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MASH TL-3 DESIGN, TESTING, AND EVALUATION OF A FLARED GUARDRAIL SYSTEM - PHASE 2

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16. Abstract

The purpose of this project was to determine the steepest allowable flare rate meeting the *Manual for Assessing Safety Hardware* (*MASH*) Test Level 3 (TL-3) for the Midwest Guardrail System (MGS) using finite element (FE) analysis and full-scale crash tests. Based on the FE impact analysis from the Phase 1 project, a 21:1 flare rate was recommended for the MGS. The performance of the 21:1 Flared MGS was assessed according to the safety-performance evaluation guidelines included in the second edition of the American Association of State Highway and Transportation Officials (AASHTO) *MASH*. The crash tests were performed in accordance with *MASH* TL-3:

1. ***MASH* Test 3-10:** An 1100C vehicle weighing 2420 lb impacting the Longitudinal Barrier while travelling at 62 mi/h and 25 degrees.
2. ***MASH* Test 3-11:** A 2270P vehicle weighing 5000 lb impacting the Longitudinal Barrier while traveling at 62 mi/h and 25 degrees.

Test 3-10 on 21:1 Flared MGS met the performance criteria for MASH TL-3 Longitudinal Barrier. However, Test 3-11 on 21:1 Flared MGS did not meet the criteria due to rail rupture. Consequently, an additional Test 3-11 on 25:1 Flared MGS was performed but did not meet MASH performance criteria due to rail rupture. Finally, additional 3-11 testing was performed on the 38:1 and 30:1 Flared MGS, both of which met MASH TL-3 performance criteria for Longitudinal Barriers. This report provides results for the impact simulations, details of the tested systems, the crash tests and results, and the performance assessment of the 21:1, 25:1, 38:1, and 30:1 Flared MGS for MASH TL-3 Longitudinal Barrier evaluation criteria.

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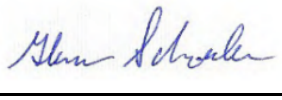
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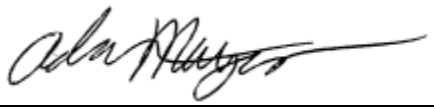
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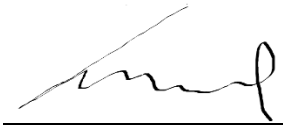
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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61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

*SI is the symbol for the International System of Units

CHAPTER 1.

INTRODUCTION

1.1. BACKGROUND

This research continues the investigation of the previously completed pooled fund project TRP#609971-01 *"Testing and Evaluation of the MGS System with Critical Flare at MASH Test Level 3 Conditions"* (*1*). The purpose of the project was to investigate and find the sharpest/critical flare rate for the Midwest Guardrail System (MGS) that meets the American Association of Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*2*) Test Level 3 (TL-3) testing and evaluation criteria.

Critical flare rates for the MGS system have only been investigated according to TL-3 criteria per previous NCHRP Report 350 standard requirements. Currently, AASHTO Roadside Design Guide (RDG) (*3*) Table 5-9 lists suggested flare rates for barrier design based on NCHRP Report 350 test results, as shown in Table 1.1.

Table 1.1. Showing Suggested Flare Rates for Barrier Design (*3*).

Design Speed km/h [mph]	Flare Rate for Barrier Inside Shy Line	Maximum Flare Rate for Rigid Barrier System at or Beyond Shy Line	Maximum Flare Rate for Semi-Rigid Barrier System at or Beyond Shy Line
110 [70]	30:1	20:1	15:1
100 [60]	26:1	18:1	14:1
90 [55]	24:1	16:1	12:1
80 [50]	21:1	14:1	11:1
70 [45]	18:1	12:1	10:1
60 [40]	16:1	10:1	8:1
50 [30]	13:1	8:1	7:1

Notes: *The MGS has been tested in accordance with NCHRP Report 350 TL-3 at 5:1 flare.*
Flatter flare rates for the MGS installations also are acceptable. The MGS should be installed using the flare rates shown or flatter for semi-rigid barriers beyond the shy line when installed in rock formations

Under project 609971-01 (*1*), the research team conducted engineering analysis, computer simulations, and crash tests on flared MGS systems using three different configurations. Based off the RDG guidance, the project initially crash tested the MGS system with standard 6 ft–3 inches post spacing, with standard 6-foot-long steel posts, and with a 7:1 flare rate. The system was tested under the *MASH* Test 3-10 (passenger car) and the test failed due to the rail rupture. Next, a second MASH Test 3-11 (pick-up truck) crash test was conducted on the MGS system with a flatter 11:1 flare rate. The test failed due to anchorage failure. Finally, a last MASH Test 3-11 (pick-up truck) crash test was performed which was very similar to the second test(the test was conducted on the MGS system with

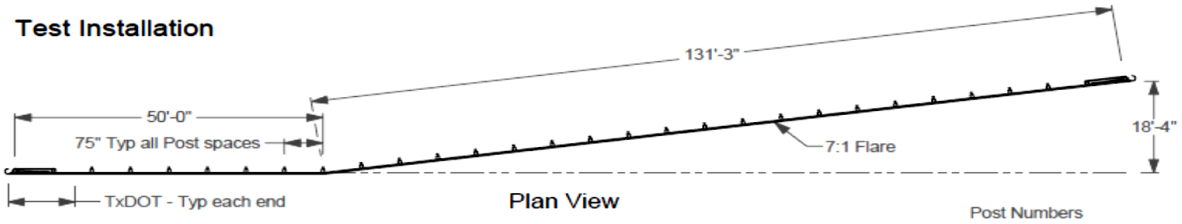
the same 11:1 flare rate but used a proprietary *MASH* end terminal rather than a generic *MASH* compliant anchor). The test failed due to the rail rupture. Figure 1.1 through Figure 1.3 show the tested system layouts, photos of the test installations after impact, and the reasons for failure.

Since all crash tests conducted under project 609971-01 (*1*) failed due to structural inadequacy, the research team opted to use its remaining resources to conduct computer simulations using the data obtained from the three failed crash tests. First, computer simulations were run on an unmodified MGS system with flare rates of 15:1, 18:1, and 21:1. The three simulations indicated likely failure due to excessive lateral deflection/pocketing leading to probable rail rupture or high levels of ridedown acceleration forces. Next, computer simulations were run on potential modified MGS system. The MGS system was modified by utilizing half post spacing, utilizing shortened blockouts, and adding a rubrail. The simulations indicated that the modified MGS system with a 15:1 flare rate would likely pass MASH crash testing.

To continue research for developing a *MASH* TL-3 compliant flared MGS, the research team conducted a preliminary poll with pooled fund state agencies after project 609971-01 *(1)* was completed. The state agencies were requested to select their preferred research option: a) Evaluate the unmodified MGS at a flatter than 21:1 flare rate using computer simulations (and perform crash tests if simulations show the barrier is likely to pass *MASH*); or b) Perform crash tests on the modified MGS at a 15:1 flare rate. The majority of the state agencies who responded to the poll preferred continuing the investigation of the unmodified MGS at a flatter than 21:1 flare rate.

1.2. OBJECTIVE

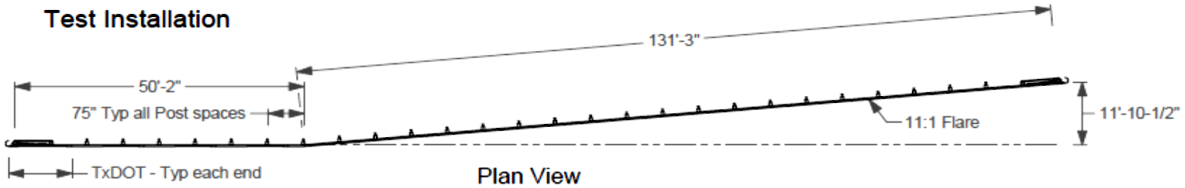
The purpose of the tests reported herein was to identify the sharpest critical flare rate for the MGS that complies with *MASH* Test Level 3 (TL-3), and to evaluate the performance of the MGS at this flare rate according to the safety-performance evaluation guidelines outlined in in *MASH* (*2*). The crash tests were performed in accordance with *MASH* TL-3, which requires two crash tests as discussed in Chapter 4 of this report.





rail rupture

Figure 1.1. Failed Test with 7:1 Flared MGS under Project 609971-01 (*1*)





anchor failure

Figure 1.2. Failed Test with 11:1 Flared MGS under Project 609971-01 (*1*)

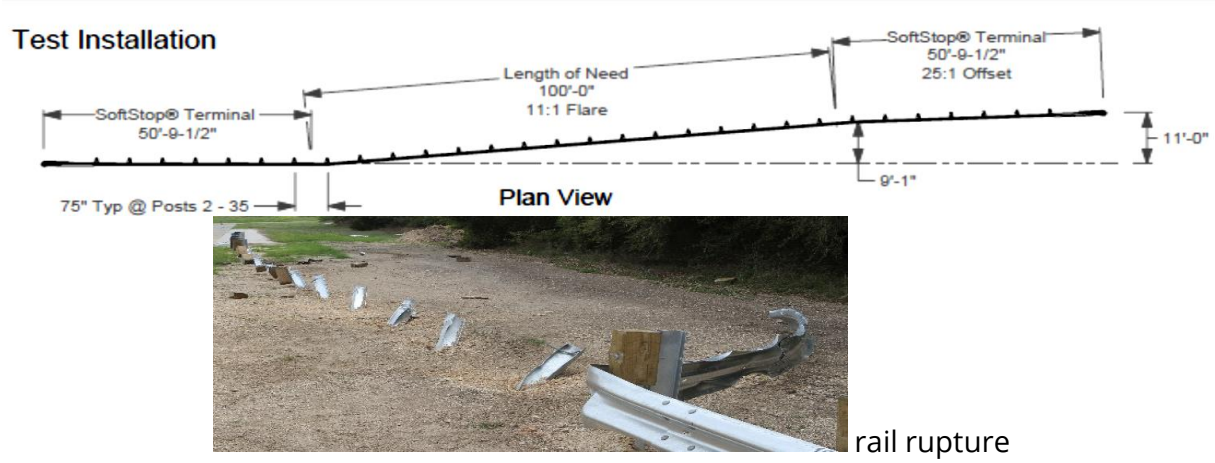


Figure 1.3. Failed Test with 11:1 Flared MGS with SoftStop Terminal under Project 609971-01 (*1*)

CHAPTER 2.

SIMULATION

2.1. INTRODUCTION

The research team conducted computer simulations to evaluate the crashworthiness of the unmodified MGS at different flare rates in accordance with *MASH* TL-3 conditions.

During testing performed under project 609971 (*1*), the primary cause of failure in the unmodified MGS was rail rupture. However, since rail rupture typically initiates with a very small and localized tear, it is difficult to predict using finite element (FE) analysis with a material failure model. Although an element erosion model could have been used as a predictive method, it was not chosen as the recommended approach due to its lack of reliability across different modeling scenarios and varying impact conditions.

Final determinations of barrier crashworthiness were therefore reached based on the following factors:

- the interaction between the vehicle and the barrier system,
- the extent of lateral deflection of the system during impact,
- the predicted stress and strain levels in the rails, and;
- the measured occupant risk values along with vehicle stability metrics.

In particular, the lateral movement of the system was investigated by examining the maximum deflections and pocketing potential. These system factors suggest the possibility of vehicle entrapment, which could then result in excessive forces on the guardrail beam rail and subsequently causing rail rupture.

This section presents the results of FE analysis using LS-DYNA (*4*). FE models for the flared MGS were developed and detailed crashworthiness analyses were performed in accordance with *MASH* TL-3 impact conditions.

2.2. VALIDATION

In simulations conducted under project 609971 (*1*), numerical issues were identified when impacting the flared MGS model with a small car (1100C) model. For this research project, the small car model used the 2010 Toyota Yaris FE model developed by the Center for Collision Safety and Analysis (CCSA) at George Mason University (GMU) (*5*). The vehicle model has been further improved over the course of various research projects. The FE model was validated by comparing simulation results to full-scale test data from Test 609971-01-1 (*1*). Figure 2.1 illustrates the impact conditions representing Test 609971-01-1 (*MASH* Test 3-10) on the 7:1 Flared MGS. The impact speed was set at 61.8 mi/h with an

impact angle of 24.8 degrees relative to the flat portion of the system (the effective angle was 32.9 degrees).

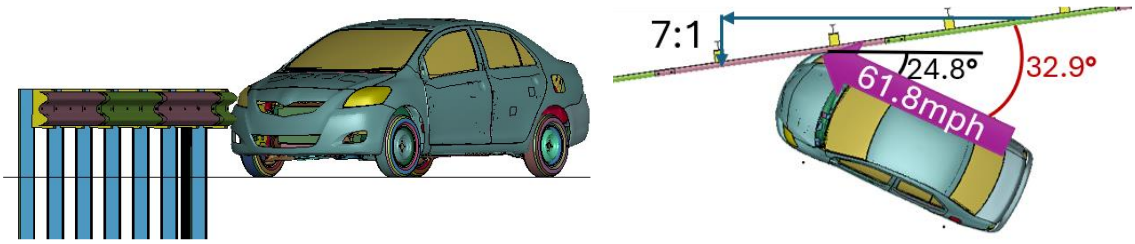


Figure 2.1. Impact Simulation Setup to Represent 7:1 Flared MGS Test (MASH Test 609971-01-1)

Figure 2.2 shows sequential images comparing the FE simulations of the 7:1 flared MGS to the results from Test 609971-01-1, up to the point when rail rupture occurred. The FE simulation showed strong similarity to the full-scale test before rail rupture. Although the FE model did not include a rail failure mode, the results were promising and suggested that the simulation is reliable for use in further FE simulation investigations.

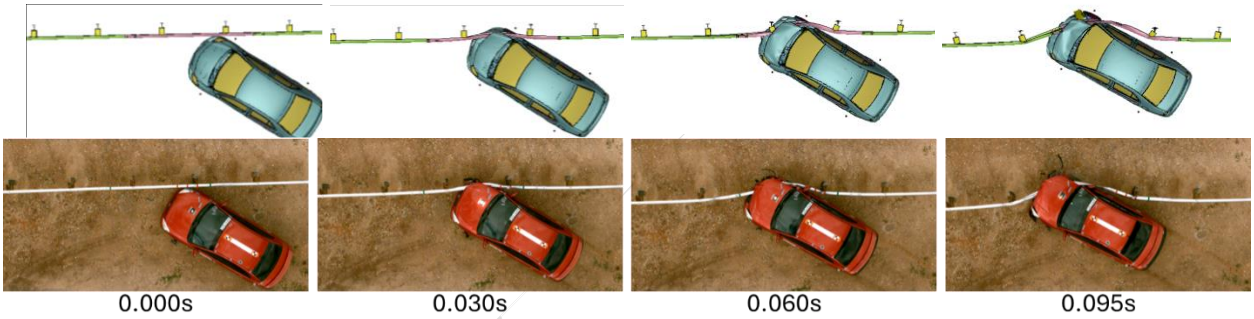


Figure 2.2. Sequential Frames Comparing FE Simulation (Top) to *MASH* Test 609971-01-1 (*1*) Immediately Leading to Rail Rupture Event.

The finite element (FE) model was further validated using a pickup truck simulation. Comparisons were made between *MASH* Test 3-11 simulations and the results from *MASH* Test 609971-03-2 (*1*) and NCHRP 350 Test No. 2214MG-2 (*6*). For this validation, a publicly available FE model of a 2018 RAM was used to represent a *MASH* 2270P vehicle. The RAM model was developed by the CCSA at GMU (*7*), and it underwent additional refinements in various research projects to enhance its validation and robustness. Figure 2.4 and Figure 2.6 shows sequential frames comparing the FE impact simulations to *MASH* Test 3-11 on 11:1 flared MGS and NCHRP 350 Test 3-11 on non-flared MGS, respectively. For the 11:1 flared MGS simulation validation, the impact speed was set at 60.3 mi/h with an impact angle of 24.5 degrees relative to the flat portion of the system (the effective angle was 29.7 degrees). For the non-flared MGS simulation validation, the impact speed was set at 62 mi/h with an impact angle of 25-degrees.

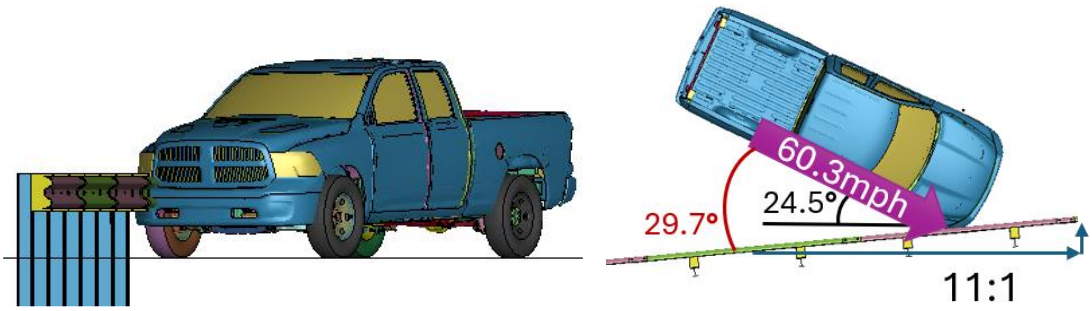


Figure 2.3. Impact Simulation Setup to Represent 11:1 Flared MGS Test (MASH TEST 609971-03-2)

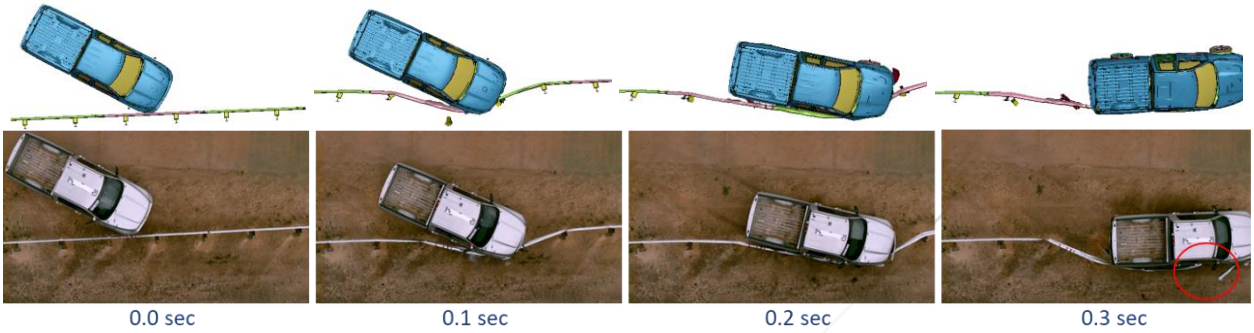


Figure 2.4. Sequential Frames Comparing FE Simulation to *MASH* Test 609971-03-2 (*1*) Immediately Leading to Rail Rupture Event.

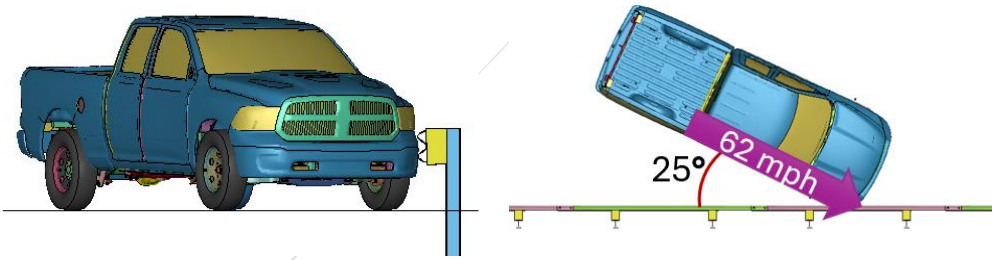


Figure 2.5. Impact Simulation Setup to Represent 11:1 Flared MGS Test (NCHRP 350 Test No. 2214MG-2)

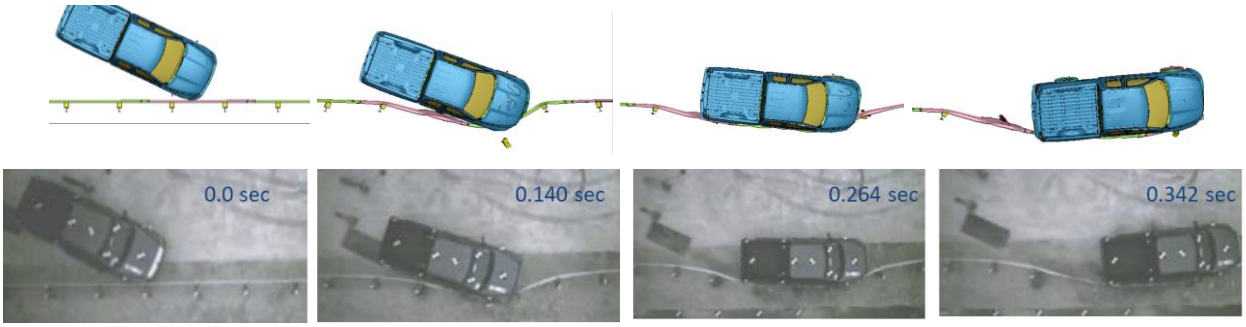


Figure 2.6. Sequential Frames Comparing FE Simulation on standard MGS to NCHRP 350 Test No. 2214MG-2 (*6*).

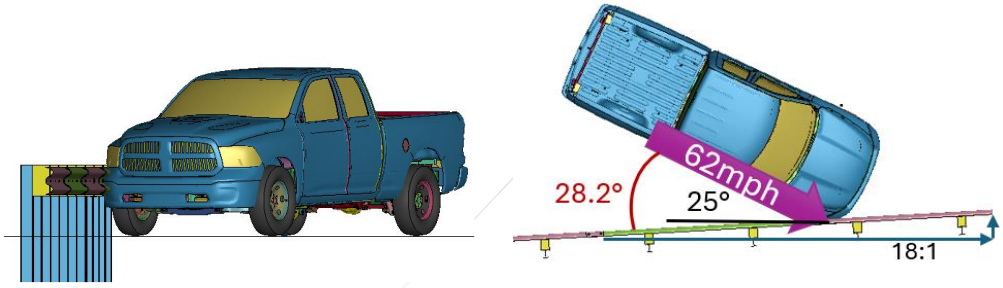
Overall, the vehicle and system behaviors in the simulations closely matched the trends observed in full-scale testing. Therefore, the FE model was considered to be sufficiently validated to a level to provide a reliable basis for further FE investigations of various flare rates.

2.3. SIMULATIONS OF DIFFERENT FLARE RATES

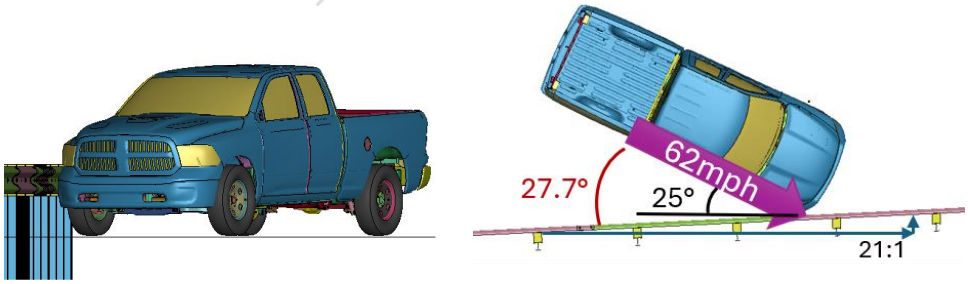
In this section, results are provided for the impact simulations conducted to evaluate the performance of MGS at different flare rates. Based off data from project 609971-01 (1), flare rates of 18:1 and 21:1 were selected for analysis. To evaluate the performance of the flared MGS systems under MASH TL-3 conditions, the impact speed and angles were set as 62 mi/h and 25 degrees relative to flat portion of the installation. The effective angles, accounting for the flared section of the system, were 28.2 degrees for the 18:1 flared MGS and 27.7 degrees for the 21:1 flared MGS.

2.3.1. MASH 2270P Pickup Truck

Figure 2.7 shows the initial simulation setup for a pickup truck impacting the MGS at flare rates of 18:1 and 21:1 under MASH TL-3 conditions.



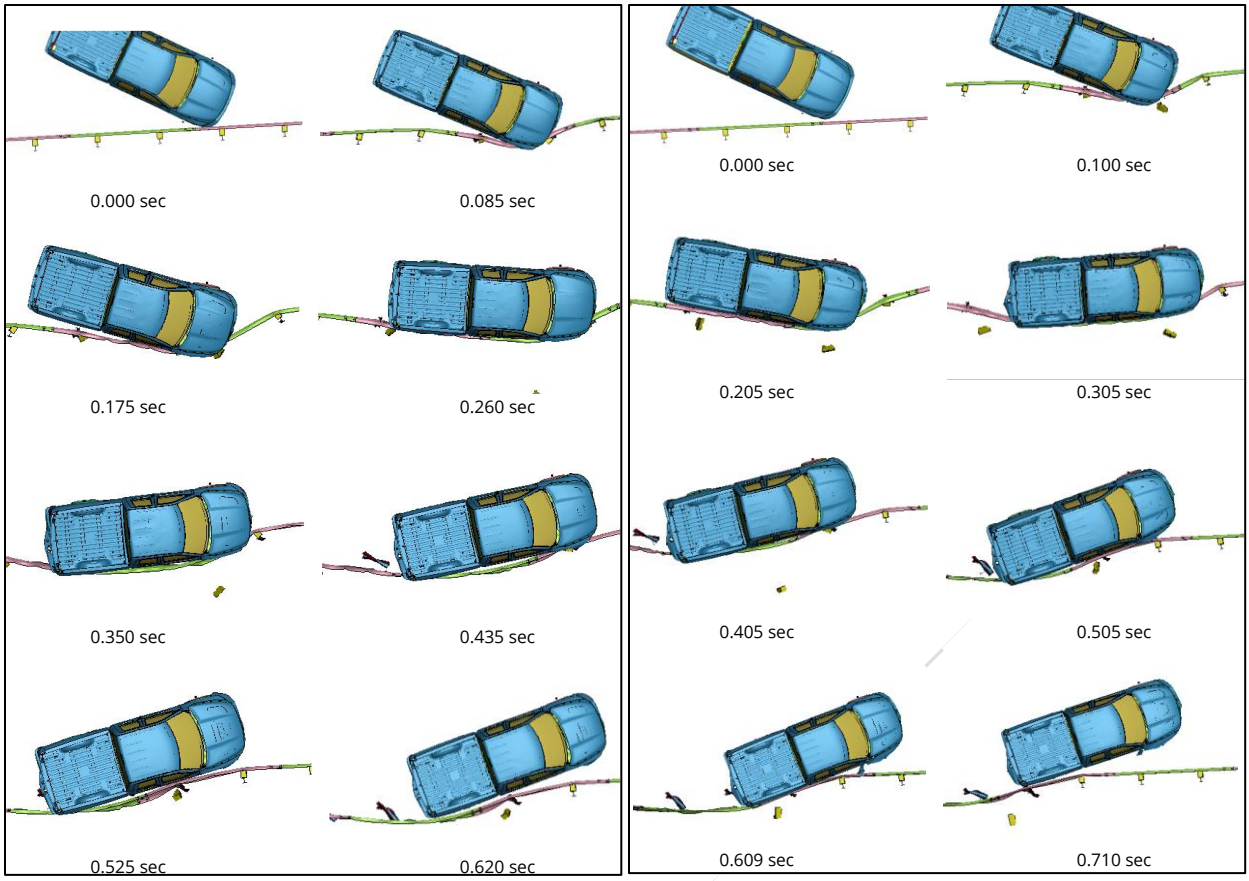
(a) Test setup with 18:1 flared MGS



(b) Test setup with 21:1 flared MGS

Figure 2.7. Initial Setup for Test 3-11 Simulation on Flared MGS

Figure 2.8 shows sequential images from Test 3-11 simulations involving impacts to the 18:1 and 21:1 flared MGS. Both the 18:1 and 21:1 flared MGS successfully contained and redirected the pickup truck during the simulations. No significant differences were observed between the two flare rates with respect to vehicle containment and redirection performance.



(a) 18:1 Flared Rate (b) 21:1 Flared Rate

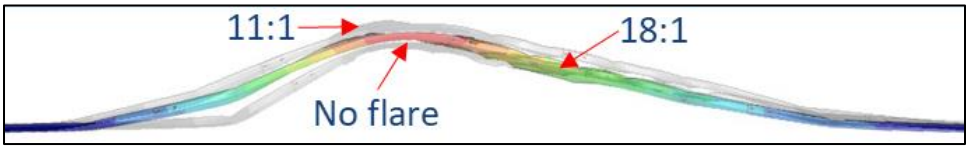
Figure 2.8. Sequential Images of Pickup Truck Impacting MGS with 18:1 and 21:1 Flare Rates

Table 2.1 lists the occupant risk factors calculated using Test Risk Assessment Program (TRAP) (8). All occupant risk factors met the *MASH* evaluation criteria.

Table 2.1. Occupant Risk Factors for Test 3-11 Comparing Impact Simulations to Tests

Test Parameter	MASH Limit (2)	No-flare (Test 2214MG-2)	11:1 Flare (Test 609971-03-2)	18:1 Flare (Simulation)	21:1 Flare (Simulation)
OIV, Longitudinal (ft/s)	40	15.3	18.7	18.3	21.7
OIV, Lateral (ft/s)	40	15.6	13.9	15.2	14.2
RA Longitudinal. (g)	20.49	8.23	4.8	8.4	12.1
RA, Lateral (g)	20.49	6.93	5.0	11.9	10.4
Max. Roll (°)	75	2.5	8.9	5.8	5.1
Max. Pitch (°)	75	5.9	5.6	4.2	4.8
Max. Yaw (°)	N/A	44.4	194.4	46.7	50.0
Max. Deflection (in.)	N/A	43.9	52.9 (before rupture)	47.5	45.9

In addition to assessing overall vehicle stability and the occupant risk factors, the maximum lateral deflection was measured and investigated to further evaluate the performance of the flared MGS systems. Figure 2.9 compares the maximum rail deflections. The maximum deflections for both the 18:1 and 21:1 flared MGS simulations were compared to the 11:1 flared system and the standard non-flared system crash tests. The deflection profile for the simulated 18:1 flared MGS rail was closer to the crash tested 11:1 flared MGS than crash tested non-flared MGS, while the deflection profile for the simulated 21:1 flared MGS was centered in between crash tested 11:1 flared MGS and non-flared MGS.



(a) Comparing maximum rail deflection for 18:1 MGS



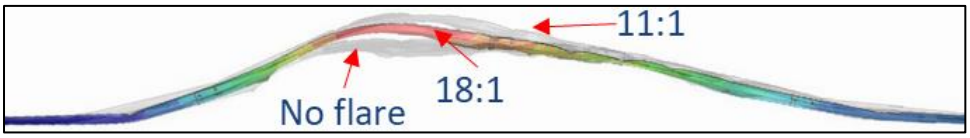
(b) Comparing maximum rail deflection for 21:1 MGS

Figure 2.9. Rail Deflection Profiles Comparing Maximum Dynamic Deflection for Test 3-11 Impact Simulation

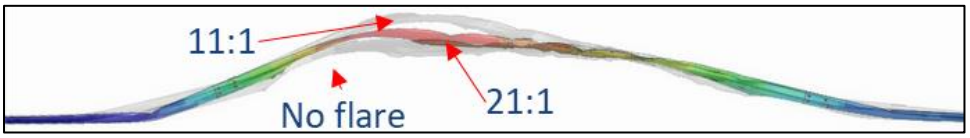
The maximum deflection profile cannot solely be used to determine the potential for rupture in the rail. Therefore, structural performance was also assessed by investigating vehicle pocketing potential. The 18:1 and 21:1 MGS rail deflection profiles were compared to those for the standard non-flared MGS, and the 11:1 flared MGS which failed due to rail rupture. Figure 2.10 depicts the rail deflection profiles for each flare rate immediately prior to vehicle redirection to show the vehicle pocketing potential. This captures the geometry of the rail at the exact instant the vehicle is about to redirect. If the deflection profile shows a sharp, localized bend in the deflection profile, it indicates that the rail is forming 'a pocket' that could snag the vehicle and cause high tension on the rail, which often leads to rail rupture. Conversely, a gradual, shallow and smooth deflection profile indicates that the rail will allow the vehicle to safely redirect along the rail with no rupture.

When comparing the deflection profiles for the two flare rate configurations, the simulated 18:1 flared MGS shows deflection angles that fall between those observed for the crash tested 11:1 flare and standard non-flared MGS profiles which indicates an increased vehicle pocketing risk. Although the maximum rail deflection angle for the 18:1 flare is distinctly lower than that of the 11:1 configuration which indicates a reduced pocketing risk, it does not achieve the optimal deflection profile seen with the non-flared system. The simulated 21:1 flared MGS further reduces the rail deflection angle when

compared to the simulated 18:1 configuration. Its deflection profile characteristics fall closer to that of the non-flared system.



(a) Comparing 18:1 Flared MGS rail pocketing potential

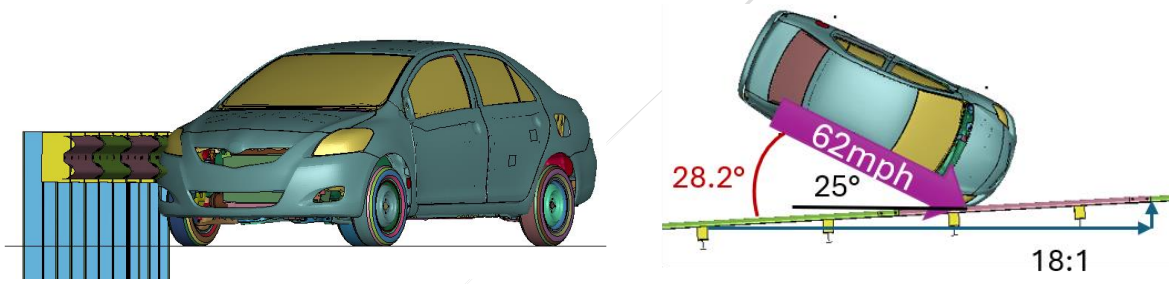


(b) Comparing 21:1 Flared MGS rail pocketing potential

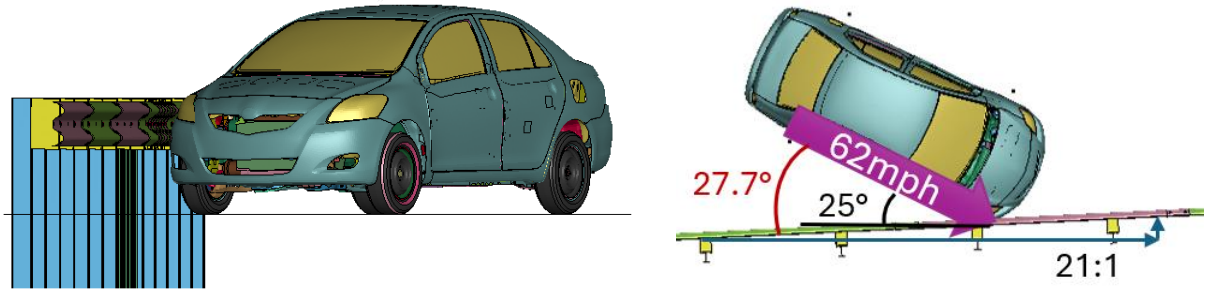
Figure 2.10. Rail Deflection Profiles Right Before Redirection for Test 3-11 Impact Simulation

2.3.2. MASH 1100C Small Car

Figure 2.11 shows the initial test setup with small car impacting flared MGS at flare rates of 18:1 and 21:1 under MASH TL-3 impact conditions.



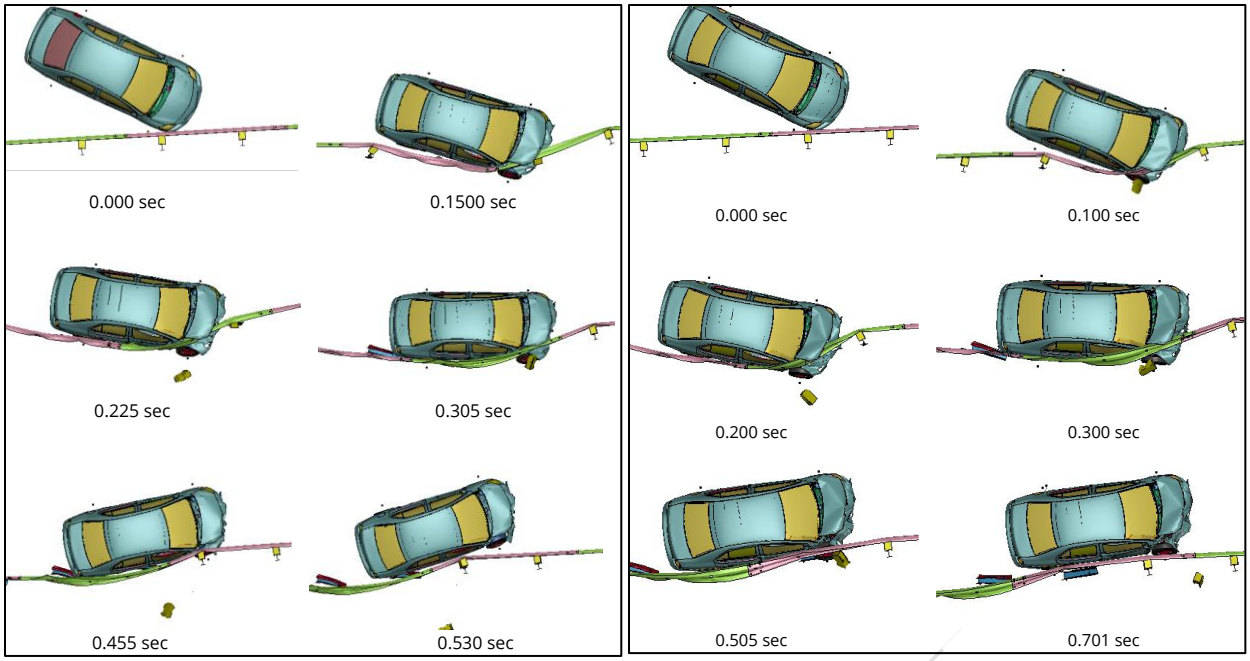
(a) Test setup with 18:1 flared MGS



(b) Test setup with 21:1 flared MGS

Figure 2.11. Impact Setup for Test 3-10 Simulation on Flared MGS

Figure 2.12 shows sequential images for Test 3-10 simulations impacting the 18:1 and 21:1 flared MGS. MGS at both flare rates were able to contain and redirect the small car. No significant differences were observed between the two flared MGS.



(a) 18:1 Flared MGS (b) 21:1 Flared MGS

Figure 2.12. Sequential Images for Test 3-10 with Small Car Impacting MGS with 18:1 and 21:1 Flare Rates

Since no significant differences were observed in the small car simulations between the 18:1 and 21:1 flared MGS, the research team performed an additional investigation into the performance of 27:1 flared MGS with the small car. Figure 2.13 shows sequential images of the small car impact simulation on the 27:1 flared MGS. The 27:1 flared MGS effective angle was 27.1 degrees.

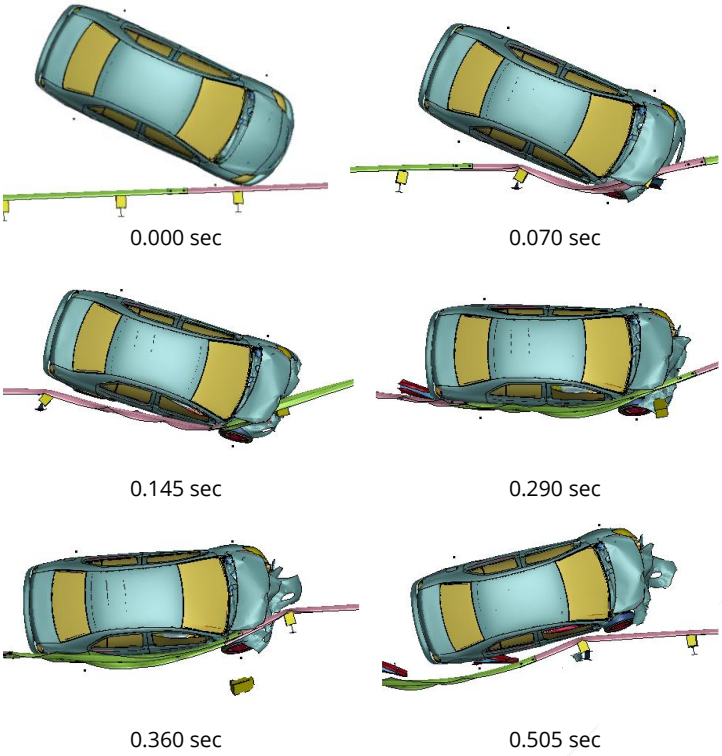


Figure 2.13. Sequential Images Impacting 27:1 flared MGS with Small Car

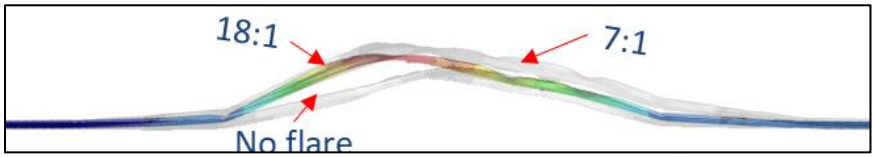
Table 2.2 lists the occupant risk factors calculated by using TRAP (8). All occupant risk factors met the MASH evaluation criteria.

Table 2.2. Occupant Risk Factors for Test 3-10 Comparing Impact Simulations to Tests

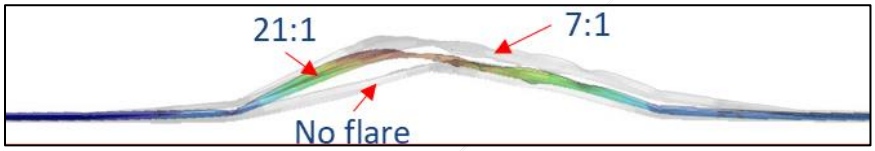
Test Parameter	MASH Limit (2)	No flare (Test 420020-5)	7:1 (Test 609971-01-1)	18:1 (Simulation)	21:1 (Simulation)	27:1 (Simulation)
OIV, Longitudinal (ft/s)	40	21.0	21.8	26.3	23.4	24.6
OIV, Lateral (ft/s)	40	17.4	12.8	17.2	17.2	16.4
Ridedown, Longitudinal (g)	20.49	8.8	8.3	15.5	14.4	14.1
Ridedown, Lateral (g)	20.49	6.8	9.4	7.7	8.5	8.0
Max. Roll (°)	75	16	393	11.0	9.4	9.6
Max. Pitch (°)	75	11	26	3.3	2.6	3.5
Max. Yaw (°)	NA	49	91	46	32.9	41.1
Max. Deflection (in.)	NA	28.6	28.6	36.0	35.1	35.9

The maximum lateral deflections measured in the simulations were also compared though these values were not as significant as those observed in the simulations involving pickup truck impacts (see Figure 2.14). The measured maximum deflection for the 27:1 flared MGS was 0.8 inches greater than that of the 21:1 flared MGS. This difference is attributed to increased engagement between the bottom of the rail and the vehicle during redirection at approximately 0.3 seconds after impact. As depicted in Figure 2.15, the rail deflection profiles for all three flared MGS configurations were more similar to the profile of the 7:1 flared MGS—which was previously tested and failed due to rail rupture under project 609971-01 (*1*) —than to the profile of the standard, non-flared MGS.

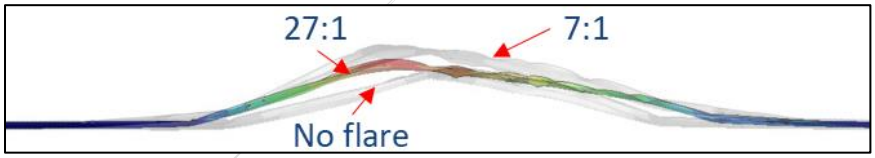
When comparing the deflecting angles just before the redirection (see Figure 2.15), the pocketing potentials were decreased for both 21:1 and 27:1 flared MGS when compared to the 7:1 flared MGS. However, the deflecting angle for the 18:1 flared MGS was very similar to the 7:1 flared MGS deflecting angle.



(a) Comparing maximum rail deflection for Flared 18:1 MGS

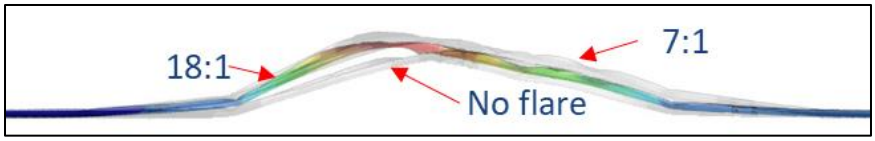


(b) Comparing maximum rail deflection for Flared 21:1 MGS

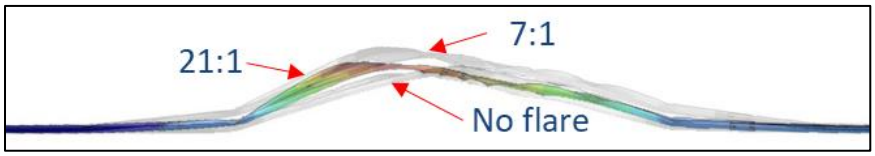


(c) Comparing maximum rail deflection for Flared 27:1 MGS

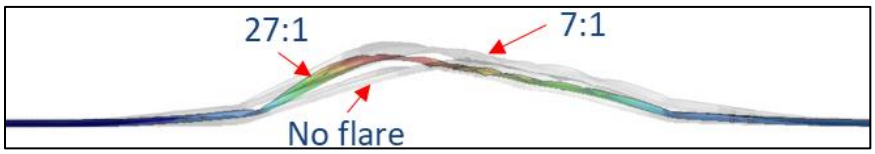
Figure 2.14. Rail Deflection Profiles Comparing Maximum Dynamic Deflection for Test 3-10 Impact Simulation



(a) Comparing Flared 18:1 MGS rail pocketing potential



(b) Comparing Flared 21:1 MGS rail pocketing potential



(c) Comparing Flared 27:1 MGS rail pocketing potential

Figure 2.15. Rail Deflection Profiles Right Before Redirection for Test 3-10 Impact Simulation

2.4. DISCUSSION AND RECOMMENDATIONS

Table 2.3 provides a summary of the simulation results. The occupant risk metrics for all of the evaluated MGS flare rates remained below the upper MASH limits. Next, maximum rail deflections were analyzed to assess the risk of rail rupture, which is considered more critical for pickup truck impacts than for small car impacts. Finally, since maximum rail deflections alone cannot reliably predict the likelihood of rail rupture, rail deflection angles right before vehicle redirection were also examined to better estimate the risk of vehicle pocketing.

For the pickup truck, both 18:1 (3.2 degrees) and 21:1 (2.7 degrees) flared MGS configurations exhibited reduced rail deflection and lower pocketing potential compared to the 11:1 flared system which had previously failed in full-scale testing due to rail rupture. In addition, the 21:1 flared MGS showed more reduction in rail deflection relative to the 18:1 flared system, and its structural performance was closer to that of a non-flared configuration.

For the small car, both the 18:1 and 21:1 flared MGSs demonstrated improved performance over the 7:1 flare rate which experienced rail rupture in prior full-scale testing due to rail rupture. Comparing the two flare rates, the 21:1 flare rate was associated with a lower pocketing potential than the 18:1 flare rate. However, the improvement was not seen to be as significant as the pickup truck. MGS at a shallower flare rate of 27:1 was also investigated. While the 27:1 flare rate exhibited a slight reduction in deflection compared to

the 21:1 flare rate system, the corresponding flare angle of 2.1 degrees is likely to have a negligible positive effect on overall system performance.

Table 2.3. Simulation Summary of Occupant Risk Metrics from FE Models of MGS with Different Flare Rates

Test Parameter	MASH Limit (*2*)	18:1 (3.2°) Flare Rate Pickup	18:1 (3.2°) Flare Rate Small Car	21:1 (2.7°) Flare Rate Pickup	21:1 (2.7°) Flare Rate Small Car	27:1 (2.1°) Flare Rate Pickup
OIV, Longitudinal (ft/s)	40	21.7	26.3	18.3	23.4	24.6
OIV, Lateral (ft/s)	40	14.2	17.2	15.2	17.2	16.4
Ridedown, Longitudinal (g)	20.49	12.1	15.5	8.4	14.4	14.1
Ridedown, Lateral (g)	20.49	10.4	7.7	11.9	8.5	8.0
Max. Roll (°)	75	5.1	11.0	5.8	9.4	9.6
Max. Pitch (°)	75	4.8	3.3	4.2	2.6	3.5
Max. Yaw (°)	N/A	50	46	46.7	32.9	41.1
Max. Deflection (in.)	N/A	47.5	36.0	45.9	35.1	35.9

Therefore, based on the computer simulation findings, it was recommended that full-scale crash testing be conducted on the 21:1 flared MGS for further investigation. Emphasis should be placed on evaluating its performance with small car impacts, as simulation data suggest these may represent the most critical loading scenario.

Also, it is important to note that Midwest Roadside Safety Facility (MwRSF) tested a 25:1 flared thrie-beam approach guardrail transition (AGT) under TL-3 conditions, which successfully met all the *MASH* required evaluation criteria (*9*). If the 21:1 flared MGS fails to satisfy the *MASH* evaluation criteria, then subsequent testing of a 25:1 flared MGS configuration should be considered to leverage the successful performance of the 25:1 flared thrie-beam AGT as a precedent. Furthermore, if both the 21:1 and 25:1 flared MGS fails to meet MASH evaluation criteria, then a possible upper bound flattest flare rate of 38:1 should be considered for crash testing. The 38:1 flare rate value corresponds to the maximum allowable 1.5-degree variation given in the MASH manual (2) for vehicle impact angle tolerance. If the 38:1 configuration performs successfully, a 30:1 (1.9 degrees) flared MGS should then be be considered for crash testing to identify a viable flare rate between 25:1 (2.3 degrees) and 38:1 (1.5 degrees). Note: it is the researchers opinion that further computer simulations would provide no meaningful benefit for flared MGS configurations without design modifications, as the predicted performance of the unmodified MGS lies at a threshold where the exact nature of system failure or success cannot be reliably replicated by simulation. These flare configurations are therefore recommended to proceed directly to full-scale MASH crash testing with a pickup truck (2270P) if warranted.

