Texas A&M Transportation Institute
Proving Ground

Test Report No. 441203-01

DESIGN AND EVALUATION OF TRANSITION FOR TXDOT *MASH* TEST LEVEL 4 (TL-4) GUARDRAIL SYSTEM

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Texas Department of Transportation (TxDOT)

TEXAS A&M TRANSPORTATION INSTITUTE PROVING GROUND
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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 3 (TL-3) compliant guardrail transition system (hereafter referred to as Transition) that enables transitioning and terminating the ends of the Texas Department of Transportation *MASH* TL-4 guardrail system with *MASH*-compliant guardrail end terminals. The researchers designed the Transition using finite element simulation analysis, details of which are presented in this report. The researchers performed vehicle impact simulations to improve the initial design concept of the Transition and developed the final design for full-scale crash testing. The researchers then constructed a test installation prototype and performed two full-scale crash tests that are also reported herein.

The purpose of the tests was to assess the performance of the Transition according to the safety-performance evaluation guidelines included in the second edition of the American Association of State Highway and Transportation Officials *MASH* (*1*). The crash tests were performed in accordance with *MASH* TL-3 criteria, which require two crash tests:

1. ***MASH* Test 3-20:** An 1100C vehicle weighing 2,420 lb impacting the longitudinal barrier transition while traveling at 62 mi/h and 25 degrees.
2. ***MASH* Test 3-21:** A 2270P vehicle weighing 5,000 lb impacting the longitudinal barrier transition while traveling at 62 mi/h and 25 degrees.

This report provides details of the Transition, the crash tests and results, and the performance assessment of the Transition for *MASH* TL-3 evaluation criteria for longitudinal barriers.

The Transition met the *MASH* TL-3 performance criteria for longitudinal barriers.

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DISCLAIMER

This research was sponsored by 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.

TTI PROVING GROUND DISCLAIMER

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

REPORT AUTHORIZATION

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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

In 2021, the Texas A&M Transportation Institute (TTI) developed a metal beam guardrail system for the Texas Department of Transportation (TxDOT) that met the crash testing and evaluation criteria of American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test Level 4 (TL-4) (*1, 2*). This TxDOT *MASH* TL-4 guardrail is available for use on Texas roadways. However, full implementation of the TxDOT *MASH* TL-4 guardrail requires *MASH*-compliant transitions to enable termination of the ends of the TL-4 guardrail with *MASH*-compliant end treatments. Since the currently available guardrail terminals are *MASH* Test Level 3 (TL-3) compliant, a transition design is needed to transition from the TxDOT *MASH* TL-4 guardrail to the standard W-beam guardrail, which can then be terminated using a *MASH* TL-3 compliant guardrail end terminal.

1.2. OBJECTIVE

The objective of this research project was to design and test a transition system that allows transitioning from the TxDOT *MASH* TL-4 guardrail to a standard 31-inch-tall W-beam guardrail and terminate the guardrail using a *MASH* TL-3 compliant end terminal. This system is hereafter referred to as "Transition." The Transition was required to be *MASH* TL-3 compliant.

1.3. RESEARCH APPROACH AND SCOPE

To meet the research objective, TTI researchers evaluated a design concept for the Transition through finite element modeling and simulation. The researchers developed a full-scale model of the Transition and performed vehicle impact simulations using *MASH* TL-3 impact conditions. Results of the simulations were used to improve the initial design concept and make recommendations for the final design for crash testing. The design and simulation work is presented in Chapter 2 of this report. The researchers then constructed a test installation prototype and performed full-scale crash testing in accordance with *MASH* TL-3 testing criteria for transitions for longitudinal barriers. Details of the test installation and the crash testing are presented in the subsequent chapters of this report.

Chapter 2. DESIGN AND SIMULATION ANALYSIS

This chapter presents the work performed by the research team when designing the Transition system. Included are the details and results of the finite element (FE) modeling and simulation performed to evaluate the design concept of the Transition, as well as the design recommendations for crash testing based on the results of the analyses performed.

2.1. INITIAL DESIGN CONCEPT SUMMARY

The initial design concept was previously developed under TxDOT Project 0-7019, in which the design and testing of the TxDOT *MASH* TL-4 guardrail system was performed (Figure 2.1) (*2*). The installation of the *MASH* TL-4 guardrail crash tested under Project 0-7019 incorporated the end transition shown in Figure 2.1. However, the project scope was limited to evaluation of the length-of-need (LON) section of the TL-4 guardrail. The transition section was not evaluated through simulation or crash testing.

Under the current project (0-7120), the transition shown in Figure 2.1 was the initial design evaluated using full-scale FE modeling and impact simulations. This design transitions the TxDOT *MASH* TL-4 guardrail to the standard *MASH* TL-3 31-inch-tall W-beam guardrail system, which is then terminated using a *MASH* crash-tested guardrail end terminal. The transition design was comprised of a standard 12-gauge W-beam guardrail and a 5-inch × 4-inch × ¼-inch hollow structural section (HSS) turn-down rail. The 12-gauge W-beam rail was attached to the 10-gauge W-beam rail of the TL-4 guardrail system using a standard guardrail splice connection. The height of the W-beam transitioned from 27 inches to the standard 31 inches over two rail segments, as shown in Figure 2.1. The W-beam was supported by standard W6×9 guardrail posts that were 72 inches long. The W-beam guardrail had standard 6-inch-wide, 8-inch-deep, and 14-inch-tall wood blockouts.

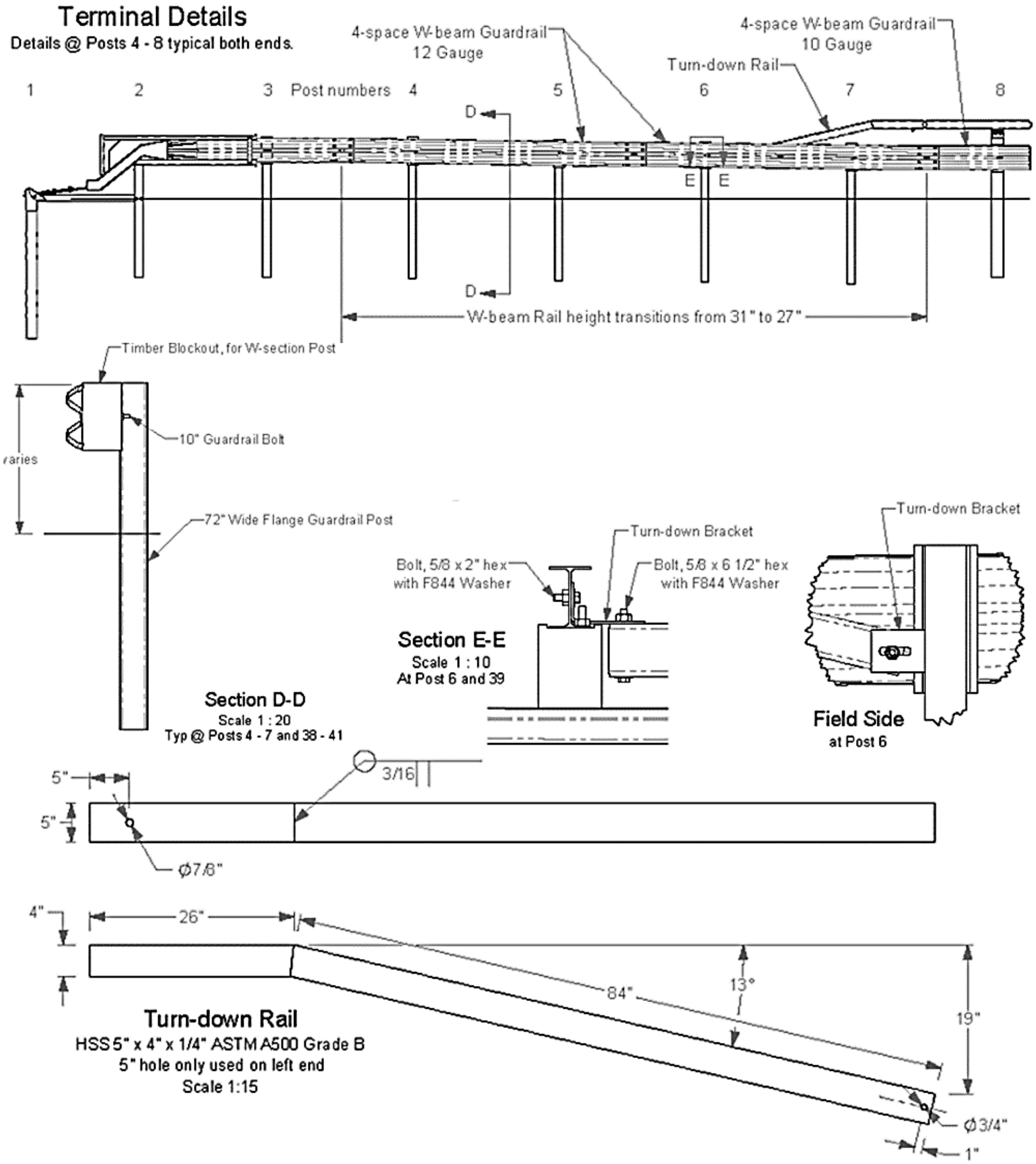


Figure 2.1. Initial Design Concept Selected for Simulation Analysis and Detailed Design.

The turn-down rail was attached to the top HSS rail of the TL-4 guardrail. It was turned down and terminated behind the W-beam guardrail by attaching it to the W6×9 guardrail post using an L-shape turn-down bracket (Figure 2.1).

Once the W-beam guardrail transitioned in height to achieve the standard 31-inch rail height, it was attached to a *MASH*-compliant terminal. A SoftStop® terminal was used under Project 0-7019. In the testing performed under Project 0-7019, and as shown in Figure 2.1, an abbreviated terminal length was used since the objective at the time was only to provide anchorage to the W-beam rail for the LON testing. However, under the current project, as per the specifications of the terminal manufacturer, the full length of the W-beam guardrail terminal was used.

2.2. SIMULATION ANALYSIS SCOPE

The research team developed a detailed FE model of the initial Transition design and performed full-scale dynamic impact simulations. The impact simulations were performed using the impact conditions of *MASH* for TL-3 transition systems. This involved simulating *MASH* Test 3-21 (5,000-lb pickup truck impacting at 62 mi/h and 25 degrees) and Test 3-20 (2,420-lb passenger car impacting at 62 mi/h and 25 degrees). Results of the simulations were used to determine if the Transition design was likely to meet *MASH* TL-3 testing criteria in full-scale crash testing.

Based on the results of the simulations, several design changes were made to improve the performance of the Transition. These design changes were then also modeled and new impact simulations were performed to arrive at the final Transition design recommendations presented herein.

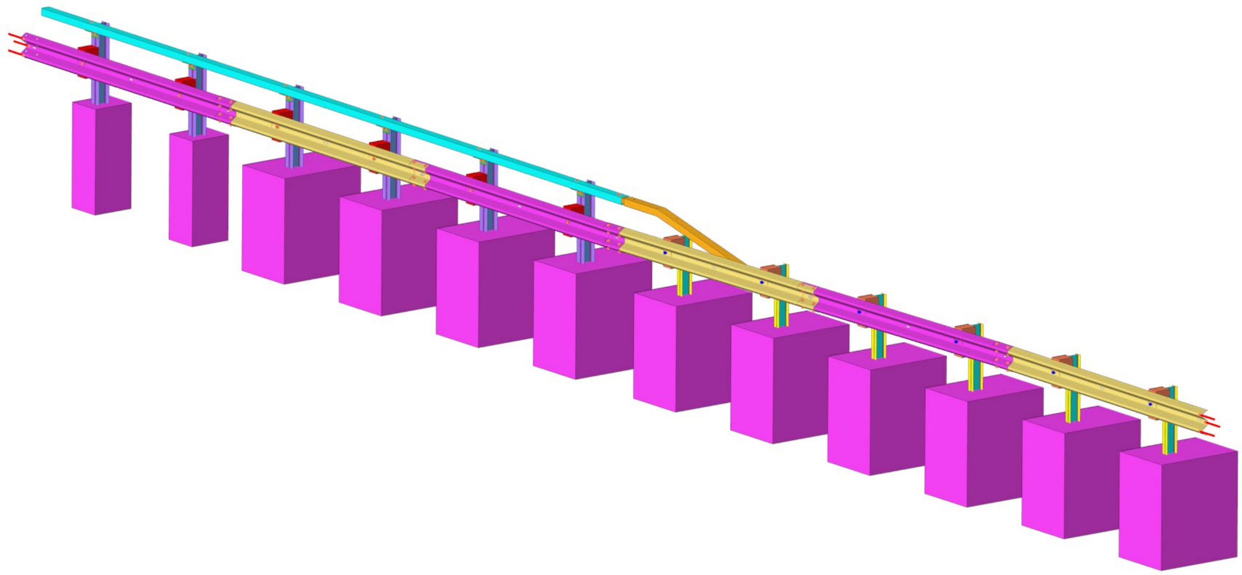
Following are the details of the FE models, results of the various simulations that guided the design changes made to the initial Transition design, and detailed results of the impact simulations performed on the final design recommended for full-scale crash testing.

2.3. FINITE ELEMENT MODELING

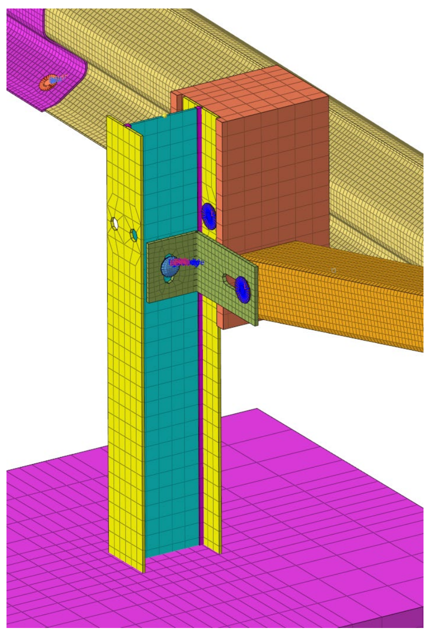
All FE simulations were performed using LS-DYNA, which is a commercially available general-purpose FE analysis software. All key guardrail parts were represented with elastic-plastic material models. These included the W-beam and the HSS beam rails, posts, splices, blockouts, and HSS rail attachment angle.

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. 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 simulations were publicly available models developed by the Center for Collision Safety and Analysis under Federal Highway Administration (FHWA) and National Highway Traffic Safety Administration (NHTSA) sponsorship. These models have been further improved by the research team over the course of various research projects to achieve greater validation and robustness for different barrier applications.



a. Isometric View



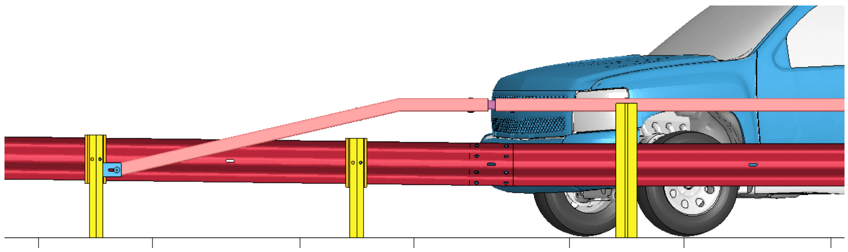
b. Connection Details

Figure 2.2. Finite Element Model of the Initial Transition Design.

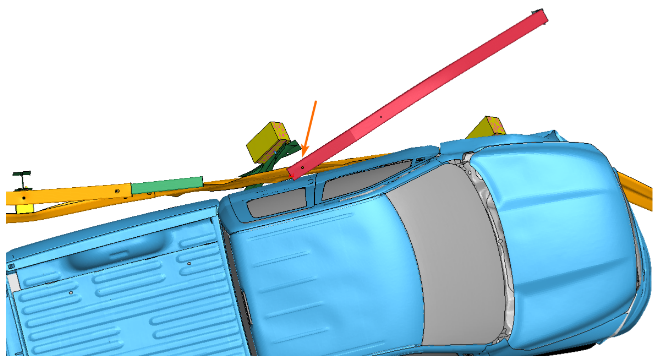
2.4. SIMULATION ANALYSIS AND DESIGN DEVELOPMENT

After developing the system model of the initial Transition design, the researchers performed *MASH* TL-3 impact simulations. Based on these simulations, several improvements were made to the transition design, as discussed in this section.

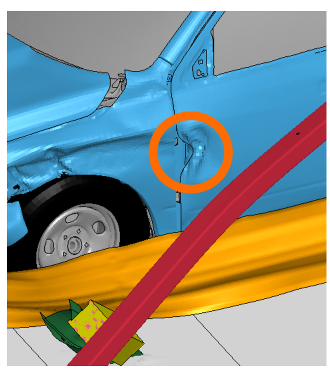
The researchers first performed an impact simulation with the pickup truck impacting the Transition in the reverse direction, as shown in Figure 2.3. The impact was performed following *MASH* Test 3-21 impact conditions. While this is not a commonly crash-tested direction for a roadside guardrail transition, it is possible for a vehicle to impact the Transition in this direction. The researchers wanted to evaluate the vehicle's interaction with the turn-down rail. Key results from the simulation are shown in Figure 2.3. The turn-down rail disengaged from the top HSS rail at the expansion splice. Its interaction with the vehicle caused it to rotate, and the upstream end of the turn-down rail came close to impacting the side window of the pickup. There was also moderate vehicle door snagging caused by the turn-down rail while it disengaged from the HSS rail at the top splice.



a. Side View



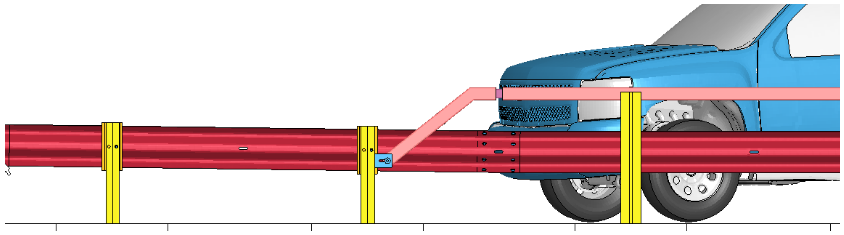
b. Top View



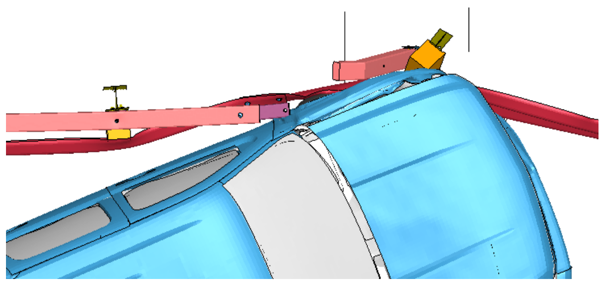
c. Close-Up Isometric View

Figure 2.3. Reverse-Direction Impact of the Initial Design with the *MASH* Pickup Truck.

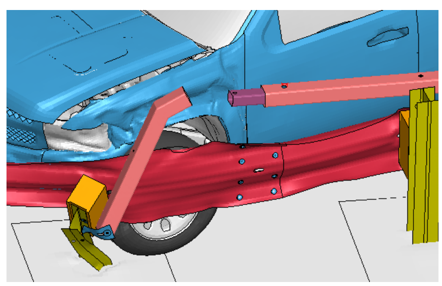
To reduce the possibility of the turn-down rail interacting with the side windows, the researchers reduced the length of the turn-down rail, as shown in Figure 2.4. Instead of terminating it at the second post downstream from the splice, the modified design terminated the turn-down rail at the first post downstream from the splice. The length of the top insert was also reduced to allow the turn-down rail to disengage more readily in reverse-direction impacts. A simulation with these changes was performed, and the key results are shown in Figure 2.4. The turn-down rail disengaged from the top HSS rail quickly, while the vehicle's door and the side windows were still upstream of the splice.



a. Side View



b. Top View



c. Close-Up Isometric View

Figure 2.4. Reverse-Direction Pickup Truck Impact of the Shortened Turn-Down Rail Design.

The researchers then performed impact simulations of the modified Transition design (Figure 2.4) from the opposite direction of travel using *MASH* Test 3-21 impact conditions. Simulations were performed with the vehicle impacting the transition while traveling in the direction from the W-beam guardrail to the TL-4 guardrail. The researchers performed simulations at three different impact points (IPs), as shown in Figure 2.5. These impact points, IP1, IP2, and IP3, were 86 inches, 161 inches, and 236 inches upstream of the center of the splice between the top HSS rail and the turn-down rail, respectively. The purpose of performing simulations at multiple impact points was to determine the most critical impact location for crash testing.

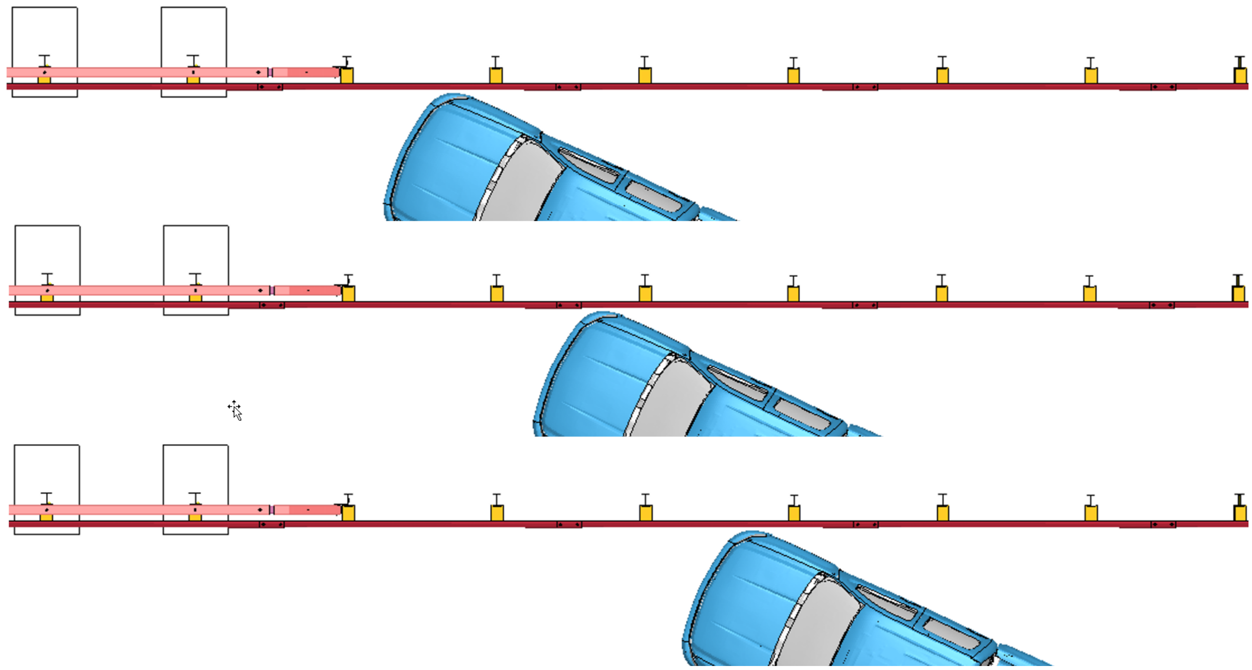
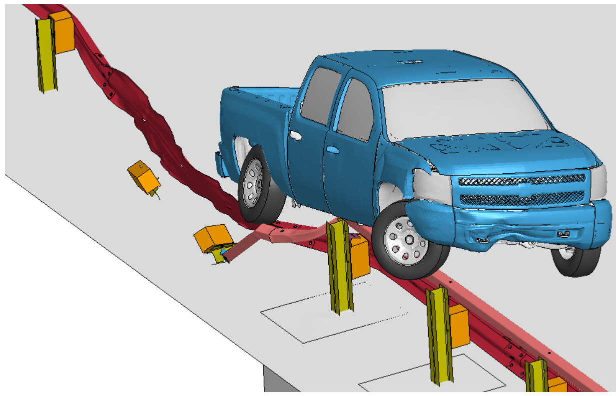
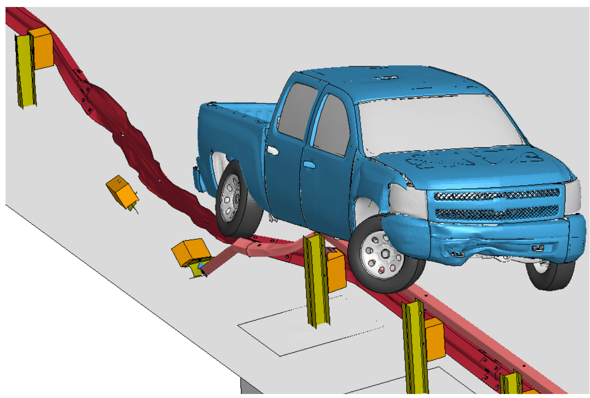


Figure 2.5. Impact Points for Test 3-21 Simulations (IP1 [top], IP2 [center], IP3 [bottom]).

The vehicle was successfully contained and redirected for IP3. However, for IP1 and IP2, the vehicle was not contained or redirected. The results of the simulation showed that the W-beam guardrail upstream of the TL-4 guardrail was not stiff enough. This resulted in the vehicle pocketing upstream of the TL-4 guardrail, which eventually led to the vehicle's impact-side front and rear tires riding up and over the guardrail without containment or redirection (Figure 2.6). The results of these simulations showed that there was a need to stiffen the guardrail in the transition region upstream of the TL-4 guardrail.



a. IP1



b. IP2

Figure 2.6. Simulation Results of Initial Transition Design for IP1 and IP2.

