Texas A&M Transportation Institute
Proving Ground

Test Report No. 617771-01&02

MASH TESTING OF A GUARDRAIL SYSTEM ON 1H:1V SLOPE

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Roadside Safety Pooled Fund

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16. Abstract

The purpose of the tests reported herein was to design, simulate and assess the performance of a guardrail system on a 1H:1V slope according to the safety-performance evaluation guidelines included in the second edition of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*1*). The crash tests were performed in accordance with *MASH* Test Level 3 (TL-3):

1. ***MASH* Test 3-10:** An 1100C vehicle weighing 2420 lb impacting the longitudinal barrier while travelling at 62.0 mi/h and 25.0 degrees.
2. ***MASH* Test 3-11:** A 2270P vehicle weighing 5000 lb impacting the longitudinal barrier while traveling at 62.0 mi/h and 25.0 degrees.

This report provides development history and details of the Guardrail System on 1H:1V Slope, the crash tests and results, and the performance assessment of the Guardrail System on 1:1 Slope for *MASH* TL-3 Longitudinal Barrier evaluation criteria.

The Guardrail System on 1:1 Slope met the performance criteria for *MASH* TL-3 Longitudinal Barrier.

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MASH Testing of a Guardrail System on 1H:1V Slope

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

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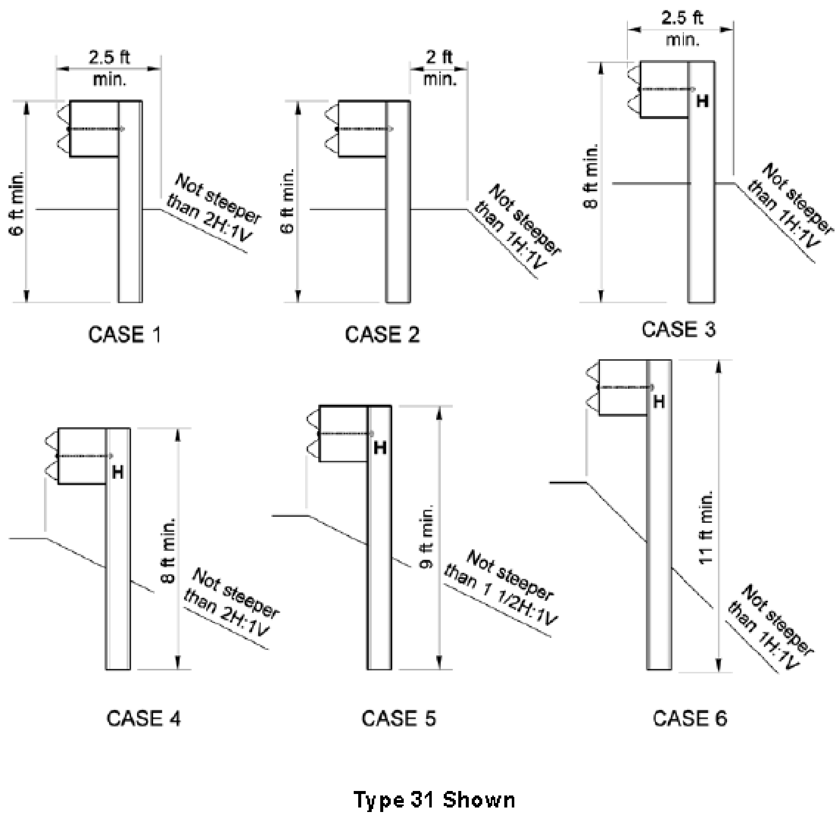
SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square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

*SI is the symbol for the International System of Units

CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

The American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide (1) recommends that guardrail be installed with the back edges of the guardrail post being 2 ft from a slope break. In many areas with tight environmental controls, this width is difficult to provide. As a result, designers often make a trade-off between reduced shoulder width and a less than optimal guardrail placement. The Washington State Department of Transportation (WSDOT) Design Manual (2) provides for the placement of the guardrail post closer to or on slopes as steep as 1:1 slope as shown in Figure 1.1.



Notes:

- Use Cases 1 and 3 when there is a 2.5-foot or greater shoulder widening from face of guardrail to the breakpoint.
- Use Case 2 when there is a 4.0-foot or greater shoulder widening from the face of the guardrail to the breakpoint.
- Use Cases 4, 5, and 6 when there is less than a 2.5-foot shoulder widening from face of guardrail to the breakpoint.

Figure 1.1. Allowable Post on Slope Installation Cases from WSDOT Design Manual; Beam Guardrail Post Installation — Exhibit 1610-11 (2).

In an earlier project, Abu-Odeh et al. (3) conducted two full scale crash tests of a 31-in high guardrail system placed on 2:1 slope. 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 1.2.

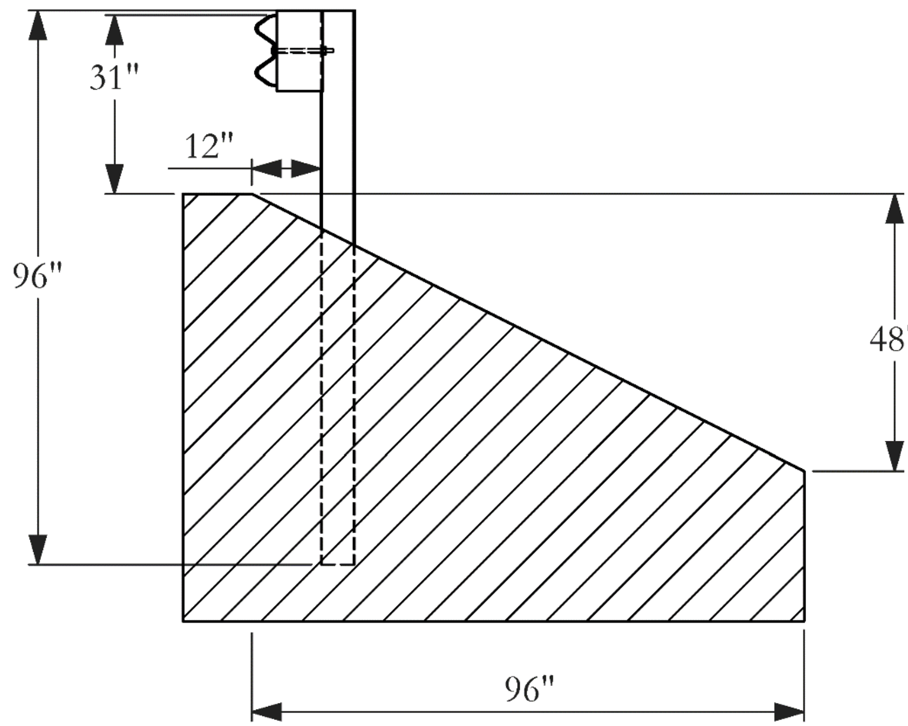


Figure 1.2. Cross Section of the Guardrail on Slope System Tested by Abu-Odeh et al. (3).

The crash tests conducted were *MASH* Test 3-11 and *MASH* test 3-10, which involves a 2270 kg pickup truck and a 1100 kg small car, respectively, in accordance with American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (4). Both test vehicles were setup, so 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 vehicle redirected successfully as shown in the sequential images in Figure 1.3. 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 Administration (FHWA).

Abu-Odeh *et al*. (5) investigated the feasibility of guardrail placement on steeper slopes such as 1:1 through nonlinear finite element analyses. Simulations for both *MASH* Tests 3-10 and 3-11 indicated a likelihood of successful outcome of testing for a regularly spaced posts, 31-inch tall W-beam guardrail system. The posts were placed 1-ft from the slope break such a design was tested in pool fund project, but the w-beam rail ruptured once impacted by the small car as shown in Figure 1.4.

(a) Test No. 405160-20-1

(b) Test No. 405160-20-2

Figure 1.3. Sequential Photos of *MASH* 3-11 and *MASH* 3-10 (3).

Figure 1.4. *MASH* 3-10 Test Resulted in Rupture of the W-Beam Rail Element (*5*).

1.2. OBJECTIVE

The purpose of the tests reported herein was to assess the performance of the proposed the Thrie-beam Guardrail System on 1:1 Slope according to the safety performance evaluation guidelines included in *MASH* (*4*). The crash tests were performed in accordance with *MASH* Test Level 3 (TL-3), which requires two crash tests including *MASH* Tests 3-10 and 3-11 (as discussed in Chapter 4).

1.3. BENEFITS

The envisioned research outcome is a *MASH* TL-3 compliant system to replace the non-tested and non-standard, inadequate systems, in place in locations that have restricted roadside.

A guardrail system in which the face of the rail is aligned with the slope break will provide significant increase in shoulder width in mountainous areas as well as other locations that have very restrictive space. This increased shoulder width will reduce nuisance hits while providing increased safety.

CHAPTER 2. DESIGN OPTIONS FOR GUARDRAIL ON 1:1 SLOPE AND FINITE ELEMENT SIMULATIONS

2.1. DESIGN OPTIONS

Five different design options were proposed to prevent rail rupture observed in Test 609301-01-1(5). The first key design change is to switch the W-beam rail to a thrie-beam rail to provide additional strength to the system. Secondly, the length of each post installed on the slope is increased from 8 ft to 9 ft, while the size of the wood bock is kept as 6-inch × 8-inch × 14-inch. The steel post used in the model is a W6×8.5 steel post. Each post is placed at 6 ft 3-inch spacing which is the standard spacing using in W-beam guardrail system.

The design options for the guardrail system on 1:1 slope were investigated using LS-DYNA (*8*) under *MASH* Tests 3-10 and 3-11 condition (*4*). In the initial simulations, the used FE vehicle models were a 2010 Toyota Yaris model and a 2018 Dodge Ram model developed by the Center for Collision Safety and Analysis (CCSA) at George Mason University (6*, 7*).

Table 2.1 lists the five design options investigated along with a brief description of each. The design options varied in terms of the Thrie-beam height and the presence of a rubrail. The Thrie-beam heights were 31 inches and 34 inches, and the rubrail options included a C6×8.2 channel rubrail at 12-inch height from the flat ground and plate rubrail at 12-inch and 8-inch heights from the flat ground.

Table 2.1. Design Options for Guardrail on 1:1 Slope.

Option No.	System	Thrie-beam height	Rubrail
1	31-inch Thrie-beam	31-inch from flat ground	No
2	34-inch Thrie-beam	34-inch from flat ground	No
3	34-inch Thrie-beam with channel rubrail at 12-in height	34-inch from flat ground	channel rubrail at 12-in height
4	34-inch Thrie-beam with plate rubrail at 12-in height	34-inch from flat ground	plate rubrail at 12-in height
5	34-inch Thrie-beam with plate rubrail at 8-in height	34-inch from flat ground	plate rubrail at 8-in height

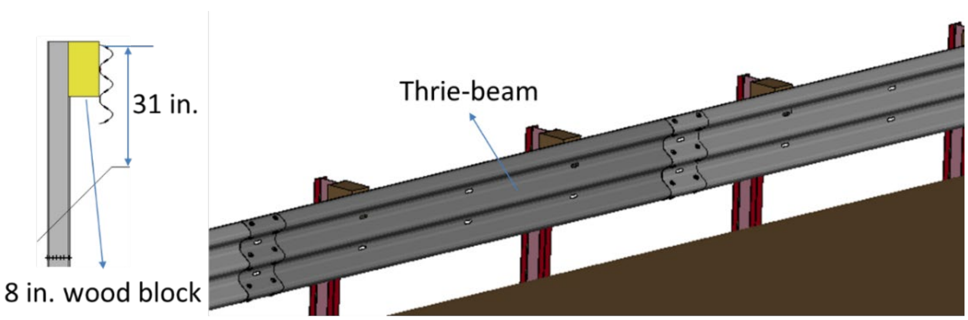
Figure 2.1 through Figure 2.5 show key components of each design option and key simulation results, respectively. To simulate *MASH* TL-3 tests, the impact angle and speed were set at 25 degrees and 62 mi/h.

Based on the simulation results, the 31-inch high guardrail system met applicable *MASH* evaluation criteria for *MASH* Test 3-10. However, the pickup truck rolled on the side (see Figure 2.1(a)), which indicated that this design option did not meet the *MASH* Test 3-11 evaluation criteria.

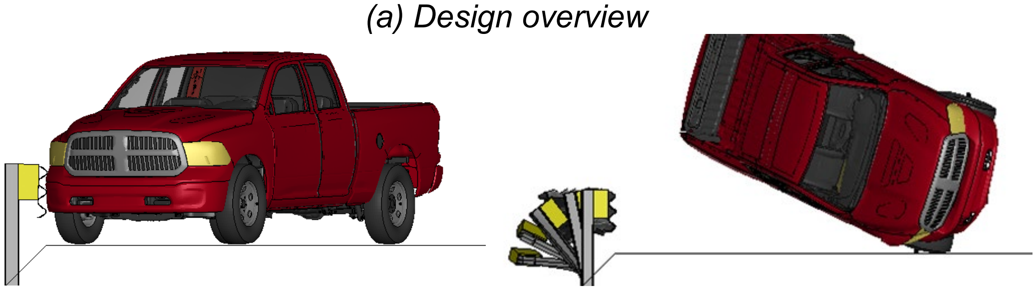
A 34-inch high thrie-beam guardrail system was proposed to address the pickup truck overriding and rolling over. The simulation results indicated that the 34-inch tall thrie system met *MASH* Test 3-11 evaluation criteria. However, a tire snagging potential (see Figure 2.2(b)) and a higher value of longitudinal occupant ridedown acceleration than *MASH* evaluation criteria limit was observed on the small car simulation for the *MASH* Test 3-10.

To avoid under riding and tire snagging behavior, a rubrail was added to the 34-inch thrie-beam guardrail system. Two design options for the rubrail were considered: (a) C6×8.2 steel channel rubrail with 12-inch height from the flat ground and (b) 5.5-inch (wide) × ¼-inch (thick) steel plate rubrail with 12-inch height from the flat ground. The simulations showed that with the channel rubrail, the pickup truck overrode the channel and rolled on the side (see Figure 2.3(b)), while with the plate rubrail system, the longitudinal occupant ridedown acceleration for the small car was 23.3 g which exceeded *MASH* evaluation limit of 20.49 g.

To address these issues, a system with a lowered plate rubrail was proposed. This system consists of 34-inch Thrie-beam guardrail and a steel plate rubrail with 8-inch height from the flat ground. The simulations showed that this system met *MASH* requirements with both small car and pickup (see Figure 2.5(b)).

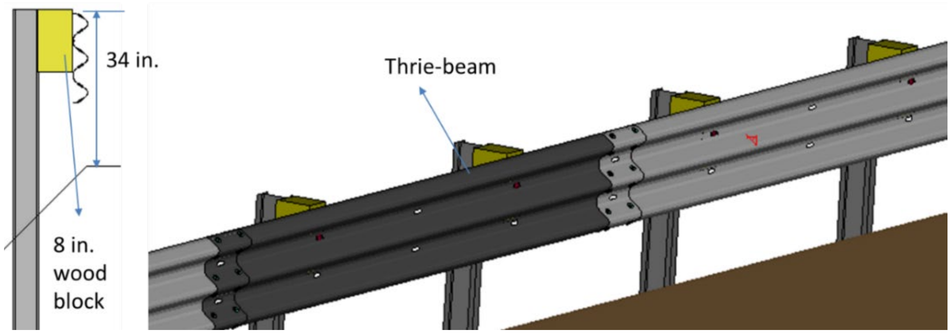


(a) Design overview

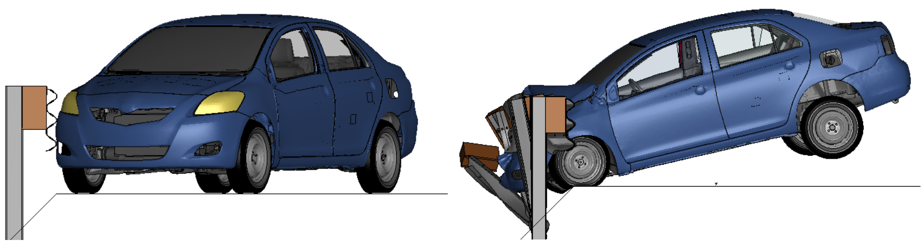


(b) Simulation-truck rolled on side

Figure 2.1. Option 1: 31-inch Thrie-beam

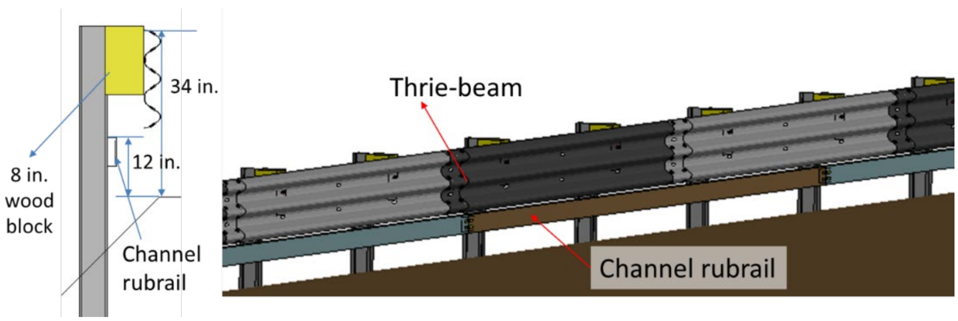


(a) Design overview

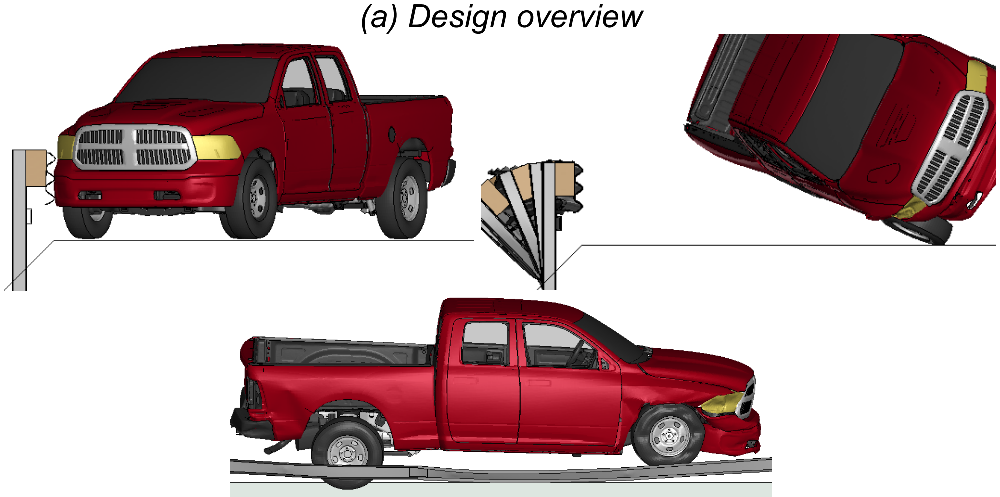


(b) Simulation - small car resulted in high occupant ridedown acceleration

Figure 2.2. Option 2: 34-inch Thrie-beam

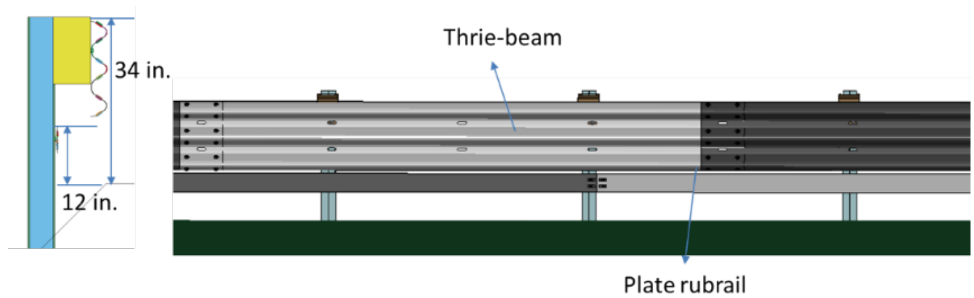


(a) Design overview

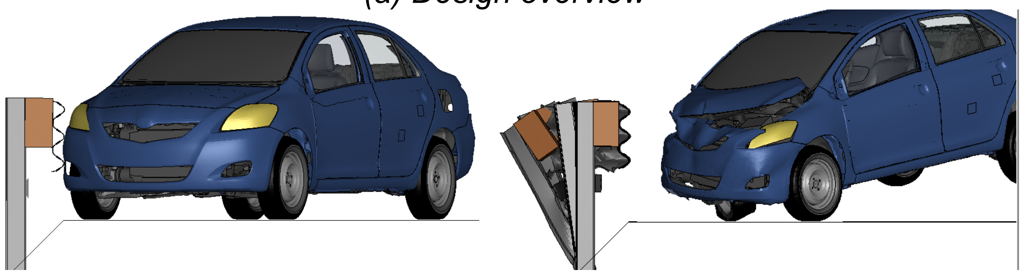


(b) Simulation - truck rode on channel rubrail and rolled on side

Figure 2.3. Option 3: 34-inch Thrie-beam with channel rubrail at 12-in height

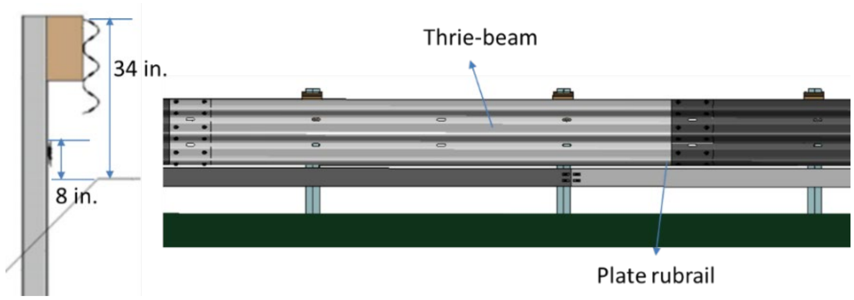


(a) Design overview

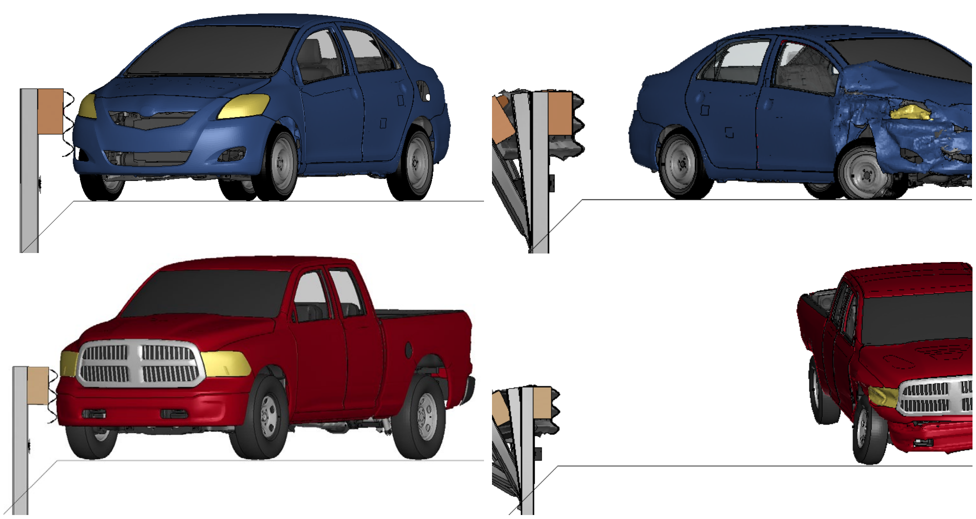


(b) Simulation – small car resulted in high occupant ridedown acceleration

Figure 2.4. Option 4: 34-inch Thrie-beam with plate rubrail at 12-in height



(a) Design overview



(b) Simulation – both small car and truck tests met MASH TL-3 evaluation criteria

Figure 2.5. Option 5: 34-inch Thrie-beam with plate rubrail at 8-in height

2.2. SIMULATIONS USING FE VEHICLE MODELS WITH IMPROVED SUSPENSION

Based on the initial simulations, it was observed that the wheel of the small car snags with the guardrail posts since the sloped ground gives the opportunity for this interaction. Since the vehicle models used in those simulations did not include fully defined suspension failure, the researcher team reinvestigated the thrie-beam system performance without a rubrail using vehicle models with an enhanced suspension failure to qualify the wheel to post snagging potential without having a rubrail.

