Development of *MASH* TL-2 Crashworthy W-Beam Terminals For Low-Speed/Volume Roads

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DEVELOPMENT OF *MASH* TL-2 CRASHWORTHY W-BEAM TERMINALS FOR LOW-SPEED/VOLUME ROADS

Sponsored by

Federal Highway Administration
Office of Federal Lands Highway

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16. Abstract

The objective of this research was to design a simple low-cost guardrail terminal at *Manual for Assessing Safety Hardware* (*MASH*) Test Level 2 (TL-2) (44 mi/h) that assumed use of a current generic MGS W-beam guardrail, which is the most widely used guardrail in the country. The terminal design was tested and evaluated according to the safety-performance evaluation guidelines included in the second edition of *MASH* [1]. The crash tests were performed in accordance with *MASH* TL-2.

This report provides details on the development and simulations of different designs for the TL-2 W-beam end terminal, the crash tests and results, and the performance assessment of the TL-2 W-beam end terminal for *MASH* TL-2 gating terminal evaluation criteria.

The final TL-2 W-beam end terminal design met the performance criteria for *MASH* Tests 2-35, 2-30, 2-31, and 2-37b for gating terminals.

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The results reported herein apply only to the article tested. The full-scale crash tests were performed according to TTI Proving Ground quality procedures and American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware, Second Edition (*MASH*) guidelines and standards.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	ft	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 ft	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 ft	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	ft	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 ft	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 ft	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

Chapter 1. INTRODUCTION AND BACKGROUND

1.1. INTRODUCTION

The objective of this research was to design a simple low-cost guardrail terminal at American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test Level 2 (TL-2) (44 mi/h) that assumed use of a current generic MGS W-beam guardrail, which is the most widely used guardrail in the country. The terminal design was tested and evaluated according to the safety-performance evaluation guidelines included in the second edition of *MASH* (*1*). The crash tests were performed in accordance with *MASH* TL-2 for gating end terminals (as discussed in Chapter 6).

1.2. BACKGROUND

Guardrail terminals have been developed and evaluated for decades to improve safety during vehicle crashes with the end section of guardrail systems. A few of the previously tested TL-2 guardrail terminal systems are summarized in this section.

1.2.1. Vermont Guardrail Terminal

The Vermont W-beam guardrail terminal was evaluated by the Texas A&M Transportation Institute (TTI) according to National Cooperative Highway Research Program (NCHRP) Report 350 TL-2 (*2*).

The terminal consisted of a flared radius end section across two steel posts. The total flare offset was 58 inches. The length-of-need (LON) section was anchored at the third post, where the end treatment transitions to the tangent LON section, using an anchor spider. Figure 1.1 shows the Vermont W-beam guardrail terminal. The terminal end component was a standard W-beam end section.

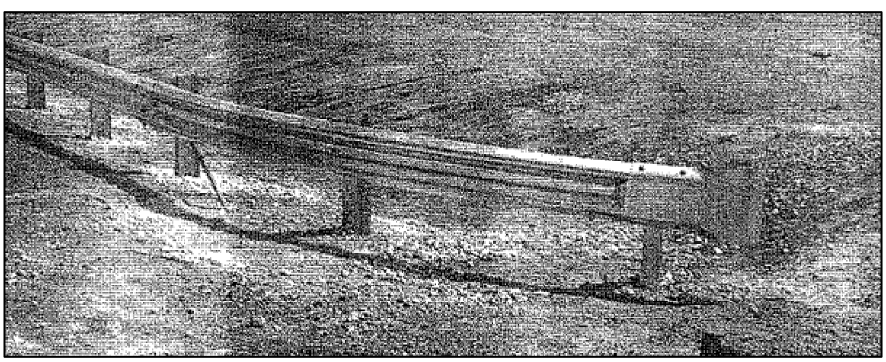


Figure 1.1. Vermont W-Beam Guardrail Terminal (*2*).

Three crash tests were conducted to evaluate the crashworthy performance of the Vermont W-beam guardrail terminal: NCHRP Report 350 Tests 2-30, 2-34, and 2-35.

For NCHRP Report 350 Test 2-30, the vehicle gated through the terminal and came to a stop behind the installation. During the vehicle impact, the first steel post yielded and was deflected down toward the ground as the vehicle traversed over it. The end rail section bent backward during vehicle impact and was curved around the second post. There was minimal movement of the other posts. The damage to the vehicle was acceptable, and the occupant risk values were within the limits. Figure 1.2 shows the vehicle and test installation after the crash test.

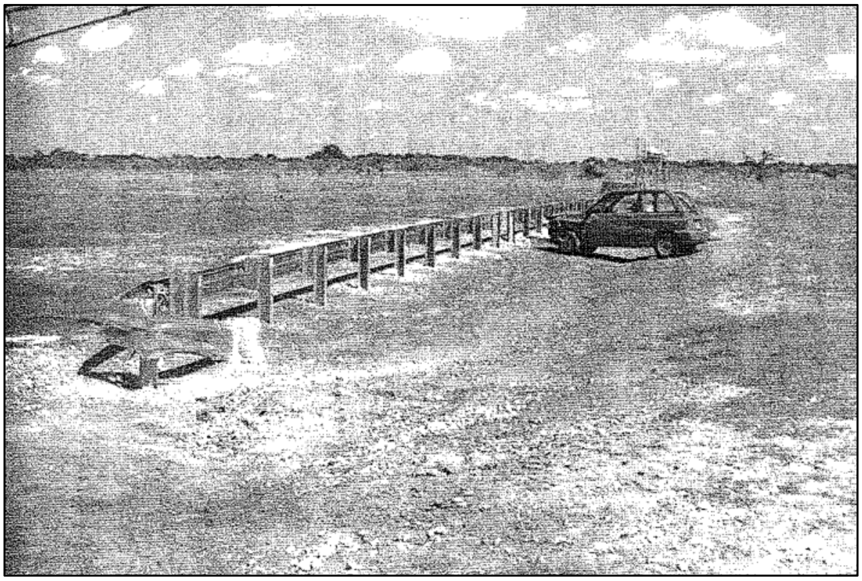


Figure 1.2. Vehicle and Test Installation after Test 2-30 (*2*).

For NCHRP Report 350 Test 2-34, the small car vehicle came to a controlled stop after impacting the end terminal. The second steel post yielded during vehicle impact and was deflected down toward the ground. The rail end section detached at posts 1 and 2. No other significant damage was noted for the installation. The damage to the vehicle was acceptable, and the occupant risk values were within the limits. Figure 1.3 shows the vehicle and test installation after the crash test.

Figure 1.3. Vehicle and Test Installation after Test 2-34 (*2*).

For NCHRP Report 350 Test 2-35, the pickup truck vehicle was successfully contained and redirected. There was minimal damage to the test installation. The damage to the vehicle was acceptable, and the occupant risk values were within the limits.

The Vermont W-beam guardrail terminal met all the evaluation criteria for NCHRP Report 350 TL-2 end terminals.

1.2.2. Texas Turndown Terminal

A turndown version of a guardrail terminal was developed and evaluated by TTI according to NCHRP Report 153 and later to NCHRP Report 230 (*3*).

The turndown terminal system consisted of a 25-ft guardrail section twisted down from the guardrail LON height to the ground. There were no guardrail posts in this section, and the rail was attached to a concrete foundation. The twisted guardrail section was not attached to the first five wood posts. The section was held in place by steel straps that were attached to W-beam backup plates connected to the wood posts. Figure 1.4 shows the terminal system.

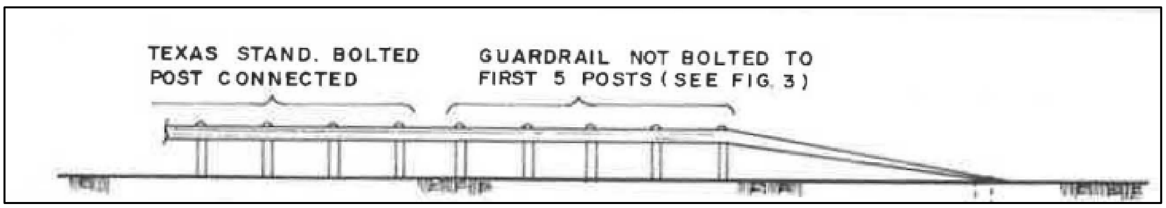


Figure 1.4. Texas Turndown Terminal System (*3*).

Five crash tests were conducted to evaluate the crashworthy performance of the Texas turndown terminal. The terminal system was considered satisfactory for the NCHRP Report 153 evaluation criteria. The turndown system allowed the vehicle to ride over the twisted section without rolling over. In the head-on crash test, the vehicle depressed the rail and rode along the length of the guardrail installation. Figure 1.5 shows the vehicle after the crash test.

Figure 1.5. Test Vehicle after Head-On Crash Test (*3*).

The Texas turndown terminal was later evaluated according to NCHRP Report 230. The design failed NCHRP Report 230 Test 45 because the vehicle launched into the air during the head-on impact and rolled over. Different adaptions of the Texas turndown terminal were developed and evaluated over the years. These systems were also found to be unsuccessful for NCHRP Report 230. The main components of the twisted, unsupported, and ground-anchored rail were similar among the different designs.

1.2.3. Slotted Rail Terminal

The slotted rail terminal (SRT) is a guardrail end terminal that has been tested and evaluated according to NCHRP Report 350 and *MASH* TL-3 (*4*). The SRT incorporates some of the following design elements: a cable release anchor post, steel terminal posts, two slotted W-beam rails, and a standard cable anchor bracket. The use of slotted rails was considered during the design phase of this project. The other design elements of the SRT were not considered in this research.

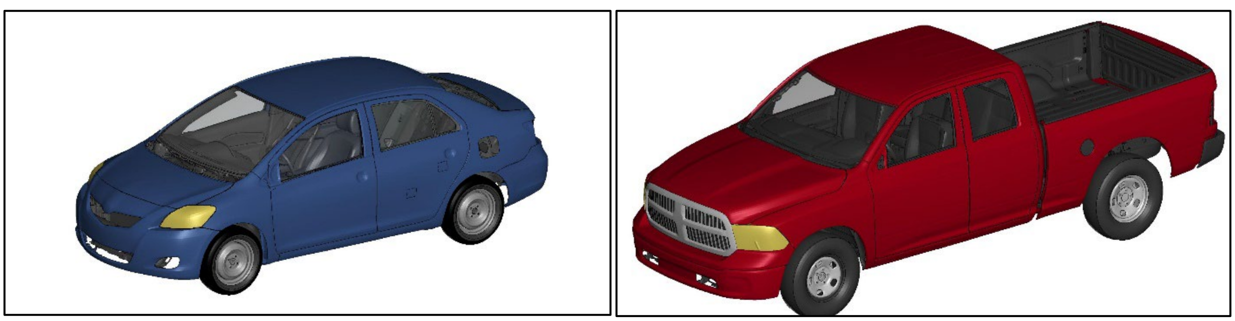
Chapter 2. SYSTEM DESIGN

2.1. SIMULATION INTRODUCTION

Finite element (FE) computer simulations were utilized to evaluate three end terminal design concepts according to *MASH* TL-2 evaluation criteria. The three design concepts were similar to the systems discussed in Chapter 1. The simulations were conducted using LS-DYNA, which is a general-purpose FE program capable of simulating complex engineering systems with impact-contact phenomena (*5*). This chapter discusses the simulation setup, design concepts, and computer simulation results. The designs considered early in this project were based on the non-proprietary systems, mainly the Vermont terminal and the Texas twist or turned down terminal due to their simplicity. Neither of these designs has been tested per *MASH* test conditions, and known performance issues have to be addressed through design modification to evaluate their performance per *MASH* test conditions and evaluation criteria.

2.2. SIMULATION SETUP

Representative FE models of the 1100C and 2270P test vehicles are shown in Figure 2.1. The vehicle models were developed by the Center for Collision Safety and Analysis. These vehicle models were used to evaluate the crashworthy performance of the end terminal models.



(a) 1100C FE Model (b) 2270P FE Model

Figure 2.1. FE Vehicle Models.

Geometrical representations of the three end terminal design concepts were developed, and an FE mesh was applied to each of the parts. Appropriate section and material properties were applied for the end terminal system components (steel posts, wood posts, guardrail, anchor, etc.). Boundary conditions and contact between the vehicle and end terminal model were defined.

2.3. TEXAS TWIST DESIGN EVALUATION

The Texas twist end terminal design was evaluated with FE computer simulations. Figure 2.2 shows the FE model of the end terminal. A standard 12-ft section of W-beam guardrail was anchored at groundline (applied boundary constraint) and twisted to attach at the first steel post. The remaining system consists of a standard LON guardrail.

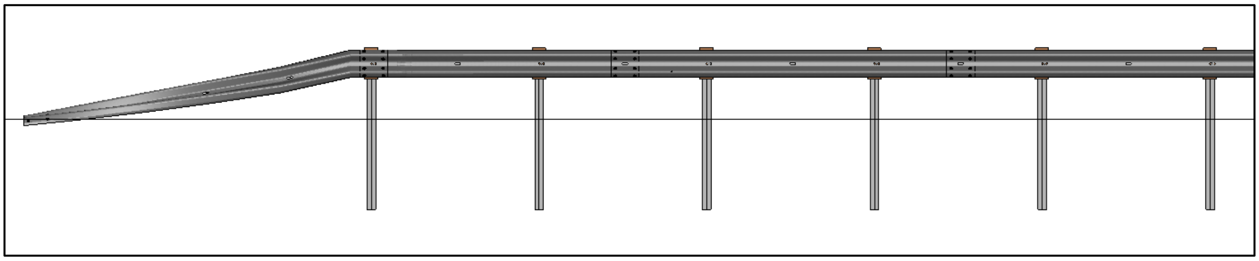
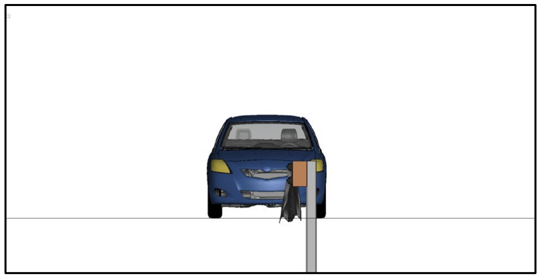
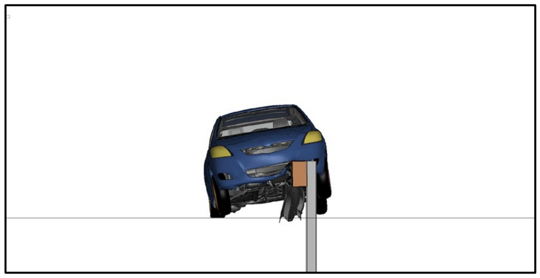


Figure 2.2. FE Model of Texas Twist End Terminal Design.

The first impact simulation for this system was *MASH* Test 2-30, which is a head-on impact. This test involved impacting the end terminal with the 1100C vehicle model at a speed of 44 mi/h and an angle of 0 degrees. The 1100C vehicle model impacted the terminal system with the quarter point of the vehicle bumper aligned with the tangent guardrail. Figure 2.3 shows sequential images for the *MASH* Test 2-30 simulation impact. The small car vehicle model climbed the rail during impact and rolled over. Thus, the system would be considered unsatisfactory according to *MASH*. Additional simulations were not conducted on this system based on the unsatisfactory performance.



(a) 0.0 s



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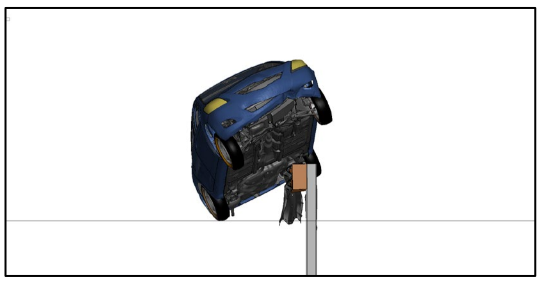

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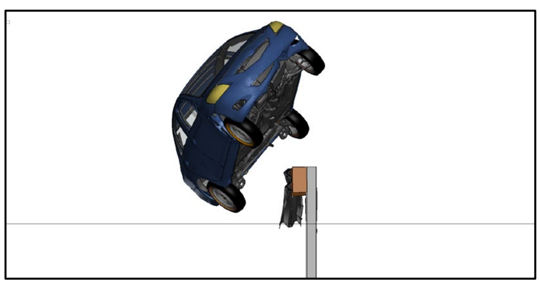

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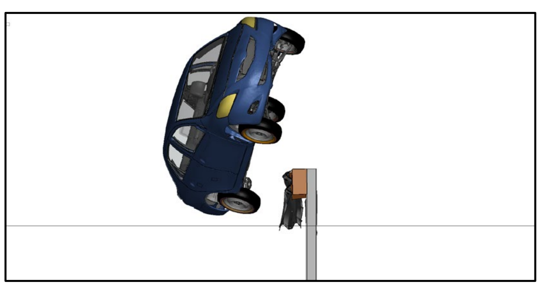
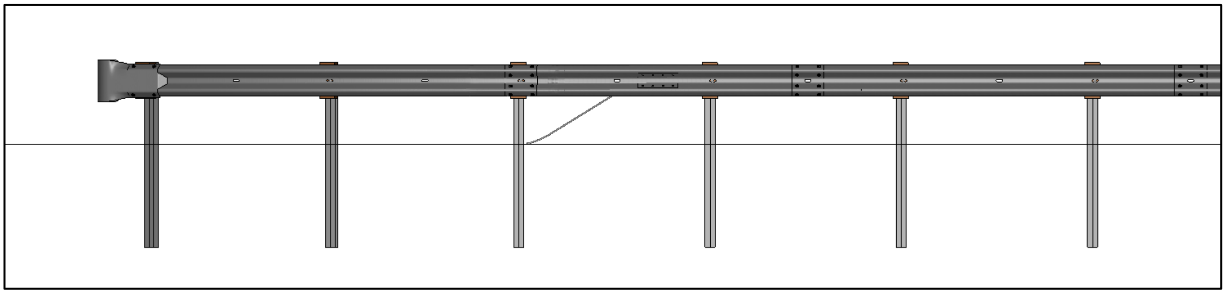


(e) 0.8 s

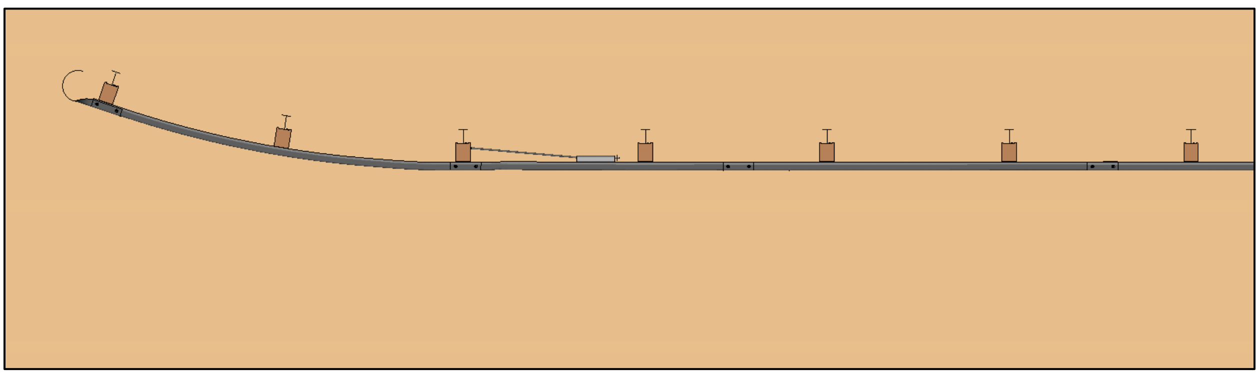
Figure 2.3. Texas Twist Test 2-30 Simulation Sequential Images (Downstream View).

2.4. VERMONT TERMINAL DESIGN CONCEPT

The Vermont end terminal design was evaluated with FE computer simulations. Figure 2.4 shows the FE model of the end terminal. The first two posts are attached to a curved section of W-beam guardrail. A rounded W-beam end section is located at the end of the terminal. The remaining system consists of a standard LON guardrail. An anchor cable is connected between the tangent guardrail section and the third steel post.



(a) Elevation view

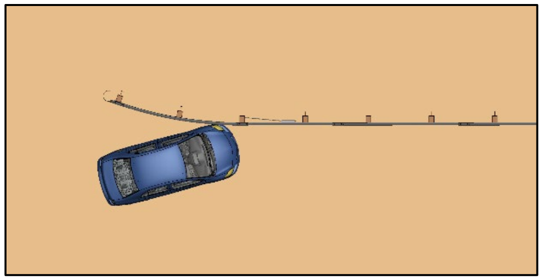


(b) Plan view

Figure 2.4. FE Model of Vermont End Terminal Design.

The following impact simulations were performed on the Vermont terminal model system: *MASH* Tests 2-30, 2-31, 2-32, 2-33, 2-34, 2-35, and 2-37b. For conciseness, only the results of the *MASH* Test 2-34 simulation are discussed.

MASH Test 2-34 involved impacting the end terminal with the 1100C vehicle model at a speed of 44 mi/h and an angle of 15 degrees. The 1100C vehicle model impacted the terminal system 30 inches upstream of the third steel post. Figure 2.5 shows sequential images for the *MASH* Test 2-34 simulation impact. The impact side front wheel of the car model snagged on the cable anchor during impact. This resulted in a longitudinal occupant ridedown acceleration (ORA) of 25.6 g, which was above the *MASH* limit. Thus, the system would be considered unsatisfactory according to *MASH*. Additional simulations were not conducted on this system based on the unsatisfactory performance.



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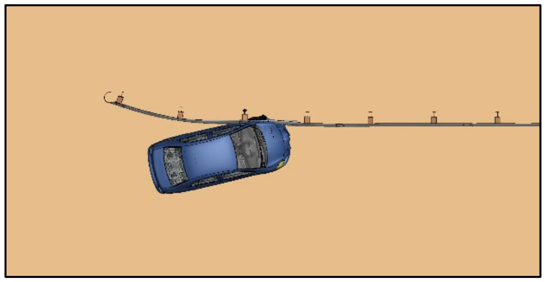

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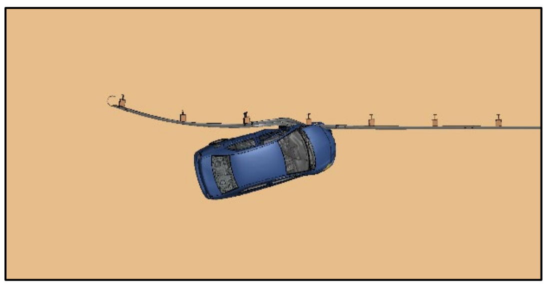

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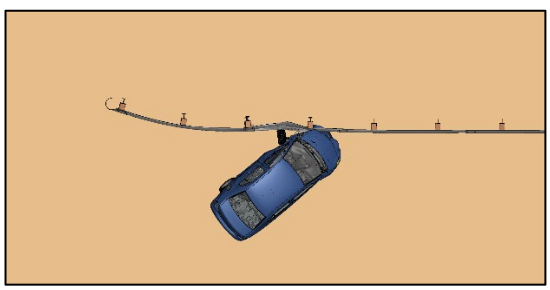

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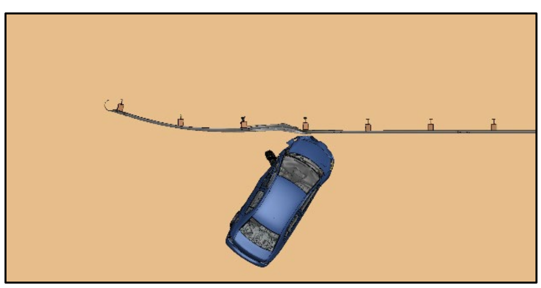
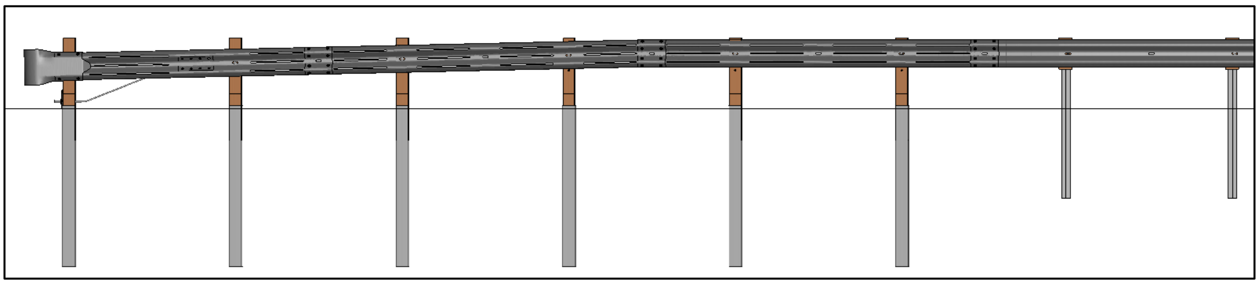


(e) 0.4 s

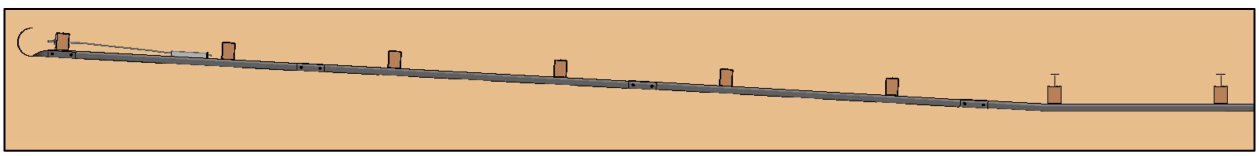
Figure 2.5. Vermont Terminal Test 2-34 Simulation Sequential Images (Overhead View).

2.5. FLARED SLOTTED TERMINAL DESIGN CONCEPT

The flared slotted end terminal design was evaluated with FE computer simulations. Figure 2.6 shows the FE model of the end terminal. The first two slotted rail sections transitioned from a height of 25 inches to 31 inches. The first six posts were wood breakaway posts inserted in steel sleeves. The remaining guardrail posts were standard steel posts. The terminal was anchored at the first wood breakaway post with a steel anchor cable. The remaining system consists of a standard LON guardrail.



(a) Elevation view

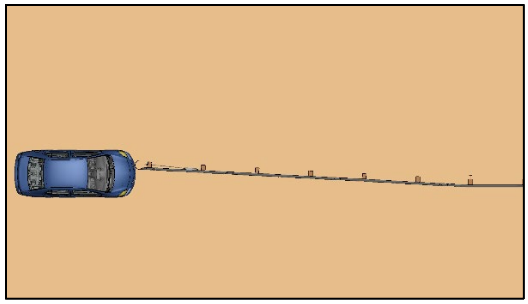


(b) Plan view

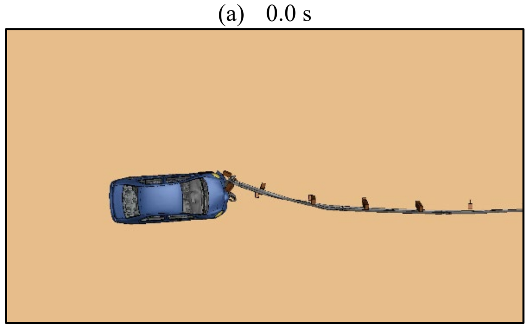
Figure 2.6. FE Model of Flared Slotted End Terminal Design.

Two critical impact simulations were performed on the flared slotted end terminal model system: *MASH* Tests 2-30 and 2-35.

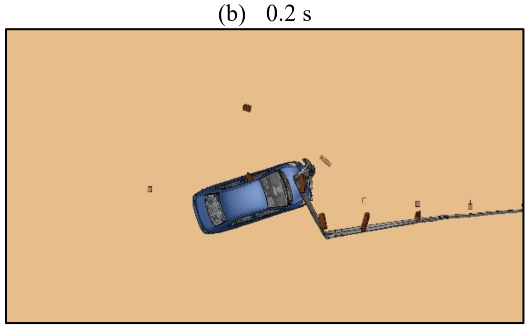
MASH Test 2-30 involved impacting the end terminal with the 1100C vehicle model at a speed of 44 mi/h and an angle of 0 degrees. The 1100C vehicle model impacted the terminal system with the quarter point of the vehicle bumper aligned with the end terminal head. Figure 2.7 shows sequential images for the *MASH* Test 2-30 simulation impact. The end terminal released as designed, and the vehicle gated through the system. The occupant risk values were within the *MASH* limits.



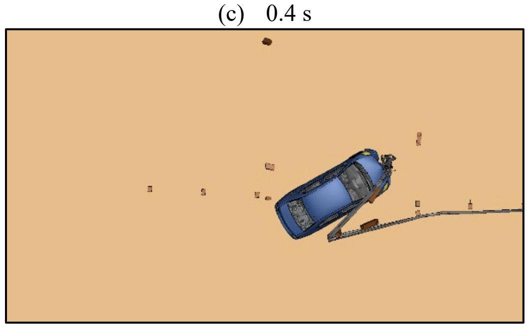
(a) 0.0 s



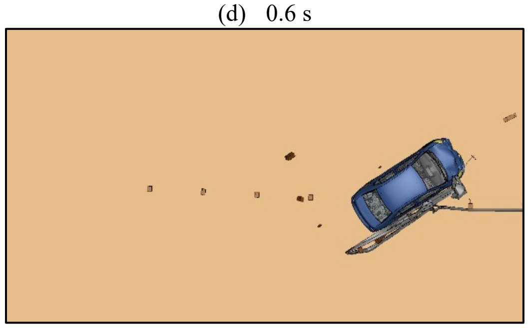
(b) 0.2 s



(c) 0.4 s



(d) 0.6 s



(e) 0.8 s

Figure 2.7. Flared Slotted Terminal Test 2-30 Simulation Sequential Images (Overhead View).

2.6. DISCUSSION

Three end terminal design concepts were evaluated according to *MASH* TL-2 evaluation criteria. FE computer simulations were performed with impact conditions representative of the *MASH* TL-2 crash test conditions for end terminals.

The small car vehicle rolled over during the *MASH* Test 2-30 impact simulation with the Texas twist end terminal system. This result indicates that more design modifications must be done for the Texas twist terminal system to have a chance at eliminating vehicular rollover.

The Vermont terminal design did perform acceptably for most of the *MASH* TL-2 crash tests. However, the small car wheel snagged on the cable anchor during the Test 2-34 impact simulation. This snagging phenomenon led to ridedown accelerations exceeding the *MASH* limit. The failure of the vehicle suspension is a complex phenomenon to be accurately modeled and simulated. Thus, having a simulated higher ridedown acceleration value is not necessarily going to be reflected in the physical tests given that small car suspension fails easily from an overall anecdotal observation of recent testing.

The flared slotted end terminal design did perform acceptably for *MASH* Test 2-30 but had unsatisfactory performance for *MASH* Test 2-35. The anchor cable assembly needed modification to successfully contain and redirect the pickup truck.

These initial simulations indicated that the Vermont terminal design was the candidate to be evaluated via crash testing. Use of a slotted rail was also appropriate given that the rail would have less stiffness than a non-slotted rail for head-on impacts. The initial tests were focused on the terminal end performance in a head-on impact. The redirection tests were not evaluated first since the anchors in these candidate systems have historically performed well. Consequently, a Texas twist terminal was evaluated with weaker rail segments via slotting of initial rail segments. This evaluation provided an assessment on whether making changes to the design would be worth pursuing if the performance was significantly improved and the vehicular rollover was prevented.

Chapter 3. INITIAL TESTING

Several different designs were tested before the final configuration successfully completed the *MASH* Tests 2-35, 2-30, 2-31, and 2-37b for gating terminals. Those installations, their differences, and any test failure mechanisms are presented in this chapter.

3.1. *MASH* TEST 2-32 (CRASH TEST NO. 615181-01-1, TEST DATE 2021-08-31)

3.1.1. Test Article and Installation Details

The test installation was 131 ft 3 inches long. A TL-2 Terminal, which was approximately 21.8 ft. long, was at one end, and a Steel Post Terminal which was approximately 9.5 ft was at the opposite end. Between the two end terminals was 100 ft. of standard length-of-need guardrail. The LON consisted of 12-gauge W-beam supported by W6×8.5 posts with timber blockouts. All posts were spaced at 75 inches.

The TL-2 Terminal spanned four posts, with the first one offset toward the field side 24 inches and the second one offset 5½ inches. All other posts were in line with the LON. A BCT anchor cable was attached to the W-beam between posts 3 and 4 and anchored to a W6×15 post on the traffic side of post 3. This anchor post protruded 3 inches above grade.

Figure 3.1 and Figure 3.2 present the overall information on the TL-2 Terminal, and Figure 3.3 and Figure 3.4 provide photographs of the installation.

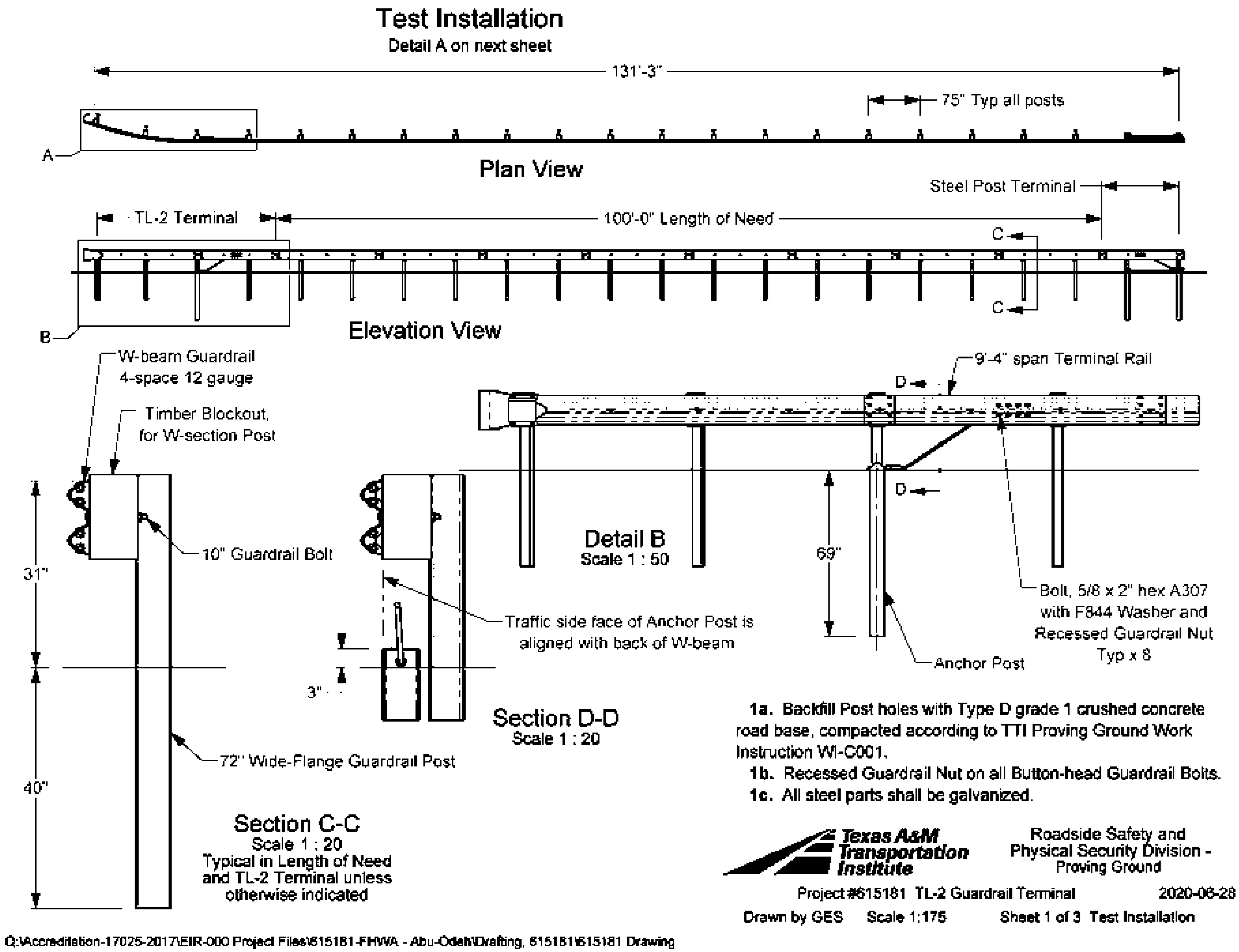


Figure 3.1. Details of TL-2 Terminal on MGS for Crash Test 615181-01-1.

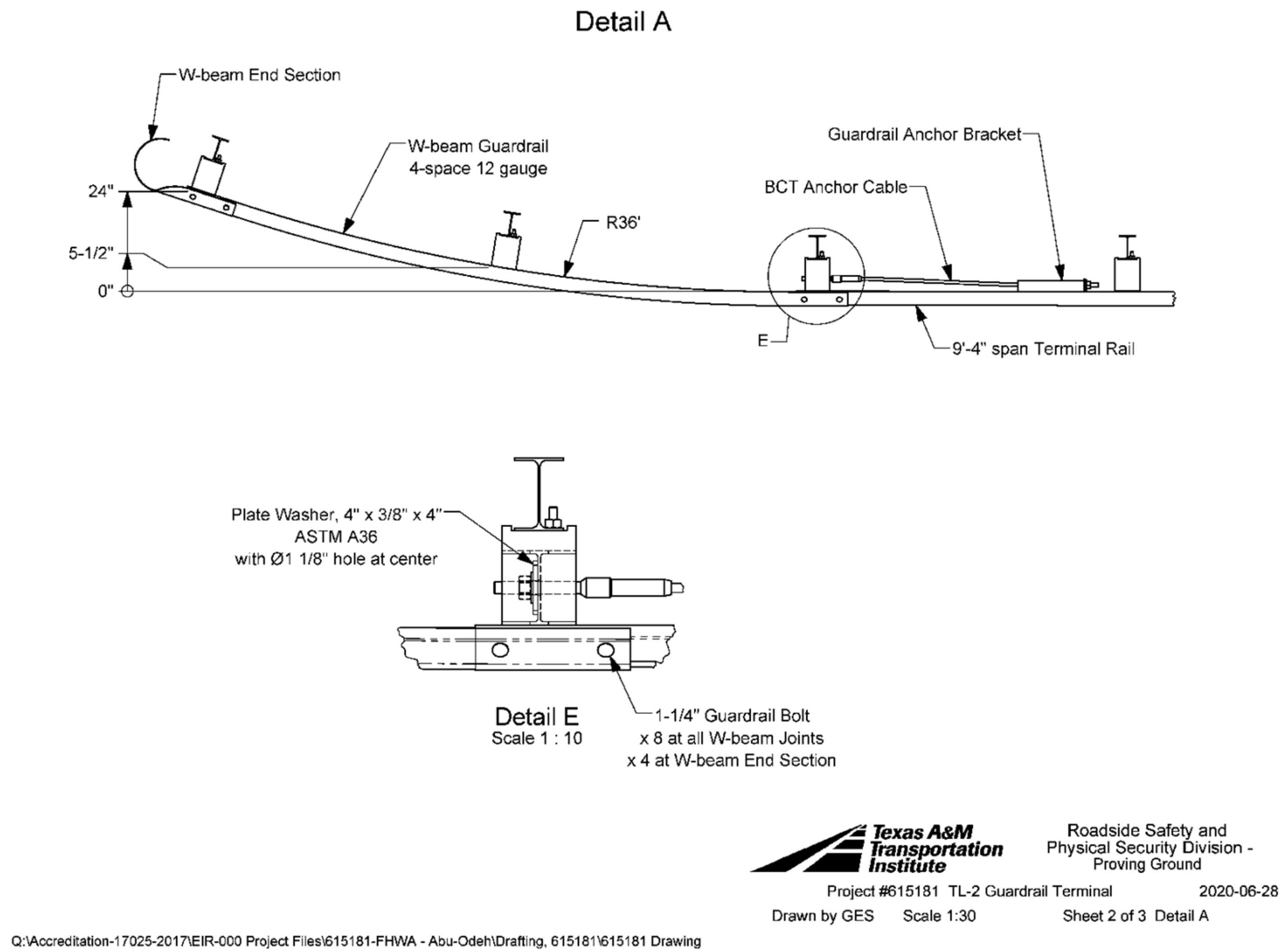


Figure 3.2. Upstream Terminal Details of TL-2 Terminal on MGS for Crash Test 615181-01-1.

Figure 3.3. TL-2 Terminal on MGS prior to Crash Test 615181-01-1.

Figure 3.4. In-Line View of the TL-2 Terminal on MGS prior to Crash Test 615181-01-1.

3.1.2. Crash Test Results for Crash Test 615181-01-1

The TL-2 Terminal for crash test 615181-01-1 met the performance criteria for *MASH* TL-2 Test 2-32 for Gating Terminals. Thus, crash test 615181-01-2 for *MASH* Test 2-30 was performed next. Its details follow in section 3.2.

Figure 3.5 shows the installation and vehicle post impact.

Figure 3.5. TL-2 Terminal on MGS Post Impact for Crash Test 615181-01-1.

3.2. *MASH* TEST 2-30 (CRASH TEST NO. 615181-01-2, TEST DATE 2021-09-02)

3.2.1. Test Article and Installation Details

The 615181-01-2 test installation differed from the 615181-01-1 installation in that the TL-2 terminal was used on both ends of the installation. This shortened the overall length of the installation by 1 ft-3 inches to 130 ft-0 inches.

Figure 3.6 and Figure 3.7 present the overall information on the TL-2 Terminal on MGS, and Figure 3.8 and Figure 3.9 provide photographs of the installation.

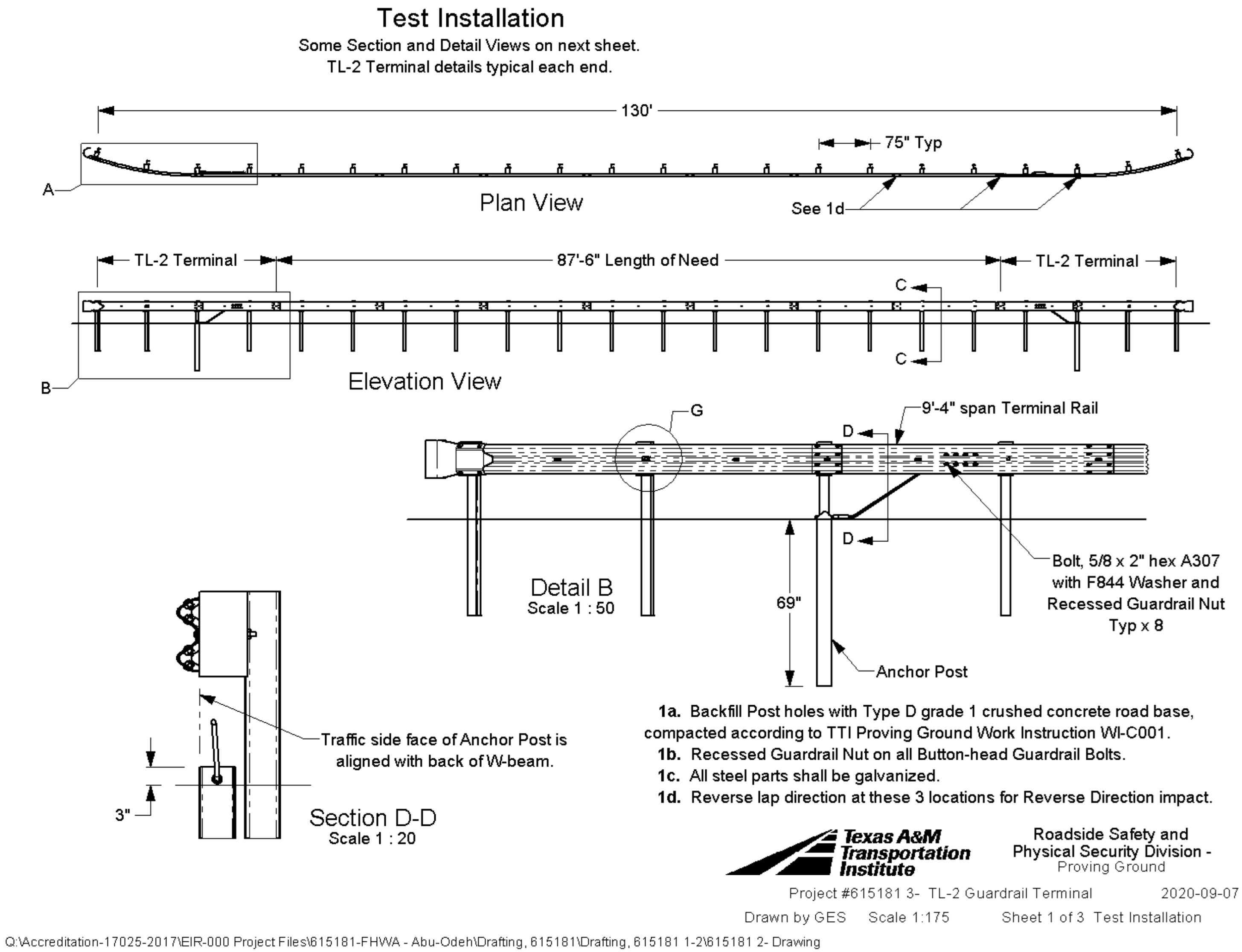


Figure 3.6. Details of TL-2 Terminal on MGS for Crash Test 615181-01-2.

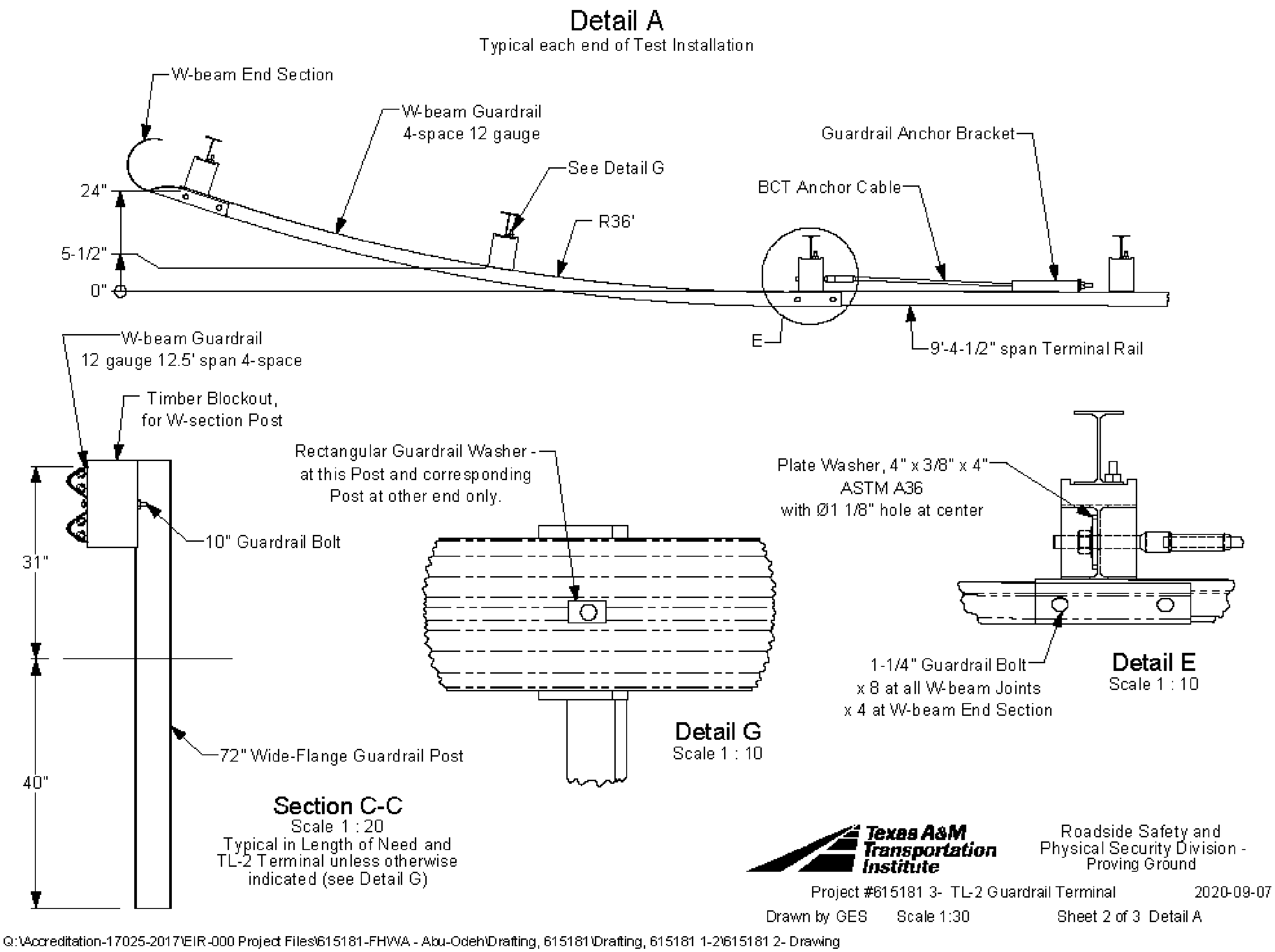


Figure 3.7. Upstream Terminal Details of TL-2 Terminal on MGS for Crash Test 615181-01-2.


Figure 3.8. TL-2 Terminal on MGS prior to Crash Test 615181-01-2.


Figure 3.9. In-Line View of the TL-2 Terminal on MGS prior to Crash Test 615181-01-2.

3.2.2. Crash Test Results for Crash Test 615181-01-2

The TL-2 Terminal for *MASH* Test 2-30 crash test 615181-01-2 did not meet the performance criteria for *MASH* TL-2 Gating Terminals. The rail impacted and tore the windshield, thus showing potential for penetration of the occupant compartment, which is considered a failure under *MASH* Evaluation Criteria D, as detailed in Chapter 6. The installation was redesigned, and the details of the 615181-01-10 installation for *MASH* Test 2-30 are presented in section 3.3.

Figure 3.10, Figure 3.11, and Figure 3.12 show the installation and vehicle damage after impact.

Figure 3.10. TL-2 Terminal on MGS Post Impact for Crash Test 615181-01-2.

Figure 3.11. Detailed View of the Windshield after Crash Test 615181-01-2.

Figure 3.12. Overall View of the Windshield after Crash Test 615181-01-2.

3.3. *MASH* TEST 2-30 (CRASH TEST NO. 615181-01-10, TEST DATE 2021-12-15)

3.3.1. Test Article and Installation Details

The 615181-01-10 test installation differed from the 615181-01-2 installation in that the W-beam rails from posts 1 through 6 and 17 through 22 were slotted along the two ridges and the valley of the rail in between the connection slots, and the rail did not attach to post 7. The flare was also increased from spanning 3 posts to spanning 7 posts on each end of the installation. The embedded anchor post in front of post 3 was also not used, and the rail was anchored to post 1 using an anchor cable assembly.

Figure 3.13 and Figure 3.14 present the overall information on the TL-2 Terminal on MGS for crash test 615181-01-10, and Figure 3.15 and Figure 3.16 provide photographs of the installation.

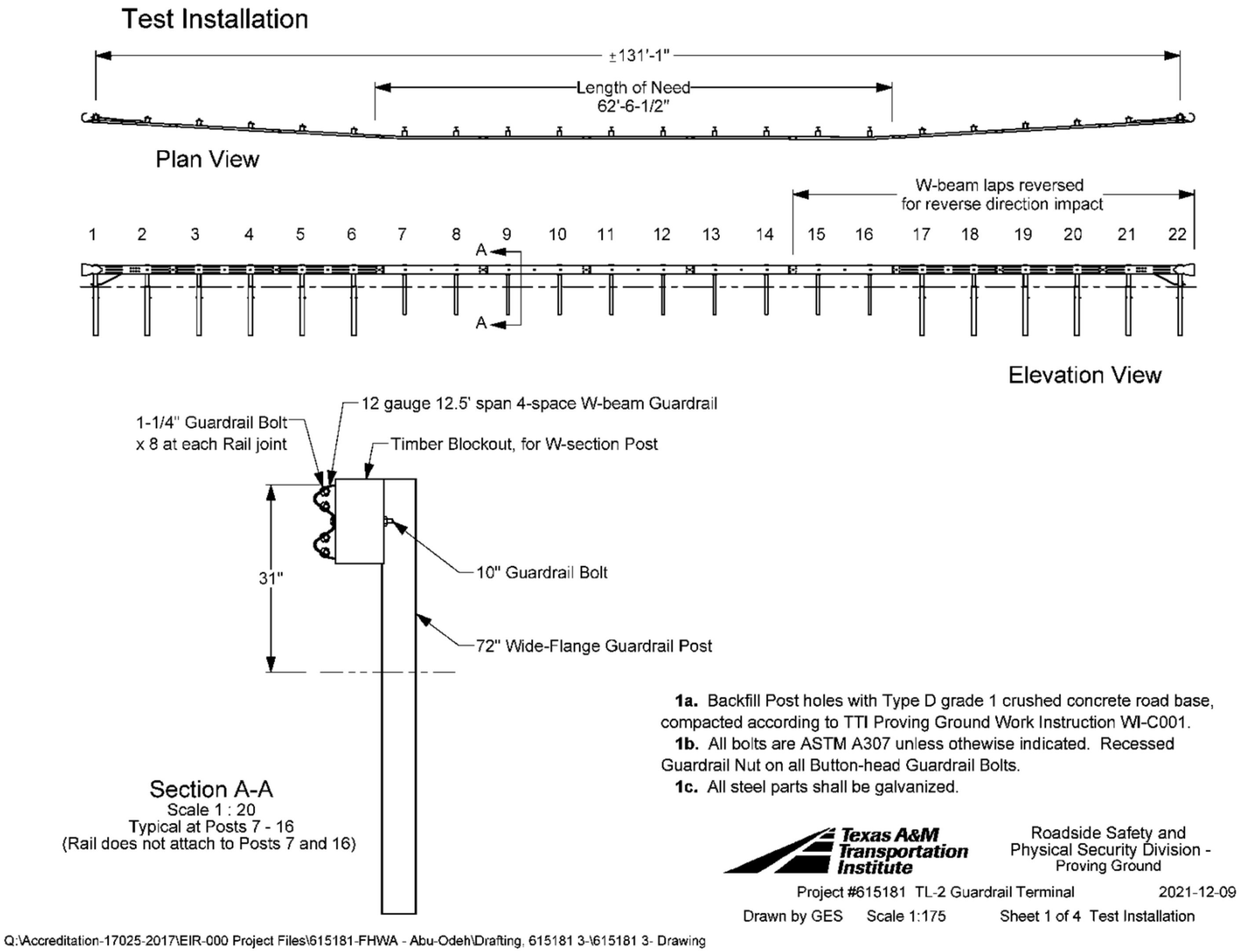


Figure 3.13. Details of TL-2 Terminal on MGS for Crash Test 615181-01-10.

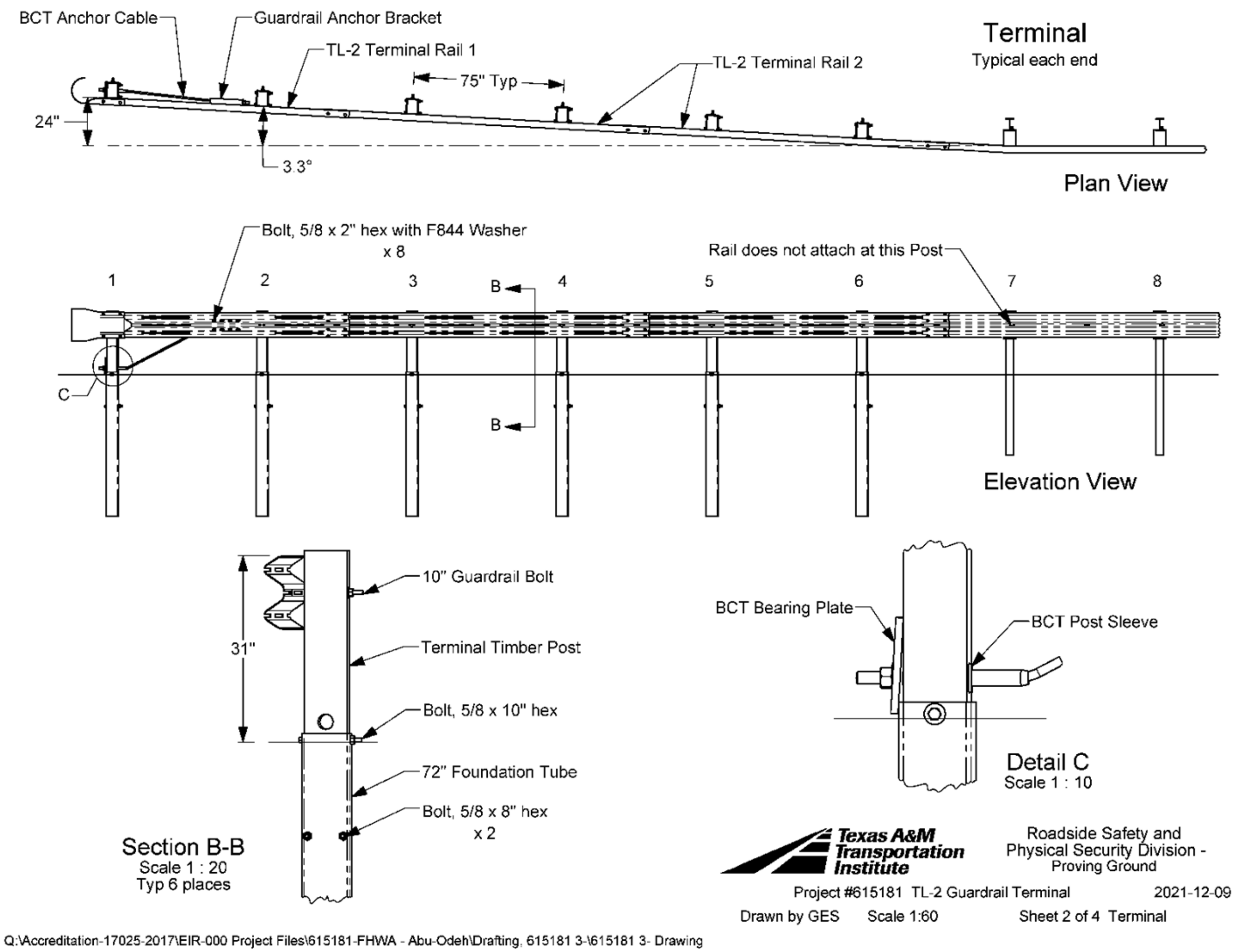


Figure 3.14. Upstream Terminal Details of TL-2 Terminal on MGS for Crash Test 615181-01-10.

Figure 3.15. TL-2 Terminal on MGS prior to Crash Test 615181-01-10.

Figure 3.16. In-Line View of the TL-2 Terminal on MGS prior to Crash Test 615181-01-10.

3.3.2. Crash Test Results for Crash Test 615181-01-10

The TL-2 Terminal for crash test 615181-01-10 did not meet the performance criteria for *MASH* TL-2 Gating Terminals. The rail impacted and tore the windshield thus showing potential for penetration of the occupant compartment, which is considered a failure under *MASH* Evaluation Criteria D as detailed in Chapter 6. The installation was redesigned, and the details of the 615181-01-9 installation and crash test are presented in section 3.3.

Figure 3.17, Figure 3.18, and Figure 3.19 show the installation and vehicle damage after impact.

Figure 3.17. TL-2 Terminal on MGS Post Impact Crash Test 615181-01-10.

Figure 3.18. TL-2 Terminal on MGS Post Impact Crash Test 615181-01-10.

Figure 3.19. TL-2 Terminal on MGS Post Impact Crash Test 615181-01-10.

3.4. *MASH* TEST 2-30 (CRASH TEST NO. 615181-01-9, TEST DATE 2022-02-11)

3.4.1. Test Article and Installation Details

The 615181-01-9 test installation differed from the 615181-01-10 installation in that the rail height was lowered upstream of post 7 and downstream of post 16 from 31 inches to a height of 25 inches at the end posts.

Figure 3.20 and Figure 3.21 present the overall information on the TL-2 Terminal on MGS for crash test 615181-01-9, and Figure 3.22 and Figure 3.23 provide photographs of the installation.

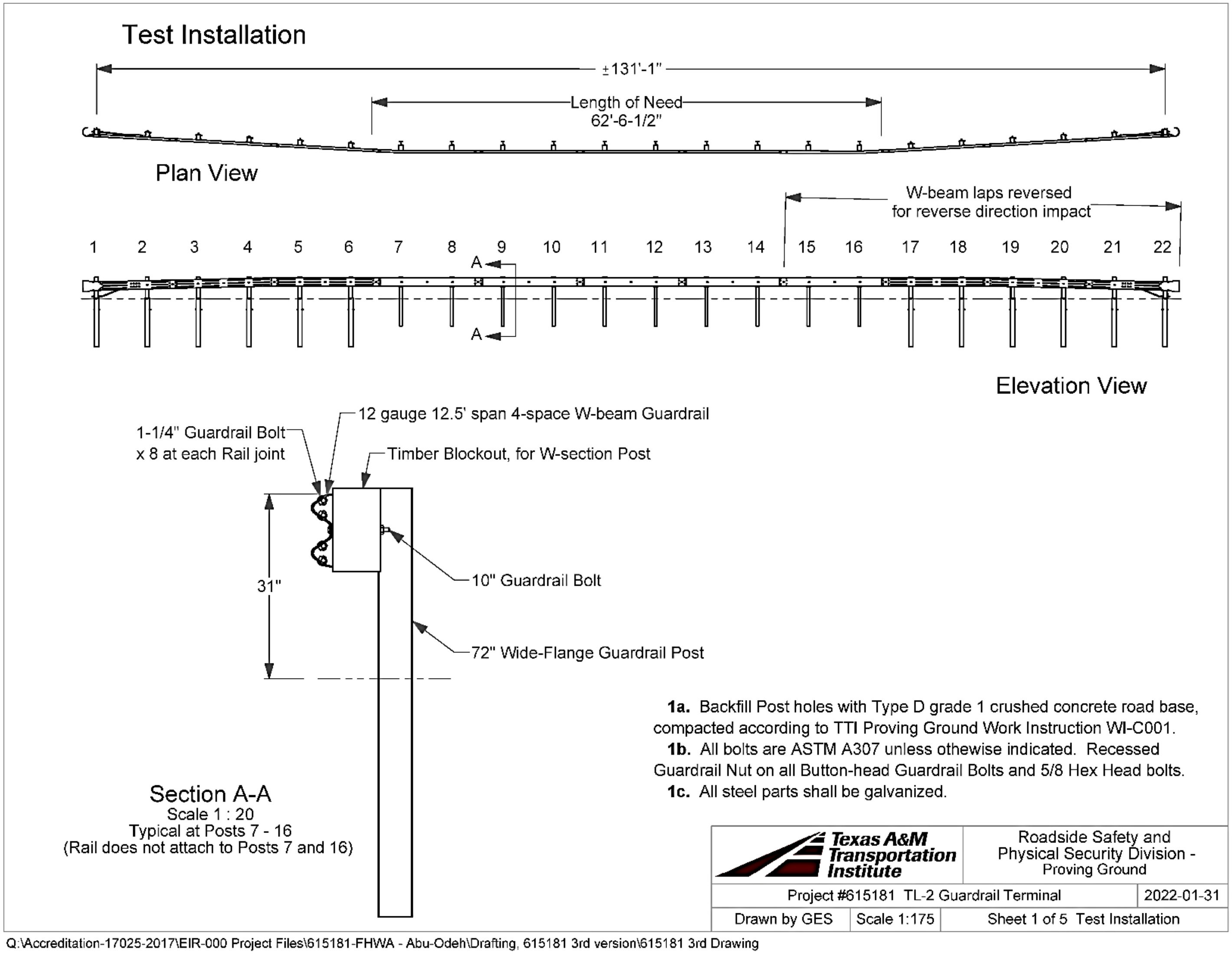


Figure 3.20. Details of TL-2 Terminal on MGS for Crash Test 615181-01-9.

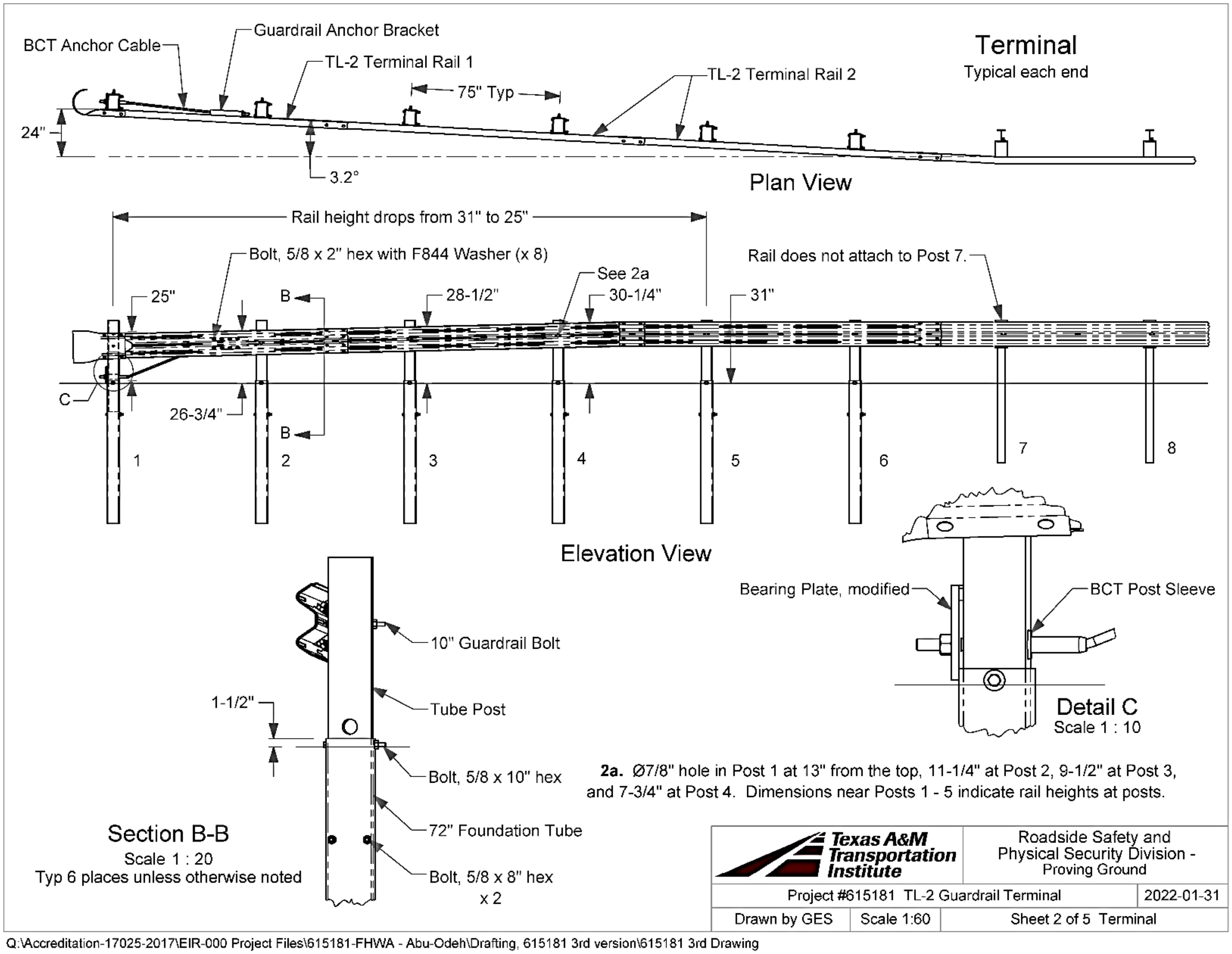


Figure 3.21. Details of TL-2 Terminal on MGS for Crash Test 615181-01-9.

Figure 3.22. TL-2 Terminal on MGS prior to Crash Test 615181-01-9.

Figure 3.23. In-Line View of the TL-2 Terminal on MGS prior to Crash Test 615181-01-9.

3.4.2. Crash Test Results for Crash Test 615181-01-9

The TL-2 Terminal for crash test 615181-01-9 met the performance criteria for *MASH* TL-2 Test 2-30 for Gating Terminals. Therefore, testing continued with *MASH* Test 2-31 as Test 615181-01-3. Its details are in section 3.5.

Figure 3.24 shows the installation and vehicle after impact.

Figure 3.24. TL-2 Terminal on MGS Post Impact for Crash Test 615181-01-9.

3.5. *MASH* TEST 2-31 (CRASH TEST NO. 615181-01-3, TEST DATE 2022-02-16)

3.5.1. Test Article and Installation Details

The installation details for Test 615181-01-3 were the same as those for Test 615181-01-9.Crash Test Results for Crash Test 615181-01-3

The TL-2 Terminal for *MASH* Test 2-31 crash test 615181-01-3 met the performance criteria for *MASH* TL-2 Gating Terminals. Therefore, testing continued with *MASH* Test 2-35 as Test 615181-01-8, which is detailed in section 3.6.

Figure 3.25 shows the installation and vehicle after impact.

Figure 3.25. TL-2 Terminal on MGS Post Impact for Crash Test 615181-01-3.

3.6. *MASH* TEST 2-35 (CRASH TEST NO. 615181-01-8, TEST DATE 2022-04-06)

3.6.1. Test Article and Installation Details

A crash test simulation showed that the 2270P vehicle could override the system as tested in 615181-01-3 when tested to *MASH* Test 2-35 criteria, therefore a strut was added between posts 1 and 2, and then again at posts 25 and 26. The length of need was also increased, which led to an overall length of 156 ft- 1 inch. All other details remained the same as the installations for crash tests 615181-01-09 and 615181-01-3.

Figure 3.26 presents the overall information on the TL-2 Terminal on MGS for crash test 615181-01-8, and Figure 3.27 and Figure 3.28 provide photographs of the installation

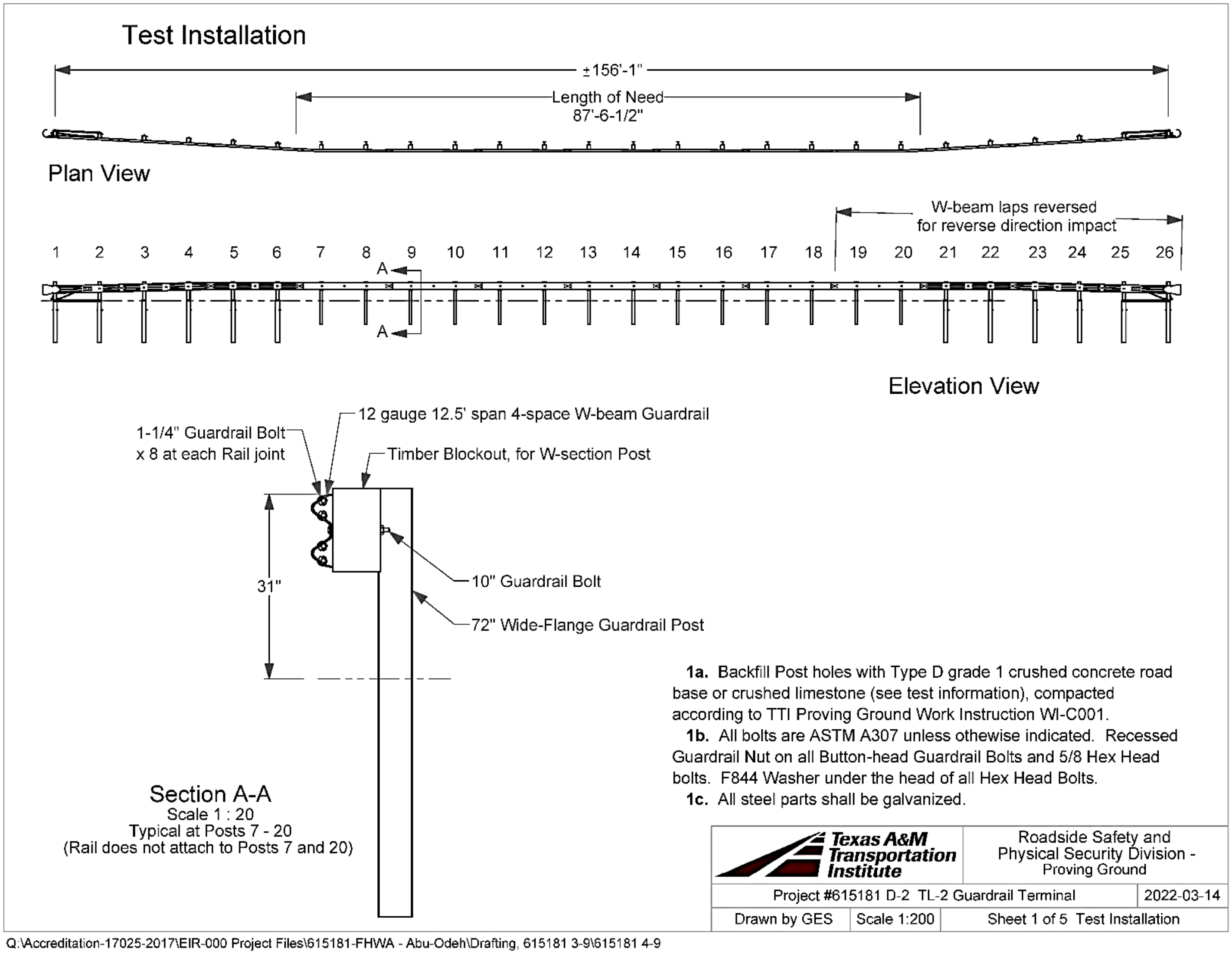


Figure 3.26. Details of TL-2 Terminal on MGS for Crash Test 615181-01-8.

Figure 3.27. TL-2 Terminal on MGS prior to Crash Test 615181-01-8.

Figure 3.28. In-Line View of the TL-2 Terminal on MGS prior to Crash Test 615181-01-8.

3.6.2. Crash Test Results for Crash Test 615181-01-8

The TL-2 Terminal for crash test 615181-01-8 did not meet the performance criteria for *MASH* TL-2 Test 2-35 for Gating Terminals. The installation did not redirect the vehicle, which is considered a failure under *MASH* Evaluation Criteria A as detailed in Chapter 6. The installation was redesigned, and the details of the 615181-01-4 installation and crash test are presented in section 3.7.

Figure 3.29 shows the installation and vehicle after impact.

