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MASH TEST 3-21 EVALUATION OF SHORT W-BEAM TRANSITION

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16. Abstract

When roadways intersect with restrictive features such as a bridge rail, it becomes difficult to fit a transition system with proper length. For this project, American Association of State Highway and Transportation (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*)Test Level 3 (TL-3) W beam transitions with shorter length are desired to be tested. These systems are used when State Departments of Transportation (DOTs) need to implement a shorter transition without compromising the integrity of the guardrail system.

The objective of this study was to model and crash test shorter W-beam transition systems for *MASH* TL-3 compliance. A *MASH* compliant transition with shorter length would provide the members of the Roadside Safety Pooled Fund with a valuable option in restrictive conditions against roadside hazards.

Due to the high occupant ridedown acceleration during the crash test, the short transition did not satisfy the performance criteria for *MASH* Test 3-21 for transitions.

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

*SI is the symbol for the International System of Units

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CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

When roadways intersect with restrictive features such as a bridge rail, it becomes difficult to fit a transition system with proper length. For this project, American Association of State Highway and Transportation (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test Level 3 (TL-3) W beam transitions with shorter length are desired to be tested (*1*). These systems are used when State Departments of Transportation (DOTs) need to implement a shorter transition without compromising the integrity of the guardrail system.

The objective of this study was to model and crash test shorter W-beam transition systems for *MASH* TL-3 compliance. A *MASH* compliant transition with shorter length would provide the members of the Roadside Safety Pooled Fund with a valuable option in restrictive conditions against roadside hazards.

Figure 1.1 shows a similar transition design that was used for the installation constructed during this project. The objective was to reduce the 25-ft transition length. For this purpose, the TTI research team first performed an engineering review of available transition systems and their design variables to shortlist a set of candidates for modeling and evaluation. The researchers conducted a series of simulations of the candidate set. The final design was then crash tested for *MASH* TL-3 compliance.

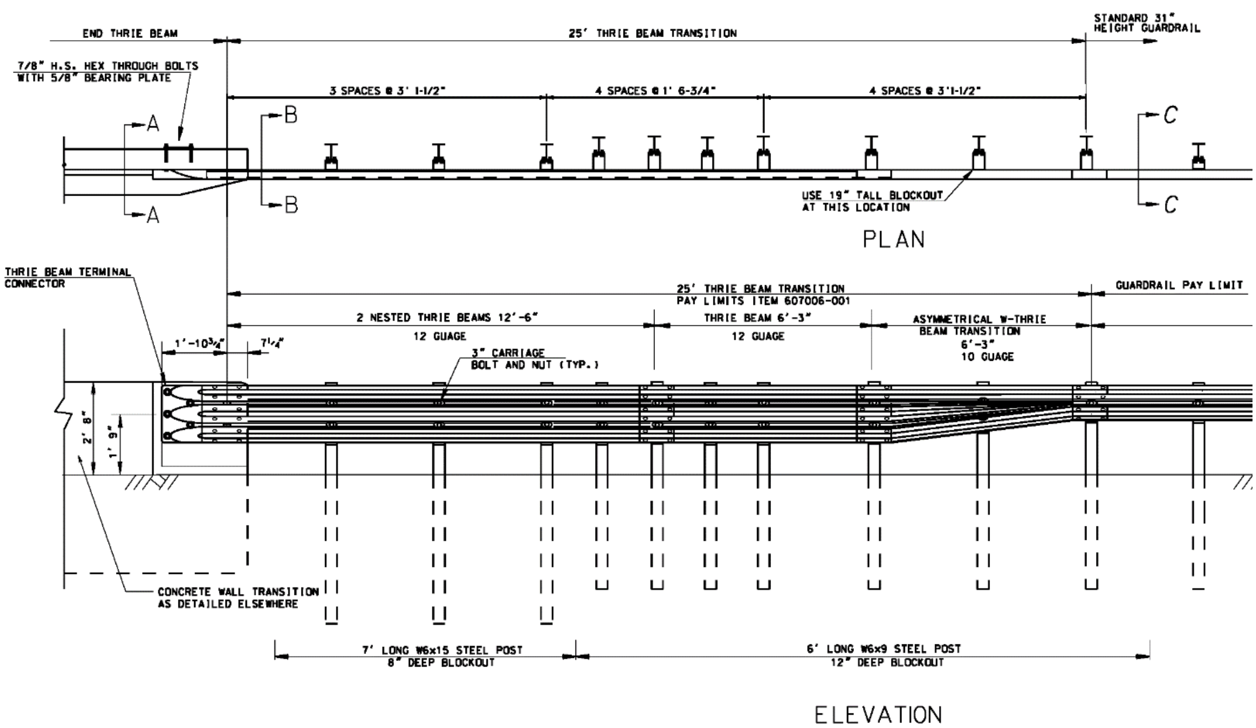


Figure 1.1. Thrie Beam Guardrail Bridge Transition and Connection [WVDOT Standard Drawing, 2016].

1.2. WORK PLAN

The work plan for the project consisted of four tasks. Details of the tasks are described below:

1.2.1. Task 1: Engineering Analysis and Review

The TTI research team performed a thorough engineering review of the available transition systems and their design variables to prepare a set of simulation design concepts. The proposed design concept list was simulated under Task 2.

1.2.2. Task 2: Simulation

The TTI research team modeled the concept transition systems and conducted extensive simulations to evaluate the impact performance of the systems to finalize an optimized shorter transition for full-scale crash testing under Task 3.

1.2.3. Task 3: *MASH* Test 3-21 Crash Testing of the Transition with Shorter Length

The TTI research team completed full-scale *MASH* Test 3-21 on a transition with shorter length. The *MASH* 2270P (5000-lb) pickup truck impacts the transition at a speed of 62 mph and an angle of 25 degrees. This test evaluates the performance of a shorter transition system upon impact with the 2270P pickup truck.

1.2.4. Task 4: Evaluation and Reporting

The TTI research team prepared this research report fully documenting the simulation and evaluation of the crash test completed in this project. The report includes detailed engineering drawings of the transition system.

CHAPTER 2. LITERATURE REVIEW*

2.1. INTRODUCTION

A literature review was performed and completed for this project. The engineering review of the available transition systems satisfies the requirement of Task 1.

2.2. DEVELOPMENT OF MGS APPROACH GUARDRAIL TRANSITION USING STANDARDIZED STEEL POSTS

The researchers at Midwest Roadside Safety Facility (MwRSF) developed a simplified version of the original Midwest Guardrail System (MGS) stiffness transition by utilizing two common sizes of steel posts, and it was full-scale crash tested according to *MASH* TL-3 criteria (*2*). The design of the stiffness transition for this project included a standard MGS, a previously accepted thrie beam approach guardrail transition (AGT) system, and an asymmetrical W-beam to thrie beam transition element.

A new, simplified steel-post stiffness transition between the MGS and a thrie beam AGT previously accepted by FHWA was developed and tested for this project. This system consists of standard steel posts and an asymmetric W-to-thrie transition element. A very stiff thrie beam guardrail transition was used during the full-scale crash test. This system satisfied all *MASH* TL-3 criteria. Figure 2.1 illustrates the details of the recommended transition design for the MGS system to thrie beam. The design is similar to the standard approach transition that West Virginia Department of Transportation is using.

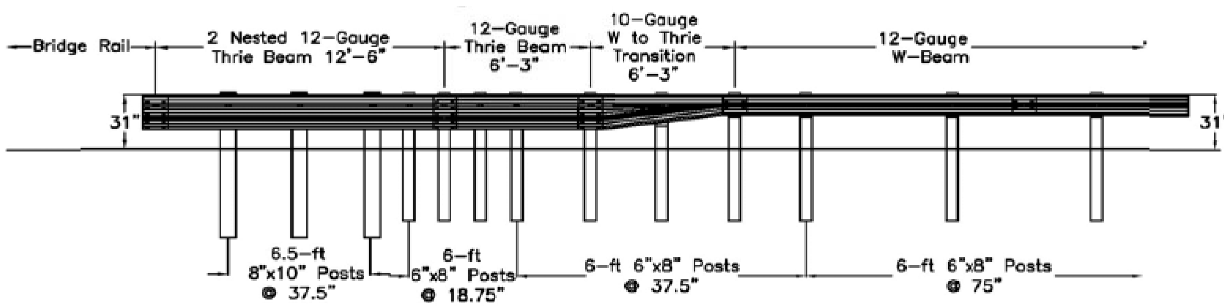


Figure 2.1. MwRSF Simplified Steel Post Stiffness Transition System.

2.3. *MASH* TEST 3-21 ON TL-3 THRIE BEAM TRANSITION WITHOUT CURB

TTI researchers evaluated the performance of a simplified approach transition design without a curb or a rubrail (Figure 2.2) (*3*). The test was performed in accordance with the *MASH* criteria under the impact conditions for Test Designation 3-21.

* 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. Simplified Thrie Beam transition without Curb and Rubrail.

The single slope bridge rail was constructed according to the Texas Department of Transportation (TxDOT) standards with a height of 36 inches. The guardrail was constructed using 19 posts. Posts 1 and 2 were installed as part of the standard 31-inch ET-2000 Terminal. Posts 3 through 11 were installed as part of a standard 12-gauge W-Beam Guardrail (RWM04a). Each post in this section is a 72-inch long W6×8.5 SLP (PEW01) attached to the 12-gauge rail element using an 8-inch wood blockout. The posts were placed at the mid-span of each rail. Between posts 11 and 13, a 10-gauge thrie beam to W-beam asymmetric transition piece is utilized and is supported by a 72-inch long W6×8.5 SLP. A nested 12-gauge thrie beam (RTM02a) rail is used between post 13 and the end of the single slope barrier. In this section, 84-inch long W6×8.5 posts with 6×8×18-inch wood blockouts are used. A 10-gauge thrie beam end shoe (RTE01b) is used to attach the nested thrie beam to the ¼-inch thick adapter plate.

The TxDOT TL-3 transition did not perform acceptably for MASH Test 3-21 due to a pickup truck rollover. Signs of wheel snagging at the blunt end of the single slope concrete barrier could have contributed to destabilizing the vehicle.

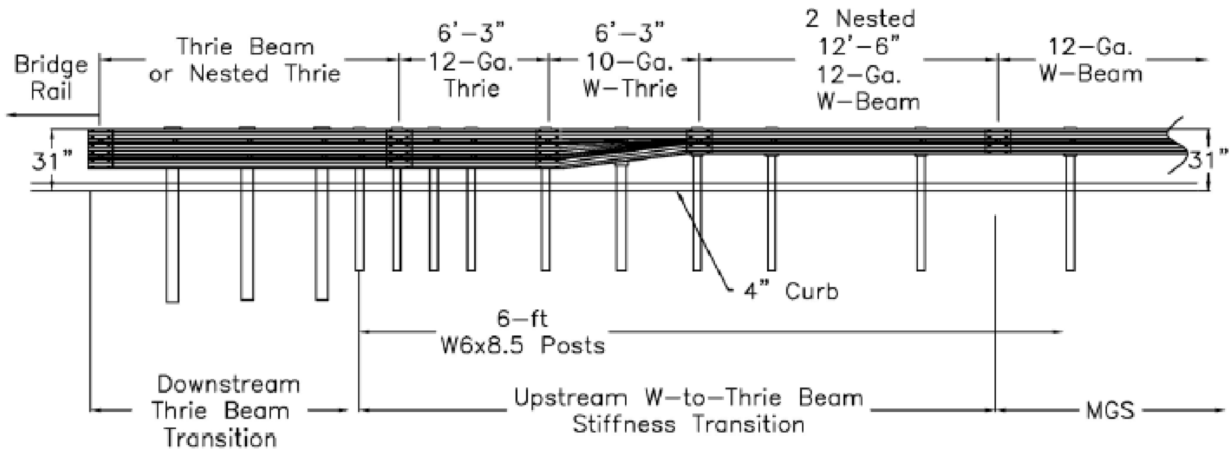
Three design modifications to improve the system performance were proposed:

1. A short curb may be placed at the end of the parapet under the rail to help prevent the wheel snagging.
2. The steel blockout at the end of the parapet could be increased in depth to offset the rail to decrease the amount of snagging.
3. The posts in the nested section of the guardrail could be strengthened by using a larger size post and increasing the embedment depth.

2.4. DYNAMIC EVALUATION OF MGS STIFFNESS TRANSITION WITH CURB

MwRSF Research Project Number TPF-5(193)

MwRSF researchers developed a stiffness transition with a 4-inch tall concrete curb to connect MGS to a previously developed thrie beam approach guardrail system (*4*). The test installation is shown in Figure 2.3.



(b)

Figure 2.3. MGS to Thrie Beam Stiffness Transition Details with Curb.

Three crash tests were conducted: Test Nos. MWTC-1, MWTC-2, and MWTC-3. Test Nos. MWTC-1 and MWTC-2 were performed according to test designation *MASH* Test No. 3-20 with an 1100C small car. Test No. MWTC-3 was performed according to test designation MASH Test No. 3-21 with a 2270P pickup truck. In the first crash test (Test No. MWTC-1), the MGS Stiffness Transition with Curb did not perform acceptably. The front of the 1100C vehicle penetrated under the W-beam rail while the wheel overrode the curb. The combination of these events resulted in the W-beam rail to rupture at the splice adjacent to the rail elements, which eventually caused the W-beam rail to rupture.

After the failed crash test, the design was modified to incorporate an additional 12 gauge W-beam segment such that 12.5 ft of nested guardrail preceded the asymmetric W-beam to thrie beam transition element. After this modification was incorporated in the stiffness transition system, Test Nos. MWTC-2 and MWTC-3 were performed with an 1100C small car and 2270P pickup truck, respectively. The modification resulted in a successful completion of the *MASH* TL-3 testing matrix. Therefore, this system was found to satisfy current safety standards.

2.5. *MASH* TL-3 EVALUATION OF GUARDRAIL TO RIGID BARRIER TRANSITION ATTACHED TO BRIDGE OR CULVERT STRUCTURE

TTI Test Report No. FHWA/TX-19/0-6954-R1

TTI researchers evaluated a guardrail to rigid barrier transition attached to a bridge or culvert structure using computer simulations and full-scale crash testing (5).

The Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure installation consisted of a 16-ft long reinforced concrete parapet and moment slab, a 27 ft-6¼ inch long W-beam to thrie-beam to parapet transition section that was anchored to the parapet, 50 ft of W-beam guardrail, and a TxDOT Downstream Anchor Terminal (DAT). The posts in the thrie-beam portion of the installation were anchored to a reinforced concrete wingwall that was embedded in the soil with the top at grade, and the rest of the posts were embedded directly into the soil. The top edge of the thrie-beam and W-beam rails were at 31 inches above grade. The wingwall was 13 ft long, 12 inches thick, and 5 ft deep. A C6×8.2 rub rail was positioned below the thrie-beam section of the transition. Figure 2.4 shows the transition installation on a wingwall.

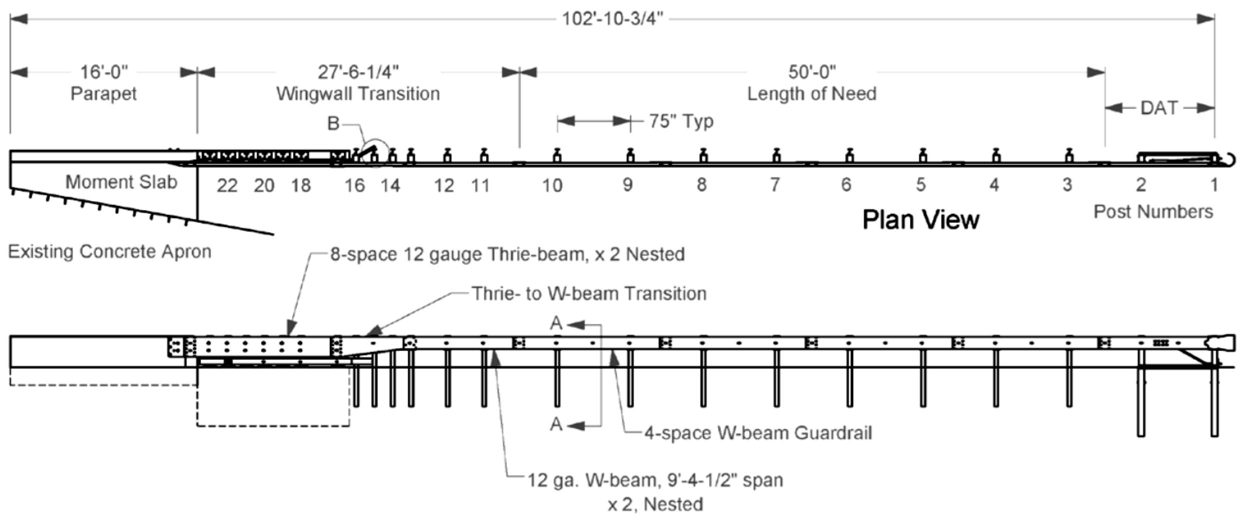


Figure 2.4. Installation Details for Transition on Wingwall.

The target critical impact points (CIPs) were determined using computer simulation. Three crash tests were conducted. Two on the upstream of the transition and one on the downstream. The target CIPs for *MASH* Test 3-20 (Test No. 469549-01-1) and *MASH* Test 3-21 (Test No. 469549-01-2) were the centerline of post 13 and 14, respectively. The target CIP for *MASH* Test 3-21 (Test No. 469549-01-4) was 5 inches downstream of the centerline of post 19 at the connection with the rail.

The Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure performed acceptably for *MASH* TL-3 criteria.

2.6. *MASH* TL-3 EVALUATION OF 2019 *MASH* 2-TUBE BRIDGE RAIL THRIE BEAM TRANSITION

TTI Test Report No. 608331-4-6

TTI researchers assessed the performance of the 2019 *MASH* 2-Tube Bridge Rail Thrie Beam Transition according to the safety-performance evaluation guidelines included in AASHTO *MASH* (*6*).

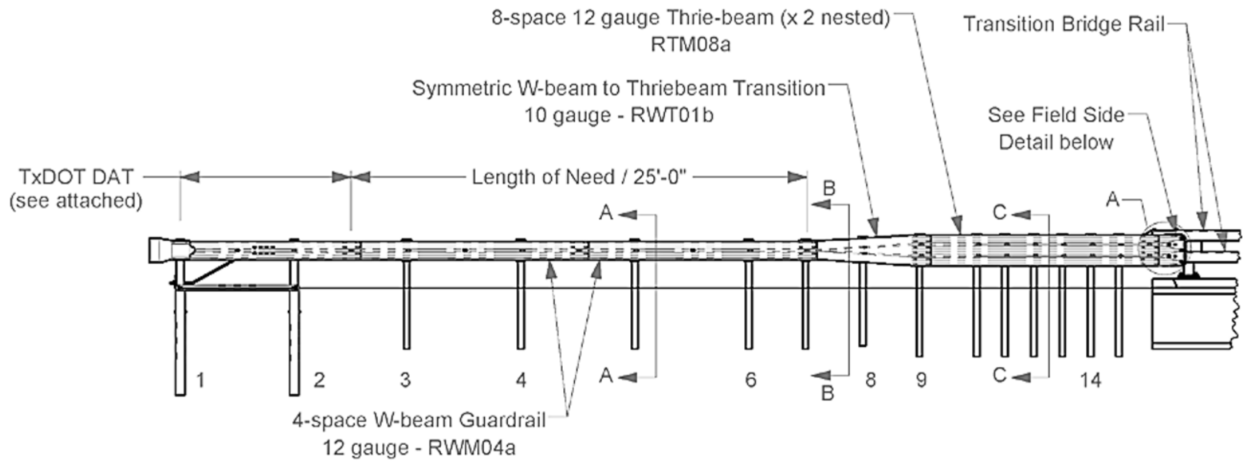


Figure 2.5. Details of 2019 *MASH* 2-Tube Bridge Rail Thrie Beam Transition.

The target critical impact point (CIP) for each test was determined in accordance with the guidance provided in *MASH*. For *MASH* Test 3-20, the target CIP was 5.1 ft upstream of the end of the concrete parapet. The target CIP for *MASH* Test 3-21 on the thrie beam to bridge rail transition was 7.0 ft upstream of the concrete parapet. The target CIP for *MASH* Test 3-21 on the W-beam to thrie beam transition was 7.3 ft upstream of the centerline of post 7. TTI researchers determined that *MASH* Test 3-20 on the W-beam to thrie beam transition was not necessary and was therefore not performed.

The 2019 *MASH* 2-Tube Bridge Rail Thrie Beam Transition performed acceptably for a *MASH* TL-3 transition.

2.7. SUMMARY AND CONCLUSIONS FROM LITERATURE SEARCH

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

1. In the case of not using a curb or rubrail, the blunt end of the concrete parapet needs to be protected to reduce the possibility of wheel snagging.
2. The thrie beam upstream of the parapet needs to be nested.
3. Crash testing should be performed on the nested thrie beam or the W-to-thrie transition section.

CHAPTER 3. SIMULATION*

1.1. INTRODUCTION

Finite element modeling simulations were conducted on the transition design as part of Task 2. The computer simulations were performed using LS-DYNA.

3.2. SYSTEM DESIGN

The 99 ft-5¼ inch installation consists of four sections: A 16-ft vertical wall parapet, a 24 ft-4-¾ inch transition section, a 50 ft length of need, and a 9 ft-½ inch TxDOT DAT. All the posts are 72-inch long W6×8.5 with 6×8×14-inch wood blockouts throughout the test installation. A 6 ft-¼ inch long nested Thrie beam is connecting the W-to-thrie segment to the concrete parapet via a 10 gauge thrie beam end shoe. Figure 3.1 through Figure 3.4 show details of the transition design used in the preliminary simulation effort.

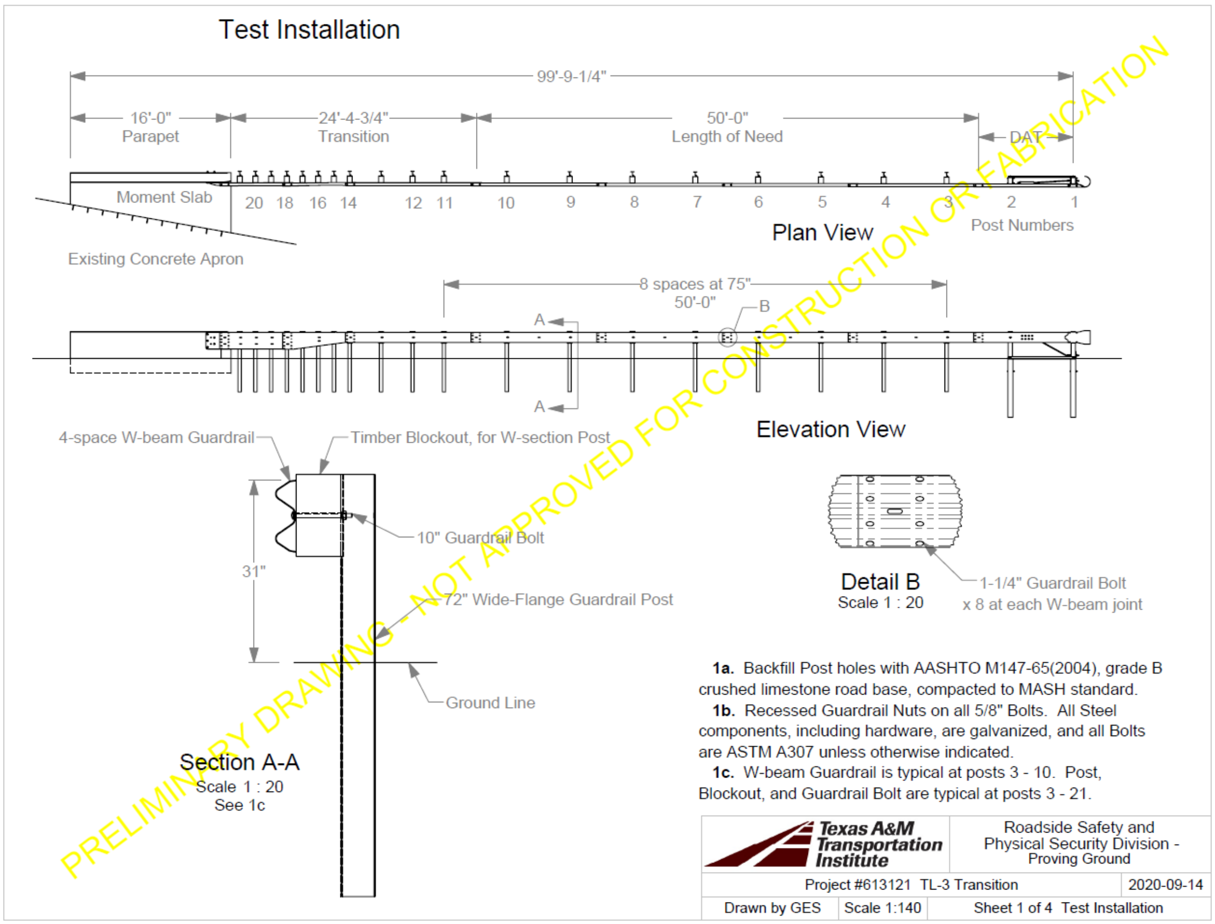


Figure 3.1. Plan View and Elevation of Installation.

