Texas A&M Transportation Institute
Proving Ground

Test Report No. 619441-01 09&10

DESIGN AND EVALUATION OF ASPHALT VEGETATION CONTROL TREATMENT FOR STEEL-POST W-BEAM GUARDRAIL SYSTEM

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16. Abstract

This report presents the design and development of an asphalt vegetation control treatment that allows installation of a steel-post W-beam guardrail system with posts installed directly in asphalt. The asphalt vegetation control design was developed using a series of bogie vehicle impact tests that evaluated the guardrail post's performance in various asphalt thicknesses, at various offsets from the edge of the asphalt. The force-deflection response of the posts installed in asphalt was compared to the response of the posts installed directly in soil. Using these comparisons, a design of the asphalt vegetation control treatment was recommended for full-scale crash testing of the steel-post W-beam guardrail system.

Testing of the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment was performed 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 tests were performed in accordance with *MASH* Test Level 3 (TL-3), which involves performing *MASH* Test 3-10 and *MASH* Test 3-11.

This report provides details on the Steel-Post W-beam Guardrail in Asphalt Vegetation Control Treatment, the crash tests and results, and the performance assessment of the guardrail for *MASH* TL-3 evaluation criteria for longitudinal barriers. The Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment met the performance criteria for *MASH* TL-3 for longitudinal barriers.

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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

Vegetation growth around the posts of the W-beam guardrail installed in soil results in hiding the guardrail from the view of the traffic. Furthermore, uncontrolled vegetation growth results in poor aesthetics of the roadside. It is common for transportation agencies to periodically remove the vegetation growth; however, this requires continuous maintenance of the guardrail system, which results in increased maintenance personnel exposure to adjacent traffic, potential traffic delays due to lane closures, and increased life-cycle cost for installing and maintaining the guardrail system.

Installing the guardrail post directly in a concrete or asphalt pavement (instead of soil) changes the post deflection behavior of the guardrail. The pavement acts to constrict the lateral deflection of the posts at the ground level, resulting in premature bending of the posts. This is known to cause problems with proper rail release from the posts, and possibly resulting in vehicle override or underride, rail rupture, or vehicle pocketing, all of which can lead to failed performance of the guardrail. Past testing has demonstrated the failure of the W-beam guardrail for such conditions (*2*).

To allow the posts to deflect as needed for proper functioning of the guardrail, a concrete mow-strip design for vegetation control is available for the W-beam guardrail system (*3*). This design requires constructing a 4-inch thick strip of concrete pavement with cutouts at guardrail post locations. Once the guardrail is installed, the cutouts are backfilled with very low-strength grout. On vehicle impact, the low-strength grout allows the posts to deflect as needed for proper functioning of the guardrail. Installing the concrete mow-strip with cutouts, however, is not ideal since it requires placing forms for the cutouts. Furthermore, the low-strength backfill grout is sometimes hard to achieve in small quantities and it is difficult to inspect it for field installations.

There is a need to install the W-beam guardrail system in asphalt without having to construct a concrete mow-strip to control vegetation. Currently there is no design solution available for vegetation control that would allow the guardrail to be installed by directly embedding the posts in asphalt.

In this project, the researchers designed and developed an asphalt vegetation control treatment that allows installation of a steel-post W-beam guardrail system with posts installed directly in asphalt. The asphalt vegetation control design was developed using a series of bogie vehicle impact tests that evaluated the guardrail post's performance in various asphalt thicknesses, at various offsets from the edge of the asphalt. The force-deflection response of the posts installed in asphalt were compared to the response of the posts installed directly in soil. Using these comparisons, a design of the asphalt vegetation control treatment was recommended for full-scale crash testing of the steel-post W-beam guardrail system.

Testing of the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment was performed 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 tests were performed in accordance with *MASH* Test Level 3 (TL-3), which involves performing *MASH* Test 3-10 and *MASH* Test 3-11. Chapter 2 of this report presents the bogie testing and the design recommendations for full-scale testing. Details of the test installations and full-scale crash testing are presented in Chapters 3 through 8.

Chapter 2. BOGIE VEHICLE TESTING AND DESIGN*

2.1. INTRODUCTION

The objective of the bogie testing described herein was to compare the impact performance of steel guardrail posts embedded in nominal 2-inch and 3-inch asphalt with varying spacing from the non-impact side of the post to the edge of the asphalt on the non-impact side. There were also two posts embedded in Type D grade 1 crushed concrete which served as control tests representing standard guardrail post installed in compacted soil. A total of 8 tests were performed at a target impact speed of 17 mi/h. Table 2.1 shows the test matrix.

Table 2.1. Bogie Test Matrix.

Test Number	Width of Asphalt on Non-Impact Side of Post	Post Embedment
619441-01-1	N/A	In Soil
619441-01-2	6 inches	2-inch Asphalt
619441-01-3	10 inches	2-inch Asphalt
619441-01-4	8 inches	2-inch Asphalt
619441-01-5	9 inches	3-inch Asphalt
619441-01-6	6 inches	3-inch Asphalt
619441-01-7	12 inches	2-inch Asphalt
619441-01-8	N/A	In Soil

2.2. TEST ARTICLE AND INSTALLATION DETAILS

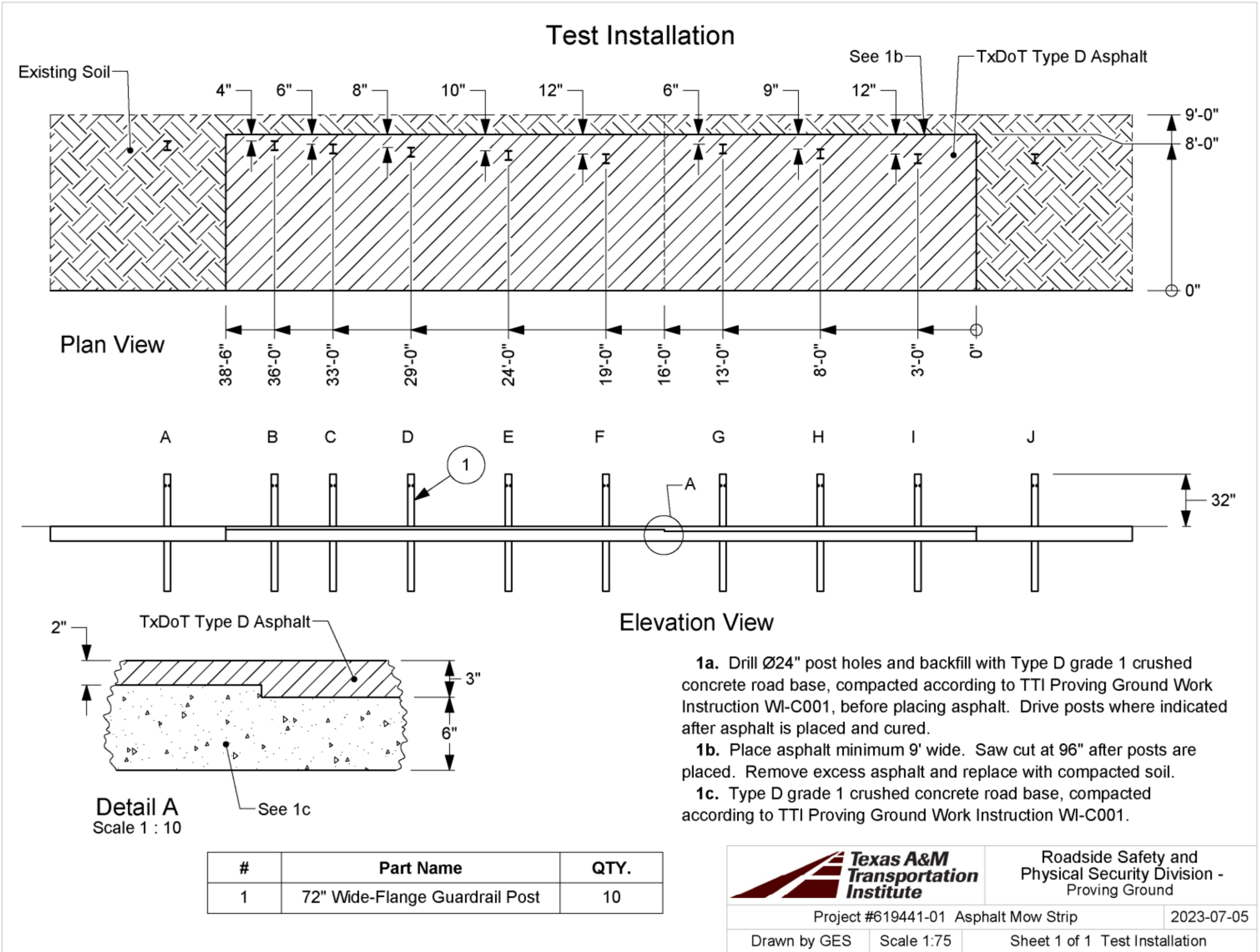
The steel posts used in the bogie testing were W6x8.5 x 72-inch long Guardrail Posts. The drilled holes into which the posts were installed were backfilled with compacted crushed concrete road base. The asphalt pad was 38 feet and 6 inches long and 8 feet wide. The first and last posts (A and J) were embedded in soil without asphalt, posts B through F were embedded in nominally 2-inch thick asphalt and posts G through I were embedded in nominally 3-inch thick asphalt.

Posts A and J were placed in drilled holes, which were then backfilled with compacted crushed concrete road base. Posts B through I were installed by impacting the posts with a post driver after the asphalt pad was constructed over the compacted crushed concrete road base. All posts had above grade height of 32 inches. Figure 2.1 presents overall information on the posts and asphalt for the bogie testing.

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

2.3. SOIL CONDITIONS

The posts were installed in standard soil meeting Type D grade 1 of AASHTO standard specification M147-65(2004) “Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses.”



#	Part Name	QTY.
1	72" Wide-Flange Guardrail Post	10

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Figure 2.1. Details of Direct Embedded Posts.

2.4. WEATHER CONDITIONS

Test Numbers	619441-01-1, 2, 3, & 4	619441-01-5&6	619441-01-7&8
Date of Test	2023-07-13	2023-07-19	2023-07-20
Wind Speed (mi/h)	12 – 15	12 – 13	8 – 9
Wind Direction (deg)	116 – 152	130 – 137	130 – 148
Temperature (°F)	80 – 89	83 – 88	84 – 89
Relative Humidity (%)	45 – 69	66 – 82	65 – 81
Vehicle Traveling (deg)	80	80	80

2.5. BOGIE TEST VEHICLE

Figure 2.2 and Figure 2.3 show the bogie test vehicle used for the impact tests. In tests 616441-01-1, 2, 3, and 4, the bogie's test inertia weight was 4914 lb, and its gross static weight was 4914 lb. In tests 616441-01-5, 6, 7, and 8, the bogie's test inertia weight was 4964 lb, and its gross static weight was 4964 lb. The bogie test vehicle was towed into the test installations using a steel cable guidance and reverse tow system. A steel cable for guiding the bogie test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the bogie test vehicle. A 1:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the bogie test vehicle was released and travelled unrestrained. The bogie remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site, after which the brakes were activated, if needed, to bring the bogie test vehicle to a safe and controlled stop.

Figure 2.2. Post/Bogie Test Vehicle Geometrics for Test No. 619441-01-1.

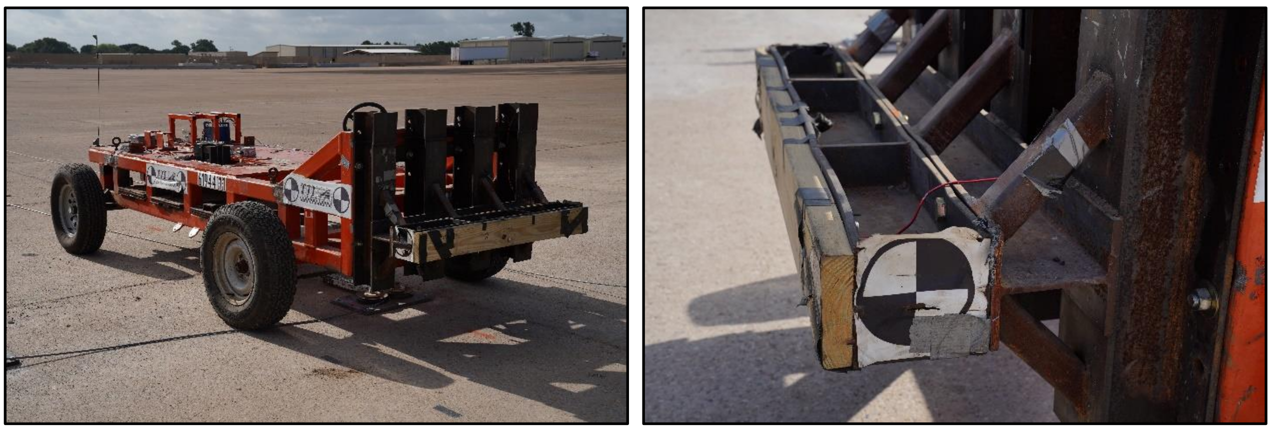

Figure 2.3. Bogie Test Vehicle before Test No. 619441-01-1.

2.6. EMBEDDED POSTS IN SOIL

2.6.1. Bogie Test No. 619441-01-1

The bogie impacted the post embedded in soil at 90° while traveling at a speed of 16.9 mi/h. The post was pushed toward the non-impact side and was leaning 31.6° toward the non-impact side. Figure 2.4 and Figure 2.5 show the post and bogie after the test, respectively.

Figure 2.4. Soil Embedded Post after Test No. 619441-01-1.

Figure 2.5. Soil Embedded Test Vehicle after Test No. 619441-01-1.

2.6.2. Bogie Test No. 619441-01-8

The bogie impacted the post embedded in soil at 90° while traveling at a speed of 17.0 mi/h. The post was pushed toward the non-impact side and was leaning 32.2° toward the non-impact side. Figure 2.6 and Figure 2.7 show the post and bogie, respectively, after the test.

Figure 2.6. Soil Embedded Post after Test No. 619441-01-8.

Figure 2.7. Bogie Test Vehicle after Test No. 619441-01-8.

2.7. EMBEDDED POSTS IN 2” ASPHALT

2.7.1. Bogie Test No. 619441-2

This test was performed with post embedded in asphalt with a 6-inch offset from the non-impact side of the asphalt pad. The bogie impacted the post at 90° while traveling at a speed of 17.2 mi/h. The post was pushed toward the non-impact side and was leaning 26.9° toward the non-impact side. Figure 2.8 and Figure 2.9 show the post and bogie, respectively, after the test.

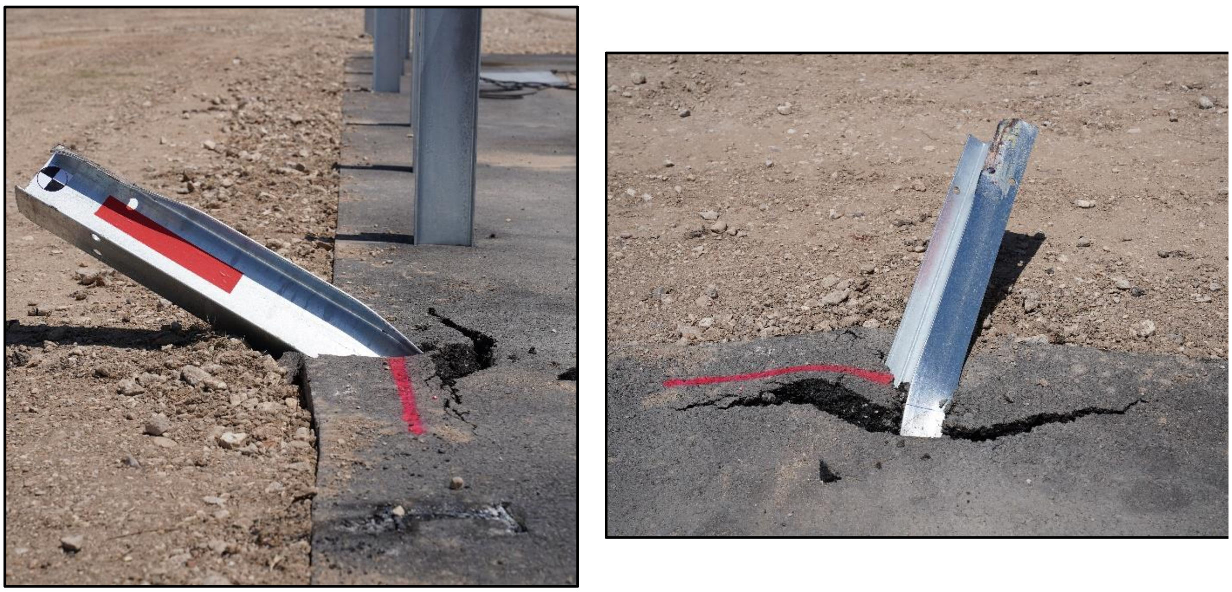

Figure 2.8. Post after Test No. 619441-01-2.

Figure 2.9. Bogie Test Vehicle after Test No. 619441-01-2.

2.7.2. Bogie Test No. 619441-3

This test was performed with post embedded in asphalt with a 10-inch offset from the non-impact side of the asphalt pad. The bogie impacted the post at 90° while traveling at a speed of 17.6 mi/h. The post was pushed toward the non-impact side and was leaning 27.3° toward the non-impact side. Figure 2.10 and Figure 2.11 show the post and bogie, respectively, after the test.

Figure 2.10. Post after Test No. 619441-01-3.

Figure 2.11. Bogie Test Vehicle after Test No. 619441-01-3.

2.7.3. Bogie Test No. 619441-01-4

This test was performed with post embedded in asphalt with an 8-inch offset from the non-impact side of the asphalt pad. The bogie impacted the post at 90° while traveling at a speed of 17.8 mi/h. The post was pushed toward the non-impact side and was leaning 27.9° toward the non-impact side. Figure 2.12 and Figure 2.13 show the post and bogie, respectively, after the test.

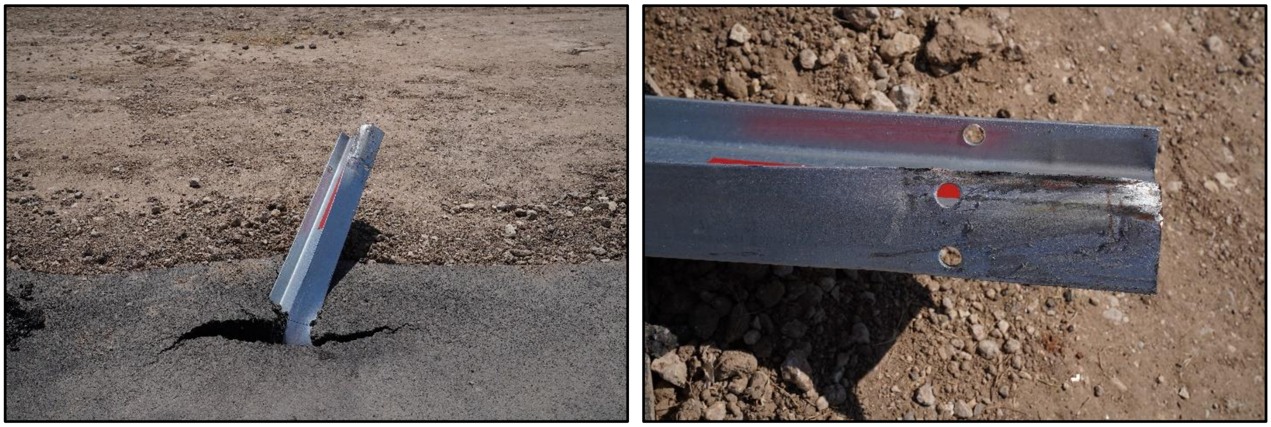

Figure 2.12. Post after Test No. 619441-01-4.

Figure 2.13. Bogie Test Vehicle after Test No. 619441-01-4.

2.7.4. Bogie Test No. 619441-01-7

This test was performed with post embedded in asphalt with a 12-inch offset from the non-impact side of the asphalt pad. The bogie impacted the post at 90° while traveling at a speed of 17.0 mi/h. The post was pushed toward the non-impact side and was leaning 29.9° toward the non-impact side. Figure 2.14 and Figure 2.15 show the post and bogie, respectively, after the test.

Figure 2.14. Post after Test No. 619441-01-7.

Figure 2.15. Bogie Test Vehicle after Test No. 619441-01-7.

2.8. EMBEDDED POSTS IN 3” ASPHALT

2.8.1. Bogie Test No. 619441-01-5

This test was performed with post embedded in asphalt with a 9-inch offset from the non-impact side of the asphalt pad. The bogie impacted the post at 90° while traveling at a speed of 17.2 mi/h. The post was pushed toward the non-impact side and was leaning 32.2° toward the non-impact side. Figure 2.16 and Figure 2.17 show the post and bogie, respectively, after the test.

 

Figure 2.16. Post in Steel Sleeve after Test No. 619441-01-5

 

Figure 2.17. Bogie Test Vehicle after Test No. 619441-01-5

2.8.2. Bogie Test No. 619441-01-6

This test was performed with post embedded in asphalt with a 6-inch offset from the non-impact side of the asphalt pad. The bogie impacted the post at 90° while traveling at a speed of 17.1 mi/h. The direct embedded post was pushed toward the non-impact side and was leaning 30.2° toward the non-impact side. Figure 2.18 and Figure 2.19 show the post and bogie, respectively, after the test.

