 S78.2 CE (%) : 0.42

Other Test Results

Yield (PSI) : 61500
Yield (PSI) : 61000
Tensile (PSI) : 78200
Tensile (PSI) : 78000
Elongation in 8" (%) : 20.3
Elongation in 8" (%) : 20.0

Comments:

NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/A36M-14; A529/529M-05(2009) GR50(345); A572/572M-07 GR50(345); A709/709M-10 GR36(250) & GR50(345); CSA G40.21-04 GR44W(300W)& GR50W(350W); AASHTO M270/M270M-10 GR36(270) & GR50(345); ASME SA36/SA36M-07; MEETS REPORTING REQUIREMENTS OF EN10204 SEC 3.1

1. All manufacturing processes of the steel, including melting, casting & hot rolling, have been performed in U.S.A
2. Mercury in any form has not been used in the production or testing of this product.
3. Welding or weld repair was not performed on this material.
4. This material conforms to the specifications described on this document and may not be reproduced, except in full, without written approval of Nucor Corporation.
5. Results reported ASTM E45 (Inclusion content) and ASTM E381 (Macro-etch) are provided as interpretation of ASTM procedures.

Robert Fortson, Quality Assurance

TR No. 610461-01-3&4

METALLURGICAL TEST REPORT

DATE 02/05/2021
TIME 15:36:19
USER T.GOSE

SOLD TO
16475
Metals 2 Go
224 North Hewitt Drive
Hewitt TX 76643-3044

SHIP TO
16475
Metals 2 Go
224 North Hewitt Drive
Hewitt TX 76643-3044

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
2808165-0070	70164896TM	1/2 48 X 96 A36 TEMPERPASSED STPMP	41.000	26,791.040		44364	01/26/2021

Chemical Analysis

Heat No. A015014 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS

Melted and Manufactured in the USA
Produced from Coil
Country of Origin: USA

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.2200	0.4600	0.0050	0.0040	0.0200	0.0300	0.0600	0.0100	0.0000	0.0900	0.0220	0.0010	0.0020	0.0000	0.0079	0.0040

Mechanical / Physical Properties

Mill Coil No. 20B804973

Tensile	Yield	Elong (2 in)	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
72000.000	45500.000	32.80			0	NA			
67500.000	43500.000	34.80			0	NA			
70400.000	43700.000	32.00			0	NA			
67300.000	41900.000	35.40			0	NA			

Batch 1000063101	8 EA	5,227.520 LB	Batch 1000063109	8 EA	5,227.520 LB	Batch 1000063110	8 EA	5,227.520 LB
Batch 1000063111	9 EA	5,880.960 LB	Batch 1000063081	8 EA	5,227.520 LB			

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

2021-08-16

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

Project No: 610461 Casting Date: 2019-08-13 Mix Design (psi): 5000

Name of Technician Taking Sample: B. H Griffith

Name of Technician Breaking Sample: B. H Griffith

Signature of Technician Taking Sample:

Signature of Technician Breaking Sample:

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	7030	5592583	North Segment of Barrier

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-10-09	58 days	170000	6013	1
1	1	1	180000	6367	6137
1	1	1	170500	6031	1

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

Project No: 610461 **Casting Date:** 2017-08-23 **Mix Design (psi):** 5000

Name of Technician Taking Sample: [signature]

Name of Technician Breaking Sample: B. Griffith

Signature of Technician Taking Sample: B. Griffith

Signature of Technician Breaking Sample: [signature]

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	7124	5613590	South End Barrier Section

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2017-10-09	486days	166500	5889	1
1	1	1	160000	5659	5912
1	1	1	175000	6190	1

TICKET NO. 5592583

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
8:53	9:13	:	9:43	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 15 GAL.
ALLOWABLE WATER (withheld from batch) 11.8 GAL.
TEST CYLINDER TAKEN ❑ YES ❑ NO BY
CYLINDER TAKEN ❑ BEFORE ❑ AFTER WATER

ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IN EXCESS OF SPECIFIED SLUMP IS AT CUSTOMER'S RISK.

CUSTOMER SIGNATURE
X

DELIVERY OF THESE MATERIALS IS SUBJECT TO THE TERMS AN CONDITIONS ON THE REVERSE SIDE HEREOF AS ACCEPTED B SIGNATURE ABOVE .

CUSTOMER NAME AND DELIVERY ADDRESS
TTI-RIVERSIDE CAMPUS

PLANT 617 TRUCK 030 ORDER NO. 032 SLUMP 5.0 P.O. #/JOB/LOT GRID
DRIVER NAME Los Bretherton 8/13/ DATE
CUSTOMER NUMBER PROJECT 546 CUM. QTY 8.00 ORDERED QTY 00

LOAD QUANTITY	PRODUCT CODE	DESCRIPTION	UNIT PRICE	AMOUNT
8.00	CYDS	R9Z50547 COM, RG, Z, 5000, RE		
1.00	ea	12987 FREIGHT CHARGE		

610461-

SPECIAL DELIVERY INSTRUCTIONS
RIGHT LEONARD RD, RIGHT ON HWY 47, LEFT INTO RELLIS, THEY WILL MEET YOU AT THE ROUND A BOUT

SALES TAX
TOTAL

DANGER! MAY CAUSE ALKALI BURNS.
SEE WARNINGS ON REVERSE SIDE.

FOR OFFICE USE ONLY **FORM:** 2680066

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
7030	946310	user	5592583	78356	8:53	8/13/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
8.00	CYDS R9Z50547				D	79397

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"RG	1300 lb	10442 lb	10440 lb	-0.02%	0.40% M	5 gl
3/8"PG	525 lb	4211 lb	4200 lb	-0.26%	0.26% M	1 gl
SAND-1	1266 lb	10441 lb	10440 lb	-0.01%	3.00% M	38 gl
CMT-I/II	548 lb	4384 lb	4380 lb	-0.09%		
FLYASH-C	127 lb	1016 lb	1010 lb	-0.59%		
H20	256 lb	1582 lb	1584 lb	0.13%		190 gl
ZY-610	22 oz	307 oz	306 oz	-0.29%		
Actual	Num Batches: 1					

Load Total: 32073 lb Design 0.379 Water/Cement 0.380 T Design 245.4 gl Actual 233.7 gl To Add: 11.8 gl
Slump: 5.00 in % Water in Truck: 0.0 gl Adjust Water: 0.0 gl / Load Trim Water: -1.5 gl/ CYD

CUSTOMER'S COPY

TICKET NO. 5613990

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
:	:	:	:	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST _____ GAL.
ALLOWABLE WATER (withheld from batch) _____ GAL.
TEST CYLINDER TAKEN ❑ YES ❑ NO BY _____
CYLINDER TAKEN ❑ BEFORE ❑ AFTER WATER

ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IN EXCESS OF SPECIFIED SLUMP IS AT CUSTOMER'S RISK.

CUSTOMER SIGNATURE
X

DELIVERY OF THESE MATERIALS IS SUBJECT TO THE TERMS AN CONDITIONS ON THE REVERSE SIDE HEREOF AS ACCEPTED E SIGNATURE ABOVE .

CUSTOMER NAME AND DELIVERY ADDRESS
TEXAS A & M UNIVERSI
TTI-RELLIS CAMPUS

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
617	7124	2025	5.0	610461	

DRIVER NAME: Bobby Kenney
DATE: 8/23/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
782659	79546	8.00	8.00

LOAD QUANTITY	PRODUCT CODE	DESCRIPTION	UNIT PRICE	AMOUNT
8.00	CYDS	R9Z50547	CON, RG, 4, 5000, RE	
1.00	ea	12987	FREIGHT CHARGE	

610461

SPECIAL DELIVERY INSTRUCTIONS
SOUTH 2818, RIGHT LEONARD RD, RIGHT HWY 47, LEFT INTO RELLIS, THEY WILL MEET YOU AT THE ROUND ABOUT

SALES TAX
TOTAL

DANGER! MAY CAUSE ALKALI BURNS.
SEE WARNINGS ON REVERSE SIDE.

FOR OFFICE USE ONLY **FORM:** 2680297

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
7124	948507	user	5613990	78583	6:52	8/23/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
8.00	CYDS R9Z50547				D	79626

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"RG	1300 lb	10437 lb	10440 lb	0.03%	0.35% M	4 gl
3/8"PG	525 lb	4212 lb	4200 lb	-0.29%	0.29% M	1 gl
SAND-I	1266 lb	10495 lb	10480 lb	-0.15%	3.50% M	44 gl
CMT-I/II	540 lb	4384 lb	4400 lb	0.36%		
FLYASH-C	127 lb	1016 lb	1020 lb	0.39%		
H20	256 lb	1532 lb	1533 lb	0.08%		184 gl
ZY-610	22 oz	307 oz	306 oz	-0.25%		

Actual Num Batches: 1
Load Total: 32092 lb Design 0.379 Water/Cement 0.378 T Design 245.4 gl Actual 233.5 gl To Add: 11.9 gl
Slump: 5.00 in # Water in Truck: 0.0 gl Adjust Water: 0.0 gl / Load Trim Water: -1.5 gl/ CYD

APPENDIX C. *MASH* TEST 3-10 (CRASH TEST NO. 610461-01-3)

C.1. VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 610461-01-3.