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

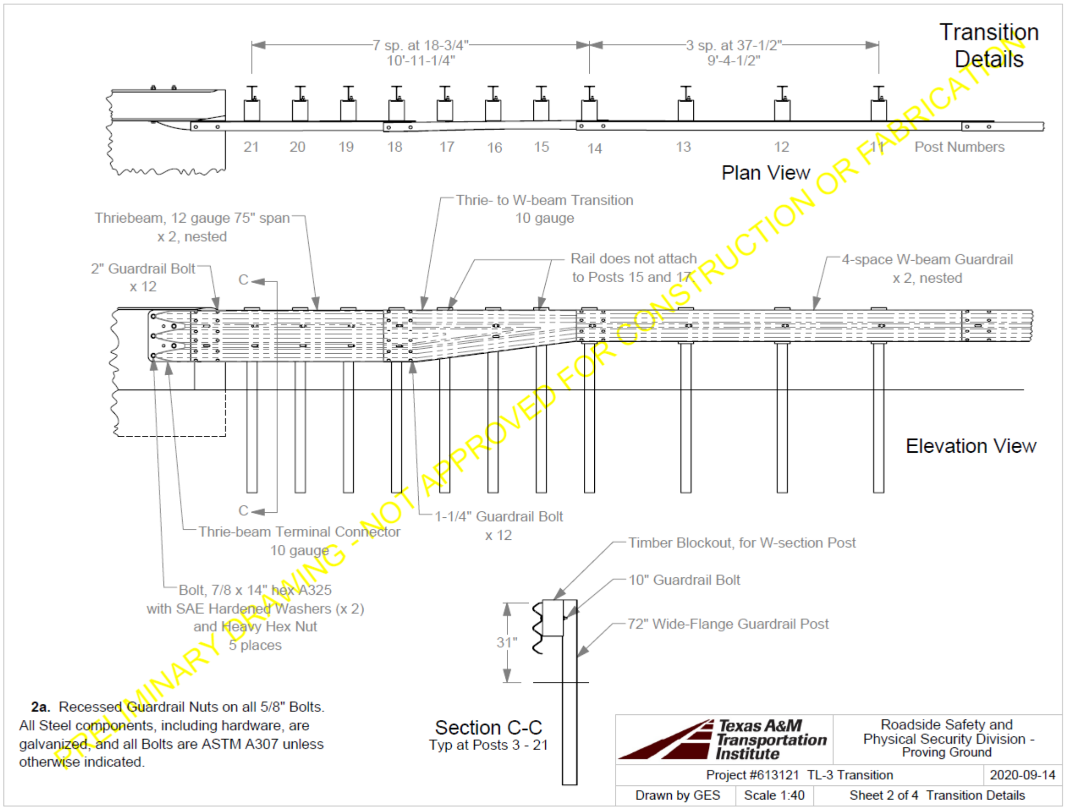


Figure 3.2. Preliminary Transition Details.

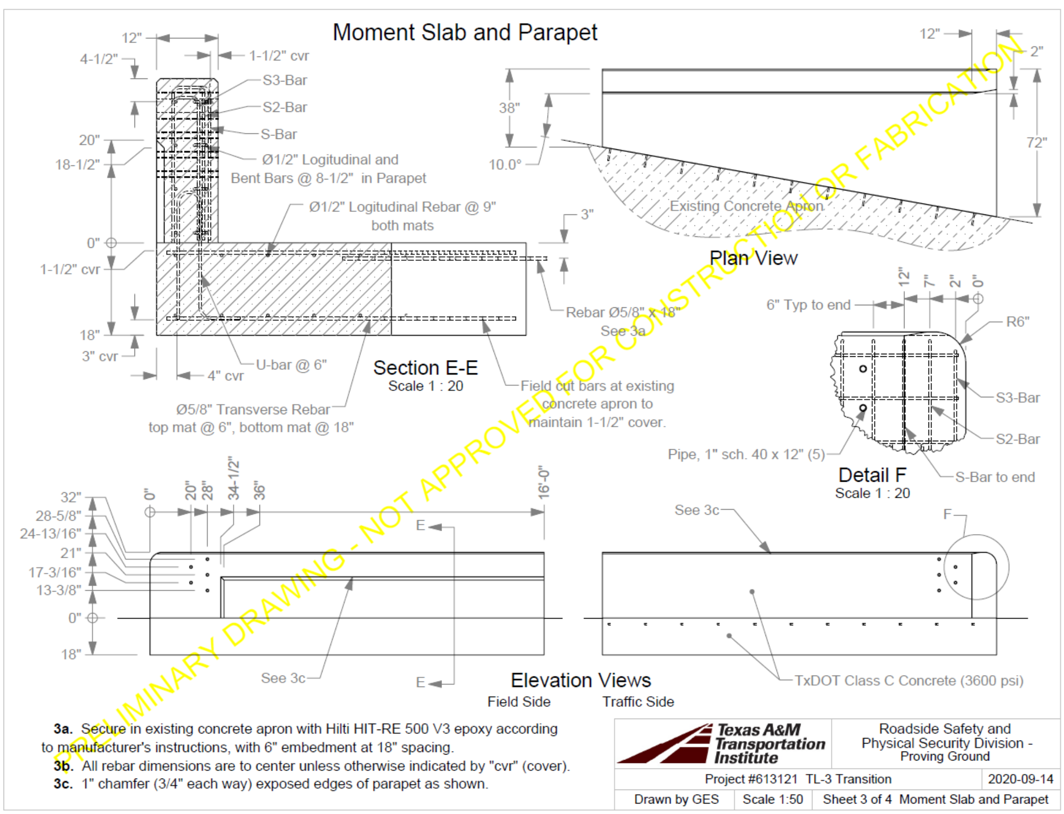


Figure 3.3. Moment Slab and Parapet Details.

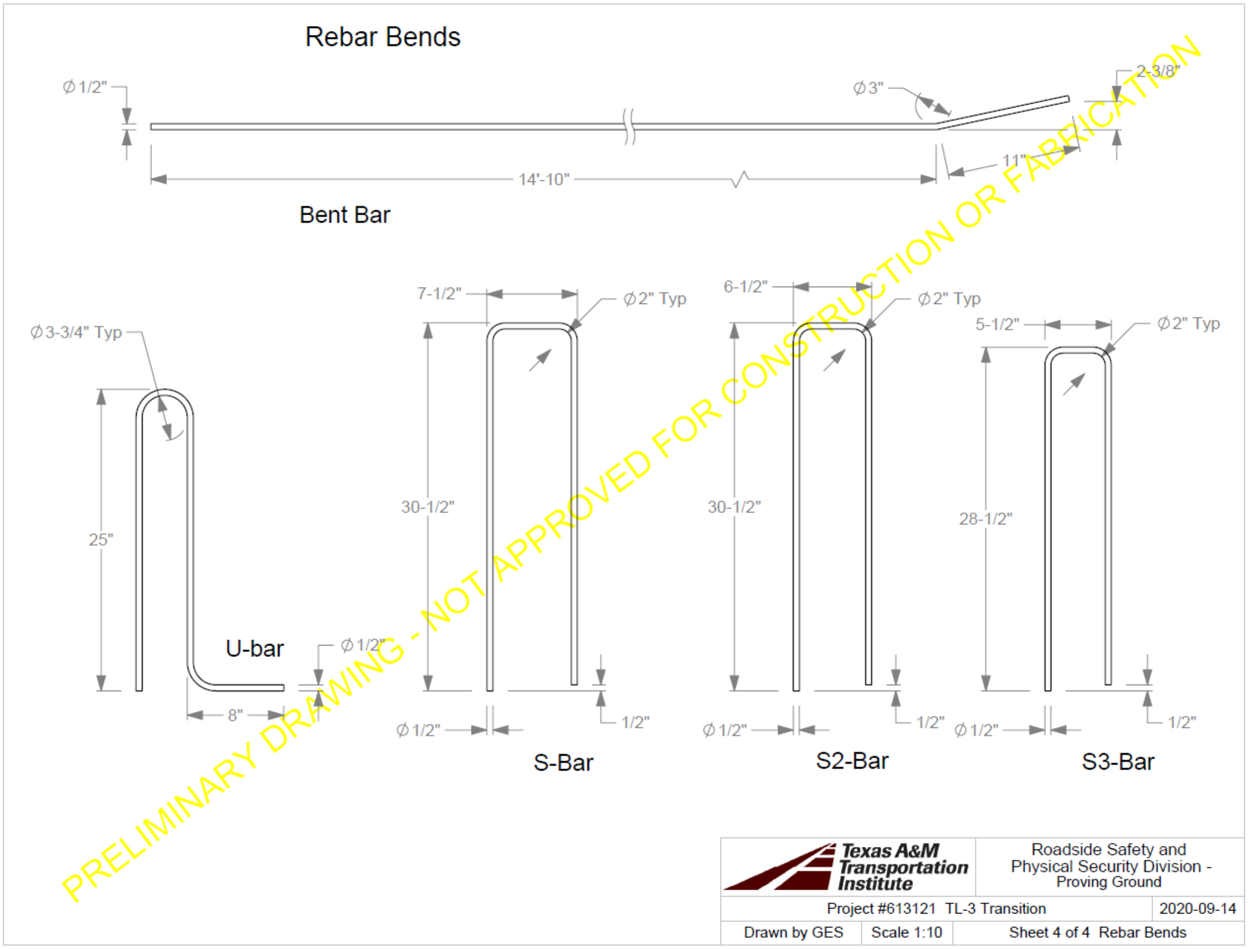


Figure 3.4. Rebar Details.

3.3. DETAILED MODELING

An explicit finite element model of the transition system was created using detailed geometrical and material properties. Figure 3.5 and Figure 3.6 show the front and rear views of the system modeled, including the moment slab, parapet, transition posts, nested thrie section, and approaching W-beam guardrail. The rear view shows the utilization of 14-inch blockouts all through the system. The moment slab was modeled as rigid and did not consider any material failure from the impact loads. The shorter transition system comprised of a nested 6 ft-3 inch 12 gauge thrie-beam followed by an asymmetric W-to-thrie transition segment. Figure 3.7 shows views of the *MASH* 1100C and 2270P vehicle models used in the computer simulations.

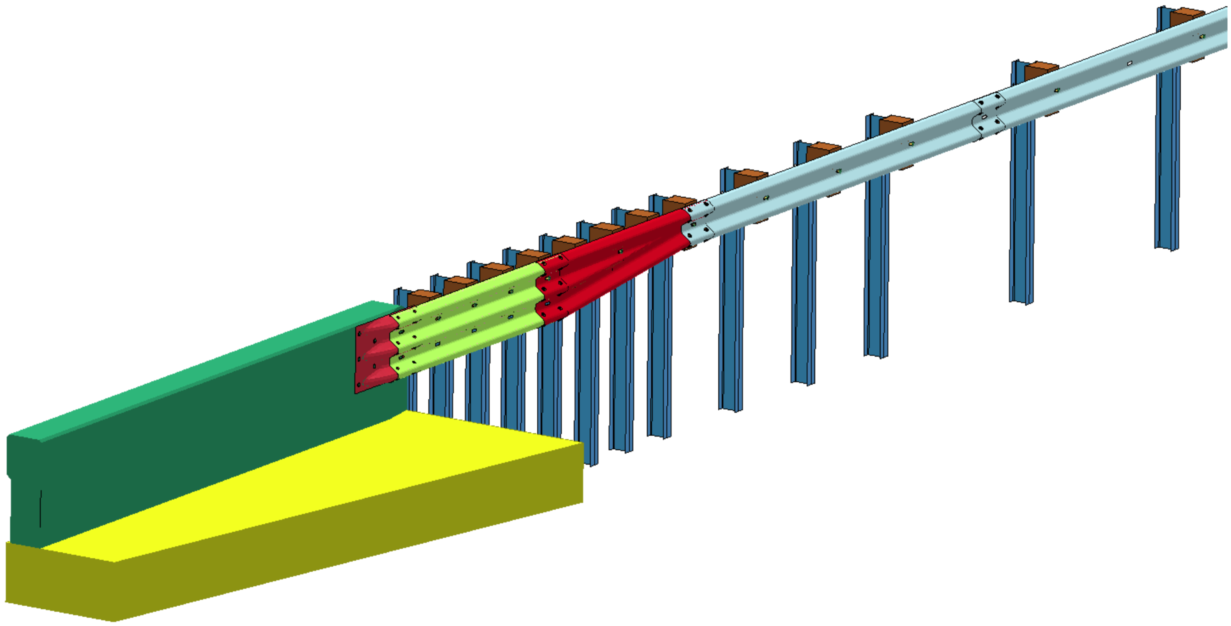


Figure 3.5. Front View of System.

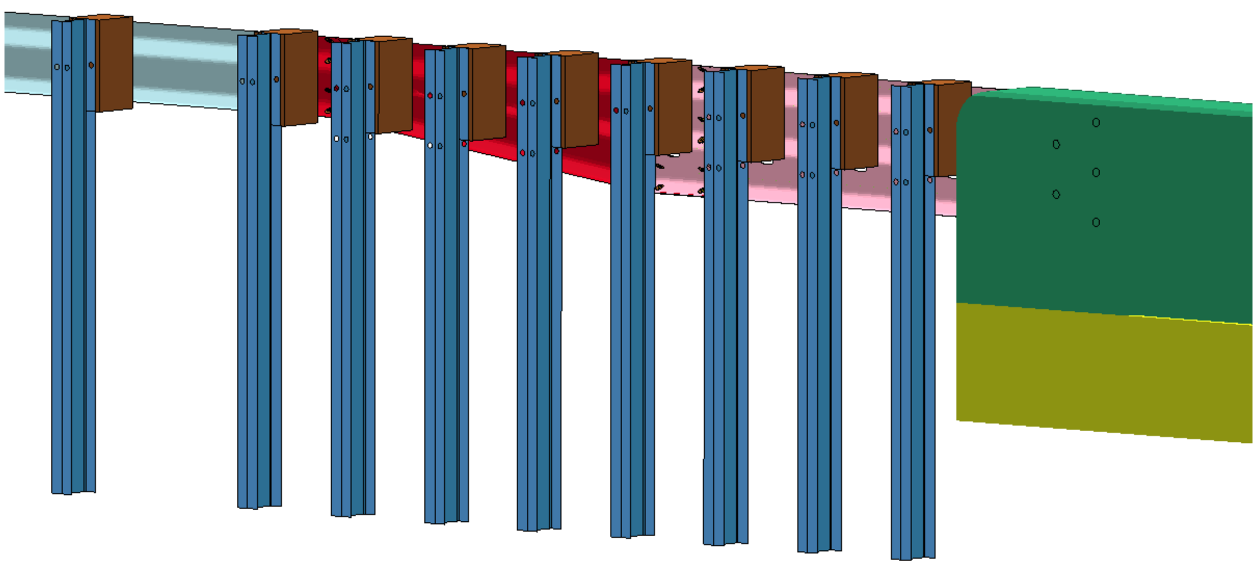
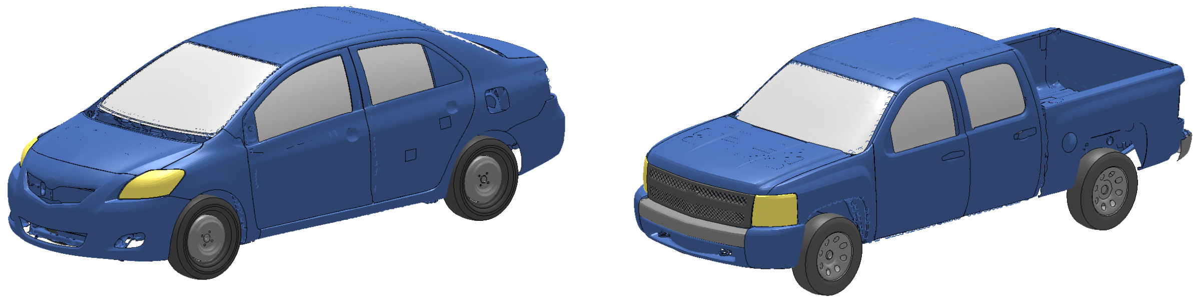


Figure 3.6. Rear View of System.



(a) (b)

Figure 3.7. MASH Test Vehicles: (a) 1100C and (b) 2270P.

3.4. SIMULATION

All impact simulations were performed under *MASH* TL-3 impact conditions. The research team performed an extensive parametric analysis to investigate the system and impacting vehicles performance at various impact points. The objective was to identify the critical impact point for the full-scale crash testing. Table 3.1 and Table 3.2 show the test conditions and evaluation criteria for transitions, respectively. The simulation procedure and the results are presented below.

Table 3.1. Test Conditions and Evaluation Criteria for Transitions According to *MASH* TL-3.

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

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

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

3.4.1. MASH Test 3-21: Pickup Truck Impacting the Shorter Transition

Figure 3.8 through Figure 3.10 show the images of the vehicle setup for this impact simulation. The vehicle used in this simulation is a 2270P vehicle weighing 5000 lb and impacting the barrier at a speed of 62 mph and an angle of 25 degrees.

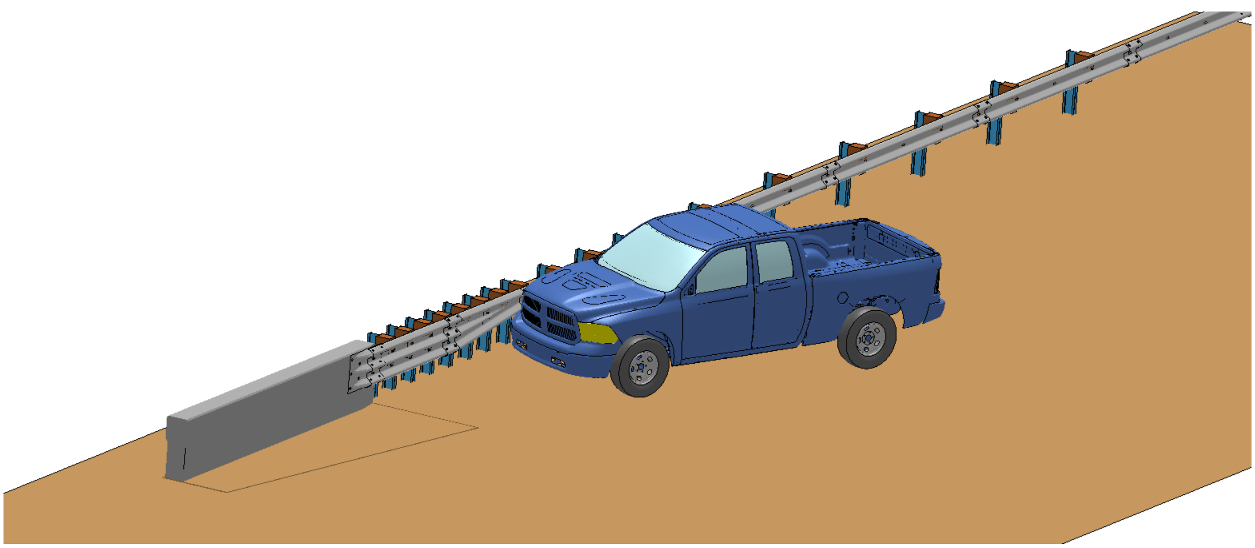


Figure 3.8. *MASH* 2270P Vehicle/Installation Setup – Isometric View.

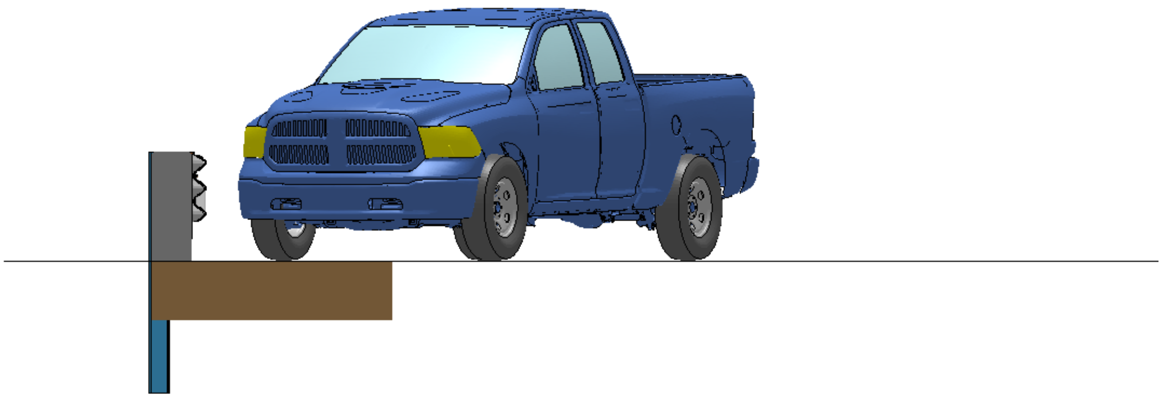


Figure 3.9. *MASH* 2270P Vehicle/Installation Setup – Front View.

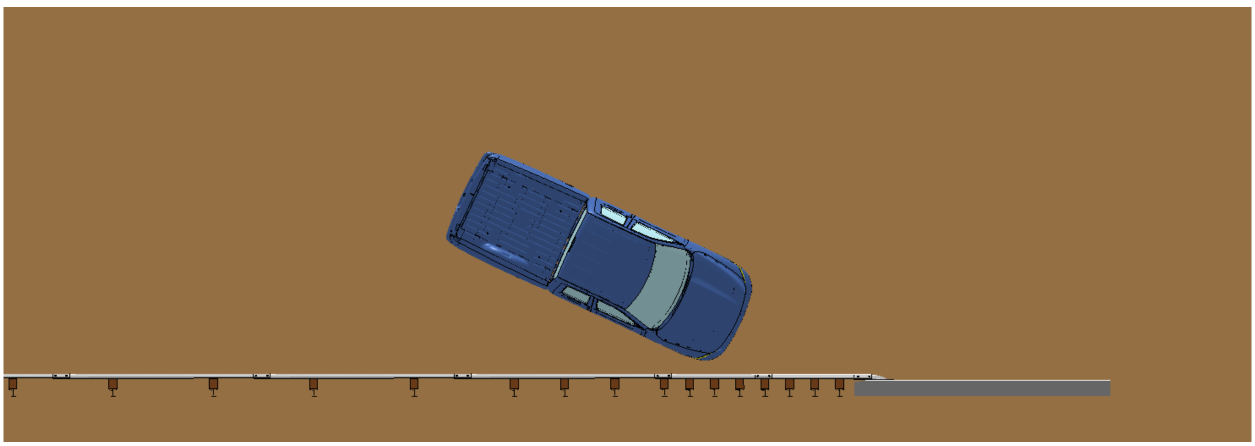


Figure 3.10. *MASH* 2270P Vehicle/Installation Setup – Top View.

According to the literature review section, in transitions without curb or rubrail, the main reason for failing full-scale crash test was vehicle rollover. Thus, the researchers investigated various design modifications to improve the system performance and reduce vehicular instability. The parametric analysis indicated that the maximum roll angle occurs when the target critical impact point (CIP) is the centerline of post 17 (Figure 3.11). The sequential images of the simulation are presented in Figure 3.12.

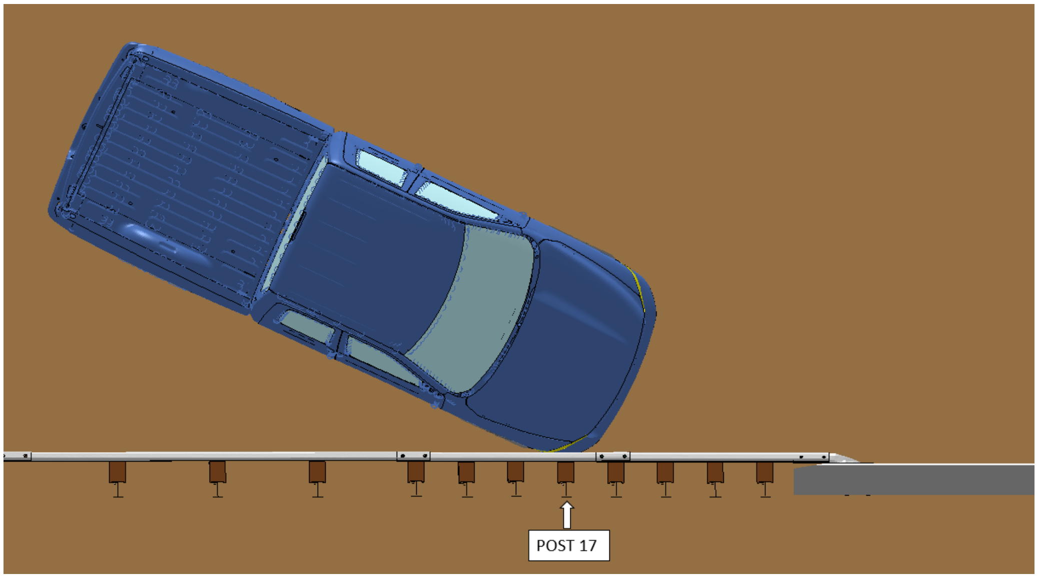


Figure 3.11. Target CIP for *MASH* Test 3-21.

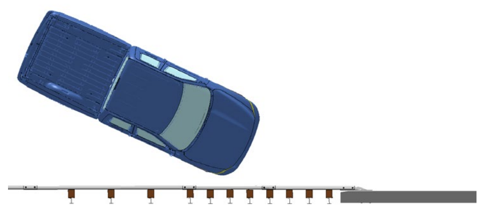
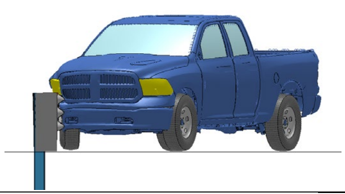
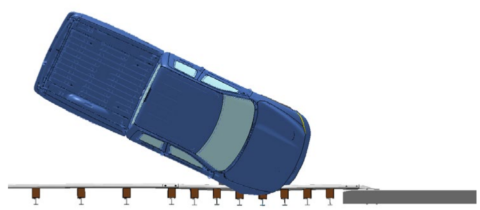
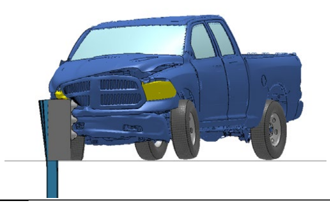
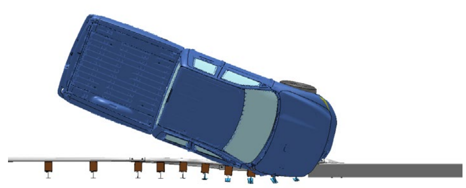
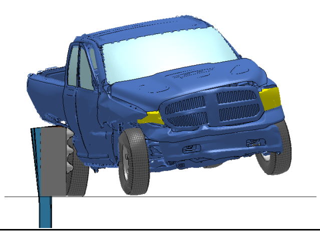
Frontal View	Top View	Time (s)
		0.00
		0.05
		0.10
		0.25

Figure 3.12. Sequential Images of *MASH* Test 3-21 for Shorter Terminal.

