Roadside Safety Pooled Fund

Texas A&M Transportation Institute
Proving Ground

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MASH TL-3 EVALUATION OF GUARDRAIL ON 6H:1V SLOPE

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16. Abstract

The American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide recommends that guardrail be installed with the back edges of the guardrail post 2 ft from a slope break. In many mountainous areas, or in locations with tight environmental controls, this width is difficult to provide. As a result, designers often must make a trade-off between reduced shoulder width and a less than optimal guardrail placement (i.e., on the slope past the slope break point). Hence, many state DOTs have a need to place the guardrail directly on sloped terrain. Site restriction might dictate the need for steeper slopes, or placement closer to the slope breakpoint. Another scenario points to the desire to place guardrail on slopes further away from the roadway in order to reduce the number of incidental hits. Hence, developing guidelines for identifying acceptable placement range will be of great benefit to state DOTs.

The guardrail on 6H:1V slope did not meet the performance criteria for *MASH* TL-3 longitudinal barriers due to penetration of the guardrail by the 2270P vehicle in *MASH* Test 3-11.

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

*SI is the symbol for the International System of Units

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Chapter 1. INTRODUCTION

1.1 PROBLEM STATEMENT

The American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide recommends that guardrail be installed with the back edges of the guardrail post 2 ft from a slope break (*1*). In many mountainous areas, or in locations with tight environmental controls, this width is difficult to provide. As a result, designers often have to make a trade-off between reduced shoulder width and a less than optimal guardrail placement i.e., on the slope past the slope break point. Hence, many states DOT have a need to place the guardrail directly on sloped terrain. Although these conditions often point to steeper slopes, one example from the WSDOT Design Manual is the guidance for the placement of guardrail on slopes as steep as 6H:1V as illustrated in Figure 1.1, but with the restriction of 12-ft minimum offset (*2*). Site restriction might dictate the need for steeper slopes, or placement closer to the slope breakpoint. Another scenario points to the desire to place guardrail on slopes further away from the roadway in order to reduce the number of incidental hits. Hence, developing guidelines for identifying acceptable placement range will be of great benefit to states DOTs.

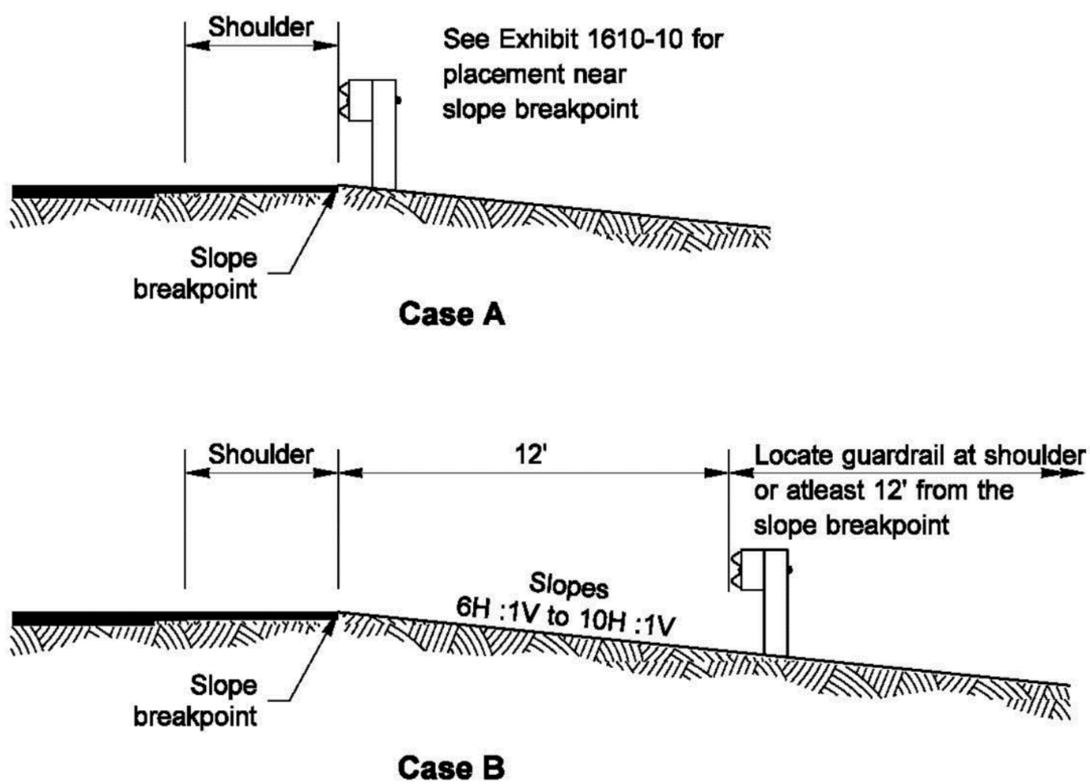


Figure 1.1. Beam Guardrail Installation on 6H:1V and 10H:1V Slopes (WSDOT Manual Exhibit 1610-9).

1.2 BACKGROUND

Several studies and crash tests have been conducted by researchers and testing labs to evaluate guardrail placement on different slope rates. Two of them are presented here for brevity. First, the MwRSF (MwRSF Report TRP-03-188-08) conducted two National Cooperative Highway Research Program (NCHRP) Report 350 TL-3 crash tests for an MGS placed 5-ft from the slope breakpoint on a 8H:1V slope (*3*, *4*). The placement of the guardrail and the critical impact point was selected based on available finite element model. Figure 1.2 and Figure 1.3 show the impact position for the NCHRP Report 350 C2500 and 850C vehicles respectively.

Figure 1.2. NCHRP Report 350 Pickup Truck at Impact Point of MSG Guardrail on 8H:1V Slope (MwRSF Report TRP-03-188-08).

Figure 1.3. NCHRP Report 350 Small Car at Impact Point of MSG Guardrail on 8H:1V Slope (MwRSF Report TRP-03-188-08).

Although the tests were deemed passed per the NCHRP Report 350 criteria, the guardrail was barely able to prevent the pickup truck from overriding it as shown in Figure 1.4.

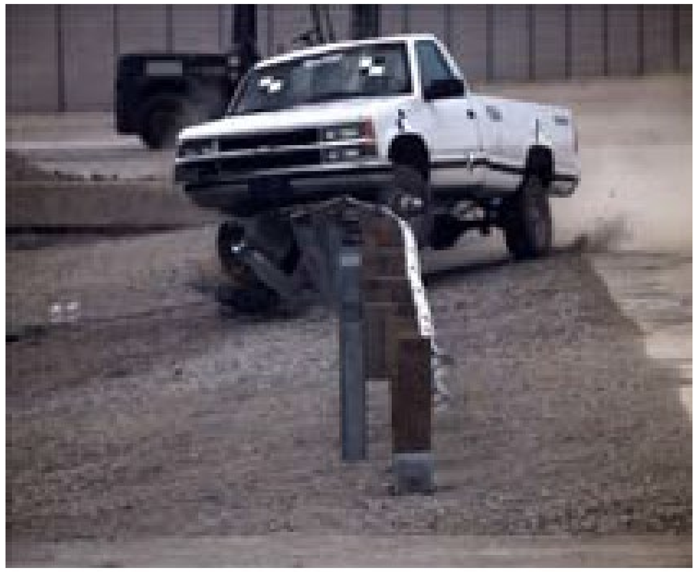


Figure 1.4. Pickup Truck almost Overriding MSG Guardrail on 8H:1V Slope (MwRSF Report TRP-03-188-08).

A more recent effort by TTI resulted in conducting two full scale AASHTO *Manual for Assessing Safety Hardware* (*MASH*) TL-3 crash tests of a 31-in high guardrail system placed on 2H:1V slope (*5*, *6*, *7*). The posts were placed 1-ft from the slope break such that the face of the guardrail was aligned with the slope break as shown in Figure 1.5, Figure 1.6, and Figure 1.7.

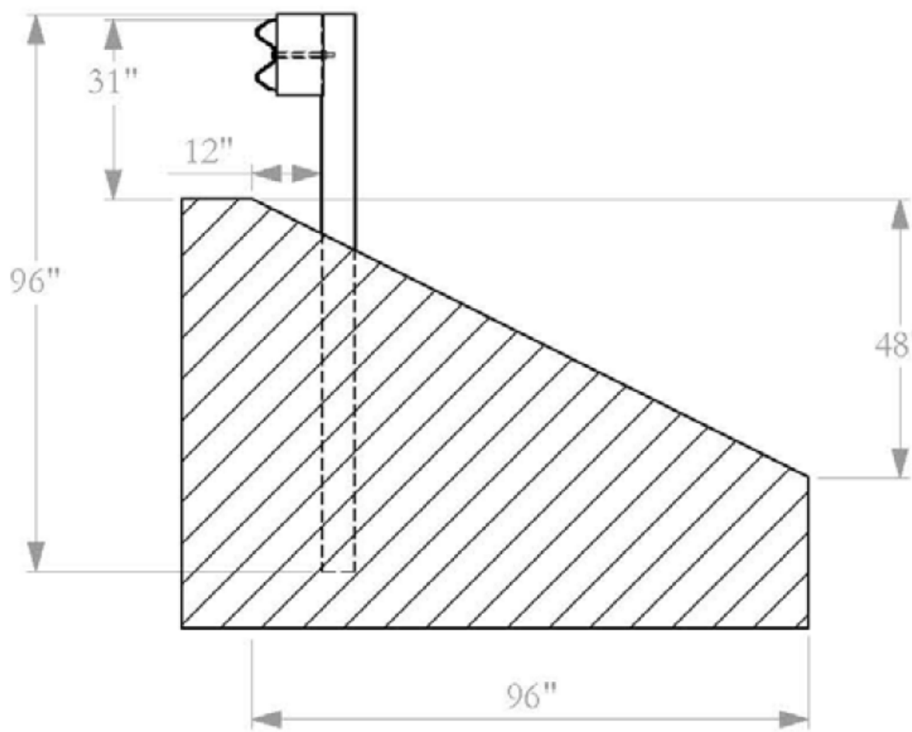


Figure 1.5. Cross Section of Guardrail on 2H:1V Slope System Tested by TTI.

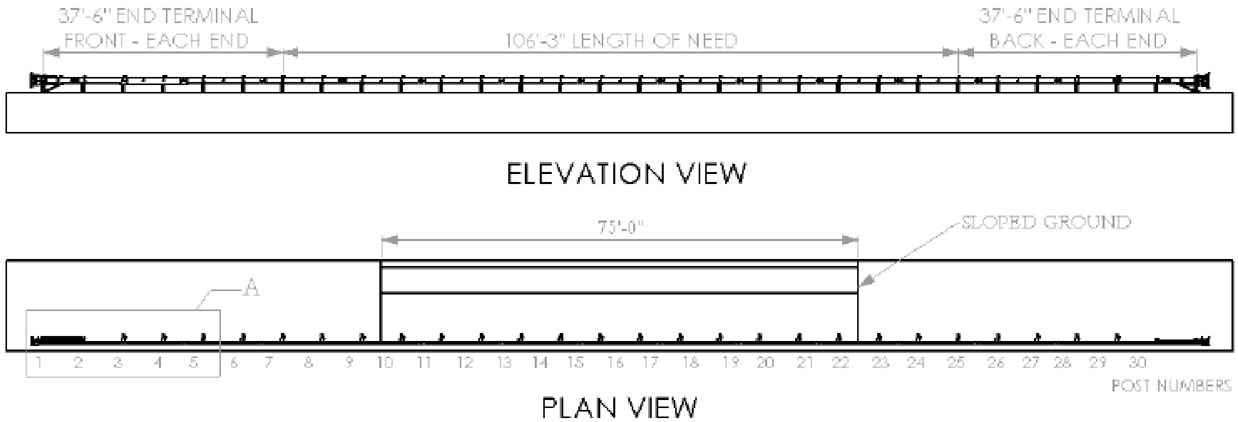


Figure 1.6. Guardrail on 2H:1V Slope System Tested by TTI.

Figure 1.7. Sequential of *MASH* Tests 3-11 and 3-10 of the Guardrail on 2H:1V Slope System.

The crash tests conducted were *MASH* test designation 3-11 and *MASH* test designation 3-10, which involve a 2270 kg pickup truck and a 1100 kg small car respectively. Both test vehicles were setup so that they impact the CIP of the length of need section at a nominal speed of 100 km/h (62 mi/h) and a nominal angle of 25 degrees. Each test resulted in the vehicle redirecting successfully as shown in the above sequential images. The impact severity metrics were within the acceptable criteria of *MASH* guidelines for each test. Therefore, these tests passed the *MASH* test evaluation criteria and subsequently an eligibility letter is in the process of being issued by the Federal Highway Association (FHWA).

1.3 OBJECTIVE

The objective of this study was to determine the appropriate offset distance from the slope break point of a 6H:1V slope to the face of the rail for an MGS guardrail system (using 8-inch blockouts).

1.4 BENEFITS

The outcome of this project provides state DOT's with a guidance on the acceptable placement location of MGS guardrail on a 6H:1V slope. The two *MASH* TL-3 crash tests (if passed) will serve as a compliant system ready for implementation.

1.5 SCOPE

The work plan to achieve the objectives of this project consisted of the following tasks:

1.5.1 Task 1 – Trajectory and Impact Simulation

The researchers conducted vehicular trajectory simulations of both the small car and the pickup truck over a 6H:1V slope to find the profile of the front stiff point (such as bumper corner) trajectory over the 6H:1V slope. Once these trajectories were developed, the researchers identified the most critical location for guardrail placement on the 6H:1V slope based on worst vehicular orientation from these profiles. A sample vehicle trajectory is shown in Figure 1.8

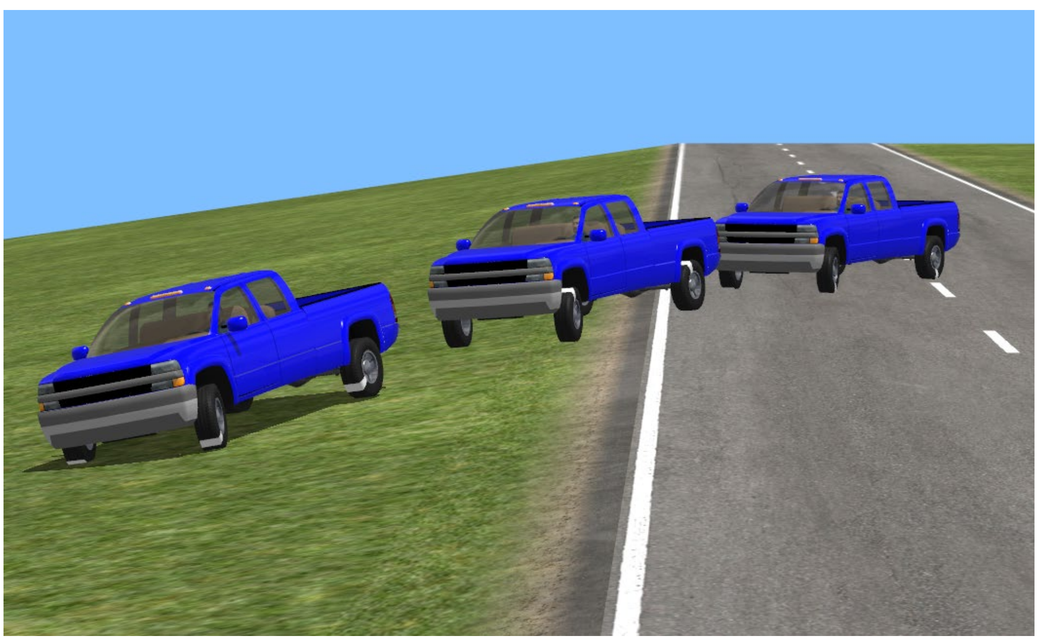


Figure 1.8. Vehicular Trajectory Simulation.

Subsequently, full finite element simulation was conducted using the determined worst placement. Depending on the performance of both vehicles in these particular analyses, two other placements could be used such as a foot above and a foot down the slope from the determined critical placement.

The researchers used these analyses to determine the closest installation offset beyond the slope break point where an MGS guardrail will likely meet *MASH* criteria (i.e., critical placement).

Based on the results of the analyses, the researchers recommended a critical placement for use in testing (Task 2).

1.5.2 Task 2 – Crash Testing Following *MASH* TL-3 Conditions

TTI constructed a guardrail at the recommended placement offset based on the results of Task 1. TTI conducted *MASH* Test 3-11 and *MASH* Test 3-10 crash test to verify the performance recommended from Task 1, and to determine whether the proposed system was *MASH* compliant (if both tests pass criteria values).

1.5.3 Task 3 – Placement Guidelines and Reporting

TTI prepared this documentation of both tests and helped develop the placement of guidelines for guardrail on 6H:1V slopes based on the results of the crash tests.

Chapter 2. VEHICLE TRAJECTORY SIMULATIONS

2.1 CARSIM MODEL

Based on the vehicle properties for Test No. 608431-01-1 (*MASH* 2270P) and 608431-01-2 (*MASH* 1100C), a CarSim vehicle model (pickup truck/passenger car) has been developed using sprung mass model (*8*). Table 2.1 shows the total masses for pickup truck and passenger car vehicle models. Based on the total mass, the differences between CarSim models and tested vehicles used as a reference are acceptable with the error of less than 0.5 percent each.

Table 2.1. Total Mass for CarSim Vehicle Model

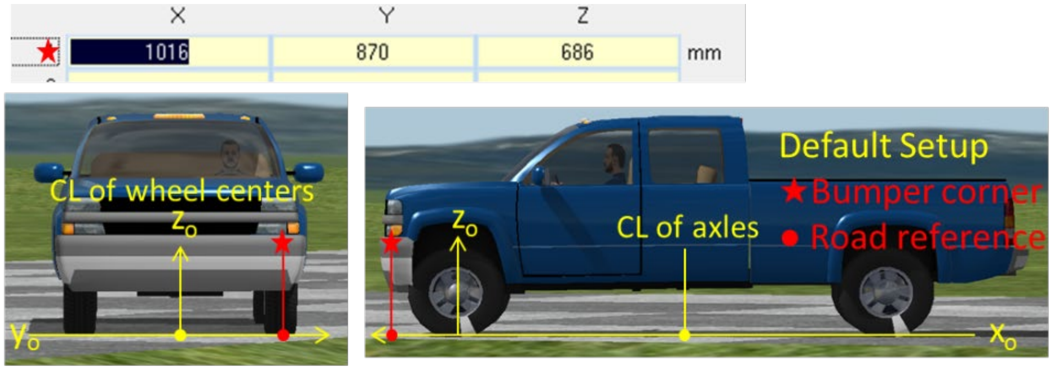
Pickup Truck Model

Front Left	Front Right	Rear Left	Rear Right	Total	Unit
5874.40	6186.68	4790.32	5633.33	22484.73	N
598.8175	630.650357	488.3099	574.24363	2292.02	kg
1320.565	1390.76566	1076.864	1266.3726	5054.57	lb
			Reference	5035	lb

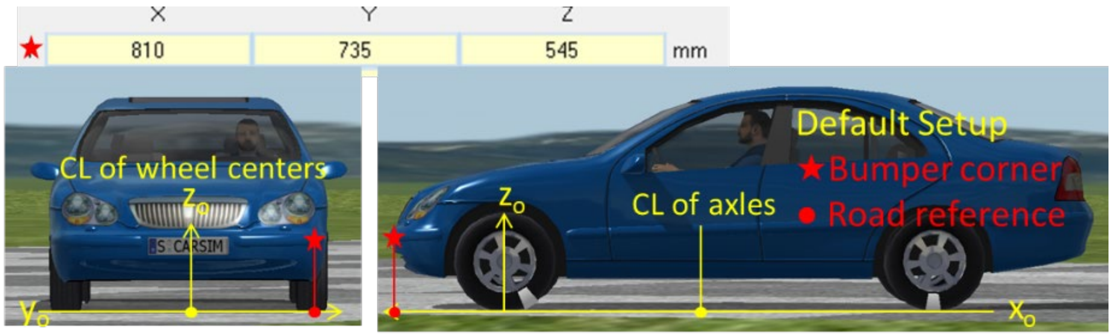
Passenger Car Model

Front Left	Front Right	Rear Left	Rear Right	Total	Unit
3205.81	3437.8	1994.8	2211.7	10850.08	N
326.79	350.4	203.3	225.5	1106.02	kg
720.6661	772.8	448.4	497.2	2439.10	lb
			Reference	2427	lb

To find the profile of the front stiff point (bumper corner) trajectory over the slope, the bumper corner and road reference were set up for CarSim models. Figure 2.1 shows the setup points for both pickup truck and passenger car models.



(a) Pickup Truck



(b) Passenger Car

Figure 2.1. Bumper Corner and Road Reference Points for Trajectory.

2.2 LS-DYNA VEHICLE MODEL

For LS-DYNA simulation, the Center for Collision Safety and Analysis Team at the George Mason University developed the finite element (FE) truck and passenger car models. To obtain more data for trajectory profiles for the pickup truck, two different models (shown in Figure 2.2) were used: a FE Chevrolet Silverado model and a FE Dodge Ram model. For the passenger car, a FE Toyota Yaris model shown in Figure 2.3 was used.

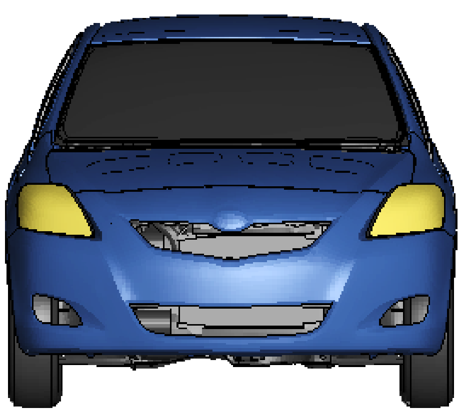
(a) Chevrolet Silverado - Front view

(b) Chevrolet Silverado - Isometric view

(a) Dodge Ram - Front view

(b) Dodge Ram - Isometric view

Figure 2.2. Truck Models used for FE Simulation.



(a) Toyota Yaris - Front view

(b) Toyota Yaris - Isometric view

Figure 2.3. Passenger Car Model used for FE Simulation.

2.3 VEHICULAR TRAJECTORY PROFILES FOR CARSIM AND LS-DYNA MODELS

Trajectory simulations were conducted to find the profile of the bumper corner by using both CarSim and LS-DYNA. Figure 2.4 shows the profiles of vehicle bumper height with respect to local terrain along the slope. Each model has a different trajectory profile. The differences are caused by the properties of vehicles, such as steering and suspension linkages, joints, and springs and dampers properties (*9*). Therefore, in this study both the trajectory simulation results from CarSim and LS-DYNA models are used to obtain various vehicular trajectory profiles.

All three truck models landed at approximately the same location (18.5 ft from the slope break). The maximum difference of truck bumper corner heights is 1 ft at 26 ft away from the slope break. For passenger car models, CarSim model landed at a location 17 ft away from the slope break, while the LS-DYNA model flight was approximately 2 ft less than the CarSim model. The maximum passenger car bumper corner height difference is 0.5 ft at 30 ft apart from the slope break.

However, this study focuses on the guardrail placement less than 12 ft offset from the slope break since there is a design manual with the minimum 12 ft offset (*2*). Therefore, the researchers are focused on the trajectory profiles with an initial 10 ft from the slope break where the maximum relative height is reached as shown in Figure 2.5. The difference between the minimum and maximum bumper corner heights is approximately 1.5 ft within the 10-ft offset range. Therefore, a guardrail system should be designed to accommodate the difference while adopting a guardrail system that is previously successfully designed and tested in accordance with *MASH* TL-3.

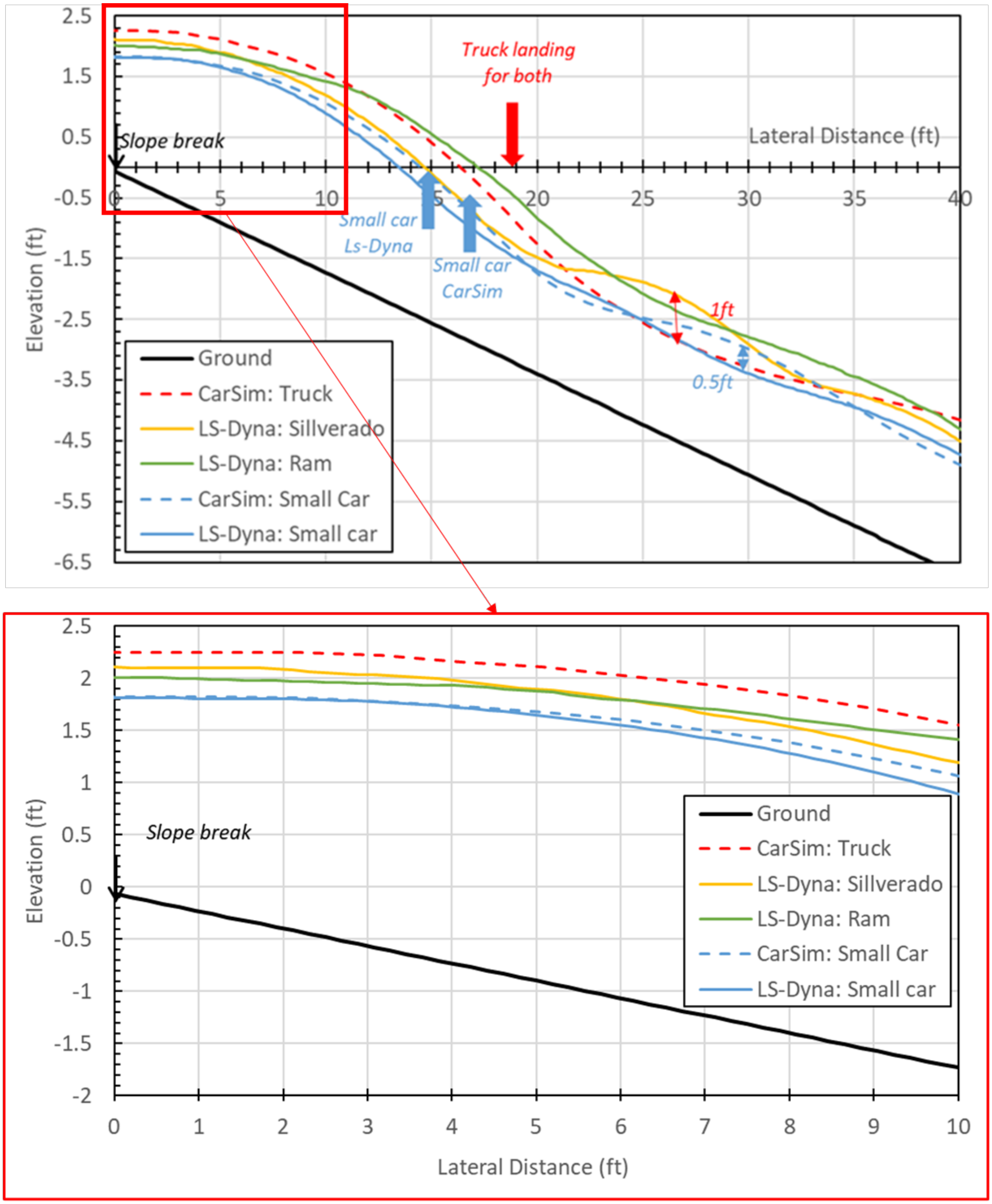


Figure 2.4. Vehicular Bumper Corner Height for CarSim and LS-DYNA Models.

