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DESIGN AND TESTING OF *MASH* TL-3 THRIE-BEAM GUARDRAIL SYSTEM (TGS) FOR ROADSIDE AND MEDIAN APPLICATIONS

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16. Abstract

Thrie-beam guardrail systems are used when enhanced Test Level 3 (TL-3) protection above what is typically provided with W-beam guardrail is desired. Currently, an AASHTO *Manual for Assessing Safety Hardware* (*MASH*) compliant Thrie-beam guardrail system for roadside applications exists, but a median version has yet to be developed. (*1*) Furthermore, the currently available roadside system incorporates components that are more costly to fabricate and install and create a wider footprint than conventional W-beam barrier alternatives. Therefore, the Roadside Safety Pooled Fund prioritized a project to develop *MASH* compliant cost-effective Thrie-beam guardrail systems for both roadside and median applications. These systems were crash tested to *MASH* specifications. Lastly, transition designs from these newly developed systems to standard W-beam systems were developed through computer simulation.

The developed Thrie-beam Guardrail system (TGS) utilizes all MGS standard components with the exception of the Thrie-beam itself. TGS has a thrie-beam rail mounted at 34-inches to top as opposed to MGS with a W-beam rail mounted at 31-inches. The two systems are attached together using symmetric W-beam-to-thrie-beam transition segments.

*Based on the results of the three successful full-scale crash tests and the computer simulation effort, both roadside and median TGS configurations met all safety requirements for *MASH* TL-3.

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

17. Key Words
Longitudinal barrier, transition, guardrail, W-beam, thrie beam, crash testing, roadside safety, *MASH*

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

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Chapter 1. INTRODUCTION

1.1 PROBLEM STATEMENT

Thrie-beam guardrail systems are used when enhanced Test Level 3 (TL-3) protection above what is typically provided with W-beam guardrail is desired. Currently, an AASHTO *Manual for Assessing Safety Hardware* (*MASH*) compliant Thrie-beam guardrail system for roadside applications exist, but a median version has yet to be developed (*1*). Furthermore, the currently available roadside system incorporates components that are more costly to fabricate and install, and create a wider footprint that standard W-beam guardrail. Therefore, the Roadside Safety Pooled Fund prioritized a project to develop *MASH* compliant cost-effective Thrie-beam guardrail systems for both roadside and median applications. These systems were crash tested to *MASH* specifications. Lastly, transition designs from these newly developed systems to standard W-beam systems were developed through computer simulation.

1.2 WORK PLAN

1.2.1 Task 1: Literature and Engineering Review

The research team reviewed the current literature and previous research related to Thrie-beam guardrail systems and transitions between W-beam and Thrie-beam sections. This included reviewing the National Cooperative Highway Research Program (NCHRP) *Report 350* compliant systems and the current *MASH* compliant systems (*2*). The research team also completed a preliminary analysis of the roadside, median, and transition systems in preparation for the computer simulation

1.2.2 Task 2: Computer Modeling and Simulation

The primary objective of Task 2 was to use computer simulation to develop designs for the following systems:

1) Roadside Thrie-beam guardrail.
2) Median Thrie-beam guardrail.
3) Transition from roadside Thrie-beam guardrail to W-beam guardrail.
4) Transition from median Thrie-beam guardrail to W-beam guardrail.

The design objectives included being *MASH* compliant, cost-efficient, and easy to install. The TTI research team used the results of these simulations to assess the probability of each design concept meeting *MASH* impact performance requirements and other desirable functional characteristics.

The TTI research team used the explicit finite element code to perform impact simulations using the developed barrier model and available vehicle models, as shown in Chapter 3.

The TTI research team used a combination of previous research, *MASH* guidelines, and computer simulations to determine the critical impact points for the *MASH* crash tests. Once the critical impact points had been determined, the TTI research team reviewed the findings with the technical representative before constructing the test installations and conducting crash testing.

1.2.3 Task 3: *MASH* Crash Testing

The TTI research team completed full-scale *MASH* crash tests on the roadside and median systems. The budget allowed for three full-scale crash tests. Therefore, the results from the computer simulations were used to identify the critical *MASH* TL-3 tests to be performed.

The computer simulation results were used to identify the most critical tests to perform on the Thrie-beam systems and transitions. In this case the three tests were *MASH* 3-10, 3-11, and 3-21. Test 3-11 was performed on the thrie beam roadside barrier, Test 3-10 was performed on the thrie beam median barrier, and Test 3-21 was performed on the (roadside, median) transition. These tests include the *MASH* 2270P (5000 lb) pickup truck and the *MASH* 1100C (2420 lb) small car.

1.2.4 Task 4: Evaluation and Reporting

The TTI research team prepared this research report to fully document all the work completed in this project. The report includes detailed engineering drawings of the Thrie-beam systems.

CHAPTER 2 LITERATURE REVIEW

2.1 BACKGROUND

A literature review was performed and completed for this project. The engineering review of the available systems for length-of-need (LON) and transition satisfies the requirement of Task 1: Literature and Engineering Review.

2.1.1 Length of Need

The original evaluation and testing of the modified thrie beam guardrail was performed by the Texas A&M Transportation Institute (TTI) in 1982 *(3)*. The modified thrie beam guardrail was utilized 14-in. deep M14x17.2 blockouts with an angled cutout and an increased mounting height to 34 in. To reduce the possibility of stress concentrations that could occur as the thrie beam wrapped around the edge of the blockout during the impact, backup plates were included between the thrie beams and the blockouts. The modified thrie beam was evaluated by impacting the barrier with a 20,040-lb International school bus impacting at 55.8 mph and an angle of 15.0 degrees. The system safely redirected the bus with a dynamic deflection of 34 in. A subsequent test was conducted to evaluate the possibility of vehicle snagging using a small car. A 2,276-lb Honda Civic was used to impact the barrier at 62.5 mph and an angle of 15.0 degrees. The small car was safely redirected with a dynamic deflection of 9.6 in. No snagging of the vehicle on the system posts was noted.

There have been several previous research projects evaluating the G9 Thrie-beam system and modified Thrie-beam system under NCHRP Report No. 350 (Figure 2.1) *(4).* In 1995, TTI researchers conducted test designation 3-11 on the G9 system. The G9 system utilized W6x9 wide flange sections as blockouts. The G9 guardrail system successfully contained and redirected the vehicle with a maximum dynamic deflection of 3.5 ft. However, the vehicle exited the test installation at a high roll angle and subsequently rolled two and a quarter revolution after exiting the test installation. In summary, the impact performance of the thrie-beam (G9) guardrail system was judged to be unsatisfactory according to evaluation criteria outlined in NCHRP Report 350 because of post-impact rollover.

In 1998, TTI conducted Test No. 3-11 on a strong wood post Thrie beam guardrail system that utilized wood posts and wood blockouts. The system met all required criteria for NCHRP Report 350 test designation 3-11 (*5*).

Unlike the G9 system with steel post, the modified Thrie-beam guardrail system successfully contained and redirected the vehicle and met all evaluation criteria outlined in NCHRP Report 350 for TL-3 and TL-4 conditions (*6, 7*).

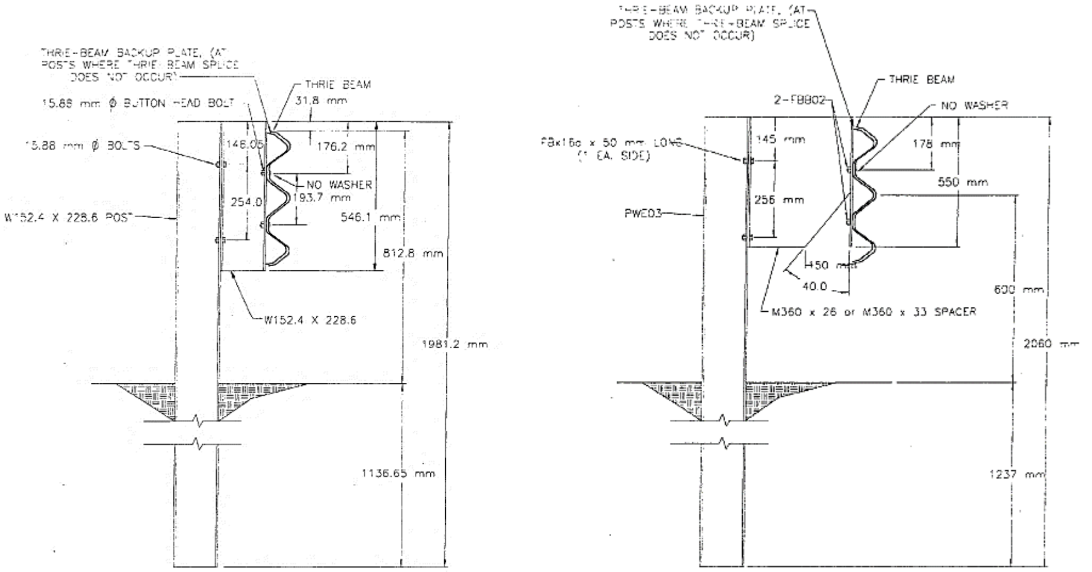


Figure 2.1. G9 guardrail system and modified thrie beam system.

TTI researchers evaluated the G9 thrie beam system presented in Figure 2.2 by using the proposed update of National Cooperative Highway Research Program (NCHRP) Report 350, referred to as the Manual for Assessing Safety Hardware (MASH08) *(8)*. The G9 thrie beam guardrail system consisted of a 12-gauge thrie beam rail mounted on 6 ft-6-inch long W6x8.5 steel posts spaced 6 ft-3 inches apart with 6-inch x 8-inch x 22-inch-long routed wood blockouts. The blockout was attached to the post with 5/8-inch diameter bolts without washers. The mounting height of the thrie beam rail element was 31.625 inches to the top of the thrie beam element. The thrie beam guardrail length-of-need was 100 ft long and transitioned to 37 ft-6-inch ET W-beam terminals attached to each end. The total installation length was 187 ft–6 inch. The G9 thrie beam guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the thrie beam during the test was 33.2 inches. However, the 2270P vehicle rolled after losing contact with the guardrail hence the did not perform acceptably under MASH criteria when impacted by the 2270P vehicle.

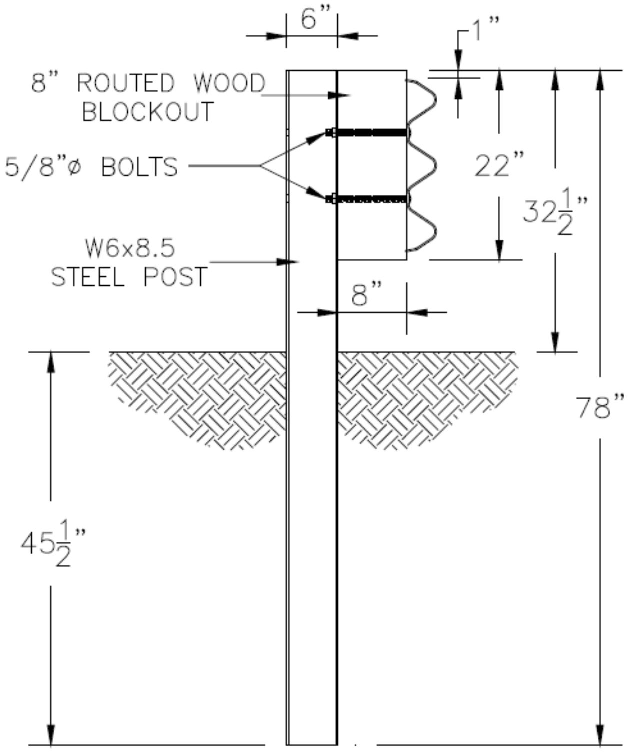


Figure 2.2. Cross-section of the G9 thrie beam guardrail.

Marzougui et al investigated the performance of standard G9 Thrie beam barrier using computer simulation. They constructed finite element models for the G9 Thrie-beam and the G4(1S) median barriers. For the G9 Thrie Beam barrier, various options were considered in an attempt to mitigate the rollover observed in the crash test. The variations included notched steel blockouts which is similar to what has been successfully crash tested as the Modified Thrie beam system by MwRSF *(9)* as well as using shorter blockouts behind the Thrie beam. For the G4(1S) median barrier, raising the mounting height of the barrier was recommended *(10, 11)*.

In 2020, the Midwest Roadside Safety Facility (MwRSF) researchers evaluated the New Jersey Department of Transportation (NJDOT) modified thrie beam guardrail system in both a single-sided roadside configuration and a dual-sided median configuration under Manual for Assessing Safety Hardware 2016 (MASH 2016) Test-Level 3 (TL-3) criteria (Figure 2.3). Both single-sided roadside configuration and the dual-sided median configuration was constructed utilized 81-in. long W6x8.5 steel posts at 75-in. post spacing, W14x22 steel blockouts, and 12-gauge guardrail sections. Both crash tests were deemed successful according to MASH 2016 TL-3 safety performance criteria *(9)*.

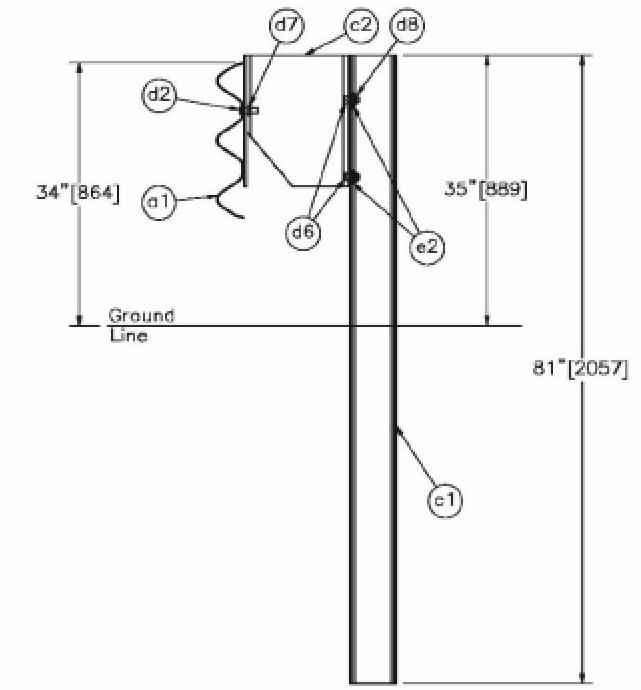


Figure 2.1. Typical single-sided cross-section of the modified thrie beam guardrail system tested by MwRSF.

2.1.2 Transition

TTI researchers assessed the performance of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition according to the safety-performance evaluation guidelines included in AASHTO *MASH (12).*The 2019 *MASH* 2-Tube Bridge Rail test installation was comprised of a 154-ft long section of reinforced concrete bridge deck that incorporated two steel rails, a 12½-ft long section of two nested thrie beams attached to the bridge rails with a thrie beam terminal connector and unique guardrail connector, a standard symmetrical 75-inch long thrie-to-W-beam transition rail section, 25 ft of W-beam guardrail LON, and a standard 9 ft-4½ inch long TxDOT DAT terminal at the end. Figure 2.4 presents overall information on the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition. The target critical impact point (CIP) for each test was determined in accordance with the guidance provided in MASH. For MASH Test 3-20, the target CIP was 5.1 ft upstream of the end of the concrete parapet. The target CIP for MASH Test 3-21 on the thrie beam to bridge rail transition was 7.0 ft upstream of the concrete parapet. The target CIP for MASH Test 3-21 on the W-beam to thrie beam transition was 7.3 ft upstream of the centerline of post 7. TTI researchers determined that MASH Test 3-20 on the W-beam to thrie beam transition was not necessary and was therefore not performed. The 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition performed acceptably for a MASH TL-3 transition.

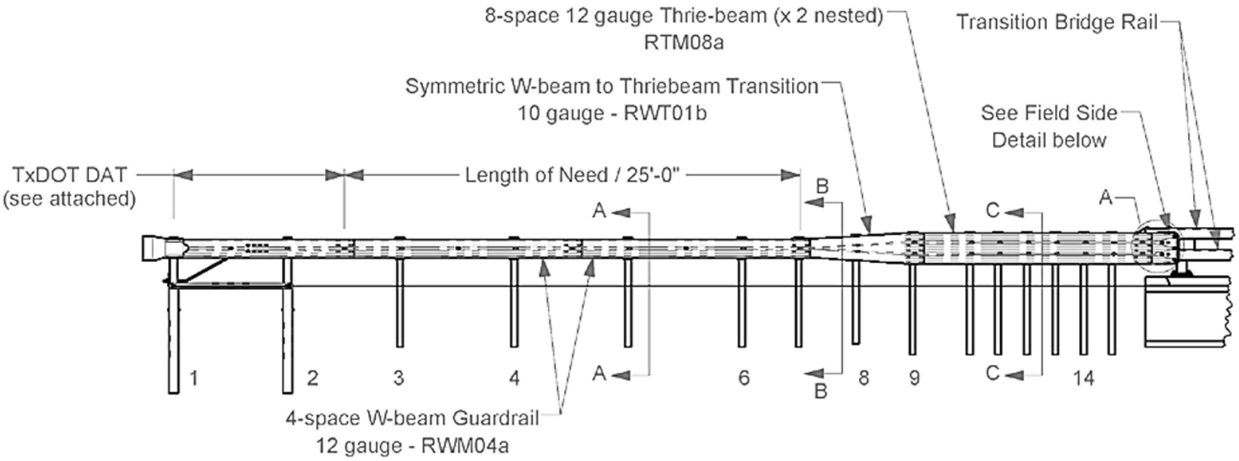


Figure 2.2. Details of 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition.

2.2 SUMMARY AND CONCLUSIONS FROM LITERATURE SEARCH

Based on the engineering review of previous studies, the following conclusions can be drawn:

1. The mounting height of the rail shouldn’t be less than 34 inches.
2. Using W-beam standard blockouts (6x8x14 inch) instead of Thrie-beam blockouts (6x8x22 inch) may improve the stability of the vehicle during the impact.
3. Utilizing a symmetric W-to-thrie transition segment provides a proper height transition from TGS to standard MGS.

CHAPTER 3 FINITE ELEMENT MODEL SIMULATIONS

3.1 INTRODUCTION

Finite element modeling simulations were conducted on the designs as part of Task 2: Computer Modeling and Simulation. The computer simulations were performed using LS-DYNA ().

3.2 SYSTEM DESIGN

The 218 ft 9 inch installation consisted of 81 ft 3 inch TGS that is attached to standard W-beam rail using symmetric W-beam-to-thrie-beam transition segments. The post spacing was 75 inches, except for in the transition section where it was 37½ inches. Figure 3.1 and Figure 3.2 show the details of the roadside and median TGS design concepts.

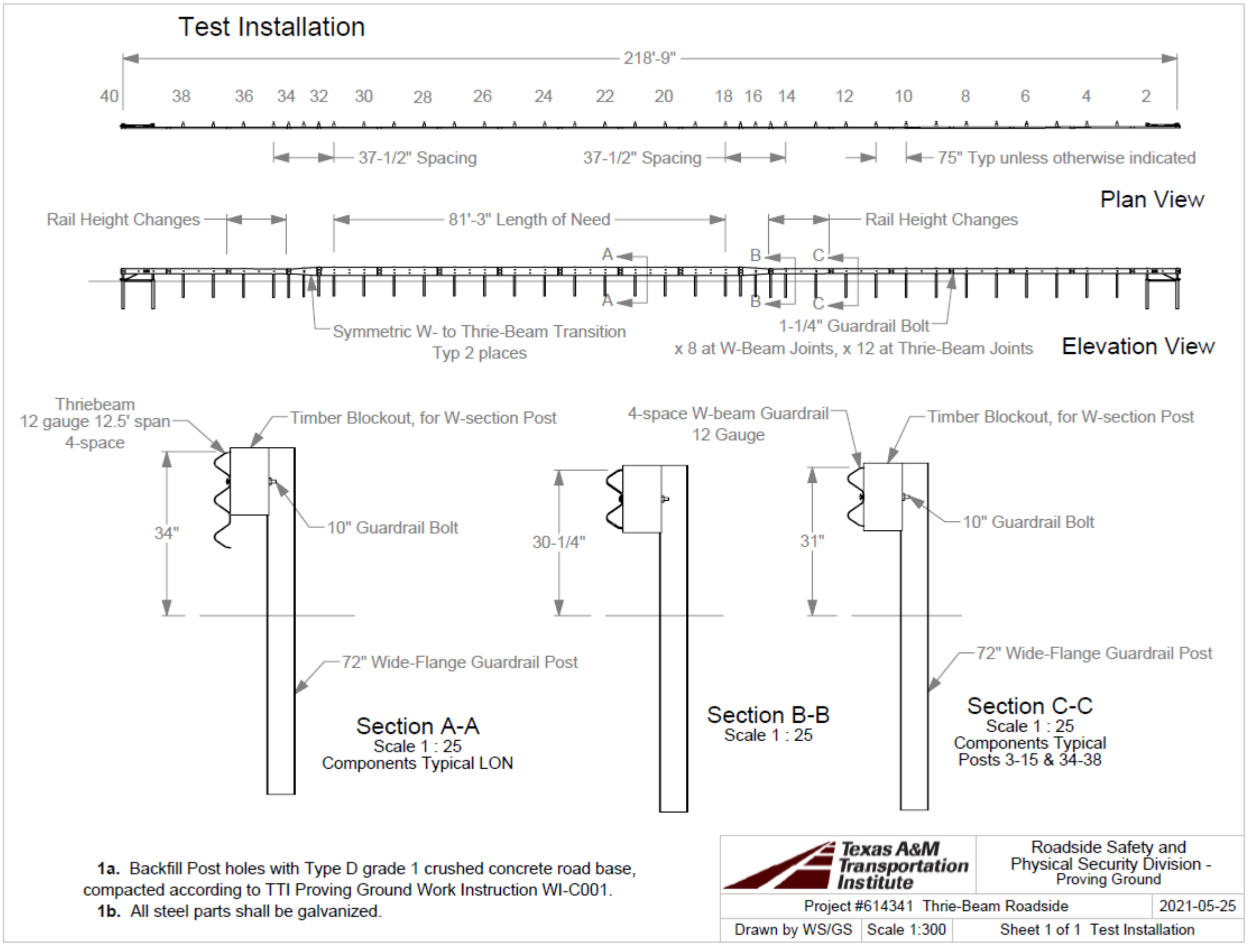


Figure 3.1. Plan View and Elevation View of Roadside TGS Installation.

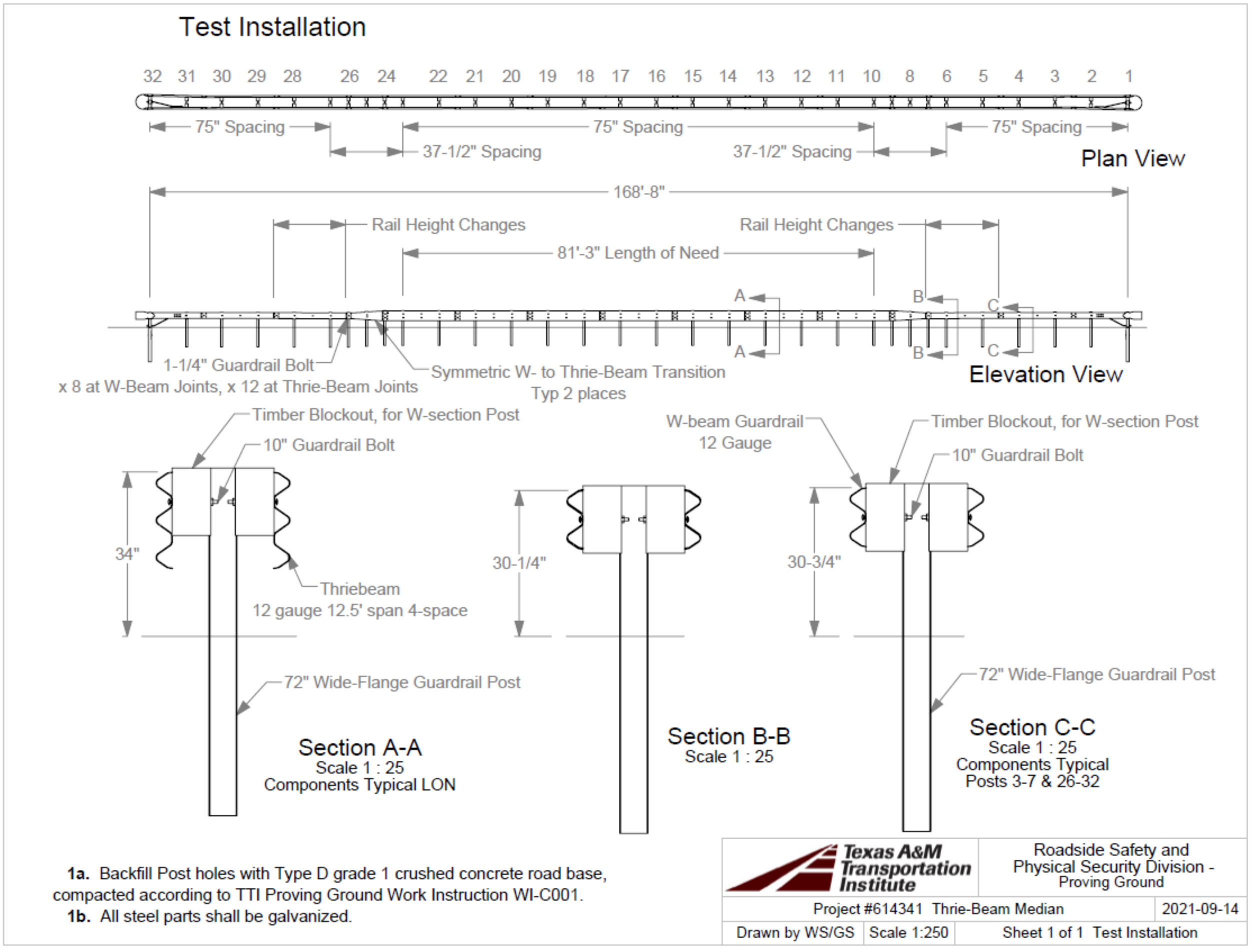


Figure 3.2. Plan View and Elevation View of Median TGS Installation.

3.3 DETAILED MODELING

Explicit finite element models of the systems were created using detailed geometrical and material properties. Figure 3.3 to Figure 3.6 show various views and specifications of the modeled systems. The figures show the utilization of 14-inch tall blockouts throughout the systems. Figure 3.7 shows views of the *MASH* 1100C and 2270P vehicle models used in the computer simulations (*14*).

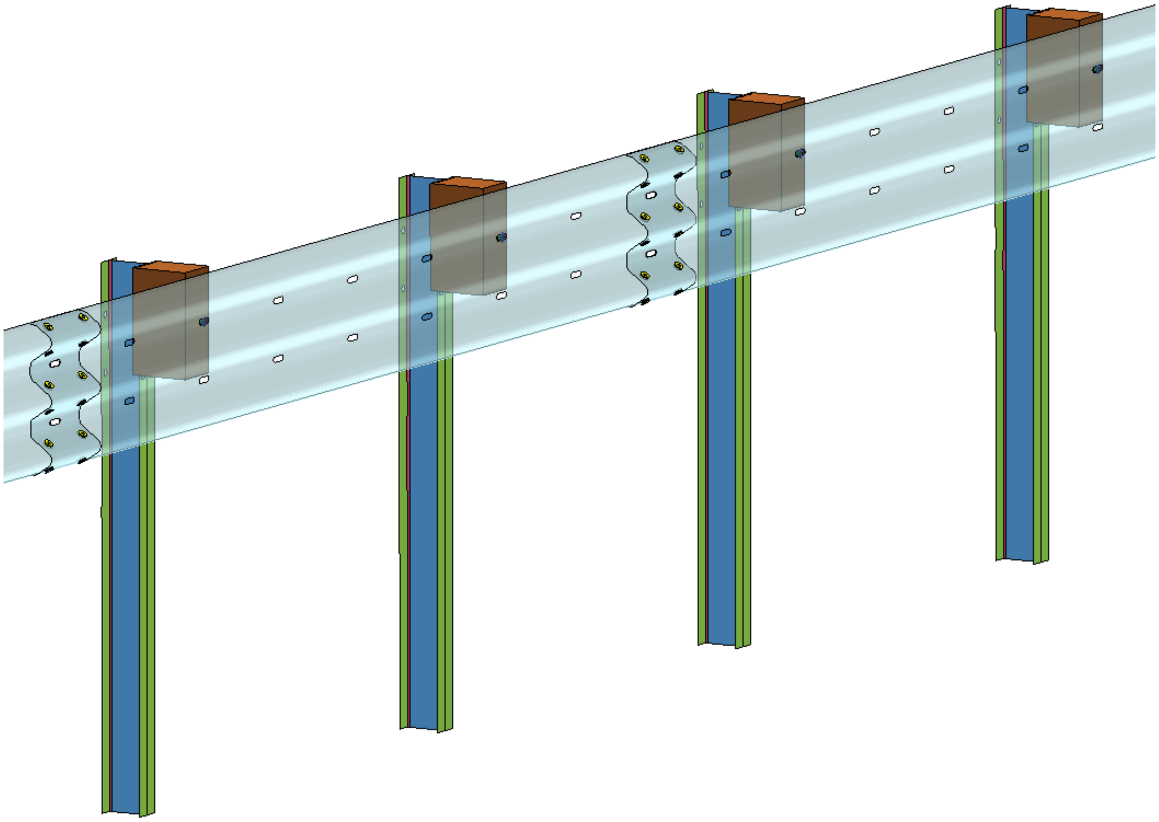


Figure 3.3. Roadside TGS Length-of-Need (LON) model.

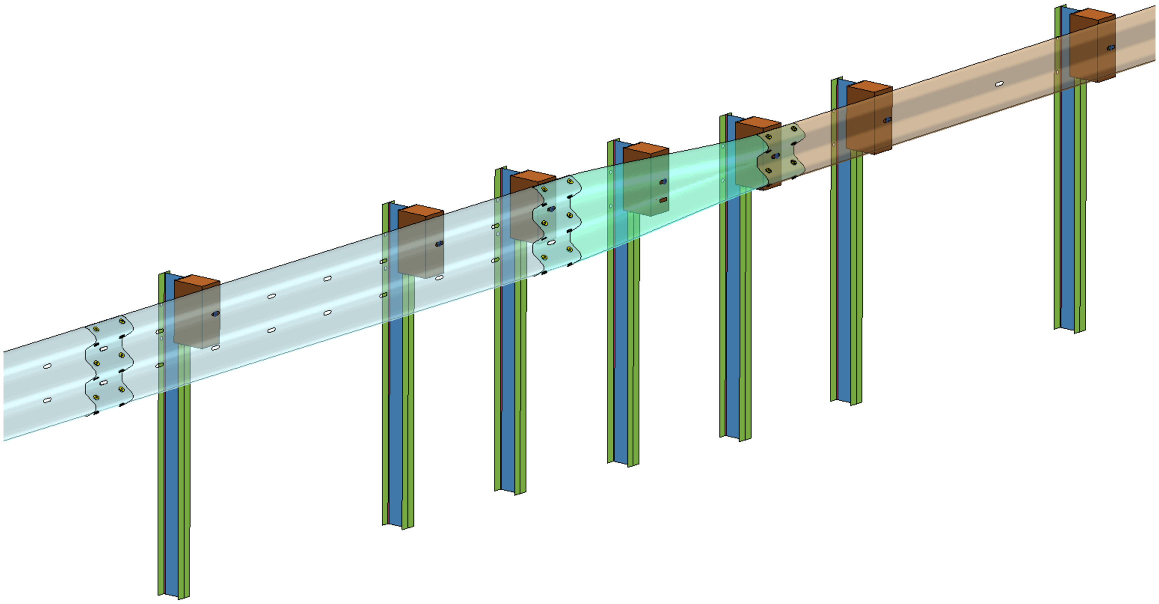


Figure 3.4. Roadside TGS Transition model.

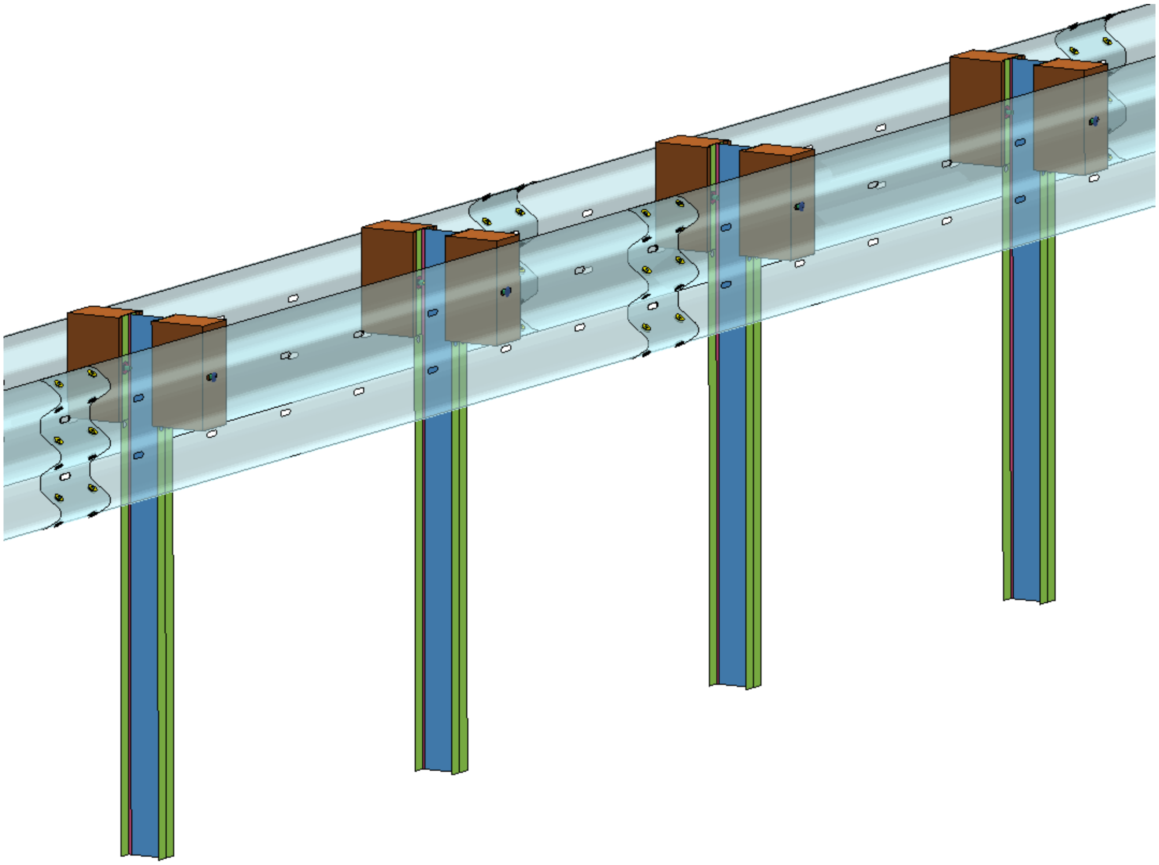


Figure 3.5. Median TGS LON model.

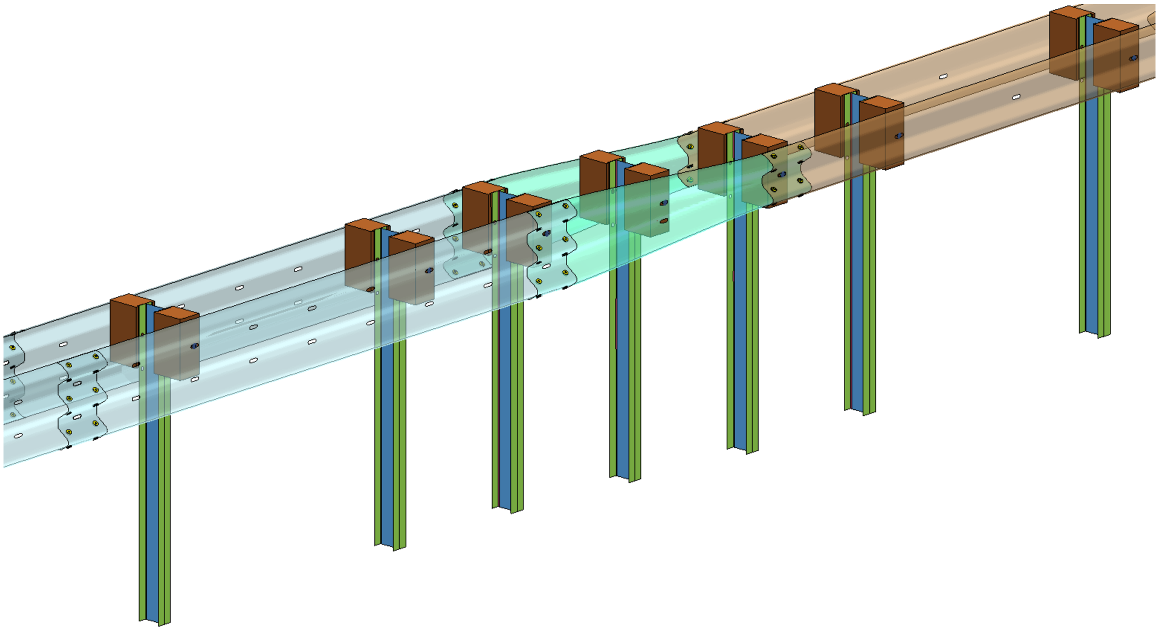
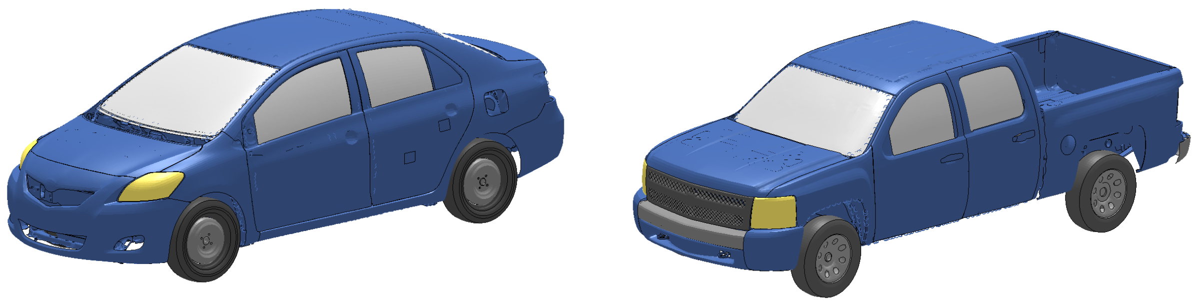


Figure 3.6. Median TGS Transition model.