Figure 2.18. Post after Test No. 619441-01-6.

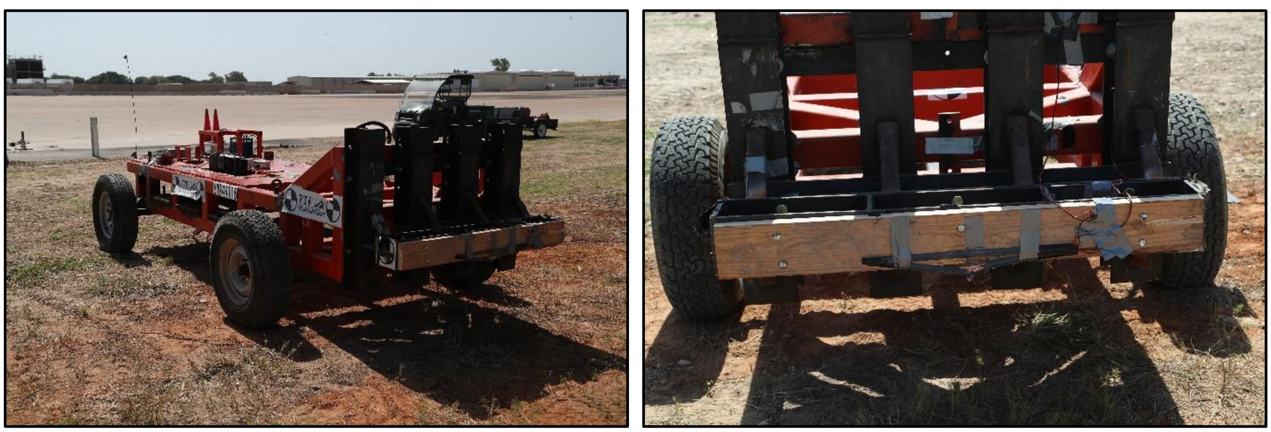

Figure 2.19. Bogie Test Vehicle after Test No. 619441-01-6.

2.9. POST RESPONSE COMPARISON AND DESIGN SELECTION

Acceleration data was collected from each of the eight bogie tests close to the center of gravity of the bogie vehicle. Using the bogie vehicle's mass, acceleration-time data in the test, and post deflection-time data from high-speed videos, the researchers determined the force-deflection response of the post for each bogie test. Figure 2.20 shows the 10-ms average force versus the deflection of the post for all bogie tests.

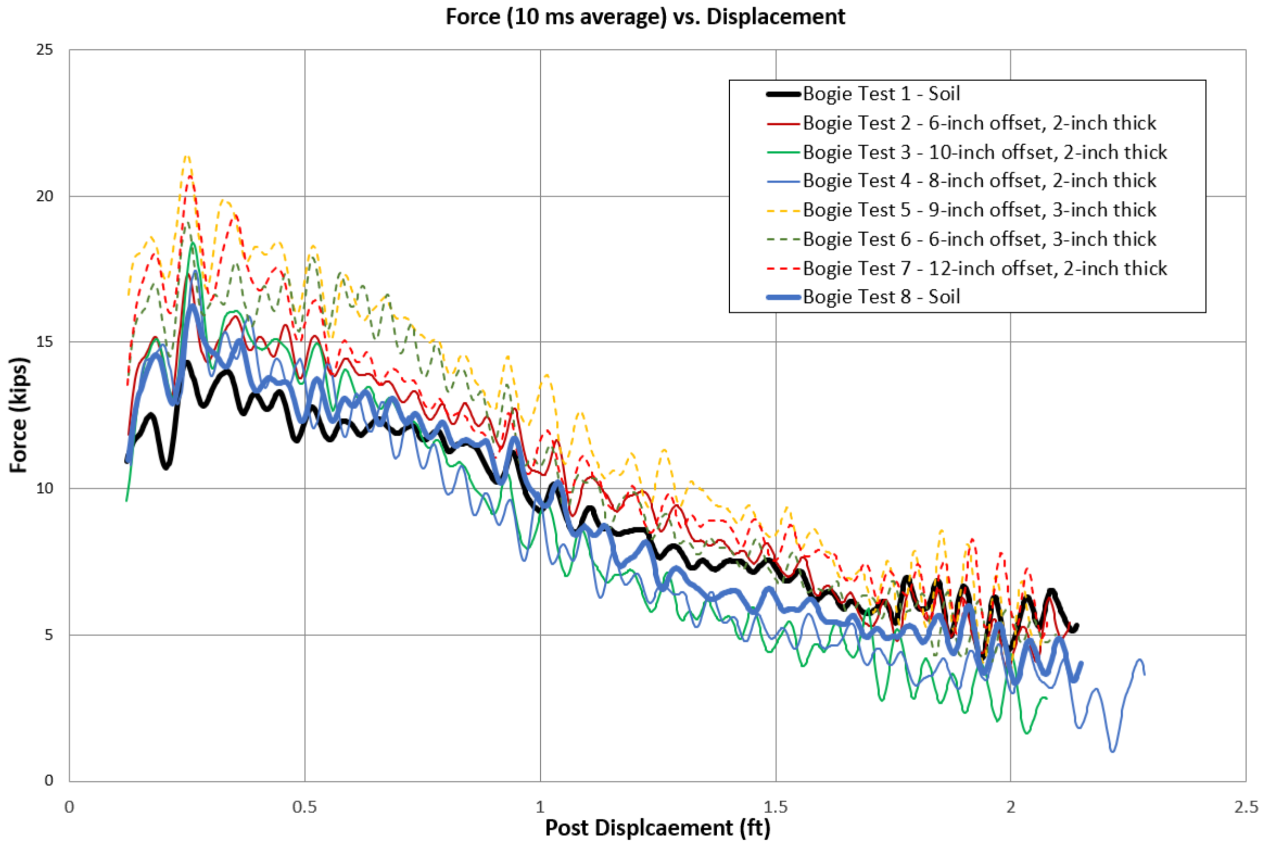

Figure 2.20. Force Versus Deflection Response of Posts for all Bogie Tests.

The force-deflection response is a good representation of how the post is expected to deflect in response to vehicle impact. By comparing the force-deflection response of the posts installed in asphalt to the posts installed only in soil, the researchers picked the asphalt thickness and offset from the edge of the asphalt pad that would allow the post to behave like the post installed in soil.

The force-deflection response of the posts installed in nominal 3-inch thick asphalt (Tests 619441-01-5 and 6) showed higher force levels compared to the two tests performed with post in soil only (Tests 616441-01-1 and 8). Similarly, the post installed in nominal 2-inch thick asphalt with a 12-inch offset (Test 619441-01-7) also showed higher force levels compared to the tests with post in soil only. These configurations were not considered further for the final design of the asphalt vegetation control treatment design.

The force-deflection response of the posts installed in 2-inch thick asphalt with 6-inch, 8-inch, and 10-inch offset from the edge of the asphalt showed similar peak force and overall force-deflection response compared to the posts installed in soil only. The researchers wanted to maximize the offset behind the post to allow more room for mowing operations adjacent to the asphalt. While the 10-inch offset would have allowed slightly greater offset of the post, it had higher peak force in comparison to the 6-inch and 8-inch offset designs, and in comparison to the posts installed in soil. For this reason, the researchers picked the 8-inch offset with the 2-inch thick asphalt as the design for full-scale crash testing.

This design was used to construct the test installation of the W-beam guardrail system and perform full-scale *MASH* crash testing, details of which are presented in the subsequent chapters of this report.

Chapter 3. SYSTEM DETAILS

3.1. TEST ARTICLE AND INSTALLATION DETAILS

The Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment was comprised of a W-beam guardrail system installed near the edge of an asphalt pad. The W-beam guardrail was 181 feet and 3 inches long, with 30 steel posts embedded 40 inches deep into the ground. The post holes were backfilled with Type D grade 1 crushed concrete road base. Posts 1-2 and 29-30 were reinforced by 10 feet and 5-inch long steel terminals with the middle 26 posts spaced at 75 inches apart. The top of the W-beam rail was 31 inches above grade, and it was supported by nominal 6x8 inch timber blockouts attached to wide-flange steel posts at each post location. Posts 9-21 were embedded in the crushed concrete road base with the top 2 inches comprised of Type D asphalt. These posts were driven into the asphalt with a post driver after the asphalt pad was constructed over the crushed concrete road base. Posts 9-21 were installed with an 8-inch offset from the edge of the asphalt to the back of the steel posts. The soil adjacent to the edge of the asphalt pad on the back side of the guardrail was not compacted. Posts 1-8 and 22-30 were installed in the crushed concrete road base without the asphalt.

Figure 3.1 presents the overall information on the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment, and Figure 3.2 thru Figure 3.7 provide photographs of the installation. Appendix B provides further details on the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by TTI Proving Ground personnel.

3.2. DESIGN MODIFICATIONS DURING TESTS

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

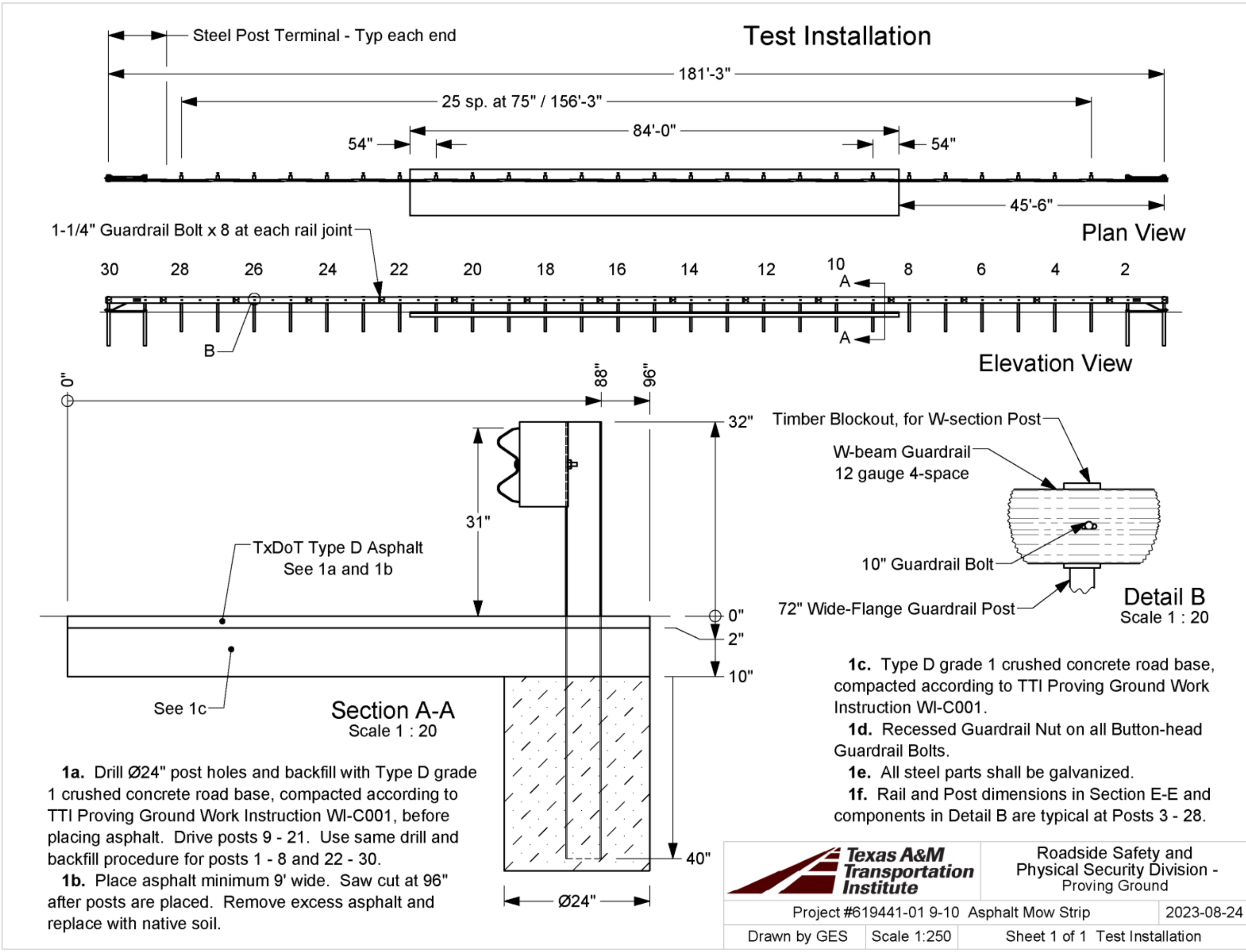

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Figure 3.1. Details of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

Figure 3.2. Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment Prior to Testing.

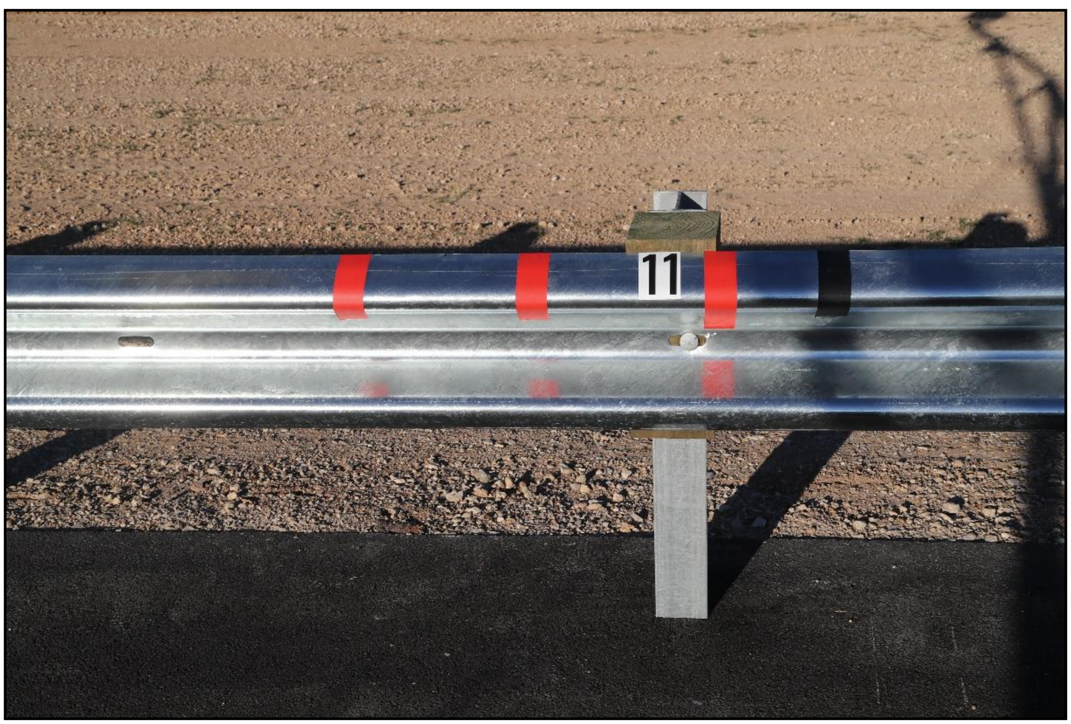


Figure 3.3. Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment at Impact Prior to Testing.

Figure 3.4. Field Side View of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment Prior to Testing.

Figure 3.5. Oblique Downstream View of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment Prior to Testing.

Figure 3.6. Closeup of Steel Post with Timber Blockout on Asphalt Vegetation Control Treatment with Guardrail Prior to Testing.

Figure 3.7. Field Side Closeup View of Steel Post with Timber Blockout on Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment Prior to Testing.

3.3. MATERIAL SPECIFICATIONS

Appendix C provides material certification documents for the materials used to install/construct the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

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." Details of the standardization dynamic test of soil are shown in Figure C.1 in Appendix C.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment for full-scale crash testing, two 6-ft long W6×16 posts were installed in the immediate vicinity of the guardrail system 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, 2023-10-03, loads on the post at deflections were as follows: the backfill material in which the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment was installed met minimum *MASH* requirements for soil strength.

Table 3.1. Soil Strength for 619441-01-9.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	7090
10	4981	8272
15	5282	9000

On the day of Test 3-11, 2023-10-18, loads on the post at deflections were as follows: the backfill material in which the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment was installed met minimum *MASH* requirements for soil strength.

Table 3.2. Soil Strength for 619441-01-10.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	9424
10	4981	10,939
15	5282	10,272

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 barriers. The target critical impact points (CIPs) for each test were determined using the information provided in *MASH* Section 2.2.4 and Section 2.3.2. Figure 4.1 shows the target CIP for *MASH* TL-3 tests on the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

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

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

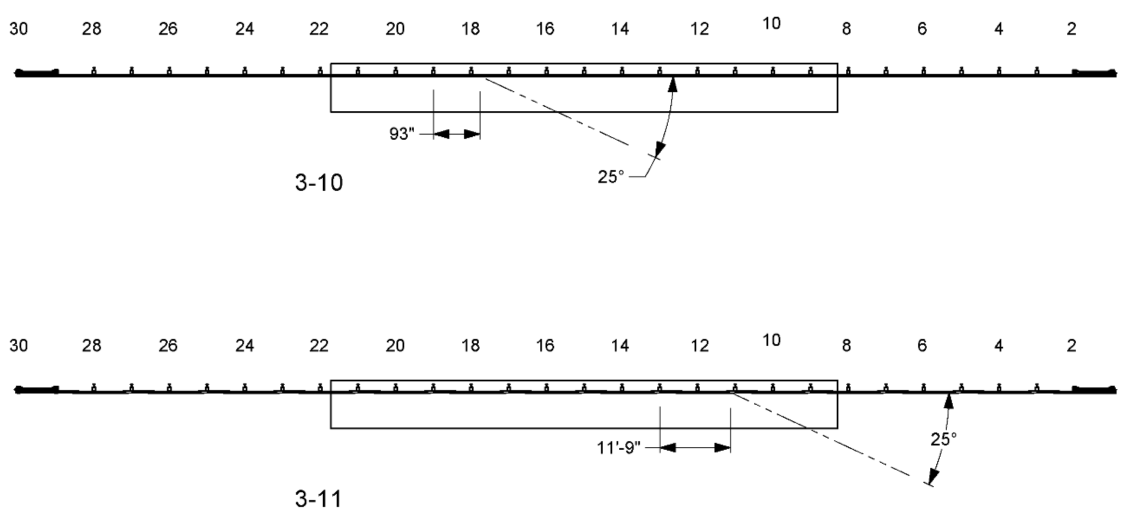


Figure 4.1. Target CIP for *MASH* TL-3 Tests on Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

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

4.2. EVALUATION CRITERIA

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

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

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

Chapter 5. TEST CONDITIONS

5.1. TEST FACILITY

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

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

The 1100C and 2270P vehicles were 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/opposite side of impact of the 1100C vehicle. The dummy was not instrumented.

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

5.3.3. Photographic Instrumentation Data Processing

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

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

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the guardrail. 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 619441-01-9)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 6.1 for details of 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 619441-01-9.

Test Parameter	***MASH* Specification**	**Tolerance**	**Measured**
Impact Speed (mi/h)	62	±2.5 mi/h	62.1
Impact Angle (deg)	25	±1.5°	25
Impact Severity (kip-ft)	51	≥51 kip-ft	56
Impact Location	93 inches upstream from centerline of post 19	±12 inches	93.2 inches upstream from centerline of post 19

Table 6.2. Exit Parameters for *MASH TEST 3-10,* Crash Test 619441-01-9.

Exit Parameter	**Measured**
Speed (mi/h)	35.2
Trajectory (deg)	13.3
Heading (deg)	15.7
Brakes applied post impact (s)	Brakes were not applied
Vehicle at rest position	86 ft downstream of impact point. 70 ft to the traffic side. Vehicle positioned 90° left relative to the installation.
Comments:	Vehicle remained upright and stable. The vehicle did not meet the exit box [a] criteria by crossing the exit box 25 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. Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment/Test Vehicle Geometrics for Test 619441-01-9.

Figure 6.2. Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment/Test Vehicle Impact Location 619441-01-9.

6.2. WEATHER CONDITIONS

Table 6.3 provides the weather conditions for Test 619441-01-9.

Table 6.3. Weather Conditions for Test 619441-01-9.

Date of Test	2023-10-03
Wind Speed (mi/h)	10
Wind Direction (deg)	52
Temperature (°F)	84
Relative Humidity (%)	66
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 D.1 in Appendix D.1 gives additional dimensions and information on the vehicle.

Figure 6.3. Impact Side of Test Vehicle Before Test 619441-01-9.

Figure 6.4. Opposite Impact Side of Test Vehicle Before Test 619441-01-9.

Table 6.4. Vehicle Measurements for Test 619441-01-9.

Test Parameter	Specification	Tolerance	Measured
Dummy (if applicable)[a] (lb)	165	N/A	165
Inertial Weight (lb)	2420	±55	2430
Gross Static[a] (lb)	2585	±55	2595
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	41.1
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 619441-01-9. Figures D.4, D.5, and D.6 in Appendix D.2 present sequential photographs during the test.