Date: 2021-04-07 Test No.: 610461-01-3 VIN No.: 3N1CN7AP9FL863557

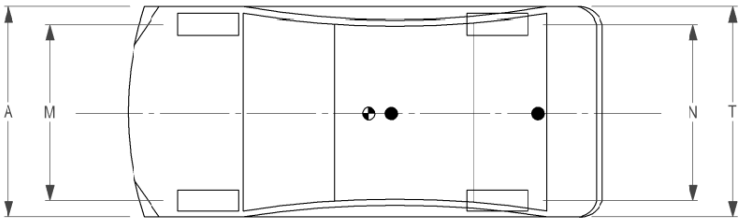
Year: 2015 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 70485 Tire Size: P185/65R15

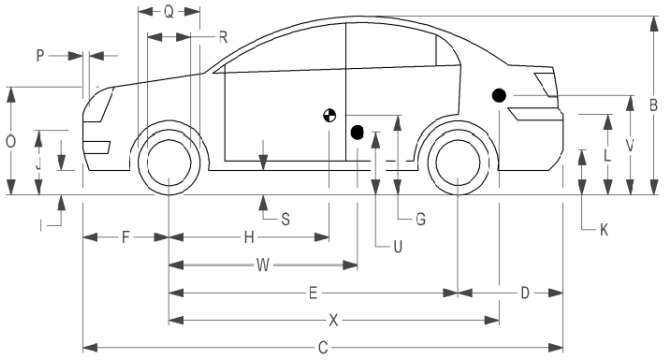
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None



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



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

Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	40.91	M	58.30	R	16.25	W	40.90
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 -0.01

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}	1443	1456	1541
Back	1687	M_{rear}	991	969	1049
Total	3389	M_{Total}	2434	2425	2590

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

Mass Distribution:
lb LF: 766 RF: 690 LR: 464 RR: 505

Table C.2. Exterior Crush Measurements for Test No. 610461-01-3.

Date:	2021-4-7	Test No.:	610461-01-3	VIN No.:	3N1CN7AP9FL863557
Year:	2015	Make:	NISSAN	Model:	VERSA

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front Plane at bumper ht	14	7	48	-	-	-	-	-	-	-8
2	Side Plane above bmp ht	14	10	60	-	-	-	-	-	-	64
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

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

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

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

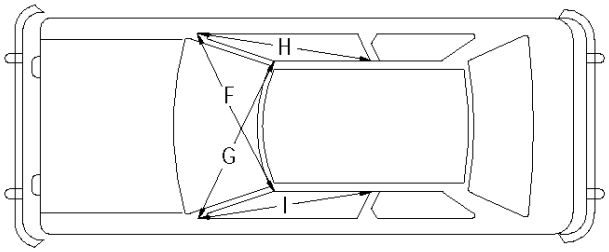
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

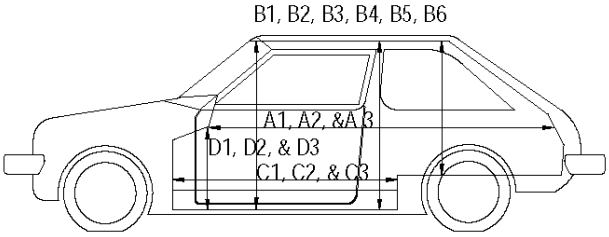
***Measure and document on the vehicle diagram the location of the maximum crush.

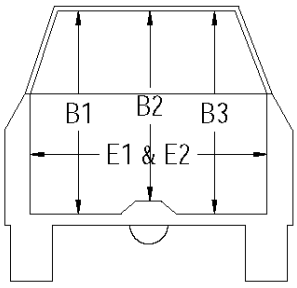
Note: Use as many lines/columns as necessary to describe each damage profile.

Table C.3. Occupant Compartment Measurements for Test No. 610461-01-3.

Date:	2021-04-07	Test No.:	610461-01-3	VIN No.:	3N1CN7AP9FL863557
Year:	2015	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	23.00	-3.00
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	48.00	3.00
E2	48.75	51.75	3.00
F	47.50	47.50	0.00
G	47.50	47.50	0.00
H	39.00	38.50	-0.50
I	39.00	39.00	-0.50
J*	48.50	46.00	-2.50

C.2. SEQUENTIAL PHOTOGRAPHS

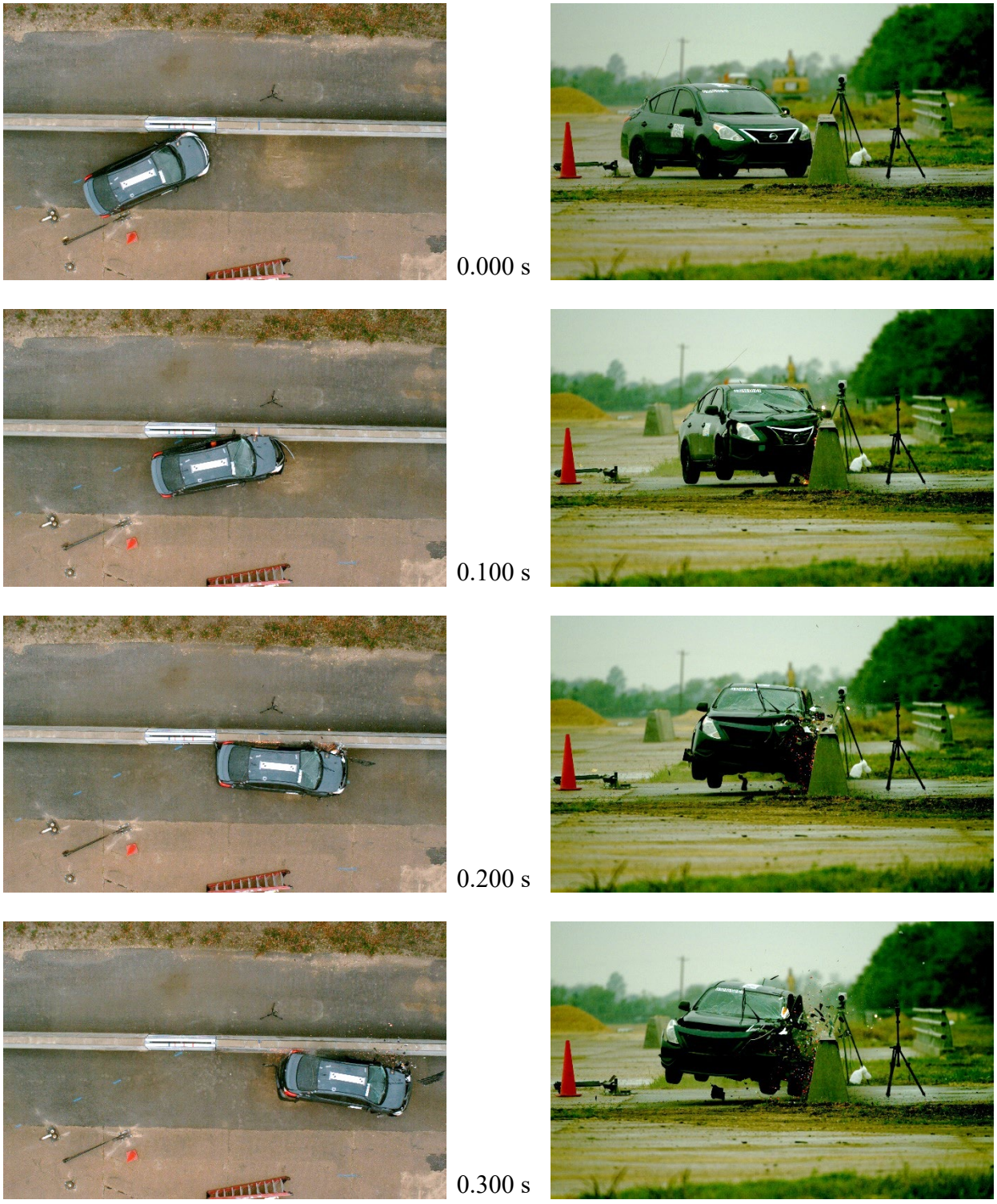
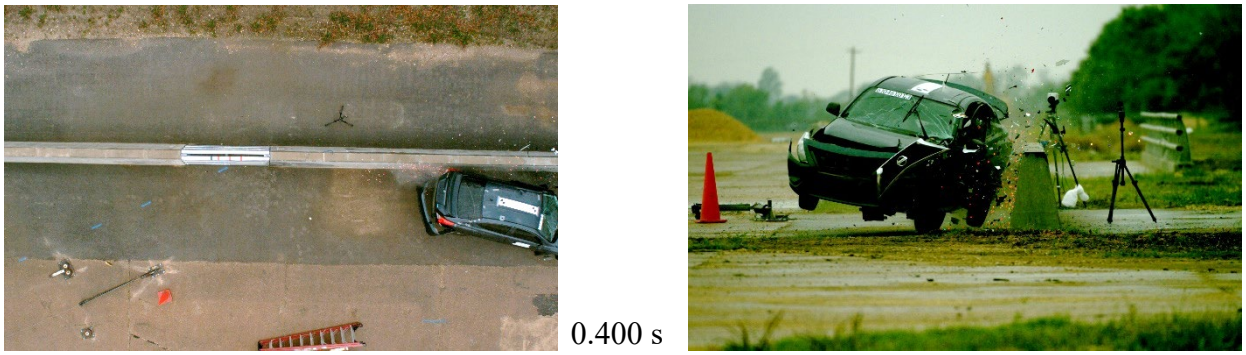