(a) (b)

Figure 3.7. MASH Test Vehicle Models; (a) 1100C; (b) 2270P.

3.4 SIMULATION

All impact simulations on each roadside and median TGS were performed under *MASH* TL-3 impact conditions presented in Table 3.1. The research team performed an extensive parametric analysis to investigate the systems and impacting vehicles performance at various impact points. Table 3.2 lists the evaluation criteria. The simulation procedure and the results are presented below.

Table 3.1. Test Conditions and Required Evaluation Criteria for MASH TL-3.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barriers	3-10	1100C	62 mi/h	25°	A, D, F, H, I
	3-11	2270P	62 mi/h	25°	A, D, F, H, I
Transitions	3-20	1100C	62 mi/h	25°	A, D, F, H, I
	3-21	2270P	62 mi/h	25°	A, D, F, H, I

Table 3.2. Evaluation Criteria for Transitions According to *MASH* TL-3.

Evaluation Factors		Evaluation Criteria
Structural Adequacy	*A.*	*Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*
Occupant Risk	*D.*	*Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*
	F.	*The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*
	H.	*Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*
	I.	*The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*

3.4.1 Length-of-Need

The reason for the failure of the modified G9 Thrie-beam guardrail system under MASH was vehicle rollover. Thus, the modified G9 system was modeled to provide a baseline model for validation (Figure 3.8) and was redesigned to develop a crashworthy system through computer simulation.

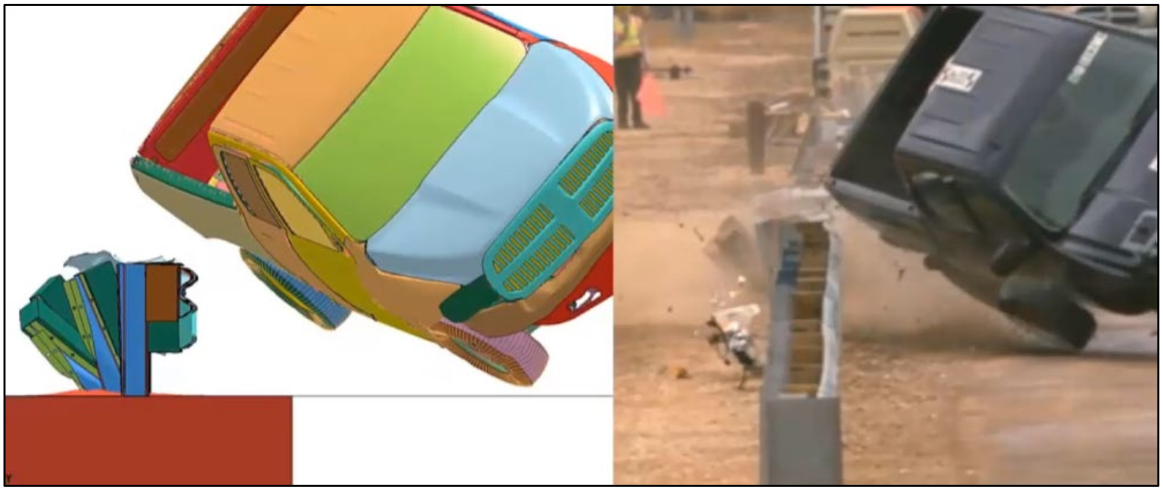


Figure 3.8. G9 System Simulation Vs. Crash Test.

Various design concepts were simulated, including different blockout heights and rail mounting heights. It was concluded that the primary cause of the vehicle rollover was the interaction of the front impact side tire with the bottom of the 22” tall Thrie-beam blockout. Figure 3.9 illustrates the tire position upon impact for the G9 system and TGS. Shorter blockouts (14-inch-tall W-beam blockouts) behind the Thrie-beam allows the bottom of the Thrie-beam to bend inward upon impact, which reduces the possibility of climb and excessive roll angle that may cause vehicle rollover *(15).*

Figure 3.10 shows how the redesigned system improves vehicle stability during and after impact. The roadside and median versions of the redesigned system were evaluated for structural adequacy, vehicle stability, and occupant risk factors. Extensive computer simulation indicated that the system performs acceptably for all *MASH* criteria for TL-3 impact conditions. Figure 3.11 shows the vehicle’s stability after impact for both roadside and median versions.

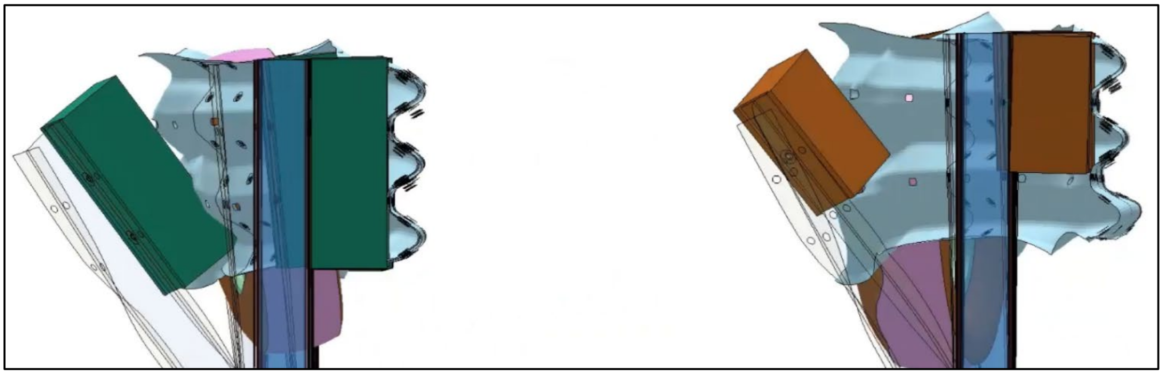


Figure 3.9. Vehicle Tire Position during impact to the G9 system (left) vs. the TGS (right).

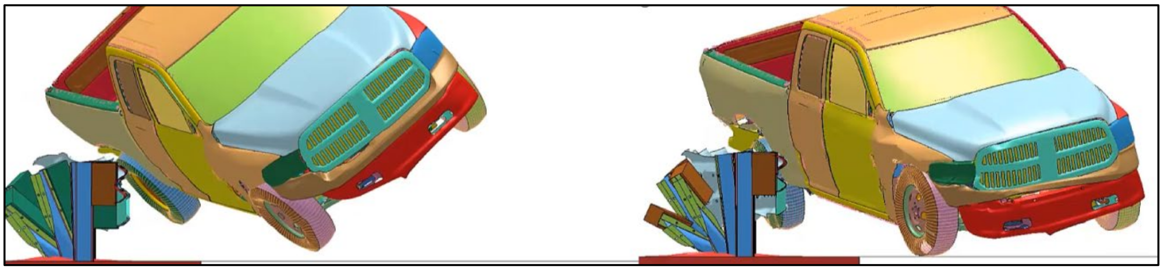


Figure 3.10. Pickup truck stability comparison between the G9 system (left) vs. the TGS (right).

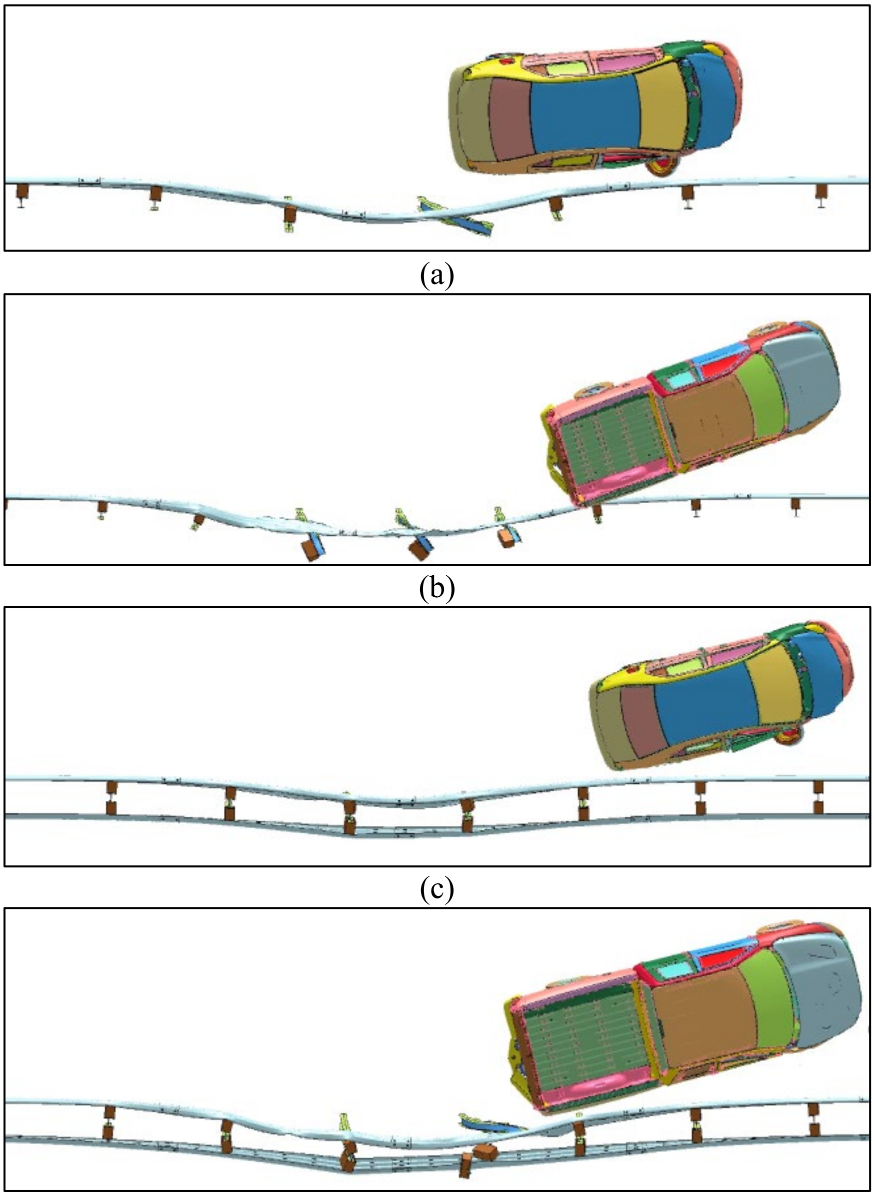
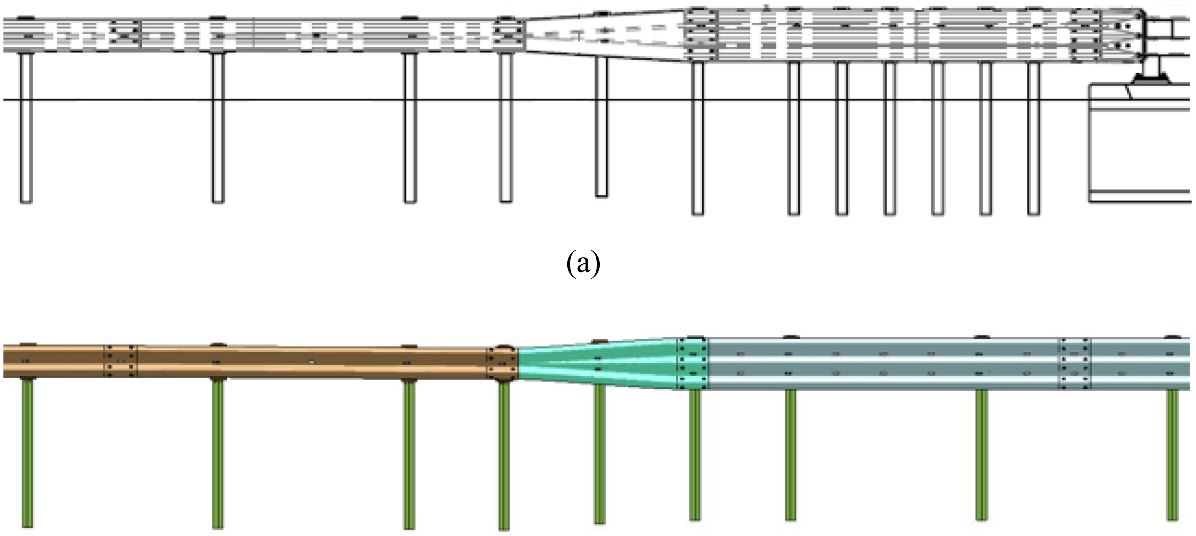

(a)
(b)
(c)
(d)

Figure 3.11. Vehicle stability after impact on LON: (a) Small car on Roadside TGS; (b) Pickup truck on Roadside TGS; (c) Small car on Median TGS; (d) Pickup truck on Median TGS

3.4.2 Transition

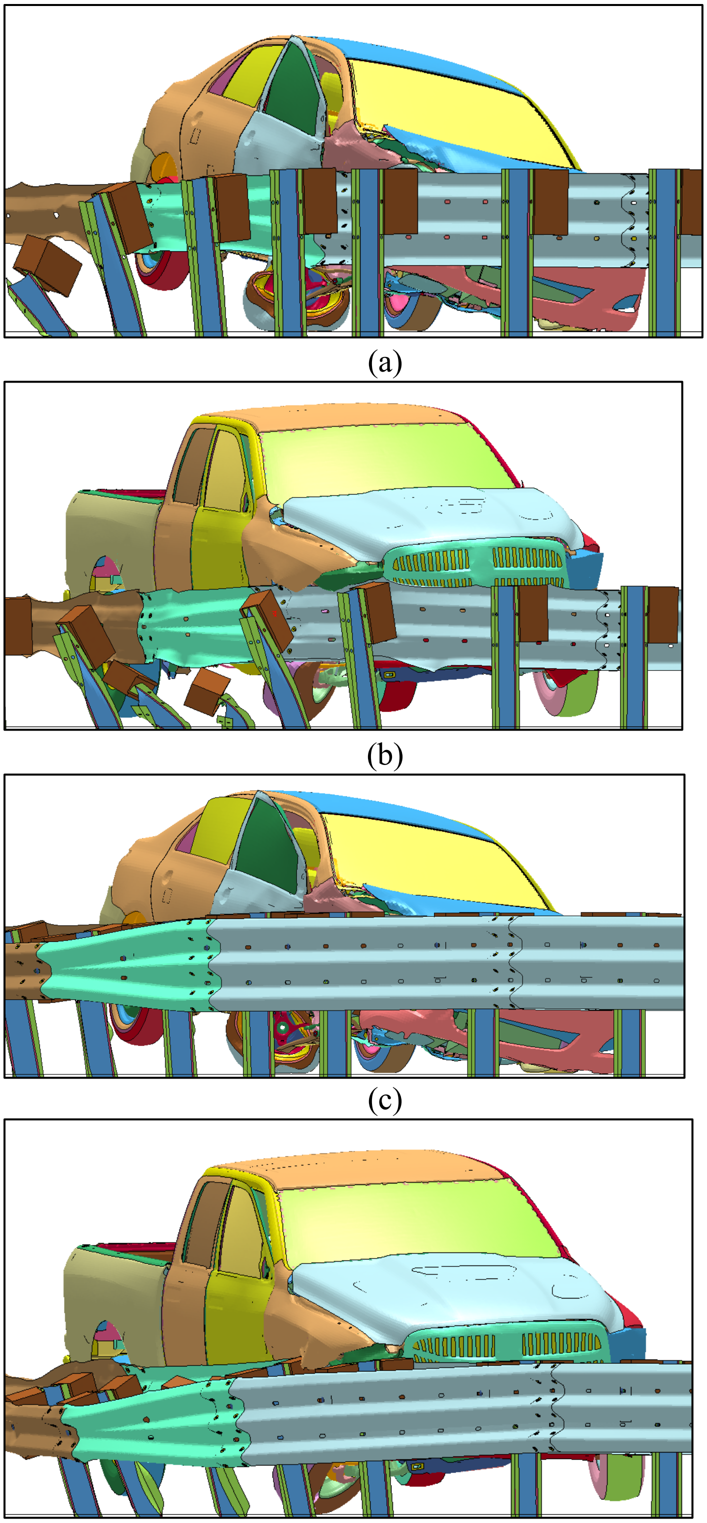
The transition design concept was developed based on the Alaska transition design that was successfully crash tested by TTI researchers in 2019 *(12)*. Figure 3.12 shows the *MASH* TL-3 compliant Alaska transition and the proposed TGS to MGS transition concept. The proposed transition concept has a different downstream stiffness and utilizes wood (W-beam) blockouts instead of steel tube blockouts. Computer simulation showed that the small car tire snagging did not cause any vehicle instability or excessive occupant risk. Thus, it is decided that test designation number 3-21 would be conducted to evaluate the structural adequacy of the roadside version of the transition. Figure 3.13 illustrates the vehicles' stability and tire-post interactions.



(a)

(b)

Figure 3.12. (a) Alaska Transition Design, (b) Proposed TGS to MGS transition concept.



(a)

(b)

(c)

(d)

Figure 3.13. Vehicle Stability after Impact on Transition: (a) Small Car on Roadside TGS; (b) Pickup Truck on Roadside TGS; (c) Small Car on Median TGS; (d) Pickup Truck on Median TGS

3.5 SUMMARY AND CONCLUSIONS FROM COMPUTER SIMULATION

Considering that both roadside and median TGS and their transitions needed to be evaluated, TTI researchers proposed to run test designation numbers 3-10, 3-11, and 3-21 on the critical configuration of the barriers. Test 3-10 was proposed to be conducted on the median version since higher stiffness of the median version would increase impact load and occupant risk values. Conversely, test 3-11 was proposed to be conducted on the roadside version to evaluate the structural integrity of the system as well as maximum dynamic deflection and working width values. Previous evaluations of the T-39 Thrie-beam barrier and the Modified Thrie-beam system for both roadside and median versions followed a similar methodology which agrees with the simulation results presented herein *(9, 16)*. Computer simulation indicated that test designation number 3-21 on the roadside version was the most critical transition test to evaluate the system's structural adequacy. The tire snagging for the small car was not causing any issues concerning vehicle stability and occupant risks. Therefore, TTI researchers determined that *MASH* Test 3-20 on the transition was not necessary and was not performed.

Table 3.3 shows the critical impact points for the three crash tests. The LON distances are from a post downstream of a rail splice location and the transition CIP is from the upstream end of the W-beam-to-thrie-beam transition segment.

Table 3.3 Critical Impact Points According to Computer Simulations.

Crash Test Matrix				
System		**Vehicle**	**Test No.**	**CIP (ft)**
LON	**Roadside TGS**	**Pickup Truck**	3-11	13.25
	Median TGS	**Small Car**	3-10	9.33
Transition	**Roadside TGS**	**Pickup Truck**	3-21	7.33

CHAPTER 4 TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 CRASH TEST PERFORMED/MATRIX

Table 4.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for longitudinal barriers and transitions. 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 and they were verified using computer simulation. Figure 4.1 and Figure 4.2 show the target CIP for *MASH* Tests 3-11 and 3-21 on the roadside Thrie-beam system, respectively, and Figure 4.3 shows the target CIP for *MASH* Test 3-10 on the median Thrie-beam system.

Table 4.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Longitudinal Barriers and Transitions.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barriers	3-10	1100C	62 mi/h	25°	A, D, F, H, I
	3-11	2270P	62 mi/h	25°	A, D, F, H, I
Transitions	3-20	1100C	62 mi/h	25°	A, D, F, H, I
	3-21	2270P	62 mi/h	25°	A, D, F, H, I

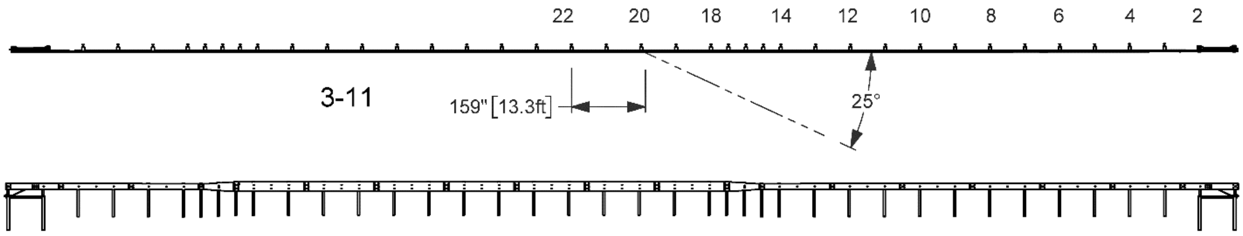


Figure 4.1. Target CIP for *MASH* Test 3-11 on Roadside Thrie-beam System.

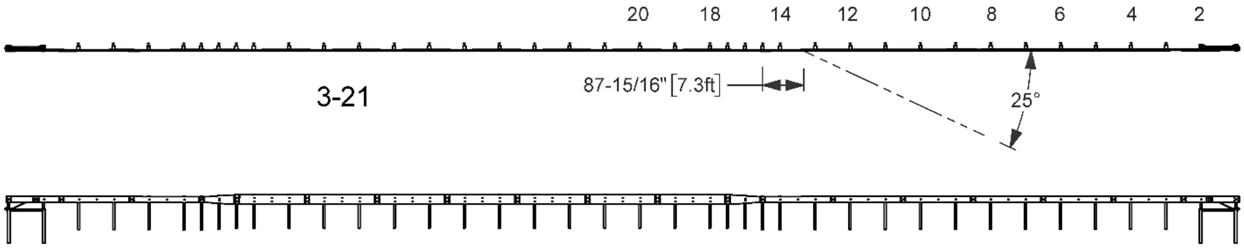


Figure 4.2. Target CIP for *MASH* Test 3-21 on Roadside W-beam to Thrie-beam Transition System.

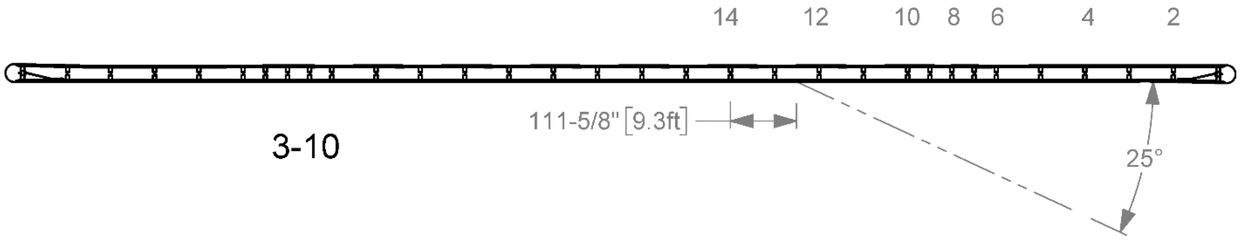


Figure 4.3. Target CIP for *MASH* Test 3-10 on Median Thrie-beam System.

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

4.2 EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. Table 4.1. lists the test conditions and evaluation criteria required for *MASH* TL-3, and Table 4.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 8.

MASH Test 3-11 was conducted on the roadside version to evaluate the structural adequacy of the system and to record the maximum dynamic deflection of the system. *MASH* Test 3-10 was conducted on the median configuration to evaluate the possible vehicle tire snagging as well as higher occupant risk factors due to the higher stiffness and reduced dynamic deflection. Computer simulation indicated that the small car tire snagging is not an issue for the transition system of roadside and median configurations. Thus, *MASH* Test 3-20 on the transition was not necessary and was not performed.

Table 4.2. Evaluation Criteria Required for *MASH* TL-3 Longitudinal Barriers and Transitions.

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, 3-11, 3-20, and 3-21*
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, 3-11, 3-20, and 3-21*
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	*3-10, 3-11, 3-20, and 3-21*
	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, 3-11, 3-20, and 3-21*
	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, 3-11, 3-20, and 3-21*

CHAPTER 5 TEST CONDITIONS

5.1 TEST FACILITY

The full-scale crash tests reported herein were performed at the TTI Proving Ground, an International Standards Organization (ISO)/International Electrotechnical Commission (IEC) 17025-accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing Certificate 2821.01. The full-scale crash tests were performed according to TTI Proving Ground quality procedures, as well as *MASH* guidelines and standards.
The test facilities of the TTI Proving Ground are located on The Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 mi northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, highway pavement durability and efficacy, and roadside safety hardware and perimeter protective device evaluation. The site selected for construction and testing of the Thrie-beam systems was along the edge of an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement but are otherwise flat and level.

5.1 VEHICLE TOW AND GUIDANCE SYSTEM

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

5.2 DATA ACQUISITION SYSTEMS

5.2.1 Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained onboard data acquisition system. The signal conditioning and acquisition system is a multi-channel data acquisition system (DAS) 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 data acquisition hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each channel 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 a pressure tape switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the DAS 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 DAS 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 DAS-captured data to compute the occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with an SAE Class 180-Hz low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

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

5.2.2 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.

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 roadside Thrie-beam system was 34 inches, a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

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

CHAPTER 6 *MASH* TESTING OF ROADSIDE THRIE-BEAM SYSTEM

6.1. SYSTEM DETAILS

6.1.1. Test Article and Installation Details

The installation consisted of an 81 ft-3-inch Thrie-beam length-of-need (LON) that transitioned on both ends to a standard W-beam rail for a total installation length of 218 ft-9 inches. Standard 72-inch long W6x8.5 guardrail posts and W-beam standard blockouts (6x8x14 in.) were used throughout the installation. The top of the Thrie-beam was located 34 inches above the roadway. The W-beam height beyond the thrie-beam-to-W-beam transitions was 31 inches. Post spacing was 75 inches, except in the transition sections where it was 37½ inches. Each end of the installation was terminated with a steel post end terminal.

Figure 6.1 presents overall information on the roadside Thrie-beam system, and Figure 6.2 provides photographs of the installation. Appendix A provides further details on the roadside Thrie-beam system. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by DMA Construction Inc. and supervised TTI Proving Ground personnel.

6.1.2. Design Modifications during Tests

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

6.1.3. Material Specifications

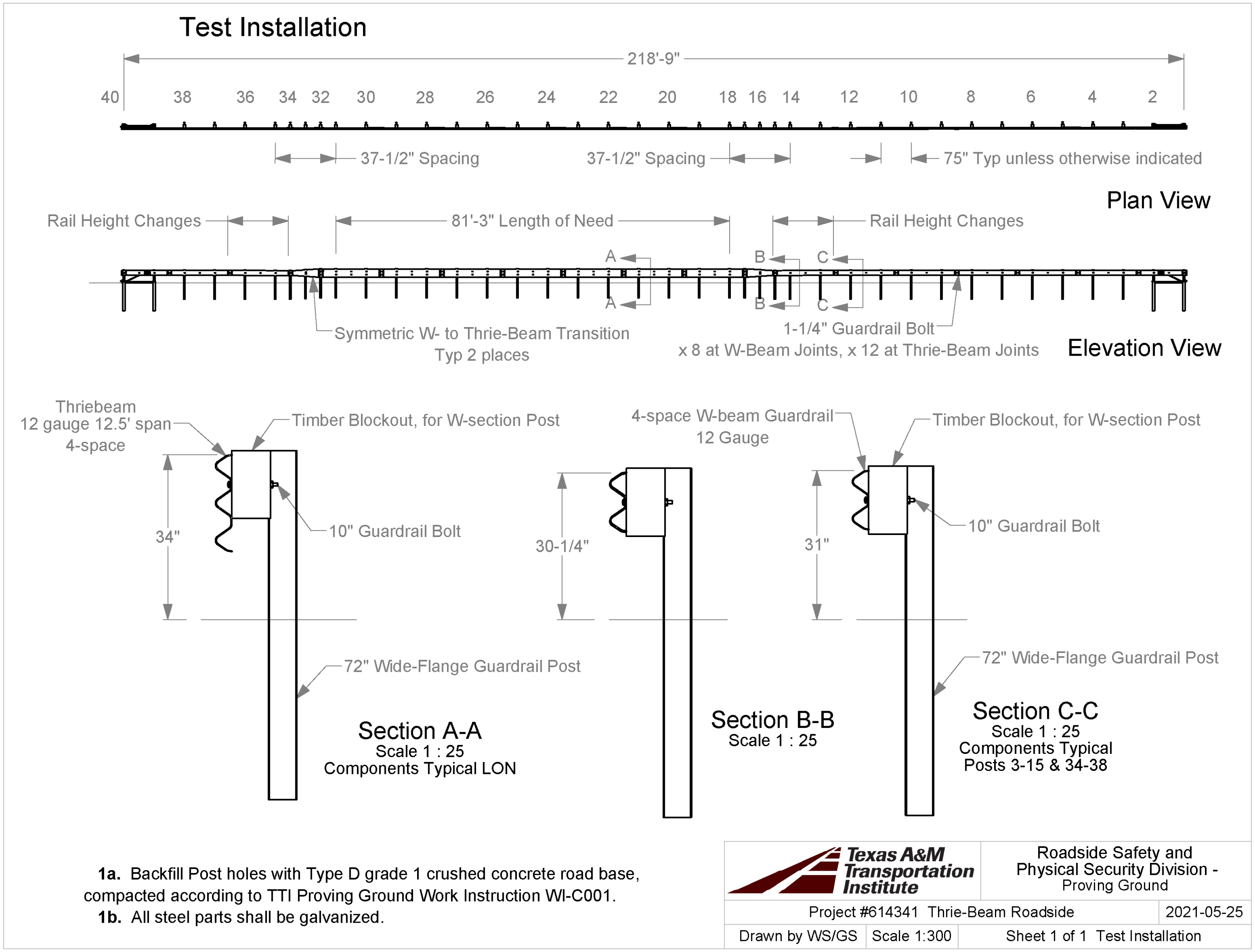
Appendix B provides material certification documents for the materials used to install/construct the roadside Thrie-beam system.

6.1.4. Soil Conditions

The test installation was installed in crushed concrete meeting grading D of AASHTO standard specification M147-17 “Materials for Aggregate and Soil-Aggregate Subbase, Base, and Surface Courses.”

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the roadside Thrie-beam system for full-scale crash testing, two 6-ft long W6×16 posts were installed in the immediate vicinity of the roadside Thrie-beam system using the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table C.1 in Appendix C presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B. As determined by the tests summarized in Appendix C, Table C.1, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 4420 lbf, 4981 lbf, and 5282 lbf (90 percent of static load for the initial standard installation).

On the day of Test No. 614341-01-1, August 16, 2021, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 8454 lbf, 8878 lbf, and 9090 lbf. Table C.2 in Appendix C shows the strength of the backfill material in which the roadside Thrie-beam system was installed met minimum *MASH* requirements for soil strength.



1a. Backfill Post holes with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.

1b. All steel parts shall be galvanized.

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project #614341 Thrie-Beam Roadside	2021-05-25
Drawn by WS/GS	Scale 1:300	Sheet 1 of 1 Test Installation

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Figure 6.1. Details of Roadside Thrie-beam System.

Figure 6.2. Roadside Thrie-beam System prior to Testing.

On the day of Test No. 614341-01-3, August 20, 2021, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 7727 lbf, 8665 lbf, and 8575 lbf. Table C.3 in Appendix C shows the strength of the backfill material in which the roadside Thrie-beam system was installed met minimum *MASH* requirements for soil strength.

6.1 *MASH* TEST 3-11 (CRASH TEST NO. 614341-01-1)

6.1.1 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 roadside Thrie-beam system was 13.3 ft ± 1 ft upstream of the centerline of post 22. Figure 4.1 and Figure 6.3 depict the target impact setup.

Figure 6.3. Roadside Thrie-beam System/Test Vehicle Geometrics for Test No. 614341-01-1.

The 2270P vehicle weighed 5057 lb, and the actual impact speed and angle were 60.4 mi/h and 25.9 degrees. The actual impact point was 13.6 ft upstream of the centerline of post 22. Minimum target IS was 106 kip-ft, and actual IS was 118 kip-ft.

6.1.2 Weather Conditions

The test was performed on the morning of August 16, 2021. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h; wind direction: 187 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 86°F; relative humidity: 73 percent.

6.1.3 Test Vehicle

Figure 6.4 shows the 2015 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5057 lb, and its gross static weight was 5222 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and the height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.75 inches. Tables D.1 and D.2 in Appendix D.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.4. Test Vehicle before Test No. 614341-01-1.

6.1.4 Test Description

Table 6.1 lists events that occurred during Test No. 614341-01-1. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 6.1. Events during Test No. 614341-01-1.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0175	Post 20 began to deflect toward field side
0.2060	Right rear corner of vehicle contacted installation
0.2810	Vehicle traveling parallel with installation

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 4.1 s after impact, and the vehicle subsequently came to rest 225 ft downstream of the point of impact and 33 ft toward traffic lanes.

6.1.5 Damage to Test Installation

Figure 6.5 shows the damage to the roadside Thrie-beam system. The rail released from posts 13, 21, 22 and 23. Posts 13 and 24 through 30 were rotated counterclockwise, while posts 3 through 12 and 14 through 20 were rotated clockwise. The blockouts were missing from posts 21 through 23. The blockout for post 21 came to rest 19 ft towards the field side and was in-line with the midspan between posts 22 and 23. The blockout for post 22 came to rest 36 ft towards the field side and was in-line with the midspan between posts 23 and 24. The blockout for post 23 came to rest 2 ft towards the field side and was in-line with the centerline of post 26.
Table 6.2 shows post movements after the test.

Working width* was 55.2 inches, and height of working width was 60.4 inches. Maximum dynamic deflection during the test was 42.1 inches, and maximum permanent deformation was 26.9 inches.

Figure 6.5. Roadside Thrie-beam System after Test No. 614341-01-1.

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

Table 6.2. Post Movements after Test No. 614341-01-1.

Post No.	Lean from Vertical		Soil Gap (inches)			
	F/S	D/S	U/S	D/S	T/S	F/S
1	-	-	½	¾	-	-
2	-	-	-	½	-	-
21	5°	70°	-	-	-	-
22	5°	70°	-	-	-	-
23	5°	70°	-	-	-	-
19	4°	-	-	-		¾
20	11°	-	-	-	3½	2
24	4°	-	-	-	-	1
25	1°	-	-	-	⅛	
40	-	-	-	¼	-	-

F/S=Field Side; D/S=Downstream; U/S=Upstream; T/S=Traffic Side

6.1.6 Damage to Test Vehicle

Figure 6.6 shows the damage sustained by the vehicle. The front bumper, grill, right front tire and rim, fight front fender, right front and rear doors, right rear lower cab corner, right rear exterior bed, and rear bumper were damaged. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 8.0 inches in the front plane at the right front corner at bumper height. No occupant compartment deformation or intrusion was observed. Figure 6.7 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 6.6. Test Vehicle after Test No. 614341-01-1.

Figure 6.7. Interior of Test Vehicle after Test No. 614341-01-1.

