Design and *MASH* TL-3 Evaluation of Surface Mounted Median Guardrail

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DESIGN AND *MASH* TL-3 EVALUATION OF SURFACE MOUNTED MEDIAN GUARDRAIL

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16. Abstract

This report presents the development and crash testing of a surface-mounted median guardrail on concrete. The research team developed several preliminary design concepts of the median guardrail. One of these was selected by the Texas Department of Transportation for further development through finite element simulation analysis and full-scale crash testing. The safety performance of the final design of the surface-mounted median guardrail was evaluated in accordance with the guidelines included in the American Association of State Highway and Transportation Officials *Manual for Assessing Safety Hardware* (*MASH*), Second Edition (*1*). The design was evaluated for Test Level 3 (TL-3) of *MASH*, for which the following two crash tests were performed.

1. ***MASH* Test 3-10:** An 1100C small passenger sedan weighing 2420 lb, impacting the median guardrail while traveling at a speed and angle of 62 mi/h and 25 degrees.
2. ***MASH* Test 3-11:** A 2270P pickup truck weighing 5000 lb, impacting the median guardrail while traveling at a speed and angle of 62 mi/h and 25 degrees.

The new surface-mounted median guardrail design passed the *MASH* evaluation criteria for both tests. This report provides details on the surface-mounted median guardrail, the crash tests and results, and the performance assessment of the median guardrail using the evaluation criteria of *MASH* TL-3 for longitudinal barriers.

17. Key Words Median Rail, Longitudinal Barrier, Crash Testing, Roadside Safety, *MASH*	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia 22312 http://www.ntis.gov

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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		
in2	square inches	645.2	square millimeters	mm2
ft2	square feet	0.093	square meters	m2
yd2	square yards	0.836	square meters	m2
ac	acres	0.405	hectares	ha
mi2	square miles	2.59	square kilometers	km2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft3	cubic feet	0.028	cubic meters	m3
yd3	cubic yards	0.765	cubic meters	m3
	NOTE: volumes greater than 1000L shall be shown in m3			
		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/in2	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		
mm2	square millimeters	0.0016	square inches	in2
m2	square meters	10.764	square feet	ft2
m2	square meters	1.195	square yards	yd2
ha	hectares	2.47	acres	ac
km2	square kilometers	0.386	square miles	mi2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m3	cubic meters	35.314	cubic feet	ft3
m3	cubic meters	1.307	cubic yards	yd3
		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/in2

*SI is the symbol for the International System of Units

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1. INTRODUCTION

Concrete median barriers are commonly used in areas that have high average daily traffic, or where there is a higher chance of a vehicle intruding into opposing lanes due to curves or other geometric features. Concrete barriers are generally expensive to construct, and a metal-rail median guardrail has the potential to reduce construction costs. In many urban and high-traffic-volume roadways, a median with soil is not available. This limits the use of existing guardrail systems since they require metal posts that are embedded in soil. The goal of this project was to develop a metal-rail median guardrail that can be mounted directly on concrete pavement. Such a design will allow the Texas Department of Transportation (TxDOT) to protect opposing traffic in many areas where it was previously cost prohibitive to do so with concrete median barriers.

The research team developed several concepts of the surface-mounted median guardrail for TxDOT's review. One of these concepts was selected for further development through a series of component-level dynamic impact testing and finite element (FE) simulations. The research team developed a full-system model of the guardrail and performed vehicle impact simulations to determine the likelihood that the design would meet *Manual for Assessing Safety Hardware* (*MASH*) testing requirements (*1*). Once this full-system design was reviewed and approved by TxDOT, the research team conducted *MASH* Test 3-11 and Test 3-10 with a pickup truck and a small passenger car, respectively, to verify the performance of the new surface-mounted median barrier design.

Details of the preliminary conceptual designs, component-level dynamic impact testing, and FE simulation analysis are presented in Chapter 2 of this report. Chapter 3 presents the details of the surface-mounted median guardrail design that was crash tested. Subsequent chapters present details of the *MASH* crash testing and results.

Chapter 2. DESIGN AND SIMULATION ANALYSES

This chapter presents the work performed by the research team to arrive at the final design of the surface-mounted median barrier system. The design process was comprised of conceptual design, subcomponent testing using a surrogate bogie vehicle, and FE simulations of dynamic vehicle impacts with the barrier model using *MASH* test conditions. Details of activities are presented below.

2.1. CONCEPTUAL DESIGN

The research team developed three preliminary design concepts and reviewed them in conjunction with TxDOT to select concepts for further development through simulation and testing. Two of the concepts developed were based on the Midwest Guardrail System (MGS) median barrier system design with posts installed in soil. One other concept was based on TxDOT's T631 weak-post at-grade bridge rail design. All three of these systems have previously passed *MASH* Test Level 3 (TL-3) and provided a good basis for the design of the surface-mounted median barrier. Details of the three concepts including key features, advantages, and anticipated challenges.

2.1.1. Concept 1

Figure 2.1 shows the details of Concept 1. Following are some of the key design features, advantages, and anticipated challenges associated with this concept.

- Key Design Features:
  - The post is attached to a baseplate that is bolted to the underlying concrete.
  - Post-to-baseplate connection uses anchors bolted on the baseplate with shear bolts.
  - Shear bolts are to be designed to fail to release the post from the baseplate.
- Advantages:
  - The baseplate and angles should be mostly reusable after impact. Shear bolts would need to be replaced.
  - 6-ft 3-inch standard W-beam post spacing is used.
- Challenges:
  - Design process needed to include determination of suitable shear bolt and angle sizes.
  - The baseplates need threaded holes for angles.

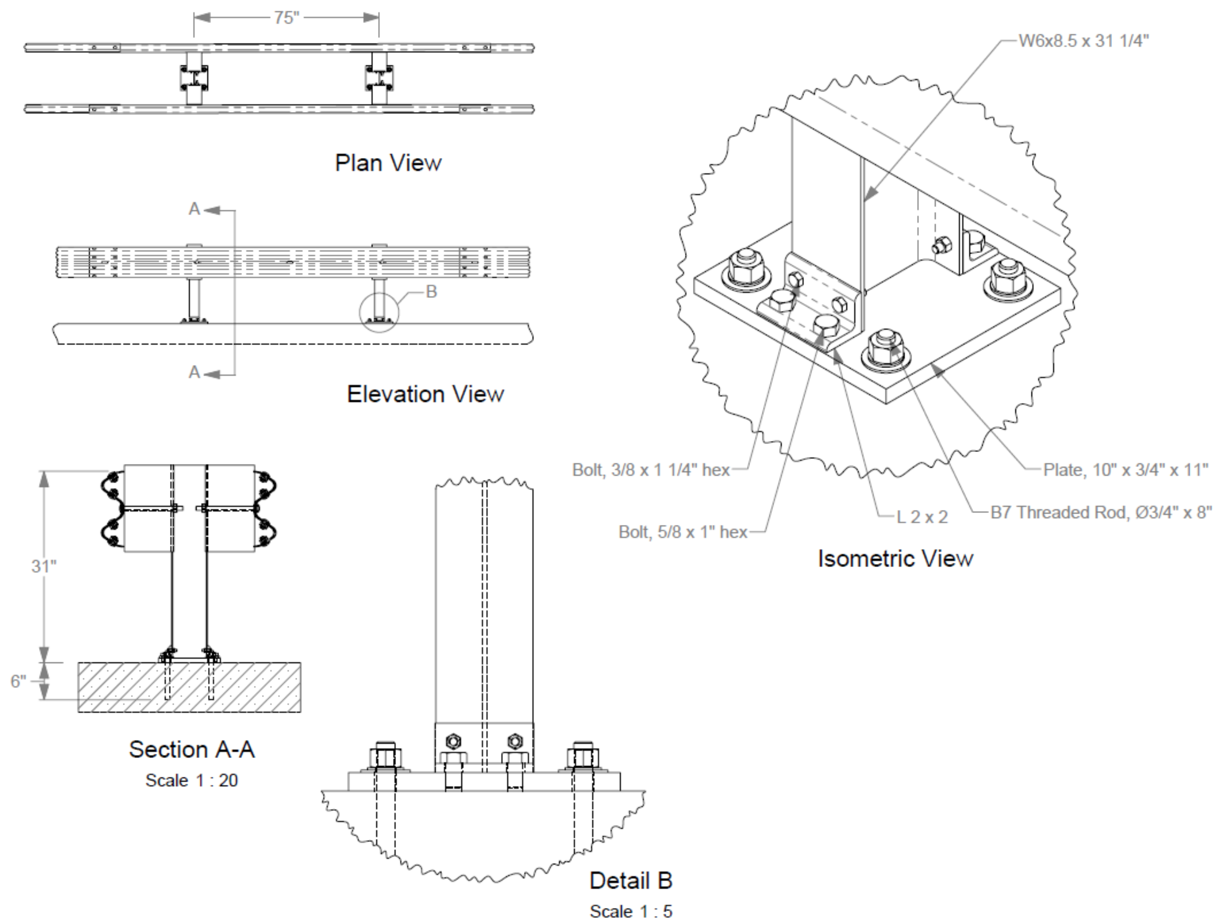


Figure 2.1. Details of Design Concept 1.

2.1.2. Concept 2

Figure 2.2 shows the details of Concept 2. Following are some of the key design features, advantages, and anticipated challenges noted during the review of this concept.

- Key Design Features:
  - Posts are welded to a baseplate that is epoxied to the underlying concrete.
  - Half-post spacing is used compared to the standard strong-post W-beam guardrail.
  - Design does not need wood blockouts between the rail and the post.
- Advantages:
  - Surface-mounted performance of the roadside bridge rail version of this system had passed *MASH* (*2*).
  - Transition between the weak-post to the strong-post W-beam was relatively straightforward. Half-post spacing of the weak post is considered approximately equivalent to the full-post spacing of the strong-post W-beam guardrail (*3*).
- Challenges:
  - More posts and baseplates are needed due to the half-post spacing.
  - Anchors attaching the baseplates to the concrete were expected to be reusable, but the baseplates would need to be replaced after impact.

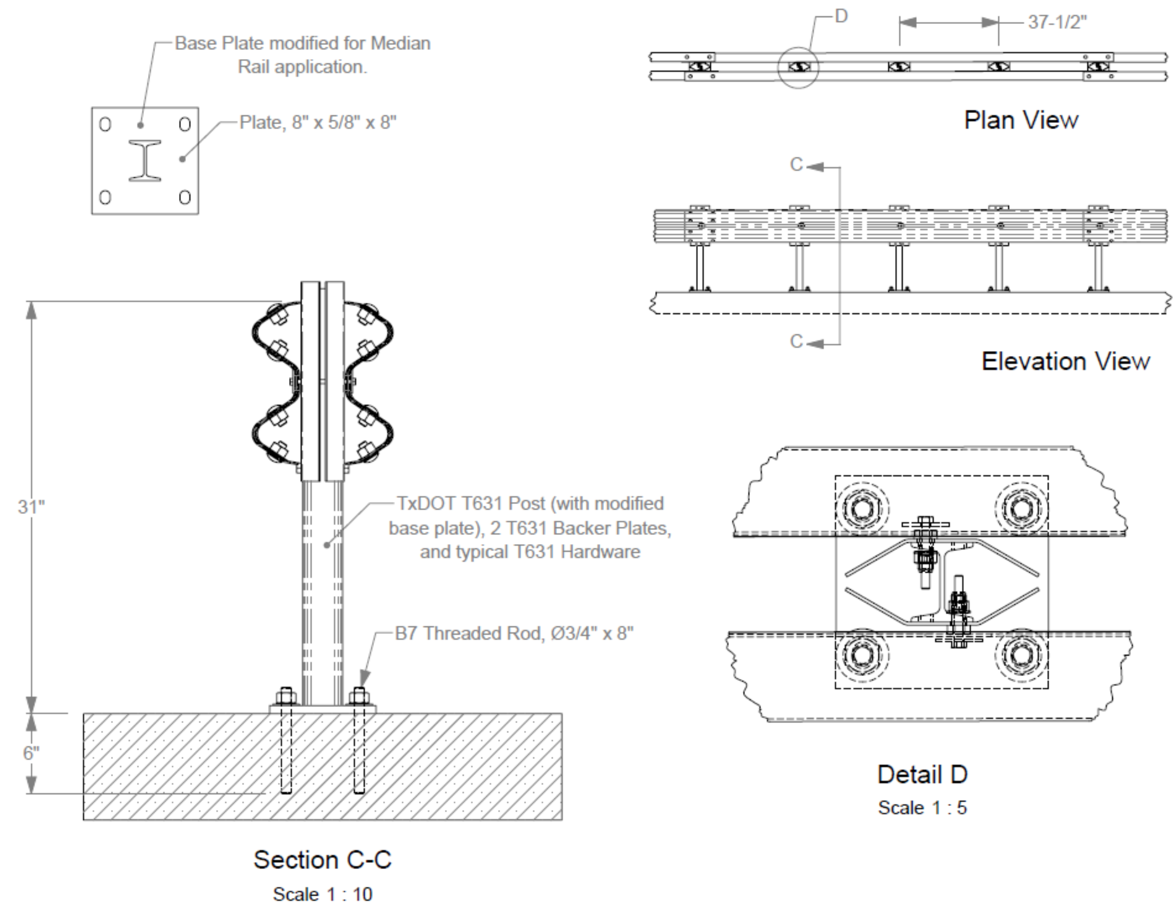


Figure 2.2. Details of Design Concept 2.

2.1.3. Concept 3

Figure 2.3 shows the details of Concept 3. Following are some of the key design features, advantages, and anticipated challenges noted during the review of this concept.

- Key Design Features:
  - Posts are attached to a baseplate that is bolted to the underlying concrete with epoxy anchors.
  - Post flanges have elongated slots. Connection to the baseplate is made by bolting flanges to stiff vertical tabs on the baseplate.
  - The post designed to release on impact by tearing the flanges at the slot locations.
- Advantages:
  - The baseplate and stiff tabs are expected to be reusable after a vehicle impact, but the posts would need to be replaced.
  - Threaded holes are not needed (unlike Concept 1).
  - 6-ft 3-inch standard W-beam post spacing is used.

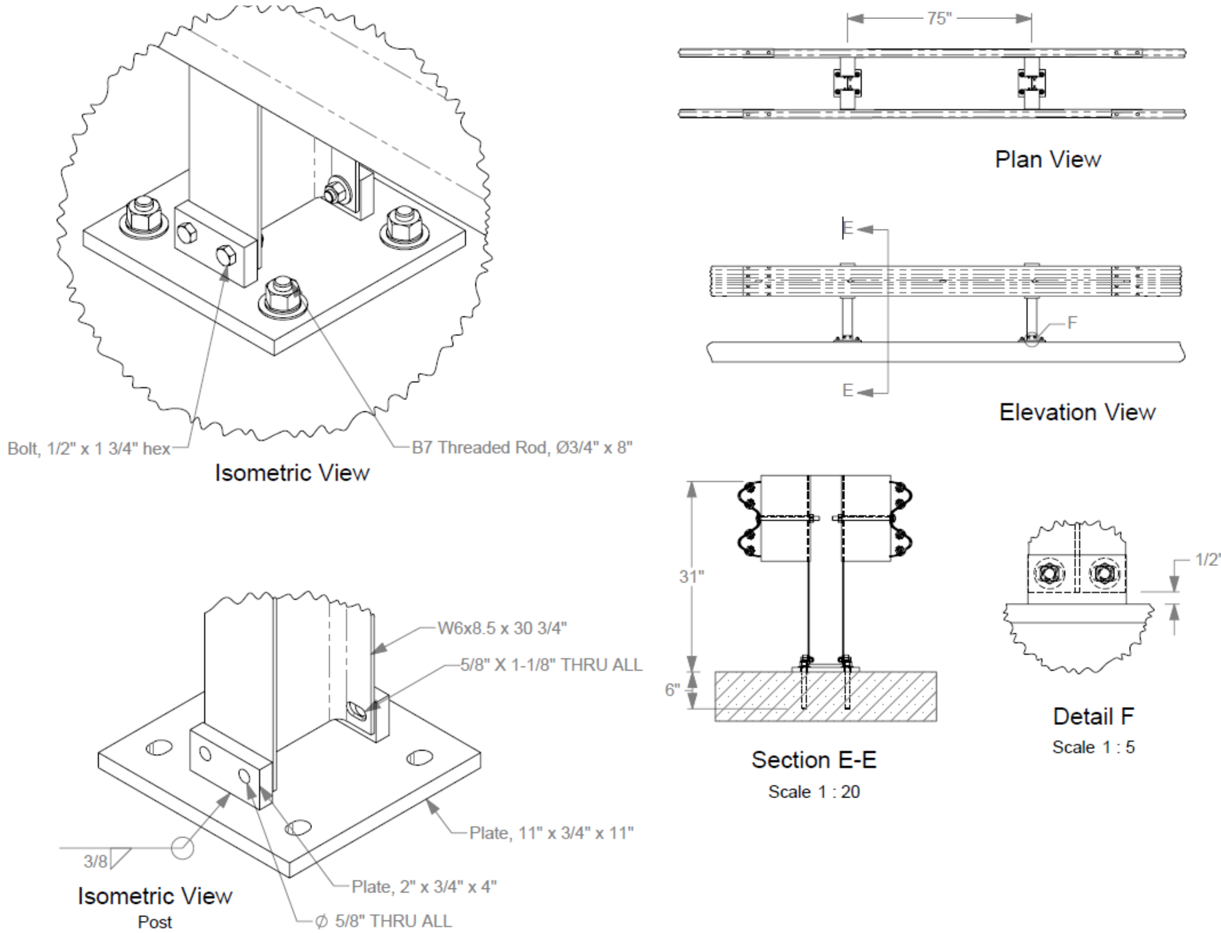


Figure 2.3. Details of Design Concept 3.

2.1.4. Preliminary Design Selection

The concepts described above were presented to TxDOT along with the research team's recommendation. Among the three design concepts, the research team's recommendation was to select Concept 2, the weak-post system, because its surface-mounted performance was better known due to previously successful *MASH* testing of the roadside bridge rail version (TxDOT T631 Bridge Rail) (*2*). Furthermore, a successful design based on this concept would facilitate developing the end transitions by transitioning to the standard strong-post W-beam guardrail system and terminating with *MASH*-compliant end terminals. As mentioned previously, the half-post spacing of a weak-post system is roughly equivalent to the full-post spacing of the strong-post W-beam guardrail (*3*). Thus, the transition from the weak-post to the strong-post W-beam system could be achieved by simply changing to full-post spacing with the W6×8.5 posts.

TxDOT accepted this recommendation, and Concept 2 was approved for further development through simulation analysis and full-scale crash testing.

2.2. COMPONENT-LEVEL TESTING WITH BOGIE VEHICLE

The researchers conducted three component-level impact tests with a surrogate bogie vehicle. These tests were performed to verify the design of the post and baseplate installed on concrete, determine the deflection response of the post and baseplate under dynamic impact load, and determine the overall dynamic response of a short segment of the proposed surface-mounted median guardrail. Results of these tests were also used in developing the FE simulation model of the full guardrail system.

In all tests, the impacting bogie vehicle weighed 2,130 lb and had a rigidized pipe nose (Figure 2.4). Presented next are details of the test articles and results of the component-level testing.

Figure 2.4. Test Bogie Vehicle with Rigidized Pipe Nose.

2.2.1. Test Articles for Component-Level Testing

The three bogie impact tests performed were numbered 440521-01-B1, 440521-01-B2, and 440521-01-B3. The installation for Tests 440521-01-B1 and 440521-01-B2 consisted of two S3×5.7×31⅜ posts welded onto an 8-inch × ⅝-inch × 8-inch baseplate (Figure 2.5). The posts were mounted to a concrete slab measuring 12 ft 6 inches wide, 45 ft long, and 8 inches deep. The installation for Test 440521-01-B3 was a 25-ft section of W-beam median barrier mounted on the same post types and installed on the same concrete pavement. The baseplates were anchored to the concrete pavement using four ¾-inch diameter B7 threaded rods that were each installed with an F844 washer, an F436 washer, and a heavy hex nut. The threaded rods were 8 inches long, of which 6 inches was embedded in concrete and secured with Hilti HIT-RE 500 V3 epoxy. The concrete slab was unreinforced. The specified minimum compressive strength of the concrete was 3,500 psi. The actual compressive strength on the day of all three tests was 5,070 psi.

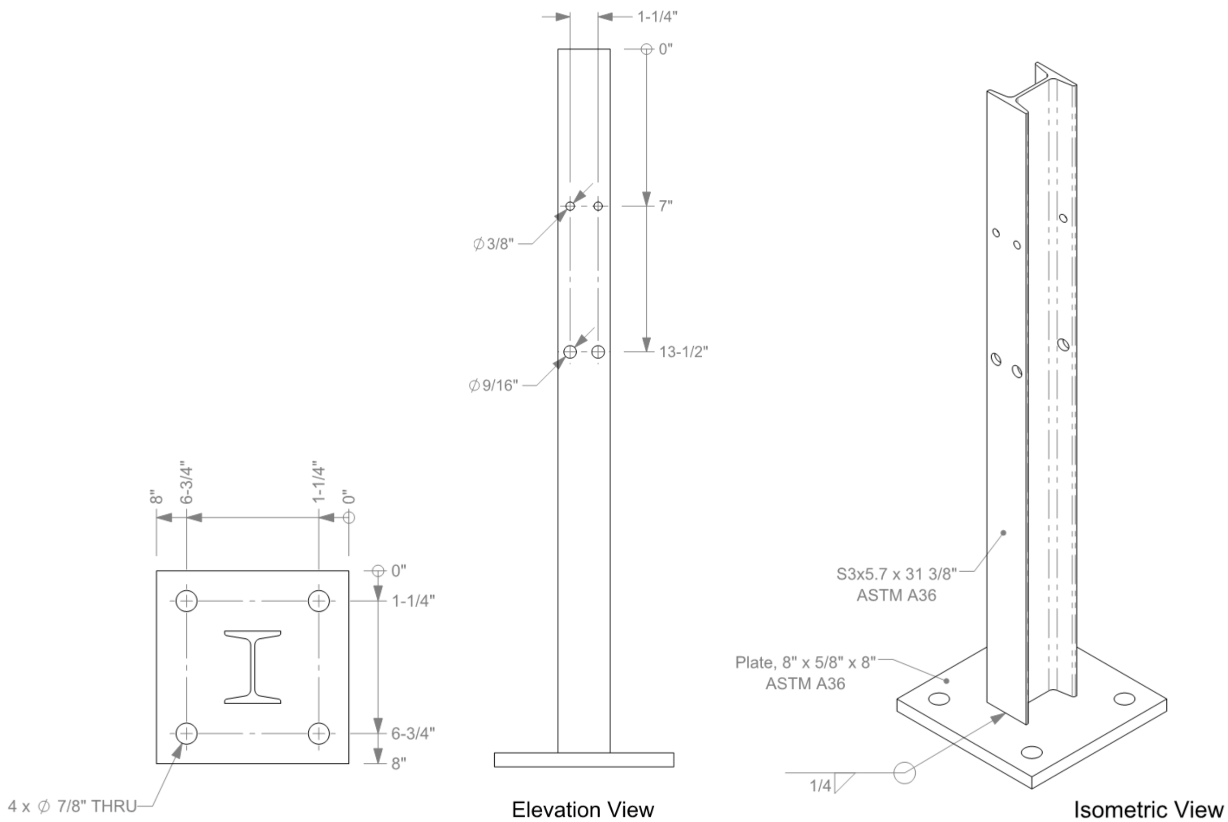


Figure 2.5. Post and Baseplate Details for All Tests.

For test 440521-01-B1, the posts were mounted to the concrete slab such that the interior anchor bolts were spaced 5 inches apart (Figure 2.6). For test 440521-01-B2, the posts were rotated so that the flanges of the posts were at a 26.6-degree angle from the impact path (Figure 2.7). The interior field side bolt holes were spaced 5 inches apart, and the exterior field side bolt holes were 14¾ inches apart.

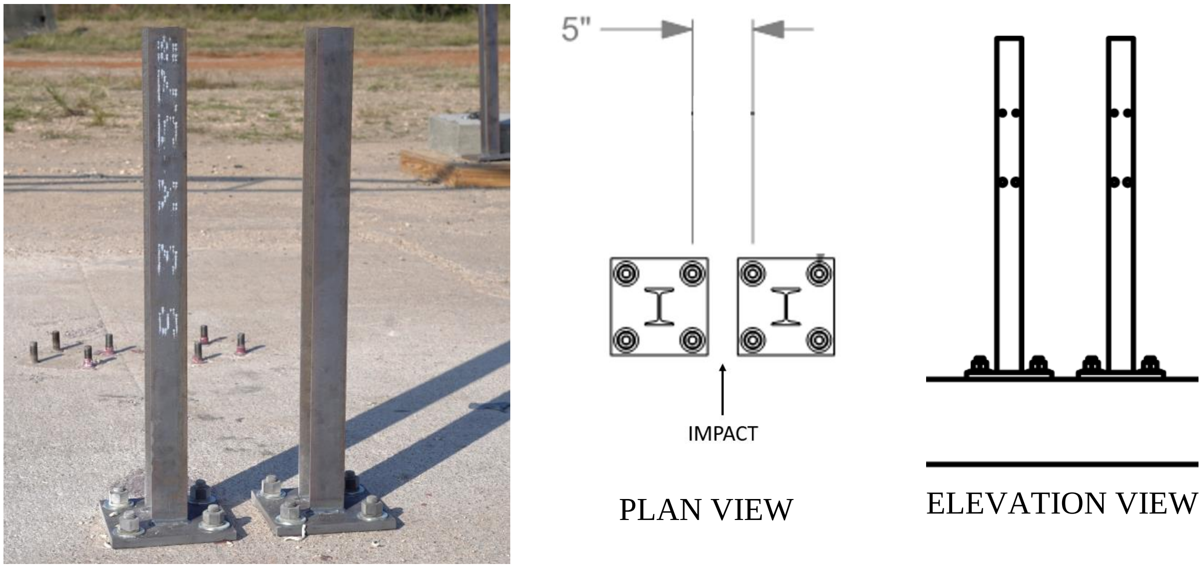


Figure 2.6. Post Setup for Test 440521-01-B1.

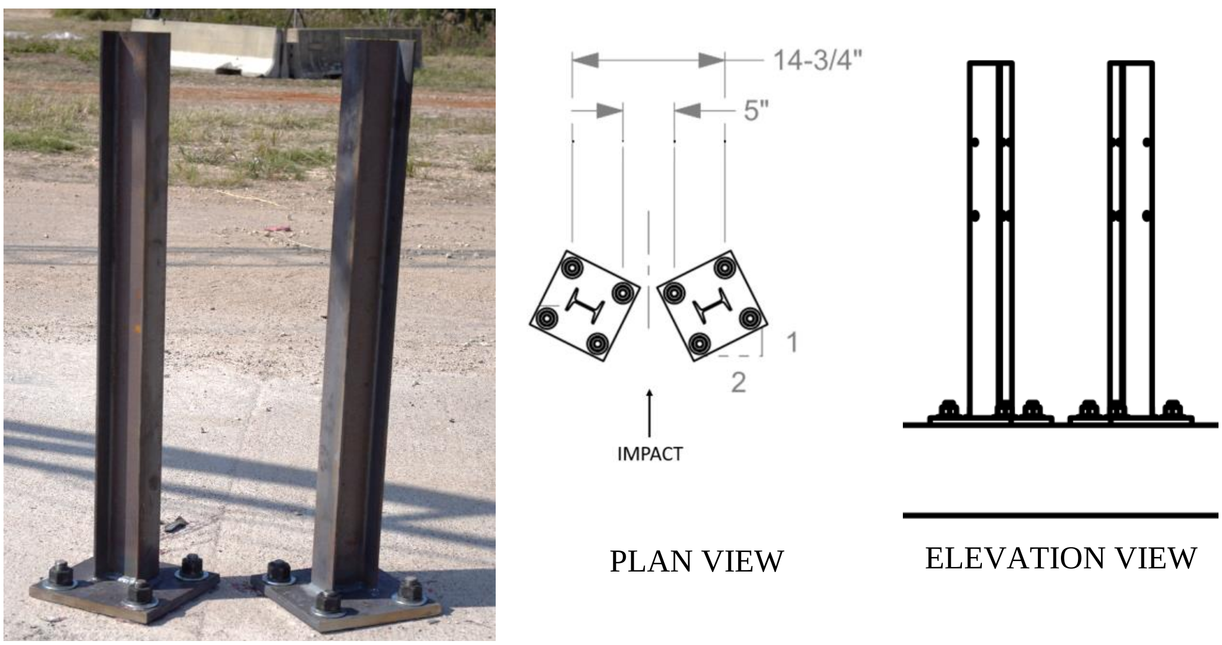
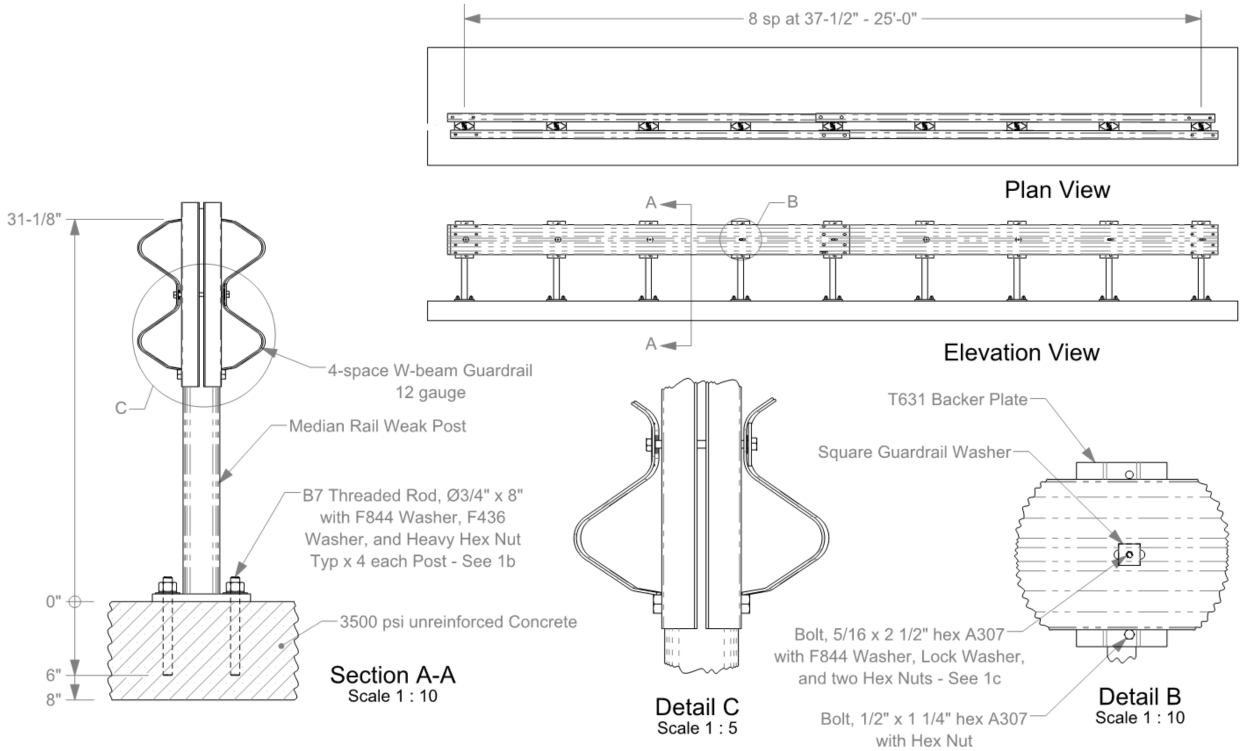


Figure 2.7. Post Setup for Test 440521-01-B2.