2.4.1. Design with Quarter and Half Post Spacings

To stiffen the W-beam guardrail upstream of the TL-4 guardrail, the researchers added additional W6×9 posts, as shown in Figure 2.7. A post was added between the W6×25 TL-4 guardrail post and the W6×9 post to which the turn-down rail was attached. Upstream of this, four posts were positioned at quarter post spacing (i.e., 18.75-inch post spacing), followed by four posts at half post spacing (i.e., 37.5-inch post spacing), followed by the standard W-beam guardrail with full post spacing (i.e., 75-inch post spacing). By adding these posts at varying post spacings, the lateral stiffness of the Transition's W-beam guardrail was increased upstream of the TL-4 guardrail.

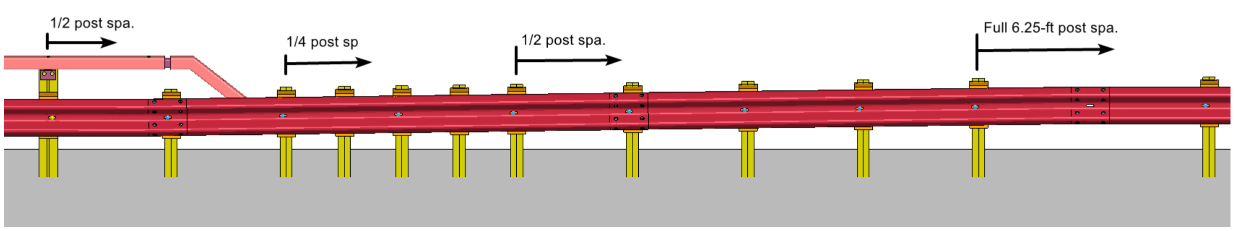


Figure 2.7. Transition Design with Posts Installed at Quarter and Half Post Spacings.

The researchers performed impact simulations with *MASH* Test 3-21 impact conditions at the three impact points used previously (Figure 2.5). Some key frames from the simulation results are presented in Figure 2.8 through Figure 2.10. Simulation results indicated that the vehicle was successfully contained and redirected for all the impact points.

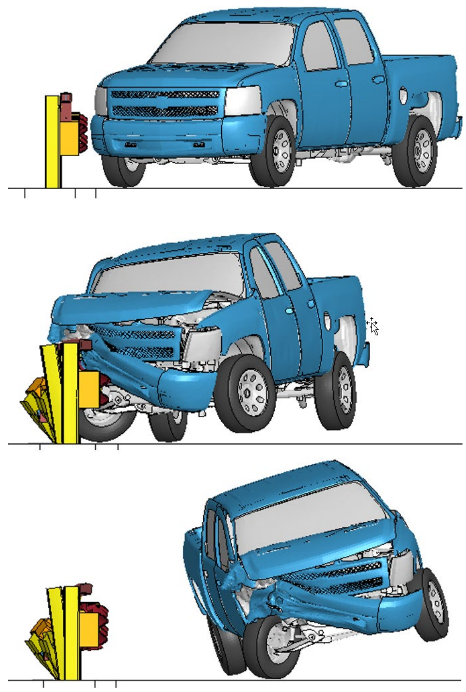


Figure 2.8. Simulation at IP1 for Transition Design with Quarter and Half Post Spacings.

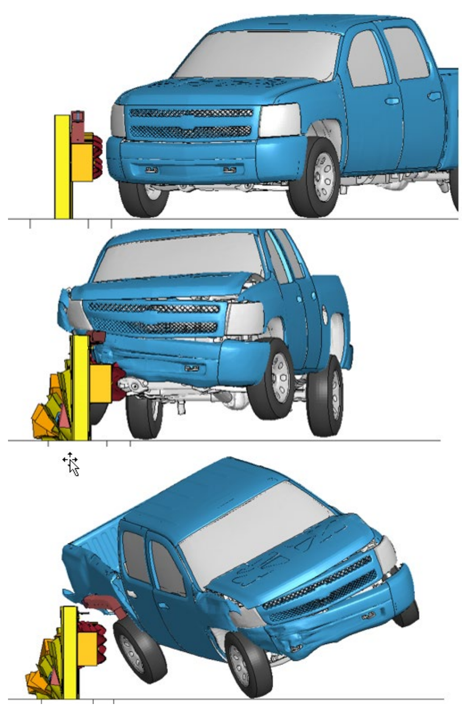


Figure 2.9. Simulation at IP2 for Transition Design with Quarter and Half Post Spacings.

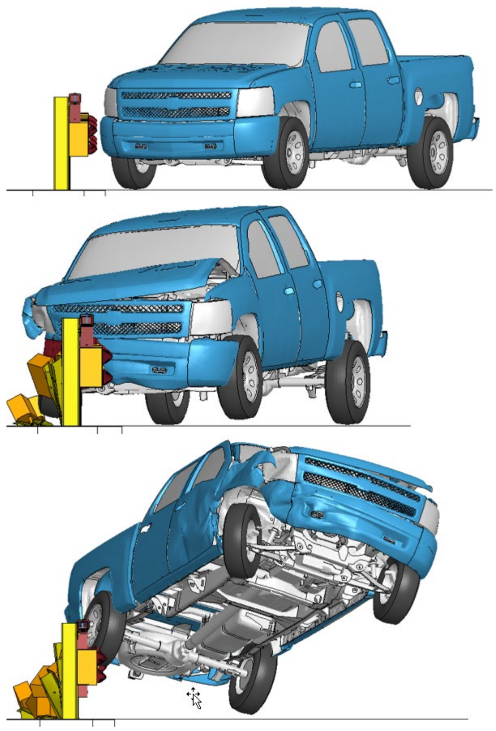


Figure 2.10. Simulation at IP3 for Transition Design with Quarter and Half Post Spacings.

2.4.2. Design with Half Post Spacing

While the results of the simulations were satisfactory, the researchers felt that the design of the transition could potentially be simplified by using only the half post spacing of 37.5 inches. To evaluate this option, the researchers modified the Transition design as shown in Figure 2.11. The modified Transition was comprised of eight W6×9 posts with 37.5-inch post spacing.

In addition to half post spacing of the Transition posts, the blockouts of these posts were 10 inches tall. The reduction in the blockout length was incorporated based on full-scale crash testing performed under another project at TTI (*3*). In that project, *MASH* Test 3-21 on a W-beam transition from full post spacing to half post spacing failed due to rail rupture. Another test was performed by reducing the height of the blockout from 14 inches to 10 inches (as shown in Figure 2.11). This prevented the rail from rupturing, and the transition passed *MASH* testing. The modified Transition design shown in Figure 2.11 incorporates the design features of the passed full post spacing to half post spacing transition. Successful testing of this Transition on the upstream end eliminated the need to evaluate it under this project.

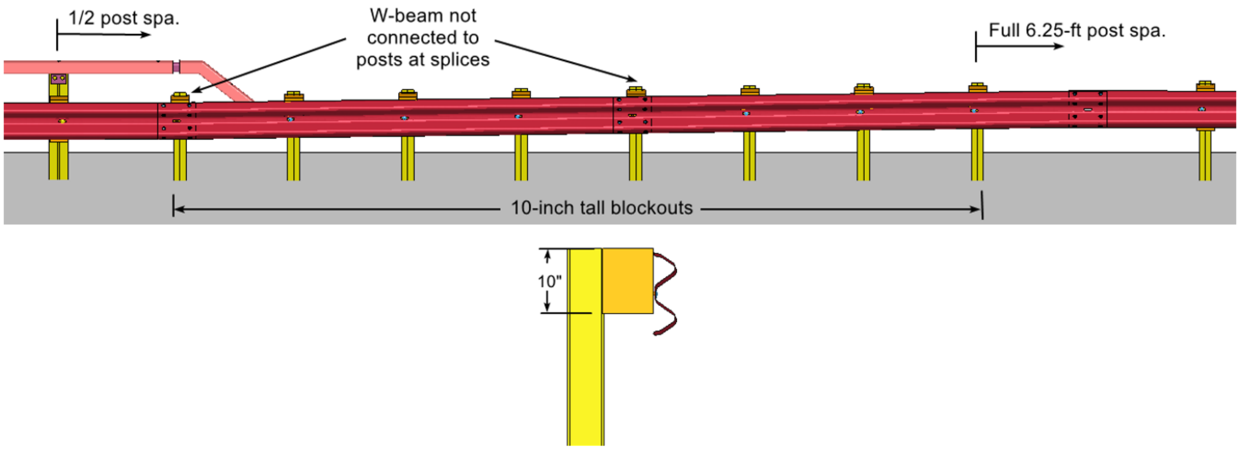


Figure 2.11. Modified Transition Design with Half Post Spacing.

The researchers performed three impact simulations on the modified design shown in Figure 2.11. These simulations were performed using the impact points shown in Figure 2.5 with *MASH* Test 3-21 impact conditions. The results of these simulations are shown in Figure 2.12 through Figure 2.14. For all three impact simulations, the Transition system successfully contained and redirected the pickup truck.

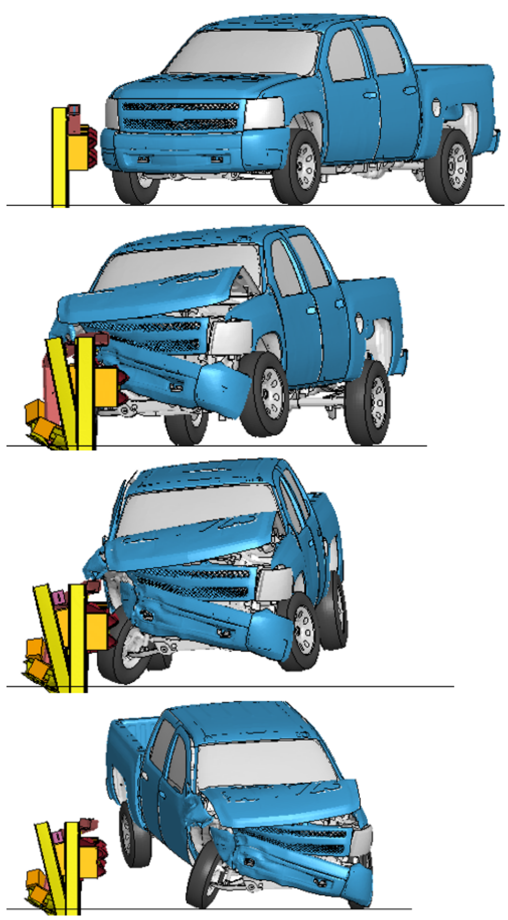


Figure 2.12. Simulation at IP1 for Transition Design with Half Post Spacing.

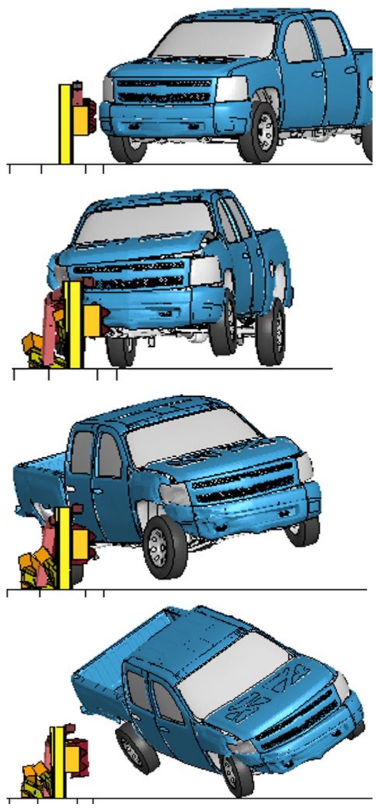


Figure 2.13. Simulation at IP2 for Transition Design with Half Post Spacing.

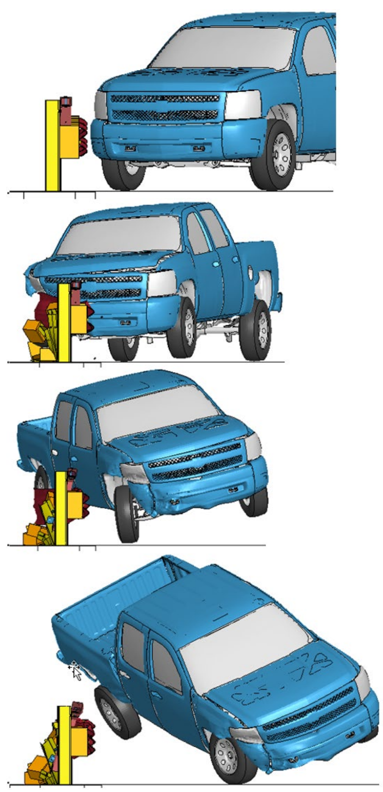


Figure 2.14. Simulation at IP3 for Transition Design with Half Post Spacing.

Since this system was simplified compared to the system with quarter and half post spacings, the researchers picked this design for further evaluation with the passenger car. The researchers performed three impact simulations using *MASH* Test 3-20 impact conditions (i.e., 2,420-lb small car, impacting at 62 mi/h and 25 degrees).

The simulations were performed at IP4, IP5, and IP6, which were 66 inches, 103.5 inches, and 141 inches upstream from the center of the splice between the top HSS rail and the turn-down rail, respectively (see Figure 2.15).

The results of these simulations are shown in Figure 2.16 through Figure 2.18. The Transition system successfully contained and redirected the small passenger car in all three impact simulations.

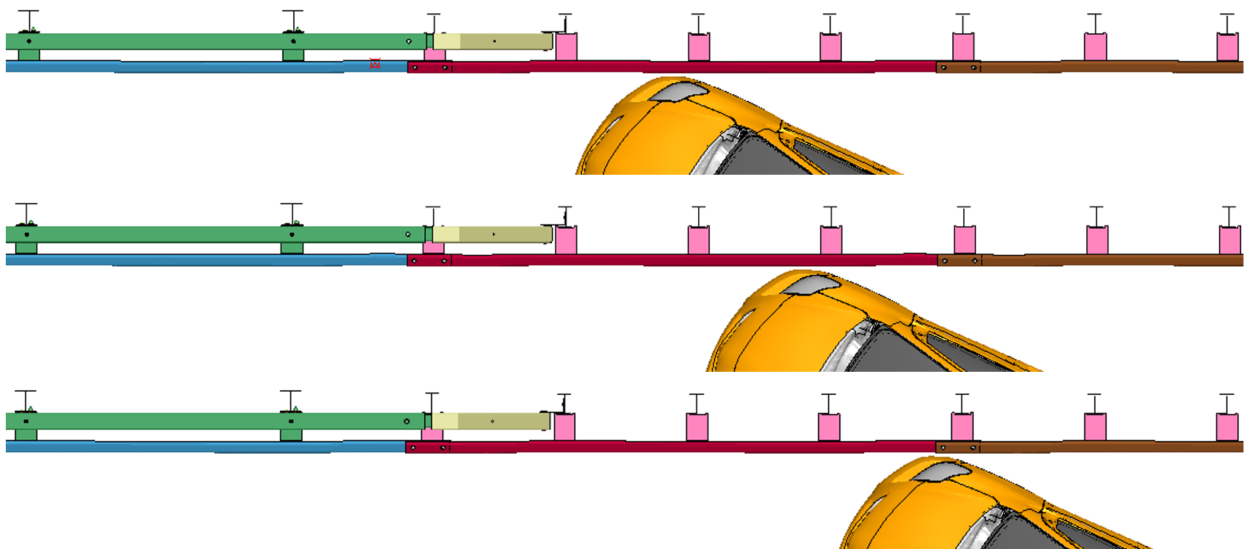


Figure 2.15. Impact Points for Test 3-20 Simulations (IP4 [top], IP5 [center], IP6 [bottom]).

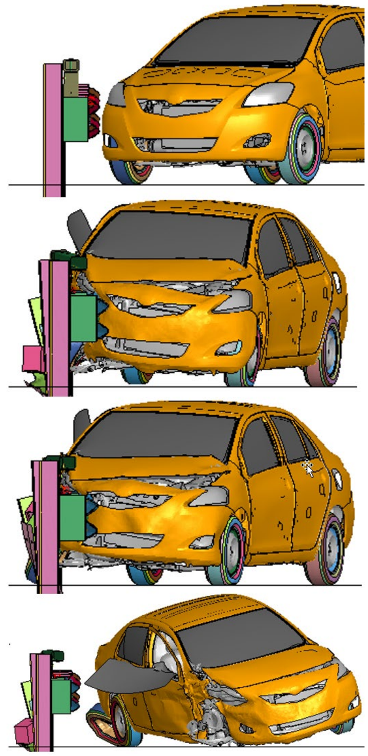


Figure 2.16. Simulation at IP4 for Transition Design with Half Post Spacing.

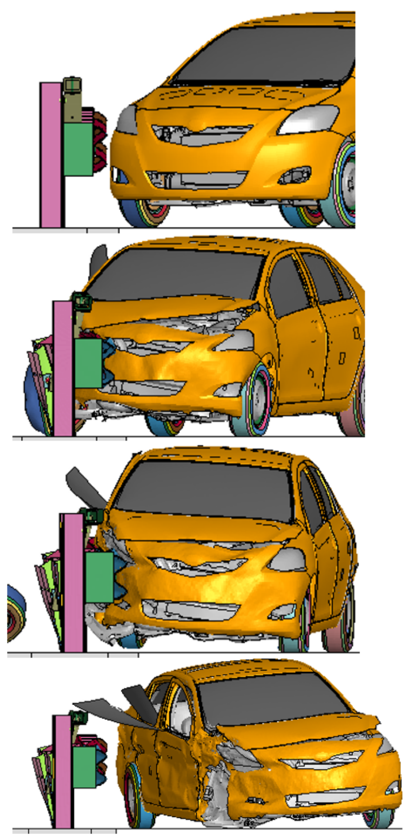


Figure 2.17. Simulation at IP5 for Transition Design with Half Post Spacing.

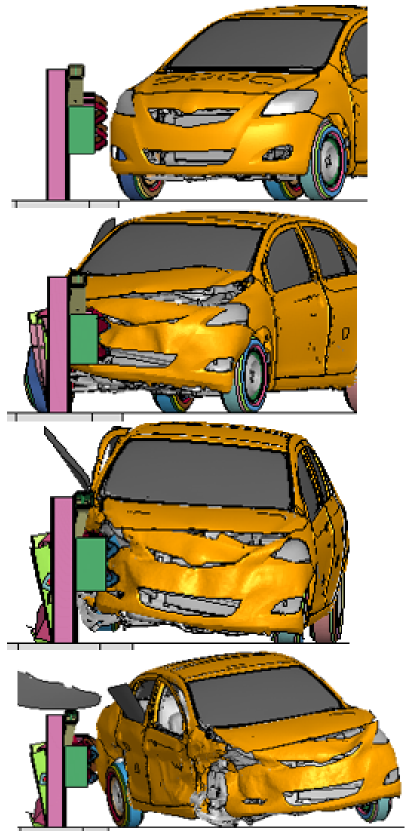


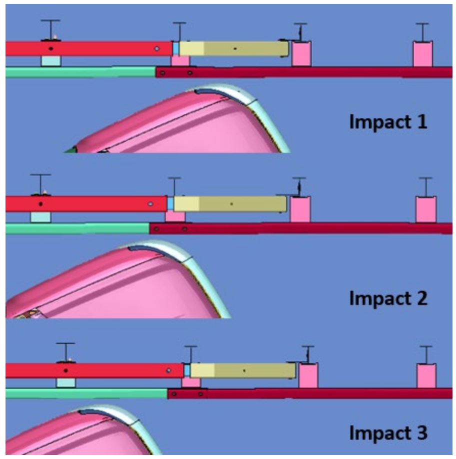
Figure 2.18. Simulation at IP6 for Transition Design with Half Post Spacing.

2.4.3. Reverse-Direction Impact Evaluation

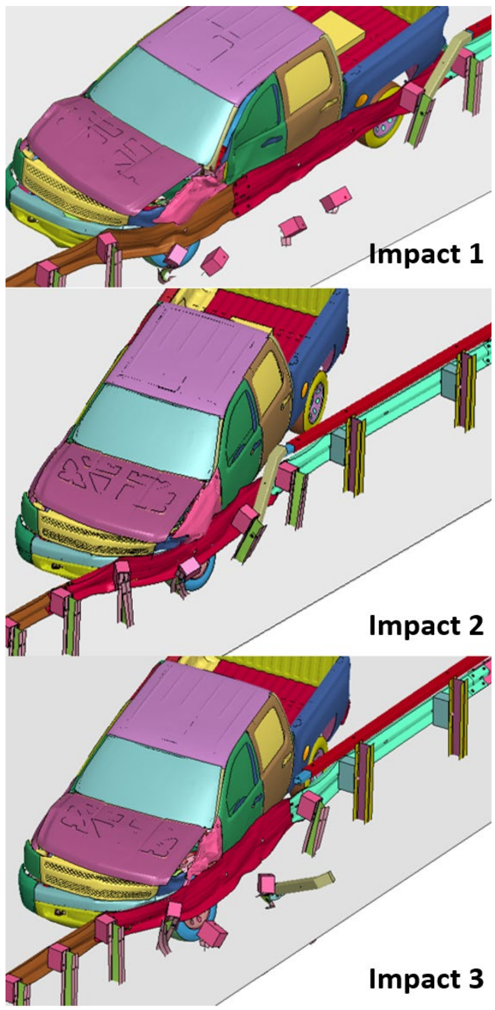
The researchers performed six additional impact simulations with the Transition design in Figure 2.11. Three of these simulations were performed with the pickup truck and three with the small car. In these simulations, the vehicle impacted the Transition in the reverse direction.

The pickup truck simulations were performed using *MASH* Test 3-21 impact conditions. The impact points for these three simulations and an image of the key result from each simulation are shown in Figure 2.19. The small car simulations were performed using *MASH* Test 3-20 impact conditions. The impact points of these three simulations and an image of the key result from each simulation are shown in Figure 2.20.

In all six simulations, the Transition design successfully contained and redirected the impacting vehicle. Furthermore, the simulation results indicated that the turn-down rail easily disengaged from the top HSS rail and moved away from the vehicle. The results did not indicate any concern with the turn-down rail interacting with the side windows.

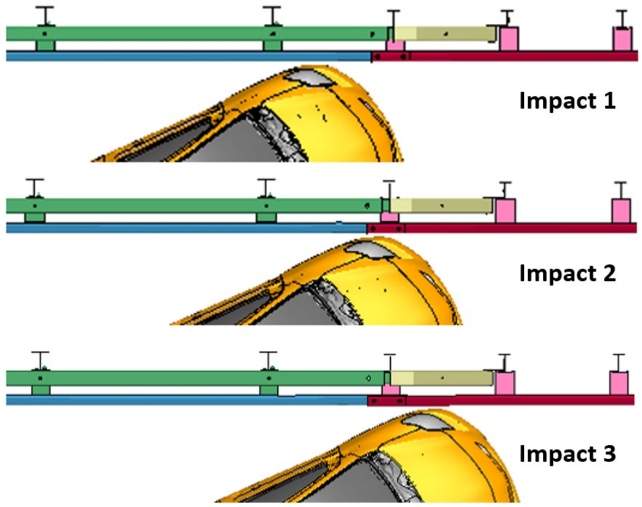


a. Impact Points

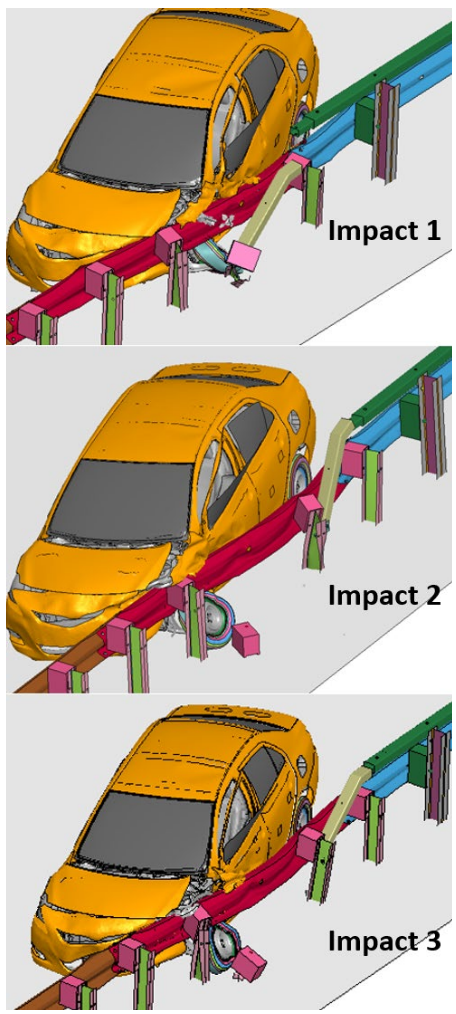


b. Key Result for Each Impact Point

Figure 2.19. Results of Reverse-Direction Impact Simulations Performed at Three Impact Locations with *MASH* Pickup Truck Model.



a. Impact Points



b. Key Result for Each Impact Point

Figure 2.20. Results of Reverse-Direction Impact Simulations Performed at Three Impact Locations with *MASH* Small Passenger Sedan Model.

2.5. CRITICAL IMPACT POINTS AND TESTING RECOMMENDATIONS

Since the half post spacing Transition design is simpler than the design with quarter and half post spacings, and because it performed acceptably in the simulations of Test 3-21 and Test 3-20 in both directions of travel, it was recommended for full-scale crash testing. The researchers evaluated the simulation results of this design to determine the critical impact points (CIPs) for full-scale crash testing.

Figure 2.21 shows the comparison of the pickup truck in the *MASH* Test 3-21 simulations for the three impact points at the time of maximum lateral rail deflection. The vehicle for IP3 had redirected at this time and was parallel to the guardrail. The vehicles in IP1 and IP2 had not fully redirected. The vehicle in IP1, however, was the least redirected. This finding indicates that the relative vehicle snagging potential with the stiffer TL-4 guardrail was the highest for IP1. IP1 was thus selected as the CIP for *MASH* Test 3-21. As mentioned previously, this point is 86 inches upstream of the center of the splice between the top HSS rail and the turn-down rail.

