



Test Report No. 469940-03, 469942-01, and 469943-01



**DEVELOP A RETROFIT DESIGN FOR GUARD FENCE SYSTEM TO
ENHANCE MOTORCYCLE SAFETY
COOPERATIVE RESEARCH PROGRAM**

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16. Abstract <p>Motorcyclists are among the most vulnerable users of the roadway system. The appropriate design of roadside safety systems plays an important role in the severity of injuries caused by motorcycle crashes. Data show that from 2004 to 2017, the number of fatalities related to motorcycle impacts against safety barriers was greater than the number of fatalities recorded from passenger car impacts against the same roadside safety devices.</p> <p>Although there are no guidelines addressing the proper testing and use of motorcycle retrofit barriers, there is a need to develop an appropriately designed guard fence system to address motorcycle-rider barrier impacts in which the rider is either in a sliding or upright position. Additionally, the retrofit guard fence system should maintain <i>Manual for Assessing Safety Hardware (MASH)</i> Test Level 3 (TL-3) compliance.</p> <p>This report provides details on the design conceptualization, crash tests and results, and performance assessment of the enhanced motorcycle guard fence system for <i>MASH</i> TL-3 and for motorcyclist impacts.</p> <p>The enhanced motorcycle guard fence system met the performance criteria for <i>MASH</i> TL-3 longitudinal barriers and did not show any snagging potential when the instrumented dummy interacted with the system. However, there were high neck axial forces observed in the anthropomorphic test device.</p>					
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The results of the crash testing reported herein apply only to the article tested.

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TABLE OF CONTENTS

	Page
List of Figures	xiv
List of Tables	xxi
Chapter 1. Introduction.....	1
1.1. Background	1
1.2. Objective	1
1.3. Research Outline.....	1
Chapter 2. Literature Review.....	3
2.1. Introduction.....	3
2.2. Motorcyclist Fatality and Injury Statistics	3
2.3. Standards, Protocols, and Criteria.....	5
2.4. Motorcycle Crash Testing and Related Studies.....	10
Chapter 3. Crash Data Analysis	13
3.1. Introduction.....	13
3.2. Background	13
3.2.1. CRIS	13
3.2.2. Google Earth.....	14
3.2.3. Crash Reports.....	16
3.2.4. Vehicle Identification Number (VIN) Decoding.....	18
3.3. Descriptive Statistical Analysis	18
3.3.1. Environmental Crash Characteristics.....	18
3.3.2. Narrative and Diagram Review	30
3.3.3. Motorcycle and Rider Review	33
3.4. Summary	36
Chapter 4. Development of Concepts for Retrofit Design	37
4.1. Introduction.....	37
4.2. Design Options.....	37
4.2.1. Protection on Top	37
4.2.2. Protection on Bottom	42
4.3. Conclusions.....	47
Chapter 5. Computer Simulations.....	51
5.1. Upright Motorcycle Impact.....	52
5.2. MASH Test 3-11 Impact	54
5.3. Design Modification	55
Chapter 6. System Details	57
6.1. Test Article and Installation Details	57
6.2. Design Modifications during Tests.....	57
6.3. Material Specifications	66
Chapter 7. Test Requirements and Evaluation Criteria.....	69
7.1. Crash Test Performed/Matrix	69
7.2. Evaluation Criteria	73
Chapter 8. Test Conditions.....	75
8.1. Test Facility	75
8.2. Vehicle Tow and Guidance System.....	75

8.3.	Data Acquisition Systems.....	75
8.3.1.	Vehicle Instrumentation and Data Processing	75
8.3.2.	Anthropomorphic Dummy Instrumentation.....	76
8.3.3.	Photographic Instrumentation Data Processing.....	77
Chapter 9.	MASH Test 3-10 (Crash Test 469940-03-1).....	79
9.1.	Test Designation and Actual Impact Conditions	79
9.2.	Weather Conditions.....	81
9.3.	Test Vehicle.....	81
9.4.	Test Description	83
9.5.	Damage to Test Installation.....	83
9.6.	Damage to Test Vehicle	85
9.7.	Occupant Risk Factors	88
9.8.	Test Summary	88
Chapter 10.	MASH Test 3-11 (Crash Test 469940-03-2).....	91
10.1.	Test Designation and Actual Impact Conditions	91
10.2.	Weather Conditions.....	93
10.3.	Test Vehicle.....	93
10.4.	Test Description	95
10.5.	Damage to Test Installation.....	95
10.6.	Damage to Test Vehicle	97
10.7.	Occupant Risk Factors	100
10.8.	Test Summary	100
Chapter 11.	Upright Motorcycle Test (Crash Test 469940-03-3).....	103
11.1.	Test Designation and Actual Impact Conditions	103
11.2.	Weather Conditions.....	105
11.3.	Test Vehicle.....	105
11.4.	Test Description	106
11.5.	Damage to Test Installation.....	107
11.6.	Damage to Test Vehicle	108
11.7.	Test Summary	109
Chapter 12.	Sliding ATD (Crash Test 469940-03-4A).....	113
12.1.	Test Designation and Actual Impact Conditions	113
12.2.	Weather Conditions.....	114
12.3.	Test Description	115
12.4.	Damage to Test Installation.....	115
12.5.	Damage to ATD.....	117
12.6.	Test Summary	119
12.7.	Discussion.....	119
Chapter 13.	Computer Simulations—Redesign.....	121
13.1.	Model Calibration	121
13.2.	Design Evaluations.....	122
13.2.1.	Channel Rubrail	123
13.2.2.	W-Beam Rubrail.....	125
13.2.3.	Inward V-Shape Rubrail	127
13.2.4.	Summary.....	129
13.3.	Design Evaluations—Secondary Impact Location.....	129

13.4.	Summary	130
Chapter 14.	Sliding ATD (Crash Test 469942-01-1)	133
14.1.	Test Designation and Actual Impact Conditions	133
14.2.	Weather Conditions	135
14.3.	Test Description	135
14.4.	Damage to Test Installation.....	135
14.5.	Damage to ATD.....	137
14.6.	Test Summary	139
14.7.	Discussion	139
Chapter 15.	Computer Simulations—Redesign No. 2	141
Chapter 16.	Sliding ATD (Crash Test 469943-01-1A).....	145
16.1.	Test Designation and Actual Impact Conditions	145
16.2.	Weather Conditions	146
16.3.	Test Description	147
16.4.	Damage to Test Installation.....	147
16.5.	Damage to ATD.....	149
16.6.	Test Summary	151
16.7.	Discussion	151
Chapter 17.	Sliding ATD (Crash Test 469943-01-2)	153
17.1.	Test Designation and Actual Impact Conditions	153
17.2.	Weather Conditions	154
17.3.	Test Description	155
17.4.	Damage to Test Installation.....	155
17.5.	Damage to ATD.....	157
17.6.	Test Summary	159
Chapter 18.	MASH Test 3-10 (Crash Test 469943-01-3).....	161
18.1.	Test Designation and Actual Impact Conditions	161
18.2.	Weather Conditions	163
18.3.	Test Vehicle.....	163
18.4.	Test Description	165
18.5.	Damage to Test Installation.....	165
18.6.	Damage to Test Vehicle	167
18.7.	Occupant Risk Factors	170
18.8.	Test Summary	170
Chapter 19.	MASH Test 3-11 (Crash Test 469943-01-4).....	173
19.1.	Test Designation and Actual Impact Conditions	173
19.2.	Weather Conditions	175
19.3.	Test Vehicle.....	175
19.4.	Test Description	177
19.5.	Damage to Test Installation.....	177
19.6.	Damage to Test Vehicle	179
19.7.	Occupant Risk Factors	182
19.8.	Test Summary	182
Chapter 20.	Placement Guidance	185
20.1.	RDFO Motorcycle Crashes.....	185
20.2.	Crash Severity Models	190

20.3.	Selection of High-Risk Locations	192
20.3.1.	Random Forests to Select Important Factors	192
20.3.2.	Risk Factor Groups	193
20.3.3.	Site Selection	196
20.4.	Conclusions.....	197
Chapter 21.	Summary and Conclusions.....	199
21.1.	Assessment of <i>MASH</i> Test Results.....	199
21.2.	Assessment of Motorcycle Test Results.....	199
21.3.	Conclusions.....	200
Chapter 22.	Implementation	201
References	203
Appendix A.	Details of Enhanced Motorcycle Guard Fence System	205
A.1.	Details for Crash Tests 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.....	206
A.2.	Details for Crash Test 469942-01-1	220
A.3.	Details for Crash Tests 469943-01-1A, 469943-01-2, 469943-01-3, and 469943-01-4	236
Appendix B.	Supporting Certification Documents	251
Appendix C.	<i>MASH</i> Test 3-10 (Crash Test 469940-03-1).....	265
C.1.	Vehicle Properties and Information	265
C.2.	Sequential Photographs	268
C.3.	Vehicle Angular Displacements.....	271
C.4.	Vehicle Accelerations	272
Appendix D.	<i>MASH</i> Test 3-11 (Crash Test 469940-03-2).....	275
D.1.	Vehicle Properties and Information	275
D.2.	Sequential Photographs	278
D.3.	Vehicle Angular Displacements.....	281
D.4.	Vehicle Accelerations	282
Appendix E.	<i>MASH</i> Test (Crash Test 469940-03-3).....	285
E.1.	Vehicle Properties and Information	285
E.2.	Sequential Photographs	286
Appendix F.	<i>MASH</i> Test (Crash Test 469940-03-4A)	289
F.1.	Sequential Photographs	289
Appendix G.	<i>MASH</i> Test (Crash Test 469942-01-1).....	293
G.1.	Sequential Photographs	293
Appendix H.	<i>MASH</i> Test (Crash Test 469943-01-1A)	297
H.1.	Sequential Photographs	297
Appendix I.	<i>MASH</i> Test (Crash Test 469943-01-2).....	301
I.1.	Sequential Photographs	301
Appendix J.	<i>MASH</i> Test 3-10 (Crash Test 469943-01-3).....	305
J.1.	Vehicle Properties and Information	305
J.2.	Sequential Photographs	308
J.3.	Vehicle Angular Displacements.....	311
J.4.	Vehicle Accelerations	312
Appendix K.	<i>MASH</i> Test 3-11 (Crash Test 469943-01-4).....	314
K.1.	Vehicle Properties and Information	314

K.2.	Sequential Photographs	317
K.3.	Vehicle Angular Displacements	320
K.4.	Vehicle Accelerations	321

LIST OF FIGURES

	Page
Figure 2.1. Passenger Vehicle Occupant Deaths and Motorcyclist Deaths in the United States from 1975–2013 (5).....	4
Figure 2.2. ISO 13232-2 Impact Configurations (12).....	6
Figure 2.3. Metal Beam Guardrail Design 1 (left) and Design 2 (right).....	10
Figure 3.1. Street View from Google Earth Pro Software.....	14
Figure 3.2. Satellite View from Google Earth Pro Software.....	14
Figure 3.3. Map of Fatal and Suspected Serious Injury Motorcycle Crashes Involving Guardrail Contact, 2010–2017.....	22
Figure 3.4. Examples of Cruiser, Touring, and Sport-Touring Motorcycles.....	34
Figure 3.5. Examples of Sport and Traditional Motorcycles.....	34
Figure 4.1. Option 1 Conceptual Drawing for Bent Plate Top Protection.....	38
Figure 4.2. Option 2 Conceptual Drawing for Flat Plate Top Protection.....	40
Figure 4.3. Option 3 Conceptual Drawing for Top Protection Cap for MGS Steel Posts.....	42
Figure 4.4. Option A Conceptual Drawing for Flat Plate for Bottom Protection.....	43
Figure 4.5. Option B Conceptual Drawing for Flat Plate Attached to Connection Plates.....	45
Figure 4.6. Option C Conceptual Drawing for Inclined Plate Attached to Posts.....	47
Figure 5.1. Motorcycle and ATD FE Model.....	51
Figure 5.2. FE Model of Retrofit Guardrail System.....	52
Figure 5.3. Sequential Images of Upright Motorcyclist Impact with Barrier.....	53
Figure 5.4. Sequential Images of <i>MASH</i> Test 3-11 Impact with Barrier.....	54
Figure 5.5. FE Model of Modified Retrofit Guardrail System.....	55
Figure 5.6. ATD Sliding Impact with System.....	56
Figure 6.1. Details of Enhanced Motorcycle Guard Fence System for Crash Tests 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.....	58
Figure 6.2. Enhanced Motorcycle Guard Fence System prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.....	59
Figure 6.3. Enhanced Motorcycle Guard Fence System Rail Detail prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.....	59
Figure 6.4. Field-Side View of the Enhanced Motorcycle Guard Fence System prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.....	60
Figure 6.5. Enhanced Motorcycle Guard Fence System Rubrail Bracket Detail prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.....	60
Figure 6.6. Enhanced Motorcycle Guard Fence System W-Beam Hardware Detail prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.....	61
Figure 6.7. Enhanced Motorcycle Guard Fence System Cap Rail Hardware Detail prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.....	61

Figure 6.8. Details of Enhanced Motorcycle Guard Fence System for Crash Test 469942-01-1.....	62
Figure 6.9. Field-Side View of the Enhanced Motorcycle Guard Fence System prior to Testing for 469942-01-1.....	63
Figure 6.10. Enhanced Motorcycle Guard Fence System Rubrail Bracket Detail prior to Testing for 469942-01-1.....	63
Figure 6.11. Details of Enhanced Motorcycle Guard Fence System for Crash Tests 469943-01-1A, 469943-01-2, 469943-01-3, and 469943-01-4.....	64
Figure 6.12. Field-Side View of the Enhanced Motorcycle Guard Fence System prior to Testing for 469943-01-1A, 469943-01-2, 469943-01-3, and 469943-01-4.....	65
Figure 6.13. Enhanced Motorcycle Guard Fence System Rubrail Detail prior to Testing for 469943-01-1A, 469943-01-2, 469943-01-3, and 469943-01-4....	65
Figure 7.1. Target CIP for 469940-03-1 and 469940-03-2 Crash Tests on Enhanced Motorcycle Guard Fence System.....	70
Figure 7.2. Target CIP for 469940-03-3 and 469940-03-4A Crash Tests on Enhanced Motorcycle Guard Fence System.....	70
Figure 7.3. Target CIP for 469942-01-1 Crash Test on Enhanced Motorcycle Guard Fence System.....	71
Figure 7.4. Target CIP for 469943-01-1A Crash Test on Enhanced Motorcycle Guard Fence System.....	71
Figure 7.5. Target CIP for 469943-01-2 Crash Test on Enhanced Motorcycle Guard Fence System.....	72
Figure 7.6. Target CIP for 469943-01-3 and 469943-01-4 Crash Tests on Enhanced Motorcycle Guard Fence System.....	72
Figure 9.1. Enhanced Motorcycle Guard Fence System/Test Vehicle Geometrics for Test 469940-03-1.....	80
Figure 9.2. Enhanced Motorcycle Guard Fence System/Test Vehicle Impact Location for Test 469940-03-1.....	80
Figure 9.3. Impact Side of Test Vehicle before Test 469940-03-1.....	81
Figure 9.4. Opposite Impact Side of Test Vehicle before Test 469940-03-1.....	82
Figure 9.5. Enhanced Motorcycle Guard Fence System at Impact Location after Test 469940-03-1.....	84
Figure 9.6. Enhanced Motorcycle Guard Fence System at the Rubrail at Impact after Test 469940-03-1.....	85
Figure 9.7. Impact Side of Test Vehicle after Test 469940-03-1.....	85
Figure 9.8. Rear Impact Side of Test Vehicle after Test 469940-03-1.....	86
Figure 9.9. Overall Interior of Test Vehicle after Test 469940-03-1.....	86
Figure 9.10. Interior of Test Vehicle on Impact Side after Test 469940-03-1.....	87
Figure 9.11. Summary of Results for <i>MASH</i> Test 3-10 on Enhanced Motorcycle Guard Fence System.....	89
Figure 10.1. Enhanced Motorcycle Guard Fence System/Test Vehicle Geometrics for Test 469940-03-2.....	92
Figure 10.2. Enhanced Motorcycle Guard Fence System/Test Vehicle Impact Location for Test 469940-03-2.....	92
Figure 10.3. Impact Side of Test Vehicle before Test 469940-03-2.....	93