Figure 3.29. TL-2 Terminal on MGS Post Impact for Crash Test 615181-01-8.

3.7. *MASH* TEST 2-30 (CRASH TEST NO. 615181-01-4, TEST DATE 2022-07-20).

3.7.1. Test Article and Installation Details

The 615181-01-4 test installation differed from the 615181-01-8 installation in that an anchor post was added upstream of post 1 and the rail began to turn down starting at post 2 and connected to the anchor post at grade. The downstream terminal remained unchanged. The spacing on the posts between posts 2 and 6 also changed.

Figure 3.30 presents the overall information on the TL-2 Terminal on MGS, and Figure 3.31 and Figure 3.32 provide photographs of the installation.

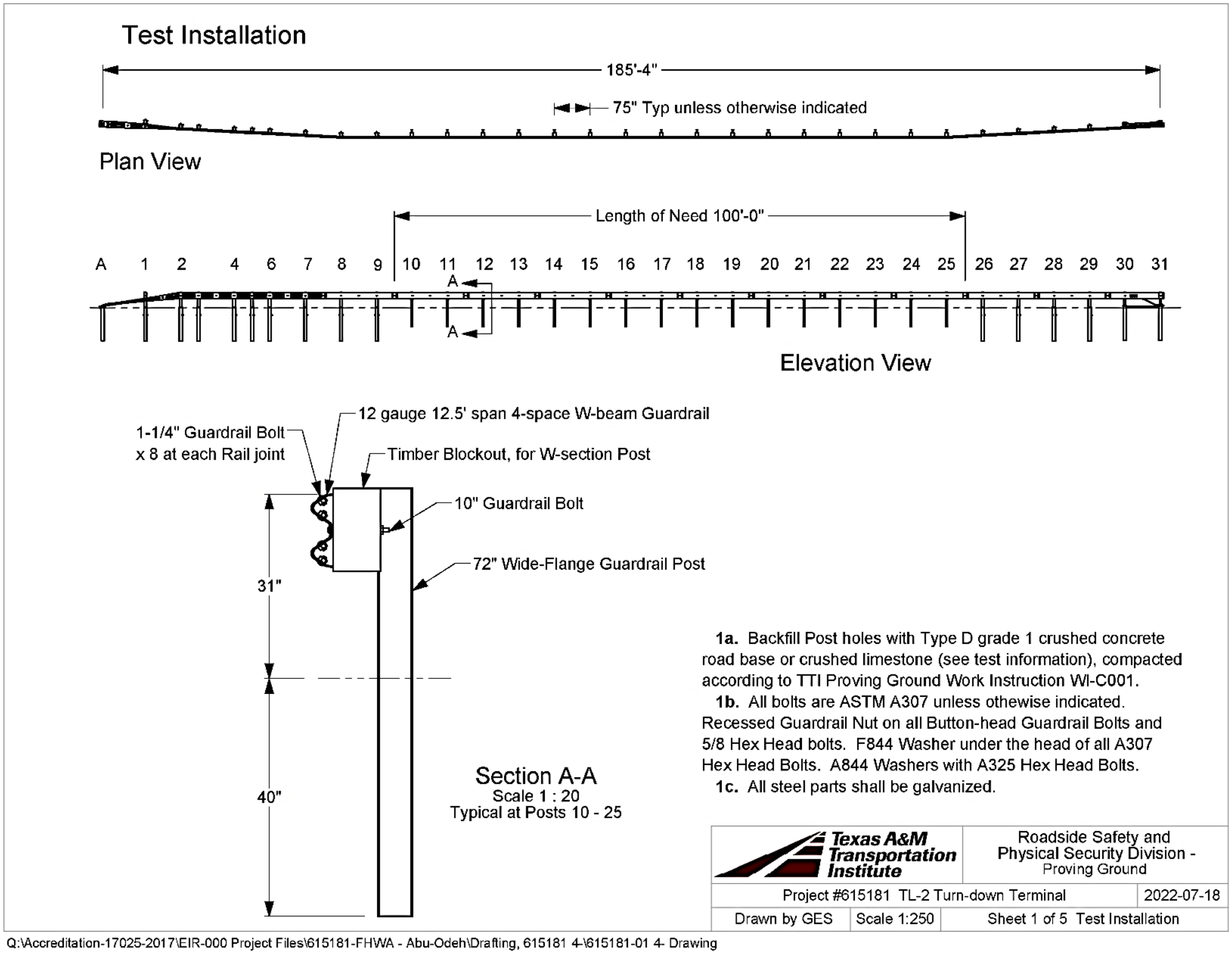


Figure 3.30. Details of TL-2 Terminal on MGS for Crash Test 615181-01-3.

Figure 3.31. TL-2 Terminal on MGS prior to Crash Test 615181-01-3.

Figure 3.32. In-Line View of the TL-2 Terminal on MGS prior to Crash Test 615181-01-3.

3.7.2. Crash Test Results for Crash Test 615181-01-4

The TL-2 Terminal for crash test 615181-01-4 did not meet the performance criteria for *MASH* TL-2 Gating Terminals. The vehicle rolled 103°, which exceeds the 75° maximum specified in *MASH* Evaluation Criteria F as detailed in Chapter 6. The installation was redesigned, and the details of the final designs are presented in the remainder of this report.

Figure 3.33 shows the installation and vehicle after impact.

Figure 3.33. TL-2 Terminal on MGS Post Impact for Crash Test 615181-01-3.

Chapter 4. FINAL END TERMINAL SYSTEM EVALUATION

4.1. MODEL DESIGN CONCEPT AND SIMULATION INTRODUCTION

An additional end terminal model design concept was developed for evaluation according to *MASH* TL-2. This design incorporates a new anchor mechanism to enhance the anchor performance when it is subjected to the tensile force due to the redirectional impact of the *MASH* 2-35 test by the 2270P vehicle while being easily releasable from the direct impact by the small car under *MASH* 2-30 conditions. This innovative anchor design is based on the generic cable anchor design with two simple innovative components: a supporting member for the anchor plate that consists of two steel angles that are welded to the foundation tube of the first post and a thin gage pull plate that is nailed to the upstream face of the first post and extends downward behind the anchor plate. This innovative design is depicted in Figure 4.1.

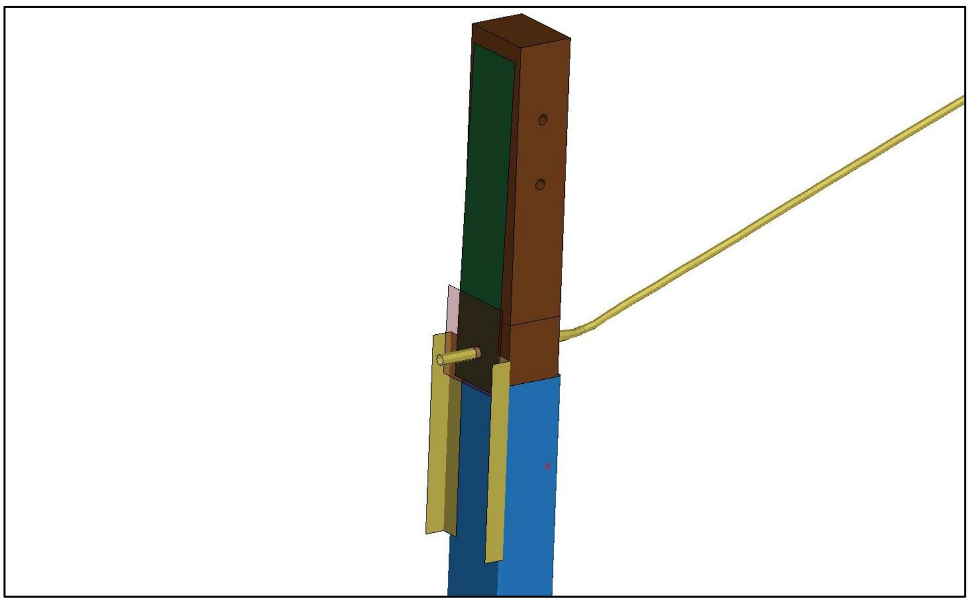


Figure 4.1. Rendered Model of the First Post with the Anchor Details.

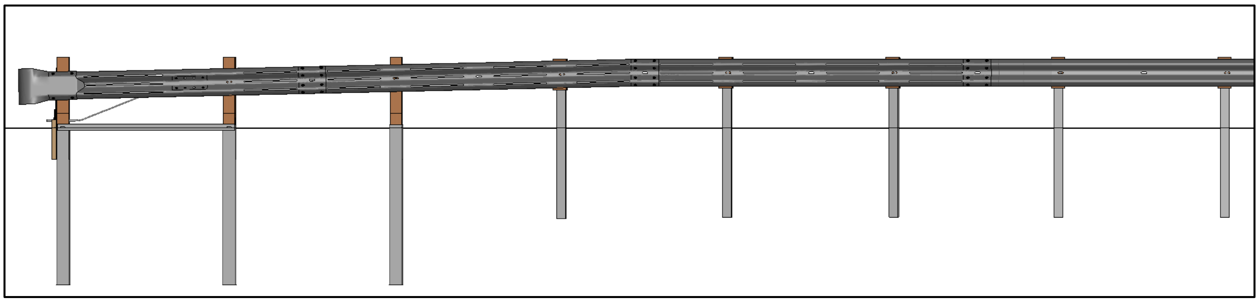
The new design keeps the slotted rail segments to reduce the severity of the head-on impact given that it does not have a terminal head commonly used to act as an energy absorption mechanism in different terminal designs. The design keeps the tapered initial section of the rail to prevent the rail components from sliding on the vehicle hood and interacting with the windshield of the vehicle. Such an interaction might cause cracks and holes in the windshield that violate *MASH* evaluation criteria relating to occupant risk.

FE simulations were performed to evaluate the crashworthiness of the system. The model details and impact simulation results are discussed in this chapter. The following critical impact simulations were conducted:

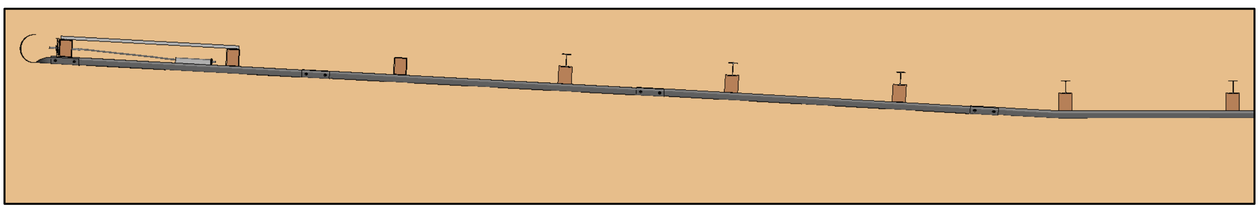
- *MASH* Test 2-30—small car head-on impact at 44 mi/h.
- *MASH* Test 2-31—pickup truck head-on impact at 44 mi/h.
- *MASH* Test 2-35—pickup truck redirective impact at 44 mi/h.
- *MASH* Test 2-37b—small car opposite-direction impact at 44 mi/h.

4.2. FLARED END TERMINAL MODEL

The flared terminal design concept consisted of three slotted rail sections connecting to a standard LON guardrail section. The first two slotted rail sections transitioned from a height of 25 inches to 31 inches. The first three posts were wood breakaway posts inserted in steel sleeves. The remaining guardrail posts were standard steel posts. The terminal was anchored at the first wood breakaway post with a BCT anchor cable. To enhance the performance of the anchor assembly, two steel angles were added to the upstream side of the first wood breakaway post steel sleeve. Figure 4.2 shows the FE model of the end terminal.



(a) Elevation view

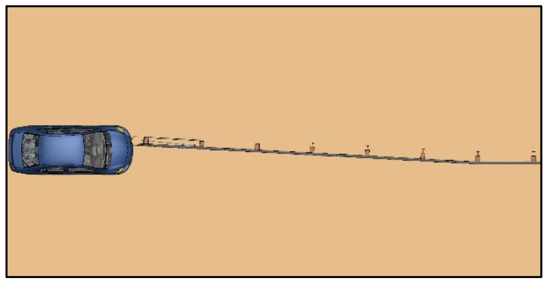


(b) Plan view

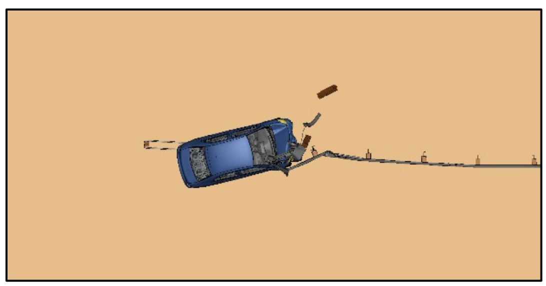
Figure 4.2. FE Model of Flared Terminal Design.

4.3. TEST 2-30 SIMULATION

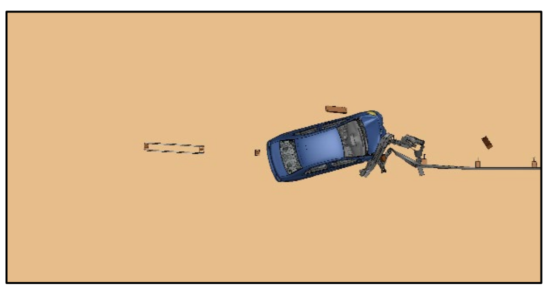
MASH Test 2-30 involved impacting the end terminal with the 1100C vehicle model at a speed of 44 mi/h and an angle of 0 degrees. The 1100C vehicle model impacted the terminal system with the quarter point of the vehicle bumper aligned with the terminal head. Figure 4.3 and Figure 4.4 show sequential images for the *MASH* Test 2-30 simulation impact. The end terminal released as designed, and the vehicle came to a controlled stop. The occupant risk values were within the *MASH* limits.



(a) 0.0 s

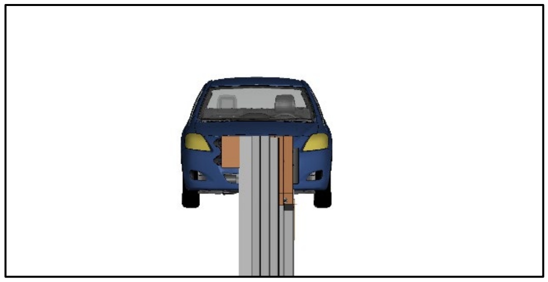


(b) 0.4 s

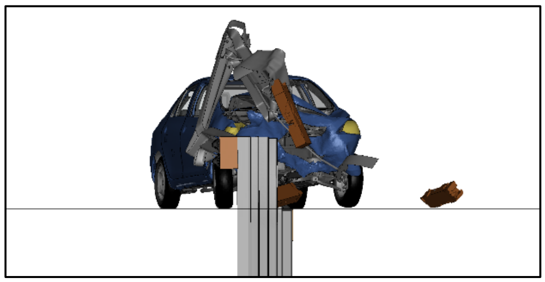


(c) 0.8 s

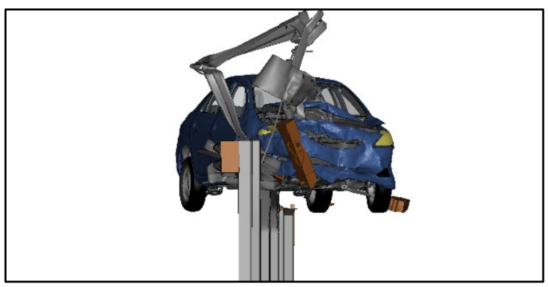
Figure 4.3. Flared Terminal Test 2-30 Simulation Sequential Images (Overhead View).



(a) 0.0 s



(b) 0.4 s

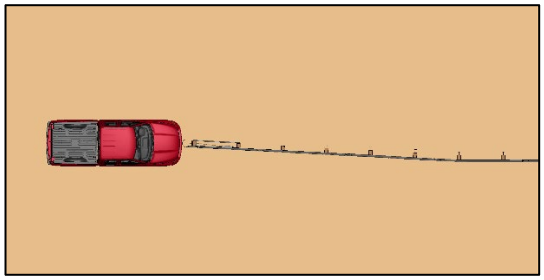


(c) 0.8 s

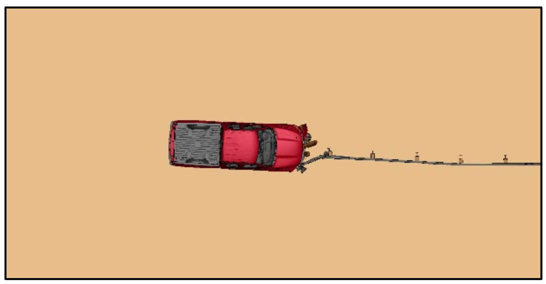
Figure 4.4. Flared Terminal Test 2-30 Simulation Sequential Images (Downstream View).

4.4. TEST 2-31 SIMULATION

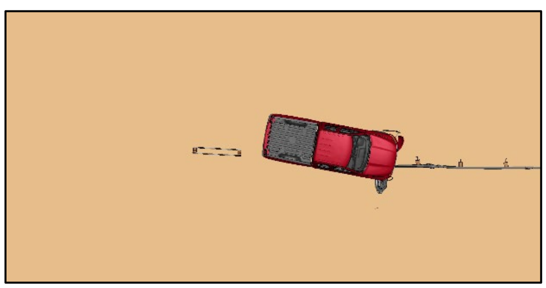
MASH Test 2-31 involved impacting the end terminal with the 2270P vehicle model at a speed of 44 mi/h and an angle of 0 degrees. The 2270P vehicle model impacted the terminal system with the centerline of the truck aligned with the terminal head. Figure 4.5 and Figure 4.6 show sequential images for the *MASH* Test 2-31 simulation impact. The end terminal released as designed, and the vehicle came to a controlled stop. The occupant risk values were within the *MASH* limits.



(a) 0.0 s

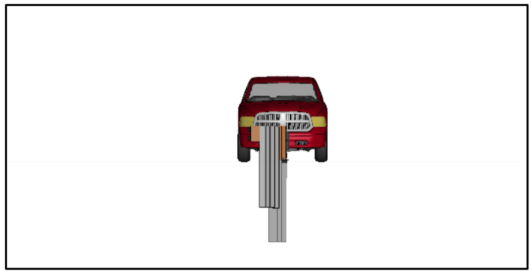


(b) 0.3 s

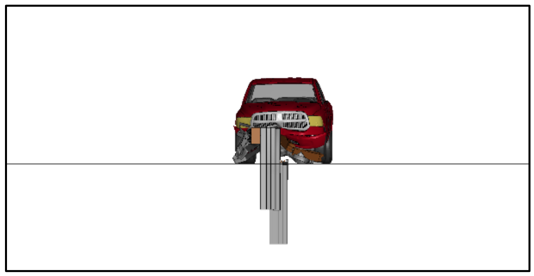


(c) 0.6 s

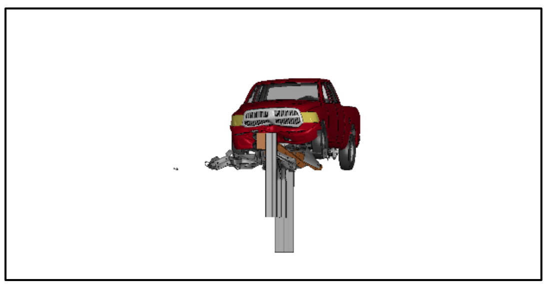
Figure 4.5. Flared Terminal Test 2-31 Simulation Sequential Images (Overhead View).



(a) 0.0 s



(b) 0.3 s

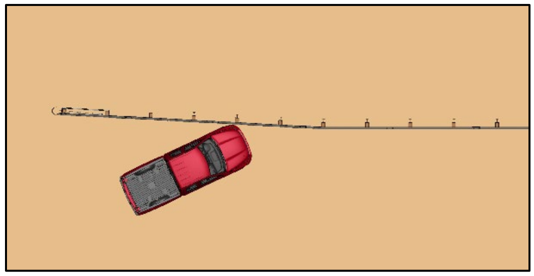


(c) 0.6 s

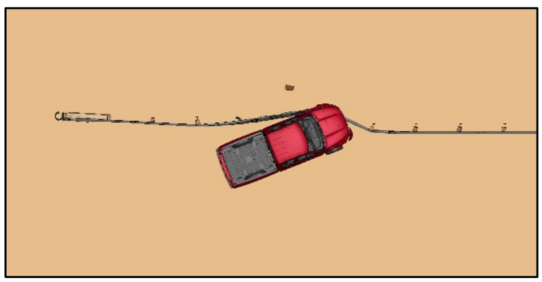
Figure 4.6. Flared Terminal Test 2-31 Simulation Sequential Images (Downstream View).

4.5. TEST 2-35 SIMULATION

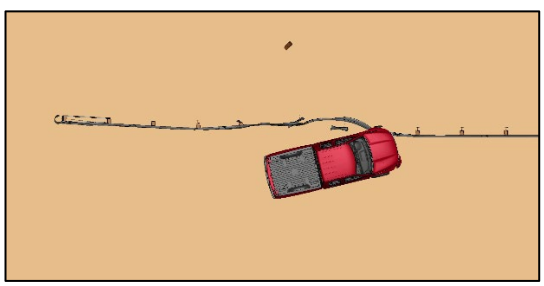
MASH Test 2-35 involved impacting the end terminal with the 2270P vehicle model at a speed of 44 mi/h and an angle of 25 degrees. The 2270P vehicle model impacted the terminal system at the beginning of the LON section. Figure 4.7 and Figure 4.8 show sequential images for the *MASH* Test 2-35 simulation impact. The pickup truck vehicle was successfully contained and redirected. The occupant risk values were within the *MAS*H limits.



(a) 0.0 s

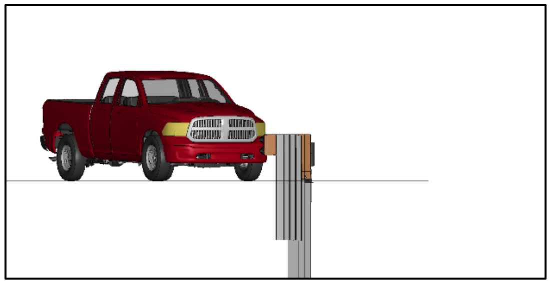


(b) 0.3 s

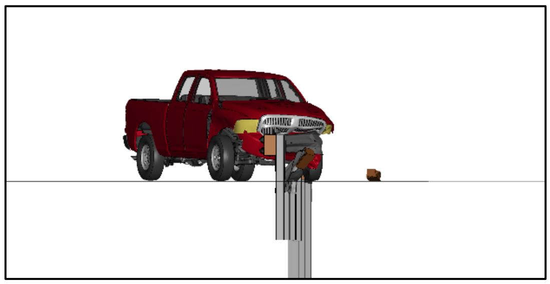


(c) 0.6 s

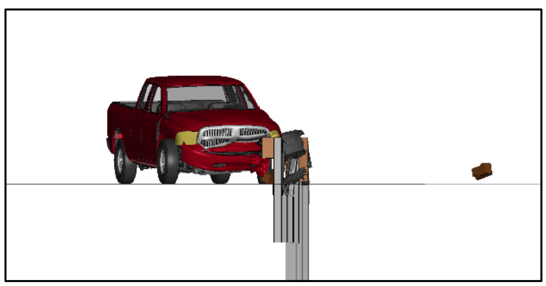
Figure 4.7. Flared Terminal Test 2-35 Simulation Sequential Images (Overhead View).



(a) 0.0 s



(b) 0.3 s

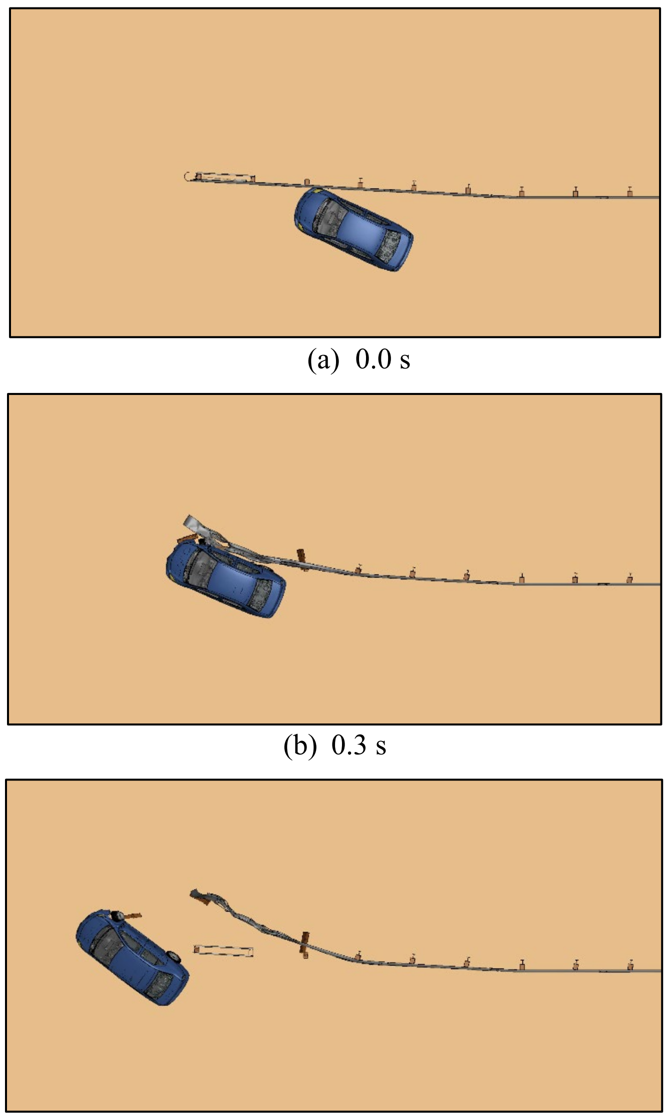


(c) 0.6 s

Figure 4.8. Flared Terminal Test 2-35 Simulation Sequential Images (Downstream View).

4.6. TEST 2-37B SIMULATION

MASH Test 2-37b involved impacting the end terminal with the 1100C vehicle model at a speed of 44 mi/h and an angle of 25 degrees. The 1100C vehicle model impacted the terminal system in the reverse direction. Four different impact locations were evaluated to determine which was most critical. Figure 4.9 and Figure 4.10 show sequential images for one of the *MASH* Test 2-37b impact simulations. For the three impact locations nearest to the second steel post, the end terminal released, and the vehicle gated through the system. For the impact location farthest upstream from the second steel post, the end terminal did not release, and the vehicle was contained and redirected. Table 4.1 shows a comparison of the occupant risk values for each impact location. The impact location of 42 inches upstream of post 2 resulted in the highest longitudinal ORA value and the highest roll angle. Thus, this impact location was determined to be most critical.

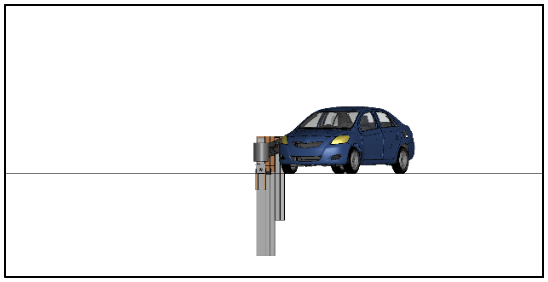


(a) 0.0 s

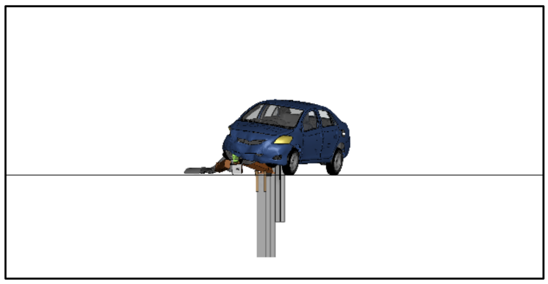
(b) 0.3 s

(c) 0.6 s

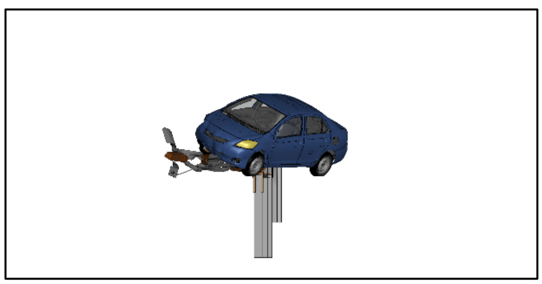
Figure 4.9. Flared Terminal Test 2-37b Simulation Sequential Images (Overhead View).



(a) 0.0 s



(b) 0.3 s



(c) 0.6 s

Figure 4.10. Flared Terminal Test 2-37b Simulation Sequential Images (Downstream View).

Table 4.1. Flared Terminal Test 2-37b Occupant Risk.

Impact Location	OIV Longitudinal (m/s)	OIV Lateral (m/s)	ORA Longitudinal (g)	ORA Lateral (g)	Max. Roll (deg)	Max. Pitch (deg)	Max. Yaw (deg)
6 inches u/s post 2	3.6	2.8	−1.6	2.4	−1.5	0.9	−9.5
42 inches u/s post 2[a]	5.8	3.0	−10.6	−5.0	−23.9	−1.5	19.2
76 inches u/s post 2	−7.9	−6.5	−6.7	−5.3	4.4	−5.7	−33.4
156 inches u/s post 2	5.4	6.3	−5.3	−3.9	−2.8	−1.8	19.2

[a] Impact location that resulted in the highest longitudinal ORA value and the highest roll angle, and thus determined to be most critical.
Note: u/s = upstream.

4.7. DISCUSSION

The simulation cases with the new design indicated that this design with the enhanced anchorage had a significant chance of passing *MASH* TL-2 testing for the critical tests simulated, and thus this design was recommended for further evaluation by full-scale crash testing.

Chapter 5. SYSTEM DETAILS

5.1. TEST ARTICLE AND INSTALLATION DETAILS

For crash test 615181-01-5 (*MASH* Test 2-35), the test installation was 156 ft - 1-inch long. A TL-2 Terminal (approximately 46 ft - 3 inches long) was installed on the upstream end and a Steel Post Terminal on the opposite end, with 75 ft. of standard Length-of-Need guardrail between them. Posts 1, 2, and 3 were wood timber posts, and posts 4 through 24 were standard Wide-Flange W6×8.5 guardrail posts with timber blockouts supporting 12-gauge W-beam guardrail. All posts were spaced at 75 inches.

The TL-2 Terminal spanned eight posts, with the first one offset toward the field side 24 inches, and posts 2 through 6 gradually positioned closer to the Length-of-Need. The downstream terminal was similarly flared. There was a brace cable attached to the W-beam between posts 1 and 2 and anchored to the upstream side of post 1 at its base. The bearing plate was a single 8-inch × 8-inch × ⅝-inch thick plate. The bearing plate rested on a 6-inch × 30-inch × 0.1875-inch thick pull plate that was added to the upstream side of the first post. The rail at the terminal sloped downward, beginning at a height of 31 inches at the top of the rail at post 5, and terminating with a final height of 25 inches at post 1. The first three rails on the upstream end of the installation had slots along the two ridges and the valley of the rail in between the connection slots, and the rail did not attach to posts 3 and 7. The guardrail post bolt slot on the upstream end of the first rail was extended to the upstream end of the rail.

Figure 5.1 presents the overall information on the TL-2 W-beam End Terminal, and Figure 5.2 thru Figure 5.7 provide photographs of the installation. Appendix A provides further details on the TL-2 W-beam End Terminal. Drawings were provided by the TTI Proving Ground, and construction was performed by TTI Proving Ground personnel.

5.2. DESIGN MODIFICATIONS DURING TESTS

For crash tests 615181-01-11 (*MASH* Test 2-30) and 615181-01-12 (*MASH* Test 2-31), the flanges on posts 4 through 7 were rounded at the top, and a wood trapezoidal block was attached to the upstream side of the webbing so that the top of the block was flush with the top of the post. These modifications were warranted due to the penetration of the post flanges into the floorboard of the vehicle during test 615181-01-7 (*MASH* Test 2-30). At the opposite end, the downstream terminal was sloped downward in the same manner as the upstream terminal and likewise, the last three rails were slotted to match the first three rails. On the downstream terminal, the posts were not rounded, and trapezoidal blocks were not added to the posts. The Length-of-Need was also shortened to 63 ft - 6 inches since both terminals now spanned 46 ft - 3 inches. The overall length remained 156 ft – 1 inch. All other details remained the same.

Figure 5.8 presents the overall information on the TL-2 W-beam End Terminal, and Figure 5.9 thru Figure 5.12 provide photographs of the installation for tests 615181-01-11 (*MASH* Test 2-30) and 615181-01-12 (*MASH* Test 2-31),. Appendix A provides further details on the TL-2 W-beam End Terminal. Drawings were provided by the TTI Proving Ground, and construction was performed by TTI Proving Ground personnel.

To accommodate the reverse direction impact for crash test 615181-01-13 (*MASH* Test 2-37b), top rounded posts were used, and trapezoidal blocks were added to posts 20 through 23. The order that the guardrail was overlapped was reversed for the last three sections of rail in order to simulate a reverse direction impact.

Figure 5.13 presents the overall information on the TL-2 W-beam End Terminal, and Figure 5.14 thru Figure 5.17 provide photographs of the installation for test 615181-01-13 (*MASH* Test 2-37b). Appendix A provides further details on the TL-2 W-beam End Terminal. Drawings were provided by the TTI Proving Ground, and construction was performed by TTI Proving Ground personnel.

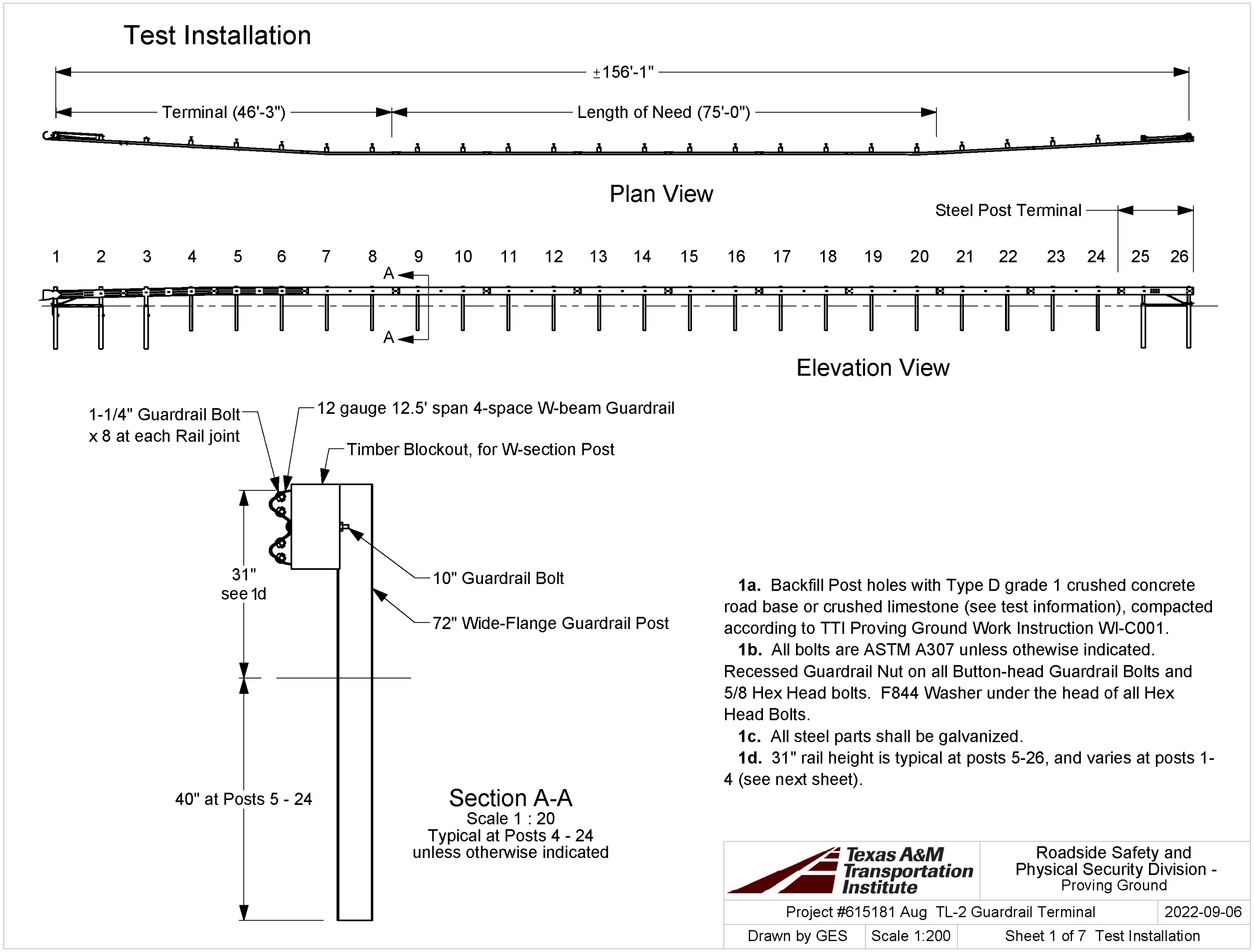


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Figure 5.1. Details of TL-2 W-beam End Terminal Test 615181-01-5.

Figure 5.2. TL-2 W-beam Installation prior to Test 615181-01-5.

Figure 5.3. TL-2 W-beam End Terminal prior to Test 615181-01-5.

Figure 5.4. TL-2 W-beam End Terminal at Posts 3 and 4 prior to Test 615181-01-5.


Figure 5.5. TL-2 W-beam End Terminal at Post 5 prior to Test 615181-01-5.

Figure 5.6. Field Side of theTL-2 W-beam End Terminal prior to Test 615181-01-5.

Figure 5.7. Field Side of the TL-2 W-beam End Terminal Installation prior to Test 615181-01-5.

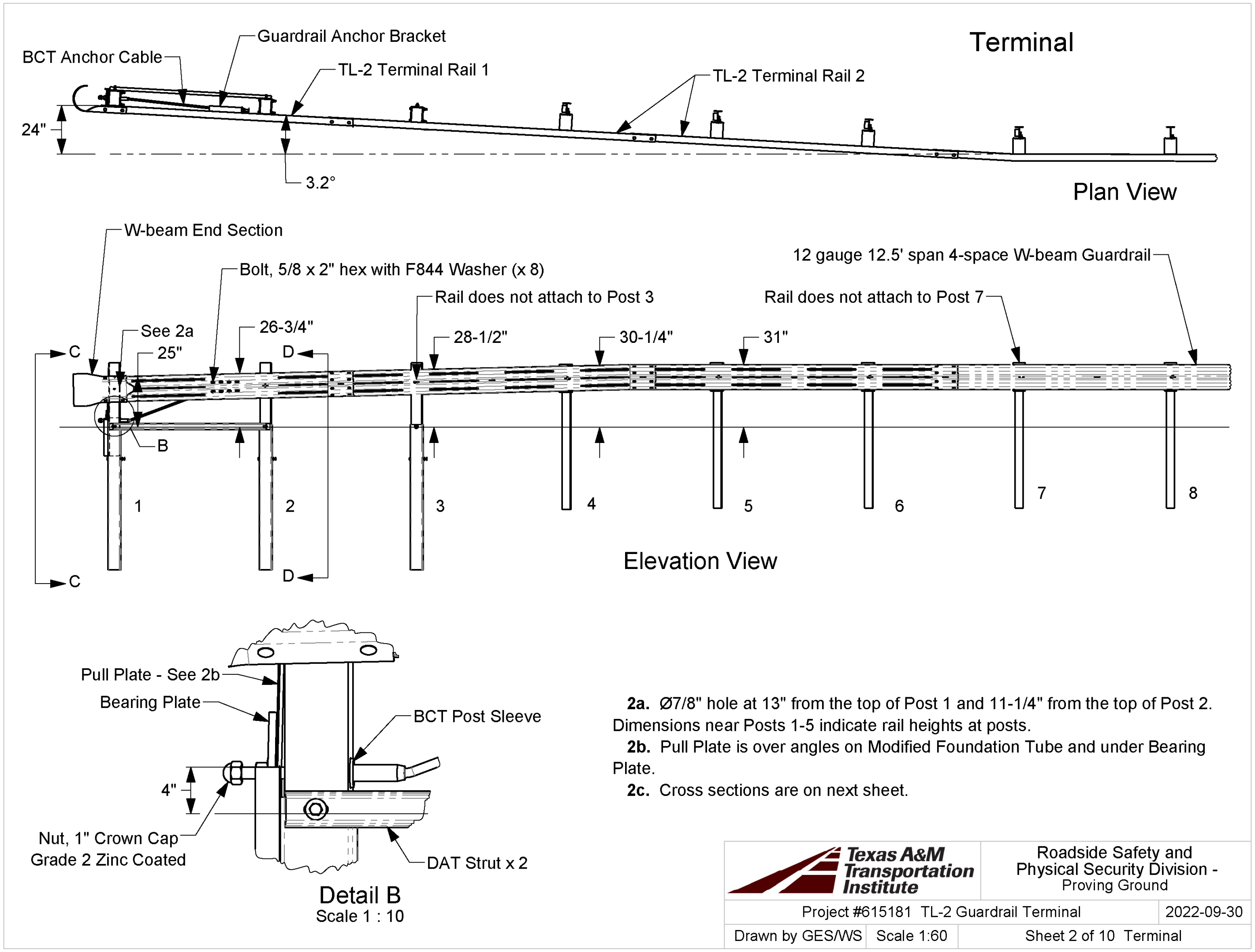

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Figure 5.8. Details of TL-2 W-beam End Terminal Tests 615181-01-11 & 615181-01-12.

Figure 5.9. TL-2 W-beam End Terminal prior to Tests 615181-01-11 & 615181-01-12.

Figure 5.10. The Anchor Bolt with Cap Nut on the TL-2 W-beam End Terminal prior to Tests 615181-01-11 & 615181-01-12.

Figure 5.11. TL-2 W-beam End Terminal on the Impact Side of Post 4 prior to Tests 615181-01-11 & 615181-01-12.

Figure 5.12. TL-2 W-beam End Terminal on the Non-Impact Side of Post 4 prior to Tests 615181-01-11 & 615181-01-12.

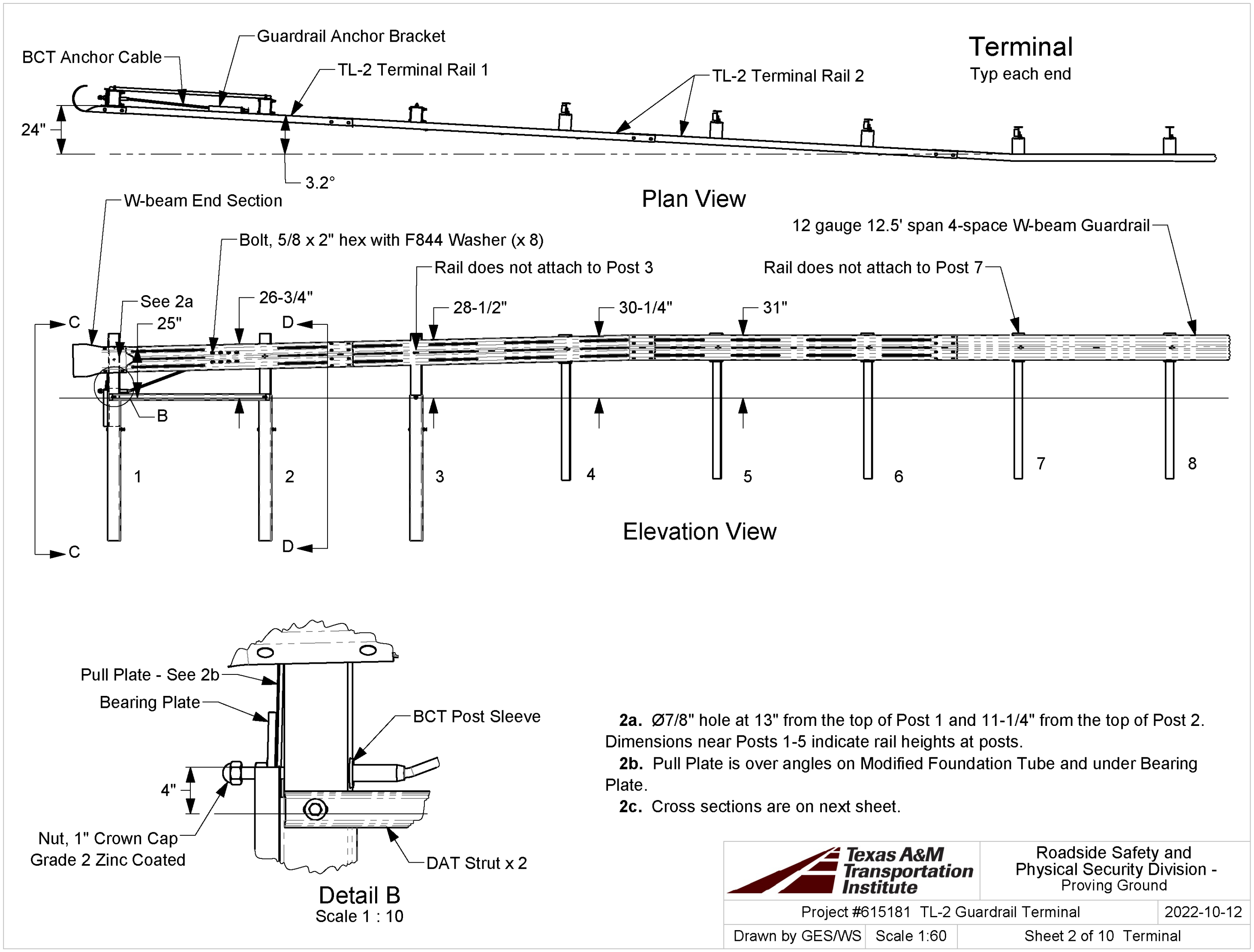

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Figure 5.13. Details of TL-2 W-beam End Terminal Test 615181-01-13.

Figure 5.14. TL-2 W-beam End Terminal Prior to Test 615181-01-13.

Figure 5.15. TL-2 W-beam End Terminal Anchor Post Prior to Test 615181-01-13.

Figure 5.16. Rear View of the TL-2 W-beam End Terminal Prior to Test 615181-01-13.

Figure 5.17. Downstream View of the TL-2 W-beam End Terminal Prior to Test 615181-01-13.

5.3. MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the TL-2 W-beam End Terminal.

5.4. SOIL CONDITIONS

The test installation was installed in standard soil meeting Type 1 Grade D of AASHTO standard specification M147-17 “Materials for Aggregate and Soil Aggregate Subbase, Base, and Surface Courses.”

In accordance with Appendix B of *MASH*, soil strength was measured the day of each crash test. During installation of the TL-2 W-beam End Terminal for full-scale crash testing, 6-ft long W6×16 posts were installed in the immediate vicinity of the TL-2 W-beam End Terminal using the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table B.1 through Table B.4 in Appendix B presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

On the day of *MASH* Test 2-35, 2022-09-09, loads on the post at deflections were as follows: the backfill material in which the TL-2 W-beam End Terminal was installed met minimum *MASH* requirements for soil strength.

Table 5.1. Soil Strength for Crash Test 615181-01-5.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	8120
10	4981	8664
15	5282	9181

On the day of *MASH* Test 2-30, 2022-10-06, loads on the post at deflections were as follows: the backfill material in which the TL-2 W-beam End Terminal was installed met minimum *MASH* requirements for soil strength. Due to the load measurements far surpassing the minimum requirements at 5 and 10 inches, the 15 inch measurement was not taken.

Table 5.2. Soil Strength for Crash Test 615181-01-11.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	9515
10	4981	10909
15	5282	-

On the day of *MASH* Test 2-31, 2022-10-11, loads on the post at deflections were as follows: the backfill material in which the TL-2 W-beam End Terminal was installed met minimum *MASH* requirements for soil strength.

Table 5.3. Soil Strength for Crash Test 615181-01-12.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	7404
10	4981	8757
15	5282	9727

On the day of *MASH* Test 2-37b, 2022-10-20, loads on the post at deflections were as follows: the backfill material in which the TL-2 W-beam End Terminal was installed met minimum *MASH* requirements for soil strength.

Table 5.4. Soil Strength for Crash Test 615181-01-13.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	5818
10	4981	6333
15	5282	6545

Chapter 6. TEST REQUIREMENTS AND EVALUATION CRITERIA

6.1. CRASH TEST PERFORMED/MATRIX

Table 6.1 shows the test conditions and evaluation criteria for *MASH* TL-2 for gating terminals. The target critical impact points (CIPs) for each test were determined using the information provided in *MASH* Section 2.2.1 and Section 2.3.2. Figure 6.1 through Figure 6.4 show the target CIP for *MASH* Tests 2-35, 2-30, 2-31, and 2-37b on the TL-2 W-beam End Terminal.

Table 6.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-2 Gating Terminals

Test Designation	TTI Test Number	Test Vehicle	Impact Speed	Impact Angle	Evaluation Criteria
2-35	615181-01-5	2270P	44 mi/h	25º	A, D, F, H, I
2-30	615181-01-11	1100C	44 mi/h	0°	C, D, F, H, I, N
2-31	615181-01-12	2270P	44 mi/h	0°	C, D, F, H, I, N
2-37b	615181-01-13	1100C	44 mi/h	25º	C, D, F, H, I, N

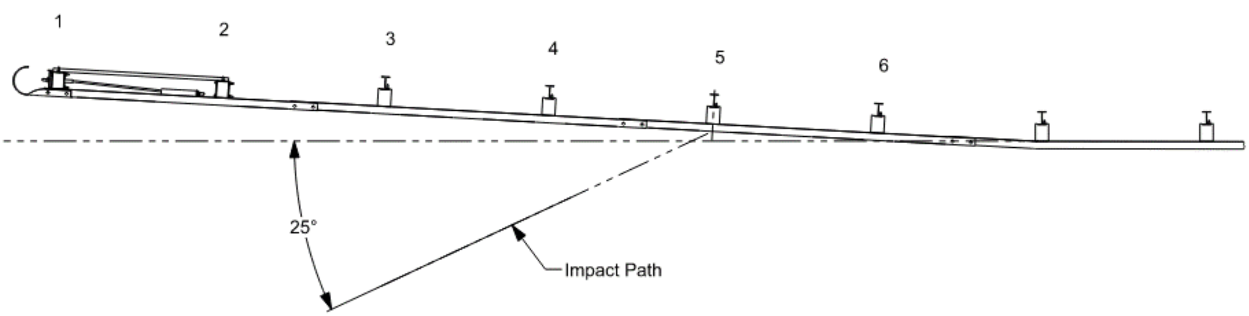

Figure 6.1. Target CIP for *MASH* 2-35 Test on TL-2 W-beam End Terminal Test 615181-01-5.

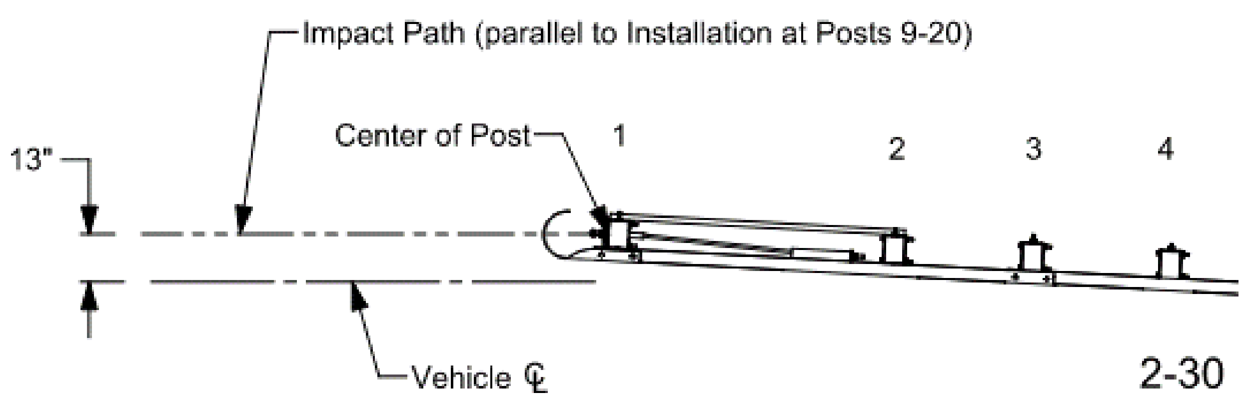

Figure 6.2. Target CIP for *MASH* 2-30 Test on TL-2 W-beam End Terminal Test 615181-1-11

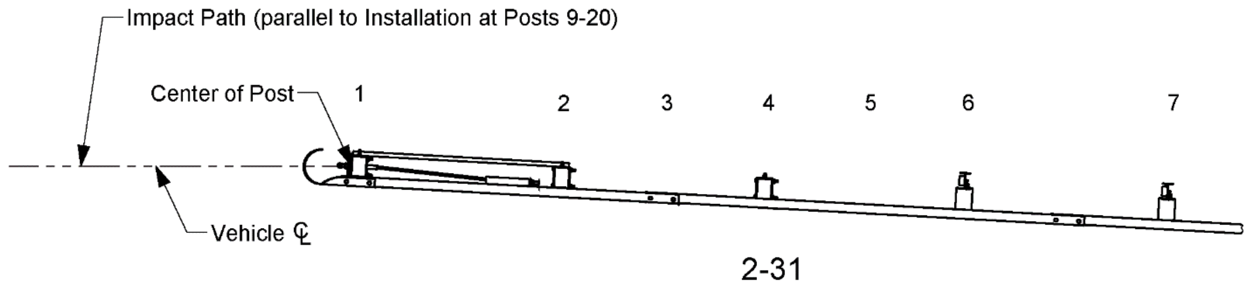

Figure 6.3. Target CIP for *MASH* 2-31 Test on TL-2 W-beam End Terminal Test 615181-1-12

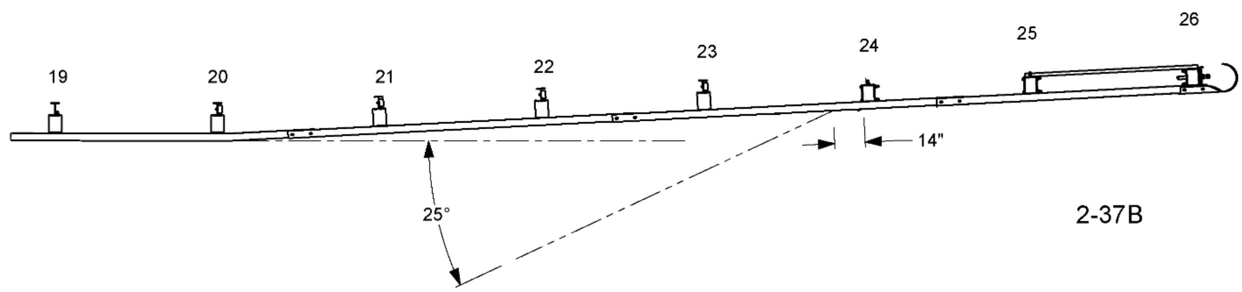

Figure 6.4. Target CIP for *MASH* 2-37b Test on TL-2 W-beam End Terminal Test 615181-1-13

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

6.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2.2 and 5.1 of *MASH* were used to evaluate the crash tests reported herein. Table 6.1 lists the test conditions and evaluation criteria required for *MASH* TL-2, and Table 6.2 provides detailed information on the evaluation criteria.

Table 6.2. Evaluation Criteria Required for *MASH* Testing.

Evaluation Factors	Evaluation Criteria	*MASH* Test
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.	35
C.	Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	30, 31, & 37b

Evaluation Factors	**Evaluation Criteria**	***MASH* Test**
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*.	30, 31, 35, & 37b
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	30, 31, 35, & 37b
H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	30, 31, 35, & 37b
I.	The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	30, 31, 35, & 37b
N.	Vehicle trajectory behind the test article is acceptable.	30, 31, & 37b

Chapter 7. TEST CONDITIONS

7.1. TEST FACILITY

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

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

7.2. VEHICLE TOW AND GUIDANCE SYSTEM

For the testing utilizing the 1100C and 2270P vehicles, each 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.

7.3. DATA ACQUISITION SYSTEMS

7.3.1. Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained onboard data acquisition system. The signal conditioning and acquisition system is a multi-channel data acquisition system (DAS) produced by Diversified Technical Systems Inc. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid-state units designed for crash test service. The data acquisition hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 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 DAS unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

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

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

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

7.3.2. 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/opposite side of impact of the 1100C vehicle. The dummy was not instrumented.

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

7.3.3. Photographic Instrumentation Data Processing

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

- For all tests, one camera was located overhead with a field of view perpendicular to the ground and directly over the impact point.
- For *MASH* tests 2-35 and 2-37b (615181-1-5 and -1-13), one camera was 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.
- For *MASH* tests 2-30 and 2-31 (615181-1-11 and -1-12), one camera was placed downstream from the installation at an angle to have an oblique view of the interaction of the vehicle with the installation.
- For all tests, one camera was 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 TL-2 W-beam End Terminal. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

Chapter 8. *MASH* TEST 2-35 (CRASH TEST NO. 615181-01-5)

8.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 8.1 for details on *MASH* impact conditions for this test and Table 8.2 for the exit parameters. Figure 8.1 and Figure 8.2 depict the target impact setup.

Table 8.1. Impact Conditions for Test 615181-01-5.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	45 mi/h	± 2.5 mi/h	45.9
Impact Angle (deg)	25°	± 1.5°	25
Impact Severity (kip-ft)	52 kip-ft	≥52 kip-ft	63.6
Impact Location	Centerline of post 5.	± 12 inches	3.8 inches upstream from the centerline of post 5

Table 8.2. Exit Parameters for Test 615181-01-5.

Exit Parameter	Measured
Speed (mi/h)	20.8
Trajectory (deg)	23
Heading (deg)	17
Brakes applied post impact (s)	≥5
Vehicle at rest position	163 ft downstream of impact point 3 ft to the traffic side 3° right
Comments:	Vehicle remained upright and stable. Vehicle did not cross exit box [a].

[a] Not less than 32.8 ft downstream from loss of contact for cars and pickups is optimal.

Figure 8.1. TL-2 W-beam End Terminal/Test Vehicle Geometrics for Test 615181-01-5.

Figure 8.2. TL-2 W-beam End Terminal/Test Vehicle Impact Location 615181-01-5.

8.2. WEATHER CONDITIONS

Table 8.3 provides the weather conditions for 615181-01-5.

Table 8.3. Weather Conditions 615181-01-5.

Date of Test	2022-09-09 AM
Wind Speed (mi/h)	5
Wind Direction (deg)	88
Temperature (°F)	85
Relative Humidity (%)	65
Vehicle Traveling (deg)	325

8.3. TEST VEHICLE

Figure 8.3 and Figure 8.4 show the 2016 RAM 1500 used for the crash test. Table 8.4 shows the vehicle measurements. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.

Figure 8.3. Impact Side of Test Vehicle before Test 615181-01-5.

Figure 8.4. Opposite Impact Side of Test Vehicle before Test 615181-01-5.

Table 8.4. Vehicle Measurements 615181-01-5.

Test Parameter	***MASH***	**Allowed Tolerance**	**Measured**
Dummy (if applicable)[a] (lb)	165	N/A	N/A
Vehicle Inertial Weight (lb)	5000 lbs	± 110 lbs	5054
Gross Static[a] (lb)	5000	± 110	5054
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40.0
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46.0
Track Width[b] (inches)	67	±1.5	68.25
CG aft of Front Axle[c] (inches)	63	±4	61.1
CG above Ground[c,d] (inches)	28	≥28	28.5

[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

8.4. TEST DESCRIPTION

Table 8.5 lists events that occurred during Test No. 615181-01-5. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 8.5. Events during Test 615181-01-5.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0080	Post 5 began to lean toward the field side
0.0290	Post 6 began to lean back toward field side
0.0600	Vehicle began to redirect
0.1020	Post 7 began to lean back toward field side
0.1630	Rail released from post 2 and 3
0.3050	Rear driver side bumper impacted rail near post 5
0.3350	Vehicle was parallel to installation
0.8010	Vehicle lost contact with rail, exiting the system at 20.8 mi/h, at a heading and vehicle trajectory of 22.6 and 16.9 degrees respectively.

8.5. DAMAGE TO TEST INSTALLATION

The rail released from posts 2 through 9, and the blockouts were missing from posts 6 and 7. Posts 6 through 8 were twisted 90° clockwise. Table 8.6 describes the damage to the TL-2 W-beam End Terminal. u/s = upstream d/s = downstream f/s = field side t/s = traffic side

Table 8.7 describes the deflections of the TL-2 W-beam End Terminal. Figure 8.5 and Figure 8.6 show the damage to the TL-2 W-beam End Terminal.

Table 8.6. Damage to TL-2 W-beam End Terminal 615181-01-5.

Post Number	Soil Gap	Post Lean from Vertical
1	1½ inches u/s	-
2	⅜-inch u/s; ½-inch d/s	-
3	-	-
4	Soil Disturbed	0.7°
5	1¾ inches t/s; ½-inch f/s	4.7°
6	-	15°
7	-	15°
8	-	15°
9	½-inch t/s; ⅛-inch f/s	1.2°

u/s = upstream d/s = downstream f/s = field side t/s = traffic side

Table 8.7. Deflections of the TL-2 W-beam End Terminal 615181-01-5.

Test Parameter	Measured
Permanent Deflection/Location	29.0 inches toward field side, 12 inches downstream of post 7
Dynamic Deflection	38.2 inches toward field side
Working Width [a] and Height	46.5 inches, at a height of 62.3 inches at the left side mirror

[a] 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 8.5. TL-2 W-beam End Terminal after Test at Impact Location 615181-01-5.

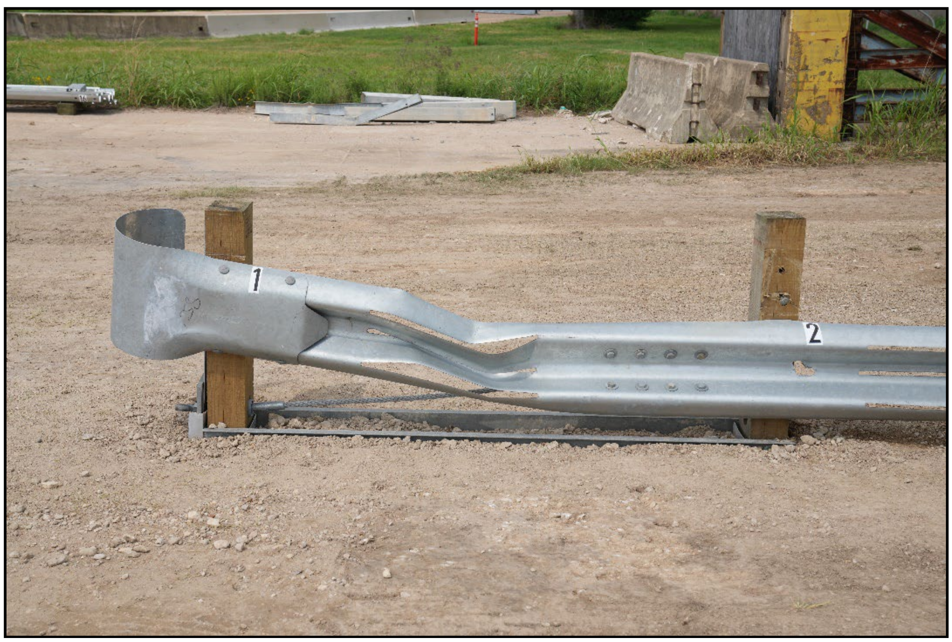

Figure 8.6. TL-2 W-beam End Terminal after Test at the Upstream End Terminal 615181-01-5.

8.6. DAMAGE TO TEST VEHICLE

Figure 8.7 and Figure 8.8 show the damage sustained by the vehicle. Figure 8.9 and Figure 8.10 show the interior of the test vehicle. Table 8.8 and Table 8.9 provide details on the occupant compartment deformation and exterior vehicle damage. Tables C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

Figure 8.7. Impact Side of Test Vehicle after Test 615181-01-5.

Figure 8.8. Rear Impact Side of Test Vehicle after Test 615181-01-5.

Figure 8.9. Overall Interior of Test Vehicle after Test 615181-01-5.

Figure 8.10. Interior of Test Vehicle on Impact Side after Test 615181-01-5.

Table 8.8. Occupant Compartment Deformation 615181-01-5.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	0 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	0 inches
Front Door (above Seat)	≤9.0 inches	0 inches
Front Door (below Seat)	≤12.0 inches	0 inches

Table 8.9. Exterior Vehicle Damage 615181-01-5.

Side Windows	The side windows remained intact
Maximum Exterior Deformation	10 inches in the front plane at the right front corner at bumper height
VDS	11FLQ2
CDC	11FLEW2
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, left front headlight, left front quarter fender, left front tire and rim, left front door, left rear door, left cab corner, left rear quarter fender, and rear bumper were damaged.

8.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 8.10. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.6 in Appendix C.4 show acceleration versus time traces.

Table 8.10. Occupant Risk Factors for Test 615181-01-5.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0	16.7	0.1799 seconds on left side of interior
OIV, Lateral (ft/s)	≤40.0	13.6	0.1799 seconds on left side of interior
Ridedown, Longitudinal (g)	≤20.49	5.4	0.3789 - 0.3889 seconds
Ridedown, Lateral (g)	≤20.49	4.7	0.3308 - 0.3408 seconds
THIV (m/s)	N/A	6.3	0.1738 seconds on left side of interior
ASI	N/A	0.6	0.1459 - 0.1959 seconds
50-ms MA Longitudinal (g)	N/A	-4.8	0.1247 - 0.1747 seconds
50-ms MA Lateral (g)	N/A	3.5	0.1248 - 0.1748 seconds
50-ms MA Vertical (g)	N/A	2.0	0.5180 - 0.5680 seconds
Roll (deg)	≤75	6	1.2355 seconds
Pitch (deg)	≤75	5	0.6396 seconds
Yaw (deg)	N/A	44	0.7093 seconds

8.8. TEST SUMMARY

Figure 8.11 presents the summary results for crash test 615181-01-5.

0.000 s

0.200 s

0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 2-35
TTI Project No.	615181-01-5
Test Date	2022-09-09
TEST ARTICLE	
Type	Gating Terminal
Name	TL-2 W-beam End Terminal
Length	156 ft 1-inch
Key Materials	W-beam guardrail, Wood timber posts, Steel guardrail posts
Soil Type and Condition	AASHTO M147-17, Grading D Crushed Concrete
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2016 RAM 1500
Inertial Weight (lb)	5054
Dummy (lb)	N/A
Gross Static (lb)	5054
IMPACT CONDITIONS	
Impact Speed (mi/h)	45.9
Impact Angle (deg)	25
Impact Location	3.8 inches upstream from the centerline of post 5
Impact Severity (kip-ft)	63.6
EXIT CONDITIONS	
Exit Speed (mi/h)	20.8
Trajectory/Heading Angle (deg)	23 / 17
Exit Box Criteria	Did not cross
Stopping Distance	163 ft downstream 3 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	38.2
Permanent (inches)	29.0
Working Width / Height (inches)	46.5 / 62.3
VEHICLE DAMAGE	
VDS	11FLQ2
CDC	11FLEW2
Max. Ext. Deformation	10
Max Occupant Compartment Deformation	No occupant compartment deformation

OCCUPANT RISK VALUES

Long. OIV (ft/s)	16.7	Long. Ridedown (g)	5.4	Max 50-ms Long. (g)	-4.8	Max Roll (deg)	6
Lat. OIV (ft/s)	13.6	Lat. Ridedown (g)	4.7	Max 50-ms Lat. (g)	3.5	Max Pitch (deg)	5
THIV (m/s)	6.3	ASI	0.6	Max 50-ms Vert. (g)	2.0	Max Yaw (deg)	44

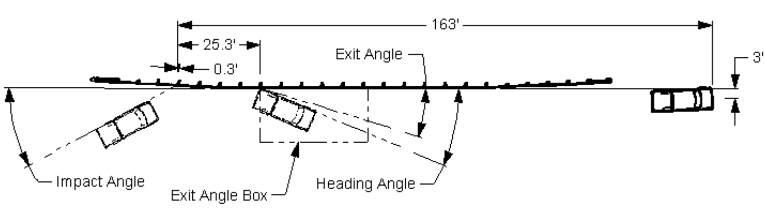

Figure 8.11. Summary of Results for *MASH* Test 2-35 on TL-2 W-beam End Terminal.

Chapter 9. FAILED TESTS

9.1. *MASH* TEST 2-30 (CRASH TEST NO. 615181-01-6, TEST DATE 2022-09-14)

9.1.1. Test Article and Installation Details

The installation details were the same as 615181-01-5.

9.1.2. Crash Test Results for Crash Test 615181-01-6

The TL-2 Terminal for crash test 615181-01-6 did not meet the performance criteria for *MASH* TL-2 Gating Terminals. The threaded rod on the anchor cable punctured the floor board of the vehicle, penetrating into the occupant compartment, which is considered a failure under *MASH* Evaluation Criteria D, which is detailed in Chapter 6. Changes were made to the installation and the details of the 615181-01-7 installation and crash test are presented in section 9.2.

Figure 9.1, Figure 9.2, and Figure 9.3 show the installation and vehicle damage after impact.

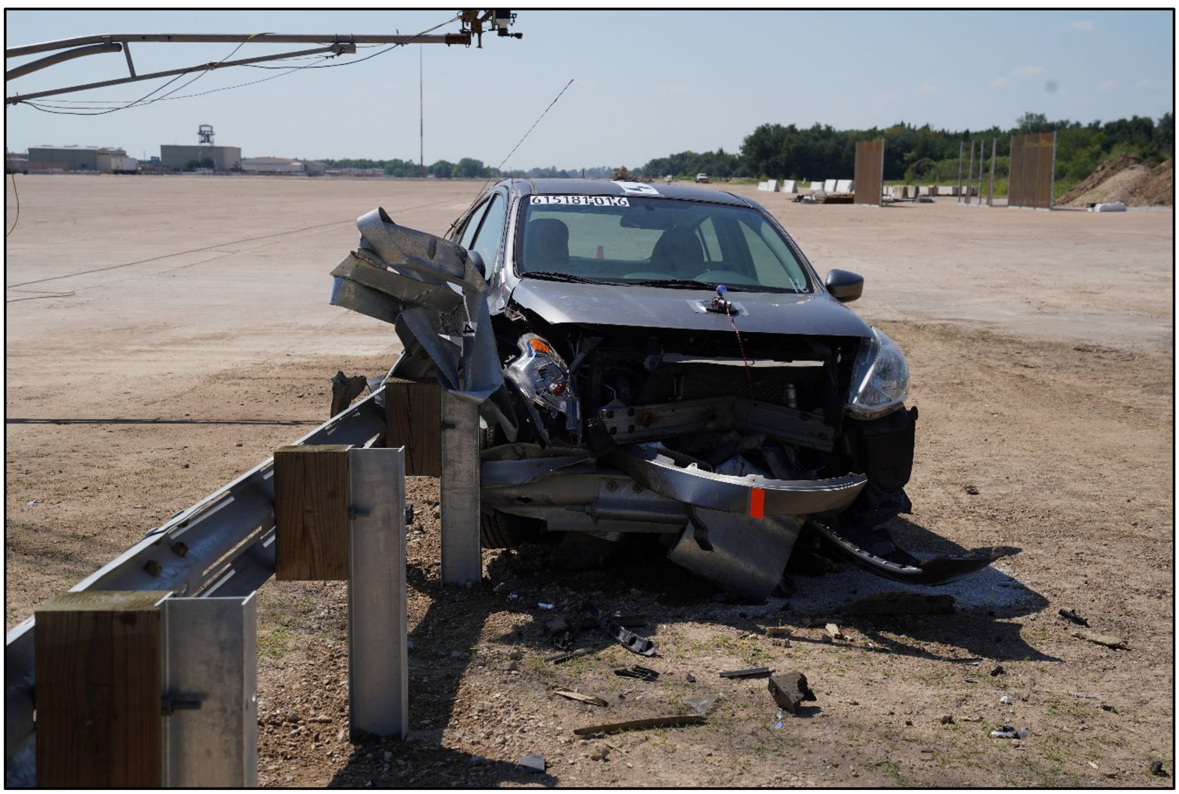

Figure 9.1. TL-2 Terminal on MGS Post Impact for Crash Test 615181-01-6.

Figure 9.2. Occupant Compartment Penetration after Crash Test 615181-01-6.

Figure 9.3. Undercarriage Damage after Crash Test 615181-01-6.

9.2. *MASH* TEST 2-30 (CRASH TEST NO. 615181-01-7, TEST DATE 2022-09-20)

9.2.1. Test Article and Installation Details

The installation differed from crash test 615181-01-6 in that a crown cap nut was added to the threaded rod of the anchor cable, and the pull plate thickness was changed to ⅛-inch.