The installation for Test 440521-01-B3 consisted of a double-sided W-beam guardrail system with nine posts spaced at 37½ inches, for a total length of 25 ft. Attached between the traffic and field side of each post and the guardrails was a T631 backer plate. The guardrail system was mounted onto the same concrete slab as Tests 440521-01-B1 and 440521-01-B2. Figure 2.8 and Figure 2.9 show the test installation details. This installation represented a short segment of the surface-mounted median guardrail concept that was selected for development under this project. Presented next are the results of each bogie test.



1a. Rail and hardware typical each side of Posts, with hardware on opposite sides of the Post to avoid interference.
1b. Secure with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions.
1c. Hand tighten first nut, with Backup Plate, Rail, and Post in contact, then tighten one more turn with wrench. Secure with second nut.

Figure 2.8. Bogie Test Installation for Test 440521-01-B3 (Not for System Construction).

Figure 2.9. Test Installation Photos for Test 440521-01-B3.

2.2.2. Test 440521-01-B1

In this test, the bogie vehicle impacted at the centerline of the post pair at an impact speed of 18.9 mi/h. The impact occurred at a height of 24.5 inches from grade. Figure 2.10 shows the post installation after the test. The left post was leaning 35.5 degrees back from vertical and 30.0 degrees to the right from vertical. The right post was leaning 36.5 degrees back from vertical and 5.5 degrees to the right. Both posts were deformed at the base, but no damage to the welds or the concrete pavement was noted. Figure 2.11 shows the forward displacement of the top of the posts as a function of time.

Figure 2.10. Posts after Test 440521-01-B1.

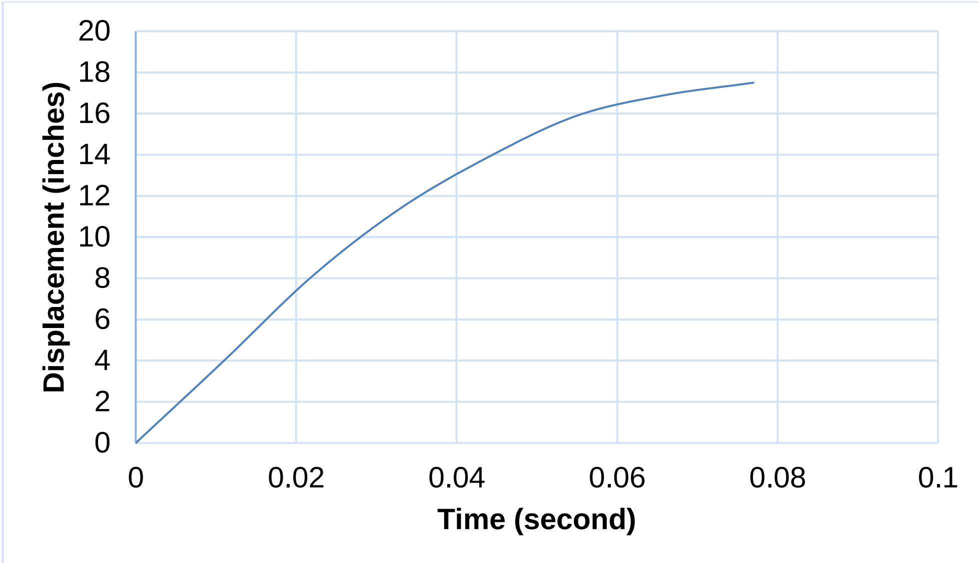


Figure 2.11. Forward Displacement of the Top of the Post for Test 440521-01-B1.

2.2.3. Test 440521-01-B2

In this test, the bogie vehicle impacted at the centerline of the post pair at an impact speed of 20.8 mi/h. The impact occurred at a height of 22.5 inches from grade. Figure 2.12 shows the post installation after the test. The left post was leaning 59.9 degrees back from vertical and 8.5 degrees to the right. The right post was leaning 61.0 degrees back from vertical and 9.5 degrees to the left. Both posts were deformed at the base, but no damage to the welds or the concrete pavement was noted. Figure 2.13 shows the forward displacement of the top of the posts as a function of time.

Figure 2.12. Posts after Test 440521-01-B2.

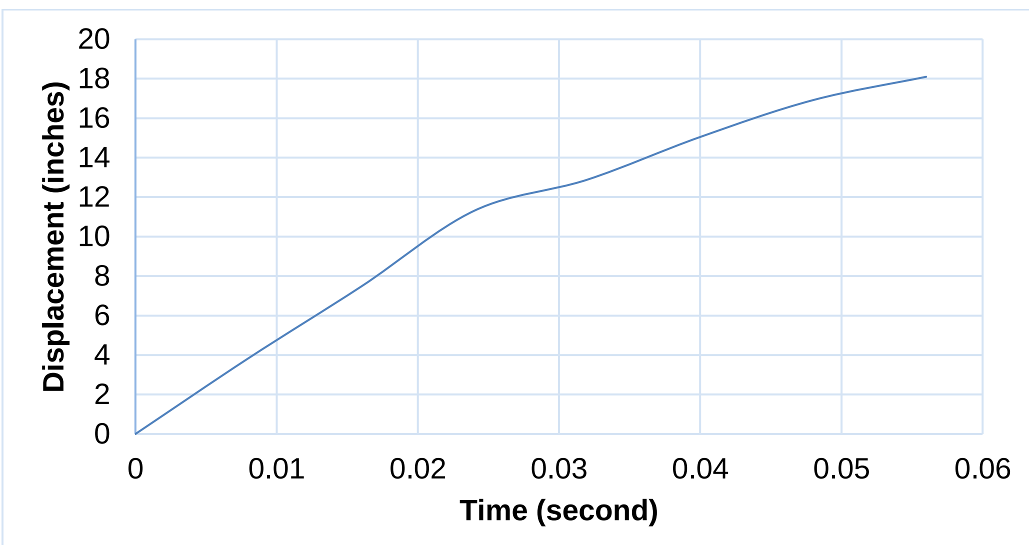


Figure 2.13. Forward Displacement of the Top of the Post for Test 440521-01-B2.

2.2.4. Test 440521-01-B3

In this test, the bogie vehicle impacted the center of the median guardrail section at an impact speed of 21.4 mi/h and an impact angle of 90 degrees. The impact occurred at a height of

22.6 inches from grade. Figure 2.14 shows the damage to the installation. The traffic-side rail released from posts 4 through 8, and the field-side rail released from post 3.

The bogie vehicle came to a stop after impact and then rebounded. The welds of the posts at the baseplate did not fail. There was also no damage to the concrete pavement at the baseplate locations. Figure 2.15 shows the forward displacement versus time response of the field-side splice at the impact post.

Figure 2.14. Installation after Test 440521-01-B3.

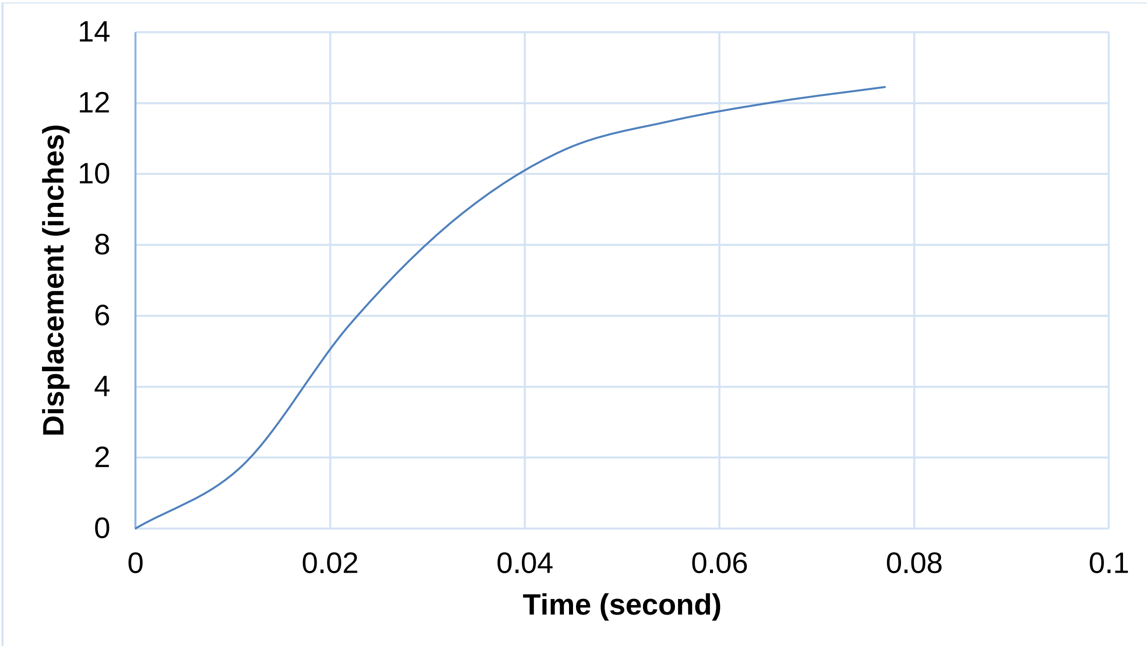


Figure 2.15. Forward Displacement of the Splice at Impact Post for Test 440521-01-B3.

2.2.5. Conclusions

The three bogie tests presented herein were performed to verify that the baseplate design performs acceptably, such that the posts bend without much damage to the concrete pavement and the adhesive anchor rods. Results showed that the concrete pavement and the adhesive anchors were not damaged in all three tests. Another key objective of these tests was to determine the response of the posts and a short segment of the median guardrail concept. The data collected in these tests were used to validate the FE models of these key components in subsequent design tasks, as described next.

2.3. SIMULATION ANALYSIS

The research team conducted the simulation analysis by developing a model of the surface-mounted median guardrail and performing impact simulations with *MASH* TL-3 impact conditions. All simulations were performed using the FE method. LS-DYNA, which is a commercially available general-purpose FE analysis software, was used for the analysis.

2.3.1. Subcomponent Models and Validation

The researchers first developed an FE model of the post and baseplate and performed simulations of the component-level bogie impact test described earlier. The goal of these simulations was to verify that the post and baseplate model adequately captures the post deflection response observed in the bogie impact tests. Figure 2.16 and Figure 2.17 show the post and baseplate model and comparison of the simulation results of the post pair deflection versus time. Figure 2.16 shows the comparison of the post deflection versus time response for Test 440521-01-B1, in which the posts were impacted along the strong axis of the posts.

Figure 2.17 shows the comparison of the post deflection versus time response for Test 440521-01-B2, in which the posts were impacted at an angle. The post and baseplate model adequately captured the post deflection response observed in both tests.

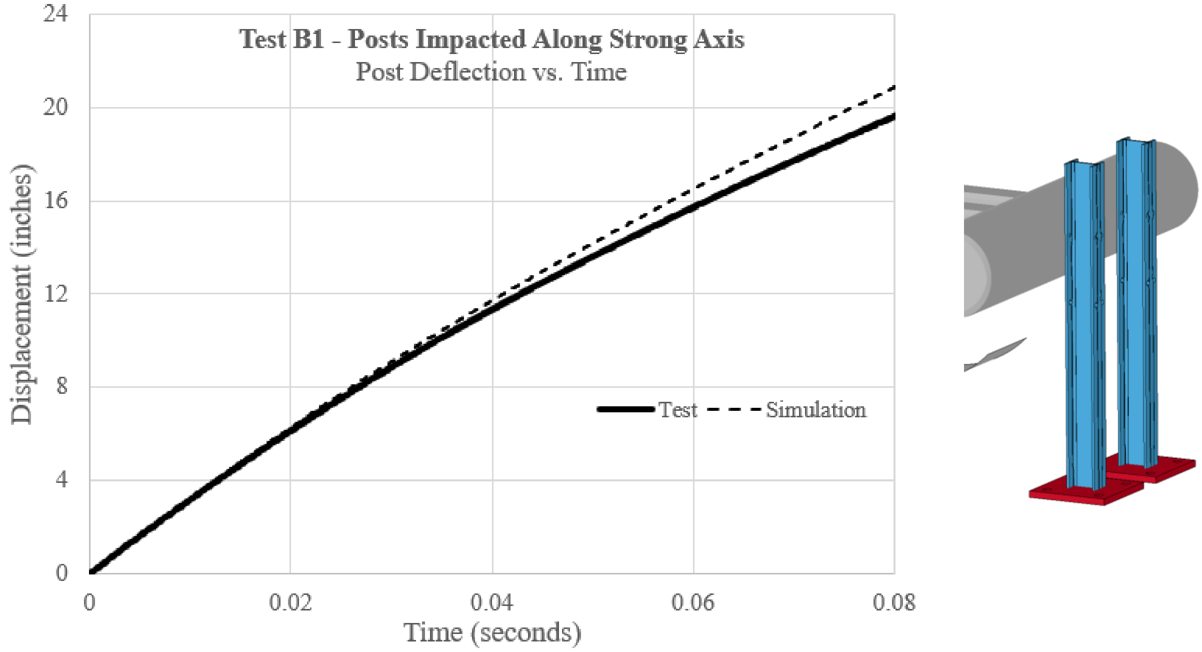


Figure 2.16. Simulation and Test Post Deflection for Posts Impacted along the Strong Axis.

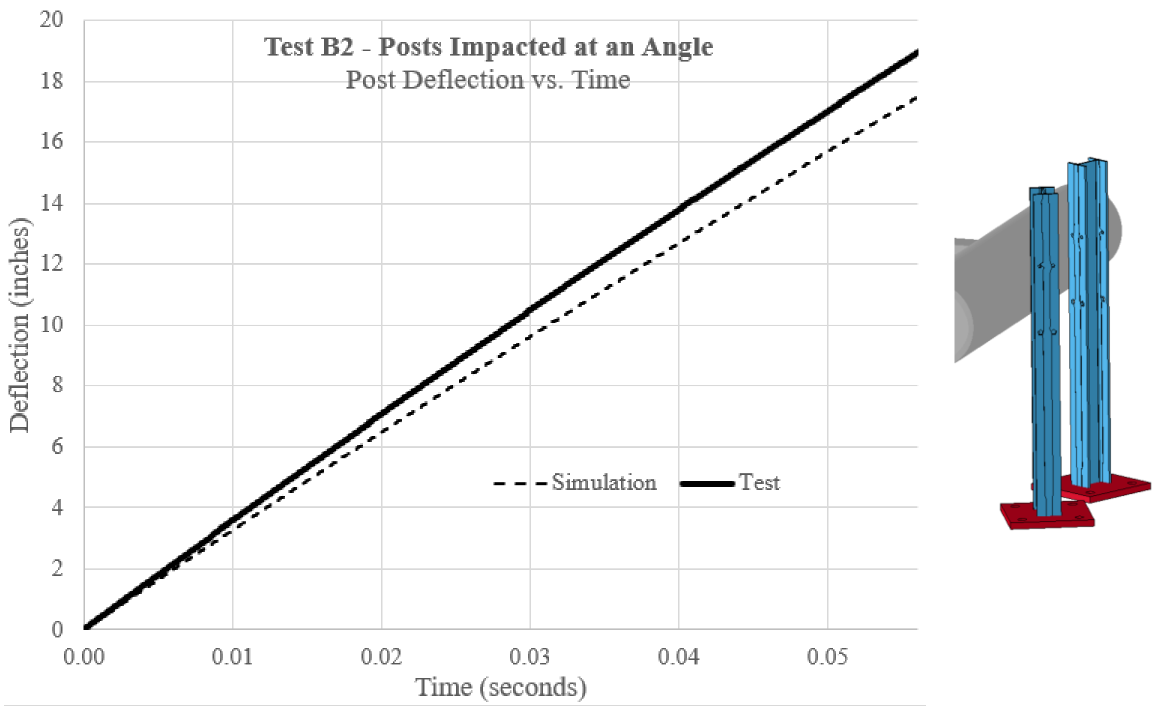


Figure 2.17. Simulation and Test Post Deflection for Posts Impacted at an Angle.

Having achieved reasonable validation of the post deflection response, the researchers developed a model of the short guardrail section of Figure 2.8 and incorporated the validated post and baseplate model. The researchers incorporated the model of the W-beam guardrail and the rail-to-post attachments. All key guardrail parts were represented with elastic-plastic material models. These included the W-beam, backer plate, posts, and baseplates. The shear bolts attaching the rail to the posts were modeled with beam elements that incorporated a strain-based failure criteria calibrated to fail and release the guardrail as expected in a crash event. The ends of the W-beam rails were unrestrained, as they were in the bogie testing.

Figure 2.18 shows the deflected state of the guardrail section after the bogie impact in the test and simulation. It also shows the comparison of the guardrail deflection as a function of time between the bogie test and the simulation. The results showed that the simulation model adequately captured the impact response determined in the crash test and that the model could be further extended to a full-scale guardrail system for vehicle impact simulations.

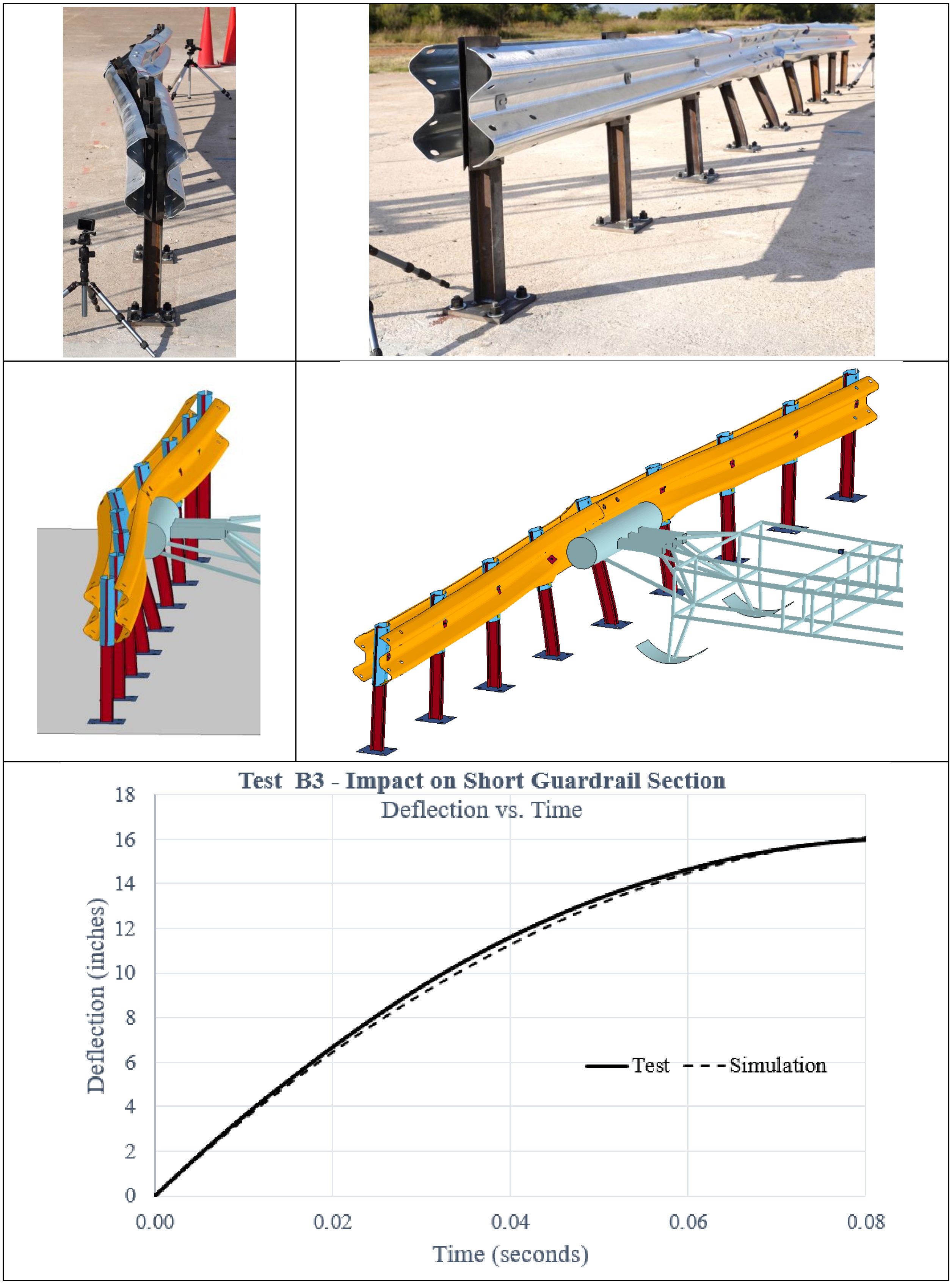


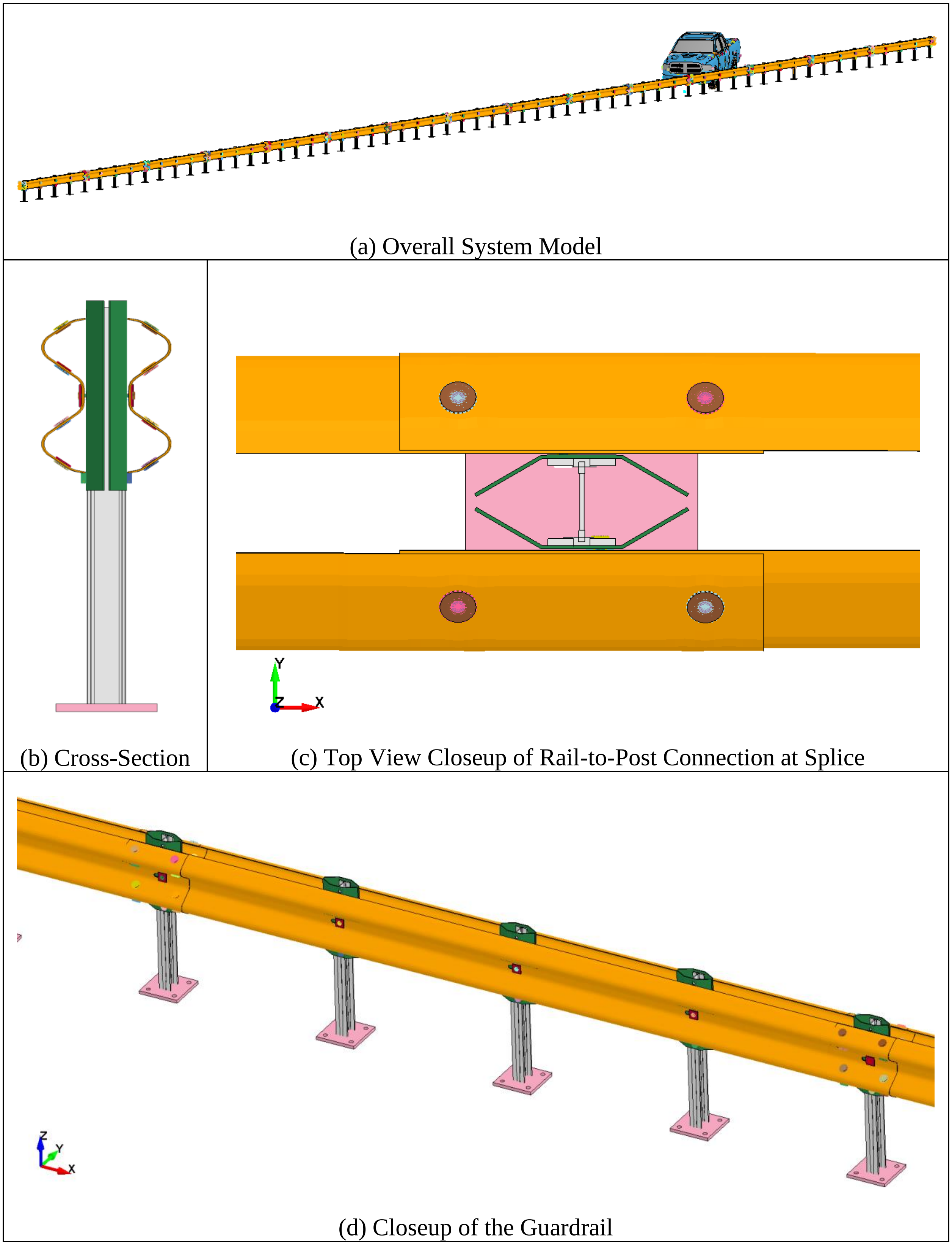
Figure 2.18. Simulation and Test Results of Bogie Impact with Short Guardrail Section.

2.3.2. Full-System Model and Vehicle Impact Simulations

The research team developed a system-level FE model of the surface-mounted median guardrail design and performed full-scale dynamic impact simulations. The impact simulations were performed using the impact conditions of *MASH* for TL-3. This involved simulating *MASH* Test 3-11 (5,000-lb pickup truck impacting at 62 mi/h and 25 degrees) and Test 3-10 (2,420-lb small passenger car impacting at 62 mi/h and 25 degrees). Results of the simulations were used to determine if the guardrail system was likely to meet *MASH* TL-3 testing criteria in full-scale crash testing.

The model developed and validated for the short segment of the guardrail was expanded to develop the full-scale system model. The overall guardrail system was approximately 187.5 ft long and was comprised of 61 posts with a 37 ½-inch post spacing. At each end of the system, the two W-beam rail elements of the median guardrail were constrained together and attached to spring elements that provided force-deflection response of attaching the rails to a single guardrail end terminal.

Figure 2.19 presents images of the overall surface-mounted median guardrail system model, as well as details of various key components of the model. Vehicle models used in the simulation analysis were publicly available models developed by the Center for Collision Safety and Analysis under Federal Highway Administration and National Highway Traffic Safety Administration (NHTSA) sponsorships. These models have been further improved by the research team over the course of various research projects to achieve greater validation and robustness.



(a) Overall System Model

(b) Cross-Section

(c) Top View Closeup of Rail-to-Post Connection at Splice

(d) Closeup of the Guardrail

Figure 2.19. Finite Element Model of the Surface-Mounted Median Guardrail System.

The researchers performed the impact simulation for *MASH* Test 3-11 with a Dodge Ram pickup truck model. The vehicle was successfully contained and redirected. Key results of the simulation are presented in Table 2.1. Results of the simulation showed that the surface-mounted median guardrail design could be expected to pass *MASH* Test 3-11 evaluation criteria in a full-scale crash test. Figure 2.20 shows the deformed state of the guardrail as the vehicle exited the guardrail system. Sequential images of various views of the simulation are shown in Figure 2.21.

The researchers also performed the impact simulation for *MASH* Test 3-10 with a Toyota Yaris small car model. The vehicle was successfully contained and redirected. Key results of the simulation are presented in Table 2.2. Results of the simulation showed that the surface-mounted median guardrail design could be expected to pass *MASH* Test 3-10 evaluation criteria in a full-scale crash test. Figure 2.22 shows the deformed state of the guardrail as the vehicle exited the guardrail system. Sequential images of various views of the simulation are shown in Figure 2.23.

Based on the successful performance of the guardrail in impact simulations of *MASH* Tests 3-10 and 3-11, the researchers proceeded with developing the full-system installation drawings for TxDOT approval and crash testing. Details of the full guardrail system are presented in the following chapter.

Table 2.1. *MASH* Test 3-11 Impact Simulation.