2.2.1. Simulation on 31-inch Thrie-beam Guardrail System

This 31-inch high thrie-beam system simply consisted of a thrie-beam, a wood block, and posts spaced at 75 inches. The height of the system was 31 inches which was adopted from *MASH* TL-3 compliant W-beam guardrail system on 2:1 slope.

In the initial evaluation of the 31-inch thrie-beam system, it was found that the system met *MASH* evaluation criteria for the small car, while the truck simulation result did not meet the *MASH* evaluation criteria.

Figure 2.6 shows sequential images for the truck simulations at different time markers. Images in the left column show the initial simulation without suspension and tire failure, while the images in the right column show the new simulation result with the updated suspension failure model. Even with the tire and suspension failure in the vehicle model, the truck rolled on a side and failed to meet *MASH* evaluation criteria. Since the truck simulation did not pass the *MASH* evaluation criteria, the small car simulation was not performed.

Figure 2.6 Sequential Images of Truck Simulation with 31-inch Thrie-beam Guardrail.

2.2.2. Simulation on 34-inch Thrie-beam Guardrail System

The 34-inch thrie-beam guardrail design was proposed to prevent the rollover of the truck by increasing the height of the 31-inch thrie-beam guardrail system.

Based on the initial simulation, the small car wheels snagged with the steel posts. Due to the snagging, the occupant ridedown acceleration value was also higher than the *MASH* limit. Therefore, the researchers conducted a simulation using a small car model with improved suspension failure prior to the pickup truck case.

The small car model with suspension failure was set with initial angle and speed with 25 degrees and 62 mi/h to replicate *MASH* Test 3-10. Table 2.2 lists the occupant risk factors. In the initial simulation, the occupant ridedown acceleration value was 24.5 g, while the occupant ridedown acceleration value from the new simulation was reduced to 20.5 g. This value is still higher than *MASH* limit of 20.49 g by a magnitude of 0.01 g.

Figure 2.7 shows the sequential images for the simulations using a small car model without suspension failure in the middle column and with the improved suspension failure in the right column. The initial simulation using the passenger car model without suspension failure stayed on the road and remained upright after impacting, but a tire snagged on a post, and front parts of the vehicle showed the potential to underride the thrie-beam. However, in the simulation performed with a vehicle model with suspension failure, the front impact side tire was detached after impact and the vehicle was redirected.

Table 2.2. *MASH* Test 3-10 with 34-inch Thrie-beam Guardrail System Simulation Result.

Vehicle model		Initial (w/o suspension failure)	New (w/ suspension failure)
Occupant Impact Velocity (ft/s)	Longitudinal	16.7	18.5
	Lateral	23.6	20.8
Occupant Ridedown Accelerations (g)	Longitudinal	*24.5*	*20.5*
	Lateral	14.2	12.9
Max Angles (degrees)	Roll	22.6	5.4
	Pitch	15.5	3.0
	Yaw	62.3	53.8

Although the small car simulation did not meet *MASH* criteria by a very small margin, a simulation with the truck model was conducted with the 34-inch thrie-beam system using the vehicle model with suspension failure to investigate this system performance under *MASH* Test 3-11 impact conditions.

Figure 2.8 shows the sequential images for the truck simulation test. The truck was redirected and maintained upright for both simulations. The occupant risk factors are listed in Table 2.3, and the values are under *MASH* TL-3 limits.

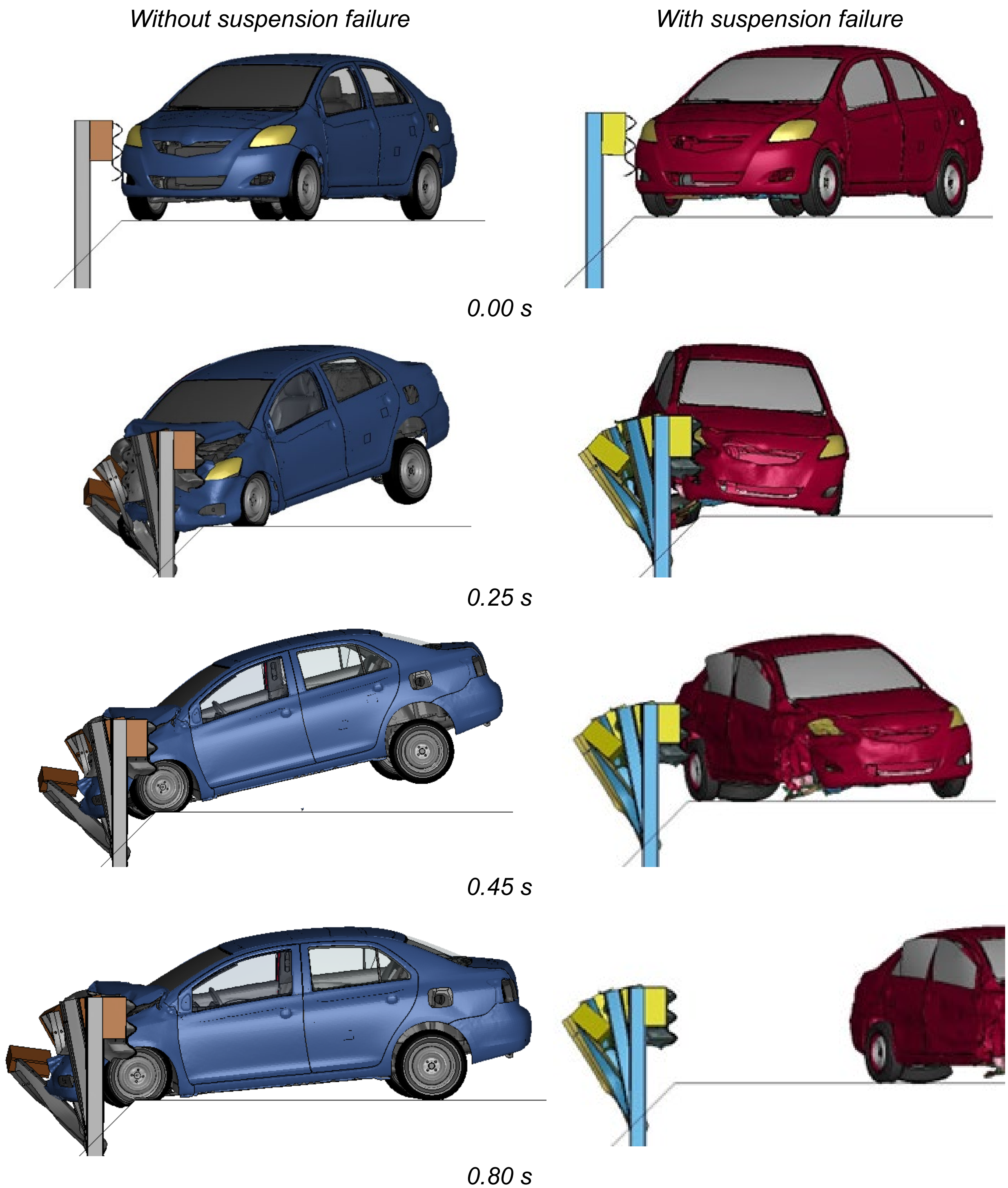


Figure 2.7 Sequential Images of Passenger Car Simulations with 34-inch Thrie-beam Guardrail.

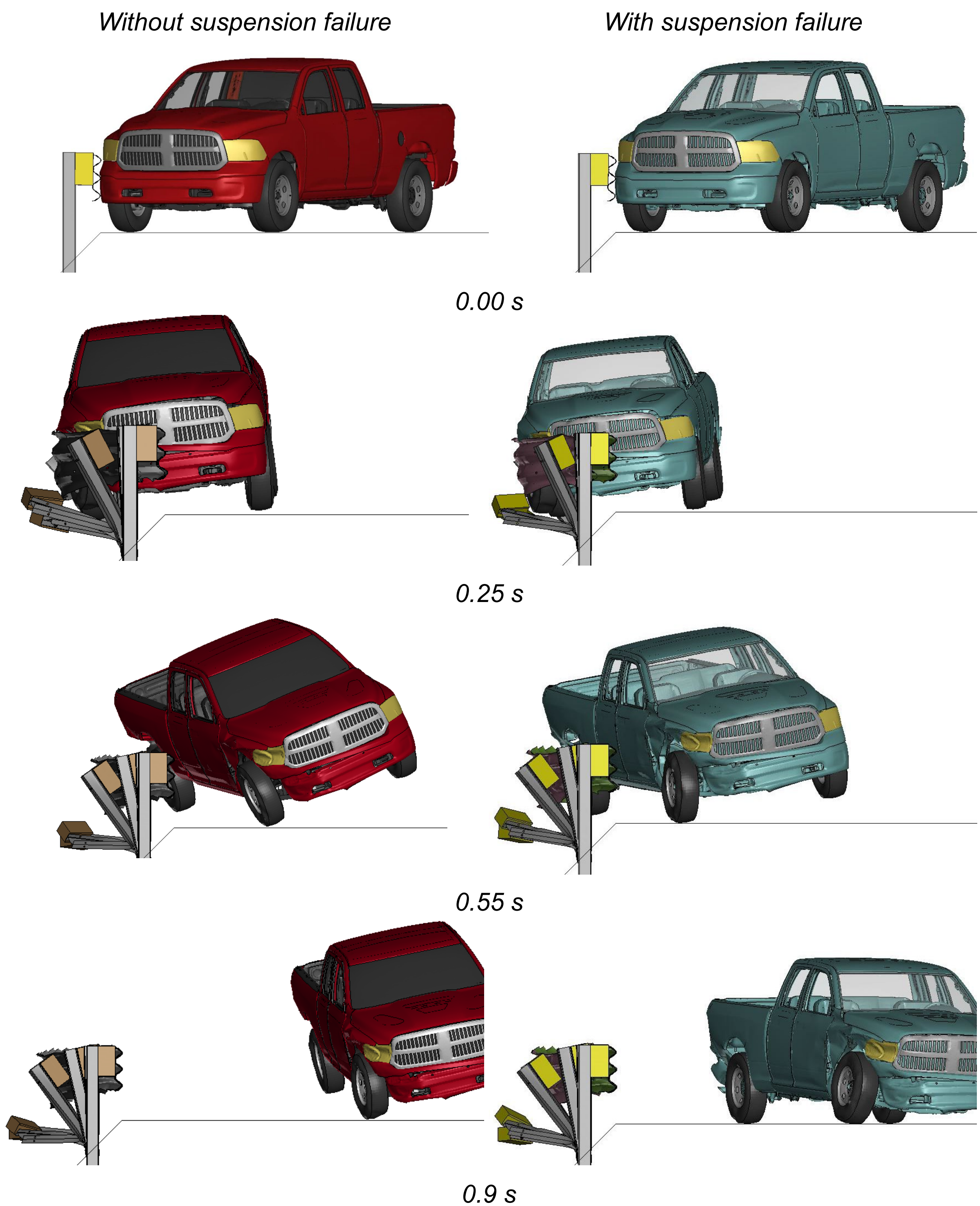


Figure 2.8. Sequential Images of Truck Simulations with 34-inch Thrie-beam Guardrail.

Table 2.3. *MASH* Test 3-11 with 34-inch Thrie-beam Guardrail System Simulation Result.

Vehicle model		Initial (w/o suspension failure)	New (w/ suspension failure)
Occupant Impact Velocity (ft/s)	Longitudinal	15.06	14.7
	Lateral	54.9	14.8
Occupant Ridedown Accelerations (g)	Longitudinal	6.6	5.8
	Lateral	8.9	7.2
Max Angles (degrees)	Roll	20.5	15.3
	Pitch	6.2	2.2
	Yaw	44.1	44.8

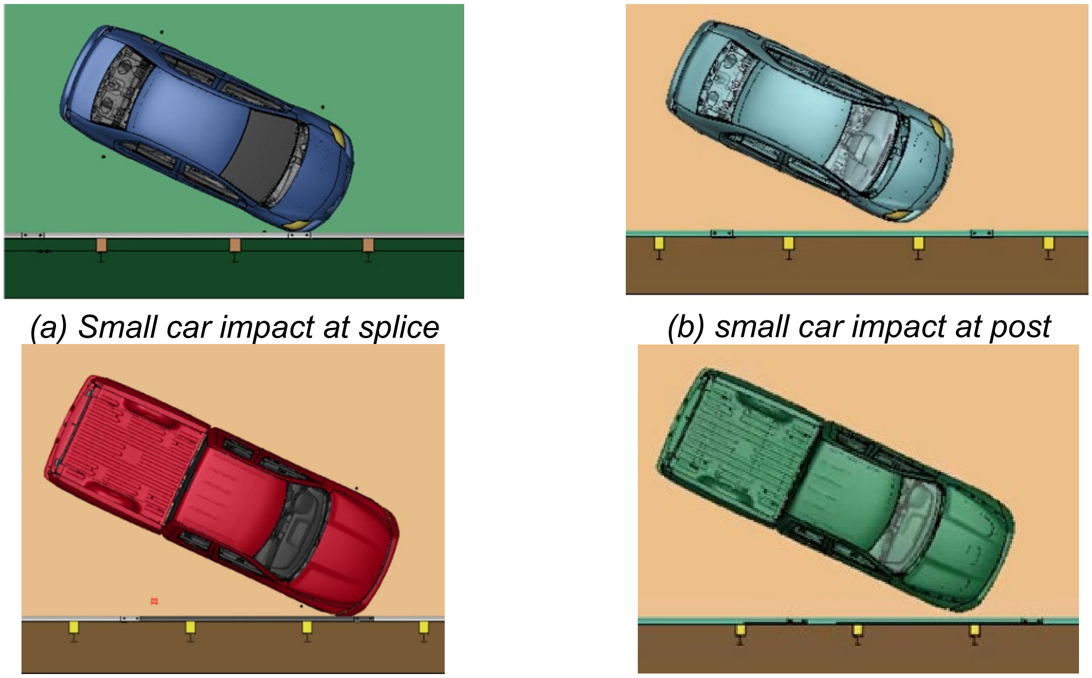
2.2.3. Summary and Conclusion

Based on the simulation results, 31-inch and 34-inch tall thrie-beam systems without rubrail did not meet certain *MASH* TL-3 evaluation criteria. However, it is the experience of the researchers that FE models tend to present stiffer vehicular response upon impact. Moreover, the strength of the suspension components due to lack of fully calibrated suspension model with failure. Therefore, these simulation results can be on the conservative side. Taking this into account, the 34-inch thrie-beam system without a rubrail was considered as a design option for further investigation through full-scale testing along with the design option including a 5.5-inch (wide) × ¼-inch (thick) steel plate rubrail installed at 8-inch height from the flat ground.

The 34-inch thrie-beam system without rub rail was selected for evaluation through full-scale crash testing. The design is considered better in terms of constructability and maintenance. Additionally, the research team’s experience with the small car model suspension indicates that the stiffer response observed in the simulation may very well be an overestimation of the physical behavior. Hence, full scale crash testing is the logical next step to evaluate the system. The research team performed simulations to identify the CIP locations for both the *MASH* 3-10 and *MASH* 3-11 tests in the next section.

2.3. CRITICAL IMPACT POINT (CIP) INVESTIGATION

In this section, a critical impact point (CIP) for the 34-inch thrie-beam system design without rubrail was determined. Two different impact points were investigated to identify the most critical impact location for each crash test: (a) point of impact at a splice and (b) point of impact at a post. Figure 2.9 shows vehicles setup at each impact point. Through the simulations, the structural performance of the system and the vehicular behavior were assessed. Table 2.4 lists the occupational risk factors for each case.



(a) Small car impact at splice (b) small car impact at post (c) Pickup truck impact at splice (d) Pickup track impact at post

Figure 2.9. Vehicle Impact at Critical Impact Point.

Table 2.4. Occupant Risk Factors for Truck and Small Car Simulations.

Vehicle Type		Small Car		Pickup truck	
CIP		At splice	At splice	At post	At post
Occupant Impact Velocity (m/sec)	Long.	18.5	20.3	14.7	15.6
	Lateral	20.8	17.1	14.8	15.0
Ridedown Acceleration (g)	Long.	20.5	15.8	5.8	8.6
	Lateral	12.9	12.4	7.2	9.3
Max. Angles (degrees)	Roll	5.4	5.4	15.3	16.0
	Pitch	3.0	2.3	2.2	4.0
	Yaw	53.8	41.6	44.8	41.9
Maximum deflection (in.)	Dynamic	27.7	29.0	45.9	48.2
	Permanent	25.0	26.3	35.9	36.3

The CIP was determined to be most critical as at a post for the truck (2270P) *MASH* 3-11 impact due to relatively higher occupant risk values for post impact as shown in Table 2.4. The CIP for small car (100C) *MASH* 3-10 impact was determined to be at a splice due to higher ridedown acceleration values for splice impact as shown in Table 2.4. and Figure 2.10 show key sequential images both the truck and the small car impact at each CIP location.

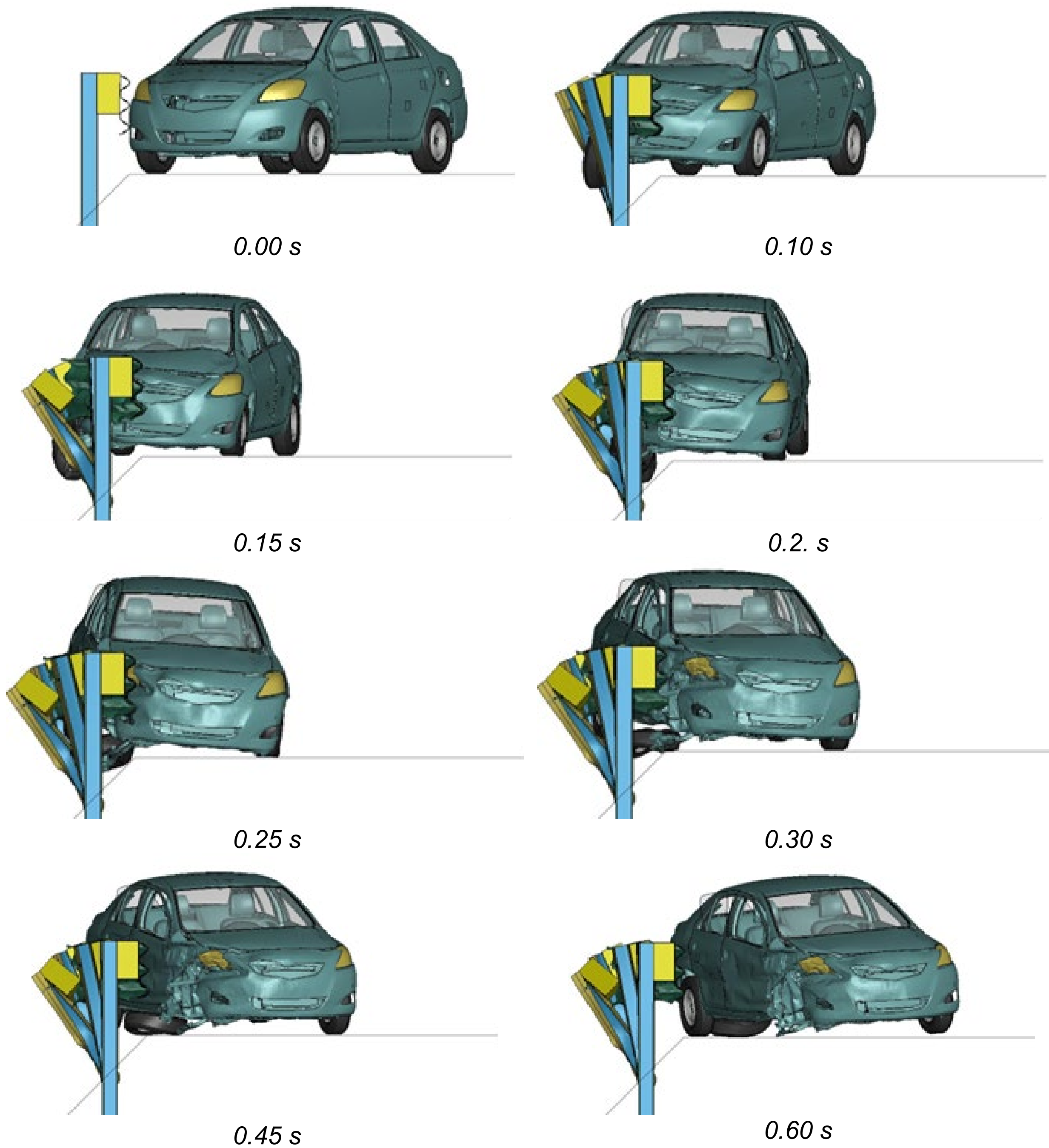


Figure 2.10 Sequential Images of Small Car Impacting at Splice (CIP) of 34-inch Thrie-beam System on 1H:1V Slope.