Figure 10.4. Opposite Impact Side of Test Vehicle before Test 469940-03-2.	94
Figure 10.5. Enhanced Motorcycle Guard Fence System at Impact Location on the Traffic Side after Test 469940-03-2.	96
Figure 10.6. Enhanced Motorcycle Guard Fence System at Impact Location on the Field Side after Test 469940-03-2.	96
Figure 10.7. Impact Side of Test Vehicle after Test 469940-03-2.	97
Figure 10.8. Rear Impact Side of Test Vehicle after Test 469940-03-2.	97
Figure 10.9. Overall Interior of Test Vehicle after Test 469940-03-2.	98
Figure 10.10. Interior of Test Vehicle on Impact Side after Test 469940-03-2.	98
Figure 10.11. Summary of Results for <i>MASH</i> Test 3-11 on Enhanced Motorcycle Guard Fence System.	101
Figure 11.1. Enhanced Motorcycle Guard Fence System/Test Vehicle Geometrics for Test 469940-03-3.	104
Figure 11.2. Enhanced Motorcycle Guard Fence System/Test Vehicle Impact Location for Test 469940-03-3.	104
Figure 11.3. Impact Side of Test Vehicle before Test 469940-03-3.	105
Figure 11.4. Opposite Impact Side of Test Vehicle before Test 469940-03-3.	106
Figure 11.5. Isometric View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469940-03-3.	107
Figure 11.6. Elevation View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469940-03-3.	108
Figure 11.7. Impact Side of Test Vehicle after Test 469940-03-3.	108
Figure 11.8. Rear Impact Side of Test Vehicle after Test 469940-03-3.	109
Figure 11.9. Opposite Impact Side of Test Vehicle after Test 469940-03-3.	109
Figure 11.10. Summary of Results for Upright Motorcycle Test on Enhanced Motorcycle Guard Fence System.	111
Figure 12.1. Right Side of the ATD prior to Test 469940-03-4A.	113
Figure 12.2. Left Side of the ATD prior to Test 469940-03-4A.	114
Figure 12.3. Enhanced Motorcycle Guard Fence System at Impact Location on the Traffic Side after Test 469940-03-4A.	116
Figure 12.4. Enhanced Motorcycle Guard Fence System at Impact Location on the Field Side after Test 469940-03-4A.	116
Figure 12.5. Backside of the ATD after Test 469940-03-4A.	117
Figure 12.6. Front of the ATD after Test 469940-03-4A.	117
Figure 12.7. Back Helmet and ATD Neck Damage after Test 469940-03-4A.	118
Figure 12.8. ATD Neck Damage after Test 469940-03-4A.	118
Figure 12.9. Summary of Results for Modified EN 1317-8 Test on Enhanced Motorcycle Guard Fence System.	120
Figure 13.1. ATD Finite Element Model.	121
Figure 13.2. Computer Simulation of Sliding Dummy Impact.	122
Figure 13.3. V-Shape Rubrail Design Option.	127
Figure 14.1. Side View of the ATD on the Sled Delivery System Prior to Test 469942-01-1.	134
Figure 14.2. In-Line View of the ATD on the Sled Delivery System Prior to Test 469942-01-1.	134

Figure 14.3. Enhanced Motorcycle Guard Fence System at Impact Location after Test 469942-01-1.....	136
Figure 14.4. Enhanced Motorcycle Guard Fence System Rubrail at Impact Location after Test 469942-01-1.....	136
Figure 14.5. Left Side of ATD after Test 469942-01-1.....	137
Figure 14.6. Upper Torso Detail of the ATD after Test 469942-01-1.....	137
Figure 14.7. Backside of the ATD after Test 469942-01-1.....	138
Figure 14.8. Backside Detail of the ATD Helmet after Test 469942-01-1.....	138
Figure 14.9. Summary of Results for Modified EN 1317-8 Test on Enhanced Motorcycle Guard Fence System.....	140
Figure 16.1. Side View of the ATD on the Sled Delivery System prior to Test 469943-01-1A.....	145
Figure 16.2. In-Line View of the ATD on the Sled Delivery System prior to Test 469943-01-1A.....	146
Figure 16.3. Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-1A.....	148
Figure 16.4. Enhanced Motorcycle Guard Fence System Rubrail at Impact Location after Test 469943-01-1A.....	148
Figure 16.5. Right Side of ATD after Test 469943-01-1A.....	149
Figure 16.6. ATD Head and Helmet after Test 469943-01-1A.....	149
Figure 16.7. ATD after Test 469943-01-1A.....	150
Figure 16.8. Rear Side of ATD after Test 469943-01-1A.....	150
Figure 16.9. Summary of Results for Modified EN 1317-8 Test on Enhanced Motorcycle Guard Fence System.....	152
Figure 17.1. Side View of the ATD on the Sled Delivery System prior to Test 469943-01-2.....	153
Figure 17.2. In-Line View of the ATD on the Sled Delivery System prior to Test 469943-01-2.....	154
Figure 17.3. Traffic Side of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-2.....	156
Figure 17.4. Field Side of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-2.....	156
Figure 17.5. Left Side of the ATD after Test 469943-01-2.....	157
Figure 17.6. Front of the ATD after Test 469943-01-2.....	157
Figure 17.7. Helmet Damage after Test 469943-01-2.....	158
Figure 17.8. Shoulder Damage after Test 469943-01-2.....	158
Figure 17.9. Summary of Results for Modified EN 1317-8 Test on Enhanced Motorcycle Guard Fence System.....	160
Figure 18.1. Enhanced Motorcycle Guard Fence System/Test Vehicle Geometrics for Test 469943-01-3.....	162
Figure 18.2. Enhanced Motorcycle Guard Fence System/Test Vehicle Impact Location for Test 469943-01-3.....	162
Figure 18.3. Impact Side of Test Vehicle before Test 469943-01-3.....	163
Figure 18.4. Opposite Impact Side of Test Vehicle before Test 469943-01-3.....	164
Figure 18.5. Traffic-Side View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-3.....	166

Figure 18.6. Field-Side View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-3.	167
Figure 18.7. Impact Side of Test Vehicle after Test 469943-01-3.	167
Figure 18.8. Rear Impact Side of Test Vehicle after Test 469943-01-3.	168
Figure 18.9. Overall Interior of Test Vehicle after Test 469943-01-3.	168
Figure 18.10. Interior of Test Vehicle on Impact Side after Test 469943-01-3.	169
Figure 18.11. Summary of Results for <i>MASH</i> Test 3-10 on Enhanced Motorcycle Guard Fence System.	171
Figure 19.1. Enhanced Motorcycle Guard Fence System/Test Vehicle Geometrics for Test 469943-01-4.	174
Figure 19.2. Enhanced Motorcycle Guard Fence System/Test Vehicle Impact Location for Test 469943-01-4.	174
Figure 19.3. Impact Side of Test Vehicle before Test 469943-01-4.	175
Figure 19.4. Opposite Impact Side of Test Vehicle before Test 469943-01-4.	176
Figure 19.5. Traffic-Side View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-4.	178
Figure 19.6. In-Line View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-4.	179
Figure 19.7. Impact Side of Test Vehicle after Test 469943-01-4.	179
Figure 19.8. Rear Impact Side of Test Vehicle after Test 469943-01-4.	180
Figure 19.9. Overall Interior of Test Vehicle after Test 469943-01-4.	180
Figure 19.10. Interior of Test Vehicle on Impact Side after Test 469943-01-4.	181
Figure 19.11. Summary of Results for <i>MASH</i> Test 3-11 on Enhanced Motorcycle Guard Fence System.	183
Figure 20.1. Temporal Distribution of RDFS Motorcycle Crashes.	186
Figure 20.2. Important Variables Associated with Motorcycle Crash Severity.	193
Figure 20.3. Decision Tree for Identifying Risk Factor Groups.	194
Figure 20.4. Number of Severe Crashes at High-Risk Sites.	196
Figure 20.5. Low- to High-Risk Sites.	197
Figure C.1. Vehicle Properties for Test 469940-03-1.	265
Figure C.2. Exterior Crush Measurements for Test 469940-03-1.	266
Figure C.3. Occupant Compartment Measurements for Test 469940-03-1.	267
Figure C.4. Sequential Photographs for Test 469940-03-1 (Overhead Views).	268
Figure C.5. Sequential Photographs for Test 469940-03-1 (Frontal Views).	269
Figure C.6. Sequential Photographs for Test 469940-03-1 (Rear Views).	270
Figure C.7. Vehicle Angular Displacements for Test 469940-03-1.	271
Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test 469940-03-1 (Accelerometer Located at Center of Gravity).	272
Figure C.9. Vehicle Lateral Accelerometer Trace for Test 469940-03-1 (Accelerometer Located at Center of Gravity).	272
Figure C.10. Vehicle Vertical Accelerometer Trace for Test 469940-03-1 (Accelerometer Located at Center of Gravity).	273
Figure D.1. Vehicle Properties for Test 469940-03-2.	275
Figure D.2. Exterior Crush Measurements for Test 469940-03-2.	276
Figure D.3. Occupant Compartment Measurements for Test 469940-03-2.	277
Figure D.4. Sequential Photographs for Test 469940-03-2 (Overhead Views).	278

Figure D.5. Sequential Photographs for Test 469940-03-2 (Frontal Views).....	279
Figure D.6. Sequential Photographs for Test 469940-03-2 (Rear Views).....	280
Figure D.7. Vehicle Angular Displacements for Test 469940-03-2.....	281
Figure D.8. Vehicle Longitudinal Accelerometer Trace for Test 469940-03-2 (Accelerometer Located at Center of Gravity).....	282
Figure D.9. Vehicle Lateral Accelerometer Trace for Test 469940-03-2 (Accelerometer Located at Center of Gravity).....	282
Figure D.10. Vehicle Vertical Accelerometer Trace for Test 469940-03-2 (Accelerometer Located at Center of Gravity).....	283
Figure E.1. Vehicle Properties for Test 469940-03-3.....	285
Figure E.2. Sequential Photographs for Test 469940-03-3 (Overhead Views).....	286
Figure E.3. Sequential Photographs for Test 469940-03-3 (Frontal Views).....	287
Figure E.4. Sequential Photographs for Test 469940-03-3 (Rear Views).....	288
Figure F.1. Sequential Photographs for Test 469940-03-4A (Overhead Views).....	289
Figure F.2. Sequential Photographs for Test 469940-03-4A (Frontal Views).....	290
Figure F.3. Sequential Photographs for Test 469940-03-4A (Rear Views).....	291
Figure G.1. Sequential Photographs for Test 469942-01-1 (Overhead Views).....	293
Figure G.2. Sequential Photographs for Test 469942-01-1 (Frontal Views).....	294
Figure G.3. Sequential Photographs for Test 469942-01-1 (Rear Views).....	295
Figure H.1. Sequential Photographs for Test 469943-01-1A (Overhead Views).....	297
Figure H.2. Sequential Photographs for Test 469943-01-1A (Frontal Views).....	298
Figure H.3. Sequential Photographs for Test 469943-01-1A (Rear Views).....	299
Figure I.1. Sequential Photographs for Test 469943-01-2 (Overhead Views).....	301
Figure I.2. Sequential Photographs for Test 469943-01-2 (Frontal Views).....	302
Figure I.3. Sequential Photographs for Test 469943-01-2 (Rear Views).....	303
Figure J.1. Vehicle Properties for Test 469943-01-3.....	305
Figure J.2. Exterior Crush Measurements for Test 469943-01-3.....	306
Figure J.3. Occupant Compartment Measurements for Test 469943-01-3.....	307
Figure J.4. Sequential Photographs for Test 469943-01-3 (Overhead Views).....	308
Figure J.5. Sequential Photographs for Test 469943-01-3 (Frontal Views).....	309
Figure J.6. Sequential Photographs for Test 469943-01-3 (Rear Views).....	310
Figure J.7. Vehicle Angular Displacements for Test 469943-01-3.....	311
Figure J.8. Vehicle Longitudinal Accelerometer Trace for Test 469943-01-3 (Accelerometer Located at Center of Gravity).....	312
Figure J.9. Vehicle Lateral Accelerometer Trace for Test 469943-01-3 (Accelerometer Located at Center of Gravity).....	312
Figure J.10. Vehicle Vertical Accelerometer Trace for Test 469943-01-3 (Accelerometer Located at Center of Gravity).....	313
Figure K.1. Vehicle Properties for Test 469943-01-4.....	314
Figure K.2. Exterior Crush Measurements for Test 469943-01-4.....	315
Figure K.3. Occupant Compartment Measurements for Test 469943-01-4.....	316
Figure K.4. Sequential Photographs for Test 469943-01-4 (Overhead Views).....	317
Figure K.5. Sequential Photographs for Test 469943-01-4 (Frontal Views).....	318
Figure K.6. Sequential Photographs for Test 469943-01-4 (Rear Views).....	319
Figure K.7. Vehicle Angular Displacements for Test 469943-01-4.....	320

Figure K.8. Vehicle Longitudinal Accelerometer Trace for Test 469943-01-4 (Accelerometer Located at Center of Gravity).....	321
Figure K.9. Vehicle Lateral Accelerometer Trace for Test 469943-01-4 (Accelerometer Located at Center of Gravity).....	321
Figure K.10. Vehicle Vertical Accelerometer Trace for Test 469943-01-4 (Accelerometer Located at Center of Gravity).....	322

LIST OF TABLES

	Page
Table 2.1. ISO 13232-2 Impact Conditions (11).....	6
Table 2.2. L.I.E.R. Test Impact Configurations (14).....	7
Table 2.3. L.I.E.R. Test Specifications.....	7
Table 2.4. EN 1317-8 Impact Configurations for Tests (16).....	8
Table 2.5. EN 1317-8 Test Specifications.....	8
Table 3.1. SMV Motorcycle Crashes Involving Guardrail Contact, 2010–2017.....	13
Table 3.2. Single-Vehicle Motorcycle Crashes Involving Guardrail Contact by Lighting Condition, 2010–2017.....	19
Table 3.3. Single-Vehicle Motorcycle Crashes Involving Guardrail Contact by Hour of Day, 2010–2017.....	20
Table 3.4. Single-Vehicle Motorcycle Crashes Involving Guardrail Contact by Weather Condition, 2010–2017.....	21
Table 3.5. Number of SMV Crashes Involving Guardrail Contact by County, 2010– 2017.....	23
Table 3.6. Number of Crashes by County and Control Section, 2010–2017.....	24
Table 3.7. Number of Crashes Not Associated with Control Section in CRIS Database, 2010–2017.....	27
Table 3.8. Reported Speed Limit for Fatal and Suspected Serious Injury SMV Motorcycle Crashes Involving Guardrail Contact, 2010–2017.....	29
Table 3.9. Reported Alignment for Fatal and Suspected Serious Injury SMV Motorcycle Crashes Involving Guardrail Contact, 2010–2017.....	30
Table 3.10. Motorcycle Position at Impact in Fatal and Suspected Serious Injury SMV Crashes, 2010–2017.....	30
Table 3.11. Impact Location on Guardrail in Fatal and Suspected Serious Injury SMV Crashes, 2010–2017.....	31
Table 3.12. Guardrail Type in Fatal and Suspected Serious Injury SMV Crashes, 2010–2017.....	32
Table 3.13. Percentage of Fatal and Suspected Serious Injury Crashes by Guardrail Type, 2010–2017.....	32
Table 3.14. Estimated Angle of Impact in Fatal and Suspected Serious Injury SMV Crashes, 2010–2017.....	32
Table 3.15. Motorcycle Makes Involved in Fatal and Suspected Serious Injury SMV Motorcycle Crashes Involving Guardrail Contact, 2010–2017.....	33
Table 3.16. Motorcycle Body Class Involved in Fatal and Suspected Serious Injury SMV Motorcycle Crashes Involving Guardrail Contact, 2010–2017.....	34
Table 3.17. Ages of Riders Involved in Fatal and Suspected Serious Injury SMV Crashes Involving Guardrail Contact, 2010–2017.....	35
Table 3.18. SMV Motorcycle Crashes Resulting in Rider Being Ejected.....	36
Table 4.1. Option 1 Potential Advantages and Disadvantages for Bent Top Plate Protection.....	39
Table 4.2. Option 2 Potential Advantages and Disadvantages for Flat Plate Top Protection.....	41

Table 4.3. Option 3 Potential Advantages and Disadvantages for Top Protection Cap for MGS Steel Posts.	42
Table 4.4. Option A Potential Advantages and Disadvantages for Flat Plate for Bottom Protection.....	44
Table 4.5. Option B Potential Advantages and Disadvantages for Flat Plate Attached to Connection Plates.....	46
Table 4.6. Proposed Design Options for Top Protection.....	48
Table 4.7. Proposed Design Options for Bottom Protection.....	49
Table 6.1. Soil Strength for Test 469940-03-1.....	66
Table 6.2. Soil Strength for Test 469940-03-2.....	66
Table 6.3. Soil Strength for Test 469940-03-3.....	66
Table 6.4. Soil Strength for Test 469943-01-3.....	67
Table 6.5. Soil Strength for Test 469943-01-4.....	67
Table 7.1. Test Conditions and Evaluation Criteria Specified for the Crash Tests on Enhanced Motorcycle Guard Fence System.....	69
Table 7.2. Evaluation Criteria Required for <i>MASH</i> Testing.....	73
Table 9.1. Impact Conditions for <i>MASH</i> Test 3-10, Crash Test 469940-03-1.....	79
Table 9.2. Exit Parameters for <i>MASH</i> Test 3-10, Crash Test 469940-03-1.....	79
Table 9.3. Weather Conditions for Test 469940-03-1.....	81
Table 9.4. Vehicle Measurements for Test 469940-03-1.....	82
Table 9.5. Events during Test 469940-03-1.....	83
Table 9.6. Soil Gap and Post Lean after Test 469940-03-1.....	83
Table 9.7. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469940-03-1.....	84
Table 9.8. Occupant Compartment Deformation for Test 469940-03-1.....	87
Table 9.9. Exterior Vehicle Damage for Test 469940-03-1.....	87
Table 9.10. Occupant Risk Factors for Test 469940-03-1.....	88
Table 10.1. Impact Conditions for <i>MASH</i> Test 3-11, Crash Test 469940-03-2.....	91
Table 10.2. Exit Parameters for <i>MASH</i> Test 3-11, Crash Test 469940-03-2.....	91
Table 10.3. Weather Conditions for Test 469940-03-2.....	93
Table 10.4. Vehicle Measurements for Test 469940-03-2.....	94
Table 10.5. Events during Test 469940-03-2.....	95
Table 10.6. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469940-03-2.....	95
Table 10.7. Occupant Compartment Deformation for Test 469940-03-2.....	99
Table 10.8. Exterior Vehicle Damage for Test 469940-03-2.....	99
Table 10.9. Occupant Risk Factors for Test 469940-03-2.....	100
Table 11.1. Impact Conditions for Crash Test 469940-03-3.....	103
Table 11.2. Exit Parameters for Crash Test 469940-03-3.....	103
Table 11.3. Weather Conditions for Test 469940-03-3.....	105
Table 11.4. Vehicle Measurements for Test 469940-03-3.....	106
Table 11.5. Events during Test 469940-03-3.....	106
Table 11.6. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469940-03-3.....	107
Table 12.1. Impact Conditions for Crash Test 469940-03-4A.....	113
Table 12.2. Exit Parameters for Crash Test 469940-03-4A.....	113