Figure 9.4 presents the overall information on the TL-2 Terminal on MGS, and Figure 9.5 and Figure 9.6 provide photographs of the installation

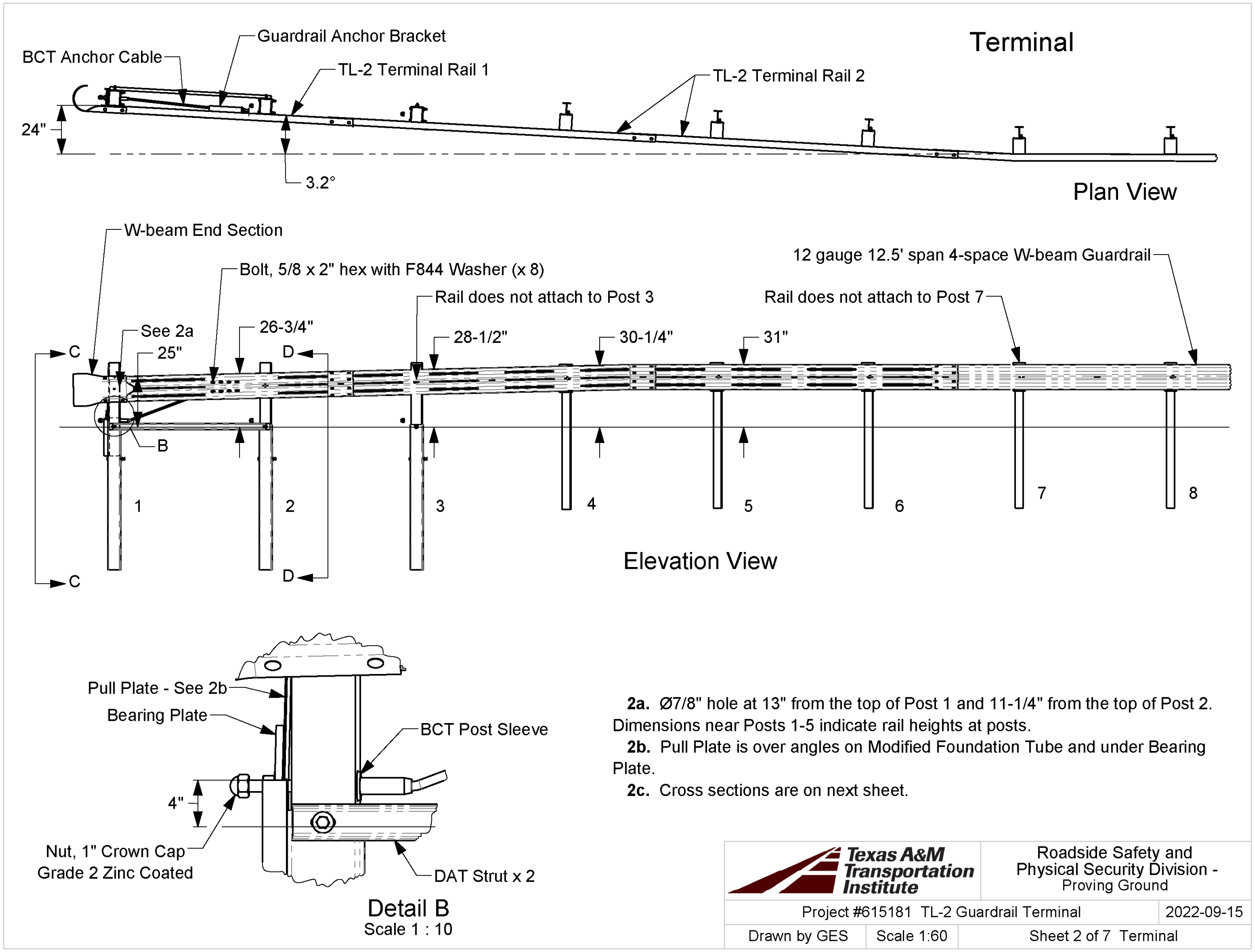

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Figure 9.4. Details of TL-2 Terminal on MGS for Crash Test 615181-01-7.

Figure 9.5. TL-2 Terminal on MGS prior to Crash Test 615181-01-7.

Figure 9.6. In-Line View of the TL-2 Terminal on MGS prior to Crash Test 615181-01-7.

9.2.2. Crash Test Results for Crash Test 615181-01-7

The TL-2 Terminal for crash test 615181-01-7 did not meet the performance criteria for *MASH* TL-2 gating terminals. An upstream corner of a steel guardrail post punctured the floor board of the vehicle, penetrating into the occupant compartment, which is considered a failure under *MASH* Evaluation Criteria D as detailed in Chapter 6. Additional changes were made (as described in chapter 7) to the installation and the crash tests are presented in the remainder of this report.

Figure 9.7, Figure 9.8, and Figure 9.9 show the installation and vehicle damage post impact.

Figure 9.7. TL-2 Terminal on MGS Post Impact for Crash Test 615181-01-7.

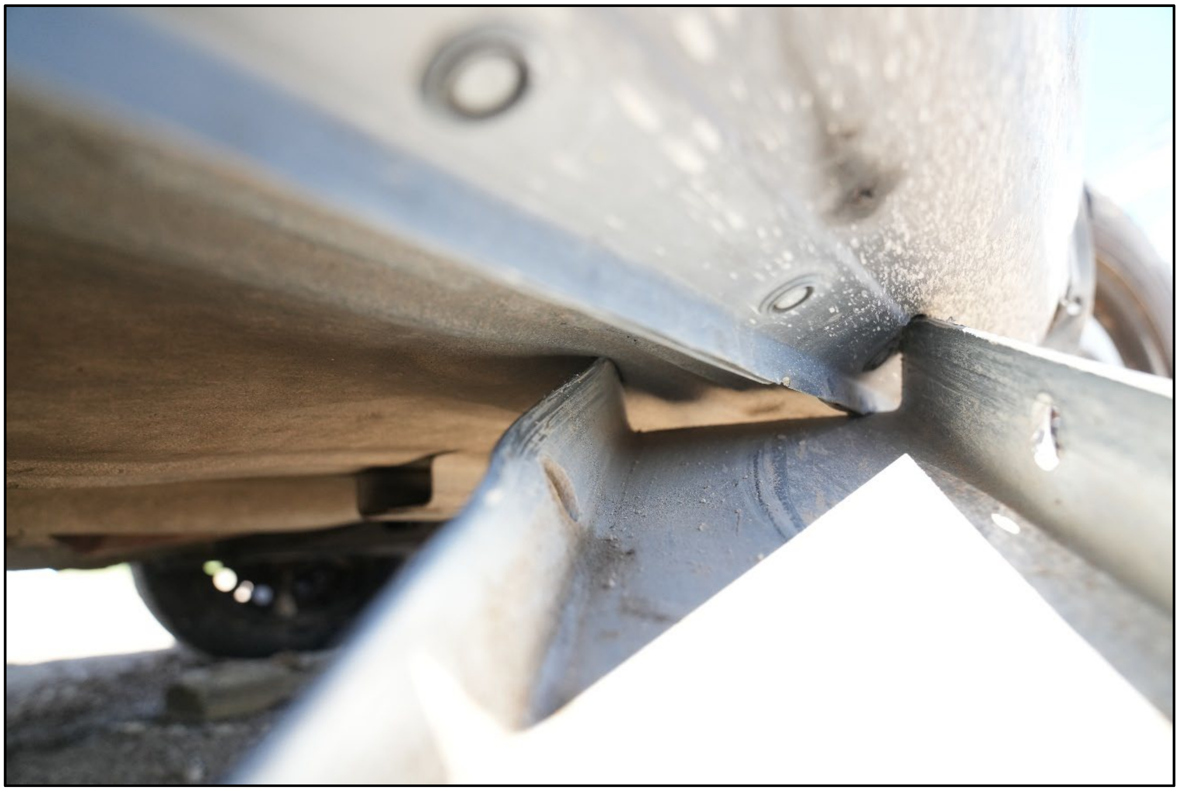


Figure 9.8. Post Engaged with Undercarriage of Vehicle after Crash Test 615181-01-7.

Figure 9.9. Occupant Compartment Damage after Crash Test 615181-01-7.

Chapter 10. *MASH* TEST 2-30 (CRASH TEST NO. 615181-01-11)

10.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 10.1 for details on *MASH* impact conditions for this test and Table 10.2 for the exit parameters. Figure 10.1 and Figure 10.2 depict the target impact setup.

Table 10.1. Impact Conditions for Test 615181-01-11.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	45	±2.5 mi/h	45.6
Impact Angle (deg)	0	±1.5°	0
Kinetic Energy (kip-ft)	141	≥141 kip-ft	168.2
Impact Location	Centerline of post 1 aligned 13 inches off the centerline of the vehicle toward drivers side.	± 6 inches	Centerline of post 1 aligned 14.4 inches off the centerline of the vehicle toward drivers side.

Table 10.2. Exit Parameters for Test 615181-01-11.

Exit Parameter	Measured
Speed (mi/h)	N/A
Trajectory (deg)	N/A
Heading (deg)	N/A
Brakes applied post impact (s)	Brakes not applied
Vehicle at rest position	27 ft downstream of impact point 3 ft to the field side 3° left
Comments:	Vehicle remained upright and stable.

Figure 10.1. TL-2 W-beam End Terminal/Test Vehicle Geometrics for Test 615181-01-11.

Figure 10.2. TL-2 W-beam End Terminal/Test Vehicle Impact Location 615181-01-11.

10.2. WEATHER CONDITIONS

Table 10.3 provides the weather conditions for 615181-01-11.

Table 10.3. Weather Conditions 615181-01-11.

Date of Test	2022-10-06 AM
Wind Speed (mi/h)	1
Wind Direction (deg)	309
Temperature (°F)	81
Relative Humidity (%)	57
Vehicle Traveling (deg)	350

10.3. TEST VEHICLE

Figure 10.3 and Figure 10.4 show the 2017 Nissan Versa used for the crash test. Table 10.4 shows the vehicle measurements. Table D.1 in Appendix D.1 gives additional dimensions and information on the vehicle.

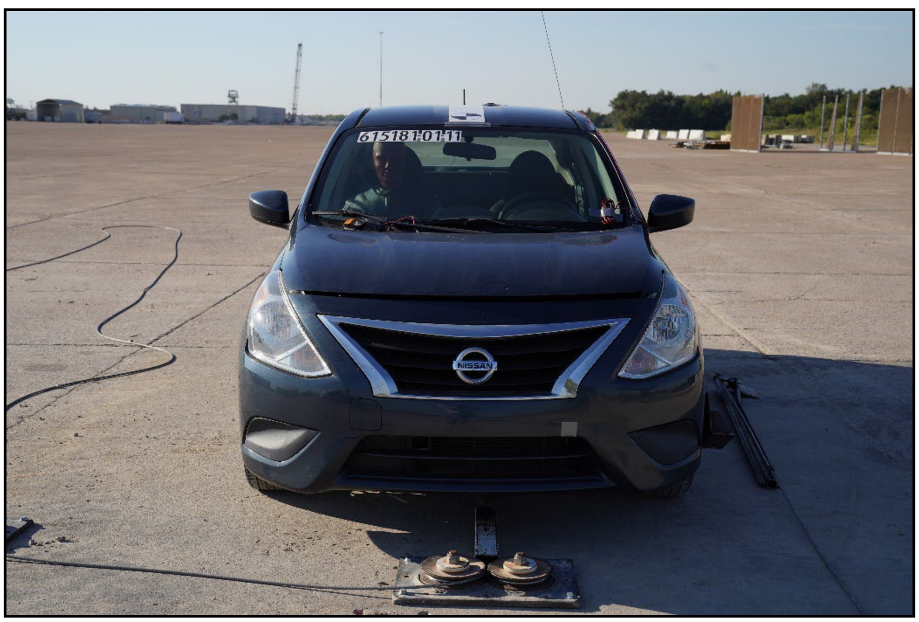


Figure 10.3. Impact Side of Test Vehicle before Test 615181-01-11.

Figure 10.4. Overall Interior of Test Vehicle before Test 615181-01-11.

Table 10.4. Vehicle Measurements 615181-01-11.

Test Parameter	***MASH***	**Allowed Tolerance**	**Measured**
Dummy (if applicable)[a] (lb)	165	N/A	165
Inertial Weight (lb)	2420	±55	2420
Gross Static[a] (lb)	2585	±25	2585
Wheelbase (inches)	98	±5	102.4
Front Overhang (inches)	35	±4	32.5
Overall Length (inches)	169	±8	175.4
Overall Width (inches)	65	±3	66.7
Hood Height (inches)	28	±4	30.5
Track Width[b] (inches)	59	±2	58.4
CG aft of Front Axle[c] (inches)	39	±4	41.4
CG above Ground[c,d] (inches)	N/A	N/A	N/A

[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

10.4. TEST DESCRIPTION

Table 10.5 lists events that occurred during Test No. 615181-01-11. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 10.5. Events during Test 615181-01-11.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0090	Post 1 began to move to the right (toward traffic side)
0.0150	Rail began to buckle between posts 1 and 2
0.0260	Vehicle contacted Post 1, and the post began to move downstream
0.0600	Post 2 began to move upstream toward vehicle
0.0830	Rail began to buckle between posts 2 and 3
0.1030	Post 2 began to move downstream
0.1100	Post 2 began to break longitudinally along post
0.1500	Rail began to buckle between posts 3 and 4
0.2760	Post 3 contacted by debris and vehicle and began to move downstream
0.3210	Rail began to buckle between posts 4 and 5
0.4160	Post 4 contacted by vehicle, began to move downstream
0.6660	Post 5 contacted by the vehicle and debris, began to move downstream
0.3850	Post 6 was contacted by debris in front of the vehicle and began to move downstream
0.9880	Vehicle stopped

10.5. DAMAGE TO TEST INSTALLATION

Posts 1 through 3 were broken off at grade. Post 4 was leaning downstream 30° and post 5 was leaning downstream 54°. The rail released from posts 1 through 5, and it was crumpled in front of the small car. Figure 10.5 and Figure 10.6 show the damage to the TL-2 W-beam End Terminal.

Figure 10.5. TL-2 W-beam End Terminal after Test at Impact Location 615181-01-11.

Figure 10.6. TL-2 W-beam End Terminal after Test after the Small Car was Removed 615181-01-11.

10.6. DAMAGE TO TEST VEHICLE

Figure 10.7 and Figure 10.8 show the damage sustained by the vehicle. Figure 10.9 and Figure 10.10 show the interior of the test vehicle. Table 10.6 and Table 10.7 provide details on the occupant compartment deformation and exterior vehicle damage. Tables D.2 and D.3 in Appendix D.1 provide exterior crush and occupant compartment measurements.

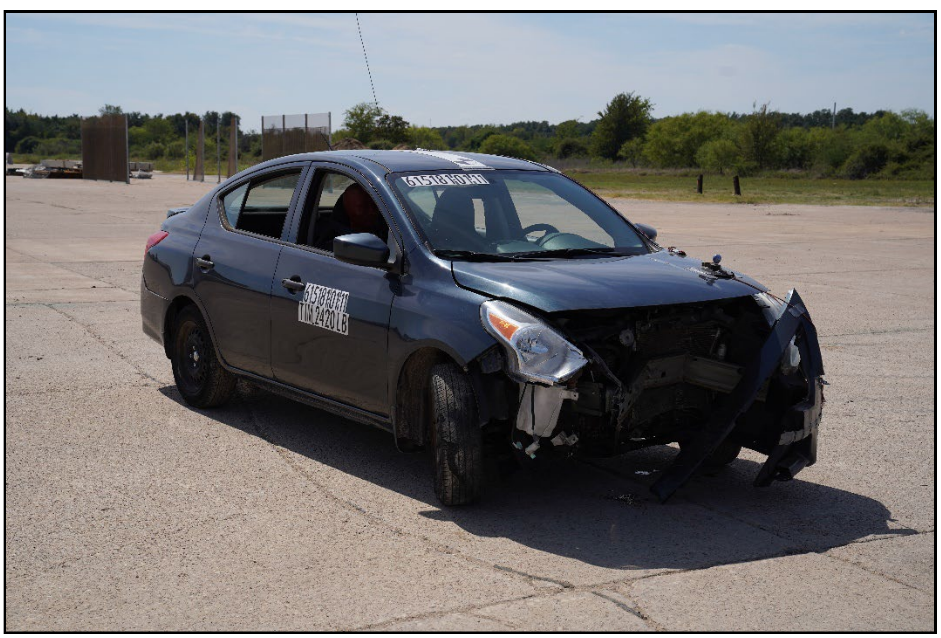


Figure 10.7. Right Side of Test Vehicle after Test 615181-01-11.

Figure 10.8. Left Side of Test Vehicle after Test 615181-01-11.

Figure 10.9. Overall Interior of Test Vehicle after Test 615181-01-11.

Figure 10.10. Interior of Test Vehicle on Impact Side after Test 615181-01-11.

Table 10.6. Occupant Compartment Deformation 615181-01-11.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	0 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	0 inches
Front Door (above Seat)	≤9.0 inches	0 inches
Front Door (below Seat)	≤12.0 inches	0 inches

Table 10.7. Exterior Vehicle Damage 615181-01-11.

Side Windows	The side windows remained intact
Maximum Exterior Deformation	13 inches in the front plane at bumper height
VDS	12FC2
CDC	12FCEN1
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, right and left headlights, bottom of the floor pan and oil pan were damaged. There was a 8-inch × 1-inch × ½-inch deep dent in the underside of the floor pan, but there was no hole or cut. There was a hole in the oil pan.

10.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 10.8. 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.

Table 10.8. Occupant Risk Factors for Test 615181-01-11.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0	18.6	0.2023 seconds on front of interior
OIV, Lateral (ft/s)	≤40.0	2.1	0.2023 seconds on front of interior
Ridedown, Longitudinal (g)	≤20.49	11.0	0.2768 - 0.2868 seconds
Ridedown, Lateral (g)	≤20.49	6.0	0.2885 - 0.2985 seconds
THIV (m/s)	N/A	5.7	0.2032 seconds on front of interior
ASI	N/A	0.4	0.7111 - 0.7611 seconds
50-ms MA Longitudinal (g)	N/A	-4.7	0.1045 - 0.1545 seconds
50-ms MA Lateral (g)	N/A	-2.3	0.6865 - 0.7365 seconds
50-ms MA Vertical (g)	N/A	2.1	0.3026 - 0.3526 seconds
Roll (deg)	≤75	9	1.4426 seconds
Pitch (deg)	≤75	8	0.7862 seconds
Yaw (deg)	N/A	9	0.6206 seconds

10.8. TEST SUMMARY

Figure 10.11 presents the summary results for crash test 615181-01-11.

0.000 s

0.200 s

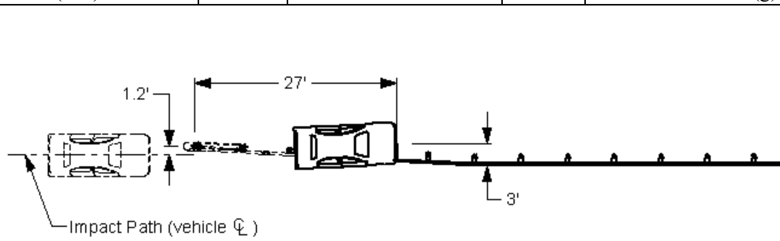
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 2-30
TTI Project No.	615181-01-11
Test Date	2022-10-06
TEST ARTICLE	
Type	Gating Terminal
Name	TL-2 W-beam End Terminal
Length	156 ft 1-inch
Key Materials	W-beam guardrail, Wood timber posts, Steel guardrail posts
Soil Type and Condition	AASHTO M147-17 Grading D (crushed concrete)
TEST VEHICLE	
Type/Designation	1100C
Year, Make and Model	2017 Nissan Versa
Inertial Weight (lb)	2420
Dummy (lb)	165
Gross Static (lb)	2585
IMPACT CONDITIONS	
Impact Speed (mi/h)	45.6
Impact Angle (deg)	0
Impact Location	Centerline of post 1 aligned 14.4 inches off the centerline of the vehicle toward drivers side.
Impact Severity (kip-ft)	168.2
EXIT CONDITIONS	
Exit Speed (mi/h)	N/A
Trajectory/Heading Angle (deg)	N/A / N/A
Stopping Distance	27 ft downstream 3 ft to the field side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	N/A
Permanent (inches)	N/A
Working Width / Height (inches)	N/A / N/A
VEHICLE DAMAGE	
VDS	12FC2
CDC	12FCEN1
Max. Ext. Deformation	13
Max Occupant Compartment Deformation	There was no occupant compartment deformation

OCCUPANT RISK VALUES

Long. OIV (ft/s)	18.6	Long. Ridedown (g)	11.0	Max 50-ms Long. (g)	-4.7	Max Roll (deg)	9
Lat. OIV (ft/s)	2.1	Lat. Ridedown (g)	6.0	Max 50-ms Lat. (g)	-2.3	Max Pitch (deg)	8
THIV (m/s)	5.7	ASI	0.4	Max 50-ms Vert. (g)	2.1	Max Yaw (deg)	9



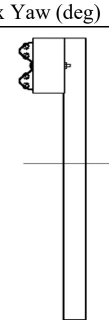


Figure 10.11. Summary of Results for *MASH* Test 2-30 on TL-2 W-beam End Terminal.

Chapter 11. *MASH* TEST 2-31 (CRASH TEST NO. 615181-01-12)

11.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 11.1 for details on *MASH* impact conditions for this test and Table 11.2 for the exit parameters. Figure 11.1 and Figure 11.2 depict the target impact setup.

Table 11.1. Impact Conditions for Test 615181-01-12.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	45 mi/h	± 2.5 mi/h	46.1
Impact Angle (deg)	0°	± 1.5°	0
Impact Severity (kip-ft)	291 kip-ft	≥291 kip-ft	360.3
Impact Location	Centerline of post 1 aligned with the centerline of the vehicle	± 6 inches	Centerline of post 1 aligned with the centerline of the vehicle

Table 11.2. Exit Parameters for Test 615181-01-12.

Exit Parameter	Measured
Speed (mi/h)	N/A
Trajectory (deg)	N/A
Heading (deg)	N/A
Brakes applied post impact (s)	Brakes not applied
Vehicle at rest position	37 ft downstream of impact point 3 ft to the traffic side 80° right
Comments:	Vehicle remained upright and stable

Figure 11.1. TL-2 W-beam End Terminal/Test Vehicle Geometrics for Test 615181-01-12.

Figure 11.2. TL-2 W-beam End Terminal/Test Vehicle Impact Location 615181-01-12.

11.2. WEATHER CONDITIONS

Table 11.3 provides the weather conditions for 615181-01-12.

Table 11.3. Weather Conditions 615181-01-12.

Date of Test	2022-10-11 AM
Wind Speed (mi/h)	10
Wind Direction (deg)	162
Temperature (°F)	79
Relative Humidity (%)	67
Vehicle Traveling (deg)	350

11.3. TEST VEHICLE

Figure 11.3 and Figure 11.4 show the 2017 RAM 1500 used for the crash test. Table 11.4 shows the vehicle measurements. Table E.1 in Appendix E.1 gives additional dimensions and information on the vehicle.

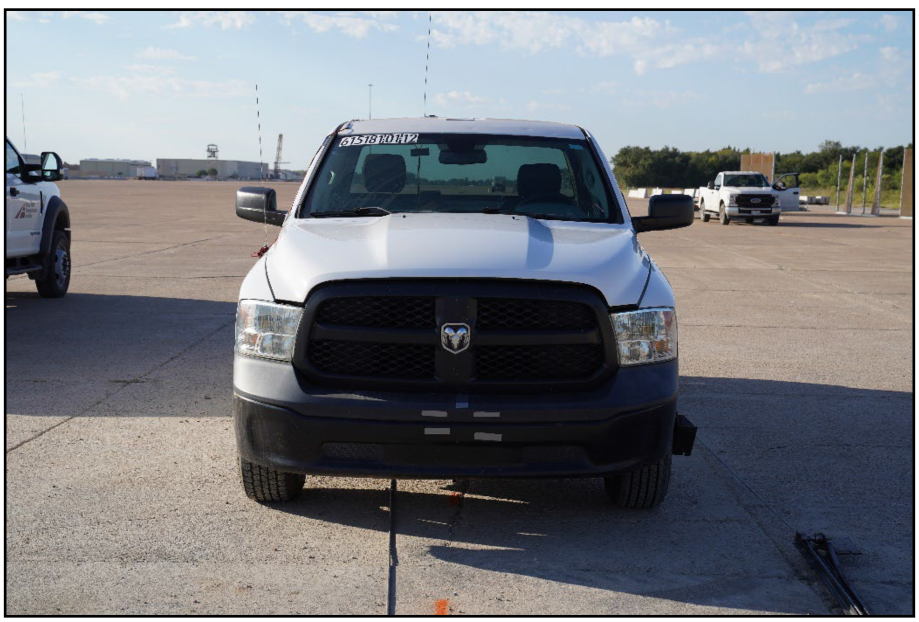


Figure 11.3. Impact Side of Test Vehicle before Test 615181-01-12.

Figure 11.4. Interior of the Test Vehicle before Test 615181-01-12.

Table 11.4. Vehicle Measurements 615181-01-12.

Test Parameter	*MASH*	Allowed Tolerance	Measured
Dummy (if applicable)[a] (lb)	165	N/A	N/A
Inertial Weight (lb)	5000	± 110	5072
Gross Static[a] (lb)	5000	± 110	5072
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40.0.
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46.0
Track Width[b] (inches)	67	±1.5	68.25
CG aft of Front Axle[c] (inches)	63	±4	60.0
CG above Ground[c,d] (inches)	28	≥28	28.4

[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

11.4. TEST DESCRIPTION

Table 11.5 lists events that occurred during Test No. 615181-01-12. Figures E.1 and E.2 in Appendix E.2 present sequential photographs during the test.

Table 11.5. Events during Test 615181-01-12.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0200	Vehicle contacted Post 1, and the post began to move downstream
0.0320	Rail began to buckle between posts 1 and 2
0.0470	Post 1 began to break at grade
0.0980	Rail began to buckle between posts 2 and 3
0.0112	Post 2 began to split and move downstream from impact
0.1240	Post 2 began to break at grade
0.1480	Rail began to buckle between posts 3 and 4
0.1850	Post 3 contacted by debris and vehicle and began to move downstream
0.2480	Rail began to buckle between posts 4 and 5
0.3570	Post 4 contacted by vehicle, began to move downstream
0.3700	Rail began to buckle between posts 4 and 5
0.4870	Truck began to yaw to the left
0.4970	Post 5 contacted by the vehicle, began to move downstream
0.6310	Post 6 contacted by the vehicle, began to move downstream
0.6560	Rail began to buckle between posts 6 and 7
0.7700	Rail began to release from post 8
0.0808	Rail was fully released from all posts
2.0030	Vehicle stopped

11.5. DAMAGE TO TEST INSTALLATION

The rail released from all posts and was shifted 7 inches downstream. Posts 1 through 3 were broken off at grade and Posts 4 through 6 were leaning 15° downstream from vertical. Posts 21 and 23 were split, and 22 and 24 were broken off at grade. Post 25 was leaning over, and post 26 released from the rail. Posts 22 through 24 had a ⅛-inch gap in the soil on the downstream side. Figure 11.5 and Figure 11.6 show the damage to the TL-2 W-beam End Terminal.

Figure 11.5. TL-2 W-beam End Terminal after Test at Impact Location 615181-01-12.

Figure 11.6. TL-2 W-beam End Terminal after Test at the Downstream Terminal 615181-01-12.

11.6. DAMAGE TO TEST VEHICLE

Figure 11.7 and Figure 11.8 show the damage sustained by the vehicle. Figure 11.9 and Figure 11.10 show the interior of the test vehicle. Table 11.6 and Table 11.7 provide details on the occupant compartment deformation and exterior vehicle damage. Tables E.2 and E.3 in Appendix E.1 provide exterior crush and occupant compartment measurements.

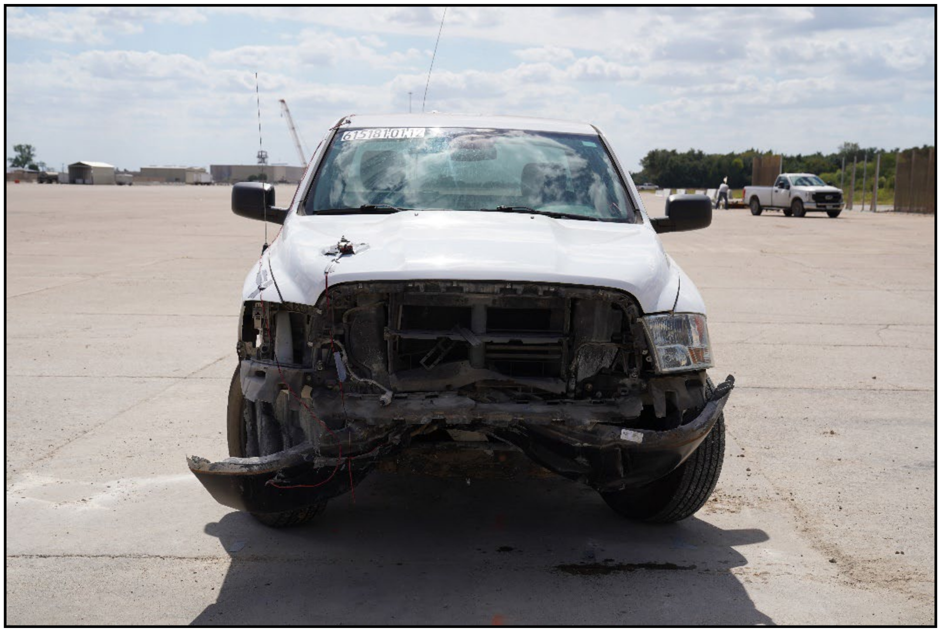


Figure 11.7. Impact Side of Test Vehicle after Test 615181-01-12.

Figure 11.8. Left Side of Test Vehicle after Test 615181-01-12.

Figure 11.9. Overall Interior of Test Vehicle after Test 615181-01-12.

Figure 11.10. Interior of Test Vehicle on Impact Side after Test 615181-01-12.

Table 11.6. Occupant Compartment Deformation 615181-01-12.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	0 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	0 inches
Front Door (above Seat)	≤9.0 inches	0 inches
Front Door (below Seat)	≤12.0 inches	0 inches

Table 11.7. Exterior Vehicle Damage 615181-01-12.

Side Windows	The side windows remained intact
Maximum Exterior Deformation	14 inches in the front plane at bumper height
VDS	12FC2
CDC	FCEN2
Fuel Tank Damage	Yes, there was some scuff marks on the fuel tank but no puncture or hole
Description of Damage to Vehicle:	The front bumper, grill, right and left head lights, radiator and support, left front quarter fender, right rocker, tail pipe, fuel tank, and transmission pan were damaged.

11.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 11.8. Figure E.3 in Appendix E.3 shows the vehicle angular displacements, and Figures E.4 through E.6 in Appendix E.4 show acceleration versus time traces.

Table 11.8. Occupant Risk Factors for Test 615181-01-12.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0	12.6	0.2898 seconds on front of interior
OIV, Lateral (ft/s)	≤40.0	1.1	0.2898 seconds on front of interior
Ridedown, Longitudinal (g)	≤20.49	8.9	0.7741 - 0.7841 seconds
Ridedown, Lateral (g)	≤20.49	4.4	0.7759 - 0.7859 seconds
THIV (m/s)	N/A	3.9	0.2898 seconds on front of interior
ASI	N/A	0.7	0.7821 - 0.8321 seconds
50-ms MA Longitudinal (g)	N/A	-7.3	0.7512 - 0.8012 seconds
50-ms MA Lateral (g)	N/A	2.1	1.4256 - 1.4756 seconds
50-ms MA Vertical (g)	N/A	-4.5	0.8311 - 0.8811 seconds
Roll (deg)	≤75	9	0.8403 seconds
Pitch (deg)	≤75	5	0.9134 seconds
Yaw (deg)	N/A	75	1.9640 seconds

11.8. TEST SUMMARY

Figure 11.11 presents the summary results for crash test 615181-01-12.

0.000 s

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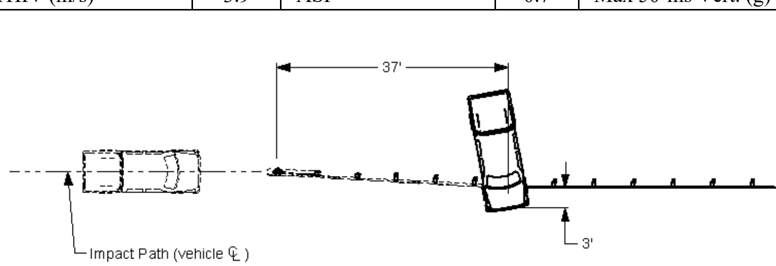
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 2-31
TTI Project No.	615181-01-12
Test Date	2022-10-11
TEST ARTICLE	
Type	Gating Terminal
Name	TL-2 W-beam End Terminal
Length	156 ft 1-inch
Key Materials	W-beam guardrail, Wood timber posts, Steel guardrail posts
Soil Type and Condition	AASHTO M147-17 Grading D (crushed concrete)
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2017 RAM 1500
Inertial Weight (lb)	5072
Dummy (lb)	N/A
Gross Static (lb)	5072
IMPACT CONDITIONS	
Impact Speed (mi/h)	46.1
Impact Angle (deg)	0
Impact Location	Centerline of post 1 aligned with the centerline of the vehicle
Impact Severity (kip-ft)	360.3
EXIT CONDITIONS	
Exit Speed (mi/h)	N/A
Trajectory/Heading Angle (deg)	N/A / N/A
Exit Box Criteria	N/A
Stopping Distance	37 ft downstream 3 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	N/A
Permanent (inches)	N/A
Working Width / Height (inches)	N/A / N/A
VEHICLE DAMAGE	
VDS	12FC2
CDC	FCEN2
Max. Ext. Deformation	14
Max Occupant Compartment Deformation	There was no occupant compartment deformation

OCCUPANT RISK VALUES

Long. OIV (ft/s)	12.6	Long. Ridedown (g)	8.9	Max 50-ms Long. (g)	-7.3	Max Roll (deg)	9
Lat. OIV (ft/s)	1.1	Lat. Ridedown (g)	4.4	Max 50-ms Lat. (g)	2.1	Max Pitch (deg)	5
THIV (m/s)	3.9	ASI	0.7	Max 50-ms Vert. (g)	-4.5	Max Yaw (deg)	75



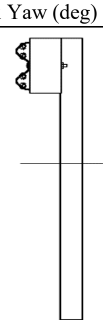


Figure 11.11. Summary of Results for *MASH* Test 2-31 on TL-2 W-beam End Terminal.

Chapter 12. *MASH* TEST 2-37B (CRASH TEST NO. 615181-01-13)

12.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 12.1 for details on *MASH* impact conditions for this test and Table 12.2 for the exit parameters. Figure 12.1 and Figure 12.2 depict the target impact setup.

Table 12.1. Impact Conditions for Test 615181-01-13.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	45	±2.5 mi/h	45.3
Impact Angle (deg)	25	±1.5°	24.5
Impact Severity (kip-ft)	25	≥25 kip-ft	28.9
Impact Location	14 inches upstream from upstream edge of post 24.	± 12 inches	11.4 inches upstream from upstream edge of post 24.

Table 12.2. Exit Parameters for Test 615181-01-13.

Exit Parameter	Measured
Speed (mi/h)	27.9
Trajectory (deg)	8
Heading (deg)	7
Brakes applied post impact (s)	Brakes Not Applied
Vehicle at rest position	99 ft downstream of impact point 3 ft to the field side Facing downstream
Comments:	Vehicle remained upright and stable.

Figure 12.1. TL-2 W-beam End Terminal/Test Vehicle Geometrics for Test 615181-01-13.

Figure 12.2. TL-2 W-beam End Terminal/Test Vehicle Impact Location 615181-01-13.

12.2. WEATHER CONDITIONS

Table 12.3 provides the weather conditions for 615181-01-13.

Table 12.3. Weather Conditions 615181-01-13.

Date of Test	2022-10-20 PM
Wind Speed (mi/h)	10
Wind Direction (deg)	211
Temperature (°F)	81
Relative Humidity (%)	37
Vehicle Traveling (deg)	325

12.3. TEST VEHICLE

Figure 12.3 and Figure 12.4 show the 2017 Nissan Versa used for the crash test. Table 12.4 shows the vehicle measurements. Table F.1 in Appendix F.1 gives additional dimensions and information on the vehicle.

Figure 12.3. Impact Side of Test Vehicle before Test 615181-01-13.

Figure 12.4. Opposite Impact Side of Test Vehicle before Test 615181-01-13.

Table 12.4. Vehicle Measurements 615181-01-13.

Test Parameter	***MASH***	**Allowed Tolerance**	**Measured**
Dummy (if applicable)[a] (lb)	165	N/A	165
Inertial Weight (lb)	2420	±55	2450
Gross Static[a] (lb)	2585	±55	2615
Wheelbase (inches)	98	±5	102.4
Front Overhang (inches)	35	±4	32.5
Overall Length (inches)	169	±8	175.4
Overall Width (inches)	65	±3	66.7
Hood Height (inches)	28	±4	30.5
Track Width[b] (inches)	59	±2	58.4
CG aft of Front Axle[c] (inches)	39	±4	41.7
CG above Ground[c,d] (inches)	N/A	N/A	N/A

[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

12.4. TEST DESCRIPTION

Table 12.5 lists events that occurred during Test No. 615181-01-13. Figures F.1 and F.2 in Appendix F.2 present sequential photographs during the test.

Table 12.5. Events during Test 615181-01-13.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0110	Post 24 began to lean toward field side
0.0200	Vehicle began to redirect
0.0210	Post 25 began to lean toward field side
0.1900	Vehicle impacted post 26
0.2100	Post 26 began to break
0.3180	Vehicle lost contact with rail and exited the system at 27.9 mi/h and at a trajectory of 8 degrees and vehicle heading of 7.5 degrees.
0.4320	Vehicle was parallel with rail

12.5. DAMAGE TO TEST INSTALLATION

The soil was disturbed at post 23, and post 24 was leaning 3.5° back from vertical. Posts 25 and 26 broke off at grade and released from the rail. Figure 12.5 and Figure 12.6 show the damage to the TL-2 W-beam End Terminal.

Figure 12.5. TL-2 W-beam End Terminal after Test at Impact Location 615181-01-13.

Figure 12.6. End of the Rail and Anchor Post of the TL-2 W-beam End Terminal after Test 615181-01-13.

12.6. DAMAGE TO TEST VEHICLE

Figure 12.7 and Figure 12.8 show the damage sustained by the vehicle. Figure 12.9 and Figure 12.10 show the interior of the test vehicle. Table 12.6 and Table 12.7 provide details on the occupant compartment deformation and exterior vehicle damage. Tables F.2 and F.3 in Appendix F.1 provide exterior crush and occupant compartment measurements.

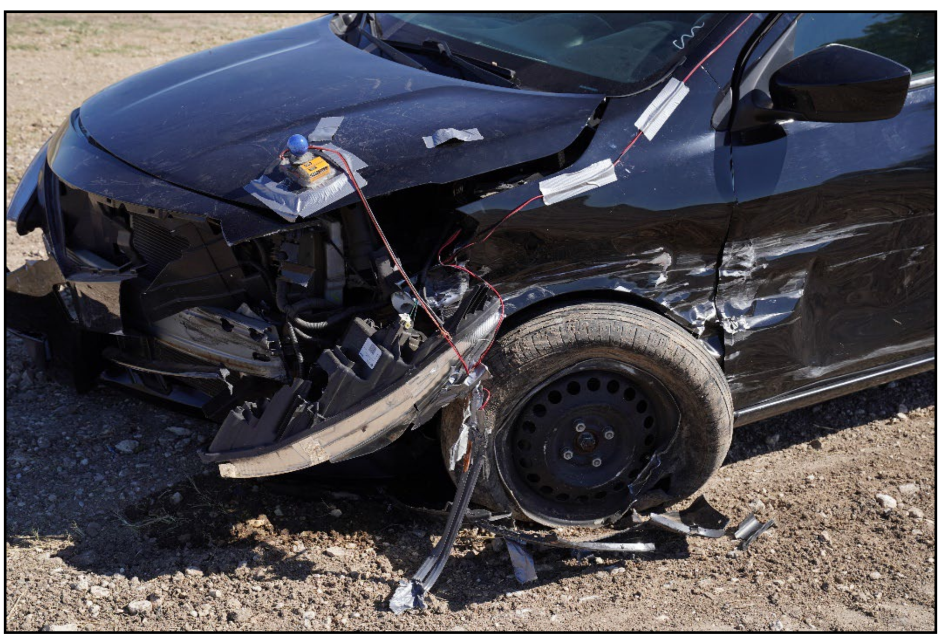


Figure 12.7. Impact Side of Test Vehicle after Test 615181-01-13.

Figure 12.8. Rear Impact Side of Test Vehicle after Test 615181-01-13.

Figure 12.9. Overall Interior of Test Vehicle after Test 615181-01-13.

Figure 12.10. Interior of Test Vehicle on Impact Side after Test 615181-01-13.

Table 12.6. Occupant Compartment Deformation 615181-01-13.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	0 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	0 inches
Front Door (above Seat)	≤9.0 inches	0 inches
Front Door (below Seat)	≤12.0 inches	0 inches

Table 12.7. Exterior Vehicle Damage 615181-01-13.

Side Windows	The side windows remained intact.
Maximum Exterior Deformation	6 inches in the front plane at the left front corner at bumper height
VDS	11LFQ2
CDC	11FLEW2
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, left head light, left front tire and rim, oil pan, left front strut and tower, left front quarter fender, left front door, left rear door, and left rear quarter fender were damaged. The left front door had a 1¼-inch gap at the top of the door.

12.7. OCCUPANT RISK FACTORS

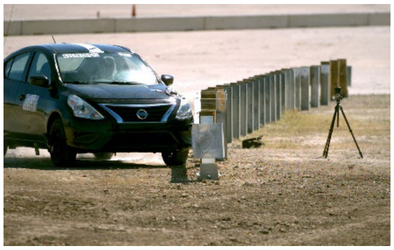
Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 12.8. Figure F.3 in Appendix F.3 shows the vehicle angular displacements, and Figures F.4 through F.6 in Appendix F.4 show acceleration versus time traces.

Table 12.8. Occupant Risk Factors for Test 615181-01-13.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0	10.1	0.1613 seconds on left side of interior
OIV, Lateral (ft/s)	≤40.0	12.6	0.1613 seconds on left side of interior
Ridedown, Longitudinal (g)	≤20.49	11.5	0.2075 - 0.2175 seconds
Ridedown, Lateral (g)	≤20.49	6.4	0.2040 - 0.2140 seconds
THIV (m/s)	N/A	4.6	0.1565 seconds on left side of interior
ASI	N/A	0.8	0.2084 - 0.2584 seconds
50-ms MA Longitudinal (g)	N/A	-7.6	0.1839 - 0.2339 seconds
50-ms MA Lateral (g)	N/A	4.2	0.0444 - 0.0944 seconds
50-ms MA Vertical (g)	N/A	-2.6	0.1797 - 0.2297 seconds
Roll (deg)	≤75	10	0.4921 seconds
Pitch (deg)	≤75	11	4.5000 seconds
Yaw (deg)	N/A	23	0.7334 seconds

12.8. TEST SUMMARY

Figure 12.11 presents the summary results for crash test 615181-01-13.



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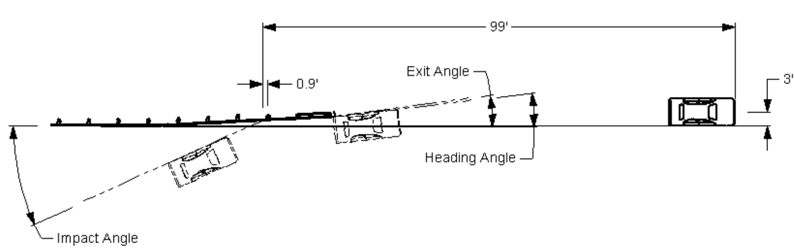
0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 2-37B
TTI Project No.	615181-01-13
Test Date	2022-10-20
TEST ARTICLE	
Type	Gating Terminal
Name	TL-2 W-beam End Terminal
Length	156 ft 0-inch
Key Materials	W-beam guardrail, Wood timber posts, Steel guardrail posts
Soil Type and Condition	AASHTO M147-17 Grading D (crushed concrete)
TEST VEHICLE	
Type/Designation	1100C
Year, Make and Model	2017 Nissan Versa
Inertial Weight (lb)	2450
Dummy (lb)	165
Gross Static (lb)	2615
IMPACT CONDITIONS	
Impact Speed (mi/h)	45.3
Impact Angle (deg)	24.5
Impact Location	11.4 inches upstream from upstream edge of post 24.
Impact Severity (kip-ft)	28.9
EXIT CONDITIONS	
Exit Speed (mi/h)	27.9
Trajectory/Heading Angle (deg)	8 / 7
Exit Box Criteria	Vehicle crossed the exit box
Stopping Distance	99 ft downstream 3 ft to the field side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	N/A
Permanent (inches)	N/A
Working Width / Height (inches)	N/A / N/A
VEHICLE DAMAGE	
VDS	11LFQ2
CDC	11FLEW2
Max. Ext. Deformation	6
Max Occupant Compartment Deformation	No occupant compartment deformation

OCCUPANT RISK VALUES

Long. OIV (ft/s)	10.1	Long. Ridedown (g)	11.5	Max 50-ms Long. (g)	-7.6	Max Roll (deg)	10
Lat. OIV (ft/s)	12.6	Lat. Ridedown (g)	6.4	Max 50-ms Lat. (g)	4.2	Max Pitch (deg)	11
THIV (m/s)	4.6	ASI	0.8	Max 50-ms Vert. (g)	-2.6	Max Yaw (deg)	23



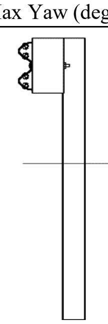


Figure 12.11. Summary of Results for *MASH* Test 2-37b on TL-2 W-beam End Terminal.

Chapter 13. NON-CRITICAL SIMULATIONS

13.1. INTRODUCTION AND JUSTIFICATION

Additional FE simulations were performed to evaluate the crashworthy performance of the system for the non-critical *MASH* tests in the TL-2 gating terminal test matrix. The following impact simulations were conducted:

- *MASH* Test 2-32—small car impact at terminal head (5–15 degrees) at 44 mi/h.
- *MASH* Test 2-33—pickup truck impact at terminal head (5–15 degrees) at 44 mi/h.
- *MASH* Test 2-34—small car redirective impact (15 degrees) at 44 mi/h.
- *MASH* Test 2-37a—reverse-direction pickup truck impact (45 degrees) at 44 mi/h.

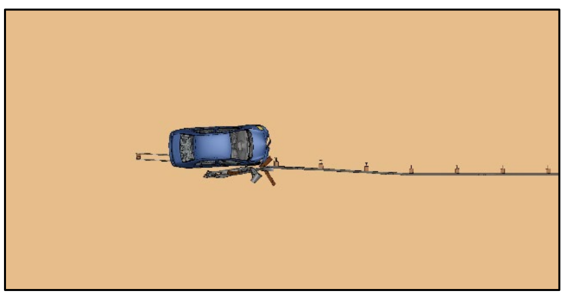
These test conditions are considered non-critical for the TL-2 terminal developed under this project. Neither *MASH* Test 2-32 nor *MASH* Test 2-33 are critical because this TL-2 terminal does not have a head component, so the vehicles will experience the impact with only the initial region of the terminal and with a shallower impact angle than *MASH* 2-30 and *MASH* 2-31 tests, and will subsequently gate. This TL-2 system passed both *MASH* Test 2-30 and *MASH* Test 2-31 full-scale crash tests, as presented in Chapter 14. *MASH* Test 2-34 has a shallower impact angle than *MASH* Test 2-35 and with a lighter vehicle (1100C) than the pickup truck (2270P) used in *MASH* Test 2-35. Since the TL-2 system passed the more severe test (*MASH* Test 2-35) in terms of angle and speed, *MASH* Test 2-34 is considered non-critical. Finally, the reverse-direction pickup truck test (*MASH* Test 2-37a) is not as critical as the small car test (*MASH* Test 2-37b) for post-and-beam terminals per *MASH* section 2.2.2.2: "For post-and-beam terminals utilizing a breakaway cable system, the 1100C will generally be the critical vehicle for this test, and the impact point should be selected to maximize the risk of the vehicle snagging on the anchor cable." The reverse small car test passed the full-scale crash testing, as presented in Chapter 12.

The flared terminal design model was the same as the one presented earlier in Chapter 4.

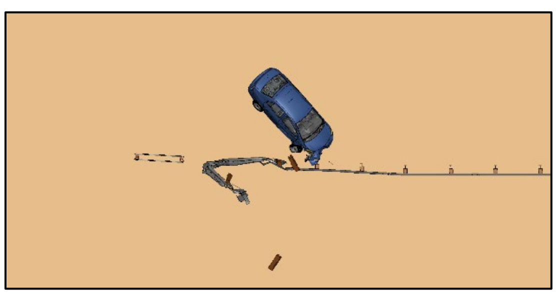
13.2. TEST 2-32 SIMULATION (5-DEGREE IMPACT ANGLE)

MASH Test 2-32 involved impacting the end terminal with the 1100C vehicle model at a speed of 44 mi/h and an angle of 5 degrees. The 1100C vehicle model impacted the terminal system with the centerline of the car aligned with the center of the terminal head. Figure 13.1 and Figure 13.2 show sequential images for the *MASH* Test 2-32 simulation impact. The end terminal released as designed, and the vehicle gated through the system. Table 13.1 shows the occupant risk values, which were within the limits of the *MASH* evaluation criteria described in Chapter 6 section 6.2.

(a) 0.0 s

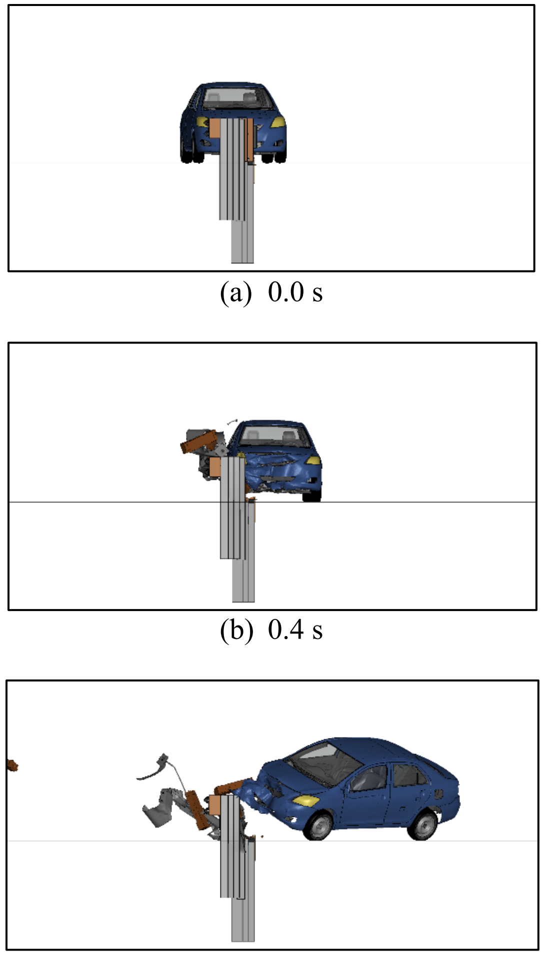


(b) 0.4 s



(c) 0.8 s

Figure 13.1. Flared Terminal Test 2-32 (5 Degrees) Simulation Sequential Images (Overhead View).



(a) 0.0 s

(b) 0.4 s

(c) 0.8 s

Figure 13.2. Flared Terminal Test 2-32 (5 Degrees) Simulation Sequential Images (Downstream View).

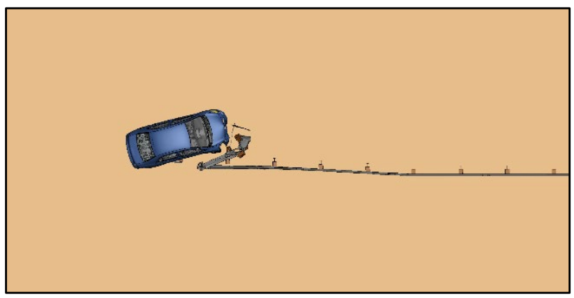
Table 13.1. Flared Terminal Test 2-32 (5 Degrees) Simulation Occupant Risk.

Impact Location	OIV Longitudinal (m/s)	OIV Lateral (m/s)	ORA Longitudinal (g)	ORA Lateral (g)	Max. Roll (deg)	Max. Pitch (deg)	Max. Yaw (deg)
Terminal Head	5.5	0.4	9.8	5.5	−23.7	−1.5	175

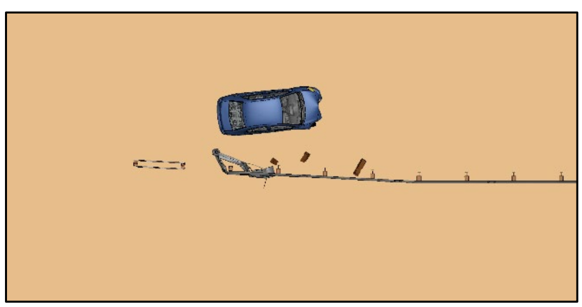
13.3. TEST 2-32 SIMULATION (15-DEGREE IMPACT ANGLE)

MASH Test 2-32 involved impacting the end terminal with the 1100C vehicle model at a speed of 44 mi/h and an angle of 15 degrees. The 1100C vehicle model impacted the terminal system with the centerline of the car aligned with the center of the terminal head. Figure 13.3 and Figure 13.4 show sequential images for the *MASH* Test 2-32 simulation impact. The end terminal released as designed, and the vehicle gated through the system. Table 13.2 shows the occupant risk values, which were within the limits of the *MASH* evaluation criteria described in Chapter 6 section 6.2.

(a) 0.0 s

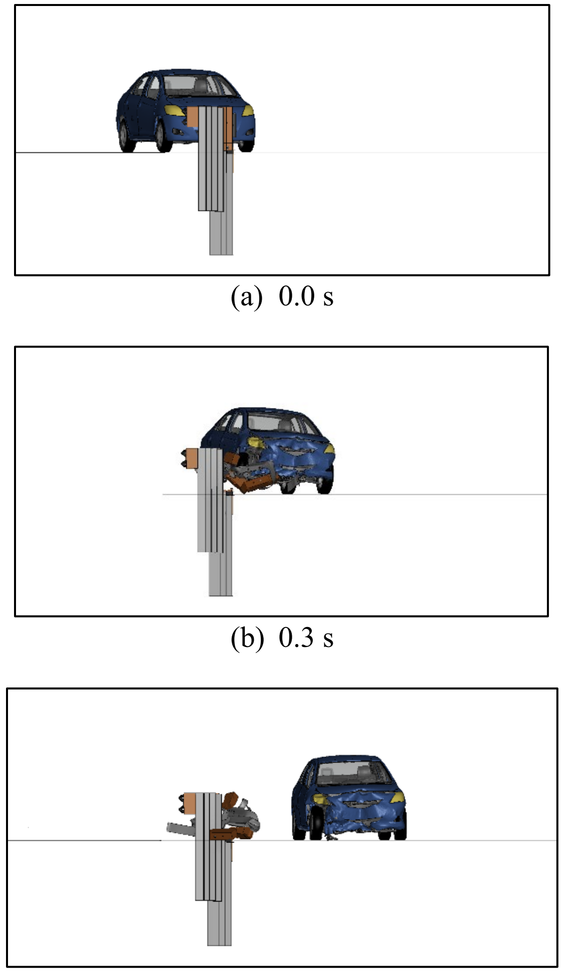


(b) 0.3 s



(c) 0.6 s

Figure 13.3. Flared Terminal Test 2-32 (15 Degrees) Simulation Sequential Images (Overhead View).



(a) 0.0 s

(b) 0.3 s

(c) 0.6 s

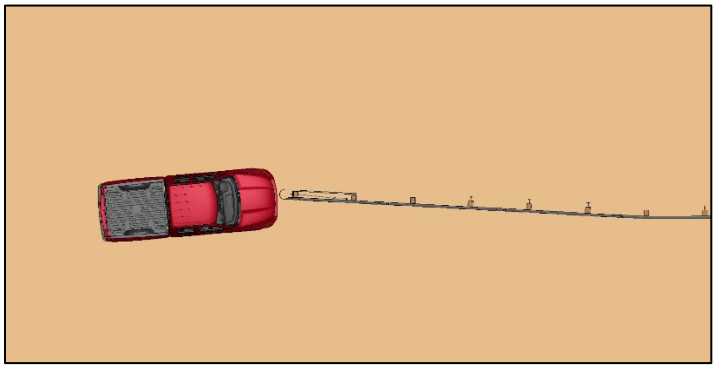
Figure 13.4. Flared Terminal Test 2-32 (15 Degrees) Simulation Sequential Images (Downstream View).

Table 13.2. Flared Terminal Test 2-32 (15 Degrees) Simulation Occupant Risk.

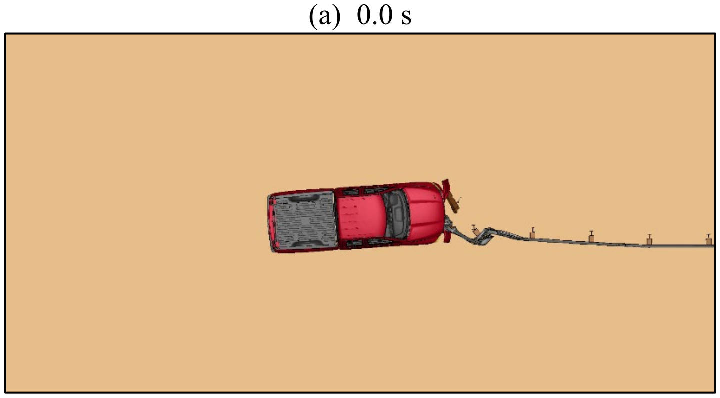
Impact Location	OIV Longitudinal (m/s)	OIV Lateral (m/s)	ORA Longitudinal (g)	ORA Lateral (g)	Max. Roll (deg)	Max. Pitch (deg)	Max. Yaw (deg)
Terminal Head	6.2	1.5	4.8	3.4	−4.6	1.7	36.8

13.4. TEST 2-33 SIMULATION (5-DEGREE IMPACT ANGLE)

MASH Test 2-33 involved impacting the end terminal with the 2270P vehicle model at a speed of 44 mi/h and an angle of 5 degrees. The 2270P vehicle model impacted the terminal system with the centerline of the truck aligned with the terminal head. Figure 13.5 and Figure 13.6 show sequential images for the *MASH* Test 2-33 simulation impact. The end terminal released as designed, and the vehicle gated through the system. Table 13.3 shows the occupant risk values, which were within the limits of the *MASH* evaluation criteria described in Chapter 6 section 6.2.



(a) 0.0 s



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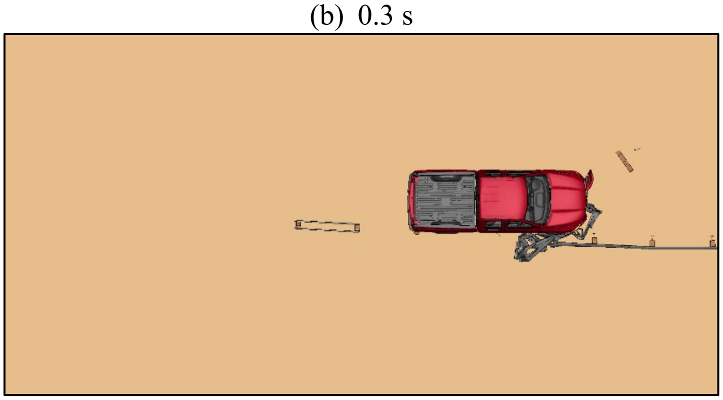
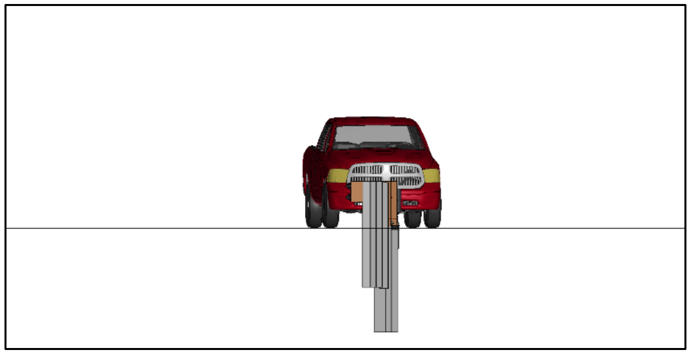


(c) 0.6 s

Figure 13.5. Flared Terminal Test 2-33 (5 Degrees) Simulation Sequential Images (Overhead View).



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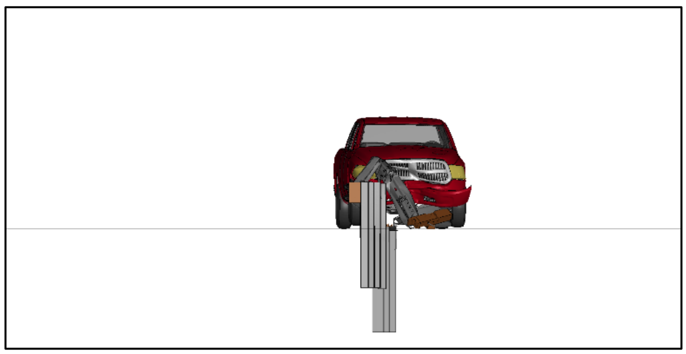

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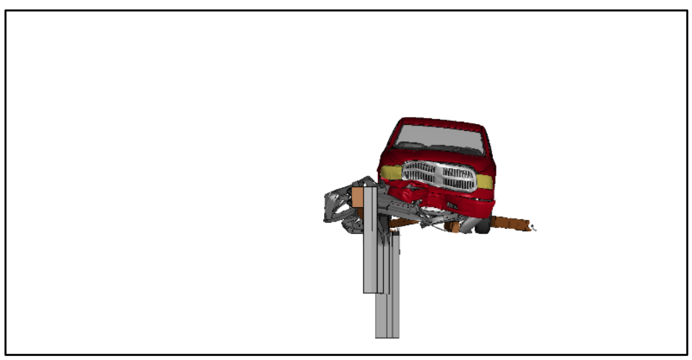


(c) 0.6 s

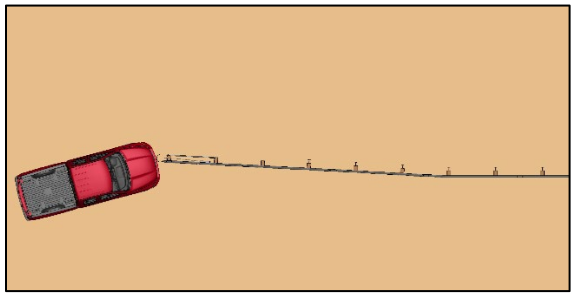
Figure 13.6. Flared Terminal Test 2-33 (5 Degrees) Simulation Sequential Images (Downstream View).

Table 13.3. Flared Terminal Test 2-33 (5 Degrees) Simulation Occupant Risk.

Impact Location	OIV Longitudinal (m/s)	OIV Lateral (m/s)	ORA Longitudinal (g)	ORA Lateral (g)	Max. Roll (deg)	Max. Pitch (deg)	Max. Yaw (deg)
Terminal Head	3.8	0.2	4.7	3.2	8.5	2.1	19.5

13.5. TEST 2-33 SIMULATION (15-DEGREE IMPACT ANGLE)

MASH Test 2-33 involved impacting the end terminal with the 2270P vehicle model at a speed of 44 mi/h and an angle of 15 degrees. The 2270P vehicle model impacted the terminal system with the centerline of the truck aligned with the center of the terminal head. Figure 13.7 and Figure 13.8 show sequential images for the *MASH* Test 2-33 simulation impact. The end terminal released as designed, and the vehicle gated through the system. Table 13.4 shows the occupant risk values, which were within the limits of the *MASH* evaluation criteria described in Chapter 6 section 6.2.



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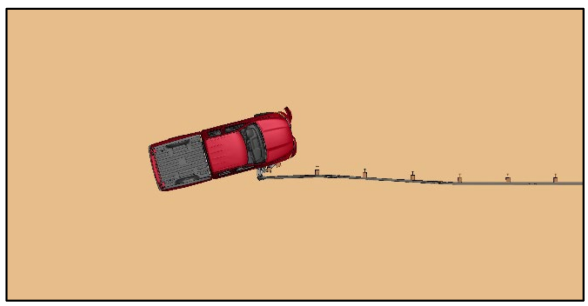

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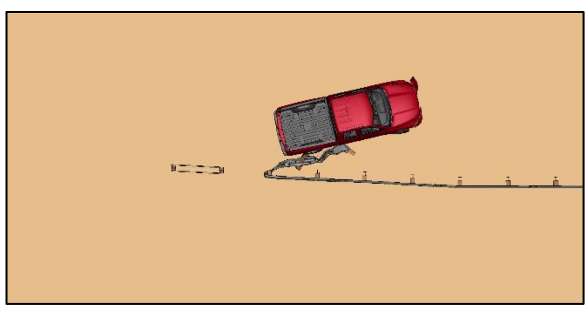

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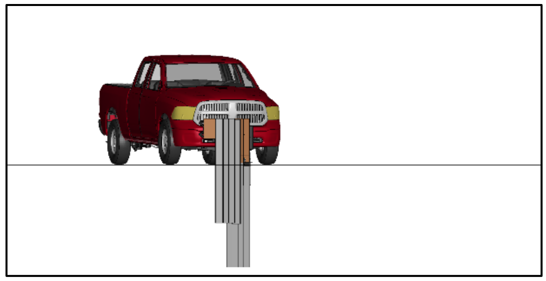
Figure 13.7. Flared Terminal Test 2-33 (15 Degrees) Simulation Sequential Images (Overhead View).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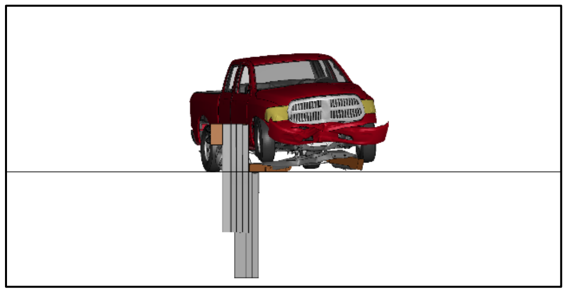
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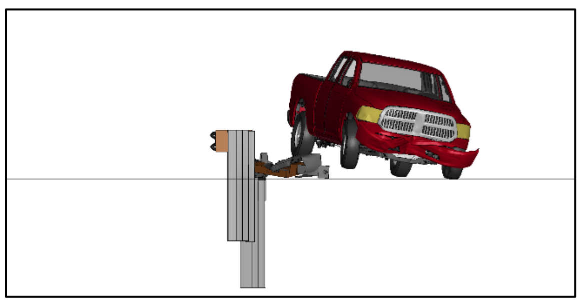

(c) 0.6 s

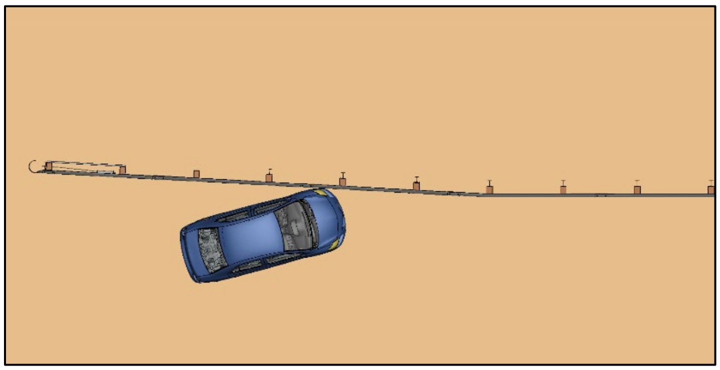
Figure 13.8. Flared Terminal Test 2-33 (15 Degrees) Simulation Sequential Images (Downstream View).

Table 13.4. Flared Terminal Test 2-33 (15 Degrees) Simulation Occupant Risk.

Impact Location	OIV Longitudinal (m/s)	OIV Lateral (m/s)	ORA Longitudinal (g)	ORA Lateral (g)	Max. Roll (deg)	Max. Pitch (deg)	Max. Yaw (deg)
Terminal Head	2.7	0.4	2.4	2.5	−10.1	−4.6	4.2

13.6. TEST 2-34 SIMULATION

MASH Test 2-34 involved impacting the end terminal with the 1100C vehicle model at a speed of 44 mi/h and an angle of 15 degrees. The 1100C vehicle model impacted the terminal system at the beginning of the LON section. Figure 13.9 and Figure 13.10 show sequential images for the *MASH* Test 2-34 simulation impact. The small car vehicle was successfully contained and redirected. Table 13.5 shows the occupant risk values, which were within the limits of the *MASH* evaluation criteria described in Chapter 6 section 6.2.



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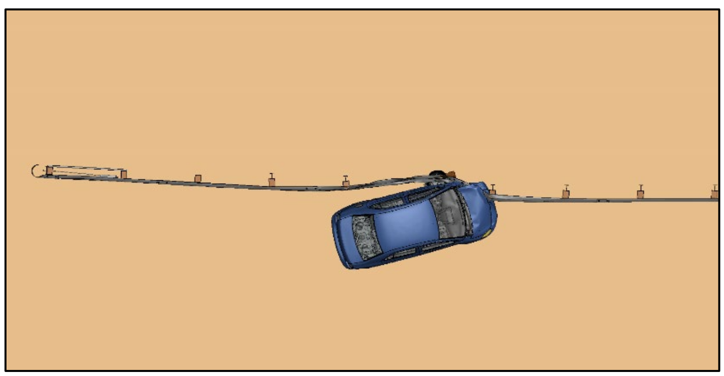

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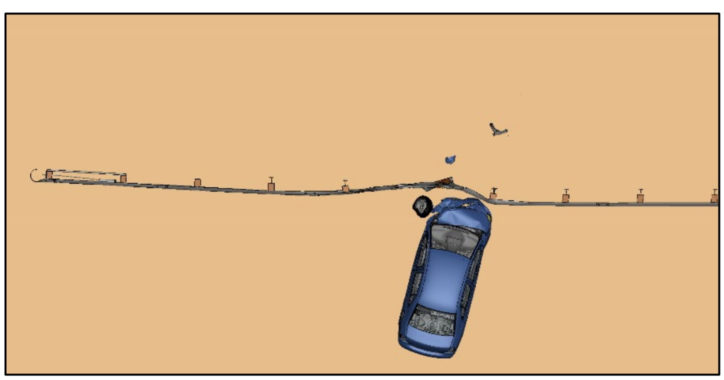
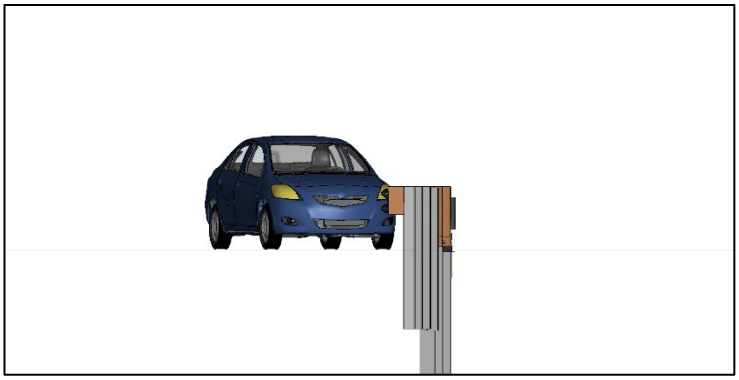


(c) 0.6 s

Figure 13.9. Flared Terminal Test 2-34 Simulation Sequential Images (Overhead View).



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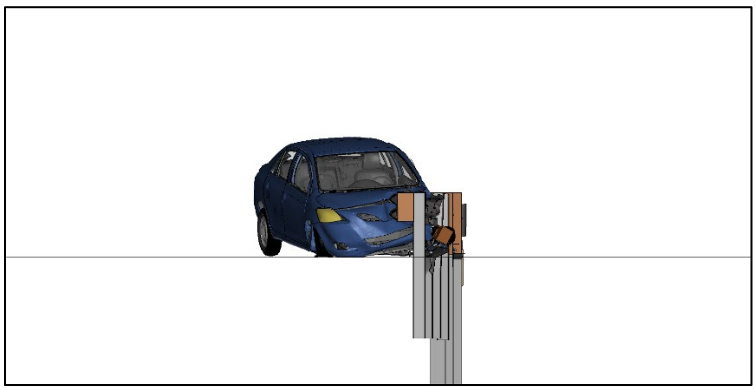

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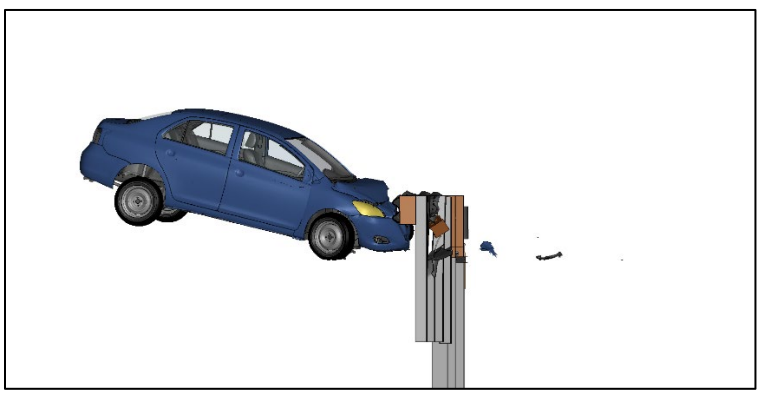


(c) 0.6 s

Figure 13.10. Flared Terminal Test 2-34 Simulation Sequential Images (Downstream View).

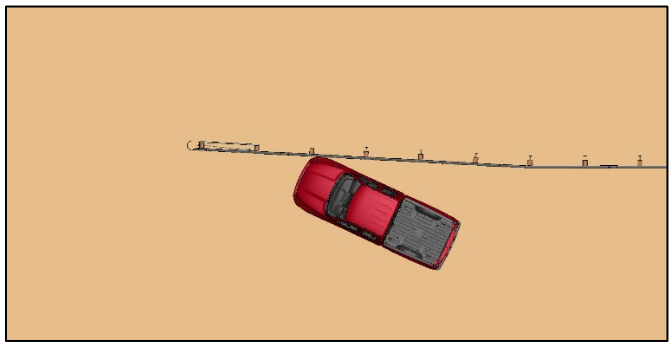
Table 13.5. Flared Terminal Test 2-34 Simulation Occupant Risk.

Impact Location	OIV Longitudinal (m/s)	OIV Lateral (m/s)	ORA Longitudinal (g)	ORA Lateral (g)	Max. Roll (deg)	Max. Pitch (deg)	Max. Yaw (deg)
18 inches u/s post 5	5.5	4.3	17.9	6.5	5.5	11.5	194.4

Note: u/s = upstream.

13.7. TEST 2-37A SIMULATION

MASH Test 2-37a involved impacting the end terminal with the 2270P vehicle model at a speed of 44 mi/h and an angle of 25 degrees. The 2270P vehicle model impacted the terminal system in the reverse direction. Figure 13.11 and Figure 13.12 show sequential images for the first CIP of the *MASH* Test 2-37a impact simulations. Figure 13.13 and Figure 13.14 show sequential images for the second CIP of the *MASH* Test 2-37a impact simulations. Table 13.6 shows the occupant risk values, which were within the limits of the *MASH* evaluation criteria described in Chapter 6 section 6.2.