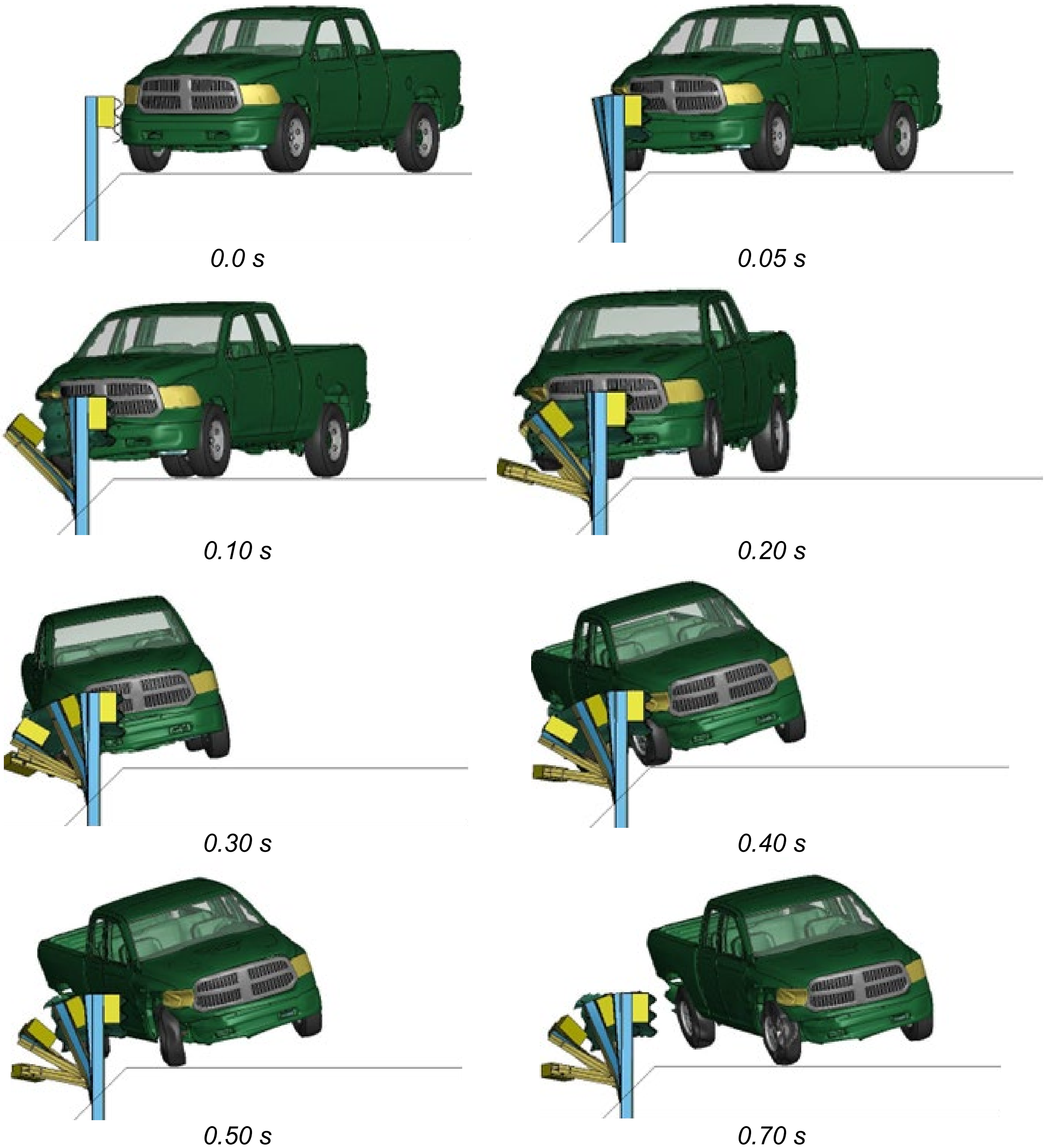


Figure 2.11 Sequential Images of Pickup Truck Impacting at Post (CIP) of 34-inch Thrie-Beam System on 1H:1V Slope.

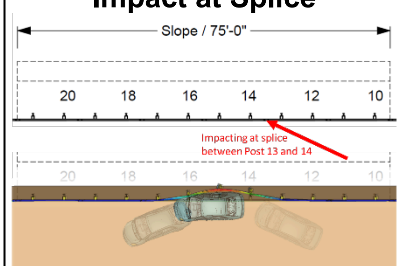
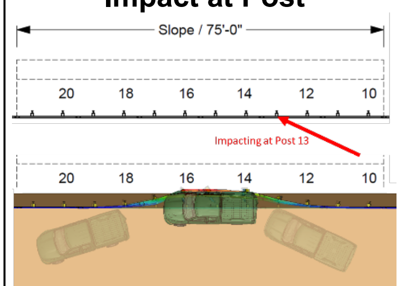
2.4. SUMMARY AND CONCLUSION

In this chapter, the 31-inch and 34-inch high thrie-beam system designs were investigated with representative test vehicle models incorporating suspension failure. The primary objective of the computational analysis was to evaluate the crashworthiness of the thrie-beam designs.

Although *MASH* Test 3-10 simulation with the suspension failure model resulted in 20.5 g of the maximum ridedown acceleration, which value is 0.01 g greater than *MASH* limit, the 34-inch thrie-beam without rubrail was considered for full-scale testing since a computational analysis result is generally on conservative side. By considering constructability, maintenance, and agency preference, the 34-inch high thrie-beam system without a rubrail was selected for full-scale testing.

Subsequently, the most critical impact points (CIP) for full-scale tests were determined. Table 2.5 provides a comprehensive list of the occupant risk factors associated with the most critical impact points for each vehicle type.

Table 2.5. Recommended CIP for *MASH* Tests 3-10 and 3-11.

<table>
<tr><th colspan="2">Vehicle type</th><th>1100C</th><th>2270P</th></tr>
<tr><td colspan="2">Impact Point</td><td>Impact at Splice

</td><td>Impact at Post

</td></tr>
<tr><td rowspan="2">Impact Velocity (ft/sec)</td><td>Longitudinal</td><td>18.5</td><td>15.6</td></tr>
<tr><td>Lateral</td><td>20.8</td><td>15.0</td></tr>
<tr><td rowspan="2">Ridedown Acceleration (g)</td><td>Longitudinal</td><td>20.5</td><td>8.6</td></tr>
<tr><td>Lateral</td><td>12.9</td><td>9.3</td></tr>
<tr><td rowspan="3">Max. Angles (degrees)</td><td>Roll</td><td>5.4</td><td>16.0</td></tr>
<tr><td>Pitch</td><td>3.0</td><td>4.0</td></tr>
<tr><td>Yaw</td><td>53.8</td><td>41.9</td></tr>
<tr><td rowspan="2">Maximum deflection (in.)</td><td>Dynamic</td><td>27.7</td><td>48.2</td></tr>
<tr><td>Permanent</td><td>25.0</td><td>36.3</td></tr>
</table>

CHAPTER 3. SYSTEM DETAILS

3.1. TEST ARTICLE AND INSTALLATION DETAILS

The installation consisted of a thrie-beam guardrail system 181 feet 3 inches in length. The steel guardrail posts were spaced at 75 inches, with a 14-inch tall timber block-out, which held the thrie-beam at 34 inches from grade to the top of the rail. Each end was terminated with a steel post terminal, and a symmetric W- to thrie-beam transition. The ground was sloped from the midspan between posts 9 and 10 to the midspan between posts 21 and 22 for a total length of 75 feet. The slope was 1:1. The base of the slope was a minimum of 72 inches below the road surface.

Figure 3.1 presents the overall information on the Guardrail System on 1:1 Slope, and Figure 3.2 thru Figure 3.7 provide photographs of the installation. Appendix A provides further details on the Guardrail System on 1:1 Slope. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by DMA Construction LLC and supervised by TTI Proving Ground personnel.

3.2. DESIGN MODIFICATIONS DURING TESTS

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

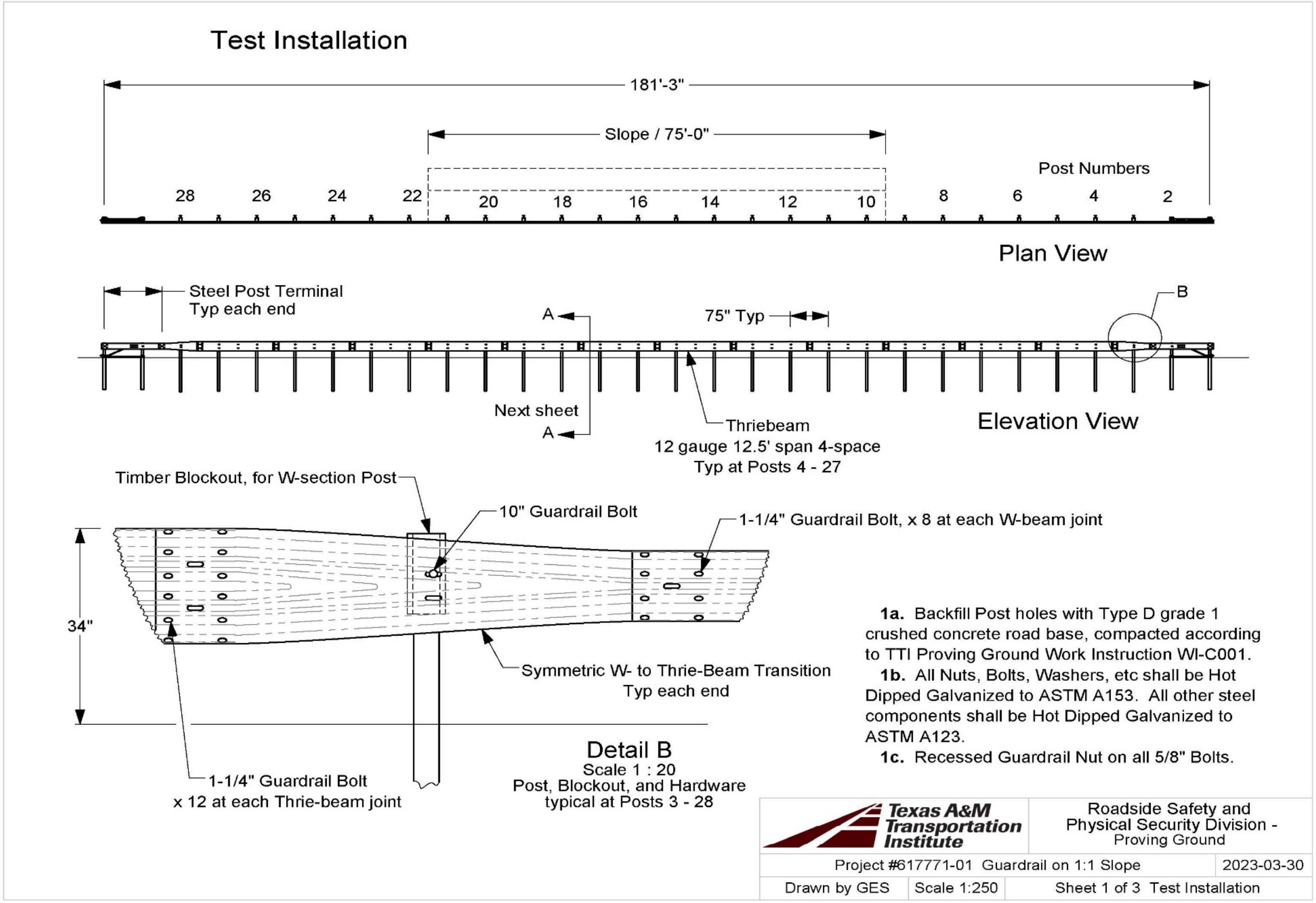


Figure 3.1. Details of Guardrail System on 1:1 Slope.

Figure 3.2. Overall View of the Guardrail System on 1:1 Slope Prior to Testing.

Figure 3.3.Upstream In-Line View of the Guardrail System on 1:1 Slope Prior to Testing.

Figure 3.4. Guardrail System on 1:1 Slope at Impact Prior to Testing.

Figure 3.5. Field Side View of the Guardrail System on 1:1 Slope Prior to Testing.

Figure 3.6. Detail of Posts in Guardrail System on 1:1 Slope Prior to Testing.

Figure 3.7.The Guardrail System on 1:1 Slope End Terminal Prior to Testing.

3.3. MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to construct the Guardrail System on 1:1 Slope.

3.4. SOIL CONDITIONS

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

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the Guardrail System on 1:1 Slope for full-scale crash testing, two 6-ft long W6×16 posts were installed in the immediate vicinity of the Guardrail System on 1:1 Slope using the same fill materials and installation procedures used in the test installation and the standard dynamic test.

On the day of Test 3-10, 2023-04-11, loads on the post at deflections were as follows: the backfill material in which the Guardrail System on 1:1 Slope was installed met *MASH* requirements for soil strength.

Table 3.1. Soil Strength for Crash Test 617771-01-1.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	6545
10	4981	6030
15	5282	5484

On the day of Test 3-11, 2023-04-25, loads on the post at deflections were as follows: the backfill material in which the Guardrail System on 1:1 Slope was installed met minimum *MASH* requirements for soil strength.

Table 3.2. Soil Strength for Crash Test 617771-01-2.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	10,696
10	4981	11,000
15	5282	N/A

CHAPTER 4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1. CRASH TEST PERFORMED/MATRIX

Table 4.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for Longitudinal Barrier. 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 4.1 shows the target CIP for *MASH* TL-3 tests on the Guardrail System on 1:1 Slope.

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

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

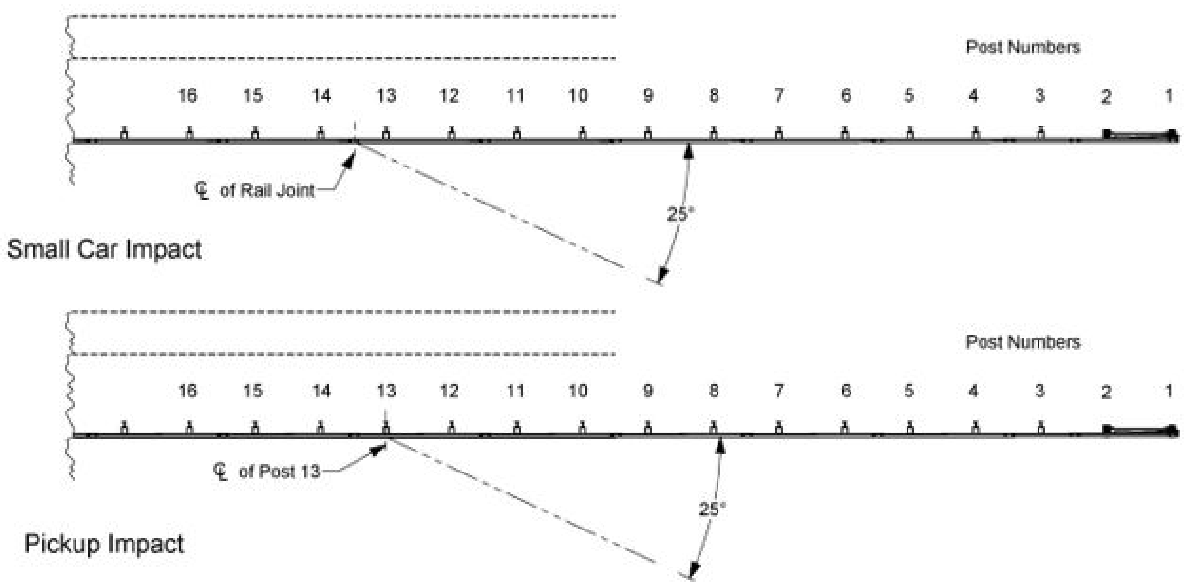


Figure 4.1. Target CIP for *MASH* TL-3 Tests on Guardrail System on 1:1 Slope.

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 5 presents brief descriptions of these procedures.

4.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 4.2 and 5.1 of *MASH* were used to evaluate the crash tests reported herein. Table 4.2 lists the test conditions and evaluation criteria required for *MASH* TL-3, and provides detailed information on the evaluation criteria.

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

Evaluation Factors	Evaluation Criteria	*MASH* Test
A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	10, 11
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*.	10, 11
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	10, 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.	10, 11
I.	The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	10, 11

CHAPTER 5. TEST CONDITIONS

5.1. TEST FACILITY

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

The test facilities of the TTI Proving Ground are located on The Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 mi northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, highway pavement durability and efficacy, and roadside safety hardware and perimeter protective device evaluation. The sites selected for construction and testing are along the edge of an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement but are otherwise flat and level.

5.2. VEHICLE TOW AND GUIDANCE SYSTEM

For the testing utilizing the 1100C and 2270P vehicles, each was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point and through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site.

5.3. DATA ACQUISITION SYSTEMS

5.3.1. Vehicle Instrumentation and Data Processing

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

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

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

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

5.3.2. Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side of the impact 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. Since the rail height of the Guardrail System on 1:1 Slope was 34 inches, a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

5.3.3. Photographic Instrumentation Data Processing

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

- One located 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 System on 1:1 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.

CHAPTER 6. *MASH* TEST 3-10 (CRASH TEST 617771-01-1)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 6.1 for details of *MASH* impact conditions for this test and Table 6.2 for the exit parameters. Figure 6.1 and Figure 6.2 depict the target impact setup.

Table 6.1. Impact Conditions for *MASH TEST 3-10,* Crash Test 617771-01-1.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62.0	±2.5 mi/h	62.8
Impact Angle (deg)	25	±1.5°	24.9
Impact Severity (kip-ft)	51	≥51 kip-ft	56.6
Impact Location	Centerline of rail joint between posts 13 and 14	±12 inches	2.8 inches downstream from the centerline of the guardrail joint between posts 13 and 14.

Table 6.2. Exit Parameters for *MASH TEST 3-10,* Crash Test 617771-01-1.

Exit Parameter	Measured
Speed (mi/h)	45.4
Trajectory (deg)	19.2
Heading (deg)	6.1
Brakes applied post impact (s)	3
Vehicle at rest position	192 ft downstream of impact point 6 ft to the field side Facing 40° left
Comments:	Vehicle remained upright and stable Vehicle crossed exit box [a] 37 ft downstream from loss of contact.

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

Figure 6.1. Guardrail System on 1:1 Slope/Test Vehicle Geometrics for Test 617771-01-1.

Figure 6.2. Guardrail System on 1:1 Slope/Test Vehicle Impact Location 617771-01-1.

6.2. WEATHER CONDITIONS

Table 6.3 provides the weather conditions for 617771-01-1.

Table 6.3. Weather Conditions 617771-01-1.

Date of Test	04-11-2023 11:11AM
Wind Speed (mi/h)	4
Wind Direction (deg)	78
Temperature (°F)	67
Relative Humidity (%)	79
Vehicle Traveling (deg)	195

6.3. TEST VEHICLE

Figure 6.3 and Figure 6.4 show the 2018 Nissan Versa used for the crash test. Table 6.4 shows the vehicle measurements. Figure C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.

Figure 6.3. Impact Side of Test Vehicle before Test 617771-01-1.

Figure 6.4. Opposite Impact Side of Test Vehicle before Test 617771-01-1.

Table 6.4. Vehicle Measurements for Test 617771-01-1.

Test Parameter	***MASH***	**Allowed Tolerance**	**Measured**
Dummy (if applicable)[a] (lb)	165	N/A	165
Inertial Weight (lb)	2420	±55	2442
Gross Static[a] (lb)	2585	±55	2607
Wheelbase (inches)	98	±5	102.4
Front Overhang (inches)	35	±4	32.5
Overall Length (inches)	169	±8	175.4
Overall Width (inches)	65	±3	66.7
Hood Height (inches)	28	±4	30.5
Track Width[b] (inches)	59	±2	58.4
CG aft of Front Axle[c] (inches)	39	±4	41.5
CG above Ground[c,d] (inches)	N/A	N/A	N/A

Note: N/A = not applicable; CG = center of gravity.
[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

6.4. TEST DESCRIPTION

Table 6.5 lists events that occurred during Test 617771-01-1. Figures C.4, C.5, and C.6 in Appendix C.2 present sequential photographs during the test.

Table 6.5. Events during Test 617771-01-1.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0170	Posts 13 and 14 began leaning toward field side
0.250	Post 15 began to lean toward field side
0.0380	Vehicle began to redirect
0.0500	Posts 12 and 16 began to lean toward field side
0.0950	Post 17 began to lean toward field side
0.0970	Rail detached from the block-out on post 15
0.1420	Post 18 began to lean toward field side
0.1810	Rear passenger side bumper contacted rail
0.1960	Vehicle was parallel with installation
0.2040	Rail detached from block-out on post 16
0.4370	Vehicle exited the installation at 45.5 mi/h with a heading of 6.1 degrees and a trajectory of 19.2 degrees

6.5. DAMAGE TO TEST INSTALLATION

Post 15 detached from the rail and leaning over. Post 16 also detached and leaning 12-degrees field side.

Table 6.6 describes the damage to the Guardrail System on 1:1 Slope. Table 6.7 describes the deflection and working width of the Guardrail System on 1:1 Slope. Figure6.5 and Figure 6.6 show the damage to the Guardrail System on 1:1 Slope.

Table 6.6. Damage to the Guardrail System on 1:1 Slope for Test 617771-01-1.