Vehicle	5,000-lb pickup truck
Impact Speed	62.2 mi/h
Impact Angle	25 degrees
Maximum Dynamic Deflection	4.75 ft
Maximum Occupant Impact Velocity (OIV)	18.6 ft/s (maximum allowed is 40 ft/s)
Maximum Ridedown Acceleration (RA)	6.6 g (maximum allowed is 20.49 g)

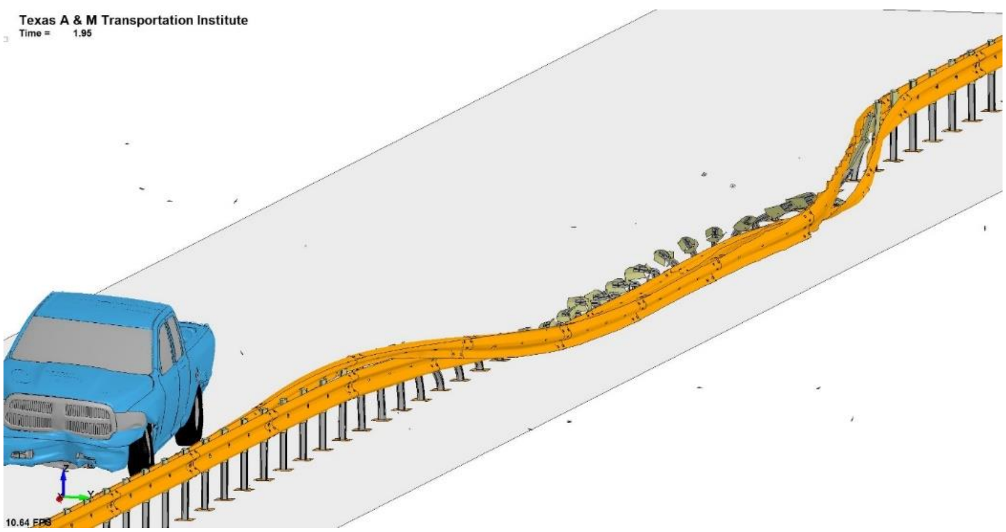


Figure 2.20. Result of *MASH* Test 3-11 Impact Simulation.

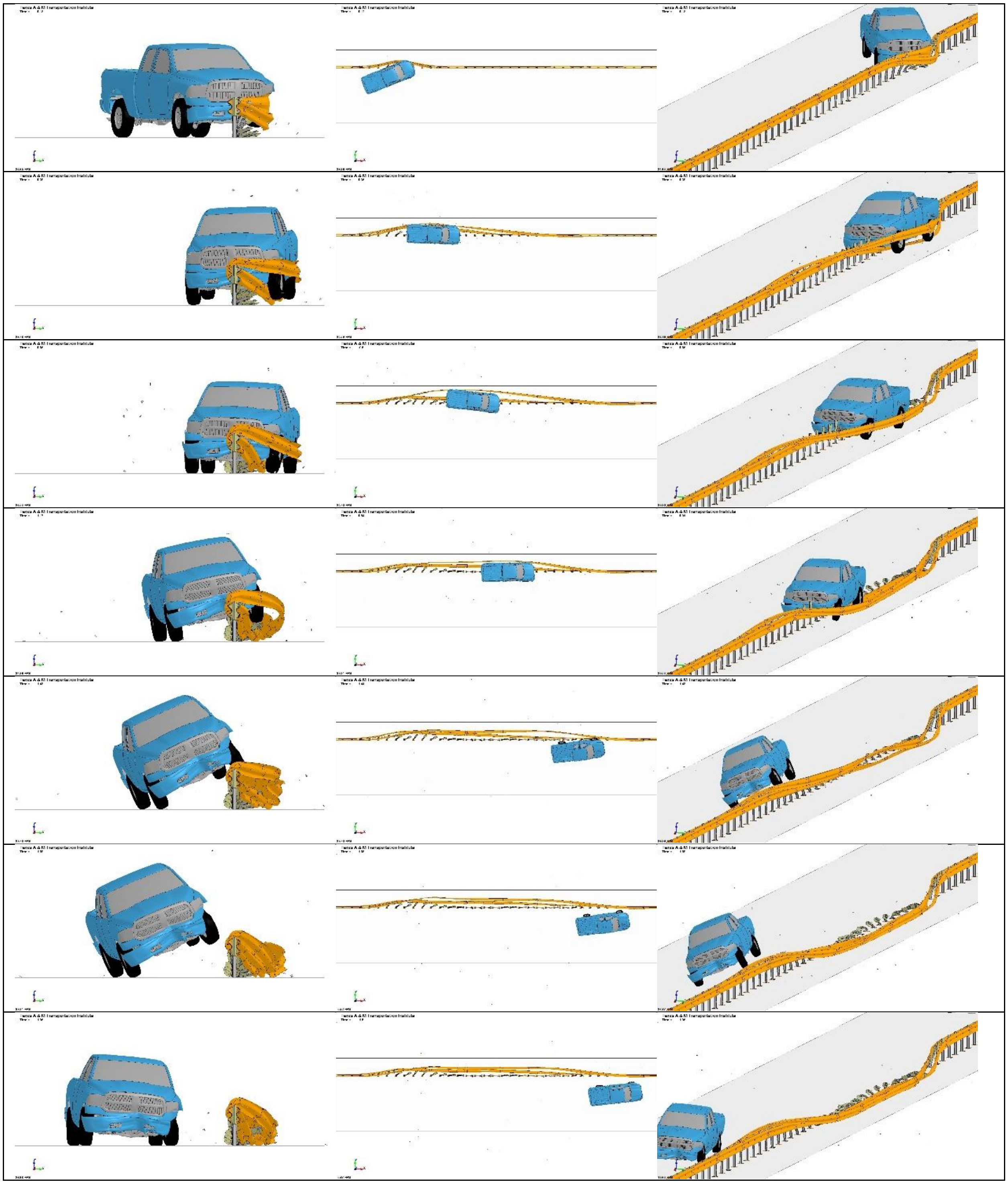


Figure 2.21. Sequential Images of *MASH* Test 3-11 Impact Simulation.

Table 2.2. *MASH* Test 3-10 Impact Simulation.

Vehicle	2,420-lb small passenger car
Impact Speed	62.2 mi/h
Impact Angle	25 degrees
Maximum Dynamic Deflection	2.5 ft
Maximum Occupant Impact Velocity	21.6 ft/s (maximum allowed is 40 ft/s)
Maximum Ridedown Acceleration	11.7 g (maximum allowed is 20.49 g)

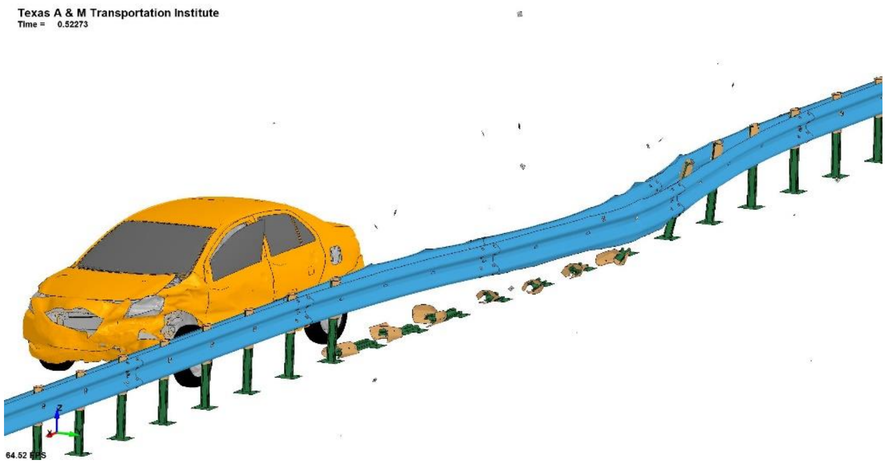


Figure 2.22. Result of *MASH* Test 3-10 Impact Simulation.

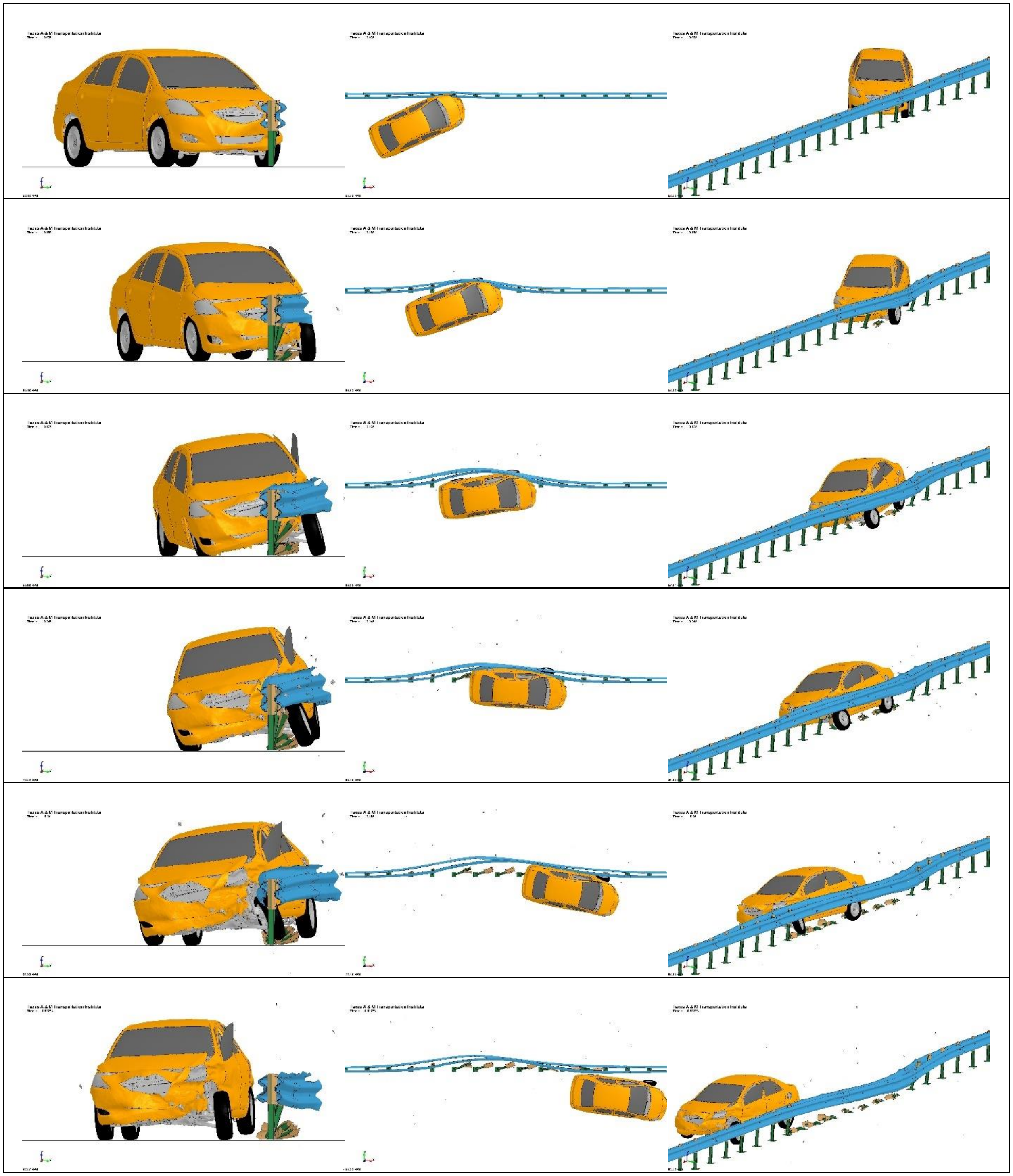


Figure 2.23. Sequential Images of *MASH* Test 3-10 Impact Simulation.

Chapter 3. SYSTEM DETAILS

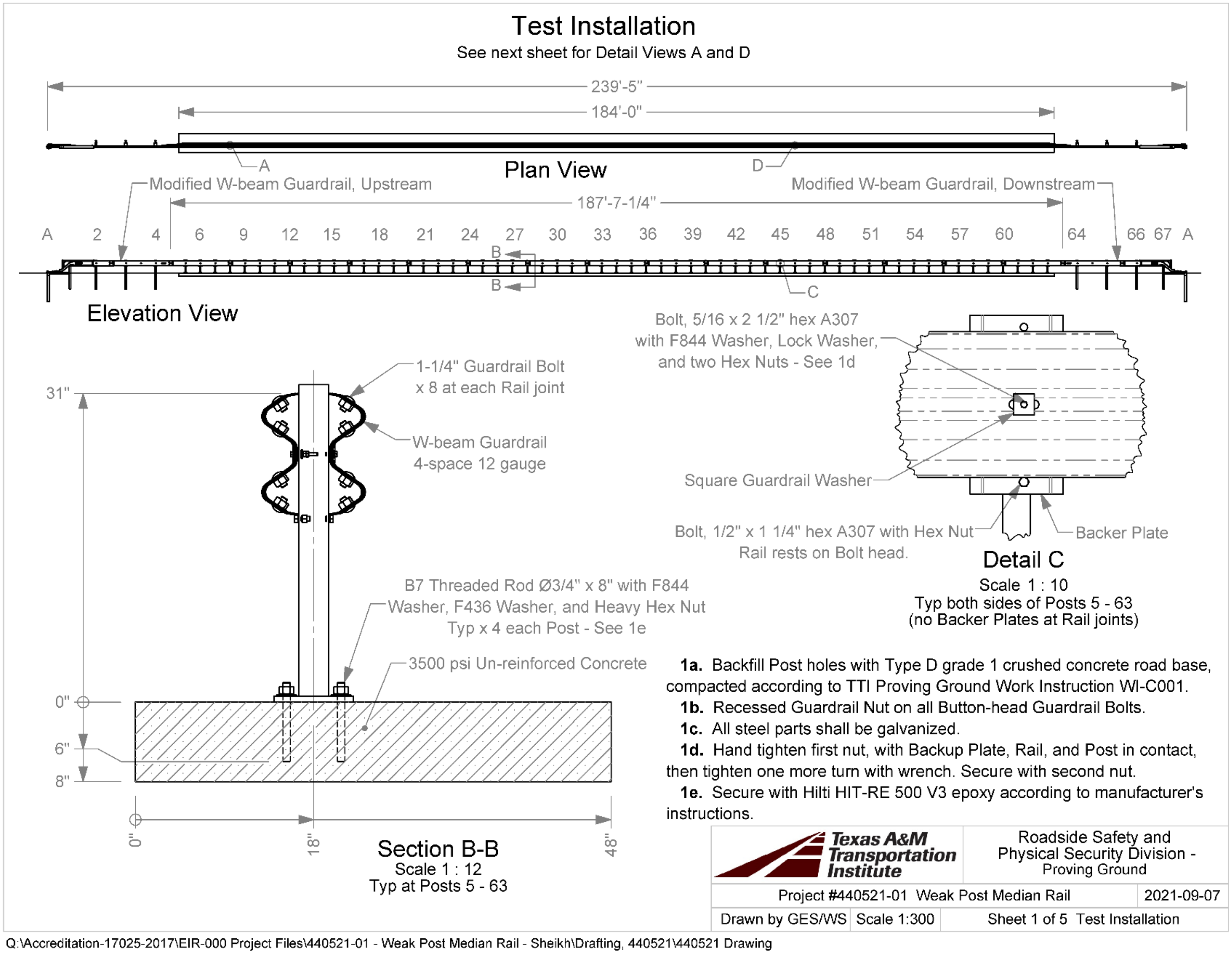
3.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of a weak-post, median W-beam guardrail system spanning 187 ft-7¼ inches (posts 5 through 63) before transitioning to a single-sided standard strong-post W-beam guardrail system and a guardrail end-terminal (posts 1 through 4 and 64 through 67) on each end of the installation. The total length of the installation was 239 ft-5 inches. The posts of the median guardrail were comprised of S3x5.7 steel welded to baseplate plates measuring 8×8×⅝ inch thick. The posts were spaced evenly at 37½ inches and were mounted onto an unreinforced 8-inch-thick concrete slab using Hilti HIT-RE500 V3 epoxy anchors. The concrete slab extended for 184 ft-0 inches onto which the 59 posts for the weak-post median guardrail were secured. Two standard W-beam rail elements were attached on each side of the S3x5.7 posts. A backer plate was placed between the post and the W-beam rail element on each side, except for the posts at the rail splice locations. The top of the rail was 31 inches above the top of the concrete slab. Each end of the weak-post median guardrail transitioned to standard strong-post W-beam guardrail and was terminated with an abbreviated, 4-post SoftStop® guardrail end-terminal as anchorage for these tests only.

Figure 3.1 presents the overall information of the surface mounted median guardrail, and Figure 3-2 provides photographs of the installation. Appendix A provides further details of the test installation. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by MBC Management and TTI Proving Ground personnel.

3.2. DESIGN MODIFICATIONS DURING TESTS

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



*Test No. 440521-01 and 440522-01 are considered the same project.

Figure 3.1. Details of Surface-Mounted Median Guardrail.

Figure 3.2. Surface- Mounted Median Guardrail prior to Testing.

3.3. MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to construct the surface-mounted median guardrail. Table 3.1 shows the average compressive strengths of the concrete.

Table 3.1. Concrete Strength.

Location	Minimum Specified Strength (psi)	Average Strength (psi)	Age (days)	Detailed Location
Slab	3,500	4,373	32	South 100 ft of the concrete slab
Slab	3,500	4,273	32	North 84 ft of the concrete slab

3.4. SOIL CONDITIONS

The strong-post W-beam guardrail at each end of the surface-mounted median guardrail was installed in standard soil meeting grading B of American Association of State Highway and Transportation Officials (AASHTO) standard specification M147-65(2004), "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses."

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

As determined by the tests summarized in Appendix B, Table B.1, the minimum post loads are shown in Table 3.2. The loads applied to the W6×16 posts in the vicinity of the test installation at various deflections on the day of *MASH* Test 3-10, September 27, 2021, are also shown in the table. The backfill materials in which the strong-post guardrail posts were installed met the minimum *MASH* requirements for soil strength.

Table 3.2. Soil Strength for *MASH* Test 3-10 (Test 440522-1-01).

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4,420	8,666
10	4,981	10,151
15	5,282	11,333

Loads on the post at various deflections on the day of *MASH* Test 3-11, October 6, 2021, are shown in Table 3.3. The backfill material for this test also met the minimum *MASH* requirements for soil strength.

Table 3.3. Soil Strength for *MASH* Test 3-11 (Test 440522-1-02).

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4,420	9,727
10	4,981	11,090
15	5,282	11,909

Chapter 4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1. CRASH TEST 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 simulation analysis Figure 4.1 shows the target CIP for *MASH* Tests 3-10 and 3-11 on the surface mounted median guardrail.

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

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

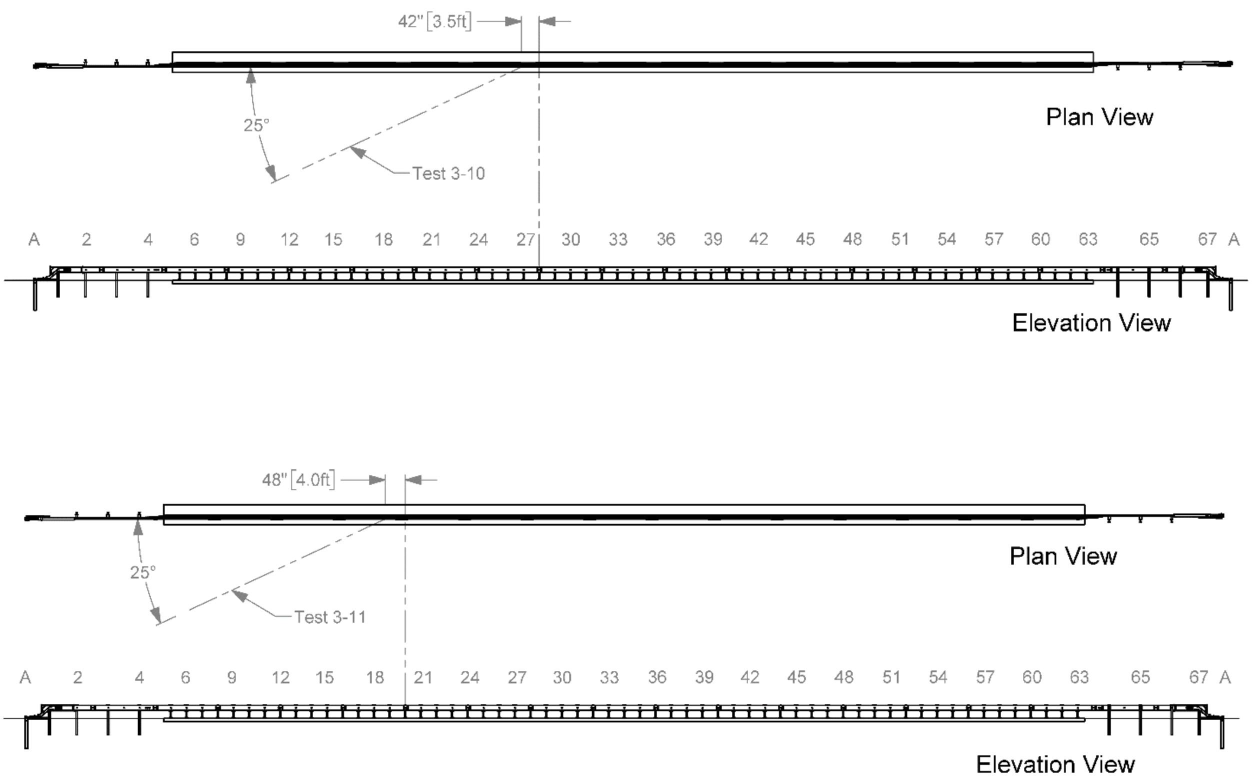


Figure 4.1. Target CIP for *MASH* TL-3 Tests on Surface-Mounted Median Guardrail.

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

4.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. 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 simulation analysis Figure 4.1 shows the target CIP for *MASH* Tests 3-10 and 3-11 on the surface mounted median guardrail.

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

Chapter 5. TEST CONDITIONS

5.1. TEST FACILITY

The full-scale crash tests reported herein were performed at the TTI Proving Ground, an International Standards Organization (ISO)/International Electrotechnical Commission (IEC) 17025-accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing Certificate 2821.01. The full-scale crash 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

Both the 1100C and 2270P vehicles used in the crash tests 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 16-channel Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems Inc. The accelerometers, which measure the x, y, and z axes of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid-state units designed for crash test service. The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the

16 channels can provide precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 samples per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit in case the primary battery cable is severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

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

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

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

5.3.2. Anthropomorphic Dummy Instrumentation

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

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

5.3.3. Photographic Instrumentation Data Processing

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

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

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the surface-mounted median 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 NO. 440522-01-01)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 6.1 for details on the *MASH* impact conditions for this test. The CIP for *MASH* Test 3-10 on the surface-mounted median guardrail was 3.5 ft ± 1 ft upstream of the centerline of post 28. Figure 6.1 depicts the target impact setup.

Table 6.1. Impact Conditions for *MASH* 3-10 440522-01-01.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	62.3
Impact Angle (deg)	25	±1.5°	25.3
Vehicle Inertial Weight (lb)	2420	±55 lb	2437
Impact Severity (kip-ft)	51	≥51 kip-ft	57.7
Impact Location	CIP	±12 inches	40.8. inches upstream of the centerline of post 28
Exit Parameters			
Vehicle crossed exit box*		37 ft d/s from loss of contact	
Speed (mi/h)		51.3	
Trajectory (deg)		7.6	
Heading (deg)		9.9	
Brakes applied post impact (s)		N/A	
Vehicle at rest position		102 ft downstream of impact 91 ft in front of the rail Facing 135° right	
Comments: Vehicle remained upright and stable.			

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

Figure 6.1. Surface-Mounted Median Guardrail/Test Vehicle Geometrics for Test 440522-01-01.

6.2. WEATHER CONDITIONS

Table 6.2 presents the weather conditions for Test 440522-01-01.

Table 6.2. Weather Conditions for Test 440522-01-01.

Date of Test	Temperature (°F)	Relative Humidity (%)
September 27, 2021	86	43
Wind Direction (deg)	**Vehicle Traveling (deg)**	**Wind Speed (mi/h)**
270	325	2

6.3. TEST VEHICLE

Figure 6.2 shows the 2015 Nissan Versa used for the crash test. Table 6.3 shows the vehicle measurements. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.

Figure 6.2. Vehicle before Test 440522-01-01.

Table 6.3. Vehicle Measurements for Test 440522-01-01.

Test Parameter	*MASH*	Allowed Tolerance	Measured
Dummy (if applicable)[a] (lb)	165	N/A	165
Test Inertial Weight (lb)	2,420	±55	2,381
Gross Static[a] Weight (lb)	2,420	±55	2,602
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)	56	±2	58.4
CG aft of Front Axle[c] (inches)	36	±4	41
CG above Ground[c,d] (inches)	N/A	N/A	N/A

Note: CG = center of gravity; N/A = not applicable.
[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 6.4 lists events that occurred during Test 440522-01-01. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 6.4. Events during Test 440522-01-01.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0238	Posts 27 and 28 began to deflect toward the field side
0.0420	Vehicle began to redirect
0.2730	Vehicle was parallel with the installation
0.5400	Vehicle exited the installation at 51.3 mi/h with a heading of 9.9 degrees and a trajectory of 7.6 degrees

6.5. DAMAGE TO TEST INSTALLATION

Table 6.5 lists the post displacement details for the guardrail. Posts 28 through 34 had their upstream traffic-side flange torn at the base. The rail was scuffed and deformed at impact. No cracks or concrete damage was observed around the post baseplates. The baseplates and their epoxy anchors were also undamaged. The backer plates remained attached to the posts.

* D/S = Downstream; U/S = Upstream; T/S = Traffic Side; F/S = Field Side.

Table 6.6 describes the damage to the surface-mounted median guardrail, and Figure 6.3 illustrates that damage.

Table 6.5. Post Displacement Details for Guardrail in Test 440522-01-01.

Post #	Lean toward Field Side from Vertical	Disconnected from Rail		Soil Gap (inches)		
		Traffic Side	Field Side	U/S	T/S	F/S
1-24	No Movement Observed	—	—	—	—	—
25	1°	—	—	Posts anchored to concrete and not installed in soil		
26	5°	—	—			
27	10°	✓	—			
28	90°	✓	✓			
29	90°	✓	✓			
30	90°	✓	✓			
31	90°	✓	✓			
32	90°	✓	✓			
33	90°	✓	✓			
34	90°	✓	✓	—	—	—
35	0°	✓	✓	—	—	—
36	0°	✓	✓	—	—	—
37	0°	—	✓	—	—	—
38-67	No Movement Observed	—	—	—	—	—

* D/S = Downstream; U/S = Upstream; T/S = Traffic Side; F/S = Field Side.

Table 6.6. Damage to the Surface-Mounted Median Guardrail in Test 440522-01-01.

Test Parameter	Measured
Permanent Deflection/Location	15.1 inches toward field side 18 inches upstream of post 31
Dynamic Deflection	18.7 inches toward field side
Working Width* and Height	31.6 inches, at a height of 19 inches

* 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 6.3. Surface-Mounted Median Guardrail after Test 440522-01-01.

6.6. DAMAGE TO TEST VEHICLE

Figure 6.4 and Figure 6.5 show the damage sustained by the vehicle. Table 6.7 provides details on the interior and exterior damage to the vehicle. Tables C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

Figure 6.4. Test Vehicle after Test 440522-01-1.

Figure 6.5. Interior of the Test Vehicle after Test 440522-01-1.

Table 6.7. Damage to the Vehicle in Test 440522-01-1.

Test Parameter	Specification	Measured
Roof	≤ 4.0 inches	0 inches
Windshield	≤ 3.0 inches	0 inches
A and B Pillars	≤ 5.0 overall/≤ 3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤ 9.0 inches	0 inches
Floor Pan	≤ 12.0 inches	0 inches
Side Front Panel	≤ 12.0 inches	0 inches
Front Door (above Seat)	≤ 9.0 inches	1.5 inches
Front Door (below Seat)	≤ 12.0 inches	2 inches
Side Windows	Remained intact	
Maximum Exterior Deformation	9 inches in the left front plane at bumper height	
VDS: 11LFQ6	CDC: 11FLEW4	
Fuel Tank Damage	None	
Description of Damage to Vehicle: The front bumper, hood, grill, left headlight, radiator and support, left front fender, left front strut and tower, left front tire and rim, left front CV shaft, left lower control arm, left front door, left rear door, and left rear quarter panel were damaged.		

6.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and results are shown in Table 6.8. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.6 in Appendix C.4 show acceleration versus time traces.