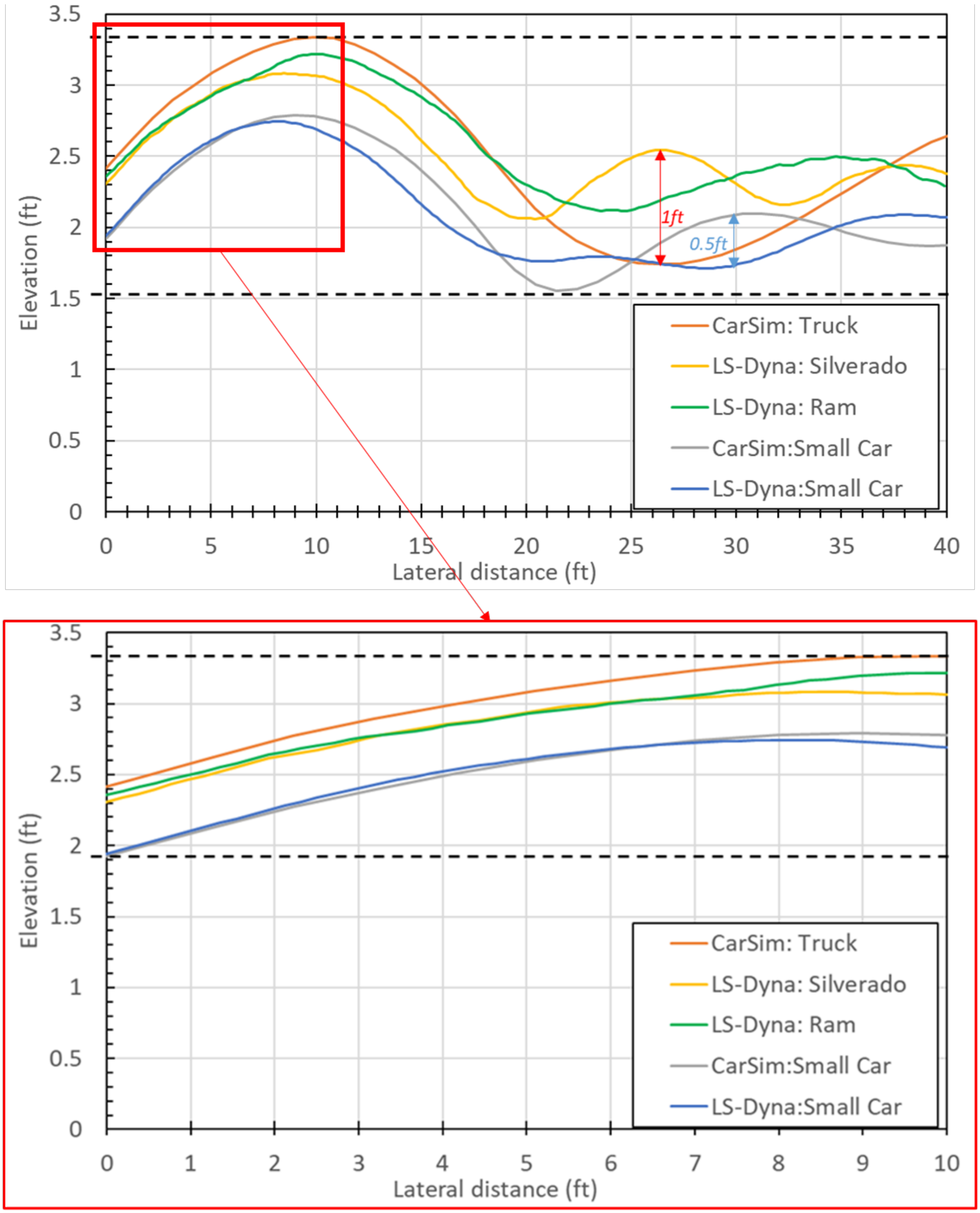
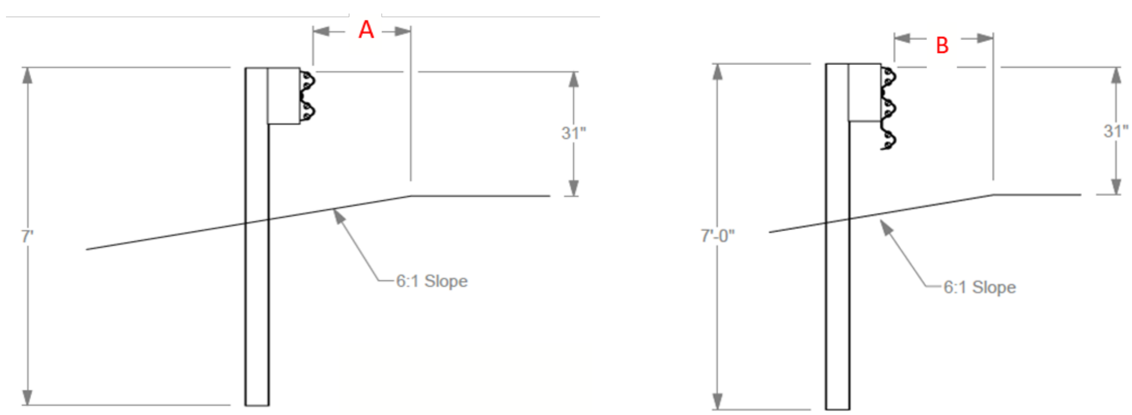


Figure 2.5. Relative Bumper Corner Height for CarSim and LS-DYNA Vehicle Models.

Chapter 3. IMPACT SIMULATION

3.1 DESIGN OPTIONS

A total of eight design options were proposed: four options were proposed for W-beam systems and the other four options for thrie-beam systems. The offset distance from the slope break ('A' and 'B') varied with each option. The height of the guardrail systems was 31 inches high from the flat ground for all options, and the post was 7 ft long. Figure 3.1 shows an overview of the suggested design options. Offset distances ('A' and 'B') are 2 ft, 4 ft, and 6 ft from the slope break. For the option with a 6-ft offset distance, an additional design option with a rubrail was suggested for each guardrail system. Table 3.1 shows the design option matrix.



(a) W-beam design option *(b) Thrie-beam design option*

Figure 3.1 Elevation View of Design Options.

Table 3.1. Design Options for Guardrail on 6H:1V Slope.

Design Option	Guardrail system	Offset distance	Rubrail
Option 1	W-beam	2-ft	No
Option 2		4-ft	No
Option 3		6-ft	No
Option 4		6-ft	Yes
Option 5	Thrie-beam	2-ft	No
Option 6		4-ft	No
Option 7		6-ft	No
Option 8		6-ft	Yes

Options are not proposed for an offset distance greater than 6 ft since the possible lowest bumper corner height should not be lower than the 31-inch height W-beam guardrail system (shaded area in Figure 3.2).

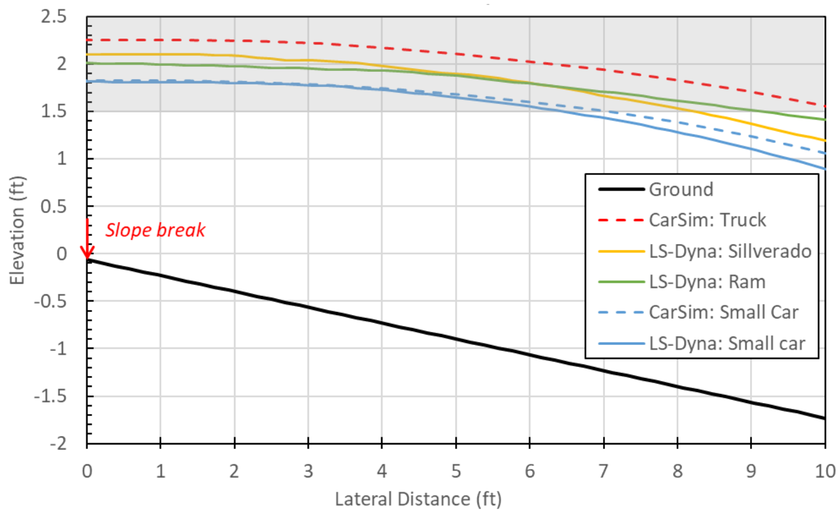


Figure 3.2. Bumper Corner Profile with Heights Covered by W-Beam (Shaded Area).

Among the proposed design options, the sponsor preferred designs were selected for an impact simulation test; Option 1 (W-beam guardrail with an offset distance of 2 ft) and Option 3 (W-beam guardrail with an offset distance of 6 ft). Figure 3.3 shows the vehicular bumper corner height profile with the location of the preferred design options. The plots show that Option 3 is more critical for the impact than Option 1 since the bumper corners are only placed on the lower part of the W-beam. Figure 3.4 shows the schematic configuration of the preferred design options.

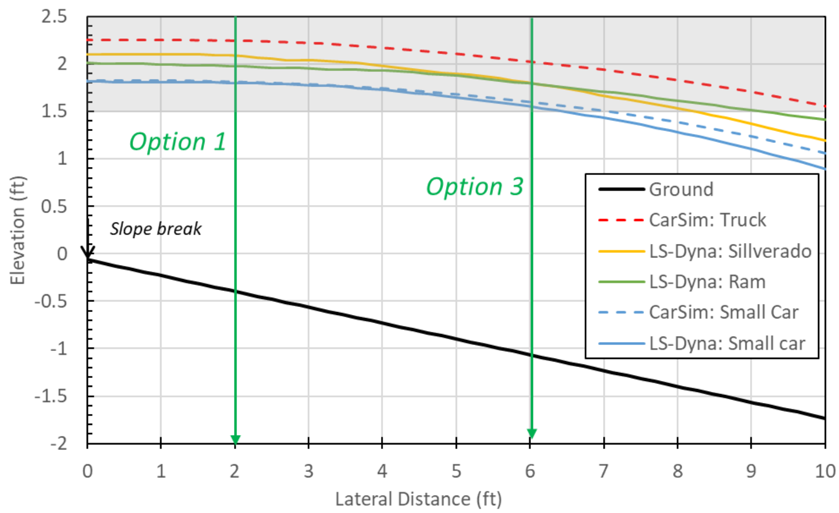
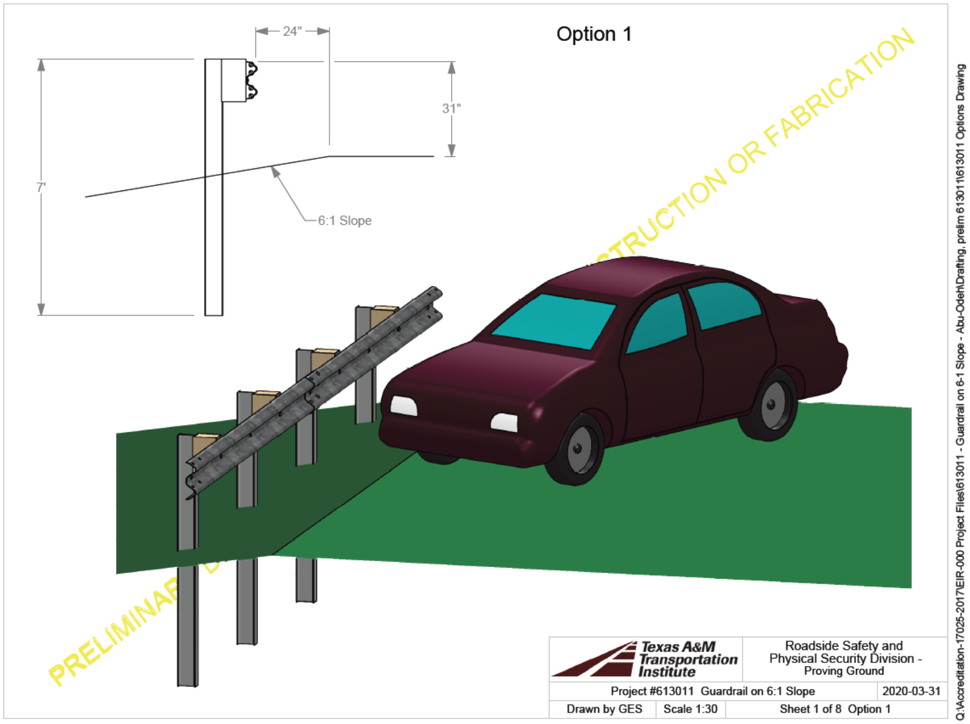
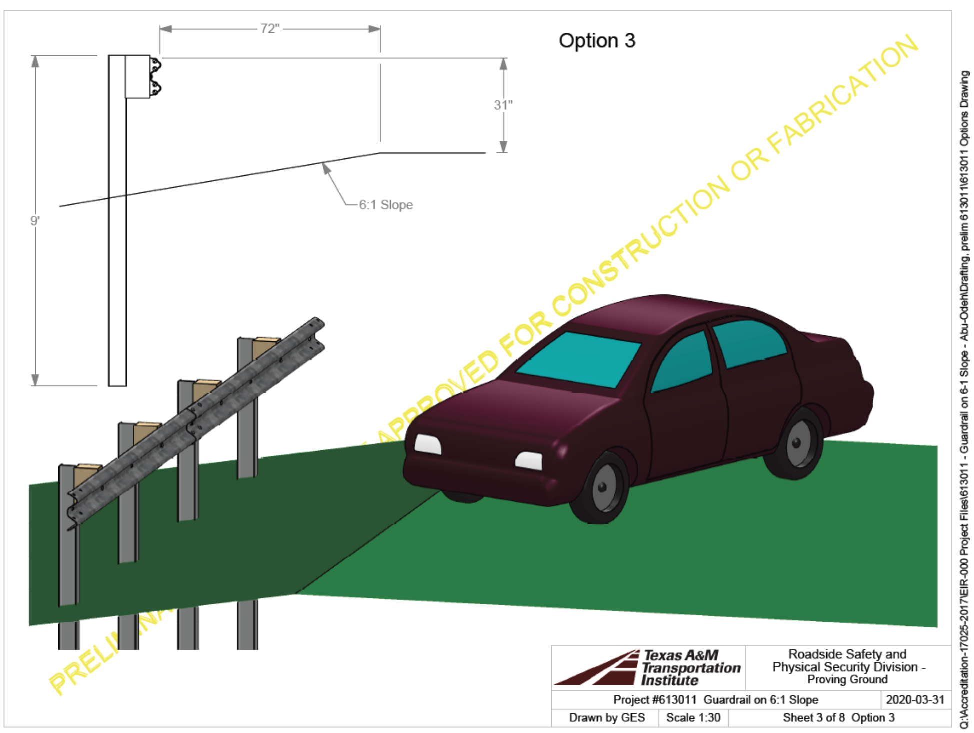


Figure 3.3. Trajectory Profile with Preferred Design Option Location.



(a) Design Option 1



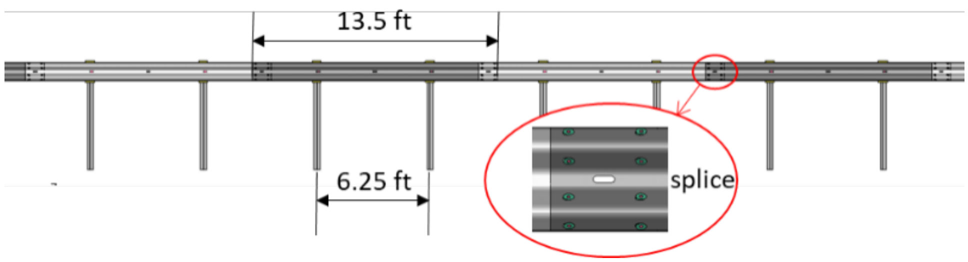
(b) Design Option 3

Figure 3.4. Preferred Design Options for Impact Simulation Test.

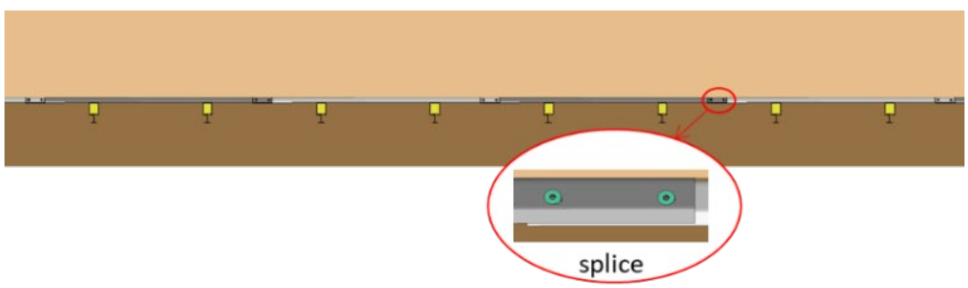
3.2 DETAILS OF W-BEAM GUARDRAIL SYSTEM

Based on previous studies on the W-beam guardrail on a slope, the finite element W-beam guardrail system model was developed to reproduce an actual guardrail system. A 13.5-ft long W-beam guardrail was used with a W6×8.5 steel post with a height of 7 ft and a 6-inch × 8-inch × 14-inch wood blockout. Each post was placed with 6.25-ft spacing.

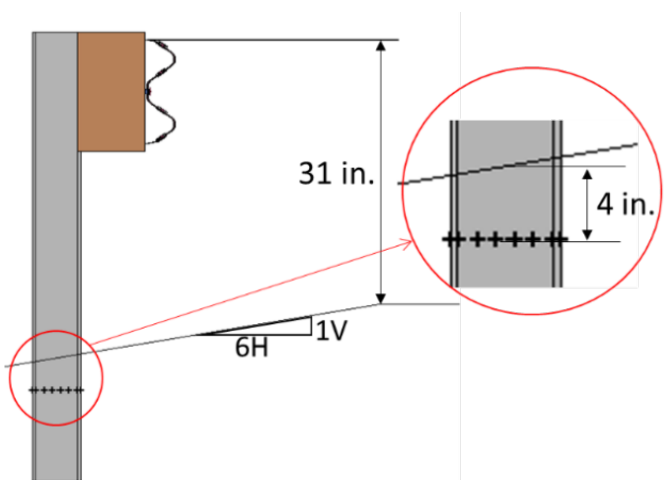
Figure 3.5 shows details of the finite element (FE) guardrail system model that was developed to perform computational impact simulations. For the time-efficient simulation run, the posts for the guardrail system were fixed, and movement was constrained 4 inches below the ground as an efficient way to approximately represent the plastic hinge of the steel post instead of explicitly modeling the soil continuum.



(a) Elevation view



(b) Plan view



(c) Side view

Figure 3.5. W-Beam Guardrail System on 6H:1V Slope used for FE Simulation.

3.3 OPTION 1: 2-FT OFFSET DISTANCE

Figure 3.6 shows the configuration of the W-beam guardrail system design Option 1 for locating the 6H:1V slope. This system does not include a rubrail.

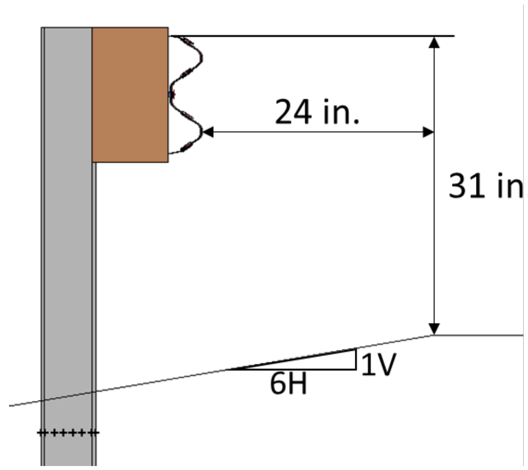


Figure 3.6. Preferred Design: W-Beam Guardrail with 24-inch (2-ft) Offset from Slope Break (Option 1).

3.3.1 *MASH* Test 3-11 Simulation with 2270P Vehicle Model

For *MASH* Test 3-11 simulation, the FE Ram model was used and set with an initial angle and speed of 25 degrees and 62.5 mph, respectively, to replicate *MASH* Test 3-11. Figure 3.7 shows the truck setup with Option 1 W-beam guardrail system with 24-inch offset.

Figure 3.7. Truck Setting with Option 1 W-Beam Guardrail with 24-inch Offset.

Figure 3.8 shows the time frame (sequential images) for the truck simulation test. The truck was redirected and maintained an upright position. The occupant risk factors determined by TRAP are listed in Table 3.2. The simulation test passed by satisfying *MASH* TL-3 limits.

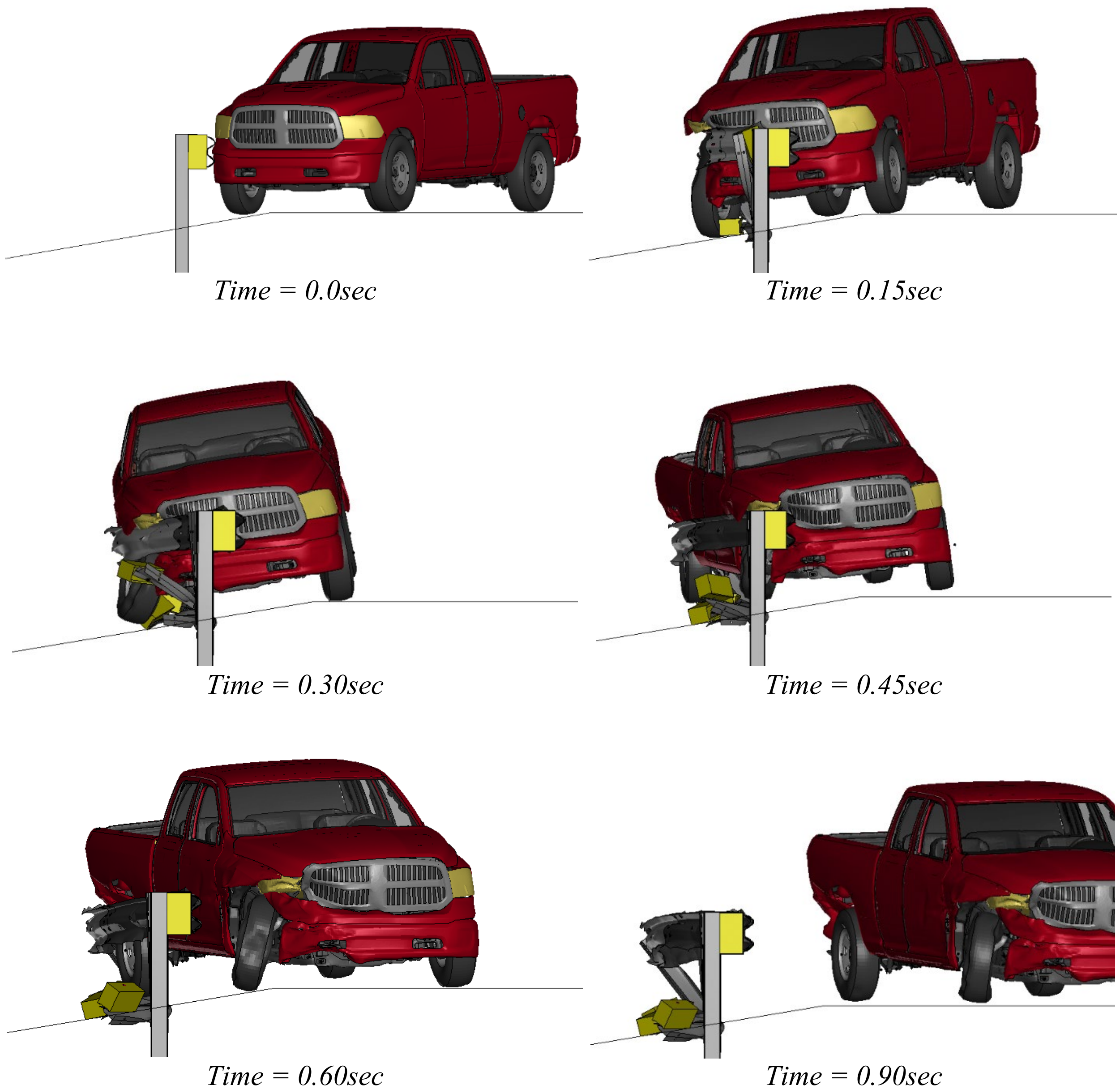


Figure 3.8. Sequential Images for Truck Simulation with W-Beam Guardrail with 24-inch Offset.

Table 3.2. *MASH* Test 3-11 Simulation Result with W-Beam Guardrail with 24-inch Offset.

Occupant Risk Factors	
OIV (ft/s)	
Longitudinal	7.2
Lateral	14.11
Occupant Ridedown Accelerations (g's)	
Longitudinal	-10.4
Lateral	-8.7
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	8.7
Pitch	11.4
Yaw	-43.4

3.3.2 *MASH* Test 3-10 Simulation with 1100C Vehicle Model

Passenger car FE model was set with initial angle and speed at 25 degrees and 62.5 mph, respectively, to replicate *MASH* Test 3-10. Figure 3.9 shows the passenger car vehicle setup with Option 1 W-beam guardrail system with 24-inch offset.

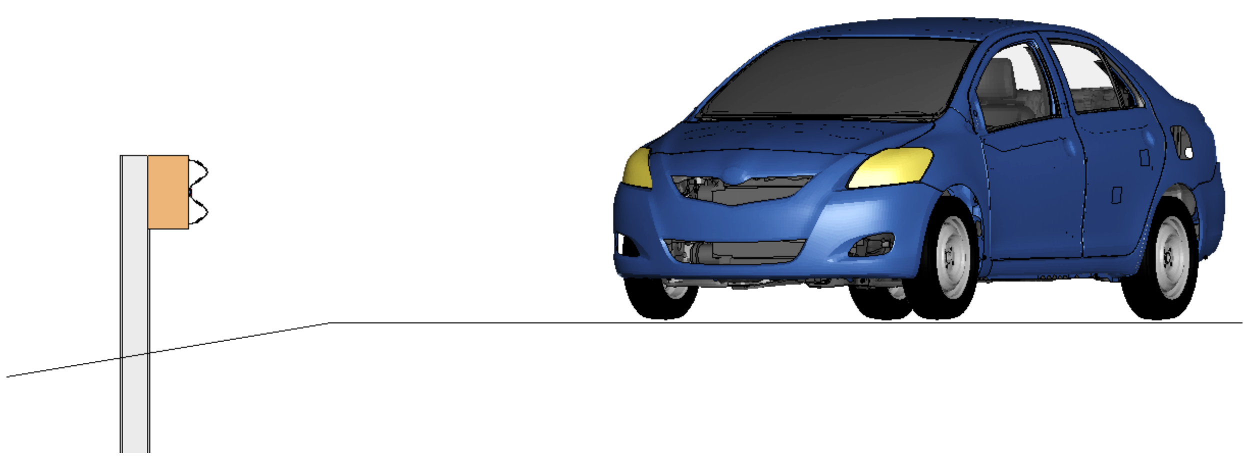


Figure 3.9. Passenger Car setting with Option 1 W-beam Guardrail with 24-inch Offset.

Figure 3.10 shows the time frame (sequential images) for the passenger car simulation test. The simulation test for the passenger car passed (the car was redirected, stayed on the road, and maintained an upright position after impacting). To investigate the occupant risk factors, TRAP was used, and Table 3.3 lists the factors. All the factors meet the limit specified in *MASH* TL-3 criteria.

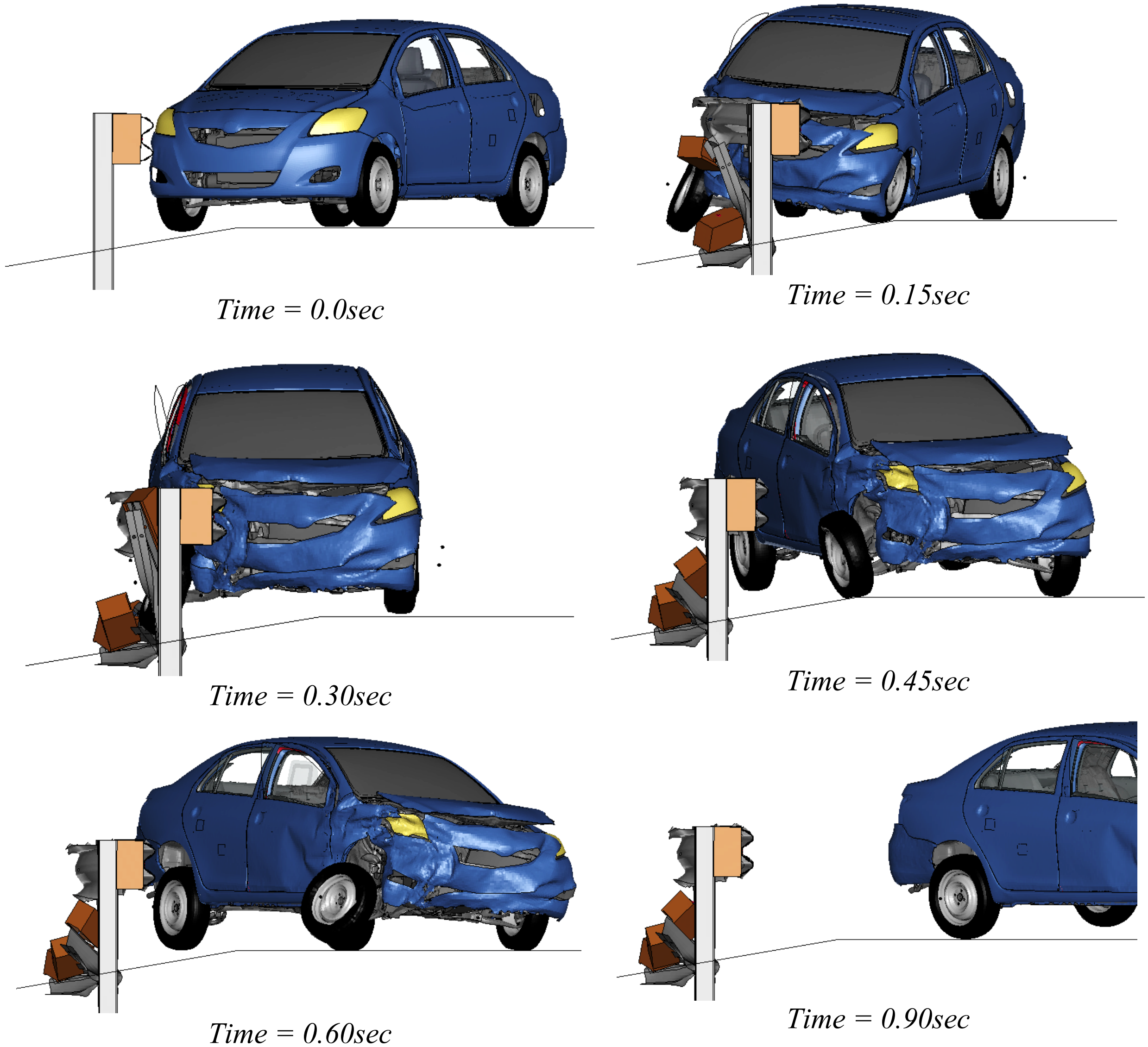


Figure 3.10. Sequential Images of Passenger Car Simulation for W-beam Guardrail with 24-inch Offset.