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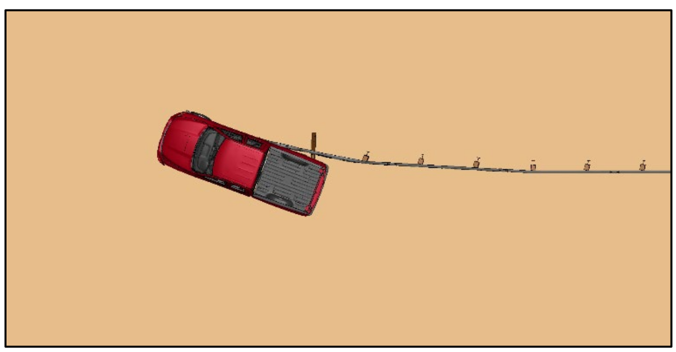

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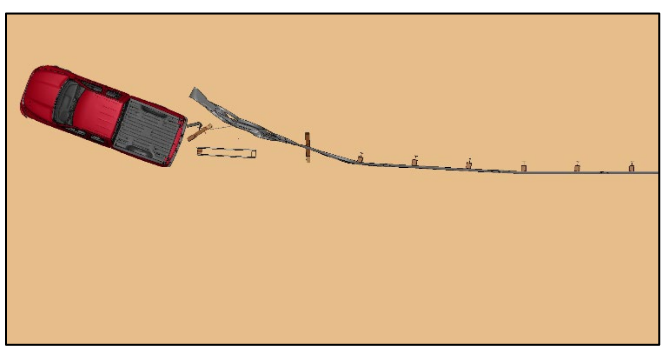

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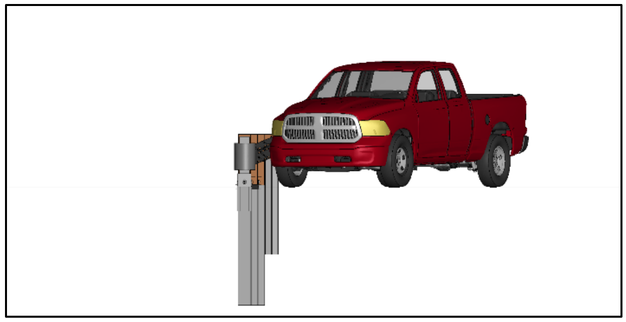
Figure 13.11. Flared Terminal Test 2-37a Simulation CIP01 Sequential Images (Overhead View).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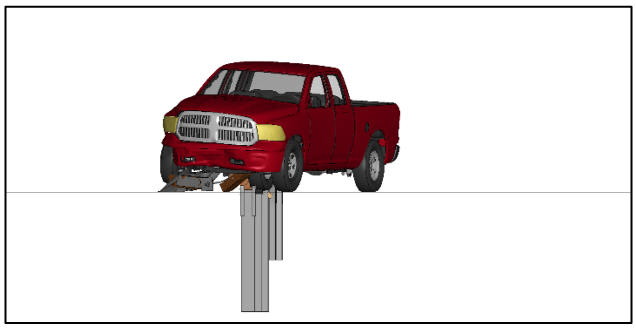
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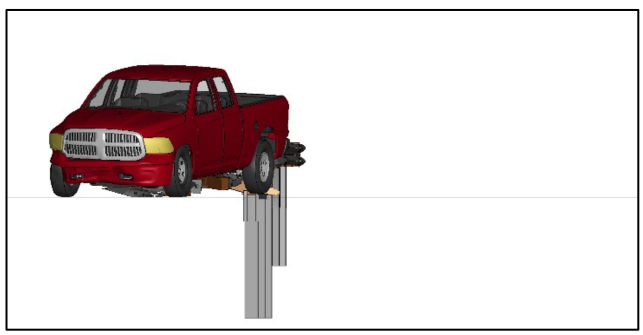
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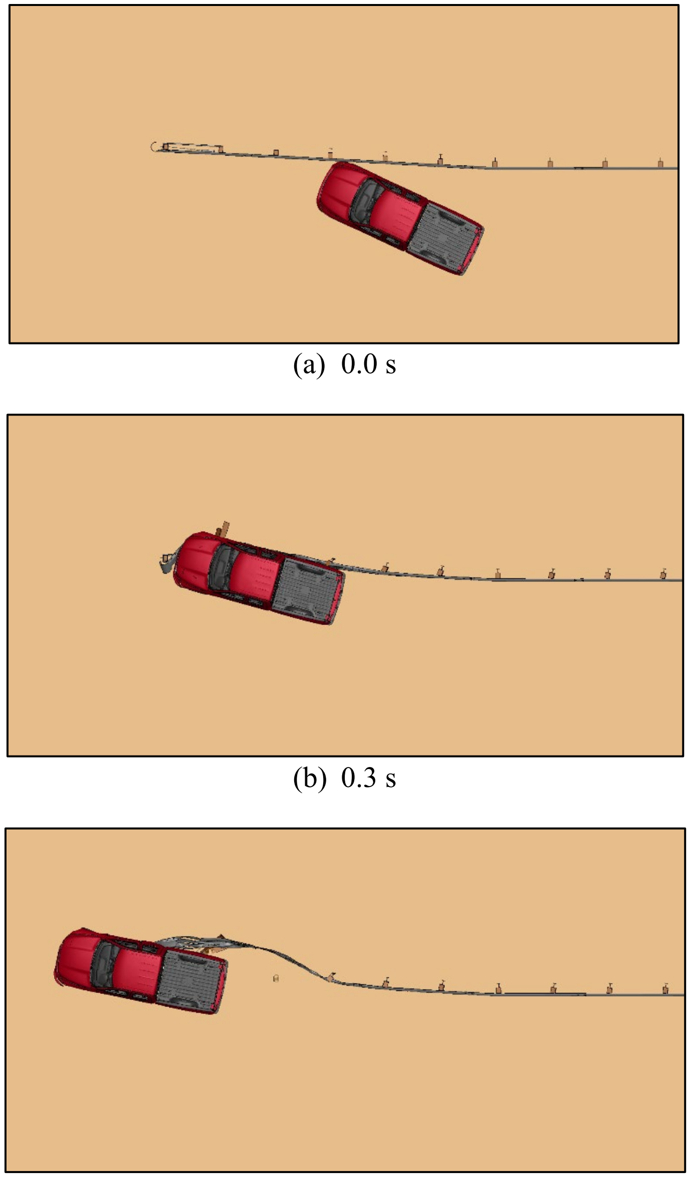
Figure 13.12. Flared Terminal Test 2-37a Simulation CIP01 Sequential Images (Downstream View).

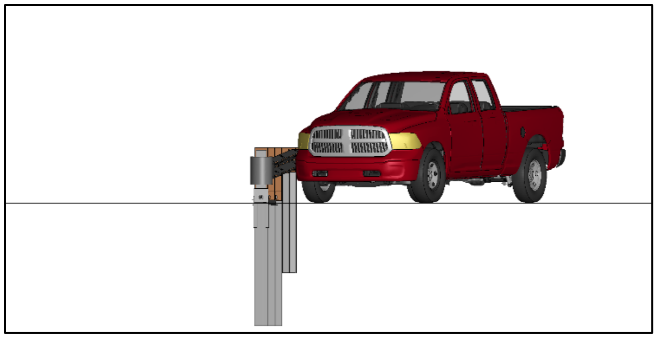


(a) 0.0 s

(b) 0.3 s

(c) 0.6 s

Figure 13.13. Flared Terminal Test 2-37a Simulation CIP02 Sequential Images (Overhead View).



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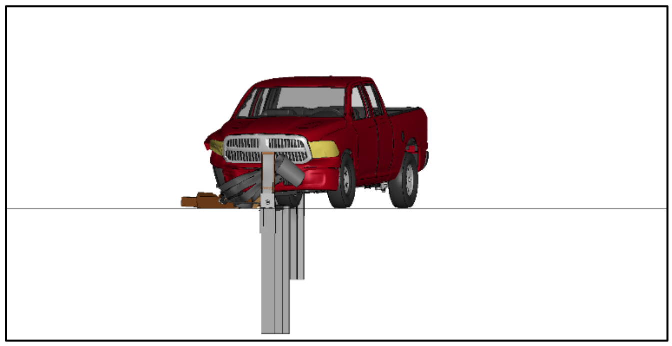

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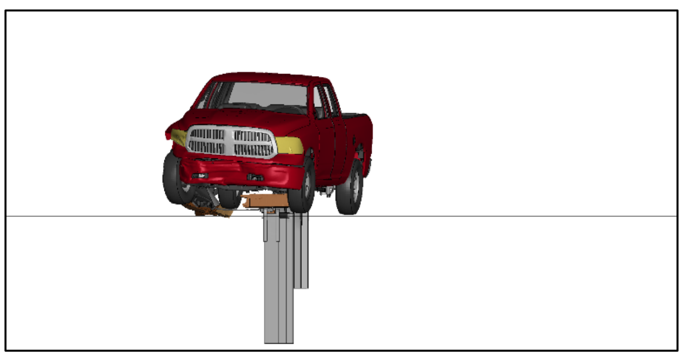

(c) 0.6 s

Figure 13.14. Flared Terminal Test 2-37a Simulation CIP02 Sequential Images (Downstream View).

Table 13.6. Flared Terminal Test 2-37a Simulation Occupant Risk.

Impact Location	OIV Longitudinal (m/s)	OIV Lateral (m/s)	ORA Longitudinal (g)	ORA Lateral (g)	Max. Roll (deg)	Max. Pitch (deg)	Max. Yaw (deg)
6 inches u/s post 2	3.2	1.4	1.8	1.9	−5.0	−3.0	5.0
92 inches u/s post 2	3.5	2.8	9.3	5.5	−4.0	2.8	−14.0

Note: u/s = upstream.

13.8. DISCUSSION

These test conditions are considered non-critical for the TL-2 terminal developed under this project, as detailed earlier in this chapter. Nevertheless, nonlinear FE simulations were conducted with the same models used to predict the testing in Chapter 4. These simulations indicated that the TL-2 terminal design passes *MASH* evaluation criteria for the non-critical tests presented herein.

Chapter 14. SUMMARY AND CONCLUSIONS

14.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-2 on the TL-2 W-beam end terminal. The tables at the end of this chapter provide an assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-2 gating terminals. Table 14.1 provides a summary of all test results for project 615181-01 in chronological order.

Table 14.1. Summary of Tests in Numerical Order.

Test Date	TTI Test No. 615181-01	*MASH* Test No.	Vehicle Class	Notes or Outcome
8/31/2021	-1	2-32	1100C	Developmental
9/2/2021	-2	2-30	1100C	Developmental
2/16/2022	-3	2-31	2270P	Developmental
7/20/2022	-4	2-30	1100C	*Failed due to Rollover*
9/9/2022	-5	2-35	2270P	**Pass**
9/14/2022	-6	2-30	1100C	*Failed due to Penetration*
9/20/2022	-7	2-30	1100C	*Failed due to Penetration*
4/6/2022	-8	2-35	2270P	Developmental
2/11/2022	-9	2-30	1100C	Developmental
12/15/2021	-10	2-30	1100C	Developmental
10/6/2022	-11	2-30	1100C	**Pass**
10/11/2022	-12	2-31	2270P	**Pass**
10/20/2022	-13	2-37b	1100C	**Pass**

14.2. CONCLUSIONS

Table 14.2 shows that the TL-2 W-beam end terminal met the performance criteria for *MASH* Tests 2-35, 2-30, 2-31, and 2-37b for gating terminals.

Table 14.2. Assessment Summary for *MASH* TL-2 Tests on TL-2 W-beam End Terminal.

Evaluation Criteria[a]	Description	Test No. 615181-01-5 *MASH* 2-35	Test No. 615181-01-11 *MASH* 2-30	Test No. 615181-01-12 *MASH* 2-31	Test No. 615181-01-13 *MASH* 2-37b
A	Contain, redirect, or controlled stop	S	N/A	N/A	N/A
C	Redirect, controlled penetration, or controlled stop	N/A	S	S	S
D	No penetration into occupant compartment	S	S	S	S
F	Roll and pitch limit	S	S	S	S
H	OIV threshold	S	S	S	S
I	Ridedown threshold	S	S	S	S
N	Trajectory behind is acceptable	N/A	S	S	S
Overall Evaluation	Results Per Test	Pass	Pass	Pass	Pass

[a] See Table 6.2 for details.
Note: S = Satisfactory; N/A = Not Applicable.

14.3. ENGINEERING OPINION ON THE RESULTS OF *MASH* TESTING*

MASH Tests 2-32 and 2-33 are specified with an angle from 5 to 15 degrees with the roadway, which makes them less critical than *MASH* Tests 2-30 and 2-31 that have 0-degree angles with the roadway. Without a terminal head, the vehicle would not engage much of the system other than the first post. *MASH* states that "However, gating redirective systems are designed to allow a vehicle to penetrate behind the system, and increasing the lateral load on the device will likely accentuate the gating process. Therefore, gating redirective terminals and crash cushions should be tested at much lower impact angles, closer to the 5-dgree minimum values." Thus, *MASH* Tests 2-32 and 2-33 are considered non-critical since the design of this system does not incorporate a head at the terminal end for a vehicle to trip on, accentuate the gating process, or present potential for subsequent dynamic instability. Both *MASH* Tests 2-30 and 2-31 were tested in this project and passed *MASH* evaluation criteria. Nevertheless, the research team conducted FE simulations for the *MASH* 2-32 and 2-33 tests, incorporating both ends of the impact angle range. These simulations, presented previously in this report, showed that the system performance meets the evaluation criteria of *MASH*.

MASH Test 2-34 involves the small car redirecting at a 15-degree impact angle. This test is considered non-critical since the system was able to redirect the pickup test vehicle at the more acute impact angle of 25 degrees per *MASH* 2-35 conditions. The *MASH* 2-35 test was physically performed under this project, and the system was able to redirect the vehicle while meeting required *MASH* evaluation criteria. Thus, a redirective impact with a lesser mass vehicle and shallower impact angle is not expected to be more critical than the one (*MASH* 2-35) tested. As an additional check, the research team performed FE simulation of the *MASH* 2-34 test, and the results of the simulation were passing when assessed per *MASH* evaluation criteria. The impact location of the *MASH* 2-35 test was post number 5. The same impact point was used for the simulation of *MASH* 2-34 test. The testing of *MASH* 2-35 and the simulation of *MASH* 2-34 resulted in the vehicle being redirected. Hence, the beginning of the length of need (LON) for this system is defined to be post number 5.

Finally, *MASH* Test 2-37b (car) is considered the critical test since *MASH* states the following: "For post-and-beam terminals utilizing a breakaway cable system, the 1100C will generally be the critical vehicle for this test, and the impact point should be selected to maximize the risk of the vehicle snagging on the anchor cable." The car test (*MASH* 2-37b) was physically performed, and the outcome was passing per *MASH* evaluation criteria. Moreover, the research team performed FE simulations for the pickup truck test, *MASH* 2-37a, using two different impact conditions, as presented earlier, and each of these simulations resulted in acceptable performance per *MASH* evaluation criteria.

This terminal design does not have a special head component and utilizes the slotting in the rail elements to incorporate several innovative and easy-to-implement features:

- An open slot at the end of the first rail element to reduce tensile loading on the first post.
- Two support angle sections to better hold the bearing plate and transfer its load to the foundation tube.

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

- A pull plate at the upstream face of the first post to facilitate the release of the cable anchor during impacts engaging the first post, such as head-on and reverse impacts.
- A crown nut at the end of the cable anchor threaded rod to prevent the rod end from engaging and cutting the sheet metal of the vehicle.
- Rounded posts at the top of the first five steel posts to reduce sharp post corners interacting with the vehicle undercarriage.
- An upstream-facing trapezoidal wood block to provide separation between the post flanges and the vehicle undercarriage. This trapezoidal is made from high-quality wood, and options such as dense rubber or high-density polyethylene should provide a similar function if desired.
- The rail is not attached to post number 3 and post number 7.

It should be noted that the details of the first installation of this system that was tested under *MASH* 2-35 conditions did not include the post rounding, the trapezoidal wood block, nor the crown nut. The pull plate was $^{3}/_{16}$ inch which is thicker than the ⅛ inch pull plate used in later tests. These design modifications do not affect the performance of the system under *MASH* 2-35 since these innovative modifications interact with the vehicle only when the vehicle impacts the system in a way to release the cable such as head-on or reverse impact. These innovative modifications are meant for such impacts without affecting the system performance under re-directive impact conditions.

This system was evaluated through both testing and simulations to *MASH* TL-2 and is intended for low-speed roadways where the encroachment speed is 45 mi/h or less. Furthermore, this terminal is compatible with aesthetic coatings such as powder coating and stain.

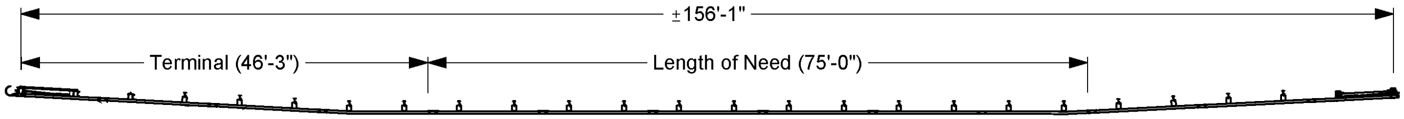
REFERENCES

1. AASHTO. *Manual for Assessing Roadside Safety Hardware*, Second Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2016.
2. Arnold, A. G., Menges, W. L., and Butler, B. G. *Testing and Evaluation of the Vermont W-Beam Guardrail Terminal for Low Speed Areas.* Report No. 473080-1. Texas Transportation Institute, College Station, TX, 1998.
3. Hirsch, T. J., Dolf, T. J., and Arnold, A. G. *Maryland Turned-Down Guardrail Terminal*. Texas Transportation Institute, College Station, TX, 1982.
4. Mak, K. K., Ross, H. E., Bligh, R. P., and Menges, W. L. NCHRP Report 350 Testing of W-Beam Slotted-Rail Terminal. *Transportation Research Record*, 1599(1), 22–31, 1997.
5. *LS-DYNA Keyword User's Manual, Volume 1 R11*. Livermore Software Technology Company (LSTC), Livermore, CA, 2018.

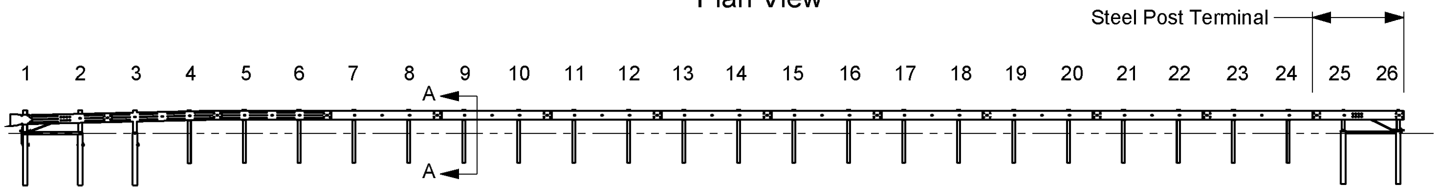
APPENDIX A. DETAILS OF TL-2 W-BEAM END TERMINAL

A.1. DRAWINGS FOR CRASH TEST 615181-01-5

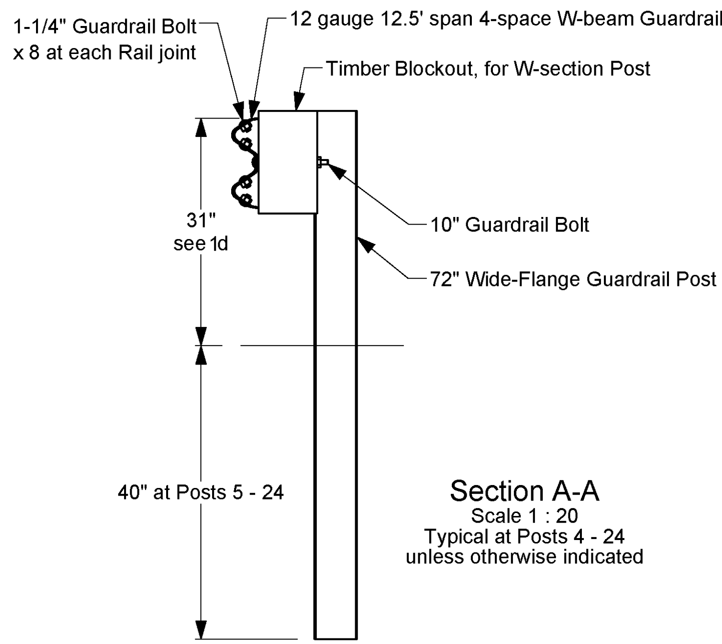
Test Installation



Plan View



Elevation View



Section A-A
Scale 1 : 20
Typical at Posts 4 - 24
unless otherwise indicated

1a. Backfill Post holes with Type D grade 1 crushed concrete road base or crushed limestone (see test information), compacted according to TTI Proving Ground Work Instruction WI-C001.

1b. All bolts are ASTM A307 unless othewise indicated. Recessed Guardrail Nut on all Button-head Guardrail Bolts and 5/8 Hex Head bolts. F844 Washer under the head of all Hex Head Bolts.

1c. All steel parts shall be galvanized.

1d. 31" rail height is typical at posts 5-26, and varies at posts 1-4 (see next sheet).

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 Aug TL-2 Guardrail Terminal		2022-09-06
Drawn by GES	Scale 1:200	Sheet 1 of 7 Test Installation

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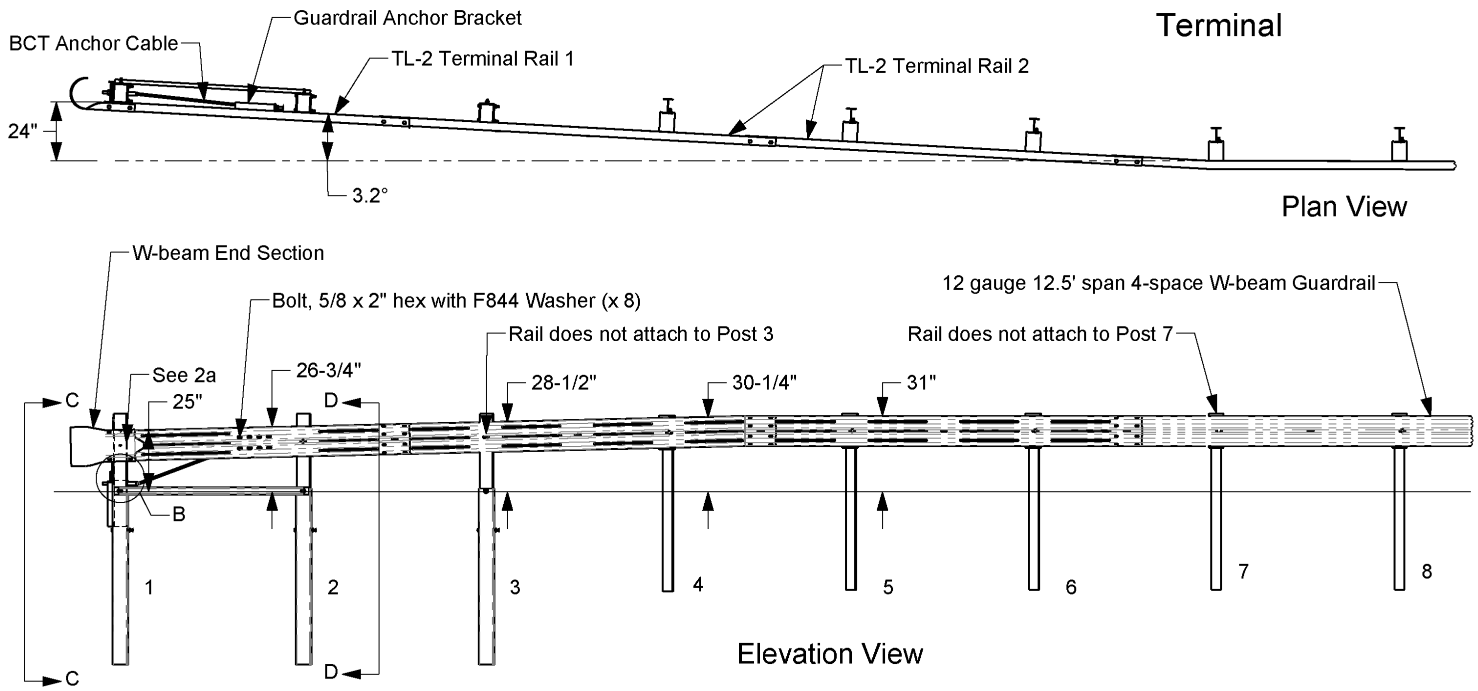

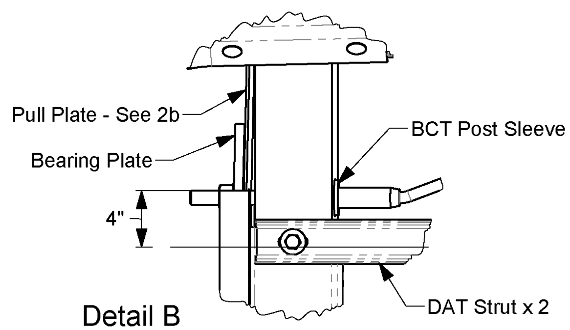

Detail B
Scale 1 : 10

2a. Ø7/8" hole at 13" from the top of Post 1 and 11-1/4" from the top of Post 2.
Dimensions near Posts 1-5 indicate rail heights at posts.
2b. Pull Plate is over angles on Modified Foundation Tube and under Bearing Plate.
2c. Cross sections are on next sheet.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 Aug TL-2 Guardrail Terminal		2022-09-06
Drawn by GES	Scale 1:60	Sheet 2 of 7 Terminal

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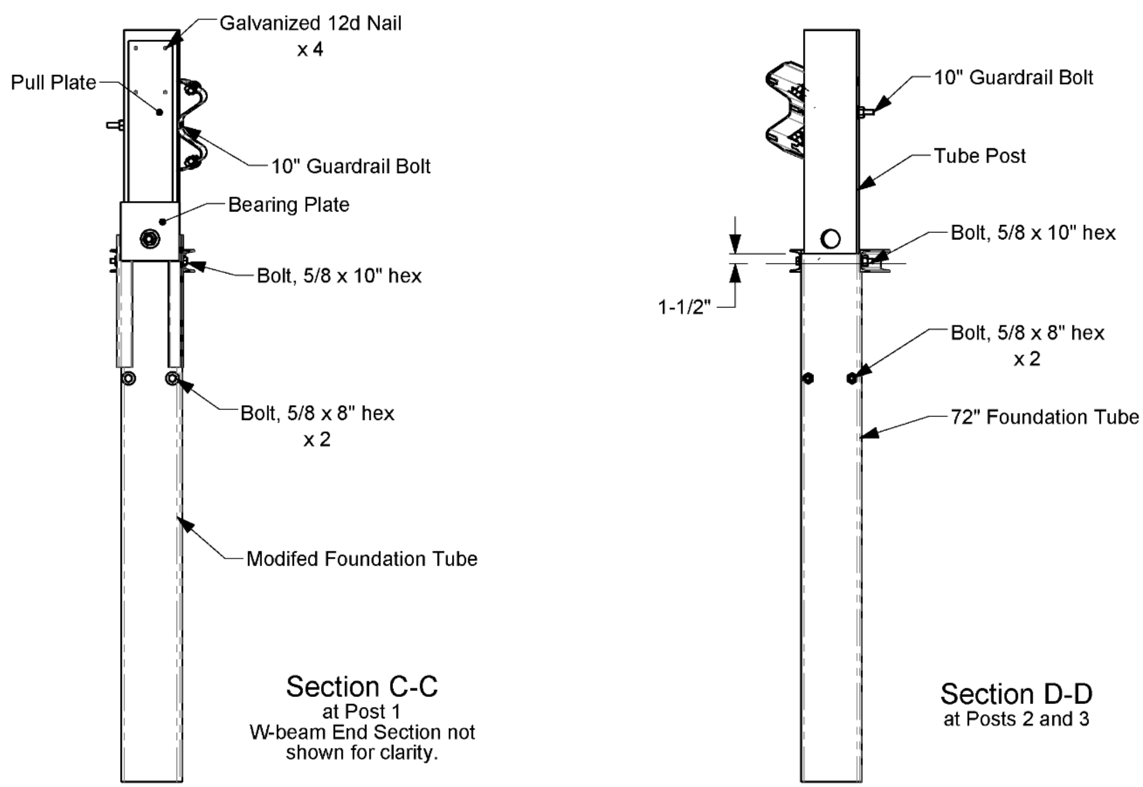
Terminal Section Views



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 Aug TL-2 Guardrail Terminal		2022-09-06
Drawn by GES	Scale 1:20	Sheet 3 of 7 Terminal Section Views

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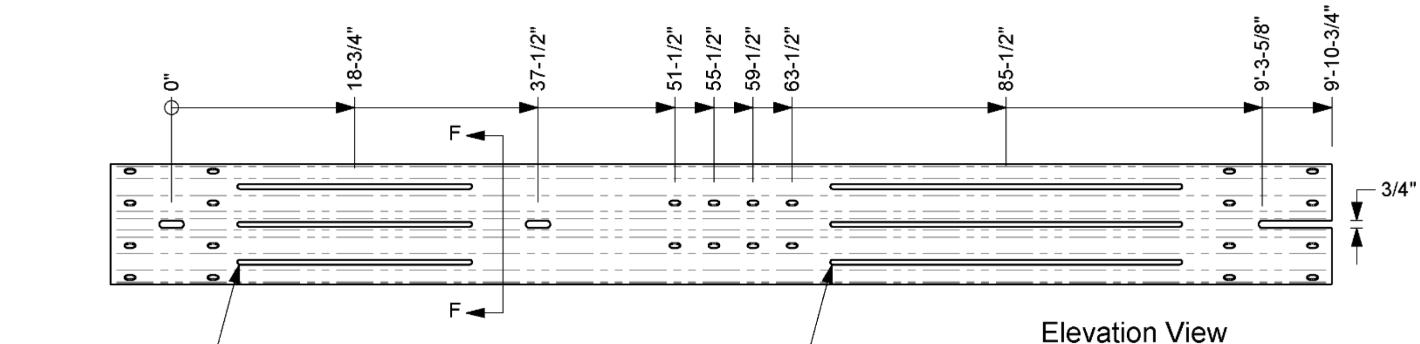
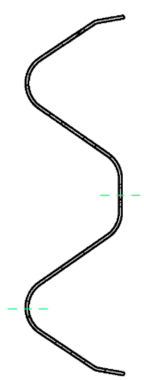
TL-2 Terminal Rail 1

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



Elevation View



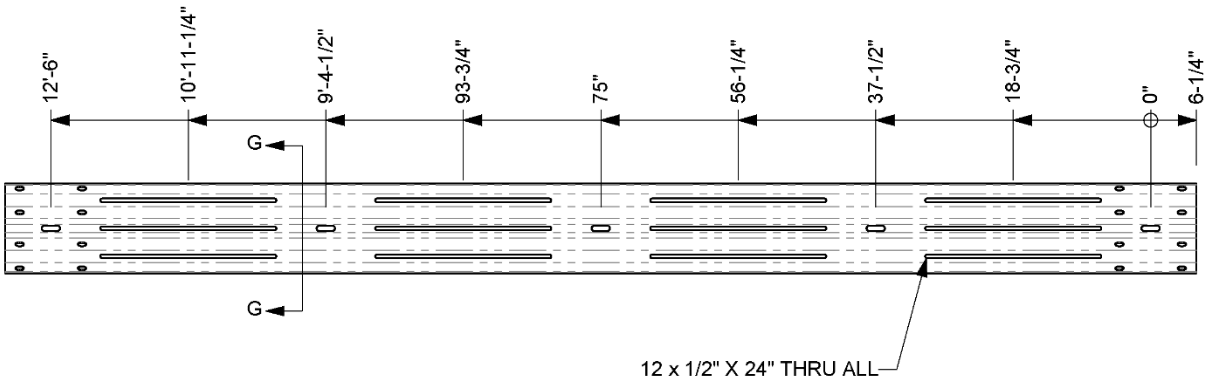
Section F-F
Scale 1 : 5

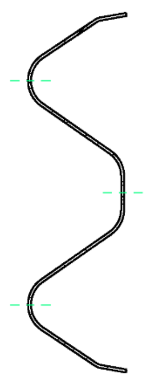
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 Aug TL-2 Guardrail Terminal		2022-09-06
Drawn by GES	Scale 1:15	Sheet 4 of 7 TL-2 Terminal Rail 1

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept\615181 Sep Drawing

TL-2 Terminal Rail 2

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

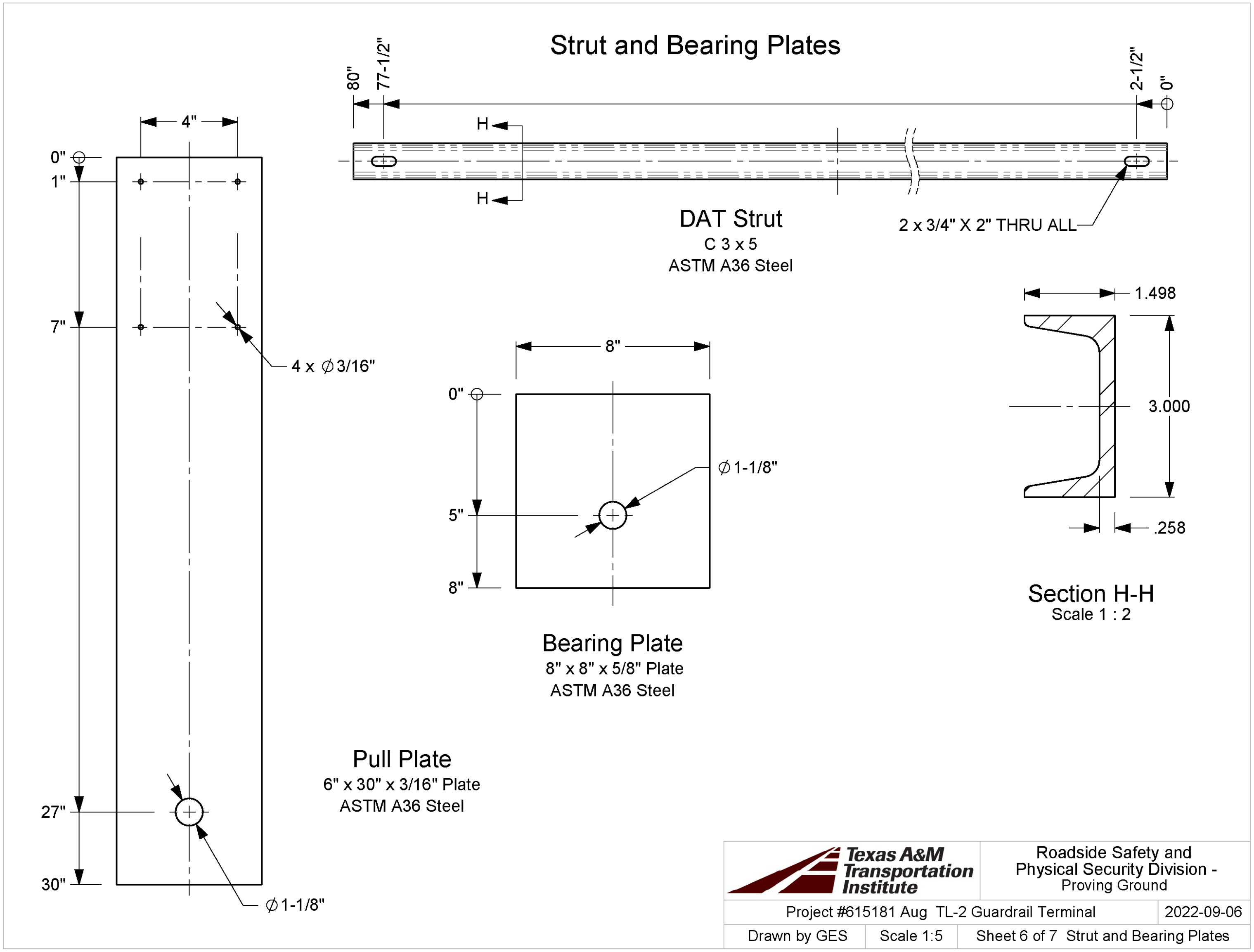




Section G-G
Scale 1 : 5

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 Aug TL-2 Guardrail Terminal		2022-09-06
Drawn by GES	Scale 1:20	Sheet 5 of 7 TL-2 Terminal Rail 2

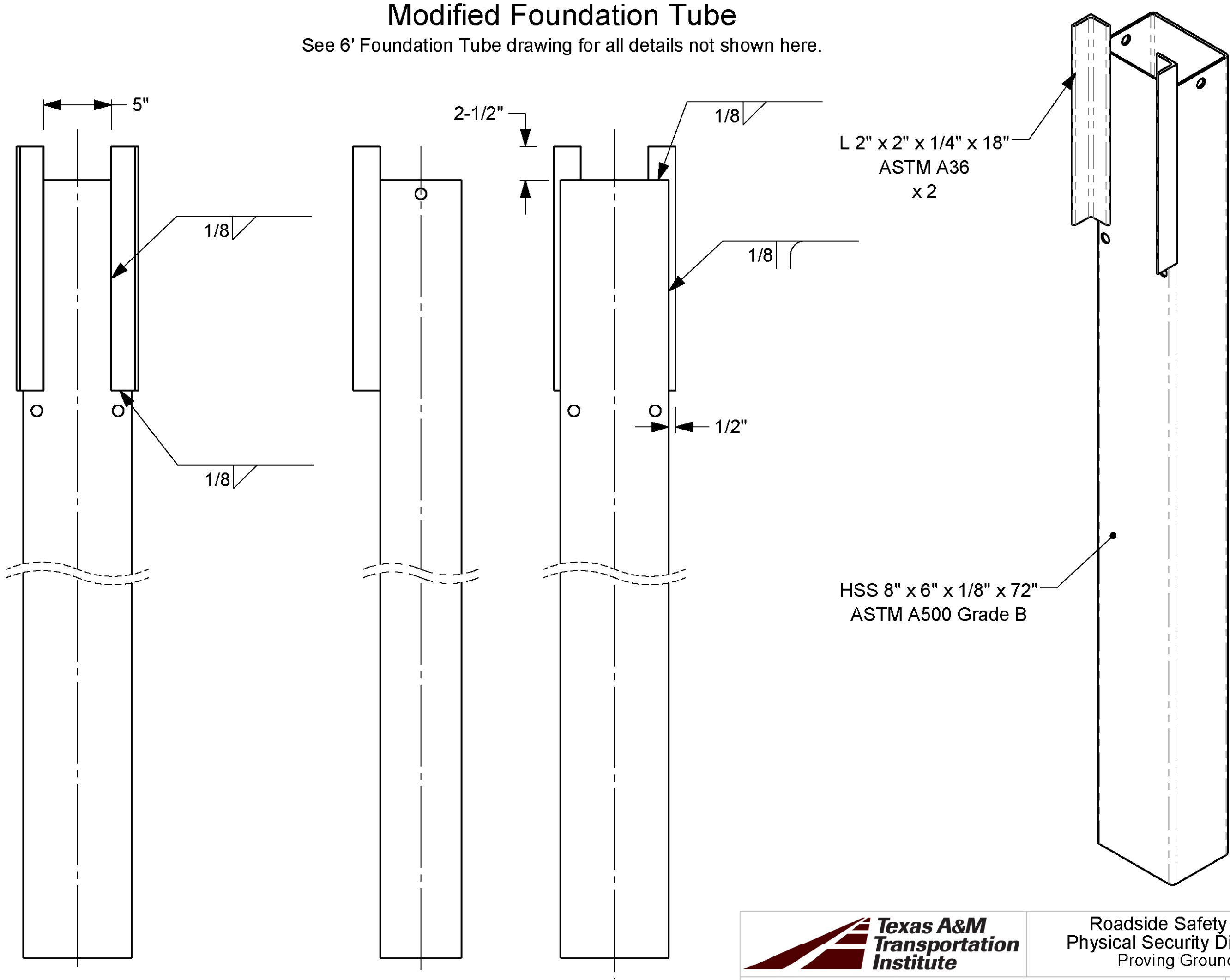
Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept\615181 Sep Drawing



Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept\615181 Sep Drawing

Modified Foundation Tube

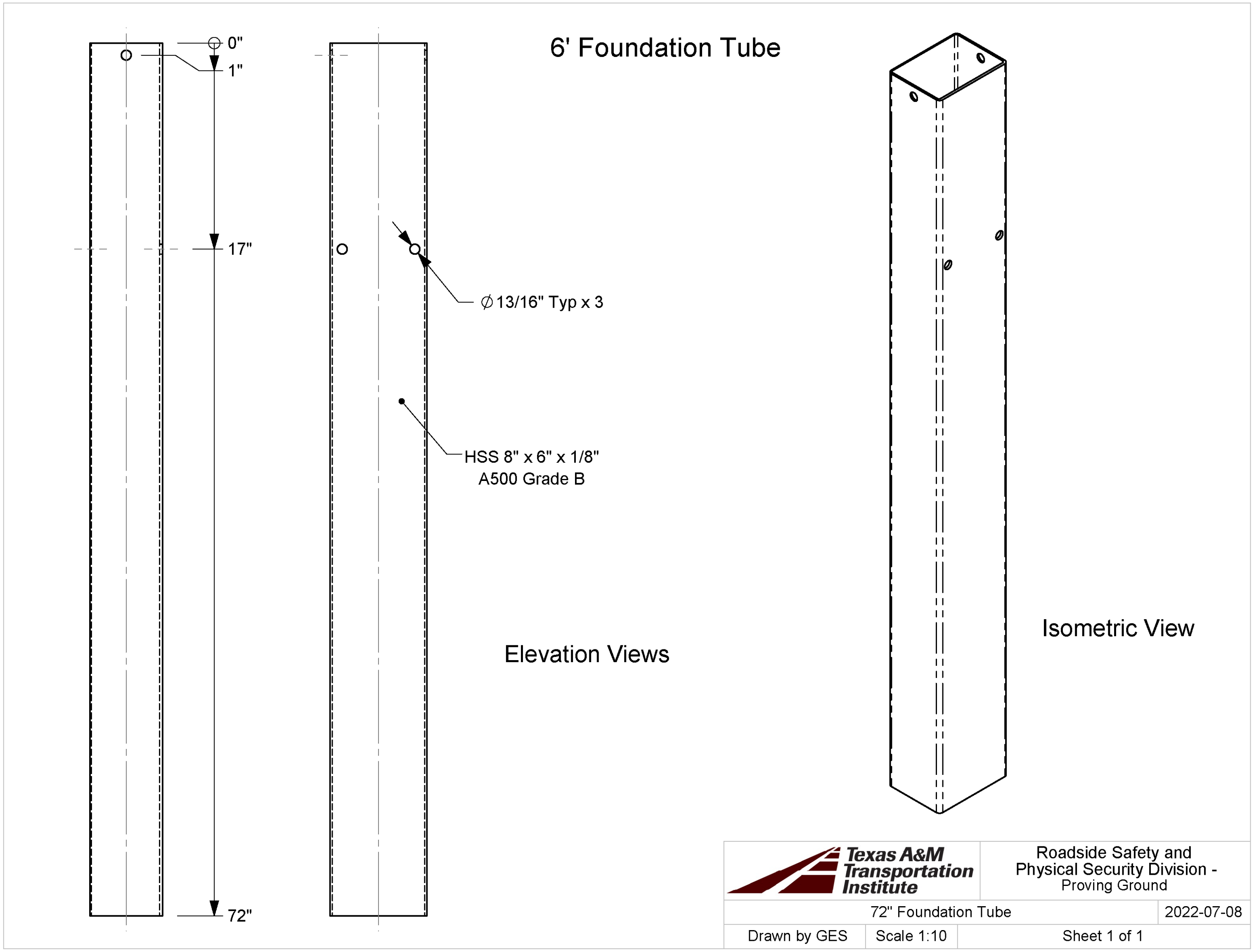
See 6' Foundation Tube drawing for all details not shown here.



Elevation Views

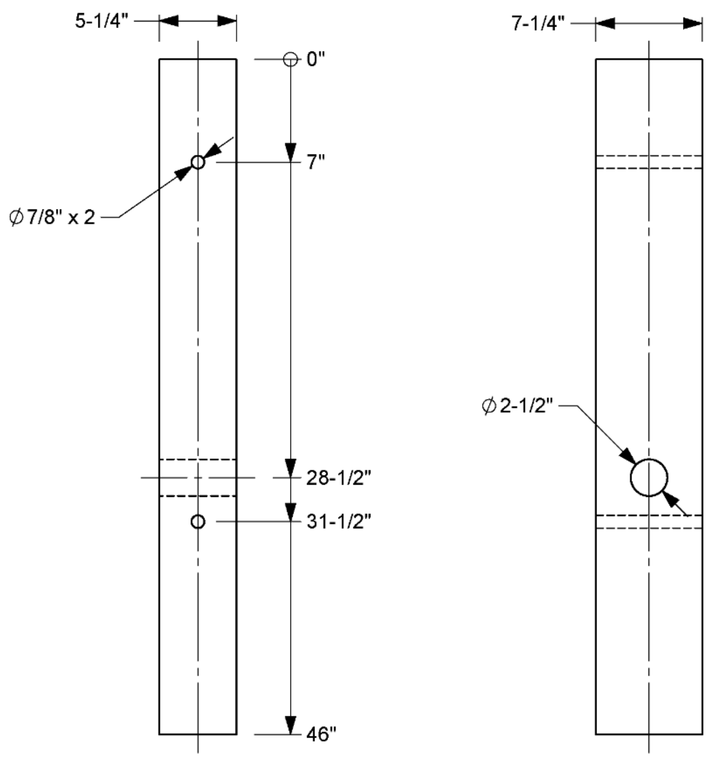
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 Aug TL-2 Guardrail Terminal		2022-09-06
Drawn by GES	Scale 1:10	Sheet 7 of 7 Modified Foundation Tube

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept\615181 Sep Drawing



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

Post, Tube



Elevation Views

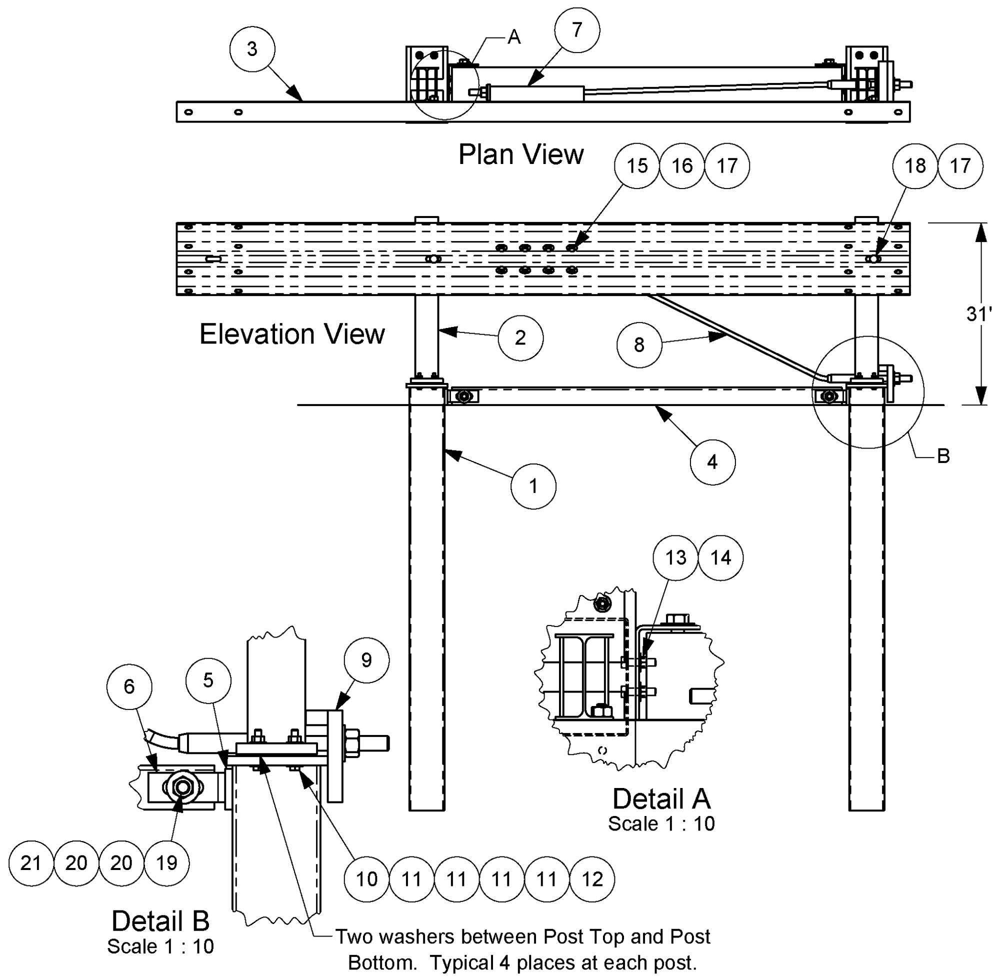
1a. Timber posts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Tube Post			2022-07-08
Drawn by GES	Scale 1:10	Sheet 1 of 1	

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

Terminal Details

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

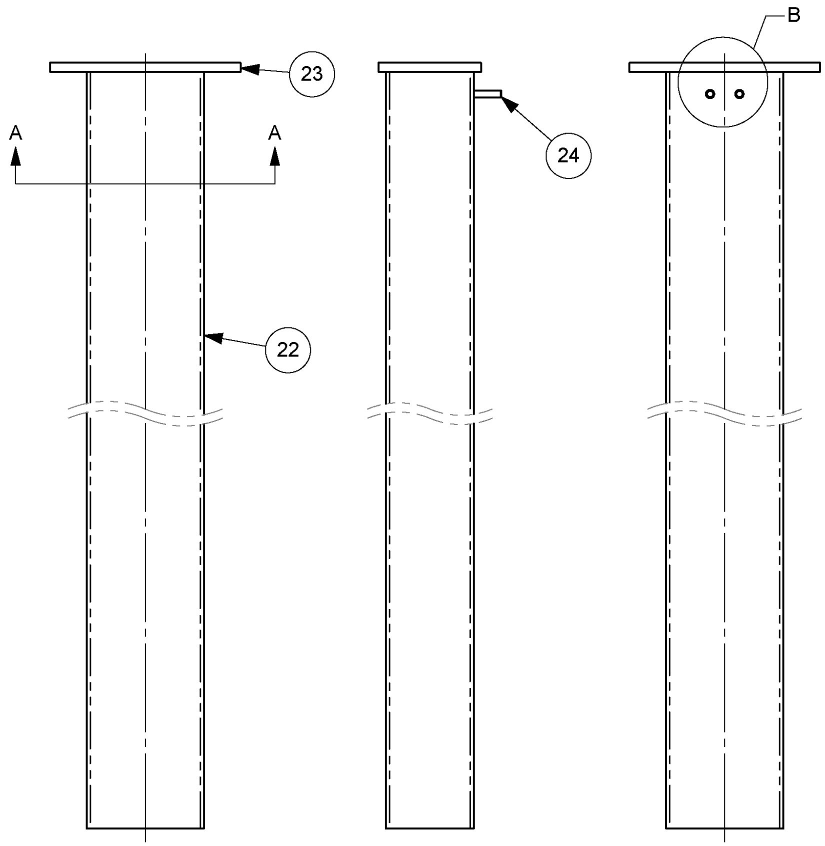


1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.
1c. All steel parts shall be galvanized.

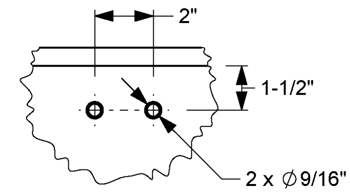
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal			2022-07-08
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details	

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

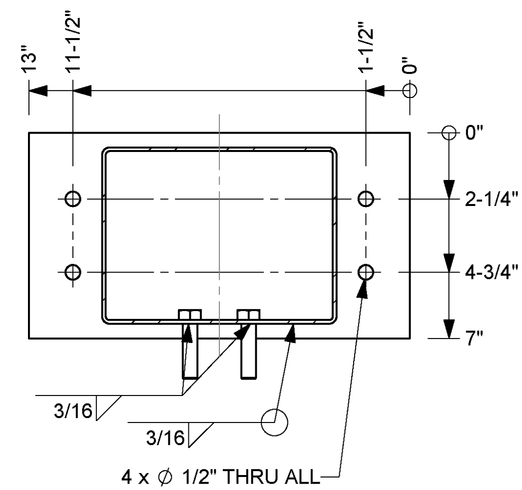
Post Bottom



Elevation Views



Detail B
Scale 1 : 5

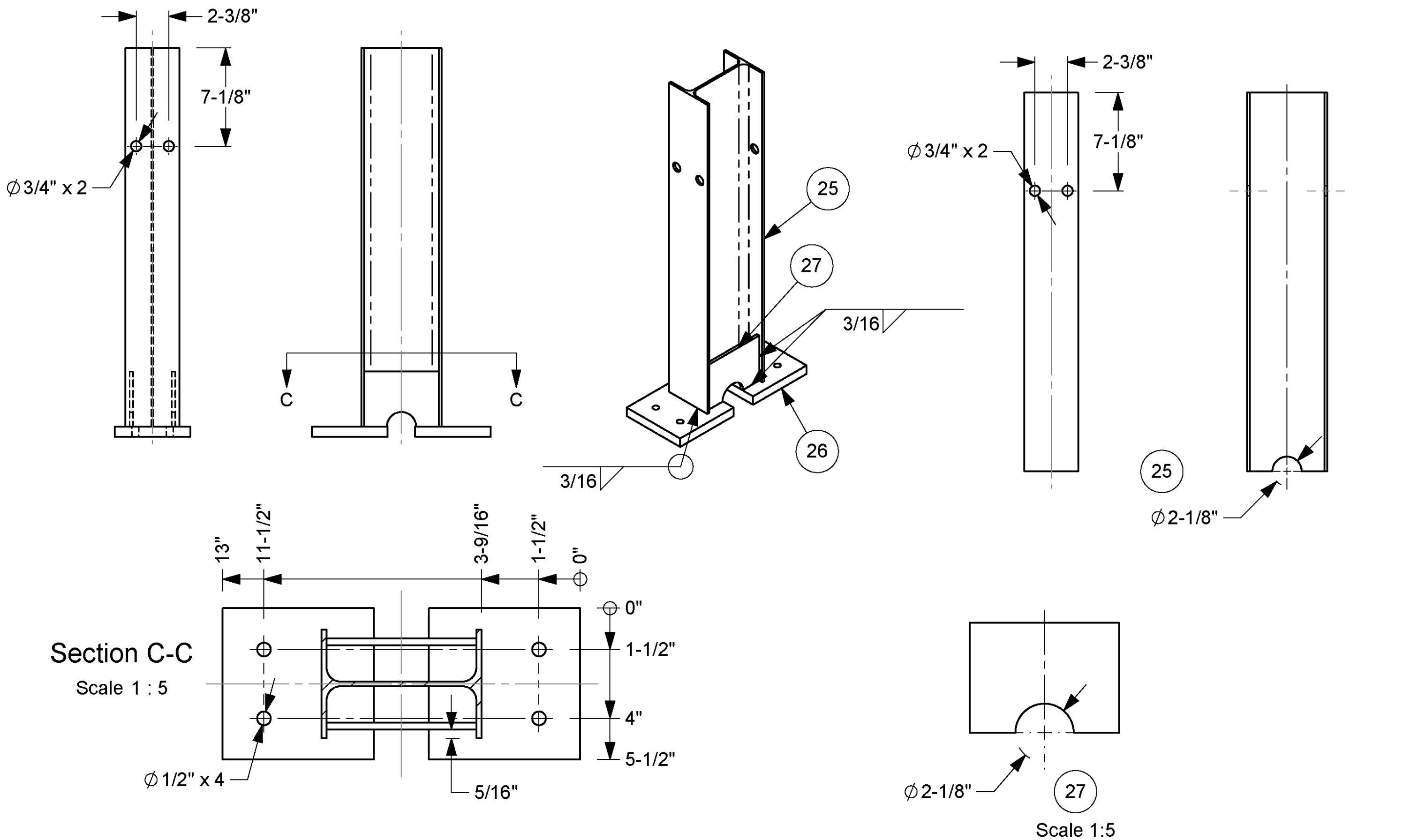


Section A-A
Scale 1 : 5

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

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
	Project # Terminal		2022-07-08
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom	

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



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

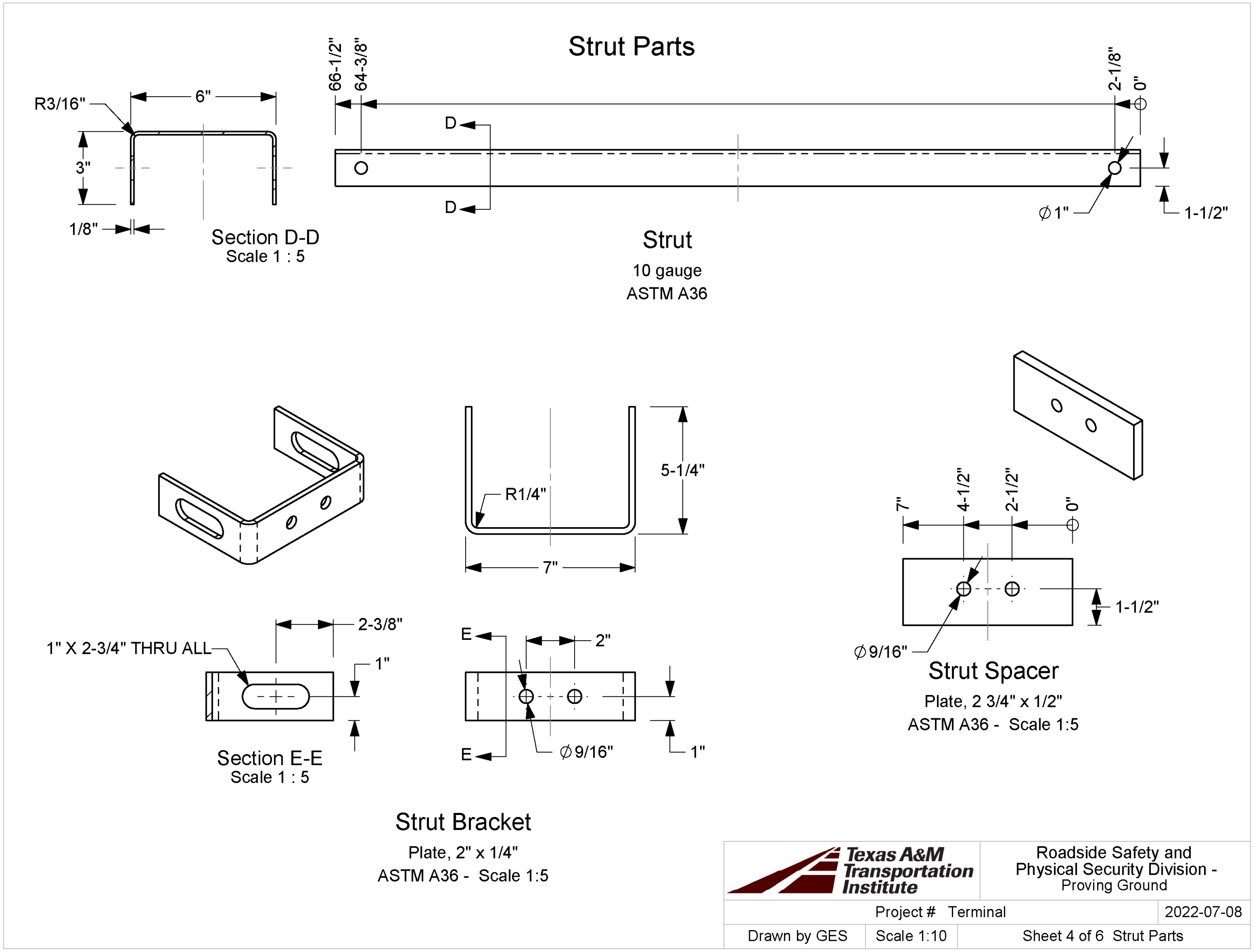
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

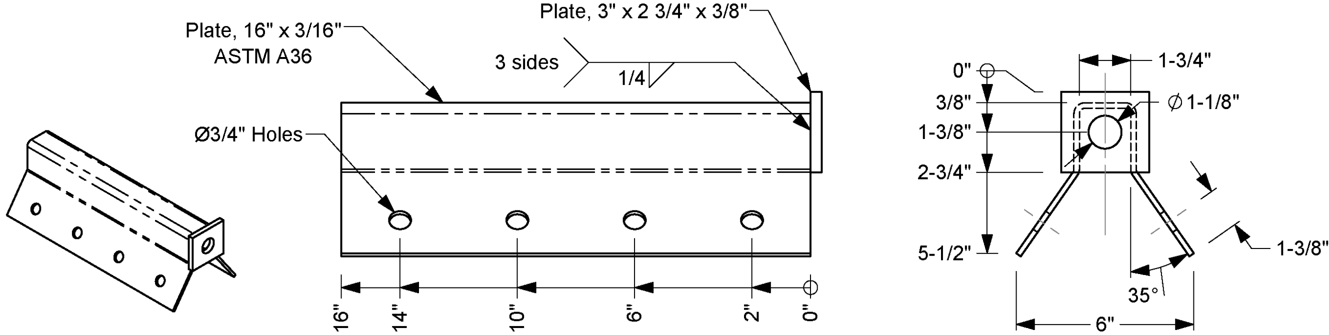
Project # Terminal 2022-07-08

Drawn by GES | Scale 1:10 | Sheet 3 of 6 Post Top

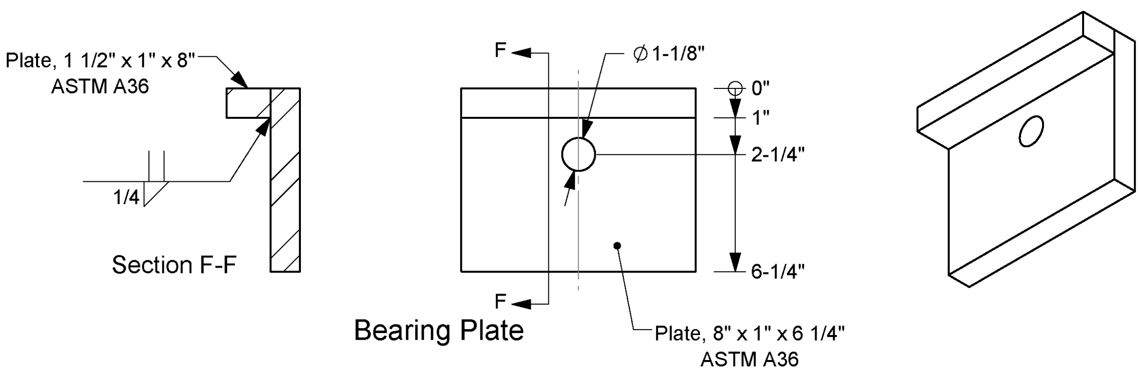
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal



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



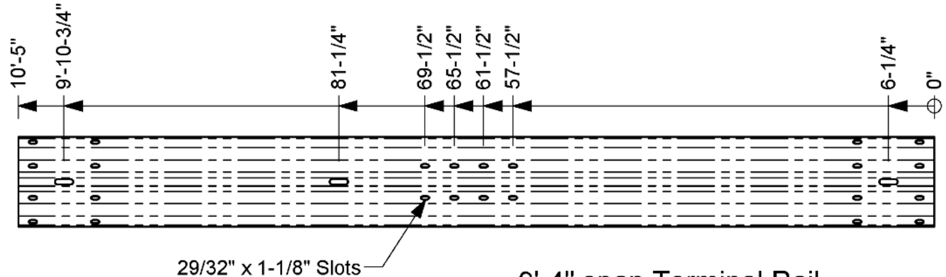
Guardrail Anchor Bracket



Bearing Plate

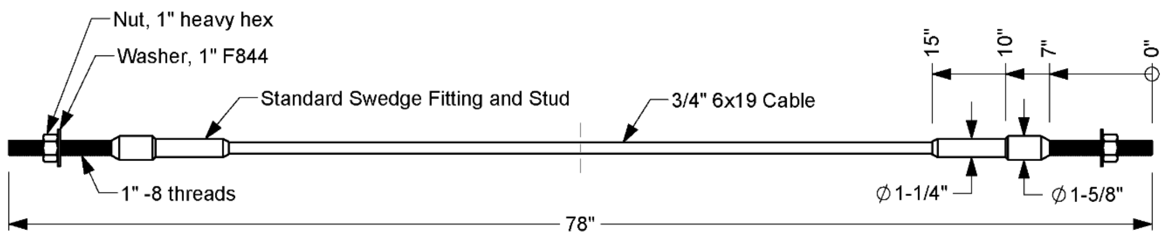
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal			2022-07-08
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A	

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



9'-4" span Terminal Rail

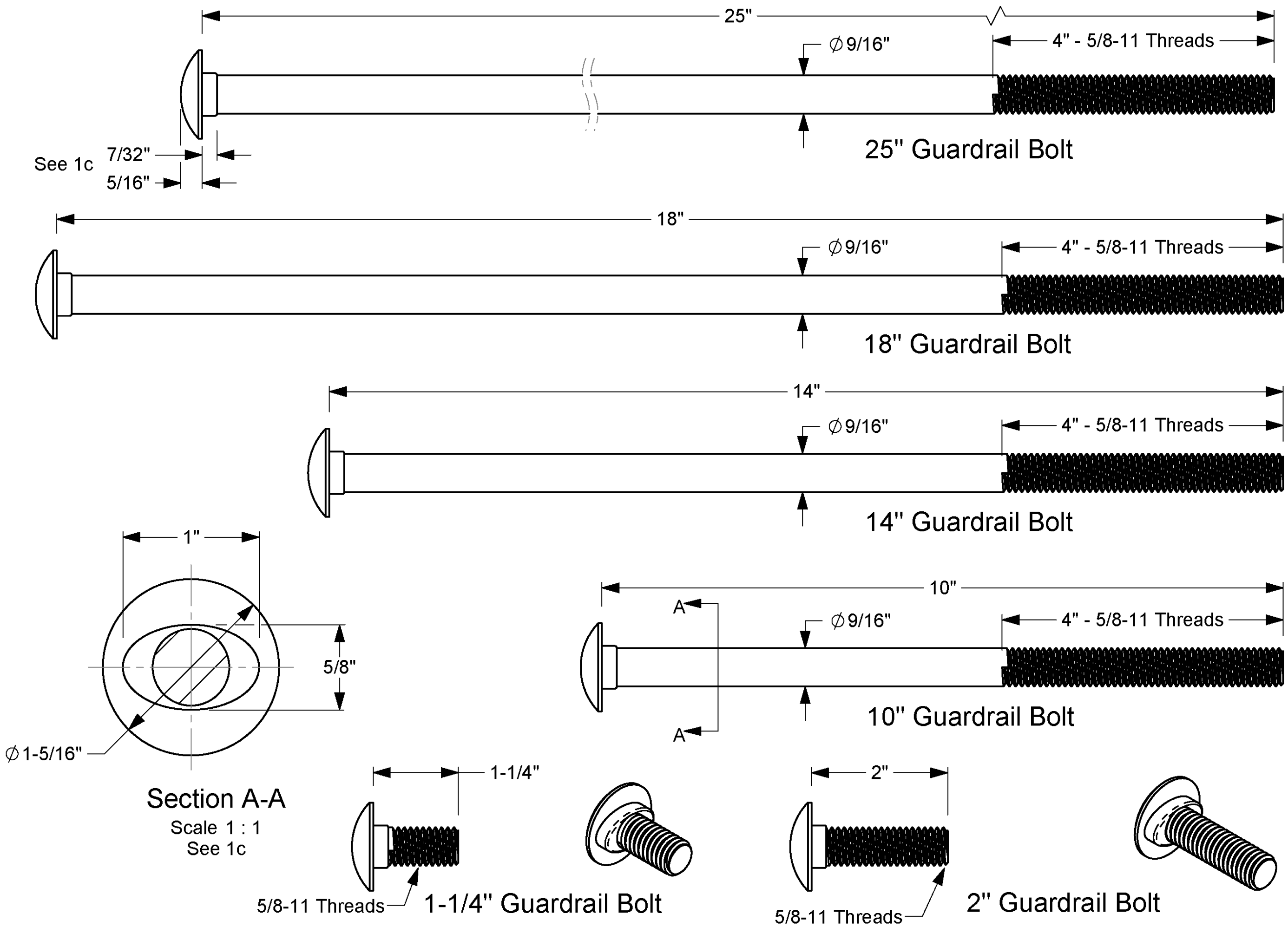
Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.



Anchor Cable Assembly

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal		2022-07-08
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B

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



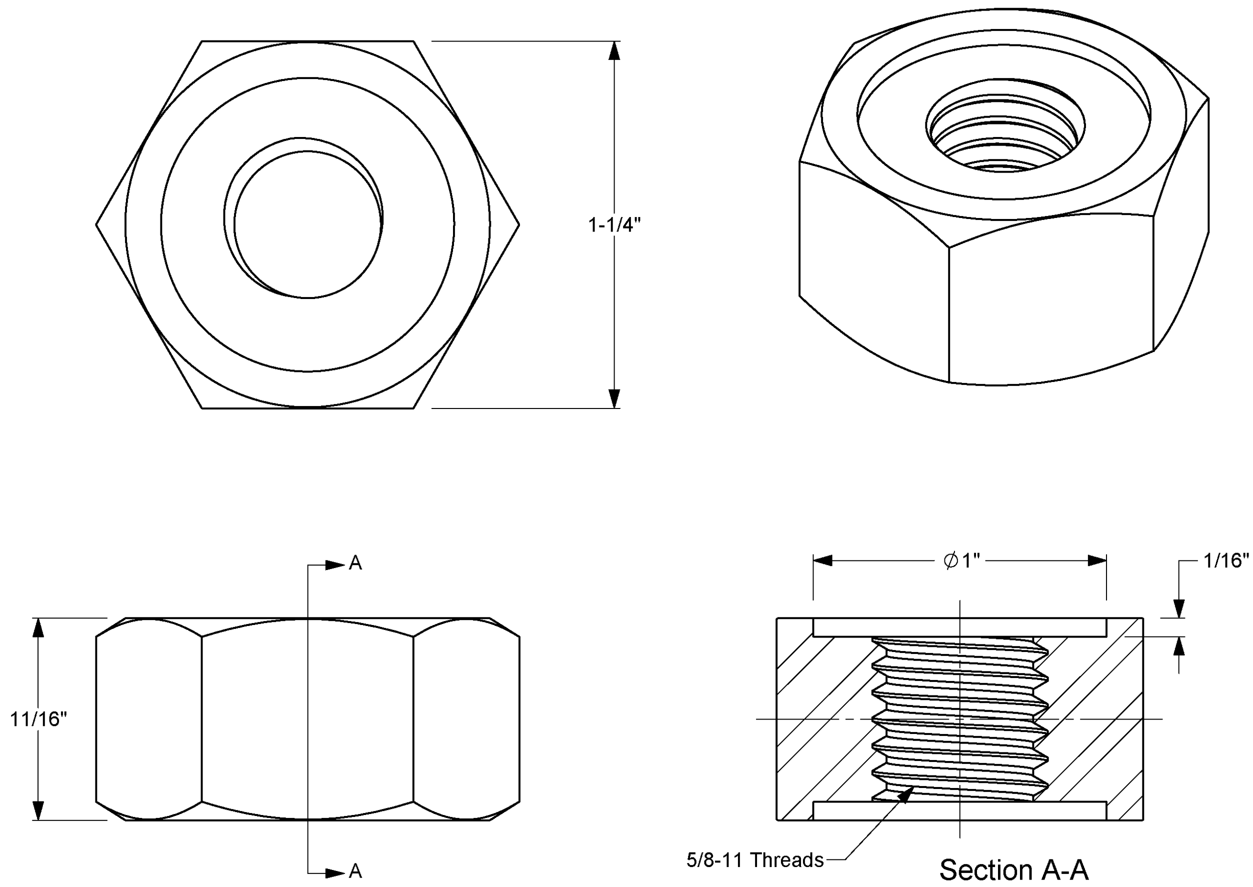
Section A-A
Scale 1 : 1
See 1c

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

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Guardrail Bolt		2020-07-08
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

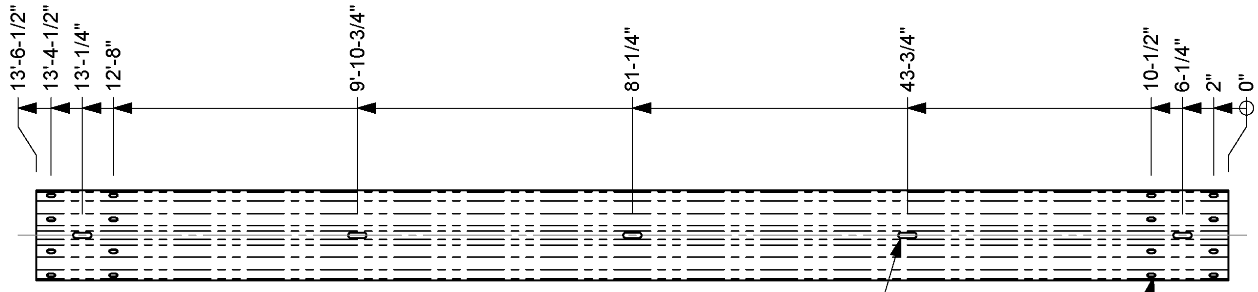
Recessed Guardrail Nut



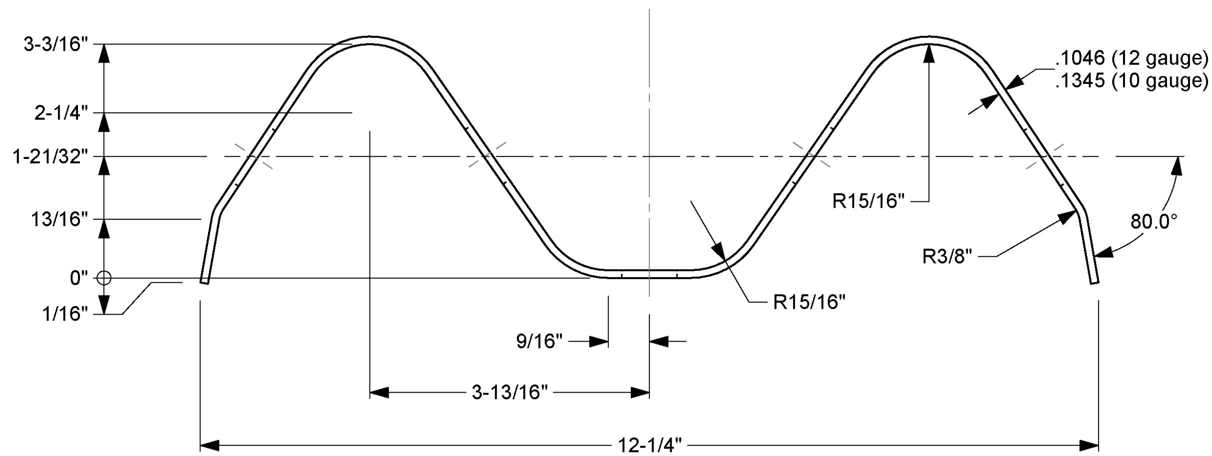
1a. Material is ASTM A 563 Grade A.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Recessed Guardrail Nut		2022-07-18	
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



Elevation View



Section View

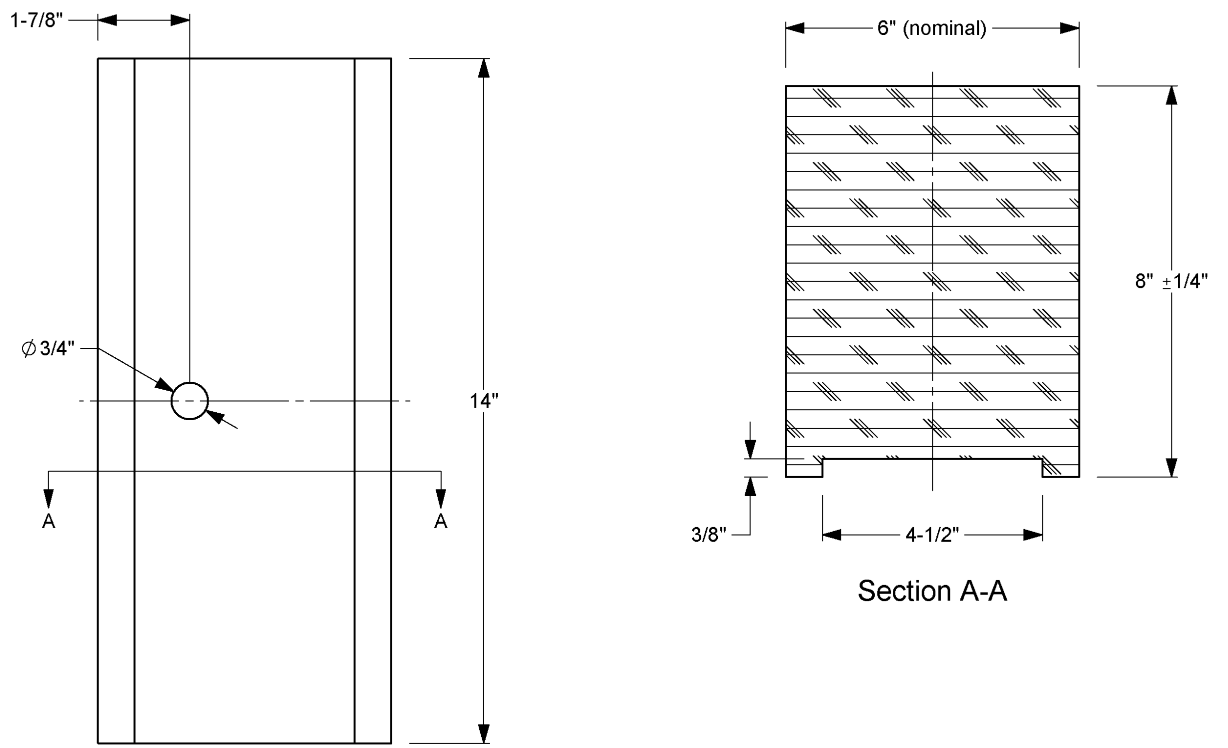
1a. Manufacture per AASHTO M180 specifications.

