TTI: 0-7019

DEVELOPMENT AND EVALUATION OF *MASH* TL-4 GUARDRAIL SYSTEM

ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
TTI Proving Ground
1254 Avenue A, Building 7091
Bryan, TX 77807

Test Report 0-7019-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
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16. Abstract

Researchers at the Texas A&M Transportation Institute (TTI) designed and tested a *Manual for Assessing Safety Hardware* (*MASH*) Test Level 4 (TL-4) compliant metal guardrail system. The researchers first developed several preliminary design concepts of the guardrail system, one of which was selected by the Texas Department of Transportation (TxDOT) for further development through simulation and crash testing. The researchers then developed a full-scale finite element model of the selected system and performed impact simulations under *MASH* TL-4 impact conditions. Using the results of these impact simulations, the researchers made further improvements to the guardrail design and developed the final system design details for crash testing. TTI then constructed the guardrail installation and performed *MASH* Test 4-12 with a single unit truck, *MASH* Test 4-11 with a pickup truck, and *MASH* Test 4-10 with a small car to meet *MASH* TL-4 compliance criteria for longitudinal barriers.

This report provides details of the guardrail design development, the crash tests and results, and the performance assessment of the guardrail system for *MASH* TL-4 longitudinal barrier evaluation criteria. The design developed under this research project provides a *MASH* TL-4 compliant guardrail system that allows TxDOT to provide enhanced roadside safety in corridors that experience above-average heavy vehicle traffic.

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DEVELOPMENT AND EVALUATION OF *MASH* TL-4 GUARDRAIL SYSTEM

by

Nauman M. Sheikh, P.E.
Associate Research Engineer
Texas A&M Transportation Institute

Roger P. Bligh, P.E.
Senior Research Engineer
Texas A&M Transportation Institute

Wanda L. Menges
Research Specialist
Texas A&M Transportation Institute

William Schroeder
Research Engineering Associate
Texas A&M Transportation Institute

Bill L. Griffith
Research Specialist
Texas A&M Transportation Institute

and

Darrell L. Kuhn, P.E.
Research Specialist
Texas A&M Transportation Institute

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TEXAS A&M TRANSPORTATION INSTITUTE
College Station, Texas 77843-3135

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Nauman M. Sheikh, P.E., Tx #105155. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

TTI PROVING GROUND DISCLAIMER

The results of the crash testing reported herein apply only to the article tested.

REPORT AUTHORIZATION

DocuSigned by:
Bill Griffith
44A122CB271845B...

Bill L. Griffith, Research Specialist
Deputy Quality Manager

DocuSigned by:
Darrell Kuhn
D4CC23E85D5B4E7...

Darrell L. Kuhn, P.E., Research Specialist
Quality Manager

DocuSigned by:
Matt Robinson
EAA22BFA5BFD417...

Matthew N. Robinson, Research Specialist
Test Facility Manager & Technical Manager

DocuSigned by:
Nauman Sheikh
662F8286A604403...

Nauman M. Sheikh, P.E.
Associate Research Engineer

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

Chapter 1. INTRODUCTION

1.1. BACKGROUND

There is a lack of public domain guardrail systems that are compliant with the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test Level 4 (TL-4), which involves testing the guardrail system with a single unit truck, a pickup truck, and a small passenger sedan (*1*). Several corridors in Texas are known to experience a larger percentage of freight and truck traffic. In these corridors, the safety of the motoring public can greatly benefit from the use of a *MASH* TL-4 compliant guardrail system. The Texas Department of Transportation (TxDOT) desired a metal guardrail system that meets the testing requirements of *MASH* TL-4.

1.2. OBJECTIVE

The objective of this research project was to design and test a *MASH* TL-4 compliant metal guardrail system.

1.3. RESEARCH APPROACH AND SCOPE

To meet the research objective, Texas A&M Transportation Institute (TTI) researchers first developed several preliminary design concepts of the guardrail system, one of which was selected by TxDOT for further development through simulation and crash testing. The researchers then developed a full-scale finite element model of the selected system and performed impact simulations under *MASH* TL-4 impact conditions. Using the results of these impact simulations, the researchers made further improvements to the guardrail design and developed the final system design details for crash testing. TTI then constructed the guardrail installation and performed *MASH* Test 4-12 with a single unit truck, *MASH* Test 4-11 with a pickup truck, and *MASH* Test 4-10 with a small car to meet *MASH* TL-4 compliance criteria for longitudinal barriers.

This report provides details of the guardrail design development, the crash tests and results, and the performance assessment of the guardrail system for *MASH* TL-4 evaluation criteria for longitudinal barriers.

Chapter 2. DESIGN AND SIMULATION*

2.1. OBJECTIVE

TTI researchers developed several preliminary design concepts of the *MASH* TL-4 guardrail for TxDOT's review. One of these was selected for further development through simulation analysis and full-scale crash testing. This chapter presents the details of the initially selected *MASH* TL-4 guardrail concept, details of the simulation modeling and impact analyses performed to evaluate and improve the initial concept, and results of the impact simulations of the final design using *MASH* TL-4 impact conditions.

2.2. PRELIMINARY DESIGN CONCEPT

Figure 2.1 shows the preliminary design concept selected for further development through simulation and testing. The design was comprised of a standard W-beam guardrail and a 5-inch × 4-inch × ¼-inch hollow structural section (HSS) tube rail, both supported on W6×25 posts with 6.25-ft post spacing. The height to the top of the W-beam and the HSS rails was 27 inches and 40 inches, respectively. The posts were embedded 40 inches in soil. The W-beam guardrail used standard 6-inch-wide and 8-inch-deep wood blockouts, while the HSS beam had 5-inch × 4-inch × ¼-inch HSS tube blockouts at the post attachment locations.

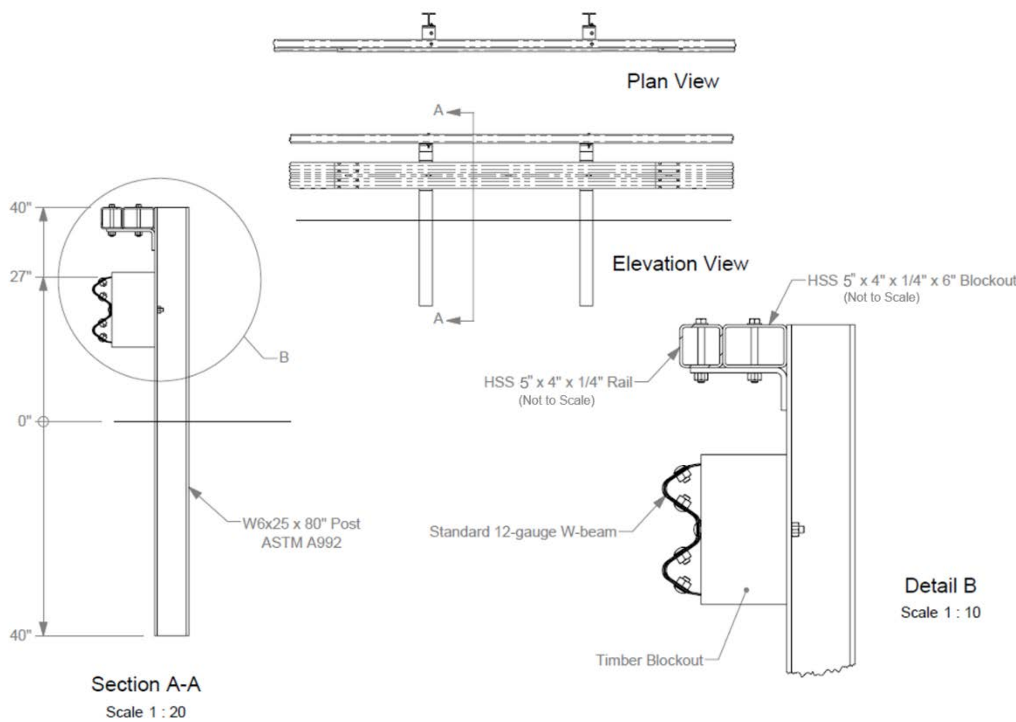


Figure 2.1. Preliminary Design Concept Selected for Simulation Analysis and Detailed Design.

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

2.3. SIMULATION ANALYSIS SCOPE

The research team developed a detailed finite element (FE) model of the selected preliminary guardrail design and performed full-scale dynamic impact simulations. The impact simulations were performed using *MASH* TL-4 impact conditions. This involved simulating *MASH* Test 4-12 (22,000-lb single unit truck [SUT]) impacting at 56 mi/h and 15 degrees), Test 4-11 (5000-lb pickup truck impacting at 62 mi/h and 25 degrees), and Test 4-10 (2420-lb small passenger car impacting at 62 mi/h and 25 degrees). Results of the simulations were used to determine if the guardrail system would likely meet *MASH* TL-4 evaluation criteria in full-scale crash testing.

Based on the results of the simulations, several design changes were made to improve the performance of the guardrail system. These design changes were then also modeled and new impact simulations were performed to arrive at the final guardrail design for full-scale crash testing.

Following are the details of the FE models developed, results of the various simulations that guided the design changes to the preliminary design, and detailed results of the impact simulation performed with the final design prior to crash testing.

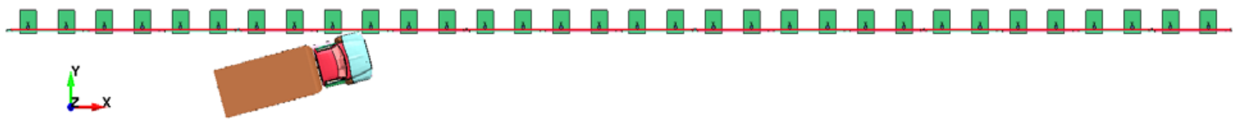
2.4. FINITE ELEMENT MODELING

All simulations were performed using the FE method. LS-DYNA, which is a commercially available general-purpose FE analysis software, was used for the analyses.

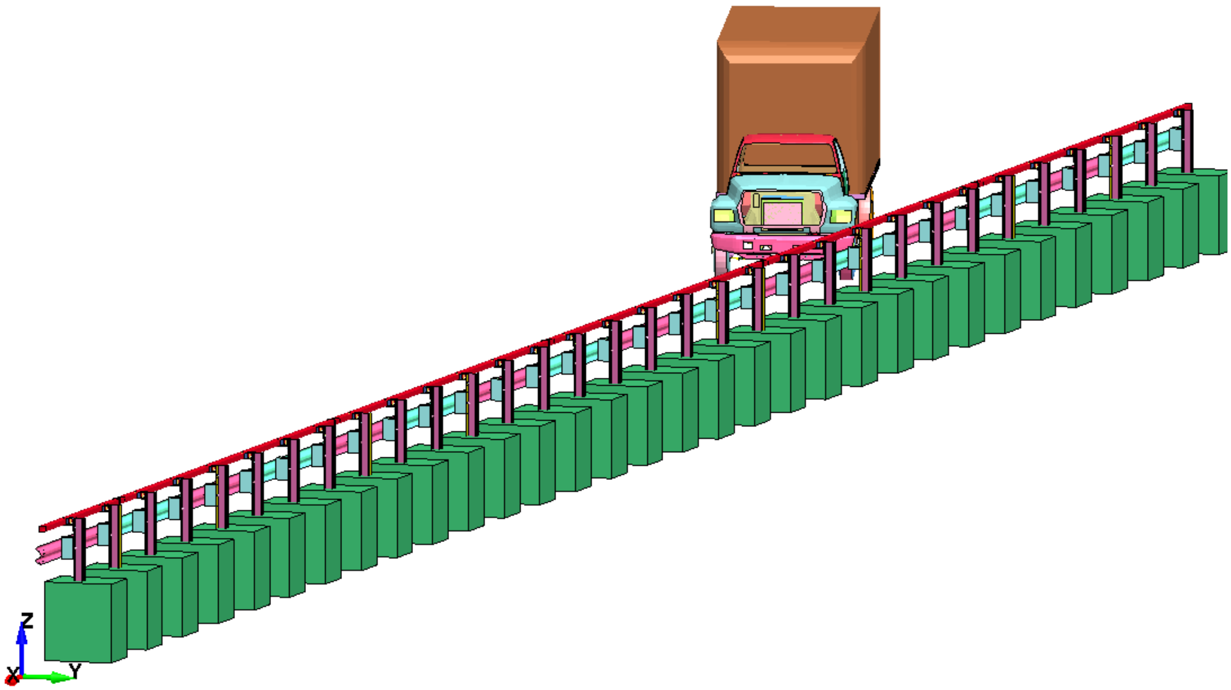
All key guardrail parts were represented with elastic-plastic material models. These included the W-beam and HSS rails, posts, splices, blockouts, and HSS rail attachment angle. The posts were modeled inside a soil continuum. The boundaries of the soil continuum were constrained to maintain the shape; however, the posts were free to deflect and rotate in the soil as a result of the impact loading.

The overall guardrail system was approximately 200 ft long and was comprised of 32 posts with 6.25-ft post spacing. Since the W-beam guardrail works by maintaining tension in the rail element during impact, it was constrained at each end using spring elements. The force-deflection properties of these spring elements have previously been calibrated by TTI to represent the presence of a guardrail end terminal. In contrast to the W-beam rail element, the HSS rail tube primarily works by providing lateral bending stiffness to the system and does not require anchoring at the ends. The HSS beam in the model was thus unrestrained at each end of the model.

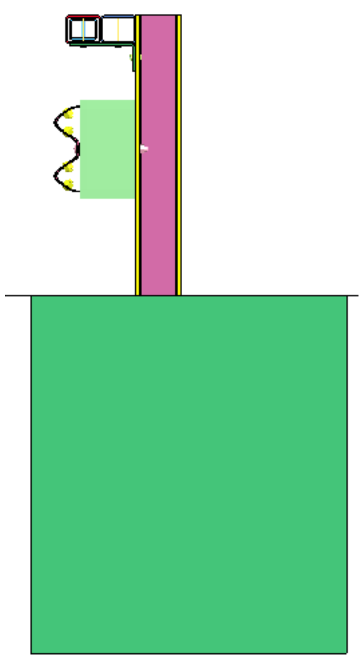
Figure 2.2 presents images of the overall guardrail system model, as well as closer details of the various key components of the model. Vehicle models used in the simulation analyses were publicly available models developed by the National Crash Analysis Center and Center for Collision Safety and Analysis under Federal Highway Administration and National Highway Traffic Safety Administration sponsorship. These models have been further improved by the research team over the course of various research projects to achieve greater validation and robustness.



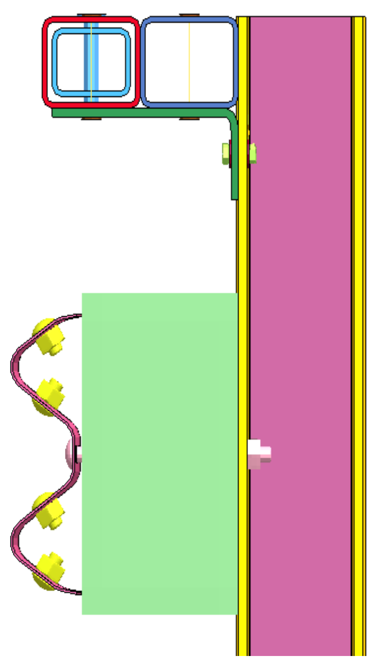
Plan View



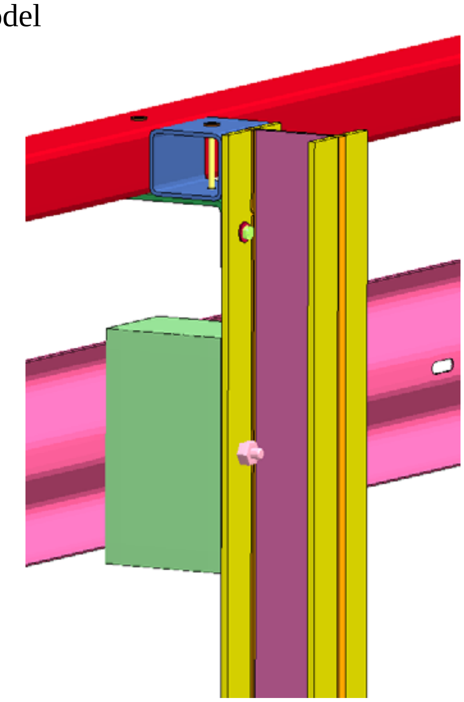
Isometric View of Full Model



Cross-Section View



Close-Up Cross-Section of Rail-to-Post Attachment



Isometric Close-Up of Rail-to-Post Attachment

Figure 2.2. Finite Element Model of Preliminary Design of Guardrail System.

2.5. DESIGN CHANGES BASED ON SIMULATION RESULTS

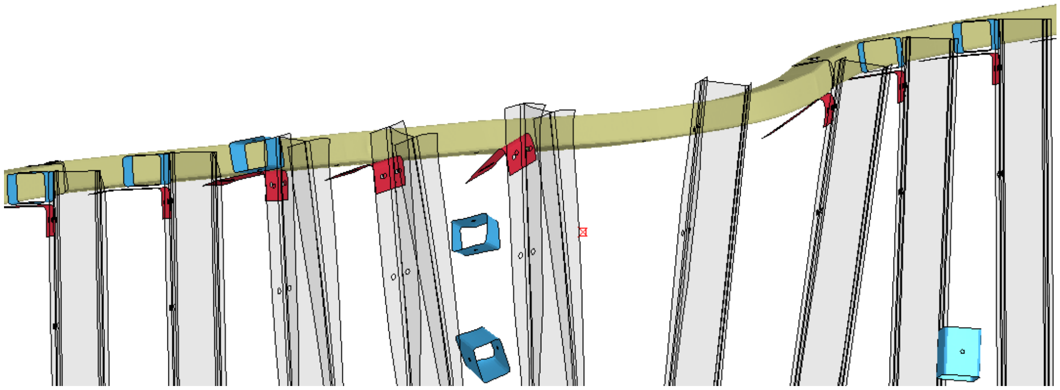
After developing the system model of the preliminary guardrail design concept, the researchers performed *MASH* Test 4-12 impact simulations with the SUT. Based on these simulations, several improvements were made to the guardrail design, as discussed in this section.

Simulation results indicated that the impact-side corner of the SUT cargo box and its underlying crossmembers had significant interaction with the HSS blockouts and the top region of the guardrail posts. This interaction occurred as the vehicle was redirecting and leaning on the guardrail. As a result of this interaction, several HSS blockouts detached from the posts, and the tops of several posts twisted undesirably (see Figure 2.3a and Figure 2.3b). Furthermore, as the vehicle leaned on the top HSS rail, the support angles attaching the rail to the post bent significantly, causing the rail to bend vertically.

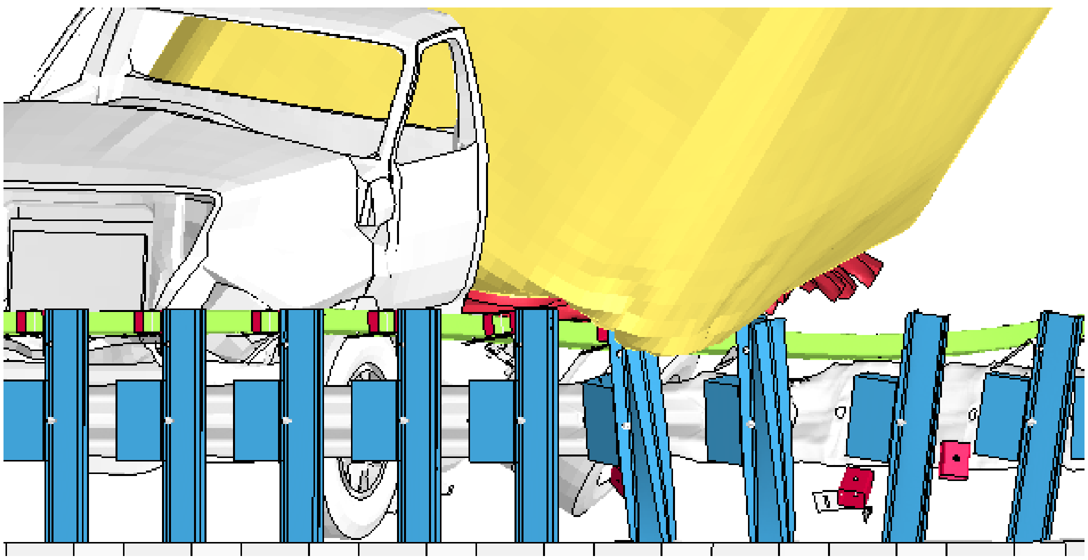
To improve the interaction of the guardrail system with the SUT cargo box, two changes were made to the design, as shown in Figure 2.4. The HSS tube blockout was removed from the design. This change brought the top rail closer to the posts, reducing the bending load on the support angles that attach the rail to the posts. Removal of the HSS blockouts also mitigated the snagging with the cargo box and its underlying crossmembers. This helped in the top rail being supported more reliably when the vehicle leaned on the rail during redirection.

The second change was reducing the height of the guardrail posts by 1.5 inches. The post embedment depth and the top rail height remained at 40 inches; however, the length of the post was reduced so that the top of the post was below the top of the rail by 1.5 inches. This change resulted in significant reduction in snagging between the SUT cargo box and its crossmembers with the top of the posts. Figure 2.3c shows the results of the improved design. The vertical bending of the top rail and the twisting of the posts were significantly reduced with the design changes.

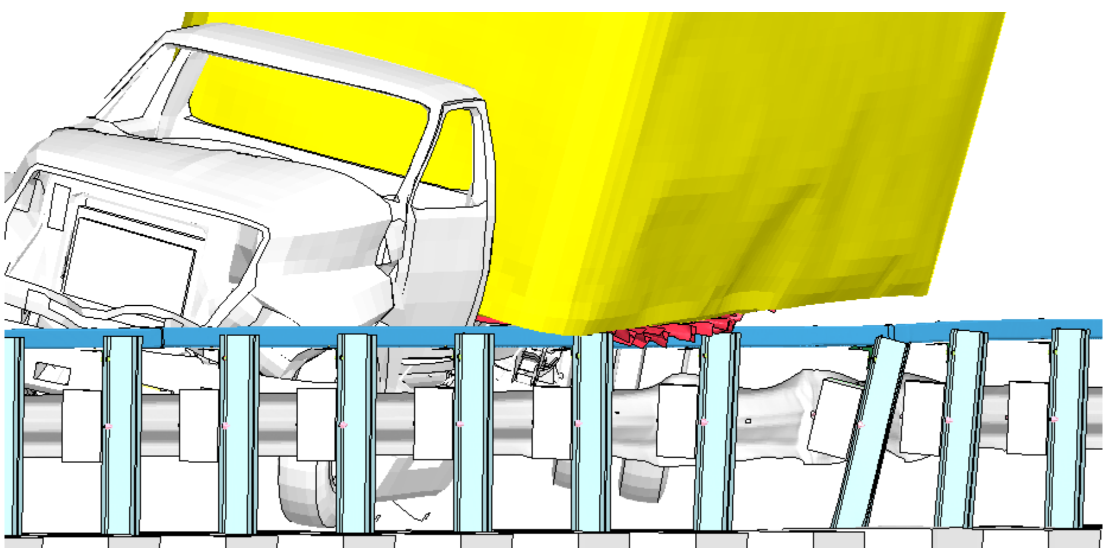
The preliminary design incorporated a 12-gauge W-beam guardrail. Impact simulation with the pickup truck showed that due to the use of stiffer posts for the TL-4 guardrail, the 12-gauge W-beam tended to wrap around the blockouts at post locations in the impact region (see Figure 2.5). This resulted in localized pocketing of the vehicle and caused vehicular instability. While the FE model of the W-beam guardrail did not incorporate material rupture, the plastic strain contours of the guardrail showed high plastic strain around the post blockouts due to the localized pocketing and interaction with the impacting vehicle (see Figure 2.6). Such high plastic strain increases the likelihood of a rail rupture during crash testing. To reduce the probability of a rail rupture, the researchers performed additional simulations using a 10-gauge W-beam guardrail. These results are also shown in Figure 2.5 and Figure 2.6. The 10-gauge W-beam guardrail significantly reduced the pocketing and the resulting plastic strains. It also improved the overall kinematics of the vehicle redirection in the simulations. Based on these results, the 10-gauge guardrail was used in the final design.



(a) Vertical Deflection of Top HSS Rail and Bending of Support Angles.

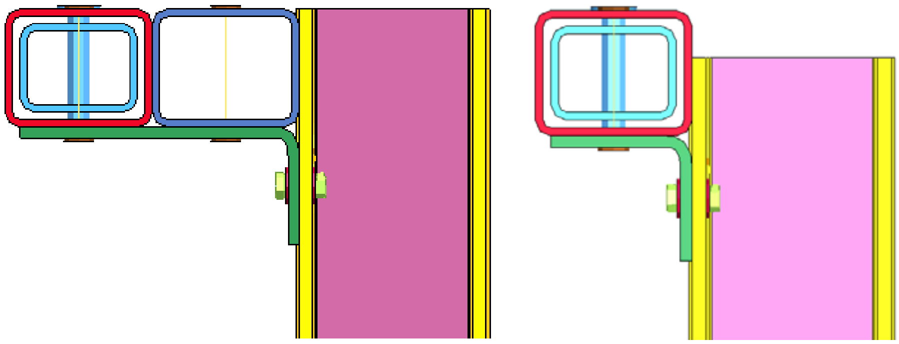


(b) Interaction between Vehicle's Box and Crossmembers with Post Tops and HSS Blockouts.



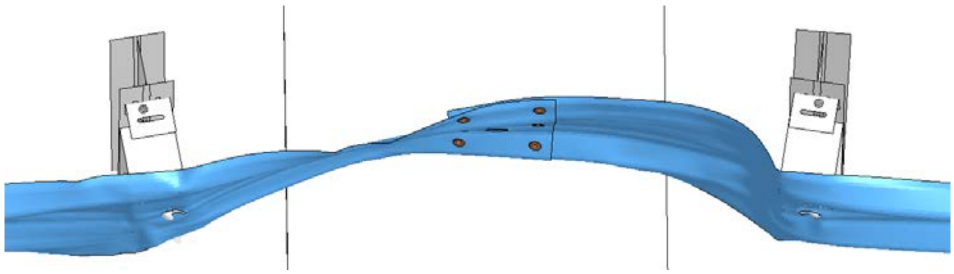
(c) Improved Design with Reduced Interaction between Post Tops and Vehicle's Box. Vertical Bending of Top Rail Is Also Reduced.

Figure 2.3. Vehicle Box and Crossmember Interaction with Post Tops and HSS Blockouts.

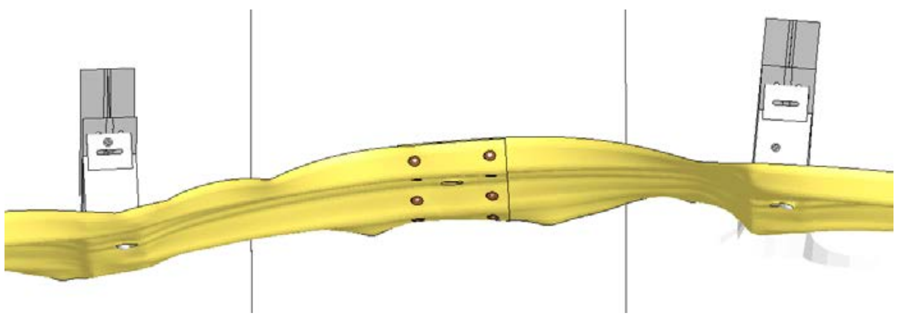


Preliminary Design Improved Design

Figure 2.4. Changes to the HSS Rail-to-Post Connection Based on Simulation Results.

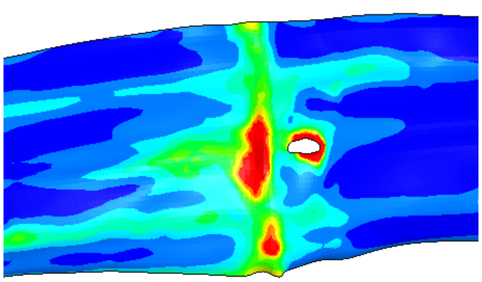


12 gauge

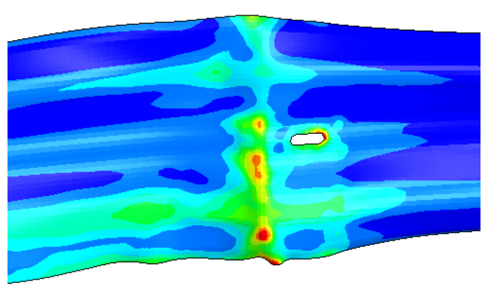


10 gauge

Figure 2.5. Localized Pocketing Comparison between 12-gauge and 10-gauge W-beam Rail.



12 gauge



10 gauge

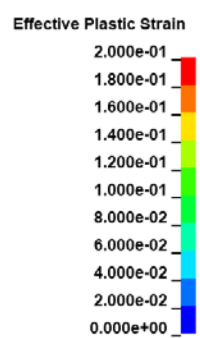


Figure 2.6. Plastic Strain Comparison between 12-gauge and 10-gauge W-beam Rail.

Simulation of the preliminary design showed that the 6-inch-wide wood blockouts attached to a 6-inch-wide post flange with a single bolt resulted in rotation of the blockouts during impact (see Figure 2.7). This rotation is not desirable because it results in the W-beam guardrail wrapping around the corners of the blockout, which causes localized stress concentrations and increases the possibility of rail rupture when the vehicle interacts with the guardrail at a post location. To prevent the blockout rotation, the researchers modified the preliminary design to incorporate two ¼-inch-diameter, 5-inch-long hex-head lag bolts that passed through the flange of the post to secure the wood blockouts. In the final crash-tested design, these lag bolts were replaced with an additional guardrail bolt for ease of installation.

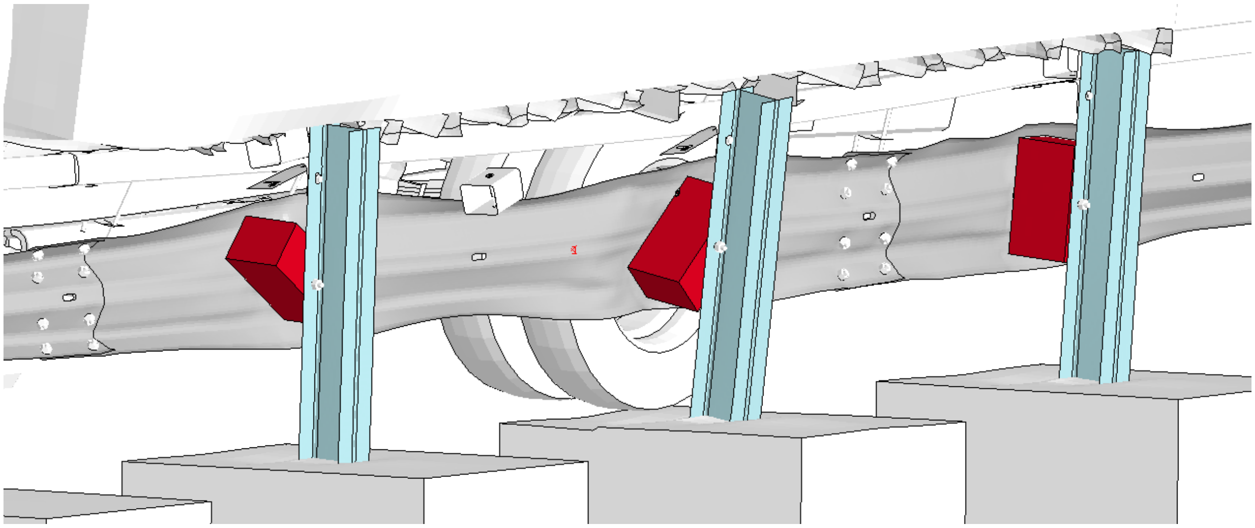


Figure 2.7. Rotation of Wood Blockouts during Impact.

2.6. MODIFIED DESIGN DETAILS

The researchers developed an FE model of the guardrail system that incorporated the modifications discussed above. This modified model, shown in Figure 2.8, was reduced by 1.5 inches. The W-beam guardrail thickness was changed to 10 gauge, and the two lag bolt constraints were added to prevent longitudinal rotation of the wood blockouts.

After developing the modified model, the researchers simulated the *MASH* impact conditions with this design, and it performed acceptably for TL-4. Details of these impact simulations are presented next.

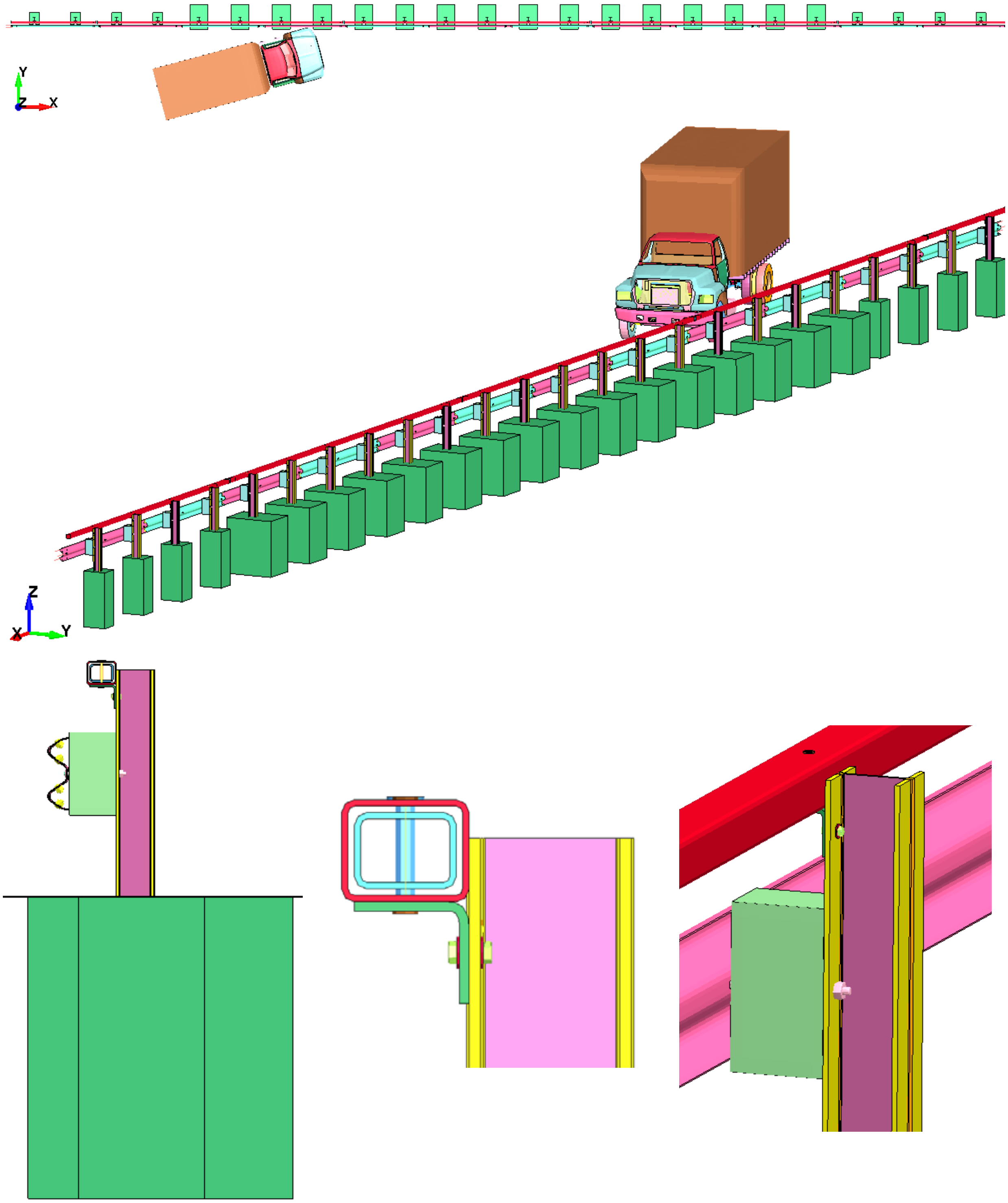


Figure 2.8. FE Model of the Guardrail System Design Recommended for Full-Scale Testing.

2.7. IMPACT ANALYSIS WITH *MASH* TEST CONDITIONS

The researchers performed impact simulation for *MASH* Test 4-12 with the SUT model. The vehicle impacted the guardrail at an impact speed and angle of 56 mi/h and 15 degrees. The impact point was 24 inches upstream of a post. This impact point maximized the potential interaction of the vehicle's impact-side front wheel with the post and was considered the critical impact point for testing. Results of the simulation are presented in Figure 2.9 and Figure 2.10. The vehicle was successfully contained and redirected in the simulation, as shown in Figure 2.9. The maximum dynamic deflection of the guardrail system was 17.7 inches. The permanent deflection was 15.3 inches. Figure 2.10 shows the damage to the barrier after the impact. Results of the simulation showed that the proposed guardrail design could be expected to pass *MASH* Test 4-12 evaluation criteria in a full-scale crash test.

The researchers performed impact simulation for *MASH* Test 4-11 with the pickup truck model. The vehicle impacted the guardrail at an impact speed and angle of 62 mi/h and 25 degrees. The impact point was 19 inches upstream of a post, with the rail splices 37.5 inches downstream of the posts. Results of this simulation are presented in Figure 2.11 and Figure 2.12. The vehicle was successfully contained and redirected in the simulation, as shown in Figure 2.11. The maximum dynamic deflection of the guardrail system was 10.8 inches. The permanent deflection was 9.6 inches. Figure 2.12 shows the damage to the barrier after the impact. Results of the simulation showed that the proposed guardrail design could be expected to pass *MASH* Test 4-11 evaluation criteria in a full-scale crash test.

The researchers also performed impact simulation for *MASH* Test 4-10 with the small car model. The vehicle impacted the guardrail at an impact speed and angle of 62 mi/h and 25 degrees. The impact point was 12 inches upstream of a post, with the rail splice 37.5 inches downstream of the post. Results of the simulation are presented in Figure 2.13 and Figure 2.14. The vehicle was successfully contained and redirected in the simulation, as shown in Figure 2.13. The maximum dynamic deflection of the guardrail system was 5.4 inches. The permanent deflection was 4.4 inches. Figure 2.14 shows the damage to the barrier after the impact. Results of the simulation showed that the proposed guardrail design could be expected to pass *MASH* Test 4-10 evaluation criteria in a full-scale crash test.

Prior to crash testing, two additional simulations were performed with the pickup truck with impact points of 36 inches and 44 inches upstream of the previously performed simulation. The results of the simulations were very similar for all three cases with regard to vehicle stability and barrier deflection. However, the impact at 36 inches had slightly higher *MASH* occupant risk numbers and was, therefore, selected as the impact point for crash testing. Similarly, two additional simulations were performed with the small car with impact points 30 inches downstream and 30 inches upstream of the previously performed impact simulation. In this case, the most critical results with regard to vehicle stability and occupant risk were associated with the initially performed impact at 12 inches upstream of the post. Thus, this impact point was selected as the critical impact point for testing.

Based on the successful results of the analyses presented herein, the research team recommended performing full-scale *MASH* TL-4 testing of the guardrail system.