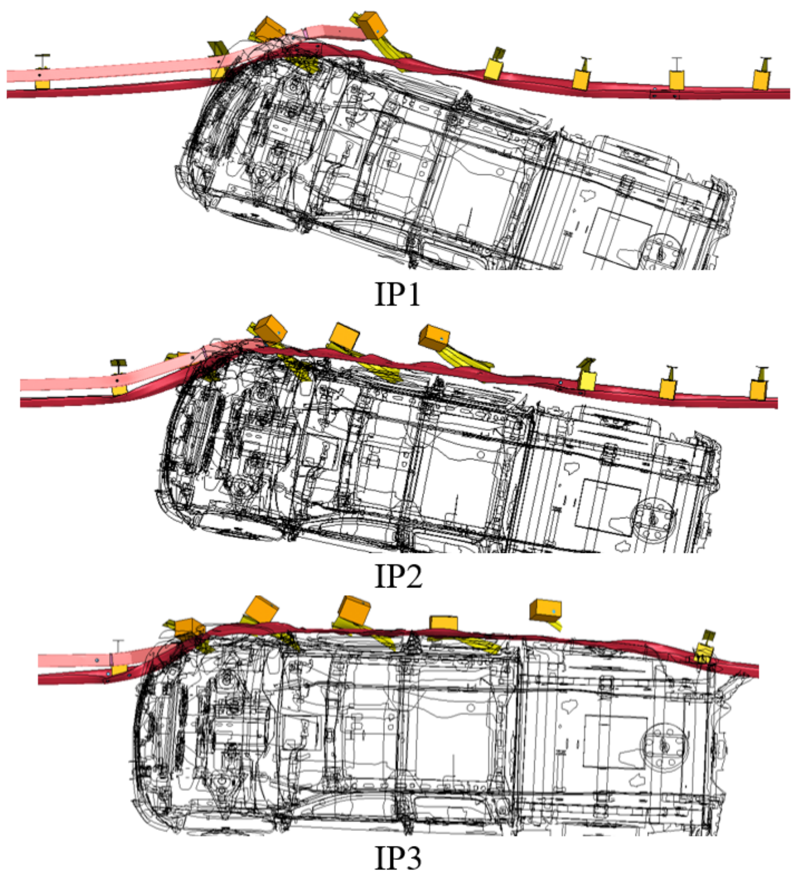


Figure 2.21. Vehicle Orientation at the Time of Maximum Lateral Rail Deflection for the Three Impact Points (Pickup Truck).

To help select the CIP for *MASH* Test 3-20 with the small car, the researchers evaluated the relative redirection of the vehicle when the front of the vehicle reached the stiffer TL-4 guardrail (Figure 2.22) and the impact-side front wheel snagged the guardrail posts (Figure 2.23). Figure 2.22 shows that for IP6, the vehicle had mostly redirected when it reached the TL-4 guardrail. The relative level of redirection was somewhat similar for IP4 and IP5, even though IP4 was slightly less redirected. Regarding the interaction of the leading front wheel of the vehicle with the guardrail posts, IP5 had a much more severe interaction than IP4. In the case of IP6, the wheel interaction occurred before the vehicle reached the TL-4 rail, and is thus not shown in Figure 2.23. Since the level of redirection of the vehicle in IP4 and IP5 was somewhat similar, the researchers selected IP5 to be the CIP for Test 3-20 due to the potential for more severe snagging with the post. As mentioned before, this point is 103.5 inches upstream of the center of the splice between the top HSS rail and the turn-down rail.

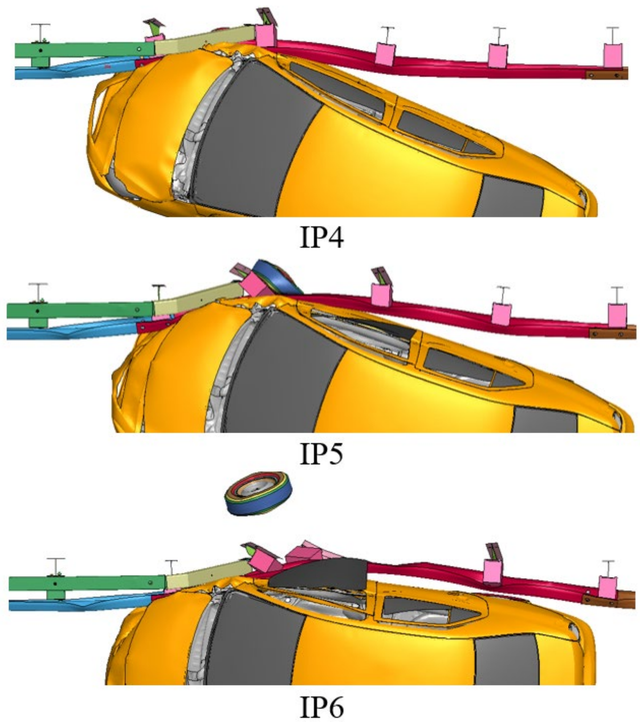


Figure 2.22. Vehicle Orientation at the Time of Maximum Lateral Rail Deflection for the Three Impact Points (Small Car).

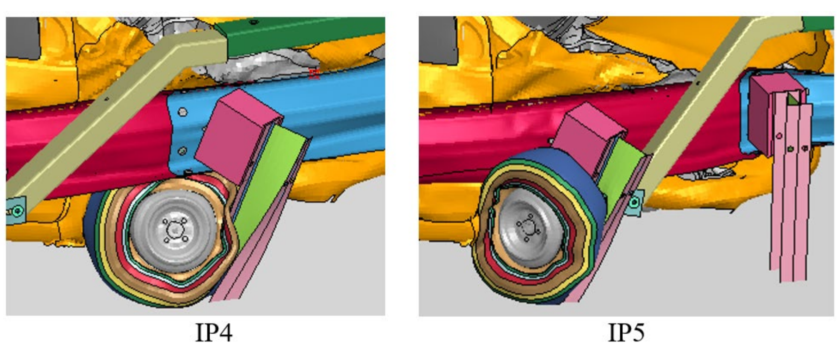


Figure 2.23. Wheel Snagging Comparison for Small Car Impact between IP4 and IP5.

2.6. CONCLUSIONS

Due to the successful containment and redirection of the vehicle in the simulation analyses, the researchers recommended performing the full-scale crash testing with the Transition design shown in Figure 2.11. The CIPs for *MASH* Test 3-21 and Test 3-20 were 86 inches and 104 inches, respectively, measured upstream of the center of the splice between the top HSS rail and turn-down rail.

Chapter 3. SYSTEM DETAILS

3.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of the Transition attached to the TxDOT *MASH* TL-4 guardrail at one end and a *MASH* terminal at the other end. The total length of the installation was 260 ft 2 inches.

The TxDOT *MASH* TL-4 guardrail consisted of a 10-guage 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.

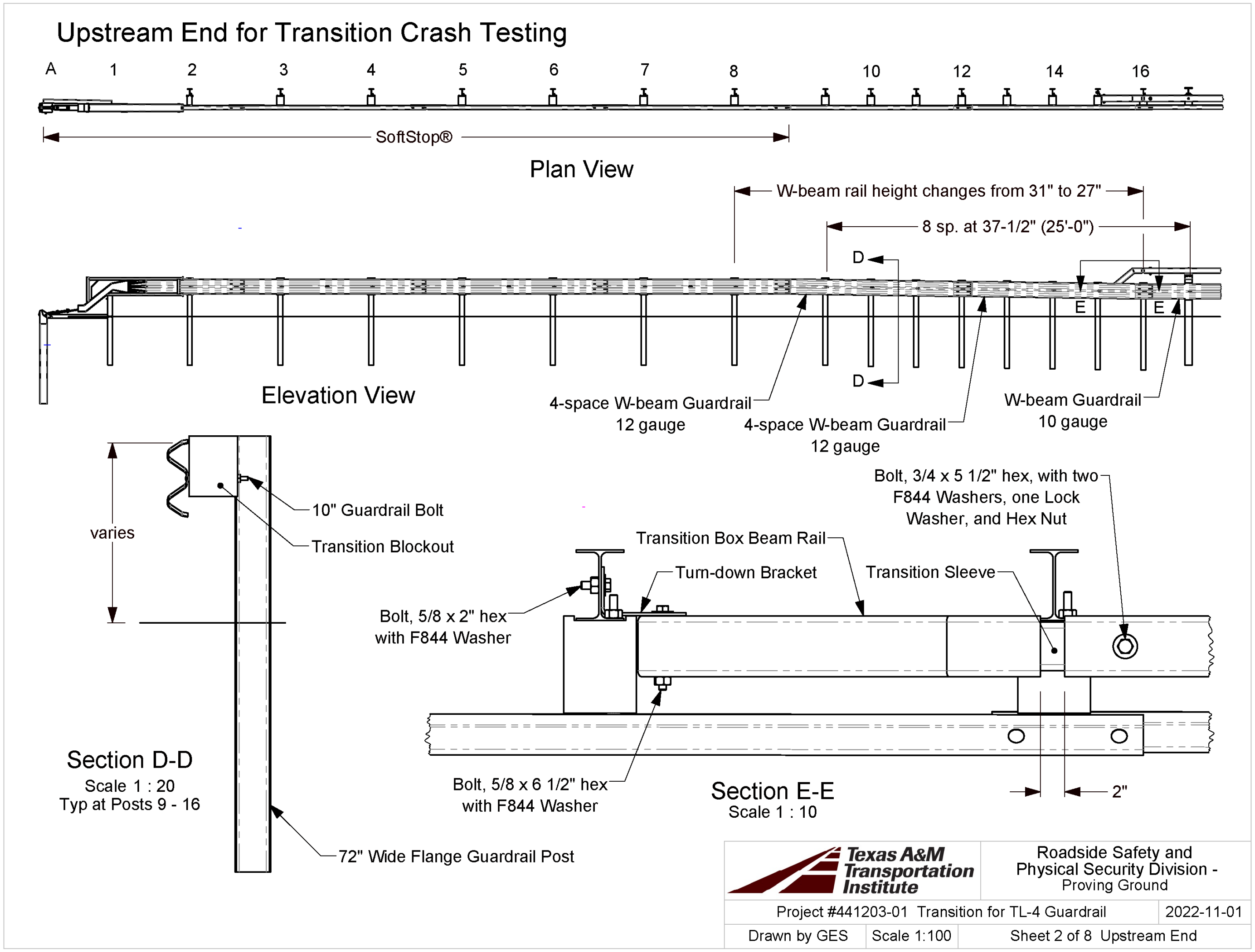
The Transition was attached on the upstream end of the TxDOT *MASH* TL-4 guardrail. It was comprised of a 12-guage W-beam guardrail mounted at a height of 27 inches at post 16, transitioning to a mounting height of 31 inches at post 9. The W-beam was attached to W6×8.5 posts. Posts 9 through 16 were spaced 37½ inches apart and were attached to the W-beam using 8-inch × 6-inch × 10-inch routered wood blocks. The upstream end of the top HSS rail of the TxDOT *MASH* TL-4 guardrail was attached to the Transition box beam rail via a transition sleeve insert. The Transition box beam rail turned down between posts 16 and 15. It was terminated by being bolted to the flange of post 15.

On the upstream end of the Transition, a SoftStop® terminal was installed. On the downstream end of the TxDOT *MASH* TL-4 guardrail, another transition system was installed. This transition was left in place from previous testing under TxDOT Project 0-7019 and was not subjected to transition testing in the current or previous project. Details of this end are provided in Appendix A.

Figure 3.1 presents overall information on the Transition, and Figure 3.2 through Figure 3.7 provide photographs of the installation. Appendix A provides further details on the test installation. Drawings for the overall installation were provided by the TTI Proving Ground, drawings for the SoftStop® end terminal were provided by Trinity Industries, and construction was performed by DMA Construction Inc. and supervised by TTI Proving Ground personnel.

3.2. DESIGN MODIFICATIONS DURING TESTS

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



S:\Accreditation-17025-2017\EIR-000 Project Files\441203-01 Transition for TL4 - Sheikh (441202-01)\Drafting, 441202-01\441202-01 Drawing

Figure 3.1. Details of Transition.

Figure 3.2. TL-4 Test Installation prior to Testing.

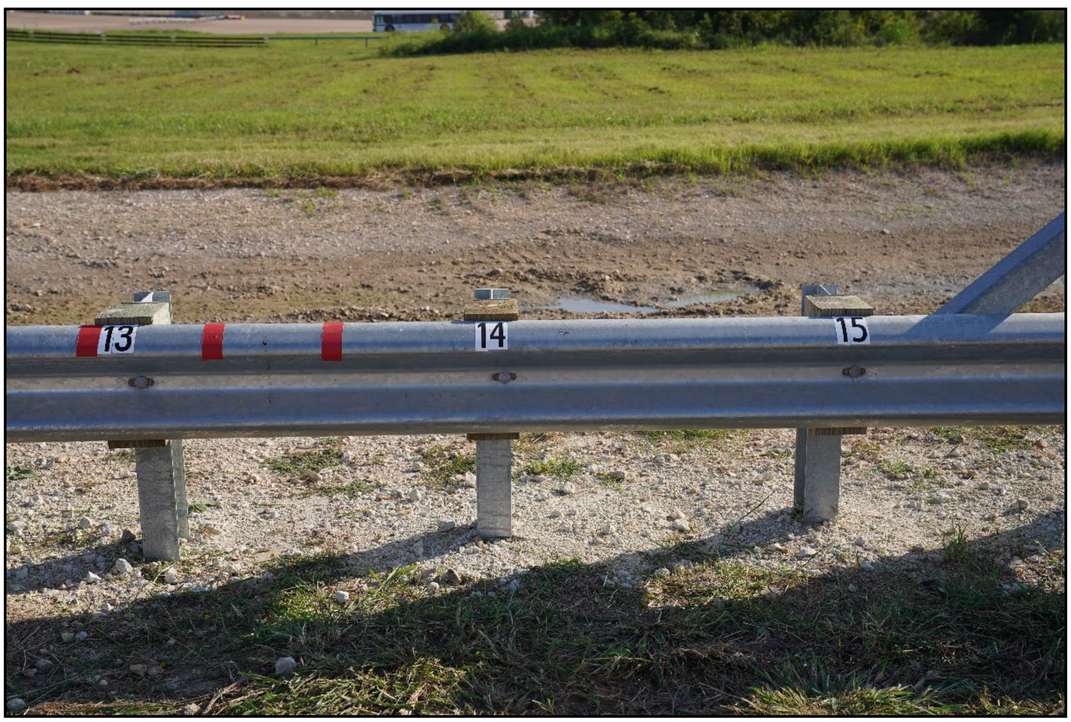


Figure 3.3. TL-4 Test Installation at Impact prior to Testing.

Figure 3.4. TL-4 Test Installation at the Transition Box Beam Rail prior to Testing.


Figure 3.5. Upstream In-Line View of the Test Installation prior to Testing.

Figure 3.6. Field Side of the Transition prior to Testing.

Figure 3.7. Transition Box Beam Rail Connection to Post 15 prior to Testing.

3.3. MATERIAL SPECIFICATIONS

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

3.4. SOIL CONDITIONS

The test installation was installed in soil meeting Grading D of AASHTO standard specification M147-17 “Materials for Aggregate and Soil Aggregate Subbase, Base, and Surface Courses.”

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

The minimum post loads are shown in Table 3.1 and Table 3.2.

Table 3.1 shows the loads on the post at specified deflections on the day of Test 3-20, September 9, 2022. The backfill material in which the Transition was installed met minimum *MASH* requirements for soil strength.

Table 3.1. Soil Strength for Crash Test 441203-01-1.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4,420	5,999
10	4,981	7,363
15	5,282	8,757

Table 3.2 shows the loads on the post at specified deflections on the day of Test 3-21, October 31, 2022. The backfill material in which the Transition was installed met minimum *MASH* requirements for soil strength.

Table 3.2. Soil Strength for Crash Test 441203-01-2.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4,420	5,909
10	4,981	7,181
15	5,282	8,242

Chapter 4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1. CRASH TEST MATRIX

Table 4.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for transitions for longitudinal barriers. The target CIPs for each test were determined using the simulation analyses presented in Chapter 2. Figure 4.1 shows the target CIPs for *MASH* Tests 3-20 and 3-21 on the Transition.

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

Test Designation	Test Vehicle	Impact Speed	Impact Angle	Evaluation Criteria
3-20	1100C	62 mi/h	25°	A, D, F, H, I
3-21	2270P	62 mi/h	25°	A, D, F, H, I

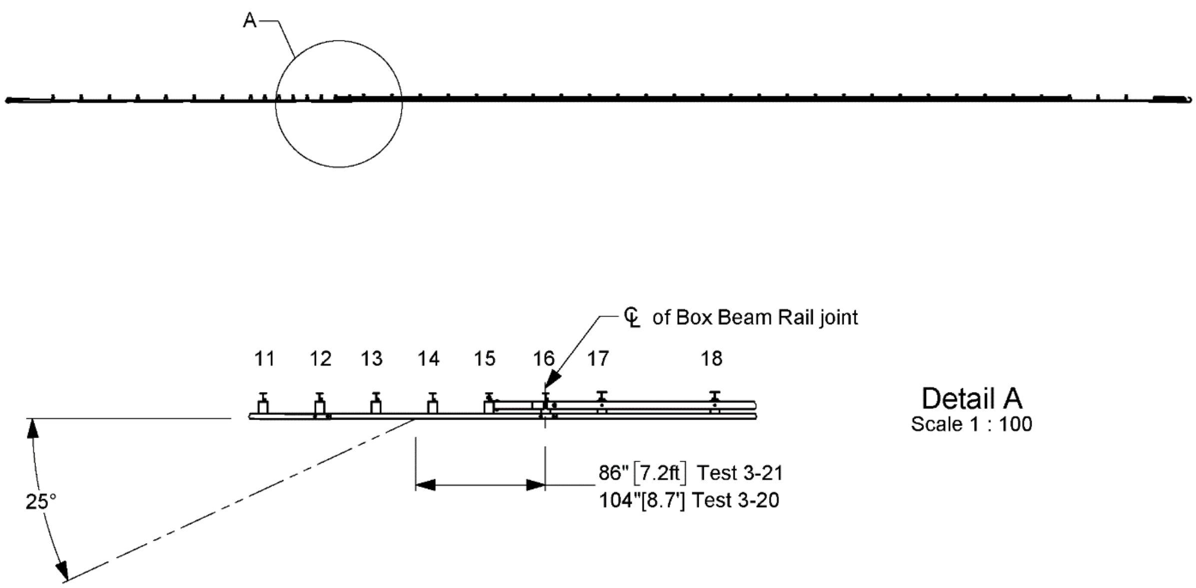


Figure 4.1. Target CIPs for *MASH* TL-3 Tests on TL-4 Guardrail Transition.

The crash tests and data analysis procedures were in accordance with the 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-3, and Table 4.2 provides detailed information on the evaluation criteria.

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

Evaluation Factors	Evaluation Criteria	*MASH* Test
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.	20, 21
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*.	20, 21
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	20, 21
H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	20, 21
I.	The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	20, 21

Chapter 5. TEST CONDITIONS

5.1. TEST FACILITY

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

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

5.2. VEHICLE TOW AND GUIDANCE SYSTEM

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

5.3. DATA ACQUISITION SYSTEMS

5.3.1. Vehicle Instrumentation and Data Processing

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

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

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

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

5.3.2. Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side of the 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 Transition 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.

5.3.3. Photographic Instrumentation Data Processing

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

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

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the Transition. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

Chapter 6. *MASH* TEST 3-20 (CRASH TEST 441203-01-1)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

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

Table 6.1. Impact Conditions for *MASH* Test 3-20, Crash Test 441203-01-1.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	63.7
Impact Angle (deg)	25	±1.5°	25.8
Impact Severity (kip-ft)	51	≥51 kip-ft	62.4
Impact Location	8.7 ft upstream from centerline of box beam rail joint at post 16	±1 ft	8.6 ft upstream from centerline of box beam rail joint at post 16

Table 6.2. Exit Parameters for *MASH* Test 3-20, Crash Test 441203-01-1.

Exit Parameter	Measured
Speed (mi/h)	44.3
Trajectory angle (deg)	11
Heading angle (deg)	20
Brakes applied post impact (s)	2.6
Vehicle at rest position	161 ft downstream of impact point 82 ft to the traffic side 30° right
Comments:	Vehicle remained upright and stable. Vehicle did not meet exit box criteria and crossed exit box[a] 27 ft downstream from loss of contact.

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

Figure 6.1. Transition and Test Vehicle Geometrics for Test 441203-01-1.

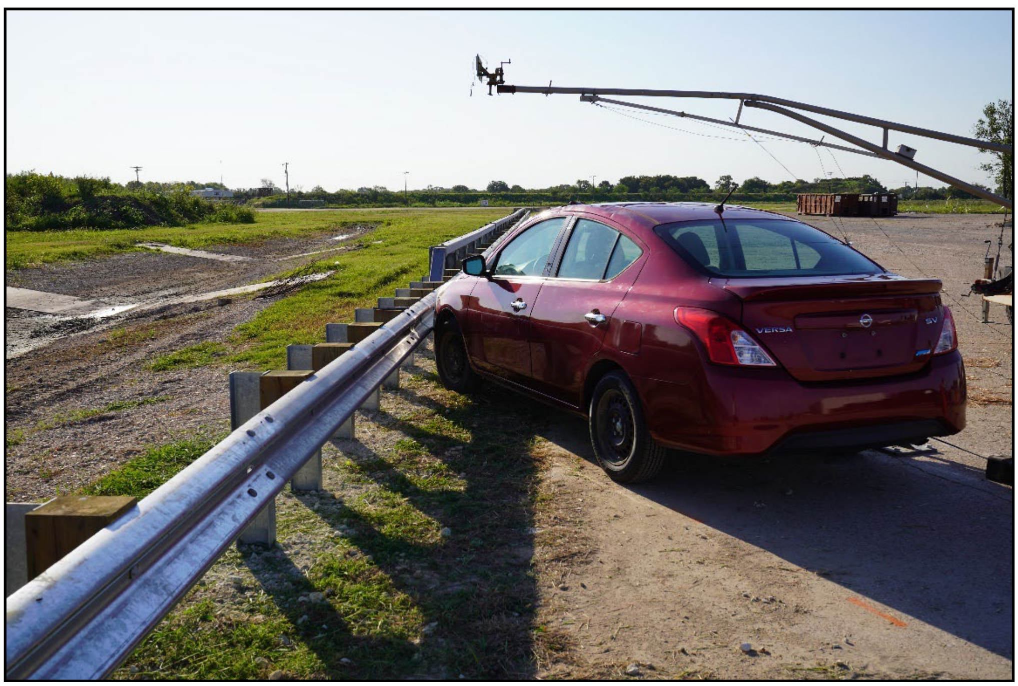


Figure 6.2. Test Vehicle at Impact Location for Test 441203-01-1.

6.2. WEATHER CONDITIONS

Table 6.3 provides the weather conditions for Test 441203-01-1.

Table 6.3. Weather Conditions for Test 441203-01-1.

Date of Test	2022-09-26 AM
Wind Speed (mi/h)	16
Wind Direction (deg)	51
Temperature (°F)	83
Relative Humidity (%)	49
Vehicle Traveling (deg)	100

6.3. TEST VEHICLE

Figure 6.3 and Figure 6.4 show the 2016 Nissan Versa used for the crash test. Table 6.4 shows the vehicle measurements. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.

Figure 6.3. Impact Side of Test Vehicle before Test 441203-01-1.

Figure 6.4. Opposite Impact Side of Test Vehicle before Test 441203-01-1.

Table 6.4. Vehicle Measurements for Test 441203-01-1.

Test Parameter	***MASH***	**Allowed Tolerance**	**Measured**
Dummy (if applicable)[a] (lb)	165	N/A	165
Inertial Weight (lb)	2,420	±55	2,427
Gross Static[a] (lb)	2,585	±55	2,592
Wheelbase (inches)	98	±5	102.4
Front Overhang (inches)	35	±4	32.5
Overall Length (inches)	169	±8	175.4
Overall Width (inches)	65	±3	66.7
Hood Height (inches)	28	±4	30.5
Track Width[b] (inches)	59	±2	58.4
CG aft of Front Axle[c] (inches)	39	±4	41.1
CG above Ground[c,d] (inches)	N/A	N/A	N/A

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

6.4. TEST DESCRIPTION

Table 6.5 lists events that occurred during Test 441203-01-1. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 6.5. Events during Test 441203-01-1.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0170	Post 15 began to lean toward field side
0.0290	Post 16 began to lean toward field side
0.0350	Vehicle began to redirect
0.0530	Post 17 began to lean toward field side
0.0740	Post 18 began to lean toward field side
0.1990	Vehicle was parallel with the installation
0.3690	Vehicle exited the installation at a speed of 44.4 mi/h with a heading angle of 20 degrees and a trajectory angle of 11 degrees

6.5. DAMAGE TO TEST INSTALLATION

The soil was disturbed at posts 10 and 11. Post 15 was twisted, and the blockout was detached from the post and the W-beam guardrail. The tire and wheel from the front impact side remained wedged beneath the rail at post 16.

Table 6.6 and Table 6.7 describe the damage to the Transition. Figure 6.5 and Figure 6.6 show the damage to the Transition.

Table 6.6. Soil Gap and Post Deflection Measurements after Test 441203-01-1.

Post Number	Soil Gap (Traffic Side)	Soil Gap (Field Side)	Angle (Back from Vertical)
12	¼ inch	—	1.0°
13	¾ inch	¼ inch	1.0°
14	3 inches	2 inches	6.0°
15	—	1 inch	19.0°
16	—	2 inches	10.0°
17	1 inch	1 inch	3.0°
18	½ inch	—	1.0°

— Indicates a zero measurement

Table 6.7. Damage to TL-4 Guardrail Transition for Test 441203-01-1.