Post Number	Soil Gap (inches)	Post Lean from Vertical (degrees)
8-11	Disturbed	-
12	0.5 t/s	1 f/s
13	2.5 t/s	4 f/s
14	7.0 t/s	10 f/s
16	-	12 f/s
17	3.5 t/s	4 f/s
18	1.25 t/s	3 f/s
19	0.2 t/s	1 f/s
20	Disturbed	-

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

Table 6.7. Deflection and Working Width of the Guardrail System on 1:1 Slope for Test 617771-01-1.

Test Parameter	Measured
Permanent Deflection/Location	17.5 inches toward field side, at Post 15
Dynamic Deflection	33.0 inches toward field side 1 foot downstream of Post 15
Working Width [a] and Height	47.8 inches, at a height of 0 inches at Post 15

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

Figure 6.5. Guardrail System on 1:1 Slope at Impact Location after Test 617771-01-1.

Figure 6.6. Guardrail System on 1:1 Slope from the Field Side after Test 617771-01-1.

6.6. DAMAGE TO TEST VEHICLE

Figure 6.7 and Figure 6.8 show the damage sustained by the vehicle. Figure 6.9 and Figure 6.10 show the interior of the test vehicle. Table 6.8 and Table 6.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figures C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

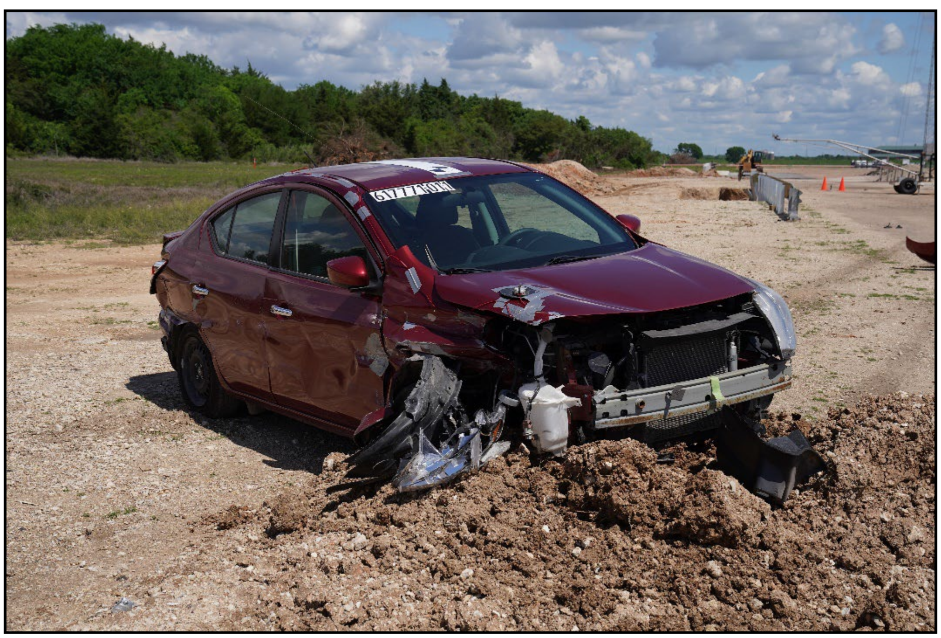


Figure 6.7. Impact Side of Test Vehicle after Test 617771-01-1.

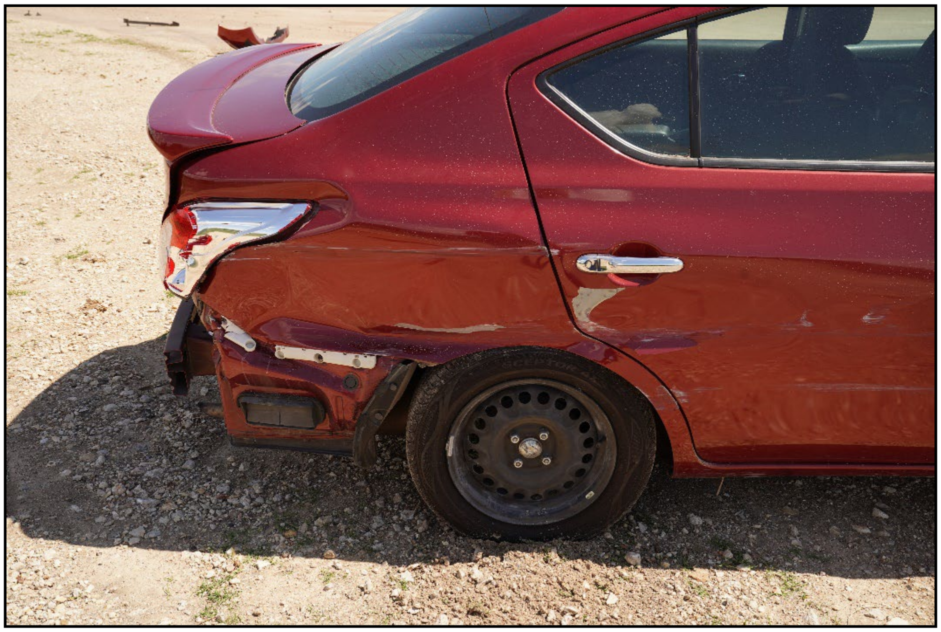


Figure 6.8. Opposite Rear Impact Side of Test Vehicle after Test 617771-01-1

Figure 6.9. Overall Interior of Test Vehicle after Test 617771-01-1.

Figure 6.10. Interior of Test Vehicle on Impact Side after Test 617771-01-1.

Table 6.8. Occupant Compartment Deformation 617771-01-1.

Test Parameter	**Specification** (inches)	**Measured** (inches)
Roof	≤4.0	0.0
Windshield	≤3.0	0.0
A and B Pillars	≤5.0 overall/≤3.0 lateral	0.0
Foot Well/Toe Pan	≤9.0	1.75
Floor Pan/Transmission Tunnel	≤12.0	0.0
Side Front Panel	≤12.0	0.5
Front Door (above Seat)	≤9.0	0.0
Front Door (below Seat)	≤12.0	0.0

Table 6.9. Exterior Vehicle Damage 617771-01-1.

Side Windows	The side windows remained intact
Maximum Exterior Deformation	8.5 inches in the front plane at the right front corner above bumper height
VDS	01RFQ5
CDC	01FREW3
Fuel Tank Damage	None
Description of Damage to Vehicle:	Front bumper hood and grill, right headlight, right front tire and wheel, right lower control arm, right fender, right front frame rail, right front door, right rear door, right rear taillight, rear bumper cover, and right front floor pan were damaged. The right front door had a 1.25-inch gap at the top. The right front floor pan was pushed in 1.25 inches.

6.7. OCCUPANT RISK FACTORS

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

Table 6.10. Occupant Risk Factors for Test 617771-01-1.

Test Parameter	*MASH* [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	13.0	0.1188 seconds on the right side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	19.8	0.1188 seconds on the right side of interior
Ridedown, Longitudinal (g)	≤20.4 15.0	7.7	0.1285 – 0.1385
Ridedown, Lateral (g)	≤20.4 15.0	10.7	0.1450 – 0.1550
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	7.2	0.1154
Acceleration Severity Index (ASI)	N/A	0.88	0.0686 - 0.1186
50-ms Moving Avg. Accelerations (MA) Longitudinal (g)	N/A	4.6	0.0571 – 0.1071
50-ms MA Lateral (g)	N/A	7.7	0.0388 – 0.0888
50-ms MA Vertical (g)	N/A	1.4	0.9741 – 1.0241
Roll (deg)	≤75	8.5	2.0000
Pitch (deg)	≤75	5.8	2.0000
Yaw (deg)	N/A	34.3	0.3180

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

6.8. TEST SUMMARY

Figure 6.11 summarizes the results of *MASH* Test 617771-01-1.

0.000 s

0.200 s

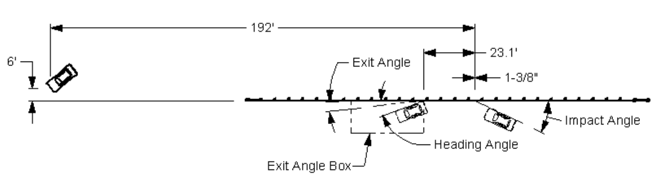
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-10
TTI Project No.	617771-01-1
Test Date	04-11-2023
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Guardrail System on 1:1 Slope
Length	181'-3"
Key Materials	12 Gauge thrie-beam, Steel Post Terminal, W-beam steel posts, timber blockouts
Soil Type and Condition	Type D grade 1 crushed concrete road base
TEST VEHICLE	
Type/Designation	1100C
Year, Make and Model	2018 Nissan Versa
Inertial Weight (lb)	2442
Dummy (lb)	165
Gross Static (lb)	2607
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.8
Impact Angle (deg)	24.8
Impact Location	2.8 inches downstream from the centerline of the guardrail joint between posts 13 and 14
Impact Severity (kip-ft)	56.6
EXIT CONDITIONS	
Exit Speed (mi/h)	45.4
Trajectory/Heading Angle (deg)	19.2 / 6.1
Exit Box Criteria	Vehicle crossed box 37 ft downstream from loss of contact.
Stopping Distance	192 ft downstream 6 ft to the field side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	33.0
Permanent (inches)	17.5
Working Width / Height (inches)	47.7 / 0
VEHICLE DAMAGE	
VDS	01RFQ5
CDC	01FREW3
Max. Ext. Deformation (inches)	8.5
Max Occupant Compartment Deformation (inches)	1.75 in Footwell

OCCUPANT RISK VALUES

Long. OIV (ft/s)	13.0	Long. Ridedown (g)	7.7	Max 50-ms Long. (g)	4.6	Max Roll (deg)	8.5
Lat. OIV (ft/s)	19.8	Lat. Ridedown (g)	10.7	Max 50-ms Lat. (g)	7.7	Max Pitch (deg)	5.8
THIV (m/s)	7.2	ASI	0.88	Max 50-ms Vert. (g)	1.4	Max Yaw (deg)	34.3



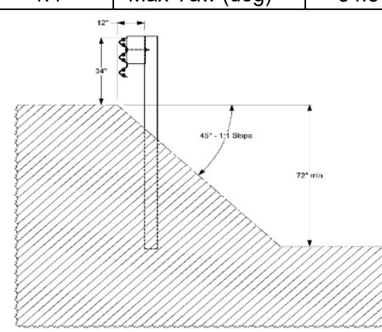


Figure 6.11. Summary of Results for *MASH* Test *3-10* on Guardrail System on 1:1 Slope.

CHAPTER 7. *MASH* TEST 3-11 (CRASH TEST 617771-01-2)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 7.1 for details of *MASH* impact conditions for this test and Table 7.2 for the exit parameters. Figure 7.1 and Figure 7.2 depict the target impact setup.

Table 7.1. Impact Conditions for *MASH* TEST 3-11, Crash Test 617771-01-2.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62.0	±2.5 mi/h	62.2
Impact Angle (deg)	25	±1.5°	25.3
Impact Severity (kip-ft)	106	≥106	118.7
Impact Location	Centerline of post 13	±12 inches	0.7 inches downstream from the centerline of post 13

Table 7.2. Exit Parameters for *MASH* TEST 3-11, Crash Test 617771-01-2.

Exit Parameter	Measured
Speed (mi/h)	Not Measurable, video ended before vehicle exited the installation
Trajectory (deg)	Not Measurable, video ended before vehicle exited the installation
Heading (deg)	Not Measurable, video ended before vehicle exited the installation
Brakes applied post impact (s)	Not applied
Vehicle at rest position	153 ft downstream of impact point 2 ft to the traffic side 175° left
Comments:	Vehicle remained upright and stable The Vehicle crossed the exit box [a] 52 ft downstream from loss of contact.

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

Figure 7.1. Guardrail System on 1:1 Slope/Test Vehicle Geometrics for Test 617771-01-2.

Figure 7.2. Guardrail System on 1:1 Slope/Test Vehicle Impact Location 617771-02-2.

7.2. WEATHER CONDITIONS

Table 7.3 provides the weather conditions for 617771-01-2.

Table 7.3. Weather Conditions 617771-01-2.

Date of Test	04-25-2023 11:00AM
Wind Speed (mi/h)	5
Wind Direction (deg)	92
Temperature (°F)	67
Relative Humidity (%)	79
Vehicle Traveling (deg)	195

7.3. TEST VEHICLE

Figure 7.3 and Figure 7.4 show the 2017 RAM 1500 used for the crash test. Table 7.4 shows the vehicle measurements. Figure D.1 in Appendix D.1 gives additional dimensions and information on the vehicle.

Figure 7.3. Impact Side of Test Vehicle before Test 617771-01-2.

Figure 7.4. Opposite Impact Side of Test Vehicle before Test 617771-01-2.

Table 7.4. Vehicle Measurements 617771-01-2

Test Parameter	*MASH*	Allowed Tolerance	Measured
Dummy (if applicable)[a] (lb)	165	N/A	165
Inertial Weight (lb)	5000	±110	5027
Gross Static[a] (lb)	5165	±110	5192
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40.0
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46.0
Track Width[b] (inches)	67	±1.5	68.25
CG aft of Front Axle[c] (inches)	63	±4	62.0
CG above Ground[c,d] (inches)	28	28.0 minimum	28.5

Note: N/A = not applicable; CG = center of gravity.
[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

7.4. TEST DESCRIPTION

Table 7.5 lists events that occurred during Test 617771-01-2. Figures D.4, D.5, and D.6 in Appendix D.2 present sequential photographs during the test.

Table 7.5. Events during Test 617771-01-2.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0060	Post 13 began to deflect towards the traffic side
0.0420	Vehicle began to redirect
0.0600	Rail released from post 14
0.2670	Vehicle was parallel with installation
0.4240	Downstream anchor post released from base
0.7840	Rail released from all posts downstream of impact
0.9430	Vehicle exited the installation

7.5. DAMAGE TO TEST INSTALLATION

All posts except Posts 12 and 13 released from the rail. Blockouts were missing from posts 14, 15, and 17. Post 30 released from the embedded anchor due to the bolts shearing off and the downstream anchor had a 0.5-inch soil gap on the downstream side of the anchor. The rail was deformed and scuffed at impact.

Table 7.6. Damage to the Guardrail System on 1:1 Slope for Test 617771-01-2.describes the damage to the Guardrail System on 1:1 Slope. Table 7.7. Deflection and Working Width of the Guardrail System on 1:1 Slope for Test 617771-01-2.describes the deflection and working width of the Guardrail System on 1:1 Slope. Figure 7.5 through Figure 7.7 show the damage to the Guardrail System on 1:1 Slope.

Table 7.6. Damage to the Guardrail System on 1:1 Slope for Test 617771-01-2.

Post Number	Soil Gap (inches)	Post Lean From Vertical (degrees)
1	1 u/s	-
2	0.125 d/s	-
10	Disturbed	-
11	0.125 t/s, 0.0625 f/s	1.9f/s
12	2 t/s	4.3f/s
13	7.5 t/s	16.6f/s
14-18	-	50 d/s
19	-	35.2f/s
20	1 t/s, 0.75 f/s	4.3f/s
21	Disturbed	-

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

Table 7.7. Deflection and Working Width of the Guardrail System on 1:1 Slope for Test 617771-01-2.

Test Parameter	Measured
Permanent Deflection/Location	Not Measurable, guardrail released from posts
Dynamic Deflection	79.4 inches toward field side, at post 16 before rail released
Working Width [a] and Height	82.6 inches, at a height of 28.6 inches, at the thrie-beam at post 16

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

Figure 7.5. Overall View of the Guardrail System on 1:1 Slope after Test 617771-01-2.

Figure 7.6. Guardrail System on 1:1 Slope at Impact Location after Test 617771-01-2.

Figure 7.7. Guardrail System on 1:1 Slope at the Downstream Anchor after Test 617771-01-2.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.8 and Figure 7.9 show the damage sustained by the vehicle. Figure 7.10 and Figure 7.11 show the interior of the test vehicle. Table 7.8 and Table 7.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figures D.2 and D.3 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 7.8. Impact Side of Test Vehicle after Test 617771-01-2.

Figure 7.9. Rear Impact Side of Test Vehicle after Test 617771-01-2.

Figure 7.10. Overall Interior of Test Vehicle after Test 617771-01-2.

Figure 7.11. Interior of Test Vehicle on Impact Side after Test 617771-01-2.

Table 7.8. Occupant Compartment Deformation 3-11

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

Table 7.9. Exterior Vehicle Damage 3-11

Side Windows	The side windows remained intact
Maximum Exterior Deformation	8 inches in the right plane at the front corner above bumper height
VDS	01RFQ5
CDC	01FREW2
Fuel Tank Damage	None
Description of Damage to Vehicle:	Right headlight, front bumper, right front fender, right front tire and wheel, arm at lower ball joint, right side of truck, right rear taillight, and rear bumper were damaged.

7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.10. Figure D.7 in Appendix D.3 shows the vehicle angular displacements, and Figures D.8 through D.10 in Appendix D.4 show acceleration versus time traces.

Table 7.10. Occupant Risk Factors for Test 617771-01-2.

Test Parameter	*MASH* [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	12.2	0.1559 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	14.7	0.1559 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	5.2	0.1839 – 0.1939
Ridedown, Lateral (g)	≤20.49 *15.0*	7.6	0.2413 – 0.2513
THIV (m/s)	N/A	5.6	0.1504 seconds on right side of interior
ASI	N/A	0.64	0.2508 – 0.3008
50-ms MA Longitudinal (g)	N/A	3.8	0.0954 – 0.1454
50-ms MA Lateral (g)	N/A	5.3	0.2314 – 0.2814
50-ms MA Vertical (g)	N/A	2.3	0.1257 – 0.1757
Roll (deg)	≤75	16.8	0.4008
Pitch (deg)	≤75	3.4	0.7373
Yaw (deg)	N/A	42.5	0.6445

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

7.8. TEST SUMMARY

Figure 7.12 summarizes the results of *MASH* Test 617771-01-2.

0.000 s

0.200 s

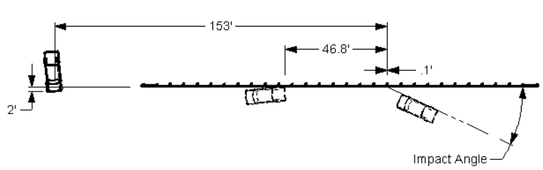
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-11
TTI Project No.	617771-01-2
Test Date	04-25-2023
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Guardrail System on 1:1 Slope
[Length Spec]	181'-3"
Key Materials	12 Gauge thrie-beam, Steel Post Terminal, w-beam steel posts, timber blockouts
Soil Type and Condition	Type D grade 1 crushed concrete road base
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2017 RAM 1500
Inertial Weight (lb)	5027
Dummy (lb)	165
Gross Static (lb)	5192
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.2
Impact Angle (deg)	25.3
Impact Location	0.7 inches downstream from the centerline of post 13
Impact Severity (kip-ft)	118.7
EXIT CONDITIONS	
Exit Speed (mi/h)	Not Measurable
Trajectory/Heading Angle (deg)	Not Measurable/ Not Measurable
Exit Box Criteria	Vehicle crossed exit box at 52 ft downstream from loss of contact.
Stopping Distance	153 ft downstream 2 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	79.4
Permanent (inches)	Not Measurable, rail released from posts
Working Width / Height (inches)	82.5 / 28.6
VEHICLE DAMAGE	
VDS	01RFQ5
CDC	01FREW2
Max. Ext. Deformation (inches)	8
Max Occupant Compartment Deformation	No occupant compartment deformation

OCCUPANT RISK VALUES

Long. OIV (ft/s)	12.2	Long. Ridedown (g)	5.2	Max 50-ms Long. (g)	3.8	Max Roll (deg)	16.8
Lat. OIV (ft/s)	14.7	Lat. Ridedown (g)	7.6	Max 50-ms Lat. (g)	5.3	Max Pitch (deg)	3.4
THIV (m/s)	5.6	ASI	0.64	Max 50-ms Vert. (g)	2.3	Max Yaw (deg)	42.5



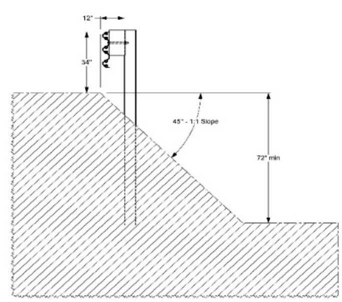


Figure 7.12. Summary of Results for *MASH* Test 3-11 on Guardrail System on 1:1 Slope.

CHAPTER 8. SUMMARY AND CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-3, which involves two tests, on the Guardrail System on 1:1 Slope.

8.2. CONCLUSIONS

Table 8.1 shows that the Guardrail System on 1:1 Slope met the performance criteria for *MASH* TL-3 Longitudinal Barrier.

Table 8.1. Assessment Summary for *MASH* TL-3 Tests on Guardrail System on 1:1 Slope.

Evaluation Criteria	Description	Test 617771-01-1	Test 617771-01-2
A	Contain, Redirect, or Controlled Stop	S	S
D	No Penetration into Occupant Compartment	S	S
F	Roll and Pitch Limit	S	S
H	OIV Threshold	S	S
I	Ridedown Threshold	S	S
Overall		Pass	Pass

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

8.3. IMPLEMENTATION*

The research team recommend the implementation of the Guardrail to use the minimum length of installation to be 182-ft which is around the total installation length tested in this project. Also, the research team recommends using a minimum of 54-ft length of flat terrain W-Beam length on either side of the sloped ditch to allow sufficient anchorage to develop. The end terminal / anchor should be strong enough to withstand the impact conditions presented herewith for A *MASH* TL-3 conditions in addition of being a *MASH* crashworthy terminal.