CHAPTER 3.

SYSTEM DETAILS

3.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation was 181 feet 3 inches long and consisted of 12-gauge W-beam guardrail supported by 6x8.5 wide flange steel posts, with the top of the guardrail set at 31 inches above grade for all five tests conducted under this project (21:1 passenger car, 21:1 pickup truck, 25:1 pickup truck, 38:1 pickup truck, and 30:1 pickup truck). All post spaces were 75 inches, and a Steel Post Terminal anchored each end for all five tests.

For all five tests, the downstream 50 feet of the test installation was positioned parallel to the nominal traffic lanes, and the remaining 131 feet 3 inches of the test installations were flared back toward the field side. The flare was set at 21:1 for tests 620851-01-1& -2 which put the offset of the first post at 75 inches. The flare was set at 25:1 for test 620851-01-3 which put the offset of the first post at 63 inches. The flare was set at 38:1 for test 620851-01-4 which put the offset of the first post at 41.5 inches. The flare was set at 30:1 for test 620851-01-5 which put the offset of the first post at 52.5 inches.

Figure 3.1 presents the overall information on the 21:1 Flared MGS, and Figure 3.2 thru Figure 3.7 provides photographs of the installation. Appendix A provides further details on the 21:1 Flared MGS.

Figure 3.8 presents the overall information on the 25:1 Flared MGS and Figure 3.9 thru Figure 3.13 provides photographs of the installation. Appendix B provides further details on the 25:1 Flared MGS.

Figure 3.14 presents the overall information on the 38:1 Flared MGS. Figure 3.15 through Figure 3.20 provides photographs of the installation. Appendix C provides further details on the 38:1 Flared MGS.

Figure 3.21 presents the overall information on the 30:1 Flared MGS. Figure 3.22 through Figure 3.27 provides photographs of the installation. Appendix D provides further details on the 30:1 Flared MGS.

Drawings for all MGS system configurations were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by the TTI Proving Ground personnel.

3.2. DESIGN MODIFICATIONS DURING TESTS 620851-01-1 & 2

No modifications were made to the installation during the testing phase.

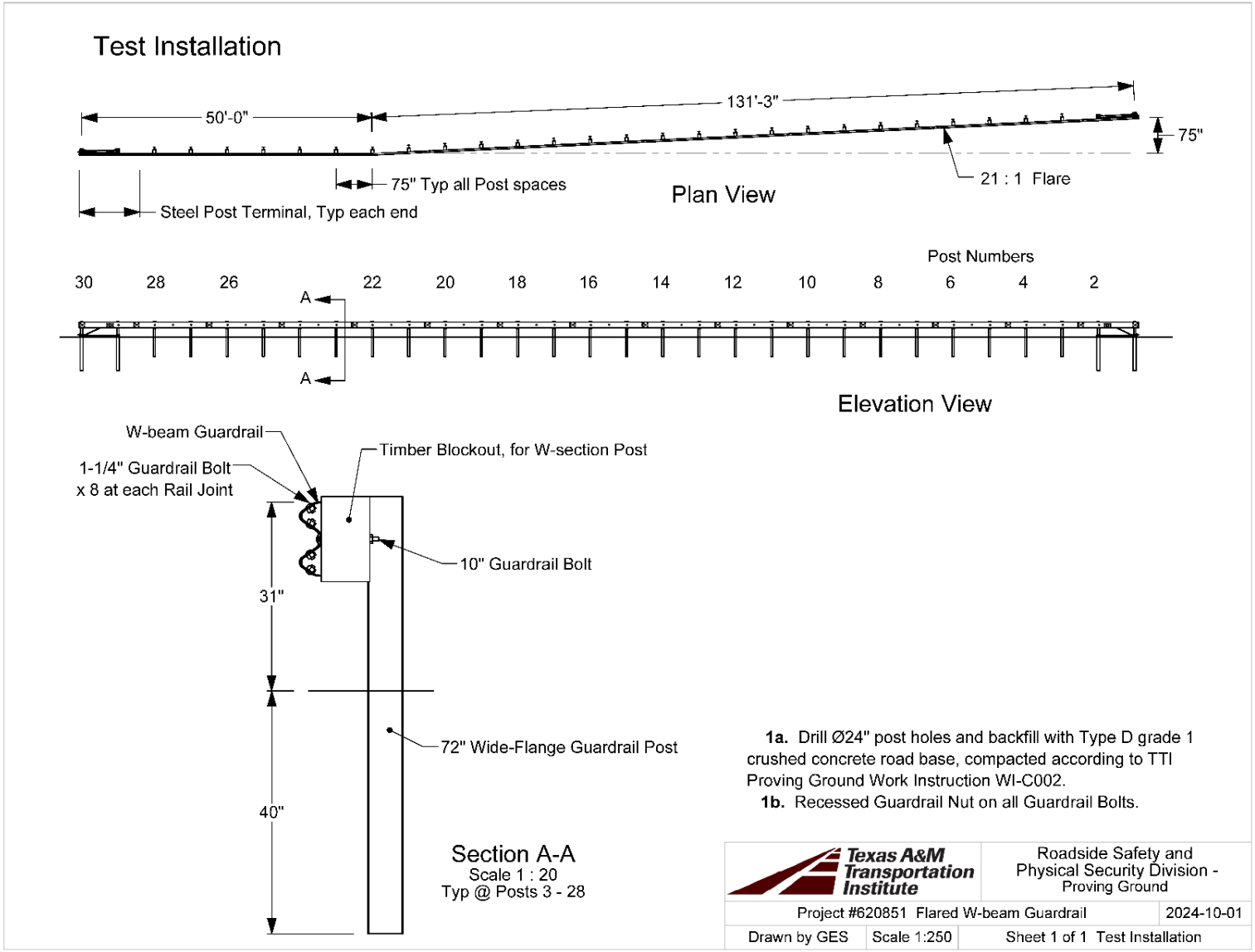


Figure 3.1. Details of 21:1 Flared MGS



Figure 3.2. 21:1 Flared MGS prior to Testing



Figure 3.3. Downstream Oblique Traffic Side View of the 21:1 Flared MGS prior to Testing



Figure 3.4. Steel Terminal for 21:1 Flared MGS prior to Testing



Figure 3.5. Downstream Oblique Field Side View of the 21:1 Flared MGS prior to Testing



Figure 3.6. Field Side View of the 21:1 Flared MGS at Impact Point prior to Testing



Figure 3.7. Downstream In-Line View of the 21:1 Flared MGS prior to Testing

3.3. DESIGN MODIFICATIONS DURING TEST 620851-01-3

No modifications were made to the installation during the testing phase.

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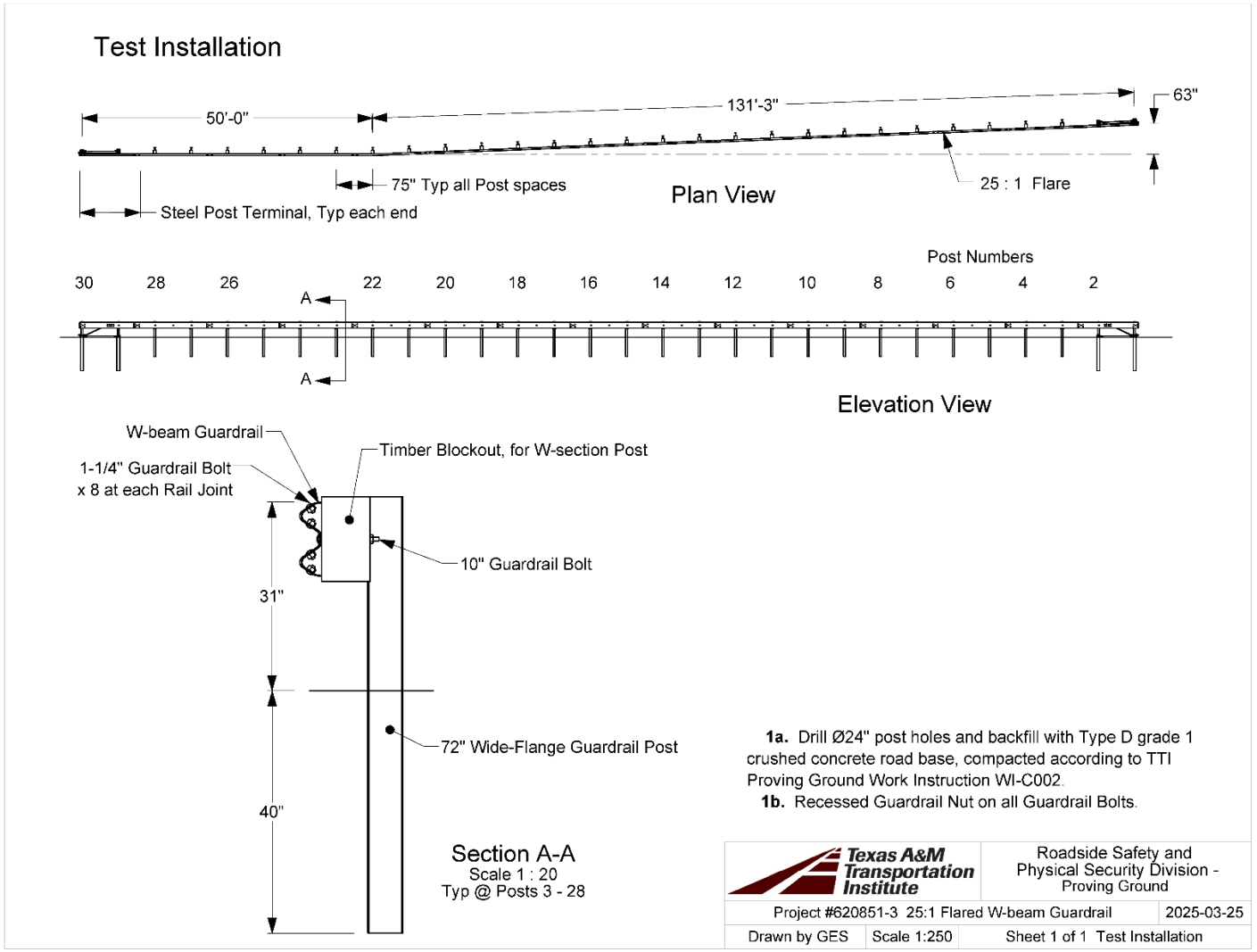


Figure 3.8. Details of 25:1 Flared MGS



Figure 3.9. 25:1 Flared MGS prior to Testing



Figure 3.10. Downstream Oblique Traffic Side View of the 25:1 Flared MGS prior to Testing



Figure 3.11. Downstream Oblique Field Side View of the 25:1 Flared MGS prior to Testing



Figure 3.12. Field Side View of the 25:1 Flared MGS at Impact Point prior to Testing



Figure 3.13. Downstream In-Line View of 25:1 Flared MGS prior to Testing

3.4. DESIGN MODIFICATIONS DURING TEST 620851-01-4

No modifications were made to the installation during the testing phase.

DRAFT

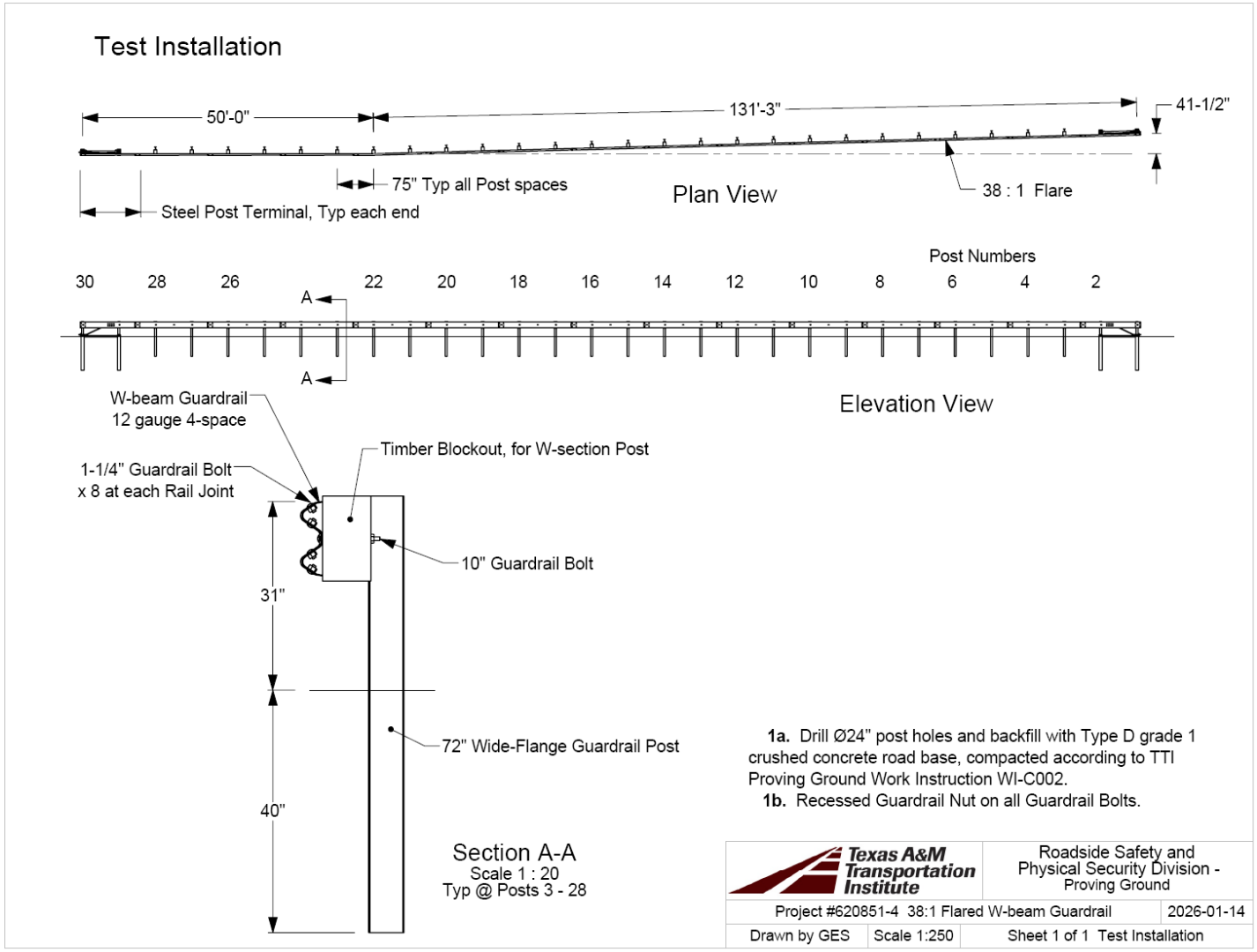


Figure 3.14. Details of 38:1 Flared MGS



Figure 3.15. 38:1 Flared MGS prior to Testing



Figure 3.16. Downstream Oblique Traffic Side View of the 38:1 Flared MGS prior to Testing



Figure 3.17. Steel Terminal for 38:1 Flared MGS prior to Testing



Figure 3.18. Downstream Oblique Field Side View of the 38:1 Flared MGS prior to Testing



Figure 3.19. Field Side View of the 38:1 Flared MGS at Impact Point prior to Testing



Figure 3.20. Downstream In-Line View of 38:1 Flared MGS prior to Testing

3.5. DESIGN MODIFICATIONS DURING TEST 620851-01-5

No modifications were made to the installation during the testing phase.

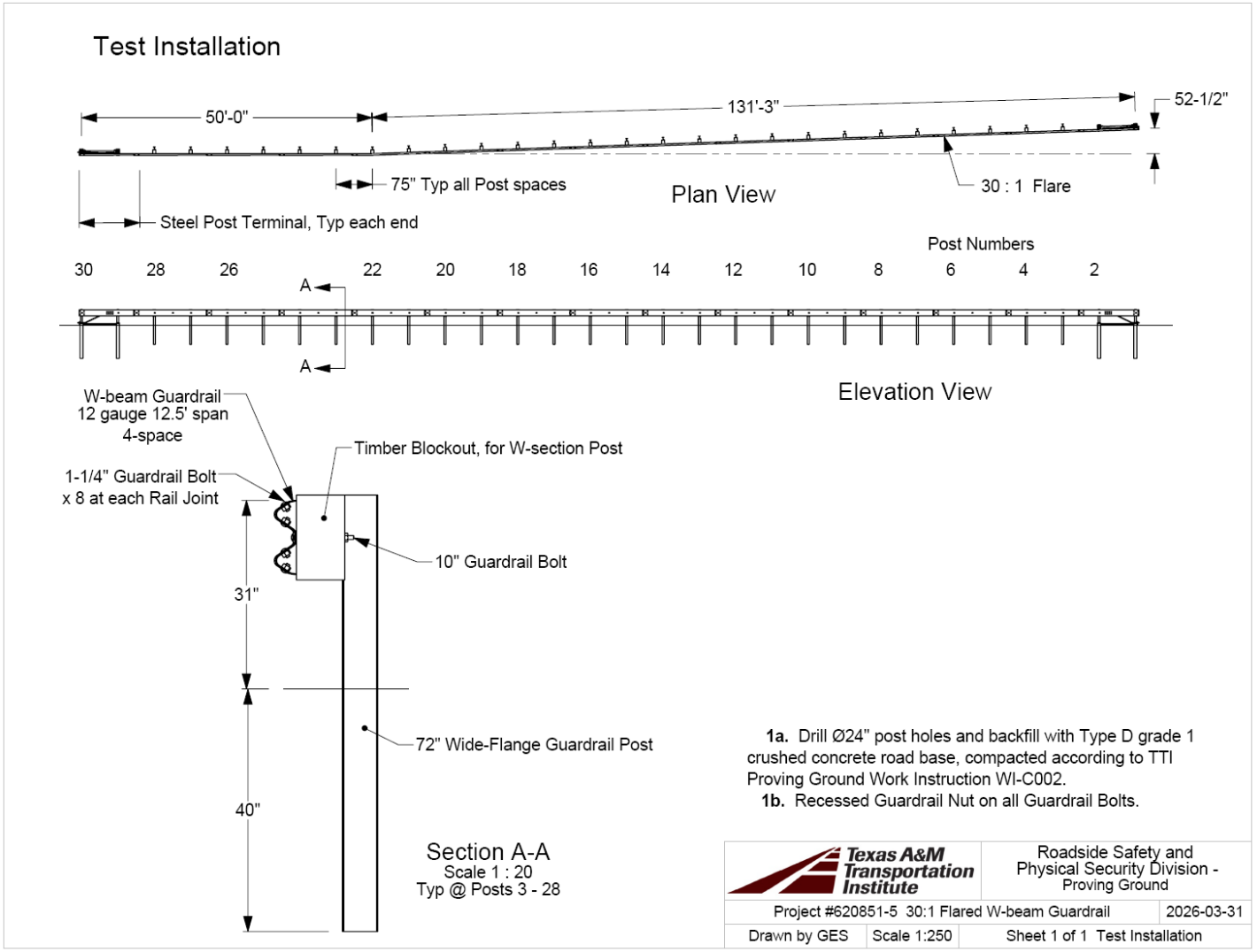


Figure 3.21. Details of 30:1 Flared MGS



Figure 3.22. 30:1 Flared MGS prior to Testing



Figure 3.23. Downstream Oblique Traffic Side View of the 30:1 Flared MGS prior to Testing



Figure 3.24. Steel Terminal for 30:1 Flared MGS prior to Testing



Figure 3.25. Downstream Oblique Field Side View of the 30:1 Flared MGS prior to Testing



Figure 3.26. Field Side View of the 30:1 Flared MGS at Impact Point prior to Testing



Figure 3.27. Downstream In-Line View of the 30:1 Flared MGS prior to Testing

3.6. MATERIAL SPECIFICATIONS

Appendix E provides material certification documents for the materials used to install/construct the five flared MGS test installations.

Due to the rupture and failure of the rail during testing of the 25:1 Flared MGS, a tensile strength analysis was conducted to ensure the steel rails met all minimum strength requirements. Based on the test results, the material properties of the W-beam met the required specifications of the rail. The results are shown in Table 3.1 and the material analysis report is included in Appendix E.

Table 3.1. Tensile Strength for 620851-01-3.

Sample ID	SQR Dim. Width (in)	SQR Dim. Thick-ness (in)	SQR Dim. Area (in^2)	Ultimate Strength Load (lbs)	Ultimate Strength PSI	Yield Strength Load (lbs)	Yield Strength PSI	Elong. (%)
1	0.4910	0.1030	0.0506	3962	78,300	3077	60,800	26.3
2	0.4950	0.1065	0.0527	4017	76,200	3046	57,800	28.7
3	0.4935	0.1055	0.0521	3993	76,600	2969	57,000	28.5
4	0.4910	0.1050	0.0516	3932	76,200	3524	68,300	27.5

3.7. SOIL CONDITIONS

The test installations were 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 on the day of each crash test. During installation of the 21:1 Flared MGS for full-scale crash testing, two 6-ft long W6×16 posts were installed in the immediate vicinity of the 21:1 Flared MGS using the same fill materials and installation procedures used in the test installation and underwent the standard dynamic test.

On the day of Test 620851-01-1 (3-10) (12-9-2024), the loads on the post and resulting deflections are shown on Table 1.1 Table 3.2. The backfill material for the 21:1 Flared MGS met minimum *MASH* requirements for soil strength.

Table 3.2. Soil Strength for Test 620851-01-1.

Displacement (inches)	Minimum Load (lb)	Actual Load (lb)
5	4420	6757
10	4981	8757
15	5282	9848

On the day of Test 620851-01-2 (3-11) (12-13-2024), the loads on the post and resulting deflections are shown on Table 3.3. The backfill material in which the 21:1 Flared MGS was installed met minimum *MASH* requirements for soil strength.

Table 3.3. Soil Strength for 620851-01-2.

Displacement (inches)	Minimum Load (lb)	Actual Load (lb)
5	4420	9424
10	4981	9848
15	5282	10,181

On the day of 620851-01-3 (Test 3-11) (5-19-2025), the loads on the post and resulting deflections are shown on Table 3.4. The backfill material in which the 25:1 Flared MGS was installed met minimum *MASH* requirements for soil strength. At 1-inch of displacement the pull force was 12,060 lbf, so the soil strength performance test was suspended as it exceeded the upper limit of the instrumentation of 10,000 lbf.

Table 3.4. Soil Strength for 620851-01-3.

Displacement (inches)	Minimum Load (lb)	Actual Load (lb)
5	4420	Not measured
10	4981	Not measured
15	5282	Not measured

On the day of Test 3-11, 2026-03-24, loads on the post at deflections are shown in Table 1.1. The backfill material in which the 38:1 Flared MGS was installed met minimum *MASH* requirements for soil strength.

Table 3.5. Soil Strength for 620851-01-4.

Displacement (inches)	Minimum Load (lb)	Actual Load (lb)
5	4420	6364
10	4981	7181
15	5282	6756

On the day of Test 3-11, 2026-05-06, loads on the post at deflections are shown in Table 3.3. The backfill material in which the 30:1 Flared MGS was installed met minimum *MASH* requirements for soil strength.

Table 3.6. Soil Strength for 620851-01-5.

Displacement (inches)	Minimum Load (lb)	Actual Load (lb)
5	4420	4849
10	4981	5787
15	5282	6424

CHAPTER 4.

TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1. CRASH TEST PERFORMED/MATRIX

Table 4.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for Longitudinal Barrier.

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

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

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH (2)*. Chapter 4 presents brief descriptions of these procedures.

4.2. EVALUATION CRITERIA

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

Table 4.2. Evaluation Criteria Required for *MASH* Testing.

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

CHAPTER 5.

TEST CONDITIONS

5.1. TEST FACILITY

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

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

5.2. 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.

5.3. DATA ACQUISITION SYSTEMS

5.3.1. Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained onboard data acquisition system. The signal conditioning and acquisition system is a 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 *MASH* recommended version of 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 ENDEVCOÒ 2901 precision primary vibration standard. This standard and its support instruments are checked annually and receive a calibration traceable to the International System of Units (SI). Measurement Uncertainties have been determined for critical parameters involved in this testing, and are available upon request by the Sponsor.

TRAP uses the DAS-captured data to compute the occupant to vehicle contact impact velocities, time of occupant to vehicle contact 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. Measurement Uncertainties

have been determined for critical parameters involved in this testing and are available upon request by the Sponsor.

5.3.2. Anthropomorphic Dummy Instrumentation

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

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

5.3.3. Photographic Instrumentation Data Processing

Photographic coverage of these tests included 3 digital high-speed cameras:

- One placed overhead with a field of view perpendicular to the ground and directly over the impact point.
- One placed with a field of view parallel to and aligned with the installation at the downstream end.
- One placed at an oblique angle upstream from the installation on the field side.

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the Flared MGS. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

CHAPTER 6.

MASH TEST 3-10 (CRASH TEST 620851-01-1)

6.1. CRITICAL IMPACT POINT LOCATION

The Critical Impact Point (CIP) for this test was located 93 inches upstream from post 13 along the rail at 25 degrees relative to the traffic lane. The target CIP for this test was determined using the information provided in *MASH* Section 2.2.1 and MASH Section 2.3.2. Figure 6.1 shows the target CIP for test 620851-01-1. Figure 6.2 and Figure 6.3 depict the vehicle at the CIP prior to test 620851-01-1.

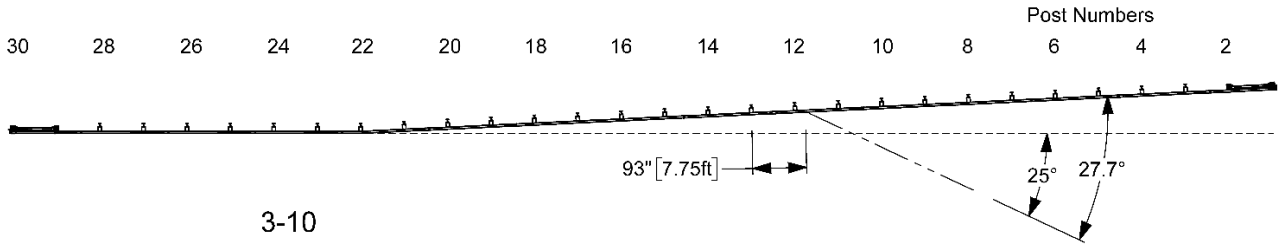


Figure 6.1. Target CIP for *MASH* Test 3-10 on 21:1 Flared MGS.



Figure 6.2. 21:1 Flared MGS/Test Vehicle Geometrics for Test 620851-01-1.



Figure 6.3. 21:1 Flared MGS/Test Vehicle Impact Location 620851-01-1.

6.2. TEST VEHICLE DETAILS PRIOR TO IMPACT

Table 6.1 shows the vehicle measurements. Figure 6.4 and Figure 6.5 show the 2019 Nissan Versa used for the crash test. Figure F.1 in Appendix F.1 gives additional dimensions and information on the vehicle.

Table 6.1. Vehicle Measurements for Test 620851-01-1.

Test Parameter	Specification	Tolerance	Measured
Dummy Mass (if applicable)[a] (lb)	165	N/A	165
Inertial Mass (lb)	2420	±55	2427
Gross Static[a] Mass (lb)	2585	±55	2592
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

Note: N/A = not applicable; CG = center of gravity.

[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.



Figure 6.4. Impact Side of Test Vehicle before Test 620851-01-1.



Figure 6.5. Opposite Impact Side of Test Vehicle before Test 620851-01-1.

6.3. TEST DESCRIPTION

6.3.1. Weather Conditions

Table 6.2 provides the weather conditions for 620851-01-1.

Table 6.2. Weather Conditions 620851-01-1.

Date of Test	2024-12-09
Wind Speed	8 mi/h
Wind Direction	207°
Temperature	66°F
Relative Humidity	83 %
Vehicle Traveling	195°

6.3.2. Test Events

Table 6.3 lists events that occurred during Test 620851-01-1. The figures in Appendix F.2 present sequential photographs during the test.

Table 6.3. Events during Test 620851-01-1.

Time (seconds)	Events
0.0000	Vehicle impacted the installation
0.0150	Post 12 began to lean toward the field side
0.0230	Post 13 began to lean toward the field side
0.0320	Vehicle began to redirect
0.0570	Post 11 began to lean toward the field side
0.0690	Post 14 began to lean toward the field side
0.2080	Rear Passenger side of bumper contacted the rail
0.2250	Vehicle was parallel with installation
0.5760	Vehicle exited the installation at 27.7 mi/h with a heading of 26.3 degrees and a trajectory of 24.4 degrees

6.4. TEST ACTUAL IMPACT CONDITIONS

Table 6.4 lists the details of the *MASH* impact conditions for this test and Table 6.5 lists the exit parameters.

Table 6.4. Impact Conditions for *MASH TEST 3-10,* Crash Test 620851-01-1.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5	61.5
Impact Angle (°)	25	±1.5	25.2
Impact Severity (kip-ft)	51	≥51	55.8
Impact Location	93 inches upstream from post 13 along the rail	±1 foot (12 inches)	90.5 inches upstream from post 13 along the rail

Table 6.5. Exit Parameters for *MASH TEST 3-10,* Crash Test 620851-01-1.

Exit Parameter	Measured
Speed	27.7 mi/h
Trajectory	24.4°
Heading	26.3°
Brakes applied post impact	3.5 seconds
Vehicle at rest position	115 ft downstream of impact point 1 ft to the traffic side
Comments:	Vehicle remained upright and stable. The vehicle met the exit box criteria[a] by crossing the exit box 33 feet downstream from loss of contact.

[a]Per the *MASH* guidelines in Section 5.2.3, the exit box for the 1100C used in this test was 15.1 ft toward the traffic side as measured from the traffic side face of the rail and 32.8 ft downstream from loss of contact.

6.5. DAMAGE TO TEST INSTALLATION

The rail was deformed and scuffed at impact. There was secondary contact with the installation between post 29 and post 30.

Table 6.6 describes the damage to the test installation. Table 6.7 describes the deflection and working width of the 21:1 Flared MGS. Figure 6.6 and Figure 6.7 show the damage to the 21:1 Flared MGS.

Table 6.6. Damage to Test Installation of the 21:1 Flared MGS for Test 620851-01-1.

Post #	Soil Gap (in inches)	Post Lean (in degrees)	Comments
1	0.1 u/s	----	
2	0.3 d/s	----	
3 – 10	Soil disturbed	----	
11	0.5 t/s	88.5	
12	Not Measurable	82.2	Soil in post embedment zone highly disrupted
13	----	11.8 d/s	Post deformed and released from rail, Blockout is missing
14	----	17.8 d/s	Post deformed released from rail, Blockout is missing
15	1.5 t/s, 0.3 f/s	69.3 d/s	Post released from rail
16	0.1 f/s	89.9 f/s	----
17 - 21	Soil disturbed	----	----

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

Table 6.7. Deflection and Working Width of the 21:1 Flared MGS for Test 620851-01-1.

Test Parameter	Measured
Permanent Deflection/Location	15.5 inches toward field side, 1.5 feet from centerline of post 13
Dynamic Deflection	30.5 inches at post 13
Working Width [a] and Height	34.5 inches, at a height of 37.6 inches at the front passenger side edge of the hood of the vehicle

[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.

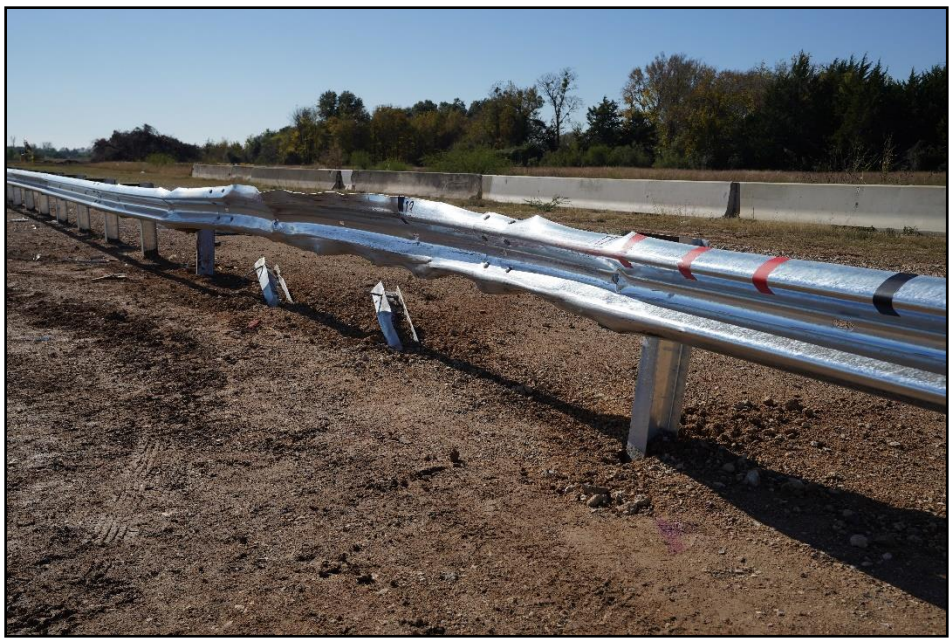


Figure 6.6. 21:1 Flared MGS at Impact Location after Test 620851-01-1.



Figure 6.7. In-Line View of the 21:1 Flared MGS after Test 620851-01-1.

6.6. DAMAGE TO TEST VEHICLE

Figure 6.8 and Figure 6.9 show the damage sustained by the vehicle. Figure 6.10 and Figure 6.11 show the interior of the test vehicle. Table 6.8 and Table 6.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figure F.2 and Figure F.3 in Appendix F.1 provides exterior crush and occupant compartment measurements.

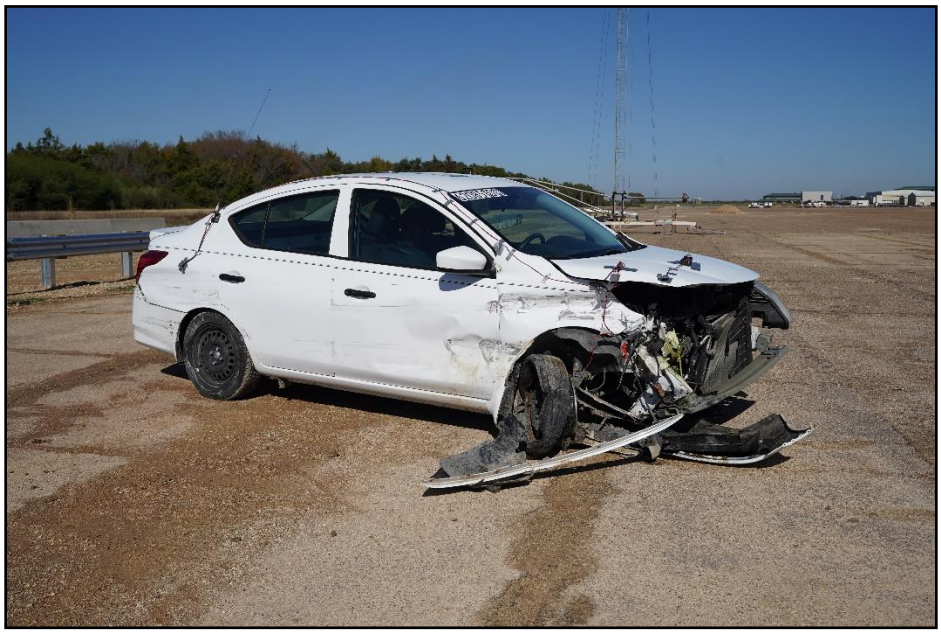


Figure 6.8. Impact Side of Test Vehicle after Test 620851-01-1.

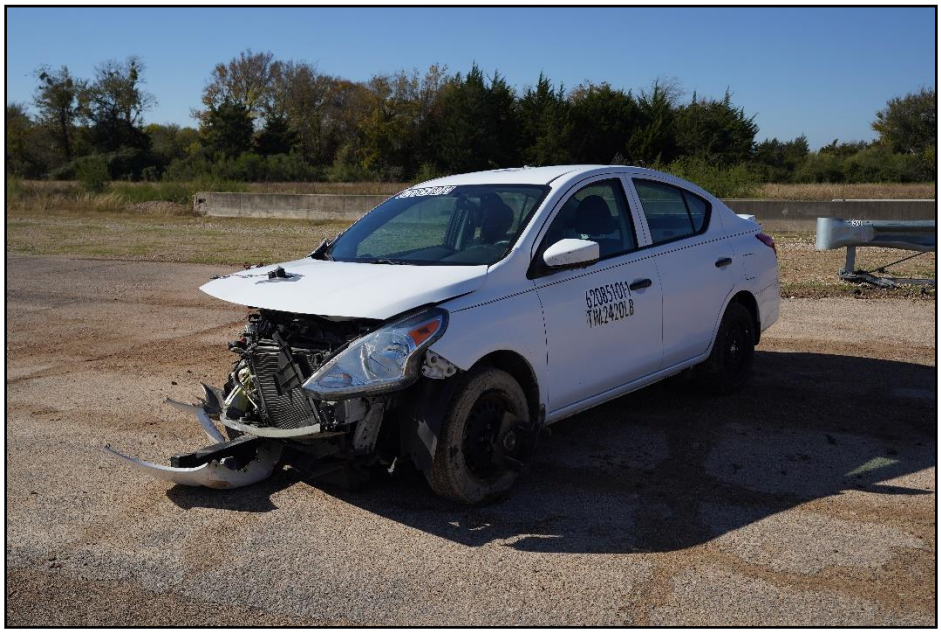


Figure 6.9. Non-Impact Side of Test Vehicle after Test 620851-01-1.



Figure 6.10. Overall Interior of Test Vehicle after Test 620851-01-1.



Figure 6.11. Interior of Test Vehicle on Impact Side after Test 620851-01-1.

Table 6.8. Occupant Compartment Deformation 620851-01-1.

Test Parameter	Specification (inches)	Measured (inches)
Roof	≤4.0	0.0
Windshield	≤3.0	0.0
A and B Pillars	≤5.0 overall/≤3.0 lateral	0.0
Foot Well/Toe Pan	≤9.0	0.3
Floor Pan/Transmission Tunnel	≤12.0	0.0
Side Front Panel	≤12.0	0.0
Front Door (above Seat)	≤9.0	0.0
Front Door (below Seat)	≤12.0	0.0

Table 6.9. Exterior Vehicle Damage 620851-01-1.

Test Parameter	Details
Side Windows	Remained intact
Maximum Exterior Deformation	12 inches at front bumper
VDS	01RFQ5
CDC	01FREC5
Fuel Tank Damage	None
Description of Damage to Vehicle:	The hood, bumper, grill, and fender were damaged. The radiator, air compressor, alternator, and right headlight were fractured. The right front frame and bumper were deformed, along with the right front wheel and foot well on the impact side. The right front tire ruptured, and there were abrasions and deformations on the right front fender, door, and rear quarter panel. The right taillight was fractured. There was a 1.3-inch gap at the top of the right front door.

6.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.10. Figure F.7 in Appendix F.3 shows the vehicle angular displacements, and Figure F.8 through Figure F.10 in Appendix F.4 show acceleration versus time traces.

Table 6.10. Occupant Risk Factors for Test 620851-01-1.

Test Parameter	Specification [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	21.3	0.1188 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	18.8	0.1188 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	-8.4	0.3000 - 0.3100 seconds
Ridedown, Lateral (g)	≤20.49 *15.0*	-9.8	0.1987 - 0.2087 seconds
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	8.1	0.1144 seconds on right side of interior
Acceleration Severity Index	N/A	1.03	0.0727 - 0.1227 seconds
50-ms Moving Avg. Accelerations (MA) Longitudinal (g)	N/A	-8.0	0.0434 - 0.0934 seconds
50-ms MA Lateral (g)	N/A	-7.2	0.0449 - 0.0949 seconds
50-ms MA Vertical (g)	N/A	-2.8	0.1161 - 0.1661 seconds
Roll (°)	≤75	-8.0	0.1893 seconds
Pitch (°)	≤75	-4.1	0.4822 seconds
Yaw (°)	N/A	-49.6	0.6796 seconds

[a.] *Values in italics are the preferred MASH values*

Note: N/A = Not Applicable

6.8. TEST SUMMARY

Figure 6.12 summarizes the results of *MASH* Test 620851-01-1.



0.000 s



0.2000 s

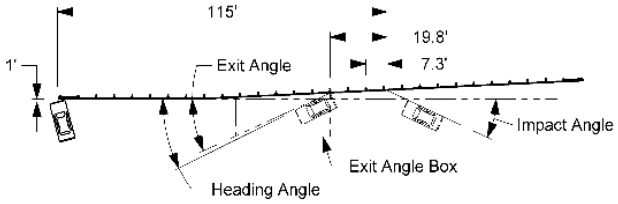


0.4000 s



0.6000s

GENERAL INFORMATION	
Test Agency:	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.:	*MASH* 2016, Test 3-10
Project No.:	620851-01-1
Test Date:	2024-12-09
TEST ARTICLE	
Type:	Longitudinal Barrier
Name:	21:1 Flared MGS
Length:	181 feet and 3 inches
Key Materials:	Steel guardrail, timber blockouts, Flared Guardrail
Soil Type and Condition:	Type D grade 1 crushed concrete, dry
TEST VEHICLE	
Type/Designation:	1100C
Year, Make and Model:	2019 Nissan Versa
Inertial Mass:	2427 lb
Dummy Mass:	165 lb
Gross Static Mass:	2592 lb
IMPACT CONDITIONS	
Impact Speed:	61.5 mi/h
Impact Angle:	25.2°
Impact Location:	90.5 inches upstream from post 13 along the rail
Impact Severity:	55.8 kip-ft
EXIT CONDITIONS	
Exit Speed:	27.7 mi/h
Trajectory/Heading Angle:	24.4° / 26.3°
Exit Box Criteria:	The vehicle met the exit box criteria
Stopping Distance:	115 ft downstream of impact point 1 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic:	30.5 inches
Permanent:	15.5 inches
Working Width:	34.5 inches
Working Width Height:	37.6 inches
VEHICLE DAMAGE	
VDS:	01RFQ5
CDC:	01FREC5
Max Exterior Deformation:	12 inches at front bumper
Max Occupant Compartment Deformation:	0.3 inches in the foot well/toe pan
OCCUPANT RISK VALUES	
Longitudinal OIV:	21.3 ft/s
Lateral OIV:	18.8 ft/s
Longitudinal Ridedown:	-8.4 g
Lateral Ridedown:	-9.8 g
THIV:	8.1 m/s
ASI:	1.03
Max 50ms Longitudinal:	-8.0 g
Max 50ms Lateral:	-7.2 g
Max 50ms Vertical:	-2.8 g
Max Roll:	-8.0°
Max Pitch:	-4.1°
Max Yaw:	-49.6°



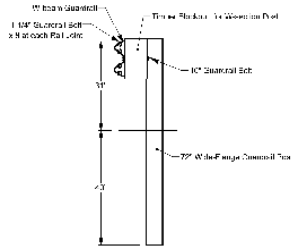


Figure 6.12. Summary of Results for *MASH* Test 3-10 on 21:1 Flared MGS.

CHAPTER 7.

MASH TEST 3-11 (CRASH TEST 620851-01-2)

7.1. CRITICAL IMPACT POINT LOCATION

The Critical Impact Point (CIP) for test 620851-01-2 is located 138 inches upstream from the joint between posts 12 and 13 along the rail. The target CIP for this test was determined using the information provided in *MASH* Section 2.2.1 and MASH Section 2.3.2. Figure 7.1 shows the target CIP for test 620851-01-2. Figure 7.2 and Figure 7.3 shows the vehicle at the CIP prior to test 620851-01-2.

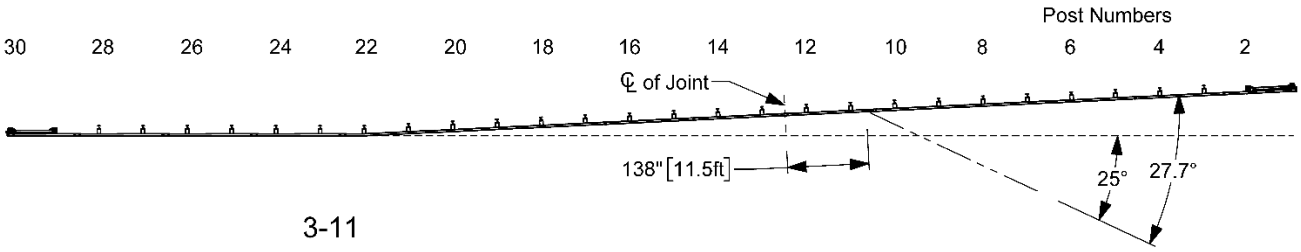


Figure 7.1. Target CIP for *MASH* Test 3-11 on 21:1 Flared MGS.



Figure 7.2. 21:1 Flared MGS/Test Vehicle Geometrics for Test 620851-01-2.



Figure 7.3. 21:1 Flared MGS/Test Vehicle Impact Location 620851-01-2.

7.2. TEST VEHICLE DETAILS PRIOR TO IMPACT

Table 7.1 shows the test vehicle measurements. Figure 7.4 and Figure 7.5 show the 2019 RAM 1500 test vehicle used for the crash test. Figure G.1 in Appendix G.1 gives additional dimensions and information on the vehicle.

Table 7.1. Vehicle Measurements for Test 620851-01-2.

Test Parameter	Specification	Tolerance	Measured
Dummy Mass (if applicable)[a] (lb)	165	N/A	N/A
Inertial Mass (lb)	5000	±110	5065
Gross Static[a] Mass (lb)	5000	±110	5065
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40.3
Overall Length (inches)	237	±13	229.0
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46.0
Track Width[b] (inches)	67	±1.5	68.3
CG aft of Front Axle[c] (inches)	63	±4	62.5
CG above Ground[c,d] (inches)	28	≥28	28.6

Note: N/A = not applicable; CG = center of gravity.

[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.



Figure 7.4. Impact Side of Test Vehicle before Test 620851-01-2.



Figure 7.5. Opposite Impact Side of Test Vehicle before Test 620851-01-2.

7.3. TEST DESCRIPTION

7.3.1. Weather Conditions

Table 7.2 provides the weather conditions for Test 620851-01-2.

Table 7.2. Weather Conditions 620851-01-2.

Date of Test	2024-12-13
Wind Speed	10 mi/h
Wind Direction	175°
Temperature	63°F
Relative Humidity	88 %
Vehicle Traveling	195°

7.3.2. Test Events

Table 7.3 lists events that occurred during Test 620851-01-2. The figures in Appendix G.2 present sequential photographs during the test.

Table 7.3. Events during Test 620851-01-2.

Time (seconds)	Events
0.0000	Vehicle impacted the installation
0.0040	Post 11 began to lean toward the field side
0.0150	Post 12 began to lean toward the field side
0.0330	Vehicle began to redirect
0.0590	Post 13 began to twist counterclockwise
0.0870	Post 12 released from rail and began to lean over completely
0.1360	The rail reached approximately 43 inches of deformation
0.1370	Rail joint between posts 12 and 13 began to rupture
0.1560	Rail Joint between posts 12 and 13 completely parted

7.4. TEST ACTUAL IMPACT CONDITIONS

Table 7.4 lists the details of the *MASH* impact conditions for Test 620851-01-2 and Table 7.5 lists the vehicle exit parameters.

Table 7.4. Impact Conditions for *MASH TEST 3-11,* Crash Test 620851-01-2.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5	60.6
Impact Angle (°)	25	±1.5	26.0
Impact Severity (kip-ft)	106	≥106	126.8
Impact Location	138 inches upstream from the joint between posts 12 and 13	±1 foot (12 inches)	135.5 inches upstream from the centerline of the joint between posts 12 and 13 along the rail

Table 7.5. Exit Parameters for *MASH TEST 3-11,* Crash Test 620851-01-2.

Exit Parameter	Measured
Speed	N/A, Vehicle penetrated the rail
Brakes applied post impact	1.6 seconds
Vehicle at rest position	106 ft downstream of impact point 37 ft to the field side
Comments:	Vehicle remained upright and stable The vehicle did not meet the exit box criteria

[a]Per the *MASH* guidelines in Section 5.2.3, the exit box for the 2270P used in this test was 16.8 ft toward the traffic side as measured from the traffic side of the unflared rail and 32.8 ft downstream from loss of contact.

7.5. DAMAGE TO TEST INSTALLATION

The upstream rail at the joint between posts 12 and 13 ruptured. The rail was deformed and scuffed.

Table 7.6 describes the damage to the 21:1 Flared MGS. Figure 7.6 and Figure 7.7 show the damage to the 21:1 Flared MGS.

Table 7.6. Damage to Test Installation for Test 620851-01-2.

Post #	Soil Gap (in inches)	Post Lean (in degrees)	Comments
1	Soil disturbed	----	----
2	0.7 d/s	----	----
3 - 8	Soil disturbed	----	----
9	0.3 t/s	----	----
10	0.7 t/s, 0.5 f/s	----	----
11	2 f/s	78.5	----
12	----	15.6 d/s	Post deformed and released from rail, Blockout missing
13	----	16.4 /s	Post deformed and released from rail, Blockout missing
14	----	20.7 d/s	Post deformed and released from rail, Blockout missing
15	----	38.5 d/s	Post deformed and released from rail
16	0.1 t/s	----	Post released from rail
17	0.5 t/s and f/s	----	Post released from rail
18	0.3 t/s and f/s	----	Post released from rail
19 - 21	Soil disturbed	----	Post released from rail
22	0.3 f/s	----	----
23	Soil disturbed	----	----



Figure 7.6. 21:1 Flared MGS at Impact Location after Test 620851-01-2.



Figure 7.7. In-Line View of the 21:1 Flared MGS after Test 620851-01-2.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.8 and Figure 7.9 show the damage sustained by the test vehicle. Table 7.7 and Table 7.8 provide details on the occupant compartment deformation and exterior vehicle damage. Figure G.2 and Figure G.3 in Appendix G.1 provide exterior crush and occupant compartment measurements.



Figure 7.8. Impact Side of Test Vehicle after Test 620851-01-2.



Figure 7.9. Non-Impact Side of Test Vehicle after Test 620851-01-2.

Table 7.7. Occupant Compartment Deformation 620851-01-2.

Test Parameter	Specification (inches)	Measured (inches)
Roof	≤4.0	0.0
Windshield	≤3.0	0.0
A and B Pillars	≤5.0 overall/≤3.0 lateral	0.0
Foot Well/Toe Pan	≤9.0	0.0
Floor Pan/Transmission Tunnel	≤12.0	0.0
Side Front Panel	≤12.0	0.0
Front Door (above Seat)	≤9.0	0.0
Front Door (below Seat)	≤12.0	0.0

Table 7.8. Exterior Vehicle Damage 620851-01-2.