Table 6.5. Events During Test 619441-01-9.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0170	Post 18 began to lean toward field side
0.0250	Post 19 began to lean toward field side
0.0290	Vehicle began to redirect
0.0800	Post 20 began to lean toward field side
0.1200	Dummy Head broke passenger side window
0.1220	Rail released from post 21
0.2520	Vehicle was parallel with installation
0.4670	Vehicle exited the installation at 35.3 mi/h with a heading of 15.7 degrees and a trajectory of 13.3 degrees

6.5. DAMAGE TO TEST INSTALLATION

Post 18 had a clockwise twist, and the rail was deformed around the blockout. The asphalt at this post location had a large crack that ran parallel to the rail on the traffic side with one large crack running perpendicular to the rail on the field side. The rail detached from Post 19 and the blockout was removed. The asphalt at this post location had the same cracking as Post 18. Post 20 had the blockout removed, and the asphalt had the same cracking as Post 18. The slot in the rail for the guardrail bolt tore. Post 25 also released from the rail. The rail between Posts 18-21 was deformed and scuffed. Table 6.6 describes the soil gap and post lean of the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

Table 6.6. Damage to the Installation for Test 619441-01-9

Post Number	Soil Gap (inches)	Post Lean from Vertical (degrees)
1	0.3 u/s	0
2	Soil disturbed	0
16	Asphalt cracked	0
17	0.1 t/s	0
18	0.8 t/s	10
19	0.8 t/s	70.3 d/s
20	0.8 t/s	72.6 d/s
21	0.8 t/s, 0.1 f/s	11.3 d/s, 14.1 f/s
22	0.1 f/s	1
23	“	0
24 – 28	Soil disturbed t/s	0
30	0.1 d/s	0

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

Table 6.7 describes the deflection and working width of the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment. Figure 6.5 through Figure 6.11 show the damage to the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

Table 6.7. Deflection and Working Width of the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment for Test 619441-01-9.

Test Parameter	Measured
Permanent Deflection/Location	17 inches toward field side at the midspan of posts 19 and 20
Dynamic Deflection	24.4 toward field side at the top of rail between posts 19 and 20
Working Width [a] and Height	38.7 inches, at a height of 1.0 inches, at the passenger front tire between posts 19 and 20

[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. Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment at Impact Location After Test 619441-01-9.

Figure 6.6. Upstream View of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-9.

Figure 6.7. View at Post 20 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-9

Figure 6.8. View of Asphalt Cracking at Post 18 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-9

Figure 6.9. View of Asphalt Cracking at Post 19 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-9

Figure 6.10. View of Asphalt Cracking at Post 20 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-9

Figure 6.11. View of Asphalt Cracking at Post 21 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-9

6.6. DAMAGE TO TEST VEHICLE

Figure 6.12 and Figure 6.13 show the damage sustained by the vehicle. Figure 6.14 and Figure 6.15 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 D.2 and D.3 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 6.12. Impact Side of Test Vehicle After Test 619441-01-9.

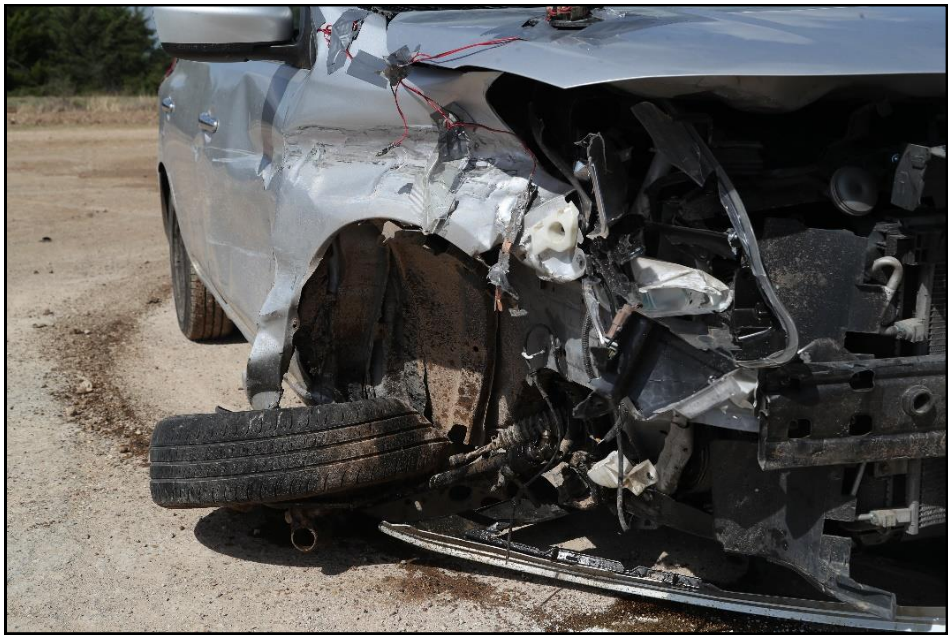


Figure 6.13. Close-Up of the Impact Side of Test Vehicle After Test 619441-01-9.

Figure 6.14. Overall Interior of Test Vehicle After Test 619441-01-9.

Figure 6.15. Interior of Test Vehicle on Impact Side After Test 619441-01-9.

Table 6.8. Occupant Compartment Deformation 619441-01-9.

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

Table 6.9. Exterior Vehicle Damage 619441-01-9.

Side Windows	Right front window was shattered.
Maximum Exterior Deformation	9 inches above the front bumper.
VDS	01RFQ4
CDC	01FREN2
Fuel Tank Damage	None
Description of Damage to Vehicle:	The headlights, bumper, and grill were removed. The right front door was dented with a 5-inch gap at the top and the glass was shattered. There was a small dent in the right rear door. The right rear had its quarter panel dented, taillight broken, and bumper cover scratched. The right front wheel was dented, and the tire was flat. The right control arm was ripped off with the right front brake line broken and frame rail bent.

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 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 6.10. Occupant Risk Factors for Test 619441-01-9.

Test Parameter	Specification [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	18	0.1174 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	18	0.1174 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	9.7	0.2031 - 0.2131 seconds
Ridedown, Lateral (g)	≤20.49 *15.0*	10.3	0.1570 - 0.1670 seconds
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	7.7	0.1130 seconds on right side of interior
Acceleration Severity Index (ASI)	N/A	1.0	0.0652 - 0.1152 seconds
50-ms Moving Avg. Accelerations (MA) Longitudinal (g)	N/A	-6.5	0.0724 - 0.1224 seconds
50-ms MA Lateral (g)	N/A	-7.5	0.0362 - 0.0862 seconds
50-ms MA Vertical (g)	N/A	-4.1	0.1089 - 0.1589 seconds
Roll (deg)	≤75	8.8	0.1700 seconds
Pitch (deg)	≤75	7.7	0.8173 seconds
Yaw (deg)	N/A	66.1	1.2579 seconds

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

6.8. TEST SUMMARY

Figure 6.16 summarizes the results of *MASH* Test 619441-01-9.

0.000 s

0.200 s

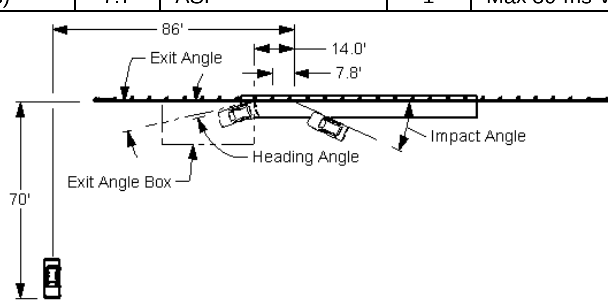
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-10
TTI Project No.	619441-01-9
Test Date	2023-10-03
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment
Length	181 feet and 3 inches
Key Materials	Galvanized steel posts, w-beam guardrail, timber blockouts, Type D asphalt
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)	2430
Dummy (lb)	165
Gross Static (lb)	2595
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.1
Impact Angle (deg)	25
Impact Location	93.2 inches upstream from centerline of post 19
Impact Severity (kip-ft)	56
EXIT CONDITIONS	
Exit Speed (mi/h)	34.5
Trajectory/Heading Angle (deg)	13.3 / 15.7
Exit Box Criteria	The vehicle did not meet the exit box criteria
Stopping Distance	86 ft downstream 70 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	24.4
Permanent (inches)	17 inches
Working Width / Height (inches)	38.7 / 1.0
VEHICLE DAMAGE	
VDS	01FREN2
CDC	01RFQ4
Max. Ext. Deformation (inches)	9 inches above front bumper
Max Occupant Compartment Deformation	No occupant compartment deformation

OCCUPANT RISK VALUES

Long. OIV (ft/s)	18	Long. Ridedown (g)	9.7	Max 50-ms Long. (g)	-6.5	Max Roll (deg)	8.8
Lat. OIV (ft/s)	18	Lat. Ridedown (g)	10.3	Max 50-ms Lat. (g)	-7.5	Max Pitch (deg)	7.7
THIV (m/s)	7.7	ASI	1	Max 50-ms Vert. (g)	-4.1	Max Yaw (deg)	66.1



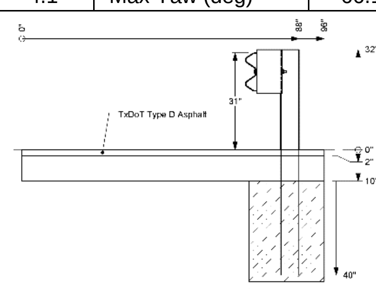


Figure 6.16. Summary of Results for *MASH* Test 3-10 on Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

Chapter 7. *MASH* TEST 3-11 (CRASH TEST 619441-01-10)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 7.1 for details of 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 619441-01-10.

Test Parameter	*MASH* Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	61.2
Impact Angle (deg)	25	±1.5°	24.9
Impact Severity (kip-ft)	106	≥106 kip-ft	111.9
Impact Location	141 inches upstream from centerline of post 13	±12 inches	140.5 inches upstream from centerline of post 13

Table 7.2. Exit Parameters for *MASH* TEST 3-11, Crash Test 619441-01-10.

Exit Parameter	Measured
Speed (mi/h)	Vehicle out of frame
Trajectory (deg)	Vehicle out of frame
Heading (deg)	Vehicle out of frame
Brakes applied post impact (s)	Brakes were not applied.
Vehicle at rest position	5 feet downstream of post 30 ft . 2.5 ft to the traffic side. Vehicle positioned 5° right relative to the installation.
Comments:	Vehicle remained upright and stable. Vehicle met the exit box criteria.

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

Figure 7.1. Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment/Test Vehicle Geometrics for Test 619441-01-10.

Figure 7.2. Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment/Test Vehicle Impact Location for Test 619441-01-10.

7.2. WEATHER CONDITIONS

Table 7.3 provides the weather conditions for Test 619441-01-10.

Table 7.3. Weather Conditions for Test 619441-01-10.

Date of Test	2023-10-18
Wind Speed (mi/h)	9
Wind Direction (deg)	189
Temperature (°F)	71
Relative Humidity (%)	72
Vehicle Traveling (deg)	195

7.3. TEST VEHICLE

Figure 7.3 and Figure 7.4 show the 2019 RAM 1500 used for the crash test. Table 7.4 shows the vehicle measurements. Figure E.1 in Appendix E.1 gives additional dimensions and information on the vehicle.

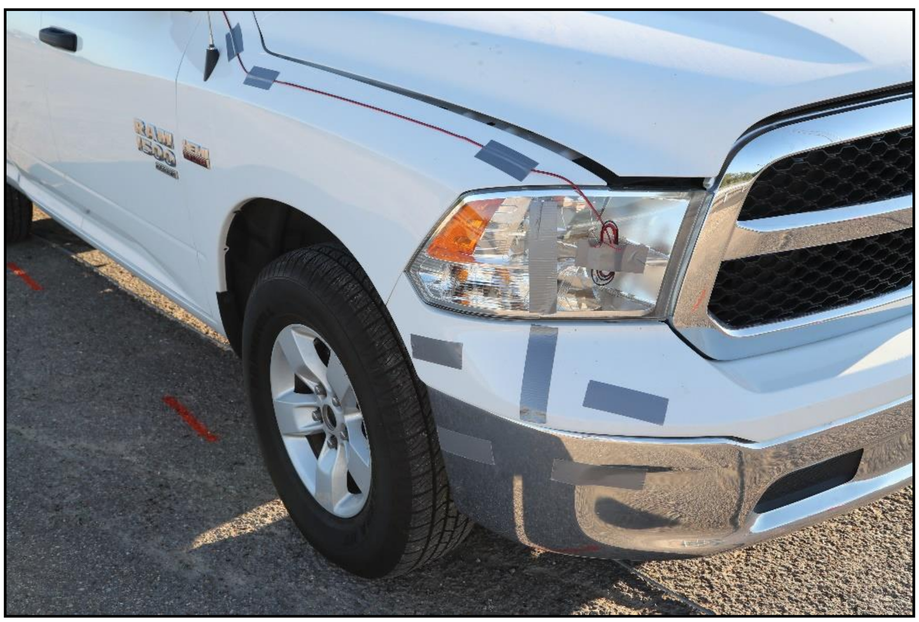


Figure 7.3. Impact Side of Test Vehicle Before Test 619441-01-10.

Figure 7.4. Opposite Impact Side of Test Vehicle Before Test 619441-01-10.

Table 7.4. Vehicle Measurements 619441-01-10.

Test Parameter	***Specification***	**Tolerance**	**Measured**
Dummy (if applicable)[a] (lb)	165	N/A	N/A
Inertial Weight (lb)	5000	±110	5049
Gross Static[a] (lb)	5000	±110	5049
Wheelbase (inches)	148	±12	140.50
Front Overhang (inches)	39	±3	40
Overall Length (inches)	237	±13	227.50
Overall Width (inches)	78	±2	78.50
Hood Height (inches)	43	±4	46
Track Width[b] (inches)	67	±1.5	68.25
CG aft of Front Axle[c] (inches)	63	±4	61.20
CG above Ground[c,d] (inches)	28	≥28	28.75

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 619441-01-10. Figures E.4, E.5, and E.6 in Appendix E.2 present sequential photographs during the test.

Table 7.5. Events during Test 619441-01-10.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0130	Post 11 began to lean toward field side
0.0180	Post 12 began to lean toward field side
0.0300	Vehicle began to redirect
0.0400	Post 13 began to lean toward field side
0.1170	Post 14 began to lean toward field side
0.2190	Rear passenger side bumper impacted rail near post 11
0.2970	Vehicle was parallel with installation

7.5. DAMAGE TO TEST INSTALLATION

The rail released from posts 3, 5-9, and 11-21. Posts 4 and 10 rotated 15 degrees and 20 degrees clockwise, respectively. Post 11 also rotated 20 degrees clockwise. The blockout was removed from posts 11 and 12. There was major asphalt damage from posts 12-16, and the rail was warped with some tearing around the guardrail bolt slots where the blockouts were released. Post 17 also rotated 10 degrees clockwise. Table 7.6 describes the soil gap (the gap formed between the edge of the soil and the post) and post lean of the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

Table 7.6. Damage to the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment for Test 619441-01-10

Post Number	Soil Gap (inches)	Post Lean from Vertical (degrees)
1	2.3 u/s	0
2	1.0 d/s	0
11	0.5 t/s	0
12	Soil collapsed around post	73.0 d/s
13	Soil collapsed around post	64.2 d/s
14	Soil collapsed around post	67.0 d/s
15	Soil collapsed around post	73.0 d/s
16	Soil collapsed around post	77.7 d/s
18	Soil disturbed	0
30	0.2 d/s	0

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

Table 7.7 describes the deflection and working width of the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment. Figure 7.5 through Figure 7.12 show the damage to the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

Table 7.7. Deflection and Working Width of the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment for Test 619441-01-10.

Test Parameter	Measured
Permanent Deflection/Location	34 inches toward field side, between posts 14 and 15
Dynamic Deflection	45.6 inches toward field side, top of rail at post 13
Working Width [a] and Height	53.7 inches, at a height of 65.1 inches, at the rear passenger side bumper

[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. Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment at Impact Location After Test 619441-01-10.

Figure 7.6. Upstream View of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-10.

Figure 7.7. View at Post 12 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment after Test 619441-01-10

Figure 7.8. View at Post 13 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-10

Figure 7.9. View at Post 14 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-10

Figure 7.10. View at Post 15 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-10

Figure 7.11. View at Post 16 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-10

Figure 7.12. View of Anchor Movement at Post 1 of Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment After Test 619441-01-10

7.6. DAMAGE TO TEST VEHICLE

Figure 7.13 and Figure 7.14 show the damage sustained by the vehicle. Figure 7.15 and Figure 7.16 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 E.2 and E.3 in Appendix E.1 provide exterior crush and occupant compartment measurements.

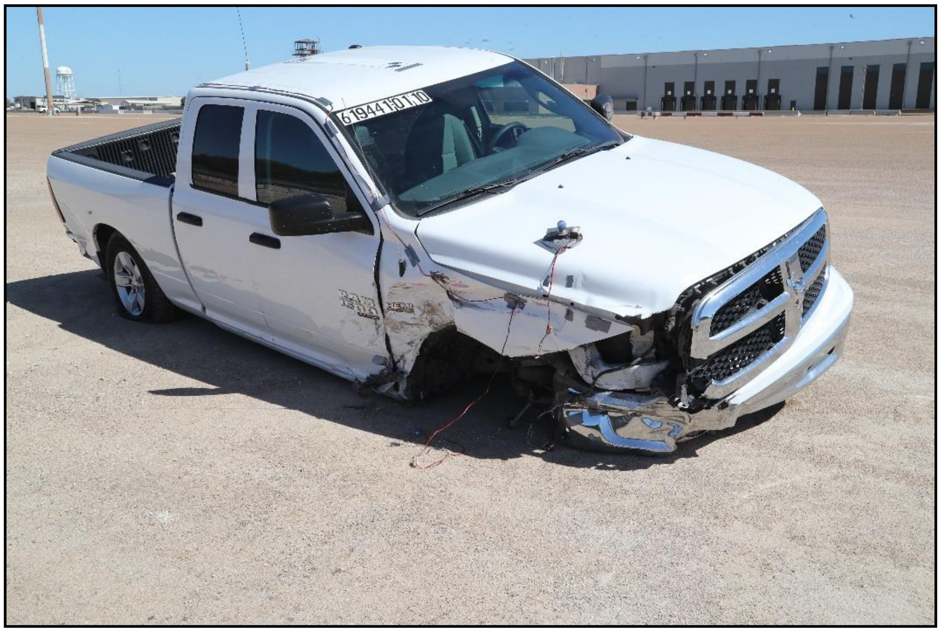


Figure 7.13. Impact Side of Test Vehicle After Test 619441-01-10.

Figure 7.14. Rear Impact Side of Test Vehicle After Test 619441-01-10.

Figure 7.15. Overall Interior of Test Vehicle After Test 619441-01-10.

Figure 7.16. Interior of Test Vehicle on Impact Side After Test 619441-01-10.

Table 7.8. Occupant Compartment Deformation 619441-01-10.

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

Table 7.9. Exterior Vehicle Damage 619441-01-10.

Side Windows	Side windows remained intact
Maximum Exterior Deformation	15 inches at front bumper
VDS	01RFQ4
CDC	01FREN2
Fuel Tank Damage	None
Description of Damage to Vehicle:	The hood, bumper, grill, and right headlight were damaged. The right front fender was dented, the control arm ripped off, the brake line was broken, front wheel was damaged, and the tire was blown out. The right front door was also dented and scratched with a 0.5-inch gap at the top of the door. There were small scratches and dents in the right rear door and bed. The right rear bumper was dented, and the tire was flat.

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 E.7 in Appendix E.3 shows the vehicle angular displacements, and Figures E.8 through E.10 in Appendix E.4 show acceleration versus time traces.

Table 7.10. Occupant Risk Factors for Test 619441-01-10.

Test Parameter	***Specification*** [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	17.3	0.1538 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	14.8	0.1538 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	10.3	0.4527 - 0.4627 seconds
Ridedown, Lateral (g)	≤20.49 *15.0*	7.0	0.1640 - 0.1740 seconds
THIV (m/s)	N/A	6.5	0.1472 seconds on right side of interior
ASI	N/A	0.6	0.2402 - 0.2902 seconds
50-ms MA Longitudinal (g)	N/A	-4.3	0.0581 - 0.1081 seconds
50-ms MA Lateral (g)	N/A	-5.1	0.2134 - 0.2634 seconds
50-ms MA Vertical (g)	N/A	1.8	0.4710 - 0.5210 seconds
Roll (deg)	≤75	10.3	2.0030 seconds
Pitch (deg)	≤75	3.5	2.8502 seconds
Yaw (deg)	N/A	32.5	0.4490 seconds

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

7.8. TEST SUMMARY

Figure 7.17 summarizes the results of *MASH* Test 619441-01-10.