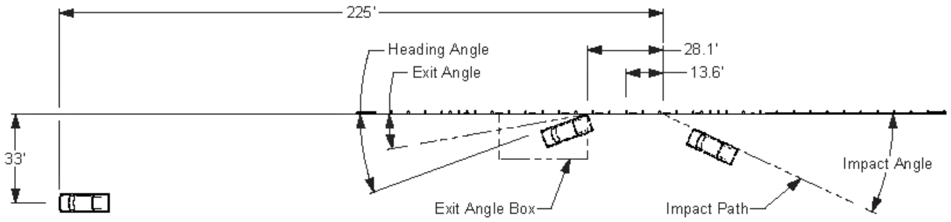
6.1.7 Occupant Risk Factors

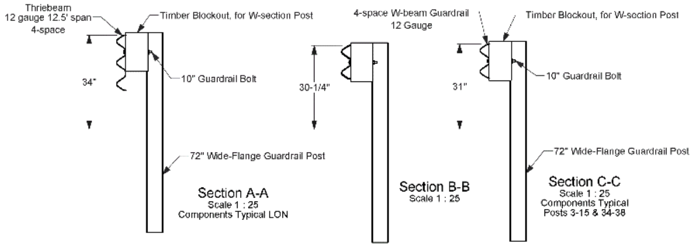
Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.3. Figure D.3 in Appendix D.3 shows the vehicle angular displacements, and Figures D.4 through D.6 in Appendix D.4 show acceleration versus time traces. Figure 6.8 summarizes pertinent information from the test.

Table 6.3. Occupant Risk Factors for Test No. 614341-01-1.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	16.8 ft/s	at 0.1549 s on right side of interior
Lateral	15.5 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	5.9 g	0.17–1 - 0.1861 s
Lateral	8.6 g	0.17–7 - 0.1887 s
THIV	6.4 m/s	at 0.1476 s on right side of interior
ASI	0.8	0.2686 - 0.3186 s
Maximum 50-ms Moving Average		
Longitudinal	−4.9 g	0.0874 - 0.1374s
Lateral	−6.9 g	0.2411 - 0.2911s
Vertical	−2.6 g	0.6744 - 0.7244s
Maximum Yaw, Pitch, and Roll Angles		
Roll	5.8°	0.3251 s
Pitch	4.1°	1.1686 s
Yaw	47.5°	0.7698 s

0.000 s | 0.200 s | 0.400 s | 0.600 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-11
TTI Test No.	614341-01-1
Test Date	2021-08-16
Test Article	
Type	Longitudinal Barrier—Guardrail
Name	Roadside Thrie-beam System
Installation Length	218 ft-9 inches
Material or Key Elements	Thrie-beam LON transitioned to W-beam rail
Soil Type and Condition	Grading D of AASHTO M147-17 (Crushed Concrete), Dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2015 RAM 1500 Pickup
Curb	5100 lb
Test Inertial	5057 lb
Dummy	165 lb
Gross Static	5222 lb

Impact Conditions	
Speed	60.4 mi/h
Angle	25.9°
Location/Orientation	13.6 ft upstream of post 22
Impact Severity	118 kip-ft
Exit Conditions	
Speed	Overhead Camera
Trajectory/Heading Angle	Failed
Occupant Risk Values	
Longitudinal OIV	16.8 ft/s
Lateral OIV	15.5 ft/s
Longitudinal Ridedown	5.9 g
Lateral Ridedown	8.6 g
THIV	6.4 m/s
ASI	0.8
Max. 0.050-s Average	
Longitudinal	−4.9 g
Lateral	−6.9 g
Vertical	−2.6 g

Post-Impact Trajectory	
Stopping Distance	225 ft downstream 33 ft twd traffic
Vehicle Stability	
Maximum Roll Angle	6°
Maximum Pitch Angle	4°
Maximum Yaw Angle	48°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	42.1 inches
Permanent	26.9 inches
Working Width	55.2 inches
Height of Working Width	60.4 inches
Vehicle Damage	
VDS	01RFQ2
CDC	01FREW2
Max. Exterior Deformation	8.0 inches
OCDI	RF0000000
Max. Occupant Compartment Deformation	None

Figure 6.8. Summary of Results for *MASH* Test 3-11 on Roadside TGS.

6.2 *MASH* TEST 3-21 (CRASH TEST NO. 614341-01-3)

6.2.1 Test Designation and Actual Impact Conditions

MASH Test 321 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the CIP of the transition 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 3-21 on the roadside Thrie-beam transition system was 7.3 ft ± 1 ft upstream of the centerline of post 15 where the symmetric transition piece connects to the W-beam system. Figure 4.2 and Figure 6.9 depict the target impact setup.

Figure 6.9. Roadside Thrie-beam System/Test Vehicle Geometrics for Test No. 614341-01-3.

The 2270P vehicle weighed 5019 lb, and the actual impact speed and angle were 61.5 mi/h and 25.3 degrees. The actual impact point was 7.5 ft upstream of the centerline of post 15. Minimum target IS was 106 kip-ft, and actual IS was 116 kip-ft.

6.2.2 Weather Conditions

The test was performed on the morning of August 20, 2021. Weather conditions at the time of testing were as follows: wind speed: 12 mi/h; wind direction: 202 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 87°F; relative humidity: 77 percent.

6.2.3 Test Vehicle

Figure 6.10 shows the 2015 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5019 lb, and its gross static weight was 5184 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and the height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.5 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 6.10. Test Vehicle before Test No. 614341-01-3.

6.2.4 Test Description

Table 6.4 lists events that occurred during Test No. 614341-01-3. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 6.4. Events during Test No. 614341-01-3.

Time (s)	Events
0.0000	Vehicle impacted installation
0.0050	Post 13 began to deflect towards the field side
0.0075	Post 14 began to deflect towards field side
0.0150	Post 15 began to deflect towards field side
0.0370	Vehicle began to redirect
0.0488	Post 16 began to deflect towards field side
0.2200	Back bumper contacted bottom rail
0.2900	Vehicle traveling parallel with installation
0.6070	Vehicle lost contact with the installation while traveling at an exit speed of 30.6 mi/h, exit trajectory angle of 18.1°, and exit heading angle of 11.3°

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 2.5 s after impact, and the vehicle subsequently came to rest 156 ft downstream of the point of impact and 12 ft toward field side.

6.2.5 Damage to Test Installation

Figure 6.11 shows the damage to the roadside Thrie-beam system. The rail released from posts 14 through 18, and the blockouts were missing from posts 14 through 17. Posts 3 through 12 were rotated clockwise, and post 18 was rotated counterclockwise. Posts 16 and 17 were pulled out of the soil completely. There was no movement noted for posts 21 through 40. Table 6.5 shows post movements after the test.

Working width* was 66.2 inches, and height of working width was 18.5 inches. Maximum dynamic deflection during the test was 38.9 inches, and maximum permanent deformation was 27.3 inches.

Figure 6.11. Roadside Thrie-beam after Test No. 614341-01-3.

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

Table 6.5. Post Movements after Test No. 614341-01-3.

	Lean from Vertical	Soil Gap (inches)			
Posts	F/S	U/S	D/S	T/S	F/S
1	-	⅝	-	-	-
2	-	-	¼	-	-
12	<1°	-	-	⅛	⅛
13	4°	-	-	1½	1½
14	53°	-	-	-	-
15	74°	-	-	-	-
18	31°	-	-	-	-
19	12°	-	-	4	2
20	2°	-	-	¾	⅛

F/S=Field Side; D/S=Downstream; U/S=Upstream; T/S=Traffic Side

6.2.6 Damage to Test Vehicle

Figure 6.12 shows the damage sustained by the vehicle. The right front bumper, grill, right front tire and rim, right front fender, and right door were damaged. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 17.0 inches in the side plane at the right front corner at bumper height. No occupant compartment deformation or intrusion was observed. Figure 6.13 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 6.12. Test Vehicle after Test No. 614341-01-3.

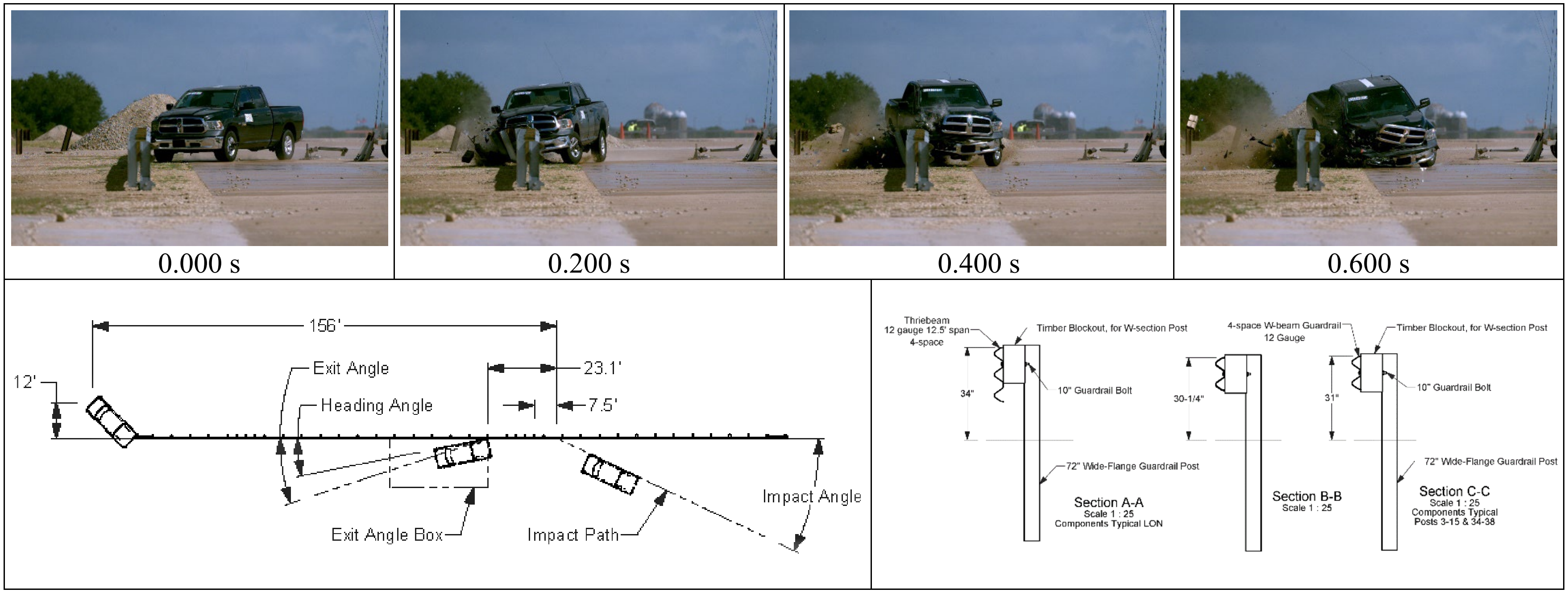
Figure 6.13. Interior of Test Vehicle after Test No. 614341-01-3.

6.2.7 Occupant Risk Factors

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.6. 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 6.14 summarizes pertinent information from the test.

Table 6.6. Occupant Risk Factors for Test No. 614341-01-3.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	18.9 ft/s	at 0.1549 s on right side of interior
Lateral	14.3 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	13.6 g	0.17–1 - 0.1861 s
Lateral	10.0 g	0.17–7 - 0.1887 s
THIV	6.8 m/s	at 0.1476 s on right side of interior
ASI	0.8	0.18–0 - 0.2310 s
Maximum 50-ms Moving Average		
Longitudinal	−7.4 g	0.17–6 - 0.2206 s
Lateral	−5.7 g	0.15–7 - 0.2077 s
Vertical	−2.6 g	1.64–9 - 1.6939 s
Maximum Yaw, Pitch, and Roll Angles		
Roll	15°	0.8129 s
Pitch	11°	0.5966 s
Yaw	37°	0.5158 s



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-21
TTI Test No.	614341-01-3
Test Date	2021-08-20
Test Article	
Type	Longitudinal Barrier—Guardrail
Name	Roadside Thrie-beam System
Installation Length	218 ft-9 inches
Material or Key Elements	Thrie-beam LON transitioned to W-beam rail
Soil Type and Condition	Grading D of AASHTO M147-17 (Crushed Concrete), Dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2015 RAM 1500 Pickup
Curb	5014 lb
Test Inertial	5019 lb
Dummy	165 lb
Gross Static	5184 lb

Impact Conditions	
Speed	61.5 mi/h
Angle	25.3°
Location/Orientation	7.5 ft upstream of post 15
Impact Severity	116 kip-ft
Exit Conditions	
Speed	30.6 mi/h
Trajectory/Heading Angle	18.1°/11.3°
Occupant Risk Values	
Longitudinal OIV	18.9 ft/s
Lateral OIV	14.3 ft/s
Longitudinal Ridedown	13.6 g
Lateral Ridedown	10.0 g
THIV	6.8 m/s
ASI	0.8
Max. 0.050-s Average	
Longitudinal	−7.4 g
Lateral	−5.7 g
Vertical	−2.6 g

Post-Impact Trajectory	
Stopping Distance	156 ft downstream 12 twd field side
Vehicle Stability	
Maximum Roll Angle	15°
Maximum Pitch Angle	11°
Maximum Yaw Angle	37°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	38.9 inches
Permanent	27.3 inches
Working Width	66.2 inches
Height of Working Width	18.5 inches
Vehicle Damage	
VDS	01RFQ4
CDC	01FREW3
Max. Exterior Deformation	17.0 inches
OCDI	RF0000000
Max. Occupant Compartment Deformation	None

Figure 6.14. Summary of Results for *MASH* Test 3-21 on Roadside TGS to W-Beam System Transition.

CHAPTER 7 CRASH TESTING OF MEDIAN THRIE-BEAM SYSTEM

7.1 SYSTEM DETAILS

7.1.1 Test Article and Installation Details

The installation consisted of an 81 ft-3-inch thrie-beam median barrier length-of-need (LON) that transitioned on both ends to a standard W-beam rail for a total installation length of 168 ft-8 inches. Standard 72-inch long W6x8.5guardrail posts and W-beam standard blockouts (6x8x14 in.) were used throughout the installation. The top of the Thrie-beam was located 34 inches above the roadway. Beyond the thrie-beam-to-W-beam transitions, the height of the W-beam median barrier rail was 30¾ inches. Post spacing was 75 inches, except in the transition sections where it was 37½ inches. The rail configuration was mirrored on the field side of the guard rail posts, and each end of the installation was terminated with a median terminal.

Figure 7.1 presents the overall information on the roadside Thrie-beam system, and Figure 7.2 provides photographs of the installation. Appendix F provides further details on the median Thrie-beam system. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by TTI Proving Ground personnel.

7.1.2 Design Modifications during Tests

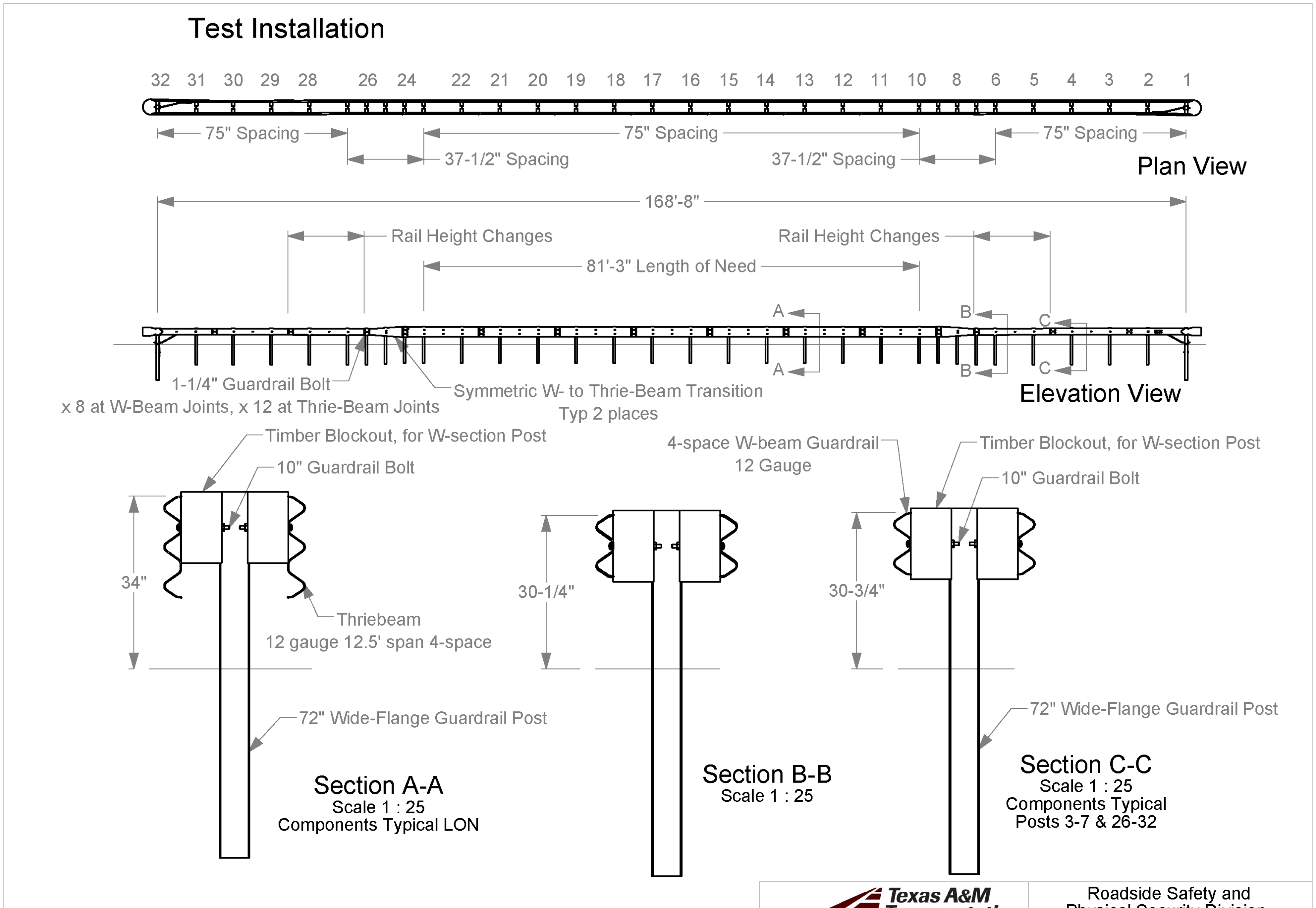
No modification was made to the installation during the testing phase.

7.1.3 Material Specifications

Appendix B provides material certification documents for the materials used to install/construct the median Thrie-beam system.

7.1.4 Soil Conditions

The test installation was installed in crushed concrete meeting grading D of AASHTO standard specification M147-17 “Materials for Aggregate and Soil-Aggregate Subbase, Base, and Surface Courses.” In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the median Thrie-beam system for full-scale crash testing, two 6-ft long W6×16 posts were installed in the immediate vicinity of the median Thrie-beam system using the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table C.1 in Appendix C presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B. As determined by the tests summarized in Appendix C, Table C.1, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 4420 lbf, 4981 lbf, and 5282 lbf (90 percent of static load for the initial standard installation).



1a. Backfill Post holes with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.

1b. All steel parts shall be galvanized.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground
Project #614341 Thrie-Beam Median	2021-04-14
Drawn by WS/GS Scale 1:250	Sheet 1 of 1 Test Installation

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Figure 7.1. Details of Median Thrie-beam System.

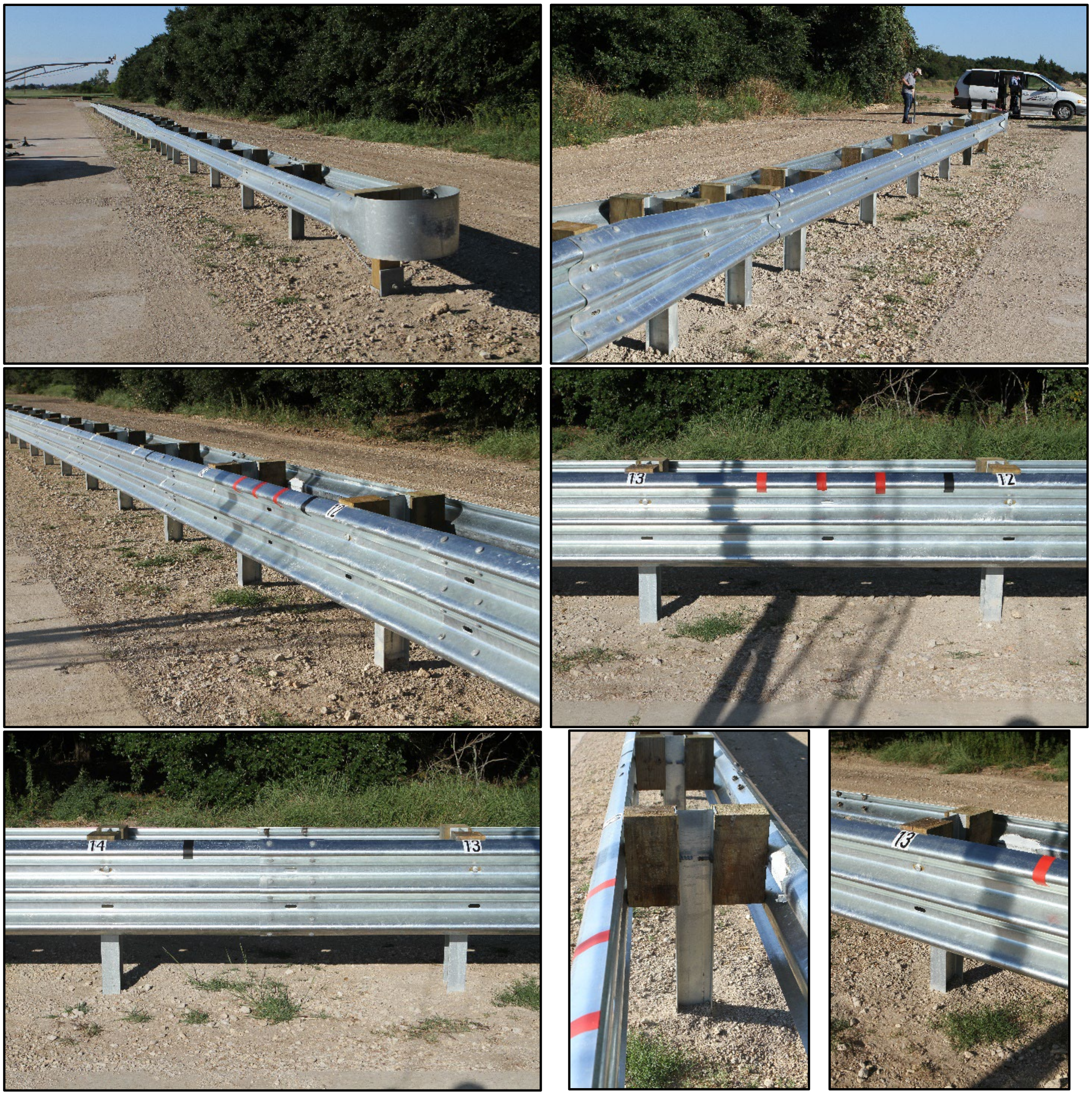

Figure 7.2. Median Thrie-beam System prior to Test No. 614314-01-2.

On the day of Test No. 614341-01-2, September 16, 2021, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 8121 lbf, 8878 lbf, and 9363 lbf. Table C.4 in Appendix C shows the strength of the backfill material in which the median Thrie-beam system was installed met minimum *MASH* requirements for soil strength.

7.2 *MASH* TEST 3-10 (CRASH TEST NO. 614341-01-2)

7.2.1 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 median Thrie-beam system was 9.3 ft ± 1 ft upstream of the center of post 14. Figure 4.3 and Figure 7.3 depict the target impact setup.

Figure 7.3. Median Thrie-beam System/Test Vehicle Geometrics for Test No. 614341-01-2.

The 1100C vehicle weighed 2455 lb, and the actual impact speed and angle were 62.6 mi/h and 25.0 degrees. The actual impact point was 9.0 ft upstream of post 14. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 57 kip-ft.

7.2.2 Weather Conditions

The test was performed on the morning of September 16, 2021. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 50 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 79°F; relative humidity: 78 percent.

7.2.3 Test Vehicle

Figure 7.4 shows the 2015 Nissan Versa used for the crash test. The vehicle's test inertia weight was 2455 lb, and its gross static weight was 2620 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 7.4. Test Vehicle before Test No. 614341-01-2.

7.2.4 Test Description

Table 7.1 lists events that occurred during Test No. 614341-01-2. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 614341-01-2.

Time (s)	Events
0.0000	Vehicle impacted transition
0.0200	Post 13 began to deflect towards the field side
0.0270	Vehicle began to redirect
0.0338	Post 14 began to deflect towards the field side
0.1800	Vehicle traveling parallel with transition
0.3370	Vehicle lost contact with transition while traveling at 42.4 mi/h, trajectory angle of 15.2°, and heading angle of 7.4°

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 4.2 s after impact, and the vehicle subsequently came to rest 275 ft downstream of the point of impact and 42 ft toward traffic lanes.

7.2.5 Damage to Test Installation

Figure 6.5 shows the damage to the median Thrie-beam system. There was no soil disturbance noted from posts 1 through 9 and 16 through 32. The soil was disturbed at post 10, and significantly disturbed, with no measurable gaps at posts 13 and 14 due to the soil caving back into the post hole. Post 14 rotated clockwise and deformed, and the traffic side blockout released from post 14 and rail due to the bolt shearing at the post. The post 14 field side blockout was damaged. The field side rail released from posts 14 through 17, and the traffic side rail released from post 14. Table 7.2 shows post movements after the test. Working width* was 38.9 inches, and height of working width was 32.5 inches. Maximum dynamic deflection during the test was 15.4 inches, and maximum permanent deformation was 8.4 inches.

Figure 7.5. Median Thrie-beam System after Test No. 614341-01-2.

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

Table 7.2. Post Movements after Test No. 614341-01-2.

	Lean from Vertical		Soil Gap (inches)	
Posts	F/S	D/S	T/S	F/S
11	-	-	⅛	1/16
12	1°	-	⅝	¼
13	6°	-	-	-
14	-	22°	-	-
15	1°	-	⅛	¾

F/S=Field Side; D/S=Downstream; U/S=Upstream; T/S=Traffic Side

7.2.6 Damage to Test Vehicle

Figure 7.6 shows the damage sustained by the vehicle. The front bumper, grill, hood, right front fender, right front strut and tower, right front tire and rim, right front floor pan, right front and rear doors, right rear quarter panel, and rear bumper were damaged. The windshield had cracks radiating upward and inward from the right lower corner. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 8.0 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation was 3.0 inches in the right front firewall/toe pan area. Figure 7.7 shows the interior of the vehicle. Tables C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

Figure 7.6. Test Vehicle after Test No. 614341-01-2.

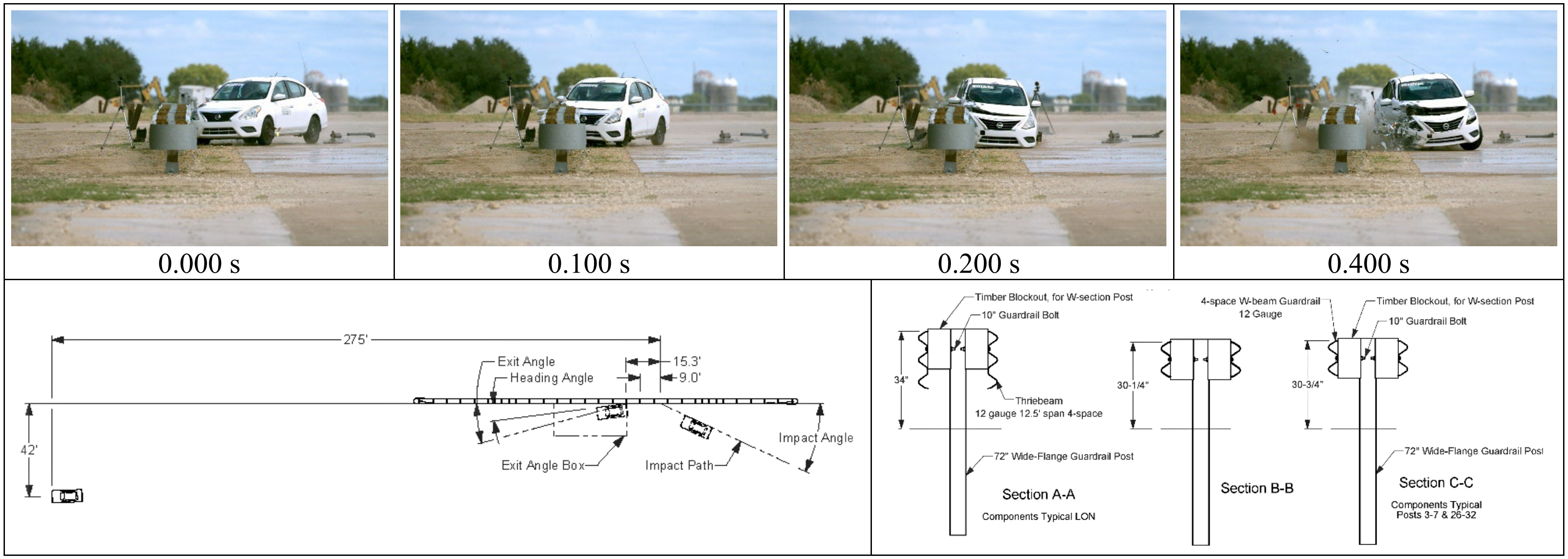
Figure 7.7. Interior of Test Vehicle after Test No. 614341-01-2.

7.2.7 Occupant Risk Factors

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.3. 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 7.8 summarizes pertinent information from the test.

Table 7.3. Occupant Risk Factors for Test No. 614341-01-2.

Occupant Risk Factor	Value	Time
OIV		at 0.1060 s on right side of interior
Longitudinal	15.9 ft/s	
Lateral	23.1 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	16.0 g	0.12–4 - 0.1364 s
Lateral	12.5 g	0.16–5 - 0.1795 s
THIV	8.3 m/s	at 0.1031 s on right side of interior
ASI	1.3	0.05–2 - 0.1062 s
Maximum 50-ms Moving Average		
Longitudinal	−7.4 g	0.08–4 - 0.1364 s
Lateral	−9.9 g	0.04–0 - 0.0900 s
Vertical	2.1 g	0.06–4 - 0.1124 s
Maximum Yaw, Pitch, and Roll Angles		
Roll	6°	0.1666 s
Pitch	4°	0.2639 s
Yaw	37°	1.0034 s



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-10
TTI Test No.	614341-01-2
Test Date	2021-09-16
Test Article	
Type	Longitudinal Barrier—Guardrail
Name	Median Thrie-beam System
Installation Length	168 ft-8 inches
Material or Key Elements	Thrie-beam LON transitioned to W-beam rail
Soil Type and Condition	Grading D of AASHTO M147-17 (Crushed Concrete), Dry
Test Vehicle	
Type/Designation	1100C
Make and Model	2015 Nissan Versa
Curb	2469 lb
Test Inertial	2455 lb
Dummy	165 lb
Gross Static	2620 lb

Impact Conditions	
Speed	62.6 mi/h
Angle	25.0°
Location/Orientation	9.0 ft upstream of post 14
Impact Severity	57 kip-ft
Exit Conditions	
Speed	42.4 mi/h
Trajectory/Heading Angle	15.2°/7.4°
Occupant Risk Values	
Longitudinal OIV	15.9 ft/s
Lateral OIV	23.1 ft/s
Longitudinal Ridedown	16.0 g
Lateral Ridedown	12.5 g
THIV	8.3 m/s
ASI	1.3
Max. 0.050-s Average	
Longitudinal	−7.4 g
Lateral	−9.9 g
Vertical	2.1 g

Post-Impact Trajectory	
Stopping Distance	275 ft downstream 42 ft twd traffic lanes
Vehicle Stability	
Maximum Roll Angle	6°
Maximum Pitch Angle	4°
Maximum Yaw Angle	37°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	15.4 inches
Permanent	8.4 inches
Working Width	38.9 inches
Height of Working Width	32.5 inches
Vehicle Damage	
VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	8.0 inches
OCDI	RF0020000
Max. Occupant Compartment Deformation	3.0 inches

Figure 7.8. Summary of Results for *MASH* Test 3-10 on Median TGS.

CHAPTER 8 SUMMARY AND CONCLUSIONS

8.1 ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-3 for longitudinal barriers and transitions. Table 8.1 through Table 8.3 provide an assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-3 longitudinal barriers and transitions.

8.2 CONCLUSIONS

The research presented in this report describes the full-scale crash testing and evaluation of cost-effective Thrie-beam guardrail systems for both roadside and median applications. According to *MASH*, two full-scale crash tests are required to evaluate a longitudinal barrier. Additionally, *MASH* recommends conducting two crash tests to evaluate a transition system. An extensive computer simulation was conducted to evaluate all the configurations and identify the critical ones for full-scale crash testing. TTI researchers conducted *MASH* Test numbers 3-10, 3-11, and 3-21 on the critical configuration of the barriers.

Test 3-10 was conducted on the median version because higher stiffness of the median version increases impact load and occupant risk values hence being more critical compared to Test 3-11 on the same system. Conversely, Test 3-11 was conducted on the roadside version to evaluate the structural adequacy of the system which is more critical than test 3-10 on roadside configuration. Test 3-21 was only conducted on the roadside transition TGS for the roadside systems which is more critical than the median version with regards to structural adequacy. *MASH* Test 3-20 for transition section is optional and using computer simulation, it was concluded that there is not a reasonable uncertainty regarding the impact performance of both roadside and median transition systems with small passenger vehicles. Thus, the 3-20 tests were not conducted.

*Based on the results of the three successful full-scale crash tests and the computer simulation effort, both roadside and median TGS configurations met all safety requirements for *MASH* TL-3. Table 8.4 shows that the median Thrie-beam system met the performance criteria for *MASH* Test 3-10, and the roadside Thrie-beam system met the performance criteria for *MASH* Test 3-11. Table 8.5 shows the roadside Thrie-beam system met the performance criteria for *MASH* Test 3-21.

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

Table 8.1. Performance Evaluation Summary for *MASH* Test 3-11 on Roadside Thrie-beam System.

Test Agency: Texas A&M Transportation Institute | Test No.: 614341-01-1 | Test Date: 2021-08-16

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 roadside Thrie-beam system contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 42.1 inches.	Pass
Occupant Risk		
D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	A few blockouts detached from the post and rail element, however, these did not penetrate or show potential for penetrating the occupant compartment or to present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	No occupant compartment deformation or intrusion was observed.	
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 6° and 4°.	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 16.8 ft/s, and lateral OIV was 15.5 ft/s.	Pass
I. *The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Longitudinal occupant ridedown acceleration was 5.9 g, and lateral occupant ridedown acceleration was 8.6 g.	Pass

Table 8.2. Performance Evaluation Summary for *MASH* Test 3-21 on Roadside W-beam to Thrie Beam Transition System.

Test Agency: Texas A&M Transportation Institute | Test No.: 614341-01-3 | Test Date: 2021-08-20

MASH Test 3-21 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 roadside Thrie-beam system contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 38.9 inches.	Pass
Occupant Risk		
D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	A few blockouts detached from the post and rail element, however, these did not penetrate or show potential for penetrating the occupant compartment or to present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	No occupant compartment deformation or intrusion was observed.	
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 15° 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 14.3 ft/s.	Pass
I. *The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Longitudinal occupant ridedown acceleration was 13.6 g, and lateral occupant ridedown acceleration was 10.0 g.	Pass

Table 8.3. Performance Evaluation Summary for *MASH* Test 3-10 on Median Thrie-beam System.

Test Agency: Texas A&M Transportation Institute Test No.: 614341-01-2 Test Date: 2021-09-16

***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 median Thrie-beam system contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 15.4 inches.	Pass
Occupant Risk		
D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	A blockout detached from the post and rail element, however, this did not penetrate or show potential for penetrating the occupant compartment or to present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 3.0 inches in the right front firewall/toe pan 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 6° and 4°.	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 15.9 ft/s, and lateral OIV was 23.1 ft/s.	Pass
I. *The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Longitudinal occupant ridedown acceleration was 16.0 g, and lateral occupant ridedown acceleration was 12.5 g.	Pass

Table 8.4. Assessment Summary for *MASH* TL-3 LON Tests on Thrie-beam Median System.

Evaluation Factors	Evaluation Criteria	Test No. 614341-01-2 on Median System	Test No. 614341-01-1 on Roadside System
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.

Table 8.5. Assessment Summary for *MASH* TL-3 Transition Test on Thrie-beam Roadside System.

Evaluation Factors	Evaluation Criteria	Not Performed	Test No. 614341-01-3 on Roadside System
Structural Adequacy	A	--	S
Occupant Risk	D	--	S
	F	--	S
	H	--	S
	I	--	S
	Test No.	***MASH* Test 3-20**	***MASH* Test 3-21**
	Pass/Fail	--	Pass

Note: S = Satisfactory.