Table 6.8. Occupant Risk Factors for Test 440522-01-1.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0	22.2	0.1165 s on left side of interior
OIV, Lateral (ft/s)	≤40.0	18.8	0.1165 s on left side of interior
Ridedown, Longitudinal (g)	≤20.49	13.5	0.1680–0.1780 s
Ridedown, Lateral (g)	≤20.49	9.4	0.1372–0.1472 s
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	8.6	0.1126 s on left side of interior
Acceleration Severity Index (ASI)	N/A	1.00	0.0606–0.1106 s
50-ms Max Longitudinal (g)	N/A	−7.9	0.0314–0.0814 s
50-ms Max Lateral (g)	N/A	6.8	0.0414–0.0914 s
50-ms Max Vertical (g)	N/A	−2.1	0.1468–0.1968 s
Roll (deg)	≤75	11	0.2220 s
Pitch (deg)	≤75	5	0.6062 s
Yaw (deg)	N/A	5	2.0000 s
Comments: N/A			

0.000 s

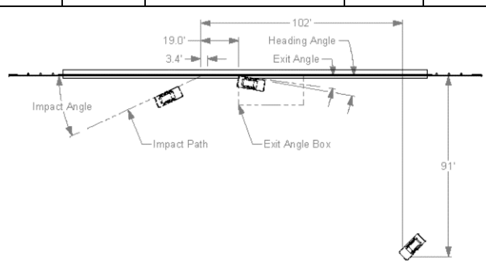
0.100 s

0.200 s

0.300 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, 3-10 Test
TTI Project No.	440522-01-1
Test Date	2021-09-27
TEST ARTICLE	
Type	Median Rail
Name	Surface-Mounted Median Guardrail
Length	239 ft 5 inches
Key Materials	S3×5.7 weak posts, 12-gauge W-beam, concrete foundation, and SoftStop® end terminals
Soil Type and Condition	AASHTO M147-65(2004), Type 1, Grade D Crushed Concrete
TEST VEHICLE	
Type/Designation	1100C
Year, Make and Model	2015 Nissan Versa
Curb Weight (lb)	2,381
Inertial Weight (lb)	2,437
Dummy (lb)	165
Gross Static (lb)	2,602
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.3
Impact Angle (deg)	25.3
Impact Location	3.4 feet upstream from the centerline of post 28
Impact Severity (kip-ft)	57.7
EXIT CONDITIONS	
Exit Speed (mi/h)	51.3
Trajectory/Heading Angle (deg)	7.6/9.9
Exit Box Criteria	Crossed
Stopping Distance (ft)	102 downstream and 91 toward traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	18.7
Permanent (inches)	15.1
Working Width/Height (inches)	31.6/19
VEHICLE DAMAGE	
VDS	11LFQ6
CDC	11FLEW4
Max. Ext. Deformation (inches)	9
Max. Occupant Compartment Deformation	2 inches in the front door panel below the seat

OCCUPANT RISK VALUES							
Long. OIV (ft/s)	22.2	Lat. OIV (ft/s)	18.8	Max. 50-ms Long. (g)	−7.9	Max. Roll (deg)	11
Long. Ridedown (g)	13.5	Lat. Ridedown (g)	9.4	Max. 50-ms Lat. (g)	6.8	Max. Pitch (deg)	5
THIV (m/s)	8.6	ASI	1.0	Max. 50-ms Vert. (g)	−2.1	Max. Yaw (deg)	53



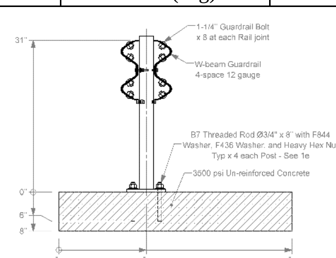


Figure 6.6. Results Summary for *MASH* Test 3-10 on Surface-Mounted Median Guardrail.

Chapter 7. *MASH* TEST 3-11 (CRASH TEST NO. 440522-01-2)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 7.1 for details on *MASH* impact conditions for this test. The CIP for *MASH* Test 3-11 on the surface-mounted median guardrail was 4.0 ft ± 1 ft upstream of the centerline of post 20. Figure 7.1 depicts the target impact setup.

Table 7.1. Impact Conditions for *MASH* 3-11 440522-01-2.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5	63.5
Impact Angle (deg)	25	±1.5	25.1
Vehicle Inertial Weight (lb)	5,000	±110	5,026
Impact Severity (kip-ft)	106	≥106	121.9
Impact Location	CIP	±1 ft	4.3 ft upstream from the centerline of post 20
Exit Parameters			
Vehicle crossed exit box*		44 ft d/s from loss of contact	
Speed (mi/h)		38.1	
Trajectory Angle (deg)		12.3	
Heading Angle (deg)		14	
Brakes applied post impact (s)		N/A	
Vehicle at rest position		167 ft downstream of impact point Against the traffic-side rail Facing 10° left	
Comments: Vehicle remained upright and stable.			

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

Figure 7.1. Surface-Mounted Median Guardrail/Test Vehicle Geometrics for Test 440522-01-2.

7.2. WEATHER CONDITIONS

Table 7.2 presents the weather conditions for Test 440522-01-2.

Table 7.2. Weather Conditions for Test 440522-01-2.

Date of Test	Temperature (°F)	Relative Humidity (%)
October 6, 2021	76	71
Wind Direction (deg)	**Vehicle Traveling (deg)**	**Wind Speed (mi/h)**
191	325	4

7.3. TEST VEHICLE

Figure 7.2 shows the 2015 Ram used for the crash test. Table 7.3 shows the vehicle measurements. Table D.1 in Appendix D.1 gives additional dimensions and information on the vehicle.

Figure 7.2. Test Vehicle before Test 440522-01-2.

Table 7.3. Vehicle Measurements for 440522-01-2.

Test Parameter	*MASH*	Allowed Tolerance	Measured
Dummy (if applicable) [a] (lb)	165	N/A	No Dummy
Test Inertial Weight (lb)	5,000	±110	4,995
Gross Static[a] (lb)	5,000	±110	5,026
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40.0
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46.0
Track Width[b] (inches)	67	±1.5	68.3
CG aft of Front Axle[c] (inches)	63	±4	61.0
CG above Ground[c,d] (inches)	28	≥28	28.3

[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 7.4 lists events that occurred during Test 440522-01-2. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 7.4. Events during Test 440522-01-2.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0163	Post 19 began to deflect toward the field side
0.0370	Vehicle began to redirect
0.0208	Rear driver side bumper impacted the rail
0.1640	Front passenger side tire lifted from the pavement
0.5710	Front passenger side tire made contact with the pavement
0.2570	Vehicle was parallel with the installation
0.6020	Vehicle exits the installation at 38.1 mi/h with a heading of 14.0 degrees and a trajectory of 12.3 degrees

7.5. DAMAGE TO TEST INSTALLATION

Table 7.5 presents the post displacement details for the guardrail. The upstream edge of posts 19, 20, 21, 23, 24, and 25 was torn, and post 20 had a broken weld at the baseplate. The rail was scuffed and deformed at impact. No cracks or concrete damage was observed around the post baseplates. The baseplates and their epoxy anchors were also undamaged. The backer plates remained attached to the posts. There was a secondary impact at the downstream terminal, and the terminal was knocked over.

Table 7.5. Post Displacement Details for the Guardrail in Test 440522-01-2.

Post #	Post Lean from Vertical (deg)		Disconnected from Rail		Soil Gap (inches)		
	D/S	U/S	T/S	F/S	U/S	T/S	F/S
Anchor					1		
1	—	—	—	—	½	—	—
2	—	—	✓	—	½	—	—
3	1	1	✓	—	Soil Disturbed		
4	—	—	✓	—	⅛	—	—
5	4	—	—	—	Posts anchored to concrete and not installed in soil		
6	2	—	—	—			
7–10	3	—	—	—			
11	3	—	—	—			
12–15	3	—	—	—			
16	4	2.5	—	—			
17	5	9	✓	—			
18	9	20	✓	—			
19–26	90	—	✓	✓			
27	51	—	✓	✓			
28	1	1	✓	✓			
29	1	—	✓	✓			
30	1	—	✓	✓			
31	1	—	—	✓			
32	1	—	—	✓			
33	—	—	—	✓			
34–63	—	—	—	—	—	—	—
64	—	2	—	—	—	⅜	
65	—	4	—	—	—	1½	½
66	—	5	—	—	—	1¾	
67	—	—	✓	—	—	—	—

* D/S = Downstream; U/S = Upstream; T/S = Traffic Side; F/S = Field Side.

Table 7.6 describes the damage to the surface-mounted median guardrail, and Figure 7.3 illustrates that damage.

Table 7.6. Damage to the Guardrail in Test 440522-01-2.

Test Parameter	Measured
Permanent Deflection/ Location	30.3 inches toward field side at Post 22
Dynamic Deflection	37.8 inches toward field side
Working Width* and Height	45 inches at a height of 45.8 inches

* 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 7.3. Surface-Mounted Median Guardrail after Test 440522-01-2.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.4 and Figure 7.5 show the damage sustained by the vehicle. Table 7.7 provides details on the interior and exterior damage to the vehicle. Tables D.2 and D.3 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 7.4. Test Vehicle after Test 440522-01-2.

Figure 7.5. Interior of Test Vehicle after Test 440522-01-2.

Table 7.7. Damage to the Vehicle in Test 440522-01-2.

<table>
<tr><th colspan="2">Test Parameter</th><th colspan="2">Specification</th><th colspan="2">Measured</th></tr>
<tr><td colspan="2">Roof</td><td colspan="2">≤ 4.0 inches</td><td colspan="2">0 inches</td></tr>
<tr><td colspan="2">Windshield</td><td colspan="2">≤ 3.0 inches</td><td colspan="2">0 inches</td></tr>
<tr><td colspan="2">A and B Pillars</td><td colspan="2">≤ 5.0 overall/≤ 3.0 inches lateral</td><td colspan="2">0 inches</td></tr>
<tr><td colspan="2">Foot Well/Toe Pan</td><td colspan="2">≤ 9.0 inches</td><td colspan="2">0 inches</td></tr>
<tr><td colspan="2">Floor Pan</td><td colspan="2">≤ 12.0 inches</td><td colspan="2">0 inches</td></tr>
<tr><td colspan="2">Side Front Panel</td><td colspan="2">≤ 12.0 inches</td><td colspan="2">0 inches</td></tr>
<tr><td colspan="2">Front Door (above Seat)</td><td colspan="2">≤ 9.0 inches</td><td colspan="2">0 inches</td></tr>
<tr><td colspan="2">Front Door (below Seat)</td><td colspan="2">≤ 12.0 inches</td><td colspan="2">0 inches</td></tr>
<tr><td colspan="2">Side Windows</td><td colspan="4">Remained intact</td></tr>
<tr><td colspan="2">Maximum Exterior Deformation</td><td colspan="4">8 inches in the front left plane at bumper height</td></tr>
<tr><td>VDS</td><td colspan="2">11LFQ4</td><td>CDC</td><td colspan="2">11FLEW2</td></tr>
<tr><td colspan="3">Fuel Tank Damage</td><td colspan="3">None</td></tr>
<tr><td colspan="6">Description of Damage to Vehicle:
The front bumper, hood, grill, left front fender, left front upper and lower control arms, left front tire and rim, left front door, radiator, left rear door, left rear quarter panel, left taillight, and rear bumper were damaged.</td></tr>
</table>

7.7. OCCUPANT RISK FACTORS

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

Table 7.8. Occupant Risk Factors for Test 440522-01-2.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0	18.2	0.1454 s on left side of interior
OIV, Lateral (ft/s)	≤40.0	15.1	0.1454 s on left side of interior
Ridedown, Longitudinal (g)	≤20.49	6.1	0.1582–0.1682 s
Ridedown, Lateral (g)	≤20.49	7.5	0.2556–0.2656 s
THIV (m/s)	N/A	6.9	0.1383 s on left side of interior
ASI	N/A	0.7	0.0811–0.1311 s
50-ms Max Longitudinal (g)	N/A	−5.6	0.0749–0.1249 s
50-ms Max Lateral (g)	N/A	6.1	0.2473–0.2973 s
50-ms Max Vertical (g)	N/A	−2.3	0.6444–0.6944 s
Roll (deg)	≤75	11.0	0.4894 s
Pitch (deg)	≤75	3.8	0.6534 s
Yaw (deg)	N/A	40.7	0.7428 s
Comments:			

0.000 s

0.100 s

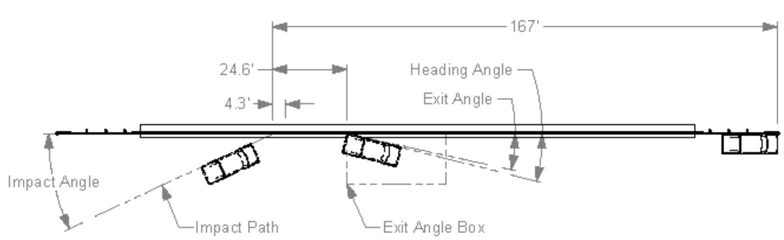
0.200 s

0.300 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, 3-11 Test
TTI Project No.	440522-01-2
Test Date	2021-10-06
TEST ARTICLE	
Type	Median Rail
Name	Surface-Mounted Median Guardrail
Length	239 ft 5 inches
Key Materials	S3×5.7×31⅜ weak posts, 12-gauge W-beam, concrete foundation, and SoftStop® end terminals
Soil Type and Condition	AASHTO M147-65(2004), Type 1, Grade D Crushed Concrete
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2015 Ram
Curb Weight (lb)	4,995
Inertial Weight (lb)	5,026
Dummy (lb)	N/A
Gross Static (lb)	5,026
IMPACT CONDITIONS	
Impact Speed (mi/h)	63.5
Impact Angle (deg)	25.1
Impact Location	4.3 ft upstream from the centerline of post 20
Impact Severity (kip-ft)	121.9
EXIT CONDITIONS	
Exit Speed (mi/h)	38.1
Trajectory/Heading Angle (deg)	12.3/14
Exit Box Criteria	Crossed
Stopping Distance (ft)	167 ft downstream and against the traffic-side rail
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	37.8
Permanent (inches)	30.3
Working Width/Height (inches)	45/45.8
VEHICLE DAMAGE	
VDS	11LFQ4
CDC	11FLEW2
Max. Ext. Deformation (inches)	8
Max. Occupant Compartment Deformation	None

OCCUPANT RISK VALUES

Long. OIV (ft/s)	18.2	Lat. OIV (ft/s)	15.1	Max. 50-ms Long. (g)	−5.6	Max. Roll (deg)	11
Long. Ridedown (g)	6.1	Lat. Ridedown (g)	7.5	Max. 50-ms Lat. (g)	6.1	Max. Pitch (deg)	4
THIV (m/s)	6.9	ASI	0.7	Max. 50-ms Vert. (g)	−2.3	Max. Yaw (deg)	41



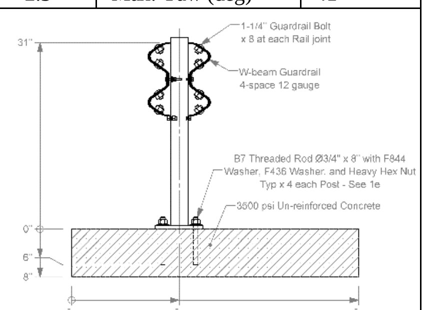


Figure 7.6. Results Summary for *MASH* Test 3-11 on Surface-Mounted Median Guardrail.

Chapter 8. SUMMARY AND CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-3 evaluation criteria for longitudinal barriers, which involved performing *MASH* Test 3-10 and Test 3-11 on the surface-mounted median guardrail. Table 8.1 and Table 8.2 provide an assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-3 for longitudinal barriers.

8.2. CONCLUSIONS

Table 8.3 shows that the surface-mounted median guardrail met the performance evaluation criteria of *MASH* TL-3 for longitudinal barriers.

Table 8.1. Performance Evaluation Summary for *MASH* Test 3-10 on Surface-Mounted Median Guardrail.

Test Agency: Texas A&M Transportation Institute   Test No.: 440522-01-1   Test Date: 2021-09-27

	***MASH* Test 3-10 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy			
A.	*Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The surface-mounted median guardrail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 18.7 inches.	Pass
Occupant Risk			
D.	*Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
	Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 2 inches in the front door panel below the seat	
F.	*The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 11 degrees and 5 degrees.	Pass
H.	*Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s (10 ft/s for supports), or maximum allowable value of 40 ft/s (16 ft/s for supports).*	Longitudinal OIV was 22.2 ft/s, and lateral OIV was 18.8 ft/s.	Pass
I.	*The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Maximum longitudinal occupant ridedown acceleration was 13.5 g, and maximum lateral occupant ridedown was 9.4 g.	Pass

Table 8.2. Performance Evaluation Summary for *MASH* Test 3-11 on Surface-Mounted Median Guardrail.

Test Agency: Texas A&M Transportation Institute Test No.: 440522-01-2 Test Date: 2021-10-06

MASH Test 3-11 Evaluation Criteria		Test Results	Assessment
Structural Adequacy			
A.	*Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The surface-mounted median guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 37.8 inches.	Pass
Occupant Risk			
D.	*Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
	Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	There was no measured occupant compartment deformation.	
F.	*The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 11 degrees and 4 degrees.	Pass
H.	*Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s (10 ft/s for supports), or maximum allowable value of 40 ft/s (16 ft/s for supports).*	Longitudinal OIV was 18.2 ft/s, and lateral OIV was 15.1 ft/s.	Pass
I.	*The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Maximum longitudinal occupant ridedown acceleration was 6.1 g, and maximum lateral occupant ridedown was 7.5 g.	Pass

Table 8.3. Assessment Summary for *MASH* TL-3 Tests on the Surface-Mounted Median Guardrail.

Evaluation Factors	Evaluation Criteria	Test No. 440522-01-1	Test No. 440522-01-2
Structural Adequacy	A	S	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
Test No.		*MASH* Test 3-10	*MASH* Test 3-11
Pass/Fail		Pass	Pass

Note: S = Satisfactory.

Chapter 9. IMPLEMENTATION

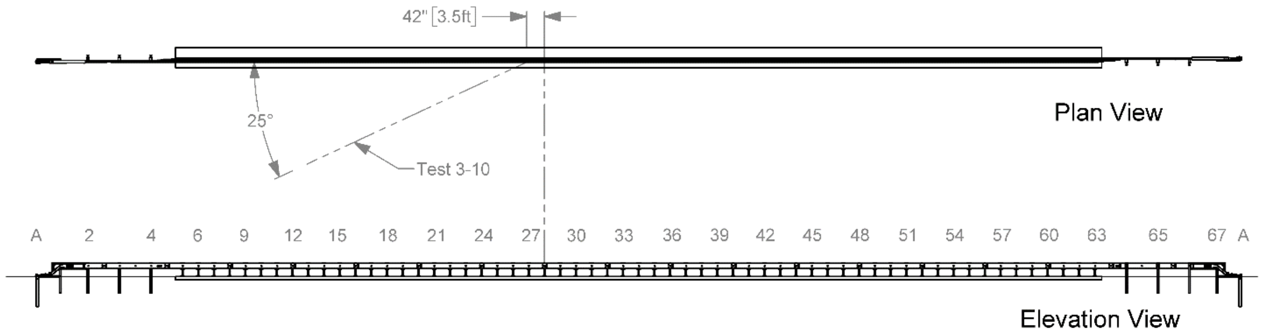
A new surface mounted median guardrail system has been developed and evaluated through full-scale crash testing per *MASH* TL-3 crash tests. This system is ready for implementation by TxDOT as a crashworthy median guardrail that can be mounted on concrete pavement or deck. Implementation of this system can be carried out by the TxDOT Design Division through development of a new standard hardware drawing following the details provided in Appendix A.

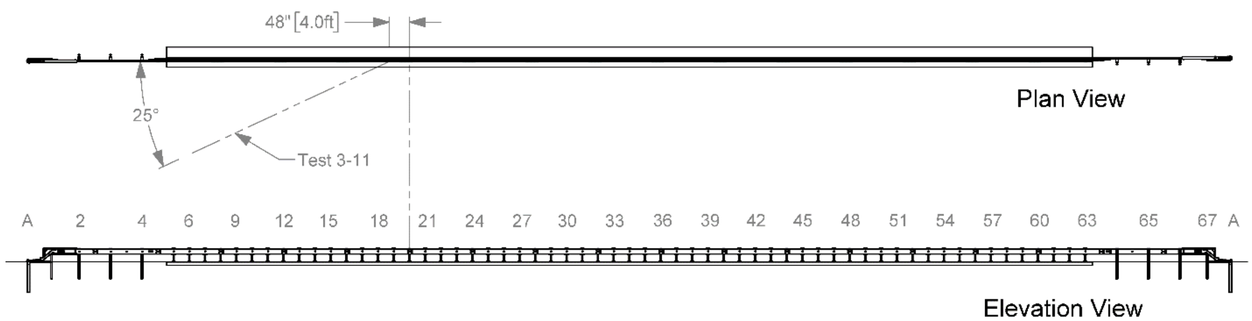
Following the procedures outlined in TxDOT's *University Handbook*, the researchers assessed the potential value of TxDOT Research Project 0-7052. Appendix E presents the value of research for this project.

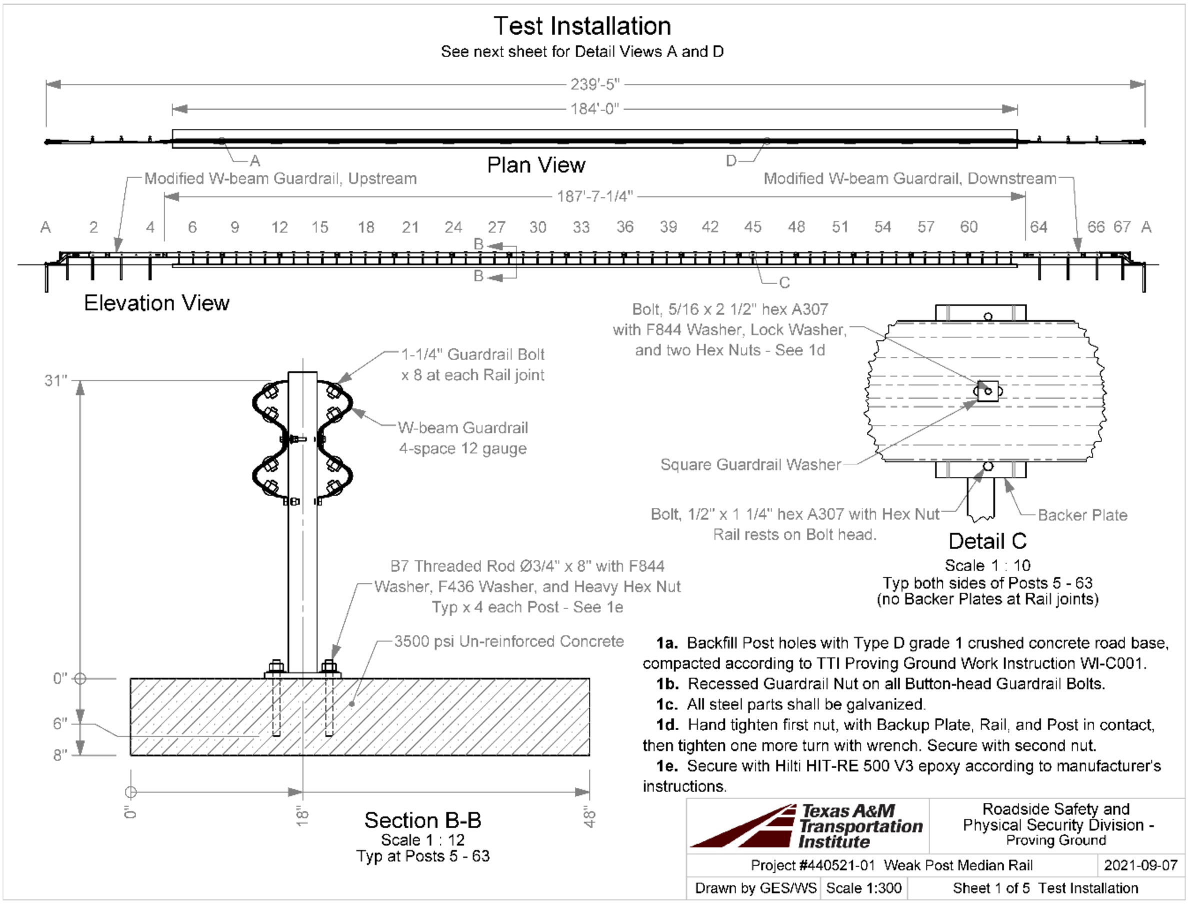
REFERENCES

1. AASHTO. *Manual for Assessing Safety Hardware*, Second Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2016.
2. Williams, W.F., Bligh, R.P., Menges, W.L., and Kuhn, D.L. *MASH TL-3 Crash Testing and Evaluation of the TxDOT T631 Bridge Rail*. Test Report 9-1002-12-12, Texas A&M Transportation Institute, Bryan, Texas, 2014.
3. Sicking, D.L., Faller, R.K., Bielenberg, R.W., Lechtenberg, K.A., Reid, J.D., and Rosenbaugh, S.K. *Development of a Low-Cost Energy-Absorbing Bridge Rail*. Research Report TRP-03-226-10, Midwest Roadside Safety Facility, Lincoln, Nebraska, 2010.

APPENDIX A. DETAILS OF SURFACE-MOUNTED MEDIAN GUARDRAIL







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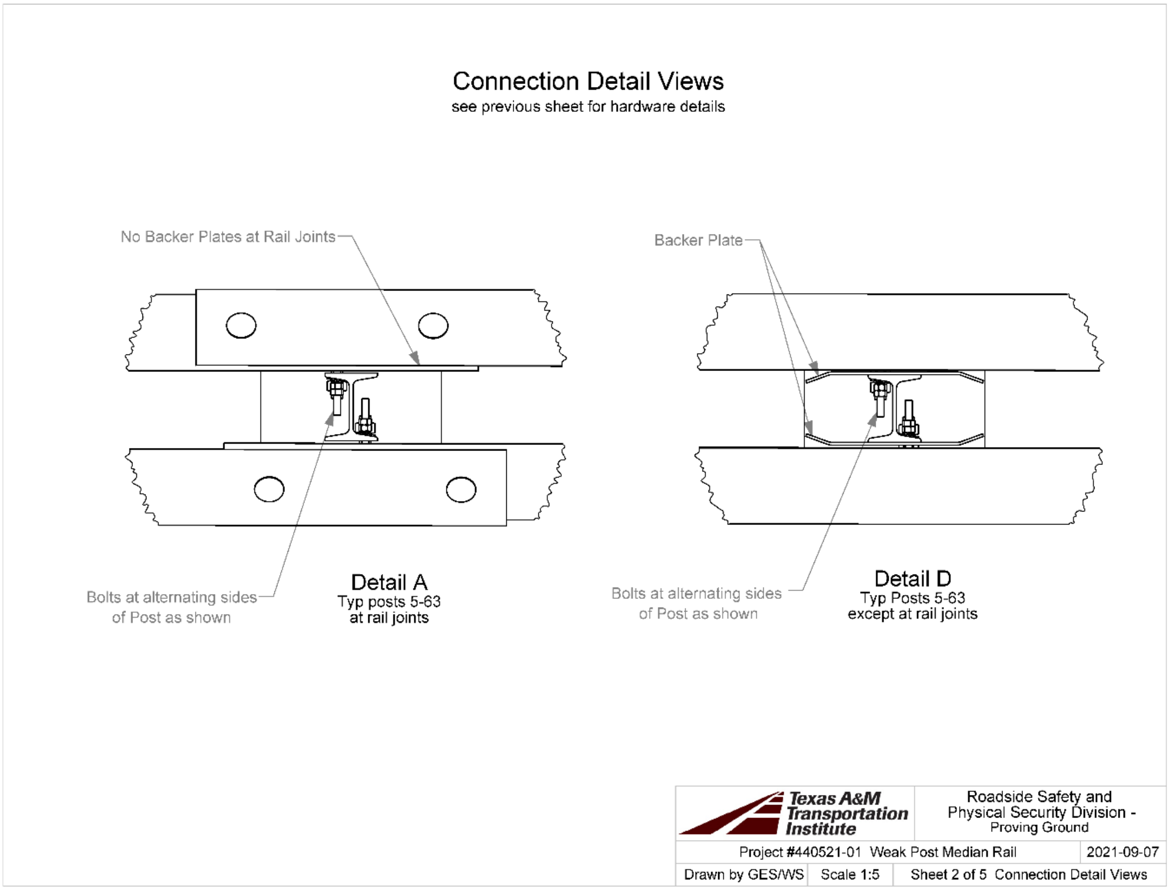