3.4.2. *MASH* Test 3-20: Small Car Impacting Shorter Transition

Figure 3.13 shows the vehicle setup for small car impact simulation. The vehicle used in this simulation is a 1100C vehicle impacting the barrier at a speed of 62 mph and an angle of 25 degrees. As depicted in Figure 3.14, the impact side tire experienced severe snagging to the parapet toe that may cause higher occupant risk factors in a full-scale crash test. To reduce the possibility of tire snagging, a deflector plate was placed between the parapet toe and the field side flange of Post 20 (the second post from the parapet) (Figure 3.15).

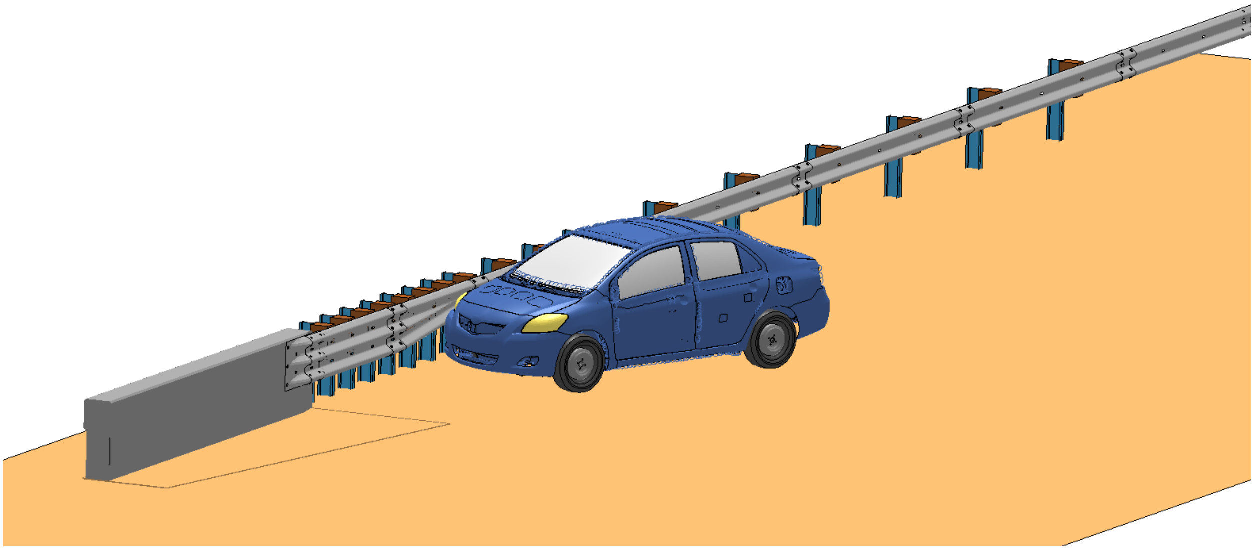


Figure 3.13. *MASH* 1100C Vehicle/Installation Setup – Isometric View.

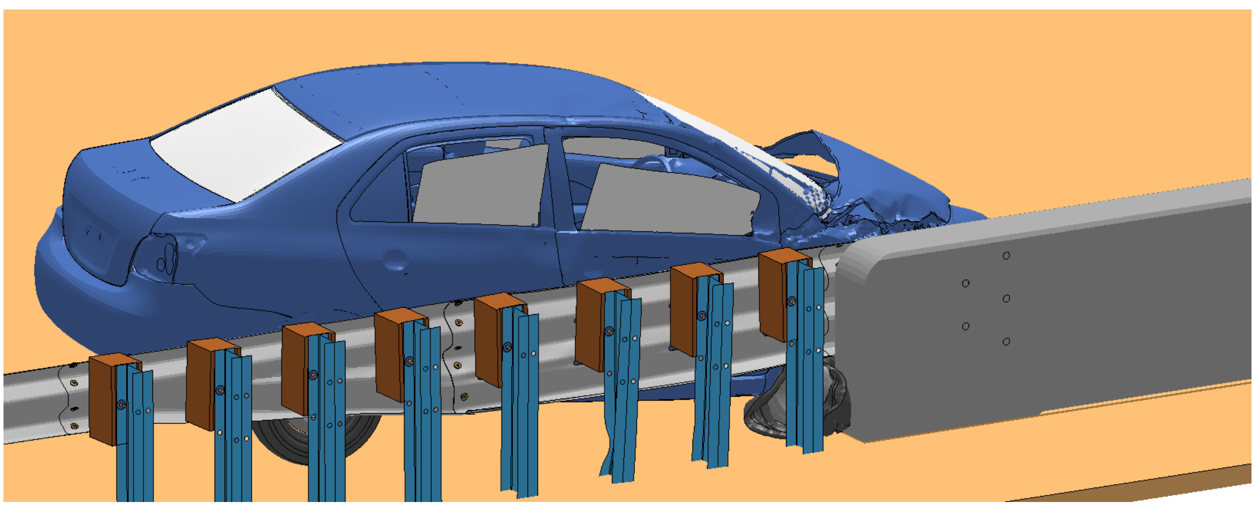


Figure 3.14. *MASH* 1100C Vehicle/Installation Setup – Tire Snagging to Parapet.

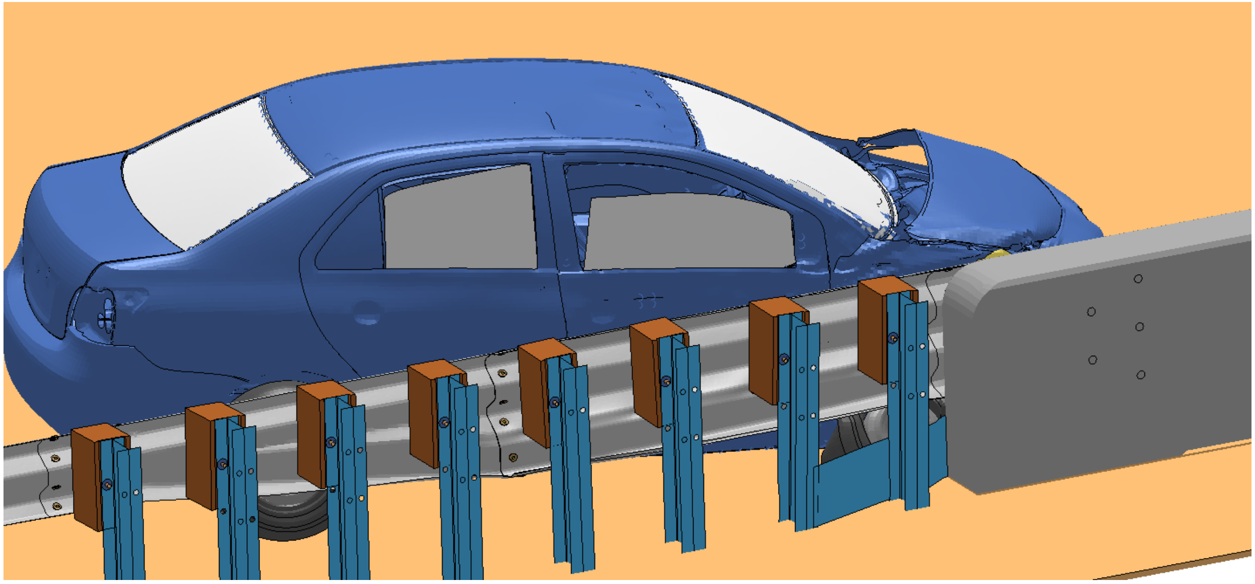


Figure 3.15. *MASH* 1100C Vehicle/Installation Setup – Effect of Added Deflector Plate in Reducing Tire Snagging.

3.5. SUMMARY AND CONCLUSIONS

Based on the simulation effort, the recommended system for evaluation needs to have the following specifications:

- Shorter blockouts (14-inch W-beam blockouts) behind the thrie beam to allow the bottom of the thrie beam to bend inward upon the impact to dissipate the energy and consequently reduce the bottom of the vehicle bouncing back. This design would reduce the possibility of excessive roll angle observed in previous transitions of similar structure (transitions without any curb and/or rubrail) that caused vehicular instability, and rollover in some cases.
- A deflector place or a similar method for a smooth redirection of the small car tire from the concrete parapet's blunt end.

MASH recommends conducting Test 3-20 "if there is a reasonable uncertainty regarding the impact performance of the system for impact with small car." By utilizing the deflector plate that controls the tire snagging at the concrete parapet toe, the immediate area upstream of the concrete parapet appeared favorable for *MASH* Test 3-20, so this test did not need to be performed.

CHAPTER 4. SYSTEM DETAILS

4.1 TEST ARTICLE AND INSTALLATION DETAILS

The test installation was 99 ft-9¼ inches long and consisted of an upstream Texas Department of Transportation Downstream Anchor Terminal (DAT) guardrail terminal, a length of W-beam guardrail transitioning to thrie-beam guardrail, and a downstream reinforced concrete parapet. The top edge of the guardrail measured 31 inches above grade and was supported by steel posts with timber blockouts. Beginning at the end of the DAT, posts 2 through 11 supporting the W-beam were spaced at 75 inches for 50 ft, followed by posts 11 through 14 spaced at 37½ inches for 9 ft-4½ inches. At this point, the W-beam asymmetrically transitioned to a thrie-beam over 75 inches, followed by two nested 75-inch-long sections of thrie-beam guardrail. Posts 14 through 21 were spaced at 18¾ inches in the transition and thrie-beam sections, spanning 10 ft-11¼ inches. The rail was not attached to posts 15, 17, 19, and 21 in the transition and thrie-beam sections. Guardrail splices were located mid-span between the posts except for the splices located at posts 14 and 18. The developed system was desired to be readily installation existing vertical concrete end posts.

The nested thrie-beam rails were attached to a thrie-beam end shoe, which was secured to a 16-ft long 32-inch-tall steel reinforced concrete parapet that had a vertical traffic side face. A deflector plate was attached to the traffic side face of the parapet below the thrie-beam. It angled toward the field side of the installation, passed on the traffic side of post 21 (the post nearest the parapet), and was secured to post 20 on its field side. This plate was 8 inches wide, ¼-inch thick, and approximately 36 inches long, with two bends.

Figure 4.1 presents the overall information on the short transition, and Figure 4.2 provides photographs of the installation. Appendix A provides further details on the short transition. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and rail construction was performed by DMA Construction Inc. supervised by TTI Proving Ground personnel. Concrete construction was performed by TTI Proving Ground personnel.

4.2 DESIGN MODIFICATIONS DURING TESTS

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

4.3 MATERIAL SPECIFICATIONS

The specified compressive strength of the TxDOT Class C concrete used in the parapet was 3600 psi. On April 8, 2021, the average compressive strength of the concrete was 5900 psi.

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

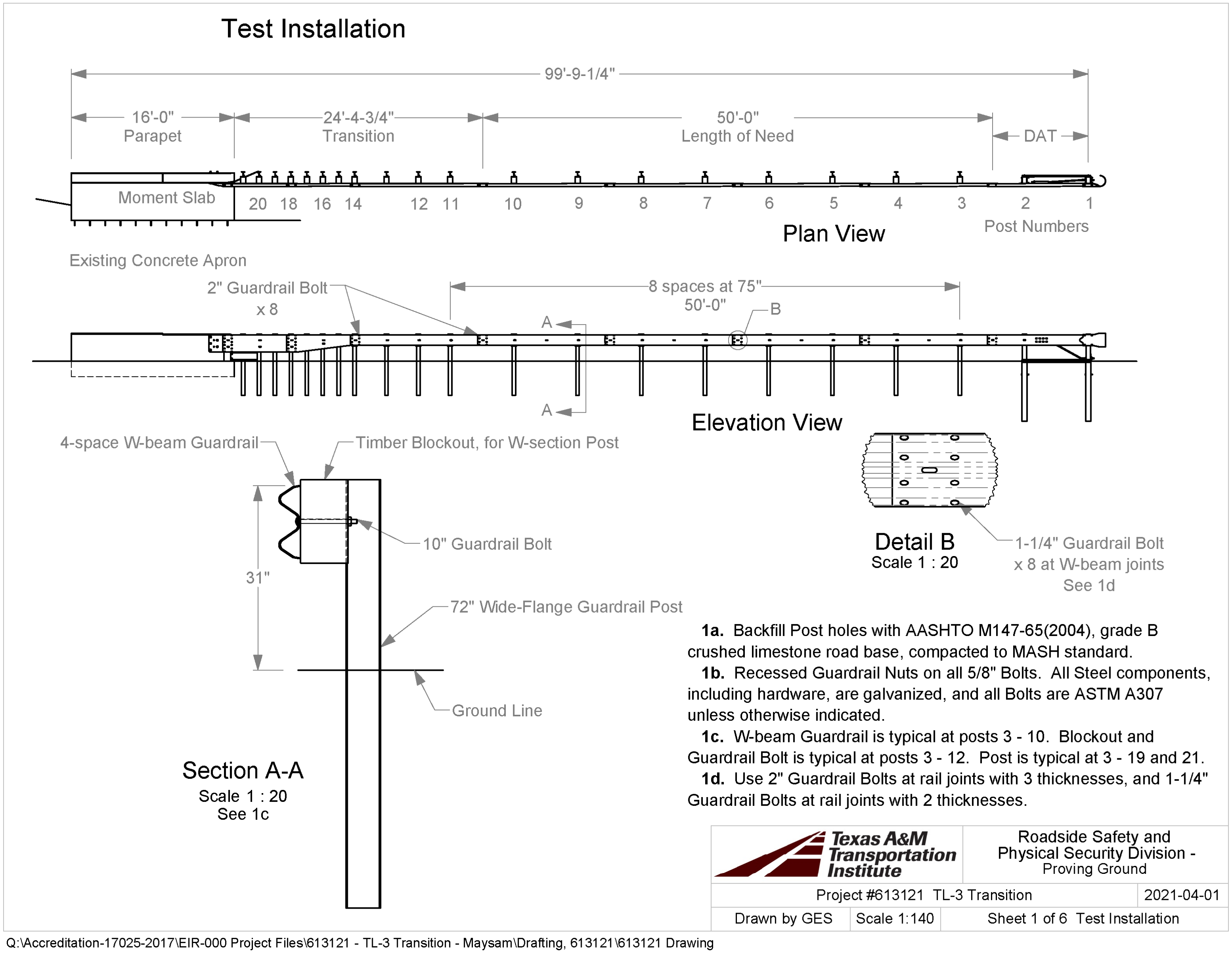


Figure 4.1. Details of Transition.

Figure 4.2. Transition prior to Testing.

4.4 SOIL CONDITIONS

The test installation was installed in standard soil meeting grading B of AASHTO standard specification M147-65(2004) "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses."

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

As determined by the tests summarized in Appendix C, Table C.1, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 3940 lbf, 5500 lbf, and 6540 lbf (90 percent of static load for the initial standard installation). On the day of the test, April 19, 2021, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 7020 lbf, 7777 lbf, and 8383 lbf. Table C.2 in Appendix C shows the strength of the backfill material in which the transition was installed met minimum *MASH* requirements for soil strength.

CHAPTER 5. TEST REQUIREMENTS AND EVALUATION CRITERIA

5.1 CRASH TEST PERFORMED/MATRIX

Table 5.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for transitions. The target critical impact points (CIPs) for each test were determined using the information provided in *MASH* Section 2.2.2. Figure 5.1 shows the target CIP for *MASH* Test 3-21 on the transition.

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

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

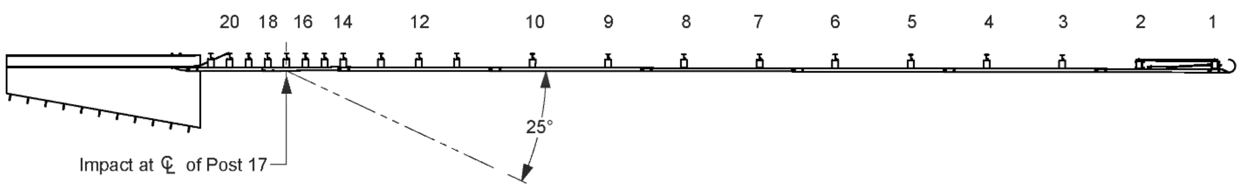


Figure 5.1. Target CIP for *MASH* Test 3-21 on Transition.

Based on the transition design evaluation by computer simulation, *MASH* Test 3-20 did not present reasonable uncertainty of success, so this test was not performed (considered optional for *MASH*).

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 2-3 and 5-1 of *MASH* were used to evaluate the crash test reported herein. Table 5.1. lists the test conditions and evaluation criteria required for *MASH* TL-3, and Table 5.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 8.

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

Evaluation Factors	Evaluation Criteria	*MASH* Test
Structural Adequacy	*A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	*3-20 and 3-21*
Occupant Risk	*D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*	*3-20 and 3-21*
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	*3-20 and 3-21*
	H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	*3-20 and 3-21*
	I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	*3-20 and 3-21*

CHAPTER 6. TEST CONDITIONS

6.1 TEST FACILITY

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

The test facilities of the TTI Proving Ground are located on The Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 mi northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, highway pavement durability and efficacy, and roadside safety hardware and perimeter protective device evaluation. The site selected for construction and testing of the 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

The 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.

6.3. DATA ACQUISITION SYSTEMS

6.3.1. Vehicle Instrumentation and Data Processing

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

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

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

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

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 of the 2270P vehicle. The dummy was not instrumented.

6.3.3. Photographic Instrumentation Data Processing

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

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

- A third placed with a field of view parallel to and aligned with the installation at the downstream end.

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

7 *MASH* TEST 3-21 (CRASH TEST NO. 613121-01-1)

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 longitudinal barrier at an impact speed of 62 mi/h ± 2.5 mi/h and an angle of 25 degrees ± 1.5 degrees. The CIP for *MASH* Test 3-21 on the short transition was at the centerline of post 17 ±1 ft. Figure 5.1 and Figure 7.1 depict the target impact setup.

Figure 7.1. Transition/Test Vehicle Geometrics for Test No. 613121-01-1.

The 2270P vehicle weighed 5061 lb, and the actual impact speed and angle were 62.6 mi/h and 25.4 degrees. The actual impact point was the centerline of post 17. Minimum target impact severity (IS) was 106 kip-ft, and actual IS was 122 kip-ft.

7.2. WEATHER CONDITIONS

The test was performed on the morning/afternoon of April 19, 2021. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h; wind direction: 296 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 64°F; relative humidity: 59 percent.

7.3. TEST VEHICLE

Figure 7.2 shows the 2016 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5061 lb, and its gross static weight was 5226 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.25 inches. Tables D.1 and D.2 in Appendix D.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.2. Test Vehicle before Test No. 613121-01-1.

7.4. TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 613121-01-1. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 613121-01-1.

Time (s)	Events
0.0000	Vehicle impacts the transition
0.0380	Vehicle begins to redirect
0.1090	Left front tire lifts off of the pavement
0.1100	Left rear tire lifts off of the pavement
0.2080	Vehicle traveling parallel with transition
0.2213	Left rear bumper contacts the installation
0.3850	Vehicle loses contact with transition while traveling at 46.9 mi/h, at a trajectory of 9.7 degrees, and a heading of 12.9 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 after the vehicle exited the test site. The vehicle came to rest 165 ft downstream of the point of impact and 68 ft toward traffic lanes.

7.5. DAMAGE TO TEST INSTALLATION

Figure 7.3 and Figure 7.4 show the damage to the transition. The existing cracks were marked in black, and the post-impact cracks were marked in red. The rail was scuffed and deformed at impact. The soil was disturbed at posts 14 and 15, and there was slight spalling on the upstream end of the concrete barrier. Table 7.2 provides additional measurements and damage details. Working width* was 27.6 inches, and height of working width was 29.7 inches. Maximum dynamic deflection during the test was 10.4 inches, and maximum permanent deformation was 7.8 inches.

Figure 7.3. Transition after Test No. 613121-01-1.

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

Figure 7.4. Field Side of Transition after Test No. 613121-01-1.

Table 7.2. Post Movement after Test No. 613121-01-1.

Post #	Lean from Vertical	Traffic Side Gap in Soil (inches)
16	2°	$^{5}/_{8}$
17	4°	$1^{3}/_{8}$
18	8°	$2^{1}/_{4}$
19	10°	$2^{3}/_{4}$
20	9°	4
21	6°	-

7.6. DAMAGE TO TEST VEHICLE

Figure 7.5 shows the damage sustained by the vehicle. The front bumper, hood, grill, radiator and support, right front fender, right frame rail, right upper and lower control arms, right front tire and rim, right front corner of the floor pan, right front door, right front and rear doors, right lower cab corner, right exterior bed, right rear rim, and rear bumper were damaged. The windshield sustained stress cracks radiating upward and inward from the right lower corner. 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 7.75 inches in the right front firewall/toe pan area. Figure 7.6 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 7.5. Test Vehicle after Test No. 613121-01-1.

Figure 7.6. Interior of Test Vehicle after Test No. 613121-01-1.

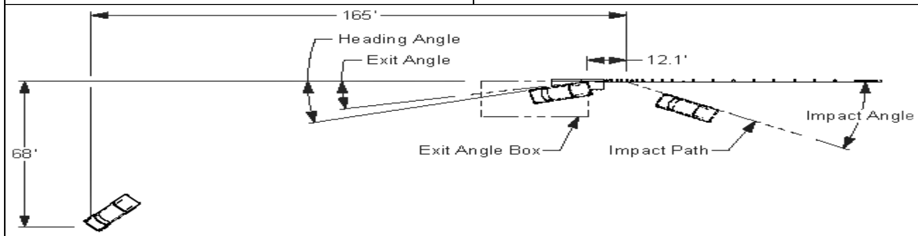
7.7. OCCUPANT RISK FACTORS

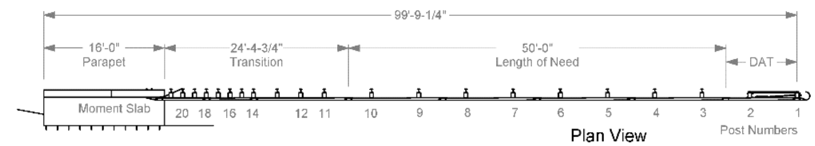
Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.3. Figure D.3 in Appendix D.3 shows the vehicle angular displacements, and Figures D.4 through D.6 in Appendix D.4 show acceleration versus time traces. Figure 7.7 summarizes pertinent information from the test.

Table 7.3. Occupant Risk Factors for Test No. 613121-01-1.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	22.3 ft/s	at 0.1053 s on right side of interior
Lateral	27.3 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	24.3 g	0.1054 - 0.1154 s
Lateral	10.3 g	0.1053 - 0.1153 s
Theoretical Head Impact Velocity (THIV)	10.3 m/s	at 0.1029 s on right side of interior
Acceleration Severity Index (ASI)	1.7	0.0931 - 0.1431 s
Maximum 50-ms Moving Average		
Longitudinal	−13.6 g	0.0657 - 0.1157 s
Lateral	−12.6 g	0.0534 - 0.1034 s
Vertical	3.7 g	0.1112 - 0.1612 s
Maximum Yaw, Pitch, and Roll Angles		
Roll	22°	0.5159 s
Pitch	18°	0.7082 s
Yaw	61°	2.0000 s

0.000 s	0.100 s	0.200 s	0.400 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-21
TTI Test No.	613121-01-1
Test Date	2021-04-19
Test Article	
Type	Transition
Name	Short Transition
Installation Length	99 ft-9¼ inches
Material or Key Elements	W-beam transitioning to thrie-beam attached to concrete parapet
Soil Type and Condition	AASHTO M147 Grade B Soil, dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2016 RAM 1500 Pickup
Curb	5085 lb
Test Inertial	5061 lb
Dummy	165 lb
Gross Static	5226 lb

Impact Conditions	
Speed	62.6
Angle	25.4°
Location/Orientation	Centerline post 17
Impact Severity	122 kip-ft
Exit Conditions	
Speed	46.9 mi/h
Trajectory/Heading Angle	9.7°/12.9°
Occupant Risk Values	
Longitudinal OIV	22.3 ft/s
Lateral OIV	27.3 ft/s
Longitudinal Ridedown	24.3 g
Lateral Ridedown	10.3 g
THIV	10.3 m/s
ASI	1.7
Max. 0.050-s Average	
Longitudinal	−13.6 g
Lateral	−12.6 g
Vertical	3.7 g

Post-Impact Trajectory	
Stopping Distance	165 ft downstream 68 ft twd traffic lanes
Vehicle Stability	
Maximum Roll Angle	22°
Maximum Pitch Angle	18°
Maximum Yaw Angle	61°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	10.4 inches
Permanent	7.8 inches
Working Width	27.6 inches
Height of Working Width	29.7 inches
Vehicle Damage	
VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	16.0 inches
OCDI	RF0235100
Max. Occupant Compartment Deformation	7.75 inches

Figure 7.7. Summary of Results for *MASH* Test 4-21 on Short Transition.

8 CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS

The crash test reported herein was performed in accordance with *MASH* Test 3-21 on the transition. Table 8.1 provides an assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-21 for transitions.