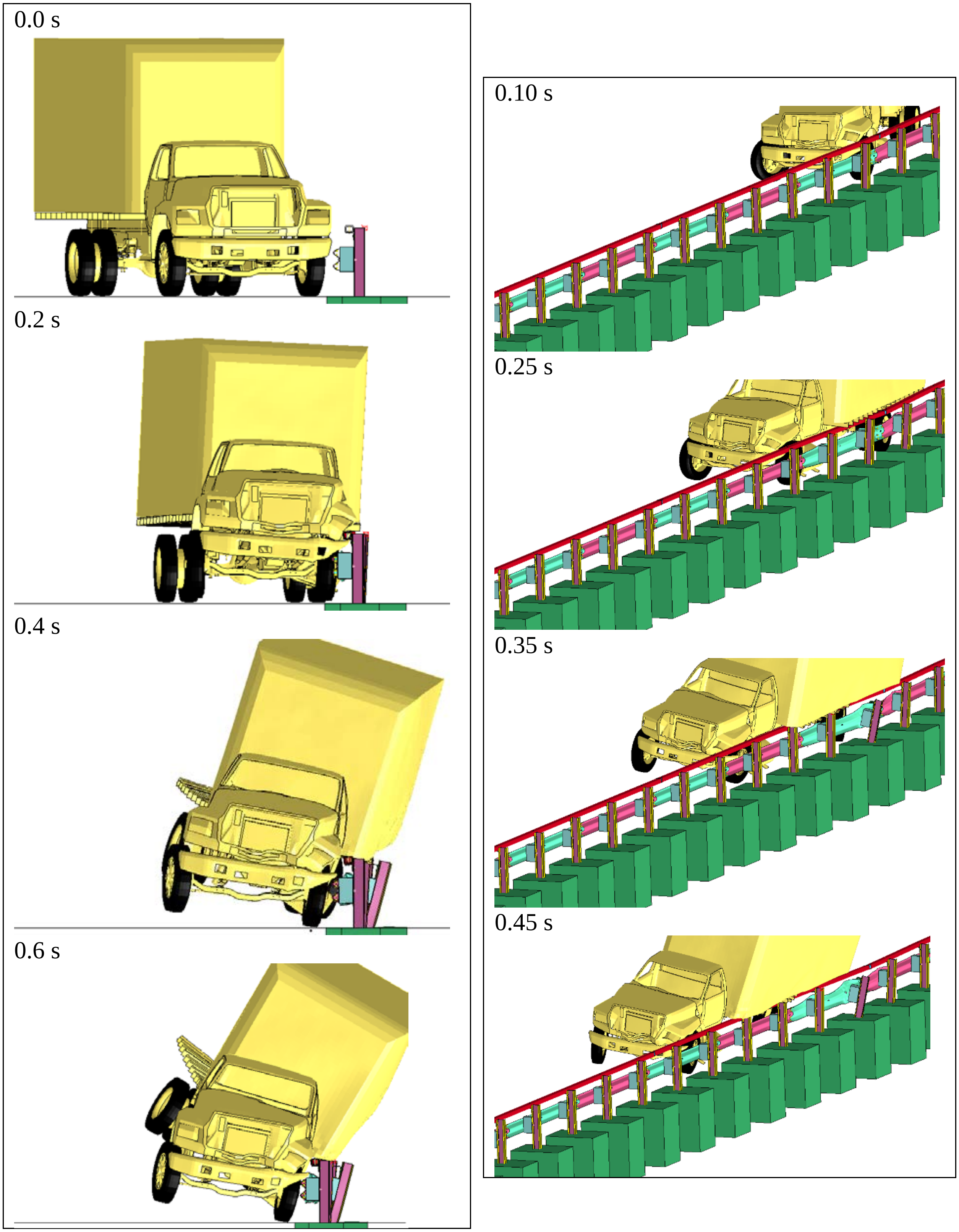


Figure 2.9. FE Simulation Results of Proposed Design for *MASH* Test 4-12 Impact.

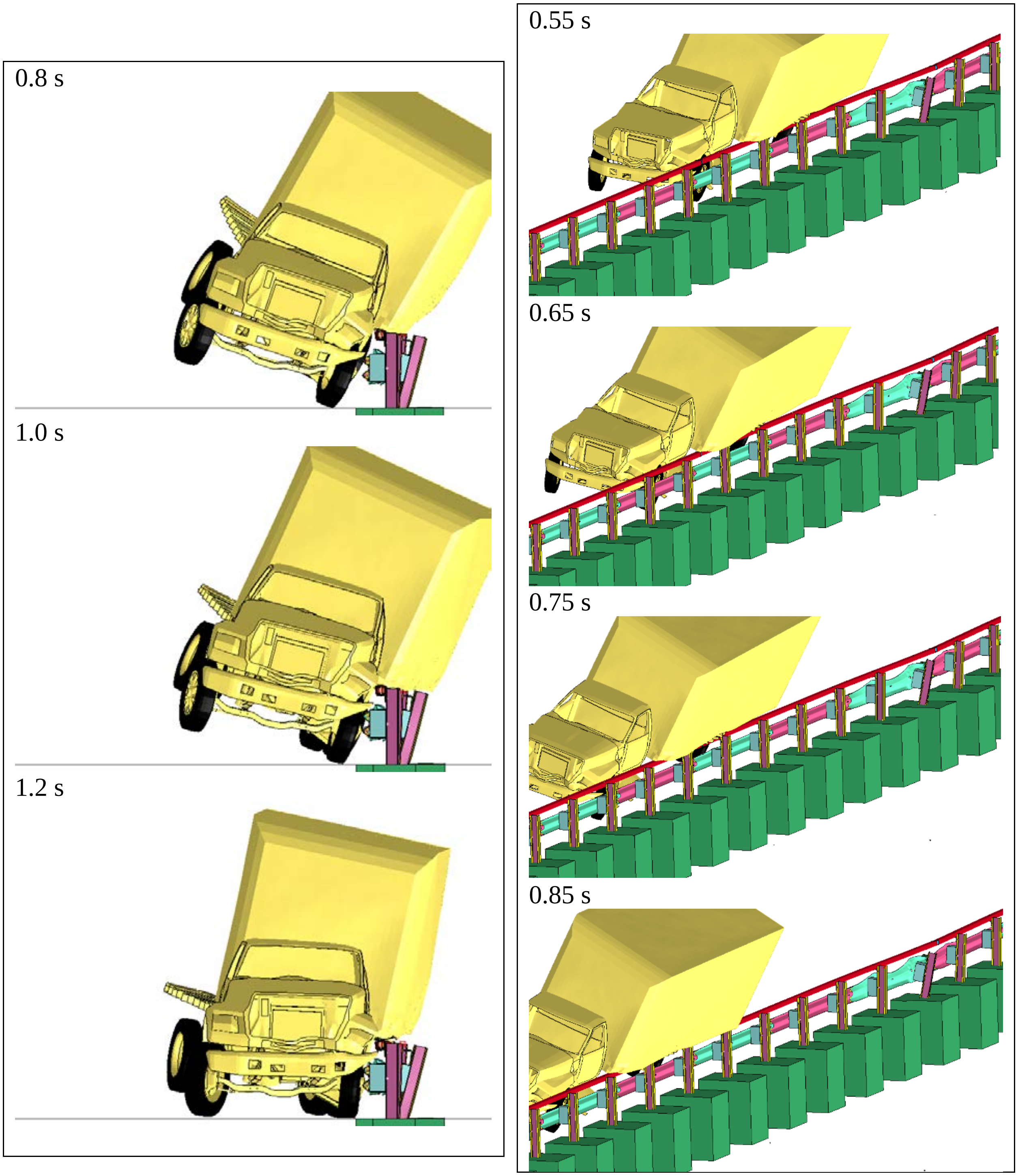


Figure 2.9. FE Simulation Results of Proposed Design for *MASH* Test 4-12 Impact (Continued).

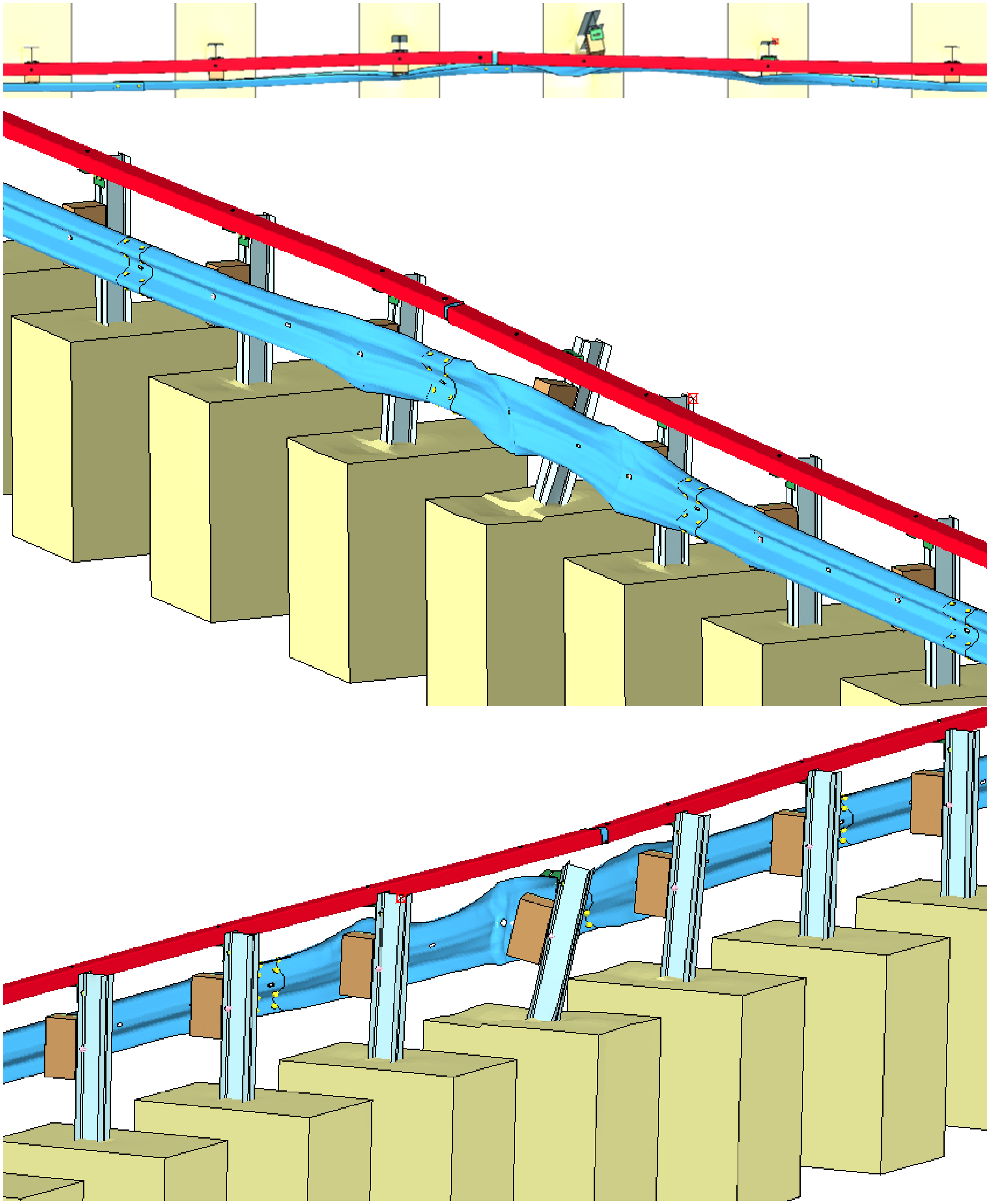


Figure 2.10. Barrier Damage after *MASH* Test 4-12 Impact Simulation.

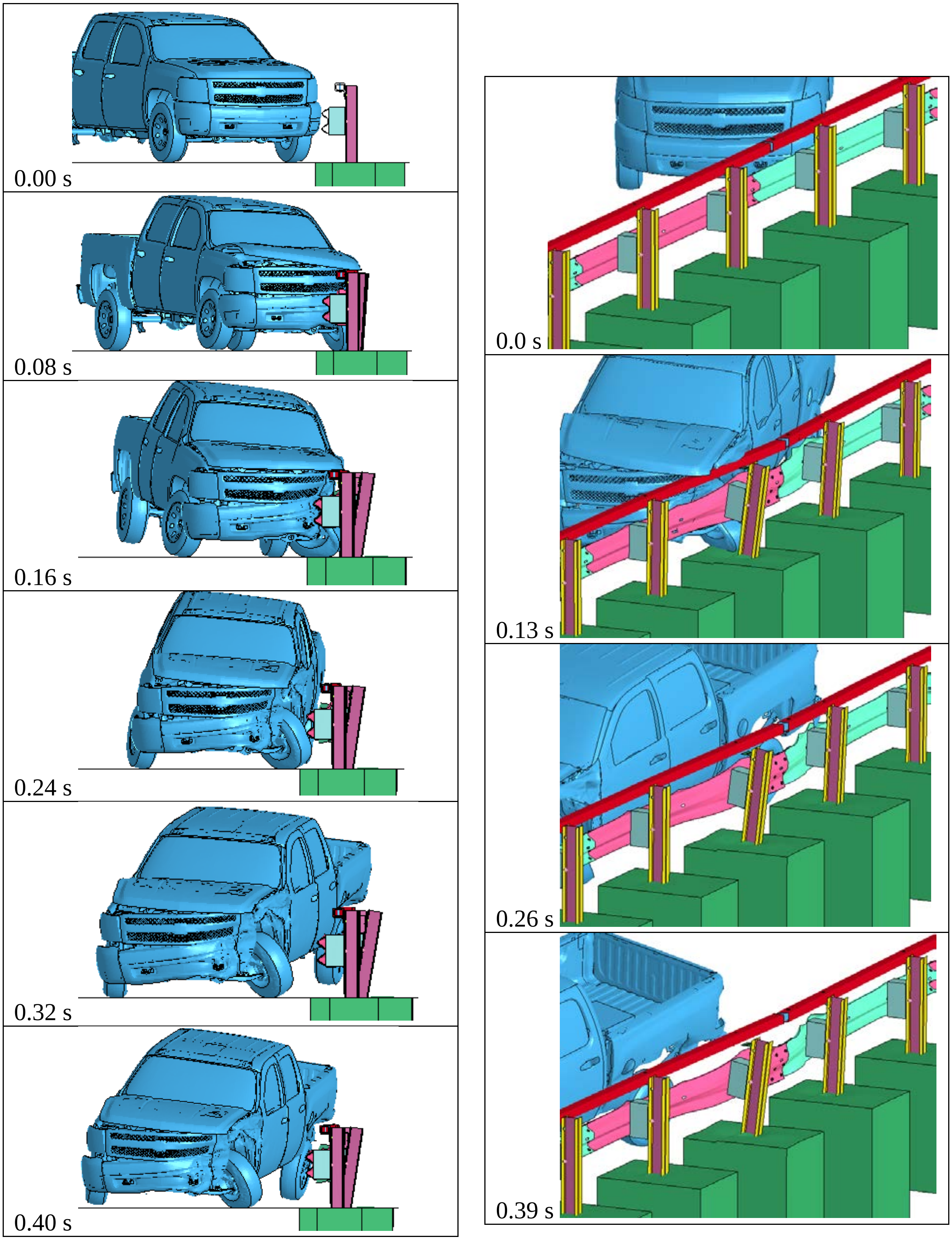
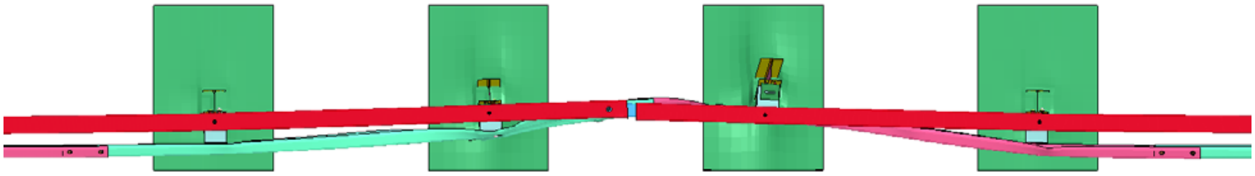
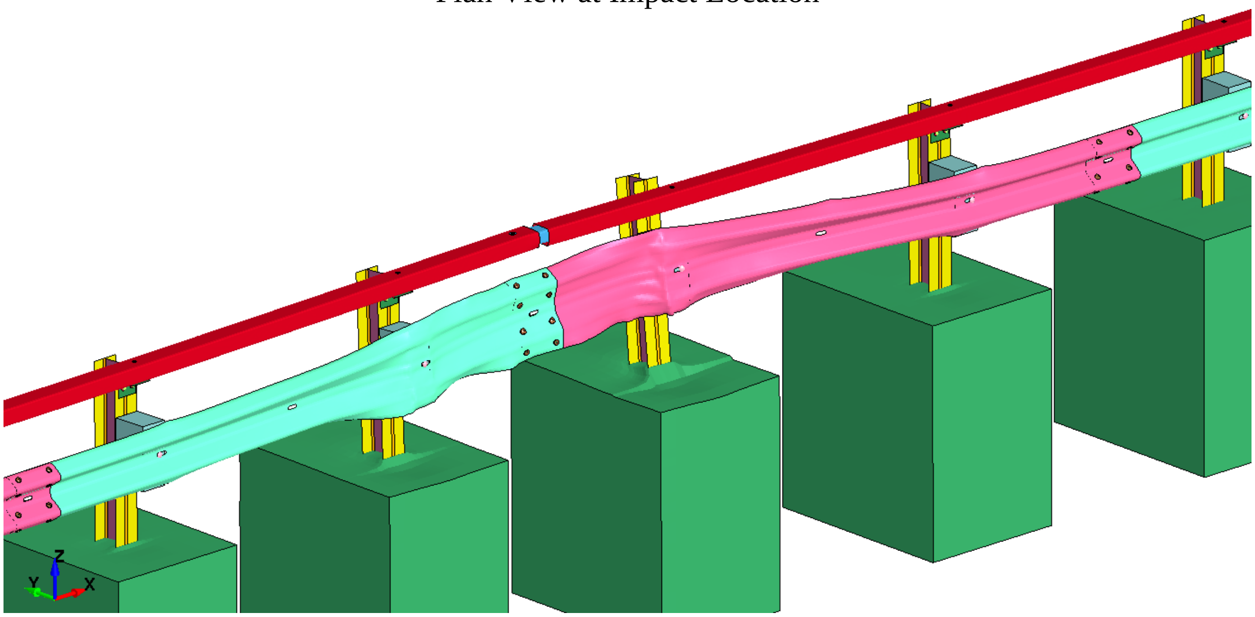


Figure 2.11. FE Simulation Results of Proposed Design for *MASH* Test 4-11 Impact.



Plan View at Impact Location



Isometric View at Impact Location

Figure 2.12. Barrier Damage after *MASH* Test 4-11 Impact Simulation.

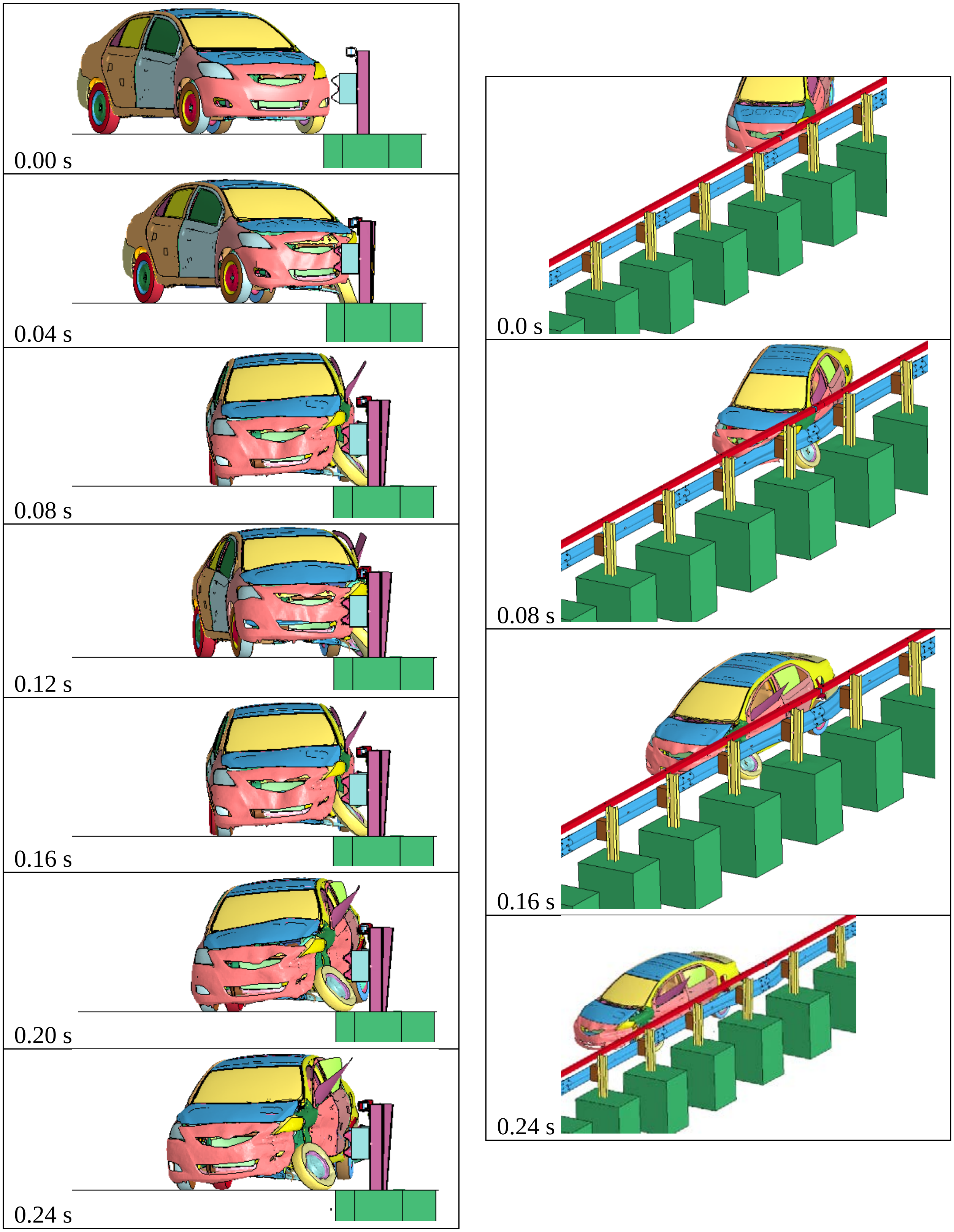
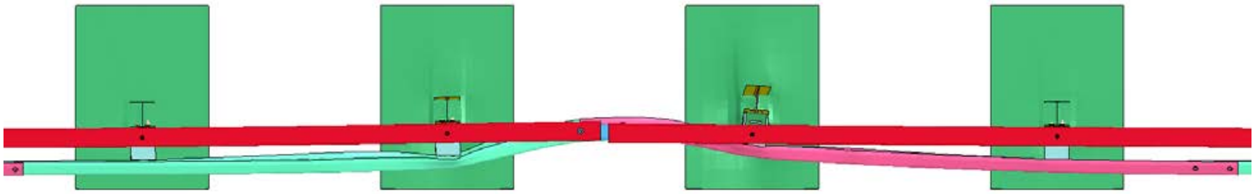
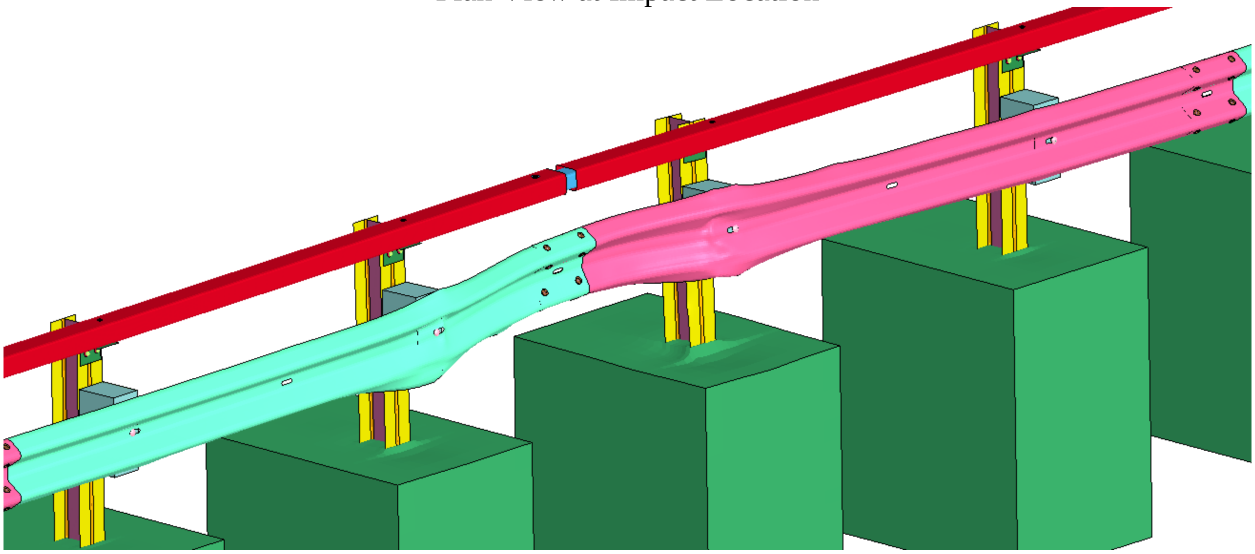


Figure 2.13. FE Simulation Results of Proposed Design for *MASH* Test 4-10 Impact.



Plan View at Impact Location



Isometric View at Impact Location

Figure 2.14. Barrier Damage after *MASH* Test 4-10 Impact Simulation.

Chapter 3. SYSTEM DETAILS

3.1. TEST ARTICLE AND INSTALLATION DETAILS

The *MASH* TL-4 guardrail installation consisted of a 10-gauge W-beam rail and a rectangular HSS tube rail attached to W6×25 wide flange steel posts. The height of the top of the HSS tube was 40 inches, and the height to the top of the W-beam rail was 27 inches. The height to the top of the wide flange posts was 38.5 inches. The wide flange steel posts were spaced 75 inches apart. The W-beam rail was separated from the posts by wood blockouts. The HSS steel tube was attached to the posts with supporting angle brackets that were bolted to the posts underneath the rail.

The top HSS rail started at post 6 at a height of 21 inches to the top of the rail and transitioned vertically to a height of 40 inches near post 7. On the opposite end, the HSS rail started transitioning downward just before post 38 and terminated at a height of 21 inches at post 39.

On the upstream end, the height to the top of the W-beam rail transitioned from 27 inches to 31 inches between posts 7 through 4, and it was maintained at 31 inches for posts 3 and 2. On the downstream end, the height to the top of the W-beam rail transitioned from 27 inches to 31 inches between posts 38 and 41, and it was maintained at 31 inches for posts 42 and 43. An abbreviated length (shortened) Softstop® terminal was installed at the upstream end of the installation, and the downstream end was terminated with a standard TxDOT downstream anchor terminal (DAT). The total length of the installation was 260 ft 1½ inches.

Figure 3.1 presents the overall information on the *MASH* TL-4 guardrail system, and Figure 3.2 provides photographs of the installation. Appendix A provides further details on the guardrail system. Drawings were provided by the TTI Proving Ground, and construction was performed by DMA Construction Inc. and supervised by TTI Proving Ground personnel.

3.2. DESIGN MODIFICATIONS DURING TESTS

No modification was made to the test installation design during the testing phase.

3.3. MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install and construct the test installation.

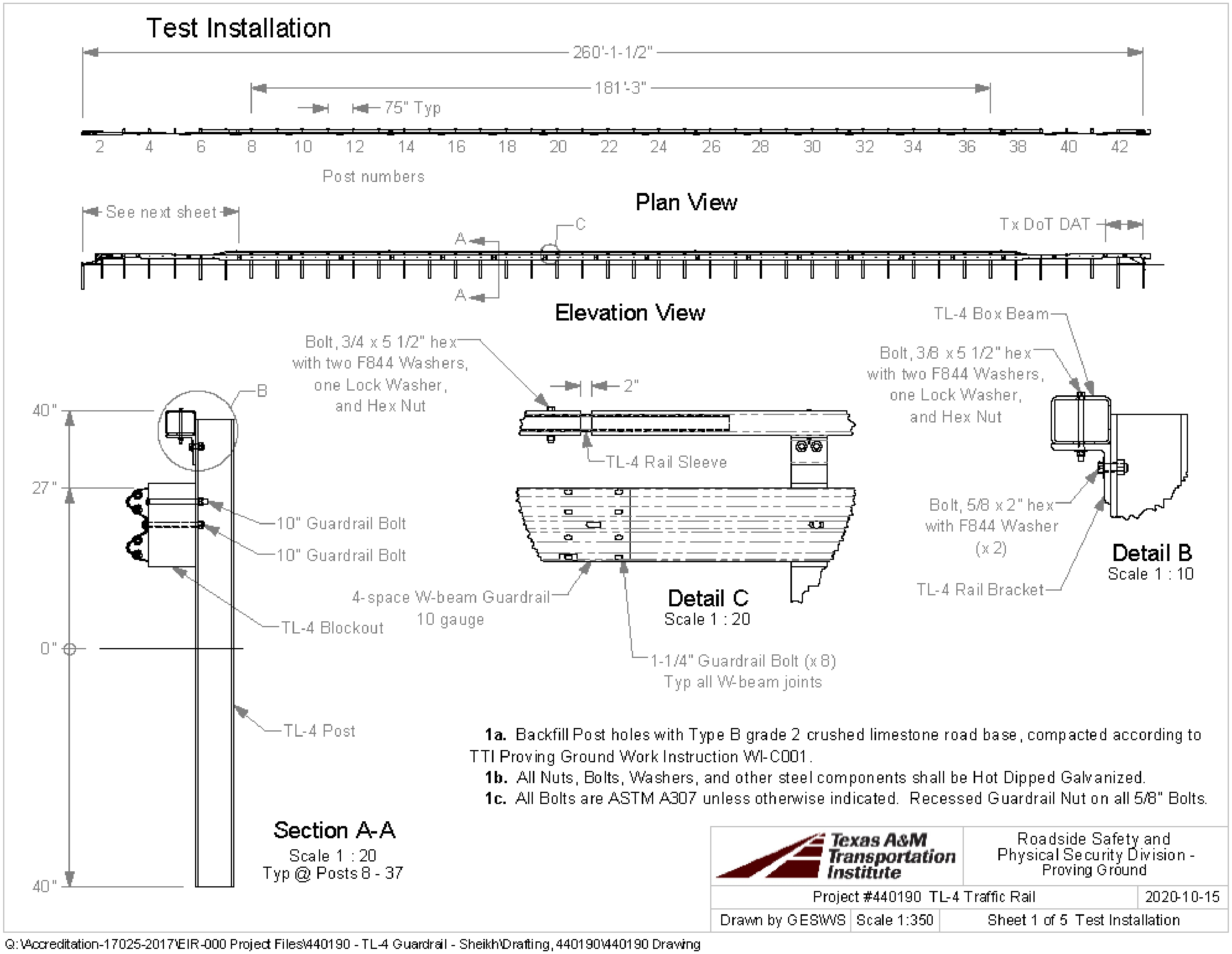


Figure 3.1. *MASH* TL-4 Guardrail System Details.

Figure 3.2. *MASH* TL-4 Guardrail System prior to Testing.

3.4. SOIL CONDITIONS

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

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the *MASH* TL-4 guardrail system, additional 6-ft-long W6×16 posts were installed in the immediate vicinity of the guardrail using the same fill materials and installation procedures used in the test installation and the standard dynamic test prescribed by AASHTO M147-65(2004). Table C.1 in Appendix C presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

As determined by the tests summarized in Table C.2 in Appendix C, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, were 3940 lbf, 5500 lbf, and 6540 lbf (90 percent of static load for the initial standard installation).

On the day of Crash Test No. 440190-01-1 (SUT), September 30, 2020, loads obtained on one of the additional posts at deflections of 5 inches, 10 inches, and 15 inches were 7121 lbf, 7222 lbf, and 6868 lbf. Table C.2 in Appendix C shows the strength of the backfill material in which the guardrail was installed compared to the required minimum soil strength. The soil for this test met minimum *MASH* requirements for soil strength.

On the day of Crash Test No. 440190-01-3, October 15, 2020, loads obtained on one of the additional posts at deflections of 5 inches, 10 inches, and 15 inches were 7020 lbf, 6919 lbf, and 6313 lbf. On the day of Crash Test No. 440190-01-2, October 20, 2020, loads on another additional post at deflections of 5 inches, 10 inches, and 15 inches were 6111 lbf, 6414 lbf, and 6363 lbf.

Tables C.3 and Table C.4 in Appendix C show the strength of the backfill material in which the guardrail was installed for Test 440190-01-3 (small car) and Test 440190-01-2 (pickup truck). For both tests, the soil strength exceeded the minimum threshold for post deflections of 5 inches and 10 inches. However, the soil strength was slightly less (approximately 200 lbf) than the *MASH* threshold for the 15-inch post deflection for both tests. Due to the expected low deflection of the test installation posts for the small car and pickup truck tests, soil strength being slightly below the *MASH* threshold for the 15-inch deflection was not considered critical. Based on the much higher soil strength for the 5-inch and 10-inch post deflections, the soil conditions were considered adequate to proceed with full-scale crash testing.

Chapter 4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1. CRASH TEST PERFORMED/MATRIX

Table 4.1 shows the test conditions and evaluation criteria for *MASH* TL-4 for longitudinal barriers. The target critical impact points (CIPs) for each test were determined using the impact simulations of the FE model of the guardrail system under *MASH* TL-4 impact conditions. Figure 4.1 shows the target CIP for *MASH* Tests 4-10, 4-11, and 4-12 on the guardrail system.

Table 4.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-4 Longitudinal Barriers.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	4-10	1100C	62 mi/h	25°	A, D, F, H, I
	4-11	2270P	62 mi/h	25°	A, D, F, H, I
	4-12	10000S	56 mi/h	15°	A, D, G

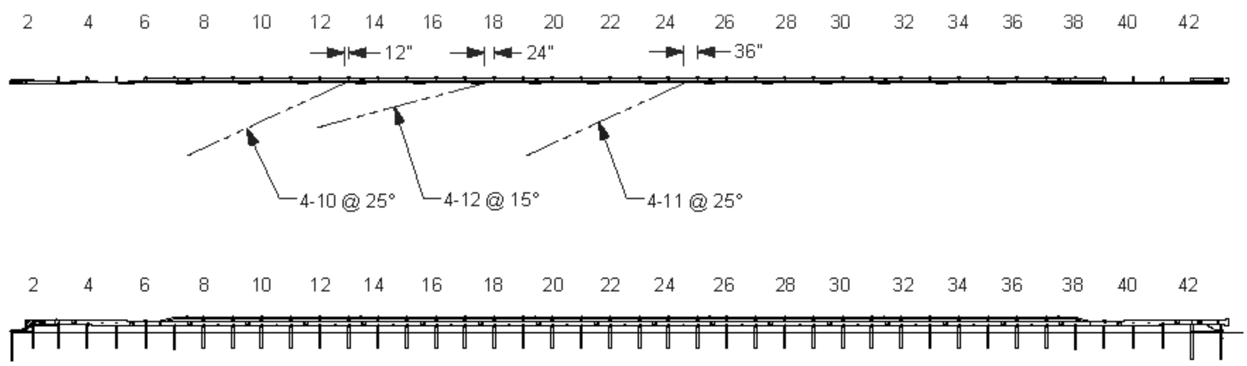


Figure 4.1. Target CIP for *MASH* TL-4 Tests on *MASH* TL-4 Guardrail System.

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 lists the test conditions and evaluation criteria required for *MASH* TL-4, and Table 4.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 8.

Table 4.2. Evaluation Criteria Required for *MASH* TL-4 Longitudinal Barriers.

Evaluation Factors	Evaluation Criteria	*MASH* Test
Structural Adequacy	*A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	*10, 11, 12*
Occupant Risk	*D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*	*10, 11, 12*
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	*10, 11*
	G. It is preferable, although not essential, that the vehicle remain upright during and after the collision.	*12*
	H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	*10, 11*
	I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	*10, 11*

Chapter 5. TEST CONDITIONS

5.1. TEST FACILITY

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

The test facilities of the TTI Proving Ground are located on The Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 mi northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, highway pavement durability and efficacy, and roadside safety hardware and perimeter protective device evaluation. The site selected for construction and testing of the *MASH* TL-4 guardrail system was 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

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

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

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

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

TRAP uses the data from the roll, pitch, and yaw 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. However, *MASH* recommends that a dummy be used when testing "any longitudinal barrier with a height greater than or equal to 33 inches." More specifically, use of the dummy in the 2270P vehicle is recommended for tall rails to evaluate the "potential for an occupant to extend out of the vehicle and come into direct contact with the test article." Although this information is reported, it is not part of the impact performance evaluation. Since the rail height of the *MASH* TL-4 guardrail system was 40 inches, a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

MASH does not recommend or require use of a dummy in the 10000S vehicle, and no dummy was placed in the vehicle.

5.3.3. Photographic Instrumentation Data Processing

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

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

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the guardrail system. 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 4-12 (CRASH TEST NO. 440190-01-1)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-12 involves a 10000S vehicle weighing 22,000 lb ± 660 lb impacting the CIP of the longitudinal barrier at an impact speed of 56 mi/h ± 2.5 mi/h and an angle of 15 degrees ± 1.5 degrees. The CIP for *MASH* Test 4-12 on the *MASH* TL-4 guardrail system was 2.0 ft ± 1 ft upstream of the centerline of post 18. Figure 4.1 and Figure 6.1 depict the target impact setup.

Figure 6.1. Guardrail System and Test Vehicle Geometrics for Test No. 440190-01-1.

The 10000S vehicle weighed 22,290 lb, and the actual impact speed and angle were 58.6 mi/h and 15.0 degrees. The actual impact speed exceeded the *MASH* upper tolerance by 0.1 mi/h and thus imparted slightly greater impact energy to the guardrail system. A successful performance of the guardrail with this higher speed implies that it will also perform acceptably for impact speeds within the *MASH* specifications. The minimum target impact severity (IS) was 142 kip-ft, and the actual IS was 171 kip-ft. The actual impact point was 2.2 ft upstream of the centerline of post 18.

6.2. WEATHER CONDITIONS

The test was performed on the afternoon of September 30, 2020. Weather conditions at the time of testing were as follows: wind speed: 7 mi/h; wind direction: 236 degrees (vehicle was traveling at a heading of 290 degrees); temperature: 83°F; relative humidity: 24 percent.

6.3. TEST VEHICLE

Figure 6.2 shows the 2012 International 4300 SUT used for the crash test. The vehicle's test inertia weight was 22,290 lb, and its gross static weight was 22,290 lb. The height to the lower edge of the vehicle bumper was 18.25 inches, and the height to the upper edge of the bumper was 33.25 inches. The height to the center of gravity of the vehicle's ballast was 62.8 inches. Table D.1 in Appendix D.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.2. Test Vehicle before Test No. 440190-01-1.

6.4. TEST DESCRIPTION

Table 6.1 lists events that occurred during Test No. 440190-01-1. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 6.1. Events during Test No. 440190-01-1.

