



Test Report No. 441203-01



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

Sponsored by
Texas Department of Transportation (TxDOT)

TEXAS A&M TRANSPORTATION INSTITUTE PROVING GROUND

Roadside Safety & Physical Security
Texas A&M University System RELLIS Campus
Building 7091
1254 Avenue A
Bryan, TX 77807



1. Report No. FHWA/TX-23/0-7120-R1		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle DESIGN AND EVALUATION OF TRANSITION FOR TXDOT MASH TEST LEVEL 4 (TL-4) GUARDRAIL SYSTEM				5. Report Date March 2023	
				6. Performing Organization Code	
7. Author(s) Nauman M. Sheikh, Roger P. Bligh, William J. L. Schroeder, and Darrell L. Kuhn				8. Performing Organization Report No. Report 0-7120-R1 Test Report 441203-01	
9. Performing Organization Name and Address Texas A&M Transportation Institute Proving Ground 3135 TAMU College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Project 0-7120	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 6230 E Stassney Lane Austin, Texas 78744				13. Type of Report and Period Covered Technical Report: August 2021–November 2022	
				14. Sponsoring Agency Code	
15. Supplementary Notes Project sponsored by the Texas Department of Transportation and the Federal Highway Administration. Project Title: Develop Transition for <i>MASH</i> Test Level 4 (TL-4) Compliant Guardrail System URL: https://tti.tamu.edu/documents/0-7120-R1.pdf					
16. Abstract <p>Researchers at the Texas A&M Transportation Institute (TTI) designed and tested a <i>Manual for Assessing Safety Hardware (MASH)</i> 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 <i>MASH</i> TL-4 guardrail system with <i>MASH</i>-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.</p> <p>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 <i>MASH (I)</i>. The crash tests were performed in accordance with <i>MASH</i> TL-3 criteria, which require two crash tests:</p> <ol style="list-style-type: none"> 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. 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. <p>This report provides details of the Transition, the crash tests and results, and the performance assessment of the Transition for <i>MASH</i> TL-3 evaluation criteria for longitudinal barriers.</p> <p>The Transition met the <i>MASH</i> TL-3 performance criteria for longitudinal barriers.</p>					
17. Key Words Longitudinal Barriers, TL-3, TL-4, Transition, Crash Test, <i>MASH</i> , Steel Post, Guardrail, W-beam, Finite Element Analysis, FEA, Simulation			18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia 22312 http://www.ntis.gov		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 144	22. Price

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

by

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

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

William J. L. Schroeder
Research Engineering Associate
Texas A&M Transportation Institute

and

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

Report 0-7120-R1
Test Report 441203-01
Project 0-7120

Project Title: Develop Transition for *MASH* Test Level 4 (TL-4) Compliant Guardrail System

Sponsored by the

Texas Department of Transportation
and the
Federal Highway Administration

June 2023

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

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

Bill L. Griffith, Research Specialist
Deputy Quality Manager

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

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

Nauman M. Sheikh, P.E.
Principal Investigator, Research Engineer

ACKNOWLEDGMENTS

This project was sponsored by TxDOT and FHWA. The authors thank TxDOT Project Director Wade Odell and Christopher Lindsey and Kenneth Mora of the TxDOT Project Monitoring Committee for their guidance and feedback during the project. The authors also thank Texas A&M High Performance Research Computing for providing computing resources for advance simulation analyses performed under this research.

TABLE OF CONTENTS

	Page
List of Figures	ix
List of Tables	xi
Chapter 1. Introduction	1
1.1. Background	1
1.2. Objective	1
1.3. Research Approach and Scope	1
Chapter 2. Design and Simulation Analysis	3
2.1. Initial Design Concept Summary	3
2.2. Simulation Analysis Scope	5
2.3. Finite Element Modeling	5
2.4. Simulation Analysis and Design Development	6
2.4.1. Design with Quarter and Half Post Spacings	10
2.4.2. Design with Half Post Spacing	12
2.4.3. Reverse-Direction Impact Evaluation	17
2.5. Critical Impact Points and Testing Recommendations	20
2.6. Conclusions	22
Chapter 3. System Details	23
3.1. Test Article and Installation Details	23
3.2. Design Modifications during Tests	23
3.3. Material Specifications	27
3.4. Soil Conditions	28
Chapter 4. Test Requirements and Evaluation Criteria	29
4.1. Crash Test Matrix	29
4.2. Evaluation Criteria	29
Chapter 5. Test Conditions	31
5.1. Test Facility	31
5.2. Vehicle Tow and Guidance System	31
5.3. Data Acquisition Systems	31
5.3.1. Vehicle Instrumentation and Data Processing	31
5.3.2. Anthropomorphic Dummy Instrumentation	32
5.3.3. Photographic Instrumentation Data Processing	33
Chapter 6. MASH Test 3-20 (Crash Test 441203-01-1)	35
6.1. Test Designation and Actual Impact Conditions	35
6.2. Weather Conditions	37
6.3. Test Vehicle	37
6.4. Test Description	38
6.5. Damage to Test Installation	39
6.6. Damage to Test Vehicle	40
6.7. Occupant Risk Factors	43
6.8. Test Summary	44
Chapter 7. MASH Test 3-21 (Crash Test 441203-01-2)	47
7.1. Test Designation and Actual Impact Conditions	47
7.2. Weather Conditions	49

7.3.	Test Vehicle	49
7.4.	Test Description	51
7.5.	Damage to Test Installation	51
7.6.	Damage to Test Vehicle.....	53
7.7.	Occupant Risk Factors	56
7.8.	Test Summary	56
Chapter 8.	Summary and Conclusions	59
8.1.	Assessment of Test Results.....	59
8.2.	Conclusions.....	59
Chapter 9.	Implementation.....	61
References	63
Appendix A.	Details of TL-4 Guardrail Transition.....	65
Appendix B.	Supporting Certification Documents.....	81
Appendix C.	MASH Test 3-20 (Crash Test 441203-01-1).....	107
C.1.	Vehicle Properties and Information	107
C.2.	Sequential Photographs.....	110
C.3.	Vehicle Angular Displacements	113
C.4.	Vehicle Accelerations	114
Appendix D.	MASH Test 3-21 (Crash Test 441203-01-2).....	117
D.1.	Vehicle Properties and Information	117
D.2.	Sequential Photographs.....	120
D.3.	Vehicle Angular Displacements	123
D.4.	Vehicle Accelerations	124
Appendix E.	Value of Research.....	127

LIST OF FIGURES

	Page
Figure 2.1. Initial Design Concept Selected for Simulation Analysis and Detailed Design.	4
Figure 2.2. Finite Element Model of the Initial Transition Design.	6
Figure 2.3. Reverse-Direction Impact of the Initial Design with the <i>MASH</i> Pickup Truck.	7
Figure 2.4. Reverse-Direction Pickup Truck Impact of the Shortened Turn-Down Rail Design.	8
Figure 2.5. Impact Points for Test 3-21 Simulations (IP1 [top], IP2 [center], IP3 [bottom]).	9
Figure 2.6. Simulation Results of Initial Transition Design for IP1 and IP2.	10
Figure 2.7. Transition Design with Posts Installed at Quarter and Half Post Spacings.	10
Figure 2.8. Simulation at IP1 for Transition Design with Quarter and Half Post Spacings.	11
Figure 2.9. Simulation at IP2 for Transition Design with Quarter and Half Post Spacings.	11
Figure 2.10. Simulation at IP3 for Transition Design with Quarter and Half Post Spacings.	12
Figure 2.11. Modified Transition Design with Half Post Spacing.	13
Figure 2.12. Simulation at IP1 for Transition Design with Half Post Spacing.	13
Figure 2.13. Simulation at IP2 for Transition Design with Half Post Spacing.	14
Figure 2.14. Simulation at IP3 for Transition Design with Half Post Spacing.	14
Figure 2.15. Impact Points for Test 3-20 Simulations (IP4 [top], IP5 [center], IP6 [bottom]). ...	15
Figure 2.16. Simulation at IP4 for Transition Design with Half Post Spacing.	16
Figure 2.17. Simulation at IP5 for Transition Design with Half Post Spacing.	16
Figure 2.18. Simulation at IP6 for Transition Design with Half Post Spacing.	17
Figure 2.19. Results of Reverse-Direction Impact Simulations Performed at Three Impact Locations with <i>MASH</i> Pickup Truck Model.	18
Figure 2.20. Results of Reverse-Direction Impact Simulations Performed at Three Impact Locations with <i>MASH</i> Small Passenger Sedan Model.	19
Figure 2.21. Vehicle Orientation at the Time of Maximum Lateral Rail Deflection for the Three Impact Points (Pickup Truck).	20
Figure 2.22. Vehicle Orientation at the Time of Maximum Lateral Rail Deflection for the Three Impact Points (Small Car).	21
Figure 2.23. Wheel Snagging Comparison for Small Car Impact between IP4 and IP5.	21
Figure 3.1. Details of Transition.	24
Figure 3.2. TL-4 Test Installation prior to Testing.	25
Figure 3.3. TL-4 Test Installation at Impact prior to Testing.	25
Figure 3.4. TL-4 Test Installation at the Transition Box Beam Rail prior to Testing.	26
Figure 3.5. Upstream In-Line View of the Test Installation prior to Testing.	26
Figure 3.6. Field Side of the Transition prior to Testing.	27
Figure 3.7. Transition Box Beam Rail Connection to Post 15 prior to Testing.	27
Figure 4.1. Target CIPs for <i>MASH</i> TL-3 Tests on TL-4 Guardrail Transition.	29
Figure 6.1. Transition and Test Vehicle Geometrics for Test 441203-01-1.	36
Figure 6.2. Test Vehicle at Impact Location for Test 441203-01-1.	36
Figure 6.3. Impact Side of Test Vehicle before Test 441203-01-1.	37
Figure 6.4. Opposite Impact Side of Test Vehicle before Test 441203-01-1.	38
Figure 6.5. Transition after Test at Impact Location for Test 441203-01-1.	40
Figure 6.6. Transition after Test from the Field Side of the Installation for Test 441203-01-1. ...	40
Figure 6.7. Impact Side of Test Vehicle after Test 441203-01-1.	41

Figure 6.8. Rear Impact Side of Test Vehicle after Test 441203-01-1.....	41
Figure 6.9. Overall Interior of Test Vehicle after Test 441203-01-1.....	42
Figure 6.10. Interior of Test Vehicle on Impact Side after Test 441203-01-1.	42
Figure 6.11. Summary of Results for <i>MASH</i> Test 3-20 on TL-4 Guardrail Transition.....	45
Figure 7.1. Transition and Test Vehicle Geometrics for Test 441203-01-2.....	48
Figure 7.2. Test Vehicle at Impact Location for Test 441203-01-2.	48
Figure 7.3. Impact Side of Test Vehicle before Test 441203-01-2.	49
Figure 7.4. Opposite Impact Side of Test Vehicle before Test 441203-01-2.....	50
Figure 7.5. Transition at the Impact Location after Test 441203-01-2.....	52
Figure 7.6. In-Line View with the Transition after the Impact for Test 441203-01-2.	53
Figure 7.7. Impact Side of Test Vehicle after Test 441203-01-2.	53
Figure 7.8. Rear Impact Side of Test Vehicle after Test 441203-01-2.....	54
Figure 7.9. Overall Interior of Test Vehicle after Test 441203-01-2.....	54
Figure 7.10. Interior of Test Vehicle on Impact Side after Test 441203-01-2.	55
Figure 7.11. Summary of Results for <i>MASH</i> Test 3-21 on Transition.	57
Figure C.1. Vehicle Properties for Test 441203-01-1.....	107
Figure C.2. Exterior Crush Measurements for Test 441203-01-1.	108
Figure C.3. Occupant Compartment Measurements for Test 441203-01-1.....	109
Figure C.4. Sequential Photographs for Test 441203-01-1 (Overhead Views).....	110
Figure C.5. Sequential Photographs for Test 441203-01-1 (Frontal Views).....	111
Figure C.6. Sequential Photographs for Test 441203-01-1 (Rear Views).....	112
Figure C.7. Vehicle Angular Displacements for Test 441203-01-1.	113
Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test 441203-01-1 (Accelerometer Located at Center of Gravity).	114
Figure C.9. Vehicle Lateral Accelerometer Trace for Test 441203-01-1 (Accelerometer Located at Center of Gravity).	114
Figure C.10. Vehicle Vertical Accelerometer Trace for Test 441203-01-1 (Accelerometer Located at Center of Gravity).	115
Figure D.1. Vehicle Properties for Test 441203-01-2.	117
Figure D.2. Exterior Crush Measurements for Test 441203-01-2.....	118
Figure D.3. Occupant Compartment Measurements for Test 441203-01-2.	119
Figure D.4. Sequential Photographs for Test 441203-01-2 (Overhead Views).....	120
Figure D.5. Sequential Photographs for Test 441203-01-2 (Oblique Views).	121
Figure D.6. Sequential Photographs for Test 441203-01-2 (Rear Views).....	122
Figure D.7. Vehicle Angular Displacements for Test 441203-01-2.....	123
Figure D.8. Vehicle Longitudinal Accelerometer Trace for Test 441203-01-2 (Accelerometer Located at Center of Gravity).	124
Figure D.9. Vehicle Lateral Accelerometer Trace for Test 441203-01-2 (Accelerometer Located at Center of Gravity).	124
Figure D.10. Vehicle Vertical Accelerometer Trace for Test 441203-01-2 (Accelerometer Located at Center of Gravity).	125
Figure E.1. Value of Research for TxDOT Project 0-7120.	129

LIST OF TABLES

	Page
Table 3.1. Soil Strength for Crash Test 441203-01-1.....	28
Table 3.2. Soil Strength for Crash Test 441203-01-2.....	28
Table 4.1. Test Conditions and Evaluation Criteria Specified for <i>MASH</i> TL-3 Longitudinal Barriers.....	29
Table 4.2. Evaluation Criteria Required for <i>MASH</i> Testing.....	30
Table 6.1. Impact Conditions for <i>MASH</i> Test 3-20, Crash Test 441203-01-1.....	35
Table 6.2. Exit Parameters for <i>MASH</i> Test 3-20, Crash Test 441203-01-1.....	35
Table 6.3. Weather Conditions for Test 441203-01-1.....	37
Table 6.4. Vehicle Measurements for Test 441203-01-1.....	38
Table 6.5. Events during Test 441203-01-1.....	39
Table 6.6. Soil Gap and Post Deflection Measurements after Test 441203-01-1.....	39
Table 6.7. Damage to TL-4 Guardrail Transition for Test 441203-01-1.....	39
Table 6.8. Occupant Compartment Deformation for Test 441203-01-1.....	43
Table 6.9. Exterior Vehicle Damage for Test 441203-01-1.....	43
Table 6.10. Occupant Risk Factors for Test 441203-01-1.....	44
Table 7.1. Impact Conditions for <i>MASH</i> Test 3-21, Crash Test 441203-01-2.....	47
Table 7.2. Exit Parameters for <i>MASH</i> Test 3-21, Crash Test 441203-01-2.....	47
Table 7.3. Weather Conditions for Test 441203-01-2.....	49
Table 7.4. Vehicle Measurements for Test 441203-01-2.....	50
Table 7.5. Events during Test 441203-01-2.....	51
Table 7.6. Soil Gap and Post Deflection Measurements after Test 441203-01-2.....	51
Table 7.7. Damage to Transition after Test 441203-01-2.....	52
Table 7.8. Occupant Compartment Deformation for Test 441203-01-2.....	55
Table 7.9. Exterior Vehicle Damage for Test 441203-01-2.....	55
Table 7.10. Occupant Risk Factors for Test 441203-01-2.....	56
Table 8.1. Assessment Summary for <i>MASH</i> TL-3 Tests on TL-4 Guardrail Transition.....	59

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 \times 4-inch \times 1/4-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 \times 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.

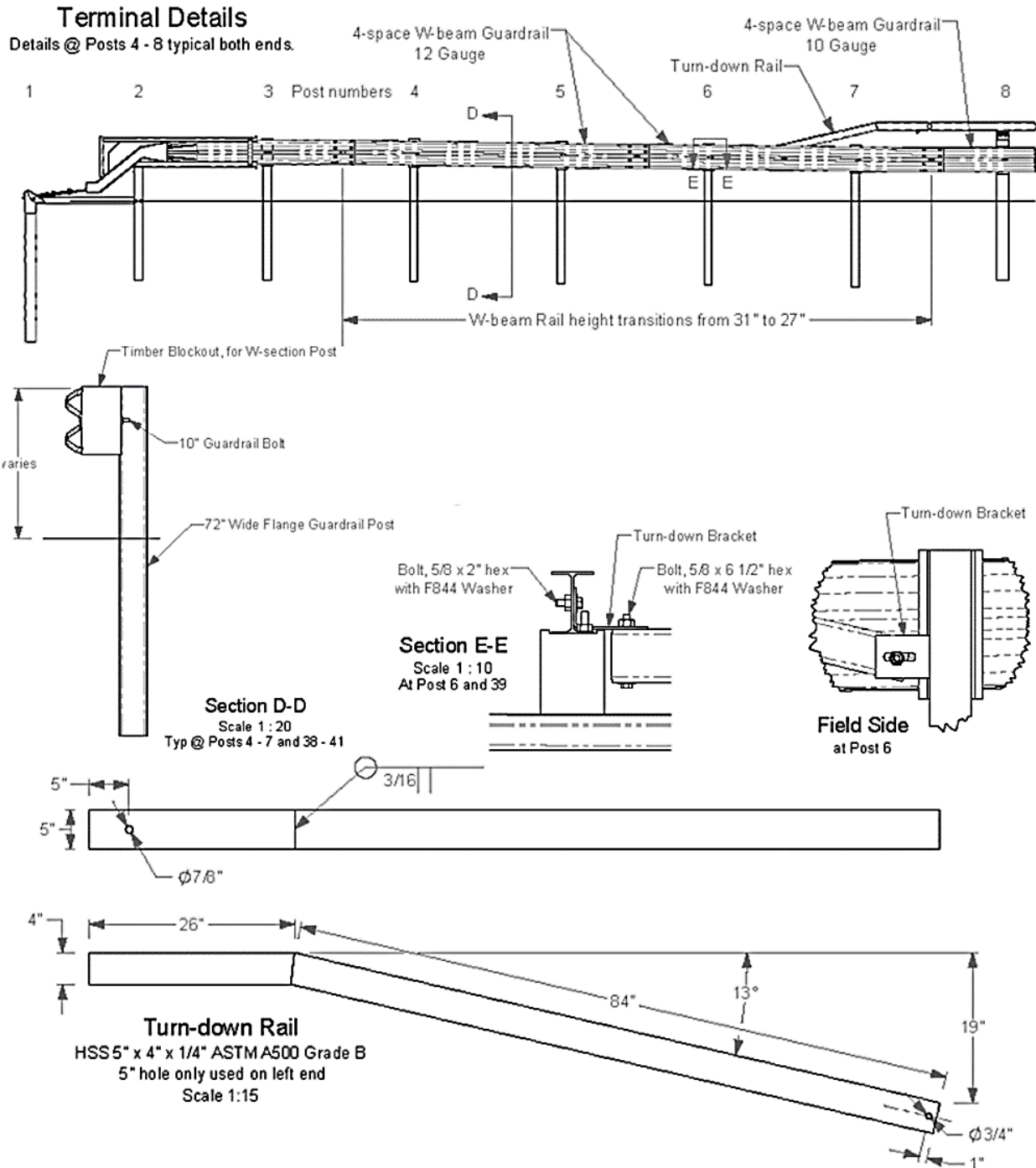


Figure 2.1. Initial Design Concept Selected for Simulation Analysis and Detailed Design.

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.

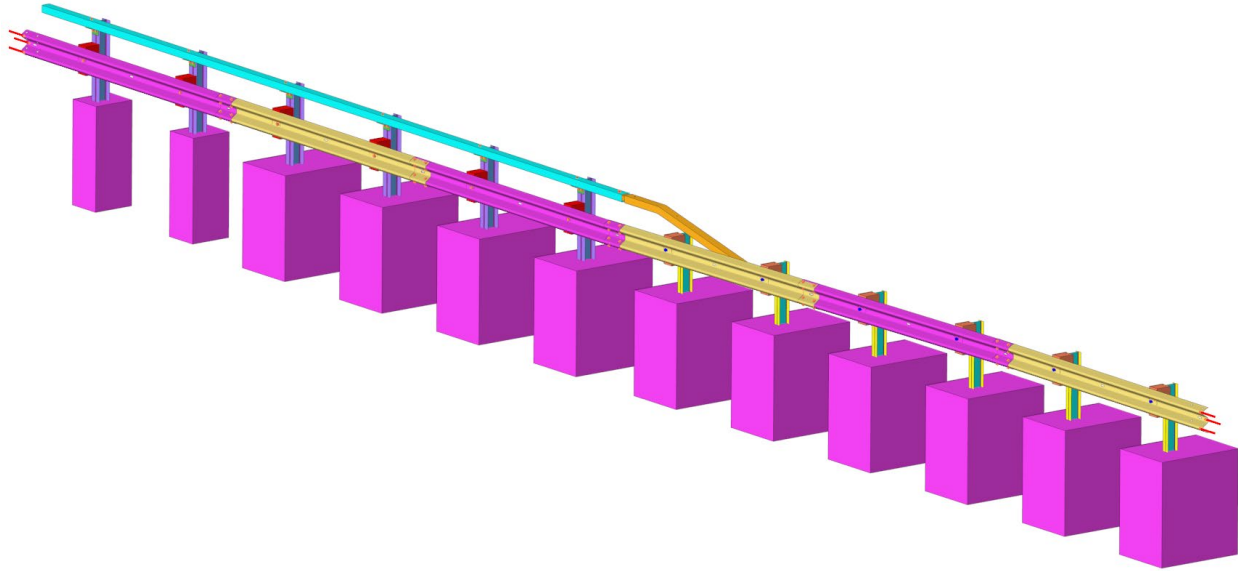
Following are the details of the FE models, results of the various simulations that guided the design changes made to the initial Transition design, and detailed results of the impact simulations performed on the final design recommended for full-scale crash testing.