Table 3.3. *MASH* Test 3-10 Simulation Result with W-Beam Guardrail with 24-inch Offset.

Occupant Risk Factors	
OIV (ft/s)	
Longitudinal	16.08
Lateral	22.97
Occupant Ridedown Accelerations (g's)	
Longitudinal	-15.2
Lateral	-14.5
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	8.6
Pitch	-7.1
Yaw	-73.6

3.4 OPTION 3: 6-FT OFFSET DISTANCE

Figure 3.11 shows the configuration of the W-beam guardrail system Option 3, which has an offset distance of 72 inches (6 ft) from the slope break. This system does not have a rubrail. As mentioned previously, this design option is more critical for impacting than Option 1. Therefore, to find the critical impact point (CIP), computational simulations were conducted for impacting a vehicle model at four different points (mid-span, post before splice, splice, and post after splice). To assess the criticality of the impact points, occupant risk factors were evaluated for the simulations designed to impact four different impact points.

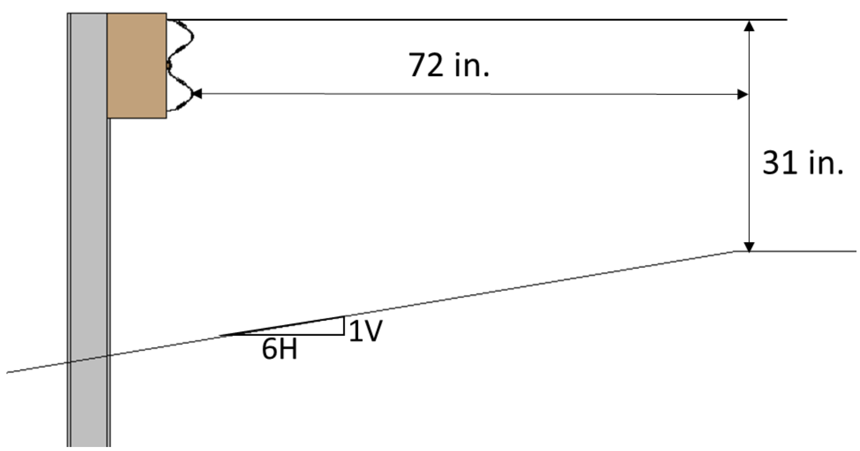


Figure 3.11. Preferred Design: W-Beam Guardrail with 72-inch (6-ft) Offset from Slope Break (Option 3).

3.4.1 *MASH* Test 3-11 Simulation with 2270P Vehicle Model

For *MASH* Test 3-11 impact simulation, the FE Ram model was used and set with an initial angle and speed of 25 degrees and 62.5 mph to replicate *MASH* Test 3-11. Figure 3.12 shows the truck setup with Option 3 W-beam guardrail system.

Figure 3.12. Truck Setting with Option 3 W-Beam Guardrail with 72-inch Offset.

To evaluate the criticality of impact points, the occupant risk factors were obtained by TRAP and are listed in Table 3.4. All impact simulations passed by satisfying *MASH* TL-3 limits. Based on the occupant risk factors, the most critical impact point was determined to be at the *post after splice* for the pickup truck model.

Table 3.4. Pickup Truck Occupant Risk Factors for Each Impact Point.

Occupant Risk Factors					
Impact Point					
		Mid Span w/o splice	Post before splice	Splice	Post after splice
Impact Velocity (ft/sec)	Longitudinal	9.18	7.87	10.17	**9.51**
	Lateral	16.73	17.06	17.06	**15.74**
Ridedown Acceleration (g)	Longitudinal	-8.2	-10.4	-9.8	**-13.9**
	Lateral	-8.8	-8.6	-10.8	**-10.3**
Max. Angles (degrees)	Roll	4.7	7.0	-7.6	**-6.5**
	Pitch	6.0	9.5	5.7	**3.4**
	Yaw	-30.3	-40.3	-30.8	**-28.4**

Figure 3.13 shows the time frame (sequential images) for the truck impact simulation impacting a post after a splice.

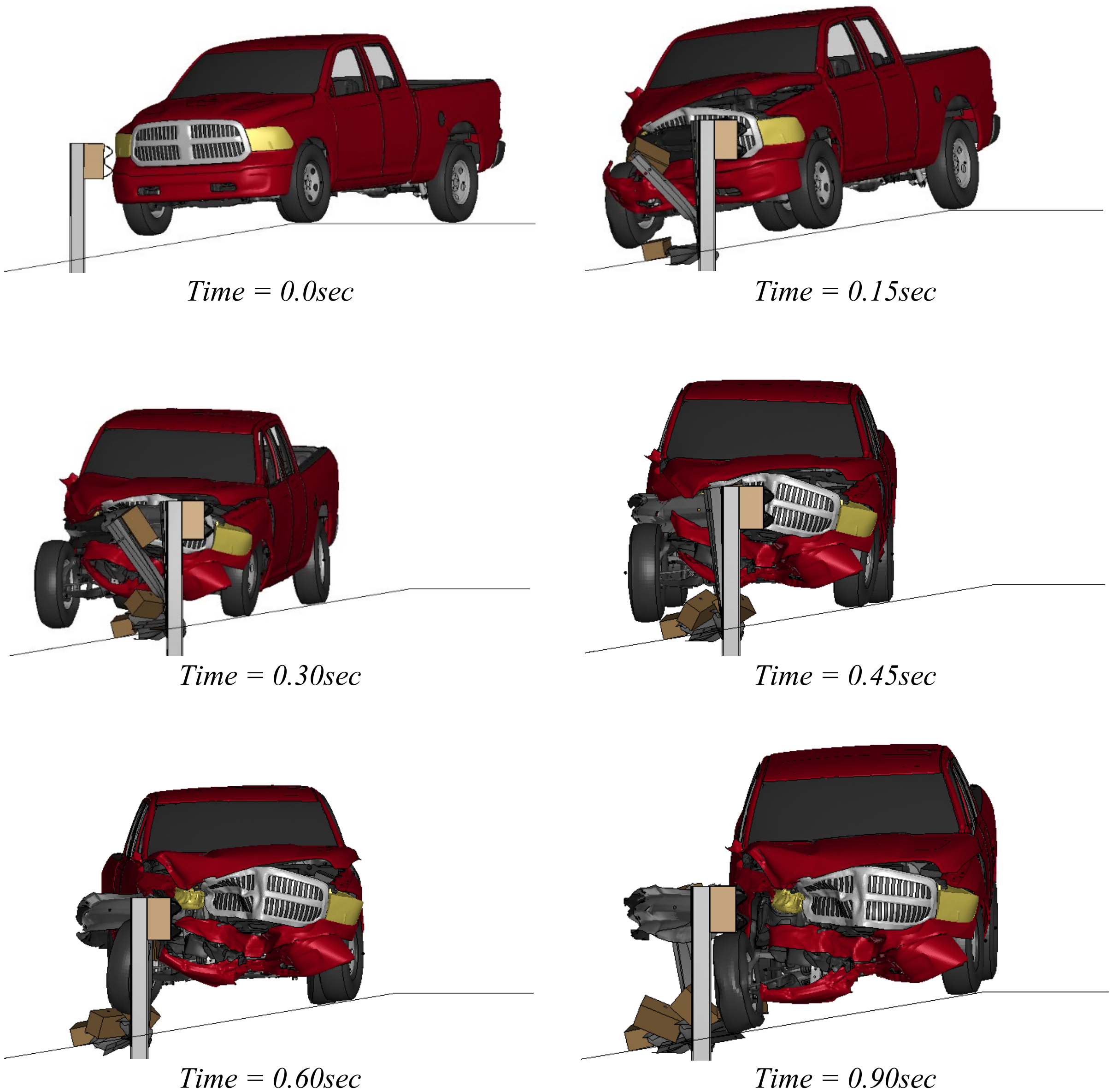


Figure 3.13. Sequential Images for Truck Simulation Impacting at Post after Splice of W-Beam Guardrail with 72-inch Offset.

3.4.2 *MASH* Test 3-10 Simulation with 1100C Vehicle Model

FE Yaris model was set with initial angle and speed at 25 degrees and 62.5 mph, respectively, to replicate *MASH* Test 3-10. Figure 3.14 shows the passenger car vehicle setup with Option 3 W-beam guardrail system with 72-inch offset.

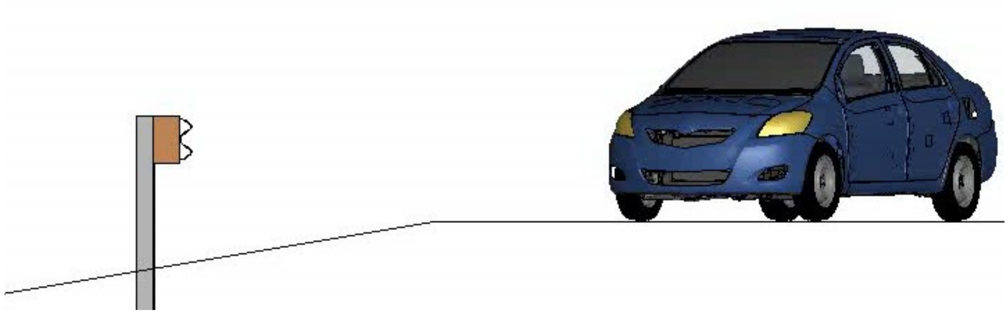


Figure 3.14. Passenger Car setting with Option 3 W-beam Guardrail with 72-in Offset.

To assess the criticality of impact points, the occupant risk factors listed in Table 3.5 were used. The impact simulations for all impact points passed by satisfying *MASH* TL-3 limits. Based on the occupant risk factors, the most critical impact point was determined to be at a *splice* for the passenger car model.

Table 3.5. Passenger Car Occupant Risk Factors for Each Impact Point.

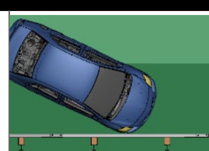
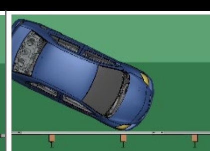
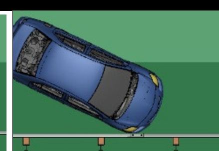
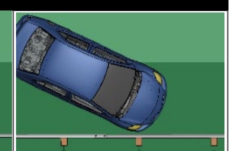
Occupant Risk Factors					
Impact Point					
		Mid Span w/o splice	Post before splice	Splice	Post after splice
Impact Velocity (ft/sec)	Longitudinal	13.45	11.81	**14.43**	14.1
	Lateral	20.0	18.37	**19.35**	18.7
Ridedown Acceleration (g)	Longitudinal	-8.9	-9.0	**-16.4**	-14.2
	Lateral	-11.3	-13.0	**-12.2**	-16.0
Max. Angles (degrees)	Roll	11.5	10.3	**-6.4**	-14.2
	Pitch	-9.2	-8.4	**-10.6**	-9.9
	Yaw	-48.3	-49.5	**-28.4**	-44

Figure 3.15 shows the time frame (sequential images) for the simulation with the passenger car impacting at a splice.

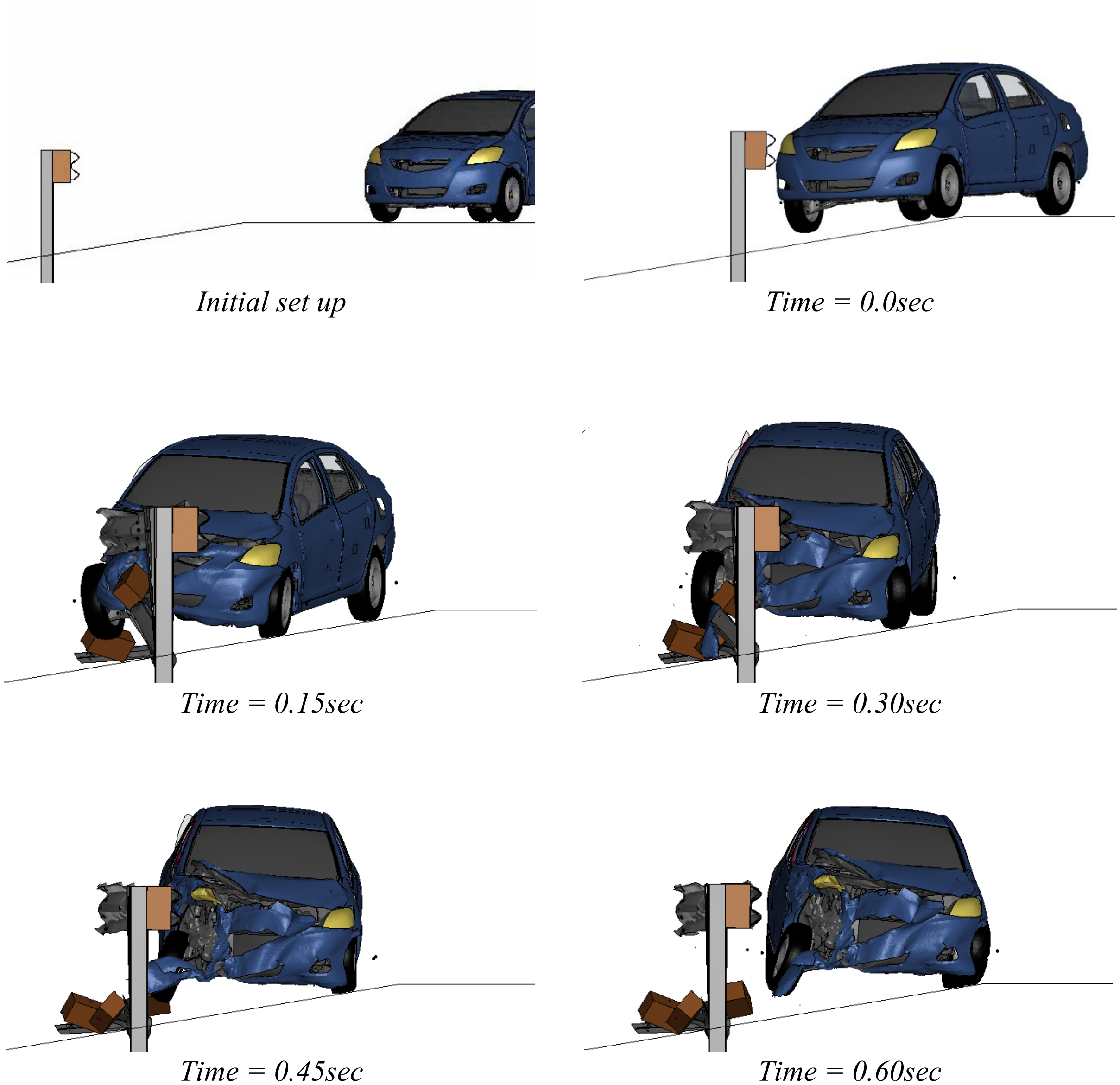


Figure 3.15. Sequential Images for Passenger Car Simulation Impacting at Splice of W-Beam Guardrail with 72-inch Offset.

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Chapter 4. SYSTEM DETAILS

4.1 TEST ARTICLE AND INSTALLATION DETAILS

The installation consisted of a W-beam guardrail system embedded on a 6H:1V slope that measured 15 ft wide. The top of the slope was 72 inches from the front of the rail, and 31 inches below the top of the rail. The W-beam guardrail was supported by standard wood blockouts and 8-ft long W6×8.5 steel posts. The posts were evenly spaced at 75 inches for a length of need of 162 ft-6 inches. Each end was terminated with a standard Texas Department of Transportation Downstream Anchor Terminal (DAT), which brought the total length of the installation to 181 ft-3 inches. The rail uniformly sloped downward 12½ inches toward each end starting 25 ft before the DATs.

Figure 4.1 presents the overall information on the guardrail on 6H:1V slope, and Figure 4.2 provides photographs of the installation. Appendix A provides further details on the guardrail on 6H:1V slope. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by DMA Construction Inc. and supervised by TTI Proving Ground personnel.

4.2 DESIGN MODIFICATIONS DURING TESTS

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

4.3 MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the guardrail on 6H:1V slope.

4.4 SOIL CONDITIONS

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

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

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

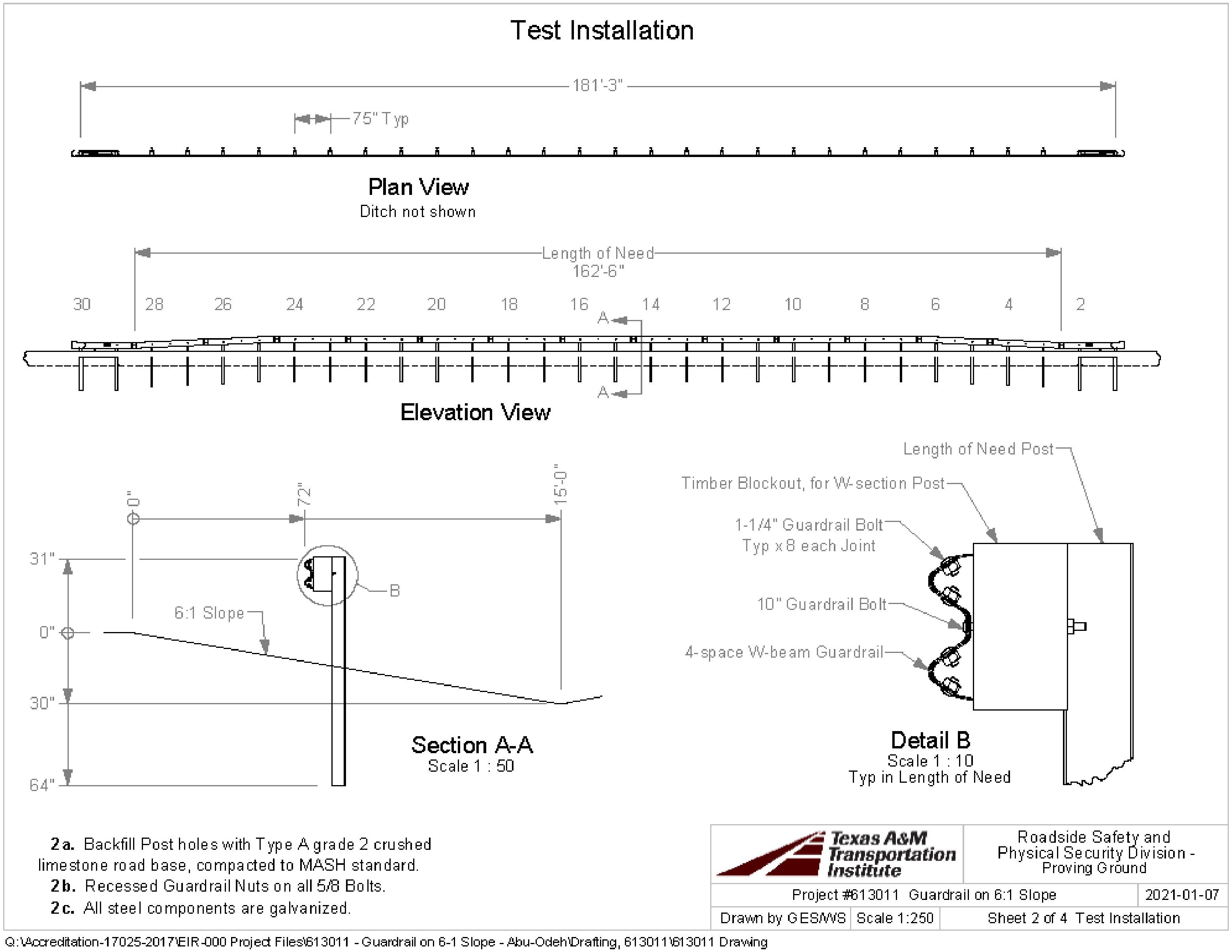

Figure 4.1. Details of Guardrail on 6H:1V Slope.

Figure 4.2. Guardrail on 6H:1V Slope prior to Testing.

On the day of Test No. 613011-01-1, January 6, 2021, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 8383 lbf, 8636 lbf, and 9040 lbf. Table C.2 in Appendix C shows the strength of the backfill material in which the guardrail on 6H:1V slope was installed met minimum *MASH* requirements for soil strength.

On the day of Test No. 613011-01-2, January 25, 2021, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 8686 lbf, 9646 lbf, and 8989 lbf. Table C.3 in Appendix C shows the strength of the backfill material in which the guardrail on 6H:1V slope was installed met minimum *MASH* requirements for soil strength.

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Chapter 5. TEST REQUIREMENTS AND EVALUATION CRITERIA

5.1 CRASH TEST PERFORMED/MATRIX

Table 5.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for longitudinal barriers. The target critical impact points (CIPs) for each test were determined using the information provided in *MASH* Section 2.2.1 and Section 2.3.2. Figure 5.1 shows the target CIP for *MASH* Test 3-10 and Figure 5.2 shows the target CIP for *MASH* 3-11 on the guardrail on 6H:V1 slope.

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

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

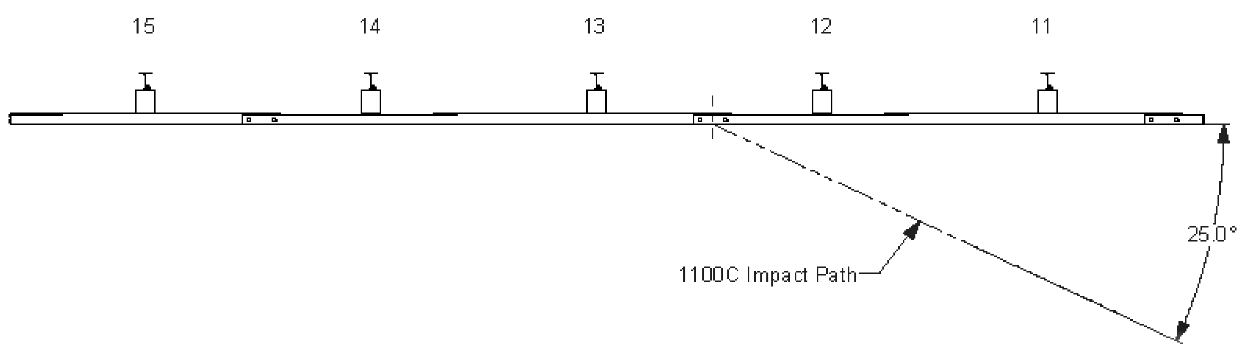

Figure 5.1. Target CIP for *MASH* Test 3-10 on Guardrail on 6H:1V Slope.

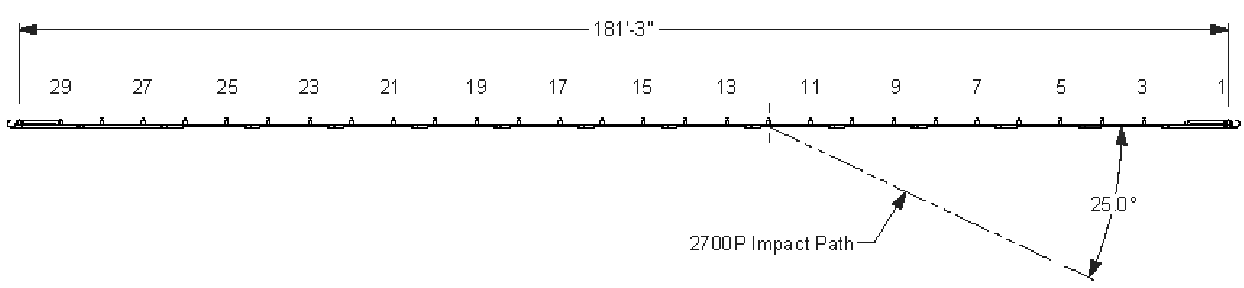

Figure 5.2. Target CIP for MASH Test 3-11 on Guardrail on 6H:1V Slope.

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

5.2 EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. Table 5.1 lists the test conditions and evaluation criteria required for *MASH* TL-3, and Table 5.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 9.

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

Evaluation Factors	Evaluation Criteria	*MASH* Test
Structural Adequacy	*A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	*3-10 and 3-11*
Occupant Risk	*D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*	*3-10 and 3-11*
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	*3-10 and 3-11*
	H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	*3-10 and 3-11*
	I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	*3-10 and 3-11*

Chapter 6. TEST CONDITIONS

6.1 TEST FACILITY

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

The test facilities of the TTI Proving Ground are located on The Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 mi northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, highway pavement durability and efficacy, and roadside safety hardware and perimeter protective device evaluation. The site selected for construction and testing of the guardrail on 6H:1V slope was along the edge of an out-of-service runway. The 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.

6.2. VEHICLE TOW AND GUIDANCE SYSTEM

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

6.3. DATA ACQUISITION SYSTEMS

6.3.1. Vehicle Instrumentation and Data Processing

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

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

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

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

6.3.2. Anthropomorphic Dummy Instrumentation

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

According to *MASH*, use of a dummy in the 2270P vehicle is optional. However, *MASH* recommends that a dummy be used when testing “any longitudinal barrier with a height greater than or equal to 33 inches.” More specifically, use of the dummy in the 2270P vehicle is recommended for tall rails to evaluate the “potential for an occupant to extend out of the vehicle and come into direct contact with the test article.” Although this information is reported, it is not part of the impact performance evaluation. The rail height of the guardrail on 6H:1V slope was 31 inches relative to the roadway (less than 33 inches), however a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

6.3.3. Photographic Instrumentation Data Processing

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

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

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the guardrail on 6H:1V slope. 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.

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Chapter 7. *MASH* TEST 3-10 (CRASH TEST NO. 613011-01-1)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-10 involves a 1100C vehicle weighing 2420 lb ± 55 lb impacting the CIP of the longitudinal barrier at an impact speed of 62 mi/h ± 2.5 mi/h and an angle of 25 degrees ± 1.5 degrees. The CIP for *MASH* Test 3-10 on the guardrail on 6H:1V slope was the centerline of the splice in the rail element between posts 12 and 13 ± 1 ft. Figure 5.1 and Figure 7.1 depict the target impact setup.

Figure 7.1. Guardrail/Test Vehicle Geometrics for Test No. 613011-01-1.

The 1100C vehicle weighed 2434 lb, and the actual impact speed and angle were 64.8 mi/h and 25.6 degrees. The actual impact point was 1.0 inch upstream of the centerline of the splice in the rail element between posts 12 and 13. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 64 kip-ft.

7.2. WEATHER CONDITIONS

The test was performed on the morning of January 6, 2021. Weather conditions at the time of testing were as follows: wind speed: 11 mi/h; wind direction: 173 degrees (vehicle was traveling at a heading of 330 degrees); temperature: 64°F; relative humidity: 92 percent.

7.3. TEST VEHICLE

Figure 7.2 shows the 2015 Nissan Versa used for the crash test. The vehicle's test inertia weight was 2434 lb, and its gross static weight was 2599 lb. The height to the lower edge of the vehicle bumper was 7.0 inches, and the height to the upper edge of the bumper was 22.25 inches. Table D.1 in Appendix D.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

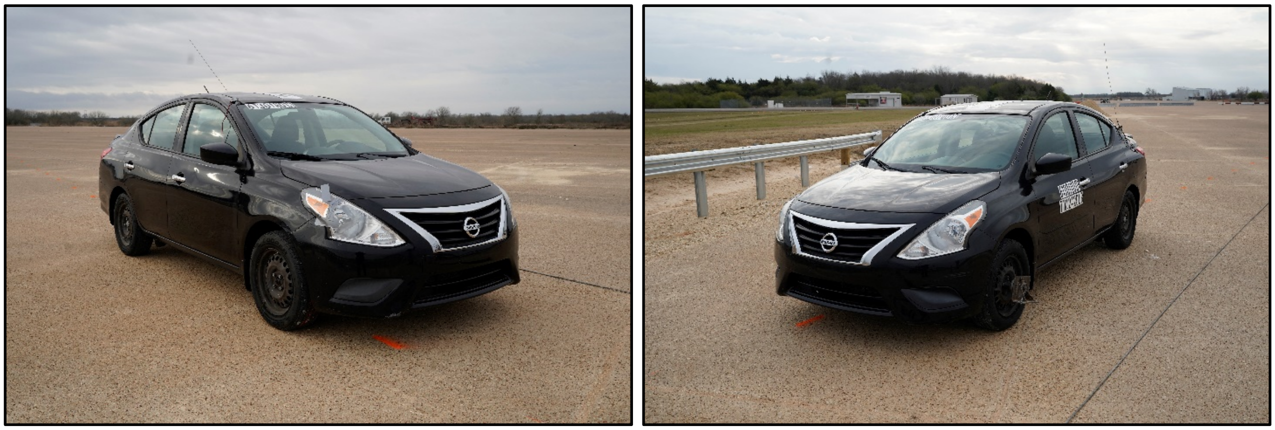


Figure 7.2. Test Vehicle before Test No. 613011-01-1.