8.2. CONCLUSIONS

Due to the high occupant ridedown acceleration during the crash test, the short transition did not satisfy the performance criteria for *MASH* Test 3-21 for transitions.

8.3. RECOMMENDATIONS*

The researchers believe that excessive deflection at the immediate upstream regions caused a higher interaction of the vehicle with the parapet blunt end which resulted in a higher ridedown acceleration than the *MASH* maximum limit. The deflector plate helped to reduce tire snagging and possible instability of the vehicle that was observed in previous similar systems. However, the deflector plate was not adequate in controlling the vehicle-parapet interaction. The following are possible design changes that could improve the performance of the system.

First, using two W6×15 posts at the upstream of the parapet would reduce the excessive dynamic deflection which should mitigate the pickup interaction with the parapet. This would be a viable option when the parapet/bridge rail already existed, and the purpose is to retrofit the system.

Second, using a concrete parapet with larger tapering reduces the interaction of the rail with the parapet's blunt end. This would be a good option if it is a new installation and the parapet can be designed and constructed this way.

Further development, analysis, and full-scale crash testing would be required to evaluate any of these proposed modifications.

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

Table 8.1. Performance Evaluation Summary for *MASH* Test 3-21 on Short Transition.

Test Agency: Texas A&M Transportation Institute — Test No.: 613121-01-1 — Test Date: 2021-04-19

***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 transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 10.4 inches.	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 7.75 inches in the right front firewall/toe pan area	
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 22° and 18°.	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 22.3 ft/s, and lateral OIV was 27.3 ft/s.	Pass
I. *The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Maximum longitudinal occupant ridedown acceleration was 24.3 g, and maximum lateral occupant ridedown acceleration was 10.3 g.	Fail

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2. S. K. Rosenbaugh, R. K. Faller, R. W. Bielenberg, K. A. Lechtenberg, D. L. Sicking, and J. D. Reid. *Development of the MGS Approach Guardrail Transition using Standardized Steel Posts*. MwRSF Research Report NO. TRP-03-210-10, Midwest Roadside Safety Facility, Lincoln, NE, December 21, 2010.
3. D. R. Arrington, R. P. Bligh, and W. L. Menges. *MASH Test 3-21 on TL-3 Thrie Beam Transition without Curb*. TTI Test Report No. 9-1002-12-3. Texas A&M Transportation Institute, College Station, TX, July 2013.
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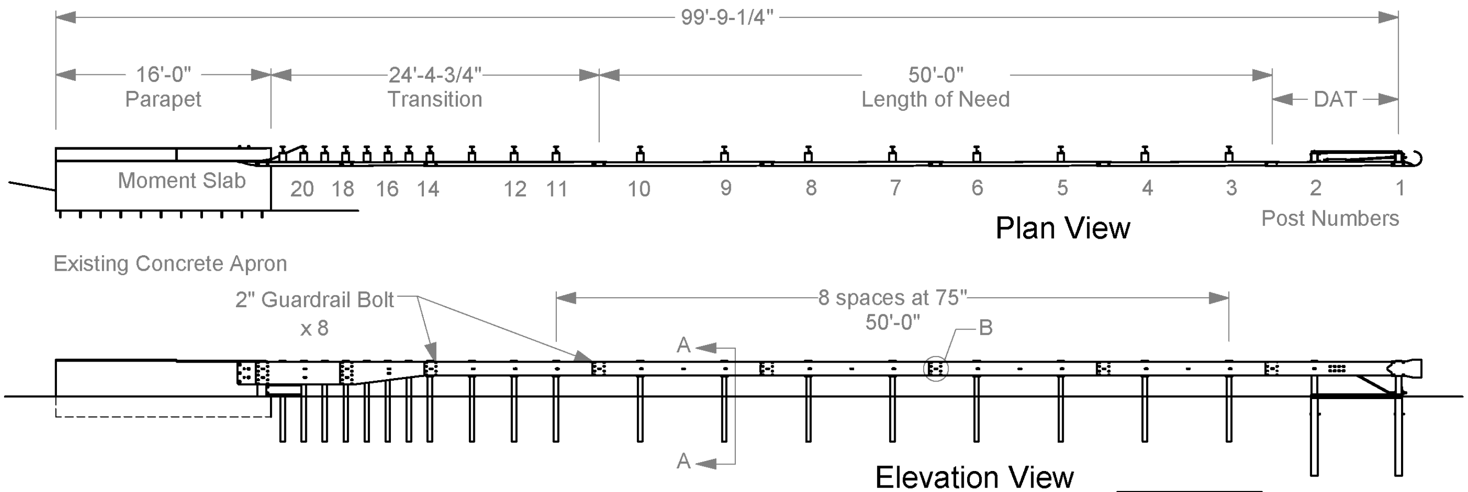
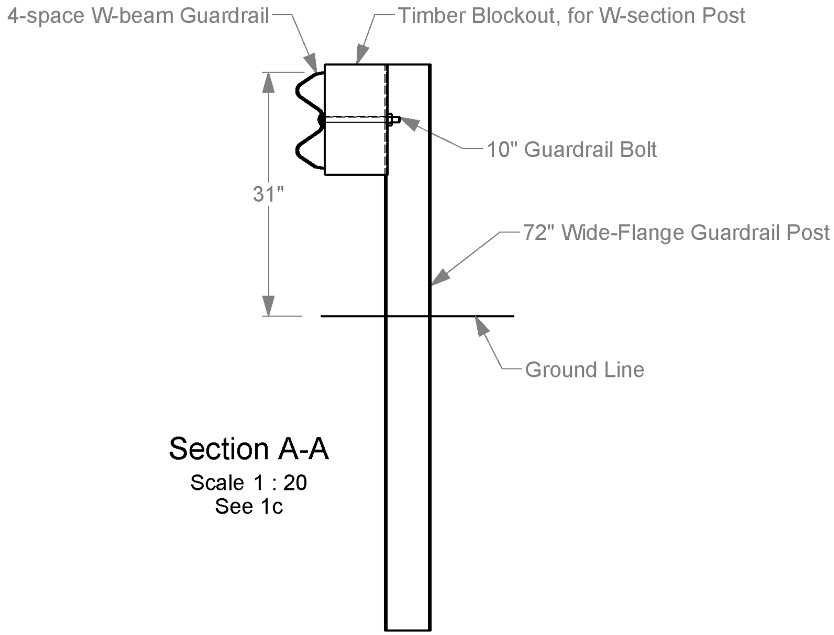
5. W. F. Williams, A.Y. Abu-Odeh, M. Kiani, M. Martinez, S. Moran, W. L. Menges, G. E. Schroeder, B. L. Griffith. Mash TL-3 Evaluation of Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure, Report No. FHWA/TX-19/0-6954-R1, Texas A&M Transportation Institute, College Station, TX, 2019.
6. W. F. Williams, W. L. Menges, G. E. Schroeder, D. L. Kuhn. Mash TL-3 Evaluation of 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition, Test Report No. 608331-01-4-6, Texas A&M Transportation Institute, College Station, TX, 2020.

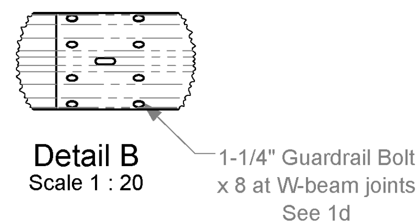
APPENDIX A. DETAILS OF SHORT TRANSITION

Test Installation





Section A-A
Scale 1 : 20
See 1c



Detail B
Scale 1 : 20

1a. Backfill Post holes with AASHTO M147-65(2004), grade B crushed limestone road base, compacted to MASH standard.

1b. Recessed Guardrail Nuts on all 5/8" Bolts. All Steel components, including hardware, are galvanized, and all Bolts are ASTM A307 unless otherwise indicated.

1c. W-beam Guardrail is typical at posts 3 - 10. Blockout and Guardrail Bolt is typical at posts 3 - 12. Post is typical at 3 - 19 and 21.

1d. Use 2" Guardrail Bolts at rail joints with 3 thicknesses, and 1-1/4" Guardrail Bolts at rail joints with 2 thicknesses.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #613121 TL-3 Transition		2021-04-01
Drawn by GES	Scale 1:140	Sheet 1 of 6 Test Installation

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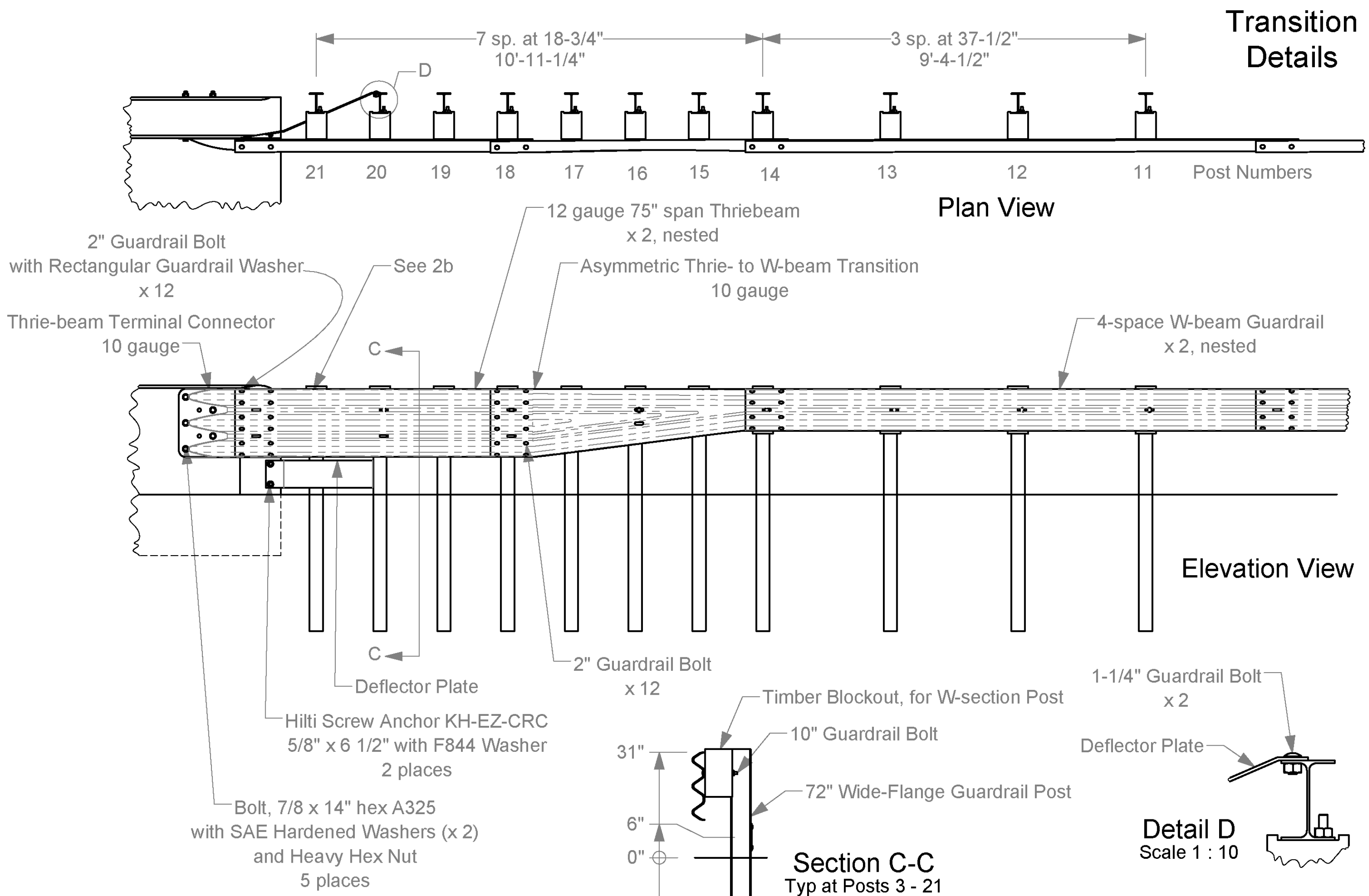

2a. Recessed Guardrail Nuts on all 5/8" Bolts. All Steel components, including hardware, are galvanized, and all Bolts are ASTM A307 unless otherwise indicated.

2b. Rail does not attach at Posts 15, 17, 19, and 21.

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Project #613121 TL-3 Transition		2021-04-01
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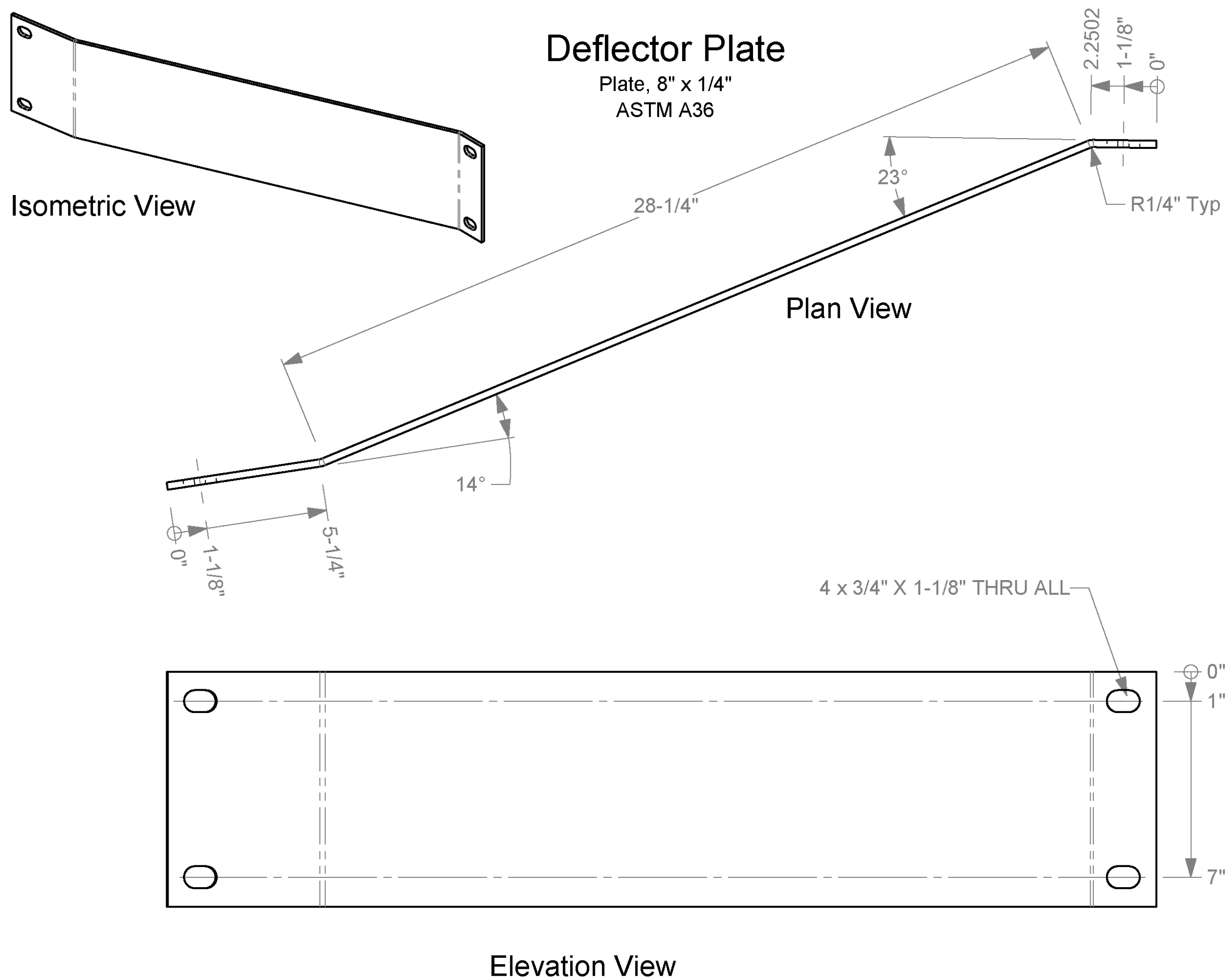

Texas A&M Transportation Institute

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Project #613121 TL-3 Transition	2021-04-01

Drawn by GES	Scale 1:5	Sheet 3 of 6 Plate Details

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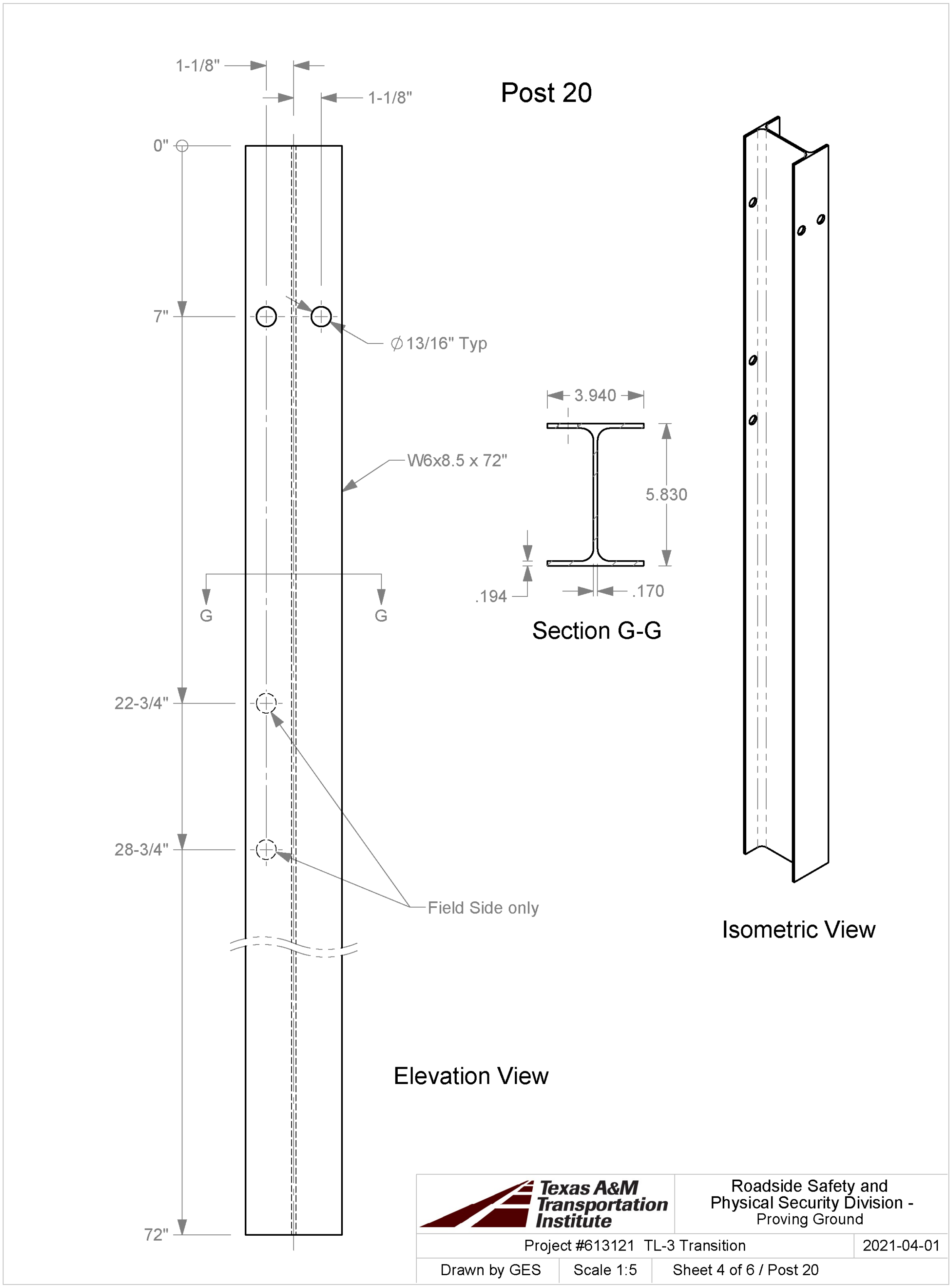

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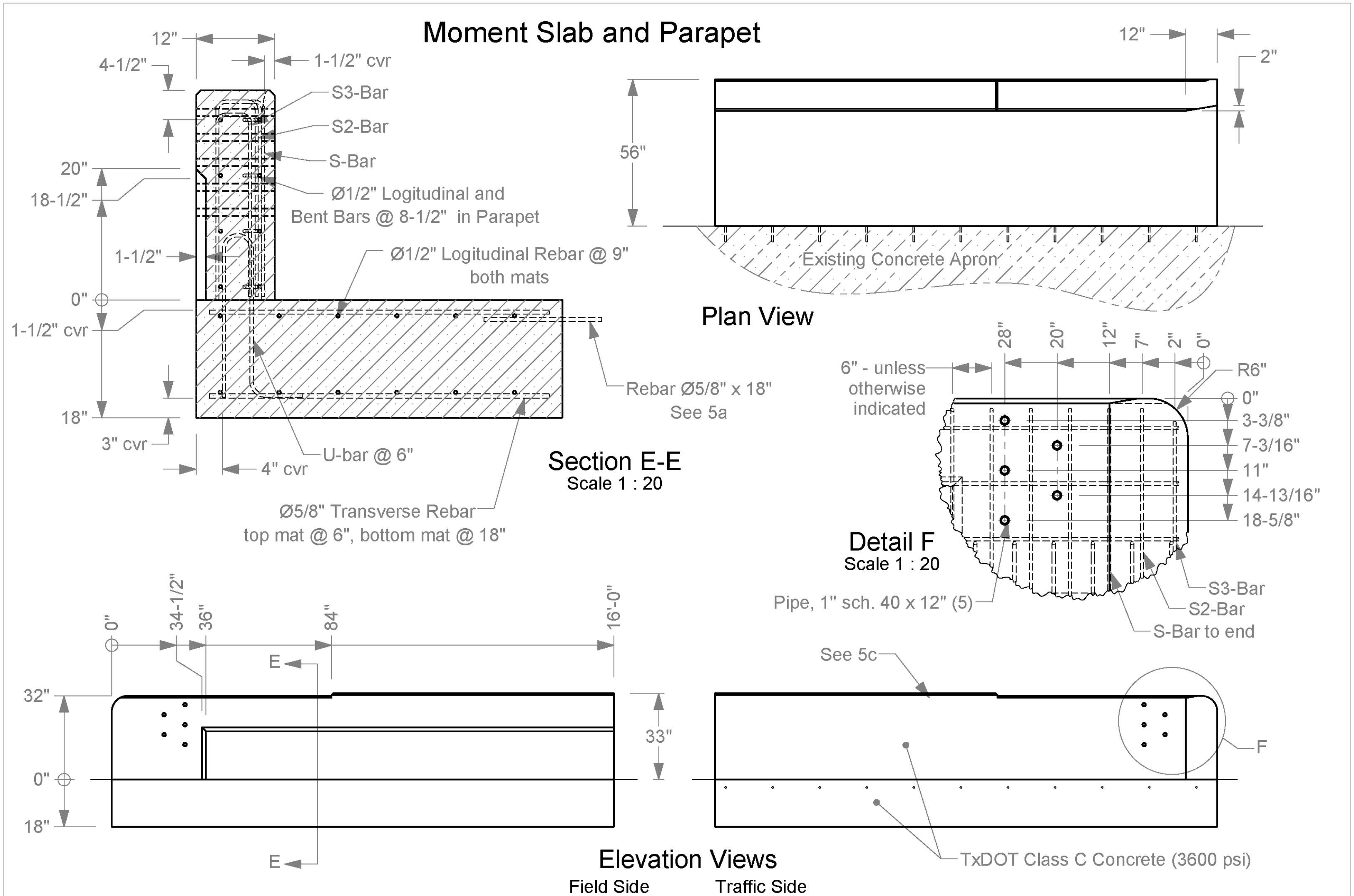
Moment Slab and Parapet



5a. Secure in existing concrete apron with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 6" embedment at 18" spacing.

5b. All rebar dimensions are to center unless otherwise indicated by "cvr" (cover).