Time (s)	Events
0.000	Vehicle contacts the guardrail
0.039	Vehicle begins to redirect
0.296	Left rear lower corner of the box truck contacts the top rail element
0.343	Right front tire leaves the pavement
0.357	Vehicle starts traveling parallel with the guardrail
1.059	Front left top corner of the box contacts the top of the rail, and the box begins sliding down the rail on its side
2.678	Left side of the box loses contact with the rail
2.757	Left side of the box lands on the pavement

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 65.6 ft for heavy vehicles). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were not applied. After loss of contact with the barrier, the vehicle came to rest 138 ft downstream of the point of impact, with the front of the vehicle adjacent to the traffic face of the guardrail.

6.5. DAMAGE TO TEST INSTALLATION

Figure 6.3 through Figure 6.5 show the damage to the guardrail. The soil was disturbed between posts 5 and 15, and also at post 26. At post 14, the top rail bolt sheared at the bottom. The top rail was disconnected from posts 18 through 20, and both rails were disconnected from post 21. The wood blockout at post 21 remained attached to the post and had a slight counterclockwise rotation. The top rail bolts sheared and were missing at posts 25, 37, and 38. The top rail bolts sheared at posts 30 and 31 but were present in the bolt holes. The top of post 39 was bent toward the traffic side, and the blockout was rotated 45 degrees clockwise. The bottom rail released from the wood blockout at post 40. The bottom rail was deformed from the point of impact until post 22, and then again from posts 39 through 41. The bottom rail had a horizontal 5-inch-long gash just downstream of the joint between posts 17 and 18. Table 6.2 provides movement noted at the posts.

Working width* was 103.8 inches, and height of working width was 122.6 inches. Maximum dynamic deflection and permanent deformation of the guardrail system were 30.2 inches and 20.5 inches, respectively. For the upper HSS rail, the maximum dynamic deflection was 30.2 inches and the maximum permanent deformation was 10.25 inches at post 21. For the lower W-beam rail, the maximum dynamic deflection was 25.9 inches and the maximum permanent deformation was 20.5 inches at 29 inches upstream from the centerline of post 20.

Figure 6.3. Guardrail after Test No. 440190-01-1.

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

Figure 6.4. Traffic Side of Guardrail after Test No. 440190-01-1.

Figure 6.5. Field Side of Guardrail after Test No. 440190-01-1.

Table 6.2. Post Movement during Test No. 440190-01-1.

Post Number	Soil Gap (Traffic Side)	Soil Gap (Field Side)	Angle (Toward Field Side from Vertical)
16	¼ inch	—	2°
17	1 inch	¾ inch	4°
18	4 inches	1 inch	9°
19	—	1¾ inches	24°
20	—	5 inches	25°
21	—	1½ inches	22°
22	3¼ inches	6 inches	8°
23	1¾ inches	1½ inches	5°
24	1¼ inches	⅛ inch	1°
41	½ inch	—	—

6.6. DAMAGE TO TEST VEHICLE

Figure 6.6 and Figure 6.7 show the damage sustained by the vehicle. The front bumper, hood, left front spring assembly, left front U-bolts, left front axle, left front tire and rim, left front floor pan, left door and window glass, windshield, left cab corner, left battery box and side steps, left side of box, and left rear outside tire and rim were damaged. No damage to the fuel tank was observed. Maximum exterior crush to the vehicle was 9.5 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 3.0 inches in the left front corner of the floor pan. Figure 6.8 shows the interior of the vehicle.

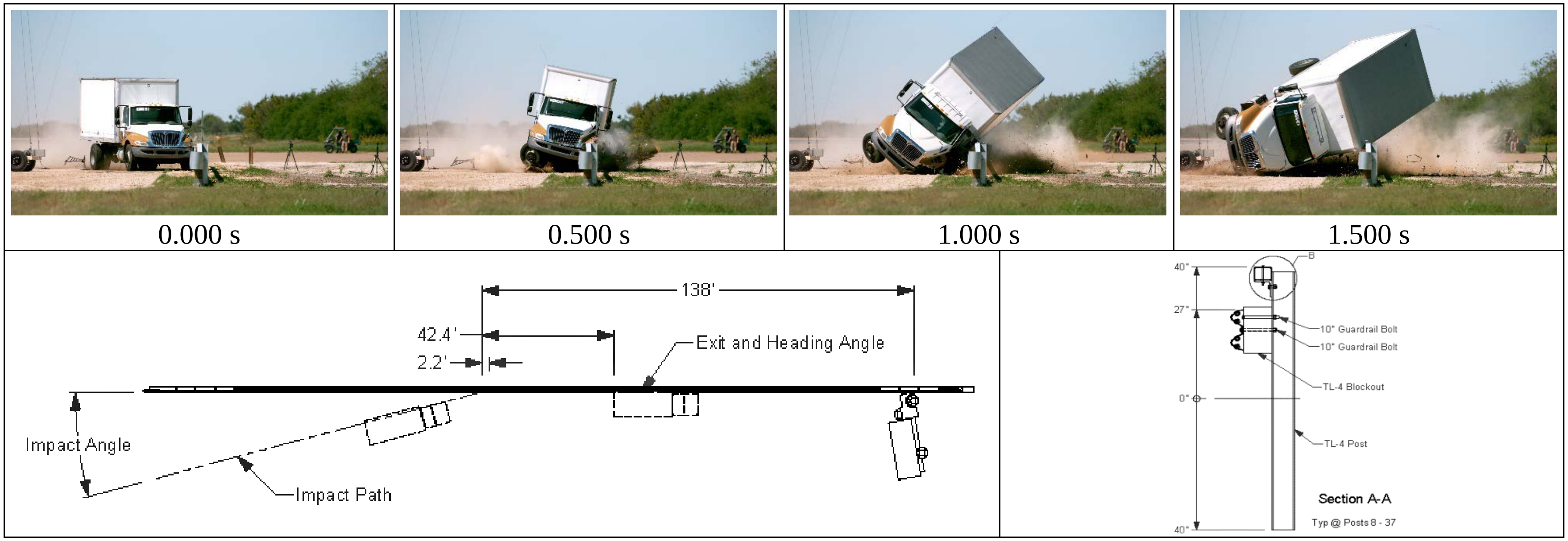
Figure 6.6. Test Vehicle after Test No. 440190-01-1.

Figure 6.7. Test Vehicle after Being Uprighted after Test No. 440190-01-1.

Figure 6.8. Interior of Test Vehicle after Test No. 440190-01-1.

6.7. VEHICLE INSTRUMENTATION

Data from the accelerometers were digitized for informational purposes only, and results are reported in Figure 6.9. Figure D.3 in Appendix D.3 shows the vehicle angular displacements, and Figures D.4 through D.9 in Appendix D.4 show acceleration versus time traces. Figure 6.9 summarizes pertinent information from the test.



General Information
- Test Agency........................ Texas A&M Transportation Institute (TTI)
- Test Standard Test No. .... *MASH* Test 4-12
- TTI Test No. 440190-01-1
- Test Date 2020-09-30

Test Article
- Type .... Longitudinal Barrier—Guardrail
- Name.................................. *MASH* TL-4 Guardrail System
- Installation Length.............. 260 ft 1½ inches
- Material or Key Elements ... Guardrail system with W-beam and HSS tube rail elements mounted on steel posts

Soil Type and Condition ..... AASHTO M147-65, Grade B Soil (crushed limestone)

Test Vehicle
- Type/Designation............... 10000S
- Make and Model .... 2012 International 4300 SUT
- Curb.................................... 13,460 lb
- Test Inertial......................... 22,290 lb
- Dummy .... No dummy
- Gross Static .... 22,290 lb

Impact Conditions
- Speed .... 58.6 mi/h
- Angle .... 15.0°
- Location/Orientation .... 2.2 ft upstream of post 18

Impact Severity.................... 171 kip-ft

Exit Conditions
- Speed .... Stopped
- Trajectory/Heading Angle ... Along guardrail

Occupant Risk Values
- Longitudinal OIV .... 10.2 ft/s
- Lateral OIV......................... 9.2 ft/s
- Longitudinal Ridedown .... 3.0 g
- Lateral Ridedown .... 4.8 g
- THIV .... 3.9 m/s
- ASI...................................... 0.4
- Max. 0.050-s Average
  - Longitudinal .... −2.2 g
  - Lateral............................. 3.5 g
  - Vertical............................ 3.3 g

Post-Impact Trajectory
- Stopping Distance..................... 138 ft downstream Adjacent to traffic face

Vehicle Stability
- Maximum Roll Angle .... 130°
- Maximum Pitch Angle .... 14°
- Maximum Yaw Angle .... 223°
- Vehicle Snagging...................... No
- Vehicle Pocketing .... No

Test Article Deflections
- Dynamic.................................... 30.2 inches
- Permanent .... 20.5 inches
- Working Width........................... 103.8 inches
- Height of Working Width .... 122.6 inches

Vehicle Damage
- VDS .... N/A
- CDC.. N/A
- Max. Exterior Deformation......... 9.5 inches
- OCDI... N/A
- Max. Occupant Compartment Deformation........................... 3.0 inches

Note: THIV = Theoretical Head Impact Velocity; ASI = Acceleration Severity Index; N/A = Not Applicable.

Figure 6.9. Summary of Results for *MASH* Test 4-12 on *MASH* TL-4 Guardrail System.

Chapter 7. *MASH* TEST 4-10 (CRASH TEST NO. 440190-01-3)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-10 involves an 1100C vehicle weighing 2420 lb ± 55 lb impacting the CIP of the longitudinal barrier at an impact speed of 62 mi/h ± 2.5 mi/h and an angle of 25 degrees ± 1.5 degrees. The CIP for *MASH* Test 4-10 on the *MASH* TL-4 guardrail system was 1 ft ± 1 ft upstream of the centerline of post 13. Figure 4.1 and Figure 7.1 depict the target impact setup.

Figure 7.1. Guardrail System/Test Vehicle Geometrics for Test No. 440190-01-3.

The 1100C vehicle weighed 2428 lb, and the actual impact speed and angle were 64.4 mi/h and 25.3 degrees. The actual impact point was 1.1 ft upstream of the centerline of post 13. Minimum target IS was 51 kip-ft, and actual IS was 62 kip-ft.

7.2. WEATHER CONDITIONS

The test was performed on the morning of October 15, 2020. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 230 degrees (vehicle was traveling at a heading of 280 degrees); temperature: 78°F; relative humidity: 89 percent.

7.3. TEST VEHICLE

Figure 7.2 shows the 2015 Nissan Versa used for the crash test. The vehicle's test inertia weight was 2428 lb, and its gross static weight was 2593 lb. The height to the lower edge of the vehicle bumper was 7.0 inches, and the height to the upper edge of the bumper was 22.25 inches. Table E.1 in Appendix E.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.2. Test Vehicle before Test No. 440190-01-3.

7.4. TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 440190-01-3. Figures E.1 and E.2 in Appendix E.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 440190-01-3.

Time (s)	Events
0.000	Vehicle impacts the rail
0.036	Vehicle begins to redirect
0.075	Left front tire contacts post 14
0.201	Vehicle starts traveling parallel to the rail
0.205	Rear of the vehicle contacts the top rail
0.358	Vehicle loses contact with the rail while traveling at 43.3 mi/h, an exit trajectory angle of 12.7°, and an exit heading angle of 15.9°

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 3.25 s after impact. After loss of contact with the barrier, the vehicle came to rest 178 ft downstream of the point of impact and 99 ft toward traffic lanes.

7.5. DAMAGE TO TEST INSTALLATION

Figure 7.3 shows the damage to the *MASH* TL-4 guardrail system. The soil was disturbed from posts 3 through 11 and from posts 17 through 19. Post 12 had a ⅛-inch gap in the soil on the traffic side. Post 13 had a 2-inch gap on the traffic side, a ½-inch gap on the field side, and was leaning 6 degrees back from vertical. Post 14 had a 5½-inch gap on the traffic side and a ¾-inch gap on the field side. Post 14 was leaning back 14 degrees from vertical, and the W-beam rail released from its blockout. Post 15 had a 1-inch gap on the traffic side and was leaning 2 degrees back from vertical. The bottom rail was deformed from impact until post 15, and the top rail was detached from posts 13 through 15. There was also scuffing present on both rails along the length of contact. Working width[*] was 36.5 inches, and height of working width was 38.1 inches. Maximum dynamic deflection during the test was 15.1 inches, and maximum permanent deformation was 11.6 inches.

Figure 7.3. Guardrail after Test No. 440190-01-3.

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[*] 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.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.4 shows the damage sustained by the vehicle. The front bumper, hood, left front fender, radiator and support, left front strut and tower, left control arm, left tire and rim, sway bar, left tie rod end, left front and rear doors, left front floor pan, left rear quarter panel, and rear bumper were damaged. The windshield sustained stress cracks radiating upward and inward from the left A-post. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 12.0 inches in the front plane at the left front corner at bumper height. Maximum occupant compartment deformation was 4.0 inches in the left front kick panel area. Figure 7.5 shows the interior of the vehicle. Tables E.2 and E.3 in Appendix E.1 provide exterior crush and occupant compartment measurements.

Figure 7.4. Test Vehicle after Test No. 440190-01-3.

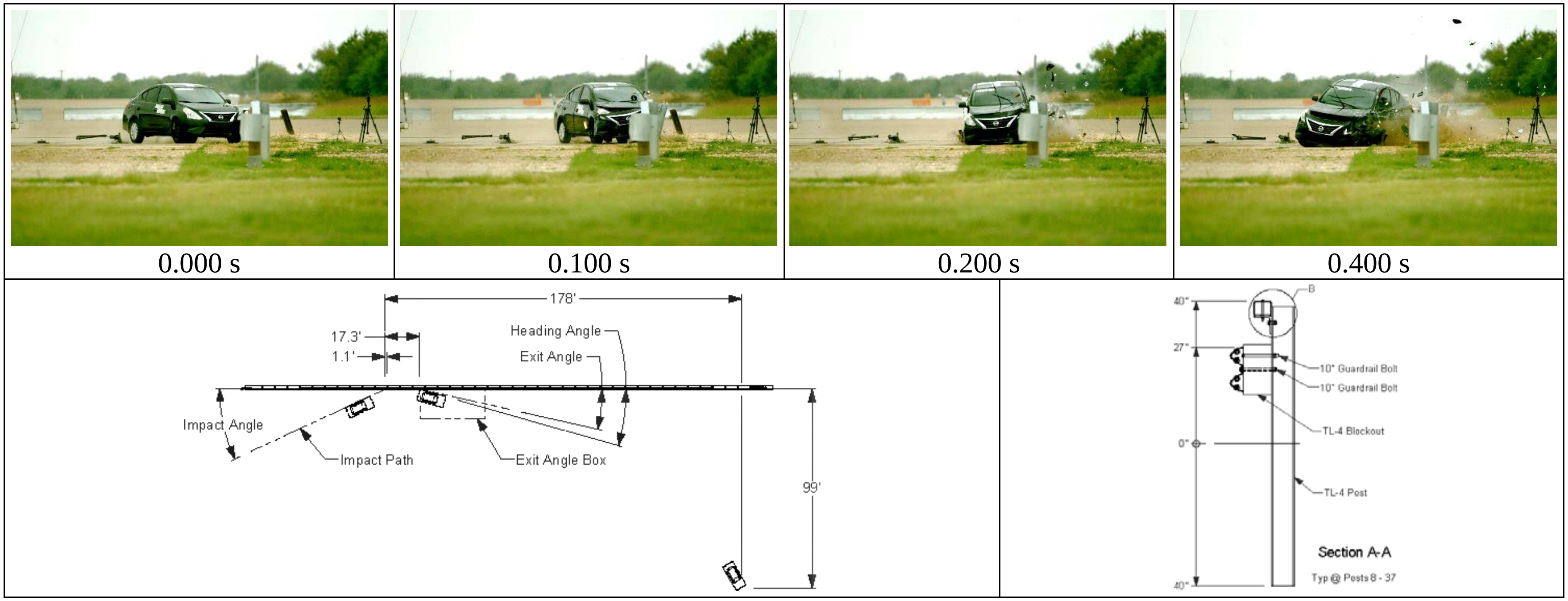
Figure 7.5. Interior of Test Vehicle after Test No. 440190-01-3.

7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.2. Figure E.3 in Appendix E.3 shows the vehicle angular displacements, and Figures E.4 through E.6 in Appendix E.4 show acceleration versus time traces. Figure 7.6 summarizes pertinent information from the test.

Table 7.2. Occupant Risk Factors for Test No. 440190-01-3.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	19.4 ft/s	at 0.0995 s on left side of interior
Lateral	25.3 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	13.6 g	0.0995–0.1095 s
Lateral	11.0 g	0.1280–0.1380 s
THIV	9.6 m/s	at 0.0971 s on left side of interior
ASI	1.4	0.0789–0.1289 s
Maximum 50-ms Moving Average		
Longitudinal	−10.2 g	0.0637–0.1137 s
Lateral	11.3 g	0.0363–0.0863 s
Vertical	3.0 g	0.0830–0.1330 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	15°	2.5000 s
Pitch	7°	1.2202 s
Yaw	61°	1.2206 s



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 4-10
TTI Test No.	440190-01-3
Test Date	2020-10-15
Test Article	
Type	Longitudinal Barrier—Guardrail
Name	*MASH* TL-4 Guardrail System
Installation Length	260 ft 1½ inches
Material or Key Elements	Guardrail system with W-beam and HSS tube rail elements mounted on steel posts
Soil Type and Condition	AASHTO M147-65, Grade B Soil (crushed limestone)
Test Vehicle	
Type/Designation	1100C
Make and Model	2015 Nissan Versa
Curb	2420 lb
Test Inertial	2428 lb
Dummy	165 lb
Gross Static	2593 lb

Impact Conditions	
Speed	64.4 mi/h
Angle	25.3°
Location/Orientation	1.1 ft upstream of post 13
Impact Severity	62 kip-ft
Exit Conditions	
Speed	43.3 mi/h
Trajectory/Heading Angle	12.7°/15.9°
Occupant Risk Values	
Longitudinal OIV	19.4 ft/s
Lateral OIV	25.3 ft/s
Longitudinal Ridedown	13.6 g
Lateral Ridedown	11.0 g
THIV	9.6 m/s
ASI	1.4
Max. 0.050-s Average	
Longitudinal	−10.2 g
Lateral	11.3 g
Vertical	3.0 g

Post-Impact Trajectory	
Stopping Distance	178 ft downstream 99 ft toward traffic
Vehicle Stability	
Maximum Roll Angle	15°
Maximum Pitch Angle	7°
Maximum Yaw Angle	61°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	15.1 inches
Permanent	11.6 inches
Working Width	36.5 inches
Height of Working Width	38.1 inches
Vehicle Damage	
VDS	11LFQ5
CDC	11FLEW4
Max. Exterior Deformation	12.0 inches
OCDI	FL0000100
Max. Occupant Compartment Deformation	4.0 inches

Figure 7.6. Summary of Results for *MASH* Test 4-10 on *MASH* TL-4 Guardrail System.

Chapter 8. *MASH* TEST 4-11 (CRASH TEST NO. 440190-01-2)

8.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-11 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the CIP of the longitudinal barrier at an impact speed of 62 mi/h ± 2.5 mi/h and an angle of 25 degrees ± 1.5 degrees. The CIP for *MASH* Test 4-11 on the *MASH* TL-4 guardrail system was 3 ft ± 1 ft upstream of the centerline of post 25. Figure 4.1 and Figure 8.1 depict the target impact setup.

Figure 8.1. Guardrail System/Test Vehicle Geometrics for Test No. 440190-01-2.

The 2270P vehicle weighed 5073 lb, and the actual impact speed and angle were 64.4 mi/h and 25.0 degrees. The actual impact point was 3.5 ft upstream of the centerline of post 25. Minimum target IS was 106 kip-ft, and actual IS was 126 kip-ft.

8.2. WEATHER CONDITIONS

The test was performed on the morning of October 20, 2020. Weather conditions at the time of testing were as follows: wind speed: 7 mi/h; wind direction: 134 degrees (vehicle was traveling at a heading of 280 degrees); temperature: 80°F; relative humidity: 78 percent.

8.3. TEST VEHICLE

Figure 8.2 shows the 2016 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5073 lb, and its gross static weight was 5238 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.0 inches. Tables F.1 and F.2 in Appendix F.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 8.2. Test Vehicle before Test No. 440190-01-2.

8.4. TEST DESCRIPTION

Table 8.1 lists events that occurred during Test No. 440190-01-2. Figures F.1 and F.2 in Appendix F.2 present sequential photographs during the test.

Table 8.1. Events during Test No. 440190-01-2.

Time (s)	Events
0.000	Vehicle impacts the rail
0.050	Vehicle begins to redirect
0.100	Left front tire contacts the rail
0.182	Right front tire loses contact with the pavement
0.199	Rear bumper contacts the bottom rail
0.205	Vehicle starts traveling parallel to rail
0.206	Rear of vehicle contacts the top rail
0.397	Right rear tire loses contact with the pavement
0.430	Vehicle loses contact with the rail while traveling at 44.0 mi/h, an exit trajectory angle of 15.9°, and an exit heading angle of 9.8°
0.494	Right front tire touches the pavement

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. The vehicle subsequently came to rest 369 ft downstream of the point of impact and 20 ft toward the field side.

8.5. DAMAGE TO TEST INSTALLATION

Figure 8.3 and Figure 8.4 show the damage to the guardrail, and Table 8.2 provides post movement. The top rail released from posts 24–26, and the bottom rail released from post 26. There was also scuffing and deformation of the bottom rail between posts 24 and 26. The blockout at post 25 was rotated counterclockwise. The maximum deformation of the top rail was

2 inches at the joint between posts 24 and 25, and the maximum deformation of the bottom rail was 13 inches at 14 inches upstream of post 25. Working width[*] was 40.9 inches, and height of working width was 30.1 inches. Maximum dynamic deflection during the test was 20.2 inches, and maximum permanent deformation was 13.0 inches.

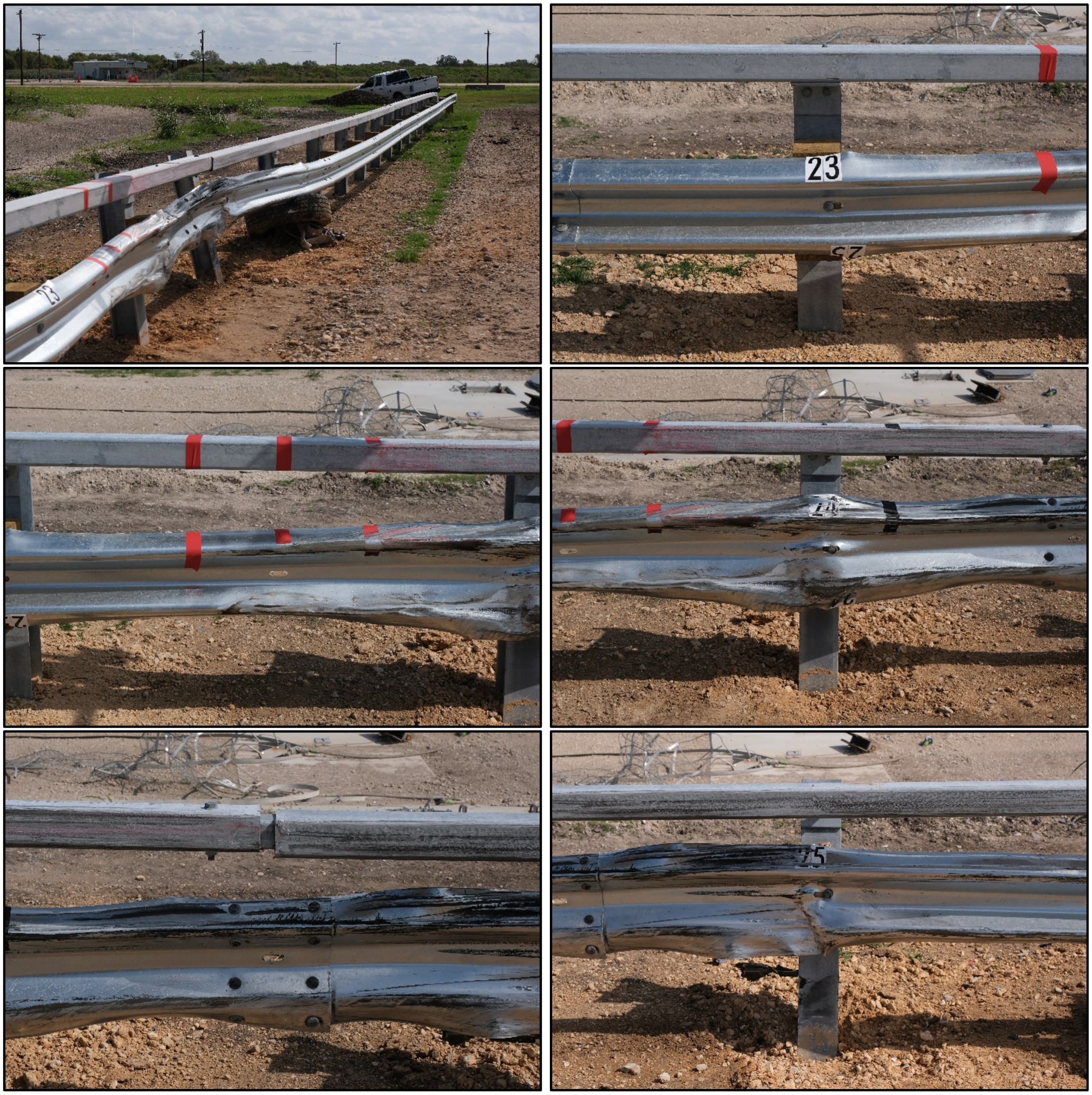


Figure 8.3. Guardrail after Test No. 440190-01-2.

[*] 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 8.4. Field Side of Guardrail after Test No. 440190-01-2.

Table 8.2. Post Movement during Test No. 440190-01-2.

Post Number	Soil Gap (Traffic Side)	Soil Gap (Field Side)	Angle (Toward Field Side from Vertical)
1–22	—	—	—
23	½ inch	1 inch	2°
24	—	2½ inches	7°
25	—	2 inches	15°
26	2 inches	—	7°
27	⅛ inch	⅛ inch	1°
28–42	—	—	—

8.6. DAMAGE TO TEST VEHICLE

Figure 8.5 shows the damage sustained by the vehicle. The front bumper, hood, grill, radiator and support, left front fender, left front tire and rim, left upper and lower control arms, sway bar, left tie rod end, left front and rear door, left rear exterior bed, left rear tire and rim, and rear bumper were damaged. The windshield sustained stress cracks radiating upward and inward from the left lower corner. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 11.0 inches in the front plane at the left front corner at bumper height. Maximum occupant compartment deformation was 0.5 inches in the left front firewall area and the left front kick panel. Figure 8.6 shows the interior of the vehicle. Tables F.3 and F.4 in Appendix F.1 provide exterior crush and occupant compartment measurements.

Figure 8.5. Test Vehicle after Test No. 440190-01-2.

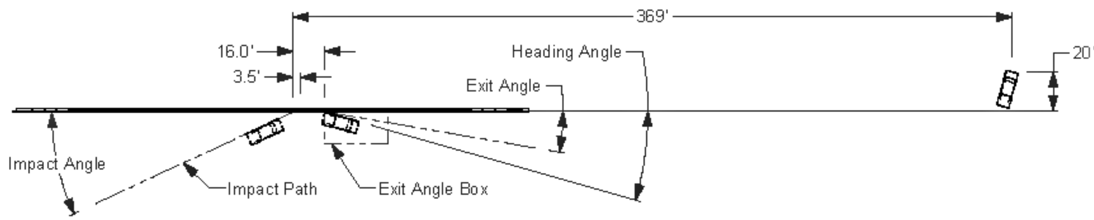
Figure 8.6. Interior of Test Vehicle after Test No. 440190-01-2.

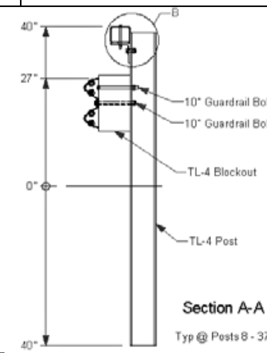
8.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 8.3. Figure F.3 in Appendix F.3 shows the vehicle angular displacements, and Figures F.4 through F.6 in Appendix F.4 show acceleration versus time traces. Figure 8.7 summarizes pertinent information from the test.

Table 8.3. Occupant Risk Factors for Test No. 440190-01-2.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	18.0 ft/s	at 0.1257 s on left side of interior
Lateral	20.3 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	8.8 g	0.1258–0.1358 s
Lateral	8.1 g	0.1475–0.1575 s
THIV	8.0 m/s	at 0.1211 s on left side of interior
ASI	1.0	0.0676–0.1176 s
Maximum 50-ms Moving Average		
Longitudinal	−6.5 g	0.0929–0.1429 s
Lateral	7.9 g	0.0424–0.0924 s
Vertical	−2.8 g	0.5936–0.6436 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	18°	5.0000 s
Pitch	11°	4.9986 s
Yaw	37°	0.3451 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 4-11
TTI Test No.	440190-01-2
Test Date	2020-10-20
Test Article	
Type	Longitudinal Barrier—Guardrail
Name	*MASH* TL-4 Guardrail System
Installation Length	260 ft 1½ inches
Material or Key Elements	Guardrail system with W-beam and HSS tube rail elements mounted on steel posts
Soil Type and Condition	AASHTO M147-65, Grade B Soil (crushed limestone)
Test Vehicle	
Type/Designation	2270P
Make and Model	2016 RAM 1500 Pickup
Curb	5042 lb
Test Inertial	5073 lb
Dummy	165 lb
Gross Static	5238 lb

Impact Conditions	
Speed	64.4 mi/h
Angle	25.0°
Location/Orientation	3.5 ft upstream of post 25
Impact Severity	126 kip-ft
Exit Conditions	
Speed	44.0 mi/h
Trajectory/Heading Angle	15.9°/9.8°
Occupant Risk Values	
Longitudinal OIV	18.0 ft/s
Lateral OIV	20.3 ft/s
Longitudinal Ridedown	8.8 g
Lateral Ridedown	8.1 g
THIV	8.0 m/s
ASI	1.0
Max. 0.050-s Average	
Longitudinal	−6.5 g
Lateral	7.9 g
Vertical	−2.8 g

Post-Impact Trajectory	
Stopping Distance	369 ft downstream 20 ft twd field side
Vehicle Stability	
Maximum Roll Angle	18°
Maximum Pitch Angle	11°
Maximum Yaw Angle	37°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	20.2 inches
Permanent	13.0 inches
Working Width	40.9 inches
Height of Working Width	30.1 inches
Vehicle Damage	
VDS	11LFQ5
CDC	11FLEW4
Max. Exterior Deformation	11.0 inches
OCDI	FL0010000
Max. Occupant Compartment Deformation	0.5 inches

Figure 8.7. Summary of Results for *MASH* Test 4-11 on *MASH* TL-4 Guardrail System.

Chapter 9. SUMMARY AND CONCLUSIONS

9.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-4, which involves three tests on the *MASH* TL-4 guardrail system. Table 9.1 through Table 9.3 provide an assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-4 longitudinal barriers.

9.2. CONCLUSIONS

Table 9.4 shows that the *MASH* TL-4 guardrail system met the performance criteria for *MASH* TL-4 longitudinal barriers.

Table 9.1. Performance Evaluation Summary for *MASH* Test 4-12 on *MASH* TL-4 Guardrail System.

Test Agency: Texas A&M Transportation Institute | Test No.: 440190-01-1 | Test Date: 2020-09-30

***MASH* Test 4-12 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u>		
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The *MASH* TL-4 guardrail system contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 30.2 inches.	Pass
<u>Occupant Risk</u>		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	No detached elements, fragments, or other debris from the installation were present to penetrate or show potential for penetrating the occupant compartment, or present undue 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 3.0 inches in the left front corner of the floor pan.	
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The 10000S vehicle rolled 130° and came to rest on the left side.	For information only

Table 9.2. Performance Evaluation Summary for *MASH* Test 4-10 on *MASH* TL-4 Guardrail System.

Test Agency: Texas A&M Transportation Institute | Test No.: 440190-01-3 | Test Date: 2020-10-15

MASH Test 4-10 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 *MASH* TL-4 guardrail system contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 15.1 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 from the installation were present to penetrate or show potential for penetrating the occupant compartment, or present undue 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 4.0 inches in the left front kick panel area.	
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 15° and 7°.	Pass
H. *Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*	Longitudinal OIV was 19.4 ft/s, and lateral OIV was 25.3 ft/s.	Pass
I. *The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	Longitudinal occupant ridedown acceleration was 13.6 g, and lateral occupant ridedown acceleration was 11.0 g.	Pass

Table 9.3. Performance Evaluation Summary for *MASH* Test 4-11 on *MASH* TL-4 Guardrail System.

Test Agency: Texas A&M Transportation Institute | Test No.: 440190-01-2 | Test Date: 2020-10-20

MASH Test 4-11 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 *MASH* TL-4 guardrail system contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 20.2 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 from the installation were present to penetrate or show potential for penetrating the occupant compartment, or present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 0.5 inches in the left front firewall area and the left front kick panel.	
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 18° and 11°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 18.0 ft/s, and lateral OIV was 20.3 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Longitudinal occupant ridedown acceleration was 8.8 g, and lateral occupant ridedown acceleration was 8.1 g.	Pass

Table 9.4. Assessment Summary for *MASH* TL-4 Tests on *MASH* TL-4 Guardrail System.

Evaluation Factors	Evaluation Criteria	Test No. 440190-01-3	Test No. 440190-01-2	Test No. 440190-01-1
Structural Adequacy	A	S	S	S
Occupant Risk	D	S	S	S
	F	S	S	N/A
	G	N/A	N/A	S
	H	S	S	N/A
	I	S	S	N/A
	Test No.	***MASH* Test 4-10**	***MASH* Test 4-11**	***MASH* Test 4-12**
	Pass/Fail	Pass	Pass	Pass

Note: S = Satisfactory; N/A = Not Applicable.

Chapter 10. IMPLEMENTATION*

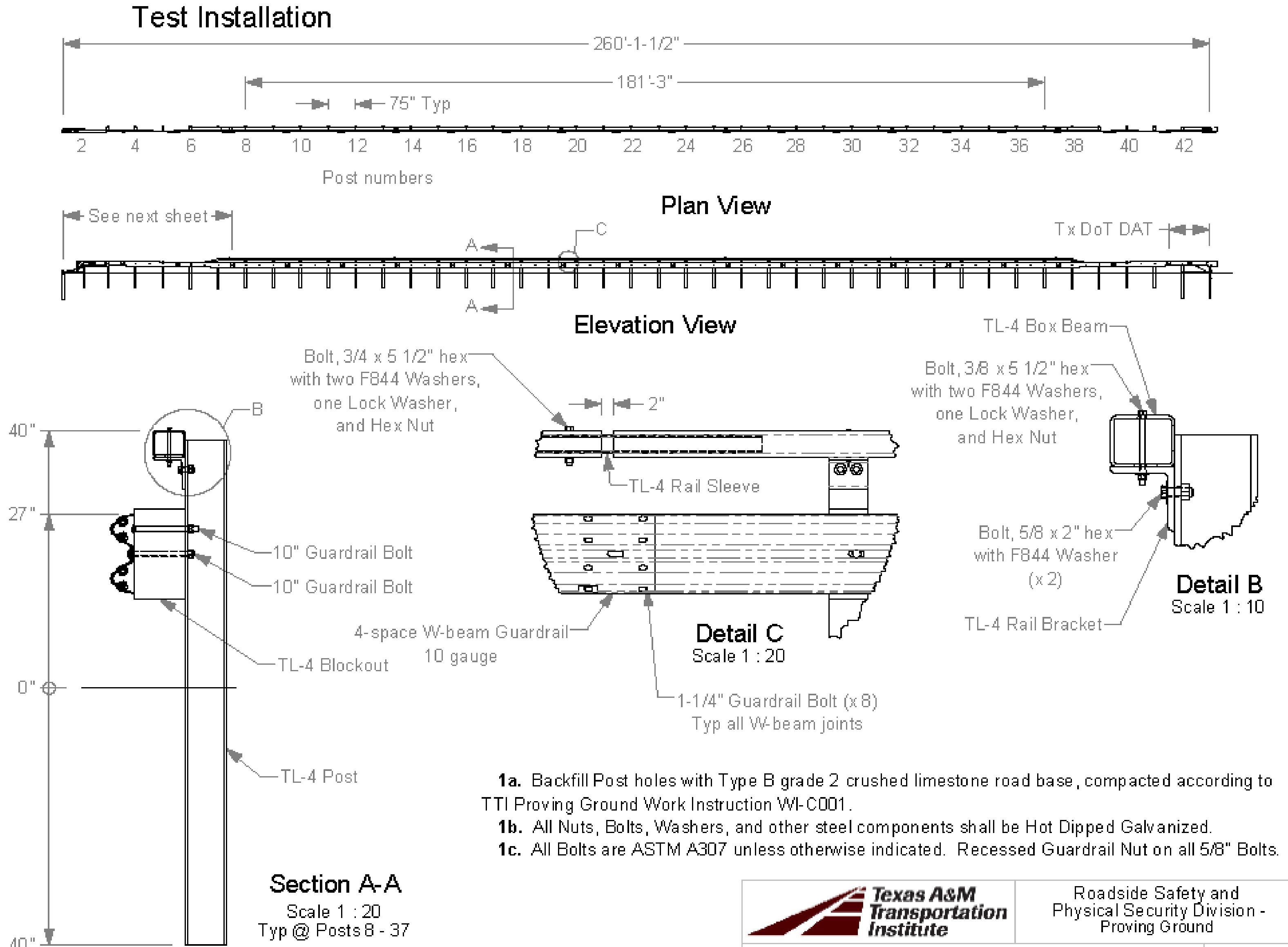
The *MASH* TL-4 guardrail design developed in this project passed *MASH* testing requirements for longitudinal barriers and is ready for implementation in the field. This implementation can be achieved by developing a design standard for the guardrail system. The Value of Research (VOR) for this project is presented in Appendix G.

The scope of the current project did not include design and testing of an end transition for the guardrail system. The research team, however, did present a transition design that allows transitioning from the TL-4 guardrail to standard *MASH* TL-3 guardrail end terminals. While the researchers believe that this transition design has a good probability of meeting the transition testing criteria of *MASH*, they recommend that in future research, the transition design be evaluated through impact simulation analysis and full-scale crash testing.

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

REFERENCES

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



1a. Backfill Post holes with Type B grade 2 crushed limestone road base, compacted according to TTI Proving Ground Work Instruction WI-C001.

1b. All Nuts, Bolts, Washers, and other steel components shall be Hot Dipped Galvanized.