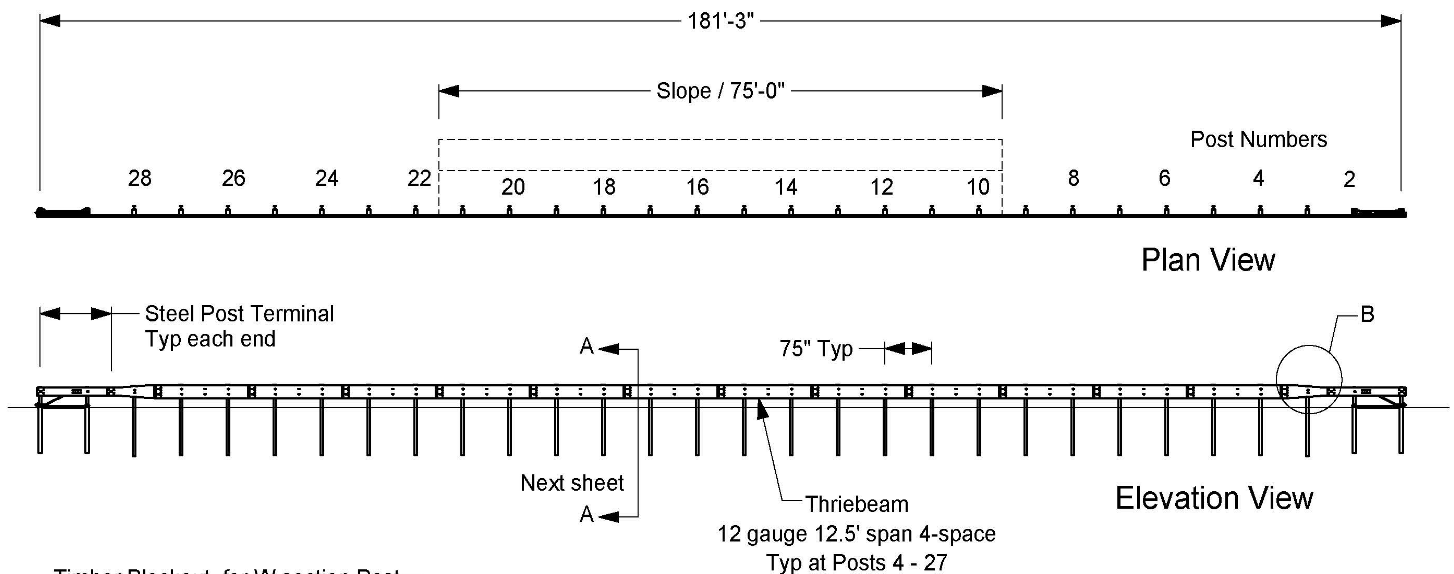
* *The opinions/interpretations identified/expressed in this section of the report are outside the scope of TTI Proving Ground's A2LA Accreditation.*

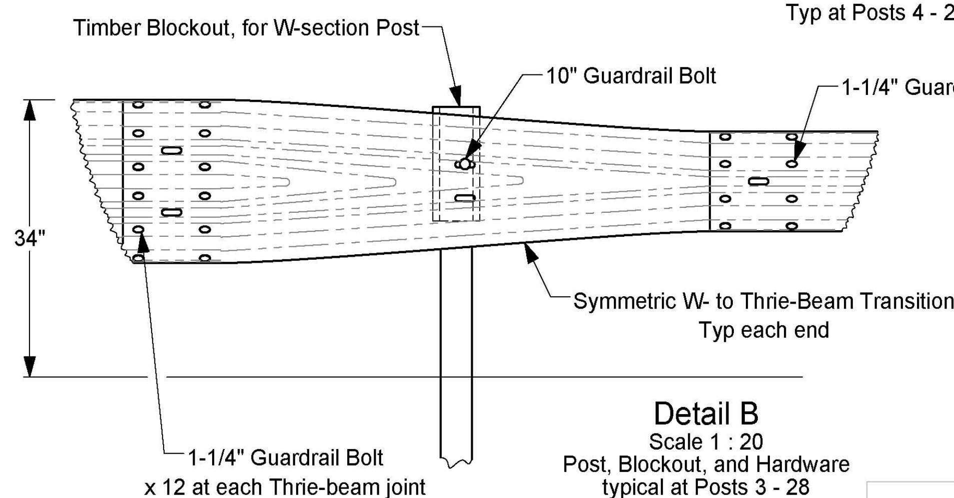
REFERENCES

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. 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.
4. AASHTO. *Manual for Assessing Safety Hardware*, Second Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2016.
5. Akram Y. Abu-Odeh, Wanda L. Menges, Glenn E. Schroeder, and Darrell L. Kuhn. *MASH Test 3-10 of Guardrail System on 1H:1V Slope*. Test Report No. 609301-01, Texas A&M Transportation Institute, College Station, Tx, March 2020.
6. Center for Collision Safety and Analysis (CCSA), 2016. 2010 Toyota Yaris Finite Element Model Validation Detailed Mesh, Presentation | doi:10.13021/G8CC7G. George Mason University.
7. Center for Collision Safety and Analysis (CCSA), 2022. 2018 Dodge Ram 1500 FE Detailed Mesh Model v3 – Validation, Presentation | doi:10.13021/g8je-0t34. George Mason University.
8. LS-DYNA KEYWORD USER'S MANUAL, Livermore Software Technology (LST), AN ANSYS COMPANY, Livermore, California, 2021.

APPENDIX A. DETAILS OF GUARDRAIL SYSTEM ON 1:1 SLOPE

Test Installation





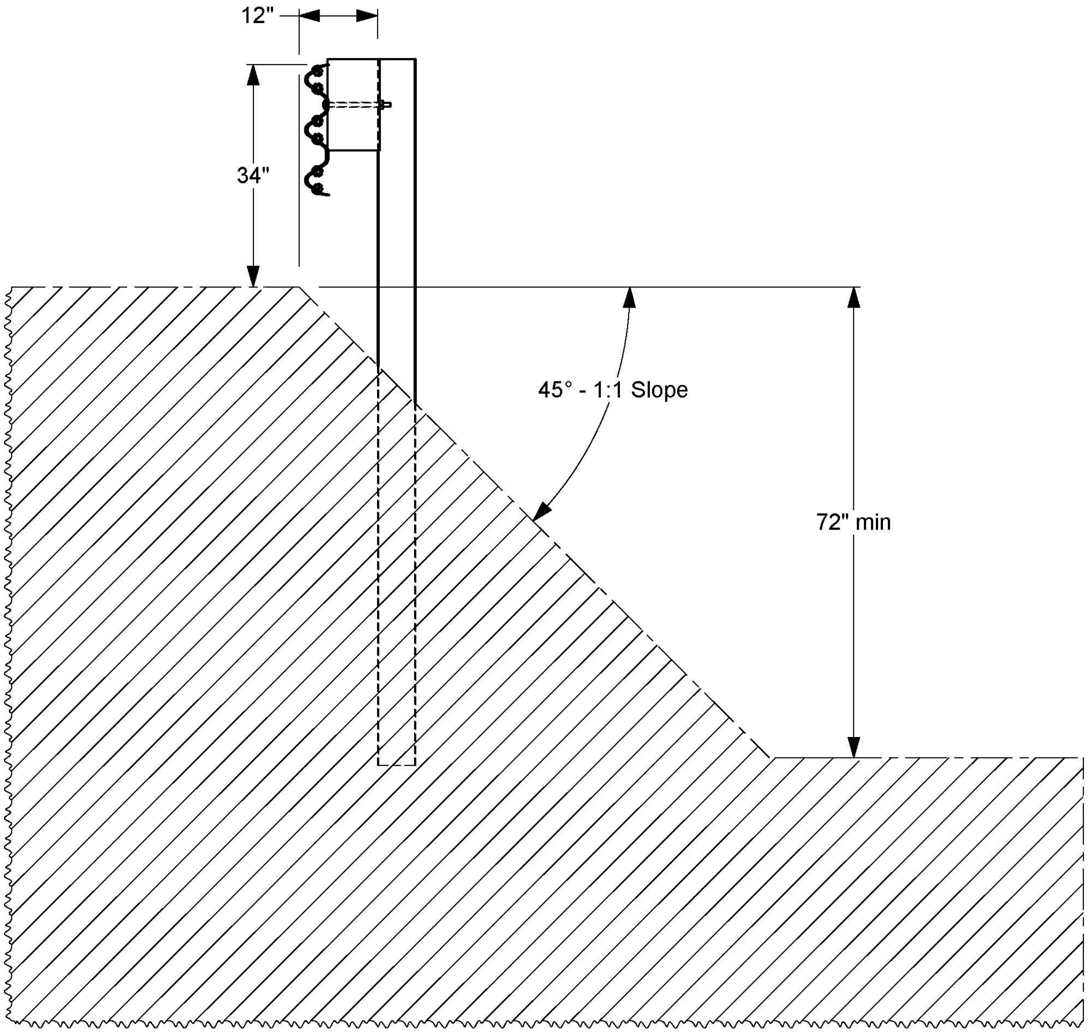
Detail B
Scale 1 : 20
Post, Blockout, and Hardware
typical at Posts 3 - 28

1a. Backfill Post holes with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.

1b. All Nuts, Bolts, Washers, etc shall be Hot Dipped Galvanized to ASTM A153. All other steel components shall be Hot Dipped Galvanized to ASTM A123.

1c. Recessed Guardrail Nut on all 5/8" Bolts.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project #617771-01 Guardrail on 1:1 Slope			2023-03-30
Drawn by GES	Scale 1:250	Sheet 1 of 3 Test Installation	

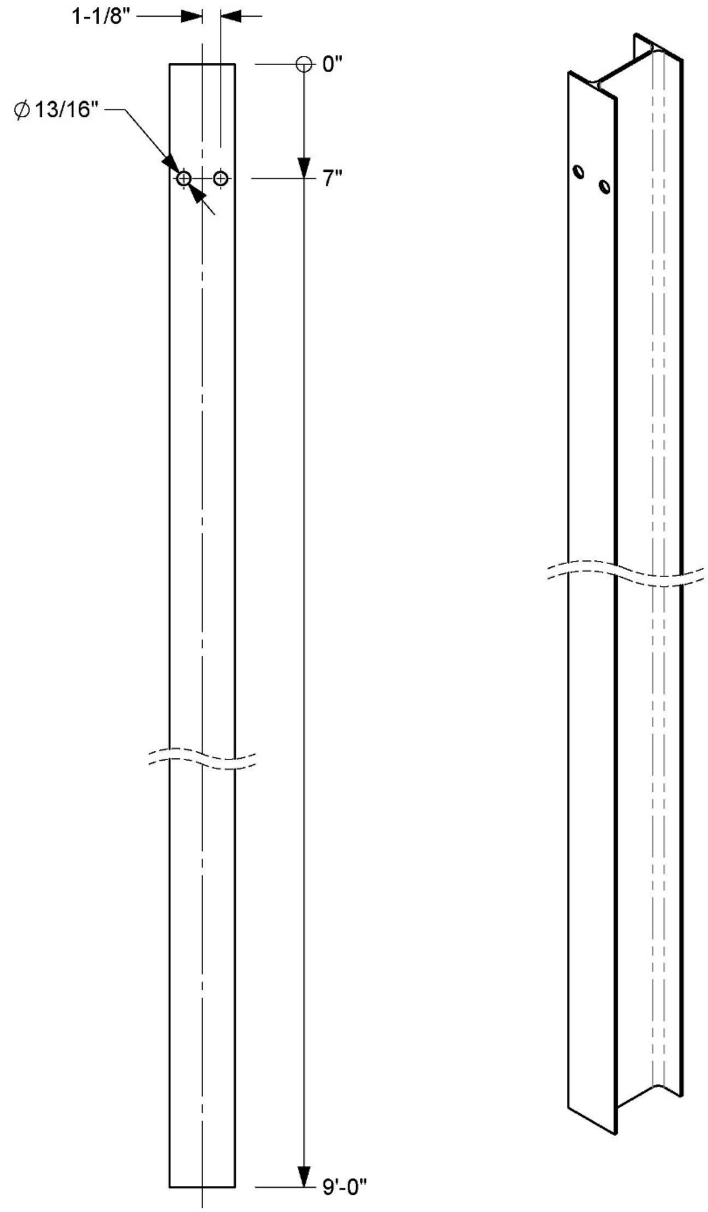


Section A-A
Scale 1 : 25

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #617771-01 Guardrail on 1:1 Slope		2023-03-30
Drawn by GES	Scale 1:25	Sheet 2 of 3 Cross Section

Post Details

Galvanize after fabrication
(see sheet 1 for galvanizing specs)



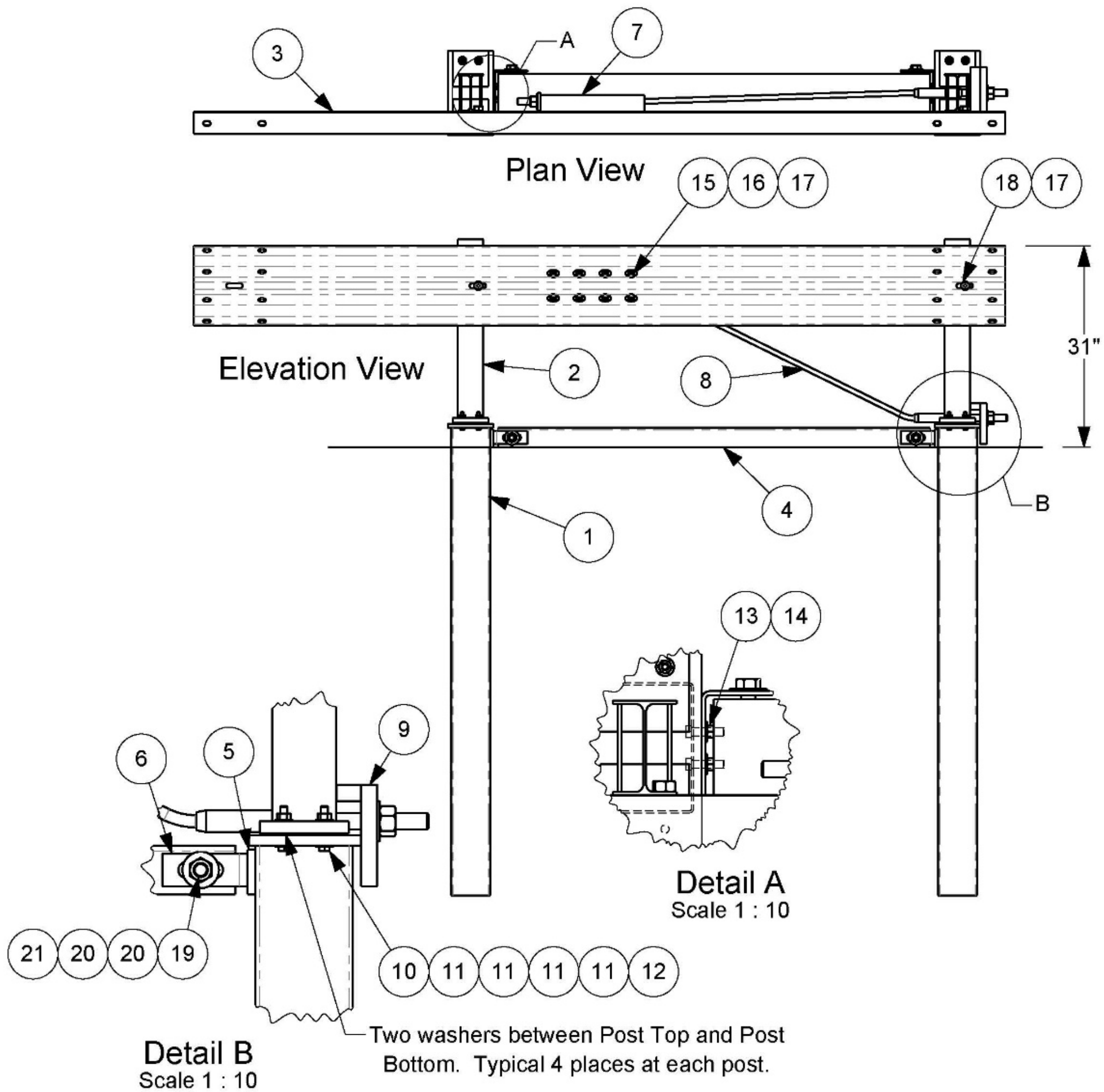
1:1 Slope Guardrail Post

W6x8.5 x 108"

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #617771-01 Guardrail on 1:1 Slope		2023-03-30
Drawn by GES	Scale 1:10	Sheet 3 of 3 Post Details

Terminal Details

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

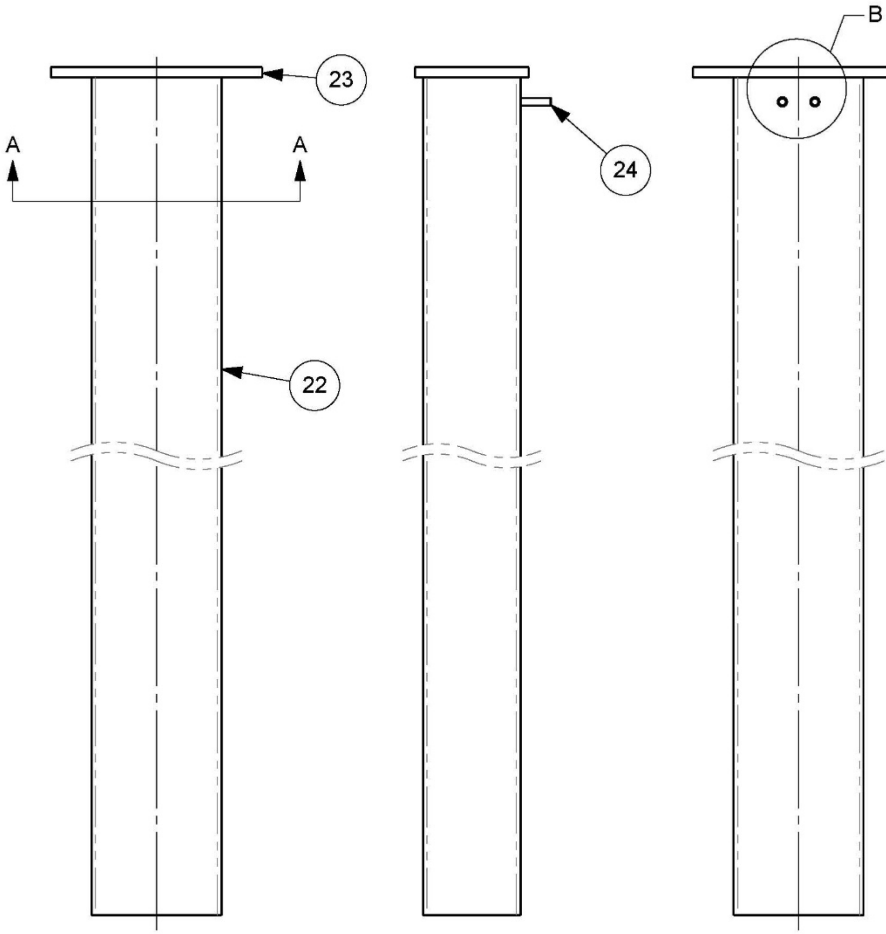


1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.

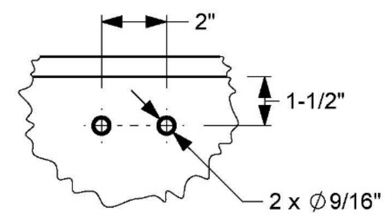
1c. All steel parts shall be galvanized.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal		2022-11-10
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details

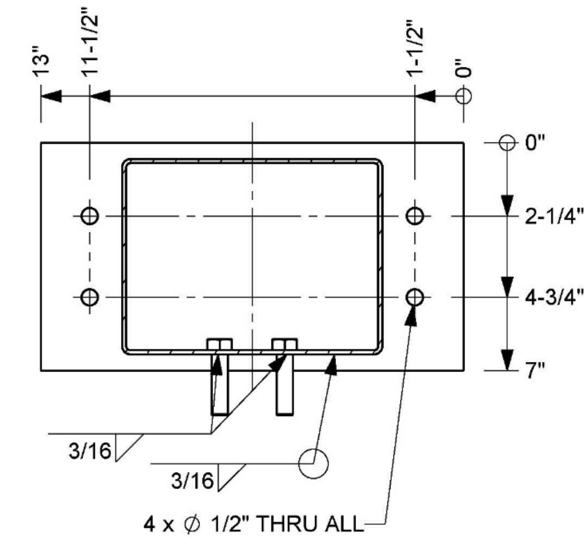
Post Bottom



Elevation Views



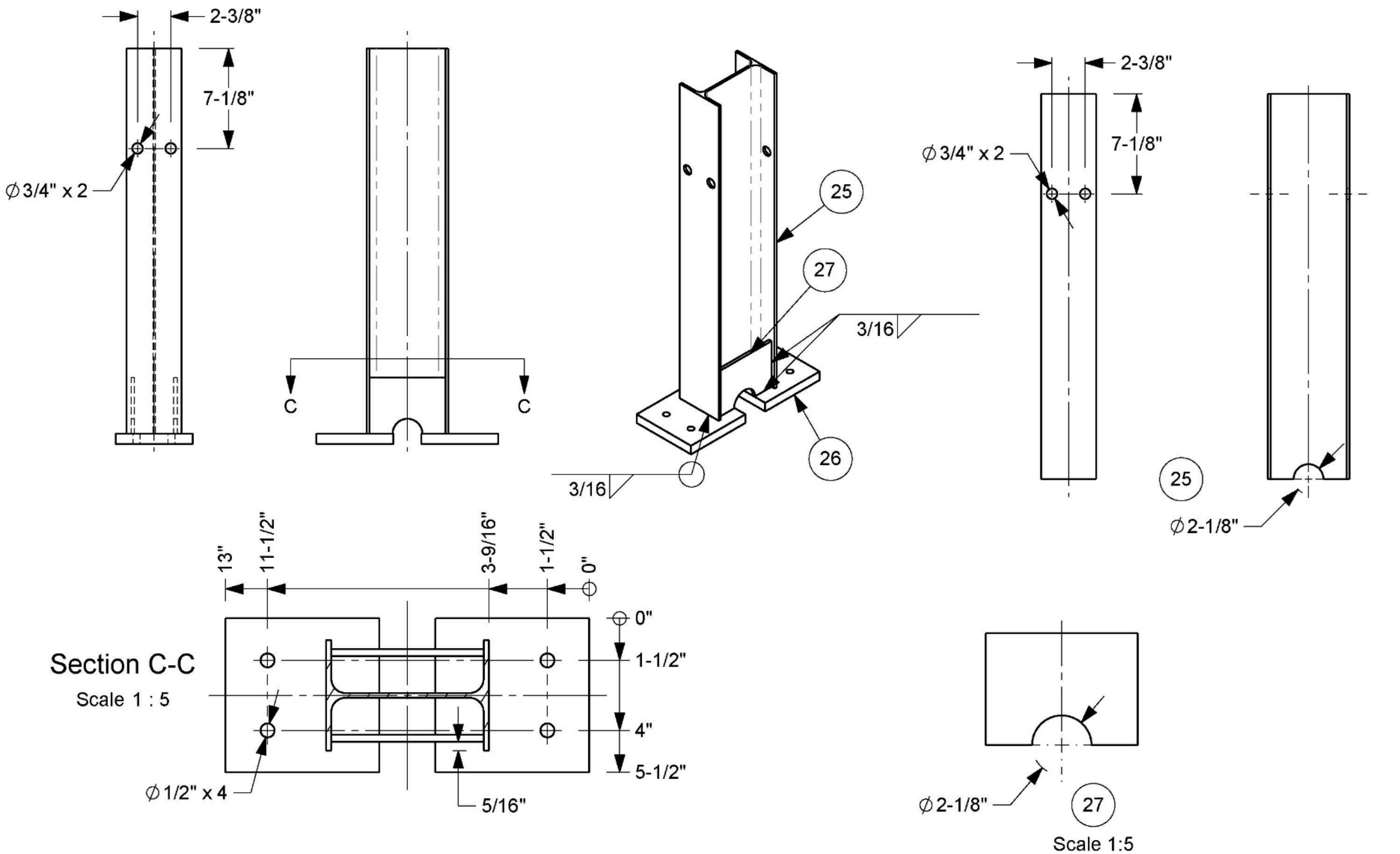
Detail B
Scale 1 : 5



Section A-A
Scale 1 : 5

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

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
	Project # Terminal		2022-11-10
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom	



