MASH TL-3 TRANSITION BETWEEN MEDIAN GUARDRAIL AND MEDIAN CONCRETE BARRIER

ISO 17025 Laboratory
Testing Certificate # 2821.01

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

Test Report 0-6990-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

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

The purpose of this research was to develop a *Manual for Assessing Safety Hardware* (*MASH*) Test Level 3 (TL-3) compliant transition between a median guardrail and median concrete barrier, and then test the design according to *MASH* TL-3 crash testing guidelines. The design was developed using finite element computer simulations.

This report provides details on the computer simulations, the Texas Department of Transportation (TxDOT) median transition system, the crash tests and results, and the performance assessment of the median transition for *MASH* TL-3 transition evaluation criteria.

The TxDOT median transition met the performance criteria for *MASH* TL-3 transitions.

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and the
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DISCLAIMER

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

TTI PROVING GROUND DISCLAIMER

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

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

CHAPTER 1:
BACKGROUND

1.1 INTRODUCTION

The Texas Department of Transportation (TxDOT) is in the process of implementing roadside safety hardware on Texas highways in compliance with the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*1*). The focus is to enhance safety on Texas highways. TxDOT currently has a *MASH* Test Level 3 (TL-3) compliant double-faced guardrail in use. However, this system needs end termination or connectivity adapters to other barriers. The connectivity between the median guardrail and the median concrete barrier is the transition section. This transition must be *MASH* compliant. There is a safety need to develop a *MASH*-compliant transition between the double-faced median guardrail and the median concrete barrier. Thus, in this study, the Texas A&M Transportation Institute used finite element computer simulations and full-scale crash testing to develop and evaluate a double-faced median guardrail for MASH TL-3 compliance.

1.2 PROBLEM

Transition sections are commonly used to connect a flexible guardrail system to a more rigid barrier (i.e., concrete parapet). The purpose of the transition is to gradually change the stiffness of the rail section so a vehicle impacting the flexible approach rail does not snag severely on the end of the stiffer barrier (*2*). The change in stiffness is generally accomplished through a combination of changing post strength and spacing, and/or increasing the guardrail stiffness.

Transition elements are subject to two crash tests according to AASHTO *MASH*. The two tests are *MASH* Tests 3-20 and 3-21, which consist of the small car vehicle and pickup truck vehicle, respectively. Both tests consist of an impact speed of 62 mi/h and impact angle of 25 degrees. The critical impact point is dependent on the design of the system. Figure 1.1 shows an example of a transition system with impact configurations.

As specified in *MASH* Section 2.2.1.1, two impact regions should be considered for transitions that connect a flexible system to a rigid system. The testing agency should conduct the tests at locations upstream of the rigid system and upstream of the flexible system.

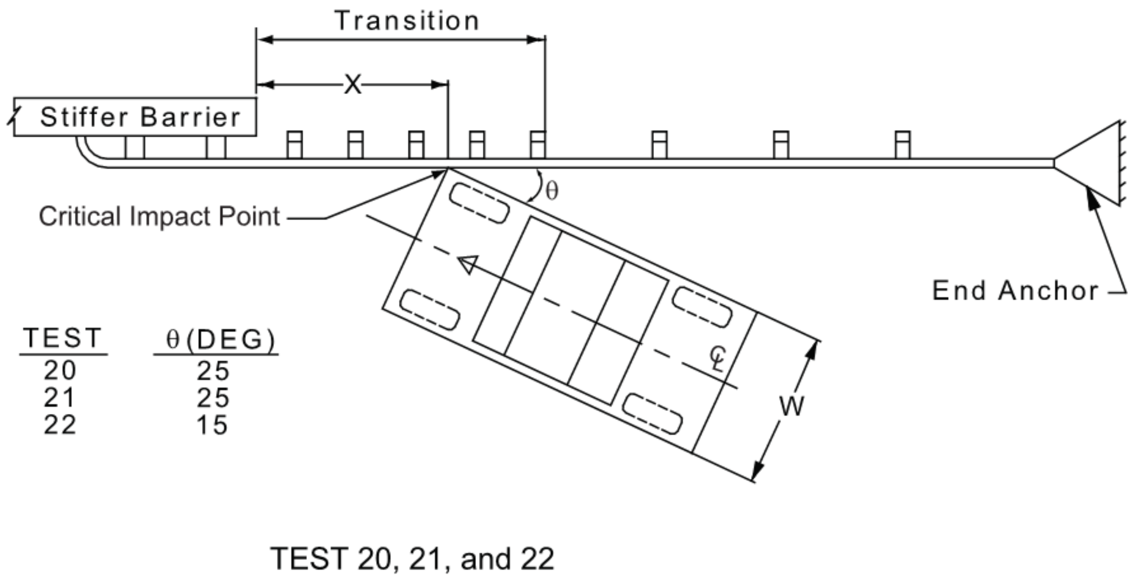


Figure 1.1. *MASH* Crash Test Impact Configuration for Transition Element (*1*).

1.3 BACKGROUND

Current guidance regarding the testing and evaluating of barrier transitions is contained in the second edition of *MASH*, which was published in 2016 (*1*). The crash testing guidelines present matrices for vehicular tests that are defined in terms of vehicle type, impact conditions (i.e., speed and angle), and impact location. *MASH* further prescribes how to assess the performance of a safety feature based on occupant risk, structural adequacy, exposure to workers and pedestrians who may be in the debris path resulting from the impact, and post-impact condition of the vehicle.

Some of the primary concerns associated with a median barrier transition between a W-beam and a rigid barrier correspond to the desired overlap length of the guardrail and the rigid barrier, the size and spacing of the transition posts, and the availability of a rub rail and/or curb. The considerable difference between two barrier type stiffnesses could result in vehicle snagging, pocketing, and/or occupant risk due to vehicle instability. TTI researchers determined that a proper transition system to connect these systems was necessary since a crashworthy median barrier stiffness transition is currently unavailable.

1.4 OBJECTIVE/SCOPE OF RESEARCH

The purpose of this research study was to develop a *MASH* TL-3 compliant transition between a median guardrail and median concrete barrier, and test the design according to *MASH* crash testing guidelines. Finite element computer simulations were utilized to aid in the design of a median transition. Full-scale crash testing was performed to assess the safety performance of the double-faced W-beam median barrier transition to the concrete parapet according to the safety performance evaluation guidelines included in *MASH* for TL-3. Data obtained from these crash tests were analyzed, and the results were utilized to guide the project conclusions and recommendations. Additionally, implementation guidance for the new transition system was developed.

1.5 RESEARCH STRUCTURE

Multiple tasks were included in this research project. A literature review, computer simulations, and full-scale crash testing were performed to accomplish the project objectives. The tasks are listed below:

- Task 1: Project Management and Research Coordination.
- Task 2: Literature Review and Design Constraint Development.
- Task 3: Simulation and Design Development.
- Task 4: Full-Scale Crash Testing.

CHAPTER 2:
LITERATURE REVIEW*

2.1 CRASH TESTED HARDWARE

2.1.1 *MASH* Test 3-21 on Nested W-beam with Rub Rail

MASH Test 3-21 was conducted on the Pennsylvania Department of Transportation (PennDOT) W-beam transition (*2*). The W-beam transition consists of two nested 12-gauge W-beam guardrails blocked out from the end of a concrete parapet. The transition also has a flared-back rub rail. TTI constructed 16.4 ft of Pennsylvania standard bridge parapet from details provided by PennDOT. Figure 2.1 shows the transition prior to testing.

A 2007 Chevrolet Silverado pickup, traveling at an impact speed of 62.8 mi/h, impacted the W-beam transition 8.6 ft upstream from the end of the concrete parapet at an impact angle of 25.7 degrees. Damage to the W-beam transition is shown in Figure 2.2. Maximum dynamic deflection during the test was 3.8 inches. The W-beam transition met the criteria specified in *MASH.*

Figure 2.1. W-beam Transition before Testing (*2*).

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

Figure 2.2. W-beam Transition after Testing (*2*).

2.1.2 *MASH* Test 3-11 on 27-inch W-beam Median Barrier

Bullard et al. conducted *MASH* Test 3-11 on a G4(1S) W-beam median barrier that was a 27-inch-tall, strong steel post, W-beam median barrier (Figure 2.3) (*2*). A 2007 Chevrolet Silverado pickup, traveling at an impact speed of 64 mi/h, impacted the double-faced W-beam median barrier at an impact angle of 25.1 degrees. Maximum dynamic deflection during the test was 23.2 inches, and the median barrier did not meet the criteria specified in *MASH* (Figure 2.4).

Figure 2.3. G4(1S) W-beam Median Barrier before *MASH* Test 3-11 (*2*).

Figure 2.4. G4(1S) W-beam Median Barrier after *MASH* Test 3-11 (*2*).

2.1.3 *MASH* Test 3-11 on TxDOT 31-inch W-beam Median Barrier

To develop and evaluate a *MASH* TL-3 31-inch W-beam median barrier, researchers evaluated the previously failed *MASH* Test 3-11 on the G4(1S) W-beam median barrier and simulated the vaulting phenomena of the vehicle in computer simulations (Figure 2.5) (*3*).

Figure 2.5. Simulation of *MASH* Test 3-11 as 2270P Vehicle Vaults over 27-inch Median Barrier (*3*).

The new 31-inch median barrier consisted of 12-gauge W-beam guardrails attached to 6-ft-long W6×8.5 steel posts spaced 6 ft 3 inches on center. The W-beam guardrails were offset from the posts using wood blockouts nominally 6 inches wide × 8 inches deep × 14 inches high.

The height of the TxDOT W-beam median barrier test installation was 31 inches. The length of need for the installation was 106 ftThe total overall test installation length was 156 ft. Figure 2.6 provides a cross-section of the TxDOT 31-inch W-beam median barrier. Photographs of the completed installation are shown in Figure 2.7. The constructed W-beam median barrier with rail splices offset from the posts and 8-inch offset blocks (AASHTO Designation SGM06a) was successfully crash tested in accordance with *MASH* (Figure 2.8 and Figure 2.9) (*3*).

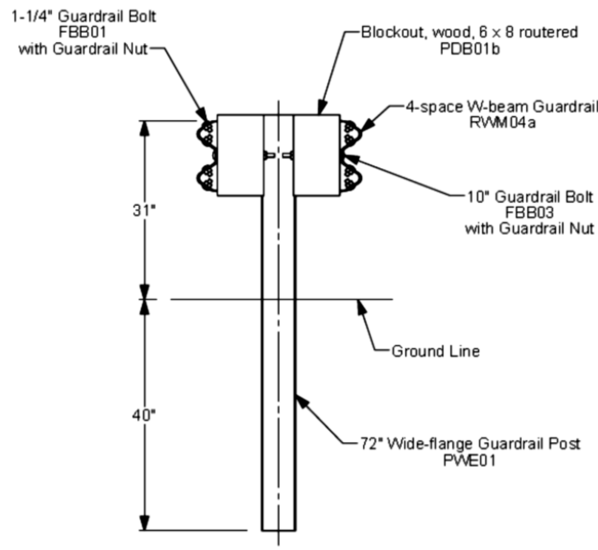


Figure 2.6. Cross-Section of TxDOT 31-inch W-beam Median Barrier (*3*).

Figure 2.7. TxDOT 31-inch W-beam Median Barrier before Testing (*3*).

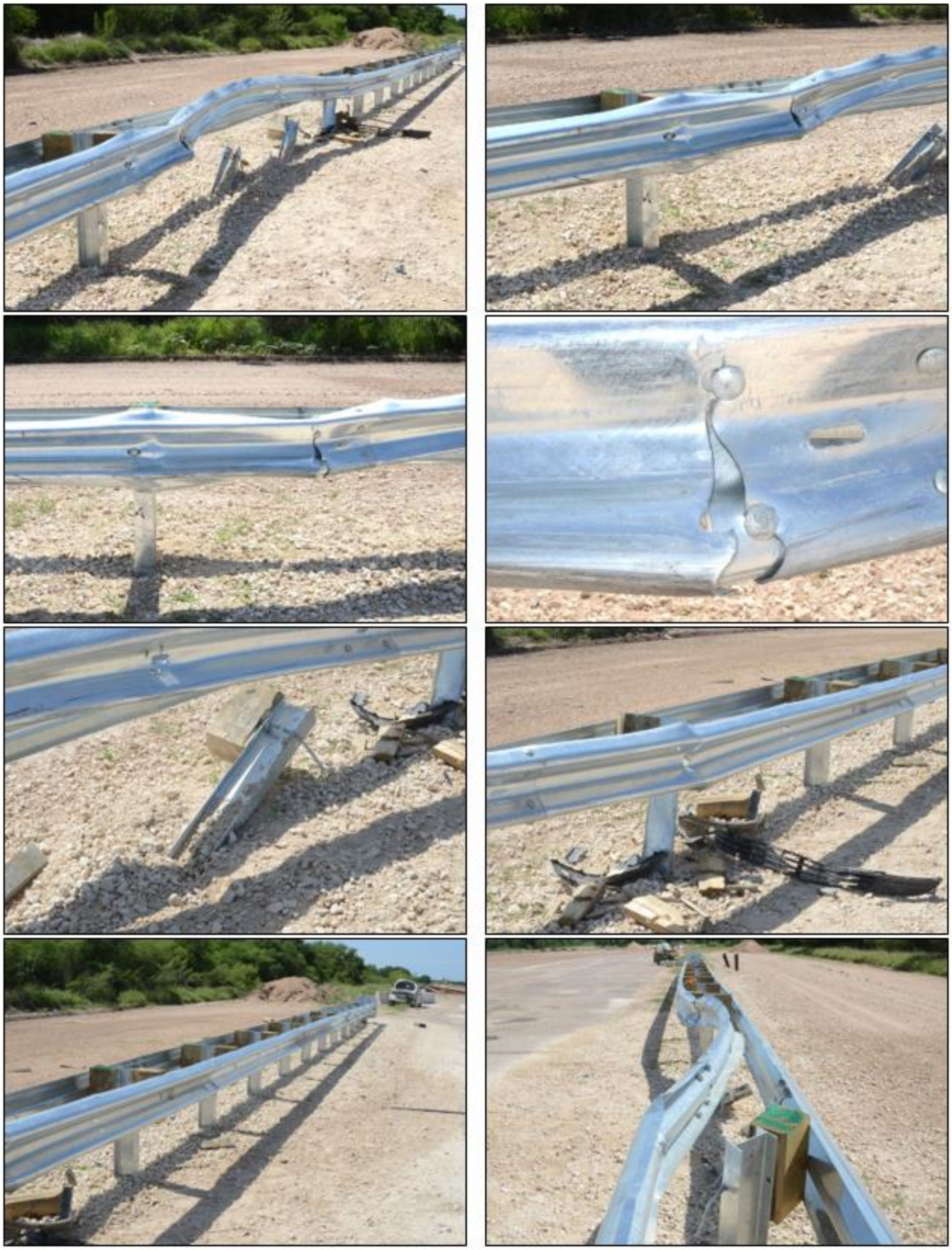


Figure 2.8. Installation after *MASH* Test 3-10 (Small Car) (*3*).

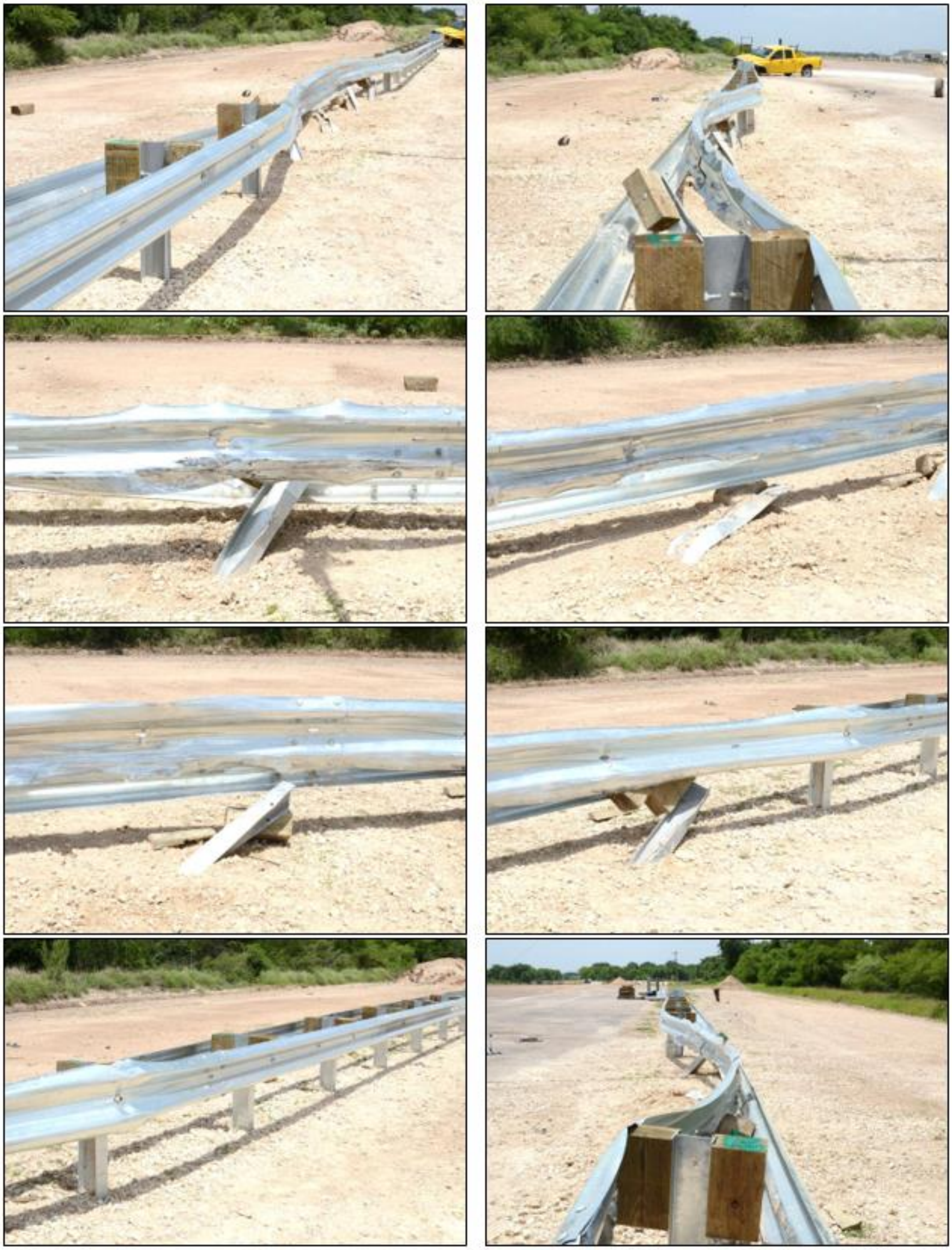


Figure 2.9. Installation after *MASH* Test 3-11 (Pickup Truck) (*3*).

2.1.4 NCHRP Report 350 TL-3 Median Barrier Transition

Soyland et al. developed and crash tested two approach guardrail transitions for use with single-slope concrete median barriers (CMBs) at the Midwest Roadside Safety Facility (MwRSF) (*4*). The transition was built with 10-gauge thrie-beam guardrails and supported by nine W6×9 steel posts. A single-slope connector connected the thrie beam to the single-slope CMB, and structural spacer blocks were employed to use with the thrie-beam guardrail transition.

Figure 2.10 through Figure 2.12 show the test installation configuration and the two designs used for full-scale crash tests.

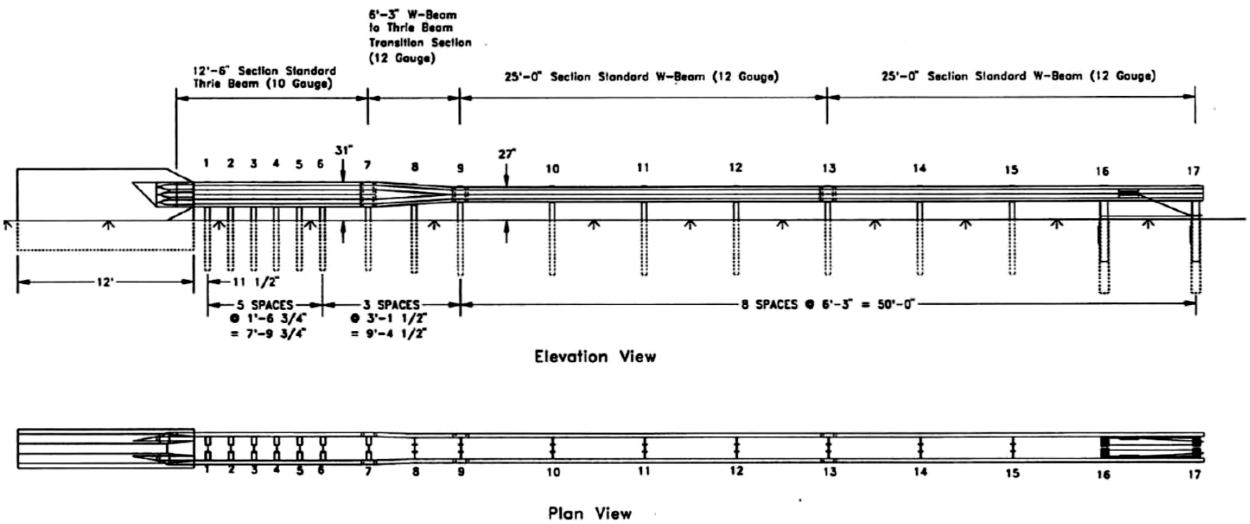


Figure 2.10. Test Installation Configuration (*4*).

The first crash test of the approach guardrail transition, shown in Figure 2.11, failed due to excessive occupant compartment deformation. Following that crash test, the transition and the single-slope CMB end section were redesigned by flattening the upper slope at the end of the CMB from 2:1 to 8:1; removing the thrie-beam backup plates; shortening the steel single-slope connector plate; shortening the bottom section of the structural tube, thrie-beam, spacer blocks; providing a negative slope at the top of the structural tube, thrie-beam, spacer blocks; and reducing the height of the thrie-beam post above the ground by increasing the embedment depth. The safety performance of the redesigned approach guardrail transition attached to a single-slope CMB (shown in Figure 2.12) was determined to be acceptable according to TL-3 of the National Cooperative Highway Research Program (NCHRP) Report 350 criteria (*5*).

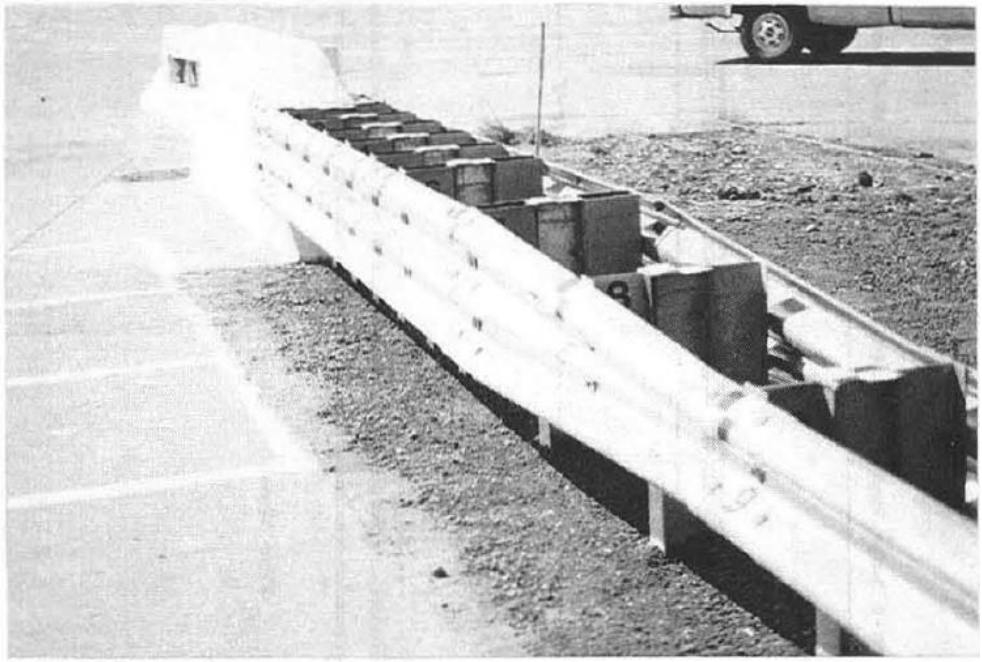


Figure 2.11. Approach Guardrail Transition, Design No. I (*4*).

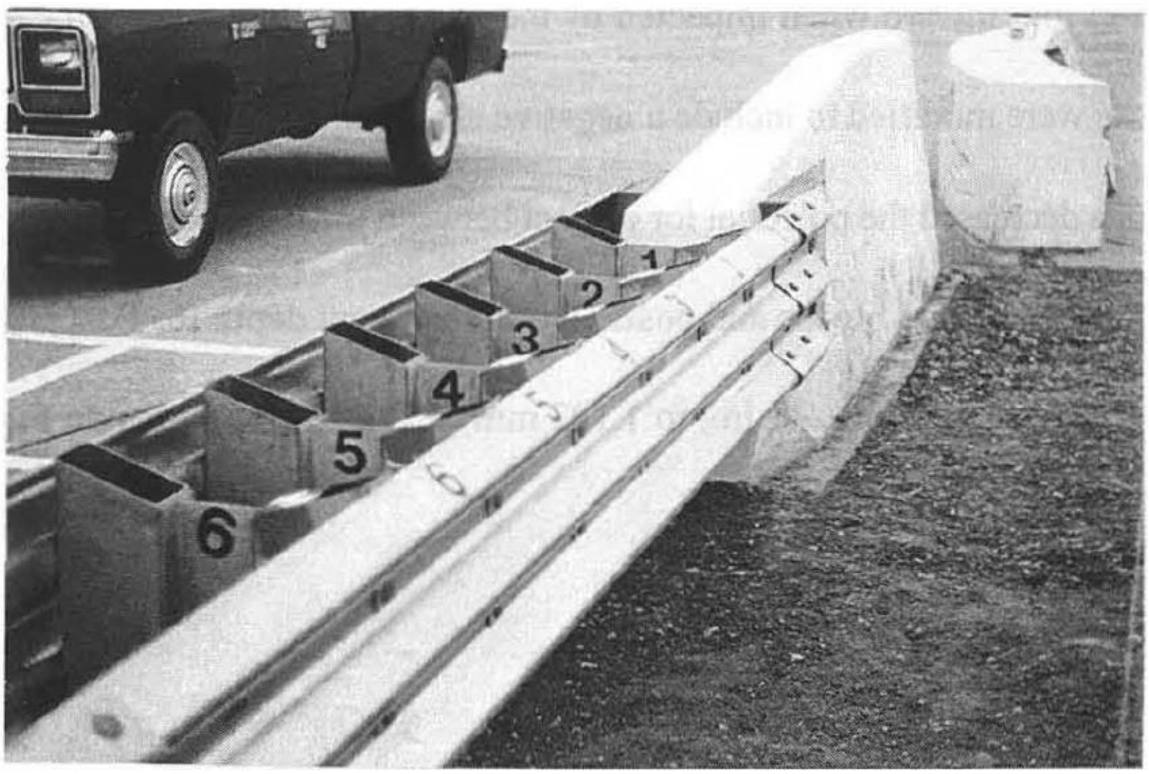


Figure 2.12. Approach Guardrail Transition, Design No. II (*4*).

2.1.5 *MASH* 3-21 Stacked W-beam Guardrail Transition

In 2016, Dobrovolny investigated the crashworthiness of a stacked W-beam guardrail transition design for use with a 31-inch guardrail system according to *MASH* Test 3-21 evaluation criteria (*6*). The overall length of the test installation was 100 ft 8 inches. The installation was comprised of a 31-inch-tall 12-gauge W-beam guardrail attached to a 32-inch-tall, 16-ft-long cast-in-place concrete bridge deck parapet wall on the downstream end. Additionally, a nested 12-gauge W-beam rub rail was installed between grade and the upper W-beam from post 13 to the concrete parapet. Figure 2.13 and Figure 2.14 show the installation before and after the test, respectively. Due to the vehicle rollover, the stacked W-beam transition did not meet specifications for *MASH* Test 3-21 (*6*).

Figure 2.13. Stacked W-beam Transition before Test (*6*).

Final Rest After Being Uprighted

Figure 2.14. Stacked W-beam Transition after Test (*6*).

2.1.6 *MASH* 3-21 Modified TxDOT Thrie-Beam Transition

In 2013, Arrington et al. evaluated the impact performance of a modified TxDOT thrie-beam transition to a rigid concrete barrier without a curb element below the transition rail (*7*). The test was performed in accordance with *MASH* guidelines following the impact conditions for Test 3-21.

The modified thrie-beam transition without curb failed to meet *MASH* TL-3 requirements due to rollover of the vehicle. There were indications of wheel snagging on the end of the concrete parapet that may have contributed to the destabilization of the vehicle. The researchers suggested the following to improve the system:

- Placing a short curb at the end of the parapet to prevent wheel snagging.
- Increasing the blockout depth at the end of the parapet to reduce snagging.
- Strengthening the posts in the nested section of the guardrail.

Figure 2.15 and Figure 2.16 show the transition installation before and after testing, respectively (*7*).

Figure 2.15. TxDOT TL-3 Transition Installation before Testing (*7*).

Figure 2.16. TxDOT TL-3 Transition after Testing (*7*).

2.1.7 *MASH* TL-3 W-beam to Thrie-Beam Stiffness Transition

Researchers at MwRSF developed a W-beam to thrie-beam stiffness transition to connect the Midwest Guardrail System (MGS) to a previously approved thrie-beam approach guardrail transition to a bridge rail. BARRIER VII computer simulation modeling, in combination with post-in-soil bogie tests, was used to evaluate multiple transition configurations (*8*). The optimal configuration was the shortest design to successfully eliminate excessive pocketing and wheel snag (Figure 2.17).

Three full-scale crash tests were conducted, and following the successful containment and redirection of both the ½-ton quad cab pickup truck (2270P) and the small car (1100C) test vehicles, the safety performance of the stiffness transition between the MGS and a thrie-beam approach guardrail transition system, including an asymmetrical guardrail element, was determined to be acceptable according to the TL-3 evaluation criteria specified in *MASH* (Figure 2.18).

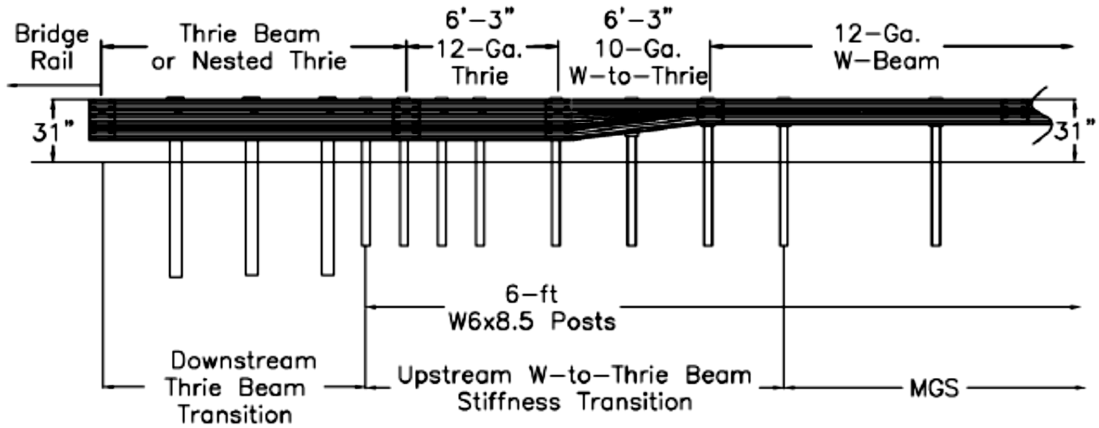
Figure 2.17. Optimal Configuration of Transition Element before Testing (*8*).

Figure 2.18. Rail Deformation after Testing (*8*).

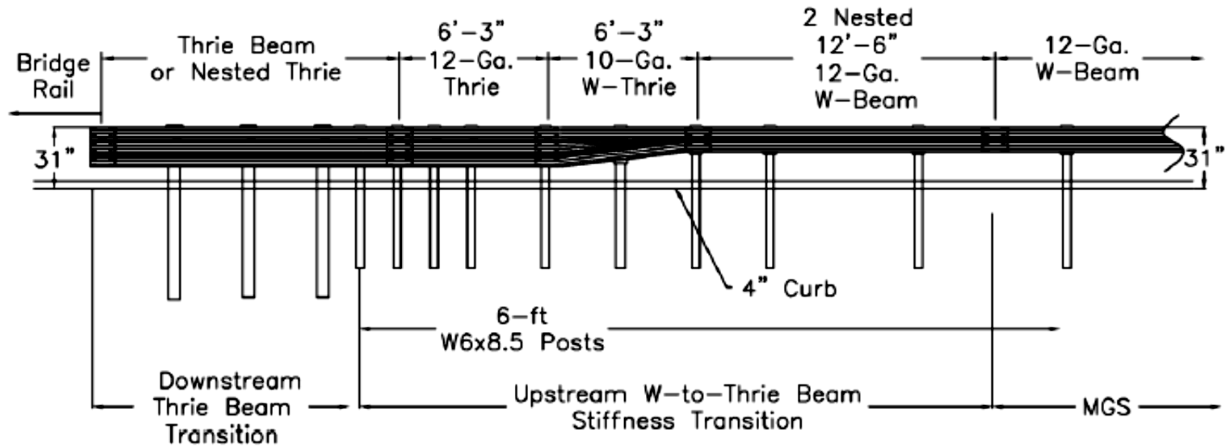
2.1.8 *MASH* TL-3 W-beam to Thrie-Beam Transition with Curb

In 2014, researchers at MwRSF developed a W-beam to thrie-beam stiffness transition with a 4-inch-tall concrete curb to connect the 31-inch MGS to a previously approved thrie-beam approach guardrail bridge transition system (*9*).

Three full-scale crash tests were conducted according to TL-3 safety standards provided in *MASH*. During the first test, the 1100C small car extended and wedged under the rail and contacted posts while traversing the curb. Subsequently, the W-beam rail ruptured at a splice location. A repeat of *MASH* Test 3-20 was performed on an updated design that used a 12-ft 6-inch long, nested W-beam rail segment upstream from the W-beam to thrie-beam transition element. The 1100C small car was successfully contained and redirected. During *MASH* Test 3-21, a 2270P pickup truck was successfully contained and redirected. Following the crash testing program, the system was deemed acceptable according to the TL-3 safety performance criteria specified in *MASH*. Figure 2.**19** shows details on the recommended transition system with and without a curb tested for this project (*9*).



(a)



(b)

Figure 2.19**. MGS to Thrie-Beam Stiffness Transition Details (a) without Curb and (b) with 4-inch Curb (*9*).**

2.2 STATE STANDARD HARDWARE (NOT CRASH TESTED)

The following are the median transition barrier systems in various state department of transportation (DOT) standard drawings. The listed hardware is not crash tested under *MASH*.

2.2.1 Florida DOT

Figure 2.20 shows a double-faced approach transition from Florida DOT (FDOT) standard plans (*10*). The transition consists of a 12-gauge 12-ft 6-inch nested W-beam, a 10-gauge 6-ft 3-inch asymmetrical W-beam to thrie-beam transition, and a 12-gauge thrie-beam panel nested with a 25-ft panel (half of the 25-ft panel is overlapped with the concrete parapet). Trimmed offset blocks have been used for attaching the overlapped thrie-beam panel to the concrete barrier. The shape of the offset block depends on the rigid barrier cross-section (Figure 2.21).

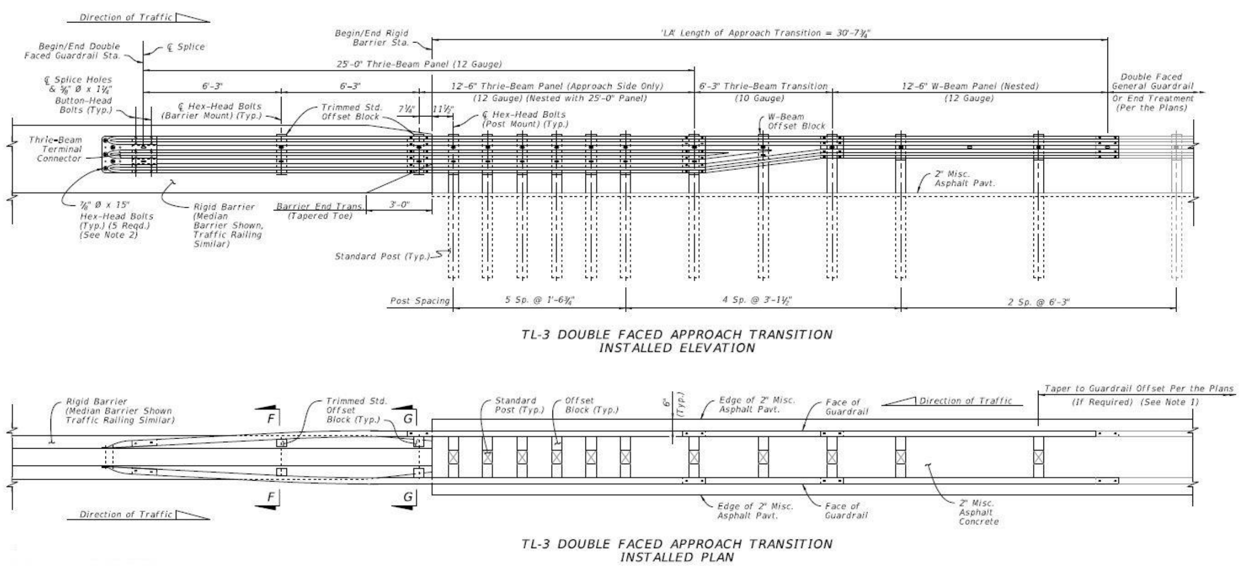


Figure 2.20. TL-3 Double-Faced Approach Transition (*10*).

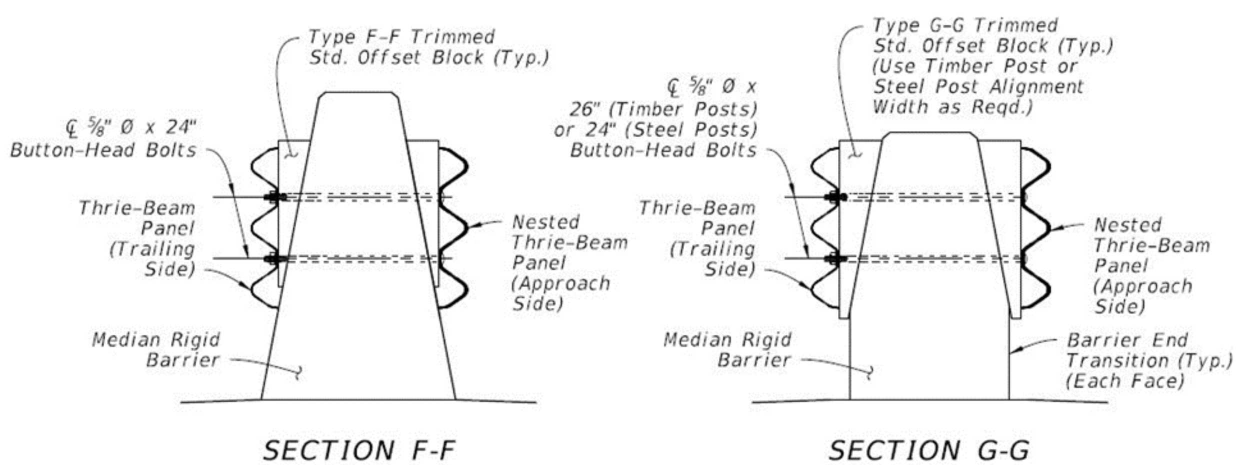


Figure 2.21. Offset Block Attachment (*10*).

2.2.2 Massachusetts DOT

Similar to FDOT standard plans, Figure 2.22 shows a double-faced approach transition from Massachusetts DOT (MassDOT) standard drawings (*11*). The transition consists of a

12-gauge 12-ft 6-inch nested W-beam, a 10-gauge 6-ft 3-inch asymmetrical W-thrie transition, and a 12-gauge thrie-beam panel nested with a 25-ft panel (half of the 25-ft panel is overlapped with the F-shape concrete median barrier). Trimmed offset blocks have been used for attaching the overlapped thrie beam to the concrete barrier. The shape of the offset block depends on the distance from the concrete barrier and the overlapped thrie beam (Figure 2.23). Availability of a curb or rub rail is not mentioned in this system.

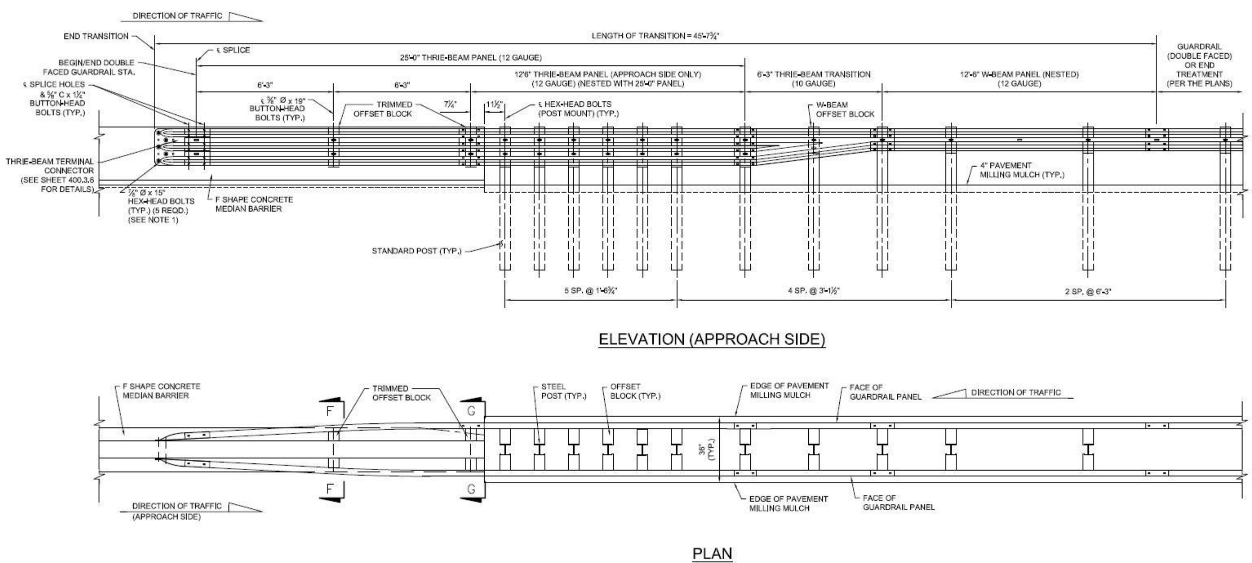


Figure 2.22. Double-Faced Approach Transition (*11*).

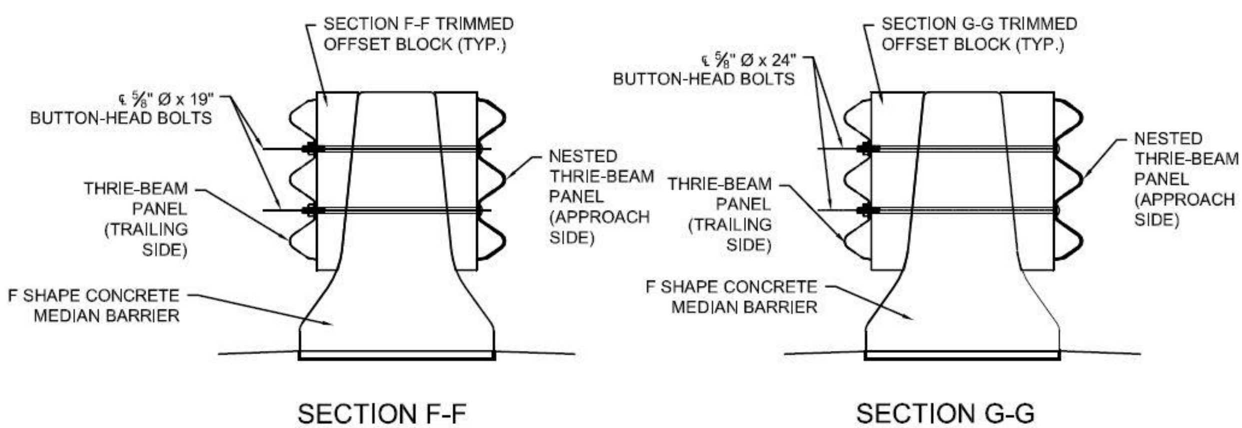


Figure 2.23. Offset Block Attachment (*11*).

2.2.3 New Hampshire DOT

Figure 2.24 shows a double-faced approach transition with the symmetrical W-beam to W-thrie-beam transition from New Hampshire DOT (NHDOT) standard plans (*12*). The transition consists of a 12-gauge 6-ft 3-inch W-beam, a 10-gauge 6-ft 3-inch symmetrical W-thrie transition, and a 12-gauge 25-ft nested thrie-beam panel. The only overlapped part of the guardrail system is the 28-inch end shoe. The shape of the concrete parapet at the connection section is transitioned to vertical for direct attachment of the rail to the concrete barrier

(Figure 2.25). This system does not have a rub rail; however, there is a 4-inch curb along the thrie-beam section.

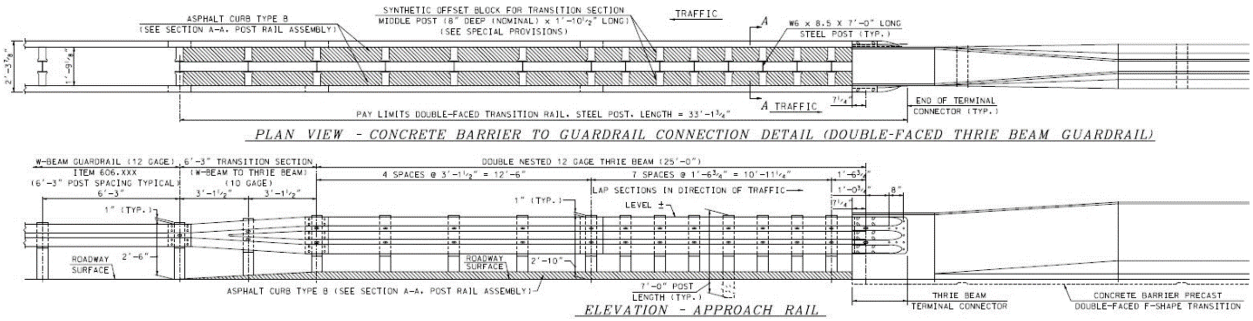


Figure 2.24. Concrete Barrier to W-beam Transition (*12*).

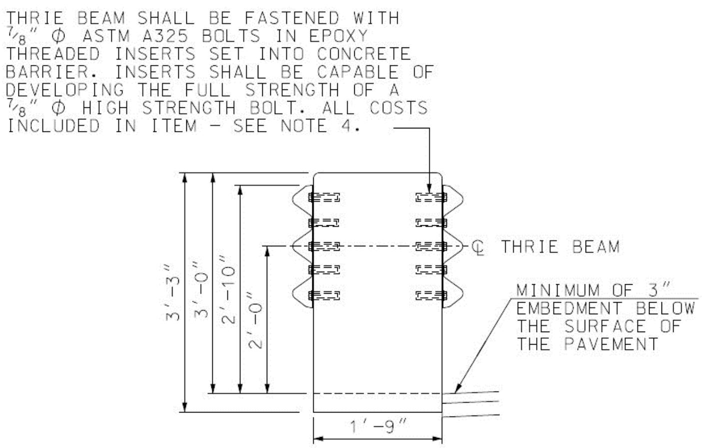


Figure 2.25. Double-Faced Thrie-Beam Attachment (*12*).

2.2.4 New Jersey DOT

Figure 2.26 and Figure 2.27 show a double-faced approach transition with the symmetrical W-beam to W-thrie-beam transition from New Jersey DOT (NJDOT) standard construction details (*13*). The transition consists of a standard W-beam, a 6-ft 3-inch symmetrical W-thrie transition, and a 12-ft 6-inch nested thrie-beam panel. The only overlapped part of the guardrail system is the end shoe. The shape of the concrete parapet at the connection section is modified for direct attachment of the rail to the concrete barrier (Figure 2.27). This system does not have a curb; however, there is a rub rail added to the transition system on the approaching traffic side.

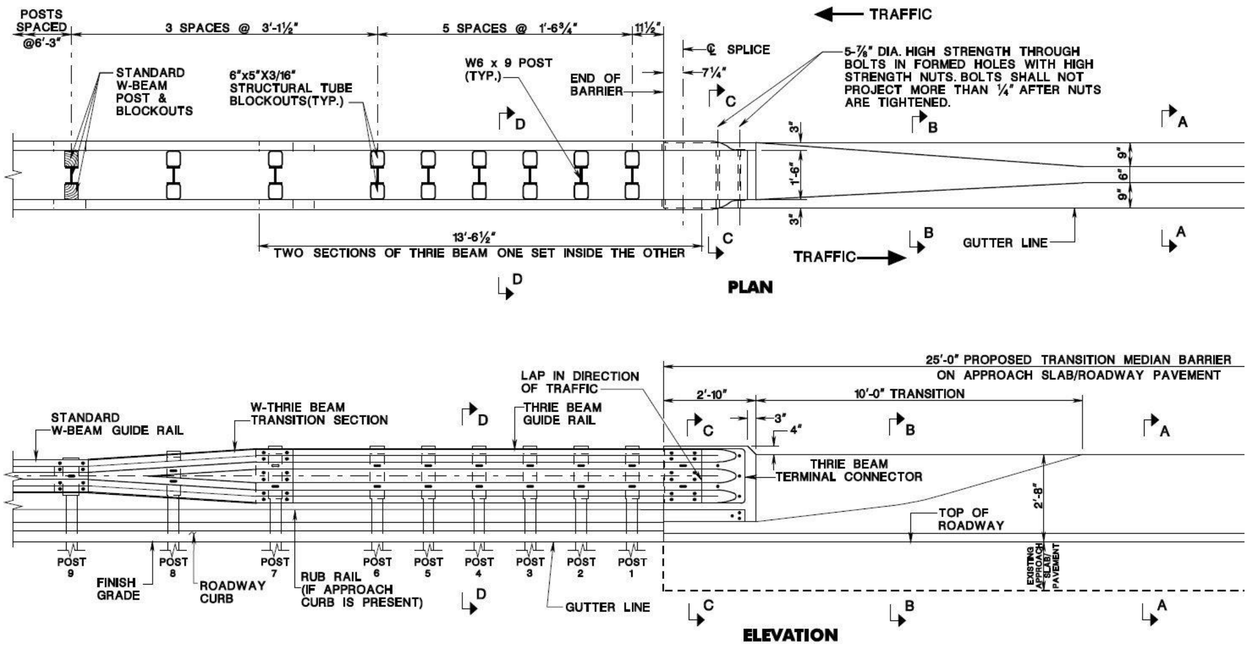


Figure 2.26. Bidirectional Beam Guide Rail Details (*13*).

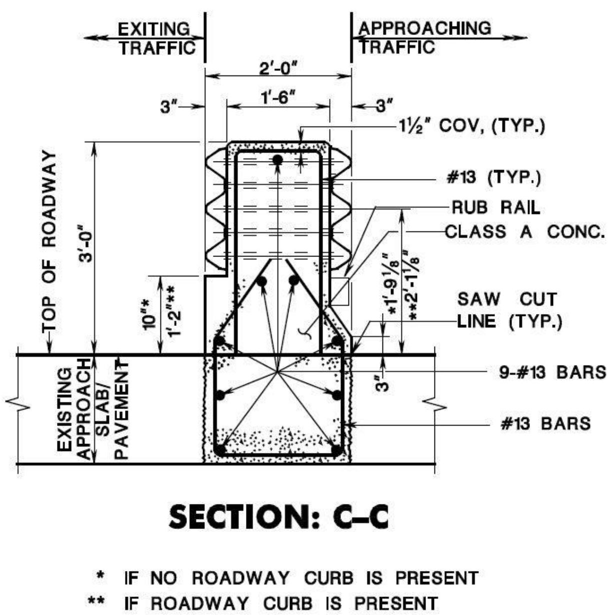


Figure 2.27. Thrie-Beam Attachment to F-shape Median Barrier (*13*).

2.2.5 Utah DOT

Figure 2.28 shows a double-faced W-beam approach transition from Utah DOT (UDOT) standard drawings (*14*). The transition consists of a standard W-beam that is nested in the attachment section to the New Jersey style barrier (half of the 12-ft 6-inch rail is overlapped with the concrete barrier). Modified blocks are used to line up the guardrail and rub rail to the concrete barrier (Figure 2.29).

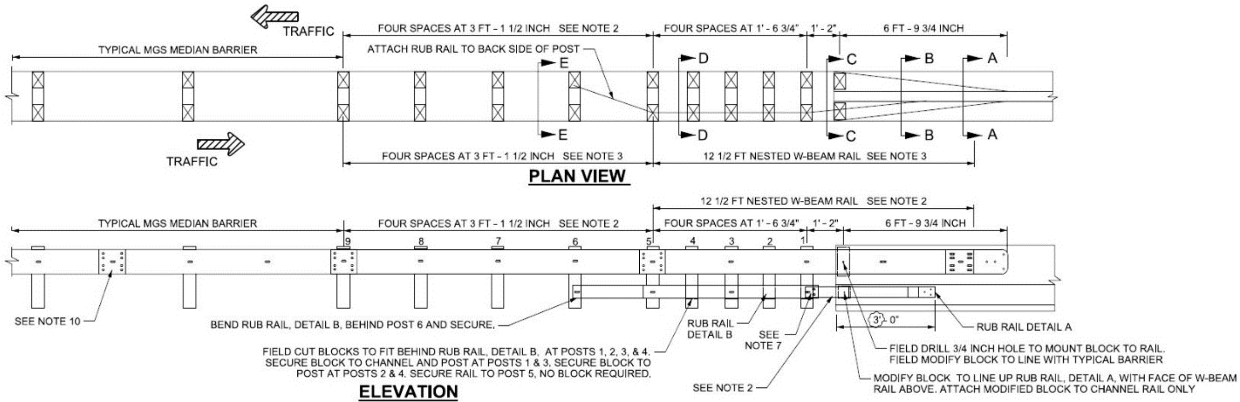


Figure 2.28. F-shape Concrete Barrier to Guardrail Transition (*14*).

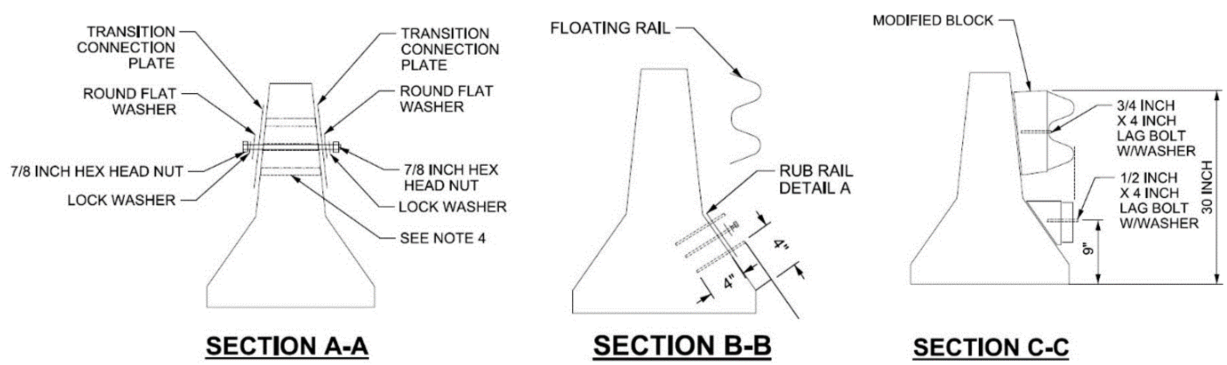


Figure 2.29. Thrie-Beam Attachment to F-shape Barrier in Various Sections (*14*).

CHAPTER 3: SIMULATION*

3.1 DESIGN

Before running finite element (FE) simulations on the design concepts for the median barrier transition, it was necessary to validate the behavior of the pickup truck vehicle model with a similar barrier system. The researchers developed a detailed FE model of the stacked W-beam transition system to calibrate the model based on previous full-scale crash tests. The pickup truck vehicle model incorporated a recently developed detailed tire model. Figure 3.1 shows the vehicle model with the detailed tires.

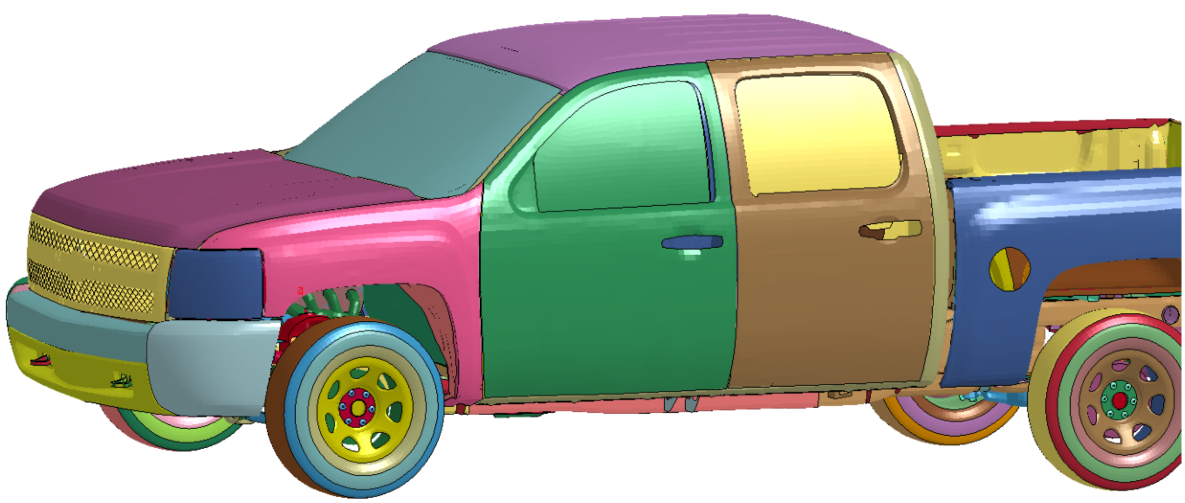


Figure 3.1. 2270P FE Vehicle Model with Detailed Tires.

There were two types of posts in the barrier model. Post types A and B were W8×13 and W6×8.5 steel sections, respectively. The post elements were comprised of different thicknesses to accurately capture the shape of the wide flange sections (Figure 3.2). Figure 3.3 shows the vehicle and the 31-inch stacked W-beam transition system.

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

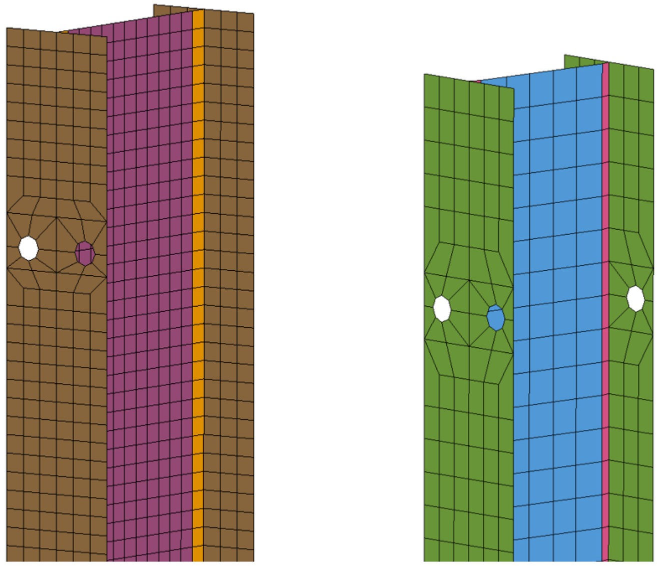


Figure 3.2. Right: Post Type A (W8×13×90); Left: Post Type B (W6×8.5×72).

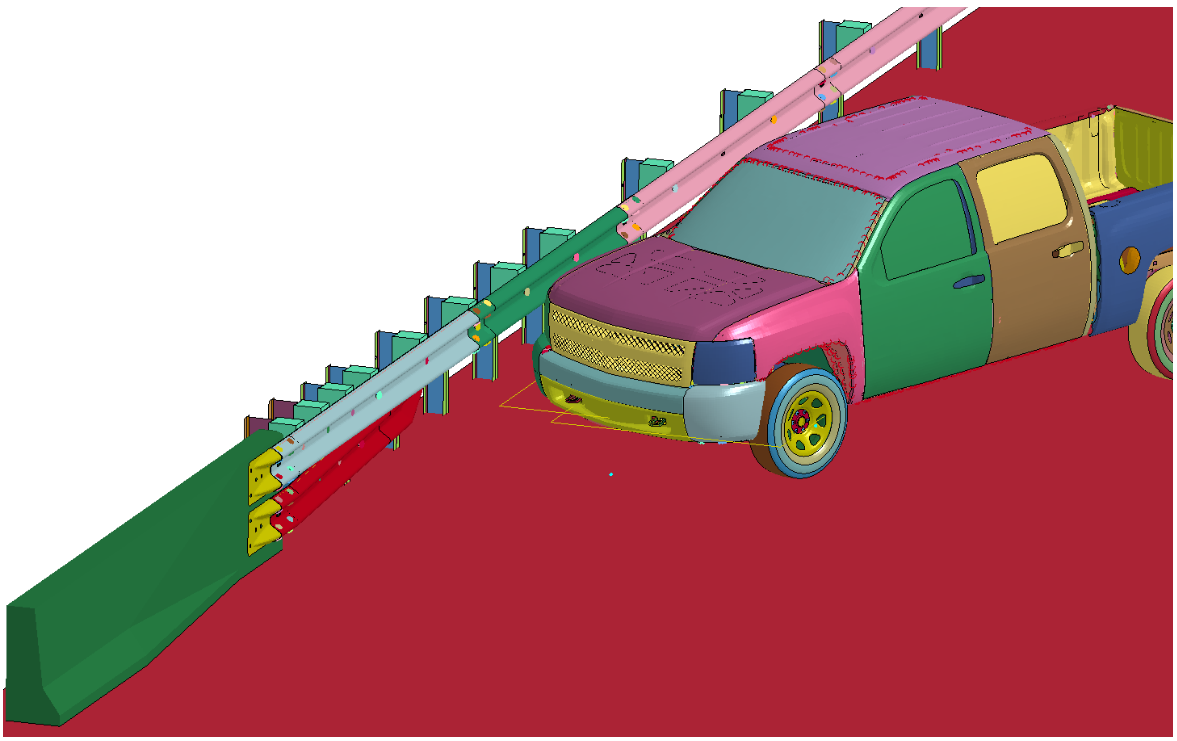


Figure 3.3. FE Model of Stacked W-beam Transition Barrier System.

The simulation was conducted with the same impact conditions as the crash test. The FE vehicle model impacted the system at a speed of 64.3 mi/h and an angle of 25.0 degrees. The impact point was 6.3 ft upstream of the beginning of the concrete parapet, which is the same as the full-scale crash test.

Table 3.1 and Table 3.2 show a comparison of sequential gut and overhead images from the crash test and simulation at various times during the impact event.

Table 3.1. Sequential Comparison of Full-Scale Crash Test and Computer Simulation (Gut View).

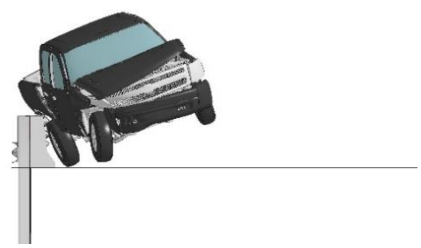
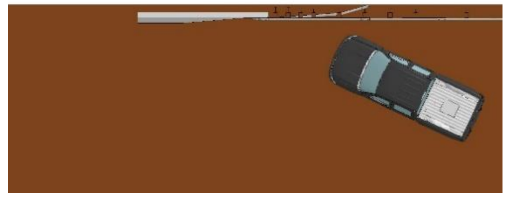
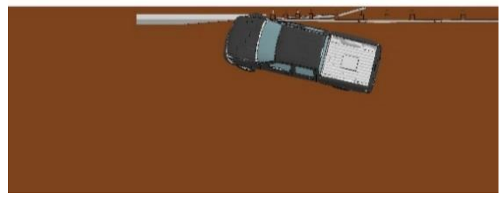
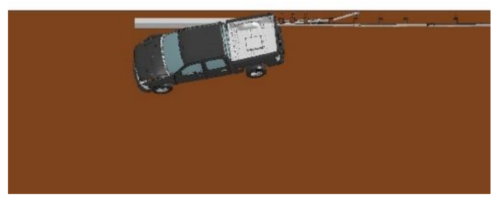
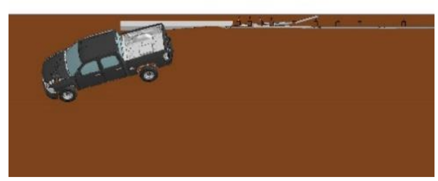
Time (s)	Full-Scale Crash Test	Time (s)	Computer Simulation
0.000		0.000	
0.150		0.150	
0.300		0.300	
0.450		0.450	

Table 3.2. Sequential Comparison of Full-Scale Crash Test and Computer Simulation (Overhead View).

Time (s)	Full-Scale Crash Test	Time (s)	Computer Simulation
0.000		0.000	
0.150		0.150	
0.300		0.300	
0.450		0.450	

In addition to comparing sequential time events for the full-scale crash tests and computer simulation, the research team also compared occupant risk values. Table 3.3 shows a comparison of the occupant risk values from full-scale crash tests and computer simulation. The occupant risk values determined from the computer simulation were comparable to those observed in the crash test.

Table 3.3. Comparison of Occupant Risk Values for Crash Test and Computer Simulation.

	Full-Scale Crash Test	Computer Simulation
Longitudinal OIV (m/s)	5.9	6.2
Lateral OIV (m/s)	9.1	8.5
Longitudinal ORA (g)	−5.6	−3.7
Lateral ORA (g)	−15.0	−10.3
Roll (deg.)	87.2	87.2
Pitch (deg.)	4.9	−14.1
Yaw (deg.)	−84.8	−46.9

Note: OIV = occupant impact velocity; ORA = occupant ridedown acceleration.

The research team validated the performance of the vehicle and barrier model against the previously tested stacked W-beam transition crash test. The vehicle model and barrier component models were utilized in the predictive simulations performed to analyze new design concepts.

3.2 DEVELOPMENT OF DESIGN CONCEPTS

Several design concepts that considered various design variables were developed. Drawings were developed for the top six design concepts and presented to the sponsor for consideration. Based on the traffic flow on both sides of the median transition barrier, two different systems were considered in this research: asymmetric traffic flow concepts and symmetric traffic flow concepts.

3.2.1 Asymmetric Concepts

3.2.1.1 Stacked W-beams Option 1

This transition system is comprised of two stacked W-beams, with the top row of W-beams nested, as shown in Figure 3.4. This schematic shows the configuration for the stacked W-beams to a modified single-slope CMB transition. The parapet end is tapered at its connection to the guardrail. Furthermore, a vertical face to accommodate the bottom W-beam end shoe is implemented in the parapet.

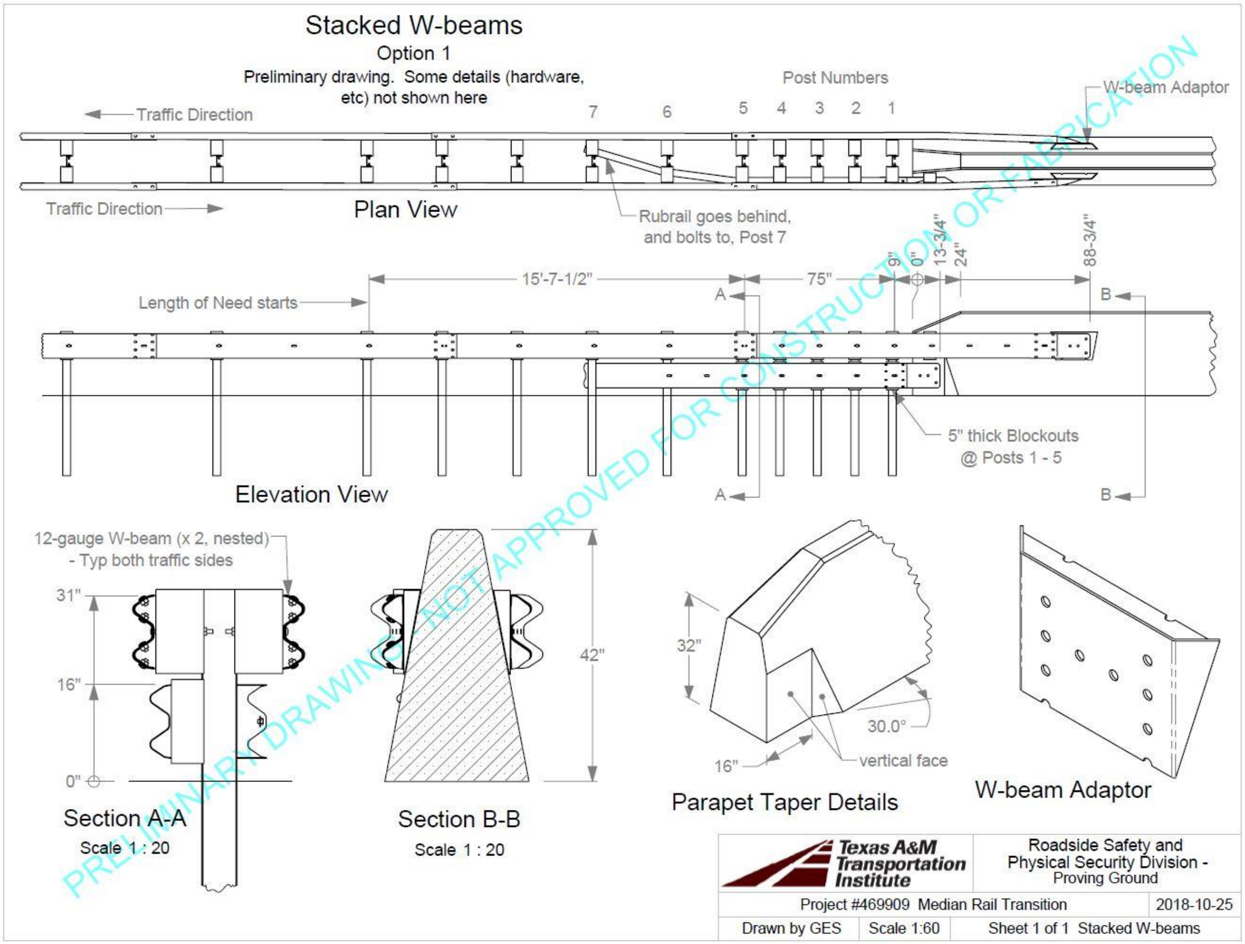


Figure 3.4. Stacked W-beams Option 1.

The top W-beams on both traffic sides are nested and overlapped on the single-slope CMB through the W-beam end shoe and adaptor, shown in Figure 3.5 and Figure 3.6, respectively. At the upstream end of the lower W-beam, the rail is flared behind the post to help mitigate wheel snagging during impact.

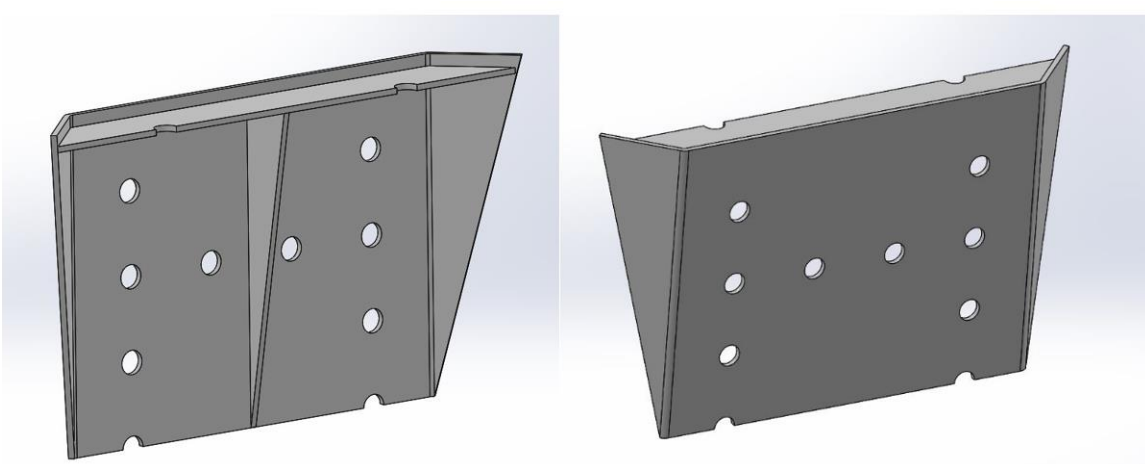


Figure 3.5. W-beam to Single-Slope CMB Adaptor.