Test Parameter	Details
Side Windows	Remained intact
Maximum Exterior Deformation	20 inches at front bumper
VDS	12FC3
CDC	12FCEW5
Fuel Tank Damage	None
Description of Damage to Vehicle:	The deformation of the grill, bumper, radiator, and support pushed the radiator and fan into the motor block. Both headlights were dislodged and the right front frame was deformed. The right front fender and door had deformations and abrasions. The right front tire ruptured and there were deformations and abrasions on the bumper.

7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.9. Figure G.7 in Appendix G.3 shows the test vehicle angular displacements, and Figure G.8 through Figure G.10 in Appendix G.4 show acceleration versus time traces.

Table 7.9. Occupant Risk Factors for Test 620851-01-2.

Test Parameter	Specification [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	20.4	0.1486 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	17.2	0.1486 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	7.8	0.2493 - 0.2593 seconds
Ridedown, Lateral (g)	≤20.49 *15.0*	4.0	0.2232 - 0.2332 seconds
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	7.6	0.1426 seconds on right side of interior
Acceleration Severity Index	N/A	0.7	0.1272 - 0.1772 seconds
50-ms Moving Avg. Accelerations (MA) Longitudinal (g)	N/A	-5.7	0.0667 - 0.1167 seconds
50-ms MA Lateral (g)	N/A	-5.1	0.1023 - 0.1523 seconds
50-ms MA Vertical (g)	N/A	1.7	0.0824 - 0.1324 seconds
Roll (°)	≤75	6.5	0.6240 seconds
Pitch (°)	≤75	3.4	0.8109seconds
Yaw (°)	N/A	24.6	0.5661 seconds

[a.] *Values in italics are the preferred MASH values*

Note: N/A = Not Applicable

7.8. TEST SUMMARY

Figure 7.10 summarizes the results of *MASH* Test 620851-01-2.



0.000 s



0.2000 s



0.4000 s



0.6000s

GENERAL INFORMATION	
Test Agency:	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.:	*MASH* 2016, Test 3-11
Project No.:	620851-01-2
Test Date:	2024-12-13

TEST ARTICLE	
Type:	Longitudinal Barrier
Name:	21:1 Flared MGS
Length:	181 feet and 3 inches
Key Materials:	Steel guardrail, timber blockouts, Flared Guardrail
Soil Type and Condition:	Type D grade 1 crushed concrete, dry

TEST VEHICLE	
Type/Designation:	2270P
Year, Make and Model:	2019 RAM 1500
Inertial Mass:	5065 lb
Dummy Mass:	No dummy
Gross Static Mass:	5065 lb

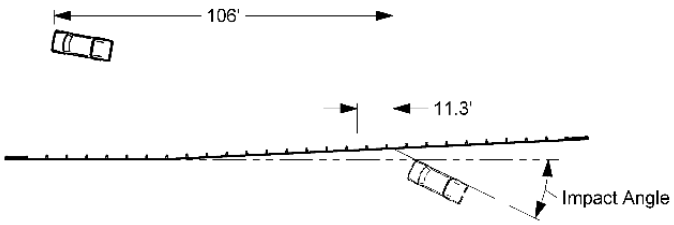
IMPACT CONDITIONS	
Impact Speed:	60.6 mi/h
Impact Severity:	126.8 kip-ft

EXIT CONDITIONS	
Exit Speed:	N/A, Vehicle penetrated the rail
Exit Box Criteria:	The vehicle did not meet the exit box criteria
Stopping Distance:	106 ft downstream 37 ft to the field side

TEST ARTICLE DEFLECTIONS	
Dynamic:	N/A; rail ruptured
Permanent:	N/A; rail ruptured
Working Width:	N/A; rail ruptured
Working Width Height:	N/A; rail ruptured

VEHICLE DAMAGE	
VDS:	12FC3
CDC:	12FCEW5
Max Exterior Deformation:	20 inches at front bumper
Max Occupant Compartment Deformation:	No occupant compartment deformation

OCCUPANT RISK VALUES	
Longitudinal OIV:	20.4 ft/s
Lateral OIV:	17.2 ft/s
Longitudinal Ridedown:	7.8 g
Lateral Ridedown:	4.0 g
THIV:	7.6 m/s
ASI:	0.7
Max 50ms Longitudinal:	-5.7 g
Max 50ms Lateral:	-5.1 g
Max 50ms Vertical:	1.7 g
Max Roll:	6.5°
Max Pitch:	3.4°
Max Yaw:	24.6°



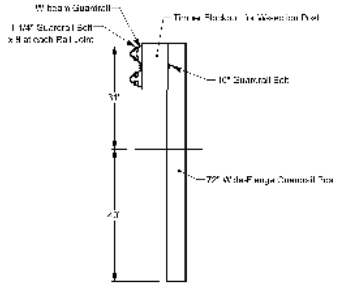


Figure 7.10. Summary of Results for *MASH* Test 3-11 on 21:1 Flared MGS.

CHAPTER 8.

MASH TEST 3-11 (CRASH TEST 620851-01-3)

8.1. CRITICAL IMPACT POINT LOCATION

The Critical Impact Point (CIP) for Test 620851-03 was located 138 inches upstream from the centerline of the joint between posts 12 and 13 along the rail. The target CIP for this test was determined using the information provided in *MASH* Section 2.2.1 and MASH Section 2.3.2. Figure 8.1 shows the target CIP for test 620851-01-3. Figure 8.2 and Figure 8.3 depict the vehicle at the CIP prior to test 620851-01-3.

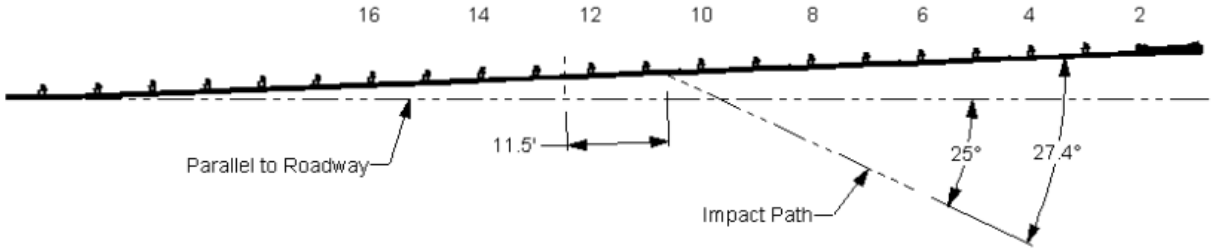


Figure 8.1. Target CIP for *MASH* Test 3-11 on 25:1 Flared MGS.



Figure 8.2. 25:1 Flared MGS/Test Vehicle Geometrics for Test 620851-01-3.



Figure 8.3. 25:1 Flared MGS/Test Vehicle Impact Location 620851-01-3.

8.2. TEST VEHICLE DETAILS PRIOR TO IMPACT

Table 8.1 shows the test vehicle measurements. Figure 8.4 and Figure 8.5 show the 2020 RAM 1500 test vehicle used for the crash test. Figure H.1 in Appendix H.1 gives additional dimensions and information on the test vehicle.

Table 8.1. Vehicle Measurements for Test 620851-01-3.

Test Parameter	Specification	Tolerance	Measured
Dummy Mass (if applicable)[a] (lb)	165	N/A	N/A
Inertial Mass (lb)	5000	±110	5038
Gross Static[a] Mass (lb)	5000	±110	5038
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	68.3
CG aft of Front Axle[c] (inches)	63	±4	60.1
CG above Ground[c,d] (inches)	28	≥28	29.0

Note: N/A = not applicable; CG = center of gravity.

[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.



Figure 8.4. Impact Side of Test Vehicle before Test 620851-01-3.



Figure 8.5. Opposite Impact Side of Test Vehicle before Test 620851-01-3.

8.3. TEST DESCRIPTION

8.3.1. Weather Conditions

Table 8.2 provides the weather conditions for test 620851-01-3.

Table 8.2. Weather Conditions 620851-01-3.

Date of Test	5/19/2025
Wind Speed	18 mi/h
Wind Direction	131°
Temperature	86°F
Relative Humidity	76 %
Vehicle Traveling	195°

8.3.2. Test Events

Table 8.3 lists events that occurred during Test 620851-01-3. The figures in Appendix H.2 present sequential photographs during the test.

Table 8.3. Events during Test 620851-01-3.

Time (seconds)	Events
0.0000	Vehicle impacted the installation
0.0030	Post 11 began to deflect toward the field side
0.0250	Post 12 began to deflect toward the field side
0.0400	Vehicle began to redirect
0.0400	Right front tire engaged Post 11
0.0610	Right front corner of the bumper engaged Post 12
0.0680	Post 12 began to twist in a counter-clockwise direction
0.0800	Post 12 released from the rail
0.0880	Post 13 began to deflect towards the field side
0.0880	Right front tire engaged Post 12
0.0950	Post 13 began to twist in a counter-clockwise direction
0.0990	The rail released from post 15
0.1150	Right front corner of the bumper engaged Post 13
0.1230	Post 13 released from the rail
0.1340	Post 14 began to deflect toward the field side
0.1670	The rail reached approximately 48 inches of deformation
0.1680	The rail began to tear at the post 13 slot location
0.1810	The rail ruptured completely
0.3760	Vehicle was parallel with installation

8.4. TEST ACTUAL IMPACT CONDITIONS

Table 8.4 lists the details of the *MASH* impact conditions for Test 620851-03 and Table 8.5 lists the exit parameters.

Table 8.4. Impact Conditions for *MASH TEST 3-11,* Crash Test 620851-01-3.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5	62.6
Impact Angle (°)	25	±1.5	25.4
Impact Severity (kip-ft)	106	≥106	121.4
Impact Location	138 inches upstream from the centerline of the joint between posts 12 and 13 along the rail	±1 foot (12 inches)	135 inches upstream from the centerline of the joint between posts 12 and 13 along the rail

Table 8.5. Exit Parameters for *MASH TEST 3-11,* Crash Test 620851-01-3.

Exit Parameter	Measured
Speed	N/A, Vehicle penetrated the rail
Brakes applied post impact	Brakes not applied
Vehicle at rest position	86 ft downstream of impact point 19 ft to the field side
Comments:	Vehicle rolled.

8.5. DAMAGE TO TEST INSTALLATION

The rail ruptured at the bolt slot for post 13 and released from posts 10 through 25. The blockouts for posts 11 and 12 were released and the posts were twisted counterclockwise. Post 13 had a tear in the traffic side flange at 12.6 inches from the top of the post. The blockouts for posts 14 and 15 had heavy damage and splintering. The rail was deformed on the bottom corner at the joint between posts 12 and 13. There were tears on the rail at posts 10 through 12 at the slot locations, a 6-inch-long tear which started at the bottom of the rail downstream from post 13, and a 2.5-inch long tear at the bottom of the rail 6 inches downstream from post 14. There was a hole 6 inches downstream of post 14 and 4 inches from the top of the rail. The rail bent toward the traffic side at post 15, with a tear at the bolt hole location.

Table 8.6 describes the damage to the 25:1 Flared MGS. Figure 8.6 and Figure 8.7 show the damage to the 25:1 Flared MGS.

Table 8.6. Damage to Test Installation for Test 620851-01-2.

Post #	Soil Gap (in inches)	Post Lean (in degrees)	Comments
1	Soil disturbed	----	----
3	Soil disturbed	----	----
6	Soil disturbed	----	----
8	Soil disturbed	----	Blockout twisted counterclockwise
9	Soil disturbed	----	Blockout twisted counterclockwise
10	0.2 f/s, 0.1 t/s	----	----
11	0.5 f/s	70.4	----
12-17	----	----	Posts deformed and Leaning d/s



Figure 8.6. 25:1 Flared MGS at Impact Location after Test 620851-01-3.



Figure 8.7. 25:1 Ruptured Downstream end of the Flared MGS after Test 620851-01-3.

8.6. DAMAGE TO TEST VEHICLE

Figure 8.8 and Figure 8.9 show the damage sustained by the test vehicle. Figure 8.10 and Figure 8.11 show the interior of the test vehicle. Table 8.7 and Table 8.8 provide details on the occupant compartment deformation and exterior test vehicle damage. Figure H.2 and Figure H.3 in Appendix H.1 provide exterior crush and occupant compartment measurements.



Figure 8.8. At Rest Positions of the Test Vehicle after Test 620851-01-3.



Figure 8.9. Front View of the Test Vehicle after Test 620851-01-3.



Figure 8.10. Undercarriage of the Test Vehicle at the Front Bumper after Test 620851-01-3.



Figure 8.11. Detail of the Test Vehicle Undercarriage on the Impact Side after Test 620851-01-3.

Table 8.7. Occupant Compartment Deformation 620851-01-3.

Test Parameter	Specification (inches)	Measured (inches)
Roof	≤4.0	1.0
Windshield	≤3.0	0.0
A and B Pillars	≤5.0 overall/≤3.0 lateral	0.0
Foot Well/Toe Pan	≤9.0	0.0
Floor Pan/Transmission Tunnel	≤12.0	0.0
Side Front Panel	≤12.0	0.0
Front Door (above Seat)	≤9.0	0.0
Front Door (below Seat)	≤12.0	0.0

Table 8.8. Exterior Vehicle Damage 620851-01-3.

Test Parameter	Details
Side Windows	Remained intact
Maximum Exterior Deformation	16 inches at the front bumper
VDS	01RFQ3
CDC	01FREO3
Fuel Tank Damage	None
Description of Damage to Vehicle:	The vehicle rolled and came to rest on its roof. The bumper, right fender, and right headlight were dislodged. The right front wheel fractured and the tire ruptured. The windshield had several cracks, and the right rearview mirror was fractured. There were deformations and abrasions down the right side, and deformations in the roof and left side of the bumper. There was a tear on the right side of the bumper and at the fog light 1 inch wide by 2 inches long.

8.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 8.9. Figure H.7 in Appendix H.3 shows the test vehicle angular displacements, and Figure H.8 through Figure H.10 in Appendix H.4 show acceleration versus time traces.

Table 8.9. Occupant Risk Factors for Test 620851-01-3.

Test Parameter	Specification [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	18.3	0.1525 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	14.5	0.1525 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	-5.3	0.1680 – 0.1780 seconds
Ridedown, Lateral (g)	≤20.49 *15.0*	-8.3	2.2050 – 2.2150 seconds
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	6.8	0.1458 seconds on the right side of interior
Acceleration Severity Index	N/A	0.6	0.0682 – 0.1182 seconds
50-ms Moving Avg. Accelerations (MA) Longitudinal (g)	N/A	-5.4	0.0516 - 0.1016 seconds
50-ms MA Lateral (g)	N/A	-4.8	0.1265 - 0.1765 seconds
50-ms MA Vertical (g)	N/A	3.9	2.2462 - 2.2962 seconds
Roll (°)	≤75	186.7	3.0556 seconds
Pitch (°)	≤75	-29.6	9.5174 seconds
Yaw (°)	N/A	-266.1	10.0000 second

[a.] *Values in italics are the preferred MASH values*

Note: N/A = Not Applicable

8.8. TEST SUMMARY

Figure 8.12 summarizes the results of *MASH* Test 620851-01-3.



0.000 s



0.2000 s

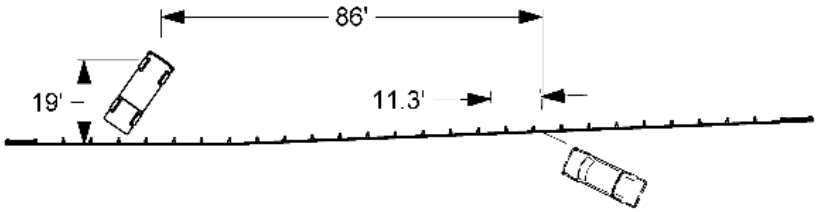


0.4000 s



0.6000s

GENERAL INFORMATION	
Test Agency:	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.:	*MASH* 2016, Test 3-11
Project No.:	620851-01-3
Test Date:	5/19/2025
TEST ARTICLE	
Type:	Longitudinal Barrier
Name:	25:1 Flared MGS
Length:	181 feet and 3 inches
Key Materials:	Steel guardrail, timber blockouts, Flared Guardrail
Soil Type and Condition:	Type D grade 1 crushed concrete, dry
TEST VEHICLE	
Type/Designation:	2270P
Year, Make and Model:	2020 RAM 1500
Inertial Mass:	5038 lb
Dummy Mass:	N/A
Gross Static Mass:	5038 lb
IMPACT CONDITIONS	
Impact Speed:	62.6 mi/h
Impact Angle:	25.4°
Impact Location:	135 inches upstream from the centerline of the joint between posts 12 and 13 along the rail
Impact Severity:	121.4
EXIT CONDITIONS	
Exit Speed:	N/A, Vehicle penetrated the rail
Trajectory/Heading Angle:	N/A, Vehicle penetrated the rail
Exit Box Criteria:	N/A
Stopping Distance:	86 ft downstream 19 ft to the field side
TEST ARTICLE DEFLECTIONS	
Dynamic:	N/A; rail ruptured
Permanent:	N/A; rail ruptured
Working Width:	N/A; rail ruptured
Working Width Height:	N/A; rail ruptured
VEHICLE DAMAGE	
VDS:	01RFQ3
CDC:	01FREO3
Max Exterior Deformation:	16 inches at front bumper
Max Occupant Compartment Deformation:	1 inch in the roof
OCCUPANT RISK VALUES	
Longitudinal OIV:	18.3 ft/s
Lateral OIV:	14.5 ft/s
Longitudinal Ridedown:	-5.3g
Lateral Ridedown:	-8.3g
THIV:	6.8 m/s
ASI:	0.6
Max 50ms Longitudinal:	-5.4g
Max 50ms Lateral:	-4.8g
Max 50ms Vertical:	3.9 g
Max Roll:	186.7°
Max Pitch:	-29.6°
Max Yaw:	-266.1°



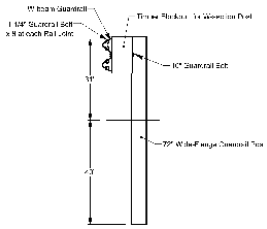


Figure 8.12. Summary of Results for *MASH* Test 3-11 on 25:1 Flared MGS.

CHAPTER 9.

MASH TEST 3-11 (CRASH TEST 620851-01-4)

9.1. CRITICAL IMPACT POINT LOCATION

The Critical Impact Point (CIP) for this test was 138 inches [11.5 feet] upstream from the centerline of the joint between posts 12 and 13 at 25 degrees. The target CIP for this test was determined using the information provided in *MASH* Section 2.2.1 and MASH Section 2.3.2. Figure 9.1 shows the target CIP for test 620851-01-4. Figure 9.2 and Figure 9.3 depict the vehicle at the CIP prior to test 620851-01-4.

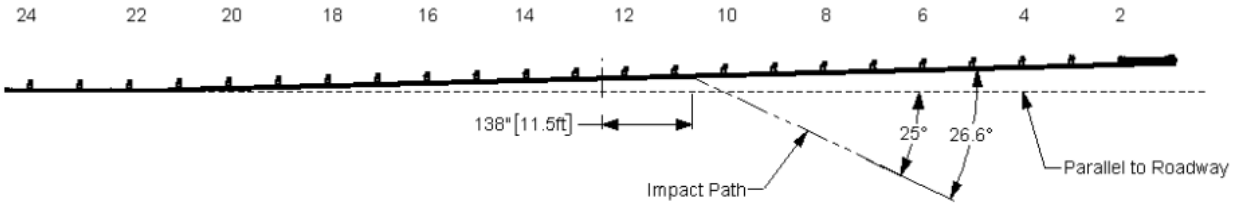


Figure 9.1. Target CIP for *MASH* Test 3-11 on 38:1 Flared MGS.

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Figure 9.2. 38:1 Flared MGS/Test Vehicle Geometrics for Test 620851-01-4.



Figure 9.3. 38:1 Flared MGS/Test Vehicle Impact Location 620851-01-4.

9.2. TEST VEHICLE DETAILS PRIOR TO IMPACT

Table 9.1 shows the vehicle measurements. Figure 9.4 and Figure 9.5 show the 2021 RAM 1500 used for the crash test. Figure I.1 in Appendix I.1 gives additional dimensions and information on the vehicle.

Table 9.1. Vehicle Measurements for Test 620851-01-4.

Test Parameter	Specification	Tolerance	Measured
Dummy Mass (if applicable)[a] (lb)	165	N/A	N/A
Inertial Mass (lb)	5000	±110	5070
Gross Static[a] Mass (lb)	5000	±110	5070
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	81	±2.5	78.5
Hood Height (inches)	43	±4	46
Track Width[b] (inches)	68	±1.5	68.3
CG aft of Front Axle[c] (inches)	63	±4	62.3
CG above Ground[c,d] (inches)	≥28	N/A	29.3

Note: N/A = not applicable; CG = center of gravity.

[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.

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Figure 9.4. Impact Side of Test Vehicle before Test 620851-01-4.



Figure 9.5. Opposite Impact Side of Test Vehicle before Test 620851-01-4.

9.3. TEST DESCRIPTION

9.3.1. Weather Conditions

Table 9.2 provides the weather conditions for 620851-01-4. Values for wind direction and vehicle travel are in reference to the degrees on a compass, with North being 0 degrees.

Table 9.2. Weather Conditions 620851-01-4.

Date of Test	2026-03-24
Wind Speed	9 mi/h
Wind Direction	180 °
Temperature	72°F
Relative Humidity	79 %
Vehicle Traveling	195°

9.3.2. Test Events

Table 9.3 lists events that occurred during Test 620851-01-4. The figures in Appendix I.2 present sequential photographs during the test.

Table 9.3. Events during Test 620851-01-4.

Time (seconds)	Events
0.0000	Vehicle impacted the installation
0.0080	Post 10 and 11 began to lean toward the field side
0.0230	Post 12 began to lean toward the field side
0.0480	Vehicle began to redirect
0.0580	Post 13 began to lean toward the field side
0.0890	Post 14 began to lean toward the field side
0.1330	Joint between posts 12 and 13 began to tear from the bottom
0.1400	Post 15 began to lean toward the field side
0.2230	Rear right side bumper contacted the rail.
0.2980	Vehicle was parallel with the installation

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9.4. TEST ACTUAL IMPACT CONDITIONS

Table 9.4 lists the details of the *MASH* impact conditions for this test and Table 9.5 lists the exit parameters.

Table 9.4. Impact Conditions for *MASH TEST 3-11,* Crash Test 620851-01-4.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5	61.7
Impact Angle (°)	25	±1.5	25.6
Impact Severity (kip-ft)	106	≥106	120.5
Impact Location	138 inches [11.5 feet] upstream from the centerline of the joint between posts 12 and 13	±1 foot (12 inches)	136 inches [11.3 feet] upstream from the centerline of the joint between posts 12 and 13

Table 9.5. Exit Parameters for *MASH TEST 3-11,* Crash Test 620851-01-4.

Exit Parameter	Measured
Speed	Not measurable[a]
Trajectory	Not measurable[a]
Heading	Not measurable[a]
Brakes applied post impact	Brakes not applied
Vehicle at rest position	152 ft downstream of impact point 24 ft to the field side
Comments:	Vehicle remained upright and stable. The vehicle met the exit box criteria[b] by crossing the exit box on the downstream end

[a]The test vehicle exited the installation outside of the frame of the overhead high speed camera where these measurements are performed.
[b]Per the *MASH* guidelines in Section 5.2.3, the exit box for the 2270P used in this test was 16.8 ft toward the traffic side as measured from the traffic side face of the rail and 32.8 ft downstream from loss of contact.

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9.5. DAMAGE TO TEST INSTALLATION

The rail partially tore at the joint between posts 12 and 13. There was a secondary impact by the test vehicle on the downstream terminal. Table 9.6 describes the damage to the installation, and Table 9.7 describes the deflection and working width of the 38:1 Flared MGS. Figure 9.6 and Figure 9.7 show the damage to the 38:1 Flared MGS.

Table 9.6. Damage to Test Installation for Test 620851-01-4.

Post #	Soil Gap (in inches)	Post Lean (in degrees)	Comments
1	0.5 d/s	-	
2	0.4 d/s	-	
8	Soil Disturbed	-	
9	0.1 t/s	-	Post twisted clockwise
10	0.8 t/s | 0.5 f/s	2.7 f/s	
11	2.5 f/s | t/s filled	11.7 f/s	
12-14	Soil filled back in	70 d/s	Posts deformed and released from blockouts and rail
15	Soil filled back in	45 d/s | 45 f/s	Post deformed and released from blockout and rail
16	0.5 t/s | 0.5 f/s	2.1 f/s	Post released from rail
17	Soil Disturbed	-	Post released from rail

Note: d/s: downstream; f/s: field side; t/s: traffic side; - : no measurement or no movement

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Table 9.7. Deflection and Working Width of the 38:1 Flared MGS for Test 620851-01-4.

Test Parameter	Measured
Permanent Deflection/Location	29.3 inches toward field side, at 12 inches upstream from the center of post 14
Dynamic Deflection	41.5 inches toward field side at the rail between posts 13 and 14
Working Width [a] and Height	52.2 inches, at a height of 52.0 inches at the right 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.

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Figure 9.6. 38:1 Flared MGS at Impact Location after Test 620851-01-4.



Figure 9.7. 38:1 Flared MGS at the Joint Between Posts 12 and 13 after Test 620851-01-4.

9.6. DAMAGE TO TEST VEHICLE

Figure 9.8 and Figure 9.9 show the damage sustained by the vehicle. Figure 9.10 and Figure 9.11 show the interior of the test vehicle. Table 9.8 and Table 9.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figure I.2 and Figure I.3 in Appendix I.1 provide exterior crush and occupant compartment measurements.



Figure 9.8. Impact Side of Test Vehicle after Test 620851-01-4.



Figure 9.9. Rear Impact Side of Test Vehicle after Test 620851-01-4.



Figure 9.10. Overall Interior of Test Vehicle after Test 620851-01-4.



Figure 9.11. Interior of Test Vehicle on Impact Side after Test 620851-01-4.

Table 9.8. Occupant Compartment Deformation 620851-01-4.

Test Parameter	Specification (inches)	Measured (inches)
Roof	≤4.0	0.0
Windshield	≤3.0	0.0
A and B Pillars	≤5.0 overall/≤3.0 lateral	0.0
Foot Well/Toe Pan	≤9.0	0.0
Floor Pan/Transmission Tunnel	≤12.0	0.0
Side Front Panel	≤12.0	0.0
Front Door (above Seat)	≤9.0	0.0
Front Door (below Seat)	≤12.0	0.0

Table 9.9. Exterior Vehicle Damage 620851-01-4.

Test Parameter	Details
Side Windows	The side windows remained intact
Maximum Exterior Deformation	20 inches in the right front corner at bumper height
VDS	01RFQ4
CDC	01FREW2
Fuel Tank Damage	None
Description of Damage to Vehicle:	The radiator and support, grill, right front A-arm, brake disc, and caliper fractured. The right side of the bumper, right front fender, right front door, right rear quarter panel, and rear bumper were deformed. The deformation in the front right door created a 1.4-inch gap between the door and the body of the vehicle. The right front wheel released from the vehicle, and the right rear wheel was bent. There was damage to the right rear tire, but it still held air.

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9.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 9.10. Figure I.7 in Appendix I.3 shows the vehicle angular displacements, and Figure I.8 through Figure I.10 in Appendix I.4 show acceleration versus time traces.

Table 9.10. Occupant Risk Factors for Test 620851-01-4.

Test Parameter	Specification [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *≤30.0*	17.8	0.1516 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *≤30.0*	15.8	0.1516 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *≤15.0*	5.8	0.1709 - 0.1809 seconds
Ridedown, Lateral (g)	≤20.49 *≤15.0*	6.2	0.2106 - 0.2206 seconds
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	6.9	0.1451 seconds on right side of interior
Acceleration Severity Index	N/A	0.7	0.2335 - 0.2835 seconds
50-ms Moving Avg. Accelerations (MA) Longitudinal (g)	N/A	-4.8	0.1047 - 0.1547 seconds
50-ms MA Lateral (g)	N/A	-5.5	0.2066 - 0.2566 seconds
50-ms MA Vertical (g)	N/A	1.5	0.5390 - 0.5890 seconds
Roll (°)	≤75	6.1	0.9266 seconds
Pitch (°)	≤75	4.8	1.0787 seconds
Yaw (°)	N/A	41.1	0.7952 seconds

[a.] *Values in italics are the preferred MASH values*

Note: N/A = Not Applicable

9.8. TEST SUMMARY

Figure 9.12 summarizes the results of *MASH* Test 620851-01-4.

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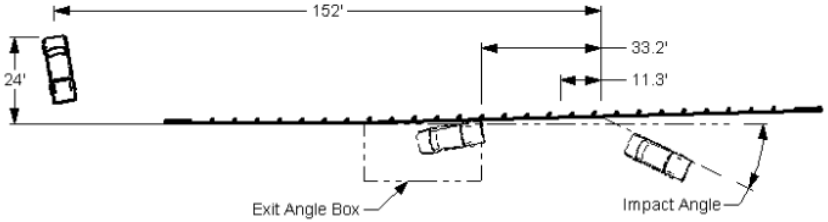


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GENERAL INFORMATION	
Test Agency:	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.:	*MASH* 2016, Test 3-11
Project No.:	620851-01-4
Test Date:	2026-03-24
TEST ARTICLE	
Type:	Longitudinal Barrier
Name:	38:1 Flared MGS
Length:	181 ft 3 inches
Key Materials:	Steel guardrail, timber blockouts, Flared Guardrail
Soil Type and Condition:	Type D grade 1 crushed concrete roadbase, damp
TEST VEHICLE	
Type/Designation:	2270P
Year, Make and Model:	2021 RAM 1500
Inertial Mass:	5070 lb
Dummy Mass:	N/A
Gross Static Mass:	5070 lb
IMPACT CONDITIONS	
Impact Speed:	61.7 mi/h
Impact Angle:	25.6°
Impact Location:	136 inches [11.3 feet] upstream from the centerline of the joint between posts 12 and 13
Impact Severity:	120.5 kip-ft
EXIT CONDITIONS	
Exit Speed:	Not measurable
Trajectory/Heading Angle:	Not measurable
Exit Box Criteria:	The vehicle met the exit box criteria
Stopping Distance:	152 ft downstream 24 ft to the field side
TEST ARTICLE DEFLECTIONS	
Dynamic:	41.5 inches
Permanent:	29.3 inches
Working Width:	52.2 inches
Working Width Height:	52.0 inches
VEHICLE DAMAGE	
VDS:	01RFQ4
CDC:	01FREW2
Max Exterior Deformation:	20 inches in the right front corner at bumper height
Max Occupant Compartment Deformation:	No occupant compartment deformation
OCCUPANT RISK VALUES	
Longitudinal OIV:	17.8 ft/s
Lateral OIV:	15.8 ft/s
Longitudinal Ridedown:	5.8 g
Lateral Ridedown:	6.2 g
THIV:	6.9 m/s
ASI:	0.7
Max 50ms Longitudinal:	-4.8 g
Max 50ms Lateral:	-5.5 g
Max 50ms Vertical:	1.5 g
Max Roll:	6.1°
Max Pitch:	4.8°
Max Yaw:	41.1°



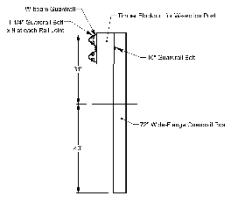


Figure 9.12. Summary of Results for *MASH* Test 3-11 on 38:1 Flared MGS.

CHAPTER 10.

MASH TEST 3-11 (CRASH TEST 620851-01-5)

10.1. CRITICAL IMPACT POINT LOCATION

The Critical Impact Point (CIP) for this test was 138 inches [11.5 feet] upstream from the centerline of the joint between posts 12 and 13 at 25 degrees. The target CIP for this test was determined using the information provided in *MASH* Section 2.2.1 and MASH Section 2.3.2. Figure 10.1 shows the target CIP for test 620851-01-5. Figure 10.2 and Figure 10.3 depict the vehicle at the CIP prior to test 620851-01-5.

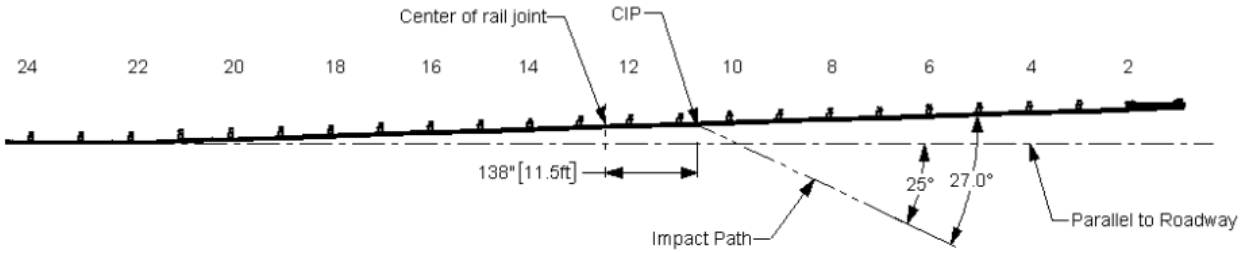


Figure 10.1. Target CIP for *MASH* Test 3-11 on 30:1 Flared MGS.

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Figure 10.2. 30:1 Flared MGS/Test Vehicle Geometrics for Test 620851-01-5.



Figure 10.3. 30:1 Flared MGS/Test Vehicle Impact Location 620851-01-5.

10.2. TEST VEHICLE DETAILS PRIOR TO IMPACT

Table 10.1 shows the vehicle measurements. Figure 10.4 and Figure 10.5 show the 2021 RAM 1500 used for the crash test. Figure J.1 in Appendix J.1 gives additional dimensions and information on the vehicle.

Table 10.1. Vehicle Measurements for Test 620851-01-5.

Test Parameter	Specification	Tolerance	Measured
Dummy Mass (if applicable)[a] (lb)	165	N/A	N/A
Inertial Mass (lb)	5000	±110	5046
Gross Static[a] Mass (lb)	5000	±110	5046
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	81	±2.5	78.5
Hood Height (inches)	43	±4	46
Track Width[b] (inches)	68	±1.5	68.3
CG aft of Front Axle[c] (inches)	63	±4	61.4
CG above Ground[c,d] (inches)	≥28	N/A	28.4

Note: N/A = not applicable; CG = center of gravity.

[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.

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Figure 10.4. Impact Side of Test Vehicle before Test 620851-01-5.



Figure 10.5. Opposite Impact Side of Test Vehicle before Test 620851-01-5.

10.3. TEST DESCRIPTION

10.3.1. Weather Conditions

Table 10.2 provides the weather conditions for 620851-01-5. Values for wind direction and vehicle travel are in reference to the degrees on a compass, with North being 0 degrees.

Table 10.2. Weather Conditions 620851-01-5.

Date of Test	2026-05-06
Wind Speed	2 mi/h
Wind Direction	112°
Temperature	79°F
Relative Humidity	80 %
Vehicle Traveling	195°

10.3.2. Test Events

Table 10.3 lists events that occurred during Test 620851-01-5. The figures in Appendix J.2 present sequential photographs during the test.

Table 10.3. Events during Test 620851-01-5.

Time (seconds)	Events
0.0000	Vehicle impacted the installation
0.0060	Post 10 and 11 began to lean toward the field side
0.0280	Post 12 began to lean toward the field side
0.0580	Vehicle began to redirect
0.0650	Post 13 began to lean toward the field side
0.0960	Post 14 began to lean toward the field side
0.1100	Post 15 began to lean toward the field side
0.2170	Rear right side bumper contacted the rail.
0.2740	Vehicle was parallel with the installation

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10.4. TEST ACTUAL IMPACT CONDITIONS

Table 10.4 lists the details of the *MASH* impact conditions for this test and Table 10.5 lists the exit parameters.

Table 10.4. Impact Conditions for *MASH TEST 3-11,* Crash Test 620851-01-5.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5	62.1
Impact Angle (°)	25	±1.5	24.9
Impact Severity (kip-ft)	106	≥106	115.3
Impact Location	138 inches [11.5 feet] upstream from the centerline of the joint between posts 12 and 13	±1 foot (12 inches)	138 inches [11.5 feet] upstream from the centerline of the joint between posts 12 and 13

Table 10.5. Exit Parameters for *MASH TEST 3-11,* Crash Test 620851-01-5.

Exit Parameter	Measured
Speed	28.9mi/h
Trajectory	13.5°
Heading	8.7°
Brakes applied post impact	Brakes not applied
Vehicle at rest position	135 ft downstream of impact point In-line
Comments:	Vehicle remained upright and stable. The vehicle met the exit box criteria[a] by crossing the exit box on the downstream end

[a]Per the *MASH* guidelines in Section 5.2.3, the exit box for the 2270P used in this test was 16.8 ft toward the traffic side as measured from the traffic side face of the rail and 32.8 ft downstream from loss of contact.

10.5. DAMAGE TO TEST INSTALLATION

The rail partially tore at the joint between posts 12 and 13, as well as at the slot at post 13. There was a secondary impact by the test vehicle at post 28.

Table 10.6 describes the damage to the installation and Table 10.7 describes the deflection and working width of the 30:1 Flared MGS. Figure 10.6 and Figure 10.7 show the damage to the 30:1 Flared MGS.

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Table 10.6. Damage to Test Installation for Test 620851-01-5.

Post #	Soil Gap (in inches)	Post Lean (in degrees)	Comments
1	Soil Disturbed	-	-
8	Soil Disturbed	-	-
9	0.3 t/s	0.4 f/s	-
10	0.8 t/s | 1.0 f/s	5.6 f/s	-
11	4.5 f/s	14.4 f/s	-
12-13	Soil filled back in	22 d/s	Post deformed and released from the rail and blockouts
14	-	-	Post pulled out of ground and released from the rail and blockout
15	Soil filled back in	6 d/s	Post released from the rail
16	0.3 t/s | 0.3 f/s	1.8 f/s	-

Note: d/s: downstream; f/s: field side; t/s: traffic side; - : no measurement or no movement

Table 10.7. Deflection and Working Width of the 30:1 Flared MGS for Test 620851-01-5.

Test Parameter	Measured
Permanent Deflection/Location	25.8 inches toward field side, at 2 feet upstream from the centerline of post 14
Dynamic Deflection	40.1 inches toward field side at the rail between posts 13 and 14
Working Width [a] and Height	49.5 inches, at a height of 51.2 inches at the right 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.

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Figure 10.6. 30:1 Flared MGS at Impact Location after Test 620851-01-5.



Figure 10.7. 30:1 Flared MGS at the Joint Between Posts 12 and 13 after Test 620851-01-5.

10.6. DAMAGE TO TEST VEHICLE

Figure 10.8 and Figure 10.9 show the damage sustained by the vehicle. Figure 10.10 and Figure 10.11 show the interior of the test vehicle. Table 10.8 and Table 10.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figure J.2 and Figure J.3 in Appendix J.1 provide exterior crush and occupant compartment measurements.



Figure 10.8. Impact Side of Test Vehicle after Test 620851-01-5.



Figure 10.9. Rear Impact Side of Test Vehicle after Test 620851-01-5.



Figure 10.10. Overall Interior of Test Vehicle after Test 620851-01-5.



Figure 10.11. Interior of Test Vehicle on Impact Side after Test 620851-01-5.

Table 10.8. Occupant Compartment Deformation 620851-01-5.

Test Parameter	Specification (inches)	Measured (inches)
Roof	≤4.0	0.0
Windshield	≤3.0	0.0
A and B Pillars	≤5.0 overall/≤3.0 lateral	0.0
Foot Well/Toe Pan	≤9.0	0.5
Floor Pan/Transmission Tunnel	≤12.0	0.5
Side Front Panel	≤12.0	1.0
Front Door (above Seat)	≤9.0	0.3
Front Door (below Seat)	≤12.0	0.0

Table 10.9. Exterior Vehicle Damage 620851-01-5.

Test Parameter	Details
Side Windows	The side windows remained intact.
Maximum Exterior Deformation	24 inches in the right front corner at bumper height
VDS	01RFQ4
CDC	01FREW2
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front grill, right headlight, radiator and support, right front upper and lower control arms, and tie rod fractured. The front bumper, right front quarter panel, right front and rear doors, rear quarter panel, and rear bumper were deformed. The right front wheel deformed, and the tire released from the vehicle. The front right spring also released from the vehicle. Due to the deformation of the front right door, there was a 2-inch gap between the top of the door and the body of the vehicle.

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10.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 10.10. Figure J.7 in Appendix J.3 shows the vehicle angular displacements, and Figure J.8 through Figure J.10 in Appendix J.4 show acceleration versus time traces.

Table 10.10. Occupant Risk Factors for Test 620851-01-5.

Test Parameter	Specification [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *≤30.0*	17.6	0.1532 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *≤30.0*	15.7	0.1532 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *≤15.0*	6.8	0.3116 - 0.3216 seconds
Ridedown, Lateral (g)	≤20.49 *≤15.0*	8.0	0.2541 - 0.2641 seconds
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	6.8	0.1468 seconds on right side of interior
Acceleration Severity Index	N/A	0.8	0.2501 - 0.3001 seconds
50-ms Moving Avg. Accelerations (MA) Longitudinal (g)	N/A	-4.9	0.1072 - 0.1572 seconds
50-ms MA Lateral (g)	N/A	-6.7	0.2230 - 0.2730 seconds
50-ms MA Vertical (g)	N/A	-2.3	0.7570 - 0.8070 seconds
Roll (°)	≤75	7.2	0.7863 seconds
Pitch (°)	≤75	4.5	1.4622 seconds
Yaw (°)	N/A	35.3	0.7655 seconds

[a.] *Values in italics are the preferred MASH values*

Note: N/A = Not Applicable

10.8. TEST SUMMARY

Figure 10.12 summarizes the results of *MASH* Test 620851-01-5.

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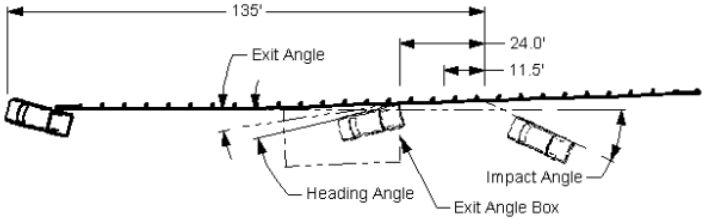
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GENERAL INFORMATION	
Test Agency:	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.:	*MASH* 2016, Test 3-11
Project No.:	620851-01-5
Test Date:	2026-05-06
TEST ARTICLE	
Type:	Longitudinal Barrier
Name:	30:1 Flared MGS
Length:	181 ft 3 inches
Key Materials:	
Soil Type and Condition:	Type D grade 1 crushed concrete roadbase, damp
TEST VEHICLE	
Type/Designation:	2270P
Year, Make and Model:	2021 RAM 1500
Inertial Mass:	5046 lb
Dummy Mass:	N/A lb
Gross Static Mass:	5046 lb
IMPACT CONDITIONS	
Impact Speed:	62.1 mi/h
Impact Angle:	24.9°
Impact Location:	138 inches [11.5 feet] upstream from the centerline of the joint between posts 12 and 13
Impact Severity:	115.3 kip-ft
EXIT CONDITIONS	
Exit Speed:	28.9mi/h
Trajectory/Heading Angle:	13.5° / 8.7°
Exit Box Criteria:	The vehicle met the exit box criteria
Stopping Distance:	135 ft downstream In-line

TEST ARTICLE DEFLECTIONS	
Dynamic:	40.1 inches
Permanent:	25.8 inches
Working Width:	49.5 inches
Working Width Height:	51.2 inches
VEHICLE DAMAGE	
VDS:	01RFQ4
CDC:	01FREW2
Max Exterior Deformation:	24 inches in the right front corner at bumper height
Max Occupant Compartment Deformation:	1 inches in the side front panel
OCCUPANT RISK VALUES	
Longitudinal OIV:	17.6 ft/s
Lateral OIV:	15.7 ft/s
Longitudinal Ridedown:	6.8 g
Lateral Ridedown:	8.0 g
THIV:	6.8 m/s
ASI:	0.8
Max 50ms Longitudinal:	-4.9 g
Max 50ms Lateral:	-6.7 g
Max 50ms Vertical:	-2.3 g
Max Roll:	7.2°
Max Pitch:	4.5°
Max Yaw:	35.3°



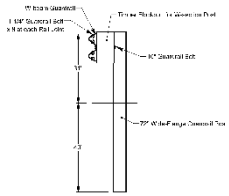


Figure 10.12. Summary of Results for *MASH* Test 3-11 on 30:1 Flared MGS.

DRAFT

CHAPTER 11.

SUMMARY AND CONCLUSIONS

The objective of this research study was to identify the critical flare rate for application to the MGS. This research attempted to determine the steepest flare rate that could be safely used on standard non-modified installations of MGS.

Phase I (Report No. 609971-01) *(1)* of the research involved three-full scale crash tests on 7:1 and 11:1 flared MGS configurations. The flare rates were selected according to AASHTO RDG (*3*) Table 5-9 (see Table 1.1 of this report). The first test, conducted with a *MASH* 1100C small car on the 7:1 flared MGS, failed to meet *MASH* criteria due to rail rupture. The second test, conducted with a MASH 2270P pickup truck on the 11:1 flared MGS, failed to meet MASH criteria due to anchorage failure. The third test, conducted with a MASH 2270P pickup truck on the 11:1 flared MGS with a proprietary MASH end terminal replacing the generic wood anchor, failed due to rail rupture.

Following the failed crash tests, a Phase 2 flared MGS project was implemented by the pooled fund. A baseline computer simulation model of the flared MGS was developed and validated against the observed failure modes from the tests conducted under the previous phase (Report No. 609971-01) *(1)* . The validated model was used to evaluate the performance of the MGS at 18:1 and 21:1 flare rates using the 2018 Dodge Ram and the 2010 Toyota Yaris vehicle models. The performance of the MGS at these flare rates were assessed by examining rail deflection profiles since a reliable rail failure model was not available and therefore not included in the FE analysis. In addition, the flare rates were further assessed by examining rail deflections immediately before vehicle redirection for vehicle pocketing potential. Based on the simulation results, the 21:1 flare rate was selected as the critical flare rate to undergo full-scale crash testing, as it exhibited improved rail deflection, reduced pocketing potential, and enhanced vehicle stability compared to the failed flared MGS systems and the simulated 18:1 flared MGS.

The crash tests reported herein were performed in accordance with *MASH* TL-3 on the 21:1 Flared MGS, 25:1 Flared MGS, 38:1 Flared MGS, and 30:1 Flared MGS. The tests on the 38:1 and 30:1 Flared MGS were subsequently performed because the 21:1 flared MGS and 25:1 flared MGS failed to meet MASH Test 3-11 criteria.

Table 11.1 shows that the 3-10 tests on the 21:1 Flared MGS met the performance criteria for *MASH* TL-3 Longitudinal Barriers. The 3-11 tests on the 21:1 Flared MGS and the 25:1 Flared MGS did not meet the performance criteria for *MASH* TL-3 Longitudinal Barriers. The 3-11 tests on the 38:1 and 30:1 Flared MGS met the performance criteria for *MASH* TL-3 Longitudinal Barriers.

Since rail rupture was the main reason for test failures on the 21:1 and 25:1 Flared MGS, a material test was conducted on the ruptured rail component to ensure the steel

rails met all minimum strength requirements. Based on the test results, the material properties of the W-beam met the required specifications of the rail. The test specimens and results are provided in Figure E.1and Figure E.2.

Table 11.1. Assessment Summary for *MASH* TL-3 Tests on 21:1, 25:1, 38:1, and 30:1 Flared MGS.

Evaluation Criteria	**Description**	**Test 620851-01-1** *(MASH* Test 3-10) 21:1 Flared MGS	**Test 620851-01-2** *(MASH* Test 3-11) 21:1 Flared MGS	**Test 620851-01-3** *(MASH* Test 3-11) 25:1 Flared MGS	**Test 620851-01-4** *(MASH* Test 3-11) 38:1 Flared MGS	**Test 620851-01-5** *(MASH* Test 3-11) 30:1 Flared MGS
A	Contain, Redirect, or Controlled Stop	S	**FAIL**	**FAIL**	S	S
D	No Penetration into Occupant Compartment	S	S	S	S	S
F	Roll and Pitch Limit	S	S	**FAIL**	S	S
H	OIV Threshold	S	S	S	S	S
I	Ridedown Threshold	S	S	S	S	S
Overall	Evaluation	Pass	**Fail**	**Fail**	Pass	Pass

Note: S = Satisfactory; N/A = Not Applicable.
[1] See Table 4.2 for details

Tests on the 21:1 and 25:1 flared MGS configurations under TL-3 conditions did not meet *MASH* evaluation criteria. Therefore, future research could include evaluating alternative flared MGS configurations. These alternatives may involve adopting flare rates shallower than 25:1 without design modifications to the MGS, or retrofitting/modifying the MGS at flare rates of 14:1 or flatter. MGS configurations without design modifications would not require additional FE simulations prior to MASH crash testing, as simulation performance is at a threshold where the exact nature of MGS system failure or success is unlikely to be reliably replicated by simulation. Unmodified MGS systems with flare rates between 25:1 and 30:1 need to be further evaluated through full-scale crash testing with a pickup truck (2270P) to ensure MASH compliance and barrier system crashworthiness. A

full-scale test with a small car (1100C) is not necessary, given that Test 3-10 has already passed at a steeper flare rate of 21:1. For retrofitted/modified MGS systems at 14:1 or flatter flare rates, an FE analysis will be required to evaluate different design modification options to identify the most efficient and robust configuration accommodating the steepest flare rates prior to conducting full-scale testing. The Testing and Evaluation of Flared MGS System at MASH Test Level 3 Conditions project (Report No. 609971-01) *(1)* has further discussion and computer simulations of possible modifications to the MGS system at flare rates of 14:1.