0.000 s

0.200 s

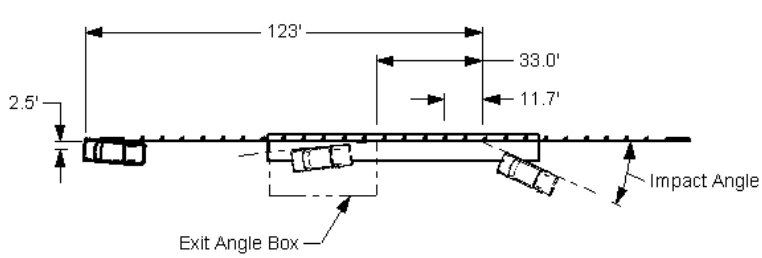
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-11
TTI Project No.	619441-01-10
Test Date	2023-10-18
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment
Length	181 feet and 3 inches
Key Materials	Galvanized steel posts, w-beam guardrail, timber blockouts, Type D asphalt
Soil Type and Condition	Type D grade 1 crushed concrete road base
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2019 RAM 1500
Inertial Weight (lb)	5049
Dummy (lb)	N/A
Gross Static (lb)	5049
IMPACT CONDITIONS	
Impact Speed (mi/h)	61.2
Impact Angle (deg)	24.88
Impact Location	140.5 inches upstream from centerline of post 13
Impact Severity (kip-ft)	111.9
EXIT CONDITIONS	
Exit Speed (mi/h)	N/A
Trajectory/Heading Angle (deg)	N/A
Exit Box Criteria	Vehicle did not cross the exit box but met the criteria
Stopping Distance	5 feet downstream of post 30 2.5 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	45.6
Permanent (inches)	34 inches
Working Width / Height (inches)	53.7 / 65.1
VEHICLE DAMAGE	
VDS	01RFQ4
CDC	01FREN2
Max. Ext. Deformation (inches)	15 inches at front bumper
Max Occupant Compartment Deformation	No occupant compartment deformation

OCCUPANT RISK VALUES

Long. OIV (ft/s)	17.3	Long. Ridedown (g)	10.3	Max 50-ms Long. (g)	-4.3	Max Roll (deg)	10.3
Lat. OIV (ft/s)	14.8	Lat. Ridedown (g)	7.0	Max 50-ms Lat. (g)	-5.1	Max Pitch (deg)	3.5
THIV (m/s)	6.5	ASI	0.6	Max 50-ms Vert. (g)	1.8	Max Yaw (deg)	32.5



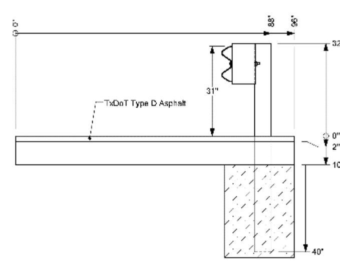


Figure 7.17. Summary of Results for *MASH* Test 3-11 on Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

Chapter 8. SUMMARY AND CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS AND CONCLUSIONS

The crash tests reported herein were performed in accordance with *MASH* TL-3 on the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

Table 8.1 shows that the Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment met the performance criteria for *MASH* TL-3 Longitudinal Barrier.

Table 8.1. Assessment Summary for *MASH* TL-3 Tests on Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment.

Evaluation Criteria	Description	Test 619441-01-9	Test 619441-01-10
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	Evaluation	Pass	Pass

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

8.2. IMPLEMENTATION*

Since the asphalt vegetation control design for the steel-post W-beam guardrail system passed MASH TL-3 testing, it is ready for implementation in the field. In the crash tested installation, the asphalt was 2 inches thick, and the guardrail was installed with an 8-inch offset from the back of the guardrail post to the edge of the asphalt. In field installations, a thinner asphalt pad and/or a smaller offset from the edge of the asphalt may be used without compromising the MASH performance of the guardrail. Such variations are expected to decrease the resistance of the asphalt pad, making the guardrail design more like the standard W-beam guardrail design with posts embedded directly in soil. It should be noted, however, that the thickness or the offset should not

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

be increased from the crash tested values without further testing. Increasing asphalt thickness or edge offset are expected to increase the resistance of the asphalt and may result in premature buckling of the posts, resulting in failed performance of the guardrail from MASH perspective.

The length of the asphalt vegetation control treatment section in the crash tested installation was 84 feet. This length does not constitute a minimum or a maximum length for a field installation. Field installations may use the asphalt vegetation control treatment over shorter or greater lengths of the W-beam guardrail system as needed.

The steel post W-beam guardrail section in the asphalt vegetation control treatment was connected to the standard steel post W-beam guardrail on each end. Field installations of this system may be connected to the wood post W-beam guardrail systems as well. Previous testing of the wood post systems has shown similar maximum dynamic deflection as the system tested herein (*4,5*). This implies that the lateral stiffness of the steel post system in vegetation control treatment design is very close to wood posts systems installed in soil, and therefore a special transition is not needed to attach to those systems. It should be noted, however, that the asphalt vegetation control treatment was designed and tested with steel posts only and may not be used with wood posts without additional research.

If the steel post guardrail in asphalt vegetation control treatment design is used to retrofit an existing W-beam guardrail system with posts installed in soil, the thickness of the asphalt and the width behind the posts should not exceed 2 inches and 8 inches, respectively. Asphalt compaction and the width of the asphalt on the traffic side of the guardrail may be specified as needed since they do not influence the performance of the guardrail installed in the asphalt vegetation control treatment.

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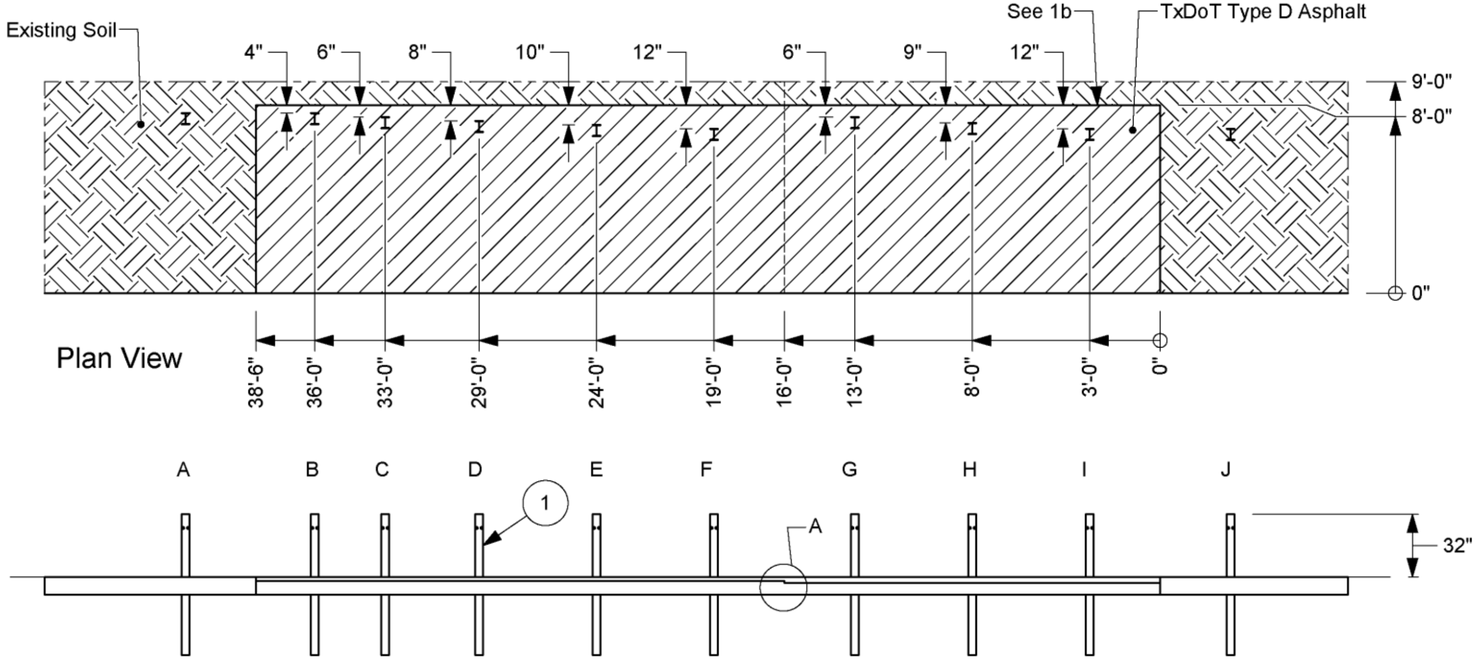
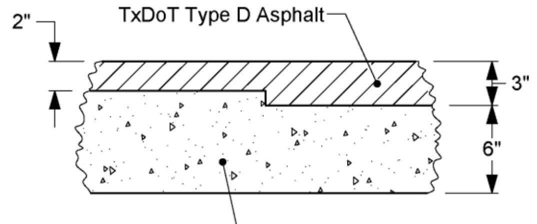
2. M.E. Sweigard, K.A. Lechtenberg, R.K. Faller, J.D. Reid, and E.L. Urbank. *MASH 2016 Test No. 3-10 of MGS Installed in an Asphalt Mow Strip with Nearby Curb (Test No. GAA-1).* Midwest Roadside Safety Facility, Report TRP-03-377-17, Lincoln, Nebraska, 2017.
3. N.M. Sheikh, W.L. Menges, and D.L. Kuhn. *MASH TL-3 Evaluation of 31-inch W-beam Guardrail with Wood and Steel Posts in Concrete Mow Strip*. Texas A&M Transportation Institute, Report 608551-01-1-5, College Station, Texas, 2019.
4. J.C. Kovar, R.P. Bligh, B.L. Griffith, D.L. Kuhn, and G.E. Schroeder, *MASH Test 3-11 Evaluation of Modified TxDOT Round Wood Post Guardrail System*. Report FHWA/TX-18/0-6968-R4, Texas A&M Transportation Institute, College Station, Texas, 2019.
5. D.A. Gutierrez, K.A. Lechtenberg, R.W. Bielenberg, R.K. Faller, J.D. Reid, D.L. Sicking, *Midwest Guardrail System (MGS) With Southern Yellow Pine Posts.* Report TRP-03-272-13, Midwest Roadside Safety Facility, Lincoln, Nebraska, 2013.

APPENDIX A. DETAILS OF TEST INSTALLATION FOR SURROGATE BOGIE VEHICLE TESTING

Test Installation





Detail A
Scale 1 : 10

1a. Drill Ø24" post holes and backfill with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001, before placing asphalt. Drive posts where indicated after asphalt is placed and cured.

1b. Place asphalt minimum 9' wide. Saw cut at 96" after posts are placed. Remove excess asphalt and replace with compacted soil.

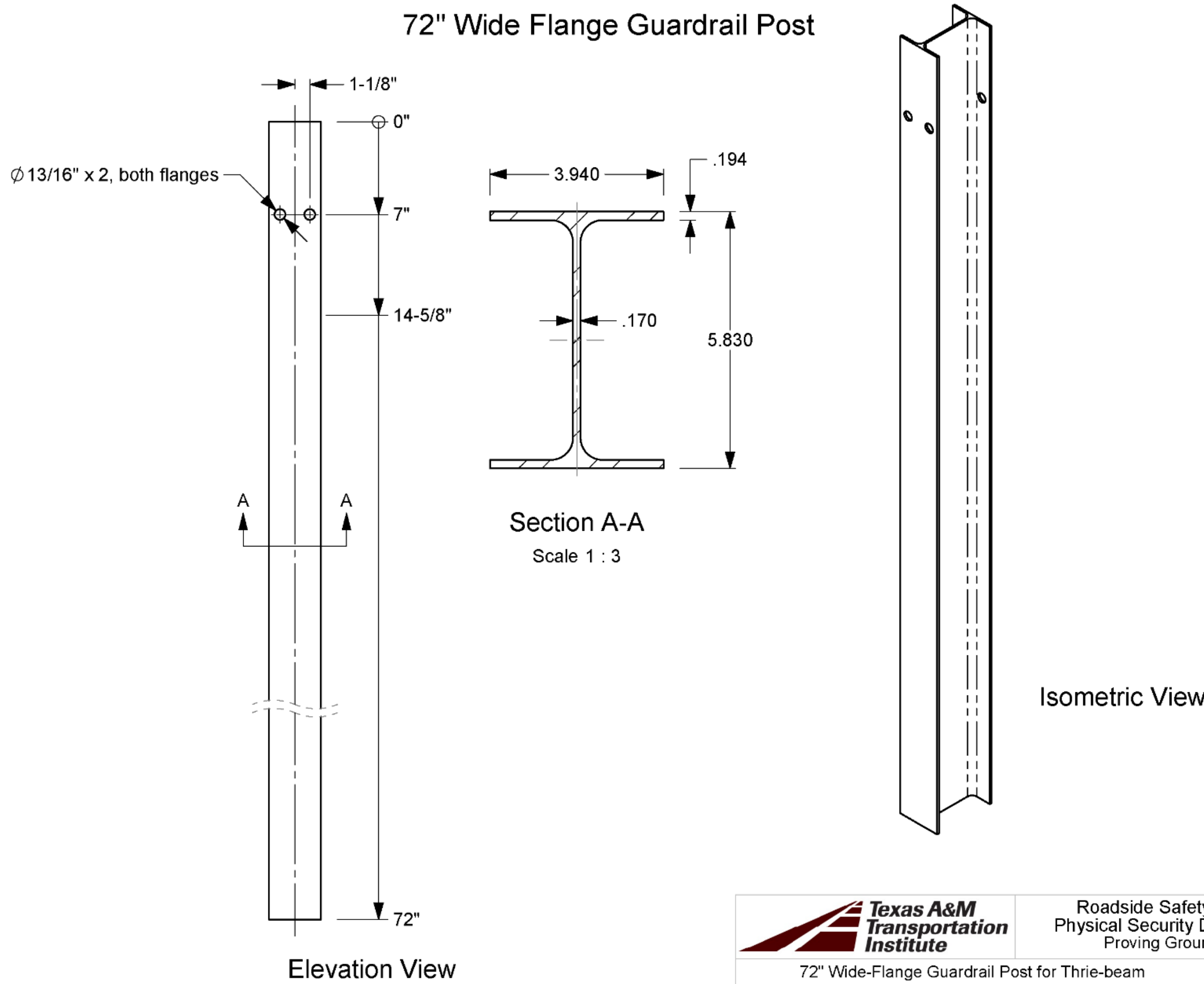
1c. Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.

#	Part Name	QTY.
1	72" Wide-Flange Guardrail Post	10

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #619441-01 Asphalt Mow Strip		2023-07-05
Drawn by GES	Scale 1:75	Sheet 1 of 1 Test Installation

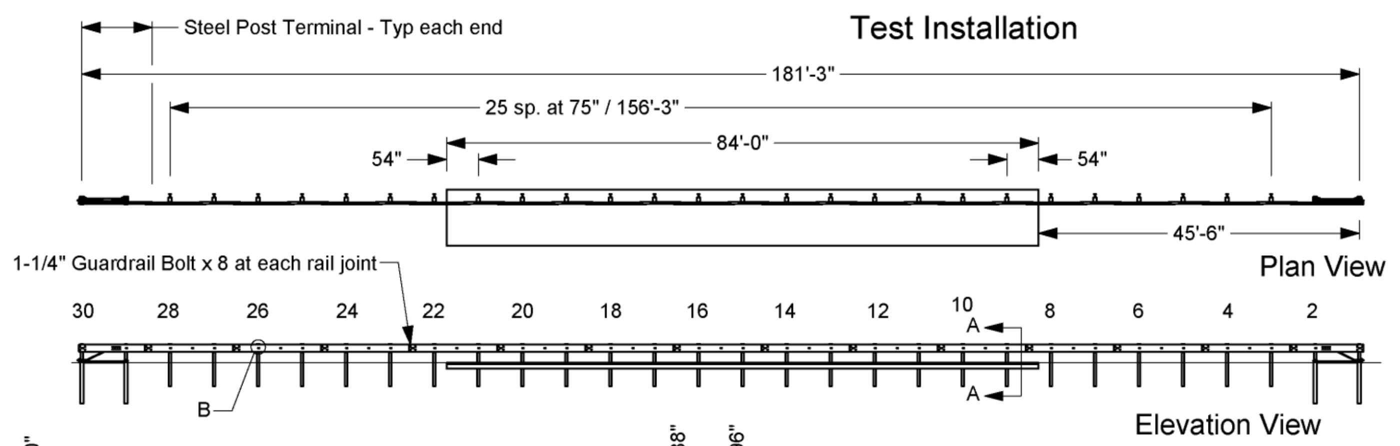
S:\Accreditation-17025-2017\EIR-000 Project Files\619441 - Asphalt Mow-Strip Guardrail - Nauman\Drafting, 619441\619441 Drawing

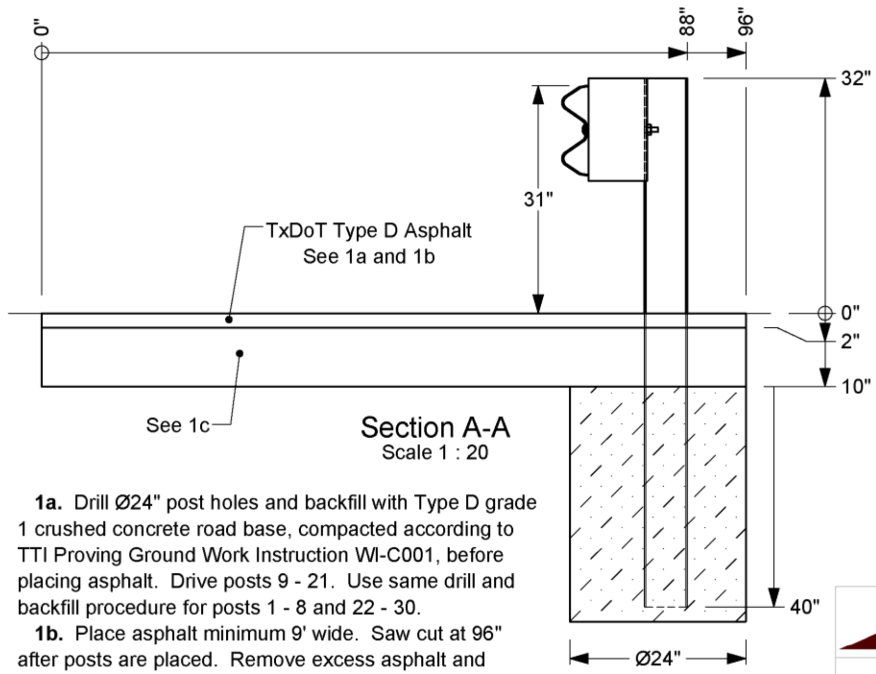
72" Wide Flange Guardrail Post



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

APPENDIX B. DETAILS OF STEEL POST W-BEAM GUARDRAIL IN ASPHALT VEGETATION CONTROL TREATMENT

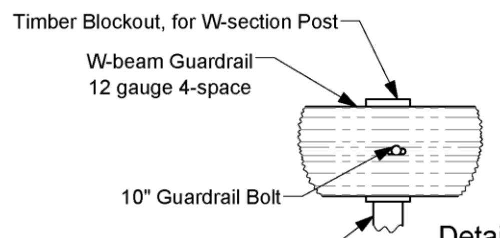




Section A-A
Scale 1 : 20

1a. Drill Ø24" post holes and backfill with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001, before placing asphalt. Drive posts 9 - 21. Use same drill and backfill procedure for posts 1 - 8 and 22 - 30.

1b. Place asphalt minimum 9' wide. Saw cut at 96" after posts are placed. Remove excess asphalt and replace with native soil.



Detail B
Scale 1 : 20

1c. Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.

1d. Recessed Guardrail Nut on all Button-head Guardrail Bolts.

1e. All steel parts shall be galvanized.