7.4. TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 613011-01-1. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 613011-01-1.

Time (s)	Events
0.0000	Vehicle impacts guardrail
0.0240	Post 13 begins to deflect toward field side
0.0370	Post 12 begins to deflect toward field side
0.0410	Vehicle begins to redirect
0.0430	Post 14 begins to deflect toward field side
0.0480	Right front tire contacts post 13
0.0870	Post 15 begins to deflect toward field side
0.1140	Post 16 begins to deflect toward field side
0.2920	Vehicle traveling parallel with guardrail

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 139 ft downstream of the point of impact and 78 ft toward traffic lanes.

7.5. DAMAGE TO TEST INSTALLATION

Figure 7.3 through Figure 7.5 show the damage to the guardrail on 6H:1V slope. The rail released from posts 1 through 18. The blockouts released from posts 13 through 17. One blockout came to rest 89 ft to the field side and 140 downstream of the impact point. Post 1 had a ¾-inch gap in the soil on the upstream side. Post 2 had a ⅛-inch gap on the downstream side, and the rail was ripped at the bolt. There was no movement noted for posts 3 through 11. Post 12 had a ½-inch gap on the traffic side, a ¼-inch gap on the field side and the post was leaning

1 degree from vertical toward the field side, with a slight rotation. Post 13 had a 3-inch gap on the traffic side and a ½-inch gap on the field side. and it was leaning toward the field side 45 degrees from vertical. The soil was very disturbed at post 14, and it was leaning toward the field side 54 degrees from vertical. Post 15 was leaning toward the field side and downstream 51 degrees and post 16 was leaning toward the field side and downstream 55 degrees from vertical. Post 17 was leaning toward the field side and downstream 62 degrees from vertical. Post 18 was leaning toward the field side 1 degree from vertical and there was a ½-inch gap in the soil on the traffic side of the post. There was no movement or damage noted from post 19 until the end of the installation. Working width* was 43.7 inches, and height of working width was 31.0 inches. Maximum dynamic deflection during the test was 38.4 inches.

Figure 7.3. Guardrail on 6H:1V Slope after Test No. 613011-01-1.

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

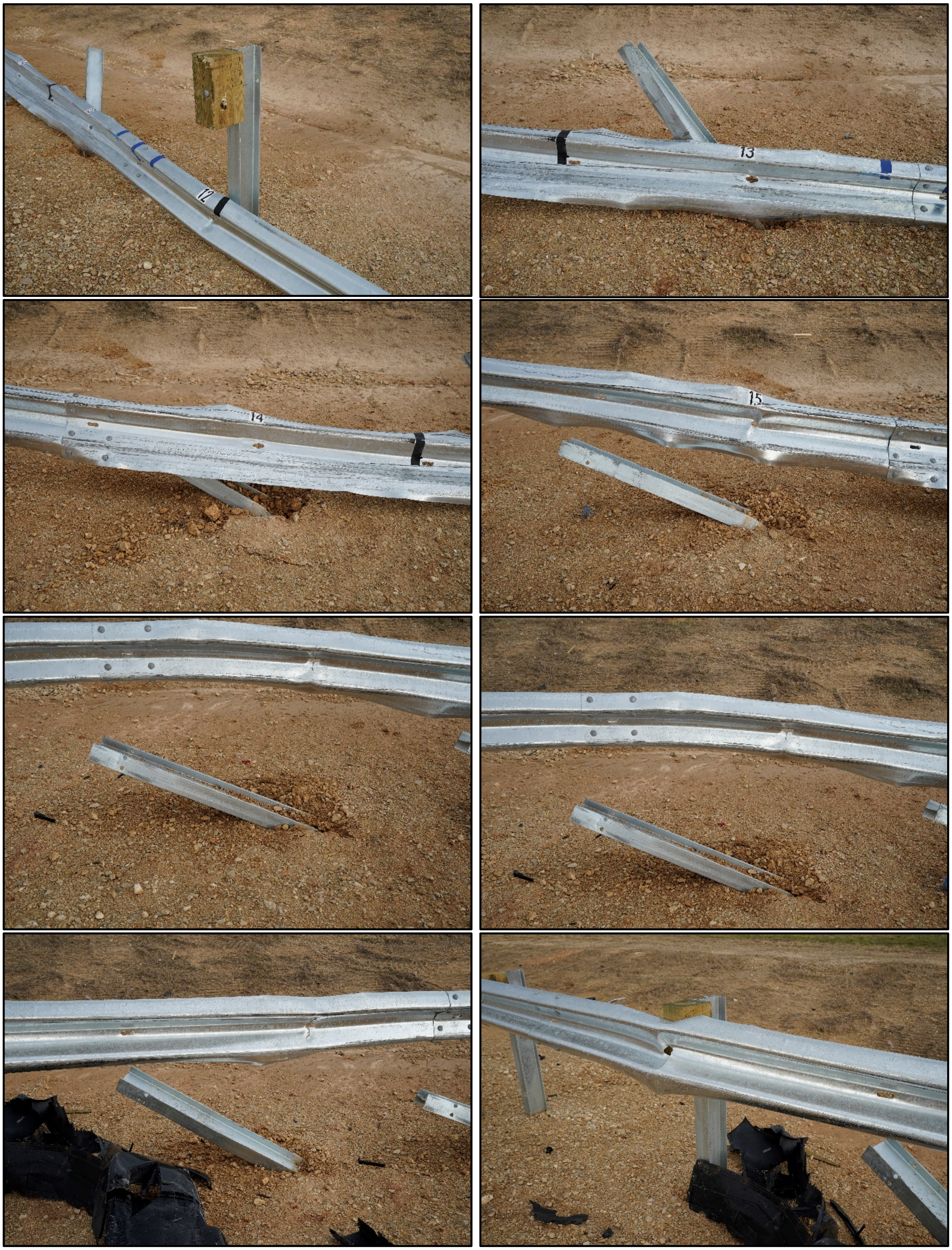


Figure 7.4. Damage to Posts 12-19 after Test No. 613011-01-1.

Figure 7.5. Field Side after Test No. 613011-01-1.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.6 shows the damage sustained by the vehicle. The front bumper, hood, radiator and support, right front fender, right front tire and rim, floor pan, right front door and window glass, right rear door, right rear quarter panel, and rear bumper were damaged. The windshield sustained stress cracking radiating upward and inward from the right lower corner. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 7.0 inches in the front and side planes at the right front corner at bumper height. Maximum occupant compartment deformation was 0.5 inch in the right side floor pan. Figure 7.7 shows the interior of the vehicle. Tables D.2 and D.3 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 7.6. Test Vehicle after Test No. 613011-01-1.

Figure 7.7. Interior of Test Vehicle after Test No. 613011-01-1.

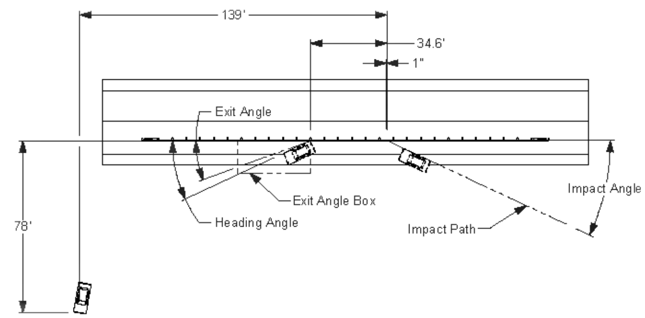
7.7. OCCUPANT RISK FACTORS

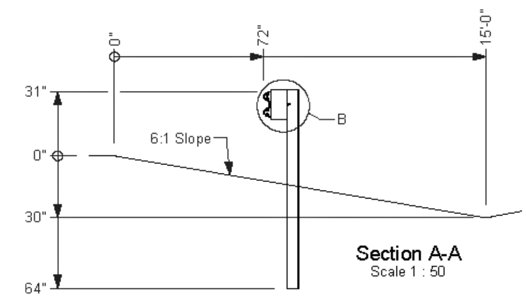
Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.2. Figure D.3 in Appendix D.3 shows the vehicle angular displacements, and Figures D.4 through D.6 in Appendix D.4 show acceleration versus time traces. Figure 7.8 summarizes pertinent information from the test.

Table 7.2. Occupant Risk Factors for Test No. 613011-01-1.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	17.7 ft/s	at 0.1380 s on right side of interior
Lateral	16.1 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	11.0 g	0.4115 - 0.4215 s
Lateral	6.4 g	0.3534 - 0.3634 s
Theoretical Head Impact Velocity (THIV)	7.0 m/s	at 0.1334 s on right side of interior
Acceleration Severity Index (ASI)	0.8	0.0850 - 0.1350 s
Maximum 50-ms Moving Average		
Longitudinal	−6.3 g	0.0639 - 0.1139 s
Lateral	−5.5 g	0.0411 - 0.0911 s
Vertical	−5.1 g	0.2085 - 0.2585 s
Maximum Yaw, Pitch, and Roll Angles		
Roll	39 degrees	2.0000 s
Pitch	6 degrees	0.6249 s
Yaw	50 degrees	2.0000 s

0.000 s | 0.200 s | 0.400 s | 0.600 s





General Information
- Test Agency .... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. .... *MASH* Test 3-10
- TTI Test No. 613011-01-1
- Test Date 2021-01-06

Test Article
- Type .... Longitudinal Barrier—Guardrail
- Name .... Guardrail on 6H:1V Slope
- Installation Length .... 181 ft-3 inches
- Material or Key Elements ... W-beam guardrail system embedded on a 6H:1V slope

Soil Type and Condition ..... AASHTO M147-65(2004), grading B Soil (crushed limestone), damp

Test Vehicle
- Type/Designation 1100C
- Make and Model .... 2015 Nissan Versa
- Curb .... 2418 lb
- Test Inertial .... 2434 lb
- Dummy .... 165 lb
- Gross Static .... 2599 lb

Impact Conditions
- Speed .... 64.8 mi/h
- Angle .... 25.6 degrees
- Location/Orientation .... 1 inch upstream of splice at Posts 12-13

Impact Severity .... 64 kip-ft

Exit Conditions
- Speed .... Out of view
- Trajectory/Heading Angle ... Out of view

Occupant Risk Values
- Longitudinal OIV .... 17.7 ft/s
- Lateral OIV .... 16.1 ft/s
- Longitudinal Ridedown .... 11.0 g
- Lateral Ridedown .... 6.4 g
- THIV .... 7.0 m/s
- ASI 0.8

Max. 0.050-s Average
- Longitudinal .... −6.3 g
- Lateral .... −5.5 g
- Vertical .... −5.1 g

Post-Impact Trajectory
- Stopping Distance .... 139 ft downstream, 78 ft twd traffic lanes

Vehicle Stability
- Maximum Roll Angle .... 39 degrees
- Maximum Pitch Angle .... 6 degrees
- Maximum Yaw Angle .... 50 degrees
- Vehicle Snagging .... No
- Vehicle Pocketing .... Yes

Test Article Deflections
- Dynamic .... 38.4 inches
- Permanent .... Separated from rail
- Working Width .... 43.7 inches
- Height of Working Width .... 31.0 inches

Vehicle Damage
- VDS 01RFQ5
- CDC 01FREW4
- Max. Exterior Deformation .... 7.0 inches
- OCDI RF0001000
- Max. Occupant Compartment Deformation .... 0.5 inch

Figure 7.8. Summary of Results for *MASH* Test 3-10 on Guardrail on 6H:1V Slope.

Chapter 8. *MASH* TEST 3-11 (CRASH TEST NO. 613011-01-2)

8.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-11 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the CIP of the longitudinal barrier at an impact speed of 62 mi/h ± 2.5 mi/h and an angle of 25 degrees ± 1.5 degrees. The CIP for *MASH* Test 3-11 on the guardrail on 6H:1V slope was centerline of post 12 ± 1 ft. Figure 5.2 and Figure 8.1 depict the target impact setup.

Figure 8.1. Guardrail/Test Vehicle Geometrics for Test No. 613011-01-2.

The 2270P vehicle weighed 5064 lb, and the actual impact speed and angle were 63.0 mi/h and 26.3 degrees. The actual impact point was 3.2 inches downstream of the centerline of post 12. Minimum target IS was 106 kip-ft, and actual IS was 132 kip-ft.

8.2. WEATHER CONDITIONS

The test was performed on the morning of January 25, 2021. Weather conditions at the time of testing were as follows: wind speed: 8 mi/h; wind direction: 314 degrees (vehicle was traveling at a heading of 330 degrees); temperature: 65°F; relative humidity: 74 percent.

8.3. TEST VEHICLE

Figure 8.2 shows the 2015 RAM 1500 pickup truck used for the crash test. The vehicle’s test inertia weight was 5064 lb, and its gross static weight was 5229 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle’s center of gravity was 28.5 inches. Tables E.1 and E.2 in Appendix E.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

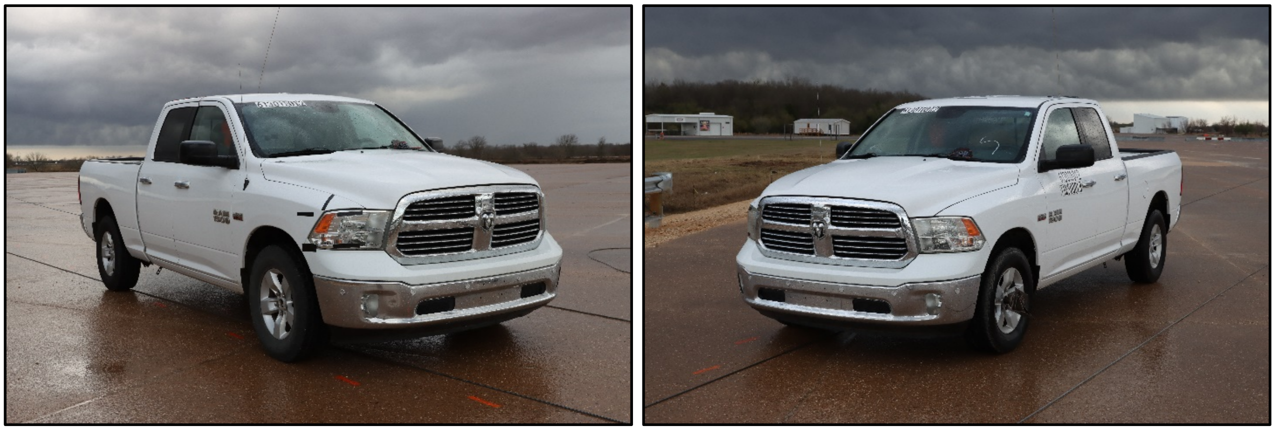


Figure 8.2. Test Vehicle before Test No. 613011-01-2.

8.4. TEST DESCRIPTION

Table 8.1 lists events that occurred during Test No. 613011-01-2. Figures E.1 and E.2 in Appendix E.2 present sequential photographs during the test.

Table 8.1. Events during Test No. 613011-01-2.

Time (s)	Events
0.0000	Vehicle impacts guardrail
0.0390	Vehicle begins to redirect
0.0630	Rail begin to release from the posts, starting with post 13
0.1810	Rear of vehicle contacts the rail
0.3140	Vehicle traveling parallel with guardrail
0.7650	Downstream DAT post begins to shear
1.0070	Vehicle completely on field side of guardrail

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were not applied. The vehicle came to rest 138 ft downstream of the point of impact and 17 ft toward field side.

8.5. DAMAGE TO TEST INSTALLATION

Figure 8.3 shows the damage to the guardrail on 6H:1V slope. The rail released from all posts and blockouts. The slot at post 2 tore 1¼ inches downward. The upstream rail at the joint between posts 16 and 17 ripped from the top to the center of the rail. All other slots at locations where they were mounted onto a post were damaged from the bolts pulling through.

Post 1 sheared at the top of the bottom brace. The remaining section of post had a 1¼-inch gap in the soil on the downstream side, and it was leaning 3 degrees downstream from vertical. The broken off section of post came to rest 41 ft downstream and 18 ft towards the traffic lanes. Post 2 had a ⅝-inch gap in the soil on the upstream side, and a ¾-inch gap on the downstream side. The post was slightly splintered as well. For posts 3 through 10, the only noted damage was that the soil was disturbed. Post 11 was twisted 45 degrees clockwise and had a ⅛-inch gap in the soil on the traffic side of the post. Post 12 was twisted 80 degrees clockwise, had a 3¼-inch gap on the traffic side of the post, and a ¾-inch gap on the field side.

The blockout was missing from posts 13 through 18, and deflection could not be measured because all the soil and. Post 13 was leaning 74 degrees downstream, and its blockout landed 81 ft towards the field side and 111 ft downstream. Post 14 was leaning 66 degrees downstream, and the bolt hole was ripped open. Its blockout split in half vertically, with one half landing 3 ft toward the field side and 53 inches downstream, and the other half landing 40 ft toward the field side and 96 ft downstream. The bolt hole on post 15 ripped open as well, and the post was leaning 69 degrees downstream. Its blockout came to rest 25 ft towards the field side and 151 ft downstream. Post 16 was leaning 73 degrees downstream, and its blockout landed 10 ft towards the field side and 121 feet downstream. Post 17 was leaning 67 degrees downstream, and its blockout fell 9 ft towards the field side and 111 ft downstream. Post 18 was leaning 68 degrees downstream, and its blockout came to rest 3 ft towards the field side and 40 ft downstream. Post 19 was leaning downstream 20 degrees and rotated 25 degrees clockwise.

Post 20 was leaning 39 degrees downstream. Posts 21 and 22 were both still vertical, and the soil around each post was disturbed. Post 23 was leaning 42 degrees downstream, and post 24 was leaning 30 degrees downstream. Post 25 was leaning 8 degrees downstream, and post 26 was leaning 38 degrees downstream and had a ⅜-inch gap in the soil on the upstream side of the post. Post 27 was leaning 6 degrees downstream, its blockout was rotated 45 degrees counterclockwise, and it had a ¼-inch gap in the soil on the upstream side of the post. The soil was disturbed at posts 28 and 29. Post 30 broke off even with the top of the DAT's bottom brace, and came to rest 23 ft downstream and 9 ft towards the field side.

Figure 8.3. Guardrail after Test No. 613011-01-2.

8.6. DAMAGE TO TEST VEHICLE

Figure 8.4 shows the damage sustained by the vehicle. The front bumper, grill, hood, radiator and support, right front fender, right front door, right rear exterior bed, rear bumper, left front fender, and left rear exterior bed were damaged. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 9.0 inches in the front and side planes at the right front corner at bumper height. No occupant compartment deformation or intrusion was noted. Figure 8.5 shows the interior of the vehicle. Tables E.3 and E.4 in Appendix E.1 provide exterior crush and occupant compartment measurements.

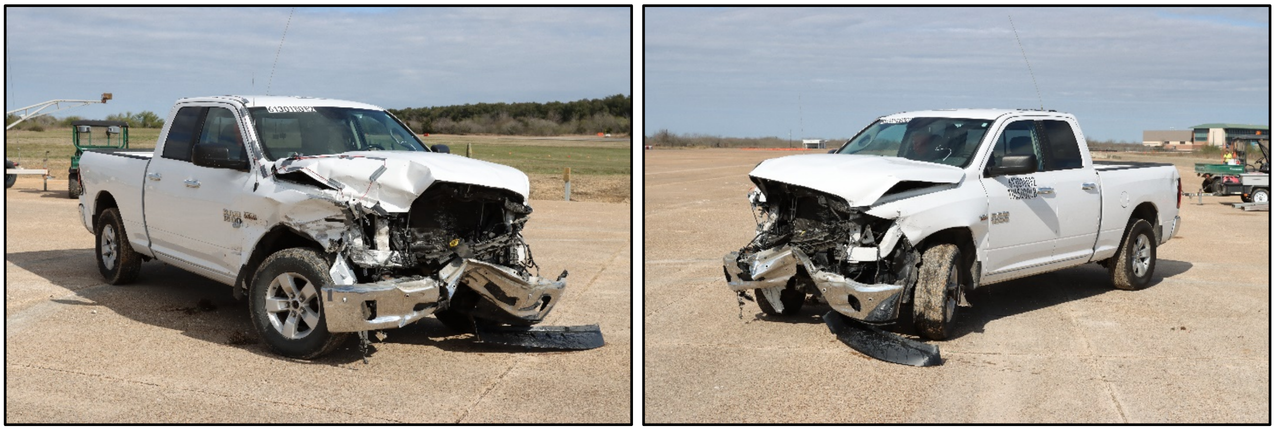


Figure 8.4. Test Vehicle after Test No. 613011-01-2.

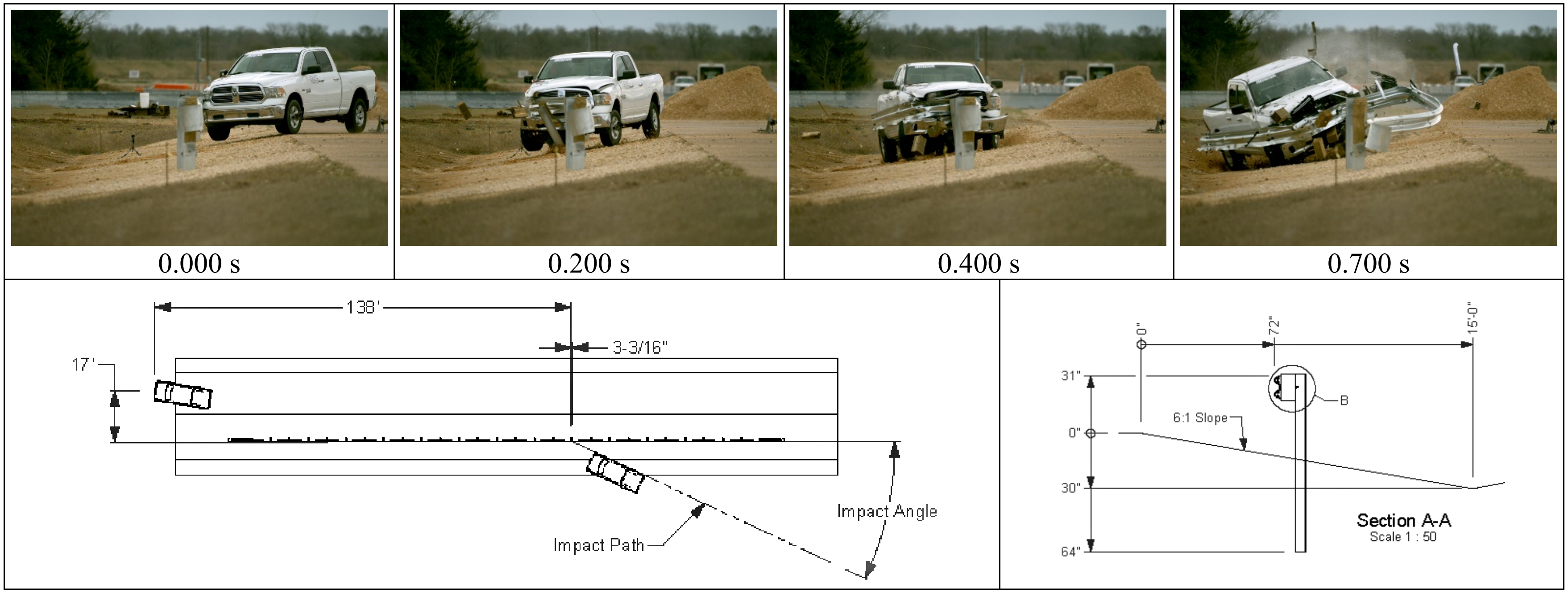
Figure 8.5. Interior of Test Vehicle after Test No. 613011-01-2.

8.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 8.2. Figure E.3 in Appendix E.3 shows the vehicle angular displacements, and Figures E.4 through E.6 in Appendix E.4 show acceleration versus time traces. Figure 8.6 summarizes pertinent information from the test.

Table 8.2. Occupant Risk Factors for Test No. 613011-01-2.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	13.5 ft/s	at 0.1740 s on right side of interior
Lateral	13.1 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	8.4 g	0.4455 - 0.4555 s
Lateral	4.7 g	0.3861 - 0.3961 s
Theoretical Head Impact Velocity (THIV)	5.4 m/s	at 0.1672 s on right side of interior
Acceleration Severity Index (ASI)	0.5	0.4448 - 0.4948 s
Maximum 50-ms Moving Average		
Longitudinal	−5.3 g	0.4039 - 0.4539 s
Lateral	−3.0 g	0.0819 - 0.1319 s
Vertical	−2.1 g	0.3555 - 0.4055 s
Maximum Yaw, Pitch, and Roll Angles		
Roll	91°	5.0000 s
Pitch	20°	5.0000 s
Yaw	46°	1.0312 s



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-11
TTI Test No.	613011-01-2
Test Date	2017-01-25
Test Article	
Type	Longitudinal Barrier—Guardrail
Name	Guardrail on 6H:1V Slope
Installation Length	181 ft-3 inches
Material or Key Elements	W-beam guardrail system embedded on a 6H:1V slope
Soil Type and Condition	AASHTO M147-65(2004), Type A Grade 2 soil (crushed limestone), damp
Test Vehicle	
Type/Designation	2270P
Make and Model	2015 RAM 1500 Pickup
Curb	5110 lb
Test Inertial	5064 lb
Dummy	165 lb
Gross Static	5229 lb

Impact Conditions	
Speed	63.0 mi/h
Angle	26.3°
Location/Orientation	3.2 inches dwnstrm of post 12
Impact Severity	132 kip-ft
Exit Conditions	
Speed	Anchor Failure
Trajectory/Heading Angle	Anchor Failure
Occupant Risk Values	
Longitudinal OIV	13.5 ft/s
Lateral OIV	13.1 ft/s
Longitudinal Ridedown	8.4 g
Lateral Ridedown	4.7 g
THIV	5.4 m/s
ASI	0.5
Max. 0.050-s Average	
Longitudinal	−5.3 g
Lateral	−3.0 g
Vertical	−2.1 g

Post-Impact Trajectory	
Stopping Distance	138 ft downstream 17 ft twd field side
Vehicle Stability	
Maximum Roll Angle	91°
Maximum Pitch Angle	20°
Maximum Yaw Angle	46°
Vehicle Snagging	No
Vehicle Pocketing	Yes
Test Article Deflections	
Dynamic	Anchor Failure
Permanent	Anchor Failure
Working Width	Anchor Failure
Height of Working Width	Anchor Failure
Vehicle Damage	
VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	9.0 inches
OCDI	RF0000000
Max. Occupant Compartment Deformation	None

Figure 8.6. Summary of Results for *MASH* Test 3-11 on Guardrail on 6H:1V Slope.

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Chapter 9. SUMMARY AND CONCLUSIONS

9.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-3, which involves two tests, on the guardrail on 6H:1V slope. Table 9.1 and Table 9.2 provide an assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-3 longitudinal barriers.

9.2. CONCLUSIONS

Table 9.3 shows that the guardrail on 6H:1V slope did not meet the performance criteria for *MASH* TL-3 longitudinal barriers due to penetration of the guardrail by the 2270P vehicle in *MASH* Test 3-11.

Since the anchorage failure was observed during the test, using a different end anchor technology is recommended in any subsequent evaluation of a variation of this system. Furthermore, the tearing of the rail elements observed (shown in Figure 7.4) in this test can be reduced by using thrie-beams elements instead of W-beam rail elements.

Table 9.1. Performance Evaluation Summary for *MASH* Test 3-10 on Guardrail on 6H:1V Slope.