Table 12.3. Weather Conditions for Test 469940-03-4A.....	114
Table 12.4. Events during Test 469940-03-4A.....	115
Table 12.5. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469940-03-4A.....	115
Table 12.6. ATD Head and Neck Injury Criteria for Test 469940-03-4A.....	119
Table 13.1. Injury Criteria Comparison.....	122
Table 13.2. Injury Criteria for Channel Rubrail Designs.....	124
Table 13.3. Injury Criteria for W-Beam Rubrail Designs.....	126
Table 13.4. Injury Criteria for V-Shape Rubrail Designs.....	128
Table 13.5. Impact at Splice—Rubrail Design Comparison.....	130
Table 14.1. Impact Conditions for Crash Test 469942-01-1.....	133
Table 14.2. Exit Parameters for Crash Test 469942-01-1.....	133
Table 14.3. Weather Conditions for Test 469942-01-1.....	135
Table 14.4. Events during Test 469942-01-1.....	135
Table 14.5. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469942-01-1.....	135
Table 14.6. ATD Head and Neck Injury Criteria for Test 469942-01-1.....	139
Table 15.1. Injury Criteria for Rubrail Designs.....	142
Table 15.2. Injury Criteria for Modified Rubrail Designs.....	143
Table 16.1. Impact Conditions for Crash Test 469943-01-1A.....	145
Table 16.2. Exit Parameters for Crash Test 469943-01-1A.....	145
Table 16.3. Weather Conditions for Test 469943-01-1A.....	146
Table 16.4. Events during Test 469943-01-1A.....	147
Table 16.5. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469943-01-1A.....	147
Table 16.6. ATD Head and Neck Injury Criteria for Test 469943-01-1A.....	151
Table 17.1. Impact Conditions for Crash Test 469943-01-2.....	153
Table 17.2. Exit Parameters for Crash Test 469943-01-2.....	153
Table 17.3. Weather Conditions for Test 469943-01-2.....	154
Table 17.4. Events during Test 469943-01-2.....	155
Table 17.5. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469943-01-2.....	155
Table 17.6. ATD Head and Neck Injury Criteria for Test 469943-01-2.....	159
Table 18.1. Impact Conditions for <i>MASH</i> Test 3-10, Crash Test 469943-01-3.....	161
Table 18.2. Exit Parameters for <i>MASH</i> Test 3-10, Crash Test 469943-01-3.....	161
Table 18.3. Weather Conditions for Test 469943-01-3.....	163
Table 18.4. Vehicle Measurements for Test 469943-01-3.....	164
Table 18.5. Events during Test 469943-01-3.....	165
Table 18.6. Soil Gap and Post Lean for Test 469943-01-3.....	165
Table 18.7. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469943-01-3.....	166
Table 18.8. Occupant Compartment Deformation for Test 469943-01-3.....	169
Table 18.9. Exterior Vehicle Damage for Test 469943-01-3.....	169
Table 18.10. Occupant Risk Factors for Test 469943-01-3.....	170
Table 19.1. Impact Conditions for <i>MASH</i> Test 3-11, Crash Test 469943-01-4.....	173
Table 19.2. Exit Parameters for <i>MASH</i> Test 3-11, Crash Test 469943-01-4.....	173

Table 19.3. Weather Conditions for Test 469943-01-4.....	175
Table 19.4. Vehicle Measurements for Test 469943-01-4.....	176
Table 19.5. Events during Test 469943-01-4.	177
Table 19.6. Soil Gap and Post Lean for Test 469943-01-4.	177
Table 19.7. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469943-01-4.....	178
Table 19.8. Occupant Compartment Deformation for Test 469943-01-4.....	181
Table 19.9. Exterior Vehicle Damage for Test 469943-01-4.	181
Table 19.10. Occupant Risk Factors for Test 469943-01-4.....	182
Table 20.1. Number and Percentage of RDFS Motorcycle Crash Severities.....	185
Table 20.2. Fixed Object Types.	187
Table 20.3. Descriptive Statistics of Quantitative Variables.	188
Table 20.4. Description of Qualitative Variables.....	189
Table 20.5. Multinomial Logit Estimation Results.....	191
Table 20.6. Roadway Characteristics of Low-, Moderate-, and High-Risk Sites.	195
Table 20.7. Number of Sites and Crashes per Risk Level.....	196
Table 21.1. Assessment Summary for <i>MASH</i> TL-3 Tests on Enhanced Motorcycle Guard Fence System.	199

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

Motorcyclists are among the most vulnerable users of the roadway system. The appropriate design of roadside safety systems plays an important role in the severity of injuries caused by motorcycle crashes. Data (1) show that the number of fatalities related to motorcycle impacts against safety barriers was greater than the number of fatalities recorded from passenger car impacts against the same roadside safety devices.

Although there are no guidelines addressing the proper testing and use of motorcycle retrofit barriers, there is a need to develop an appropriately designed guard fence system retrofit to address motorcycle-rider fatalities associated with barrier impacts in which the rider is either in a sliding or upright position. Researchers at the Texas A&M Transportation Institute (TTI) considered such a retrofit system for placement on appropriate high-speed roadways at locations that are more likely to be associated with motorcycle impact fatalities and severe injuries. The researchers developed an appropriate motorcycle-friendly retrofit guard fence system for evaluation in compliance with the 2016 edition of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware (MASH)*, in accordance with the Federal Highway Administration (FHWA) (2).

1.2. OBJECTIVE

The research objective was to develop and evaluate a retrofit guard fence system that can accommodate motorcyclist impacts in a sliding or upright position and maintain *MASH* Test Level 3 (TL-3) crashworthiness. Additionally, this research investigated motorcycle-involved crashes in Texas to identify common characteristics for these crash types.

1.3. RESEARCH OUTLINE

The work plan consisted of eight tasks to achieve the project objectives:

- Task 1. Conduct Project Management and Research Coordination.
- Task 2. Conduct Literature Review.
- Task 3. Perform Crash Data Analysis.
- Task 4. Develop Concepts for Retrofit Design Options and Select Design.
- Task 5. Develop Design Details and Perform Engineering Analysis.
- Task 6. Recommend Test Plan for Full-Scale Crash Testing and Evaluate Options.
- Task 7. Construct Retrofit System and Conduct Full-Scale Crash Testing.
- Task 8. Determine Placement Guidance.

This report provides details on the results and outcomes of these tasks.

Chapter 2. LITERATURE REVIEW

2.1. INTRODUCTION

Past years have seen a significant rise in the use of motorcycles as a commute vehicle. With an increase in the number of motorcycles on the road, there is an urgent need to treat motorcycle safety as an important aspect when designing roadside safety systems. Motorcyclists are the most vulnerable users of road safety systems, and the severities of injuries caused by motorcycle crashes are essentially affected by these systems. Data (1) suggest that the number of fatalities related to motorcycle impacts against safety barriers is greater than the number of fatalities from passenger car impacts against the same roadside safety devices.

The objective of this literature review was to consider the most up-to-date national and international studies, standards, system designs, protocols, implementations, and suggested measures that can be employed to provide a motorcycle-friendly retrofit guard fence system. Specific attention was given to devices that are used or have been proposed for retrofitting roadside barriers for motorcycle safety. Researchers gathered information from scholarly journals, the internet, and other articles related to the area of study. An overview of various research studies across the globe that focused on motorcycle safety, guidelines, and different crash test approaches is included.

2.2. MOTORCYCLIST FATALITY AND INJURY STATISTICS

This section briefly presents international data on motorcyclist fatalities and injuries, including data on motorcycle impacts with roadside safety systems.

According to data collected in 2013 by the European Commission (3), motorcyclists killed on roadways accounted for 15 percent of all road deaths. Also, 11 motorcyclists per 100,000 registered two-wheelers, compared to five car-driver victims per 100,000 registered cars, were involved in a fatal accident. According to an analysis done by Stock et al. (4) in different parts of Germany, one in seven people killed in a roadway accident in 2008 was a motorcyclist. Also, motorcycles involved approximately 10 percent of the accidents with injuries.

Meanwhile, according to the National Highway Traffic Safety Administration (NHTSA) (5), 4,668 motorcyclists died in traffic crashes in 2013 in the United States. Also, 59 motorcyclists per 100,000 registered two-wheelers, compared to 10 car-driver victims per 100,000 registered cars, were involved in a fatal accident, which—particularly when compared to the European Commission (3) data—shows that motorcycle safety is an important issue to be considered in the United States. Furthermore, as estimated by the federal government, motorcyclist deaths occurred 26 times more frequently than car-occupant fatalities in road accidents per vehicle mile traveled.

Florida had the highest number of motorcyclist fatalities recorded in 2013 in the United States, with 467, followed by Texas with 457 (5). Alcohol consumption is one of

the leading factors in motorcycle accidents. In fact, the percentage of motorcycle riders killed who had a blood alcohol content of 0.08 or higher was 37 percent in Texas.

Figure 2.1 illustrates how motorcycle deaths remained almost constant from 1975 to 2013 in the United States (5). There was a small decrease from about 1980 to 1995 and then an increase from 1997 to 2009.

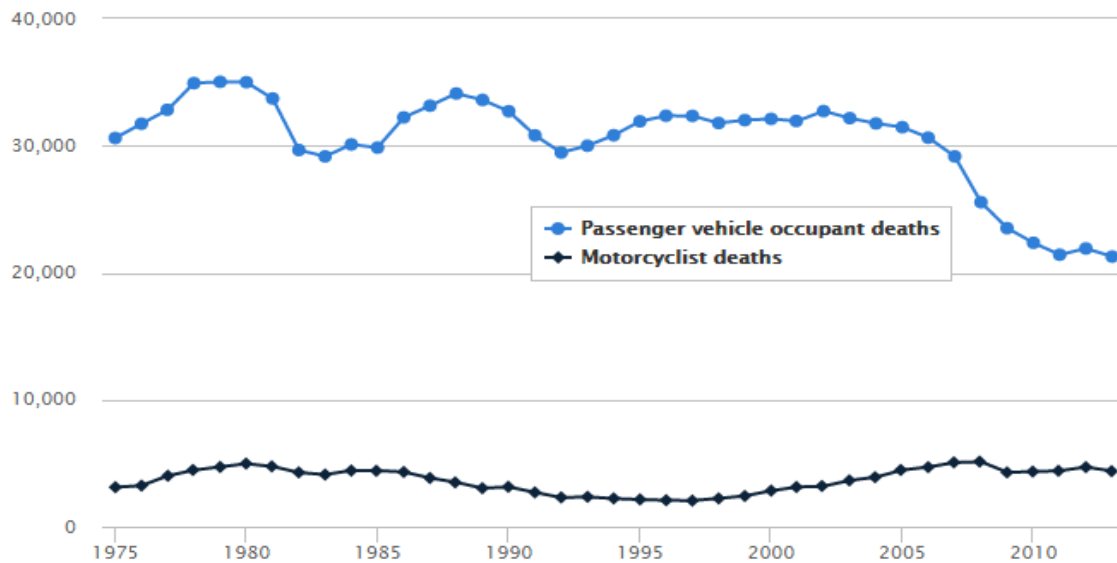


Figure 2.1. Passenger Vehicle Occupant Deaths and Motorcyclist Deaths in the United States from 1975–2013 (5).

Based on a 2015 study involving U.S. data from the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES), 4,976 motorcyclists were killed in 2015, which accounted for an increase of 8 percent over 2014. Six percent of the motorcyclists killed were passengers, thus highlighting passenger risk. In that same year, approximately 88,000 motorcyclists received injuries, which was 3 percent less than the previous year. Moreover, a fatality involving a passenger car occupant was 29 times less frequent than a motorcyclist fatality, and the fatality rate was six times greater for a motorcyclist than for an occupant of a passenger car.

According to an FHWA study based on data obtained from 351 crashes and 702 control rider interviews, the number of motorcycle-rider fatalities in 2009 was more than twice the amount recorded in 1997 (6). In this same time period, there was a 27 percent decrease in the number of passenger car and light truck fatalities.

Nabors et al. (7) observed a 43 percent increase in motorcycle fatalities from 2003 to 2008, a decrease from 2008 to 2009, and then another increase from 2009 to 2012. They also found that the ratio of motorcycle fatalities increased from 1 in every 20 to 1 in every 7 motor vehicle fatalities from 1997 to 2004, which indicates an increased risk to motorcyclists.

According to existing data and studies, a motorcyclist is more vulnerable than a passenger vehicle occupant to injury during impact with a barrier or other vehicle. A two-year study (8) in Australia on the role of the infrastructure elements in motorcycle

safety found that motorcycle fatalities occurred most frequently on curves (39 percent), followed by intersections (38 percent), and then straight roadways (23 percent). Roadside hazards and roadside conditions accounted for 75 percent of single-vehicle collisions, with some of the most commonly struck objects being trees (24–31 percent), fences/safety barriers (10–12 percent), street light or traffic light poles (9 percent), and drainage and drain pipes (5 percent).

Regarding the position of the rider during impact of motorcycles with barriers, an evaluation by Berg et al. (9) of 57 real-world accidents reported that motorcyclists impacted the barriers in an upright position in 51 percent of the cases and in a sliding position in 45 percent of the cases. A study by Peldschus et al. (10) involving crash testing reported that in about 75 percent of cases, the motorcycle was in an upright position during an impact with fixed objects. However, as stated above, currently there are no standards or guidelines that provide proper testing of safety systems. Thus, rider impacts for both upright and sliding positions were considered in this research.

2.3. STANDARDS, PROTOCOLS, AND CRITERIA

This section details relevant literature related to testing standards and protocols for performing motorcyclist impact testing.

In order to develop an international standard for physical crash testing of a motorcycle impacting a vehicle, the International Organization for Standardization (ISO) appointed a group of motorcyclist safety experts to create guidelines in 1996, resulting in the ISO 13232 standard (11).

This standard consists of eight parts:

- Part 1: Definitions, symbols, and general considerations.
- Part 2: Definition of impact conditions in relation to accident data.
- Part 3: Motorcyclist anthropometric impact dummy.
- Part 4: Variables to be measured, instrumentation, and measurement procedures.
- Part 5: Injury indices and risk/benefit analysis.
- Part 6: Full-scale impact test procedures.
- Part 7: Standardized procedure for performing computer simulations of motorcycle impact tests.
- Part 8: Documentation and reporting.

Figure 2.2 illustrates the seven impact configurations specified by ISO 13232-2 to determine severity of motorcycle (MC) impact against an opposing vehicle (OV). Table 2.1 gives the details of the seven configurations.

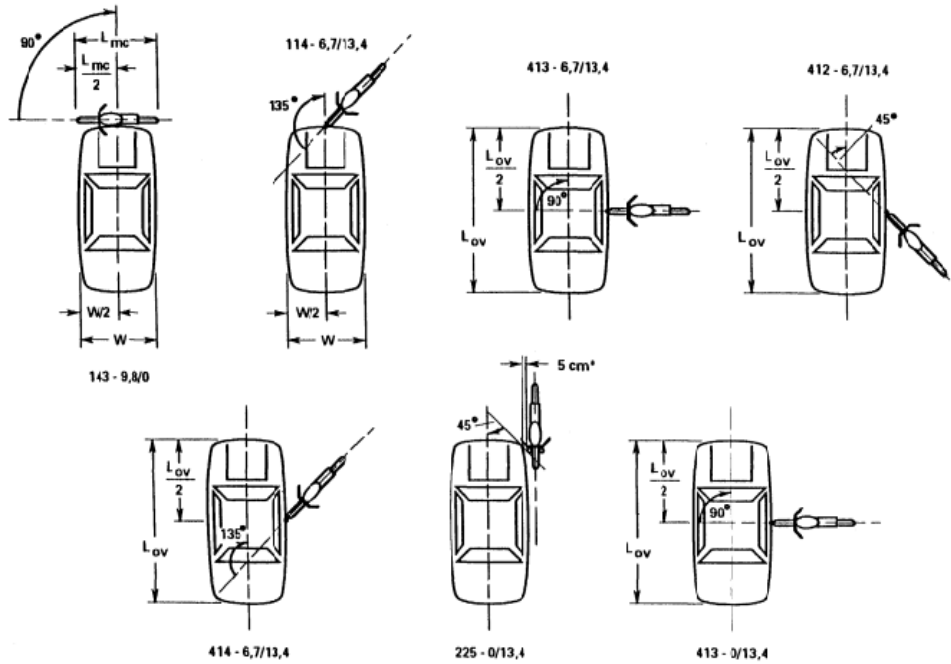


Figure 2.2. ISO 13232-2 Impact Configurations (12).