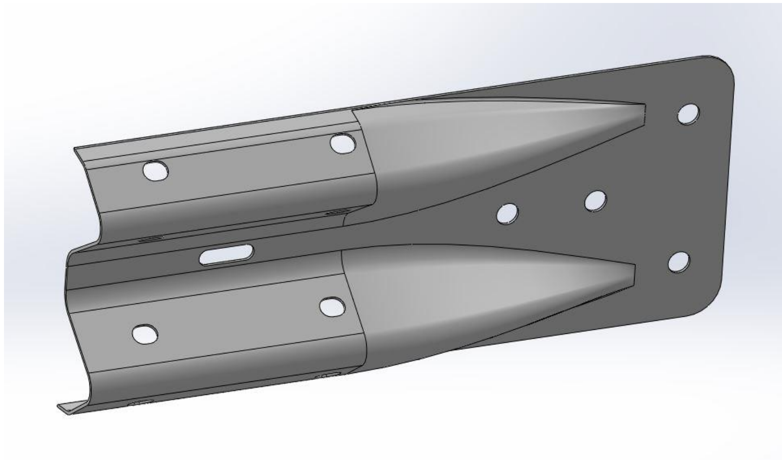


Figure 3.6. W-beam End Shoe.

3.2.1.2 Stacked W-beams Option 2

This transition system is comprised of two stacked W-beams, with the top row of W-beams nested, as shown in Figure 3.7. This schematic shows the configuration for the stacked W-beams to single-slope CMB transition. A W-beam adaptor and end shoe are used for attachment of the W-beam to the parapet. At the upstream end of the lower W-beam, the rail is flared between the post flanges to prevent possible wheel snagging during impact. The main advantage of this system compared to Option 1 is less modification for the concrete parapet. Furthermore, the bottom W-beam section is cut off to fit between the post 6 flanges, so no special treatment of the rail end may be necessary.

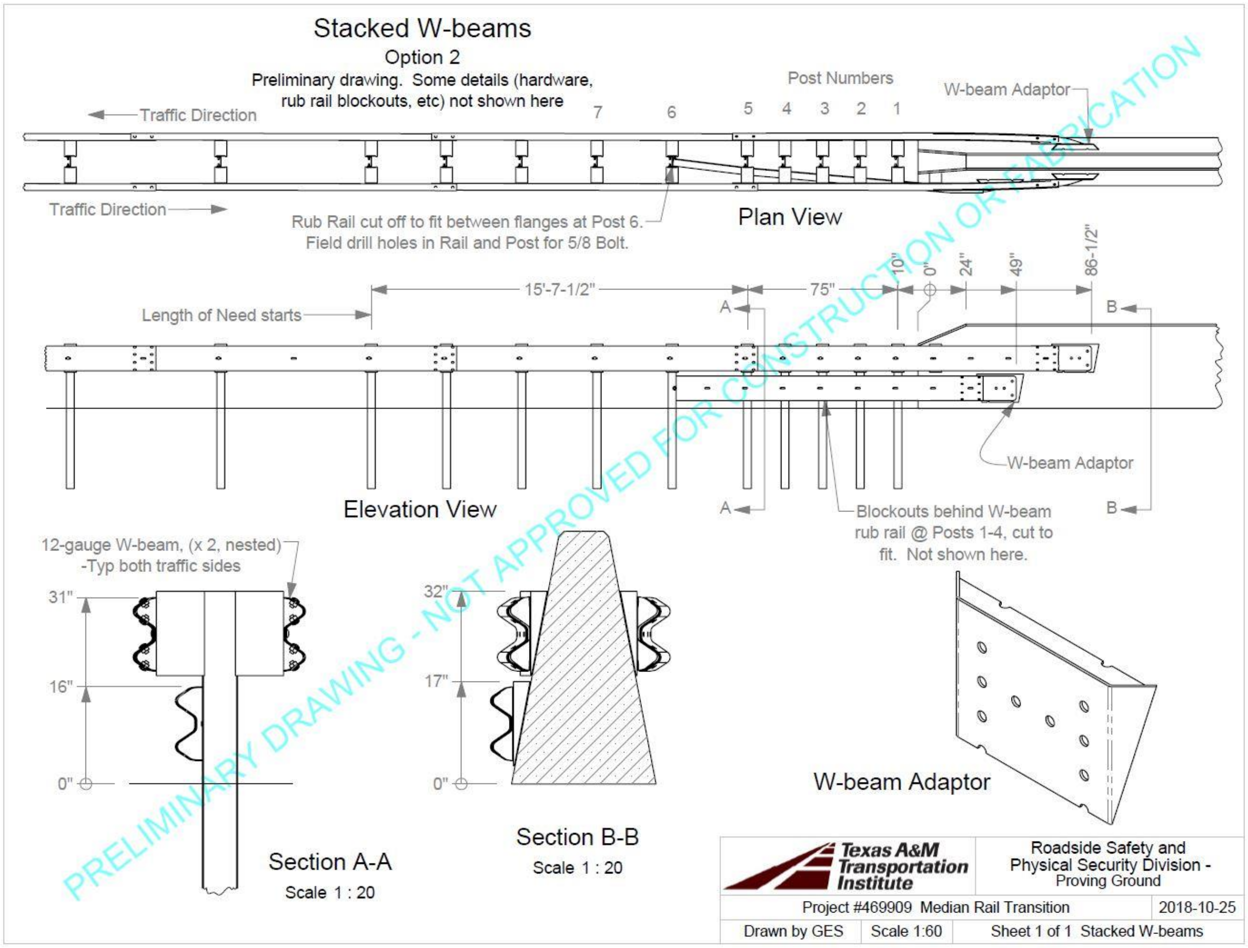


Figure 3.7. Stacked W-beams Option 2.

3.2.1.3 W-beam to F-shape

This asymmetric W-beam to F-shape transition consists of nested W-beam rails on both traffic sides and a rub rail at the bottom, as shown in Figure 3.8. In this system, the W-beams are modified (bent, twisted, etc.) to attach to the parapet directly through the end shoes (without adaptors). The rub rail is connected to posts 1–4 with modified blockouts and is flared on the upstream end behind post 6.

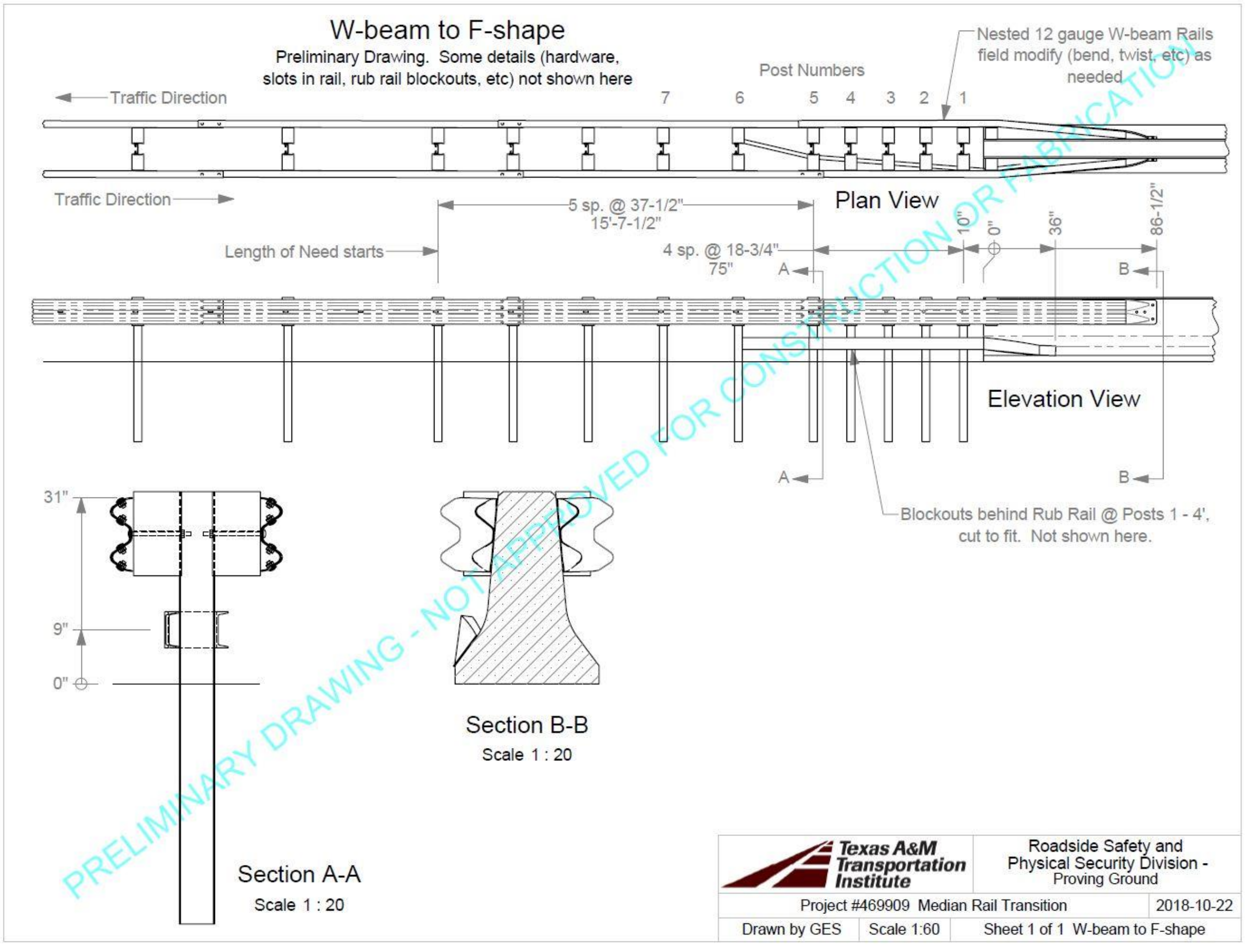


Figure 3.8. W-beam to F-shape.

3.2.1.4 Thrie-Beam to F-shape

The thrie-beam to F-shape system consists of nested thrie beams on both traffic sides attached to a modified F-shape parapet (Figure 3.9). The F-shape barrier is tapered and modified to a vertical shape for direct attachment of the thrie-beam end shoes. A curb is utilized on one traffic side.

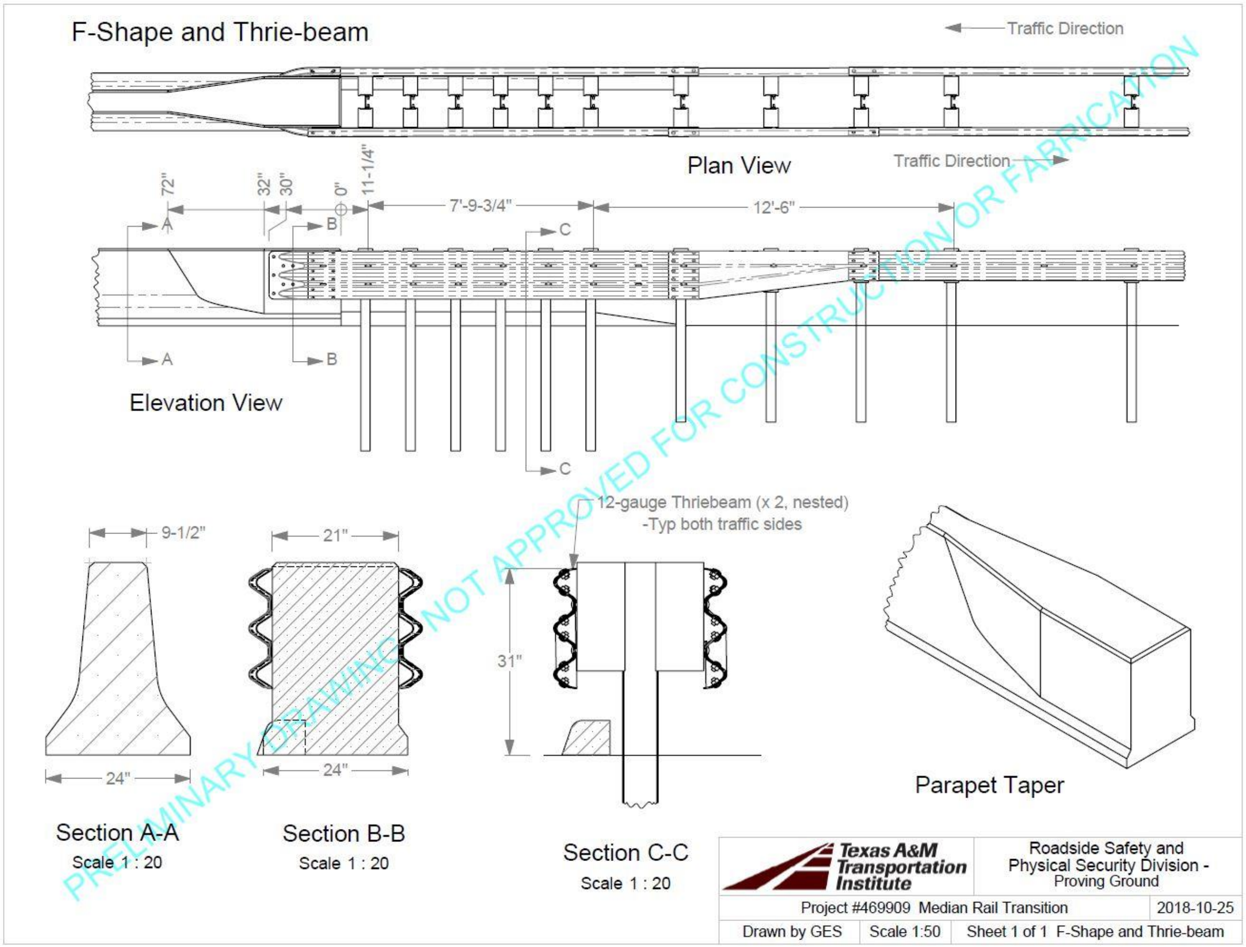


Figure 3.9. Thrie Beam to F-shape.

3.2.2 Symmetric Concepts

3.2.2.1 W-beam to F-shape Option 1

This transition system is comprised of nested W-beams in both traffic directions along with rub rails on each side (Figure 3.10). The W-beams are modified (bent, twisted, etc.) to attach to the parapet directly through the end shoes. The rub rails are attached to the end face of the parapet using brackets, and at the upstream end, they are bent down, forming a turndown for both sides of traffic. A 2-inch-thick blockout is placed behind the rub rails for posts 1 through 6.

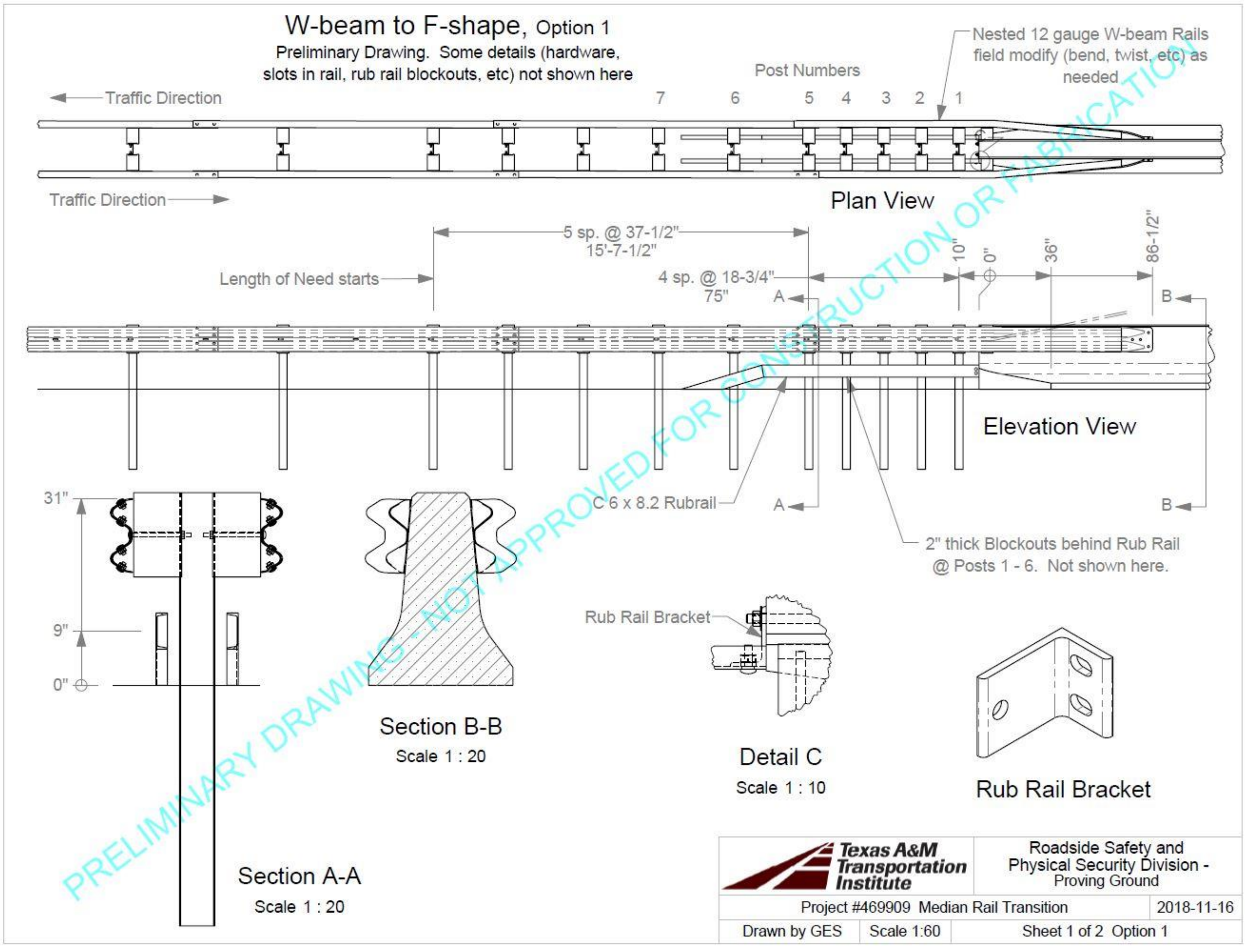


Figure 3.10. W-beam to F-shape Option 1.

3.2.2.2 W-beam to F-shape Option 2

Similar to Option 1, this transition system is comprised of nested W-beams in both traffic directions along with rub rails on each side, as shown in Figure 3.11. The W-beams are modified (bent, twisted, etc.) to attach to the parapet directly through the end shoes. The rub rails are attached to the end face of the parapet using brackets. The difference in this system and Option 1 is that the rub rails are flared inward and secured next to post 6 on the upstream end.

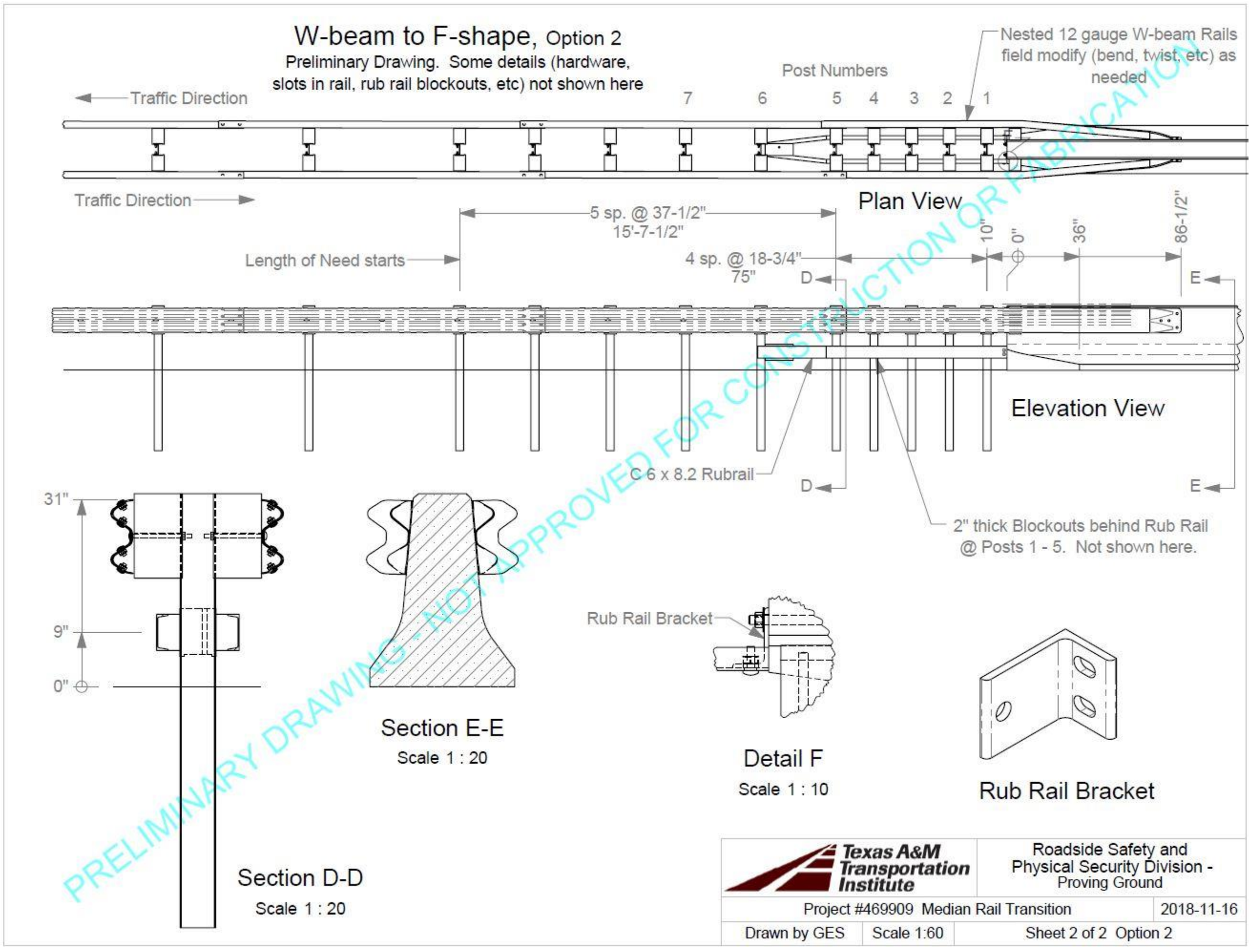


Figure 3.11. W-beam to F-shape Option 2.

3.3 ASYMMETRIC MEDIAN TRANSITION SIMULATIONS

The selected design was an asymmetric transition with stacked W-beam rails attached to a single-slope concrete parapet. Figure 3.12 shows a sketch of the transition design.

A computer model was developed for the asymmetric transition design and is shown in Figure 3.13. Computer simulations were conducted at various locations along the transition to evaluate the performance of the system and to determine critical impact locations. *MASH* Tests 3-20 and 3-21 were conducted for each transition region. This particular transition system consisted of three transition regions, which were each evaluated. The first region consisted of the transition from the median guardrail system with nested W-beams and quarter post spacing to the rigid parapet. The second region consisted of the transition from the median guardrail with nested W-beams and half post spacing to the median guardrail with nested W-beams and quarter post spacing. The third region consisted of the transition from the standard TxDOT median guardrail system to the median guardrail with nested W-beams and half post spacing. Figure 3.14 shows the three transition regions.

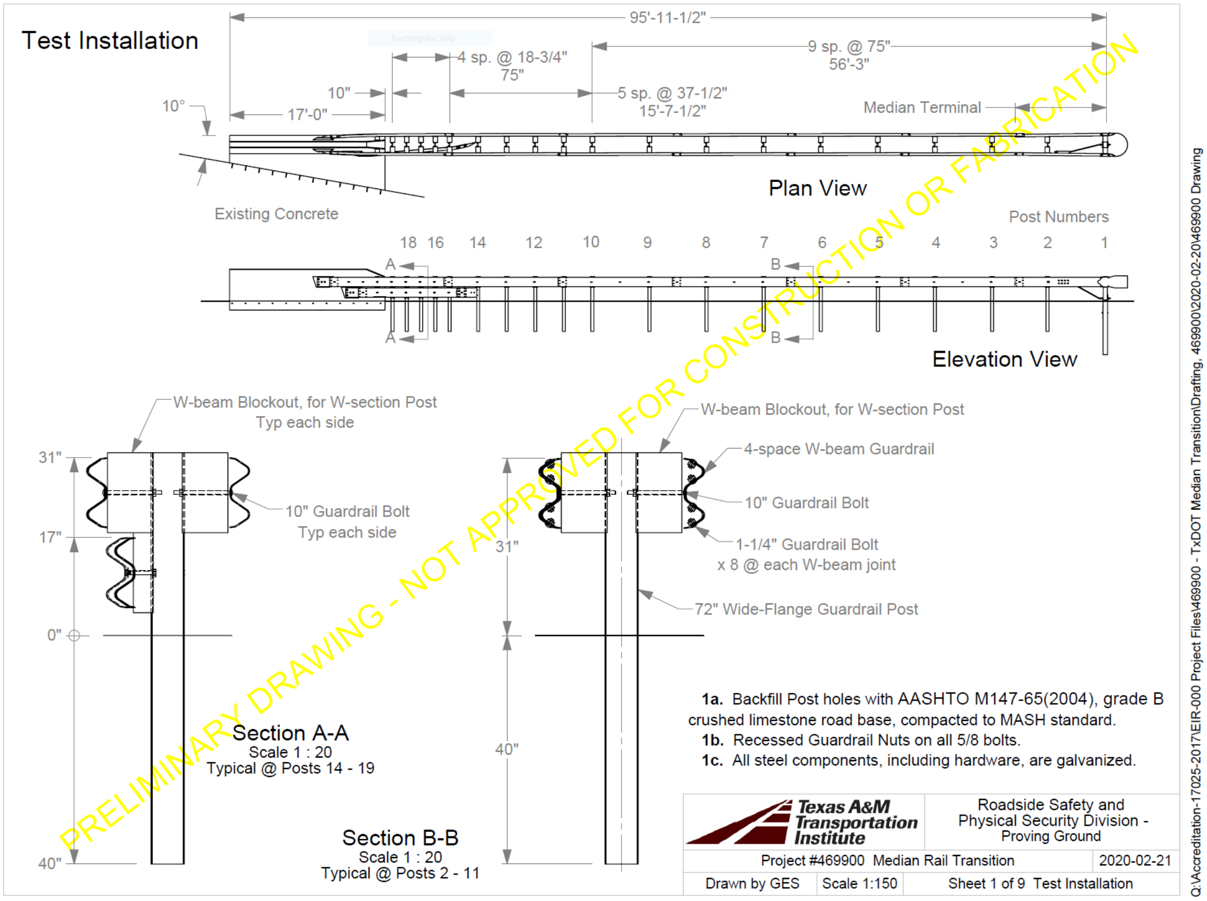


Figure 3.12. Asymmetric Median Transition Design.

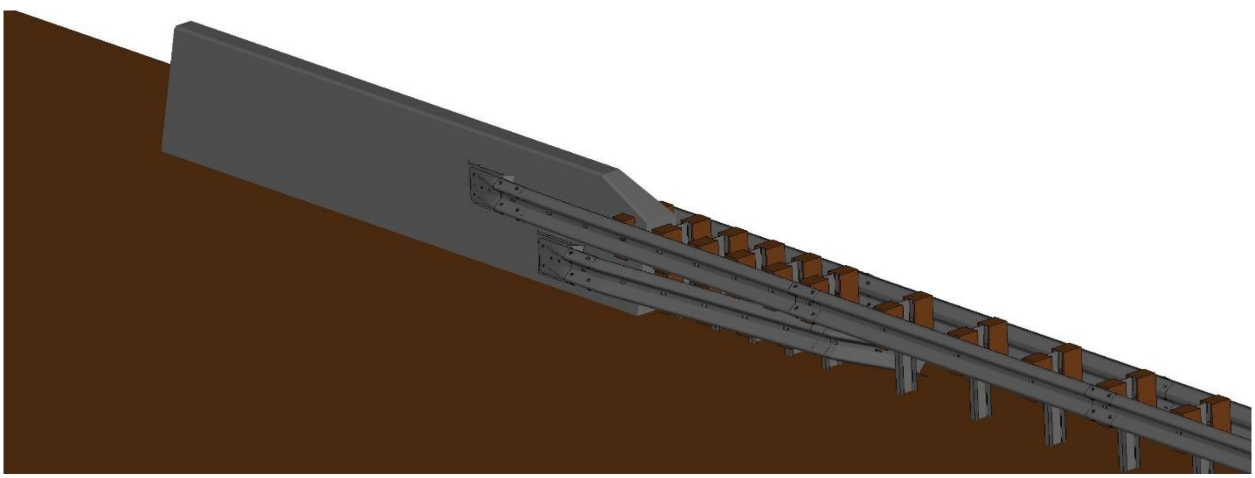


Figure 3.13. Computer Model of Asymmetric Transition.

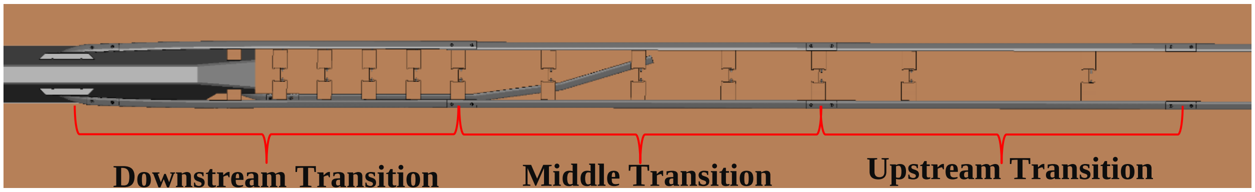


Figure 3.14. Transition Regions for *MASH* Evaluation.

3.3.1 *MASH* Test 3-20 at Downstream Transition

Four simulations were conducted to investigate the critical impact point for the section that transitioned from guardrail quarter post spacing to a rigid concrete parapet. The first simulation was conducted with the vehicle impacting 8.5 ft upstream of the end of the rigid concrete parapet. Figure 3.15 shows the vehicle at impact with the system. The other three simulations were conducted with the impact location shifted 2 ft downstream for each iteration.

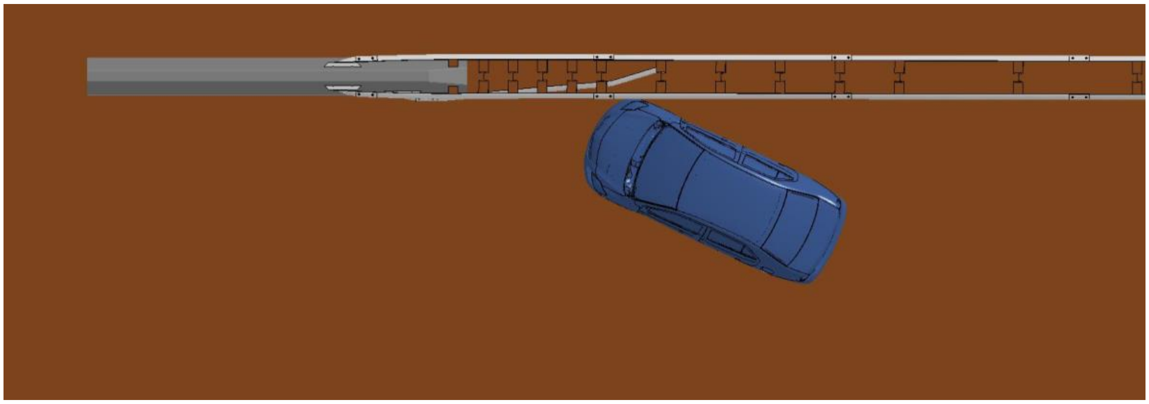


Figure 3.15. Impact Location for First Simulation at Downstream Transition.

To determine the critical impact location, the occupant risk values were calculated for each simulation and compared. Table 3.4 shows the occupant risk values for the four simulations. The impact location of 8.5 ft upstream of the end of the rigid concrete parapet resulted in the highest OIV and is near the MASH limit of 12.0 m/s. The impact location of 4.5 ft upstream of the end of the rigid concrete parapet had a slightly higher ORA value but is well below the MASH limit of 20 g's. Thus, the impact location of 8.5 ft upstream of the end of the rigid parapet was determined to be the critical impact location since the OIV value is close to the MASH limit. No additional simulations were performed upstream of the 8.5 ft impact location as this would be moving into the next transition region.

Table 3.4. Occupant Risk Comparison for *MASH* Test 3-20 at Downstream Transition.

	8.5 ft upstream	6.5 ft upstream	4.5 ft upstream	2.5 ft upstream
Longitudinal OIV (m/s)	9.6	9.3	9.1	9.0
Lateral OIV (m/s)	10.1	9.3	9.8	9.7
Longitudinal ORA (g)	8.9	7.1	10.9	8.9
Lateral ORA (g)	10.0	7.9	6.9	7.5
Roll (deg.)	6.0	5.5	7.0	9.3
Pitch (deg.)	5.2	8.1	8.3	7.9
Yaw (deg.)	45.1	93.6	61.6	50.8

3.3.2 *MASH* Test 3-20 at Middle Transition

Four simulations were conducted to investigate the critical impact point for the section that transitioned from guardrail half post spacing to guardrail quarter post spacing. The first simulation was conducted with the vehicle impacting 3.5 ft upstream of the centerline of the last post in the quarter post spacing section. Figure 3.16 shows the vehicle at impact with the system. The other three simulations were conducted with the impact location shifted 2 ft upstream for each iteration.

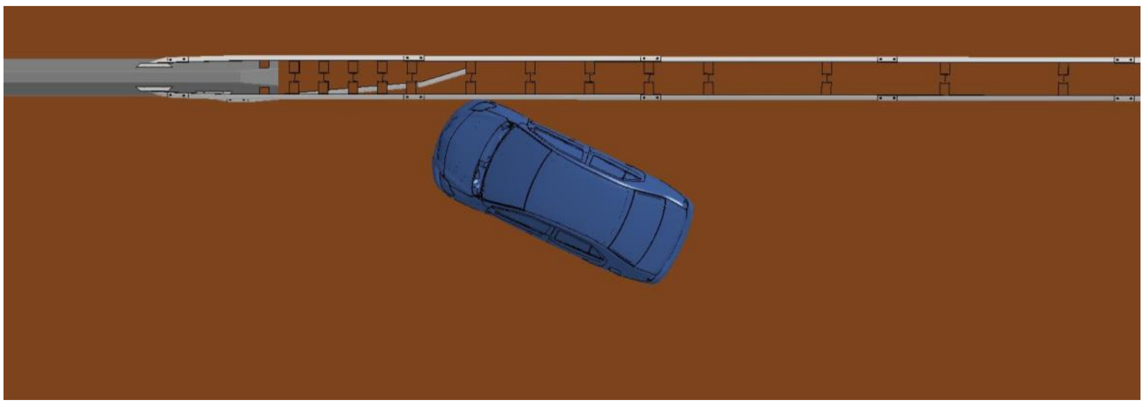


Figure 3.16. Impact Location for First Simulation at Middle Transition.

To determine the critical impact location, the occupant risk values were calculated for each simulation and compared. Table 3.5 shows the occupant risk values for the four simulations. The impact location of 7.5 ft upstream of the centerline of the last post in the quarter post spacing section resulted in the highest ORA and was determined to be the critical impact location.

Table 3.5. Occupant Risk Values for *MASH* Test 3-20 at Middle Transition.

	3.5 ft upstream	5.5 ft upstream	7.5 ft upstream	9.5 ft upstream
Longitudinal OIV (m/s)	9.4	9.9	10.5	10.8
Lateral OIV (m/s)	9.2	9.4	7.1	8.5
Longitudinal ORA (g)	8.5	12.0	29.7	17.0
Lateral ORA (g)	6.4	8.3	10.5	12.3
Roll (deg.)	6.0	27.6	30.2	33.2
Pitch (deg.)	4.9	6.2	6.7	5.8
Yaw (deg.)	49.9	54.9	65.6	31.6

3.3.3 *MASH* Test 3-20 at Upstream Transition

Three simulations were conducted to investigate the critical impact point for the section that transitioned from guardrail regular post spacing to guardrail half post spacing. The first simulation was performed with the impact point 2.0 ft upstream of the centerline of the last post in the half post spacing section. Figure 3.17 shows the vehicle at impact with the system. The other two simulations were conducted with the impact location shifted 2 ft upstream for each iteration.

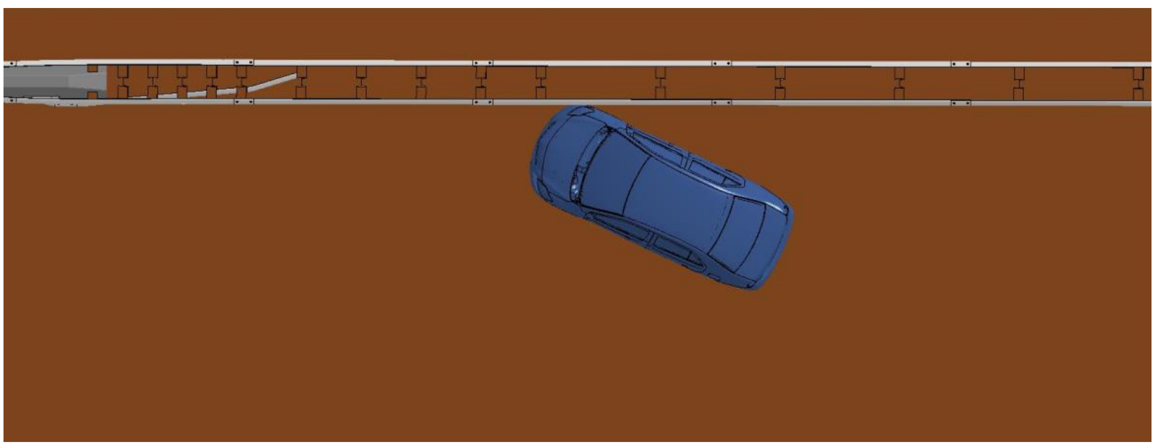


Figure 3.17. Impact Location for First Simulation at Upstream Transition.

To determine the critical impact location, the occupant risk values were calculated for each simulation and compared. Table 3.6 shows the occupant risk values for the three simulations. All of the simulations resulted in ORA values exceeding the MASH limit of 20 gs. The current vehicle model does not allow any failure of the suspension components or joints. In full-scale crash testing, it is likely that some of these components would fail and reduce the high ORA values seen in the simulations. For the purposes of selecting the critical impact location, the impact location of 2.0 ft upstream of the centerline of the last post in the half post spacing section was determined to be the critical impact location as it had the highest ORA value.

Table 3.6. Occupant Risk Values for *MASH* Test 3-20 at Upstream Transition.

	2.0 ft upstream	4.0 ft upstream	6.0 ft upstream
Longitudinal OIV (m/s)	9.9	12.9	14.4
Lateral OIV (m/s)	7.1	6.6	5.8
Longitudinal ORA (g)	34.4	25.3	27.8
Lateral ORA (g)	9.6	9.5	7.9
Roll (deg.)	34.1	31.3	3.7
Pitch (deg.)	6.7	9.7	12.8
Yaw (deg.)	33.8	56.8	88.8

3.3.4 *MASH* Test 3-21 at Downstream Transition

Three simulations were conducted to investigate the critical impact point for the section that transitioned from guardrail quarter post spacing to a rigid concrete parapet. The first simulation was conducted with the vehicle impacting 4.0 ft upstream of the end of the rigid concrete parapet. Figure 3.18 shows the vehicle at impact with the system. The other two simulations were conducted with the impact location shifted 2 ft upstream for each iteration.

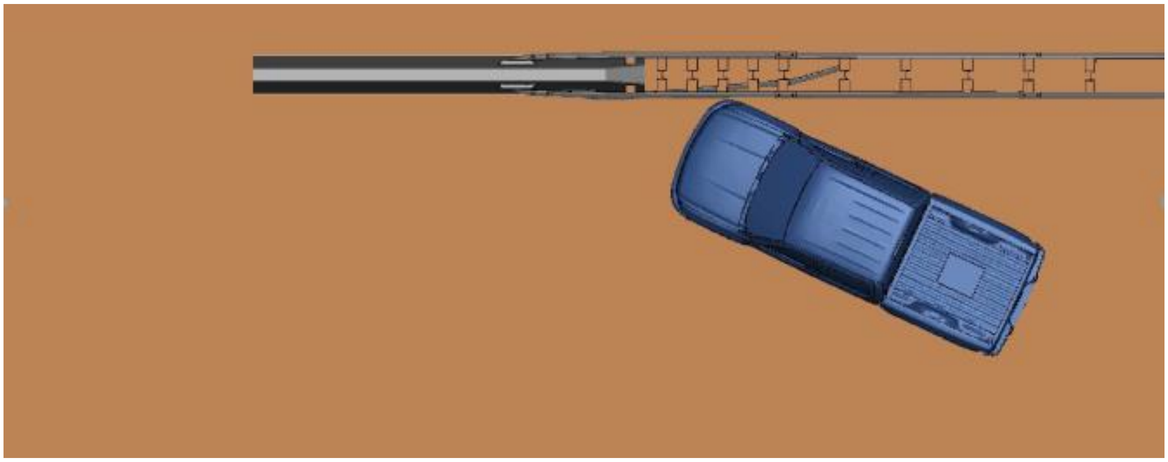


Figure 3.18. Impact Location for First Simulation at Downstream Transition.

To determine the critical impact location, the occupant risk values were calculated for each simulation and compared. Table 3.7 shows the occupant risk values for the three simulations. The impact location of 8.0 ft upstream of the end of the rigid concrete parapet resulted in rollover of the truck and was determined to be the critical impact location. The current Silverado vehicle model has been observed to have an overly stiff rear suspension system, which sometimes leads to overpredicting roll angles. Additional simulations were performed with a preliminary Dodge Ram pickup truck model and no rollover was observed.

Table 3.7. Occupant Risk Values for *MASH* Test 3-21 at Downstream Transition.

	4.0 ft upstream	6.0 ft upstream	8.0 ft upstream
Longitudinal OIV (m/s)	5.5	5.5	5.4
Lateral OIV (m/s)	8.5	8.4	8.3
Longitudinal ORA (g)	3.8	3.7	5.7
Lateral ORA (g)	14.1	11.7	10.2
Roll (deg.)	29.8	65.5	161.5
Pitch (deg.)	9.1	8.9	6.5
Yaw (deg.)	33.1	58.3	74.9

3.3.5 *MASH* Test 3-21 at Middle Transition

Four simulations were conducted to investigate the critical impact point for the section that transitioned from guardrail half post spacing to guardrail quarter post spacing. The first simulation was conducted with the vehicle impacting 5.0 ft upstream of the centerline of the last post in the quarter post spacing section. Figure 3.19 shows the vehicle at impact with the system. The other three simulations were conducted with the impact location shifted 2 ft upstream for each iteration.

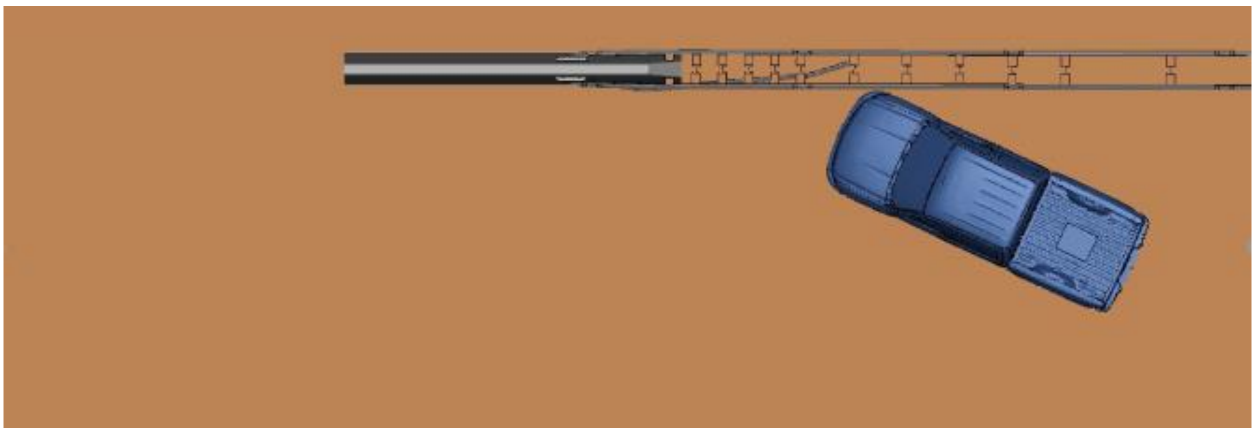


Figure 3.19. Impact Location for First Simulation at Middle Transition.

To determine the critical impact location, the occupant risk values were calculated for each simulation and compared. Table 3.8 shows the occupant risk values for the four simulations. The impact location of 6.0 ft upstream of the centerline of the last post in the quarter post spacing section resulted in rollover of the pickup truck and was determined to be the critical impact location.

Table 3.8. Occupant Risk Values for *MASH* Test 3-21 at Middle Transition.

	4.0 ft upstream	6.0 ft upstream	8.0 ft upstream	10.0 ft upstream
Longitudinal OIV (m/s)	5.5	5.5	5.5	5.3
Lateral OIV (m/s)	8.5	8.6	7.9	7.4
Longitudinal ORA (g)	6.9	7.6	8.1	4.9
Lateral ORA (g)	12.8	10.2	11.0	11.7
Roll (deg.)	73.7	104.6	55.7	24.2
Pitch (deg.)	7.7	6.7	10.1	9.6
Yaw (deg.)	65.5	71.1	54.5	41.7

3.3.6 *MASH* Test 3-21 at Upstream Transition

Three simulations were conducted to investigate the critical impact point for the section that transitioned from guardrail regular post spacing to guardrail half post spacing. The first simulation was performed with the impact point 3.0 ft upstream of the centerline of the last post in the half post spacing section. Figure 3.20 shows the vehicle at impact with the system. The other two simulations were conducted with the impact location shifted 2 ft upstream for each iteration.

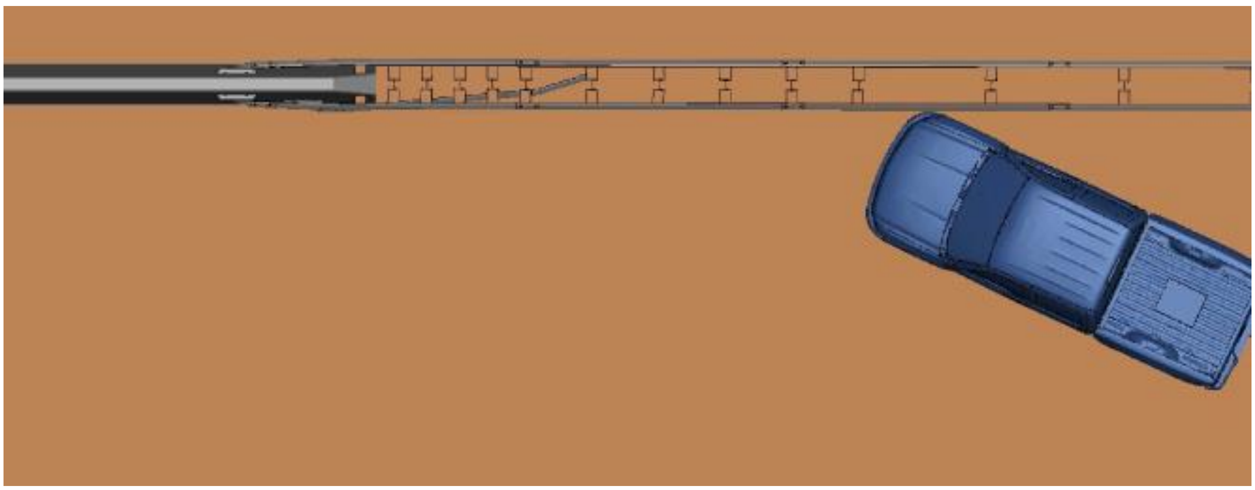


Figure 3.20. Impact Location for First Simulation at Upstream Transition.

To determine the critical impact location, the occupant risk values were calculated for each simulation and compared. Table 3.9 shows the occupant risk values for the three simulations. The impact location of 7.0 ft upstream of the centerline of the last post in the half post spacing section resulted in the highest ORA and was determined to be the critical impact location. No additional simulations were performed upstream of the 7.0 ft impact location as this would be moving into the standard median guardrail region.

Table 3.9. Occupant Risk Values for *MASH* Test 3-21 at Upstream Transition.

	3.0 ft upstream	5.0 ft upstream	7.0 ft upstream
Longitudinal OIV (m/s)	6.9	9.2	7.7
Lateral OIV (m/s)	6.8	6.3	5.1
Longitudinal ORA (g)	9.5	10.8	18.6
Lateral ORA (g)	9.5	9.4	8.5
Roll (deg.)	19.3	48.0	5.5
Pitch (deg.)	13.9	8.5	10.8
Yaw (deg.)	40.0	54.0	43.4

3.4 SYMMETRIC MEDIAN TRANSITION

A modified transition design that consisted of a median guardrail system with W-beam rub rail on both sides of the system was developed. The rub rails were connected to the face of the concrete parapet at one end and were connected together at the other end with a spacer tube.

A computer model was developed for the symmetric transition design and is shown in Figure 3.21. Computer simulations were conducted at the downstream transition from the median guardrail to the concrete parapet. *MASH* Test 3-21 was performed to evaluate the symmetric design. *MASH* Test 3-20 was not considered with the symmetric transition design since the pickup truck impact was shown to be more critical in the previous simulations. No other changes were made to the system details, so it was not necessary to reevaluate the middle and upstream transition sections.

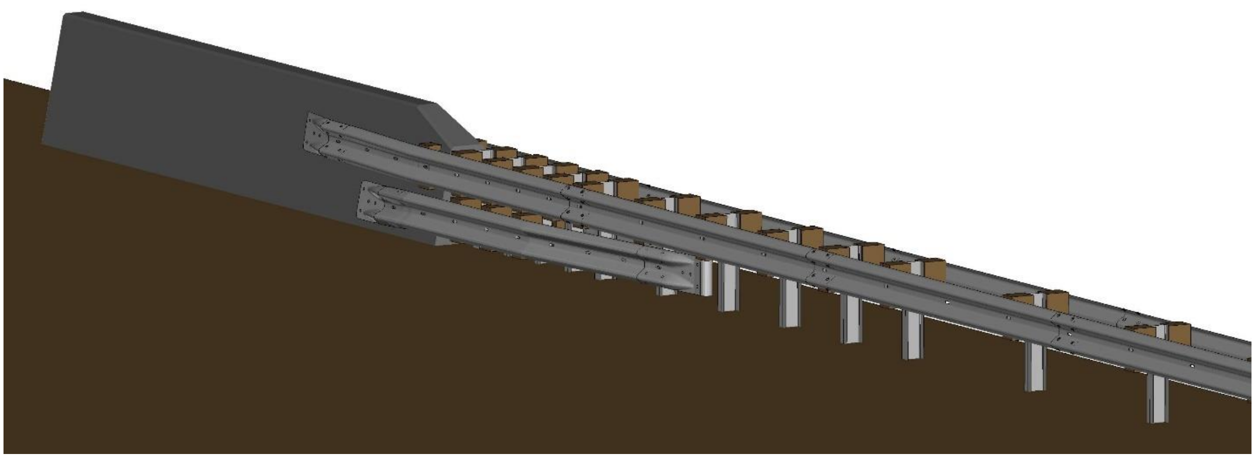


Figure 3.21. Computer Model of Symmetric Transition.

Computer simulations were conducted to evaluate the symmetric design according to *MASH* Test 3-21 evaluation criteria. The same pickup truck computer model used for the asymmetric design was used to evaluate the symmetric design. Figure 3.22 shows the vehicle at impact. The impact location was 8 ft upstream of the end of the parapet.

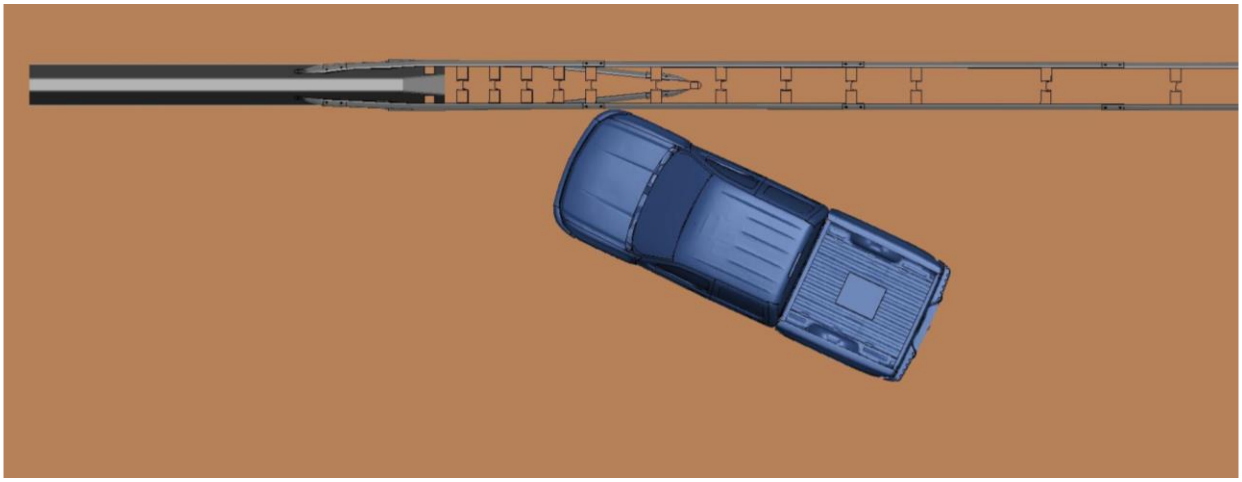


Figure 3.22. ***MASH*** **Test 3-21 on Symmetric Design.**

The computer simulation resulted in rollover of the pickup truck. Figure 3.23 shows the pickup truck after impact with the symmetric transition design.

Figure 3.23. Pickup Truck Rollover after Impact.

A modification was made to the pickup truck to allow failure of the tire joints, thus allowing release of the tire during impact. A simulation was performed with the updated vehicle model to evaluate the potential for rollover. In the simulation, the pickup truck tire released during initial impact, but the truck still rolled over.

A RAM 1500 pickup truck model was recently developed by Center for Collision Safety and Analysis (CCSA) and released to the roadside safety community for use in computer simulations. This vehicle model has been shown to have more realistic suspension characteristics than the Chevy Silverado pickup truck model. Thus, the research team proceeded with integrating the RAM 1500 computer model with the median transition system model. Figure 3.24 shows the RAM pickup truck model, and Figure 3.25 shows the pickup truck model prior to impact with the median transition.

Figure 3.24. RAM Pickup Truck Model.

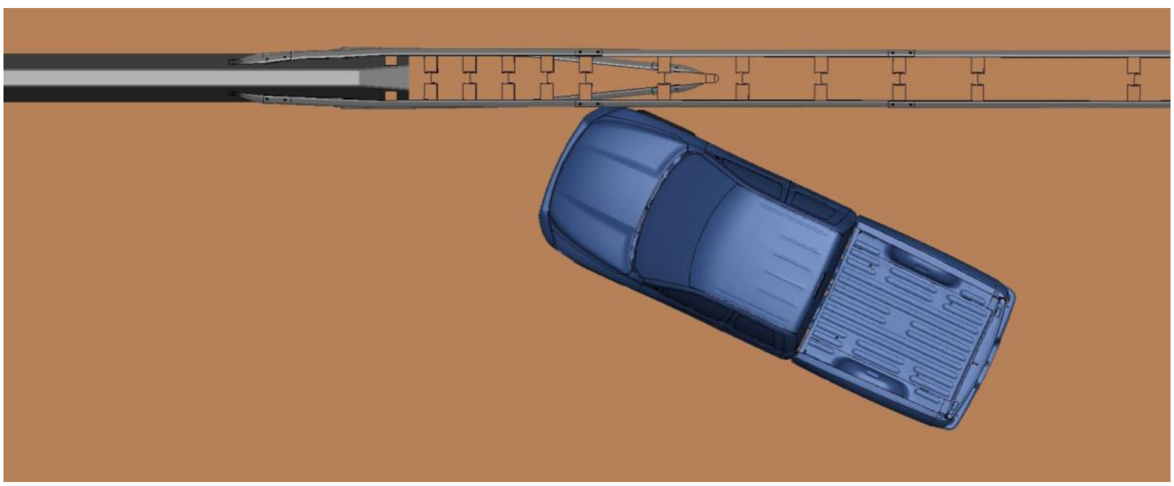


Figure 3.25. RAM Pickup Truck Impact with Symmetric Transition.

The computer simulation with the RAM vehicle model impacting the symmetric transition resulted in improved vehicle behavior, and no rollover of the vehicle occurred. Figure 3.26 shows the vehicle after impact.

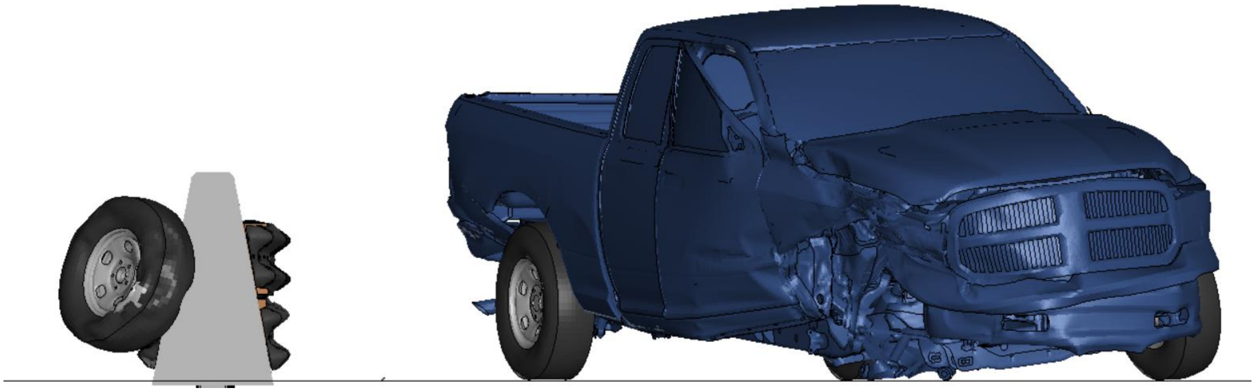


Figure 3.26. RAM Pickup Truck after Impact with Symmetric Transition.

3.5 CONCLUSIONS

After computer simulations showed a reasonable chance of passing the *MASH* 3-21 test with the RAM pickup truck model, full-scale crash testing was initiated to evaluate the symmetric transition design experimentally.

CHAPTER 4:
SYSTEM DETAILS

4.1 TEST ARTICLE AND INSTALLATION DETAILS

The installation consisted of a double-sided, 31-inch-tall W-beam median guardrail attached to a concrete terminal barrier via W-beam terminal connectors. A second 17-inch-high W-beam section rub rail was installed just below the guardrail on both sides for a distance of approximately 14 ft upstream of the concrete terminal barrier. The total length of the installation was 95 ft 11 $^{7}/_{16}$ inches. The W-beam medial guardrail was installed on both sides of 72-inch-long wide flange guardrail posts and terminated on the downstream end with a simple terminal that provides anchorage functionality to the system. The rails were offset from the posts by W-beam blockouts.

4.2 DESIGN MODIFICATIONS DURING TESTS

Modifications were made to the system after the first crash test (Test No. 469900-01-1). A description of the modifications can be found in Section 7.8. Also, Figure 7.6 presents overall information on the modified transition system, and Figure 7.7 provides photographs of the modified installation. Appendix A2 provides further details on the modified median barrier transition.

4.3 MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the median barrier transition.

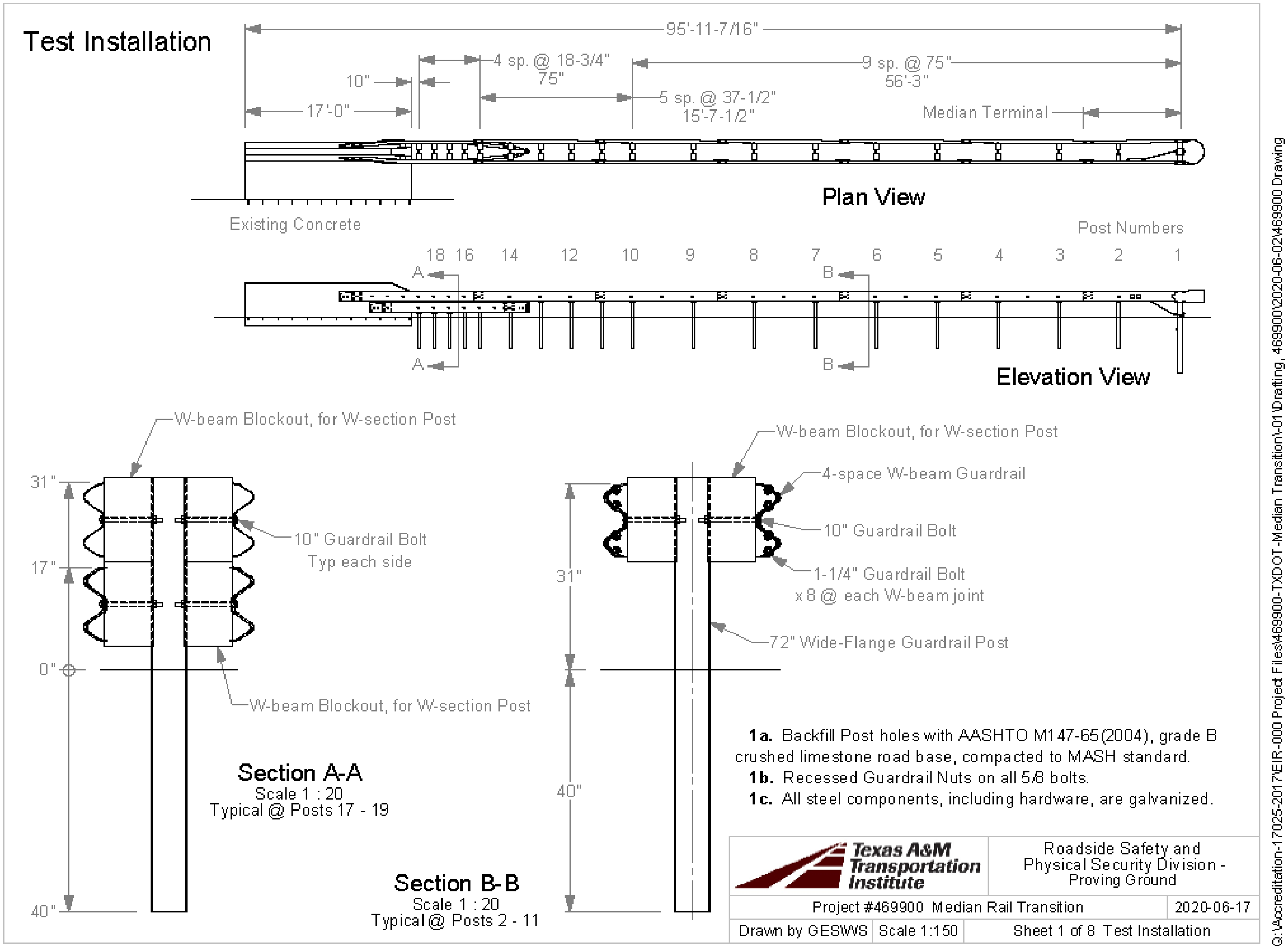


Figure 4.1. Overall Details on Median Barrier Transition.

Figure 4.2. Median Barrier Transition prior to Testing.

4.4 SOIL CONDITIONS

The test installation was installed in standard soil meeting AASHTO standard specifications for “Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses,” designated M147-65(2004), Grade B.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the median barrier transition for full-scale crash testing, two standard 6-ft-long W6×16 posts were installed in the immediate vicinity of the median barrier transition, using the same fill materials and installation procedures that were used in the standard dynamic test (see Table C.1 in Appendix C for establishment of minimum soil strength properties in the dynamic test performed in accordance with *MASH* Appendix B).

As determined in the tests shown in Appendix C, Table C.1, the minimum post load required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, was 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial standard installation).

On the day of Test No. 469900-01-1, June 18, 2020, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 7222 lbf, 8131 lbf, and 8989 lbf, respectively. Table C.2 in Appendix C shows that the strength of the backfill material in which the transition was installed met minimum requirements.

For Test No. 469900-01-2 on August 13, 2020, the loads on the post were 7070 lbf, 7575 lbf, and 8080 lbf at 5 inches, 10 inches, and 15 inches. Table C.3 in Appendix C shows that the strength of the backfill material in which the transition was installed met minimum requirements.

For Test No. 469900-01-3 on August 25, 2020, the loads on the post were 8333 lbf, 9191 lbf, and 10,101 lbf at 5 inches, 10 inches, and 15 inches. Table C.4 in Appendix C shows that the strength of the backfill material in which the transition was installed met minimum requirements.

For Test No. 469900-01-4 on September 28, 2020, the loads on the post were 8282 lbf, 9249 lbf, and 9595 lbf at 5 inches, 10 inches, and 15 inches. Table C.5 in Appendix C shows that the strength of the backfill material in which the transition was installed met minimum requirements.

For Test No. 469900-01-5 on October 5, 2020, the loads on the post were 9090 lbf, 10,505 lbf, and 11,060 lbf at 5 inches, 10 inches, and 15 inches. Table C.6 in Appendix C shows that the strength of the backfill material in which the transition was installed met minimum requirements.

4.5 CONCRETE STRENGTH

Concrete for the steel-reinforced parapet/barrier and foundation slab was specified as TxDOT Class C (3600 psi). On June 18, 2020, the compressive concrete strengths for the parapet/barrier and the foundation slab averaged 4947 psi at 52 days and 4847 psi at 31 days. Appendix B provides additional information.

CHAPTER 5:
TEST REQUIREMENTS AND EVALUATION CRITERIA

5.1 CRASH TEST MATRIX

Table 5.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for transitions. Figure 5.1 through Figure 5.4 show the target critical impact points (CIPs) for each crash test per the previous failed single sided stacked w-beam transition for the first test and a combination of simulations and engineering judgment for the other tests. As specified in *MASH* Section 2.2.1.1, two impact regions should be considered for transitions that connect a flexible system to a rigid system. For this particular transition system, three impact regions were considered: (a) the transition from median guardrail with rub rail and quarter post spacing to median concrete parapet; (b) the transition from median guardrail with half post spacing to median guardrail with rub rail and quarter post spacing; and (c) the transition from median guardrail to median guardrail with half post spacing.

The CIPs were determined using the results from the computer simulations presented in Chapter 3 and the information provided in *MASH* Section 2.2.1 and Section 2.3.2. The first test (*MASH* 3-21) CIP was selected based on a known failed test for a single-sided, stacked W-beam transition. The optional *MASH* 3-20 test at the transition from the median guardrail with rub rail to the concrete parapet was not conducted since it is not as critical as the other regions' CIP for the small car test. This transition region has more surface area than the other regions and does not have room for tire-to-post interaction due to the presence of the W-beam rub rail.

Table 5.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Transition.

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

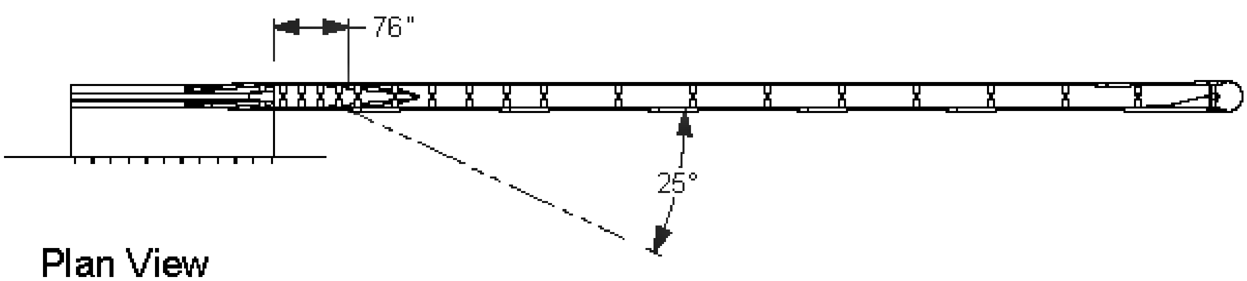


Figure 5.1. Target CIP for *MASH* Test 3-21 on Both the Original and the Modified Median Transition to Concrete Barrier.

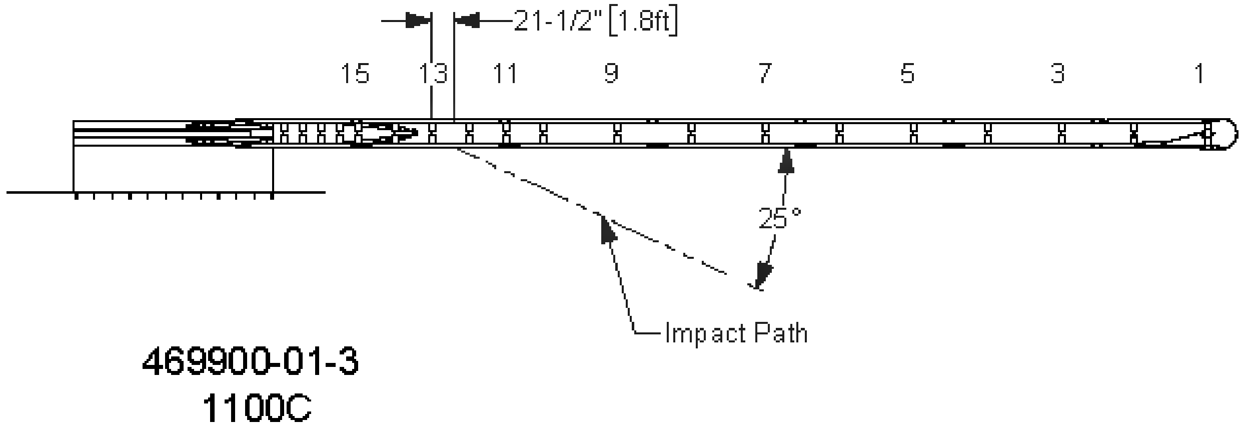


Figure 5.2. Target CIP for *MASH* Test 3-20 on Modified Median Transition.

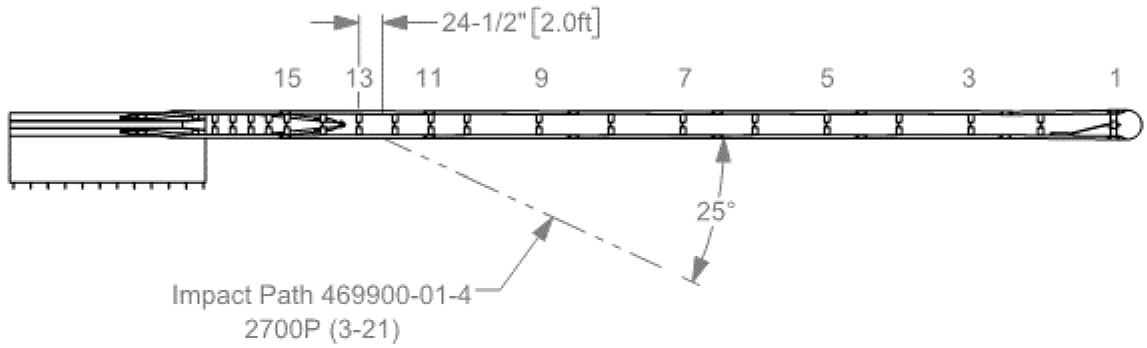


Figure 5.3. Target CIP for *MASH* Test 3-21 on Median Guardrail to Modified Median Transition.

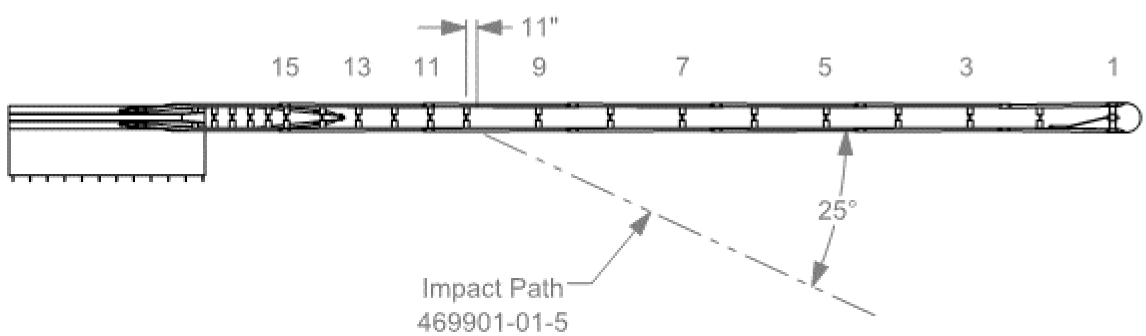


Figure 5.4. Target CIP for *MASH* Test 3-20 on Median Guardrail to Modified Median Transition.

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 6 presents brief descriptions of these procedures.

5.2 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. The test conditions and evaluation criteria required for

MASH TL-3 transitions are listed in Table 5.1, and a detailed explanation of the evaluation criteria is included in Table 5.2. An evaluation of the crash test results is presented in Chapter 13.

Table 5.2. Evaluation Criteria Required for *MASH* TL-3 Transitions.

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.*

CHAPTER 6:
TEST CONDITIONS

6.1 TEST FACILITY

The full-scale crash tests reported herein were performed at 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, and according to the *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 median barrier transition 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.

6.2 VEHICLE TOW AND GUIDANCE SYSTEM

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

6.3 DATA ACQUISITION SYSTEMS

6.3.1 Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained, onboard data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems Inc. The accelerometers, which measure the x, y, and z axes of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid state units designed for crash test service. The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 values per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit in case the primary battery cable is severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units is returned to the factory annually for complete recalibration and to ensure that all instrumentation used in the vehicle conforms to all 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 any time data are suspect. Acceleration data are measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k = 2).