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

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
W-beam Guardrail			2022-07-13
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

Timber Blockout for W-section Post



Elevation View

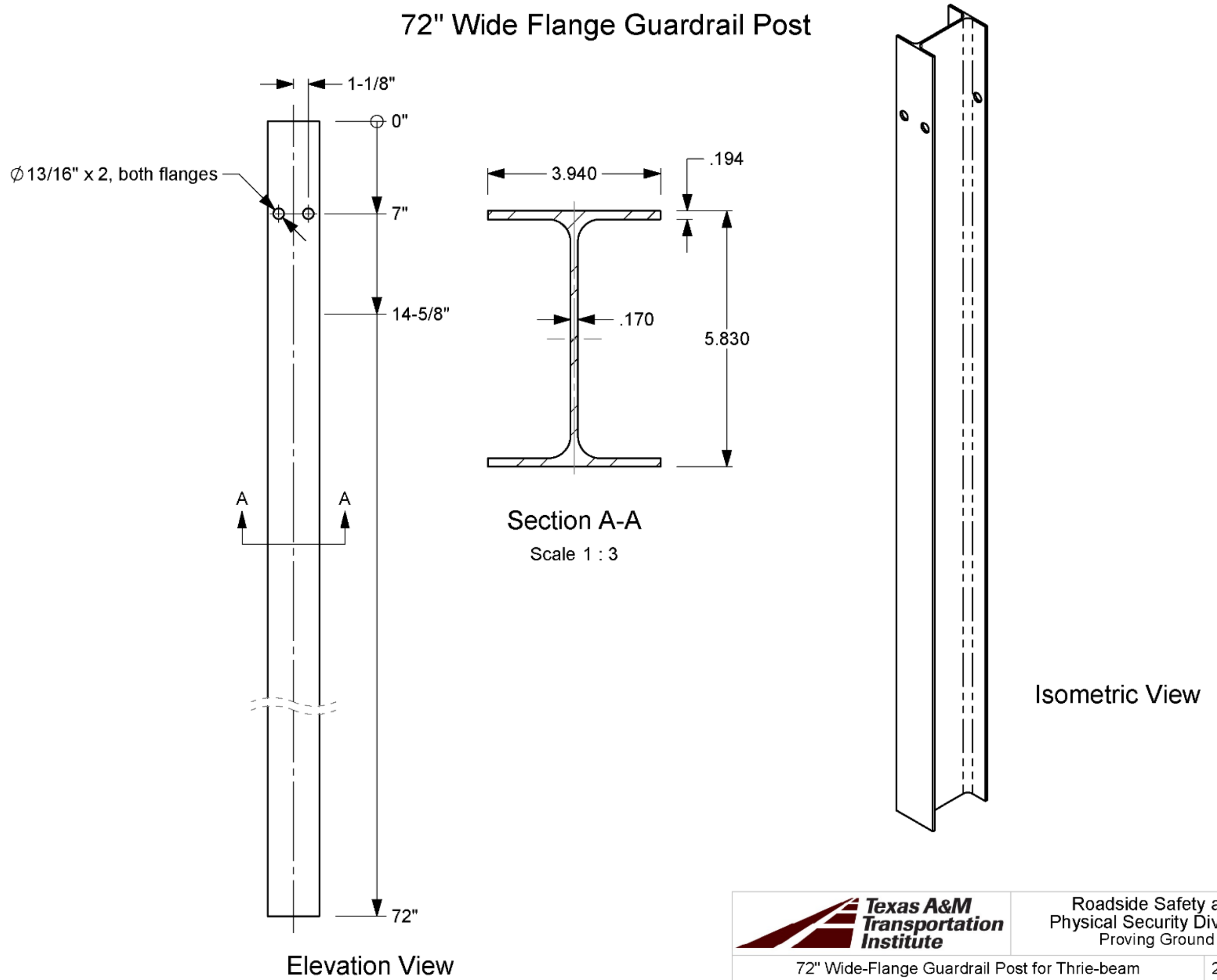
Section A-A

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			2022-07-08
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

72" Wide Flange Guardrail Post

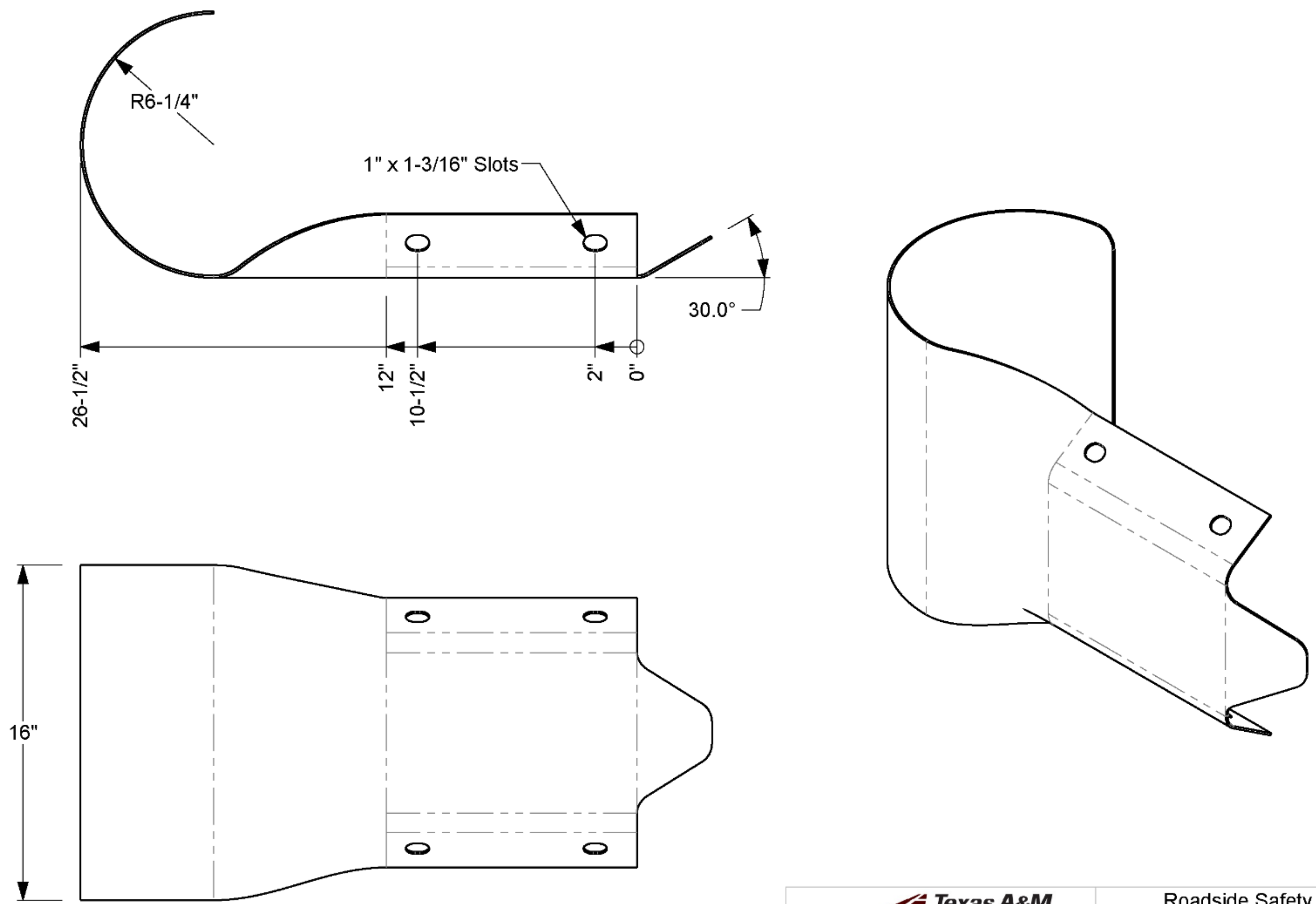


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
72" Wide-Flange Guardrail Post for Thrie-beam		2022-07-08
Drawn by GES	Scale 1:10	Sheet 1 of 1

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

W-beam End Section

12 gauge galvanzied steel

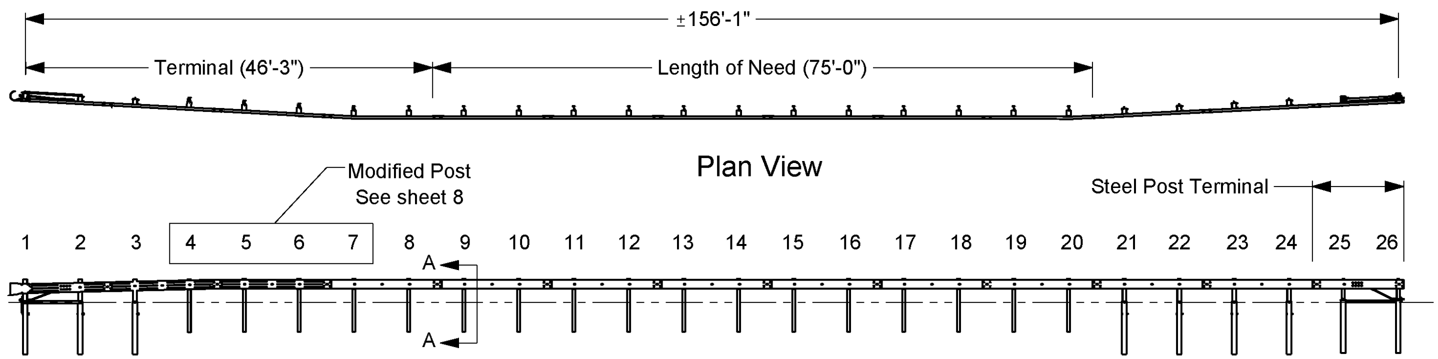


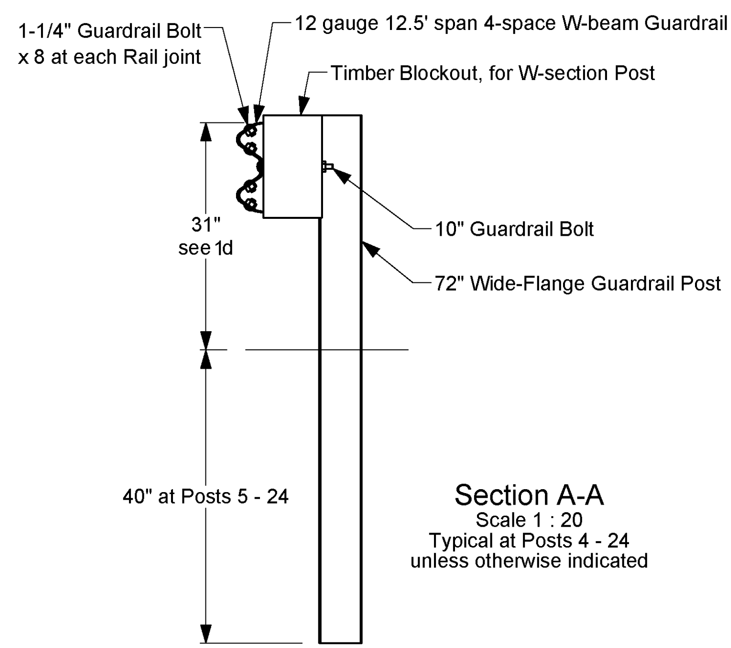
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
W-beam End Section		2022-08-26
Drawn by GES	Scale 1:7	Sheet 1 of 1

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

A.2. DRAWINGS FOR CRASH TEST 615181-01-11 & 615181-01-12

Test Installation





Section A-A
Scale 1 : 20
Typical at Posts 4 - 24
unless otherwise indicated

1a. Backfill Post holes with Type D grade 1 crushed concrete road base or crushed limestone (see test information), compacted according to TTI Proving Ground Work Instruction WI-C001.

1b. All bolts are ASTM A307 unless othewise indicated. Recessed Guardrail Nut on all Button-head Guardrail Bolts and 5/8 Hex Head bolts. F844 Washer under the head of all Hex Head Bolts.

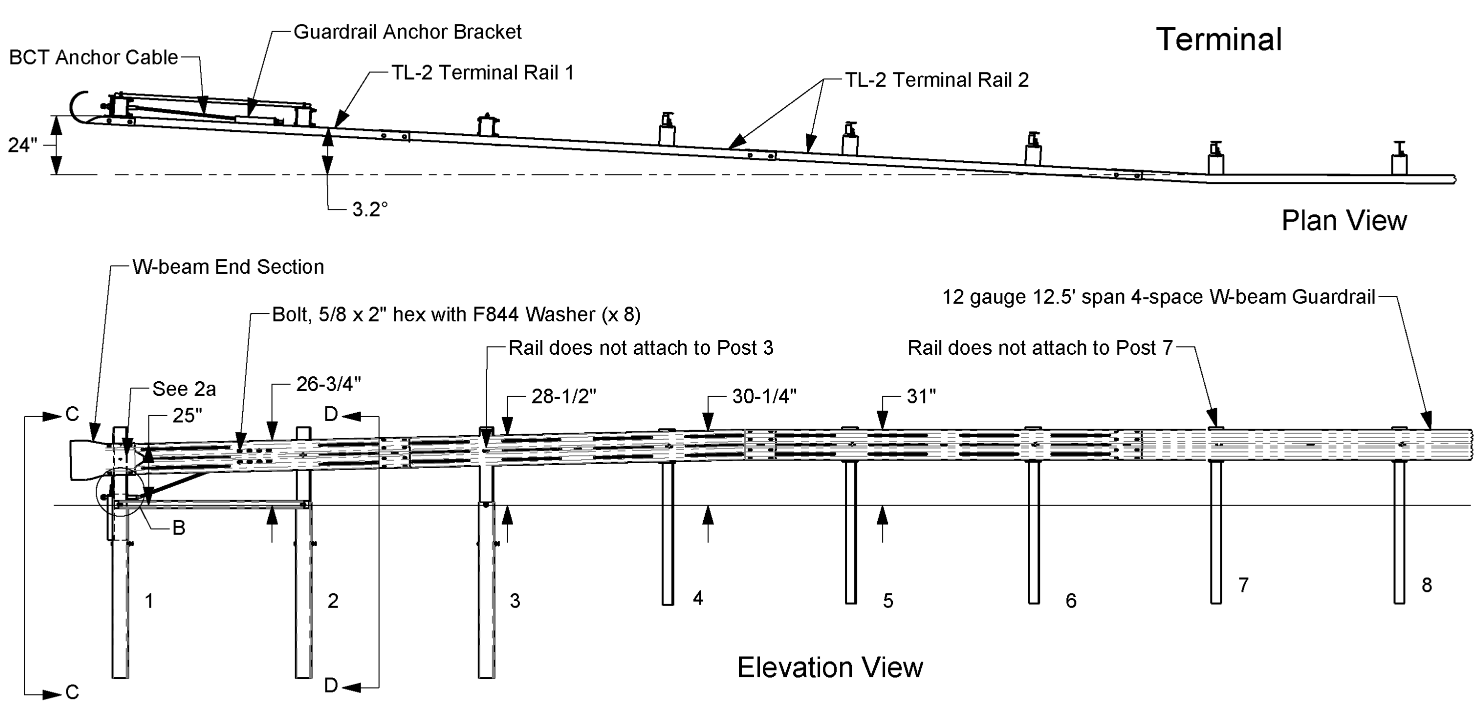
1c. All steel parts shall be galvanized.

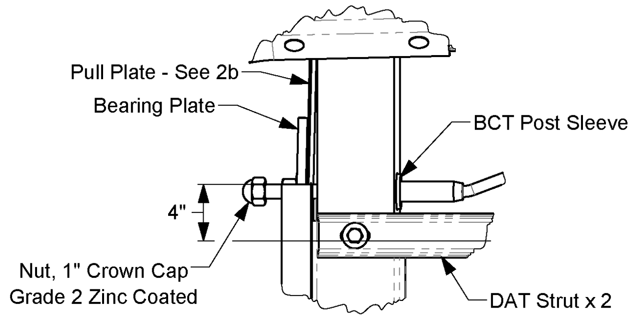
1d. 31" rail height is typical at posts 5-26, and varies at posts 1-4 (see next sheet).

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-09-30
Drawn by GES/WS	Scale 1:200	Sheet 1 of 10 Test Installation

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept-e\615181 Sep-d Drawing

Terminal





Detail B
Scale 1 : 10

2a. Ø7/8" hole at 13" from the top of Post 1 and 11-1/4" from the top of Post 2. Dimensions near Posts 1-5 indicate rail heights at posts.

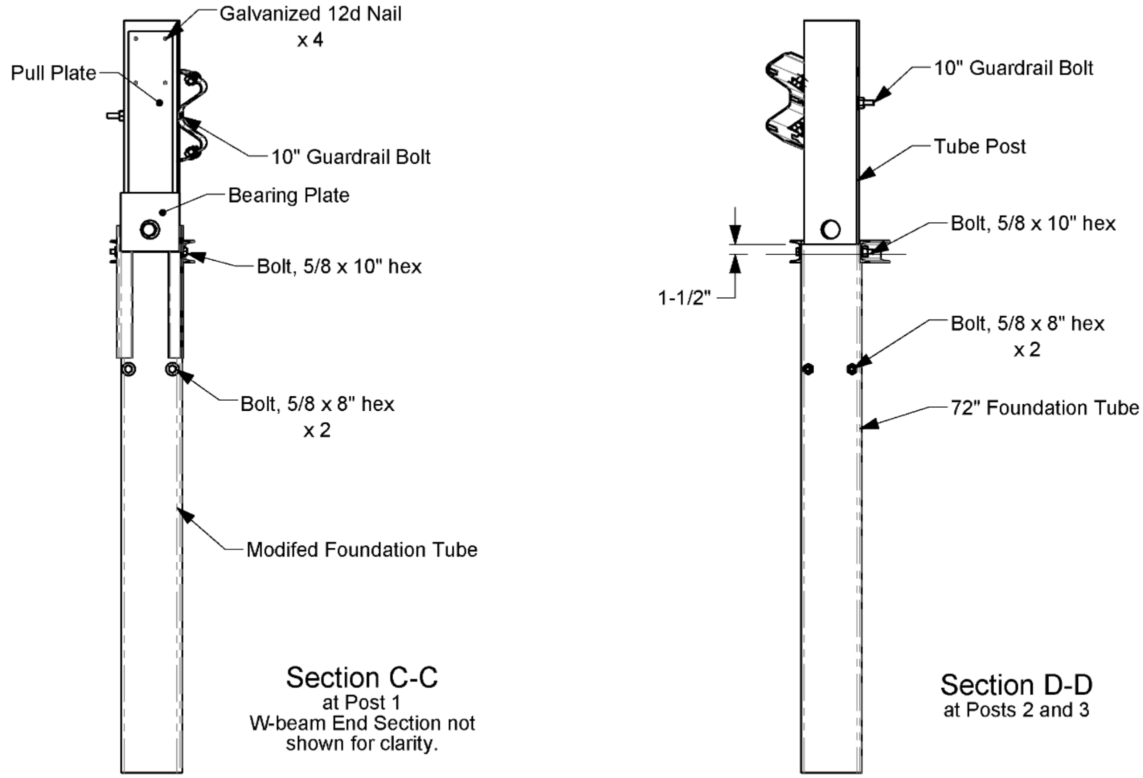
2b. Pull Plate is over angles on Modified Foundation Tube and under Bearing Plate.

2c. Cross sections are on next sheet.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-09-30
Drawn by GES/WS	Scale 1:60	Sheet 2 of 10 Terminal

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept-e\615181 Sep-d Drawing

Terminal Section Views



Section C-C
at Post 1
W-beam End Section not shown for clarity.

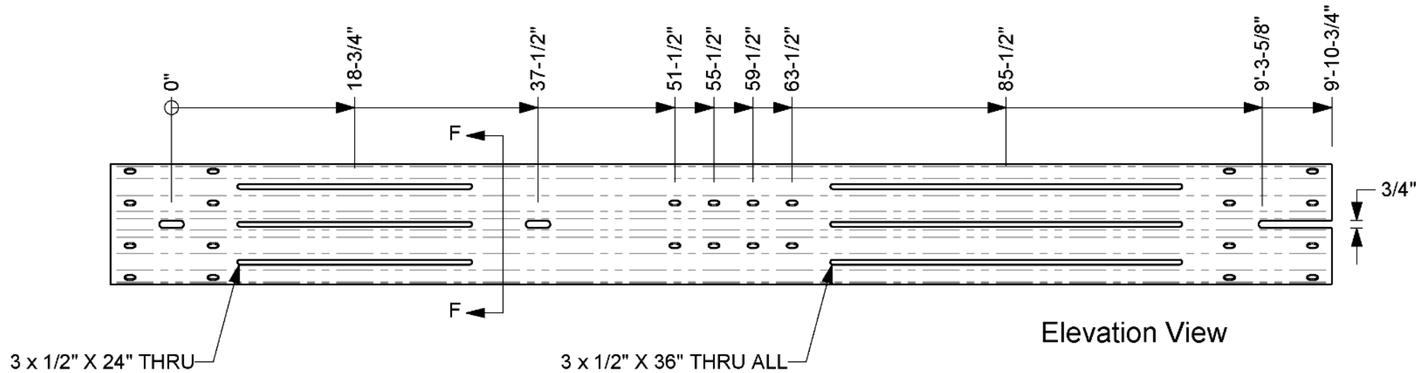
Section D-D
at Posts 2 and 3

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-09-30
Drawn by GES/WS	Scale 1:20	Sheet 3 of 10 Terminal Section Views

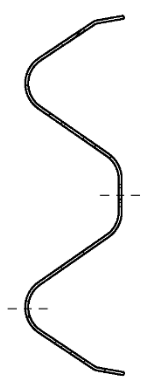
Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept-e\615181 Sep-d Drawing

TL-2 Terminal Rail 1

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



Elevation View



Section F-F
Scale 1 : 5

Texas A&M Transportation Institute

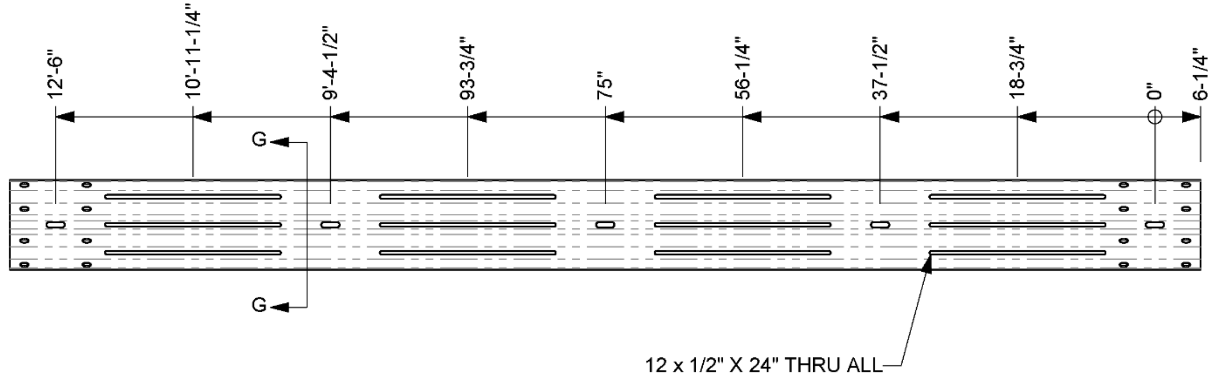
Roadside Safety and Physical Security Division - Proving Ground

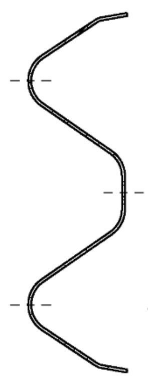
Project #615181 TL-2 Guardrail Terminal		2022-09-30
Drawn by GES/WS	Scale 1:15	Sheet 4 of 10 TL-2 Terminal Rail 1

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept-e\615181 Sep-d Drawing

TL-2 Terminal Rail 2

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

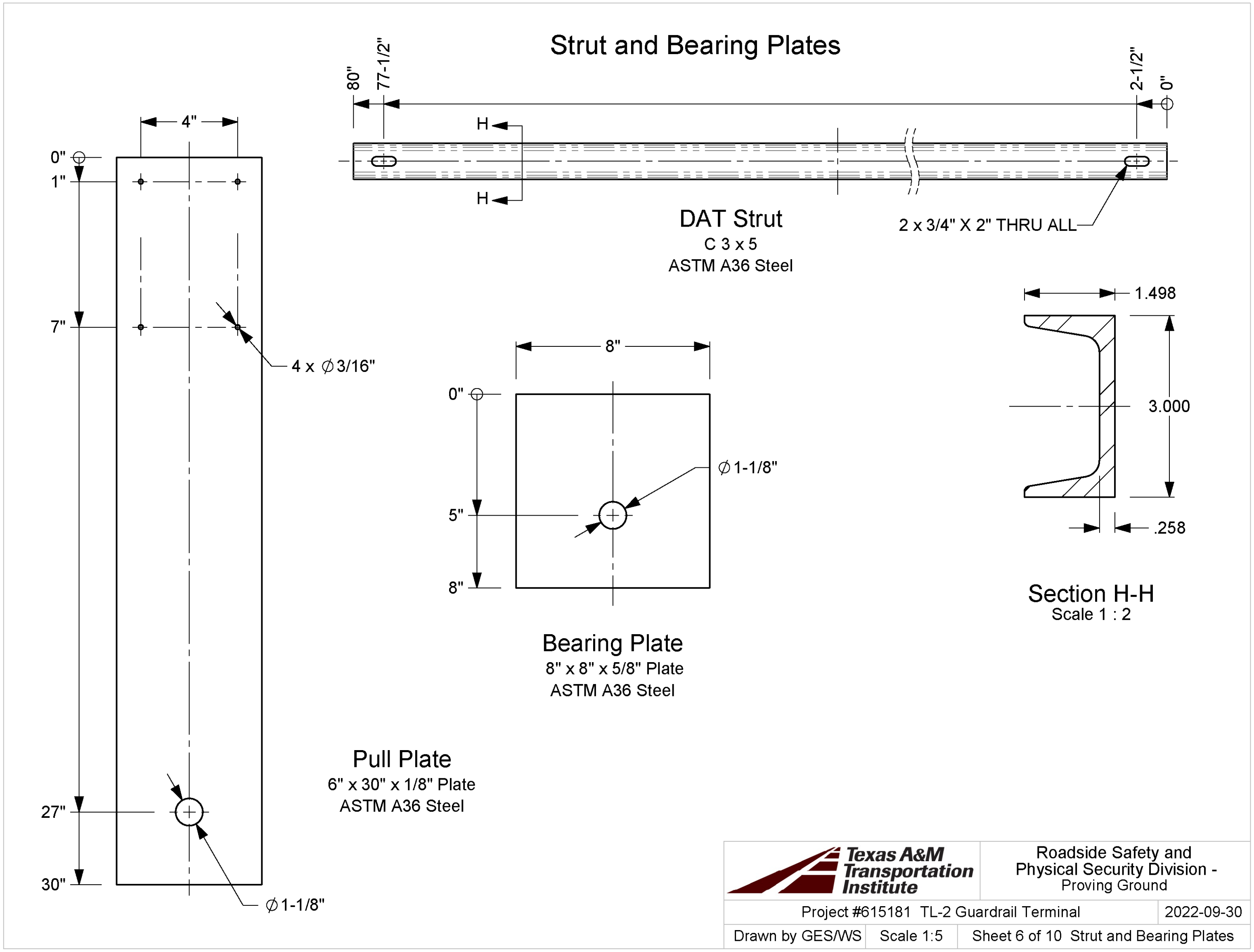




Section G-G
Scale 1 : 5

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #615181 TL-2 Guardrail Terminal		2022-09-30
Drawn by GES/WS	Scale 1:20	Sheet 5 of 10 TL-2 Terminal Rail 2

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept-e\615181 Sep-d Drawing



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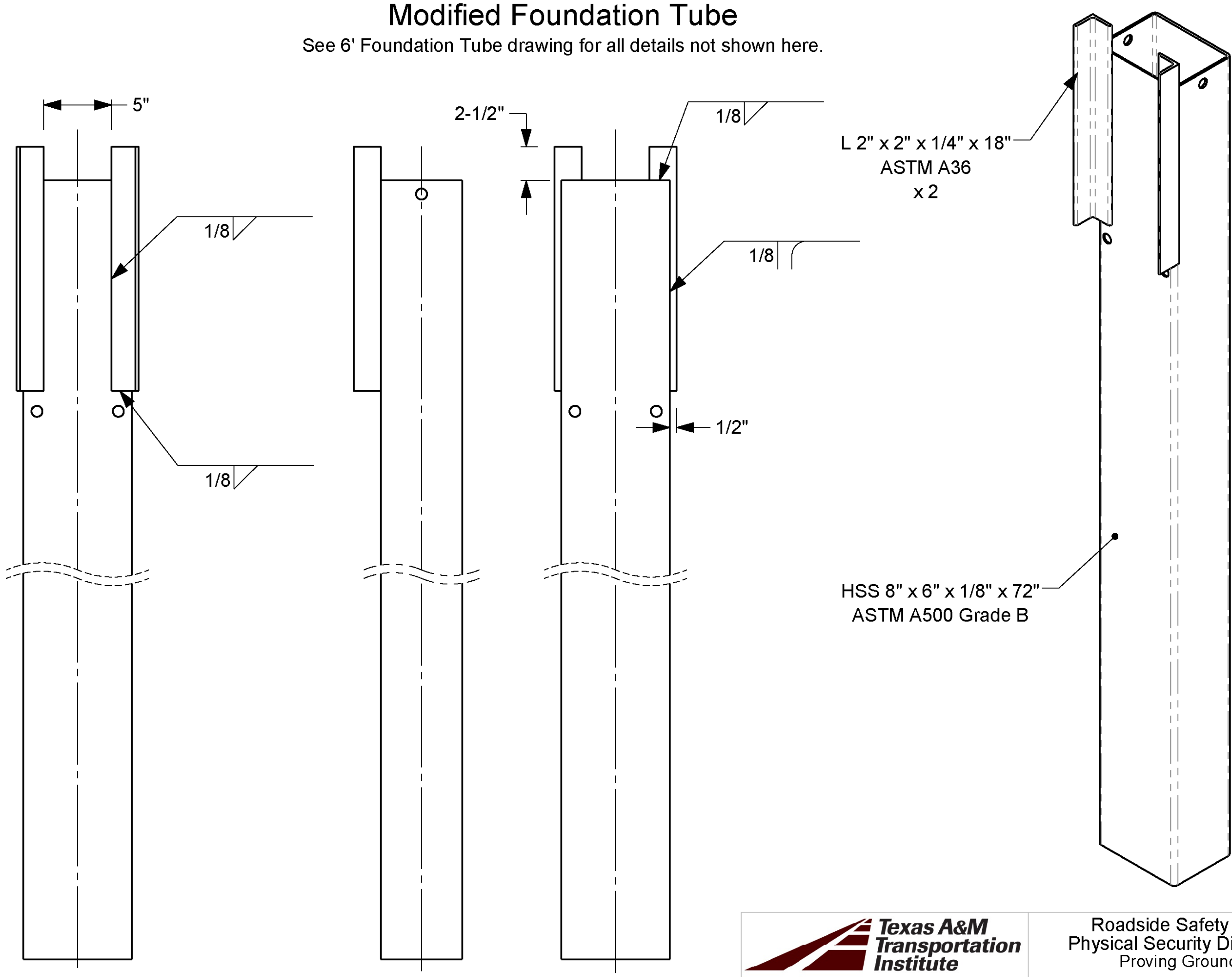
Modified Foundation Tube

See 6' Foundation Tube drawing for all details not shown here.



Elevation Views

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project #615181 TL-2 Guardrail Terminal		2022-09-30
Drawn by GES/WS	Scale 1:10	Sheet 7 of 10 Modified Foundation Tube

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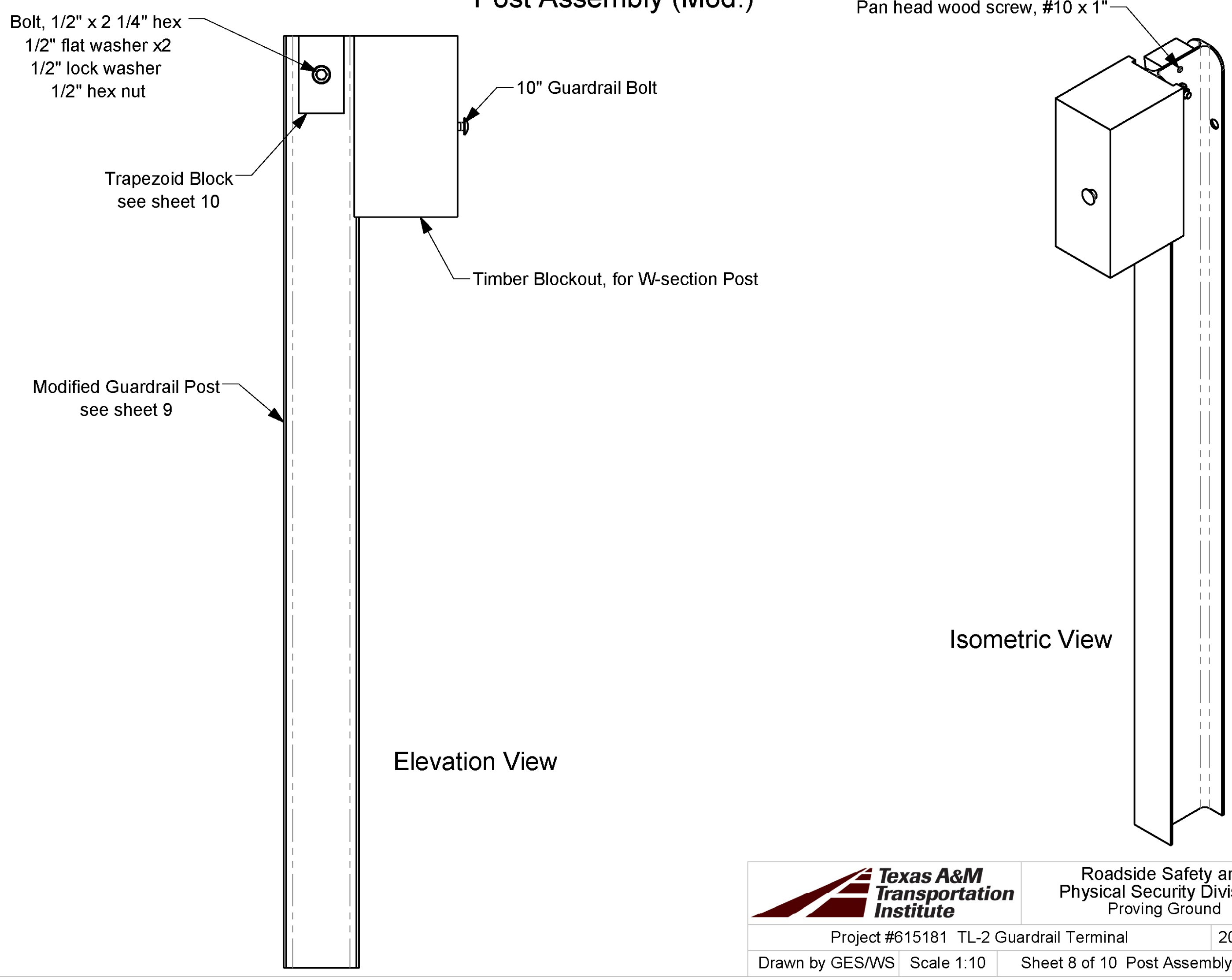
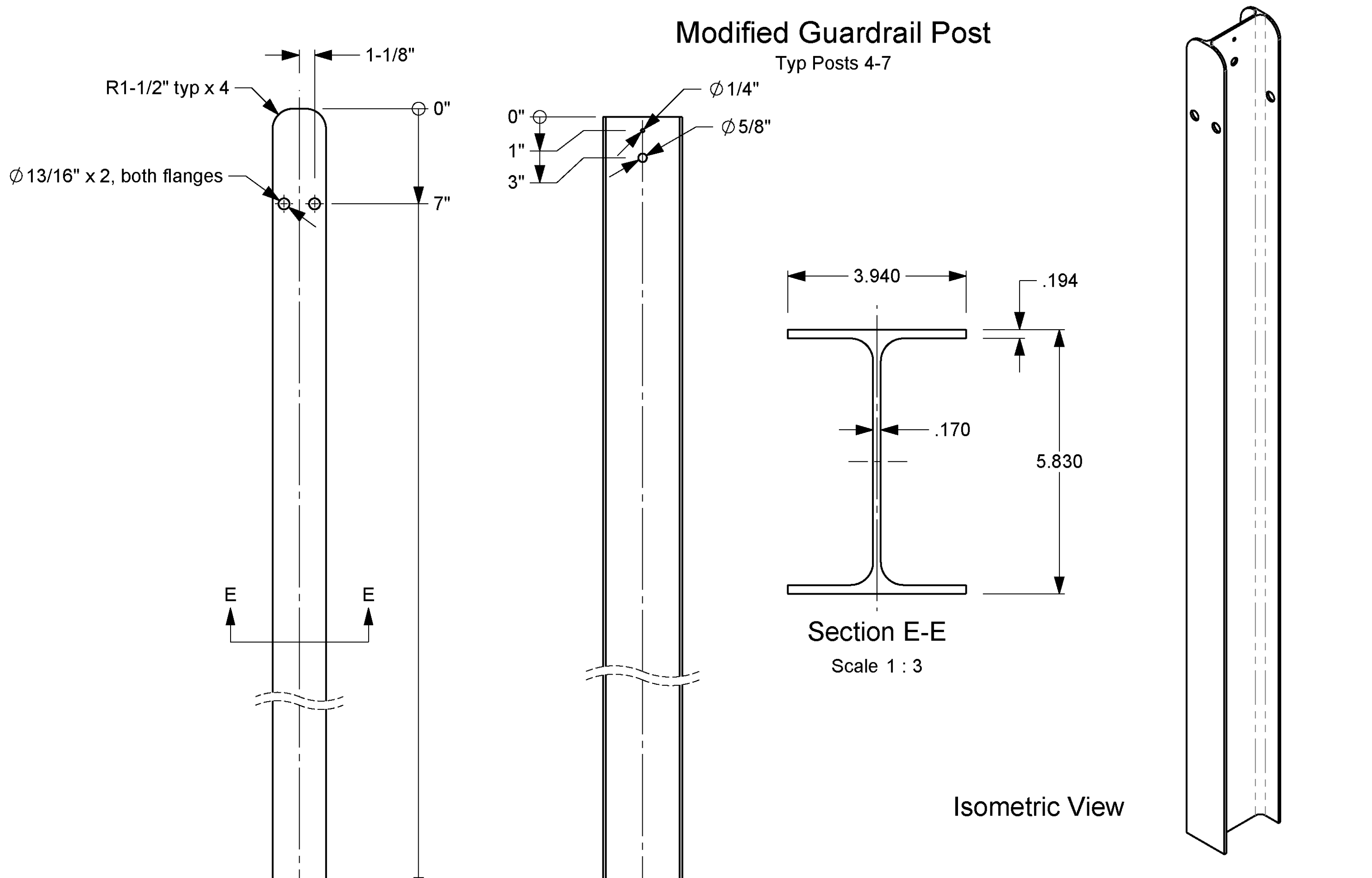
Post Assembly (Mod.)



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-09-30
Drawn by GES/WS	Scale 1:10	Sheet 8 of 10 Post Assembly (Mod.)

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept-e\615181 Sep-d Drawing

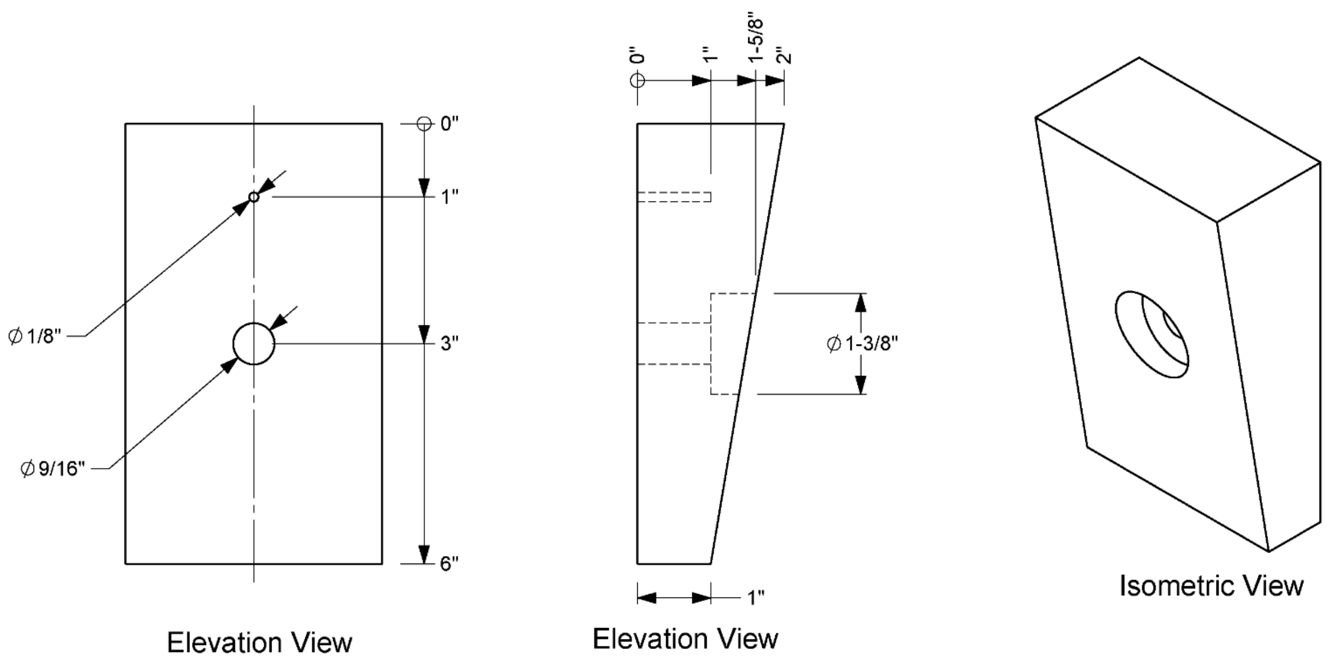


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-09-30
Drawn by GES/WS	Scale 1:10	Sheet 9 of 10 Modified Guardrail Post

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Sept-e\615181 Sep-d Drawing

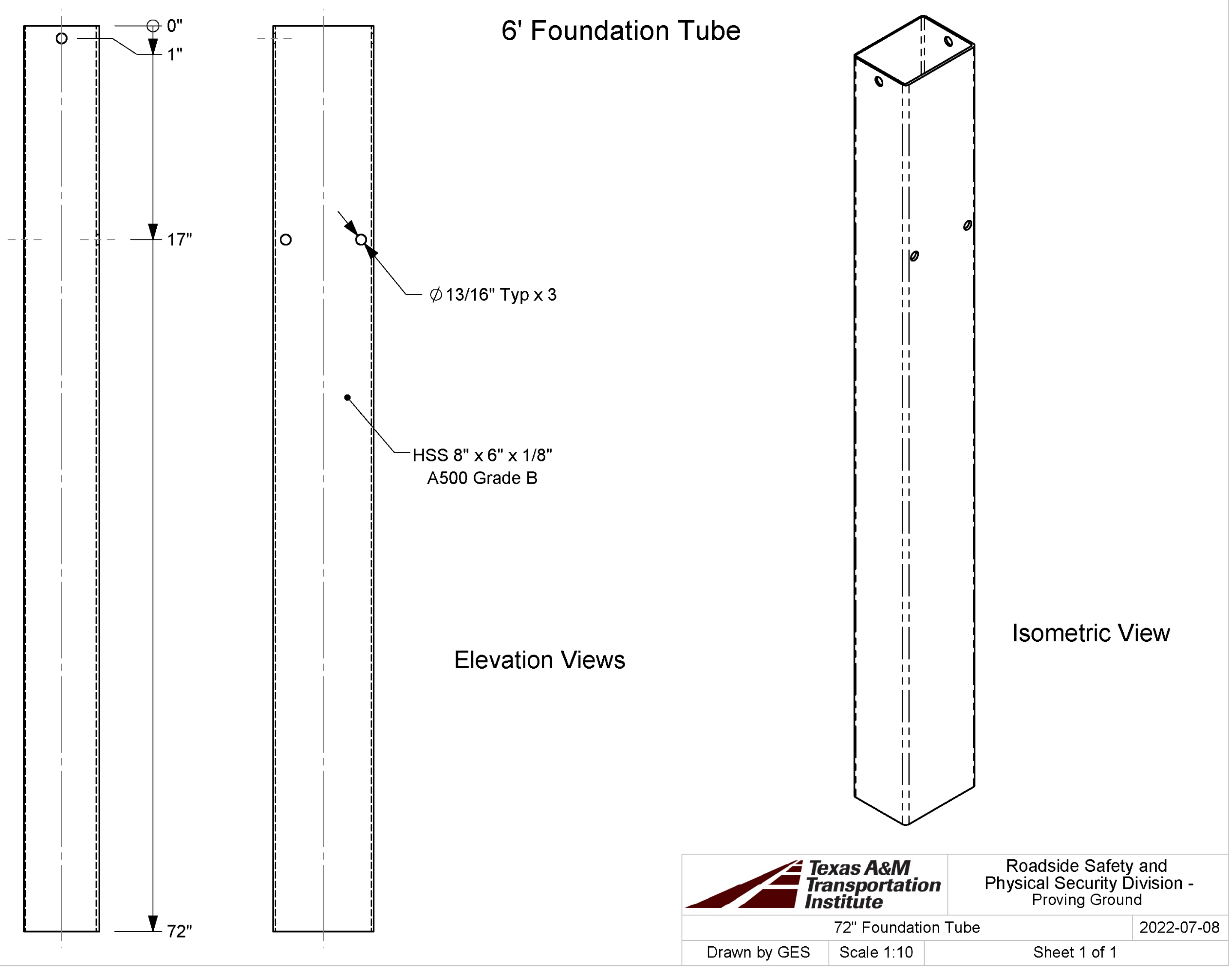
Trapezoid Block

4 x 4 nominal



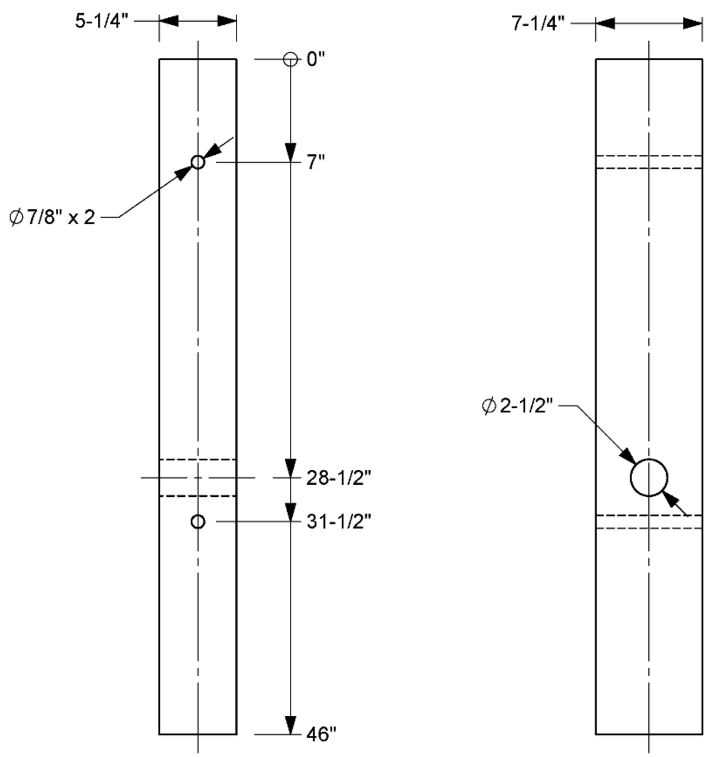
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-09-30
Drawn by GES/WS	Scale 1:2	Sheet 10 of 10 Trapezoid Block

6' Foundation Tube



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

Post, Tube



Elevation Views

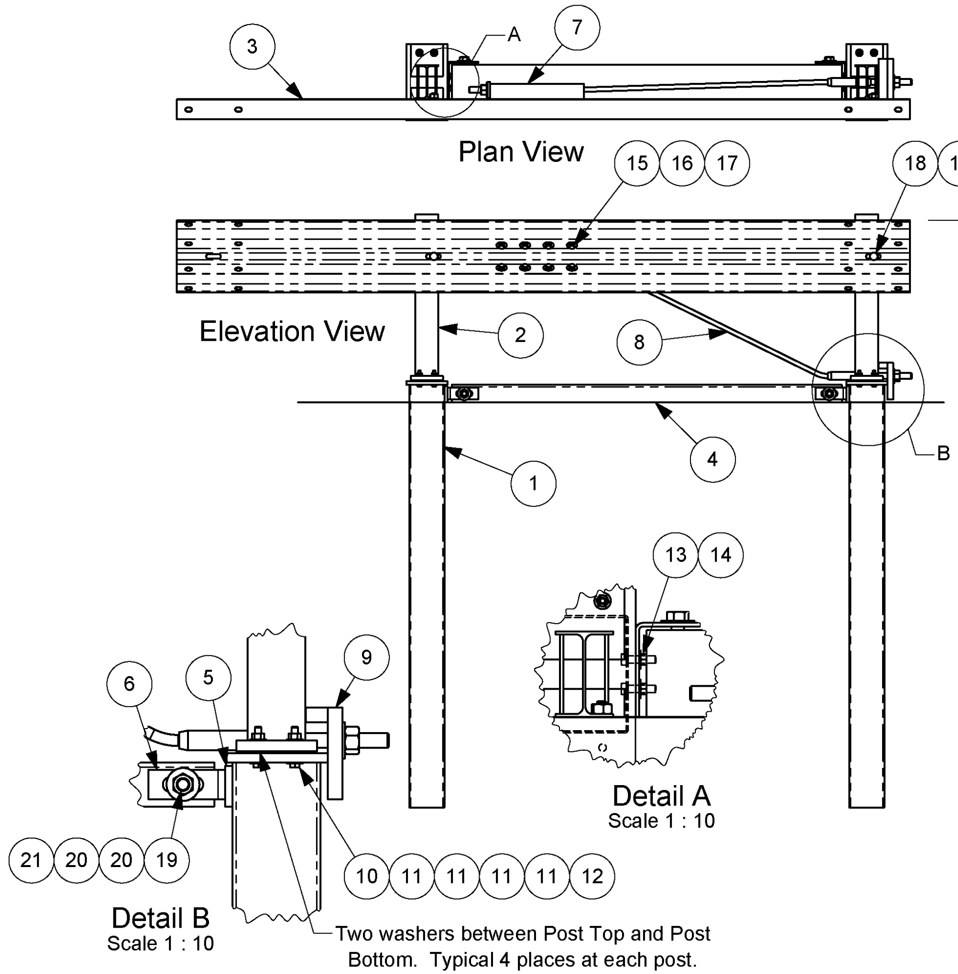
1a. Timber posts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Tube Post			2022-07-08
Drawn by GES	Scale 1:10	Sheet 1 of 1	

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

Terminal Details

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



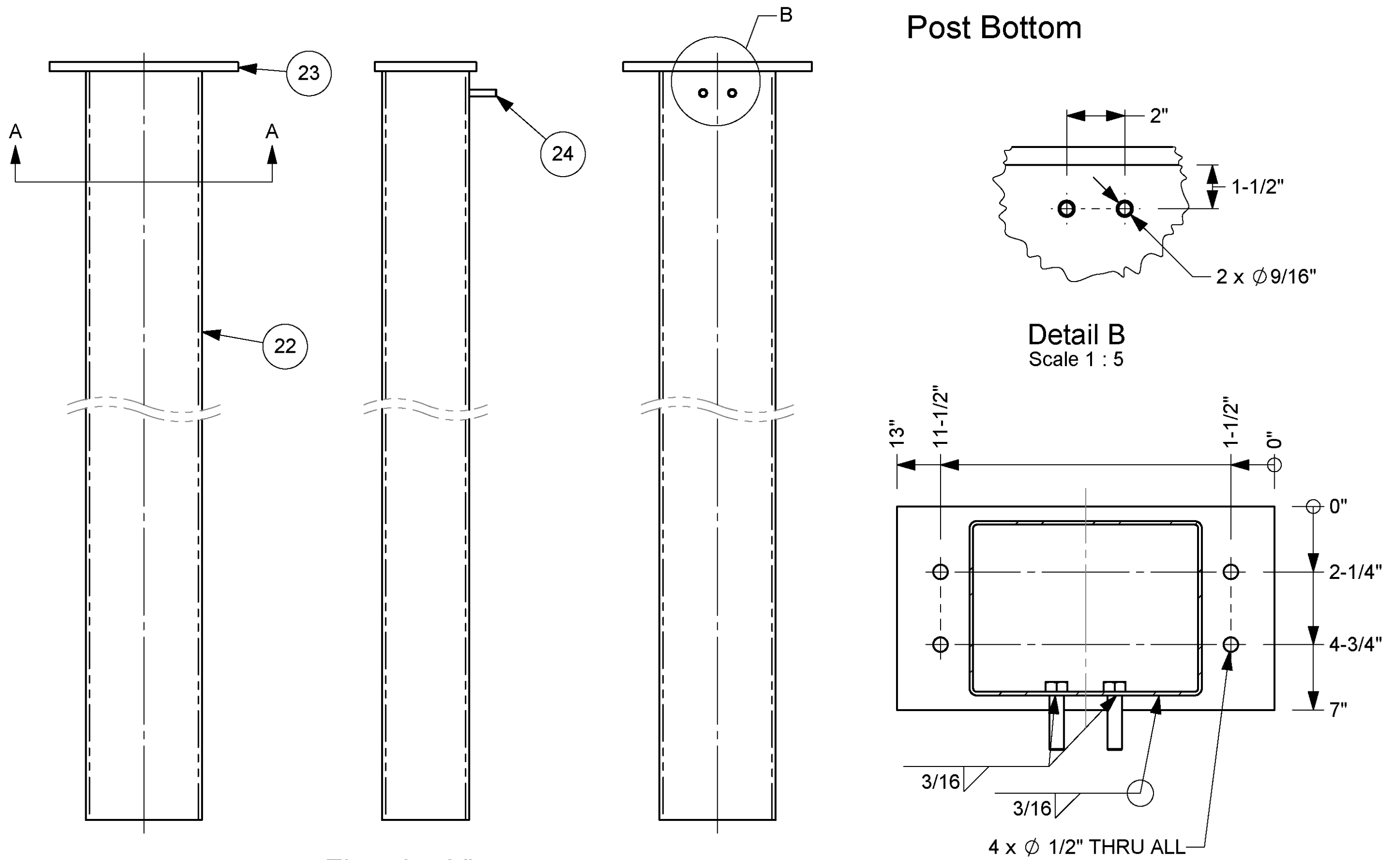
1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.

1c. All steel parts shall be galvanized.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2022-07-08
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details

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

Post Bottom

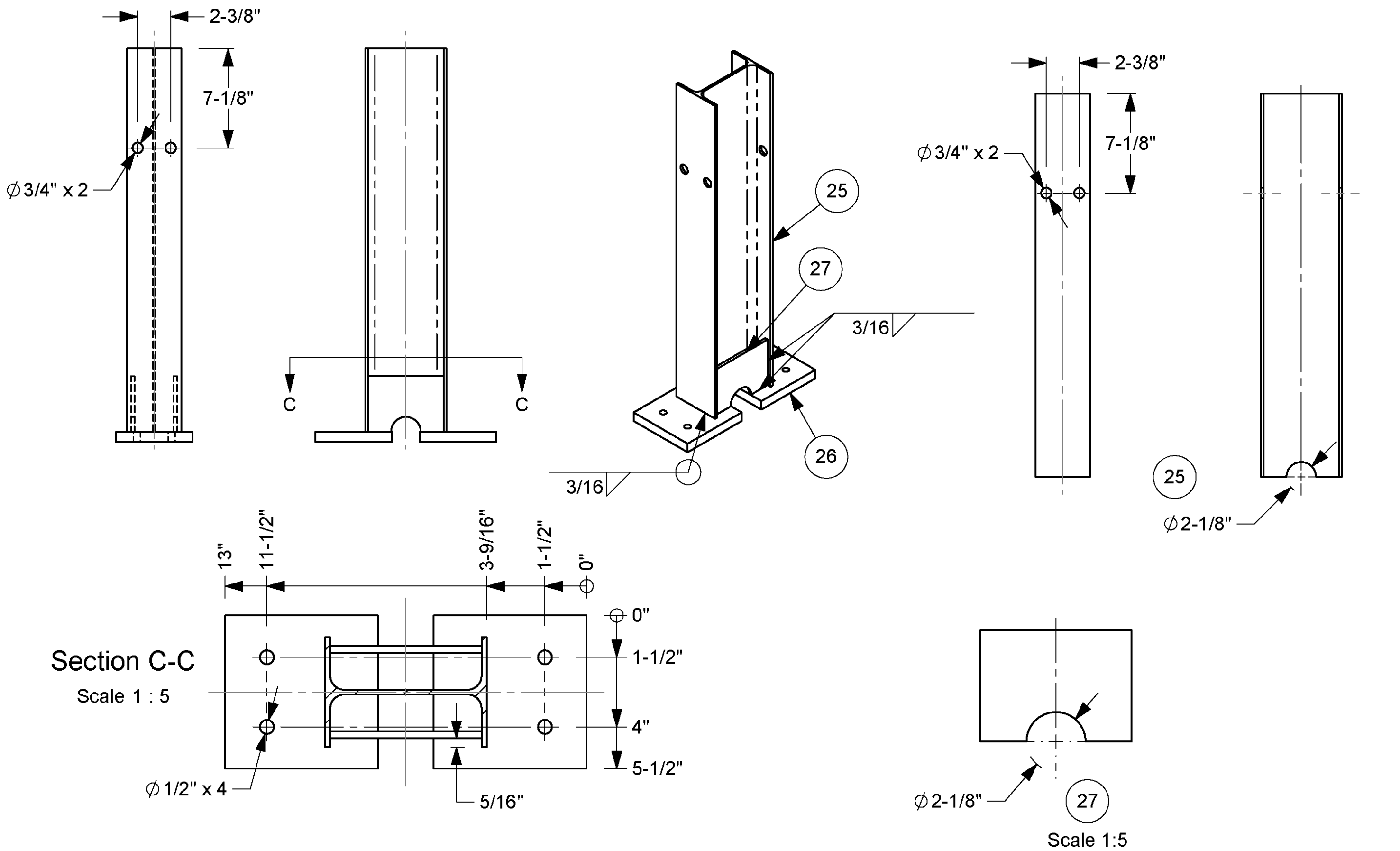


Elevation Views

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

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2022-07-08
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom

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



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

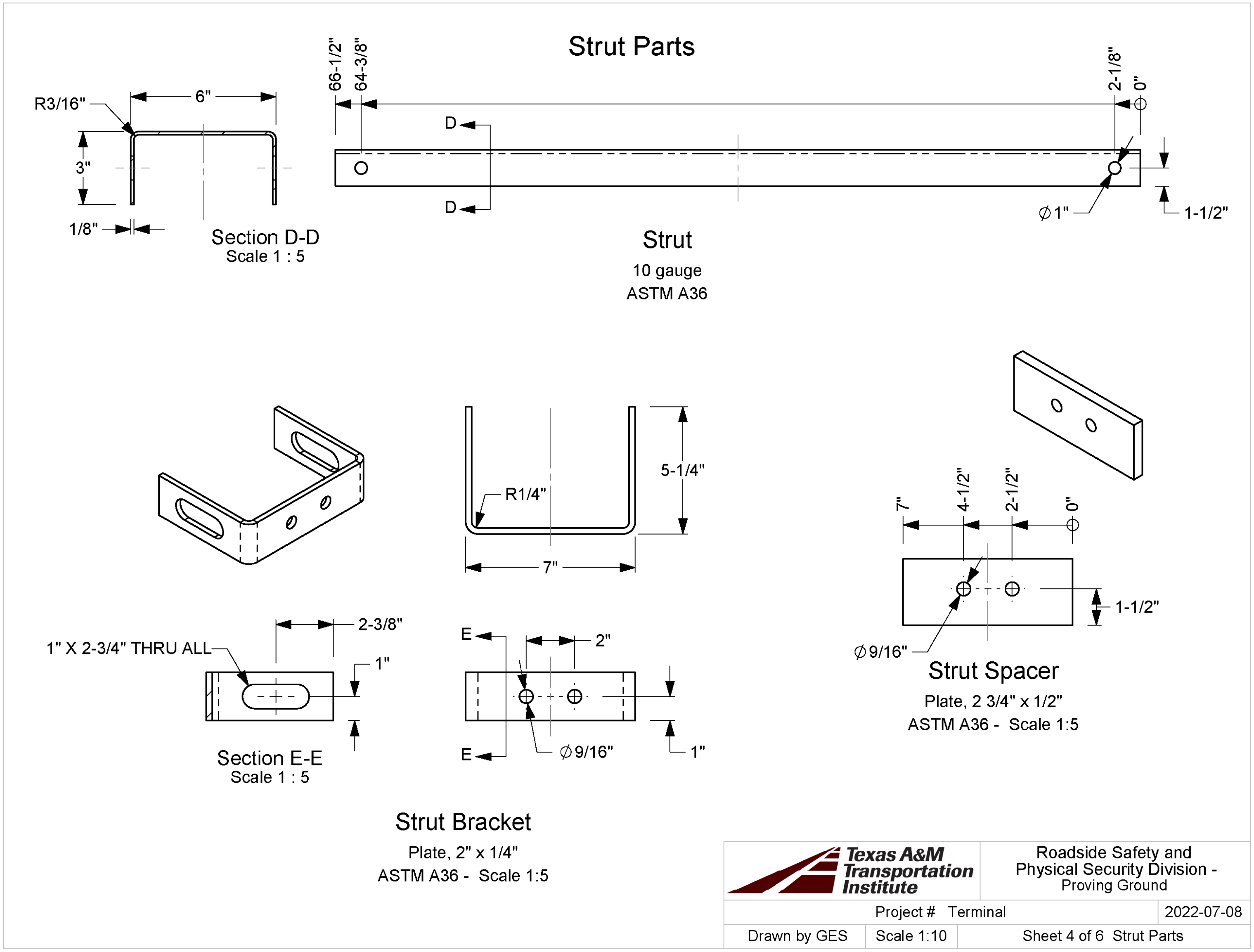
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project # Terminal | 2022-07-08

Drawn by GES | Scale 1:10 | Sheet 3 of 6 Post Top

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



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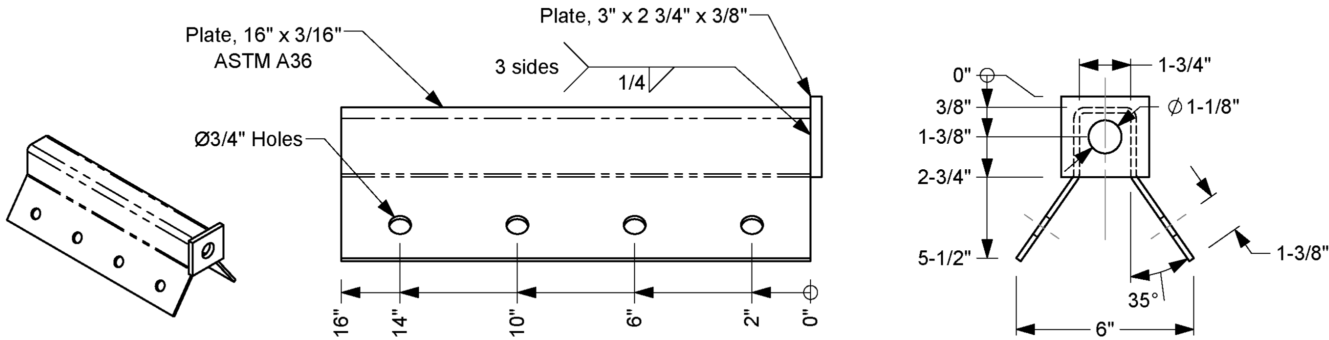
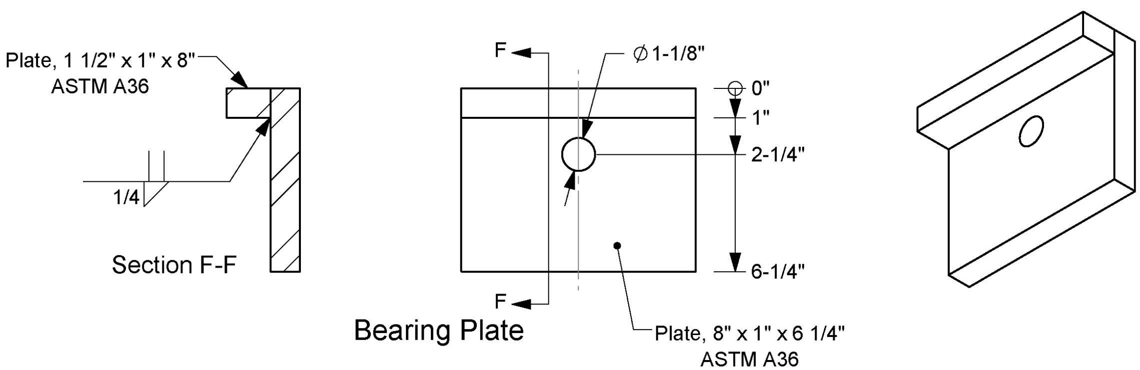


Guardrail Anchor Bracket

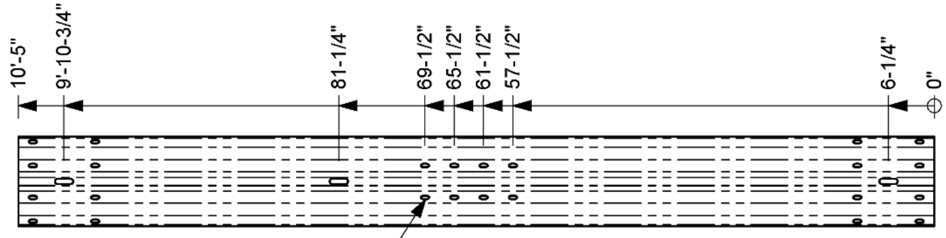


Section F-F

Bearing Plate

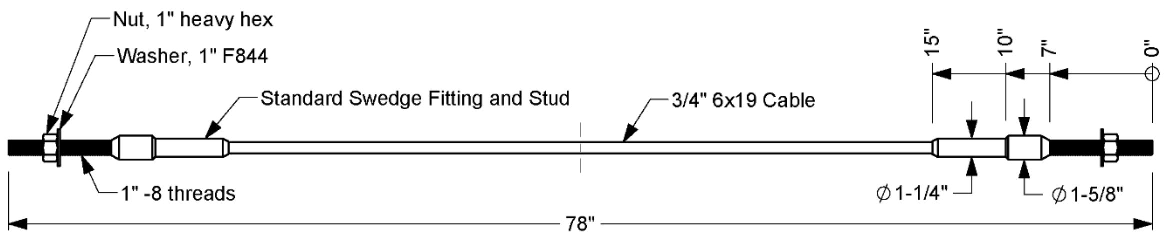
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2022-07-08
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A

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



9'-4" span Terminal Rail

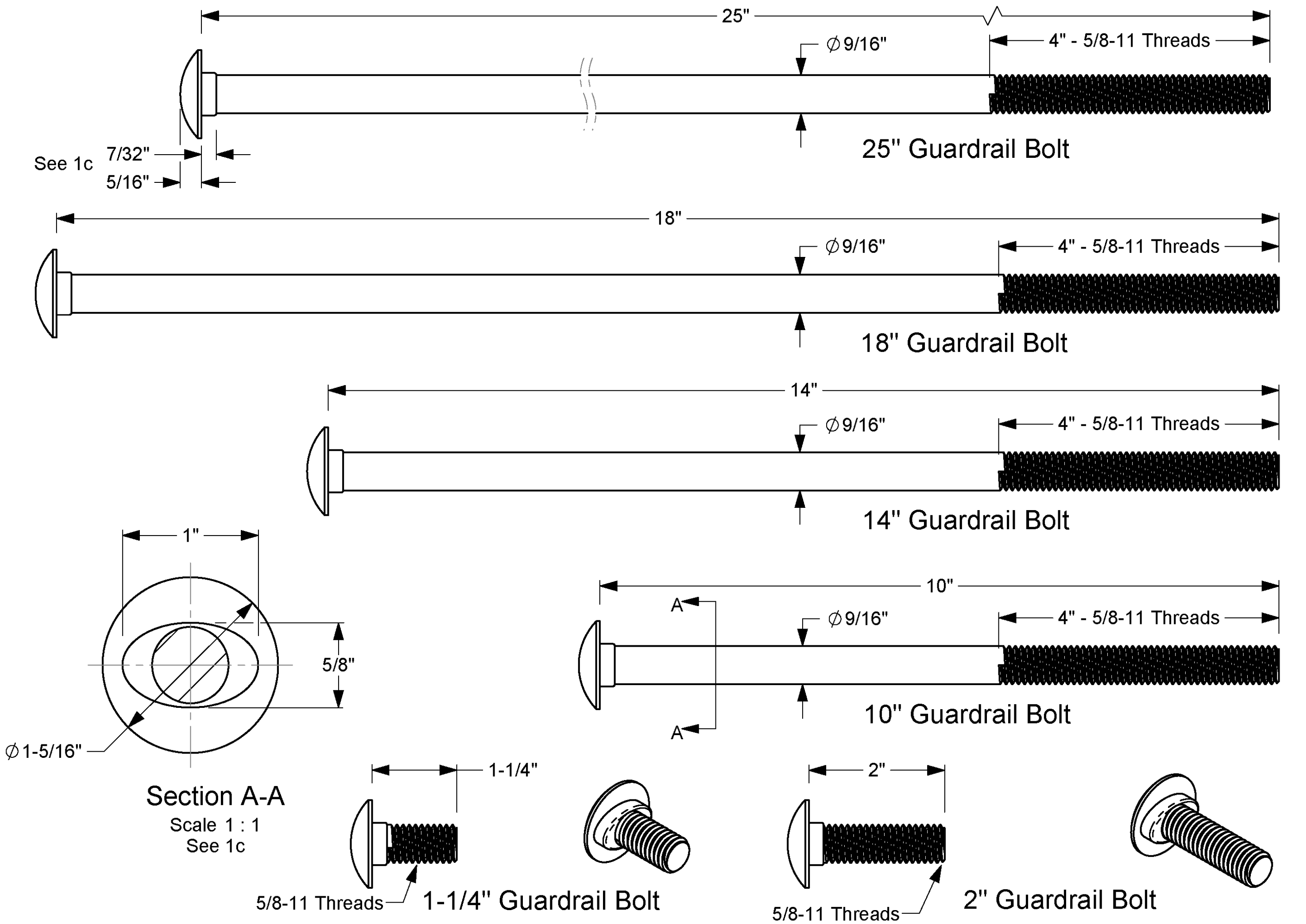
Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.