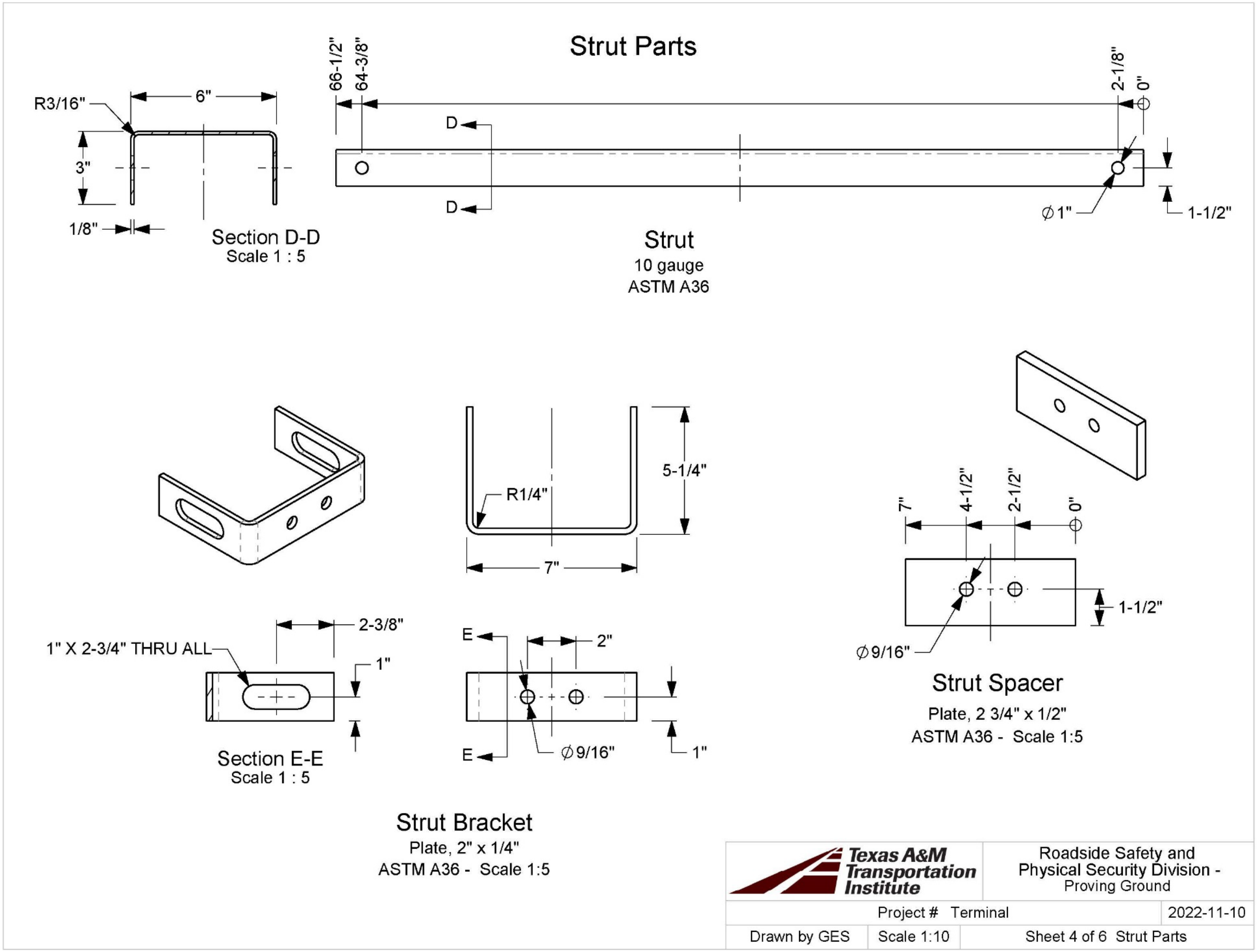
#	Description	Length	Material	Qty
25	W6x8.5	27 1/2"	ASTM A992	1
26	Plate, 5 1/2" x 3/4"	5 1/2"	ASTM A36	2
27	Plate, 5 7/16" x 1/4"	4"	ASTM A36	2

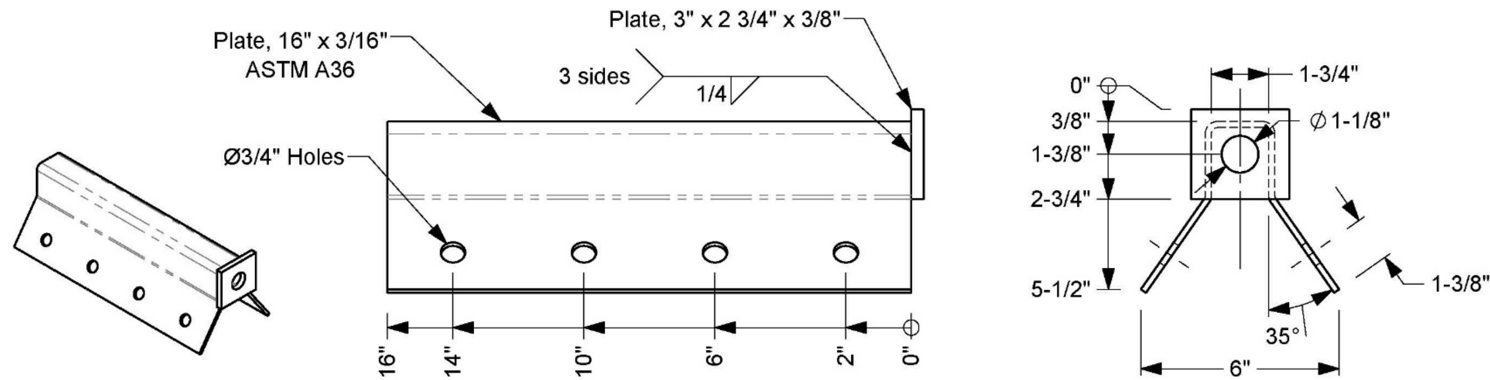
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

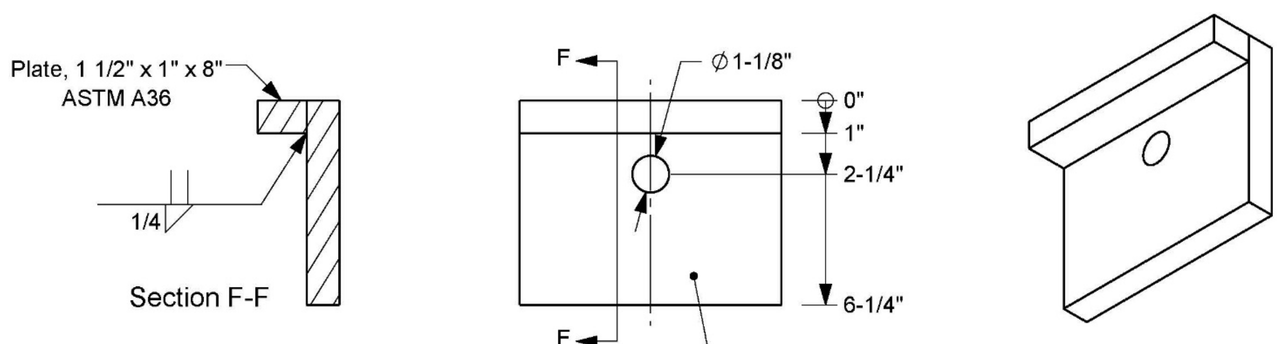
Project # Terminal | 2022-11-10

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


Strut Parts
R3/16"
6"
3"
1/8"
Section D-D
Scale 1 : 5
66-1/2"
64-3/8"
2-1/8"
0"
D
D
Ø1"
1-1/2"
Strut
10 gauge
ASTM A36
R1/4"
5-1/4"
7"
1" X 2-3/4" THRU ALL
2-3/8"
1"
Section E-E
Scale 1 : 5
E
E
2"
Ø9/16"
1"
Strut Bracket
Plate, 2" x 1/4"
ASTM A36 - Scale 1:5
7"
4-1/2"
2-1/2"
0"
1-1/2"
Ø9/16"
Strut Spacer
Plate, 2 3/4" x 1/2"
ASTM A36 - Scale 1:5
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal
2022-11-10
Drawn by GES
Scale 1:10
Sheet 4 of 6 Strut Parts

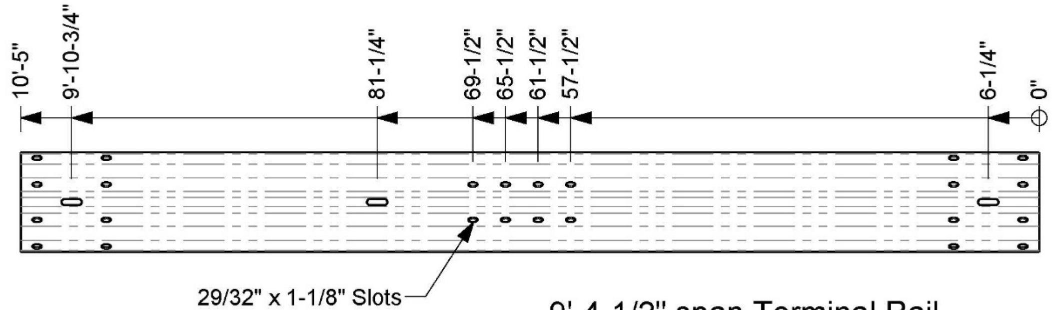


Guardrail Anchor Bracket



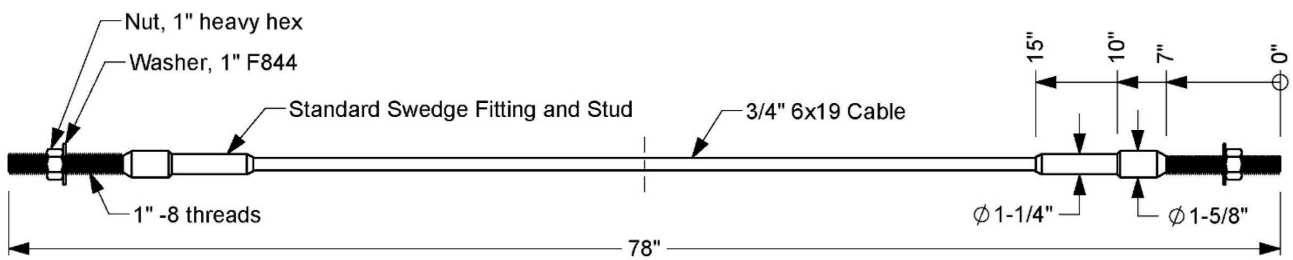
Bearing Plate

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2022-11-10
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A



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

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

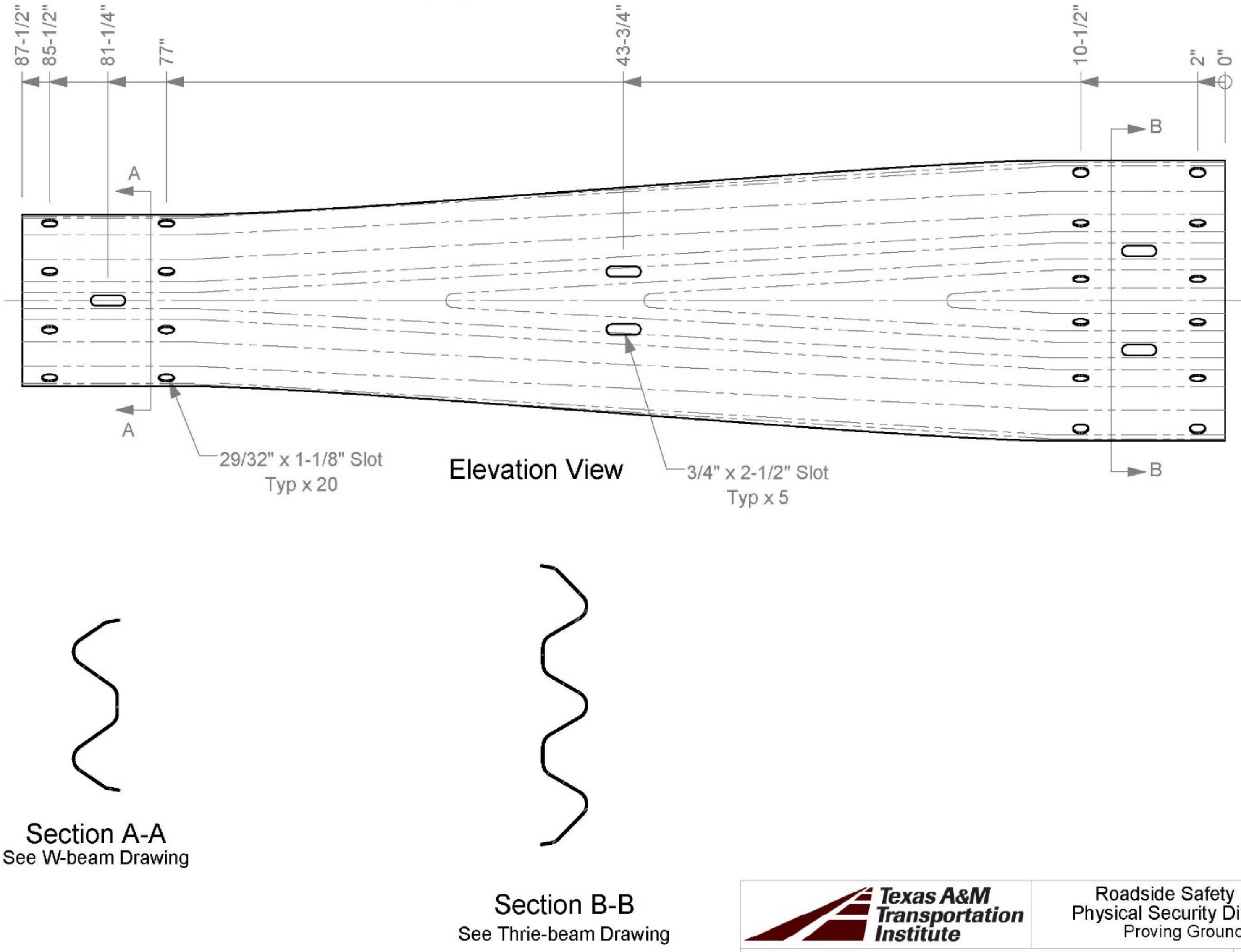


Anchor Cable Assembly

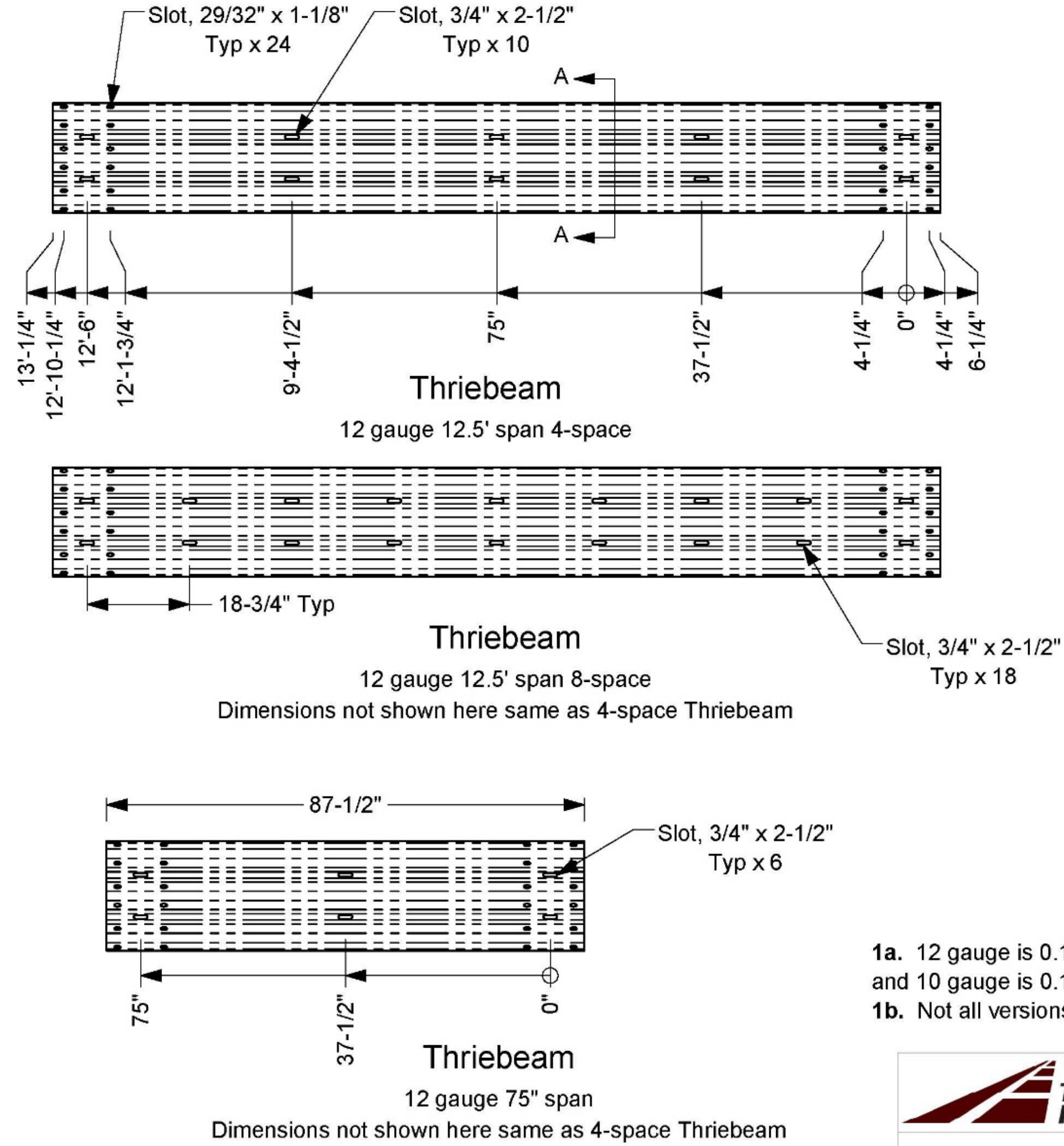
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal			2022-11-10
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B	

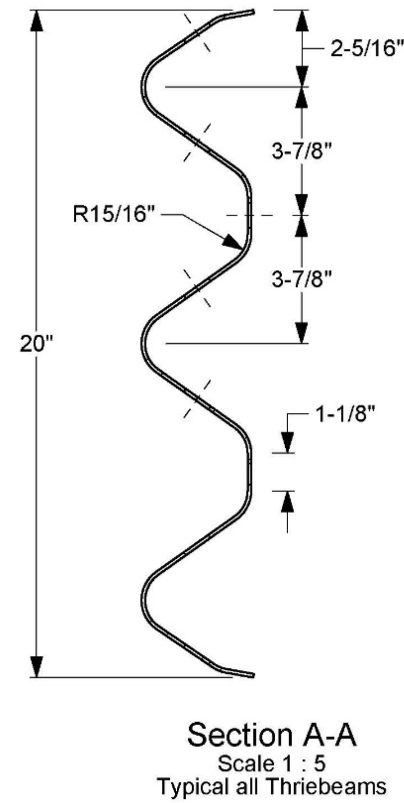
W- to Thrie-Beam, symmetric

10 gauge



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Symmetric W- to Thre-beam Transition			2020-10-13
Drawn by GES	Scale 1:10	Sheet 1 of 1	



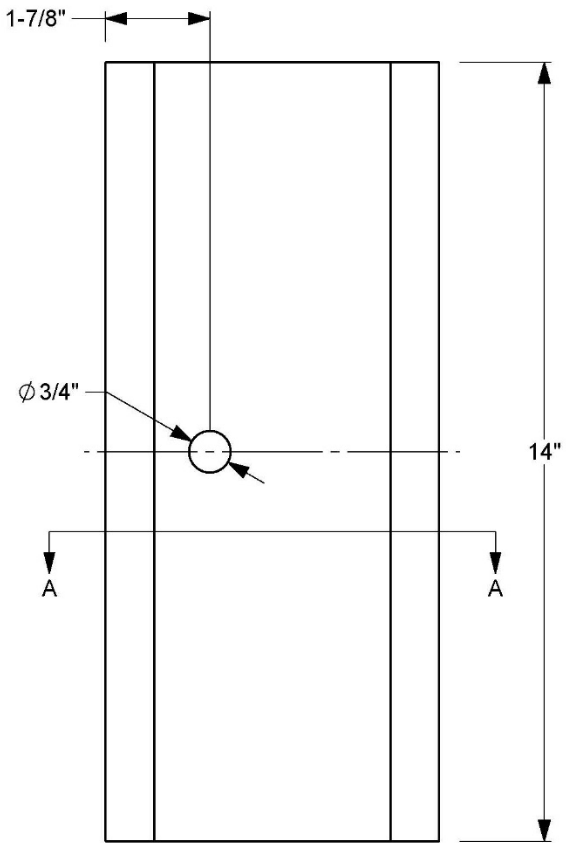


1a. 12 gauge is 0.1046" before galvanizing and 0.1084" after, and 10 gauge is 0.1345" before galvanizing and 0.1382" after.
1b. Not all versions shown here used in all installations.