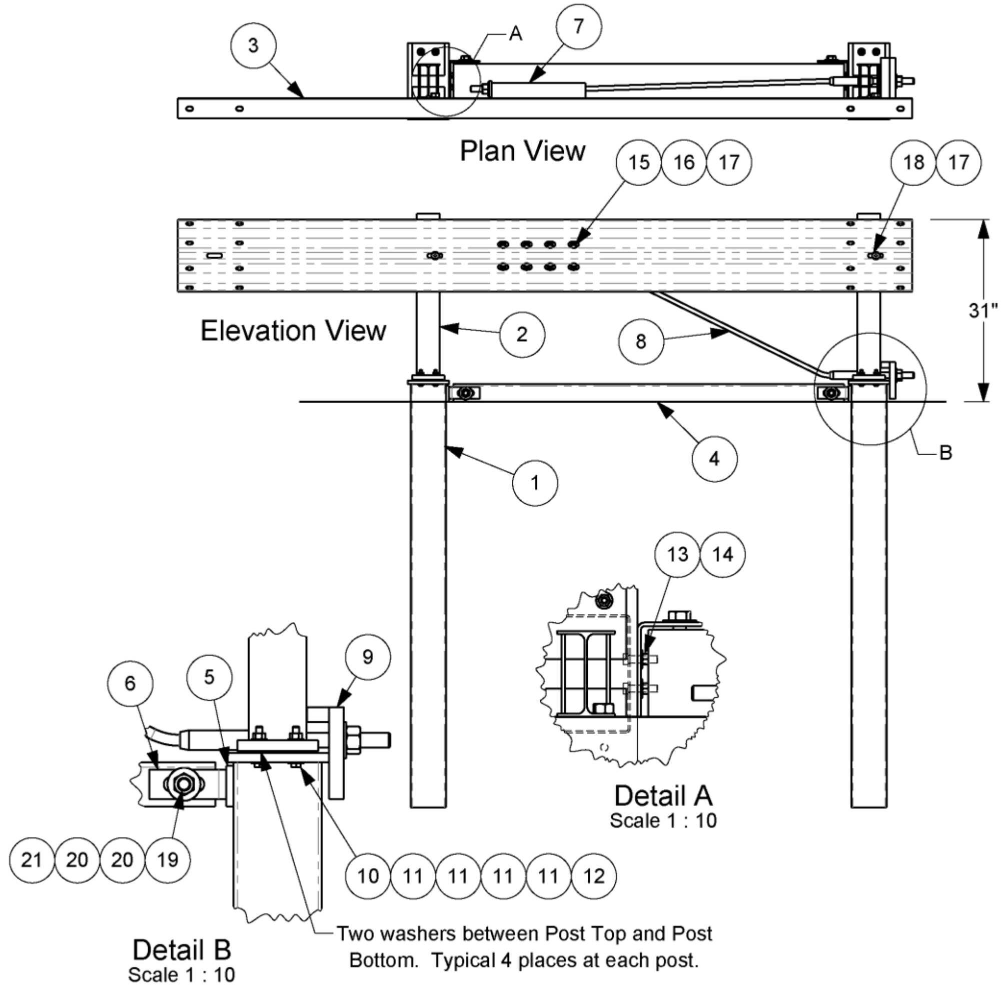
1f. Rail and Post dimensions in Section E-E and components in Detail B are typical at Posts 3 - 28.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #619441-01 9-10 Asphalt Mow Strip		2023-08-24
Drawn by GES	Scale 1:250	Sheet 1 of 1 Test Installation

S:\Accreditation-17025-2017\EIR-000 Project Files\619441 - Asphalt Mow-Strip Guardrail - Nauman\Drafting, 619441 9-10\619441 9-10 Drawing

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



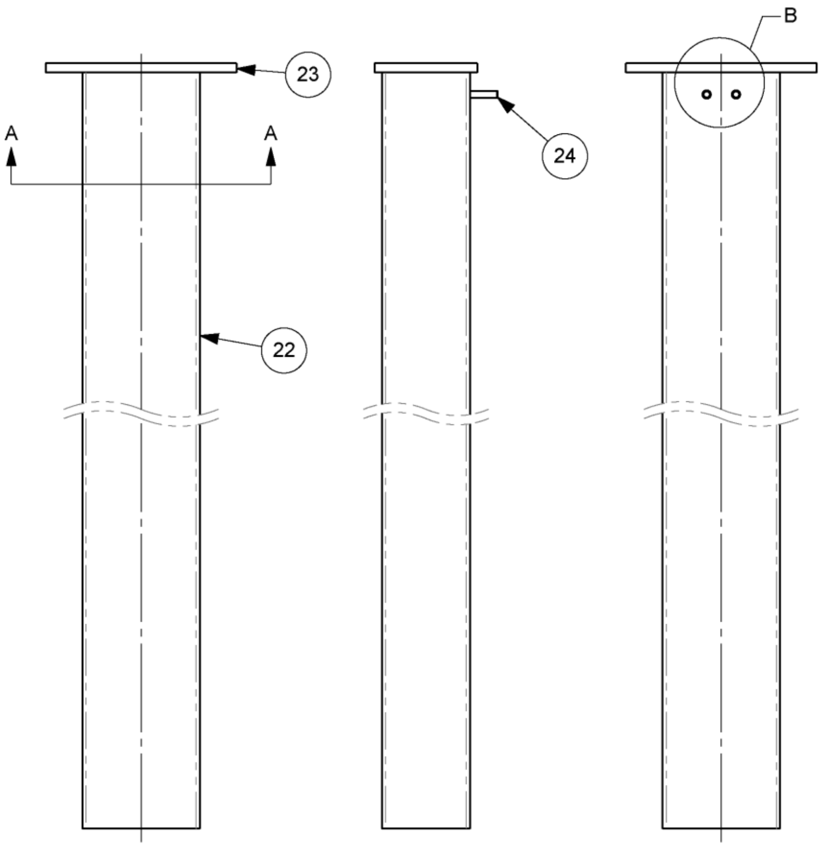
1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.
1c. All steel parts shall be galvanized.

Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground

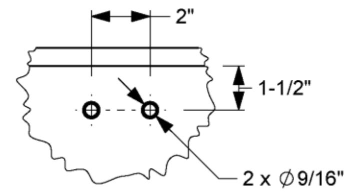
Project # Terminal | 2022-11-10
Drawn by GES | Scale 1:25 | Sheet 1 of 6 Terminal Details

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

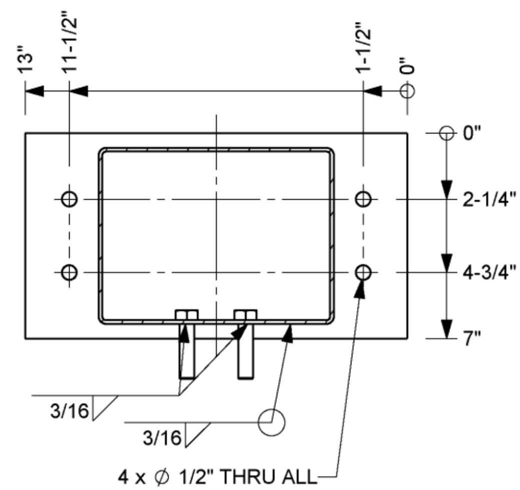
Post Bottom



Elevation Views



Detail B
Scale 1 : 5



Section A-A
Scale 1 : 5

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

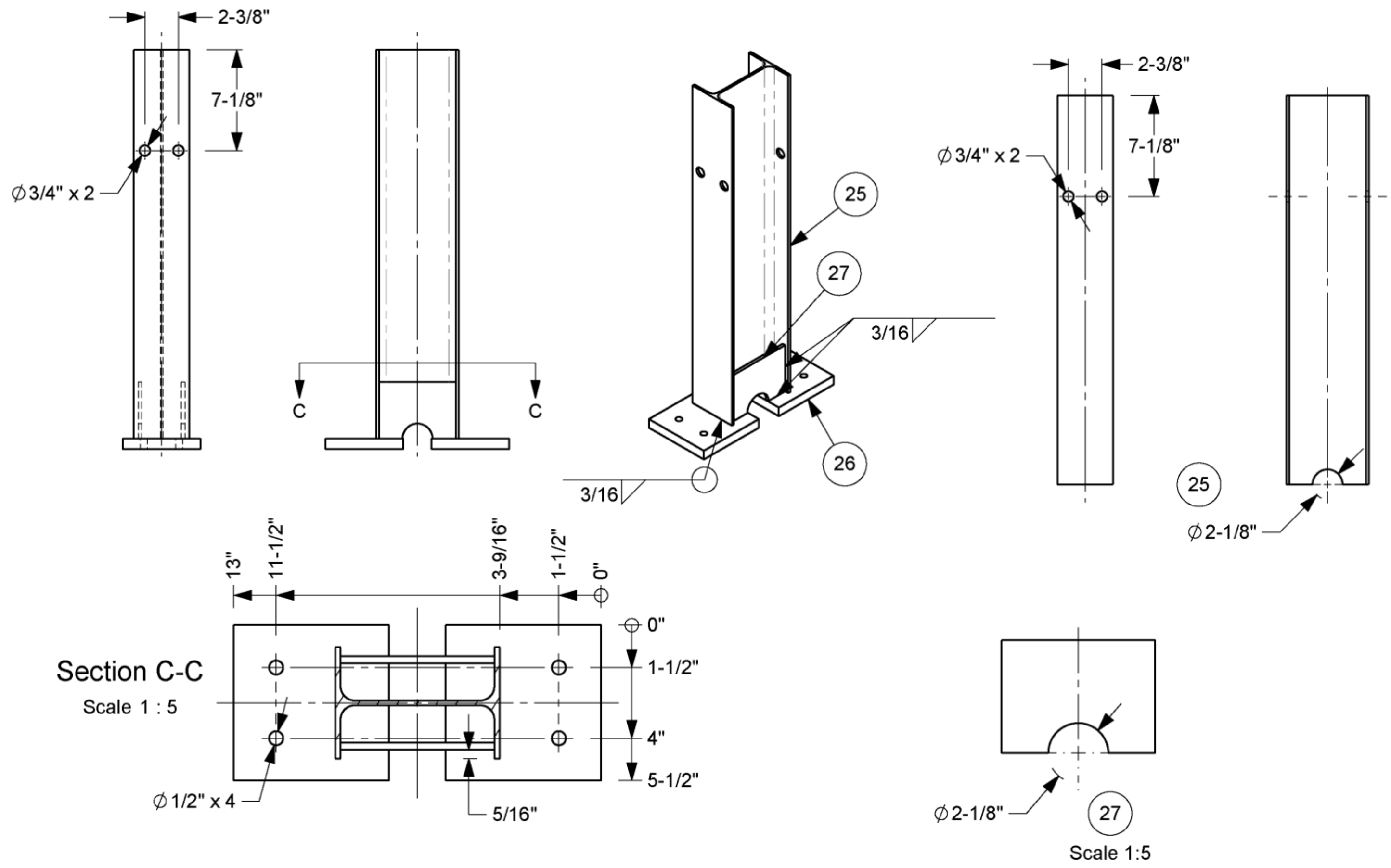
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project # Terminal | 2022-11-10

Drawn by GES | Scale 1:10 | Sheet 2 of 6 Post Bottom

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



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

Texas A&M Transportation Institute

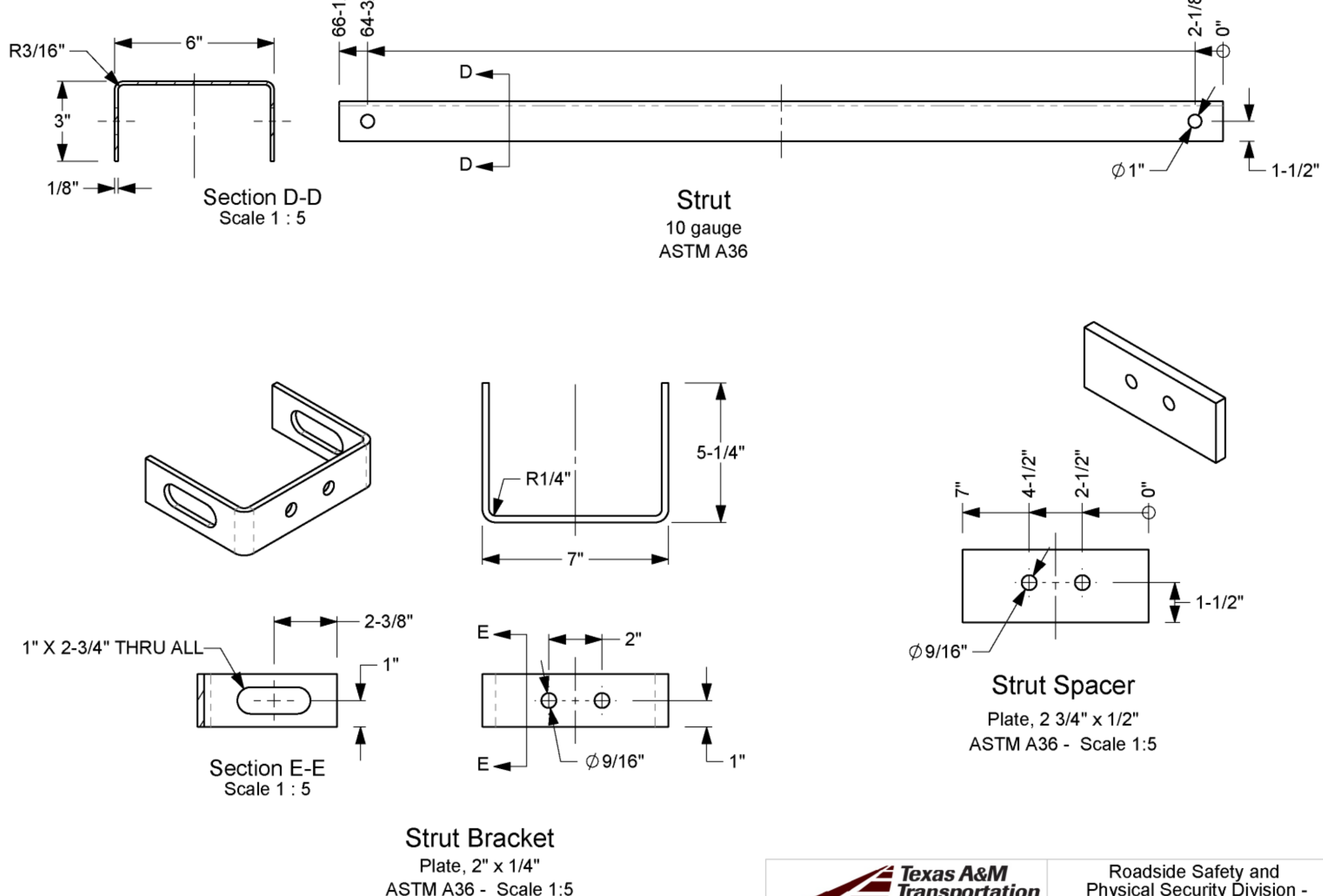
Roadside Safety and Physical Security Division - Proving Ground

Project # Terminal 2022-11-10

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

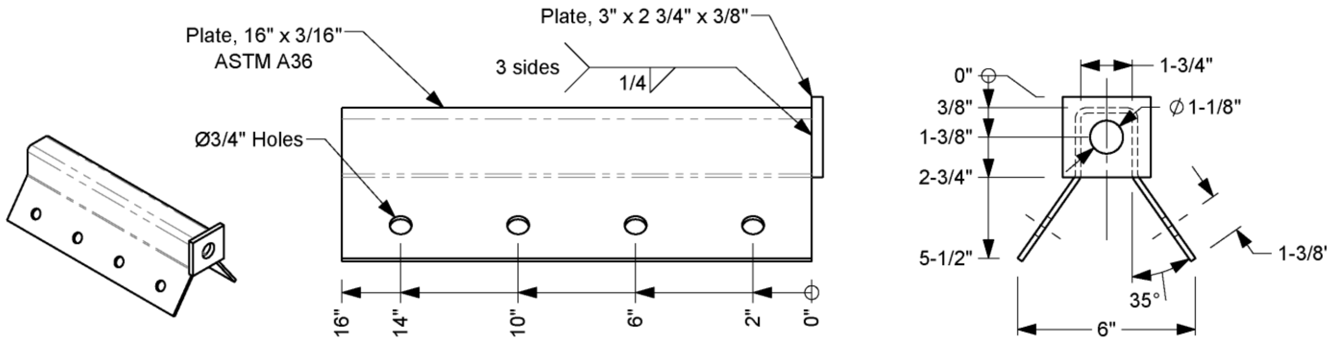
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal

Strut Parts

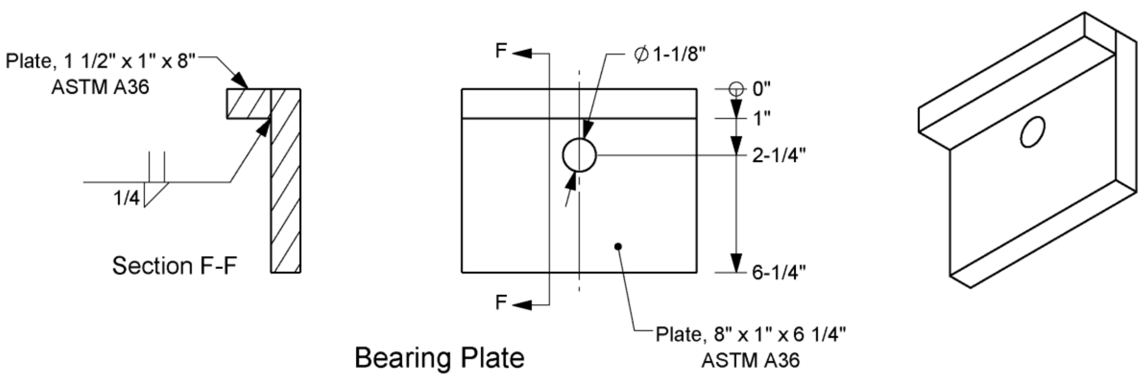


Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
	Project # Terminal	2022-11-10
Drawn by GES	Scale 1:10	Sheet 4 of 6 Strut Parts

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



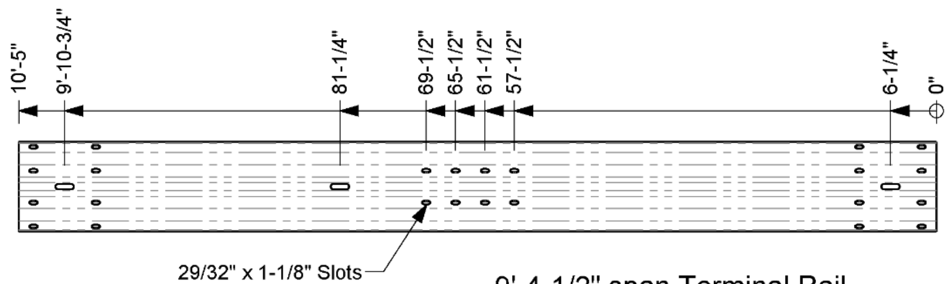
Guardrail Anchor Bracket



Bearing Plate

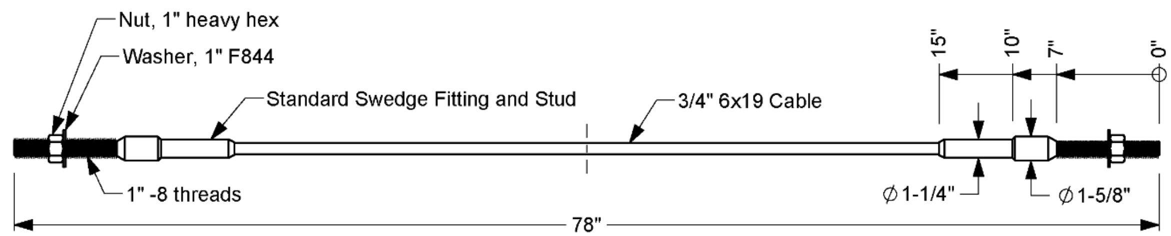
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2022-11-10
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A

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



9'-4-1/2" 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	

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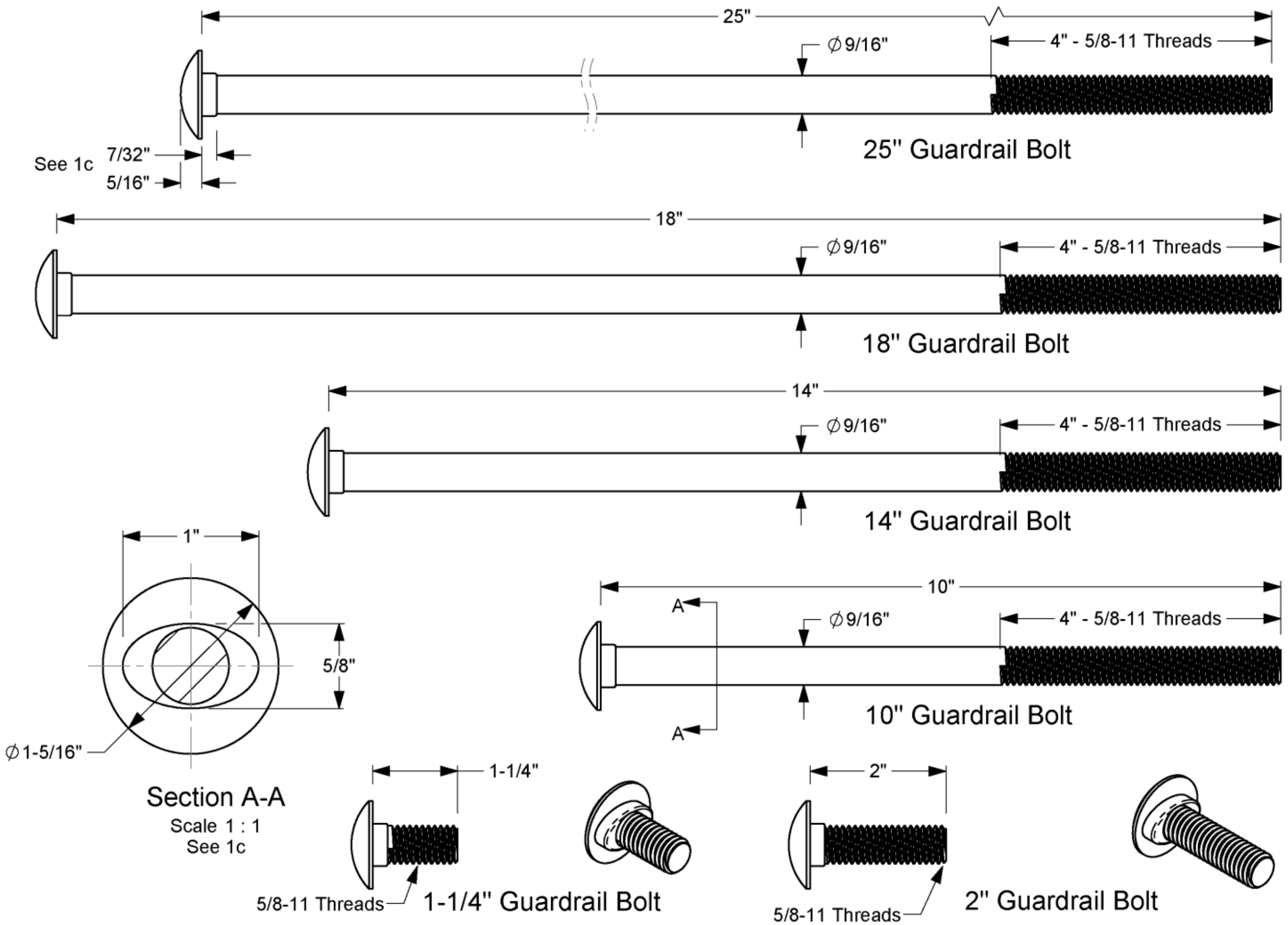

1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all lengths.