TRAP uses the data from the TDAS Pro to compute 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).

6.3.2 Anthropomorphic Dummy Instrumentation

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

According to *MASH*, use of a dummy in the 2270P vehicle is optional. However, it is recommended that a dummy be used when testing “any longitudinal barrier with a height greater than or equal to 33 inches.” 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 concrete parapet to which the median barrier transitioned was 42 inches, a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

6.3.3 Photographic Instrumentation and Data Processing

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

- One placed overhead with a field of view perpendicular to the ground and directly over the impact point.
- One placed behind the installation at an angle.
- 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 median barrier transition. 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 7: *MASH* TEST 3-21 (CRASH TEST NO. 469900-01-1) ON MEDIAN TRANSITION TO CONCRETE BARRIER

7.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-21 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 transition to the concrete median barrier was 6.3 ft ± 1 ft upstream of the end of the concrete parapet. Figure 5.1 and Figure 7.1 depict the target impact setup.

Figure 7.1. Transition/Test Vehicle Geometrics for Test No. 469900-01-1.

The 2270P vehicle weighed 5002 lb, and the actual impact speed and angle were 63.3 mi/h and 25.1 degrees. The actual impact point was 6.3 ft upstream of the end of the concrete parapet. Minimum target impact severity (IS) was 106 kip-ft, and actual IS was 121 kip-ft.

7.2 WEATHER CONDITIONS

The test was performed on the morning of June 18, 2020. Weather conditions at the time of testing were as follows: wind speed: 11 mi/h; wind direction: 167 degrees (vehicle was traveling at a heading of 330 degrees); temperature: 87°F; relative humidity: 63 percent.

7.3 TEST VEHICLE

Figure 7.2 shows the 2014 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5002 lb, and its gross static weight was 5167 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 29.5 inches. Tables 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 the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.2. Test Vehicle before Test No. 469900-01-1.

7.4 TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 469900-01-1. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 469900-01-1.

TIME (s)	EVENTS
0.000	Vehicle bumper impacts transition
0.027	Vehicle begins to redirect
0.106	Left front tire leaves pavement
0.121	Left rear tire leaves pavement
0.195	Rear right bumper contacts transition
0.208	Vehicle travels parallel with barrier
0.360	Vehicle loses contact with transition while traveling at 49.5 mi/h, a trajectory angle of 4.2 degrees, and a vehicle heading angle of 8.4 degrees
0.561	Right front corner of vehicle contacts pavement

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied after the vehicle exited the test site, and the vehicle subsequently came to rest on its right side 218 ft downstream of the impact point and 50 ft toward the traffic lanes.

7.5 DAMAGE TO TEST INSTALLATION

Figure 7.3 shows the damage to the transition. The rail was scuffed and deformed at the site of impact. There was no movement noted on posts 1 through 13. Post 14 was pushed back ¼ inch. Posts 15 and 16 were both pushed back ½ inch, and posts 17 and 18 were pushed back 1 inch. The soil at post 19 was disturbed. At the single-sloped blockouts holding the rail away from the concrete barrier, the rail was pushed against the barrier. Working width* was 33.3 inches, and height of working width was 28.5 inches. Maximum dynamic deflection during the test was 3.3 inches.

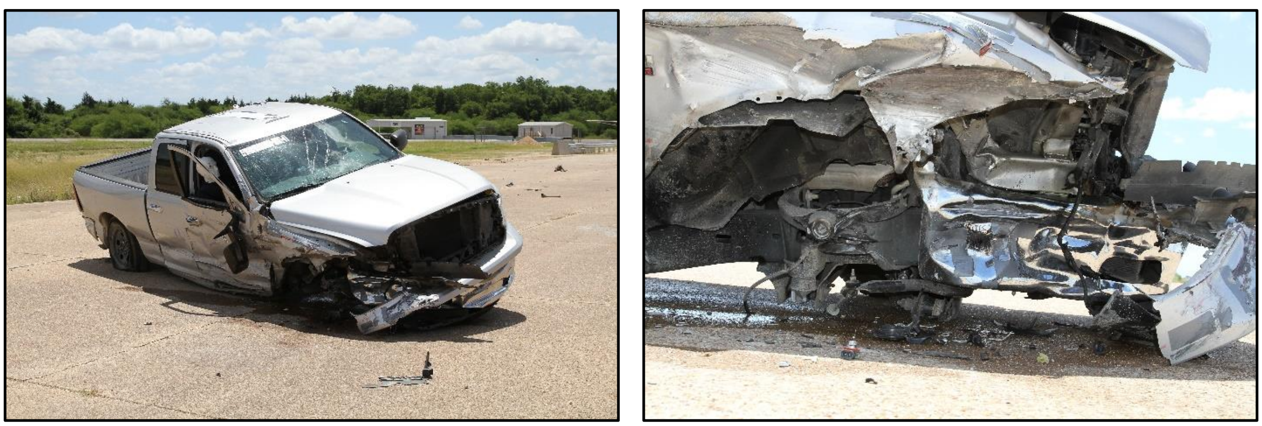
Figure 7.3. Transition after Test No. 469900-01-1.

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

7.6 DAMAGE TO TEST VEHICLE

Figure 7.4 shows the damage sustained by the vehicle. The front bumper, radiator and support, right frame rail, right and left upper and lower control arms, right front tire and rim, sway bar, right front floor pan, right front door and window glass, right rear door, right exterior cab corner, right rear exterior bed, right rear tire and rim, and rear bumper were damaged. The windshield was cracked, radiating from the right lower corner upward and inward across the entire windshield. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 16.0 inches in the front and side planes at the right front corner at bumper height. Maximum occupant compartment deformation was 7.0 inches in the right front firewall and the kick panel area. Tables D.3 and D.4 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Before being uprighted



After being uprighted

Figure 7.4. Test Vehicle after Test No. 469900-01-1.

7.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 7.2. Figure 7.5 summarizes these data and other pertinent information from the test. Figure D.3 in Appendix D.3 shows the vehicle angular displacements, and Figures D.4 through D.6 in Appendix D.4 show accelerations versus time traces.

Table 7.2. Occupant Risk Factors for Test No. 469900-01-1.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	21.0 ft/s	at 0.1052 s on right side of interior
Lateral	25.9 ft/s	
Ridedown Accelerations		
Longitudinal	11.6 g	0.1052–0.1152 s
Lateral	12.4 g	0.2410–0.2510 s
Theoretical Head Impact Velocity (THIV)	10.0 m/s	at 0.1025 s on right side of interior
Acceleration Severity Index (ASI)	1.4	0.0853–0.1353 s
Maximum 50-ms Moving Average		
Longitudinal	−8.9 g	0.0793–0.1293 s
Lateral	−11.7 g	0.0461–0.0961 s
Vertical	−3.0 g	0.0183–0.0683 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	53°	@ 1.2982 s (vehicle rolled 90° after end of data collection)
Pitch	18°	0.6146 s
Yaw	70°	2.0000 s

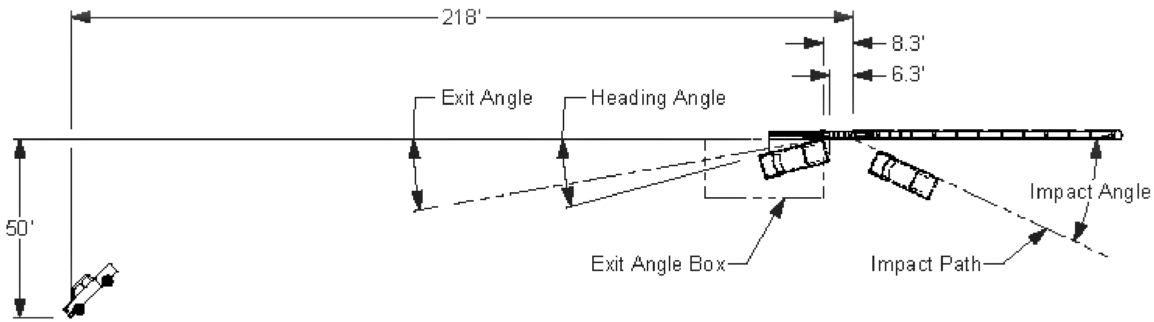
7.8 RESULTS AND CONCLUSIONS

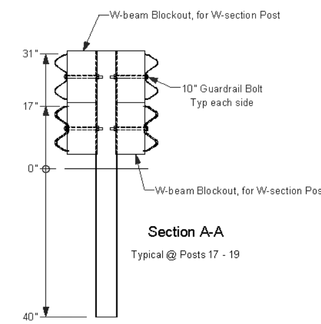
Due to rollover of the pickup truck, the design failed to redirect the vehicle in a safe and stable manner. To improve the performance of the system, several modifications were made to the transition system. First, the lower W-beam rail was attached to the end face of the concrete parapet with a steel bracket. This was done by moving the lower W-beam rail toward the post line via reducing the size of the wood blocks. Thus, the modified design has no W-beam terminal connector for the lower rail.

Second, an extra post was added upstream of the quarter spacing region to smooth the stiffness transition between the half-spaced posts and the quarter-spaced posts where the rub-rail terminates. Third, a vertical taper was added to the toe at the end of the concrete barrier parapet.

Figure 7.6 presents overall information on the median transition, and Figure 7.7 provides photographs of the installation. Appendix A2 provides further details on the modified median barrier transition.

0.000 s | 0.200 s | 0.400 s | 0.700 s





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-21
TTI Test No.	469900-01-1
Test Date	2020-06-18

Test Article

Type	Transition
Name	Median Transition
Installation Length	95 ft 11$^{7}/_{16}$ inches
Material or Key Elements	Steel W-beam guardrail and posts, concrete barrier with steel rebar

Soil Type and Condition .. AASHTO M147-65, Grade B soil (crushed limestone)

Test Vehicle

Type/Designation	2270P
Make and Model	2014 RAM 1500 pickup truck
Curb	4947 lb
Test Inertial	5002 lb
Dummy	165 lb
Gross Static	5167 lb

Impact Conditions

Speed	63.3 mi/h
Angle	25.1°
Location/Orientation	6.3 ft upstream of end of parapet

Impact Severity .... 121 kip-ft

Exit Conditions

Speed	49.5 mi/h
Trajectory/Heading Angle	4.2°/8.4°

Occupant Risk Values

Longitudinal OIV	21.0 ft/s
Lateral OIV	25.9 ft/s
Longitudinal Ridedown	11.6 g
Lateral Ridedown	12.4 g
THIV	10.0 m/s
ASI	1.4
Max. 0.050-s Average	
Longitudinal	−8.9 g
Lateral	−11.7 g
Vertical	−3.0 g

Post-Impact Trajectory

Stopping Distance	218 ft downstream 50 ft twd traffic

Vehicle Stability

Maximum Roll Angle	53°
Maximum Pitch Angle	18°
Maximum Yaw Angle	70°
Vehicle Snagging	Yes
Vehicle Pocketing	No

Test Article Deflections

Dynamic	3.3 inches
Permanent	Undetermined
Working Width	33.3 inches
Height of Working Width	28.5 inches

Vehicle Damage

VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	16.0 inches
OCDI	RF0020000
Max. Occupant Compartment Deformation	7.0 inches

Figure 7.5. Summary of Results for *MASH* Test 3-21 on Median Transition.

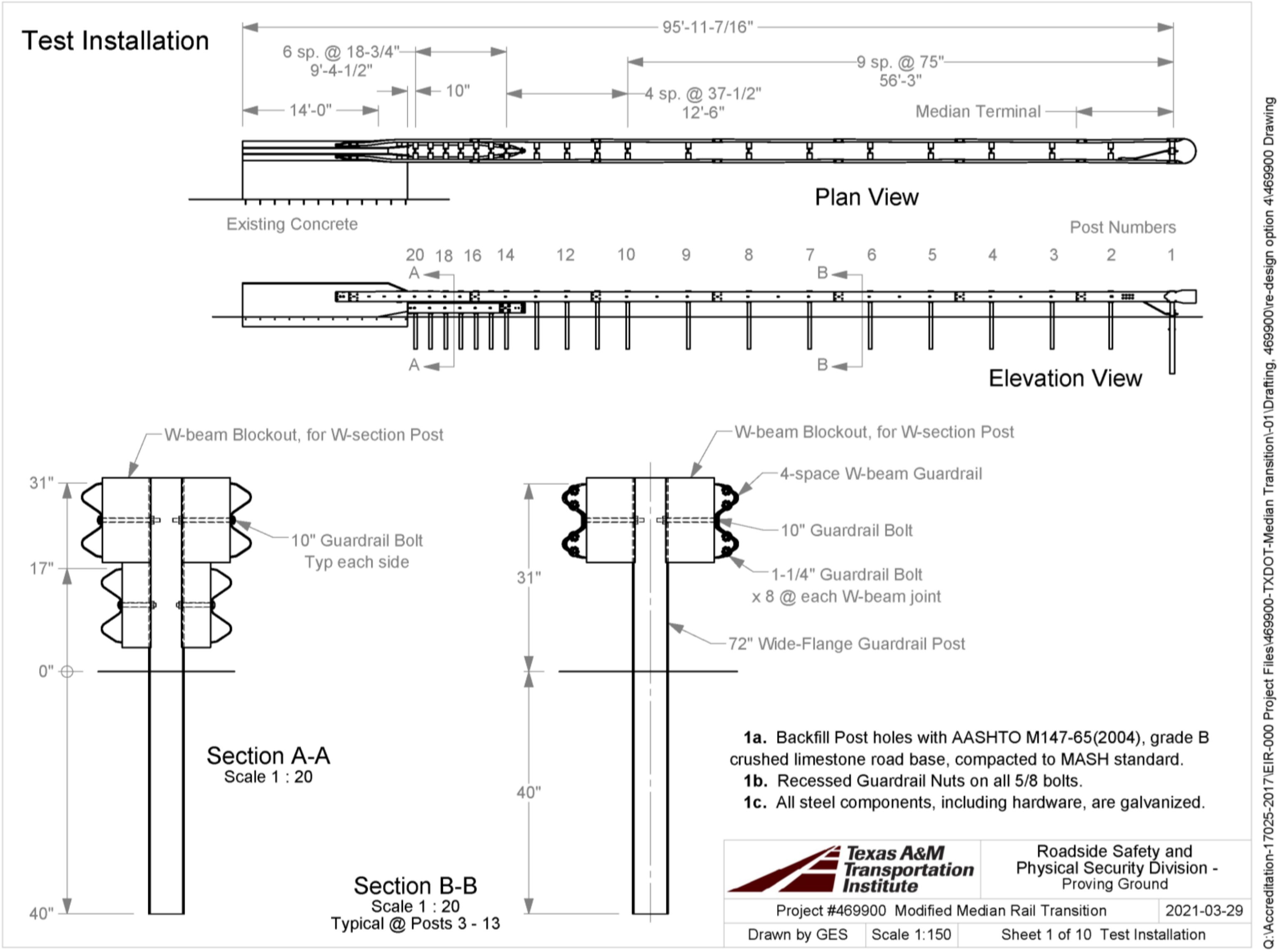


Figure 7.6. Overall Details on Modified Median Barrier Transition.

Figure 7.7. Modified Median Barrier Transition prior to Testing.

CHAPTER 8: *MASH* TEST 3-21 (CRASH TEST NO. 469900-01-2) ON MODIFIED MEDIAN TRANSITION TO CONCRETE BARRIER

8.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-21 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 modified transition to the concrete median barrier was 6.3 ft ± 1 ft upstream of the end of the concrete parapet. Figure 5.1 and Figure 8.1 depict the target impact setup.

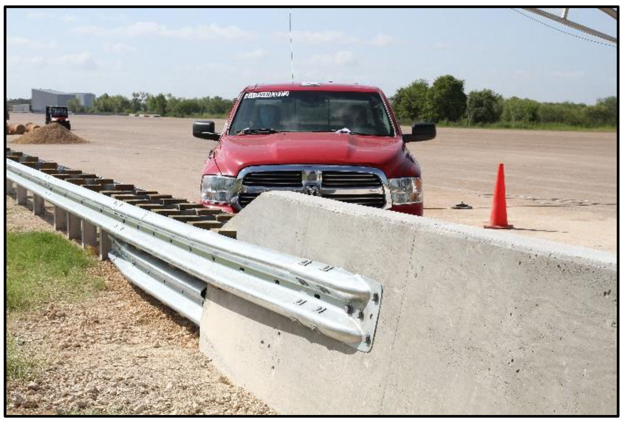


Figure 8.1. Modified Transition/Test Vehicle Geometrics for Test No. 469900-01-2.

The 2270P vehicle weighed 5008 lb, and the actual impact speed and angle were 61.9 mi/h and 24.7 degrees. The actual impact point was 6.6 ft upstream of the end of the concrete parapet. Minimum target IS was 106 kip-ft, and actual IS was 112 kip-ft.

8.2 WEATHER CONDITIONS

The test was performed on the morning of August 13, 2020. Weather conditions at the time of testing were as follows: wind speed: 9 mi/h; wind direction: 211 degrees (vehicle was traveling at a heading of 330 degrees); temperature: 90°F; relative humidity: 67 percent.

8.3 TEST VEHICLE

Figure 8.2 shows the 2014 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5008 lb, and its gross static weight was 5173 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.8 inches. Tables E.1 and E.2 in Appendix E.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 8.2. Test Vehicle before Test No. 469900-01-2.

8.4 TEST DESCRIPTION

Table 8.1 lists events that occurred during Test No. 469900-01-2. Figures E.1 and E.2 in Appendix E.2 present sequential photographs during the test.

Table 8.1. Events during Test No. 469900-01-2.

TIME (s)	EVENTS
0.000	Vehicle impacts transition
0.106	Left front tire begins to lift off the pavement
0.119	Left rear tire lifts off pavement
0.214	Right rear corner of vehicle contacts transition
0.448	Vehicle begins to redirect
0.468	Right front corner of vehicle returns to pavement
0.590	Vehicle travels parallel with transition
0.761	Vehicle loses contact with the transition traveling at 45.9 mi/h, a trajectory angle of 5.3 degrees, and a heading angle of 12.8 degrees

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 3.25 s after impact. After loss of contact with the barrier, the vehicle came to rest 224 ft downstream of the impact point and 9 ft toward the field side.

8.5 DAMAGE TO TEST INSTALLATION

Figure 8.3 shows the damage to the modified transition. The rail was scuffed and deformed at the site of impact. The maximum permanent deformation of the system was 2.75 inches at post 18. There was no movement noted on posts 1 through 13. The following gaps in the soil were noted at the front of these posts: 0.25 inches at post 14, 0.5 inches at post 15, 0.75 inches at posts 16 and 17, and 1 inch at post 18. The soil appeared to be disturbed at posts

19 and 20. No movement or cracking was noted on the concrete barrier. Working width[*] was 33.0 inches, and height of working width was 28.7 inches. Maximum dynamic deflection during the test was 5.4 inches, and maximum permanent deformation was 2.75 inches.

Figure 8.3. Modified Transition after Test No. 469900-01-2.

[*] 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.

8.6 DAMAGE TO TEST VEHICLE

Figure 8.4 shows the damage sustained by the vehicle. The front bumper, grill, hood, radiator and support, right front fender, right upper and lower control arms, right front tire and rim, right A-post, right front door and window glass, right front floor pan, right rear door, right rear cab corner, right rear exterior bed, right rear rim, right taillight, and rear bumper were damaged. The windshield sustained stress cracking initiating from the right lower corner of the windshield upward and inward. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 16.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 5.5 inches in the right front firewall area. Figure 8.5 shows the interior of the vehicle after the test. Tables E.3 and E.4 in Appendix E.1 provide exterior crush and occupant compartment measurements.

Figure 8.4. Test Vehicle after Test No. 469900-01-2.

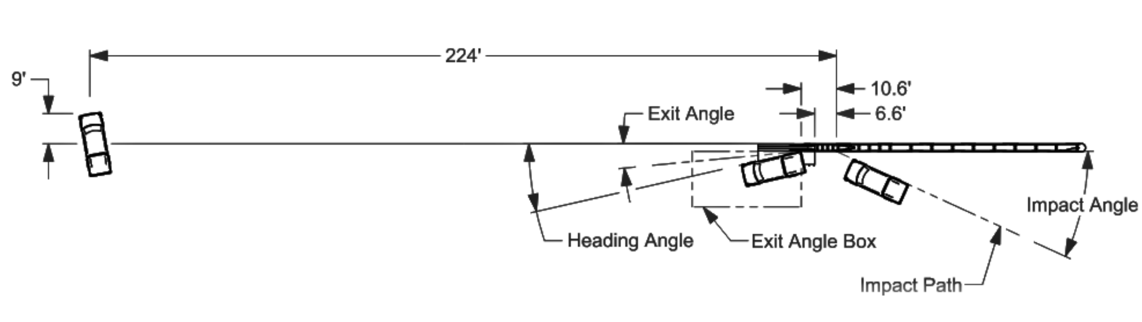
Figure 8.5. Interior of Vehicle after Test No. 469900-01-2.

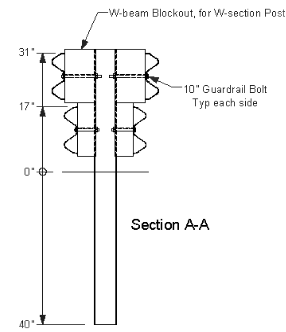
8.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 8.2. Figure 8.6 summarizes these data and other pertinent information from the test. Figure E.3 in Appendix E.3 shows the vehicle angular displacements, and Figures E.4 through E.6 in Appendix E.4 show accelerations versus time traces.

Table 8.2. Occupant Risk Factors for Test No. 469900-01-2.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	20.7 ft/s	at 0.1055 s on right side of interior
Lateral	25.6 ft/s	
Ridedown Accelerations		
Longitudinal	7.1 g	0.1055–0.1155 s
Lateral	7.3 g	0.2665–0.2765 s
THIV	10.5 m/s	at 0.1091 s on right side of interior
ASI	1.7	0.0685–0.1185 s
Maximum 50-ms Moving Average		
Longitudinal	−9.3 g	0.0517–0.1017 s
Lateral	−12.7 g	0.0428–0.0928 s
Vertical	−2.4 g	0.0236–0.0736 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	37°	0.7477 s
Pitch	44°	1.4255 s
Yaw	42°	5.0000 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-21
TTI Test No.	469900-01-2
Test Date	2020-08-13
Test Article	
Type	Transition
Name	Modified Median Transition
Installation Length	95 ft $11^{7}/_{16}$ inches
Material or Key Elements	Steel W-beam guardrail and posts, steel rebar reinforced concrete barrier
Soil Type and Condition	AASHTO M147-65, Grade B soil (crushed limestone)
Test Vehicle	
Type/Designation	2270P
Make and Model	2014 RAM 1500 pickup truck
Curb	5089 lb
Test Inertial	5008 lb
Dummy	165 lb
Gross Static	5173 lb

Impact Conditions	
Speed	61.9 mi/h
Angle	24.7°
Location/Orientation	6.6 ft upstream of end of parapet
Impact Severity	112 kip-ft
Exit Conditions	
Speed	45.9 mi/h
Trajectory/Heading Angle	5.3°/12.8°
Occupant Risk Values	
Longitudinal OIV	20.7 ft/s
Lateral OIV	25.6 ft/s
Longitudinal Ridedown	7.1 g
Lateral Ridedown	7.3 g
THIV	10.5 m/s
ASI	1.7
Max. 0.050-s Average	
Longitudinal	−9.3 g
Lateral	−12.7 g
Vertical	−2.4 g

Post-Impact Trajectory	
Stopping Distance	224 ft downstream 9 ft twd field side
Vehicle Stability	
Maximum Roll Angle	37°
Maximum Pitch Angle	44°
Maximum Yaw Angle	42°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	5.4 inches
Permanent	2.75 inches
Working Width	33.0 inches
Height of Working Width	28.7 inches
Vehicle Damage	
VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	16.0 inches
OCDI	RF0021200
Max. Occupant Compartment Deformation	5.5 inches

Figure 8.6. Summary of Results for *MASH* Test 3-21 on Modified Median Transition.

CHAPTER 9: *MASH* TEST 3-20 (CRASH TEST NO. 469900-01-3) ON MODIFIED MEDIAN TRANSITION TO CONCRETE BARRIER

9.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-20 involves an 1100C vehicle weighing 2420 lb ± 55 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 3-20 on the section transitioning from median guardrail with half post spacing to median guardrail with quarter post spacing and rub rail was 21.5 inches upstream of the centerline of post 13. Figure 5.2 and Figure 9.1 depict the target impact setup.


Figure 9.1. Transition/Test Vehicle Geometrics for Test No. 469900-01-3.

The 1100C vehicle weighed 2420 lb, and the actual impact speed and angle were 62.9 mi/h and 25.2 degrees. The actual impact point was 20.7 inches upstream of the centerline of post 13. Minimum target IS was 51 kip-ft, and actual IS was 58 kip-ft.

9.2 WEATHER CONDITIONS

The test was performed on the afternoon of August 25, 2020. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 48 degrees (vehicle was traveling at a heading of 330 degrees); temperature: 97°F; relative humidity: 44 percent.

9.3 TEST VEHICLE

Figure 9.2 shows the 2015 Nissan Versa used for the crash test. The vehicle's test inertia weight was 2420 lb, and its gross static weight was 2585 lb. The height to the lower edge of the vehicle bumper was 7.0 inches, and height to the upper edge of the bumper was 22.25 inches. Table F.1 in Appendix F.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 9.2. Test Vehicle before Test No. 469900-01-3.

9.4 TEST DESCRIPTION

Table 9.1 lists events that occurred during Test No. 469900-01-3. Figures F.1 and F.2 in Appendix F.2 present sequential photographs during the test.

Table 9.1. Events during Test No. 469900-01-3.

TIME (s)	EVENTS
0.000	Vehicle impacts transition
0.018	Post 13 deflects toward field side
0.043	Vehicle begins to redirect
0.045	Right front tire contacts end of rub rail
0.177	Vehicle travels parallel with transition
0.338	Vehicle loses contact with transition while traveling at 46.6 mi/h, a trajectory angle of 6.3 degrees, and a heading angle of 12.7 degrees

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 3.25 s after impact, and the vehicle subsequently came to rest 198 ft downstream of the impact point and 27 ft toward the field side of the transition.

9.5 DAMAGE TO TEST INSTALLATION

Figure 9.3 shows the damage to the transition. The soil was disturbed at posts 11 through 18, and there was scraping and scuffing on the rail. The end cap of the bottom rail was pushed toward the field side, and the rail detached from posts 14 and 15. The blockout at post 13 was slightly crushed on the bottom of the downstream side. Working width* was 32.1 inches, and height of working width was 28.5 inches. Maximum dynamic deflection during the test was 5.2 inches, and maximum permanent deformation was 1.25 inches.

Figure 9.3. Transition after Test No. 469900-01-3.

* 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.

9.6 DAMAGE TO TEST VEHICLE

Figure 9.4 shows the damage sustained by the vehicle. The front bumper, grill, hood, radiator and support, right front fender, right front strut and tower, right front tire and rim, right lower control arm, right A-post, right front door and window glass, right front floor pan, right rear door, right rear quarter panel, and rear bumper were damaged. The windshield was cracked, radiating from the right lower corner upward and inward across the entire windshield, with some separation in the laminate due to vehicle body flex (not from contact with transition). No fuel tank damage was observed. Maximum exterior crush to the vehicle was 12.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 4.5 inches in the right front kick panel area. Figure 9.5 shows the interior of the vehicle after the test. Tables F.2 and F.3 in Appendix F.1 provide exterior crush and occupant compartment measurements.

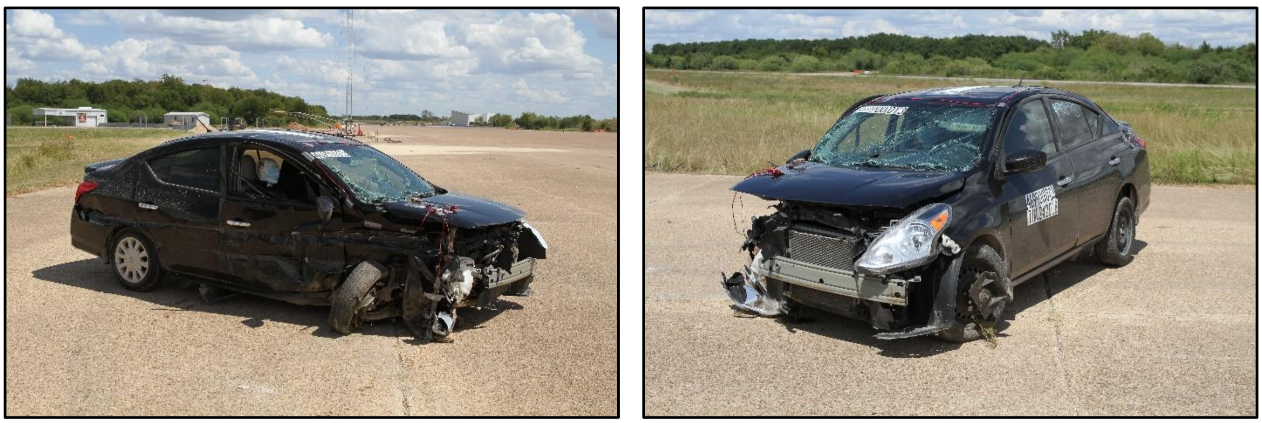


Figure 9.4. Test Vehicle after Test No. 469900-01-3.

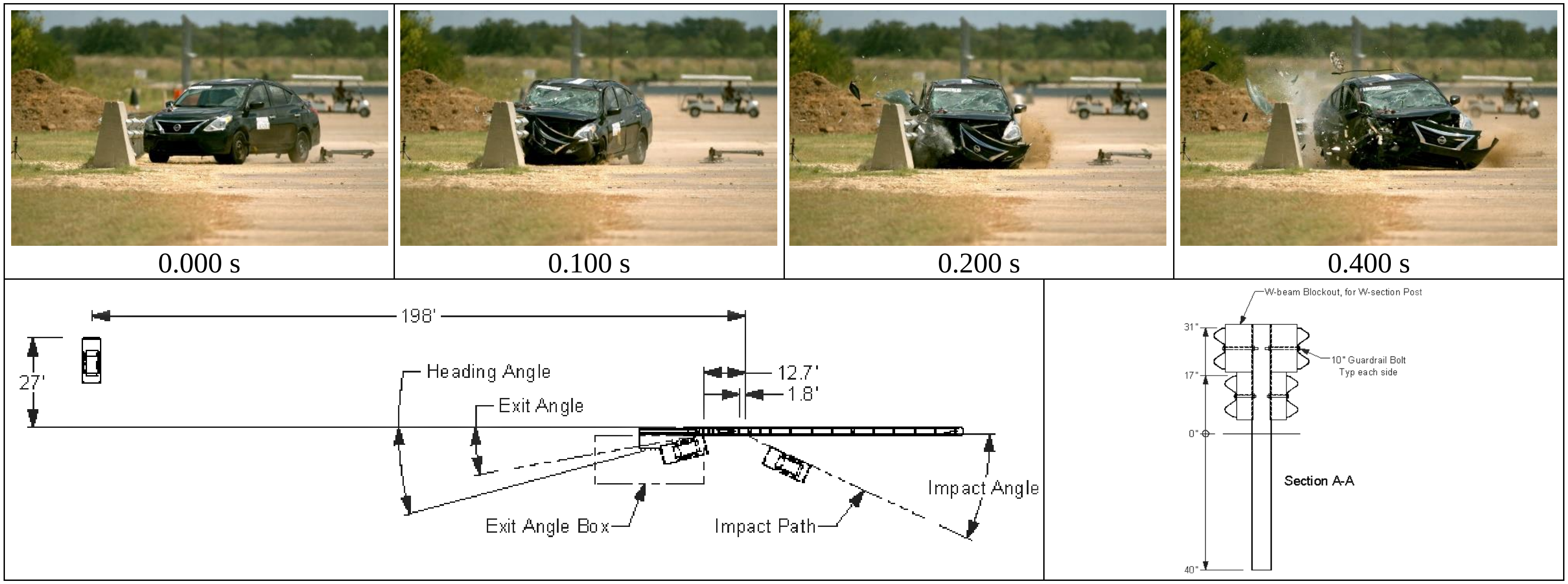
Figure 9.5. Interior of Vehicle after Test No. 469900-01-3.

9.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 9.2. Figure 9.6 summarizes these data and other pertinent information from the test. Figure F.3 in Appendix F.3 shows the vehicle angular displacements, and Figures F.4 through F.6 in Appendix F.4 show accelerations versus time traces.

Table 9.2. Occupant Risk Factors for Test No. 469900-01-3.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	23.6 ft/s	at 0.0909 s on right side of interior
Lateral	26.2 ft/s	
Ridedown Accelerations		
Longitudinal	5.5 g	0.1002–0.1102 s
Lateral	14.7 g	0.0931–0.1031 s
THIV	11.5 m/s	at 0.0954 s on right side of interior
ASI	2.1	0.0567–0.1067 s
Maximum 50-ms Moving Average		
Longitudinal	−11.8 g	0.0384–0.0884 s
Lateral	−15.5 g	0.0290–0.0790 s
Vertical	−2.7 g	0.0756–0.1256 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	6°	1.4913 s
Pitch	3°	0.5802 s
Yaw	47°	0.6658 s



General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-20
TTI Test No.	469900-01-3
Test Date	2020-08-25

Test Article

Type	Transition
Name	Modified Median Transition
Installation Length	95 ft 11 $^{7}/_{16}$ inches
Material or Key Elements	Steel W-beam guardrail with posts, steel rebar reinforced concrete barrier

Soil Type and Condition AASHTO M147-65, Grade B soil (crushed limestone)

Test Vehicle

Type/Designation	1100C
Make and Model	2015 Nissan Versa
Curb	2371 lb
Test Inertial	2420 lb
Dummy	165 lb
Gross Static	2585 lb

Impact Conditions

Speed	62.9 mi/h
Angle	25.2°
Location/Orientation	20.7 inches upstream of post 13

Impact Severity 58 kip-ft

Exit Conditions

Speed	46.6 mi/h
Trajectory/Heading Angle	6.3°/12.4°

Occupant Risk Values

Longitudinal OIV	23.6 ft/s
Lateral OIV	26.2 ft/s
Longitudinal Ridedown	5.5 g
Lateral Ridedown	14.7 g
THIV	11.5 m/s
ASI	2.1
Max. 0.050-s Average	
Longitudinal	−11.8 g
Lateral	−15.5 g
Vertical	−2.7 g

Post-Impact Trajectory

Stopping Distance	198 ft downstream 27 ft twd field side

Vehicle Stability

Maximum Roll Angle	6°
Maximum Pitch Angle	3°
Maximum Yaw Angle	47°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	5.2 inches
Permanent	1.25 inches
Working Width	32.1 inches
Height of Working Width	28.5 inches

Vehicle Damage

VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	12.0 inches
OCDI	RF0000000
Max. Occupant Compartment Deformation	4.5 inches

Figure 9.6. Summary of Results for *MASH* Test 3-20 on Modified Median Transition.

CHAPTER 10:
MASH TEST 3-21 (CRASH TEST NO. 469900-01-4) ON MEDIAN GUARDRAIL TO MODIFIED MEDIAN TRANSITION

10.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-21 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 section transitioning from median guardrail with half post spacing to median guardrail with quarter post spacing and rub rail was 24.5 inches ± 12 inches upstream of the centerline of post 13. Figure 5.3 and Figure 10.1 depict the target impact setup.

Figure 10.1. Transition/Test Vehicle Geometrics for Test No. 469900-01-4.

The 2270P vehicle weighed 5025 lb, and the actual impact speed and angle were 62.2 mi/h and 25.0 degrees. The actual impact point was 25.6 inches upstream of the centerline of post 13. Minimum target IS was 106 kip-ft, and actual IS was 116 kip-ft.

10.2 WEATHER CONDITIONS

The test was performed on the morning of September 28, 2020. Weather conditions at the time of testing were as follows: wind speed: 17 mi/h; wind direction: 354 degrees (vehicle was traveling at a heading of 330 degrees); temperature: 73°F; relative humidity: 42 percent.

10.3 TEST VEHICLE

Figure 10.2 shows the 2017 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5025 lb, and its gross static weight was 5190 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.00 inches. The height to the vehicle's center of gravity was 29.0 inches. Tables G.1 and G.2 in Appendix G.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

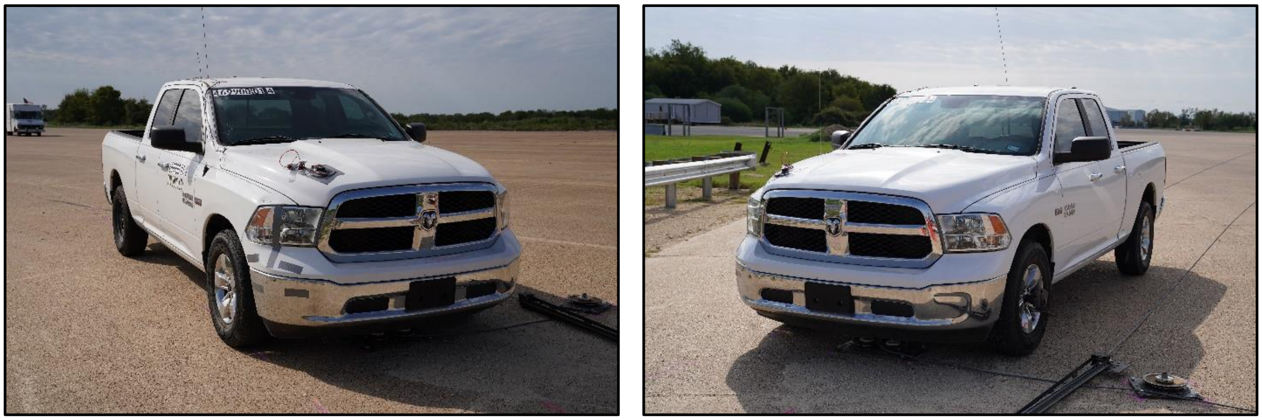


Figure 10.2. Test Vehicle before Test No. 469900-01-4.

10.4 TEST DESCRIPTION

Table 10.1 lists events that occurred during Test No. 469900-01-4. Figures G.1 and G.2 in Appendix G.2 present sequential photographs during the test.

Table 10.1. Events during Test No. 469900-01-4.

TIME (s)	EVENTS
0.000	Vehicle impacts transition
0.044	Vehicle begins to redirect
0.138	Left front tire and left rear tire lift off pavement
0.208	Vehicle travels parallel with transition
0.222	Right rear quarter panel contacts transition
0.387	Vehicle loses contact with transition while traveling at 45.5 mi/h, a trajectory angle of 7.5 degrees, and a heading angle of 13.4 degrees

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 3.75 s after impact. After loss of contact with the barrier, the vehicle came to rest 342 ft downstream of the impact point and 17 ft toward the field side.

10.5 DAMAGE TO TEST INSTALLATION

Figure 10.3 shows the damage to the transition. The soil was disturbed at post 10. There was a ¼-inch gap in the soil on the traffic side of post 11, and it was leaning back 2 degrees from vertical. There was a ⅝-inch gap in the soil on the traffic side of post 12, and it was leaning back 3 degrees from vertical. There was a ½-inch gap on the traffic side and a 1-inch gap on the field side of post 13, and it was leaning back 5 degrees from vertical. The blockout for post 13 was rotated clockwise. There was a 1-inch gap in the soil on the field side of both posts 14 and 15. Post 14 was leaning back 5 degrees and post 15 was leaning back 4 degrees from vertical. The blockout for post 15 was broken and rotated as well. Post 16 was leaning back 3 degrees and post 17 was leaning back 3 degrees from vertical. Post 18 was leaning back 3 degrees and posts 19 and 20 were leaning back 1 degree from vertical. The rub rail was deformed from post 14 through post 16, and the top rail was deformed between posts 12 and 14, with scuffing on both rails running the length of contact. Working width* was 36.5 inches, and height of working width was 28.5 inches. Maximum dynamic deflection during the test was 9.8 inches, and maximum permanent deformation was 5.5 inches.

Figure 10.3. Transition after Test No. 469900-01-4.

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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.

10.6 DAMAGE TO TEST VEHICLE

Figure 10.4 shows the damage sustained by the vehicle. The front bumper, grill, hood, radiator and support, right front fender, right frame rail, right upper and lower control arms, right front tie rod and sway bar, right front tire and rim, right front floor pan, right front and rear doors, right rear cab corner, right rear exterior bed, and rear bumper were damaged. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 16.0 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation was 4.0 inches in the right front firewall/toe pan/floor pan/kick panel area. Figure 10.5 shows the interior of the vehicle after the test. Tables G.3 and G.4 in Appendix G.1 provide exterior crush and occupant compartment measurements.

Figure 10.4. Test Vehicle after Test No. 469900-01-4.

Figure 10.5. Interior of Vehicle after Test No. 469900-01-4.

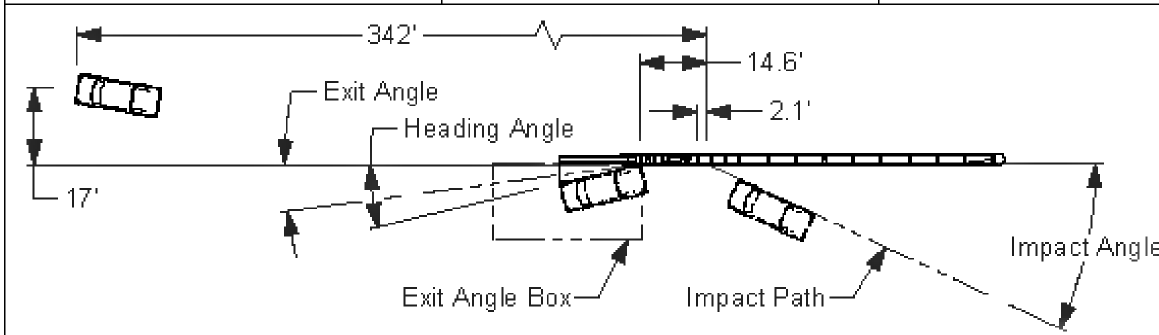
10.7 OCCUPANT RISK FACTORS

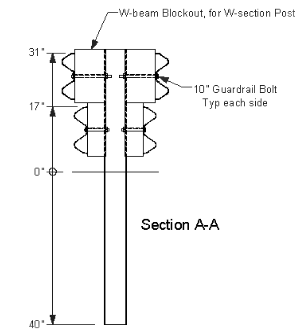
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 10.2. Figure 10.6 summarizes these data and other pertinent information from the test. Figure G.3 in Appendix G.3 shows the vehicle angular displacements, and Figures G.4 through G.6 in Appendix G.4 show accelerations versus time traces.

Table 10.2. Occupant Risk Factors for Test No. 469900-01-4.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	21.0 ft/s	at 0.1129 s on right side of interior
Lateral	25.3 ft/s	
Ridedown Accelerations		
Longitudinal	10.8 g	0.1168–0.1268 s
Lateral	12.1 g	0.1175–0.1275 s
THIV	9.8 m/s	at 0.1102 s on right side of interior
ASI	1.4	0.0944–0.1444 s
Maximum 50-ms Moving Average		
Longitudinal	−9.1 g	0.0778–0.1278 s
Lateral	−11.0 g	0.0776–0.1276 s
Vertical	2.4 g	0.2731–0.3231 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	33°	0.6231 s
Pitch	8°	0.5299 s
Yaw	49°	0.9256 s

0.000 s | 0.100 s | 0.200 s | 0.300 s





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-21
TTI Test No.	469900-01-4
Test Date	2020-09-28

Test Article

Type	Transition
Name	Modified Median Transition
Installation Length	95 ft 11 $^{7}/_{16}$ inches
Material or Key Elements	Steel W-beam guardrail and posts, steel rebar reinforced concrete barrier
Soil Type and Condition	AASHTO M147-65, Grade B soil (crushed limestone)

Test Vehicle

Type/Designation	2270P
Make and Model	2017 RAM 1500 pickup truck
Curb	5059 lb
Test Inertial	5025 lb
Dummy	165 lb
Gross Static	5190 lb

Impact Conditions

Speed	62.2 mi/h
Angle	25.0°
Location/Orientation	25.6 inches upstream of post 13
Impact Severity	116 kip-ft

Exit Conditions

Speed	45.5 mi/h
Trajectory/Heading Angle	7.5°/13.4°

Occupant Risk Values

Longitudinal OIV	21.0 ft/s
Lateral OIV	25.3 ft/s
Longitudinal Ridedown	10.8 g
Lateral Ridedown	12.1 g
THIV	9.8 m/s
ASI	1.4
Max. 0.050-s Average	
Longitudinal	−9.1 g
Lateral	−11.0 g
Vertical	2.4 g

Post-Impact Trajectory

Stopping Distance	342 ft downstream 17 ft twd field side

Vehicle Stability

Maximum Roll Angle	33°
Maximum Pitch Angle	8°
Maximum Yaw Angle	49°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	9.8 inches
Permanent	5.5 inches
Working Width	36.5 inches
Height of Working Width	28.5 inches

Vehicle Damage

VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	16.0 inches
OCDI	RF0011000
Max. Occupant Compartment Deformation	4.0 inches

Figure 10.6. Summary of Results for *MASH* Test 3-21 on Modified Median Transition.

CHAPTER 11: *MASH* TEST 3-20 (CRASH TEST NO. 469900-01-5) ON MEDIAN GUARDRAIL TO MODIFIED MEDIAN TRANSITION

11.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-20 involves an 1100C vehicle weighing 2420 lb ± 55 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 3-20 on the section transitioning from median guardrail to median guardrail with half post spacing and nested W-beam was 11 inches ± 12 inches upstream of the centerline of post 10. Figure 5.4 and Figure 11.1 depict the target impact setup.

Figure 11.1. Transition/Test Vehicle Geometrics for Test No. 469900-01-5.

The 1100C vehicle weighed 2424 lb, and the actual impact speed and angle were 63.0 mi/h and 25.0 degrees. The actual impact point was 9.6 inches upstream of the centerline of post 10. Minimum target IS was 51 kip-ft, and actual IS was 57 kip-ft.

11.2 WEATHER CONDITIONS

The test was performed on the morning of October 5, 2020. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h; wind direction: 146 degrees (vehicle was traveling at a heading of 330 degrees); temperature: 73°F; relative humidity: 73 percent.

11.3 TEST VEHICLE

Figure 11.2 shows the 2014 Nissan Versa used for the crash test. The vehicle's test inertia weight was 2424 lb, and its gross static weight was 2589 lb. The height to the lower edge of the vehicle bumper was 7.0 inches, and height to the upper edge of the bumper was 22.25 inches. Table H.1 in Appendix H.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

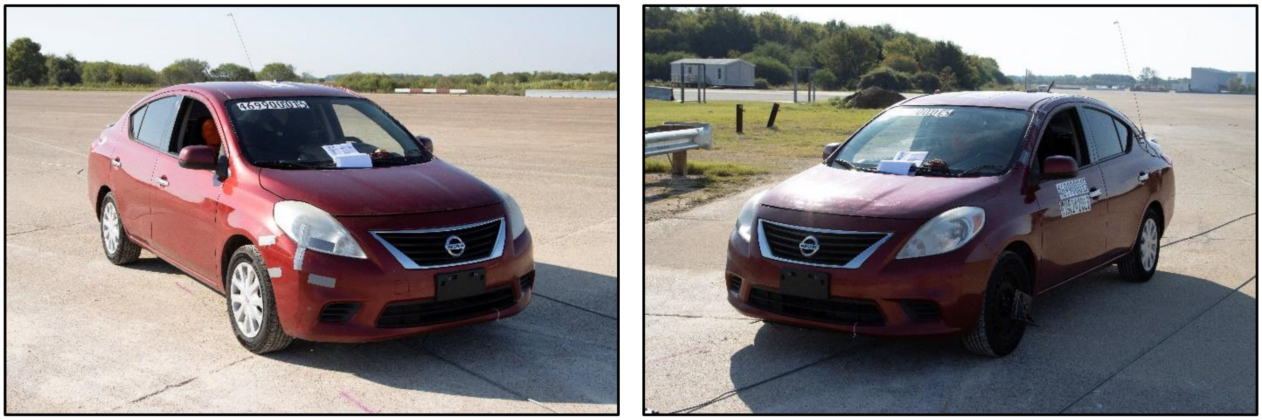


Figure 11.2. Test Vehicle before Test No. 469900-01-5.

11.4 TEST DESCRIPTION

Table 11.1 lists events that occurred during Test No. 469900-01-5. Figures H.1 and H.2 in Appendix H.2 present sequential photographs during the test.

Table 11.1. Events during Test No. 469900-01-5.

TIME (s)	EVENTS
0.000	Vehicle contacts transition
0.017	Posts 11 and 10 begin to deflect toward field side
0.043	Post 12 begins to deflect toward field side
0.048	Vehicle begins to redirect
0.054	Front right tire of vehicle contacts post 11
0.172	Vehicle travels parallel with transition
0.301	Vehicle loses contact with transition while traveling at 45.2 mi/h, a trajectory angle of 9.9 degrees, and a heading angle of 7.3 degrees

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 2.8 s after impact, and the vehicle subsequently came to rest 246 ft downstream of the impact point and 121 ft toward the traffic lanes.

11.5 DAMAGE TO TEST INSTALLATION

Figure 11.3 shows the damage to the transition. There was no movement noted from posts 1 through 7 and from post 15 until the end of the installation. The soil was disturbed at posts 8 and 9. Post 10 had a ¾-inch gap in the soil on the traffic side of the post, had a ½-inch gap on the field side, and was leaning back 2 degrees from vertical. Post 11 had a 1-inch gap on the field side, was deformed, and was leaning back 7 degrees from vertical. The blockout for post 11 was also rotated slightly, and the tire from the vehicle was captured between posts 11 and 12. Post 12 had a 1¼-inch gap on the traffic side, had a 1-inch gap on the field side, and was leaning back 4 degrees from vertical. Post 13 had a 1-inch gap on the field side and was leaning back 2 degrees from vertical. Post 14 had a ¼-inch gap on the field side of the post. There was some minor deformation and scuffing of the rail at impact. Working width[*] was 36.0 inches, and height of working width was 28.5 inches. Maximum dynamic deflection during the test was 10.6 inches, and maximum permanent deformation was 4.9 inches.

Figure 11.3. Transition after Test No. 469900-01-5.

[*] 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.

11.6 DAMAGE TO TEST VEHICLE

Figure 11.4 shows the damage sustained by the vehicle. The front bumper, hood, radiator and support, right front fender, right front strut and tower, right front tire and rim, right control arm, right A-post, right front and rear doors, right front floor pan, right rear quarter panel, and rear bumper were damaged. The windshield sustained stress cracks radiating inward and upward from the right lower corner. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 10.0 inches in the front and side planes near bumper height. Maximum occupant compartment deformation was 4.0 inches in the right front kick panel area and at hip height across the door panels. Figure 11.5 shows the interior of the vehicle after the test. Tables H.2 and H.3 in Appendix H.1 provide exterior crush and occupant compartment measurements.

Figure 11.4. Test Vehicle after Test No. 469900-01-5.

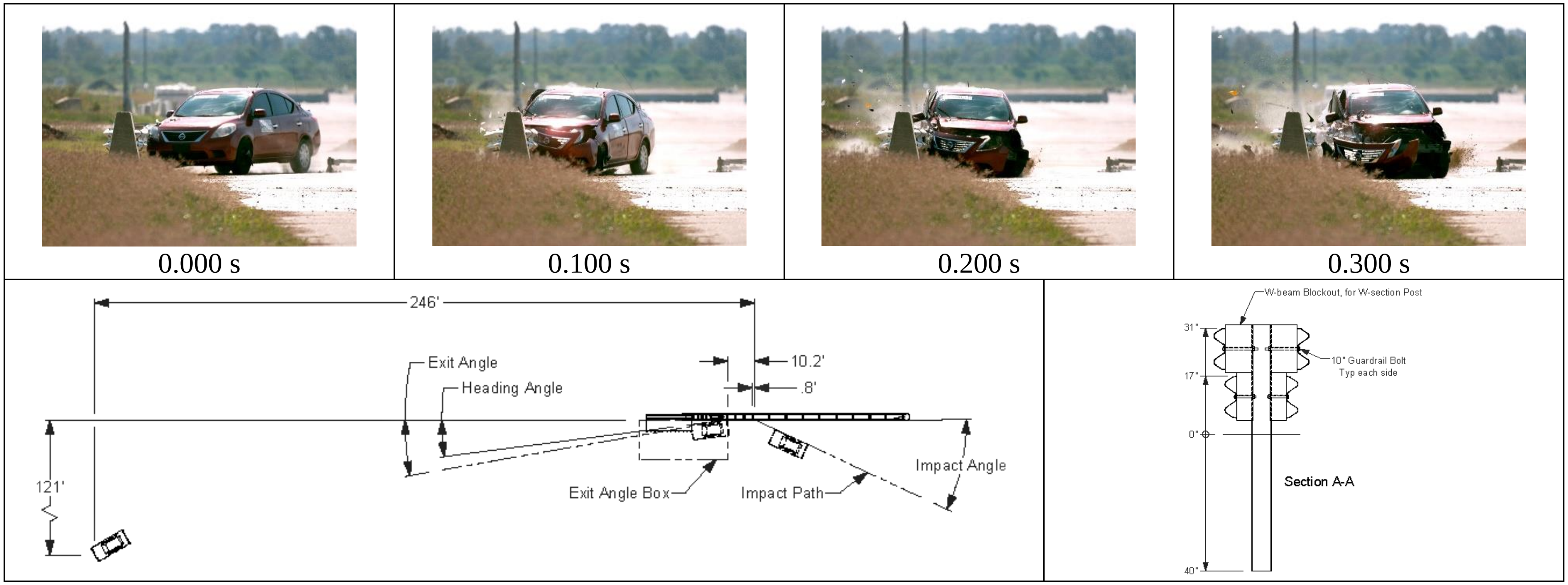
Figure 11.5. Interior of Vehicle after Test No. 469900-01-5.

11.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 11.2. Figure 11.6 summarizes these data and other pertinent information from the test. Figure H.3 in Appendix H.3 shows the vehicle angular displacements, and Figures H.4 through H.6 in Appendix H.4 show accelerations versus time traces.

Table 11.2. Occupant Risk Factors for Test No. 469900-01-5.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	24.0 ft/s	at 0.0962 s on right side of interior
Lateral	27.9 ft/s	
Ridedown Accelerations		
Longitudinal	4.9 g	0.1120–0.1220 s
Lateral	10.3 g	0.1054–0.1154 s
THIV	10.5 m/s	at 0.0938 s on right side of interior
ASI	1.8	0.0616–0.1116 s
Maximum 50-ms Moving Average		
Longitudinal	−11.7 g	0.0450–0.0950 s
Lateral	−12.9 g	0.0460–0.0960 s
Vertical	−2.3 g	0.1641–0.2141 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	12°	0.8916 s
Pitch	7°	0.9403 s
Yaw	47°	0.9161 s



General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-20
TTI Test No.	469900-01-5
Test Date	2020-10-05

Test Article

Type	Transition
Name	Modified Median Transition
Installation Length	95 ft 11$^7/_{16}$ inches
Material or Key Elements	Steel W-beam guardrail and posts, and steel rebar reinforced concrete barrier
Soil Type and Condition	AASHTO M147-65, Grade B soil (crushed limestone)

Test Vehicle

Type/Designation	1100C
Make and Model	2014 Nissan Versa
Curb	2412 lb
Test Inertial	2424 lb
Dummy	165 lb
Gross Static	2589 lb

Impact Conditions

Speed	63.0 mi/h
Angle	25.0°
Location/Orientation	9.6 inches upstream of post 10
Impact Severity	57 kip-ft

Exit Conditions

Speed	45.2 mi/h
Trajectory/Heading Angle	9.9°/7.3°

Occupant Risk Values

Longitudinal OIV	24.0 ft/s
Lateral OIV	27.9 ft/s
Longitudinal Ridedown	4.9 g
Lateral Ridedown	10.3 g
THIV	10.5 m/s
ASI	1.8
Max. 0.050-s Average	
Longitudinal	−11.7 g
Lateral	−12.9 g
Vertical	−2.3 g

Post-Impact Trajectory

Stopping Distance	246 ft downstream 121 ft twd traffic

Vehicle Stability

Maximum Roll Angle	12°
Maximum Pitch Angle	7°
Maximum Yaw Angle	47°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	10.6 inches
Permanent	4.9 inches
Working Width	36.0 inches
Height of Working Width	28.5 inches

Vehicle Damage

VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	10.0 inches
OCDI	RF0001000
Max. Occupant Compartment Deformation	4.0 inches

Figure 11.6. Summary of Results for *MASH* Test 3-20 on Modified Median Transition.

CHAPTER 12:
POST CRASH TEST SIMULATION CHECKS*

To further verify the performance of the symmetric median transition design after full-scale crash testing, additional computer simulations were conducted with the small car vehicle model and pickup truck vehicle model at different impact locations. For the small car vehicle model, the two upstream transition sections were investigated. For the pickup truck vehicle model, the second upstream transition section was investigated. The initial simulations replicated the impact point of the previous crash tests. Additional simulations were conducted at 3 ft upstream of the impact location and 3 ft downstream of the impact location to give a reasonable account of performance variation outside the 1-ft *MASH* tolerance of the actual CIP.

12.1 TEST 3-20 AT UPSTREAM TRANSITION

Three simulations were conducted to analyze the performance of the median barrier transition system for the section that transitioned from guardrail regular post spacing to guardrail half post spacing. The first simulation was performed with the impact point 10 ft upstream of the centerline of the last post (post 14) in the quarter post spacing section. Figure 12.1 shows the vehicle at impact with the system. The other two simulations were conducted with the impact location shifted 3 ft downstream and 3 ft upstream.

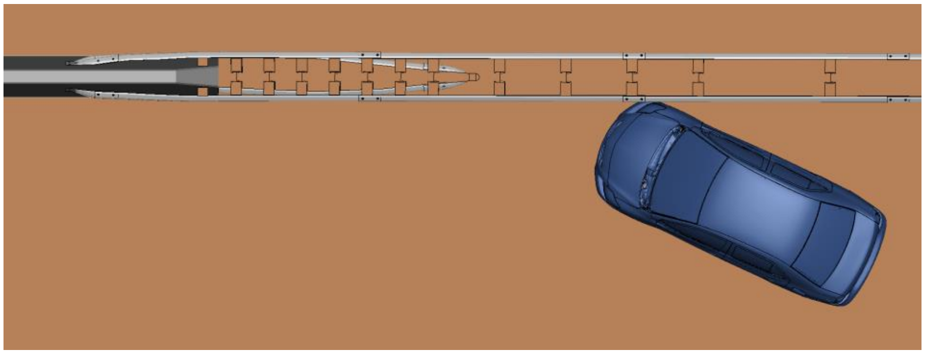


Figure 12.1. Impact Location for First Simulation at Upstream Transition.

To analyze the performance of the system, the occupant risk values were calculated for each simulation and compared. Table 12.1 shows the occupant risk values for the three simulations. The actual crash test CIP was reflective of the highest combined severity of the CIP at 13 ft upstream of the referenced post 14 in the table.

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

Table 12.1. Occupant Risk Comparison for Test 3-20 at Upstream Transition.

	7.0 ft upstream	10.0 ft upstream	13.0 ft upstream
Longitudinal OIV (m/s)	9.7	9.4	10.1
Lateral OIV (m/s)	8.9	8.1	8.1
Longitudinal ORA (g)	11.1	15.1	18.5
Lateral ORA (g)	8.1	15.3	11.7
Roll (deg.)	27.2	34.3	35.9
Pitch (deg.)	5.7	7.8	8.3
Yaw (deg.)	83.3	75.4	29.3

12.2 TEST 3-20 AT MIDDLE TRANSITION

The researchers noted during one of the crash tests with the small car vehicle that the impact tire released while snagging on a post. Figure 12.2 shows the vehicle after the crash test, and Figure 12.3 shows the tire stuck in the median transition system.

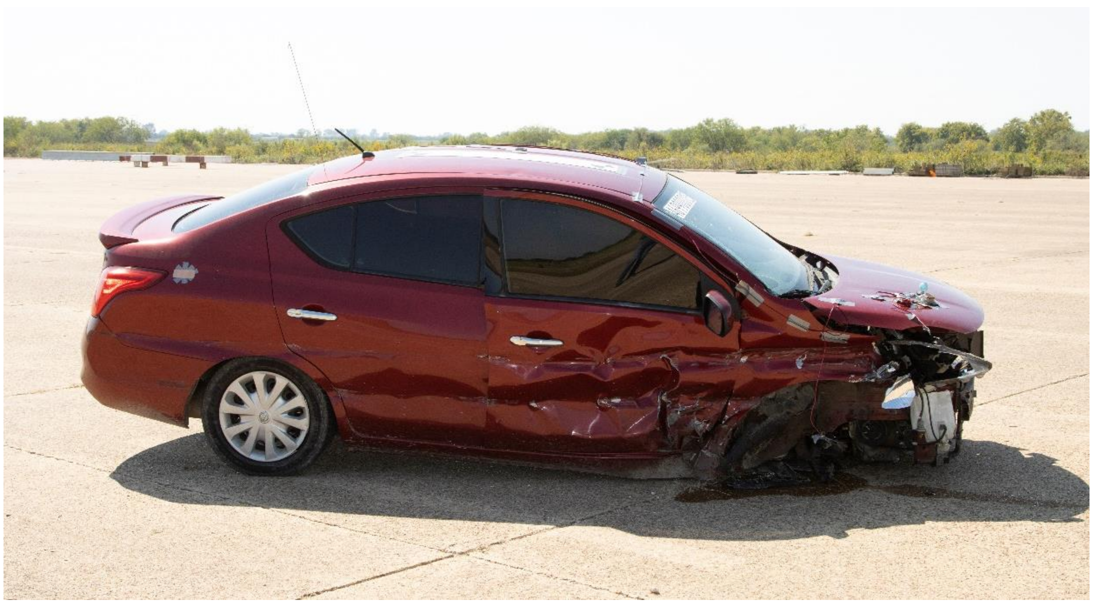


Figure 12.2. Small Car Vehicle after Crash Test.

Figure 12.3. Median Rail after Crash Test.

In order to capture this phenomenon in the computer simulations, the small car tire model was modified to allow failure of the tire joints and release during severe snagging events. The simulations discussed below incorporated this modified small car model, and one of the simulations resulted in the tire releasing during impact with the median transition system.

Three simulations were conducted to analyze the performance of the median barrier transition system for the section that transitioned from guardrail half post spacing to guardrail quarter post spacing. The first simulation was conducted with the vehicle impacting 5 ft upstream of the centerline of the last post in the quarter post spacing section (post 14). Figure 12.4 shows the vehicle at impact with the system. The other two simulations were conducted with the impact location shifted 3 ft downstream and 3 ft upstream.

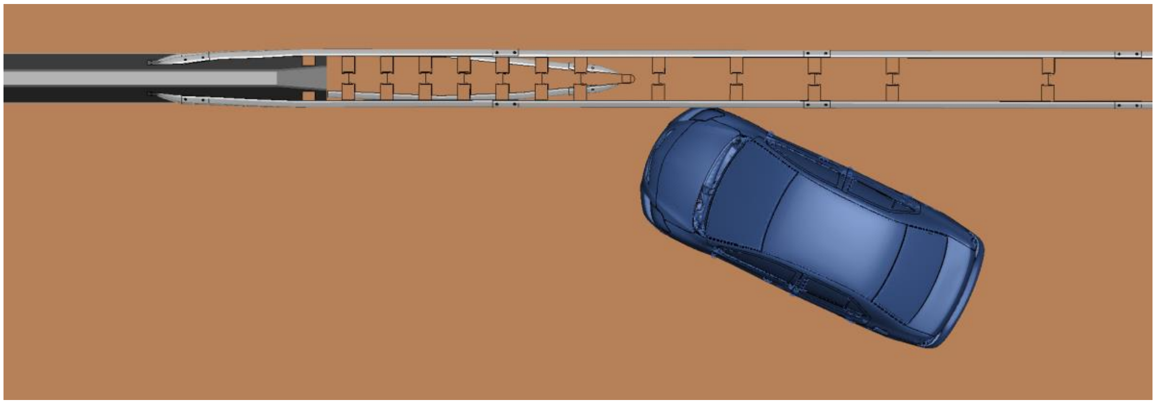


Figure 12.4. Impact Location for First Simulation at Middle Transition.

To analyze the performance of the system, the occupant risk values were calculated for each simulation and compared. Table 12.2 shows the occupant risk values for the three simulations. The actual crash test CIP was reflective of the highest combined severity of the CIP at 5 ft upstream of the referenced post 14 in the table.

Table 12.2. Occupant Risk Comparison for Test 3-20 at Middle Transition.

	2.0 ft upstream	5.0 ft upstream	8.0 ft upstream
Longitudinal OIV (m/s)	7.4	8.0	6.9
Lateral OIV (m/s)	9.9	10.0	8.8
Longitudinal ORA (g)	2.9	5.1	7.5
Lateral ORA (g)	11.5	7.5	9.3
Roll (deg.)	7.6	6.8	10.0
Pitch (deg.)	7.1	4.9	5.0
Yaw (deg.)	45.3	55.7	67.9

12.3 TEST 3-21 AT MIDDLE TRANSITION

Three simulations were conducted to analyze the performance of the median barrier transition system for the section that transitioned from guardrail half post spacing to guardrail quarter post spacing. The first simulation was conducted with the vehicle impacting 5.0 ft upstream of the centerline of post 14 in the quarter post spacing section. Figure 12.5 shows the vehicle at impact with the system. The other two simulations were conducted with the impact location shifted 3 ft downstream and 2 ft upstream.

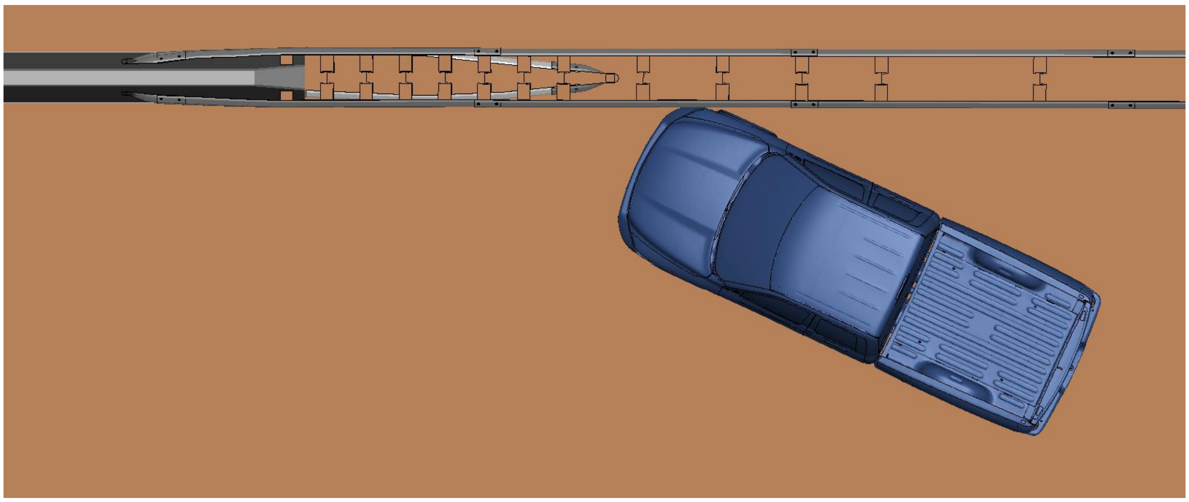


Figure 12.5. Impact Location for First Simulation at Middle Transition.

To analyze the performance of the system, the occupant risk values were calculated for each simulation and compared. Table 12.3 shows the occupant risk values for the three simulations. The actual crash test CIP was reflective of the relatively highest combined severity of the CIP at 5 ft upstream of the referenced post 14 in the table. Although all simulation occupant risk values were below the preferred limit, the highest ORA of 11.2 g was calculated at the referenced 5-ft CIP along with a relatively higher angular roll angle.

Table 12.3. Occupant Risk Comparison for Test 3-21 at Middle Transition.

	2.0 ft upstream	5.0 ft upstream	7.0 ft upstream
Longitudinal OIV (m/s)	7.1	7.2	7.2
Lateral OIV (m/s)	7.4	7.3	7.3
Longitudinal ORA (g)	8.6	11.2	10.3
Lateral ORA (g)	10.7	10.0	11.1
Roll (deg.)	8.5	11.8	7.0
Pitch (deg.)	5.6	5.3	4.6
Yaw (deg.)	43.8	50.9	46.3

These simulations confirmed that the actual CIP selections were the most critical given the calculated occupant risk criteria.

CHAPTER 13: SUMMARY AND CONCLUSIONS

13.1 ASSESSMENT OF RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-3. An assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-3 transitions is provided in Table 13.1 through Table 13.5.

During the first *MASH* Test 3-21 on the transition, the 2270P vehicle rolled onto its right side. To improve the performance of the system, several modifications were made to the transition system. First, the lower W-beam rail was terminated and attached to the end of the concrete parapet with a steel bracket. Second, one post was added to the quarter spacing line of posts. Third, a vertical taper was added to the toe at the end of the concrete parapet.

The results for the crash tests performed on the modified system are shown in Table 13.2 through Table 13.5.

13.2 CONCLUSIONS

Table 13.6 shows that the new TxDOT median transition performed acceptably as a *MASH* TL-3 transition.

Table 13.1. Performance Evaluation Summary for *MASH* Test 3-21 on Median Transition to Concrete Barrier.

Test Agency: Texas A&M Transportation Institute | Test No.: 469900-01-1 | Test Date: 2020-06-18

***MASH* Test 3-21 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The median transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the transition was 3.3 inches.	Pass
<u>Occupant Risk</u> D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or 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 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 7.0 inches in the right front firewall and the kick panel area.	
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle rolled onto its right side. Maximum roll and pitch angles were 90° and 18°.	Fail
H. *Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*	Longitudinal OIV was 21.0 ft/s, and lateral OIV was 25.9 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.*	Maximum longitudinal occupant ridedown acceleration was 11.6 g, and maximum lateral occupant ridedown acceleration was 12.4 g.	Pass

Table 13.2. Performance Evaluation Summary for *MASH* Test 3-21 on Modified Median Transition to Concrete Barrier.

Test Agency: Texas A&M Transportation Institute | Test No.: 469900-01-2 | Test Date: 2020-08-13

***MASH* Test 3-21 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> *A.* *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The modified median transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the transition was 5.4 inches.	Pass
<u>Occupant Risk</u> *D.* *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or 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 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 5.5 inches in the right front firewall area.	
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 37° and 44°.	Pass
H. *Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*	Longitudinal OIV was 20.7 ft/s, and lateral OIV was 25.6 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.*	Maximum longitudinal occupant ridedown acceleration was 7.1 g, and maximum lateral occupant ridedown acceleration was 7.3 g.	Pass

Table 13.3. Performance Evaluation Summary for *MASH* Test 3-20 on Modified Median Transition to Concrete Barrier.

Test Agency: Texas A&M Transportation Institute | Test No.: 469900-01-3 | Test Date: 2020-08-25

***MASH* Test 3-20 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The modified median transition contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the transition was 5.2 inches.	Pass
<u>Occupant Risk</u> D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or 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 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 4.5 inches in the right front kick panel 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 3°.	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 23.6 ft/s, and lateral OIV was 26.2 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.*	Maximum longitudinal occupant ridedown acceleration was 5.5 g, and maximum lateral occupant ridedown acceleration was 14.7 g.	Pass

Table 13.4. Performance Evaluation Summary for *MASH* Test 3-21 on Median Guardrail to Modified Median Transition.

Test Agency: Texas A&M Transportation Institute | Test No.: 469900-01-4 | Test Date: 2020-09-28

***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 modified median transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the transition was 9.8 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.*	No detached elements, fragments, or other debris were present to 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 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 4.0 inches in the right front firewall/toe pan/floor pan/kick panel area.	
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 33° and 8°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 21.0 ft/s, and lateral OIV was 25.3 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.	Maximum longitudinal occupant ridedown acceleration was 10.8 g, and maximum lateral occupant ridedown acceleration was 12.1 g.	Pass

Table 13.5. Performance Evaluation Summary for *MASH* Test 3-20 on Median Guardrail to Modified Median Transition.

Test Agency: Texas A&M Transportation Institute | Test No.: 469900-01-5 | Test Date: 2020-10-05

***MASH* Test 3-20 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u>		
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable	The modified median transition contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the transition was 10.6 inches.	Pass
<u>Occupant Risk</u>		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or 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 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 4.0 inches in the right front kick panel area and at hip height across the door panels.	
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 12° and 7°.	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 24.0 ft/s, and lateral OIV was 27.9 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.	Maximum longitudinal occupant ridedown acceleration was 4.9 g, and maximum lateral occupant ridedown acceleration was 10.3 g.	Pass

Table 13.6. Assessment Summary for *MASH* TL-3 Tests on Modified Median Transition.

Evaluation Factors	Evaluation Criteria	Median Barrier to			
		Test No. 469900-01-2	Test No. 469900-01-3	Test No. 469900-01-4	Test No. 469900-01-5
Structural Adequacy	A	S	S	S	S
Occupant Risk	D	S	S	S	S
	F	S	S	S	S
	H	S	S	S	S
	I	S	S	S	S
	Test No.	***MASH* Test 3-21**	***MASH* Test 3-20**	***MASH* Test 3-21**	***MASH* Test 3-20**
	Pass/Fail	Pass	Pass	Pass	Pass

Note: S = Satisfactory.