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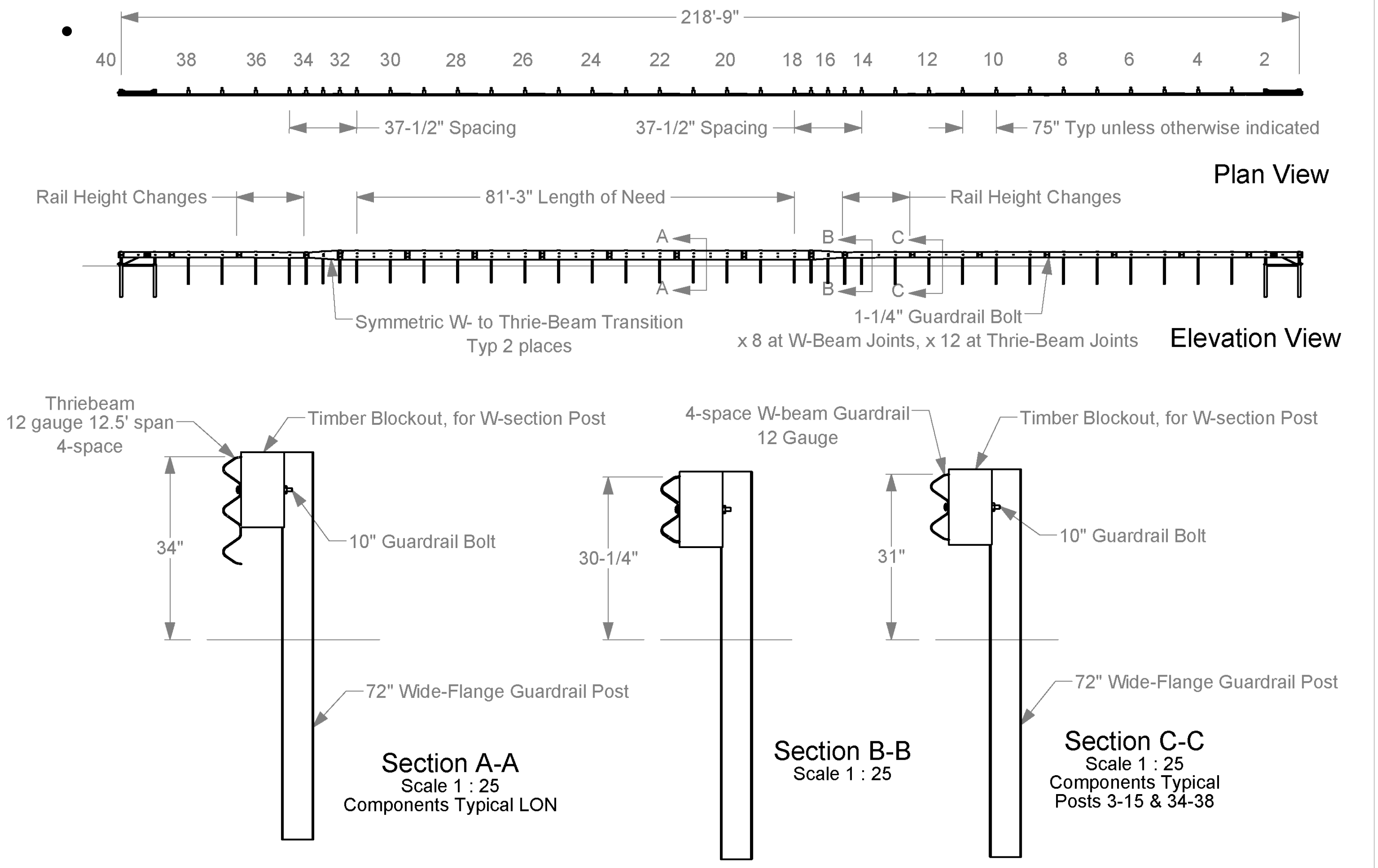
16. Griffith, M.S., Federal Highway Administration (FHWA), Eligibility Letter HSA-10/B-148 for: T-39 Thrie-Beam Guardrail, June 2, 2006.

Test Installation



1a. Backfill Post holes with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.

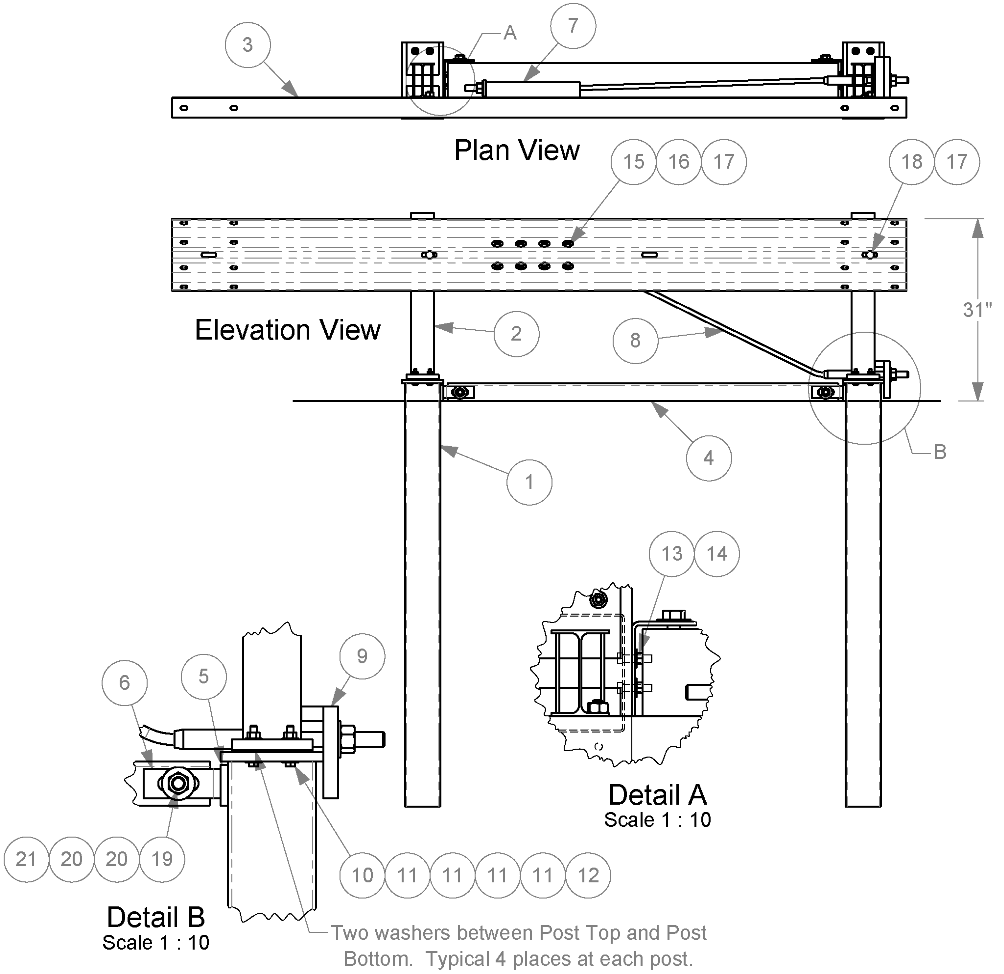
1b. All steel parts shall be galvanized.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #614341 Thrie-Beam Roadside		2021-05-25
Drawn by WS/GS	Scale 1:300	Sheet 1 of 1 Test Installation

Q:\Accreditation-17025-2017\EIR-000 Project Files\614341 - Thrie-Beam Roadside-Median - Kiani\Drafting, 614341\614341 Roadside Drawing

Terminal Details

#	Part Name	QTY.
1	Post Bottom	2
2	Post Top	2
3	9'-4" span Terminal Rail	1
4	Strut	1
5	Strut Spacer	2
6	Strut Bracket	2
7	Guardrail Anchor Bracket	1
8	Anchor Cable Assembly	1
9	Bearing Plate	1
10	Bolt, 7/16 x 2 1/2" hex	8
11	Washer, 7/16 F844	32
12	Nut, 7/16 heavy hex	8
13	Nut, 1/2 hex	4
14	Washer, 1/2 F844	4
15	Bolt, 5/8 x 1 1/2" hex	8
16	Washer, 5/8 F844	8
17	Recessed Guardrail Nut	10
18	1-1/4" Guardrail Bolt	2
19	Bolt, 7/8 x 8 1/2" hex	2
20	Washer, 7/8 F844	4
21	Nut, 7/8 hex	2



Two washers between Post Top and Post Bottom. Typical 4 places at each post.

1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.

1c. All steel parts shall be galvanized.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal		2021-06-01
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details

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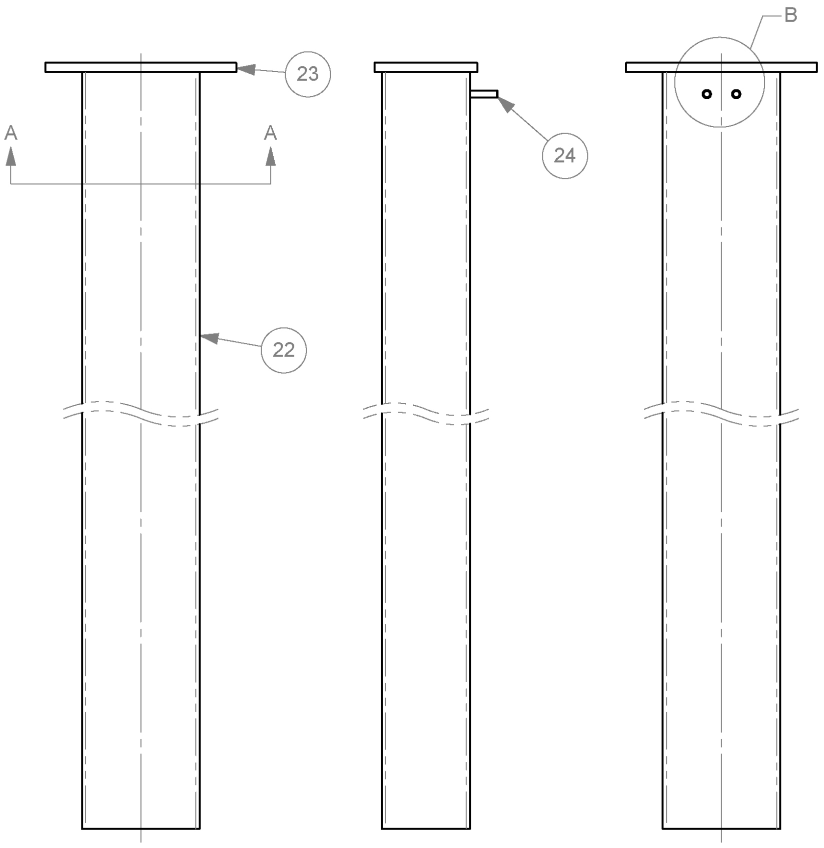
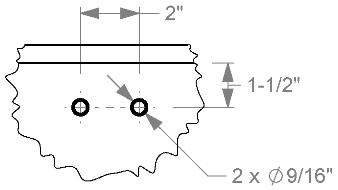
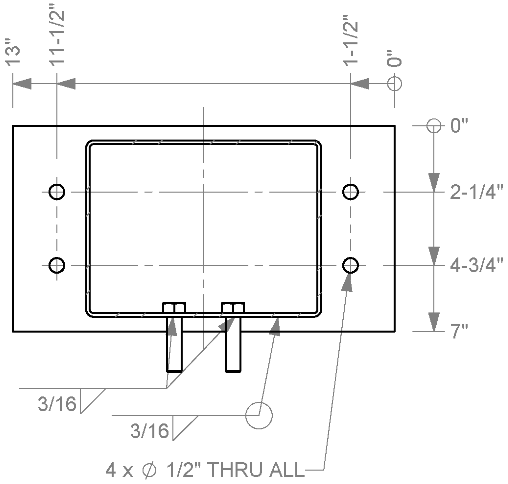
Post Bottom



Elevation Views



Detail B
Scale 1 : 5



Section A-A
Scale 1 : 5

#	Description	Length	Material	Qty
22	HSS 8" x 6" x 1/8"	72"	ASTM A500 Grade B	1
23	Plate, 7" x 5/8"	13"	ASTM A36	1
24	Bolt, 1/2 x 2 hex		ASTM A307	2

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2021-06-01
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom

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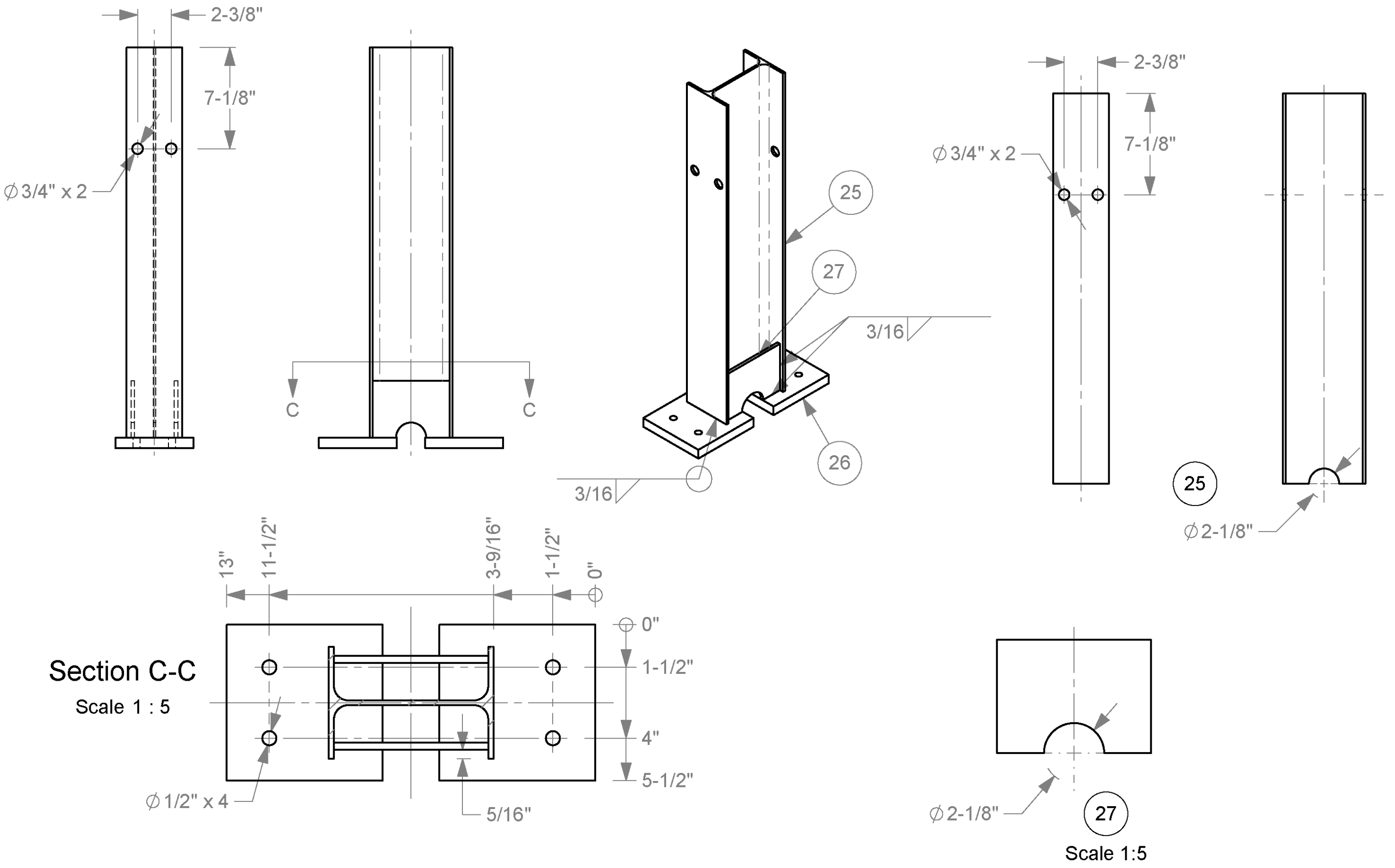

#	Description	Length	Material	Qty
25	W6x8.5	27 1/2"	ASTM A992	1
26	Plate, 5 1/2" x 3/4"	5 1/2"	ASTM A36	2
27	Plate, 5 7/16" x 1/4"	4"	ASTM A36	2

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project # Terminal			2021-06-01
Drawn by GES	Scale 1:10	Sheet 3 of 6 Post Top	

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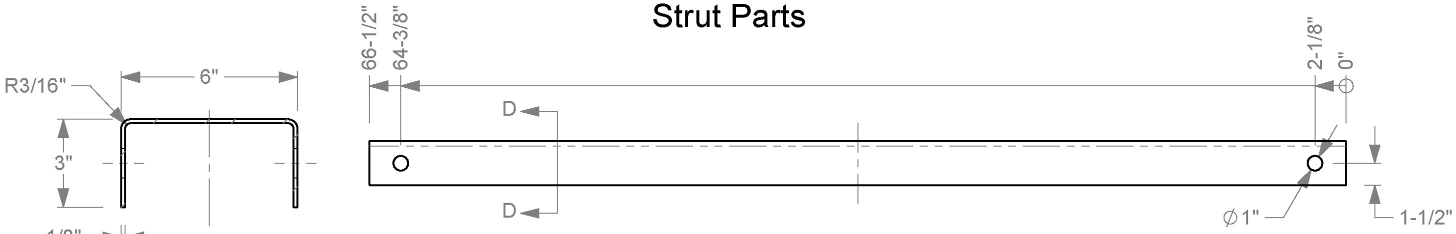
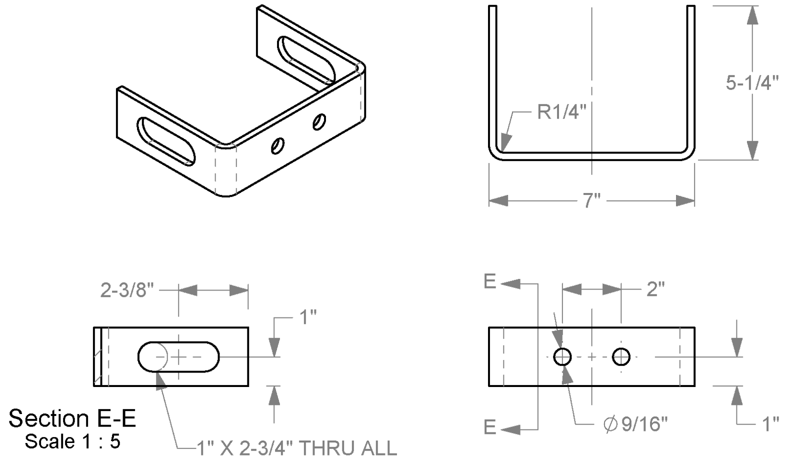
Strut Parts



Section D-D
Scale 1 : 5

Strut

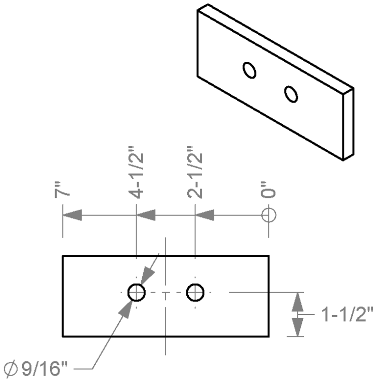
10 gauge
ASTM A36



Section E-E
Scale 1 : 5

Strut Bracket

Plate, 2" x 1/4"
ASTM A36 - Scale 1:5



Strut Spacer

Plate, 2 3/4" x 1/2"
ASTM A36 - Scale 1:5

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal	2021-06-01
Drawn by GES	Scale 1:10
Sheet 4 of 6 Strut Parts	

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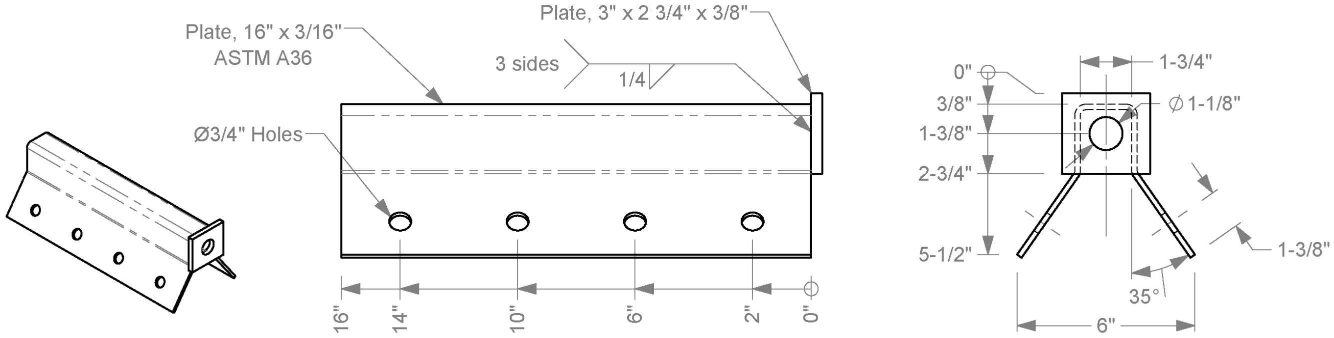
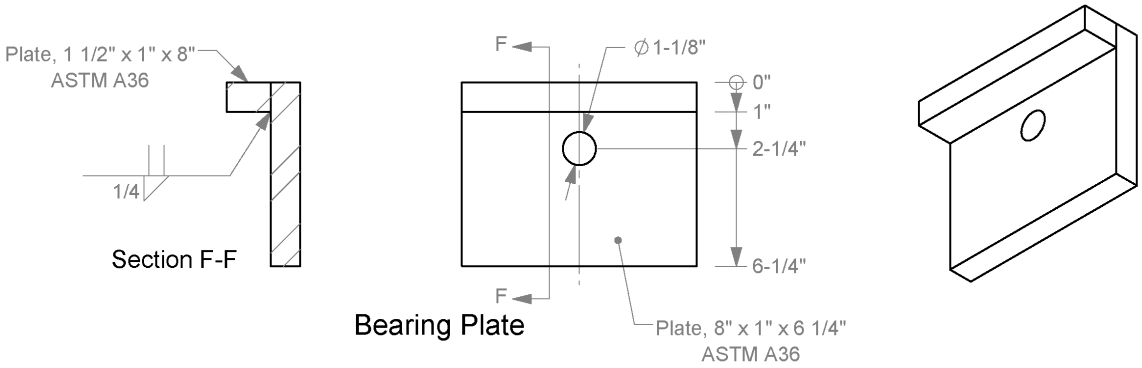


Guardrail Anchor Bracket



Section F-F

Bearing Plate

Texas A&M Transportation Institute

Roadside Safety and
Physical Security Division -
Proving Ground

Project # Terminal		2021-06-01
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A

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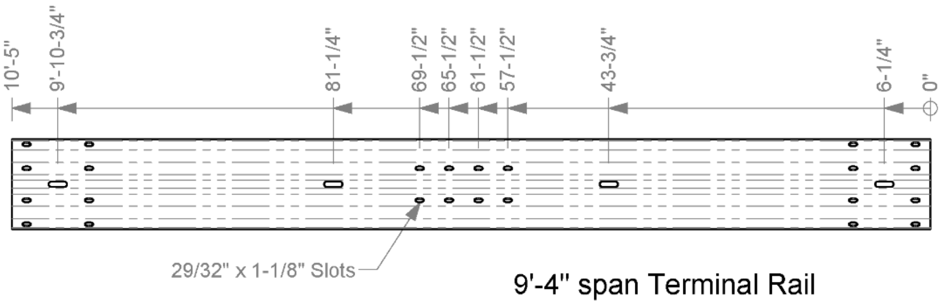
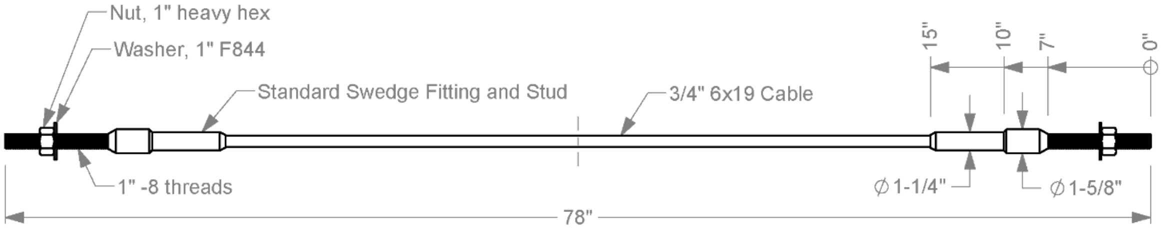


9'-4" span Terminal Rail

Scale 1:20 - See 4-space W-beam Guardrail drawing
for cross-section and other dimensions.



Anchor Cable Assembly

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal	2021-06-01
Drawn by GES	Scale 1:5
Sheet 6 of 6 Assorted Parts B	

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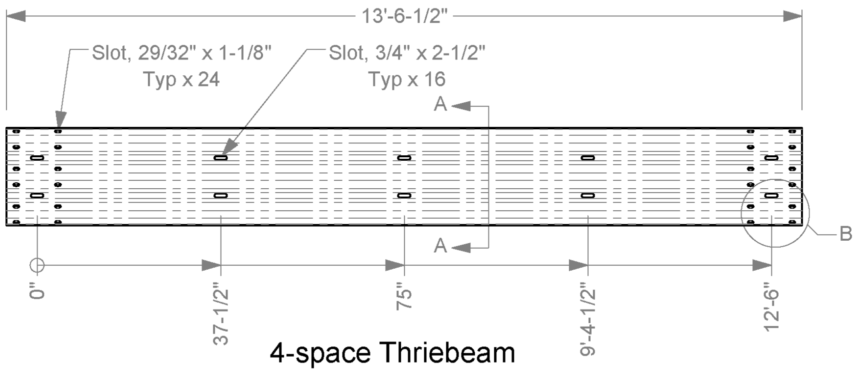
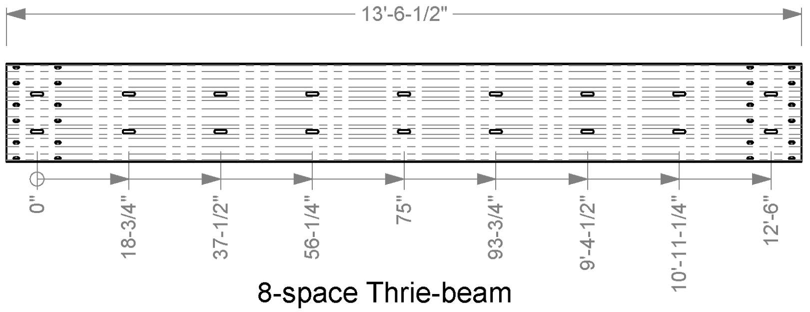
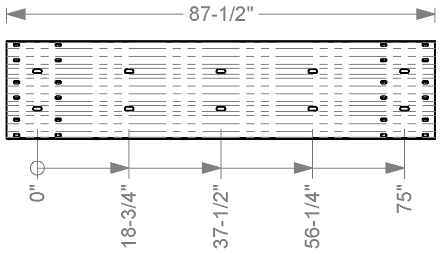


4-space Thriebeam



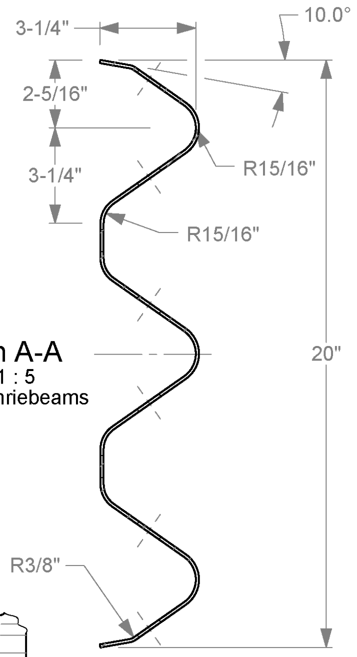
8-space Thrie-beam

Dimensions not shown here same as 4-space Thriebeam



Thriebeam, 12 gauge 75" span

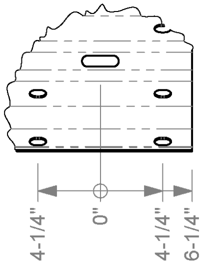
Dimensions not shown here same as 4-space Thriebeam



Section A-A

Scale 1 : 5

Typical all Thriebeams



Detail B

Scale 1 : 10

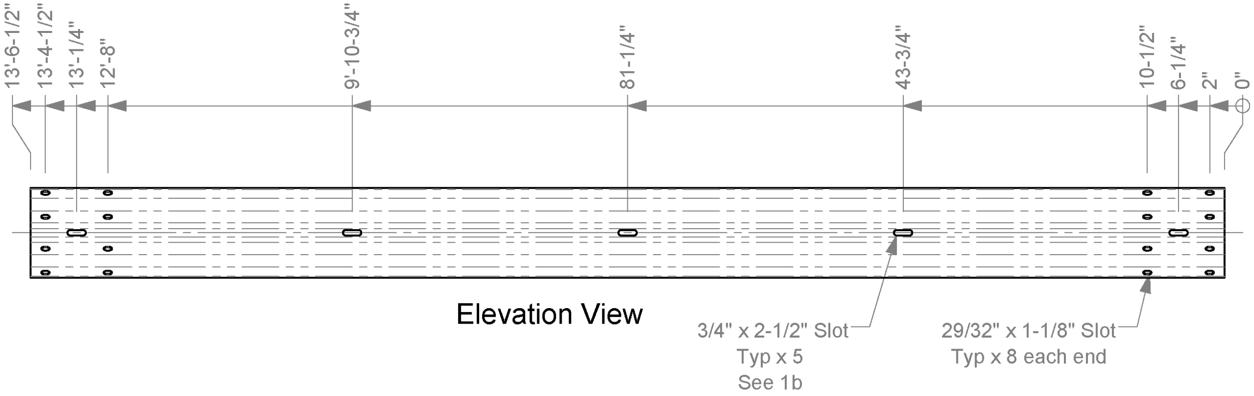
Typical all Thriebeams,
both ends

1a. 12 gauge is 0.1046" before galvanizing and 0.1084" after, and 10 gauge is 0.1345" before galvanizing and 0.1382" after.

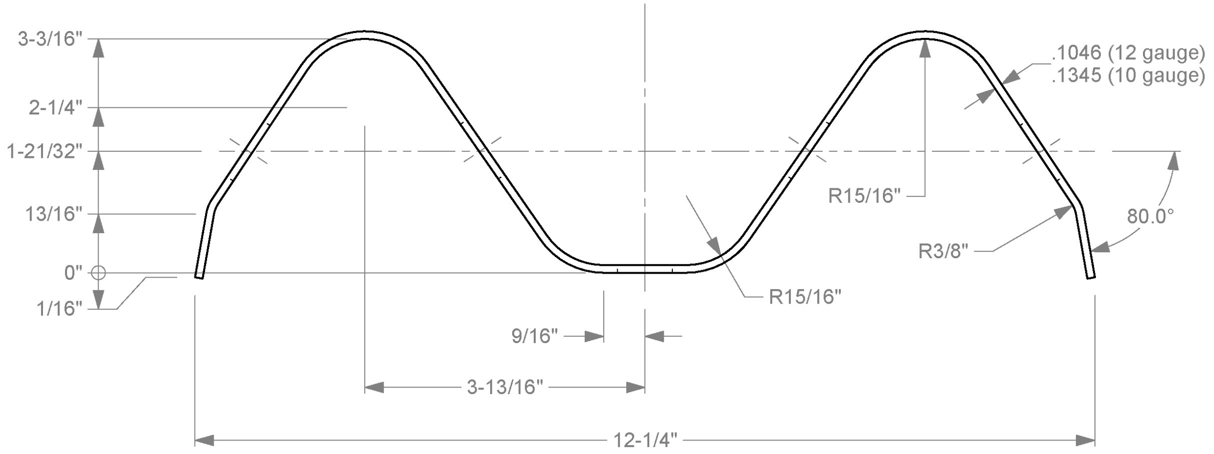
1b. Not all versions shown here used in all installations.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Thrie-beam		2020-03-31
Drawn by GES	Scale 1:30	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Thrie-Beam



Elevation View



Section View

1a. Manufacture per AASHTO M180 specifications.