Table 2.1. ISO 13232-2 Impact Conditions (11).

OV Contact Location	Relative Heading Angle (deg)	OV/MC Speeds (m/s)	OV/MC Speeds (mph)
Front	90	9.8/0	22/0
Front	135	6.7/13.4	15/30
Front Corner	180	0/13.4	0/30
Side	90	0/13.4	0/30
Side	135	6.7/13.4	15/30
Side	90	6.7/13.4	15/30
Side	45	6.7/13.4	15/30

ISO 13232-2 recommends a Hybrid III 50th percentile male dummy with sit/stand construction, standard non-sliding knees, and head/neck assembly compatible with either a 3- or a 6-axis upper-neck load cell. Also, the dummy requires some additional modifications, such as sit/stand pelvis, modified elbow bushing, frangible upper-leg components, and leg-retaining cables (11).

The L.I.E.R. procedure (13) consists of two tests with the dummy impacting the protection system with different configurations but with the same impact conditions, as shown in Table 2.2. The test specifications are given in Table 2.3. Point of impact of the dummy with the system is approximately in the middle of the system and opposite the barrier post (rigid element). The dummy is equipped with sensors to measure acceleration of the head and calculate forces and moments.

Table 2.2. L.I.E.R. Test Impact Configurations (14).

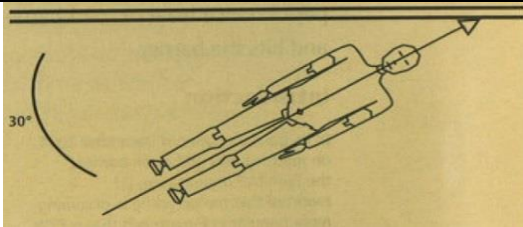
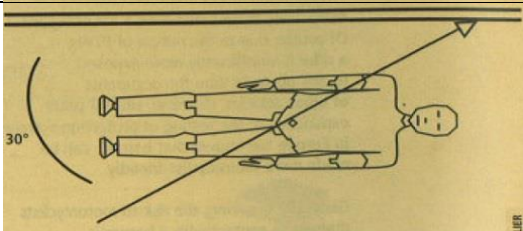
<p>Test 1. Dummy aligned w/ launch path</p>	
<p>Test 2. Dummy parallel to the test item</p>	

Table 2.3. L.I.E.R. Test Specifications.

Impact Speed	60 km/h, 37.3 mi/h
Impact Angles	Test 1: 30° Test 2: 30°
ATD	Standard Dummy Model
Dummy Helmet	Standard Motorcycle Helmet
Dummy Clothing	Standard Motorcyclist Clothing
Approval Criteria	<ul style="list-style-type: none"> • Dummy head acceleration, forces, and moments should be within biomechanical limits. • The dummy must not pass through the system nor remain trapped within.

Note: ATD = anthropomorphic test device.

The UNE-135900 test protocol was undertaken to further develop the L.I.E.R. procedure, and thus it is similar but has some differences. This test standard includes an additional test speed of 70 km/h (15). In this procedure, the protection system that is locally around the post (discontinuous system) is also considered and tested with the post-centered test, in addition to a head-first test where point of impact is at an offset with reference to the post. As opposed to the L.I.E.R. protocol, the second impact is conducted between two posts and not opposite a post (rigid element). Also, based on biomechanical measurements, two different performance classes are determined for the protection system.

The EN 1317-8 specification (16) was proposed to further add to the EN 1317 standard for testing motorcyclist protection systems to address motorcyclist safety. This specification was the only one of its kind during the time of proposal to consider the rider position during impact for testing of the protection system. The European Committee for Standardization, CEN, thus concentrated on developing a standard to improve the safety of sliding motorcyclists and considered impact configurations and specifications as given in Table 2.4 and Table 2.5. Initially, this standard was adopted as compulsory throughout the European Community, but due to lack of experience of some countries with this test specification, it was decided to accept the standard as a

technical specification. Thus, this standard is not compulsory for any country to follow, and each country is free to install a barrier that is intended to increase safety. However, in this case, the particular country would be responsible for the decision and not the National Road Authority.

Table 2.4. EN 1317-8 Impact Configurations for Tests (16).

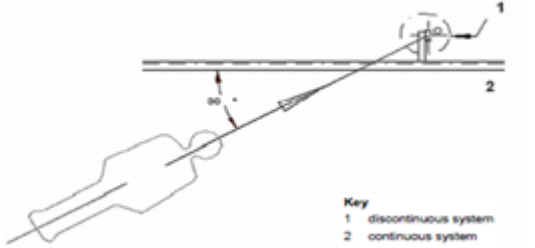

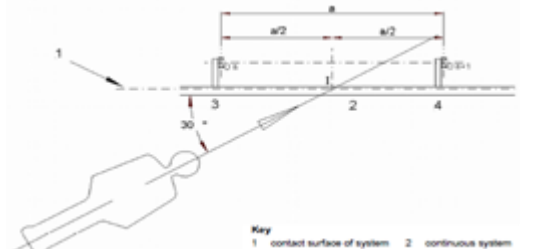
<p>Test 1. Launch Configuration 1: Post-Centered Impact</p>	 <p>Key 1 discontinuous system 2 continuous system</p>
<p>Test 2. Launch Configuration 2: Post-Offset Impact</p>	 <p>Key 1 discontinuous system</p>
<p>Test 3. Launch Configuration 3: Midspan Impact</p>	 <p>Key 1 contact surface of system 2 continuous system 3 post-n 4 post-n+1</p>

Table 2.5. EN 1317-8 Test Specifications.

Impact Speed	Test 1, 2, and 3: 60 km/h (37.3 mi/h) or 70 km/h (43.5 mi/h)
Impact Angles	Test 1, 2, and 3: 30°
ATD	Modified Hybrid III 50th percentile male
Dummy Helmet	Motorcycle helmet (polycarbonate shell) satisfying Regulation 22 of ECE/TRANS/505 requirements
Dummy Clothing	Complying EN 1621-1 requirements for motorcyclist clothing
Approval Criteria	MPS: Any longitudinal element of the test item must not have complete rupture. ATD: The ATD shall not remain trapped in the test item. Parts of dummy shall not be completely detached (except the upper extremity, which can be detached due to rupture of the frangible screws in the shoulder assembly).

Note: MPS = motorcycle protection system.

In EN 1317-8, full-scale tests with the ATD impacting the barrier with an MPS is carried out with the ATD sliding on its back. Motorcycle performance is evaluated based on two classes:

- Speed class—based on impact speed of tests.
- Severity level—based on biomechanical values obtained from ATD test measurements.

Germany's Federal Highway Research Institute, BAST, defined a homologation procedure for impact protectors (17) that evaluates the deceleration value during the impact against the protector. Evaluation criteria involve limiting this value to a 60-g peak value, and 40 g over a 3-ms interval. Further, the report classifies two different classes of devices as follows:

- Class 1—tested with impact speed of 12.4 mi/h (20 km/h).
- Class 2—tested with impact speed of 21.7 mi/h (35 km/h).

The Australian/New Zealand testing standard (AS/NZS) consists of two parts (18):

1. AS/NZS 3845.1:2015 provides requirements for permanent and temporary safety barrier systems, including longitudinal road safety barriers, terminals, crash cushions, interfaces including transitions, and longitudinal barrier gates.
2. Part 2 provides requirements for permanent and temporary road safety devices such as bollards, pedestrian fences and channelizers, truck- or trailer-mounted attenuators, and sign support structures and poles.

The AS/NZS 3845 series of standards and the Austroad research regarding road design and safety barrier assessment processes are similar to each other, except that the Austroad guidelines (8) specify the road and roadside configurations that identify the location where road safety barriers may be required to be installed, while the standards set out requirements for road safety barrier systems.

Three other standards that are commonly adopted are described in the AZ/NZS standard. However, the AS/NZS standard suggests that, apart from the head injury criteria (HIC) as considered by other standards, additional thorax compression criterion testing should be conducted since many riders suffer critical injuries in the thorax region.

Also, this standard states that previous standards, such as the Spanish standard, L.I.E.R. testing protocol, and EN 1317-8, involved a dummy sliding into the barrier, so motorcyclists impacting roadside barriers in an upright position are not taken into consideration. Therefore, the barriers suggested by other standards are less effective in preventing rider injuries while impacting barriers in the upright position.

These newly retrofitted devices should also be crash tested with cars because these motorcycle protection system devices that are provided around critical posts and beams can prove to be less effective during barrier-car impacts. The standard suggests further research and development regarding understanding the risk of riders impacting barriers in an upright position and contacting the barrier on the top.

2.4. MOTORCYCLE CRASH TESTING AND RELATED STUDIES

This section reviews literature on crash tests and other studies focused on reducing motorcyclist impact severity and improving motorcycle safety.

Three tests were performed by Quincy et al. (19): two with one design, and one with another design (Figure 2.3). Tests were performed with a dummy placed on a platform lying on its back (head forward) ejected with a sled. Impact speed and angles for the tests were 34.2 mi/h (all tests), and 32 degrees (Design 1) and 30 degrees (Design 2), respectively.

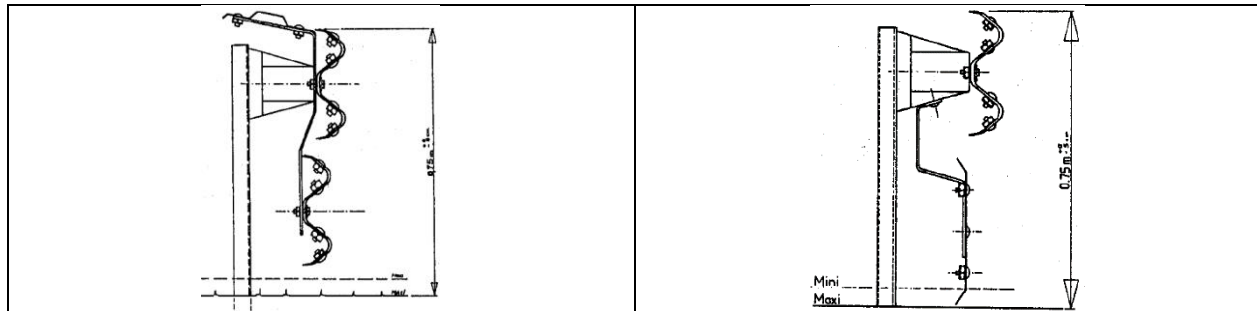


Figure 2.3. Metal Beam Guardrail Design 1 (left) and Design 2 (right).

The deceleration levels and HIC criteria registered on different parts of the dummy were lower than the limit values. After this research was conducted, the motorcycle barrier was approved by the French Transportation Ministry, and some highways were provided with these barriers. However, sufficient accident data were not available to evaluate the system.

Three motorcycle–barrier crash tests were conducted by Nieboer et al. (20). Two motorcycle (with rider)–passenger car (Mazda 323) crash tests were also conducted. A special trolley was used to guide the motorcycle. Impact speeds and angles for the tests were:

- Motorcycle–Barrier Tests: 20 mi/h, 90 degrees; 30 mi/h, 90 degrees; and 37 mi/h, 67 degrees.
- Motorcycle–Passenger Car Tests: 20 mi/h, 45 degrees; and 30 mi/h, 90 degrees.

Four crash tests were conducted with a combination of different impact situations with the motorcycle in (a) upright and (b) sliding conditions while impacting the barrier (9). The road surface was kept wet. Impact speed and angles for the tests were 37.3 mi/h (all tests) and 12 degrees (upright) and 25 degrees (skidding on side). Severe snagging and aggressive contact were observed in the upright motorcyclist impacts with a concrete barrier and guardrail.

Two crash tests were performed with two impact configurations: upward driving and rider inclined causing sliding (10). The data collected were divided into two parts: primary data (specific to impact with guardrails) and secondary (specific to impact of head to ground). Impact speeds and angles were 60 km/h (both tests) and 12 degrees (upright) and 25 degrees (inclined).

An analysis of motorcycle accidents in different areas of Germany (4) was carried out. Important findings included the following:

- In 2008, motorcyclists accounted for nearly one in seven people who were killed in a roadway accident.
- 10 percent of accidents resulting in injuries involved motorcycles.
- Inexperienced riders had a higher risk of injuries and fatalities.
- Incorrect right-of-way maneuvering and improper rider driving skills while navigating corners were some of the primary reasons for the high number of motorcycle accidents.

Five major points were suggested to enhance motorcyclist safety:

- Increase awareness among authorities regarding motorcycle safety.
- Analyze and discuss accident figures, causes, and facts.
- Provide thorough maintenance of roads.
- Train and inform road users.
- Implement road construction and traffic engineering measures for improved road safety.

A crash analysis that categorized crashes on the basis of week days (commuting period crashes) or holidays (recreational period crashes) was carried out (8). The Australian Road Research Board (ARRB) completed many safety audits to perform a comparative study between vehicles and motorcycles that showed how infrastructure elements can influence the likelihood and severity of crashes represented by risk factors. The report summarizes various measures to be taken for motorcycle safety enhancement.

Seventeen staged motorcycle crash tests were performed at the World Reconstruction Exposition 2000 (21). Seven crash tests were conducted with Kawasaki–concrete barrier crash tests, while others included Kawasaki–1989 Ford Thunderbird impact tests. Tests were performed with a motorcycle tow system. Impact speeds and angles for tests were 10 mi/h to 49 mi/h and 90 degrees.

Researchers developed design alternatives for a containment system and tested it with engineering analysis, finite element simulations, pendulum testing, and full-scale crash testing (22). Full-scale impact tests were performed with a motorcycle rider. Impact speed and angle for full-scale crash tests were 35 mi/h \pm 2.5 mi/h and 18 degrees \pm 1.5 degrees.

The first phase of research by Franco et al. (23) included selecting a system from a range of alternatives and creating a model. The second phase included conducting finite element analysis to determine strength and perform impact simulations on the model. The final phase confirmed if the proposed design satisfied *MASH* impact performance requirements. Impact speeds and angles for the tests were 45 mi/h and 15 degrees.

A study by Shaffer et al. (24) was conducted with the aim of improving planning and organization of infrastructure advancements for motorcyclists. The team focused on the states of Florida, Maryland, and Wisconsin. The report provides some mitigation measures for infrastructure improvements.

Nicol et al. (25) focused on assessing and evaluating infrastructure improvements, maintenance practices, and traffic operation strategies to enhance motorcycle safety in Germany, Belgium, France, England, and Norway. The team consisted of 12 transportation engineers who proposed that U.S. agencies establish goals to reduce motorcycle injuries through roadway design, operations, and maintenance practices.

A study by Nabors et al. (7) investigated road safety issues and found the locations that posed the greatest opportunity for improvement. The study aimed to better understand different conditions that influence overall safety of motorcyclists. The related report consists of three road safety audits, each of which focuses on various roadside facilities.

Nazemetz et al.'s study (6) focused on increasing awareness of the need to improve motorcycle safety and to show the role of different crash causation factors, which in turn would allow for effective countermeasures to be put in place according to the new recommendations. Oklahoma State University, Southern Plains Transportation Center, and various other companies and research teams were involved in this study.

A recent study by Gabler et al. (1) aimed to identify factors contributing to serious injury and fatal motorcycle collisions with traffic barriers. The first phase of research included completing a literature review, crash characteristics report, and revised work plan for Phase II, which involved execution of the approved plan and submittal of a final report containing the entire research work, with future research and injury mitigation recommendations.

Chapter 3. CRASH DATA ANALYSIS

3.1. INTRODUCTION

This chapter presents details on the descriptive statistical analysis of Texas Department of Transportation (TxDOT) Crash Record Information System (CRIS) data related to a motorcycle making contact with man-made or placed objects (i.e., guard fence along public roadways). Researchers focused on the following crash characteristics:

- Vehicles identified as motorcycles.
- Single motor vehicle (SMV) crashes.
- Run-off-road crashes.
- First harmful event and most harmful event, both depicted as “hit guardrail.”
- Injury severity: fatal, suspected serious injury (K+A in KABCO scale [K = fatality; A = suspected serious injury; B = non-incapacitating injury; C = possible injury; and O = no injury or a property damage-only (PDO) crash]).

Researchers supplemented the CRIS data with a review of information found using Google Earth and crash reports.

3.2. BACKGROUND

The following subsections provide a brief discussion of the information researchers used to perform the crash data analysis.