Figure C.1. Sequential Photographs for Test No. 610461-01-3 (Overhead and Frontal Views).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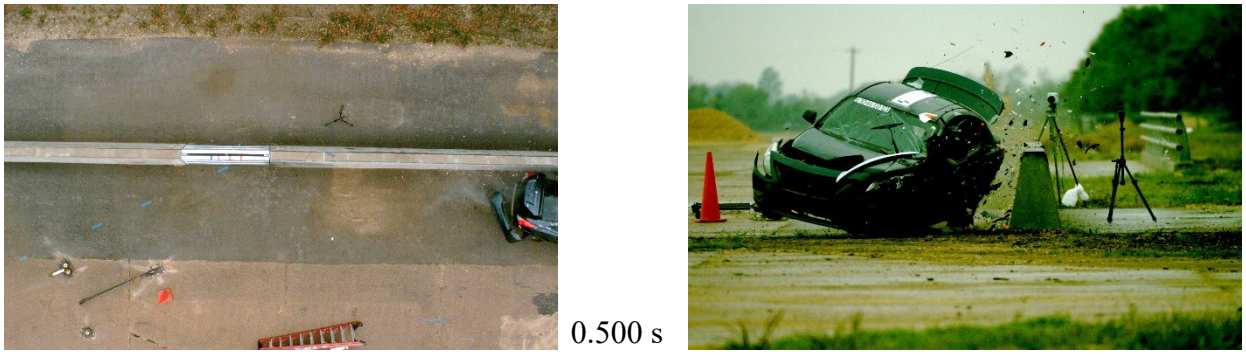
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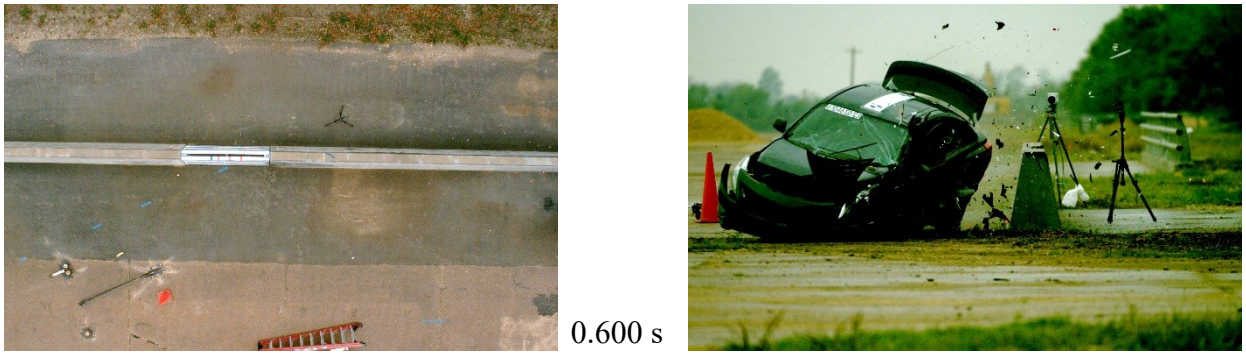
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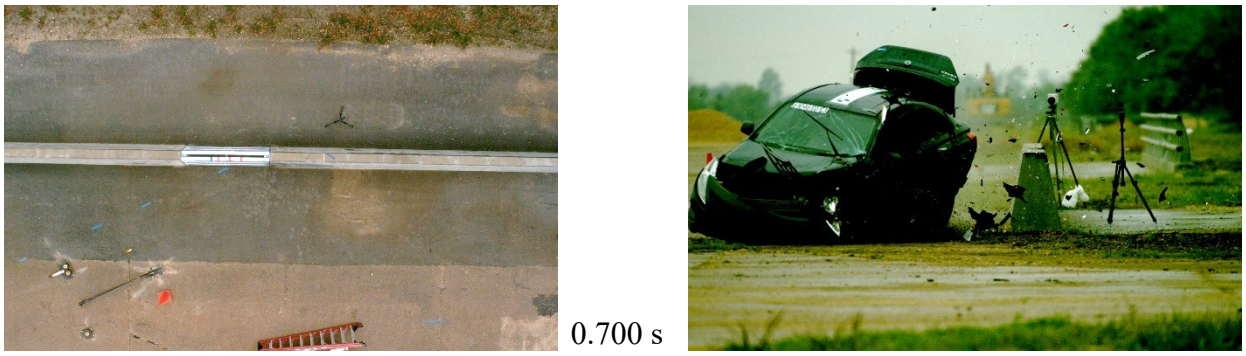

0.700 s

Figure C.1. Sequential Photographs for Test No. 610461-01-3 (Overhead and Frontal Views) (Continued).


0.000 s


0.400 s


0.100 s


0.500 s

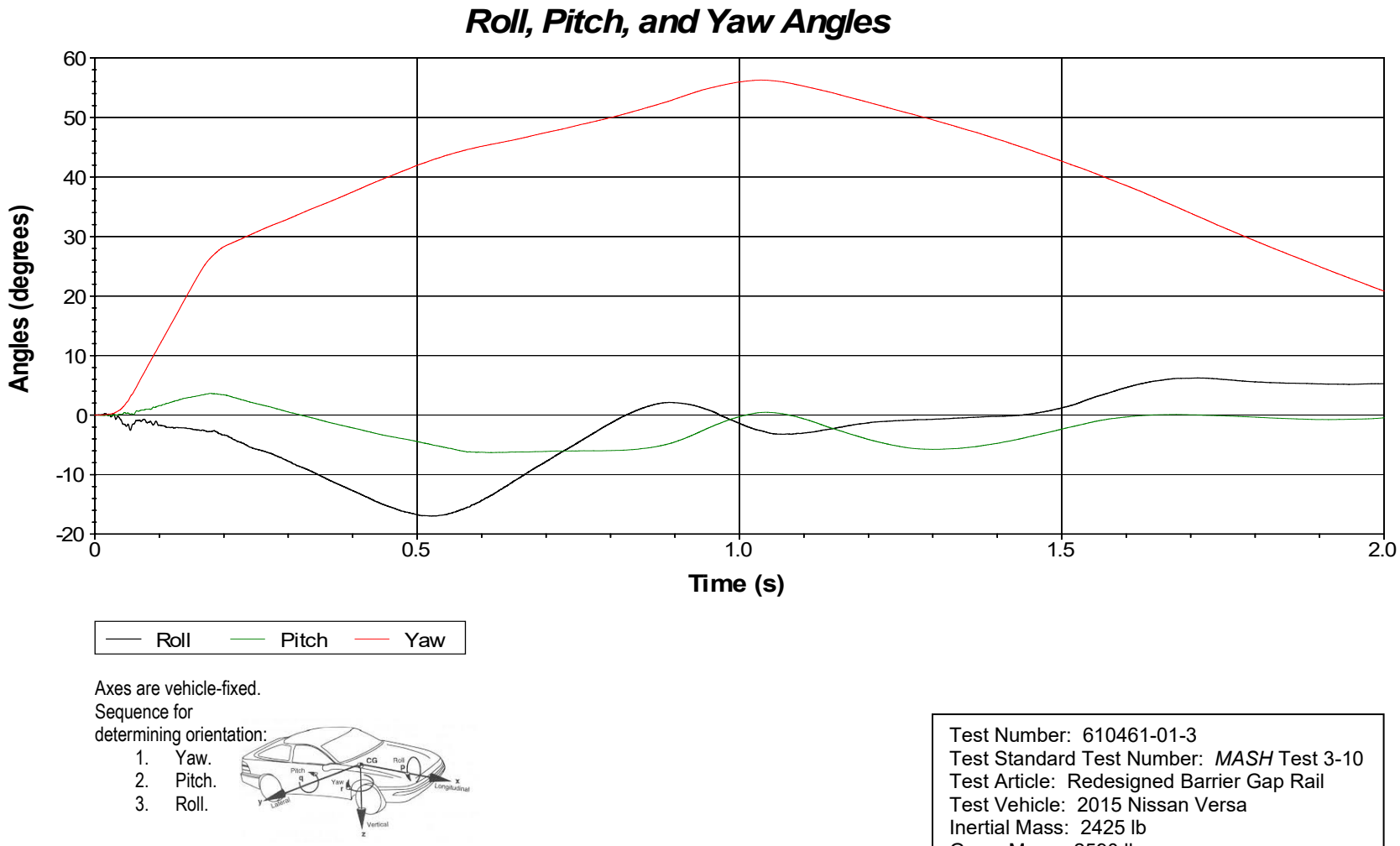

0.200 s


0.600 s


0.300 s


0.700 s

Figure C.2. Sequential Photographs for Test No. 610461-01-3 (Rear View).