1c. All Bolts are ASTM A307 unless otherwise indicated. Recessed Guardrail Nut on all 5/8" Bolts.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #440190 TL-4 Traffic Rail		2020-10-15
Drawn by GESWS	Scale 1:350	Sheet 1 of 5 Test Installation

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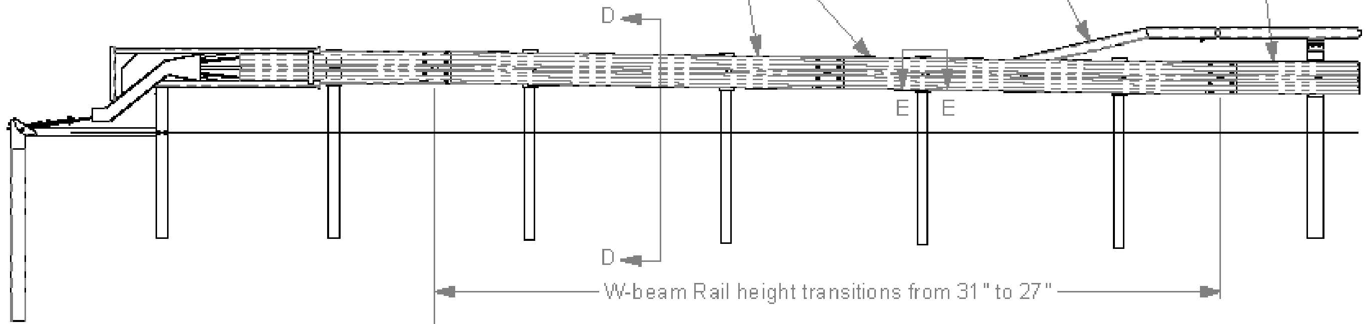
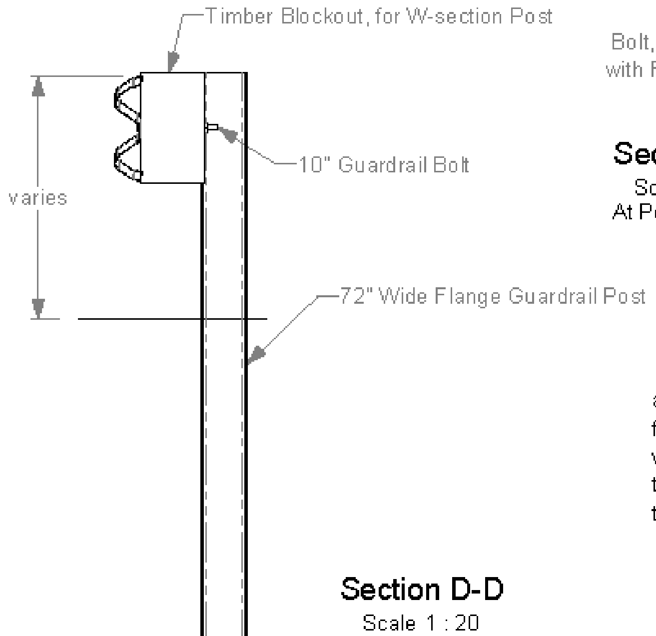
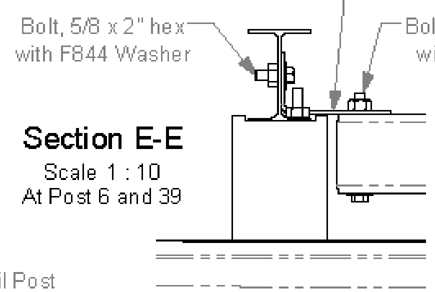
Terminal Details

Details @ Posts 4 - 8 typical both ends.

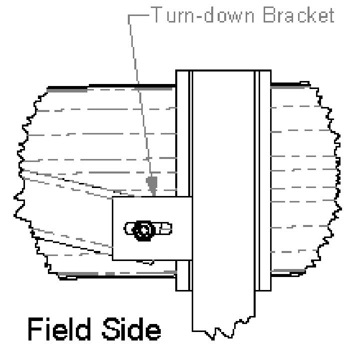




Section D-D
Scale 1 : 20
Typ @ Posts 4 - 7 and 38 - 41



Section E-E
Scale 1 : 10
At Post 6 and 39



Field Side
at Post 6

2a. SoftStop® length was abbreviated for LON testing of TxDOT TL4 Traffic Rail application, as it is not being impacted during testing and is providing system anchorage only. In actual field installations the full terminal length, per manufacturer's specification and in accordance with FHWA Eligibility Letter(s) and state specifications is required. In actual field installations, the appropriate full length SoftStop® would be utilized upstream of the 25' long height transition shown in these drawings - which is located at the splice between posts 3 and 4.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #440190 TL-4 Traffic Rail		2020-10-15
Drawn by GESWS	Scale 1:60	Sheet 2 of 5 Terminal Details

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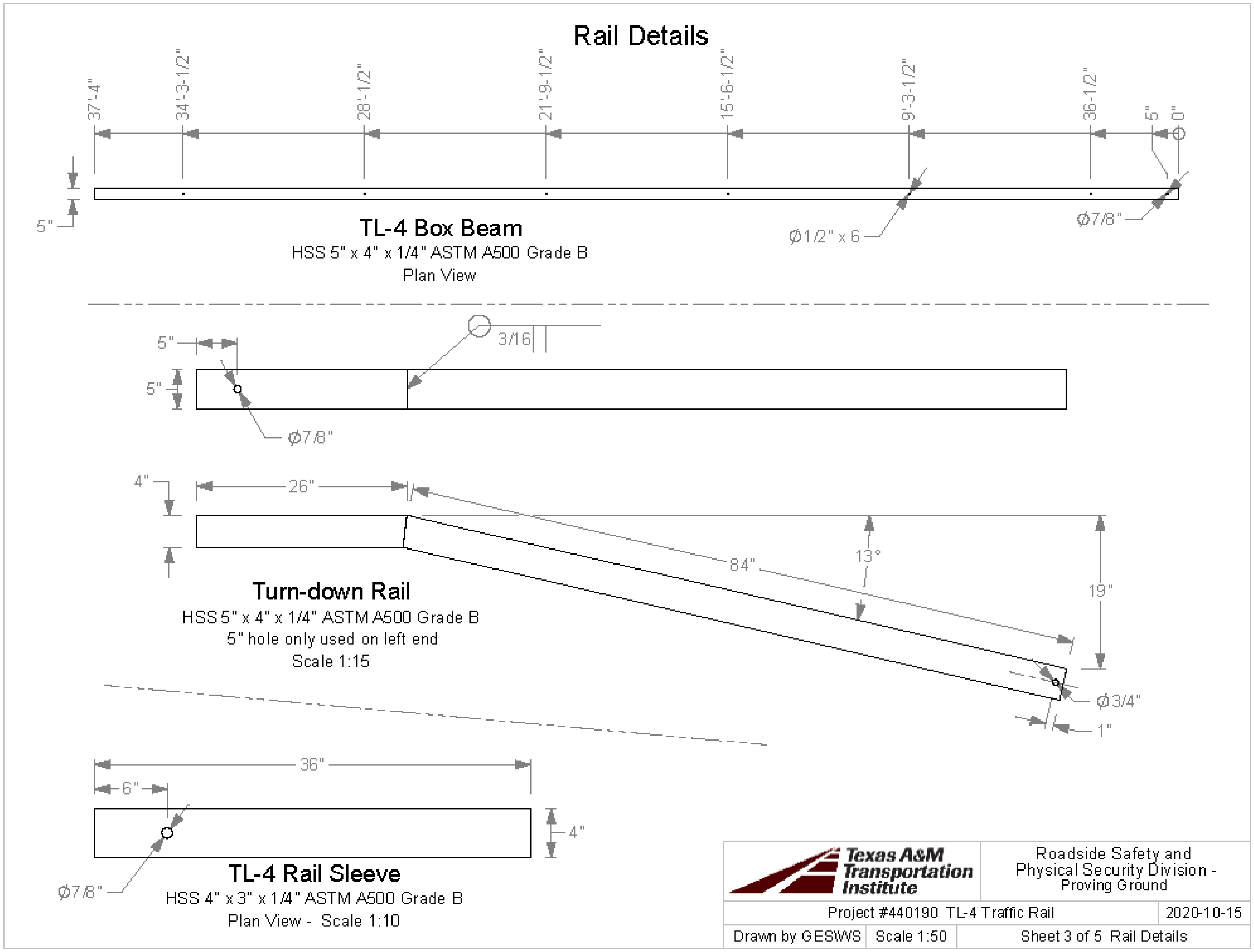

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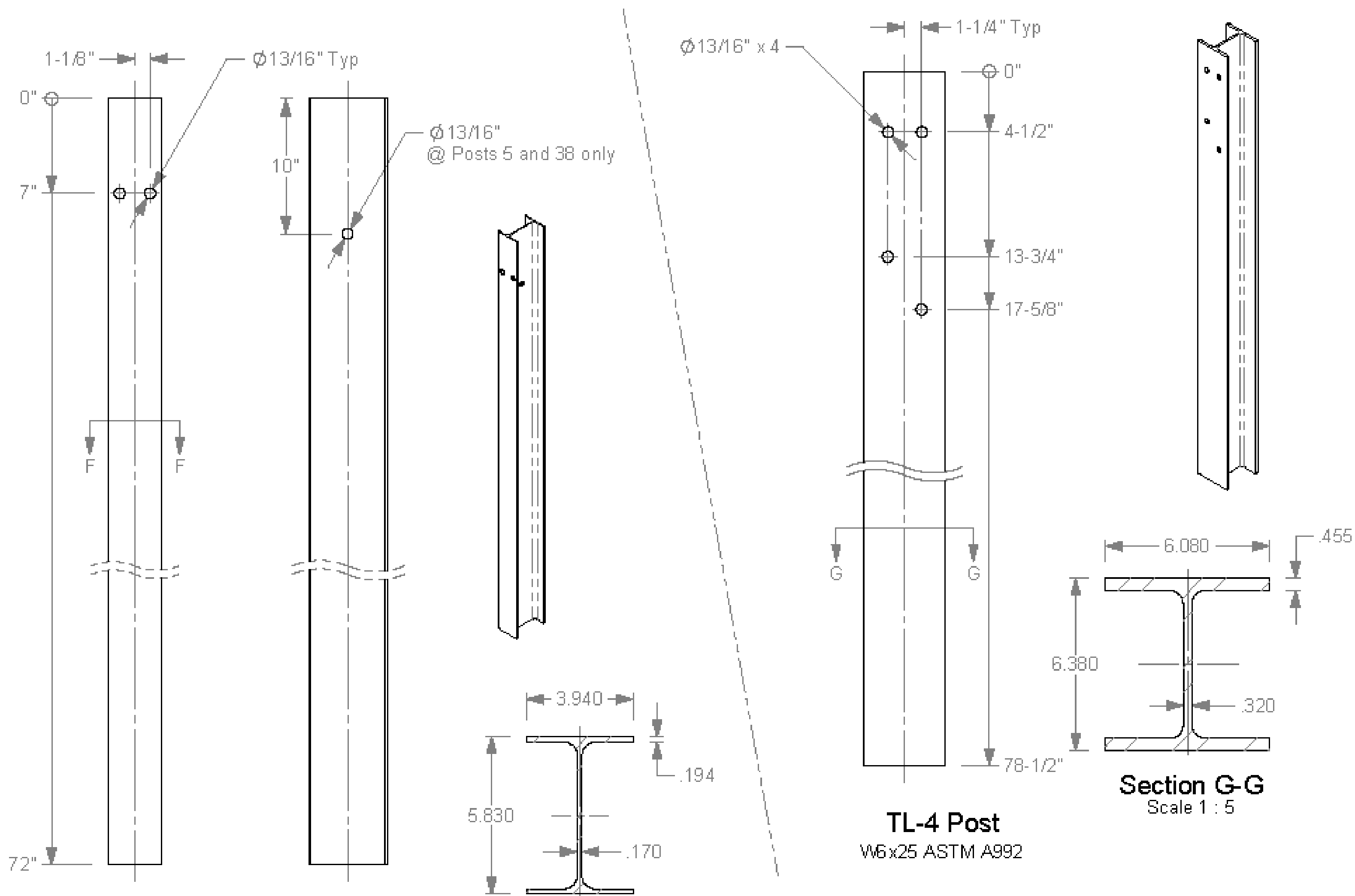


72" Wide Flange Guardrail Post
W6x8.5 ASTM A992

Section F-F
Scale 1 : 5

TL-4 Post
W6x25 ASTM A992

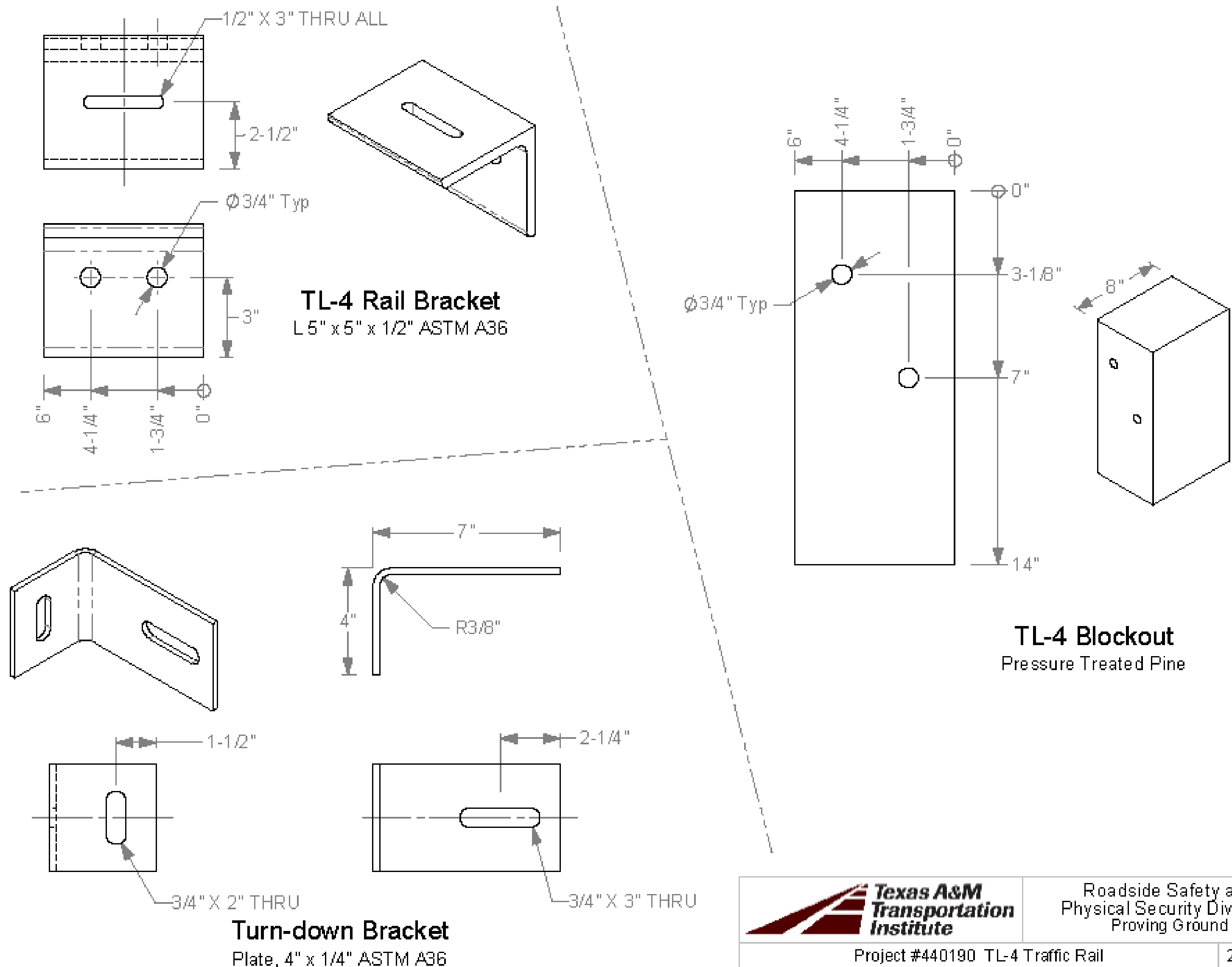
Section G-G
Scale 1 : 5

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

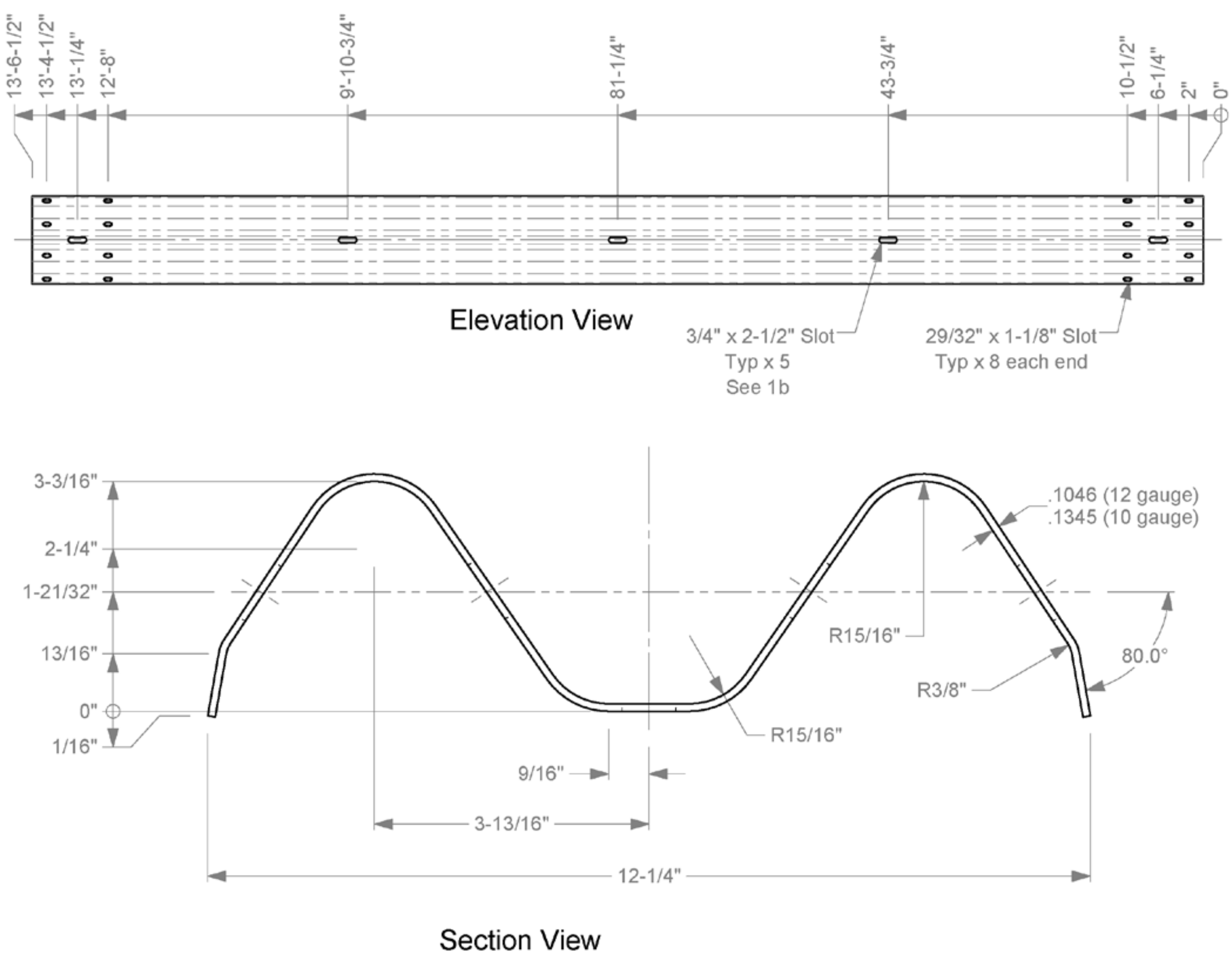
Project #440190 TL-4 Traffic Rail		2020-10-15
Drawn by GESWS	Scale 1:10	Sheet 4 of 5 Posts

Q:\Accreditation-17025-2017\EIR-000 Project Files\440190 - TL-4 Guardrail - Sheikh\Drafting, 440190\440190 Drawing



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #440190 TL-4 Traffic Rail		2020-10-15
Drawn by GESWS	Scale 1:5	Sheet 5 of 5 Assorted Parts

Q:\Accreditation-17025-2017\EIR-000 Project Files\440190 - TL-4 Guardrail - Sheikh\Drafting, 440190\440190 Drawing



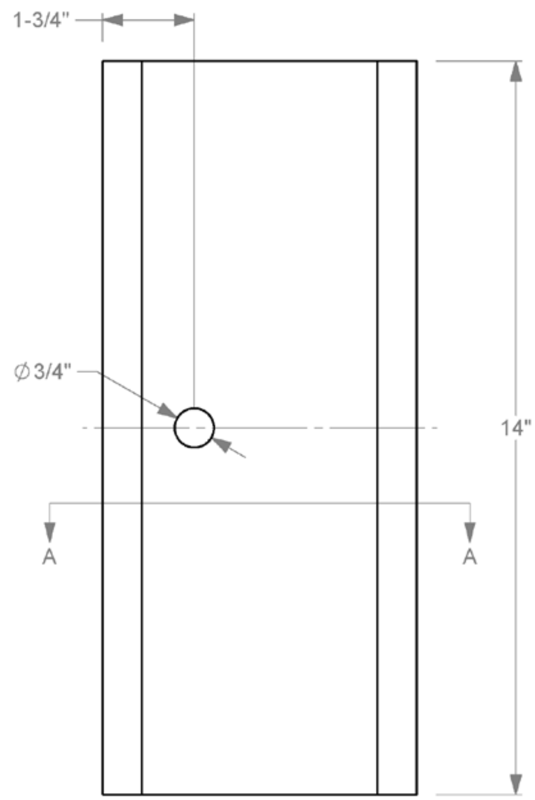
1a. Manufacture per AASHTO M180 specifications.

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

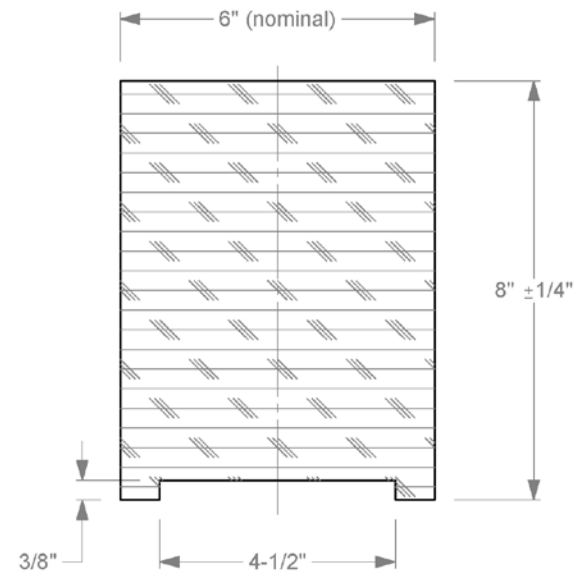
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
4-space W-beam Guardrail		2020-06-05
Drawn by GES	Scale 1:20	Sheet 1 of 1

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

Timber Blockout for W-section Post



Elevation View



Section A-A

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

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

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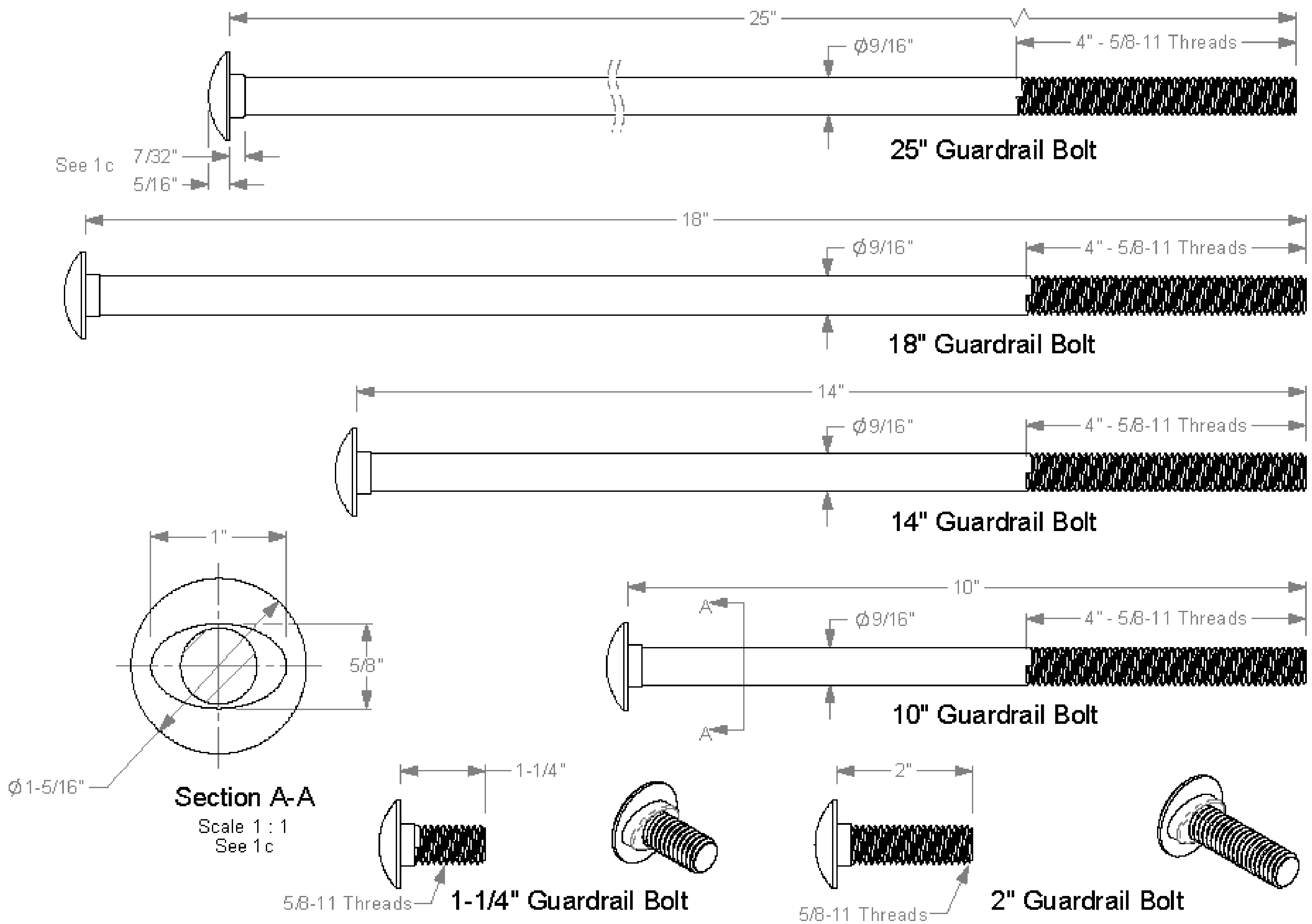
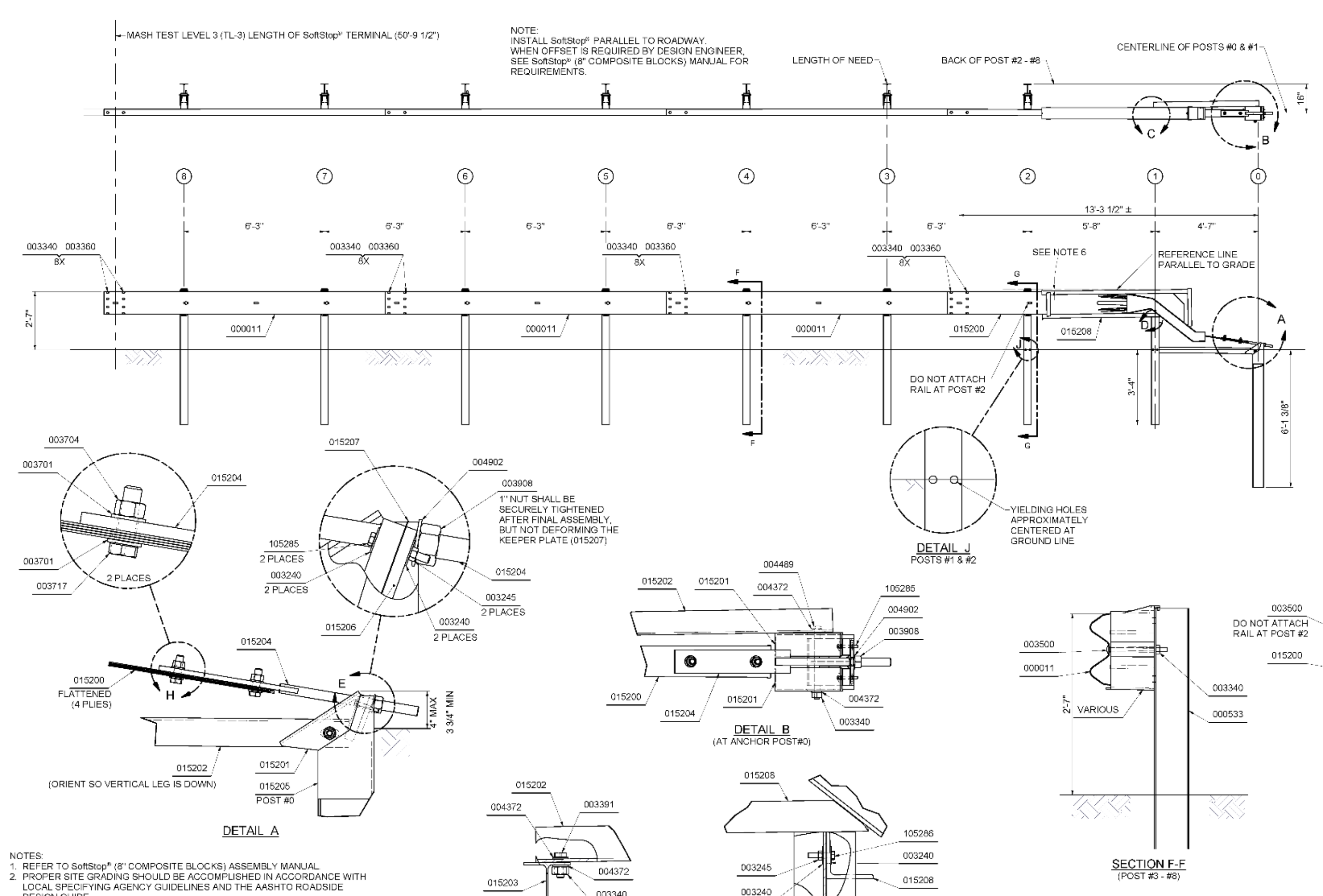


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.

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



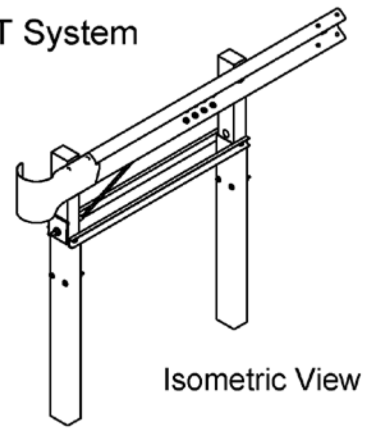
PARTS LIST		
PART NO.	QTY.	DESCRIPTION
000011	3	12/12'6/3'1.5/S
000533	6	6'-0" POST / W6 x 8.5#
VARIOUS	7	8" COMPOSITE BLOCK
015000	1	6'0 SYT PST/8.5/31" GR HT
015200	1	SFST-ANCHOR G.RAIL 12'-6"
015202	1	SFST-ANGLE STRUT
015203	1	SFST-POST#1 SYTP
015204	1	SFST-ANCHOR PADDLE
015205	1	SFST-POST#0
015208	1	SFST-IMPACT HEAD
		HARDWARE KIT 034429
003240	6	5/16 ROUND WASHER WIDE
003245	3	5/16 HEX NUT
003340	41	NUT,HX,5/8,G,RAIL
003360	32	5/8"X1.25" GR BOLT
003391	1	5/8"X1.75" HEX BOLT A325
003500	7	5/8"X10" GR BOLT A307
003701	4	3/4" ROUND WASHER F436
003704	2	3/4" HVY HEX NUT A563 DH
003717	2	3/4"X2.5" HEX BOLT A325
003908	1	1" HVY HEX NUT A563 DH
004372	4	5/8" WASHER F436
004489	1	5/8"X9" HEX BOLT A325
004902	1	1" ROUND WASHER F436
105285	2	5/16" X 2.5" HEX BOLT GRD 5
105286	1	5/16" X 1.5" HEX BOLT GRD 5
015201	2	SFST-ANCHOR ANGLE
015206	1	SFST-PLATE WASHER
015207	1	SFST-KEEPER PLATE

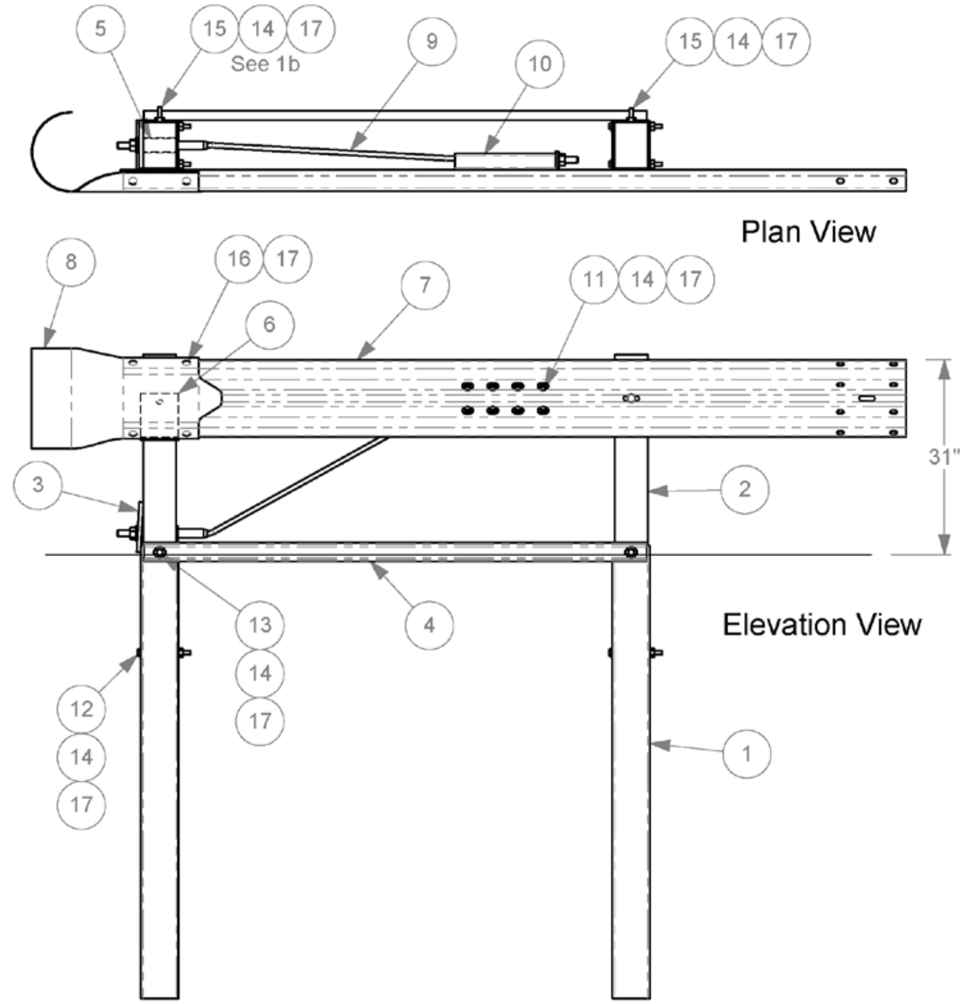
NOTES:
1. REFER TO SoftStop® (8" COMPOSITE BLOCKS) ASSEMBLY MANUAL.
2. PROPER SITE GRADING SHOULD BE ACCOMPLISHED IN ACCORDANCE WITH LOCAL SPECIFYING AGENCY GUIDELINES AND THE AASHTO ROADSIDE DESIGN GUIDE.
3. DO NOT ATTACH THE SoftStop® DIRECTLY TO A RIGID BARRIER.
4. UNDER NO CIRCUMSTANCES SHALL THE GUARDRAIL WITHIN THE SoftStop® BE CURVED.
5. MANUFACTURER SUGGESTS CUSTOMER TO PROVIDE REFLECTORIZATION OF THE TERMINAL.
6. IT IS ACCEPTABLE TO INSTALL THE SoftStop® IMPACT HEAD PARALLEL TO THE GRADE LINE OR WITH AN UPWARD TILT. SEE SoftStop® ASSEMBLY MANUAL FOR SPECIFIC DETAILS.