3.2.1. CRIS

CRIS contains 68,838 TxDOT reportable motorcycle-involved crashes that occurred between 2010 and 2017. A TxDOT reportable crash is a crash that occurs on a public roadway and results in a fatality, injury, or \$1,000 or more in damage. For this analysis, 689 of those crashes were identified as involving a motorcycle making contact with a guardrail. The majority (646, or 94 percent) of those crashes were classified as SMV crashes. Of the 646 single-vehicle motorcycle crashes involving contact with a guardrail, 109 (17 percent) resulted in a fatality (K) and 215 (33 percent) resulted in a suspected serious injury (A). Table 3.1 shows the crash severity breakdown.

Table 3.1. SMV Motorcycle Crashes Involving Guardrail Contact, 2010–2017.

Crash Severity	Count per Crash Severity	Percentage of Total
Fatality	109	17%
Suspected Serious Injury	215	33%
Non-incapacitating Injury	211	33%
Possible Injury	74	11%
No Injury	25	4%
Unknown	12	2%
Grand Total	646	100%

Focusing on the fatal and the suspected serious injury crashes, the researchers decided to use the available crash coordinates from the CRIS data to collect guardrail data from satellite imagery for 325 crashes, which included 300 of the single-vehicle motorcycle crashes involving guardrail contact. Twenty-four of the crashes did not have crash coordinates associated with them. The Texas Peace Officer's Crash Reports for the 350 fatal and suspected serious injury crashes with guardrail involvement, including the SMV crashes, were also reviewed to collect crash details from the crash narratives and illustrations, which are not maintained in CRIS.

3.2.2. Google Earth

The researchers used the Google Earth program to determine some of the variables considered for the analysis. These variables were decided after consideration of different aspects and suggestions regarding motorcycle crashes and guardrail design. With the latitude and longitude coordinates from the crash data, the researchers were able to look up the crash site and note the guardrail type, road conditions, guardrail retrofit, and street type. The street view facility (Figure 3.1) available in the Google Earth Pro software was used to obtain information. Also, the historical satellite imagery option was used to match the satellite view with the crash year for some reports (Figure 3.2).



Figure 3.1. Street View from Google Earth Pro Software.

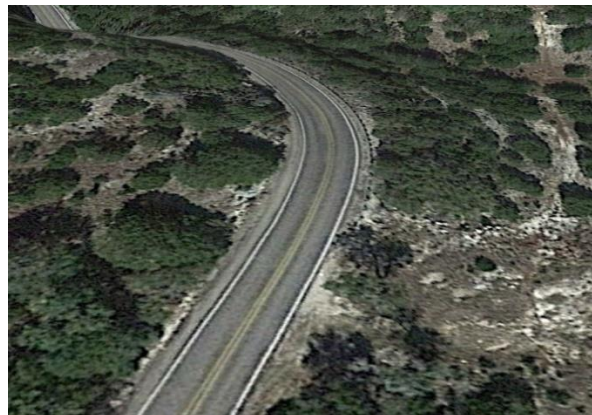


Figure 3.2. Satellite View from Google Earth Pro Software.

All 692 crash reports with a motorcycle crashing into a guardrail were analyzed with Google Earth. These cases included fatal, suspected serious injury, non-incapacitating injury, no injury, and possible injury crash severities. Crash data with crash year, crash severity, county, city, crash latitude, crash longitude, crash road speed limit, first harmful event, collision manner, and object struck information were available.

By inputting crash latitude and longitude into Google Earth, the researchers were able to retrieve the approximate location of the crash. With the street view feature, the following variables were determined:

- **Curve:** The researchers deemed it important to know whether the road section on which the crash took place had a curve. A curved section can generally be observed to have more fatal injuries compared to other sections.
- **Type of street:** This variable was used to segregate two-way and one-way streets on which a motorcycle crashed into a guardrail. Also, this field was marked as an intersection if the crash location was at an intersection. This variable helped the researchers determine if street type had any effect on the crash severity and frequency of crash.
- **Guardrail:** The Google Earth street view enabled the researchers to look at the type of guardrail, which could have a significant effect on the crash severity. Most of the guardrails were the W-beam type, with either wood or steel I-beam posts. However, there were a few other cases, such as cylindrical rails or double steel rails. Determining guardrail type was an important factor in the crash data analysis because it helped the researchers determine the retrofit or guardrail option according to the crash severity associated with specific types.
- **Retrofit to guardrail:** Through the street view feature, the researchers checked whether the impacted guardrail already had a retrofit option available. It was necessary to determine this information since it would directly signify whether or not a retrofit option had any effect on motorcycle crashes over time. However, there were very few cases with a retrofit available over the length of the guardrail. The most common type of retrofit observed was the end terminal cushion provided at the ends of the guardrail. However, these were ineffective because they were only provided at the ends and were not motorcycle friendly.

All crash severity types were analyzed with Google Earth, and the above-mentioned variables were determined. However, the following assumptions were considered while incorporating these variables:

- Crash latitude and longitude gave the approximate location of the crash. Thus, the Google Earth street view for a particular set of coordinates would not show the exact crash site. This would sometimes lead to a location that might not have a guardrail at all—just a guardrail some distance from the coordinates. Thus, during inputting guardrail type, the researchers assumed that the crash site (which was very near to the coordinates given) would have the same guardrail type as that on the street view obtained by the crash coordinates.
- Some guardrails were provided with wood posts for a major portion of the rail and steel I-beam posts for the initial and terminating portion, or vice versa. The

researchers classified the type of guardrail with the posts occupying the major portion of the guardrail length. Such guardrails were again verified with the crash report data and checked to determine if there were any specific details about the posts available. Necessary corrections were made for any changes.

- Many guardrails had an initial portion with wood posts cut at the top level. Thus, the protruding part of the post had a square cross section. However, no segregation was done for this type of post, and those posts were simply classified as wood posts due to the fact that a major portion of the guardrail was composed of the cylindrical top wood posts.
- An end terminal cushion was considered a retrofit to the guardrail since it was an addition to normal rails. However, terminal cushions minimally contribute to reduction of the crash severity for motorcycle crashes. Thus, for crashes taking place in the middle portion of the guardrail where the end terminal cushion was not visible anywhere near the crash coordinates, the retrofitting field was marked as “no.” Thus, the retrofit variable was concerned only with the crash site and not the whole length of the guardrail.
- Exceptional cases with no information available about variables were marked with “no info” in the variable field.

Each crash analyzed by Google Earth was linked with a crash ID. After analyzing all cases and inputting variables per the above-mentioned assumptions in an Excel file, researchers analyzed the actual crash reports with crash IDs. Exceptional cases were again checked with the crash reports, and information was confirmed with the data and report drawings available. Necessary changes were made after checking.

3.2.3. Crash Reports

After completing the Google Earth analysis, the crash reports for fatal and suspected serious injury crash severities were analyzed. Fatal crashes accounted for 122 reports, while suspected serious injury crashes accounted for 228 reports. These police crash reports provided valuable information, such as crash ID, number of units involved in the crash, vehicle make and model, rider (and passenger, if any) details, road on which crash occurred, investigator’s narrative opinion about the incident, and a field diagram representing the crash.

The variables considered while analyzing crash reports included:

- **Direction of travel:** This field was obtained from the field diagram displaying coordinates or from the investigator’s narrative. Thus, this field was marked with either northbound, southbound, eastbound, or westbound. This variable was determined to obtain travel direction of the motorcycle rider when the crash happened. This provided the researchers with information on rider trajectory before the crash and relative location of rider and guardrail before the crash, especially for a two-way street with guardrail on one side of the road.
- **Impact location of the road section:** This variable was determined from the field diagram and investigator’s narrative, which specified if the motorcyclist was entering, leaving, or at the middle of the road section just before the crash. This

variable provided information about the effects of changes in the road section on the crash and its severity.

- **Crash in an upright or sliding position:** This was an important variable with regards to the objective of this project. This information was obtained from field diagrams and narratives available in the report. Although there were comparatively fewer cases where narratives clearly described the sliding position before the crash, field diagrams were used to judge and fill in this variable field. This variable helped the researchers determine the percentage of crashes in upright or sliding positions, their frequency, and the associated crash severity. In general, this information is very important to keep in mind while designing guardrails and can help associate crash position with road sections.
- **After impact:** This information was available from the field diagrams and narratives given by the investigators. This variable provided information about after-impact conditions of the rider. Thus, it helped researchers determine if the rider was ejected, and if so, if the rider was on the field or traffic side of the guardrail, or if no information was available from the crash report. This also helped the researchers know whether containment criteria of the guardrails were satisfied. Guardrails should be designed to contain the rider after impact and to prevent ejecting the rider to the other side, which can cause severe or fatal injuries.
- **Angle of impact:** This field was obtained from field diagrams. Although no definite angle was mentioned in the crash reports, an arbitrary angle per the researcher's judgment was assigned based on the diagram's point of impact line. This variable helped determine if the collision was head on or if the rider sideswiped the guardrail. This variable can also be used to determine full-scale crash test configurations.
- **On post/middle:** This field was obtained from diagrams and narratives given in crash reports. This variable was used to determine if the motorcycle rider directly hit the post or hit the guardrail between two posts. The majority of the reports did not clearly mention whether or not the rider hit the post. However, some field diagrams indicated clear impact with posts, and some narratives defined whether or not the rider hit a post. Generally, direct impact with a post results in fatal injuries, so this variable would be important to show how protruding elements in a guardrail can be fatal.
- **Driver characteristics:** This variable was determined from the investigator's narrative. It showed driver behavior before the crash, including if the rider was intoxicated, speeding, distracted, driving recklessly, normal, lost control, was an amateur rider, or a combination of these factors. This variable helped determine if rider behavior had any effect on the crash severity. Note that rider behavior was stated as normal if the rider him/herself was not responsible for the crash but other units had a role in the crash—for example, a motorcycle being hit from behind or animal suddenly hitting the rider on the road. Similarly, driving a vehicle at an unsafe speed for weather conditions at the time of the crash was marked as a speeding case.
- **Other:** This field provides a short description or keywords for the actual crash scenario and important factors resulting in the crash. This information was

obtained from the narrative provided in the report. This is supplementary information provided along with other data to promote a better understanding of the crash situation.

As noted, all variables were determined from the investigator's narrative and the field diagram. Data such as the year the crash occurred and crash ID from these reports were used for the Google Earth part of this analysis. Exceptional cases with no information available about variables were marked with "no info" in the variable field. Other crash severity reports were not analyzed since it would have been unreasonable to analyze all cases considering time constraints and labor required.

Some of these variables were determined based on researchers' judgment when analyzing the crash report. Exact situations of the crash could vary depending on the accuracy of the data provided in the reports and in field diagrams. The aim in choosing these variables was to extract the maximum information available from the crash reports to include in the analysis to determine relations between different factors involved in the crash.

Thus, the entire crash data analysis used a total of 12 variables to obtain important statistical and analytical data and the relation between different factors governing crashes. Results obtained can be very useful for retrofitting or designing a guardrail to ensure motorcyclist safety.

3.2.4. Vehicle Identification Number (VIN) Decoding

Using the VIN information collected by law enforcement on the crash reports, the researchers batch-processed 349 VIN numbers via NHTSA's online VIN Decoder (26). The program returned information for 329 motorcycles.

3.3. DESCRIPTIVE STATISTICAL ANALYSIS

The descriptive statistical analysis was based on the 324 fatal and suspected serious injury single-vehicle motorcycle crashes that involved contact with a guardrail. Using the crash ID from CRIS and the data obtained from Google Earth, the researchers linked the crash reports with the CRIS data. The CRIS data included crash, unit (i.e., motorcycle), and rider level data. The final data set contained CRIS, Google Earth, crash report, and VIN data.

3.3.1. Environmental Crash Characteristics

In order to verify that SMV motorcycle crashes involving guardrails were not a result of environmental characteristics, the researchers analyzed lighting conditions, weather conditions, location, speed limit, and roadway alignment.

3.3.1.1. Lighting Conditions

Motorcycle crashes are classified by the lighting conditions under which the crash occurred. For the crashes of interest, 58 percent were classified as occurring in

daylight conditions and 41 percent in dark conditions. Table 3.2 lists the counts and percentages per the lighting condition options.

Table 3.2. Single-Vehicle Motorcycle Crashes Involving Guardrail Contact by Lighting Condition, 2010–2017.

Lighting Condition	Count	Percentage
Daylight	187	58%
Dark, Lighted	55	17%
Dark, Not Lighted	74	23%
Dark, Unknown Lighting	2	1%
Dusk	5	2%
Dawn	1	0%
Grand Total	324	100%

This information was also supported by the breakdown of crashes per hour. The time of day and the lighting condition did not appear to play a role in whether a guardrail crash occurred. Table 3.3 lists the crash counts and percentages by hour of the day.

Table 3.3. Single-Vehicle Motorcycle Crashes Involving Guardrail Contact by Hour of Day, 2010–2017.

Hour of the Day	Count per Hour	Percentage per Hour
00:00–00:59	8	2.5%
01:00–01:59	12	3.7%
02:00–02:59	21	6.5%
03:00–03:59	6	1.9%
04:00–04:59	3	0.9%
05:00–05:59	1	0.3%
06:00–06:59	4	1.2%
07:00–07:59	9	2.8%
08:00–08:59	10	3.1%
09:00–09:59	3	0.9%
10:00–10:59	14	4.3%
11:00–11:59	24	7.4%
12:00–12:59	18	5.6%
13:00–13:59	19	5.9%
14:00–14:59	22	6.8%
15:00–15:59	14	4.3%
16:00–16:59	21	6.5%
17:00–17:59	15	4.6%
18:00–18:59	14	4.3%
19:00–19:59	14	4.3%
20:00–20:59	18	5.6%
21:00–21:59	18	5.6%
22:00–22:59	19	5.9%
23:00–23:59	17	5.2%
Grand Total	324	100.0%

3.3.1.2. Weather Conditions

Although it is more challenging to operate a motorcycle in less-than-ideal weather conditions, the weather condition listed by law enforcement at the time of the SMV motorcycle crashes was “clear” 85 percent of the time. Table 3.4 indicates the count and percentage of crashes by weather conditions at the time of the crash.

Similarly, the surface conditions reported for the crashes indicate that 93 percent were crashes with dry roadway surface conditions. Less than 1 percent of the crashes had any indication that sand, mud, or dirt on the roadway played a role in the crash.

Table 3.4. Single-Vehicle Motorcycle Crashes Involving Guardrail Contact by Weather Condition, 2010–2017.

Weather Condition	Count	Percentage
Clear	278	85.8%
Cloudy	37	11.4%
Rain	5	1.5%
Severe Crosswinds	2	0.6%
Fog	1	0.3%
Other (Explain in Narrative)	1	0.3%
Grand Total	324	100.0%

3.3.1.3. Location

Figure 3.3 shows that fatal and suspected serious injury SMV motorcycle crashes involving guardrails occurred in 77 of the 254 Texas counties between 2010 and 2017.

Tarrant and Real Counties both had 35 crashes during that time period. Tarrant is a much more urban county than Real. Real County is the location of one of the most popular motorcycle rides in the state, and Tarrant County has one of the highest rates of vehicle miles traveled. Table 3.5 lists the number of crashes by county.

Fatal or suspected serious injury SMV motorcycle crashes involving guardrails occurred on 174 different roadways between 2010 and 2017. RM 337 in Real County was identified as having the most crashes. Crashes that occurred on state-maintained roadways are associated with a control section. Associating a crash with a control section allows for the crash to be linked to the roadway inventory for that section of roadway. Of the 324 crashes in this analysis, 248 were associated with a roadway control section. Table 3.6 lists these associations.

For crashes not associated with a control section in the CRIS database, the crashes were identified by county and the roadway to which the crash was assigned. A review of those 76 crashes found that some were assigned to roadways that may be on the state system, but the majority of the crashes occurred on roadways that would be considered local roads. Table 3.7 lists these associations.