Test Number: 610461-01-3
Test Standard Test Number: *MASH* Test 3-10
Test Article: Redesigned Barrier Gap Rail
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2425 lb
Gross Mass: 2590 lb
Impact Speed: 62.5 mi/h
Impact Angle: 24.5 degrees

Figure C.3. Vehicle Angular Displacements for Test No. 610461-01-3.

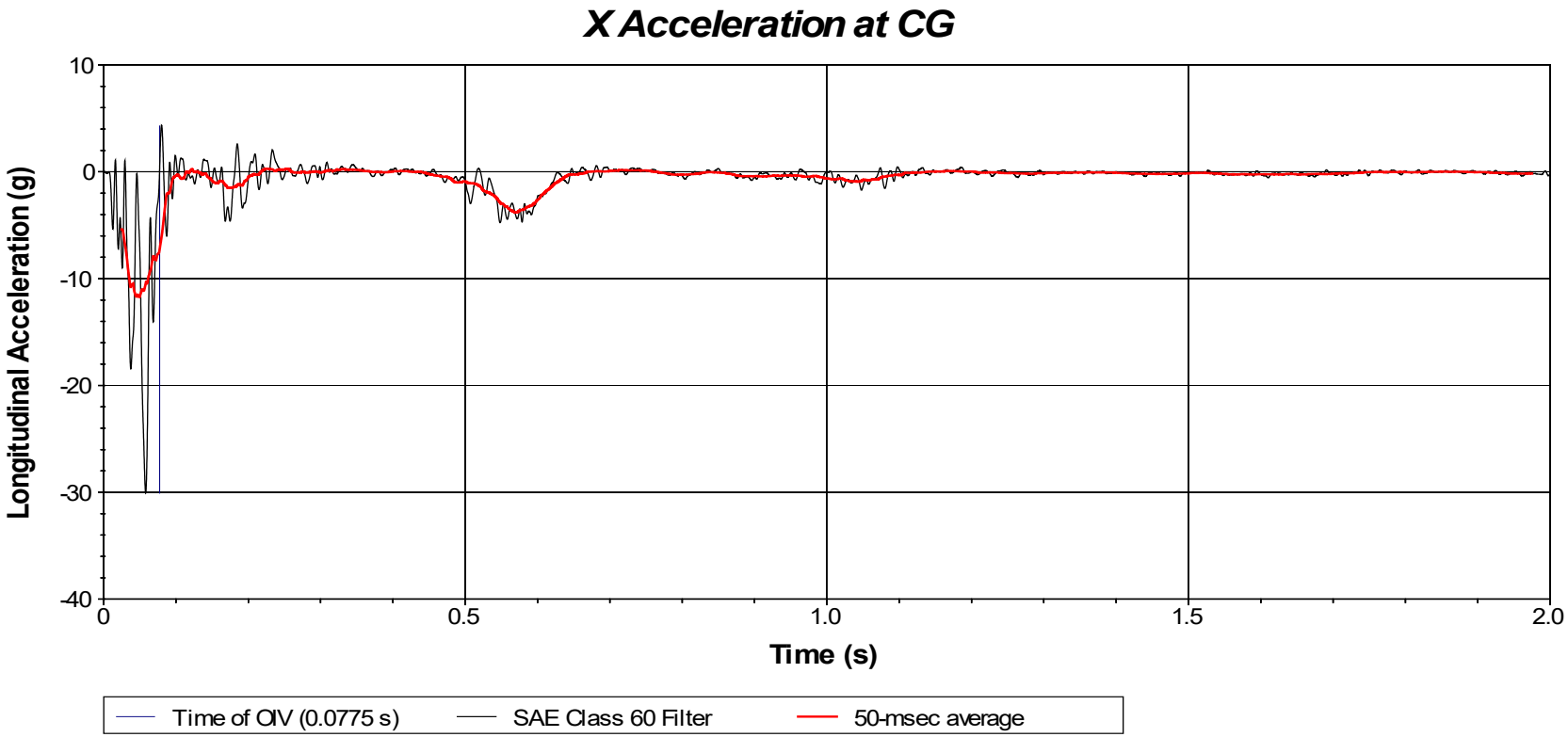
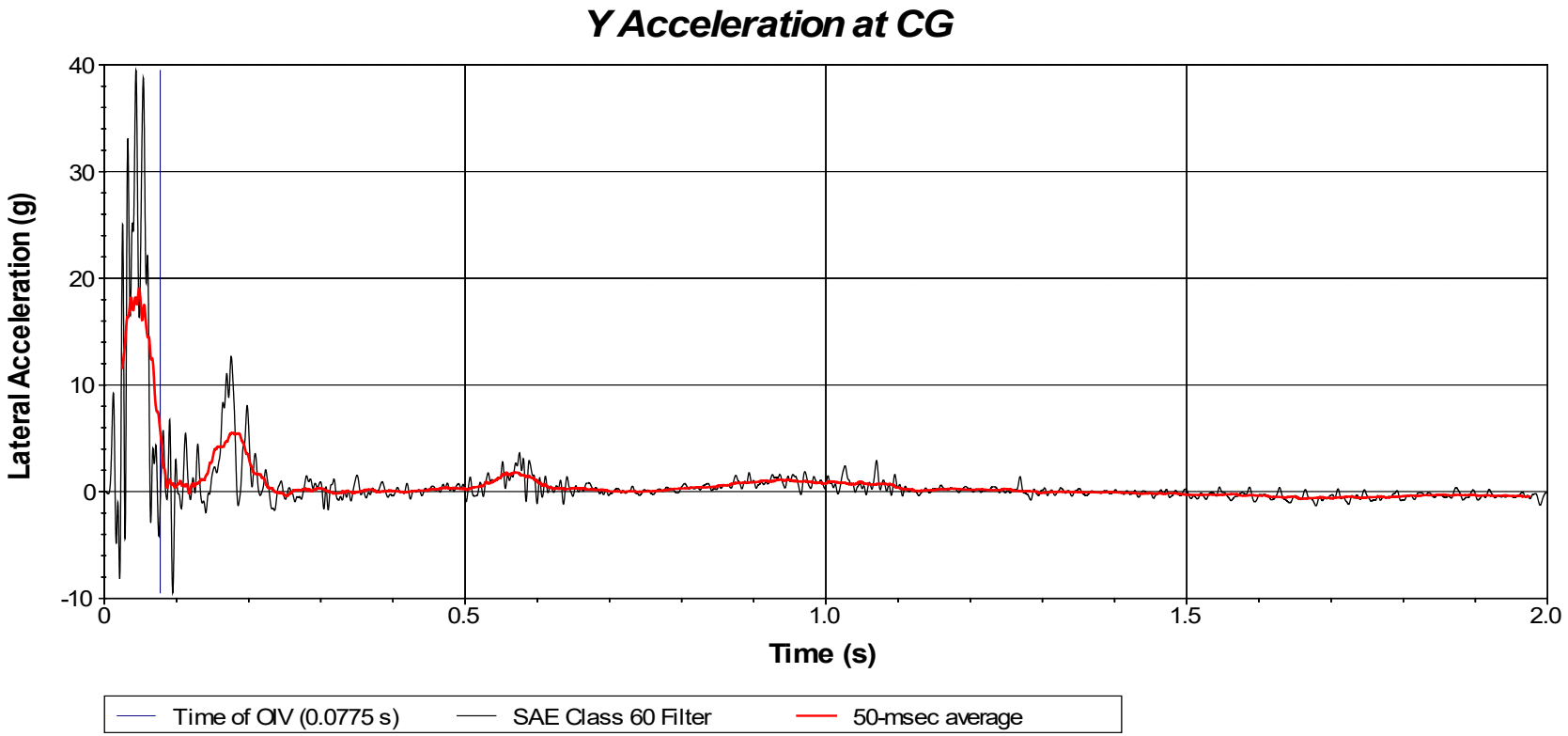


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 610461-01-3 (Accelerometer Located at Center of Gravity).