Test Agency: Texas A&M Transportation Institute | Test No.: 613011-01-1 | Test Date: 2021-01-06

***MASH* Test 3-10 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The Guardrail on 6H:1V Slope contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 38.4 inches.	Pass
<u>Occupant Risk</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 0.5 inch in the right-side floor pan	
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 39 degrees and 6 degrees.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 17.7 ft/s, and lateral OIV was 16.1 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Longitudinal occupant ridedown acceleration was 11.0 g, and lateral occupant ridedown acceleration was 6.4 g.	Pass

Table 9.2. Performance Evaluation Summary for *MASH* Test 3-11 on Guardrail on 6H:1V Slope.

Test Agency: Texas A&M Transportation Institute | Test No.: 613011-01-2 | Test Date: 2021-01-25

MASH Test 3-11 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The Guardrail on 6H:1V Slope did not contain or redirect the 2270P vehicle. The vehicle penetrated the installation and came to rest on the field side of the guardrail.	Fail
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	The rail element separated from the posts and some of the wood blockouts separated from the posts, however, none of these penetrated the occupant compartment. The rail element wrapped around the front of the vehicle.	Pas
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	No occupant compartment deformation or intrusion was observed.	
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 91 degrees and 20 degrees.	Pass
H. *Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*	Longitudinal OIV was 13.5 ft/s, and lateral OIV was 13.1 ft/s.	Pass
I. *The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Longitudinal occupant ridedown acceleration was 8.4 g, and lateral occupant ridedown acceleration was 4.7 g.	Pass

Table 9.3. Assessment Summary for *MASH* TL-3 Tests on Guardrail on 6H:1V Slope.

Evaluation Factors	Evaluation Criteria	Test No. 613011-01-1	Test No. 613011-01-2
Structural Adequacy	A	S	U
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
	Test No.	***MASH* Test 3-10**	***MASH* Test 3-11**
	Pass/Fail	Pass	Fail

Note: S = Satisfactory; U = Unsatisfactory.

REFERENCES

1. AASHTO Roadside Design Guide. American Association of State Highway and Transportation Officials, Washington, DC.

2. Washington State Department of Transportation (WSDOT) Design Manual, https://wsdot.wa.gov/Publications/Manuals/M22-01.htm, last accessed 2020-09-27.

3. MwRSF Report TRP-03-188-08.

4. H.E. Ross, Jr., D.L. Sicking, R.A. Zimmer and J.D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

5. AASHTO. *Manual for Assessing Safety Hardware, Second Edition.* American Association of State Highway and Transportation Officials: Washington, DC, 2016.

6. Akram Y. Abu-Odeh, Kelly Ha, Ivan Liu, and Wanda L. Menges. *MASH TL-3 Testing and Evaluation of the W-Beam Guardrail on Slope*, Test Report No. 405160-20, Texas A&M Transportation Institute, College Station, Tx, March 2013.

7. Sun Hee Park, Akram Y Abu-Odeh, Wanda L. Menges, Glenn E. Schroeder, and Darrell L. Kuhn. *MASH Test 3-10 of Guardrail on 1H:1V Slope*, Texas A&M Transportation Institute, College Station, Tx, October 2020.

8. Chiara Silvestri Dobrovolny, Wanda L. Menges, and Darrell L. Kuhn. *MASH Tests 3-34 and 3-35 on the 31-inch Buried-in-Backslope Terminal Compatible with MGS Guardrail*. Test Report No. 608431-01-1&2, Texas A&M Transportation Institute, College Station, TX, October 2018.

9. Nauman M. Sheikh, Roger P. Bligh, Sofokli Cakalli, and Shaw-Pin Miaou. *Guidelines for Traversability of Roadside Slopes*. National Academies of Sciences, Engineering, and Medicine 2019. Washington, DC: The National Academies

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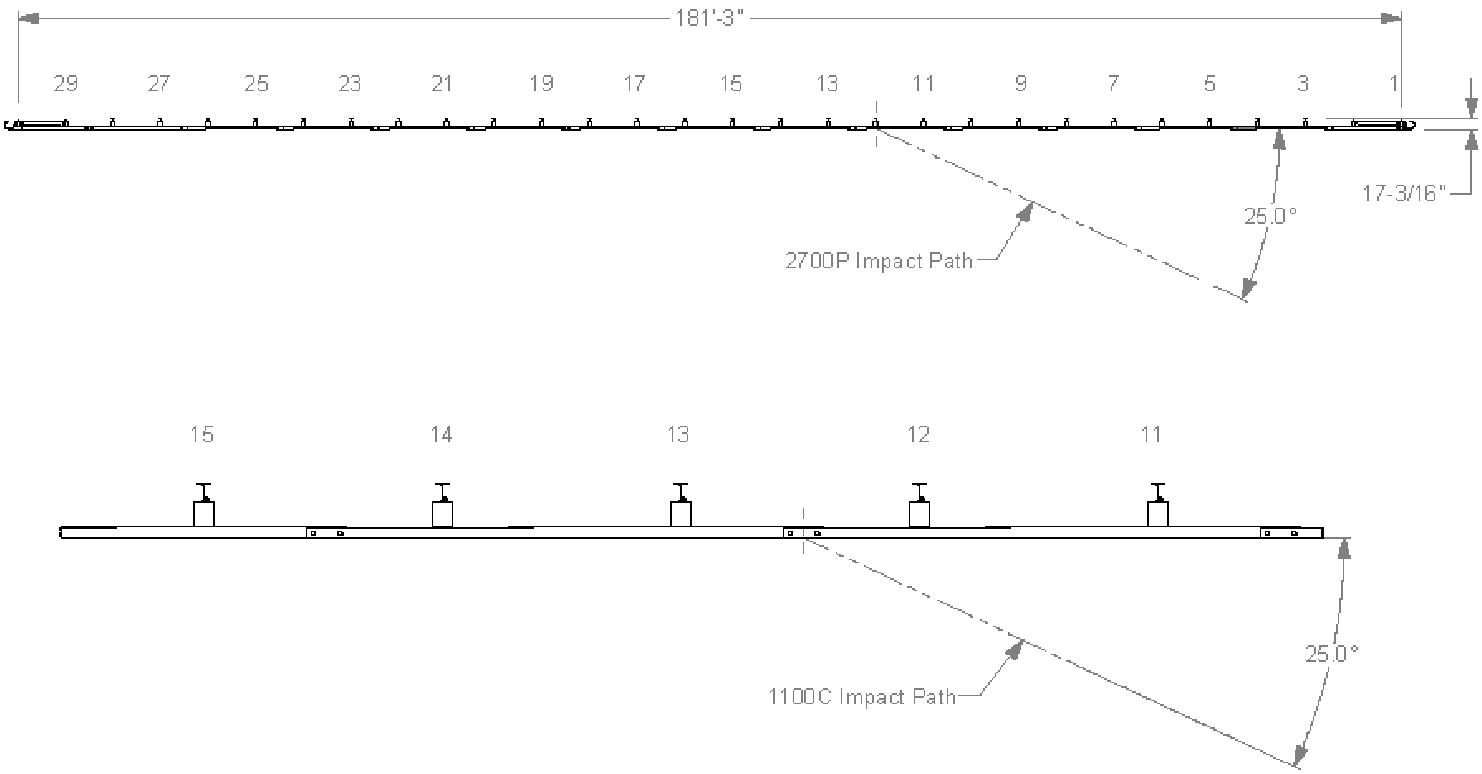
APPENDIX A. DETAILS OF GUARDRAIL ON 6H:1V SLOPE

Impact



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #613011 Guardrail on 6:1 Slope		2021-01-07
Drawn by GES/WS	Scale 1:250	Sheet 1 of 4 Impact

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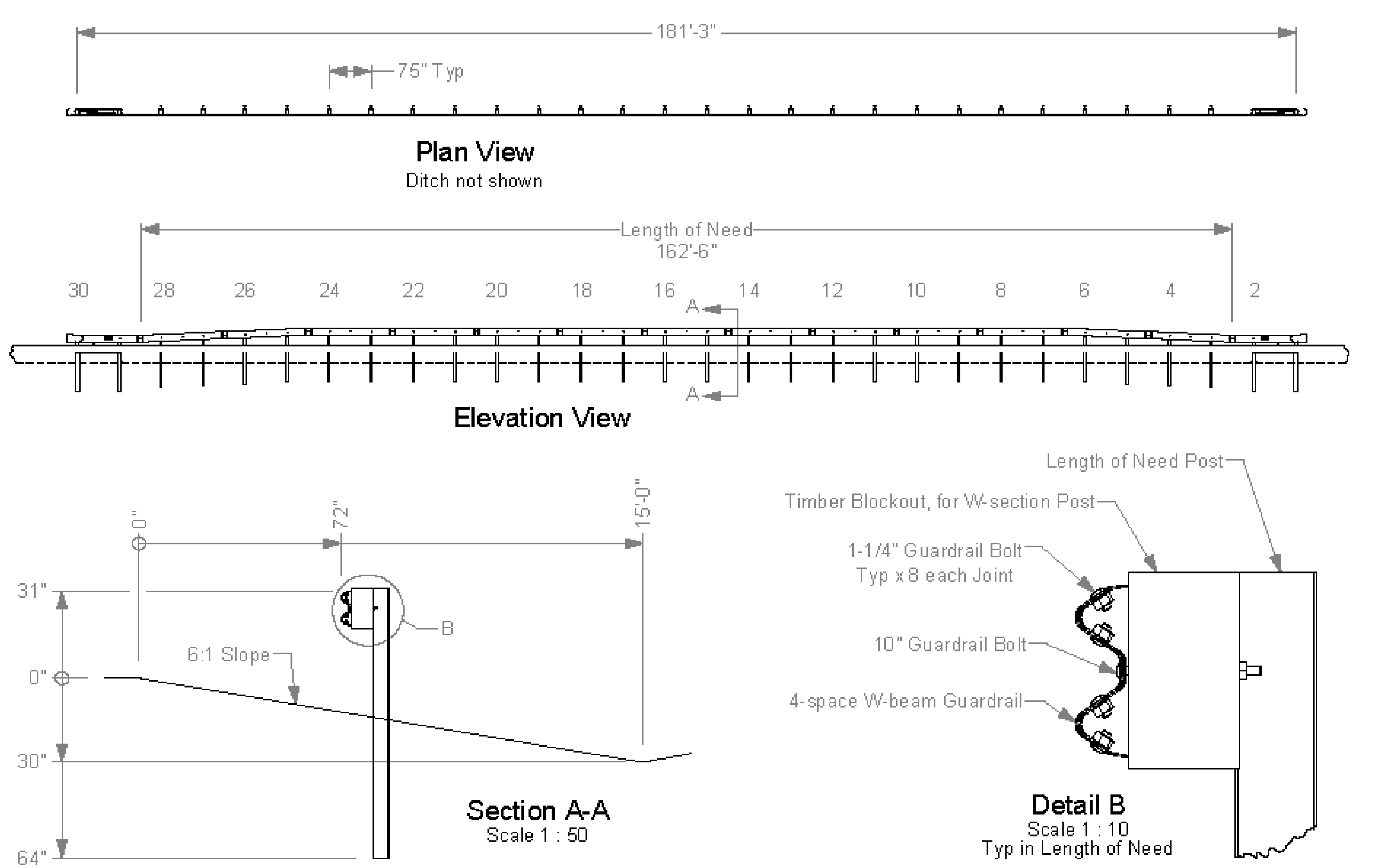
Test Installation



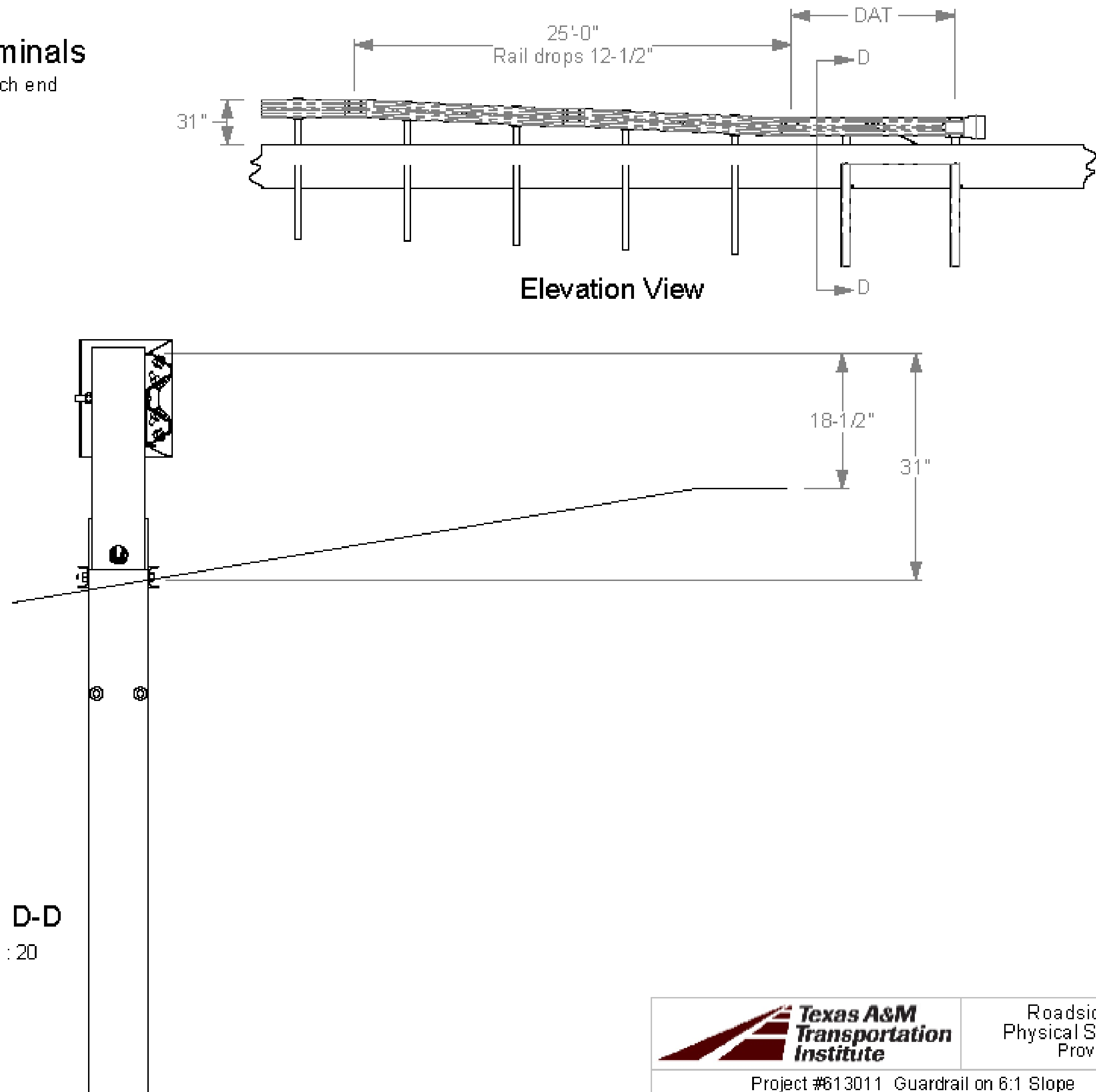
2a. Backfill Post holes with Type A grade 2 crushed limestone road base, compacted to MASH standard.
2b. Recessed Guardrail Nuts on all 5/8 Bolts.
2c. All steel components are galvanized.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #613011 Guardrail on 6:1 Slope		2021-01-07
Drawn by GES/WS	Scale 1:250	Sheet 2 of 4 Test Installation

Q:\Accreditation-17025-2017\EIR-000 Project Files\613011 - Guardrail on 6-1 Slope - Abu-Odeh\Drafting, 613011\613011 Drawing

Rail Terminals

Typical each end



Elevation View

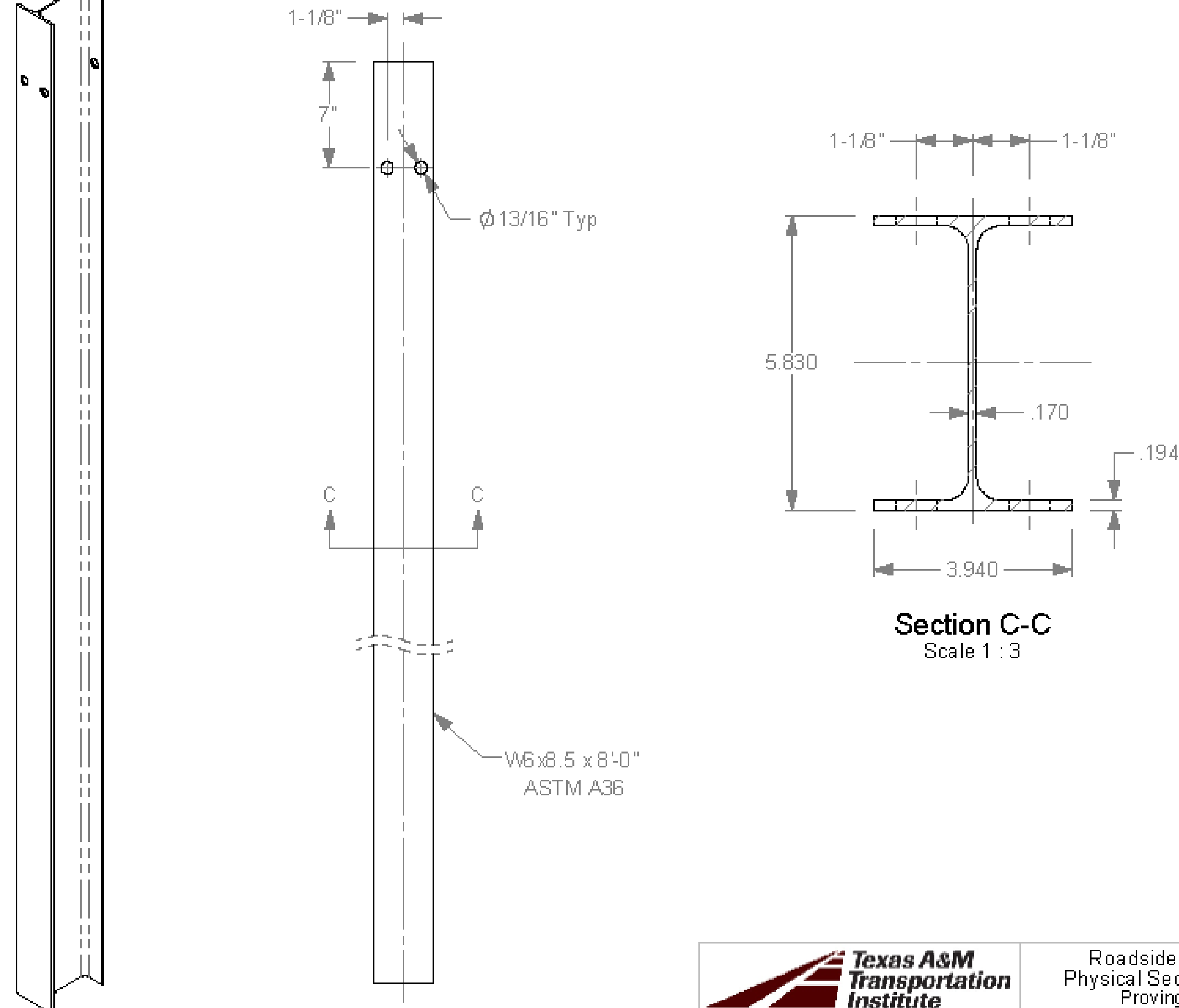
Section D-D

Scale 1 : 20

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #613011 Guardrail on 6:1 Slope		2021-01-07
Drawn by GES/WS	Scale 1:100	Sheet 3 of 4 Rail Terminals

Q:\Accreditation-17025-2017\EIR-000 Project Files\613011 - Guardrail on 6-1 Slope - Abu-Odeh\Drafting, 613011\613011 Drawing

Length of Need Post

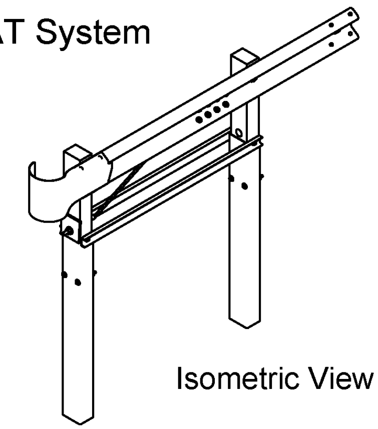


Section C-C
Scale 1 : 3

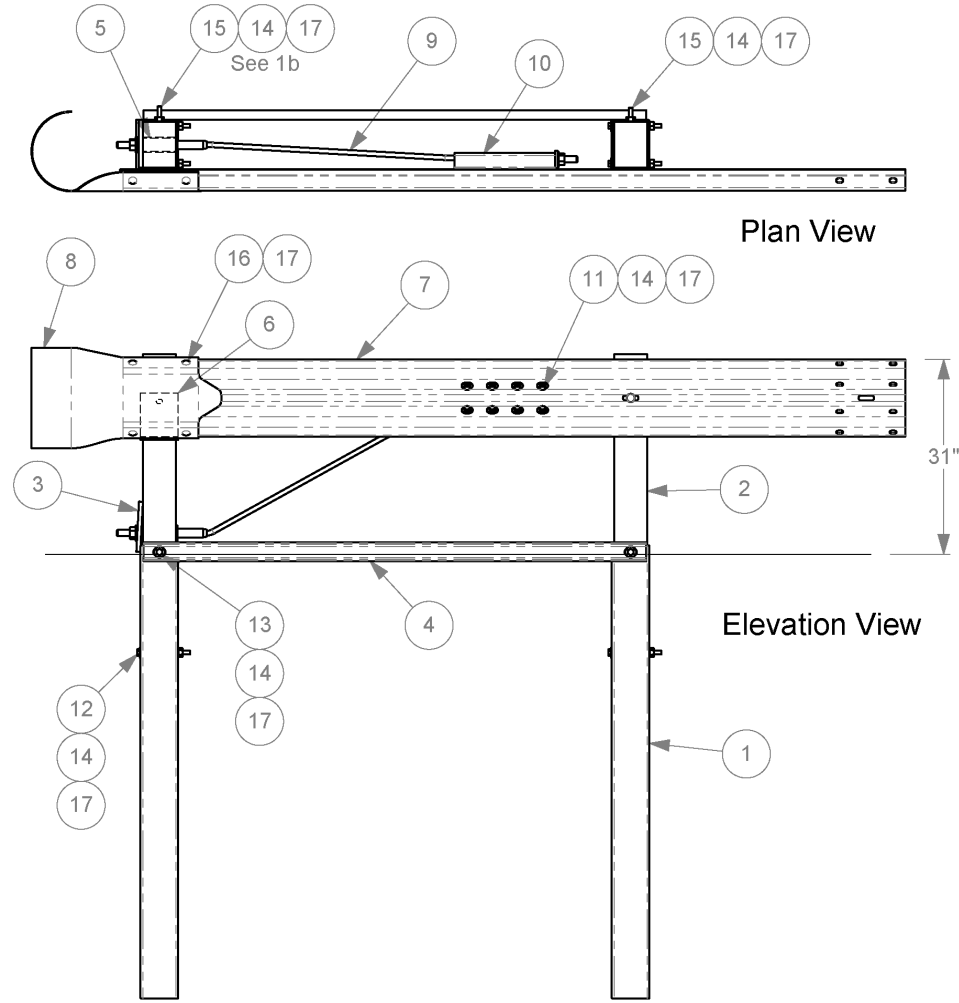
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #613011 Guardrail on 6:1 Slope		2021-01-07
Drawn by GES/WS	Scale 1:10	Sheet 4 of 4 Post Details

Q:\Accreditation-17025-2017\EIR-000 Project Files\613011 - Guardrail on 6-1 Slope - Abu-Odeh\Drafting, 613011\613011 Drawing

DAT System



Isometric View



Plan View

Elevation View

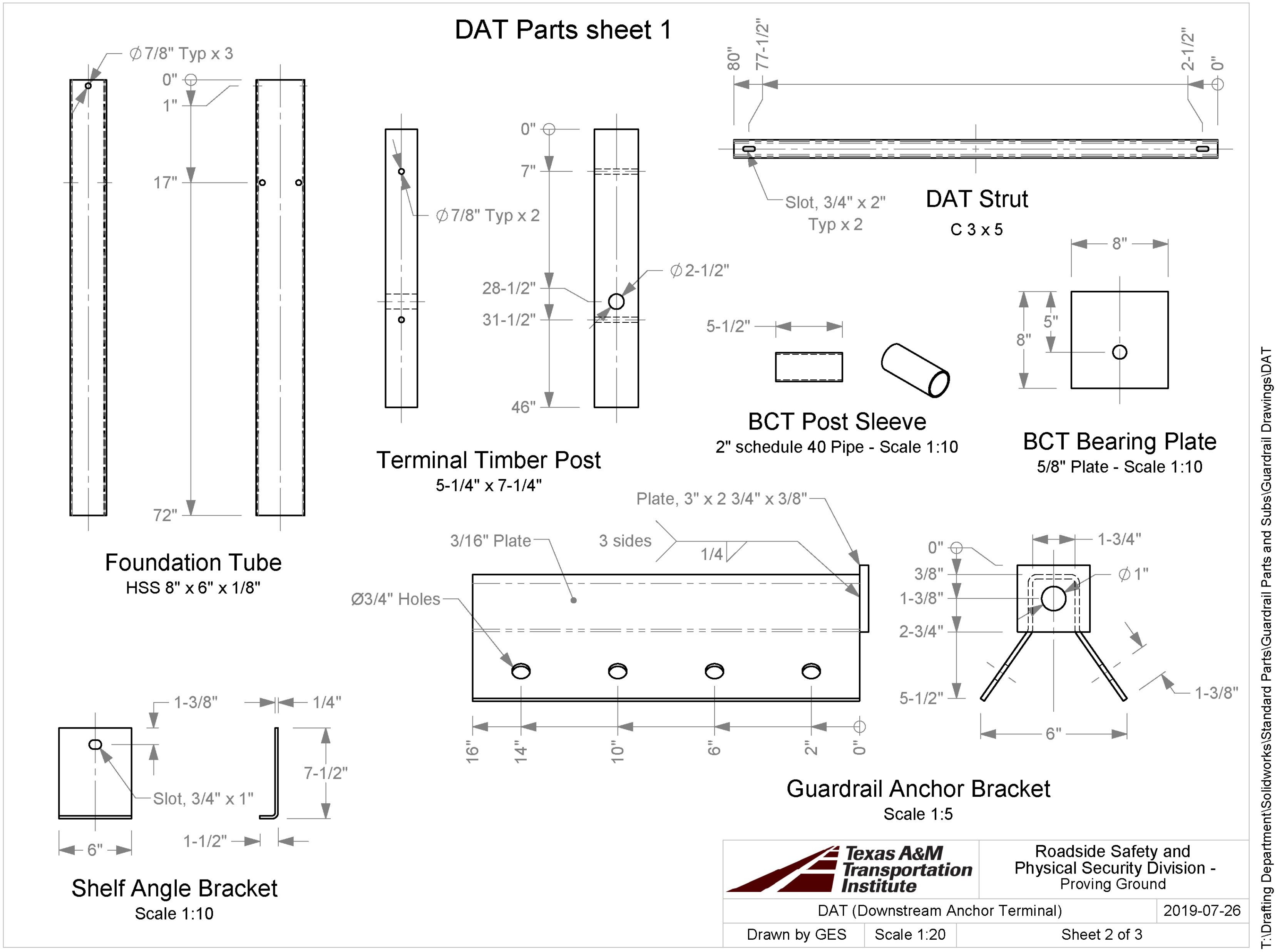
#	Part Name	Qty.
1	Foundation Tube	2
2	Terminal Timber Post	2
3	BCT Bearing Plate	1
4	DAT Strut	2
5	BCT Post Sleeve	1
6	Shelf Angle Bracket	1
7	DAT Terminal Rail	1
8	W-beam End Section	1
9	Anchor Cable Assembly	1
10	Guardrail Anchor Bracket	1
11	Bolt, 5/8 x 2" hex	8
12	Bolt, 5/8 x 8" hex	4
13	Bolt, 5/8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

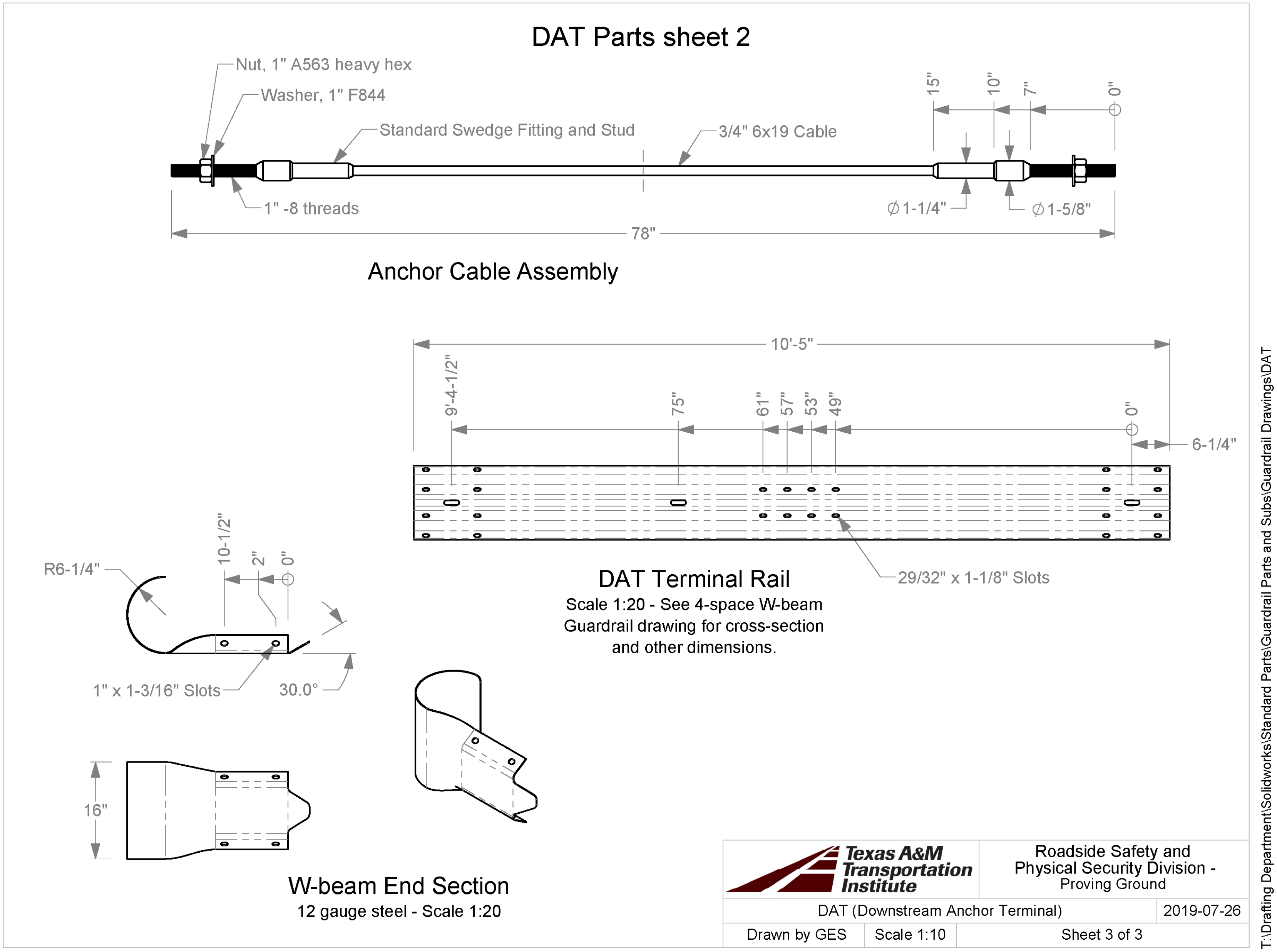
1a. All bolts are ASTM A307.