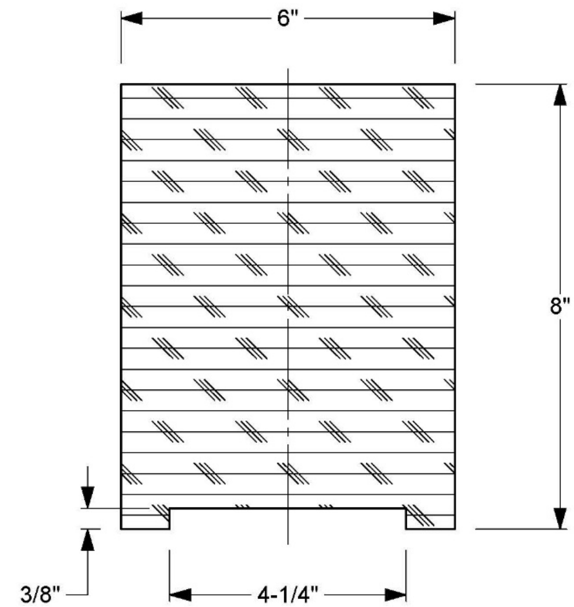
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Thrie-beam			2022-07-18
Drawn by GES	Scale 1:30	Sheet 1 of 1	

Timber Blockout for W-section Post

All dimensions except hole diameter are nominal



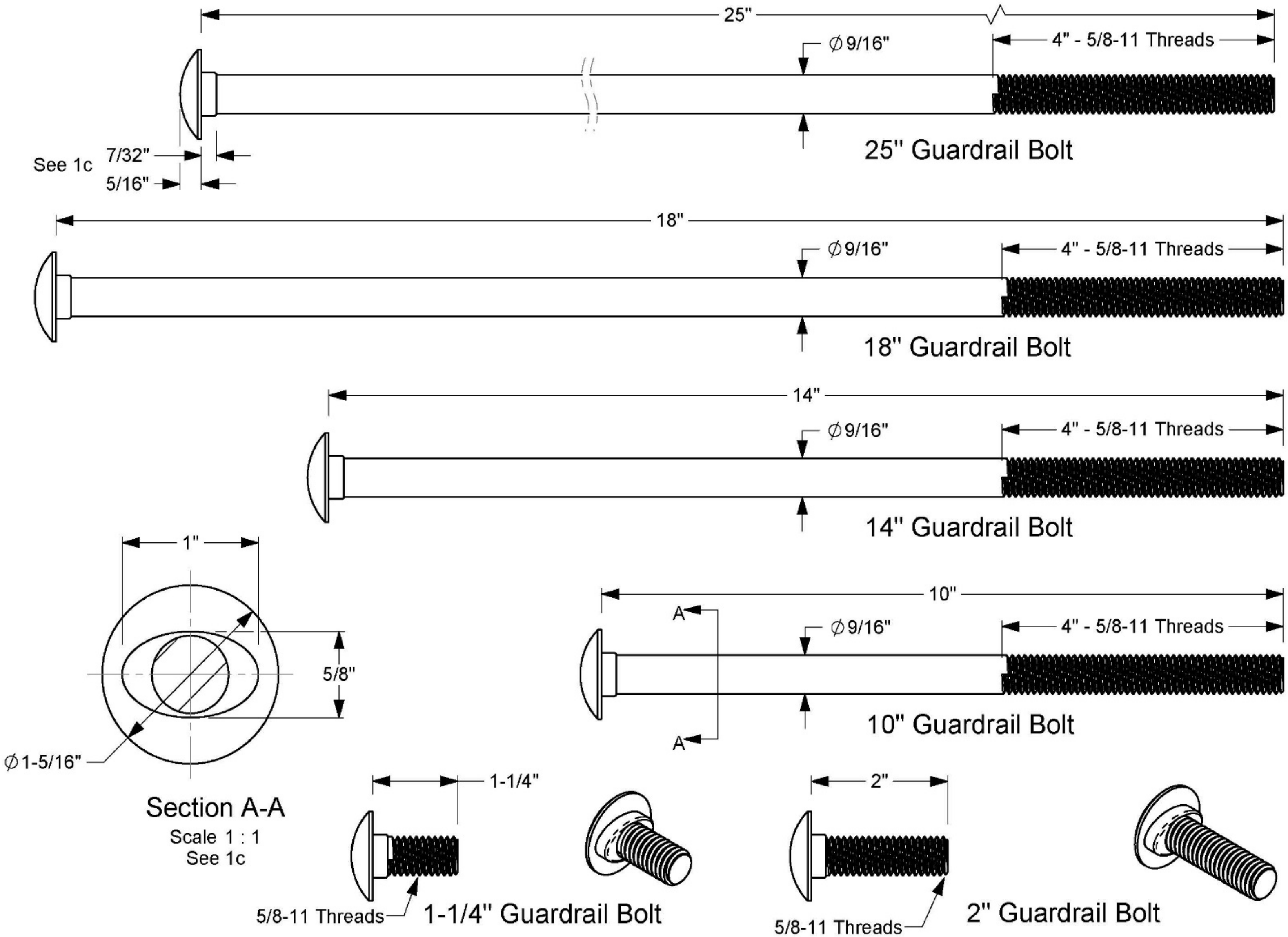
Elevation View



Section A-A

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

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Timber Blockout, for W-section Post		2022-12-16
Drawn by GES	Scale 1:3	Sheet 1 of 1



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

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

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

Certified Analysis

VALTIR

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

Customer: TEXAS A&M TRANSPORTATION INSTI
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Order Number: 1354934 Prod Ln Grp: 0-OE2.0
Customer PO: 617771
BOL Number: 90213 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 2/15/23

Project: STOCK

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn
17	211G	T12/12'6/3'1.5/S				F10623												
			M-180	A		284571	64,233	82,511	23.3	0.190	0.730	0.010	0.002	0.020	0.100	0.000	0.060	0.002
			M-180	A		284573	63,865	82,865	24.7	0.200	0.740	0.009	0.002	0.010	0.100	0.000	0.060	0.001
			M-180	A		284575	63,029	81,435	23.2	0.019	0.730	0.009	0.002	0.010	0.100	0.000	0.060	0.002
			M-180	A		284594	62,126	80,601	24.9	0.190	0.730	0.006	0.002	0.002	0.080	0.001	0.040	0.002
	211G		RHC			L32921												
			M-180	A		257708	62,118	79,701	25.3	0.190	0.730	0.012	0.003	0.010	0.100	0.000	0.060	0.000
			M-180	A		257709	60,995	78,200	24.6	0.190	0.720	0.011	0.003	0.020	0.080	0.000	0.060	0.002
			M-180	A		258791	63,229	80,751	23.4	0.190	0.720	0.013	0.003	0.020	0.120	0.000	0.120	0.001
			M-180	A		260785	63,219	79,560	23.1	0.190	0.720	0.010	0.004	0.010	0.120	0.000	0.070	0.013
			M-180	B		261611	63,795	82,065	24.5	0.190	0.720	0.011	0.003	0.010	0.120	0.000	0.080	0.000
2	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	282521	63,263	82,882	23.7	0.180	0.730	0.012	0.004	0.010	0.100	0.000	0.060	0.001
175	3340G	5/8" GR HEX NUT	FAST			22-35-012												
150	3360G	5/8"X1.25" GR BOLT	A307-3360G			A15007-7												
28	3500G	5/8"X10" GR BOLT A307	A307-3500G			A44446-1												
28	4076B	WD BLK RTD 6X8X14	WOOD			4850												
34	24938G	9'0 POST/8.5#/DR	A-36			55081013	58,992	77,056	23.7	0.100	0.093	0.013	0.028	0.200	0.290	0.017	0.140	0.001

Upon delivery, all materials subject to Valtir, LLC Storage Stain Policy QMS-LQ-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.

Certified Analysis

VALTIR

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

Customer: TEXAS A&M TRANSPORTATION INSTI
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Order Number: 1354934 Prod Ln Grp: 0-OE2.0
Customer PO: 617771 As of: 2/15/23
BOL Number: 90213 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

Project: STOCK

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 15th day of February, 2023 .

Notary Public:
Commission Expires: / /

Angela Ruth Humphrey
My Commission Expires
6/24/2026
Notary ID 133827723

Certified By: Valtir, LLC
Quality Assurance

APPENDIX C. *MASH* TEST 3-10 (CRASH TEST 617771-01-1)

C.1. VEHICLE PROPERTIES AND INFORMATION

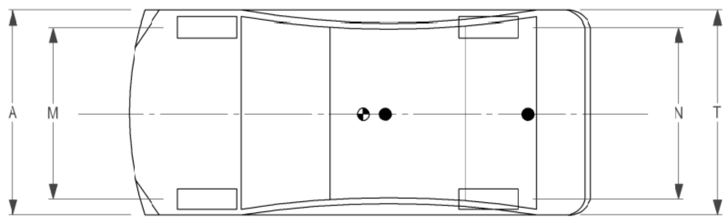
Date: 2023-04-11 Test No.: 617771-01-1 VIN No.: 3N1CN7AP6JL882964

Year: 2018 Make: Nissan Model: Versa

Tire Inflation Pressure: 36 PSI Odometer: 73582 Tire Size: P185/65R15

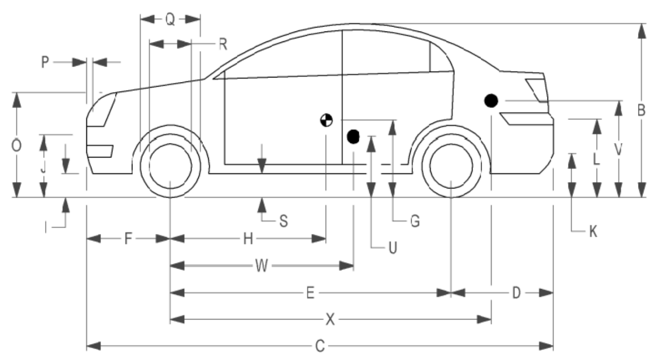
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.



NOTES: None

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



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

Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G	0.00	L	26.00	Q	24.00	V	21.25
C	175.40	H	41.50	M	58.30	R	16.25	W	41.50
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.50	O	30.50	T	64.50		

Wheel Center Ht Front 11.50 Wheel Center Ht Rear 11.50 W-H 0.00

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}	1428	1452	1537
Back	1687	M_{rear}	990	990	1070
Total	3389	M_{Total}	2418	2442	2607

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

Mass Distribution:
lb LF: 661 RF: 791 LR: 532 RR: 458

Figure C.1. Vehicle Properties for Test 617771-01-1.

Date:	2023-04-11	Test No.:	617771-01-1	VIN No.:	3N1CN7AP6JL882964
Year:	2018	Make:	Nissan	Model:	Versa

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FT BUMPER	13	5	50	-	-	-	-	-	-	+5
2	ABOVE FT BUMPER	13	8.5	47	-	-	-	-	-	-	49
	Measurements recorded										
	☑ **inches** **or** ☐ **mm**										

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

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

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

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

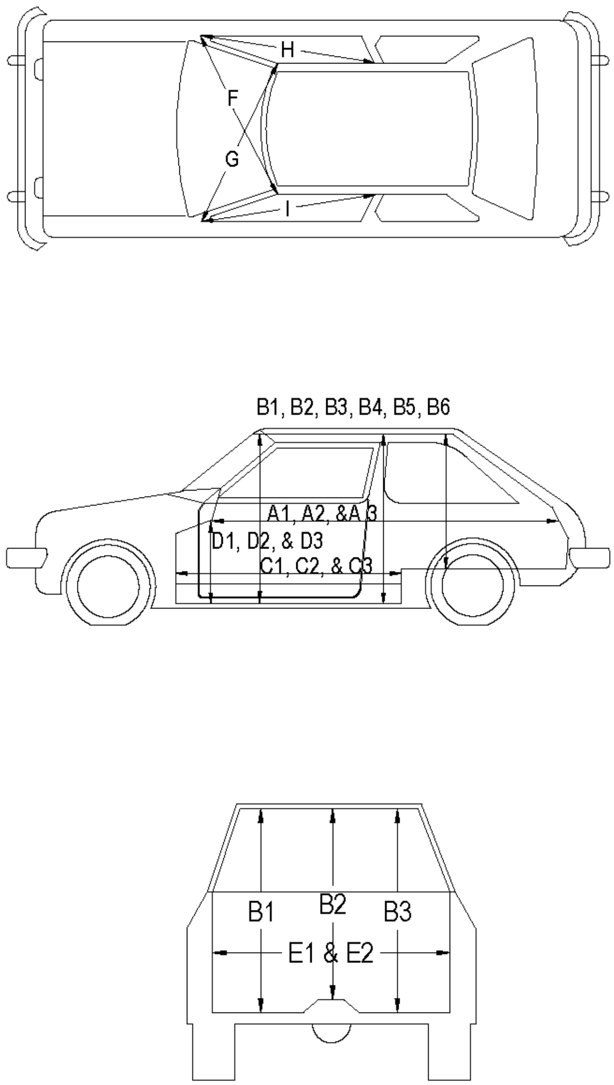
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Figure C.2. Exterior Crush Measurements for Test 617771-01-1.

Date: 2023-04-11 Test No.: 617771-01-1 VIN No.: 3N1CN7AP6JL882964

Year: 2018 Make: Nissan Model: Versa



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.50	67.50	0.00
A2	67.25	67.25	0.00
A3	67.75	67.75	0.00
B1	40.50	40.50	0.00
B2	39.00	39.00	0.00
B3	40.50	40.50	0.00
B4	36.25	36.25	0.00
B5	36.00	36.00	0.00
B6	36.25	36.25	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	24.25	-1.75
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	9.50	0.00
E1	51.50	51.50	0.00
E2	51.00	51.00	0.00
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	51.00	50.50	-0.50

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

Figure C.3. Occupant Compartment Measurements for Test 617771-01-1.

C.2. SEQUENTIAL PHOTOGRAPHS

(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s

Figure C.4. Sequential Photographs for Test 617771-01-1 (Overhead Views).


(a) 0.000 s

(b) 0.100 s


(c) 0.200 s

(d) 0.300 s


(e) 0.400 s

(f) 0.500 s


(g) 0.600 s

(h) 0.700 s

Figure C.5. Sequential Photographs for Test 617771-01-1 (Frontal Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

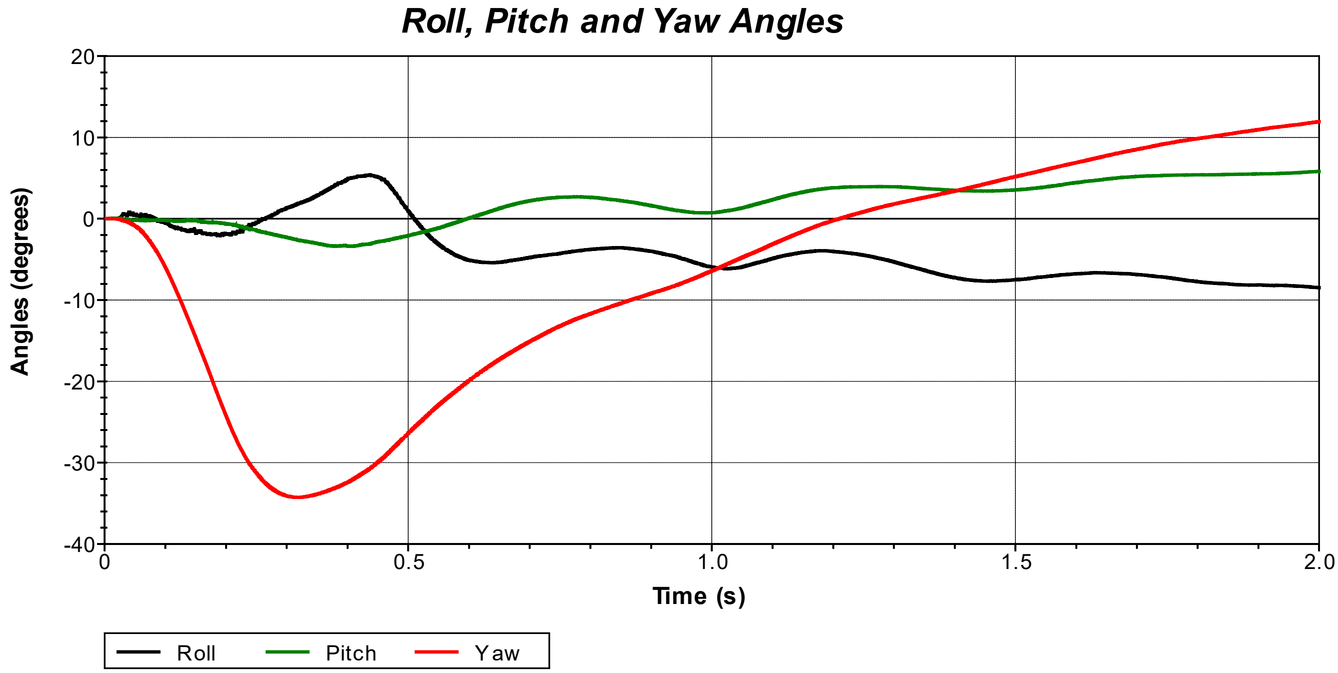
(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

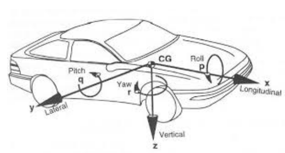
Figure C.6. Sequential Photographs for Test 617771-01-1 (Rear Views).

C.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 617771-01-1
Test Standard Test Number: *MASH* Test 3-10
Test Article: Guardrail System on 1:1 Slope
Test Vehicle: 2018 Nissan Versa
Inertial Mass: 2422 lbs
Gross Mass: 2607 lbs
Impact Speed: 62.8 mi/h
Impact Angle: 24.9°

Figure C.7. Vehicle Angular Displacements for Test 617771-01-1.

C.4. VEHICLE ACCELERATIONS

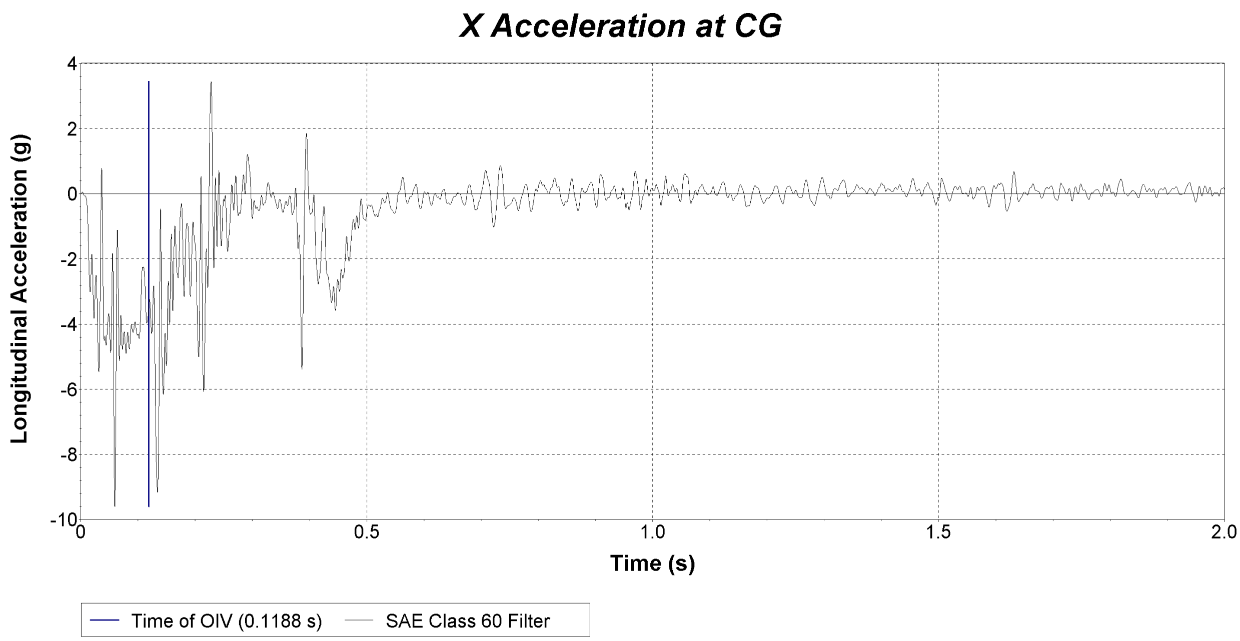


Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test 617771-01-1 (Accelerometer Located at Center of Gravity).