2.3. FINITE ELEMENT MODELING

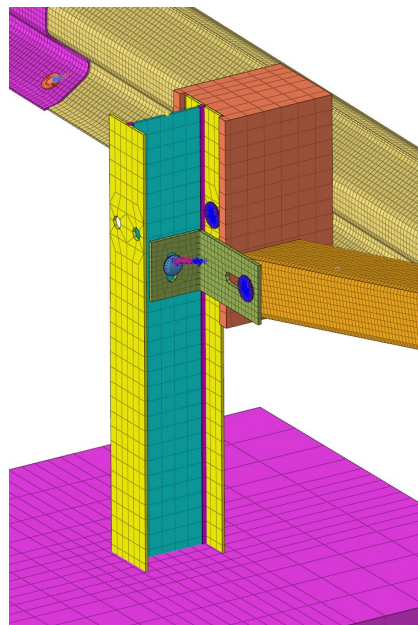
All FE simulations were performed using LS-DYNA, which is a commercially available general-purpose FE analysis software. All key guardrail parts were represented with elastic-plastic material models. These included the W-beam and the HSS beam rails, posts, splices, blockouts, and HSS rail attachment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

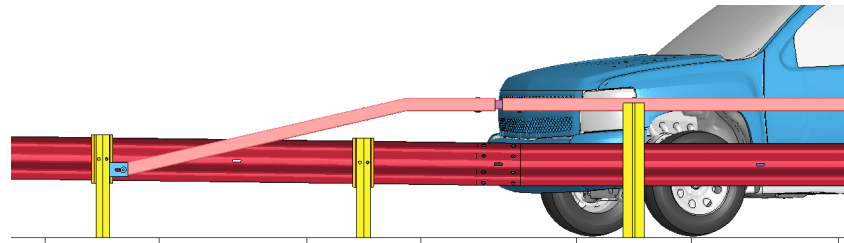
Figure 2.2. Finite Element Model of the Initial Transition Design.

2.4. SIMULATION ANALYSIS AND DESIGN DEVELOPMENT

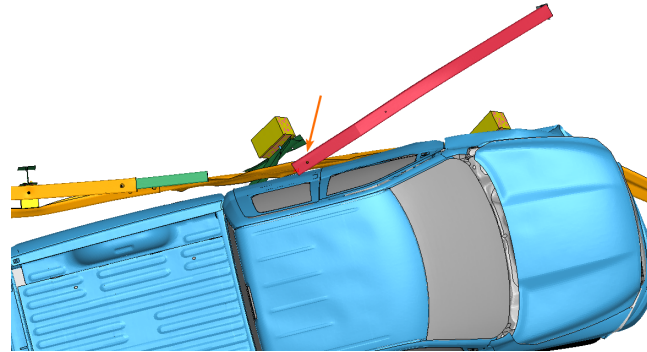
After developing the system model of the initial Transition design, the researchers performed *MASH* TL-3 impact simulations. Based on these simulations, several improvements were made to the transition design, as discussed in this section.

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

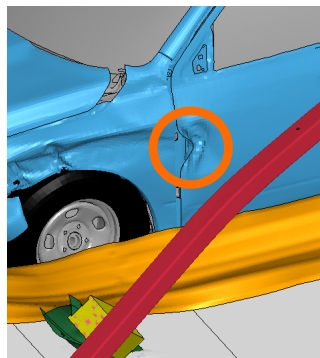
roadside guardrail transition, it is possible for a vehicle to impact the Transition in this direction. The researchers wanted to evaluate the vehicle's interaction with the turn-down rail. Key results from the simulation are shown in Figure 2.3. The turn-down rail disengaged from the top HSS rail at 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.

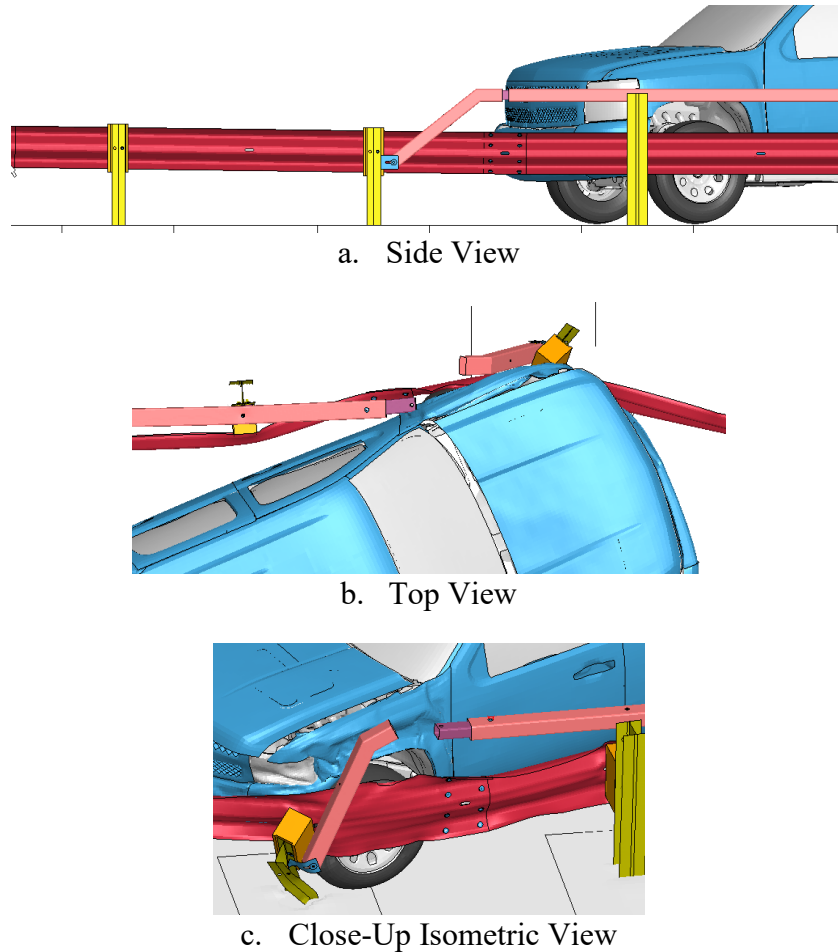


Figure 2.4. Reverse-Direction Pickup Truck Impact of the Shortened Turn-Down Rail Design.

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.

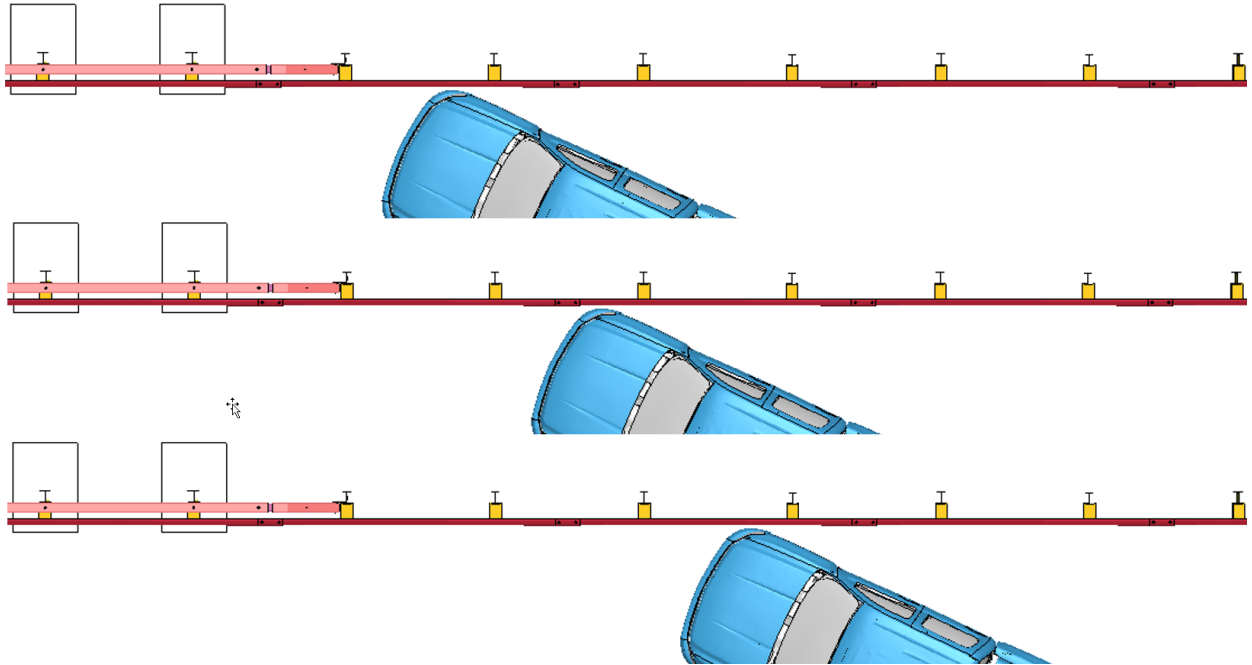
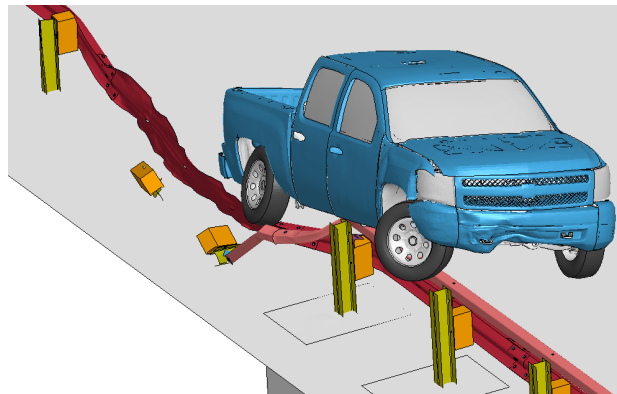
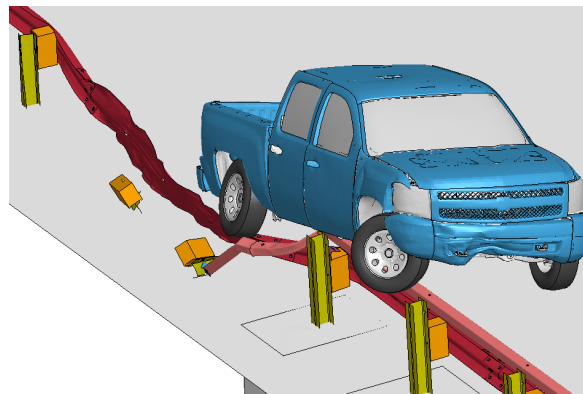


Figure 2.5. Impact Points for Test 3-21 Simulations (IP1 [top], IP2 [center], IP3 [bottom]).

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.

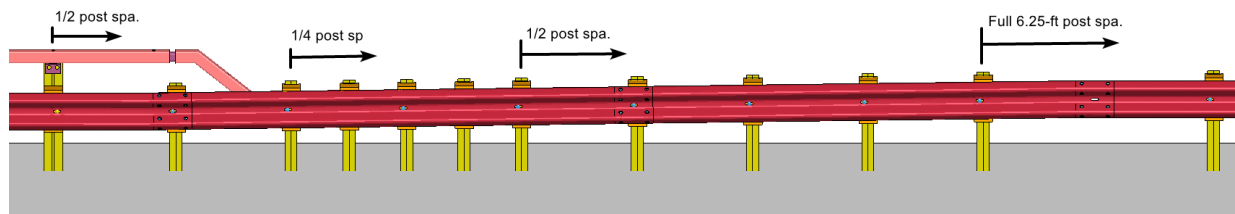


Figure 2.7. Transition Design with Posts Installed at Quarter and Half Post Spacings.

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.

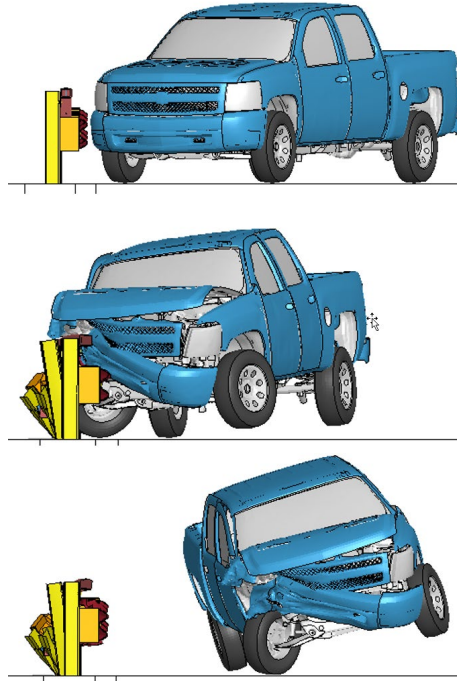


Figure 2.8. Simulation at IP1 for Transition Design with Quarter and Half Post Spacings.

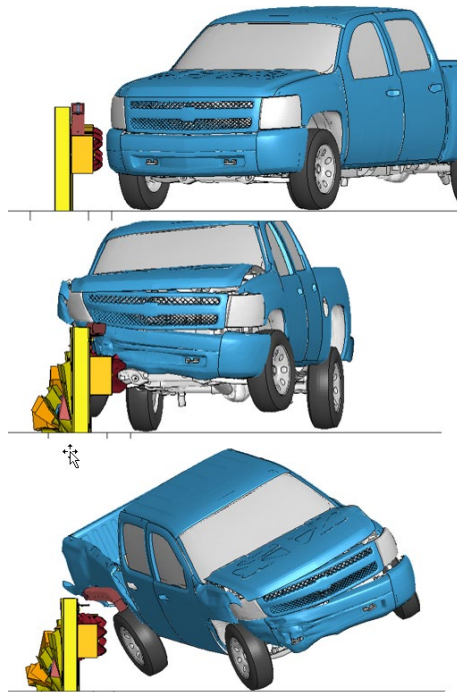


Figure 2.9. Simulation at IP2 for Transition Design with Quarter and Half Post Spacings.

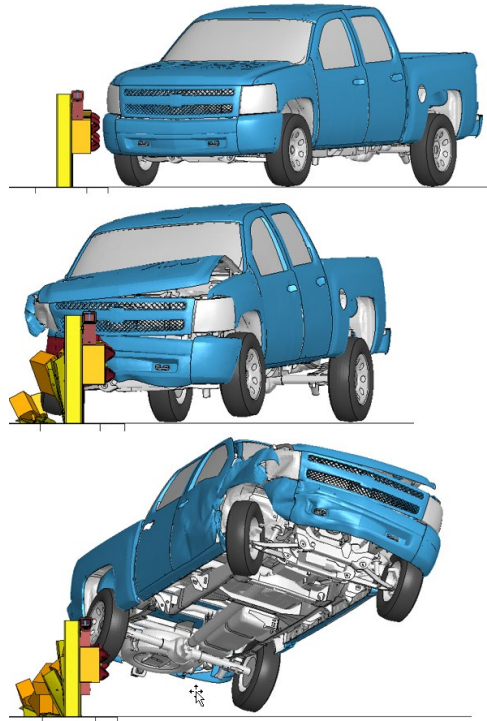


Figure 2.10. Simulation at IP3 for Transition Design with Quarter and Half Post Spacings.

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.

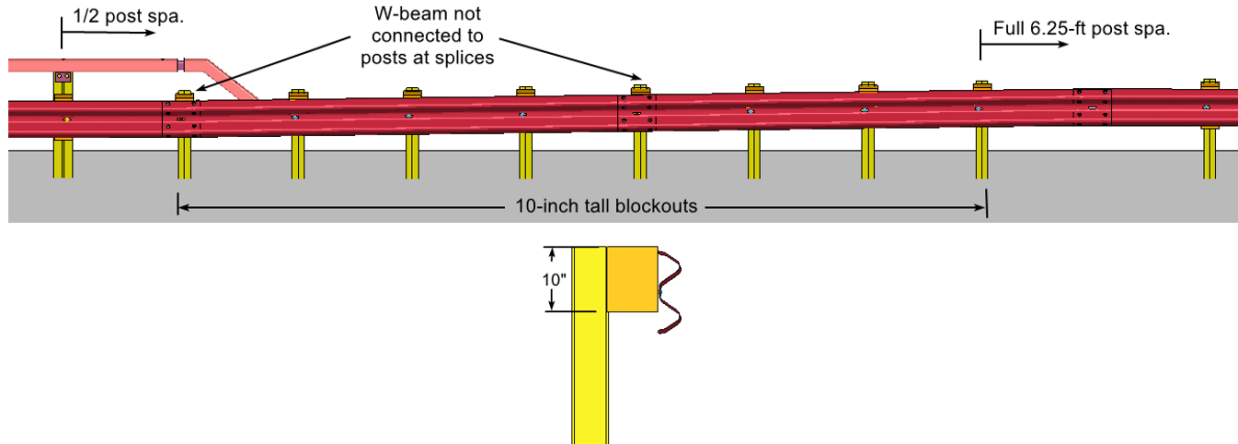


Figure 2.11. Modified Transition Design with Half Post Spacing.

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.

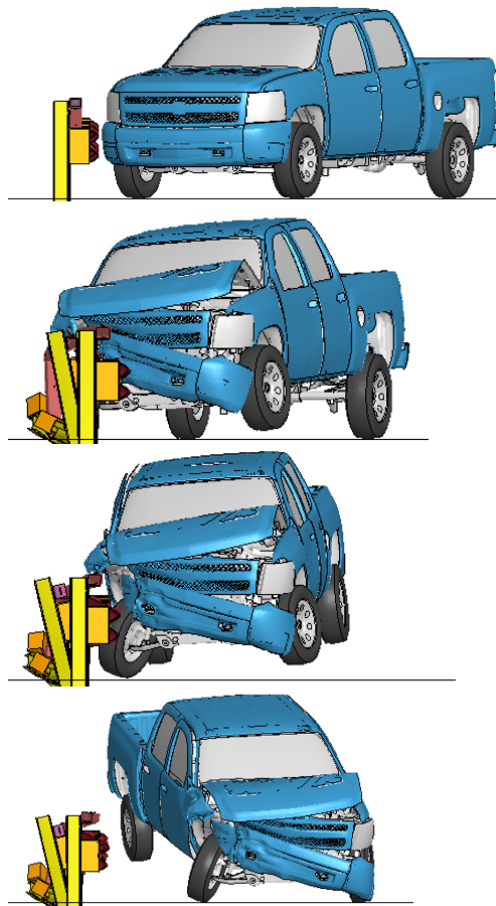


Figure 2.12. Simulation at IP1 for Transition Design with Half Post Spacing.

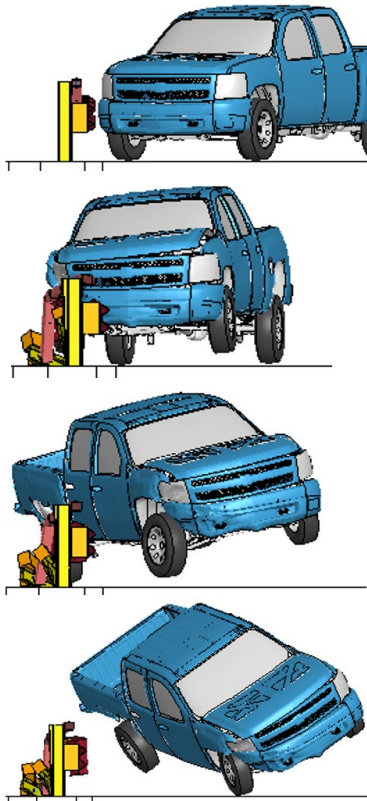


Figure 2.13. Simulation at IP2 for Transition Design with Half Post Spacing.

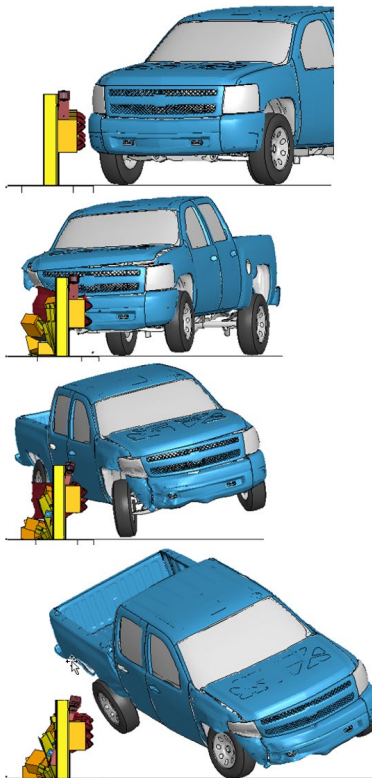


Figure 2.14. Simulation at IP3 for Transition Design with Half Post Spacing.

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.