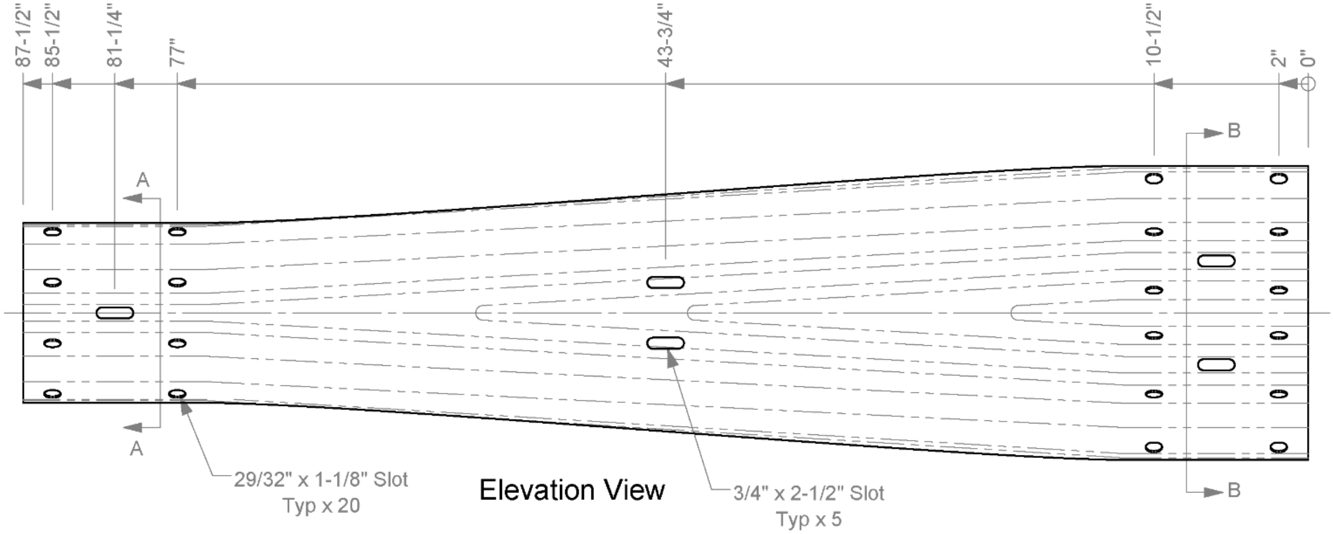
1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
4-space W-beam Guardrail		2020-06-05
Drawn by GES	Scale 1:20	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-Beam Guardrail

W- to Thrie-Beam, symmetric

10 gauge



Elevation View

Section A-A

See W-beam Drawing

Section B-B

See Thrie-beam Drawing

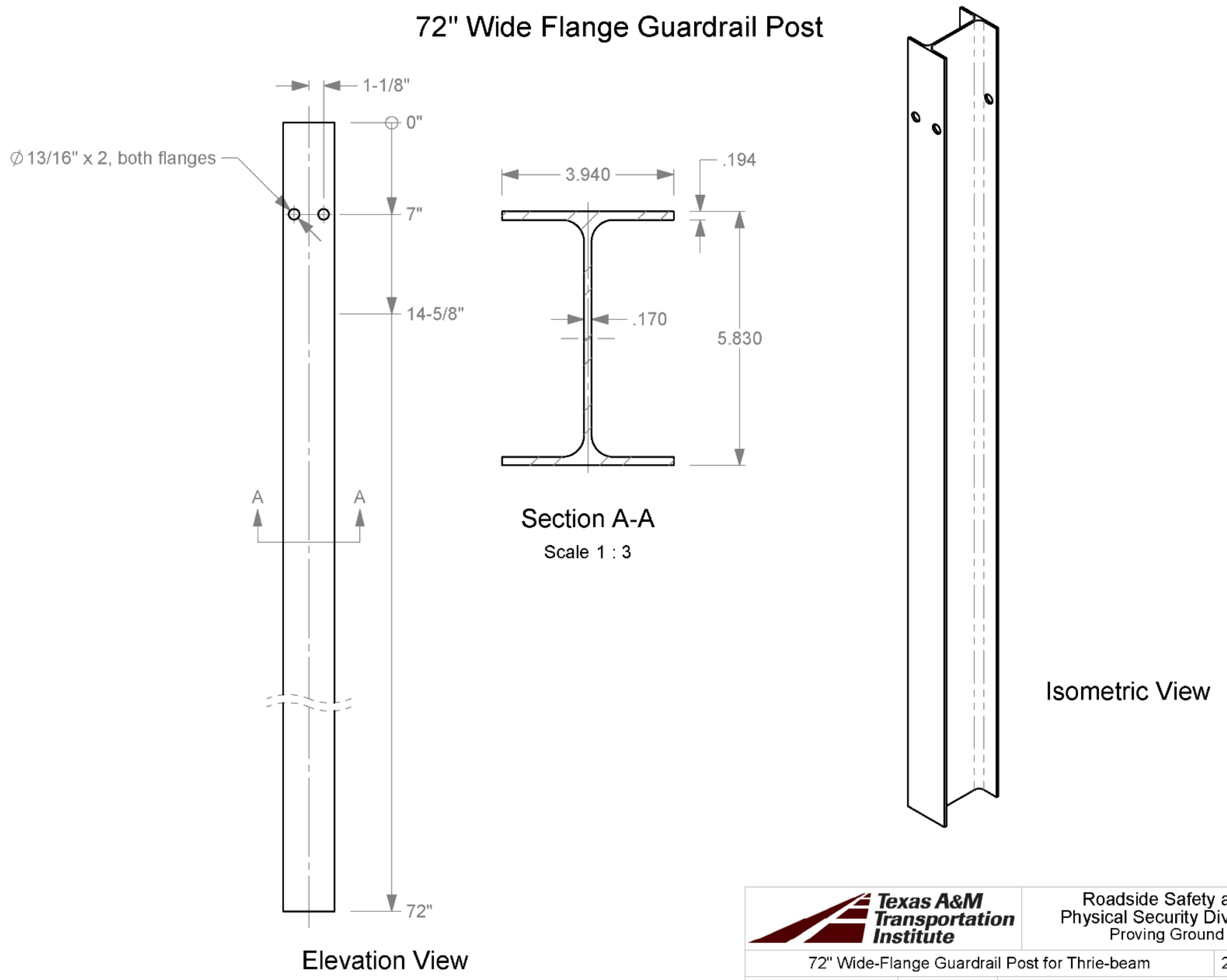
Texas A&M Transportation Institute

Roadside Safety and
Physical Security Division -
Proving Ground

Symmetric W- to Thre-beam Transition	2020-10-13

Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts\Guardrail Drawings\W- to Thrie-Beam, symmetric



Texas A&M Transportation Institute

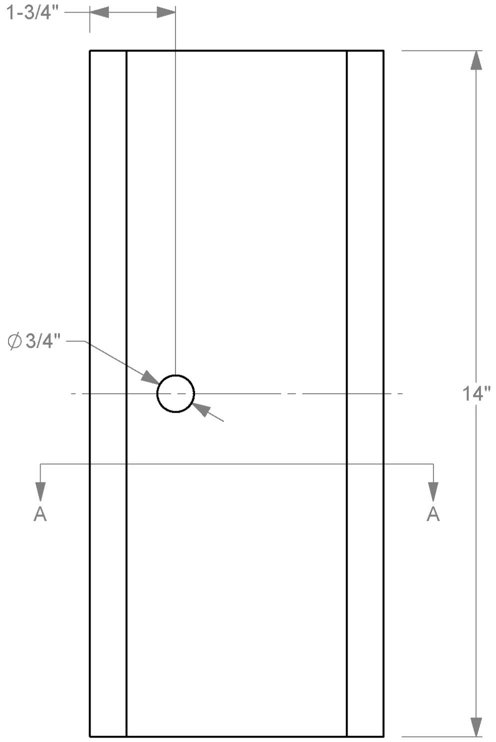
Roadside Safety and
Physical Security Division -
Proving Ground

72" Wide-Flange Guardrail Post for Thrie-beam	2020-11-10

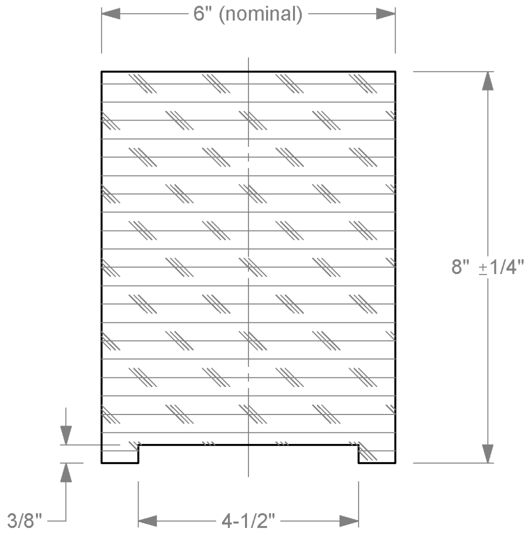
Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

Timber Blockout for W-section Post



Elevation View

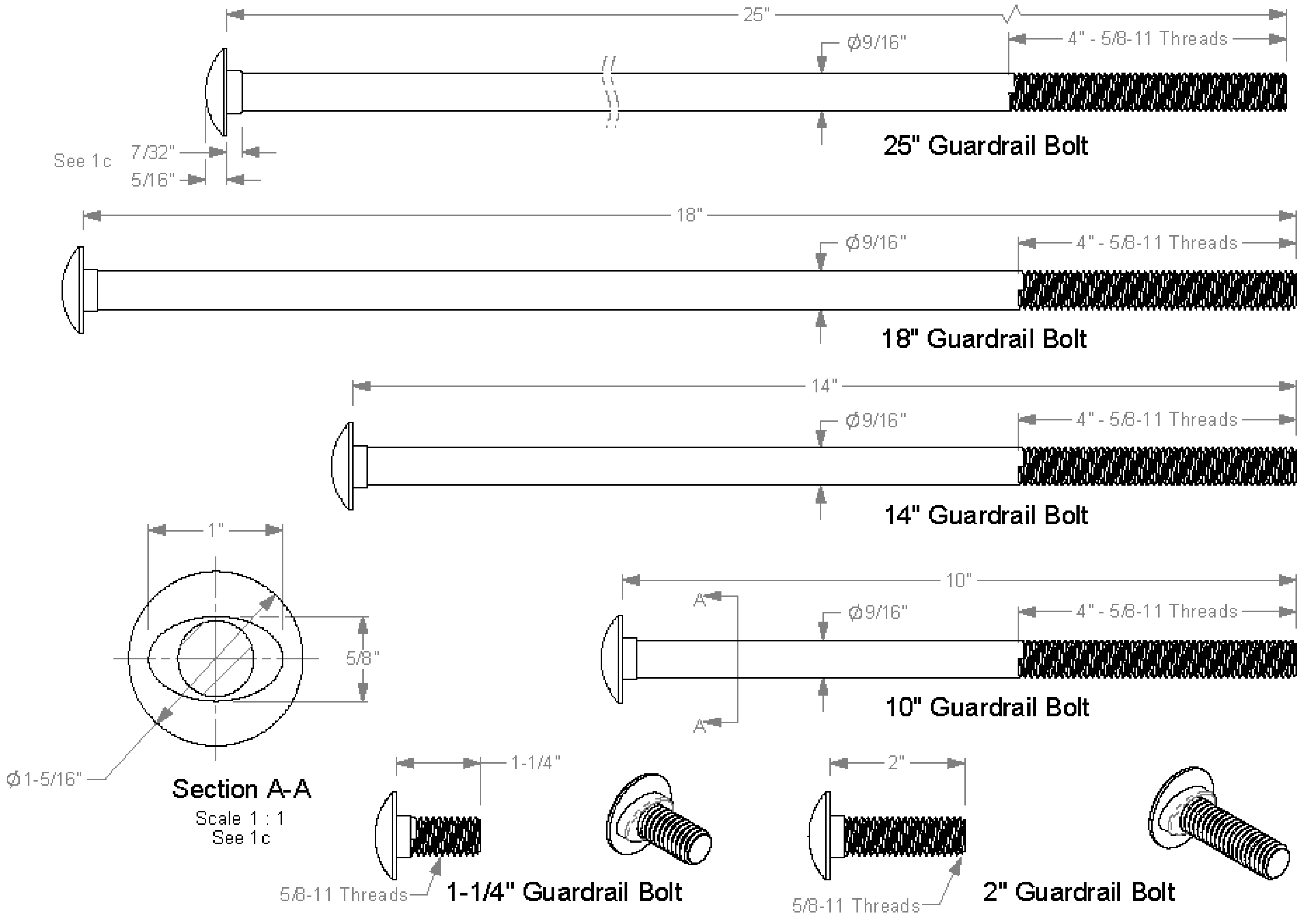


Section A-A

1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Timber Blockout, for W-section Post		2019-07-03
Drawn by GES	Scale 1:3	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts\Guardrail Drawings\Timber Blockout for W-section Post

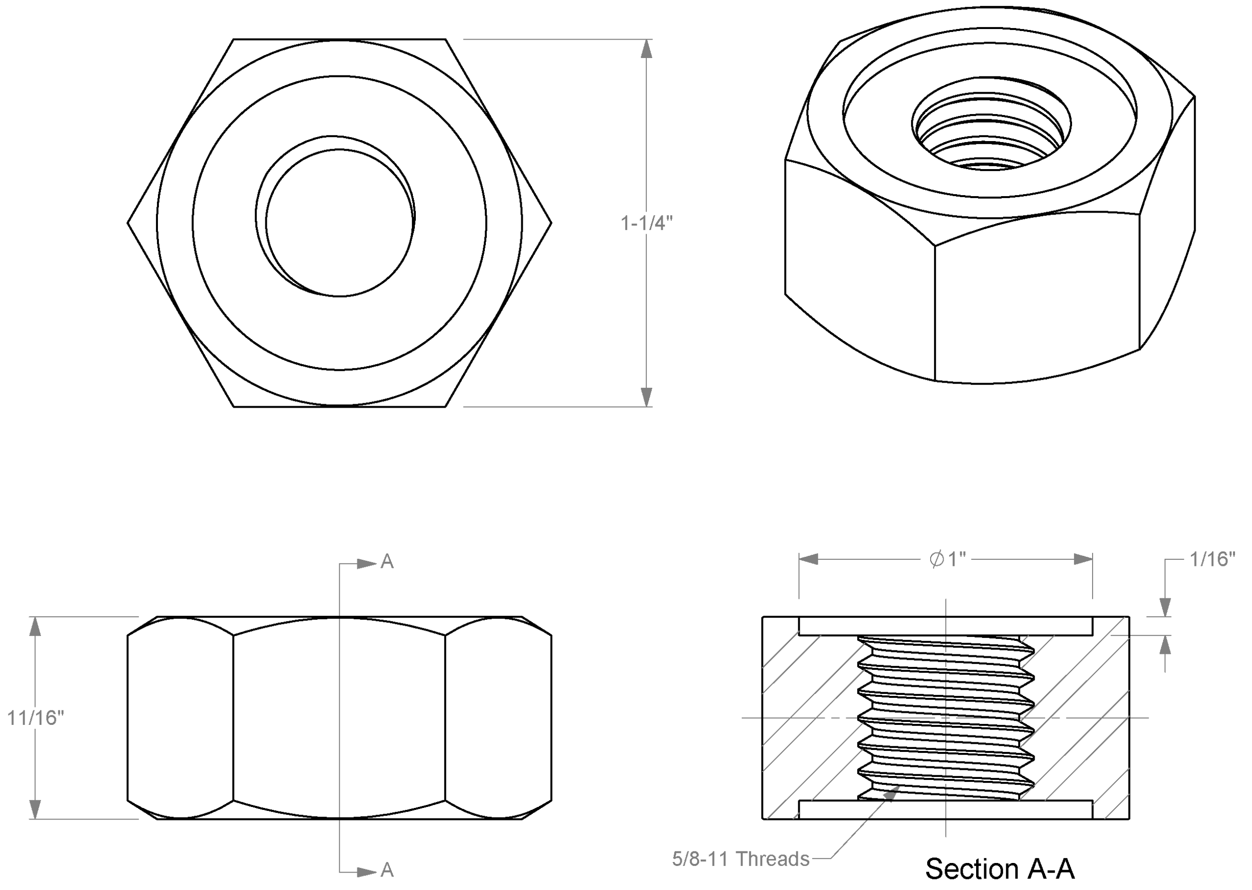


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Guardrail Bolt			2020-04-22
Drawn by GES/WS	Scale 1:2	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Guardrail Bolt

Recessed Guardrail Nut

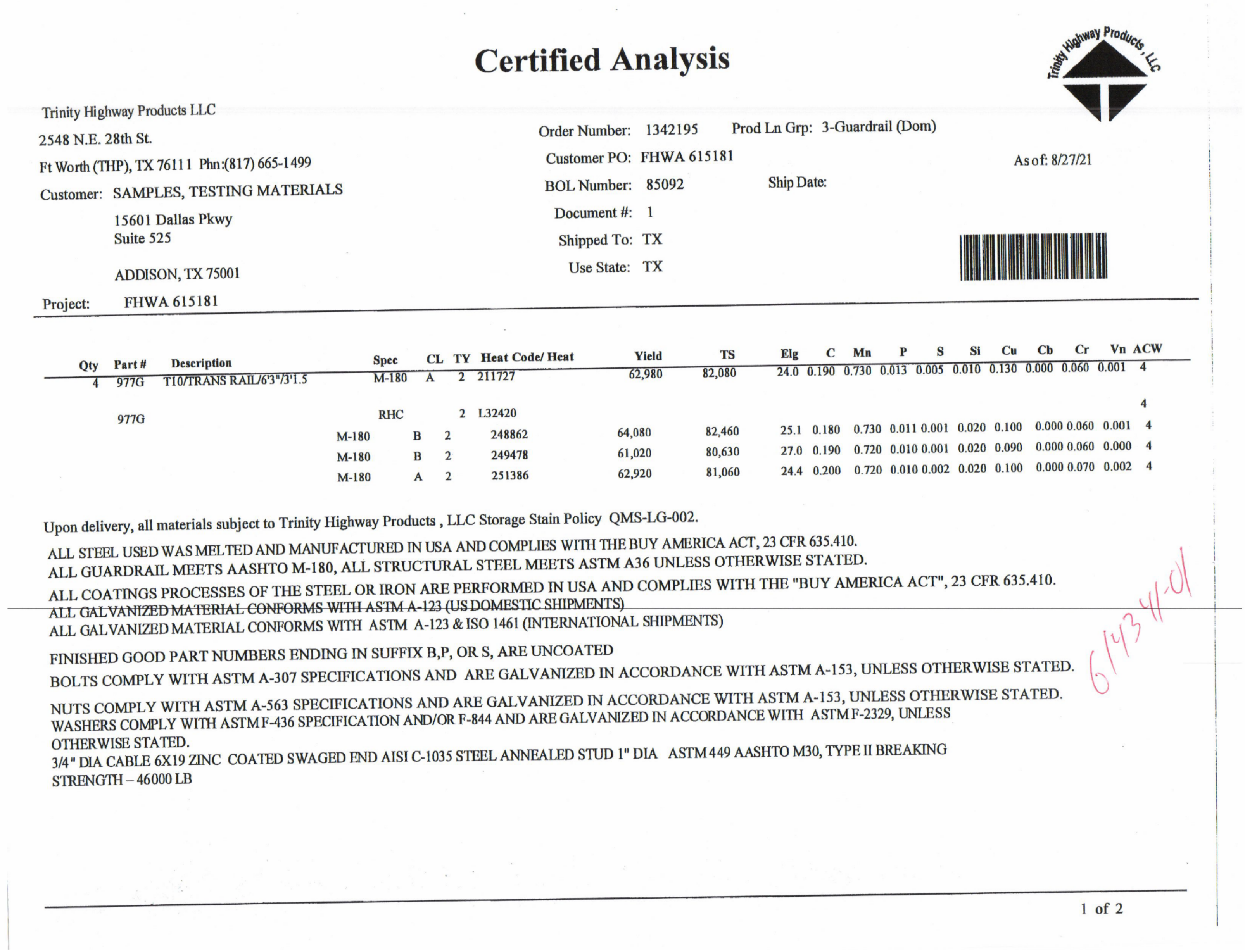


1a. Material is ASTM A 563 Grade A.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Recessed Guardrail Nut			2019-06-27
Drawn by GES	Scale 2:1	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts\Guardrail Drawings\Nut, Recessed Guardrail

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS



Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525

ADDISON, TX 75001

Project: FHWA 615181

Order Number: 1342195 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: FHWA 615181
BOL Number: 85092 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/27/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
4	977G	T10/TRANS RAIL/6'3"/3'1.5	M-180	A	2	211727	62,980	82,080	24.0	0.190	0.730	0.013	0.005	0.010	0.130	0.000	0.060	0.001	4
	977G		RHC		2	L32420													4
			M-180	B	2	248862	64,080	82,460	25.1	0.180	0.730	0.011	0.001	0.020	0.100	0.000	0.060	0.001	4
			M-180	B	2	249478	61,020	80,630	27.0	0.190	0.720	0.010	0.001	0.020	0.090	0.000	0.060	0.000	4
			M-180	A	2	251386	62,920	81,060	24.4	0.200	0.720	0.010	0.002	0.020	0.100	0.000	0.070	0.002	4

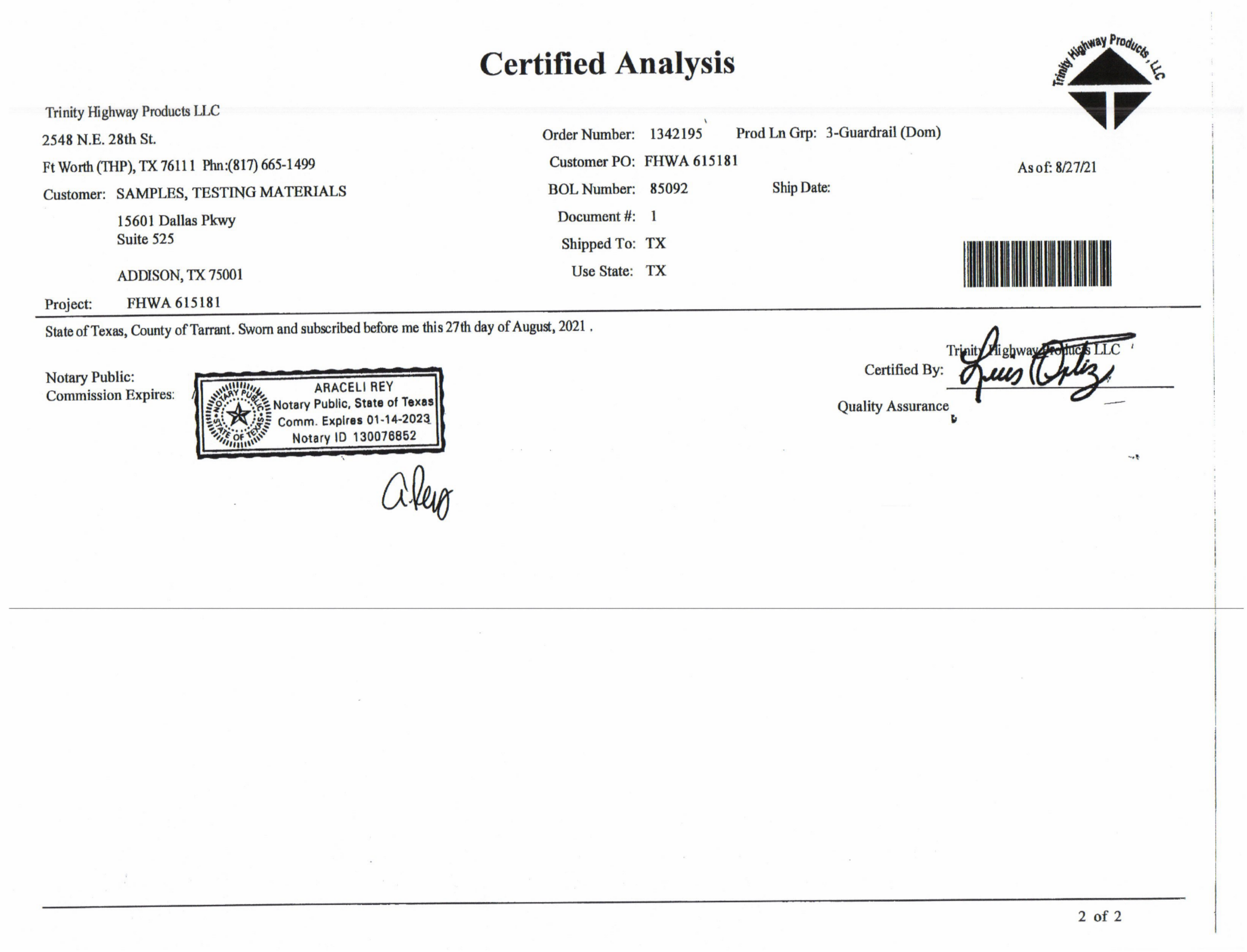
Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

614341-01

1 of 2



Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
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Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525

ADDISON, TX 75001

Project: FHWA 615181

Order Number: 1342195 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: FHWA 615181
BOL Number: 85092 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/27/21

State of Texas, County of Tarrant. Sworn and subscribed before me this 27th day of August, 2021 .

Notary Public:
Commission Expires:

ARACELI REY
Notary Public, State of Texas
Comm. Expires 01-14-2023
Notary ID 130076852

Trinity Highway Products LLC
Certified By: Luis Ortiz
Quality Assurance

2 of 2

APPENDIX C. SOIL PROPERTIES

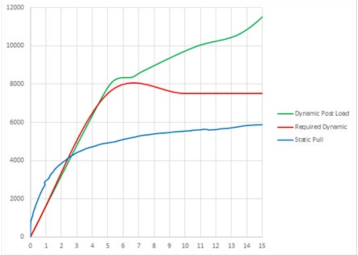
Dynamic Test Setup

Post-Test Photo of post

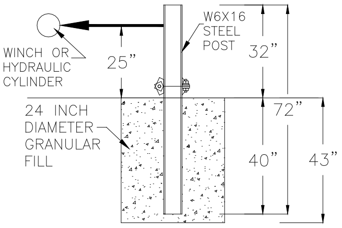
Static Load Test

Post-Test Photo

Dynamic Test Installation Details



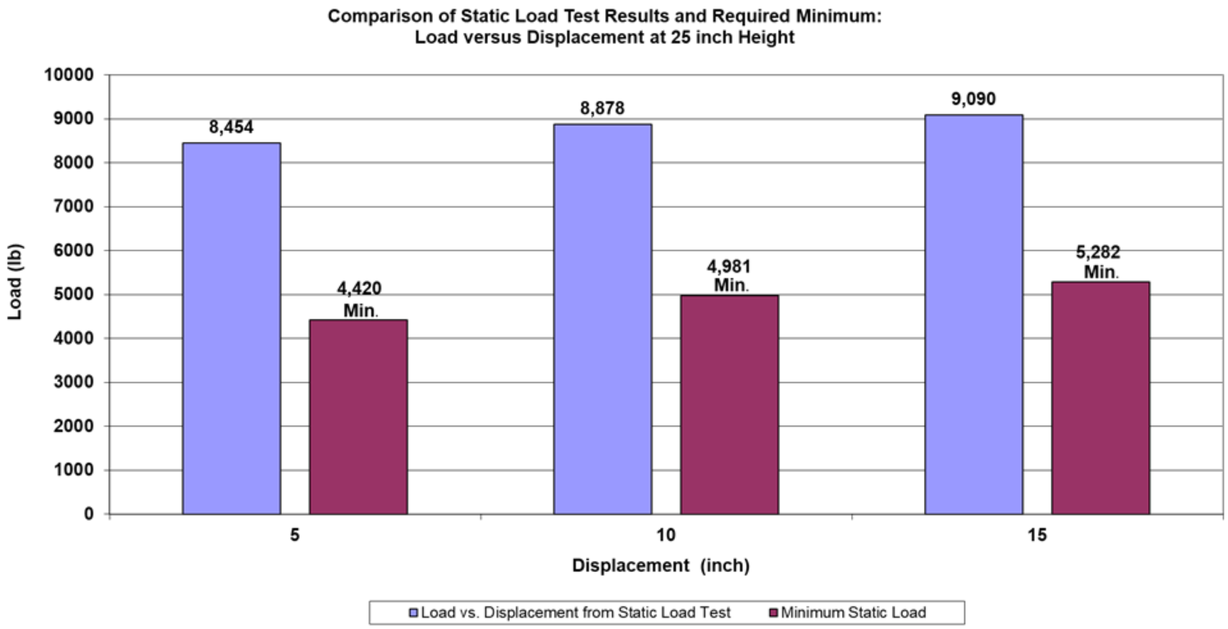
Comparison of Load vs. Displacement



Static Load Test Installation Details

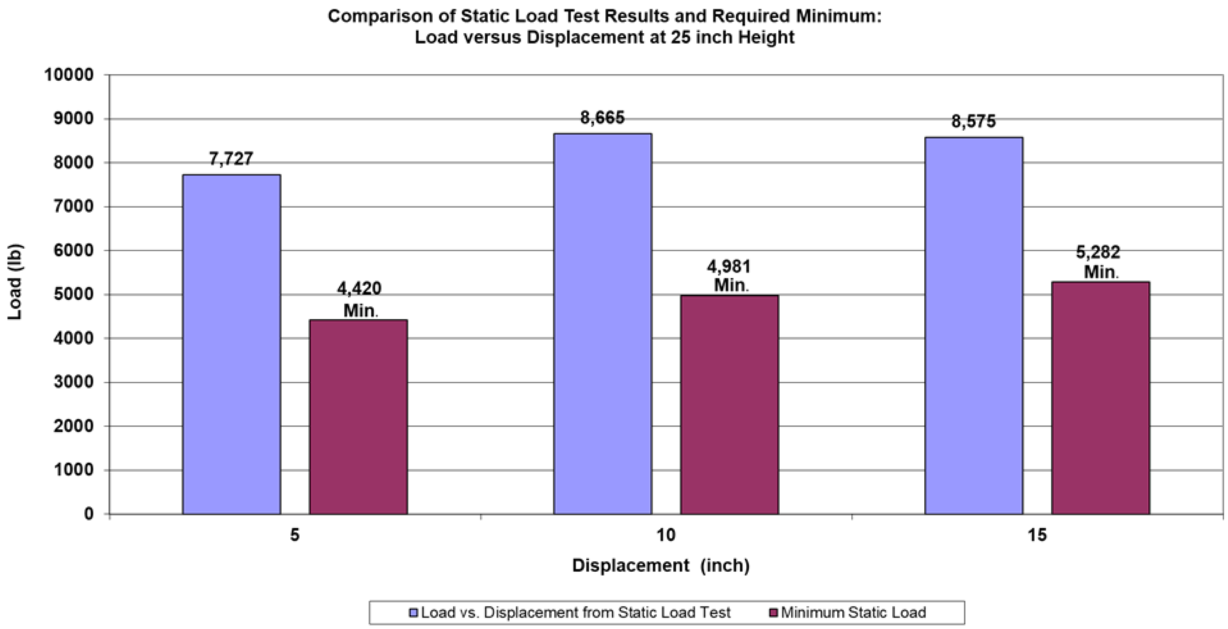
Date	2020-02-02
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147-17 Grading D or Type D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 sec
Bogie Weight	2020 lb
Impact Velocity	19.2 mph

Figure C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.



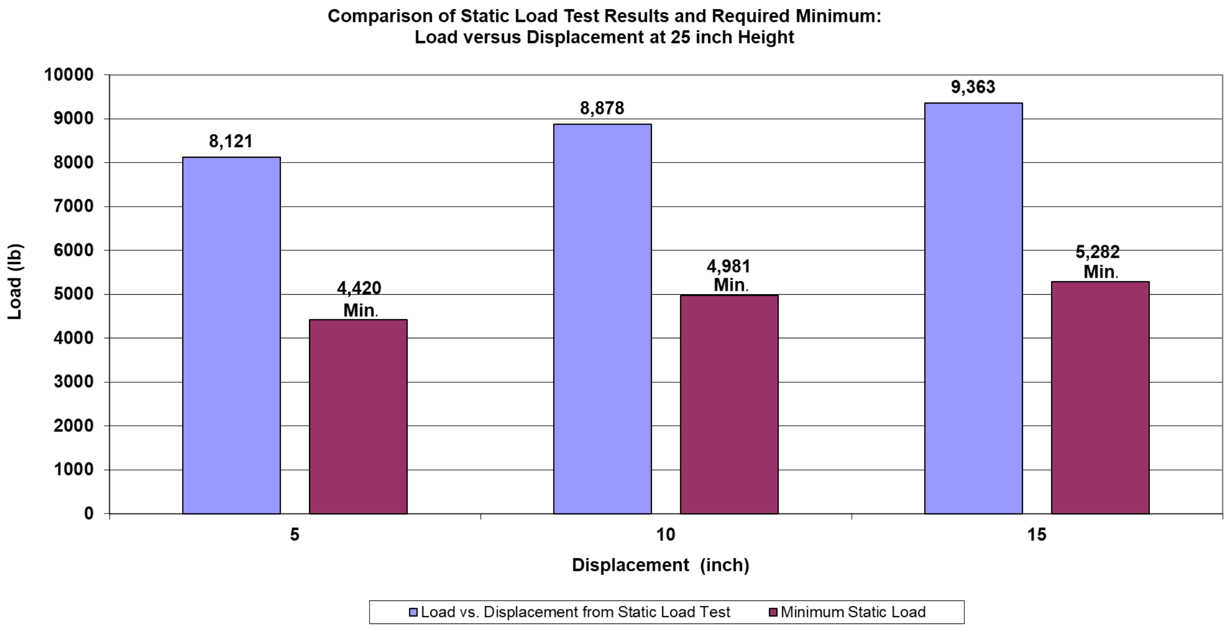
Date	2021-08-16 – Test No. 614341-01-1
Test Facility and Site Location	TTI Proving Ground, 1254 Avenue A, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade D or Type D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with pneumatic compactor for 20 s

Figure C.2. Soil Strength for Test No. 614341-01-1.



Date	2021-08-20 – Test No. 614341-01-3
Test Facility and Site Location	TTI Proving Ground, 1254 Avenue A, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade D or Type D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with pneumatic compactor for 20 s

Figure C.3. Soil Strength for Test No. 614341-01-3.



Date	2021-09-16 – Test No. 614341-01-2
Test Facility and Site Location	TTI Proving Ground, 1254 Avenue A, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade D or Type D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with pneumatic compactor for 20 s

Figure C.4. Soil Strength for Test No. 614341-01-2.

APPENDIX D. *MASH* TEST 3-11 (CRASH TEST NO. 614341-01-1)

D.1. VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 614341-01-1.

Date: 2021-8-16 Test No.: 614341-01-1 VIN No.: 1C6RR6GT0FS589409

Year: 2015 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 242958

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None

Engine Type: V-8

Engine CID: 5.7L

Transmission Type:

☑ Auto or ☐ Manual

☐ FWD ☑ RWD ☐ 4WD

Optional Equipment:

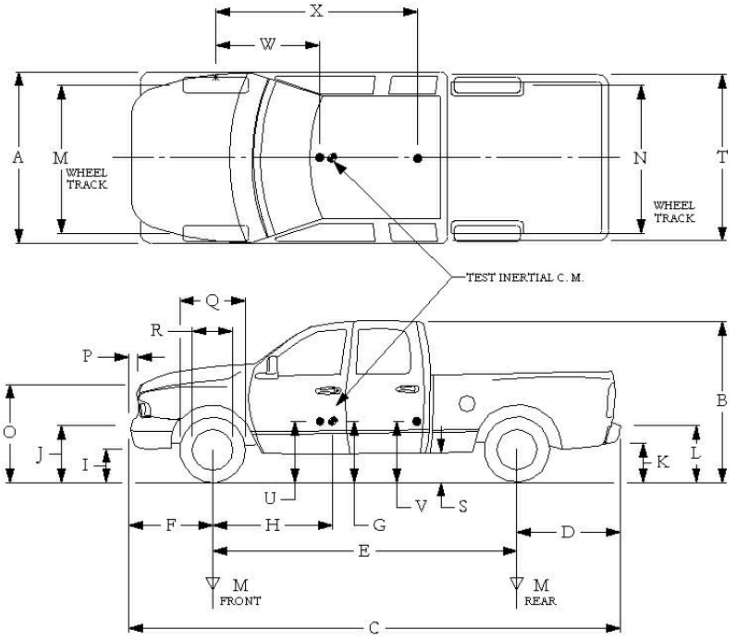
None

Dummy Data:

Type: 50th Percentile male

Mass: 165 lb

Seat Position: IMPACT SIDE



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.75	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.40	M	68.50	R	18.00	W	61.40
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2940	2847	2932
Back	3900	M_{rear}	2160	2210	2290
Total	6700	M_{Total}	5100	5057	5222

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

Mass Distribution:

lb LF: 1370 RF: 1477 LR: 1130 RR: 1080

Table D.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 614341-01-1.

Date: 2021-8-16 Test No.: 614341-01-1 VIN: 1C6RR6GT0FS589409

Year: 2015 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 242958

Engine: 5.7L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 125 (440 lb max)

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

Measured Vehicle Weights: (lb)

LF:	1370	RF:	1477	Front Axle:	2847
LR:	1130	RR:	1080	Rear Axle:	2210
Left:	2500	Right:	2557	Total:	5057
					5000 ±110 lb allowed

Wheel Base: 140.50 inches Track: F: 68.50 inches R: 68.00 inches

148 ±12 inches allowed Track = (F+R)/2 = 67 ±1.5 inches allowed

Center of Gravity, SAE J874 Suspension Method

X: 61.40 inches Rear of Front Axle (63 ±4 inches allowed)

Y: 0.38 inches Left - Right + of Vehicle Centerline

Z: 28.75 inches Above Ground (minumum 28.0 inches allowed)

Hood Height: 46.00 inches Front Bumper Height: 27.00 inches

43 ±4 inches allowed

Front Overhang: 40.00 inches Rear Bumper Height: 30.00 inches

39 ±3 inches allowed

Overall Length: 227.50 inches

237 ±13 inches allowed

Table D.3. Exterior Crush Measurements for Test No. 614341-01-1.

Date: 2021-8-16 Test No.: 614341-01-1 VIN No.: 1C6RR6GT0FS589409

Year: 2015 Make: RAM Model: 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bmp ht	14	8	24	-	-	-	-	-	-	-24
2	Side plane above bmp	14	6	55	-	-	-	-	-	-	76
	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).

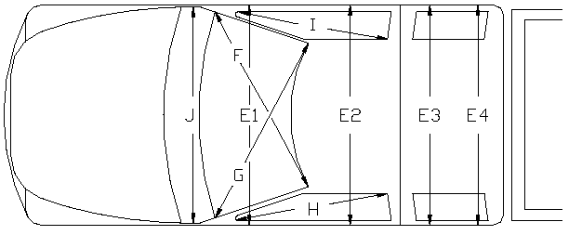
***Measure and document on the vehicle diagram the location of the maximum crush.

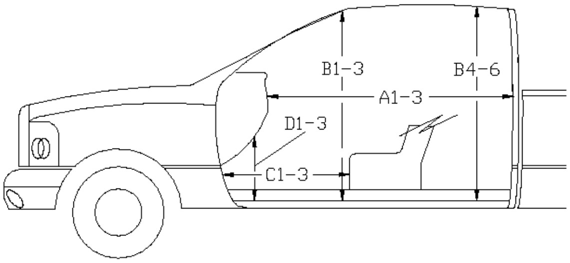
Note: Use as many lines/columns as necessary to describe each damage profile.

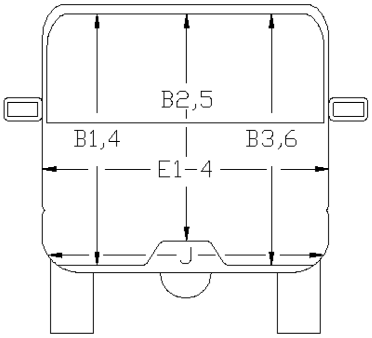
Table D.4. Occupant Compartment Measurements for Test No. 614341-01-1.

Date: 2021-8-16 Test No.: 614341-01-1 VIN No.: 1C6RR6GT0FS589409

Year: 2015 Make: RAM Model: 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

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

D.2. SEQUENTIAL PHOTOGRAPHS

0.000 s

0.100 s

0.200 s

0.300 s

Figure D.1. Sequential Photographs for Test No. 614341-01-1 (Frontal and Rear Views).