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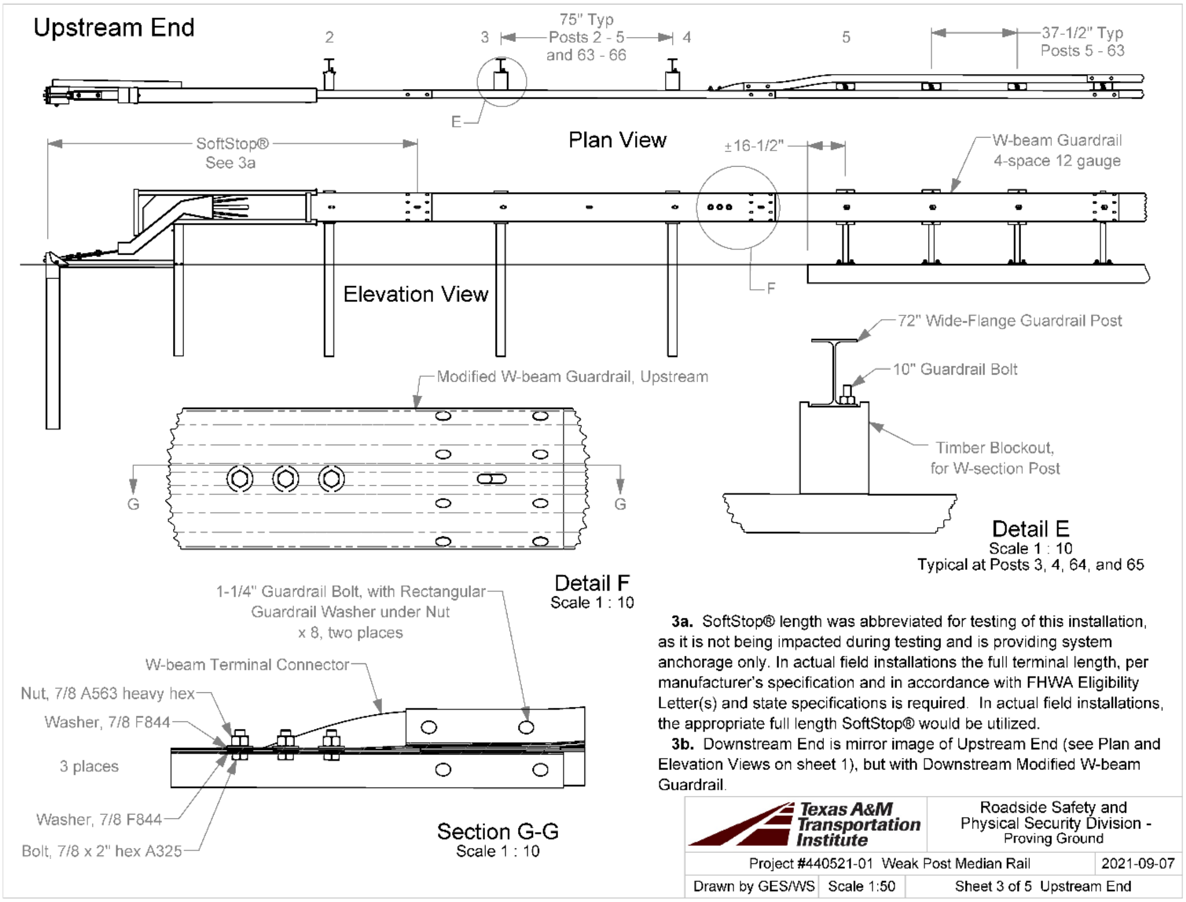

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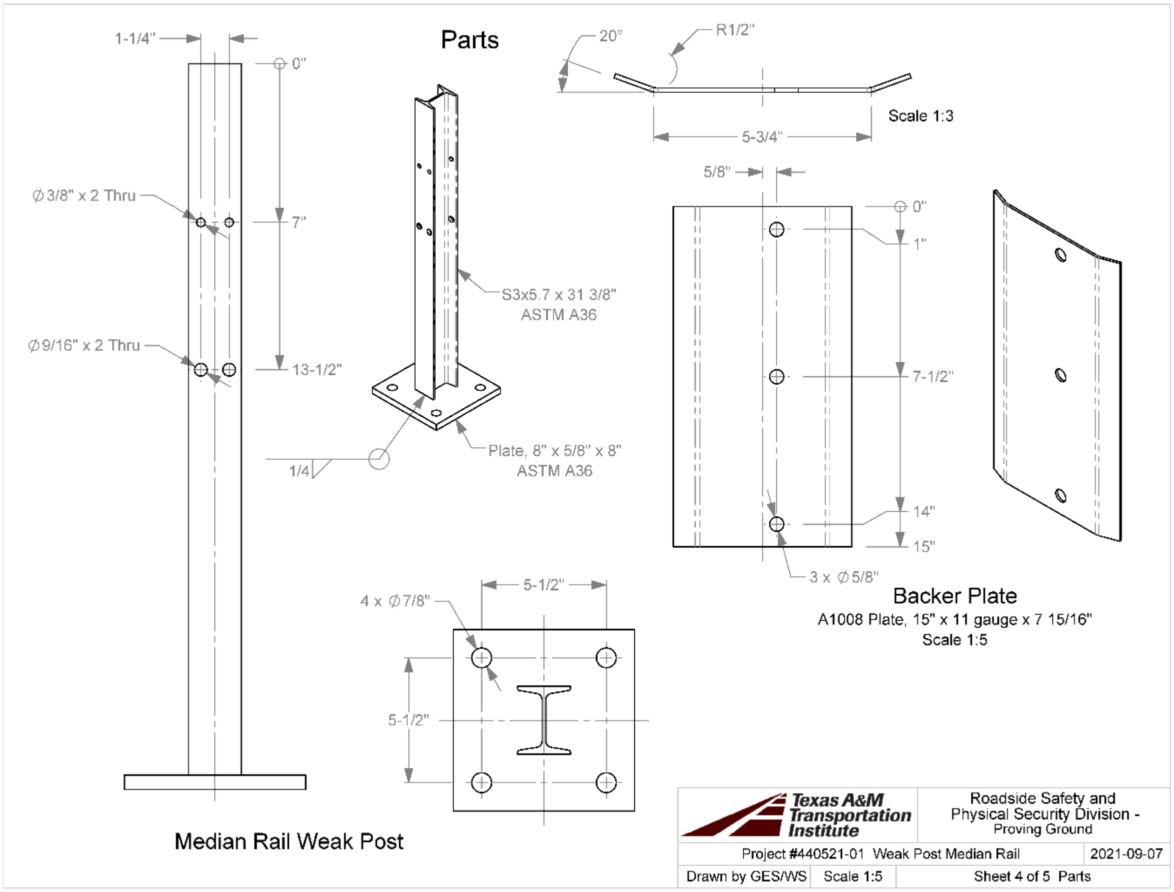

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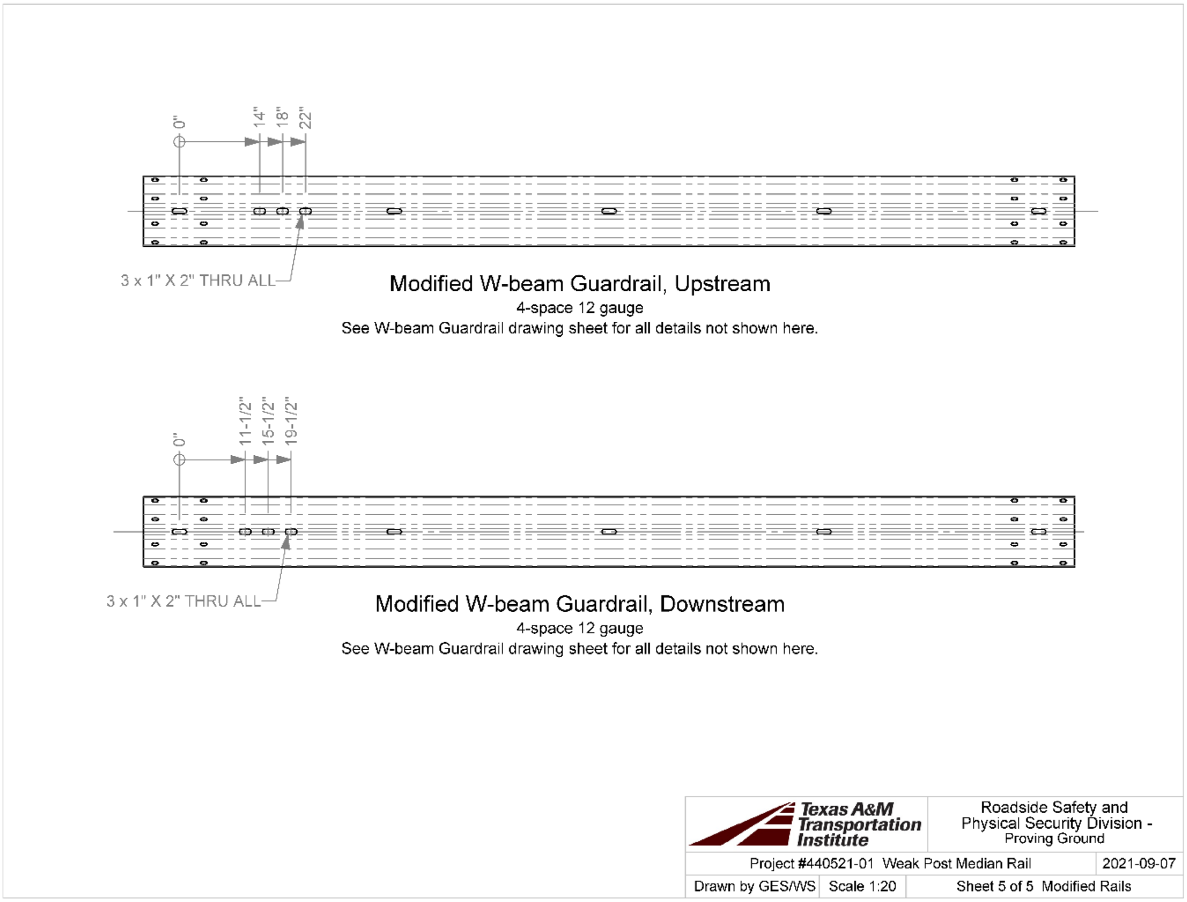

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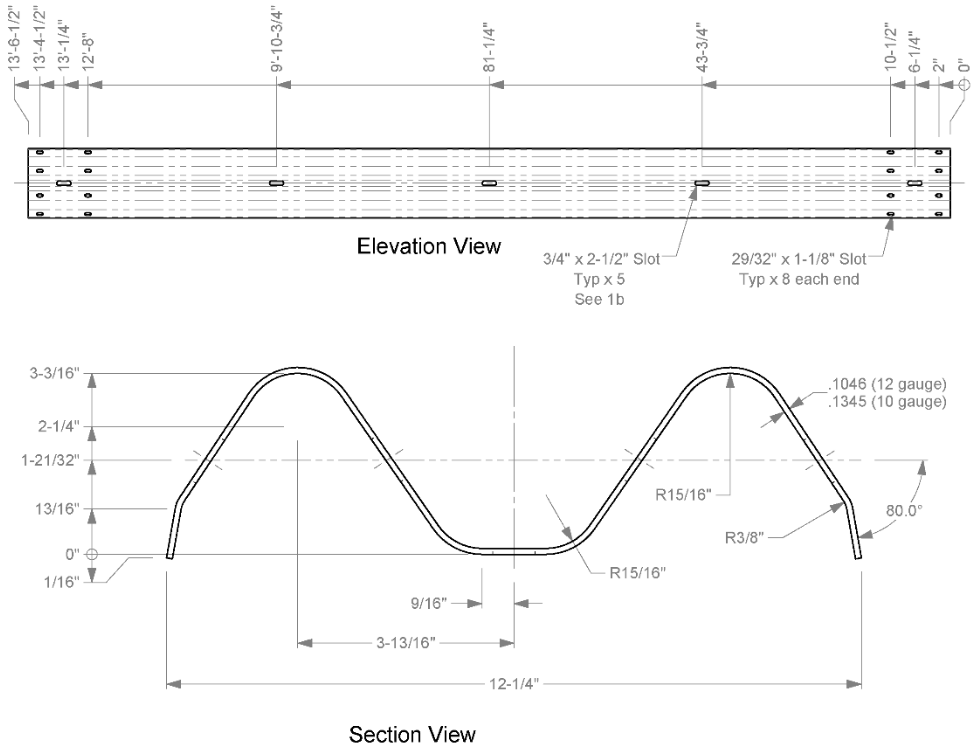

1a. Manufacture per AASHTO M180 specifications.

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

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

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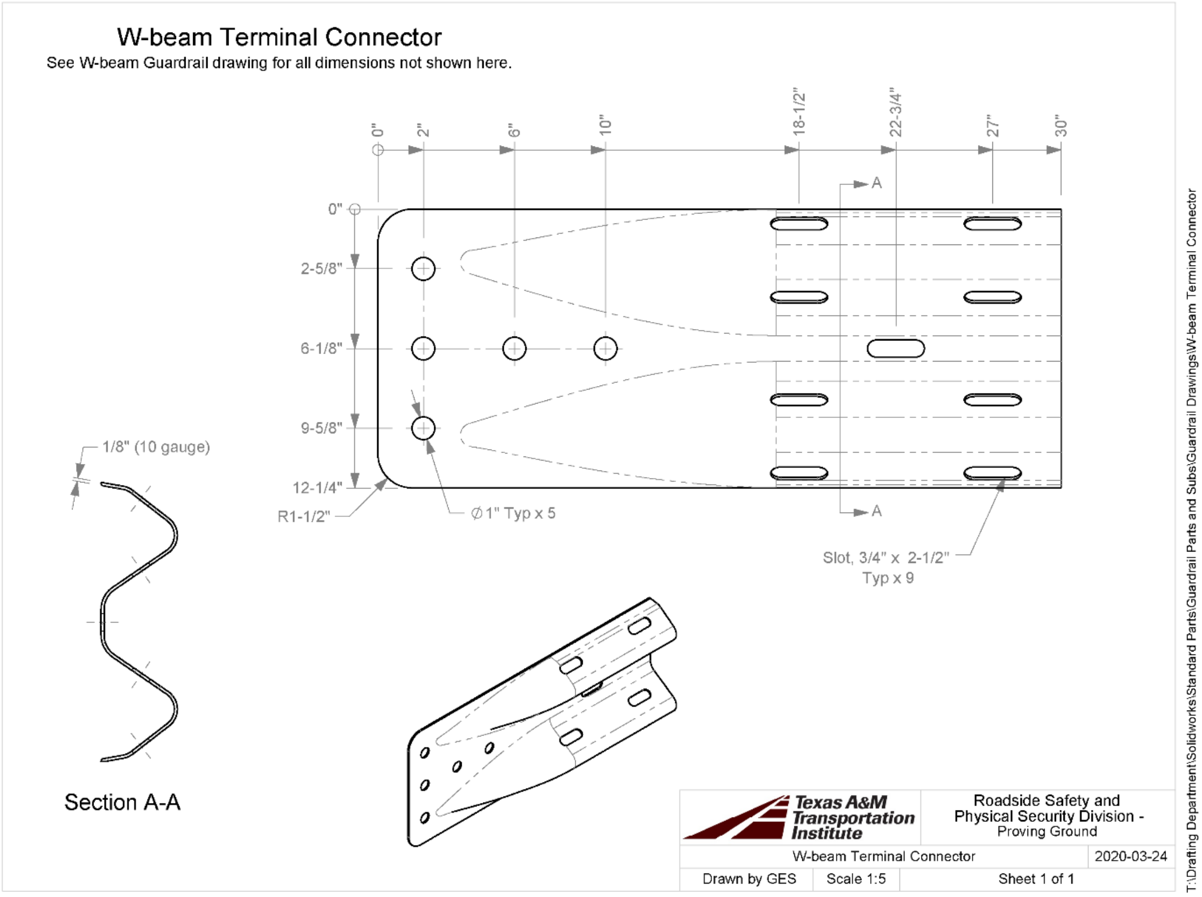

W-beam Terminal Connector
See W-beam Guardrail drawing for all dimensions not shown here.
0"
2"
6"
10"
18-1/2"
22-3/4"
27"
30"
A
0"
2-5/8"
6-1/8"
9-5/8"
12-1/4"
R1-1/2"
∅1" Typ x 5
A
Slot, 3/4" x 2-1/2"
Typ x 9
1/8" (10 gauge)
Section A-A
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
W-beam Terminal Connector
2020-03-24
Drawn by GES
Scale 1:5
Sheet 1 of 1
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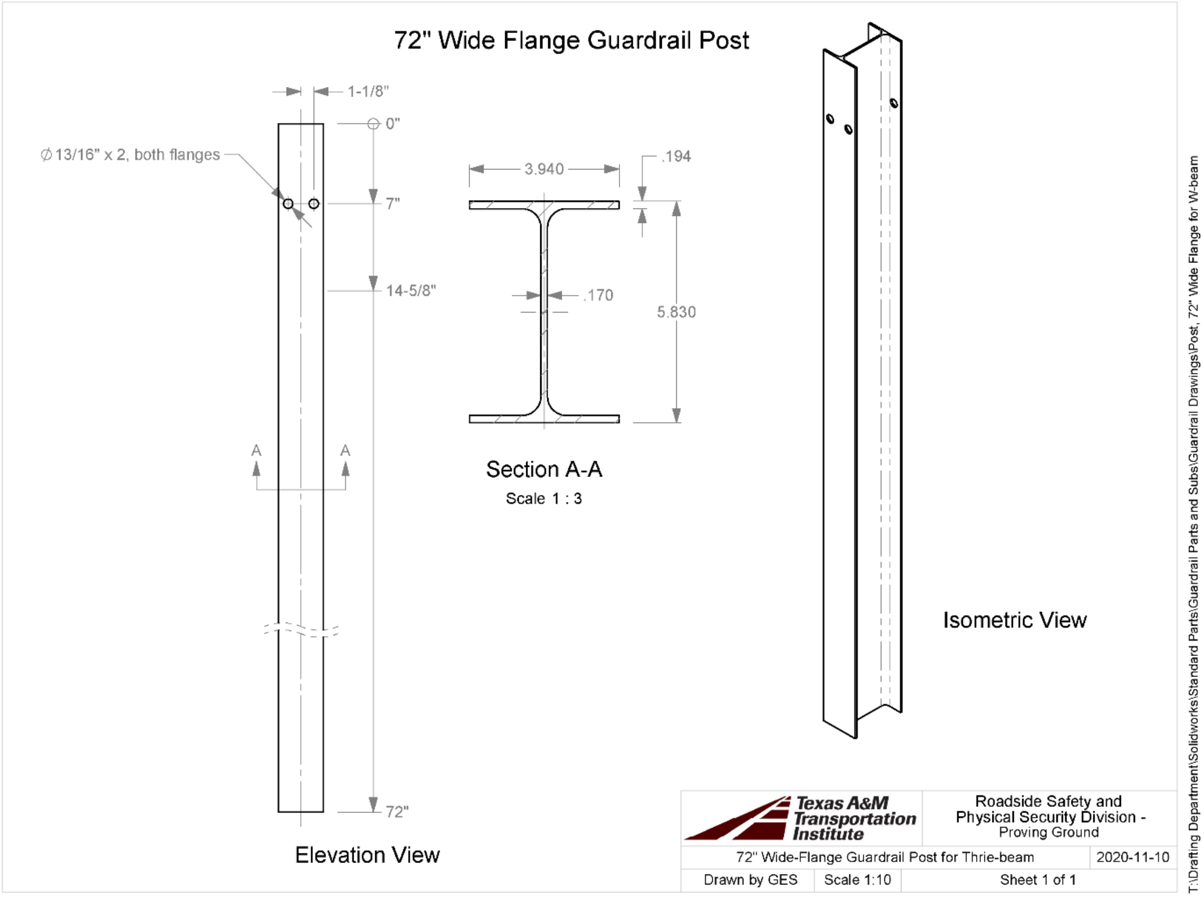

72" Wide Flange Guardrail Post
1-1/8"
0"
∅13/16" x 2, both flanges
7"
14-5/8"
A
A
72"
Elevation View
3.940
.194
.170
5.830
Section A-A
Scale 1 : 3
Isometric View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
72" Wide-Flange Guardrail Post for Thrie-beam
2020-11-10
Drawn by GES
Scale 1:10
Sheet 1 of 1
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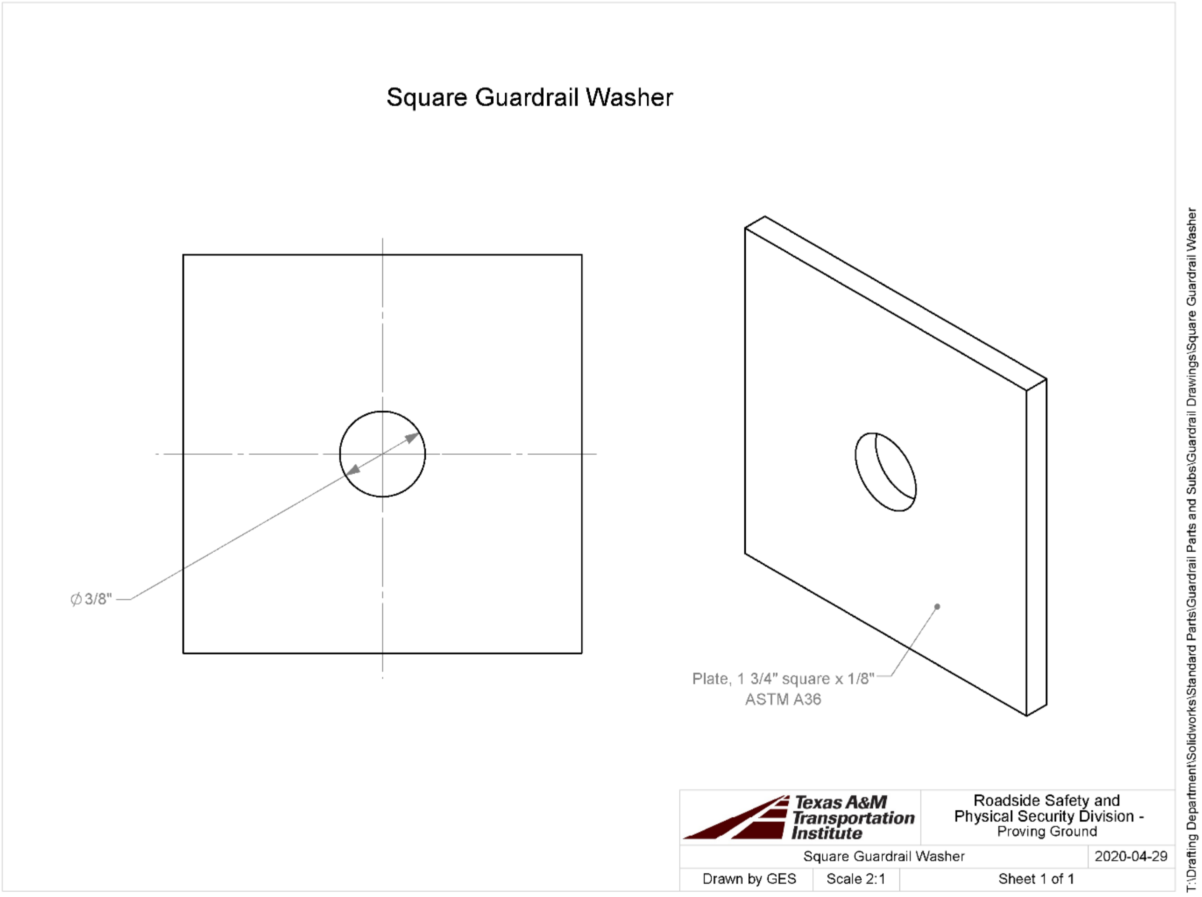
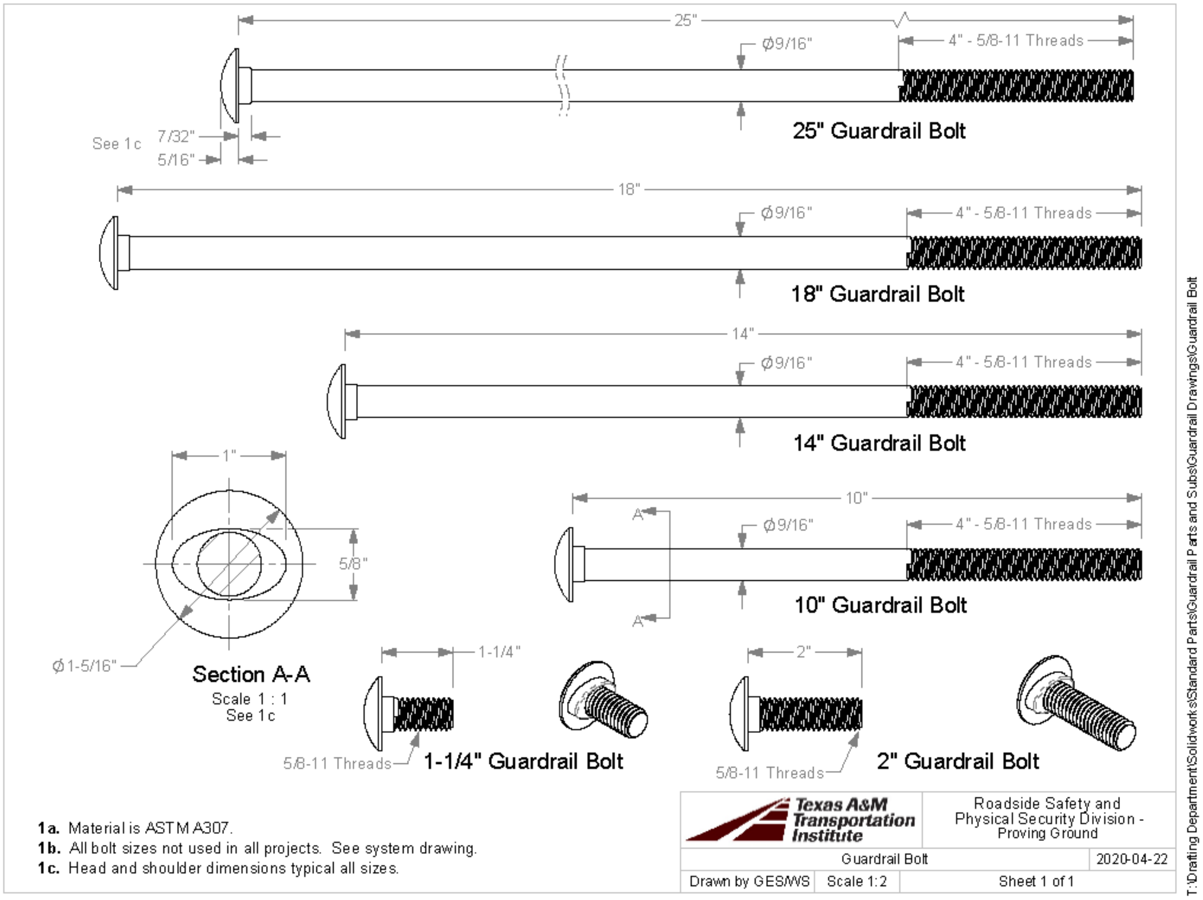
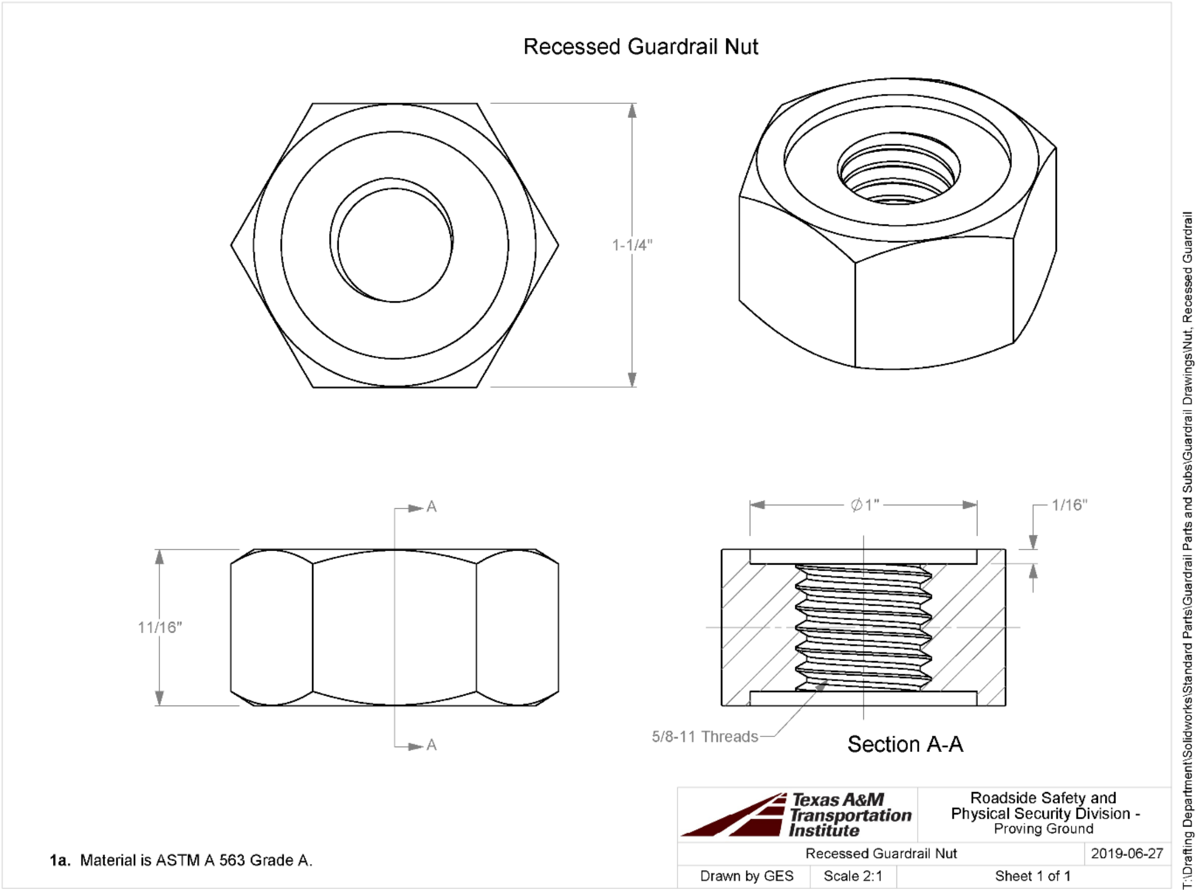
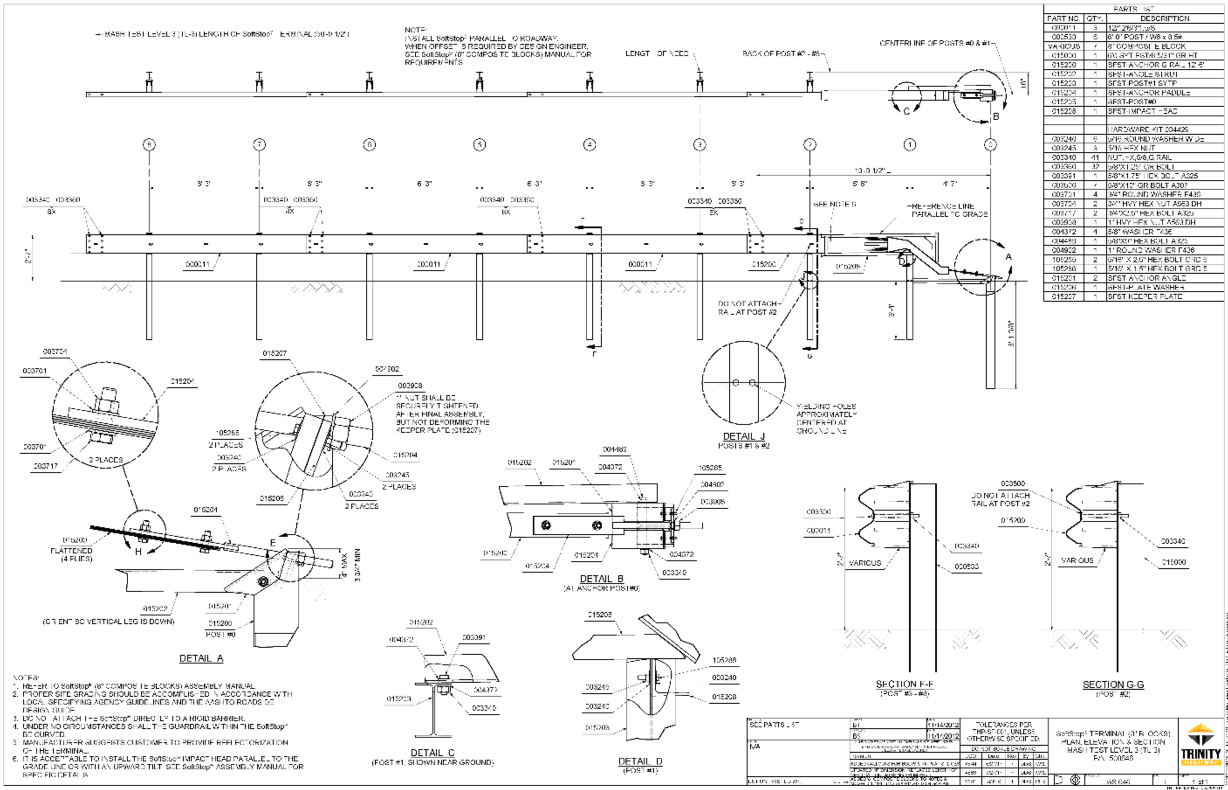