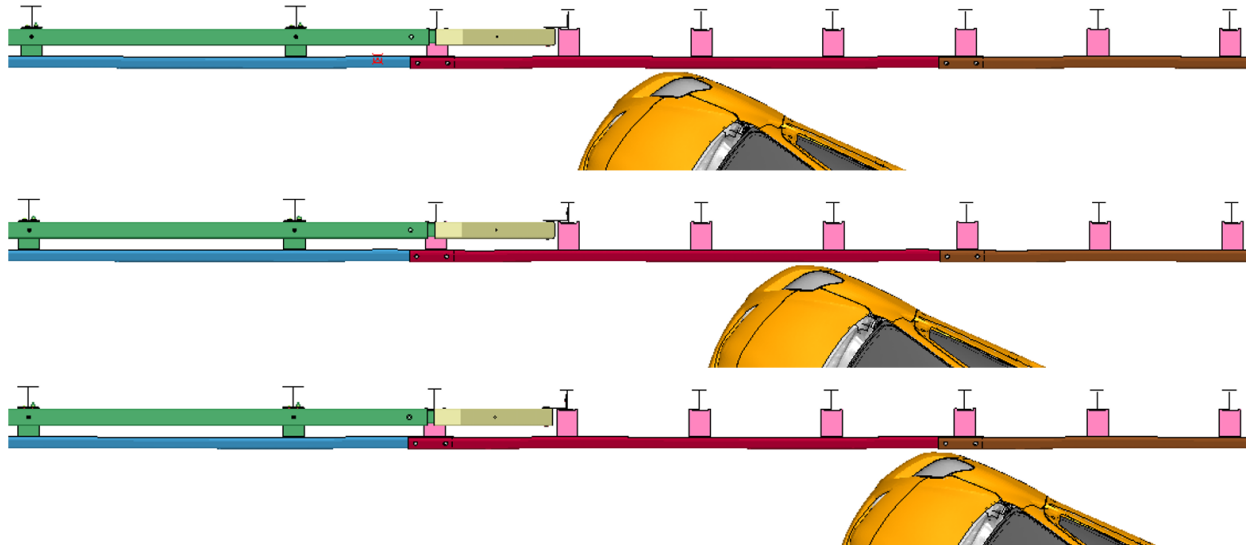


Figure 2.15. Impact Points for Test 3-20 Simulations (IP4 [top], IP5 [center], IP6 [bottom]).

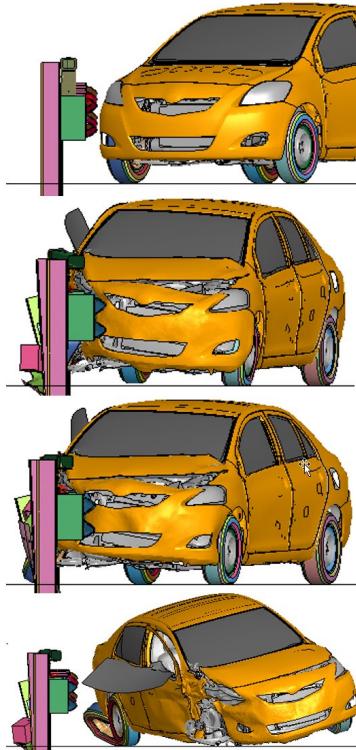


Figure 2.16. Simulation at IP4 for Transition Design with Half Post Spacing.

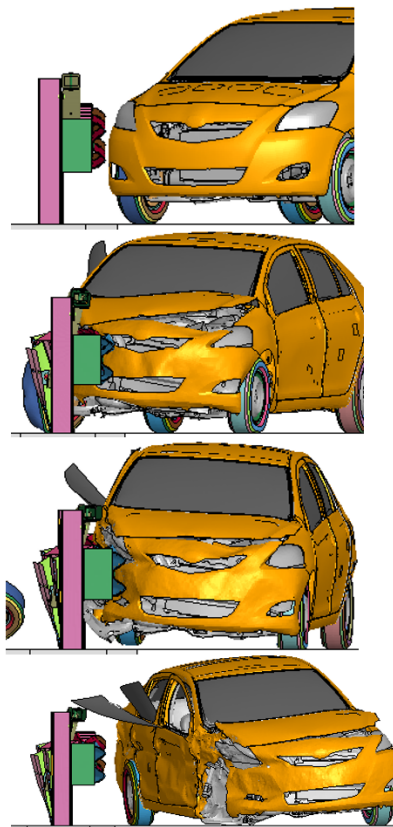


Figure 2.17. Simulation at IP5 for Transition Design with Half Post Spacing.

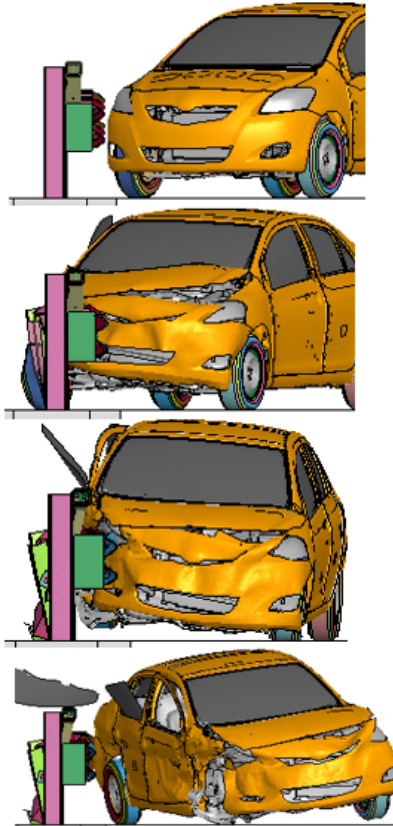


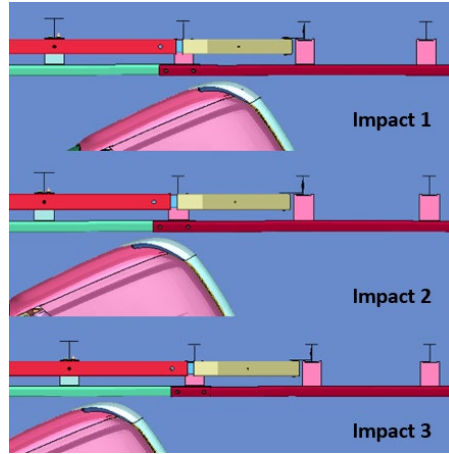
Figure 2.18. Simulation at IP6 for Transition Design with Half Post Spacing.

2.4.3. Reverse-Direction Impact Evaluation

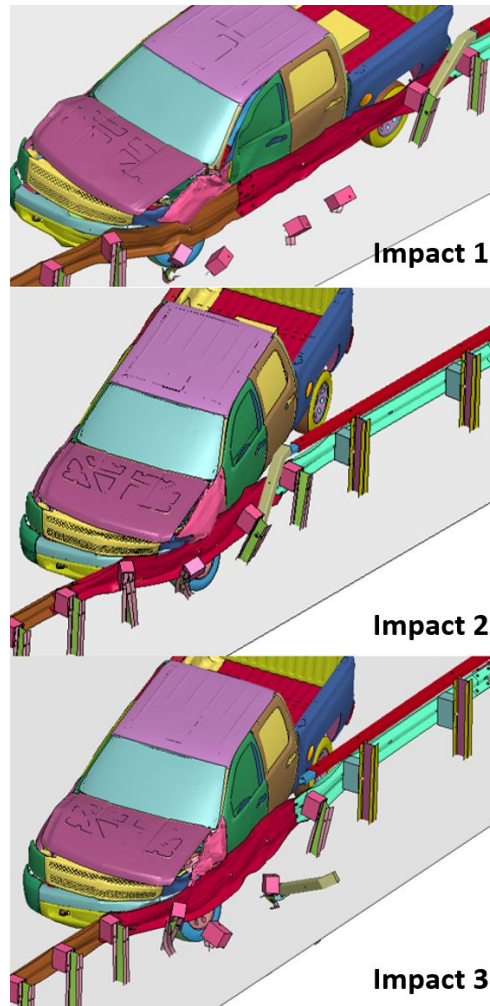
The researchers performed six additional impact simulations with the Transition design in Figure 2.11. Three of these simulations were performed with the pickup truck and three with the small car. In these simulations, the vehicle impacted the Transition in the reverse direction.

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.

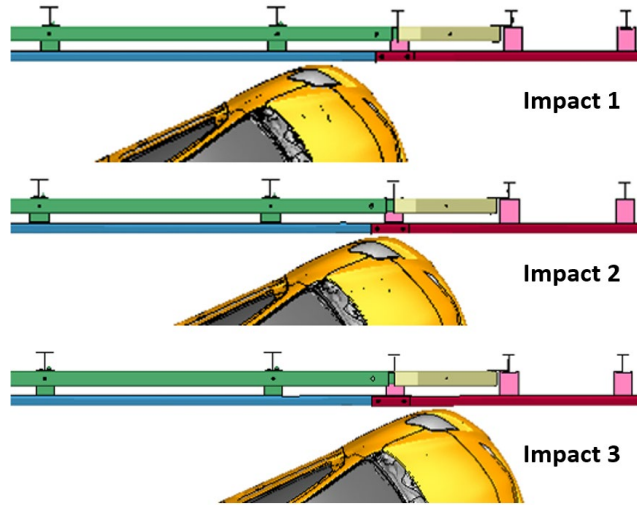


a. Impact Points

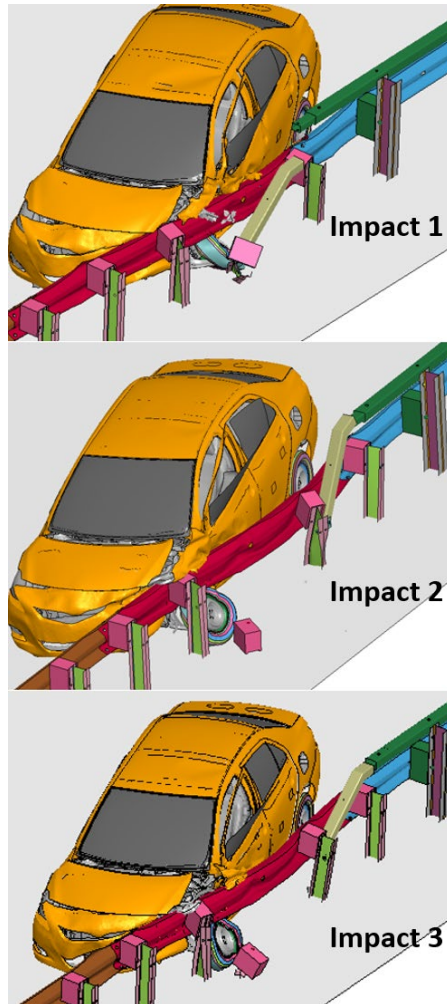


b. Key Result for Each Impact Point

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.

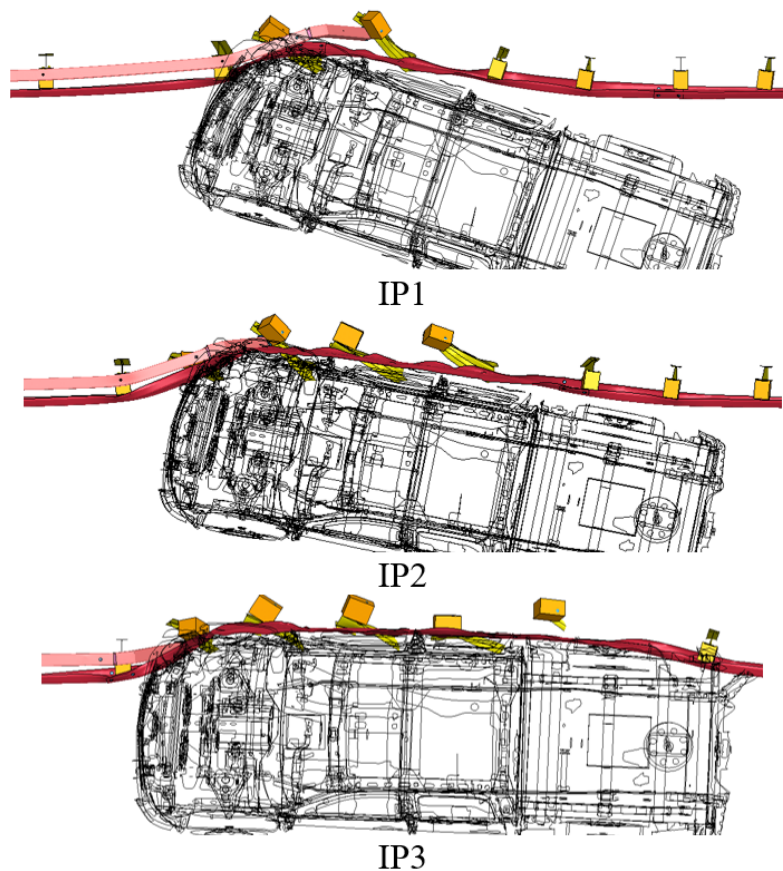


Figure 2.21. Vehicle Orientation at the Time of Maximum Lateral Rail Deflection for the Three Impact Points (Pickup Truck).

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.

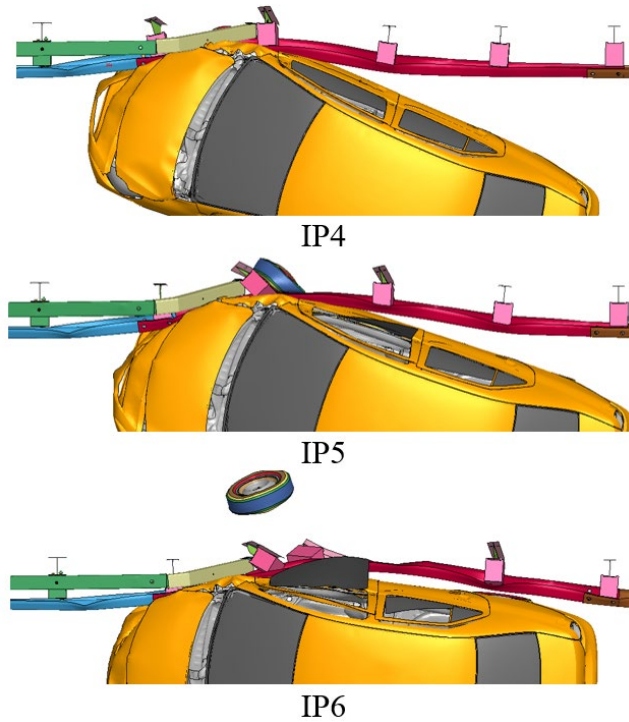


Figure 2.22. Vehicle Orientation at the Time of Maximum Lateral Rail Deflection for the Three Impact Points (Small Car).

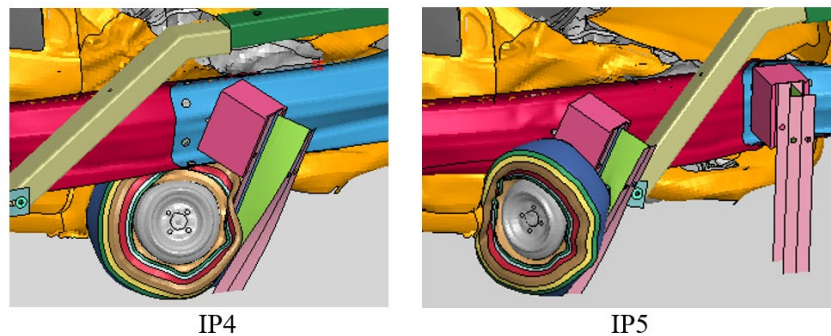


Figure 2.23. Wheel Snagging Comparison for Small Car Impact between IP4 and IP5.

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

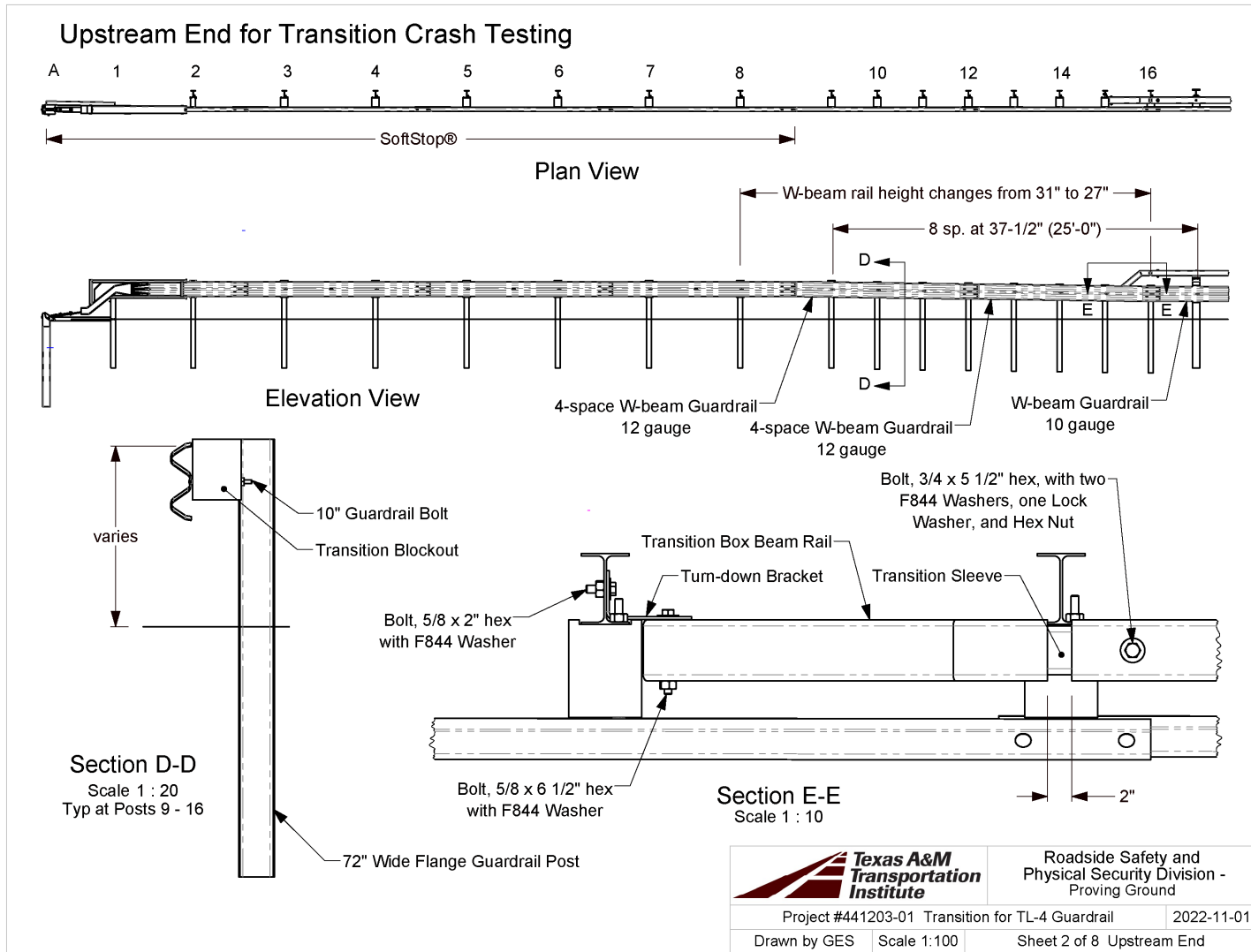
The Transition was attached on the upstream end of the TxDOT *MASH* TL-4 guardrail. It was comprised of a 12-gauge W-beam guardrail mounted at a height of 27 inches at post 16, transitioning to a mounting height of 31 inches at post 9. The W-beam was attached to W6×8.5 posts. Posts 9 through 16 were spaced 37½ inches apart and were attached to the W-beam using 8-inch × 6-inch × 10-inch routed 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

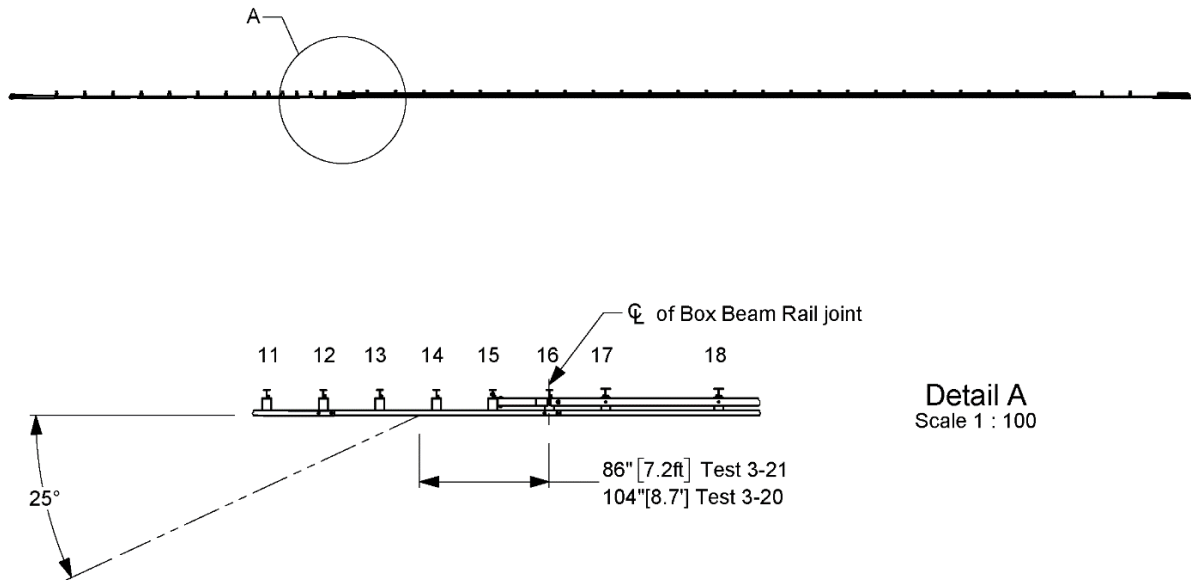


Figure 4.1. Target CIPs for *MASH* TL-3 Tests on TL-4 Guardrail Transition.