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

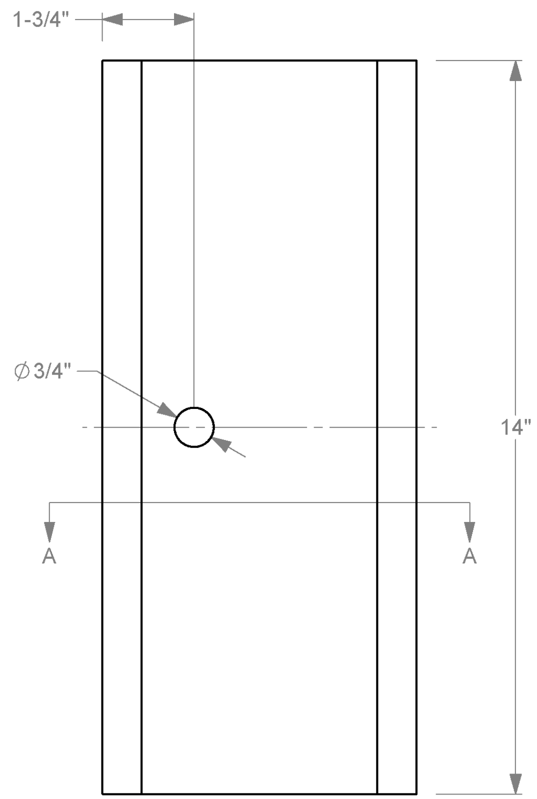
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
DAT (Downstream Anchor Terminal)		2019-07-26
Drawn by GES	Scale 1:25	Sheet 1 of 3

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

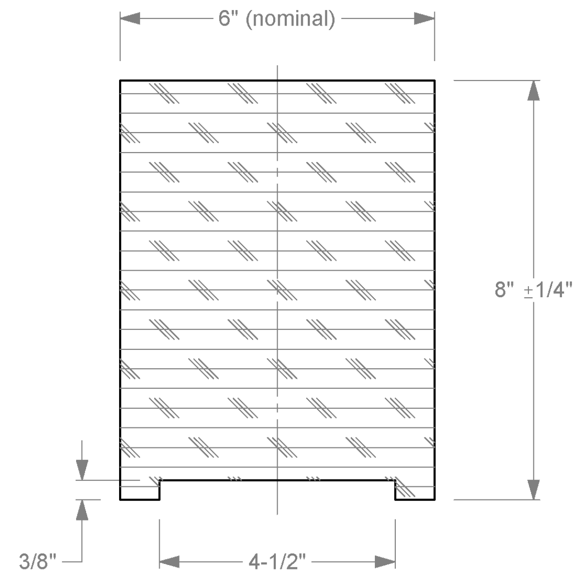

DAT Parts sheet 1
Ø7/8" Typ x 3
0"
1"
17"
72"
Foundation Tube
HSS 8" x 6" x 1/8"
0"
7"
Ø7/8" Typ x 2
Ø2-1/2"
28-1/2"
31-1/2"
46"
Terminal Timber Post
5-1/4" x 7-1/4"
80"
77-1/2"
2-1/2"
0"
Slot, 3/4" x 2"
Typ x 2
DAT Strut
C 3 x 5
5-1/2"
BCT Post Sleeve
2" schedule 40 Pipe - Scale 1:10
8"
8"
5"
BCT Bearing Plate
5/8" Plate - Scale 1:10
Plate, 3" x 2 3/4" x 3/8"
3/16" Plate
3 sides
1/4
Ø3/4" Holes
16"
14"
10"
6"
2"
0"
0"
3/8"
1-3/8"
2-3/4"
5-1/2"
1-3/4"
Ø1"
1-3/8"
6"
Guardrail Anchor Bracket
Scale 1:5
1-3/8"
1/4"
7-1/2"
Slot, 3/4" x 1"
6"
1-1/2"
Shelf Angle Bracket
Scale 1:10
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)
2019-07-26
Drawn by GES
Scale 1:20
Sheet 2 of 3
T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts\Guardrail Drawings\DAT


DAT Parts sheet 2
Nut, 1" A563 heavy hex
Washer, 1" F844
Standard Swedge Fitting and Stud
3/4" 6x19 Cable
15"
10"
7"
0"
1" -8 threads
∅1-1/4"
∅1-5/8"
78"
Anchor Cable Assembly
10'-5"
9'-4-1/2"
75"
61"
57"
53"
49"
0"
6-1/4"
29/32" x 1-1/8" Slots
DAT Terminal Rail
Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.
R6-1/4"
10-1/2"
2"
0"
1" x 1-3/16" Slots
30.0°
16"
W-beam End Section
12 gauge steel - Scale 1:20
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)
2019-07-26
Drawn by GES
Scale 1:10
Sheet 3 of 3
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\DAT

Timber Blockout for W-section Post



Elevation View



Section A-A

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

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

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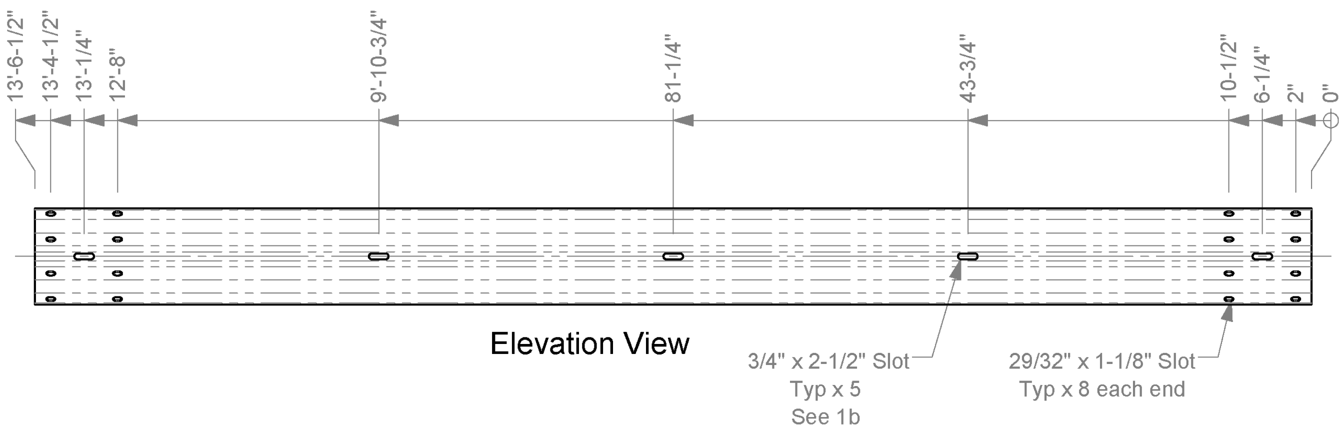
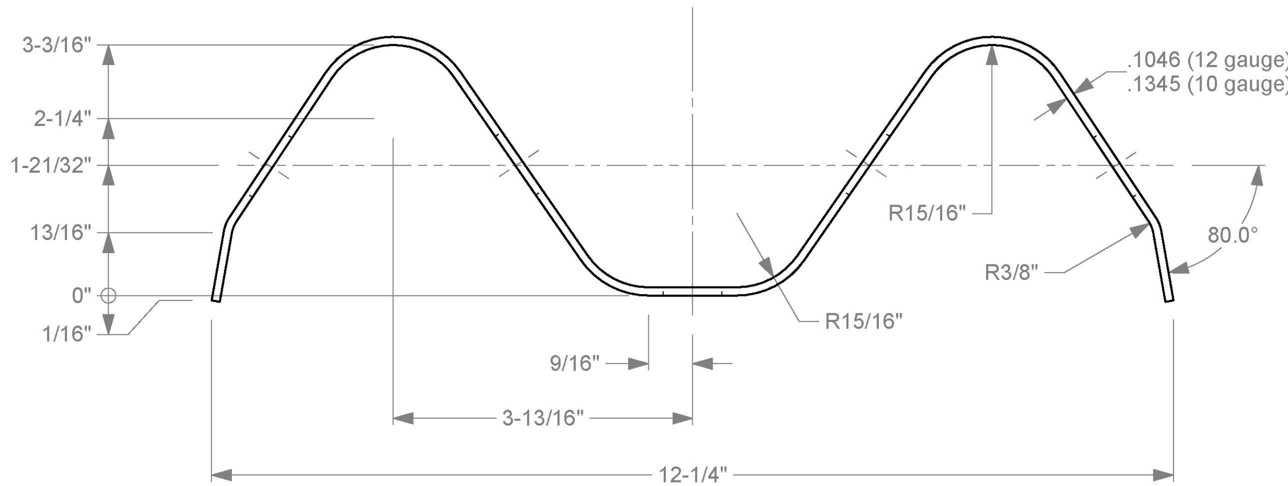


Elevation View



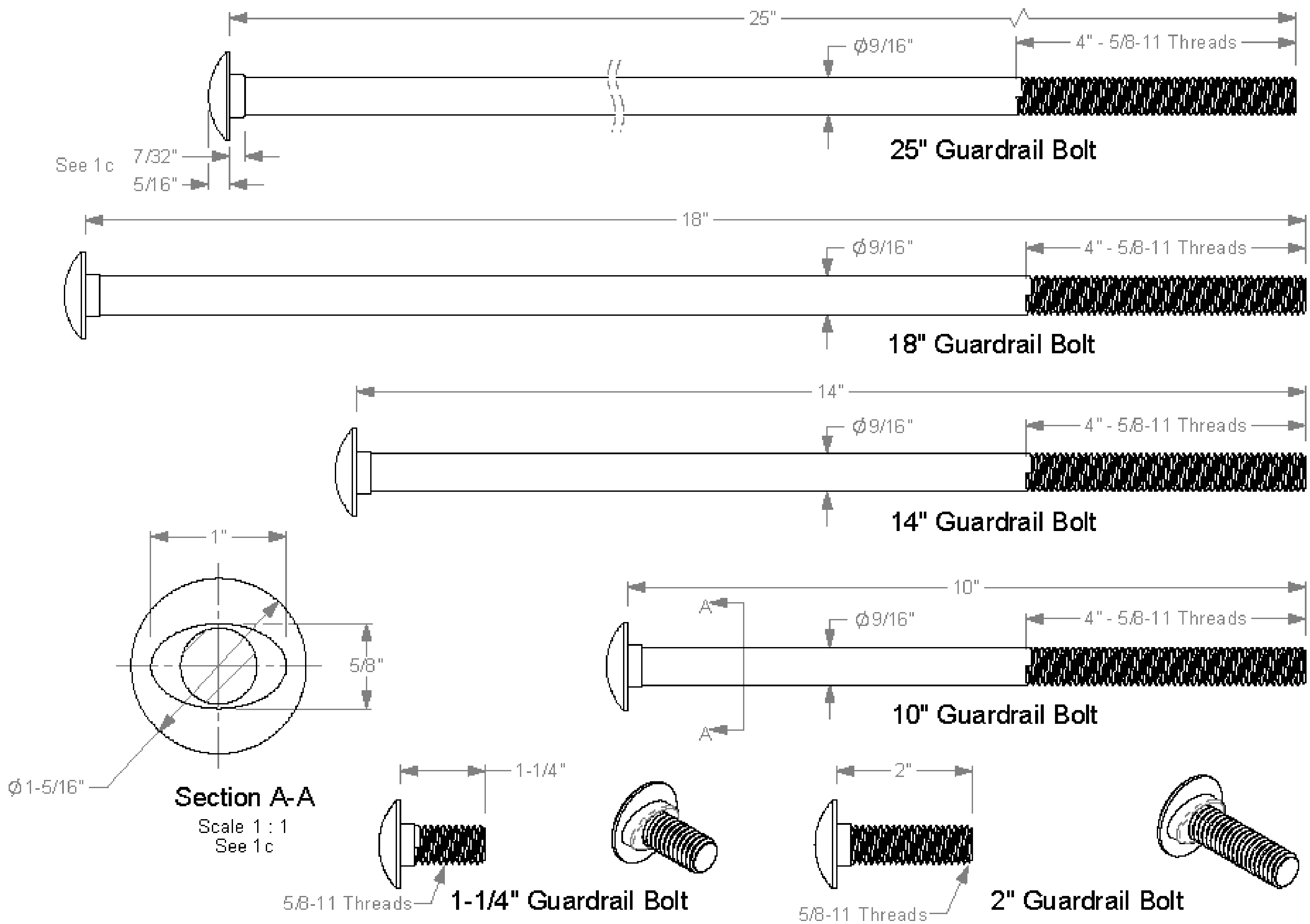
Section View

1a. Manufacture per AASHTO M180 specifications.

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

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

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



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

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

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Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: SAMPLES, TESTING MATERIALS
2525 STEMMONS FRWY

DALLAS, TX 75207

Project: WASHINGTON DOT TEST MATERIAL

Order Number: 1332025
Customer PO: WDOT
BOL Number: 81674
Document #: 1
Shipped To: TX
Use State: TX

Prod Ln Grp: 3-Guardrail (Dom)
613011
Ship Date:

As of: 11/6/20

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
26	11G	12/12'6/3'1.5/S			2	F14020													
			M-180	A	2	2104901	58,500	88,900	21.0	0.220	0.790	0.009	0.001	0.030	0.140	0.003	0.050	0.004	4
			M-180	A	2	2205428	62,900	86,700	23.0	0.220	0.800	0.010	0.001	0.030	0.110	0.003	0.050	0.004	4
			M-180	A	2	2205429	66,700	88,000	20.0	0.210	0.800	0.009	0.002	0.030	0.120	0.002	0.050	0.004	4
			M-180	A	2	2200760	62,800	85,200	25.0	0.210	0.770	0.009	0.002	0.020	0.090	0.000	0.040	0.003	4
			M-180	A	2	2200763	55,900	80,400	25.0	0.210	0.780	0.008	0.017	0.030	0.100	0.000	0.040	0.002	4
	11G				2	F14220													
			M-180	A	2	2104901	58,500	88,900	21.0	0.220	0.790	0.009	0.001	0.030	0.140	0.003	0.050	0.004	4
			M-180	A	2	2104902	56,200	88,400	21.0	0.210	0.780	0.009	0.002	0.030	0.130	0.002	0.050	0.003	4
			M-180	A	2	2104903	60,300	85,400	23.0	0.200	0.770	0.008	0.001	0.030	0.140	0.002	0.040	0.004	4
			M-180	A	2	2205427	54,200	84,100	24.0	0.220	0.770	0.009	9.000	0.040	0.120	0.001	0.040	0.004	4
			M-180	A	2	2205428	62,900	86,700	23.0	0.220	0.800	0.010	0.001	0.030	0.110	0.003	0.050	0.004	4
			M-180	A	2	2205429	66,700	88,000	20.0	0.210	0.800	0.009	0.002	0.030	0.120	0.002	0.050	0.004	4
3	850G	12/BUFFER/ROLLED	M-180	A	2	31847970	48,400	62,300	35.0	0.060	0.450	0.015	0.001	0.030	0.090	0.000	0.070	0.002	4
	850G		M-180	A	2	11719850	51,600	62,400	33.0	0.050	0.520	0.009	0.003	0.040	0.100	0.001	0.050	0.002	4
	850G		M-180	A	2	216690	65,000	83,340	22.8	0.190	0.730	0.012	0.003	0.020	0.100	0.000	0.070	0.002	4
3	3000G	CBL 3/4X6'6/DBL	WIRE			S394298													4
260	3340G	5/8" GR HEX NUT	FAST			20-35-004													4
220	3360G	5/8"X1.25" GR BOLT	A307-3360			922031-5													4
40	3500G	5/8"X10" GR BOLT A307	A307-3500			921743-7													4

TR No. 613011-01 70 2021-08-05

Certified Analysis

Trinity Highway Products, LLC

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: SAMPLES, TESTING MATERIALS
2525 STEMMONS FRWY

DALLAS, TX 75207

Project: WASHINGTON DOT TEST MATERIAL

Order Number: 1332025 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: WDOT
BOL Number: 81674 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 11/6/20

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
40	4076B	WD BLK RTD 6X8X14	WOOD			1826													
40	14268G	8'0 POST/8.5#/DR				TF4520B													
			A-36			58044605	60,771	72,364	22.2	0.090	0.930	0.008	0.027	0.190	0.210	0.015	0.140	0.001	4
			A-36			59094246	53,321	65,141	23.9	0.100	0.930	0.008	0.027	0.210	0.270	0.013	0.170	0.001	4
			A-36			59094248	62,127	73,553	22.6	0.090	0.980	0.009	0.019	0.200	0.290	0.014	0.210	0.001	4
			A-36			59094249	61,757	74,320	22.1	0.080	0.890	0.009	0.018	0.180	0.290	0.014	0.200	0.000	4
6	19481G	C3X5#X6'-8" RUBRAIL	A-36			3077310	55,400	77,200	32.0	0.170	0.560	0.013	0.039	0.210	0.330	0.002	0.090	0.017	4
	19481G		A-36			3086787	56,100	76,000	29.0	0.150	0.630	0.013	0.035	0.210	0.320	0.000	0.130	0.000	4
3	20207G	12/9'4.5/8-HOLE ANCH/S			2	F14120													
			M-180	A	2	2104901	58,500	88,900	21.0	0.220	0.790	0.009	0.001	0.030	0.140	0.003	0.050	0.004	4
			M-180	A	2	2104902	56,200	88,400	21.0	0.210	0.780	0.009	0.002	0.030	0.130	0.002	0.050	0.003	4
			M-180	A	2	2205429	66,700	88,000	20.0	0.210	0.800	0.009	0.002	0.030	0.120	0.002	0.050	0.004	4
3	36120A	DAT-31-TX-HDW-CAN	A-36			2064020	56,500	75,300	28.0	0.140	0.640	0.013	0.021	0.210	0.300	0.000	0.150	0.000	4
	36120A		A-36			4140645	45,400	64,800	35.0	0.190	0.400	0.009	0.010	0.010	0.020	0.001	0.030	0.001	4
	36120A		HW			025689													
	36120A		HW			025689													
	36120A		A-36			97627D	49,200	70,000	32.0	0.190	0.940	0.016	0.008	0.009	0.040	0.000	0.060	0.000	4
	36120A		A307-3500			921743-7													4

Certified Analysis

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

Customer: SAMPLES, TESTING MATERIALS
2525 STEMMONS FRWY

DALLAS, TX 75207

Project: WASHINGTON DOT TEST MATERIAL

Order Number: 1332025 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: WDOT
BOL Number: 81674 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 11/6/20

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
	36120A		F844-3900			P38875 R71579-01													4
	36120A		A563-3910			P38851 R71907													4
	36120A		A307-4470			893006-7													4
	36120A		A307-4500			929997-4													4
	36120A		A-36			1100008623	58,600	60,100	21.0	0.130	0.820	0.022	0.020	0.212	0.310	0.000	0.190	0.057	4
	36120A		A-500			B919189	70,500	75,000	29.0	0.070	0.350	0.009	0.003	0.020	0.090	0.000	0.000	0.000	4
	36120A		A-36			1053561	60,000	77,100	23.0	0.160	0.750	0.018	0.024	0.180	0.330	0.001	0.200	0.032	4
	36120A		F844-3300			P39615 R74522													4
	36120A		FAST			20-35-004													4
	36120A		A307-3360			922031-5													4
	36120A		A307-3403			848773-8													4
6	130896G	6'0 TUBE SL/.125X8X6	A-500			SK5670	59,785	76,938	29.0	0.200	0.410	0.007	0.002	0.042	0.110	0.006	0.050	0.003	4
6	626079B	WD 3'10 POST	WOOD			2689													

Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: SAMPLES, TESTING MATERIALS
2525 STEMMONS FRWY

DALLAS, TX 75207
Project: WASHINGTON DOT TEST MATERIAL

Order Number: 1332025 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: WDOT
BOL Number: 81674 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 11/6/20

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

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

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

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

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

State of Texas, County of Tarrant. Sworn and subscribed before me this 6th day of November, 2020 .