Square Guardrail Washer
⌀3/8"
Plate, 1 3/4" square x 1/8"
ASTM A36
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Square Guardrail Washer
2020-04-29
Drawn by GES
Scale 2:1
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Square Guardrail Washer


25"
Ø9/16"
4" - 5/8-11 Threads
25" Guardrail Bolt
See 1c
7/32"
5/16"
18"
Ø9/16"
4" - 5/8-11 Threads
18" Guardrail Bolt
14"
Ø9/16"
4" - 5/8-11 Threads
14" Guardrail Bolt
1"
5/8"
10"
A
Ø9/16"
4" - 5/8-11 Threads
10" Guardrail Bolt
A
Ø1-5/16"
Section A-A
Scale 1 : 1
See 1c
1-1/4"
5/8-11 Threads
1-1/4" Guardrail Bolt
2"
5/8-11 Threads
2" Guardrail Bolt
1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Guardrail Bolt
2020-04-22
Drawn by GES/WS
Scale 1:2
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Guardrail Bolt


Recessed Guardrail Nut
1-1/4"
A
11/16"
A
Ø1"
1/16"
5/8-11 Threads
Section A-A
1a. Material is ASTM A 563 Grade A.
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Recessed Guardrail Nut
2019-06-27
Drawn by GES
Scale 2:1
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Nut, Recessed Guardrail


DETAIL A
DETAIL B
DETAIL C
DETAIL D
DETAIL J
SECTION F-F
SECTION G-G
TRINITY

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

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

Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525

ADDISON, TX 75001

Sales Order: 1341822
Customer PO: TXDOT
BOL # 85091
Document # 1

Print Date: 8/27/21
Project: TXDOT TESTING

Shipped To: TX
Use State: TX

Trinity Highway Products LLC

Certificate Of Compliance For Trinity Highway Products, LLC

Pieces	Description	Part No
192	5/8"X1.25" GR BOLT	003360G
6	5/8"X10" GR BOLT A307	003500G
12	7/8" WASHER F844 TYPE A/N	003725G
6	7/8" HVY HEX NUT A563 DH	003742G
42	12/12'6/3'1.5/S	000011G
3	10/END SHOE/EXTRA HOLE	000926G
160	WASHER,FLAT,5/16 W,TY A,G	003240G
320	5/16" HEX NUT A563	003245G
160	1/2"X1.25" HEX BOLT A307	003286G
160	1/8"X1.75"X1.75" WSHR PL	003319G
160	WASHER,LOCK,5/16,G	118097G
160	5/16"X2 1/2"HEX BOLT A307	119159G
2	HDPE BLK4X7.5X14KING,M16	119303B
2	SOFTSTOP MASH TL3 SS-673	500673B
2	12/25/3'1.5/S	000061G
12	6'0 POST/8.5/DDR	000533G
14	PLY MNDO BLK 4X8X14 W/HGR	006565B
2	6'0 SYT PST/8.5/31" GR HT	015000G
2	SFST-ANGLE STRUT	015202G
2	SFST-POST#1 SYTP	015203G
2	SFST-ANCHOR PADDLE	015204A
2	SFST-POST#0	015205A
2	SFST-IMPACT HEAD	015208A
2	SFST-ANCHOR G.RAIL 25'-0"	015215G
2	SFST-CAN SS-646/SS-673	034429G
6	7/8"X2" HEX BOLT A325	003751G
4	WD BLK RTD 6X8X14	004076B
160	1/2" HEX NUT A563 GR A	004303G

440521

1 of 2

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

Customer: SAMPLES, TESTING MATERIALS 15601 Dallas Pkwy Suite 525 ADDISON, TX 75001	Sales Order: 1341822 Customer PO: TXDOT BOL # 85091 Document # 1	Print Date: 8/27/21 Project: TXDOT TESTING Shipped To: TX Use State: TX

Trinity Highway Products LLC

Certificate Of Compliance For Trinity Highway Products, LLC

Pieces	Description	Part No
2	REFL SHT 5X24 Y/B LT	005851B
2	REFL SHT 5X24 Y/B RT	005852B
2	PLY MNDO BLK 4X8X14 W/HGR	006565B
16	3/16"X1.75"X3" WASHER	003320G
198	5/8" GR HEX NUT	003340G

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED .
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT" , 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)
FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329,UNLESS OTHERWISE STATED.
IF APPLICABLE,3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Texas, County of Tarrant. Sworn and Subscribed before me this 27th day of August, 2021 .

Notary Public:
Commission Expires:

ARACELI REY
Notary Public, State of Texas
Comm. Expires 01-14-2023
Notary ID 130076852

Trinity Highway Products LLC
Certified By:
Quality Assurance

SerialNbr	Model	Mfg Origin	Mfg Date	SerialNbr	Model	Mfg Origin	Mfg Date	SerialNbr	Model	Mfg Origin	Mfg Date
FS0057688	SOFTSTOP	FT WORTH TX	08/2021	FS0057690	SOFTSTOP	FT WORTH TX	08/2021				

Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525

ADDISON, TX 75001
Project: TXDOT TESTING

Order Number: 1341822
Customer PO: TXDOT
BOL Number: 85091
Document #: 1
Shipped To: TX
Use State: TX

Prod Ln Grp: 9-End Terminals (Dom)
Ship Date:

As of: 8/27/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
42	11G	12/12'6/3'1.5/S			2	F10521													
			M-180	A	2	2107037	63,900	85,600	22.0	0.210	0.780	0.009	0.001	0.030	0.090	0.001	0.040	0.004	4
			M-180	A	2	2107660	59,400	82,900	24.0	0.200	0.770	0.012	0.001	0.030	0.080	0.002	0.060	0.003	4
			M-180	B	2	2110285	57,300	79,200	27.0	0.220	0.770	0.009	0.002	0.020	0.080	0.001	0.050	0.002	4
			M-180	A	2	2208099	55,700	81,100	24.0	0.240	0.970	0.009	0.002	0.020	0.080	0.001	0.050	0.004	4
			M-180	A	2	2210348	53,600	76,300	28.0	0.190	0.780	0.009	0.002	0.030	0.080	0.002	0.050	0.003	4
			M-180	A	2	2210350	57,100	76,900	29.0	0.190	0.800	0.009	0.002	0.030	0.090	0.002	0.050	0.003	4
	11G				2	F11421													
			M-180	A	2	2110284	56,300	76,900	26.0	0.200	0.800	0.009	0.001	0.030	0.080	0.002	0.060	0.003	4
			M-180	A	2	2110285	57,300	79,200	27.0	0.220	0.770	0.009	0.002	0.020	0.080	0.001	0.050	0.002	4
			M-180	A	2	2111226	58,200	85,700	25.0	0.240	1.000	0.009	0.001	0.030	0.120	0.003	0.060	0.005	4
			M-180	A	2	2111227	57,700	85,300	24.0	0.230	0.970	0.009	0.001	0.030	0.130	0.002	0.060	0.004	4
			M-180	A	2	2210349	61,100	84,200	26.0	0.190	0.780	0.008	0.001	0.030	0.090	0.002	0.050	0.003	4
			M-180	A	2	2210351	61,900	83,100	26.0	0.190	0.780	0.011	0.001	0.030	0.110	0.002	0.050	3.000	4
			M-180	A	2	2211345	58,300	83,800	25.0	0.240	1.000	0.011	0.001	0.030	0.140	0.002	0.060	0.004	4
			M-180	A	2	2211346	59,600	85,300	25.0	0.230	1.020	0.009	0.001	0.030	0.140	0.001	0.050	0.004	4
			M-180	A	2	2211347	58,800	85,100	25.0	0.230	0.990	0.009	0.001	0.030	0.100	0.001	0.050	0.004	4
	11G				2	F11521													
			M-180	A	2	2111225	58,700	94,300	27.0	0.230	0.990	0.009	0.016	0.020	0.120	0.002	0.060	0.000	4
			M-180	A	2	2111226	58,200	85,700	25.0	0.240	1.000	0.009	0.001	0.030	0.120	0.003	0.060	0.005	4
			M-180	A	2	2111227	57,700	85,300	24.0	0.230	0.970	0.009	0.001	0.030	0.130	0.002	0.060	0.004	4
			M-180	A	2	2211346	59,600	85,300	25.0	0.230	1.020	0.009	0.001	0.030	0.140	0.001	0.050	0.004	4
3	926G	10/END SHOE/EXTRA HOLE	M-180	A	2	259851	62,403	81,461	22.8	0.190	0.720	0.014	0.001	0.020	0.110	0.000	0.050	0.001	4
	926G		RHC		2	L11921													4
			M-180	B	2	260786	62,000	80,172	24.7	0.190	0.730	0.011	0.002	0.020	0.130	0.000	0.080	0.000	4

Certified Analysis

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

Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525
ADDISON, TX 75001

Project: TXDOT TESTING

Order Number: 1341822 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: TXDOT
BOL Number: 85091 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/27/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
			M-180	A	2	260788	63,565	80,754	25.4	0.180	0.720	0.011	0.003	0.020	0.080	0.000	0.080	0.002	4
			M-180	A	2	260791	64,389	83,182	22.3	0.200	0.720	0.011	0.002	0.020	0.120	0.000	0.070	0.000	4
			M-180	A	2	261141	61,855	79,140	23.9	0.190	0.710	0.010	0.003	0.020	0.130	0.000	0.060	0.001	4
			M-180	A	2	261147	61,123	79,606	24.2	0.190	0.720	0.009	0.003	0.010	0.110	0.000	0.070	0.001	4
			M-180	A	2	261612	63,653	81,142	26.6	0.190	0.720	0.011	0.005	0.010	0.100	0.001	0.080	0.002	4
			M-180	A	2	261614	61,668	78,433	24.0	0.180	0.720	0.012	0.003	0.020	0.120	0.000	0.100	0.002	4
			M-180	A	2	262184	61,577	79,100	25.4	0.190	0.730	0.012	0.003	0.020	0.060	0.000	0.060	0.000	4
			M-180	A	2	262455	65,000	826,100	24.5	0.190	0.730	0.013	0.002	0.030	0.110	0.000	0.080	0.002	4
			M-180	A	2	262456	62,025	80,574	24.9	0.190	0.720	0.011	0.003	0.020	0.110	0.000	0.060	0.007	4
160	3240G	WASHER,FLAT,5/16 W,TY A,G	F436 -3240			P39949 R75795													4
320	3245G	5/16" HEX NUT A563	A563-3245			21-02-010													4
160	3286G	1/2"X1.25" HEX BOLT A307	FAST			1749944													4
160	3319G	1/8"X1.75"X1.75" WSHR PL	FAST			889255-1													4
16	3320G	3/16"X1.75"X3" WASHER	M180-3320		2	1058225													4
198	3340G	5/8" GR HEX NUT	FAST			21-35-008													4
192	3360G	5/8"X1.25" GR BOLT	A307-3360G			949605-10													4
6	3500G	5/8"X10" GR BOLT A307	A307-3500G			954676-7													4
12	3725G	7/8" WASHER F844 TYPE A/N	F844-3725			P39270 R73233-01													4

Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525
ADDISON, TX 75001
Project: TXDOT TESTING

Order Number: 1341822
Customer PO: TXDOT
BOL Number: 85091
Document #: 1
Shipped To: TX
Use State: TX

Prod Ln Grp: 9-End Terminals (Dom)
Ship Date:

As of: 8/27/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
6	3742G	7/8" HVY HEX NUT A563 DH	A563 -3742			P38907 R71855													4
4	4076B	WD BLK RTD 6X8X14	WOOD			4850													
160	4303G	1/2" HEX NUT A563 GR A	A563-4303			P38839 R71717													4
2	5851B	REFL SHT 5X24 Y/B LT	LABELS			203291													
2	5852B	REFL SHT 5X24 Y/B RT	LABELS			211141													
2	6565B	PLY MNDO BLK 4X8X14 W/HGR	PLAST			41848													
160	118097G	WASHER,LOCK,5/16,G	B18.21.1-118			SH-000557829													4
2	119303B	HDPE BLK4X7.5X14KING,M16	PLAST			25996													
2	500673B	SOFTSTOP MASH TL3 SS-673	F3125 -3391			0129999													
	500673B		A-36			1801947	55,000	68,200	25.6	0.070	0.830	0.007	0.028	0.250	0.090	0.014	0.040	0.003	
	500673B		A563-3245			21-02-010													
	500673B		FAST			21-35-008													
	500673B		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	
	500673B		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	

Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525

ADDISON, TX 75001
Project: TXDOT TESTING

Order Number: 1341822
Customer PO: TXDOT
BOL Number: 85091
Document #: 1
Shipped To: TX
Use State: TX

Prod Ln Grp: 9-End Terminals (Dom)

Ship Date:

As of: 8/27/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
	500673B		MISC			40111-2													
	500673B		PLAST			41848													
	500673B		MISC			59613													
	500673B		F3125-4489			949217-2													
	500673B		A307-3360G			949605-10													
	500673B		A307-3500G			954676-7													
	500673B		F3125-3717			969650-1													
	500673B		RHC		2	F12418													
			M-180	A	2	1282057	54,300	76,300	25.0	0.190	0.790	0.006	0.001	0.030	0.120	0.003	0.050	0.002	
			M-180	A	2	1282057	54,300	76,300	25.0	0.190	0.790	0.006	0.001	0.030	0.120	0.003	0.050	0.002	
			M-180	A	2	1282058	56,100	77,200	28.0	0.190	0.760	0.006	0.002	0.020	0.110	0.003	0.050	0.002	
			M-180	A	2	1282058	56,100	77,200	28.0	0.190	0.760	0.006	0.002	0.020	0.110	0.003	0.050	0.002	
			M-180	A	2	1282059	61,900	82,700	22.0	0.200	0.770	0.007	0.000	0.030	0.120	0.003	0.050	0.002	
			M-180	A	2	1282059	61,900	82,700	22.0	0.200	0.770	0.007	0.000	0.030	0.120	0.003	0.050	0.002	
	500673B		A563 -3908			P39673 R75029													
	500673B		F436-4372			P39829 R75331													
	500673B		A563 -3704			P39842 R75403													
	500673B		B18.21.1-490			P39845 R75442													

Certified Analysis

Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525
ADDISON, TX 75001
Project: TXDOT TESTING

Order Number: 1341822 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: TXDOT
BOL Number: 85091 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/27/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
	500673B		F436 -3240			P39949 R75795													
	500673B		F436-3701			P39974 R75883													

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

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

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 27th day of August, 2021 .

Notary Public:
Commission Expires:

ARACELI REY
Notary Public, State of Texas
Comm. Expires 01-14-2023
Notary ID 130076852

Trinity Highway Products LLC
Certified By:
Quality Assurance

5 of 6

Certified Analysis

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

Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525

ADDISON, TX 75001

Project: TXDOT TESTING

Order Number: 1341822 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: TXDOT
BOL Number: 85091 Ship Date:
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Shipped To: TX
Use State: TX

As of: 8/27/21

SerialNbr	Model	Mfg Origin	Mfg Date	SerialNbr	Model	Mfg Origin	Mfg Date	SerialNbr	Model	Mfg Origin	Mfg Date
FS0057688	SOFTSTOP	FT WORTH TX	08/2021								
FS0057690	SOFTSTOP	FT WORTH TX	08/2021								

6 of 6

Texas A&M Transportation Institute	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Revision Date: 2020-07-29
Quality Form	Revised by: B.L. Griffith Approved by: D. L. Kuhn	Revision: **7**	Page: 1 of 1

Project No: 440521-01 **Casting Date:** 8/20/2021 **Mix Design (psi):** 3500 psi

Name of Technician Taking Sample: Terracon

Name of Technician Breaking Sample: Terracon

Signature of Technician Taking Sample: Terracon

Signature of Technician Breaking Sample: Terracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	6	83086	South 100 feet of Concrete Deck
T2	125	83087	North 84 feet section of Concrete Deck

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average

TEXCRETE
Redi-mix Concrete Company

REMIT PAYMENT TO:
P.O. BOX138
KURTEN, TX 77862

TEXCRETE

5222 Sandy Point RD.
Bryan, Tx 77807

17534 SH 6 South
College Station, TX 77845

83086

DISPATCH - 979-316-2906
OFFICE - 979-985-3636
ESPANOL - 512-658-7809

MBC MANAGEMENT
TTI-RELLIS CAMPUS, BRYAN, TX

COME IN OFF HWY 47, STAY STRAIGHT THROUGH
THE ROUND-A-BOUT, DOWNTO GATE

TIME	FORMULA	LOAD SIZE	YARD ORDERED		DRIVER/TRUCK		PLANT TRANSACTION#
8:41	FN93520050	10.00	20.00	PO#	WARREN THOMAS	6	49057
DATE		LOAD#	YARDS DEL.	BATCH#	WATER TRIM	SLUMP	TICKET NUMBER
8/20/21	TTI-BMM	10.00	10.00			5.00 in	47187

QUANTITY	CODE	DESCRIPTION	UNIT PRICE	EXTENDED PRICE
10.00 yd	FN935200500	3500 PSI		

Thank you for your business

LEFT PLANT	ARRIVED JOB	START UNLOADING	SLUMP	CONCRETE TEMP.	AIR TEMP
8:55AM	9:10AM	9:15AM			
FINISH UNLOADING	LEFT JOB	ARRIVED AT PLANT	ON SITE TESTING		
			TESTING LAB: TERRACON GESSNER CME	OTHER	
	TESTED		AIR	CYLINDERS	
	☐ YES ☐ NO				

Tax
Prev. AMT
Ticket Total

ADDITIONAL CHARGE 1 ______

ADDITIONAL CHARGE 2 ______

GRAND TOTAL

WARNING
IRRITATING TO THE SKIN AND EYES

Contains Portland Cement, Wear Rubber Boots and Gloves. PROLONGED CONTACT MAY CAUSE BURNS. Avoid Contact With Eyes and Prolonged Contact with Skin. In Case of Contact with Skin or Eyes, Rinse Thoroughly With Water. If Irritation Persists. Get Medical Attention. **KEEP CHILDREN AWAY.**

CONCRETE is a PERISHABLE COMMODITY and BECOMES THE PROPERTY of the PURCHASER UPON LEAVING the PLANT. ANY CHANGES or CANCELLATION of ORIGINAL INSTRUCTIONS MUST be TELEPHONED to the OFFICE BEFORE LOADING starts. The undersigned promises to pay all costs, including reasonable attorney's fees. incurred in collecting any sums owed.

All accounts not paid within 30 days of delivery will bear interest at the rate of 18% per annum. Not Responsible For Reactive Aggregate or Color Quality. No Claim Allowed Unless Made at Time Material is Delivered. A $25.00 Service Charge and Loss of the Cash Discounted will be Collected on all Returned Checks. Demerge charge after 90 min. will be $100.00/hr.

PROPERTY DAMAGE RELEASE
(TO BE SIGNED IF DELIVERY TO BE MADE INSIDE CURB LINE)

Dear Customer - The driver of this truck in presenting this RELEASE to you for your signature is of the opinion that the size and weight of this truck may possibly cause damage to the premises and/or adjacent property if he places the material in this load where you desire it. It is our wish to help you in everyway that we can, but in order to do this the driver is requesting that you sign this RELEASErelieving him and this supplier from any responsibility from damage that may occur to the premises and or adjacent property, buildings, sidewalks, driveways, curbs, etc. by the delivery of this material and that you also agree to help him remove mud from the wheels of his vehicle so that he will not liter the public streets. Further as additional consideration; the undersigned agrees to indemnify and hold harmless the driver of this truck and this supplier for any and all damage to the premises and /or adjacent property which may be claimed by anyone to have arisen out of delivery of this order SIGNED:

X______

Excessive Water is Detrimental to Concrete Performance.
H_20 Added by Request/Authorized By:

5 GAL X______

WEIGHMASTER

Surcharge for credit cards

NOTICE: MY SIGNATURE BELOW INDICATES THAT I HAVE READ THE HEALTH WARNING NOTICE AND SUPPLIER WILL NOT BE RESPONSIBLE FOR ANY DAMAGE CAUSED WHEN DELIVERING INSIDE CURB LINE.

LOAD RECEIVED BY

x______

Truck----Driver----User------Disp-Ticket Num--Ticket-ID--Time--Date--------
126 user 47187 73942 8:41 8/20/21
Load Size Mix Code Returned Qty Mix Age Seq Load ID
10.00 CYDS FN935200500 D 49057

83086

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat	Trim
CEMENT1	380.0 lb	3800.0 lb	3910.0 lb	0.77%			
FLYASH	97.0 lb	970.0 lb	960.0 lb	-1.03%			
RIVERROCK	1346 lb	13494 lb	13520 lb	0.20%	0.25% M	4 gl	
EAGRAVEL	498 lb	4992 lb	4980 lb	-0.25%	0.25% M	1 gl	
AND	1435 lb	14924 lb	14940 lb	0.11%	4.00% M	69 gl	
ATER1	30.00 gl	185.69 gl	184.00 gl	-0.91%		184.00 gl	-3.00 gl
E	14.55 oz	145.50 oz	146.00 oz	0.34%			100.00 %
RWR	29.10 oz	291.00 oz	290.00 oz	-0.34%			100.00 %

Actual Num Batches: 1
Load Total: 39873 lb Design 0.516 Water/Cement 0.514 T Design 300.0 gl Actual 258.4 gl To Add: 31.6 gl
Slump: 5.00 in Water in Truck: 10.0 gl Adjust Water: 0.0 gl / Load Trim Water: -3.0 gl/ CYD

TEXCRETE
Redi-mix Concrete Company

REMIT PAYMENT TO:
P.O. BOX138
KURTEN, TX 77862

TEXCRETE

5222 Sandy Point RD.
Bryan, Tx 77807

17534 SH 6 South
College Station, TX 77845

83087

DISPATCH - 979-316-2906
OFFICE - 979-985-3636
ESPANOL - 512-658-7809

MBC MANAGEMENT
TTI-RELLIS CAMPUS, BRYAN, TX

COME IN OFF HWY 47, STAY STRAIGHT THROUGH
THE ROUND-A-BOUT, DOWNTO GATE

TIME	FORMULA	LOAD SIZE	YARD ORDERED		DRIVER/TRUCK		PLANT TRANSACTION#
8:46	FN93520050	10.00	20.00	FOB	RAYMOND B. 125		49058
DATE		**LOAD#**	**YARDS DEL.**	**BATCH#**	**WATER TRIM**	**SLUMP**	**TICKET NUMBER**
8/20/21	TTI-SMM	10.00	20.00			5.00 in	47188

QUANTITY	CODE	DESCRIPTION	UNIT PRICE	EXTENDED PRICE
10.00 yd	FN935200500	3500 PSI		

Thank you for your business

Tax
Prev. AMT
Ticket Total

LEFT PLANT	ARRIVED JOB	START UNLOADING	SLUMP	CONCRETE TEMP.	AIR TEMP
9:04	9:24				
FINISH UNLOADING	**LEFT JOB**	**ARRIVED AT PLANT**	**ON SITE TESTING**		
			TESTING LAB: TERRACON / GESSNER / CME	OTHER	
	TESTED		AIR	CYLINDERS	
	☐ YES ☐ NO				

ADDITIONAL CHARGE 1 ____________

ADDITIONAL CHARGE 2 ____________

GRAND TOTAL

WARNING
IRRITATING TO THE SKIN AND EYES

Contains Portland Cement, Wear Rubber Boots and Gloves. PROLONGED CONTACT MAY CAUSE BURNS. Avoid Contact With Eyes and Prolonged Contact with Skin. In Case of Contact with Skin or Eyes, Rinse Thoroughly With Water. If Irritation Persists. Get Medical Attention. **KEEP CHILDREN AWAY.**

CONCRETE is a PERISHABLE COMMODITY and BECOMES THE PROPERTY of the PURCHASER UPON LEAVING the PLANT. ANY CHANGES or CANCELLATION of ORIGINAL INSTRUCTIONS MUST be TELEPHONED to the OFFICE BEFORE LOADING starts. The undersigned promises to pay all costs, including reasonable attorney's fees. incurred in collecting any sums owed.

All accounts not paid within 30 days of delivery will bear interest at the rate of 18% per annum. Not Responsible For Reactive Aggregate or Color Quality. No Claim Allowed Unless Made at Time Material is Delivered.
A $25.00 Service Charge and Loss of the Cash Discounted will be Collected on all Returned Checks. Demerge charge after 90 min. will be $100.00/hr.

PROPERTY DAMAGE RELEASE
(TO BE SIGNED IF DELIVERY TO BE MADE INSIDE CURB LINE)

Dear Customer - The driver of this truck in presenting this RELEASE to you for your signature is of the opinion that the size and weight of this truck may possibly cause damage to the premises and/or adjacent property if he places the material in this load where you desire it. It is our wish to help you in everyway that we can, but in order to do this the driver is requesting that you sign this RELEASErelieving him and this supplier from any responsibility from damage that may occur to the premises and or adjacent property, buildings, sidewalks, driveways, curbs, etc. by the delivery of this material and that you also agree to help him remove mud from the wheels of his vehicle so that he will not liter the public streets. Further as additional consideration; the undersigned agrees to indemnify and hold harmless the driver of this truck and this supplier for any and all damage to the premises and /or adjacent property which may be claimed by anyone to have arisen out of delivery of this order SIGNED:

X____________________

Excessive Water is Detrimental to Concrete Performance.
H_2O Added by Request/Authorized By:

________GAL X____________________

WEIGHMASTER

Surcharge for credit cards

NOTICE: MY SIGNATURE BELOW INDICATES THAT I HAVE READ THE HEALTH WARNING NOTICE AND SUPPLIER WILL NOT BE RESPONSIBLE FOR ANY DAMAGE CAUSED WHEN DELIVERING INSIDE CURB LINE.