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	

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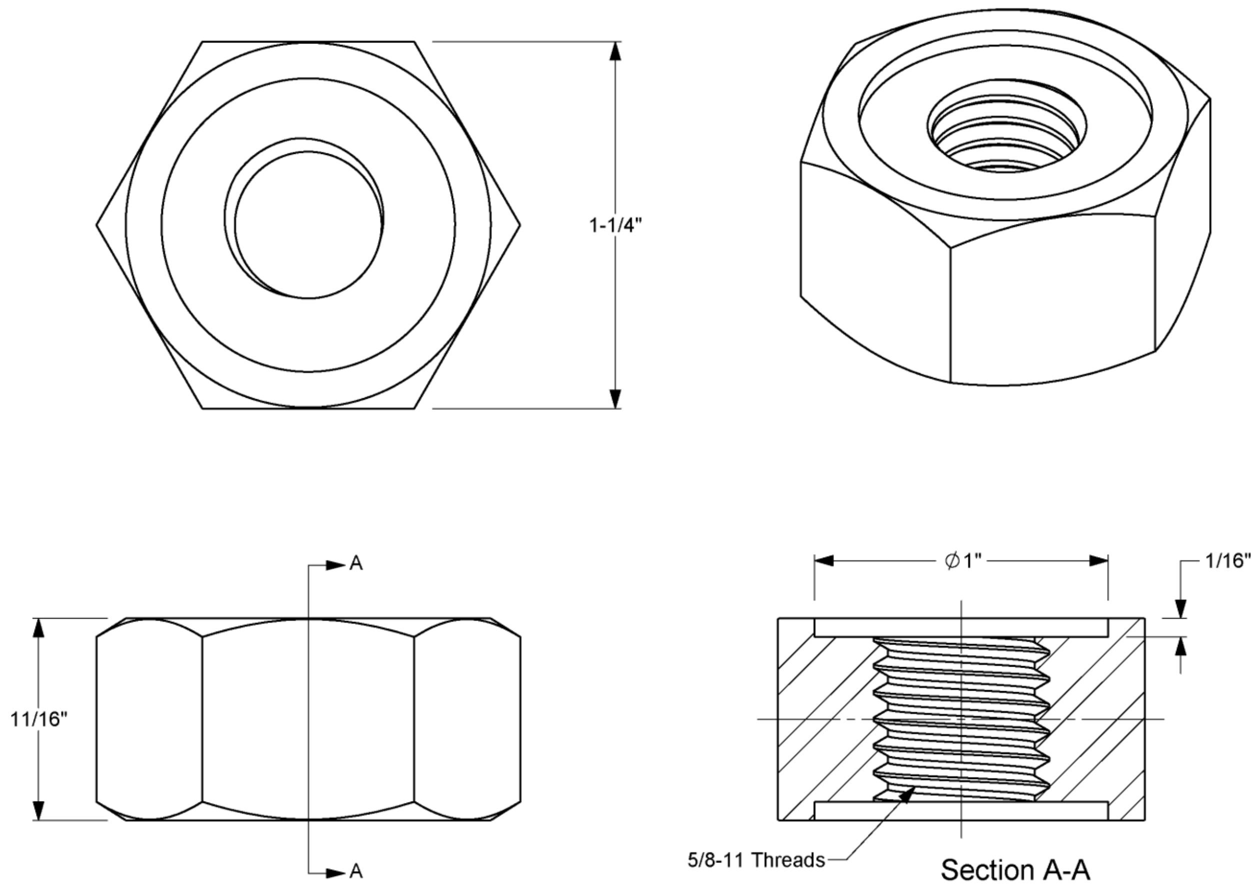
Recessed Guardrail Nut



1a. Material is ASTM A 563 Grade A.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Recessed Guardrail Nut		2022-07-18
Drawn by GES	Scale 2:1	Sheet 1 of 1

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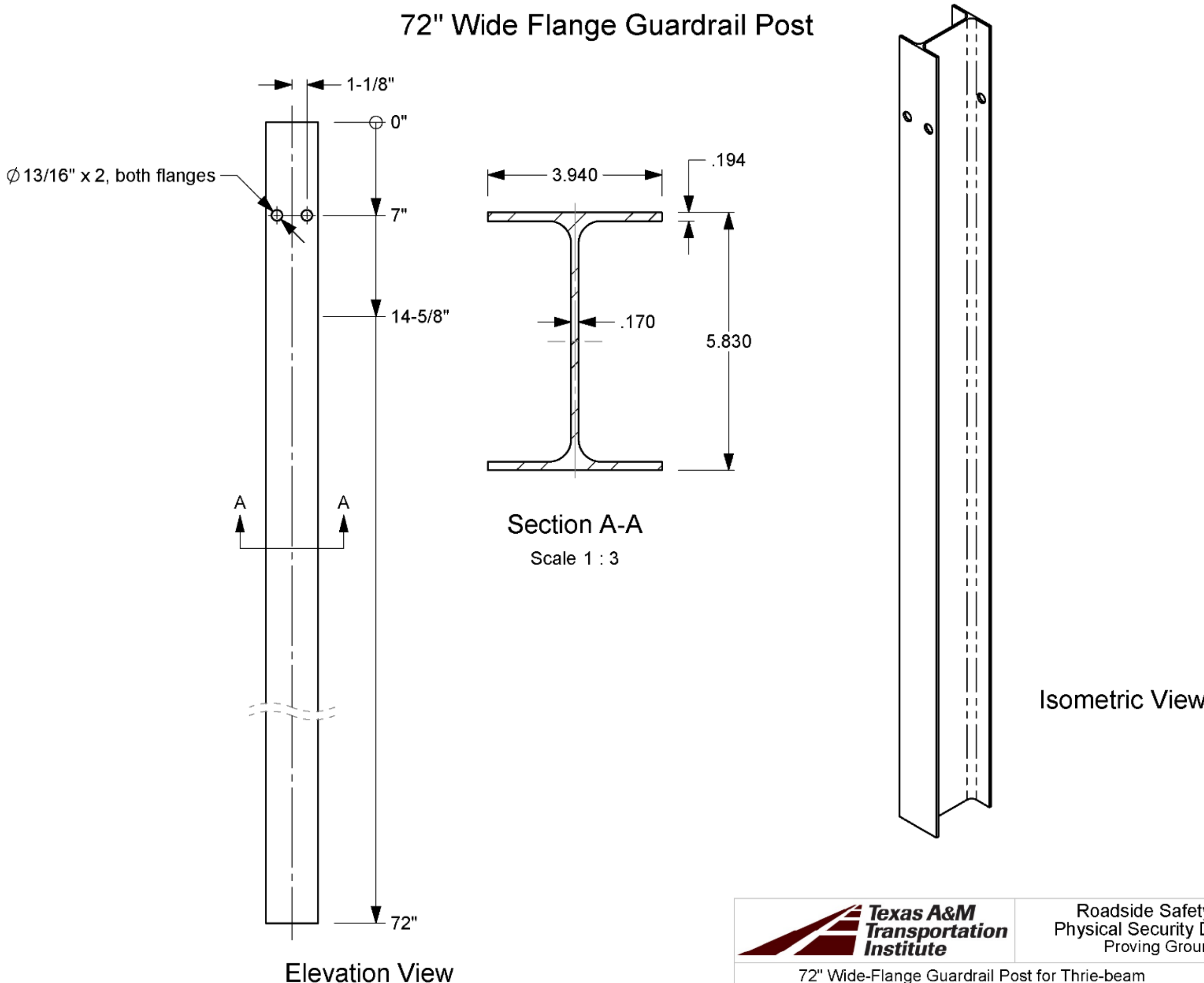
2024-01-24

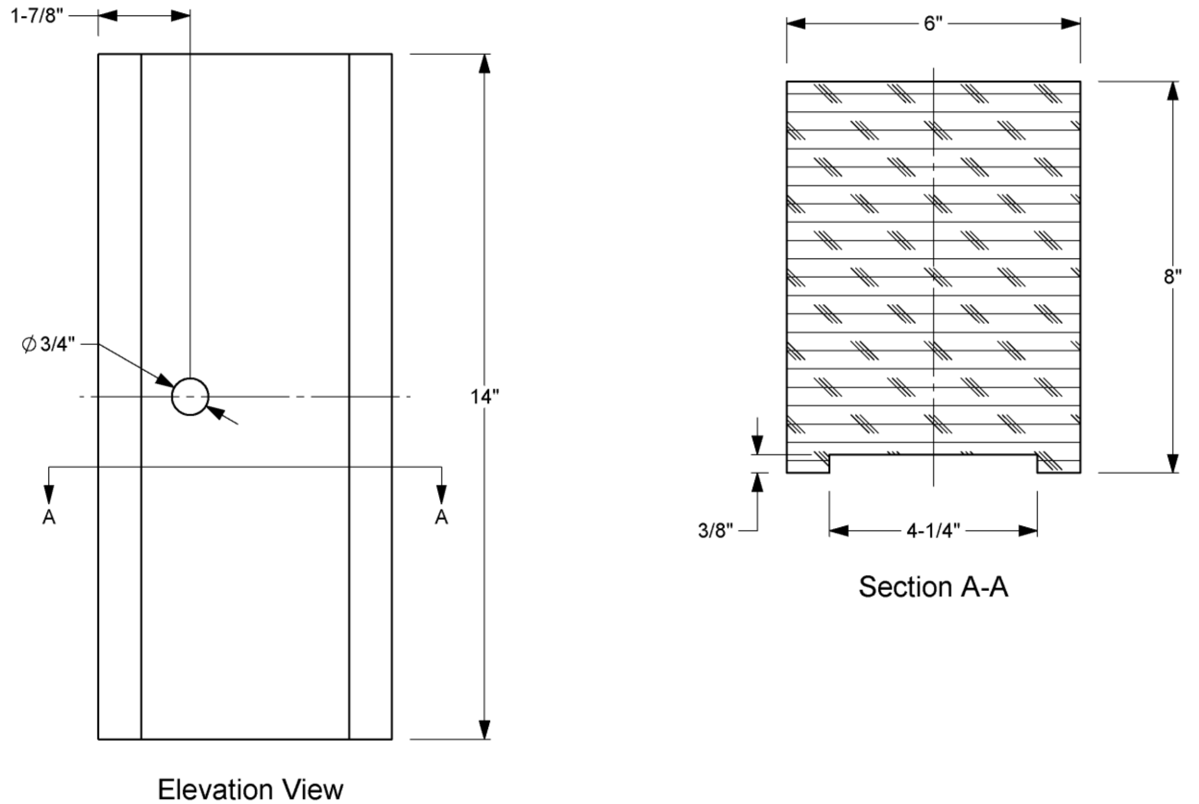
72" Wide Flange Guardrail Post



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

Timber Blockout for W-section Post

All dimensions except hole diameter are nominal



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

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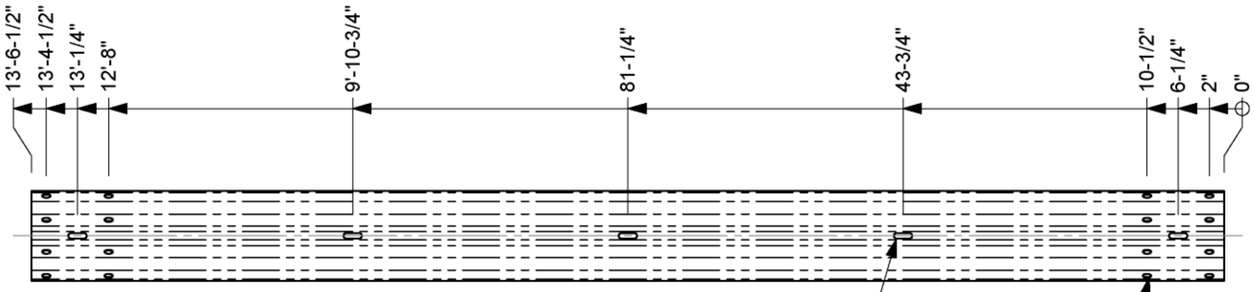
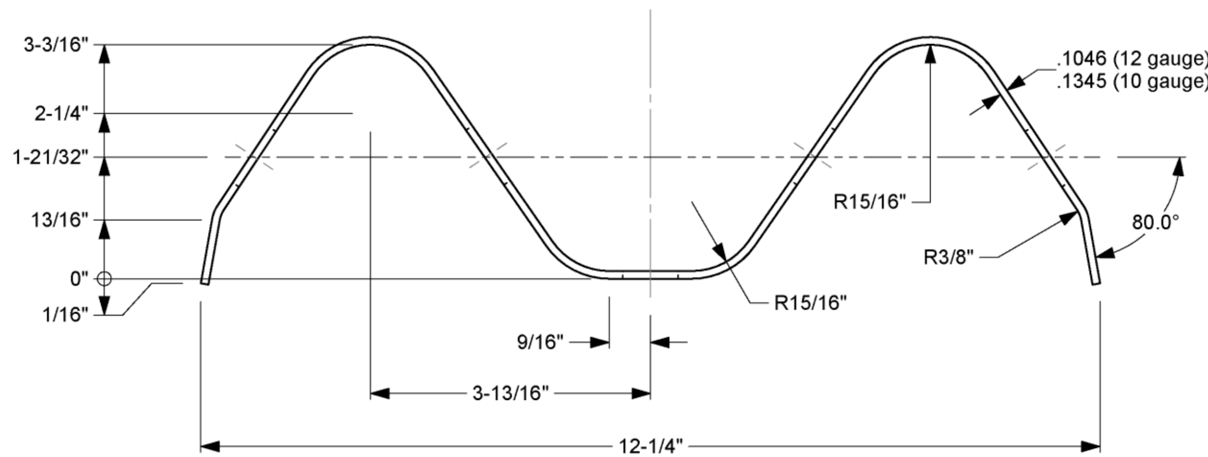


Elevation View



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	
W-beam Guardrail		2022-07-13
Drawn by GES	Scale 1:20	Sheet 1 of 1

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

APPENDIX C. SUPPORTING CERTIFICATION DOCUMENTS

Certified Analysis

619441

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

Project: STOCK

Order Number: 1360179
Prod Ln Grp: 0-OE2.0
Customer PO: 619441
BOL Number: 91829
Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/16/23

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn
15	11G	12/12'6/3'1.5/S			2	F11823												
			M-180	A	2	AA8107	59,700	86,800	21.0	0.210	0.490	0.007	0.001	0.020	0.013	0.000	0.090	0.002
			M-180	A	2	AA8108	56,700	80,000	24.0	0.210	0.480	0.007	0.002	0.020	0.120	0.001	0.090	0.002
			M-180	A	2	AA8110	62,400	86,800	20.0	0.230	0.470	0.008	0.002	0.020	0.110	0.000	0.090	0.002
			M-180	A	2	AA8112	62,800	84,400	23.0	0.210	0.480	0.006	0.002	0.030	0.120	0.000	0.080	0.003
	11G				2	F11923												
					2	287476												
					2	288226												
					2	288238												
			M-180	A	2	AA8107	59,700	86,800	21.0	0.210	0.490	0.007	0.001	0.020	0.013	0.000	0.090	0.002
			M-180	A	2	AA8110	62,400	86,800	20.0	0.230	0.470	0.008	0.002	0.020	0.110	0.000	0.090	0.002
			M-180	A	2	AA8112	62,800	84,400	23.0	0.210	0.480	0.006	0.002	0.030	0.120	0.000	0.080	0.003
	11G				2	F12223												
					2	288226												
					2	288237												
					2	288238												
					2	288239												
			M-180	A	2	AA8110	62,400	86,800	20.0	0.230	0.470	0.008	0.002	0.020	0.110	0.000	0.090	0.002
			M-180	A	2	EA3750	57,100	80,000	23.0	0.190	0.500	0.014	0.002	0.020	0.140	0.000	0.050	0.002
	11G				2	F12323												
					2	288226												
					2	288239												
			M-180	A	2	AA8471	59,100	81,200	20.0	0.200	0.460	0.007	0.001	0.030	0.090	0.000	0.050	0.002
			M-180	A	2	CA7527	58,900	80,300	19.0	0.200	0.490	0.007	0.003	0.030	0.120	0.000	0.070	0.002
28	533G	6'0 POST/8.5/DDR/7	A-36			1114803	54,500	67,500	28.3	0.070	0.840	0.007	0.022	0.230	0.130	0.015	0.040	0.002

Certified Analysis

619441

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

Project: STOCK

Order Number: 1360179 Prod Ln Grp: 0-OE2.0
Customer PO: 619441
BOL Number: 91829 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/16/23

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn
	533G		A-36			2104723	54,000	66,200	26.0	0.070	80.000	0.013	0.020	0.200	0.100	0.014	0.040	0.002
	533G		A-709			59110730	59,045	72,898	23.3	0.090	0.860	0.012	0.024	0.220	0.250	0.013	0.150	0.001
125	3340G	5/8" GR HEX NUT	FAST			23-54-013												
100	3360G	5/8"X1.25" GR BOLT	A307-3360G			A69106-2												
25	3500G	5/8"X10" GR BOLT A307	A307-3500G			A44446-5												
26	4076B	WD BLK RTD 6X8X14	WOOD			4850												

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

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

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

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

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

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

Certified Analysis

619441

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

Project: STOCK

Order Number: 1360179 Prod Ln Grp: 0-OE2.0
Customer PO: 619441
BOL Number: 91829 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/16/23

State of Texas, County of Tarrant. Sworn and subscribed before me this 16th day of August, 2023 .

Notary Public:
Commission Expires: / /

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

Angela Ruth Humphrey

Valtir, LLC
Certified By: Luis Ortiz
Quality Assurance

Certified Analysis

VALTIR

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

619441

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

Project: STOCK

Order Number: 1358753 Prod Ln Grp: 0-OE2.0
Customer PO: 619441
BOL Number: 91312 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 6/19/23

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn
12	533G	6'0 POST/8.5/DDR/7	A-36			1114803	54,500	67,500	28.3	0.070	0.840	0.007	0.022	0.230	0.130	0.015	0.040	0.002
	533G		A-36			2104723	54,000	66,200	26.0	0.070	80.000	0.013	0.020	0.200	0.100	0.014	0.040	0.002
	533G					VF1923B												
			A-709			59110729	58,770	71,691	22.7	0.070	0.840	0.011	0.031	0.220	0.260	0.013	0.014	0.001
			A-709			59110730	59,045	72,898	23.3	0.090	0.860	0.012	0.024	0.220	0.250	0.013	0.150	0.001
			A-709			59110732	58,972	73,363	23.3	0.080	0.950	0.013	0.021	0.220	0.029	0.011	0.150	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.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

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

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

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

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

Certified Analysis

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

Project: STOCK

Order Number: 1358753 Prod Ln Grp: 0-OE2.0

Customer PO: 619441

BOL Number: 91312 Ship Date:

Document #: 1

Shipped To: TX

Use State: TX

As of: 6/19/23

State of Texas, County of Tarrant. Sworn and subscribed before me this 19th day of June, 2023 .