5c. 1" chamfer (3/4" each way) exposed edges of parapet as shown.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #613121 TL-3 Transition		2021-04-01
Drawn by GES	Scale 1:50	Sheet 5 of 6 Moment Slab and Parapet

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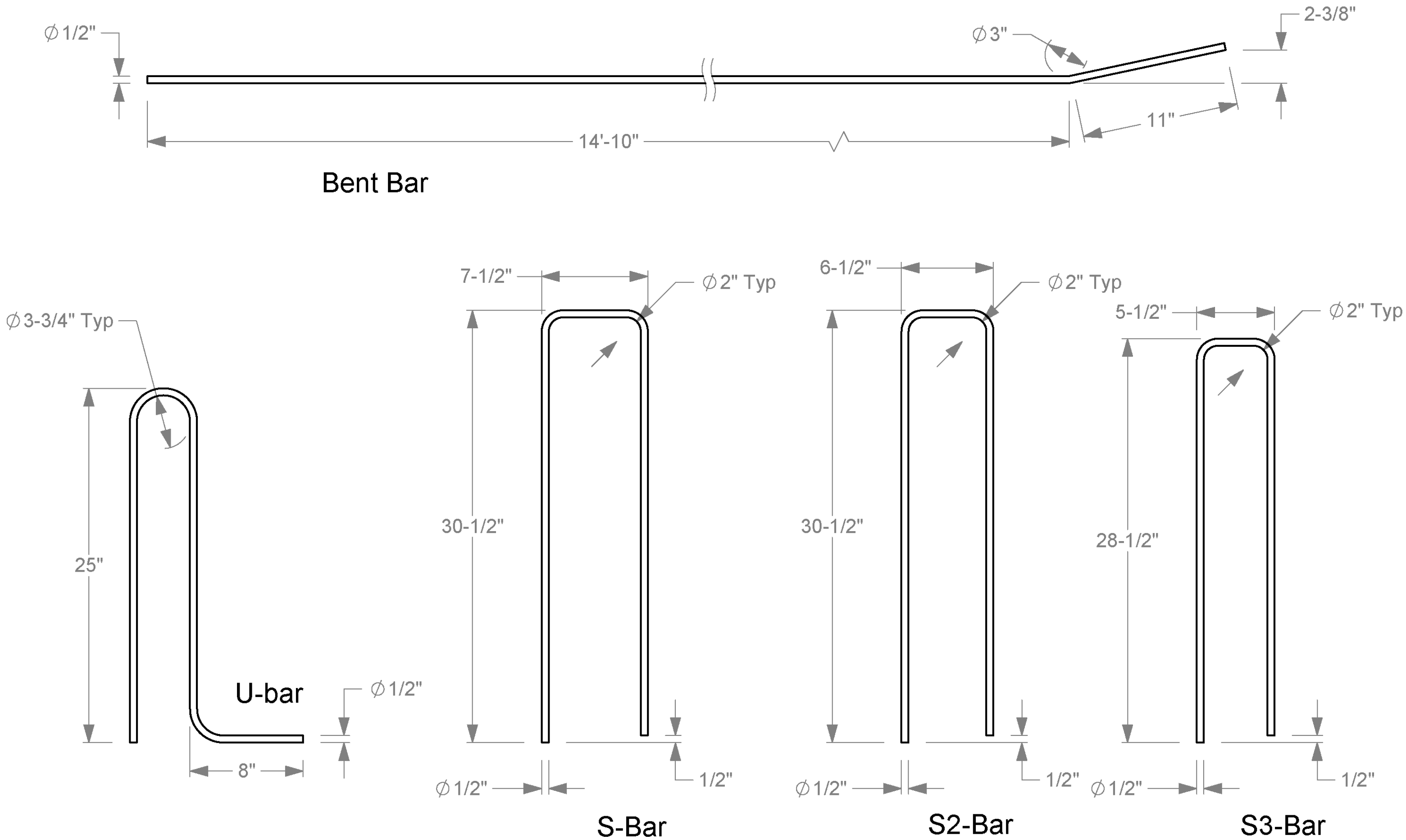
Rebar Bends



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground
Project #613121 TL-3 Transition	2021-04-01
Drawn by GES / Scale 1:10	Sheet 6 of 6 Rebar Bends

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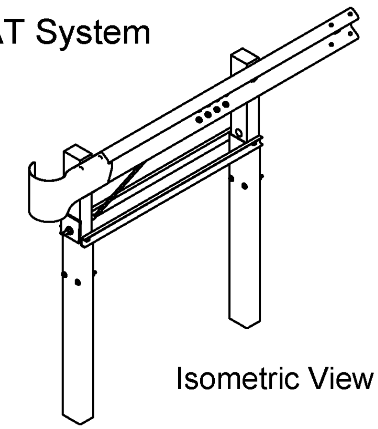
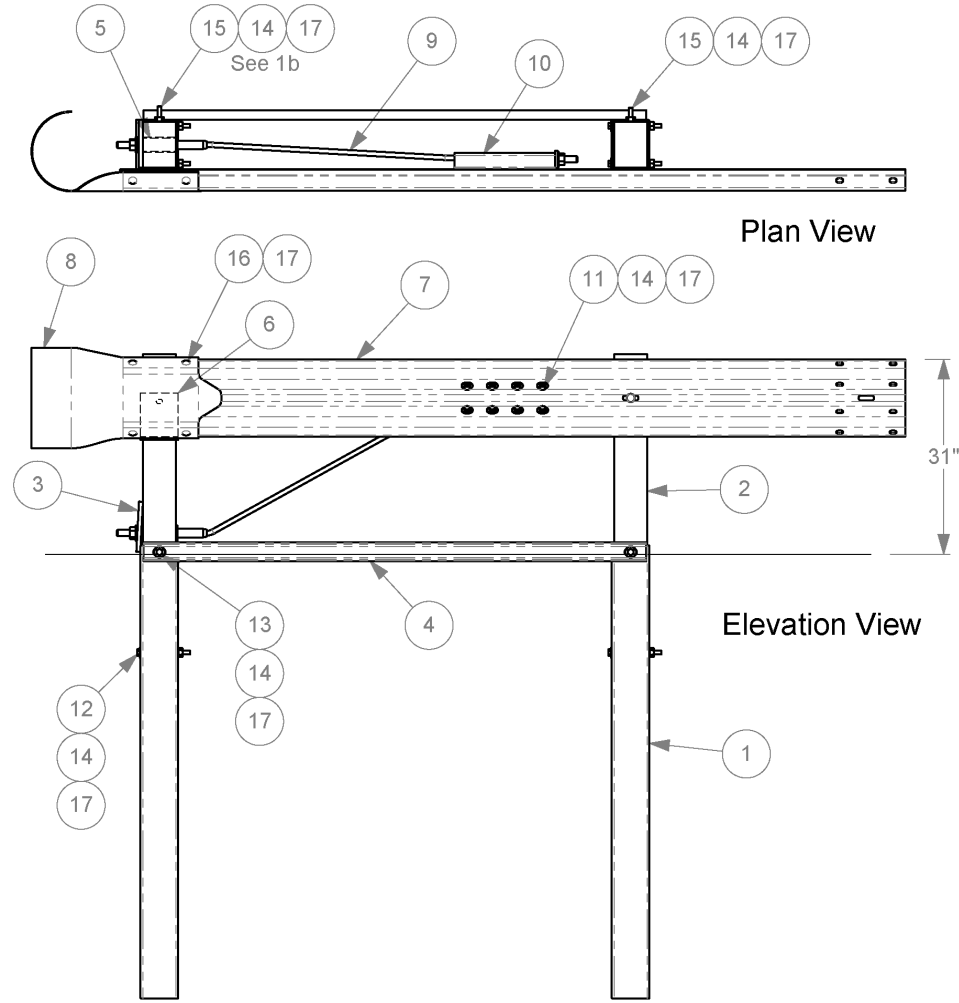
DAT System





#	Part Name	Qty.
1	Foundation Tube	2
2	Terminal Timber Post	2
3	BCT Bearing Plate	1
4	DAT Strut	2
5	BCT Post Sleeve	1
6	Shelf Angle Bracket	1
7	DAT Terminal Rail	1
8	W-beam End Section	1
9	Anchor Cable Assembly	1
10	Guardrail Anchor Bracket	1
11	Bolt, 5/8 x 2" hex	8
12	Bolt, 5/8 x 8" hex	4
13	Bolt, 5/8 x 10" hex	2
14	Washer, 5/8 F844	16
15	10" Guardrail Bolt	2
16	1-1/4" Guardrail Bolt	4
17	Recessed Guardrail Nut	20

1a. All bolts are ASTM A307.

1b. Hardware secures Shelf Angle Bracket to Post. Rail is supported by Shelf Angle Bracket and does not attach directly to Post.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
DAT (Downstream Anchor Terminal)			2019-07-26
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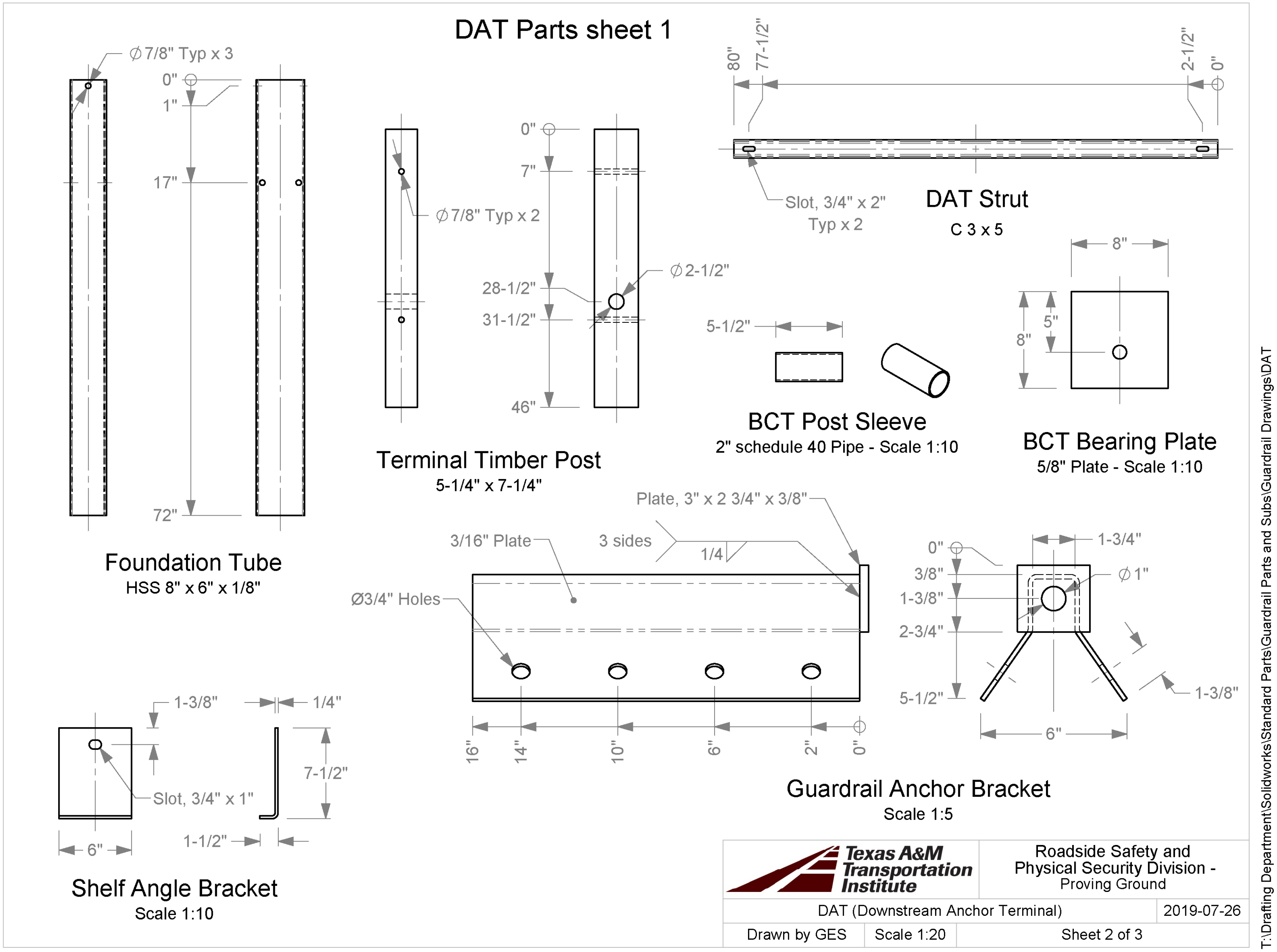

DAT Parts sheet 1
∅7/8" Typ x 3
0"
1"
17"
72"
Foundation Tube
HSS 8" x 6" x 1/8"
0"
7"
∅7/8" Typ x 2
28-1/2"
31-1/2"
46"
∅2-1/2"
Terminal Timber Post
5-1/4" x 7-1/4"
80"
77-1/2"
2-1/2"
0"
Slot, 3/4" x 2"
Typ x 2
DAT Strut
C 3 x 5
5-1/2"
BCT Post Sleeve
2" schedule 40 Pipe - Scale 1:10
8"
5"
8"
BCT Bearing Plate
5/8" Plate - Scale 1:10
Plate, 3" x 2 3/4" x 3/8"
3/16" Plate
3 sides
1/4
Ø3/4" Holes
16"
14"
10"
6"
2"
0"
0"
3/8"
1-3/8"
2-3/4"
5-1/2"
1-3/4"
∅1"
1-3/8"
6"
Guardrail Anchor Bracket
Scale 1:5
1-3/8"
1/4"
Slot, 3/4" x 1"
7-1/2"
1-1/2"
6"
Shelf Angle Bracket
Scale 1:10
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)
2019-07-26
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Sheet 2 of 3
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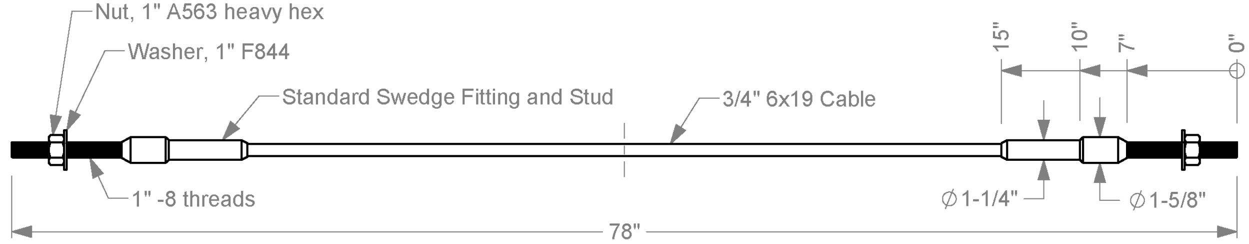
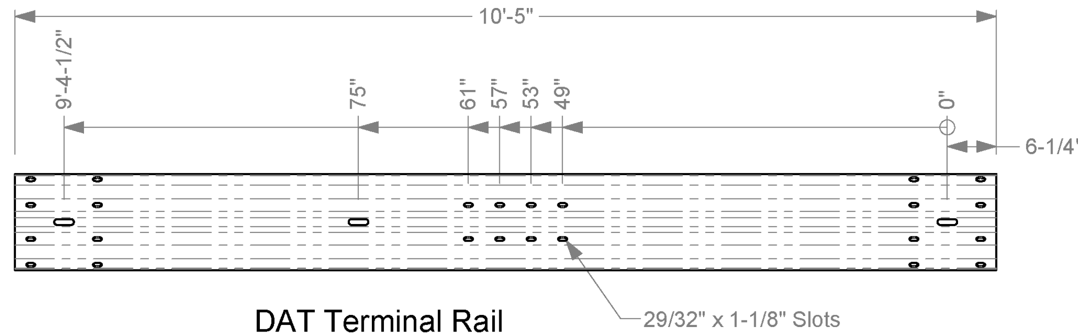
DAT Parts sheet 2

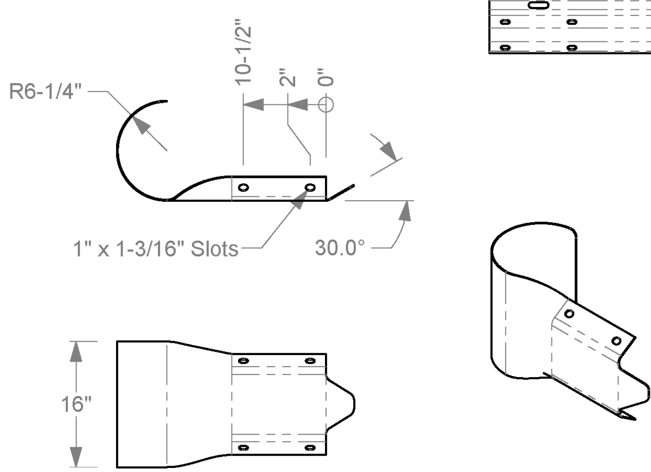


Anchor Cable Assembly



DAT Terminal Rail

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



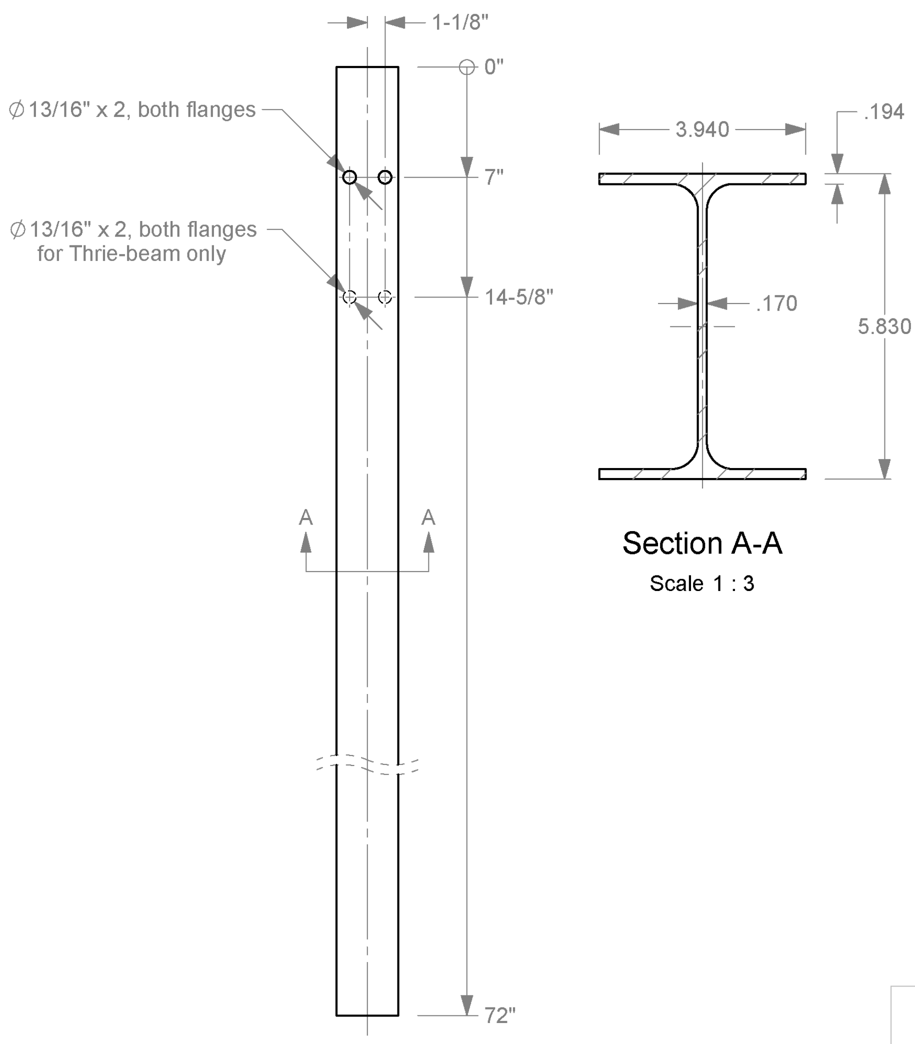
W-beam End Section

12 gauge steel - Scale 1:20

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
DAT (Downstream Anchor Terminal)		2019-07-26
Drawn by GES	Scale 1:10	Sheet 3 of 3

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

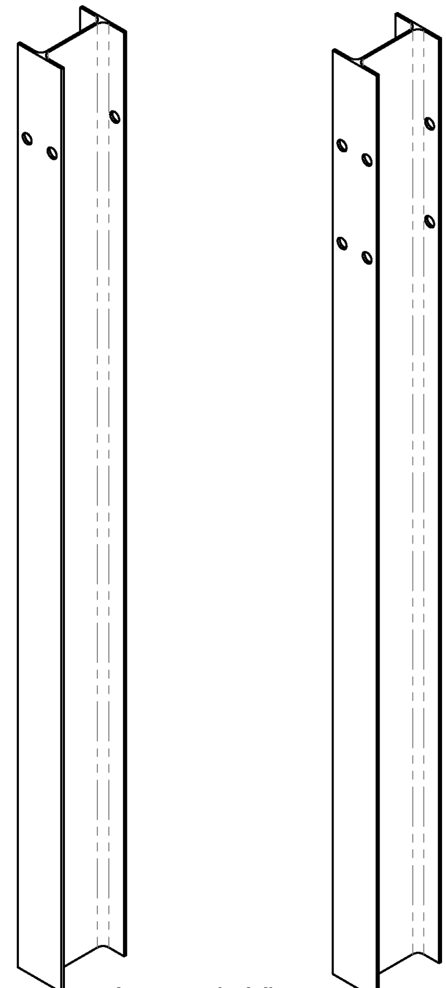
72" Wide Flange Guardrail Post



Elevation View

Section A-A

Scale 1 : 3



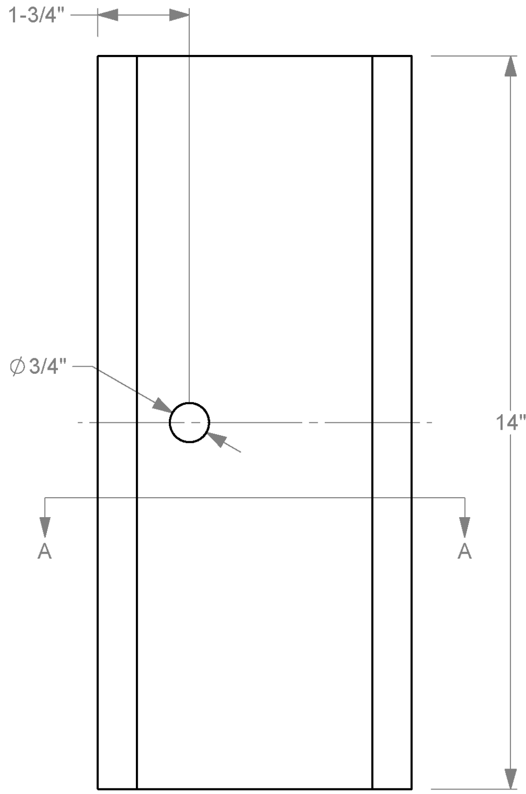
Isometric Views

for W- and Thrie-beam

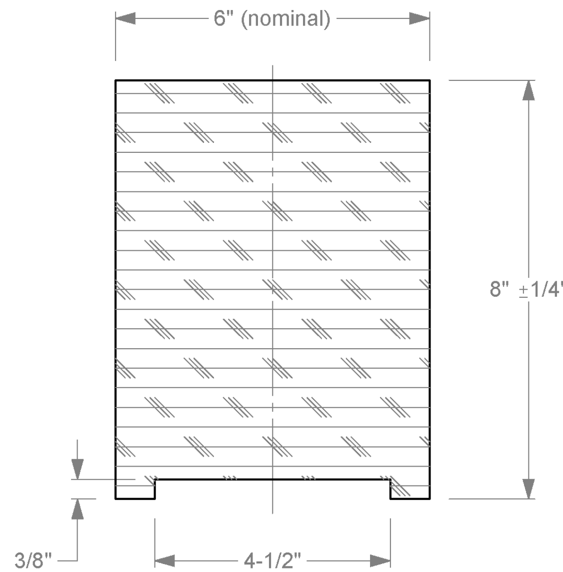
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
72" Wide-Flange Guardrail Post for Thrie-beam		2020-09-14
Drawn by GES	Scale 1:10	Sheet 1 of 1