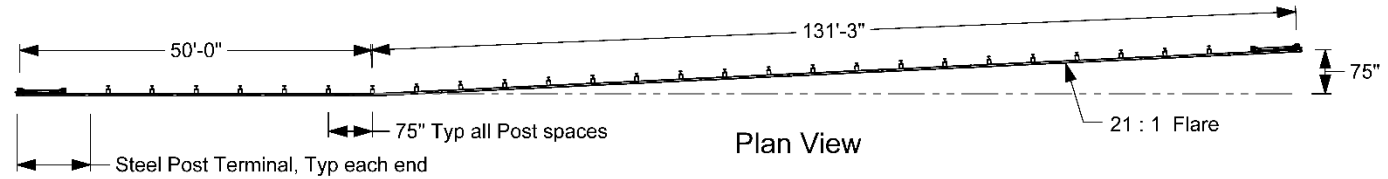
REFERENCES

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2. American Association of State Highway and Transportation Officials (AASHTO). *Manual for Assessing Safety Hardware,* Second Edition, American Association of State Highway and Transportation Officials, Washington, DC, 2016.
3. American Association of State Highway and Transportation Officials (AASHTO). Roadside Design Guide. Washington, D.C. American Association of State Highway and Transportation Officials, 2011.
4. Livermore Software Technology Corporation. *LS-DYNA keyword user's manual (Version R15)*. Livermore, CA: LSTC. 2024.
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6. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, R.W. and Reid, J.D. *Performance Evaluation of the Midwest Guardrail System–Update to NCHRP 350 Test No. 3-11 with 28" CG Height (*2214MG-2), 2006.
7. Center for Collision Safety & Analysis. *2018 Dodge Ram 1500 FE Detailed Mesh Model v3 Validation.* George Mason University, 2022. https://www.ccsa.gmu.edu/wp-content/uploads/2022/05/2018-dodge-ram-detailed-validation-v3.pdf
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9. Midwest Roadside Safety Facility, University of Nebraska–Lincoln. MwRSF Research Update. Task Force 13 – Spring Meeting, April 18, 2025. Retrieved from https://tf13.org/wp-content/uploads/2025/09/TF13-MwRSF-Research-Update-R3.pdf

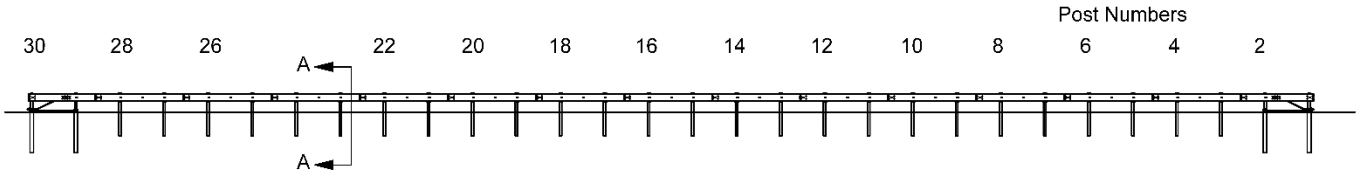
APPENDIX A.

DETAILS OF 21:1 FLARED MGS

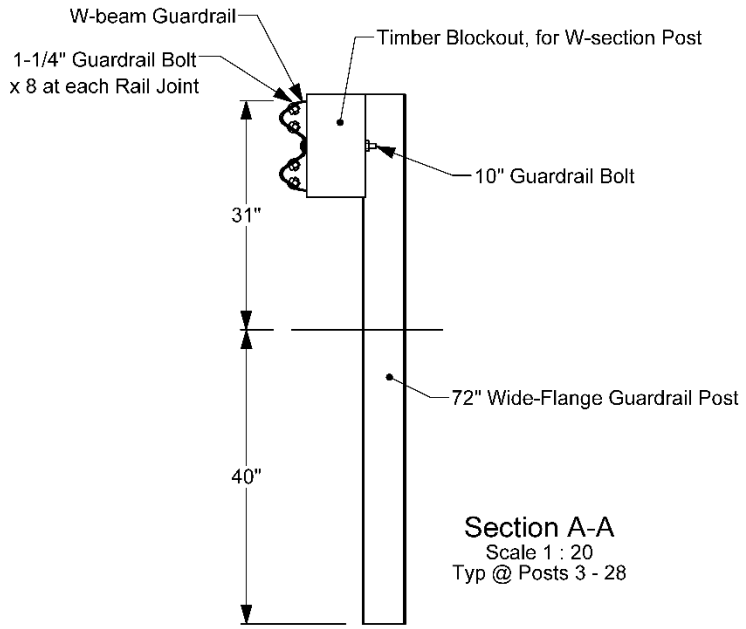
Test Installation



Plan View



Elevation View



Section A-A
Scale 1 : 20
Typ @ Posts 3 - 28

1a. Drill Ø24" post holes and backfill with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C002.

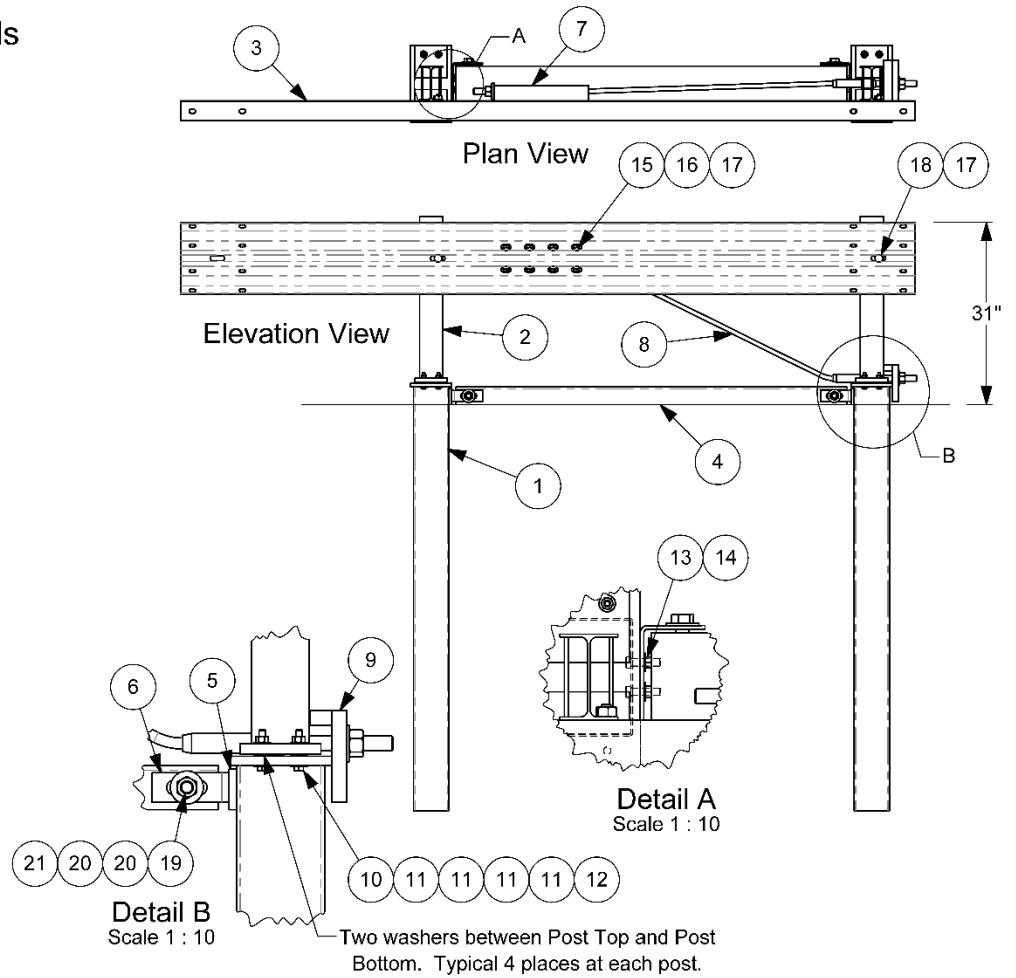
1b. Recessed Guardrail Nut on all Guardrail Bolts.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project #620851 Flared W-beam Guardrail			2024-10-01
Drawn by GES	Scale 1:250	Sheet 1 of 1 Test Installation	

S:\Accreditation-17025-2017\EIR-000 Project Files\620851 - Flared W-beam Guardrail - Park\Drafting, 620851\620851 Drawing

Steel Post Terminal Details

#	Part Name	QTY.
1	Post Bottom	2
2	Post Top	2
3	9'-4-1/2" 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



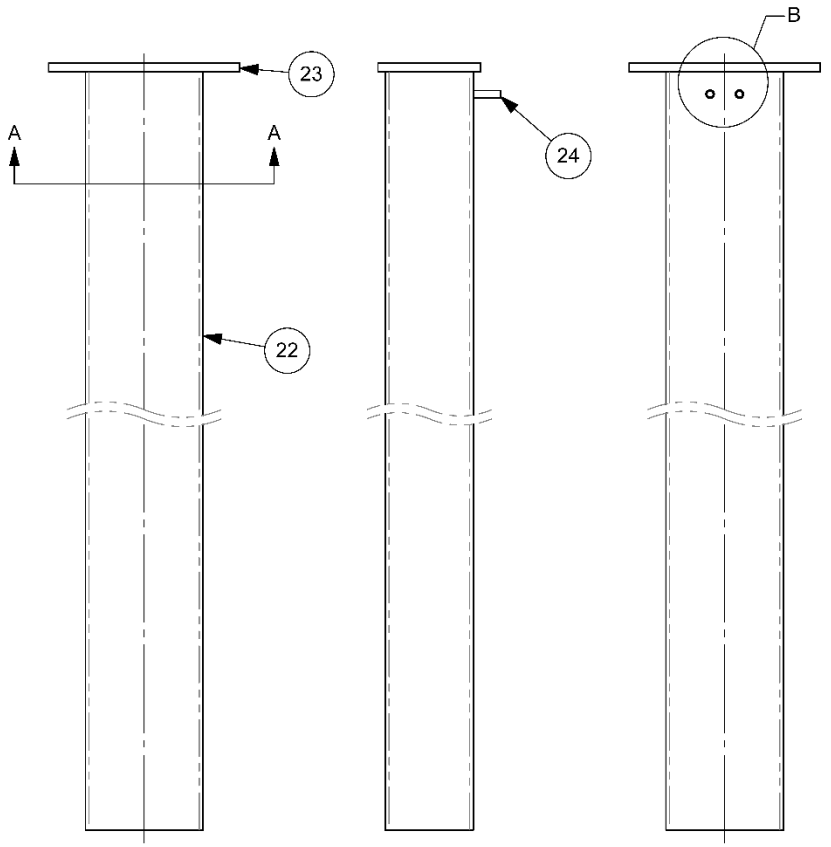
1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.

1b. All steel parts shall be galvanized.

1c. This specific terminal configuration has not been tested. It is used as a barrier anchorage device for crash testing purposes.

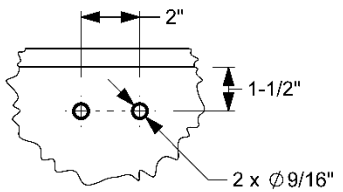
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2023-02-08
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details

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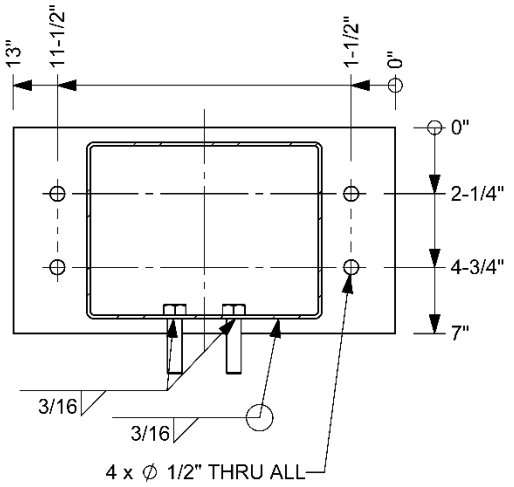


Elevation Views

Post Bottom



Detail B
Scale 1 : 5

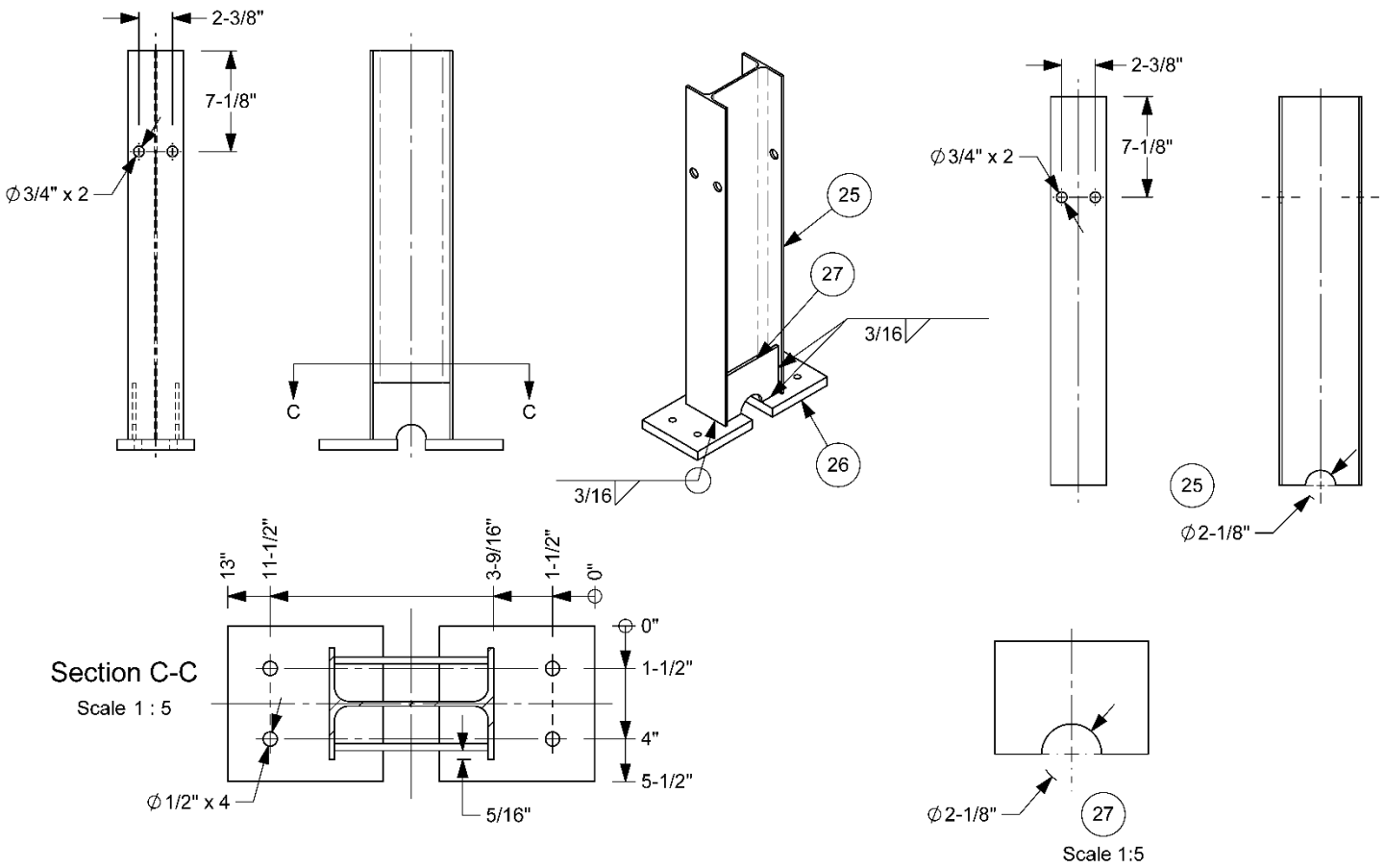


Section A-A
Scale 1 : 5

#	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		2023-02-08
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom

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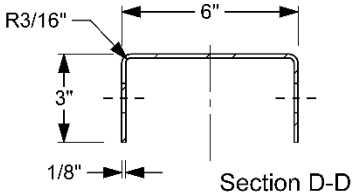


#	Description	Length	Material	Qty
25	W6x8.5	27 1/2"	ASTM A992	1
26	Plate, 5 1/2" x 3/4"	5 1/2"	ASTM A36	2
27	Plate, 5 7/16" x 1/4"	4"	ASTM A36	2

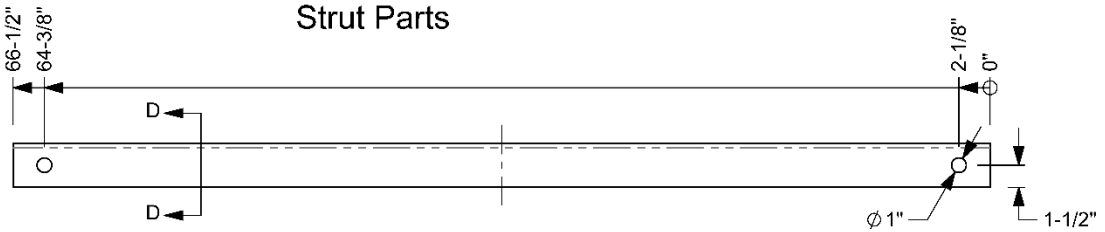
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
	Project # Terminal		2023-02-08
Drawn by GES	Scale 1:10	Sheet 3 of 6 Post Top	

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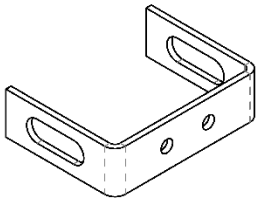
Strut Parts

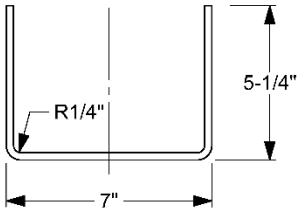


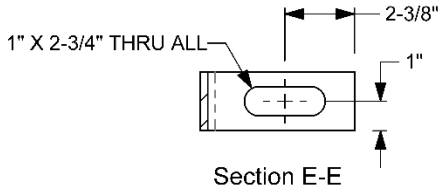
Section D-D
Scale 1 : 5



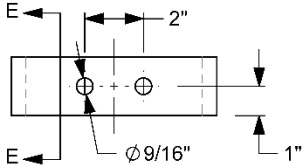
Strut
10 gauge
ASTM A36



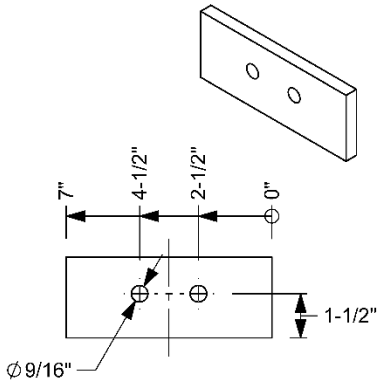




Section E-E
Scale 1 : 5



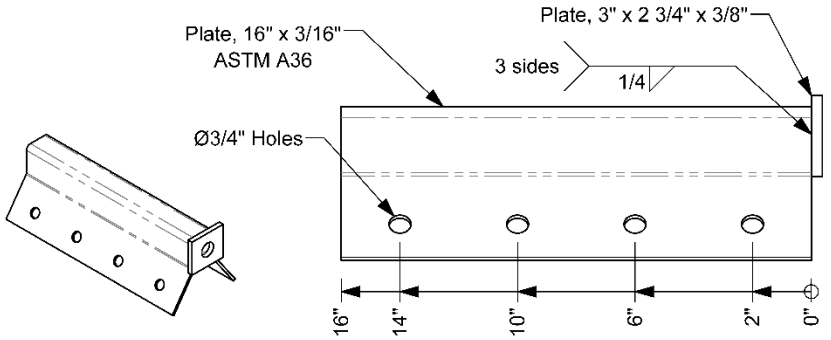
Strut Bracket
Plate, 2" x 1/4"
ASTM A36 - Scale 1:5

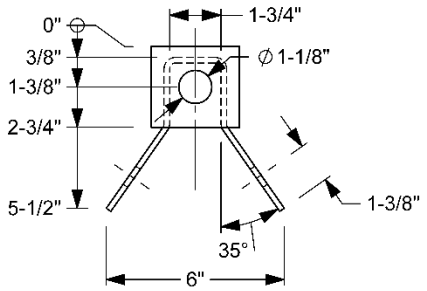


Strut Spacer
Plate, 2 3/4" x 1/2"
ASTM A36 - Scale 1:5

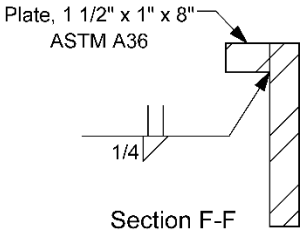
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
	Project # Terminal		2023-02-08
Drawn by GES	Scale 1:10	Sheet 4 of 6 Strut Parts	

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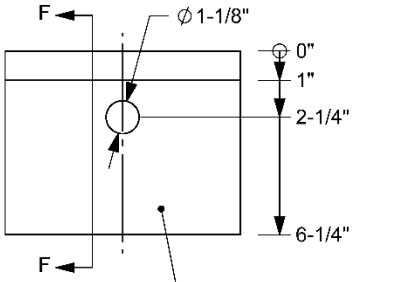




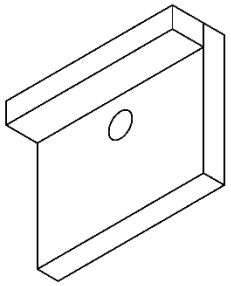
Guardrail Anchor Bracket



Section F-F

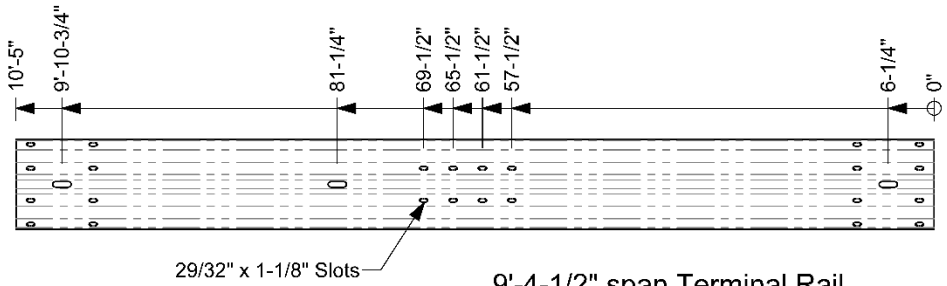


Bearing Plate



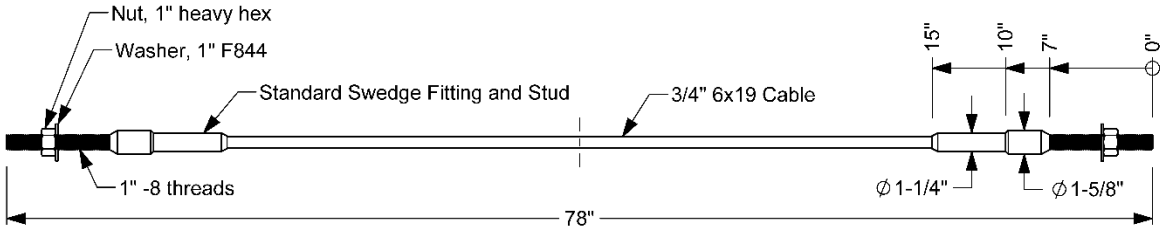
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
	Project # Terminal		2023-02-08
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A	

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9'-4-1/2" 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			2023-02-08
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B	

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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

All dimensions except hole diameter are nominal

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		2022-12-16
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

W6x8.5

Elevation View

Section A-A

Scale 1 : 3

Isometric View

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
72" Wide-Flange Guardrail Post for W-beam		2023-12-04
Drawn by GES	Scale 1:10	Sheet 1 of 1

S:\Accreditation-17025-2017\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

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.

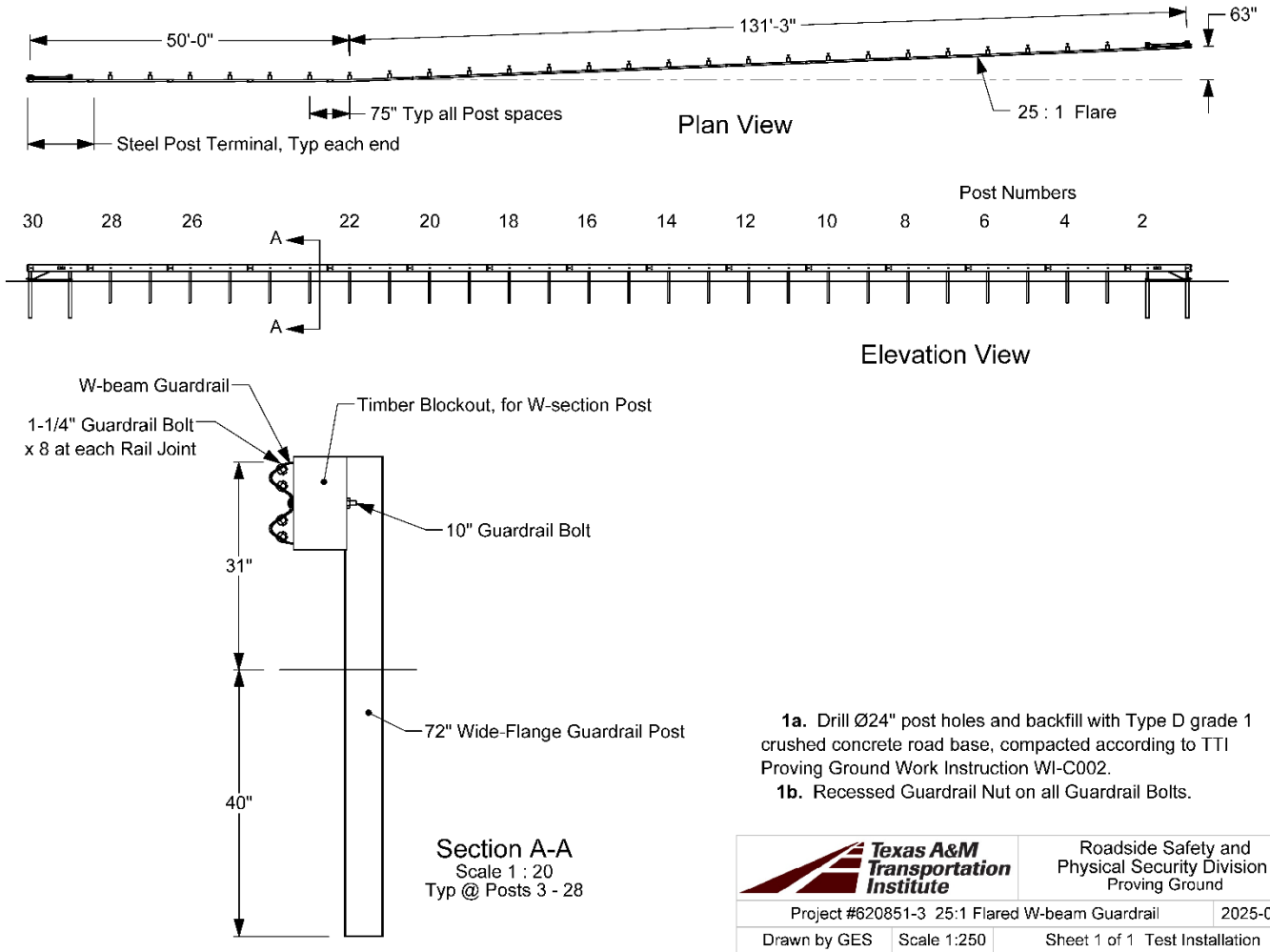
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground
Guardrail Bolt	2020-07-08
Drawn by GES/WS	Scale 1:2	Sheet 1 of 1

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

APPENDIX B.

DETAILS OF 25:1 FLARED MGS

Test Installation



1a. Drill Ø24" post holes and backfill with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C002.

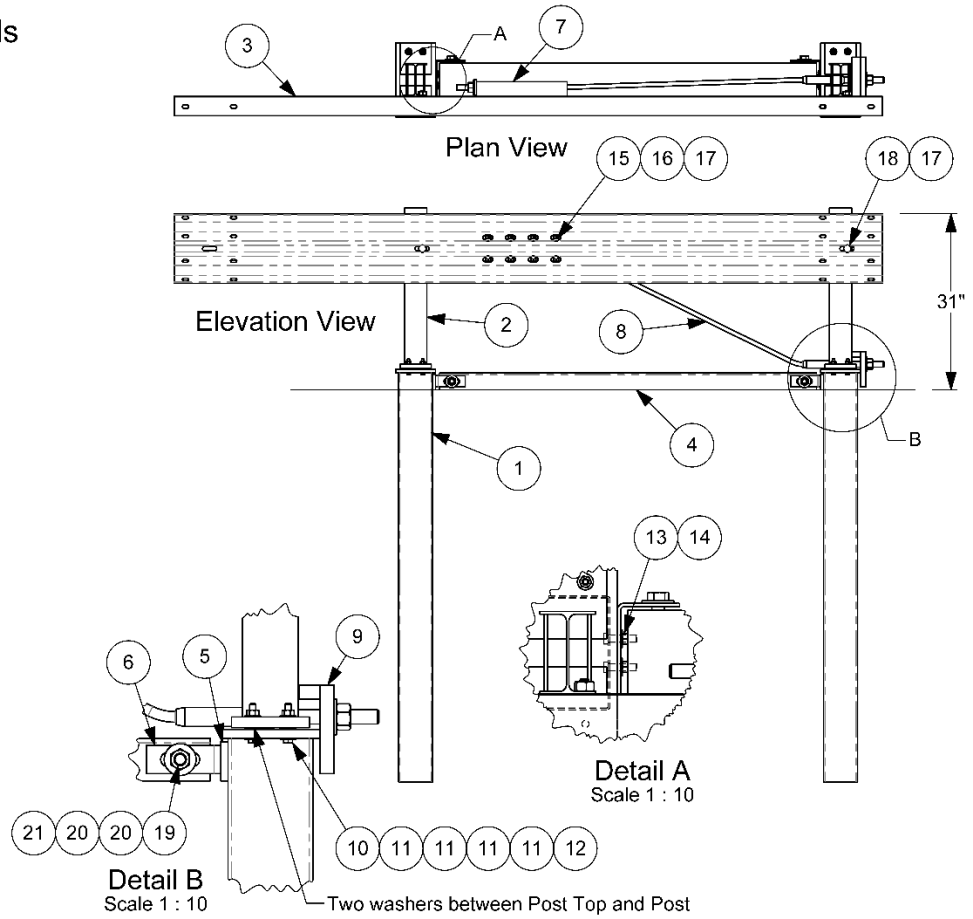
1b. Recessed Guardrail Nut on all Guardrail Bolts.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project #620851-3 25:1 Flared W-beam Guardrail			2025-03-26
Drawn by GES	Scale 1:250	Sheet 1 of 1 Test Installation	

S:\Accreditation-17025-2017\EIR-000 Project Files\620851 - Flared W-beam Guardrail - Park\Drafting, 620851 3-\620851-3 Drawing

Steel Post Terminal Details

#	Part Name	QTY.
1	Post Bottom	2
2	Post Top	2
3	9'-4-1/2" 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



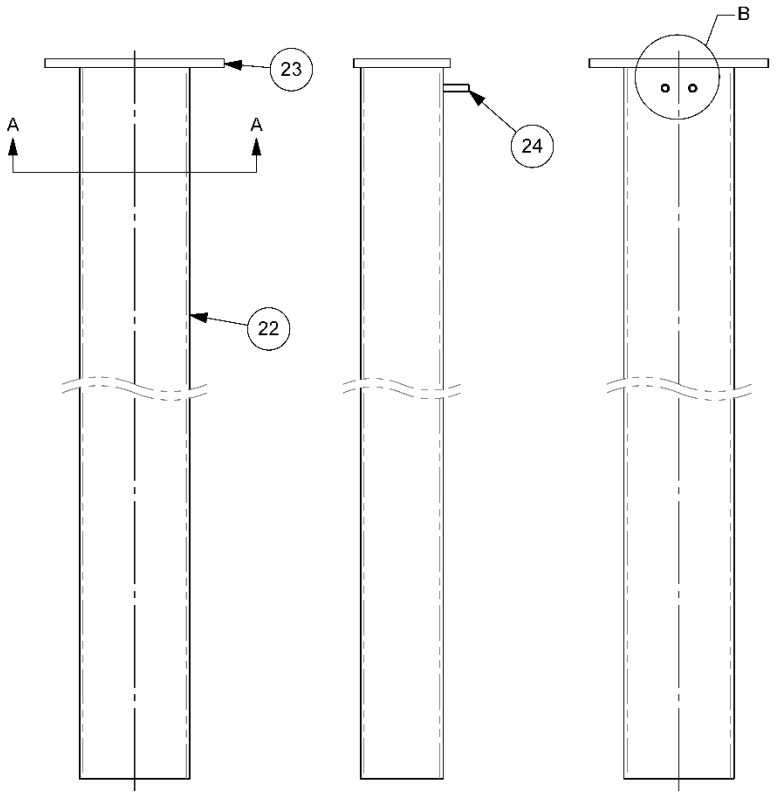
1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.

1b. All steel parts shall be galvanized.

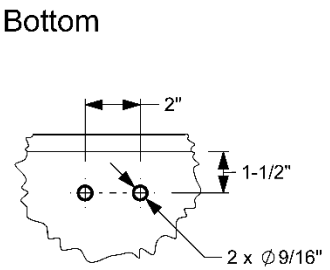
1c. This specific terminal configuration has not been tested. It is used as a barrier anchorage device for crash testing purposes.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2023-02-08
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details

S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal

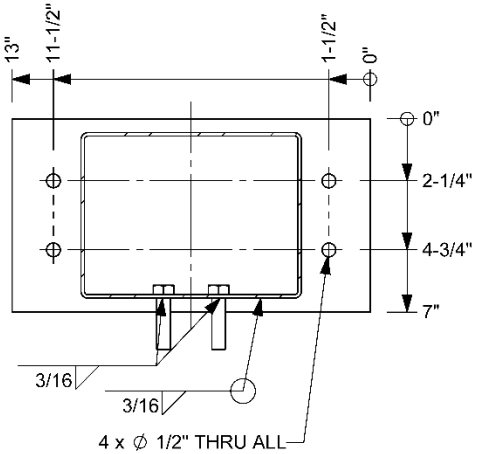


Elevation Views



Post Bottom

Detail B
Scale 1 : 5



Section A-A
Scale 1 : 5

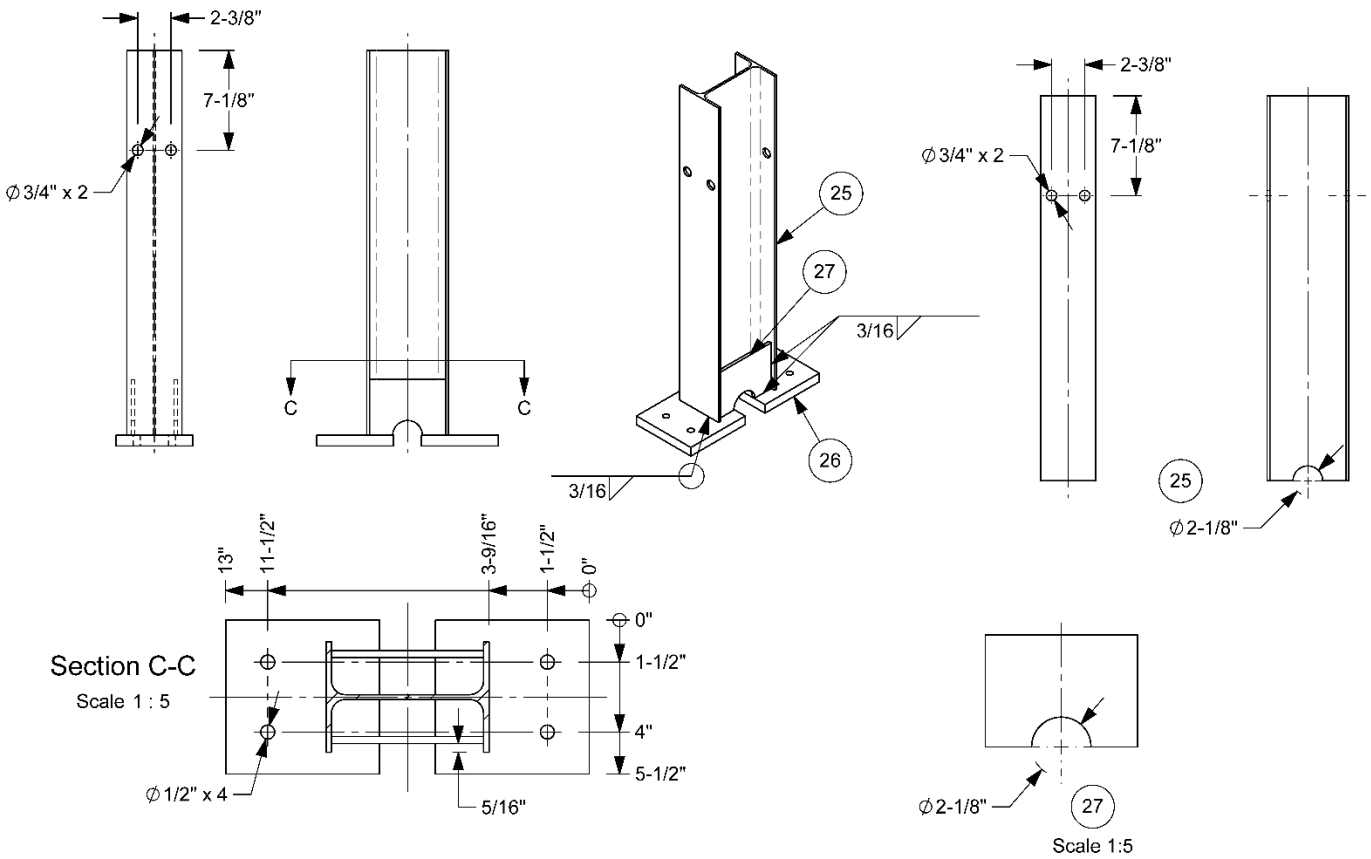
#	Description	Length	Material	Qty
22	HSS 8" x 6" x 1/8"	72"	ASTM A500 Grade B	1
23	Plate, 7" x 5/8"	13"	ASTM A36	1
24	Bolt, 1/2 x 2 hex		ASTM A307	2

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project # Terminal		2023-02-08
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom

S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



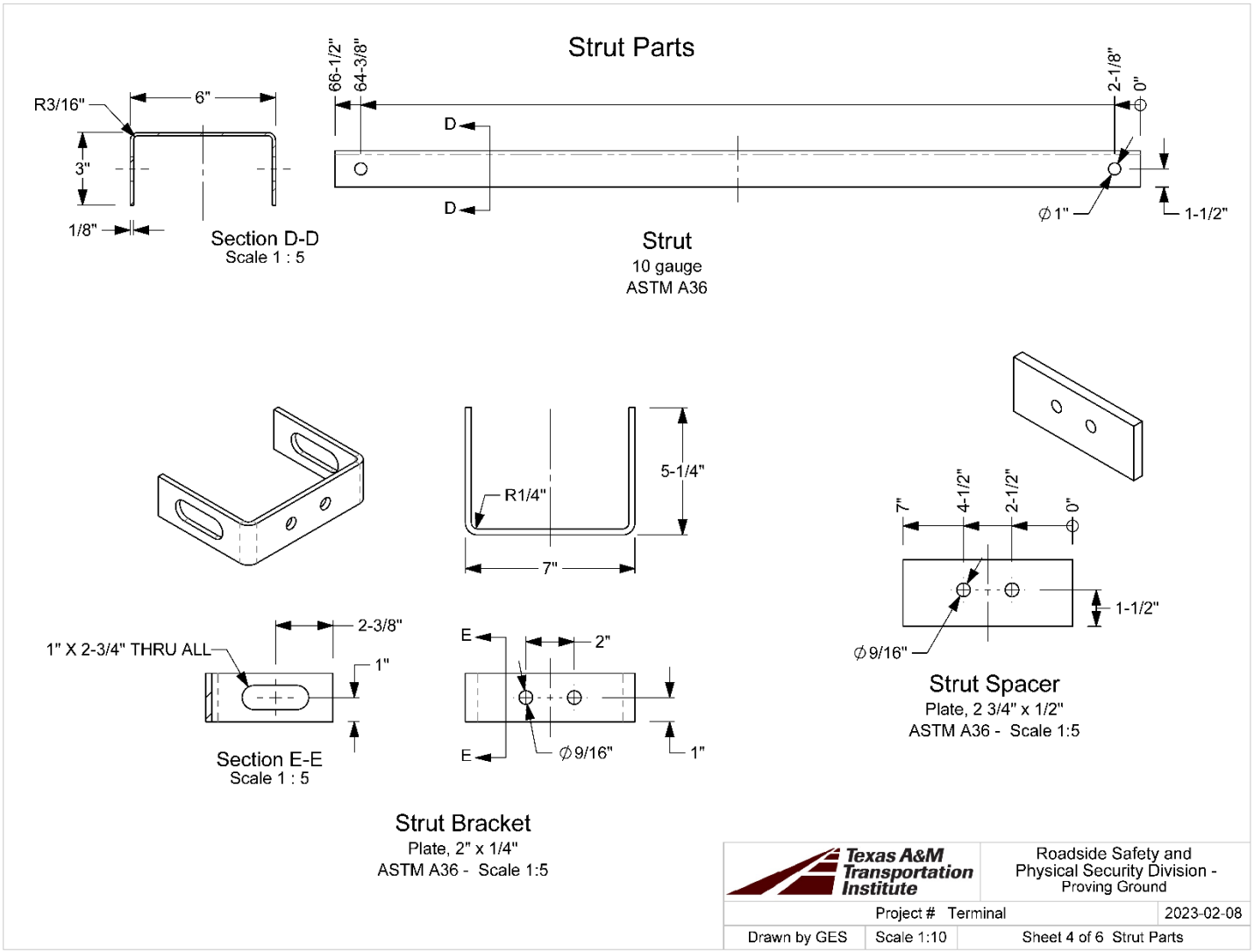
#	Description	Length	Material	Qty
25	W6x8.5	27 1/2"	ASTM A992	1
26	Plate, 5 1/2" x 3/4"	5 1/2"	ASTM A36	2
27	Plate, 5 7/16" x 1/4"	4"	ASTM A36	2

Texas A&M Transportation Institute

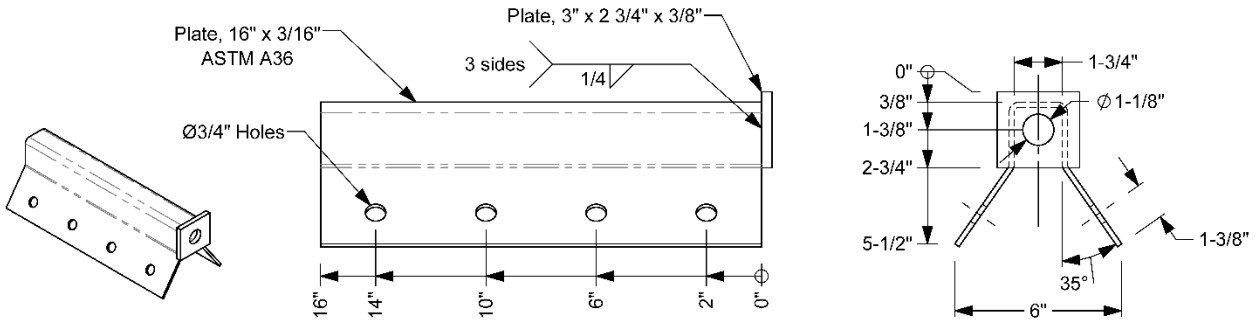
Roadside Safety and Physical Security Division - Proving Ground

Project # Terminal		2023-02-08
Drawn by GES	Scale 1:10	Sheet 3 of 6 Post Top

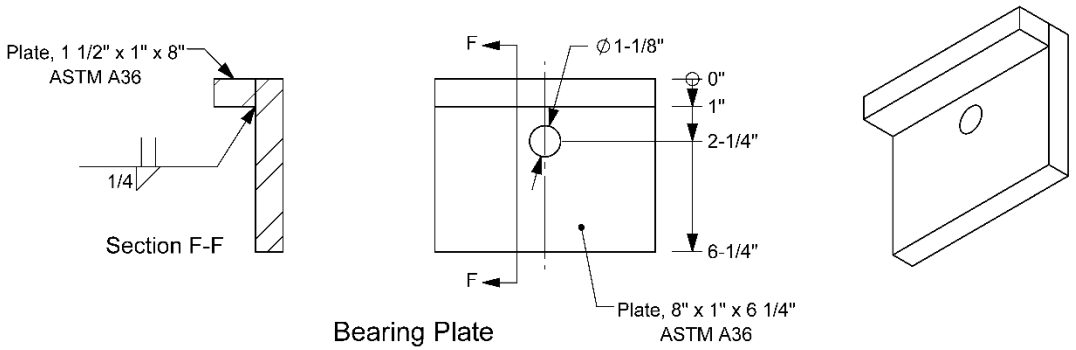
S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



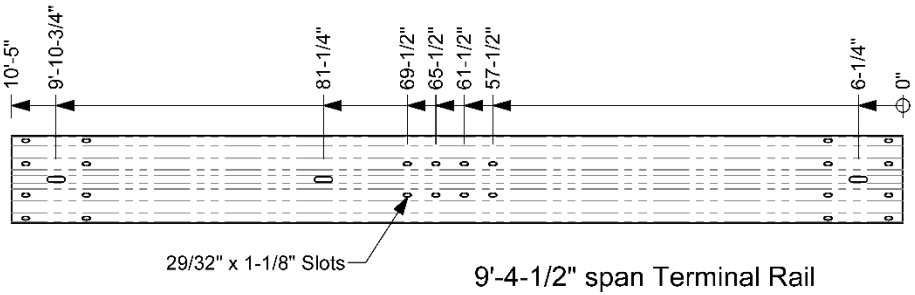
Guardrail Anchor Bracket



Bearing Plate

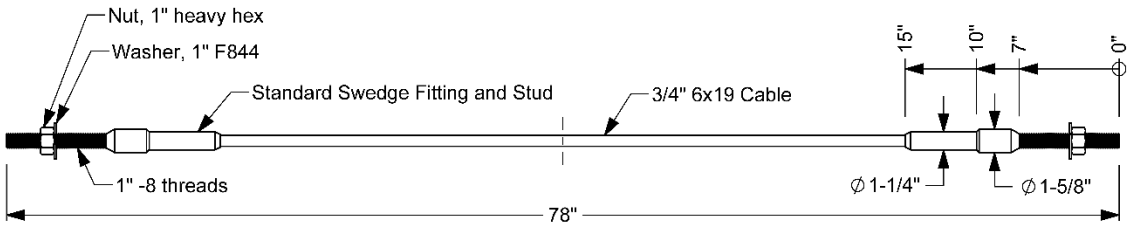
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2023-02-08
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A

S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



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

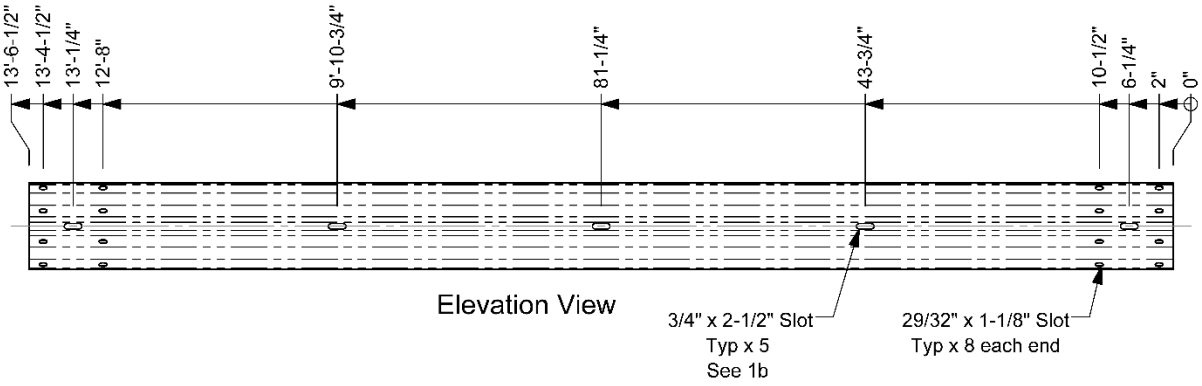
Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.



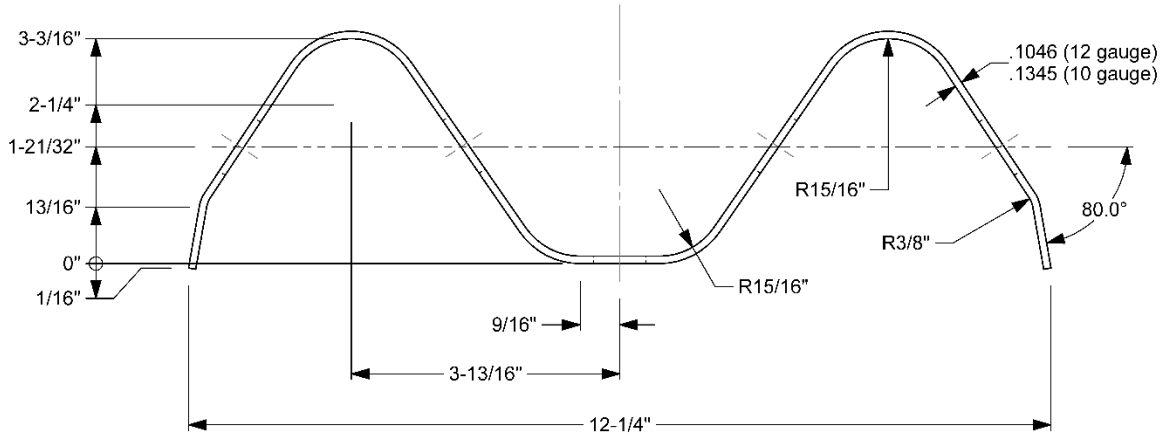
Anchor Cable Assembly

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
	Project # Terminal		2023-02-08
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B	

S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



Elevation View



Section View

1a. Manufacture per AASHTO M180 specifications.