Notary Public:
Commission Expires:

MARIANA GISELA SALINAS
Notary Public, State of Texas
Comm. Expires 03-16-2027
Notary ID 134255660

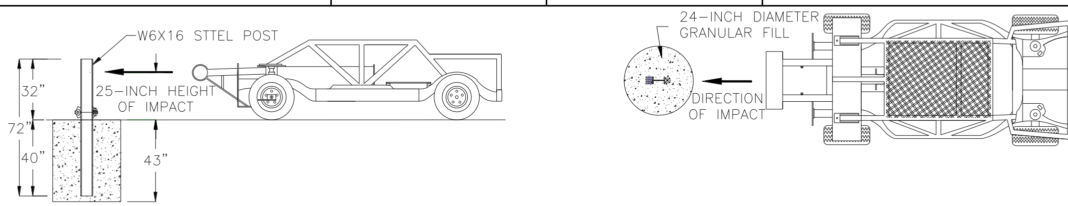
Valtir, LLC
Certified By:
Quality Assurance


Dynamic Test Setup

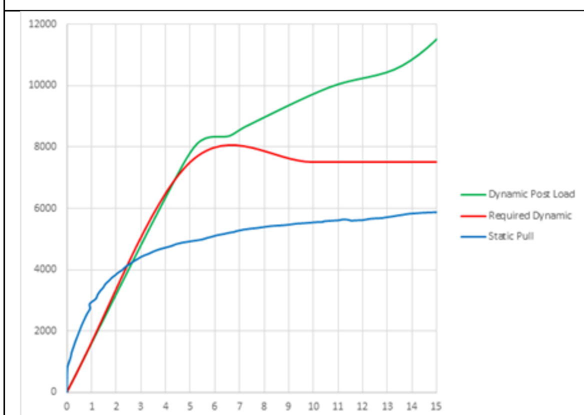

Post-Test Photo of post


Static Load Test

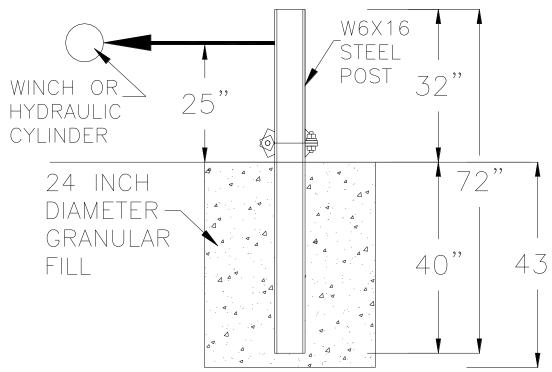

Post-Test Photo



Dynamic Test Installation Details



Comparison of Load vs. Displacement



Static Load Test Installation Details

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

Figure C.1. Baseline Soil Properties Test

APPENDIX D. *MASH* TEST 3-10 (CRASH TEST 619441-01-9)

D.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2023-10-03 Test No.: 619441-01-9 VIN No.: 3N1CN7AP1JK397427

Year: 2018 Make: Nissan Model: Versa

Tire Inflation Pressure: 36 PSI Odometer: 135216 Tire Size: P185/65R15

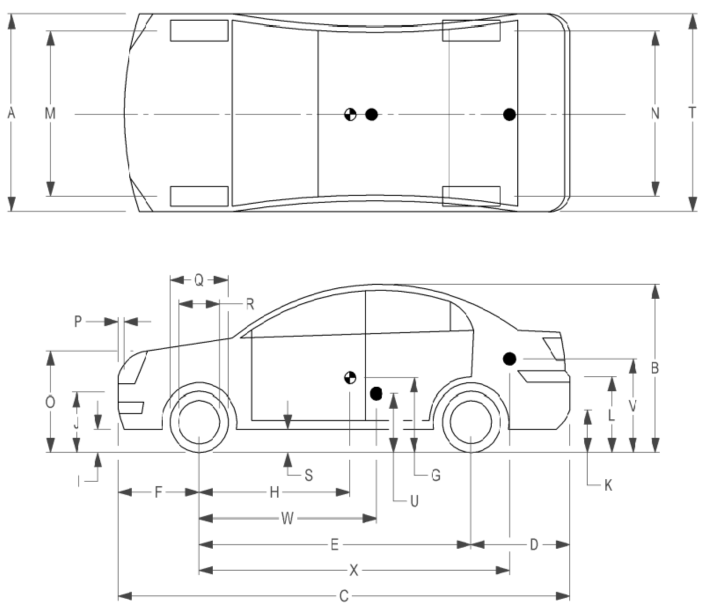
Describe any damage to the vehicle prior to test: None

● 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:



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	41.08	M	58.30	R	16.25	W	41.00
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 -0.08

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}	1426	1455	1540
Back	1687	M_{rear}	981	975	1055
Total	3389	M_{Total}	2407	2430	2595

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

Mass Distribution:
lb LF: 760 RF: 695 LR: 460 RR: 515

Figure D.1. Vehicle Properties for Test 619441-01-9.

Date:	2023-10-03	Test No.:	619441-01-9	VIN No.:	3N1CN7AP1JK397427
Year:	2018	Make:	Nissan	Model:	Versa

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FRONT BUMPER	10	8	31	-	-	-	-	-	-	+12
2	ABOVE FT BUMPER	25	9	43	-	-	-	-	-	-	60
	Measurements recorded										
	☑ **inches** **or** ☐ **mm**										

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

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

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

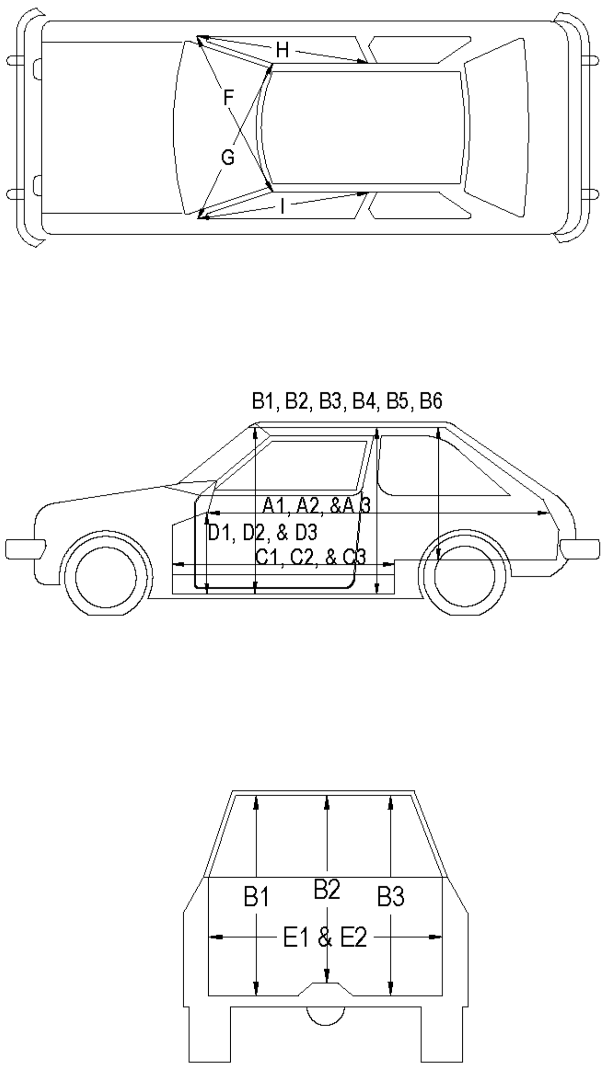
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Figure D.2. Exterior Crush Measurements for Test 619441-01-9.

Date:	2023-10-03	Test No.:	619441-01-9	VIN No.:	3N1CN7AP1JK397427
Year:	2018	Make:	Nissan	Model:	Versa



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

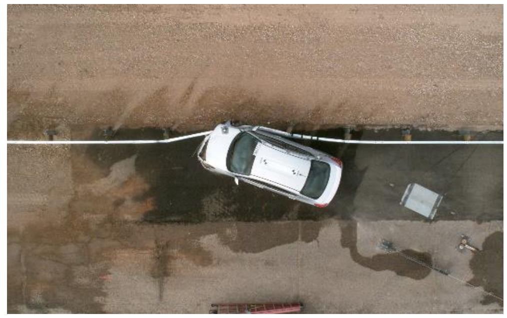
	Before	After (inches)	Differ.
A1	67.50	67.50	0.00
A2	67.25	67.25	0.00
A3	67.75	67.75	0.00
B1	40.50	40.50	0.00
B2	39.00	39.00	0.00
B3	40.50	40.50	0.00
B4	36.25	36.25	0.00
B5	36.00	36.00	0.00
B6	36.25	36.25	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00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

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

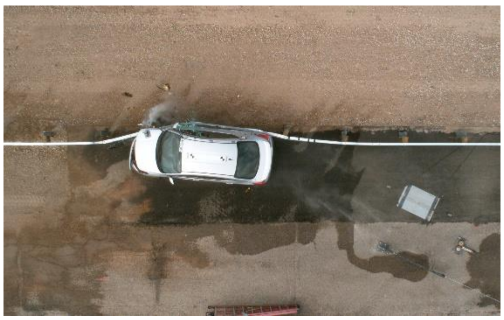
Figure D.3. Occupant Compartment Measurements for Test 619441-01-9.

D.2. SEQUENTIAL PHOTOGRAPHS

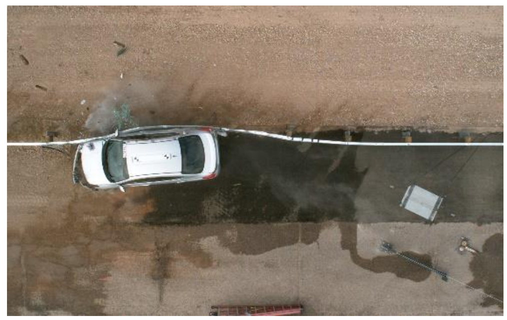
(a) 0.000 s



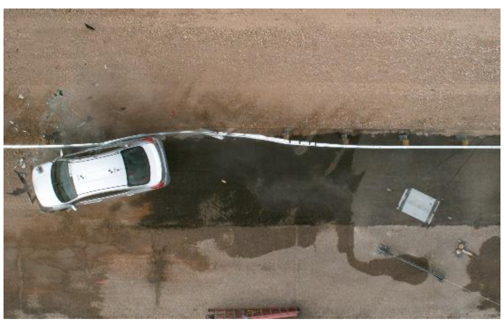
(b) 0.100 s



(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 619441-01-9 (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 619441-01-9 (Frontal Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

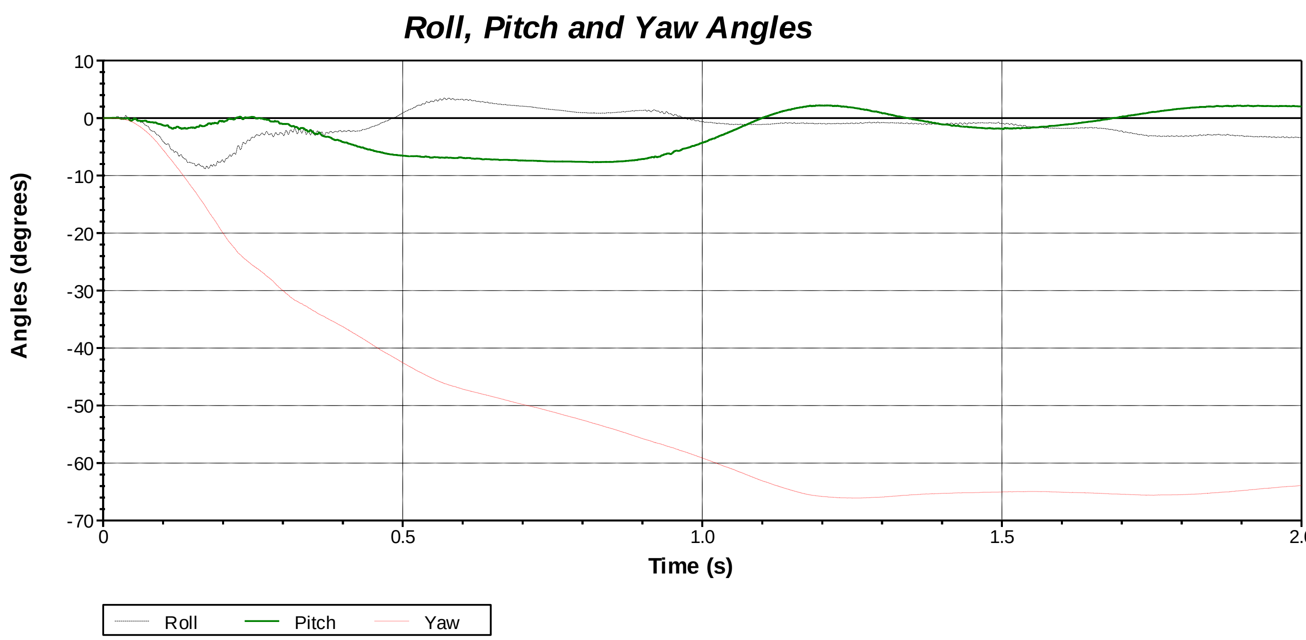
(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

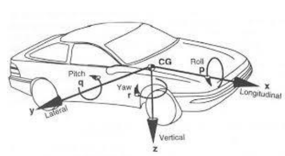
Figure D.6. Sequential Photographs for Test 619441-01-9 (Rear Views).

D.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 619441-01-09
Test Standard Test Number: *MASH* Test 3-10
Test Article: Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment
Test Vehicle: 2018 Nissan Versa
Inertial Mass: 2430 lbs
Gross Mass: 2595 lbs
Impact Speed: 62.1 mi/h
Impact Angle: 25 °

Figure D.7. Vehicle Angular Displacements for Test 619441-01-9.

D.4. VEHICLE ACCELERATIONS

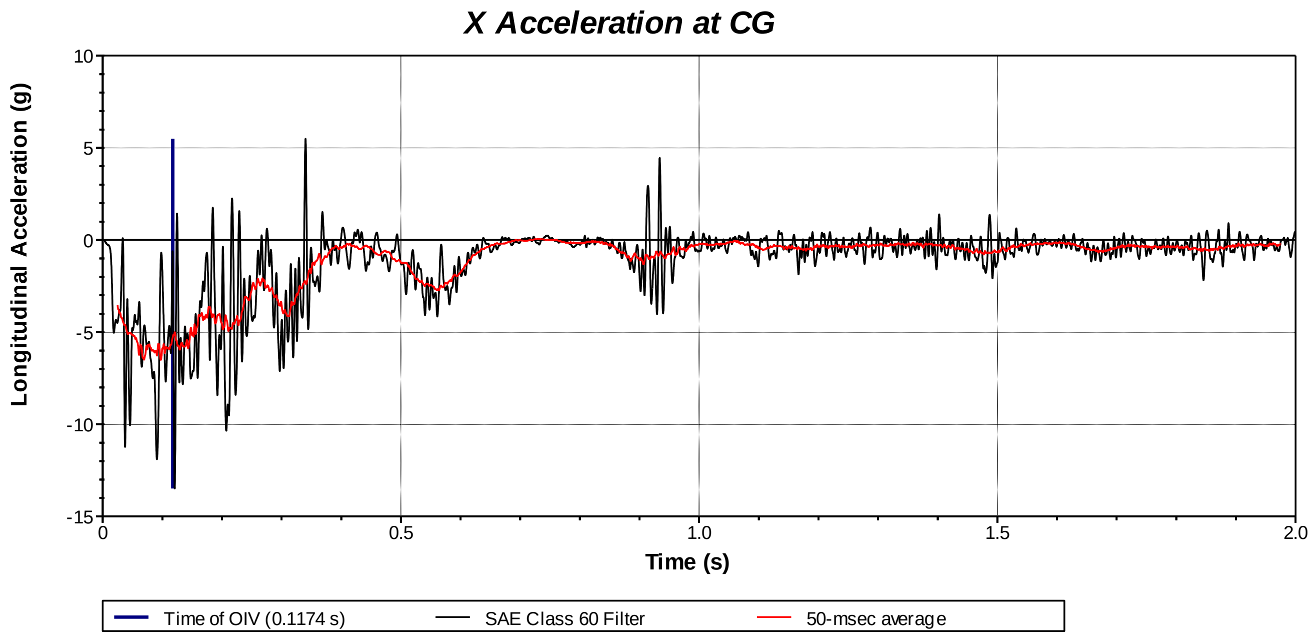


Figure D.8. Vehicle Longitudinal Accelerometer Trace for Test 619441-01-9 (Accelerometer Located at Center of Gravity).

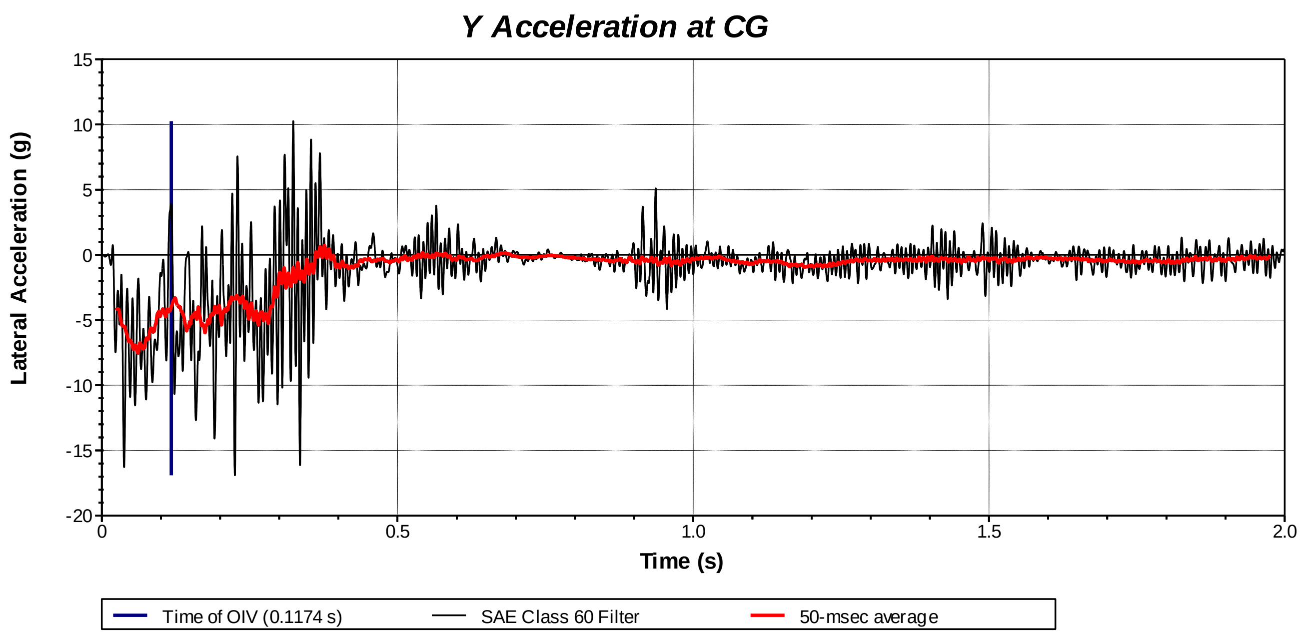


Figure D.9. Vehicle Lateral Accelerometer Trace for Test 619441-01-9 (Accelerometer Located at Center of Gravity).

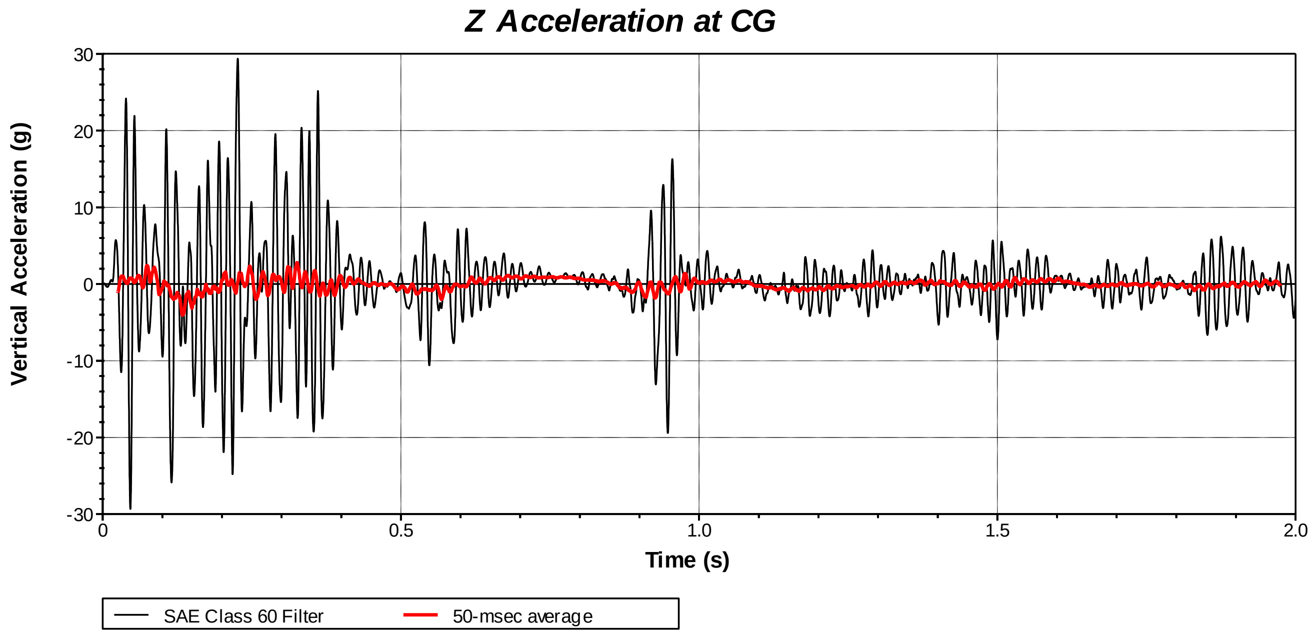


Figure D.10. Vehicle Vertical Accelerometer Trace for Test 619441-01-9 (Accelerometer Located at Center of Gravity).