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

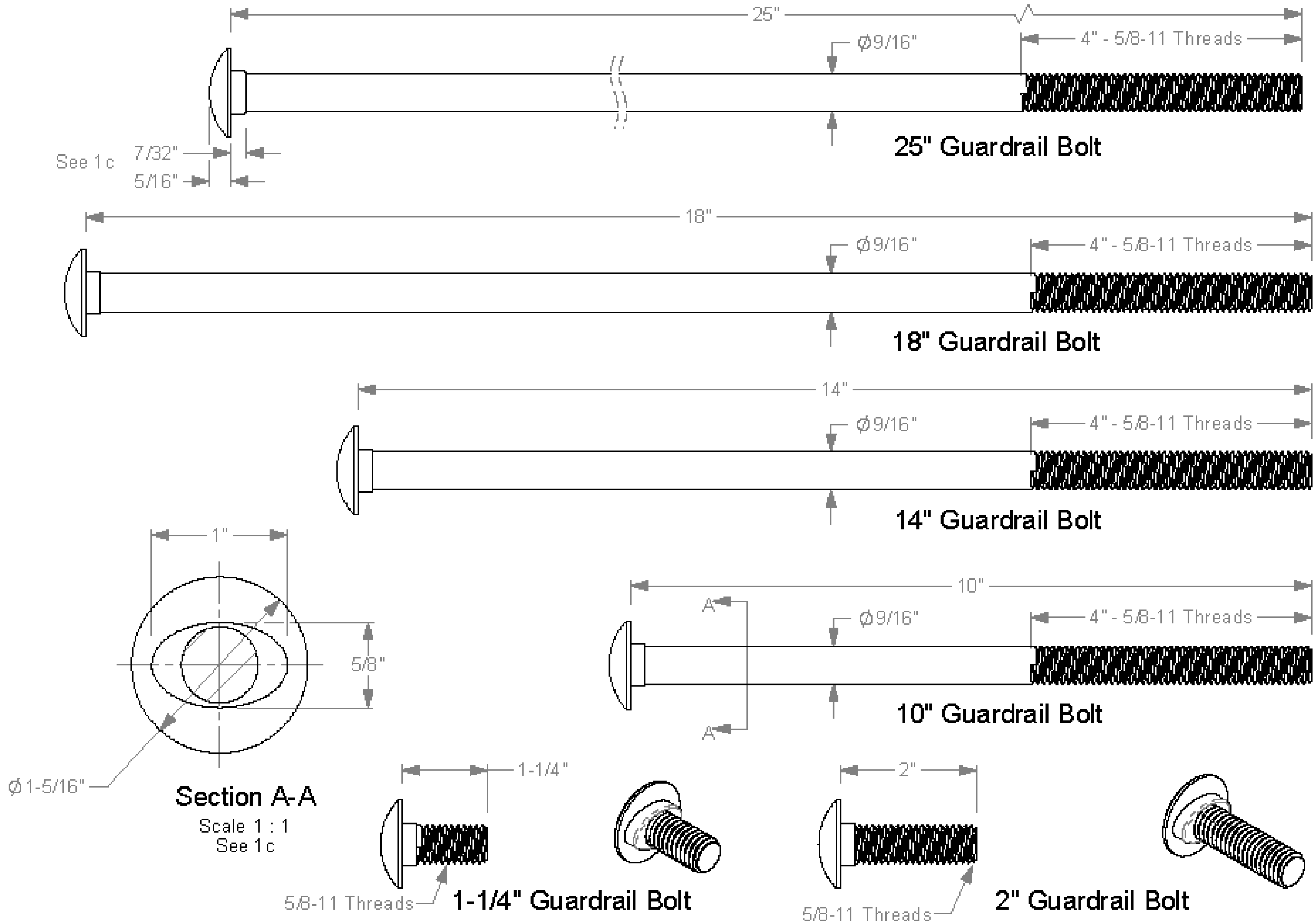


Section A-A

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

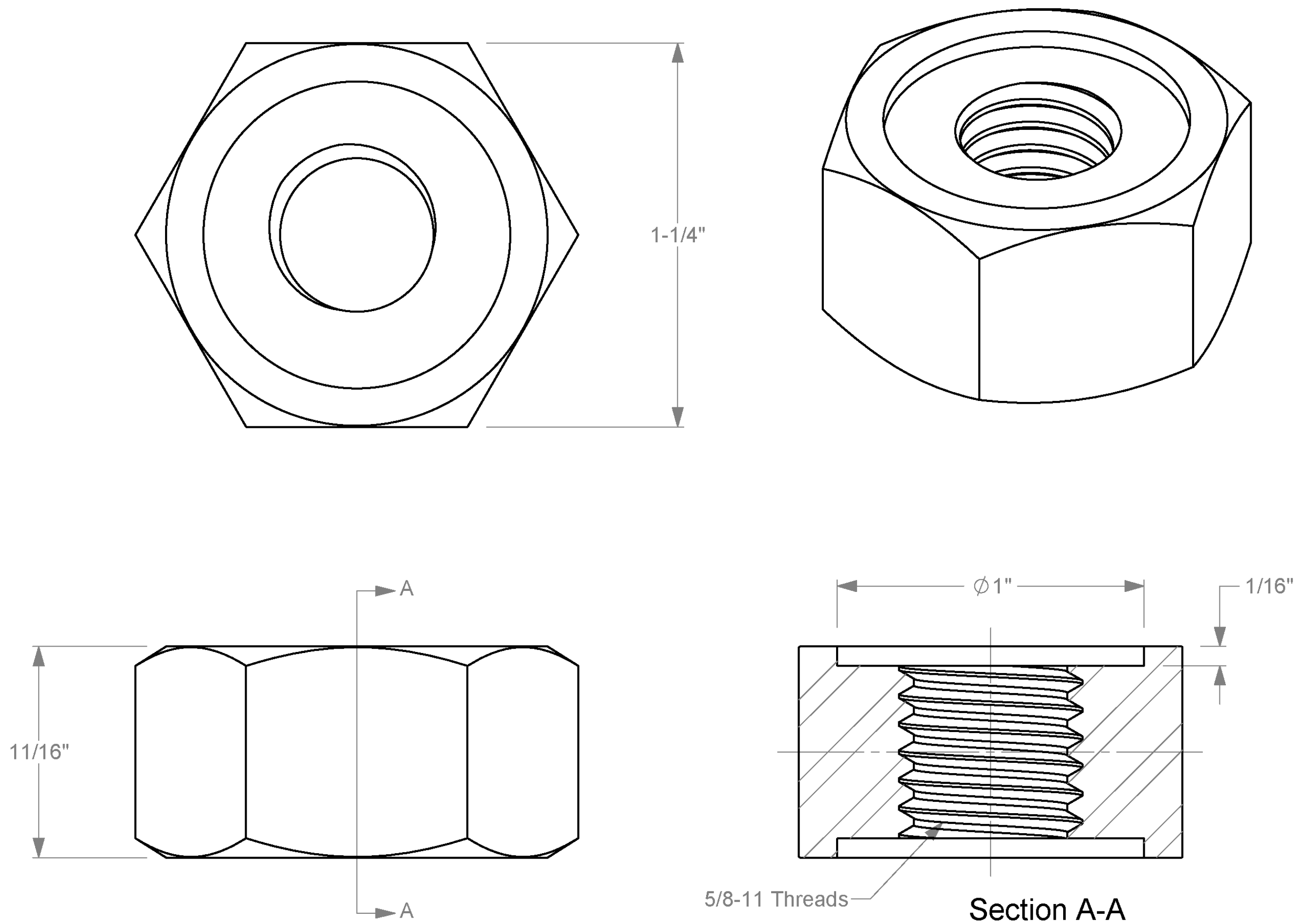


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.

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

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

Recessed Guardrail Nut



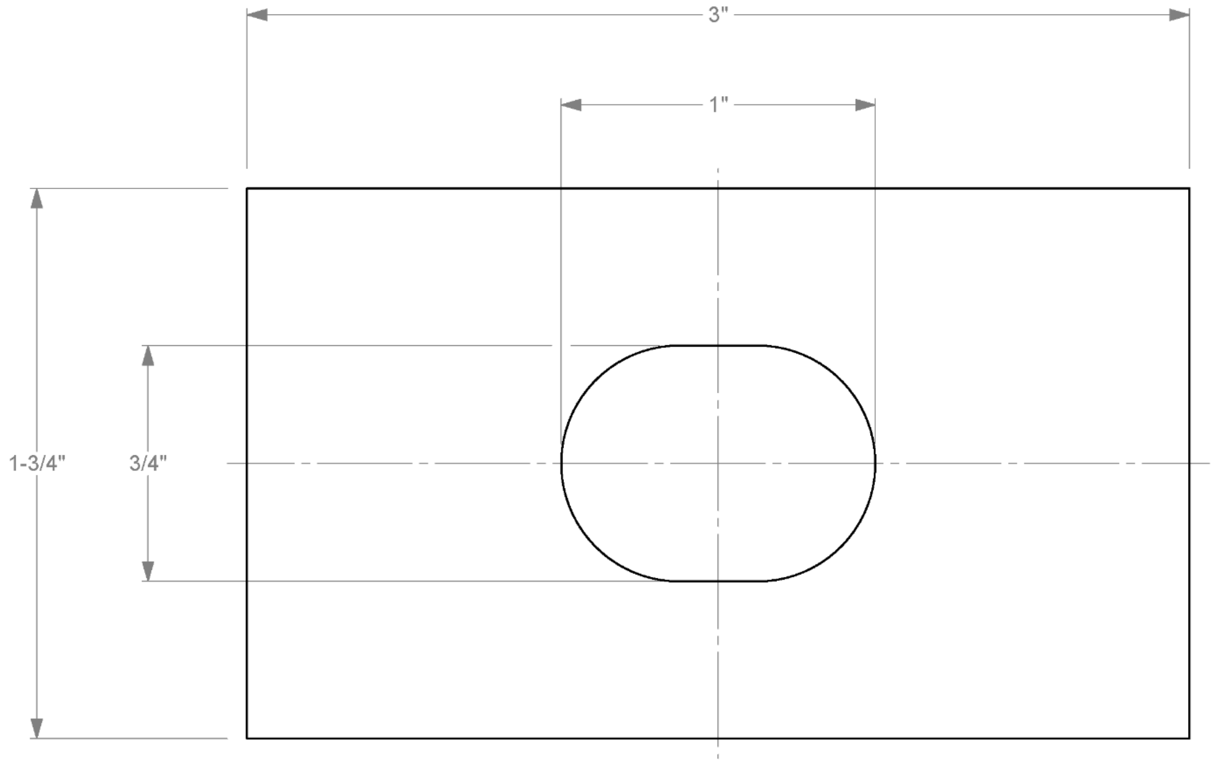
1a. Material is ASTM A 563 Grade A.

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

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

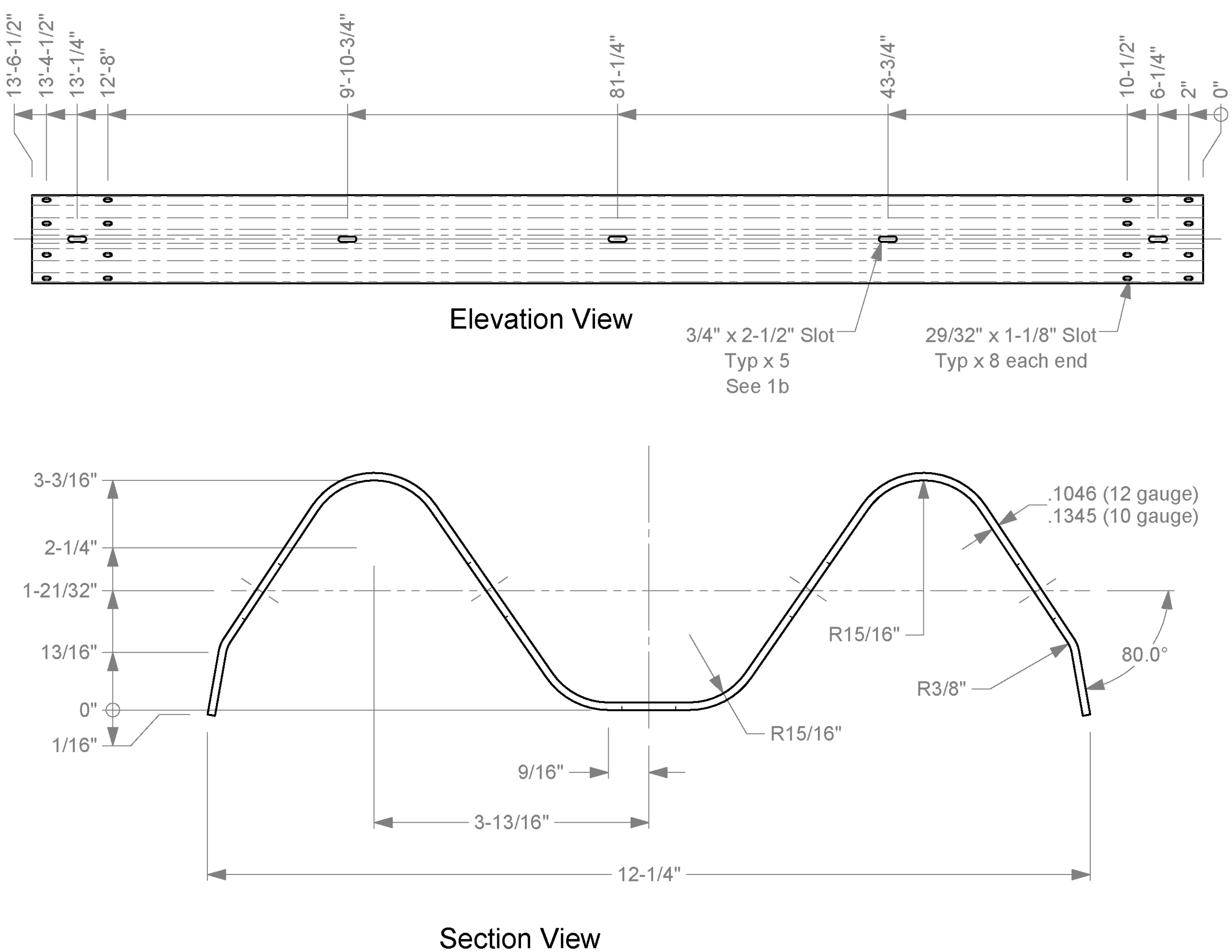
Rectangular Guardrail Washer

0.20" thick



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Rectangular Guardrail Washer			2019-08-08
Drawn by GES	Scale 2:1	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Washer, rect.



1a. Manufacture per AASHTO M180 specifications.

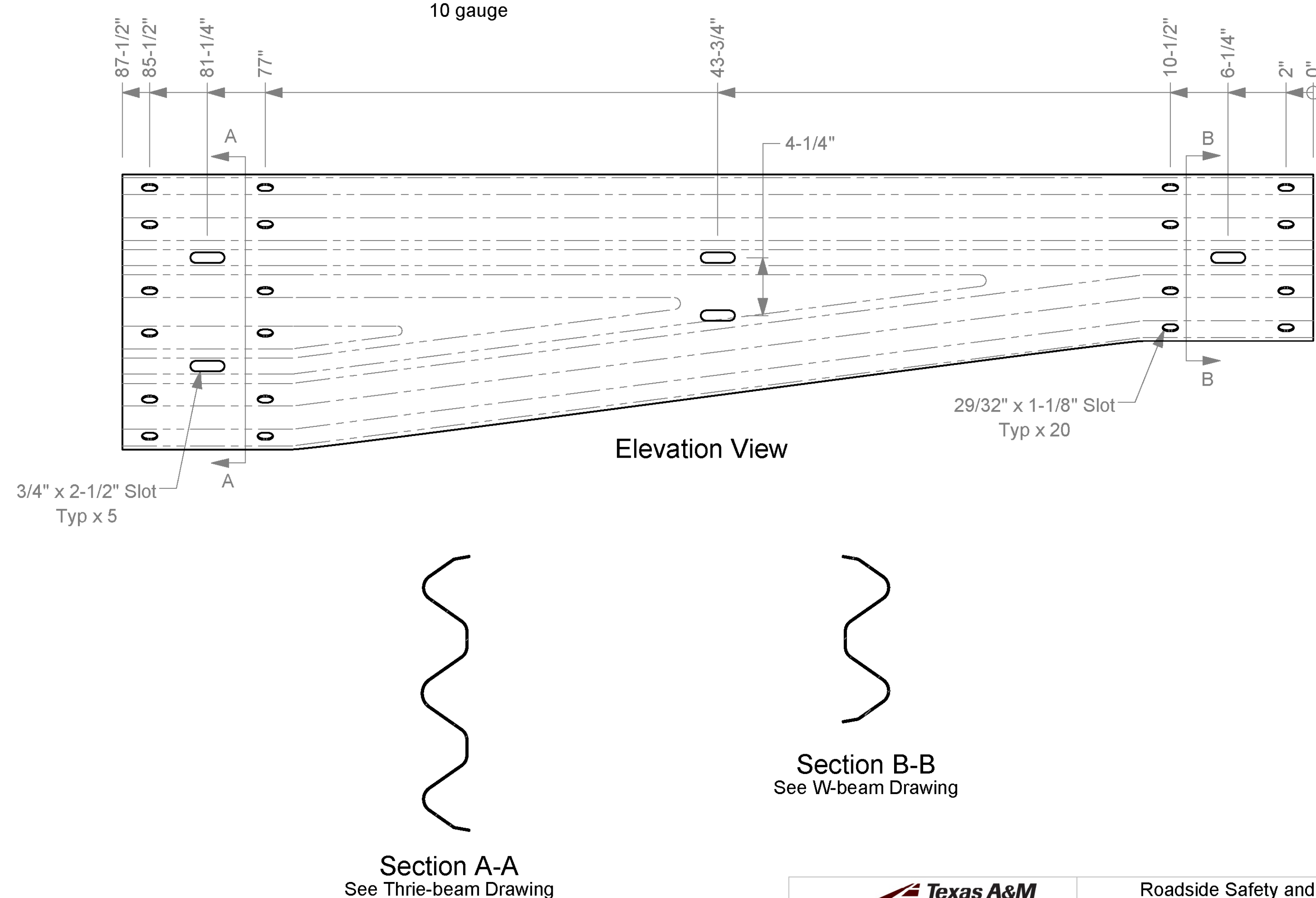
1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

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

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

Thrie to W-Beam, asymmetric

10 gauge

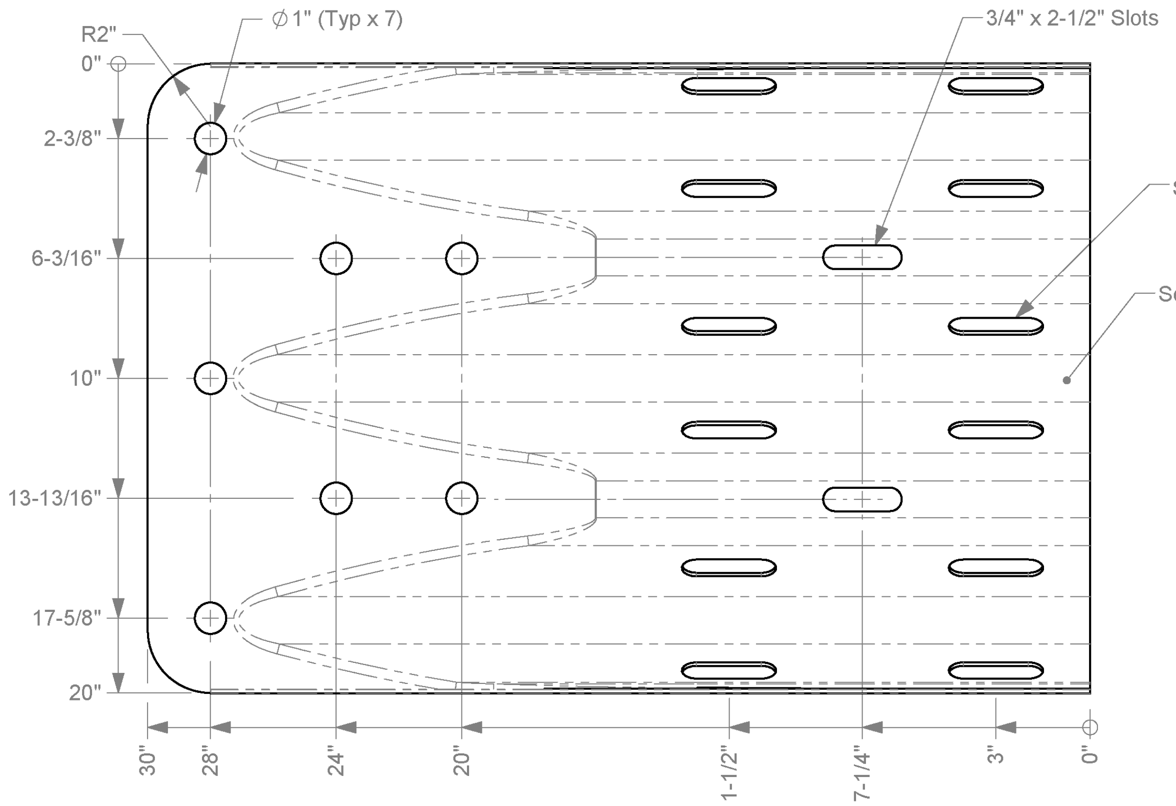


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Thrie- to W-beam Transition		2019-08-22
Drawn by GES	Scale 1:10	Sheet 1 of 1

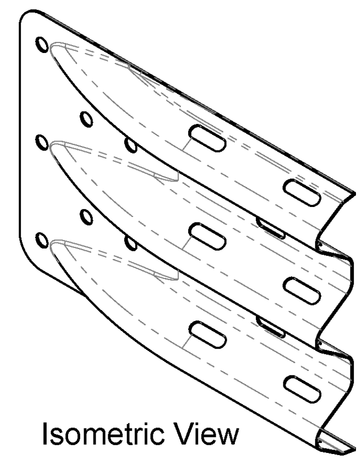
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Thrie to W-Beam, asymmetric

Thrie-beam End Shoe

10 gauge (0.1345" before galvanizing)



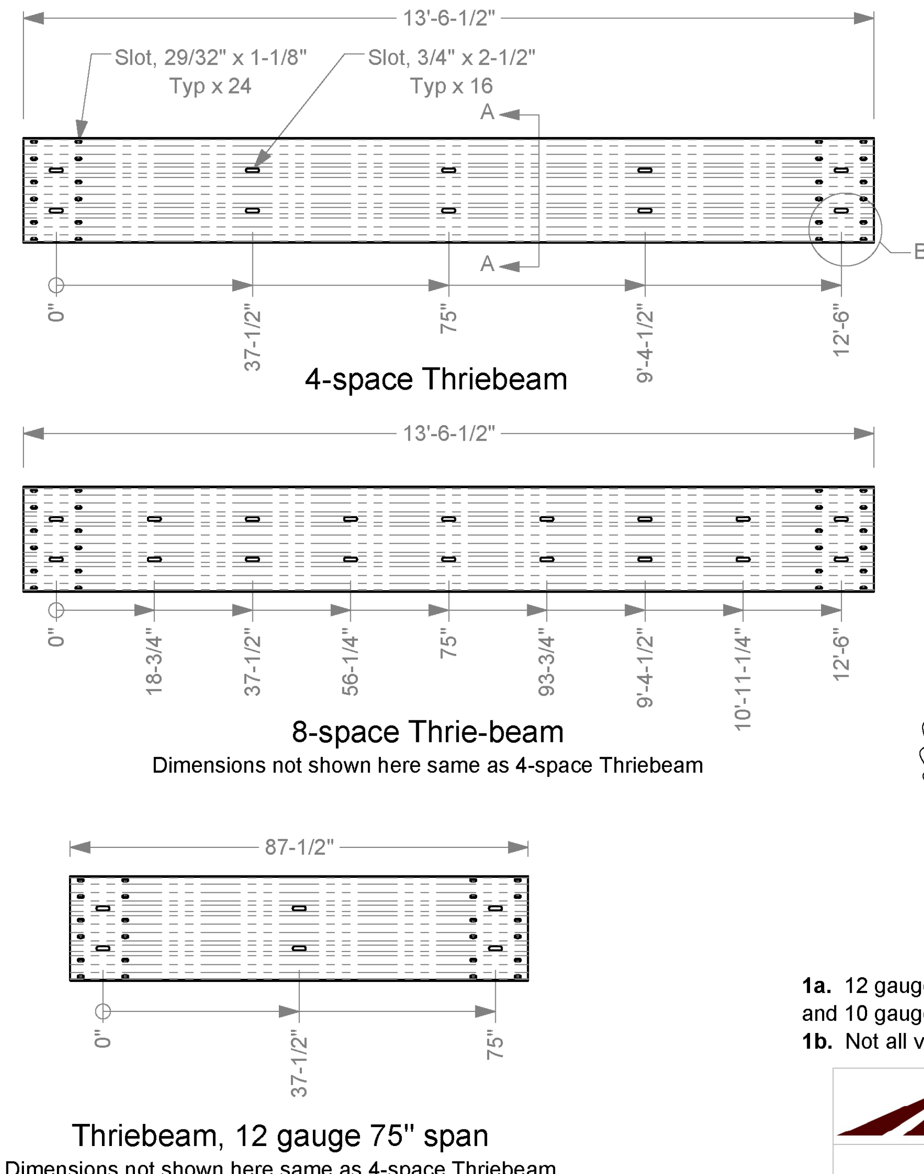
Elevation View

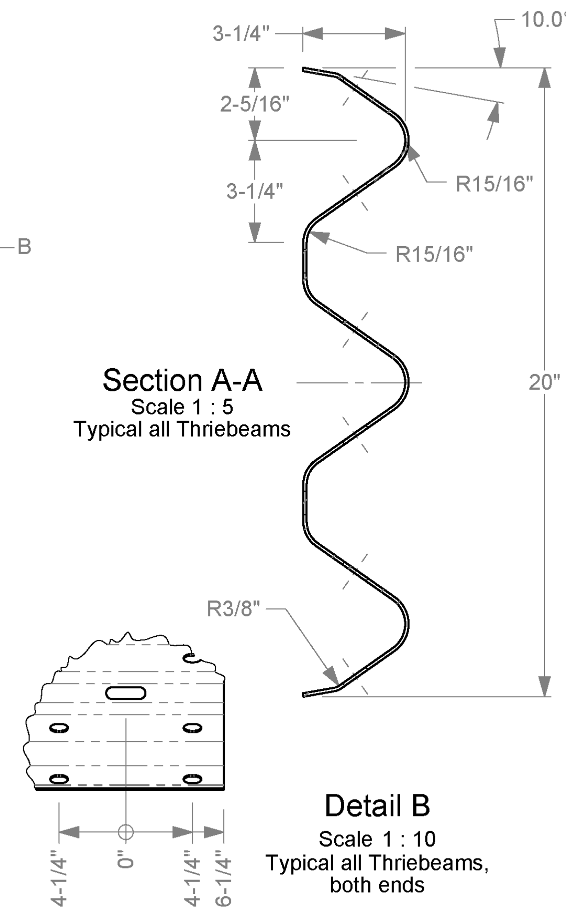


Isometric View

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Thrie-beam Terminal Connector		2019-07-29
Drawn by GES	Scale 1:5	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Thrie-beam End Shoe





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

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Thrie-beam		2021-04-01
Drawn by GES	Scale 1:30	Sheet 1 of 1

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

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

This Memorandum is an acknowledgement that a Bill of Lading has been issued and is not the original Bill of Lading, nor a copy or duplicate, covering the property named herein, and is intended solely for filing or record.

Carrier

Shipper's No. 16-83397

S/O No. 1335835

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading,
at Ft Worth (THP), TX 4-9 20, 21 from Trinity Highway Products, LLC
the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, consigned and destined as shown below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or routes, or within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, including the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.
TRINITY HIGHWAY PRODUCTS, LLC
Per Trinity Highway Products, LLC
(Signature of Consignor)

If charges are to be prepaid, write or stamp here, "To be Prepaid." CPU
TO BE PREPAID

Received $ to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per
(The signature here acknowledges only the amount prepaid.)
Charges advanced:

Consigned to: Cust. P.O. Load No.: 20-1
Destination: SAMPLES, TESTING MATERIALS
TTI BLDG 7090
3100 STATE HWY 47
Total Weight: 80.00
City: BRYAN State: TX Zip: 77807
Ship: 4/10/2021
Arrive: 4/10/21 5:00:00PM
Contact: GARY GERKE Phone: 936-825-4061
606570
Delivering Carrier: CPU Vehicle or Car Initial: No.