Test Parameter	Measured
Permanent Deflection/Location	9 inches toward field side, at the midspan of posts 15 and 16.
Dynamic Deflection	16.2 inches toward field side between posts 15 and 16.
Working Width [a] and Height	36.6 inches, at a height of 19.4 inches.

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

Figure 6.5. Transition after Test at Impact Location for Test 441203-01-1.

Figure 6.6. Transition after Test from the Field Side of the Installation for Test 441203-01-1.

6.6. DAMAGE TO TEST VEHICLE

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

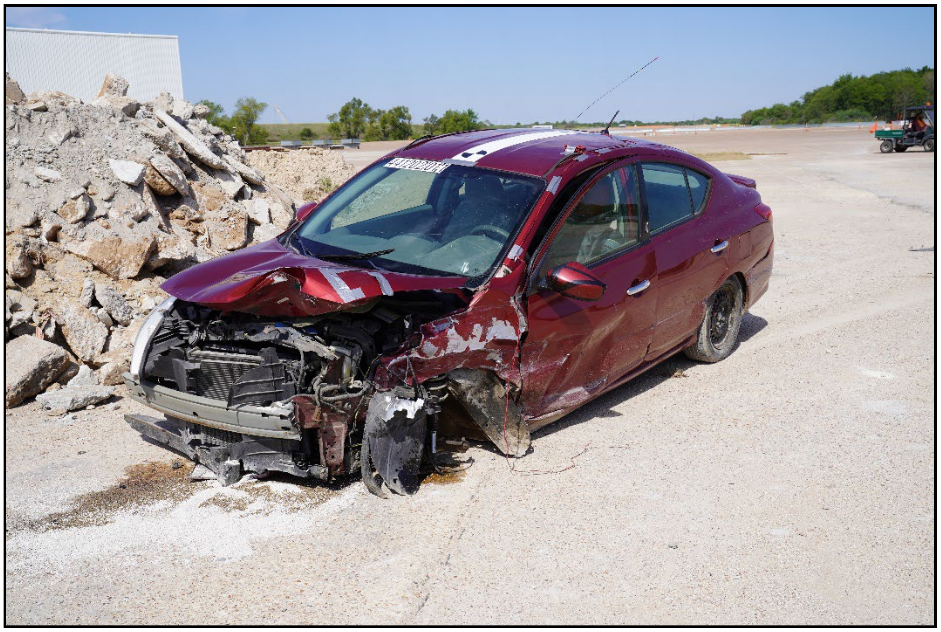


Figure 6.7. Impact Side of Test Vehicle after Test 441203-01-1.

Figure 6.8. Rear Impact Side of Test Vehicle after Test 441203-01-1.

Figure 6.9. Overall Interior of Test Vehicle after Test 441203-01-1.

Figure 6.10. Interior of Test Vehicle on Impact Side after Test 441203-01-1.

Table 6.8. Occupant Compartment Deformation for Test 441203-01-1.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	−1.0 inch
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	−2.5 inches
Front Door (above Seat)	≤9.0 inches	−2.0 inches
Front Door (below Seat)	≤12.0 inches	0 inches

Table 6.9. Exterior Vehicle Damage for Test 441203-01-1.

Side Windows	The side windows remained intact
Maximum Exterior Deformation	12 inches in the front plane at the left front corner at bumper height
VDS	11LFQ5
CDC	11FLEW4
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, radiator and support, left headlight, left front fender, left front strut and tower, left front tire and rim, left front floor pan, left CV shaft, left front control arm, left front door, left rear door, left rear rim, and the rear bumper were damaged. The left front door had a 3.5-inch gap at the top of the door, and the windshield had some cracking (due to vehicle body flexing from impact), but there was no hole or tear in the laminate.

6.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.10. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.6 in Appendix C.4 show acceleration versus time traces.

Table 6.10. Occupant Risk Factors for Test 441203-01-1.

Test Parameter	*MASH*[a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	27.2	0.1040 seconds on left side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	24.1	0.1040 seconds on left side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	11.6	0.1270–0.1370 seconds
Ridedown, Lateral (g)	≤20.49 *15.0*	14.5	0.1421–0.1521 seconds
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	10.8	0.1010 seconds on left side of interior
Acceleration Severity Index (ASI)	N/A	1.6	0.0781–0.1281 seconds
50-ms Moving Avg. Acceleration (MA) Longitudinal (g)	N/A	−13.3	0.0501–0.1001 seconds
50-ms MA Lateral (g)	N/A	11.2	0.0325–0.0825 seconds
50-ms MA Vertical (g)	N/A	−2.9	0.0913–0.1413 seconds
Roll (deg)	≤75	11	0.4823 seconds
Pitch (deg)	≤75	6	0.4165 seconds
Yaw (deg)	N/A	64	1.0260 seconds

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

6.8. TEST SUMMARY

Figure 6.11 summarizes the results of *MASH* Test 441203-01-1.

0.000 s

0.200 s

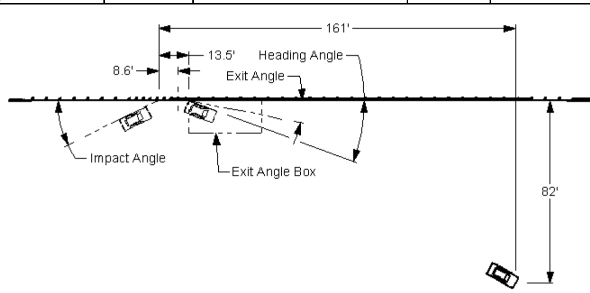
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test	*MASH* 2016, Test 3-20
TTI Project No.	441203-01-1
Test Date	2022-09-26
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Transition for TxDOT *MASH* TL-4 Guardrail
Length	260 ft 2 inches
Key Materials	Guardrail system with W-beam and HSS tube rail elements
Soil Type and Condition	AASHTO M147-17; Grading D Crushed Concrete Road Base
TEST VEHICLE	
Type/Designation	1100C
Year, Make and Model	2016 Nissan Versa
Inertial Weight (lb)	2427
Dummy (lb)	165
Gross Static (lb)	2592
IMPACT CONDITIONS	
Impact Speed (mi/h)	63.7
Impact Angle (deg)	25.8
Impact Location	8.6 ft upstream from centerline of joint in box beam rail at post 16
Impact Severity (kip-ft)	62.4
EXIT CONDITIONS	
Exit Speed (mi/h)	44.3
Trajectory/Heading Angle (deg)	11/20
Exit Box Criteria	Vehicle did not meet the exit box criteria
Stopping Distance	161 ft downstream 82 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	16.2
Permanent (inches)	9
Working Width/Height (inches)	36.6/19.4
VEHICLE DAMAGE	
VDS	11LFQ5
CDC	11FLEW4
Max. Ext. Deformation	12
Max Occupant Compartment Deformation	2.5 inches in the side panel

OCCUPANT RISK VALUES

Long. OIV (ft/s)	27.2	Long. Ridedown (g)	11.6	Max 50-ms Long. (g)	−13.3	Max Roll (deg)	11
Lat. OIV (ft/s)	24.1	Lat. Ridedown (g)	14.5	Max 50-ms Lat. (g)	11.2	Max Pitch (deg)	6
THIV (m/s)	10.8	ASI	1.6	Max 50-ms Vert. (g)	−2.9	Max Yaw (deg)	64



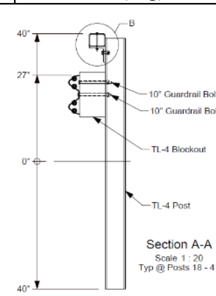


Figure 6.11. Summary of Results for *MASH* Test 3-20 on TL-4 Guardrail Transition.

Chapter 7. *MASH* TEST 3-21 (CRASH TEST 441203-01-2)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

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

Table 7.1. Impact Conditions for *MASH* Test 3-21, Crash Test 441203-01-2.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62 mi/h	±2.5 mi/h	62.1
Impact Angle (deg)	25°	±1.5°	25.1
Impact Severity (kip-ft)	106 kip-ft	≥106 kip-ft	117
Impact Location	7.2 ft upstream from centerline of joint in upper square tube rail at post 16	±1 ft	7.2 ft upstream from centerline of joint in upper square tube rail at post 16

Table 7.2. Exit Parameters for *MASH* Test 3-21, Crash Test 441203-01-2.

Exit Parameter	Measured
Speed (mi/h)	35.6
Trajectory angle (deg)	14
Heading angle (deg)	14
Brakes applied post impact (s)	Not applied
Vehicle at rest position	219 ft downstream of impact point 5 ft to the traffic side 5° right
Comments:	Vehicle remained upright and stable. Vehicle met the exit box criteria and crossed exit box[a] 48 ft downstream from loss of contact.

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

Figure 7.1. Transition and Test Vehicle Geometrics for Test 441203-01-2.

Figure 7.2. Test Vehicle at Impact Location for Test 441203-01-2.

7.2. WEATHER CONDITIONS

Table 7.3 provides the weather conditions for Test 441203-01-2.

Table 7.3. Weather Conditions for Test 441203-01-2.

Date of Test	2022-10-31 AM
Wind Speed (mi/h)	3
Wind Direction (deg)	290
Temperature (°F)	67
Relative Humidity (%)	76
Vehicle Traveling (deg)	100

7.3. TEST VEHICLE

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

Figure 7.3. Impact Side of Test Vehicle before Test 441203-01-2.

Figure 7.4. Opposite Impact Side of Test Vehicle before Test 441203-01-2.

Table 7.4. Vehicle Measurements for Test 441203-01-2.

Test Parameter	*MASH*	Allowed Tolerance	Measured
Dummy (if applicable)[a] (lb)	165	N/A	165
Inertial Weight (lb)	5,000	±110	5,043
Gross Static[a] (lb)	5,165	±110	5,208
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40.0
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46.0
Track Width[b] (inches)	67	±1.5	68.25
CG aft of Front Axle[c] (inches)	63	±4	61.0
CG above Ground[c,d] (inches)	28	≥28	28.5

[a] If a dummy is used, the gross static vehicle mass is increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

7.4. TEST DESCRIPTION

Table 7.5 lists events that occurred during Test 441203-01-2. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 7.5. Events during Test 441203-01-2.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0150	Post 14 began to lean toward field side
0.0180	Post 15 began to lean toward field side
0.0320	Post 16 began to lean toward field side
0.0400	Vehicle began to redirect
0.0560	Post 17 began to lean toward field side
0.0760	Post 18 began to lean toward field side
0.0890	Driver-side front fender snagged on square tube rail and began to peel back
0.2690	Vehicle was parallel with the installation
0.2980	Rear driver-side fender impacted square tube rail
0.5690	Vehicle exited the installation at a speed of 35.6 mi/h with a heading angle of 14 degrees and a trajectory angle of 14 degrees

7.5. DAMAGE TO TEST INSTALLATION

The soil was disturbed at posts 8 through 12. The lower rail released from posts 15 through 17, and the top rail released from posts 17 and 18. Table 7.6 and Table 7.7 describe the damage to the Transition. Figure 7.5 and Figure 7.6 show the damage to the Transition.

Table 7.6. Soil Gap and Post Deflection Measurements after Test 441203-01-2.

Post Number	Soil Gap (Traffic Side)	Soil Gap (Field Side)	Angle (Back from Vertical)	Angle (Downstream)
13	⅛ inch	⅛ inch	—	—
14	½ inch	¾ inch	2.4°	—
15	—	1 inch	17°	14°
16	—	—	—	40°
17	—	—	21°	—
18	—	2 inches	9°	—
19	2¼ inches	¾ inch	4°	—
20	1¼ inches	—	2.5°	—
21	½ inch	—	0.5°	—
22	—	⅛ inch	1°	—

Table 7.7. Damage to Transition for Test 441203-01-2.

Test Parameter	**Measured**
Permanent Deflection/Location	16.6 inches toward field side, 18 inches downstream of post 16
Dynamic Deflection	25.3 inches toward field side at post 16, at the top HSS rail
Working Width [a] and Height	56.2 inches at a height of 35.9 inches, at the front fender

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

Figure 7.5. Transition at the Impact Location after Test 441203-01-2.

Figure 7.6. In-Line View with the Transition after the Impact for Test 441203-01-2.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.7 and Figure 7.8 show the damage sustained by the vehicle. Figure 7.9 and Figure 7.10 show the interior of the test vehicle. Table 7.8 and Table 7.9 provide details on the occupant compartment deformation and exterior vehicle damage. Tables D.2 and D.3 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 7.7. Impact Side of Test Vehicle after Test 441203-01-2.

Figure 7.8. Rear Impact Side of Test Vehicle after Test 441203-01-2.

Figure 7.9. Overall Interior of Test Vehicle after Test 441203-01-2.

Figure 7.10. Interior of Test Vehicle on Impact Side after Test 441203-01-2.

Table 7.8. Occupant Compartment Deformation for Test 441203-01-2.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	0 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	0 inches
Front Door (above Seat)	≤9.0 inches	0 inches
Front Door (below Seat)	≤12.0 inches	0 inches

Table 7.9. Exterior Vehicle Damage for Test 441203-01-2.

Side Windows	The side windows remained intact
Maximum Exterior Deformation	12 inches in the front plane at the left front corner at bumper height
VDS	11LFQ3
CDC	11FLEW3
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, grill, left headlight, left front tire and rim, left lower control arm, left front fender, left front door, left rear door, left cab corner, left rear rim, left rear quarter fender, left taillight, and rear bumper were damaged.

7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.10. Figure D.3 in Appendix D.3 shows the vehicle angular displacements, and Figures D.4 through D.6 in Appendix D.4 show acceleration versus time traces.

Table 7.10. Occupant Risk Factors for Test 441203-01-2.

Test Parameter	*MASH* [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	21.4	0.1276 seconds on left side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	18.0	0.1276 seconds on left side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	14.2	0.1459–0.1559 seconds
Ridedown, Lateral (g)	≤20.49 *15.0*	8.4	0.1497–0.1597 seconds
THIV (m/s)	N/A	8.2	0.1232 seconds on left side of interior
ASI	N/A	1.0	0.0784–0.1284 seconds
50-ms MA Longitudinal (g)	N/A	−8.0	0.0834–0.1334 seconds
50-ms MA Lateral (g)	N/A	7.5	0.0465–0.0965 seconds
50-ms MA Vertical (g)	N/A	−3.2	0.5166–0.5666 seconds
Roll (deg)	≤75	13	0.5097 seconds
Pitch (deg)	≤75	17	4.9996 seconds
Yaw (deg)	N/A	39	0.4752 seconds

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

7.8. TEST SUMMARY

Figure 7.11 summarizes the results of *MASH* Test 441203-01-2.

0.000 s

0.200 s

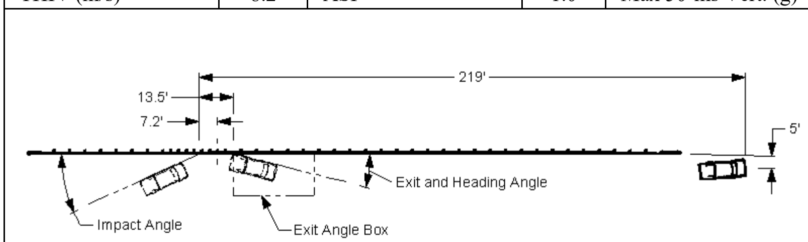
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test	*MASH* 2016, Test 3-21
TTI Project No.	441203-01-2
Test Date	2022-10-31
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Transition for TxDOT *MASH* TL-4 Guardrail
Length	260 ft 2 inches
Key Materials	Guardrail system with W-beam and HSS tube rail elements mounted
Soil Type and Condition	AASHTO M147-17, Grading D Crushed Concrete Road Base
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2017 RAM 1500
Inertial Weight (lb)	5043
Dummy (lb)	165
Gross Static (lb)	5208
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.1
Impact Angle (deg)	25.1
Impact Location	7.2 ft upstream from centerline of joint in upper square tube rail at post 16
Impact Severity (kip-ft)	117
EXIT CONDITIONS	
Exit Speed (mi/h)	35.6
Trajectory/Heading Angle (deg)	14/14
Exit Box Criteria	Vehicle met the exit box criteria
Stopping Distance	219 ft downstream 5 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	25.3
Permanent (inches)	16.6
Working Width/Height (inches)	56.2/35.9
VEHICLE DAMAGE	
VDS	11LFQ3
CDC	11FLEW3
Max. Ext. Deformation	12
Max Occupant Compartment Deformation	No occupant compartment deformation

OCCUPANT RISK VALUES

Long. OIV (ft/s)	21.4	Long. Ridedown (g)	14.2	Max 50-ms Long. (g)	−8.0	Max Roll (deg)	13
Lat. OIV (ft/s)	18.0	Lat. Ridedown (g)	8.4	Max 50-ms Lat. (g)	7.5	Max Pitch (deg)	17
THIV (m/s)	8.2	ASI	1.0	Max 50-ms Vert. (g)	−3.2	Max Yaw (deg)	39



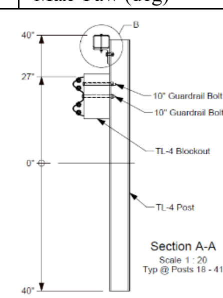


Figure 7.11. Summary of Results for *MASH* Test 3-21 on Transition.

Chapter 8. SUMMARY AND CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-3, which involves two tests on the Transition.

8.2. CONCLUSIONS

Table 8.1 shows that the Transition met the performance criteria for *MASH* TL-3 for transitions for longitudinal barriers.

Table 8.1. Assessment Summary for *MASH* TL-3 Tests on TL-4 Guardrail Transition.

Evaluation Criteria	Description	Test 441203-01-1, Test 3-20	Test 441203-01-2, Test 3-21
A	Contain, Redirect, or Controlled Stop	S	S
D	No Penetration into Occupant Compartment	S	S
F	Roll and Pitch Limit	S	S
H	OIV Threshold	S	S
I	Ridedown Threshold	S	S
Overall	Summary of Results	Pass	Pass

Note: S = Satisfactory.

Chapter 9. IMPLEMENTATION

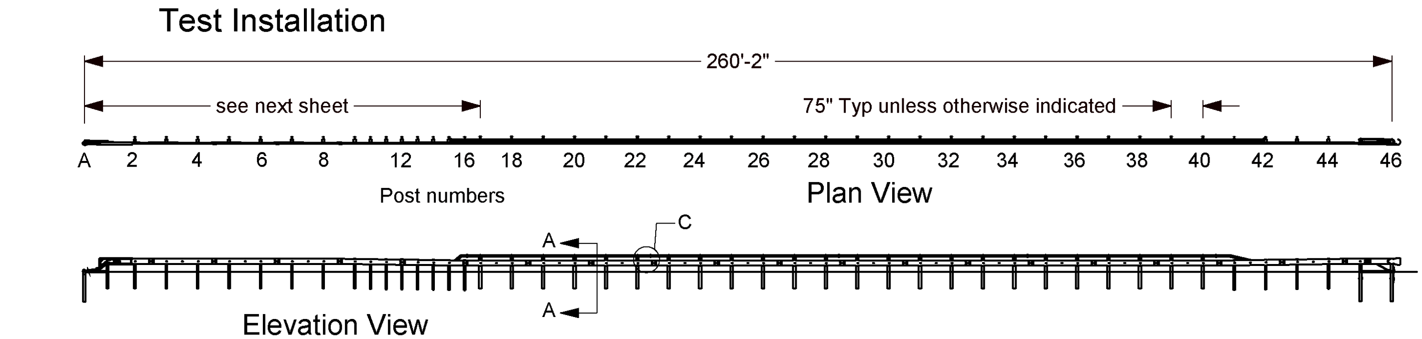
The Transition for the TxDOT *MASH* TL-4 guardrail developed in this project passed *MASH* TL-3 testing requirements for longitudinal barriers and is ready for implementation in the field. This implementation can be achieved by developing a design standard for the Transition. The value of research (VOR) for this project is presented in Appendix E.

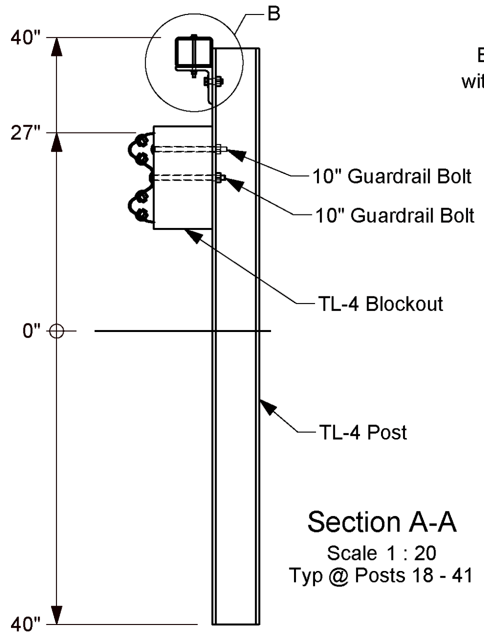
REFERENCES

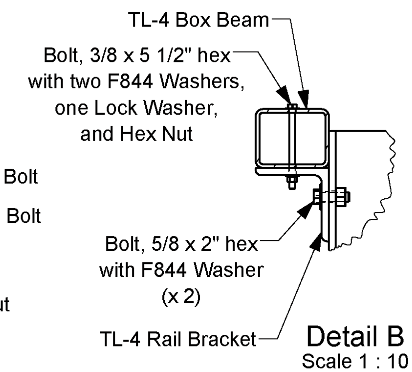
1. AASHTO. *Manual for Assessing Safety Hardware*, Second Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2016.
2. Sheikh, N. M., Bligh, R. P., Menges, W. L., Schroeder, W., Griffith, B. L., & Kuhn, D. L. *Development and Evaluation of MASH TL-4 Guardrail System* (FHWA/TX-21/0-7019-R1), Texas A&M Transportation Institute, College Station, Texas, 2021.
3. Kovar, J. C., Bligh, R. P., Menges, W. L., Schroeder, G. E., Schroeder, W., Wegenast, S. A., Griffith, B. L., and Kuhn, D. L. *MASH Crash Testing and Evaluation of the MGS Guardrail System with Reduced Post Spacing*, Test Report 610211-01, Texas A&M Transportation Institute, College Station, Texas, 2021.

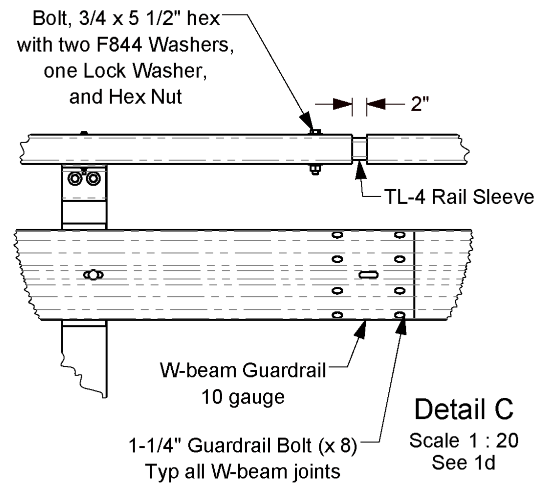
APPENDIX A. DETAILS OF TL-4 GUARDRAIL TRANSITION

Test Installation









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

1d. 10 gauge W-beam is typical at Posts 17 - 41. All other W-beam is 12 gauge. TL-4 Rail Sleeve and hardware typical 3 places.