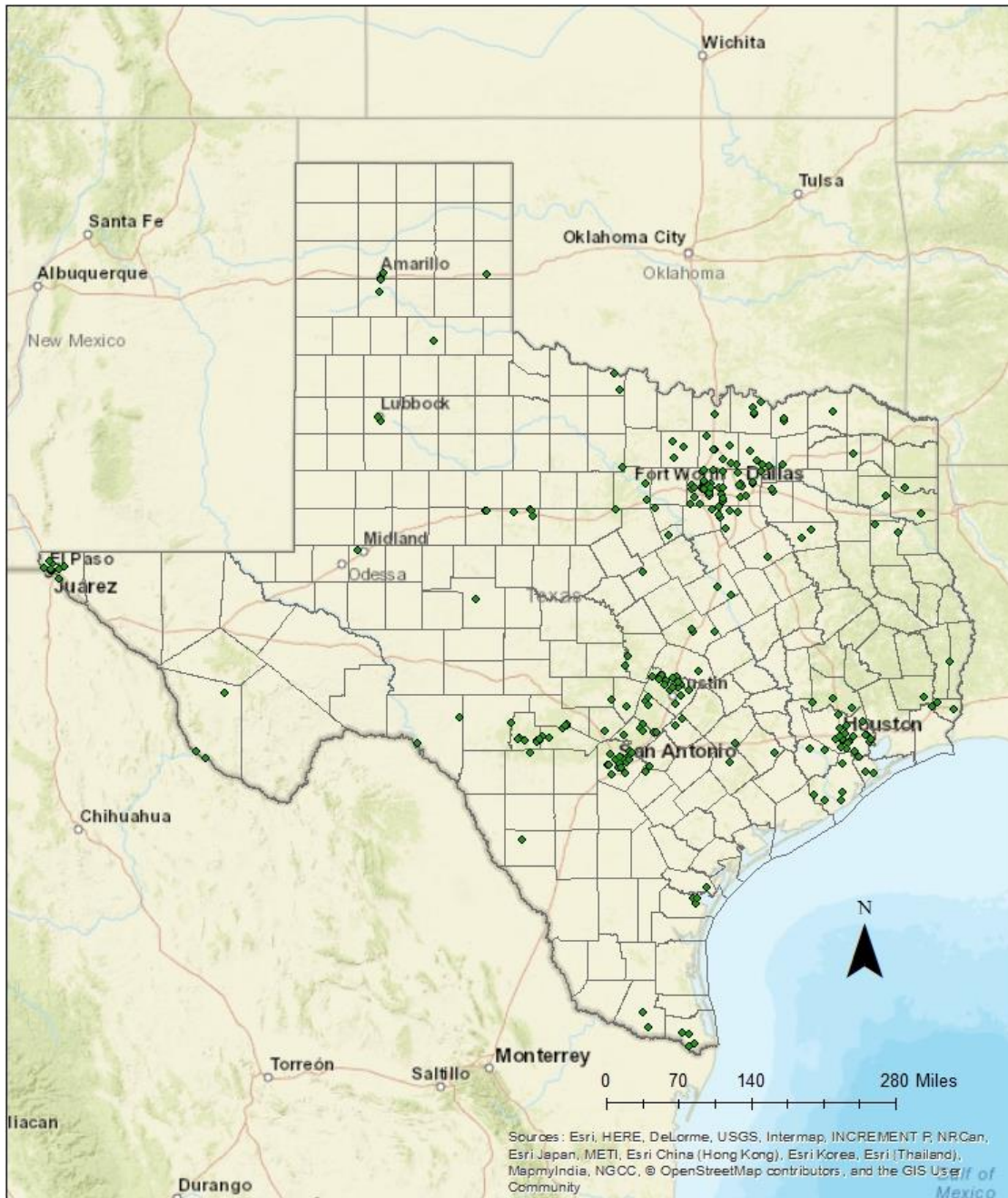


Figure 3.3. Map of Fatal and Suspected Serious Injury Motorcycle Crashes Involving Guardrail Contact, 2010–2017.

Table 3.5. Number of SMV Crashes Involving Guardrail Contact by County, 2010–2017.

County	Number of Crashes
Tarrant	35
Real	35
Harris	27
Bexar	23
Travis	16
Dallas	15
El Paso	12
Denton	11
Nueces	6
Collin	6
Brazoria	6
Comal	5
Cameron	5
Kerr	5
Williamson	5
Hays	5
Wise	4
Taylor	4
Bell	4
Grayson	4
Ellis	4
Johnson	4
Bandera	3
Presidio	3
Potter	3
Galveston	3
Burnet	3
Montgomery	3
Fannin	2
Randall	2
Orange	2
Caldwell	2
Val Verde	2
Henderson	2
Fort Bend	2
Hidalgo	2
Palo Pinto	2
Kaufman	2
Rusk	2
Lamar	2

County	Number of Crashes
Wichita	2
Lubbock	2
McLennan	2
Nolan	2
Fayette	1
Colorado	1
Starr	1
Madison	1
Wheeler	1
Marion	1
San Patricio	1
Hood	1
Briscoe	1
Midland	1
Uvalde	1
Hunt	1
Lavaca	1
Navarro	1
Harrison	1
Newton	1
Somervell	1
Hamilton	1
Edwards	1
Dimmit	1
Tom Green	1
Jefferson	1
Upshur	1
Gillespie	1
Blanco	1
Franklin	1
Cooke	1
Guadalupe	1
Wilson	1
Hardin	1
Young	1
Eastland	1
Kendall	1
Grand Total	324

Table 3.6. Number of Crashes by County and Control Section, 2010–2017.

County	Crash Control Section	Total Crashes
Real	0792-02	18
Real	0792-01	16
Bexar	0073-08	6
Tarrant	1068-02	6
Nueces	0074-06	5
Tarrant	0008-13	5
Kerr	0291-03	4
Travis	1378-01	4
Bexar	0025-02	3
Bexar	0521-04	3
Collin	1392-01	3
Dallas	0196-03	3
Denton	0816-02	3
El Paso	2121-02	3
Harris	0500-03	3
Bell	0231-04	2
Bexar	2452-03	2
Burnet	1378-04	2
Dallas	0092-14	2
Dallas	2374-02	2
El Paso	0167-01	2
Galveston	0389-07	2
Harris	0508-07	2
Harris	0598-01	2
Nolan	0006-03	2
Tarrant	0014-16	2
Tarrant	0172-06	2
Tarrant	0363-03	2
Bandera	0291-04	1
Bandera	0678-02	1
Bandera	0855-04	1
Bell	0232-01	1
Bexar	0016-07	1
Bexar	0017-09	1
Bexar	0017-10	1
Bexar	1890-01	1
Bexar	3508-01	1

County	Crash Control Section	Total Crashes
Blanco	0253-01	1
Brazoria	0111-08	1
Brazoria	0179-03	1
Brazoria	0586-01	1
Brazoria	1003-01	1
Brazoria	1004-01	1
Briscoe	0541-01	1
Burnet	0150-05	1
Caldwell	0384-04	1
Caldwell	1776-03	1
Cameron	0039-10	1
Cameron	0684-01	1
Cameron	1138-01	1
Collin	0281-02	1
Colorado	0709-01	1
Comal	0511-02	1
Cooke	0195-01	1
Dallas	0047-07	1
Dallas	0196-07	1
Dallas	1068-04	1
Dallas	2374-01	1
Dallas	2374-03	1
Denton	0081-13	1
Denton	0364-03	1
Denton	2979-01	1
Dimmit	0037-07	1
Eastland	0007-06	1
Edwards	0830-01	1
El Paso	2552-01	1
El Paso	2552-02	1
El Paso	2552-04	1
Ellis	0048-04	1
Ellis	0596-02	1
Fannin	0045-05	1
Fannin	0279-03	1
Fayette	0535-07	1
Fort Bend	0027-08	1

County	Crash Control Section	Total Crashes
Fort Bend	0543-02	1
Franklin	0610-02	1
Galveston	0192-04	1
Grayson	0047-02	1
Grayson	0047-03	1
Grayson	0202-08	1
Grayson	0728-02	1
Guadalupe	2233-02	1
Hamilton	0183-02	1
Hardin	0200-10	1
Harris	0110-05	1
Harris	0271-07	1
Harris	0271-14	1
Harris	0271-15	1
Harris	0271-17	1
Harris	0389-12	1
Harris	0502-01	1
Harris	0508-01	1
Harris	0980-02	1
Harris	1062-04	1
Harrison	0843-08	1
Hays	0016-03	1
Hays	0113-07	1
Hays	0683-03	1
Henderson	1085-01	1
Henderson	1099-03	1
Hidalgo	1427-01	1
Hood	0385-02	1
Hunt	0009-13	1
Johnson	0172-10	1
Johnson	0747-05	1
Johnson	1600-04	1
Johnson	3010-02	1
Kaufman	0495-01	1
Kaufman	0751-01	1
Kendall	1042-01	1
Lamar	0221-01	1
Lubbock	0067-11	1
Lubbock	0130-05	1

County	Crash Control Section	Total Crashes
McLennan	0015-01	1
McLennan	0049-01	1
Midland	1188-02	1
Montgomery	0523-08	1
Navarro	0166-01	1
Newton	0627-02	1
Nueces	0617-01	1
Orange	0028-11	1
Orange	0784-04	1
Palo Pinto	0007-10	1
Palo Pinto	0314-02	1
Potter	0168-10	1
Potter	0275-01	1
Presidio	0957-07	1
Presidio	0957-08	1
Presidio	1283-02	1
Randall	0168-09	1
Randall	1480-02	1
Rusk	2653-01	1
San Patricio	0180-06	1
Somervell	0259-02	1
Tarrant	0008-14	1
Tarrant	0008-15	1
Tarrant	0081-12	1
Tarrant	0171-05	1
Tarrant	1068-01	1
Tarrant	1068-03	1
Tarrant	2266-02	1
Tarrant	2374-05	1
Tarrant	2374-06	1
Taylor	0006-04	1
Taylor	0006-06	1
Taylor	2398-01	1
Tom Green	0077-06	1
Travis	0151-06	1
Travis	1186-01	1
Travis	2100-01	1
Upshur	0640-04	1
Uvalde	0036-07	1

County	Crash Control Section	Total Crashes
Val Verde	0022-07	1
Val Verde	0160-04	1
Wheeler	0275-12	1
Wichita	0044-01	1
Wichita	0156-07	1
Williamson	0015-09	1
Williamson	0204-04	1
Williamson	0683-01	1
Wilson	1437-02	1
Wise	0013-07	1
Wise	0134-07	1
Wise	1751-01	1
Young	0362-01	1

**Table 3.7. Number of Crashes Not Associated with Control Section in
CRIS Database, 2010–2017.**

County	Derived Road	Total Crashes
Bexar	IH0010	2
Harris	IH0045	2
Tarrant	WINSCOTT PLOVER RD	2
Travis	DESSAU RD	2
Bell	N WHEAT RD	1
Bexar	OLD SEGUIN RD	1
Bexar	ROADRUNNER WAY	1
Brazoria	MASTERS RD	1
Cameron	E STENGER ST	1
Cameron	FM0511	1
Collin	HARDIN BLVD	1
Collin	WATKINS RD	1
Comal	FARHILLS DR	1
Comal	FM0306	1
Comal	RIVER RD	1
Comal	S ACCESS RD	1
Dallas	LAKE RIDGE PKWY	1
Dallas	LIBERTY GROVE RD	1
Dallas	US0080	1
Denton	HIGHLAND VILLAGE RD	1
Denton	IH035W	1
Denton	IH2000	1
Denton	MARSH LN	1
Denton	N I 35E	1
El Paso	CARNEGIE AVE	1
El Paso	N COPIA ST	1
El Paso	SL 375	1
El Paso	TURNER RD	1
Ellis	FM0983	1

County	Derived Road	Total Crashes
Ellis	N WALNUT GROVE RD	1
Gillespie	LOWER ALBERT RD	1
Harris	E OREM DR	1
Harris	EASTEX FWY	1
Harris	EVERGREEN DR	1
Harris	HOMESTEAD RD	1
Harris	MEMORIAL DR	1
Harris	N COMMERCE ST	1
Harris	SH0146	1
Harris	SOUTHWEST FWY	1
Hays	QUAIL RUN	1
Hays	W FITZHUGH RD	1
Hidalgo	SEMINARY RD	1
Jefferson	BIGNER RD	1
Kerr	IHIH10	1
Lamar	US0271	1
Lavaca	FM 957	1
Madison	FM0978	1
Marion	FM 726	1
Montgomery	CARRIAGE HILLS BLVD	1
Montgomery	GRAND PKWY	1
Potter	E HASTINGS AVE	1
Real	RR0337	1
Rusk	COUNTY ROAD 156	1
Starr	US0083	1
Tarrant	BLUE MOUND RD E	1

County	Derived Road	Total Crashes
Tarrant	LAKE RIDGE PKWY	1
Tarrant	LAKESIDE DR	1
Tarrant	RANDOL MILL AVE	1
Tarrant	S HAMPTON RD	1
Tarrant	SH0114	1
Tarrant	SILVER CREEK RD N	1
Taylor	OLD ANSON RD	1
Travis	AIRPORT BLVD	1
Travis	BULLICK HOLLOW RD	1
Travis	DEE GABRIEL COLLINS RD	1
Travis	FM3238	1
Travis	OLD TX 20	1
Travis	RM 2769	1
Travis	WELLS BRANCH PKWY	1
Williamson	FM2243	1
Williamson	US0183	1
Wise	COUNTY ROAD 3470	1

3.3.1.4. Speed Limit

Law enforcement officers are asked to report the speed limit of the roadway on which a crash occurred. Of the 324 crashes, 71 percent of the fatal or suspected serious injury SMV crashes involving guardrail contact occurred on roadways with a speed limit between 45 and 65 mi/h. The highest percentage based on a single value of a reported speed limit was 25 percent at 55 mi/h. Table 3.8 summarizes crashes by speed.

Table 3.8. Reported Speed Limit for Fatal and Suspected Serious Injury SMV Motorcycle Crashes Involving Guardrail Contact, 2010–2017.

Reported Speed Limit	Count	Percentage
0	5	2%
20	2	1%
25	2	1%
30	14	4%
35	19	6%
40	19	6%
45	40	12%
50	21	6%
55	81	25%
60	60	19%
65	27	8%
70	11	3%
75	11	3%
No Data	12	4%
Grand Total	324	100%

3.3.1.5. Roadway Alignment

In addition to the speed limit, the officer is asked to report on the road alignment. A review of the roadway alignment variable in the CRIS data found that 73 percent of the fatal and suspected serious injury SMV motorcycle crashes occurred on roadways identified as curved and 26 percent on roadways with straight alignment. Table 3.9 lists the count and percentage of crashes per roadway alignment.

Table 3.9. Reported Alignment for Fatal and Suspected Serious Injury SMV Motorcycle Crashes Involving Guardrail Contact, 2010–2017.

Road Alignment	Count	Percentage
Curve, Grade	128	39.5%
Curve, Level	92	28.4%
Straight, Level	69	21.3%
Curve, Hill Crest	17	5.2%
Straight, Grade	13	4.0%
Straight, Hill Crest	4	1.2%
Other (Explain in Narrative)	1	0.3%
Grand Total	324	100.0%

3.3.2. Narrative and Diagram Review

The researchers also analyzed the crash report narratives and diagrams as part of the analysis of the 324 fatal and suspected serious injury SMV motorcycle crashes involving contact with a guardrail. The crash report narrative is a free-form field that allows the reporting officer to give additional information about the events of the crash. The diagram section of the report is a free-form field that allows the officer to illustrate the crash in a drawing (not to scale). The data collected are constrained by the level of detail contained in the narrative and diagram. Researchers reviewed motorcycle position, guardrail impact location, guardrail type, and impact angle.

3.3.2.1. Upright or Sliding Position

A key area of focus for this project was the injury sustained by a rider due to contact with a guardrail. The CRIS database does not contain information that clearly details what position the motorcyclist was in at the moment of contact. The narratives and diagrams revealed that 79 percent of the fatal and suspected serious injury SMV motorcycle crashes involved a motorcycle making contact with a guardrail while in an upright position, and 20 percent were in a sliding position. In both cases, a third of the crashes resulted in a fatality. Table 3.10 lists the position of the motorcycle during the crash.

Table 3.10. Motorcycle Position at Impact in Fatal and Suspected Serious Injury SMV Crashes, 2010–2017.

Motorcycle Position	Count	Percentage
Upright	255	78.7%
Sliding	64	19.8%
Did Not Hit	1	0.3%
Skidding Opposite Direction	1	0.3%
Skidding	1	0.3%
No Info	2	0.6%
Grand Total	324	100.0%

3.3.2.2. Impact Location on Guardrail

Classifying the crashes based on where on the guardrail the motorcycle made contact is important to the crash simulation. The majority of fatal or suspected serious injury SMV motorcycle crashes were a result of the motorcycle making contact with the middle section of the guardrail. Table 3.11 lists counts and percentages per impact locations.

Table 3.11. Impact Location on Guardrail in Fatal and Suspected Serious Injury SMV Crashes, 2010–2017.

Guardrail Impact Location	Count	Percentage
Middle	251	77.5%
Entering	39	12.0%
Leaving	28	8.6%
No Data	5	1.5%
Not Applicable	1	0.3%
Grand Total	324	100.0%

In addition to impact location on the guardrail, the crash reports were reviewed for information about whether or not the motorcycle and/or rider made contact with a guardrail post. Only 49 crashes had any information about contact with a post. The majority, 269 crashes, had no information about post contact. Of the crashes that did indicate contact with a post, 65 percent resulted in a fatality.

3.3.2.3. Guardrail Type

The crash sites were viewed through the use of Google Earth to identify the type of guardrails involved in the crashes. Table 3.12 shows that 75 percent of the guardrails involved were constructed with a W-beam with wood posts.

Researchers compared the crashes with the W-beam and wood-post guardrails to the crashes with the W-beam and steel I-beam post guardrails. Table 3.13 shows that the steel-post construction had a higher rate of fatal crashes.

3.3.2.4. Angle of Impact

The diagrams were useful in estimating the angle of impact of the motorcycle with respect to the guardrail. Of the 324 crashes, 220 (68 percent) were estimated to have an angle of impact of approximately 30 to 45 degrees. Table 3.14 lists these associations.

Table 3.12. Guardrail Type in Fatal and Suspected Serious Injury SMV Crashes, 2010–2017.