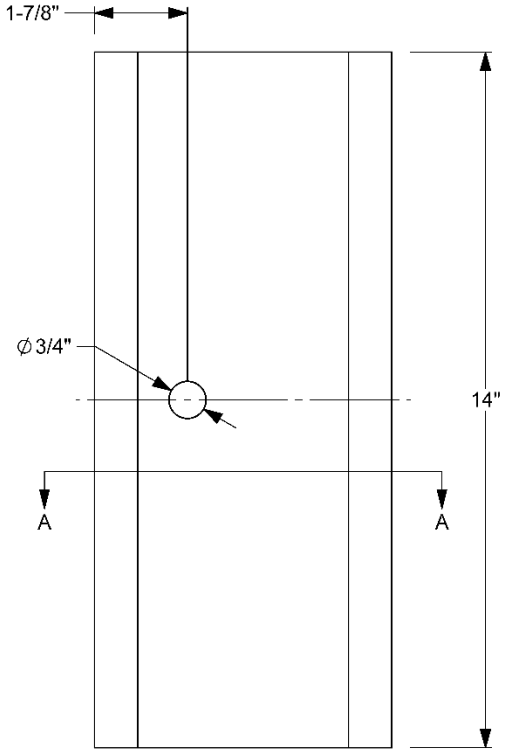
1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

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

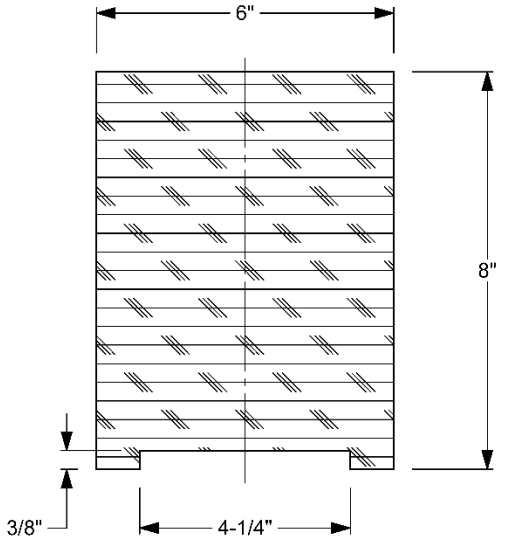
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-Beam Guardrail

Timber Blockout for W-section Post

All dimensions except hole diameter are nominal



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		2022-12-16
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

W6x8.5

Elevation View

Section A-A

Scale 1 : 3

Isometric View

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
72" Wide-Flange Guardrail Post for W-beam		2023-12-04
Drawn by GES	Scale 1:10	Sheet 1 of 1

S:\Accreditation-17025-2017\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

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

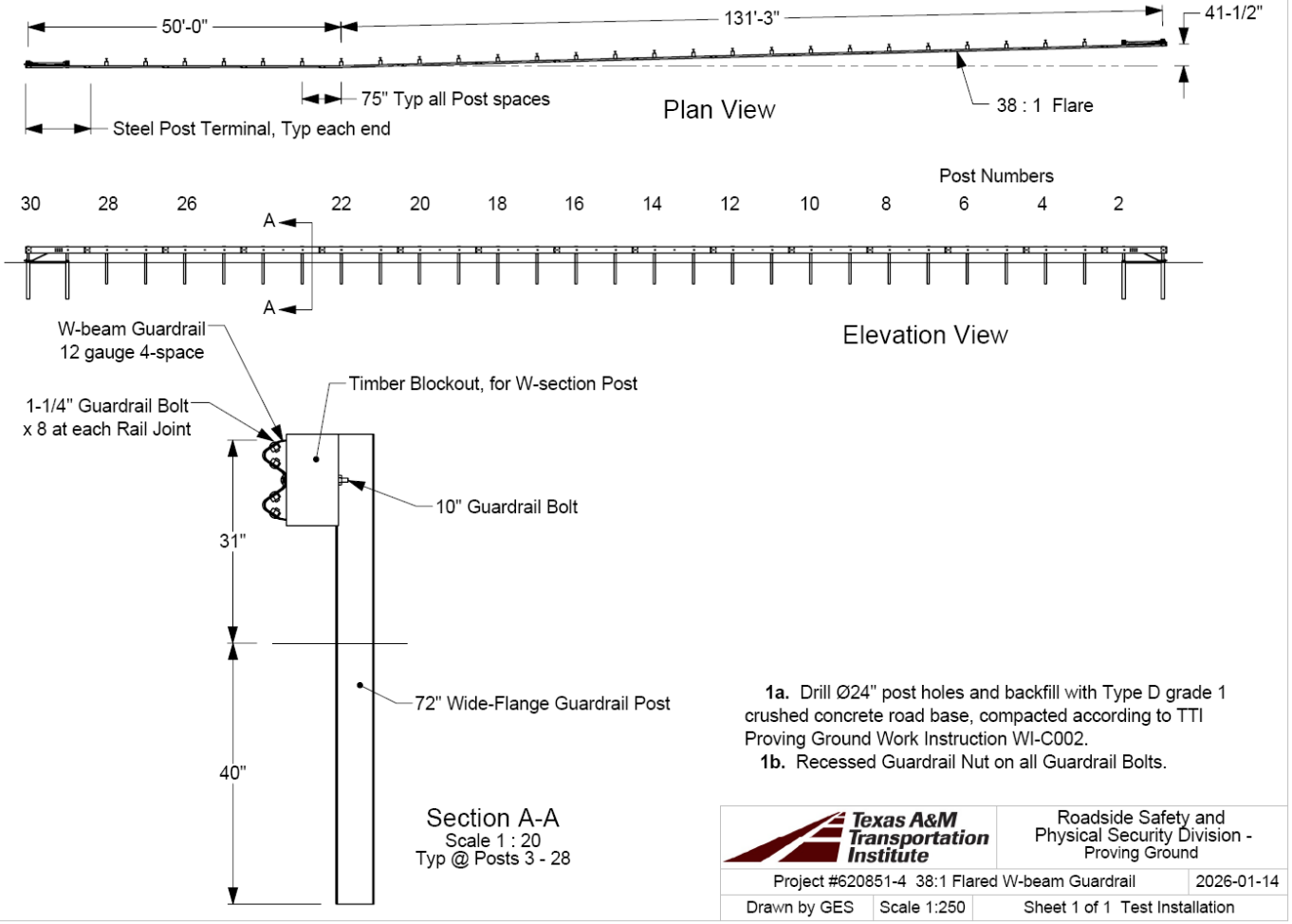
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Guardrail Bolt

APPENDIX C.

DETAILS OF 38:1 FLARED MGS

DRAFT

Test Installation



1a. Drill Ø24" post holes and backfill with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C002.

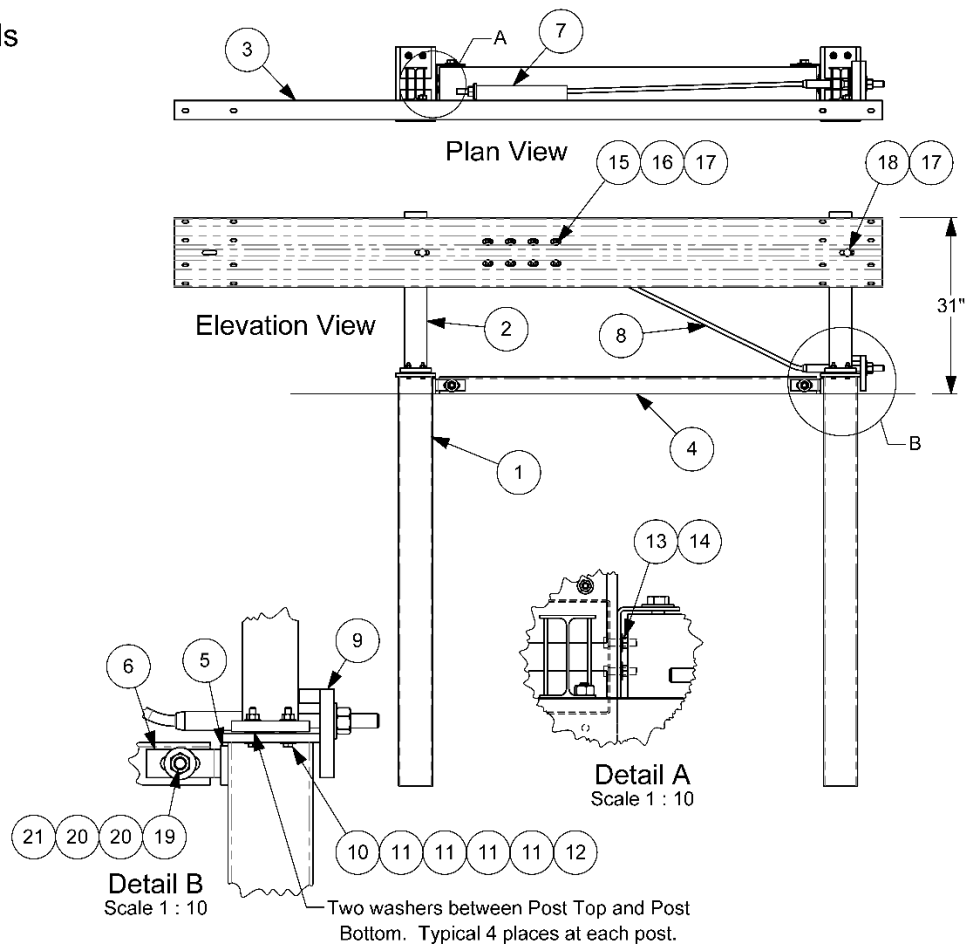
1b. Recessed Guardrail Nut on all Guardrail Bolts.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project #620851-4 38:1 Flared W-beam Guardrail			2026-01-14
Drawn by GES	Scale 1:250	Sheet 1 of 1 Test Installation	

S:\Accreditation-17025-2017\EIR-000 Project Files\620851 - Flared W-beam Guardrail - Park\-4 (3-11)\Drafting, 620851-4\620851-4 Drawing

Steel Post Terminal Details

#	Part Name	QTY.
1	Post Bottom	2
2	Post Top	2
3	9'-4-1/2" 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



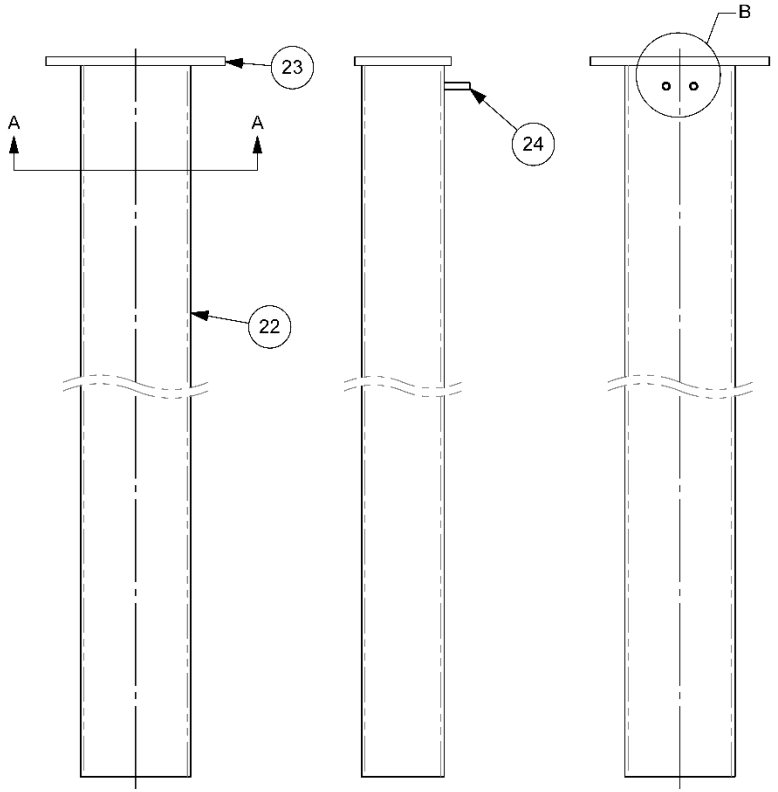
1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.

1b. All steel parts shall be galvanized.

1c. This specific terminal configuration has not been tested. It is used as a barrier anchorage device for crash testing purposes.

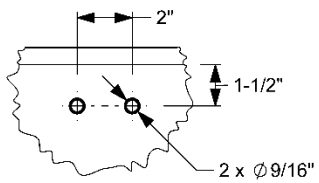
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2023-02-08
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details

S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal

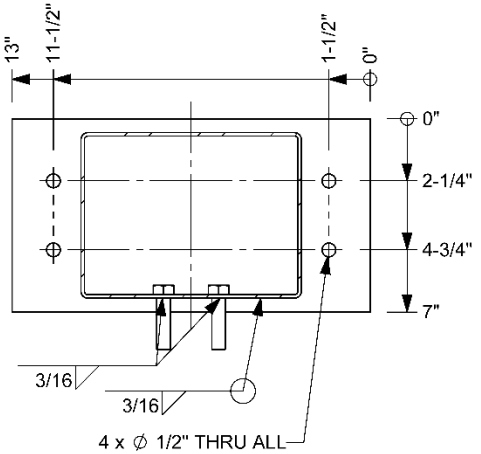


Elevation Views

Post Bottom



Detail B
Scale 1 : 5

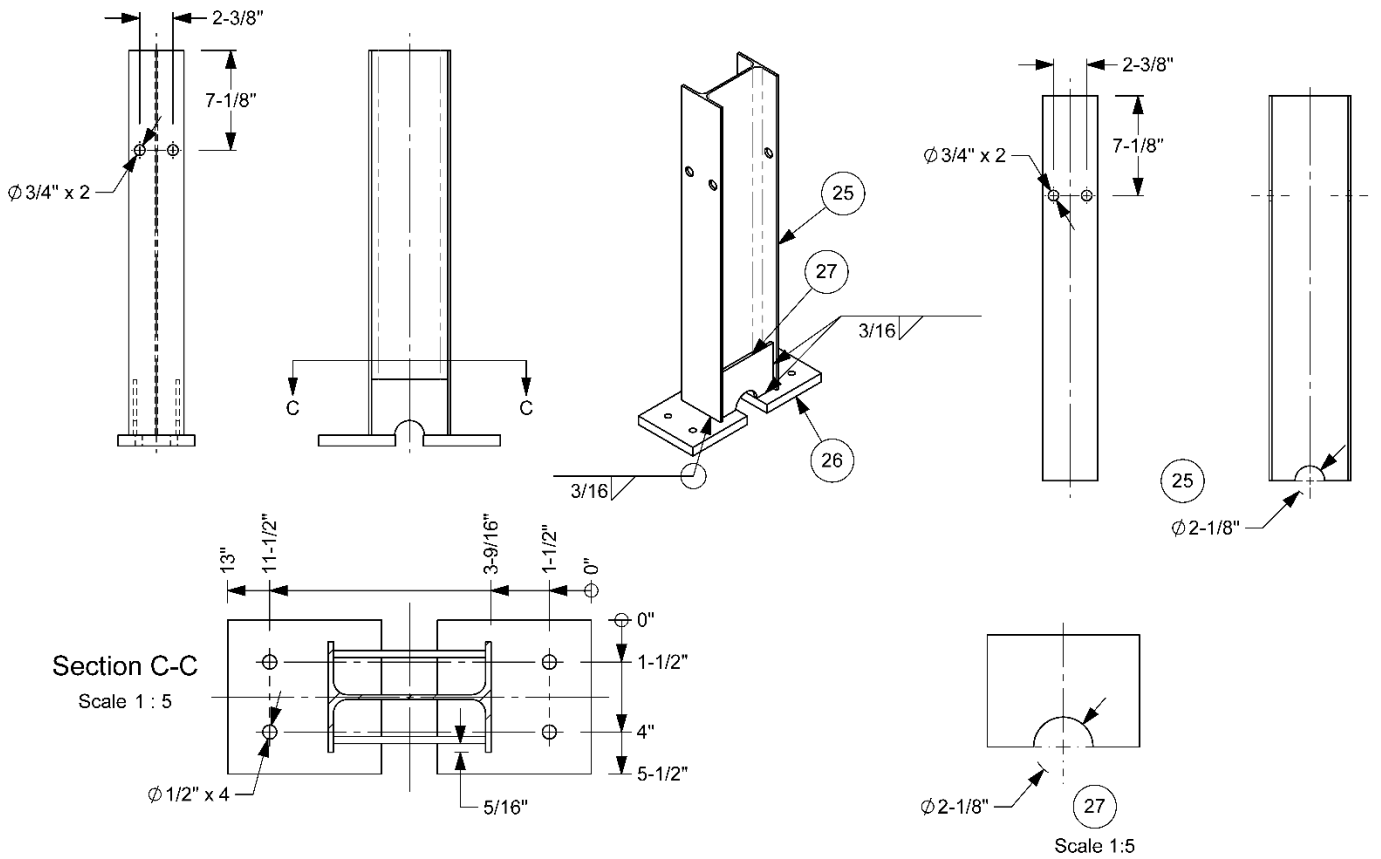


Section A-A
Scale 1 : 5

#	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		2023-02-08
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom	

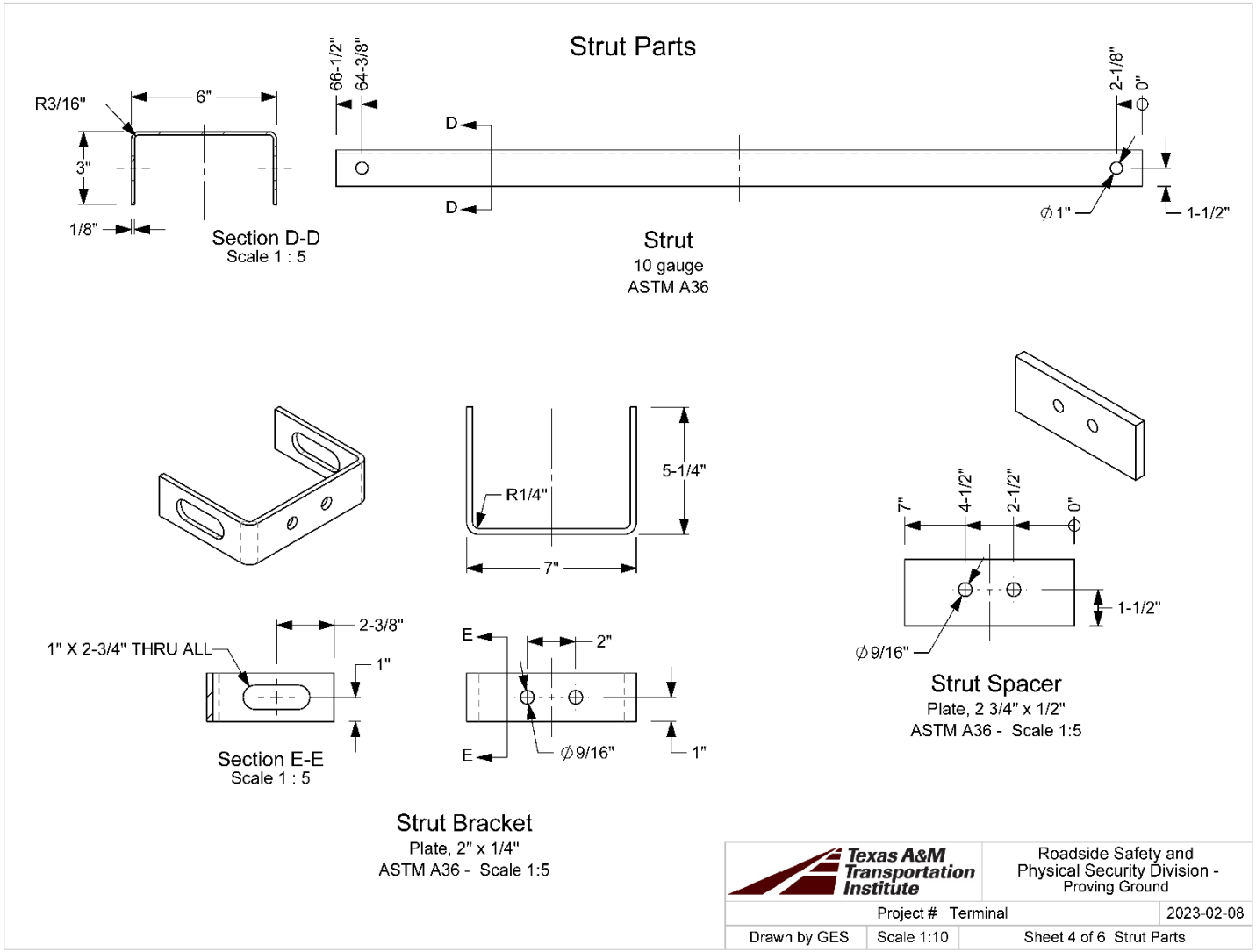
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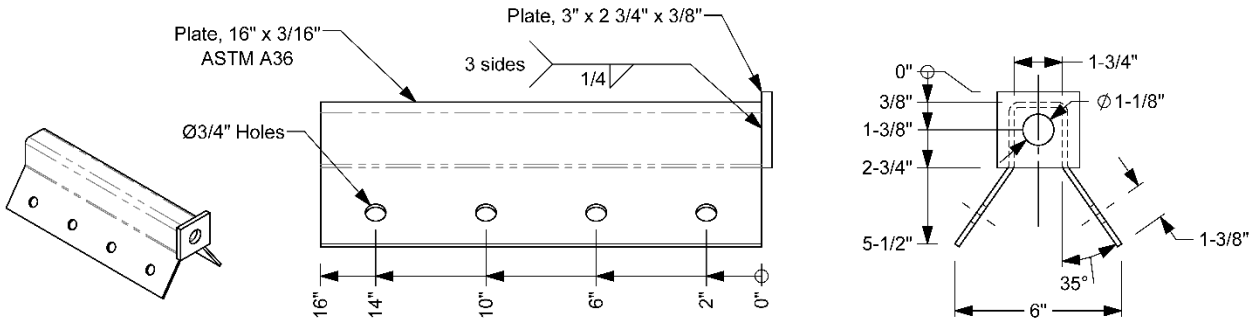
#	Description	Length	Material	Qty
25	W6x8.5	27 1/2"	ASTM A992	1
26	Plate, 5 1/2" x 3/4"	5 1/2"	ASTM A36	2
27	Plate, 5 7/16" x 1/4"	4"	ASTM A36	2

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
	Project # Terminal		2023-02-08
Drawn by GES	Scale 1:10	Sheet 3 of 6 Post Top	

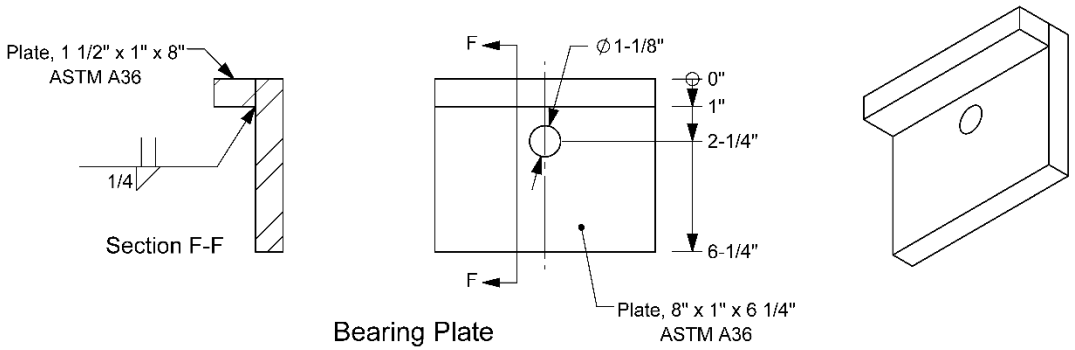
S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



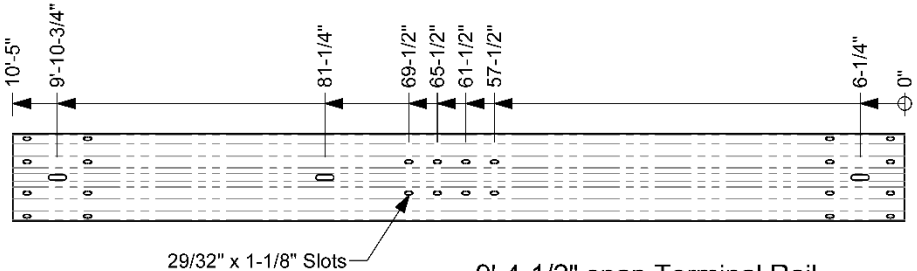
Guardrail Anchor Bracket



Bearing Plate

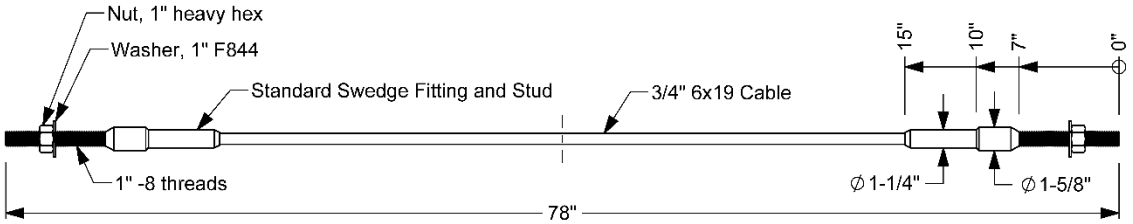
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal		2023-02-08
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A

S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



9'-4-1/2" 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		2023-02-08
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B	

S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal

Elevation View

Section View

1a. Manufacture per AASHTO M180 specifications.

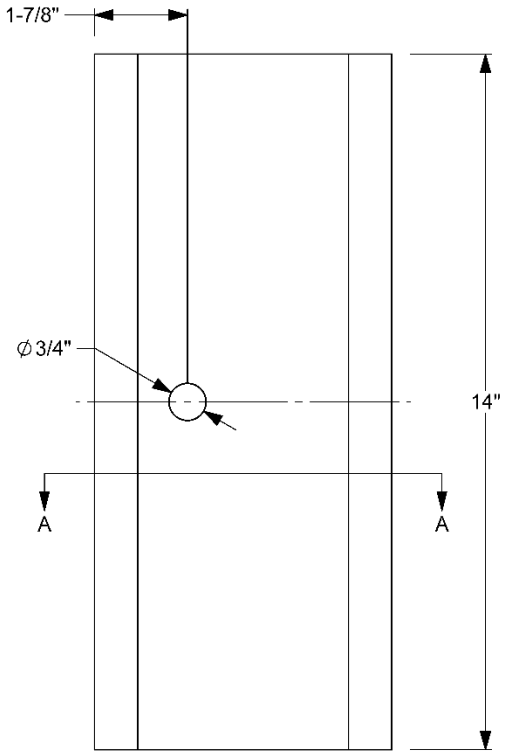
1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

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

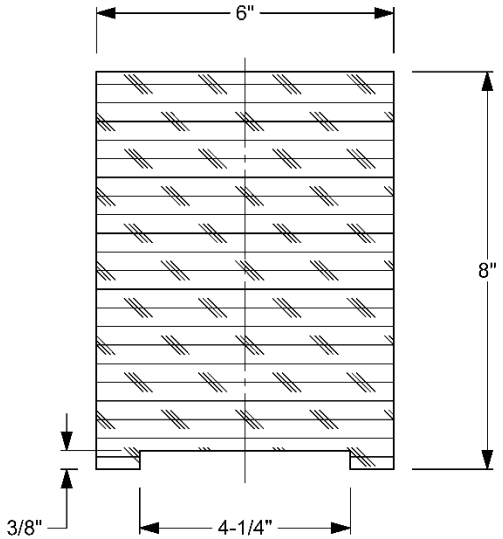
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-Beam Guardrail

Timber Blockout for W-section Post

All dimensions except hole diameter are nominal



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		2022-12-16
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

W6x8.5

Elevation View

Section A-A

Scale 1 : 3

Isometric View

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
72" Wide-Flange Guardrail Post for W-beam		2023-12-04
Drawn by GES	Scale 1:10	Sheet 1 of 1

S:\Accreditation-17025-2017\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

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.

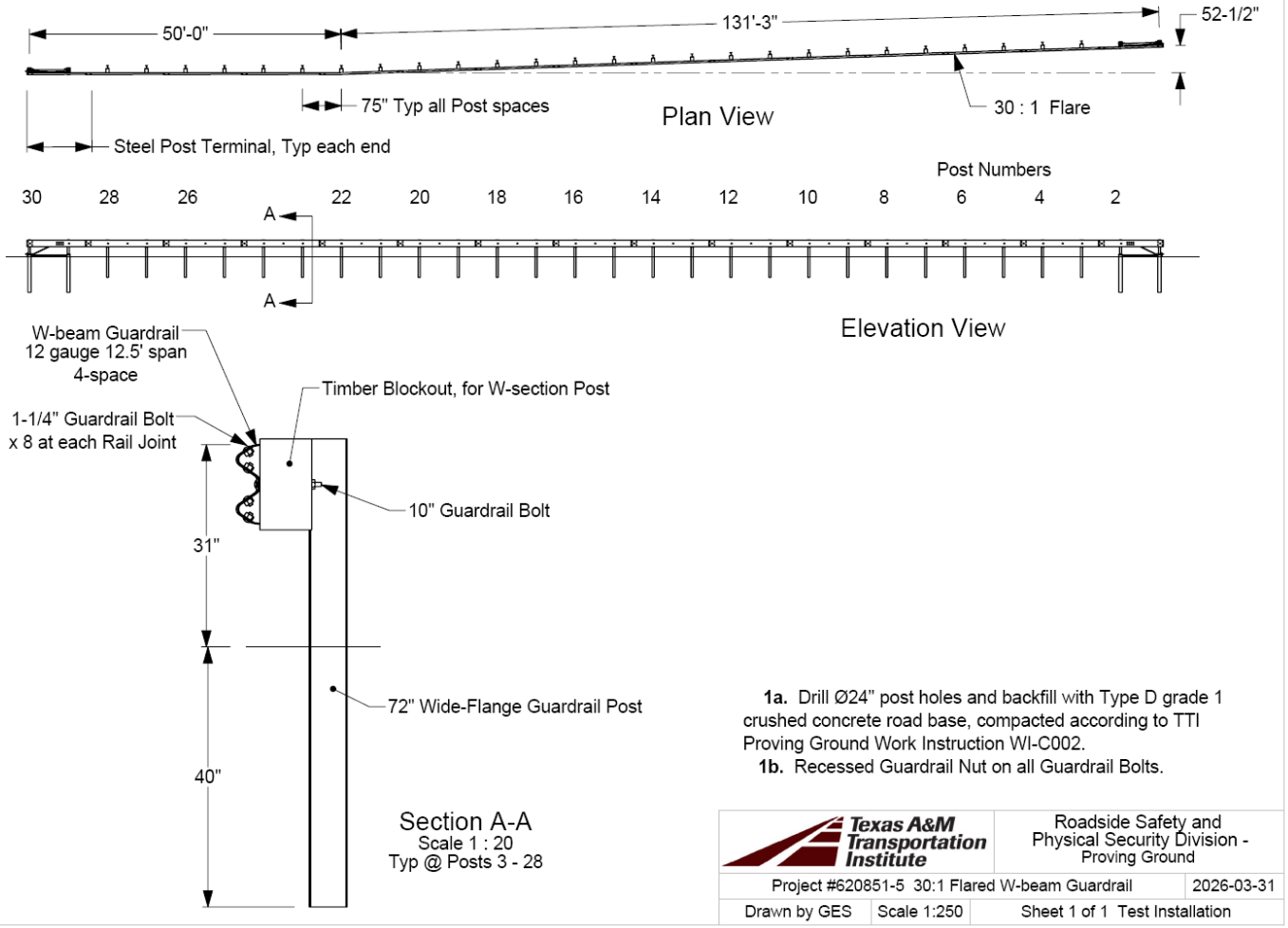
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Guardrail Bolt		2020-07-08
Drawn by GES/WS	Scale 1:2	Sheet 1 of 1

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

APPENDIX D.

DETAILS OF 30:1 FLARED MGS

Test Installation



1a. Drill Ø24" post holes and backfill with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C002.

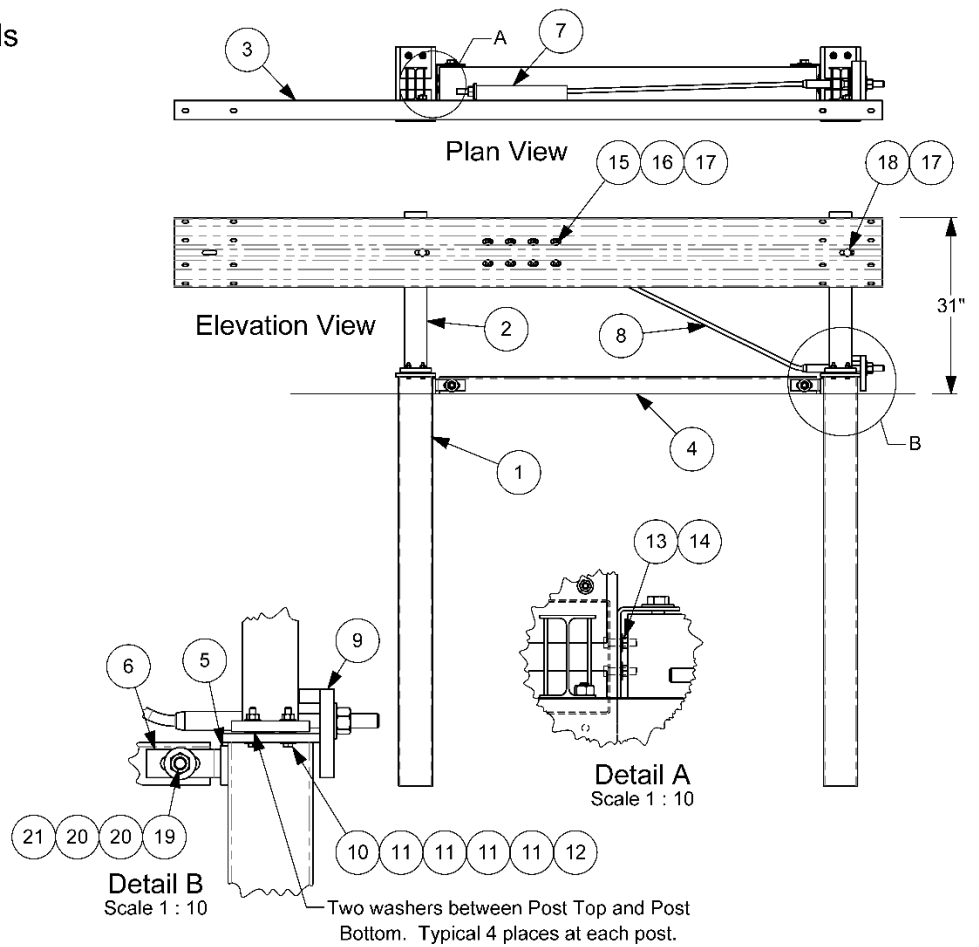
1b. Recessed Guardrail Nut on all Guardrail Bolts.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #620851-5 30:1 Flared W-beam Guardrail		2026-03-31
Drawn by GES	Scale 1:250	Sheet 1 of 1 Test Installation

Z:\Accreditation-17025-2017\EIR-000 Project Files\620851 - Flared W-beam Guardrail - Park\-5 (3-11)\Drafting, 620851-5\620851-5 Drawing

Steel Post Terminal Details

#	Part Name	QTY.
1	Post Bottom	2
2	Post Top	2
3	9'-4-1/2" 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



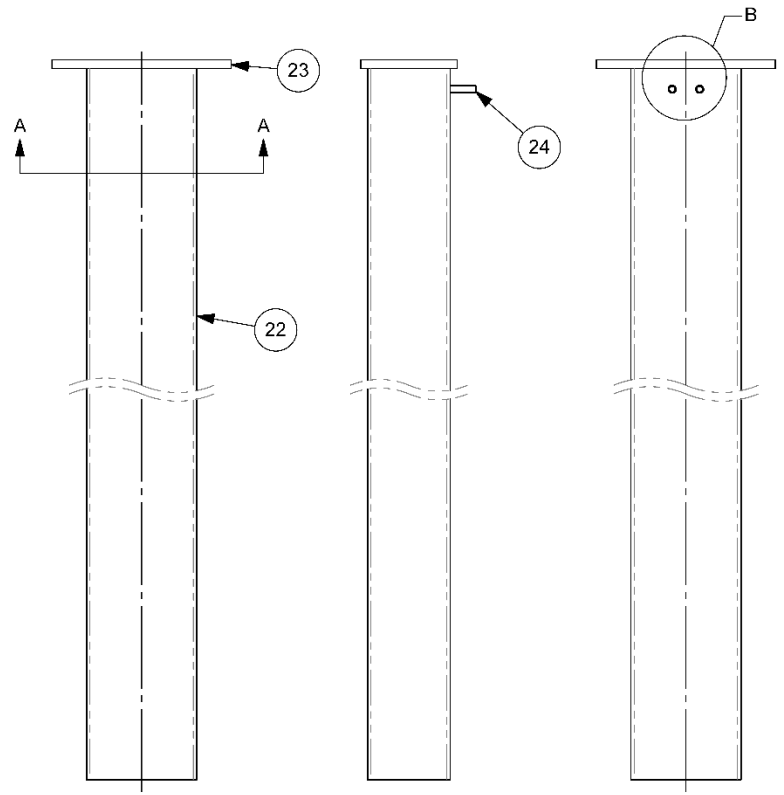
1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.

1b. All steel parts shall be galvanized.

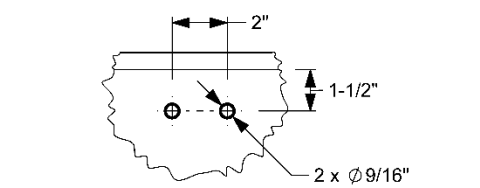
1c. This specific terminal configuration has not been tested. It is used as a barrier anchorage device for crash testing purposes.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2023-02-08
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details

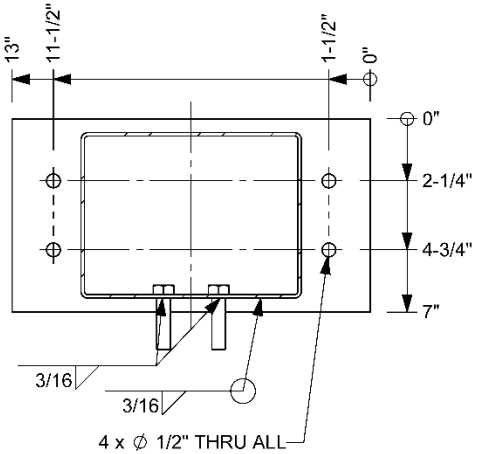
S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



Elevation Views



Detail B
Scale 1 : 5



Section A-A
Scale 1 : 5

Post Bottom

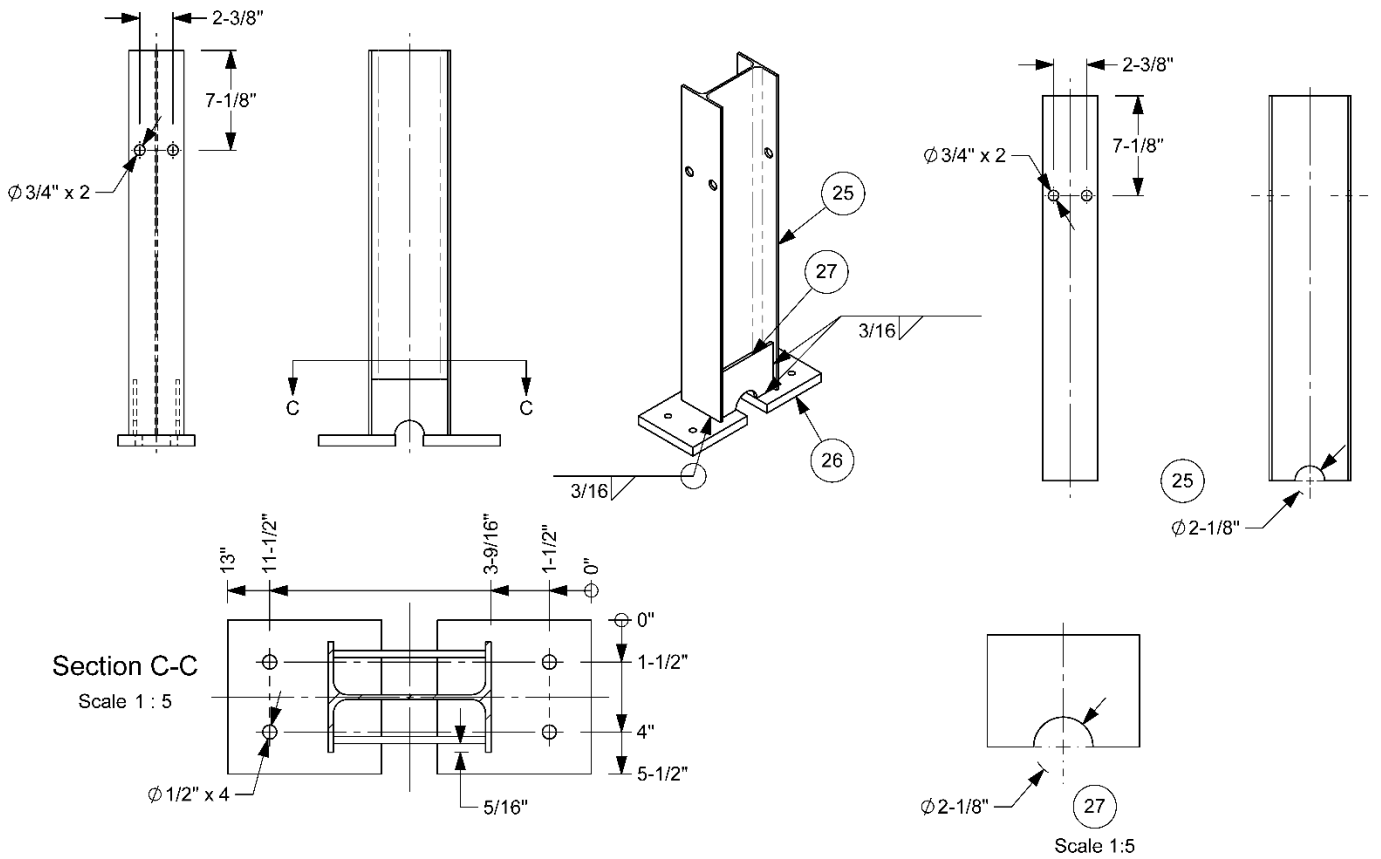
#	Description	Length	Material	Qty
22	HSS 8" x 6" x 1/8"	72"	ASTM A500 Grade B	1
23	Plate, 7" x 5/8"	13"	ASTM A36	1
24	Bolt, 1/2 x 2 hex		ASTM A307	2

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project # Terminal		2023-02-08
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom

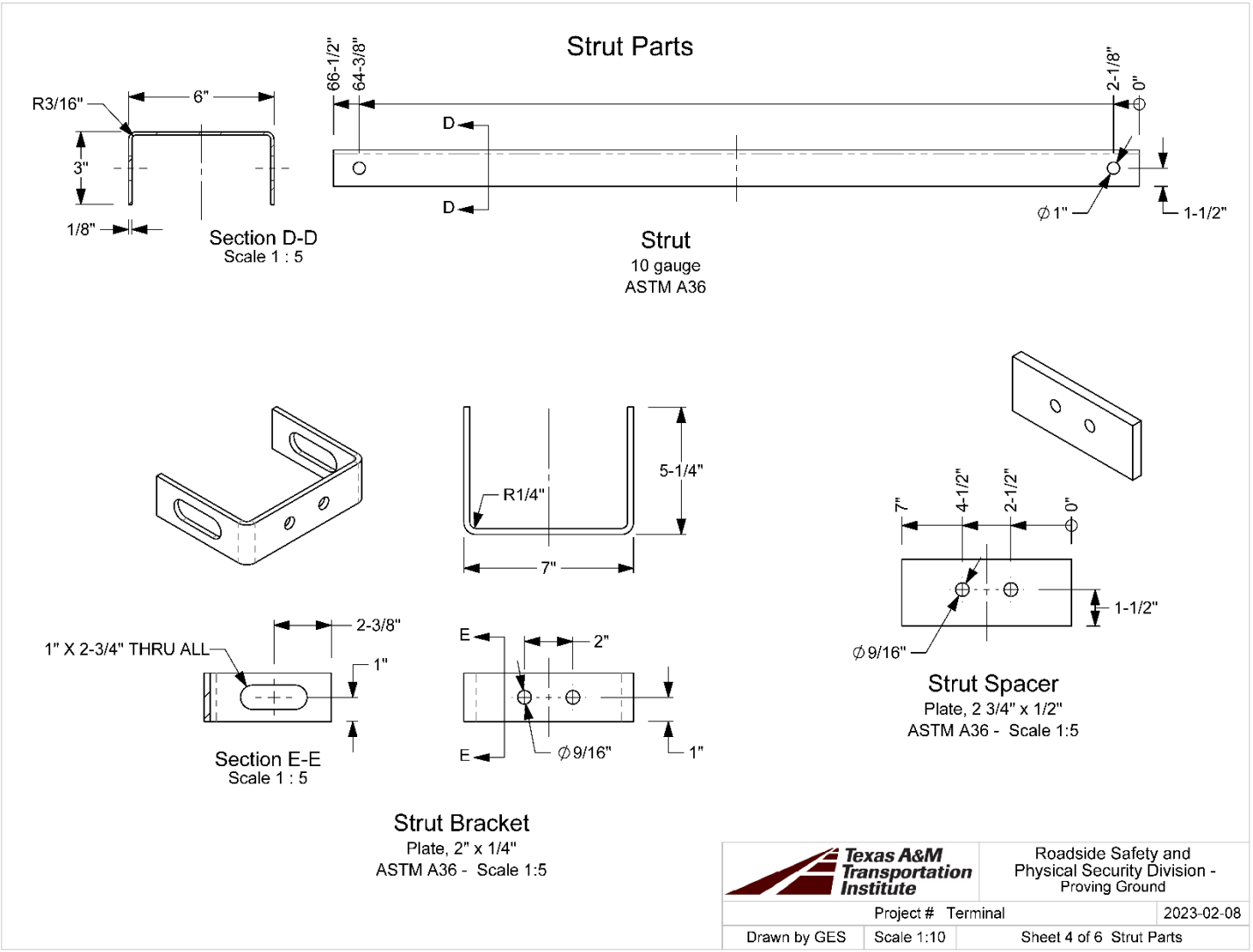
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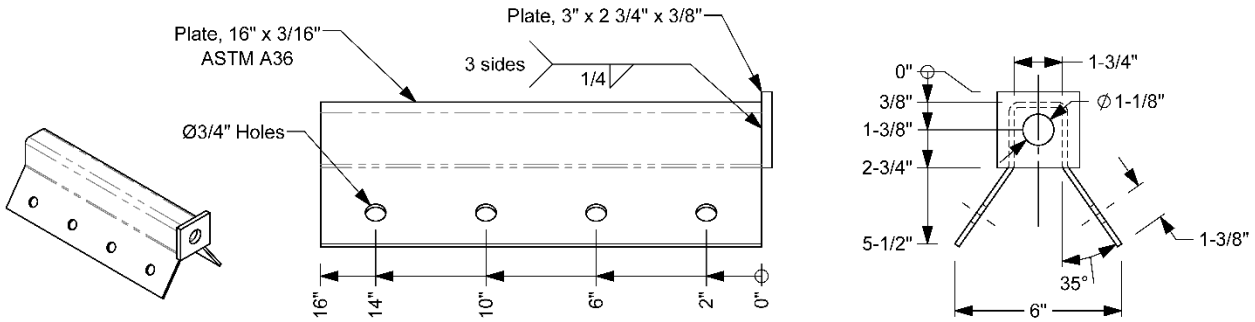
#	Description	Length	Material	Qty
25	W6x8.5	27 1/2"	ASTM A992	1
26	Plate, 5 1/2" x 3/4"	5 1/2"	ASTM A36	2
27	Plate, 5 7/16" x 1/4"	4"	ASTM A36	2

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
	Project # Terminal		2023-02-08
Drawn by GES	Scale 1:10	Sheet 3 of 6 Post Top	

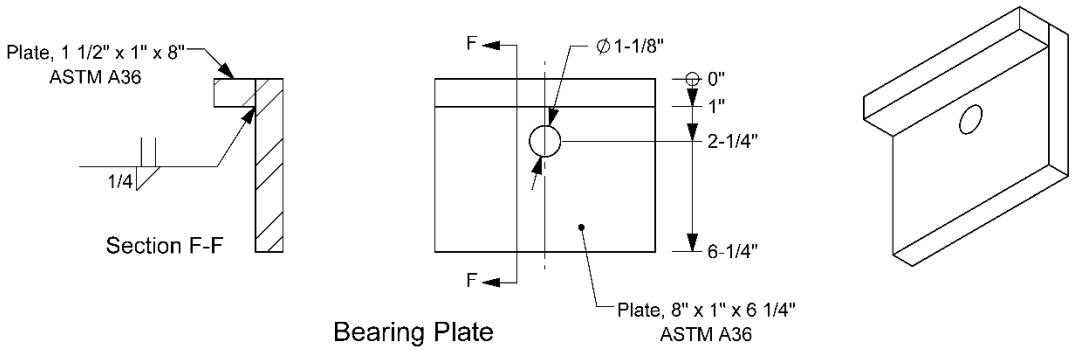
S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



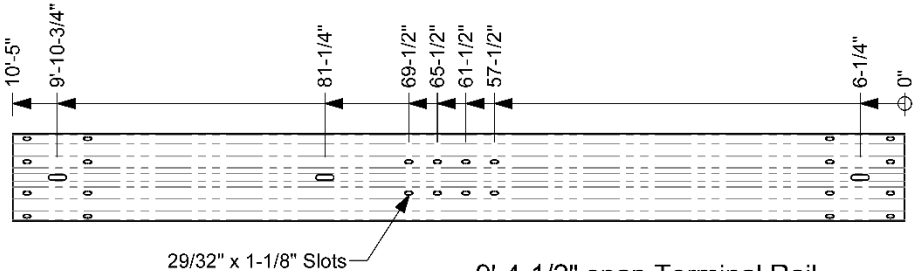
Guardrail Anchor Bracket



Bearing Plate

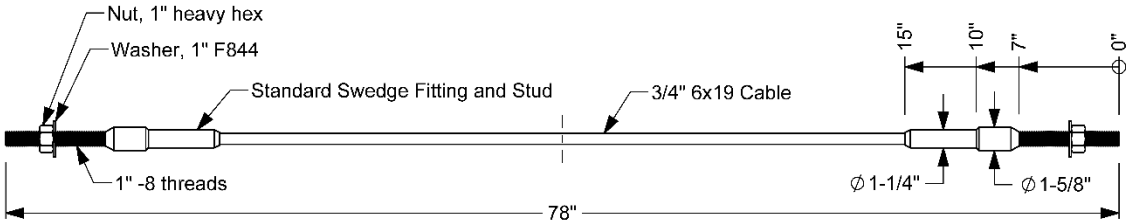
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal		2023-02-08
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A

S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal



9'-4-1/2" 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		2023-02-08
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B	

S:\engrfact\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Steel Post Terminal

Elevation View

Section View

1a. Manufacture per AASHTO M180 specifications.