Collect On Delivery:
$ and remit to:
Street City State

C.O.D. charge to be paid by Shipper ☐ Consignee ☐

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
		Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No QMS-LG-002.			
		Project Info: WEST VIRGINIA DOT 613121			
		LD Comments:			
	1	205G T12/6'3/3'1-1/2/S			

SPECIAL INSTRUCTIONS:
SHIPPER LOAD - CONSIGNEE UNLOAD 16-83397

Total Weight #80 2

*If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding per

ORIGIN
SHIPPER OR AGENT — I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof.
SIGN HERE DATE 4-9-21
AGENT OR DRIVER — This shipment received subject to exceptions as noted and according to the terms and conditions hereof.
(SIGN HERE) DATE

DESTINATION
CONSIGNEE OR AGENT — Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions.
SIGN HERE / / A.M. P.M.
DATE TIME
DRIVER NO

Permanent post-office address of shipper,
TRI 609-RF (R 10/93)
(This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.)
CARRIER COPY

This Memorandum is an acknowledgement that a Bill of Lading has been issued and is not the original Bill of Lading, nor a copy or duplicate, covering the property named herein, and is intended solely for filing or record.

Carrier

Shipper's No. 16-83397

S/O No. 1335835

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier, of the property described in the Original Bill of Lading,

at Ft Worth (THP), TX 4 - 9 20, 21 from Trinity Highway Products LLC

the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, consigned and destined as shown below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or routes, or within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, including the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.
TRINITY HIGHWAY PRODUCTS, LLC
Per Trinity Highway Products LLC
(Signature of Consignor)

If charges are to be prepaid, write or stamp here, "To be Prepaid." CPU

Received $ TO BE PREPAID
to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per
(The signature here acknowledges only the amount prepaid.)
Charges advanced:

Consigned to: SAMPLES, TESTING MATERIALS
Destination: TTI BLDG 7090
3100 STATE HWY 47
City: BRYAN State: TX Zip: 77807

Cust. P.O.
Load No.: 20-1
Total Weight: 80.00
Ship: 4/10/2021
Arrive: 4/10/21 5:00:00PM
606570

Contact: GARY GERKE Phone: 936-825-4661

Delivering Carrier: CPU Vehicle or Car Initial: No.

Collect On Delivery:
$ **and remit to:**
Street **City** **State**

C.O.D. charge to be paid by Shipper ☐ Consignee ☐

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
		Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. QMS-LG-002			
		Project Info: WEST VIRGINIA DOT 613121			
		LD Comments:			
	1	205G T12/6'3/3'1-1/2/S			

SPECIAL INSTRUCTIONS:
SHIPPER LOAD - CONSIGNEE UNLOAD 16-83397

Total Weight #80

3

*If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding per

ORIGIN
SHIPPER OR AGENT — I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof.
SIGN HERE [signature] DATE 4-9-21
AGENT OR DRIVER — This shipment received subject to exceptions as noted and according to the terms and conditions hereof.
(SIGN HERE) DATE

DESTINATION
CONSIGNEE OR AGENT — Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions.
SIGN HERE [signature] DATE / / TIME A.M. P.M.
DRIVER NO

Permanent post-office address of shipper,

TRI 609-RF (R 10/93)

(This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.)

CONSIGNEE/CUSTOMER COPY

Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525

ADDISON, TX 75001

Project: WEST VIRGINIA DOT 613121

Order Number: 1335835　Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 83397　Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 4/9/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
1	205G	T12/6'3/3'1-1/2/S	RHC		2	L32018													4
			M-180	A	2	225409	64,980	82,800	27.4	0.190	0.720	0.013	0.002	0.020	0.150	0.000	0.070	0.001	4
			M-180	A	2	225410	64,190	83,550	23.3	0.200	0.740	0.012	0.004	0.020	0.140	0.000	0.070	0.002	4
			M-180	A	2	226511	61,110	79,440	27.4	0.180	0.720	0.009	0.004	0.010	0.110	0.000	0.070	0.002	4
			M-180	A	2	226512	61,440	81,340	20.7	0.180	0.720	0.011	0.004	0.010	0.110	0.000	0.080	0.001	4
			M-180	A	2	232898	61,510	80,400	26.7	0.019	0.720	0.010	0.003	0.020	0.100	0.000	0.070	0.002	4
	205G				2	F10621													
			M-180	A	2	2106282	64,100	86,000	23.0	0.210	0.760	0.008	0.001	0.030	0.080	0.002	0.040	0.003	4

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)
FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525

ADDISON, TX 75001

Project: WEST VIRGINIA DOT 613121

Order Number: 1335835 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 83397 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 4/9/21

State of Texas, County of Tarrant. Sworn and subscribed before me this 9th day of April, 2021 .

Notary Public:
Commission Expires: /

MELISSA GUTIERREZ
Notary Public, State of Texas
Comm. Expires 01-14-2023
Notary ID 130076834

Trinity Highway Products LLC
Certified By:

Quality Assurance

Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525

ADDISON, TX 75001

Project: WEST VIRGINIA DOT 613121

Order Number: 1335835   Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 83079   Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 3/19/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
6	11G	12/12'6/3'1.5/S			2	F15120													
			M-180	A	2	2106684	65,500	88,400	20.0	0.240	1.000	0.010	0.001	0.020	0.110	0.003	0.600	0.004	4
			M-180	A	2	2207254	63,700	87,700	21.0	0.240	1.030	0.011	0.001	0.020	0.110	0.001	0.050	0.004	4
			M-180	A	2	2207255	60,100	84,200	27.0	0.230	0.990	0.011	0.001	0.020	0.110	0.002	0.060	0.004	4
1	305G	T10/6'3/3'1-1/2	RHC		2	L30221													4
			M-180	A	2	257708	62,118	79,701	25.3	0.190	0.730	0.012	0.003	0.010	0.100	0.000	0.060	0.000	4
			M-180	A	2	257709	60,995	78,200	24.6	0.190	0.720	0.011	0.003	0.020	0.080	0.000	0.060	0.002	4
			M-180	B	2	253966	60,100	79,300	27.0	0.190	0.710	0.011	0.003	0.020	0.120	0.000	0.060	0.002	4
			M-180	B	2	255520	63,200	81,750	26.0	0.190	0.730	0.009	0.002	0.010	0.090	0.001	0.060	0.002	4
19	533G	6'0 POST/8.5/DDR	A-36			1801947	55,000	68,200	25.6	0.070	0.830	0.007	0.028	0.250	0.090	0.014	0.040	0.003	4
	533G		A-36			58046122	59,584	70,959	24.4	0.070	0.900	0.015	0.038	0.200	0.330	0.020	0.210	0.001	4
	533G		A-36			2817878	59,800	71,100	25.0	0.070	0.860	0.007	0.030	0.160	0.260	0.014	0.050	0.004	4
1	850G	12/BUFFER/ROLLED	M-180	A	2	256002	63,096	80,968	21.9	0.190	0.730	0.009	0.004	0.010	0.110	0.000	0.050	0.002	4
	850G		M-180	A	2	31847970	48,400	62,300	35.0	0.060	0.450	0.015	0.001	0.030	0.090	0.000	0.070	0.002	4
	850G		M-180	A	2	256002	63,096	80,968	21.9	0.190	0.730	0.009	0.004	0.010	0.110	0.000	0.050	0.002	4
1	975G	T10/END SHOE	A-1011			95839	50,900	628,000	35.4	0.060	0.490	0.010	0.001	0.030	0.110	0.000	0.070	0.001	4
1	3000G	CBL 3/4X6'6/DBL	WIRE			S394298													4
105	3340G	5/8" GR HEX NUT	FAST			21-54-006													4

Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525
ADDISON, TX 75001
Project: WEST VIRGINIA DOT 613121

Order Number: 1335835 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 83079 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 3/19/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
50	3360G	5/8"X1.25" GR BOLT	A307-3360			922031-13													4
36	3400G	5/8"X2" GR BOLT	A307-3400			934410-9													4
19	3500G	5/8"X10" GR BOLT A307	A307-3500			931506-1													4
10	3726G	7/8" ROUND WASHER F436	F436-3726			P39340 R73428-02													4
10	3736G	7/8" HVY HEX NUT A194 2H	FAST			P39175 R72902-01													4
19	4076B	WD BLK RTD 6X8X14	WOOD			6122													
5	4850G	7/8" X14" HEX BOLT A325	FAST			40113646													4
2	19481G	C3X5#X6'-8" RUBRAIL	A-36			3077310	55,400	77,200	32.0	0.170	0.560	0.013	0.039	0.210	0.330	0.002	0.090	0.017	4
	19481G		A-36			3086787	56,100	76,000	29.0	0.150	0.630	0.013	0.035	0.210	0.320	0.000	0.130	0.000	4
1	20207G	12/9'4.5/8-HOLE ANCH/S			2	F10121													
			M-180	A	2	2106683	65,400	86,900	21.0	0.230	0.990	0.011	0.008	0.030	0.160	0.001	0.060	0.004	4
			M-180	A	2	2107036	61,900	85,900	24.0	0.220	0.800	0.010	0.017	0.030	0.100	0.001	0.050	0.004	4
			M-180	A	2	2107037	63,900	85,600	22.0	0.210	0.780	0.009	0.001	0.030	0.090	0.001	0.040	0.004	4
			M-180	A	2	2207254	63,700	87,700	21.0	0.240	1.030	0.011	0.001	0.020	0.110	0.001	0.050	0.004	4
			M-180	A	2	2207255	60,100	84,200	27.0	0.230	0.990	0.011	0.001	0.020	0.110	0.002	0.060	0.004	4
			M-180	A	2	2207619	63,800	85,300	19.0	0.210	0.790	0.009	0.001	0.030	0.080	0.001	0.030	0.004	4
1	32218G	T10/TRAN/TB:WB/ASYM/R	M-180	B	2	42014850	50,000	70,000	28.0	0.040	0.770	0.014	0.001	0.040	0.120	0.047	0.070	0.003	4
1	36120A	DAT-31-TX-HDW-CAN	A-36			4110390	47,000	66,600	34.0	0.180	0.400	0.015	0.002	0.030	0.040	0.001	0.060	1.000	4

Certified Analysis

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

ADDISON, TX 75001
Project: WEST VIRGINIA DOT 613121

Order Number: 1335835 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 83079 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 3/19/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
	36120A		WIRE			16652240													4
	36120A		A-500			X6030	61,500	65,000	29.8	0.110	0.350	0.014	0.004	0.030	0.150	0.001	0.080	0.001	4
	36120A		F844-3300			64249													4
	36120A		FAST			21-54-006													4
	36120A		A307-3360			922031-13													4
	36120A		A307-3403			848773-8													4
	36120A		A307-3500			931506-1													4
	36120A		HW			025689													
	36120A		HW			025689													
	36120A		A-36			99592D	45,000	68,000	31.0	0.180	0.780	0.015	0.011	0.009	0.020	0.000	0.040	0.000	4
	36120A		F844-3900			P39692 R74946-02													4
	36120A		A563-3910			P39341 R73497													4
	36120A		A307-4470			893006-7													4
	36120A		A307-4500			940249-4													4

Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525
ADDISON, TX 75001

Project: WEST VIRGINIA DOT 613121

Order Number: 1335835 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO:
BOL Number: 83079 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 3/19/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
	36120A		A-36			1100008623	58,600	60,100	21.0	0.130	0.820	0.022	0.020	0.212	0.310	0.000	0.190	0.057	4
	36120A		A-36			1053561	60,000	77,100	23.0	0.160	0.750	0.018	0.024	0.180	0.330	0.001	0.200	0.032	4
2	130896G	6'0 TUBE SL/.125X8X6	A-500			PL0724	56,815	76,042	31.0	0.190	0.370	0.007	0.001	0.027	0.120	0.006	0.050	0.004	4
2	626079B	WD 3'10 POST	WOOD			3660													

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED

BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

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

Texas A&M Transportation Institute	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Revision Date: 2020-07-29
Quality Form	Revised by: B.L. Griffith Approved by: D. L. Kuhn	Revision: 7	Page: 1 of 1

Project No: 613121-01-1 **Casting Date:** 2/23/2021 **Mix Design (psi):** 3600

Name of Technician Taking Sample: Terracon

Name of Technician Breaking Sample: Terracon

Signature of Technician Taking Sample: Terracon

Signature of Technician Breaking Sample: Terracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	9020	6589653	100% of repaired end of barrier

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average

CUSTOMER'S COPY

TICKET NO. 6589653

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

6589653

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
9:42	0954	1017	1035	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST ______ GAL.
ALLOWABLE WATER (withheld from batch) 7.6 GAL.
TEST CYLINDER TAKEN ☑ YES ☐ NO BY Terracon
CYLINDER TAKEN ☐ BEFORE ☐ AFTER WATER

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

CUSTOMER SIGNATURE
x [signature]

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

CUSTOMER NAME AND DELIVERY ADDRESS
TEXAS A & M UNIVERSI
TTI-Riverside Campus

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
617	9020	2025	5.0	~~[illegible]~~ 613121-01-1	MC

DRIVER NAME	DATE
CHATHAM, DEXTER	2/23/21

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783659	98321	3.00	3.00

LOAD QUANTITY		PRODUCT CODE	DESCRIPTION	UNIT PRICE	AMOUNT
3.00	CYDS	R9Z40528	COM, RG, Z, 4000, RE		
1.00	ea	12987	FREIGHT CHARGE		

SPECIAL DELIVERY INSTRUCTIONS
2818-RT ON LEONARD RT ON HWY-47-LFT INTO RIVERSIDE
CAMPUS WILL MEET AT GATE

SALES TAX

TOTAL

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

FOR OFFICE USE ONLY **FORM:**

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
9020	726159	user	6589653	90372	9:42	2/23/21

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
3.00 CYDS	R9Z40528				D	91532

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"RG	1306 lb	3966 lb	3940 lb	-0.65%	1.20% M	6 gl
3/8"PG	507 lb	1536 lb	1520 lb	-1.07%	1.00% M	2 gl
SAND-1	1412 lb	4431 lb	4420 lb	-0.25%	4.40% M	23 gl
CMT-I/II	432 lb	1296 lb	1295 lb	-0.08%		
FLYASH-C	108 lb	324 lb	325 lb	* 0.31%		
H20	250 lb	460 lb	430 lb	-6.43%		52 gl
ZY-610	17 oz	52 oz	52 oz	0.31%		

Actual Num Batches: 1
Load Total: 11933 lb Design 0.463 Water/Cement 0.463 T Design 89.9 gl Actual 82.3 gl To Add: 7.6 gl
Slump: 5.00 in # Water in Truck: 0.0 gl Adjust Water: 0.0 gl / Load Trim Water: -1.3 gl/ CYD

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0167
Service Date: 02/23/21
Report Date: 04/09/21
Task: PO# 613121-01

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength: 4,000 psi @ 28 days

Mix ID: R9Z40528
Supplier: Martin Marietta
Batch Time: 0942 **Plant:** 617
Truck No.: 9020 **Ticket No.:** 6589653

Sample Information

Sample Date: 02/23/21 **Sample Time:** 1150
Sampled By: Mohammed Mobeen
Weather Conditions: Clear, Light Wind
Accumulative Yards: 3 **Batch Size (cy):** 3
Placement Method: Direct Discharge
Water Added Before (gal):
Water Added After (gal):
Sample Location: PO #613121-01
Placement Location: PO #613121-01

Field Test Data

Test	Result	Specification
Slump (in):	5	
Air Content (%):	1.6	
Concrete Temp. (F):	65	
Ambient Temp. (F):	57	
Plastic Unit Wt. (pcf):	146.8	
Yield (Cu. Yds.):		

Laboratory Test Data

Set No.	Specimen ID	Avg Diam. (in)	Area (sq in)	Date Received	Date Tested	Age at Test (days)	Maximum Load (lbs)	Compressive Strength (psi)	Fracture Type	Tested By
1	A	6.01	28.37		04/08/21	44 F	162,590	5,730	1	SLS
1	B	6.01	28.37		04/08/21	44 F	172,250	6,070	1	SLS
1	C	6.01	28.37		04/08/21	44 F	167,390	5,900	1	SLS
1	D					Hold				

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

Comments: **F = Field Cured**

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).
Terracon Rep.: Mohammed Mobeen **Start/Stop:**
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Alex Dunigan, P.E.
(1) Texas Transportation Institute, Bill Griffith

Reviewed By:
Alexander Dunigan
Project Manager

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

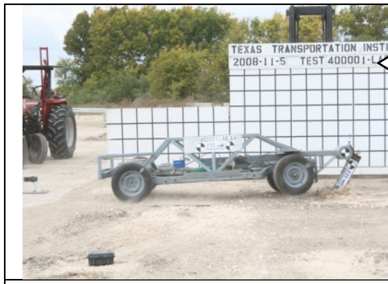
The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

Page 1 of 1

CR0001, 11-16-12, Rev.6

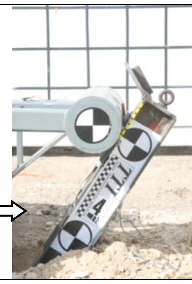
APPENDIX C. SOIL PROPERTIES

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



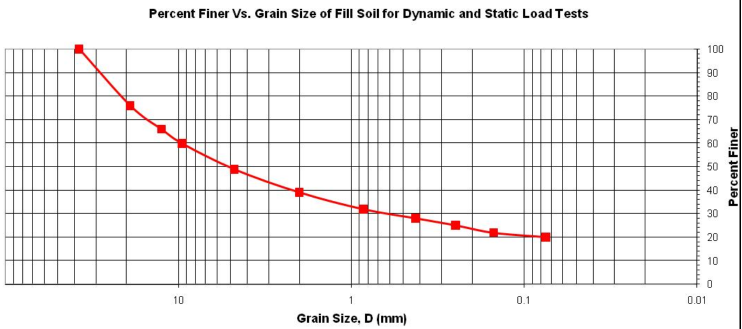
Dynamic Setup

Post-Test Photo of post

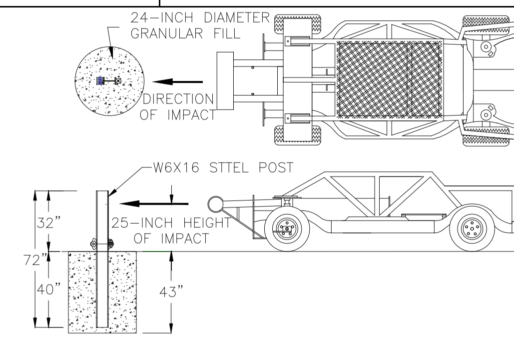


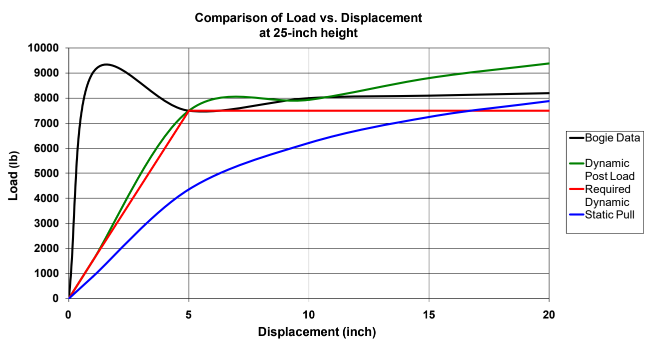
Static Load Test

Post-Test Photo

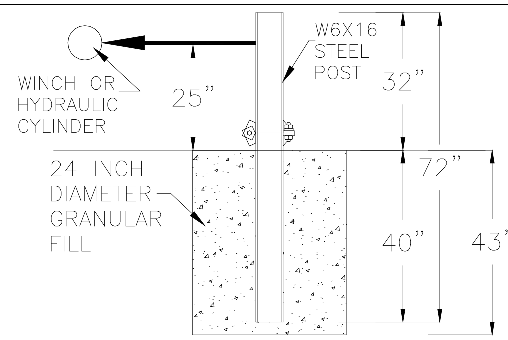


Dynamic Test Installation Details



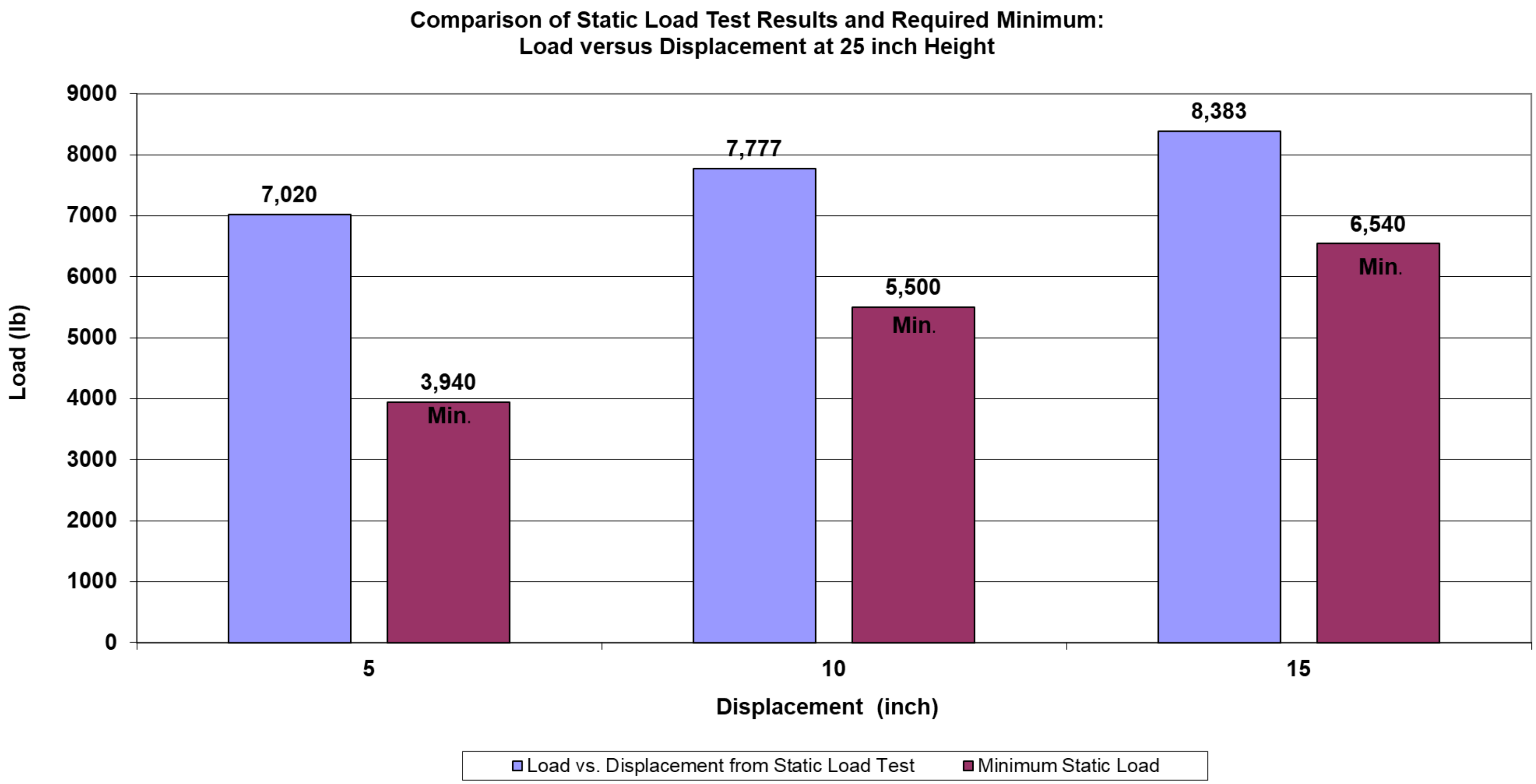


Static Load Test Installation Details



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 M147 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. 613121-01-1.



Date	2021-04-19 – Test No. 613121-01-1
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 M147 Grade B Soil-Aggregate
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

APPENDIX D. *MASH* TEST 3-21 (CRASH TEST NO. 613121-01-1)

D.1. VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 613121-01-1.

Date: 2021-4-19 Test No.: 613121-01-1 VIN No.: 1C6RR6GT0GS367972

Year: 2016 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 124409

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

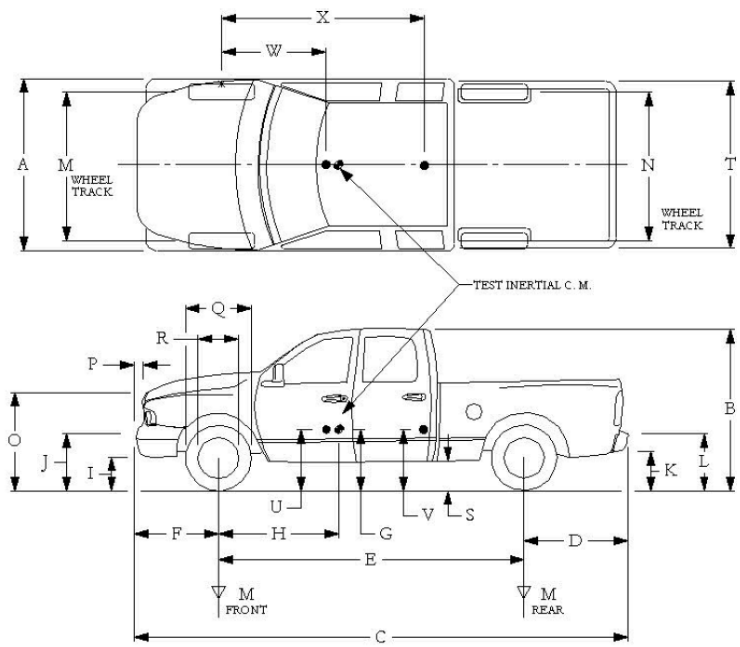
NOTES: None

Engine Type: V-8
Engine CID: 5.7 L

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

Optional Equipment:
None

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



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.25	L	30.00	Q	30.50	V	30.25
C	227.50	H	59.93	M	68.50	R	18.00	W	59.90
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2965	2902	2987
Back	3900	M_{rear}	2120	2159	2239
Total	6700	M_{Total}	5085	5061	5226

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

Mass Distribution:
lb LF: 1447 RF: 1455 LR: 1125 RR: 1034

Table D.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 613121-01-1.