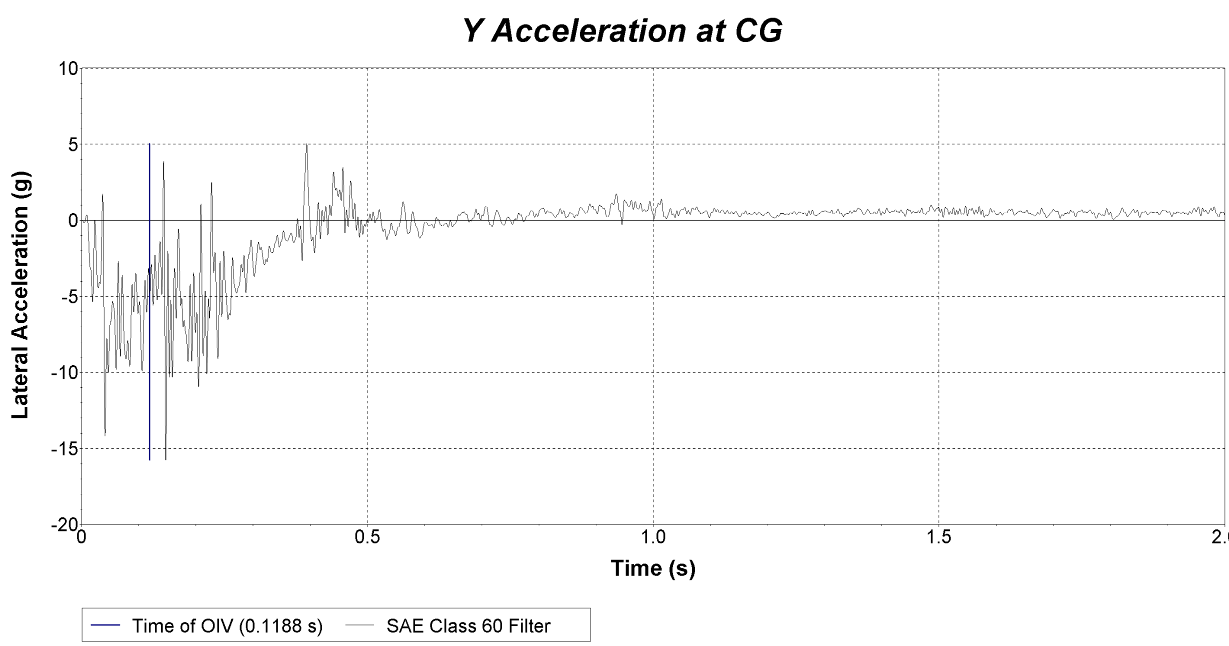


Figure C.9. Vehicle Lateral Accelerometer Trace for Test 617771-01-1 (Accelerometer Located at Center of Gravity).

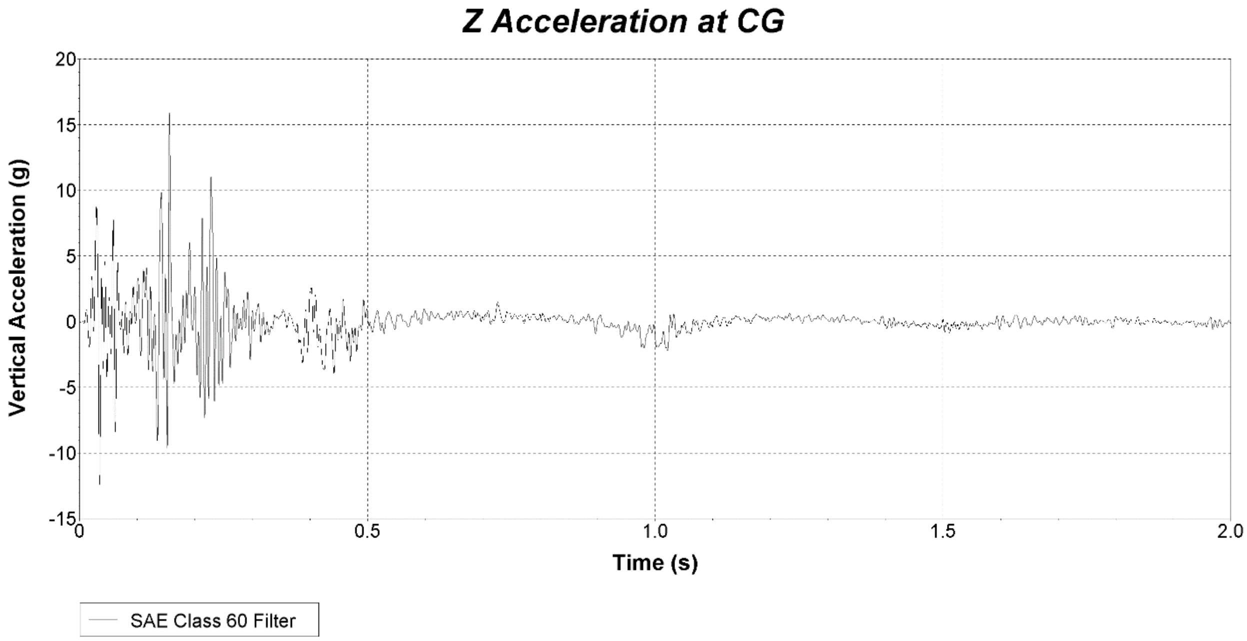


Figure C.10. Vehicle Vertical Accelerometer Trace for Test 617771-01-1 (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 3-11 (CRASH TEST 617771-01-2)

D.1. VEHICLE PROPERTIES AND INFORMATION

Texas A&M Transportation Institute Proving Ground, 3100 SH 47, Bldg 7091, Bryan, TX 77807 Texas A&M University, College Station, TX 77843, Phone 979-845-6375	LF-VPW:2270P Vehicle Parameters Worksheet for MASH 2270P	Doc. No. LF-VPW: 2270P	Revision Date: 2019-02-27
Laboratory Form	Revised by: B.L. Griffith Approved by: D. L. Kuhn	Revision: 8	Page: 1 of 1

The information contained in this document is confidential to TTI Proving Ground.

Vehicle Inventory Number: 1716

Date: 2023-04-25 Test No.: 617771-01-2 VIN No.: 1C6RR6FT2HS577184

Year: 2017 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 12730

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

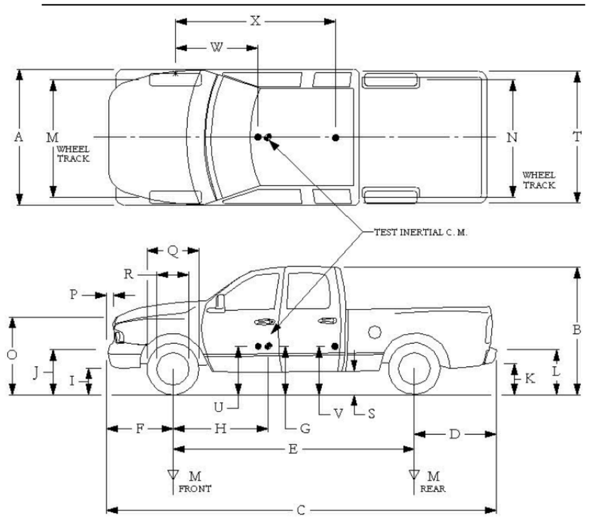
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

Dummy Data:
Type: 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	28.50	L	30.00	Q	30.50	V	30.25
C	227.50	H	62.04	M	68.50	R	18.00	W	62.00
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

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

GVWR Ratings:		Mass: lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2899	2807	2892
Back	3900	M_{rear}	2127	2220	2300
Total	6700	M_{Total}	5026	5027	5192

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

Mass Distribution:
lb LF: 1420 RF: 1387 LR: 1125 RR: 1095

Performed by: RK Date: 2023-04-25

Figure D.1. Vehicle Properties for Test 617771-01-2.

Texas A&M Transportation Institute Proving Ground, 3100 SH 47, Bldg 7091, Bryan, TX 77807 Texas A&M University, College Station, TX 77843, Phone 979-845-6375	LF-VCM: Vehicle Crush Measurement Sheet	Doc. No. LF-VCM	Revision Date: 2018-07-27
Laboratory Form	Revised by: W. L. Menges Approved by: D. L. Kuhn	Revision: 5	Page: 1 of 1

The information contained in this document is confidential to TTI Proving Ground.

Vehicle Inventory Number: 1716

Date: 2023-04-25 Test No.: 617771-01-2 VIN No.: 1C6RR6FT2HS577184

Year: 2017 Make: RAM Model: 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	AT FT BUMPER	12	4	46	-	-	-	-	-	-	+8
2	ABOVE FT BUMPER	12	8	47	-	-	-	-	-	-	49
	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.

Performed by: RK Date: 2023-04-25

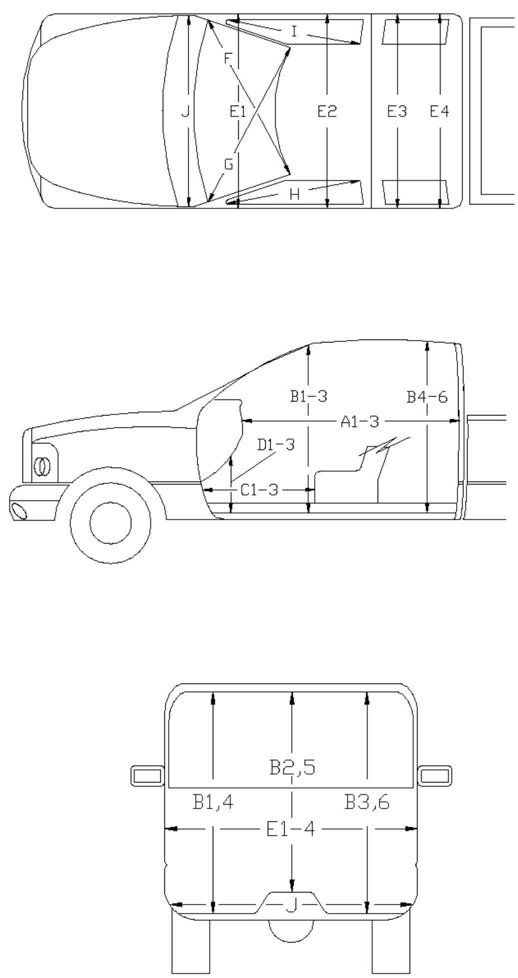
Figure D.2. Exterior Crush Measurements for Test 617771-01-2.

Texas A&M Transportation Institute Proving Ground 3100 SH 47, Bldg 7091 Bryan, TX 77807 Texas A&M University College Station, TX 77843 Phone 979-845-6375	**LF-OCD:2270P Occupant Compartment Deformation for MASH 2270P**	Doc. No. LF-OCD: 2270P	Revision Date: 2018-07-27
Laboratory Form	Revised by: W. L. Menges Approved by: D. L. Kuhn	Revision: 5	Page: 1 of 1

Vehicle Inventory Number: 1716

Date: 2023-04-25 Test No.: 617771-01-2 VIN No.: 1C6RR6FT2HS577184

Year: 2017 Make: RAM Model: 1500



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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

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

Performed by: RK Date: 2023-04-25

Figure D.3. Occupant Compartment Measurements for Test 617771-01-2.

D.2. SEQUENTIAL PHOTOGRAPHS

(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

Figure D.4. Sequential Photographs for Test 617771-01-2 (Overhead Views).

(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

Figure D.5. Sequential Photographs for Test 617771-01-2 (Frontal Views).


(a) 0.000 s


(b) 0.100 s


(c) 0.200 s


(d) 0.300 s


(e) 0.400 s

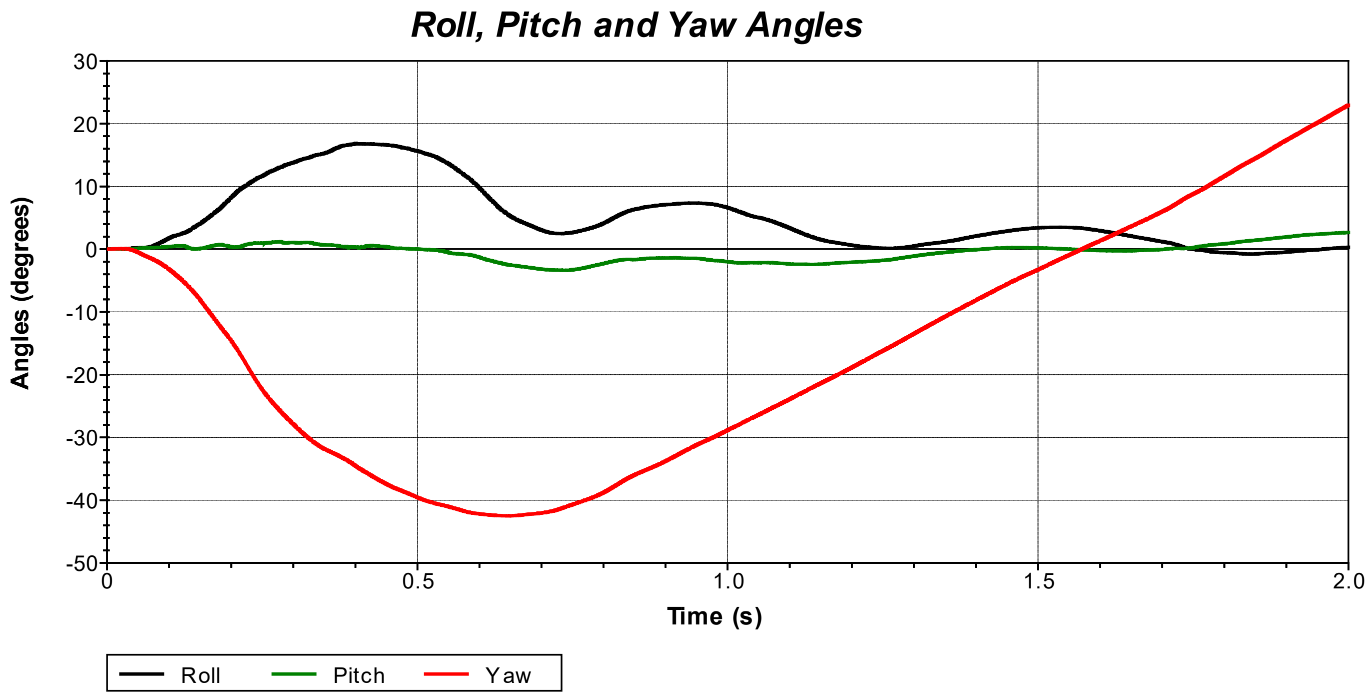

(f) 0.500 s


(g) 0.600 s


(h) 0.700 s

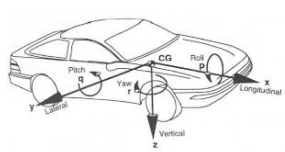
Figure D.6. Sequential Photographs for Test 617771-01-2 (Rear Views).

D.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 617771-01-2
Test Standard Test Number: *MASH* Test 3-11
Test Article: Guardrail System on 1:1 Slope
Test Vehicle: 2017 RAM 1500
Inertial Mass: 5027 lbs
Gross Mass: 5192 lbs
Impact Speed: 62.2
Impact Angle: 25.2°

Figure D.7. Vehicle Angular Displacements for Test 617771-01-2.

D.4. VEHICLE ACCELERATIONS

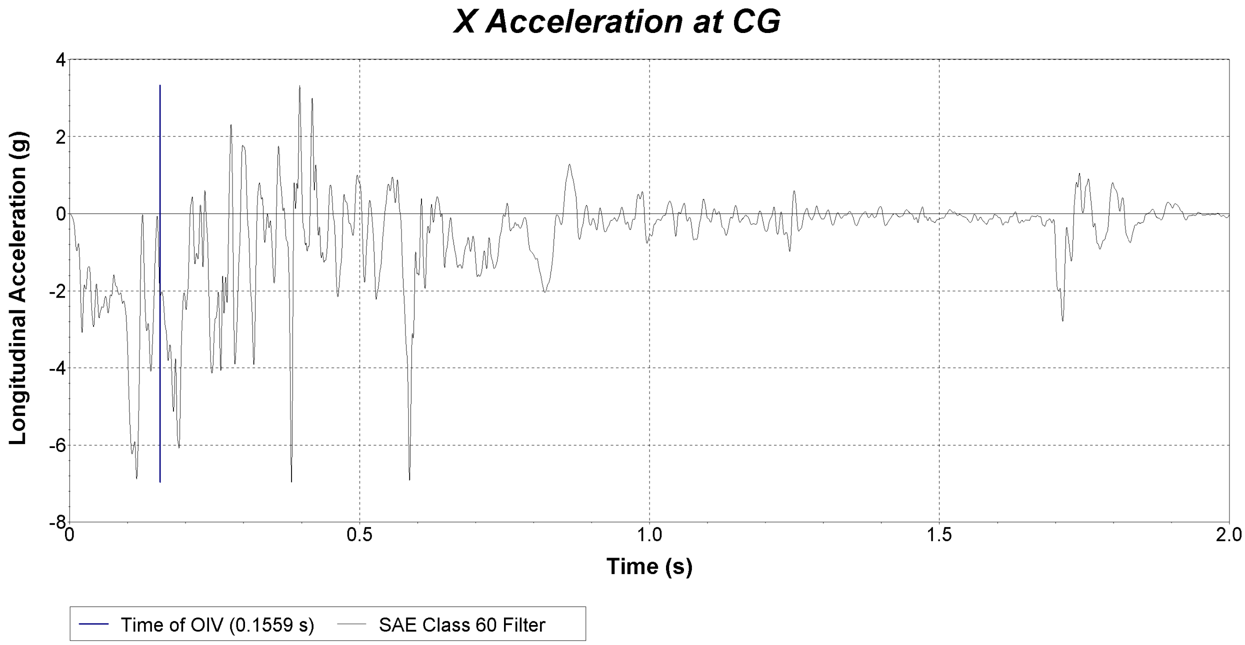


Figure D.8. Vehicle Longitudinal Accelerometer Trace for Test 617771-01-2 (Accelerometer Located at Center of Gravity).

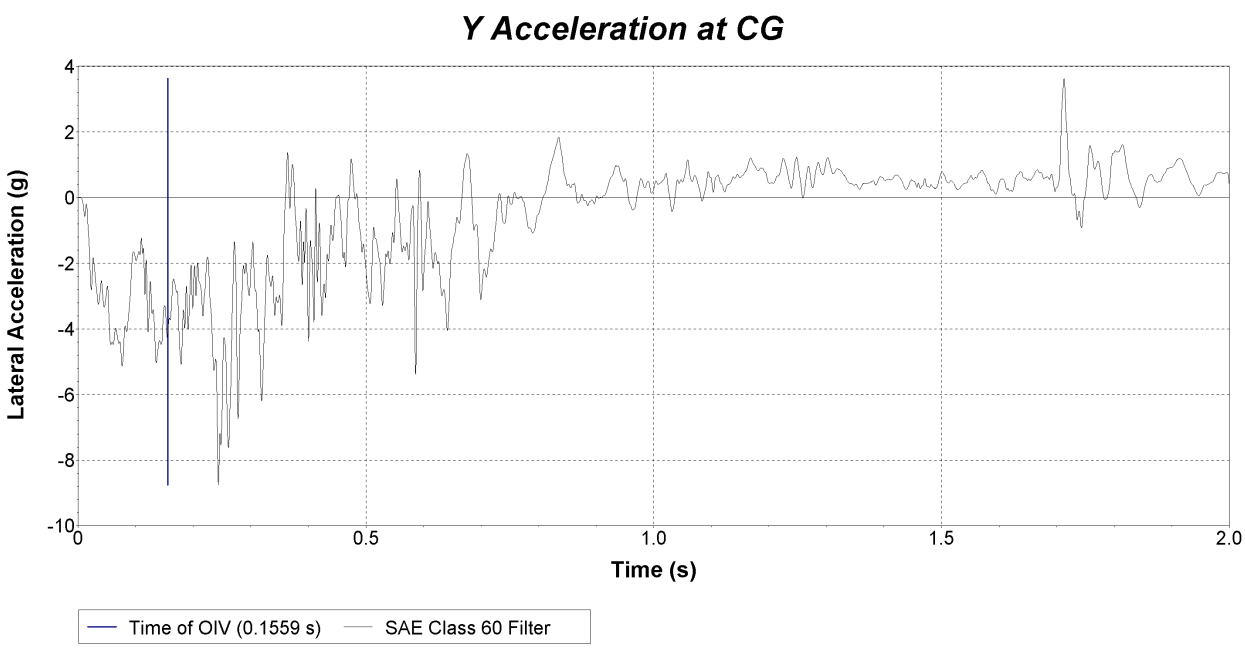


Figure D.9. Vehicle Lateral Accelerometer Trace for Test 617771-01-2 (Accelerometer Located at Center of Gravity).

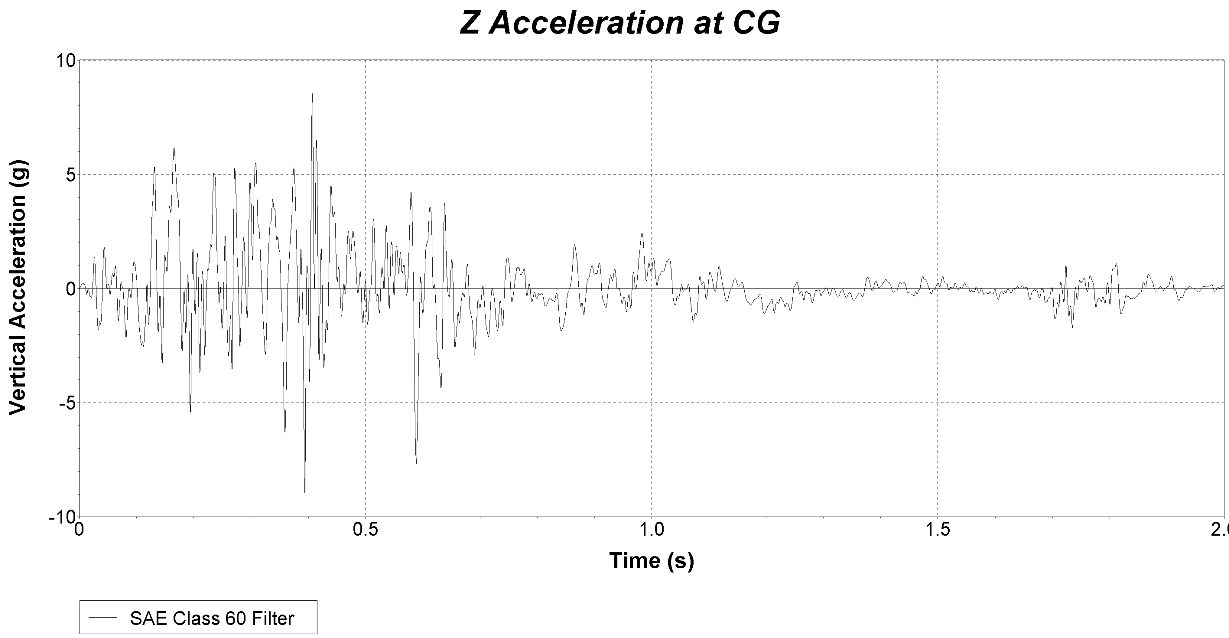


Figure D.10. Vehicle Vertical Accelerometer Trace for Test 617771-01-2