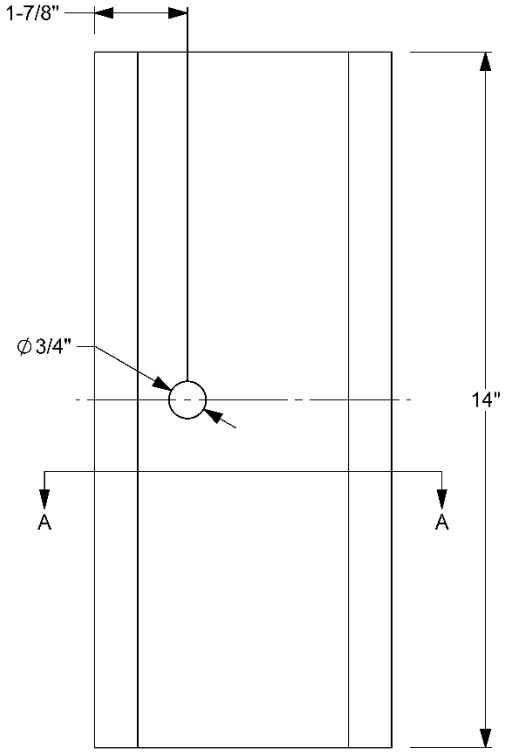
1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

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

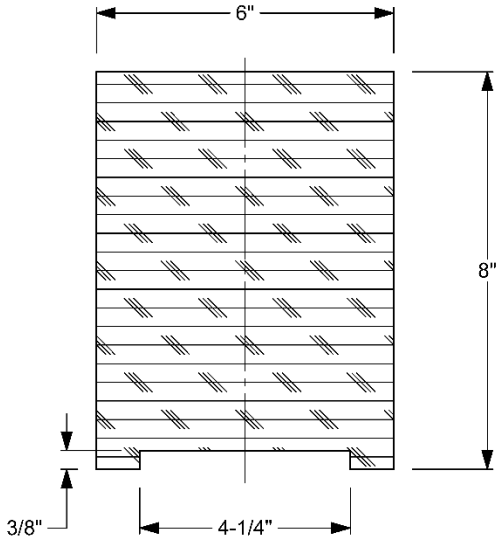
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-Beam Guardrail

Timber Blockout for W-section Post

All dimensions except hole diameter are nominal



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		2022-12-16
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
W6x8.5
1-1/8"
0"
∅13/16" x 2, both flanges
7"
14-5/8"
72"
A
A
Elevation View
3.940
.194
.170
5.830
Section A-A
Scale 1 : 3
Isometric View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
72" Wide-Flange Guardrail Post for W-beam
2023-12-04
Drawn by GES
Scale 1:10
Sheet 1 of 1
S:\Accreditation-17025-2017\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

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

APPENDIX E.

SUPPORTING CERTIFICATION DOCUMENTS

DRAFT

Table E.1. Soil Strength Analysis.



Dynamic Test Setup



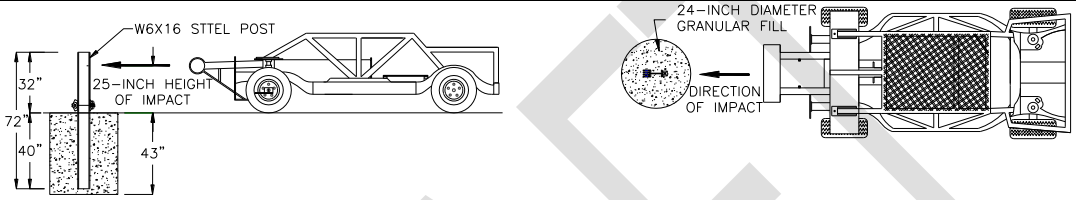
Post-Test Photo of post



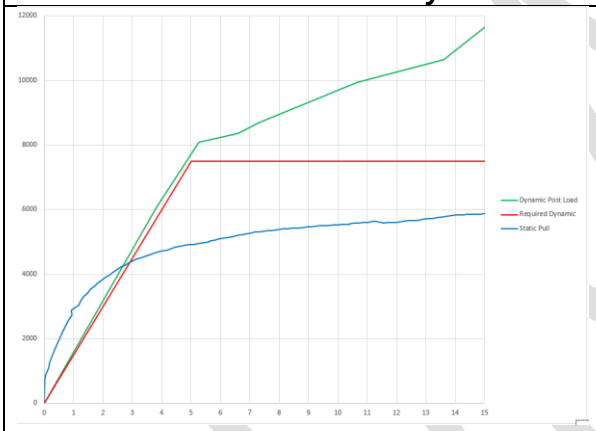
Static Load Test



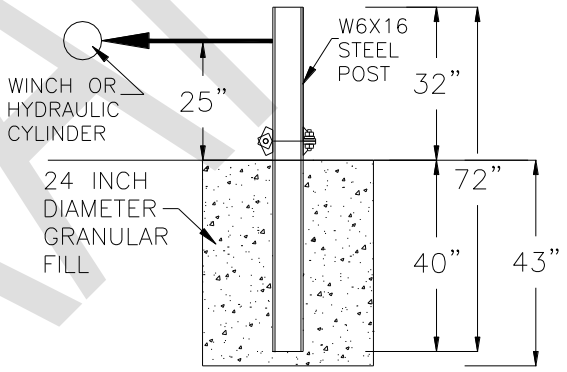
Post-TestPhoto



Dynamic Test Installation Details



Comparison of Load vs. Displacement



Static Load Test Installation Details

Date	2020-02-02
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	Type 1 Grade D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 sec
Bogie Mass	2020 lb
Impact Velocity	19.2 mph

DRAFT

METALLURGICAL ENGINEERING SERVICES, INC.

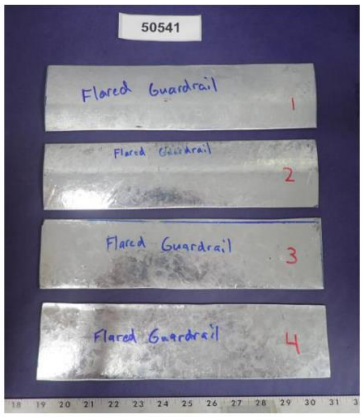
July 2, 2025

REPORT OF: Material Analysis

REPORT TO: Texas A&M Transportation Institute
Attn: Adam Mayer
3135 TAMU
College Station, TX 77843

DATE APPROVED: June 26, 2025

IDENTIFICATION: 4 ea. 3" x 12" Galvanized Steel Flared Guardrail Samples, lab identified as 1-4



PROCEDURES

Tensile testing was performed per ASTM E8-24 using a Satec Systems Model: Apex 22EMF, S/N: 1017, with a calibration due date of 4/01/2026. Testing was performed on 07/02/2025.

RESULTS: ***Next Page***

Lab No. 50541
Page 1 of 2

NOTE: Uncertainty of the results is not considered when making pass/fail decisions unless otherwise noted. Submitted material will be retained for 30 days unless otherwise notified in writing. Any interpretations and/or opinions made in our reports are not subject to the accreditation. Our letters and reports are for the exclusive use of the client to whom they are addressed. The use of our name must receive our prior written approval. Our letters and reports apply to the sample tested and/or inspected and are not necessarily indicative of the qualities of apparently identical or similar materials. The recording of false, fictitious, or fraudulent statements or entries on this certificate may be punishable as felony under federal law.

(972) 480-0033 • FAX (972) 480-0036 • 845 E. Arapaho Road - Richardson, Texas 75081 • www.metengr.com

Figure E.1. Page 1 of the Material Analysis Performed on the Ruptured Guardrail

Material Analysis
Texas A&M Transportation Institute
July 2, 2025

TENSILE TESTING

Sample ID	SQR Dimensions			Ultimate Strength		Yield Strength		Elong., (%)
	Width, (in)	Thickness, (in)	Area, (in^2)	Load, (lbs)	PSI	Load, (lbs)	PSI	
1	0.4910	0.1030	0.0506	3,962	78,300	3,077	60,800	26.3
2	0.4950	0.1065	0.0527	4,017	76,200	3,046	57,800	28.7
3	0.4935	0.1055	0.0521	3,993	76,600	2,969	57,000	28.5
4	0.4910	0.1050	0.0516	3,932	76,200	3,524	68,300	27.5

These results are based on the tests performed and are subject to change upon the receipt of new or additional information.

Respectfully submitted,

METALLURGICAL ENGINEERING SERVICES, INC.
Firm Registration No. F-2674



Daniel A. Stolk, PE, CWI
Principal Engineer

Lab No. 50541
Page 2 of 2

Figure E.2. Page 2 of the Material Analysis Performed on the Ruptured Guardrail

Certificate of Analysis

VALTIR

Valtir, LLC
2548 N.E. 28th Street
Fort Worth TX 76111
United States

Order Number: SO70136
Prod LN Grp: Guardrail
Customer PO: 620851-1
Customer: TEXAS A&M TRANSPORTATION INSTITUTE
BOL Number 1016-01396
Ship Date: 10/14/2024
Document #: 1016-01396_1

1016-01396

Shipped To: 3100 STATE HWY 47
BLDG 7091
BRYAN, Texas 77807

Use State: Texas

Project STOCK, , ,

Qty	Part #	Description	Spec-CL-TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Va
16	**0011G : 12/12'6/3'1.5/S**															
16	11G	12/12'6/3'1.5/S														
				012724												
		100012B	M180 A 2	1406167	63,200	84,800	22			0.009		0.03				
		100006G	COC Only	76028072708678												
32	**00533G : 6'0 POST/8.5/DDR**															
32	533G	6'0 POST/8.5/ DDR/7														
				6902150												
		100482B	A-36 S2	59118174	56,199	69,782	999	0.07		0.011	0.02	0.19				
		100482B	A-36 S2	59118174	56,199	69,782	999	0.07		0.011	0.02	0.19				
		100482B	A-36 S2	59118173	57,599	71,064	999	0.08		0.011	0.027	0.16				
		100482B	A-36 S2	59118173	57,599	71,064	999	0.08		0.011	0.027	0.16				
		100482B	A-36 S2	59118173	57,599	71,064	999	0.08		0.011	0.027	0.16				
		100482B	A-709-50	27963	56,000	79,000	999	0.19	0.94	0.027	0.032					
		100006G	COC Only	76028072708678												
				VF2124C												
		626906B	COC with Full Traceability	16140												
		626906B	COC with Full Traceability	16140												

1016-01396

2026-10-29
171
TR No. 620851-01-1:5

Certificate of Analysis

VALTIR

Qty	Part #	Description	Spec-CL-TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Va
		626906B	COC with Full Traceability	16140												
		626906B	COC with Full Traceability	16140												
		626906B	COC with Full Traceability	16140												
		100006G	COC Only	76028072708678												
32	**004076B : WD BLK RTD 6X8X14**															
32	4076B	WD BLK RTD 6X8X14 / 7														
		4076B	COC Only	10955												
26	**003500G : 5/8"X10" GR BOLT A307**															
26	3500G	5/8"X10" GR BOLT A307														
		3500G	A-307-A	B16137-2				0.16	0.74	0.007	0.009					
112	**003360G : 5/8"X1.25" GR BOLT**															
112	3360G	5/8"X1.25" GR BOLT														
		3360G	A-307-A	B16092-3				0.16	0.75	0.007	0.006					
		3360G	A-307-A	B16092-3				0.16	0.75	0.007	0.006					
138	**003340G : 5/8" GR HEX NUT**															
138	3340G	5/8" GR HEX NUT														
		3340G	A-563-A	24-54-028				0.11	0.39	0.006	0.005					
1	**00FREIGHTLTL : LTL CHARGE**															

UPON DELIVERY, ALL MATERIALS SUBJECT TO VALTIR, LLC STORAGE STAIN POLICY QMS-LQ-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.

1016-01396

2026-10-29
172
TR No. 620851-01-1:5

Certificate of Analysis

VALTIR

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 - 46,000 LBS.

PURSUANT TO THE INFRASTRUCTURE INVESTMENT AND JOBS ACT IIJA, PUB. L. NO. 117-58, WHICH INCLUDES THE BUILD AMERICA, BUY AMERICA ACT BABA. IIJA DIV. G §§ 70901-27, THE IRON, STEEL, MANUFACTURED PRODUCTS, AND CONSTRUCTION MATERIALS SOLD BY VALTIR, LLC AND LISTED ON THE ATTACHED WERE PRODUCED IN THE UNITED STATES AND COMPLIES WITH BUILD AMERICA, BUY AMERICA ACT BABA.

Notary Public:

Commission Expires:

CHRISTINE EMILY HARRIS
Notary ID #134494894
My Commission Expires
August 4, 2027

Certified By:

Quality Assurance:

1016-01396

2026-10-29
173
TR No. 620851-01-1:5

Certificate of Compliance

VALTIR

Valtir, LLC
2548 N.E. 28th Street
Fort Worth TX 76111
United States

Customer: TEXAS A&M TRANSPORTATION INSTITUTE

Shipped To: 3100 STATE HWY 47
BLDG 7091
BRYAN, Texas 77807

Project STOCK, , ,

Order Number: SO70136

Customer PO: 620851

BOL Number 1016-01396

Document #: 1016-01396_1

Ship Date: 10/14/2024

1016-01396

Use State: Texas

Certificate of Compliance for Valtir, LLC

Pieces	Description	Part Number
16	12/12'6/3"1.5/S	0011G
16	12/12'6/3"1.5/S	11G
32	6'0 POST/8.5/DDR	00533G
32	6'0 POST/8.5/DDR/7	533G
32	WD BLK RTD 6X8X14	004076B
32	WD BLK RTD 6X8X14 / 7	4076B
26	5/8"X10" GR BOLT A307	003500G
26	5/8"X10" GR BOLT A307	3500G
112	5/8"X1.25" GR BOLT	003360G
112	5/8"X1.25" GR BOLT	3360G
138	5/8" GR HEX NUT	003340G
138	5/8" GR HEX NUT	3340G
1	LTL CHARGE	00FREIGHTLTL

UPON DELIVERY, ALL MATERIALS SUBJECT TO VALTIR, LLC STORAGE STAIN POLICY QMS-LQ-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.

1016-01396

2026-10-29
174
TR No. 620851-01-1:5

Certificate of Compliance

VALTIR

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 - 46,000 LBS.

PURSUANT TO THE INFRASTRUCTURE INVESTMENT AND JOBS ACT IIJA, PUB. L. NO. 117-58, WHICH INCLUDES THE BUILD AMERICA, BUY AMERICA ACT BABA. IIJA DIV. G §§ 70901-27, THE IRON, STEEL, MANUFACTURED PRODUCTS, AND CONSTRUCTION MATERIALS SOLD BY VALTIR, LLC AND LISTED ON THE ATTACHED WERE PRODUCED IN THE UNITED STATES AND COMPLIES WITH BUILD AMERICA, BUY AMERICA ACT BABA.

Notary Public:

Commission Expires:

CHRISTINE EMILY HARRIS
Notary ID #134494894
My Commission Expires
August 4, 2027

Certified By:

Quality Assurance:

1016-01396

2026-10-29
175
TR No. 620851-01-1:5

2872102

10/14/2024 **BILL OF LADING - NOT NEGOTIABLE** Page 1 of 1

SHIP FROM	**Bill of Lading Number:** 1016-01396
Valtir, LLC 2548 N.E. 28th Street Fort Worth TX 76111 United States	1016-01396 **Customer P.O. Number:** 620851
SHIP TO	**Carrier Name:** Itemized SAIA
TEXAS A&M TRANSPORTATION INSTITUTE 3100 STATE HWY 47 BLDG 7091 BRYAN, Texas 77807	
THIRD PARTY FREIGHT CHARGES BILL TO	**PRO Number:**
Account #:	
Delivery Instructions:	**Freight Charge Terms:**
Accessorials: 2-BUNDLES 1-Pallet	**Project:** GUARDRAIL HWY STEEL STOCK NMFC ITEM 105460 **Notes:** CLASS 50

CARRIER INFORMATION

Handling Unit		Pieces				LTL Only
Qty	Type	Qty	Weight	**Commodity Description** Commodities requiring special or additional care or attention in handling or stowing must be so marked and packaged as to ensure safe transportation with ordinary care. See Section 2(e) of NMFC Item 360.	NMFC No.	Class
		16	95	**11G**		
		26	0.86	**3500G**		
		32	53.66	**533G**		
		32	17	**4076B**		
		112	0.189	**3360G**		
		138	0.17	**3340G**		

Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property as follows: "The agreed or declared value of property is specifically stated by the shipper to be not exceeding _____ per _____."

COD Amount: $_____ **Fee terms:** ☐ Collect ☐ Prepaid ☐ Customer check acceptable

Note: Liability limitation for loss or damage in this shipment may be applicable. See 49 USC § 14706(c)(1)(A)and(B)

Received, subject to individually determined rates or contracts that have been agreed upon in writing between the carrier and shipper, if applicable, otherwise to the rates, classifications, and rules that have been established by the carrier and are available to the shipper, on request, and to all applicable state and federal regulations.	The carrier shall not make delivery of this shipment without payment of charges and all other lawful fees. Shipper Signature _____

Shipper Signature/Date	Trailer Loaded:	Freight Counted:	**Carrier Signature/Date**
This is to certify that the above named materials are properly classified, packaged, marked, and labeled and are in proper condition for transportation according to the applicable regulations of the DOT.	☐ By shipper ☐ By driver	☐ By shipper ☐ By driver/pallets said to contain ☐ By driver/pieces	_____ Carrier acknowledges receipt of packages and required placards. Carrier certifies emergency response information was made available and/or carrier has the DOT emergency response guidebook or equivalent documentation in the vehicle. Property described above is received in good order, except as noted.

TR No. 620851-01-1:5

Certificate of Analysis

VALTIR

Valtir, LLC
2548 N.E. 28th Street
Fort Worth TX 76111
United States

Order Number: SO80421
Customer PO: 620851
Prod LN Grp: Guardrail

Customer: TEXAS A&M TRANSPORTATION INSTITUTE
BOL Number 1016-05480
Ship Date: 2/3/2026

Document #: 1016-05480_1

1016-05480

Shipped To: 3100 STATE HWY 47
BLDG 7091
BRYAN, Texas 77807

Use State: Texas

Project STOCK, , ,

Qty	Part #	Description	Spec-CL-TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Va
13	**0011G : 12/12'6/3'1.5/S**															
13	11G	12/12'6/3'1.5/S														
				F13425												
		100012B	M180-18 A 2	2254568	56,100	76,700	28			0.014		0.02				
26	**00533G : 6'0 POST/8.5/DDR**															
26	533G	6'0 POST/8.5/ DDR/7														
				VF3325A												
		100482B	A-36 S2	55100894	59,200	75,300	25	0.12		0.013	0.016	0.21				
				VL3325C												
		626906B	A-36 S2	20423	550,000	78,000	23	0.18		0.012	0.02	0.23				
26	**004076B : WD BLK RTD 6X8X14**															
26	4076B	WD BLK RTD 6X8X14 / 7														
		4076B	COC with Charge Report	26611-12												
26	**003500G : 5/8"X10" GR BOLT A307**															
26	3500G	5/8"X10" GR BOLT A307														
		3500G	COC with Full Traceability	37085												
112	**003360G : 5/8"X1.25" GR BOLT**															

1016-05480

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2026-10-29

TR No. 620851-01-1:5

178

2026-10-29

Certificate of Analysis

VALTIR

Qty	Part #	Description	Spec-CL-TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Va
112	3360G	5/8"X1.25" GR BOLT														
		3360G	COC with Full Traceability	36694-B												
138	**003340G : 5/8" GR HEX NUT**															
138	3340G	5/8" GR HEX NUT														
		3340G	COC with Full Traceability	36294-B												
1	**00FREIGHTLTL : LTL CHARGE**															

UPON DELIVERY, ALL MATERIALS SUBJECT TO VALTIR, LLC STORAGE STAIN POLICY QMS-LQ-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-180-18, 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 - 46,000 LBS.

1016-05480

TR No. 620851-01-1;5

179

2026-10-29

Certificate of Analysis

VALTIR

PURSUANT TO THE INFRASTRUCTURE INVESTMENT AND JOBS ACT IIJA, PUB. L. NO. 117-58, WHICH INCLUDES THE BUILD AMERICA, BUY AMERICA ACT BABA. IIJA DIV. G §§ 70901-27, THE IRON, STEEL, MANUFACTURED PRODUCTS, AND CONSTRUCTION MATERIALS SOLD BY VALTIR, LLC AND LISTED ON THE ATTACHED WERE PRODUCED IN THE UNITED STATES AND COMPLIES WITH BUILD AMERICA, BUY AMERICA ACT BABA. THE QUALITY ASSURANCE INDIVIDUAL IDENTIFIED IN THIS DOCUMENT HAS THE LEGAL AUTHORITY TO BIND THE MANUFACTURER OR SUPPLIER OF THE MATERIAL.

Notary Public: Amanda Ray

Commission Expires: My Commission Expires 11/21/2028 Notary ID 135179492

Amanda Ray

Certified By Signature:

Printed Name:

Title: QUALITY ASSURANCE

Signature Date:

1016-05480

TR No. 620851-01-1:5

180

2026-10-29

Certificate of Compliance

VALTIR

Valtir, LLC
2548 N.E. 28th Street
Fort Worth TX 76111
United States

Order Number: SO80421

Customer PO: 620851

Customer: TEXAS A&M TRANSPORTATION INSTITUTE

BOL Number 1016-05480

Ship Date: 2/3/2026

Document #: 1016-05480_1

1016-05480

Shipped To: 3100 STATE HWY 47
BLDG 7091
BRYAN, Texas 77807

Use State: Texas

Project STOCK, , ,

Certificate of Compliance for Valtir, LLC

Pieces	Description	Part Number
13	12/12'6/3'1.5/S	0011G
13	12/12'6/3'1.5/S	11G
26	6'0 POST/8.5/DDR	00533G
26	6'0 POST/8.5/DDR/7	533G
26	WD BLK RTD 6X8X14	004076B
26	WD BLK RTD 6X8X14 / 7	4076B
26	5/8"X10" GR BOLT A307	003500G
26	5/8"X10" GR BOLT A307	3500G
112	5/8"X1.25" GR BOLT	003360G
112	5/8"X1.25" GR BOLT	3360G
138	5/8" GR HEX NUT	003340G
138	5/8" GR HEX NUT	3340G
1	LTL CHARGE	00FREIGHTLTL

UPON DELIVERY, ALL MATERIALS SUBJECT TO VALTIR, LLC STORAGE STAIN POLICY QMS-LQ-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-180-18, 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.

1016-05480

TR No. 620851-01-1:5

181

2026-10-29

Certificate of Compliance

VALTIR

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 - 46,000 LBS.

PURSUANT TO THE INFRASTRUCTURE INVESTMENT AND JOBS ACT IIJA, PUB. L. NO. 117-58, WHICH INCLUDES THE BUILD AMERICA, BUY AMERICA ACT BABA. IIJA DIV. G §§ 70901-27, THE IRON, STEEL, MANUFACTURED PRODUCTS, AND CONSTRUCTION MATERIALS SOLD BY VALTIR, LLC AND LISTED ON THE ATTACHED WERE PRODUCED IN THE UNITED STATES AND COMPLIES WITH BUILD AMERICA, BUY AMERICA ACT BABA. THE QUALITY ASSURANCE INDIVIDUAL IDENTIFIED IN THIS DOCUMENT HAS THE LEGAL AUTHORITY TO BIND THE MANUFACTURER OR SUPPLIER OF THE MATERIAL.

Notary Public: Amanda Ray

Commission Expires: My Commission Expires 11/21/2028 Notary ID 135179492

Amanda Ray

Certified By Signature:

Printed Name:

Title: QUALITY ASSURANCE

Signature Date:

1016-05480

Valtir, LLC
Valtir, LLC
2548 N.E. 28th Street
Fort Worth TX 76111
United States

Packing Slip

#1016-05480

2/3/2026

SO80421
620851

Ship To
3100 STATE HWY 47
BLDG 7091
BRYAN, Texas 77807

Date	Tracking Numbers	Ship Via	Phone
2/3/2026		Itemized	(512) 635-3115

Item	Ordered	Back Ordered	Shipped
0011G 12/12'6/3'1.5/S	13	0	13
1: *11G* *12/12'6/3'1.5/S*			*13*
00533G 6'0 POST/8.5/DDR	26	0	26
1: *533G* *6'0 POST/8.5/DDR/7*			*26*
004076B WD BLK RTD 6X8X14	26	0	26
1: *4076B* *WD BLK RTD 6X8X14 / 7*			*26*
003500G 5/8"X10" GR BOLT A307	26	0	26
1: *3500G* *5/8"X10" GR BOLT A307*			*26*
003360G 5/8"X1.25" GR BOLT	112	0	112
1: *3360G* *5/8"X1.25" GR BOLT*			*112*
003340G 5/8" GR HEX NUT	138	0	138
1: *3340G* *5/8" GR HEX NUT*			*138*
00FREIGHTLTL LTL CHARGE	1		1

TR No. 620851-01-1:5

Certificate of Analysis

VALTIR

Valtir, LLC
2548 N.E. 28th Street
Fort Worth TX 76111
United States

Order Number: SO81988
Prod LN Grp: Guardrail
Customer PO: 620851
Customer: TEXAS A&M TRANSPORTATION INSTITUTE
BOL Number 1016-05930
Ship Date: 4/7/2026
Document #: 1016-05930_1

1016-05930

Shipped To: 3100 STATE HWY 47
BLDG 7091 - ADAM MAYER (512) 635-3115
BRYAN, Texas 77807

Use State: Texas

Project STOCK, , ,

Qty	Part #	Description	Spec-Cl-TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Va
13	**0011G : 12/12'6/3'1.5/S**															
13	11G	12/12'6/3'1.5/S														
				F13825												
		100012B	M180-18 A 2	2155378	57,800	84,700	24		0.013			0.02				
		100012B	M180-18 A 2	2254567	61,000	83,800	24		0.015			0.02				
6	**00533G : 6'0 POST/8.5/DDR**															
6	533G	6'0 POST/8.5/ DDR/7														
				VF1725B												
		100482B	A-36 S2	55098439	57,200	73,900	27	0.11	0.019	0.018		0.21				
				VL1325C												
		626906B	A-36 S2	28873	51,000	73,000	24	0.17	0.009	0.034		0.25				
6	**004076B : WD BLK RTD 6X8X14**															
6	4076B	WD BLK RTD 6X8X14 / 7														
		4076B	COC with Charge Report	26664-10												
6	**003500G : 5/8"X10" GR BOLT A307**															
6	3500G	5/8"X10" GR BOLT A307														
		3500G	COC with Full Traceability	37119												

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2026-10-29

TR No. 620851-01-1:5

184

2026-10-29

Certificate of Analysis

VALTIR

Qty	Part #	Description	Spec-CL-TY	Heat Code/ Heat	Yield	Tb	Pg	C	Mn	P	S	Si	Cu	Cb	Cr	Ni
32	003360G : 5/8"X1.25" GR BOLT															
32	3360G	5/8"X1.25" GR BOLT														
		3360G	COC with Full Traceability	37124												
38	003340G : 5/8" GR HEX NUT															
38	3340G	5/8" GR HEX NUT														
		3340G	A-563-A	36295-G				0.08	0.41	0.007	0.014					
1	00FREIGHTLTL : LTL CHARGE															

UPON DELIVERY, ALL MATERIALS SUBJECT TO VALTIR, LLC STORAGE STAIN POLICY QMS-LQ-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-180-18, 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 - 46,000 LBS.

1016-05930

TR No. 620851-01-1:5

185

2026-10-29

Certificate of Analysis

VALTIR

PURSUANT TO THE INFRASTRUCTURE INVESTMENT AND JOBS ACT IIJA, PUB. L. NO. 117-58, WHICH INCLUDES THE BUILD AMERICA, BUY AMERICA ACT BABA. IIJA DIV. G §§ 70901-27, THE IRON, STEEL, MANUFACTURED PRODUCTS, AND CONSTRUCTION MATERIALS SOLD BY VALTIR, LLC AND LISTED ON THE ATTACHED WERE PRODUCED IN THE UNITED STATES AND COMPLIES WITH BUILD AMERICA, BUY AMERICA ACT BABA. THE QUALITY ASSURANCE INDIVIDUAL IDENTIFIED IN THIS DOCUMENT HAS THE LEGAL AUTHORITY TO BIND THE MANUFACTURER OR SUPPLIER OF THE MATERIAL.

Notary Public: Amanda Ray

Commission Expires: Amanda Ray My Commission Expires 11/21/2028 Notary ID135179492

Amanda Ray

Certified By Signature:

Printed Name:

Title: QUALITY ASSURANCE

Signature Date:

1016-05930

TR No. 620851-01-1:5

Certificate of Compliance

VALTIR

Valtir, LLC
2548 N.E. 28th Street
Fort Worth TX 76111
United States

Order Number: SO81988

Customer PO: 620851

Customer: TEXAS A&M TRANSPORTATION INSTITUTE

BOL Number 1016-05930

Ship Date: 4/7/2026

Document #: 1016-05930_1

1016-05930

Shipped To: 3100 STATE HWY 47
BLDG 7091 - ADAM MAYER (512) 635-3115
BRYAN, Texas 77807

Use State: Texas

Project STOCK, , ,

Certificate of Compliance for Valtir, LLC

Pieces		Description	Part Number
13		12/12'6/3'1.5/S	0011G
	13	12/12'6/3'1.5/S	11G
6		6'0 POST/8.5/DDR	00533G
	6	6'0 POST/8.5/DDR/7	533G
6		WD BLK RTD 6X8X14	004076B
	6	WD BLK RTD 6X8X14 / 7	4076B
6		5/8"X10" GR BOLT A307	003500G
	6	5/8"X10" GR BOLT A307	3500G
32		5/8"X1.25" GR BOLT	003360G
	32	5/8"X1.25" GR BOLT	3360G
38		5/8" GR HEX NUT	003340G
	38	5/8" GR HEX NUT	3340G
1		LTL CHARGE	00FREIGHTLTL

UPON DELIVERY, ALL MATERIALS SUBJECT TO VALTIR, LLC STORAGE STAIN POLICY QMS-LQ-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-180-18, 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.

1016-05930

186

2026-10-29

TR No. 620851-01-1:5

187

2026-10-29

Certificate of Compliance

VALTIR

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 - 46,000 LBS.

PURSUANT TO THE INFRASTRUCTURE INVESTMENT AND JOBS ACT IIJA, PUB. L. NO. 117-58, WHICH INCLUDES THE BUILD AMERICA, BUY AMERICA ACT BABA. IIJA DIV. G §§ 70901-27, THE IRON, STEEL, MANUFACTURED PRODUCTS, AND CONSTRUCTION MATERIALS SOLD BY VALTIR, LLC AND LISTED ON THE ATTACHED WERE PRODUCED IN THE UNITED STATES AND COMPLIES WITH BUILD AMERICA, BUY AMERICA ACT BABA. THE QUALITY ASSURANCE INDIVIDUAL IDENTIFIED IN THIS DOCUMENT HAS THE LEGAL AUTHORITY TO BIND THE MANUFACTURER OR SUPPLIER OF THE MATERIAL.

Notary Public: Amanda Ray

Commission Expires: My Commission Expires 11/21/2028 Notary ID 135179492

Amanda Ray

Certified By Signature:

Printed Name:

Signature Date:

Title: QUALITY ASSURANCE

1016-05930

Valtir, LLC
Valtir, LLC
2548 N.E. 28th Street
Fort Worth TX 76111
United States

Packing Slip

#1016-05930

4/7/2026

SO81988
620851

Ship To
3100 STATE HWY 47
BLDG 7091 - ADAM MAYER (512) 635-3115
BRYAN, Texas 77807

Date	Tracking Numbers	Ship Via	Phone
4/7/2026		Itemized	(512) 635-3115

Item	Ordered	Back Ordered	Shipped
0011G 12/12'6/3'1.5/S	13	0	13
1: ***11G*** *12/12'6/3'1.5/S*			*13*
00533G 6'0 POST/8.5/DDR	6	0	6
1: ***533G*** *6'0 POST/8.5/DDR/7*			*6*
004076B WD BLK RTD 6X8X14	6	0	6
1: ***4076B*** *WD BLK RTD 6X8X14 / 7*			*6*
003500G 5/8"X10" GR BOLT A307	6	0	6
1: ***3500G*** *5/8"X10" GR BOLT A307*			*6*
003360G 5/8"X1.25" GR BOLT	32	0	32
1: ***3360G*** *5/8"X1.25" GR BOLT*			*32*
003340G 5/8" GR HEX NUT	38	0	38
1: ***3340G*** *5/8" GR HEX NUT*			*38*
00FREIGHTLTL LTL CHARGE	1		1

1 of 1
1016-05930

Certificate of Analysis

VALTIR

Valtir, LLC
2548 N.E. 28th Street
Fort Worth TX 76111
United States

Customer: TEXAS A&M TRANSPORTATION INSTITUTE

Shipped To: 3100 STATE HWY 47
BLDG 7091
BRYAN, Texas 77807

Project STOCK, , ,

Order Number: SO73844
Customer PO: 620851
BOL Number 1016-03013
Document #: 1016-03013_1
Use State: Texas

Prod LN Grp: Guardrail
Ship Date: 4/2/2025

1016-03013

Qty	Part #	Description	Spec-CL-TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Va
10	**0011G : 12/12'6/3'1.5/S**															
10	11G	12/12'6/3'1.5/S		01-50-24												
		100012B	M180-18 A 2	2409183	59,100	80,500	23			0.009		0.03				
6	**00533G : 6'0 POST/8.5/DDR**															
6	533G	6'0 POST/8.5/ DDR/7		6902150												
		100482B	A-36 S2	59120237	59,738	73,202	26	0.07		0.009	0.023	0.2				
		100482B	A-36 S2	59118175	59,169	73,141		0.08		0.017	0.02	0.24				
		100482B	A-36 S2	59118174	56,199	69,782	23	0.07		0.011	0.02	0.19				
		100482B	A-36 S2	59118174	56,199	69,782	23	0.07		0.011	0.02	0.19				
		100482B	A-36 S2	59118173	57,599	71,064	27	0.08		0.011	0.027	0.16				
		100482B	A-36 S2	59118173	57,599	71,064	27	0.08		0.011	0.027	0.16				
		100482B	A-36 S2	59118173	57,599	71,064	27	0.08		0.011	0.027	0.16				
		100482B	A-709-50	27963	56,000	79,000	19	0.19	0.94	0.027	0.032					
				VF2124C												
		626906B	COC with Full Traceability	16140												
		626906B	COC with Full Traceability	16140												

1016-03013

2026-10-29
189
TR No. 620851-01-1:5

Certificate of Analysis

VALTIR

Qty	Part #	Description	Spec-CL-TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Va
		626906B	COC with Full Traceability	16140												
		626906B	COC with Full Traceability	16140												
		626906B	COC with Full Traceability	16140												
1		00FREIGHTLTL : LTL CHARGE														

UPON DELIVERY, ALL MATERIALS SUBJECT TO VALTIR, LLC STORAGE STAIN POLICY QMS-LQ-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-180-18, 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 - 46,000 LBS.

PURSUANT TO THE INFRASTRUCTURE INVESTMENT AND JOBS ACT IIJA, PUB. L. NO. 117-58, WHICH INCLUDES THE BUILD AMERICA, BUY AMERICA ACT BABA. IIJA DIV. G §§ 70901-27, THE IRON, STEEL, MANUFACTURED PRODUCTS, AND CONSTRUCTION MATERIALS SOLD BY VALTIR, LLC AND LISTED ON THE ATTACHED WERE PRODUCED IN THE UNITED STATES AND COMPLIES WITH BUILD

2026-10-29

190

TR No. 620851-01-1:5

Certificate of Analysis

VALTIR

AMERICA, BUY AMERICA ACT BABA. THE QUALITY ASSURANCE INDIVIDUAL IDENTIFIED IN THIS DOCUMENT HAS THE LEGAL AUTHORITY TO BIND THE MANUFACTURER OR SUPPLIER OF THE MATERIAL.

Notary Public: Amanda Ray

Commission Expires: My Commission Expires 11/21/2028 Notary ID 135179492

Amanda Ray

Certified By Signature:

Printed Name:

Title: QUALITY ASSURANCE

Signature Date: 2026-10-29

1016-03013

TR No. 620851-01-1:5 191

Certificate of Compliance

VALTIR

Valtir, LLC
2548 N.E. 28th Street
Fort Worth TX 76111
United States

Customer: TEXAS A&M TRANSPORTATION INSTITUTE

Shipped To: 3100 STATE HWY 47
BLDG 7091
BRYAN, Texas 77807

Project STOCK, , ,

Order Number: SO73844

Customer PO: 620851

BOL Number 1016-03013

Document #: 1016-03013_1

Ship Date: 4/2/2025

1016-03013

Use State: Texas

Certificate of Compliance for Valtir, LLC

Pieces	Description	Part Number
10	12/12'6/3'1.5/S	0011G
10	12/12'6/3'1.5/S	11G
6	6'0 POST/8.5/DDR	00533G
6	6'0 POST/8.5/DDR/7	533G
1	LTL CHARGE	00FREIGHTLTL

UPON DELIVERY, ALL MATERIALS SUBJECT TO VALTIR, LLC STORAGE STAIN POLICY QMS-LQ-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-180-18, 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 - 46,000 LBS.

PURSUANT TO THE INFRASTRUCTURE INVESTMENT AND JOBS ACT IIJA, PUB. L. NO. 117-58, WHICH INCLUDES THE BUILD AMERICA, BUY AMERICA ACT BABA. IIJA DIV. G §§ 70901-27, THE IRON, STEEL, MANUFACTURED PRODUCTS, AND CONSTRUCTION MATERIALS SOLD BY VALTIR, LLC AND LISTED ON THE ATTACHED WERE PRODUCED IN THE UNITED STATES AND COMPLIES WITH BUILD AMERICA, BUY AMERICA ACT BABA. THE QUALITY ASSURANCE INDIVIDUAL IDENTIFIED IN THIS DOCUMENT HAS THE LEGAL AUTHORITY TO BIND THE MANUFACTURER OR SUPPLIER OF THE MATERIAL.

1016-03013

2026-10-29
192
TR No. 620851-01-1:5

VALTIR

Certificate of Compliance

Certified By Signature:

Signature Date:

Printed Name:

Title: QUALITY ASSURANCE

Notary Public:

Commission Expires:

Amanda Ray
My Commission Expires
11/21/2028
Notary ID 135179492

APPENDIX F.

MASH TEST 3-10 (CRASH TEST 620851-01-1)

F.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2024-12-09 Test No.: 620851-01-1 VIN No.: 3N1CN7AP1KL873560

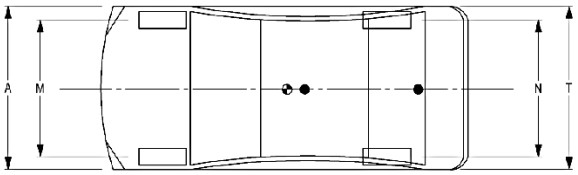
Year: 2019 Make: Nissan Model: Versa

Tire Inflation Pressure: 36 PSI Odometer: 124621 Tire Size: P185/65R15

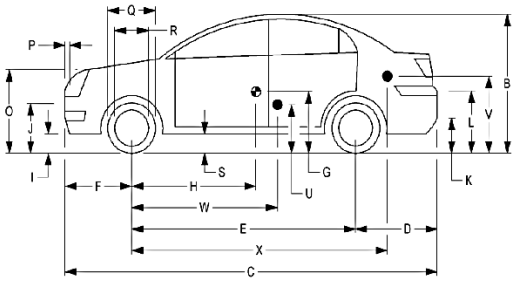
Describe any damage to the vehicle prior to test: None

● 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	0.00	L	26.00	Q	24.00	V	21.25
C	175.40	H	41.40	M	58.30	R	16.25	W	41.50
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	0.10

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}	1415	1445	1530
Back	1687	M_{rear}	960	982	1062
Total	3389	M_{Total}	2375	2427	2592

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

Mass Distribution:
lb LF: 763 RF: 682 LR: 476 RR: 506

Figure F.1. Vehicle Properties for Test 620851-01-1.

Date:	2024-12-09	Test No.:	620851-01-1	VIN No.:	3N1CN7AP1KL873560
Year:	2019	Make:	Nissan	Model:	Versa

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FRONT BUMPER	10	8.25	36	-	-	-	-	-	-	+5.5
2	AT FRONT BUMPER	10	12	47	-	-	-	-	-	-	56
	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.

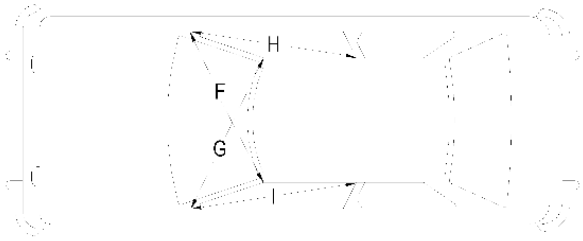
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

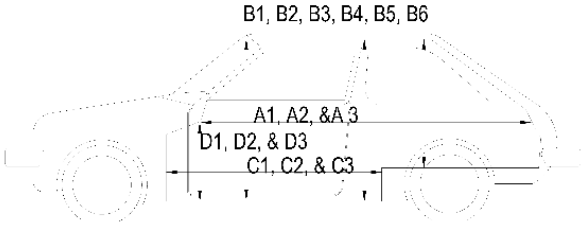
***Measure and document on the vehicle diagram the location of the maximum crush.

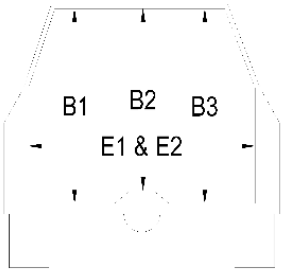
Note: Use as many lines/columns as necessary to describe each damage profile.

Figure F.2. Exterior Crush Measurements for Test 620851-01-1.

Date:	2024-12-09	Test No.:	620851-01-1	VIN No.:	3N1CN7AP1KL873560
Year:	2019	Make:	Nissan	Model:	Versa







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	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	25.75	-0.25
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

Figure F.3. Occupant Compartment Measurements for Test 620851-01-1.

F.2. SEQUENTIAL PHOTOGRAPHS



(a) 0.000 s (b) 0.1000 s



(c) 0.2000 s (d) 0.3000 s



(e) 0.4000 s (f) 0.5000 s



(g) 0.6000 s (h) 0.7000 s

Figure F.4. Sequential Photographs for Test 620851-01-1 (Overhead Views).



(a) 0.000 s (b) 0.1000 s



(c) 0.2000 s (d) 0.3000 s



(e) 0.4000 s (f) 0.5000 s



(g) 0.6000 s (h) 0.7000 s

Figure F.5. Sequential Photographs for Test 620851-01-1 (Downstream In-Line Views).



(a) 0.000 s (b) 0.1000 s



(c) 0.2000 s (d) 0.3000 s



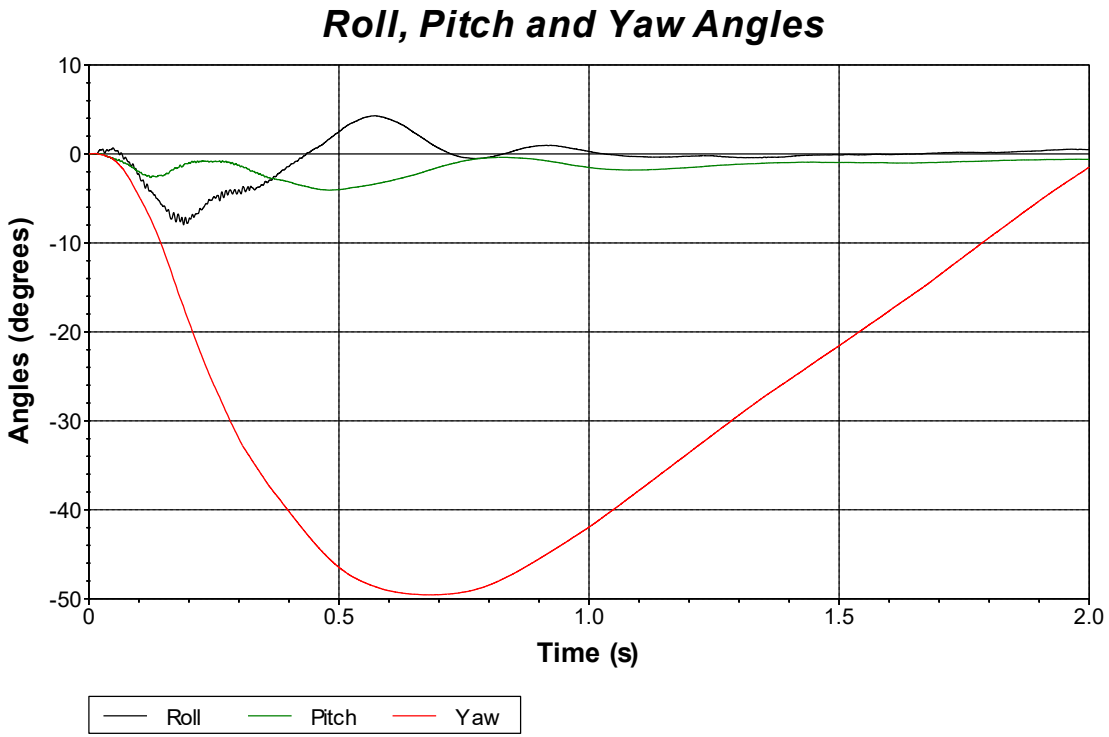
(e) 0.4000 s (f) 0.5000 s



(g) 0.6000 s (h) 0.7000 s

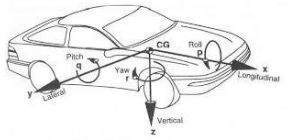
Figure F.6. Sequential Photographs for Test 620851-01-1 (Upstream Field Side Oblique Views).

F.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed. Sequence for determining orientation:

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



Test Number: 620851-01-1
Test Standard Test Number: *MASH* Test 3-10
Test Article: 21:1 Flared MGS
Test Vehicle: 2019 Nissan Versa
Inertial Mass: 2427 lbs
Gross Mass: 2592 lbs
Impact Speed: 61.5 mi/h
Impact Angle: 25.24°

Figure F.7. Vehicle Angular Displacements for Test 620851-01-1.

F.4. VEHICLE ACCELERATIONS

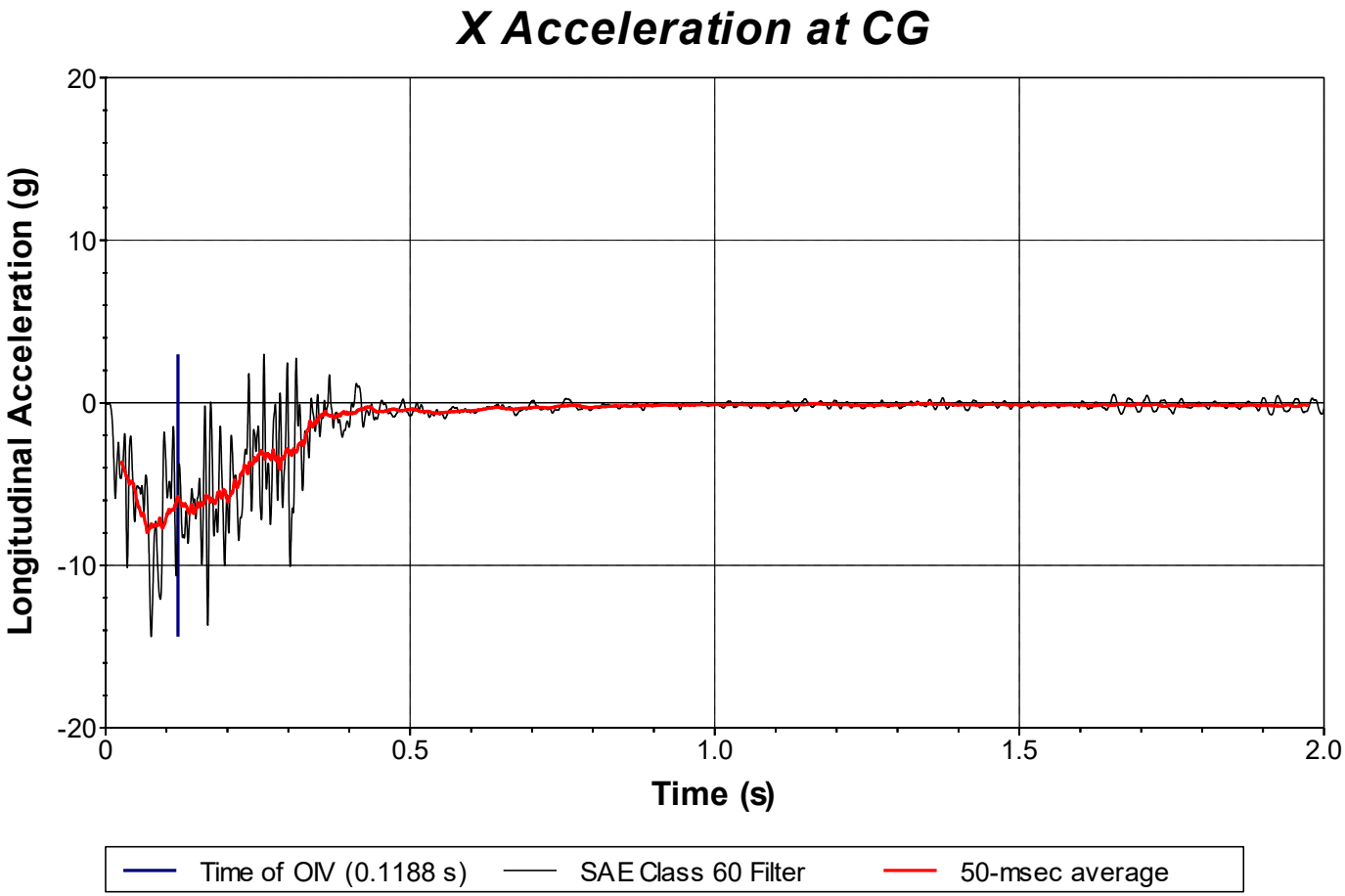


Figure F.8. Vehicle Longitudinal Accelerometer Trace for Test 620851-01-1 (Accelerometer Located at Center of Gravity).