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.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #441203-01 Transition for TL-4 Guardrail		2022-11-01
Drawn by GES	Scale 1:350	Sheet 1 of 8 Test Installation

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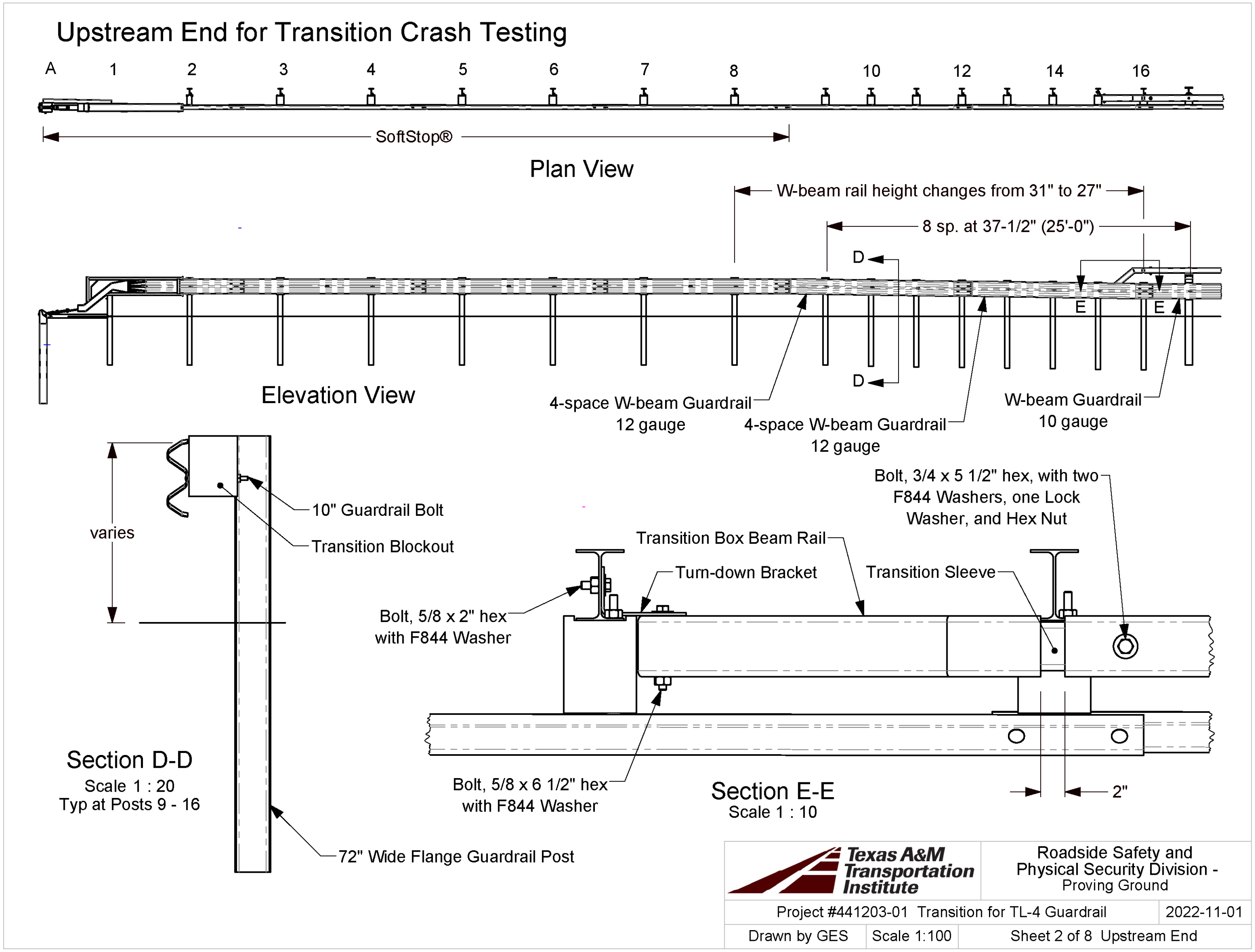

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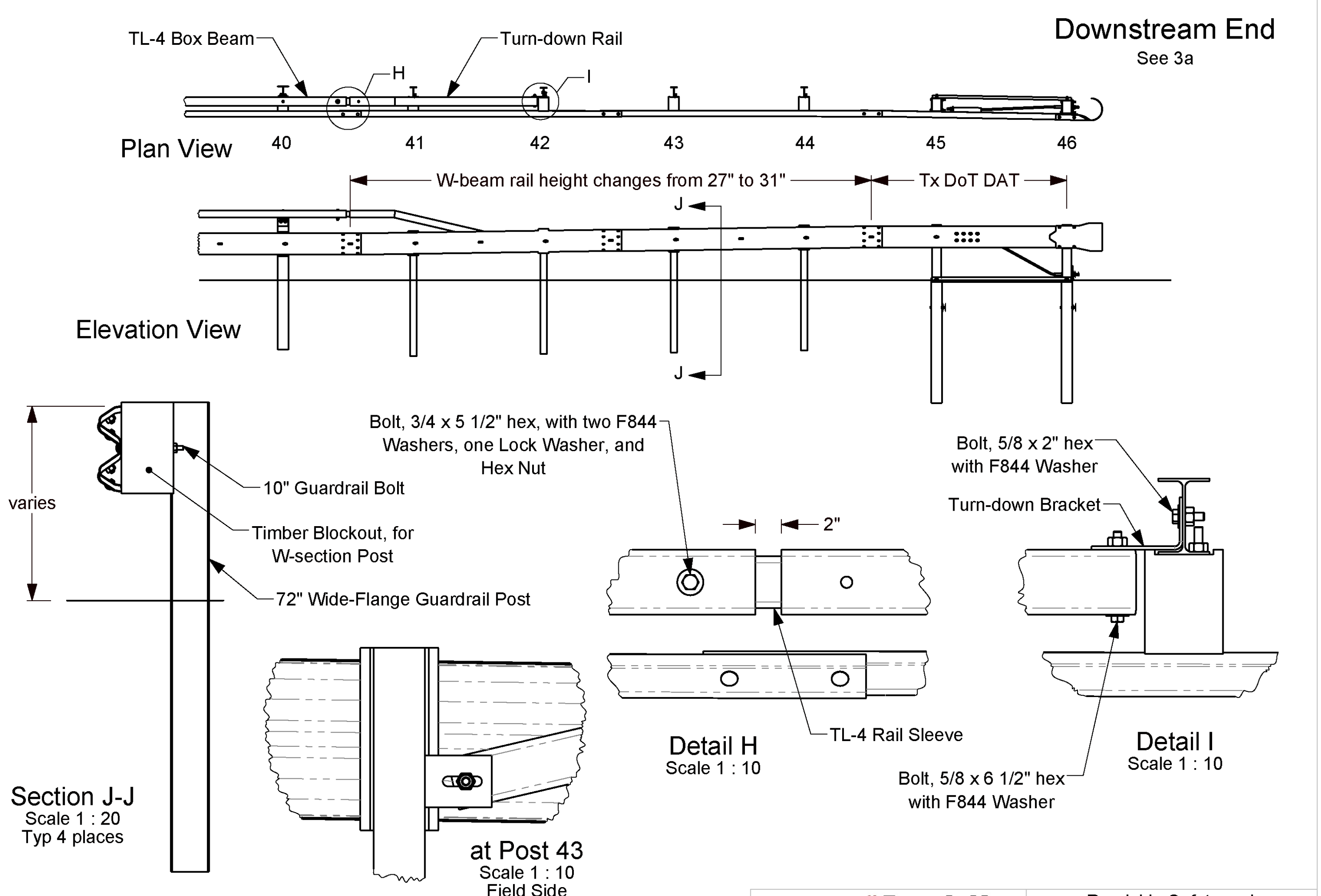

3a. Downstream End was retained from previously tested TL-4 Guardrail test installation. In actual field installation, Turn-down Rail should be replaced with Transition Box-Beam Rail, terminating at post 41.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #441203-01 Transition for TL-4 Guardrail		2022-11-01
Drawn by GES	Scale 1:75	Sheet 3 of 8 Downstream End

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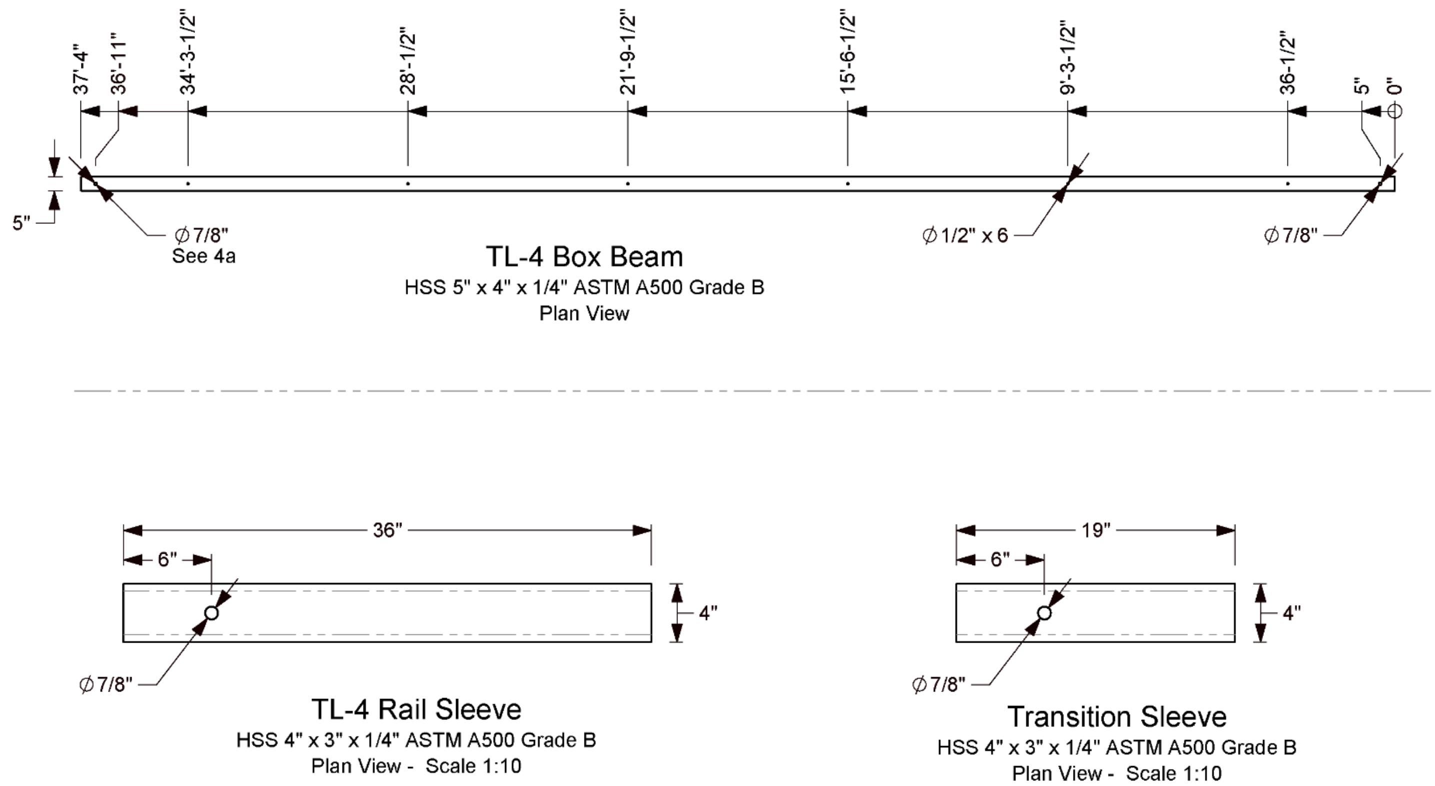
Rail Details



4a. This hole only needed on one rail (at upstream end; Posts 17 - 23).

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #441203-01 Transition for TL-4 Guardrail		2022-11-01
Drawn by GES	Scale 1:50	Sheet 4 of 8 Rail Details

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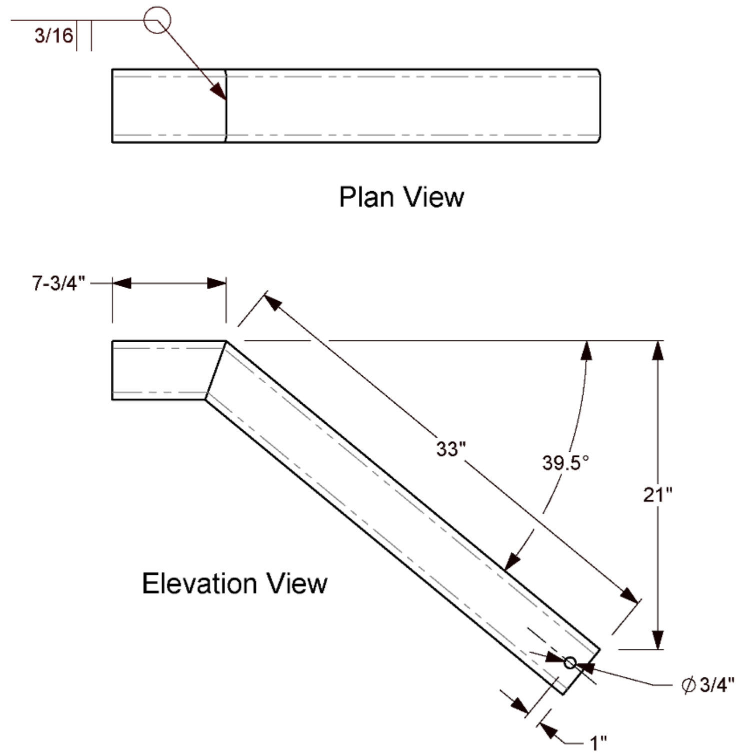
Transition Box Beam Rail

HSS 5" x 4" x 1/4" ASTM A500 Grade B



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project #441203-01 Transition for TL-4 Guardrail			2022-11-01
Drawn by GES	Scale 1:10	Sheet 5 of 8 Transition Rail	

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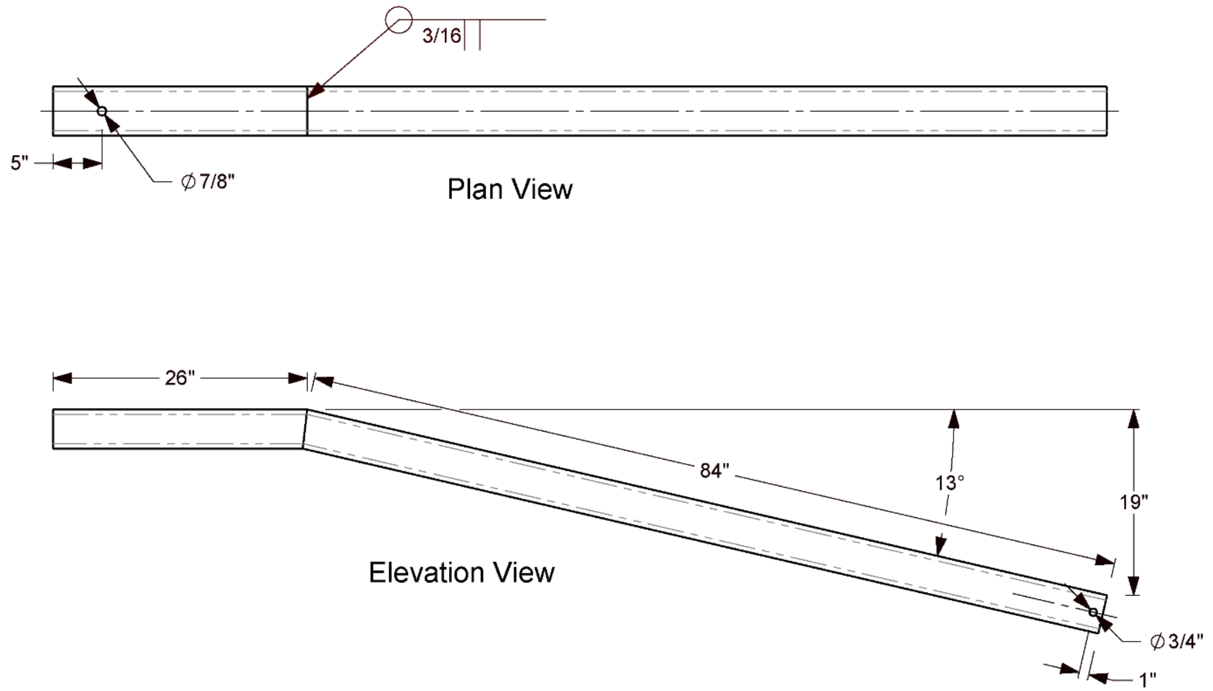
Turn-down Rail

HSS 5" x 4" x 1/4" ASTM A500 Grade B

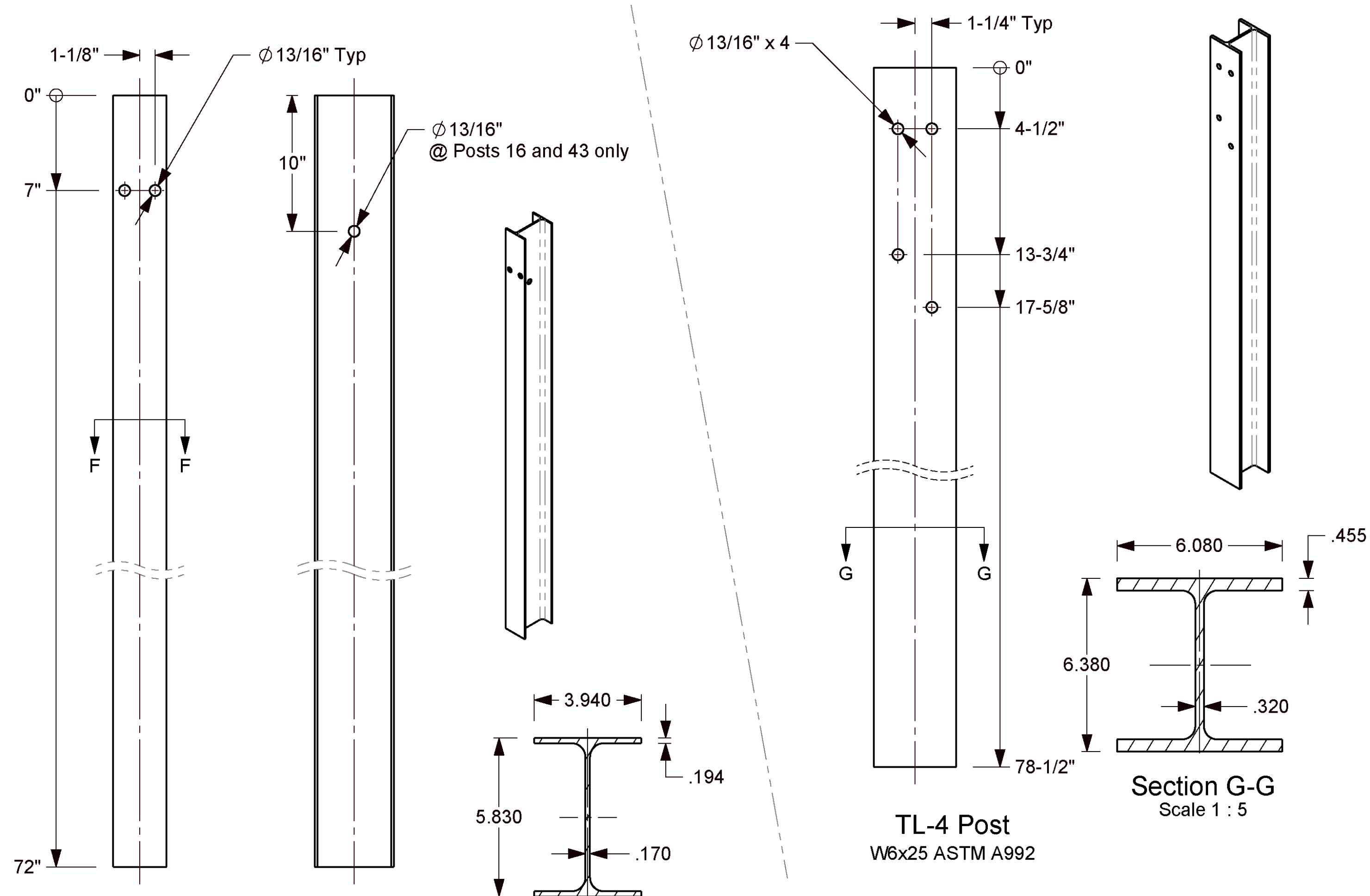
See 6a



6a. Turn-down Rail was retained from previously tested TL-4 Guardrail test installation. In actual field installation, replace Turn-down Rail with Transition Box Beam Rail, terminating at post 41. Also see 3a.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project #441203-01 Transition for TL-4 Guardrail			2022-11-01
Drawn by GES	Scale 1:15	Sheet 6 of 8 Turn-down Rail	

Q:\Accreditation-17025-2017\EIR-000 Project Files\441203-01 Transition for TL4 - Sheikh (441202-01)\Drafting, 441202-01\441202-01 Drawing



72" Wide Flange Guardrail Post
W6x8.5 ASTM A992

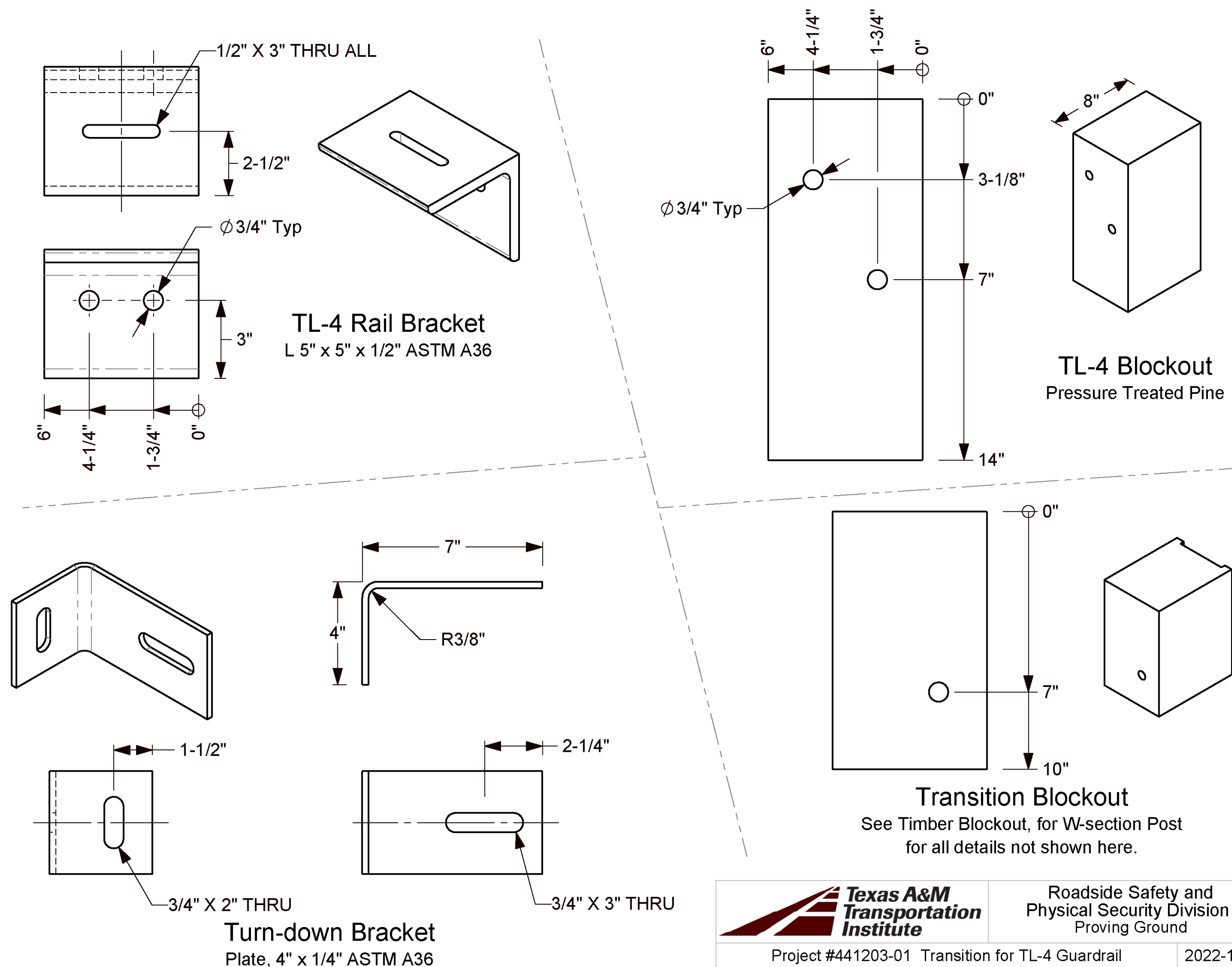
Section F-F
Scale 1 : 5

TL-4 Post
W6x25 ASTM A992

Section G-G
Scale 1 : 5

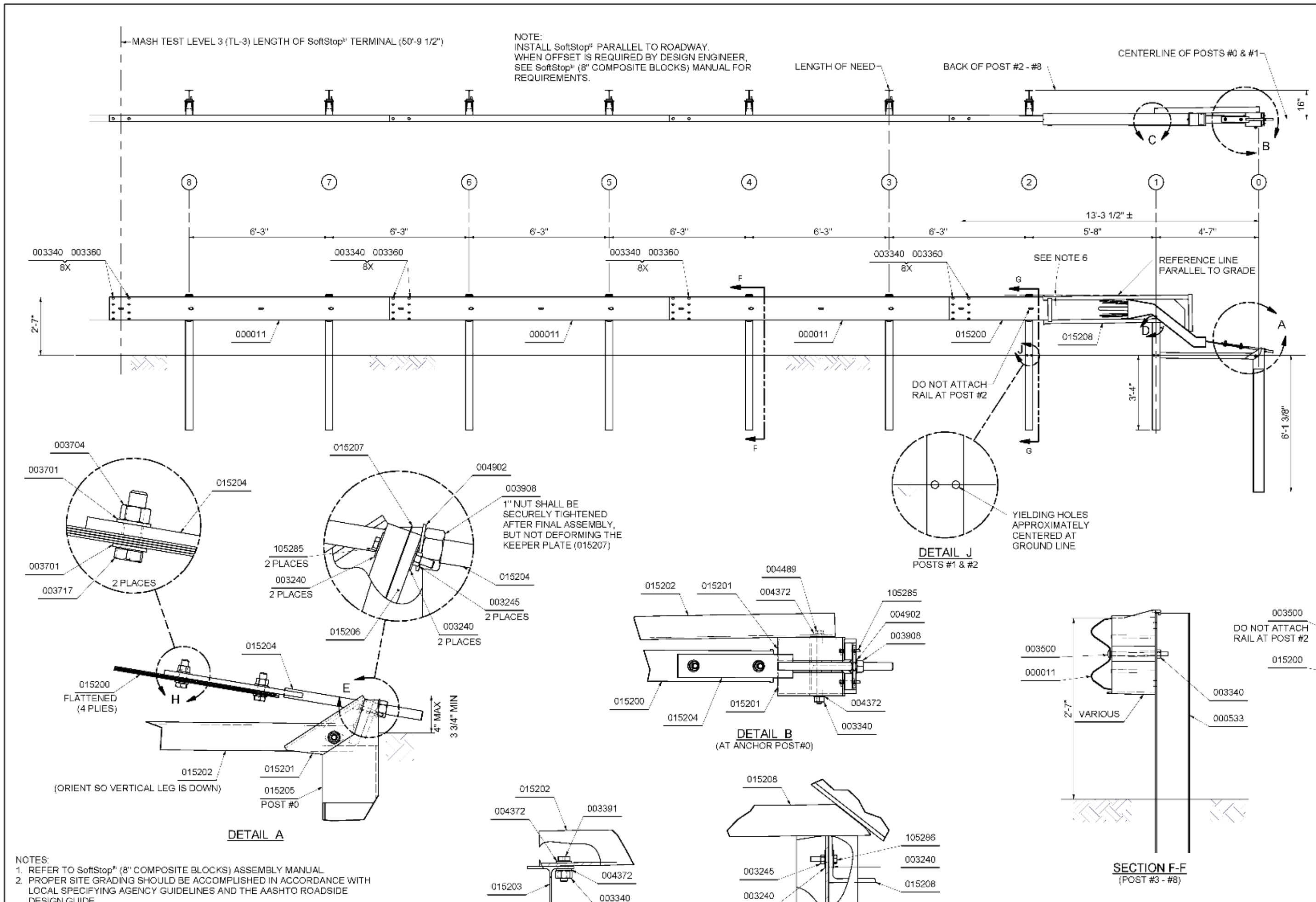
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #441203-01 Transition for TL-4 Guardrail		2022-11-01
Drawn by GES	Scale 1:10	Sheet 7 of 8 Posts