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	<i>MASH</i> Test
A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underide, 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 <i>MASH</i> .	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 RELIS 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.

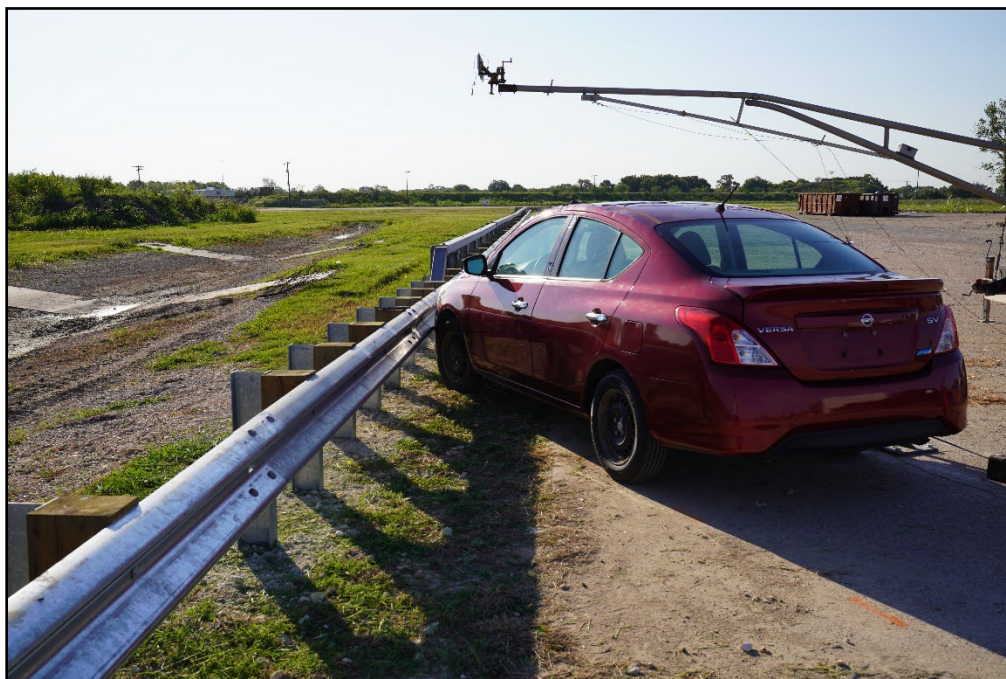


Figure 6.2. Test Vehicle at Impact Location for Test 441203-01-1.

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	<i>MASH</i>	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.

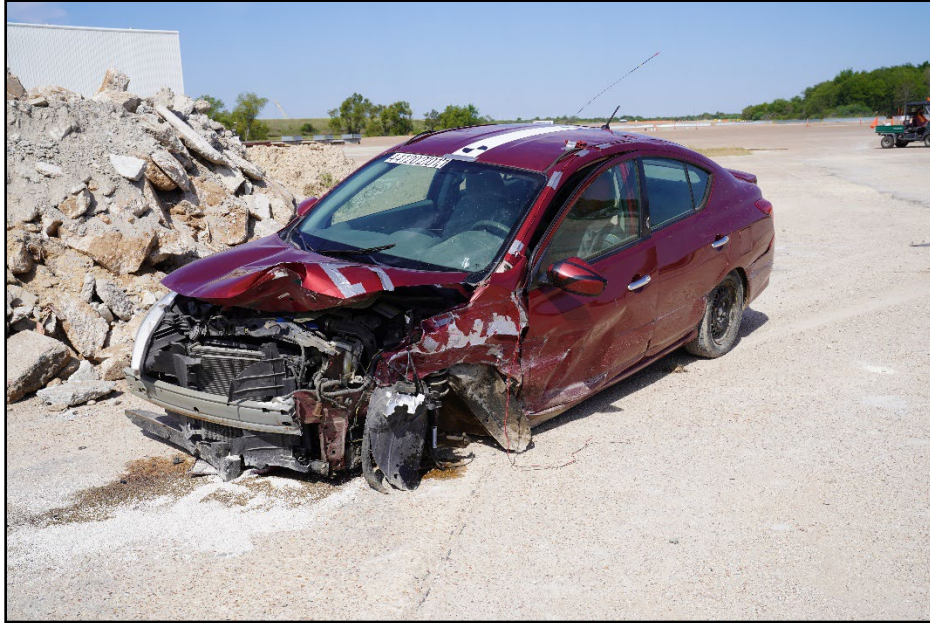


Figure 6.7. Impact Side of Test Vehicle after Test 441203-01-1.



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	<i>MASH</i>^a	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 <i>30.0</i>	27.2	0.1040 seconds on left side of interior
OIV, Lateral (ft/s)	≤40.0 <i>30.0</i>	24.1	0.1040 seconds on left side of interior
Ridedown, Longitudinal (g)	≤20.49 <i>15.0</i>	11.6	0.1270–0.1370 seconds
Ridedown, Lateral (g)	≤20.49 <i>15.0</i>	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.





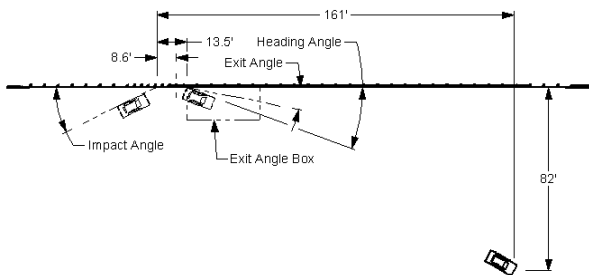
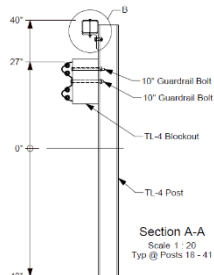
	Test Agency		Texas A&M Transportation Institute (TTI)					
	Test Standard/Test		MASH 2016, Test 3-20					
	TTI Project No.		441203-01-1					
	Test Date		2022-09-26					
	TEST ARTICLE							
	Type		Longitudinal Barrier					
	Name		Transition for TxDOT MASH TL-4 Guardrail					
	Length		260 ft 2 inches					
	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	<i>MASH</i>	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	1/8 inch	1/8 inch	—	—
14	1/2 inch	3/4 inch	2.4°	—
15	—	1 inch	17°	14°
16	—	—	—	40°
17	—	—	21°	—
18	—	2 inches	9°	—
19	2 1/4 inches	3/4 inch	4°	—
20	1 1/4 inches	—	2.5°	—
21	1/2 inch	—	0.5°	—
22	—	1/8 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	<i>MASH</i> ^a	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 <i>30.0</i>	21.4	0.1276 seconds on left side of interior
OIV, Lateral (ft/s)	≤40.0 <i>30.0</i>	18.0	0.1276 seconds on left side of interior
Ridedown, Longitudinal (g)	≤20.49 <i>15.0</i>	14.2	0.1459–0.1559 seconds
Ridedown, Lateral (g)	≤20.49 <i>15.0</i>	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.





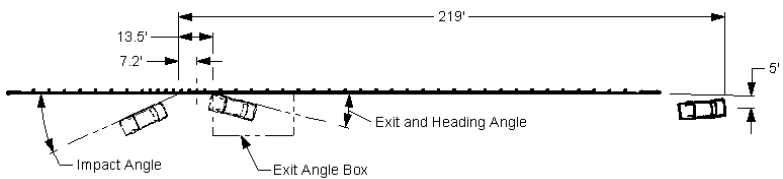
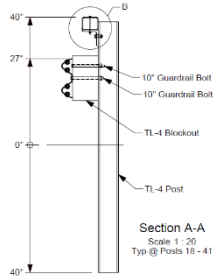
	Test Agency		Texas A&M Transportation Institute (TTI)					
	Test Standard/Test		MASH 2016, Test 3-21					
	TTI Project No.		441203-01-2					
	Test Date		2022-10-31					
	TEST ARTICLE							
	Type	Longitudinal Barrier						
	Name	Transition for TxDOT MASH TL-4 Guardrail						
	Length	260 ft 2 inches						
	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.

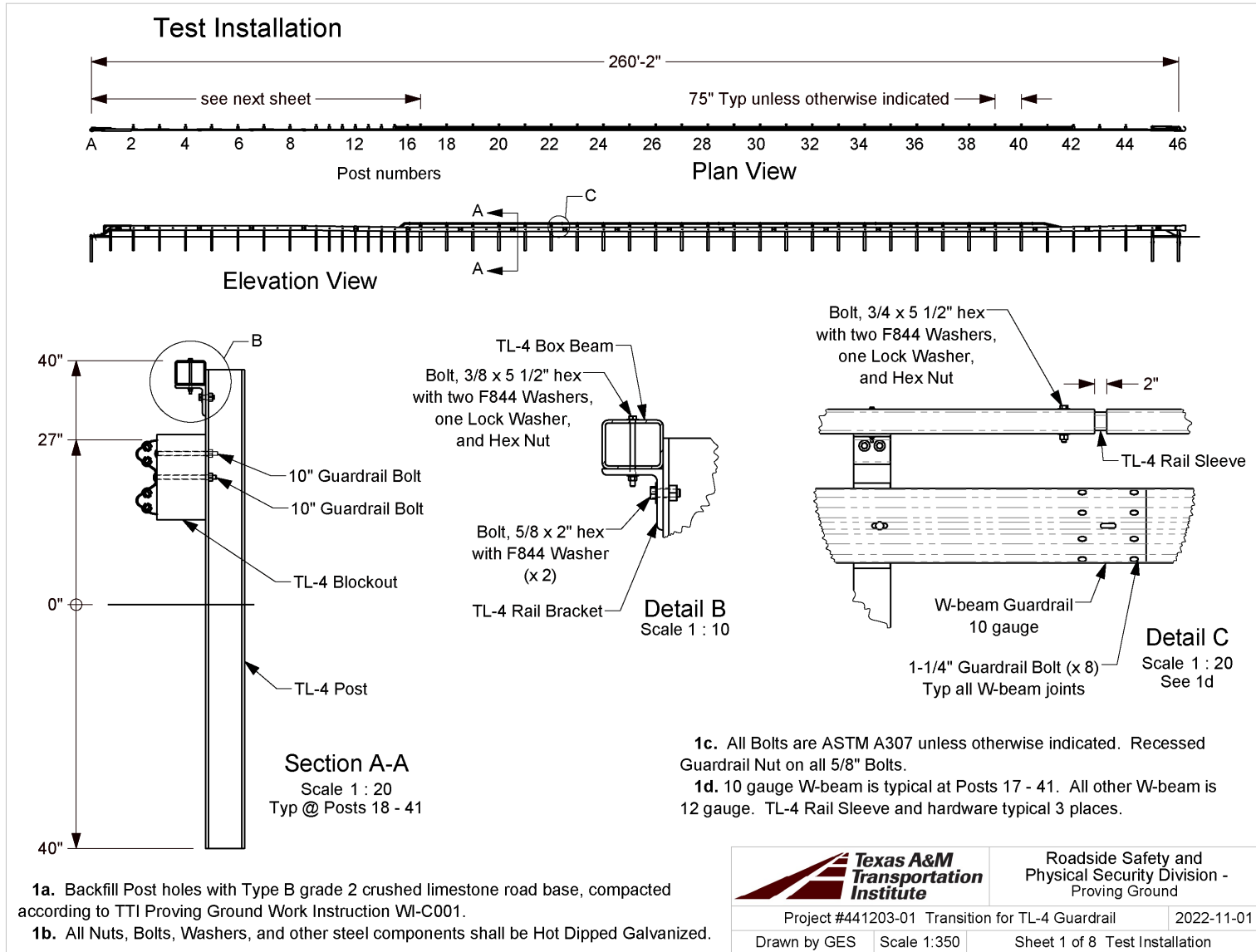
Chapter 9. IMPLEMENTATION

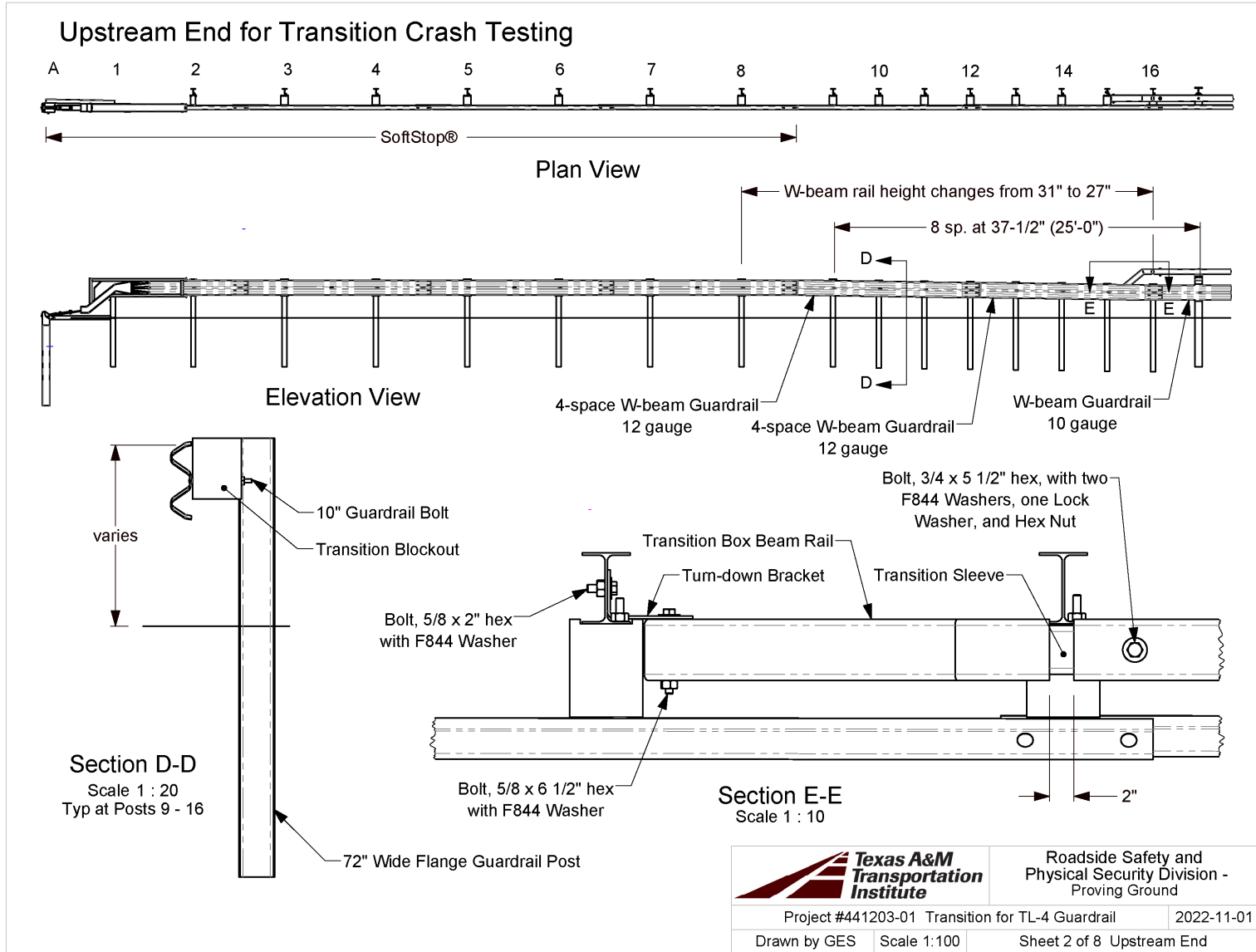
The Transition for the TxDOT *MASH* TL-4 guardrail developed in this project passed *MASH* TL-3 testing requirements for longitudinal barriers and is ready for implementation in the field. This implementation can be achieved by developing a design standard for the Transition. The value of research (VOR)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

REFERENCES

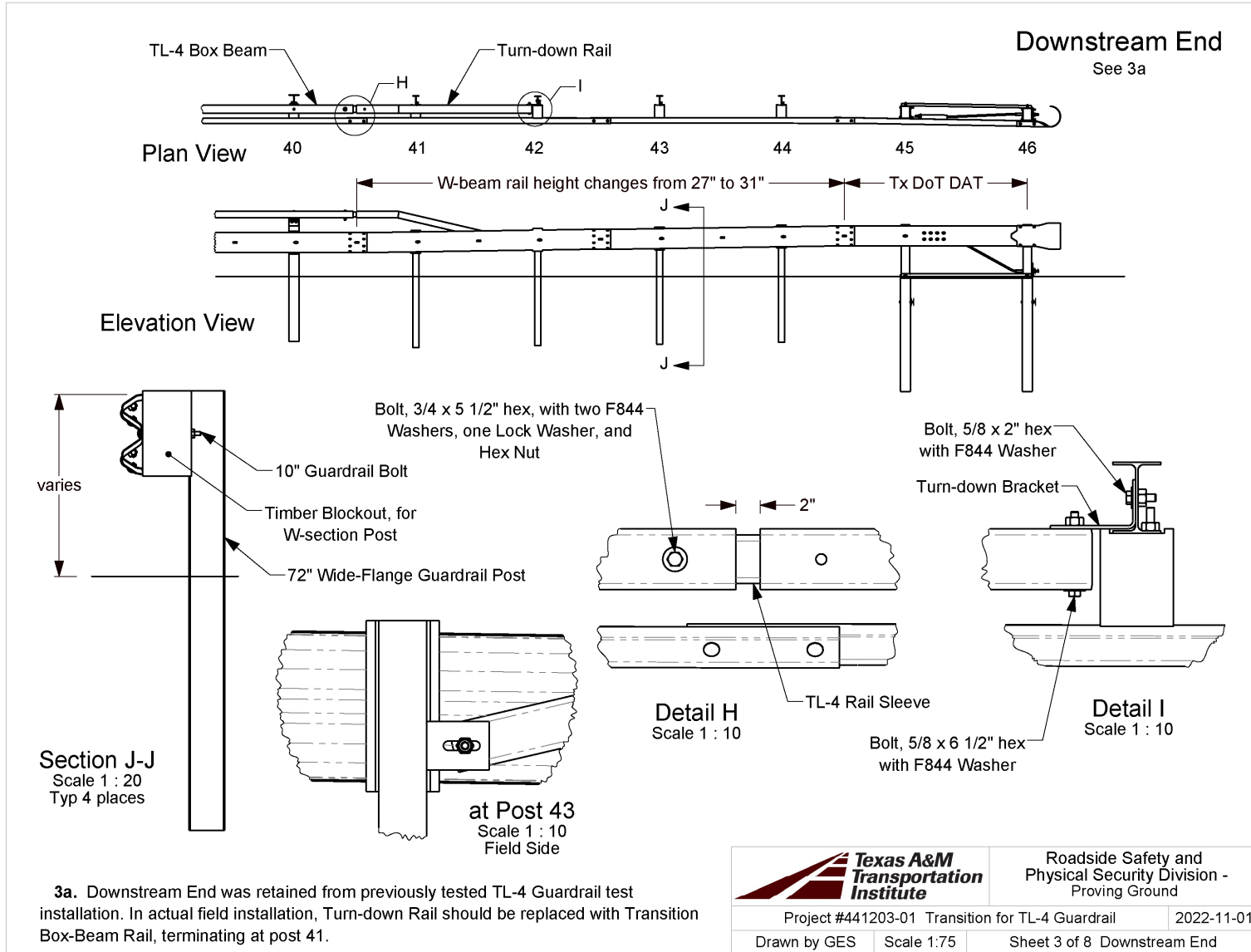
1. AASHTO. *Manual for Assessing Safety Hardware*, Second Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2016.
2. Sheikh, N. M., Bligh, R. P., Menges, W. L., Schroeder, W., Griffith, B. L., & Kuhn, D. L. *Development and Evaluation of MASH TL-4 Guardrail 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



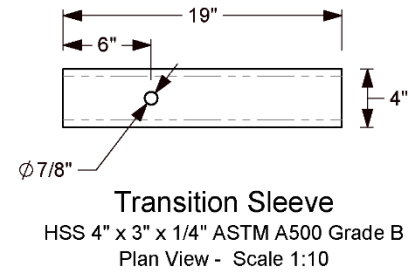
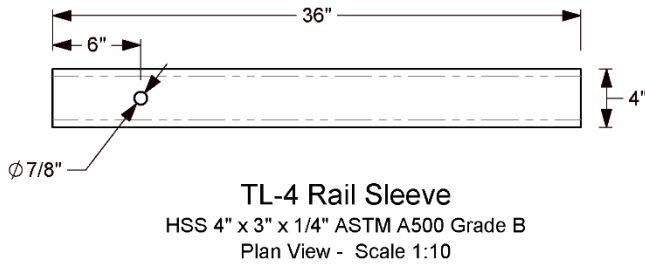
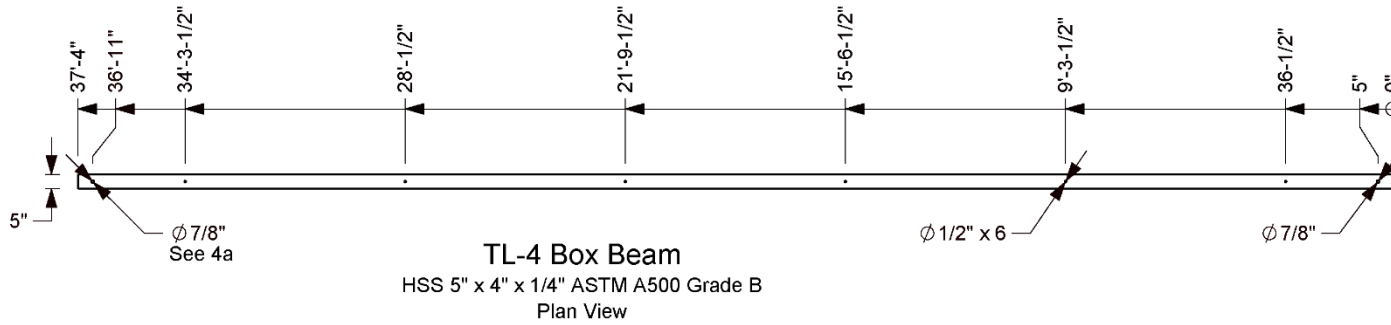


		Roadside Safety and Physical Security Division - Proving Ground
Project #441203-01 Transition for TL-4 Guardrail		2022-11-01
Drawn by GES	Scale 1:100	Sheet 2 of 8 Upstream End



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

Rail Details

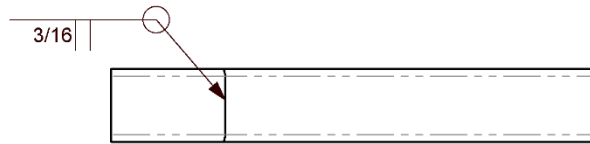


4a. This hole only needed on one rail (at upstream end; Posts 17 - 23).