LOAD RECEIVED BY

x____________________

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
125		user	47188	73943	8:46	8/20/21

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
10.00 CYDS	FN935200500				D	49058

83087

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat	Trim
CEMENT1	388.0 lb	3880.0 lb	3860.0 lb	-0.52%			
FLYASH	97.0 lb	970.0 lb	960.0 lb	-1.03%			
1RIVERROCK	1346 lb	13494 lb	13460 lb	-0.25%	0.25% M	4 gl	
PEAGRAVEL	498 lb	4992 lb	4980 lb	-0.25%	0.25% M	1 gl	
SAND	1435 lb	14924 lb	15080 lb	+ 1.05%	4.00% M	70 gl	
WATER1	30.00 gl	185.69 gl	184.00 gl	-0.91%		184.00 gl	-3.00 gl
RET	14.55 oz	145.50 oz	146.00 oz	0.34%			100.00 %
MRWR	29.10 oz	291.00 oz	290.00 oz	-0.34%			100.00 %

Actual Num Batches: 1
Load Total: 39903 lb Design 0.516 Water/Cement 0.519 T Design 300.0 gl Actual 259.0 gl To Add: 31.0 gl
Slump: 5.00 in Water in Truck: 10.0 gl Adjust Water: 0.0 gl / Load Trim Water: -3.0 gl/ CYD

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0210
Service Date: 08/20/21
Report Date: 09/22/21 Revision 1 -
Task: PO# 440521-01

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength: 3,500 psi @ 28 days

Mix ID: FN935200500
Supplier: Texcrete
Batch Time: 0841 **Plant:** 1
Truck No.: WarrenThom **Ticket No.:** 47187

Sample Information

Sample Date: 08/20/21 **Sample Time:** 0921
Sampled By: Matcek, James
Weather Conditions: Cloudy
Accumulative Yards: 10 **Batch Size (cy):** 10
Placement Method: Chute
Water Added Before (gal): 5
Water Added After (gal): 0
Sample Location: South half of median stand
Placement Location: South half of median stand

Field Test Data

Test	Result	Specification
Slump (in):	6 1/2	
Air Content (%):	1.6	
Concrete Temp. (F):	85	
Ambient Temp. (F):	83	
Plastic Unit Wt. (pcf):	149.0	
Yield (Cu. Yds.):		

Laboratory Test Data

Set No.	Specimen ID	Avg Diam. (in)	Area (sq in)	Date Received	Date Tested	Age at Test (days)	Maximum Load (lbs)	Compressive Strength (psi)	Fracture Type	Tested By
1	B	6.00	28.27		09/21/21	32 F	124,100	4,390	3	SLS
1	C	6.00	28.27		09/21/21	32 F	128,660	4,550	1	SLS
1	D	6.00	28.27		09/21/21	32 F	118,310	4,180	1	SLS
1	A					Hold				

Initial Cure: Outside **Final Cure:** Field Cured

Comments: **F = Field Cured**
Note: Reported air content does not include Aggregate Correction Factor (ACF).

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).
Terracon Rep.: Matcek, James **Start/Stop:** 0815-1000
Reported To: Gary Gerke
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Alex Dunigan, P.E.
(1) Texas Transportation Institute, Bill Griffith

Test Methods: ASTM C 31, ASTM C143, ASTM C231, ASTM C1064

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0210
Service Date: 08/20/21
Report Date: 09/22/21 Revision 1 -
Task: PO# 440521-01

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength: 3,500 psi @ 28 days

Mix ID: FN935200500
Supplier: Texcrete
Batch Time: 0846 **Plant:** 1
Truck No.: Raymond G **Ticket No.:** 47188

Sample Information

Sample Date: 08/20/21 **Sample Time:** 0932
Sampled By: Matcek, James
Weather Conditions: Cloudy
Accumulative Yards: 10 **Batch Size (cy):** 10
Placement Method: Chute
Water Added Before (gal): 10
Water Added After (gal): 0
Sample Location: North half of median stand
Placement Location: North half of median stand

Field Test Data

Test	Result	Specification
Slump (in):	5 1/2	
Air Content (%):	2.0	
Concrete Temp. (F):	85	
Ambient Temp. (F):	83	
Plastic Unit Wt. (pcf):	149.6	
Yield (Cu. Yds.):		

Laboratory Test Data

Set No.	Specimen ID	Avg Diam. (in)	Area (sq in)	Date Received	Date Tested	Age at Test (days)	Maximum Load (lbs)	Compressive Strength (psi)	Fracture Type	Tested By
2	D	6.00	28.27		09/21/21	32				
2	A	6.00	28.27		09/21/21	32 F	113,290	4,010	2	SLS
2	B	6.00	28.27		09/21/21	32 F	121,000	4,280	1	SLS
2	C	6.00	28.27		09/21/21	32 F	128,080	4,530	5	SLS

Initial Cure: Outside **Final Cure:** Field Cured

Comments: **F = Field Cured**
Note: Reported air content does not include Aggregate Correction Factor (ACF).

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).
Terracon Rep.: Matcek, James **Start/Stop:** 0815-1000
Reported To: Gary Gerke
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Alex Dunigan, P.E.
(1) Texas Transportation Institute, Bill Griffith

Reviewed By:
Alexander Dunigan
Project Manager

Test Methods: ASTM C 31, ASTM C143, ASTM C231, ASTM C1064

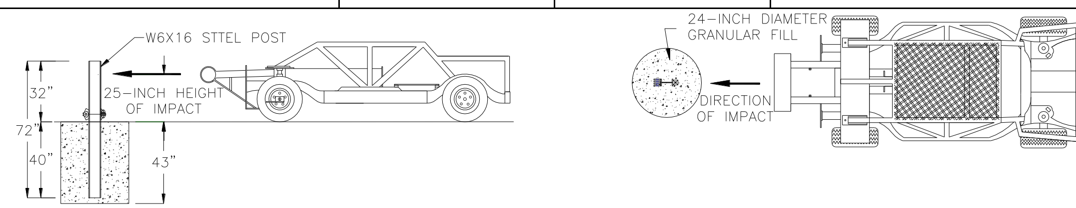
Table B.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.

Dynamic Test Setup

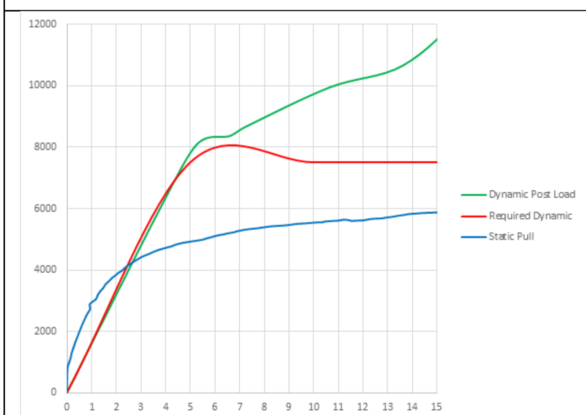
Post-Test Photo of Post

Static Load Test

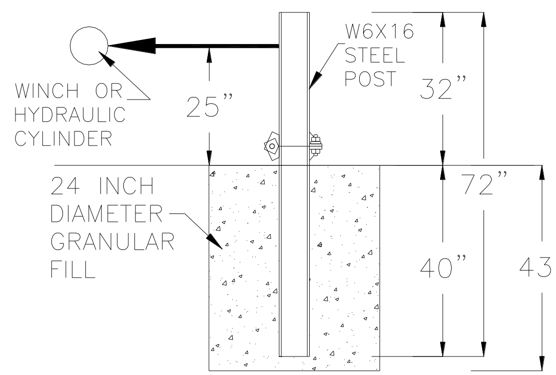
Post-Test Photo



Dynamic Test Installation Details



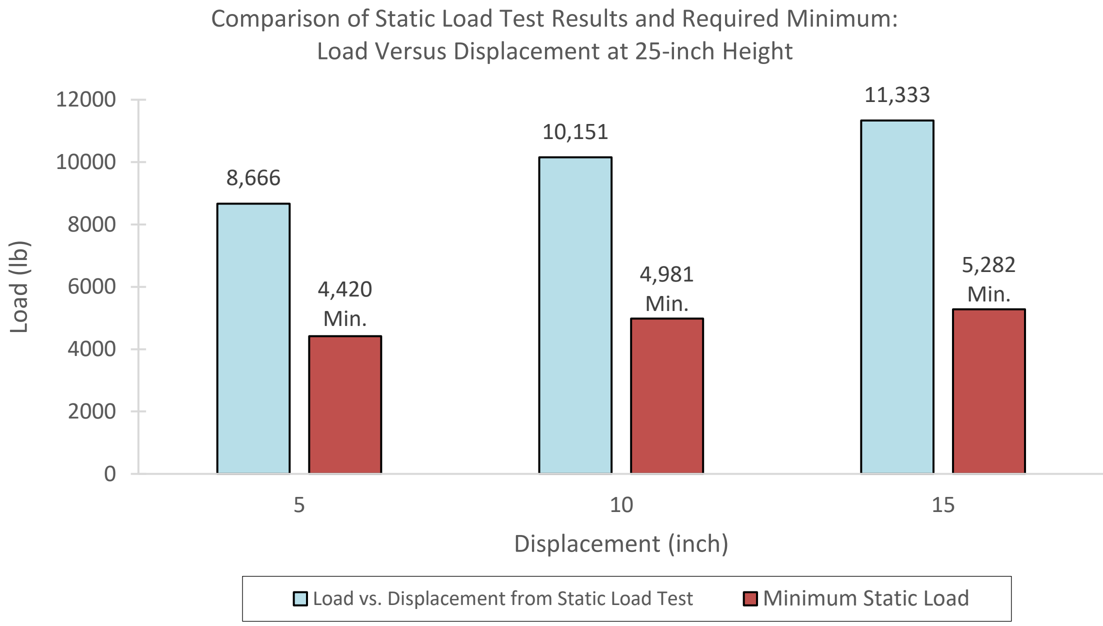
Comparison of Load vs. Displacement



Static Load Test Installation Details

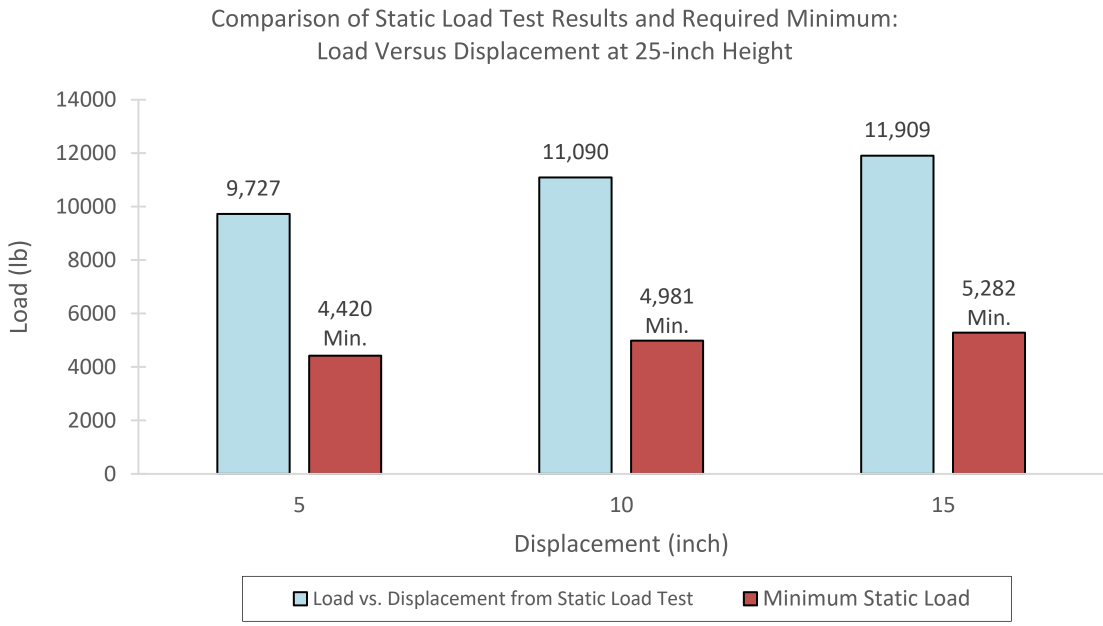
Date	2020-02-02
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis	AASHTO M147 Grade D or Type D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 sec
Bogie Weight	2020 lb
Impact Velocity	19.2 mph

Table B.2. Test Day Static Soil Strength Documentation for Test No. 440522-01-01.



Date	2021-09-29
Test Facility and Site Location	TTI Proving Ground 3100 SH 47 Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis	AASHTO M147 Grade D or Type D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 sec

Table B.3. Test Day Static Soil Strength Documentation for Test No. 440522-01-2.



Date	2021-10-06
Test Facility and Site Location	TTI Proving Ground 3100 SH 47 Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis	Type1 Grade D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 sec

APPENDIX C. *MASH* TEST 3-10 (CRASH TEST NO. 440522-01-01)

C.1. VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 440522-01-01.

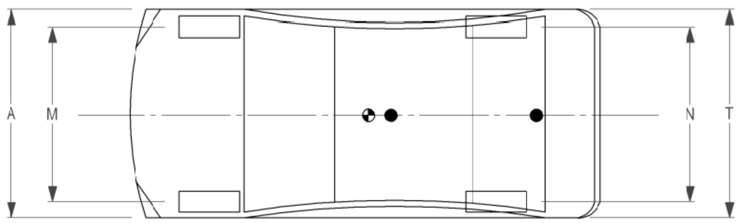
Date: 2021-9-27 Test No.: 440522-01-1 VIN No.: 3N1CN7APXFL945295

Year: 2015 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 156152 Tire Size: P185/65R15

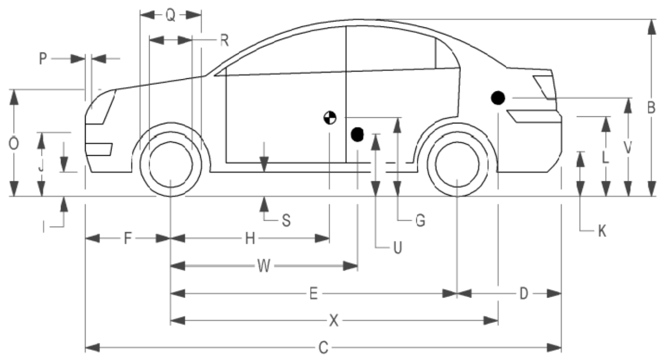
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.



NOTES: None

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



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

Geometry: inches

A	66.7	F	32.5	K	12.5	P	4.5	U	15.5
B	59.6	G		L	26	Q	24	V	21.25
C	175.4	H	41.01	M	58.3	R	16.25	W	41
D	40.5	I	7	N	58.5	S	7.5	X	79.75
E	102.4	J	22.25	O	30.5	T	64.5		

Wheel Center Ht Front 11.5 Wheel Center Ht Rear 11.5 W-H 0.00

RANGE LIMIT: A = 65 ±3 inches; C = 169 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; H = 39 ±4 inches; O (Top of Radiator Support) = 28 ±4 inches
(M+N)/2 = 59 ±2 inches; W-H < 2 inches or use MASH Paragraph A4.3.2

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1750	M_{front}	1443	1461	1546
Back	1687	M_{rear}	938	976	1056
Total	3389	M_{Total}	2381	2437	2602

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

Mass Distribution:
lb LF: 761 RF: 700 LR: 526 RR: 450

Table C.2. Exterior Crush Measurements for Test No. 440522-01-01.

Date: 2021-09-27 Test No.: 440522-01-1 VIN No.: 3N1CN7APXFL945295

Year: 2015 Make: NISSAN Model: VERSA

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	AT FT BUMPER	14	9	40	-	-	-	-	-	-	-10
2	ABOVE FT BUMPER	14	7.5	44	-	-	-	-	-	-	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).

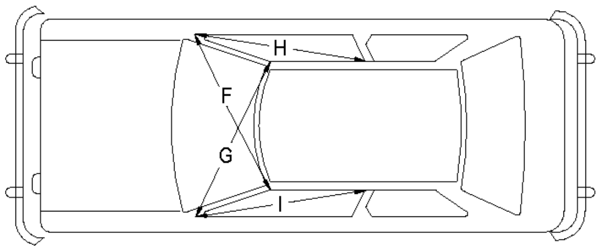
***Measure and document on the vehicle diagram the location of the maximum crush.

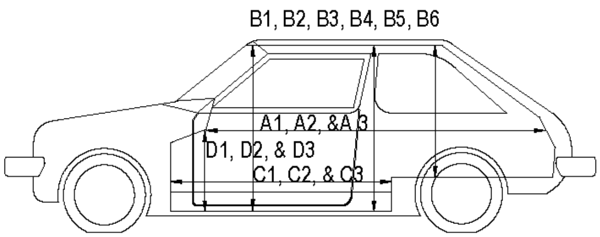
Note: Use as many lines/columns as necessary to describe each damage profile.

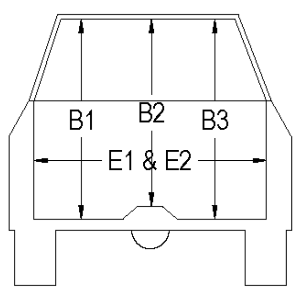
Table C.3. Occupant Compartment Measurements for Test No. 440522-01-01.

Date: 2021-09-27 Test No.: 440522-01-1 VIN No.: 3N1CN7APXFL945295

Year: 2015 Make: NISSAN Model: VERSA







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

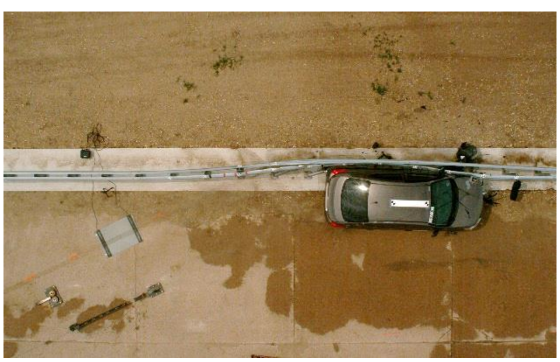
	Before	After (inches)	Differ.
A1	75	75	0
A2	74	74	0
A3	74	74	0
B1	43	43	0
B2	37	37	0
B3	43	43	0
B4	46.5	46.5	0
B5	42.5	42.5	0
B6	46.5	46.5	0
C1	26	26	0
C2	0	0	0
C3	26	26	0
D1	12.5	12.5	0
D2	0	0	0
D3	10	10	0
E1	45	46.5	1.5
E2	48.75	50.75	2
F	47.5	47.5	0
G	47.5	47.5	0
H	39	39	0
I	39	39	0
J*	48.5	48.5	0

C.2. SEQUENTIAL PHOTOGRAPHS

0.000 s

0.100 s

0.200 s



0.300 s

Figure C.1. Sequential Photographs for Test No. 440522-01-01 (Overhead and Frontal Views).

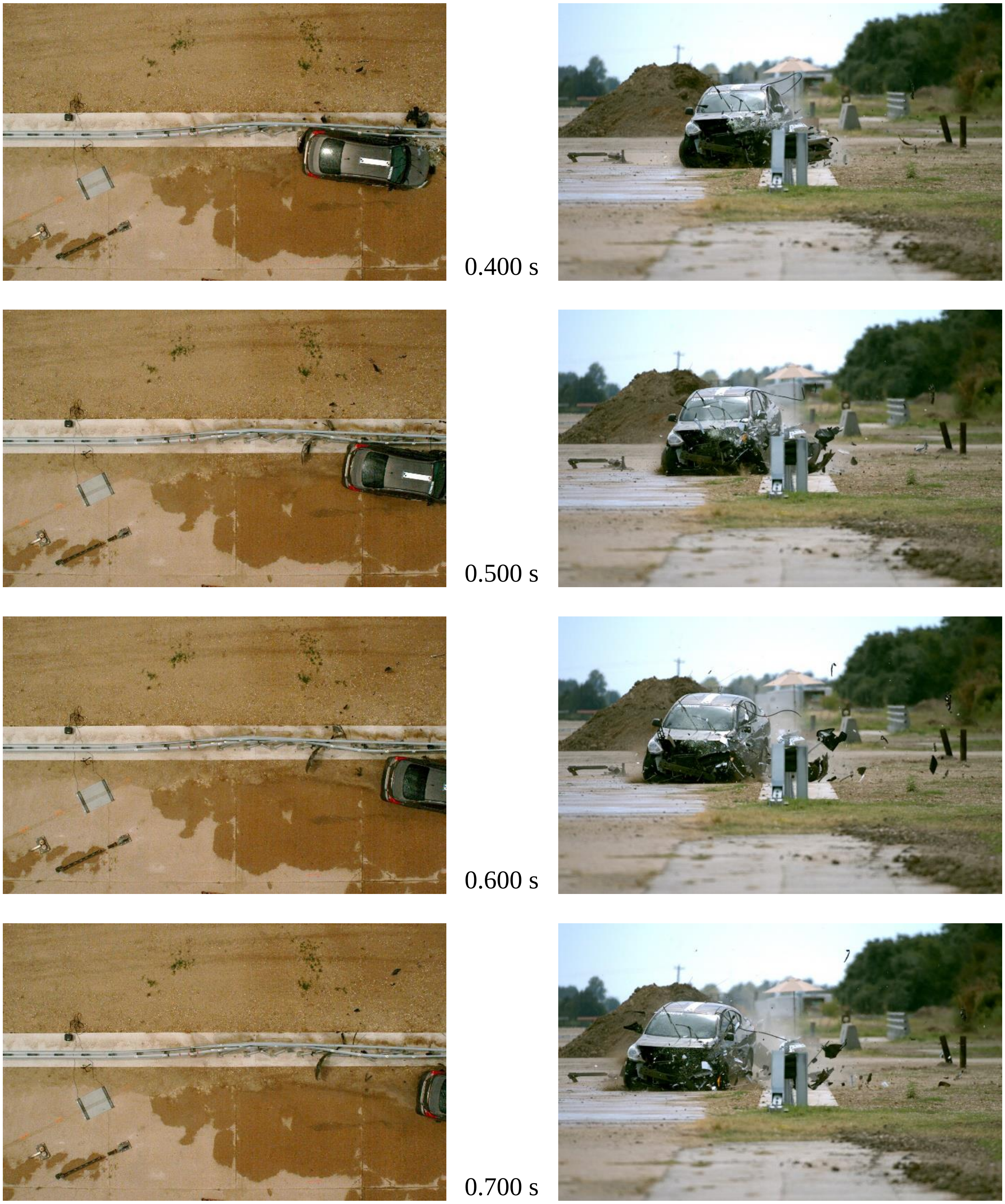


Figure C.1. Sequential Photographs for Test No. 440522-01-01 (Overhead and Frontal Views) (Continued).

0.000 s

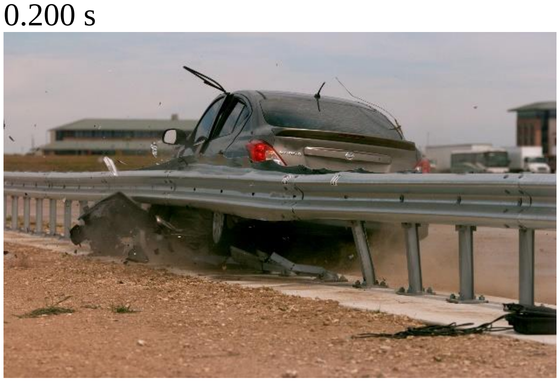
0.400 s

0.100 s

0.500 s

0.200 s

0.600 s

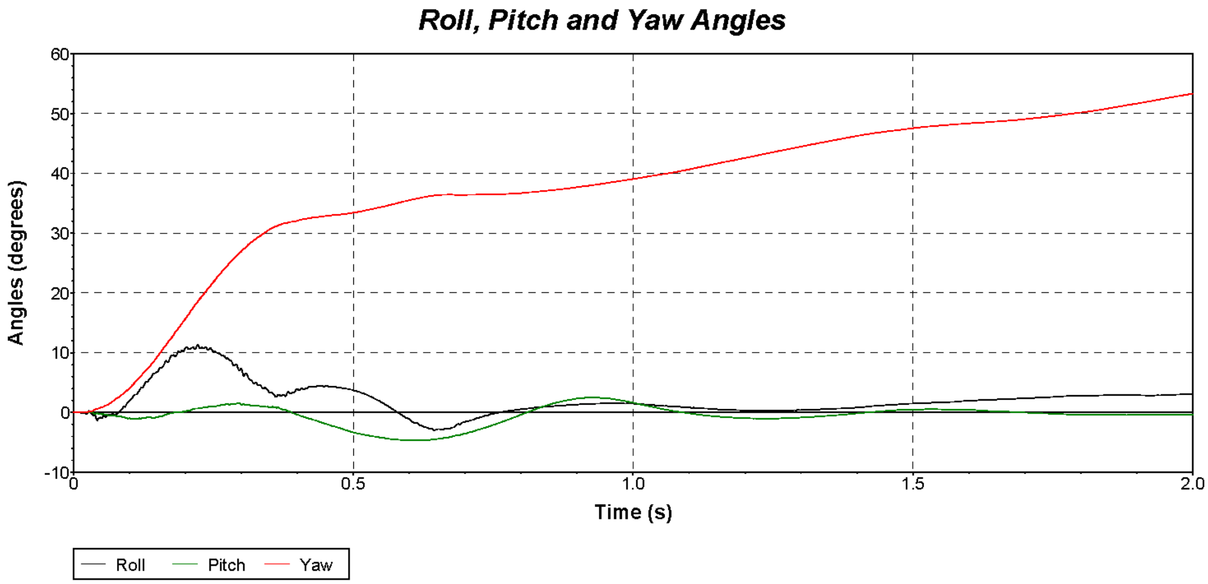


0.300 s

0.700 s

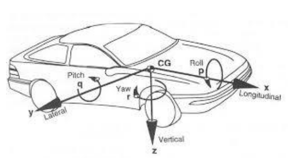
Figure C.2. Sequential Photographs for Test No. 440522-01-01 (Rear View).

C.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 440522-01-1
Test Standard Test Number: *MASH* Test 3-10
Test Article: Surface Mounted Median Guardrail
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2437 lb
Gross Mass: 2602 lb
Impact Speed: 62.3 mi/h

Figure C.3. Vehicle Angular Displacements for Test No. 440522-01-01.

C.4. VEHICLE ACCELERATIONS

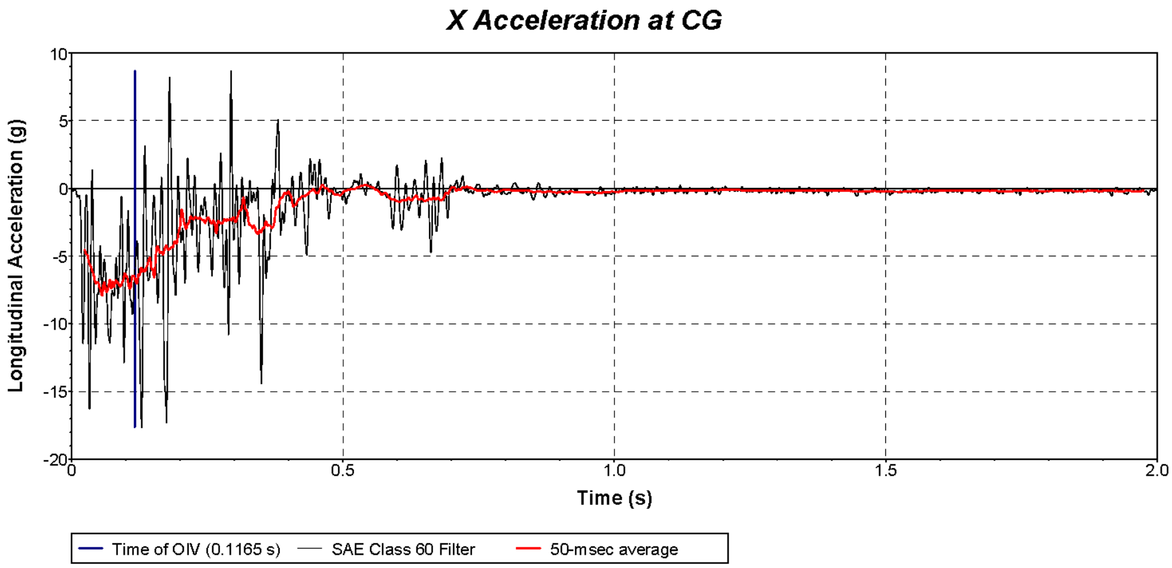


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 440522-01-01 (Accelerometer Located at Center of Gravity).

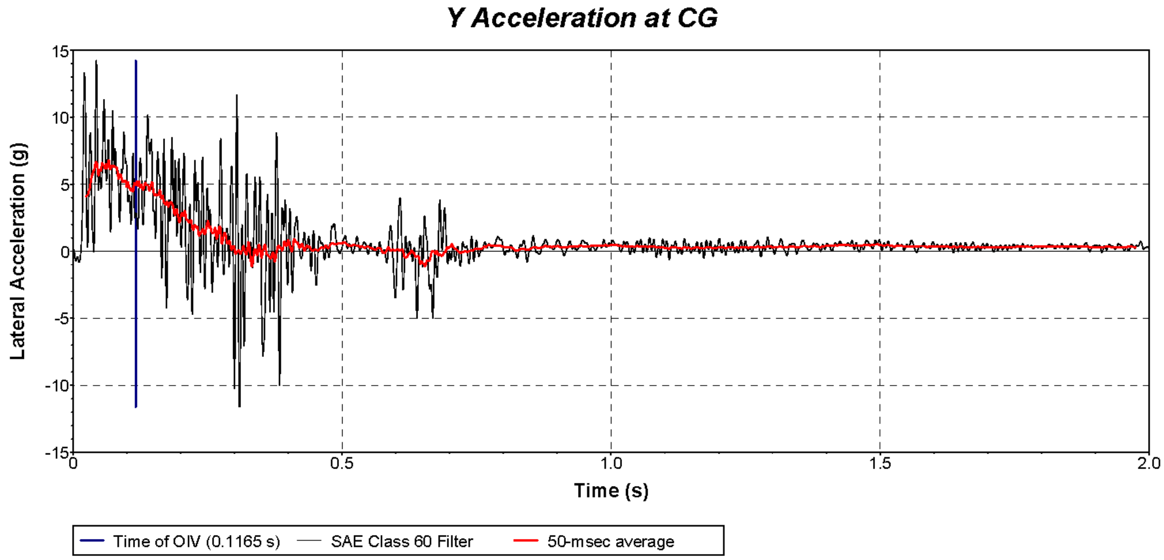


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 440522-01-01 (Accelerometer Located at Center of Gravity).