Q:\Accreditation-17025-2017\EIR-000 Project Files\441203-01 Transition for TL4 - Sheikh (441202-01)\Drafting, 441202-01\441202-01 Drawing



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #441203-01 Transition for TL-4 Guardrail		2022-11-01
Drawn by GES	Scale 1:5	Sheet 8 of 8 Assorted Parts

Q:\Accreditation-17025-2017\EIR-000 Project Files\441203-01 Transition for TL4 - Sheikh (441202-01)\Drafting, 441202-01\441202-01 Drawing



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 | BS 11/14/2012
N/A
EST UNFINISHED WT. 0.0 lbs

TOLERANCES PER THP-SF-001, UNLESS OTHERWISE SPECIFIED.
DO NOT SCALE DRAWING

Revision	ECO	Date	Rev	By	Chk
ADDED CALLOUTS FOR BOLTS & NUTS AT SPLICES	4644	6/21/17	7	DDS	KWL
UPDATED 16" DIMENSION, REPLACED LENGTH FOR NEED CALLOUT MISSING FROM REV 7	4689	7/27/17	H	DDS	KWL
ADDED 8" COMPOSITE BLOCKS TO NOTES & MOVED 015201, 015206 & 015207 TO HDWR KIT	6641	6/1/19	I	DDS	PLK

SoftStop® TERMINAL (8" BLOCKS)
PLAN, ELEVATION & SECTION
MASH TEST LEVEL 3 (TL-3)
P/N: 500646

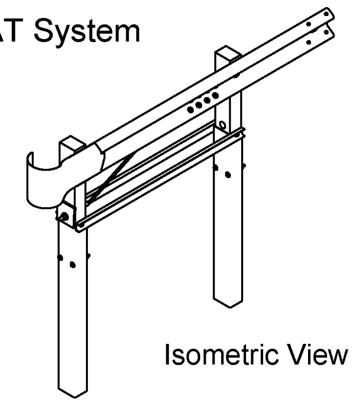
SS 646 | I | 1 of 1

TRINITY HIGHWAY

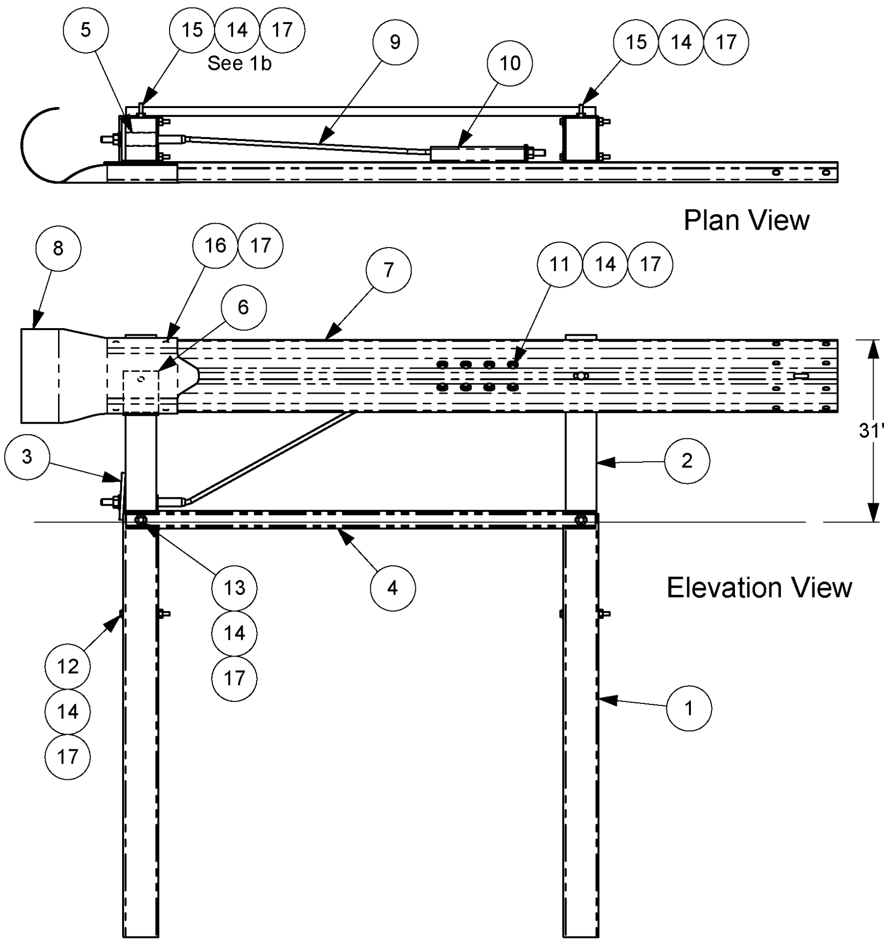
THP-FF-052 Rev D 5/20/2018

2023-06-27

DAT System



Isometric View



Plan View

Elevation View

#	Part Name	Qty.
1	72" Foundation Tube	2
2	Tube Post	2
3	BCT Bearing Plate	1
4	DAT Strut	2
5	BCT Post Sleeve	1
6	Shelf Angle Bracket	1
7	9'-4" span 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

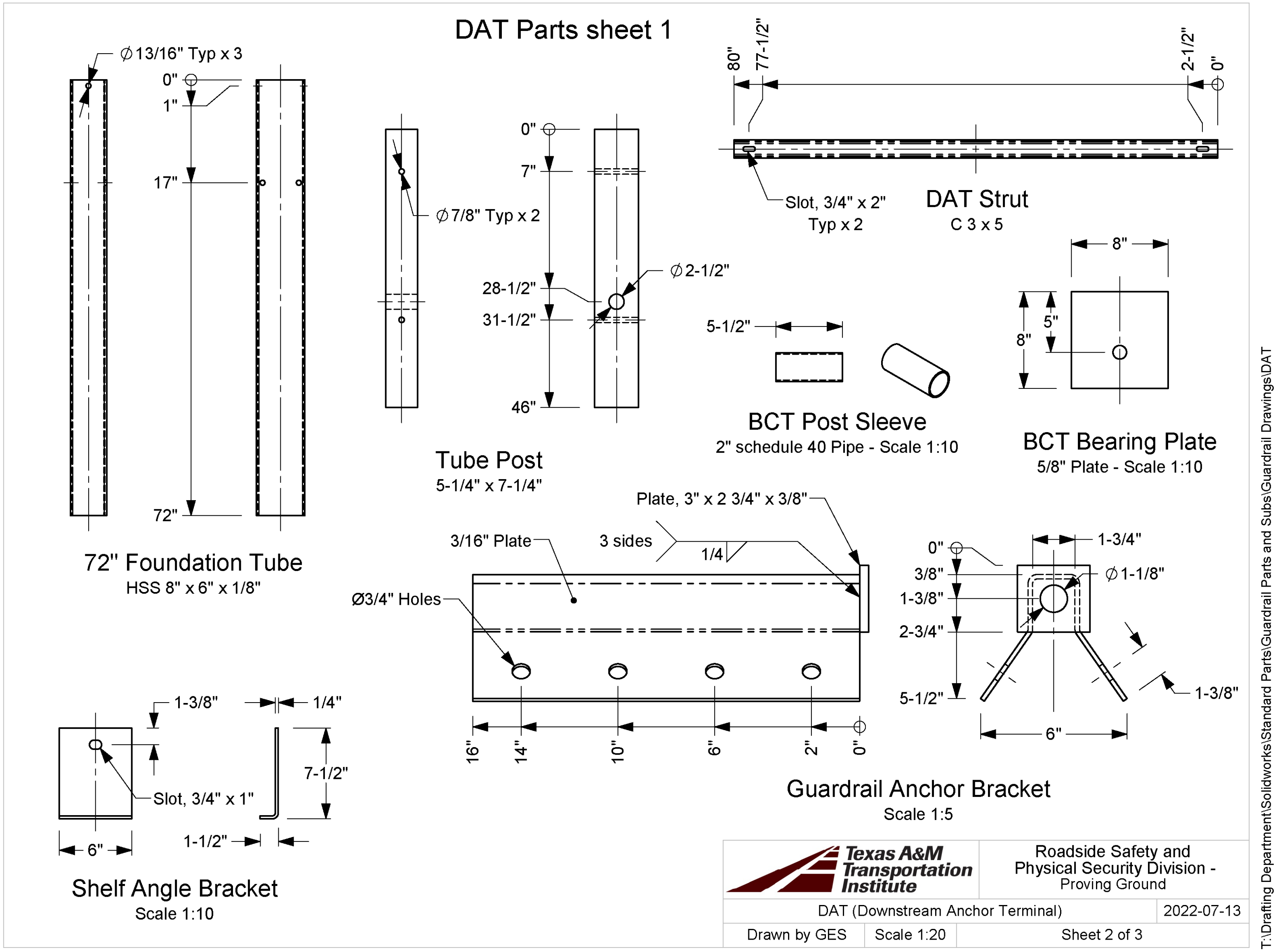
1a. All bolts are ASTM A307.

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

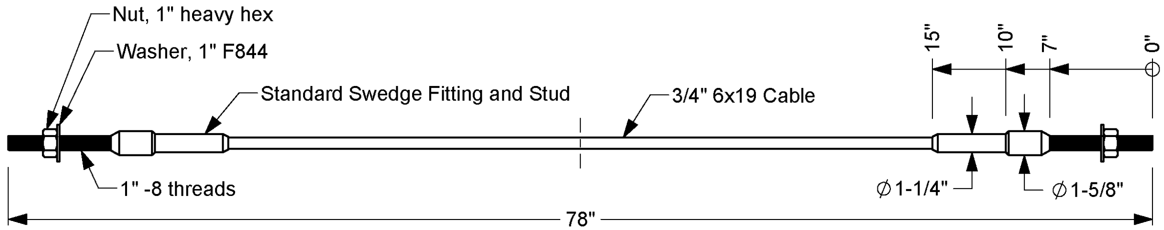
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
DAT (Downstream Anchor Terminal)	2022-07-13	
Drawn by GES	Scale 1:25	Sheet 1 of 3

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

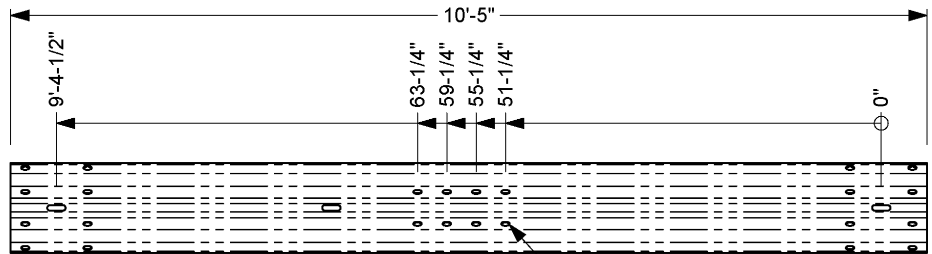
2023-06-27


DAT Parts sheet 1
⌀13/16" Typ x 3
0"
1"
17"
72"
72" Foundation Tube
HSS 8" x 6" x 1/8"
0"
7"
⌀7/8" Typ x 2
⌀2-1/2"
28-1/2"
31-1/2"
46"
Tube Post
5-1/4" x 7-1/4"
80"
77-1/2"
2-1/2"
0"
Slot, 3/4" x 2"
Typ x 2
DAT Strut
C 3 x 5
5-1/2"
BCT Post Sleeve
2" schedule 40 Pipe - Scale 1:10
8"
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"
⌀1-1/8"
1-3/8"
6"
Guardrail Anchor Bracket
Scale 1:5
1-3/8"
1/4"
7-1/2"
Slot, 3/4" x 1"
1-1/2"
6"
Shelf Angle Bracket
Scale 1:10
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)
2022-07-13
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

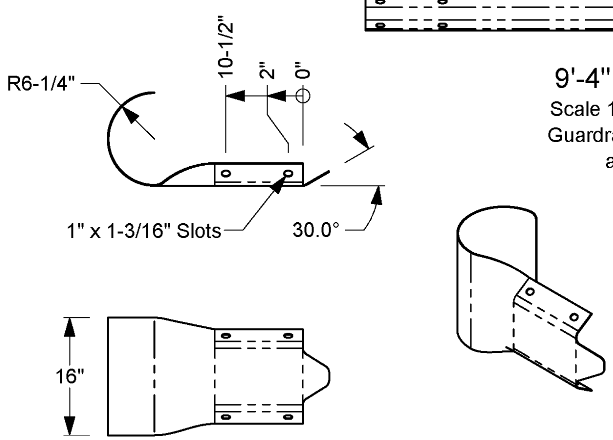


Anchor Cable Assembly



9'-4" span Terminal Rail

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

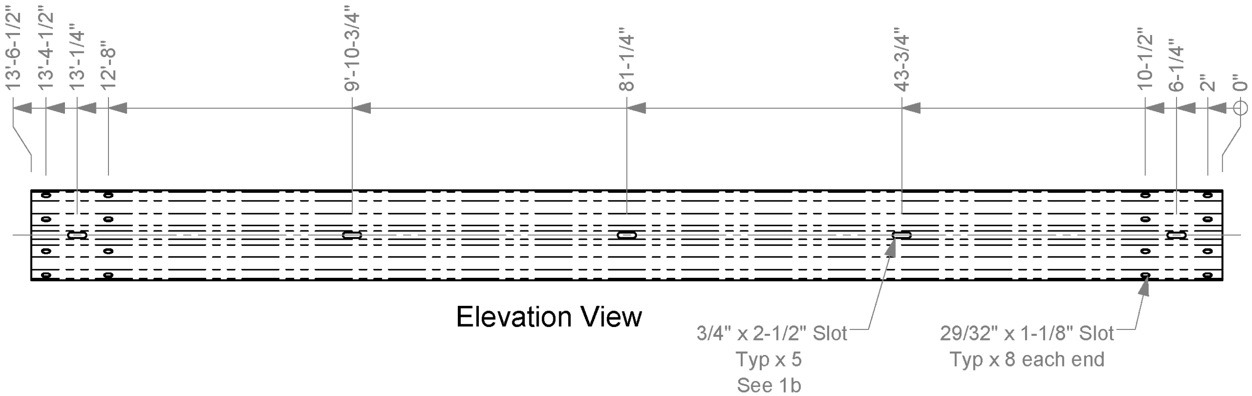


W-beam End Section

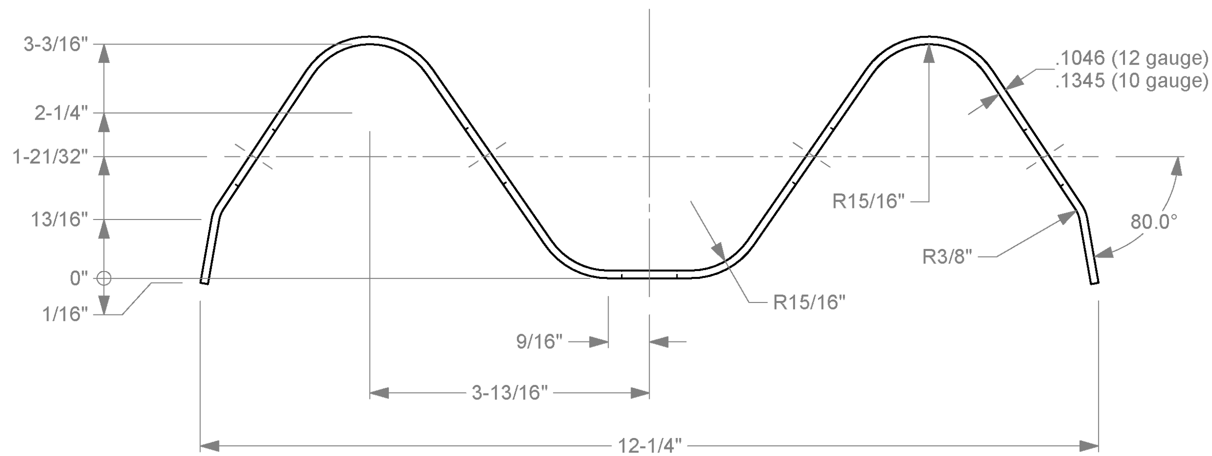
12 gauge steel - Scale 1:20

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
DAT (Downstream Anchor Terminal)		2022-07-13
Drawn by GES	Scale 1:10	Sheet 3 of 3

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



Elevation View



Section View

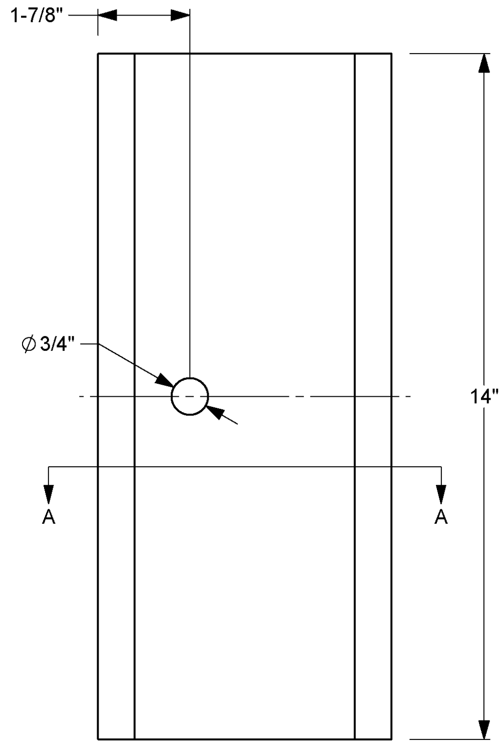
1a. Manufacture per AASHTO M180 specifications.

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

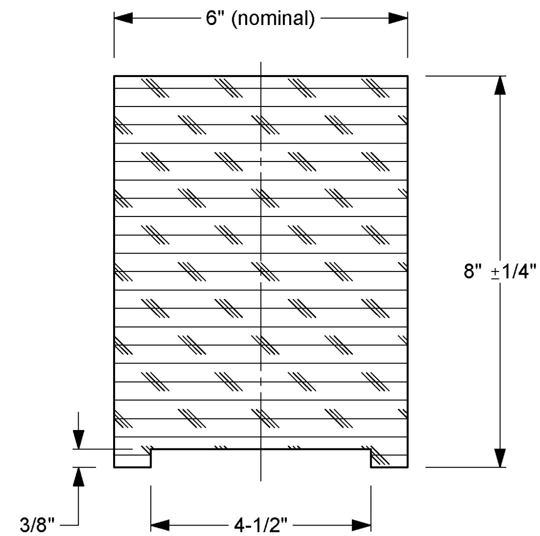
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
W-beam Guardrail		2022-07-08
Drawn by GES	Scale 1:20	Sheet 1 of 1

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

Timber Blockout for W-section Post



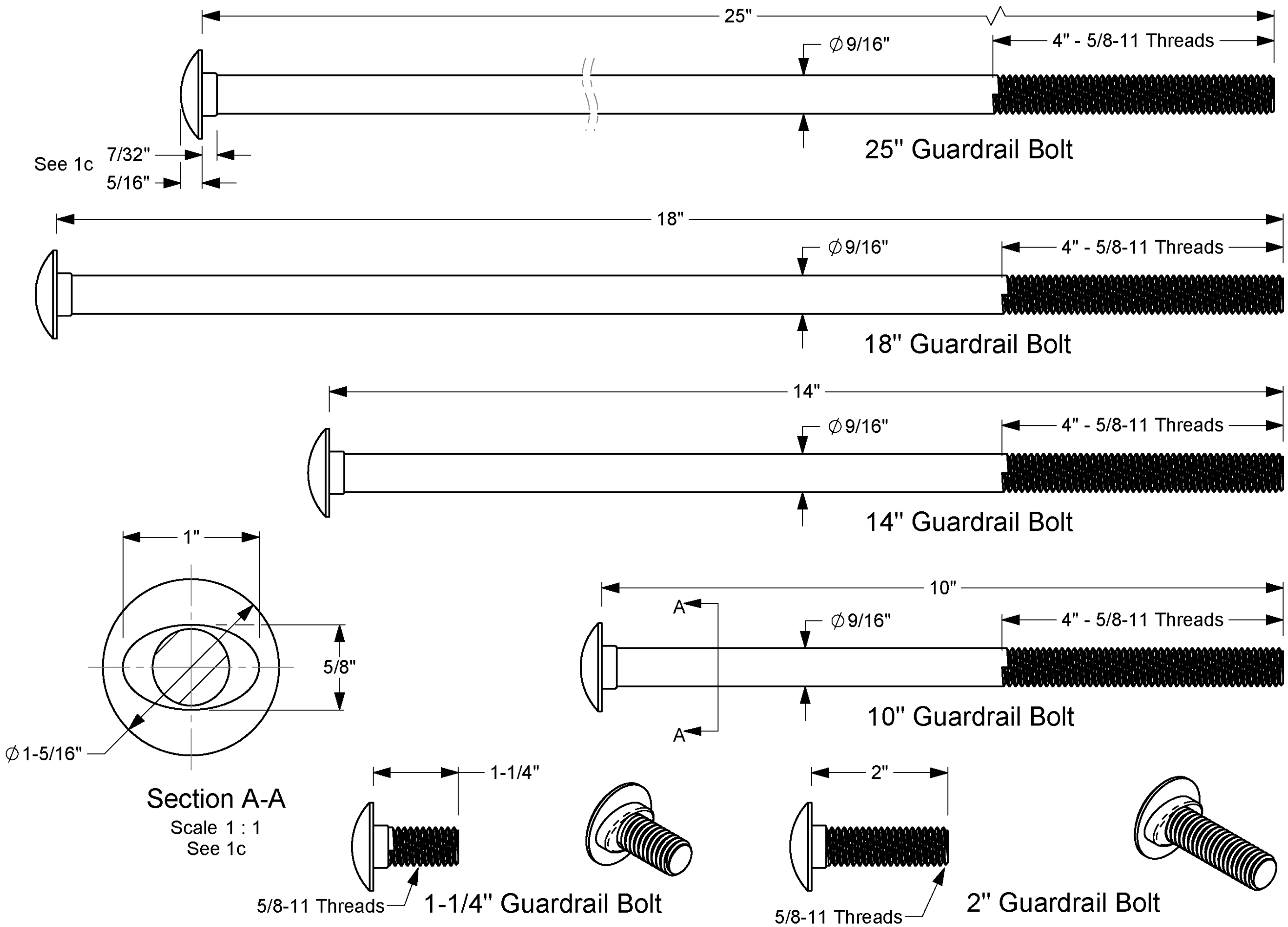
Elevation View



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			2022-07-08
Drawn by GES	Scale 1:3	Sheet 1 of 1	



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

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

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

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

A572 PLATE For WASHERS

METALLURGICAL TEST REPORT
Nucor Steel Berkeley
a division of NUCOR corporation

1455 Hagan Avenue
Huger, SC 29450

Phone: 843-336-6000
Sales Fax: 843-336-6150

Issuance Date 10/23/19 MTR# 1610508 MTR BER INQUIRIES@NUCOR.COM

Sold To: KLOECKNER METALS CORPORATION
500 COLONIAL CTR PKWY
STE 500
ROSWELL, GA 30076

Ship To: COASTAL CARGO
16800 PENINSULA BLVD
CPT CARE TERMINALS
HOUSTON, TX 77067

Ship Date 9/28/19
Bill of Lading # 1437031
Vehicle # BULKMASTER
Rls # BLUE
P/O # 7421846
Mill Order # 470453-2
Part # .24X60 A572GR50

Gauge x Width .2400 MIN X 60.0000 MIN HR HOT ROLL COIL
ASTM A1018 / HSLAS GR50 CL1 / REV: 2018

SUITABLE FOR CONVERSION TO ASTM A572 GRADE 50

Heat	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Nb	N	Ti	B	Ca
2912871	.05	1.14	.010	.003	.19	.08	.03	.03	.01	.007	.032	.007	.034	.007	.013	.000	.002
2912873	.05	1.14	.008	.003	.18	.08	.03	.03	.01	.006	.032	.006	.034	.007	.011	.000	.002

	YIELD STRENGTH (ksi)		TENSILE STRENGTH (ksi)		ELONGATION (% IN 2")		HARDNESS	N Value	
Heat/Coil#	long.	trans.	long.	trans.	long.	trans.	(Rockwell B)	long.	trans.
2912871-2		59.3		72.4		34	83		.13
2912871-4		63.8		72.5		28	84		.13
2912873-2		62.6		72.6		27	82		.13

Coil (tag) 2912871-4
(48600.00 LB)
Coil (tag) 2912873-2
(49160.00 LB)

Mill Test Reports according to EN10204 3.1

All material is sold subject to the description, specifications and terms and conditions set forth on the face and reverse side of Nucor Steel - Berkeley's sales order acknowledgment.

Tensile Testing, when applicable, is performed in accordance with ASTM A-370 specifications. Specimen is machined to standard rectangular test configuration (Figure 3 of ASTM A-370) with a 2" gage length. Yield Strength is determined at 0.2% offset.