SEE PARTS LIST	BT	11/14/2012	TOLERANCES PER THP-SF-001, UNLESS OTHERWISE SPECIFIED.				SoftStop® TERMINAL (8" BLOCKS) PLAN, ELEVATION & SECTION MASH TEST LEVEL 3 (TL-3) P/N: 500646	TRINITY HIGHWAY
	BS	11/14/2012						
N/A			DO NOT SCALE DRAWING					
	Revision		ECO	Date	Rev	By	Chk	
	ADDED CALLOUTS FOR BOLTS & NUTS AT SPLICES		4644	3/21/17	7	DDS	KW	
	UPDATED 16" DIMENSION, REPLACED LENGTH OF NEED CALLOUT MISSING FROM REV 7		4689	7/27/17	H	DDS	KW	
EST UNFINISHED WT. 0.0 lbs	ADDED 8" COMPOSITE BLOCKS TO NOTES & MOVED 015201, 015206 & 015207 TO HWR KIT		6641	6/1/19	I	DDS	PLK	SS 646 · I · 1 of 1

THP-FF-052 Rev D 5/30/2018

DAT System





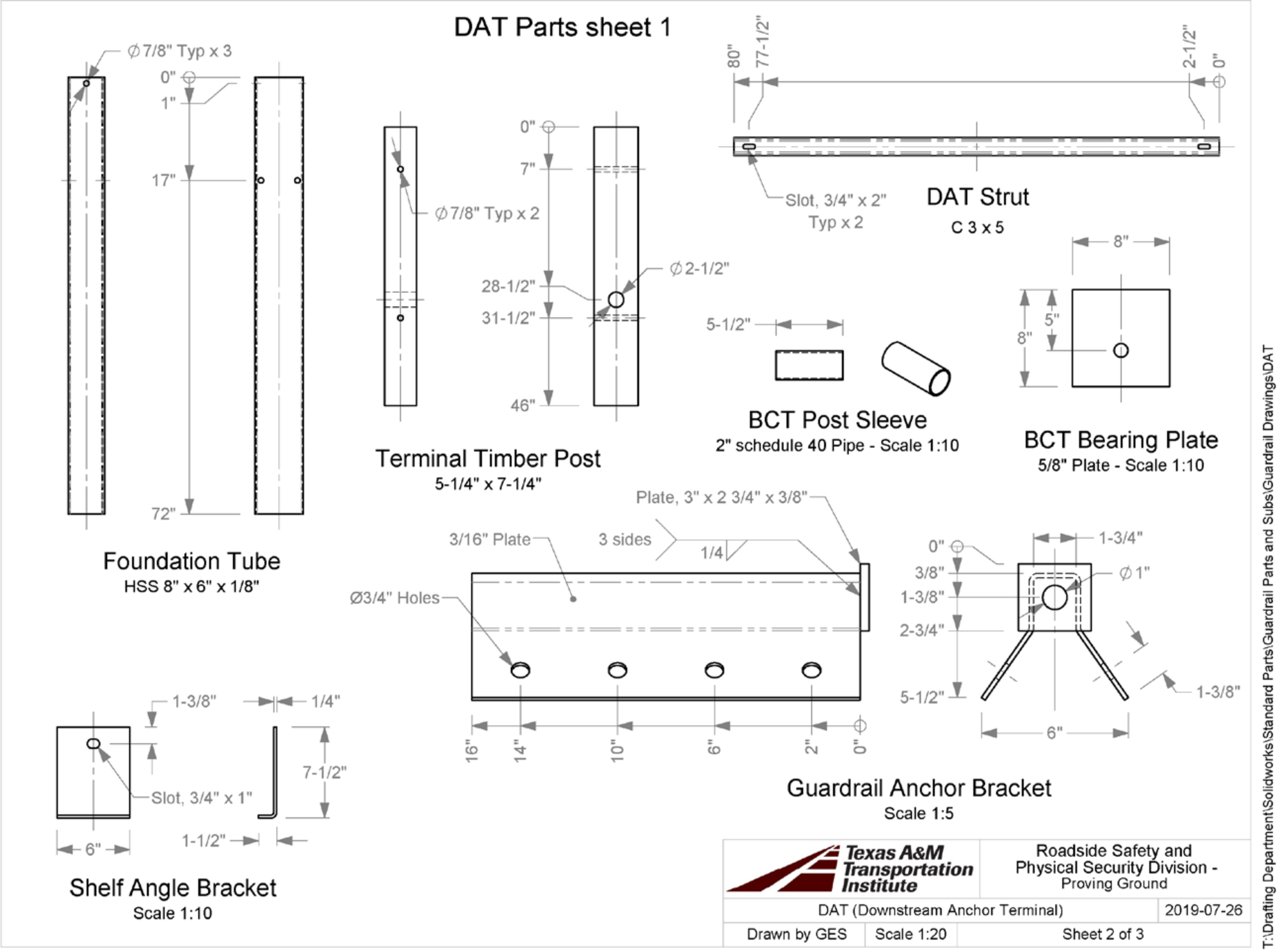
#	Part Name	Qty.
1	Foundation Tube	2
2	Terminal Timber Post	2
3	BCT Bearing Plate	1
4	DAT Strut	2
5	BCT Post Sleeve	1
6	Shelf Angle Bracket	1
7	DAT Terminal Rail	1
8	W-beam End Section	1
9	Anchor Cable Assembly	1
10	Guardrail Anchor Bracket	1
11	Bolt, 5/8 x 2" hex	8
12	Bolt, 5/8 x 8" hex	4
13	Bolt, 5/8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

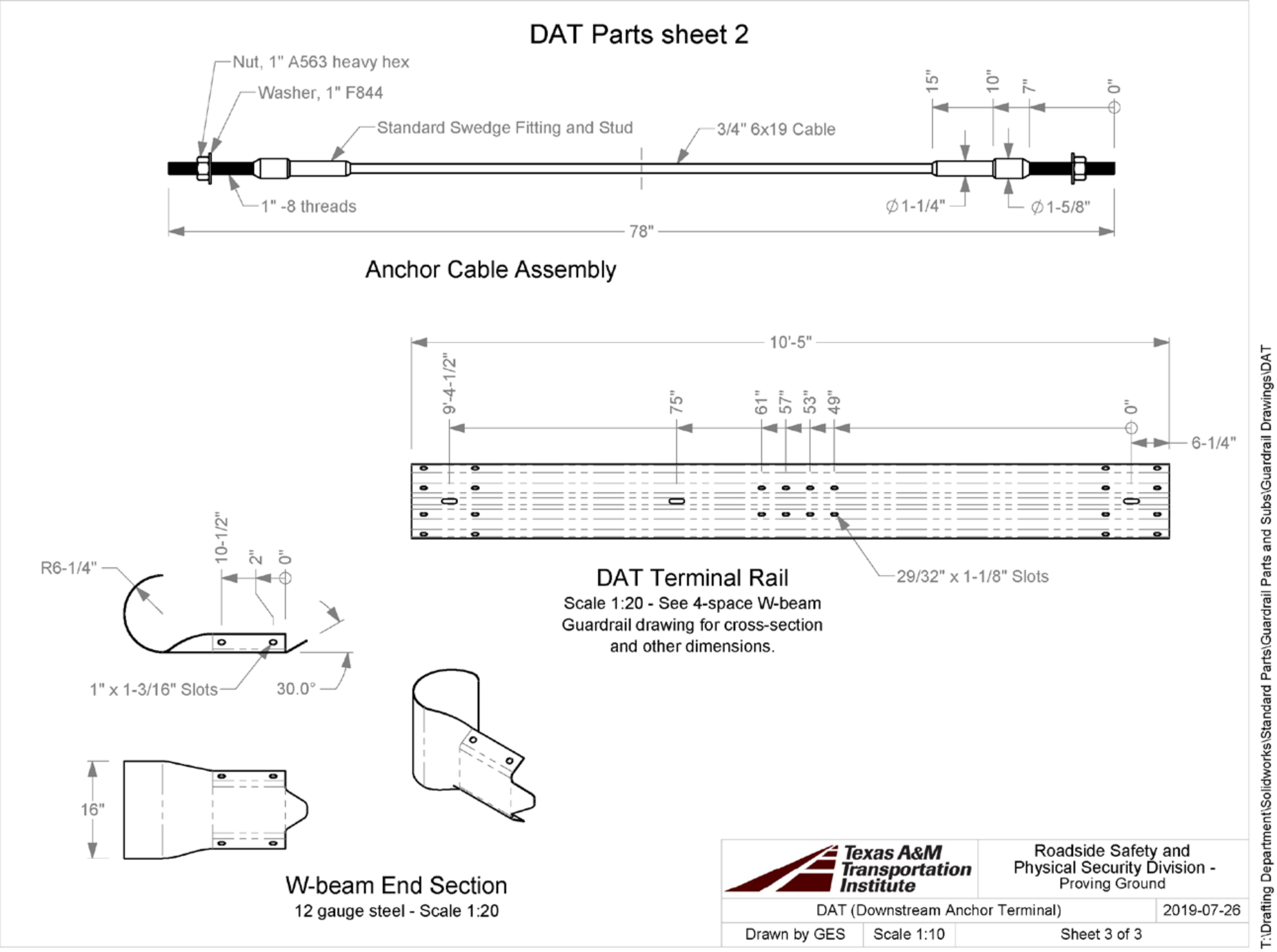
1a. All bolts are ASTM A307.

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

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

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


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


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

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

CERTIFIED MATERIAL TEST REPORT
FOR ASTM A307, GRADE A –MACHINE BOLTS

FACTORY: HANGZHOU WESTLAKE FASTENER FACTORY DATE: 2008.05.10
ADDRESS: KANG QIAO HANGZHOU CHINA
MFG LOT NUMBER:07XH1133-6

CUSTOMER: PFC PO NUMBER: PO# 17110807

SAMPE SIZE:ACC.TO ASME B18.18.2M-93

SIZE:5/8-11X6-1/2HDG QNTY:2.520MPCS PART NO:00024-3061-024

HEADMARKS:307A PLUS MFG. I. D. 307A+WL

STEEL PROPERTIES:
STEEL GRADE: Q235A HEAT NUMBER: 9908020013

	C%*100	M%*100	P%*1000	S%*1000
CHEMISTRY SPEC:	0.29max	1.20max	0.04max	0.15max
TEST:	0.18	0.45	0.015	0.036

DIMENSIONAL INSPECTIONS SPECIFICATION:ASME B18.2.1-96

CHARACTERISTICS	SPECIFIED	ACTUALRESULT	ACC.	REJ.
**********************	****************************	*****************	*******	*******
VISUAL	ASTM F788-02	PASSED	100	0
THREAD	ASME B1.1-02 2A	PASSED	32	0
WIDTH FLATS	23.82-23.02	23.60-23.25	8	0
WIDTH A/C	27.50-26.24	27.30-26.55	8	0
HEAD HEIGHT	11.27-9.61	11.10-9.85	8	0
BODY DIA	15.87-15.68	15.80-15. 68	8	0
THREAD LENGTH	44.45	46.20	8	0
LENGTH	168.65-160.53	166.00-162.00	8	0

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307-00 GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	****************	***************	******************	*******	*******
CORE HARDNESS:	ASTM E18-02	69-100HRB	71-83HRB	8	0
WEDGE TENSILE:	ASTM F606-02	MIN 60 Ksi	Min 67si	4	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
**********************	****************	******************	*****************	*******	*******
HOT DIP GALVANIZED	ASTM A153-00	MIN 0.0021"IN	MIN 0.0022 IN	5	0

ALL TESIS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION WE CERTIFY THAT THIS DATA IS A TRUE PEPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLTER AND OUR TESTING LABORATORY

WU XIAO LI
(SIGNATURE OF Q. A. LAB MGR)
(NAME OF MANUFACTURER)

Tuttle International Co., Ltd.
Room 902, Tower D, He Zhong Building, You Yi North Road,
Hexi Dist, Tianjin 300204 China PR.

Report of Chemical and Physical Properties

COUNTRY OF ORIGIN :CHINA

CUSTOMER'S NAME :BRIGHTON-BEST INTERNATIONAL(TAIWAN) INC.

MANUFACTURER ID: T633

DESCRIPTION OF MATERIAL AND SPECIFICATIONS:

PO. NO.: C05355

- PART NO.: 357044
- QUANTITY (PCs): 84000 DATE of MFG.: 6/30/2014
- DESCRIPTION: 3/8" ASTM F436 HARDENER WASHER HDG
    - MANUFACTURER'S INSIGNIA: F436&01VA
    - LOT NUMBER: 0535501

Nominal Dimensions

SPECIFICATION :F436 -11

Unit: mm

Part No.	ID MIN	ID MAX	OD MIN	OD MAX	THICKNESS MIN	THICKNESS MAX
357044	10.32	11.09	19.87	21.43	1.30	2.03

CHEMICAL ANALYSIS

HEAT NO. 13402637-2

C	Mn	P	S	Si	Cr	Cu	Ni	B
.44	.53	.015	.012	.21	.060	.03	.02	

3.0mm(-.02/+.10) THICKNESS OF STEEL METAL USED FOR THIS SIZE WASHER.
SPECIFICATION AND GRADE OF MATERIAL 45
SPECIFICATION

TEST ITEM	SPECIFIED	ACTUAL RESULT
HARDNESS (HRC)	26--45	30--32
PLATING THICKNESS(μ) ASTM F 2329-11	43.2	52--57

QUALITY MANAGER
Jikan Feng
冯吉

SUPER CHENG INDUSTRIAL CO., LTD.

CERTIFICATE OF INSPECTION ISO 9001

15 WEI-SWEI W.ROAD KANGSHAN 82005. TAIWAN,R.O.C. REGISTRATION NO:
TEL:(886-7)6225326 FAX:(886-7)6215377;6230904 7M4Y038-00

ISSUE DATE : 2007/7/31

CUSTOMER : PORTEOUS FASTENER COMPANY
PART NO. : 00200-2600-024
SAMPLING PLAN : MIL-105D S2
Mfg.LOT NO : 0706FHNC0O03
P.O. NUMBER : 17052903
QUANTITY SHIPPED : 48000 PCS
COMMODITY : FIN HEX NUT
SIZE: 3/8-16 HDG O/S 0.017
MECHANICAL SPEC : ASTM A563 GRADE A
DIMENSIONS SPEC : ANSI/ASME B18.2.2

HEAT NO. : 320612003 DIMENSION IN INCH

ITEM	SPECIFICATION	ACTUAL RESULT	ACC.	REJ.
APPEARANCE	ASTM F812	GOOD	V	
THREAD	GO/NO GO GAGE	OK	V	
W.A.F.	0.562 ~ 0.551	0.560 ~ 0.557	V	
W.A.C.	0.650 ~ 0.628	0.638 ~ 0.635	V	
THICKNESS	0.337 ~ 0.320	0.334 ~ 0.330	V	
HARDNESS	MAX 107 HRB	93.0 ~ 89.0 HRB	V	
PROOF LOAD	MIN 68000 PSI	PASS	V	

ALL TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN APPLICABLE ASTM & SAE SPECIFICATION. WE CERTIFY THAT THIS DATA IS THE A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

AUTHORIZED SIGNATURE

邢台钢铁有限责任公司
XINGTAI IRON AND STEEL CORP., LTD.
工厂检验证明书
MILL'S TEST CERTIFICATE

地 址：河北省邢台市钢铁南路226号
A D D:226 Gangtie Road, Xingtai, Hebei, China

ADDRESSED: TO WHOM IT MAY CONCERN

QUALITY:	SWRCH10A	DESCRIPT. OF GOODS:	PRIME STEEL WIRE ROD					
批 号 HEAT NO	直径 (MM) SIZE	ACTUAL CHEMICAL ANALYSIS(%)						MECHANICAL PROPERTIES	
		C	Mn	Si	S	P	Al	抗拉Rm T.S(MPa)	面缩 R.A(%)
320612413	13	0.10	0.43	0.04	0.006	0.006	0.049		
320612414	13	0.11	0.42	0.04	0.008	0.006	0.053		
320612415	13	0.11	0.42	0.04	0.007	0.004	0.033		
320612416	13	0.12	0.42	0.04	0.008	0.004	0.055		
320612417	13	0.10	0.41	0.04	0.006	0.004	0.030		
320612418	13	0.10	0.41	0.04	0.007	0.010	0.050		
320611995	14	0.11	0.42	0.04	0.014	0.010	0.073		
320611997	14	0.12	0.42	0.04	0.007	0.009	0.070		
320611998	14	0.10	0.42	0.04	0.009	0.010	0.061		
320611999	14	0.12	0.42	0.04	0.008	0.007	0.058		
320612000	14	0.12	0.43	0.05	0.008	0.008	0.062		
320612001	14	0.12	0.42	0.04	0.006	0.010	0.048		
320612002	14	0.10	0.42	0.06	0.008	0.010	0.058		
320612003 √	14	0.12	0.42	0.07	0.005	0.010	0.070		
320612004	14	0.12	0.43	0.06	0.004	0.012	0.042		
备 注 REMARK	1、质量证明书复印件不具有同等法律效应 THE COPY OF THE INSPECTION CERTIFICATE IS INEFFECTIVE LEGALLY. 2、热轧交货DELIVERY AFTER HOT ROLLING 3、DEC=DECARBURIZAION C.H.T=COLD HEADING TESI G.S=GRAIN SIZE Y.S=YIELD STRENGTH T.S=TENSILE STRENGTH E.L=ELONGATION R.A=REDUCTION OF AREA C.B.T=COLD BEND TEST C.H.T=COLD HEADING TEST							MANUFACTURER: XINGTAI IRON AND STEEL CORP., LTD. SIGNED BY	

Ma...

HANGZHOU SPRING WASHER CO.,LTD

QUALITY TEST CERTIFICATE OF SPRING LOCK WASHER

Customer: ~~ASME B 18.21.1-1999~~

Standard:

Contract No.:

Order No.: PO 16072544

Invoice No.: 06SHD330

Chemical Composition (%)	C	Si	Mn	P	S	Cr	Ni	Cu
	0.65	0.22	0.53	0.01	0.002	0.003	0.002	0.002
Heat No.	07771002069							

Specification	3/8" HDG	
Quantity	252M	
Lot No.	0608250	
Part No.	00350-2600-024	

Testing Item	Ac/n	Result	Reject	Result	Result	Reject	Result
Inside Diameter	2/100	9.88-10.18	9.89-10.10	0			
Outside Diameter	0/8	Max17.97	Max17.95	0			
Width	1/32	Min3.67	Min3.68	0			
Thickness	1/32	2.48-2.84	2.50-2.80	0			
Height	/						
Section	/						
Surface Defects	2/100	None	None	0			
Hardness	0/4	HRC38-46	HRC40-43	0			
Springing	/						
Toughness	0/8	Qualified	Qualified	0			

General:

The spring lock washers are conformed with the standard of ASME B 18.21.1-99. QUALIFIED.

Inspector: LiJia Quality Inspection Chief [signature] Date: 2007.04.26

ZHEJIANG LAIBAO PRECISION TECHNOLOGY CO.,LTD
NO.668 DONGHAI ROAD,XITANGQIAO TOWN,HAIYAN,ZHEJIANG,CHINA
TEL: +86-573-86813788 FAX:+86-573-86811201

QUALITY CERTIFICATE

Customer Name :	BRIGHTON - BEST INTERNATIONAL (TAIWAN), INC.	Country of origin:	China
INV.NO.:	BBT1101	QUANTITY:	0.540 MPcs
P.O.NO.:	U28734	TEST DATE:	08.20.2015
S/C NO.:	BBI15191	ON BOARD:	08.27.2015
PART NO.:	495129	SIZE:	3/4-10×5-1/2
LOT NO.:	1507007601	DESCRIPTION:	HEX HEAD BOLTS UNC HDG
PRODUCTION DATE:	08.16,2015		

Size: ASME B18.2.1 2012
Material and Mechanical properties: ASTM A307-2014 GR.A
Zinc Coatings: ASTM F2329-05

1.Chemical Composition Of Material（％）

STEEL GRADE /HEAT NO:	DIA. (mm)	C	Si	Mn	P	S	Cr	B	Ni	Al	Mo
Q195/180848	20	0.07	0.11	0.33	0.025	0.029					

2.Dimension

INSPECTION ITEM	SPECIFICATION	RESULT
Head Marking	LB307A	LB307A
Width A/F (inch)	1.088-1.125	1.101-1.113
Width A/C (inch)	1.240-1.299	1.250-1.261
Head Height (inch)	0.455-0.524	0.462-0.489
Body Dia (inch)	0.729-0.768	0.737-0.746
Total Length (inch)	5.400-5.600	5.465-5.512
Thread Length (inch)	NOM 1.750	1.761-1.774
Major Dia (inch)	0.7353-0.7500	0.742-0.745
GO Ring Gauge	THE NUT OF UNC 3/4-10$^{+0.40}$ 2B	OK
NO GO Ring Gauge	UNC 3/4-10 2A	OK
Tensile Strength (Psi)	MIN 60000	82145-85201
Hardness (HRB)	69-100	82-85
Visual	OK	OK
Salt Spray Test	/	/
Zinc Thickness (μm)	MIN 53	59.2-60.1

We hereby certify that the material described herein has been manufactured and tested with satisfactory results in accordance with the requirement of the above material/dimensional specifications.

海盐县莱宝精工科技有限公司 品管部

YUE LONG ZHANG
Q.C Supervisor

CERTIFIED MATERIAL TEST REPORT
FOR ASTM A307, GRADE A - MACHINE BOLTS

FACTORY: NINGBO YONGGANG FASTENER CO., LTD.
ADDRESS:NINGBO MEIXU INDUSTRIAL PARK, ZHEJIANG, CHINA

DATE: 2009-2-26

LOT NUMBER: 2008NY-511

CUSTOMER: IFI & MORGAN LTD.

PO NUMBER:18100302

SAMPE SIZE: ACC. TO ASME B18 . 18 . 2M - 93
SIZE:3/4-10x6 HDG QNTY: 2160pcs
HEADMARKS: 307A PLUS NY

PART NO: 00024-3260-024

STEEL PROPERTIES:
STEEL GRADE: SG195

HEAT NUMBER: 0740010334

	C %*100	Mn%*100	P %*1000	S %*1000
CHEMISTRY SPEC:	0.29max	1.20 max	0.04max	0.15max
TEST:	0.090	0.390	0.009	0.013
	0.090	0.390	0.009	0.013

DIMENSIONAL INSPECTIONS — SPECIFICATION: ASME B18.2.1 - 96

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	************************************	******************	********	********
VISUAL	ASTM F788-02	PASSED	100	0
THREAD	ASME B1.1-02 2A	PASSED	32	0
WIDTH FLATS	27.64-28.57	27.75-28.40	8	0
WIDTH A/C	31.50-32.99	31.85-32.75	8	0
HEAD HEIGHT	11.56-13.30	11.70-13.21	8	0
BODY DIA.	19.05max	18.98-19.05	8	0
THREAD LENGTH	41.95-46.95	42.38-46.75	8	0
LENGTH	149.90-154.90	150.36-154.67	8	0

MECHANICAL PROPERTIES: — SPECIFICATION: ASTM A307-00 GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	******************	******************	******************	********	********
CORE HARDNESS :	ASTM E18-02	69-100HRB	75-85	8	0
WEDGE TENSILE:	ASTM F606-02	Min 60000 PSI	61200-65000	4	0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

HAIYAN DAYU FASTENERS CO.,LTD

NO.8 XITANG INDUSTRY ZONE, HAIYAN, ZHEJIANG ,CHINA

TEL: +86-573-86813788 FAX:+86-573-86811201

QUALITY CERTIFICATE

INV.NO.:	BBT038	**QUANTITY:**	4.32 MPcs
P.O.NO.:	U06225	**TEST DATE:**	12.01,2011
S/C NO.:	BBI066	**ON BOARD:**	12.08,2011
PART NO.:	495131	**SIZE:**	3/4-10×6-1/2
LOT NO.:	11102000	**DESCRIPTION:**	HEX BOLTS UNC HDG
PRODUCTION DATE:	10.17,2011		

Size: ASME B18.2.1 2010

Material and Mechanical properties: ASTM A307-2010 GR.A

Zinc Coatings: ASTM F2329 2005

1.Chemical Composition Of Material （%）

STEEL GRADE /HEAT NO:	DIA. (mm)	C	Si	Mn	P	S	Cr	B	Ni	Al	Mo
Q195/184927	20	0.09	0.12	0.32	0.027	0.016					

2.Dimension

INSPECTION ITEM	SPECIFICATION	RESULT
Head Marking	LB307A	LB307A
Width A/F (inch)	1.088-1.125	1.108-1.118
Width A/C (inch)	1.240-1.299	1.261-1.269
Head Height (inch)	0.455-0.524	0.475-0.486
Body Dia (inch)	0.729-0.768	0.734-0.736
Total Length (inch)	6.320-6.640	6.385-6.419
Thread Length (inch)	NOM 2.000	2.106-2.125
Major Dia (inch)	0.7353-0.7500	0.747-0.748
GO Ring Gauge	THE NUT OF UNC 3/4-10$^{+0.40}$ 2B	OK
NO GO Ring Gauge	UNC 3/4-10 2A	OK
Tensile Strength (Psi)	MIN 60000	81218-84118
Hardness (HRB)	69-100	83-84
Visual	OK	OK
Salt Spray Test	/	/
Zinc Thickness (μm)	MIN 54	58-62

We hereby certify that the material described herein has been manufactured and tested with satisfactory results in accordance with the requirement of the above material/dimensional specifications.

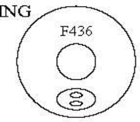
QIN YUE ZHU

HEXICO ENTERPRISE CO., LTD.

NO.355-3,SEC. 3,CHUNG SHAN ROAD,KAU-JEN,TAINAN,TAIWAN,R.O.C.

TEL : 886 - 6 - 2390616 FAX : 886 - 6 - 2308947

MARKING



INSPECTION CERTIFICATE

CUSTOMER	**PORTEOUS FASTENER CO.**		
PART NAME	ASTM F436 - 09 TYPE 1 WASHERS (HOT DIP GALV. PER ASTM A153)		
SIZE	3/4 "	DATE	April 08, 2011
PART NO.	W2A6C6000S6JV	REPORT NO.	1000408-02
CUST. PART NO.	00385-3200-024	SHIPPING NO.	
MATERIAL / DIA.	10B20 / 23 mm	ORDER NO.	10122251
HEAT(COIL) NO.	3B143	LOT NO.	022C6PF41
LOT QTY	72,000 PCS	DOCUMENT NO.	9709015
STANDARD OF SAMPLING SCHEME	ANSI / ASME B18.18.2 M		

DIMENSIONS IN inch

INSPECTION ITEM		SPECIFICATION	INSPECTION RESULTS		REMARKS
			MIN.	MAX.	
1	OUTSIDE DIAMETER	1.4360 - 1.5000	1.4547	1.4681	
2	INSIDE DIAMETER	0.8130 - 0.8450	0.8311	0.8354	
3	THICKNESS	0.1220 - 0.1770	0.1311	0.1394	
4	HARDNESS	HRC 26 - 45	26.1	27.0	
5	COATING	HOT DIP GALV. 43 µm	46.0	75.6	
6	APPEARANCE	VISUAL	OK		

HOT DIP GALV. 43 µm	1	2	3	4	5	6	7	8	9	10
SAMPLE SIZE : 10 PCS	49.1	58.2	62.0	75.6	71.4	49.2	51.4	56.9	66.7	46.0

INSPECTED BY *Yu Tain Lin* CERTIFIED BY *Jing Yeh Tsao*

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

ISO/TS 16949 BUREAU VERITAS Certification

ACCREDITED
TESTING CERT 1292-01
MECHANICAL TESTING

MANUFACTURER GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2010/04/20

PURCHASER : PORTEOUS FASTENER COMPANY.
PO. NUMBER : 19121403
COMMODITY : FINISHED HEX NUT ASTM A563 GR-A
SIZE : 3/4-10 NC O/T 0.51MM
LOT NO : 1N1010097
SHIP QUANTITY : 54,000 PCS
HEADMARKS :

PACKING NO : GEM100223004
INVOICE NO : GEM/PFC-100416 DAL
PART NO : 00200-3200-024
SAMPLING PLAN : ASME B18.18.2
HEAT NO : 330906305
MATERIAL : 1010A
FINISH : HOT DIP GALVANIZED PER ASTM A153/ASTM F2329

PERCENTAGE COMPOSITION OF CHEMISTRY :

Chemistry	Al%	C%	Mn%	P%	S%	Si%
Spec. : MIN.	0.0200	0.0800	0.3000			
MAX.		0.1300	0.6000	0.0300	0.0350	0.1000
Test Value	0.0540	0.0900	0.4000	0.0120	0.0090	0.0400

DIMENSIONAL INSPECTIONS : ACCORDING TO ASME/ANSI B18.2.2
TEST DATE : 2010/02/04 SAMPLED BY : YAN WANG SAMPLING DATE : 2010/02/04

INSPECTIONS ITEM	SAMPLE	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	32 PCS	MIL-STD-120	31.520-32.970 MM	32.200-32.230 MM	32	0
HEIGHT	32 PCS	MIL-STD-120	15.690-16.280 MM	16.100-16.120 MM	32	0
WIDTH ACROSS FLATS	32 PCS	MIL-STD-120	27.640-28.580 MM	28.000-28.020 MM	32	0
SURFACE DISCONTINUITIES	100 PCS	ASTM F812		PASSED	100	0
THREAD	32 PCS	MIL-STD-120	bolt	PASSED	32	0

MECHANICAL PROPERTIES : ACCORDING TO ASTM A563-2007
TEST DATE : 2010/03/31 SAMPLED BY : FEISHENG YU SAMPLING DATE : 2010/03/28

INSPECTIONS ITEM	SAMPLE	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	29PCS	ASTM F606/F606M	68-107 HRB	81 HRB	29	0
PROOF LOAD	15PCS	ASTM F606/F606M	Min. 22,720 LBF	OK	15	0

ALL TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM/SAE/ASME/MIL-STD-120 SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

THIS CERTIFIED MATERIAL TEST REPORT APPLIES TO THE SAMPLES TESTED AND IT CANNOT BE REPRODUCED EXCEPT IN FULL.

SIGNATURE : ____________

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

MANUFACTURER GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2010/09/28

PURCHASER : PORTEOUS FASTENER COMPANY.
P.O. NUMBER : 10061504
COMMODITY : HEX MACHINE BOLT GR-A
SIZE : 5/8-11X2 NC
LOT NO : 1B1071195
SHIP QUANTITY : 9,000 PCS
HEADMARKS : CYI & 307A

PACKING NO : GEM100902008
INVOICE NO : GEM/PFC-100928 SEA
PART NO : 00024-3024-024
SAMPLING PLAN : ASME B18.18.2
HEAT NO : 10302438-3
MATERIAL : X1008A
FINISH : HOT DIP GALVANIZED PER ASTM A153/ASTM F2329

PERCENTAGE COMPOSITION OF CHEMISTRY :

Chemistry	Al%	C%	Mn%	P%	S%	Si%
Spec. : MIN.	0.0200					
MAX.		0.1000	0.6000	0.0300	0.0350	0.1000
Test Value	0.0410	0.0700	0.3100	0.0080	0.0030	0.0400

MECHANICAL PROPERTIES : ACCORDING TO ASTM A 307A-2007
TEST DATE : 2010/09/08 SAMPLED BY : GAO MINGHUA SAMPLING DATE : 2010/09/05

INSPECTIONS ITEM	SAMPLE	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	22PCS	ASTM F606/F606M	69-100 HRB	75 HRB	22	0
TENSILE STRENGTH	15PCS	ASTM F606/F606M	Min. 60 KSI	73 KSI	15	0

ALL TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM/SAE/ASME/MIL-STD-120 SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

THIS CERTIFIED MATERIAL TEST REPORT APPLIES TO THE SAMPLES TESTED AND IT CANNOT BE REPRODUCED EXCEPT IN FULL.

SIGNATURE : Jerry

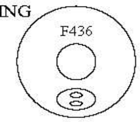
page 1 of 1

HEXICO ENTERPRISE CO., LTD.

NO.355-3,SEC. 3,CHUNG SHAN ROAD,KAU-JEN,TAINAN,TAIWAN,R.O.C.
TEL : 886 - 6 - 2390616 FAX : 886 - 6 - 2308947

INSPECTION CERTIFICATE

MARKING



CUSTOMER	**PORTEOUS FASTENER CO.**		
PART NAME	ASTM F436 - 09 TYPE 1 WASHERS (HOT DIP GALV. PER ASTM A153)		
SIZE	5/8 "	DATE	April 01, 2011
PART NO.	W2A6C5000S6JV	REPORT NO.	1000401-01
CUST. PART NO.	00385-3000-024	SHIPPING NO.	
MATERIAL / DIA.	10B20 / 20 mm	ORDER NO.	10122251
HEAT(COIL) NO.	1Q961	LOT NO.	022C5PF41
LOT QTY	72,000 PCS	DOCUMENT NO.	9802003
STANDARD OF SAMPLING SCHEME	ANSI / ASME B18.18.2 M		

DIMENSIONS IN inch

INSPECTION ITEM		SPECIFICATION	INSPECTION RESULTS		REMARKS
			MIN.	MAX.	
1	OUTSIDE DIAMETER	1.2810 - 1.3450	1.2909	1.3181	
2	INSIDE DIAMETER	0.6880 - 0.7200	0.7134	0.7197	
3	THICKNESS	0.1220 - 0.1770	0.1264	0.1421	
4	HARDNESS	HRC 26 - 45	26.5	31.4	
5	COATING	HOT DIP GALV. 43 µm	46.6	104.0	
6	APPEARANCE	VISUAL	OK		

HOT DIP GALV. 43 µm	1	2	3	4	5	6	7	8	9	10
SAMPLE SIZE : 10 PCS	46.6	50.6	99.2	84.7	81.6	104.0	101.0	88.3	65.1	70.9

INSPECTED BY *Yu Tain Lin* CERTIFIED BY *Jing Yeh Tsao*

CERTIFIED MATERIAL TEST REPORT
FOR ASTM A307, GRADE A - HEX BOLTS

FACTORY: ZHEJIANG GOLDEN AUTOMOTIVE FASTENER CO.LTD   DATE: JUN.12,2016
ADDRESS: XITANG QIAO HAIYAN ZHEJIANG CHINA

MFG LOT NUMBER: 0400009

CUSTOMER: BRIGHTON-BEST INTERNATIONAL(TAIWAN)INC.

PO NUMBER: U34597

SAMPLE SIZE: ACC. TO ASME B18 . 18 -2011 Categories 2

SIZE: 3/8-16X5-1/2" HDG QTY: 4200 PCS   PART NO: 495044

HEADMARKS: 307A + NDF

STEEL PROPERTIES:

STEEL GRADE: 1008   HEAT NUMBER: 4-B 4214197

	C %	Mn%	P %	S %
CHEMISTRY SPEC:	0.29 max	1.20 max	0.04max	0.15max
TEST:	0.06	0.28	0.019	0.015

DIMENSIONAL INSPECTIONS   SPECIFICATION: ASME B18.2.1-2012

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
**********************	************************************	******************	********	********
APPEARANCE	ASTM F788/F788M-13	PASSED	100	0
THREAD	ANSI B1.1-08 2A	PASSED	32	0
WIDTH FLATS	0.562"-0.544"	0.546"-0.558"	8	0
WIDTH A/C	0.650"-0.620"	0.635"-0.645"	8	0
HEAD HEIGHT	0.268"-0.226"	0.235"-0.252"	8	0
BODY DIA.	0.388"-0.360"	0.362"-0.368"	8	0
THREAD LENGTH	MIN1.00"	1.02"-1.05"	8	0
LENGTH	5.56"-5.40"	5.43"-5.45"	8	0

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307-2014 GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	******************	******************	*****************	********	********
CORE HARDNESS :	ASTM E18-14a	69-100 HRB	82-85 HRB	8	0
WEDGE TENSILE :	ASTM F606-14	MIN 60KSI	75-80 KSI	4	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
****************	*****************	*****************	*****************	********	********
HOT DIP GALVANZED	ASTM F2329-13	Min 0.0017"	0.0024"-0.0026"	5	0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED [illegible] APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DAIA IS A TR[illegible]TATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OU[illegible]ORATORY.

All parts meet the requirements of FQA and records of compliance are o[illegible]

Maker's ISO#CN11/20818

(SIGNATURE OF Q.A. LAB MGR.)
(ZHEJIANG GOLDEN AUTOMOTIVE FASTENER CO.LTD)

CERTIFICATE OF ANALYSIS

Beshert STEEL PROCESSING

Cert Number 44303-13 4/3/2020
Test Reference 59176

TRIPLE-S STEEL SUPPLY CO.
6000 JENSEN DRIVE
HOUSTON, TX 77026

Issued from
BESHERT STEEL PROCESSING
JOINT VENTURE OF
STEEL WAREHOUSE CO. &
TRIPLE-S STEEL HOLDINGS INC.
15355 JACINTO PORT BOULEVARD
HOUSTON, TX 77015

Sold To: TRIPLE-S STEEL SUPPLY CO., 6000 JENSEN DRIVE, HOUSTON, TX 77026
Ship To: TRIPLE-S STEEL, 6000 JENSEN DRIVE, HOUSTON, TX 77026

Reference

Customer 100200/0 **Your Order** HOU-189140 (3/30/2020)
Our Order 22068-13-1 **Packing List** 44303-1 (4/3/2020)

Product Information

TEMPERED LEVELED PLATE A36/SA36	Heat	Tag	Pcs	LBS
0.2500" x 48" x 120"	005821	26545E	24	9,805

Part PL36TML1448120
Conform To ASTM-A36-.246-.258 4/27/2013

Chemical Composition C.E.: 0.3443 D.I.: 0

C	Mn	Si	P	S	Cr	Ni	Mo
0.202	0.83	0.01	0.012	0.002	0.01	0.007	0.002
Cu	**Al**	**N**	**V**	**Ti**	**Cb**	**CbV**	
0.014	0.033	0.0042	0.001	0.001	0.00	0.001	

Physical Tests

YIELD - H (T)	TENSILE - H (T)	ELONGATION - H (T)	YIELD - M (T)
46.1 KSI	68.1 KSI	29.6 %	45.5 KSI
TENSILE - M (T)	**ELONGATION - M (T)**		
66.8 KSI	29.8 %		

Product of Coil
Country of Origin: Melted in Brazil
Manufactured in USA

4/3/2020	08:04 AM		2

**LAND 15 '
NUCOR STEEL - BERKELEY
1455 Hagan Avenue
Huger, SC 29450
Phone: (843) 336-6000

CERTIFIED MILL TEST REPORT

7/01/20 18:04:50

100% EAF MELTED AND MANUFACTURED IN THE USA
Structural sections produced by Nucor-Berkeley are cast and hot rolled to a fully killed and fine grain practice. Mercury not intentionally added at any point during manufacturing.

Sold To: TRIPLE S STEEL COMPANY
6000 JENSEN DR
PO BOX 21119
HOUSTON, TX 77226

Ship To: TRIPLE S STEEL COMPANY
6000 JENSEN DR
PO BOX 21119
HOUSTON, TX 77226

Customer #.: 997 - 1
Customer PO: HOU-190155
B.o.L. #...: 1489436
MOS: T

SPECIFICATIONS: Tested in accordance with ASTM specification A6/A6M-19 and A370. Quality Manual Rev #12 (8-27-19).
AASHTO : m270-345M270-50-19
ASME : SA-36 13
ASTM : A992-11(15:/A36-19/A529-19-50/A5725018T1/A7093618/A7095018
CSA : G40.21-44w/G40.21-50w/G40.2150WM

Description Part #	Heat# Grade(s) Test/Heat JW	Yield/ Tensile Ratio	Yield (PSI) (MPa)	Tensile (PSI) (MPa)	Elong %	C Cr ******	Mn Mo Ti	P Sn ******	S B ******	Si V N	Cu Nb ******	Ni ****** CI	CE1 CE2 Pcm
W12x19 040' 00.00" W310X28.3 012.1920m	2004760 A992-11(15	.84 .84	59600 411 58800 405	70800 488 70300 485	29.00 28.00	.07 .04	.88 .01 .001	.008 .0080	.028 .0001	.24 .004 .0047	.14 .029	.03 3.54	.24 .2837 .1326
					8 Pc(s)	6,080 lbs	Customer PO: HOU-190155	BoL#: 1489436					
W6X20 040' 00.00" W150X29.8 012.1920m	2007773 A992-11(15	.82 .82	62100 428 63000 434	75800 523 76900 530	24.00 27.00	.08 .08	1.06 .01 .001	.008 .0095	.024 .0002	.25 .002 .0063	.24 .028	.06 5.05	.29 .3362 .1549
					18 Pc(s)	14,400 lbs	Customer PO: HOU-190155	BoL#: 1489436					
W6X25 040' 00.00" W150X37.1 012.1920m	2007788 A992-11(15	.78 .78	60900 420 60600 418	78000 538 77800 536	22.00 23.00	.07 .08	1.07 .01 .001	.009 .0100	.013 .0002	.23 .002 .0068	.23 .031	.06 4.94	.28 .3272 .1459
					20 Pc(s)	20,000 lbs	Customer PO: HOU-190155	BoL#: 1489436					

Elongation based on 8" (20.32cm) gauge length. 'No Weld Repair' was performed.
CI = 26.01Cu+3.88Ni+1.20Cr+1.49Si+17.28P-(7.29Cu*Ni)-(9.10Ni*P)-33.39(Cu*Cu)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B
CE1= C+(Mn/6)+((Cr+Mo+V)/5)+((Ni+Cu)/15)

"All mechanical testing is performed by the Quality testing lab, which is independent of the production departments"
CE2 = C+((Mn+Si)/6)+((Cr+Mo+V+Cb)/5)+((Ni+Cu)/15)

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with material specifications, and when designated by the Purchaser, meet applicable specifications.

Bruce A. Work
Metallurgist/
Quality Control

TR No. 0-7019-R1

88

2021-02-03

**LAND 15,
NUCOR STEEL - BERKELEY
1455 Hagan Avenue
Huger, SC 29450
Phone: (843) 336-6000

CERTIFIED MILL TEST REPORT

7/01/20 18:04:50

100% EAF MELTED AND MANUFACTURED IN THE USA

Structural sections produced by Nucor-Berkeley are cast and hot rolled to a fully killed and fine grain practice. Mercury not intentionally added at any point during manufacturing.