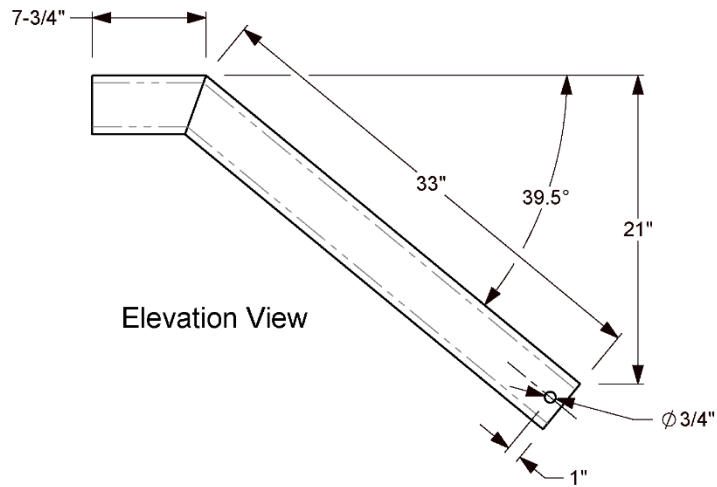
		Roadside Safety and Physical Security Division - Proving Ground	
Project #441203-01 Transition for TL-4 Guardrail		2022-11-01	
Drawn by GES	Scale 1:50	Sheet 4 of 8 Rail Details	

Transition Box Beam Rail

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

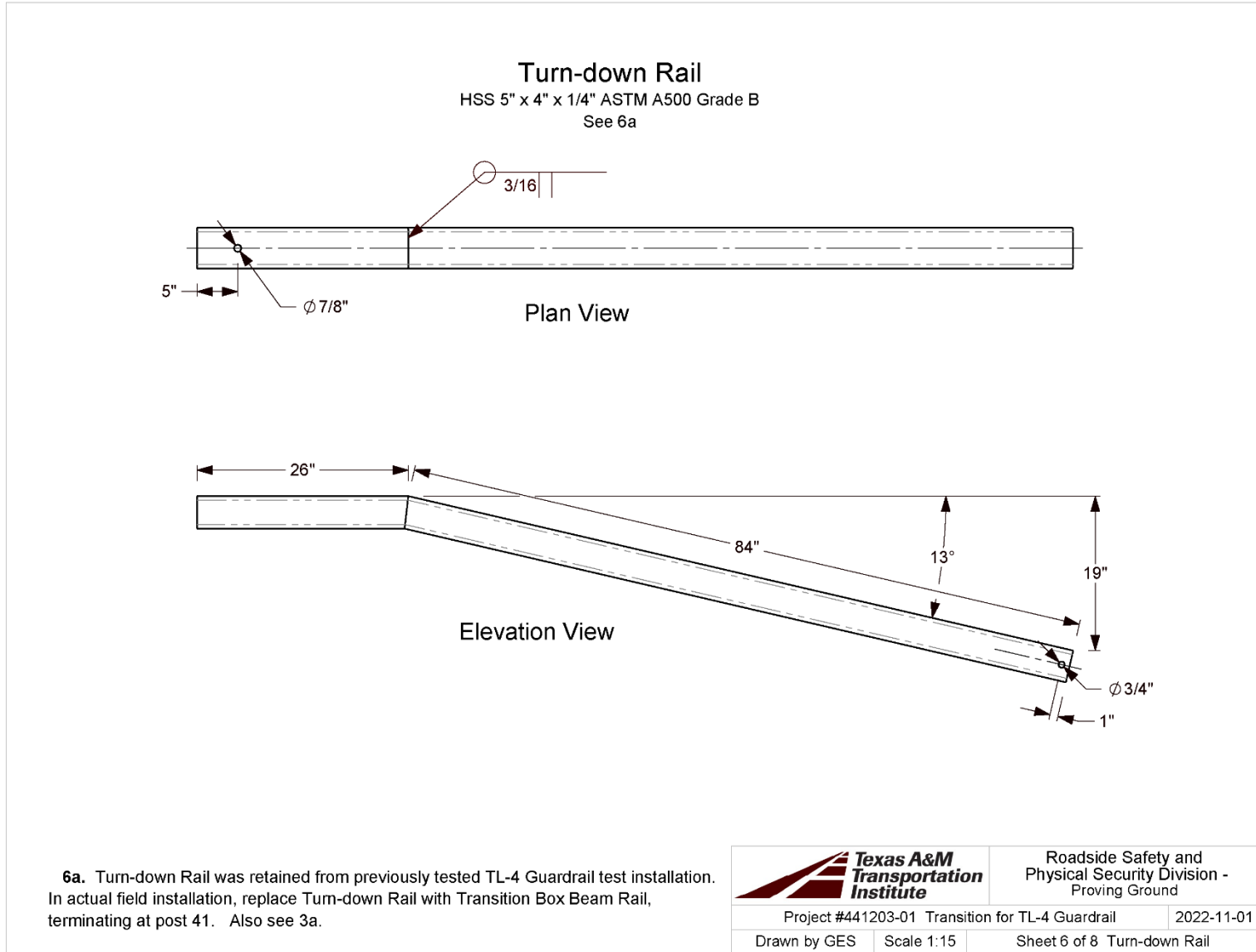


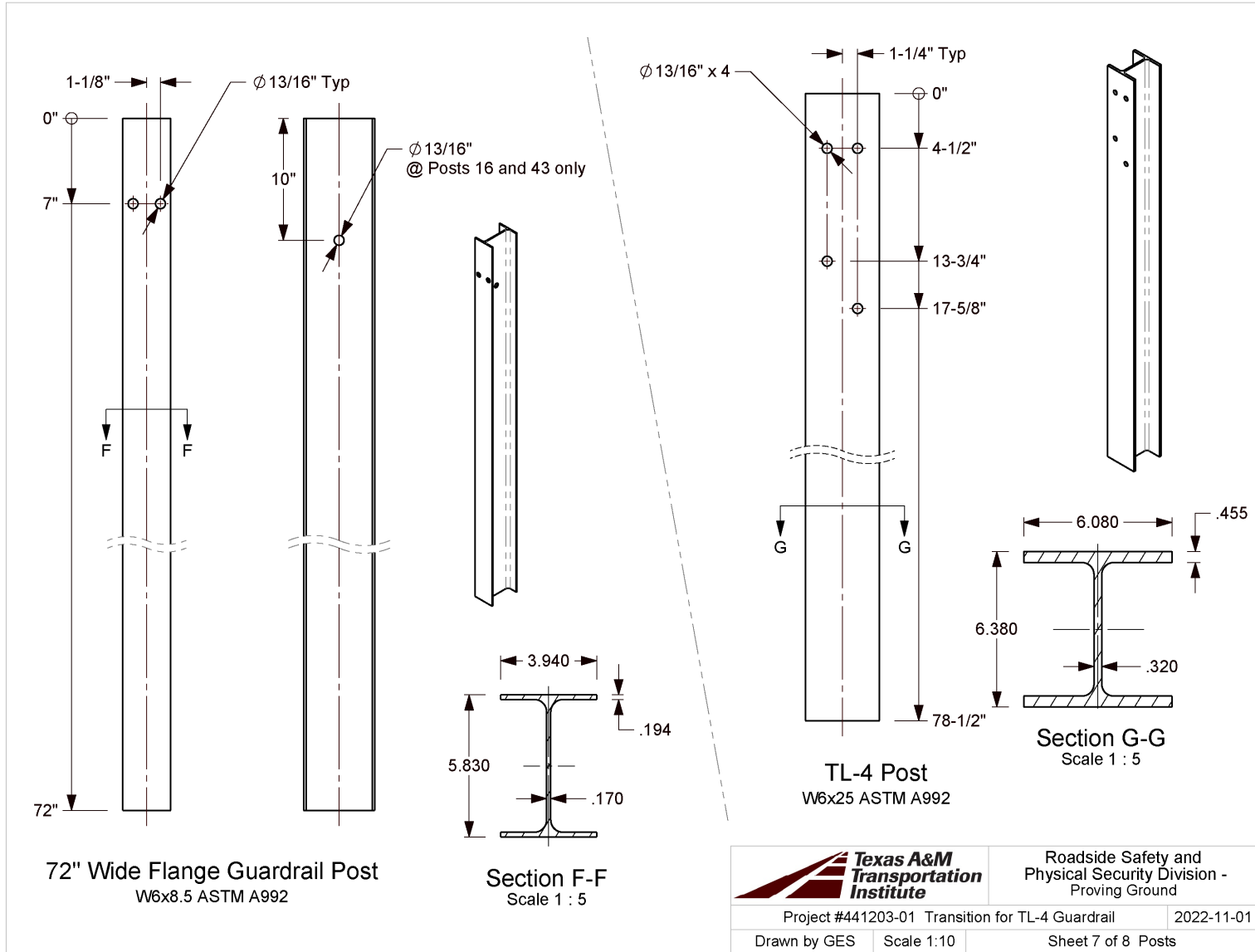
Plan View




Elevation View

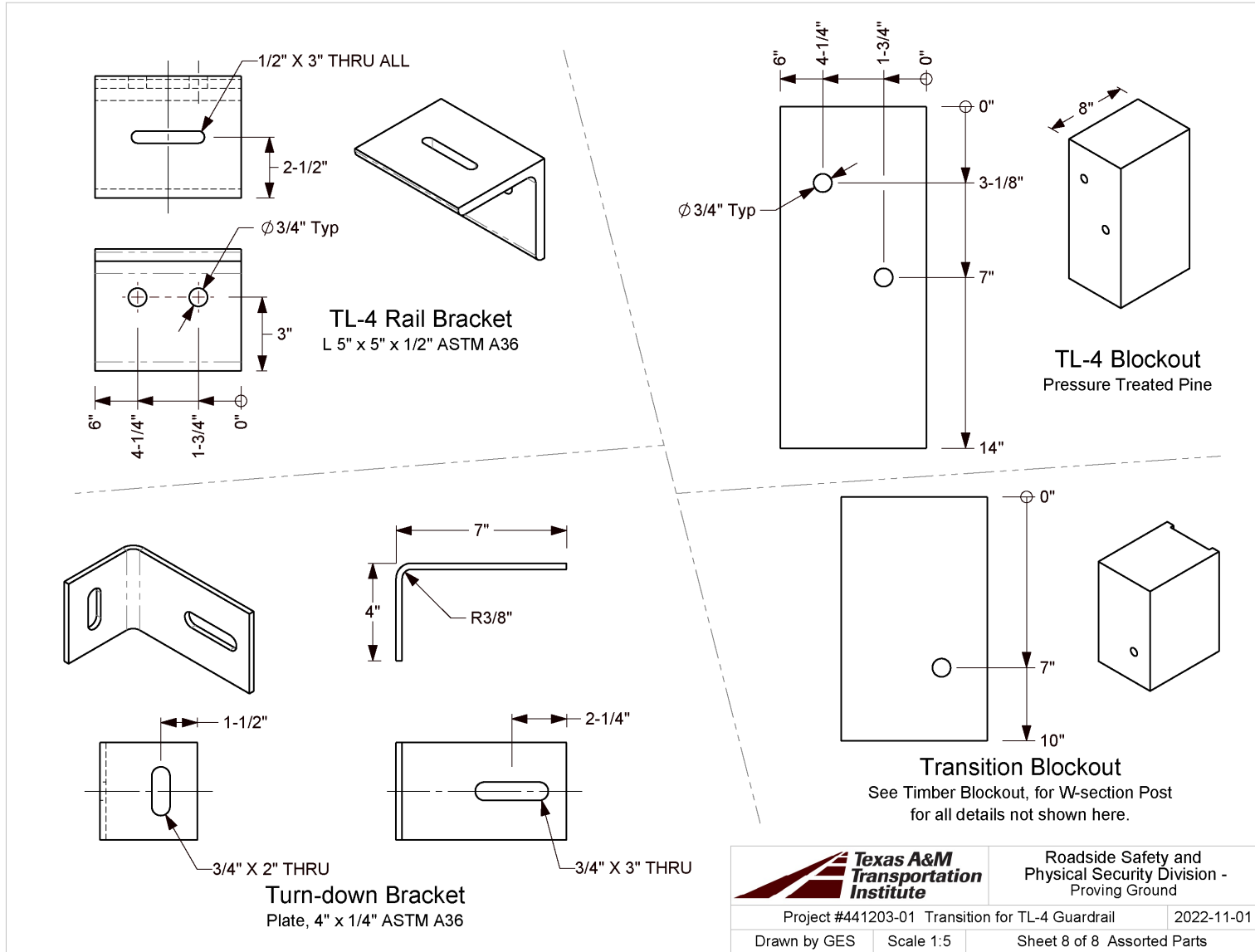
		Roadside Safety and Physical Security Division - Proving Ground
Project #441203-01 Transition for TL-4 Guardrail		2022-11-01
Drawn by GES	Scale 1:10	Sheet 5 of 8 Transition Rail





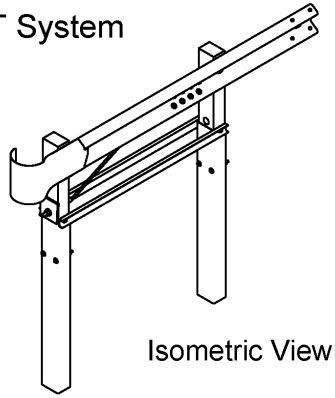
		Roadside Safety and Physical Security Division - Proving Ground	
		Project #441203-01 Transition for TL-4 Guardrail	2022-11-01
Drawn by GES	Scale 1:10	Sheet 7 of 8 Posts	

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



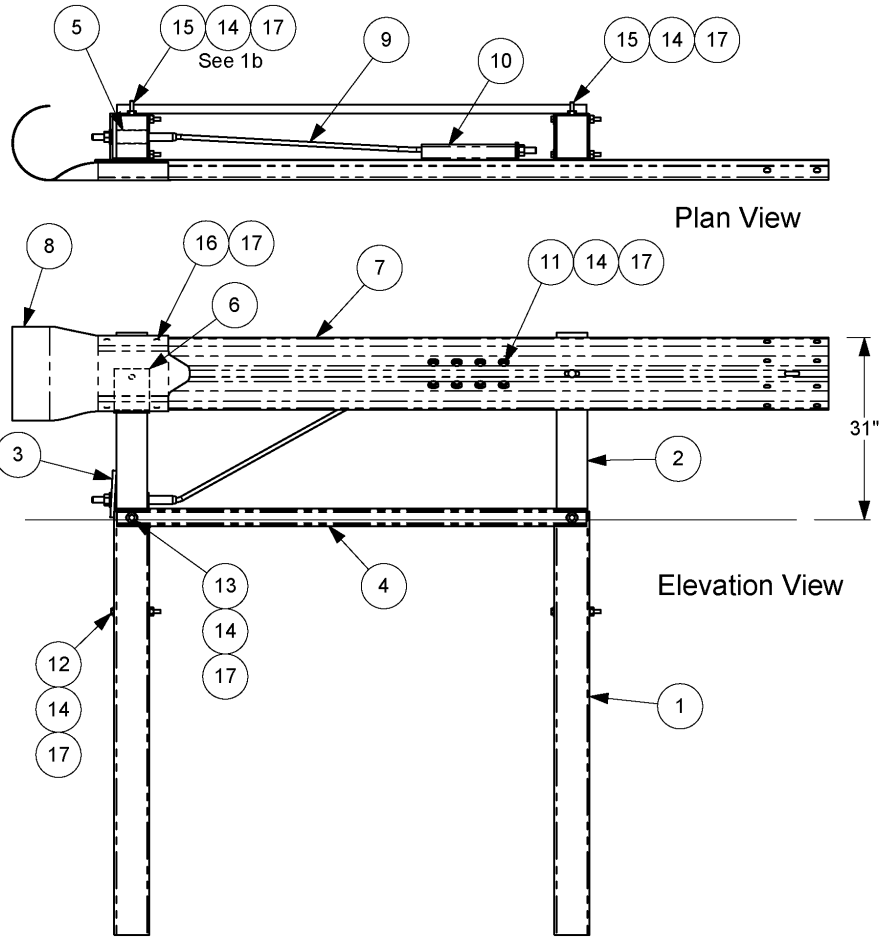
Q:\Accreditation-17025-2017\EIR-000 Project Files\441203-01 Transition for TL4 - Sheikh (441202-01)\Drafting, 441202-01\441202-01 Drawing

DAT System



Isometric 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



Plan View

Elevation View

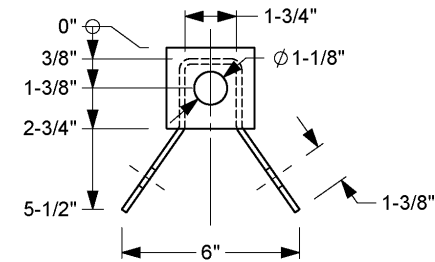
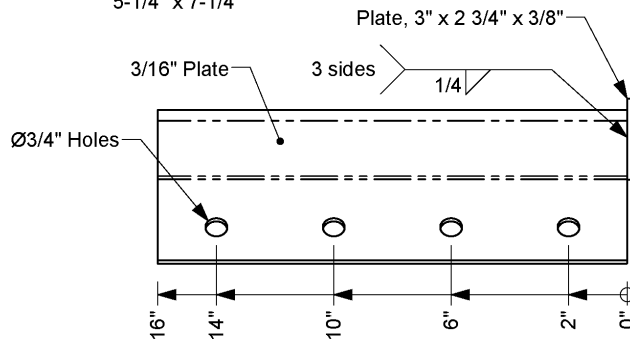
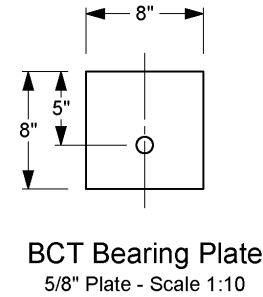
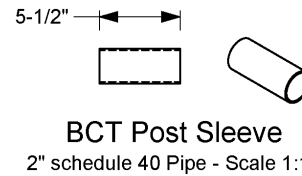
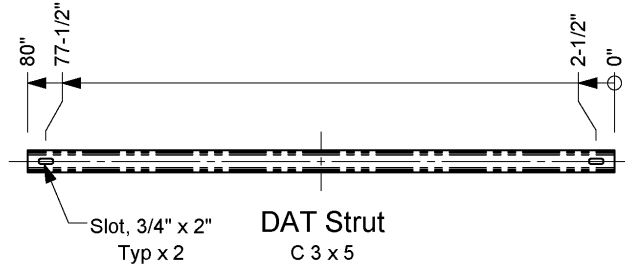
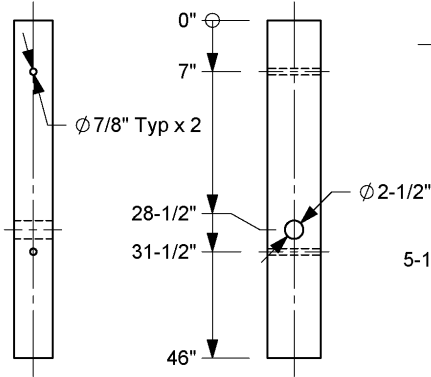
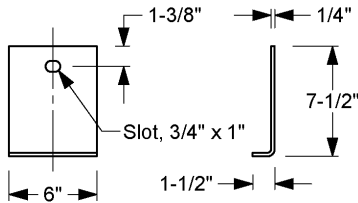
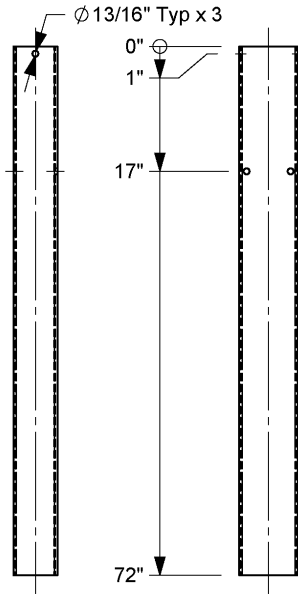
1a. All bolts are ASTM A307.
 1b. Hardware secures Shelf Angle Bracket to Post. Rail is supported by Shelf Angle Bracket and does not attach directly to Post.