Date: 2021-4-19 Test No.: 613121-01-1 VIN: 1C6RR6GT0GS367972

Year: 2016 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 124409

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:	1447		RF:	1455			Front Axle:	2902	
LR:	1125		RR:	1034			Rear Axle:	2159	
Left:	2572		Right:	2489			Total:	5061	
							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:	59.94	inches	Rear of Front Axle	(63 ±4 inches allowed)					
Y:	-0.56	inches	Left -	Right +	of Vehicle Centerline				
Z:	28.25	inches	Above Ground	(minumum 28.0 inches allowed)					

Hood Height: 46.00 inches — 43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches — 39 ±3 inches allowed

Rear Bumper Height: 30.00 inches

Overall Length: 227.50 inches — 237 ±13 inches allowed

Table D.3. Exterior Crush Measurements for Test No. 613121-01-1.

Date:	2021-4-19	Test No.:	613121-01-1	VIN No.:	1C6RR6GT0GS367972
Year:	2016	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage 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	18	16	48	-	-	-	-	-	-	12
2	Side plane above bmp	18	16	72	-	-	-	-	-	-	84
	Measurements recorded										
	☑ **inches** **or** ☐ **mm**										

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

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

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

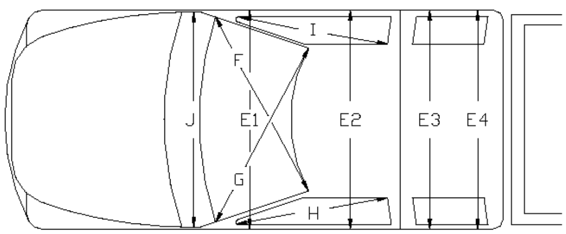
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

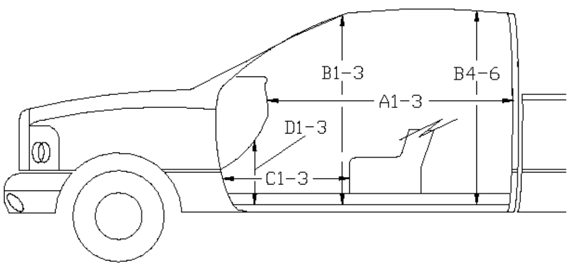
***Measure and document on the vehicle diagram the location of the maximum crush.

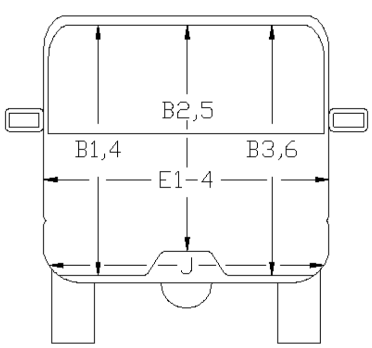
Note: Use as many lines/columns as necessary to describe each damage profile.

Table D.4. Occupant Compartment Measurements for Test No. 613121-01-1.

Date:	2021-4-19	Test No.:	613121-01-1	VIN No.:	1C6RR6GT0GS367972
Year:	2016	Make:	RAM	Model:	1500





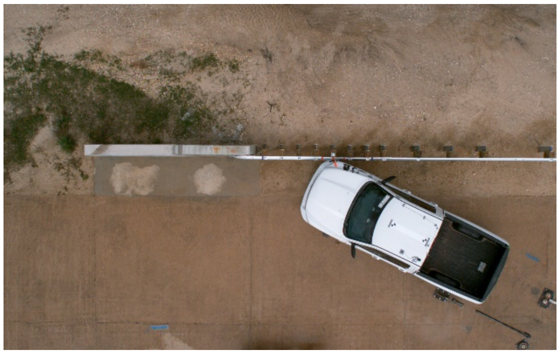


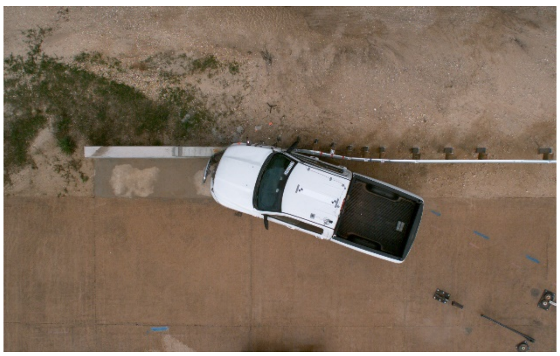
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

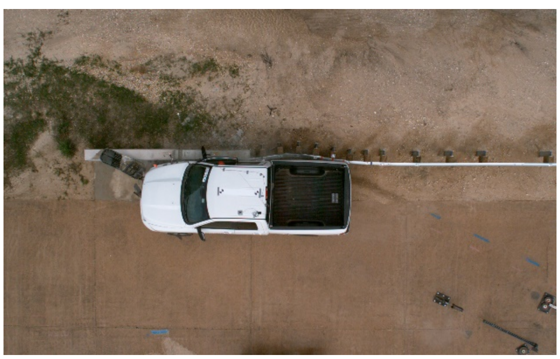
OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	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	40.00	-5.00
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	18.25	-7.75
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	6.00	-5.50
E1	58.50	53.50	-5.00
E2	63.50	66.50	3.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	36.50	-1.00
J*	25.00	19.00	-6.00

D.2. SEQUENTIAL PHOTOGRAPHS


0.000 s



0.100 s



0.200 s

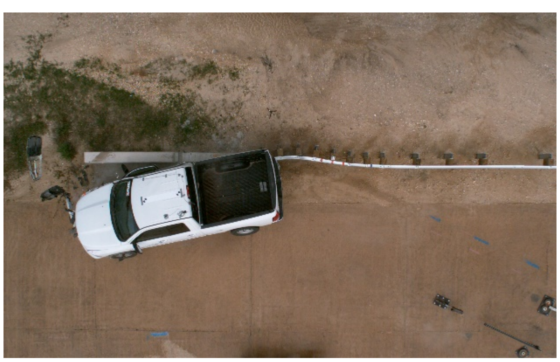


0.300 s


Figure D.1. Sequential Photographs for Test No. 613121-01-1 (Overhead and Frontal Views).

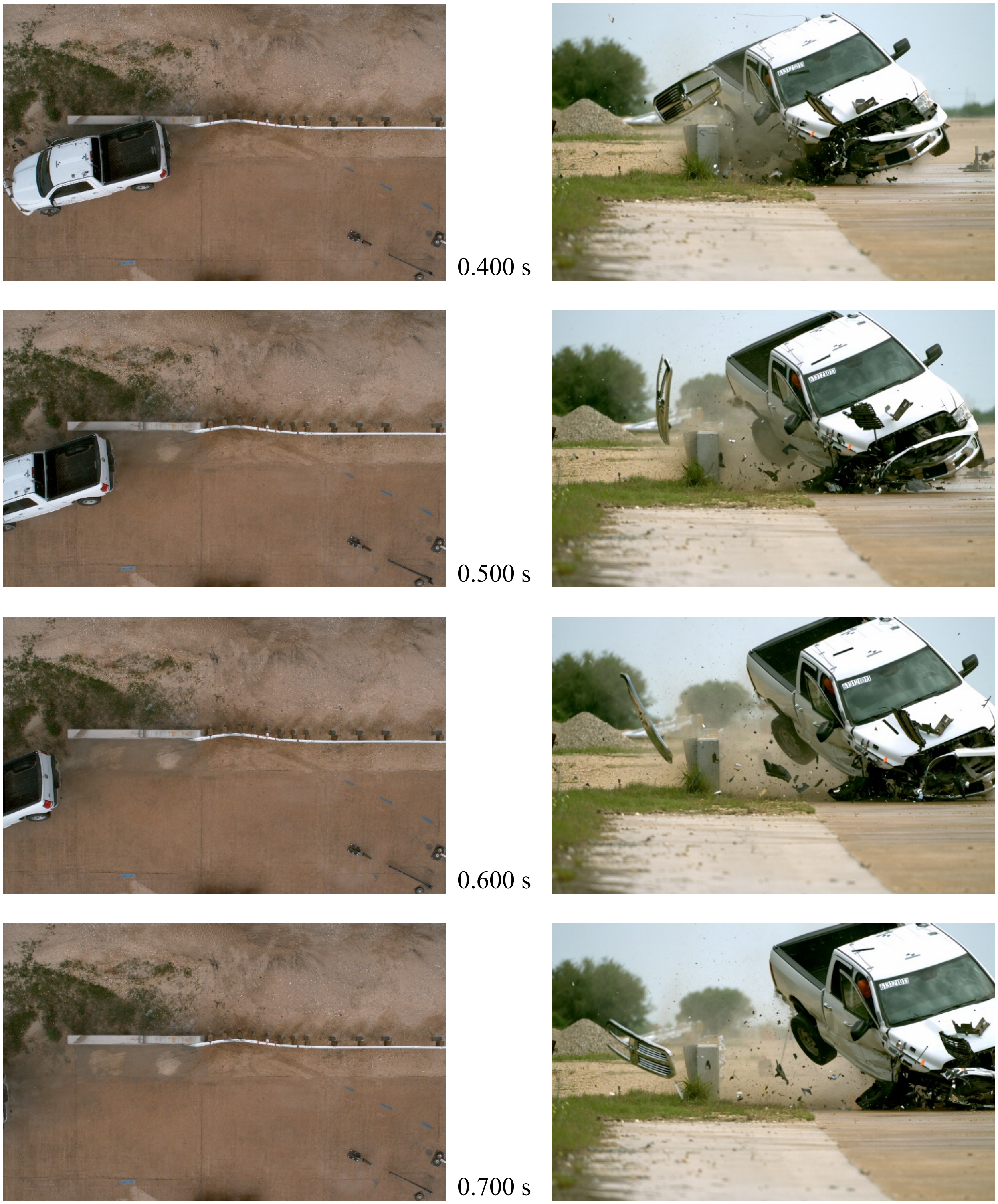


Figure D.1. Sequential Photographs for Test No. 613121-01-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

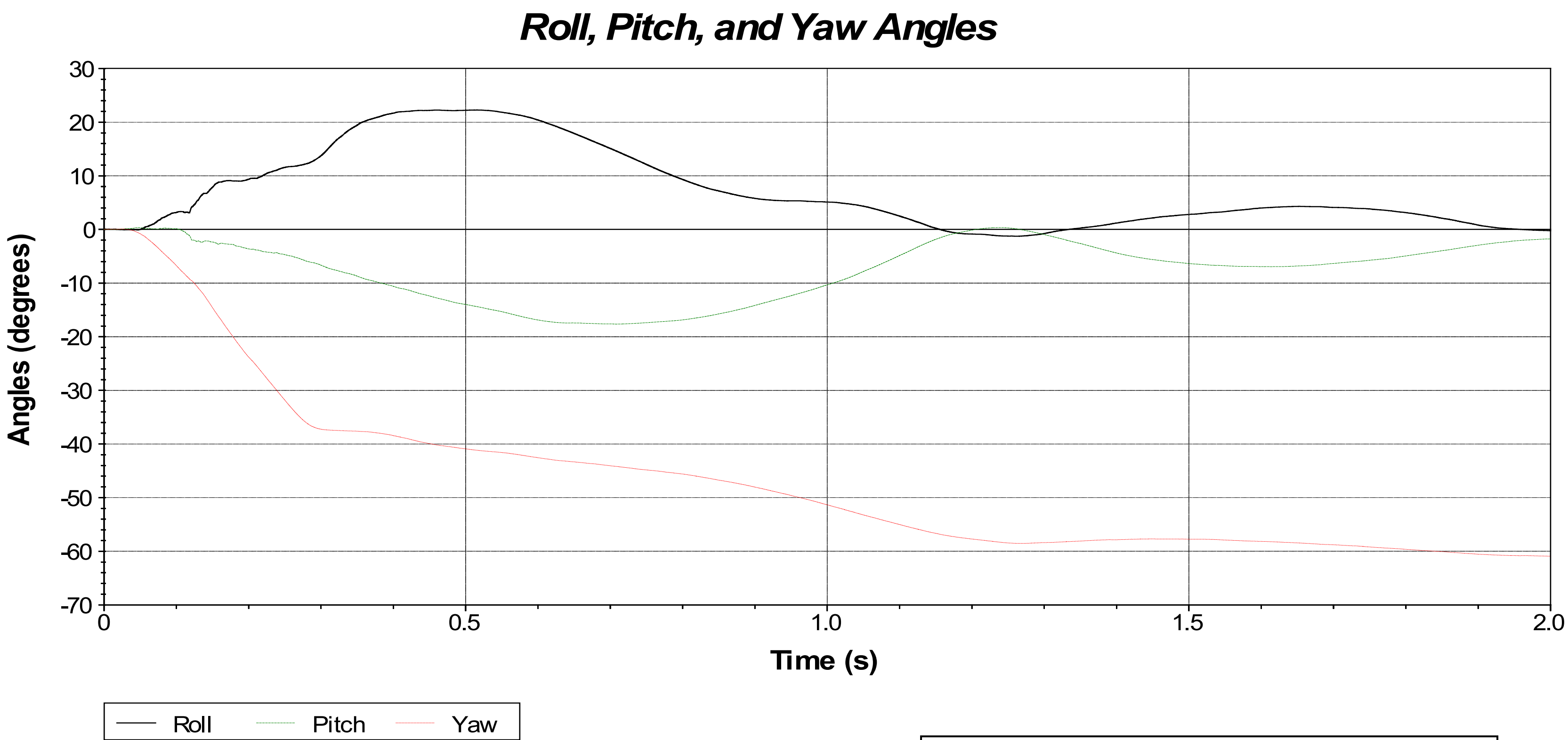
0.400 s

0.500 s

0.600 s

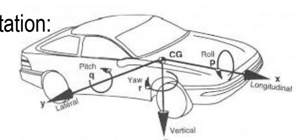
0.700 s

Figure D.2. Sequential Photographs for Test No. 613121-01-1 (Rear View).



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 613121-01-1
Test Standard Test Number: *MASH* Test 3-21
Test Article: Short Transition
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5061 lb
Gross Mass: 5226 lb
Impact Speed: 62.6 mi/h
Impact Angle: 25.4 degrees

Figure D.3. Vehicle Angular Displacements for Test No. 613121-01-1.

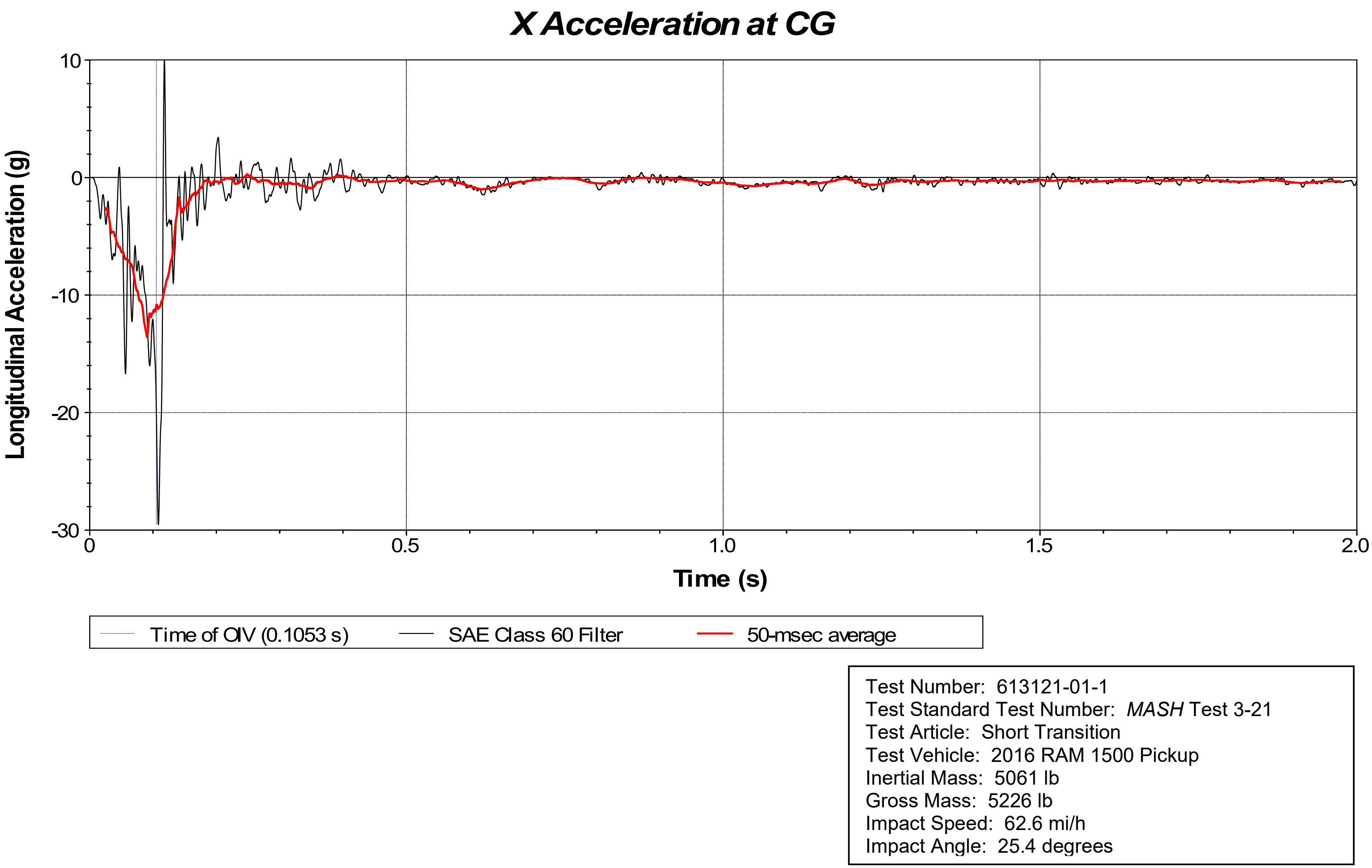
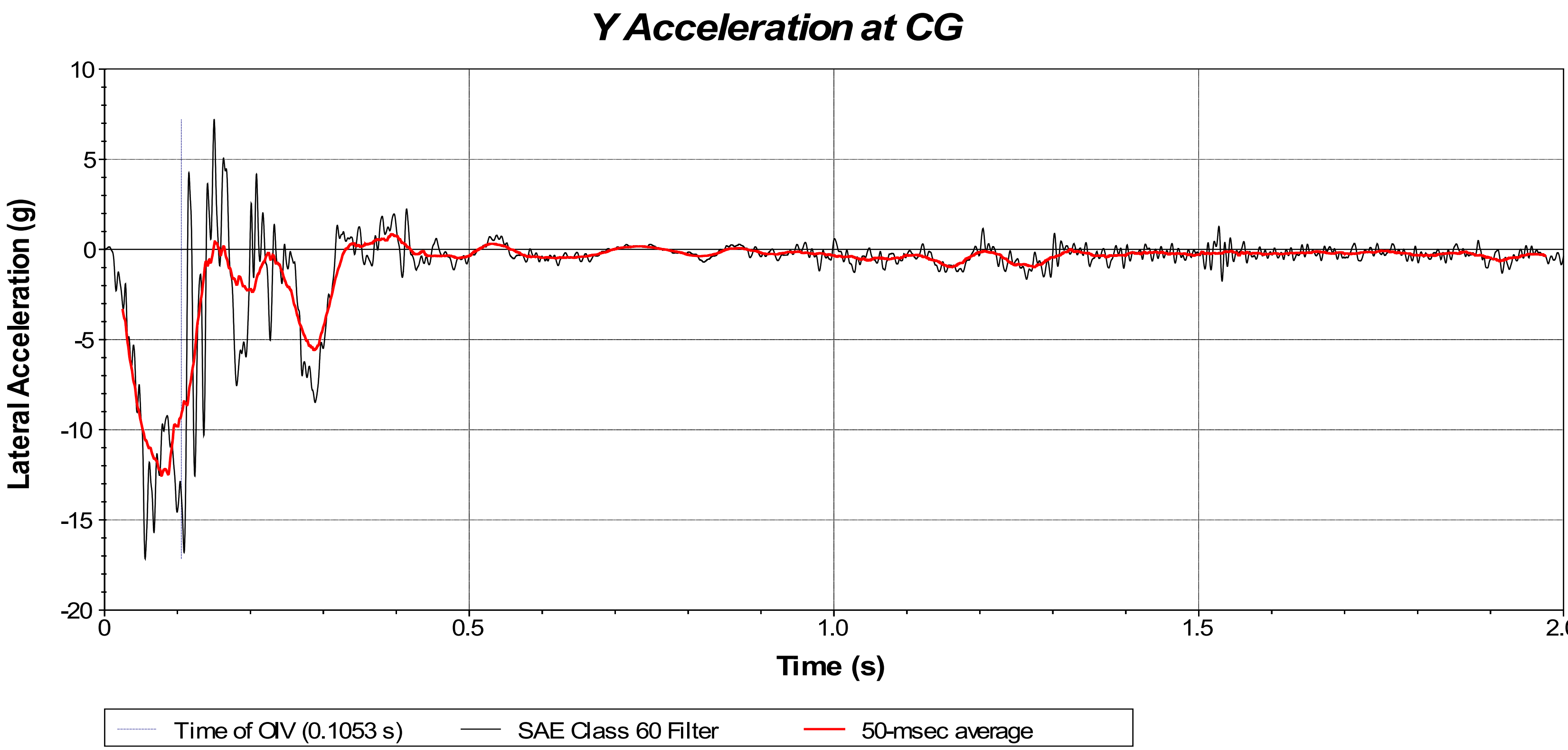
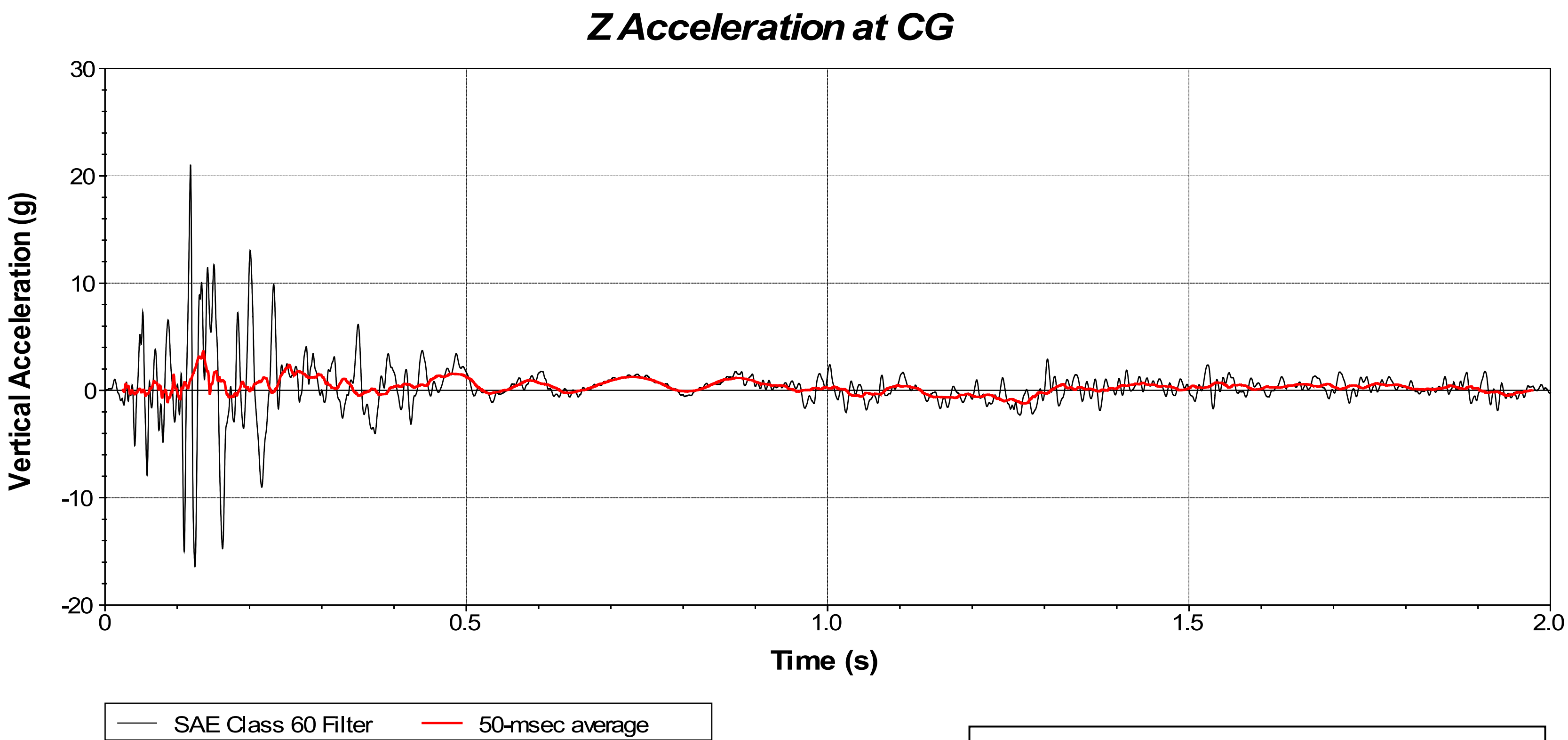


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 613121-01-1 (Accelerometer Located at Center of Gravity).



Test Number: 613121-01-1
Test Standard Test Number: *MASH* Test 3-21
Test Article: Short Transition
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5061 lb
Gross Mass: 5226 lb
Impact Speed: 62.6 mi/h
Impact Angle: 25.4 degrees

Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 613121-01-1 (Accelerometer Located at Center of Gravity).



Test Number: 613121-01-1
Test Standard Test Number: *MASH* Test 3-21
Test Article: Short Transition
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5061 lb
Gross Mass: 5226 lb
Impact Speed: 62.6 mi/h
Impact Angle: 25.4 degrees

Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 613121-01-1 (Accelerometer Located at Center of Gravity)