Sold To: TRIPLE S STEEL COMPANY
6000 JENSEN DR
PO BOX 21119
HOUSTON, TX 77226

Ship To: TRIPLE S STEEL COMPANY
6000 JENSEN DR
PO BOX 21119
HOUSTON, TX 77226

Customer #.: 997 - 1
Customer PO: HOU-190155
B.o.L. #...: 1489436

MOS: T

SPECIFICATIONS: Tested in accordance with ASTM specification A6/A6M-19 and A370. Quality Manual Rev #12 (8-27-19).
AASHTO : m270-345M270-50-19
ASME : SA-36 13
ASTM : A992-11(15:/A36-19/A529-19-50/A5725018T1/A7093618/A7095018
CSA : G40.21-44w/G40.21-50w/G40.2150WM

Description Part #	Heat# Grade(s) Test/Heat JW	Yield/ Tensile Ratio	Yield (PSI) (MPa)	Tensile (PSI) (MPa)	Elong %	C Cr ******	Mn Mo Ti	P Sn ******	S B ******	Si V N	Cu Nb ******	Ni ****** CI	CE1 CE2 Pcm
W6X25 040' 00.00" W150X37.1 012.1920m	2007786 A992-11(15	.81 .80	61300 423 59300 409	75500 521 73700 508	23.00 24.00	.07 .08	1.03 .01 .001	.008 .0095	.022 .0002	.26 .002 .0069	.23 .032	.06 4.97	.28 .3302 .1491

7 Pc(s) 7,000 lbs Customer PO: HOU-190155 BoL#: 1489436

4 Heat(s) for this MTR.

Elongation based on 8" (20.32cm) gauge length. 'No Weld Repair' was peformed.
CI = 26.01Cu+3.88Ni+1.20Cr+1.49Si+17.28P-(7.29Cu*Ni)-(9.10Ni*P)-33.39(Cu*Cu)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B
CE1 = C+(Mn/6)+((Cr+Mo+V)/5)+((Ni+Cu)/15)

"All mechanical testing is performed by the Quality testing lab, which is independent of the production departments"
CE2 = C+((Mn+Si)/6)+((Cr+Mo+V+Cb)/5)+((Ni+Cu)/15)

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with material specifications, and when designated by the Purchaser, meet applicable specifications.
**END

Bruce A. Work
Metallurgist
Quality Control

TR No. 0-7019-R1

89

2021-02-03

CMC

1SERIES-BPS ®

CMC STEEL ALABAMA
101 S 50TH STREET
BIRMINGHAM AL 35212-3525

CERTIFIED MILL TEST REPORT
For additional copies call
800-637-3227

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Marcus W. McCluney - CMC Steel AL
Quality Assurance Manager

HEAT NO.:1066214 SECTION: ANG 5 X 5x1/2 40'0" A36/52950 GRADE: ASTM A36-19/A529-14 Gr 50 ROLL DATE: 05/13/2020 MELT DATE: 05/06/2020 Cert. No.: 83120220 / 066214B693	SOLD TO: Intsel Steel Distributors LP 11310 W Little York Rd Houston TX US 77041-4917 7139379500 7136977335	SHIP TO: Intsel Steel Distributors LP 11310 W Little York Rd Houston TX US 77041-4917 7139379500 7136977335

Delivery#: 83120220
BOL#: 73632492
CUST PO#: WLY-24914
CUST P/N:
DLVRY LBS / HEAT: 29160.000 LB
DLVRY PCS / HEAT: 45 EA

Characteristic	Value	Characteristic	Value
C	0.16%	Elongation test 1	24%
Mn	0.78%	Elongation Gage Lgth test 1	8IN
P	0.012%	Yield to tensile ratio test1	0.71
S	0.020%	Yield Strength test 2	55.5ksi
Si	0.17%	Tensile Strength test 2	79.2ksi
Cu	0.38%	Elongation test 2	25%
Cr	0.15%	Elongation Gage Lgth test 2	8IN
Ni	0.17%	Yield to tensile ratio test2	0.70
Mo	0.063%		
V	0.004%		
Cb	0.013%		
Sn	0.014%		
B	0.0002%		
Ti	0.001%		
N	0.0102%		
Carbon Eq A6	0.37%		
Carbon Eq A529	0.40%		
Yield Strength test 1	55.8ksi		
Tensile Strength test 1	78.5ksi		

Characteristic | Value

JERRY GASTON JR
MY COMMISSION EXPIRES JUNE 21, 2023
NOTARY PUBLIC
STATE OF ALABAMA

The Following ... of the material represented by this MTR:

- *Material is fully killed
- *100% melted and rolled in the USA
- *EN10204:2004 3.1 compliant
- *Contains no weld repair
- *Contains no Mercury contamination
- *Manufactured in accordance with the latest version of the plant quality manual
- *Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661
- *Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS : HOT ROLLED CARBON STEEL
ALSO MEETS ASTM GRADE A36 REV 08, A572-50, A709-36, A709-50, A992, AASHTO GRADE M270-36, M270-50, CSA G40.21-04 GRADE 44W, 50W, ASME SA-36 2008A ADDEND A.

TR No. 0-7019-R1

90

2021-02-03

Atlas Tube Corp. Chicago
1855 East 122nd Street
Chicago Illinois USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

Atlas *Tube*
A DIVISION OF ZEKELMAN INDUSTRIES

REF.B/L: 80953811
Date: 05/28/2020
Customer: 192

MATERIAL TEST REPORT

Sold To
Triple S Steel Supply
PO Box 21119
HOUSTON TX 77026
USA

Shipped To
Intsel Steel Distributors
11310 West Little York
HOUSTON TX 77041
USA

Material: 12.0x12.0x250x40'10"0(2x2). **Material No:** 120120250 **Made in:** USA
Melted in: USA
Sales Order: 1511242 **Purchase Order:** WLY-24700

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N	Ca
12018040	0.170	0.740	0.014	0.001	0.040	0.028	0.080	0.001	0.010	0.040	0.060	0.002	0.002	0.0000	0.0060	0.0020

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M901147005	4	051167 Psi	068242 Psi	34 %	ASTM A500-18 GRADE B&C	CE: 0.32

Heat	MILL	Mill Location	Method	Recycled Content	Post Consumer	Pre-Consumer (Post Industrial)	% Harvested	Within Miles of Location
12018040	SDI	Butler,IN	EAF	89.00%	80.00%	9.00 %	99%	500

Material Note:
Sales Or. Note:

Material: 5.0x4.0x250x40'0"0(4x3). **Material No:** 500402504000 **Made in:** USA
Melted in: USA
Sales Order: 1521364 **Purchase Order:** WLY-24808

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N	Ca
T85152	0.200	0.780	0.011	0.007	0.013	0.039	0.020	0.004	0.007	0.010	0.040	0.001	0.001	0.0001	0.0050	0.0000

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800949735	12	056331 Psi	075165 Psi	32 %	ASTM A500-18 GRADE B&C	CE: 0.34

Heat	MILL	Mill Location	Method	Recycled Content	Post Consumer	Pre-Consumer (Post Industrial)	% Harvested	Within Miles of Location
T85152	USSTEEL	GARY,IN	BOF	36.90%	19.80%	14.40%	100%	500

Material Note:
Sales Or. Note:

Authorized by Quality Assurance: *[signature]*

The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Metals Service Center Institute

TMK IPSCO

CERTIFICATE OF TESTING
IPSCO TUBULARS INC

Page 1

Certificate Number:	365273-1
Tuesday, June 9, 2020, 3:10:58 PM	

Bill of Lading: 64998

Size: 4.000 X 3.000 in | Gage: 0.250 in | Grade: A500B | Mill Order No: 98174-07 | Customer PO: WLY-24864

Specification: ASTM A500-18
PRODUCT MEETS SPECIFICATION REQUIREMENTS
FOR GRADES B AND C.

Customer: INTSEL STEEL DISTRIBUTORS

Pieces: 12 Length: 40.00 (ft)

Heat	Product ID	Test Type			Orientation				Width (in)		YS (psi)		TS (psi)		Elong%(2 in)		Y/T	
		Wgt (%)	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Cb	Ti	B	CEQ
1297013	G-972C 1490795/	HEAT QUALIFIER			PIPE LPA				1.507		68000		73300		35.0		0.93	
		Heat:	0.21	0.78	0.009	0.002	0.02	0.06	0.03	0.04	0.010	0.003	0.030	0.003	0.000	0.001	0.0000	0.36

TPA - Transverse Pipe Axis
180° of Weld
LPA - Longitudinal Pipe Axis
90° of Weld
TWA - Transverse Weld Axis
FST - Full Section Testing
FBN - Full Body Normalized
Q&T - Quenched and Tempered
SR - Stress Relieved
form CRTR3001

Melted and Manufactured in the USA
EN 10204:2004 TYPE 3.1 CERT
No Weld Repair Performed On This Product

We certify that the product described above has been manufactured, sampled, inspected, and tested in accordance to the referenced specification. The product has been found to be in compliance with all requirements.

Joseph A Casey
QA Coordinator

Tuesday, June 9, 2020, 3:11:32 PM

MILL ADDRESS - 1201-R ST., GENEVA, NE 68361 | PHONE: (402) 759-4401

Atlas Tube Canada
200 Clark St.
Harrow Ontario Canada
N0R 1G0
Tel: 519-738-3541
Fax: 519-738-3537

Atlas Tube
A DIVISION OF ZEKELMAN INDUSTRIES

REF.B/L: 80947699
Date: 04/21/2020
Customer: 1746

MATERIAL TEST REPORT

Sold To
Service Steel Warehouse Co. L.P.
PO Box 9607
HOUSTON TX 77213
USA

Shipped To
Service Steel Warehouse Co., L.P.
8415 Clinton Drive
HOUSTON TX 77029
USA

Material: 5.0x4.0x250x48'0"0(3x3). Material No: 500402504800 Made in: Canada
Sales Order: 1509929 Purchase Order: SSW111808 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N	Ca
796873	0.190	0.820	0.011	0.007	0.018	0.057	0.032	0.005	0.003	0.010	0.034	0.002	0.002	0.0002	0.0030	0.0002

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification
M101976258	9	059433 Psi	071028 Psi	32.8 %	ASTM A500-18 GRADE B&C

CE: 0.34

Heat	MILL	Mill Location	Method	Recycled Content	Post Consumer	Pre-Consumer (Post Industrial)	% Harvested	Within Miles of Location
796873	STELCO	Nanticoke,ON	BOF	36.90%	19.80%	14.40%	100%	1000

Material Note:
Sales Or. Note:

Material: 8.0x8.0x500x48'0"0(2x2). Material No: 800805004800 Made in: Canada
Sales Order: 1510221 Purchase Order: SSW111808 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N	Ca
796965	0.190	0.800	0.009	0.009	0.014	0.036	0.061	0.004	0.008	0.029	0.056	0.002	0.002	0.0002	0.0040	0.0002

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification
M201432243	4	059342 Psi	068356 Psi	36.0 %	ASTM A500-18 GRADE B&C

CE: 0.34

Heat	MILL	Mill Location	Method	Recycled Content	Post Consumer	Pre-Consumer (Post Industrial)	% Harvested	Within Miles of Location
796965	STELCO	Nanticoke,ON	BOF	36.90%	19.80%	14.40%	100%	1000

Material Note:
Sales Or. Note:

Authorized by Quality Assurance: [signature]

The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Metals Service Center Institute

23Jan20 1:48 TEST CERTIFICATE No: CHI 241525

NUCOR TUBULAR PRODUCTS INC.
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No SSW110608
Rel
S/O No CHI 300023-001
B/L No CHI 180587-001 Shp 23Jan20
Inv No Inv

Sold To: (2734)
SERVICE STEEL WAREHOUSE CO., L.P.
PO BOX 9607
HOUSTON, TX 77213

Ship To: (1)
SERVICE STEEL WAREHOUSE CO.
8415 CLINTON DRIVE
HOUSTON, TX 77029

Tel: 713-675-2631 Fax: 713 672-7559

CERTIFICATE of ANALYSIS and TESTS Cert. No: CHI 241525
16Jan20

Part No
TUBING A500 GRADE B(C)
5" X 4" X 1/4" X 40'

Pcs	Wgt
16	8,902

* DOMESTIC STEEL M&M *

Heat Number	Tag No	Pcs	Wgt
C92384	564038	16	8,902

YLD=63791/TEN=67647/ELG=32.08

Heat Number
C92384

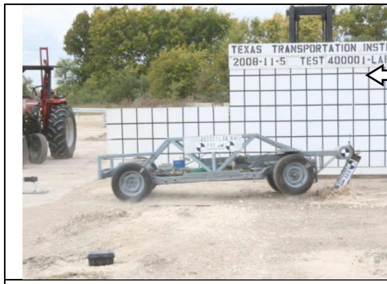
*** Chemical Analysis ***
C=0.0500 Mn=0.3900 P=0.0090 S=0.0030 Si=0.0300 Al=0.0300
Cu=0.1800 Cr=0.0800 Mo=0.0200 V=0.0030 Ni=0.0900 Nb=0.0120
Sn=0.0080 N=0.0072 B=0.0001 Ti=0.0020 Ca=0.0020
MELTED AND MANUFACTURED IN THE USA

WE PROUDLY MANUFACTURE ALL OUR PRODUCTS IN THE USA
NUCOR TUBULAR PRODUCTS ARE MANUFACTURED, TESTED
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

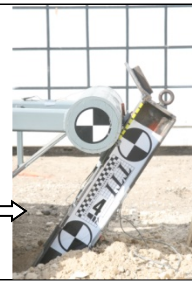
CURRENT STANDARDS:
A252-10
A500/A500M-18
A513/A513M-15
ASTM A53/A53M-12 | ASME SA-53/SA-53M-13
A847/A847M-14
A1085/A1085M-15
IN COMPLIANCE WITH EN 10204 SECTION 4.1
INSPECTION CERTIFICATE TYPE 3.1

Page: 1 .... Last

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



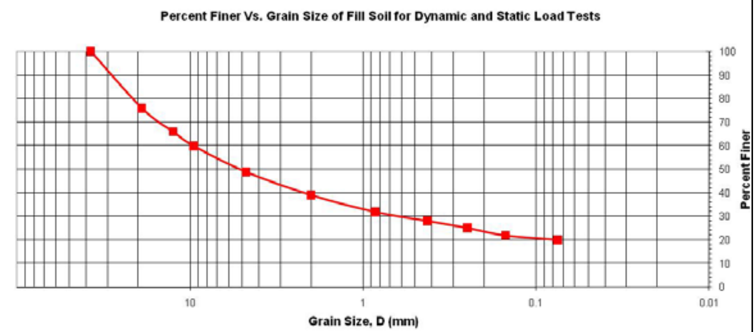
Dynamic Setup



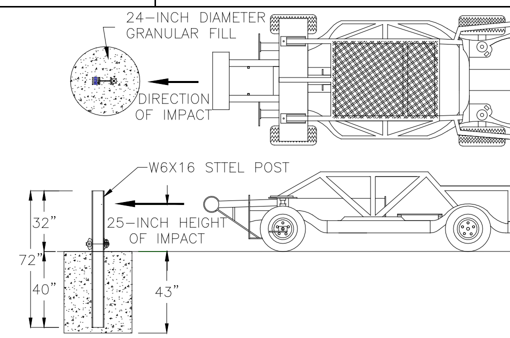
Post-Test Photo of post

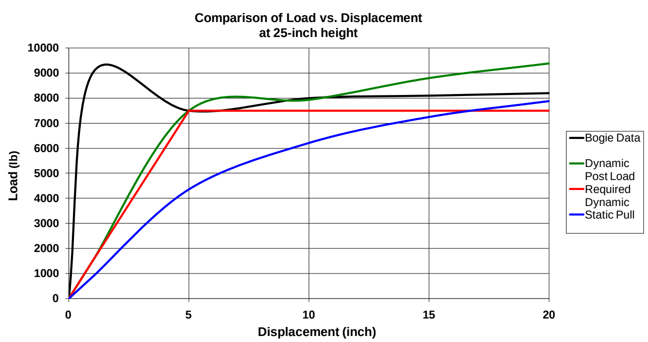
Post-Test Photo

Static Load Test

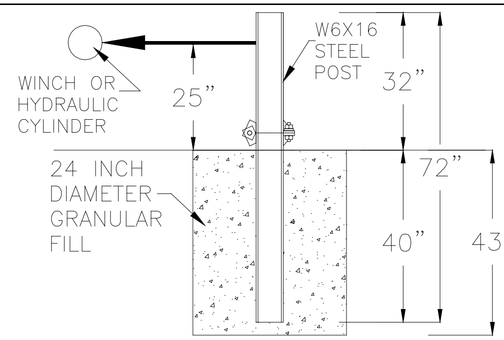


Dynamic Test Installation Details



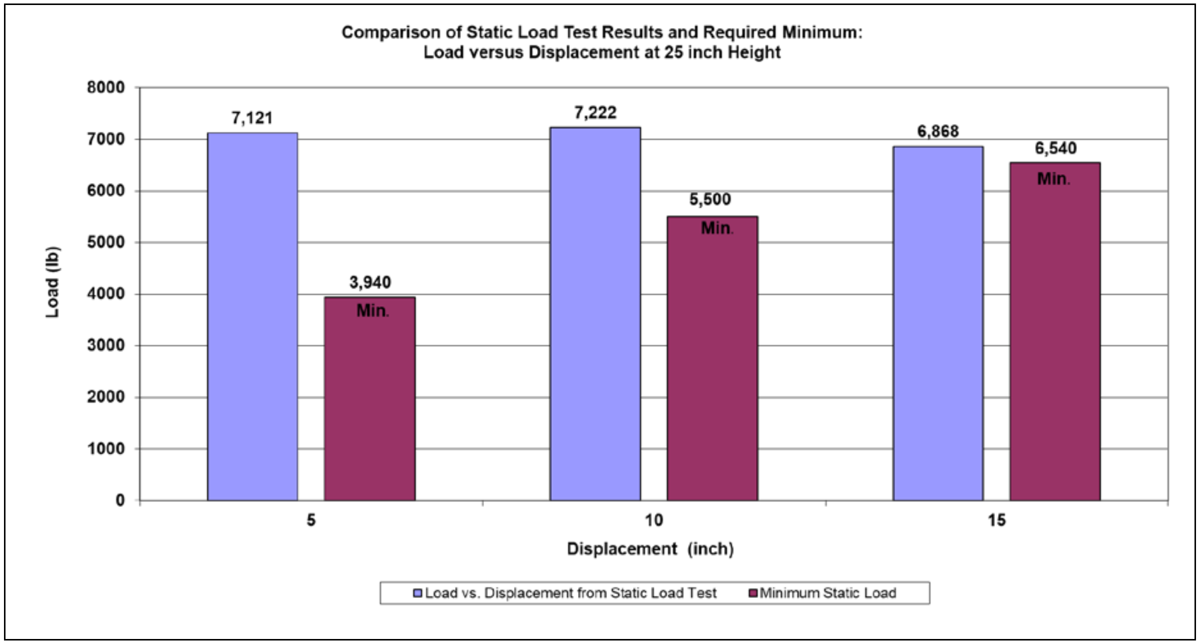


Static Load Test Installation Details



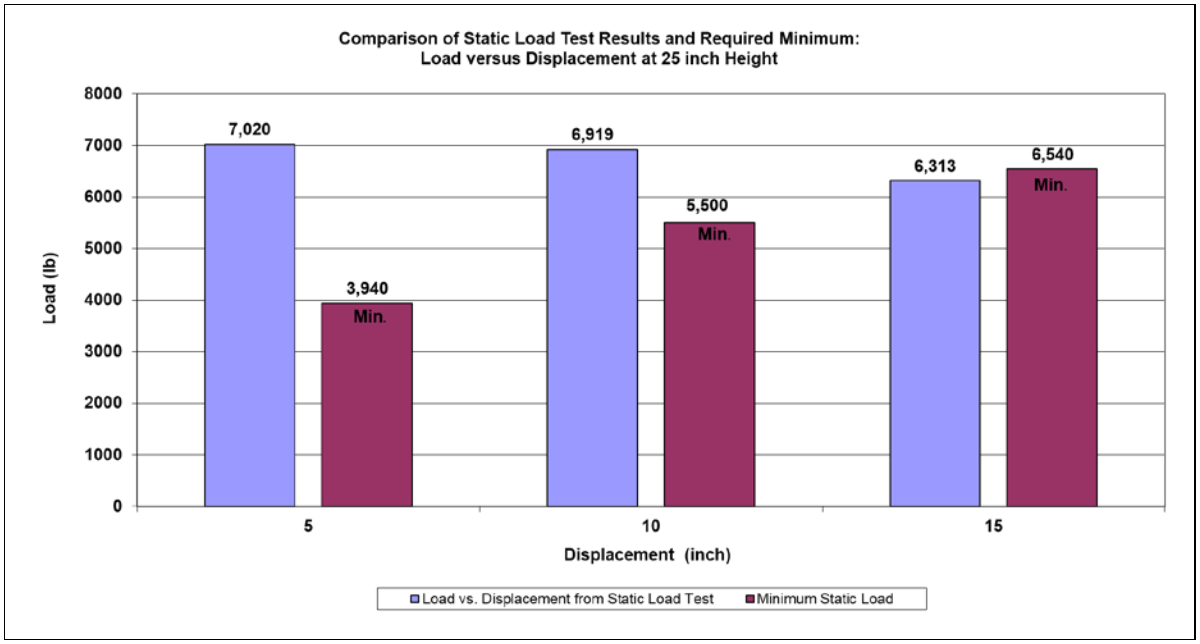
Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill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

Table C.2. Test Day Static Soil Strength Documentation for Test No. 440190-01-1.



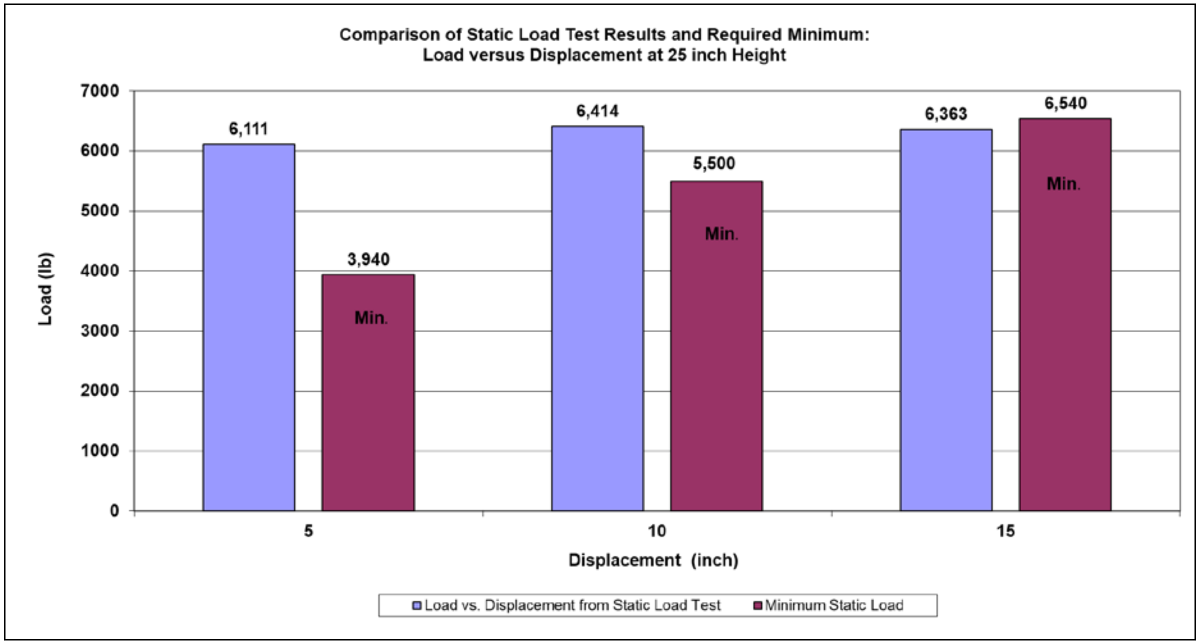
Date..	2020-09-30 for Test No. 440190-01-1
Test Facility and Site Location	TTI Proving Ground—3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis .	AASHTO M147 Grade B Soil-Aggregate
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.3. Test Day Static Soil Strength Documentation for Test No. 440190-01-3.



Date	2020-10-15 for Test No. 440190-01-3
Test Facility and Site Location	TTI Proving Ground—3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis	AASHTO M147 Grade B Soil-Aggregate
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.4. Test Day Static Soil Strength Documentation for Test No. 440190-01-2.



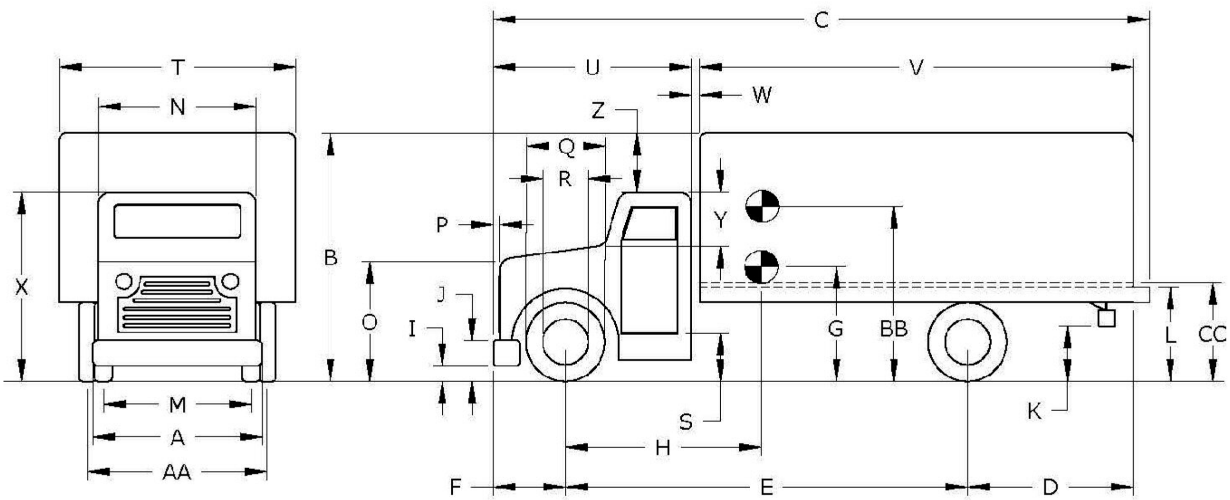
Date	2020-10-20 for Test No. 440190-2
Test Facility and Site Location	TTI Proving Ground—3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and Sieve Analysis	AASHTO M147 Grade B Soil-Aggregate
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

APPENDIX D. *MASH* TEST 4-12 (CRASH TEST NO. 440190-01-1)

D.1. VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 440190-01-1.

Date:	2020-9-30	Test No.:	440190-01-1	VIN No.:	3HAMMAANXCL148133
Year:	2012	Make:	INTERNATIONAL	Model:	4300
Odometer:	163956	Tire Size Front:	275/80R22.5	Tire Size Rear:	275/80R22.5



Vehicle Geometry: ☑ inches or ☐ mm

A	Front Bumper Width:	92.50	K	Rear Bumper Bottom:		U	Cab Length:	106.00
B	Overall Height:	134.00	L	Rear Frame Top:	38.00	V	Trailer/Box Length:	223.00
C	Overall Length:	329.70	M	Front Track Width:	80.00	W	Gap Width:	1.25
D	Rear Overhang:	83.00	N	Roof Width:	71.00	X	Overall Front Height:	98.50
E	Wheel Base:	206.70	O	Hood Height:	58.50	Y	Roof-Hood Distance:	30.00
F	Front Overhang:	40.00	P	Bumper Extension:		Z	Roof-Box Height Difference:	35.50
G	C.G. Height:		Q	Front Tire Width:	39.00	AA	Rear Track Width:	73.00
H	C.G. Horizontal Dist. w/Ballast:	125.50	R	Front Wheel Width:	23.50	BB	Ballast Center of Mass:	62.80
I	Front Bumper Bottom:	18.25	S	Bottom Door Height:	37.00	CC	Cargo Bed Height:	51.00
J	Front Bumper Top:	33.25	T	Overall Width:	96.00			

Allowable Range: C = 394 inches max.; E = 240 inches max.; CC = 49 ±2 inches; BB = 63 ±2 inches above ground;

Wheel Center Height Front	19.00	Wheel Well Clearance (Front)	9.00	Bottom Frame Height (Front)	25.50
Wheel Center Height Rear	19.00	Wheel Well Clearance (Rear)	3.00	Bottom Frame Height (Rear)	27.50

Table D.1. Vehicle Properties for Test No. 440190-01-1 (Continued).

Date: 2020-9-30 Test No.: 440190-01-1 VIN No.: 3HAMMAANXCL148133

Year: 2012 Make: INTERNATIONAL Model: 4300

WEIGHTS (☑ lb or ☐ kg)	CURB	TEST INERTIAL
$W_{front\ axle}$	7240	8750
$W_{rear\ axle}$	6220	13540
W_{TOTAL}	13460	22290

Allowable Range for CURB = 13,200 ±2200 lb | Allowable Range for TIM = 22,046 ±660 lb

Ballast: 8830 (☑ lb or ☐ kg) (as-needed) (See *MASH* Section 4.2.1.2 for recommended ballasting)

Mass Distribution (☑ lb or ☐ kg): **LF:** 4310 **RF:** 4440 **LR:** 6960 **RR:** 6580

Engine Type: DT

Engine Size: 466

Transmission Type:

☑ Auto or ☐ Manual

☐ FWD ☑ RWD ☐ 4WD

Accelerometer Locations (☑ inches or ☐ mm)

	x[1]	y	z[2]
Front:			
Center:	125.50	0	50.00
Rear:	255.00	0	50.00

Describe any damage to the vehicle prior to test: None

Other notes to include ballast type, dimensions, mass, location, center of mass, and method of attachment:

Two blocks 30 inches high x 60 inches wide x 30 inches long

Centered in middle of cargo bed

62.8 inches from ground to center of block

Tied down with four 5/16-inch cables per block

Performed by: SCD **Date:** 2020-9-30

[1] Referenced to the front axle

[2] Above ground

D.2. SEQUENTIAL PHOTOGRAPHS

0.000 s

0.250 s

0.500 s

0.750 s

Figure D.1. Sequential Photographs for Test No. 440190-01-1 (Overhead and Frontal Views).

1.000 s

1.250 s

1.500 s

1.750 s

Figure D.1. Sequential Photographs for Test No. 440190-01-1 (Overhead and Frontal Views) (Continued).

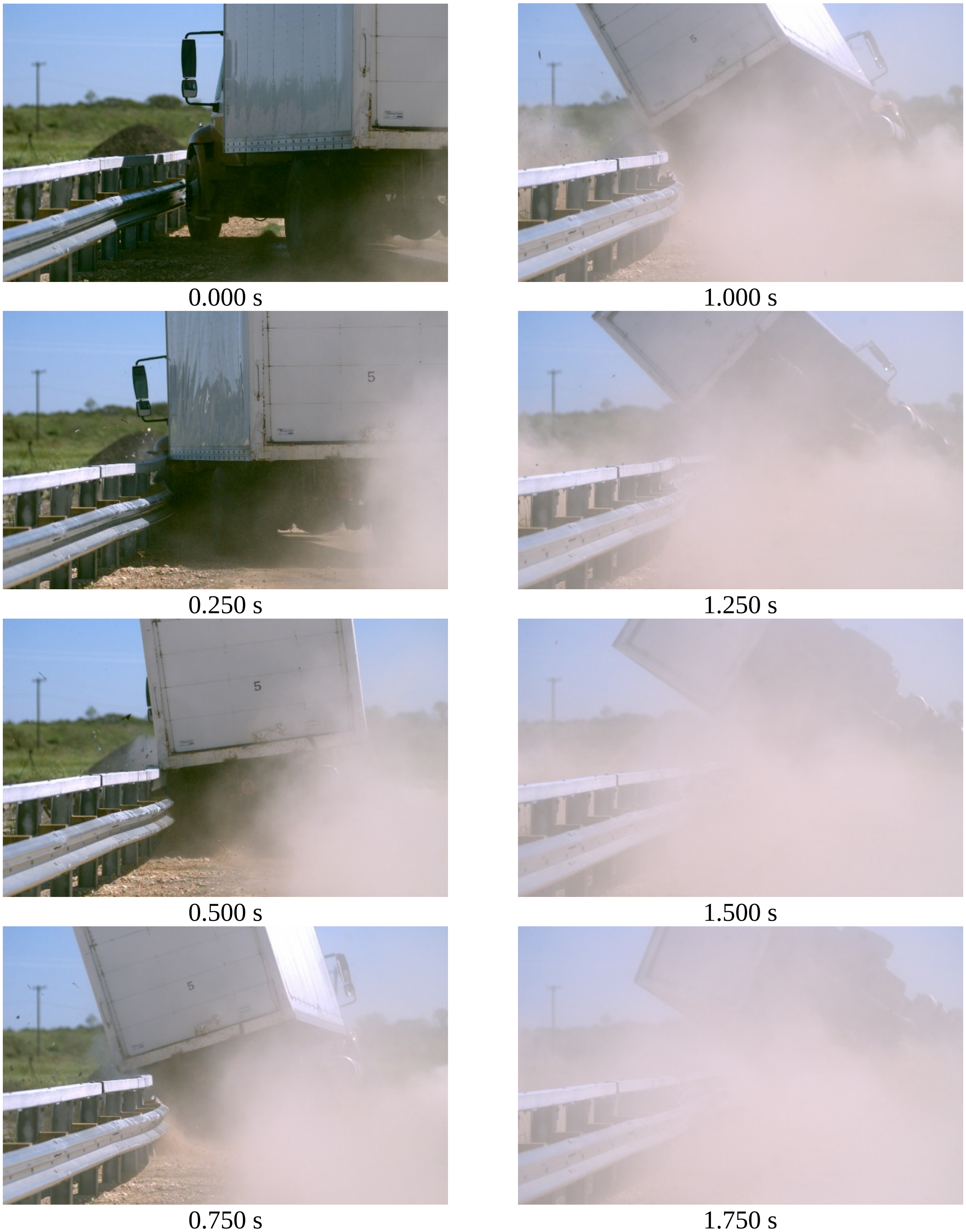
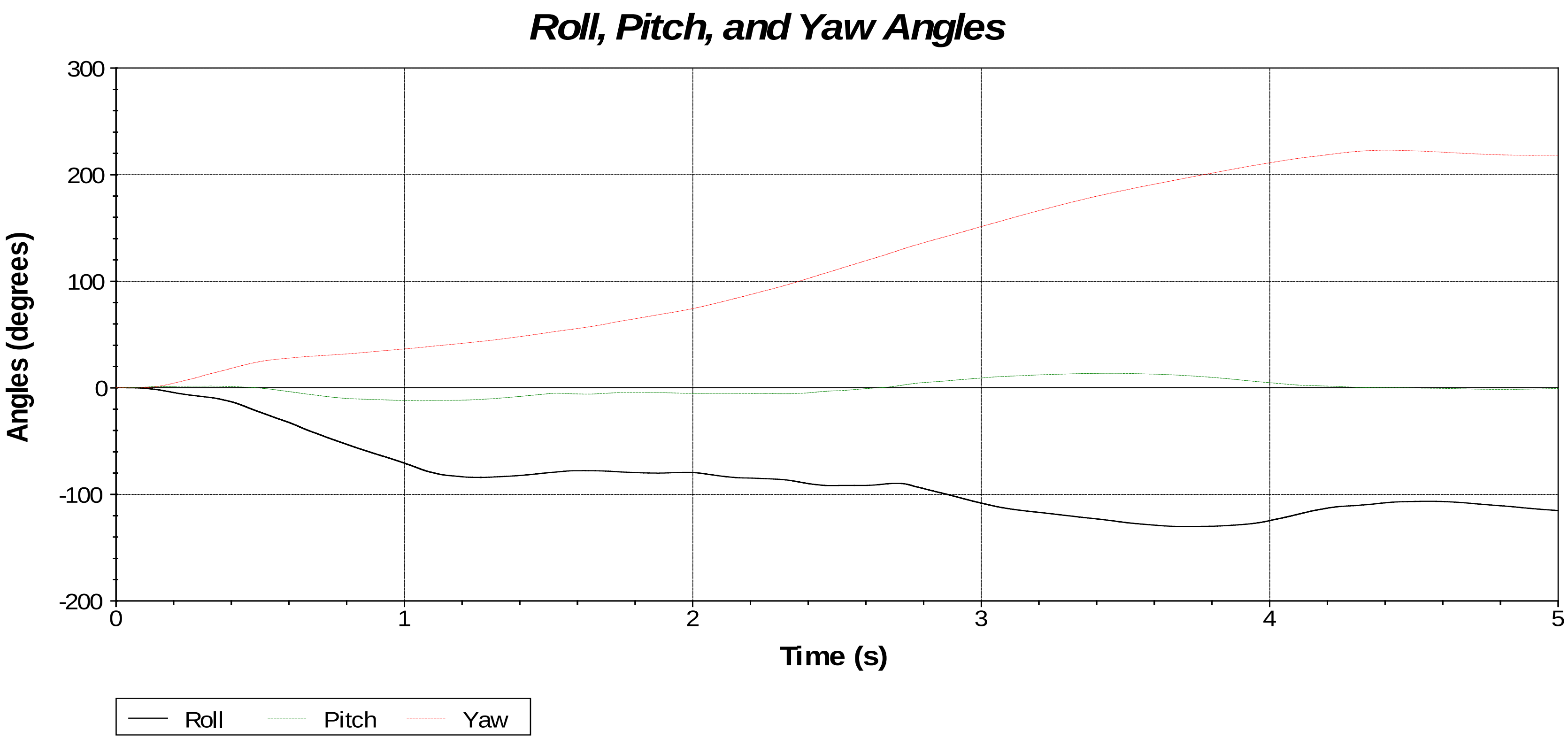
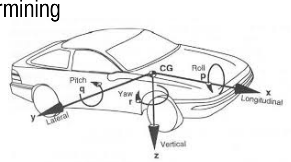


Figure D.2. Sequential Photographs for Test No. 440190-01-1 (Rear View).



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 440190-01-1
Test Standard Test Number: *MASH* Test 4-12
Test Article: *MASH* TL-4 Guardrail System
Test Vehicle: 2012 International 4300 Single Unit Truck
Inertial Mass: 22,290 lb
Gross Mass: 22,290 lb
Impact Speed: 58.6 mi/h
Impact Angle: 15.0°

Figure D.3. Vehicle Angular Displacements for Test No. 440190-01-1.