Guardrail Type	Count	Percentage
W-beam—Wood Post	244	75.3%
No Data	34	10.5%
W-beam—Steel I Post	31	9.6%
No Guardrail	6	1.9%
W-beam—Steel Posts	1	0.3%
Cable Barrier	1	0.3%
W-beam—Steel I Post—Concrete	1	0.3%
Concrete Barrier	1	0.3%
Cylindrical Steel	1	0.3%
Wire—Steel I Post	1	0.3%
Wooden Double Rail	1	0.3%
Steel Cylindrical Railing	1	0.3%
Steel Railing	1	0.3%
Grand Total	324	100.0%

Table 3.13. Percentage of Fatal and Suspected Serious Injury Crashes by Guardrail Type, 2010–2017.

Guardrail Type	Fatal Crashes	Suspected Serious Injury Crashes	Total Crashes
W-beam—Wood Post	36%	64%	100%
W-beam—Steel I Post	48%	52%	100%

Table 3.14. Estimated Angle of Impact in Fatal and Suspected Serious Injury SMV Crashes, 2010–2017.

Estimated Angle of Impact	Count	Percentage
10	39	12.0%
20	8	2.5%
30	123	38.0%
45	97	29.9%
50	1	0.3%
60	23	7.1%
70	8	2.5%
90	15	4.6%
No Data	10	3.1%
Grand Total	324	100.0%

3.3.3. Motorcycle and Rider Review

Another component of the crash data analysis involved a review of the motorcycle riders and vehicles involved in the crashes. Using the VIN data reported by law enforcement and the online batch VIN decoding tool hosted by NHTSA, researchers linked information about the motorcycles involved in the crashes to crash and rider data from CRIS.

3.3.3.1. Motorcycle Make and Body Class

Linking the crash, vehicle, and rider data to VIN data resulted in a data set with 308 motorcycle operators who were killed or severely injured. Using the information reported in the crash report, researchers found that 47 percent of the motorcycles involved were made by Harley-Davidson, as shown in Table 3.15.

Table 3.15. Motorcycle Makes Involved in Fatal and Suspected Serious Injury SMV Motorcycle Crashes Involving Guardrail Contact, 2010–2017.

Motorcycle Make	Count	Percentage
Harley-Davidson	144	46.8%
Honda	42	13.6%
Suzuki	36	11.7%
Kawasaki	36	11.7%
Yamaha	32	10.4%
Triumph	5	1.6%
No Data	4	1.3%
Unknown	3	1.0%
KTM	1	0.3%
Indian Motorcycle Co.	1	0.3%
Ducati	1	0.3%
Big Dog	1	0.3%
Polaris	1	0.3%
BMW	1	0.3%
Grand Total	308	100.0%

The data obtained from the VIN decoding gave more details about the motorcycles involved. Using the returned information on the vehicle body class, researchers obtained a better understanding of the type of motorcycles involved in the crashes. Combining the body class categories of custom, touring, and cruiser, researchers found that 57 percent of the riders were on a motorcycle that would be considered a cruiser body style. Figure 3.4 shows the different types.



Figure 3.4. Examples of Cruiser, Touring, and Sport-Touring Motorcycles.

Twenty-six percent of the motorcycles involved were classified as a sport motorcycle and 11 percent as a street motorcycle. The category of a street motorcycle refers to a motorcycle that is similar to what the motorcycle safety foundation classifies as a traditional motorcycle (27). Figure 3.5 shows the typical motorcycle categories.



Figure 3.5. Examples of Sport and Traditional Motorcycles.

Table 3.16 lists the count and percentages per body class for the motorcycles operated by riders who were killed or severely injured in an SMV crash with a guardrail.

Table 3.16. Motorcycle Body Class Involved in Fatal and Suspected Serious Injury SMV Motorcycle Crashes Involving Guardrail Contact, 2010–2017.

Body Class	Count	Percentage
Motorcycle—Sport	80	26.0%
Motorcycle—Custom	79	25.6%
Motorcycle—Touring/Sport Touring	63	20.5%
Motorcycle—Cruiser	33	10.7%
Motorcycle—Street	21	6.8%
No Data	17	5.5%
Motorcycle—Scooter	6	1.9%
Motorcycle—Standard	4	1.3%
Motorcycle—Dual Sport/Adventure/Supermoto/On/Off-Road	2	0.6%
Motorcycle—All Terrain Cycle (ATV)	1	0.3%
Motorcycle—Unenclosed Three Wheeled/Open Autocycle	1	0.3%
Motorcycle—Trike	1	0.3%
Grand Total	308	100%

CRIS data on motorcycle operators provide information about the rider’s age. The average age of riders on the cruiser type motorcycles was approximately 10 to 20 years older than the riders of sport or street style motorcycles. The majority of the

motorcycle operators, 93 percent, were identified as male. Table 3.17 shows these associations.

Table 3.17. Ages of Riders Involved in Fatal and Suspected Serious Injury SMV Crashes Involving Guardrail Contact, 2010–2017.

Body Class	Average Age of Rider
Motorcycle—Sport	30
Motorcycle—Custom	46
Motorcycle—Touring/Sport Touring	53
Motorcycle—Cruiser	45
Motorcycle—Street	38
No Data	41
Motorcycle—Scooter	48
Motorcycle—Standard	55
Motorcycle—Dual Sport/Adventure/Supermoto/On/Off-Road	42
Motorcycle—All Terrain Cycle (ATV)	30
Motorcycle—Unenclosed Three Wheeled/Open Autocycle	60
Motorcycle—Trike	58
Grand Total	43

3.3.3.2. Ejection

The crash narratives and diagrams revealed that 70 percent of the fatal and suspected serious injury SMV motorcycle crashes resulted in the rider being ejected from the motorcycle. Of the 308 motorcycle operators, 32 percent were ejected onto the roadway and 25 percent were ejected onto the field site of the guardrail after impact with the guardrail. Table 3.18 shows these associations.

Table 3.18. SMV Motorcycle Crashes Resulting in Rider Being Ejected.

After Impact	Count	Percentage
Ejected Same Side	97	31.5%
No Info	89	28.9%
Ejected Field Side	78	25.3%
Ejected	37	12.0%
Ejected—On Post	2	0.6%
Ejected—Slid into Guardrail	1	0.3%
No Impact	1	0.3%
Not Ejected	1	0.3%
Sliding	1	0.3%
No Data	1	0.3%
Grand Total	308	100.0%

3.4. SUMMARY

The crash data analysis identified specific locations where fatal and suspected serious injury single-vehicle motorcycle crashes occurred. Common types of guardrail designs, roadway speed limits, and motorcycles involved were also identified. Rider demographics and details related to the guardrail contact and the riders' resulting actions were classified. The results of this analysis were used to support the placement guidance discussed in Chapter 20.

Chapter 4. DEVELOPMENT OF CONCEPTS FOR RETROFIT DESIGN

4.1. INTRODUCTION

The research team developed design concepts for consideration as potential guardrail system retrofit options to improve motorcyclist safety. Various W-beam guardrail systems have been evaluated under *MASH* standards. These include the Midwest Guardrail System (MGS) with 8-inch and 12-inch wood blockouts, the MGS without blockouts, the MGS with steel posts, the MGS with wood posts, and a weak-post W-beam system. The researchers specifically developed retrofit options for a steel-post MGS with 8-inch blockouts since it represents the system most commonly adopted by TxDOT. There might be the opportunity, however, to adapt the proposed options to other W-beam guardrail systems reported above.

Researchers addressed basic requirements for the retrofit guardrail system, including accommodation of service loads, and developed design alternatives with the potential to meet impact performance requirements that provide other desirable functional characteristics. Specifically, researchers aimed to develop design options for a motorcycle-friendly guardrail system with the primary intent to limit severe and fatal injuries of impacting errant motorcyclists. The retrofit designs considered the impacts of errant riders in both sliding and upright configurations.

4.2. DESIGN OPTIONS

Design options discussed in this section are retrofit options to a standard MGS. The standard MGS consists of a post (W6x9 beam) at a 32-inch height above ground, a blockout 8 inches deep and 6 inches wide, and a top rail. The top of the beam and blockout are at 32 inches above the ground, while the top of the rail is at 31 inches above the ground.

Attachment of the protection system to the MGS is accomplished by bolting. The options suggested give a general idea of the anticipated behavior during an impact event. Future simulations may require modifications to the shape and dimensions of the protection system to further optimize the design to minimize injury severity. Design options were not devised to satisfy containment criteria of the rider but to minimize injury severity of the motorcyclist during an impact event.

4.2.1. Protection on Top

Figure 4.1 shows a bent plate top protection attached to a standard MGS. Option 1 consists of a plate bent to form a smooth vertex on top, gently sloping down and outward from the vertex and bent down at the ends to provide some vertical distance for attachment to the steel post. The top protection bent plate can be provided with the same material and thickness as that of the W-beam rail. Table 4.1 lists the advantages and disadvantages of Option 1.



Figure 4.1. Option 1 Conceptual Drawing for Bent Plate Top Protection.

Table 4.1. Option 1 Potential Advantages and Disadvantages for Bent Top Plate Protection.

Advantages	Disadvantages
1. The plate is deformed at its top. The bent shape provides opportunity for small vertical deformations during impact event with the ATD, which would act as an energy dissipation mechanism.	1. Need post drilling to allow for bolting connection at back of the post.
2. No special material required for the construction of this option. A 12-gauge standard steel material would be considered.	2. If post hole is drilled on site (retrofit), there is a need to re-galvanize the post hole (can be performed on site).
3. Shape can be formed with minimal effort from manufacturers.	3. If new installation, a post with punched hole already exists—however, it is more costly and would require proper inventory.
4. Plate is attached with one bolt to the steel post (back), minimizing the number of bolts drilling through the steel post.	
5. No attachment of the plate to the front W-beam or blockout. Plate is not constrained on one side (W-beam), providing more deformation flexibility during impact event with passenger vehicle.	
6. Provides a continuous post/blockout shielding option to the impacting motorcyclist.	
7. Installation can be performed on site, with no need for the existing system to be dismantled for application of the plate.	
8. No specific requirements for maintenance are anticipated.	
9. Minimal cost for material/construction and installation (cost effective).	
10. The retrofit option minimally alters the general characteristics of an existing MGS guardrail (e.g., height).	

Figure 4.2 shows a flat plate top protection attached to a standard steel-post MGS with 8-inch blockouts. Option 2 consists of a flat plate bent vertically at one end and sloped at the other end to accommodate attachment to the existing W-beam rail. Attachment is provided by a bolted connection at suitable intervals. Bent radius can be determined based on the required smoothness on top with reasonable dimensions. Top protection can be provided with the same material and thickness as that of a W-beam rail. Thickness can be reduced to a certain extent to provide adequate flexibility for

better rider protection during an impact event. Table 4.2 lists the advantages and disadvantages of Option 2.

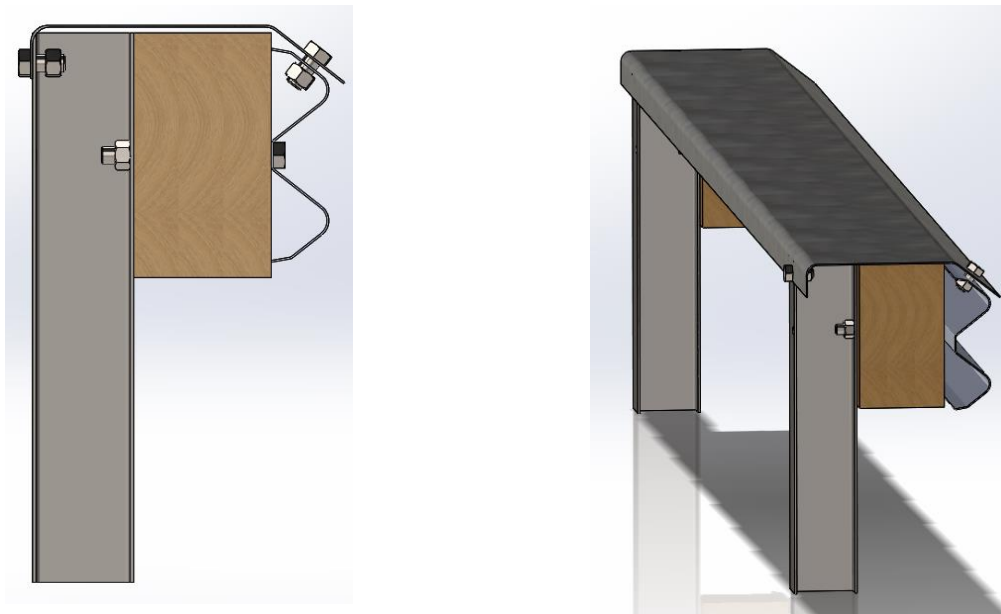


Figure 4.2. Option 2 Conceptual Drawing for Flat Plate Top Protection.

Table 4.2. Option 2 Potential Advantages and Disadvantages for Flat Plate Top Protection.

Advantages	Disadvantages
1. Provides a continuous post/blockout shielding option to the impacting motorcyclist.	1. Need post drilling to allow for bolting connection at back of the post.
2. No specific requirements for maintenance are anticipated.	2. Top width of the system provides less surface area for motorcyclist interaction while impacting in upright position.
3. Installation can be performed on site—requires replacement of W-beam rail with a special rail (with extra bolt slots) and attachment to posts and plate-rail connection on top. It can be a retrofit option, but the rail needs to be changed.	3. If post hole is drilled on site (retrofit), there is a need to re-galvanize the post hole (can be performed on site).
4. Being a continuous plate, it minimizes the possibility for multiple debris to be scattered during the impact event with a vehicle.	4. To provide sufficient bonding between top rail and plate, there is a need to provide enough in midspan connection to prevent buckling.
5. Minimally alters the general characteristics of an existing MGS guardrail (e.g., height).	5. Bolted connection of plate with top rail is exposed on the impact side of the system and might result in snagging interaction of ATD with bolts, resulting in injuries.
	6. Installation time is more compared to previous option since this option requires a new rail attachment on posts with flat plate connected on top.

Figure 4.3 shows a top protection cap for discrete posts of the standard MGS. Option 3 consists of a cap attached to the top of the steel post. Attachment is relatively easy and does not require a bolted connection. Top protection can be provided with a suitable thickness and appropriate dimensions that allow flexibility for implementation. Table 4.3 lists the advantages and disadvantages of Option 3.

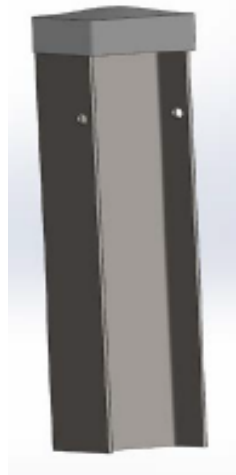


Figure 4.3. Option 3 Conceptual Drawing for Top Protection Cap for MGS Steel Posts.

Table 4.3. Option 3 Potential Advantages and Disadvantages for Top Protection Cap for MGS Steel Posts.

Advantages	Disadvantages
1. Minimal cost for material/ construction and installation (cost effective).	1. This option does not provide continuous protection throughout the barrier length.
2. The retrofit option minimally alters the general characteristics of an existing MGS guardrail (e.g., height).	2. Sides of the steel posts are exposed without protection in this option. Thus, rider can incur severe injuries due to direct impact on sides of post.
3. Minimal possibility for multiple debris to be scattered during the impact event with a vehicle.	3. Post cap does not provide energy dissipation mechanism.
4. Minimal installation time required on site (limited worker exposure).	4. Higher tolerances for fitting the cap on the post.

4.2.2. Protection on Bottom

Figure 4.4 shows a flat bottom protection for a steel-post MGS. Option A consists of a round-cornered flat bottom plate attached to the posts with two bolts (at the top and bottom of the plate). The plate is spaced at a suitable distance from the post to allow adequate deformation when a motorcyclist impacts while sliding. The plate is smoothly bent at the ends to provide sufficient length for bolting. The thickness and material of the bottom plate can be the same as those of the standard MGS top rail. However, thickness can be investigated through computer simulations to provide flexibility to dissipate adequate energy after motorcyclist impact to lower injury risk. The distance

between the flat bottom rail and the existing W-beam rail should be minimized to prevent any chance for motorcyclist limbs entangling between the rail and bottom protection. Table 4.4 lists the advantages and disadvantages of Option A.

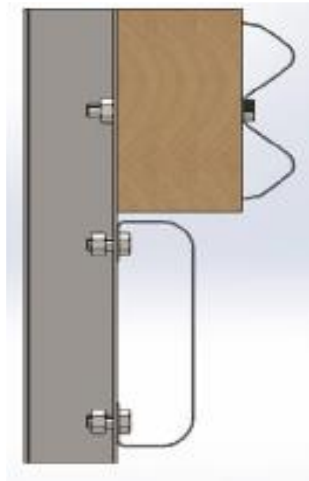


Figure 4.4. Option A Conceptual Drawing for Flat Plate for Bottom Protection.

Table 4.4. Option A Potential Advantages and Disadvantages for Flat Plate for Bottom Protection.