Roadside Safety and Physical Security Division - Proving Ground

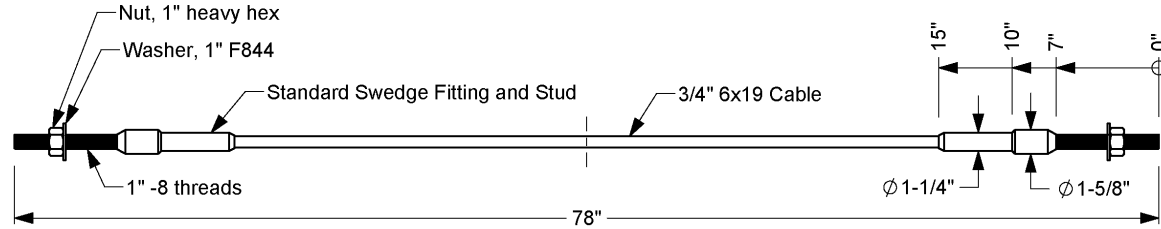
DAT (Downstream Anchor Terminal)		2022-07-13
Drawn by GES	Scale 1:25	Sheet 1 of 3

DAT Parts sheet 1

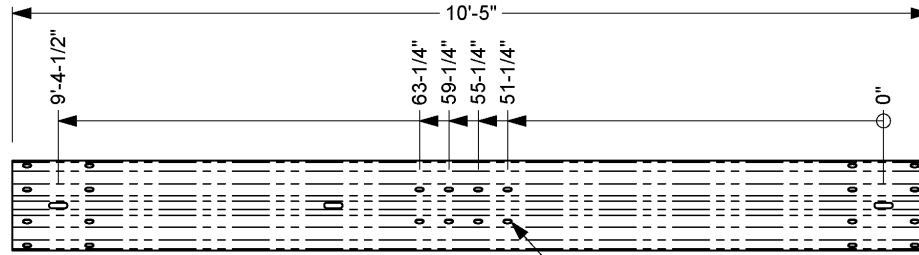


		Roadside Safety and Physical Security Division - Proving Ground	
DAT (Downstream Anchor Terminal)		2022-07-13	
Drawn by GES	Scale 1:20	Sheet 2 of 3	

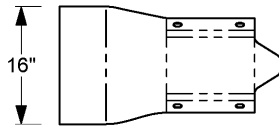
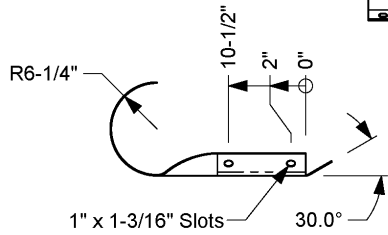
DAT Parts sheet 2



Anchor Cable Assembly



9'-4" span Terminal Rail
Scale 1:20 - See 4-space W-beam
Guardrail drawing for cross-section
and other dimensions.

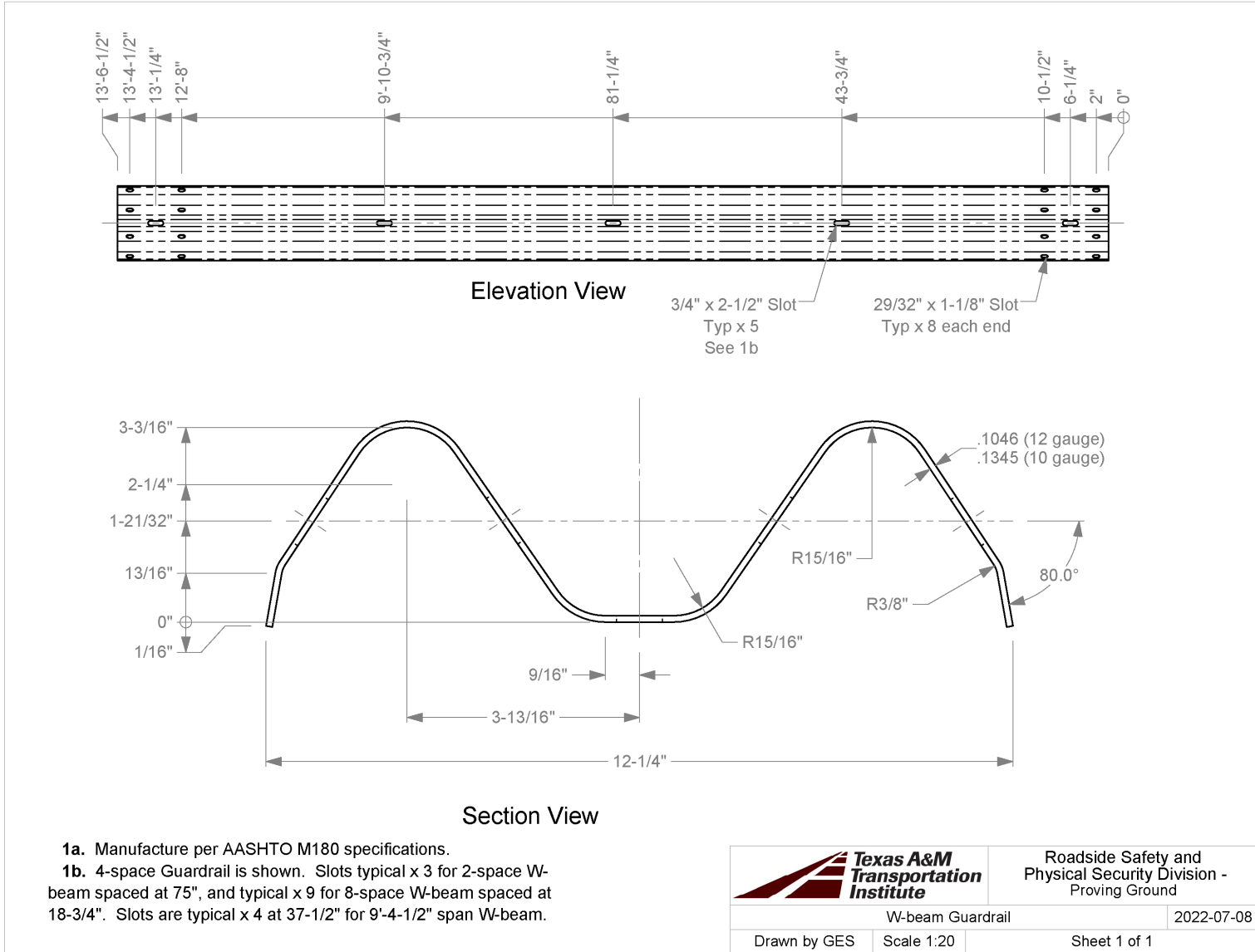


W-beam End Section
12 gauge steel - Scale 1:20



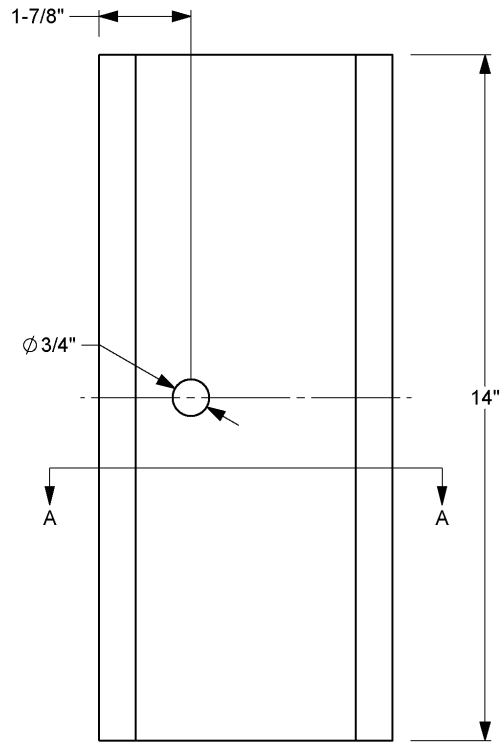
Roadside Safety and
Physical Security Division -
Proving Ground

DAT (Downstream Anchor Terminal)		2022-07-13
Drawn by GES	Scale 1:10	Sheet 3 of 3

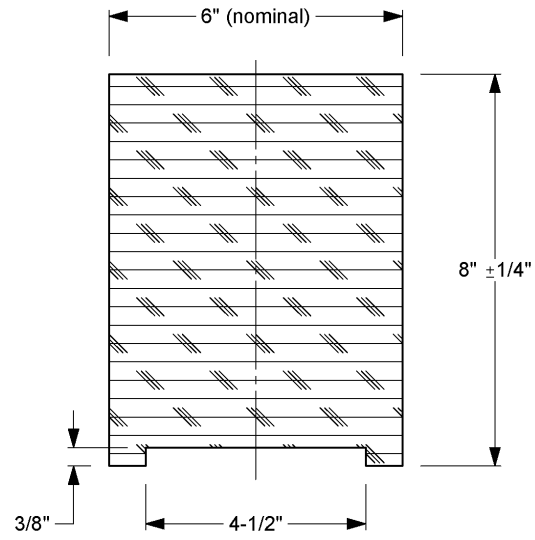


T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-Beam Guardrail

Timber Blockout for W-section Post




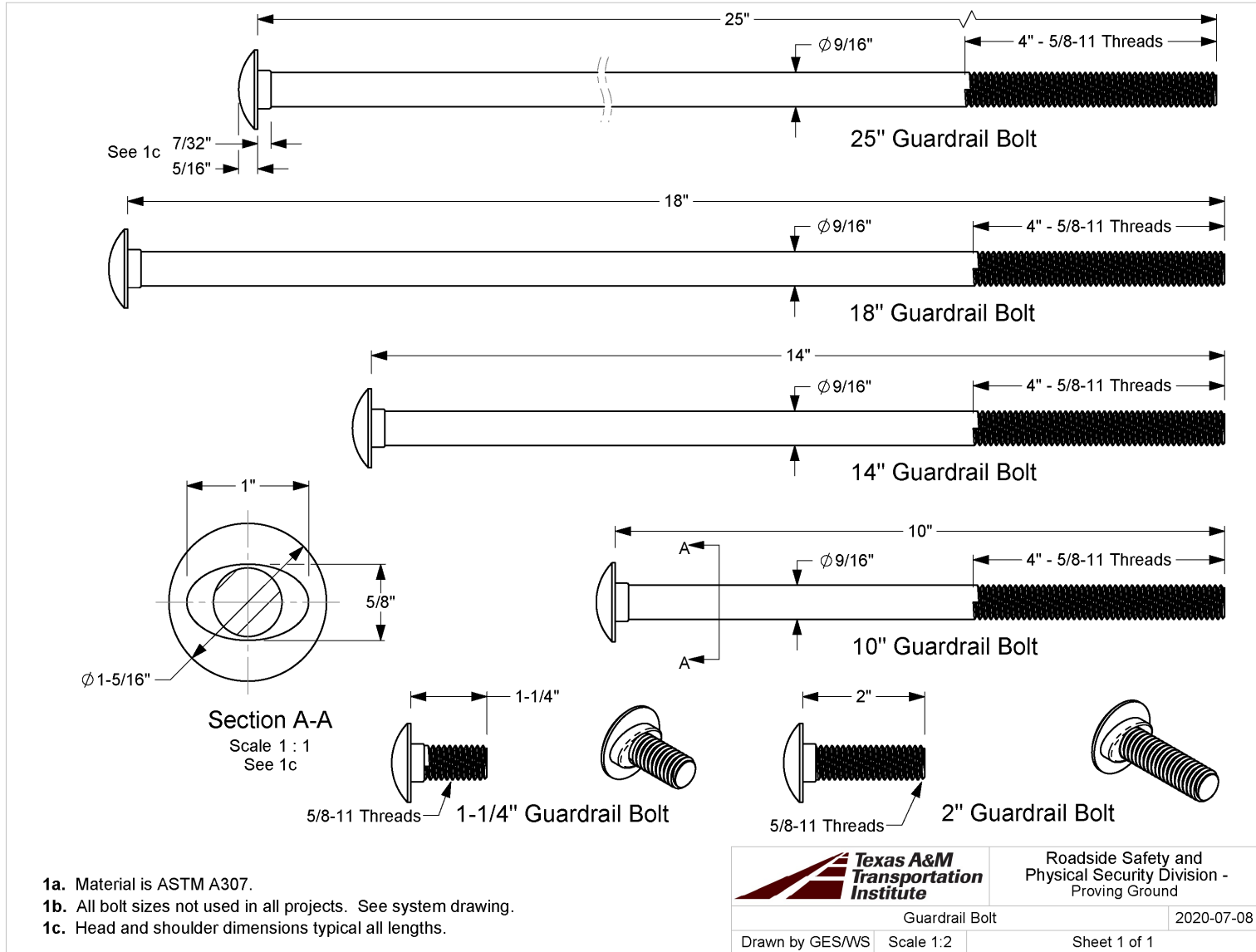
Elevation View



Section A-A

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

		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



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

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

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

A572 PLATE FOR WASHERS

1455 Hagan Avenue
 Huger, SC 29450
 Phone: 843-336-6000
 Sales Fax: 843-336-6150

METALLURGICAL TEST REPORT
 Nucor Steel Berkeley
 a division of NUCOR corporation
 Sales Fax: 843-336-6150

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

Sold KLOECKNER METALS CORPORATION Ship COASTAL CARGO
 Ship Date 9/28/19
 To: 500 COLONIAL CIR PKWY
 STE 500
 ROSWELL, GA 30076
 Bill of Lading # 1437031
 Vehicle # BULKMASTER
 R1s # BLUE
 P/O # 7421846
 Mill Order # 470453-2
 Part # .24X60 A572GR50

To: 16800 PENINSULA BLVD
 CPT CARE TERMINALS
 HOUSTON, TX 77067
 HOT ROLL COIL
 GAUGE x WIDTH .2400 MIN X 60.0000 MIN HR
 ASTM A1018 / HSLAS GR50 CLL / REV: 2018

SUITABLE FOR CONVERSION TO ASTM A572 GRADE 50

Heat	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	Nb	N	Ti	B	Ca	YIELD STRENGTH		TENSILE STRENGTH		ELONGATION		HARDNESS		N Value	
																	long.	trans.	long.	trans.	long.	trans.	(Rockwell B)	long.	trans.	(% IN 2")
2912871	.05	1.14	.008	.003	.19	.08	.03	.03	.01	.007	.032	.007	.034	.007	.013	.000	.002	59.3	72.4	72.4	34	83	.13			
2912873	.05	1.14	.008	.003	.18	.08	.03	.03	.01	.006	.032	.006	.034	.007	.011	.000	.002	63.8	72.5	72.5	28	84	.13			
																		62.6	72.6	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 standard specification. If material is ordered to a chemical specification 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 #	1035604
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.

07/20/2022

Kloeckner - 1 1/2" Round BAR

Mark Schmidt, Chief Metallurgist

Page 1 of 1

Delta - W6x8.5 beam

08/03/2022

149214



US-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CUSTOMER SHIP TO
DELTA STEEL INC
7355 ROUNDHOUSE LN
HOUSTON, TX 77078-4528
USA

CUSTOMER BILL TO
DELTA STEEL INC
7355 ROUNDHOUSE LN
HOUSTON, TX 77078
USA

GRADE
A992/A572-50G
SHAPE / SIZE
Wide Flange Beam / 6 X 8.5 X 145.0 X 13.0
LENGTH
3700"
WEIGHT
7,548 LB
HEAT / BATCH
5910565402

SALES ORDER
1208696000010
USA

CUSTOMER MATERIAL N°

CUSTOMER PURCHASE ORDER NUMBER
HOU-75105

BILL OF LADING
1327-000486052

DATE
07/27/2022

SPECIFICATION / DATE OF REVISION
ASTM A399.1X
ASTM A992-20/A572-21
CSA G40.21-13 345WAL.50W

CHEMICAL COMPOSITION
C (%) 0.12
Mn (%) 0.96
P (%) 0.009
S (%) 0.016
Si (%) 0.20
Cu (%) 0.25
Ni (%) 0.08
Cr (%) 0.16
Mn(%) 0.019
Sn (%) 0.005
V (%) 0.001
Nb (%) 0.012
Al (%) 0.002
CEq(A6) (%) 0.33

MECHANICAL PROPERTIES
YS (MPa) 408
YS (MPa) 416
UTS (PSI) 73686
UTS (PSI) 75160
Y/T ratio (%) 0.800
Y/T ratio (%) 0.800

UTS (MPa) 508
UTS (MPa) 518

G/L (inches) 8.000
G/L (inches) 8.000

G/L (mm) 200.0
G/L (mm) 200.0

Elong. (%) 23.50
Elong. (%) 23.50

COMMENTS - NOTES

Meets requirements of ASTM A6 with the exception of identification in 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.

Shastrey BHASKAR YALAMANCHILI
QUALITY DIRECTOR

Phone: (409) 267-1071 Email: Bhaskar.Yalamanchili@gerdau.com

Wade Lumpkins
QUALITY ASSURANCE MGR

Phone: 922-7793118 Email: Wade.Lumpkins@gerdau.com

Heat Number 59105654

Shipper No 329299

Customer PO# 02741

Customer Name CUSTOM FABRICATORS & REPAIR

**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: 5/8-11X6-1/2HDC QNTY: 2,520MPCS PART NO: 00024-3061-024

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

STEEL PROPERTIES:

STEEL GRADE: Q235A

HEAT NUMBER: 9908020013

CHEMISTRY SPEC:

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

TEST:

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	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 TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE
 ASTM SPECIFICATION WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF
 INFORMATION PROVIDED BY THE MATERIAL SUPPLIER 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&D1VA
 - 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

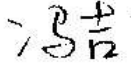
C	Mn	P	S	Si	Cr	Cu	Ni	B
.44	.53	.015	.012	.21	.060	.03	.02	

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 : 0706FHNC0003

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	DESCRPT. OF GOODS:	PRIME STEEL WIRE ROD							MECHANICAL PROPERTIES	
			直径 (MM) SIZE	C	Mn	Si	S	P	Al	抗拉强度 T.S(MPa)	伸长率 EL(%)
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: 1、质量证明书复印件不具有同等法律效力 THE COPY OF THE INSPECTION CERTIFICATE IS IMPROPERLY LEGALITY.
2、热轧交货后交货后热卷 THE COPY OF THE INSPECTION CERTIFICATE IS IMPROPERLY LEGALITY.
3、DRC=DECARBURIZATION C.R.T=COLD HEADING TEST G.S=GRAIN SIZE Y.S=YIELD STRENGTH T.S=TENSILE STRENGTH E.L=ELONGATION R.A=REDUCTION OF AREA C.H.T=COLD BEND TEST C.H.T=COLD HEADING TEST

MANUFACTURER:
XINGTAI IRON AND
STEEL CORP., LTD.
SIGNED BY: *[Signature]*

光豐國際商業銀行
唐山分行
00148
Mega ICBC Tang Shan Branch

光豐國際商業銀行
唐山分行
05---
文件保存進口商與
銀行共同負責

HANGZHOU SPRING WASHER CO.,LTD
QUALITY TEST CERTIFICATE OF SPRING LOCK WASHER

Customer: ASME B 18.21.1-1999 Contract No.: _____
 Standard: _____ Invoice No.: 06SHD330
 Order No.: PO 16072544

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	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 - BBST 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.:	BBII5191	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 ^{+0.05} 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.



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

FACTORY: NINGBO YONGGANG FASTENER CO., LTD. DATE: 2009-2-26
 ADDRESS: NINGBO MEIXU INDUSTRIAL PARK, ZHEJIANG, CHINA 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

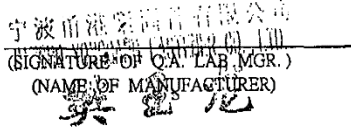
STEEL PROPERTIES:
 STEEL GRADE: SG195 HEAT NUMBER: 0740010334

CHEMISTRY SPEC:	C %*100	Mn%*100	P %*1000	S %*1000
	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 DATA 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 3/4-10 ²⁴⁰ 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.

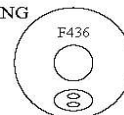
QIN YUE ZHU 公司

HEXICO ENTERPRISE CO., LTD.

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

INSPECTION CERTIFICATE

MARKING



CUSTOMER PORTEOUS FASTENER CO.
 PART NAME ASTM F436 - 09 TYPE 1 WASHERS (HOT DIP GALV. PER ASTM A153)
 SIZE 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 : CY1 & 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	22 PCS	ASTM F606/F606M	69-100 HRB	75 HRB	22	0
TENSILE STRENGTH	15 PCS	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.

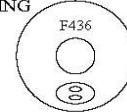
SIGNATURE : _____

HEXICO ENTERPRISE CO., LTD.

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

INSPECTION CERTIFICATE

MARKING



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

DIMENSIONS IN inch

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

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

INSPECTED BY Yu Tain Lin

CERTIFIED BY Jing Yeh Tsao

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

FACTORY: ZHEJIANG GOLDEN AUTOMOTIVE FASTENER CO.LTD
ADDRESS: XITANG QIAO HAIYAN ZHEJIANG CHINA

DATE: JUN.12,2016

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

CHEMISTRY SPEC:

C %	Mn%	P %	S %
0.29 max	1.20 max	0.04max	0.15max
0.06	0.28	0.019	0.015

TEST:

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
HOT DIP GALVANZED	ASTM F2329-13	Min 0.0017"	0.0024"-0.0026"	5	0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE SPECIFICATION ARE APPLICABLE TO THIS MATERIAL. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF THE INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR LABORATORY. All parts meet the requirements of FQA and records of compliance are on file. Maker's ISO#CN1120818



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



CERTIFICATE OF ANALYSIS

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
 15335 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

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

Product Information
 TEMPERED LEVELED PLATE A36/SA36
 0.2500" x 48" x 120"

Heat
 005821

Tag
 26545E

Pcs
 24

LBS
 9,805

Part PL38TML1448120
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).