0.400 s

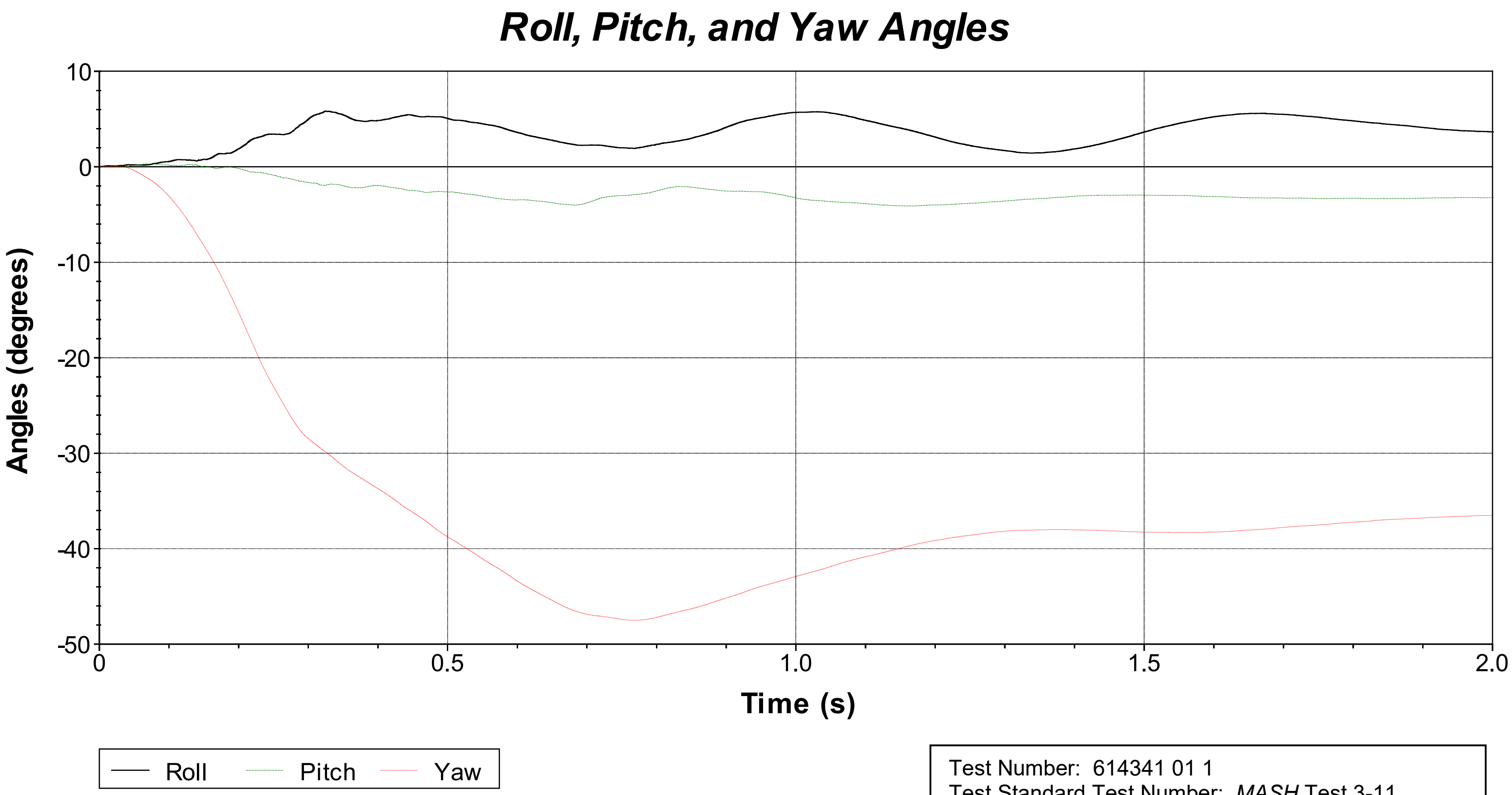
0.500 s

0.600 s

0.700 s

Figure D.1. Sequential Photographs for Test No. 614341 01 1 (Frontal and Rear Views) (Continued).

D.3. VEHICLE ANGULAR DISPLACEMENTS



Test Number: 614341 01 1
Test Standard Test Number: *MASH* Test 3-11
Test Article: Roadside Thrie Beam
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5057 lb
Gross Mass: 5222 lb
Impact Speed: 60.4 mi/h
Impact Angle: 25.9°

Axes are vehicle-fixed.
Sequence for
determining orientation:

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

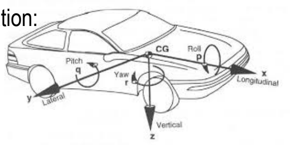
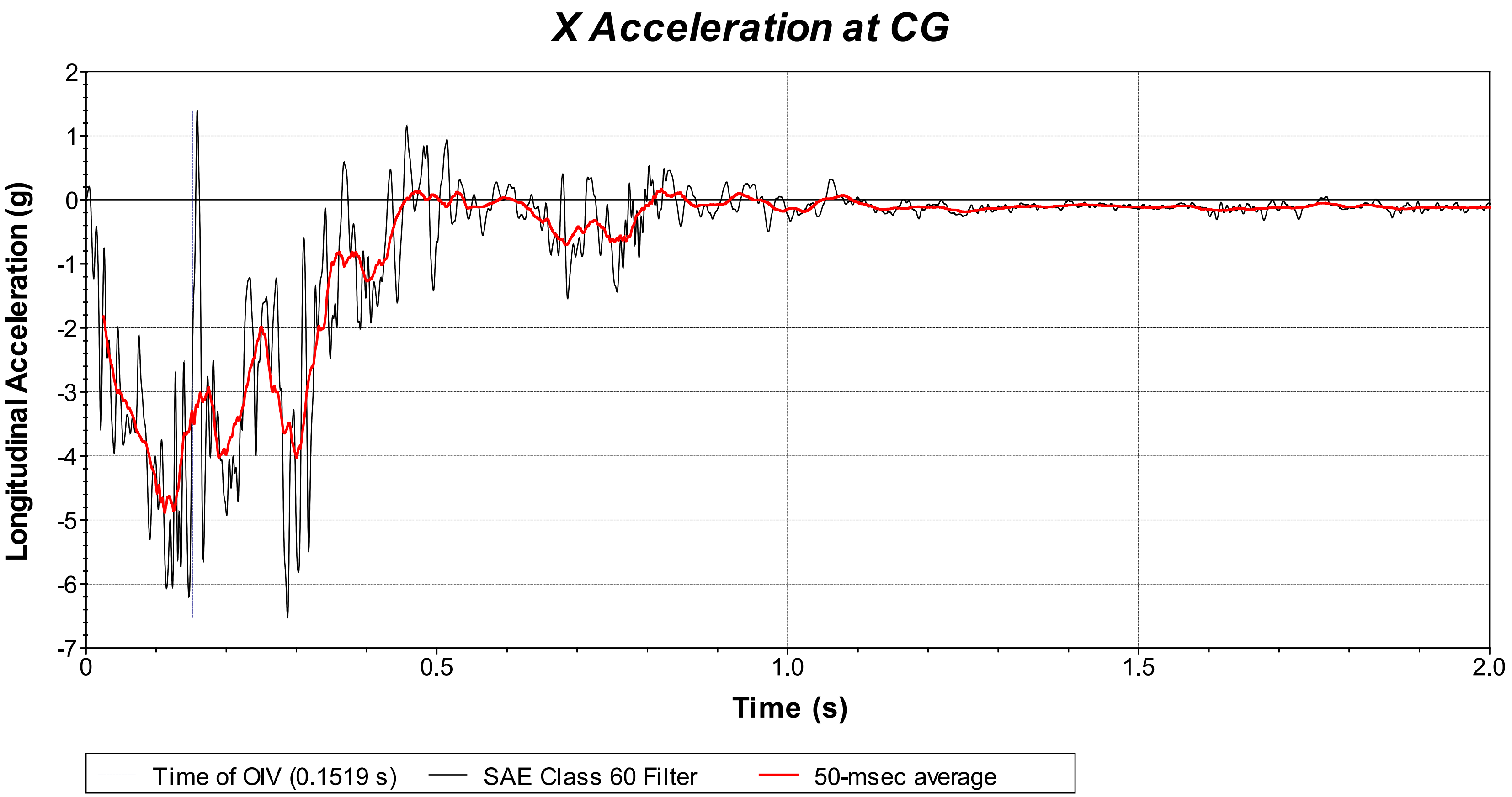


Figure D.2. Vehicle Angular Displacements for Test No. 614341-01-1.



Test Number: 614341 01 1
Test Standard Test Number: *MASH* Test 3-11
Test Article: Roadside Thrie Beam
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5057 lb
Gross Mass: 5222 lb
Impact Speed: 60.4 mi/h
Impact Angle: 25.9°

Figure D.3. Vehicle Longitudinal Accelerometer Trace for Test No. 614341-01-1 (Accelerometer Located at Center of Gravity).

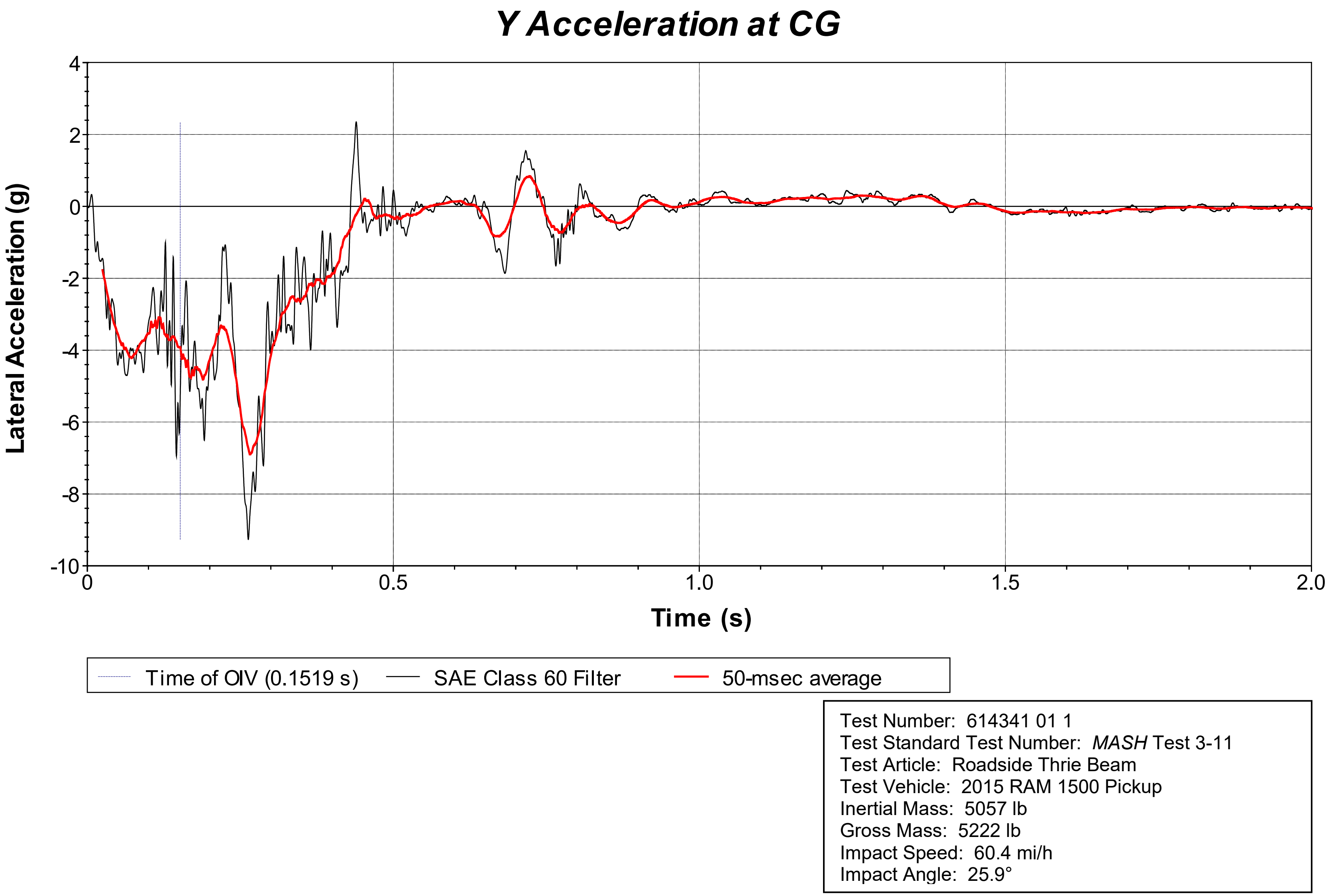
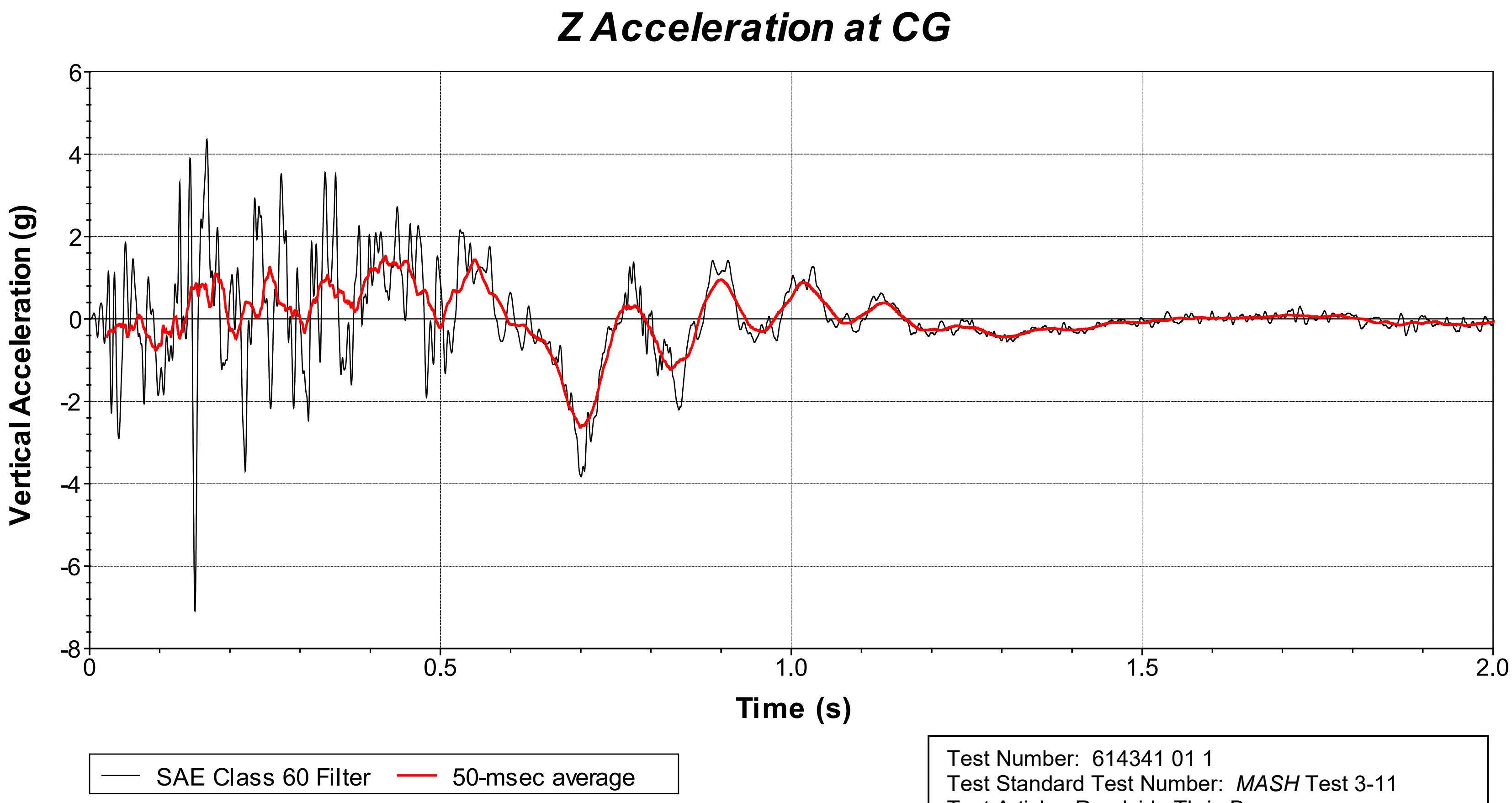


Figure D.4. Vehicle Lateral Accelerometer Trace for Test No. 614341-01-1 (Accelerometer Located at Center of Gravity).



Test Number: 614341 01 1
Test Standard Test Number: *MASH* Test 3-11
Test Article: Roadside Thrie Beam
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5057 lb
Gross Mass: 5222 lb
Impact Speed: 60.4 mi/h
Impact Angle: 25.9°

Figure D.5. Vehicle Vertical Accelerometer Trace for Test No. 614341-01-1 (Accelerometer Located at Center of Gravity).

APPENDIX E. *MASH* TEST 3-21 (CRASH TEST NO. 614341-01-3)

E.1. VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 614341-01-3.

Date: 2021-8-20 Test No.: 614341-01-3 VIN No.: 1C6RR6FT9FS613465

Year: 2015 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 115616

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

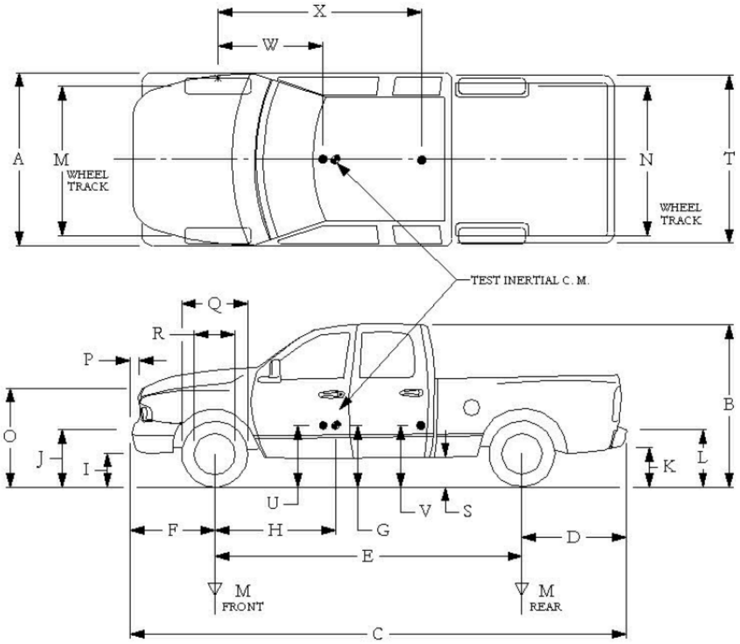
NOTES: None

Engine Type: V-8
Engine CID: 5.7L

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	28.50	L	30.00	Q	30.50	V	30.25
C	227.50	H	62.22	M	68.50	R	18.00	W	62.20
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2927	2796	2881
Back	3900	M_{rear}	2087	2223	2303
Total	6700	M_{Total}	5014	5019	5184

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

Mass Distribution:
lb LF: 1374 RF: 1422 LR: 1101 RR: 1122

Table E.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 614341-01-3.

Date: 2021-8-20 Test No.: 614341-01-3 VIN: 1C6RR6FT9FS613465

Year: 2015 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 115616

Engine: 5.7L V-8 Transmission: Automatic

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

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

Measured Vehicle Weights: (lb)						
LF:	1374	RF:	1422	Front Axle:	2796	
LR:	1101	RR:	1122	Rear Axle:	2223	
Left:	2475	Right:	2544	Total:	5019	
					5000 ±110 lb allowed	
Wheel Base:	140.50 inches	Track: F:	68.50 inches	R:	68.00	inches
	148 ±12 inches allowed		Track = (F+R)/2 = 67 ±1.5 inches allowed			
Center of Gravity, SAE J874 Suspension Method						
X:	62.23 inches	Rear of Front Axle	(63 ±4 inches allowed)			
Y:	0.47 inches	Left - Right +	of Vehicle Centerline			
Z:	28.50 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 E.3. Exterior Crush Measurements for Test No. 614341-01-3.

Date: 2021-8-20 Test No.: 614341-01-3 VIN No.: 1C6RR6FT9FS613465

Year: 2015 Make: RAM Model: 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bmp ht	14	14	37	-	-	-	-	-	-	24
2	Side plane at bmp ht	14	17	46	-	-	-	-	-	-	63
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

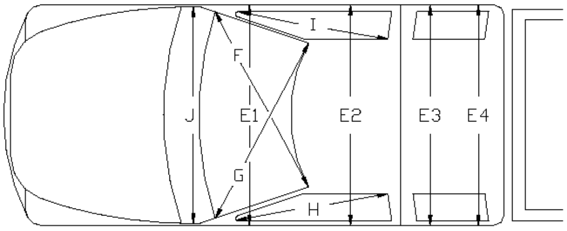
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

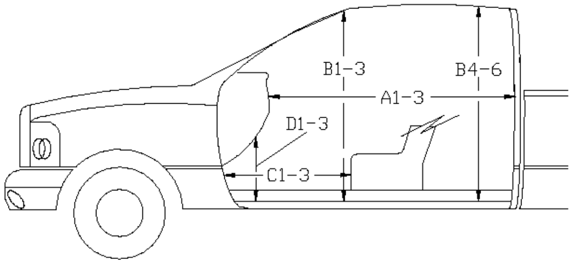
***Measure and document on the vehicle diagram the location of the maximum crush.

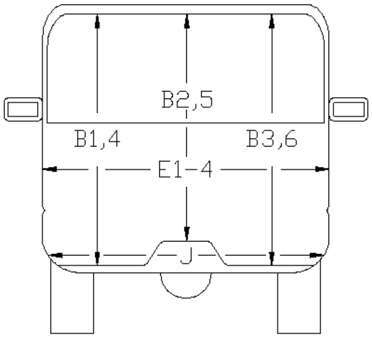
Note: Use as many lines/columns as necessary to describe each damage profile.

Table E.4. Occupant Compartment Measurements for Test No. 614341-01-3.

Date:	2021-8-20	Test No.:	614341-01-3	VIN No.:	1C6RR6FT9FS613465
Year:	2015	Make:	RAM	Model:	1500





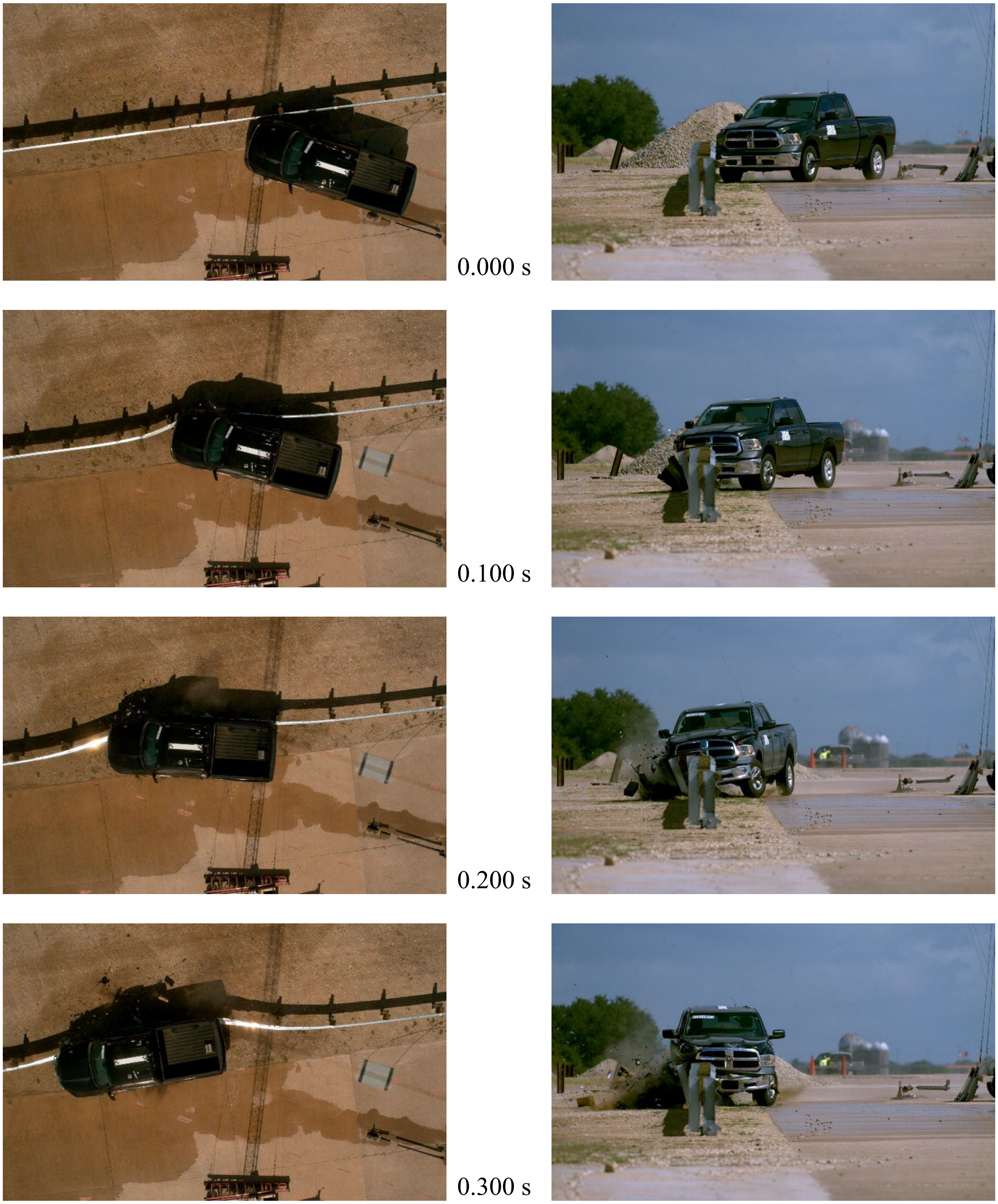


OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

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

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

E.2. SEQUENTIAL PHOTOGRAPHS



0.000 s

0.100 s

0.200 s

0.300 s

Figure E.1. Sequential Photographs for Test No. 614341-01-3 (Overhead and Frontal Views).

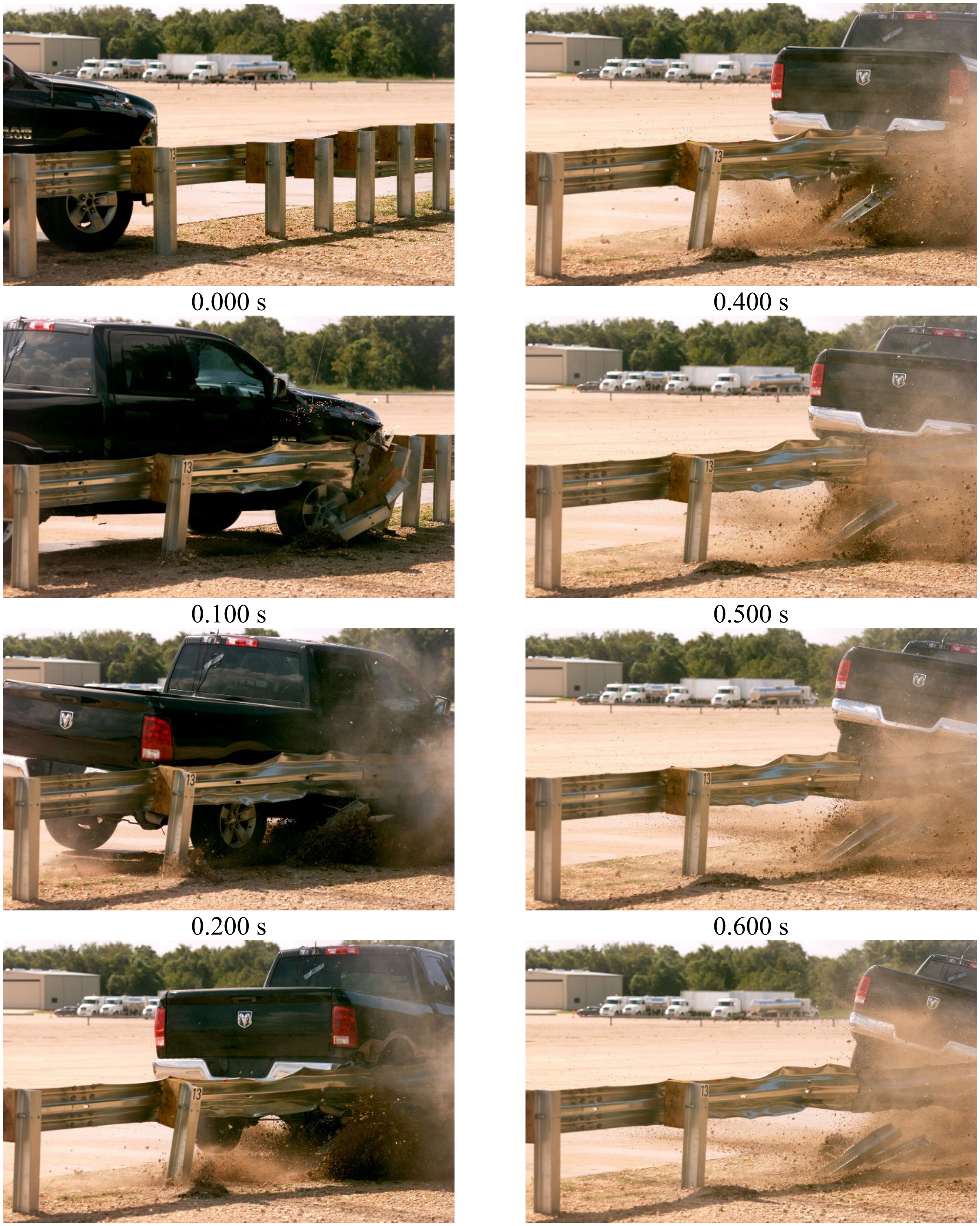

0.400 s


0.500 s


0.600 s


0.700 s

Figure E.1. Sequential Photographs for Test No. 614341-01-3 (Overhead and Frontal Views) (Continued).



0.000 s

0.100 s

0.200 s

0.300 s

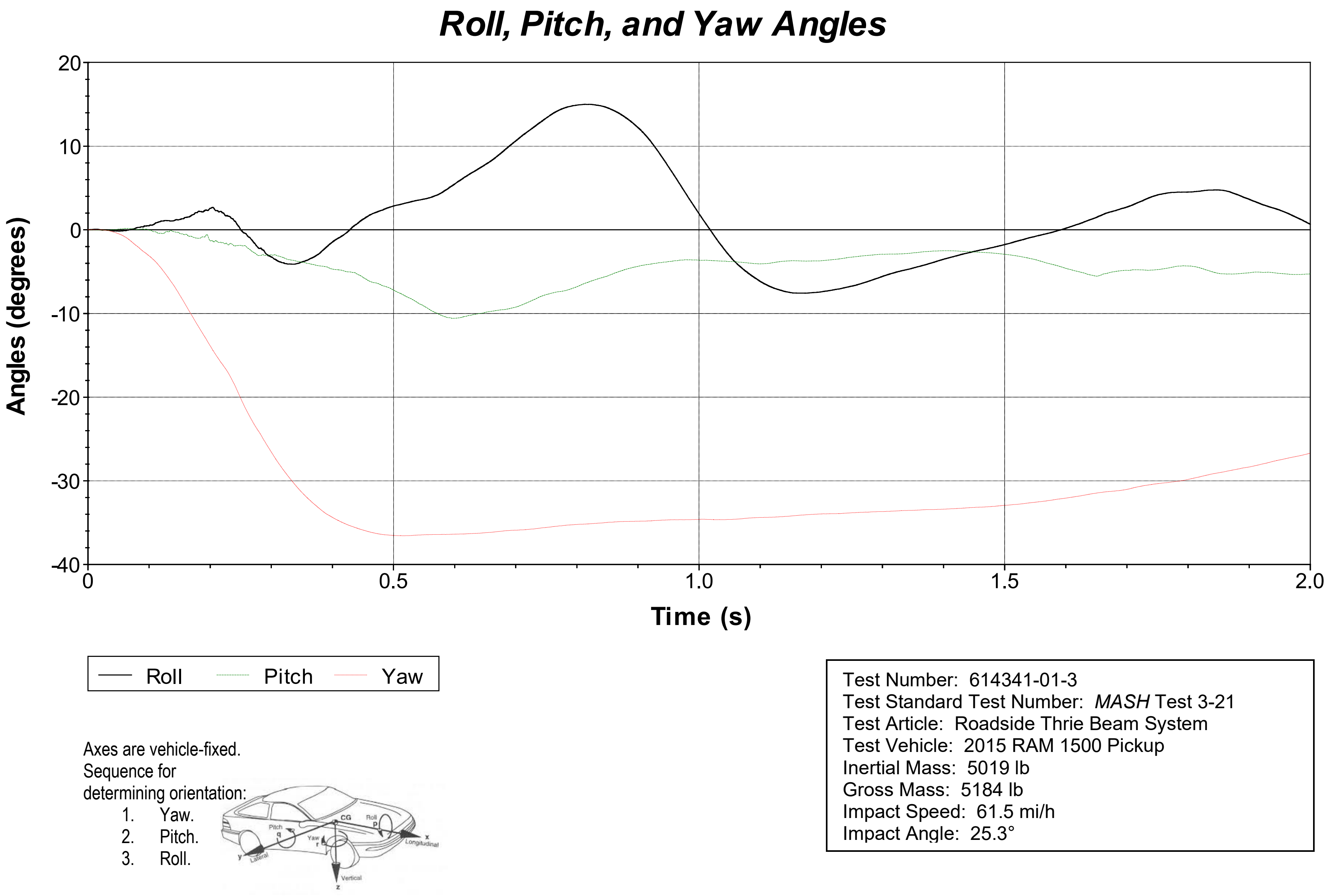
0.400 s

0.500 s

0.600 s

0.700 s

Figure E.2. Sequential Photographs for Test No. 614341-01-3 (Rear View).

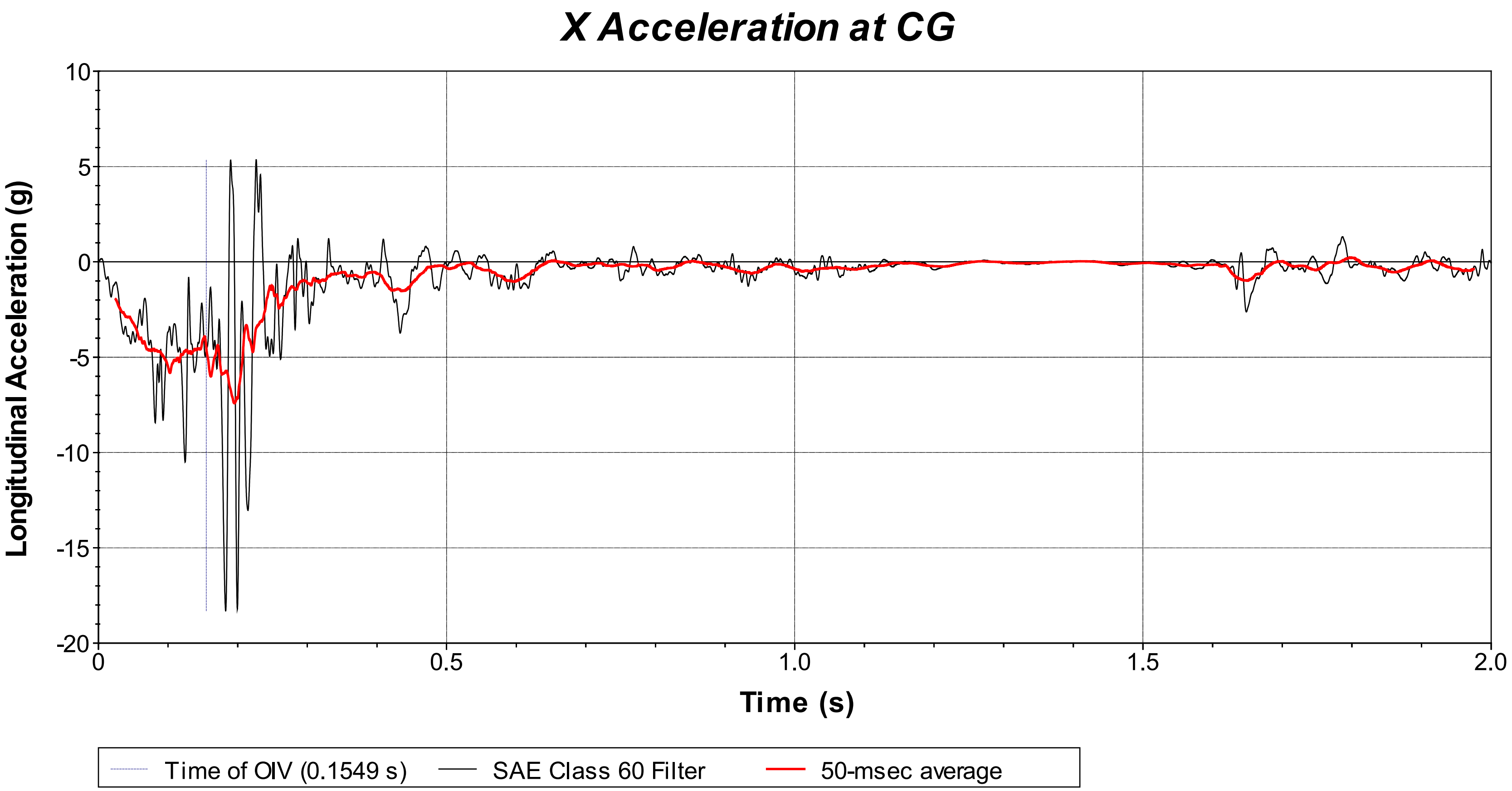


Axes are vehicle-fixed.
Sequence for
determining orientation:

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

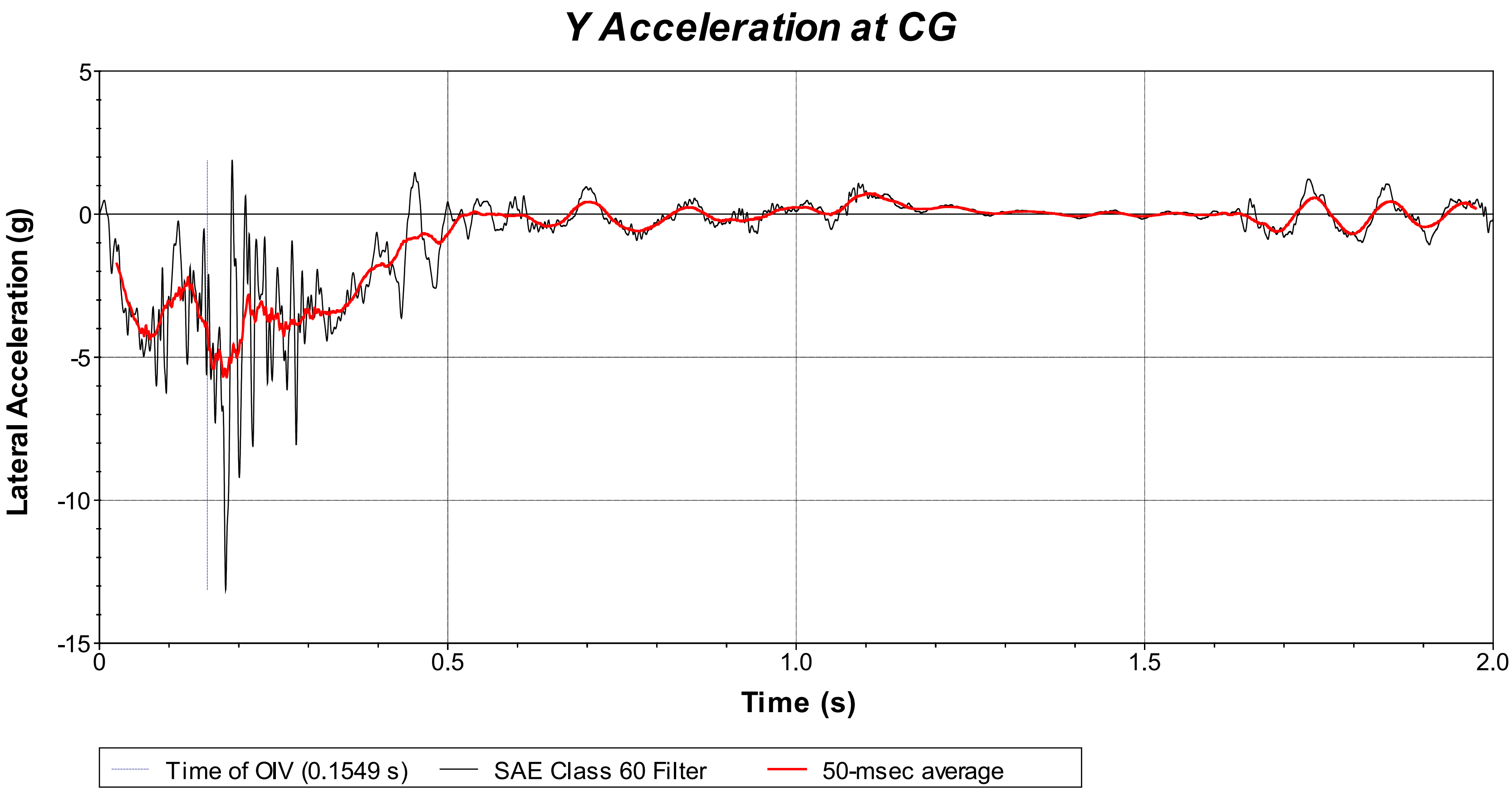
Test Number: 614341-01-3
Test Standard Test Number: *MASH* Test 3-21
Test Article: Roadside Thrie Beam System
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5019 lb
Gross Mass: 5184 lb
Impact Speed: 61.5 mi/h
Impact Angle: 25.3°

Figure E.3. Vehicle Angular Displacements for Test No. 614341-01-3.