Anchor Cable Assembly

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
	Project # Terminal	2022-07-08
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B

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



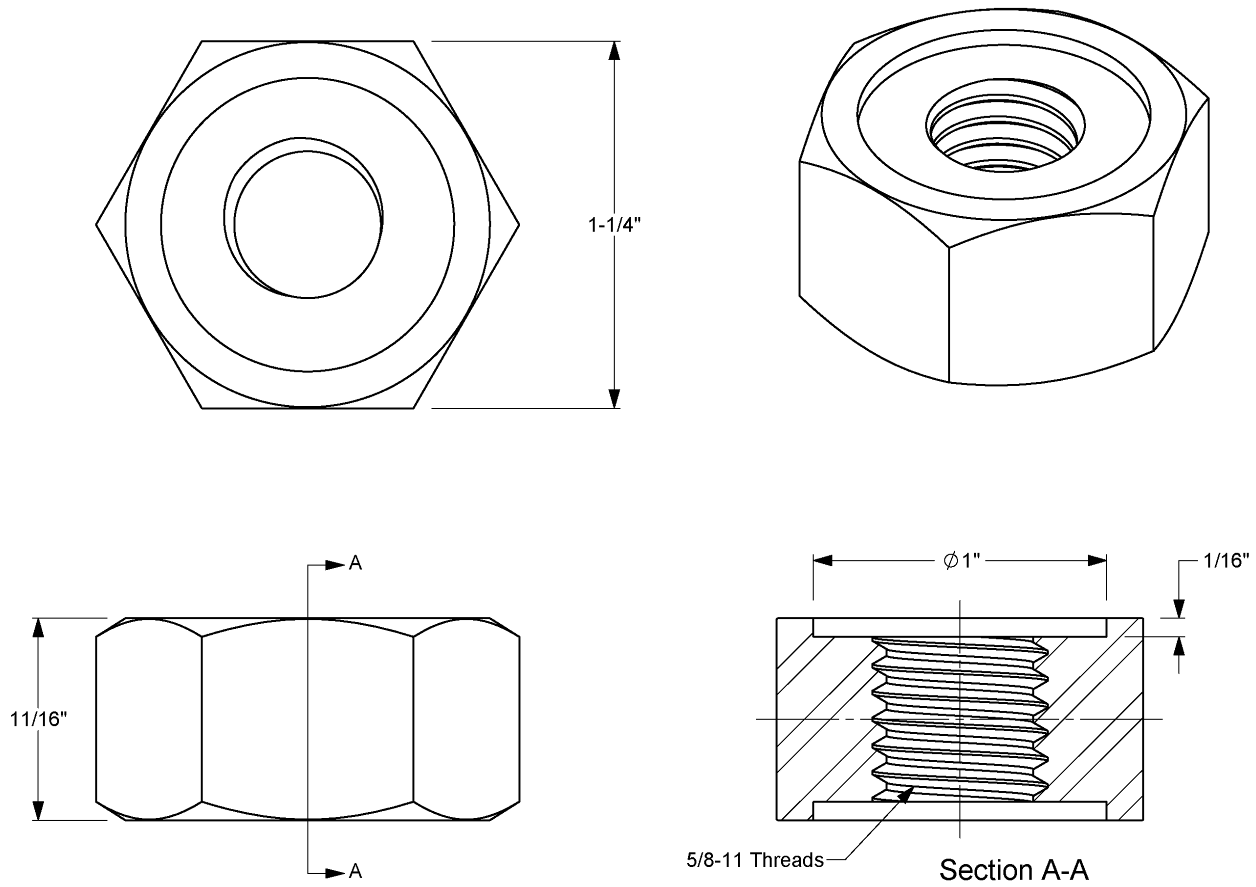
1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all lengths.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Guardrail Bolt			2020-07-08
Drawn by GES/WS	Scale 1:2	Sheet 1 of 1	

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

2023-06-05

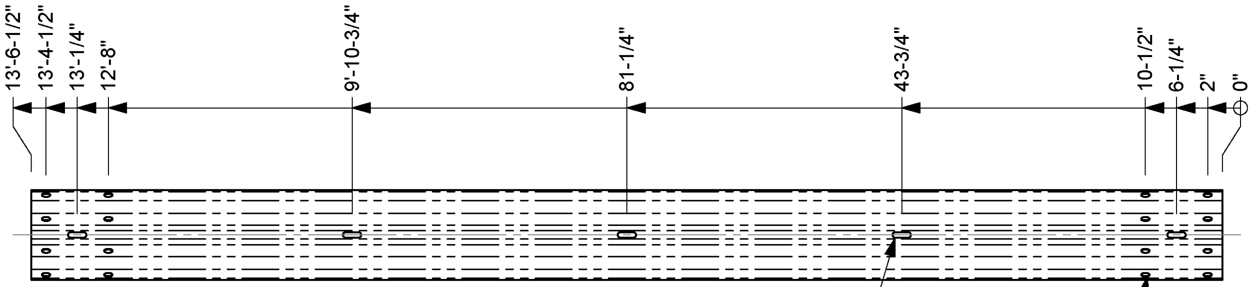
Recessed Guardrail Nut



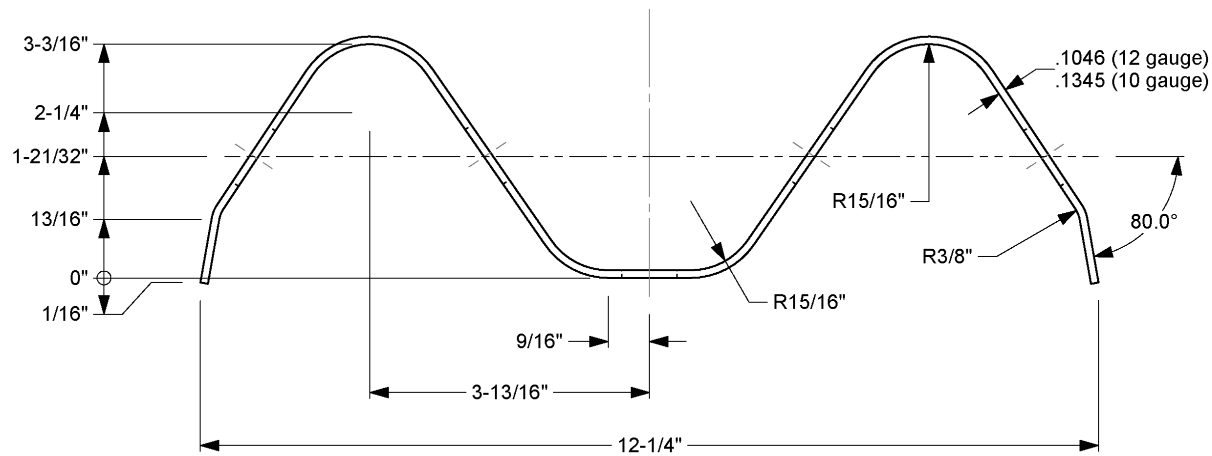
1a. Material is ASTM A 563 Grade A.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Recessed Guardrail Nut		2022-07-18
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



Elevation View



Section View

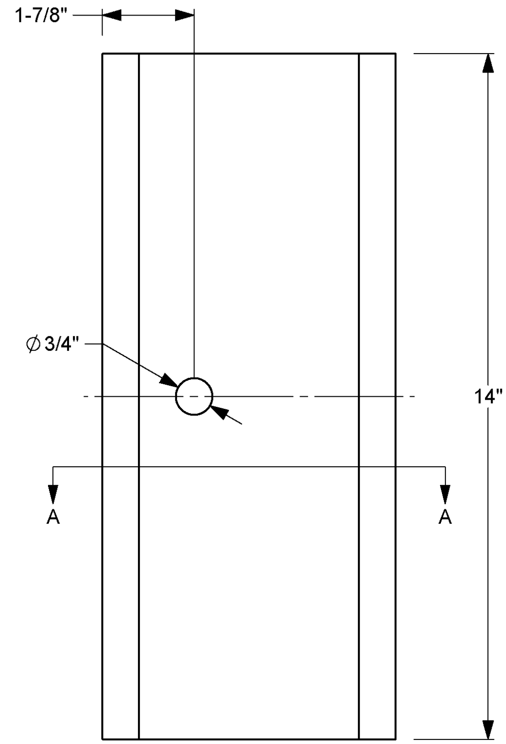
1a. Manufacture per AASHTO M180 specifications.

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

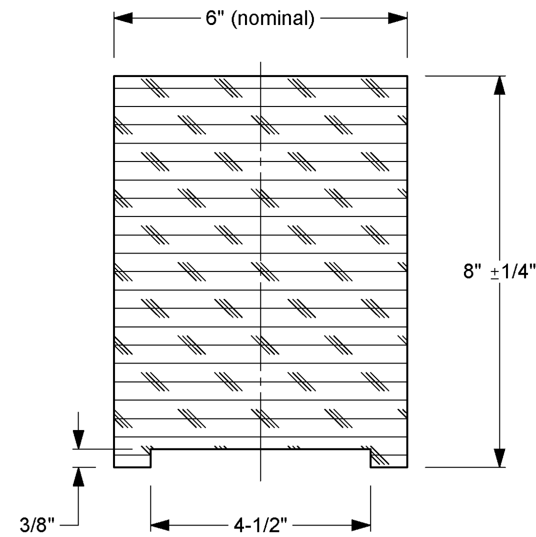
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
W-beam Guardrail		2022-07-13
Drawn by GES	Scale 1:20	Sheet 1 of 1

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

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.

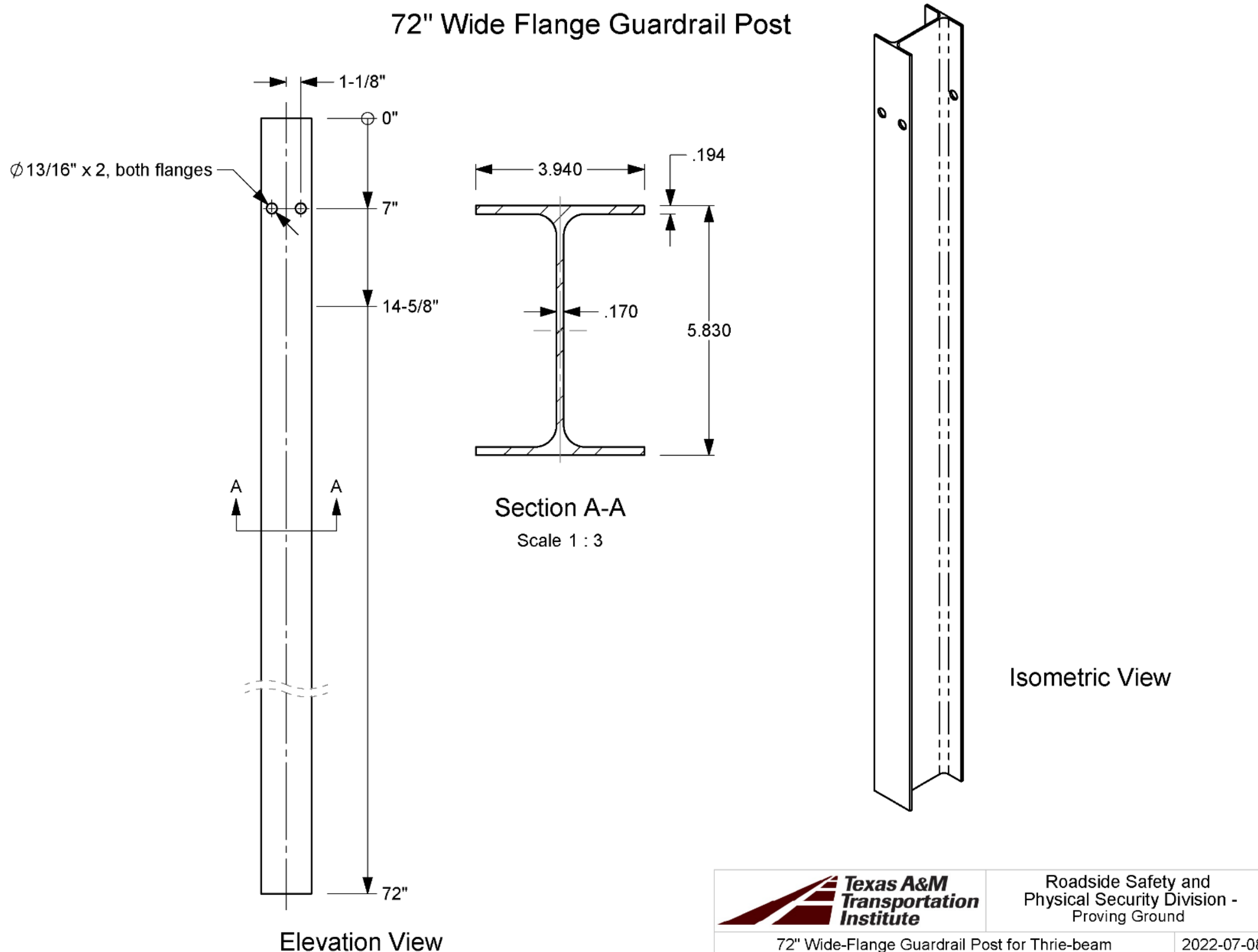
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Timber Blockout, for W-section Post		2022-07-08
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

72" Wide Flange Guardrail Post

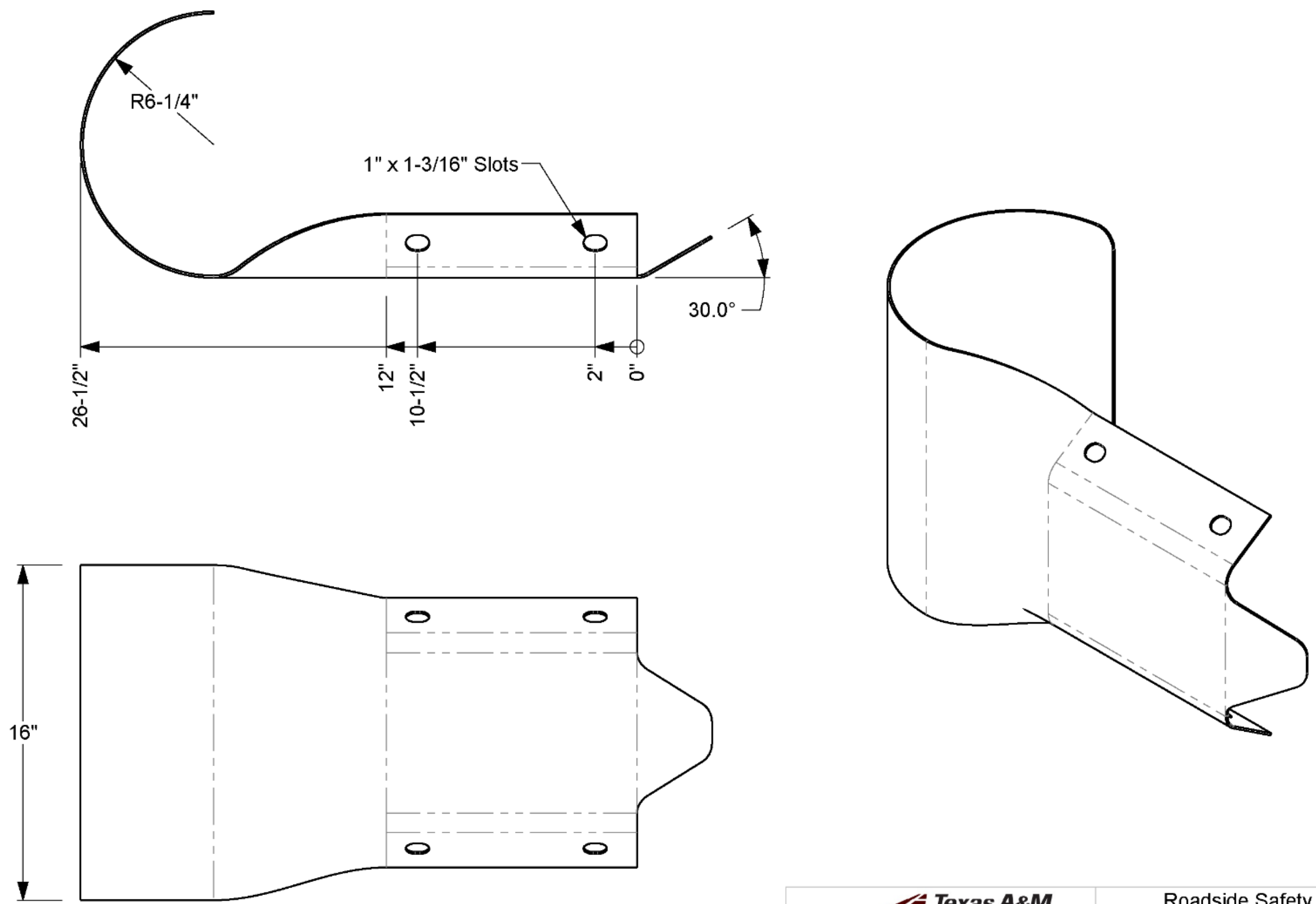


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
72" Wide-Flange Guardrail Post for Thrie-beam		2022-07-08
Drawn by GES	Scale 1:10	Sheet 1 of 1

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

W-beam End Section

12 gauge galvanzied steel

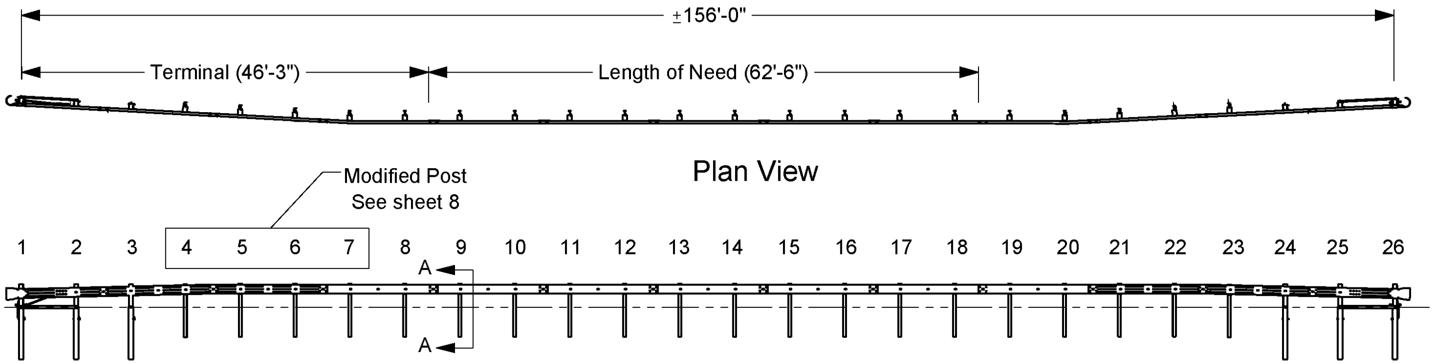


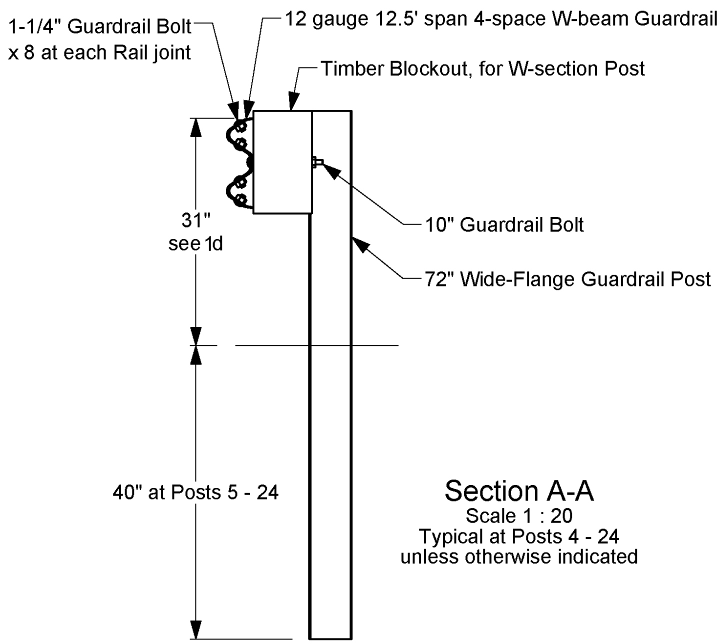
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
W-beam End Section		2022-08-26
Drawn by GES	Scale 1:7	Sheet 1 of 1

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

A.3. DRAWINGS FOR CRASH TEST 615181-01-13

Test Installation





Section A-A
Scale 1 : 20
Typical at Posts 4 - 24
unless otherwise indicated

1a. Backfill Post holes with Type D grade 1 crushed concrete road base or crushed limestone (see test information), compacted according to TTI Proving Ground Work Instruction WI-C001.

1b. All bolts are ASTM A307 unless othewise indicated. Recessed Guardrail Nut on all Button-head Guardrail Bolts and 5/8 Hex Head bolts. F844 Washer under the head of all Hex Head Bolts.

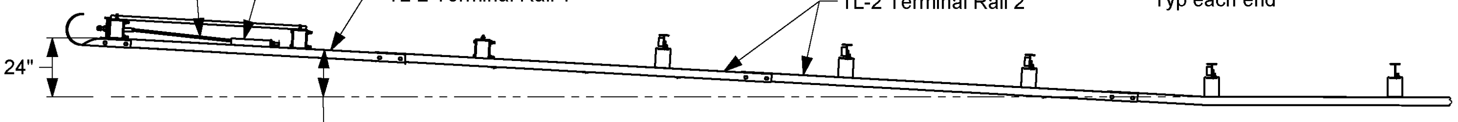
1c. All steel parts shall be galvanized.

1d. 31" rail height is typical at posts 5-26, and varies at posts 1-4 (see next sheet).

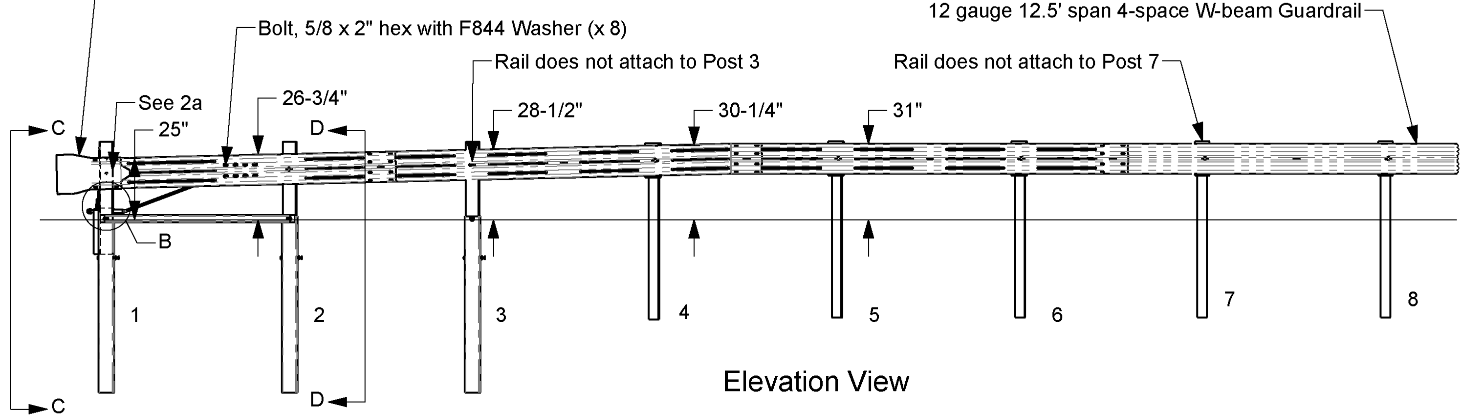
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-10-12
Drawn by GES/WS	Scale 1:200	Sheet 1 of 10 Test Installation

Terminal

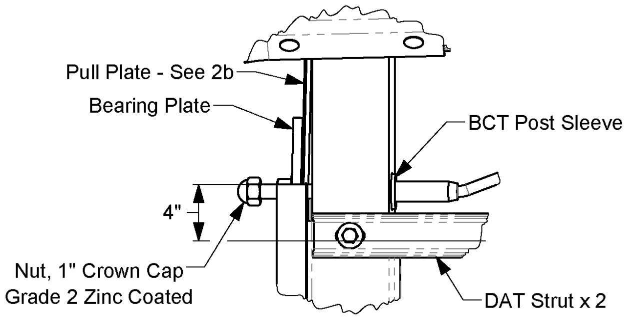
Typ each end



Plan View



Elevation View



Detail B

Scale 1 : 10

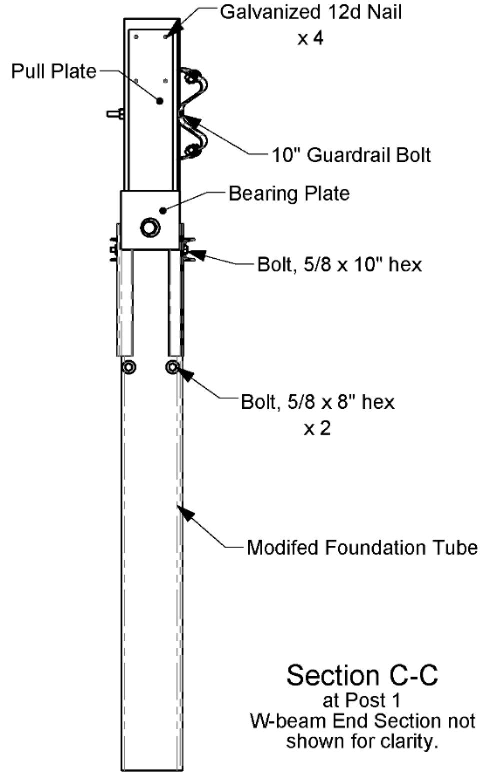
2a. Ø7/8" hole at 13" from the top of Post 1 and 11-1/4" from the top of Post 2. Dimensions near Posts 1-5 indicate rail heights at posts.

2b. Pull Plate is over angles on Modified Foundation Tube and under Bearing Plate.

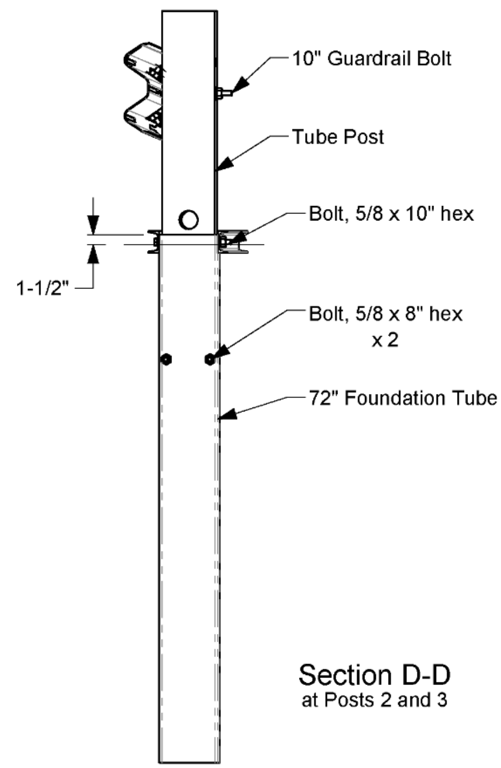
2c. Cross sections are on next sheet.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-10-12
Drawn by GES/WS	Scale 1:60	Sheet 2 of 10 Terminal

Terminal Section Views



Section C-C
at Post 1
W-beam End Section not shown for clarity.



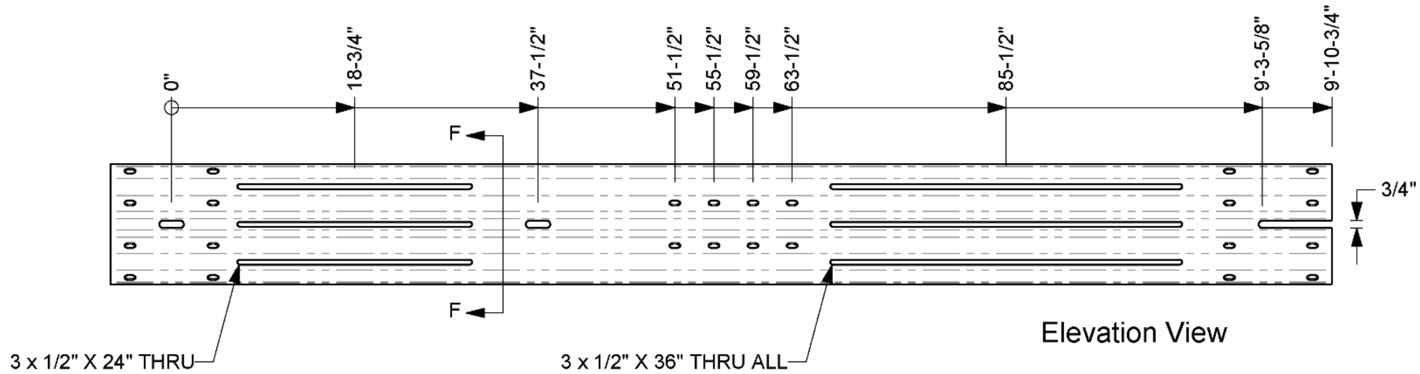
Section D-D
at Posts 2 and 3

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground
Project #615181 TL-2 Guardrail Terminal	2022-10-12
Drawn by GES/WS · Scale 1:20	Sheet 3 of 10 Terminal Section Views

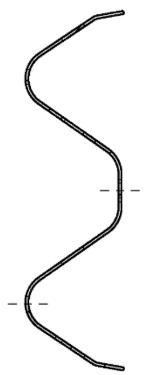
Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Oct\2022-10-12\615181 Oct Drawing

TL-2 Terminal Rail 1

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



Elevation View

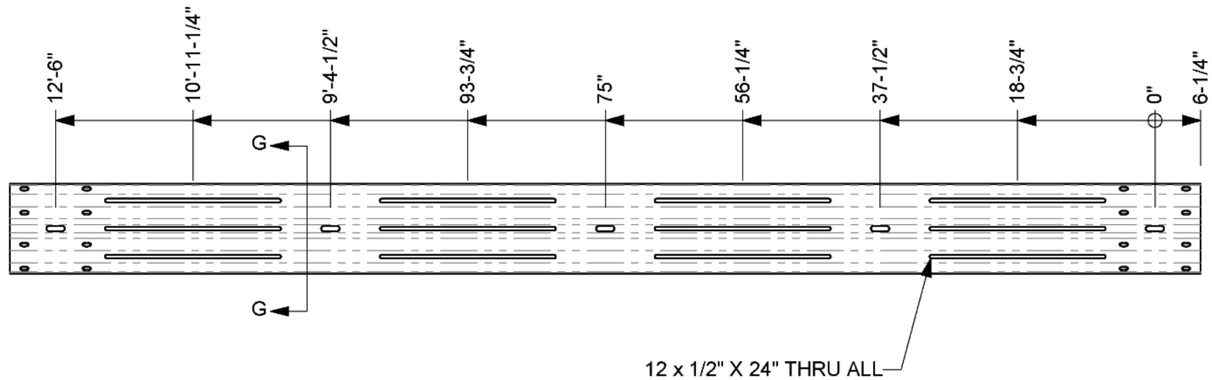


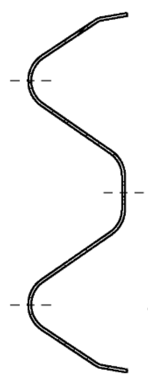
Section F-F
Scale 1 : 5

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #615181 TL-2 Guardrail Terminal		2022-10-12
Drawn by GES/WS	Scale 1:15	Sheet 4 of 10 TL-2 Terminal Rail 1

TL-2 Terminal Rail 2

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





Section G-G
Scale 1 : 5

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-10-12
Drawn by GES/WS	Scale 1:20	Sheet 5 of 10 TL-2 Terminal Rail 2

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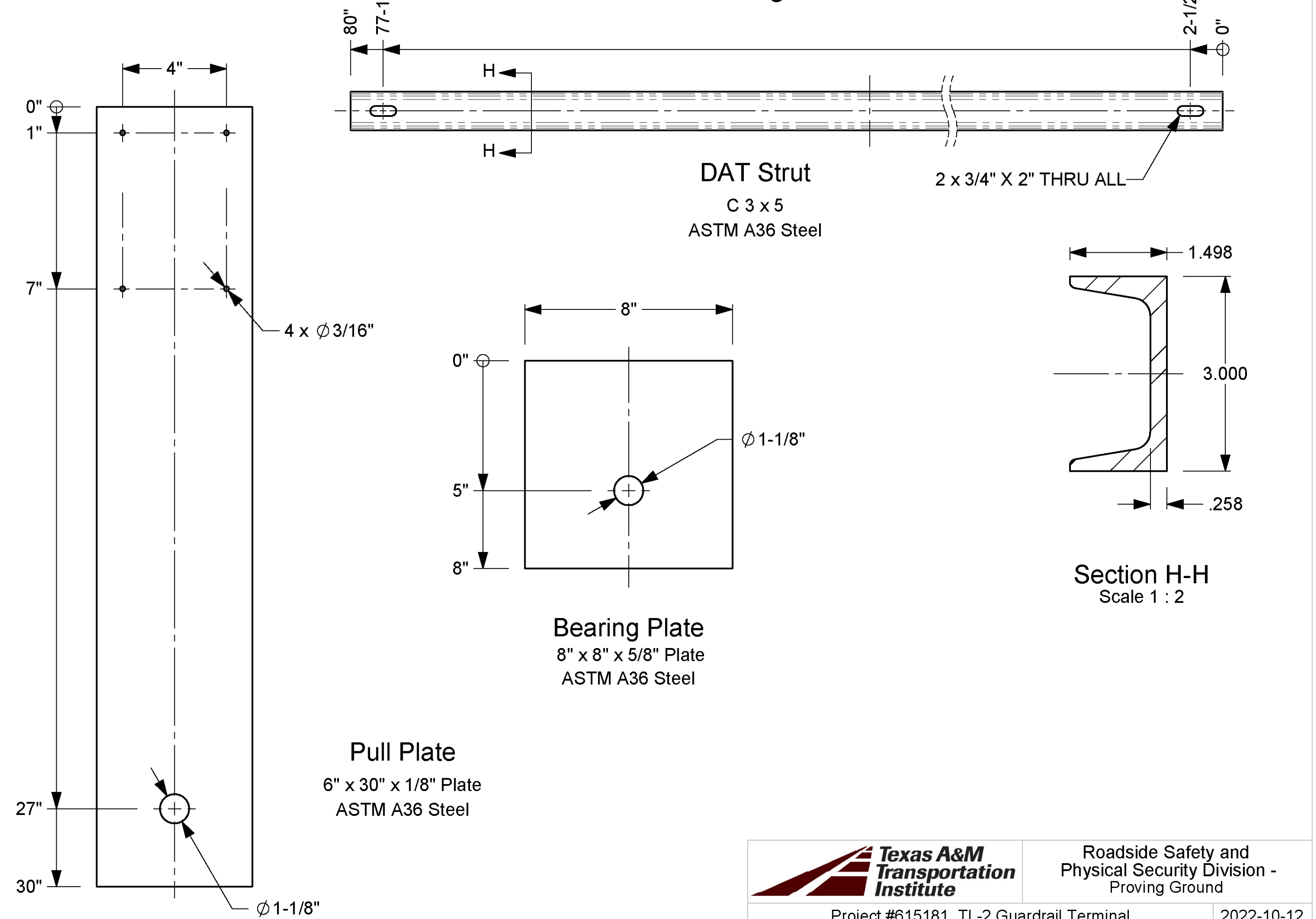
Strut and Bearing Plates

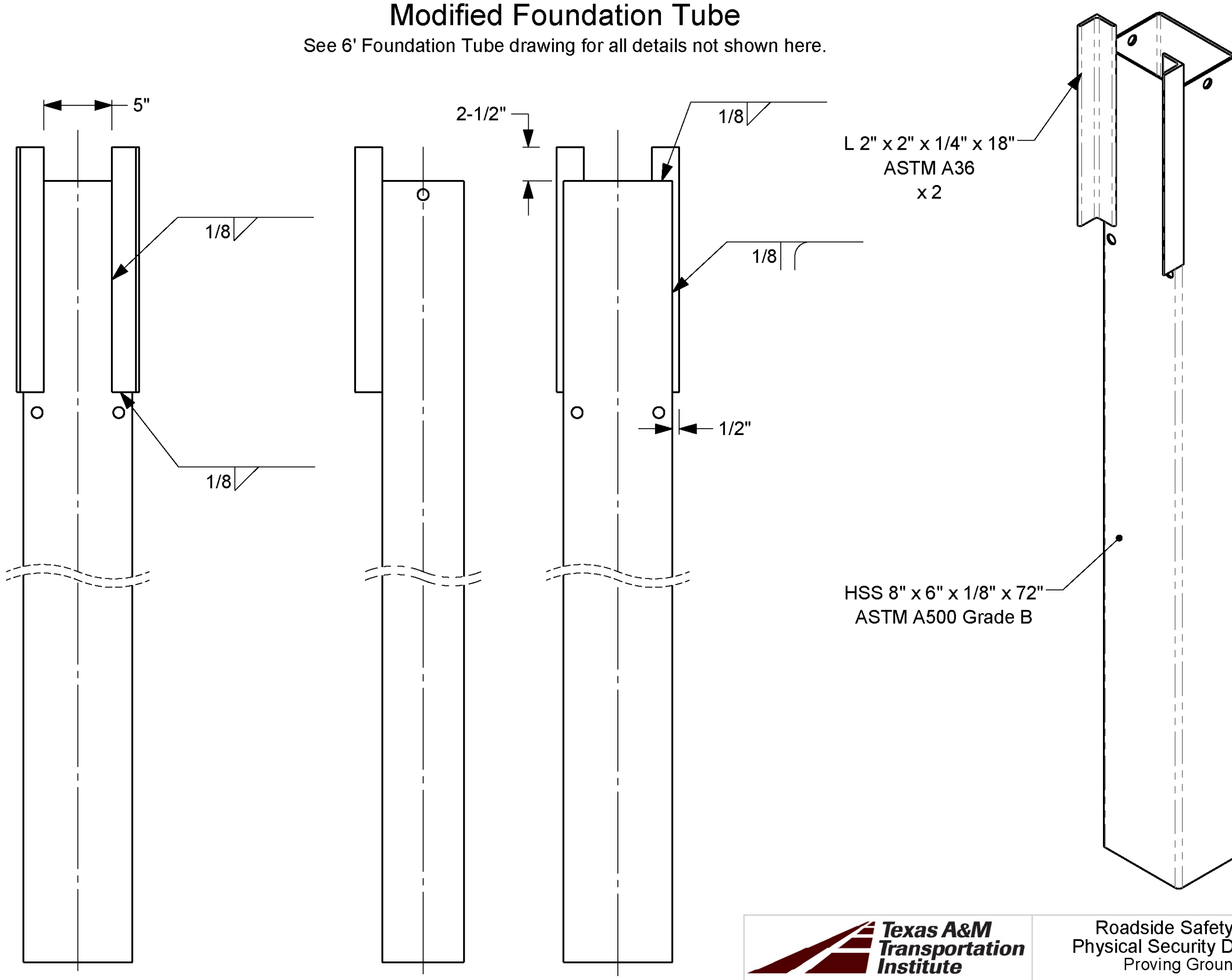


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-10-12
Drawn by GES/WS	Scale 1:5	Sheet 6 of 10 Strut and Bearing Plates

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Oct\2022-10-12\615181 Oct Drawing

Modified Foundation Tube

See 6' Foundation Tube drawing for all details not shown here.



Elevation Views

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-10-12
Drawn by GES/WS	Scale 1:10	Sheet 7 of 10 Modified Foundation Tube

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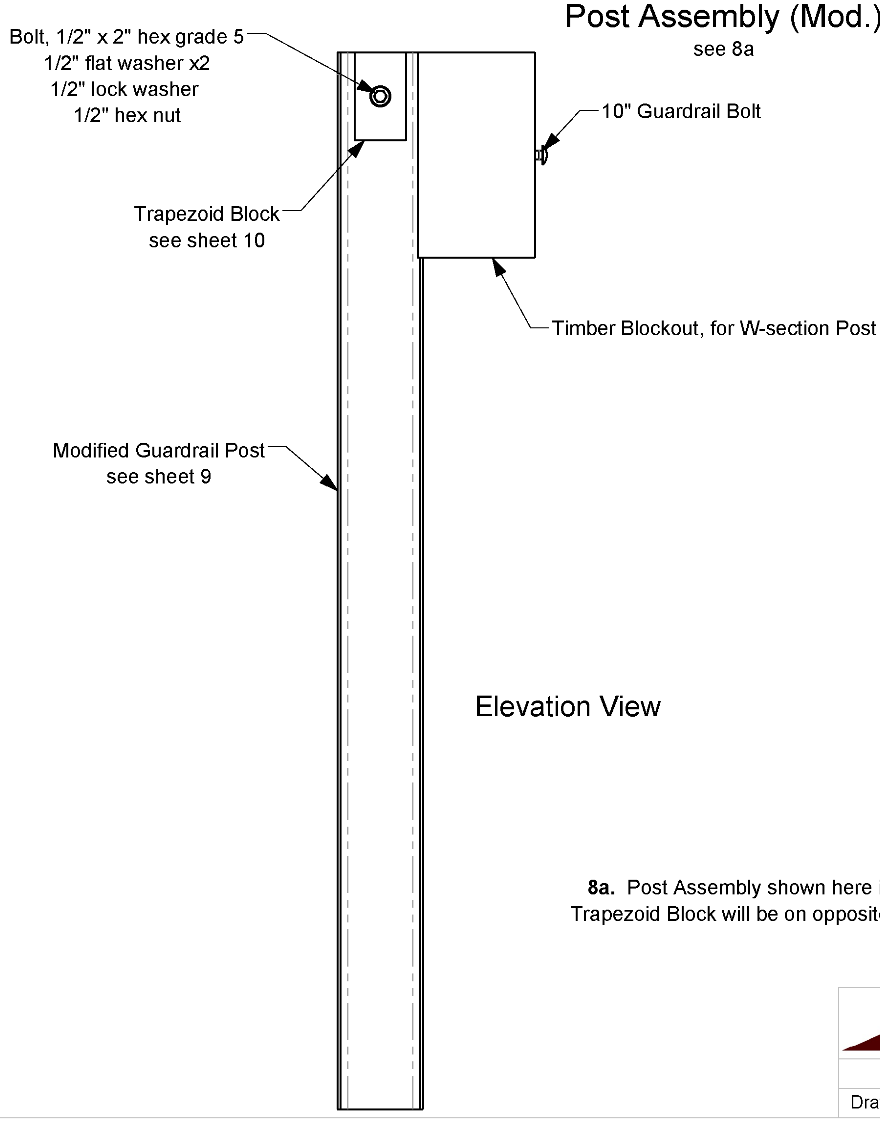
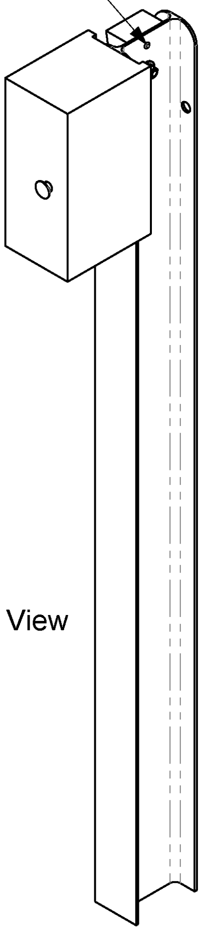
Post Assembly (Mod.)

see 8a



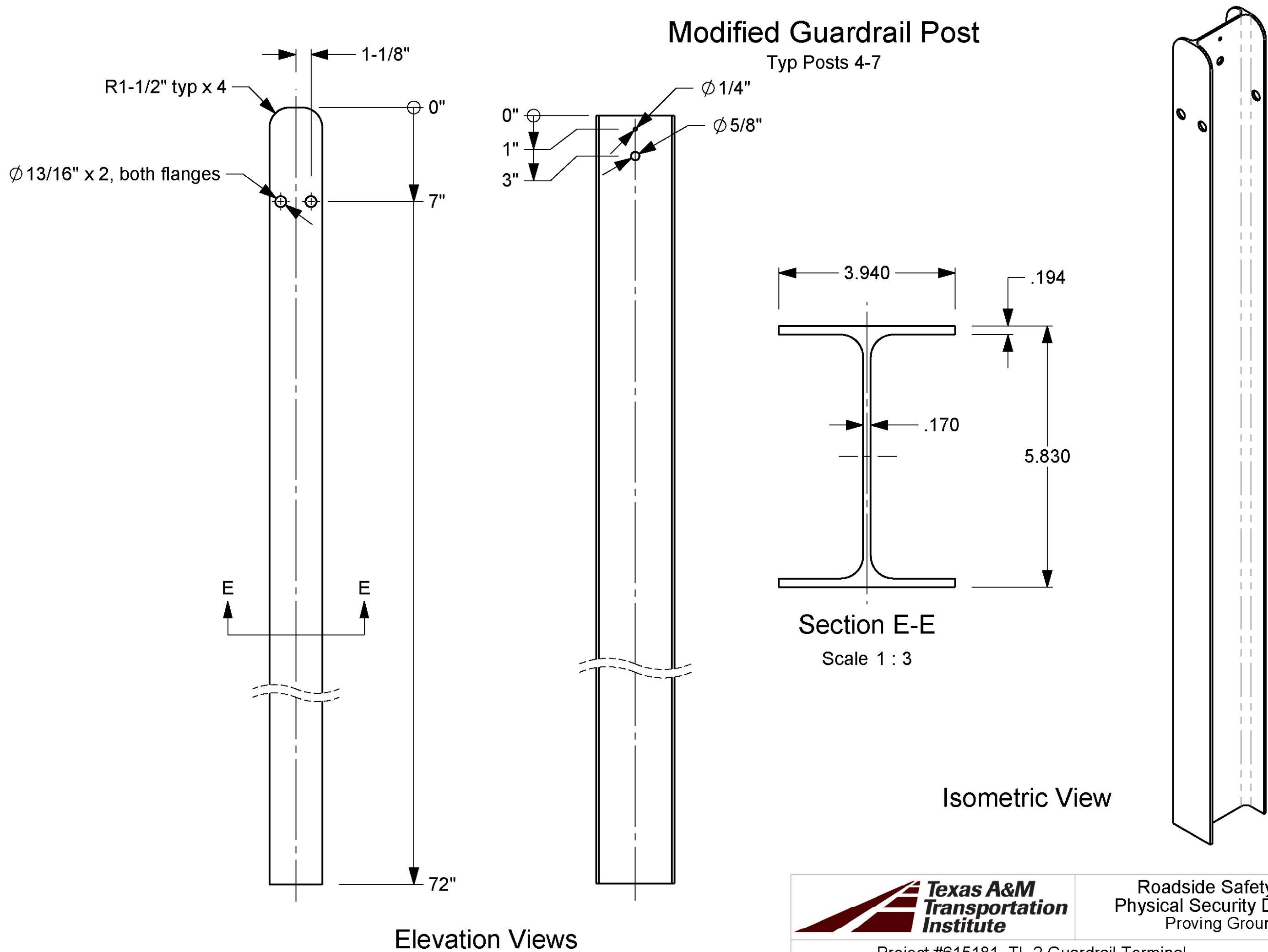


8a. Post Assembly shown here is typical at Posts 4 -7.
Trapezoid Block will be on opposite side of post at Posts 20 - 23.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-10-12
Drawn by GES/WS	Scale 1:10	Sheet 8 of 10 Post Assembly (Mod.)

Modified Guardrail Post

Typ Posts 4-7

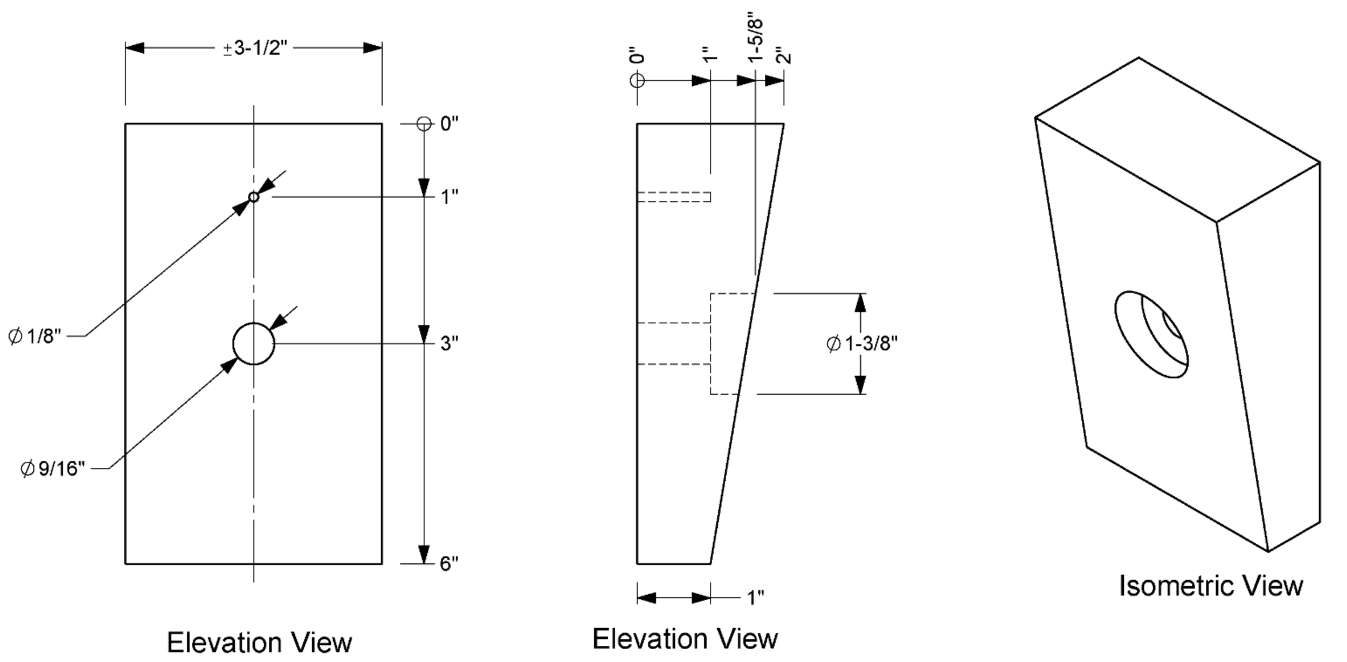


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-10-12
Drawn by GES/WS	Scale 1:10	Sheet 9 of 10 Modified Guardrail Post

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Oct\2022-10-12\615181 Oct Drawing

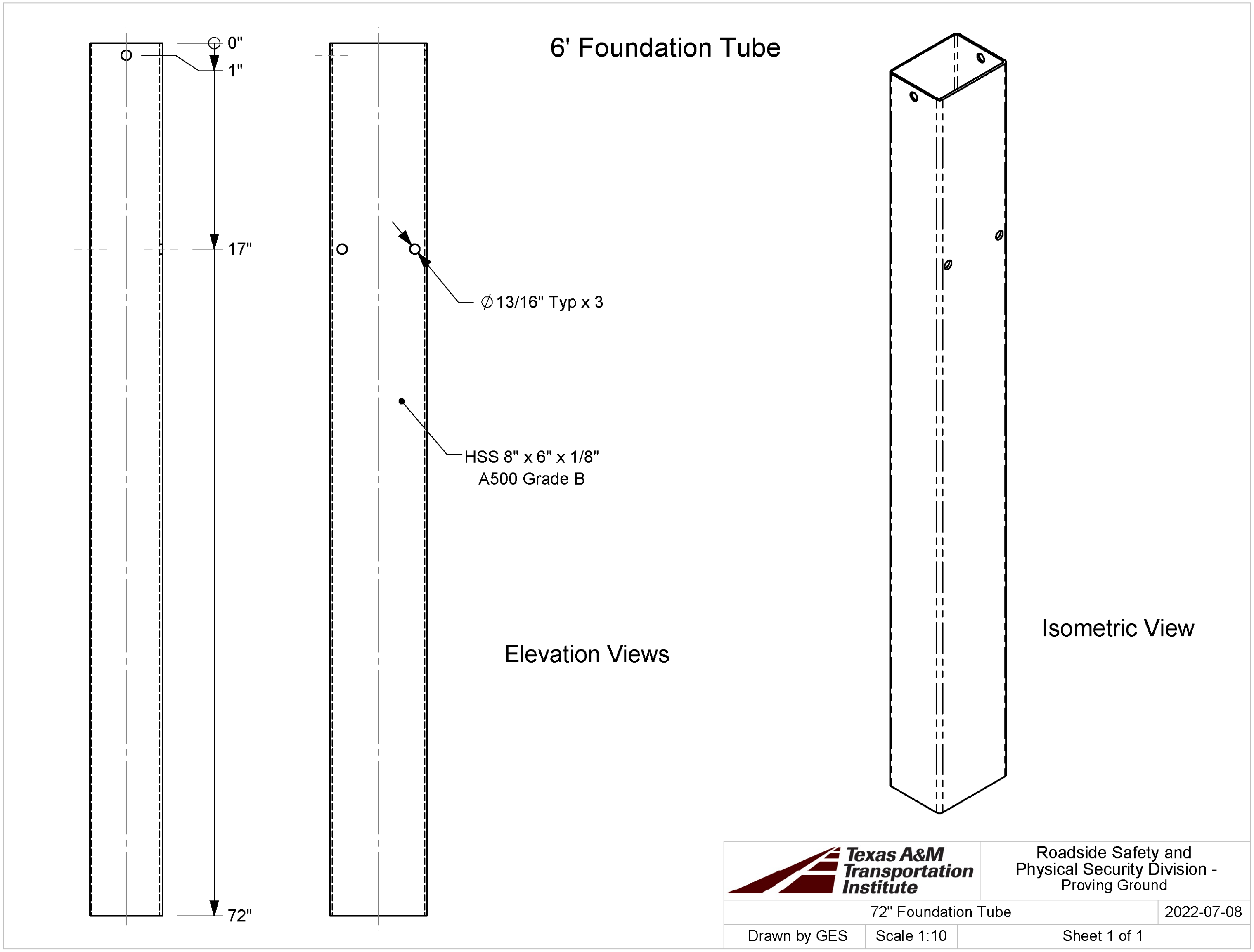
Trapezoid Block

4 x 4 nominal



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615181 TL-2 Guardrail Terminal		2022-10-12
Drawn by GES/WS	Scale 1:2	Sheet 10 of 10 Trapezoid Block

Q:\Accreditation-17025-2017\EIR-000 Project Files\615181-FHWA - Abu-Odeh\Drafting, 615181\Drafting, 615181 Oct\2022-10-12\615181 Oct Drawing



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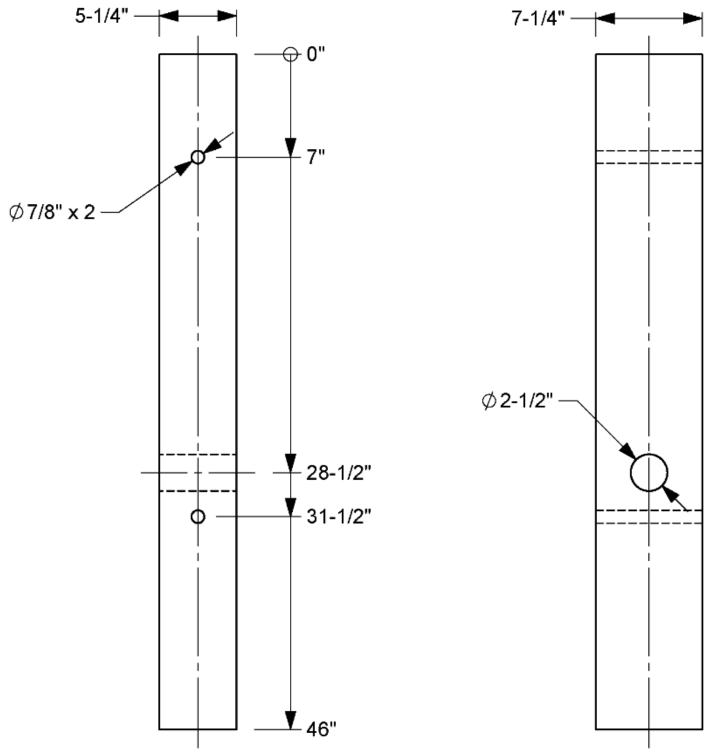
Post, Tube

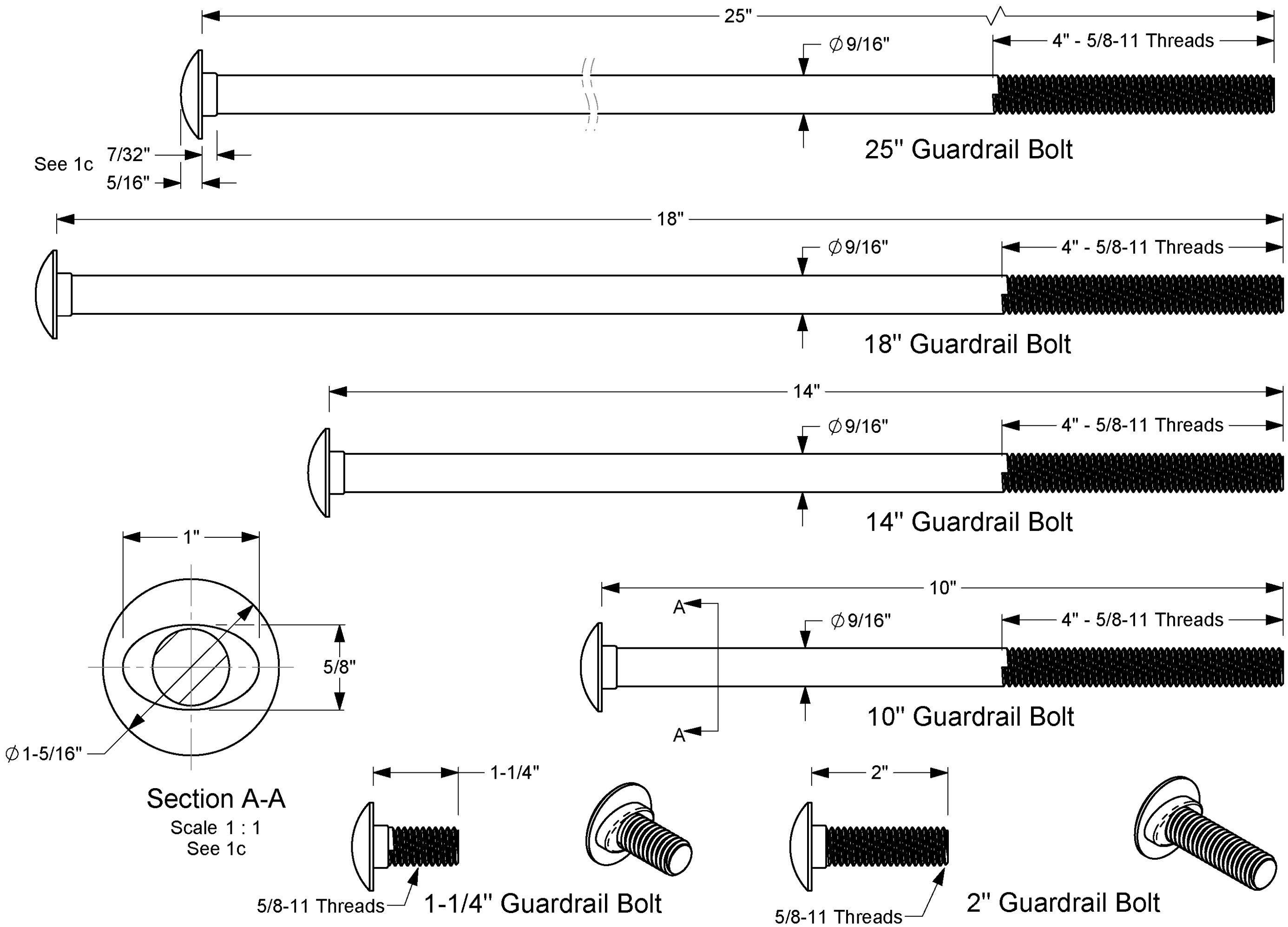


Elevation Views

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

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Tube Post		2022-07-08
Drawn by GES	Scale 1:10	Sheet 1 of 1

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

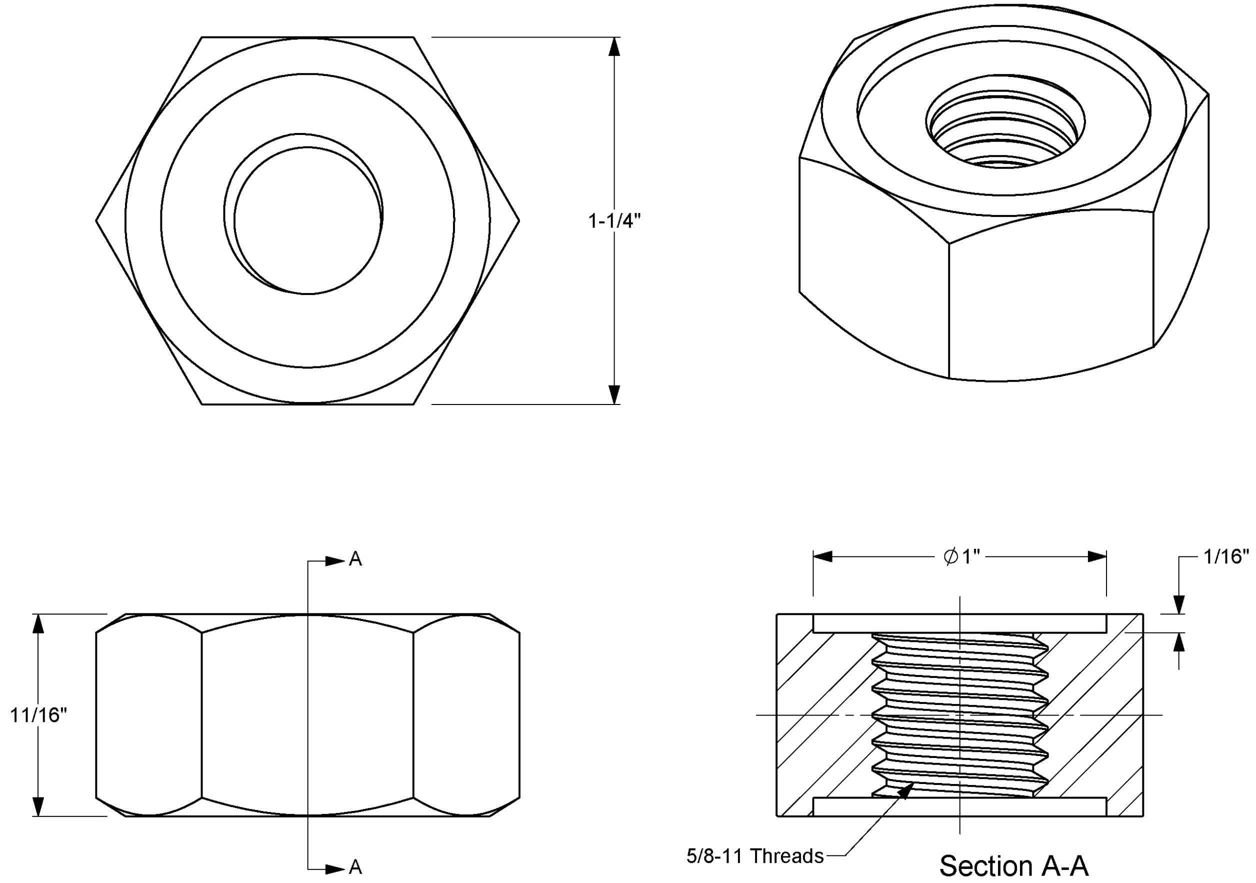


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all lengths.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Guardrail Bolt		2020-07-08
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.

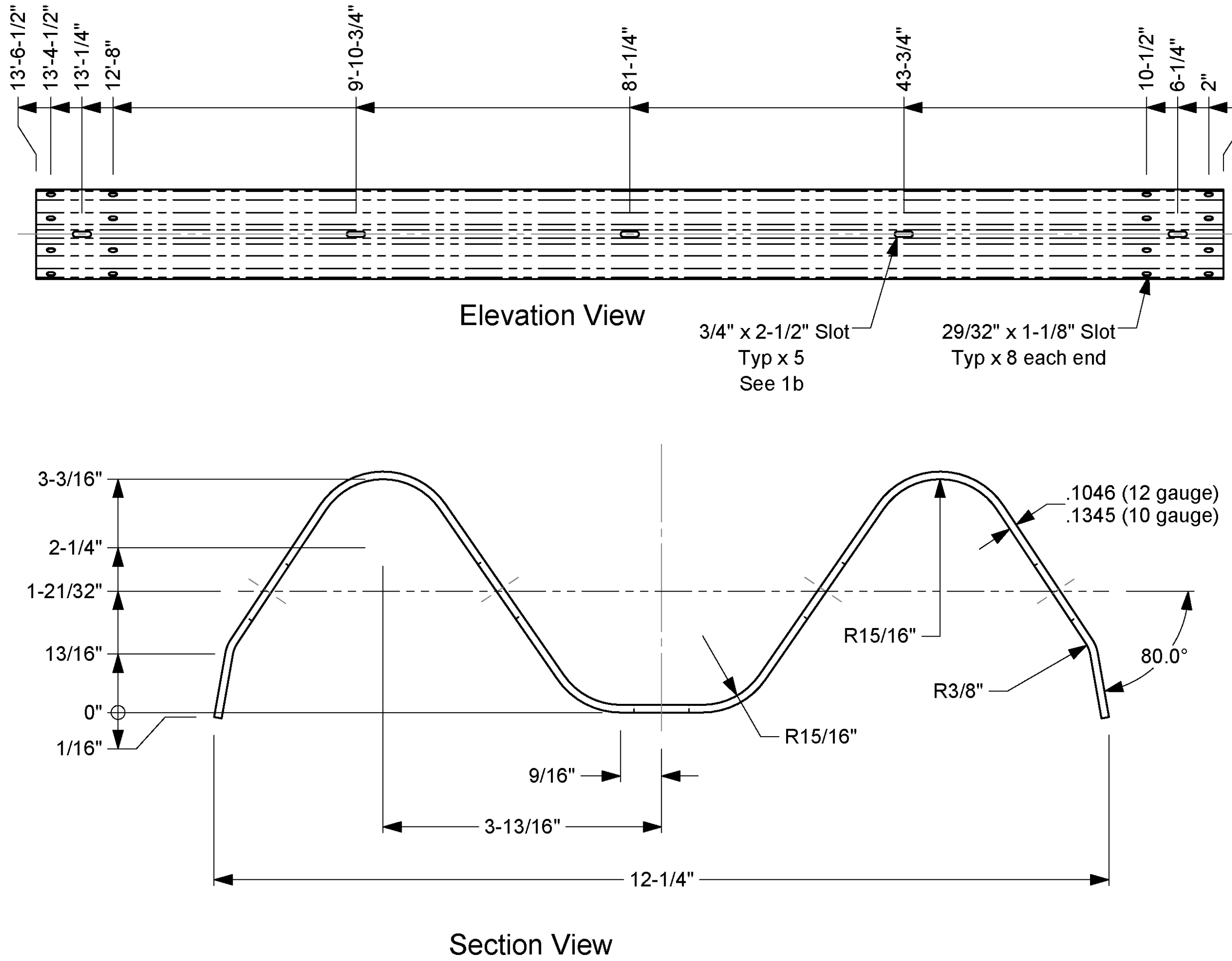
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Recessed Guardrail Nut | 2022-07-18

Drawn by GES | Scale 2:1 | Sheet 1 of 1

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



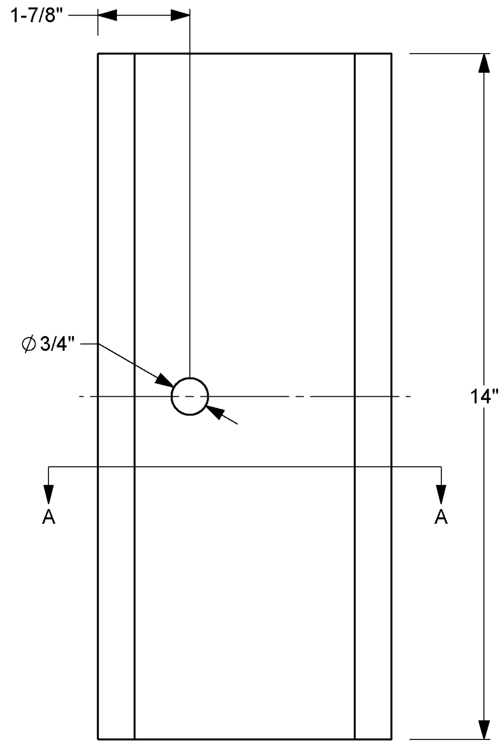
1a. Manufacture per AASHTO M180 specifications.

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.

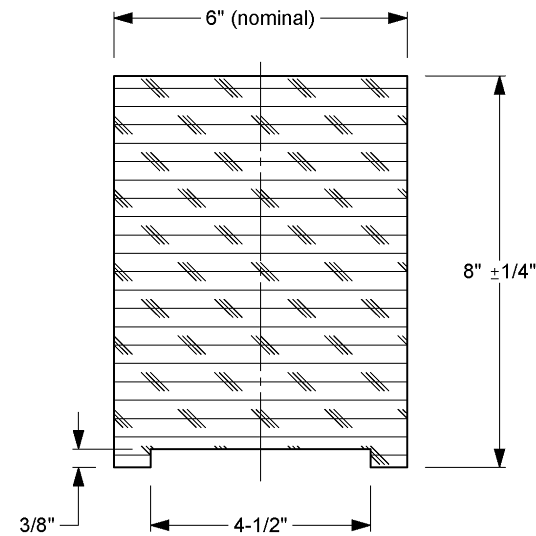
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
W-beam Guardrail		2022-07-13
Drawn by GES	Scale 1:20	Sheet 1 of 1

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

Timber Blockout for W-section Post



Elevation View



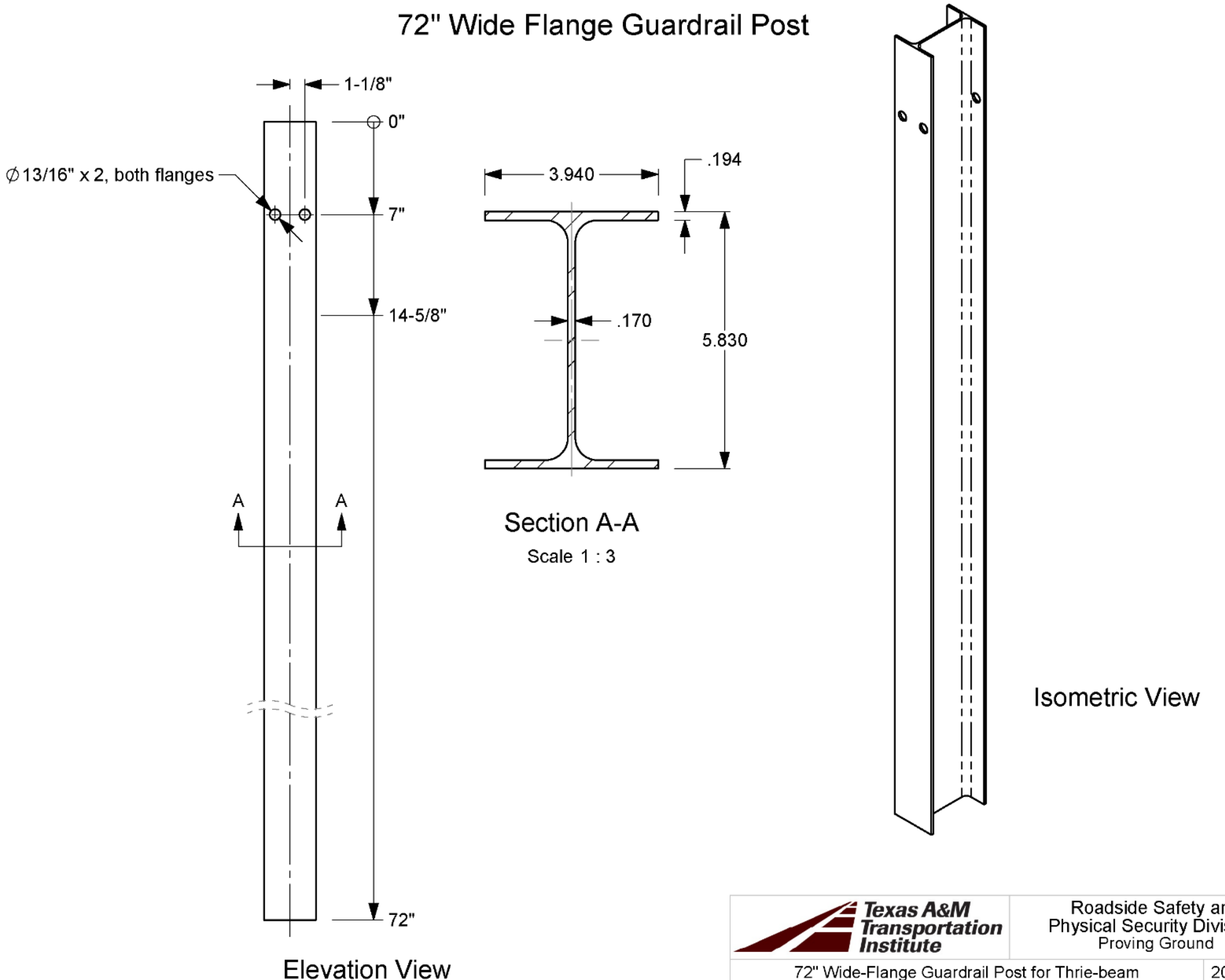
Section A-A

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		2022-07-08
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

72" Wide Flange Guardrail Post

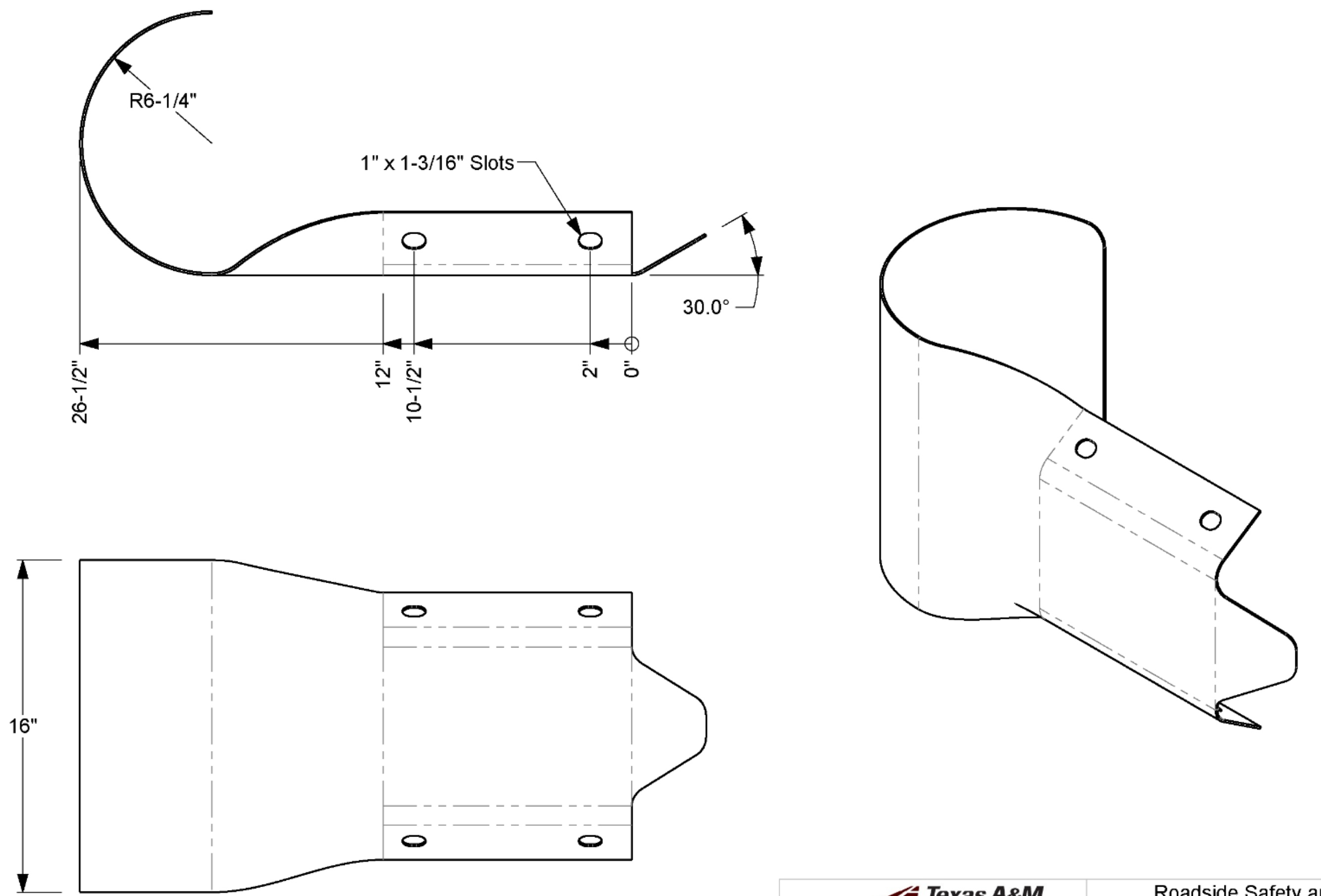


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
72" Wide-Flange Guardrail Post for Thrie-beam		2022-07-08
Drawn by GES	Scale 1:10	Sheet 1 of 1

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

W-beam End Section

12 gauge galvanzied steel



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
W-beam End Section		2022-08-26
Drawn by GES	Scale 1:7	Sheet 1 of 1

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

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

PH 216.676.5600
FX 216.676.6761
www.assemblyspecialty.com

ISO 9001:2008

14700 Brookpark Rd
Cleveland, OH 44135-5166
customerservice@assemblyspecialty.com

Certificate of Conformance

Date: September 9, 2021

To: Texas Transportation Institute
Bldg. 7091
1254 Ave. A
Bryan, TX 77807
Attn: Gary Gerke 979-825-4661

We certify that our system and procedures for the control of quality assures that all items furnished on the order will meet applicable tests, requirements and inspection requirements as required by the purchase order and applicable specifications and drawings.