CHAPTER 14: IMPLEMENTATION*

The new TxDOT median guardrail transition to a concrete parapet has been evaluated through full-scale crash testing per *MASH* TL-3 crash tests. This system is ready for implementation as a transition between a crashworthy median W-beam guardrail and a *MASH* TL-3 crashworthy median concrete barrier while maintaining the connectivity details tested in this research effort, and the concrete taper implemented in the crash-tested design. Furthermore, it is recommended that the lower W-beam end be fully covered by the vertical face of the concrete barrier.

Following the procedures outlined in TxDOT's University Handbook, the researchers assessed the potential value of TxDOT Research Project 0-6990. Table I.1 in Appendix I shows economic variables considered in developing the VOR, sources of these variables, and the description of economic based calculations used.

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

REFERENCES

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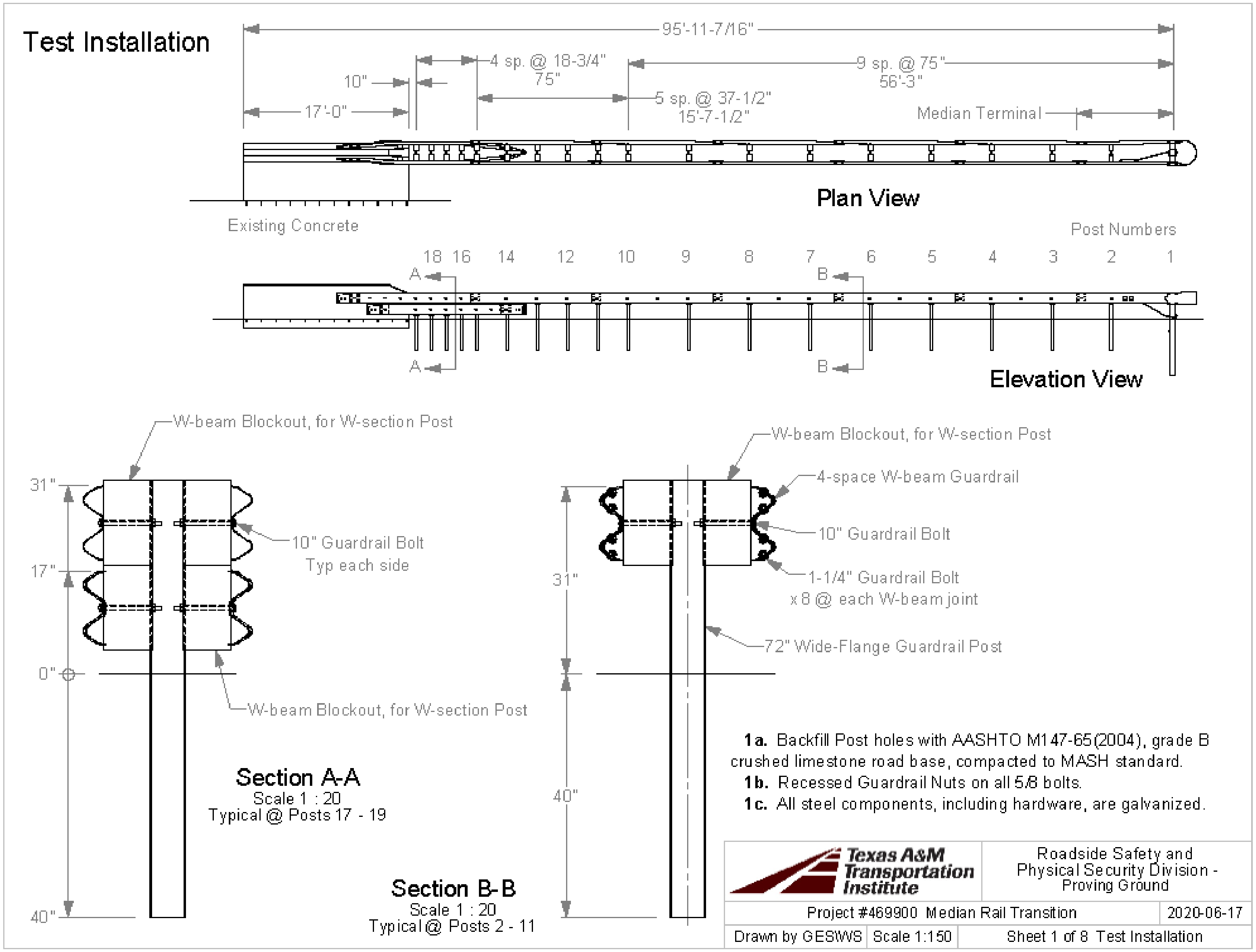
A.1 ORIGINAL TRANSITION USED FOR TEST NO. 469900-01-1



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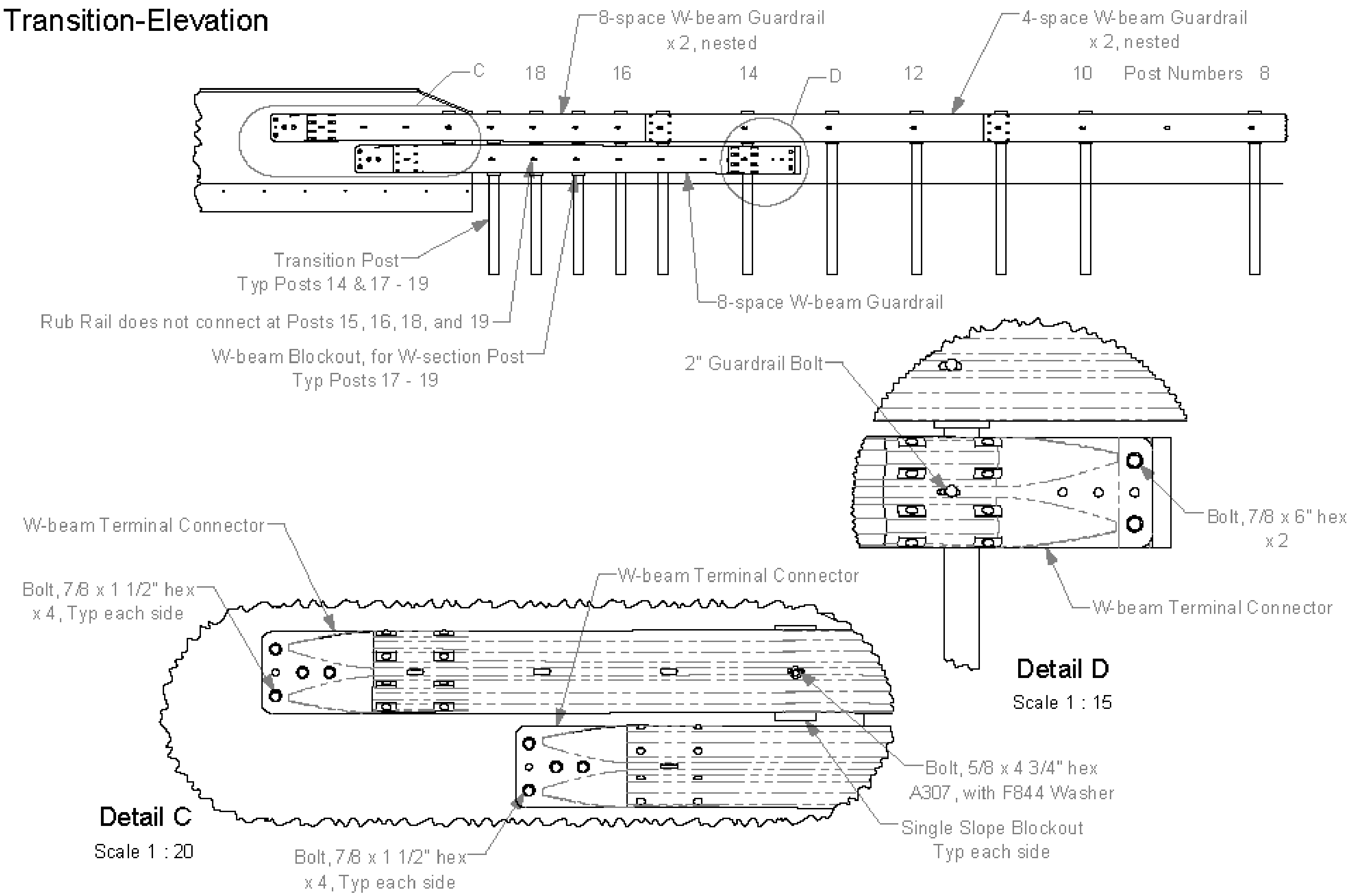
Transition-Elevation



2a. All hardware is galvanized. All 7/8 Bolts are A325.
2b. One F436 Washer under each 7/8 Nut and Bolt head.
2c. 2" Guardrail Bolts at each W-beam Terminal Connector to W-beam joint, with a Rectangular Guardrail Washer between Terminal Connector and Nut or Bolt head.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Median Rail Transition		2020-06-17
Drawn by GESWS	Scale 1:60	Sheet 2 of 8 Transition-Elevation

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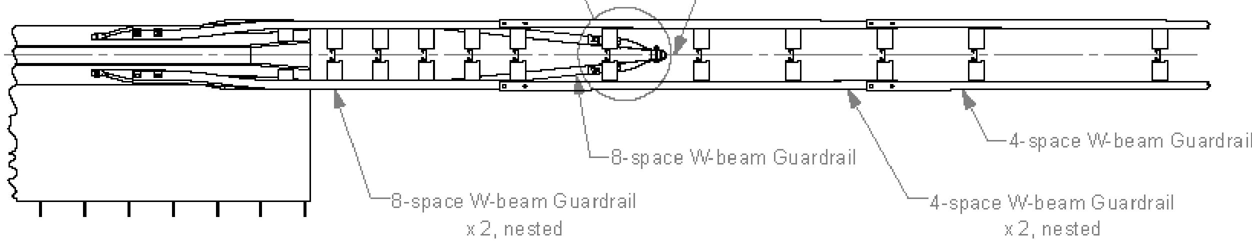
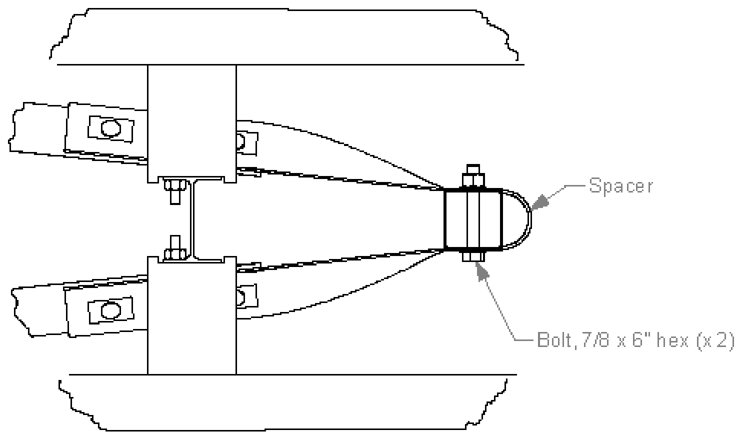
Transition-Plan





Detail E

Scale 1 : 10

3a. All hardware is galvanized. All 7/8 Bolts are A325.
3b. One F436 Washer under each 7/8 Nut and Bolt head.
3c. 2" Guardrail Bolts at each W-beam Terminal Connector to W-beam joint, with a Rectangular Guardrail Washer between Terminal Connector and Nut or Bolt head.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Median Rail Transition		2020-06-17
Drawn by GESWS	Scale 1:60	Sheet 3 of 8 Transition-Plan

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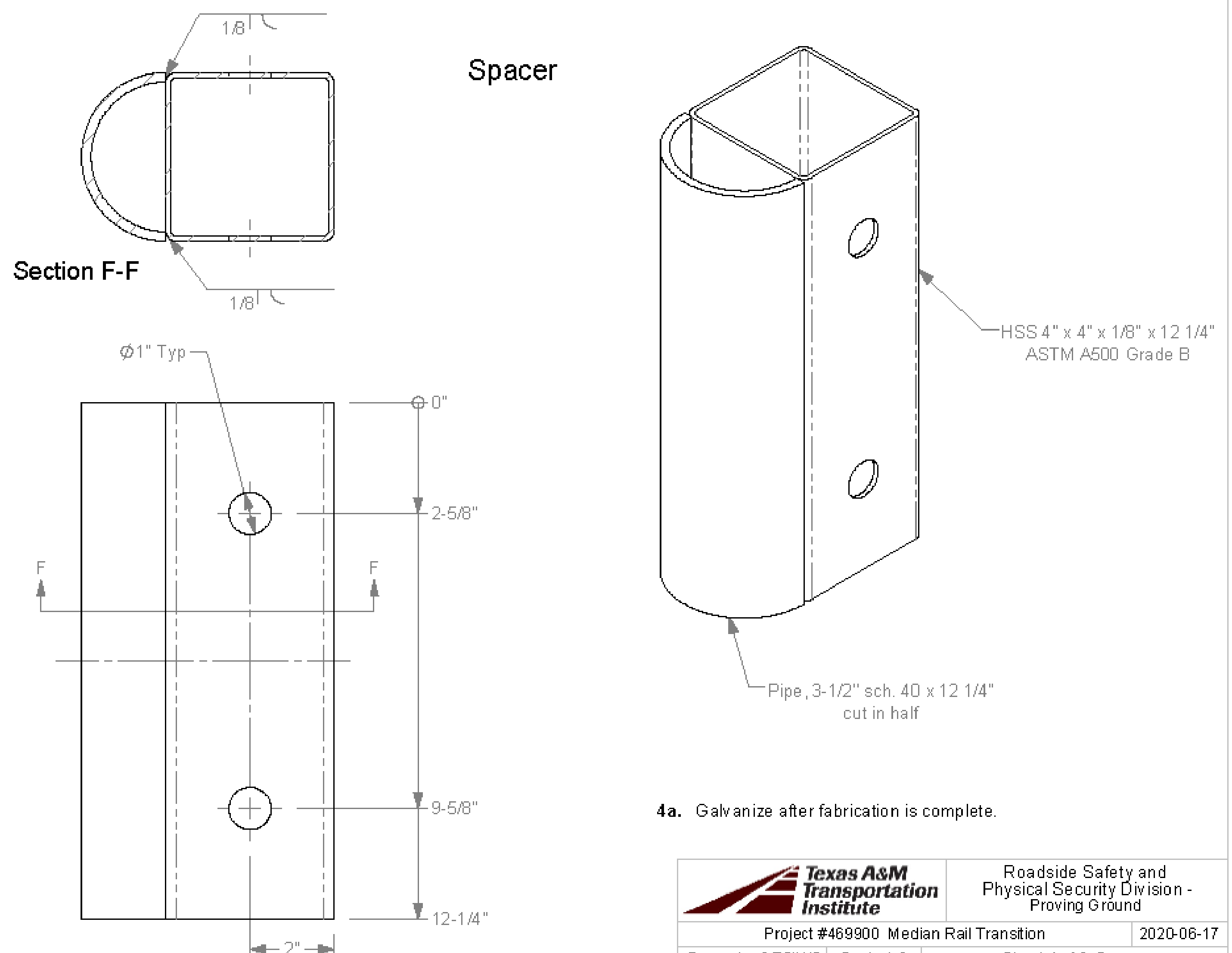
Spacer



4a. Galvanize after fabrication is complete.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Median Rail Transition		2020-06-17
Drawn by GESWS	Scale 1:3	Sheet 4 of 8 Spacer

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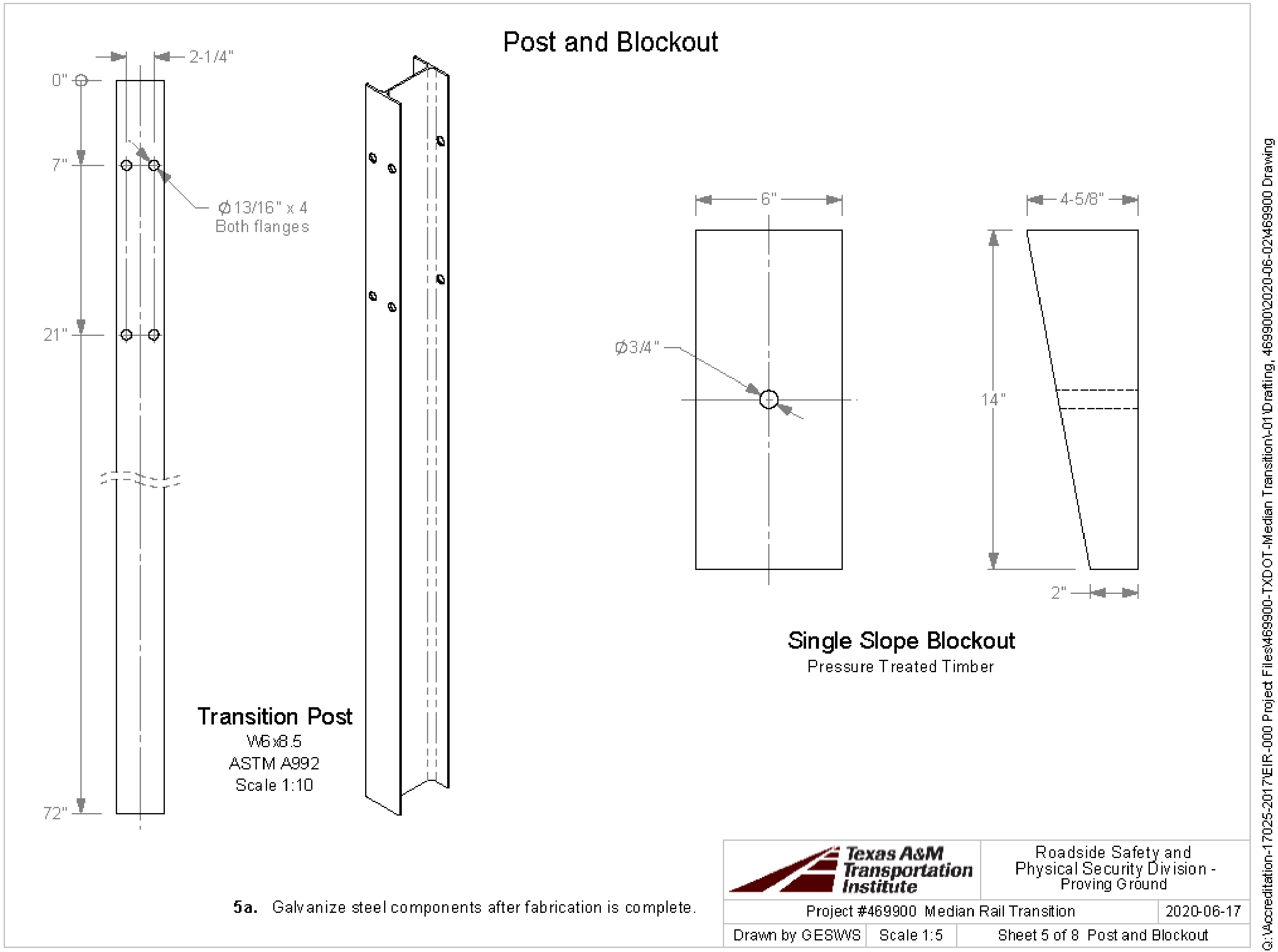
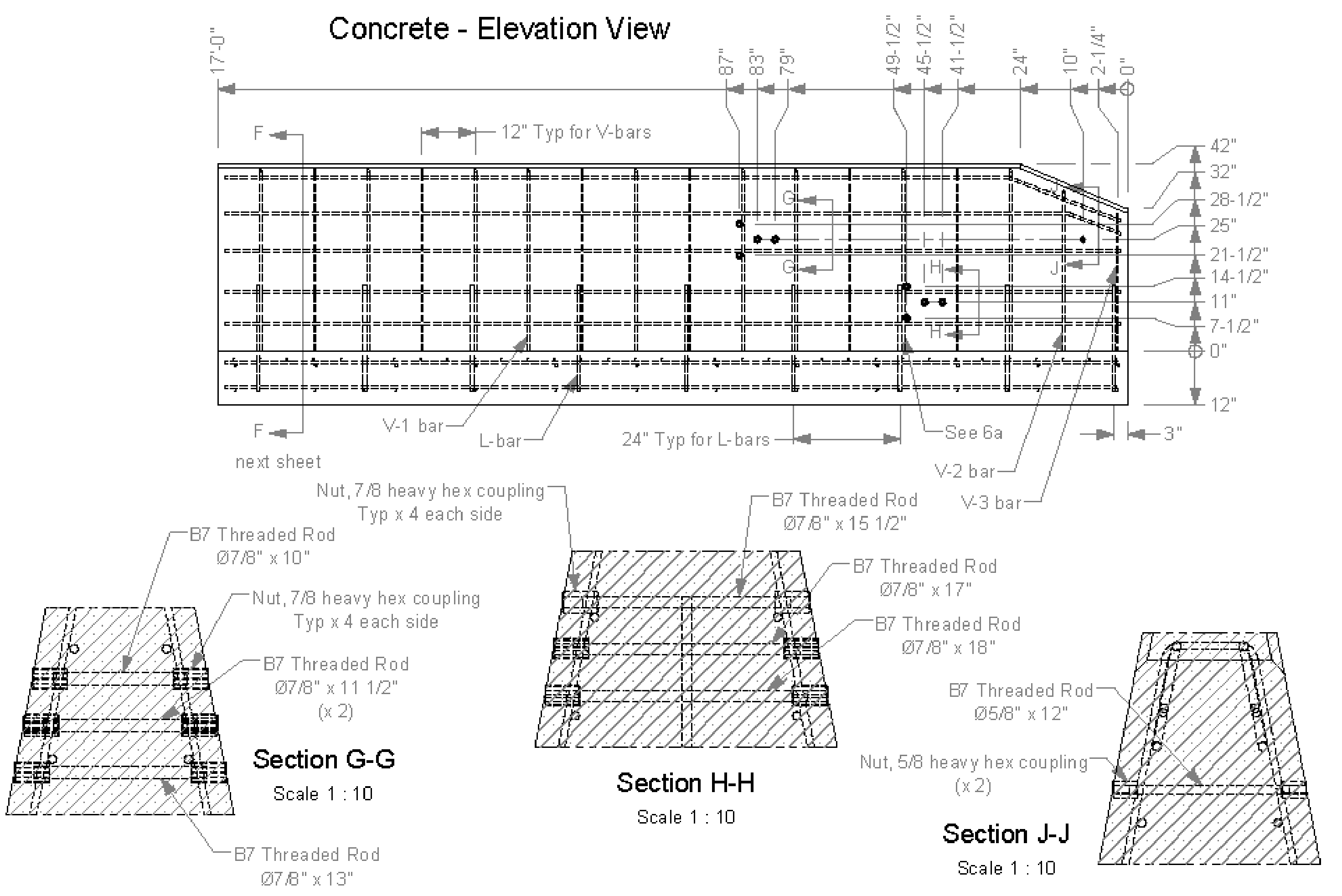
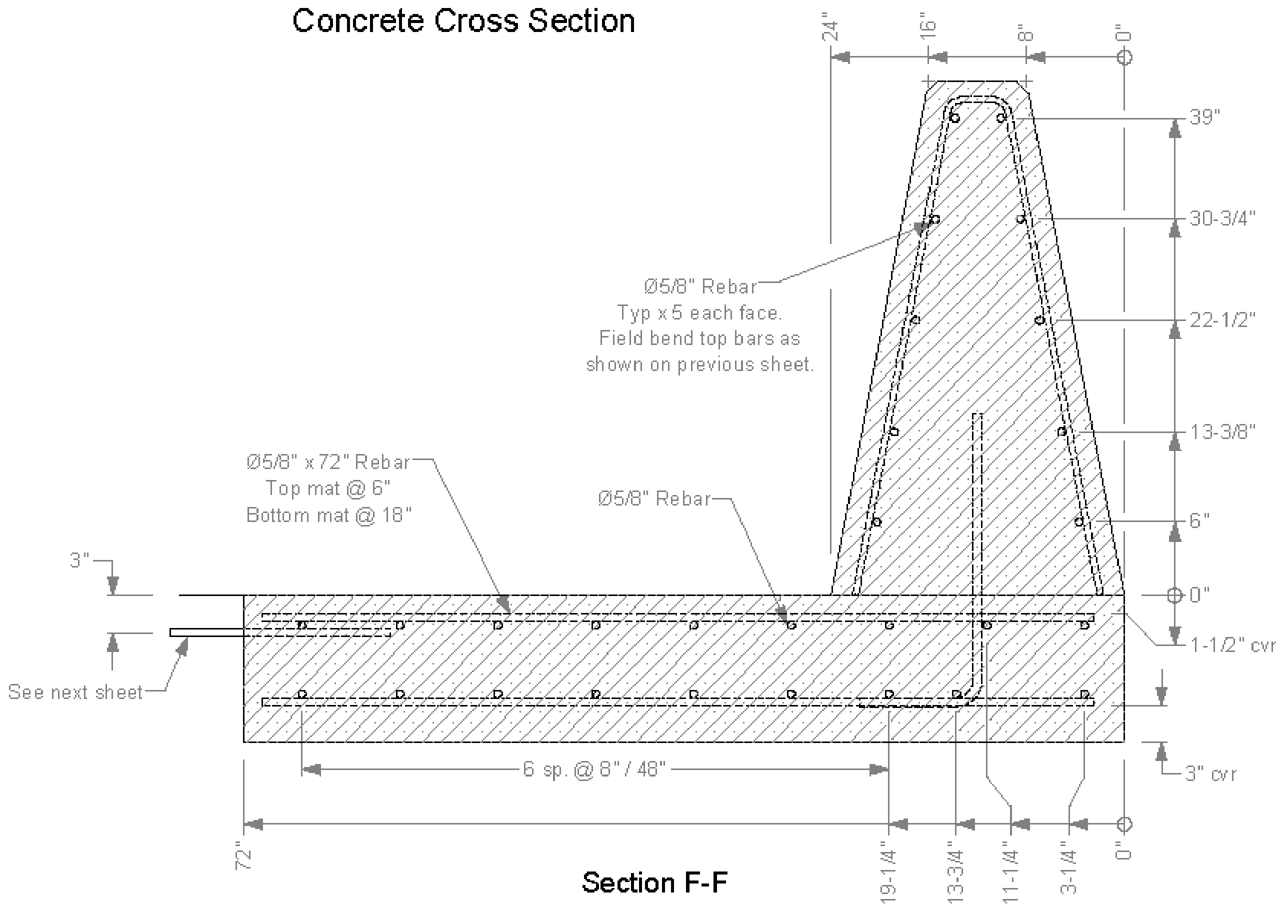

Post and Blockout
2-1/4"
0"
7"
21"
72"
ϕ13/16" x 4
Both flanges
Transition Post
W6x8.5
ASTM A992
Scale 1:10
6"
ϕ3/4"
4-5/8"
14"
2"
Single Slope Blockout
Pressure Treated Timber
5a. Galvanize steel components after fabrication is complete.
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #469900 Median Rail Transition
2020-06-17
Drawn by GESWS
Scale 1:5
Sheet 5 of 8 Post and Blockout
Q:\Accreditation-17025-2017\EIR-000 Project Files\469900-TXDOT-Median Transition\-01\Drafting, 469900\2020-06-02\469900 Drawing



6a. Concrete is TxDOT Class C (3,600 psi).
6b. Thread Bolts and B7 Threaded Rods to midpoint (+0, -1/8") of the coupling nuts.
6c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).
All rebar is grade 60.
6d. Move rebar as needed to avoid interference with hardware.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Median Rail Transition		2020-06-17
Drawn by GESWS	Scale 1:30	Sheet 6 of 8 Concrete - Elevation

Concrete Cross Section



Section F-F

7a. Concrete is TxDOT Class C (3,600 psi).
7b. 1" Chamfer (3/4" each way) top edges of parapet.
7c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover). All rebar is grade 60.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Median Rail Transition		2020-06-17
Drawn by GESWS	Scale 1:12	Sheet 7 of 8 Concrete Cross Section

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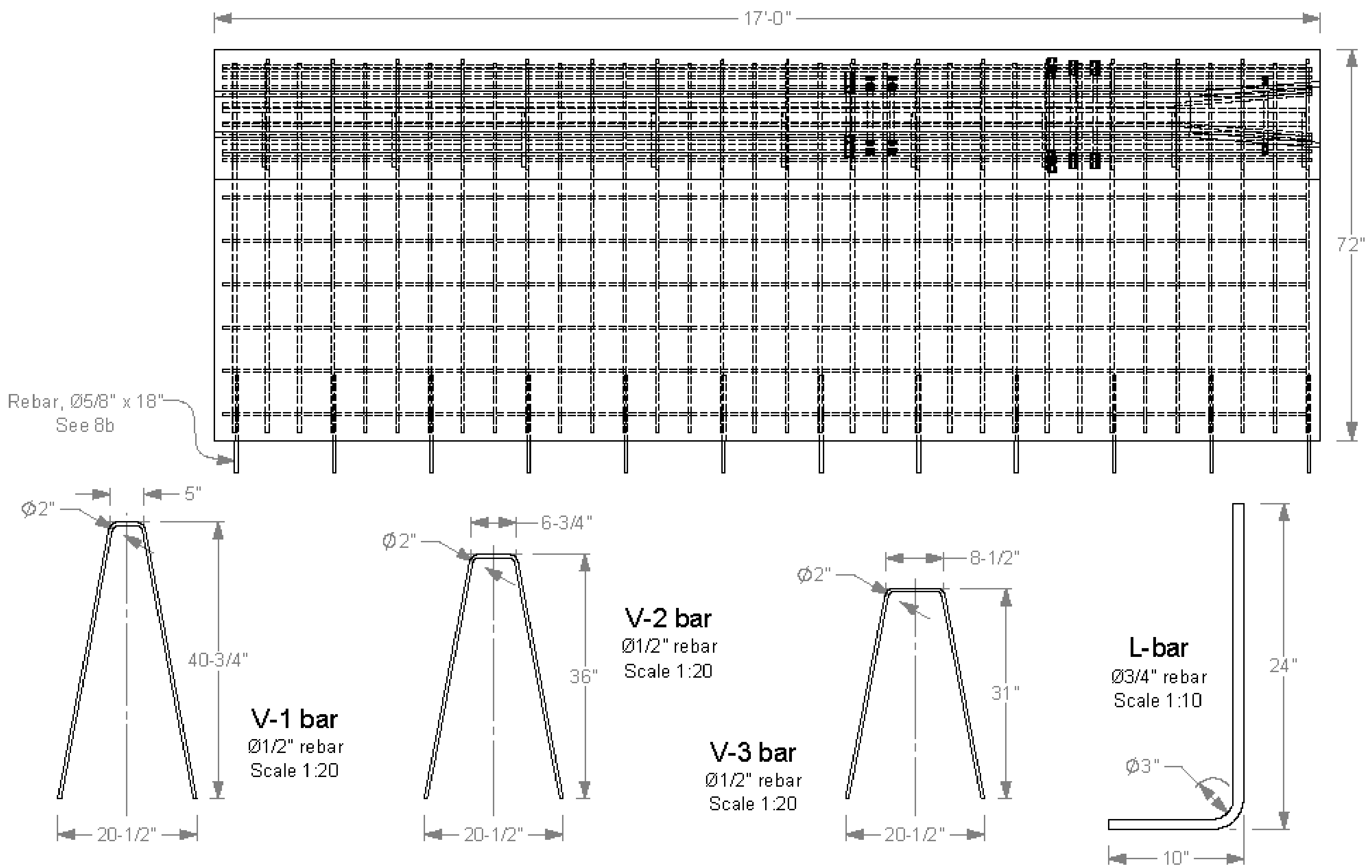
Concrete - Plan View



8a. Concrete is TxDOT Class C (3,600 psi).

8b. Secure in existing concrete with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, at 18" spacing with 6" embedment.

8c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover). All rebar is grade 60.

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project #469900 Median Rail Transition		2020-06-17
Drawn by GESWS	Scale 1:25	Sheet 8 of 8 Concrete - Plan

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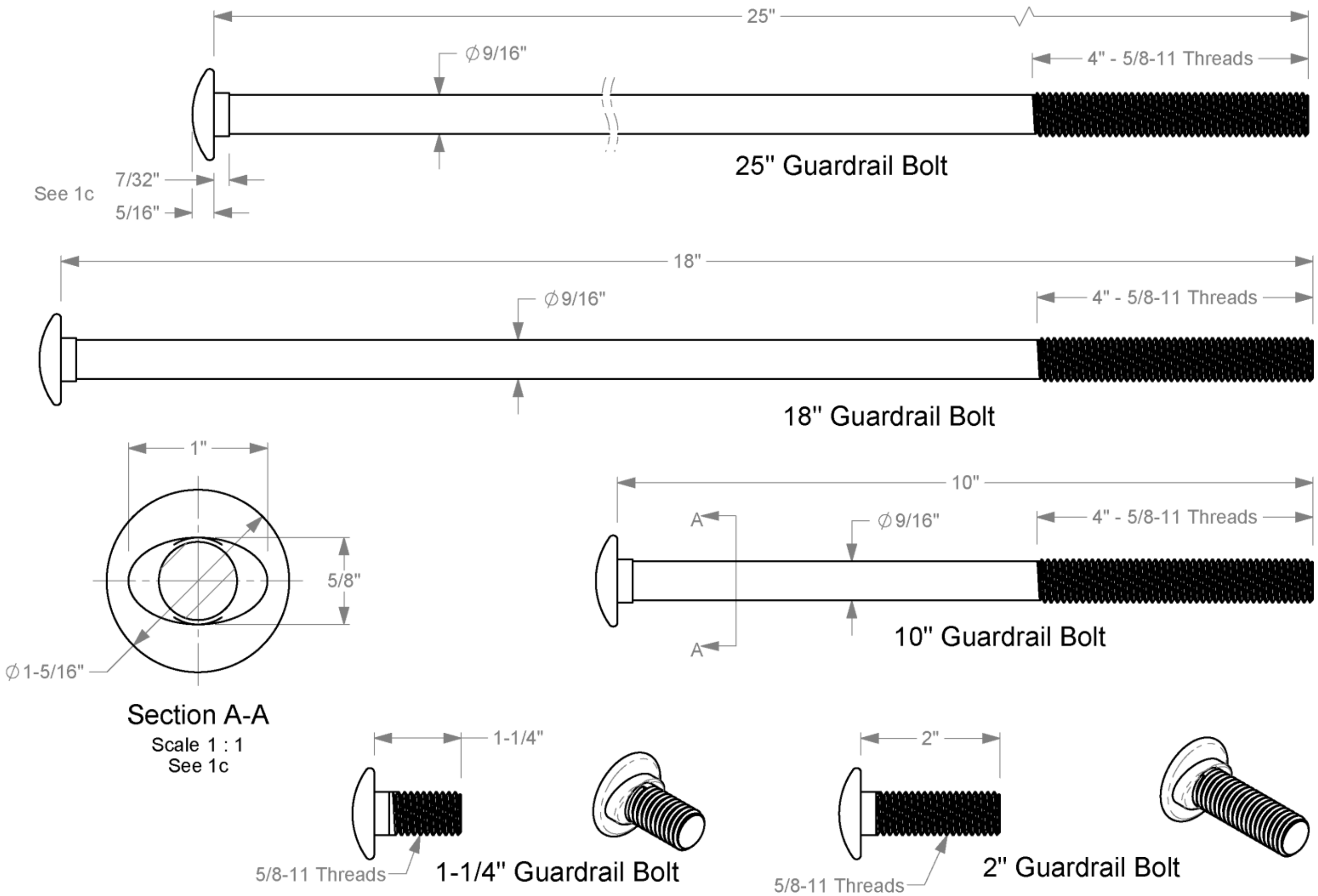

1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.

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

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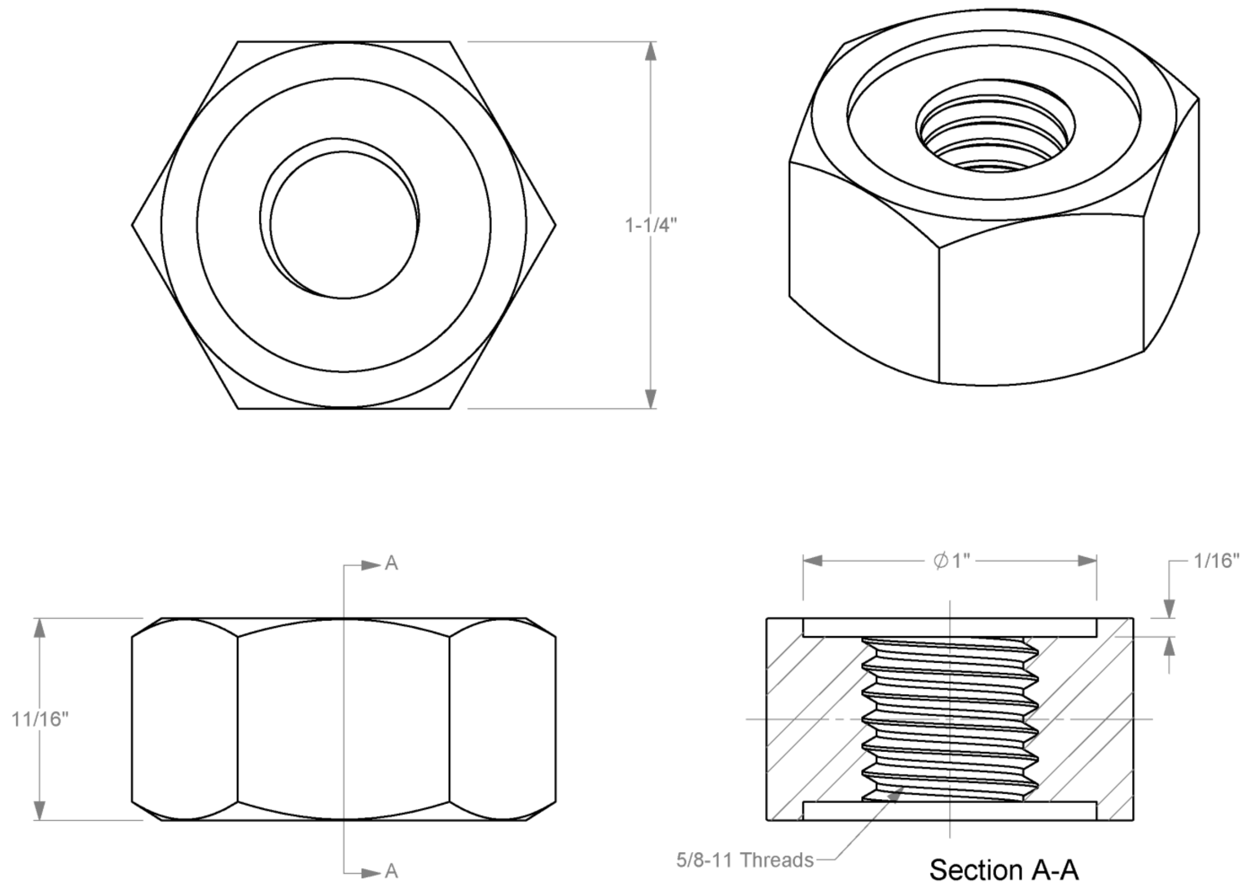
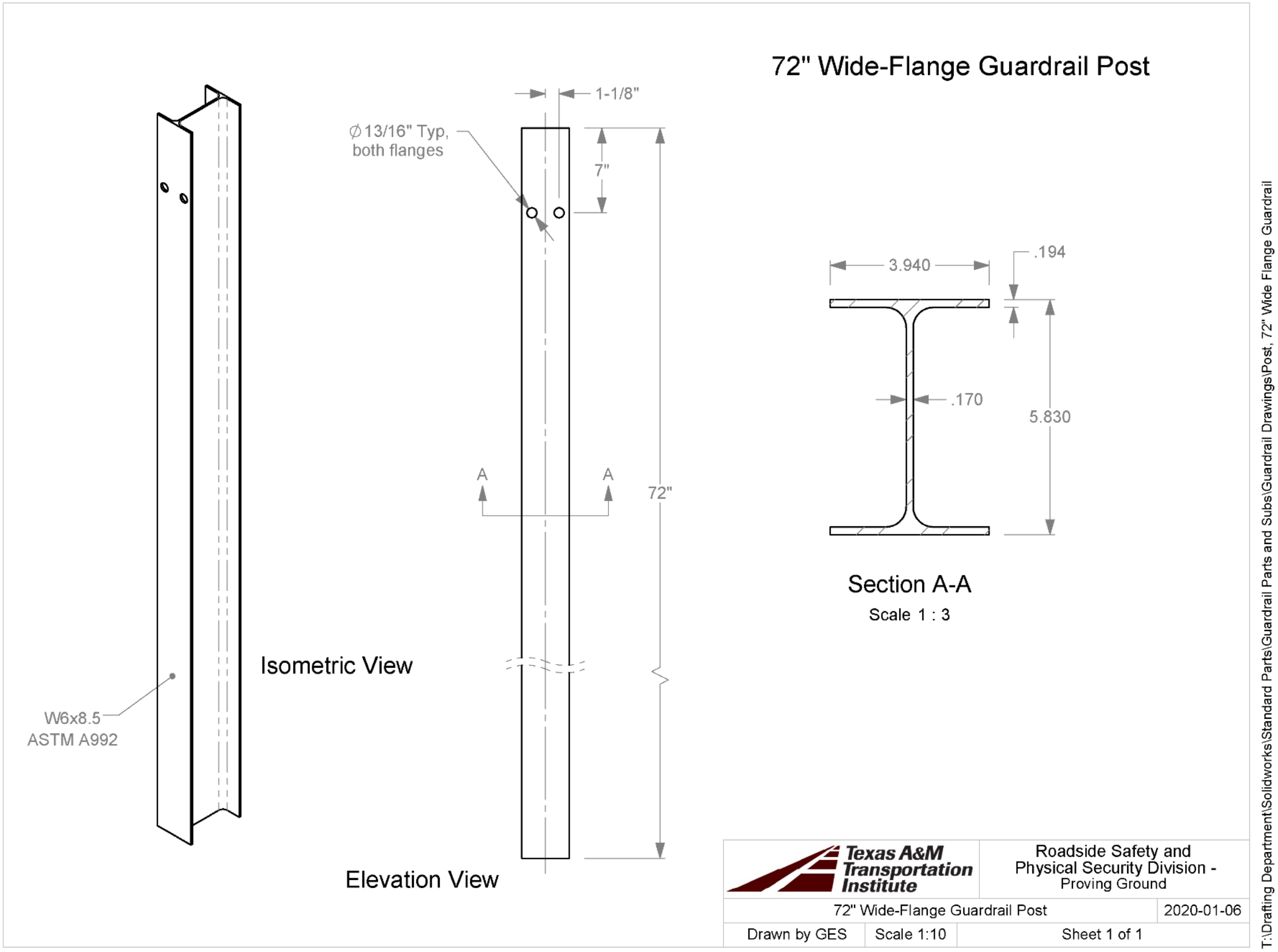
Recessed Guardrail Nut



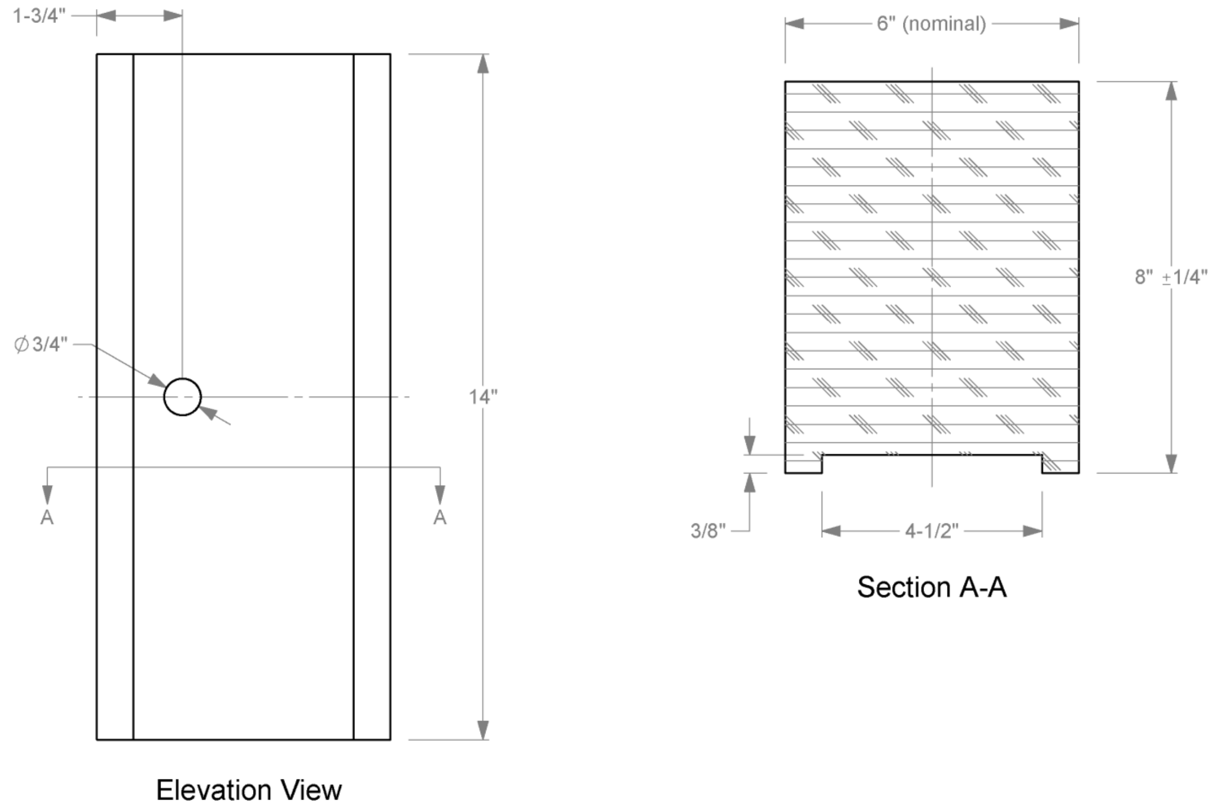
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Recessed Guardrail Nut			2019-06-27
Drawn by GES	Scale 2:1	Sheet 1 of 1	

1a. Material is ASTM A 563 Grade A.

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


72" Wide-Flange Guardrail Post
1-1/8"
Ø13/16" Typ, both flanges
7"
72"
A
A
3.940
.194
.170
5.830
Section A-A
Scale 1 : 3
Isometric View
W6x8.5
ASTM A992
Elevation View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
72" Wide-Flange Guardrail Post
2020-01-06
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 Guardrail

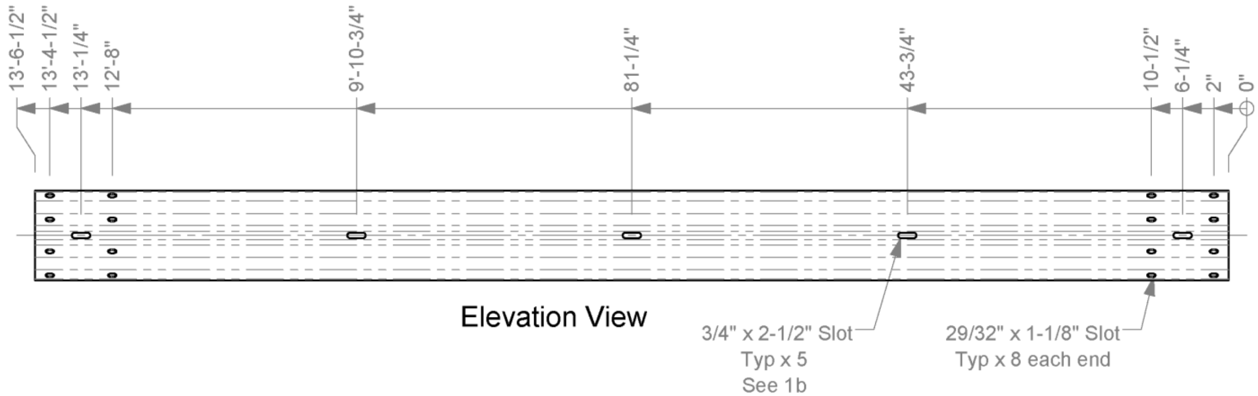
Timber Blockout for W-section Post



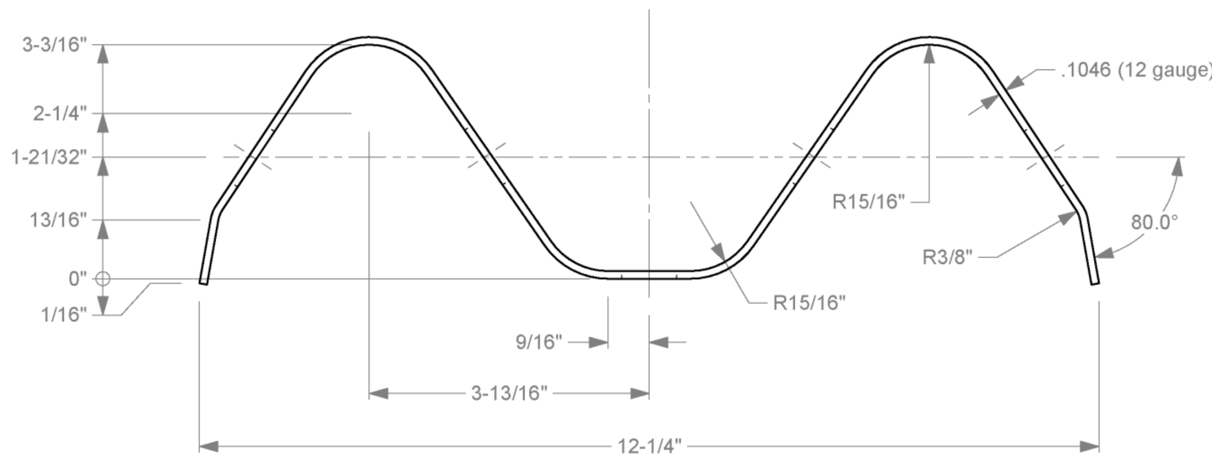
1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

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



Elevation View



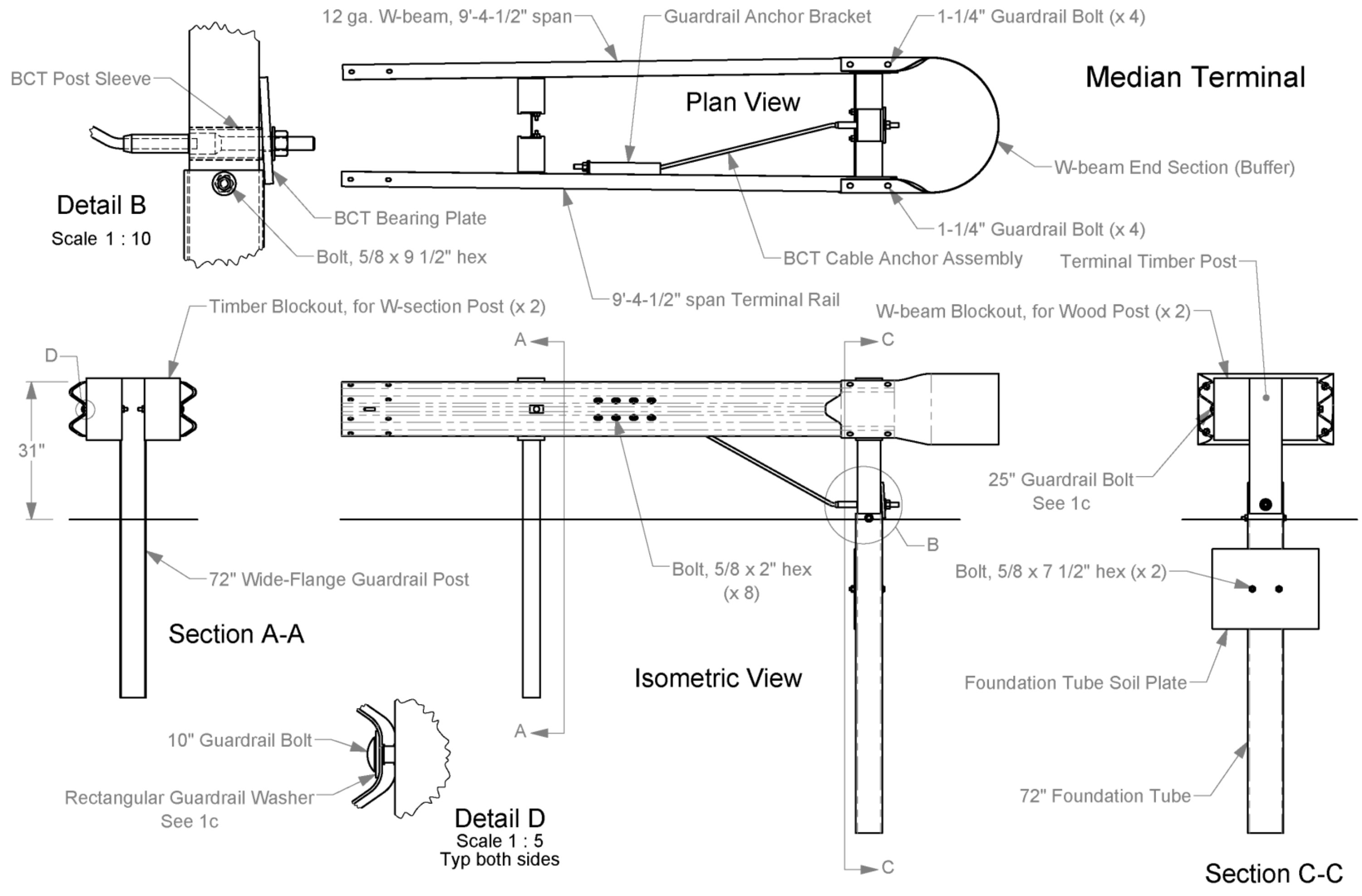
Section View

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		2020-02-19
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, 12 gauge



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 Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Median Terminal			2020-02-24
Drawn by GES	Scale 1:30	Sheet 1 of 1	

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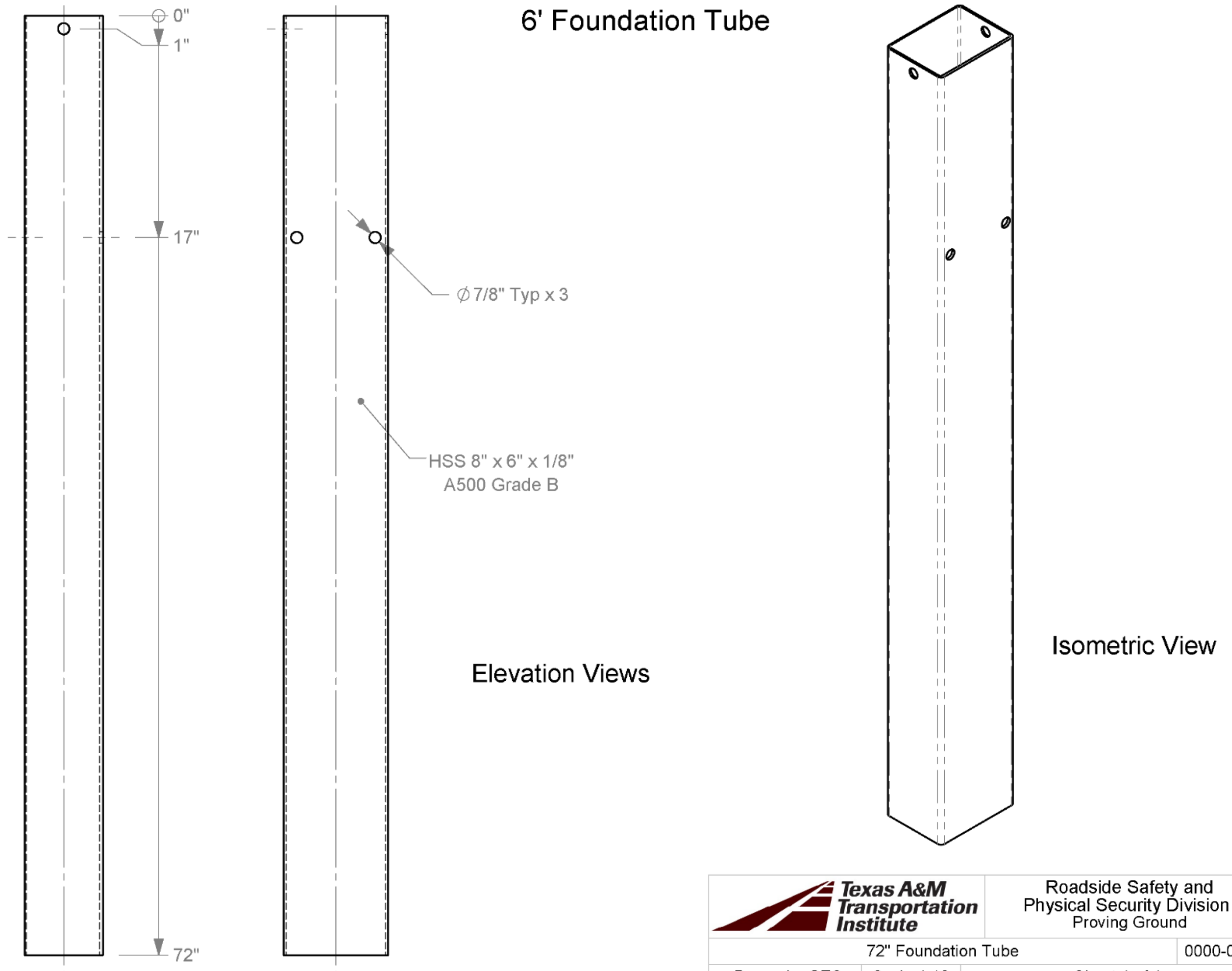
6' Foundation Tube

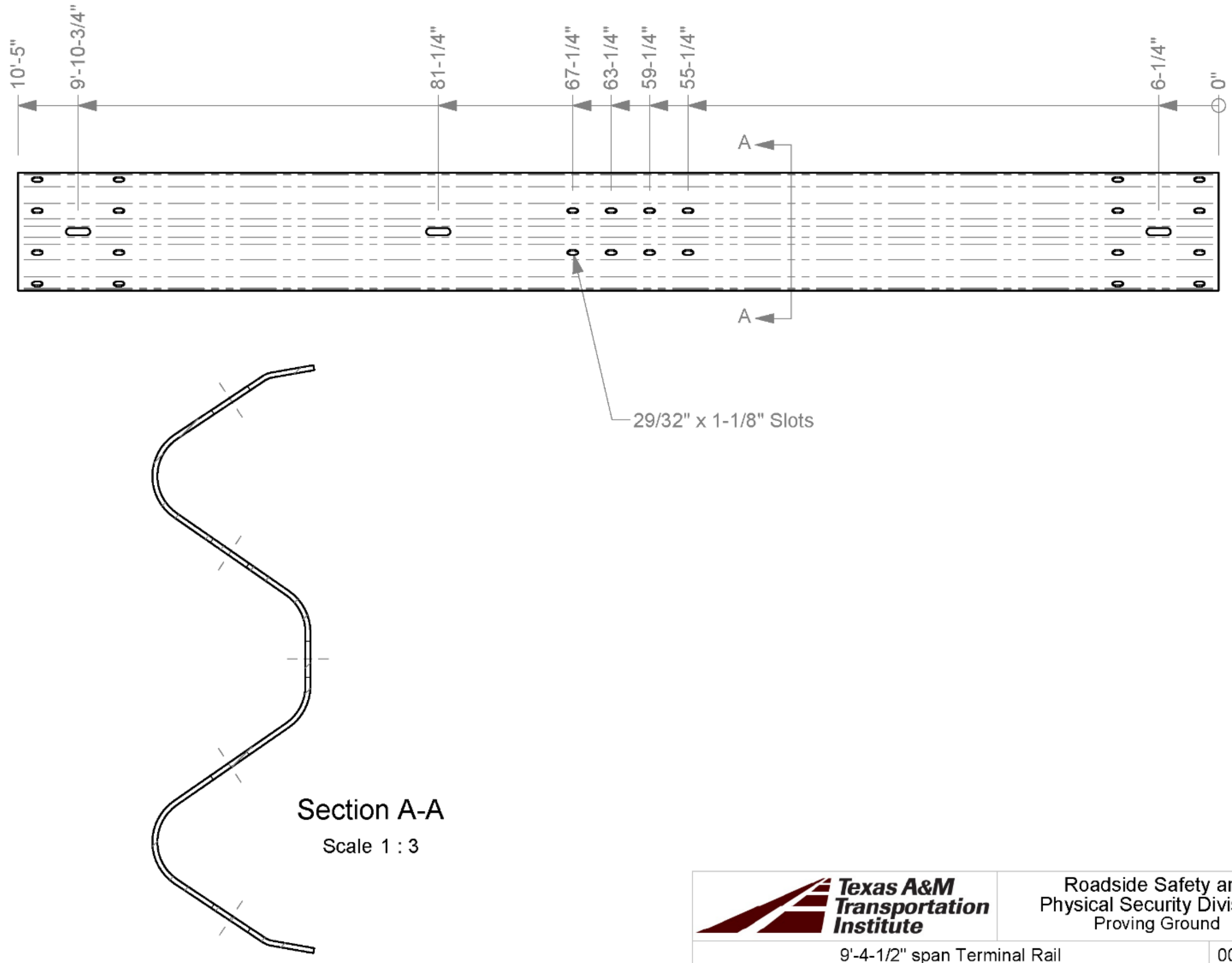


Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
72" Foundation Tube		0000-00-00
Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\6' Foundation Tube

9'-4-1/2" span Terminal Rail

See W-beam Guardrail Drawing for all dimensions not shown here.



Section A-A

Scale 1 : 3

Texas A&M Transportation Institute

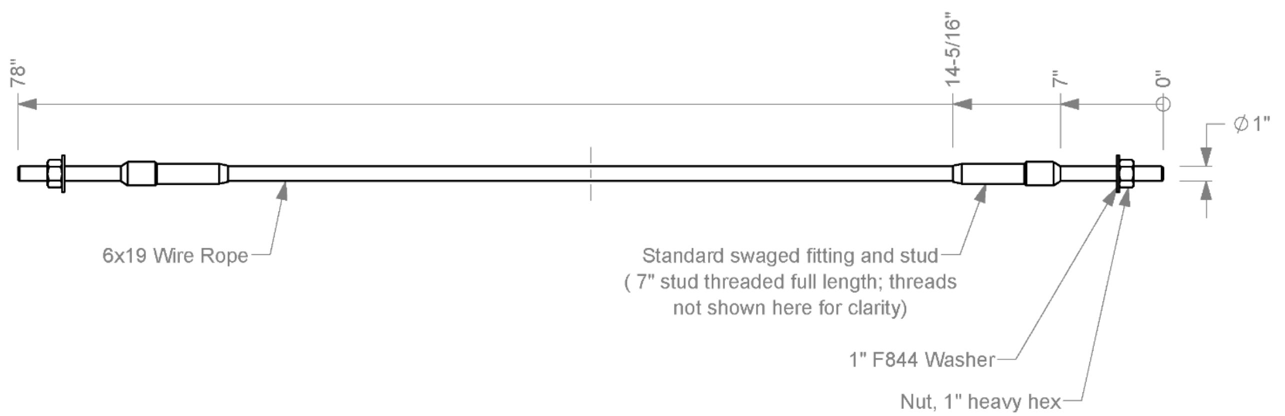
Roadside Safety and Physical Security Division - Proving Ground

9'-4-1/2" span Terminal Rail	0000-00-00

Drawn by GES	Scale 1:15	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Median Terminal\9'-4.5in span Terminal Rail

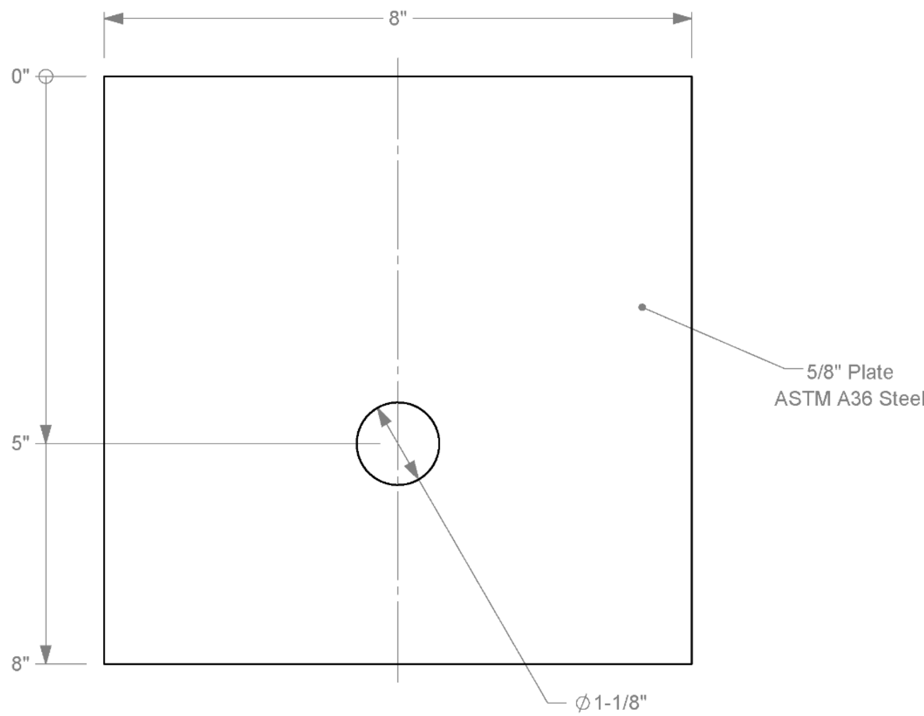
BCT Anchor Cable



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
BCT Anchor Cable		2020-02-24
Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\BCT Anchor Cable

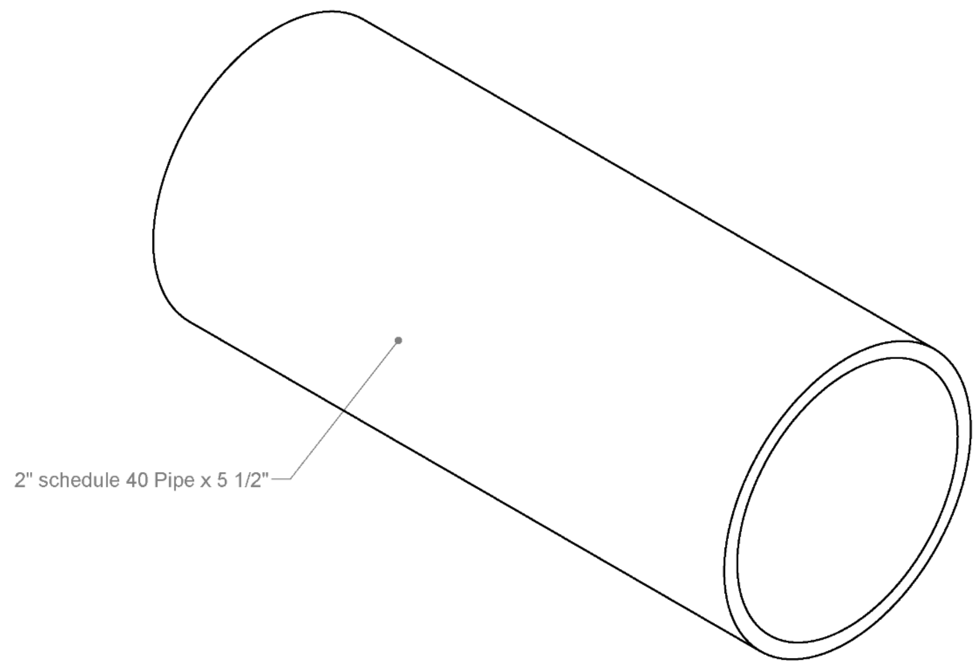
BCT Bearing Plate



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
BCT Bearing Plate			2020-02-24
Drawn by GES	Scale 1:2	Sheet 1 of 1	

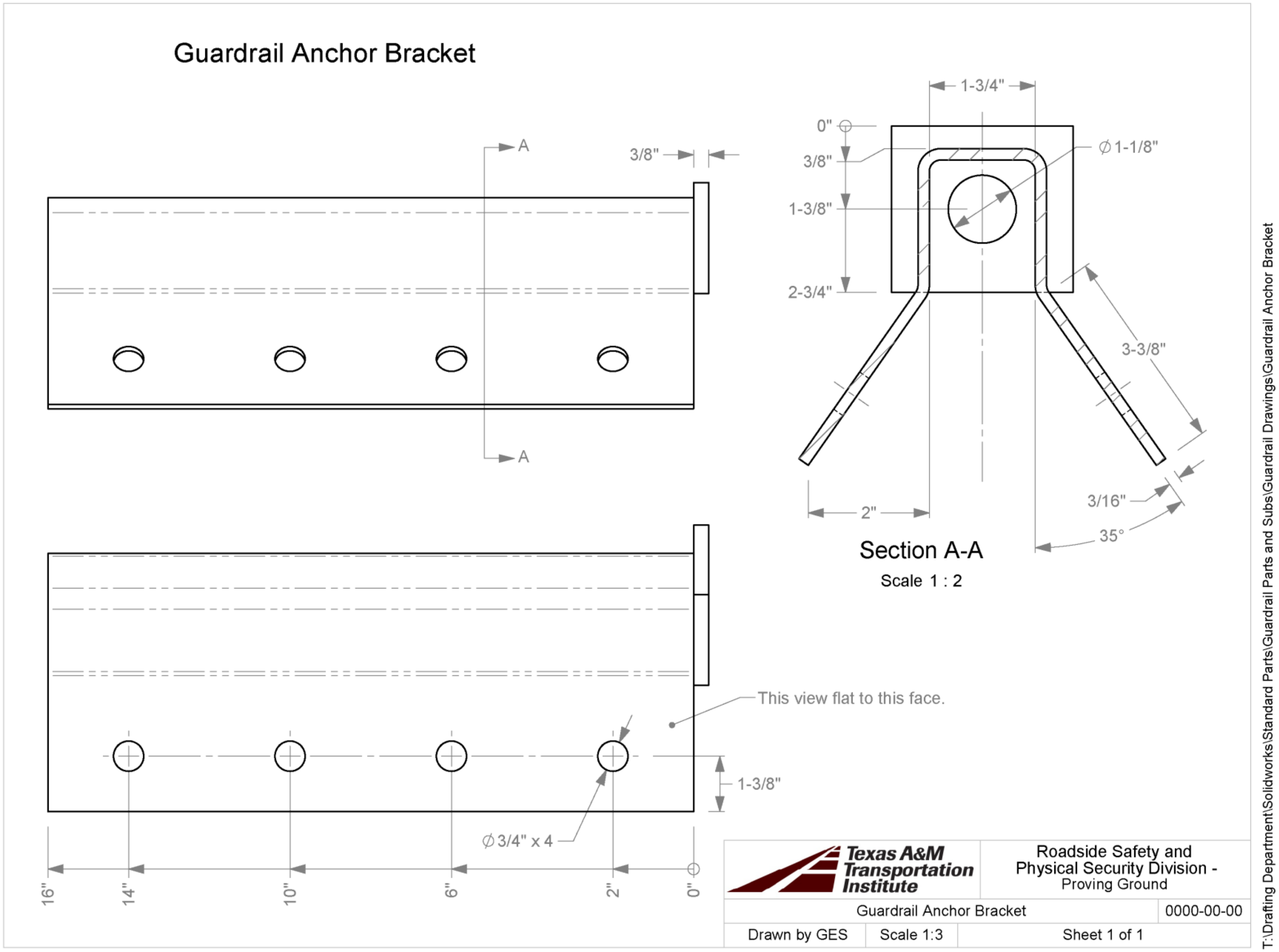
BCT Bearing Plate

BCT Post Sleeve

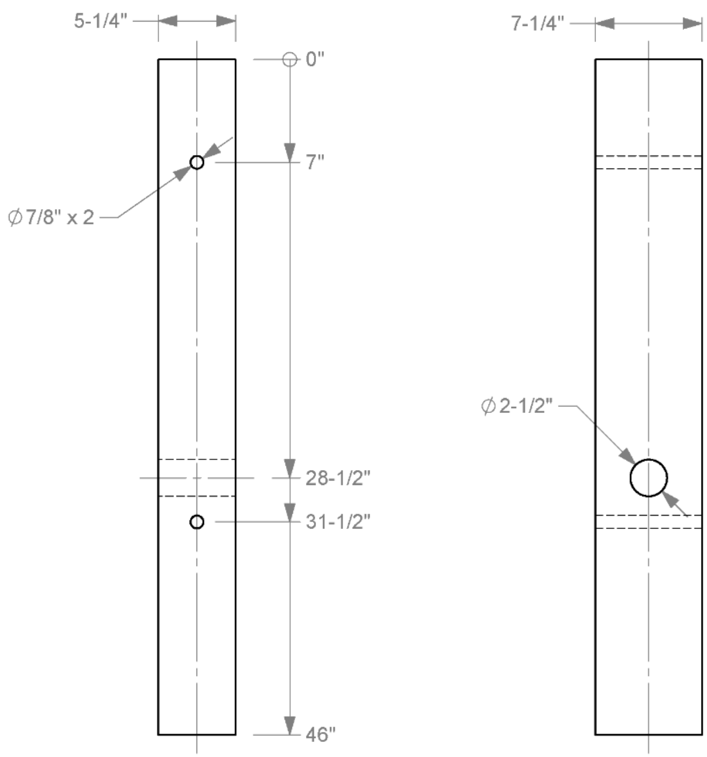


Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
BCT Post Sleeve			2020-02-24
Drawn by GES	Scale 1:1	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\BCT Post Sleeve