Test Number: 610461-01-3
Test Standard Test Number: *MASH* Test 3-10
Test Article: Redesigned Barrier Gap Rail
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2425 lb
Gross Mass: 2590 lb
Impact Speed: 62.5 mi/h
Impact Angle: 24.5 degrees

Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 610461-01-3 (Accelerometer Located at Center of Gravity).

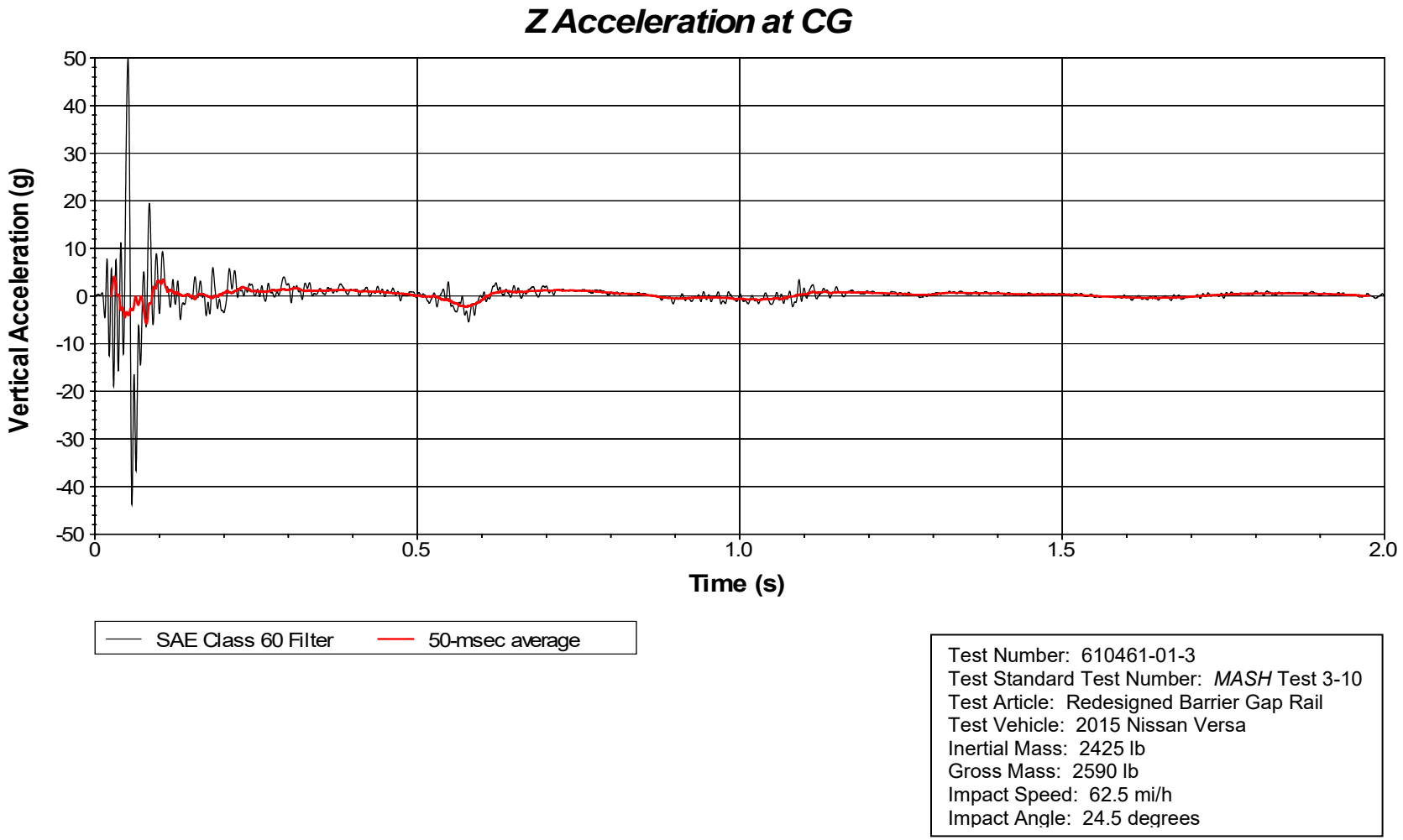


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 610461-01-3 (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 3-11 (CRASH TEST NO. 610461-01-4)

D.1. VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 610461-01-4.

Date: 2021-4-9 Test No.: 610461-01-4 VIN No.: 1C6RR6FT8GS240064

Year: 2016 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 169539

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

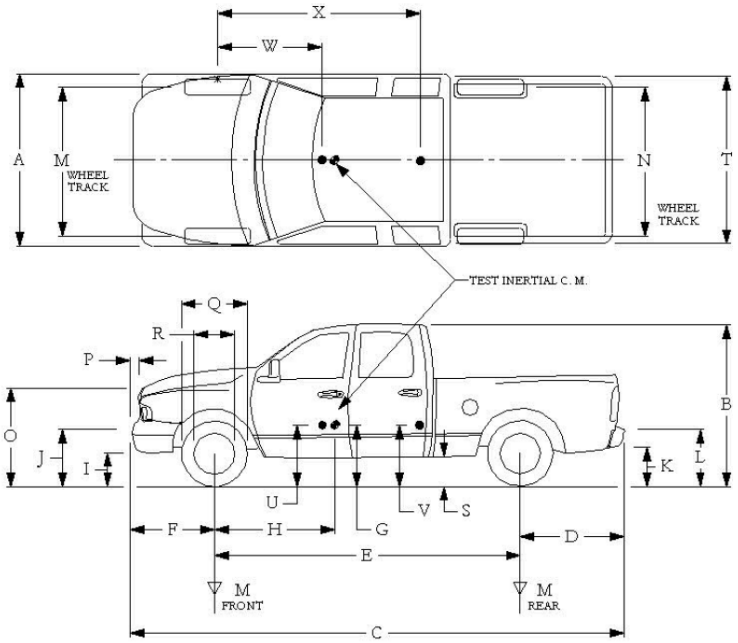
NOTES: None

Engine Type: V-8
Engine CID: 5.7 L

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

Optional Equipment:
None

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



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.25	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.59	M	68.50	R	18.00	W	60.6
D	44.00	I	11.75	N	68.00	S	13.00	X	79
E	140.50	J	27.00	O	46.00	T	77.00		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2975	2884	2969
Back	3900	M_{rear}	2116	2187	2267
Total	6700	M_{Total}	5091	5071	5236

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

Mass Distribution:
lb LF: 1450 RF: 1434 LR: 1110 RR: 1077

Table D.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 610461-01-4.

Date: 2021-4-9 Test No.: 610461-01-4 VIN: 1C6RR6FT8GS240064

Year: 2016 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 169539

Engine: 5.7 L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 130 (440 lb max)

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

Measured Vehicle Weights: (lb)									
LF:	1450		RF:	1434		Front Axle:	2884		
LR:	1110		RR:	1077		Rear Axle:	2187		
Left:	2560		Right:	2511		Total:	5071		
							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:	60.59	inches	Rear of Front Axle	(63 ±4 inches allowed)					
Y:	-0.33	inches	Left -	Right +	of Vehicle Centerline				
Z:	28.25	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. 610461-01-4.

Date:	2021-4-9	Test No.:	610461-01-4	VIN No.:	1C6RR6FT8GS240064
Year:	2016	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bmp ht	14	10	36	-	-	-	-	-	-	18
2	Side plane above bmp	14	9	60	-	-	-	-	-	-	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.

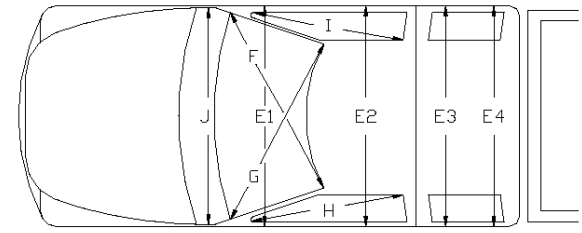
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

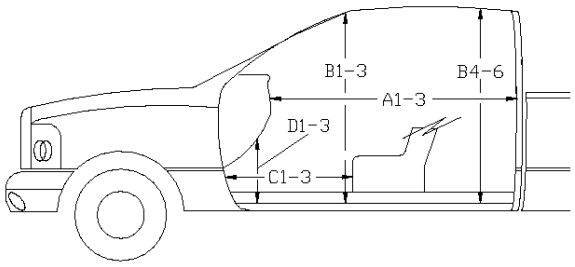
***Measure and document on the vehicle diagram the location of the maximum crush.

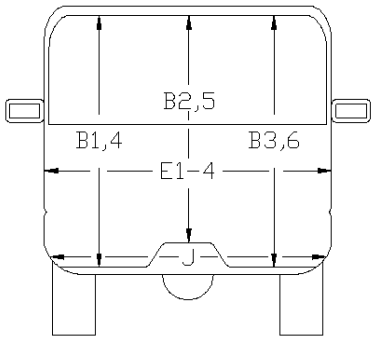
Note: Use as many lines/columns as necessary to describe each damage profile.