AAASHTO : m270-345M270-50-19
 ASME : SA-36 13
 ASTM : A992-11(15)/A36-19/A529-19-50/A575018T1/A7093618/A7095018
 CSA : G40.21-44w/G40.21-50w/G40.2150MM

Description Part #	Heat# Test/Heat JW	Yield/ Tensile Ratio	Yield (MPa)	Tensile (PSI)	Elong %	Chemical Composition															
						C	Cr	Mn	P	Sn	S	B	Si	V	Ni	Cu	Nb	CE1	CE2	Pcm	
W6X25	2007786	.81	61300	75500	23.00	.07	1.03	.008	.022	.26	.026	.002	.002	.032	.23	.06	.28	.28	.28	.28	
W150X37.1	A992-11(15)	.80	59300	73700	24.00	.08	.01	.0095	.0002	.0069	.0069	.0069	.0069	.032	.06	4.97	.3302	.3302	.3302	.3302	
012.1920m			409	508	7	Pc(s)	7,000 lbs														

4 Heat(s) for this MTR.

Elongation based on 8" (20.32cm) gauge length. 'No Weld Repair' was performed.
 CE1 = $C + (Mn+Si)/5 + ((Cr+Mo+V)/5) + ((Ni+Cu)/15)$
 CE2 = $26.01Cu + 3.88Ni + 1.20Cr + 1.49Si + 17.28P - (7.29Cu+Ni) - (9.10Ni+P) - 33.39(Cu+Cu)$
 Pcm = $C + (Si/30) + (Mn/20) + (Cu/20) + (Ni/60) + (Cr/20) + (Mo/15) + (V/10) + 5B$
 CE2 = $C + ((Mn+Si)/5) + ((Ni+Cu)/15)$

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

1 SERIES-BPS®

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
Marcus W. McCluney - CMC Steel AL
Quality Assurance Manager

HEAT NO.: 1066214 SECTION: ANG 5 X 5x1/2 4070" A36/52950 GRADE: ASTM A36-19/A529-14 Gr 50 ROLL DATE: 05/13/2020 MELT DATE: 05/06/2020 Cert. No.: 83120220 / 066214B693		S O L D T O Intsel Steel Distributors LP 11310 W Little York Rd Houston TX US 77041-4917 7139379500 7136977335		S H I P T O 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 PIN: DLVRY LBS / HEAT: 29160,000 LB DLVRY PCS / HEAT: 45 EA	
Characteristic Value		Characteristic Value		Characteristic Value		Characteristic Value	
C	0.16%	Elongation test 1	24%				
Mn	0.78%	Elongation Gage Lgth test 1	8IN				
P	0.012%	Yield to tensile ratio test 1	0.71				
S	0.020%	Yield Strength test 2	55.5ksi				
Si	0.17%	Tensile Strength test 2	79.2ksi				
Cu	0.38%	Elongation test 2	25%				
Cr	0.15%	Elongation Gage Lgth test 2	8IN				
Ni	0.17%	Yield to tensile ratio test 2	0.70				
Mo	0.063%						
V	0.004%						
Cb	0.013%						
Sn	0.014%						
B	0.0002%						
Ti	0.001%						
N	0.0102%						
Carbon Eq A6	0.37%						
Carbon Eq A529	0.40%						
Yield Strength test 1	55.8ksi						
Tensile Strength test 1	78.5ksi						

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



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

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

MATERIAL TEST REPORT

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

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

Heat No	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	V	Ti	B	N	Ca
12018040	0.170	0.740	0.014	0.001	0.040	0.028	0.080	0.001	0.010	0.010	0.002	0.002	0.000	0.0060	0.0020

Bundle No M901147005 **Yield** 051167 Psi **Tensile** 068242 Psi **Eln.2in** 34 % **CE: 0.32**
Heat 12018040 **MILL** SDI **Recycled Content** 89.00% **Post Consumer** 80.00% **Pre-Consumer (Post Industrial)** 9.00% **ASTM A500-18 GRADE B&C**
Material Note: Butler,IN **Method** EAF **Within Miles of Location** 500
Sales Or. Note:

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

Heat No	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	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	0.001	0.001	0.0001	0.0050	0.0000

Bundle No M800949735 **Yield** 056331 Psi **Tensile** 075165 Psi **Eln.2in** 32 % **CE: 0.34**
Heat T85152 **MILL** USSTEEL **Recycled Content** 36.90% **Post Consumer** 19.80% **Pre-Consumer (Post Industrial)** 14.40% **ASTM A500-18 GRADE B&C**
Material Note: GARY,IN **Method** BOF **Within Miles of Location** 500
Sales Or. Note:

Authorized by Quality Assurance: *Juan Belmont*

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.





CERTIFICATE OF TESTING IPSCO TUBULARS INC

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** Pieces: **12** Length: **40.00 (ft)**
PRODUCT MEETS SPECIFICATION REQUIREMENTS
FOR GRADES B AND C.

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	V	Al	Cb	Ti	B	CEQ	TS	Al	V	Al	Cb	Ti	B	CEQ	YS	Mo	Sn	V	Al	Cb	Ti	B
1297013	G-972C 1490795/	HEAT QUALIFIER	PIPE LPA	0.009	0.002	0.02	0.06	0.03	0.04	0.010	0.003	0.003	0.030	0.003	0.000	0.001	0.0000	73300	0.030	0.003	0.000	0.001	0.0000	0.36	68000	0.070	0.003	0.003	0.000	0.001	0.0000	0.36	35.0	0.93

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

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

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
 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

REF. B/L: 80947599
 Date: 04/21/2020
 Customer: 1746

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



MATERIAL TEST REPORT

Atlas Tube Canada
 200 Clark St.
 Harrov Ontario Canada
 M9R 1G0
 Tel: 519-738-3541
 Fax: 519-738-3537

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

Material: 5.0x4.0x250x48'0"(3x3). Material No: 500402504800
 Sales Order: 1509929 Purchase Order: SSH111808
 Heat No C Min 0.820 P 0.011 S 0.007 Si 0.018 Al 0.057 Mo 0.005 Cr 0.034 Ni 0.010 Ti 0.002 V 0.002 B 0.0002 N 0.0030 Ca 0.0002
 Bundle No M101976258 Yield 069433 Psi Elong. 32.8 % Elong. 2in
 Heat MILL 071028 Psi 32.8 % Tensile
 796873 STELCO Nanticoke,ON Method BOF Recycled Content 36.90% Post Consumer 19.80% Pre-Consumer (Post Industrial) 14.40%
 Material Note: Certification ASTM A500-18 GRADE B&C
 Sales Or. Note: CE: 0.34 % Harvested 100% Within Miles of Location 1000

Material: 8.0x8.0x500x48'0"(2x2). Material No: 800805004800
 Sales Order: 1510221 Purchase Order: SSH111808
 Heat No C Min 0.800 P 0.009 S 0.009 Si 0.014 Al 0.036 Mo 0.008 Cr 0.029 Ni 0.002 Ti 0.002 V 0.002 B 0.0002 N 0.0040 Ca 0.0002
 Bundle No M201432243 Yield 059342 Psi 36.0 % Elong. 2in
 Heat MILL 068356 Psi 36.0 % Tensile
 796965 STELCO Nanticoke,ON Method BOF Recycled Content 36.90% Post Consumer 19.80% Pre-Consumer (Post Industrial) 14.40%
 Material Note: Certification ASTM A500-18 GRADE B&C
 Sales Or. Note: CE: 0.34 % Harvested 100% Within Miles of Location 1000

Authorized by Quality Assurance: *James 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.



23Jan20 1:48 TEST CERTIFICATE No: CHI 241525

NUCOR TUBULAR PRODUCTS INC. P/O No SSW110608
6226 W. 74TH STREET Rel
CHICAGO, IL 60638 S/O No CHI 300023-001
Tel: 708-496-0380 Fax: 708-563-1950 B/L No CHI 180587-001 Shp 23Jan20
Inv No Inv

Sold To: (2734) Ship To: (1)
SERVICE STEEL WAREHOUSE CO., L.P. SERVICE STEEL WAREHOUSE CO.
PO BOX 9607 8415 CLINTON DRIVE
HOUSTON, TX 77213 HOUSTON, TX 77029

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

CERTIFICATE of ANALYSIS and TESTS

Cert. No: CHI 241525
16Jan20

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

Pcs Wgt
16 8,902

* DOMESTIC STEEL M&M *

Heat Number Tag No
C92384 564038

Pcs Wgt
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

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

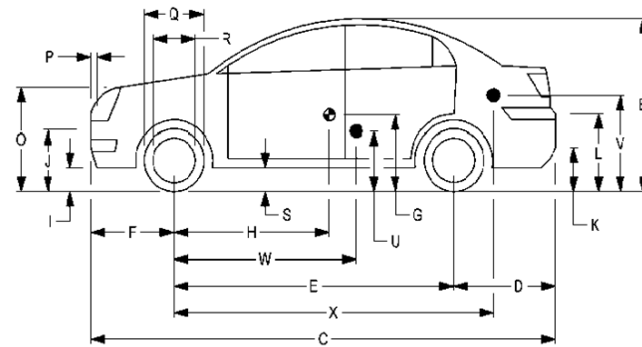
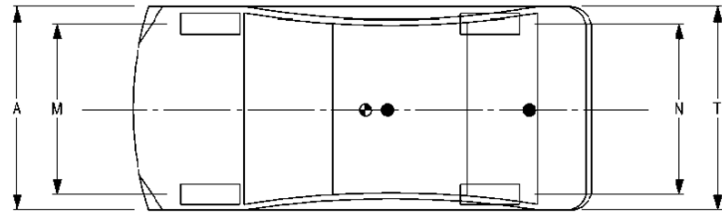
Describe any damage to the vehicle prior to test: None

• 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 <u>66.70</u>	F <u>32.50</u>	K <u>12.50</u>	P <u>4.50</u>	U <u>15.50</u>
B <u>59.60</u>	G _____	L <u>26.00</u>	Q <u>24.00</u>	V <u>21.25</u>
C <u>175.40</u>	H <u>41.05</u>	M <u>58.30</u>	R <u>16.25</u>	W <u>41.00</u>
D <u>40.50</u>	I <u>7.00</u>	N <u>58.50</u>	S <u>7.50</u>	X <u>79.75</u>
E <u>102.40</u>	J <u>22.50</u>	O <u>30.50</u>	T <u>64.50</u>	
Wheel Center Ht Front <u>11.50</u>	Wheel Center Ht Rear <u>11.50</u>	W-H <u>-0.05</u>		

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 <u>1750</u>	M _{front}	<u>1442</u>	<u>1454</u>	<u>1539</u>
Back <u>1687</u>	M _{rear}	<u>938</u>	<u>973</u>	<u>1053</u>
Total <u>3389</u>	M _{Total}	<u>2380</u>	<u>2427</u>	<u>2592</u>

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 SHEET¹

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 C₁ to C₆ 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										
	<input checked="" type="checkbox"/> inches or <input type="checkbox"/> mm										

¹Table 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.

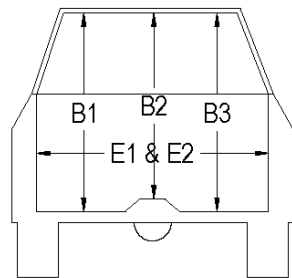
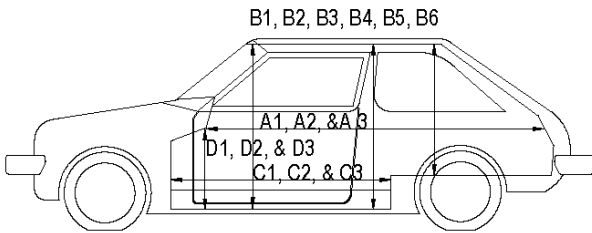
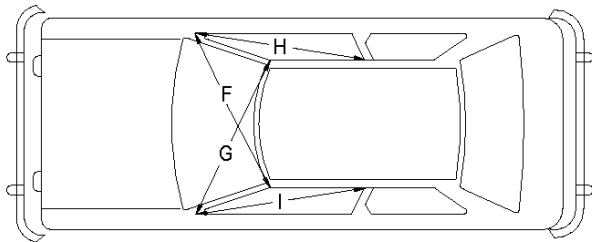
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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



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



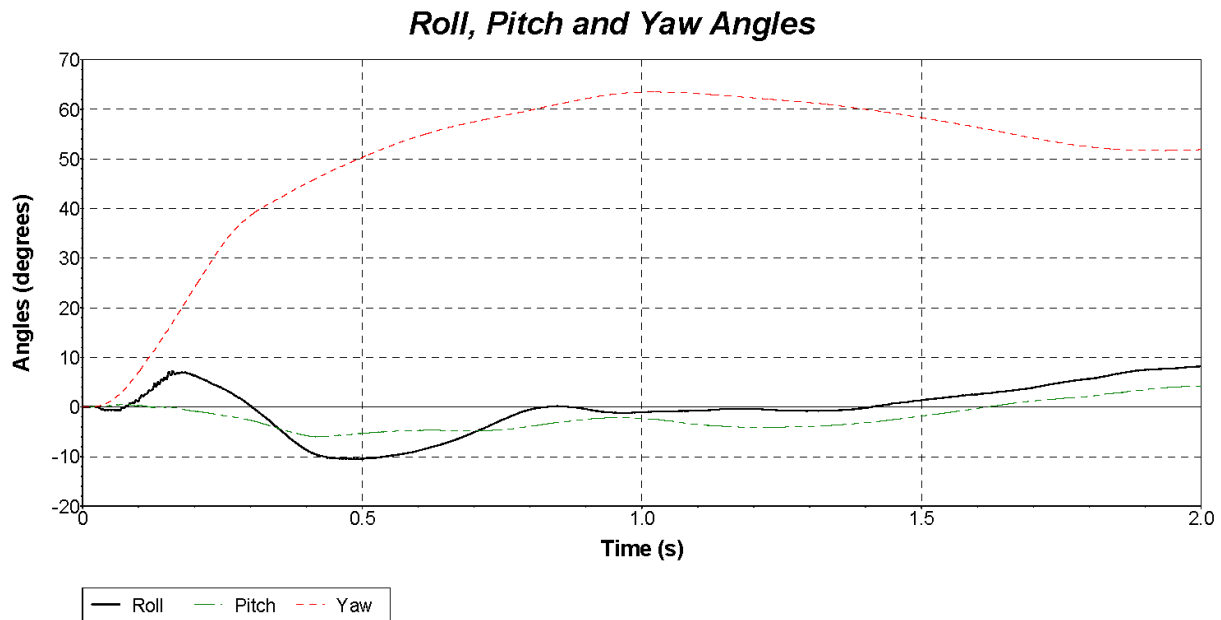
(g) 0.600 s



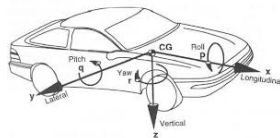
(h) 0.700 s

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

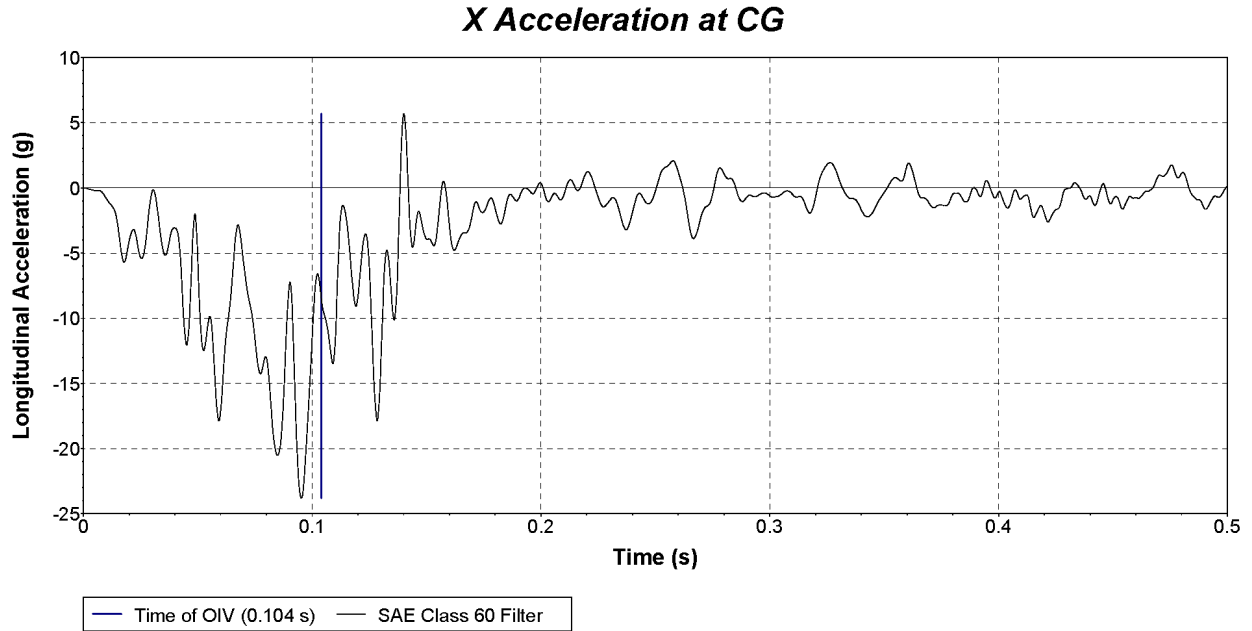


Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test 441203-01-1 (Accelerometer Located at Center of Gravity).

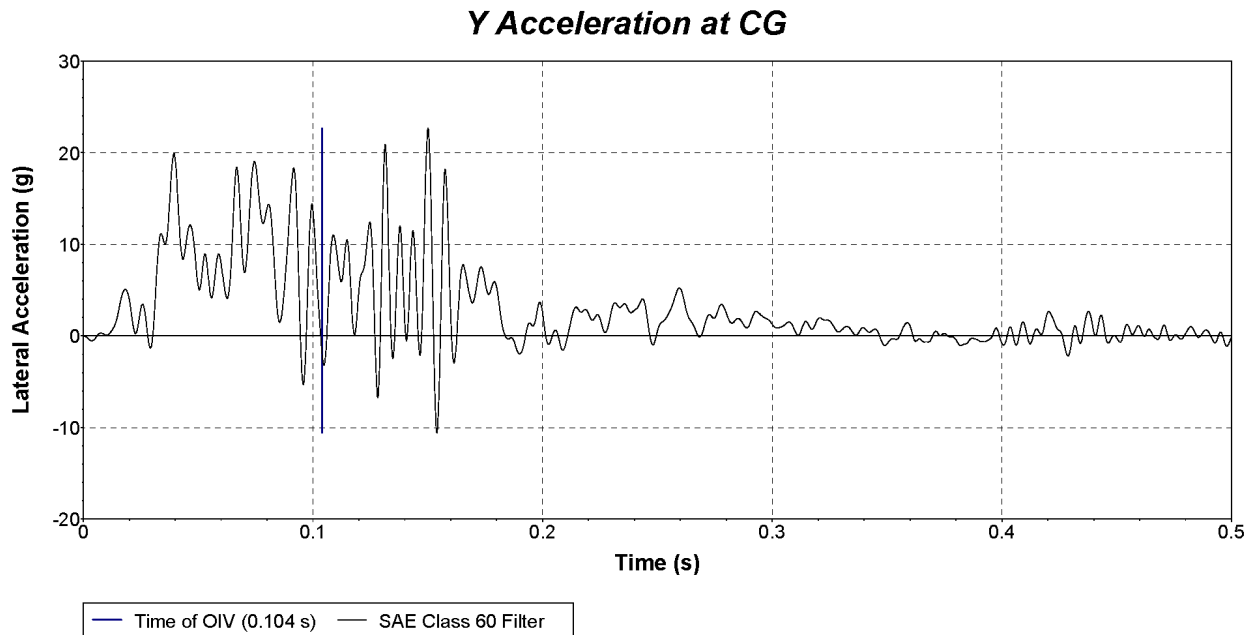
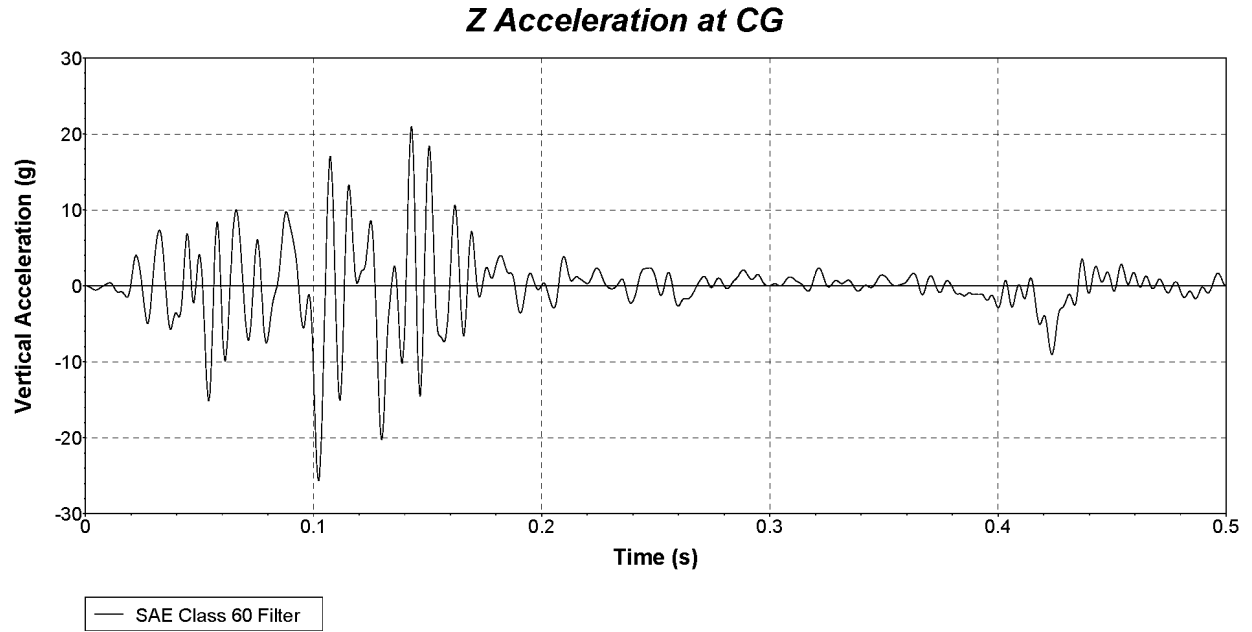


Figure C.9. Vehicle Lateral Accelerometer Trace for Test 441203-01-1 (Accelerometer Located at Center of Gravity).