This material has been produced in compliance with the chemistry and established rolling practices of the ordered specification. If material is ordered to a chemical composition only and if

07-20-2022 05:47 Load - 4119590 BL - 3920237 blr466

Custom Fabricators Heat - 8000017503

Cust. PO - 02713 Order - 21595136

3920237

NUCOR

Mill Certification

05/20/2022

MTR#:1036604-5
Lot #:800001750321
300 STEEL MILL RD
DARLINGTON, SC 29540 US
843 393-5841
Fax: 843 395-8701

Sold To: KLOECKNER METALS CORP
500 COLONIAL CENTER PKWY
STE 500
ROSWELL, GA 30076 US

Ship To: KLOECKNER METALS
4606 SINGLETON BLVD
DALLAS, TX 75212 US

Customer PO	7740260	Sales Order #	11045778 - 1.1
Product Group	Hot Roll - Merchant Bar Quality	Product #	3010243
Grade	Nucor Multigrade	Lot #	800001750321
Size	1.5"	Heat #	8000017503
BOL #	BOL-1134937	Load #	1036604
Description	Hot Roll - Merchant Bar Quality Round 1.5" (1 1/2") Nucor Multigrade 20' 0" [240"] 4001-6000 lbs	Customer Part #	MB11/2RNDMA360240
Production Date	04/28/2022	Qty Shipped LBS	14430
Product Country Of Origin	United States	Qty Shipped EA	120
Original Item Description	Hot Roll - Merchant Bar Quality Round 1.5" (1 1/2") Nucor Multigrade 20' 0" [240"]	Original Item Number	1026563

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Melt Country of Origin : United States Melting Date: 04/26/2022

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	Ti (%)	V (%)	Nb (%)
0.16	0.66	0.013	0.019	0.205	0.07	0.14	0.02	0.24	0.001	0.048	0.002

Sn (%)
0.008

ASTM A529 S78.2 CE (%) : 0.37

ASTM A992 5.4 CE (%) : 0.33

Reduction Ratio 27.67 : 1

Tensile testing

	Yield (PSI)	Tensile (PSI)	Elongation in 8" (%)
(1)	56600	76800	20.0
(2)	57300	75800	21.0

Comments:

Nucor Multigrade meets the requirements of: ASTM A36/A36M, A529/A529M GR50, A572/A572M GR50(345), A709/A709M GR36(250) & GR50(345), CSA G40.21 GR44W(300W) & GR50W(350W), AASHTO M270/M270M-10 GR36(270) & GR50(345), ASME SA36/SA36M, QQ-S-741D, CAT 1E1883. Produced to a fully killed, fine grain practice.

Welding or weld repair was not performed on this material.

Melted and Manufactured in the U.S.A and complies with the Buy American Act.

Mercury, radium, or alpha source materials not intentionally added at any point during manufacturing or testing of this material.

Material is certified to the most recent revision of the specification(s) and grade indicated at the time of production.

Kloeckner — 1½" Round BAR 07/20/2022

Mark Schmidt, Chief Metallurgist

Page 1 of 1

Delta - W6x8.5 beam 08/03/2022 149214

GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CERTIFIED MATERIAL TEST REPORT

Page 1 / 1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
DELTA STEEL INC 7355 ROUNDHOUSE LN HOUSTON,TX 77078-4528 USA	DELTA STEEL INC 7355 ROUNDHOUSE LN HOUSTON,TX 77078 USA	A992/A572-50G	Wide Flange Beam / 6 X 8.5# / 150 X 13.0	0009810803

LENGTH	PCS	WEIGHT	HEAT / BATCH
37'00"	24	7,548 LB	59105654/02

SALES ORDER	CUSTOMER MATERIAL N°
12086396/000010	

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
HOU-75105	1327-0000486052	07/27/2022

SPECIFICATION / DATE or REVISION
ASTM A6-17
ASTM A709-18
ASTM A992-20, A572-21
CSA G40.21-13 345WM, 50W

CHEMICAL COMPOSITION

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Cu (%)	Ni (%)	Cr (%)	Mo(%)	Sn (%)	V (%)	Nb (%)	Al (%)	CEqvA6 (%)
0.12	0.96	0.009	0.016	0.20	0.25	0.08	0.16	0.019	0.005	0.001	0.012	0.002	0.33

MECHANICAL PROPERTIES

YS 0.2% (PSI)	UTS (PSI)	YS (MPa)	UTS (MPa)	Y/T rati (%)	G/L (Inches)	G/L (mm)	Elong. (%)
59185	73686	408	508	0.800	8.000	200.0	23.50
60368	75160	416	518	0.800	8.000	200.0	23.50

COMMENTS / NOTES

Meets requirements of ASTM A6 with the exception of identification on each piece

The above figures are certified chemical and physical test records as contained in the permanent records of the company. We certify that these data are correct and in compliance with specified requirements. No weld repair was performed on this material. The material has not been in contact with mercury while in Gerdau possession. For all products other than billets or beam blanks, this material was produced (Electric Arc Furnace, Melted, Continuously Cast, Hot Rolled and, if applicable, Cold-Drawn) in the USA. For billets or beam blanks, this material was produced (Electric Arc Furnace, Melted and Continuously Cast) in the USA. CMTR complies with EN 10204 3.1.

Bhaskar
BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 267-1071 Email: Bhaskar.Yalamanchili@gerdau.com

Wade L. Lumpkins
WADE LUMPKINS
QUALITY ASSURANCE MGR.
Phone: 972-779-3118 Email: Wade.Lumpkins@gerdau.com

Heat Number	Shipper No	Customer PO#	Customer Name
59105654	329299	02741	CUSTOM FABRICATORS & REPAII

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) ASTMF 2329-11	43.2	52--57

QUALITY MANAGER
Jikan Feng

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

兆豐國際商業銀行 岡山分行
[illegible]B 00148
Mega ICBC Kang Shan Branch

兆豐國際商業銀行 岡山分行
[illegible] 05---

HANGZHOU SPRING WASHER CO .,LTD

QUALITY TEST CERTIFICATE OF SPRING LOCK WASHER

Customer: ~~ASME B 18.21.1-1999~~

Standard:

Order No.: PO 16072544

Contract No.:

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.

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

PART NO: 00024-3260-024

HEADMARKS: 307A PLUS NY

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

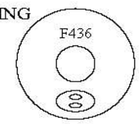
We hereby certify that the material described herein has been manufactured and tested with satisfactory results in accordance with the requirement of the above material/dimensional specifications.

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

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	29 PCS	ASTM F606/F606M	68-107 HRB	81 HRB	29	0
PROOF LOAD	15 PCS	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.

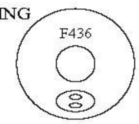
SIGNATURE : Jerry

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

MARKING



INSPECTION CERTIFICATE

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]ATION 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

Product	Heat	Tag	Pcs	LBS
TEMPERED LEVELED PLATE A36/SA36 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 8 Pc(s)	.07 .04	.88 .01 .001 6,080 lbs	.008 .0080	.028 .0001	.24 .004 .0047	.14 .029	.03 3.54	.24 .2837 .1326
								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 18 Pc(s)	.08 .08	1.06 .01 .001 14,400 lbs	.008 .0095	.024 .0002	.25 .002 .0063	.24 .028	.06 5.05	.29 .3362 .1549
								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 20 Pc(s)	.07 .08	1.07 .01 .001 20,000 lbs	.009 .0100	.013 .0002	.23 .002 .0068	.23 .031	.06 4.94	.28 .3272 .1459
								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

**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	2007786	.81	61300	75500	23.00	.07	1.03	.008	.022	.26	.23	.06	.28
040' 00.00"	A992-11(15		423	521		.08	.01	.0095	.0002	.002	.032		.3302
W150X37.1		.80	59300	73700	24.00		.001			.0069		4.97	.1491
012.1920m			409	508									

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 pefomed.
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

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
C	0.16%
Mn	0.78%
P	0.012%
S	0.020%
Si	0.17%
Cu	0.38%
Cr	0.15%
Ni	0.17%
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
Elongation test 1	24%
Elongation Gage Lgth test 1	8IN
Yield to tensile ratio test1	0.71
Yield Strength test 2	55.5ksi
Tensile Strength test 2	79.2ksi
Elongation test 2	25%
Elongation Gage Lgth test 2	8IN
Yield to tensile ratio test2	0.70

Characteristic	Value

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

The Following [illegible] 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.

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

Page: 3 of 5

CERTIFICATE OF TESTING
IPSCO TUBULARS INC

TMK IPSCO

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
NOR 1GO
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: Jason Richard

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

Page: 2 of 5

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 16 Wgt 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

APPENDIX C. *MASH* TEST 3-20 (CRASH TEST 441203-01-1)

C.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2022-09-26 Test No.: 441202-01-1 VIN No.: 3N1CN7AP0GL858006

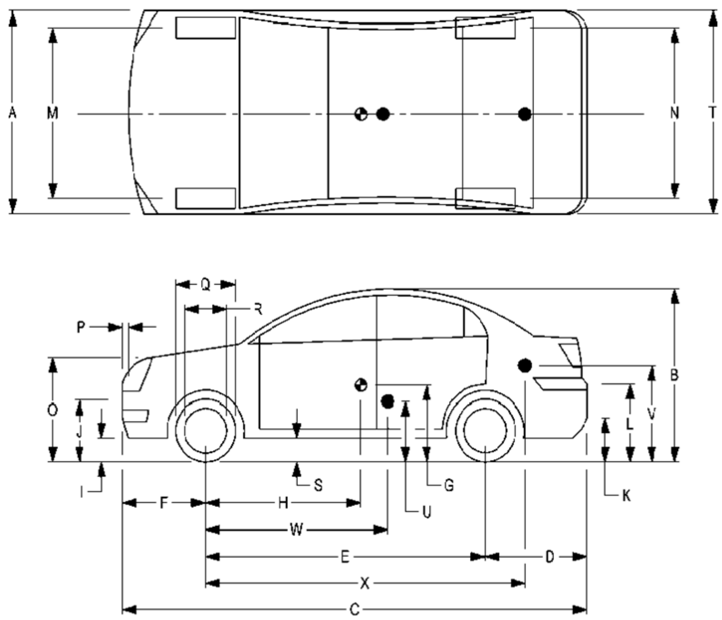
Year: 2016 Make: Nissan Model: Versa

Tire Inflation Pressure: 36 PSI Odometer: 146148 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	41.05	M	58.30	R	16.25	W	41.00
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.50	O	30.50	T	64.50		

Wheel Center Ht Front 11.50 Wheel Center Ht Rear 11.50 W-H -0.05

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}	1442	1454	1539
Back	1687	M_{rear}	938	973	1053
Total	3389	M_{Total}	2380	2427	2592

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

Mass Distribution:
lb LF: 726 RF: 728 LR: 507 RR: 466

Figure C.1. Vehicle Properties for Test 441203-01-1.

Date:	2022-09-26	Test No.:	441202-01-1	VIN No.:	3N1CN7AP0GL858006
Year:	2016	Make:	Nissan	Model:	Versa

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FT BUMPER	15	12	36							-6
2	ABOVE FT BUMPER	15	10	40							60
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

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

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

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

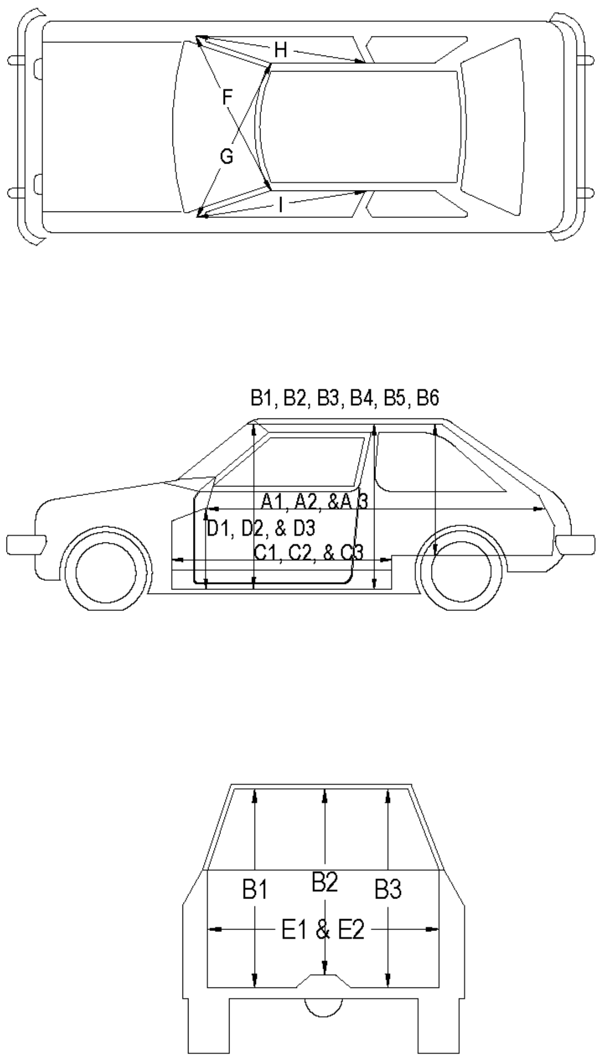
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Figure C.2. Exterior Crush Measurements for Test 441203-01-1.

Date:	2022-09-26	Test No.:	441202-01-1	VIN No.:	3N1CN7AP0GL858006
Year:	2016	Make:	Nissan	Model:	Versa



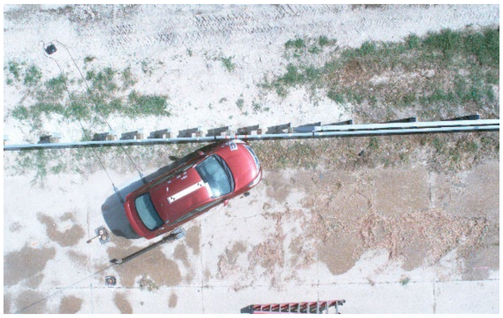
OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.50	67.50	0.00
A2	67.25	67.25	0.00
A3	67.75	67.75	0.00
B1	40.50	40.50	0.00
B2	39.00	39.00	0.00
B3	40.50	40.50	0.00
B4	36.25	36.25	0.00
B5	36.00	36.00	0.00
B6	36.25	36.25	0.00
C1	26.00	25.00	-1.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	9.50	0.00
E1	48.50	46.50	-2.00
E2	50.00	51.00	1.00
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	48.50	46.00	-2.50

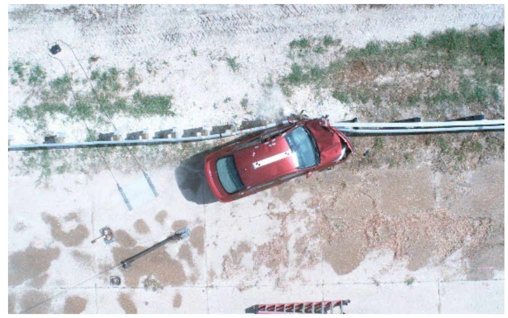
*Lateral area across the cab from driver's side kick panel to passenger's side kick panel.

Figure C.3. Occupant Compartment Measurements for Test 441203-01-1.

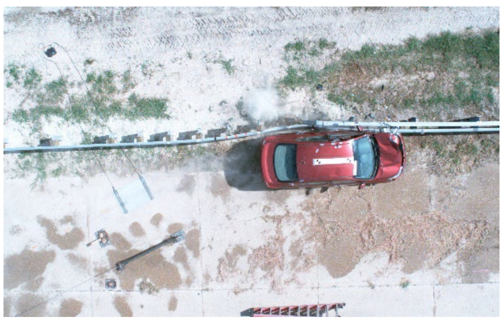
C.2. SEQUENTIAL PHOTOGRAPHS



(a) 0.000 s



(b) 0.100 s



(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure C.4. Sequential Photographs for Test 441203-01-1 (Overhead Views).

(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

Figure C.5. Sequential Photographs for Test 441203-01-1 (Frontal Views).

(a) 0.000 s (b) 0.100 s

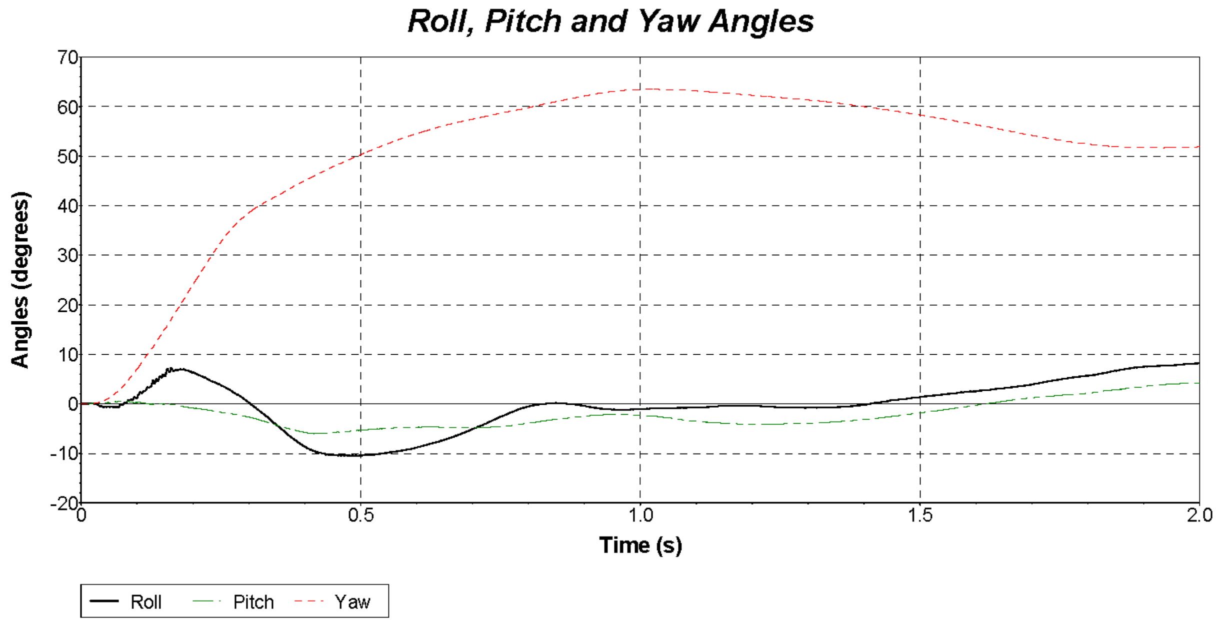
(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

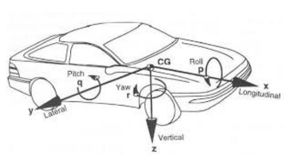
Figure C.6. Sequential Photographs for Test 441203-01-1 (Rear Views).

C.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 441203-01-1
Test Standard Test Number: *MASH* Test 3-20
Test Article: Transition
Test Vehicle: 2016 Nissan Versa
Inertial Mass: 2427 lb
Gross Mass: 2592 lb
Impact Speed: 63.7 mi/h
Impact Angle: 25.8°

Figure C.7. Vehicle Angular Displacements for Test 441203-01-1.

C.4. VEHICLE ACCELERATIONS

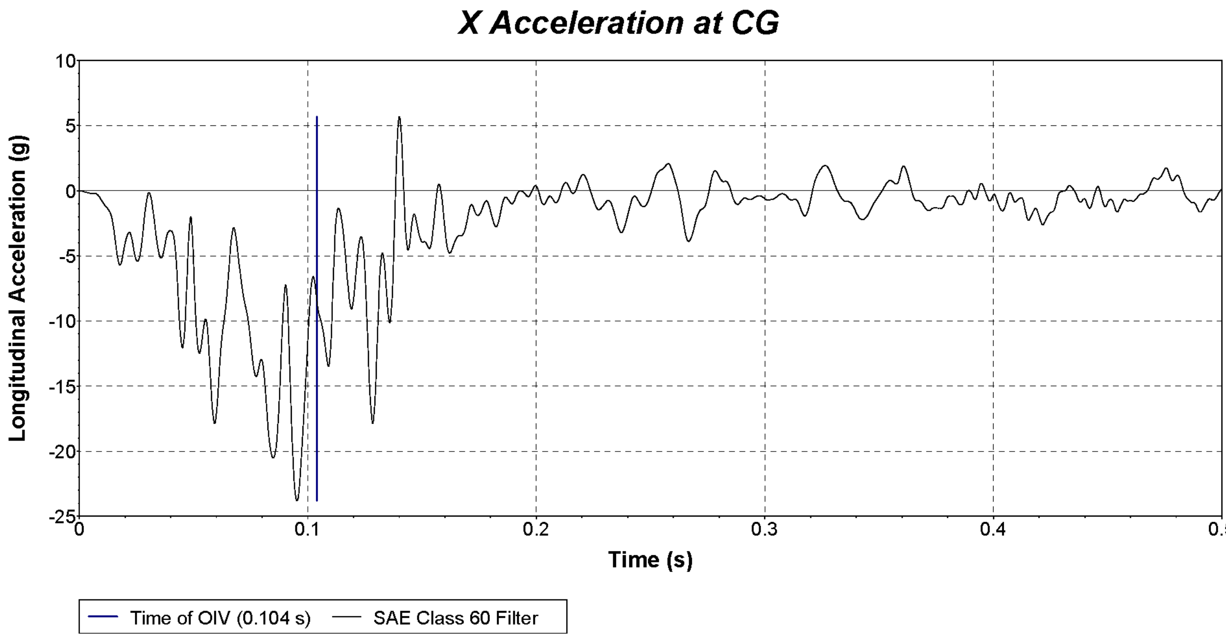


Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test 441203-01-1 (Accelerometer Located at Center of Gravity).

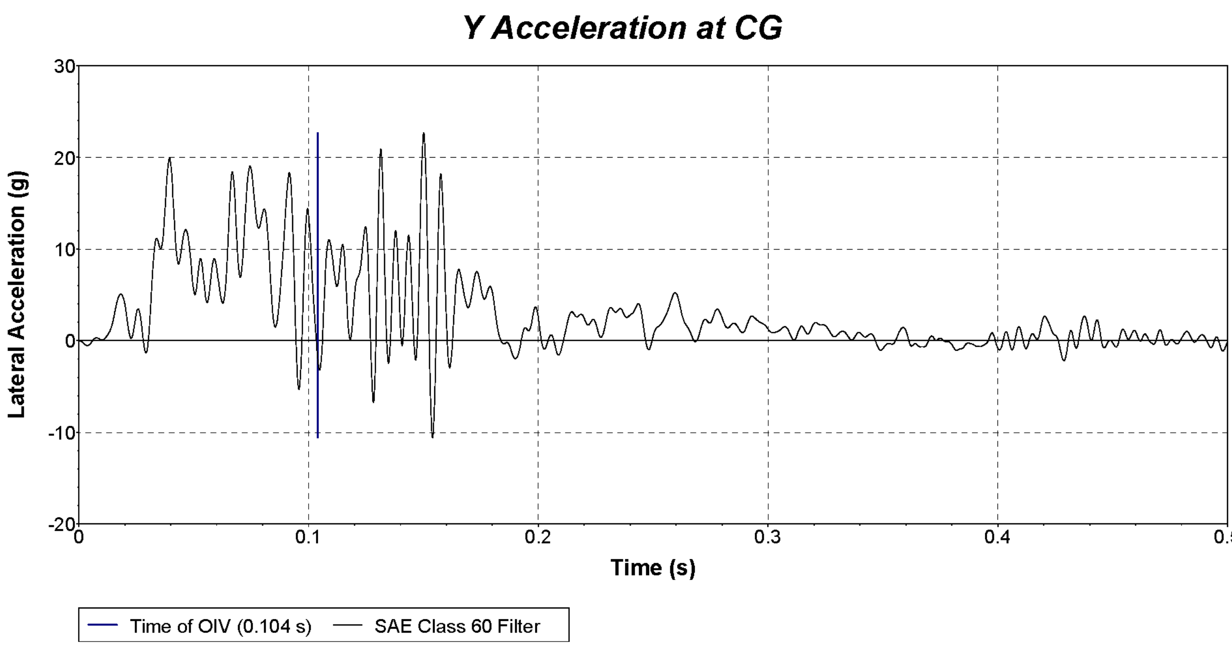


Figure C.9. Vehicle Lateral Accelerometer Trace for Test 441203-01-1 (Accelerometer Located at Center of Gravity).