Guardrail Anchor Bracket
A
A
3/8"
1-3/4"
0"
3/8"
1-3/8"
2-3/4"
∅ 1-1/8"
3-3/8"
3/16"
2"
35°
Section A-A
Scale 1 : 2
This view flat to this face.
1-3/8"
∅ 3/4" x 4
16"
14"
10"
6"
2"
0"
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Guardrail Anchor Bracket
0000-00-00
Drawn by GES
Scale 1:3
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Drawings\Guardrail Parts\Guardrail Anchor Bracket

Post, Tube

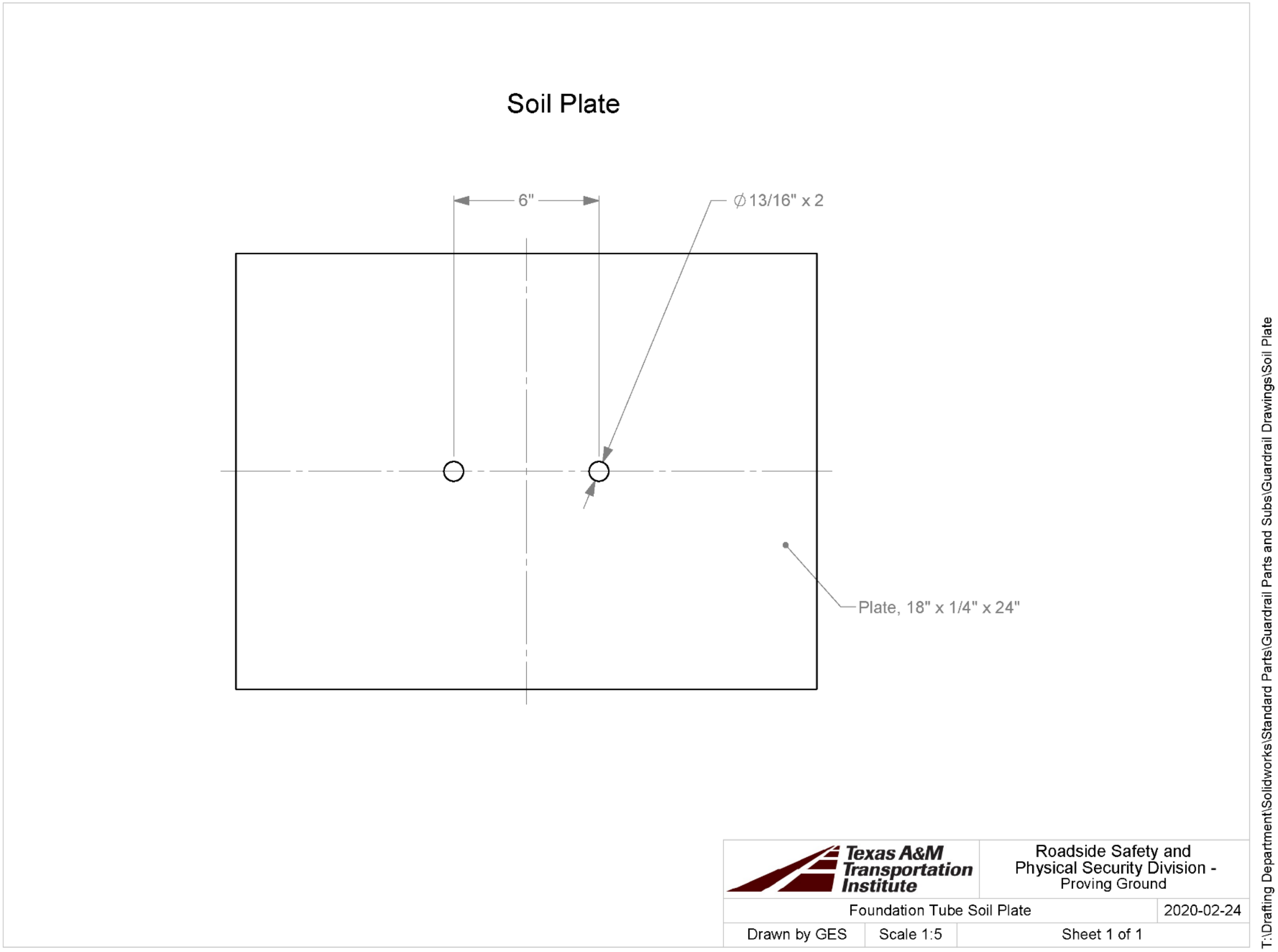


Elevation Views

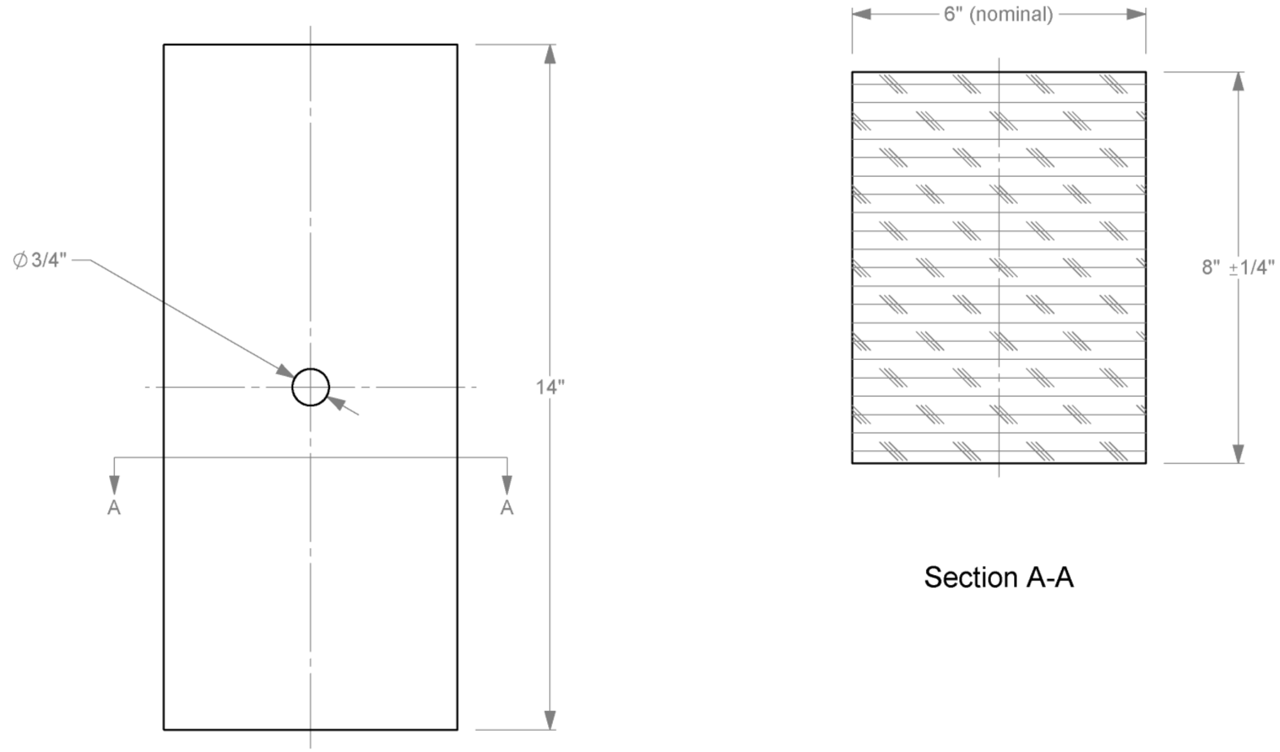
1a. Timber posts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Terminal Timber Post		2020-02-24
Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, Tube


Soil Plate
6"
∅13/16" x 2
Plate, 18" x 1/4" x 24"
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Foundation Tube Soil Plate
2020-02-24
Drawn by GES
Scale 1:5
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Soil Plate

Timber Blockout for 6x8 Wood Post



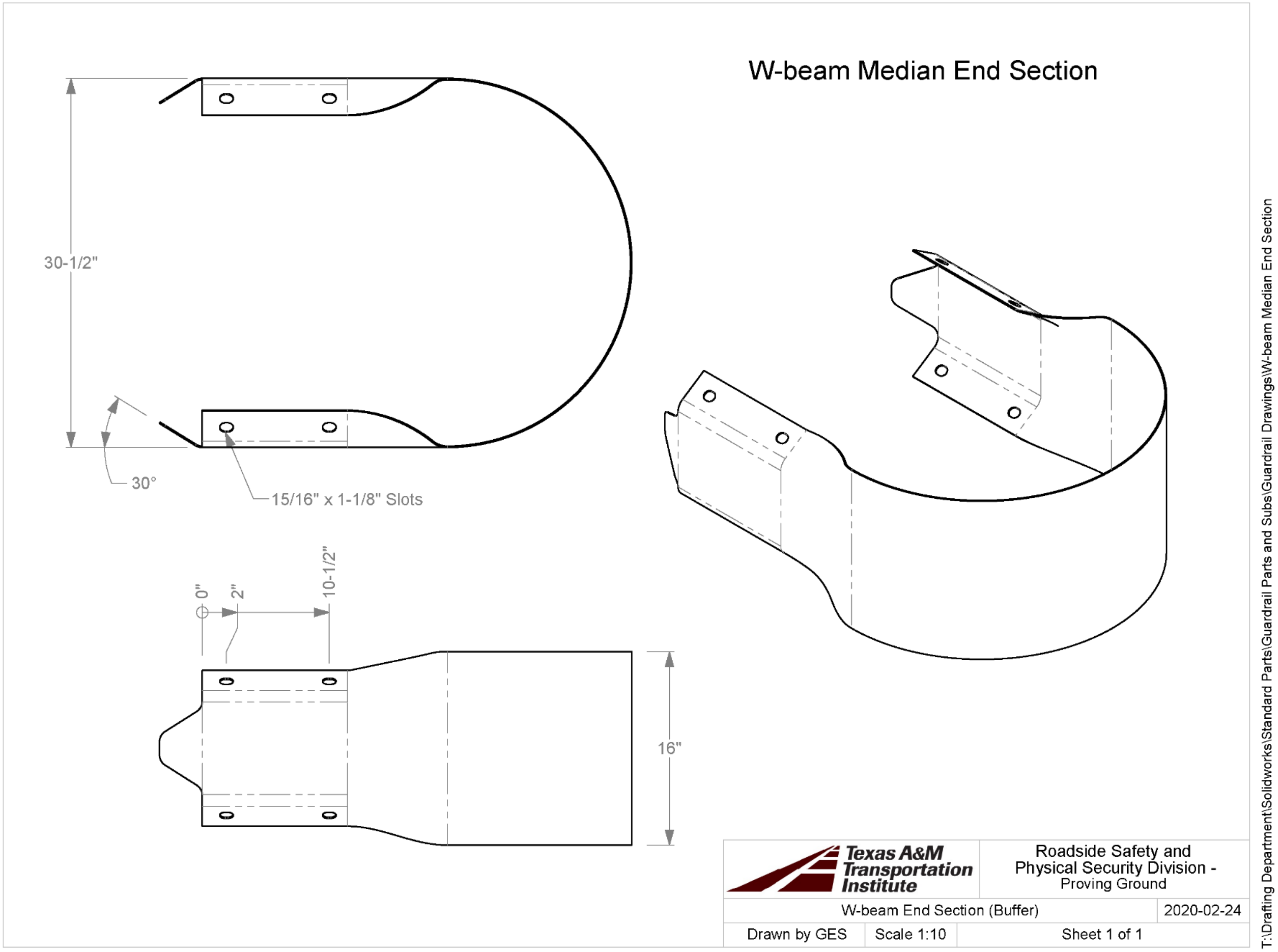
Elevation View

Section A-A

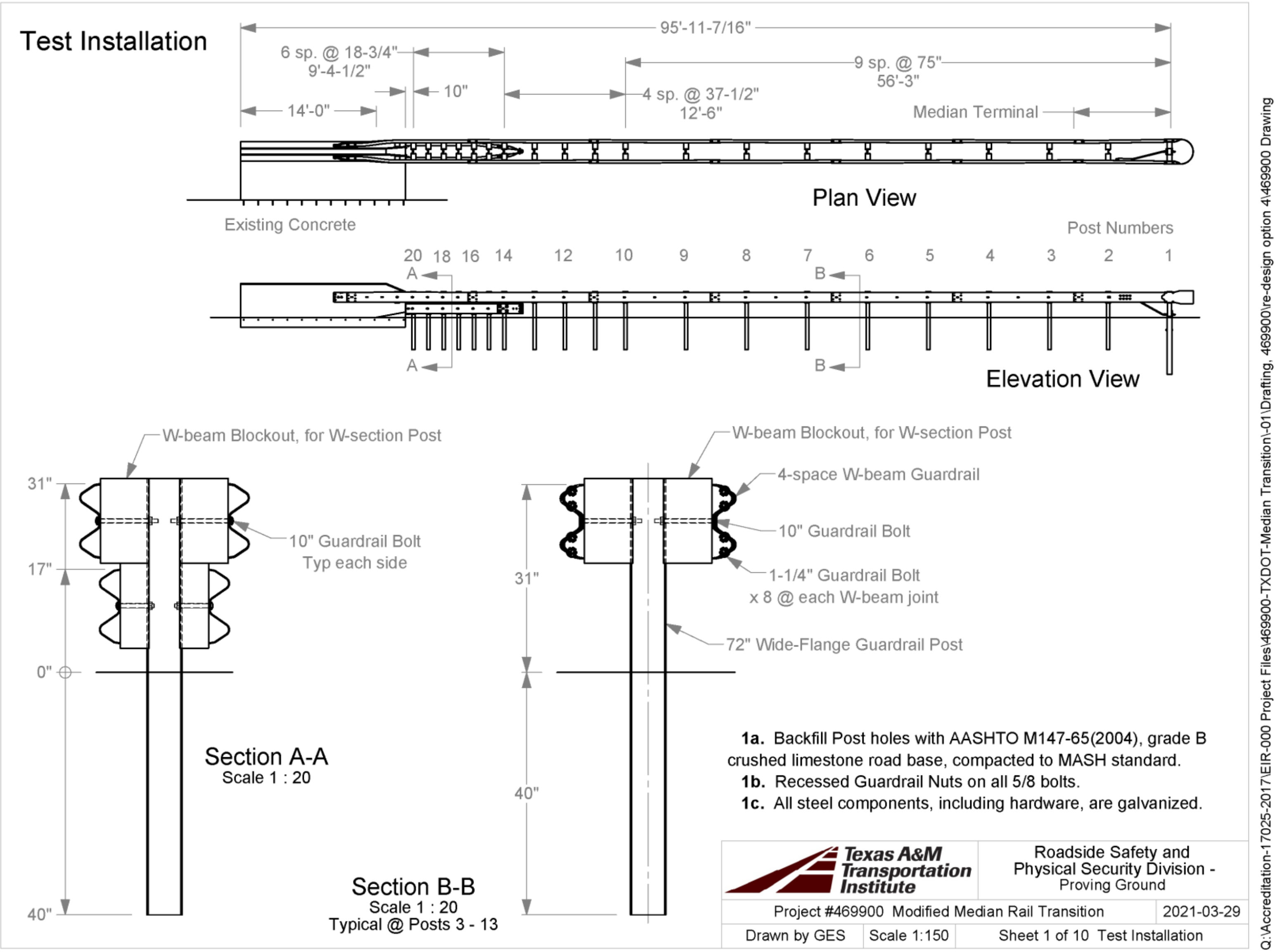
1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
W-beam Blockout, for Wood Post		2020-02-24
Drawn by GES	Scale 1:3	Sheet 1 of 1

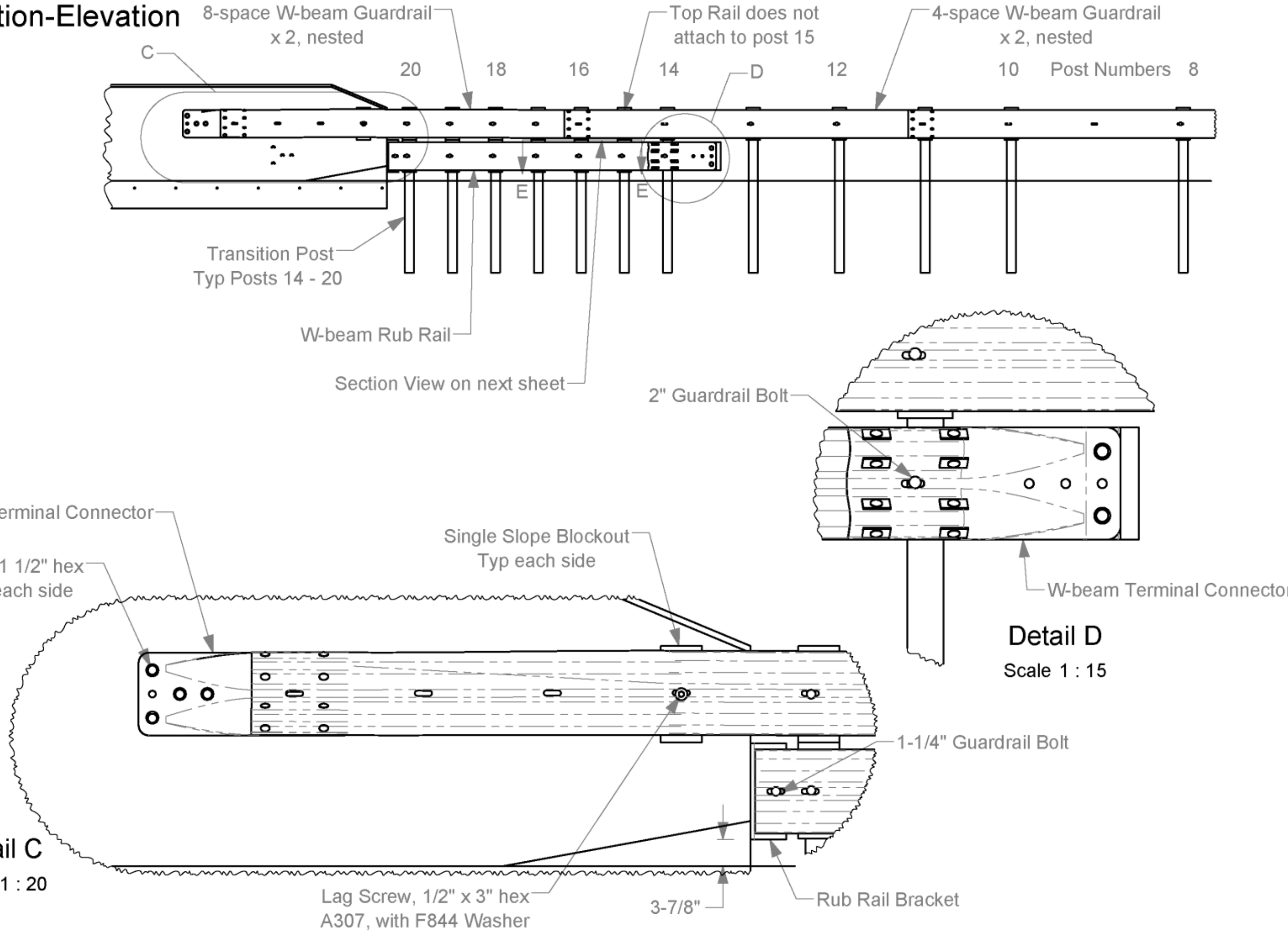
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Timber Blockout for 6x8 Wood Post


W-beam Median End Section
30-1/2"
30°
15/16" x 1-1/8" Slots
0"
2"
10-1/2"
16"
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
W-beam End Section (Buffer)
2020-02-24
Drawn by GES
Scale 1:10
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-beam Median End Section

A.2 MODIFIED TRANSITION USED FOR TEST NO. 469900-01-2 THROUGH469900-01-5



Transition-Elevation



2a. All hardware is galvanized.
2b. All 7/8 Bolts are A325. One F436 Washer under each 7/8 Nut and Bolt head.
2c. 2" Guardrail Bolts at each W-beam Terminal Connector to W-beam joint, with a Rectangular Guardrail Washer between Terminal Connector and Nut or Bolt head.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Modified Median Rail Transition		2021-03-29
Drawn by GES	Scale 1:60	Sheet 2 of 10 Transition-Elevation

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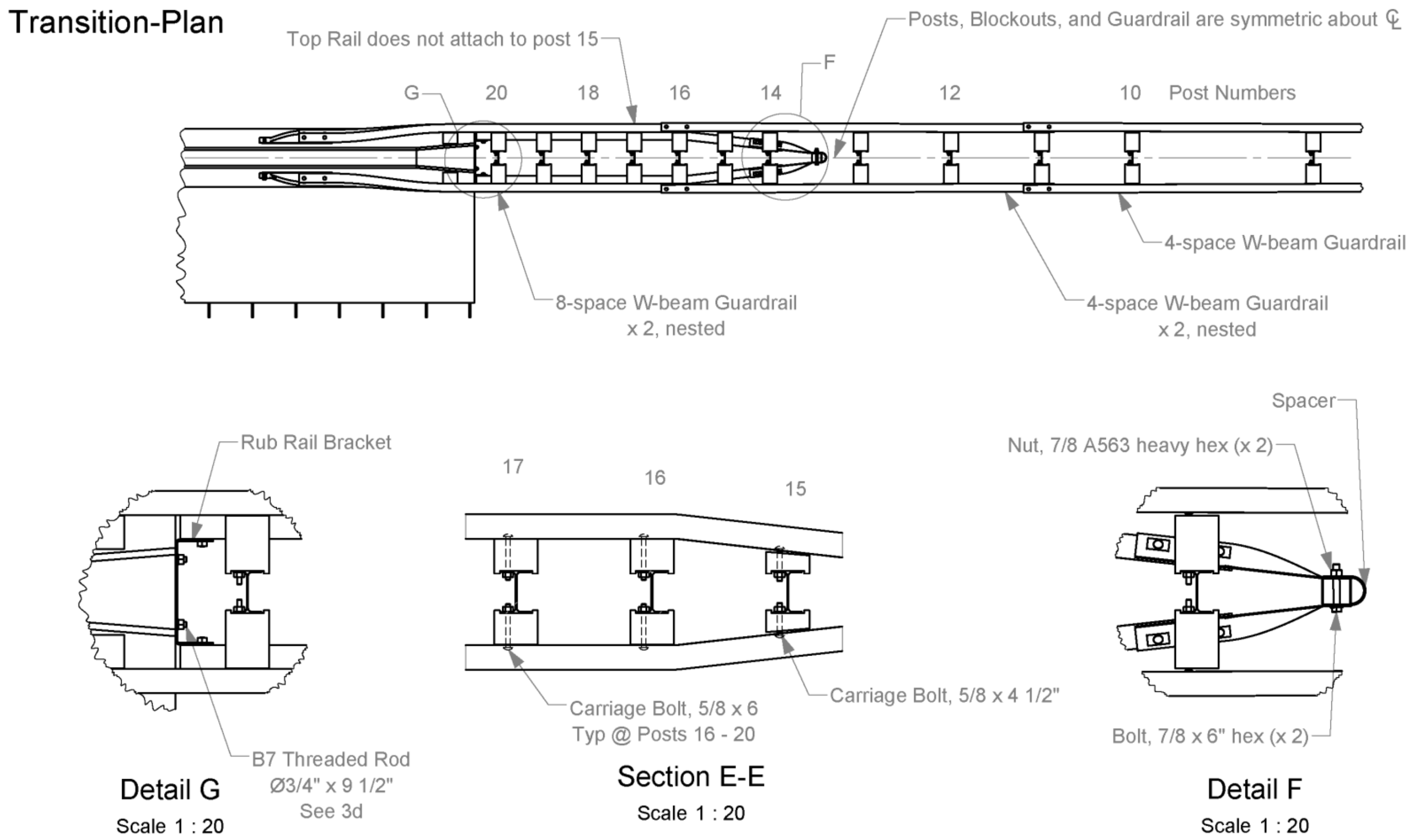


3a. All hardware is galvanized.

3b. All 7/8 Bolts are A325. One F436 Washer under each 7/8 Nut and Bolt head.

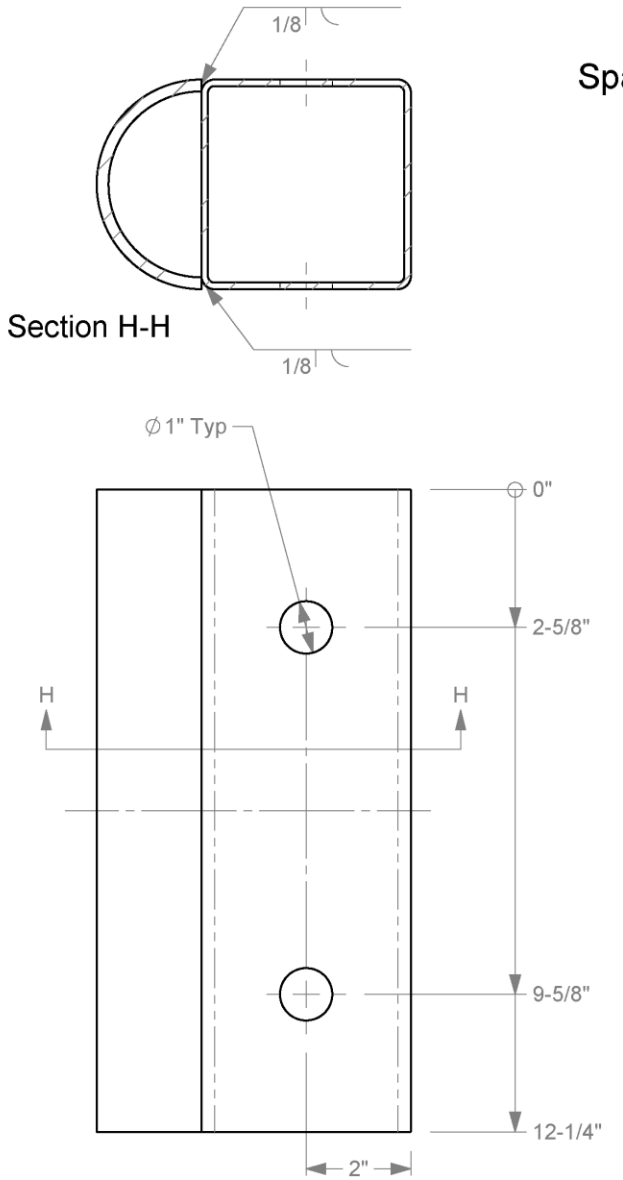
3c. 2" Guardrail Bolts at each W-beam Terminal Connector to W-beam joint, with a Rectangular Guardrail Washer between Terminal Connector and Nut or Bolt head.

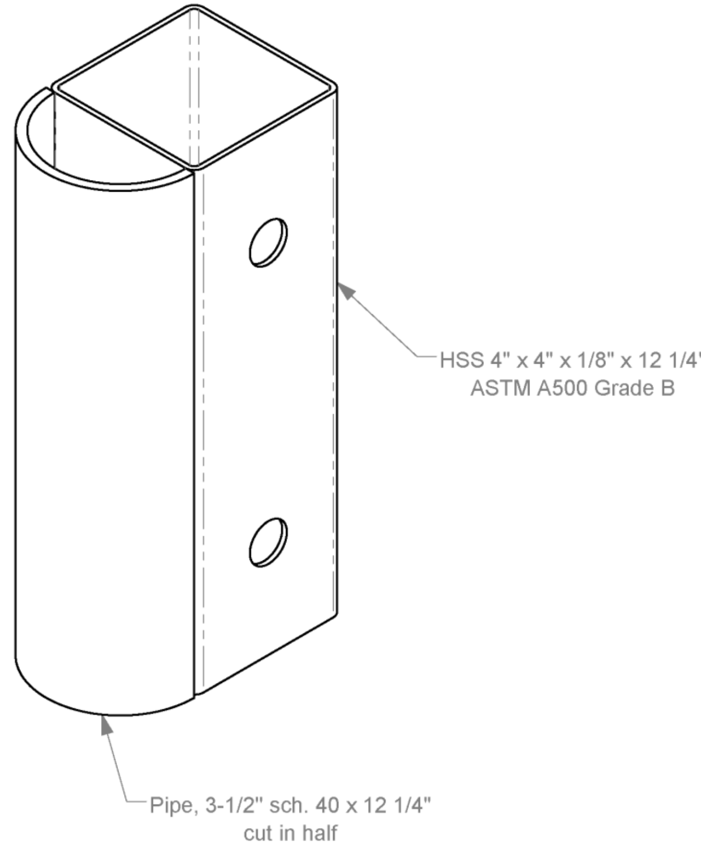
3d. With F436 Washer and Heavy Hex Nut, 4 places. Secure with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 8" embedment.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Modified Median Rail Transition		2021-03-29
Drawn by GES	Scale 1:60	Sheet 3 of 10 Transition-Plan

Q:\Accreditation-17025-2017\EIR-000 Project Files\469900-TXDOT-Median Transition\-01\Drafting, 469900\re-design option 4\469900 Drawing

Spacer



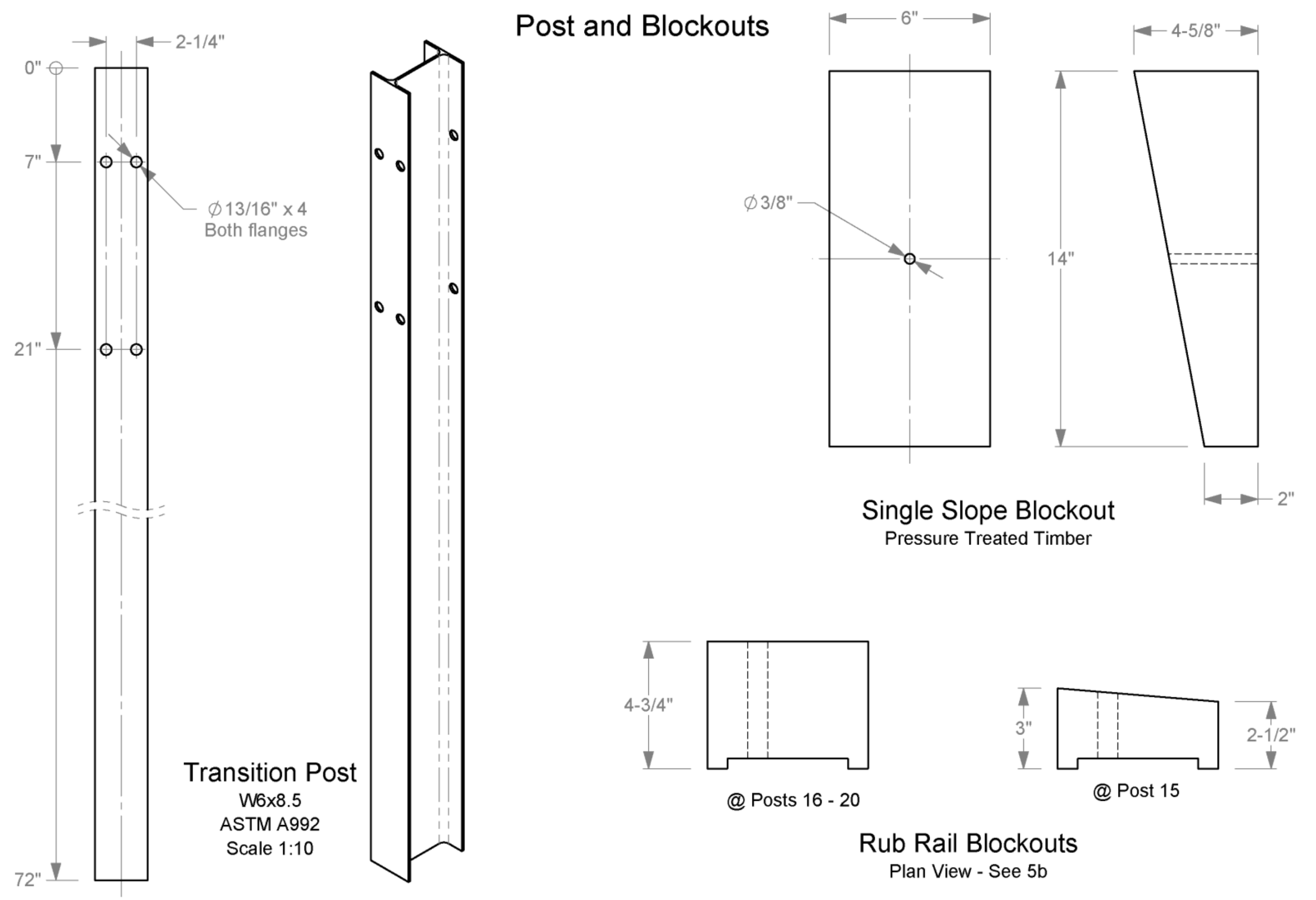


4a. Galvanize after fabrication is complete.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Modified Median Rail Transition		2021-03-29
Drawn by GES	Scale 1:3	Sheet 4 of 10 Spacer

Q:\Accreditation-17025-2017\EIR-000 Project Files\469900-TXDOT-Median Transition\-01\Drafting, 469900\re-design option 4\469900 Drawing

Post and Blockouts



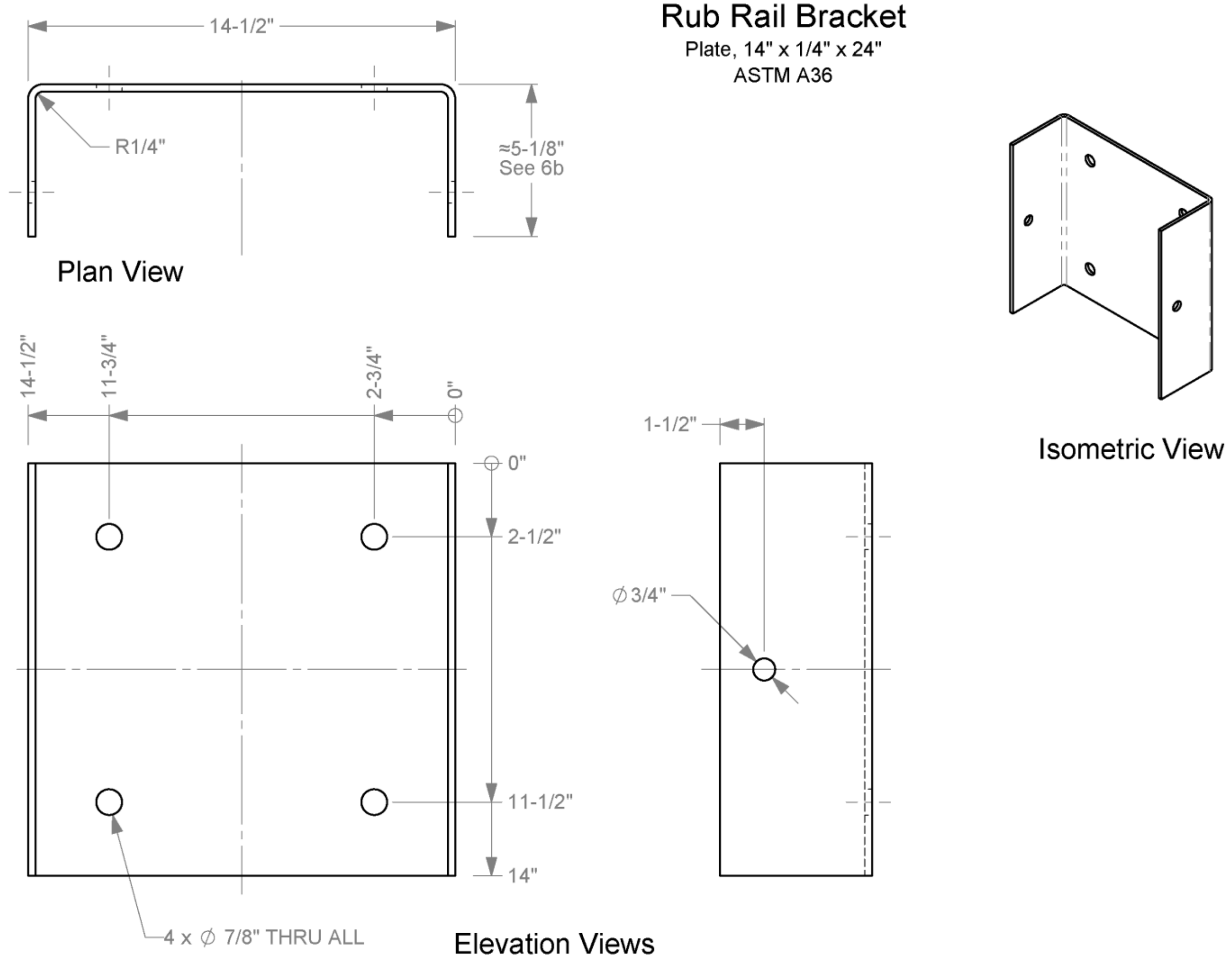
5a. Galvanize steel components after fabrication is complete.
5b. See Timber Blockout for W-section Post drawing sheet for all other dimensions.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground
Project #469900 Modified Median Rail Transition	2021-03-29
Drawn by GES · Scale 1:5	Sheet 5 of 10 Post and Blockouts

Q:\Accreditation-17025-2017\EIR-000 Project Files\469900-TXDOT-Median Transition\-01\Drafting, 469900\re-design option 4\469900 Drawing

Rub Rail Bracket

Plate, 14" x 1/4" x 24"
ASTM A36

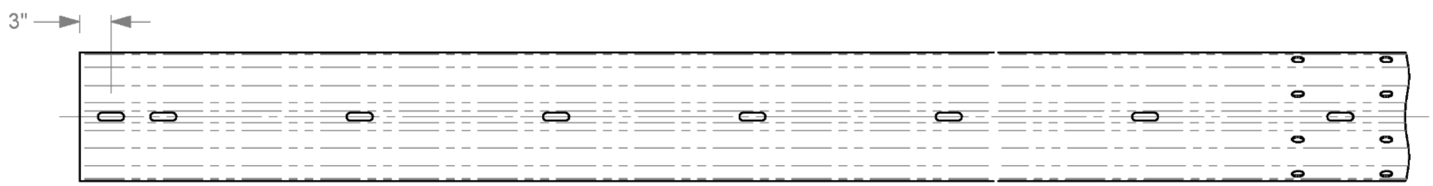


6a. Galvanize after fabrication is complete.
6b. Dimension is approximate. Plate is 24" before bending.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project #469900 Modified Median Rail Transition			2021-03-29
Drawn by GES	Scale 1:5	Sheet 6 of 10 Rub Rail Bracket	

W-beam Rub Rail

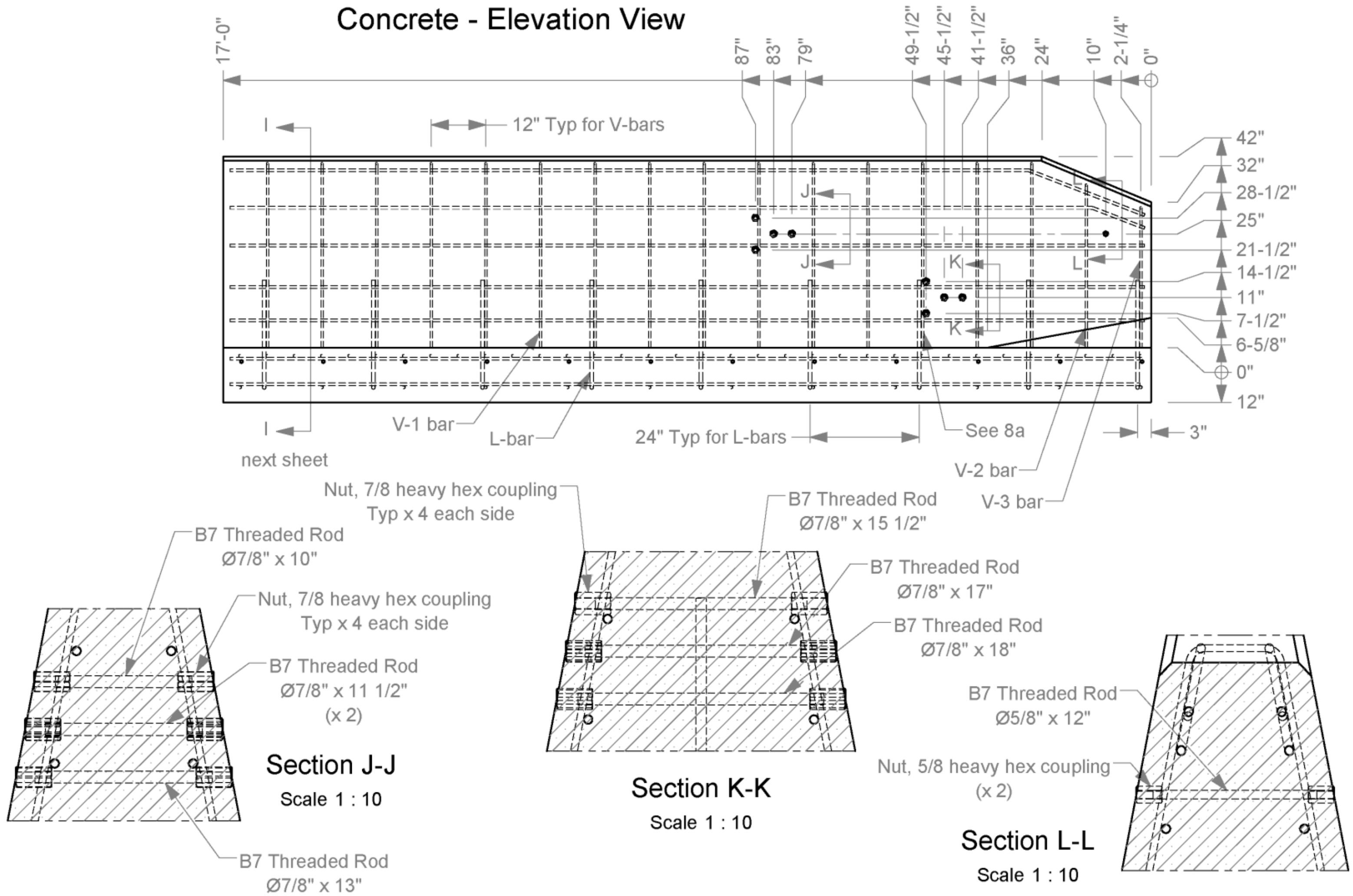
Standard 12-gauge 8-space W-beam, cut off to 127" total length, with additional 3/4" x 2-1/2" slot added where shown.



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Modified Median Rail Transition		2021-03-29
Drawn by GES	Scale 1:15	Sheet 7 of 10 W-beam Rub Rail

Q:\Accreditation-17025-2017\EIR-000 Project Files\469900-TXDOT-Median Transition\-01\Drafting, 469900\re-design option 4\469900 Drawing

Concrete - Elevation View

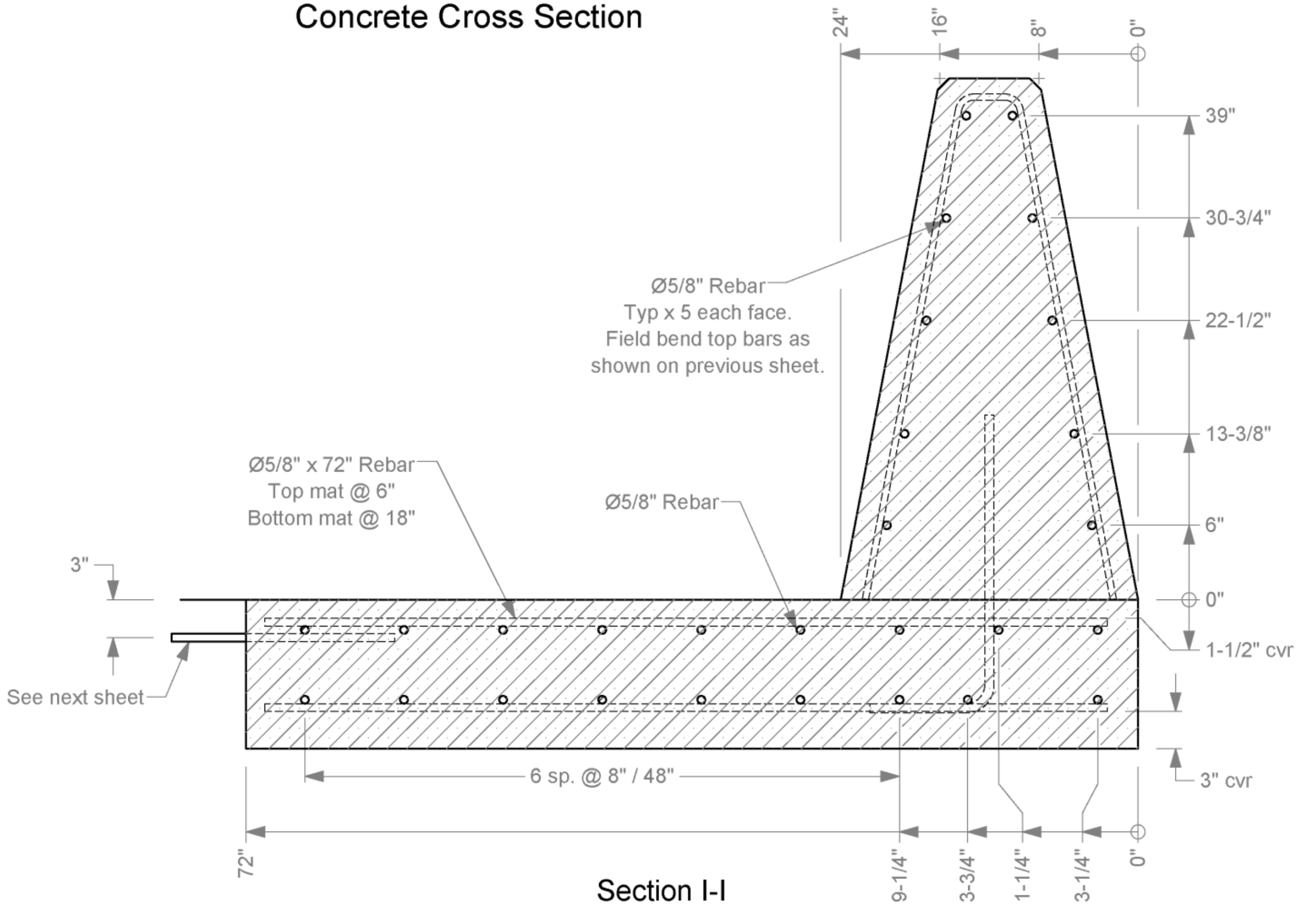


8a. Concrete is TxDOT Class C (3,600 psi).
8b. Thread Bolts and B7 Threaded Rods to midpoint (+0, -1/8") of the coupling nuts.
8c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover). All rebar is grade 60.
8d. Move rebar as needed to avoid interference with hardware.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Modified Median Rail Transition		2021-03-29
Drawn by GES	Scale 1:30	Sheet 8 of 10 Concrete - Elevation

Q:\Accreditation-17025-2017\EIR-000 Project Files\469900-TXDOT-Median Transition\-01\Drafting, 469900\re-design option 4\469900 Drawing

Concrete Cross Section

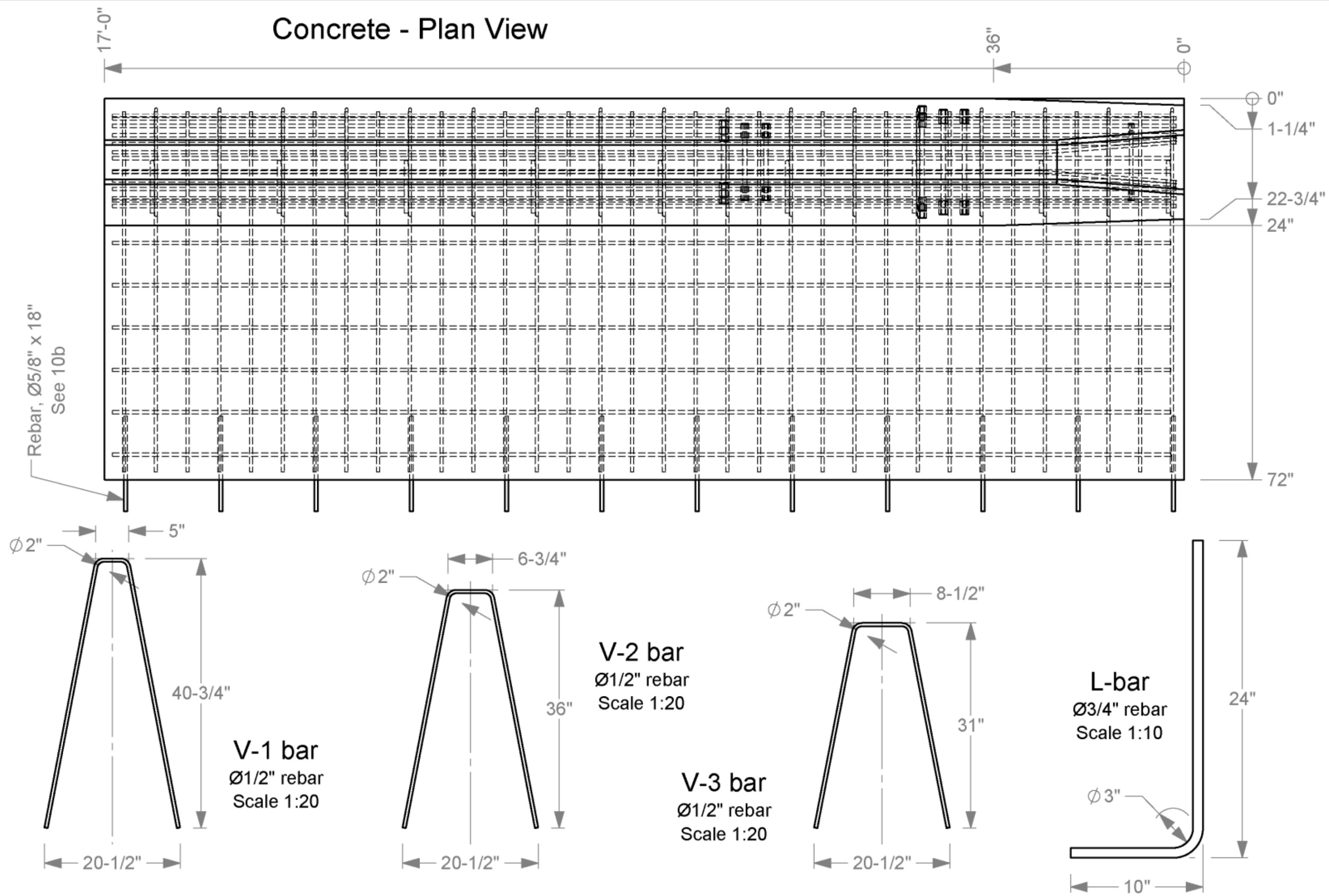


Section I-I

9a. Concrete is TxDOT Class C (3,600 psi).
9b. 1" Chamfer (3/4" each way) top edges of parapet.
9c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover). All rebar is grade 60.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Modified Median Rail Transition		2021-03-29
Drawn by GES	Scale 1:12	Sheet 9 of 10 Concrete Cross Section

Q:\Accreditation-17025-2017\EIR-000 Project Files\469900-TXDOT-Median Transition\-01\Drafting, 469900\re-design option 4\469900 Drawing



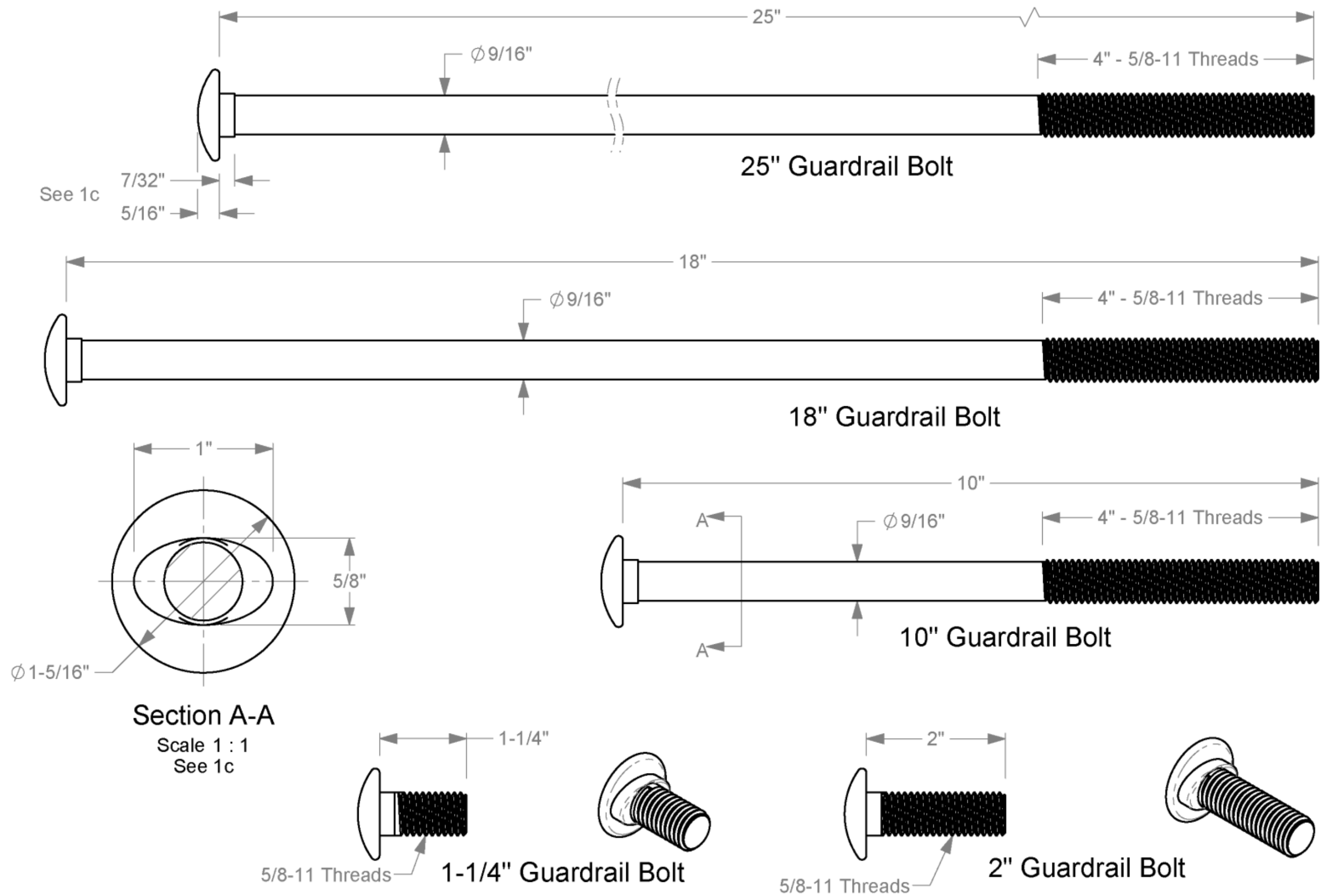
10a. Concrete is TxDOT Class C (3,600 psi).

10b. Secure in existing concrete with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, at 18" spacing with 6" embedment.

10c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover). All rebar is grade 60.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469900 Modified Median Rail Transition		2021-03-29
Drawn by GES	Scale 1:25	Sheet 10 of 10 Concrete - Plan

Q:\Accreditation-17025-2017\EIR-000 Project Files\469900-TXDOT-Median Transition\-01\Drafting, 469900\re-design option 4\469900 Drawing

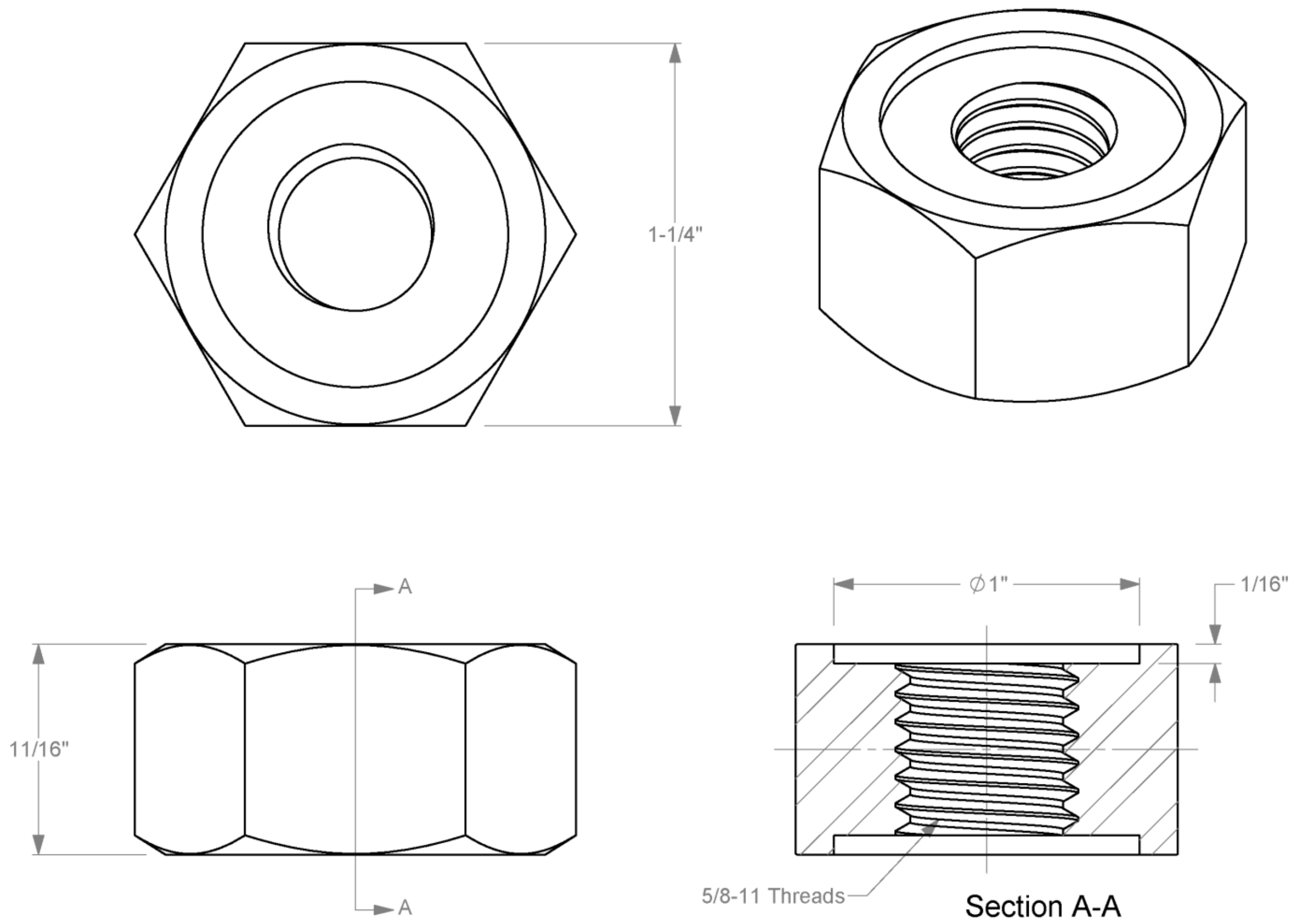


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.

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

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

Recessed Guardrail Nut

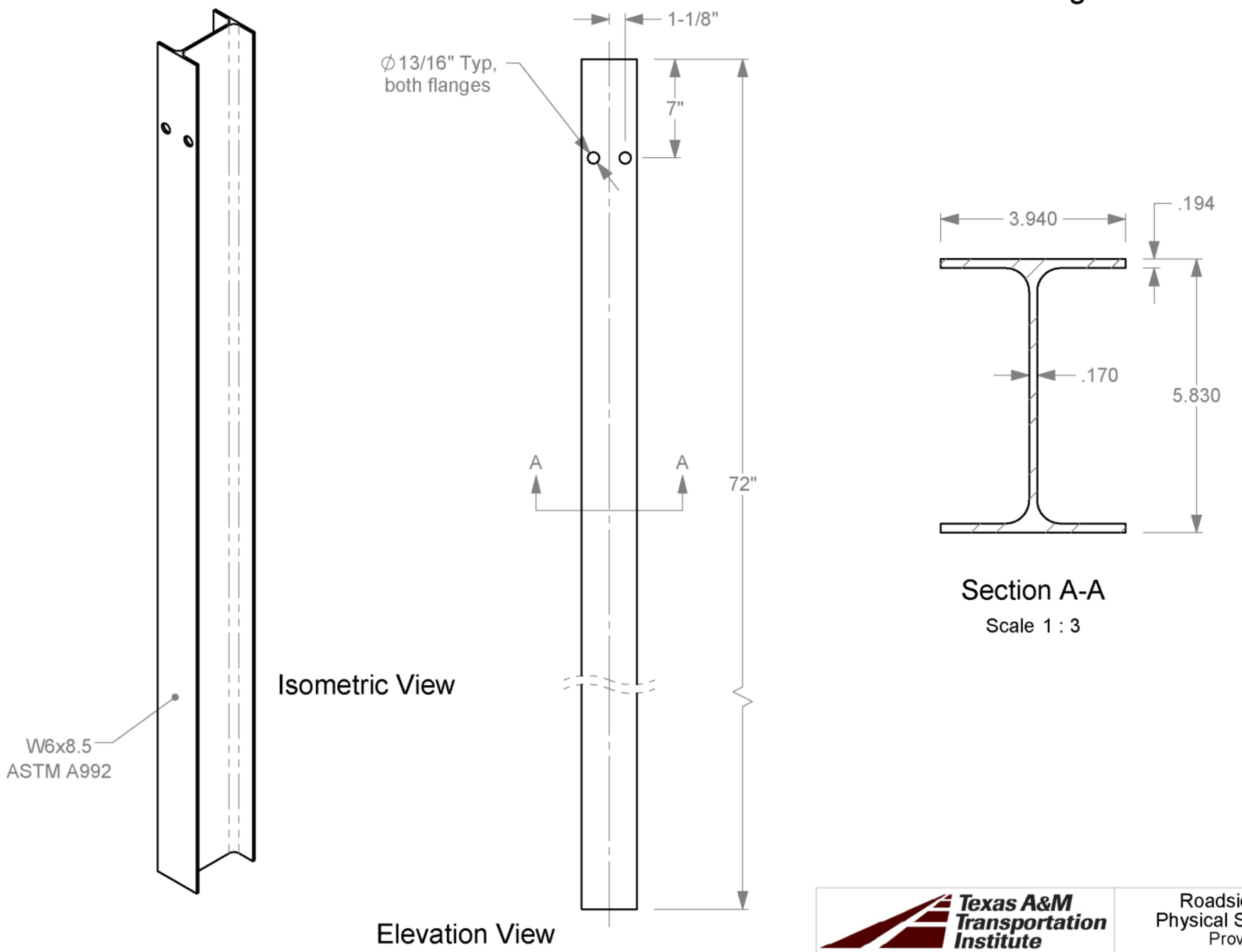


1a. Material is ASTM A 563 Grade A.

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\Guardrail Parts and Subs\Guardrail Drawings\Nut, Recessed Guardrail

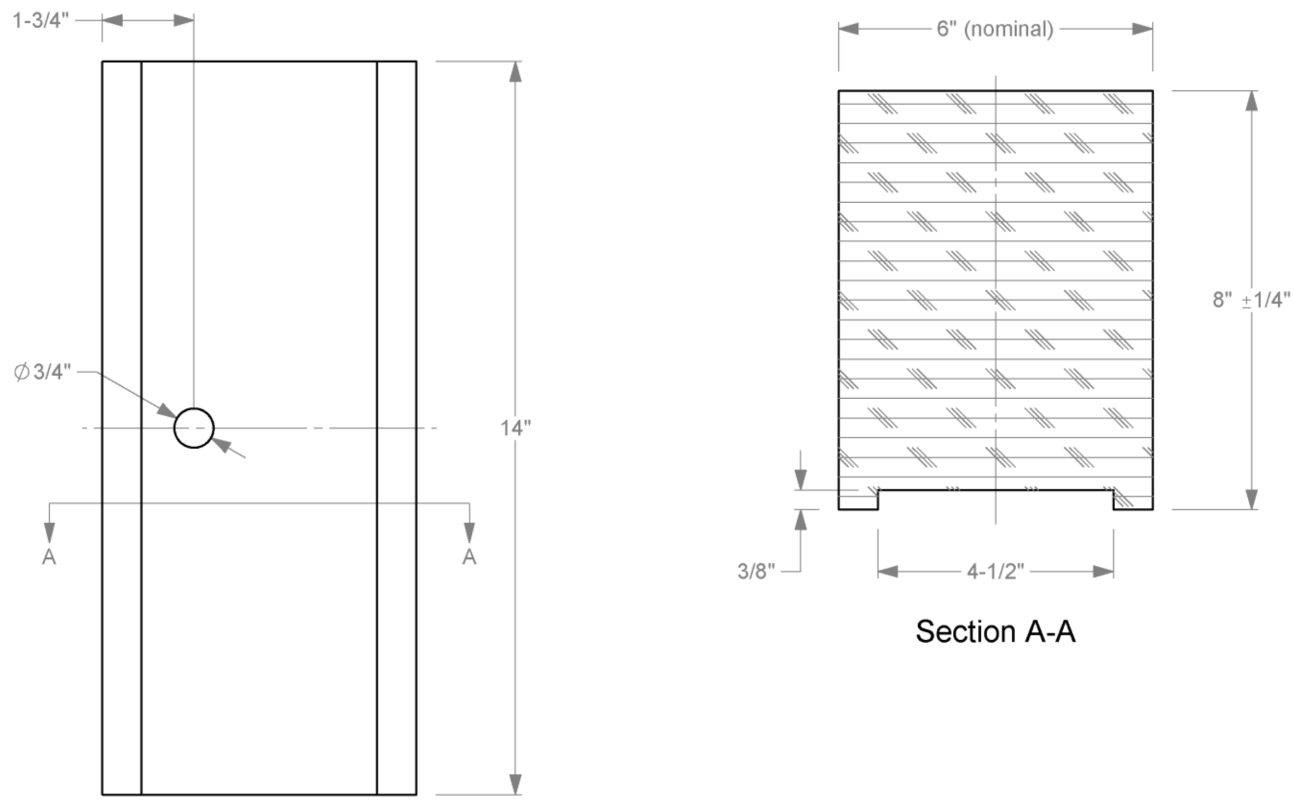
72" Wide-Flange Guardrail Post



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
72" Wide-Flange Guardrail Post		2020-01-06
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 Guardrail

Timber Blockout for W-section Post



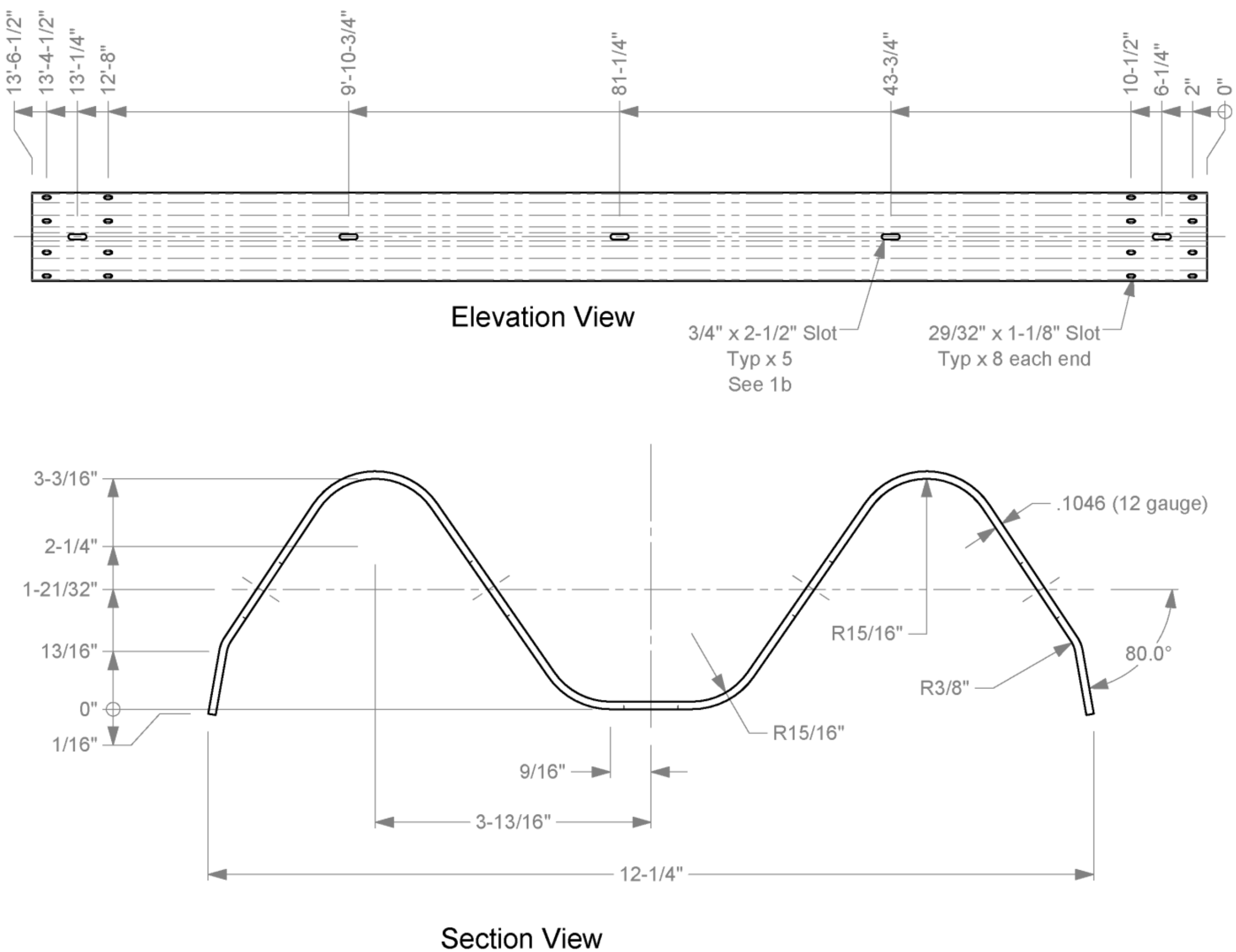
Elevation View

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

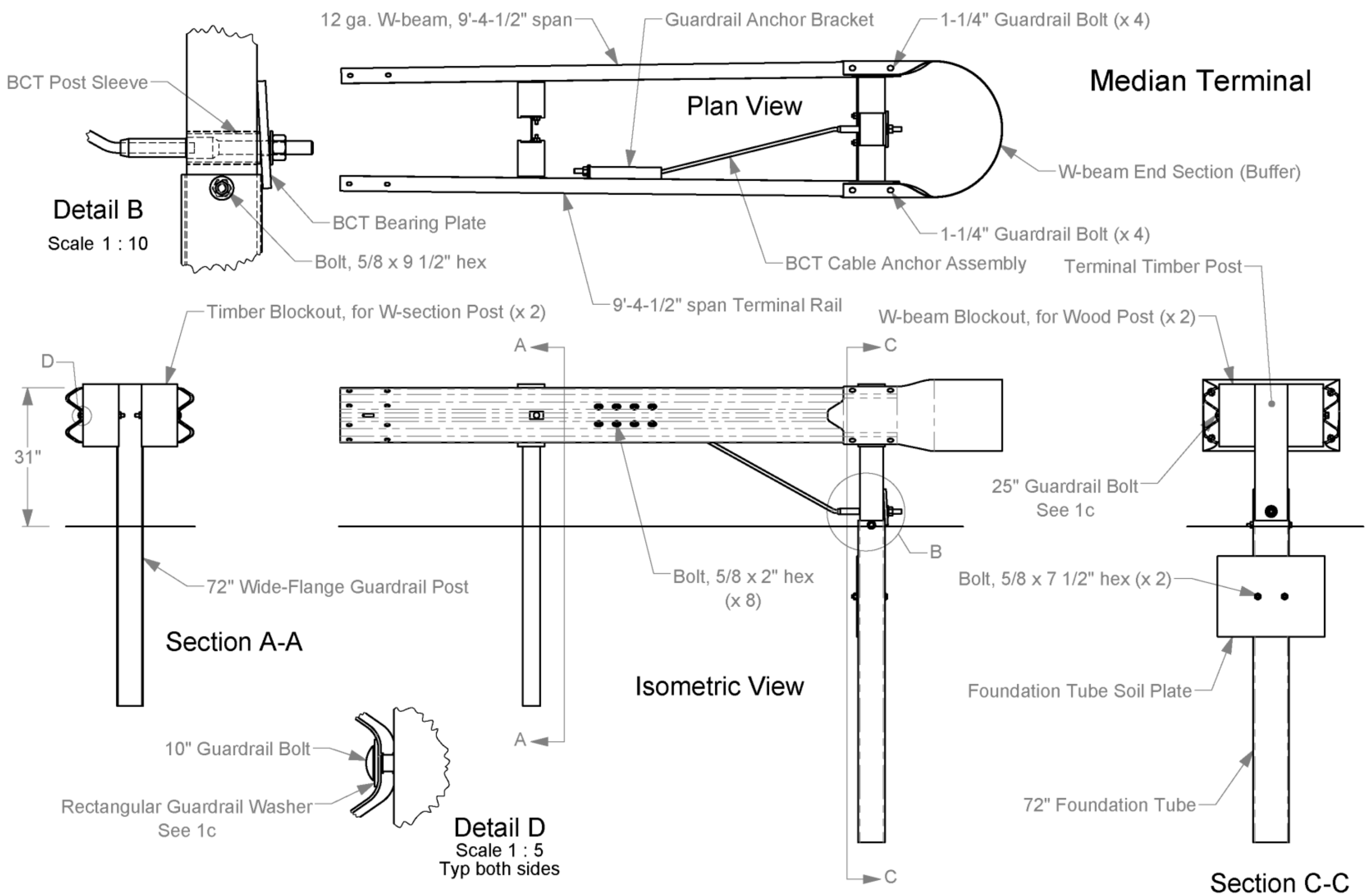


1a. Manufacture per AASHTO M180 specifications.