Table D.4. Occupant Compartment Measurements for Test No. 610461-01-4.

Date:	2021-4-9	Test No.:	610461-01-4	VIN No.:	1C6RR6FT8GS240064
Year:	2016	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	22.5	-3.50
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	57.5	-1.00
E2	63.50	66.5	3.00
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*	24	22	-2.00

D.2. SEQUENTIAL PHOTOGRAPHS

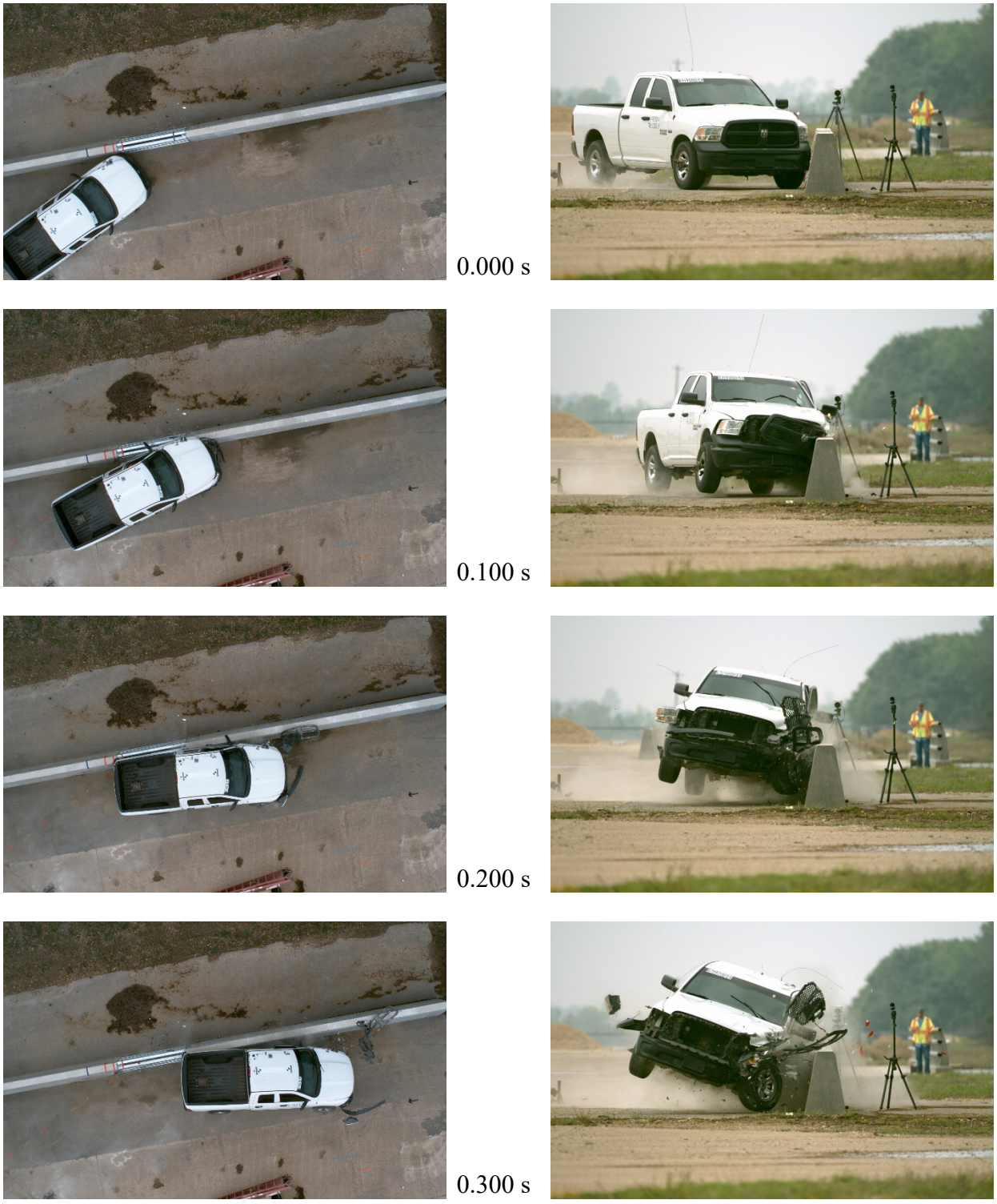
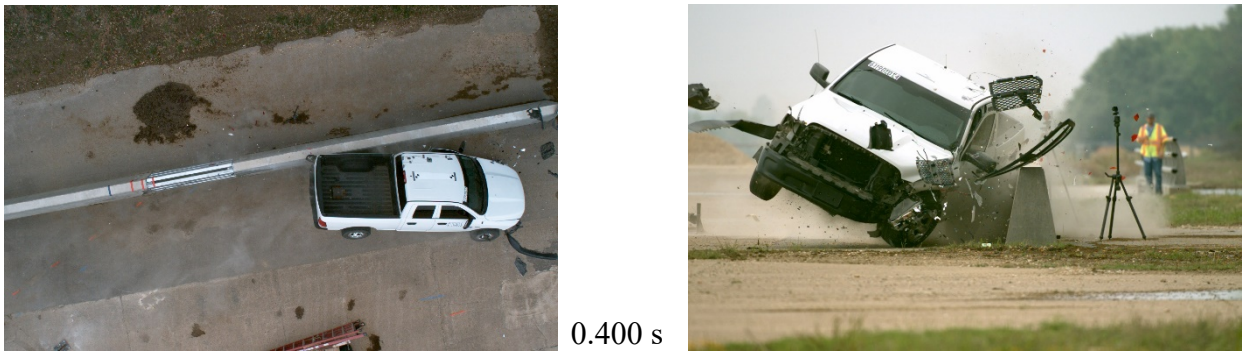


Figure D.1. Sequential Photographs for Test No. 610461-01-4 (Overhead and Frontal Views).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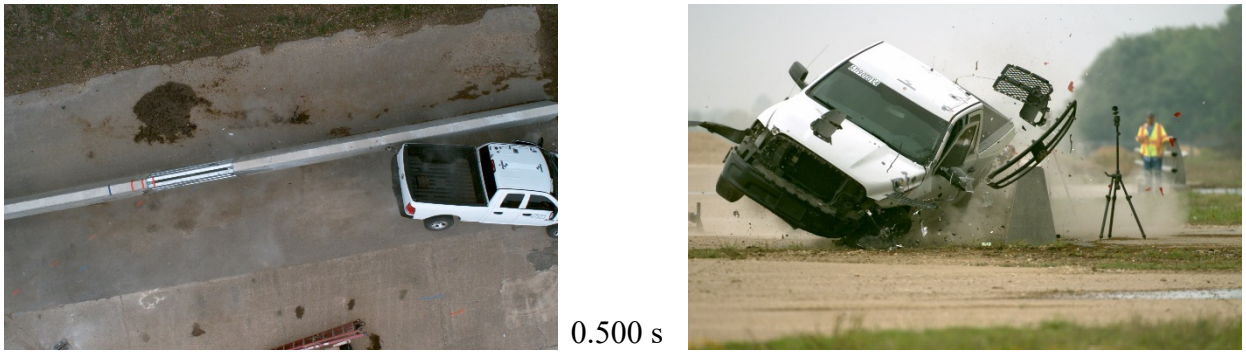
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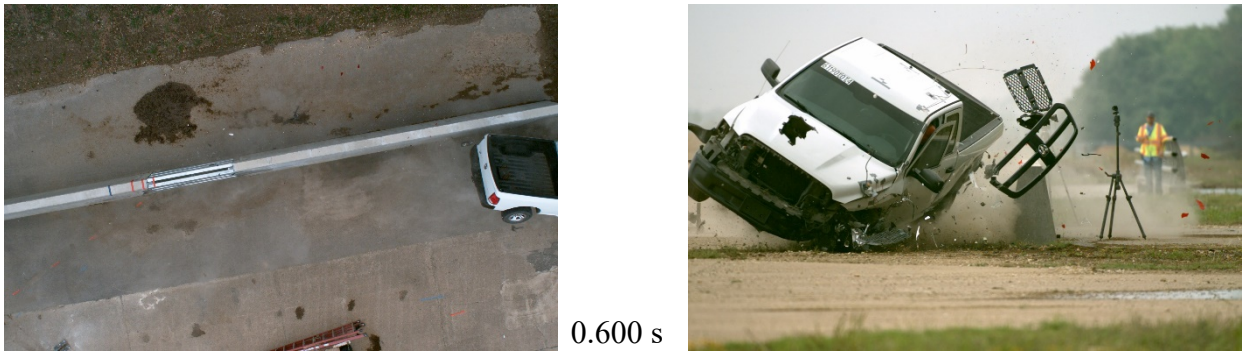
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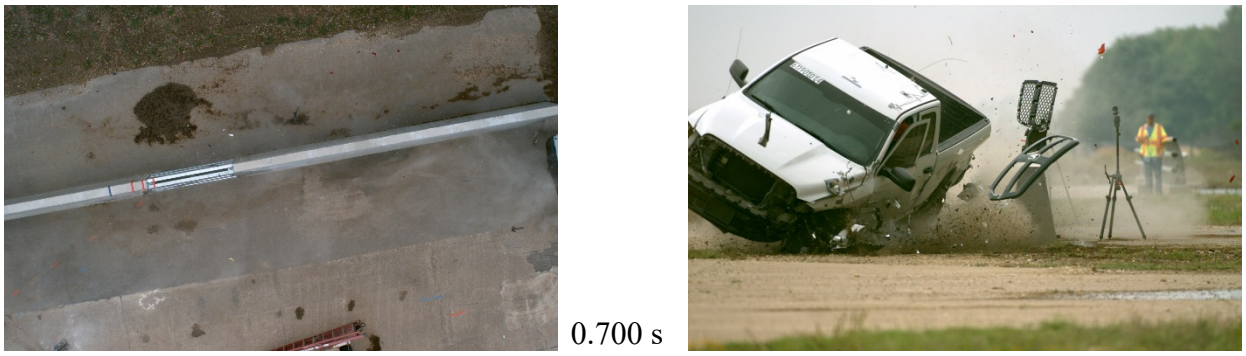