APPENDIX E. *MASH* TEST 3-11 (CRASH TEST 619441-01-10)

E.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2023-10-18 Test No.: 619441-01-10 VIN No.: 1C6RR6FT1KS561419

Year: 2019 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 108867

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

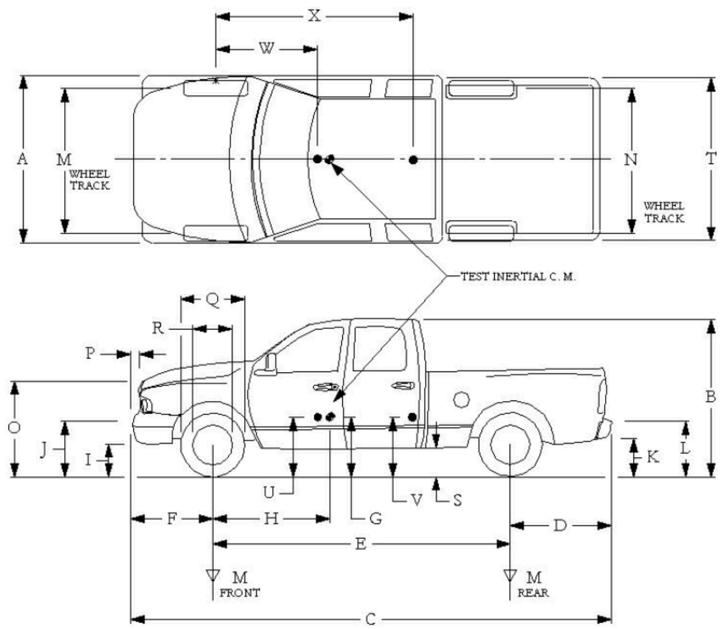
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

Dummy Data:
Type:
Mass:
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.75	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.22	M	68.50	R	18.00	W	61.00
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}	2941	2849	2849
Back	3900	M_{rear}	2111	2200	2200
Total	6700	M_{Total}	5052	5049	5049

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

Mass Distribution:
lb LF: 1423 RF: 1426 LR: 1138 RR: 1062

Figure E.1. Vehicle Properties for Test 619441-01-10.

Date:	2023-10-18	Test No.:	619441-01-10	VIN No.:	1C6RR6FT1KS561419
Year:	2019	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	AT FRONT BUMPER	19	15	28	-	-	-	-	-	-	+15
2	AT FRONT DUMPER	19	13	58	-	-	-	-	-	-	76
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

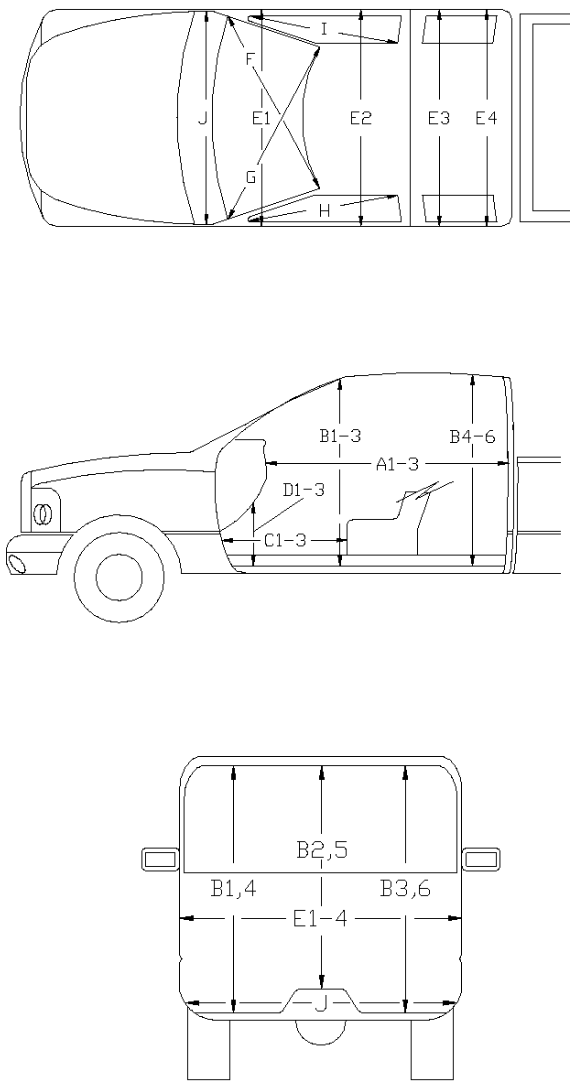
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Figure E.2. Exterior Crush Measurements for Test 619441-01-10.

Date:	2023-10-18	Test No.:	619441-01-10	VIN No.:	1C6RR6FT1KS561419
Year:	2019	Make:	RAM	Model:	1500



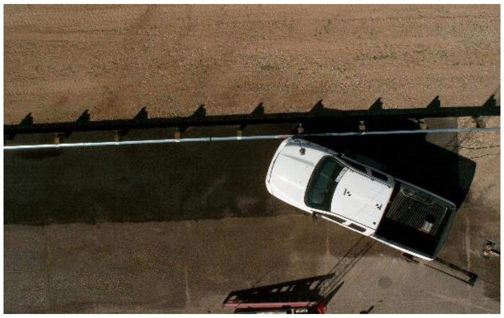
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

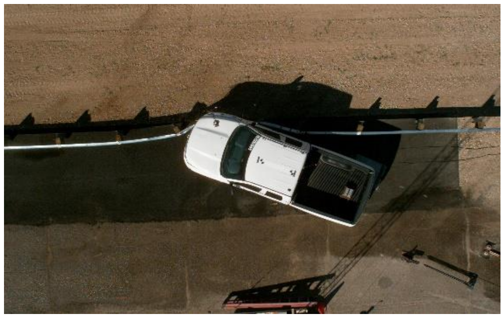
	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00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

Figure E.3. Occupant Compartment Measurements for Test 619441-01-10.

E.2. SEQUENTIAL PHOTOGRAPHS



(a) 0.000 s



(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure E.4. Sequential Photographs for Test 619441-01-10 (Overhead Views).

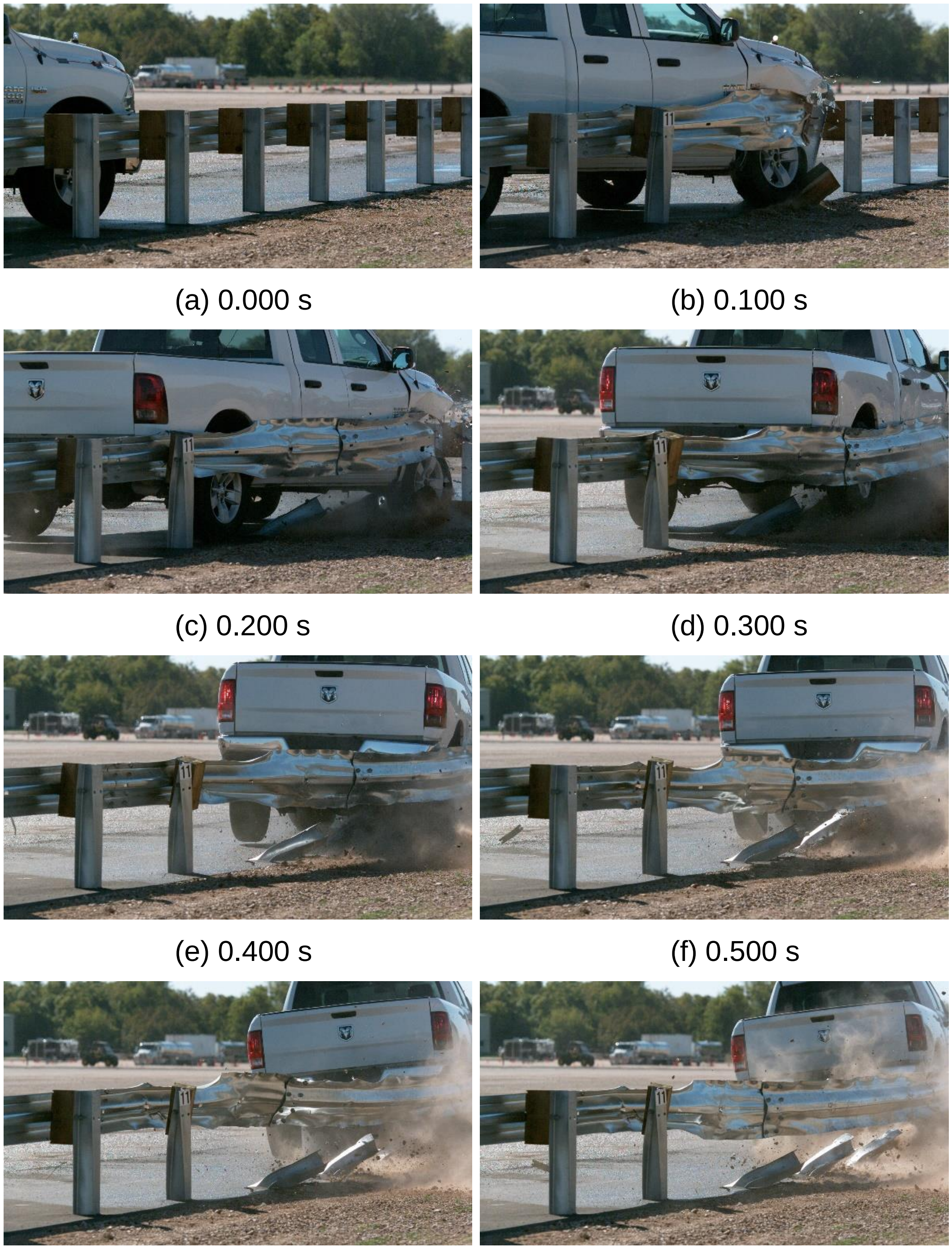

(a) 0.000 s (b) 0.100 s


(c) 0.200 s (d) 0.300 s


(e) 0.400 s (f) 0.500 s


(g) 0.600 s (h) 0.700 s

Figure E.5. Sequential Photographs for Test 619441-01-10 (Frontal Views).



(a) 0.000 s (b) 0.100 s

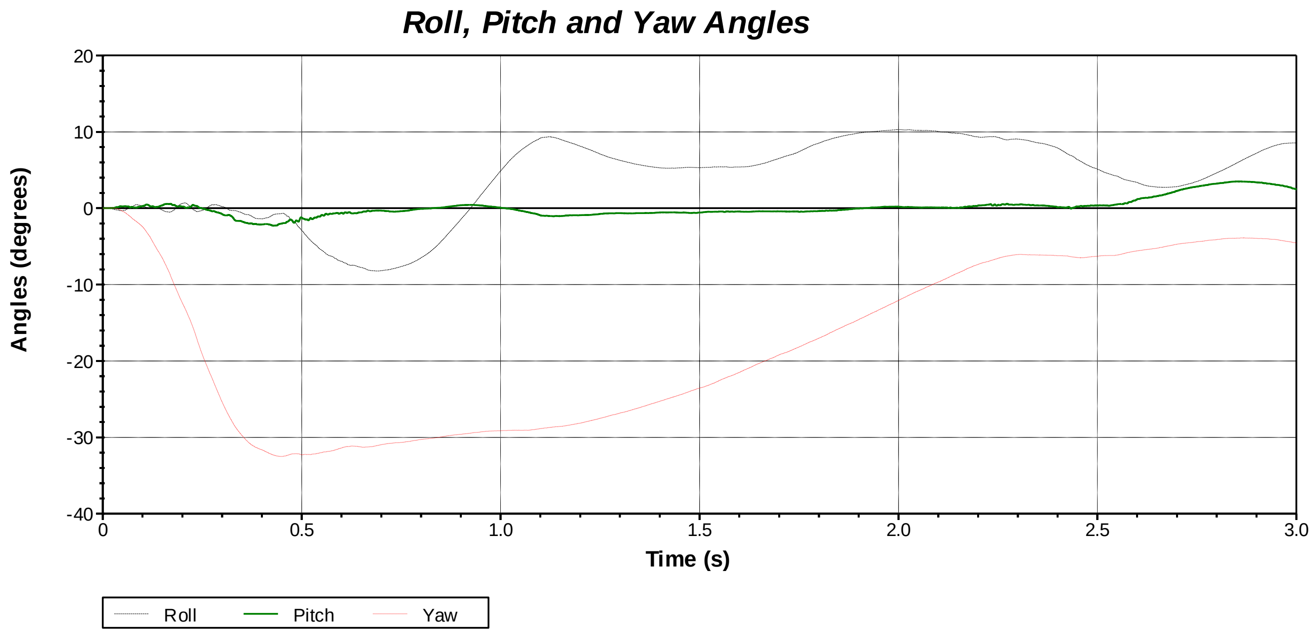
(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

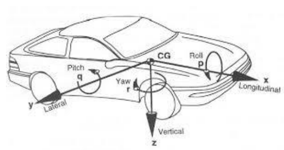
Figure E.6. Sequential Photographs for Test 619441-01-10 (Rear Views).

E.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 619441-01-10
Test Standard Test Number: *MASH* Test 3-11
Test Article: Steel Post W-beam Guardrail in Asphalt Vegetation Control Treatment
Test Vehicle: 2019 RAM 1500
Inertial Mass: 5049 lbs
Gross Mass: 5049 lbs
Impact Speed: 61.2 mi/h

Figure E.7. Vehicle Angular Displacements for Test 619441-01-10.

E.4. VEHICLE ACCELERATIONS

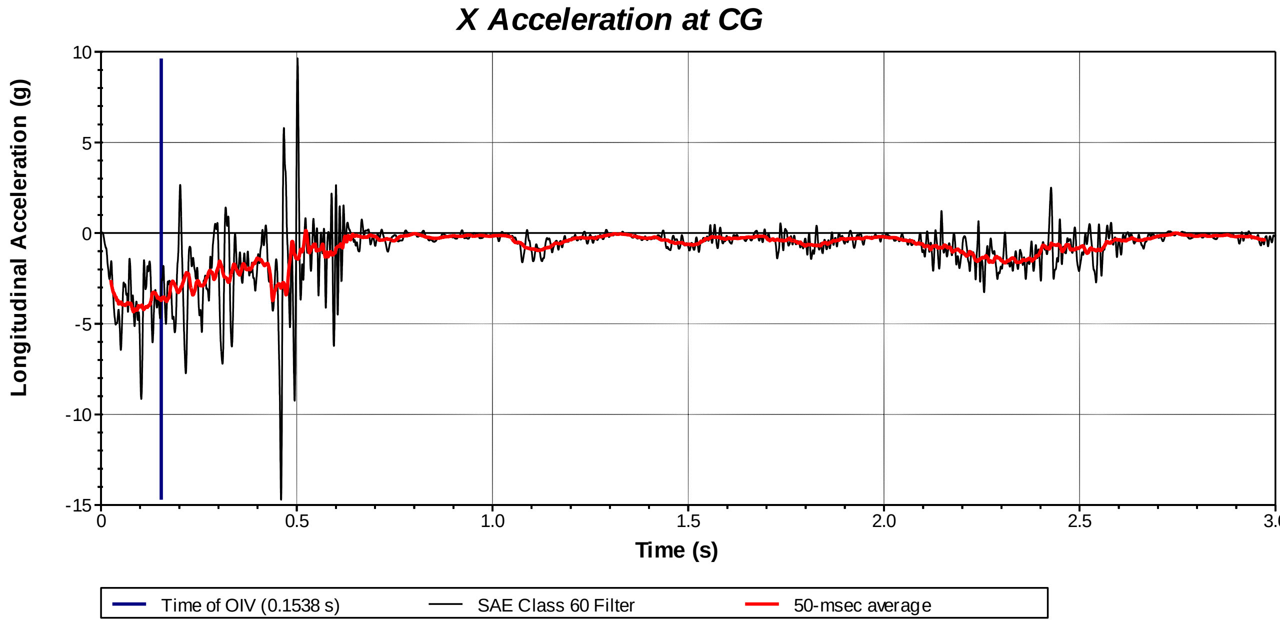


Figure E.8. Vehicle Longitudinal Accelerometer Trace for Test 619441-01-10 (Accelerometer Located at Center of Gravity).

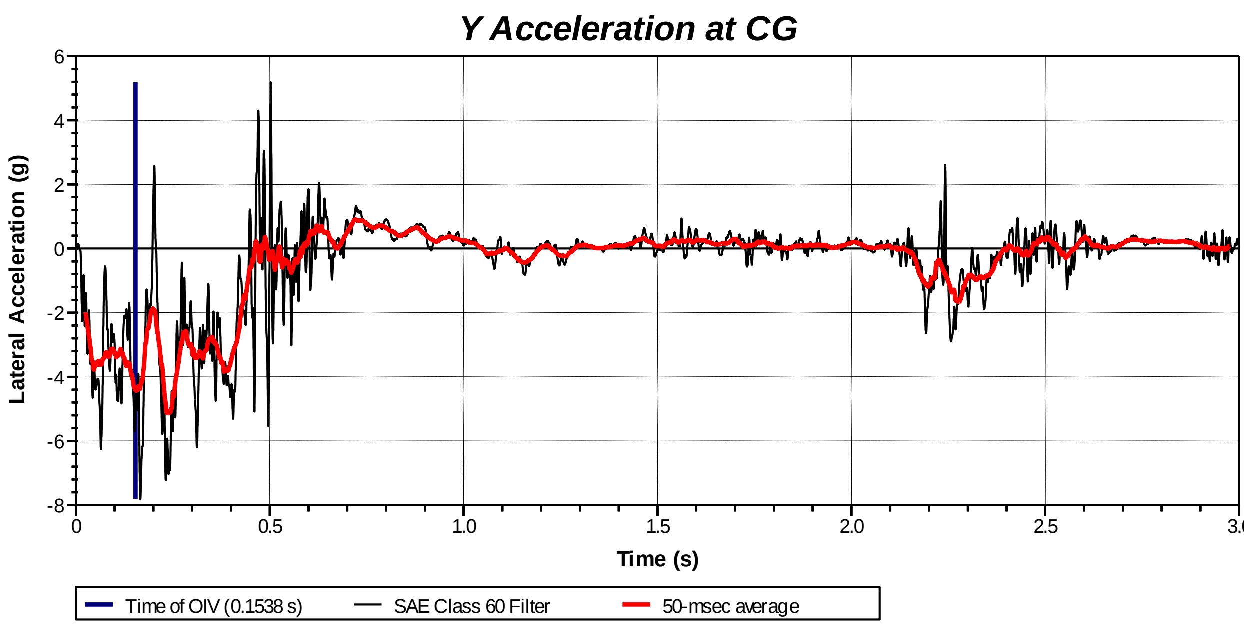


Figure E.9. Vehicle Lateral Accelerometer Trace for Test 619441-01-10 (Accelerometer Located at Center of Gravity).

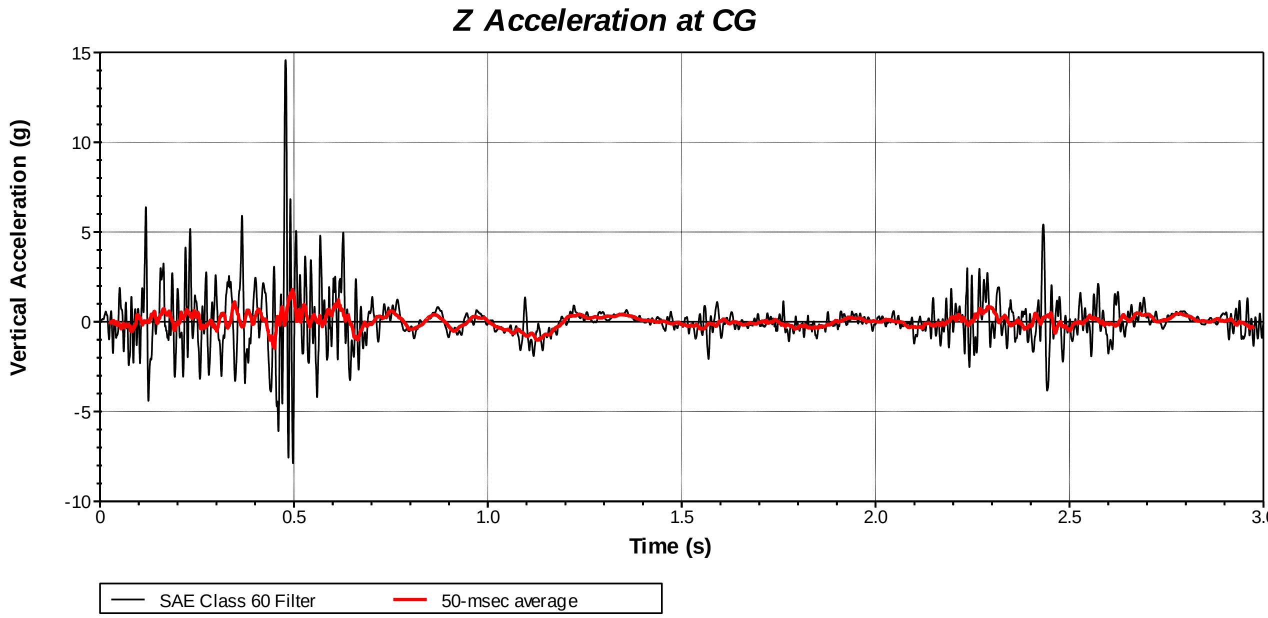


Figure E.10. Vehicle Vertical Accelerometer Trace for Test 619441-01-10 (Accelerometer Located at Center of Gravity).