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			2020-02-19
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, 12 gauge



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

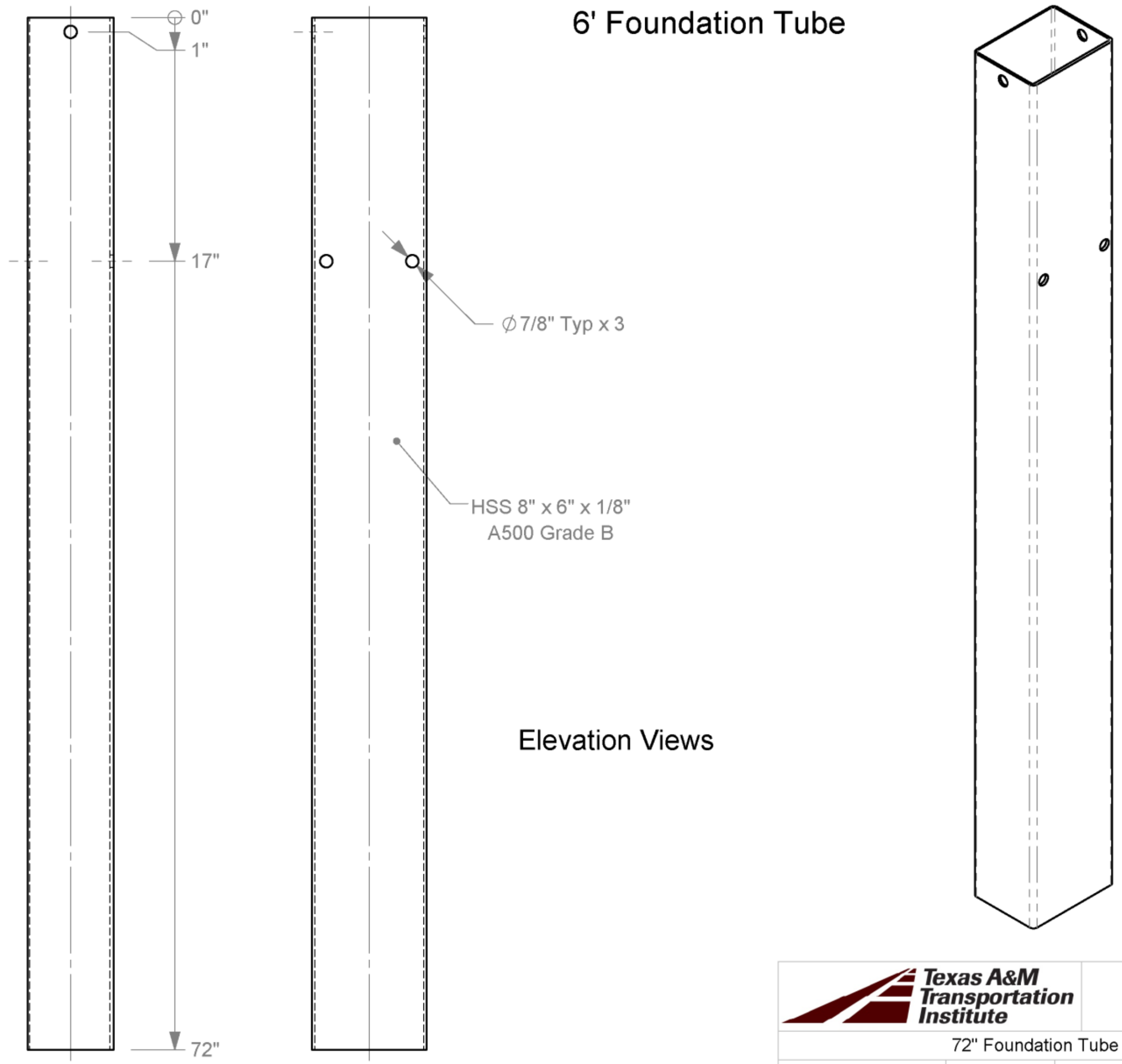
1b. Recessed Guardrail Nuts on all 5/8 bolts. Hex Head bolts are ASTM A307. F844 Flat Washer under the head of all hex bolts.

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 Transportation 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

6' Foundation Tube



Elevation Views

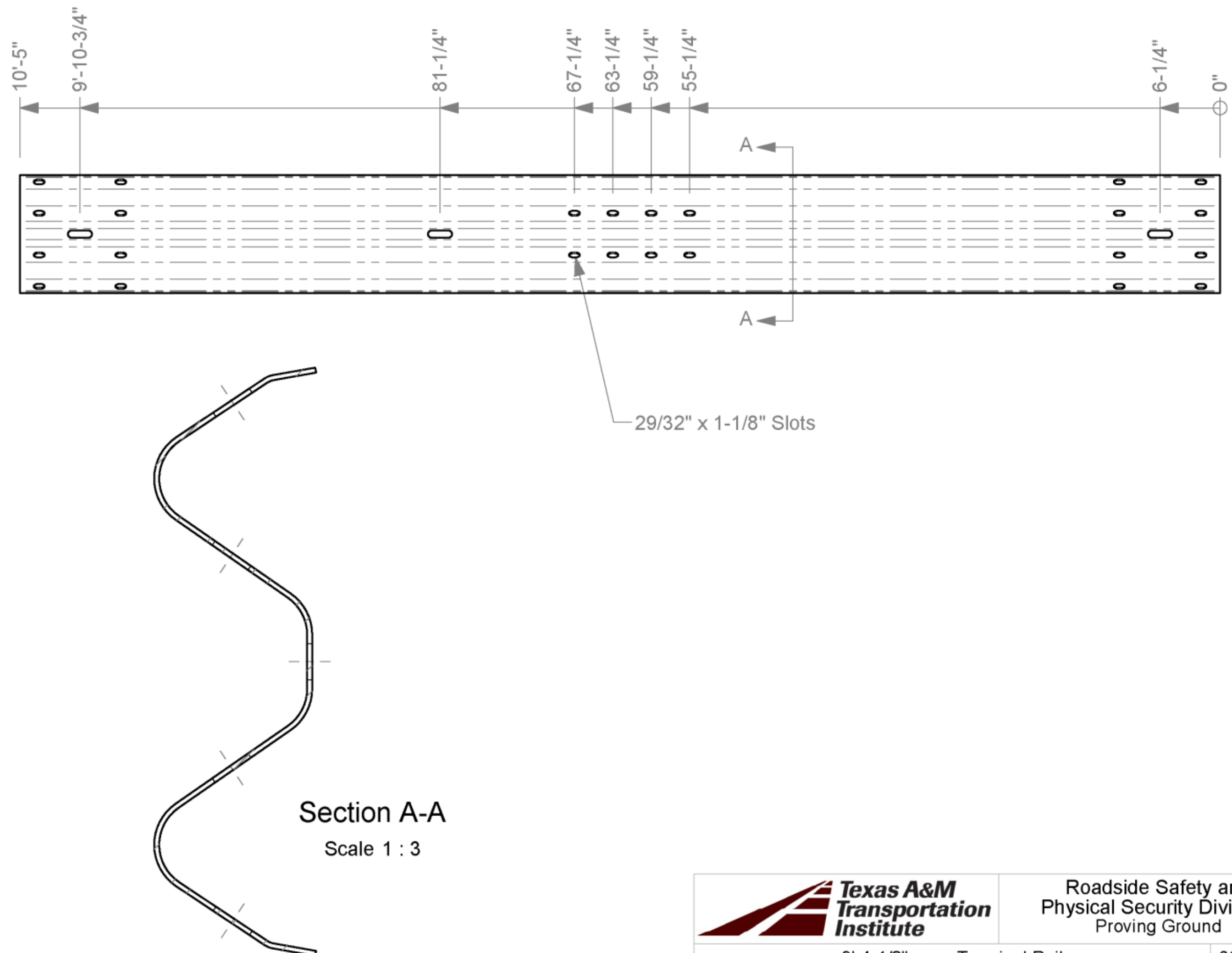
Isometric View

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
72" Foundation Tube		0000-00-00
Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\6' Foundation Tube

9'-4-1/2" span Terminal Rail

See W-beam Guardrail Drawing for all dimensions not shown here.

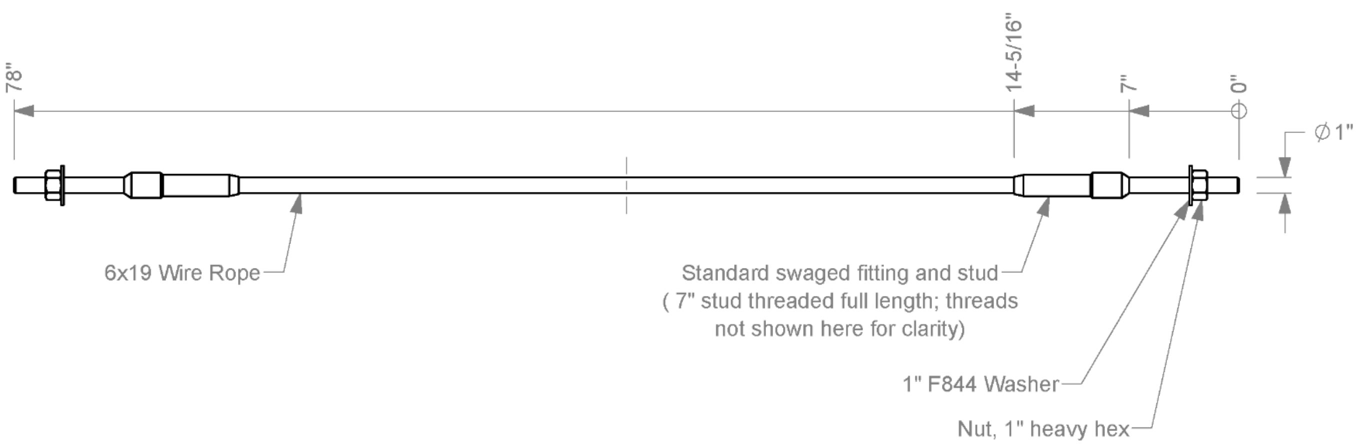


Section A-A
Scale 1 : 3

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
9'-4-1/2" span Terminal Rail		0000-00-00
Drawn by GES	Scale 1:15	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Median Terminal\9'-4.5in span Terminal Rail

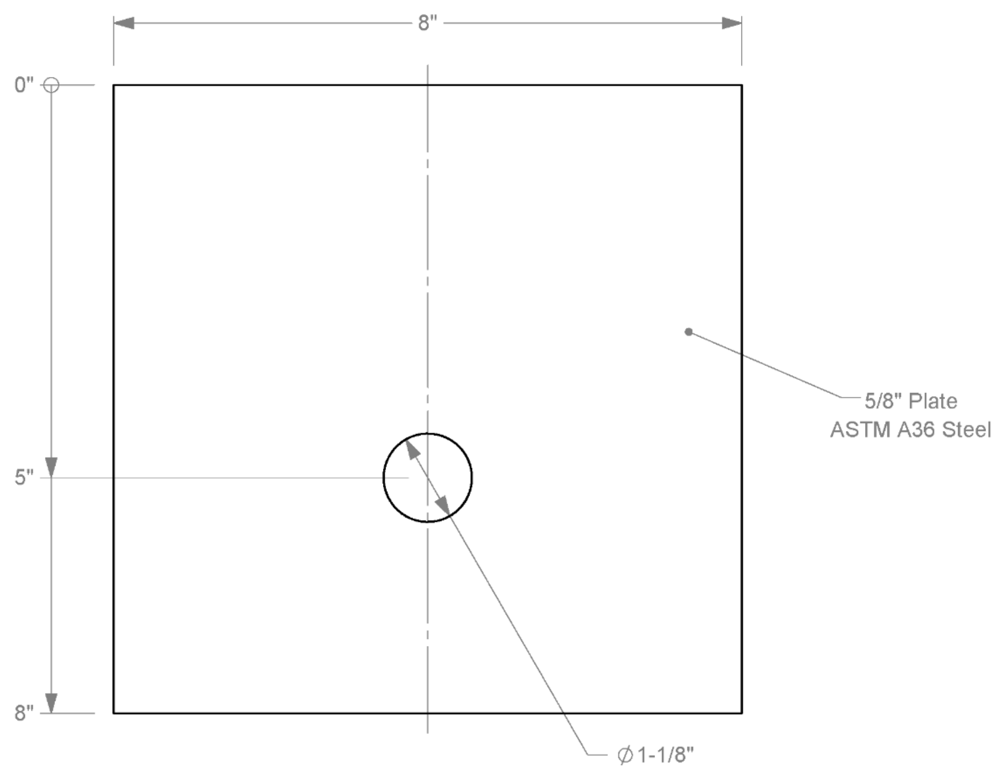
BCT Anchor Cable



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
BCT Anchor Cable		2020-02-24
Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\BCT Anchor Cable

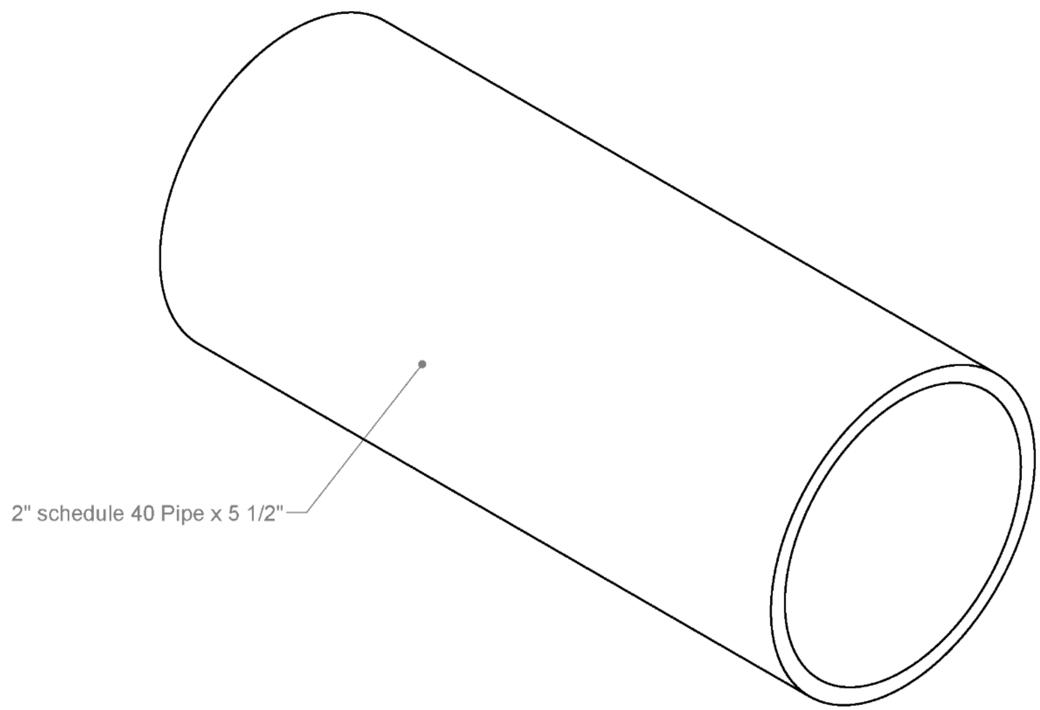
BCT Bearing Plate



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
BCT Bearing Plate			2020-02-24
Drawn by GES	Scale 1:2	Sheet 1 of 1	

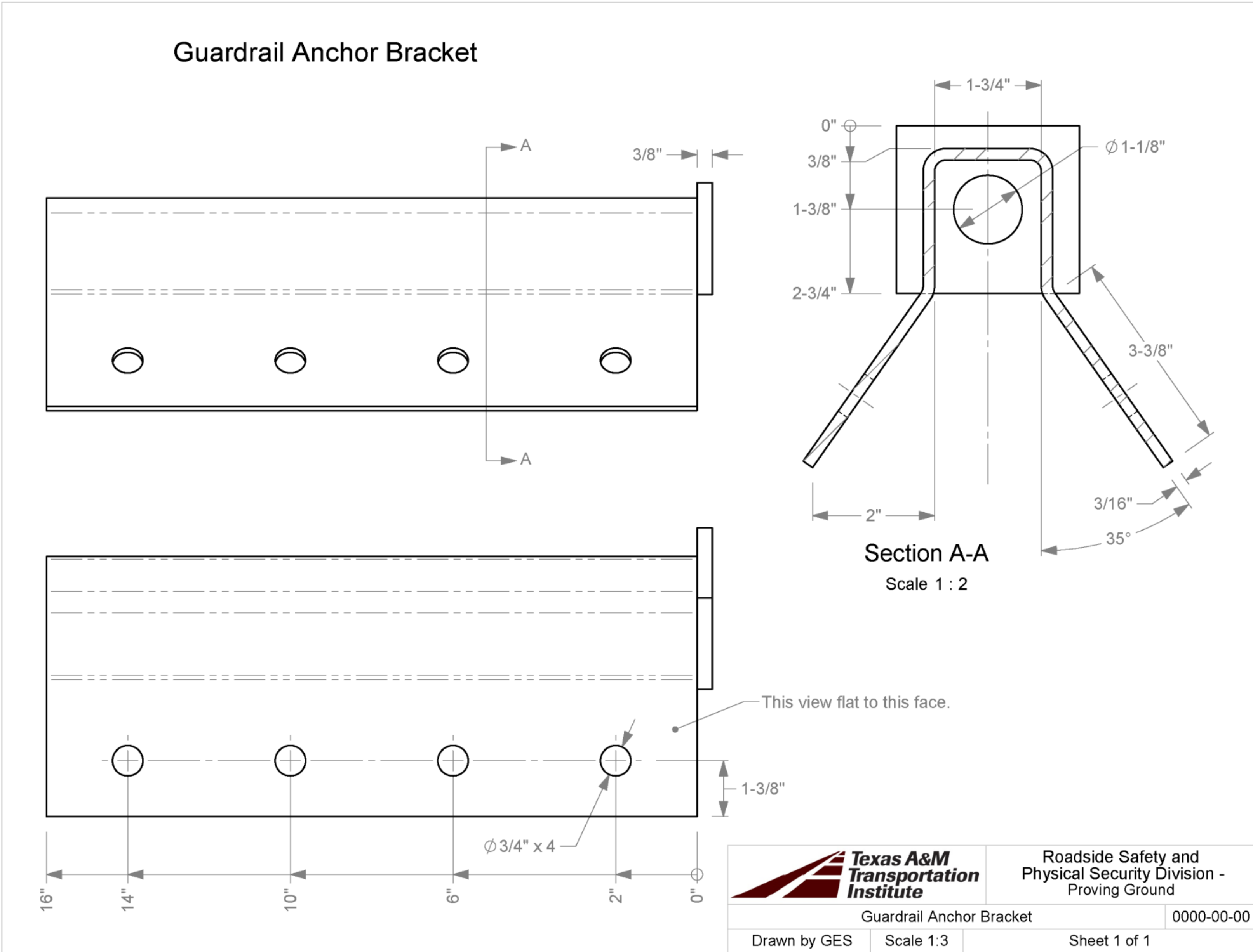
BCT Bearing Plate

BCT Post Sleeve



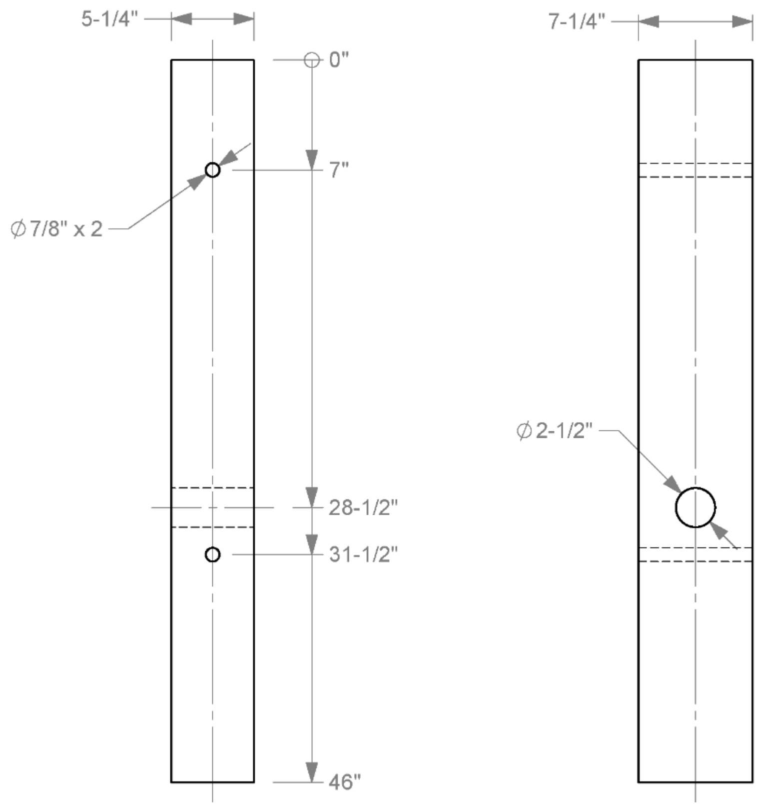
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
BCT Post Sleeve		2020-02-24
Drawn by GES	Scale 1:1	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\BCT Post Sleeve



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

Post, Tube



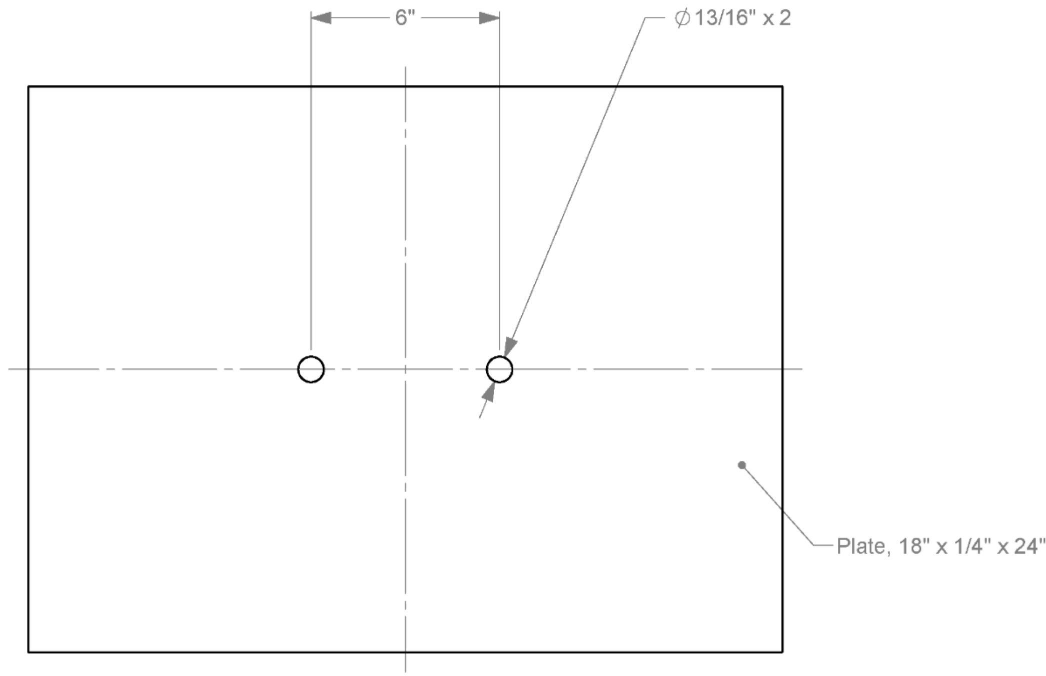
Elevation Views

1a. Timber posts 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	
Terminal Timber Post			2020-02-24
Drawn by GES	Scale 1:10	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, Tube

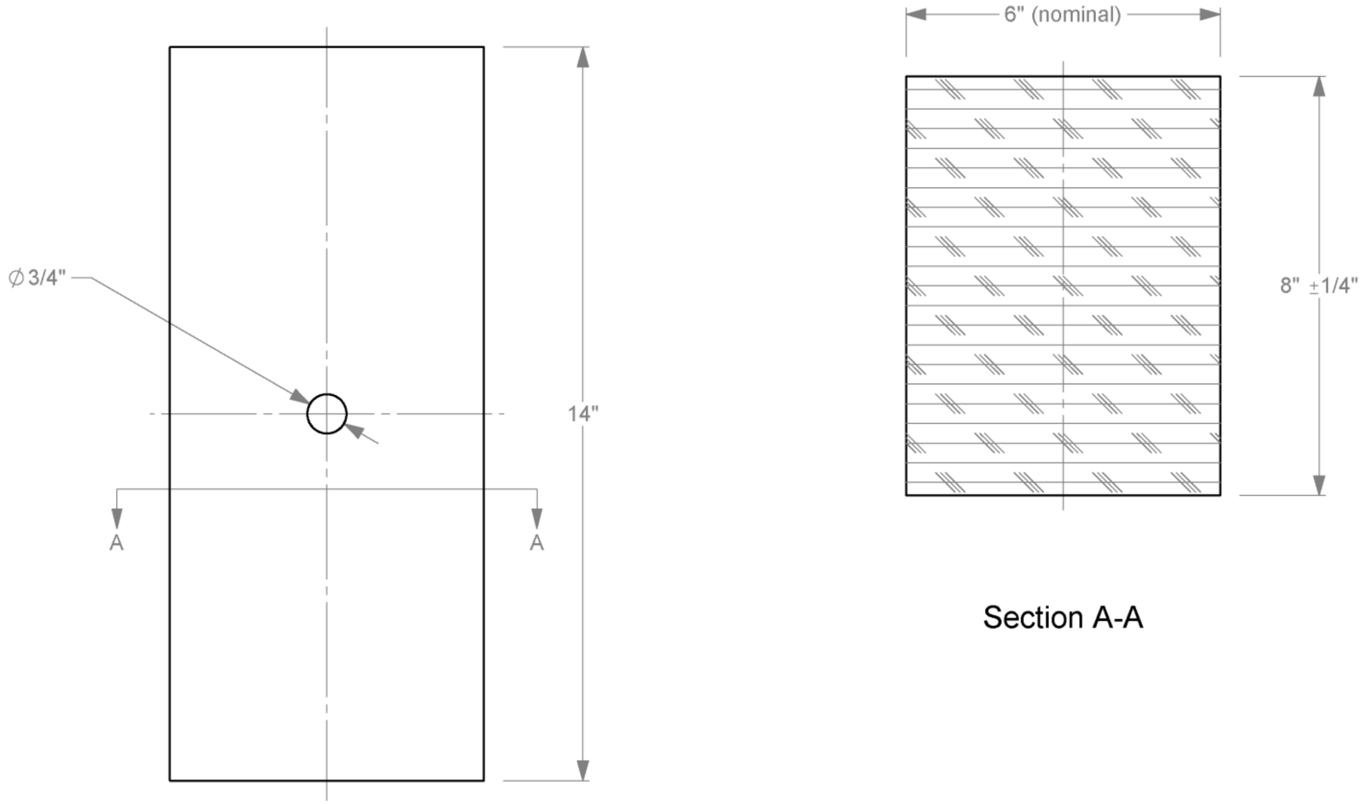
Soil Plate



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Foundation Tube Soil Plate		2020-02-24
Drawn by GES	Scale 1:5	Sheet 1 of 1

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

Timber Blockout for 6x8 Wood Post



Elevation View

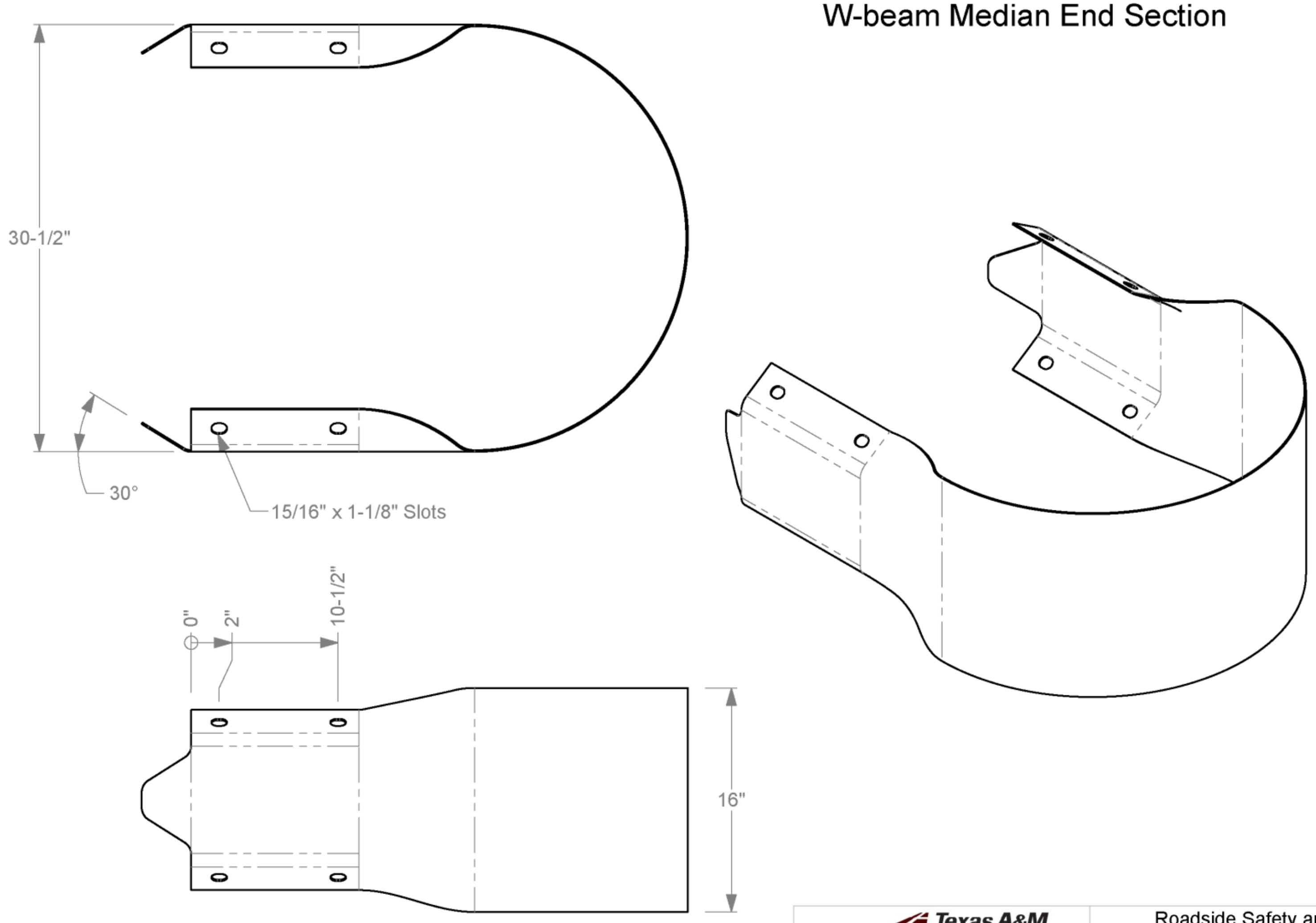
Section A-A

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
W-beam Blockout, for Wood Post		2020-02-24
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 6x8 Wood Post

W-beam Median End Section



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
W-beam End Section (Buffer)		2020-02-24
Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-beam Median End Section

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

林裕工業股份有限公司
LIN YU ENTERPRISE CO., LTD.
TEL : 886-7-6331696

469900

2014-11-20

TEST REPORT

CUSTOMER:	KANEBRIDGE CORPORATION
DESCRIPTION:	GRADE 5 HEX COUPLING NUT
ORDER NO:	332134
PI NO:	201409231
INVOICE NO:	IN-201411132
LOT NO:	201409231-001
PART NO:	874020NCUP5
HEAT NO:	345035
DIMENSION:	7/8 – 9 x 2-1/2

INSPECTION ITEM	STANDARD	ACTUAL	REMARK
ACROSS FLATS	31.35-31.75	31.40-31.56	
THICKNESS	62.71-64.29	63.43-64.05	
GO GAGE	7/8-9 2B	ACCEPT	
NO GO GAGE	7/8-9 2B	ACCEPT	
APPEARANCE	TRIVALENT (CR3) ZINC	ACCEPT	

JUDGE:	ACCEPT		
Q. C. CHIEF	THOMAS CHEN	INSPECTOR	LEONA CHANG

無放射性污染暨品質證明書
(出廠證明書)
TEST CERTIFICATE

豐興鋼鐵股份有限公司
FENG HSIN STEEL CO., LTD.

OFFICE = 臺中市后里區甲后路702號
702, CHIAHOU ROAD, HOU LI SHIUNG, TAICHUNG HSIEN, TAIWAN, ROC
TEL = (04)25565101
FAX = (04)25566955

客戶名稱 CUSTOMER NAME	路竹新益工廠股份有限公司 88342707	證明書編號 CERTIFICATE NO.	23680857-001
		交運日期 SHIPPING DATE	2014/06/23 ~ 2014/07/11
規格名稱 SPEC.	JIS G3507 SWRCH10A CN	產品名稱 PRODUCT	HOT ROLLED ROUND BAR IN COIL 熱軋捲狀棒鋼
		證明書列印日期 CERTIFICATE DATE	2014/07/15

直徑 DIA. (mm)	長度 LEN. (m)	數量 QTY (bdl.)	重量 WEIGHT (kg)	爐號 HEAT NO	拉力試驗 TENSILE 降伏YP /mm²	抗拉TS /mm²	伸長率 EL(%)	C ×100 8–13	Si ×100 10 MAX	Mn ×100 30–60	P ×1000 30 MAX	S ×1000 35 MAX	Ni ×100 20 MAX	Cr ×100 20 MAX	Mo ×100	CU ×100 30 MAX	Al ×1000 20 MIN	B ×10000	秤量單編號 SHIPPING NO.
18		1	1949	344807				10	4	34	9	4	4	4		6	32		2D3627012
18		2	3892	344807				10	4	34	9	4	4	4		6	32		2D3627014
18		4	7808	344807				10	4	34	9	4	4	4		6	32		2D3629004
18		8	15613	344807				10	4	34	9	4	4	4		6	[illegible]		2D3626081
18		13	25343	344807				10	4	34	9	4	4	4		6	[illegible]		2D3626051
18		16	31154	344807				10	4	34	9	4	4	4		6	[illegible]		2D3626040
19		2	3921	344805				9	4	33	10	6	3	3		4	[illegible]		2D3701004
20		10	19586	344805	[illegible]	[illegible]		9	4	33	10	6	3	3		4	[illegible]		2D3701006
22		8	15644	344806				9	3	35	14	8	3	4		5	[illegible]		2D3702022
25		1	1957	344653				9	4	33	8	4	3	6		5	[illegible]		2D3703033
25		1	1950	344806				9	3	35	14	8	3	4		5	[illegible]		2D3703033
25		3	5821	344899S				8	4	32	9	5	3	4		5	[illegible]		2D3703033
28		3	5870	344653				9	4	33	8	4	3	6		5	[illegible]		2D3709025
32		6	11742	345035				10	4	34	8	5	4	5		4	[illegible]		2D3708107
34		4	7832	345035	[illegible]	[illegible]	[illegible]	10	4	34	8	5	4	5		4	[illegible]		2D3709107
34		10	19599	345035				10	4	34	8	5	4	5		4	[illegible]		2D3709120
36		10	19428	345033				9	5	32	9	5	5	6		4	[illegible]		2D3711037
38		2	3882	345033S				9	5	32	9	5	5	6		4	[illegible]		2D3711037

TOTAL: 104 BUNDLES 202, 991 kgs.

REMARK:

※茲證明本表所列產品,均依材料規格製造及試驗並符合規格之要求
WE HEREBY CERTIFY THAT THE MATERIAL DESCRIBED HEREIN HAS MANUFACTURED AND TESTED WITH SATISFATORY RESULTS IN ACCORDANCE WITH THE REQUIREMENT OF THE ABOVE MATERIAL SPECIFICATION.

冶金研發處處長
MANAGER
METALLURGICAL R&D DEP.

郭志毅

CMC

CMC STEEL TENNESSEE
1919 Tennessee Avenue
Knoxville TN 37921-2686

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

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

Jim Hall

Jim Hall
Quality Assurance Manager

HEAT NO.:7007262 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-18e1 Gr 420/60 ROLL DATE: MELT DATE: 01/26/2020 Cert. No.: 83013877 / 007262L130	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 83013877 BOL#: 73462873 CUST PO#: 843459 CUST P/N: DLVRY LBS / HEAT: 2004.000 LB DLVRY PCS / HEAT: 150 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.29%	Rebar Deformation Avg. Spaci	0.330IN		
Mn	0.56%	Rebar Deformation Avg. Heigh	0.039IN		
P	0.010%	Rebar Deformation Max. Gap	0.113IN		
S	0.049%				
Si	0.17%				
Cu	0.31%				
Cr	0.14%				
Ni	0.09%				
Mo	0.011%				
V	0.003%				
Sn	0.009%				
Yield Strength test 1	90.1ksi				
Yield Strength test 1 (metri	621MPa				
Tensile Strength test 1	105.4ksi				
Tensile Strength 1 (metric)	727MPa				
Elongation test 1	12%				
Elongation Gage Lgth test 1	8IN				
Elongation Gage Lgth 1(metri	200mm				
Bend Test 1	Passed				

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

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

EMARKS :

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

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3094733 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-18e1 Gr 420/60 ROLL DATE: 02/17/2020 MELT DATE: 02/08/2020 Cert. No.: 83013837 / 094733A371	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 83013837 BOL#: 73462793 CUST PO#: 843463 CUST P/N: DLVRY LBS / HEAT: 17520.000 LB DLVRY PCS / HEAT: 840 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.42%	Bend Test Diameter	2.188IN		
Mn	0.86%				
P	0.013%				
S	0.043%				
Si	0.20%				
Cu	0.28%				
Cr	0.17%				
Ni	0.22%				
Mo	0.072%				
V	0.000%				
Cb	0.001%				
Sn	0.010%				
Al	0.000%				
Yield Strength test 1	64.4ksi				
Tensile Strength test 1	100.6ksi				
Elongation test 1	15%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.56				
Bend Test 1	Passed				

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

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

REMARKS :

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

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3093398 SECTION: REBAR 19MM (#6) 20'0" 420/60 GRADE: ASTM A615-18e1 Gr 420/60 ROLL DATE: 12/15/2019 MELT DATE: 12/15/2019 Cert. No.: 83008747 / 093398A619	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 83008747 BOL#: 73455293 CUST PO#: 843000 CUST P/N: DLVRY LBS / HEAT: 2163.000 LB DLVRY PCS / HEAT: 72 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.44%	Bend Test Diameter	3.750IN		
Mn	0.83%				
P	0.010%				
S	0.047%				
Si	0.21%				
Cu	0.36%				
Cr	0.11%				
Ni	0.24%				
Mo	0.082%				
V	0.000%				
Cb	0.001%				
Sn	0.017%				
Al	0.000%				
Yield Strength test 1	66.7ksi				
Tensile Strength test 1	106.8ksi				
Elongation test 1	15%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.60				
Bend Test 1	Passed				

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

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

REMARKS :

PERFILES COMERCIALES SIGOSA S.A. DE . C.V.

SIGOSA

Certificado de Calidad de Pruebas Físicas y Químicas
(Mill Test Report)

Información del Cliente / Client Information : | **Orden / Order:62810** | **Certificado / Certificate: B67048**

METALS 2 GO

0000B67048

Fecha / Date:03/04/2020 18:19 PM
Fecha Impresión / Print Date:03/04/2020 18:19 PM

#	SERIE SERIAL	PRODUCTO PRODUCT	COLADA HEAT	GRADO GRADE	*LE *YS	*UT *TS	PE %EL	LE/UT (YS/TS)	C	Mn	Si	P	S	Cu	Cr	Ni	Mo	Sn	V	Nb	Al	CEQ
1	1201811011050	SOL 2 x 1/4 20ft	000000182776	A36/A529-50	54200	71400	30	0.76	.192	.883	.22	.018	.025	.326	.115	.107	.024	.015	.001	.002	.003	.433
2	1201908202019	SOL 2 1/2 x 1/4 20ft	000000192173	A36/A529G50	54940	76300	32	0.72	.18	.882	.2	.012	.027	.345	.107	.09	.023	.013	.001	.004	.002	.416
3	1201908201057	SOL 2 1/2 x 1/4 20ft	000000192171	A36/A529G50	56100	76500	33	0.73	.174	.857	.182	.011	.028	.331	.08	.083	.021	.014	.001	.004	.002	.395
4	1202001161008	ANG 1 1/2 x 1/8 20ft	000000192890	A36/A529-50	53200	75100	30	0.71	.18	.894	.185	.008	.024	.237	.068	.1	.023	.008	.001	.003	.003	.401
5	1201911071019	SOL 2 x 1/4 20ft	000000192909	A36	51300	73600	34	0.7	.182	.894	.184	.012	.021	.294	.078	.115	.025	.011	.001	.003	.001	.41
6	1202001181048	ANG 1 1/2 x 1/8 20ft	000000193346	A36/A529-50	52600	77100	30	0.68	.187	.904	.201	.013	.028	.36	.137	.109	.046	.019	.001	.005	.001	.439
7	1202001173003	ANG 1 1/2 x 1/8 20ft	000000193343	A36/A529-50	53200	75000	30	0.71	.187	.882	.203	.012	.027	.338	.13	.102	.03	.013	.001	.005	.002	.429
8	2202002263008	SOL 4 x 1/4 20ft	000000200324	A36/A529-50	56300	79200	32	0.71	.18	.885	.183	.014	.018	.367	.124	.149	.029	.013	.005	.017	.002	.424
9	2202002271059	SOL 4 x 1/4 20ft	000000200489	A36	56900	78600	32	0.72	.185	.876	.205	.012	.022	.528	.1	.13	.03	.017	.001	.001	.002	.435

*Las unidades expresadas en L.E. y U.T son en PSI. La composición química esta expresada en % en peso.
*The units expressed in L.E and U.T are in PSI. The chemical composition is expressed in % in weight.

Certificamos que el producto aquí descrito, cumple y ha sido fabricado, muestreado, probado e inspeccionado de acuerdo con los requisitos aplicables de la especificación:
2013: ASME SA36;ASME SA-6/SA-6M;A36;
2014: ASTM A6/ A6 M-13;A529 / A529M; ASTM A370 – 12a

We certify that the product above mentioned accomplishes and has been manufactured, sampled, tested and inspected in accordance with applicable requirements of specifications:
ASTM A6/ A6 M-13 a (2014); A36; A529 / A529M;
ASME SA-6/SA-6M; ASTM A370 – 12a (2014); ASME SA36.

Gerente de Aseguramiento de Calidad

En SIGOSA, SA DE CV nos comprometemos a satisfacer las expectativas y requerimientos de nuestros clientes, Mediante un sistema de Gestión de Calidad, la mejora continua de nuestros productos, el uso eficiente de los recursos, y la participación individual y de equipo de todo su personal.

FOR-CAL-CAL-001 REV. 4 OCTUBRE 2014.

415900

SSAB

13609 Industrial Road, Houston, TX 77015, US

Test Certificate

WARNING: This product can expose you to chemicals including nickel and nickel compounds, which are known to the State of California to cause cancer. For more information go to www.P65Warnings.ca.gov.

Form TC1: Revision 4: Date 6 Feb 2019

Customer P.O.No.:V18608-52893 | Mill Order No. 41-585708-01 | Shipping Manifest: HT126646

Product Description: ASTM A572-50/M345(18)/A709-50/M345(18)
CSA G40.21(2013) 50W/350W

Ship Date: 26 Nov 19
Cert Date: 26 Nov19

Cert No: 031223527
(Page 1 of 1)

Size: 0.250 X 96.00 X 480.0 (IN)

Heat Id	Piece Id	Piece Dimensions	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1 2 3 Avg	% Shear 1 2 3 Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp %Shr
E9I064	0307	0.250 (T.L.C)	L	56	77		35	T							
			C	57	77		36	T							
E9I064	0308	0.250 (T.L.C)	L	56	78		35	T							
			C	56	78		36	T							

Chemical Analysis

Heat Id	C	Mn	P	S	Si	Tot Al	Sol Al	Cu	Ni	Cr	Mo	Cb	V	Ti	N	ORGN
E9I064	.17	.95	.011	<.001	.19	.028	.026	.35	.16	.12	.04	.004	.022	.008	.0058	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
KILLED STEEL, PRODUCED TO A FINE GRAIN PRACTICE
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA
MATERIAL MARKED BELOW WITH AN ASTERISK IS PRODUCED FROM COIL
PRODUCTS SHIPPED:
* E9I064 0311 PCES: 3, LBS: 9801

(P) Cust Part #: 025096480A572-50

WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION

Justin Ward
SENIOR METALLURGIST - PRODUCT

469900

Atlas

A DIVISION OF ZEKELM...

80778500
08.21.2017
2358

MATERIAL TEST REP...

Material: 3.500x216x21'0"0(24x1).

Material No: [illegible]

Sales order: 1207875

Purchase Order: 67103-S

... in: USA
... in: USA

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	...	Ti	B	N
17048101	0.210	0.730	0.007	0.005	0.020	0.035	0.110	0.000	[illegible]	0.000	0.000	0.007

Bundle No	PCs	Yield	Tensile		Eln.2in
41658047	24	000000 Psi	Psi	%	

ASTM A500-...

CE: 0.36

Material Note:
Sales Or.Note:

Material: 3.500x216x21'0"0(24x1).

Material No: R03500216210...

Sales order: 1207875

Purchase Order: 67103-S-

... in: USA
... in: USA

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	...	Ti	B	N
17048101	0.210	0.730	0.007	0.005	0.020	0.035	0.110	0.000	[illegible]	0.000	0.000	0.007

Bundle No	PCs	Yield	Tensile		Eln.2in
41658048	24	000000 Psi	Psi	%	

ASTM A500-...

CE: 0.36

Material Note:
Sales Or.Note:

469900

Authorized by Quality Assurance: Jason Richard

The results reported on this report represent the actual attributes of the material furni... with ... applicable specification and contract requirements.
C... ...lated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 4 Of 4

EXLTUBE

1000 BURLINGTON STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

Customer: Metals 2 Go 224 North Hewitt Drive Hewitt TX 76643-3044	Size: 04.00X04.00 Gauge: 11	Customer Order No: 43043	Customer Part No
	Date: 04/24/2020	Delivery No: 83577178 Load No: 4297407	Length: 20 FT
	Specification: ASTM A500-13 Gr.B/C		

Heat No	Yield KSI	Tensile KSI	Elongation % 2 Inch
88854C	54.7	73.8	29.50

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
88854C	0.2100	0.7600	0.0140	0.0090	0.0100	0.0500	0.0200	0.0500	0.0100	0.0050

This material was melted & manufactured in the U.S.A. This material meets the Buy America requirement of 23 CFR 635.410.
Coil Producing Mill: UNITED STATES STEEL, Granite City, IL

We hereby certify that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above. This product was manufactured in accordance with your purchase order requirements.

This material has not come into direct contact with mercury, any of its compounds, or any mercury bearing devices during our manufacturing process, testing, or inspections.

This material is in compliance with EN 10204 Section 4.1 Inspection Certificatè Type 3.1

Tensile test completed using test specimen with 3/4" reduced area.

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe

Jonathan Wolfe
Quality Assurance Manager

465500

PERFILES COMERCIALES SIGOSA S.A. DE . C.V.

SIGOSA

Certificado de Calidad de Pruebas Físicas y Químicas
(Mill Test Report)

Información del Cliente / Client Information : | **Orden / Order:62810** | **Certificado / Certificate: B67048**

METALS 2 GO

* 0 0 0 0 B 6 7 0 4 8 *

Fecha / Date:03/04/2020 18:19 PM
Fecha Impresión / Print Date:03/04/2020 18:19 PM

#	SERIE SERIAL	PRODUCTO PRODUCT	COLADA HEAT	GRADO GRADE	*LE *YS	*UT *TS	PE %EL	LE/UT (YS/TS)	C	Mn	Si	P	S	Cu	Cr	Ni	Mo	Sn	V	Nb	Al	CEQ
1	1201811011050	SOL 2 x 1/4 20ft	000000182776	A36/A529-50	54200	71400	30	0.76	.192	.883	.22	.018	.025	.326	.115	.107	.024	.015	.001	.002	.003	.433
2	1201908202019	SOL 2 1/2 x 1/4 20ft	000000192173	A36/A529G50	54940	76300	32	0.72	.18	.882	.2	.012	.027	.345	.107	.09	.023	.013	.001	.004	.002	.416
3	1201908201057	SOL 2 1/2 x 1/4 20ft	000000192171	A36/A529G50	56100	76500	33	0.73	.174	.857	.182	.011	.028	.331	.08	.083	.021	.014	.001	.004	.002	.395
4	1202001161008	ANG 1 1/2 x 1/8 20ft	000000192890	A36/A529-50	53200	75100	30	0.71	.18	.894	.185	.008	.024	.237	.068	.1	.023	.008	.001	.003	.003	.401
5	1201911071019	SOL 2 x 1/4 20ft	000000192909	A36	51300	73600	34	0.7	.182	.894	.184	.012	.021	.294	.078	.115	.025	.011	.001	.003	.001	.41
6	1202001181048	ANG 1 1/2 x 1/8 20ft	000000193346	A36/A529-50	52600	77100	30	0.68	.187	.904	.201	.013	.028	.36	.137	.109	.046	.019	.001	.005	.001	.439
7	1202001173003	ANG 1 1/2 x 1/8 20ft	000000193343	A36/A529-50	53200	75000	30	0.71	.187	.882	.203	.012	.027	.338	.13	.102	.03	.013	.001	.005	.002	.429
8	2202002263008	SOL 4 x 1/4 20ft	000000200324	A36/A529-50	56300	79200	32	0.71	.18	.885	.183	.014	.018	.367	.124	.149	.029	.013	.005	.017	.002	.424
9	2202002271059	SOL 4 x 1/4 20ft	000000200489	A36	56900	78600	32	0.72	.185	.876	.205	.012	.022	.528	.1	.13	.03	.017	.001	.001	.002	.435

*Las unidades expresadas en L.E. y U.T son en PSI. La composición química esta expresada en % en peso.
*The units expressed in L.E and U.T are in PSI. The chemical composition is expressed in % in weight.

Certificamos que el producto aquí descrito, cumple y ha sido fabricado, muestreado, probado e inspeccionado de acuerdo con los requisitos aplicables de la especificación:
2013: ASME SA36;ASME SA-6/SA-6M;A36;
2014: ASTM A6/ A6 M-13;A529 / A529M; ASTM A370 – 12a

We certify that the product above mentioned accomplishes and has been manufactured, sampled, tested and inspected in accordance with applicable requirements of specifications:
ASTM A6/ A6 M-13 a (2014); A36; A529 / A529M;
ASME SA-6/SA-6M; ASTM A370 – 12a (2014); ASME SA36.

Gerente de Aseguramiento de Calidad

En SIGOSA, SA DE CV nos comprometemos a satisfacer las expectativas y requerimientos de nuestros clientes, Mediante un sistema de Gestión de Calidad, la mejora continua de nuestros productos, el uso eficiente de los recursos, y la participación individual y de equipo de todo su personal.

FOR-CAL-CAL-001 REV. 4 OCTUBRE 2014.

4/9/00

SSAB

13609 Industrial Road, Houston, TX 77015, US

Test Certificate

⚠ **WARNING:** This product can expose you to chemicals including nickel and nickel compounds, which are known to the State of California to cause cancer. For more information go to www.P65Warnings.ca.gov.

Form TC1: Revision 4: Date 6 Feb 2019

Customer P.O.No.: V18608-52893 | **Mill Order No.** 41-585708-01 | **Shipping Manifest:** HT126646

Product Description: ASTM A572-50/M345(18)/A709-50/M345(18)
CSA G40.21(2013) 50W/350W

Ship Date: 26 Nov 19
Cert Date: 26 Nov19

Cert No: 031223527
(Page 1 of 1)

Size: 0.250 X 96.00 X 480.0 (IN)

Heat Id	Piece Id	Piece Dimensions	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in	Elong % 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1 2 3 Avg	% Shear 1 2 3 Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp %Shr
E9I064	0307	0.250 (T.L.C)	L	56	77		35		T							
			C	57	77		36		T							
E9I064	0308	0.250 (T.L.C)	L	56	78		35		T							
			C	56	78		36		T							

Chemical Analysis

Heat Id	C	Mn	P	S	Si	Tot Al	Sol Al	Cu	Ni	Cr	Mo	Cb	V	Ti	N	ORGN
E9I064	.17	.95	.011	<.001	.19	.028	.026	.35	.16	.12	.04	.004	.022	.008	.0058	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
KILLED STEEL, PRODUCED TO A FINE GRAIN PRACTICE
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA
MATERIAL MARKED BELOW WITH AN ASTERISK IS PRODUCED FROM COIL
PRODUCTS SHIPPED:
* E9I064 0311 PCES: 3, LBS: 9801

(P) Cust Part #: 025096480A572-50

WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION

Justin Ward
SENIOR METALLURGIST - PRODUCT

465900

Atlas
A DIVISION OF ZEKELM...

80778500
08.21.2017
2358

MATERIAL TEST REP...

Material: 3.500x216x21'0"0(24x1).
Material No: R0350021821...
Sales order: 1207875
Purchase Order: 67103-S

Heat No	C	Mn	P	S	Si	Al	Cu	Cb		Ti	B	N
17048101	0.210	0.730	0.007	0.005	0.020	0.035	0.110	0.000		0.000	0.000	0.007

Bundle No	PCs	Yield	Tensile	Eln.2in
41658047	24	000000 Psi	Psi	%

ASTM A500-...

CE: 0.36

Material Note:
Sales Or.Note:

Material: 3.500x216x21'0"0(24x1).
Material No: R035002182100
Sales order: 1207875
Purchase Order: 67103-S-

Heat No	C	Mn	P	S	Si	Al	Cu	Cb		Ti	B	N
17048101	0.210	0.730	0.007	0.005	0.020	0.035	0.110	0.000		0.000	0.000	0.007

Bundle No	PCs	Yield	Tensile	Eln.2in
41658048	24	000000 Psi	Psi	%

ASTM A500-...

CE: 0.36

Material Note:
Sales Or.Note:

469900

Authorized by Quality Assurance: Jason Richard
The results reported on this report represent the actual attributes of the material furnished ... with all applicable specification and contract requirements.
Calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 4 Of 4

EXLTUBE

1000 BURLINGTON STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

Customer: Metals 2 Go 224 North Hewitt Drive Hewitt TX 76643-3044	Size: 04.00X04.00 Gauge: 11	Customer Order No: 43043	Customer Part No:
	Date: 04/24/2020	Delivery No: 83577178 Load No: 4297407	Length: 20 FT
	Specification: ASTM A500-13 Gr.B/C		

Heat No	Yield KSI	Tensile KSI	Elongation % 2 Inch
88854C	54.7	73.8	29.50

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
88854C	0.2100	0.7600	0.0140	0.0090	0.0100	0.0500	0.0200	0.0500	0.0100	0.0050

This material was melted & manufactured in the U.S.A. This material meets the Buy America requirement of 23 CFR 635.410.
Coil Producing Mill: UNITED STATES STEEL, Granite City, IL

We hereby certify that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above. This product was manufactured in accordance with your purchase order requirements.

This material has not come into direct contact with mercury, any of its compounds, or any mercury bearing devices during our manufacturing process, testing, or inspections.

This material is in compliance with EN 10204 Section 4.1 Inspection Certificatè Type 3.1

Tensile test completed using test specimen with 3/4" reduced area.

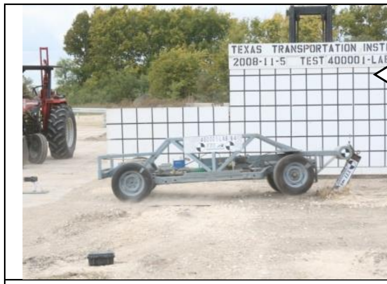
STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe

46600.

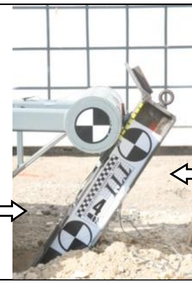
Jonathan Wolfe
Quality Assurance Manager

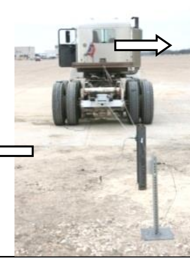
Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.



Dynamic Setup

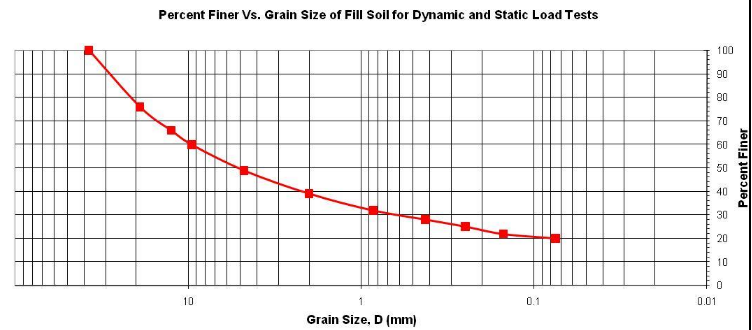
Post-Test Photo of post



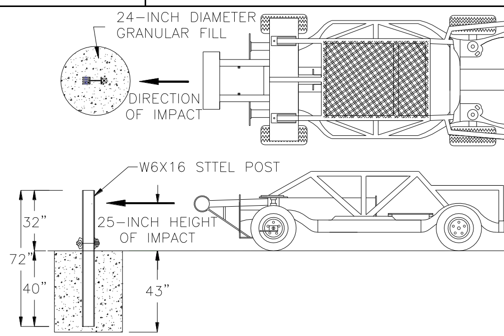


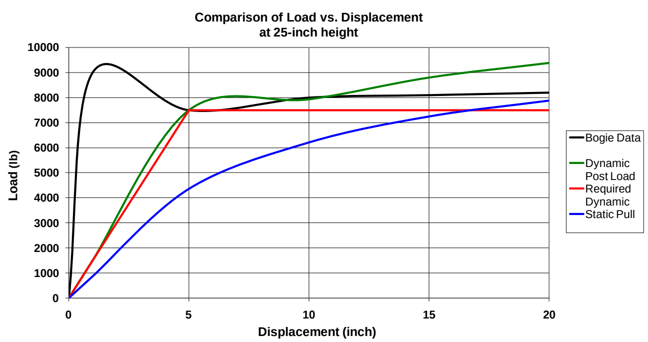
Post-Test Photo

Static Load Test

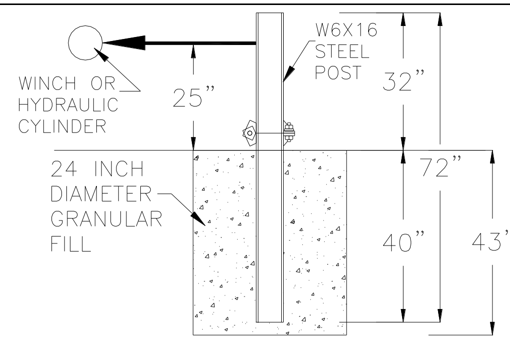


Dynamic Test Installation Details



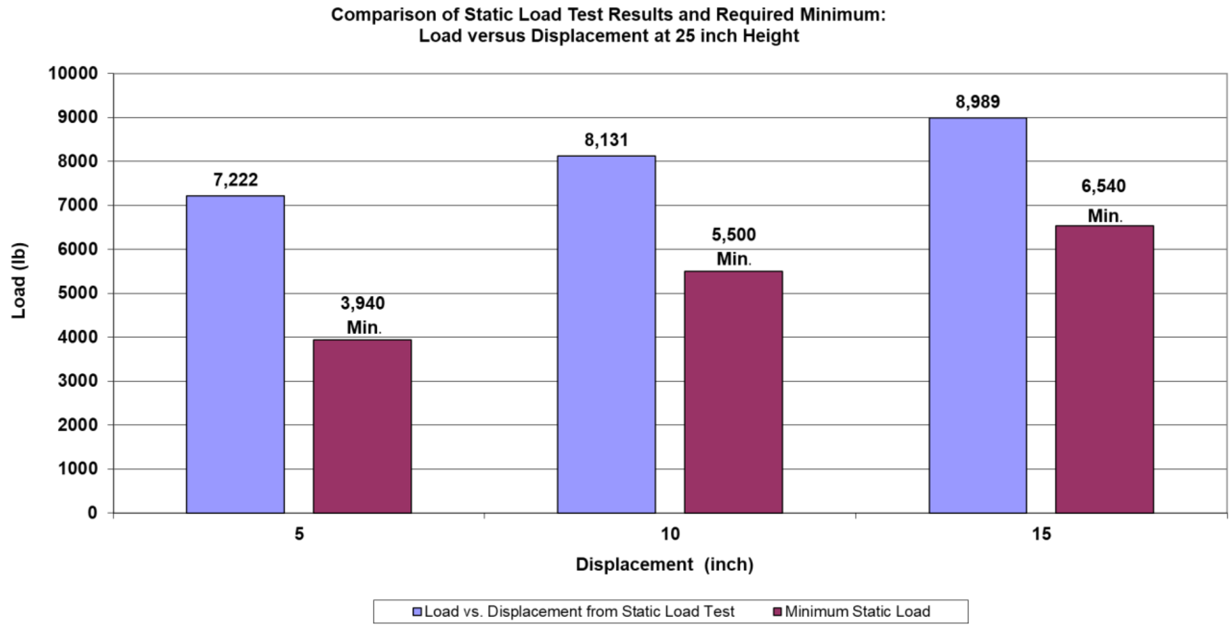


Static Load Test Installation Details



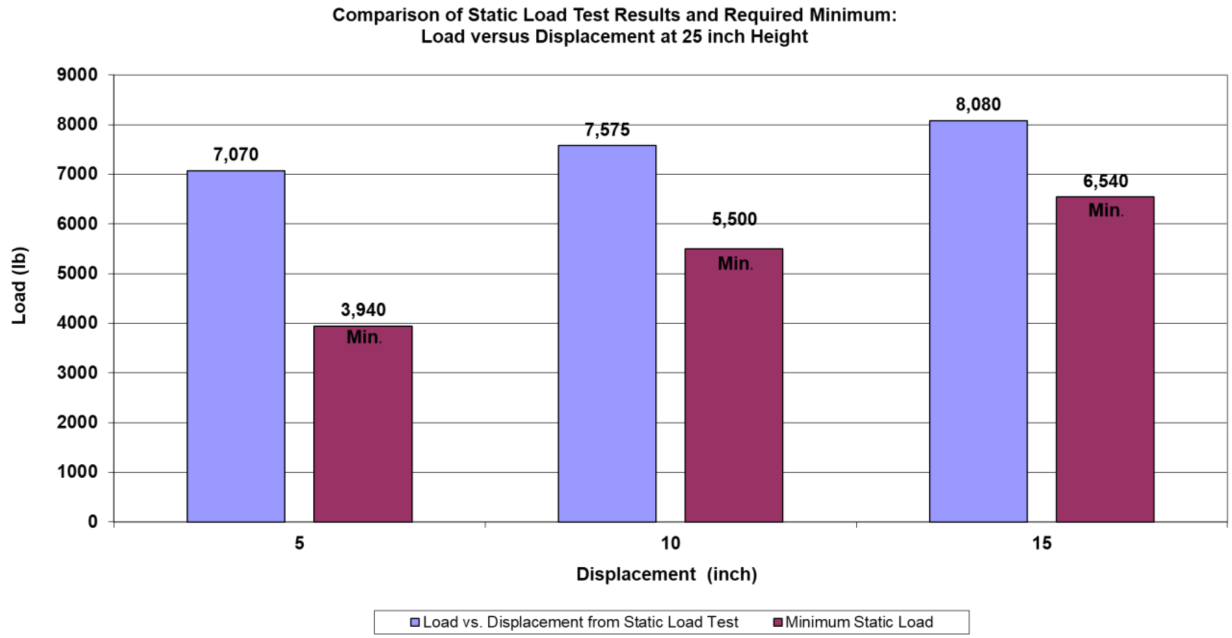
Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor
Bogie Weight	5009 lb
Impact Velocity	20.5 mph

Table C.2. Test Day Static Soil Strength Documentation for Test No. 469900-01-1.



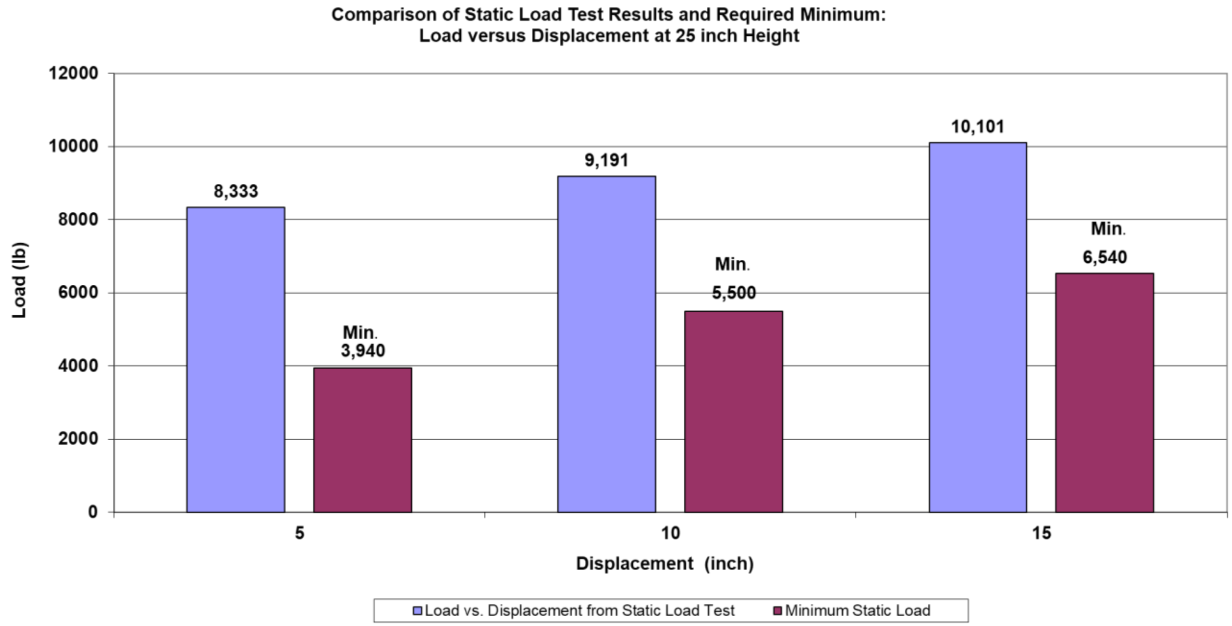
Date...	2020-06-18 for Test No. 469900-01-1
Test Facility and Site Location	TTI Proving Ground—3100 SH 47, Bryan, TX
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis .	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.3. Test Day Static Soil Strength Documentation for Test No. 469900-01-2.



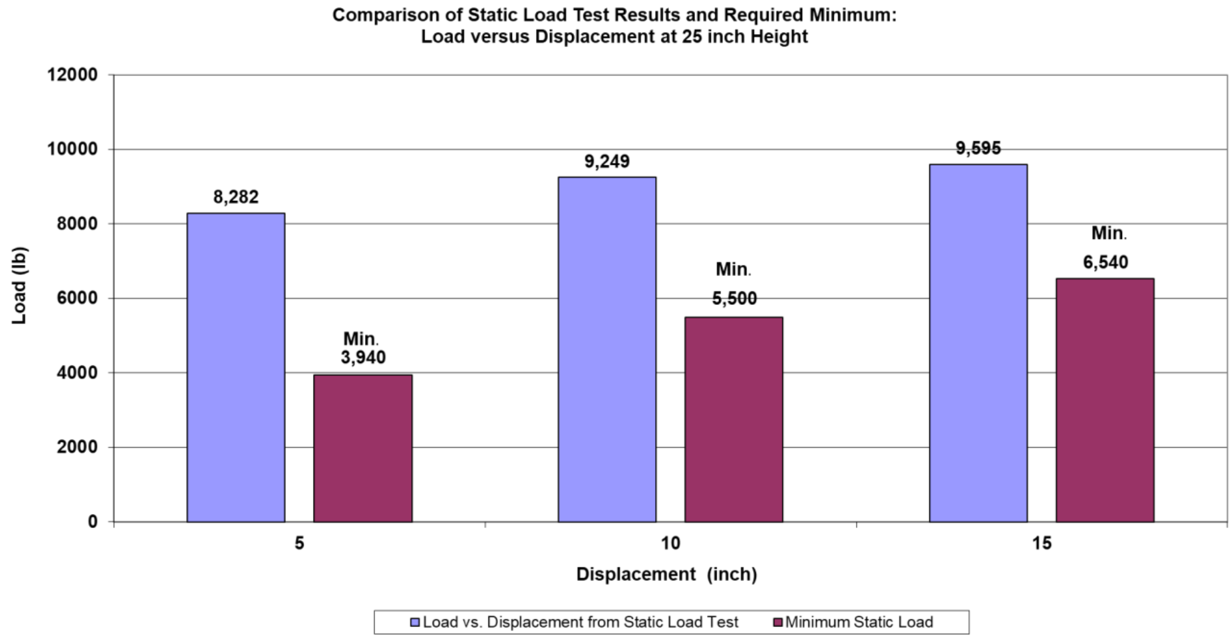
Date	2020-08-13 for Test No. 469900-01-2
Test Facility and Site Location	TTI Proving Ground—3100 SH 47, Bryan, TX
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.4. Test Day Static Soil Strength Documentation for Test No. 469900-01-3.



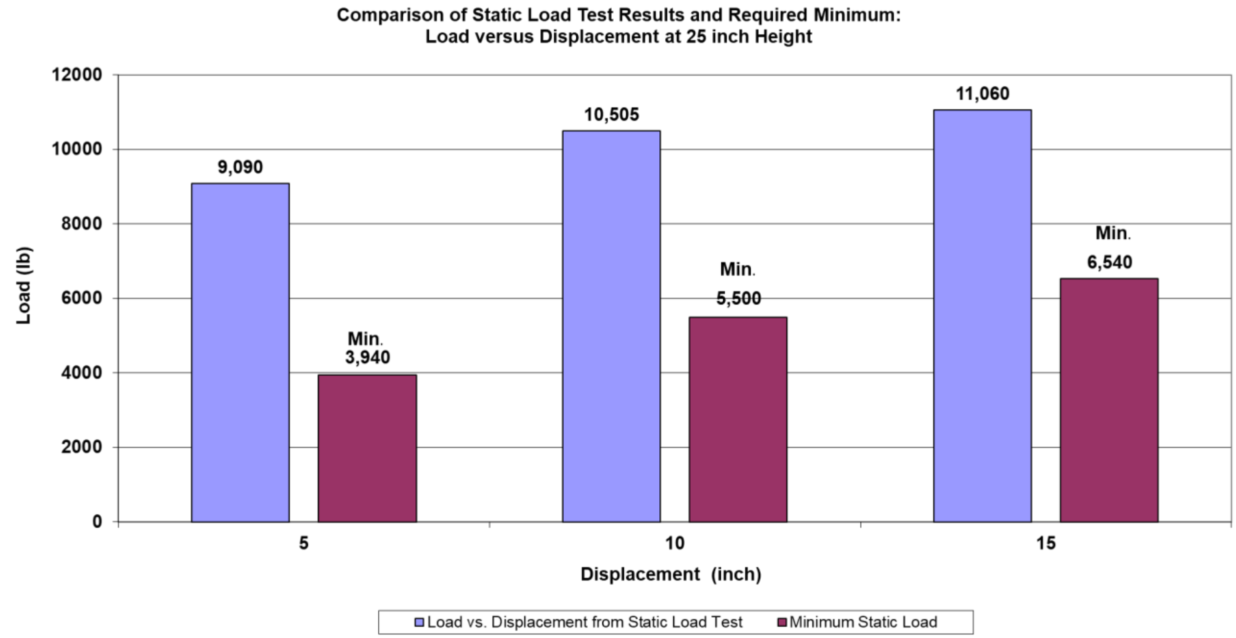
Date	2020-08-25 for Test No. 469900-01-3
Test Facility and Site Location	TTI Proving Ground—3100 SH 47, Bryan, TX
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.5. Test Day Static Soil Strength Documentation for Test No. 469900-01-4.



Date	2020-09-28 for Test No. 469900-01-4
Test Facility and Site Location	TTI Proving Ground—3100 SH 47, Bryan, TX
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.6. Test Day Static Soil Strength Documentation for Test No. 469900-01-5.