PURCHASE ORDER #: 615181
DATE SHIPPED: 09/09/2021
ASPI SALES ORDER #: 138027
MANUFACTURER: ASSEMBLY SPECIALTY PRODUCTS, INC.

QTY	CUST P/N	ASPI P/N	ASPI LOT#	DESCRIPTION
20		24-DG07UU-1	113275	Wire Rope Assembly

COMMENTS:

REMARKS:
FITTINGS GALVANIZED IN ACCORDANCE WITH ASTM A-153 CLASS C.
THREADS ARE CLASS 2A FIT PRIOR TO GALVANIZING.
WIRE ROPE MANUFACTURED IN ACCORDANCE WITH AASHTO DESIGNATION: M30-02 and ASTM A741 TYPE 2, CLASS A.

Steel used to manufacture these items was melted & manufactured in the United States of America
All manufacturing processes supplied by or performed by Assembly Specialty Products, Inc. took place in the United States of America

Signature:

Certification and Compliance Manager

PH 216.676.5600
FX 216.676.6761
www.assemblyspecialty.com

ISO 9001:2008

14700 Brookpark Rd
Cleveland, OH 44135-5166
customerservice@assemblyspecialty.com

Certificate of Conformance

PART #: 24-DG07UU-1 LOT#: 113275

We certify that our system and procedures for the control of quality assures that all items furnished on the order will meet applicable tests, requirements and inspection requirements as required by the purchase order and applicable specifications and drawings.

QTY	ASPI P/N	ASPI LOT#	DESCRIPTION
20	24-DG07UU-1	113275	P/N 105310G rev. B, Wire Rope Assembly

LOT: 111034	**Galvanized Threaded Stud Assembly**
Eaton Steel	Heat: 201981 (Hercules, ASI) [swage sleeve]
Eaton Steel	Heat: 202036 (Hercules, ASI) [swage sleeve]
ASPM	Heat: 212287 (Vulcan, ASI) [threaded rod]
Art Galvanizing Works	Galvanizing certificate [swage sleeve & threaded rod assembly]
Ziegler	Heat: 8000007905 (Nucor Fastener, Nucor Steel, Indiana Galv.) Lot 452164B Nut
Ziegler	Heat: 278164 (Prestige, Marathon, AZZ Galv.) Lot E1368 Washer

Wirerope Works:	**Certificate#: AA30965 Reel#: 1248062 [ASPI Reel 13120, 13121, 13122, 13123**
.054"	Heat: OT0021793 Optimus
.040"	Heat: OT0021852 Optimus
061"	Heat: OT0018856 Optimus
.:	Heat: OT0016343 Optimus
.046"	Heat: 20701730 Charter

REMARKS:
FITTINGS GALVANIZED IN ACCORDANCE WITH ASTM A-153 CLASS C.
THREADS ARE CLASS 2A FIT PRIOR TO GALVANIZING.
WIRE ROPE MANUFACTURED IN ACCORDANCE WITH AASHTO DESIGNATION: M30-02 and ASTM A741 TYPE 2, CLASS A.
.

Steel used to manufacture these items was melted & manufactured in the United States of America
All manufacturing processes supplied by or performed by Assembly Specialty Products, Inc. took place in the United States of America

Signature: ______________
Certification and Compliance Manager

Eaton Steel Bar Company Inspection Certificate 1941957 — EN 10204:2004-3.1

Customer	BOL	Ship Date	Customer PO	Item	Customer Item	Item Description
ASSEMBLY SPECIALTY PRODUCTS	260065	09-Jun-2021	44395	1013955 rev 003		1-5/8 CD RD 1035 12ft1in SBQ CF2 FG MT VR

All bundles listed below were produced using steel from Heat 201981 issued by ALTON STEEL and were completed from Eaton Steel Job 677056.

Chemistry	Description	Value	Units
C	Carbon	0.33	PWGT
Mn	Manganese	0.83	PWGT
P	Phosphorus	0.023	PWGT
S	Sulfur	0.027	PWGT
Si	Silicon	0.26	PWGT
Ni	Nickel	0.09	PWGT
Cr	Chromium	0.16	PWGT
Mo	Molybdenum	0.02	PWGT
Al	Aluminum	0.001	PWGT
Cu	Copper	0.22	PWGT
V	Vanadium	0.028	PWGT
Nb	Niobium		PWGT
N	Nitrogen	0.0118	PWGT
Cleanliness	**Description**	**Value**	**Units**
MACRO ETCH	No piping/voids/cracks/porosity	Satisfactory	.
SAE J422 SI	SAE J422 Silicate Rating	2.0	NUM
SAE J422 OX	SAE J422 Oxide Rating	1.0	NUM
Geometry	**Description**	**Value**	**Units**
DIAMETER	Diameter	1.6220 - 1.6250	IN
BUNDLE VARIATION	Wean Within Bundle Variation	0 - 2	IN
LENGTH	Length	145.0000 - 150.0000	IN
CF STRAIGHT	Cold Finished Deflection in 10ft.	0.0000 - 0.0625	IN
DEPTH & ANGLE	Chamfer depth & angle.	1/16-1/8 x 45	.
Cold Working	**Description**	**Value**	**Units**
SEAM DEPTH	Allowable Seam Depth	0.0000 - 0.0260	IN
Mill Processing	**Description**	**Value**	**Units**
MELT COUNTRY	Melted in Country	USA	.
ROLLED COUNTRY	Rolled in Country	USA	.
RED RATIO	Reduction Ratio	21.92	RED
ASTM Standard	**Description**	**Value**	**Units**
A29-20	Steel Bars, Carbon & Alloy, Hot Wrought	CONFORMS	.
A108-18	Steel Bars, CF Carbon & Alloy	CONFORMS	.
A576-17	Steel Bars, Carbon, Hot Roll SBQ	CONFORMS	.
Structure	**Description**	**Value**	**Units**
AUST GRAIN SIZE	Austenitic Grain Size	5 - 10	NUM
RPT GRAIN SIZE	Reported Grain Size	Fine Grain	.

Tag Number	Qty	Units	Length
019-2805003	4245	LBS	12FT7IN

Assembly Specialty Products, Inc.
PO#: 44395
REF#: RBC1035C1.625RR
INSP: QUADE
DATE: 06/10/2021

Bundle tags with Eaton Steel identifiers reference the steel grade, heat, purchase order number where applicable, part number, product description and quantity. Material produced in accordance with Eaton Steel's Quality Manual QM-00002 Rev 2 dated 10/15/2018.

We hereby certify the above to be in conformance, and a true copy of data represented in company records. This steel was not subject to weld repair or exposed to mercury while in the possession of Eaton Steel.

Created on 09-Jun-2021
Marc Benjamin, Corporate Metallurgist

10221 Capital Avenue, Oak Park, MI 48237 USA
http://www.eatonsteel.com
Tel: 248-398-3434
Fax: 248-398-1434

CERTIFIED MILL TEST REPORT

ASI ALTON STEEL INC

Alton Steel Test Lab
#5 Cut Street
Alton, IL, 62002-9011
(618) 463-4490 Ext 2486
(618) 463-4491 (Fax)

BILL TO Hercules Drawn
38901 Amrhein Road
Livonia, MI 48150

SHIP TO Hercules Drawn
38901 Amrhein Road
Livonia, MI 48150

Date	11/17/2020	**Customer PO**	154312	**Specifications**
ASI Ord No	106850	**Customer PT**	1005437	SAE 1035
ASI Ord Line No	1			ASTM A29-16, ASTM A576-17

Item Description **Strand Cast, RR = 21.92:1**
Steel Bar, Hot Rolled, 1.6870, 35' 7 "

Heat #	Yield PSI	Tensile PSI	% Elongation	% ROA	Bend Test

CHEMICAL ANALYSIS TEST METHODS ASTM E-415 & E-1019

Heat #	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	Nb/Cb	V	B	Ti	N	Pb	Ca
201981	0.33	0.83	0.023	0.027	0.26	0.22	0.086	0.160	0.024	0.010	0.001	0.002	0.028	0.0002	0.0007	0.0118	0.0028	0.0011

JOMINY HARDENABLITY USING ASTM A-255 CALCULATED FROM CHEMICAL DI

Heat #	GS	DI
201981	7	1.32

SPECIAL TEST RESULTS

	ASTM E-45 Method A								ASTM E-45 Method C		SAE J422		ASTM E-381			Charpy	Hardness				CE
Heat #	TA	TB	TC	TD	HA	HB	HC	HD	S	O	S	O	S	R	C		RC	RB	BHN	BHN2	
201981											2	1	2	4	2						

ADDITIONAL COMMENTS

No mercury, lead, radium, of alpha containing material or equipment is used or deliberately added in the production of this steel. No weld or weld repairs were performed on this material. This Steel is 100% Electric Arc Furnace Melted and Rolled in the U.S.A. Material qualifies as USMCA origination.

Subscribed and sworn to before me, a Notary Public, in and for the county of Madison, State of Illinois

this __________ Day of ____________________

My commission expires____________________

____
(Notary Public)

Alteration or reproduction of this report, except in full, is not allowed without written approval by a representative of Alton Steel Incorporated.

I hereby certify that the above tests are correct as contained in the records of ALTON STEEL INCORPORATED

Quality Leader: Josh Levi

Eaton Steel Bar Company Inspection Certificate 1941958 EN 10204:2004-3.1

Customer	BOL	Ship Date	Customer PO	Item	Customer Item	Item Description
ASSEMBLY SPECIALTY PRODUCTS	280065	09-Jun-2021	44395	1013955 rev 003		1-5/8 CD RD 1035 12ft1in SBQ CF2 FG MT VR

All bundles listed below were produced using steel from Heat 201981 issued by ALTON STEEL and were completed from Eaton Steel Job 884165.

Chemistry	Description	Value	Units
C	Carbon	0.33	PWGT
Mn	Manganese	0.83	PWGT
P	Phosphorus	0.023	PWGT
S	Sulfur	0.027	PWGT
Si	Silicon	0.26	PWGT
Ni	Nickel	0.09	PWGT
Cr	Chromium	0.16	PWGT
Mo	Molybdenum	0.02	PWGT
Al	Aluminum	0.001	PWGT
Cu	Copper	0.22	PWGT
V	Vanadium	0.028	PWGT
Nb	Niobium		PWGT
N	Nitrogen	0.0118	PWGT
Cleanliness	**Description**	**Value**	**Units**
MACRO ETCH	No piping/voids/cracks/porosity	Satisfactory	.
SAE J422 SI	SAE J422 Silicate Rating	2.0	NUM
SAE J422 OX	SAE J422 Oxide Rating	1.0	NUM
Geometry	**Description**	**Value**	**Units**
DIAMETER	Diameter	1.6220 - 1.6250	IN
BUNDLE VARIATION	Wean Within Bundle Variation	0 - 2	IN
LENGTH	Length	145.0000 - 150.0000	IN
CF STRAIGHT	Cold Finished Deflection in 10ft.	0.0000 - 0.0625	IN
DEPTH & ANGLE	Chamfer depth & angle.	1/16-1/8 x 45	.
Cold Working	**Description**	**Value**	**Units**
SEAM DEPTH	Allowable Seam Depth	0.0000 - 0.0260	IN
Mill Processing	**Description**	**Value**	**Units**
MELT COUNTRY	Melted in Country	USA	.
ROLLED COUNTRY	Rolled in Country	USA	.
RED RATIO	Reduction Ratio	21.92	RED
ASTM Standard	**Description**	**Value**	**Units**
A29-20	Steel Bars, Carbon & Alloy, Hot Wrought	CONFORMS	.
A108-18	Steel Bars, CF Carbon & Alloy	CONFORMS	.
A576-17	Steel Bars, Carbon, Hot Roll SBQ	CONFORMS	.
Structure	**Description**	**Value**	**Units**
AUST GRAIN SIZE	Austenitic Grain Size	5 - 10	NUM
RPT GRAIN SIZE	Reported Grain Size	Fine Grain	.

Tag Number	Qty	Units	Length
019-2904914	4244	LBS	12FT6IN
019-2904923	4245	LBS	12FT6IN
019-2904935	4245	LBS	12FT6IN
019-2904938	4245	LBS	12FT6IN
019-2904998	4245	LBS	12FT6IN
019-2905012	4245	LBS	12FT6IN
019-2910668	2196	LBS	12ft6in
019-2927354	4072	LBS	12FT6IN

Bundle tags with Eaton Steel identifiers reference the steel grade, heat, purchase order number where applicable, part number, product description and quantity. Material produced in accordance with Eaton Steel's Quality Manual QM-00002 Rev 2 dated 10/15/2018.

We hereby certify the above to be in conformance, and a true copy of data represented in company records. This steel was not subject to weld repair or exposed to mercury while in the possession of Eaton Steel.

Created on 09-Jun-2021
Marc Benjamin, Corporate Metallurgist

10221 Capital Avenue, Oak Park, MI 48237 USA
http://www.eatonsteel.com
Tel: 248-398-3434
Fax: 248-398-1434

CERTIFIED MILL TEST REPORT

ASI ALTON STEEL INC

Alton Steel Test Lab
#5 Cut Street
Alton, IL, 62002-9011
(618) 463-4490 Ext 2486
(618) 463-4491 (Fax)

BILL TO Hercules Drawn
38901 Amrhein Road
Livonia, MI 48150

SHIP TO Hercules Drawn
38901 Amrhein Road
Livonia, MI 48150

Date	11/17/2020	**Customer PO**	154312	**Specifications**
ASI Ord No	106850	**Customer PT**	1005437	SAE 1035
ASI Ord Line No	1			ASTM A29-16, ASTM A576-17

Item Description Strand Cast, RR = 21.92:1
Steel Bar, Hot Rolled, 1.6870, 35' 7 "

Heat #	Yield PSI	Tensile PSI	% Elongation	% ROA	Bend Test

CHEMICAL ANALYSIS TEST METHODS ASTM E-415 & E-1019

Heat #	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	Nb/Cb	V	B	Ti	N	Pb	Ca
201981	0.33	0.83	0.023	0.027	0.26	0.22	0.086	0.160	0.024	0.010	0.001	0.002	0.028	0.0002	0.0007	0.0118	0.0028	0.0011

JOMINY HARDENABLITY USING ASTM A-255 CALCULATED FROM CHEMICAL DI

Heat #	GS	DI
201981	7	1.32

SPECIAL TEST RESULTS

	ASTM E-45 Method A								ASTM E-45 Method C		SAE J422		ASTM E-381			Charpy	Hardness				CE
Heat #	TA	TB	TC	TD	HA	HB	HC	HD	S	O	S	O	S	R	C		RC	RB	BHN	BHN2	
201981											2	1	2	4	2						

ADDITIONAL COMMENTS

No mercury, lead, radium, of alpha containing material or equipment is used or deliberately added in the production of this steel. No weld or weld repairs were performed on this material. This Steel is 100% Electric Arc Furnace Melted and Rolled in the U.S.A. Material qualifies as USMCA origination.

Subscribed and sworn to before me, a Notary Public, in and for the county of Madison, State of Illinois

this ________ Day of ________________

My commission expires________________

____
(Notary Public)

I hereby certify that the above tests are correct as contained in the records of ALTON STEEL INCORPORATED

Quality Leader: Josh Levi

Josh Levi

Eaton Steel Bar Company Inspection Certificate 1928915 EN 10204:2004-3.1

Customer	BOL	Ship Date	Customer PO	Item	Customer Item	Item Description
ASSEMBLY SPECIALTY PRODUCTS	276830	12-Apr-2021	44395	1013955 rev 003		1-5/8 CD RD 1035 12ft6in SBQ CF2 FG MT VR

All bundles listed below were produced using steel from Heat 202036 issued by ALTON STEEL and were completed from Eaton Steel Job 880948.

Chemistry	Description	Value	Units
C	Carbon	0.33	PWGT
Mn	Manganese	0.85	PWGT
P	Phosphorus	0.020	PWGT
S	Sulfur	0.032	PWGT
Si	Silicon	0.26	PWGT
Ni	Nickel	0.08	PWGT
Cr	Chromium	0.18	PWGT
Mo	Molybdenum	0.03	PWGT
Al	Aluminum	0.000	PWGT
Cu	Copper	0.25	PWGT
V	Vanadium	0.029	PWGT
Cb	Columbium	0.002	PWGT
N	Nitrogen	0.0108	PWGT
Cleanliness	**Description**	**Value**	**Units**
MACRO ETCH	No piping/voids/cracks/porosity	Satisfactory	.
SAE J422 SI	SAE J422 Silicate Rating	1.0	NUM
SAE J422 OX	SAE J422 Oxide Rating	1.0	NUM
Geometry	**Description**	**Value**	**Units**
DIAMETER	Diameter	1.6220 - 1.6250	IN
BUNDLE VARIATION	Wean Within Bundle Variation	0 - 2	IN
LENGTH	Length	146.0000 - 154.0000	IN
CF STRAIGHT	Cold Finished Deflection in 10ft.	0.0000 - 0.0625	IN
DEPTH & ANGLE	Chamfer depth & angle.	1/16-1/8 x 45	.
Cold Working	**Description**	**Value**	**Units**
SEAM DEPTH	Allowable Seam Depth	0.0000 - 0.0260	IN
Mill Processing	**Description**	**Value**	**Units**
MELT COUNTRY	Melted in Country	USA	.
ROLLED COUNTRY	Rolled in Country	USA	.
RED RATIO	Reduction Ratio	21.92	RED
ASTM Standard	**Description**	**Value**	**Units**
A29/A29M-12	Steel Bars, Carbon & Alloy, Hot-Wrought	CONFORMS	.
A108-18	Steel Bars, CF Carbon & Alloy	CONFORMS	.
A576-17	Steel Bars, Carbon, Hot Roll SBQ	CONFORMS	.
Structure	**Description**	**Value**	**Units**
AUST GRAIN SIZE	Austenitic Grain Size	5 10	NUM
RPT GRAIN SIZE	Reported Grain Size	Fine Grain	.

Tag Number	Qty	Units	Length
019-2868260	4226	LBS	12FT6IN
019-2868261	4226	LBS	12FT6IN
019-2868263	4227	LBS	12FT6IN
019-2868489	4227	LBS	12FT6IN
019-2868492	4228	LBS	12FT6IN
019-2868493	4226	LBS	12FT6IN
019-2868517	4228	LBS	12FT6IN
019-2868559	4228	LBS	12FT6IN
019-2868560	4223	LBS	12FT6IN

Assembly Specialty Products, Inc
PO#: 44395
REF#: RBC1035C1.625RR
INSP: QUADE
DATE: 04/13/2021

RECEIVED
13 APR 2021

Bundle tags with Eaton Steel identifiers reference the steel grade, heat, purchase order number where applicable, part number, product description and quantity. Material produced in accordance with Eaton Steel's Quality Manual QM-00002 Rev 2 dated 10/15/2018.

We hereby certify the above to be in conformance, and a true copy of data represented in company records. This steel was not subject to weld repair or exposed to mercury while in the possession of Eaton Steel.

Created on 12-Apr-2021
Marc Benjamin, Corporate Metallurgist

M. B.

10221 Capital Avenue, Oak Park, MI 48237 USA
http://www.eatonsteel.com
Tel: 248-398-3434
Fax: 248-398-1434

CERTIFIED MILL TEST REPORT

ASI ALTON STEEL INC

Alton Steel Test Lab
#5 Cut Street
Alton, IL, 62002-9011
(618) 463-4490 Ext 2486
(618) 463-4491 (Fax)

BILL TO Hercules Drawn
38901 Amrhein Road
Livonia, MI 48150

SHIP TO Hercules Drawn
38901 Amrhein Road
Livonia, MI 48150

Date	01/07/2021	**Customer PO**	155062	**Specifications**
ASI Ord No	107727	**Customer PT**	1005437	SAE 1035
ASI Ord Line No	1			ASTM A29-20, ASTM A576-17

Item Description
Steel Bar, Hot Rolled, 1.6870, 35' 7 "

Strand Cast, RR = 21.92:1

Heat #	Yield PSI	Tensile PSI	% Elongation	% ROA	Bend Test

CHEMICAL ANALYSIS TEST METHODS ASTM E-415 & E-1019

Heat #	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	Nb/Cb	V	B	Ti	N	Pb	Ca
202036	0.33	0.85	0.020	0.032	0.26	0.25	0.078	0.179	0.025	0.010	0.000	0.002	0.029	0.0002	0.0009	0.0108	0.0036	0.0018

JOMINY HARDENABLITY USING ASTM A-255 CALCULATED FROM CHEMICAL DI

Heat #	GS	DI
202036	7	1.40

SPECIAL TEST RESULTS

	ASTM E-45 Method A								ASTM E-45 Method C		SAE J422		ASTM E-381			Charpy	Hardness				CE
Heat #	TA	TB	TC	TD	HA	HB	HC	HD	S	O	S	O	S	R	C		RC	RB	BHN	BHN2	
202036											1	1	1	1	2						

ADDITIONAL COMMENTS

No mercury, lead, radium, of alpha containing material or equipment is used or deliberately added in the production of this steel. No weld or weld repairs were performed on this material. This Steel is 100% Electric Arc Furnace Melted and Rolled in the U.S.A. Material qualifies as USMCA origination.

Subscribed and sworn to before me, a Notary Public, in and for the county of Madison, State of Illinois

this ______ Day of ____________

My commission expires____________

(Notary Public)

I hereby certify that the above tests are correct as contained in the records of ALTON STEEL INCORPORATED

Quality Leader: Josh Levi

Josh Levi

Vulcan Threaded Products
10 Cross Creek Trail
Pelham, AL 35124
Tel (205) 620-5100
Fax (205) 620-5150

JOB MATERIAL CERTIFICATION

Job No: 708961 **Job Information** **Certified Date:** 4/15/21

Containers: S18339047 S18357413

Customer: American Specialty Products and Machine Inc.

Ship To: 11937 Hwy 25
Calera, AL 35040

Vulcan Part No: ATR A449 1x12

Customer Part No: ATR A449 1x12

Customer PO No: 3073

Shipped Qty: 400 pcs

Order No: 422892

Line No: 2

Note:

Applicable Specifications

Type	Specification	Rev	Amend	Option
-	ASTM A449 Type 1	2014		

Test Results

See following pages for tests

Certified Chemical Analysis

Heat No: 212287 **Origin**: USA

C	Mn	P	S	Si	Cu	Ni	Cr	Mo
0.47	0.80	0.015	0.028	0.21	0.26	0.10	0.14	0.03
V	**Sn**	**Nb**	**Al**	**Ti**	**N**	**B**	**RR**	
0.005	0.014	0.024	0.003	0.001	0.0103	0.0002	66.58:1	

Notes

Processed material is Tempered - Stress Relieved. No weld repair performed on the material. No Mercury used in the production of this material. Melted and Manufactured in the USA.
EAF Melted

Plex 4/15/21 8:33 AM vulc.sano Page 1 of 2

Vulcan THREADED PRODUCTS, INC.

Vulcan Threaded Products
10 Cross Creek Trail
Pelham, AL 35124
Tel (205) 620-5100
Fax (205) 620-5150

JOB MATERIAL CERTIFICATION

Job No: 708961 **Job Information** **Certified Date:** 4/15/21

Containers: S18339047 S18357413

Test Results

Part No: BAR A449 .913x288

Test No: 64866 **Test**: Quench & Temper Information (Lbs)

Description	Austenitizing Temp (F)	Tempering Temp (F)	Run Speed (Ft/min)	Quench Water Temp (F)	Note
Quench & Temper Information Results	1,613	1,316	40	90	

Test No: 64867 **Test**: A449 Requirements

Description	Tensile (ksi)	Yield 0.2% (ksi)	Elongation (%)	Elongation Gage Length (4D)	ROA (%)	Midradius Hardness	Surface Hardness	Center Hardness	Hardness Test Type	Note
	138	124	17	4D	47	29	30	28	HRC	
	136	121	17	4D	46	28	30	28	HRC	
	136	121	18	4D	46	28	30	28	HRC	
	136	121	18	4D	48	28	30	28	HRC	
	137	122	17	4D	47	28	30	28	HRC	

The reported test results conform to the specifications listed above.
The reported test results are the actual values measured on the samples taken from the production lot.
Material was manufactured, tested, and inspected as required by the product standard and in accordance with Vulcans ISO 9001:2015 Quality Management System registered June 30th, 2017.
Vulcan Steel Products lab is ISO 17025:2017 accredited for tensile, Brinell and Rockwell hardness, Charpy impact, and carb/decarb testing.
Material was tested in accordance with the current revision of ASTM A370, F606, and F2328 test methods.
This test report shall not be reproduced or distributed, except in full, nor shall it be modified in any way without the written permission of Vulcan Steel Products.
Document is in accordance with EN 10204 - 3.1B of 2004 (3.1).

Sallie Norwood 4/15/21

Norwood, Sallie - Certification Engineer Date

Plex 4/15/21 8:33 AM vulc.sano Page 2 of 2

CERTIFIED MILL TEST REPORT

ASI ALTON STEEL INC

Alton Steel Test Lab
#5 Cut Street
Alton, IL, 62002-9011
(618) 463-4490 Ext 2486
(618) 463-4491 (Fax)

BILL TO Vulcan Threaded Products Inc.
P.O. Box 509
#10 Crosscreek Trail
Pelham, AL 35124

SHIP TO Vulcan Threaded Products Inc.(cust truck
Building #10
#10 Crosscreek Trail
Pelham, AL 35124

Date 03/17/2021	**Customer PO**	P281217	**Specifications**	
ASI Ord No 109781	**Customer PT**	RMB 1045 .9688x534	SAE 1045	
ASI Ord Line No 1			ASTM A29-20	

Item Description **Strand Cast, RR = 66.58:1**
Steel Bar, Hot Rolled, 0.9680, 44' 6 "

Heat #	Yield PSI	Tensile PSI	% Elongation	% ROA	Bend Test

CHEMICAL ANALYSIS TEST METHODS ASTM E-415 & E-1019

Heat #	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	Nb/Cb	V	B	Ti	N	Pb	Ca
212287	0.47	0.80	0.015	0.028	0.21	0.26	0.097	0.140	0.031	0.014	0.003	0.024	0.005	0.0002	0.0006	0.0103	0.0013	0.0022

JOMINY HARDENABLITY USING ASTM A-255 CALCULATED FROM CHEMICAL DI

Heat #	GS	DI
212287	7	1.00

SPECIAL TEST RESULTS

ADDITIONAL COMMENTS

No mercury, lead, radium, of alpha containing material or equipment is used or deliberately added in the production of this steel. No weld or weld repairs were performed on this material. This Steel is 100% Electric Arc Furnace Melted and Rolled in the U.S.A. Material qualifies as USMCA origination.

Subscribed and sworn to before me, a Notary Public, in and for the county of Madison, State of Illinois

this ________ Day of ____________________

My commission expires____________________

____
(Notary Public)

Alteration or reproduction of this report, except in full, is not allowed without written approval by a representative of Alton Steel Incorporated.

I hereby certify that the above tests are correct as contained in the records of ALTON STEEL INCORPORATED

Quality Leader: Josh Levi

CERTS

Assembly Specialty Products, Inc.
PO#: 45214
REF#: C-1208-A449 BATCH 111034
INSP: QUADE
DATE: 07/15/2021

DATE: 7/15/2021

THE ART GALVANIZING WKS., INC.

3935 VALLEY ROAD-CLEVELAND,OHIO 44109 PHONE 216-749-0020

PACKING SLIP/CERTIFICATIONS

TO: ASSEMBLY SPECIALTY PRODUCTS PO# 45214

NOTE: THE FOLLOWING MATERIAL HAS BEEN HOT DIP GALVANIZED TO ASTM A 153/F2329 OR ASTM A 123 (LATEST REVISION) SPECIFICATION AS APPLICABLE. A COPY OF OF THE ABOVE PURCHASE ORDER IS AN INTEGRAL PART OF THIS CERTIFICATION AND SHOULD BE ATTACHED. ALL PRODUCT GALVANIZED IN THE USA.

C1208-A449 1X14-1/4 THRD SLEEVE ROD
LOT#111034 3000 PCS
C1680 SLEEVE HT#201981/202036 C1681
THRD ROD HT#212287

GALV WEIGHT		12218#	GALV WEIGHT		GALV WEIGHT	
INCHES	OZ/SQ FT		INCHES	OZ/SQ FT	INCHES	OZ/SQ FT
0.0026	1.53			0.00	0	0.00
0.0034	2.00			0.00	0	0.00
0.0022	1.29			0.00	0	0.00
0.0036	2.12			0.00	0	0.00
0.0038	2.24			0.00	0	0.00
AVG	1.84		*AVG*	0.00	*AVG*	0.00

GALV WEIGHT		**GALV WEIGHT**		GALV WEIGHT	
INCHES	OZ/SQ FT	INCHES	OZ/SQ FT	INCHES	OZ/SQ FT
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
AVG	0.00	*AVG*	0.00	*AVG*	0.00

GALV WEIGHT		**GALV WEIGHT**		GALV WEIGHT	
INCHES	OZ/SQ FT	INCHES	OZ/SQ FT	INCHES	OZ/SQ FT
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
AVG	0.00	*AVG*	0.00	AVG	0.00

Page 1 Tammy L. Schroll

ZIEGLER BOLT AND NUT HOUSE

MAILING ADDRESS: PO BOX 80369 STA. C, CANTON OH 44708, FED. ID. 34-0968850
MAIN WAREHOUSE: 4848 CORPORATE ST SW, CANTON OH 44706, PH: 800-362-0628, FAX: 330-478-2031
MIDDLETOWN: 4401 LEFFERSON RD, MIDDLETOWN OH 45044, PH: 513-727-1963, FAX: 513-727-4733
DOVER: 2120 ST RTE 39 NW, DOVER OH 44622, PH: 330-343-3376, FAX: 330-343-3336
DELPHOS: 610 SEVENTH ST E, DELPHOS OH 45833, PH: 419-695-9005, FAX: 419-695-2020

WWW.ZIEGLERBOLT.COM

ISO 9002:2008
CERTIFICATION #00.129.2
CERTIFICATE OF COMPLIANCE

Assembly Specialty Products, Inc.
PO#: 45003
REF: NUT-HXH32CG
DATE: 07/23/2021
INSP: Quade

To: ASSEMBLY SPECIALTY
14700 BROOKPARK ROAD
CLEVELAND, OH 44135-5166

We certify that our system and procedures for the control of quality assures that all items furnished on the order will meet applicable tests, process requirements and inspection requirements as required by the purchase order and applicable specification and drawings.

P.O. # 45003-2
Job #
Date Shipped: 7/23/2021
Shipped Via: ZIEGLER DELIVERY
Internal Order # 1580406

2500 PCS. 1-8 HEAVY HEX NUT DOMESTI A563 DH HD. GALV.
LOT# 452164B HEAT# 8000007905
ZBN# 100CNHHGH/DOM-9244 PART# NUT-HXH32CG

MELTED & MANUFACTURED IN THE USA

NOTARIAL SEAL STATE OF OHIO
LISA F. GOODING
Notary Public, State of Ohio
My Commission Expires 03-31-2023
Lisa F. Gooding

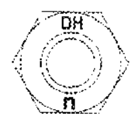
Signature: Bridget Hartong
Title: CERTIFICATION CLERK
Date: JULY 21, 2021

NUCOR
FASTENER DIVISION

LOT NO.
452164B

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
322 ZIEGLER BOLT & NUT   NUCOR ORDER #   262747
TEST REPORT SERIAL#   FB667889   CUST PART #   100CNHHGH
TEST REPORT ISSUE DATE   4/19/21
DATE SHIPPED   5/25/21   CUSTOMER P.O. # 16203162
NAME OF LAB SAMPLER: RYAN UNGER, LAB TECHNICIAN



*****************CERTIFIED MATERIAL TEST REPORT*****************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175647	49600	452164B	1-8 GR DH HV H.D.G.

MANUFACTURE DATE 2/25/21   HEX NUT H.D.G./GREEN LUBE

--CHEMISTRY   MATERIAL GRADE -1045L

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM034641	8000007905	.44	.68	.008	.015	.17

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER   NUCOR STEEL - SOUTH CAROL

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-15

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	31.8	PASS	N/A	N/A
N/A	33.9	PASS	N/A	N/A
N/A	29.9	PASS	N/A	N/A
N/A	33.1	PASS	N/A	N/A
N/A	30.6	PASS	N/A	N/A
AVERAGE VALUES FROM TESTS				
	31.9			

PRODUCTION LOT SIZE   85900 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-15   80 PCS. SAMPLED   LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-15 - GALVANIZING PERFORMED IN THE U.S.A.
1. 0.00261   2. 0.00312   3. 0.00350   4. 0.00409   5. 0.00290   6. 0.00240   7. 0.00339
8. 0.00395   9. 0.00300   10. 0.00442   11. 0.00378   12. 0.00480   13. 0.00374   14. 0.00349
15. 0.00453
AVERAGE THICKNESS FROM 15 TESTS   .00358

--HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.838	1.853
Thickness	32	0.961	0.977

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A.
PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL. CERTIFICATION FORMAT MEETS EN10204 3.1

ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/21

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

Bob Haywood

BOB HAYWOOD
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

34641

NUCOR

Mill Certification

01/12/2021

MTR#:589255-2
Lot #:800000790520
300 STEEL MILL RD
DARLINGTON, SC 29540 US
843 395-5841
Fax: 843 395-8701

Sold To: NUCOR FASTENER INDIANA
PO BOX 6100
SAINT JOE, IN 46785 US

Ship To: NUCOR FASTENER
6730 CR 60
SAINT JOE, IN 46785 US

Customer PO	211259	Sales Order #	80002937 - 4.2
Product Group	Hot Roll - Engineered Bar	Product #	3009846
Grade	1045L	Lot #	800000790520
Size	1.2813"	Heat #	8000007905
BOL #	BOL-664946	Load #	589255
Description	Hot Roll - Engineered Bar Round 1.2813" (1 9/32") 1045L 40' 0" [480"] 8001-12000 lbs	Customer Part #	025016
Production Date	01/02/2021	Qty Shipped LBS	173760
Product Country Of Origin	United States	Qty Shipped EA	990
Original Item Description		Original Item Number	

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

Melt Country of Origin : United States

Melting Date: 12/30/2020

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	Ti (%)	V (%)	B (%)
0.44	0.68	0.008	0.015	0.173	0.07	0.12	0.01	0.19	0.001	0.002	0.0003
Nb (%)	Sn (%)	Al (%)	Pb (%)	Ca (%)							
0.002	0.008	0.002	0.001	0.002							

Cu + Ni + Mo (%) : 0.27

Reduction Ratio 37.93 : 1

Other Test Results

Yield (PSI) : 59700
Tensile (PSI) : 99200
Elongation in 8" (%) : 20.0
Macroetch E381 Surface : 2
Macroetch E381 Mid Radius : 2
Macroetch E381 Center : 2

Comments:

1. Welding or weld repair was not performed on this material.
2. Melted and Manufactured in the U.S.A
3. Mercury, radium, or alpha source materials in any form have not been used in the production of this material.

James H Blew, Division Metallurgist

Page 1 of 1

INDIANA GALVANIZING, LLC

Hot-Dip Galvanizing
51702 Lovejoy Dr.
Middlebury IN, 46540
Phone: 574-822-9102 Fax: 574-822-9106

Customer
NUCOR FASTENER
6730 CR 60
Saint Joe, IN 46785

PO: 213356
DATE: 3/23/2021

Hot-Dip Galvanizing Certification

Indiana Galvanizing certifies that samples representing listed lot(s) have been tested and inspected as required by applicable specifications. The results of this inspection and testing demonstrates that the requirements for ASTM F2329, including the requirements ASTM A153, Class C that are referenced within the specification, have been met and have been galvanized in Middlebury, Indiana of the United States of America. Indiana Galvanizing is RoHS Compliant.

Kettle Temperature (Must be between 815 and 850 Degrees Fahrenheit) 840

Mil Readings

Nucor Lot Number	High	Low	Average	Number Pcs	Bin Tag Verification
452164B	4.00	2.05	3.10	79,946	X
451657A	4.15	2.10	3.05	17,264	X

Amy Kirkenall
Quality Manager or Assignee

Revised 3/1/2018

ZIEGLER BOLT AND NUT HOUSE

MAILING ADDRESS: PO BOX 80369 STA.. C CANTON OH 44708 FED. ID. 34-0968850
MAIN WAREHOUSE: 4848 CORPORATE ST SW CANTON OH 44706 PH: 800-362-0628 FAX: 330-478-2031
MIDDLETOWN: 4401 LEFFERSON RD MIDDLETOWN OH 45044 PH: 513-727-1963 FAX: 513-727-4733
DOVER: 2120 ST RTE 39 NW DOVER OH 44622 PH: 330-343-3376 FAX:330-343-3336
DELPHOS: 610 SEVENTH ST E DELPHOS OH 45833 PH: 419-695-9005 FAX: 419-695-2020
WWW.ZIEGLERBOLT.COM

ISO 9002:2008
CERTIFICATION #00.129.2
CERTIFICATE OF COMPLIANCE

Assembly Specialty Products, Inc.
PO#: 45131
REF: WSH-FL32G
DATE: 08/06/2021
INSP: Quade

To: ASSEMBLY SPECIALTY
14700 BROOKPARK ROAD
CLEVELAND, OH 44135-5166

We certify that our system and procedures for the control of quality assures that all items furnished on the order will meet applicable tests, process requirements and inspection requirements as required by the purchase order and applicable specification and drawings.

P.O. # 45131-1
Job #
Date Shipped: 8/9/2021
Shipped Via: ZIEGLER DELIVERY
Internal Order # 1583960

2000 PCS. 1" (F844) USS FLAT WASHER DOMESTIC HD GALVANIZED
LOT# E1368 HEAT# 278164
ZBN# 100NWUL0H/DOM-9244 PART# WSH-FL32G

MELTED & MANUFACTURED IN THE USA

NOTARIAL SEAL STATE OF OHIO
LISA F. GOODING
Notary Public, State of Ohio
My Commission Expires 03-31-2023
Lisa F. Gooding

Signature: Bridget Hartong
Title: CERTIFICATION CLERK
Date: AUG. 6, 2021

Prestige Stamping, LLC

23513 Groesbeck Highway
Warren, Michigan 48089
(586)773-2700 * Fax (586)773-2298
www.PrestigeStamping.com

PRODUCT CERTIFICATION

CERTIFICATION NUMBER
230112

THIS IS TO CERTIFY THE PRODUCT STATED BELOW WAS FABRICATED AND PROCESSED TO THE ORDER AS INDICATED AND CONFORMS TO THE APPLICABLE SPECIFICATIONS AND STANDARDS.

Customer: ZIEGLER BOLT & NUT HOUSE
4848 CORPORATE ST. SW
CANTON, OH 44706

Customer Part:	1"USS H/DIP	**Steel Supplier:**	MARATHON METALS, LLC
Prestige Part:	F2523MP300	**Grade:**	CSECONDARY STEEL
Part Name:	1"USS LOW CARBON H/DIP	**Lot:**	E1368
Purchase Order:	16203953	**Heat:**	278164
Shipment BOL:	B233915	**Carbon:**	.85
Shipment ID:	A0256760	**Manganese:**	.80
Quantity:	11742	**Phosphorous:**	.01
Manufacturers Marking:	"P"	**Sulfur:**	.002
		Silicon:	.223

SPECIFICATIONS	TEST RESULTS
:	:
PLATING: TEST METHOD: ASTM B499 HOT DIP GLAV ASTM F-2329 AND ASTM 153 CLASS C	PLATING: 0.0017" - 0.0025"

USS/SAE LC Washers are manufactured to the requirements of ASTM F844 specifications
Chemistry is as reported from raw material certification and does not fall under Prestige Stamping's accreditation.
This product was produced under an IATF 16949 Quality Assurance System.
IATF 16949 Certification No: 800334.
Material was melted and manufactured in the U.S.A.
This product was manufactured in Warren, Michigan U.S.A.
This product conforms to all requirements for washers as produced according to ANSI/ASMI B18.22.1.
Mechanical properties and test methods for hardness conform to ASTM F436
Sampling Plan per P.S.I W.I. # 5.4.18.015.
The test results only apply to the items tested.
This test report must not be reproduced except in full without prior written approval.
Materials used to manufacture these products are mercury, asbestos and radio activity free.
Product is RoHS compliant.
No weld repairs made to material.
All certified product is AIS compliant.

FRANK SCHUBERT
Quality Assurance Manager

Econ Information System 07/13/21 16:27 AHRS PAGE 1 of 1

Page: 1 .... Last

14May21 10: 9 TEST CERTIFICATE No: MNP 10383

E13le8

MARATHON METALS/MNP CORP
6440 MACK
DETROIT, MI 48207
Tel: 313-571-9544 Fax: 313-571-6449

P/O No 36135-01
Rel
S/O No MNP 63326-001
B/L No MNP 76104-001 Shp 17May21
Inv No Inv

Sold To: (933)
PRESTIGE STAMPING INC.
23513 GROESBECK HIGHWAY
WARREN MI 48090

Ship To: (1)
PRESTIGE STAMPING INC.
23513 GROESBECK HIGHWAY
P.O. BOX 1086
WARREN MI 48090

Tel: 586 773-2700 Fax: 586 773-2298

CERTIFICATE of ANALYSIS and TESTS Cert. No: MNP 10383
14May21

Part No F2523MP00
P&O CQ SECONDARY REF# 2N2700138
.138/.148 X 2.7000"

Pcs	Wgt
22	26,110

DOMESTIC MILL CERTS & CERTS MUST SAY
"MELTED & MFG IN USA"
ROCKWELL 95

Heat Number	Tag No	Pcs	Wgt
278164	S36158	4	4,670
278164	S36159	3	3,385
278164	S36160	3	3,355
278164	S36161	4	4,995
278164	S36162	3	3,650
278164	S36163	3	3,650
278164	S36204	1	1,160
278164	S36205	1	1,245

Heat Number *** Chemical Analysis ***
278164 C=0.8500 Mn=0.8000 P=0.0100 S=0.0020 Al=0.0280 Si=0.2230
Nb=0.0010 N=0.0080 V=0.0020 Ti=0.0030 Cu=0.0940 Sn=0.0050
Ni=0.0460 Cr=0.0640 Mo=0.0170

NUCOR

SHEET MILL GROUP
Nucor Steel-Crawfordsville
4537 South Nucor Road
Crawfordsville, IN 47933-0907

Print Date: 10/18/2017
Page: 1 of 1

Customer Name: MNP CORPORATION 5290
Customer Address: 44225 UTICA RD
UTICA MI 48318

Customer PO Number: 5897

Order Number: :
Order Dimensions: 0.1400 X 44.4100
HOT ROLLED BAND

Coil Number	Heat	Slab
	278164	05

Chemical Analysis

Heat	C	Mn	P	S	Si	Cu	Sn	Ni	Cr	Mo	Al	N	V	Nb	Ti	B	Sb
278164	0.85	0.800	0.010	0.002	0.223	0.094	0.005	0.046	0.064	0.017	0.028	0.008	0.002	0.001	0.003	<0.001	<0.001

MELTED AND ROLLED IN THE USA

THIS IS NOT A CERTIFIED TEST REPORT

AZZ GALVANIZING ROCKFORD

July 8, 2021

Prestige Stamping
23513 Groesbeck Highway
Warren, MI 48089

To Whom It May Concern:

This certifies that the following product that we have galvanized for your company meets the specifications of ASTM A153, Class C and the hot dip galvanizing requirements of ASTM F2329.

QTY OUT	PART#	DESCRIPTION	SHIPPER	SO#	LOT#	HOPPER	AVG	HIGH	LOW
7,921	F2523MP300	1" USS FLAT WASHER	P415761	SZ00424	E1368	H194	6.8	12.7	3.5

The hot dip galvanizing is RoHS compliant. The galvanizing process was conducted in a temperature range of 830F to 850F.

This certification in no way implies anything other than the quality of our hot dip galvanizing as it pertains to your order.

This product was galvanized in Rockford, IL USA

Yours very truly,

AZZ Galvanizing Rockford, IL

Peggy Doering

Peggy Doering
Office Manager

PD:ts

Wirerope Works, Inc. 100 Maynard St Williamsport, PA 17701
Manufacturer of Bethlehem Wire Rope ®
"Our Quality Management Systems are registered to ISO 9001: 2015 and API-Q1"

Assembly Specialty Products, Inc.
PO#: 44134
REF#: W-24-DG
INSP: QUADE
DATE: 08/11/2021
ASPI REEL(S): 13120, 13121, 13122, 13123

CERTIFICATE OF COMPLIANCE

CUSTOMER: ASSEMBLY SPECIALTY PRODUCTS
ORD# TR 54
CUST. PO# 44134PT

WW FILE NAME: 248062

REEL# 1248062

DESCRIPTION: 3/4" 0619 W GA IPS RR SAC TYPE II (a) GALVANIZED WIRE ROPE

SPECIFICATION: AASHTO DESIGNATION M30-15 ASTM A741-11

ACTUAL TEST RESULTS
ACTUAL BREAKING STRENGTH: 60,272 LBS
REQUIRED BREAKING STRENGTH: 42,800 LBS

MINIMUM MASS OF COATING:
WIRE DIAMETER MAINWIRES
.054" MINIMUM CLASS A COATING .40- ACTUAL RANGE .65/.74 oz/ft2
.040" MINIMUM CLASS A COATING .40- ACTUAL RANGE .45/.51 oz/ft2

STEEL CERTIFICATES FOR ROD MANUFACTURER ARE ATTACHED
The following are heat numbers and wire diameters as shown on the Steel Certificates

.054" HEAT # OT0021793
.040" HEAT # OT0021852
.061" HEAT # OT0018856 OT0016343
.046" HEAT # 20701730

ALL MATERIALS " MELTED AND MANUFACTURED IN THE USA"

Patti Watkins DATE: 08/05/2021 CERTIFICATE# AA30965
PATTI WATKINS, Inv. Control/QA Customer Coordinator
Per the authority of, ROGER GILLILAND, DIRECTOR OF ENGINEERING

OPTIMUS STEEL

US-ML-BEAUMONT
100 OLD HIGHWAY 90 WEST
VIDOR, TX 77662
USA

CERTIFIED MATERIAL TEST REPORT

WIREROPE WORKS INC

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
WIREROPE WORKS INC 100090167 100 MAYNARD ST WILLIAMSPORT, PA. 17701-5809 USA	WIREROPE WORKS INC 100 MAYNARD ST WILLIAMSPORT, PA. 17701-5809 USA	1055M1	WIRE ROD / 7/32
		WEIGHT: 47,188.00	HEAT / BATCH: OT0021793

SALES ORDER	CUSTOMER MATERIAL No	SPECIFICATION / DATE OR REVISION
990318075	600210	

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
PO109162-M	53,200	2/8/21

CHEMICAL COMPOSITION

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	N
%	%	%	%	%	%	%	%	%	%	%	%	%
0.53	0.86	0.009	0.012	0.25	0.12	0.06	0.06	0.02	0.006	0.003	0.004	0.0077

MECHANICAL PROPERTIES

Tensile	Std dev	ROA	Tensile
psi	psi	%	Mpa
128653	2092	57.3	887

COMMENTS / NOTES
No Weld repairs preformed. Mercury, radium and alpha source materials in any form have not been used in the production of this Material. The radioactivity levels are lower than the limits defined for unconditional release by IAEA.
USE CARDBOARD SEPARATORS

The above figures are certified chemical and physical test records as contained in the permanent records of company. CMTR complies with EN 10204 3.1

We certify that these data are correct and in compliance with specified requirements. This material , including the billets , was melted and manufactured in the USA.

Leonardo Radicchi

LEONARDO RADICCHI

QUALITY ASSURANCE MGR

Phone: 409-769-1086
leonardo.radicchi@optimus-steelusa.com

OPTIMUS STEEL

US-ML-BEAUMONT
100 OLD HIGHWAY 90 WEST
VIDOR, TX 77662
USA

CERTIFIED MATERIAL TEST REPORT

WIREROPE WORKS INC

CUSTOMER SHIP TO WIREROPE WORKS INC 100096167 100 MAYNARD ST WILLIAMSPORT, PA 17701-5809 USA	CUSTOMER BILL TO WIREROPE WORKS INC 100 MAYNARD ST WILLIAMSPORT, PA 17701-5909 USA	GRADE 1075M1	SHAPE / SIZE WIRE ROD / 7/32
		WEIGHT 47,078.00	HEAT / BATCH OT0021832
SALES ORDER 996318675	CUSTOMER MATERIAL No 600325	SPECIFICATION / DATE OR REVISION	

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
PO109162-M	53,332	3/10/21

CHEMICAL COMPOSITION

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	N
%	%	%	%	%	%	%	%	%	%	%	%	%
0.74	0.66	0.006	0.014	0.21	0.11	0.05	0.05	0.01	0.005	0.003	0.003	0.0071

MECHANICAL PROPERTIES

Tensile	Std dev	ROA	Tensile
psi	psi	%	Mpa
158940	2086	47.8	1096

COMMENTS / NOTES
No Weld repairs preformed. Mercury, radium and alpha source materials in any form have not been used in the production of this Material. The radioactivity levels are lower than the limits defined for unconditional release by IAEA.

The above figures are certified chemical and physical test records as contained in the permanent records of company. CMTR complies with EN 10204 3.1
We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA.

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OPTIMUS STEEL

US-ML-BEAUMONT
100 OLD HIGHWAY 90 WEST
VIDOR, TX 77662
USA

CERTIFIED MATERIAL TEST REPORT

WIREROPE WORKS INC

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
WIREROPE WORKS INC 100096167 100 MAYNARD ST WILLIAMSPORT, PA. 17701-5809 USA	WIREROPE WORKS INC 100 MAYNARD ST WILLIAMSPORT, PA. 17701-5809 USA	1055M1	WIRE ROD / 7/32

WEIGHT	HEAT / BATCH
17,188.00	OT0018856

SALES ORDER	CUSTOMER MATERIAL No	SPECIFICATION / DATE OR REVISION
996317390	600210	

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
108029-H	42,220	7/13/20

CHEMICAL COMPOSITION

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	N
%	%	%	%	%	%	%	%	%	%	%	%	%
0.55	0.81	0.013	0.012	0.24	0.18	0.06	0.09	0.02	0.007	0.002	0.003	0.0073

MECHANICAL PROPERTIES

Tensile	Std dev	ROA	Tensile
psi	psi	%	Mpa
131828	1367	58.9	909

COMMENTS / NOTES
No Weld repairs preformed. Mercury, radium and alpha source materials in any form have not been used in the production of this Material. The radioactivity levels are lower than the limits defined for unconditional release by IAEA.
USE CARDBOARD SEPARATORS

The above figures are certified chemical and physical test records as contained in the permanent records of company. CMTR complies with EN 10204 3.1

We certify that these data are correct and in compliance with specified requirements. This material , including the billets , was melted and manufactured in the USA.

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leonardo.radicchi@optimus-steelusa.com

OPTIMUS STEEL

US-ML-BEAUMONT
100 OLD HIGHWAY 90 WEST
VIDOR, TX 77662
USA

CERTIFIED MATERIAL TEST REPORT

WIREROPE WORKS INC

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
WIREROPE WORKS INC 100006167 100 MAYNARD ST WILLIAMSPORT, PA 17701-5809 USA	WIREROPE WORKS INC 100 MAYNARD ST WILLIAMSPORT, PA 17701-5806 USA	1055M1	WIRE ROD / 7/32

WEIGHT	HEAT / BATCH
47,416.00	OT0916343

SALES ORDER	CUSTOMER MATERIAL №	SPECIFICATION / DATE OR REVISION
963316688	600210	

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
107127-F	35,061	3/27/20

CHEMICAL COMPOSITION

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	N
%	%	%	%	%	%	%	%	%	%	%	%	%
0.52	0.66	0.012	0.012	0.24	0.13	0.06	0.08	0.02	0.007	0.002	0.003	0.0068

MECHANICAL PROPERTIES

Tensile	Std dev	ROA	Tensile
psi	psi	%	Mpa
129065	1331	58.5	890

COMMENTS / NOTES
NO WELD REPAIRMENT PERFORMED STEEL NOT EXPOSED TO MERCURY
USE CARDBOARD SEPARATORS

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1

Leonardo Radicchi

LEONARDO RADICCHI
QUALITY ASSURANCE MGR.

Phone: 409-769-1086
leonardo.radicchi@optimus-steelusa.com

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

EMAIL

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
Fax (262) 268-2570

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Cust P.O.	109724-4
Customer Part #	600325
Charter Sales Order	70101008
Heat #	20701730
Ship Lot #	2197787
Grade	1075 M SK CG HRQ 7/32 RNDCOIL
Process	HR
Finish Size	7/32
Ship date	25-JAN-21

Wirerope Works, Inc.
100 Maynard St.
Williamsport,PA-17701
Kind Attn :Roger Gilliland

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 20701730

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.76	.73	.005	.010	.210	.04	.06	.01	.08	.005	.002
	AL	N	B	TI	NB						
	.004	.0060	.0001	.001	.002						

Test results of Rolling Lot # 2197787

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE (KSI)	3	164.8	167.8	166.0	TENSILE LAB = 0358-04
REDUCTION OF AREA (%)	3	42	48	46	RA LAB = 0358-04
ROD SIZE (Inch)	22	.216	.223	.220	
ROD OUT OF ROUND (Inch)	8	.004	.007	.006	

REDUCTION RATIO=1301:1

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 05/12/17
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = 6000 Revision = 10 Dated = 10-MAR-17

Additional Comments: Melted and Manufactured in the United States of America

Melt Source:
Charter Steel
Cuyahoga Heights, OH, USA

This MTR supersedes all previously dated MTRs for this order

Douglas Jones Division Mgr. of Quality Assurance
jonesdo@chartersteel.com
Printed Date : 01/25/2021

Trip: 1476420

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFARS compliance, LEEDS compliance, REACH compliance, ROHS-WEEE compliance, and Conflict Materials Restrictions.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	**CSSM**	Charter Steel Melting Division	1658 Cold Springs Road, Saukville, WI 53080
0358-02	8171	**CSSR**	Charter Steel Rolling	1658 Cold Springs Road, Saukville, WI 53080
0358-07	8171	**CSSP**	Charter Steel Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	**CSFP**	Charter Steel Ohio Processing Division	6255 US Highway 23, Rising Sun, OH 43457
0358-04	125544	**CSCM/ CSCR**	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	--	Subcontracted test performed by laboratory not in Charter Steel System	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Specifications	CSSM	CSSR/ CSSP	CSFP	CSCM/ CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwelll Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/21. All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specification, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

ACCREDITED Testing Laboratory

07-11-2022 00:02 Load - 4113094 BL - 3919803 6 15 181-01 blr466

Custom Fabricators Heat - 2220804

Cust. PO - 02671 Order - 21559520

AM/NS Calvert LLC
1 AM/NS Way
Calvert, Al. , AL 36513 USA

AM/NS CALVERT

CUSTOMER ORIGINAL

Mill Certificate

Order - Item	Certificate Number	Delivery No	Ship Date	Page
240142-50	1195485140	83260986-10	06/07/2022	1 of 1

Customer No: 10213 Cust PO: HTX-7733165

Customer Part No:

Customer Sold to:	Customer Ship to:	Contact - Stan Bevans
Kloeckner Metals Corp. - Tulsa Kloeckner Metals Corp 3123 E. Apache TULSA OK 74110 USA	Kloeckner Metals Corp. 7400 Mesa Dr. HOUSTON TX 77028 USA	AM/NS Calvert LLC 1 AM/NS Way CALVERT AL 36513 USA Email: Stanley.Bevans@ArcelorMittal.com Ph : 1-251-289-3000

Steel Grade / Customer Specification
Hot Roll Black Coil Conv to A36 / 0.2400 " X 60.0000 " ACCORDING TO A1018 {Hvy 0.230"(6)-1"(25.4)}-Hot Roll Base

Type of Product/Surface
Hot Roll Black Dry Unexposed GENERAL STOCK, CTL SHEET

TEST METHOD Melted in Mexico Manufactured in USA

ASTM

MATERIAL DESCRIPTION

	ORDERED	Heat No.	Coil No.	Weight Net LB	Weight Gross LB
(mm)	6.096	2220804	1195485140	46,186.000	46,186.000
(in)	0.2400				

CHEMICAL COMPOSITION OF THE LADLE *

Heat No.	C	Si	Mn	P	S	Al	Cr	Cu	Mo	N
2220804	0.1970	0.02	0.83	0.008	0.003	0.040	0.01	0.010	0.001	0.0021
	Ni	Nb	Ti	B	V	Ca				
	0.002	0.001	0.002	0.0001	0.001	0.0006				

TENSILE TEST

Test Direction	Yield Strength	Tensile Strength	% Total Elong.
T	47 ksi	68 ksi	35

AM/NS Calvert LLC certify that the material herein described has been manufactured, sampled, tested and inspected in accordance with the contract requirements and is fully in compliance.

* - This test is not covered by our current A2LA accreditation

Yasunori Iwasa
Quality Management Director
AM/NS Calvert

Rev.

Certified Analysis

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

ADDISON, TX 75001
Project: FHWA 615181

Order Number: 1342195 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: FHWA 615181
BOL Number: 85051 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/24/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	3000G	CBL 3/4X6'6/DBL SWG/NOHWD	WIRE			SO08-00767													4
20	3900G	1" ROUND WASHER F844	F844-3900			P39757 R75233													4
20	3910G	1" HEX NUT A563	A563-3910			P39590 R75013													4
10	20207G	12/9'4.5/8-HOLE ANCH/S			2	F13321													
			M-180	A	2	2113955	55,900	82,400	25.0	0.230	0.970	0.010	0.001	0.030	0.110	0.002	0.050	0.004	4
			M-180	A	2	2113956	60,400	86,300	21.0	0.230	0.970	0.011	0.001	0.030	0.120	0.002	0.050	0.004	4
			M-180	A	2	2214154	56,300	83,300	27.0	0.240	0.990	0.013	0.002	0.030	0.120	0.002	0.080	0.005	4
			M-180	A	2	2214155	59,700	84,200	27.0	0.230	0.980	0.010	0.002	0.020	0.120	0.002	0.060	0.004	4
	20207G		RHC		2	L12019													4
			M-180	A	2	238622	61,950	81,070	23.2	0.180	0.720	0.011	0.004	0.020	0.140	0.000	0.070	0.002	4
			M-180	A	2	238623	63,640	81,270	26.4	0.190	0.730	0.013	0.003	0.020	0.130	0.000	0.080	0.001	4
			M-180	A	2	238624	61,390	80,200	26.1	0.190	0.730	0.013	0.002	0.020	0.160	0.000	0.070	0.002	4
			M-180	A	2	238625	61,150	79,980	26.5	0.200	0.730	0.011	0.004	0.020	0.130	0.000	0.080	0.001	4
			M-180	A	2	238627	61,630	80,850	25.5	0.190	0.720	0.011	0.004	0.020	0.130	0.000	0.070	0.001	4
	20207G		RHC		2	L13818													4
			M-180	B	2	228145	56,880	76,080	28.9	0.190	0.730	0.013	0.004	0.020	0.120	0.000	0.060	0.008	4
			M-180	B	2	229086	62,200	79,510	28.2	0.190	0.730	0.012	0.004	0.020	0.100	0.000	0.070	0.000	4
			M-180	A	2	230046	62,830	81,430	27.2	0.200	0.750	0.009	0.002	0.020	0.140	0.000	0.050	0.002	4
			M-180	A	2	230050	62,160	80,260	26.9	0.190	0.720	0.014	0.004	0.010	0.120	0.000	0.070	0.001	4
			M-180	A	2	231186	57,040	77,590	26.9	0.180	0.720	0.010	0.004	0.020	0.110	0.000	0.060	0.002	4
			M-180	A	2	231187	55,080	78,060	25.3	0.180	0.720	0.014	0.004	0.010	0.110	0.000	0.070	0.008	4
			M-180	A	2	231188	59,830	82,260	22.6	0.190	0.740	0.010	0.002	0.020	0.120	0.000	0.050	0.002	4
			M-180	A	2	231189	59,500	81,190	23.6	0.190	0.700	0.014	0.004	0.010	0.110	0.000	0.060	0.002	4

615181-1

Certified Analysis

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

ADDISON, TX 75001
Project: FHWA 615181

Order Number: 1342195 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: FHWA 615181
BOL Number: 85051 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/24/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
			M-180	A	2	A89864	64,500	86,000	19.7	0.200	0.720	0.015	0.002	0.030	0.050	0.001	0.060	0.001	4
			M-180	A	2	C87743	60,600	83,000	22.1	0.200	0.680	0.008	0.003	0.030	0.060	0.001	0.050	0.001	4
15	110036G	12/12'6/3' 1.5/S 36'RCX			2	F13321													
			M-180	A	2	2113955	55,900	82,400	25.0	0.230	0.970	0.010	0.001	0.030	0.110	0.002	0.050	0.004	4
			M-180	A	2	2113956	60,400	86,300	21.0	0.230	0.970	0.011	0.001	0.030	0.120	0.002	0.050	0.004	4
			M-180	A	2	2214154	56,300	83,300	27.0	0.240	0.990	0.013	0.002	0.030	0.120	0.002	0.080	0.005	4
			M-180	A	2	2214155	59,700	84,200	27.0	0.230	0.980	0.010	0.002	0.020	0.120	0.002	0.060	0.004	4
	110036G		RHC		2	L12821													4
			M-180	A	2	263871	63,962	81,744	24.4	0.190	0.730	0.014	0.003	0.010	0.120	0.000	0.060	0.000	4
			M-180	A	2	263872	64,873	83,233	22.4	0.190	0.720	0.013	0.002	0.020	0.130	0.000	0.070	0.002	4
			M-180	A	2	263873	63,778	81,794	23.7	0.190	0.720	0.012	0.002	0.020	0.110	0.000	0.060	0.000	4
			M-180	A	2	263875	65,628	83,665	22.5	0.190	0.720	0.012	0.002	0.030	0.120	0.000	0.060	0.000	4
			M-180	A	2	263876	62,484	80,825	25.7	0.190	0.730	0.012	0.004	0.020	0.130	0.000	0.070	0.001	4
			M-180	A	2	264221	56,140	75,433	27.8	0.190	0.730	0.007	0.001	0.020	0.120	0.000	0.050	0.002	4
			M-180	A	2	264921	60,113	78,971	24.7	0.190	0.720	0.010	0.003	0.010	0.100	0.000	0.070	0.002	4
			M-180	A	2	264923	59,277	77,813	26.3	0.190	0.730	0.010	0.002	0.010	0.100	0.000	0.060	0.002	4
	110036G		RHC		2	L12921													4
			M-180	A	2	263872	64,873	83,233	22.4	0.190	0.720	0.013	0.002	0.020	0.130	0.000	0.070	0.002	4
			M-180	A	2	263875	65,628	83,665	22.5	0.190	0.720	0.012	0.002	0.030	0.120	0.000	0.060	0.000	4
			M-180	A	2	263876	62,484	80,825	25.7	0.190	0.730	0.012	0.004	0.020	0.130	0.000	0.070	0.001	4
			M-180	A	2	264221	56,140	75,433	27.8	0.190	0.730	0.007	0.001	0.020	0.120	0.000	0.050	0.002	4
			M-180	A	2	264920	57,757	76,950	24.7	0.190	0.720	0.008	0.004	0.010	0.100	0.000	0.060	0.000	4
			M-180	A	2	264921	60,113	78,971	24.7	0.190	0.720	0.010	0.003	0.010	0.100	0.000	0.070	0.002	4
			M-180	A	2	264922	60,406	79,043	24.0	0.200	0.730	0.008	0.002	0.020	0.100	0.000	0.060	0.001	4
			M-180	A	2	264924	57,244	75,956	31.2	0.190	0.710	0.008	0.003	0.020	0.100	0.000	0.060	0.000	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: FHWA 615181

Order Number: 1342195 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: FHWA 615181
BOL Number: 85051 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/24/21

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

State of Texas, County of Tarrant. Sworn and subscribed before me this 24th day of August, 2021 .

Notary Public:
Commission Expires: /

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

ARey

Certified By: Trinity Highway Products LLC
Luis Ortiz
Quality Assurance

3 of 3

Table B.1. Test Day Static Soil Strength Documentation for Test No. 615181-01-5.

Date	2022-09-09
Test Facility and Site Location	TTI Proving Ground 3100 SH 47 Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147-17 Grading D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 s

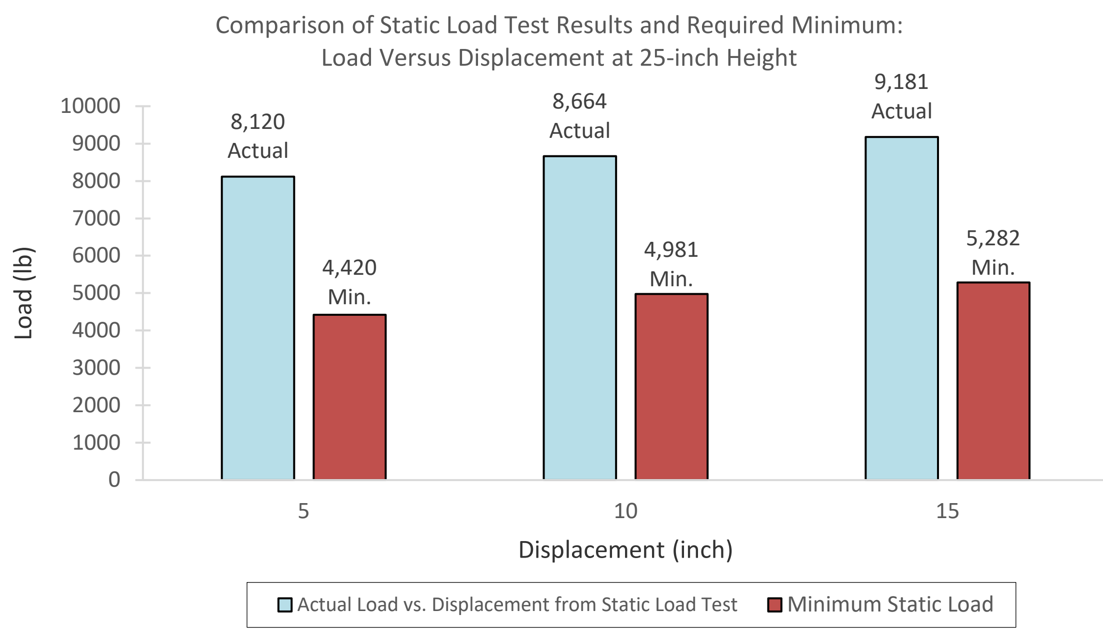


Figure B.1. Test Day Static Soil Strength Documentation for Test No. 615181-01-5.

Table B.2. Test Day Static Soil Strength Documentation for Test No. 615181-01-11.

Date	2022-10-06
Test Facility and Site Location	TTI Proving Ground 3100 SH 47 Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147-17 Grading D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 s

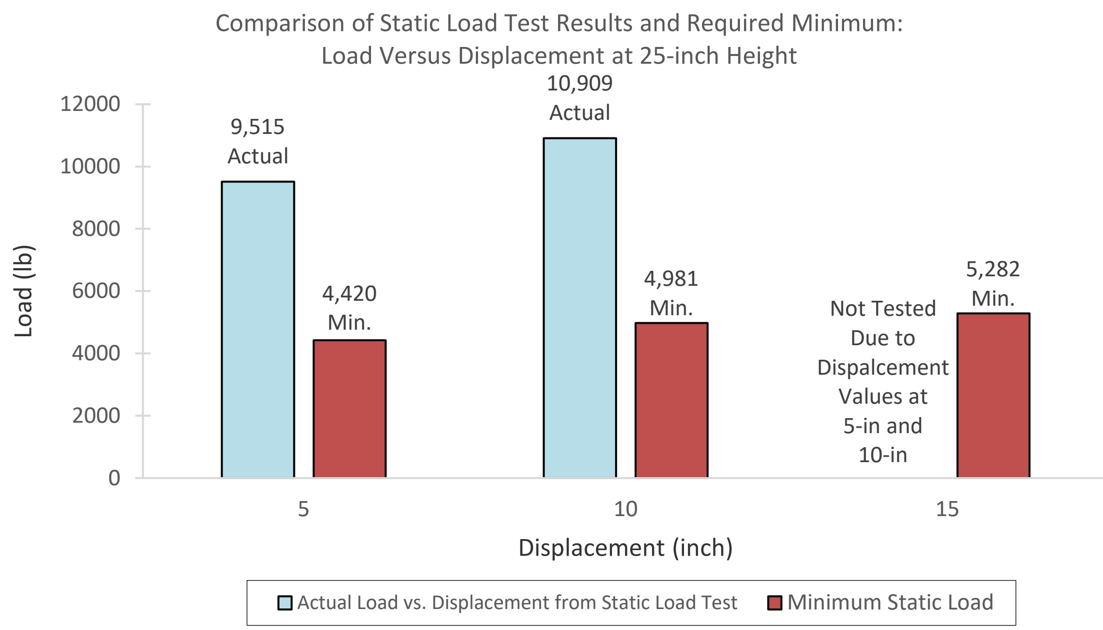


Figure B.2. Test Day Static Soil Strength Documentation for Test No. 615181-01-11.

Table B.3. Test Day Static Soil Strength Documentation for Test No. 615181-01-12.