**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.

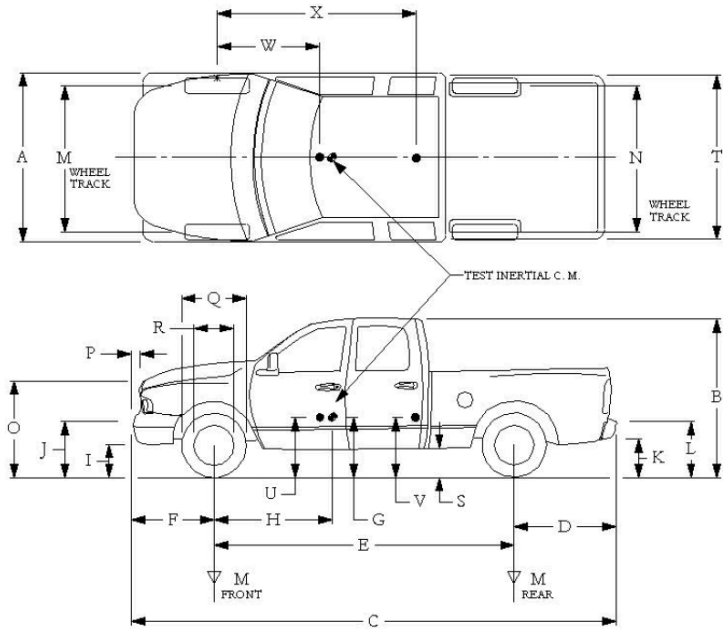
NOTES: None

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	<u>78.50</u>	F	<u>40.00</u>	K	<u>20.00</u>	P	<u>3.00</u>	U	<u>26.75</u>
B	<u>74.00</u>	G	<u>28.50</u>	L	<u>30.00</u>	Q	<u>30.50</u>	V	<u>30.25</u>
C	<u>227.50</u>	H	<u>60.98</u>	M	<u>68.50</u>	R	<u>18.00</u>	W	<u>61.00</u>
D	<u>44.00</u>	I	<u>11.75</u>	N	<u>68.00</u>	S	<u>13.00</u>	X	<u>79.00</u>
E	<u>140.50</u>	J	<u>27.00</u>	O	<u>46.00</u>	T	<u>77.00</u>		
Wheel Center Height Front	<u>14.75</u>	Wheel Well Clearance (Front)	<u>6.00</u>	Bottom Frame Height - Front	<u>12.50</u>				
Wheel Center Height Rear	<u>14.75</u>	Wheel Well Clearance (Rear)	<u>9.25</u>	Bottom Frame Height - Rear	<u>22.50</u>				

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

GWR Ratings:	Mass: lb	Curb	Test Inertial	Gross Static
Front <u>3700</u>	M _{front}	<u>3004</u>	<u>2854</u>	<u>2939</u>
Back <u>3900</u>	M _{rear}	<u>2154</u>	<u>2189</u>	<u>2269</u>
Total <u>6700</u>	M _{Total}	<u>5158</u>	<u>5043</u>	<u>5208</u>

(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 SHEET¹

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 C₁ to C₆ 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	16	12	48							-12
2	SAME	16	12	60							74
	Measurements recorded										
	<input checked="" type="checkbox"/> inches or <input type="checkbox"/> mm										

¹Table 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).

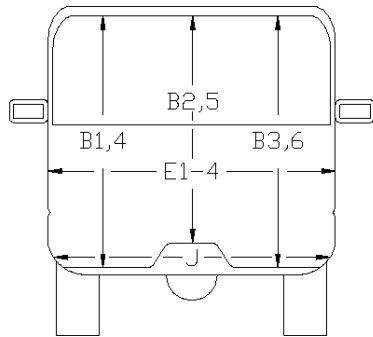
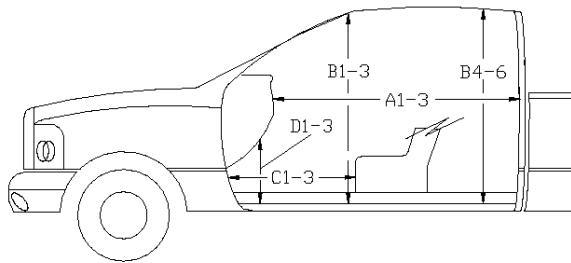
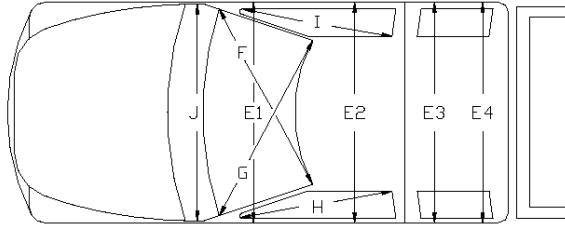
***Measure and document on the vehicle diagram the location of the maximum crush.

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

**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

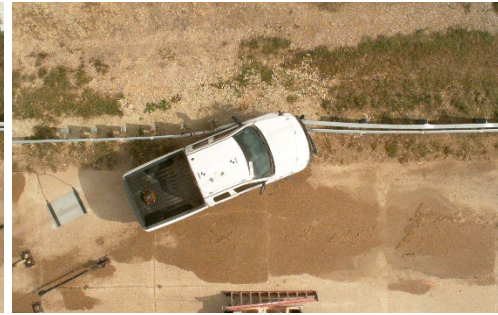
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

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

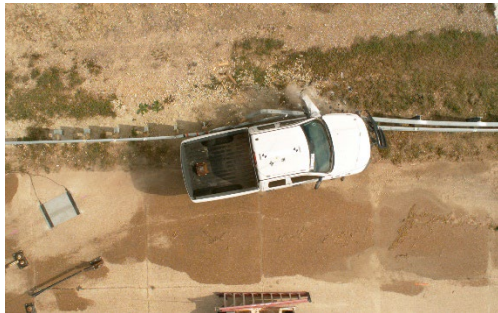
D.2. SEQUENTIAL PHOTOGRAPHS



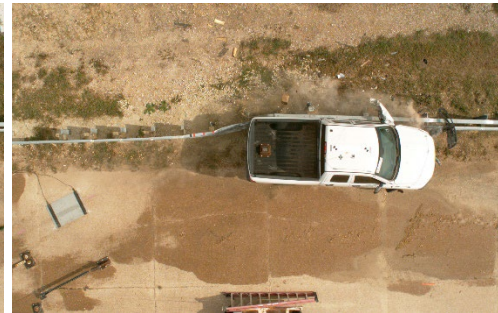
(a) 0.000 s



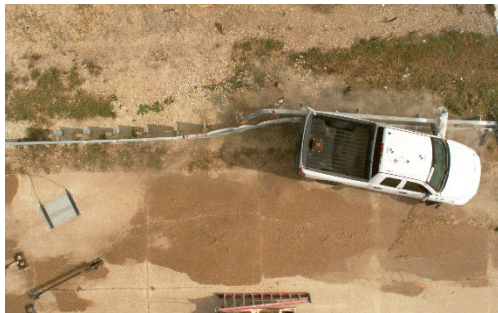
(b) 0.100 s



(c) 0.200 s



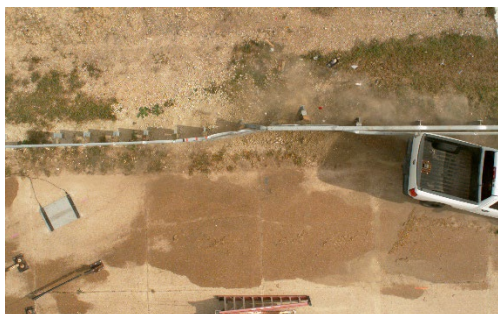
(d) 0.300 s



(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

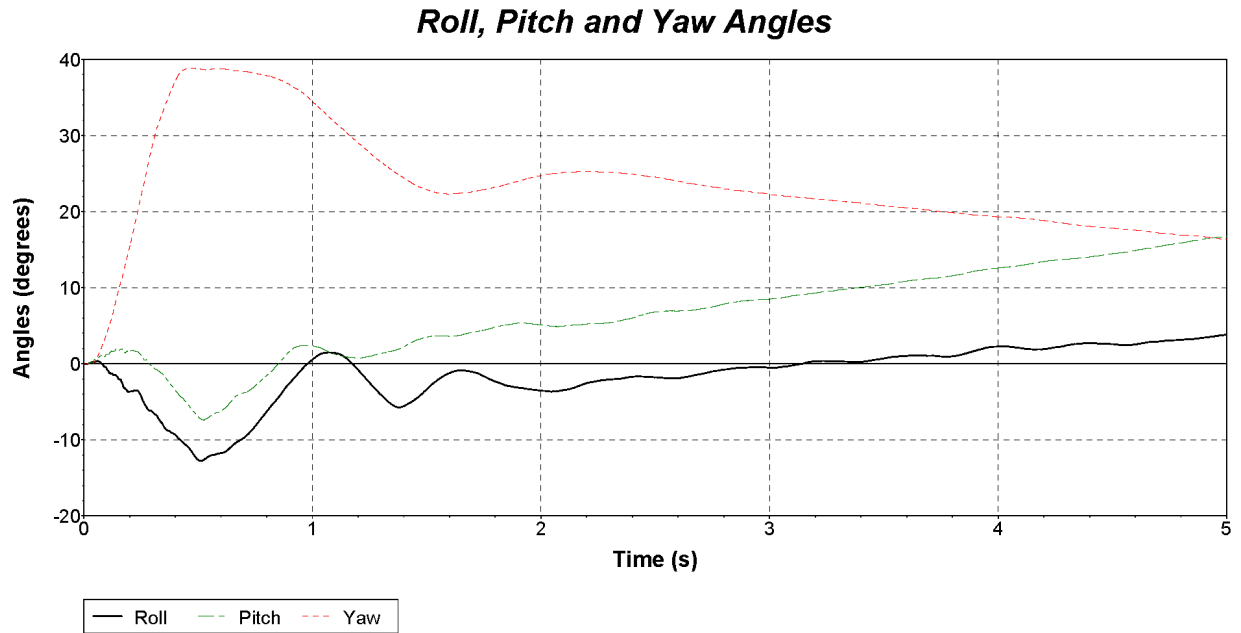


(g) 0.600 s

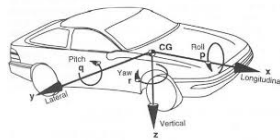
(h) 0.700 s

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

D.3. VEHICLE ANGULAR DISPLACEMENTS



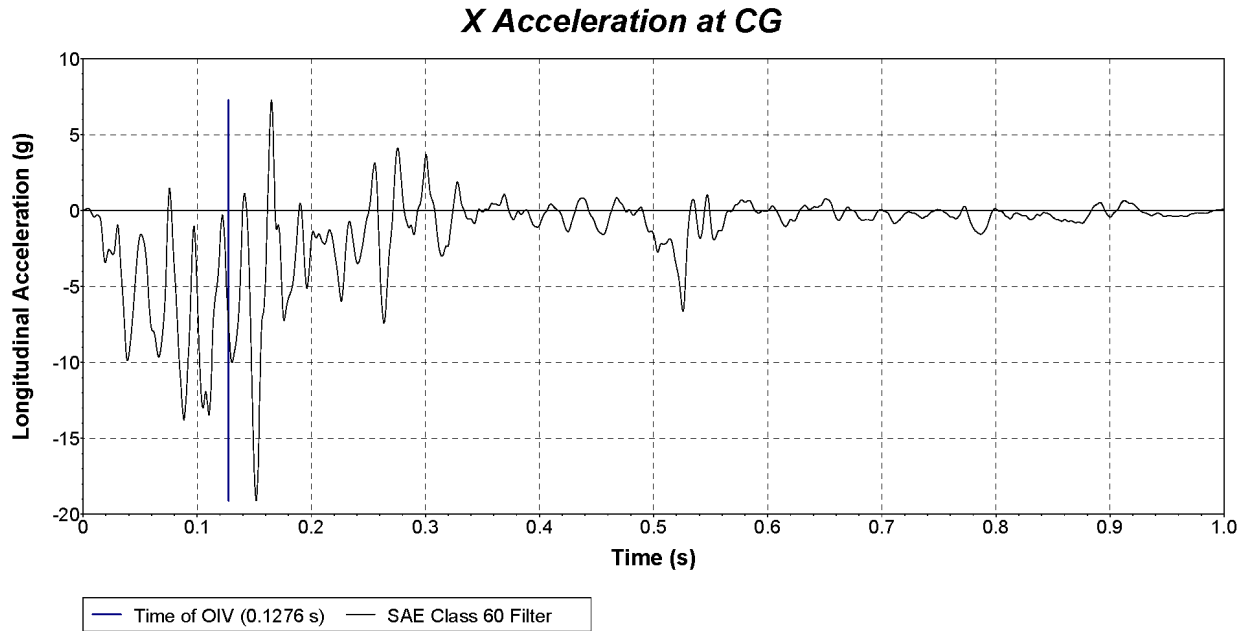
Axes are vehicle-fixed.
 Sequence for determining orientation:
 4. Yaw.
 5. Pitch.
 6. Roll.



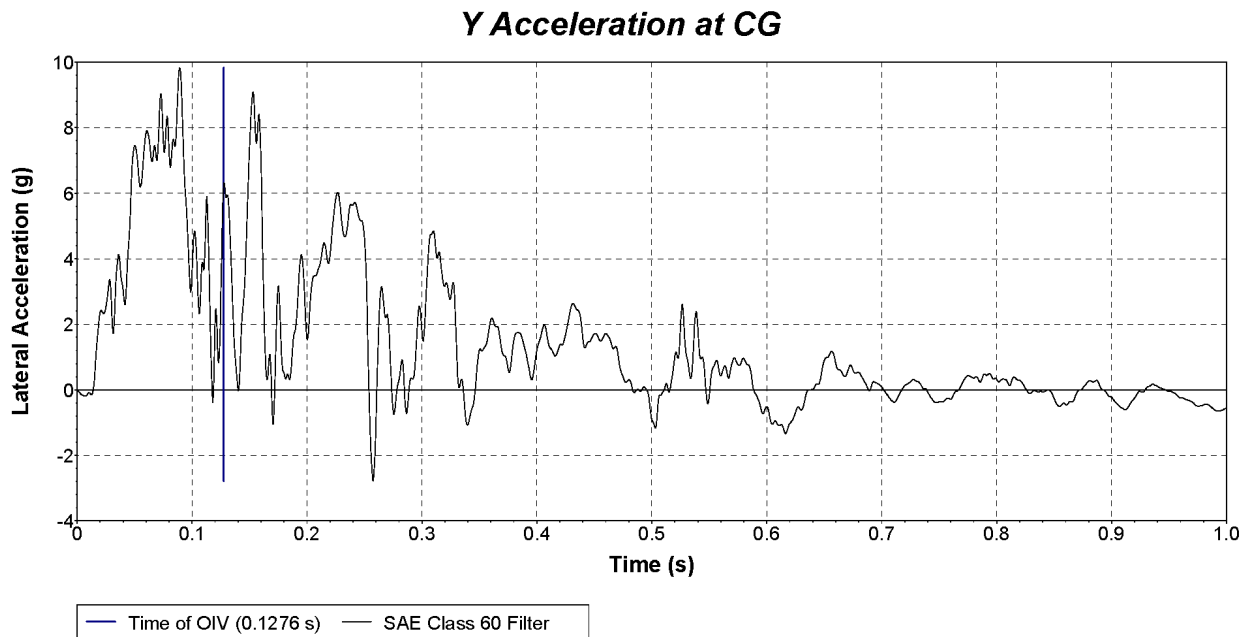
Test Number: 441203-01-2
 Test Standard Test Number: *MASH* Test 3-21
 Test Article: Transition
 Test Vehicle: 2017 RAM 1500
 Inertial Mass: 5043 lb
 Gross Mass: 5208 lb
 Impact Speed: 62.1 mi/h
 Impact Angle: 25.1°

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

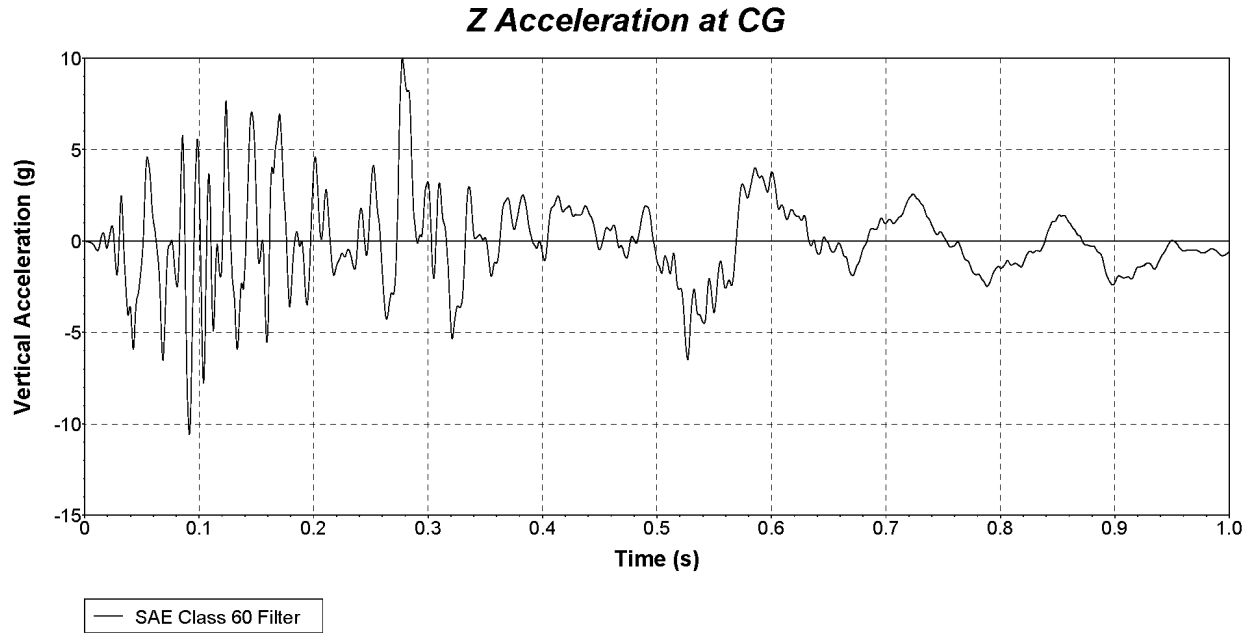
D.4. VEHICLE ACCELERATIONS



**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.

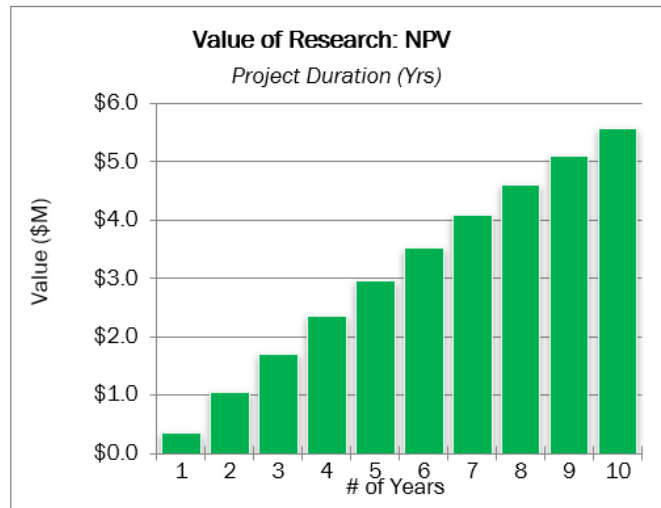
According to NHTSA, each fatality results in an average discounted lifetime economic cost of \$1.4 million, and an average comprehensive cost of \$9.1 million (“The Economic and Societal Impact of Motor Vehicle Crashes,” 2010 (Revised 2015), <http://www-nrd.nhtsa.dot.gov/pubs/812013.pdf>).

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 transition. 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.