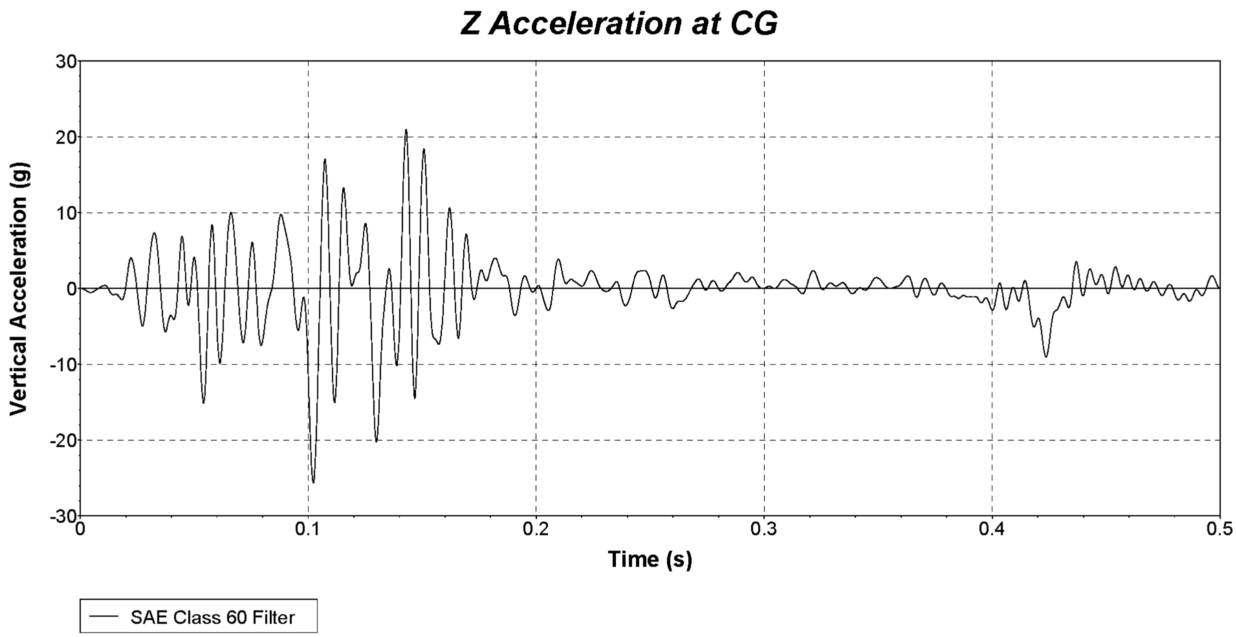


Figure C.10. Vehicle Vertical Accelerometer Trace for Test 441203-01-1 (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 3-21 (CRASH TEST 441203-01-2)

D.1. VEHICLE PROPERTIES AND INFORMATION

Date:	2022-10-31	Test No.:	441202-01-2	VIN No.:	1C6RR6FT8HS622841
Year:	2017	Make:	RAM	Model:	1500

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

Tread Type: Highway Odometer: 157965

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

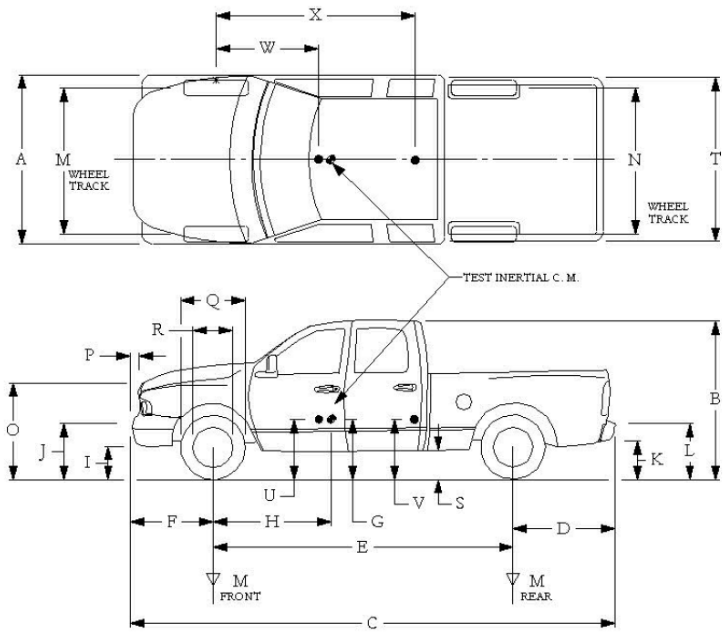
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

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



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.50	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.98	M	68.50	R	18.00	W	61.00
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	3004	2854	2939
Back	3900	M_{rear}	2154	2189	2269
Total	6700	M_{Total}	5158	5043	5208

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

Mass Distribution:
lb LF: 1450 RF: 1404 LR: 1083 RR: 1106

Figure D.1. Vehicle Properties for Test 441203-01-2.

Date:	2022-10-31	Test No.:	441202-01-2	VIN No.:	1C6RR6FT8HS622841
Year:	2017	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	AT FT BUMPER	16	12	48							-12
2	SAME	16	12	60							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.

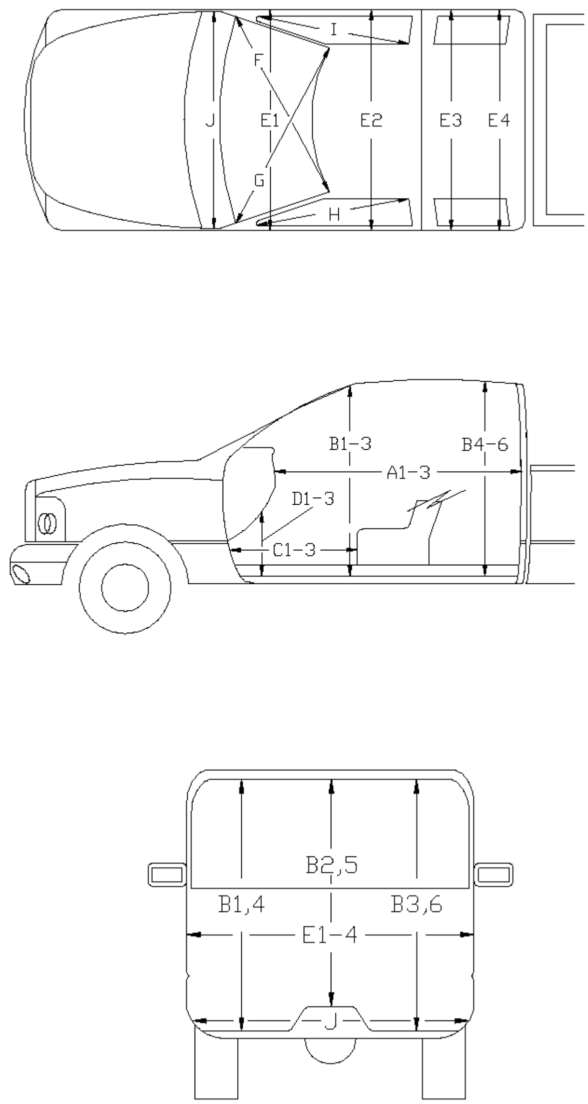
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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.

Figure D.2. Exterior Crush Measurements for Test 441203-01-2.

Date:	2022-10-31	Test No.:	441202-01-2	VIN No.:	1C6RR6FT8HS622841
Year:	2017	Make:	RAM	Model:	1500



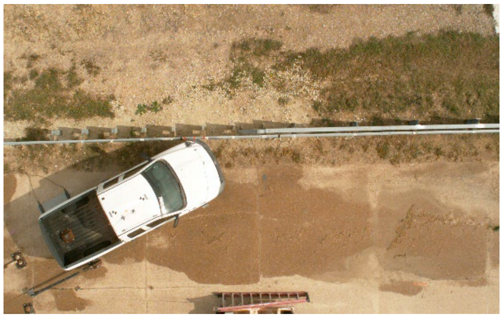
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

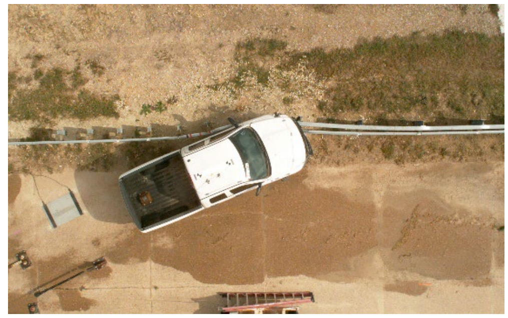
	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00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

Figure D.3. Occupant Compartment Measurements for Test 441203-01-2.

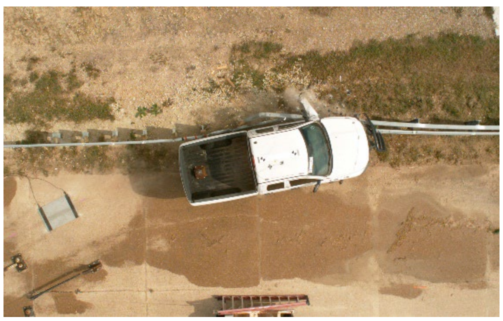
D.2. SEQUENTIAL PHOTOGRAPHS



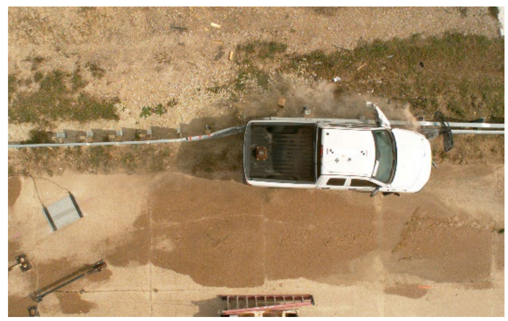
(a) 0.000 s



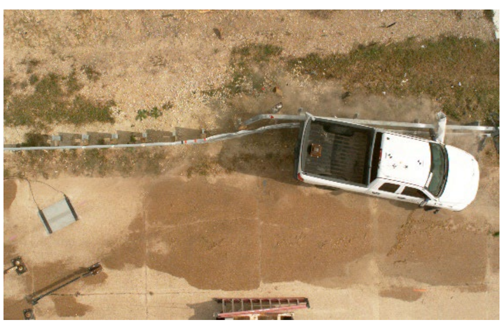
(b) 0.100 s



(c) 0.200 s



(d) 0.300 s



(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure D.4. Sequential Photographs for Test 441203-01-2 (Overhead Views).


(a) 0.000 s (b) 0.100 s


(c) 0.200 s (d) 0.300 s


(e) 0.400 s (f) 0.500 s


(g) 0.600 s (h) 0.700 s

Figure D.5. Sequential Photographs for Test 441203-01-2 (Oblique Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

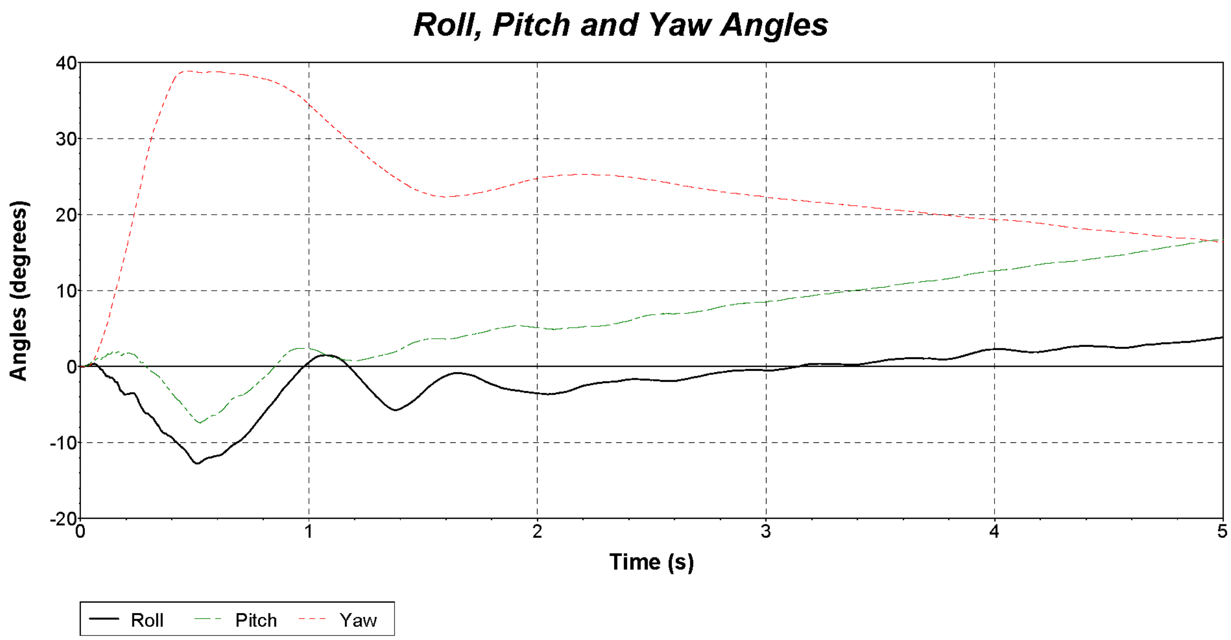
(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

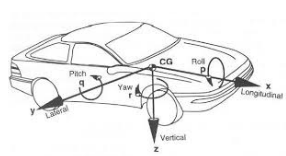
Figure D.6. Sequential Photographs for Test 441203-01-2 (Rear Views).

D.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 441203-01-2
Test Standard Test Number: *MASH* Test 3-21
Test Article: Transition
Test Vehicle: 2017 RAM 1500
Inertial Mass: 5043 lb
Gross Mass: 5208 lb
Impact Speed: 62.1 mi/h
Impact Angle: 25.1°

Figure D.7. Vehicle Angular Displacements for Test 441203-01-2.

D.4. VEHICLE ACCELERATIONS

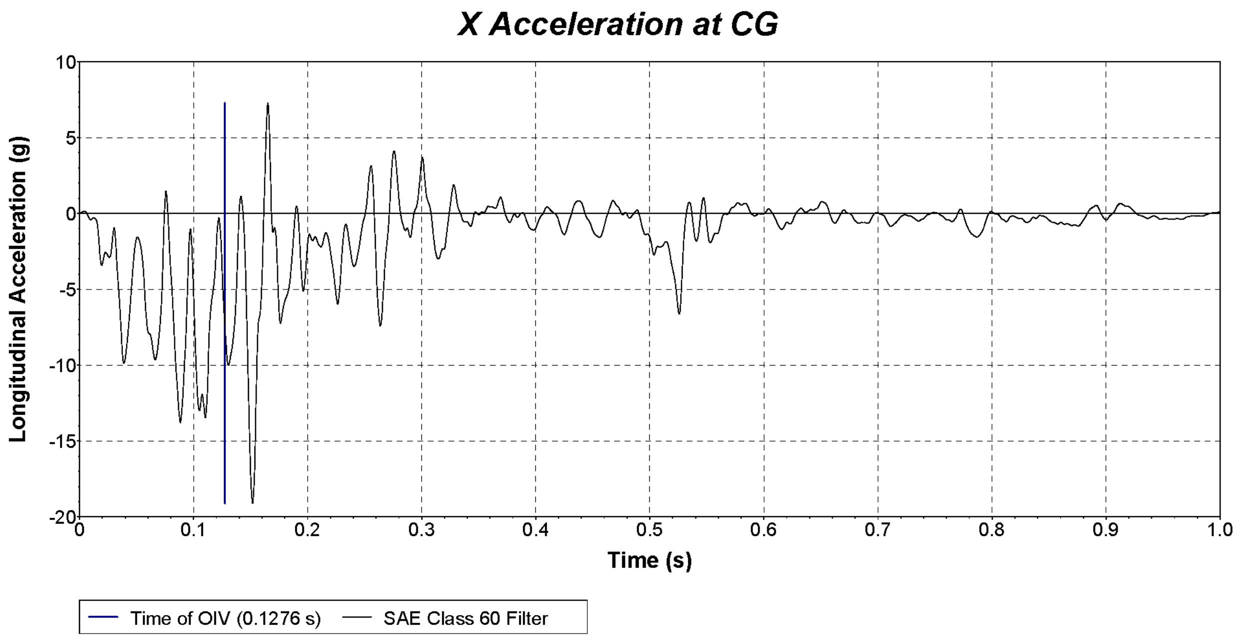


Figure D.8. Vehicle Longitudinal Accelerometer Trace for Test 441203-01-2 (Accelerometer Located at Center of Gravity).

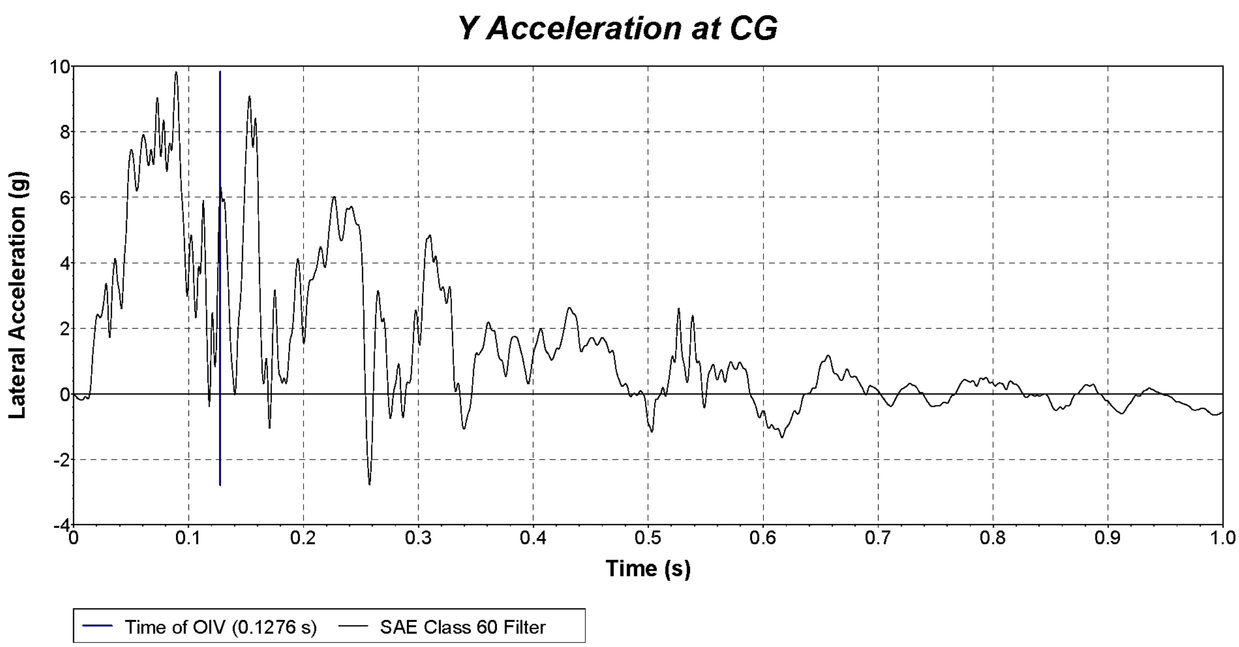


Figure D.9. Vehicle Lateral Accelerometer Trace for Test 441203-01-2 (Accelerometer Located at Center of Gravity).

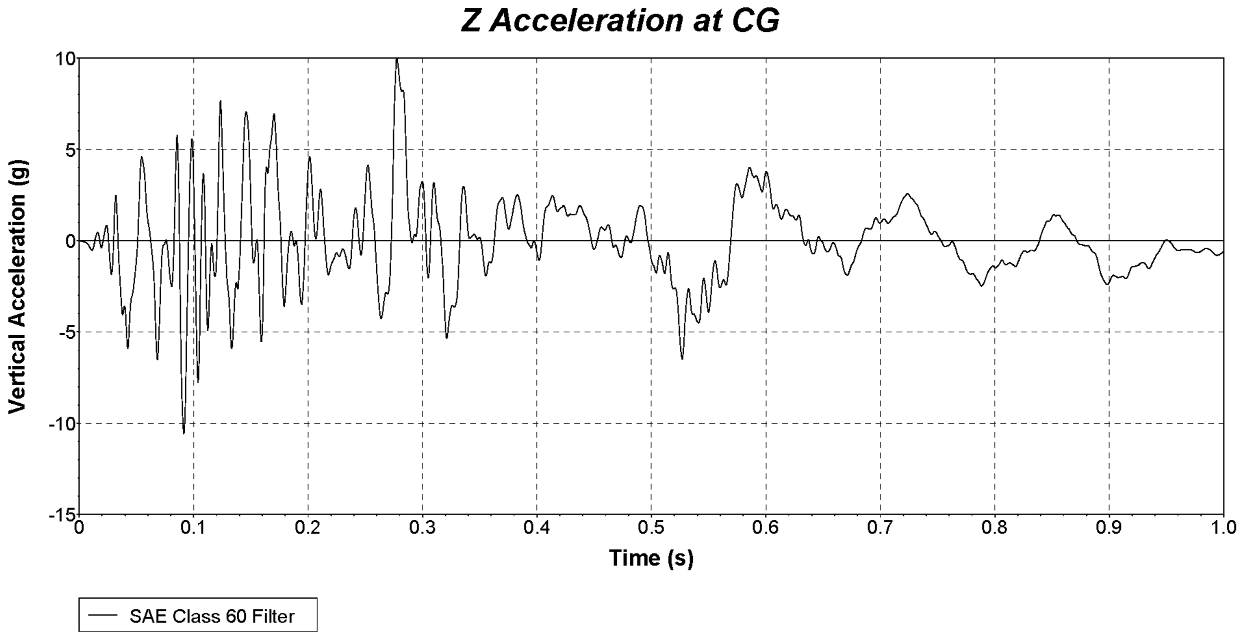


Figure D.10. Vehicle Vertical Accelerometer Trace for Test 441203-01-2 (Accelerometer Located at Center of Gravity).

APPENDIX E. VALUE OF RESEARCH

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

To determine the VOR, the researchers conservatively estimated the number of lives that could be saved by using the newly developed Transition on Texas roadways. Since this Transition was developed to be used with the TxDOT *MASH* TL-4 guardrail system, the researchers specifically focused on fatalities related to roadways that are likely to have TL-4 barriers installed.

Data obtained from the TxDOT Crash Records Information System (CRIS) indicate that in years 2018 through 2022, a total of 186 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 high-speed roads only, which are more likely candidates for *MASH* TL-4 design speeds. The researchers also excluded all types of objects struck, except for ditches and embankments. This exclusion 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.

With the above exclusions, 186 fatal crashes over a five-year period of 2018 through 2022 resulted in 37.2 fatal crashes per year.

The researchers acknowledged that the above crashes did not exclusively occur on roadways with *MASH* TL-4 design speed, for which the Transition has been designed. To account for this, the researchers used a conservative estimate that only 25 percent of these crashes could be assumed to occur on roadways that qualify as having design speeds of *MASH* TL-4. This reduced the estimated annual crashes to 9.3.

In addition, the researchers acknowledged that not all of the above crashes could be prevented by the placement of a *MASH* TL-4 barrier. Thus, it was conservatively assumed that only 25 percent of the above crashes could be prevented or have their injury severity reduced by placing a TL-4 barrier. This led to an estimated 2.33 qualified fatal crashes.

The researchers further acknowledged that the newly developed Transition for the TxDOT *MASH* TL-4 guardrail would be used in conjunction with other TxDOT TL-4 concrete barrier systems. Thus, it was conservatively assumed that only 25 percent of the above crashes could be prevented by using the TxDOT *MASH* TL-4 guardrail with the newly designed Transition. With this assumption, the number of crashes with the highest injury severity of K that could be prevented by using the new Transition and TxDOT *MASH* TL-4 guardrail system was estimated to be 0.58 per year.

Since fatal crashes sometimes involve more than one fatality, the total number of fatalities in crashes involving the highest injury severity of K is greater than the total number of such crashes. However, for conservatism, it was assumed that the number of fatalities involved in the above-mentioned 0.58 crashes was the same as the number of crashes. Thus, with the statewide use of the new Transition and TxDOT *MASH* TL-4 guardrail system, it was estimated that a minimum of 0.58 fatalities could be prevented each year.

The researchers acknowledged that crashes typically involve other less-severe injury 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.

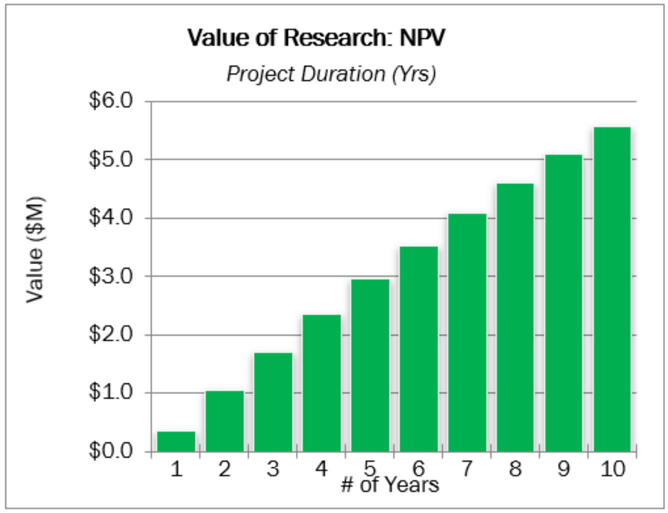
According to NHTSA, each fatality results in an average discounted lifetime economic cost of $1.4 million, and an average comprehensive cost of $9.1 million ("The Economic and Societal Impact of Motor Vehicle Crashes," 2010 (Revised 2015), http://www-nrd.nhtsa.dot.gov/pubs/812013.pdf).

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 0.58 fatalities each year, the annual expected value of this research is $812,000.

The researchers used a period of 10 years and a discount rate of 5 percent, which is typical per TxDOT's *University Handbook*, to arrive at the benefit-cost ratio of 23 for this research project. The estimated VOR is presented in Figure E.1.

Project #	0-7120		
Project Name:	Transition for MASH TL-4 Guardrail System		
Agency:	TTI	Project Budget	$ 239,131
Project Duration (Yrs)	2	Exp. Value (per Yr)	$ 812,000
Expected Value Duration (Yrs)	10	Discount Rate	5%
Economic Value			
Total Savings:	$ 7,880,869	Net Present Value (NPV):	$ 5,572,924
Payback Period (Yrs):	0.294496	Cost Benefit Ratio (CBR, $1 : $___):	$ 23

Years	Expected Value
0	-$418,479
1	$812,000
2	$812,000
3	$812,000
4	$812,000
5	$812,000
6	$812,000
7	$812,000
8	$812,000
9	$812,000
10	$812,000



Variable Justification

TxDOT recently developed TxDOT's MASH TL-4 Guardrail system that can be used on high-speed roadways with high freight traffic. To use the guardrail, an end transition design was needed that would allow terminating the blunt ends of the guardrail with existing guardrail end-terminals. This project developed a design for such a transtion. It will allow the use of TxDOT's MASH TL-4 Guardrail on roadways with high freight traffic and reduce fatalities from roadway crashes. The variable used in the calculations is the economic impact of lives saved as a result of the use of the newly design transition with the TxDOT MASH TL-4 Guradrail system.

Qualitative Value

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

Figure E.1. Value of Research for TxDOT Project 0-7120.