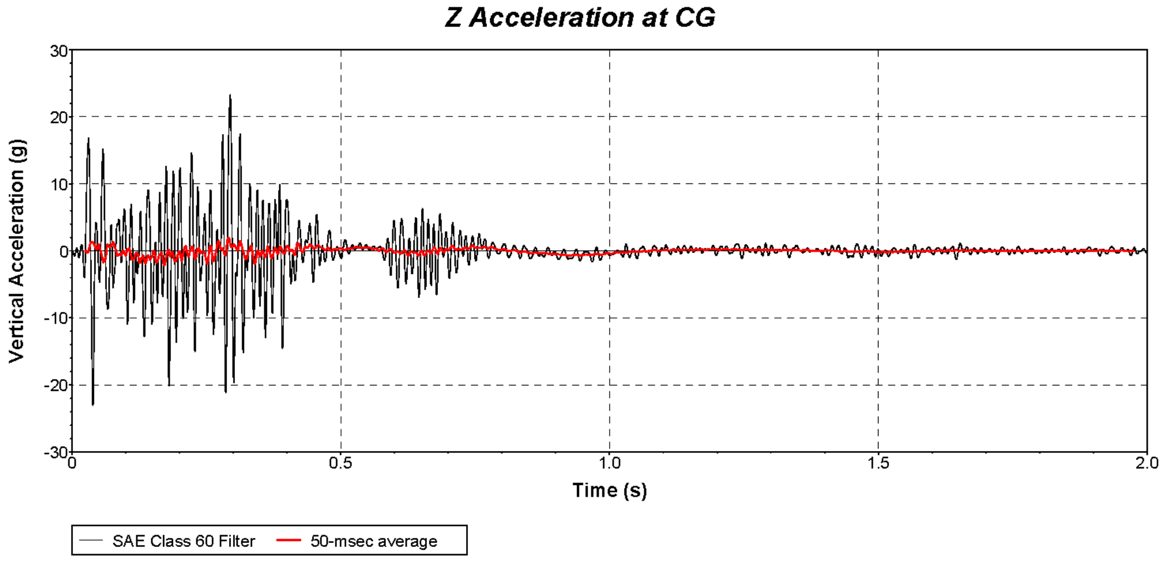


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 440522-01-01 (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 3-11 (CRASH TEST NO. 440522-01-2)

D.1. VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 440522-01-2.

Date: 2021-10-6 Test No.: 440522-01-2 VIN No.: 1C6RR6FT2FS722124

Year: 2015 Make: RAM Model:

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

Tread Type: Highway Odometer: 154465

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

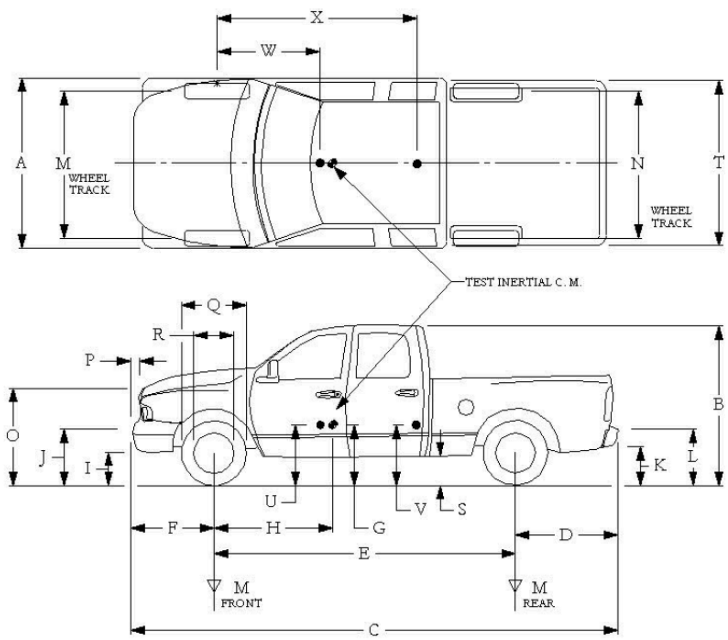
NOTES: None

Engine Type: V-8
Engine CID:

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

Optional Equipment:
None

Dummy Data:
Type:
Mass: 0 lb
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.25	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.02	M	68.50	R	18.00	W	61
D	44.00	I	11.75	N	68.00	S	13.00	X	79
E	140.50	J	27.00	O	46.00	T	77.00		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2923	2443	2443
Back	3900	M_{rear}	2072	2183	2183
Total	6700	M_{Total}	4995	5026	5026

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

Mass Distribution:
lb LF: 1443 RF: 1400 LR: 1108 RR: 1075

Table D.2. Exterior Crush Measurements for Test No. 440522-01-2.

Date:	2021-10-06	Test No.:	440522-01-2	VIN No.:	1C6RR6FT2FS722124
Year:	2015	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	AT FT BUMPER	14	8	20	-	-	-	-	-	-	-20
2	ABOVE FT BUMPER	14	8	60	-	-	-	-	-	-	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.

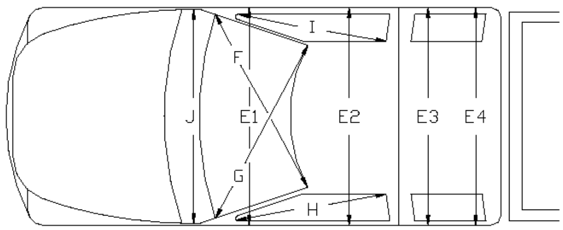
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

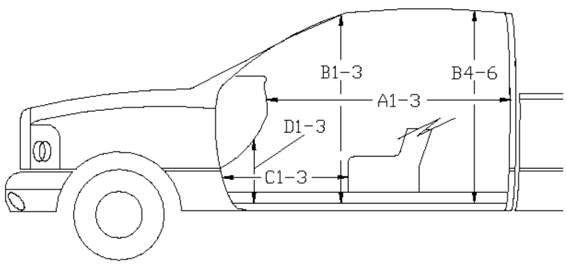
***Measure and document on the vehicle diagram the location of the maximum crush.

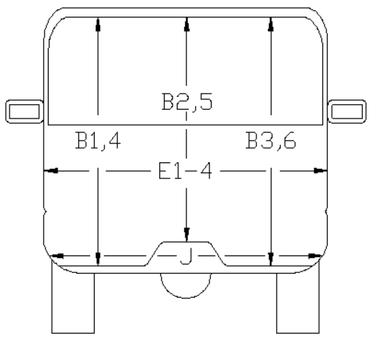
Note: Use as many lines/columns as necessary to describe each damage profile.

Table D.3. Occupant Compartment Measurements for Test No. 440522-01-2.

Date:	2021-10-06	Test No.:	440522-01-2	VIN No.:	1C6RR6FT2FS722124
Year:	2015	Make:	RAM	Model:	1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63	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

D.2. SEQUENTIAL PHOTOGRAPHS

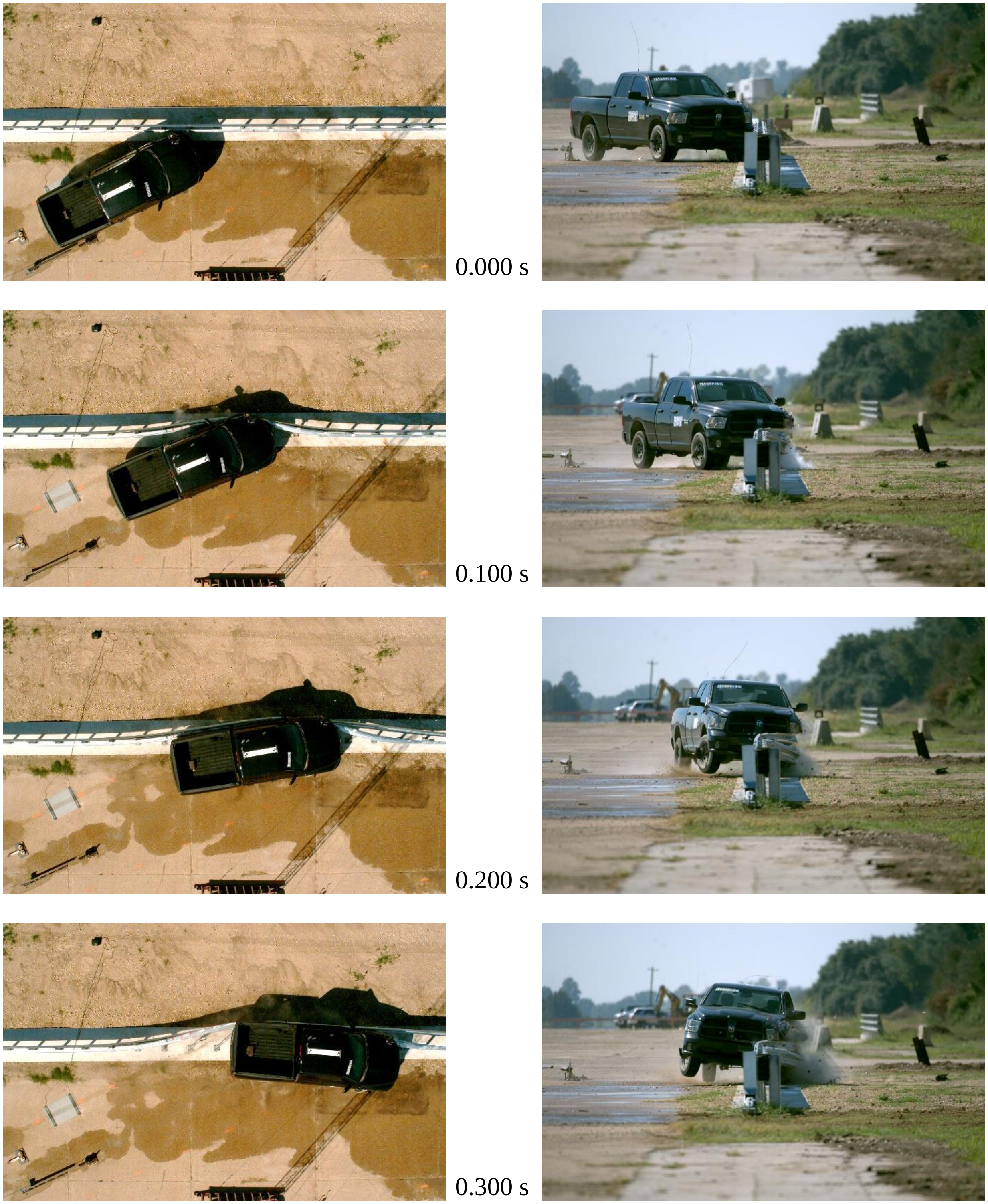


Figure D.1. Sequential Photographs for Test No. 440522-01-2 (Overhead and Frontal Views).


0.400 s


0.500 s

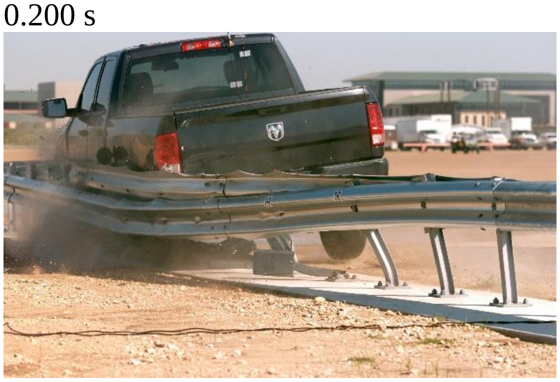

0.600 s


0.700 s

Figure D.1. Sequential Photographs for Test No. 440522-01-2 (Overhead and Frontal Views) (Continued).


0.000 s

0.100 s

0.200 s

0.300 s

0.400 s

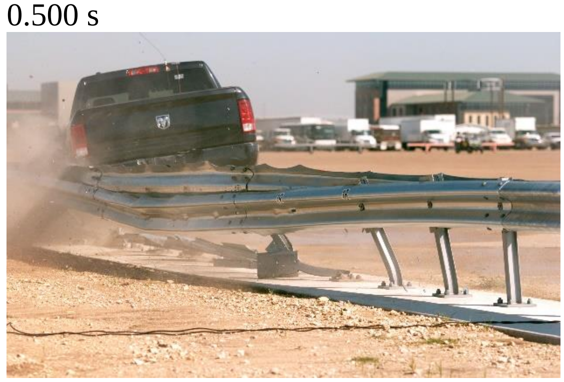
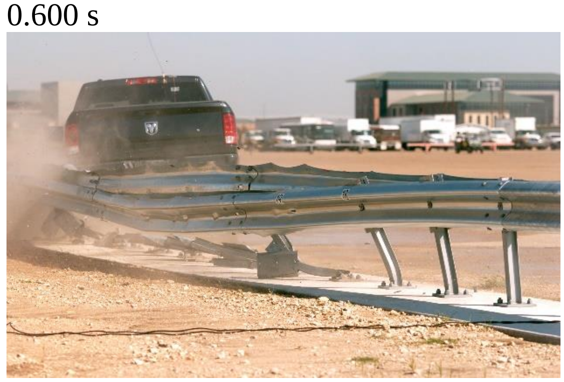
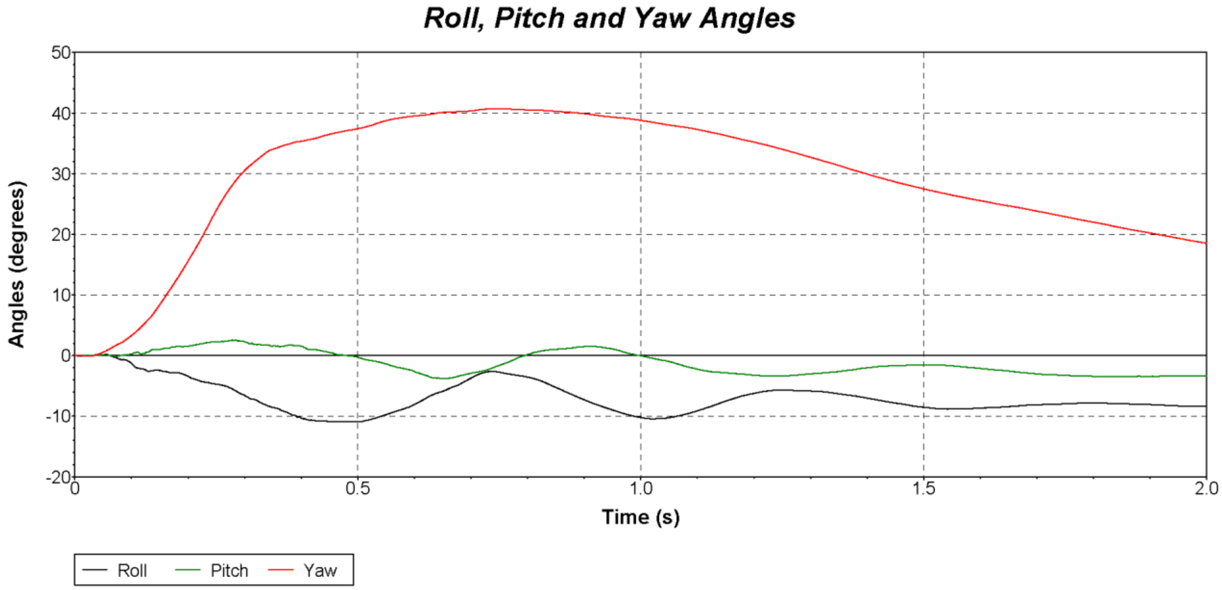
0.500 s

0.600 s

0.700 s

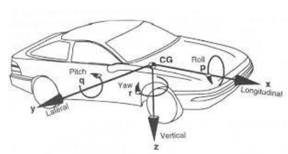
Figure D.2. Sequential Photographs for Test No. 440522-01-2 (Rear View).

D.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 440522-01-2
Test Standard Test Number: *MASH* Test 3-11
Test Article: Surface Mounted Median Guardrail
Test Vehicle: 2015 Ram
Inertial Mass: 4995 lb
Gross Mass: 5026 lb
Impact Speed: 63.5 mi/h

Figure D.3. Vehicle Angular Displacements for Test No. 440522-01-2.

D.4. VEHICLE ACCELERATIONS

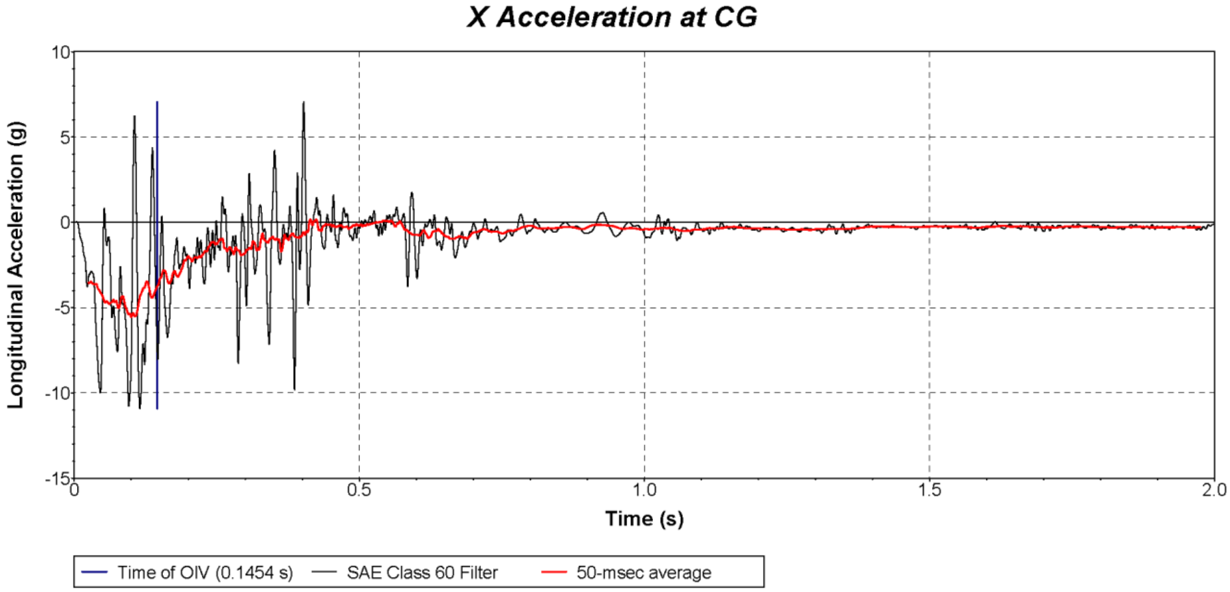


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 440522-01-2 (Accelerometer Located at Center of Gravity).

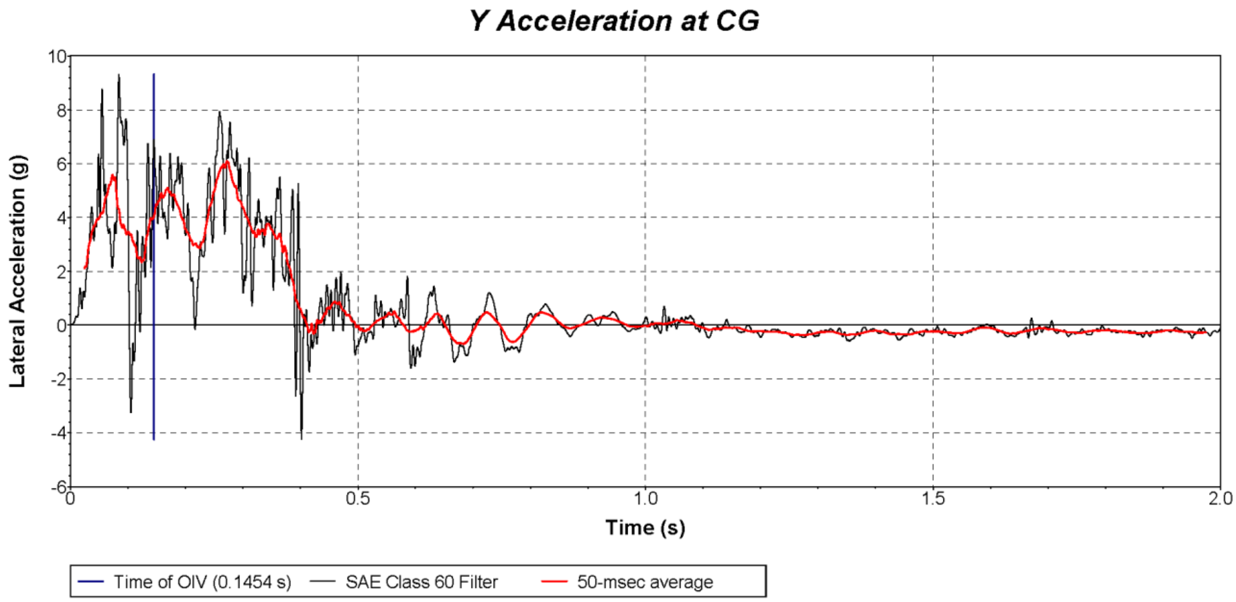


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 440522-01-2 (Accelerometer Located at Center of Gravity).

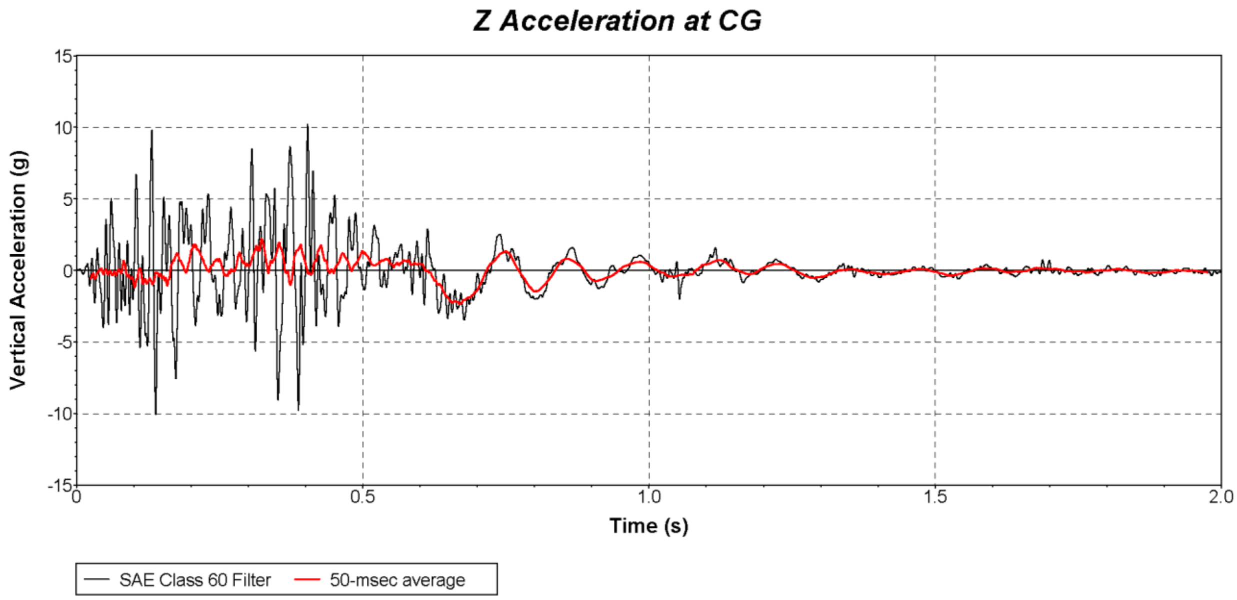


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 440522-01-2 (Accelerometer Located at Center of Gravity).

APPENDIX E. VALUE OF RESEARCH

The estimated value of research (VOR) for this project is summarized in Figure E-1. The economic variables considered in developing the VOR, sources of these variables, and economic-based calculations used are described herein.

The use of a surface-mounted median guardrail will be to prevent crossover median crashes. On roadways with concrete pavement, concrete median barriers are currently used to separate the opposing lanes of traffic. However, the cost of concrete barriers makes their use cost prohibitive at many sites that could benefit from a lower-cost metal guardrail.

The safety benefits of the newly developed surface-mounted median guardrail are expected to be realized in two forms. One is from using the barrier on existing or new sites that are typically shielded by concrete median barriers. The other is from use on new sites where the concrete barrier is cost prohibitive, and a cheaper metal guardrail would be more justifiable from a benefit-cost ratio perspective.

In estimating the VOR for this project, the researchers considered the use of the new median guardrail only on sites that typically use a concrete median barrier. To remain conservative in estimating the VOR, the researchers ignored the value of the safety provided by the median guardrail system on new sites that previously did not have any median barrier installed due to the cost prohibitive nature of the concrete median barriers.

The researchers used TxDOT's Crash Records Information System to determine the number of crashes that involved a median barrier. To avoid influence of COVID-19 related shutdowns and reduced traffic due to remote-work trends in 2019–2020, the researchers used the year 2018 data. The number of crashes in which the "object struck" was a median barrier was 17,817. This number contains crashes that struck a concrete median or a cable barrier. Since the new surface-mounted median guardrail is a *MASH* TL-3 system, in performing the above query, the researchers ignored all crashes that involved non-*MASH* TL-3 vehicles (i.e., trucks, tractors, semi-trailers, ambulances, buses, school buses, farm equipment, fire trucks, neighborhood electric vehicles, etc.).

Since the use of cable barriers is more prevalent, and because this research focuses on the barriers installed on concrete pavements or decks, the researchers conservatively assumed that only 5 percent of the above crashes involved striking a concrete median barrier installed on a concrete pavement or deck. This reduced the number of yearly crashes to 891.

The researchers acknowledged that not all of the above crashes would have resulted in a crossover median crash, and not all of the cross median crashes would result in fatalities. The researchers thus conservatively assumed that only 2 percent of the 891 crashes with concrete median barriers would have resulted in crossover median crash-related fatalities. This implies that a very conservative estimate of number of fatalities saved by use of concrete median barriers is 17.82 per year for *MASH* TL-3 type passenger vehicles.

In the interest of staying conservative, the researchers ignored the cost of serious injuries, minor injuries, property damage, etc. The researchers also conservatively assumed that only one fatality occurred in each fatal crash, even though the number of fatalities per fatal crash is usually greater than one.

The researchers further acknowledged that the newly developed surface-mounted median guardrail will be used in conjunction with other TxDOT concrete barriers. Furthermore, many of the median barrier sites require crash protection greater than TL-3 (i.e., for commercial trucks). Taking these factors into consideration, the researchers conservatively assumed that only 5 percent of the sites that currently use concrete median barriers will be shifted over to the surface-mounted median guardrail. This implies that 0.89 fatalities/year can be prevented by the use of the surface-mounted guardrail—while conservatively ignoring additional fatalities prevented by the use of the guardrail on new sites where concrete median barriers are currently cost prohibitive.

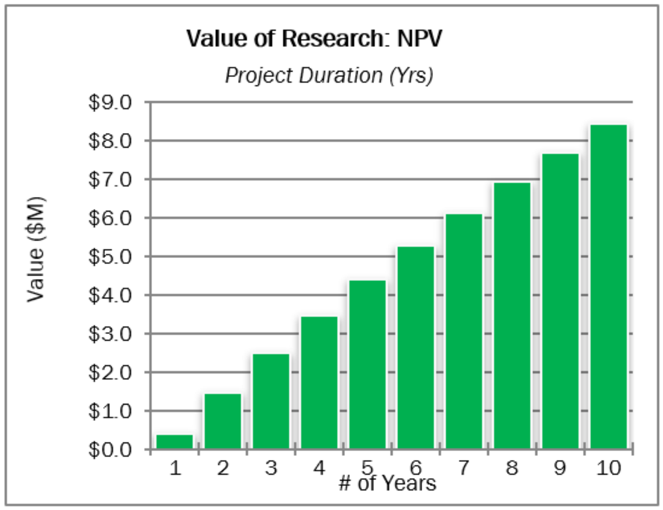
According to NHTSA, each fatality results in an average discounted lifetime economic cost of $1.4 million, and an average comprehensive cost of $9.1 million (*The Economic and Societal Impact of Motor Vehicle Crashes*, 2010 [Revised], http://www-nrd.nhtsa.dot.gov/pubs/812013.pdf).

For a conservative estimate, the researchers used the discounted economic cost of $1.4 million to arrive at the annual expected value of this research. With a reduction of 0.89 fatalities each year, a very conservative annual expected value of this research is $1,246,000.

The researchers used a period of 10 years and a discount rate of 5 percent, which is typical per TxDOT's *University Handbook*, to arrive at the benefit-cost ratio of 25 for this research project. The estimated VOR is presented in Figure E.1.

	Project #	0-7052		
	Project Name:	Evaluation of Surface Mounted Median Guardrail		
	Agency:	TTI	Project Budget	$ 336,813
	Project Duration (Yrs)	2	Exp. Value (per Yr)	$ 1,246,000
Expected Value Duration (Yrs)		10	Discount Rate	5%
Economic Value				
Total Savings:	$ 12,123,187		Net Present Value (NPV):	$ 8,415,721
Payback Period (Yrs):	0.270315		Cost Benefit Ratio (CBR, $1 : $___):	$ 25

Years	Expected Value
0	-$784,774
1	$1,246,000
2	$1,246,000
3	$1,246,000
4	$1,246,000
5	$1,246,000
6	$1,246,000
7	$1,246,000
8	$1,246,000
9	$1,246,000
10	$1,246,000



Variable Justification

See justification of the variables used in the detailed description presented in Appendix E

Qualitative Value

Benefit Area	Value
Safety	Use of the crashworthy surface mounted median guardrail to prevent vehicles from crossing over roadway medians and causing crossover median crashes will improve the safety of the motoring public. It will prevent fatilities, injuries, and property damage for the citizens of Texas.

Figure E.1. Value of Research Summary for Project 0-7052.