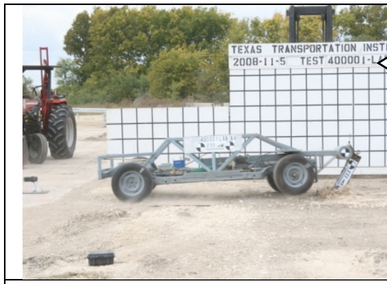
Notary Public:
Commission Expires

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

Certified By: Trinity Highway Products LLC

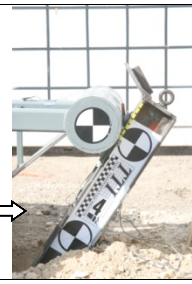
Quality Assurance

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



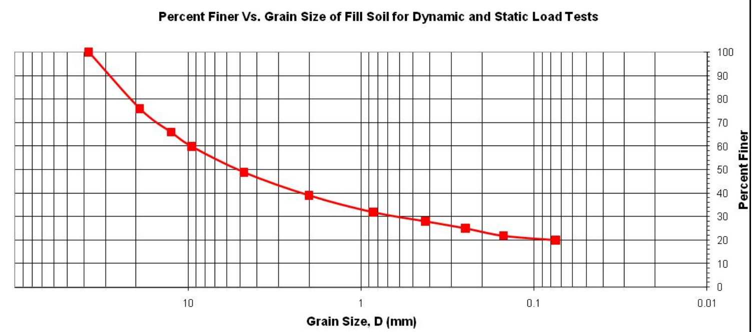
Dynamic Setup

Post-Test Photo of post

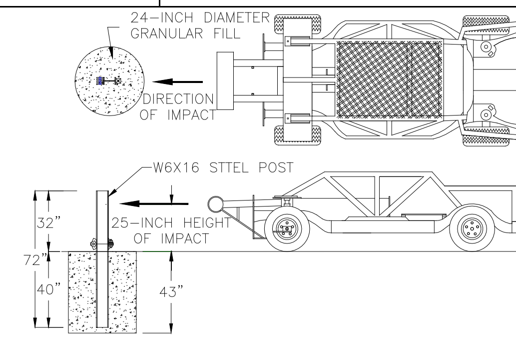


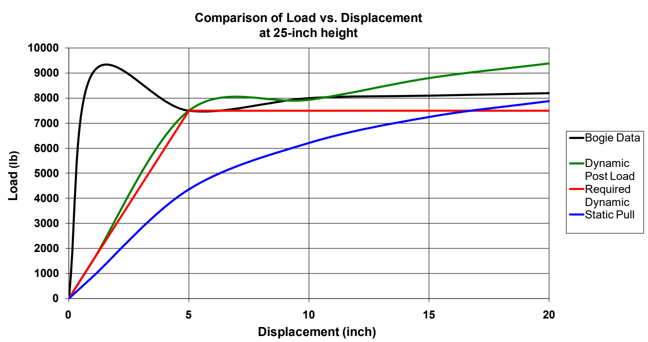
Post-Test Photo

Static Load Test

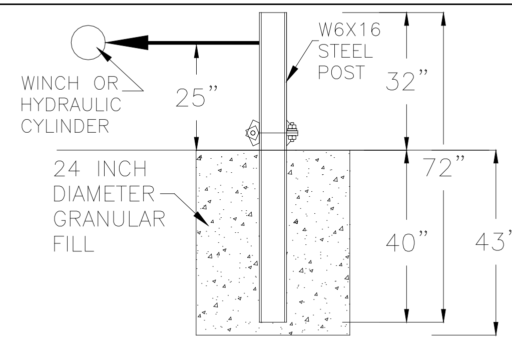


Dynamic Test Installation Details



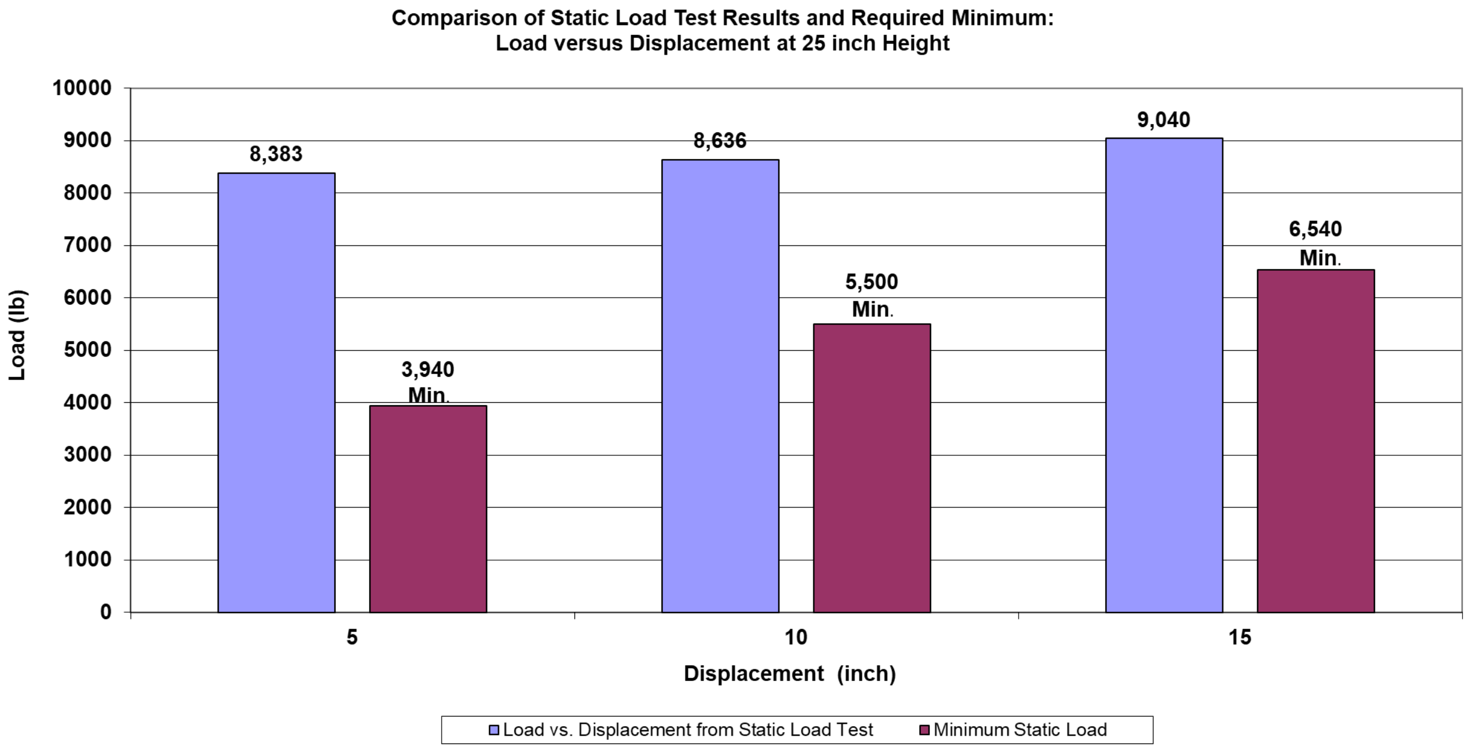


Static Load Test Installation Details



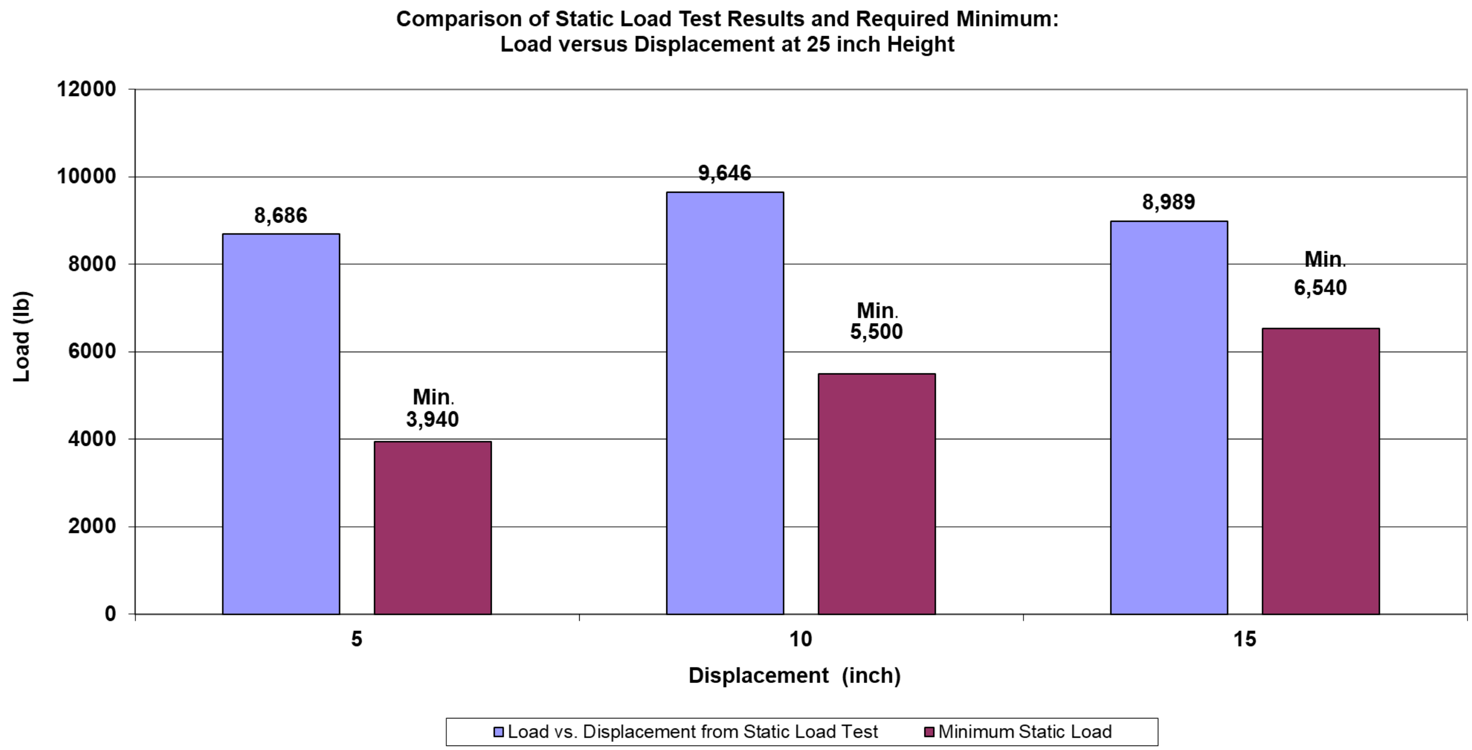
Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor
Bogie Weight..	5009 lb
Impact Velocity	20.5 mph

Table C.2. Test Day Static Soil Strength Documentation for Test No. 613011-01-1.



Date	2021-01-06 – Test No. 613011-01-1
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade B Soil-Aggregate
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.3. Test Day Static Soil Strength Documentation for Test No. 613011-01-2.



Date	2021-01-25 – Test No. 613011-01-2
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade B Soil-Aggregate
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

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APPENDIX D. *MASH* TEST 3-10 (CRASH TEST NO. 613011-01-1)

D.1. VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 613011-01-1.

Date: 2021-01-06 Test No.: 613011-01-1 VIN No.: 3N1CN7AP4F1812564

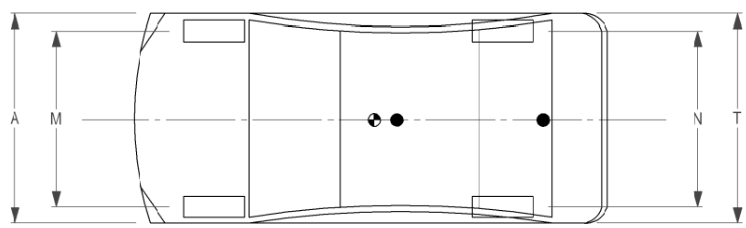
Year: 2015 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 69319 Tire Size: P185/65R15

Describe any damage to the vehicle prior to test: None

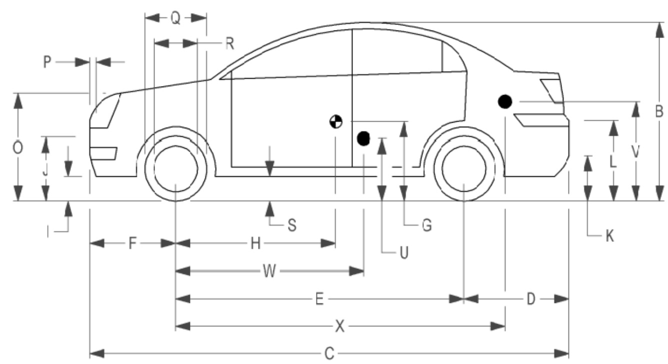
● Denotes accelerometer location.

NOTES: None



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

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



Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	41.10	M	58.30	R	16.25	W	
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.25	O	30.50	T	64.50		

Wheel Center Ht Front 11.50 Wheel Center Ht Rear 11.50 W-H -41.10

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}	1455	1457	1542
Back	1687	M_{rear}	963	977	1057
Total	3389	M_{Total}	2418	2434	2599

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

Mass Distribution:
lb LF: 774 RF: 683 LR: 481 RR: 496

Table D.2. Exterior Crush Measurements for Test No. 613011-01-1.

Date:	2021-1-6	Test No.:	613011-01-1	VIN No.:	3N1CN7AP4F1812564
Year:	2015	Make:	NISSAN	Model:	VERSA

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	14	7	30							-10
2	Side plane at bmp ht	14	7	50							55
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

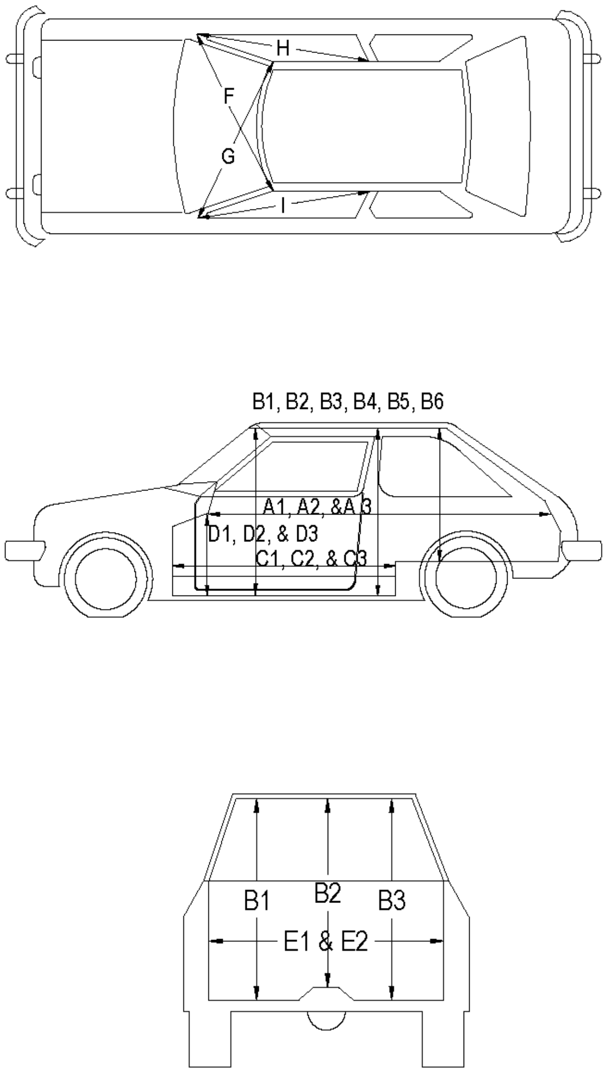
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Table D.3. Occupant Compartment Measurements for Test No. 613011-01-1.

Date:	2021-1-6	Test No.:	613011-01-1	VIN No.:	3N1CN7AP4F1812564
Year:	2015	Make:	NISSAN	Model:	VERSA

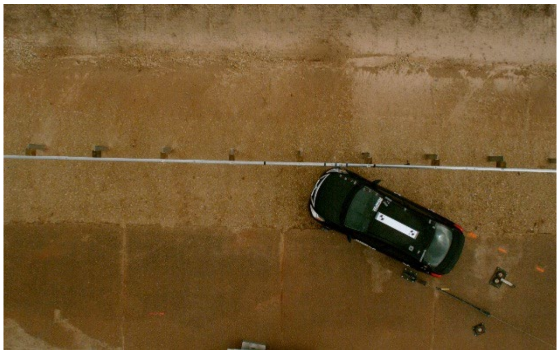


OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	75.00	75.00	0.00
A2	74.00	74.00	0.00
A3	74.00	74.00	0.00
B1	43.00	43.00	0.00
B2	37.00	37.00	0.00
B3	43.00	43.00	0.00
B4	46.50	46.50	0.00
B5	42.50	42.50	0.00
B6	46.50	46.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	12.50	12.50	0.00
D2	0.00	0.00	0.00
D3	10.00	9.50	-0.50
E1	45.00	45.00	0.00
E2	48.75	49.00	0.25
F	47.50	47.50	0.00
G	47.50	47.50	0.00
H	39.00	39.00	0.00
I	39.00	39.00	0.00
J*	48.50	48.50	0.00

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

D.2. SEQUENTIAL PHOTOGRAPHS



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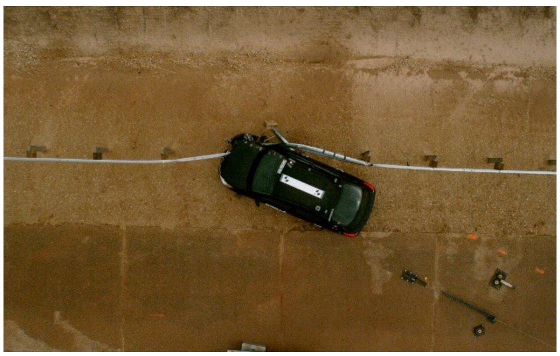

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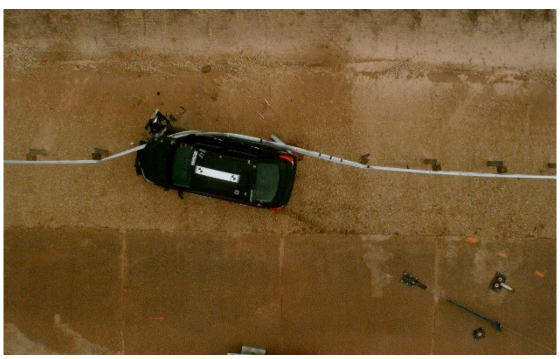


0.200 s

0.300 s

Figure D.1. Sequential Photographs for Test No. 613011-01-1 (Overhead and Frontal Views).

0.400 s

0.500 s

0.600 s

0.700 s

Figure D.1. Sequential Photographs for Test No. 613011-01-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

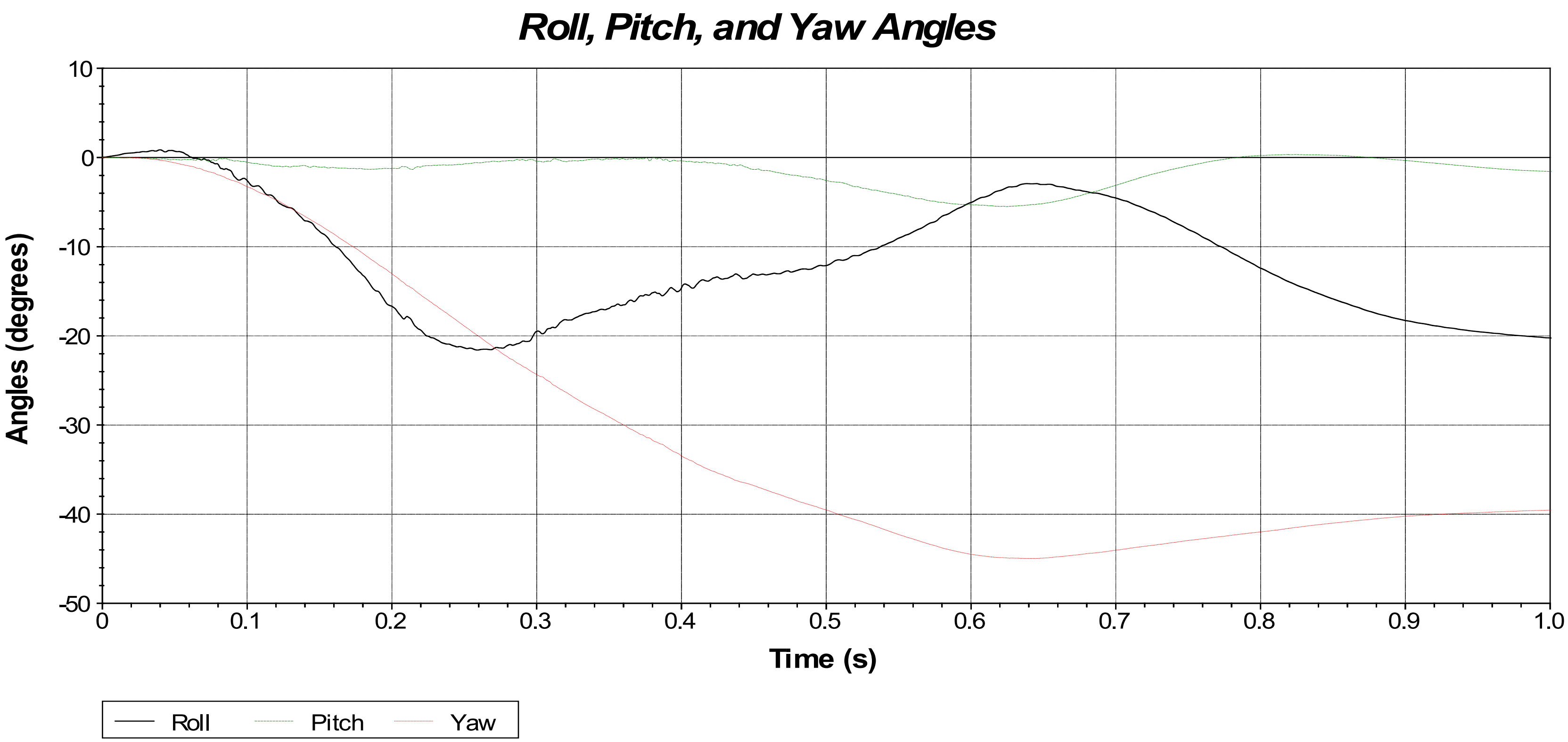
0.400 s

0.500 s

0.600 s

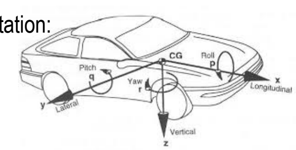
0.700 s

Figure D.2. Sequential Photographs for Test No. 613011-01-1 (Rear View).



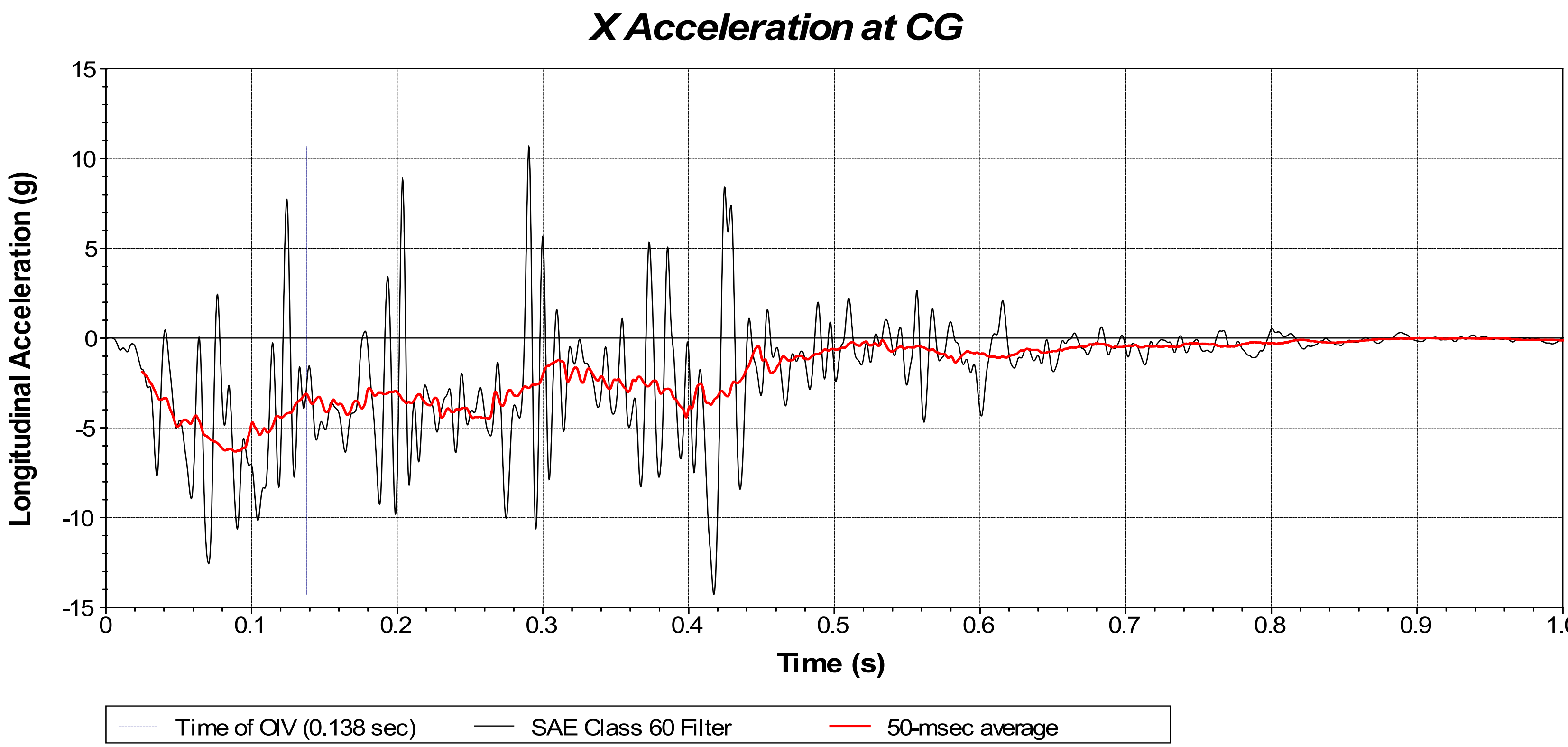
Axes are vehicle-fixed.
Sequence for
determining orientation:

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



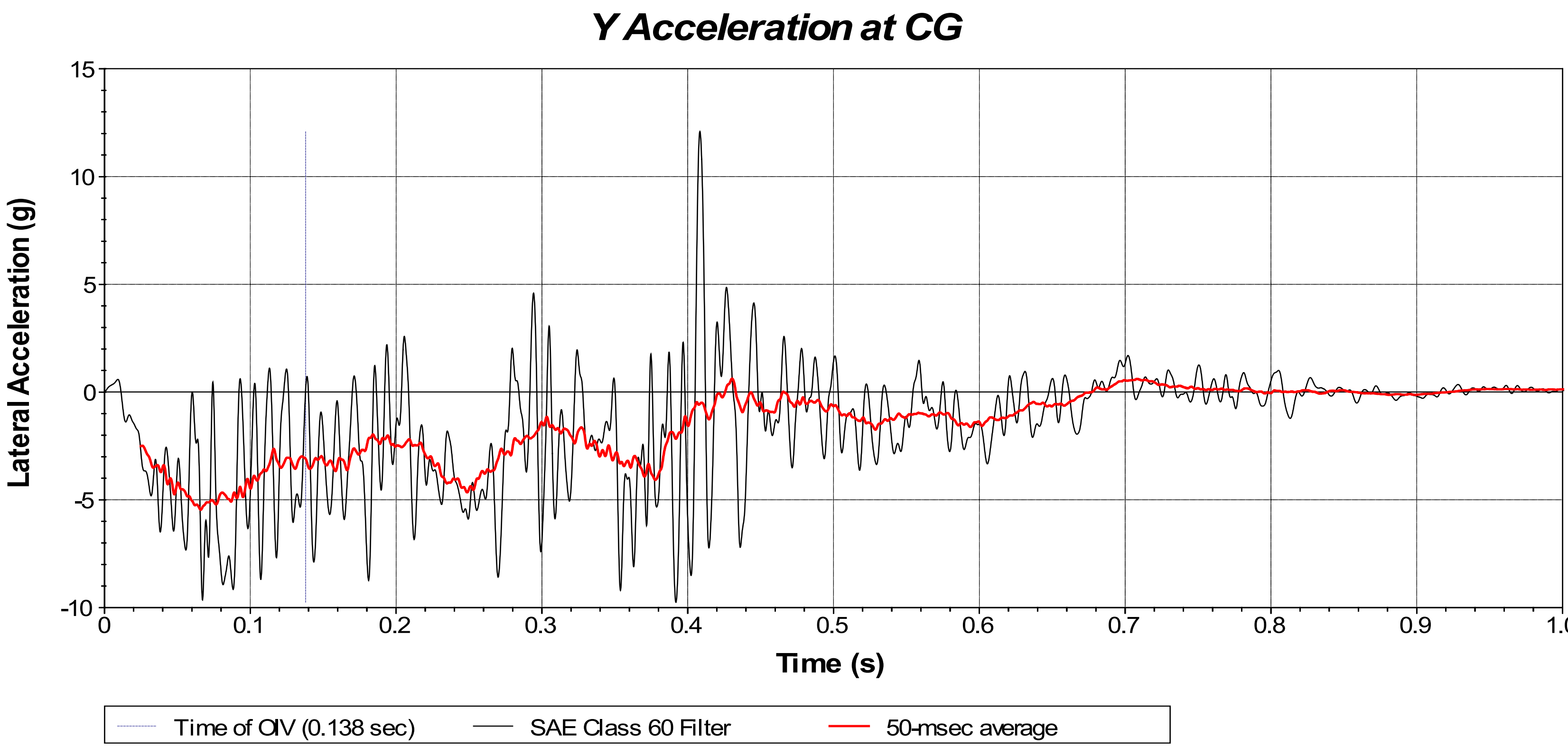
Test Number: 613011-01-1
Test Standard Test Number: *MASH* Test 3-10
Test Article: Guardrail on 6H:1V Slope
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2434 lb
Gross Mass: 2599 lb
Impact Speed: 64.8 mi/h
Impact Angle: 25.6 degrees

Figure D.3. Vehicle Angular Displacements for Test No. 613011-01-1.



Test Number: 613011-01-1
Test Standard Test Number: *MASH* Test 3-10
Test Article: Guardrail on 6H:1V Slope
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2434 lb
Gross Mass: 2599 lb
Impact Speed: 64.8 mi/h
Impact Angle: 25.6 degrees

Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 613011-01-1 (Accelerometer Located at Center of Gravity).



Test Number: 613011-01-1
Test Standard Test Number: *MASH* Test 3-10
Test Article: Guardrail on 6H:1V Slope
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2434 lb
Gross Mass: 2599 lb
Impact Speed: 64.8 mi/h
Impact Angle: 25.6 degrees

Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 613011-01-1 (Accelerometer Located at Center of Gravity).

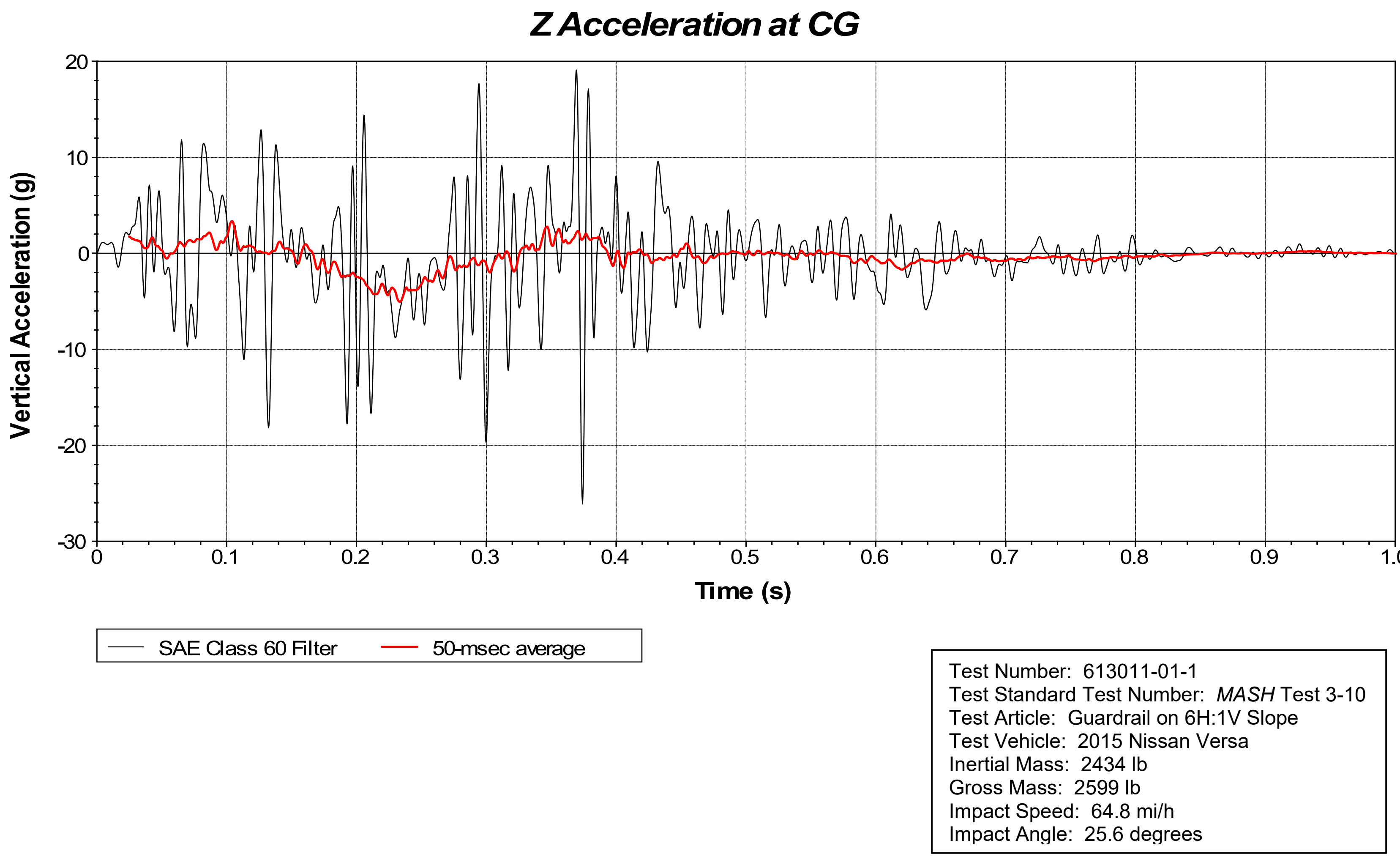


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 613011-01-1 (Accelerometer Located at Center of Gravity).