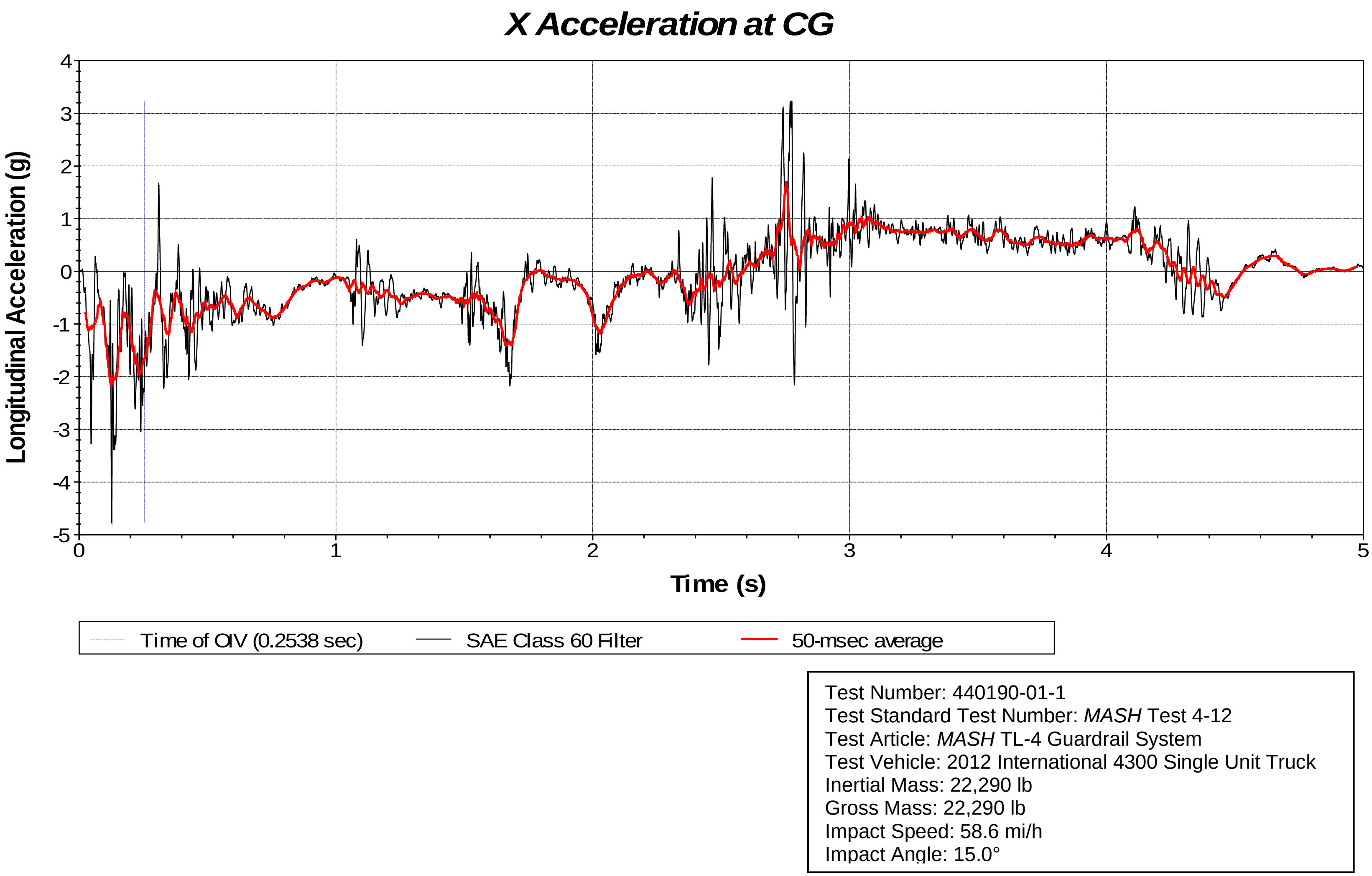
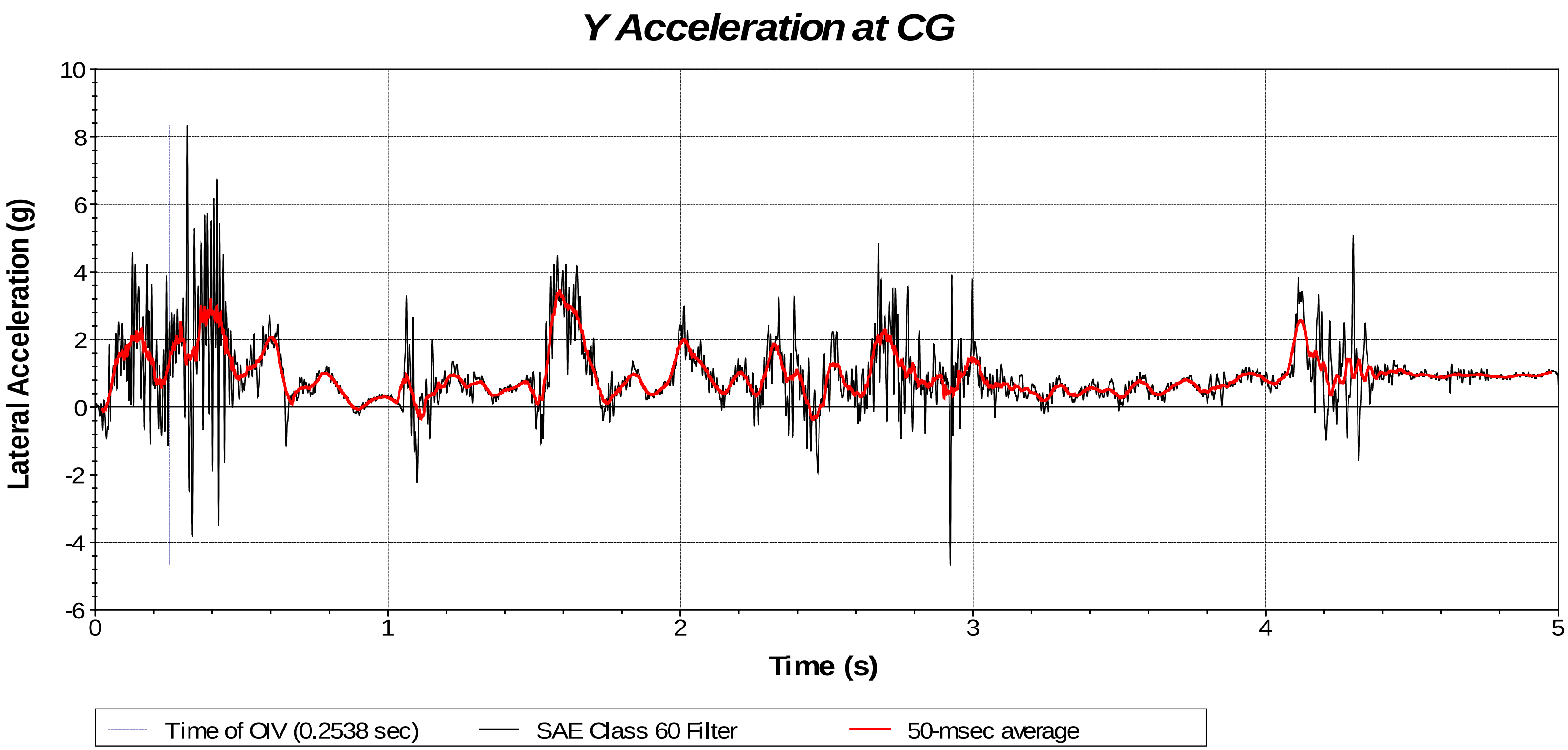


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 440190-01-1 (Accelerometer Located at Center of Gravity).



Test Number: 440190-01-1
Test Standard Test Number: *MASH* Test 4-12
Test Article: *MASH* TL-4 Guardrail System
Test Vehicle: 2012 International 4300 Single Unit Truck
Inertial Mass: 22,290 lb
Gross Mass: 22,290 lb
Impact Speed: 58.6 mi/h
Impact Angle: 15.0°

Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 440190-01-1 (Accelerometer Located at Center of Gravity).

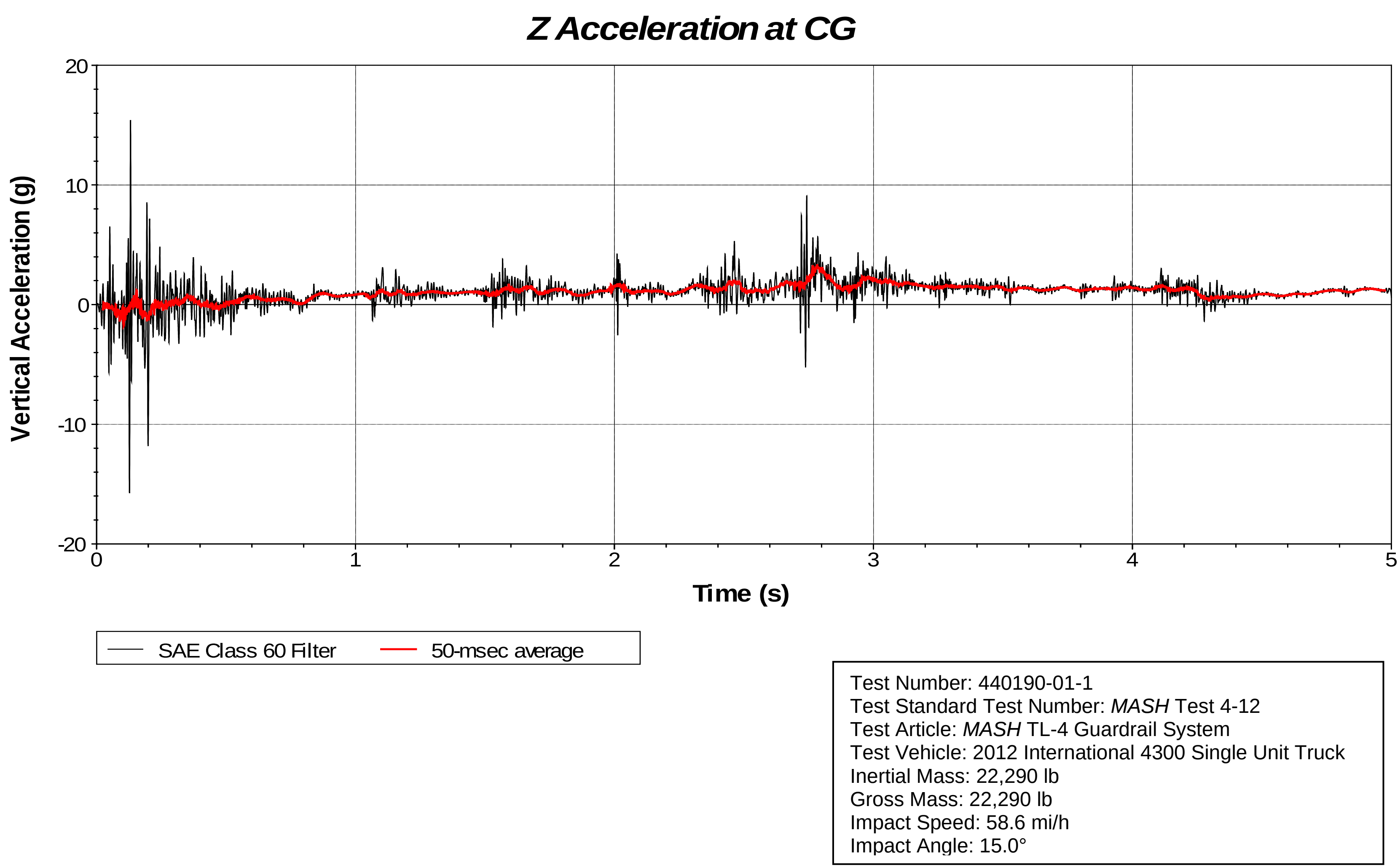


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 440190-01-1 (Accelerometer Located at Center of Gravity).

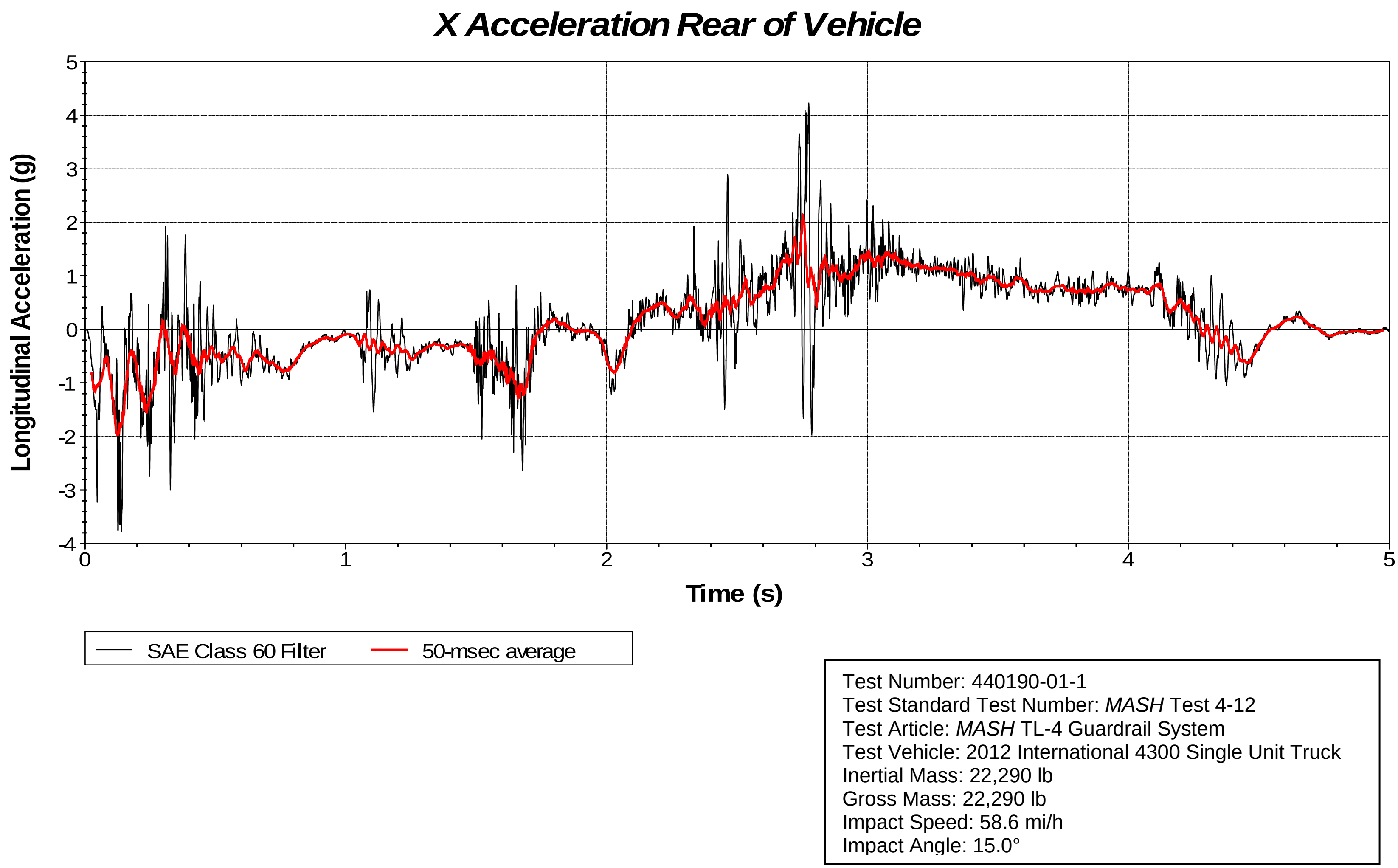


Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 440190-01-1 (Accelerometer Located at Rear of Vehicle).

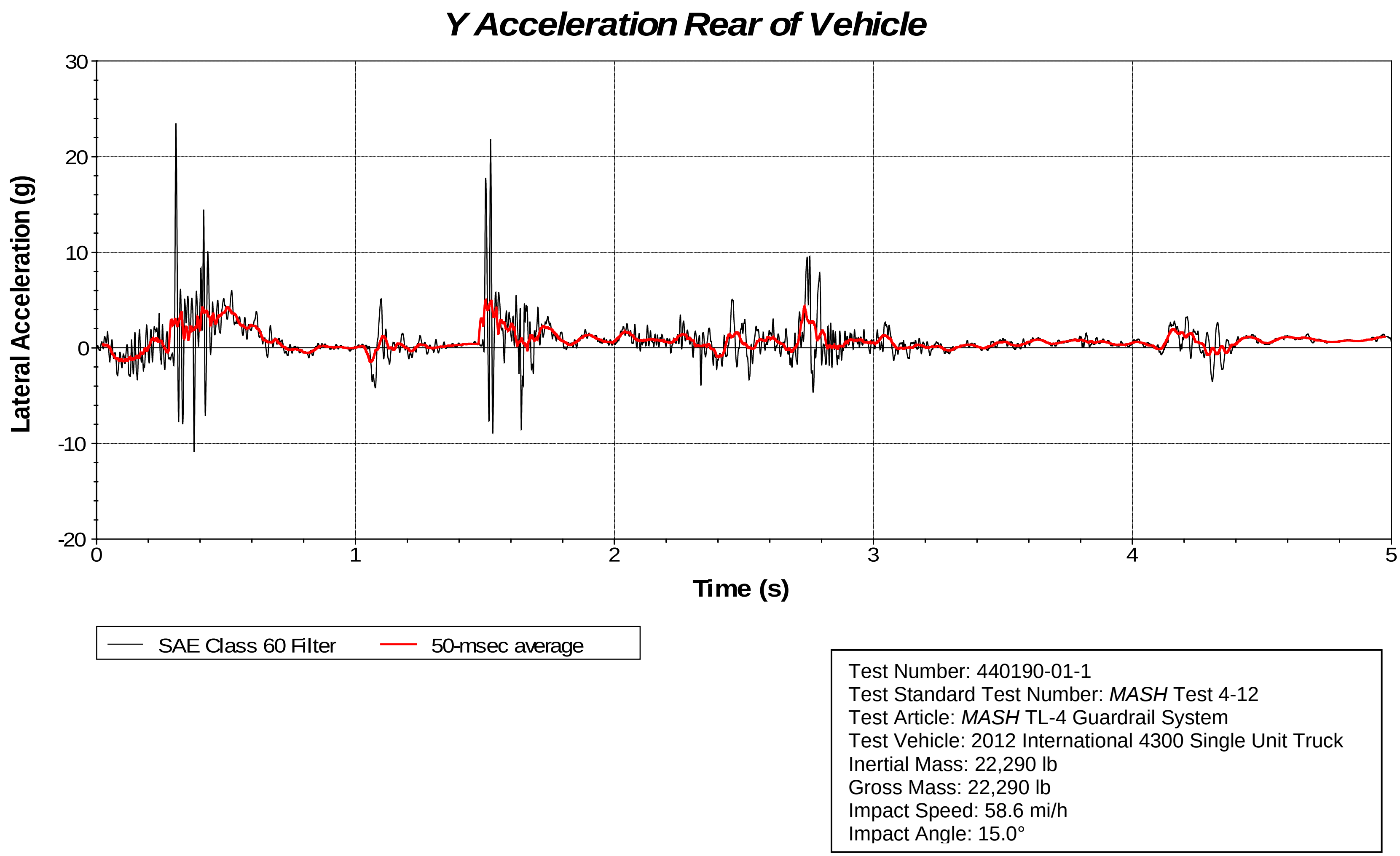
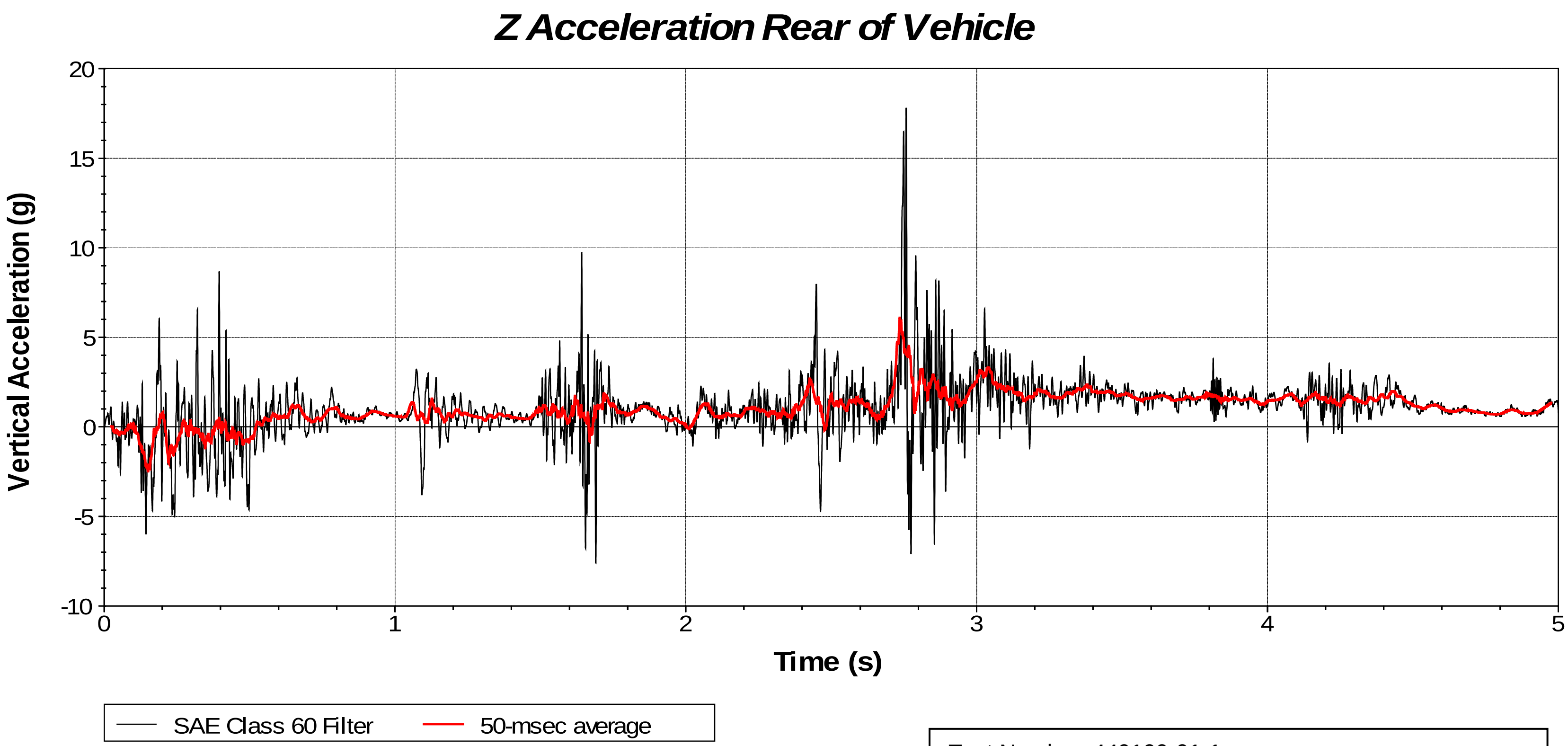


Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 440190-01-1 (Accelerometer Located at Rear of Vehicle).



Test Number: 440190-01-1
Test Standard Test Number: *MASH* Test 4-12
Test Article: *MASH* TL-4 Guardrail System
Test Vehicle: 2012 International 4300 Single Unit Truck
Inertial Mass: 22,290 lb
Gross Mass: 22,290 lb
Impact Speed: 58.6 mi/h
Impact Angle: 15.0°

Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 440190-01-1 (Accelerometer Located at Rear of Vehicle).

APPENDIX E. *MASH* TEST 4-10 (CRASH TEST NO. 440190-01-3)

E.1. VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 440190-01-3.

Date: 2020-10-15 Test No.: 440190-01-3 VIN No.: 3N1CN7AP4FL903320

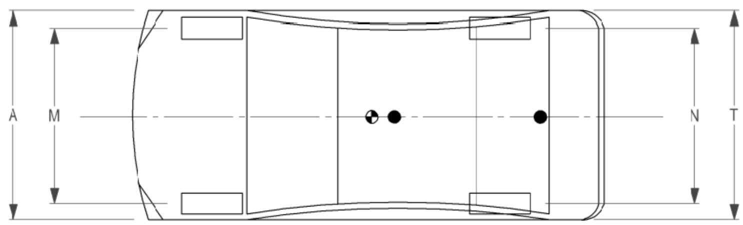
Year: 2015 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 135324 Tire Size: P185/65R15

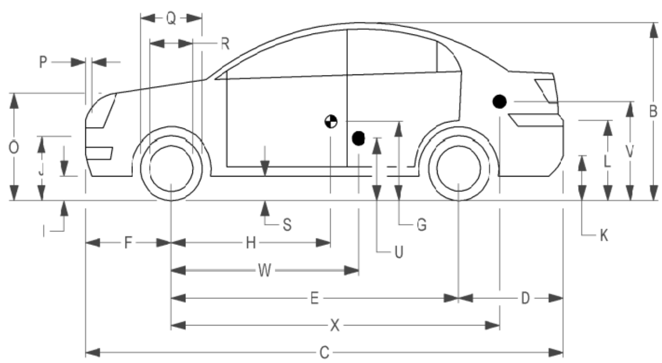
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None



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



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

Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	41.07	M	58.30	R	16.25	W	41.00
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.25	O	30.50	T	64.50		

Wheel Center Ht Front 11.50 Wheel Center Ht Rear 11.50 W-H -0.07

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}	1453	1454	1539
Back	1687	M_{rear}	967	974	1054
Total	3389	M_{Total}	2420	2428	2593

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

Mass Distribution:
lb LF: 762 RF: 692 LR: 468 RR: 506

Table E.2. Exterior Crush Measurements for Test No. 440190-01-3.

Date:	2020-10-15	Test No.:	440190-01-3	VIN No.:	3N1CN7AP4FL903320
Year:	2015	Make:	NISSAN	Model:	VERSA

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bmp ht	18	12	24	-	-	-	-	-	-	-16
2	Side plane at bmp ht	18	10	48	-	-	-	-	-	-	55
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

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

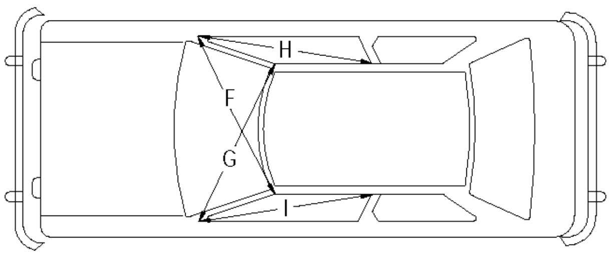
***Measure and document on the vehicle diagram the location of the maximum crush.

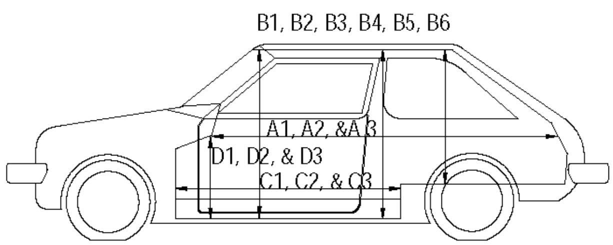
Note: Use as many lines/columns as necessary to describe each damage profile.

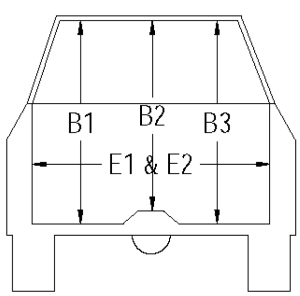
Table E.3. Occupant Compartment Measurements for Test No. 440190-01-3.

Date: 2020-10-15 Test No.: 440190-01-3 VIN No.: 3N1CN7AP4FL903320

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	75.00	75.00	0.00
A2	74.00	74.00	0.00
A3	74.00	74.00	0.00
B1	43.00	43.00	0.00
B2	37.00	37.00	0.00
B3	43.00	43.00	0.00
B4	46.50	46.50	0.00
B5	42.50	42.50	0.00
B6	46.50	46.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	12.50	12.50	0.00
D2	0.00	0.00	0.00
D3	10.00	10.00	0.00
E1	48.00	45.25	-2.75
E2	48.75	50.75	2.00
F	47.50	47.50	0.00
G	47.50	47.50	0.00
H	39.00	39.00	0.00
I	39.00	39.00	0.00
J*	48.50	44.50	-4.00

E.2. SEQUENTIAL PHOTOGRAPHS

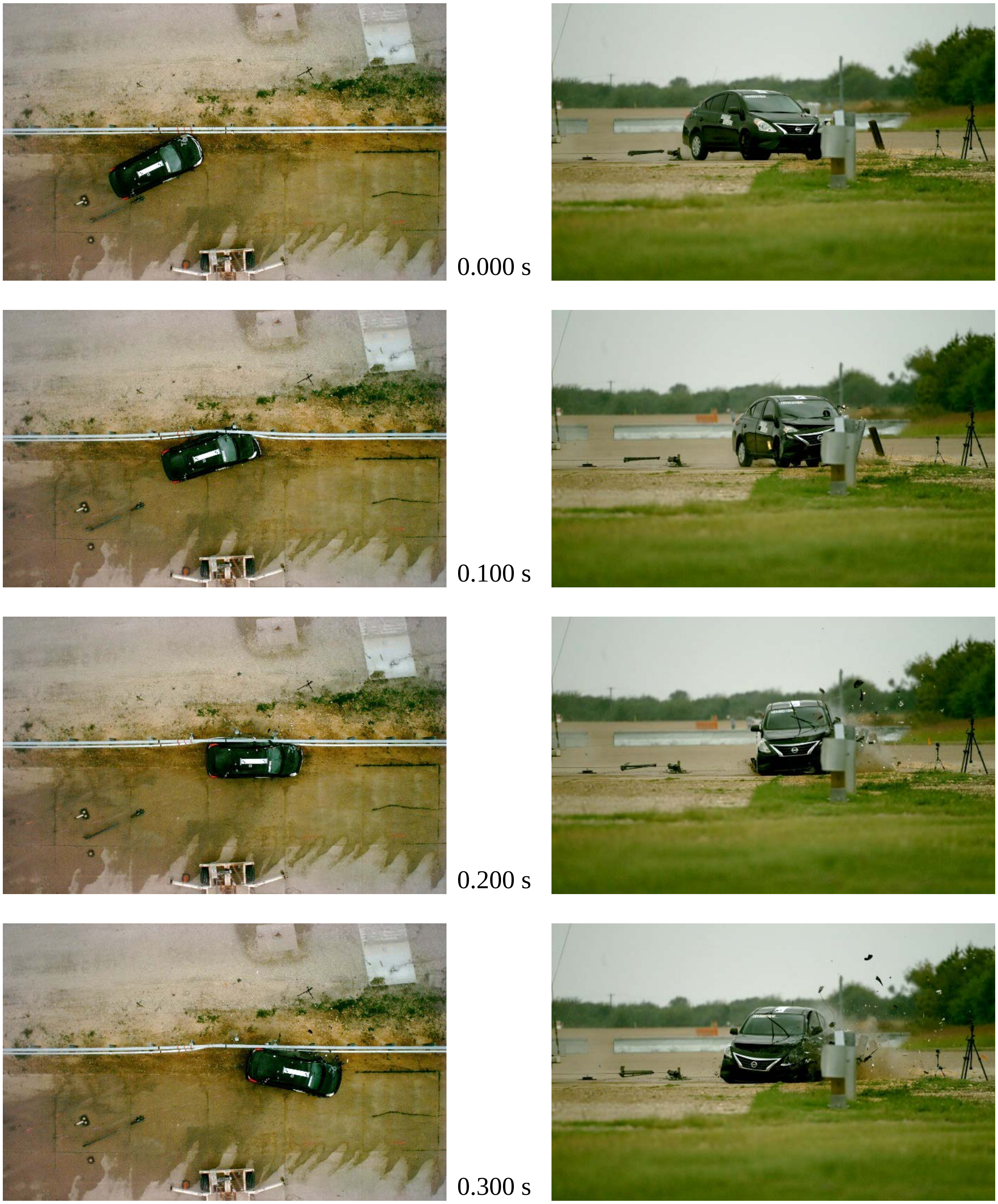
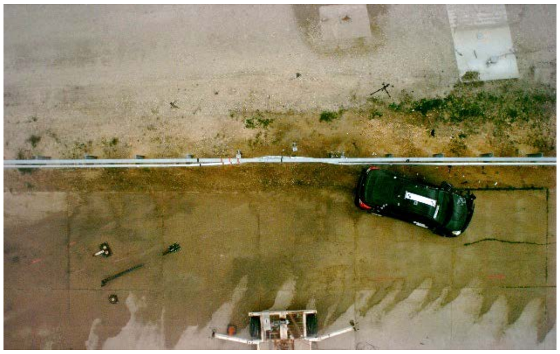


Figure E.1. Sequential Photographs for Test No. 440190-01-3 (Overhead and Frontal Views).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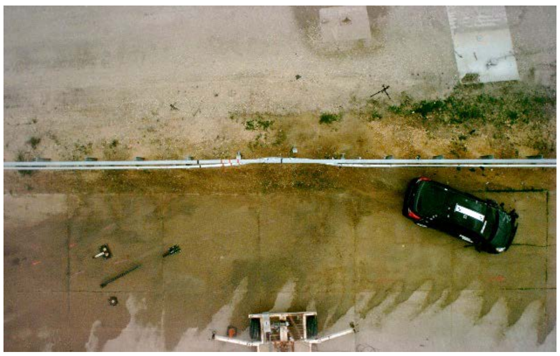

0.500 s



0.600 s



0.700 s


Figure E.1. Sequential Photographs for Test No. 440190-01-3 (Overhead and Frontal Views) (Continued).

0.000 s

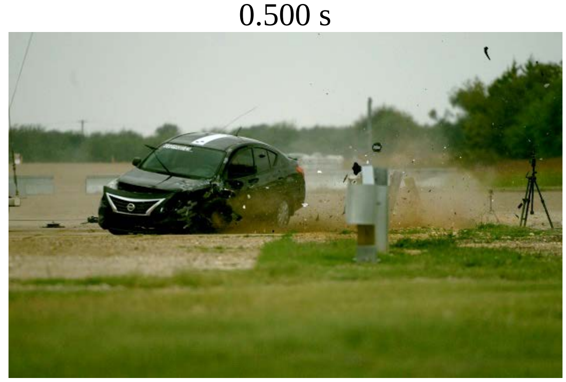
0.100 s

0.200 s

0.300 s

0.400 s

0.500 s

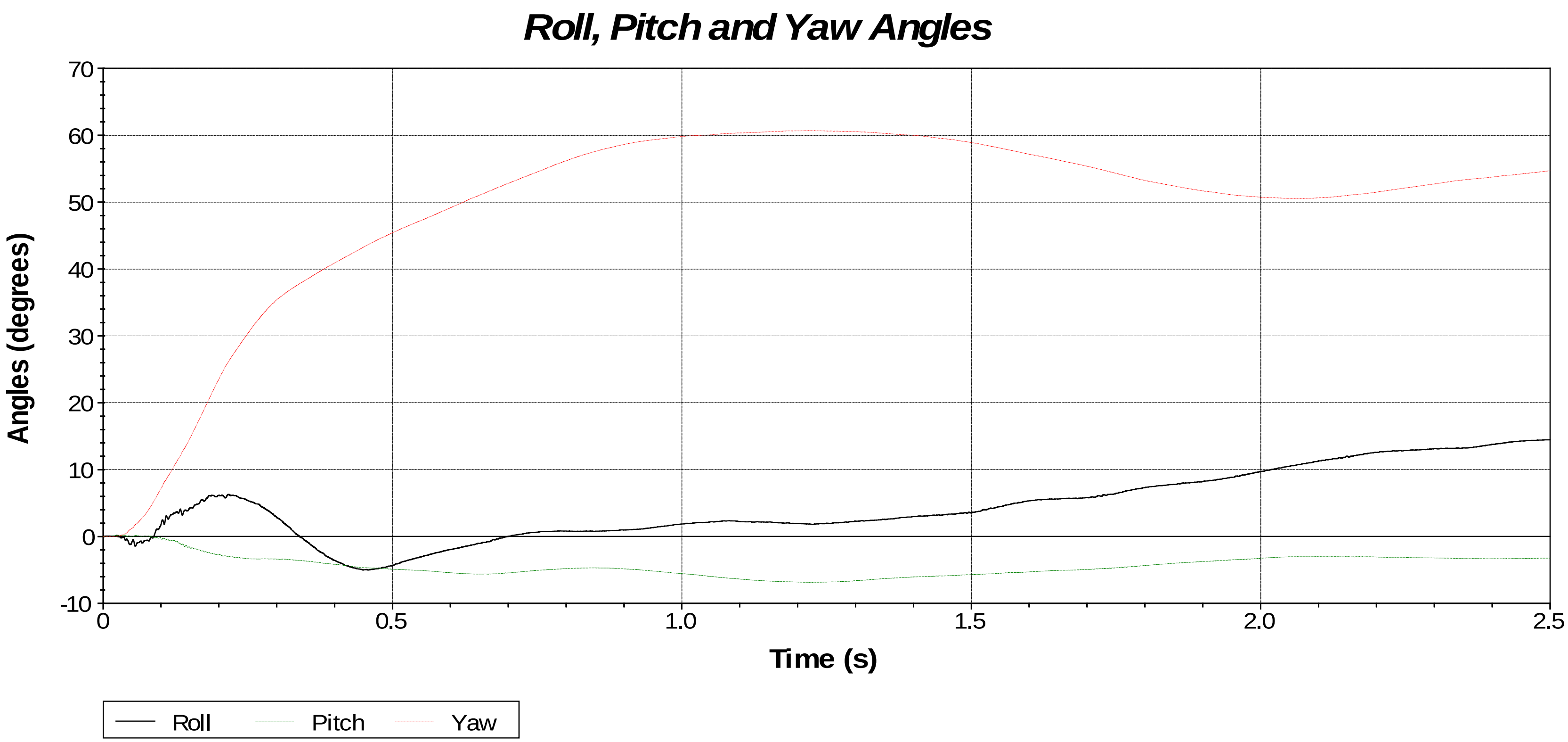


0.600 s

0.700 s

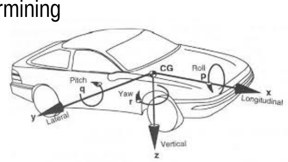
Figure E.2. Sequential Photographs for Test No. 440190-01-3 (Rear View).