Date...	2020-10-05 for Test No. 469900-01-5
Test Facility and Site Location	TTI Proving Ground—3100 SH 47, Bryan, TX
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis .	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

APPENDIX D. *MASH* TEST 3-21 (CRASH TEST NO. 469900-01-1)

D.1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 469900-01-1.

Date: 2020-6-18 Test No.: 469900-01-1 VIN No.: 1C6RR6GT6ES287251

Year: 2014 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 120140

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

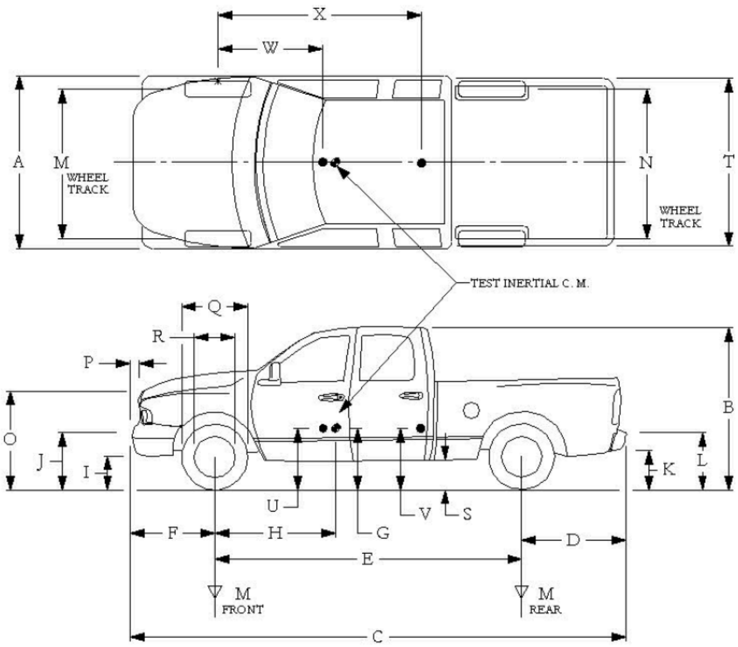
NOTES: None

Engine Type: V-8
Engine CID: 5.7L

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

Optional Equipment:
None

Dummy Data:
Type: 50th Percentile
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	29.50	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.44	M	68.50	R	18.00	W	60.44
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}	2906	2850	2935
Back	3900	M_{rear}	2041	2152	2232
Total	6700	M_{Total}	4947	5002	5167

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

Mass Distribution:
lb LF: 1402 RF: 1448 LR: 1107 RR: 1045

Table D.2. Measurements of Vehicle Vertical Center of Gravity (CG) for Test No. 469900-01-1.

Date: 2020-6-18 Test No.: 469900-01-1 VIN: 1C6RR6GT6ES287251

Year: 2014 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 120140

Engine: 5.7L V-8 Transmission: Automatic

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

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

Measured Vehicle Weights: (lb)							
LF:	1402		RF:	1448		Front Axle:	2850
LR:	1107		RR:	1045		Rear Axle:	2152
Left:	2509		Right:	2493		Total:	5002
							5000 ±110 lb allowed
Wheel Base:	140.50	inches	Track: F:	68.50	inches R:	68.00	inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed			
Center of Gravity, SAE J874 Suspension Method							
X:	60.45	inches	Rear of Front Axle	(63 ±4 inches allowed)			
Y:	-0.11	inches	Left -	Right +	of Vehicle Centerline		
Z:	29.50	inches	Above Ground	(minumum 28.0 inches allowed)			

Hood Height: 46.00 inches Front Bumper Height: 27.00 inches

43 ±4 inches allowed

Front Overhang: 40.00 inches Rear Bumper Height: 30.00 inches

39 ±3 inches allowed

Overall Length: 227.50 inches

237 ±13 inches allowed

Table D.3. Exterior Crush Measurements of Vehicle for Test No. 469900-01-1.

Date: 2020-6-18 Test No.: 469900-01-1 VIN No.: 1C6RR6GT6ES287251

Year: 2014 Make: RAM Model: 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bmp ht	26	16	36	-	-	-	-	-	-	-18
2	Side plane at bmp ht	26	16	60	-	-	-	-	-	-	70
	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.

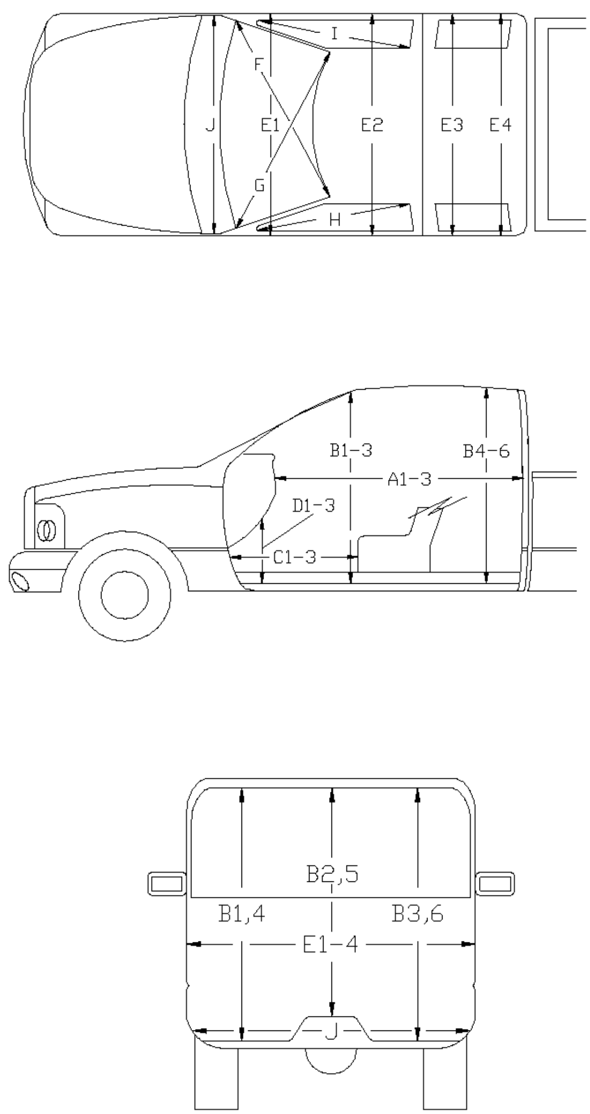
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 of Vehicle for Test No. 469900-01-1.

Date:	2020-6-18	Test No.:	469900-01-1	VIN No.:	1C6RR6GT6ES287251
Year:	2014	Make:	RAM	Model:	1500



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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	19.00	-7.00
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	60.00	1.50
E2	63.50	67.00	3.50
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	18.00	-7.00

D.2 SEQUENTIAL PHOTOGRAPHS


0.000 s



0.100 s

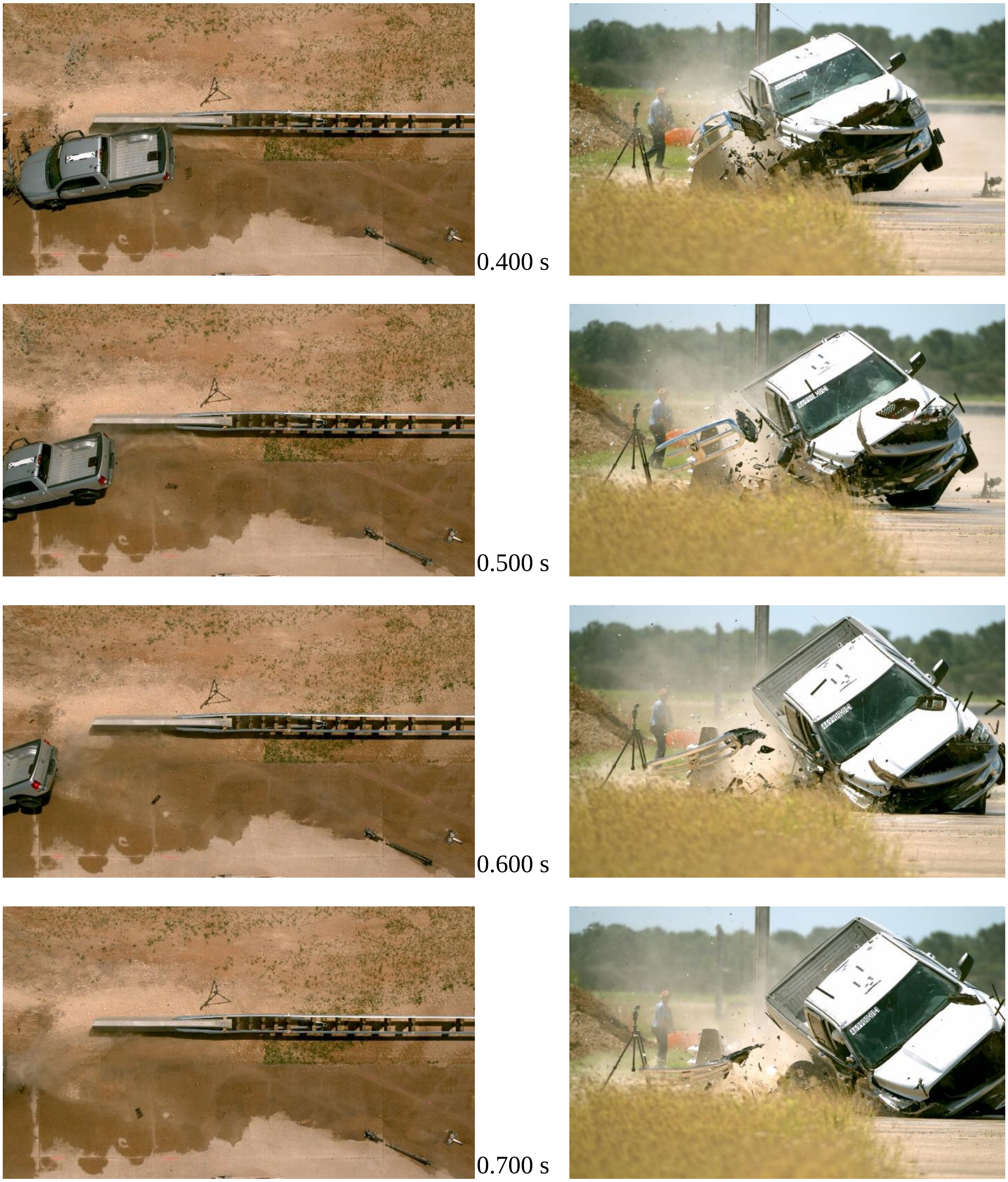


0.200 s



0.300 s


Figure D.1. Sequential Photographs for Test No. 469900-01-1 (Overhead and Frontal Views).



0.400 s

0.500 s

0.600 s

0.700 s

Figure D.1. Sequential Photographs for Test No. 469900-01-1 (Overhead and Frontal Views) (Continued).

0.000 s

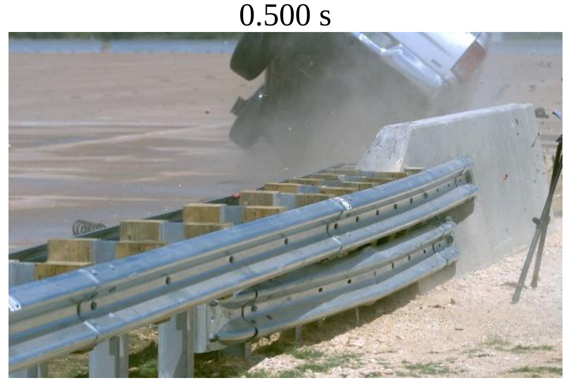
0.100 s

0.200 s

0.300 s

0.400 s

0.500 s



0.600 s

0.700 s

Figure D.2. Sequential Photographs for Test No. 469900-01-1 (Rear View).

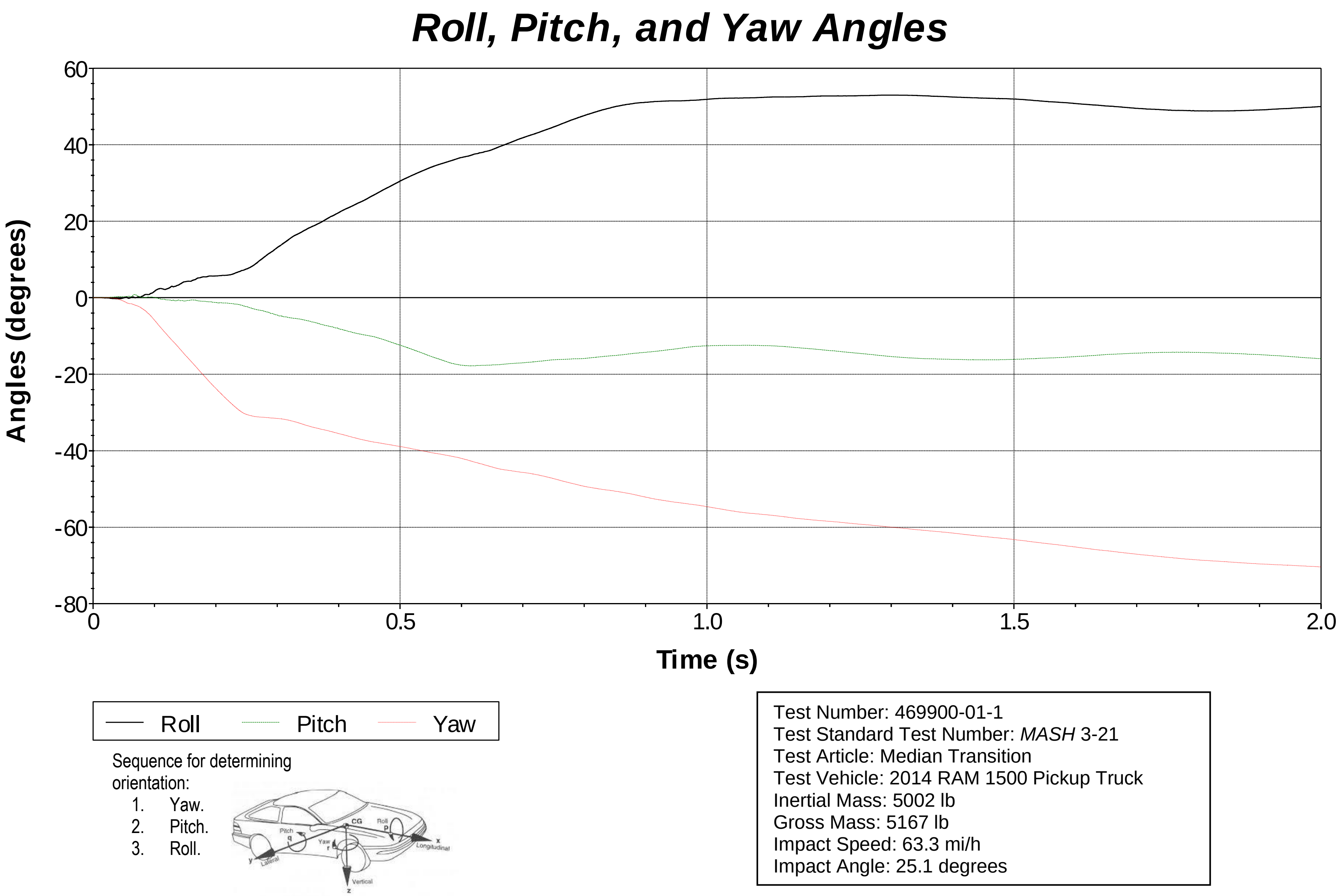


Figure D.3. Vehicle Angular Displacements for Test No. 469900-01-1.

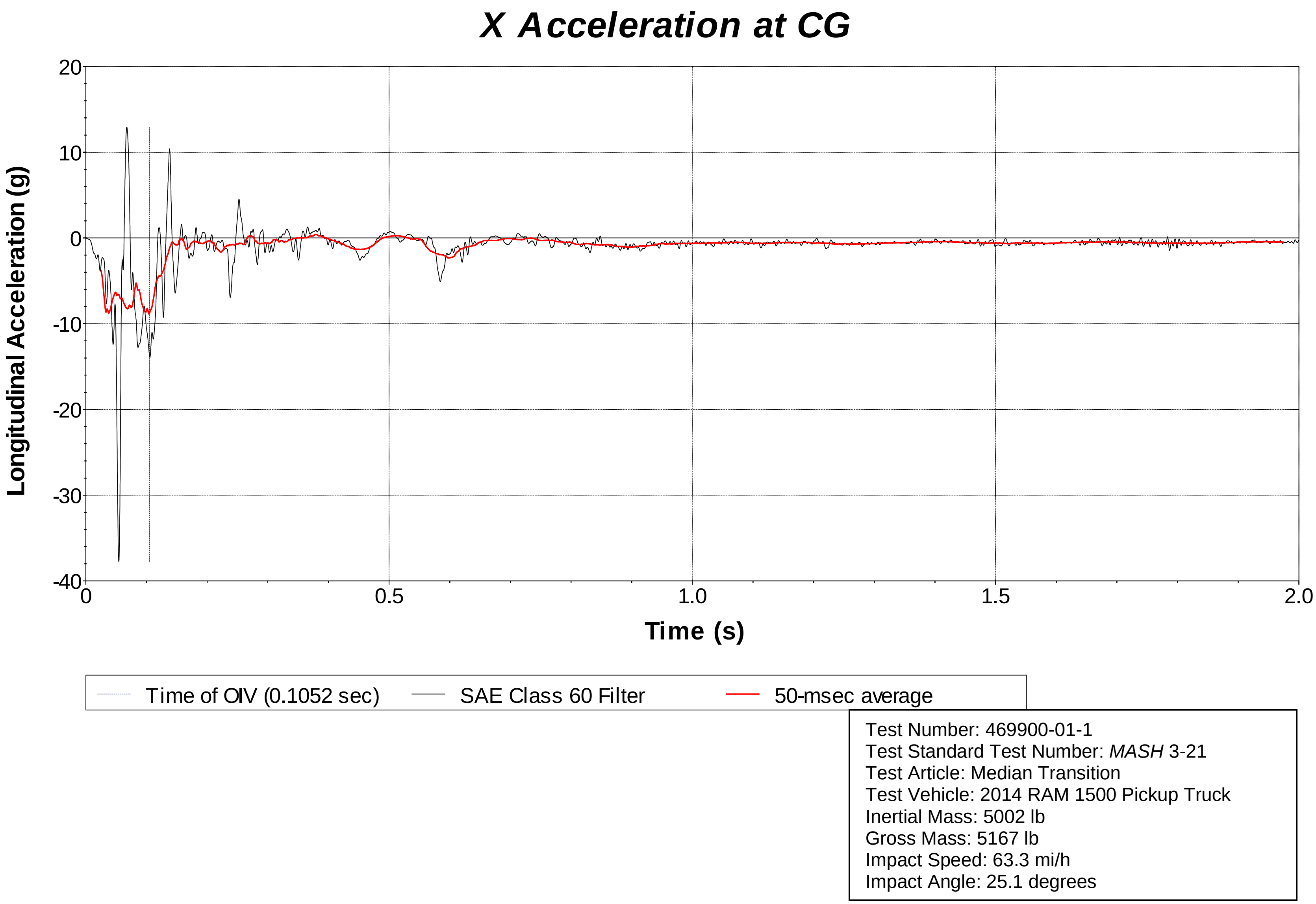


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469900-01-1 (Accelerometer Located at Center of Gravity).

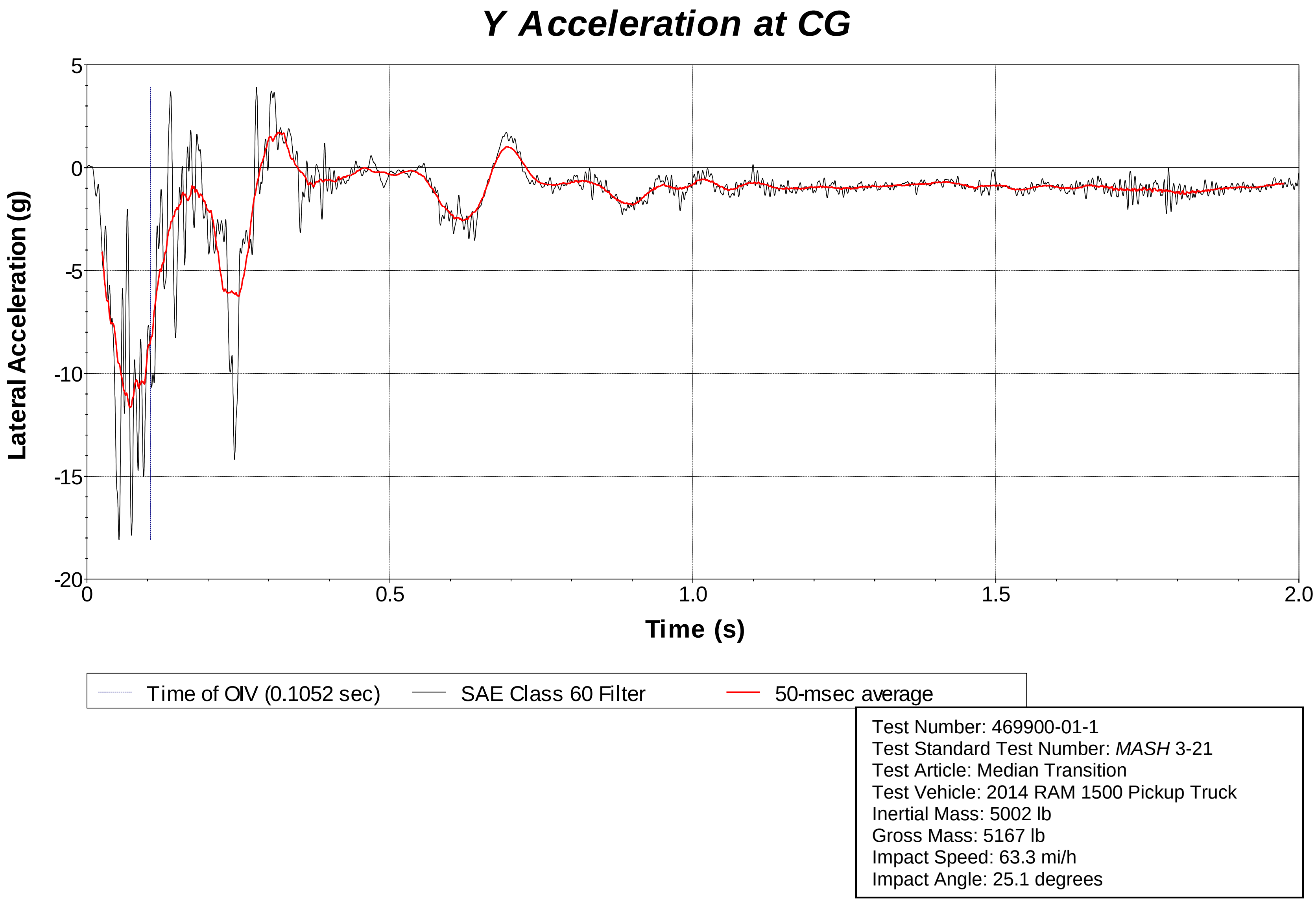


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 469900-01-1 (Accelerometer Located at Center of Gravity).

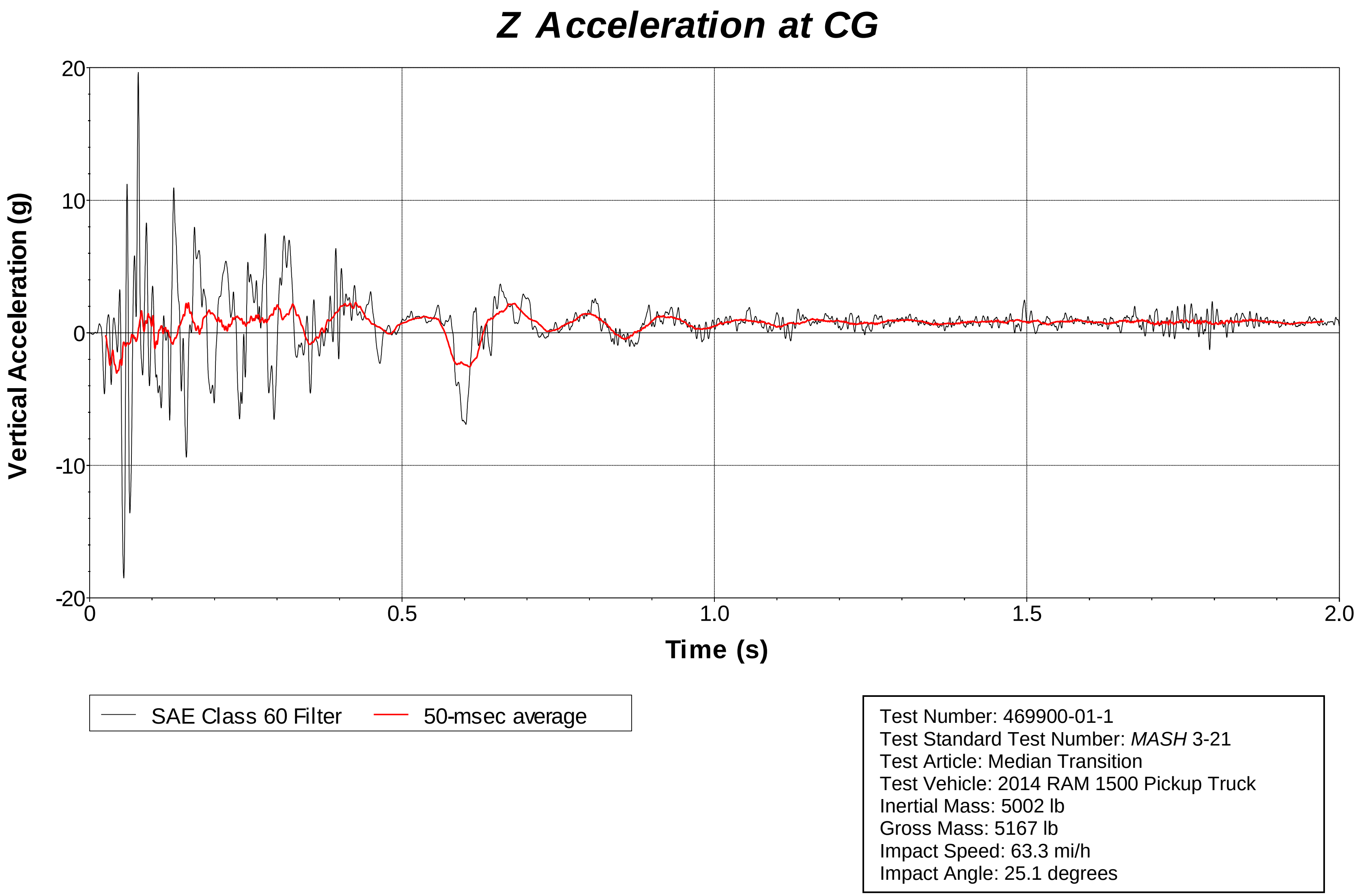


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 469900-01-1 (Accelerometer Located at Center of Gravity).

APPENDIX E. *MASH* TEST 3-21 (CRASH TEST NO. 469900-01-2)

E.1 VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 469900-01-2.

Date: 2020-8-13 Test No.: 469900-1-2 VIN No.: 1C6RR6GT4ES306606

Year: 2014 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 155404

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

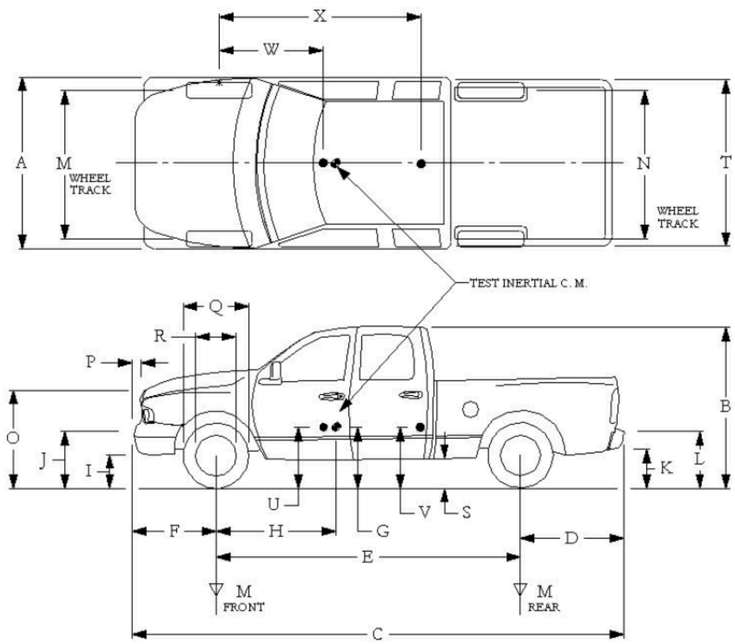
NOTES: None

Engine Type: V-8
Engine CID: 5.7 L

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

Optional Equipment:
None

Dummy Data:
Type: 50th Percentile
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	28.80	L	30.00	Q	30.50	V	30.25
C	227.50	H	59.30	M	68.50	R	18.00	W	59.30
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}	2962	2893	2978
Back	3900	M_{rear}	2127	2115	2195
Total	6700	M_{Total}	5089	5008	5173

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

Mass Distribution:
lb LF: 1449 RF: 1444 LR: 1072 RR: 1043

Table E.2. Measurements of Vehicle Vertical CG for Test No. 469900-01-2.

Date: 2020-8-13 Test No.: 469900-1-2 VIN: 1C6RR6GT4ES306606

Year: 2014 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 155404

Engine: 5.7 L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 60 (440 lb max)

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

Measured Vehicle Weights: (lb)								
LF:	1449		RF:	1444		Front Axle:	2893	
LR:	1072		RR:	1043		Rear Axle:	2115	
Left:	2521		Right:	2487		Total:	5008	
							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:	59.34	inches	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	-0.23	inches	Left -	Right +	of Vehicle Centerline			
Z:	28.80	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 of Vehicle for Test No. 469900-01-2.

Date:	2020-8-13	Test No.:	469900-1-2	VIN No.:	1C6RR6GT4ES306606
Year:	2014	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bmpr ht	18	16	44	-	-	-	-	-	-	18
2	Side plane at bmpr ht	18	15	64	-	-	-	-	-	-	74
	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.

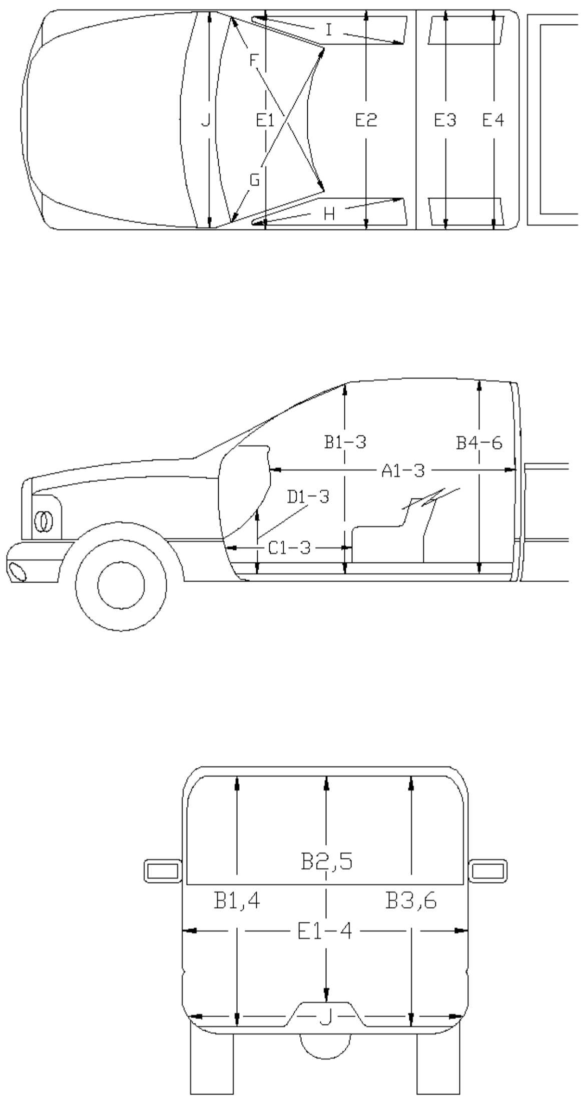
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 of Vehicle for Test No. 469900-01-2.

Date:	2020-8-13	Test No.:	469900-1-2	VIN No.:	1C6RR6GT4ES306606
Year:	2014	Make:	RAM	Model:	



*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	20.50	-5.50
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	12.75	1.25
E1	58.50	61.50	3.00
E2	63.50	68.00	4.50
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	37.00	-0.50
J*	25.00	20.00	-5.00

E.2 SEQUENTIAL PHOTOGRAPHS

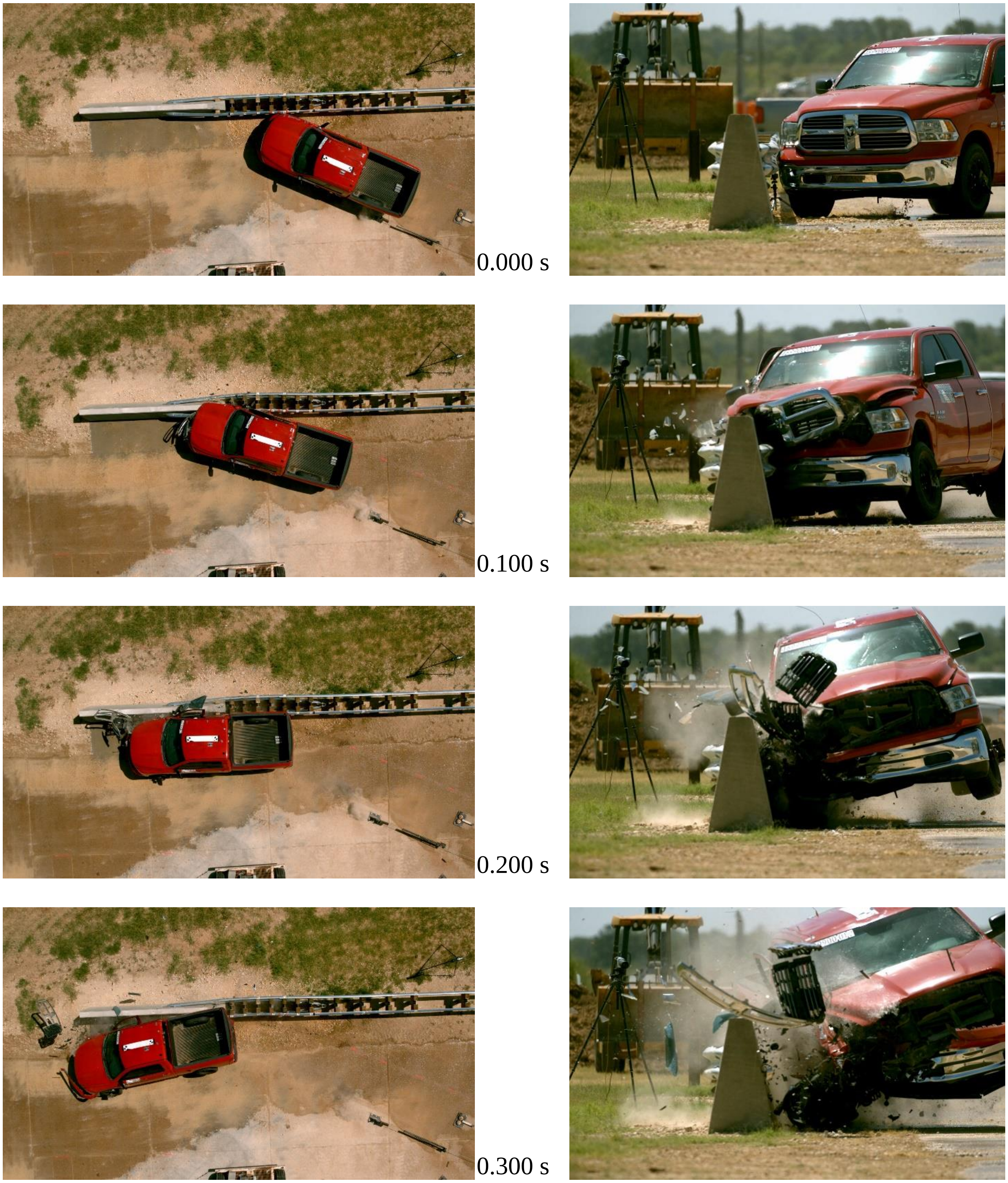


Figure E.1. Sequential Photographs for Test No. 469900-01-2 (Overhead and Frontal Views).

0.400 s

0.500 s

0.600 s

0.700 s

Figure E.1. Sequential Photographs for Test No. 469900-01-2 (Overhead and Frontal Views) (Continued).

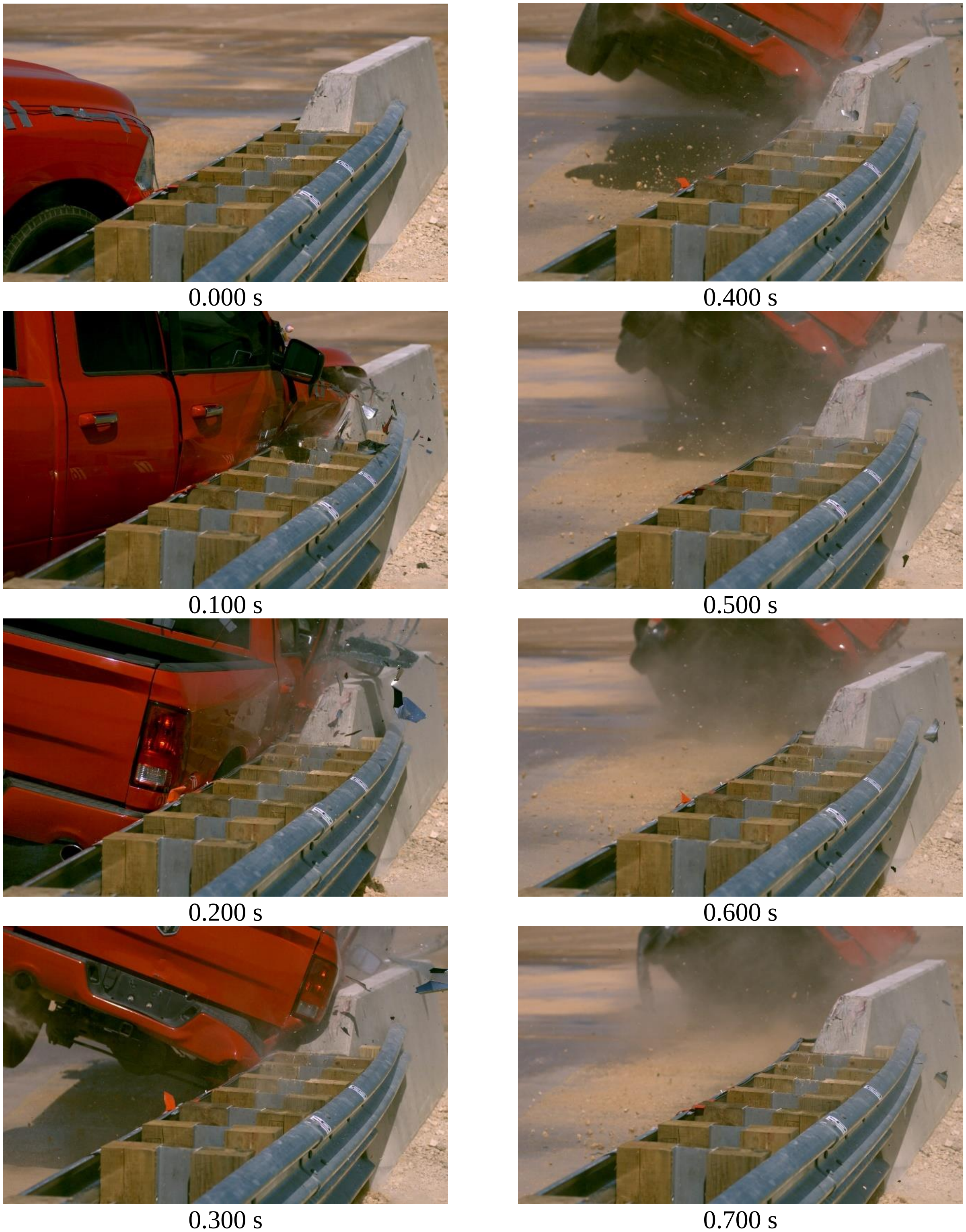
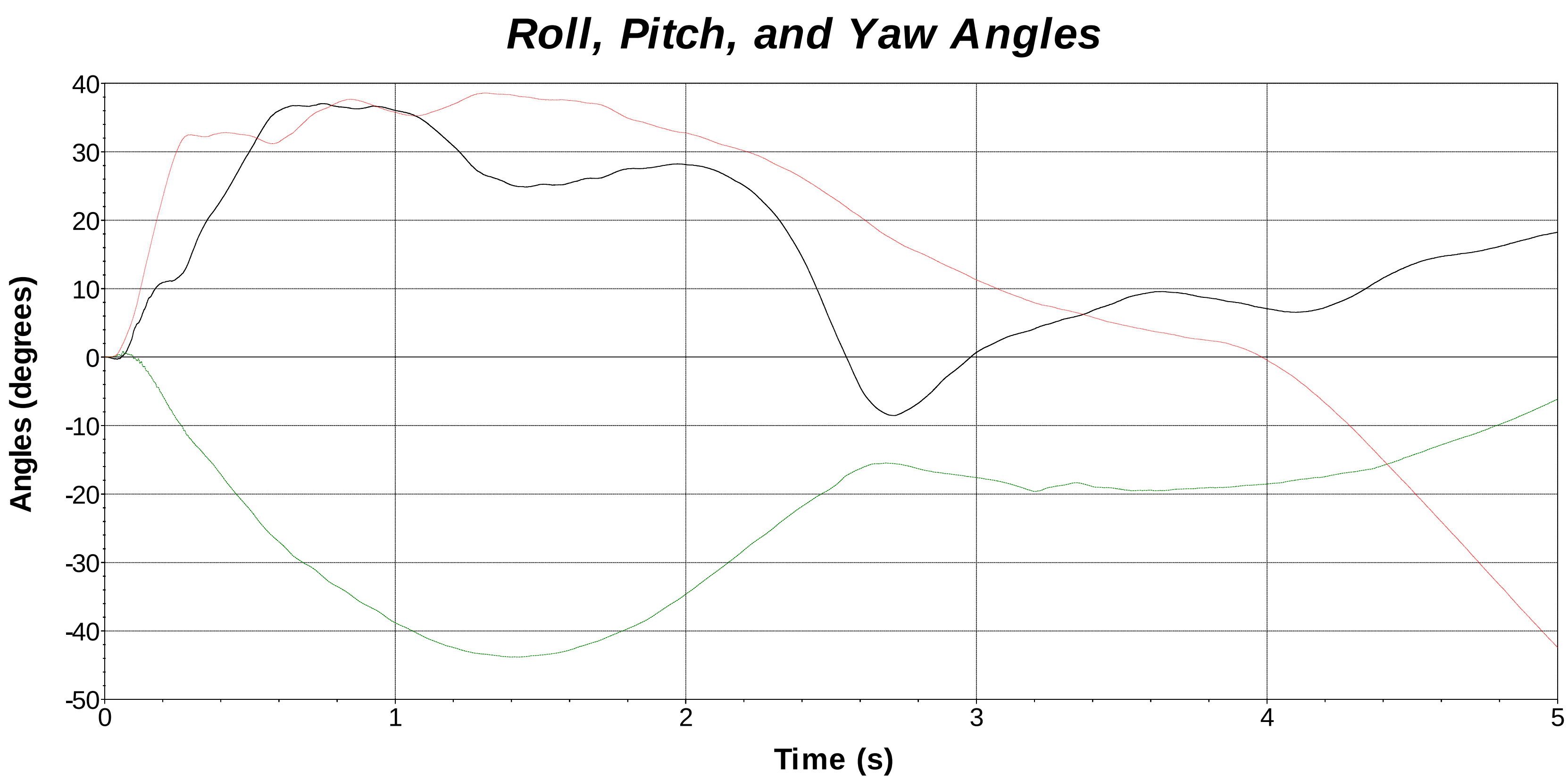
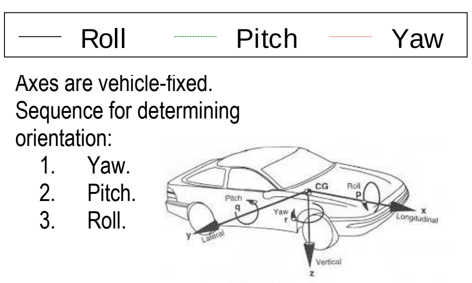


Figure E.2. Sequential Photographs for Test No. 469900-01-2 (Rear View).





Test Number: 469900-01-2
Test Standard Test Number: *MASH* 3-21
Test Article: Modified Median Transition
Test Vehicle: 2014 RAM 1500 Pickup Truck
Inertial Mass: 5008 lb
Gross Mass: 5173 lb
Impact Speed: 61.9 mi/h
Impact Angle: 24.7 degrees

Figure E.3. Vehicle Angular Displacements for Test No. 469900-01-2.

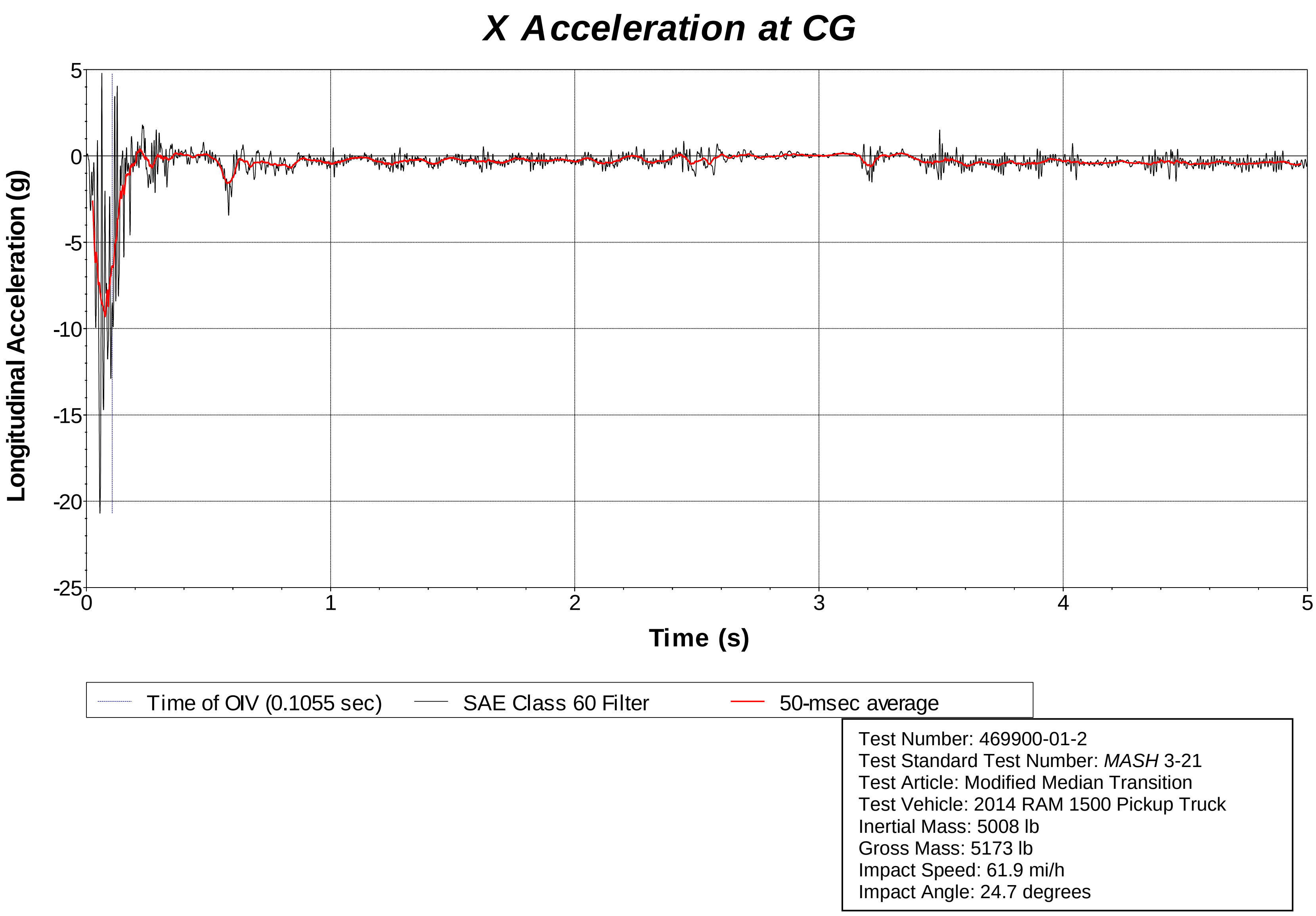
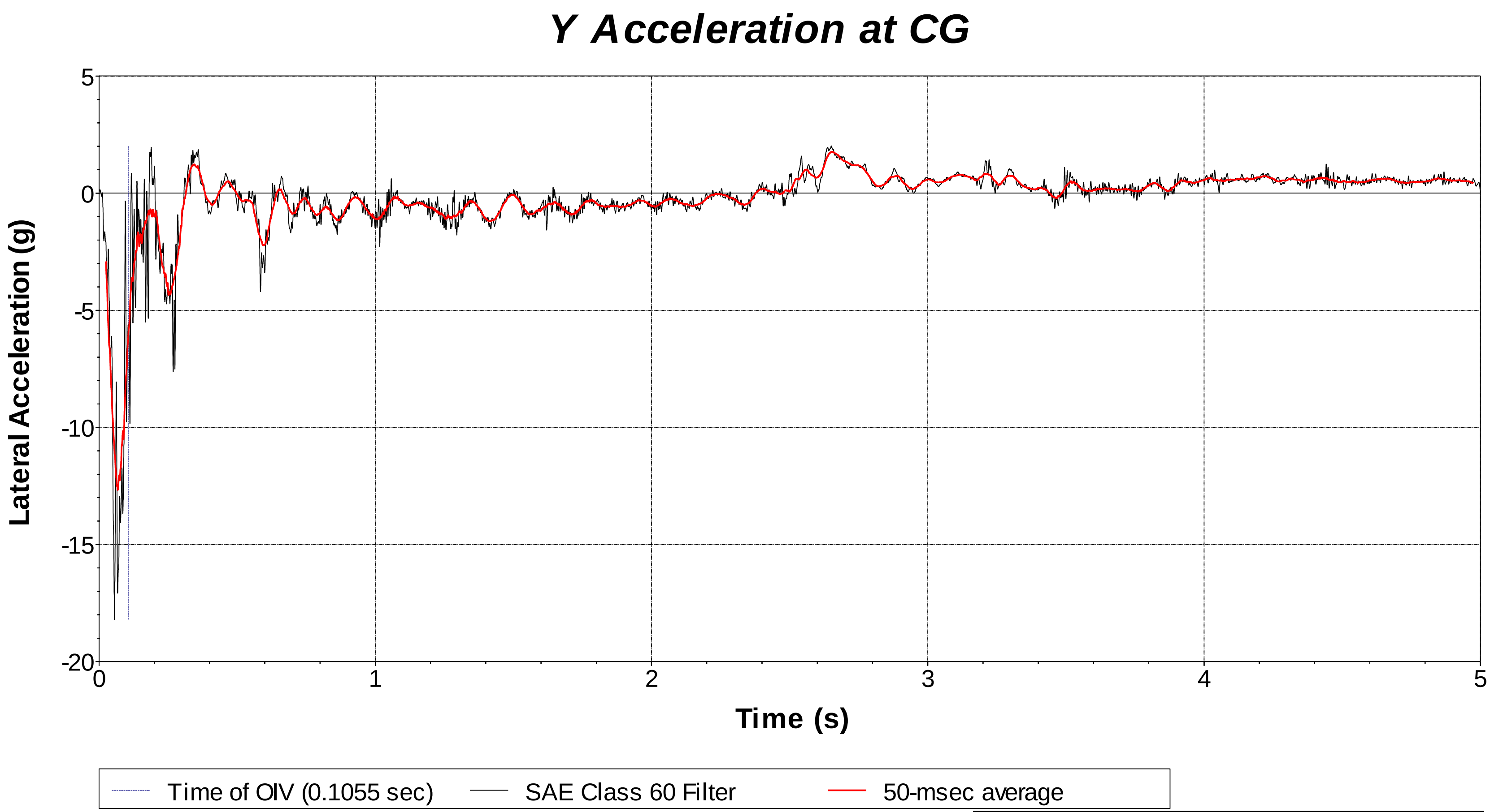
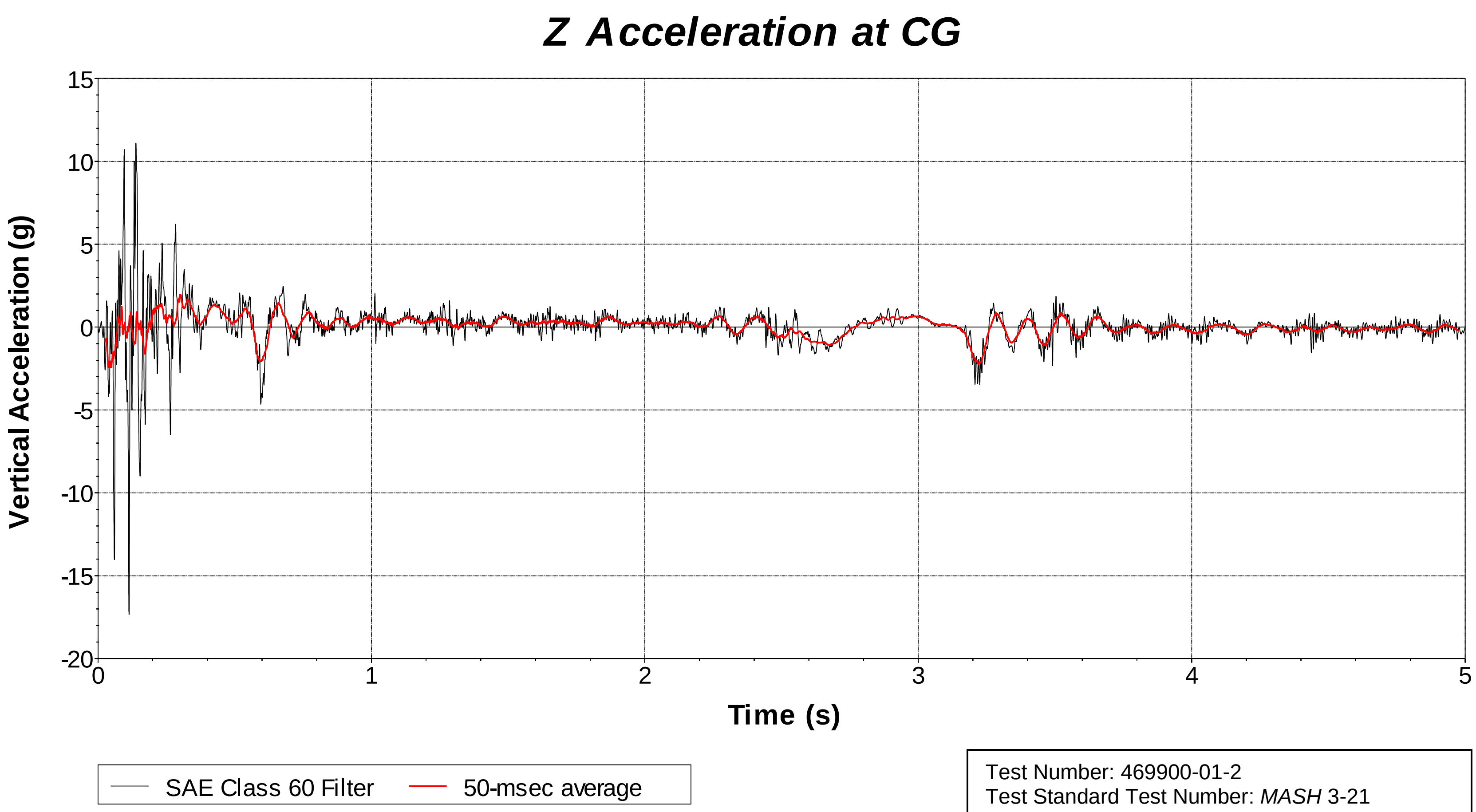


Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469900-01-2 (Accelerometer Located at Center of Gravity).



Test Number: 469900-01-2
Test Standard Test Number: *MASH* 3-21
Test Article: Modified Median Transition
Test Vehicle: 2014 RAM 1500 Pickup Truck
Inertial Mass: 5008 lb
Gross Mass: 5173 lb
Impact Speed: 61.9 mi/h
Impact Angle: 24.7 degrees

Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 469900-01-2 (Accelerometer Located at Center of Gravity).



Test Number: 469900-01-2
Test Standard Test Number: *MASH* 3-21
Test Article: Modified Median Transition
Test Vehicle: 2014 RAM 1500 Pickup Truck
Inertial Mass: 5008 lb
Gross Mass: 5173 lb
Impact Speed: 61.9 mi/h
Impact Angle: 24.7 degrees

Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 469900-01-2 (Accelerometer Located at Center of Gravity).

APPENDIX F. *MASH* TEST 3-20 (CRASH TEST NO. 469900-01-3)

F.1 VEHICLE PROPERTIES AND INFORMATION

Table F.1. Vehicle Properties for Test No. 469900-01-3.

Date: 2020-08-25 Test No.: 469900-01-3 VIN No.: 3N1CN7AP7FL908592

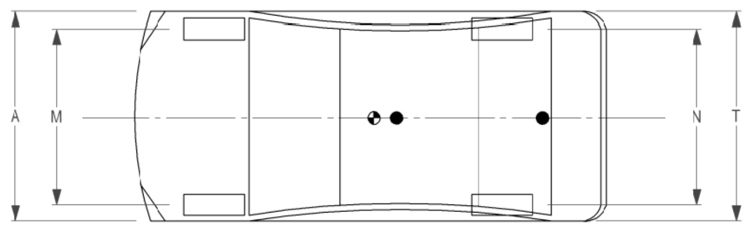
Year: 2015 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 102957 Tire Size: P185/65R15

Describe any damage to the vehicle prior to test: None

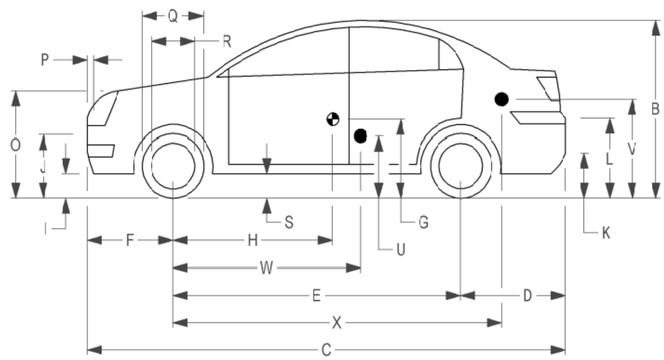
● Denotes accelerometer location.

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	40.74	M	58.30	R		W	40.70
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.25	O	30.50	T	64.50		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1750	M_{front}	1418	1457	1542
Back	1687	M_{rear}	953	963	1043
Total	3389	M_{Total}	2371	2420	2585

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

Mass Distribution:
lb LF: 774 RF: 683 LR: 463 RR: 500

Table F.2. Exterior Crush Measurements of Vehicle for Test No. 469900-01-3.

Date:	2020-8-25	Test No.:	469900-01-3	VIN No.:	3N1CN7AP7FL908592
Year:	2015	Make:	NISSAN	Model:	VERSA

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage: Width** (CDC)	Direct Damage: Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	14	12	40	-	-	-	-	-	-	68
2	Side plane at bumper ht	14	10	20	-	-	-	-	-	-	15
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

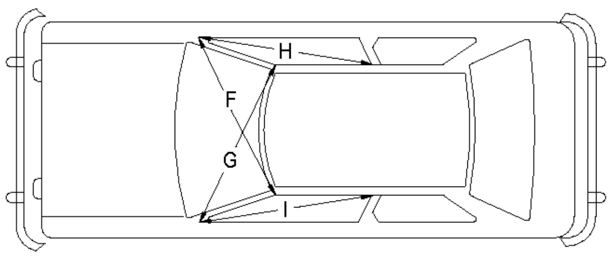
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

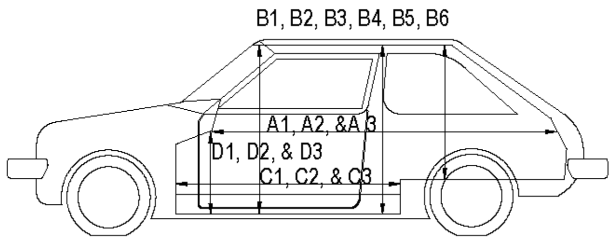
***Measure and document on the vehicle diagram the location of the maximum crush.

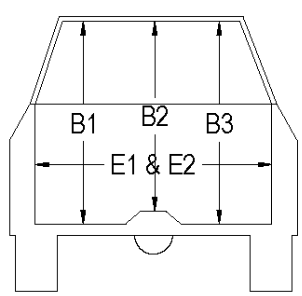
Note: Use as many lines/columns as necessary to describe each damage profile.

Table F.3. Occupant Compartment Measurements of Vehicle for Test No. 469900-01-3.

Date:	2020-8-25	Test No.:	469900-01-3	VIN No.:	3N1CN7AP7FL908592
Year:	2015	Make:	NISSAN	Model:	VERSA







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

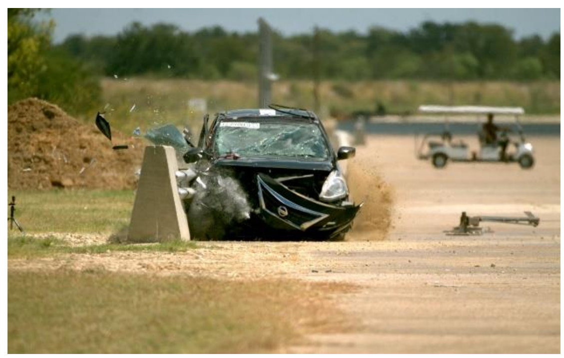
	Before	After (inches)	Differ.
A1	75.00	75.00	0.00
A2	74.00	74.00	0.00
A3	74.00	74.00	0.00
B1	43.00	43.00	0.00
B2	37.00	37.00	0.00
B3	43.00	43.00	0.00
B4	46.50	46.50	0.00
B5	42.50	42.50	0.00
B6	46.50	46.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	12.50	12.50	0.00
D2	0.00	0.00	0.00
D3	10.00	10.00	0.00
E1	45.00	43.00	-2.00
E2	48.75	53.75	5.00
F	47.50	44.00	-3.50
G	47.50	47.50	0.00
H	39.00	39.00	0.00
I	39.00	38.50	0.00
J*	48.50	44.00	-4.50

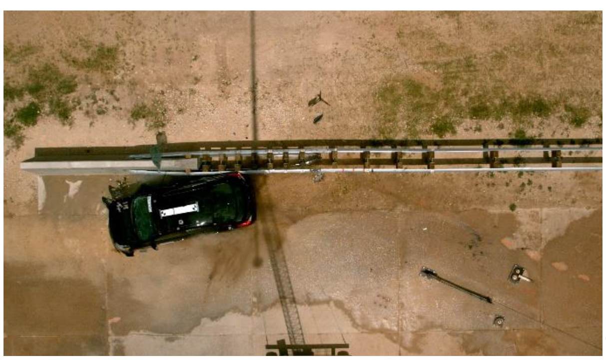
F.2 SEQUENTIAL PHOTOGRAPHS

0.000 s

0.100 s

0.200 s





0.300 s

Figure F.1. Sequential Photographs for Test No. 469900-01-3 (Overhead and Frontal Views).

0.400 s

0.500 s

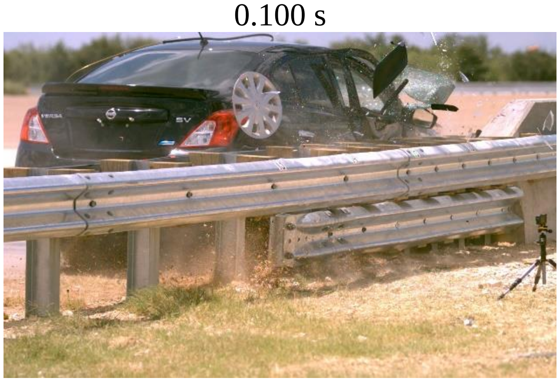
0.600 s

0.700 s

Figure F.1. Sequential Photographs for Test No. 469900-01-3 (Overhead and Frontal Views) (Continued).


0.000 s


0.100 s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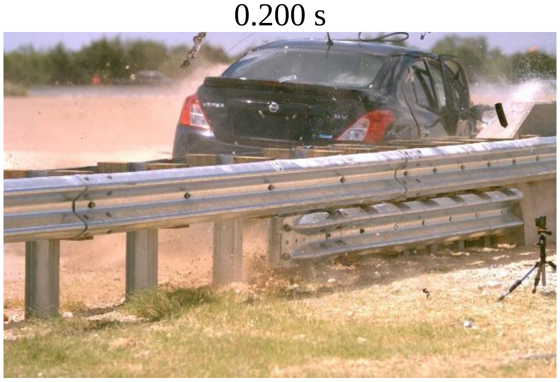
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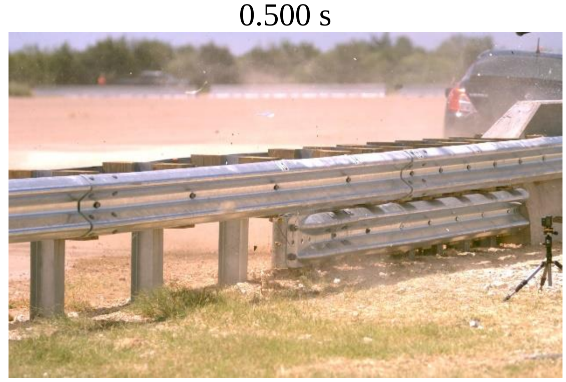
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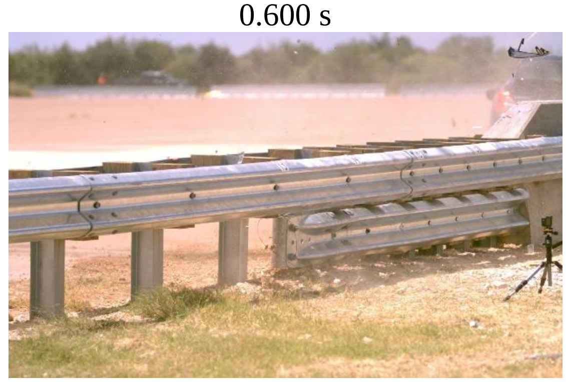
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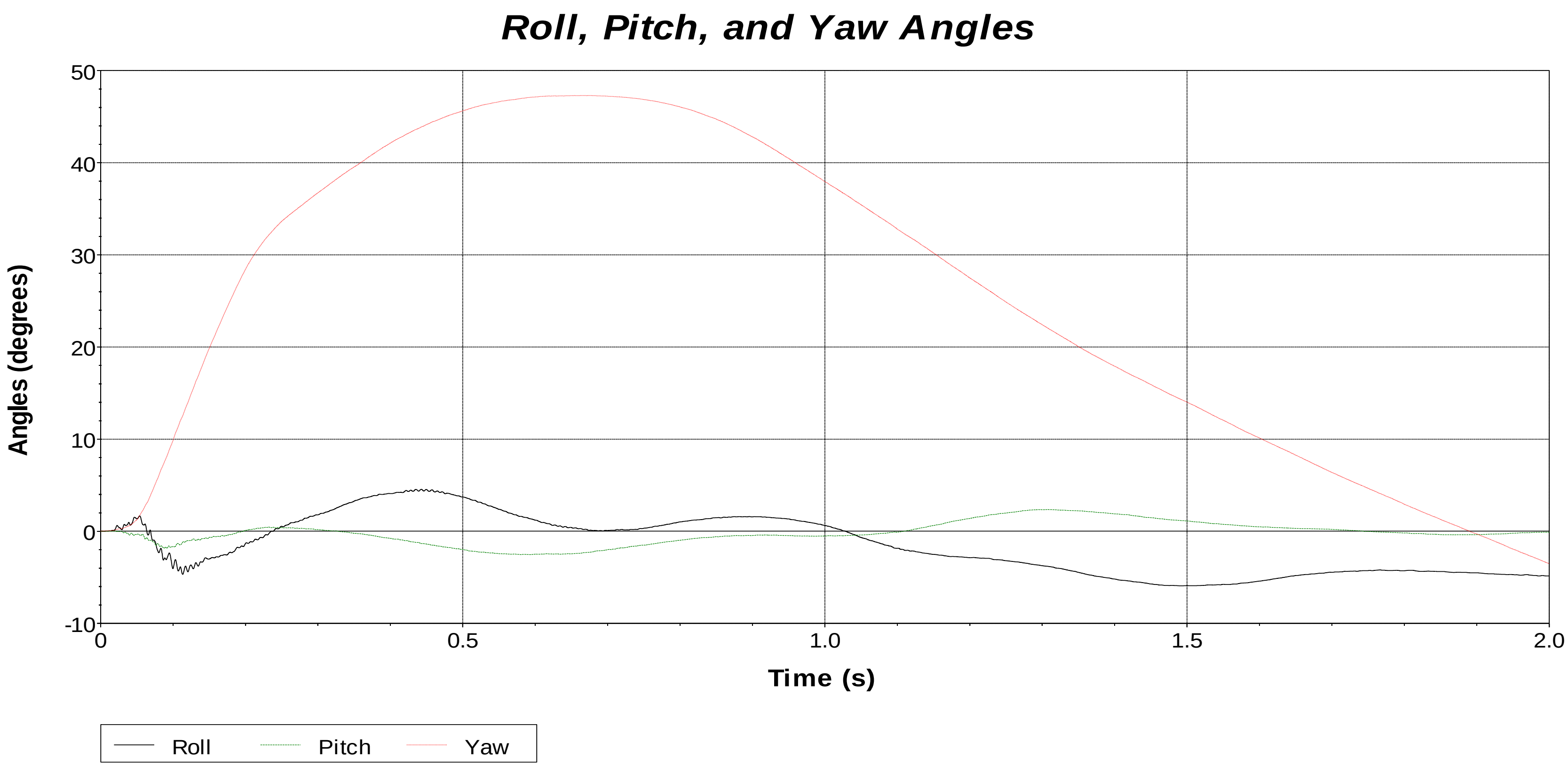
Figure F.2. Sequential Photographs for Test No. 469900-01-3 (Rear View).