0.700 s

Figure D.1. Sequential Photographs for Test No. 610461-01-4 (Overhead and Frontal Views) (Continued).

0.000 s


0.400 s


0.100 s


0.500 s

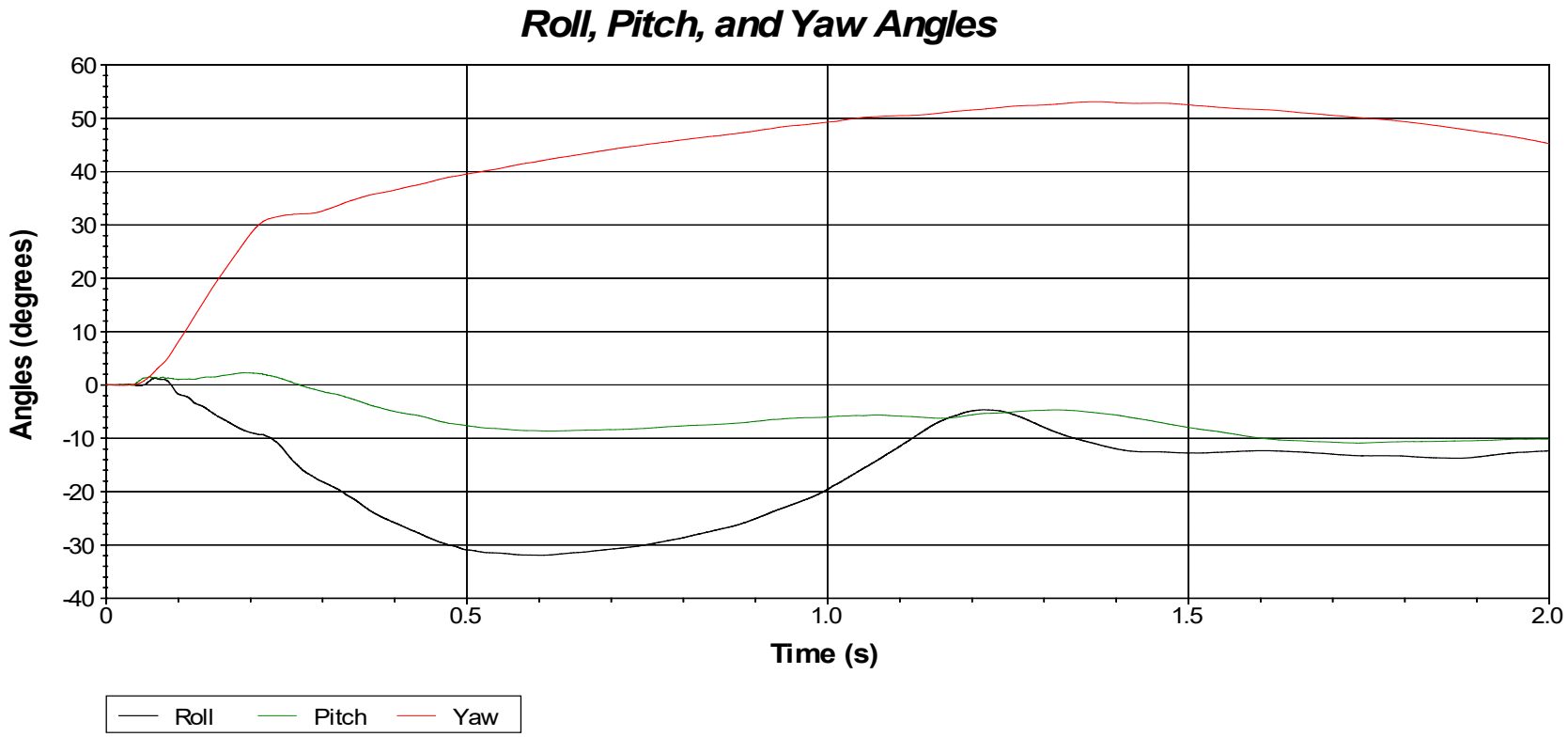

0.200 s


0.600 s


0.300 s

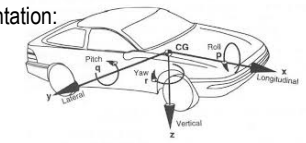

0.700 s

Figure D.2. Sequential Photographs for Test No. 610461-01-4 (Rear View).



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 610461-01-4
Test Standard Test Number: *MASH* Test 3-11
Test Article: Redesigned Barrier Gap Rail
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5071 lb
Gross Mass: 5236 lb
Impact Speed: 62.5 mi/h
Impact Angle: 25.3 degrees

Figure D.3. Vehicle Angular Displacements for Test No. 610461-01-4.

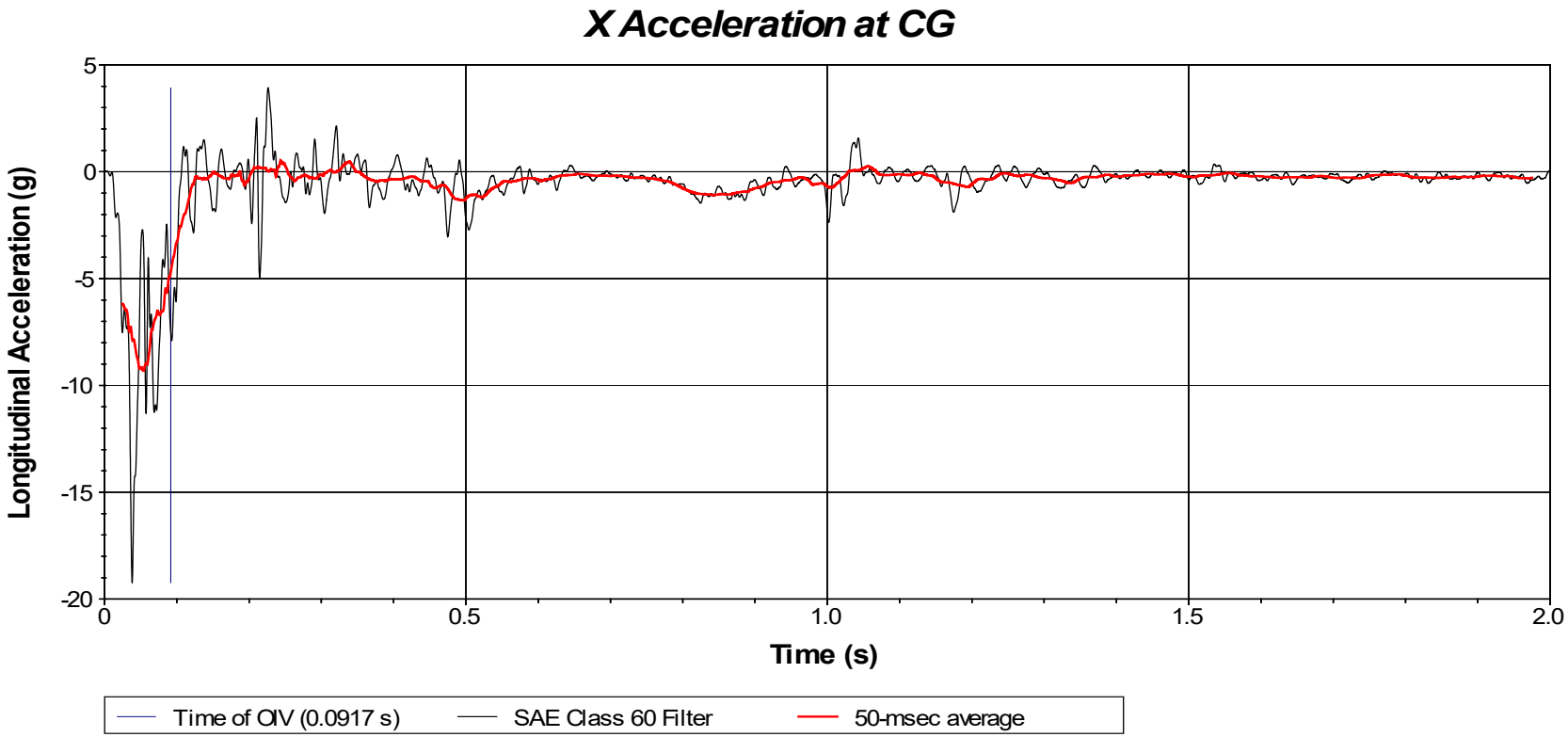


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 610461-01-4 (Accelerometer Located at Center of Gravity).