E.3. VEHICLE ANGULAR DISPLACEMENTS



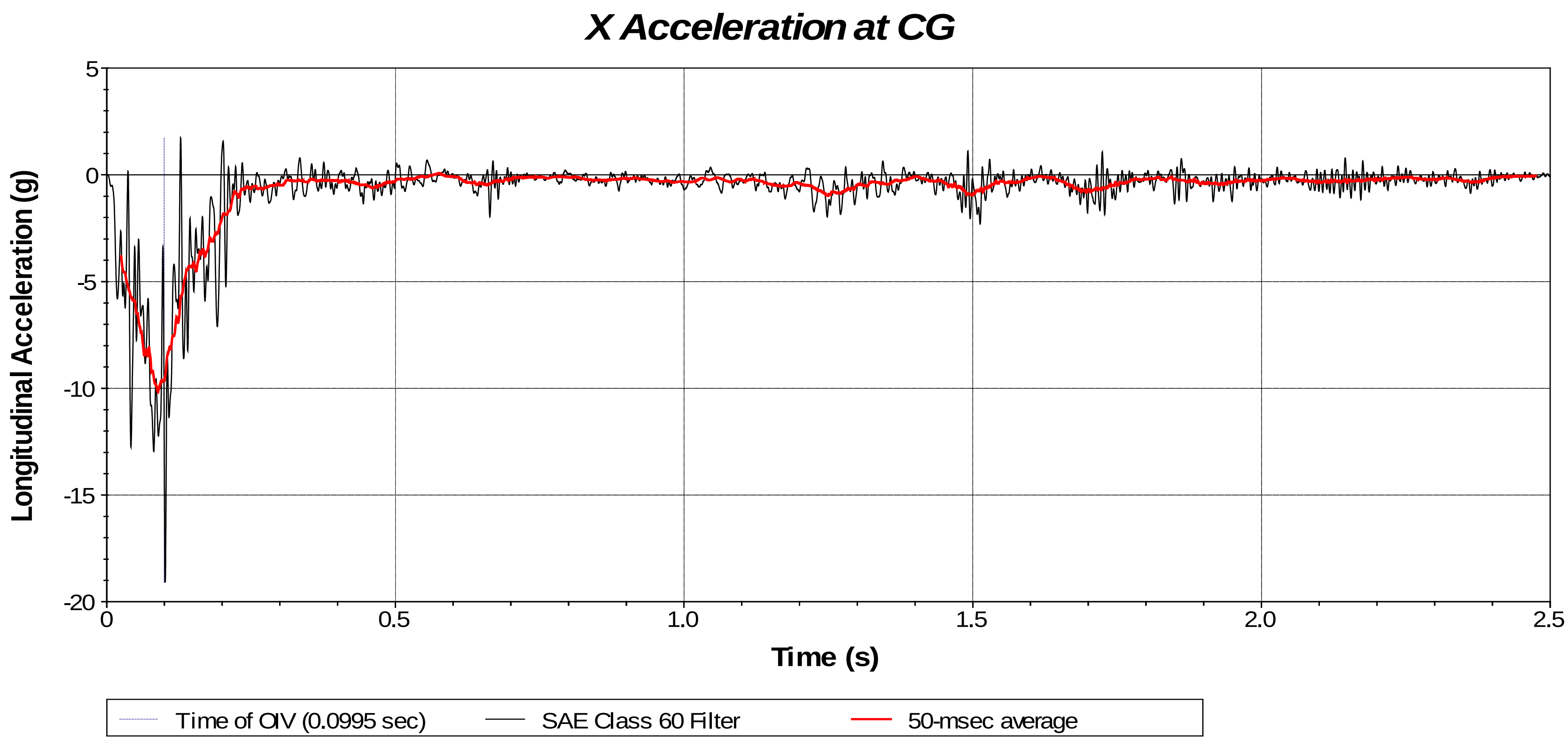
Axes are vehicle-fixed.
Sequence for determining orientation:

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



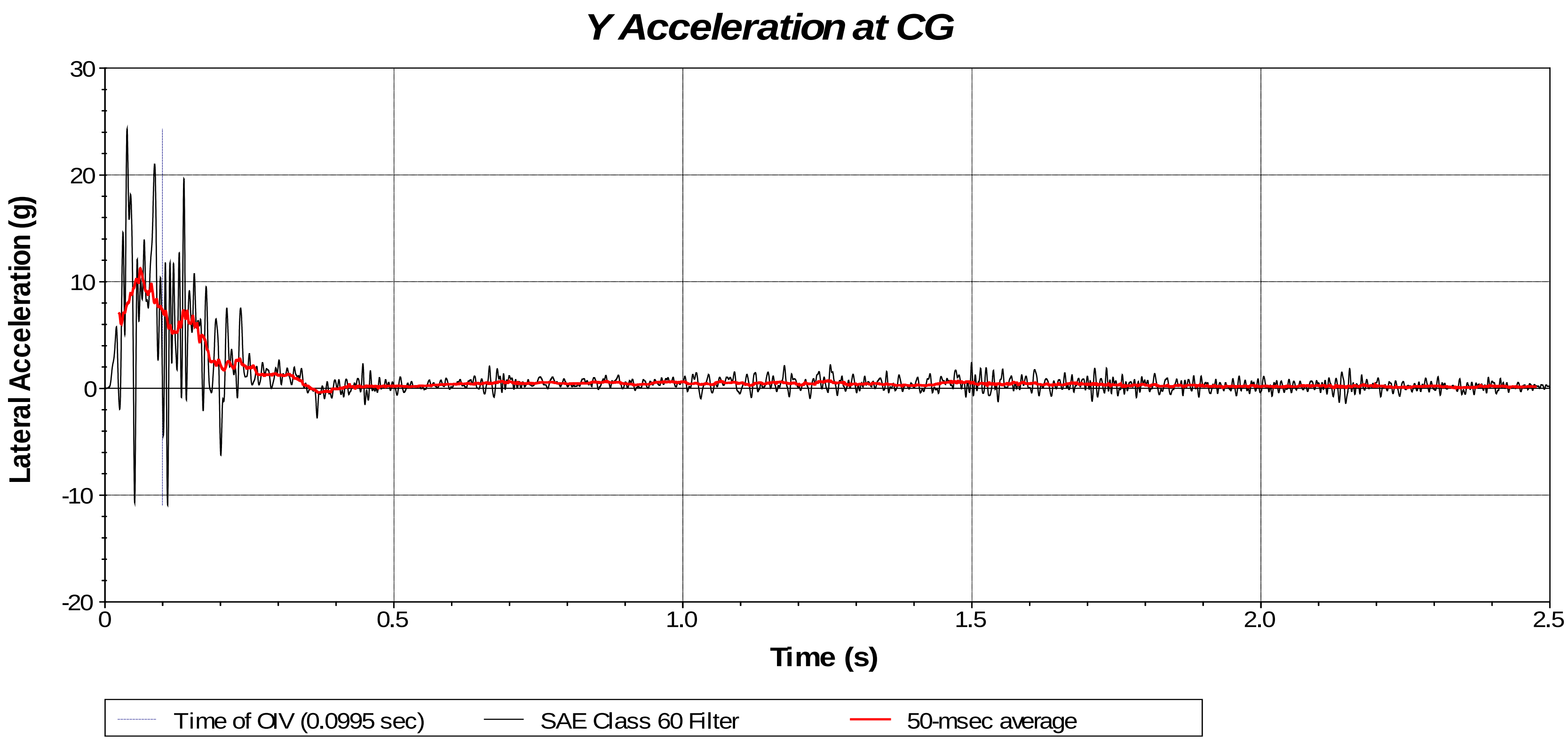
Test Number: 440190-01-3
Test Standard Test Number: *MASH* Test 4-10
Test Article: *MASH* TL-4 Guardrail System
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2428 lb
Gross Mass: 2593 lb
Impact Speed: 64.4 mi/h
Impact Angle: 25.3°

Figure E.3. Vehicle Angular Displacements for Test No. 440190-01-3.



Test Number: 440190-01-3
Test Standard Test Number: *MASH* Test 4-10
Test Article: *MASH* TL-4 Guardrail System
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2428 lb
Gross Mass: 2593 lb
Impact Speed: 64.4 mi/h
Impact Angle: 25.3°

Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 440190-01-3 (Accelerometer Located at Center of Gravity).



Test Number: 440190-01-3
Test Standard Test Number: *MASH* Test 4-10
Test Article: *MASH* TL-4 Guardrail System
Test Vehicle: 2015 Nissan Versa
Inertial Mass: 2428 lb
Gross Mass: 2593 lb
Impact Speed: 64.4 mi/h
Impact Angle: 25.3°

Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 440190-01-3 (Accelerometer Located at Center of Gravity).

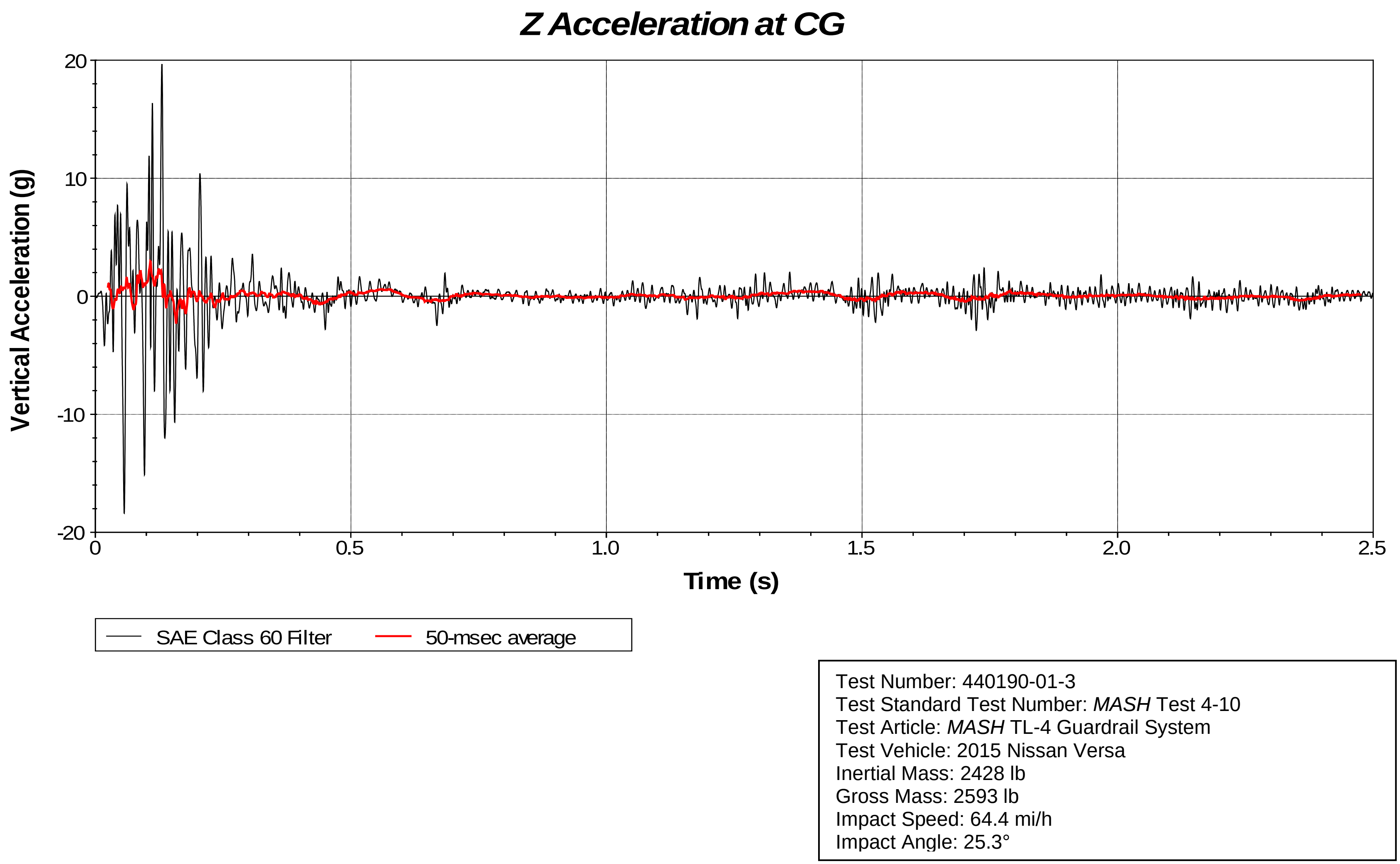


Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 440190-01-3 (Accelerometer Located at Center of Gravity).

APPENDIX F. *MASH* TEST 4-11 (CRASH TEST NO. 440190-01-2)

F.1. VEHICLE PROPERTIES AND INFORMATION

Table F.1. Vehicle Properties for Test No. 440190-01-2.

Date: 2020-10-20 Test No.: 440191-01-2 VIN No.: 1C6RR6FT5GS382081

Year: 2016 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 106996

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

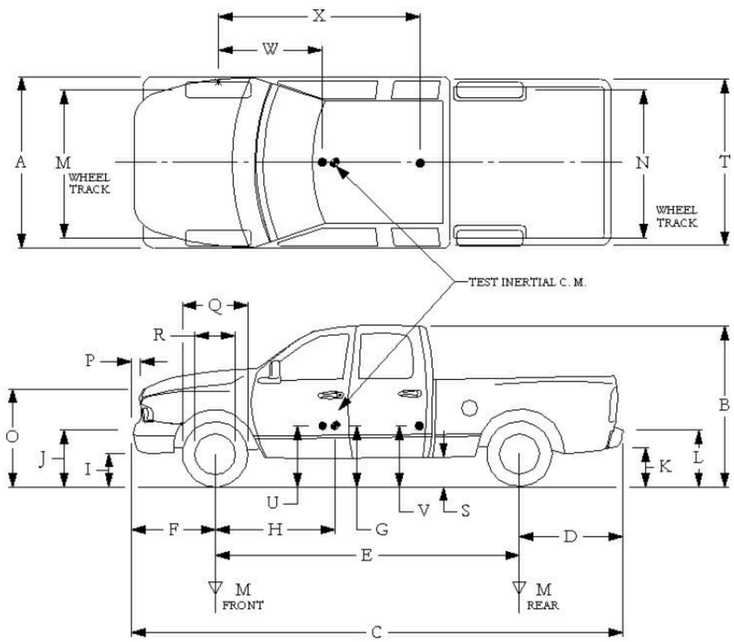
NOTES: None

Engine Type: V-8
Engine CID: 5.7 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	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.00	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.59	M	68.50	R	18.00	W	60.60
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2971	2885	2970
Back	3900	M_{rear}	2071	2188	2268
Total	6700	M_{Total}	5042	5073	5238

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

Mass Distribution:
lb LF: 1438 RF: 1447 LR: 1128 RR: 1060

Table F.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 440190-01-2.

Date: 2020-10-20 Test No.: 440191-01-2 VIN: 1C6RR6FT5GS382081

Year: 2016 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 106996

Engine: 5.7 L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 130 (440 lb max)

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

Measured Vehicle Weights: (lb)								
LF:	1438		RF:	1447		Front Axle:	2885	
LR:	1128		RR:	1060		Rear Axle:	2188	
Left:	2566		Right:	2507		Total:	5073	
							5000 ±110 lb allowed	
Wheel Base:	140.50	inches	Track: F:	68.50	inches	R:	68.00	inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed				
Center of Gravity, SAE J874 Suspension Method								
X:	60.60	inches	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	-0.40	inches	Left -	Right +	of Vehicle Centerline			
Z:	28	inches	Above Ground	(minumum 28.0 inches allowed)				

Hood Height: 46.00 inches Front Bumper Height: 27.00 inches

43 ±4 inches allowed

Front Overhang: 40.00 inches Rear Bumper Height: 30.00 inches

39 ±3 inches allowed

Overall Length: 227.50 inches

237 ±13 inches allowed

Table F.3. Exterior Crush Measurements for Test No. 440190-01-2.

Date:	2020-10-20	Test No.:	440191-01-2	VIN No.:	1C6RR6FT5GS382081
Year:	2016	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	Front plane at bmp ht	15	11	30	-	-	-	-	-	-	-8
2	Side plane at bmp ht	15	9.5	62	-	-	-	-	-	-	74
	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.

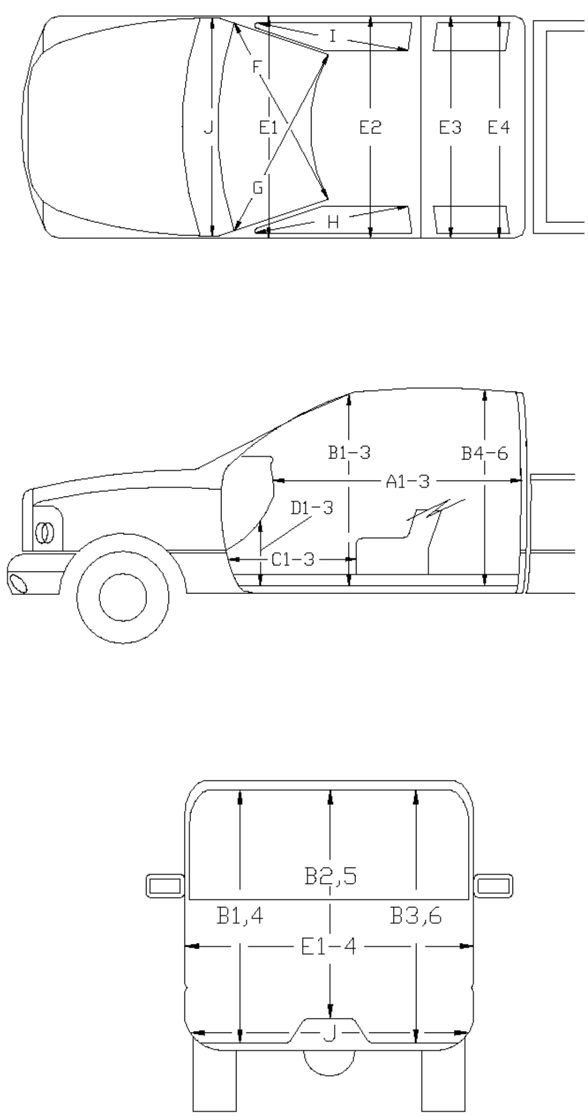
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 F.4. Occupant Compartment Measurements for Test No. 440190-01-2.

Date:	2020-10-20	Test No.:	440191-01-2	VIN No.:	1C6RR6FT5GS382081
Year:	2016	Make:	RAM	Model:	1500



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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	25.50	-0.50
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	58.50	0.00
E2	63.50	64.00	0.50
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	24.50	-0.50

F.2. SEQUENTIAL PHOTOGRAPHS

0.000 s

0.100 s

0.200 s

0.300 s

Figure F.1. Sequential Photographs for Test No. 440190-01-2 (Overhead and Frontal Views).


0.400 s



0.500 s



0.600 s



0.700 s


Figure F.1. Sequential Photographs for Test No. 440190-01-2 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

0.400 s

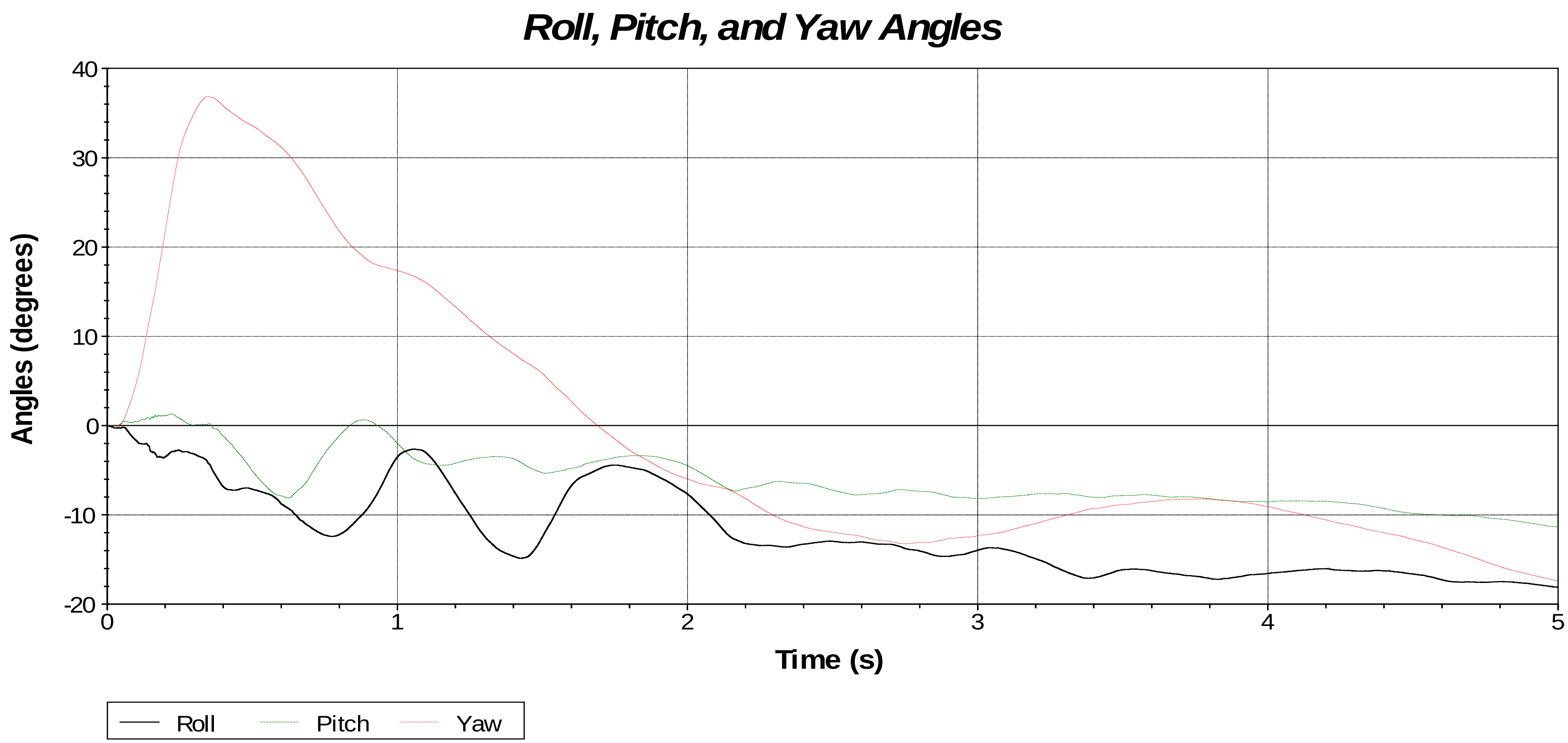
0.500 s

0.600 s

0.700 s

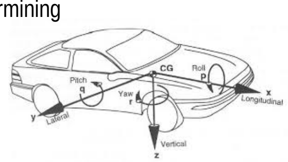
Figure F.2. Sequential Photographs for Test No. 440190-01-2 (Rear View).

F.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 440190-01-2
Test Standard Test Number: *MASH* Test 4-11
Test Article: *MASH* TL-4 Guardrail System
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5073 lb
Gross Mass: 5238 lb
Impact Speed: 64.4 mi/h
Impact Angle: 25.0°

Figure F.3. Vehicle Angular Displacements for Test No. 440190-01-2.

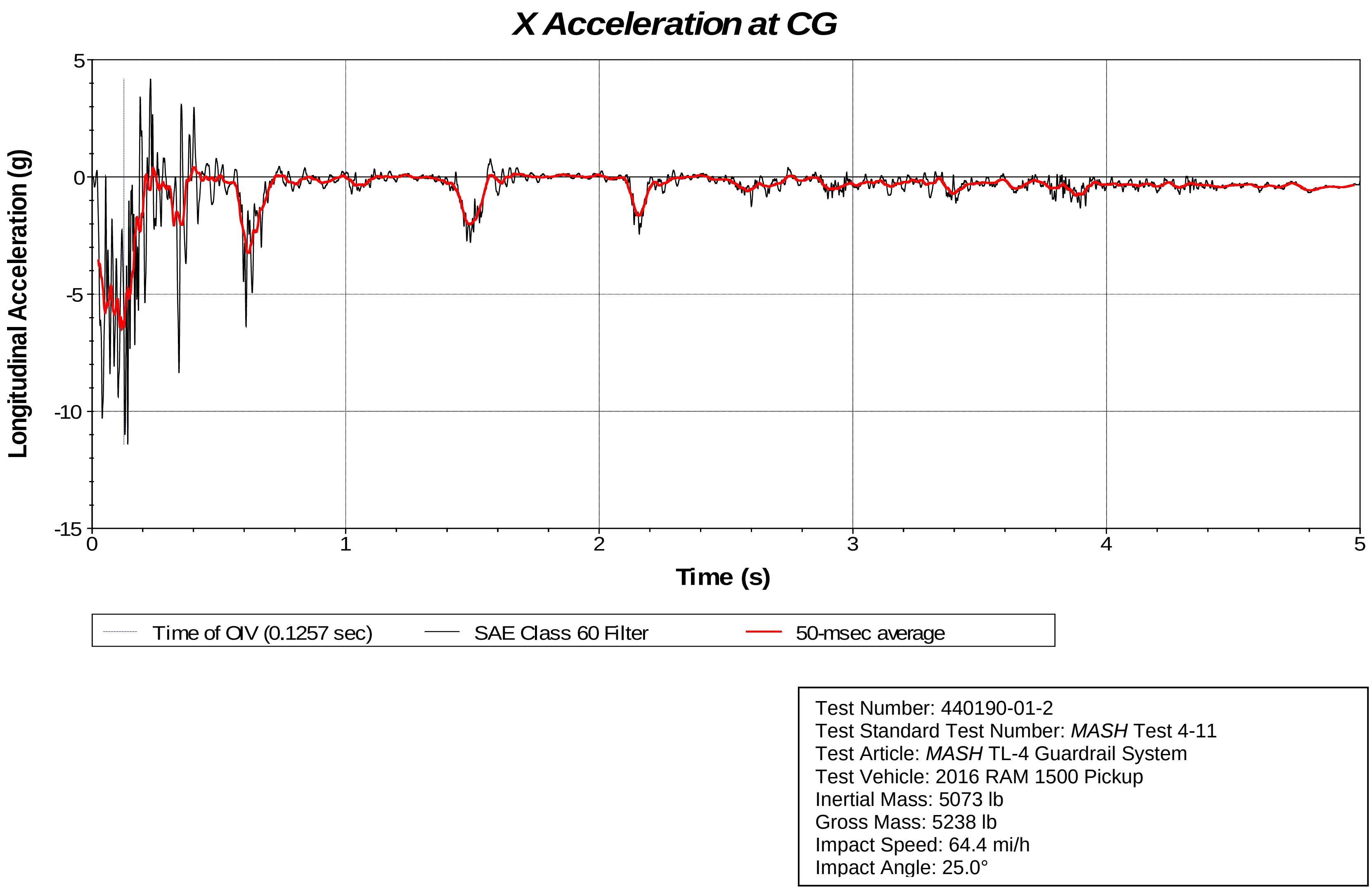
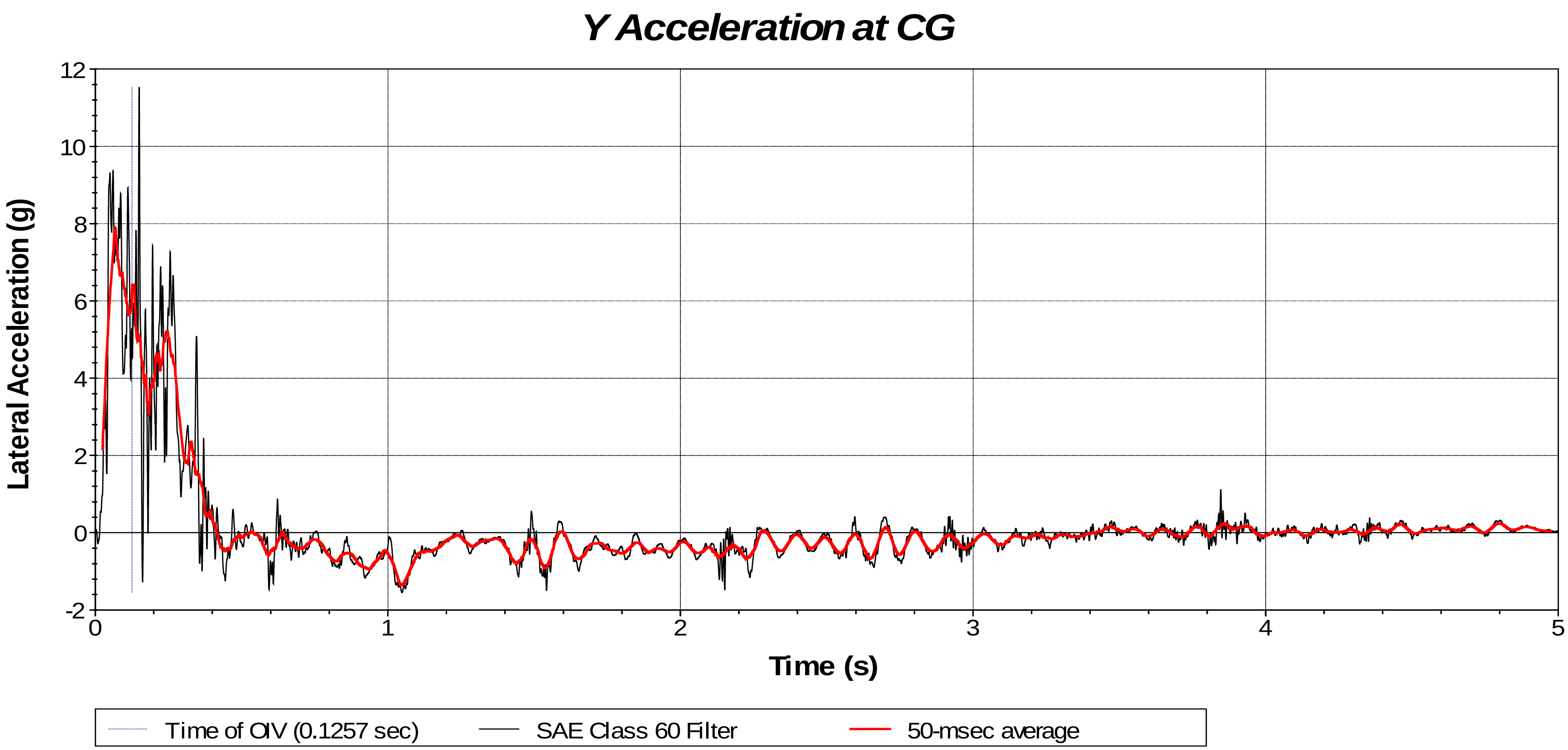


Figure F.4. Vehicle Longitudinal Accelerometer Trace for Test No. 440190-01-2 (Accelerometer Located at Center of Gravity).



Test Number: 440190-01-2
Test Standard Test Number: *MASH* Test 4-11
Test Article: *MASH* TL-4 Guardrail System
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5073 lb
Gross Mass: 5238 lb
Impact Speed: 64.4 mi/h
Impact Angle: 25.0°

Figure F.5. Vehicle Lateral Accelerometer Trace for Test No. 440190-01-2 (Accelerometer Located at Center of Gravity).

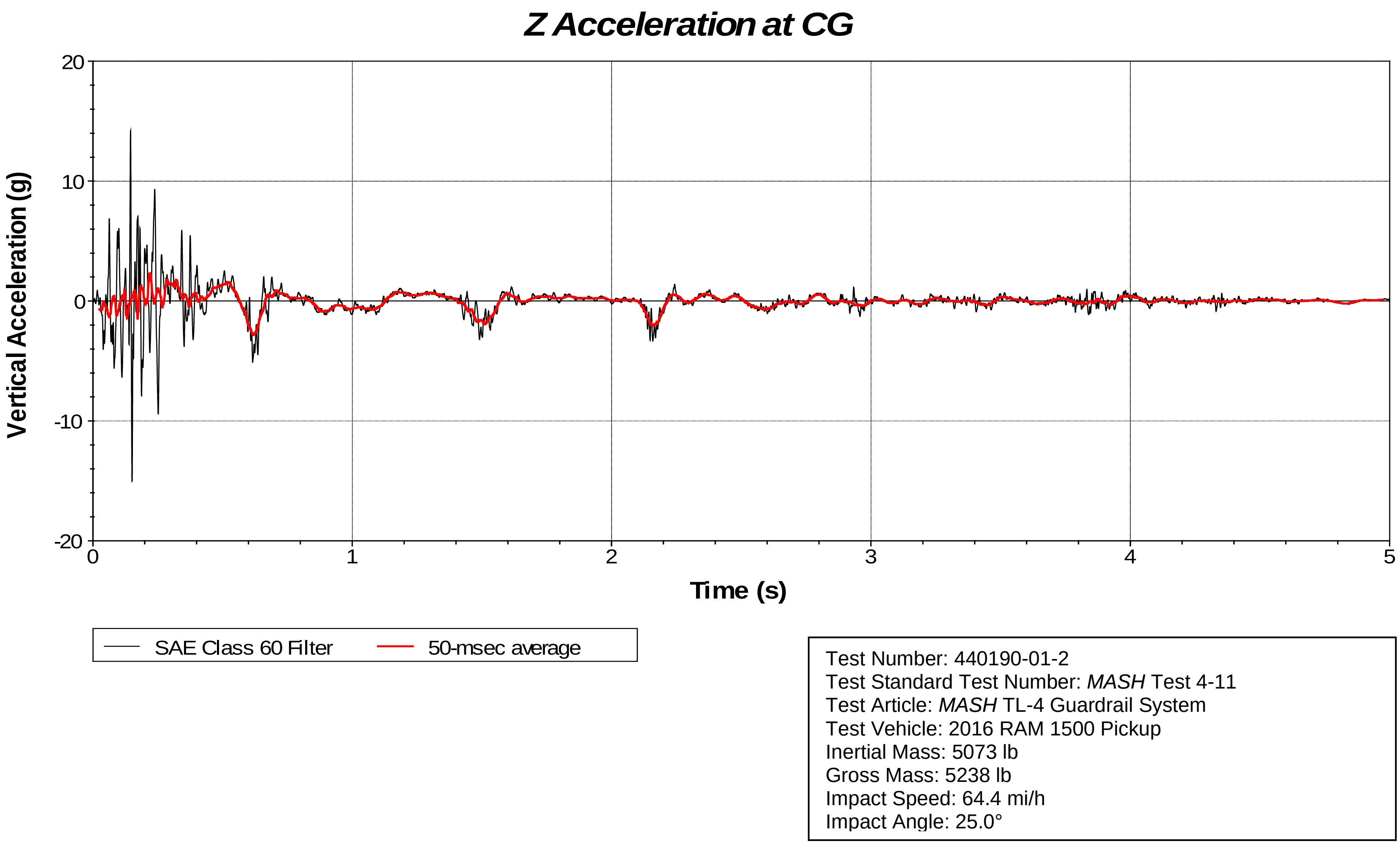


Figure F.6. Vehicle Vertical Accelerometer Trace for Test No. 440190-01-2 (Accelerometer Located at Center of Gravity).

APPENDIX G. VALUE OF RESEARCH

The estimated Value of Research (VOR) for this project is summarized in Figure G.1. The economic variables considered in developing the VOR, sources of these variables, and the description of economic based calculations used are described herein.

Data obtained from TxDOT's Crash Records Information System (CRIS) indicates that in years 2018 and 2019, a total of 144 crashes occurred across Texas where the highest crash injury severity was type K, indicating at least one fatality in the crash event. In obtaining the number of crashes, the researchers excluded any crashes that occurred on city roads, or on 'non-roadway' sites. Similarly, the researchers excluded any crashes that occurred on highways with posted speed limits of less than 50 mi/h. The above exclusions were intended to focus on highspeed roads only, which are more likely candidates for *MASH* TL-4 design speeds.

The 144 crashes included all types of 'objects struck' in the crash event. These include many roadway and roadside features such as barriers, other vehicles, work zone devices, etc. For a conservative estimate, the researchers excluded all 'object struck' types except for slopes and embankments. This implied that only those crashes in which the vehicle left the roadway without striking another object were considered. Presence of a barrier in these types of crashes has the possibility of preventing the crash or reducing the injury severity. In the 2018 to 2019 period, the number of type K severity crashes with 'object struck' as ditch and embankment were 32 and 39, respectively. The average annual number of K injury severity crashes for both categories combined was thus 35.5 crashes.

Since this number data does not exclusively include crashes involving *MASH* TL-4 design speed, the researchers used a conservative estimate that only 25% of these crashes can be assumed to be on roadways that qualify to have design speeds of *MASH* TL-4. This reduced the estimated annual crashes to 8.88.

The researchers acknowledged that not all the above crashes can be prevented by placement of a *MASH* TL-4 barrier. Thus, it was conservatively assumed that only 25% of the above crashes can be prevented or have their injury severity reduced by placing a TL-4 barrier. This led to an estimated 2.22 qualified crashes.

The researchers further acknowledged that the newly developed *MASH* TL-4 guardrail would be used in conjunction with other TxDOT concrete barriers. Thus, it was conservatively assumed that only 25% of the above crashes can be prevented by using the new *MASH* TL-4 guardrail. With this assumption, the number of crashes with highest injury severity of K that can be prevented by using the TL-4 guardrail was estimated to be 0.56 per year.

Since fatal crashes can sometimes involve more than one fatality, the total number of fatalities in crashes involving highest injury severity of K is greater than the total number of such crashes. However, for the purposes of conservatism, it was assumed that the number of fatalities involved in the above mentioned 0.56 crashes was the same as the number of crashes. Thus, with the state-wide use of the new guardrail, it was estimated that 0.56 fatalities could be prevented each year.

The researchers acknowledge that crashes typically involve other less severe injury severity types, which also contribute to the economic impact of a crash. However, to remain conservative in the estimate, the research team ignored the less severe injury types.

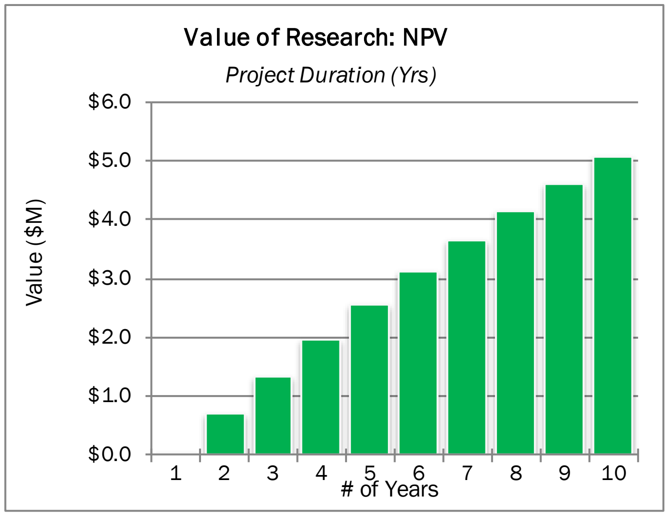
According to NHTSA, each fatality results in an average discounted lifetime economic cost of $1.4 million, and an average comprehensive cost of $9.1 million ("The Economic and Societal Impact of Motor Vehicle Crashes," 2010 (Revised), http://www-nrd.nhtsa.dot.gov/pubs/812013.pdf).

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 0.56 fatality each year, the annual expected value of this research is $784,000.

The researchers used a period of 10 years and a discount rate of 5%, which is typical per the TxDOT's University Handbook, to arrive at the benefit-cost ratio of 18 for this research project. The estimated VOR is presented in Figure G.1.

	Project #	0-7019		
	Project Name:	Development of a MASH Test Level 4 Compliant Guardrail		
	Agency:	TTI	**Project Budget**	$ 288,933
	Project Duration (Yrs)	3	**Exp. Value (per Yr)**	$ 784,000
Expected Value Duration (Yrs)		10	**Discount Rate**	5%
Economic Value				
Total Savings:	$ 7,551,067	**Net Present Value (NPV):**		$ 5,077,626
Payback Period (Yrs):	0.368537	**Cost Benefit Ratio (CBR, $1 : $___):**		$ 18

Years	Expected Value
0	-$722,333
1	$784,000
2	$784,000
3	$784,000
4	$784,000
5	$784,000
6	$784,000
7	$784,000
8	$784,000
9	$784,000
10	$784,000



Variable Justification

There is a lack of public domain metal guardrail systems that are compliant to the American Association of State Transportation and Highway Officials (AASHTO) Manual for Assessing Safety Hardware, Second Edition (MASH) Test Level 4 (TL-4) (1). This test level is used for assessing barriers that are designed to contain passenger as well as freight vehicles. Several corridors in Texas are known to experience a larger percentage of freight and truck traffic. In these corridors, the safety of the motoring public can greatly benefit from the use of a MASH TL 4 compliant metal guardrail system.

Qualitative Value

Benefit Area	Value
Safety	Use of a crashworthy guardrail to shield passenger and freight vehicles on high-speed roads from roadside hazards will improve the safety of the motoring public. It will prevent fatalities and injuries for the citizens of Texas.

Figure G.1 Value of Research for TxDOT Project 0-7019.