Date	2022-10-11
Test Facility and Site Location	TTI Proving Ground 3100 SH 47 Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147-17 Grading D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 s

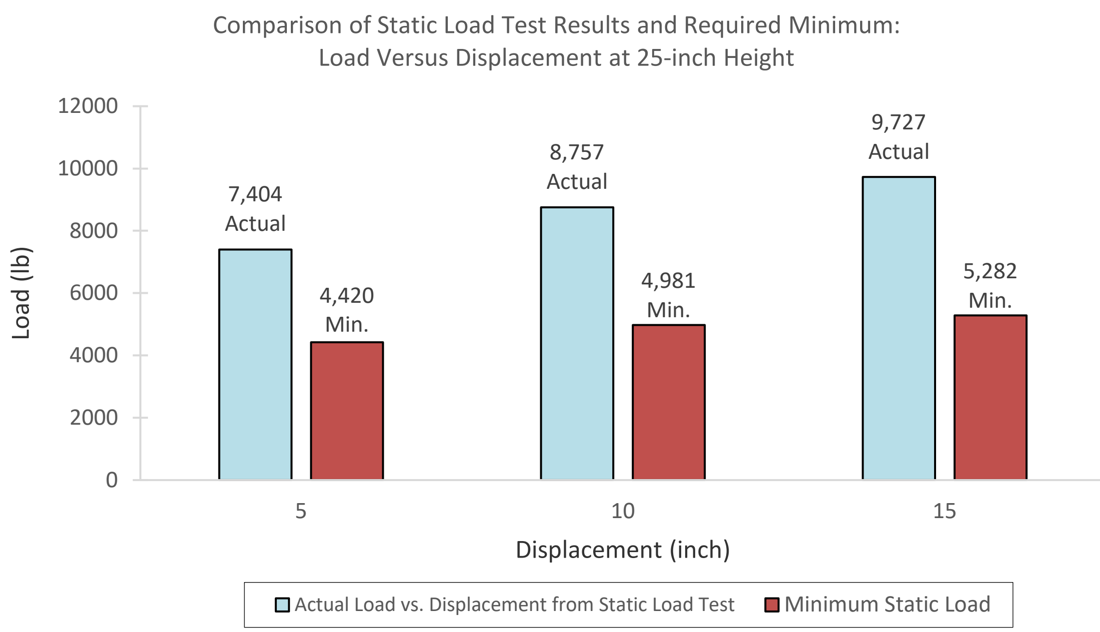


Figure B.3. Test Day Static Soil Strength Documentation for Test No. 615181-01-12.

Table B.4. Test Day Static Soil Strength Documentation for Test No. 615181-01-13.

Date	2022-10-20
Test Facility and Site Location	TTI Proving Ground 3100 SH 47 Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147-17 Grading D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 s

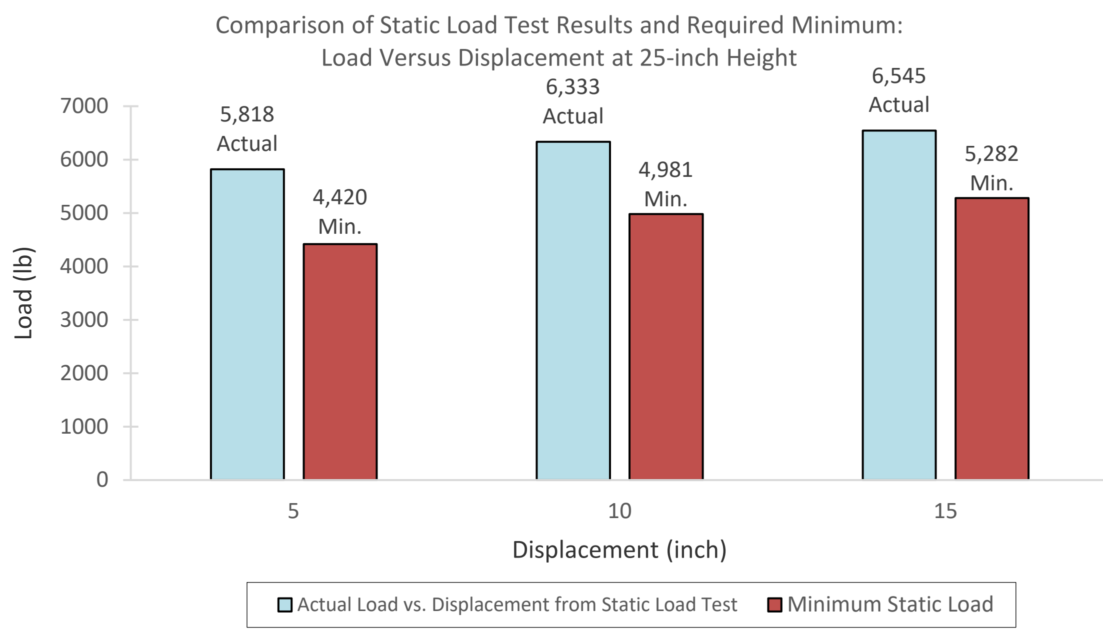


Figure B.4. Test Day Static Soil Strength Documentation for Test No. 615181-01-13.

APPENDIX C. *MASH* TEST 2-35 (CRASH TEST NO. 615181-01-5)

C.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2022-09-09 Test No.: 615181-01-5 VIN No.: 1C6RR6GT5GS164351

Year: 2016 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 161115

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

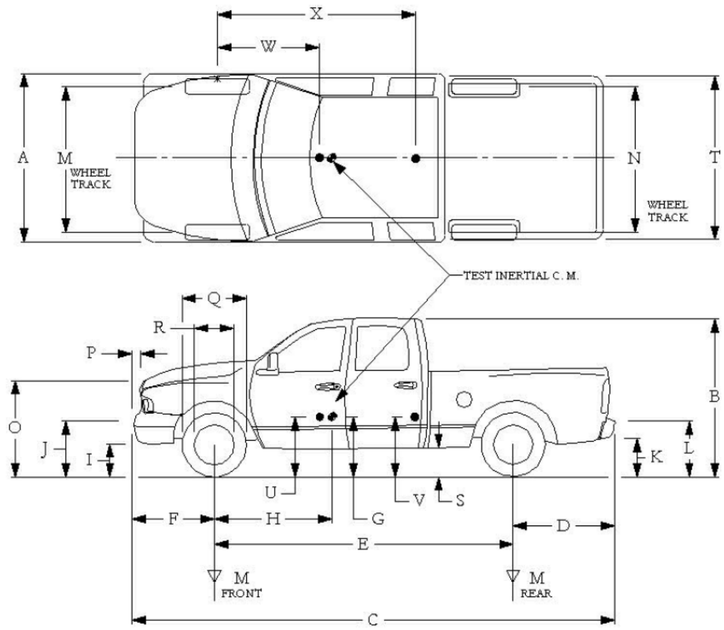
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

Dummy Data:
Type: NONE
Mass:
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.50	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.13	M	68.50	R	18.00	W	61.10
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}	2880	2855	2855
Back	3900	M_{rear}	2200	2199	2199
Total	6700	M_{Total}	5080	5054	5054

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

Mass Distribution:
lb LF: 1480 RF: 1375 LR: 1094 RR: 1105

Figure C.1. Vehicle Properties for Test No. 615181-01-5.

Date:	2022-09-09	Test No.:	615181-01-5	VIN No.:	1C6RR6GT5GS164351
Year:	2016	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FT RBUMP	14	10	36							-18
2	SAME	14	8	48							70
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

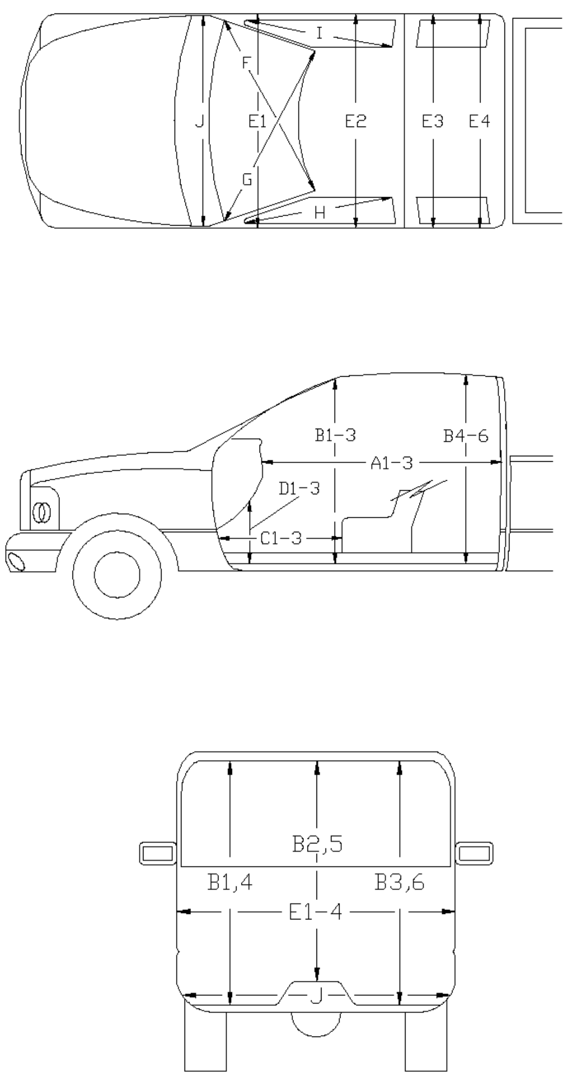
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Figure C.2. Exterior Crush Measurements for Test No. 615181-01-5.

Date:	2022-09-09	Test No.:	615181-01-5	VIN No.:	1C6RR6GT5GS164351
Year:	2016	Make:	RAM	Model:	1500



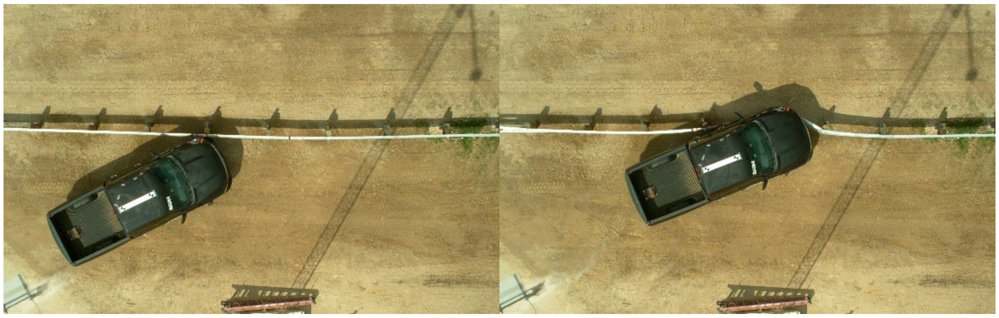
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

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	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	58.50	0.00
E2	63.50	63.50	0.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	25.00	0.00

Figure C.3. Occupant Compartment Measurements for Test No. 615181-01-5.

C.2. SEQUENTIAL PHOTOGRAPHS



(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

Figure C.4. Sequential Photographs for Test No. 615181-01-5 (Overhead Views).

(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

Figure C.5. Sequential Photographs for Test No. 615181-01-5 (Frontal Views).

(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

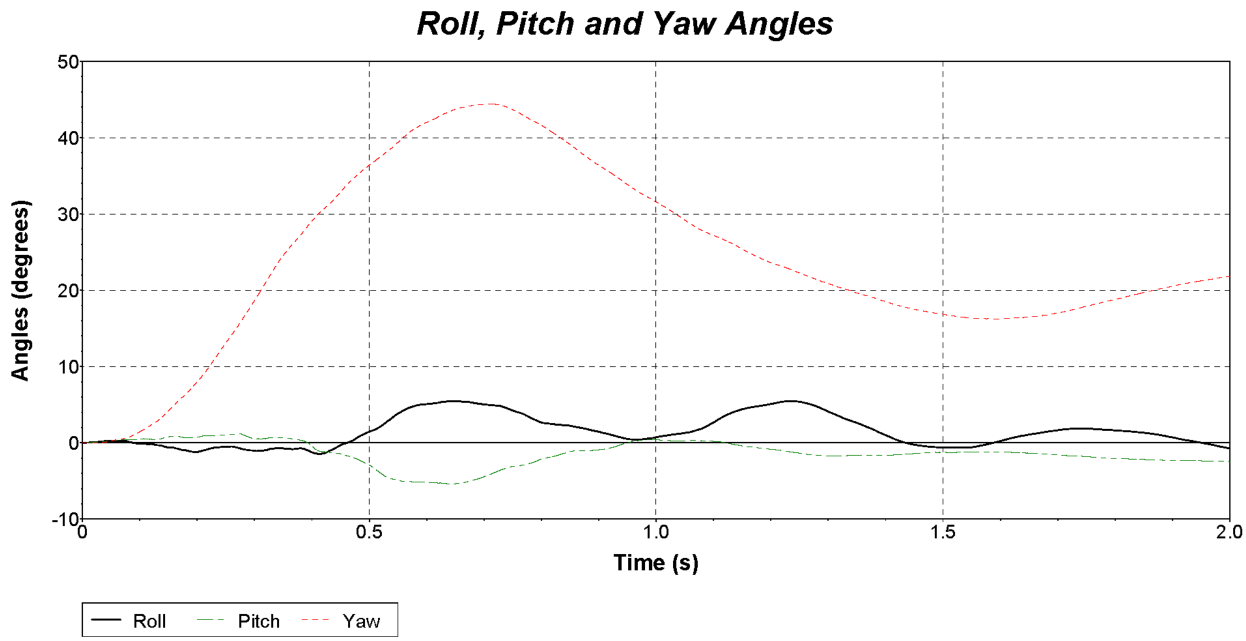
(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

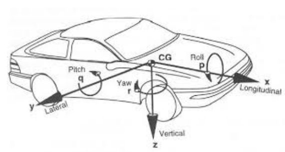
Figure C.6. Sequential Photographs for Test No. 615181-01-5 (Rear Views).

C.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 615181-01-5
Test Standard Test Number: *MASH* Test 2-35
Test Article: TL-2 W-beam End Terminal
Test Vehicle: 2016 RAM 1500
Inertial Mass: 5054 lbs
Gross Mass: 5054 lbs
Impact Speed: 45.9 mi/h
Impact Angle: 25°

Figure C.7. Vehicle Angular Displacements for Test No. 615181-01-5.

C.4. VEHICLE ACCELERATIONS

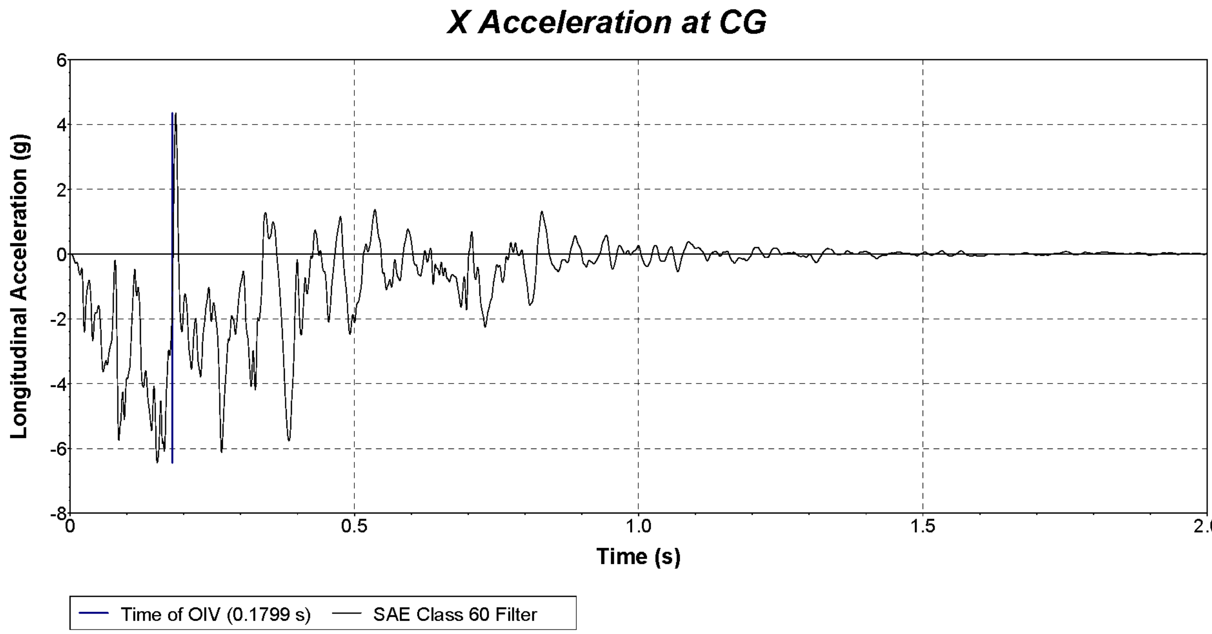


Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test No. 615181-01-5 (Accelerometer Located at Center of Gravity).

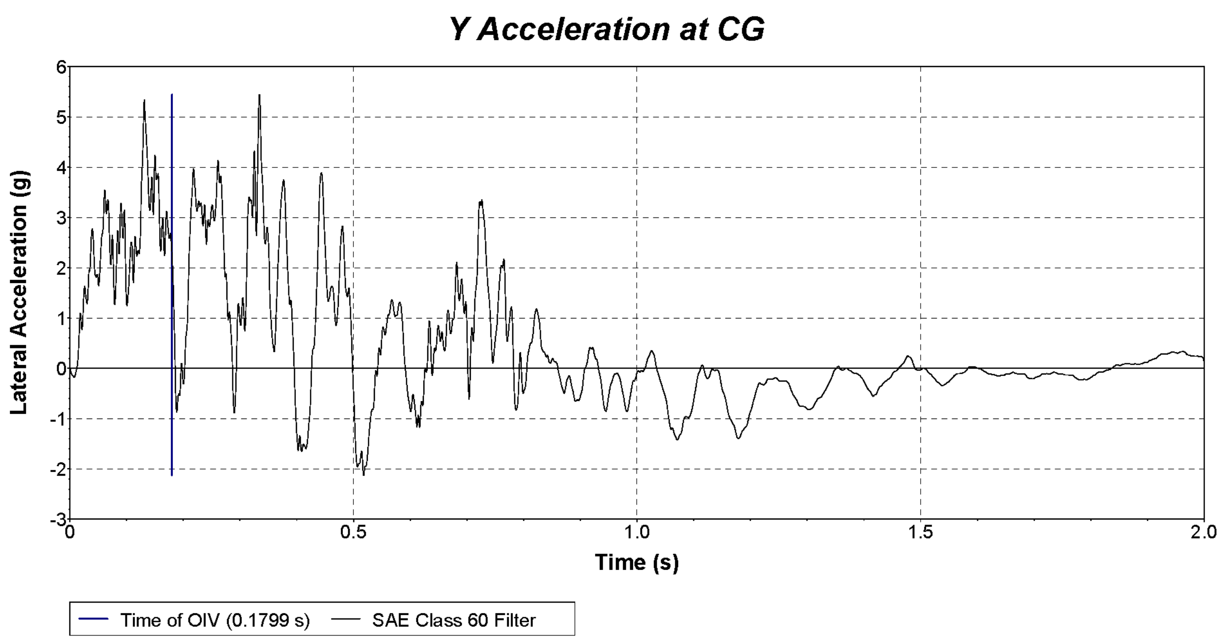


Figure C.9. Vehicle Lateral Accelerometer Trace for Test No. 615181-01-5 (Accelerometer Located at Center of Gravity).

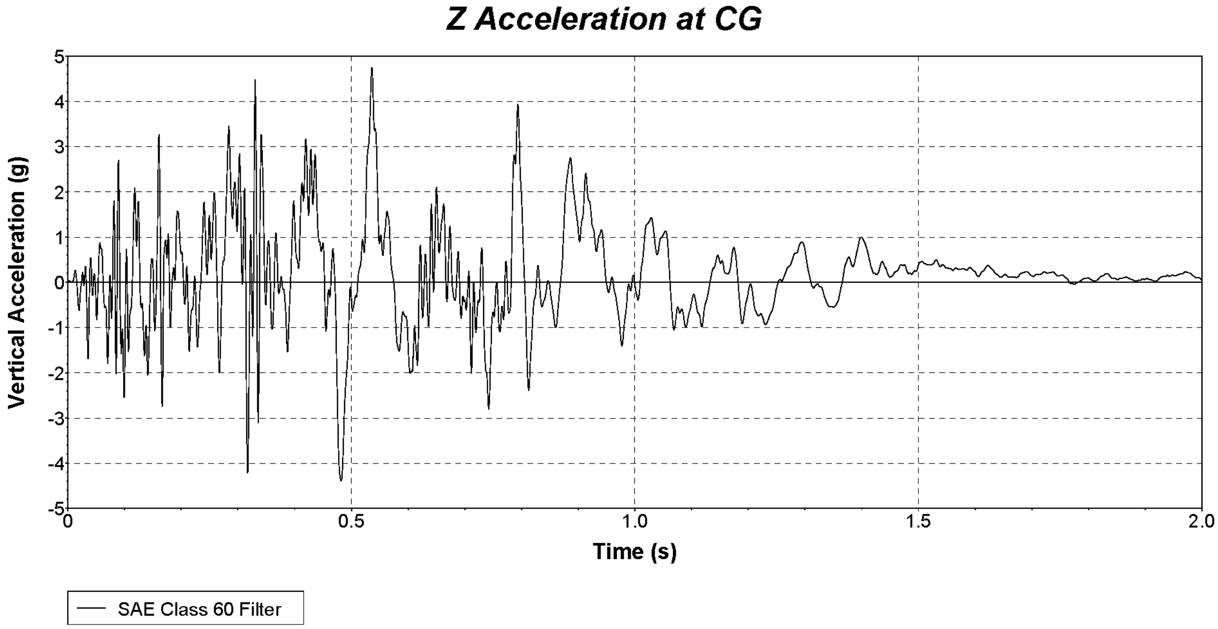


Figure C.10. Vehicle Vertical Accelerometer Trace for Test No. 615181-01-5 (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 2-30 (CRASH TEST NO. 615181-01-11)

D.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2022-10-06 Test No.: 615181-1-11 VIN No.: 3N1C7AP6HL902768

Year: 2017 Make: Nissan Model: Versa

Tire Inflation Pressure: 36 PSI Odometer: 136245 Tire Size: P185/65R15

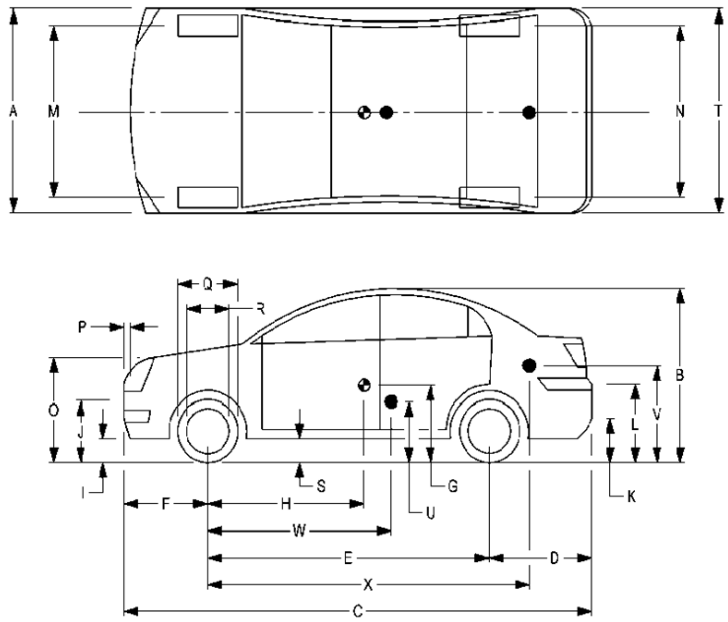
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None

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

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



Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	41.38	M	58.30	R	16.25	W	41.25
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.50	O	30.50	T	64.50		

Wheel Center Ht Front 11.50 Wheel Center Ht Rear 11.50 W-H -0.13

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1750	M_{front}	1419	1442	1527
Back	1687	M_{rear}	928	978	1058
Total	3389	M_{Total}	2347	2420	2585

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

Mass Distribution:
lb LF: 757 RF: 685 LR: 505 RR: 473

Figure D.1. Vehicle Properties for Test No. 615181-01-11.

Date:	2022-10-06	Test No.:	615181-1-11	VIN No.:	3N1CN7AP6HL902768
Year:	2017	Make:	Nissan	Model:	Versa

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	AT FT BUMPER	10	13	40							0
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

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

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

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

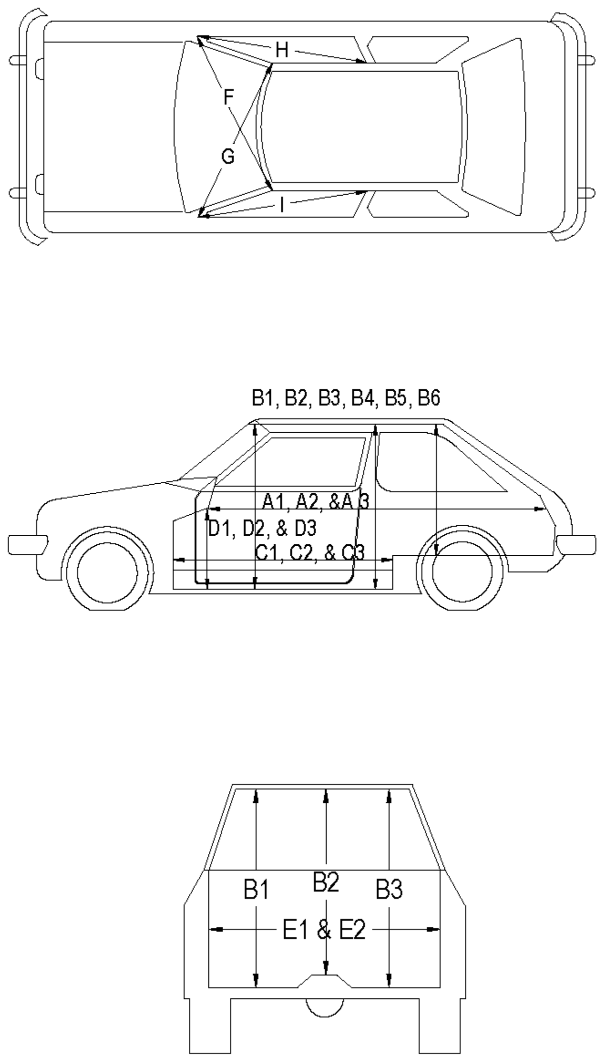
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Figure D.2. Exterior Crush Measurements for Test No. 615181-01-11.

Date:	2022-10-06	Test No.:	615181-1-11	VIN No.:	3N1CN7AP6HL902768
Year:	2017	Make:	Nissan	Model:	Versa



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.50	67.50	0.00
A2	67.25	67.25	0.00
A3	67.75	67.75	0.00
B1	40.50	40.50	0.00
B2	39.00	39.00	0.00
B3	40.50	40.50	0.00
B4	36.25	36.25	0.00
B5	36.00	36.00	0.00
B6	36.25	36.25	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	9.50	0.00
E1	51.50	51.50	0.00
E2	51.00	51.00	0.00
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	51.00	51.00	0.00

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

Figure D.3. Occupant Compartment Measurements for Test No. 615181-01-11.

D.2. SEQUENTIAL PHOTOGRAPHS


(a) 0.000 s (b) 0.100 s


(c) 0.200 s (d) 0.300 s


(e) 0.400 s (f) 0.500 s


(g) 0.600 s (h) 0.700 s

Figure D.4. Sequential Photographs for Test No. 615181-01-11 (Overhead Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure D.5. Sequential Photographs for Test No. 615181-01-11 (Frontal Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

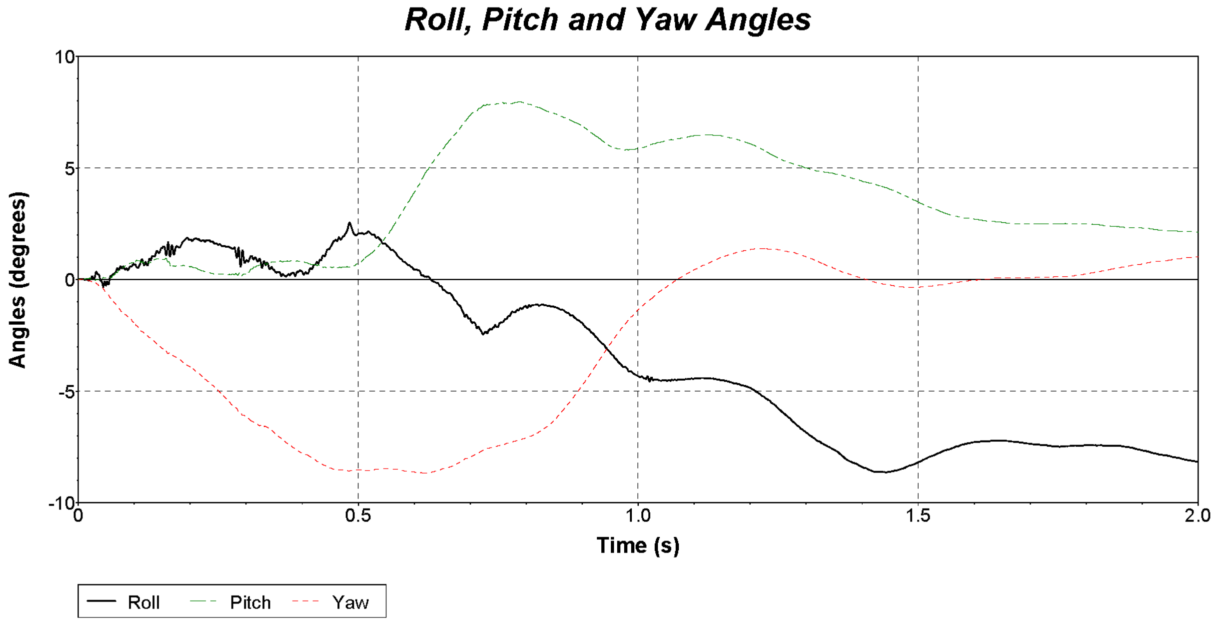
(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

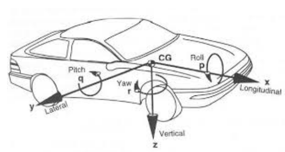
Figure D.6. Sequential Photographs for Test No. 615181-01-11 (Oblique Views).

D.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

4. Yaw.
5. Pitch.
6. Roll.



Test Number: 615181-01-11
Test Standard Test Number: *MASH* Test 2-30
Test Article: TL-2 W-beam End Terminal
Test Vehicle: 2017 Nissan Versa
Inertial Mass: 2420 lbs
Gross Mass: 2585 lbs
Impact Speed: 45.6 mi/h
Impact Angle: 0°

Figure D.7. Vehicle Angular Displacements for Test No. 615181-01-11.

D.4. VEHICLE ACCELERATIONS

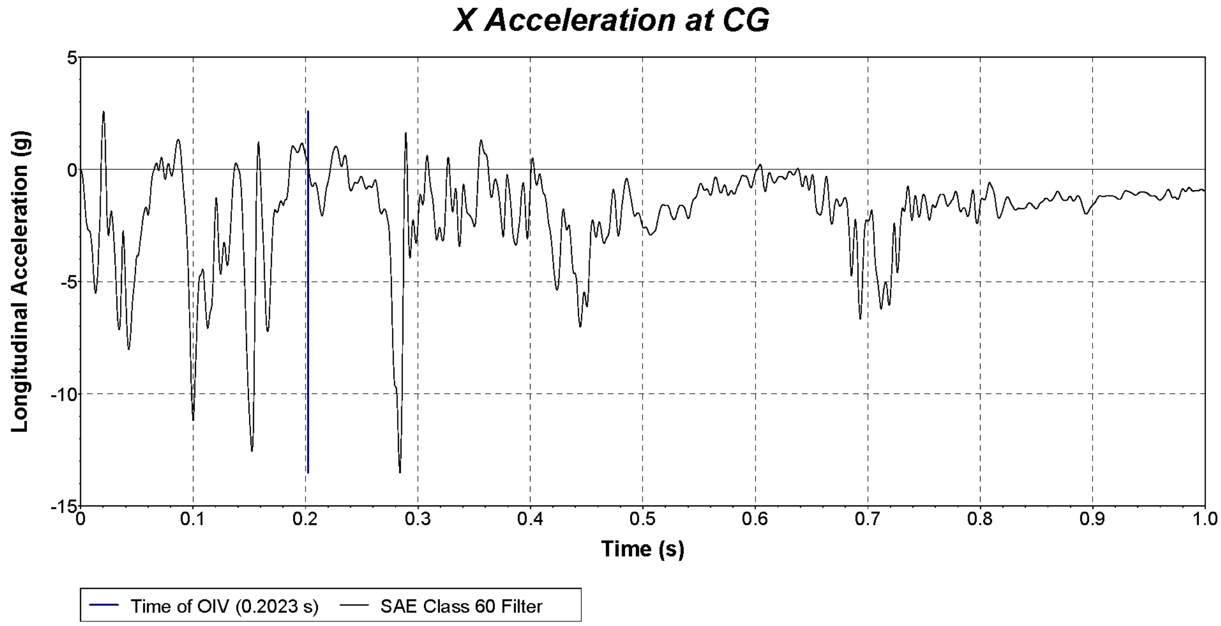


Figure D.8. Vehicle Longitudinal Accelerometer Trace for Test No. 615181-01-11 (Accelerometer Located at Center of Gravity).

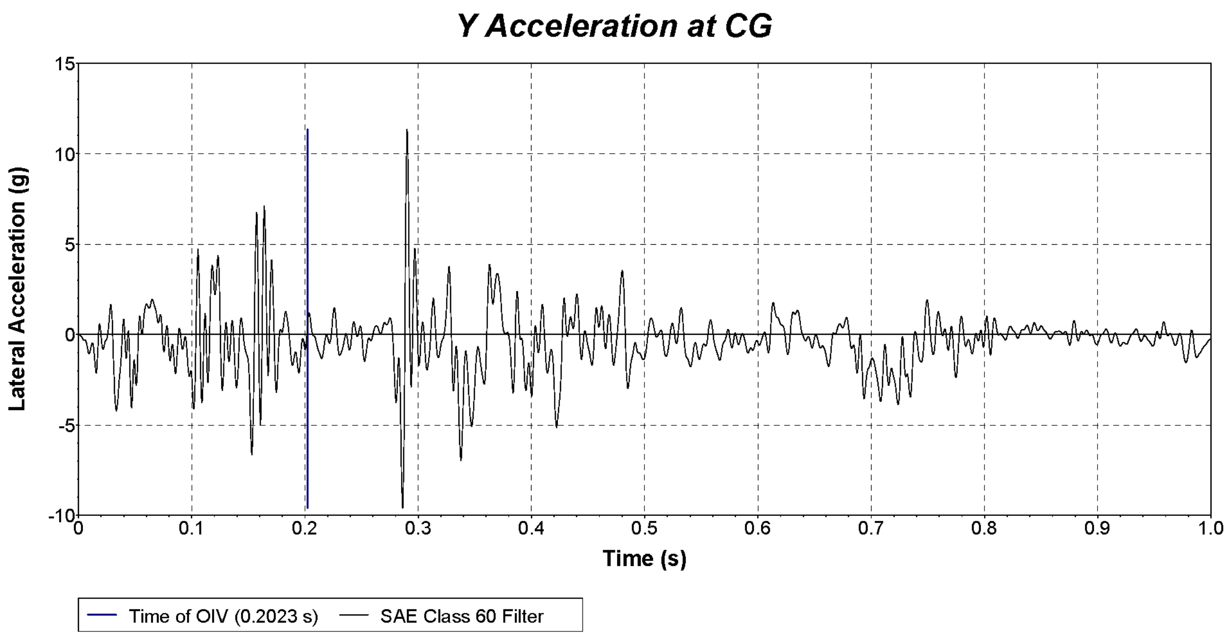


Figure D.9. Vehicle Lateral Accelerometer Trace for Test No. 615181-01-11 (Accelerometer Located at Center of Gravity).

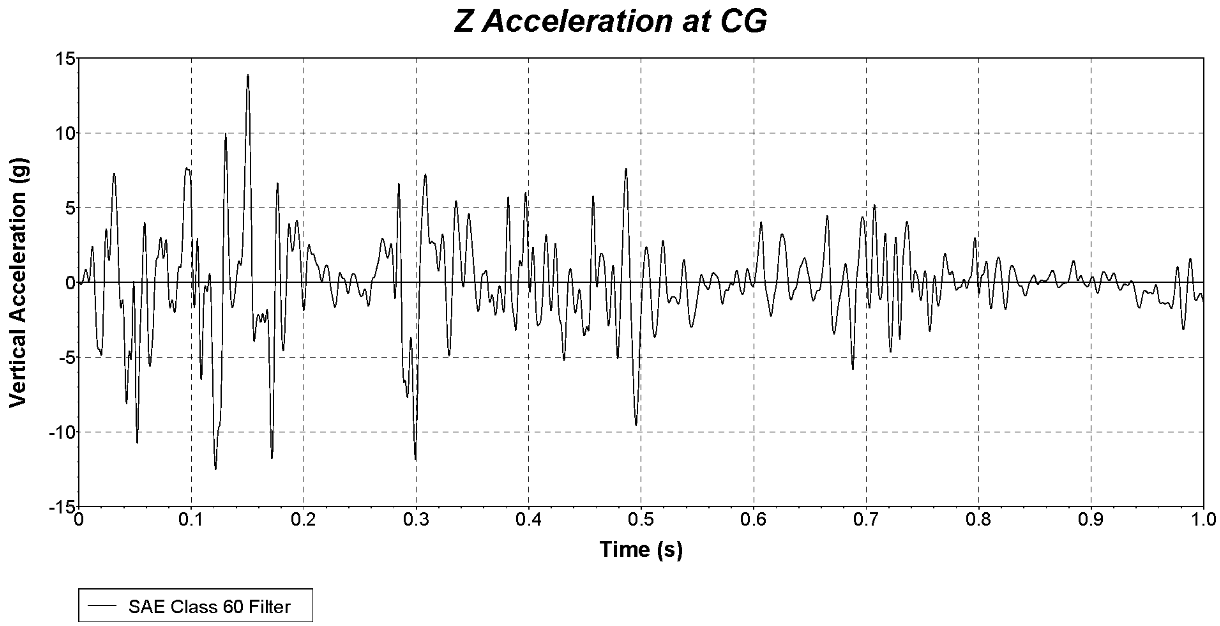


Figure D.10. Vehicle Vertical Accelerometer Trace for Test No. 615181-01-11 (Accelerometer Located at Center of Gravity).

APPENDIX E. *MASH* TEST 2-31 (CRASH TEST NO. 615181-01-12)

E.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2022-10-11 Test No.: 615181-01-12 VIN No.: 1C6RR6FT8HS542679

Year: 2017 Make: RAM Model: 1500

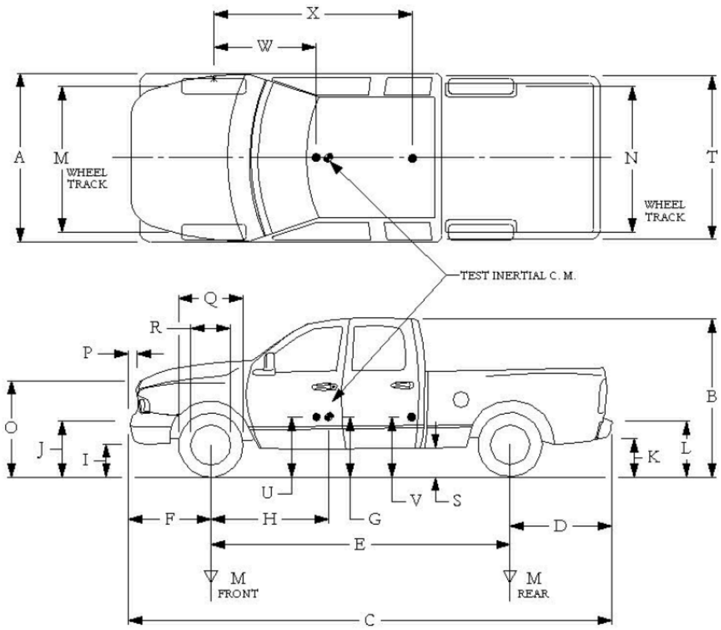
Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 102750

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None



Engine Type: V-8

Engine CID: 5.7 liter

Transmission Type:

☑ Auto or ☐ Manual

☐ FWD ☑ RWD ☐ 4WD

Optional Equipment:

None

Dummy Data:

Type: NONE

Mass:

Seat Position:

Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.40	L	30.00	Q	30.50	V	30.25
C	227.50	H	59.97	M	68.50	R	18.00	W	60.00
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2967	2907	2907
Back	3900	M_{rear}	2087	2165	2165
Total	6700	M_{Total}	5054	5072	5072

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

Mass Distribution:

lb LF: 1443 RF: 1464 LR: 1126 RR: 1039

Figure E.1. Vehicle Properties for Test No. 615181-01-12.

Date:	2022-10-11	Test No.:	615181-01-12	VIN No.:	1C6RR6FT8HS542679
Year:	2017	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	AT FT BUMPER	14	14	72							0
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

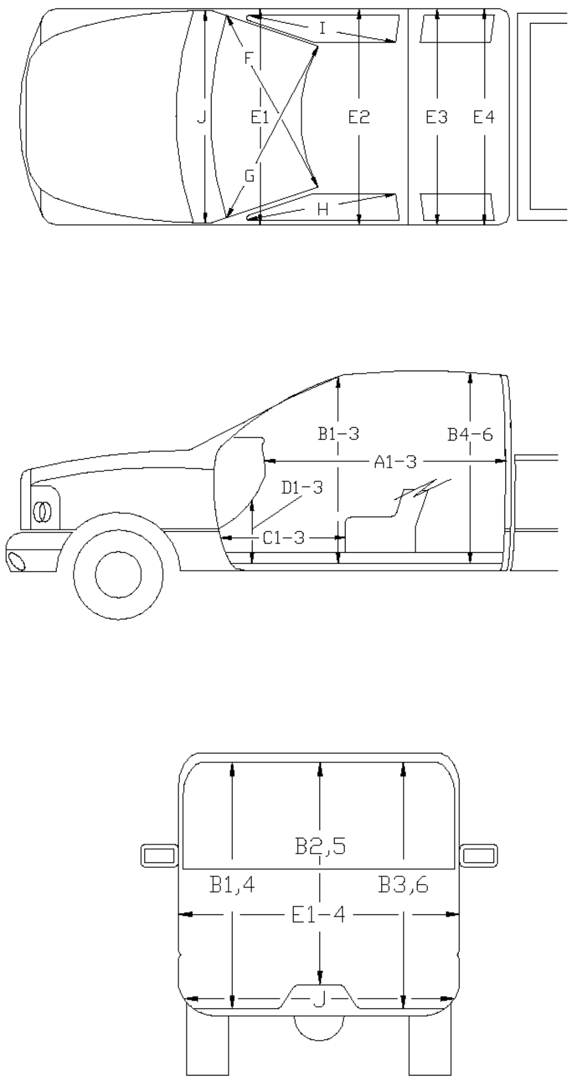
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Figure E.2. Exterior Crush Measurements for Test No. 615181-01-12.

Date:	2022-10-11	Test No.:	615181-01-12	VIN No.:	1C6RR6FT8HS542679
Year:	2017	Make:	RAM	Model:	1500



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

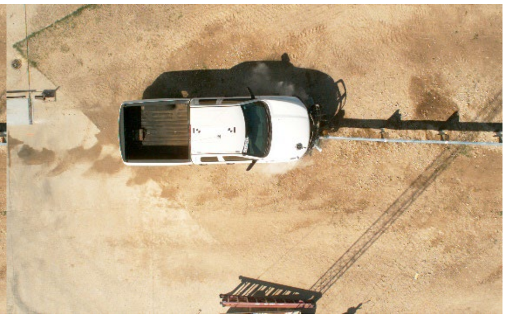
OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

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

Figure E.3. Occupant Compartment Measurements for Test No. 615181-01-12.

E.2. SEQUENTIAL PHOTOGRAPHS

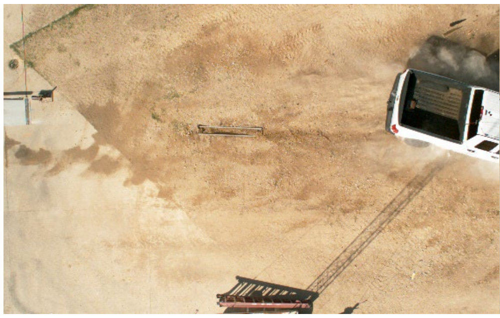
(a) 0.000 s



(b) 0.100 s

(c) 0.200 s

(d) 0.300 s



(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure E.4. Sequential Photographs for Test No. 615181-01-12 (Overhead Views).


(a) 0.000 s


(b) 0.100 s


(c) 0.200 s


(d) 0.300 s


(e) 0.400 s


(f) 0.500 s


(g) 0.600 s


(h) 0.700 s

Figure E.5. Sequential Photographs for Test No. 615181-01-12 (Frontal Views).


(a) 0.000 s
(b) 0.100 s

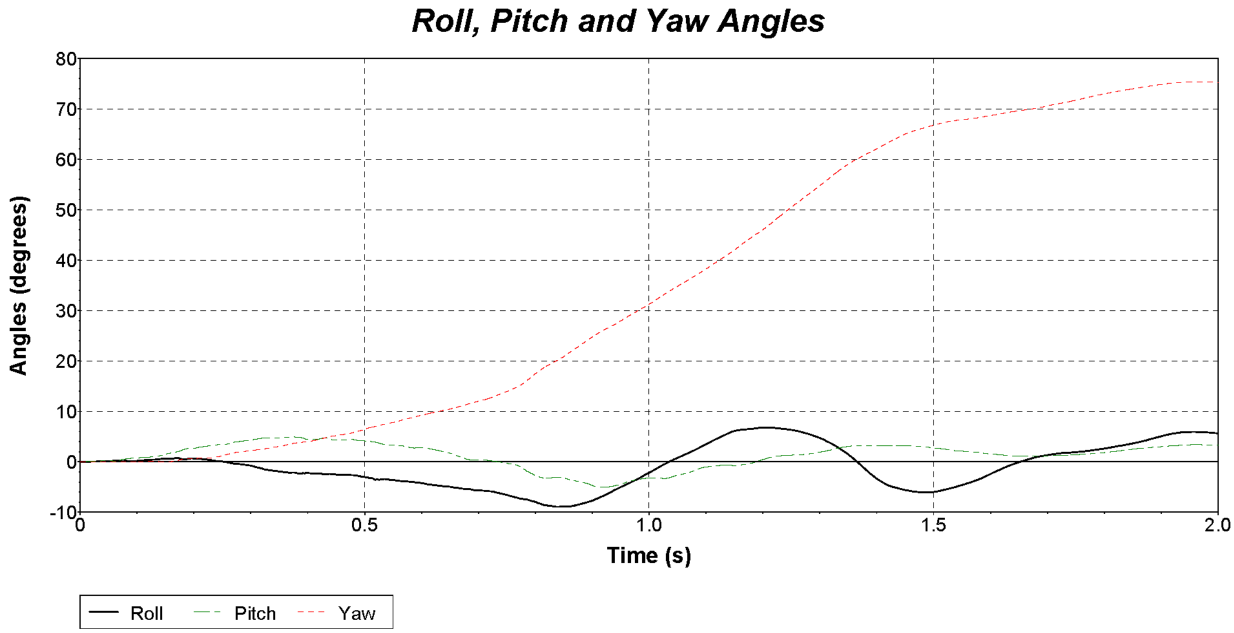

(c) 0.200 s
(d) 0.300 s


(e) 0.400 s
(f) 0.500 s


(g) 0.600 s
(h) 0.700 s

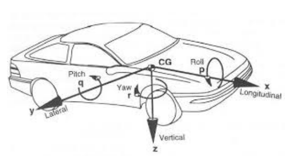
Figure E.6. Sequential Photographs for Test No. 615181-01-12 (Oblique Views).

E.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

7. Yaw.
8. Pitch.
9. Roll.



Test Number: 615181-01-12
Test Standard Test Number: *MASH* Test 2-31
Test Article: TL-2 W-beam End Terminal
Test Vehicle: 2017 RAM 1500
Inertial Mass: 5072 lbs
Gross Mass: 5072 lbs
Impact Speed: 46.1 mi/h
Impact Angle: 0°

Figure E.7. Vehicle Angular Displacements for Test No. 615181-01-12.

E.4. VEHICLE ACCELERATIONS

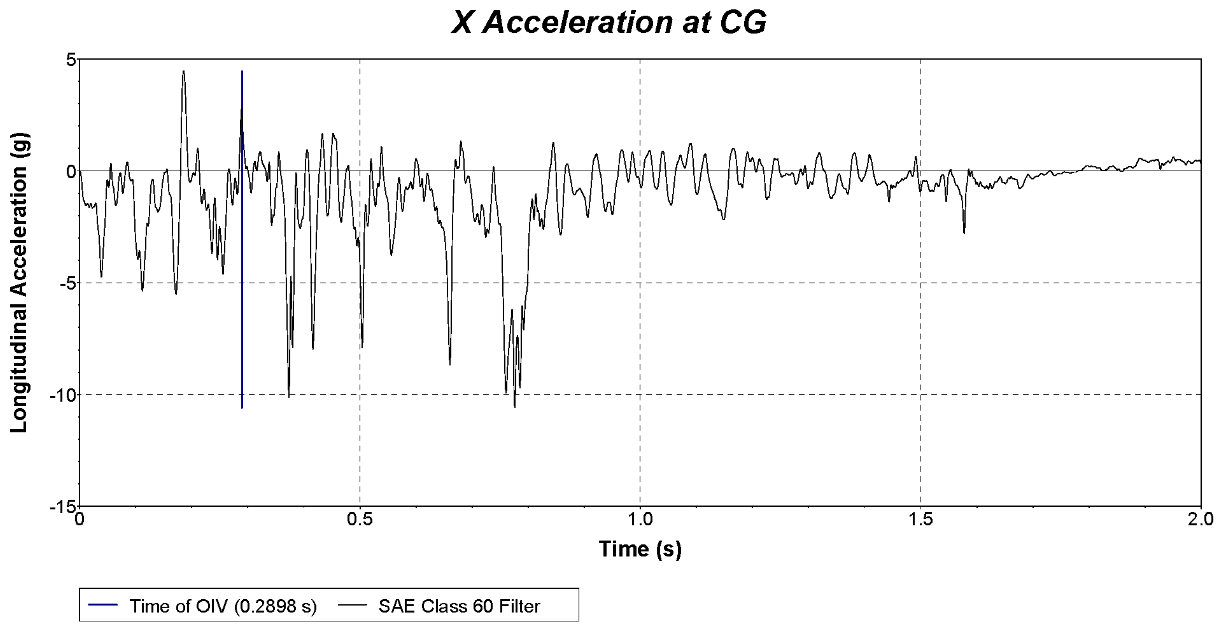


Figure E.8. Vehicle Longitudinal Accelerometer Trace for Test No. 615181-01-12 (Accelerometer Located at Center of Gravity).

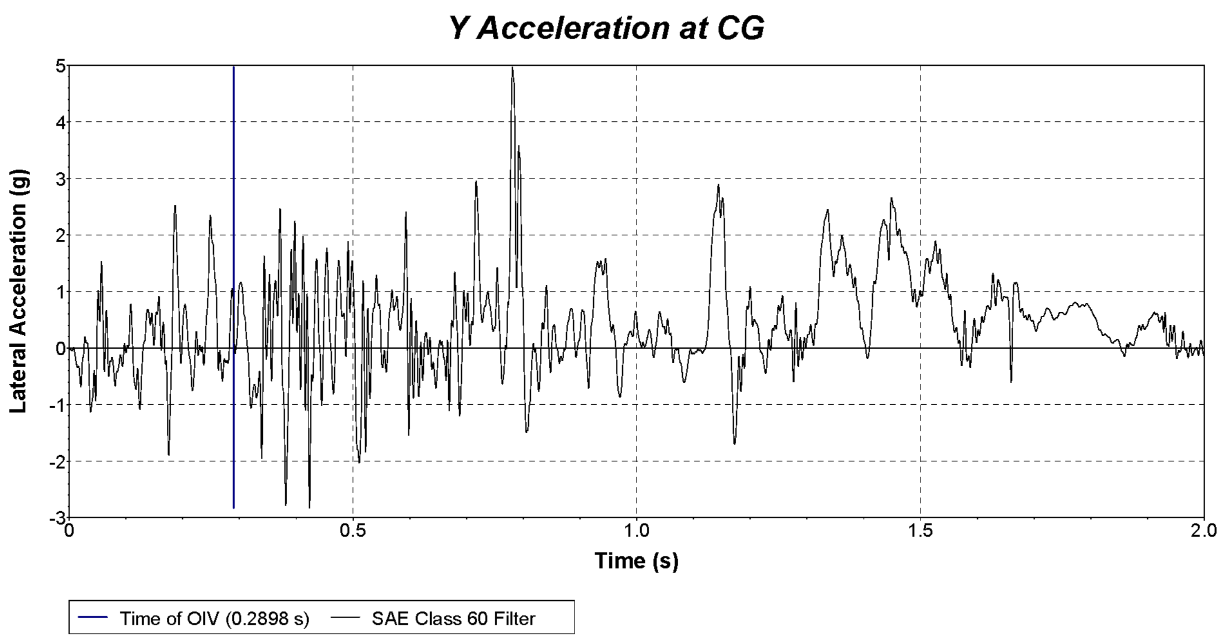


Figure E.9. Vehicle Lateral Accelerometer Trace for Test No. 615181-01-12 (Accelerometer Located at Center of Gravity).

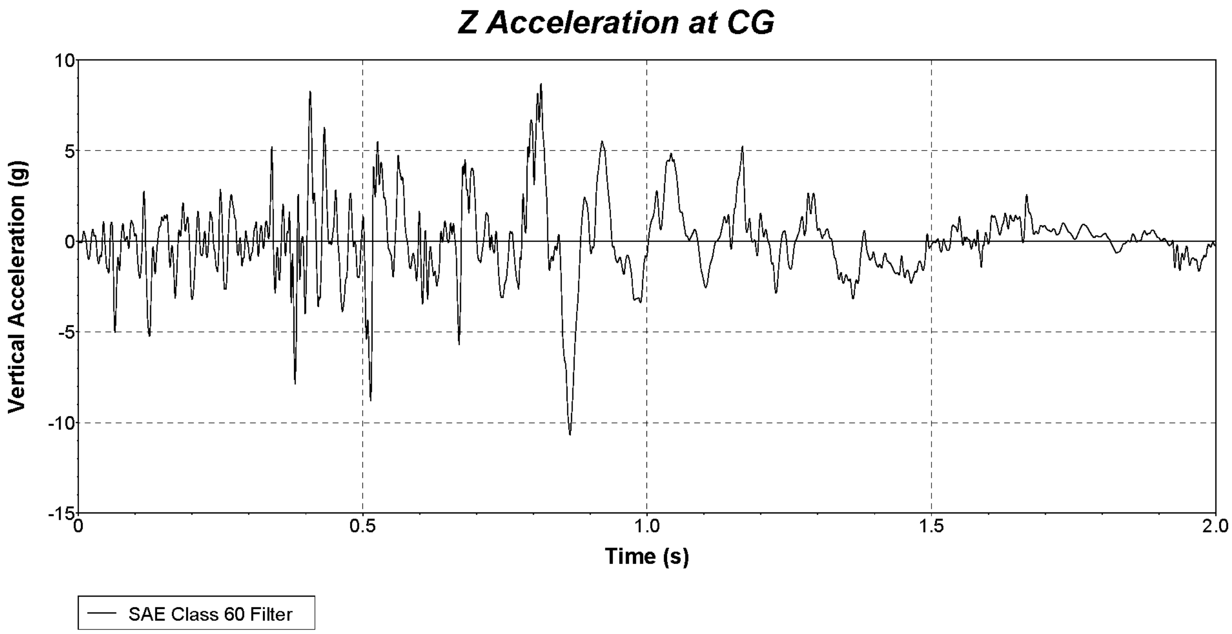


Figure E.10. Vehicle Vertical Accelerometer Trace for Test No. 615181-01-12 (Accelerometer Located at Center of Gravity).

APPENDIX F. *MASH* TEST 2-37B (CRASH TEST NO. 615181-01-13)

F.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2022-10-20 Test No.: 615181-1-13 VIN No.: 3N1CN7AP4HL8O4614

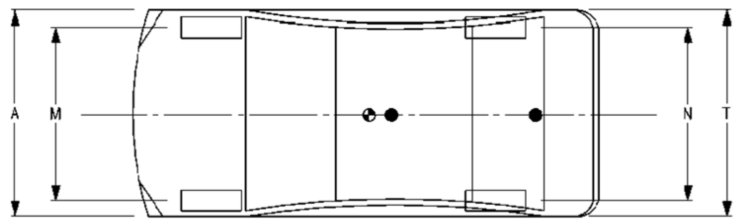
Year: 2017 Make: Nissan Model: Versa

Tire Inflation Pressure: 36 PSI Odometer: 59805 Tire Size: P185/65R15

Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None



Engine Type: 4 CYL

Engine CID: 1.6 L

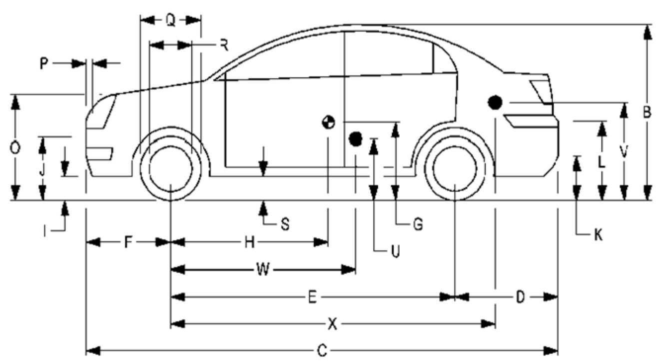
Transmission Type:

☑ Auto or ☐ Manual

☑ FWD ☐ RWD ☐ 4WD

Optional Equipment:

None



Dummy Data:

Type: 50th Percentile Male

Mass: 165 lb

Seat Position: IMPACT SIDE

Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	41.71	M	58.30	R	16.25	W	41.70
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.50	O	30.50	T	64.50		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1750	M_{front}	1443	1452	1537
Back	1687	M_{rear}	903	998	1078
Total	3389	M_{Total}	2346	2450	2615

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

Mass Distribution:

lb LF: 742 RF: 710 LR: 487 RR: 511

Figure F.1. Vehicle Properties for Test No. 615181-01-13.

Date:	2022-10-20	Test No.:	615181-1-13	VIN No.:	3N1CN7AP4HL804614
Year:	2017	Make:	Nissan	Model:	Versa

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	AT FT BUMPER	14	6	28							-14
2	ABOVE FT BUMPER	14	6	50							60
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

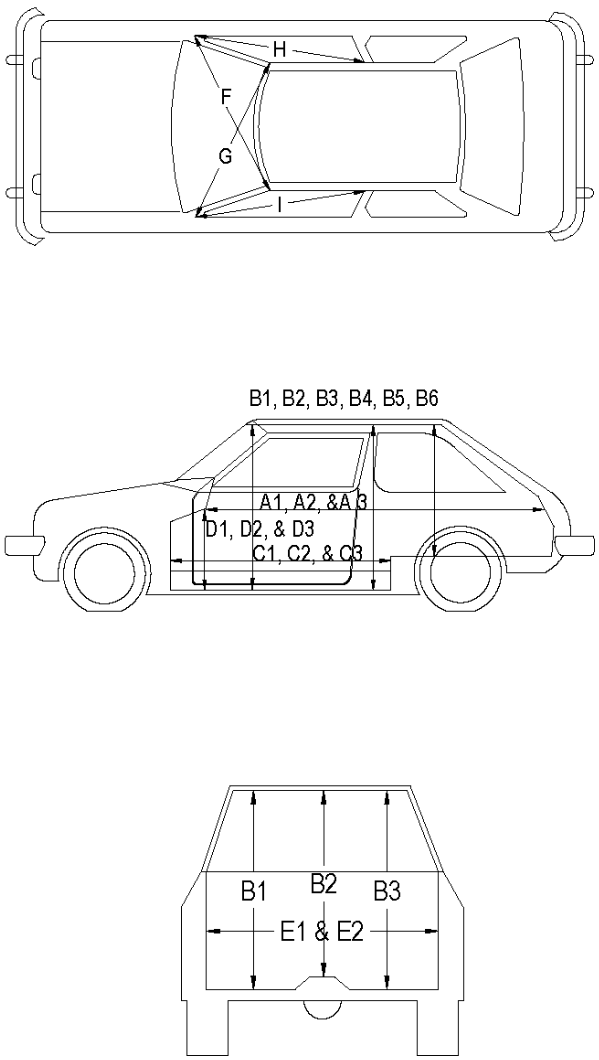
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Figure F.2. Exterior Crush Measurements for Test No. 615181-01-13.

Date:	2022-10-20	Test No.:	615181-1-13	VIN No.:	3N1CN7AP4HL804614
Year:	2017	Make:	Nissan	Model:	Versa



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.50	67.50	0.00
A2	67.25	67.25	0.00
A3	67.75	67.75	0.00
B1	40.50	40.50	0.00
B2	39.00	39.00	0.00
B3	40.50	40.50	0.00
B4	36.25	36.25	0.00
B5	36.00	36.00	0.00
B6	36.25	36.25	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	9.50	0.00
E1	51.50	51.50	0.00
E2	51.00	51.00	0.00
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	51.00	51.00	0.00

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

Figure F.3. Occupant Compartment Measurements for Test No. 615181-01-13.

F.2. SEQUENTIAL PHOTOGRAPHS

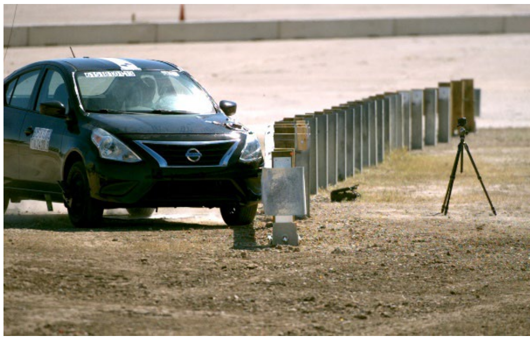
(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

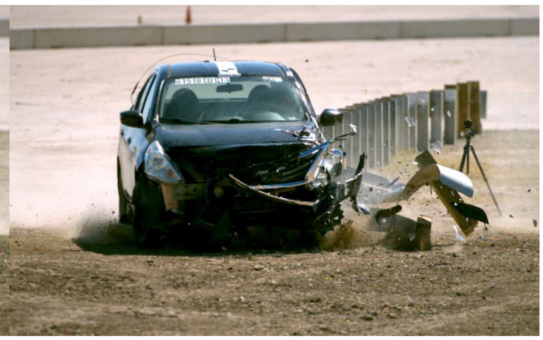
Figure F.4. Sequential Photographs for Test No. 615181-01-13 (Overhead Views).



(a) 0.000 s

(b) 0.100 s

(c) 0.200 s



(d) 0.300 s

(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure F.5. Sequential Photographs for Test No. 615181-01-13 (Frontal Views).


(a) 0.000 s


(b) 0.100 s


(c) 0.200 s


(d) 0.300 s


(e) 0.400 s

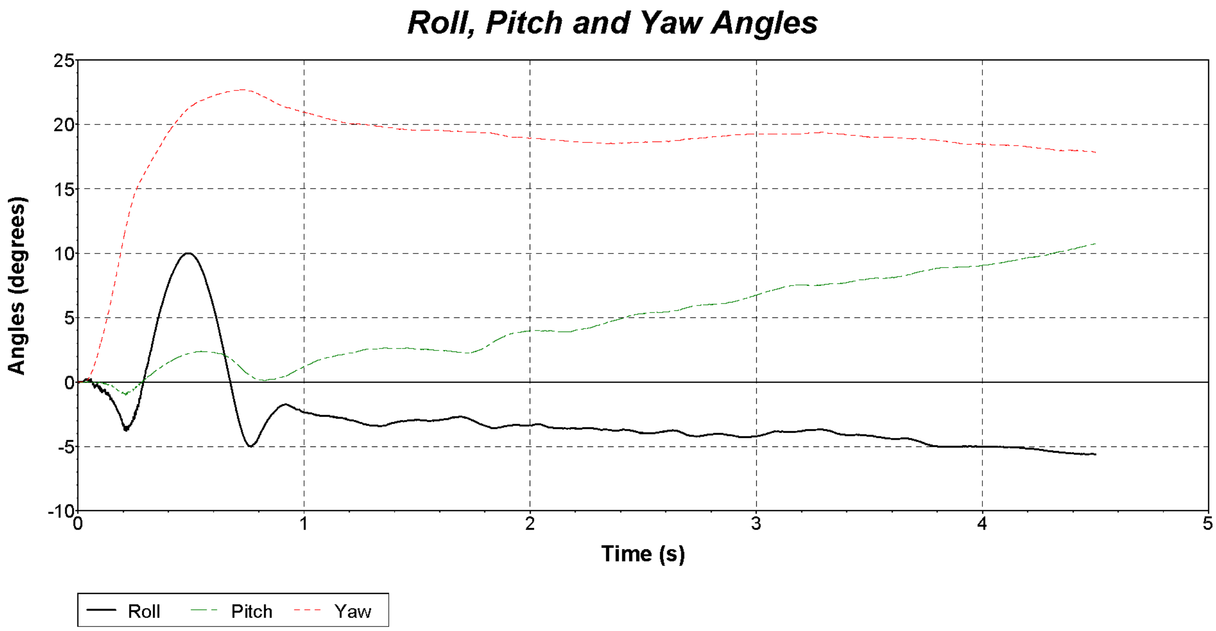

(f) 0.500 s


(g) 0.600 s


(h) 0.700 s

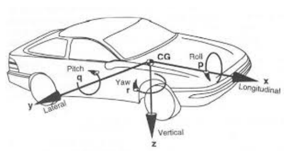
Figure F.6. Sequential Photographs for Test No. 615181-01-13 (Rear Views).

F.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

10. Yaw.
11. Pitch.
12. Roll.



Test Number: 615181-01-13
Test Standard Test Number: *MASH* Test 2-37b
Test Article: TL-2 W-beam End Terminal
Test Vehicle: 2017 Nissan Versa
Inertial Mass: 2450 lbs
Gross Mass: 2615 lbs
Impact Speed: 45.3 mi/h
Impact Angle: 24.5°

Figure F.7. Vehicle Angular Displacements for Test No. 615181-01-13.

F.4. VEHICLE ACCELERATIONS

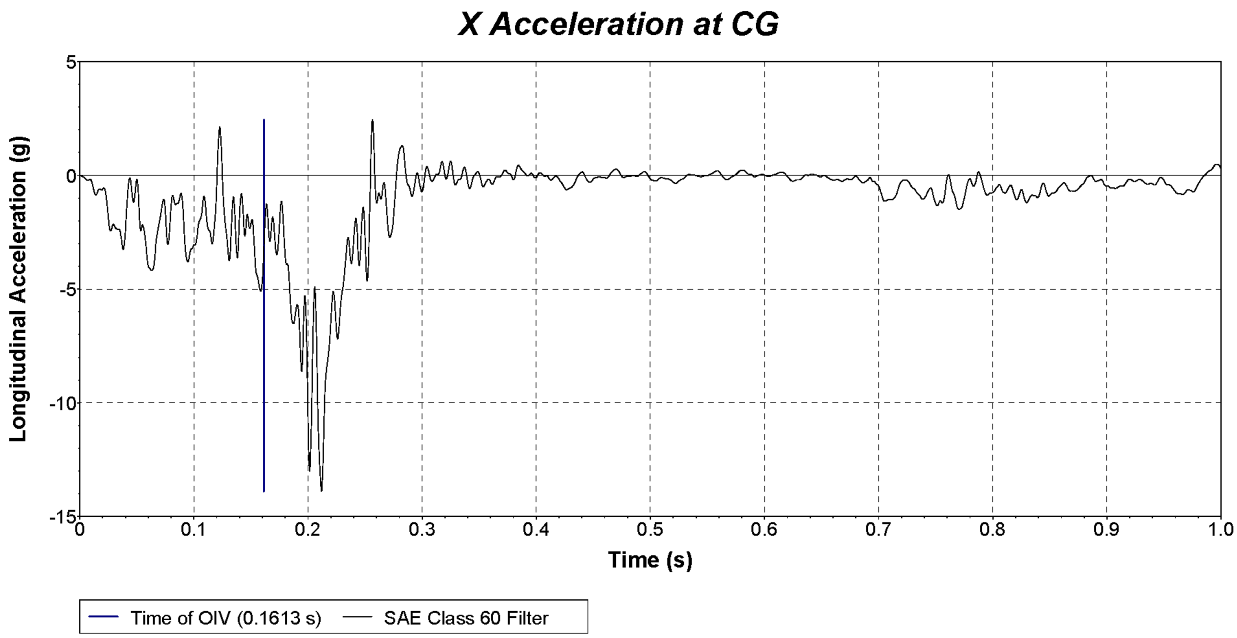


Figure F.8. Vehicle Longitudinal Accelerometer Trace for Test No. 615181-01-13 (Accelerometer Located at Center of Gravity).

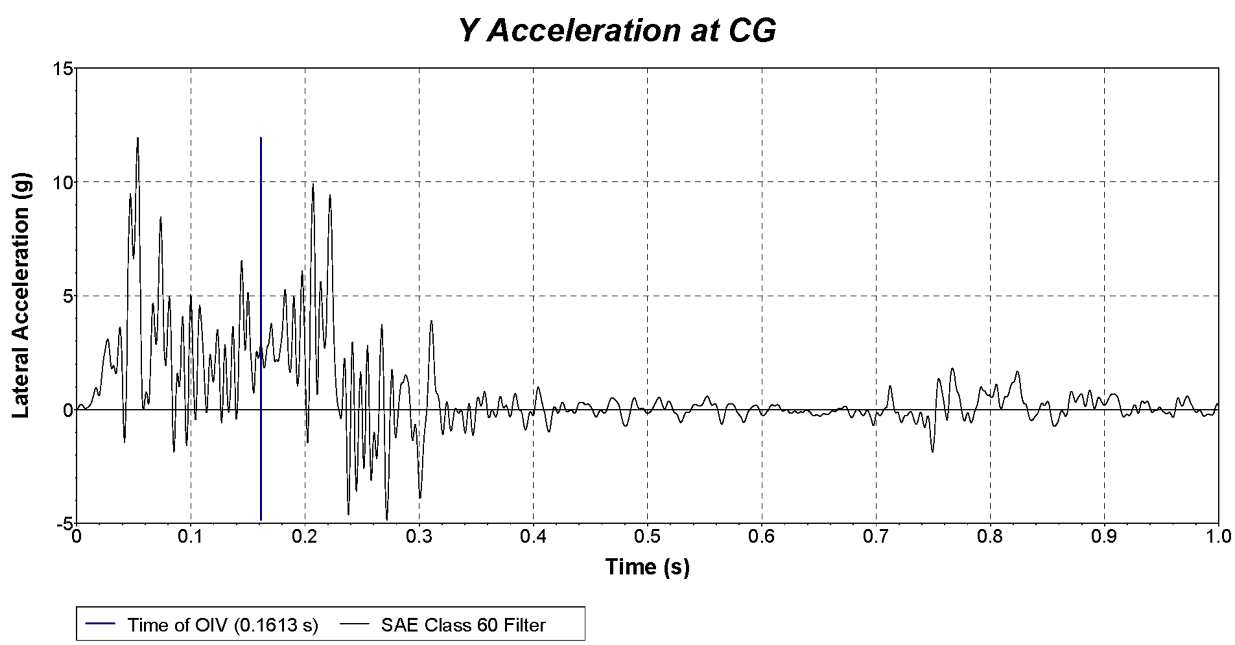


Figure F.9. Vehicle Lateral Accelerometer Trace for Test No. 615181-01-13 (Accelerometer Located at Center of Gravity).

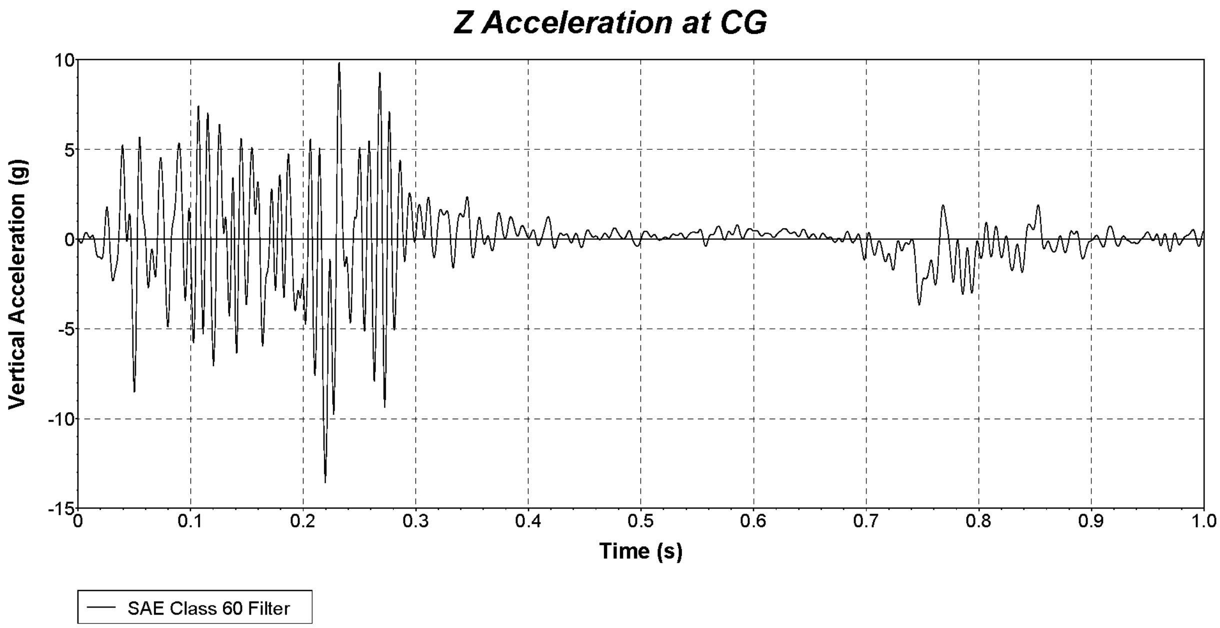


Figure F.10. Vehicle Vertical Accelerometer Trace for Test No. 615181-01-13 (Accelerometer Located at Center of Gravity).

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FHWA-FLH-23-004