APPENDIX E. *MASH* TEST 3-11 (CRASH TEST NO. 613011-01-2)

E.1. VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 613011-01-2.

Date: 2021-1-25 Test No.: 613011-01-2 VIN No.: 1C6RRGT3FS754479

Year: 2015 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 172636

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

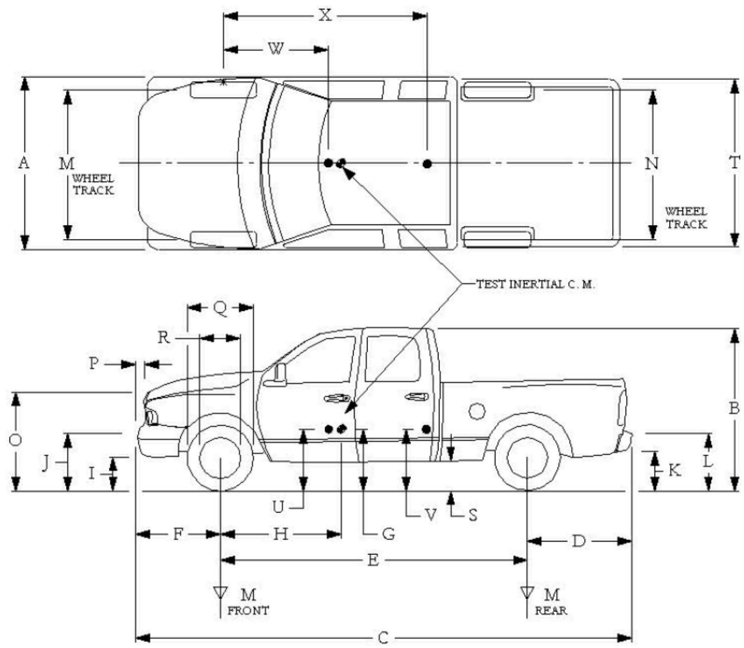
NOTES: NONE

Engine Type: V-8
Engine CID: 5.7L

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

Optional Equipment:
None

Dummy Data:
Type: 50TH Percentile male
Mass: 165 lb
Seat Position: IMPACT SIDE



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.5	L	30.00	Q	30.50	V	30.25
C	227.50	H	59.92	M	68.50	R	18.00	W	59.9
D	44.00	I	11.75	N	68.00	S	13.00	X	79
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}	2969	2904	2989
Back	3900	M_{rear}	2141	2160	2240
Total	6700	M_{Total}	5110	5064	5229

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

Mass Distribution:
lb LF: 1456 RF: 1448 LR: 1087 RR: 1073

Table E.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 613011-01-2.

Date: 2021-1-25 Test No.: 613011-01-2 VIN: 1C6RRGT3FS754479

Year: 2015 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 172636

Engine: 5.7L V-8 Transmission: Automatic

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

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

Measured Vehicle Weights: (lb)								
LF:	1456		RF:	1448		Front Axle:	2904	
LR:	1087		RR:	1073		Rear Axle:	2160	
Left:	2543		Right:	2521		Total:	5064	
						5000 ±110 lb allowed		
Wheel Base:	140.50	inches	Track: F:	68.50	inches	R:	68.00	inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed				
Center of Gravity, SAE J874 Suspension Method								
X:	59.93	inches	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	-0.15	inches	Left -	Right +	of Vehicle Centerline			
Z:	28.5	inches	Above Ground	(minumum 28.0 inches allowed)				

Hood Height: 46.00 inches
43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches
39 ±3 inches allowed

Rear Bumper Height: 30.00 inches

Overall Length: 227.50 inches
237 ±13 inches allowed

Table E.3. Exterior Crush Measurements for Test No. 613011-01-2.

Date:	2021-1-25	Test No.:	613011-01-2	VIN No.:	1C6RRGT3FS754479
Year:	2015	Make:	RAM	Model:	

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 Width** (CDC)	Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bmp ht	18	9	72							0
2	Side plane above bmp	18	9	40							64
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

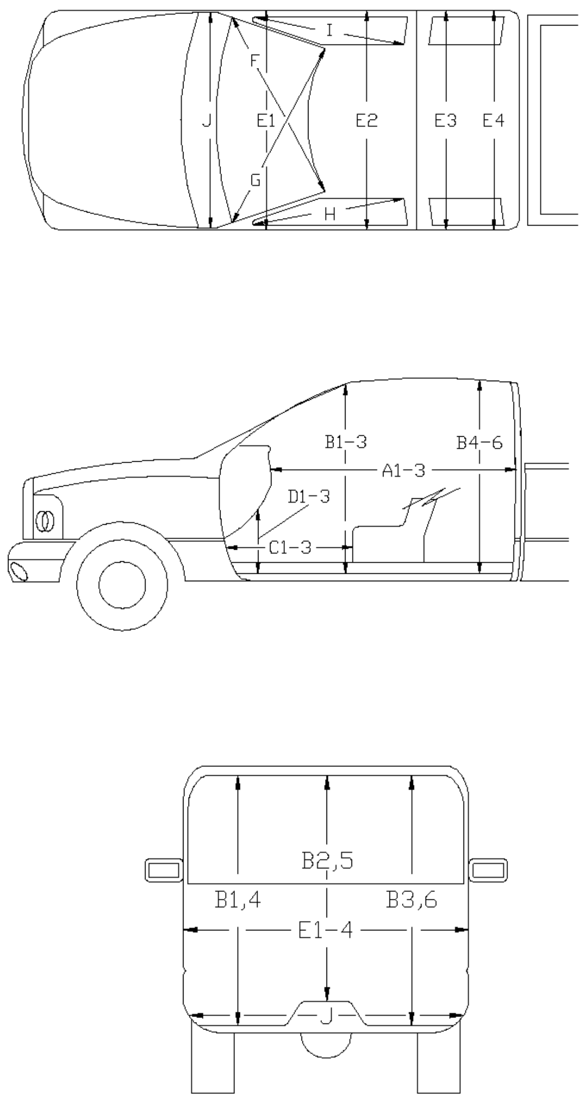
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Table E.4. Occupant Compartment Measurements for Test No. 613011-01-2.

Date:	2021-1-25	Test No.:	613011-01-2	VIN No.:	1C6RRGT3FS754479
Year:	2015	Make:	RAM	Model:	1500



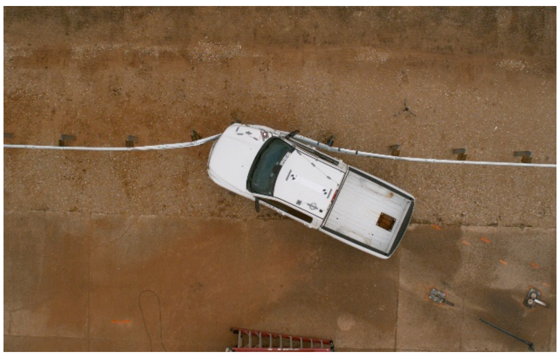
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

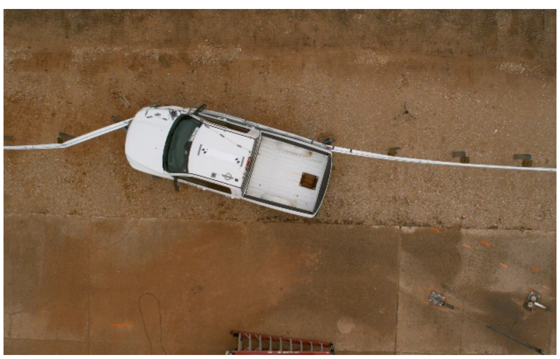
	Before	**After** (inches)	**Differ.**
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00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

E.2. SEQUENTIAL PHOTOGRAPHS

0.000 s



0.100 s



0.200 s

0.300 s

Figure E.1. Sequential Photographs for Test No. 613011-01-2 (Overhead and Frontal Views).

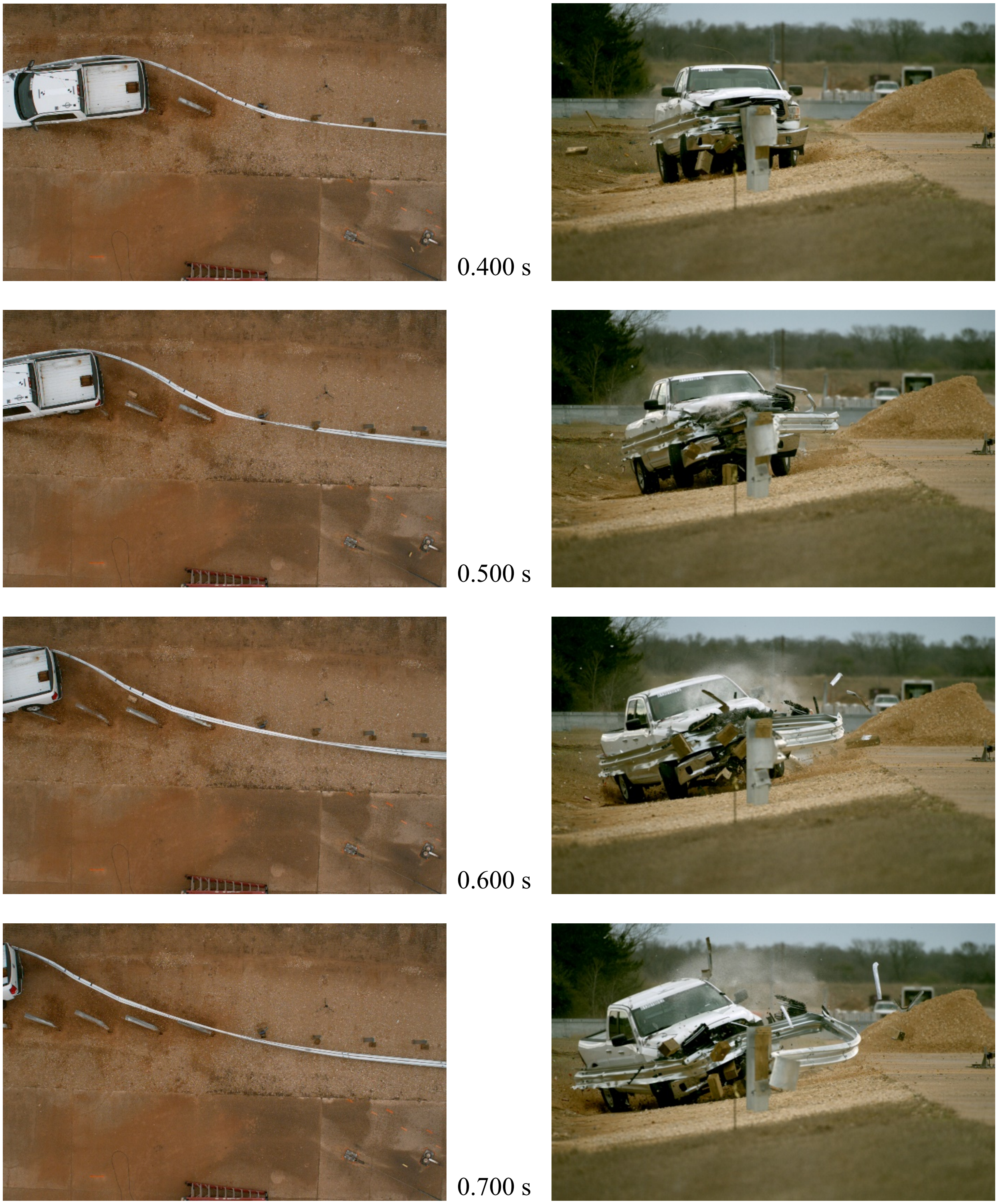


Figure E.1. Sequential Photographs for Test No. 613011-01-2 (Overhead and Frontal Views) (Continued).

0.000 s

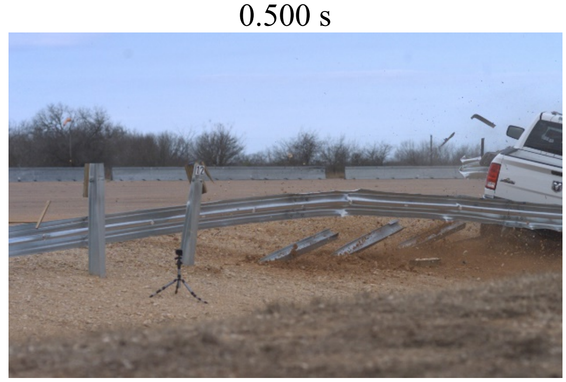
0.100 s

0.200 s

0.300 s

0.400 s

0.500 s



0.600 s

0.700 s

Figure E.2. Sequential Photographs for Test No. 613011-01-2 (Rear View).

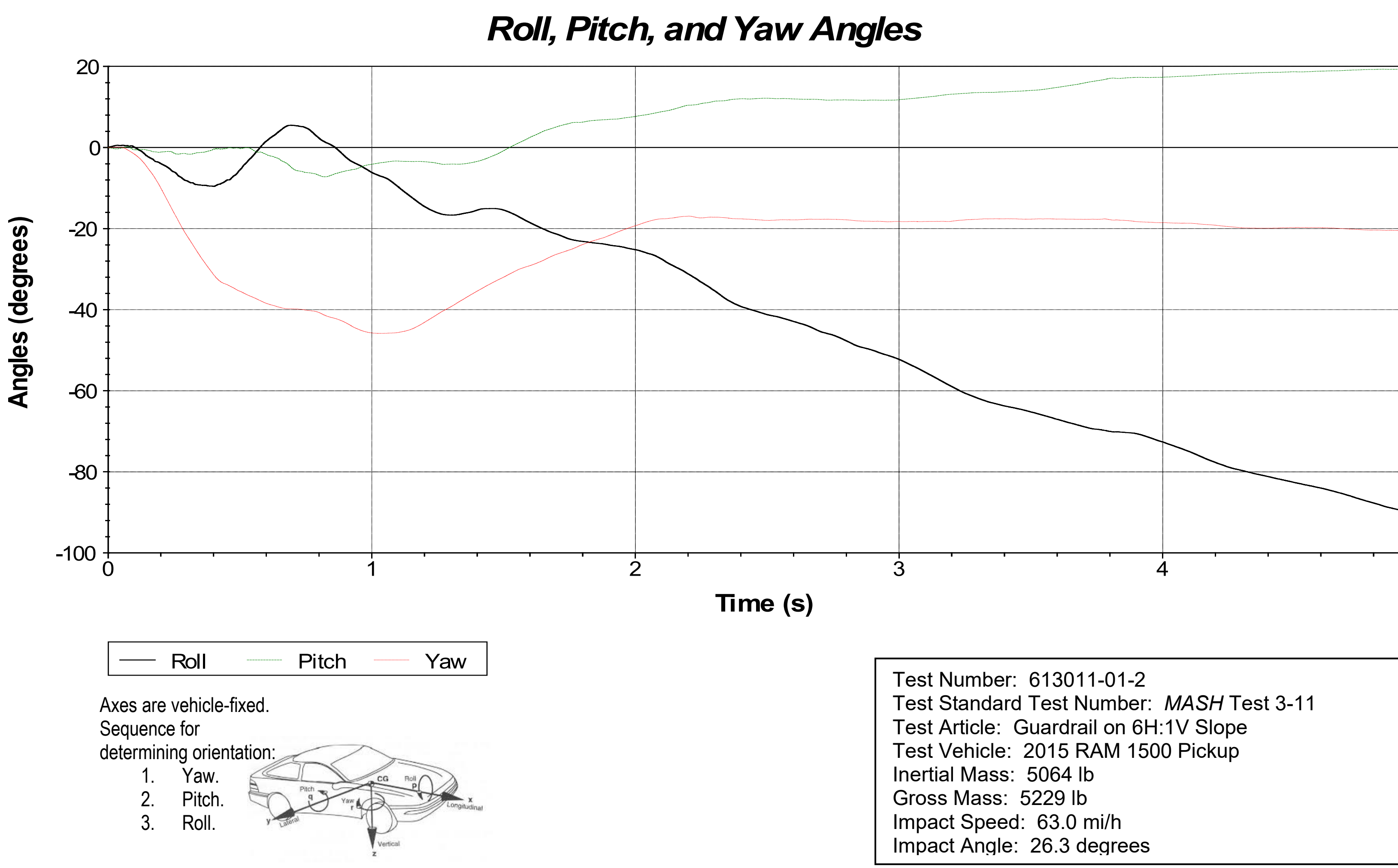
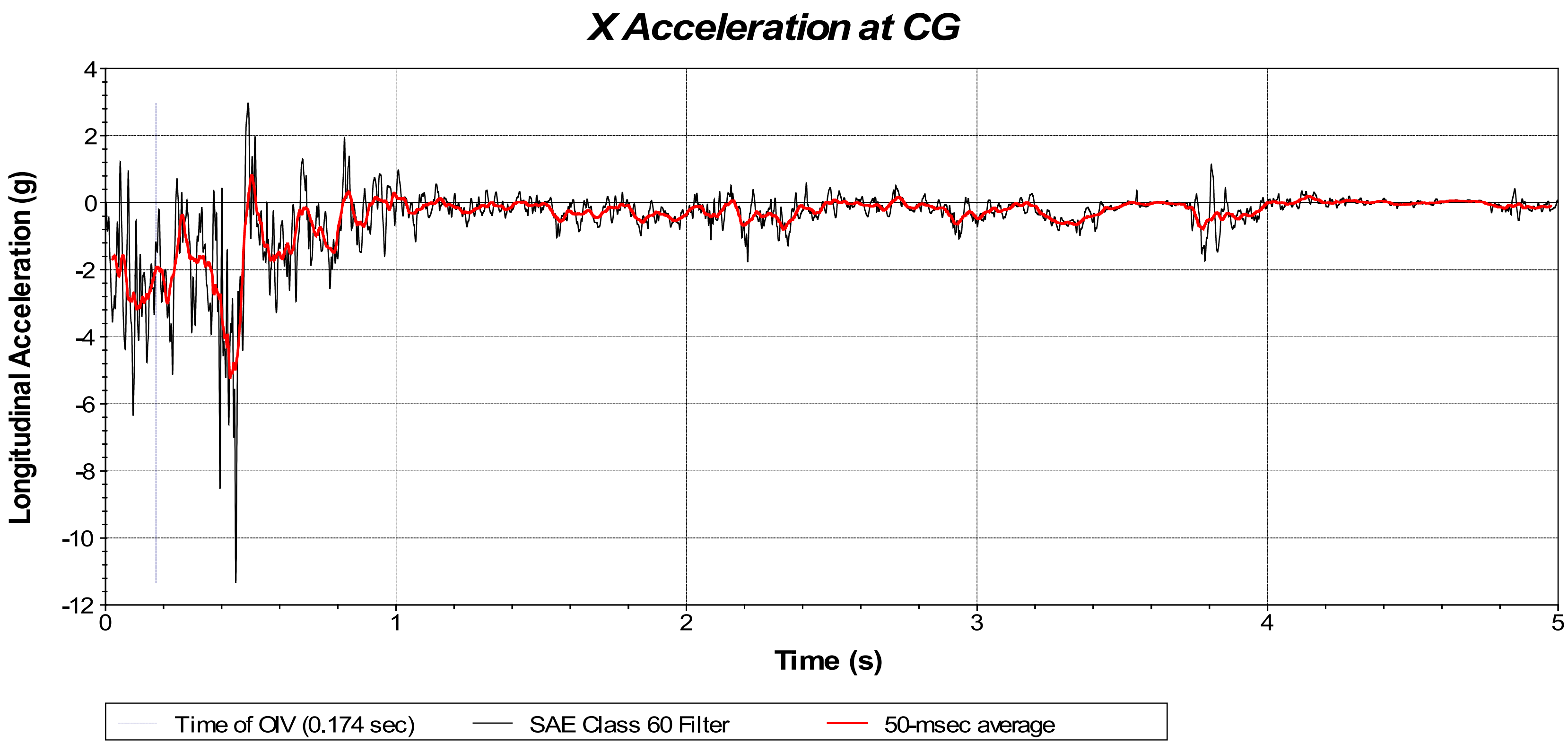


Figure E.3. Vehicle Angular Displacements for Test No. 613011-01-2.



Test Number: 613011-01-2
Test Standard Test Number: *MASH* Test 3-11
Test Article: Guardrail on 6H:1V Slope
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5064 lb
Gross Mass: 5229 lb
Impact Speed: 63.0 mi/h
Impact Angle: 26.3 degrees

Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 613011-01-2 (Accelerometer Located at Center of Gravity).

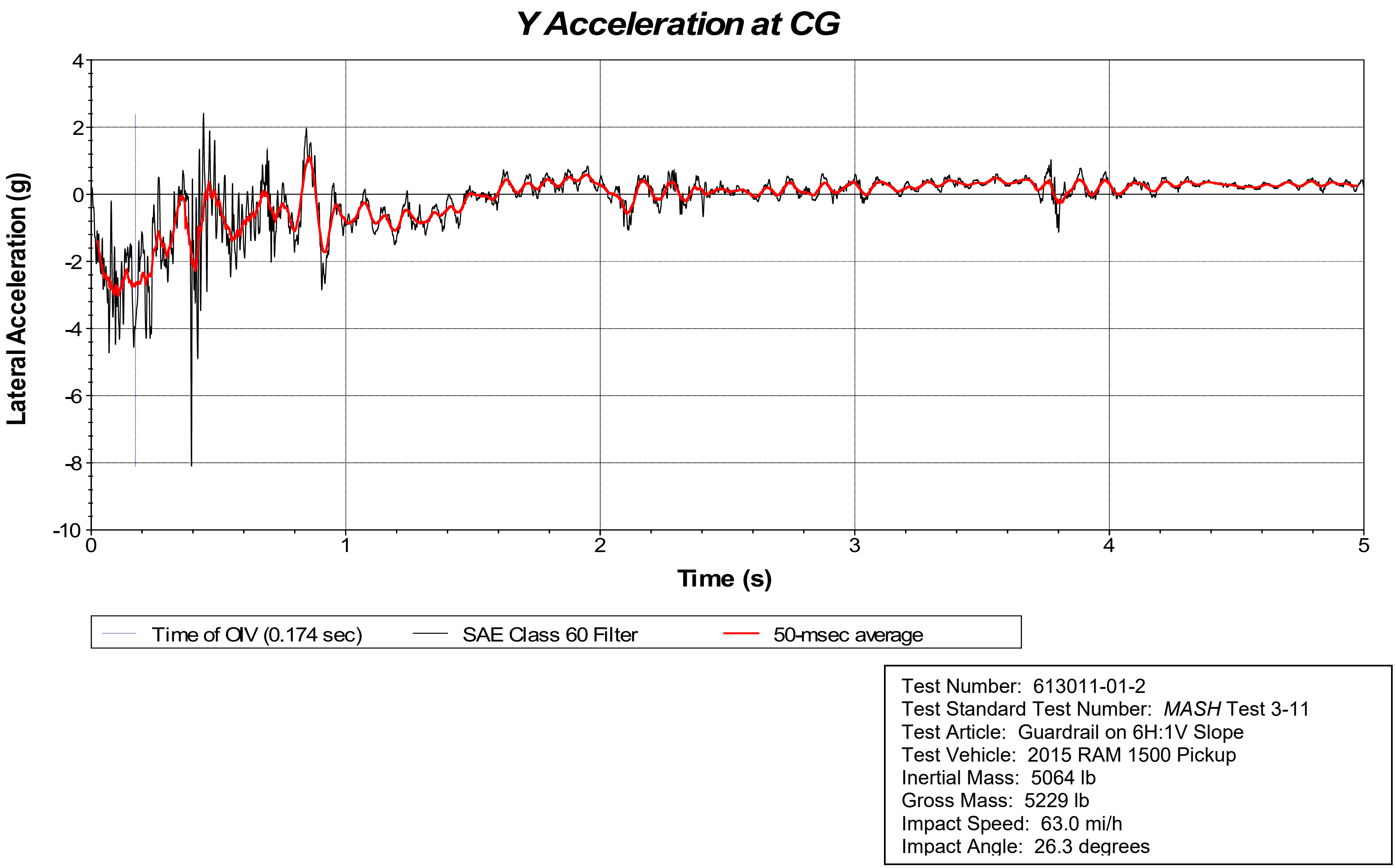
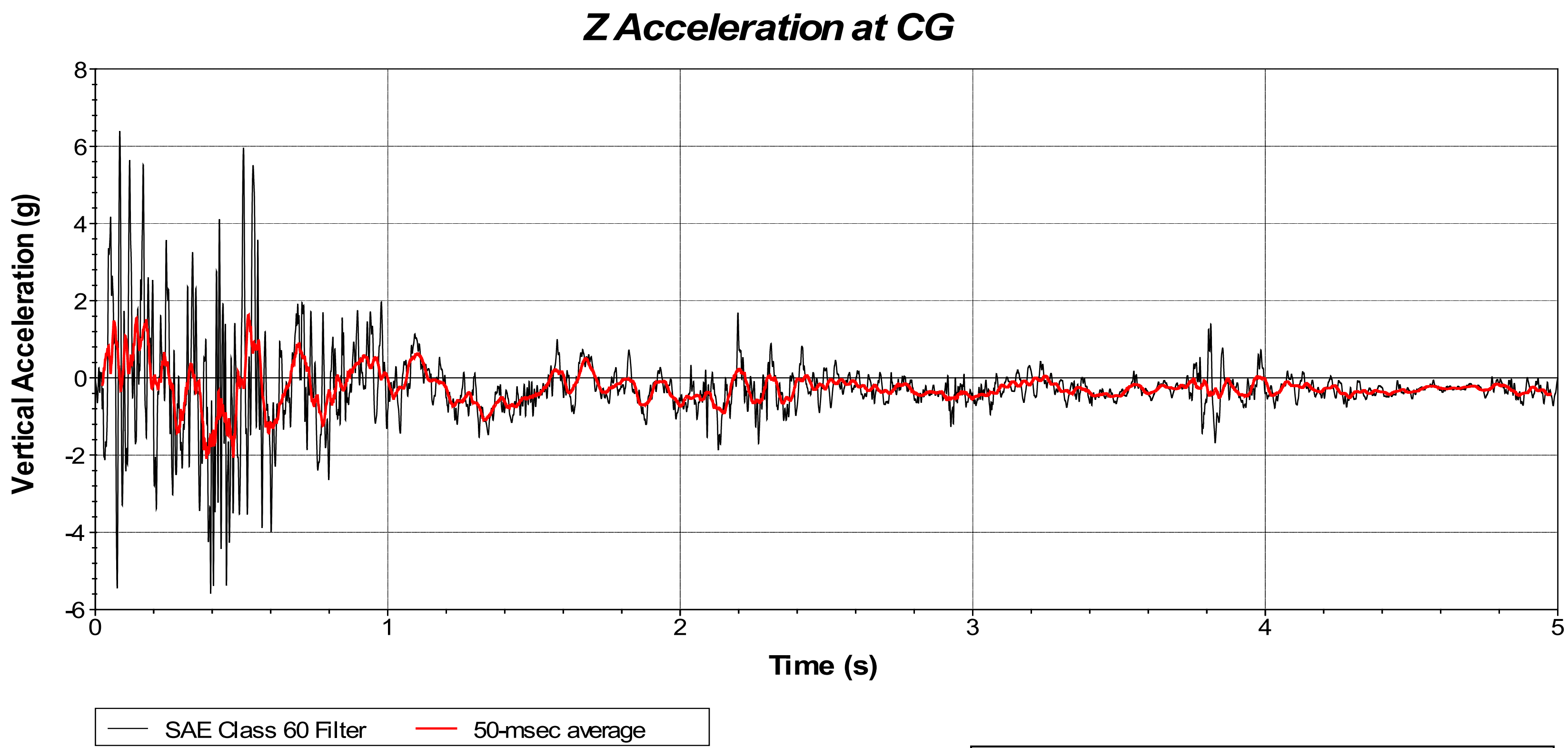


Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 613011-01-2 (Accelerometer Located at Center of Gravity).



Test Number: 613011-01-2
Test Standard Test Number: *MASH* Test 3-11
Test Article: Guardrail on 6H:1V Slope
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5064 lb
Gross Mass: 5229 lb
Impact Speed: 63.0 mi/h
Impact Angle: 26.3 degrees

Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 613011-01-2 (Accelerometer Located at Center of Gravity).