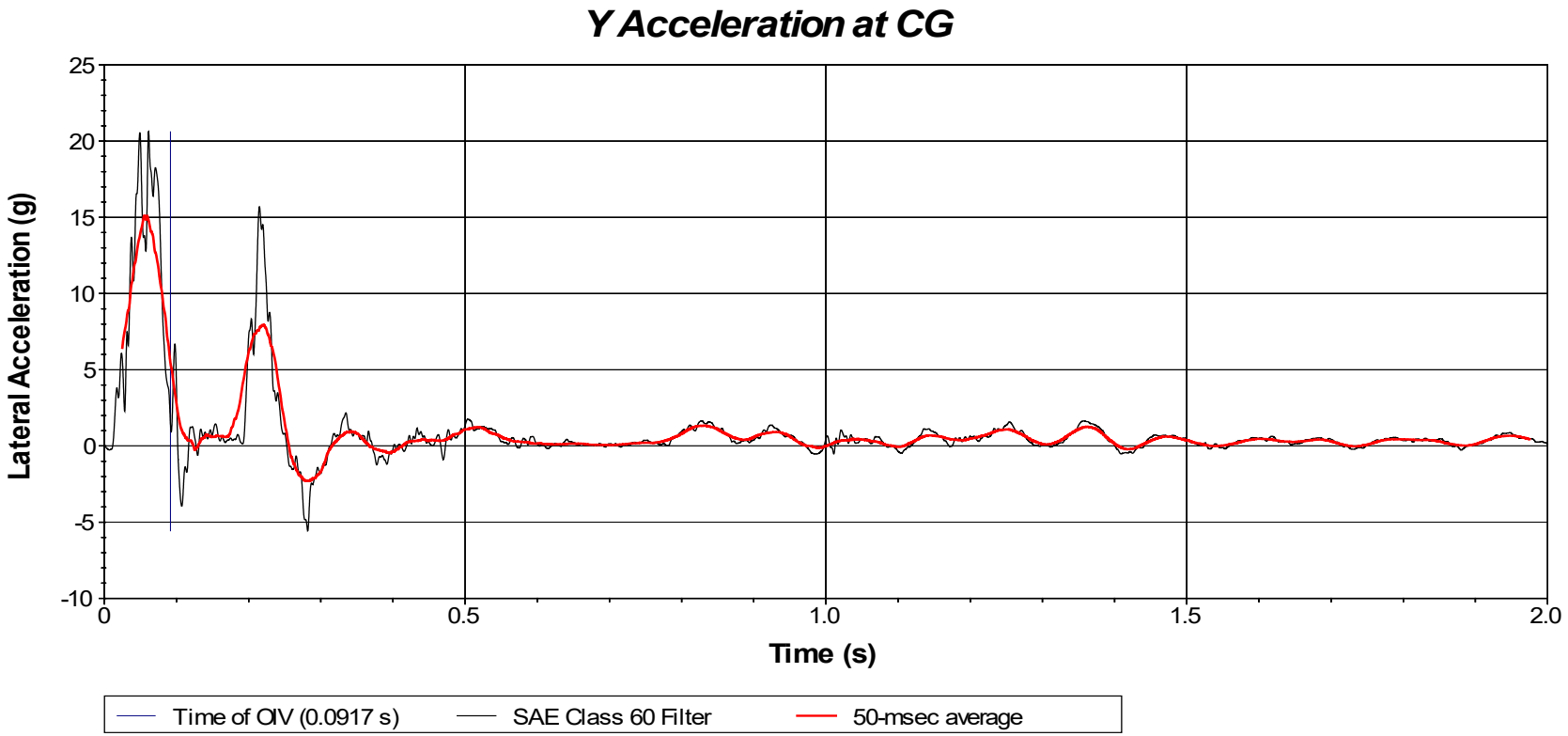


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 610461-01-4 (Accelerometer Located at Center of Gravity).

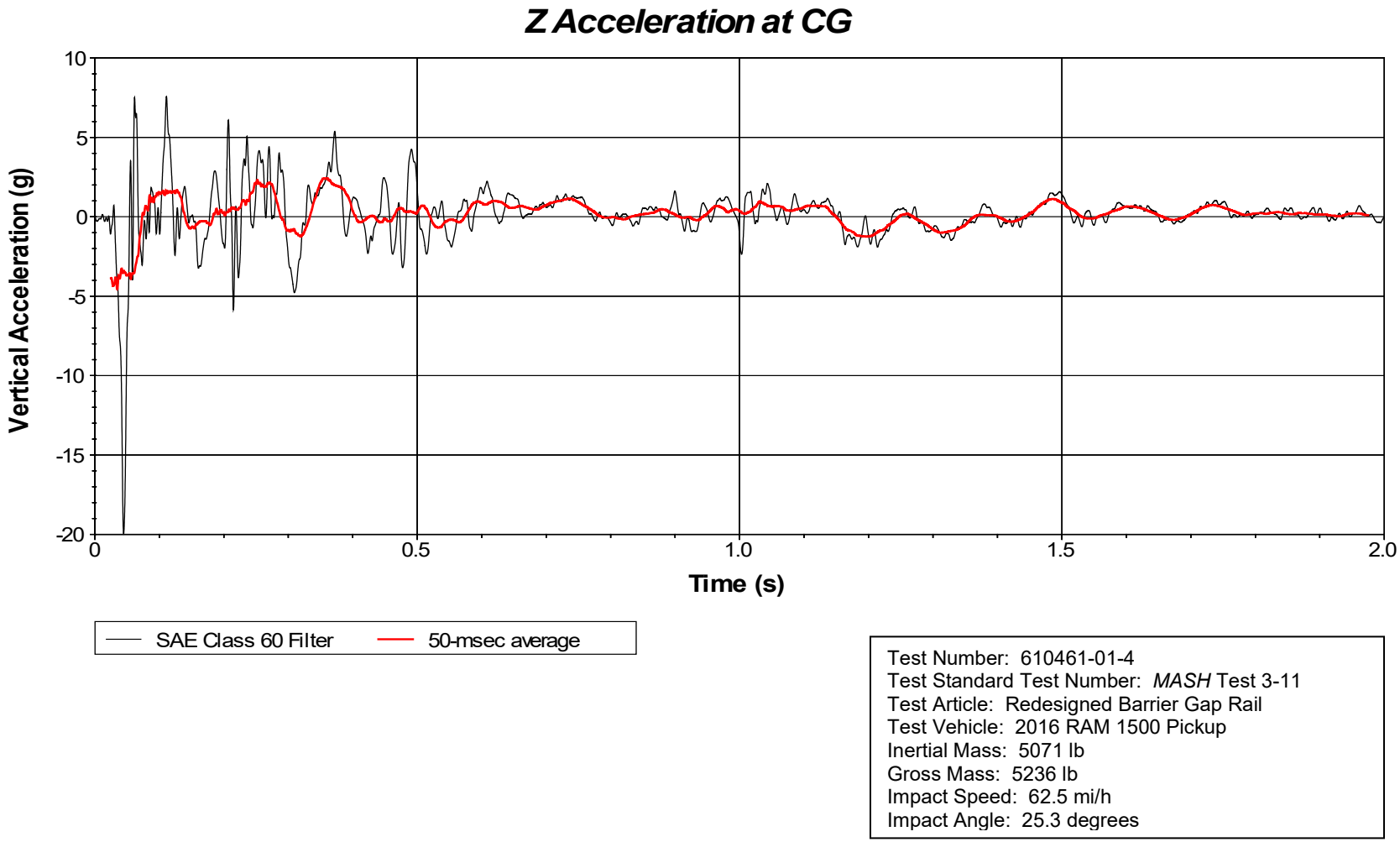


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 610461-01-4 (Accelerometer Located at Center of Gravity).