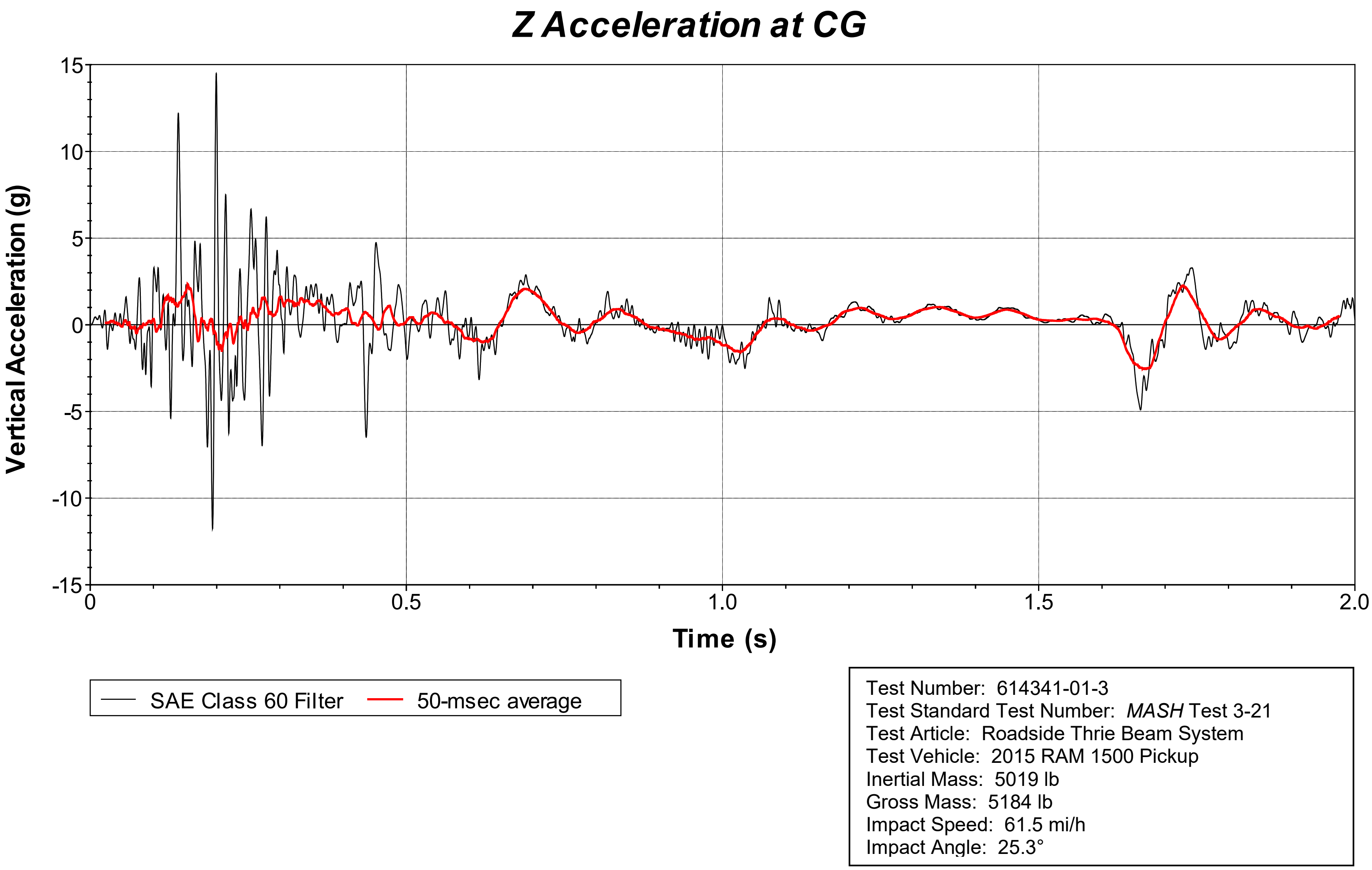
Test Number: 614341-01-3
Test Standard Test Number: *MASH* Test 3-21
Test Article: Roadside Thrie Beam System
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5019 lb
Gross Mass: 5184 lb
Impact Speed: 61.5 mi/h
Impact Angle: 25.3°

Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 614341-01-3 (Accelerometer Located at Center of Gravity).



Test Number: 614341-01-3
Test Standard Test Number: *MASH* Test 3-21
Test Article: Roadside Thrie Beam System
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5019 lb
Gross Mass: 5184 lb
Impact Speed: 61.5 mi/h
Impact Angle: 25.3°

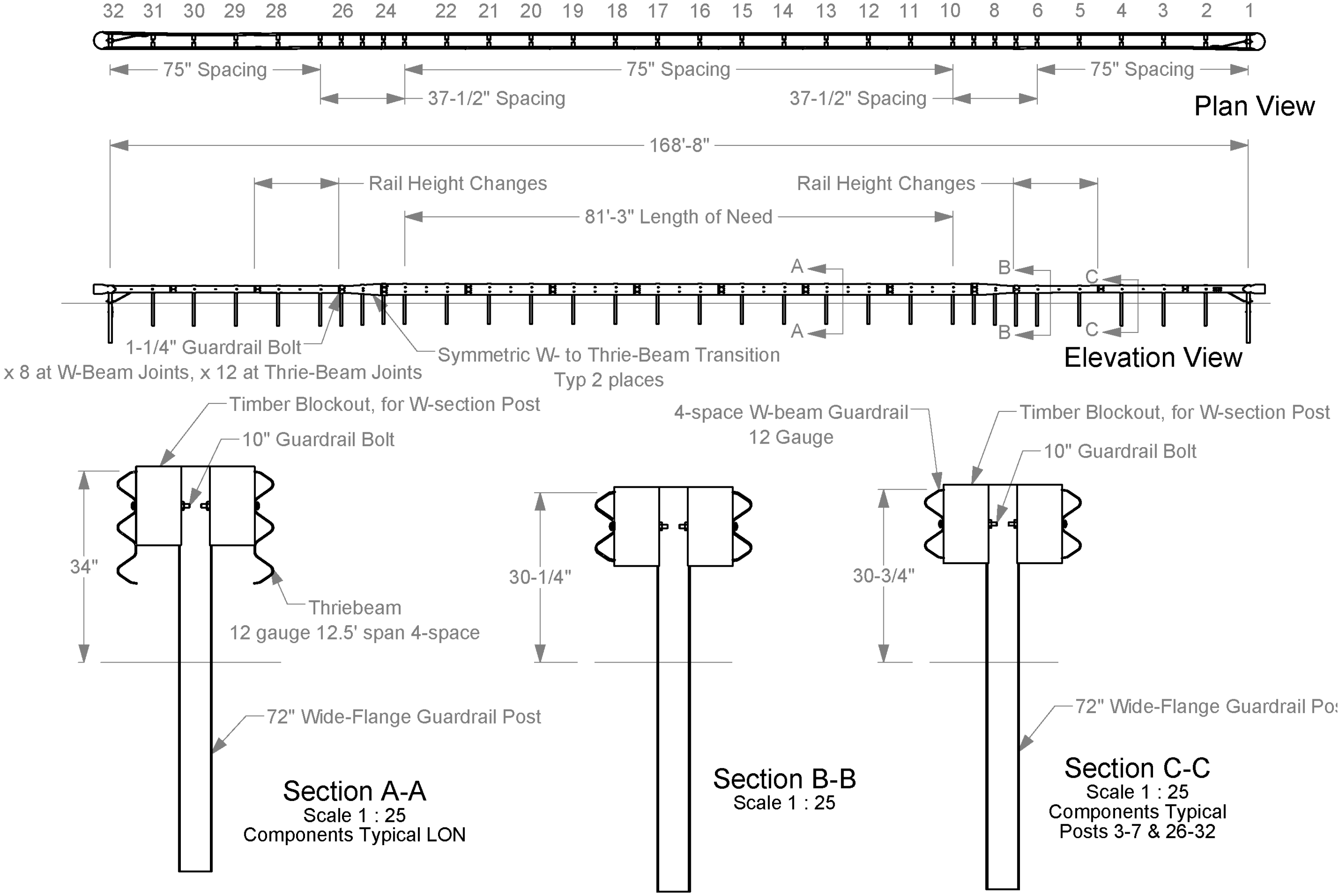
Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 614341-01-3 (Accelerometer Located at Center of Gravity).



Test Number: 614341-01-3
Test Standard Test Number: *MASH* Test 3-21
Test Article: Roadside Thrie Beam System
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5019 lb
Gross Mass: 5184 lb
Impact Speed: 61.5 mi/h
Impact Angle: 25.3°

Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 614341-01-3 (Accelerometer Located at Center of Gravity).

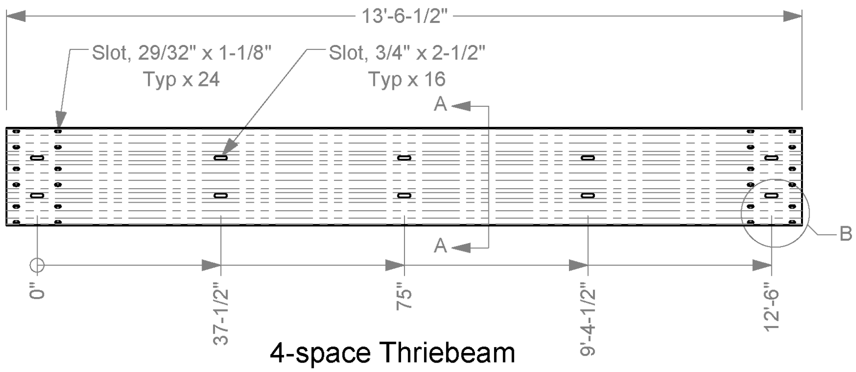
- Test Installation



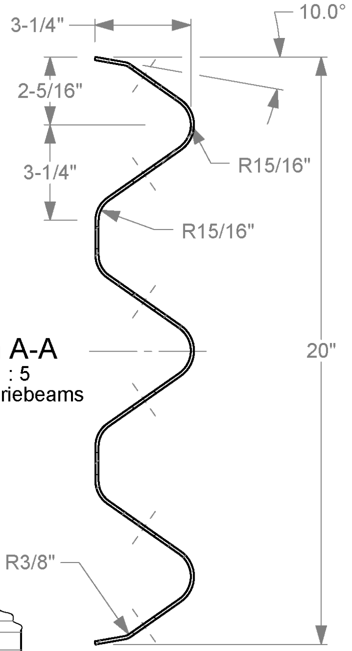
1a. Backfill Post holes with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.
1b. All steel parts shall be galvanized.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division Proving Ground	
Project #614341 Thrie-Beam Median		2021-(
Drawn by WS/GS	Scale 1:250	Sheet 1 of 1 Test Installation

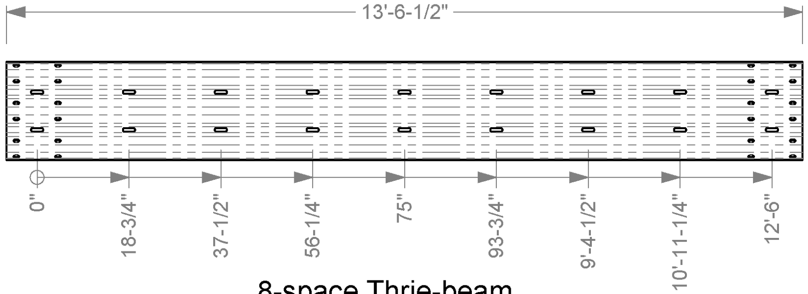
Q:\Accreditation-17025-2017\EIR-000 Project Files\614341 - Thrie-Beam Roadside-Median - Kiani\Drafting, 614341\614341 Median Drawing



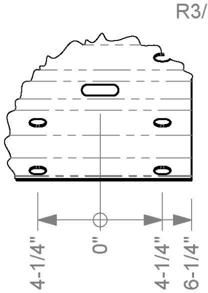
4-space Thriebeam



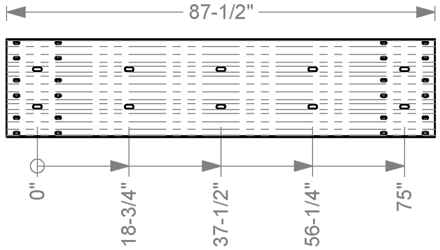
Section A-A
Scale 1 : 5
Typical all Thriebeams



8-space Thrie-beam
Dimensions not shown here same as 4-space Thriebeam



Detail B
Scale 1 : 10
Typical all Thriebeams,
both ends



Thriebeam, 12 gauge 75" span
Dimensions not shown here same as 4-space Thriebeam

1a. 12 gauge is 0.1046" before galvanizing and 0.1084" after, and 10 gauge is 0.1345" before galvanizing and 0.1382" after.
1b. Not all versions shown here used in all installations.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Thrie-beam			2020-03-31
Drawn by GES	Scale 1:30	Sheet 1 of 1	

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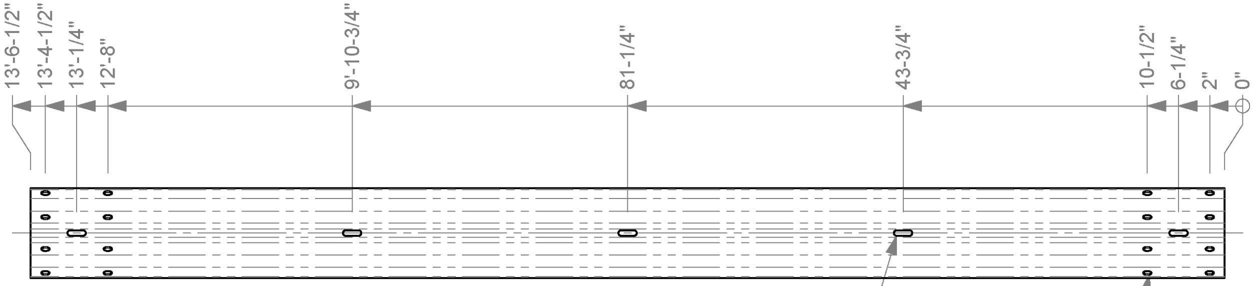
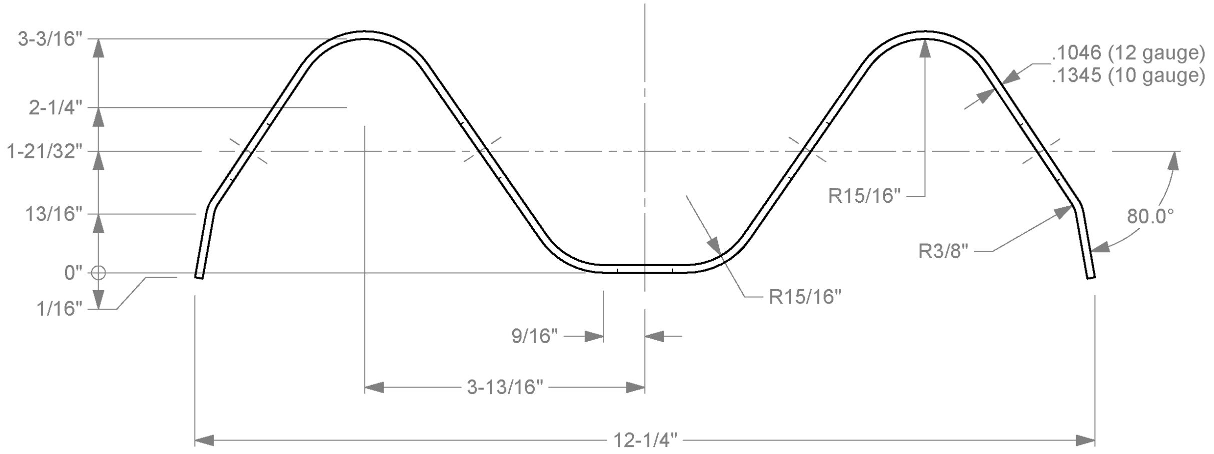


Elevation View

3/4" x 2-1/2" Slot
Typ x 5
See 1b

29/32" x 1-1/8" Slot
Typ x 8 each end



Section View

1a. Manufacture per AASHTO M180 specifications.

1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

Texas A&M Transportation Institute

Roadside Safety and
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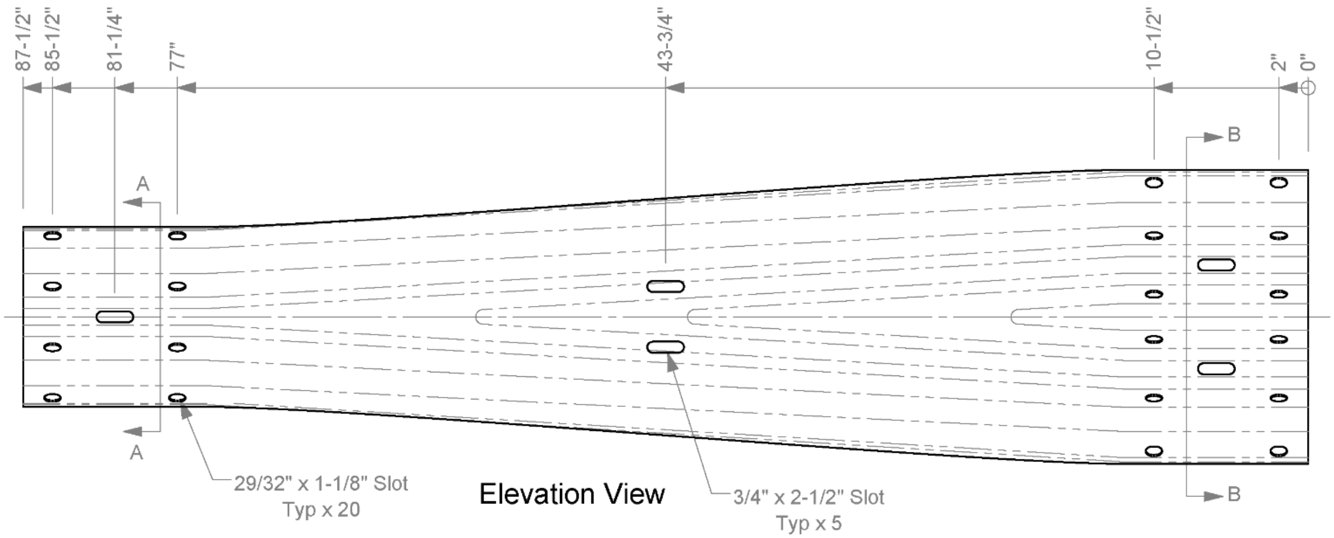
4-space W-beam Guardrail	2020-06-05

Drawn by GES	Scale 1:20	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-Beam Guardrail

W- to Thrie-Beam, symmetric

10 gauge



Elevation View

Section A-A
See W-beam Drawing

Section B-B
See Thrie-beam Drawing

Texas A&M Transportation Institute

Roadside Safety and
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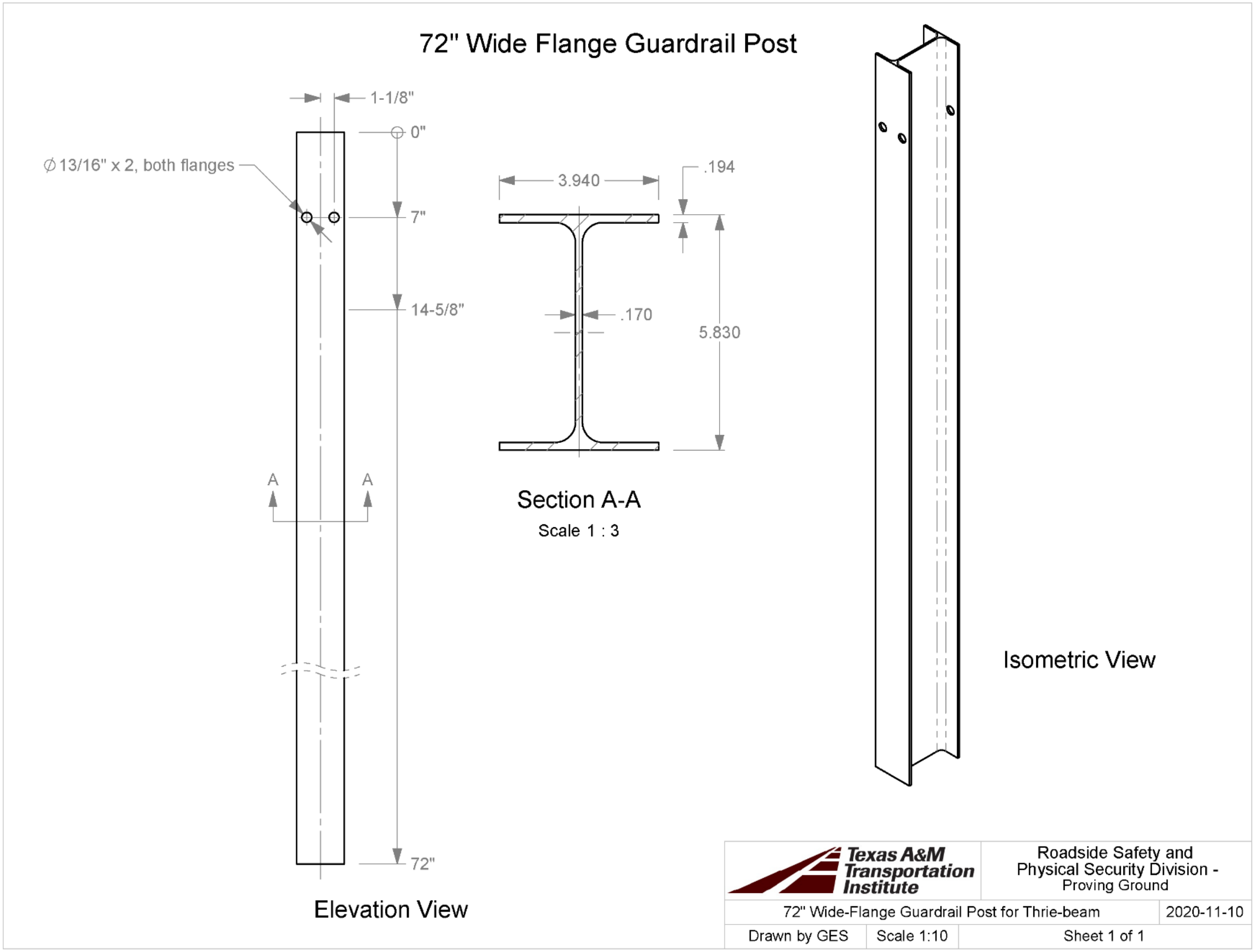
Symmetric W- to Thre-beam Transition
2020-10-13

Drawn by GES
Scale 1:10
Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts\Guardrail Drawings\W- to Thrie-Beam, symmetric



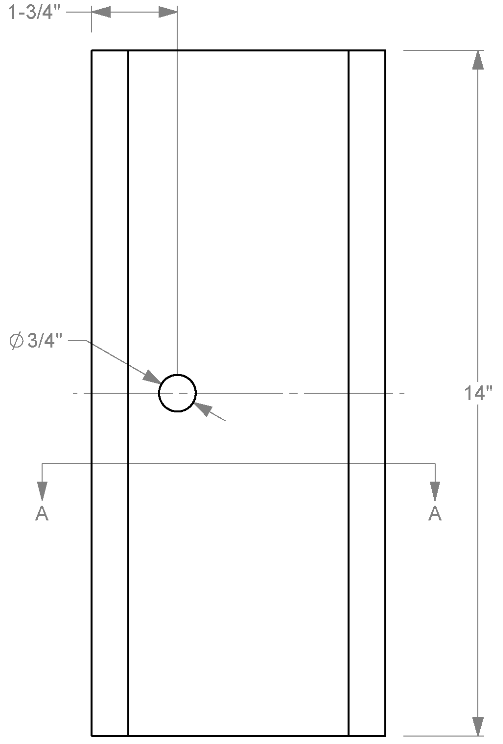
Roadside Safety and Physical Security Division - Proving Ground

72" Wide-Flange Guardrail Post for Thrie-beam 2020-11-10

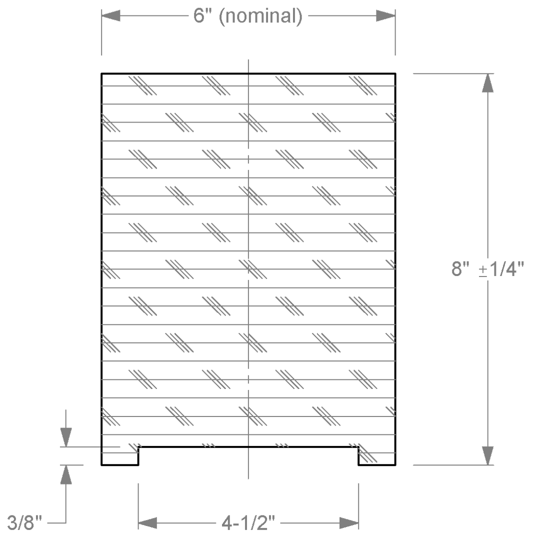
Drawn by GES Scale 1:10 Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

Timber Blockout for W-section Post



Elevation View

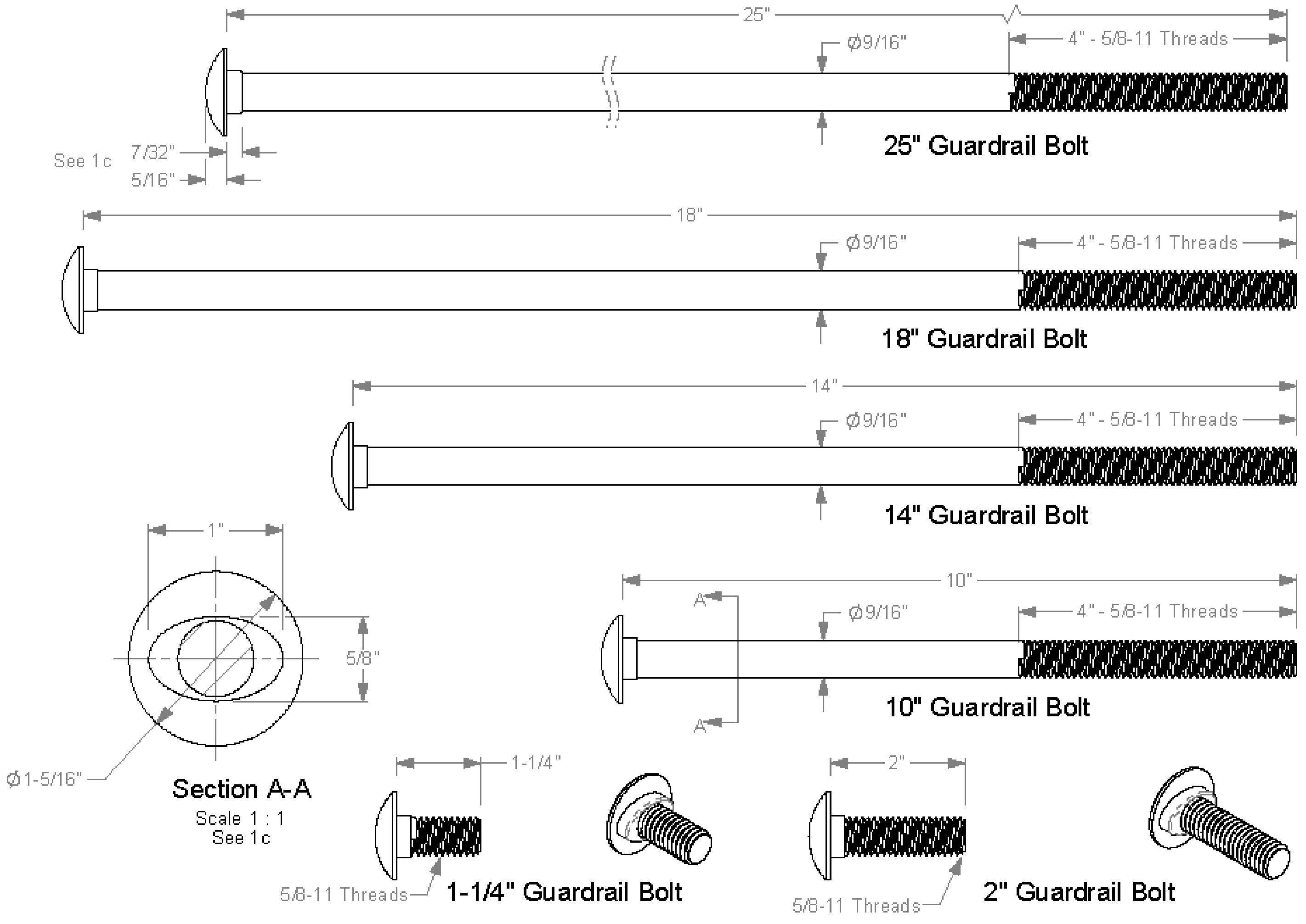


Section A-A

1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Timber Blockout, for W-section Post		2019-07-03
Drawn by GES	Scale 1:3	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Timber Blockout for W-section Post

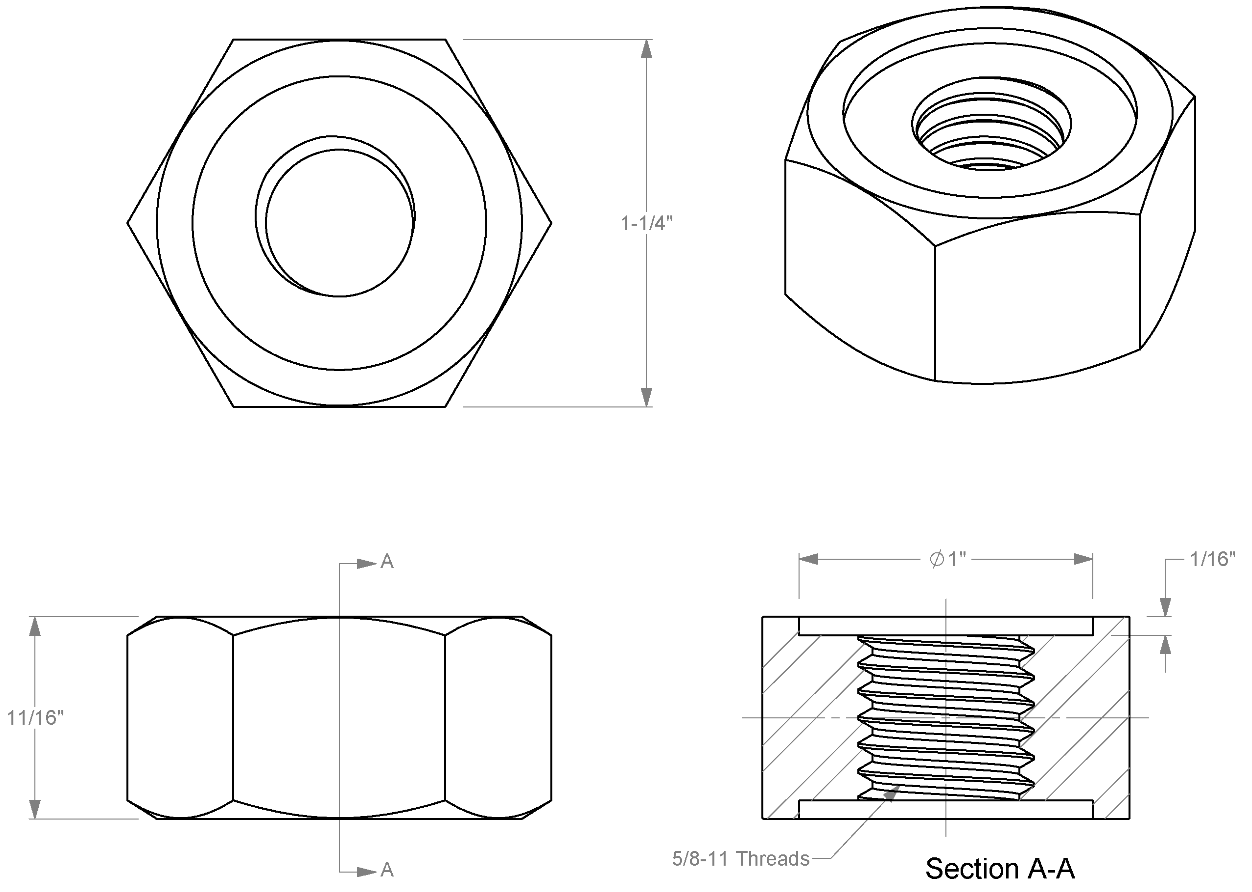


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Guardrail Bolt		2020-04-22
Drawn by GES/WS	Scale 1:2	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts\Guardrail Drawings\Guardrail Bolt

Recessed Guardrail Nut



1a. Material is ASTM A 563 Grade A.