Test Number: 469900-01-3 Test Standard Test Number: *MASH* 3-20 Test Article: Modified Median Transition Test Vehicle: 2015 Nissan Versa Inertial Mass: 2420 lb Gross Mass: 2585 lb Impact Speed: 62.9 mi/h Impact Angle: 25.2 degrees

Axes are vehicle-fixed.
Sequence for determining orientation:

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

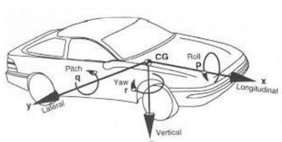
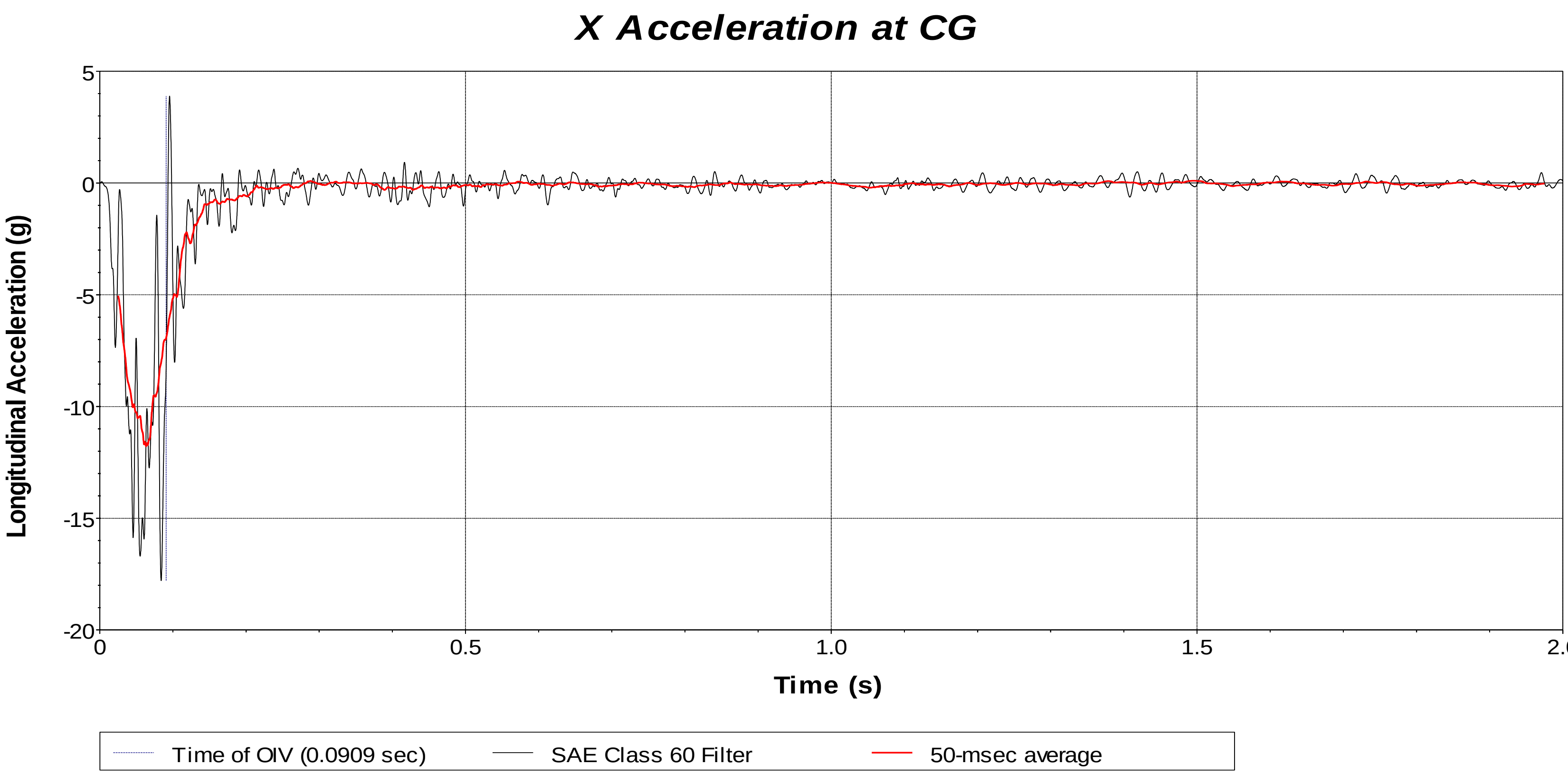
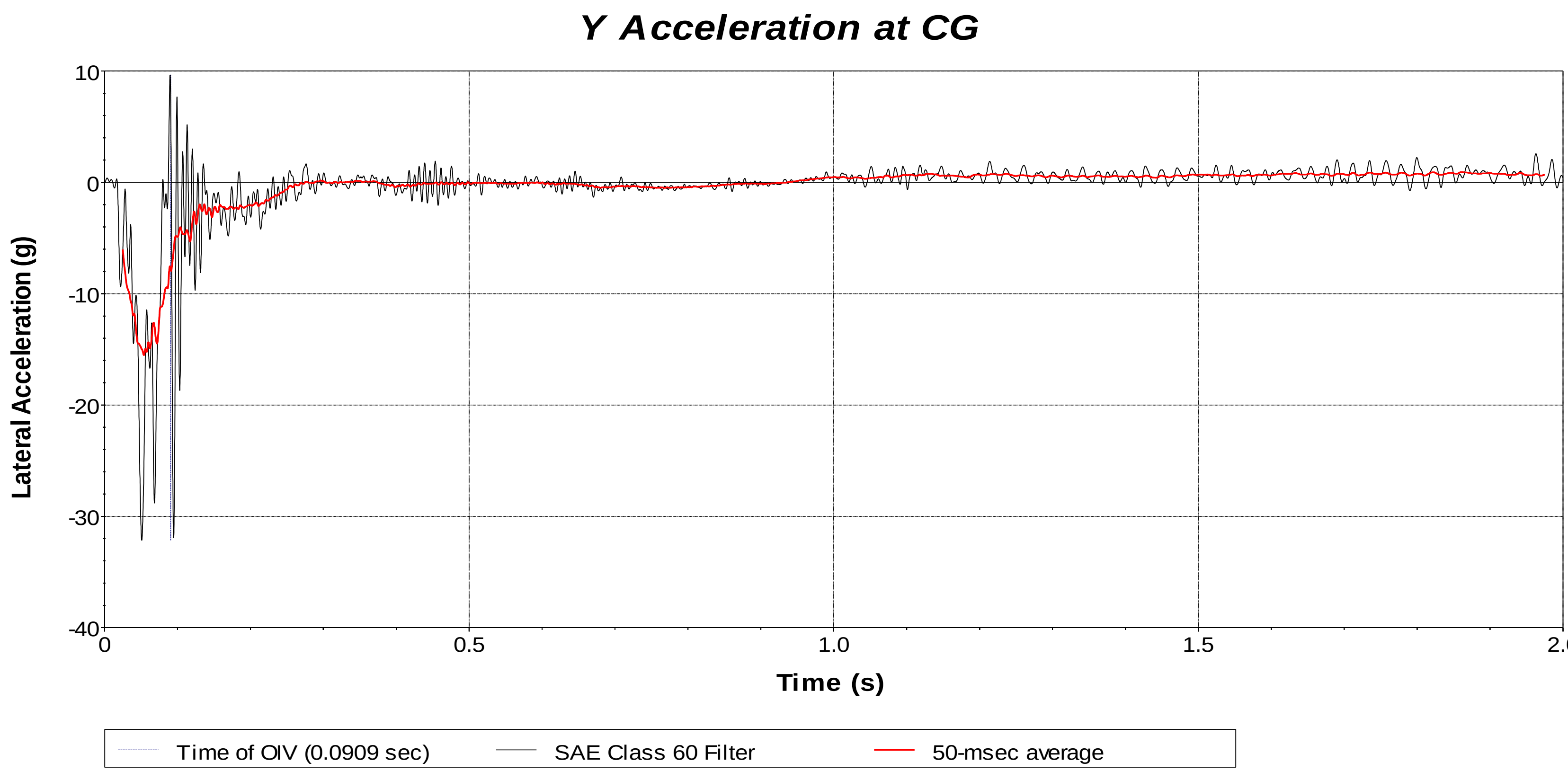


Figure F.3. Vehicle Angular Displacements for Test No. 469900-01-3.



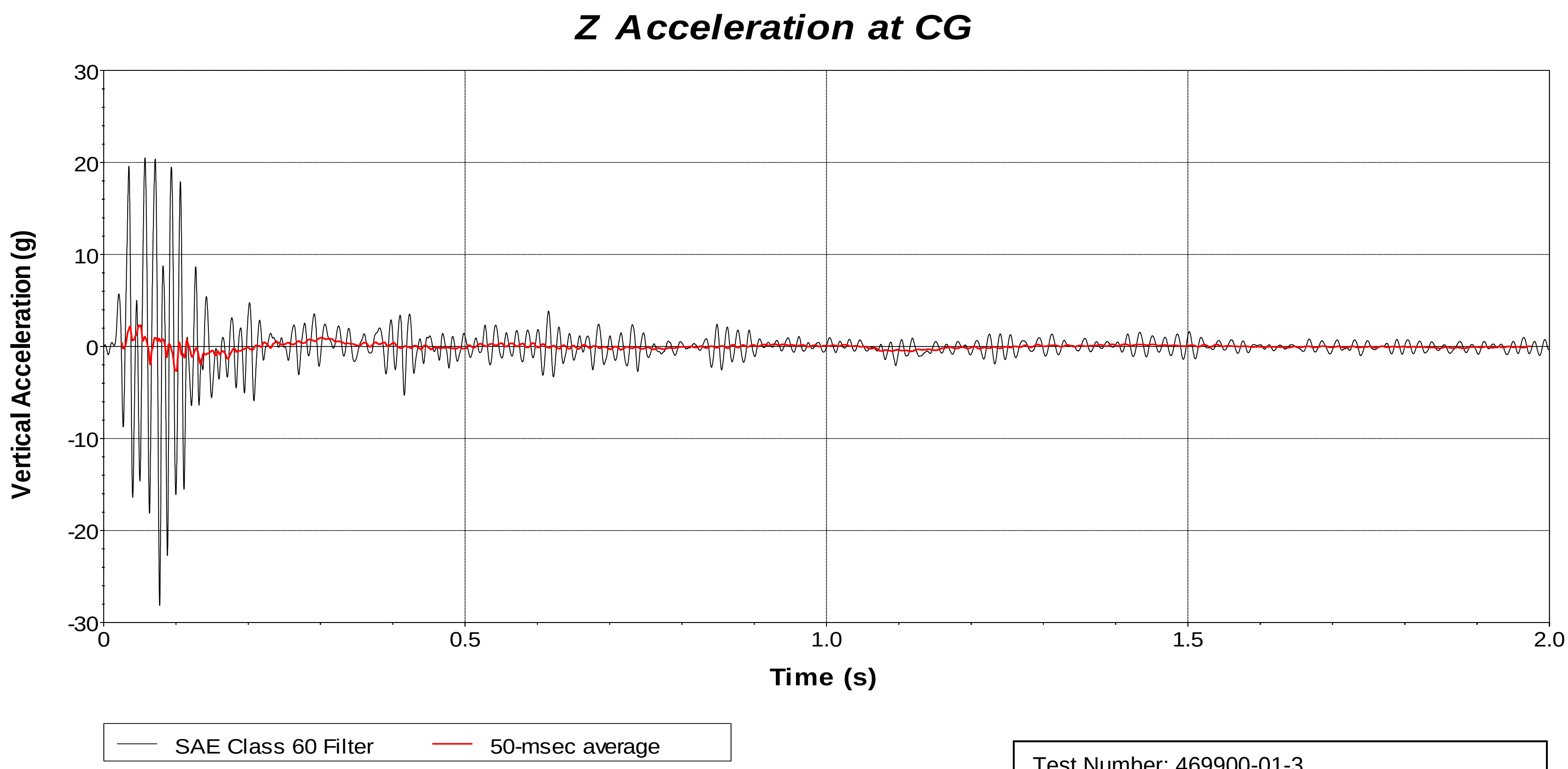
Test Number: 469900-01-3
Test Standard Test Number: *MASH* 3-20
Test Article: Modified Median Transition
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2420 lb
Gross Mass: 2585 lb
Impact Speed: 62.9 mi/h
Impact Angle: 25.2 degrees

Figure F.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469900-01-3 (Accelerometer Located at Center of Gravity).



Test Number: 469900-01-3
Test Standard Test Number: *MASH* 3-20
Test Article: Modified Median Transition
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2420 lb
Gross Mass: 2585 lb
Impact Speed: 62.9 mi/h
Impact Angle: 25.2 degrees

Figure F.5. Vehicle Lateral Accelerometer Trace for Test No. 469900-01-3 (Accelerometer Located at Center of Gravity).



Test Number: 469900-01-3
Test Standard Test Number: *MASH* 3-20
Test Article: Modified Median Transition
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2420 lb
Gross Mass: 2585 lb
Impact Speed: 62.9 mi/h
Impact Angle: 25.2 degrees

Figure F.6. Vehicle Vertical Accelerometer Trace for Test No. 469900-01-3 (Accelerometer Located at Center of Gravity).

APPENDIX G. *MASH* TEST 3-21 (CRASH TEST NO. 469900-01-4)

G.1 VEHICLE PROPERTIES AND INFORMATION

Table G.1. Vehicle Properties for Test No. 469900-01-4.

Date:	2020-9-28	Test No.:	469900-01-4	VIN No.:	1C6RR6GT9HS549865
Year:	2017	Make:	RAM	Model:	1500

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

Tread Type: Highway Odometer: 91805

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

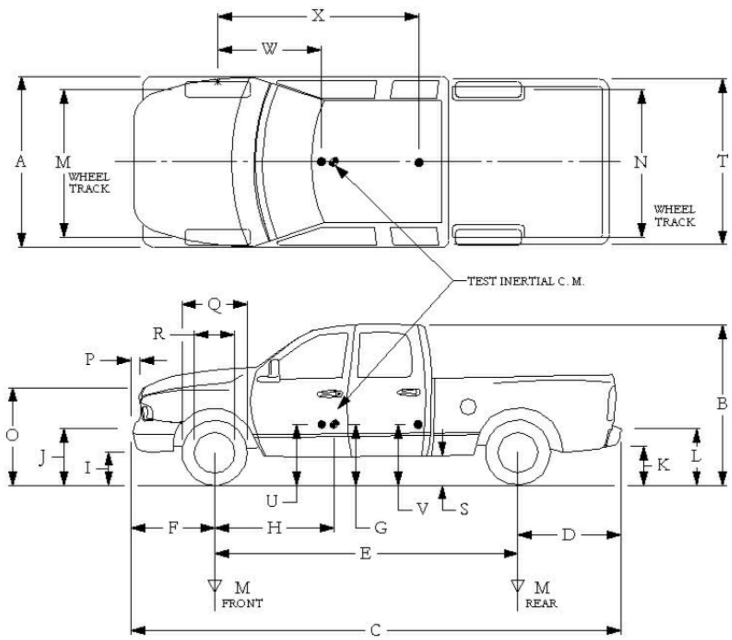
NOTES: None

Engine Type: V-8
Engine CID: 5.7

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	29.00	L	30.00	Q	30.50	V	30.25
C	227.50	H	59.60	M	68.50	R	18.00	W	59.60
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}	2963	2893	2978
Back	3900	M_{rear}	2096	2132	2212
Total	6700	M_{Total}	5059	5025	5190

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

Mass Distribution:
lb LF: 1464 RF: 1429 LR: 1072 RR: 1060

Table G.2. Measurements of Vehicle Vertical CG for Test No. 469900-01-4.

Date: 2020-9-28 Test No.: 469900-01-4 VIN: 1C6RR6GT9HS549865

Year: 2017 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 91805

Engine: 5.7 V-8 Transmission: Automatic

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

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

Measured Vehicle Weights: (lb)								
LF:	1464		RF:	1429		Front Axle:	2893	
LR:	1072		RR:	1060		Rear Axle:	2132	
Left:	2536		Right:	2489		Total:	5025	
						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:	59.61	inches	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	-0.32	inches	Left -	Right +	of Vehicle Centerline			
Z:	29.00	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 G.3. Exterior Crush Measurements of Vehicle for Test No. 469900-01-4.

Date: 2020-9-28 Test No.: 469900-01-4 VIN No.: 1C6RR6GT9HS549865

Year: 2017 Make: RAM Model: ________

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bmp ht	14	15	40	-	-	-	-	-	-	14
2	Side plane at bmp ht	14	16	54	-	-	-	-	-	-	74
	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.

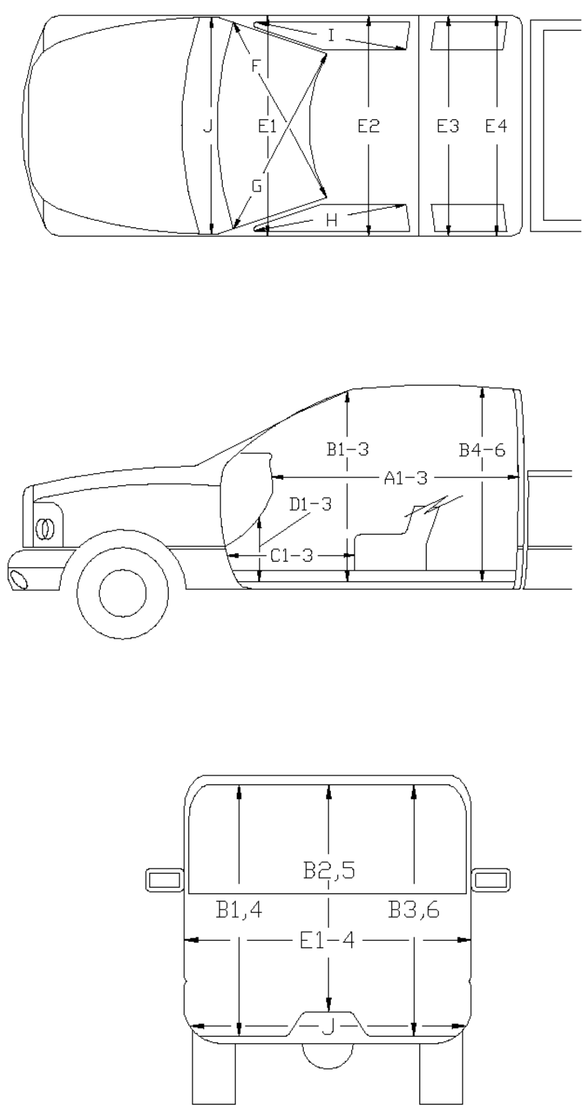
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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.4. Occupant Compartment Measurements of Vehicle for Test No. 469900-01-4.

Date:	2020-9-28	Test No.:	469900-01-4	VIN No.:	1C6RR6GT9HS549865
Year:	2017	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	24.00	-2.00
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	9.50	-2.00
E1	58.50	59.00	0.50
E2	63.50	65.00	1.50
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	21.00	-4.00

G.2 SEQUENTIAL PHOTOGRAPHS

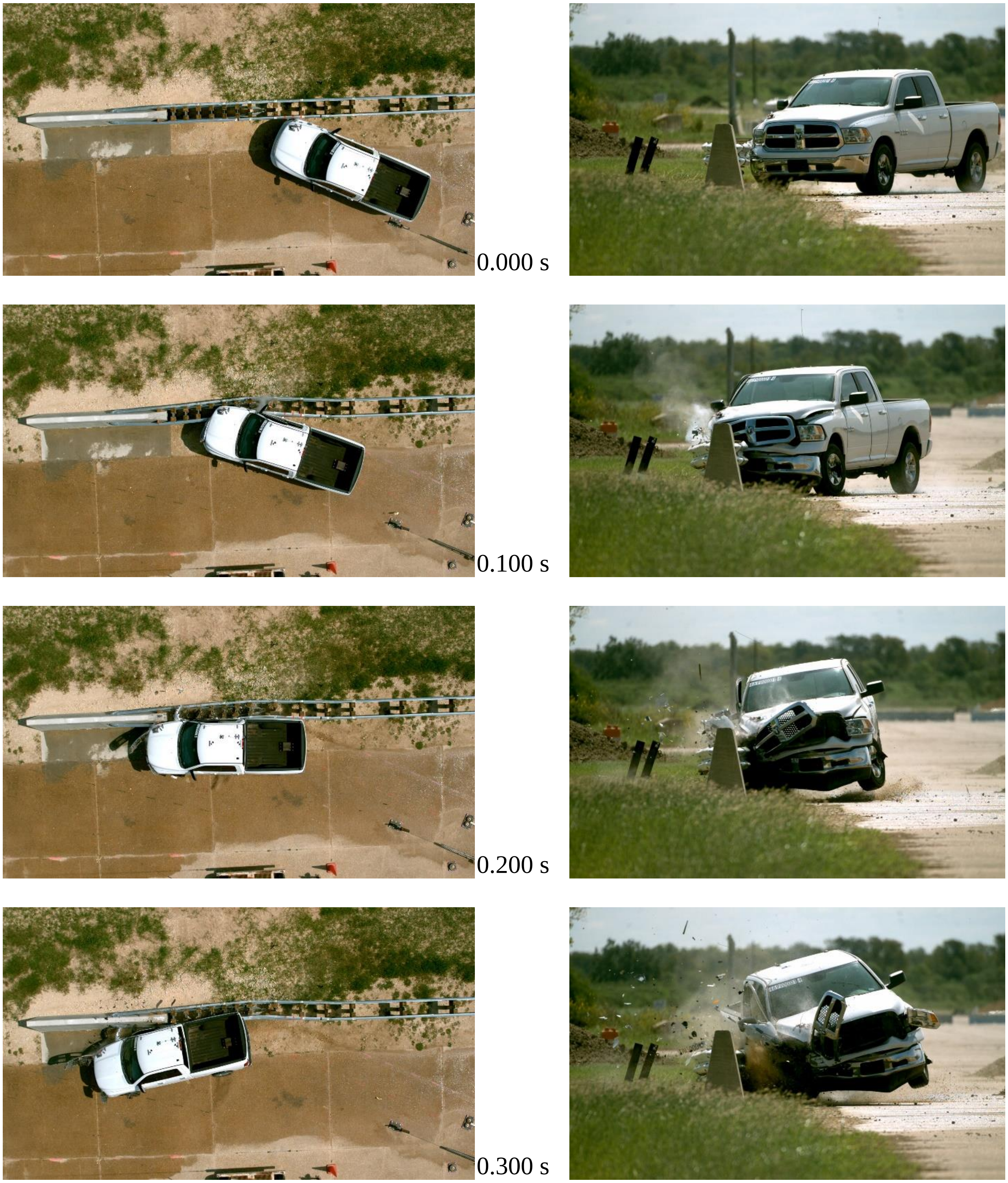


Figure G.1. Sequential Photographs for Test No. 469900-01-4 (Overhead and Frontal Views).


0.400 s



0.500 s



0.600 s

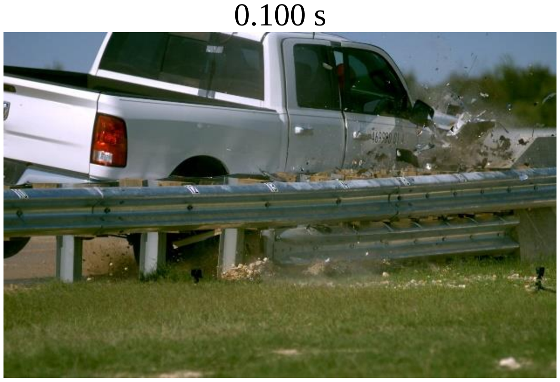


0.700 s


Figure G.1. Sequential Photographs for Test No. 469900-01-4 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

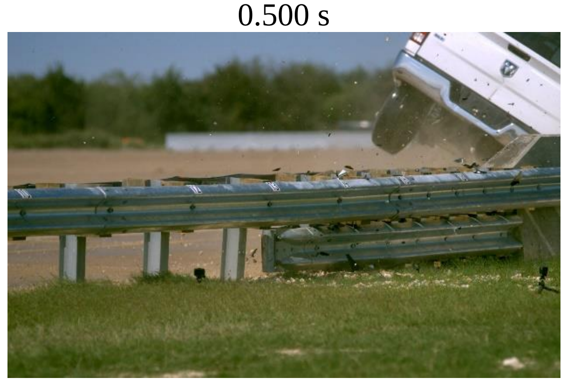


0.200 s

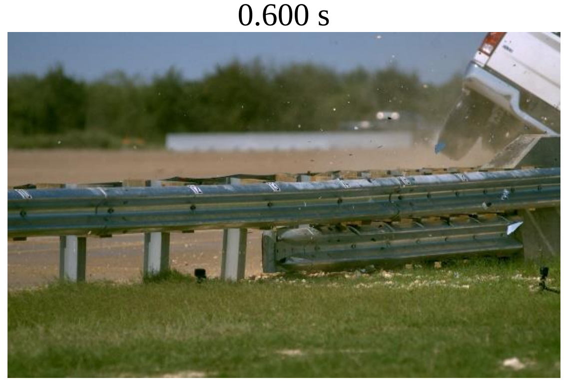
0.300 s

0.400 s

0.500 s



0.600 s



0.700 s

Figure G.2. Sequential Photographs for Test No. 469900-01-4 (Rear View).

G.3 VEHICLE ANGULAR DISPLACEMENT

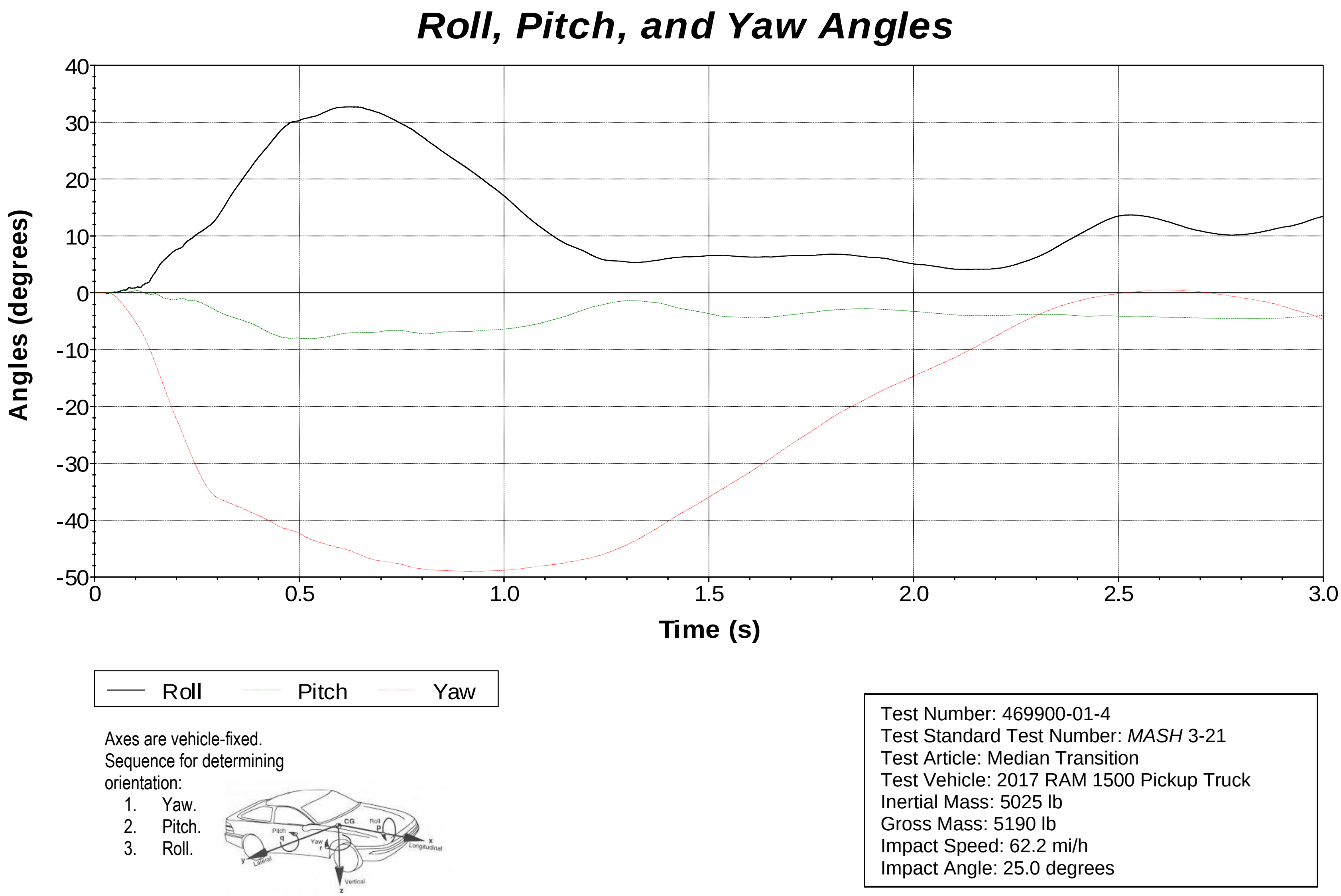
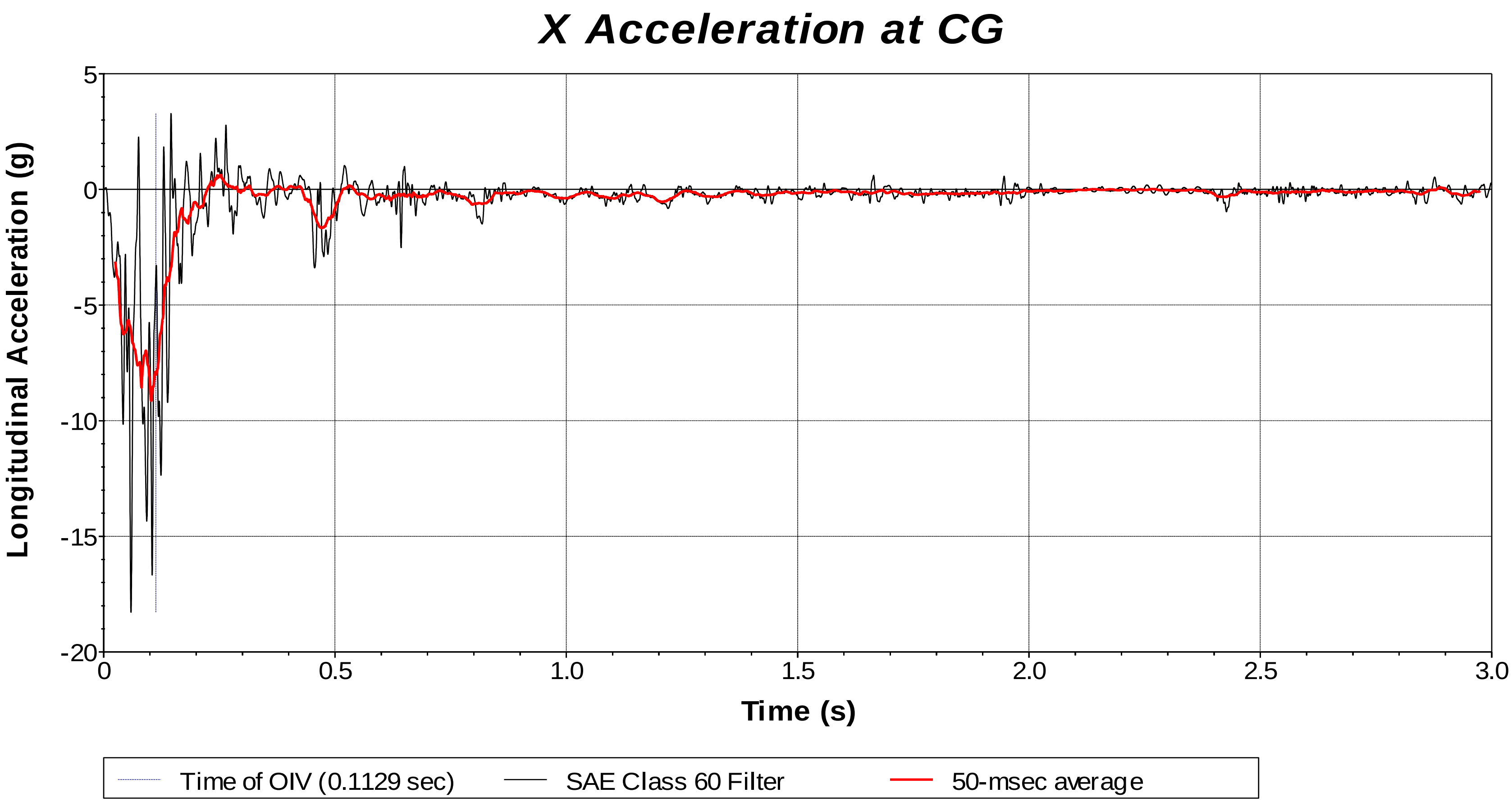
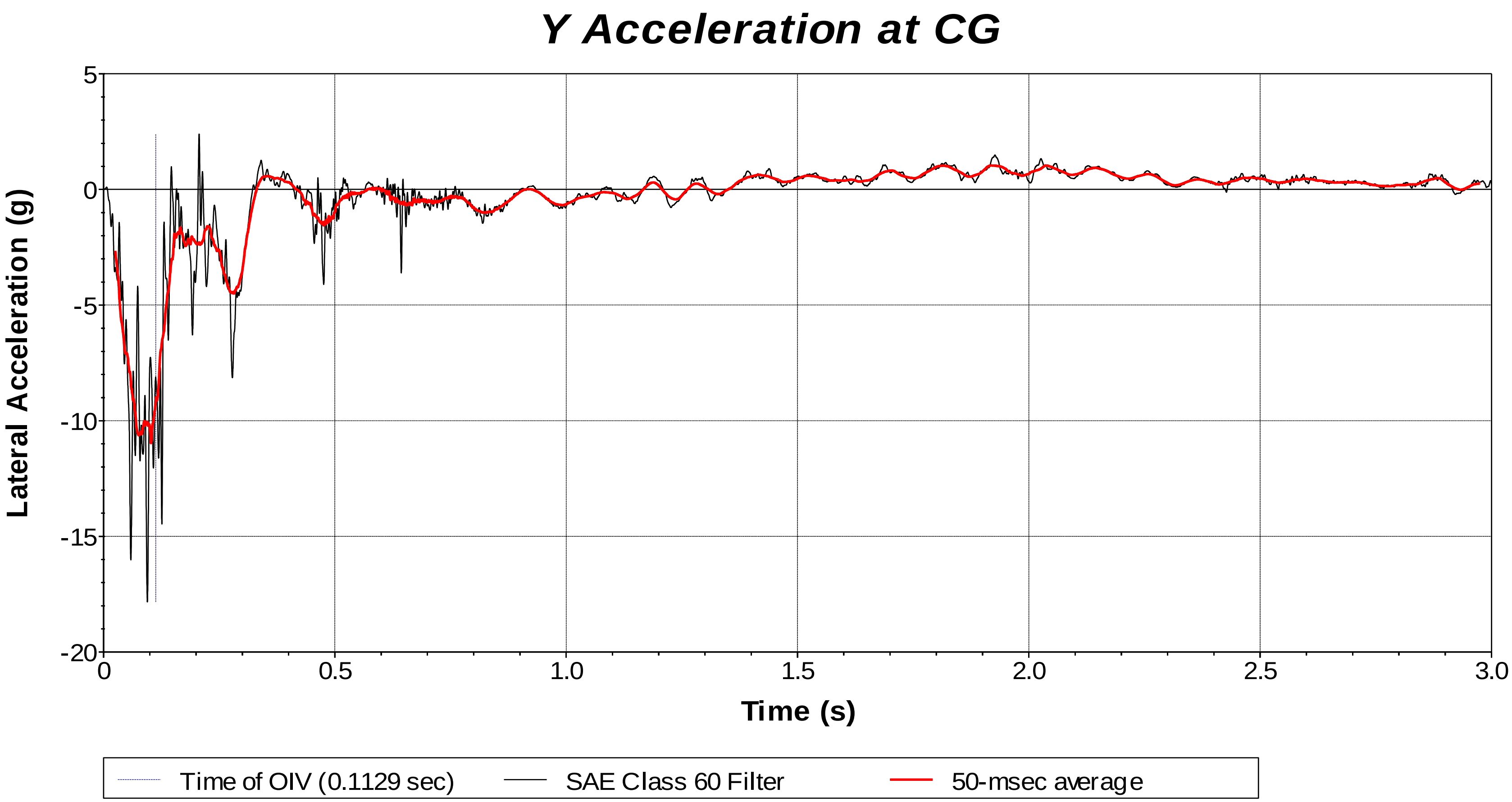


Figure G.3. Vehicle Angular Displacements for Test No. 469900-01-4.



Test Number: 469900-01-4
Test Standard Test Number: *MASH* 3-21
Test Article: Median Transition
Test Vehicle: 2017 RAM 1500 Pickup Truck
Inertial Mass: 5025 lb
Gross Mass: 5190 lb
Impact Speed: 62.2 mi/h
Impact Angle: 25.0 degrees

Figure G.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469900-01-4 (Accelerometer Located at Center of Gravity).



Test Number: 469900-01-4
Test Standard Test Number: *MASH* 3-21
Test Article: Median Transition
Test Vehicle: 2017 RAM 1500 Pickup Truck
Inertial Mass: 5025 lb
Gross Mass: 5190 lb
Impact Speed: 62.2 mi/h
Impact Angle: 25.0 degrees

Figure G.5. Vehicle Lateral Accelerometer Trace for Test No. 469900-01-4 (Accelerometer Located at Center of Gravity).

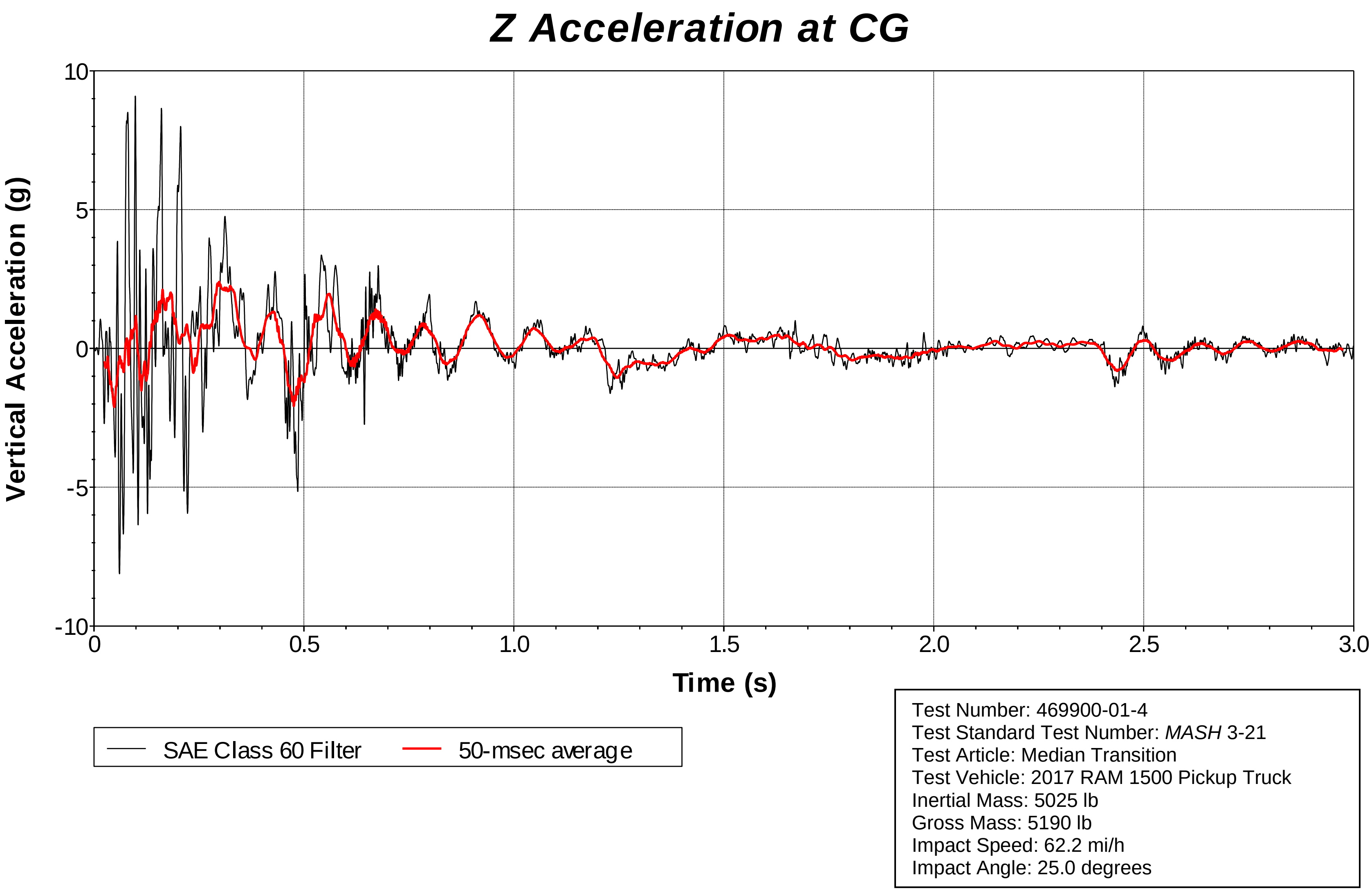


Figure G.6. Vehicle Vertical Accelerometer Trace for Test No. 469900-01-4 (Accelerometer Located at Center of Gravity).

APPENDIX H. *MASH* TEST 3-20 (CRASH TEST NO. 469900-01-5)

H.1 VEHICLE PROPERTIES AND INFORMATION

Table H.1. Vehicle Properties for Test No. 469900-01-5.

Date: 2020-10-05 Test No.: 469900-01-5 VIN No.: 3N1CN7APXEL838603

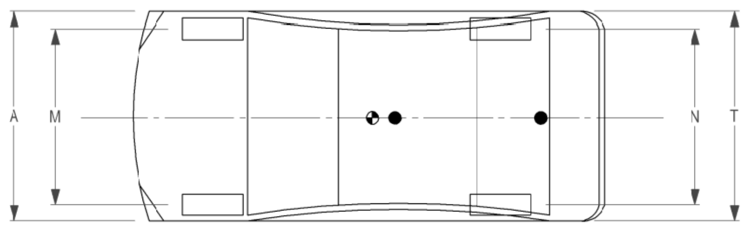
Year: 2014 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 186935 Tire Size: P185/65R15

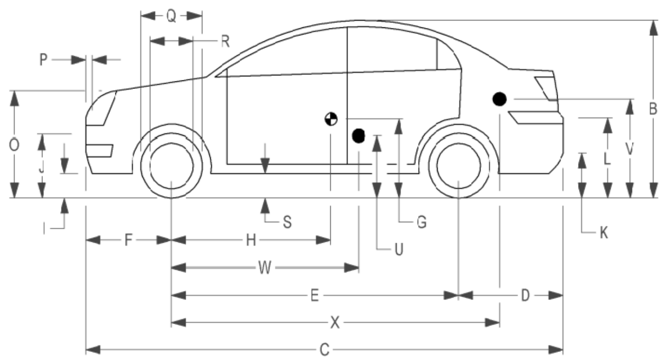
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None



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



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

Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	41.39	M	58.30	R	16.25	W	41.40
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.25	O	30.50	T	64.50		

Wheel Center Ht Front 11.50 Wheel Center Ht Rear 11.50 W-H 0.01

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1750	M_{front}	1451	1444	1529
Back	1687	M_{rear}	961	980	1060
Total	3389	M_{Total}	2412	2424	2589

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

Mass Distribution:
lb LF: 751 RF: 693 LR: 490 RR: 490

Table H.2. Exterior Crush Measurements of Vehicle for Test No. 469900-01-5.

Date:	2020-10-5	Test No.:	469900-01-5	VIN No.:	3N1C7APXEL838603
Year:	2014	Make:	NISSAN	Model:	VERSA

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage: Width** (CDC)	Direct Damage: Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	12	10	16	-	-	-	-	-	-	18
2	Side plane at bumper ht	12	10	50	-	-	-	-	-	-	72
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

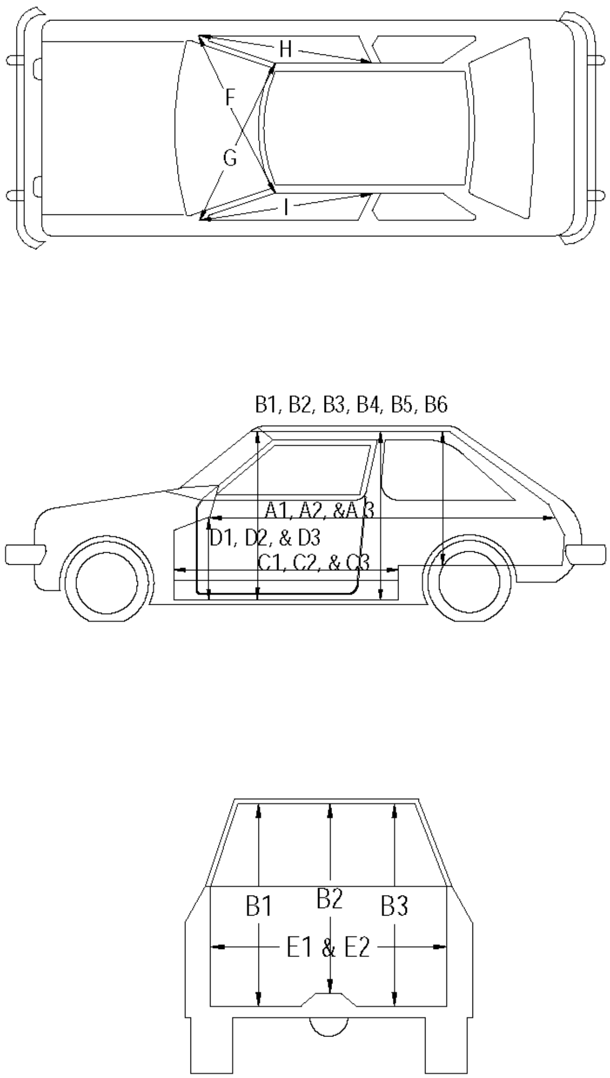
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Table H.3. Occupant Compartment Measurements of Vehicle for Test No. 469900-01-5.

Date:	2020-10-5	Test No.:	469900-01-5	VIN No.:	3N1C7APXEL838603
Year:	2014	Make:	NISSAN	Model:	VERSA



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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	75.00	75.00	0.00
A2	74.00	74.00	0.00
A3	74.00	74.00	0.00
B1	43.00	43.00	0.00
B2	37.00	37.00	0.00
B3	43.00	43.00	0.00
B4	46.50	46.50	0.00
B5	42.50	42.50	0.00
B6	46.50	46.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	12.50	12.50	0.00
D2	0.00	0.00	0.00
D3	10.00	9.75	-0.25
E1	48.25	44.25	-4.00
E2	48.75	51.75	3.00
F	47.50	47.00	-0.50
G	47.50	47.50	0.00
H	39.00	39.00	0.00
I	39.00	39.00	0.00
J*	48.50	44.50	-4.00

H.2 SEQUENTIAL PHOTOGRAPHS

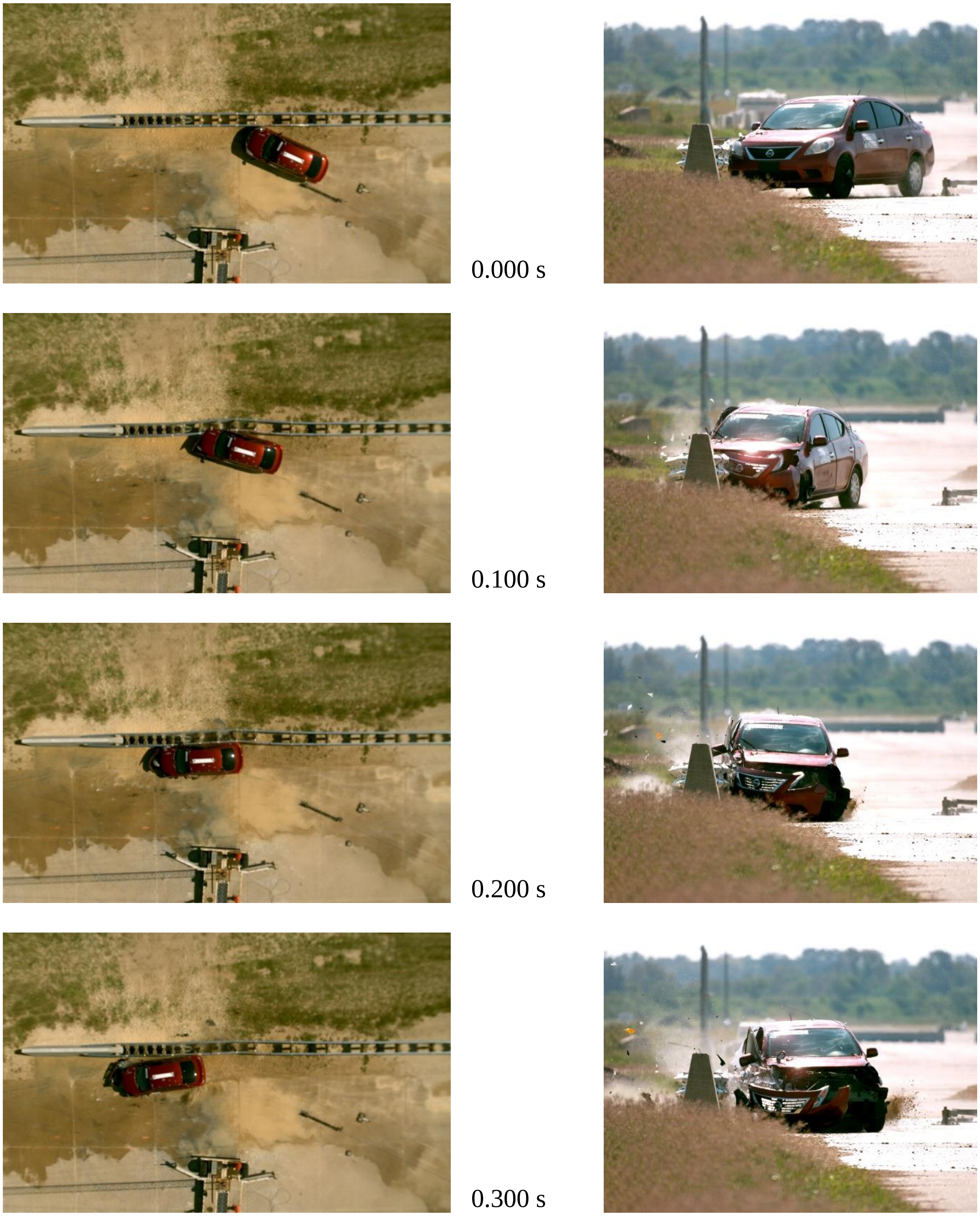
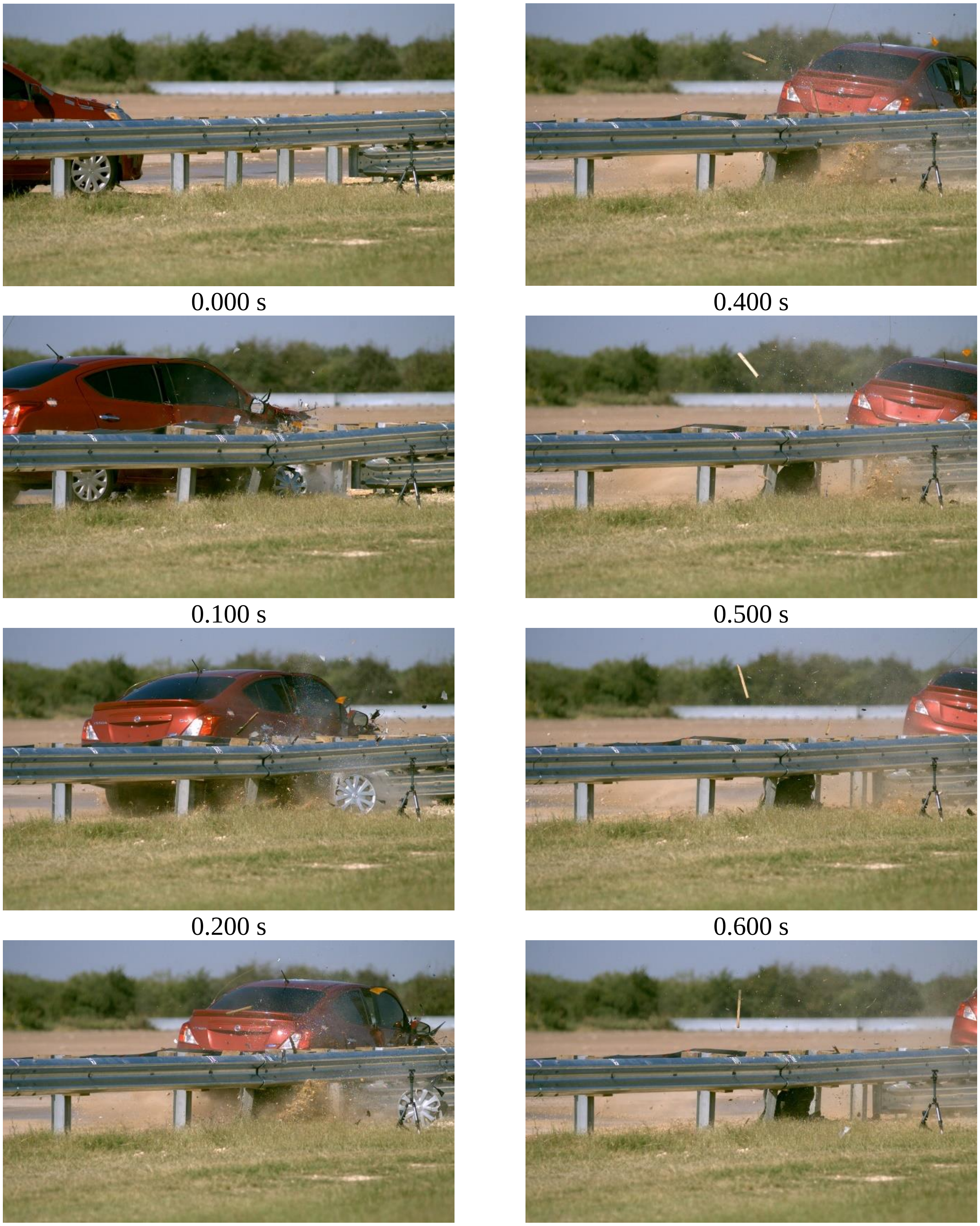


Figure H.1. Sequential Photographs for Test No. 469900-01-5 (Overhead and Frontal Views).

Figure H.1. Sequential Photographs for Test No. 469900-01-5 (Overhead and Frontal Views) (Continued).



0.000 s

0.400 s

0.100 s

0.500 s

0.200 s

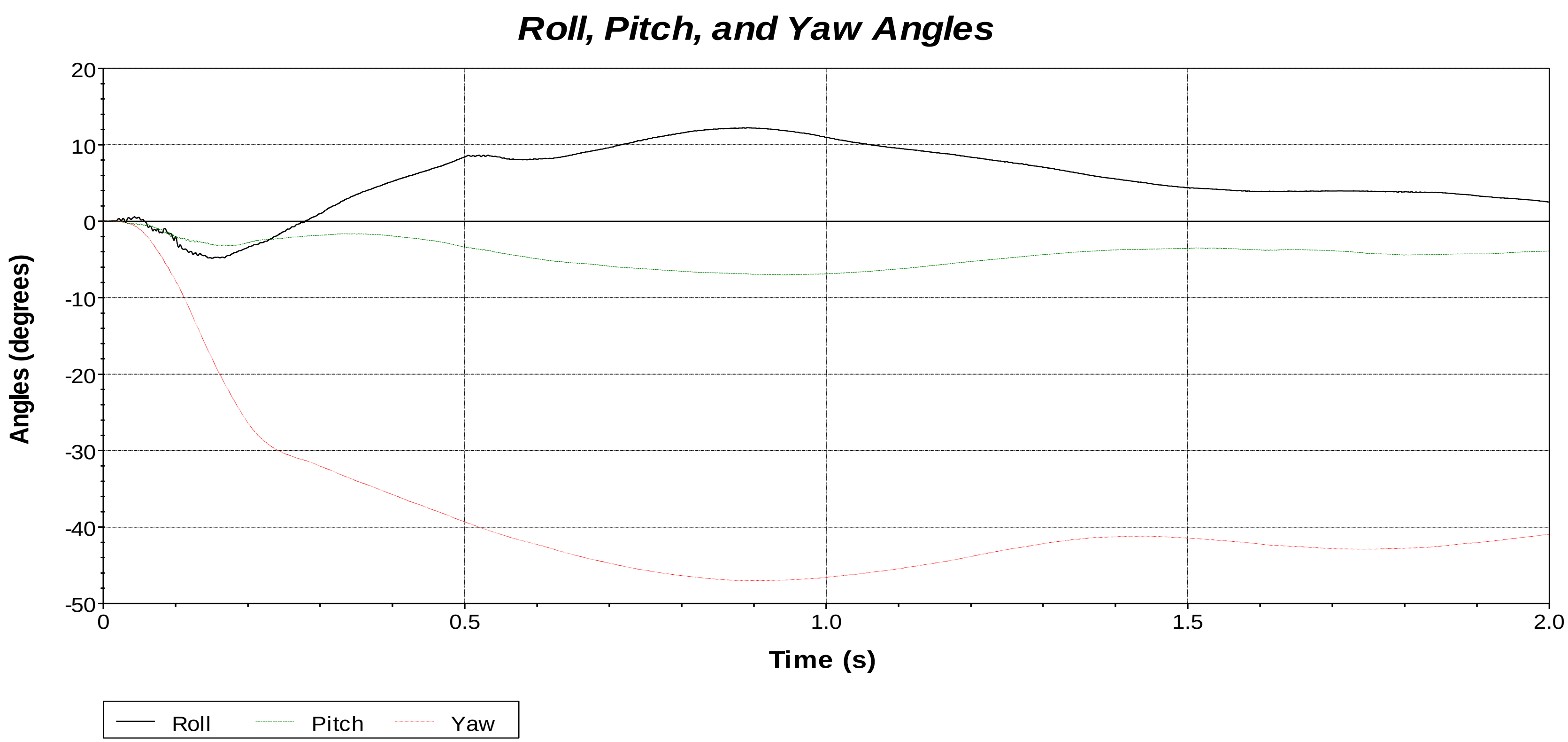
0.600 s

0.300 s

0.700 s

Figure H.2. Sequential Photographs for Test No. 469900-01-5 (Rear View).

H.3 VEHICLE ANGULAR DISPLACEMENT



Test Number: 469900-01-5
Test Standard Test Number: *MASH* 3-20
Test Article: Modified Median Transition
Test Vehicle: 2014 Nissan Versa
Inertial Mass: 2424 lb
Gross Mass: 2589 lb
Impact Speed: 63.0 mi/h
Impact Angle: 25.0 degrees

Axes are vehicle-fixed.
Sequence for determining orientation:

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

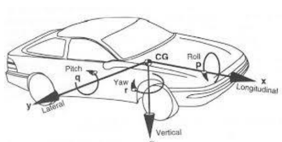
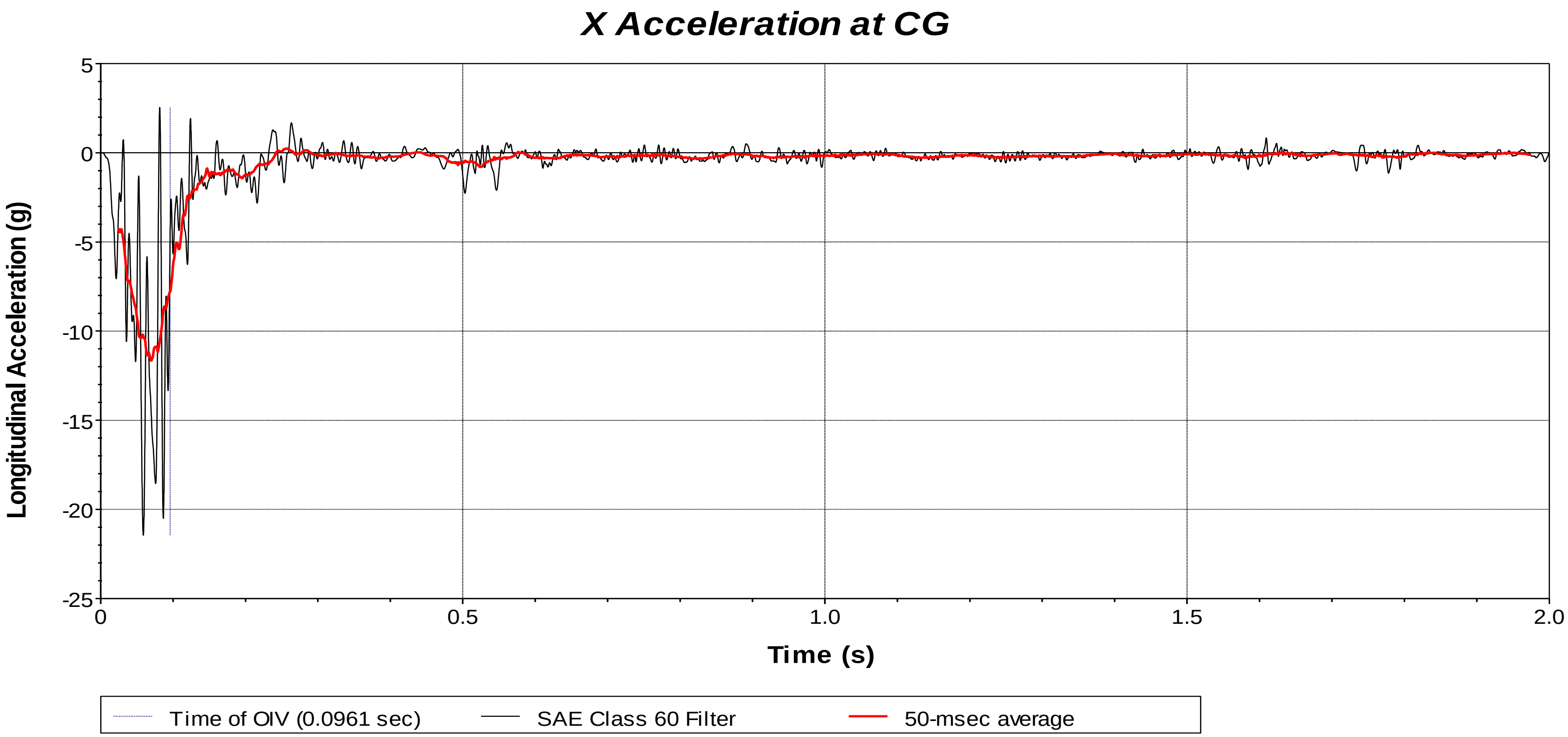


Figure H.3. Vehicle Angular Displacements for Test No. 469900-01-5.



Test Number: 469900-01-5
Test Standard Test Number: *MASH* 3-20
Test Article: Modified Median Transition
Test Vehicle: 2014 Nissan Versa
Inertial Mass: 2424 lb
Gross Mass: 2589 lb
Impact Speed: 63.0 mi/h
Impact Angle: 25.0 degrees

Figure H.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469900-01-5 (Accelerometer Located at Center of Gravity).

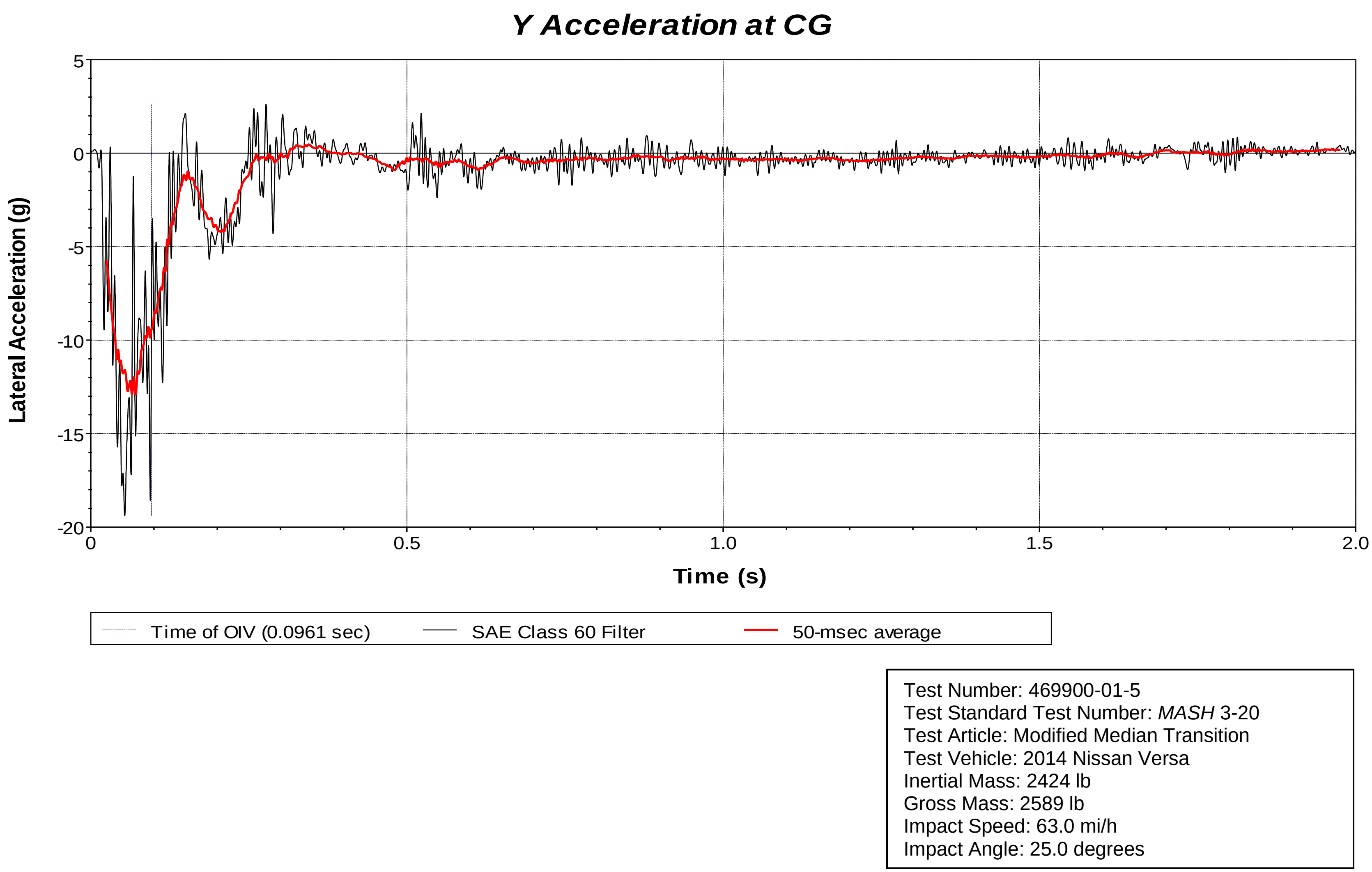


Figure H.5. Vehicle Lateral Accelerometer Trace for Test No. 469900-01-5 (Accelerometer Located at Center of Gravity).

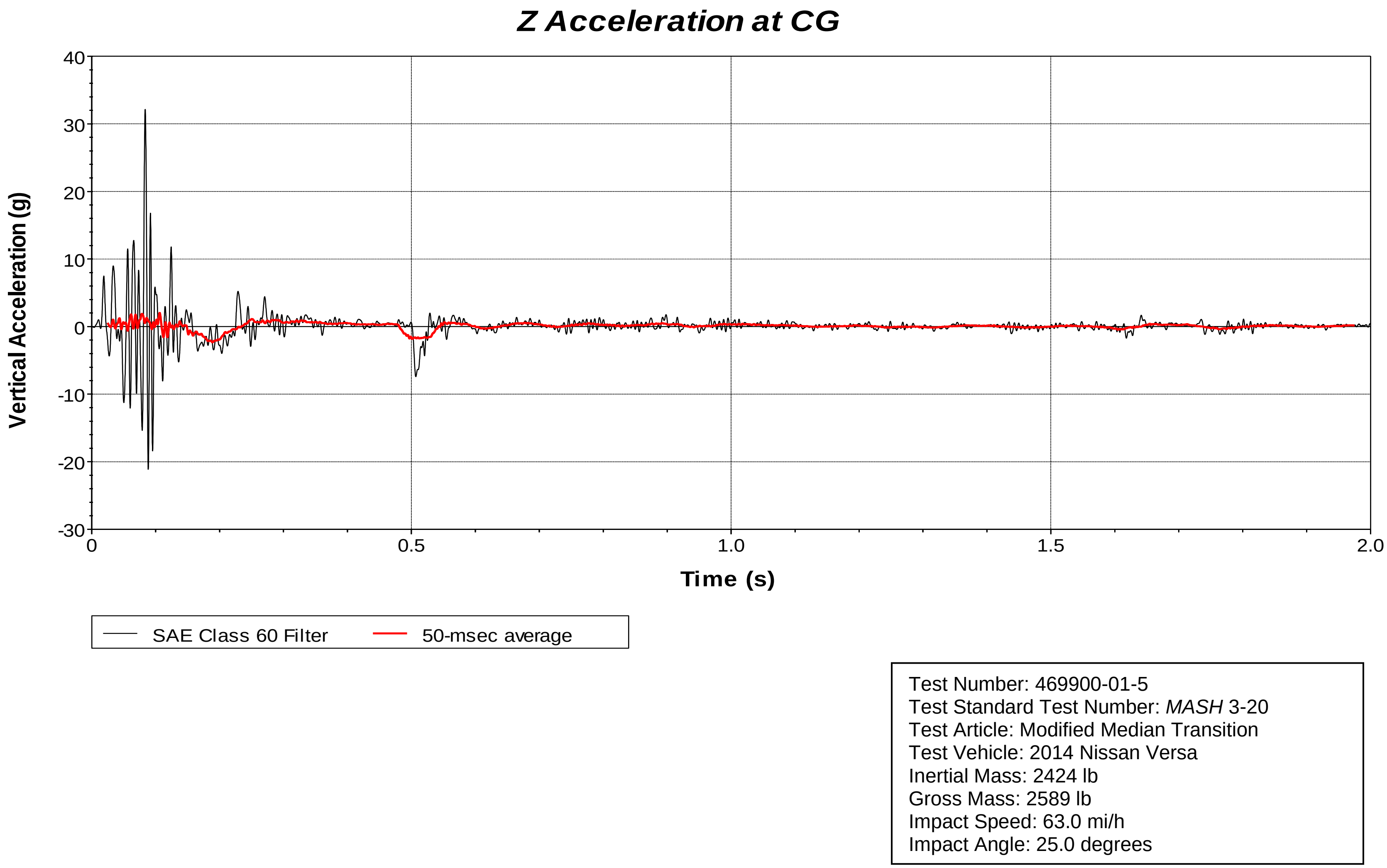


Figure H.6. Vehicle Vertical Accelerometer Trace for Test No. 469900-01-5 Accelerometer Located at Center of Gravity).

APPENDIX I. VALUE OF RESEARCH

The estimated Value of Research (VOR) for this project is summarized in Figure I.1. The economic variables considered in developing the VOR, sources of these variables, and the description of economic based calculations used are described herein.

The National Highway Traffic Safety Administration (NHTSA) published the report "The Economic and Societal Impact of Motor Vehicle Crashes," 2010 (Revised), http://www-nrd.nhtsa.dot.gov/pubs/812013.pdf) that gives an estimate on the societal cost of fatal crashes. In the report, a fatality results in an average discounted lifetime economic cost of $1.4 million, and an average comprehensive cost of $9.1 million

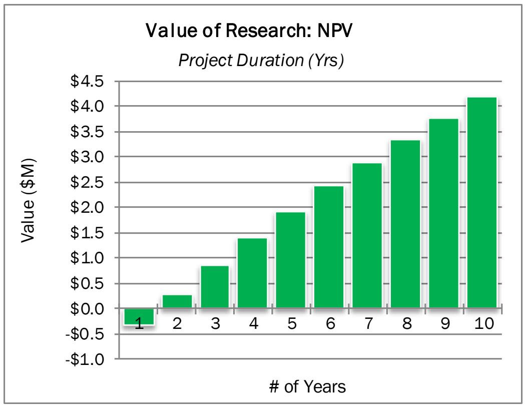
Data obtained from TxDOT's Crash Records Information System (CRIS) for the year 2018 indicates that 125 crashes that are for "K – FATAL INJURY" with the filter being set for hit median barrier. Assuming only a small fraction (0.5 fatality) per year is to be saved by this work, the conservative estimates of economic saving would be $700,000. This is calculated as (societal cost per person) * 0.5 which equals to $700,000 per year.

Since there is no direct method to estimate the value of this research without actually implementing and monitoring it for the duration of interest, the researchers looked at fatality only without adding to cost of injuries and property damages due to such crashes. Hence, as conservative estimate, the researchers used the discounted economic cost of $1.4 million to arrive at the annual expected value of this research. With a reduction of 0.50 fatality each year, the annual expected value of this research is $700,000.

The researchers used a period of 10 years and a discount rate of 5%, which is typical per the TxDOT's University Handbook, to arrive at the benefit-cost ratio of 10 for this research project. The estimated VOR is presented in Figure I.1.

	Project #	0-6990		
	Project Name:	Development of MASH Test Level 3 (TL-3) Compliant Transition between Median Guardrail and Median Concrete Barrier		
	Agency:	TTI	Project Budget	$ 415,732
	Project Duration (Yrs)	2.42	Exp. Value (per Yr)	$ 700,000
Expected Value Duration (Yrs)		10	Discount Rate	5%
Economic Value				
Total Savings:	$ 6,584,268	Net Present Value (NPV):		$ 4,189,660
Payback Period (Yrs):	0.593903	Cost Benefit Ratio (CBR, $1 : $___):		$ 10

Years	Expected Value
0	-$1,006,071
1	$700,000
2	$700,000
3	$700,000
4	$700,000
5	$700,000
6	$700,000
7	$700,000
8	$700,000
9	$700,000
10	$700,000



Variable Justification

The savings is an estimate of improved safety of a median barrier system. Discount rate is based on OMB Circular No. A-94. Expected value per year is based on a societal savings of just the K (fatality) type crashes and not accounting for sever injuries property damages. The assumption of 0.5 fatal per year per site. Using "The Economic and Societal Impact of Motor Vehicle Crashes, 2010 (Revised)" estimate for crash fatalities cost to society ($1.4 million) . It is also assumed that each year, 0.5 fatality per year per such rigid object as a conservative assumption from " Texas Motor Vehicle Traffic Crash Facts Calendar Year 2018" sheet. The numebr of fatalities on Texas roadways was 3,652 per the 2018 sheet cited.

Qualitative Value

Benefit Area	Value
Safety	Having a crashworthy median barrier system is essential to protect errant vehicles from crossing into the opposing lane. The crashworthness of the system has to be evaluate per the American Associatin of State Transportation and Highway Officials (AASHTO) Manual for Asseing Safety Hardware (MASH).
System Reliability	This project will promote improving system reliability as crashes on not crash worthy median barrier ends or unprotected medians will most likely cause user delays and unforseen costs to the Receiving Agency.

Years	Expected Value	Expected Value	Expected Value	NPV
0	-$2,434,693	-$2,434,693	-$2.43	-$0.96
1	$700,000	-$1,734,693	-$1.73	-$0.32
2	$700,000	-$1,034,693	-$1.03	$0.28
3	$700,000	-$334,693	-$0.33	$0.86
4	$700,000	$365,307	$0.37	$1.41
5	$700,000	$1,065,307	$1.07	$1.93
6	$700,000	$1,765,307	$1.77	$2.43
7	$700,000	$2,465,307	$2.47	$2.90
8	$700,000	$3,165,307	$3.17	$3.35
9	$700,000	$3,865,307	$3.87	$3.78
10	$700,000	$4,565,307	$4.57	$4.19

Figure I.1. Value of Research for TxDOT Project 0-6990.