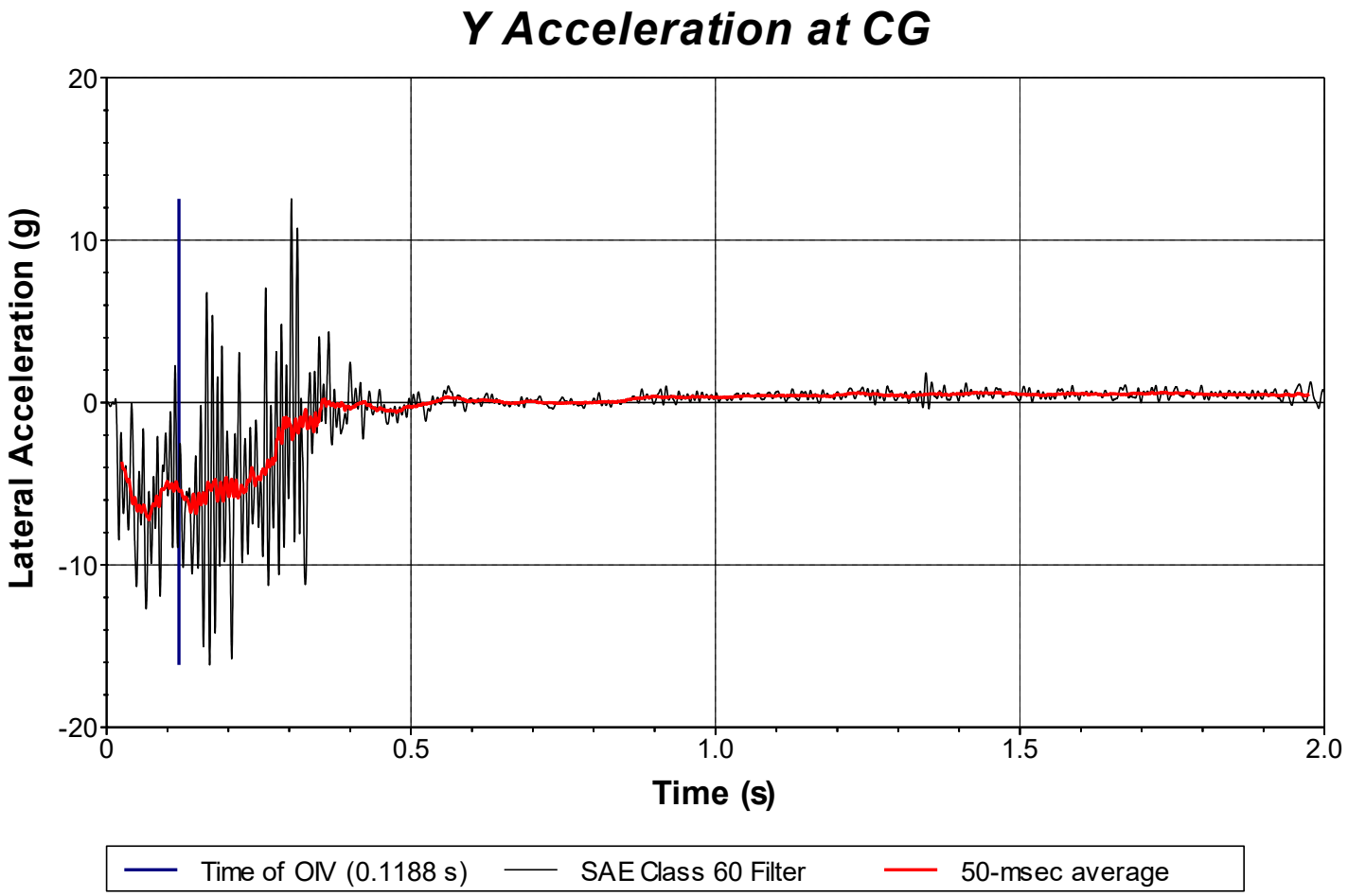


Figure F.9. Vehicle Lateral Accelerometer Trace for Test 620851-01-1 (Accelerometer Located at Center of Gravity).

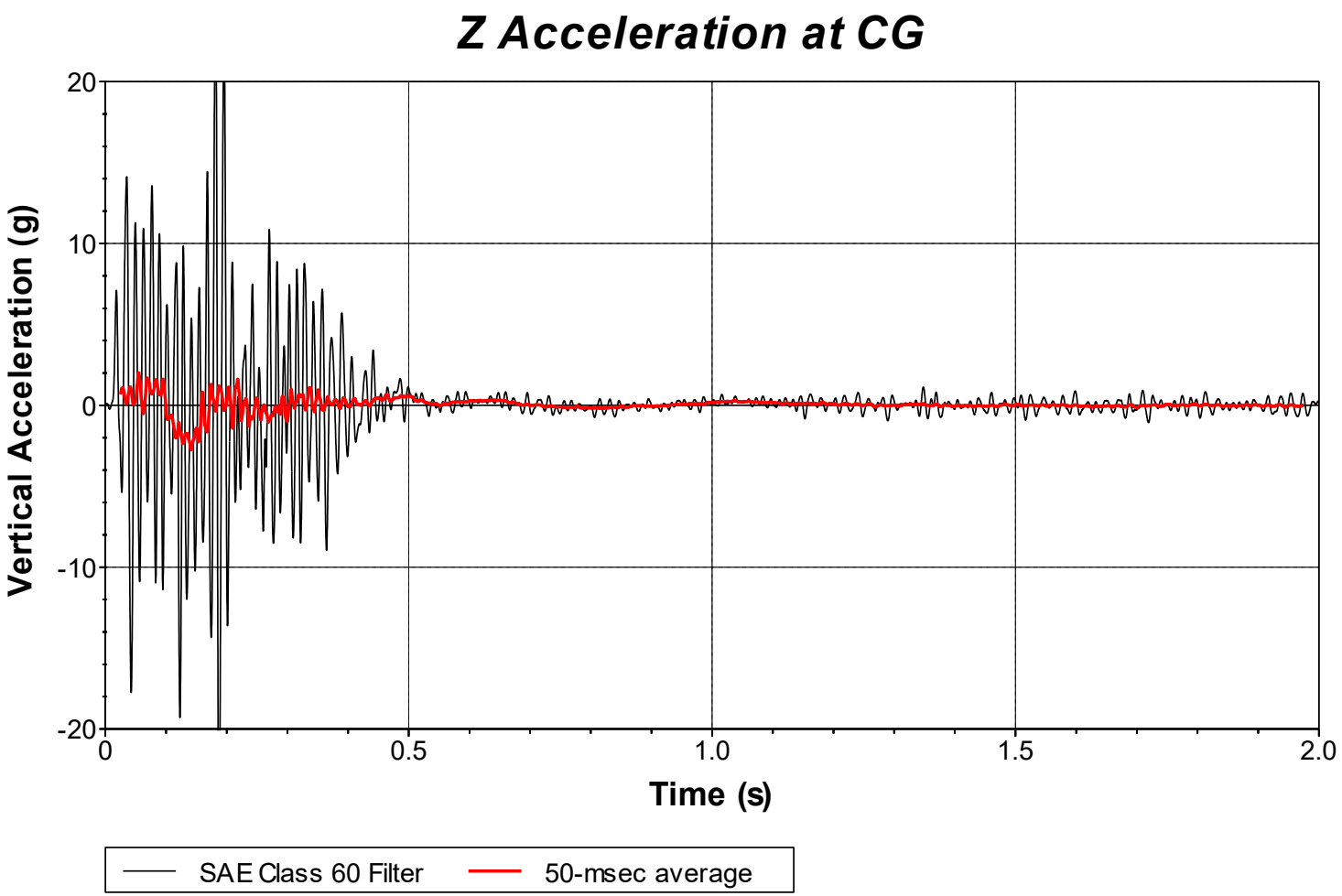


Figure F.10. Vehicle Vertical Accelerometer Trace for Test 620851-01-1 (Accelerometer Located at Center of Gravity).

APPENDIX G.

MASH TEST 3-11 (CRASH TEST 620851-01-2)

G.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2024-12-13 Test No.: 620851-01-2 VIN No.: 1C6RR6FT6KS683841

Year: 2019 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 124656

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

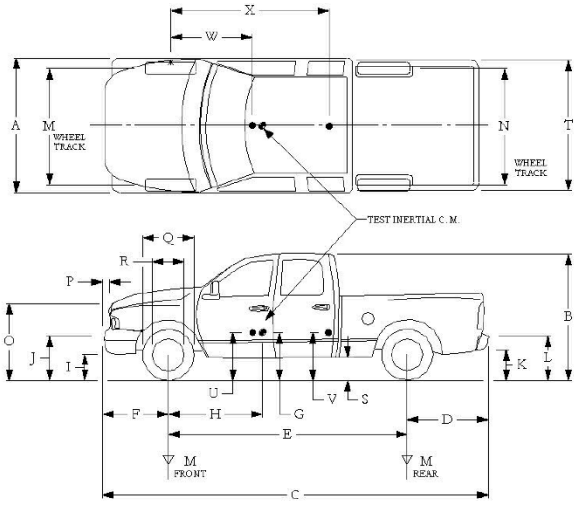
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

Dummy Data:
Type:
Mass:
Seat Position:



Geometry: inches

A	78.50	F	40.25	K	20.00	P	3.00	U	26.75
B	74.00	G	28.62	L	30.00	Q	30.50	V	30.25
C	229.00	H	62.52	M	68.50	R	18.00	W	62.50
D	48.25	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}	2907	2811	2811
Back	3900	M_{rear}	2061	2254	2254
Total	6700	M_{Total}	4968	5065	5065

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

Mass Distribution:
lb LF: 1402 RF: 1409 LR: 1101 RR: 1153

Figure G.1. Vehicle Properties for Test 620851-01-2.

Date:	2024-12-13	Test No.:	620851-01-2	VIN No.:	1C6RR6FT6KS683841
Year:	2019	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 FRONT BUMPER	18	20	60	-	-	-	-	-	-	+6
	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.

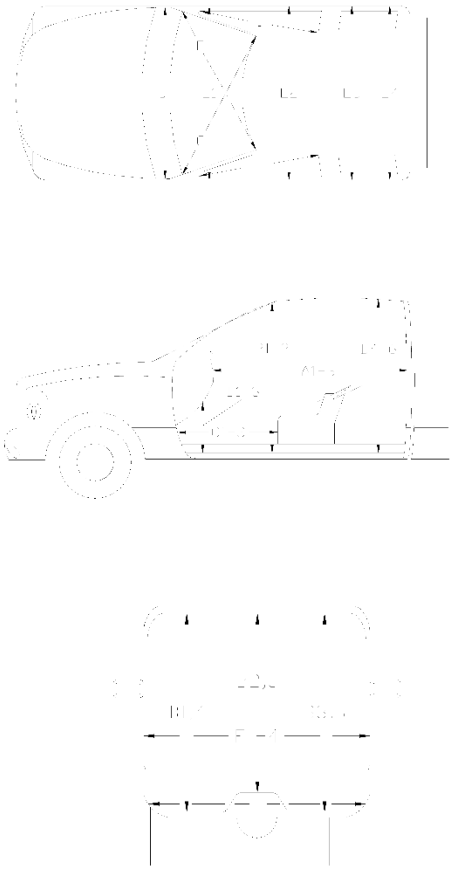
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 G.2. Exterior Crush Measurements for Test 620851-01-2.

Date:	2024-12-13	Test No.:	620851-01-2	VIN No.:	1C6RR6FT6KS683841
Year:	2019	Make:	RAM	Model:	1500



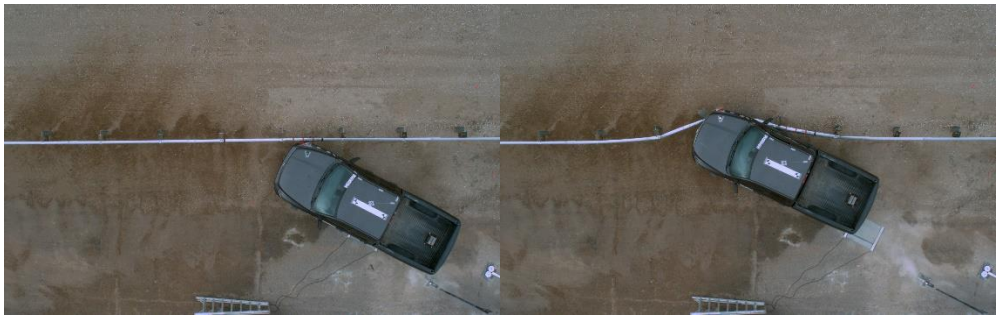
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

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 G.3. Occupant Compartment Measurements for Test 620851-01-2.

G.2. SEQUENTIAL PHOTOGRAPHS



(a) 0.000 s (b) 0.1000 s



(c) 0.2000 s (d) 0.3000 s

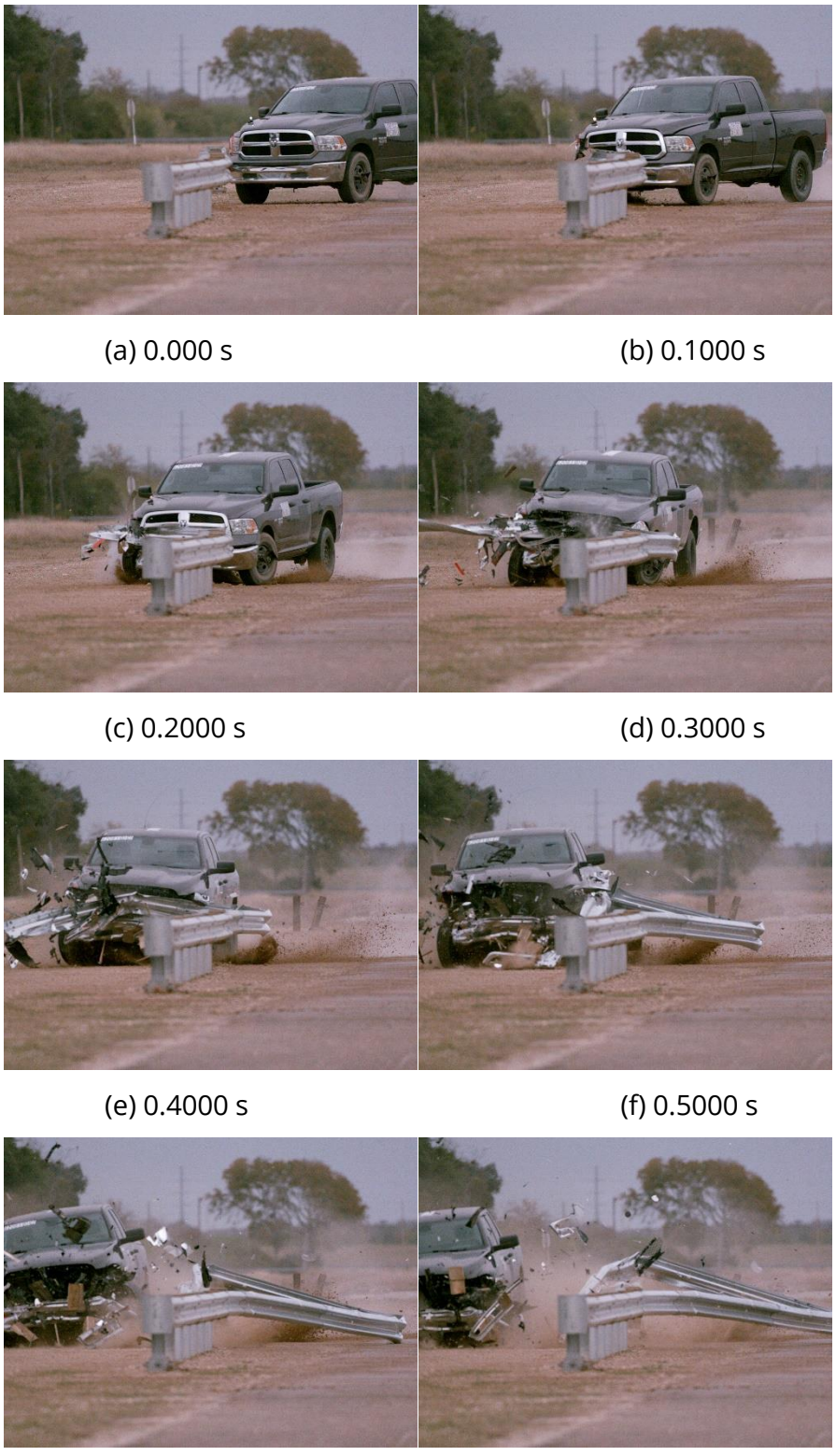


(e) 0.4000 s (f) 0.5000 s



(g) 0.6000 s (h) 0.7000 s

Figure G.4. Sequential Photographs for Test 620851-01-2 (Overhead Views).



(a) 0.000 s (b) 0.1000 s

(c) 0.2000 s (d) 0.3000 s

(e) 0.4000 s (f) 0.5000 s

(g) 0.6000 s (h) 0.7000 s

Figure G.5. Sequential Photographs for Test 620851-01-2 (Downstream Oblique Views).



(a) 0.000 s (b) 0.1000 s



(c) 0.2000 s (d) 0.3000 s



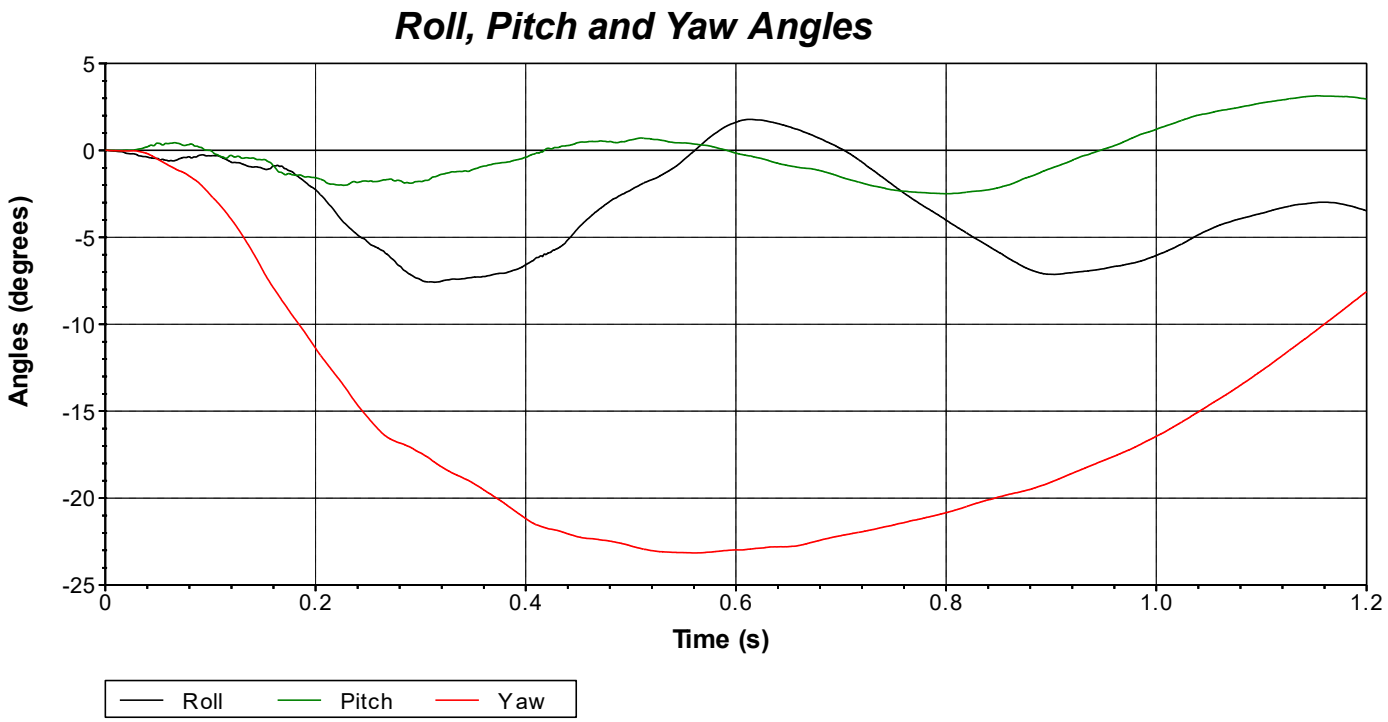
(e) 0.4000 s (f) 0.5000 s



(g) 0.6000 s (h) 0.7000 s

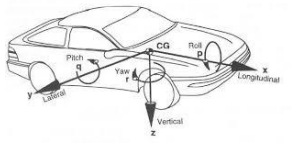
Figure G.6. Sequential Photographs for Test 620851-01-2 (Upstream Field Side Oblique Views).

G.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

4. *Yaw.*
5. *Pitch.*
6. *Roll.*



Test Number: 620851-01-2
Test Standard Test Number: *MASH* Test 3-11
Test Article: 21:1 Flared MGS
Test Vehicle: 2019 RAM 1500
Inertial Mass: 5065 lbs
Gross Mass: 5065 lbs
Impact Speed: 60.6 mi/h
Impact Angle: °

Figure G.7. Vehicle Angular Displacements for Test 620851-01-2.

G.4. VEHICLE ACCELERATIONS

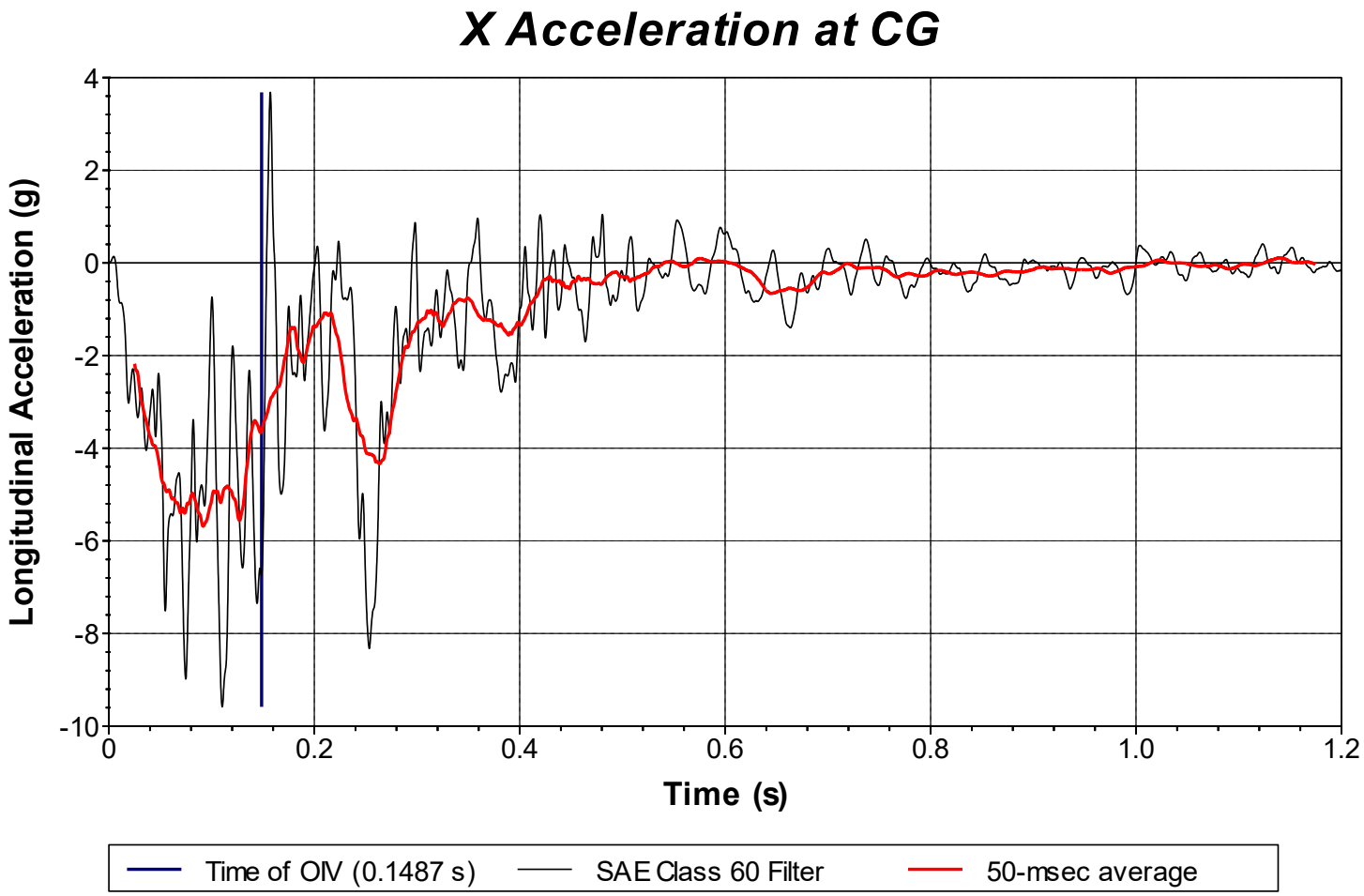


Figure G.8. Vehicle Longitudinal Accelerometer Trace for Test 620851-01-2 (Accelerometer Located at Center of Gravity).

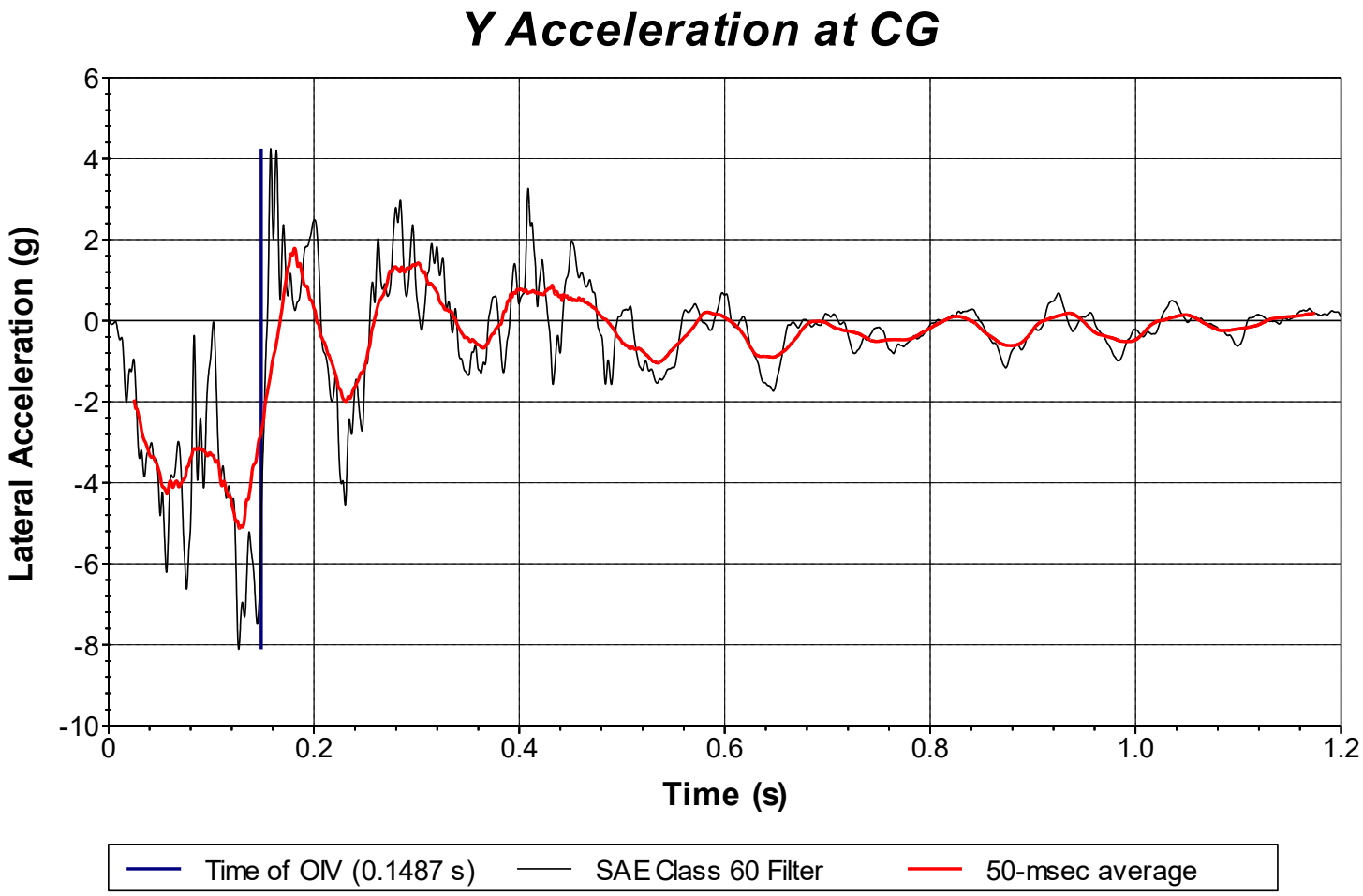


Figure G.9. Vehicle Lateral Accelerometer Trace for Test 620851-01-2 (Accelerometer Located at Center of Gravity).

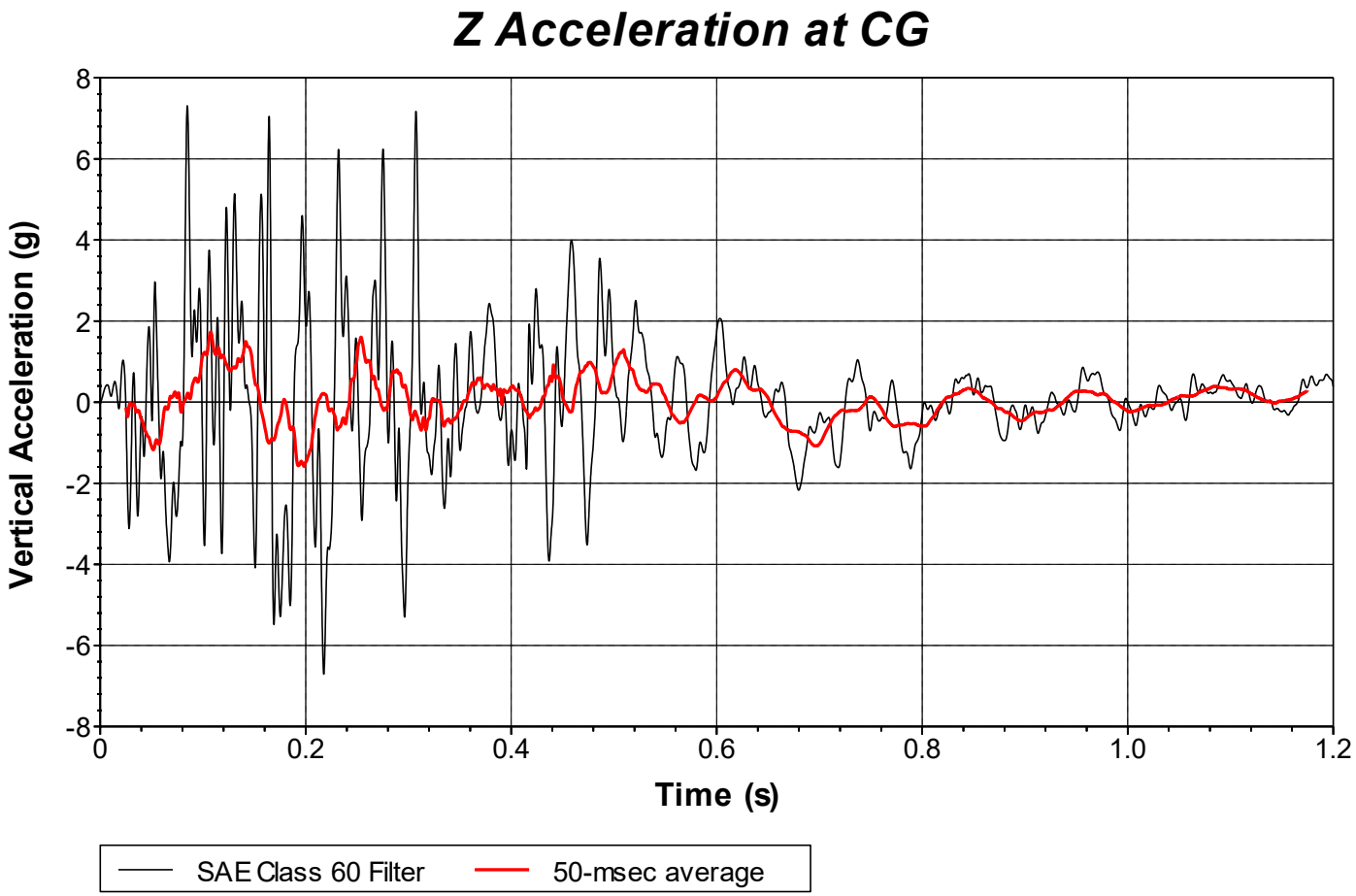


Figure G.10. Vehicle Vertical Accelerometer Trace for Test 620851-01-2 (Accelerometer Located at Center of Gravity).

APPENDIX H.

MASH TEST 3-11 (CRASH TEST 620851-01-3)

H.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2025-05-19 Test No.: 620851-01-3 VIN No.: 1C6RR6FT4LS114469

Year: 2020 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 129593

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

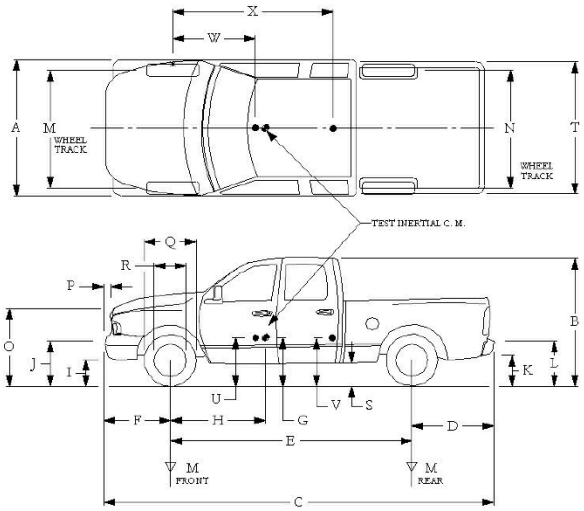
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

Dummy Data:
Type:
Mass:
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	29.00	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.10	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}	2946	2886	2886
Back	3900	M_{rear}	2129	2152	2152
Total	6700	M_{Total}	5075	5038	5038

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

Mass Distribution:
lb LF: 1418 RF: 1468 LR: 1132 RR: 1020

Figure H.1. Vehicle Properties for Test 620851-01-3.

Date:	2025-05-19	Test No.:	620851-01-3	VIN No.:	1C6RR6FT4LS114469
Year:	2020	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 FRONT BUMPER	18	10	32	-	-	-	-	-	-	+20
2	SAME	18	14	58	-	-	-	-	-	-	70
3	AT FRONT BUMPER	18	16	30	-	-	-	-	-	-	-22
	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.

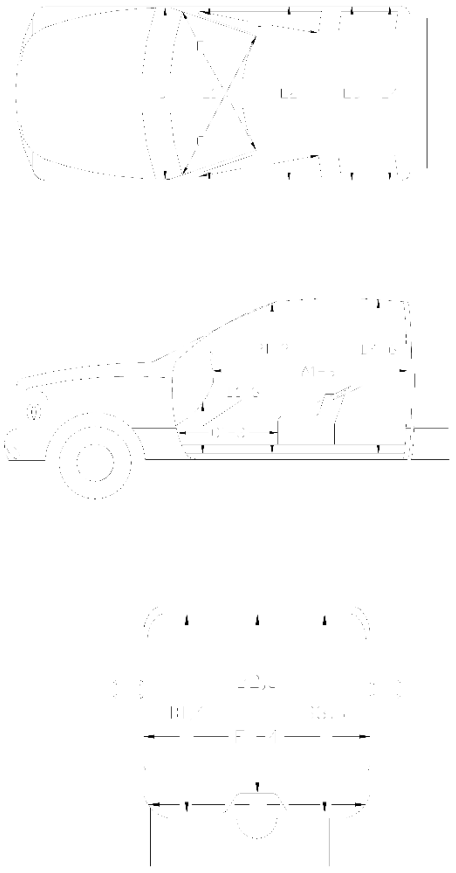
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 H.2. Exterior Crush Measurements for Test 620851-01-3.

Date:	2025-05-19	Test No.:	620851-01-3	VIN No.:	1C6RR6FT4LS114469
Year:	2020	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	44.75	-0.25
B2	38.00	37.50	-0.50
B3	45.00	44.00	-1.00
B4	39.50	39.00	-0.50
B5	43.00	42.50	-0.50
B6	39.50	39.00	-0.50
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 H.3. Occupant Compartment Measurements for Test 620851-01-3.

H.2. SEQUENTIAL PHOTOGRAPHS



(a) 0.000 s (b) 0.1000 s



(c) 0.2000 s (d) 0.3000 s



(e) 0.4000 s (f) 0.5000 s



(g) 0.6000 s (h) 0.7000 s

Figure H.4. Sequential Photographs for Test 620851-01-3 (Overhead Views).



(a) 0.000 s (b) 0.1000 s



(c) 0.2000 s (d) 0.3000 s



(e) 0.4000 s (f) 0.5000 s



(g) 0.6000 s (h) 0.7000 s

Figure H.5. Sequential Photographs for Test 620851-01-3 (Upstream Traffic Side Oblique Views).



(a) 0.000 s (b) 0.1000 s

(c) 0.2000 s (d) 0.3000 s

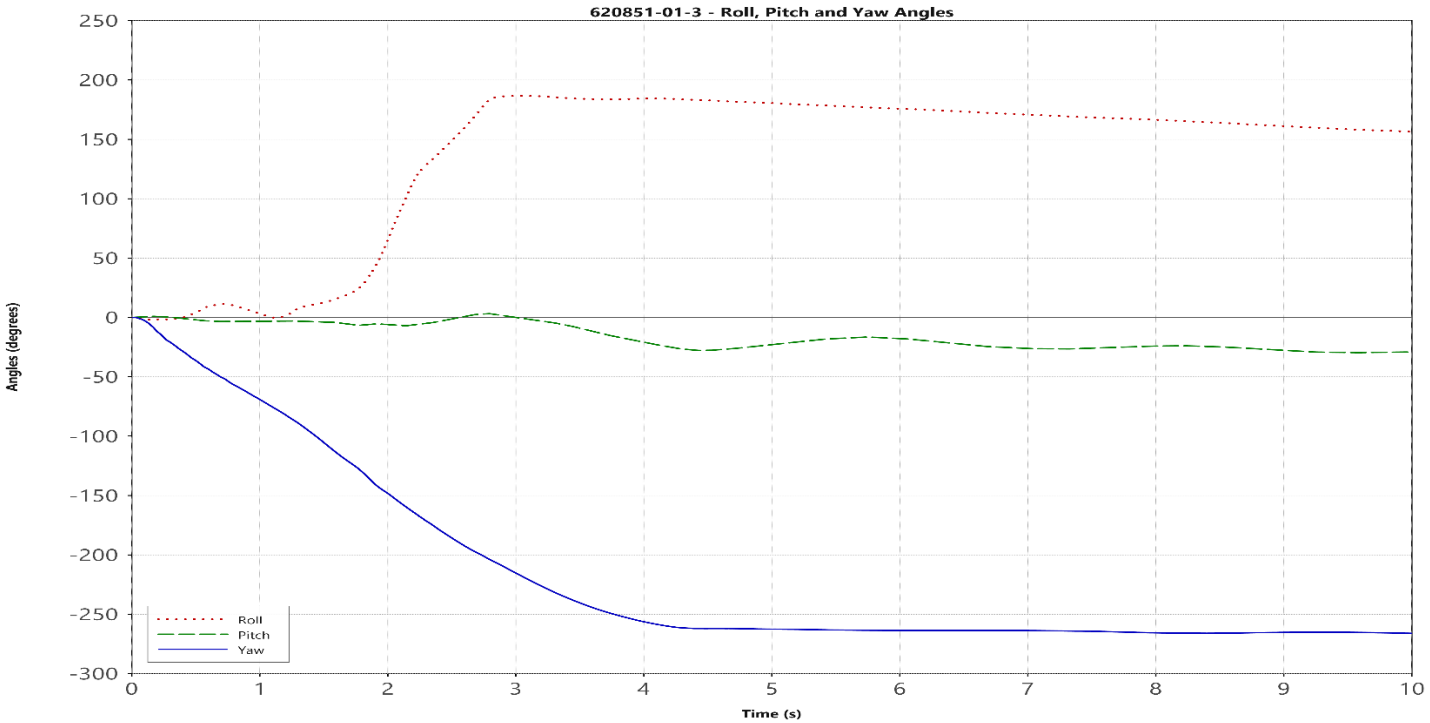
(e) 0.4000 s (f) 0.5000 s

(g) 0.6000 s (h) 0.7000 s

Figure H.6. Sequential Photographs for Test 620851-01-3 (Downstream Field Side Oblique Views).

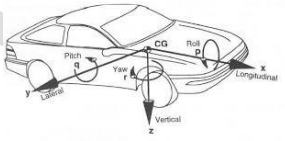
H.3. VEHICLE ANGULAR DISPLACEMENTS

DRAFT



Axes are vehicle-fixed.
Sequence for determining orientation:

7. *Yaw.*
8. *Pitch.*
9. *Roll.*



Test Number: 620851-01-3
Test Standard Test Number: *MASH* Test 3-11
Test Article: 21:1 Flared MGS
Test Vehicle: 2019 RAM 1500
Inertial Mass: 5065 lbs
Gross Mass: 5065 lbs
Impact Speed: 60.6 mi/h
Impact Angle: °

Figure H.7. Vehicle Angular Displacements for Test 620851-01-3.

H.4. VEHICLE ACCELERATIONS

DRAFT

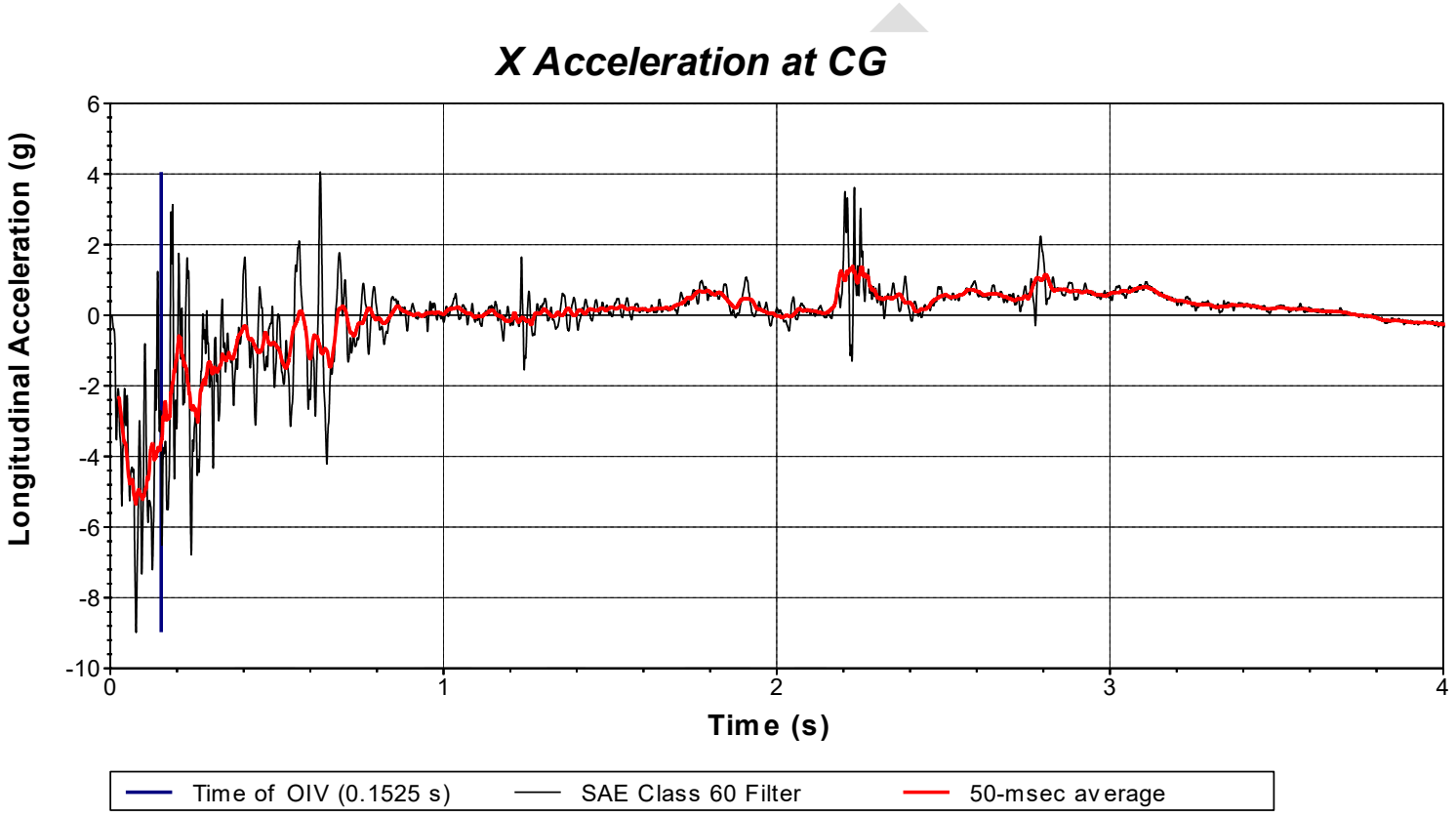


Figure H.8. Vehicle Longitudinal Accelerometer Trace for Test 620851-01-3 (Accelerometer Located at Center of Gravity).

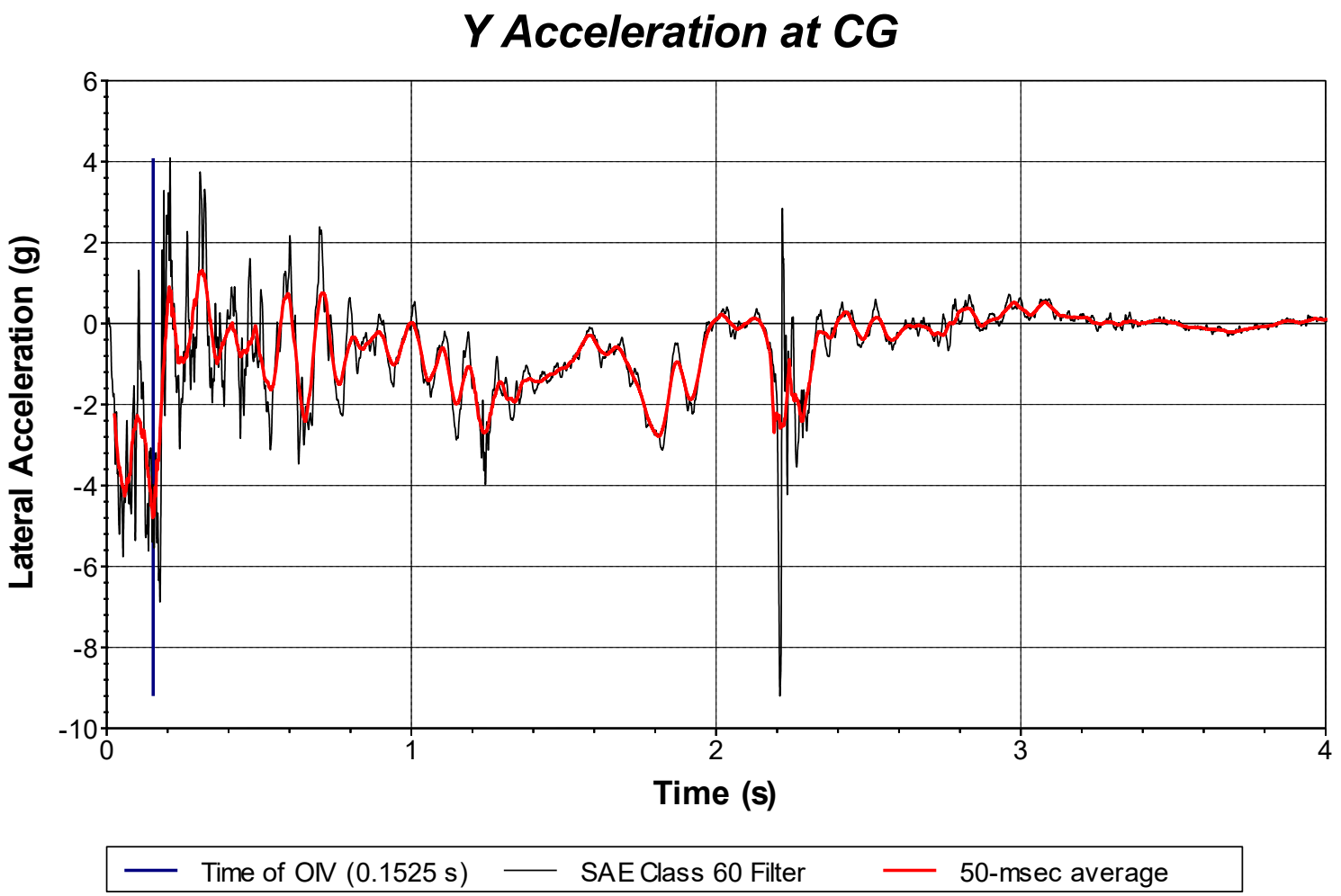


Figure H.9. Vehicle Lateral Accelerometer Trace for Test 620851-01-3 (Accelerometer Located at Center of Gravity).