Texas A&M Transportation Institute

Roadside Safety and
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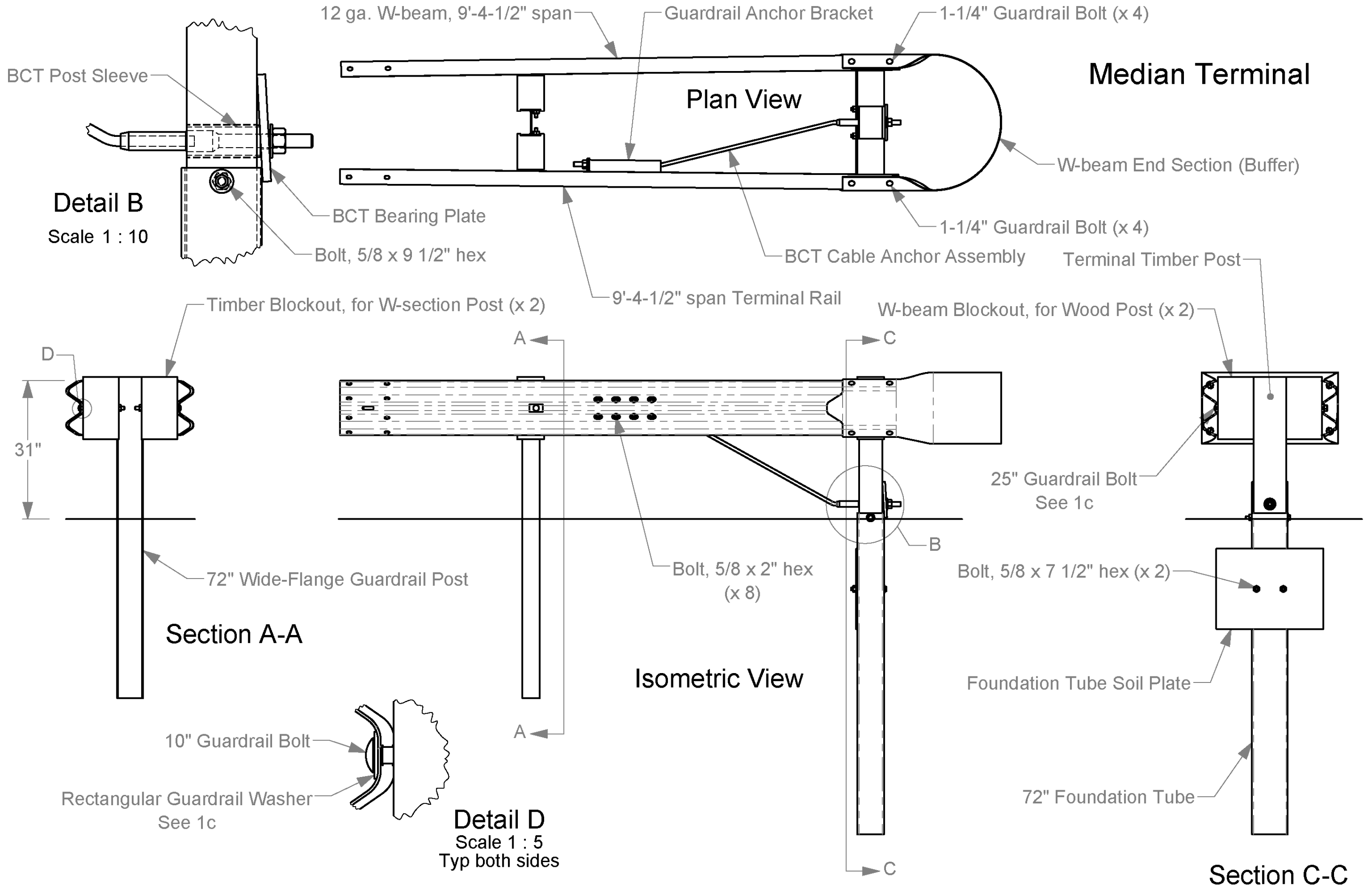
Proving Ground

Recessed Guardrail Nut
2019-06-27

Drawn by GES
Scale 2:1
Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Nut, Recessed Guardrail



1a. All steel components, including hardware, are galvanized.

1b. Recessed Guardrail Nuts on all 5/8 bolts. Hex Head bolts are ASTM A307. F844 Flat Washer under the head of all hex bolts.

1c. Rectangular Guardrail Washer typical four places; under the head of each Guardrail Bolt at Post 2, and under Bolt head and Nut at Post 1.

Texas A&M
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Institute

Roadside Safety and
Physical Security Division -
Proving Ground

Median Terminal | 2020-02-24

Drawn by GES | Scale 1:30 | Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Median Terminal\01 Median Terminal

APPENDIX G. *MASH* TEST 3-10 (CRASH TEST NO. 614341-01-2)

G.1. VEHICLE PROPERTIES AND INFORMATION

Table G.1. Vehicle Properties for Test No. 614341-01-2.

Date: 2021-09-16 Test No.: 614341-01-2 VIN No.: 3N1CN7APOFL90411

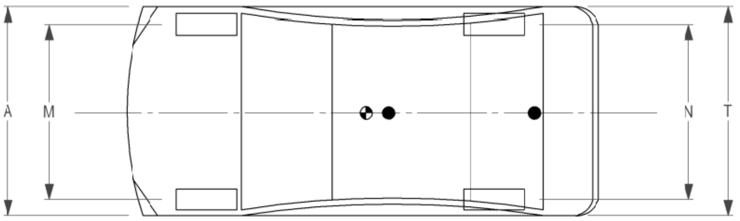
Year: 2015 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 288489 Tire Size: P185/65R15

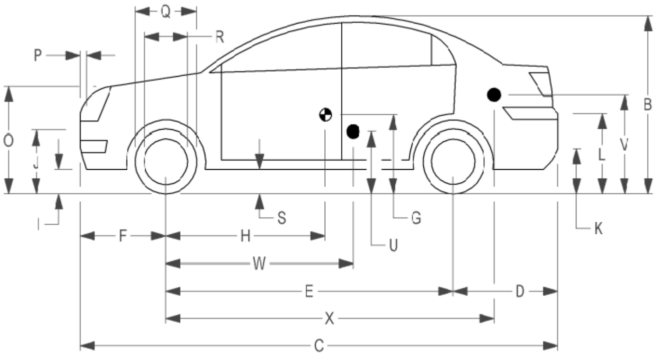
Describe any damage to the vehicle prior to test: None

● 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	40.87	M	58.30	R	16.25	W	40.80
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 -0.07

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}	1475	1475	1560
Back	1687	M_{rear}	994	980	1060
Total	3389	M_{Total}	2469	2455	2620

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

Mass Distribution:
lb LF: 780 RF: 695 LR: 480 RR: 500

Table G.2. Exterior Crush Measurements for Test No. 614341-01-2.

Date: 2021-9-16 Test No.: 614341-01-2 VIN No.: 3N1CN7APOFL90411

Year: 2015 Make: NISSAN Model: VERSA

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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	6	28	-	-	-	-	-	-	14
2	Side plane above bmp ht	14	8	40	-	-	-	-	-	-	60
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

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

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

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

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

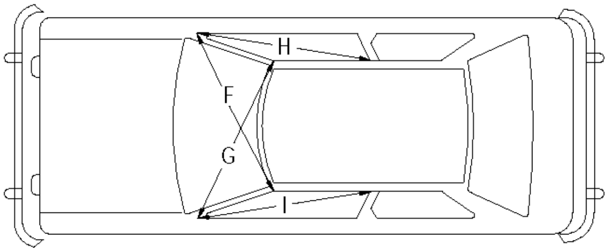
***Measure and document on the vehicle diagram the location of the maximum crush.

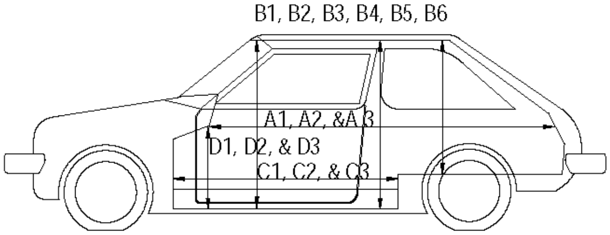
Note: Use as many lines/columns as necessary to describe each damage profile.

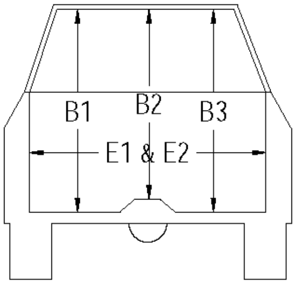
Table G.3. Occupant Compartment Measurements for Test No. 614341-01-2.

Date: 2021-9-16 Test No.: 614341-01-2 VIN No.: 3N1CN7APOFL90411

Year: 2015 Make: NISSAN Model: VERSA





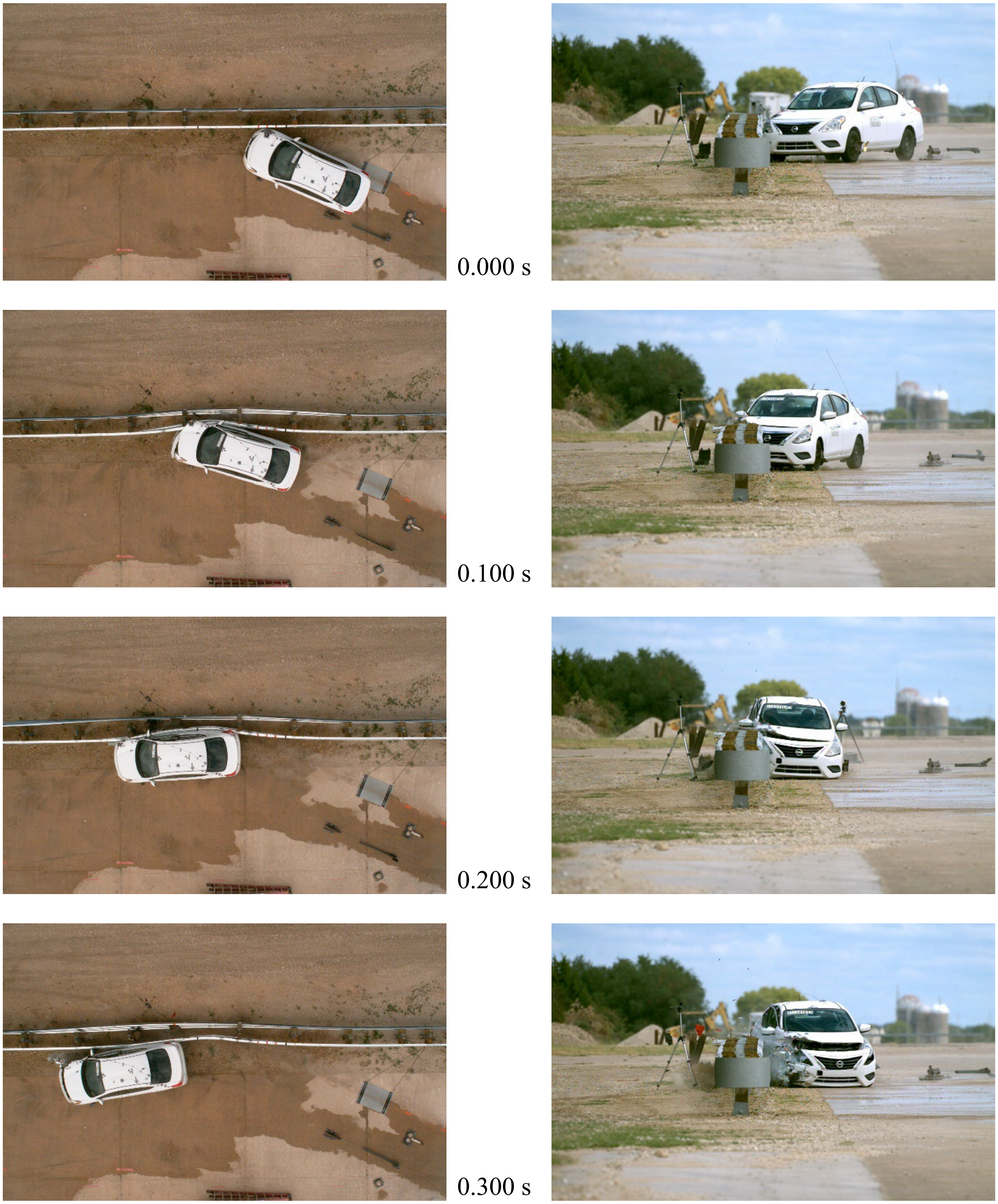


OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	75.00	75.00	0.00
A2	74.00	74.00	0.00
A3	74.00	74.00	0.00
B1	43.00	43.00	0.00
B2	37.00	37.00	0.00
B3	43.00	43.00	0.00
B4	46.50	46.50	0.00
B5	42.50	42.50	0.00
B6	46.50	46.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	23.00	-3.00
D1	12.50	12.50	0.00
D2	0.00	0.00	0.00
D3	10.00	10.00	0.00
E1	45.00	43.00	-2.00
E2	48.75	50.75	2.00
F	47.50	47.50	0.00
G	47.50	47.50	0.00
H	39.00	39.00	0.00
I	39.00	39.00	0.00
J*	48.50	46.00	-2.50

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

G.2. SEQUENTIAL PHOTOGRAPHS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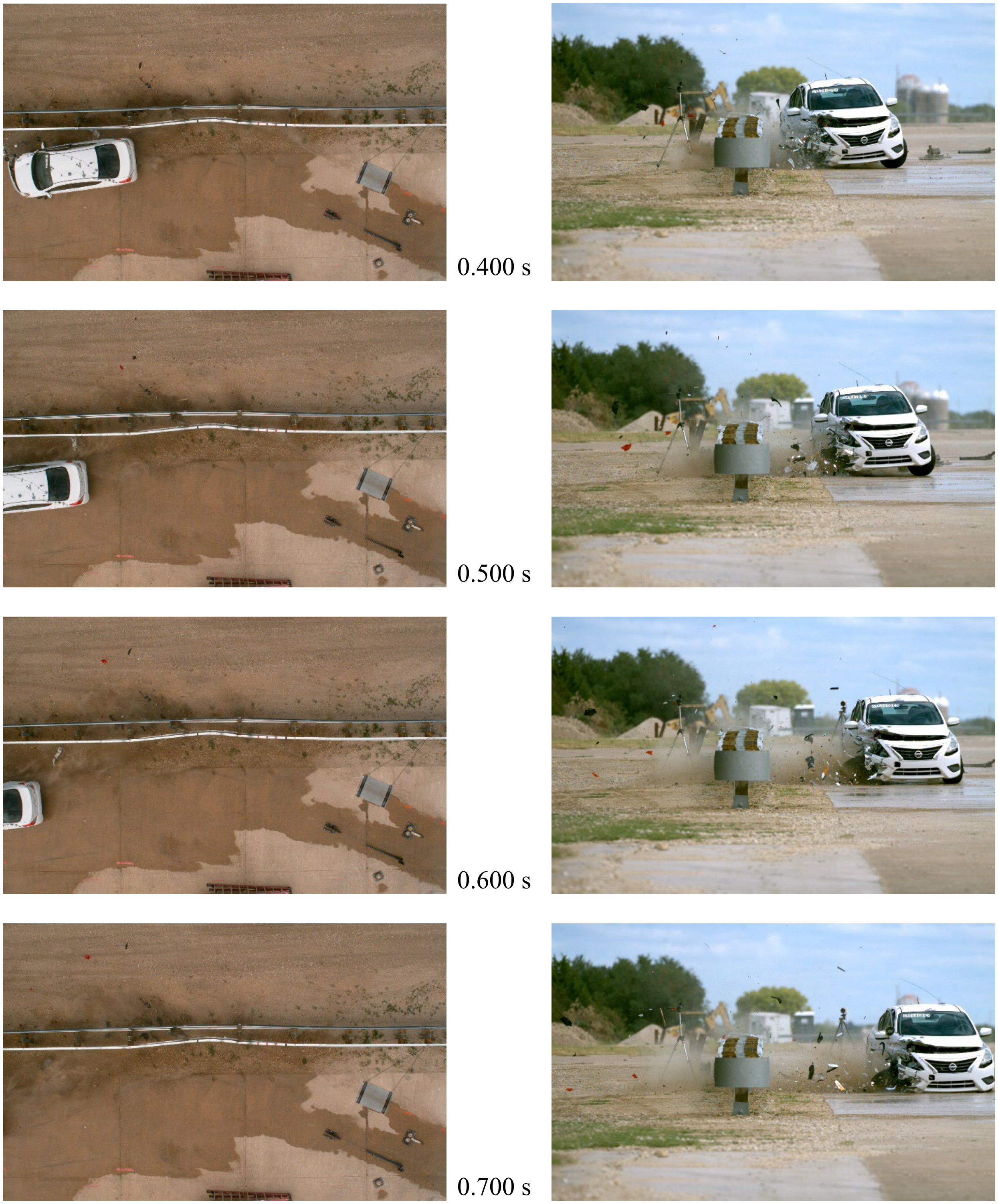
0.100 s

0.200 s

0.300 s

Figure G.1. Sequential Photographs for Test No. 614341-01-2 (Overhead and Frontal Views).



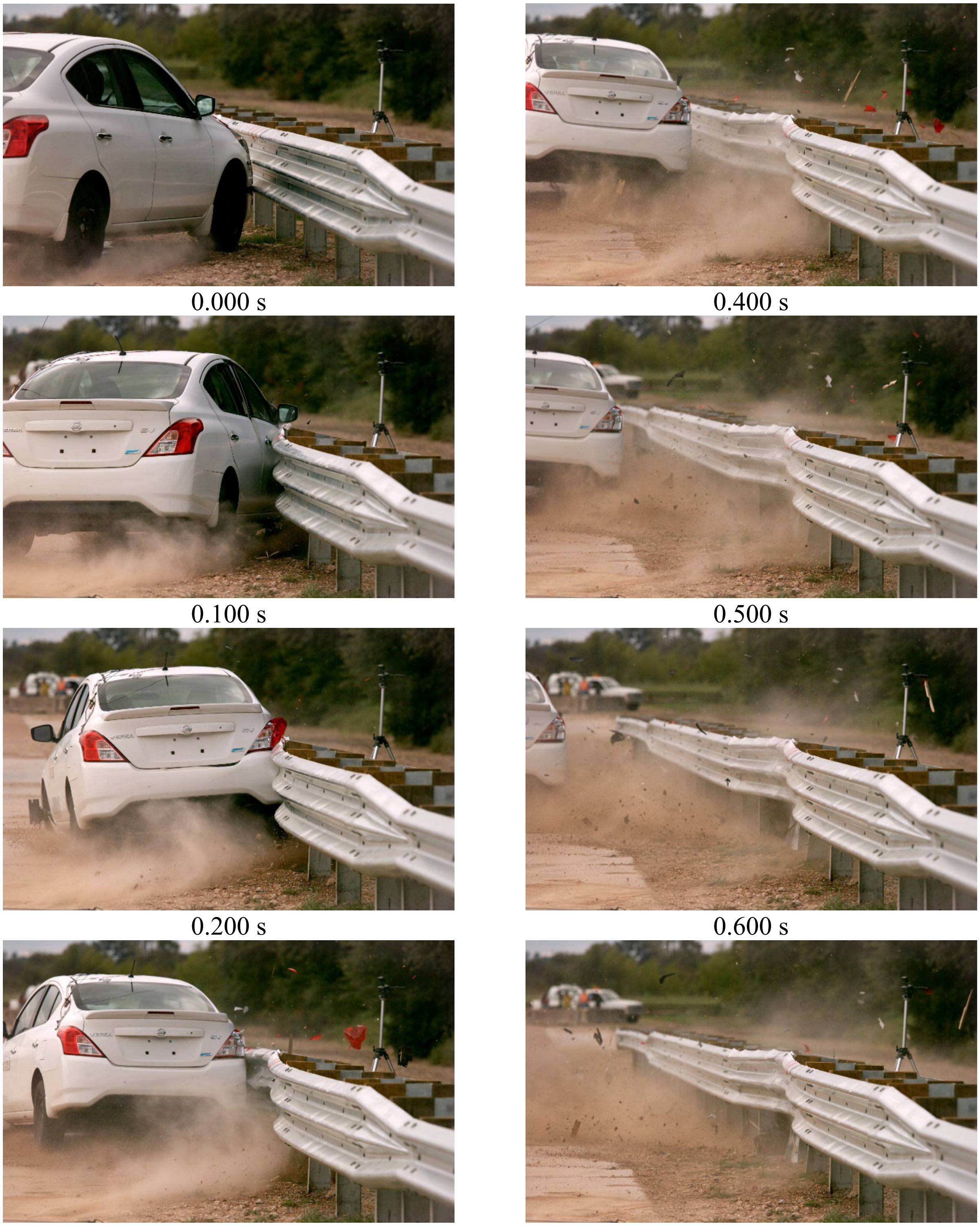
0.400 s

0.500 s

0.600 s

0.700 s

Figure G.1. Sequential Photographs for Test No. 614341 01 2 (Overhead and Frontal Views) (Continued).



0.000 s 0.400 s

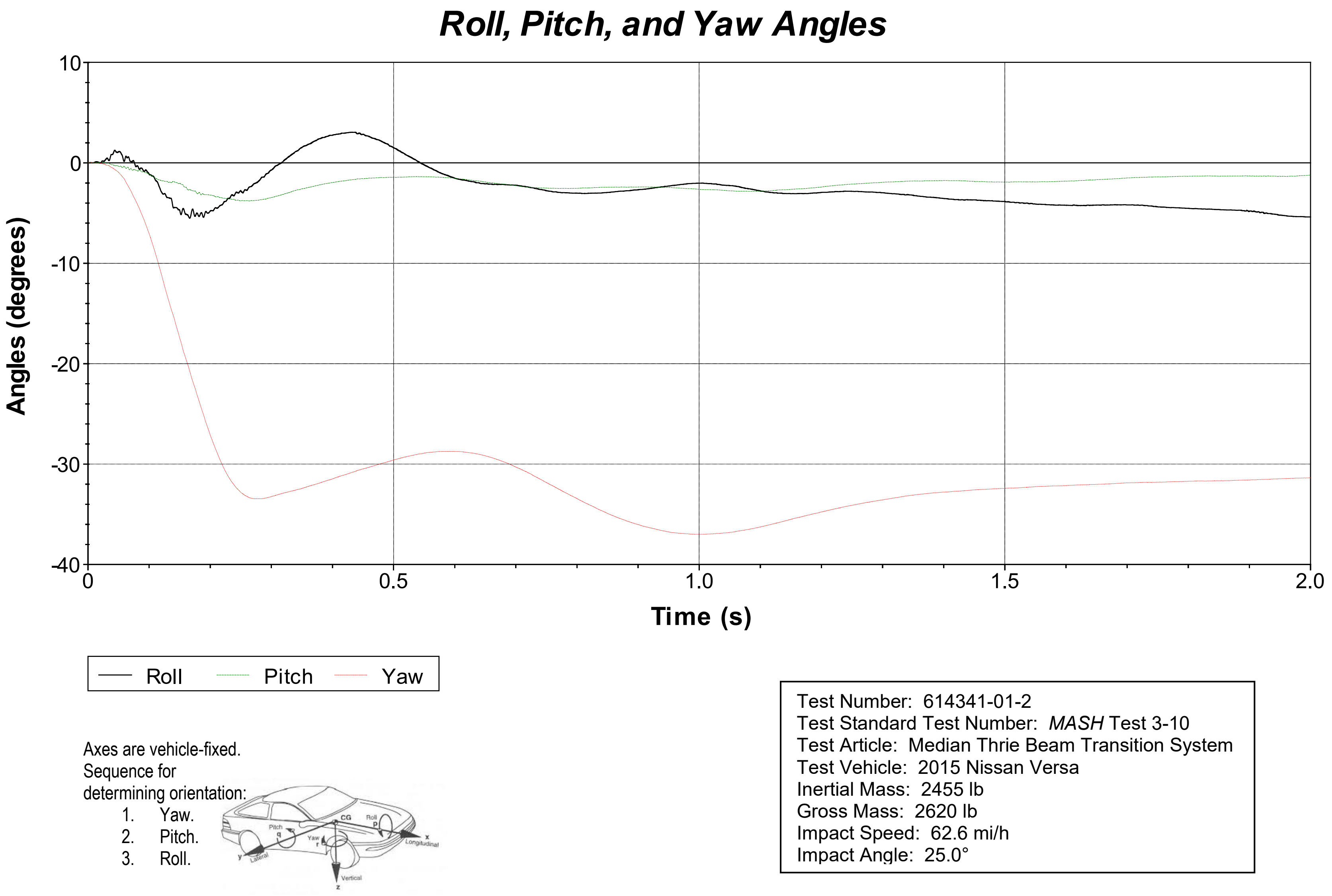
0.100 s 0.500 s

0.200 s 0.600 s

0.300 s 0.700 s

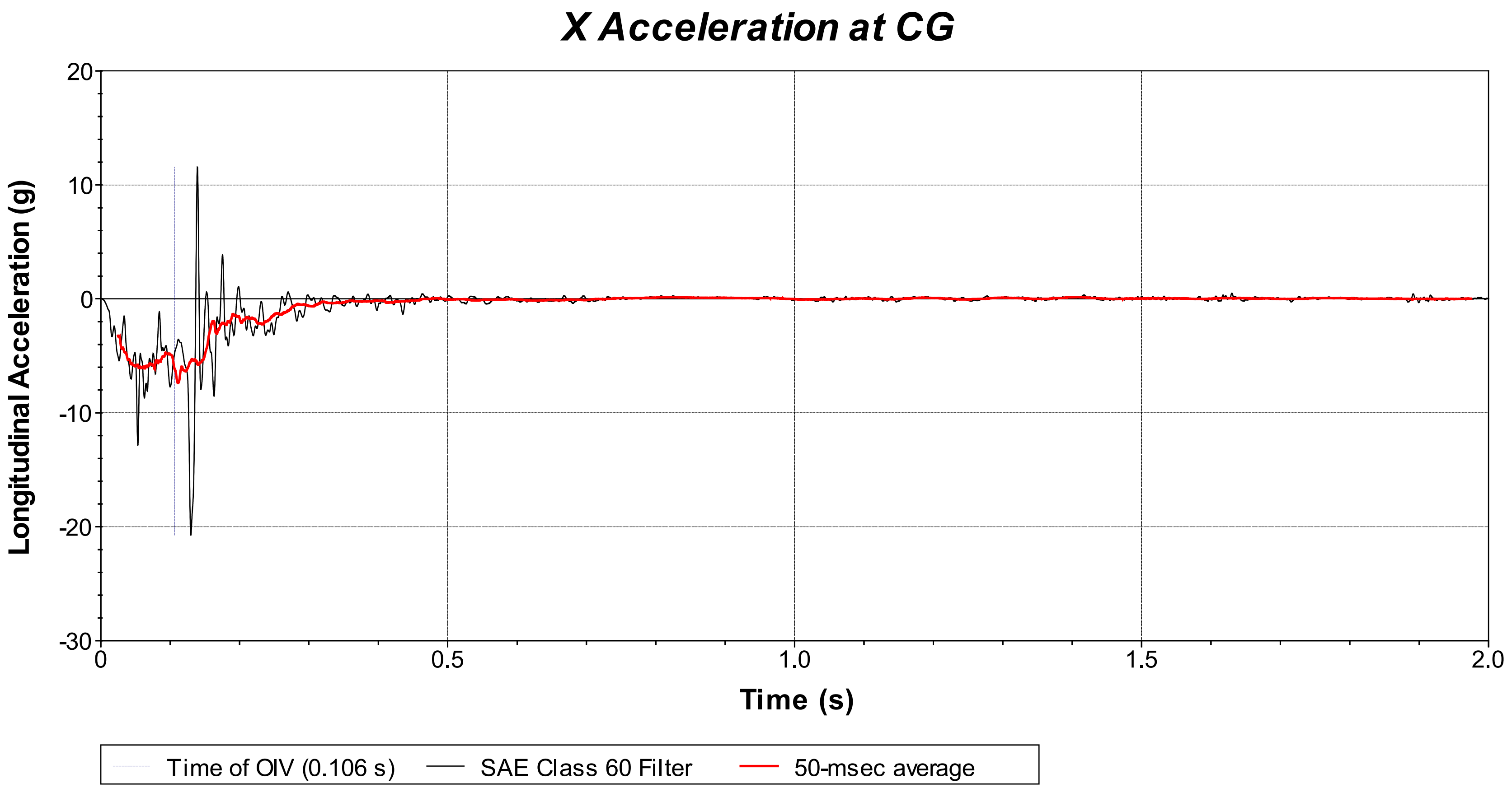
Figure G.2. Sequential Photographs for Test No. 614341-01-2 (Rear View).

G.3. VEHICLE ANGULAR DISPLACEMENTS



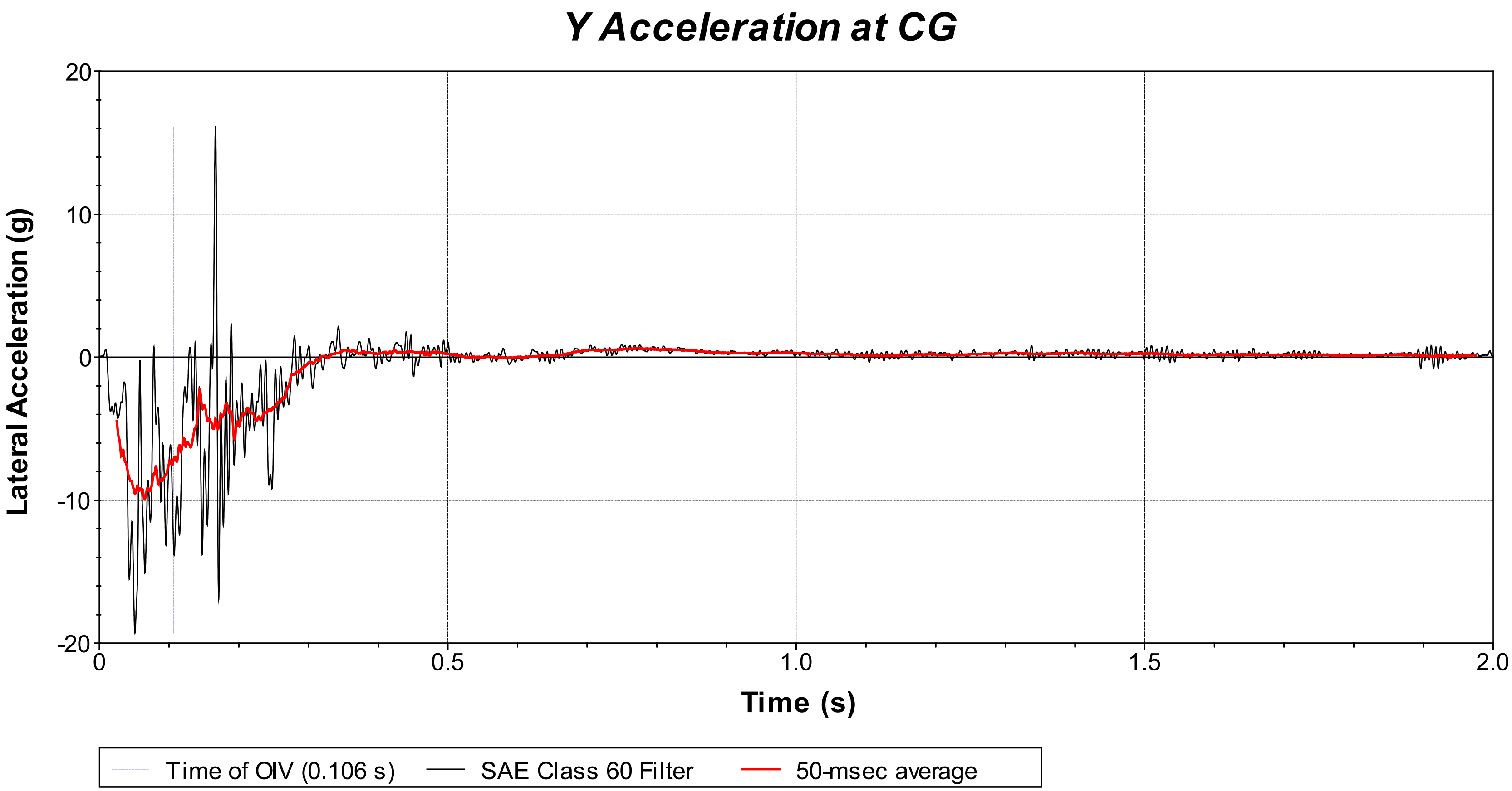
Test Number: 614341-01-2
Test Standard Test Number: *MASH* Test 3-10
Test Article: Median Thrie Beam Transition System
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2455 lb
Gross Mass: 2620 lb
Impact Speed: 62.6 mi/h
Impact Angle: 25.0°

Figure G.3. Vehicle Angular Displacements for Test No. 614341-01-2.



Test Number: 614341-01-2
Test Standard Test Number: *MASH* Test 3-10
Test Article: Median Thrie Beam Transition System
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2455 lb
Gross Mass: 2620 lb
Impact Speed: 62.6 mi/h
Impact Angle: 25.0°

Figure G.4. Vehicle Longitudinal Accelerometer Trace for Test No. 614341-01-2 (Accelerometer Located at Center of Gravity).



Test Number: 614341-01-2
Test Standard Test Number: *MASH* Test 3-10
Test Article: Median Thrie Beam Transition System
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2455 lb
Gross Mass: 2620 lb
Impact Speed: 62.6 mi/h
Impact Angle: 25.0°

Figure G.5. Vehicle Lateral Accelerometer Trace for Test No. 614341-01-2 (Accelerometer Located at Center of Gravity).

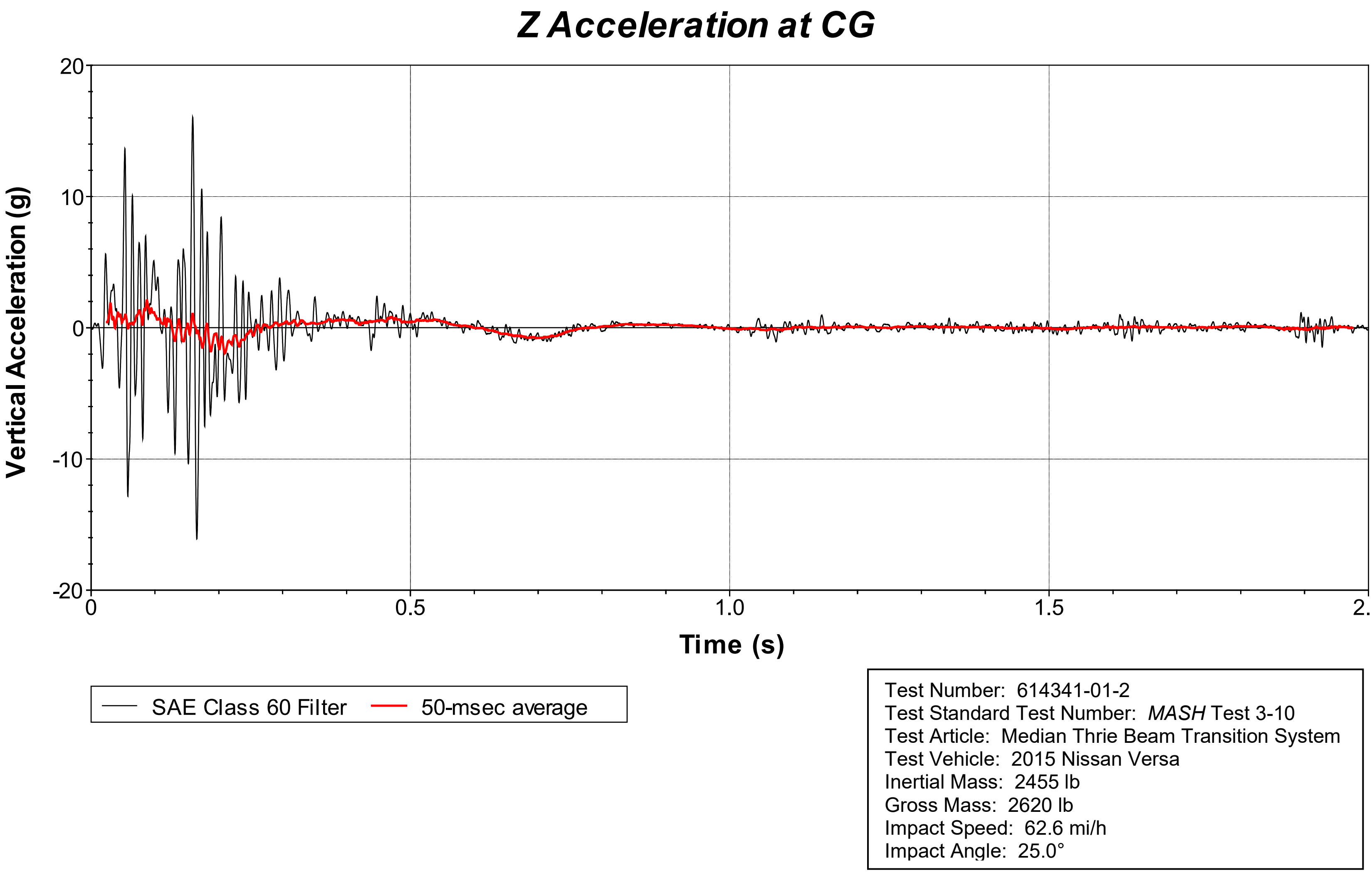


Figure G.6. Vehicle Vertical Accelerometer Trace for Test No. 614341-01-2 (Accelerometer Located at Center of Gravity).