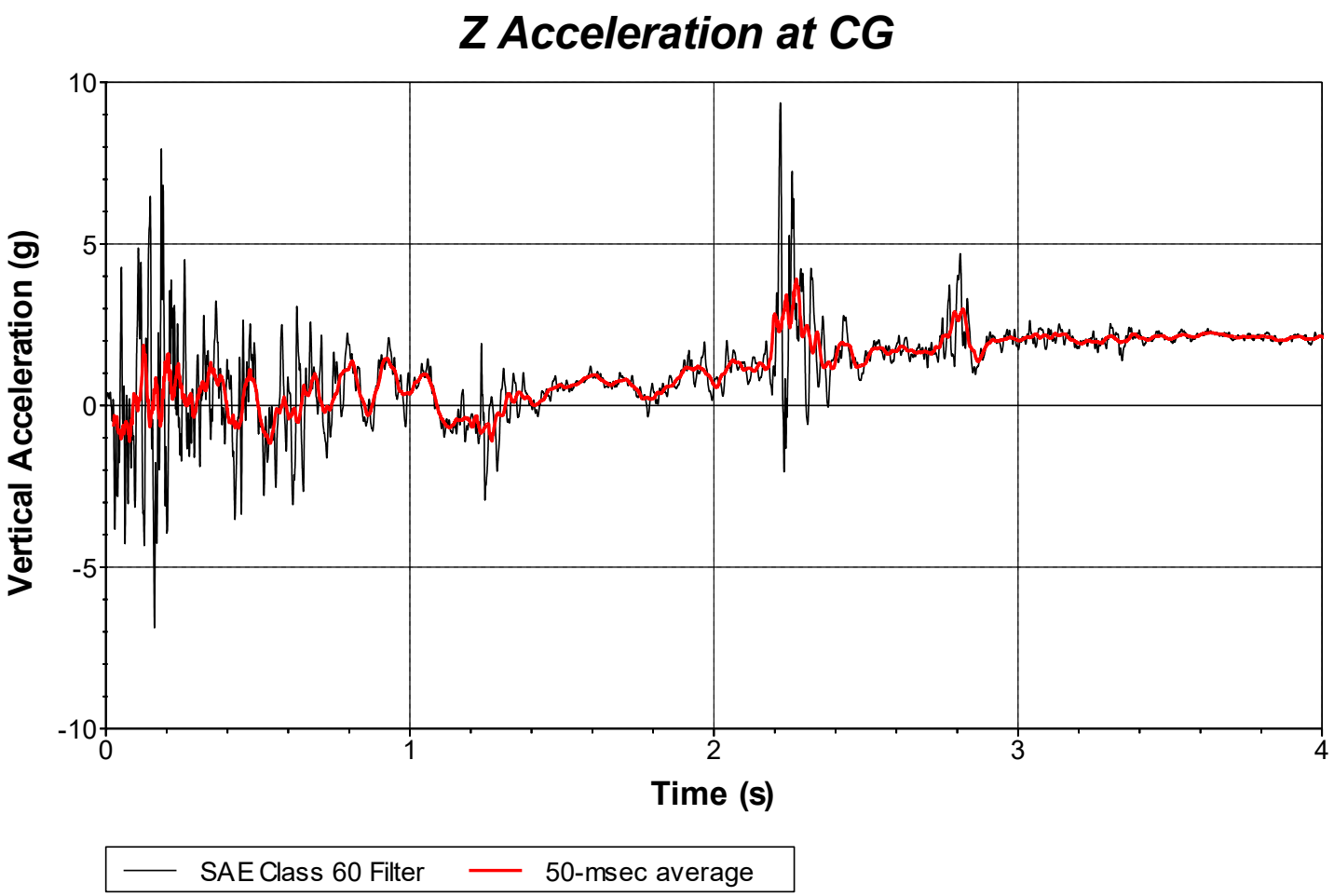


Figure H.10. Vehicle Vertical Accelerometer Trace for Test 620851-01-3 (Accelerometer Located at Center of Gravity).

APPENDIX I.

MASH TEST 3-11 (CRASH TEST 620851-01-4)

I.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2026-03-24 Test No.: 620851-01-4 VIN No.: 1C6RR6FT7MS534342

Year: 2021 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 142,411

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

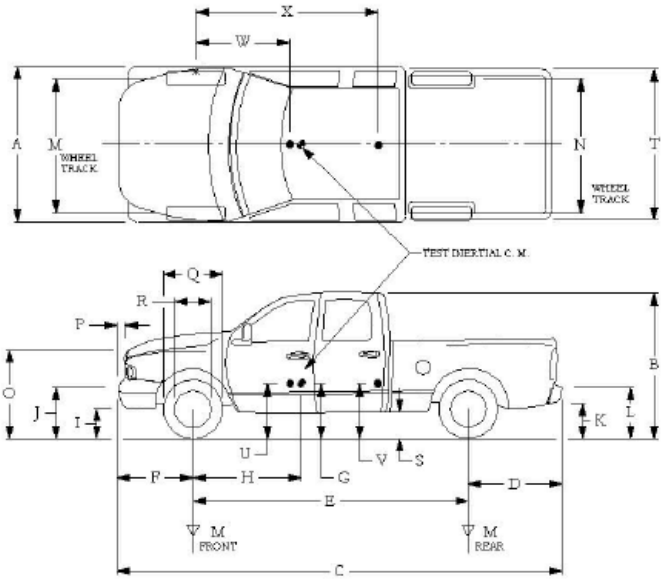
NOTES: None

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: lb
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	29.25	L	30.00	Q	30.50	V	30.25
C	227.50	H	62.30	M	68.50	R	18.00	W	0.00
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=81 ±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=68 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2900	2821	
Back	3900	M_{rear}	2027	2249	
Total	6700	M_{Total}	4927	5070	5070

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

Mass Distribution:
lb LF: 1407 RF: 1414 LR: 1139 RR: 1110

Figure I.1. Vehicle Properties for Test 620851-01-4.

Date:	2026-03-24	Test No.:	620851-01-4	VIN No.:	1C6RR6FT7MS534342
Year:	2021	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AFB	26	20	68							21
1	AFB	40	16	65							90
	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.

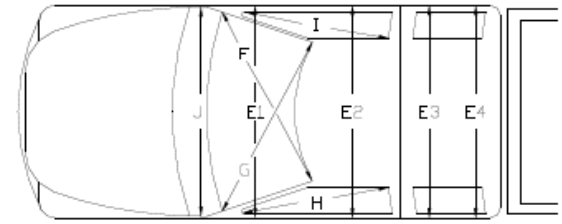
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

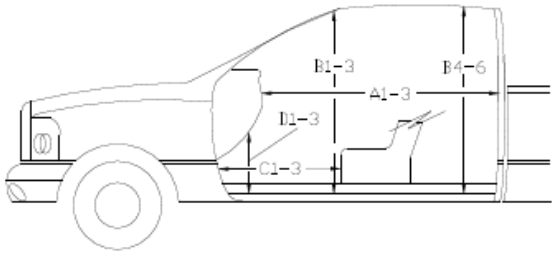
***Measure and document on the vehicle diagram the location of the maximum crush.

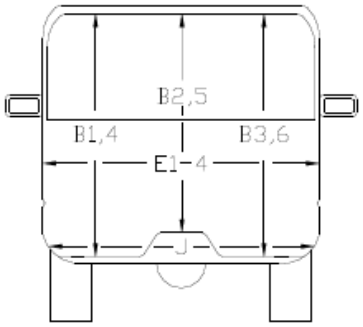
Note: Use as many lines/columns as necessary to describe each damage profile.

Figure I.2. Exterior Crush Measurements for Test 620851-01-4.

Date:	2026-03-24	Test No.:	620851-01-4	VIN No.:	1C6RR6FT7MS534342
Year:	2021	Make:	RAM	Model:	1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

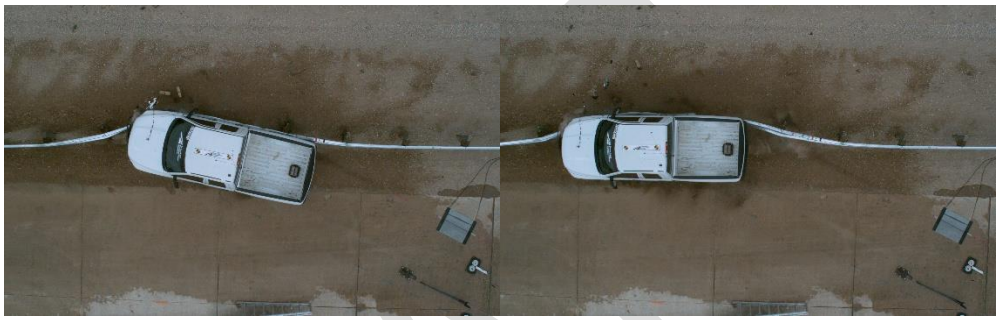
	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	58.50	0.00
E2	63.50	64.90	1.40
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 I.3. Occupant Compartment Measurements for Test 620851-01-4.

I.2. SEQUENTIAL PHOTOGRAPHS



(a) 0.000 s (b) 0.1000 s



(c) 0.2000 s (d) 0.3000 s

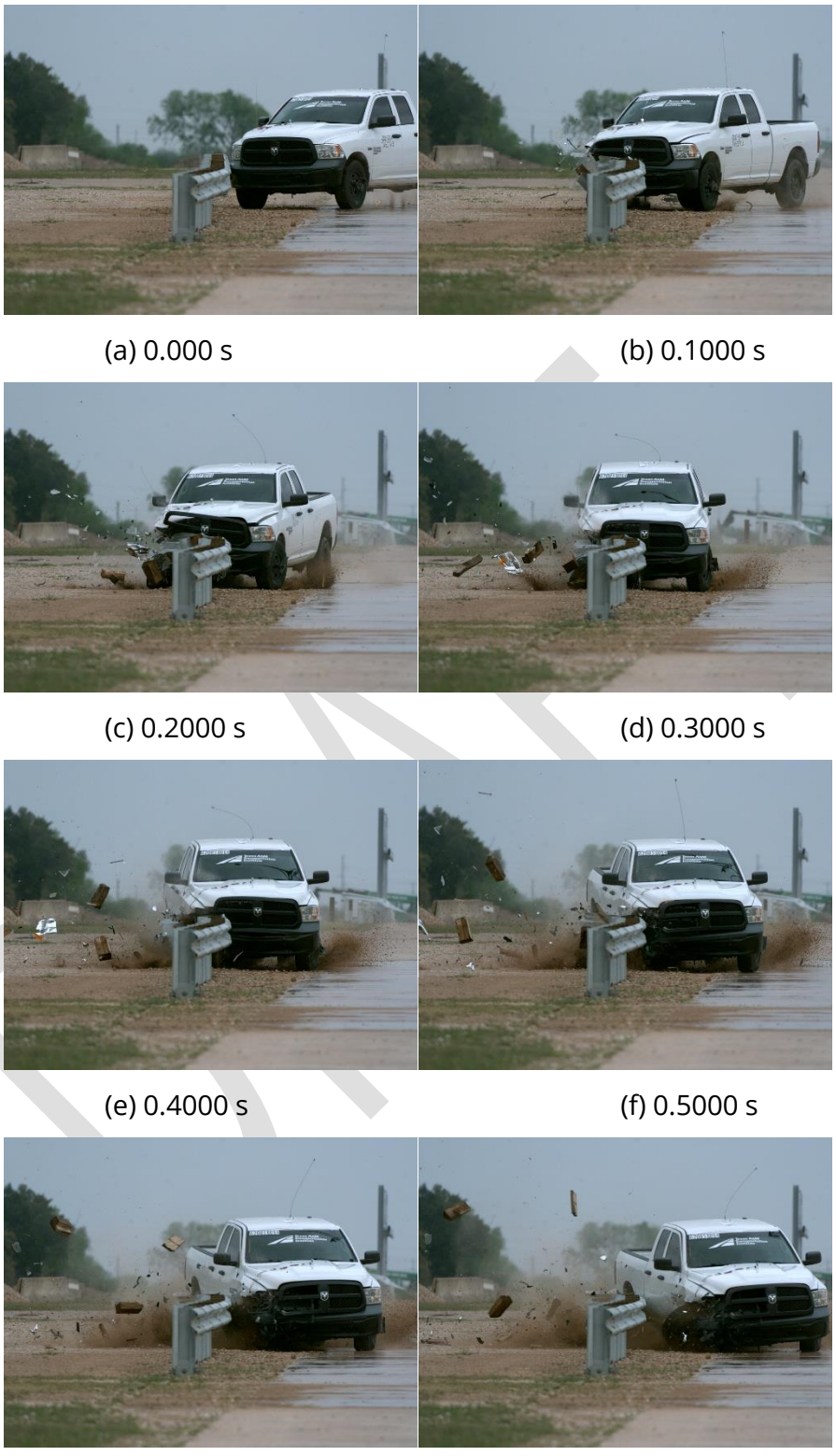


(e) 0.4000 s (f) 0.5000 s



(g) 0.6000 s (h) 0.7000 s

Figure I.4. Sequential Photographs for Test 620851-01-4 ([Camera #1] Views).



(a) 0.000 s (b) 0.1000 s

(c) 0.2000 s (d) 0.3000 s

(e) 0.4000 s (f) 0.5000 s

(g) 0.6000 s (h) 0.7000 s

Figure I.5. Sequential Photographs for Test 620851-01-4 ([Camera #2] Views).



(a) 0.000 s (b) 0.1000 s



(c) 0.2000 s (d) 0.3000 s



(e) 0.4000 s (f) 0.5000 s

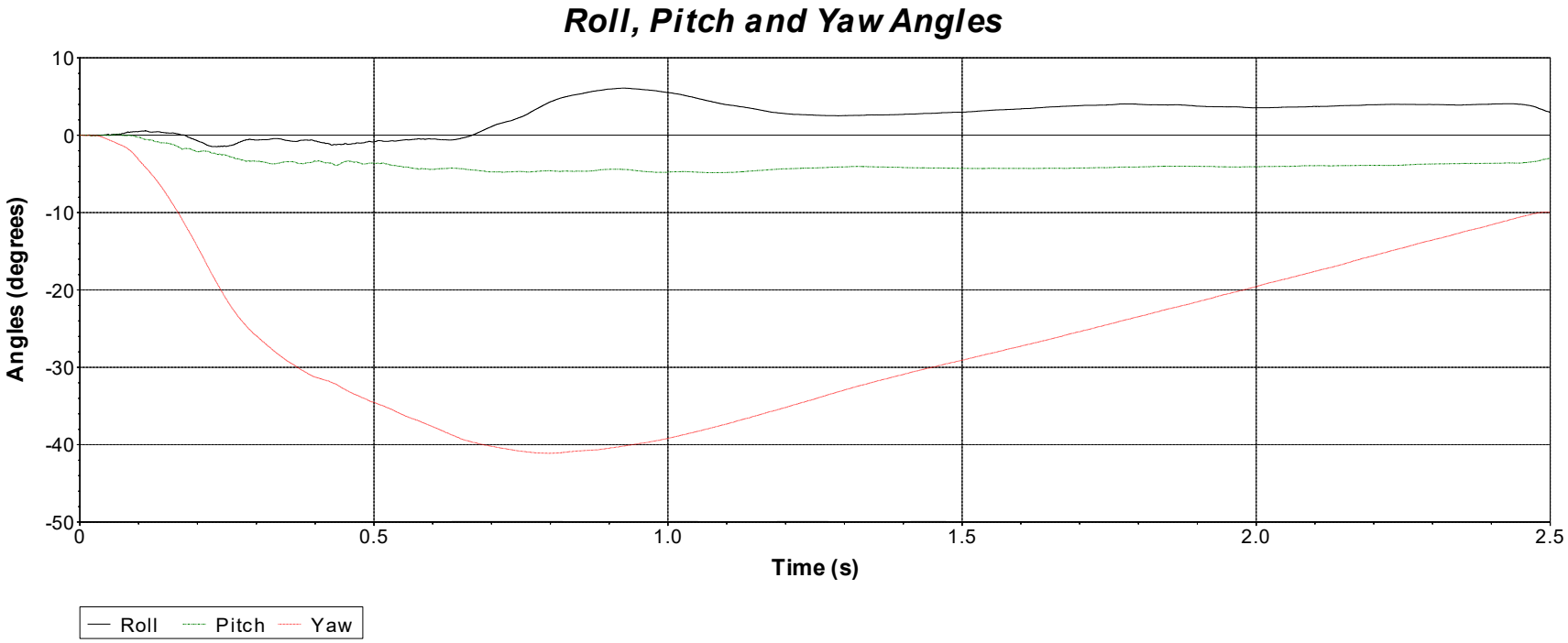


(g) 0.6000 s (h) 0.7000 s

Figure I.6. Sequential Photographs for Test 620851-01-4 ([Camera #3] Views).

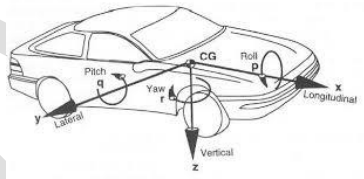
I.3. VEHICLE ANGULAR DISPLACEMENTS

DRAFT



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 620851-01-4
Test Standard Test Number: *MASH* Test 3-11
Test Article: 38:1 Flared MGS
Test Vehicle: 2021 RAM 1500
Inertial Mass: 5070 lbs
Gross Mass: 5070 lbs
Impact Speed: 61.7 mi/h
Impact Angle: 25.6°

Figure I.7. Vehicle Angular Displacements for Test 620851-01-4.

I.4. VEHICLE ACCELERATIONS

DRAFT

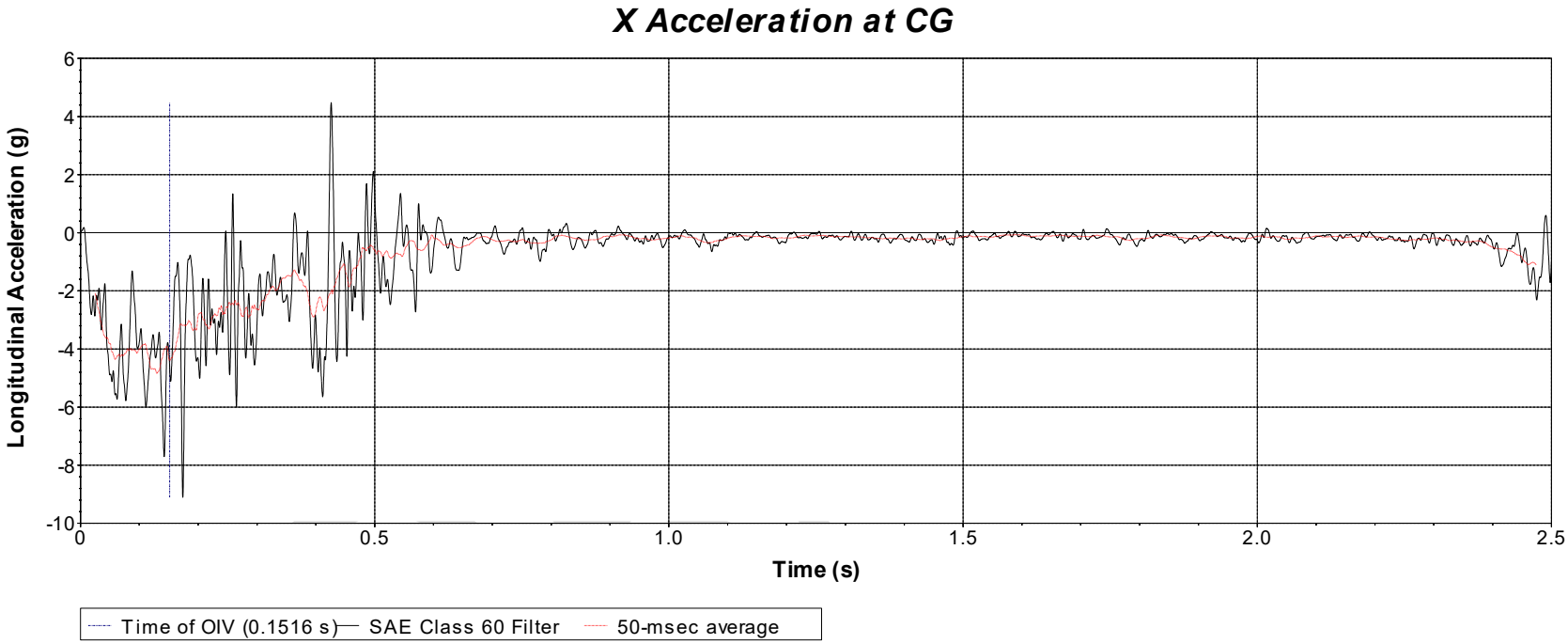


Figure I.8. Vehicle Longitudinal Accelerometer Trace for Test 620851-01-4 (Accelerometer Located at Center of Gravity).

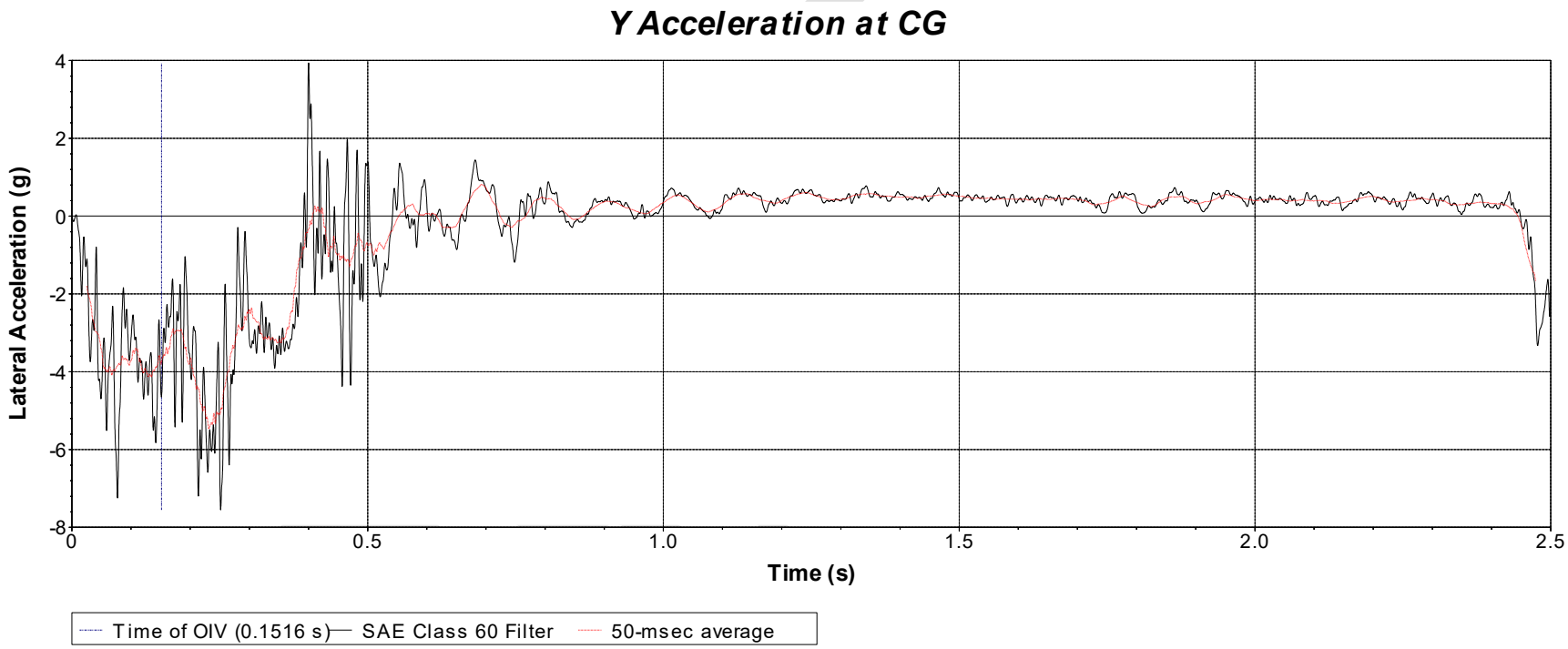


Figure I.9. Vehicle Lateral Accelerometer Trace for Test 620851-01-4 (Accelerometer Located at Center of Gravity).

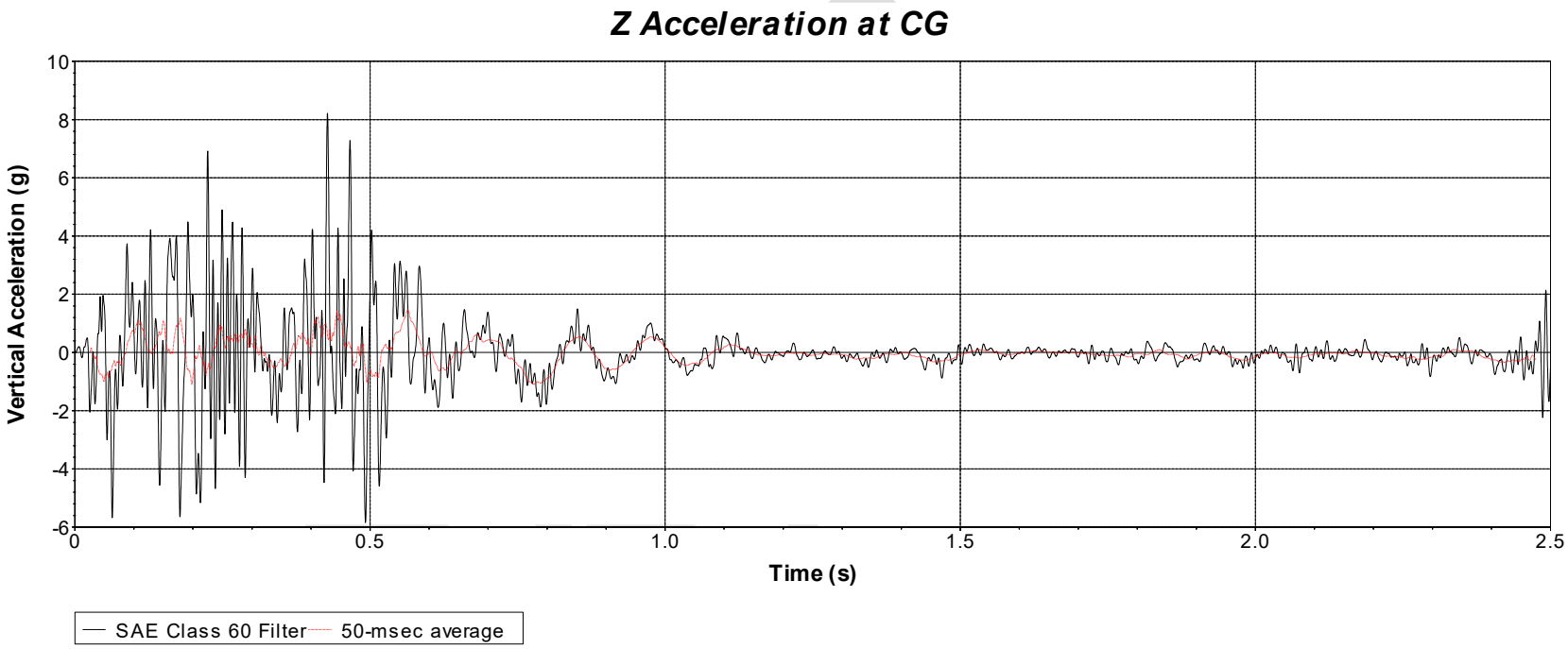


Figure I.10. Vehicle Vertical Accelerometer Trace for Test 620851-01-4 (Accelerometer Located at Center of Gravity).

APPENDIX J.

MASH TEST 3-11 (CRASH TEST 620851-01-5)

J.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2026-05-06 Test No.: 620851-01-5 VIN No.: 1C6RR6GT8MS578642

Year: 2021 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 87,692

Note any damage to the vehicle prior to test: None

• Denotes accelerometer location.

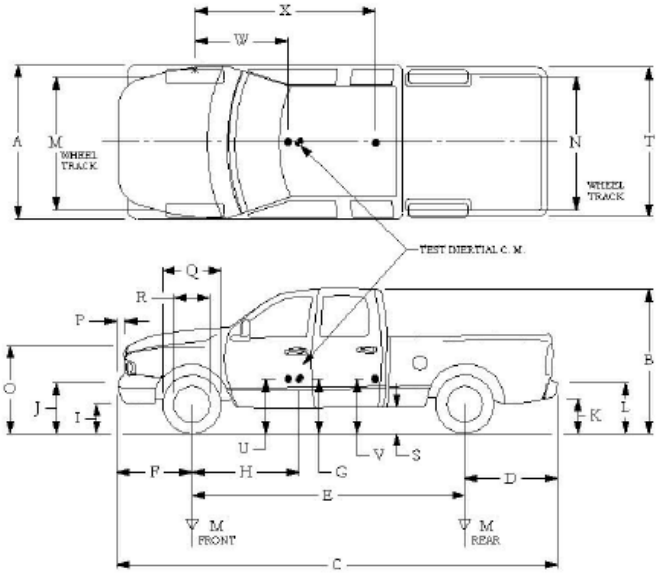
NOTES: None

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: lb
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	61.40	M	68.50	R	18.00	W	0.00
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=81 ±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=68 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2948	2841	
Back	3900	M_{rear}	2055	2205	
Total	6700	M_{Total}	5003	5046	5046

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

Mass Distribution:
lb LF: 1402 RF: 1439 LR: 1150 RR: 1055

Figure J.1. Vehicle Properties for Test 620851-01-5.

Date: 2026-05-06 Test No.: 620851-01-5 VIN No.: 1C6RR6GT8MS578642

Year: 2021 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	AFB	25	24	71							24.5
1	AFB	45	12	61							115.25
	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.

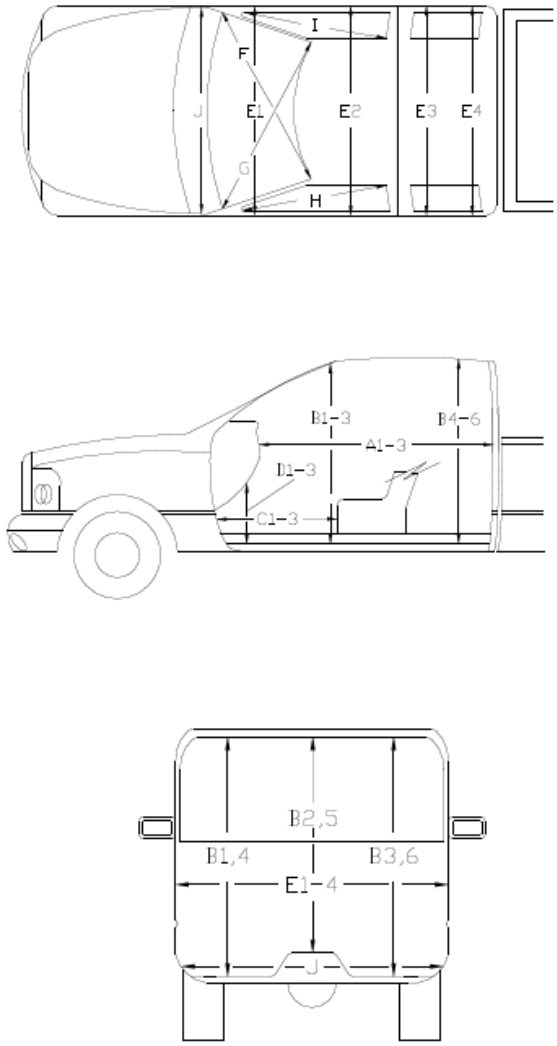
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 J.2. Exterior Crush Measurements for Test 620851-01-5.

Date:	2026-05-06	Test No.:	620851-01-5	VIN No.:	1C6RR6GT8MS578642
Year:	2021	Make:	RAM	Model:	1500



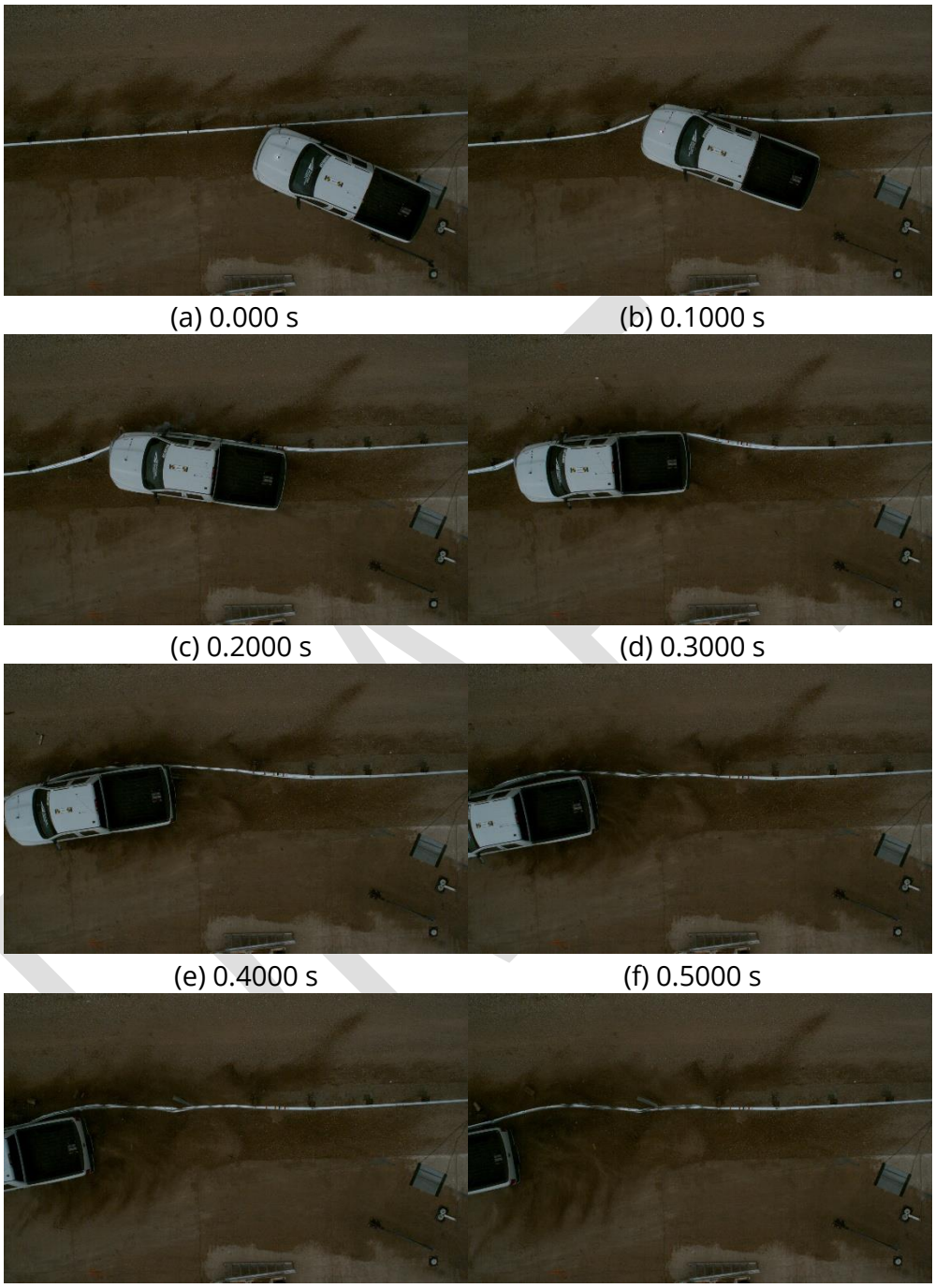
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

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	25.50	-0.50
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.00	-0.50
E1	58.50	58.25	-0.25
E2	63.50	64.00	0.50
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	24.00	-1.00

Figure J.3. Occupant Compartment Measurements for Test 620851-01-5.

J.2. SEQUENTIAL PHOTOGRAPHS



(a) 0.000 s (b) 0.1000 s

(c) 0.2000 s (d) 0.3000 s

(e) 0.4000 s (f) 0.5000 s

(g) 0.6000 s (h) 0.7000 s

Figure J.4. Sequential Photographs for Test 620851-01-5 ([Camera #1] Views).



(a) 0.000 s (b) 0.1000 s

(c) 0.2000 s (d) 0.3000 s

(e) 0.4000 s (f) 0.5000 s

(g) 0.6000 s (h) 0.7000 s

Figure J.5. Sequential Photographs for Test 620851-01-5 ([Camera #2] Views).



(a) 0.000 s (b) 0.1000 s



(c) 0.2000 s (d) 0.3000 s



(e) 0.4000 s (f) 0.5000 s

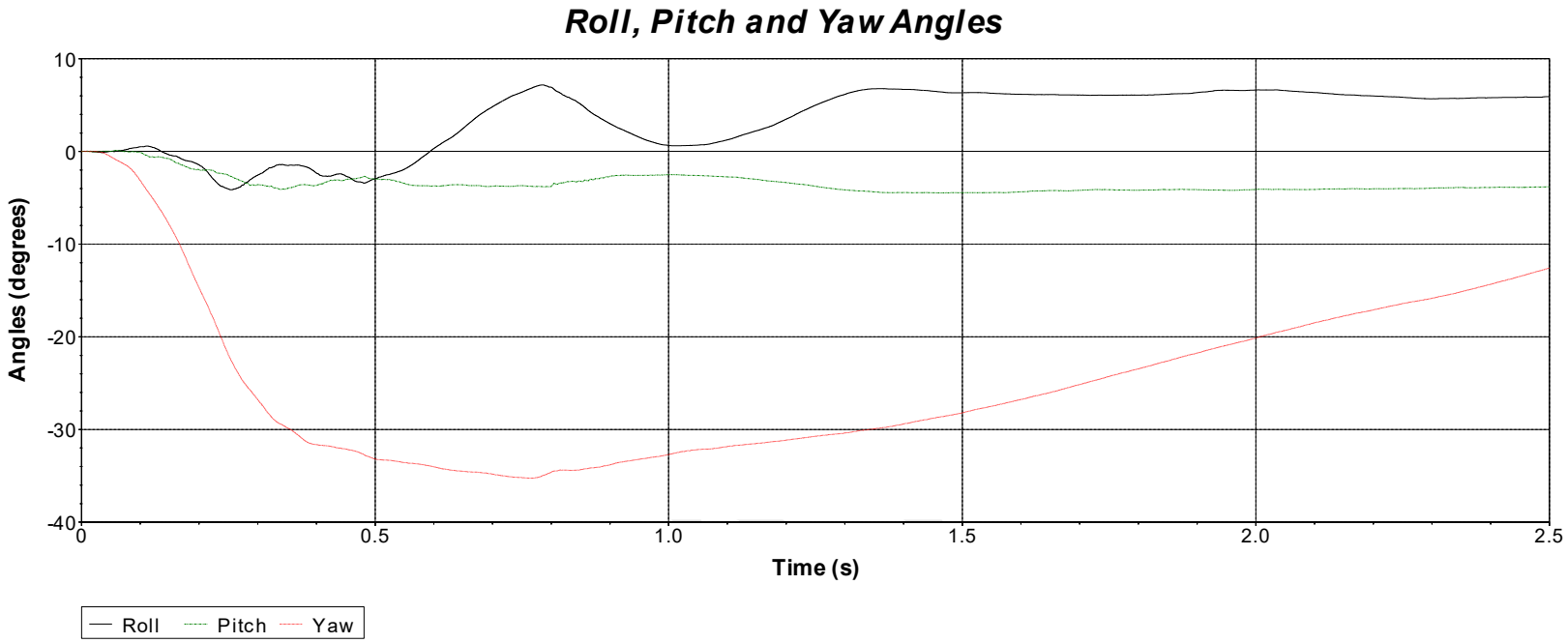


(g) 0.6000 s (h) 0.7000 s

Figure J.6. Sequential Photographs for Test 620851-01-5 ([Camera #3] Views).

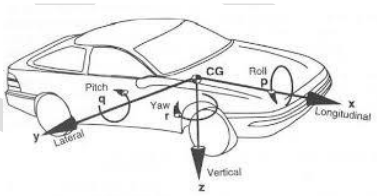
J.3. VEHICLE ANGULAR DISPLACEMENTS

DRAFT



Axes are vehicle-fixed.
Sequence for determining orientation:

4. *Yaw.*
5. *Pitch.*
6. *Roll.*



Test Number: 620851-01-5
Test Standard Test Number: *MASH* Test 3-11
Test Article: 30:1 Flared MGS
Test Vehicle: 2021 RAM 1500
Inertial Mass: 5046 lbs
Gross Mass: 5046 lbs
Impact Speed: 62.1 mi/h
Impact Angle: 24.9°

Figure J.7. Vehicle Angular Displacements for Test 620851-01-5.

J.4. VEHICLE ACCELERATIONS

DRAFT

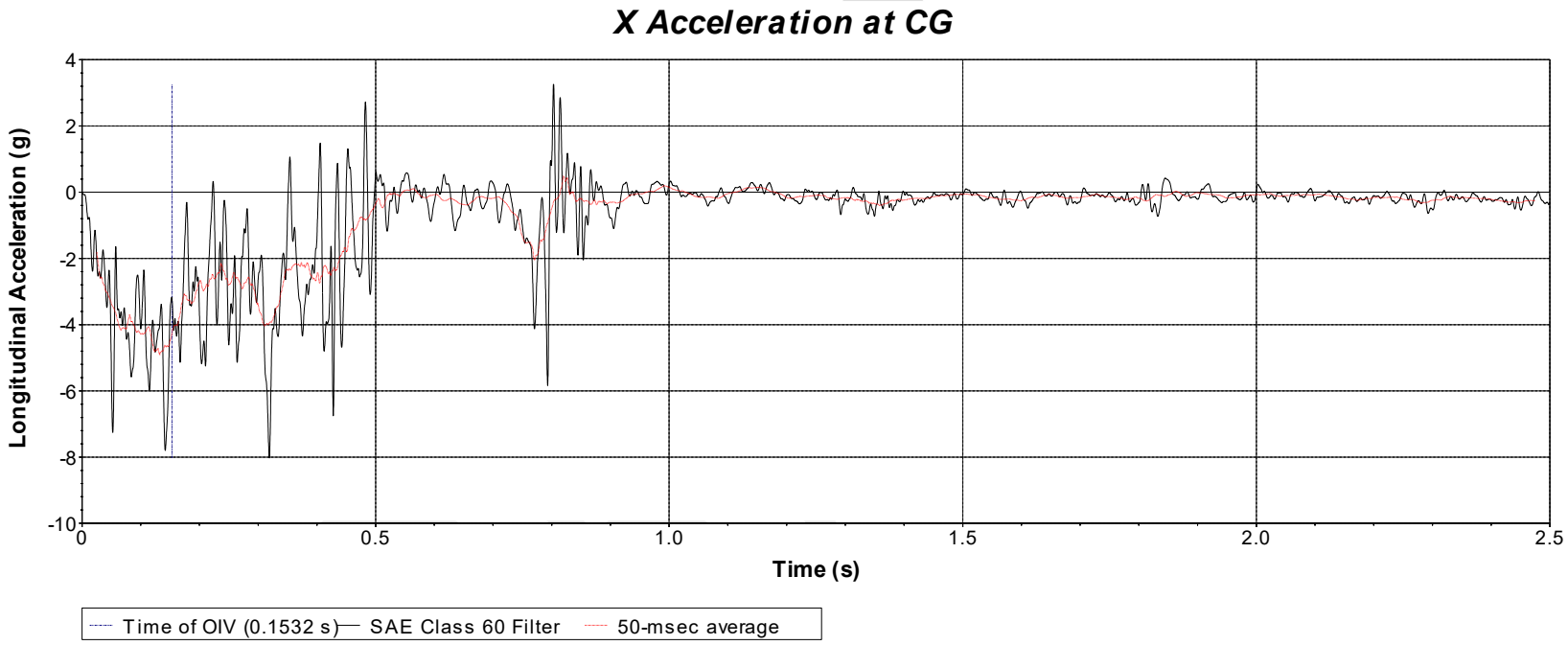


Figure J.8. Vehicle Longitudinal Accelerometer Trace for Test 620851-01-5 (Accelerometer Located at Center of Gravity).

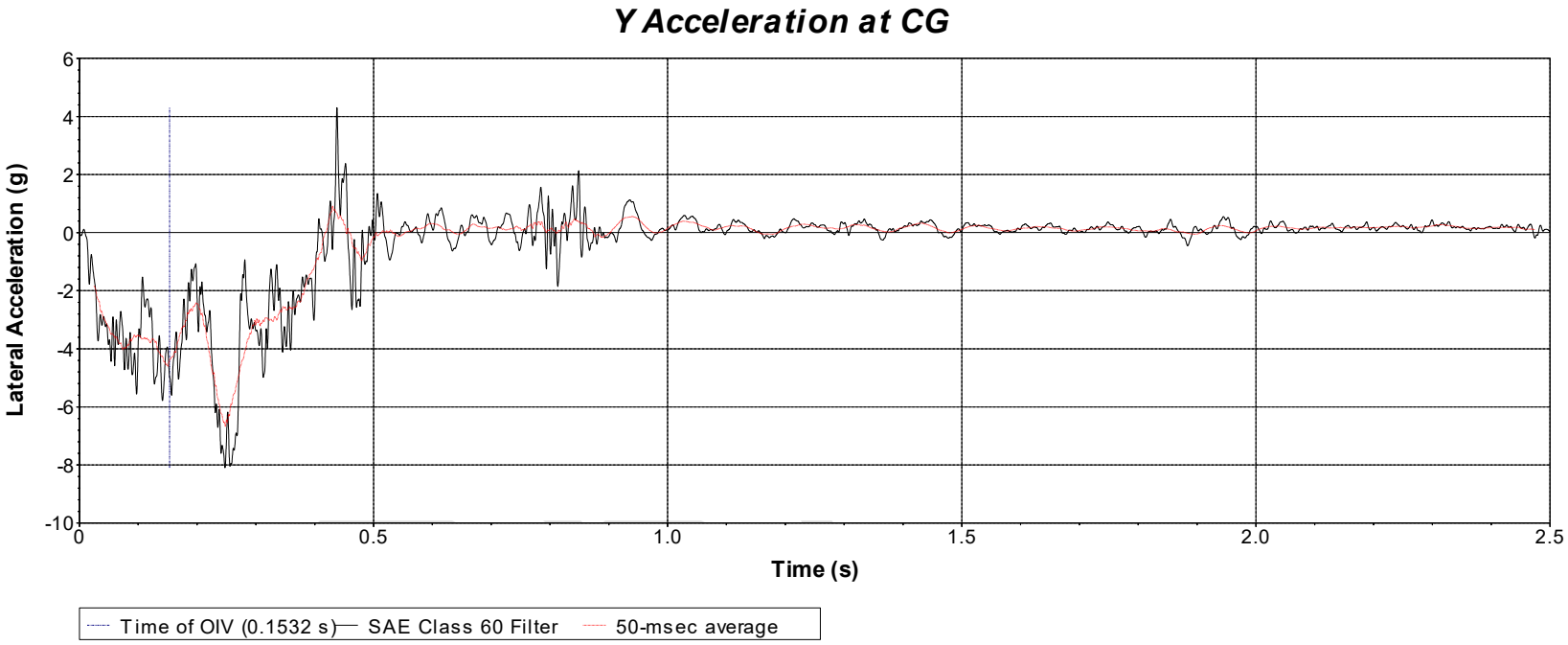


Figure J.9. Vehicle Lateral Accelerometer Trace for Test 620851-01-5 (Accelerometer Located at Center of Gravity).

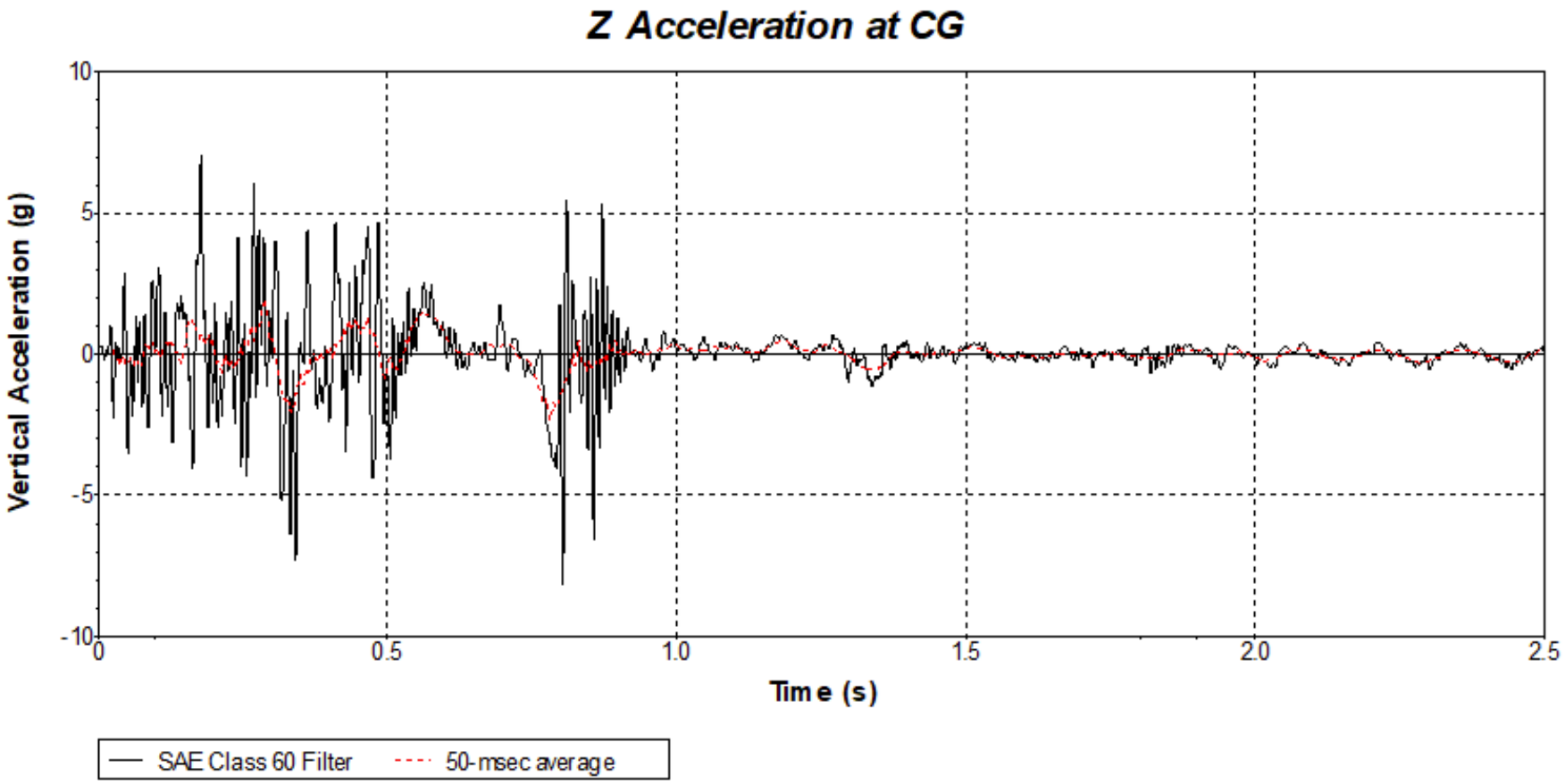


Figure J.10. Vehicle Vertical Accelerometer Trace for Test 620851-01-5 (Accelerometer Located at Center of Gravity).