Advantages	Disadvantages
1. The flat shape provides opportunity for dissipation of energy of impacting motorcyclist by accommodating small deformations during impact event.	1. Need post drilling to allow for bolting connection to the post. Two bolted connections are required at each post to provide bottom protection.
2. Provides a continuous post shielding option at bottom for the sliding motorcyclist.	2. Post drilling on site requires workers to be exposed on the traffic lane.
3. Flat plate is flexible to length criteria and thus can be made available in different lengths to take care of height tolerances at different sites.	3. Post galvanization is compromised during post drilling on site—need for post re-galvanization at hole site.
4. Flat plate acts like a rubrail at bottom. This minimizes risk of vehicle snagging after impacting system, especially in a no-blockout condition when vehicle snagging is a major risk.	4. Although plate might act as rubrail and limit vehicle snagging potential, it may cause vehicle ramping and instability.
5. Manufactured as one piece with no sharp edges, preventing severe injuries (“knifing” consequences) to the motorcyclist sliding on the system during impact event.	
6. Installation can be performed on site—no need for existing system to be dismantled for application of the suggested plate.	
7. No specific requirements for maintenance are anticipated.	
8. Minimal cost for material/ construction and installation (cost effective).	

Figure 4.5 shows a flat plate bottom protection for a steel-post MGS. Option B consists of a continuous rubrail attached to the upper W-beam rail and blockout through discrete connection plates. The plates are inserted between the top rail and the blockout through a single bolt connection. The rubrail could be inclined at an angle. The thickness and material of the plates and rubrail can be the same as those of a standard W-beam. However, thickness can be reduced based on computer simulations to provide

flexibility and energy dissipation during motorcyclist impact. The distance between the flat bottom rail and the existing W-beam rail should be minimized to reduce the chance for motorcyclist limbs entangling between the rail and bottom protection. Table 4.5 lists the advantages and disadvantages of Option B.

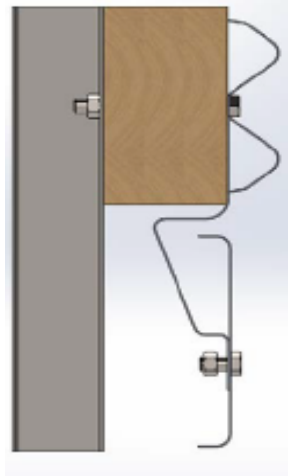


Figure 4.5. Option B Conceptual Drawing for Flat Plate Attached to Connection Plates.

Table 4.5. Option B Potential Advantages and Disadvantages for Flat Plate Attached to Connection Plates.

Advantages	Disadvantages
1. The plate shape and attachment provide opportunity for dissipation of energy of impacting motorcyclist by accommodating small deformations and rotation during impact event.	1. Installation requires existing rail to be dismantled for attachment of the suggested plate to blockout or post.
2. Provides a continuous post shielding option at bottom to the sliding motorcyclist.	2. Although plate might act as rubrail and limit vehicle snagging potential, it may cause vehicle ramping and instability.
3. No need for post drilling for bolting connection since bolting can be done through the previously available bolt hole for blockout/post.	
4. No special material required for construction of this option. A 12-gauge standard steel material would be considered.	
5. Shape can be formed with minimal effort from manufacturers.	
6. Manufactured as one piece, with no sharp edges, preventing severe injuries (“knifing” consequences) to the motorcyclist sliding on the system during impact event.	
7. No specific requirements for maintenance are anticipated.	
8. Plate acts like a rubrail at bottom. This minimizes risk of vehicle snagging after impacting system, especially in a no-blockout condition when vehicle snagging is a major risk.	
9. Minimal cost for material/ construction and installation (cost effective).	

Figure 4.6 shows the inclined plate for bottom protection for a steel-post MGS. Option C consists of a continuous plate attached to the front of the posts of the MGS and then bent to form an incline at the bottom to accommodate a sliding rider during an impact event. The thickness and material of the plate can be the same as those of the standard MGS top rail. However, thickness can be reduced based on computer simulations to provide flexibility and therefore energy dissipation during motorcyclist impact. The bottom end of the plate should be at a suitable height from the ground to prevent accumulation of debris at the bottom. The advantages and disadvantages for this option are similar to Option A (Table 4.4).

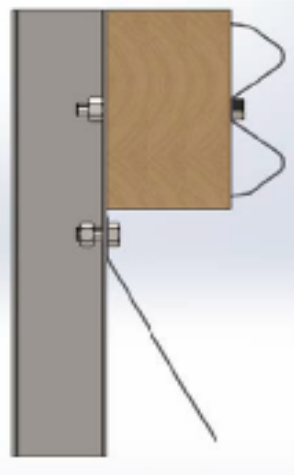


Figure 4.6. Option C Conceptual Drawing for Inclined Plate Attached to Posts.

4.3. CONCLUSIONS

Table 4.6 and Table 4.7 summarize the proposed design options for protection on the top and bottom for a standard steel-post MGS with 8-inch blockouts.

The various design options were reviewed and discussed with the TxDOT project team panel. Option 1 and Option C were prioritized for further evaluation through computer simulations. These evaluations are presented in the next chapter (Chapter 5). Additionally, the design focused on the use of round wood posts instead of steel posts.

Table 4.6. Proposed Design Options for Top Protection.

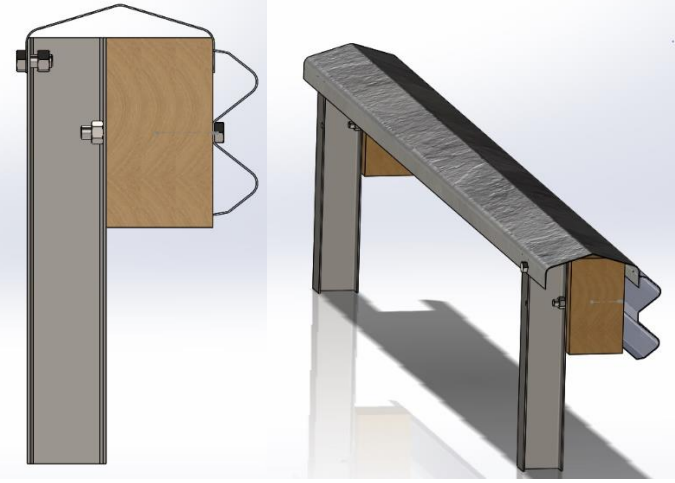
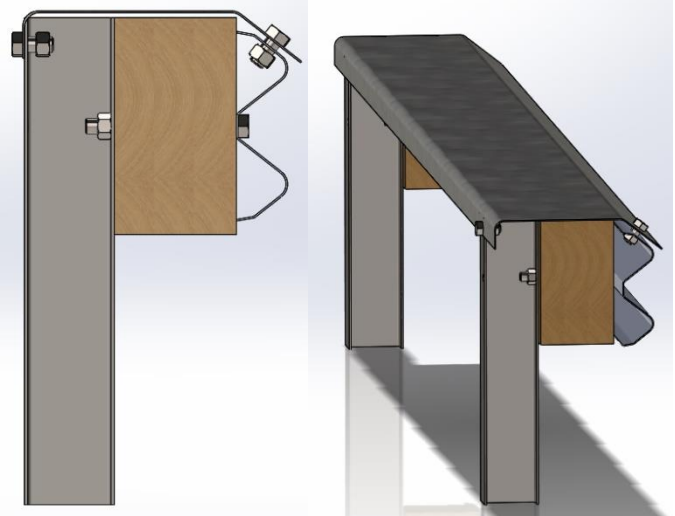
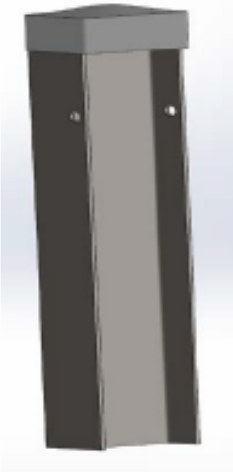
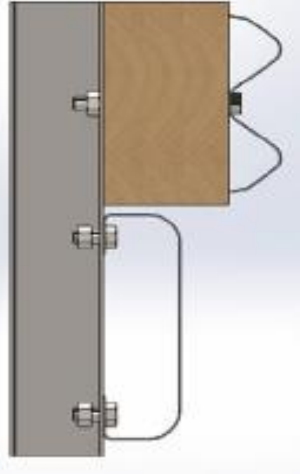
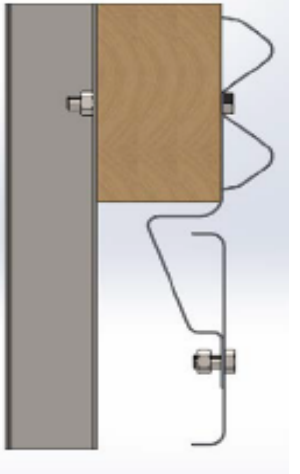
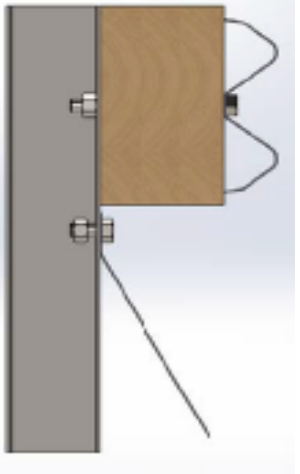
Design Option	Visual Concept
Option 1	
Option 2	
Option 3	

Table 4.7. Proposed Design Options for Bottom Protection.

Design Option	Visual Concept
Option A	
Option B	
Option C	

Chapter 5. COMPUTER SIMULATIONS

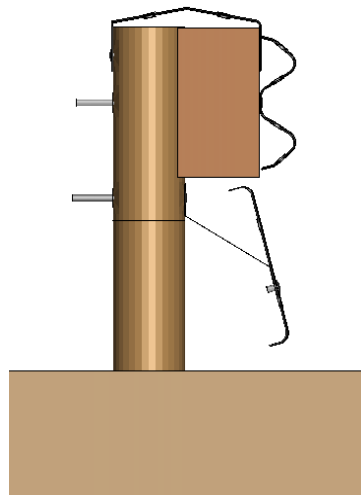
The ability of the design to meet impact performance requirements and provide desirable functional characteristics was evaluated by engineering analyses. The evaluation involved the use of finite element (FE) models and impact simulations.

An FE model of the selected design was developed, and LS-DYNA was used to perform impact simulations. The design was evaluated according to *MASH TL-3* and according to upright and sliding motorcyclist impact configurations. Figure 5.1 shows the motorcycle and Hybrid III 50th percentile ATD model. The ATD FAST Hybrid III 50th percentile model was developed by LSTC. The simulation results were used to evaluate whether any design modifications were required to the developed design system to increase the likelihood of meeting the project objectives before proceeding with full-scale crash testing.

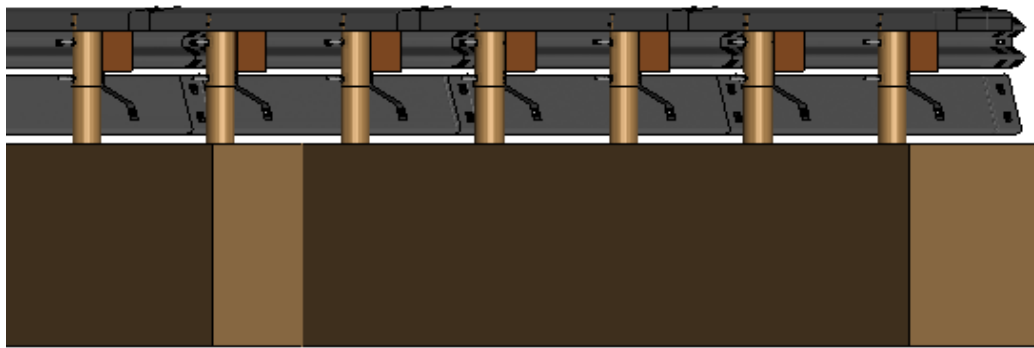


Figure 5.1. Motorcycle and ATD FE Model.

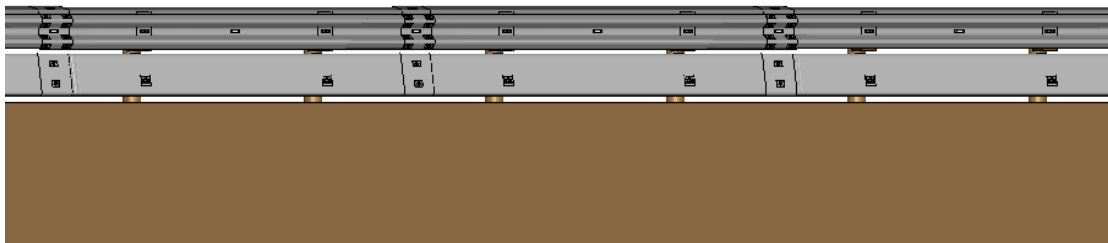
Figure 5.2 shows the model that was developed to retrofit the existing guardrail system to address errant motorcyclists' safety. This model included the top rail and rubrail design options.



(a) Side View



(b) Perspective Rear



(c) Perspective Front

Figure 5.2. FE Model of Retrofit Guardrail System.

5.1. UPRIGHT MOTORCYCLE IMPACT

The developed retrofitted computer model was used to perform simulations with a motorcycle and ATD computer model. The purpose of this simulation was to verify the general behavior of the guardrail retrofitted system during a motorcycle-rider impact event, as well as to understand the ATD interaction with the barrier during impact. The

impact conditions were determined by referring to literature of previous sliding motorcycle crash tests. The impact angle of the motorcycle with rider was 30 degrees, and the impact velocity was 37 mi/h. Figure 5.3 shows sequential images of the simulation.

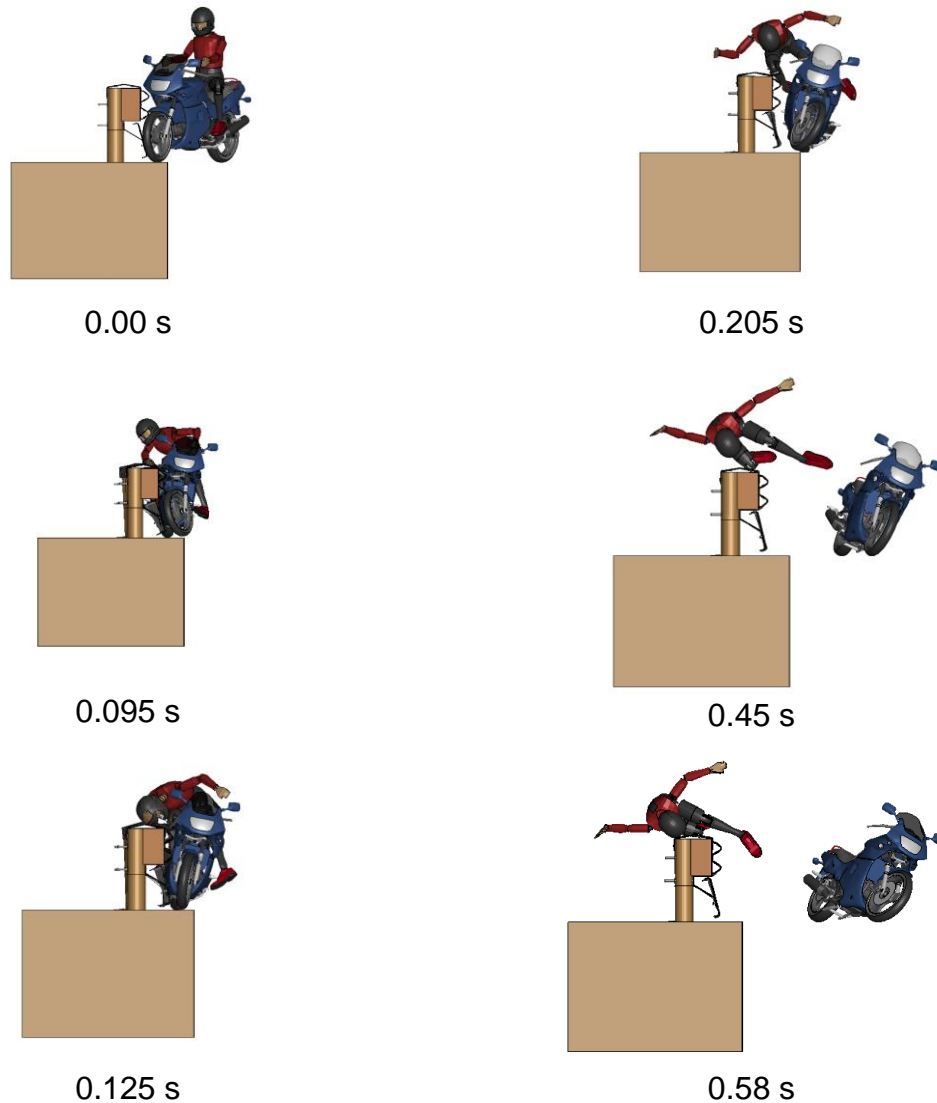


Figure 5.3. Sequential Images of Upright Motorcyclist Impact with Barrier.

During initial impact with the guardrail, the ATD began ejecting from the motorcycle and sliding across the top of the system. The ATD eventually traversed to the field side of the system. No significant snagging of any ATD limbs with the guardrail system was observed. Thus, the system appeared adequate in minimizing ATD interaction with discrete elements of the guardrail system.

5.2. MASH TEST 3-11 IMPACT

A pickup truck FE model was used to impact the retrofit guardrail system according to *MASH* Test 3-11. The impact speed was 62 mi/h, and the impact angle was 25 degrees. Figure 5.4 shows sequential images of the simulation impact.

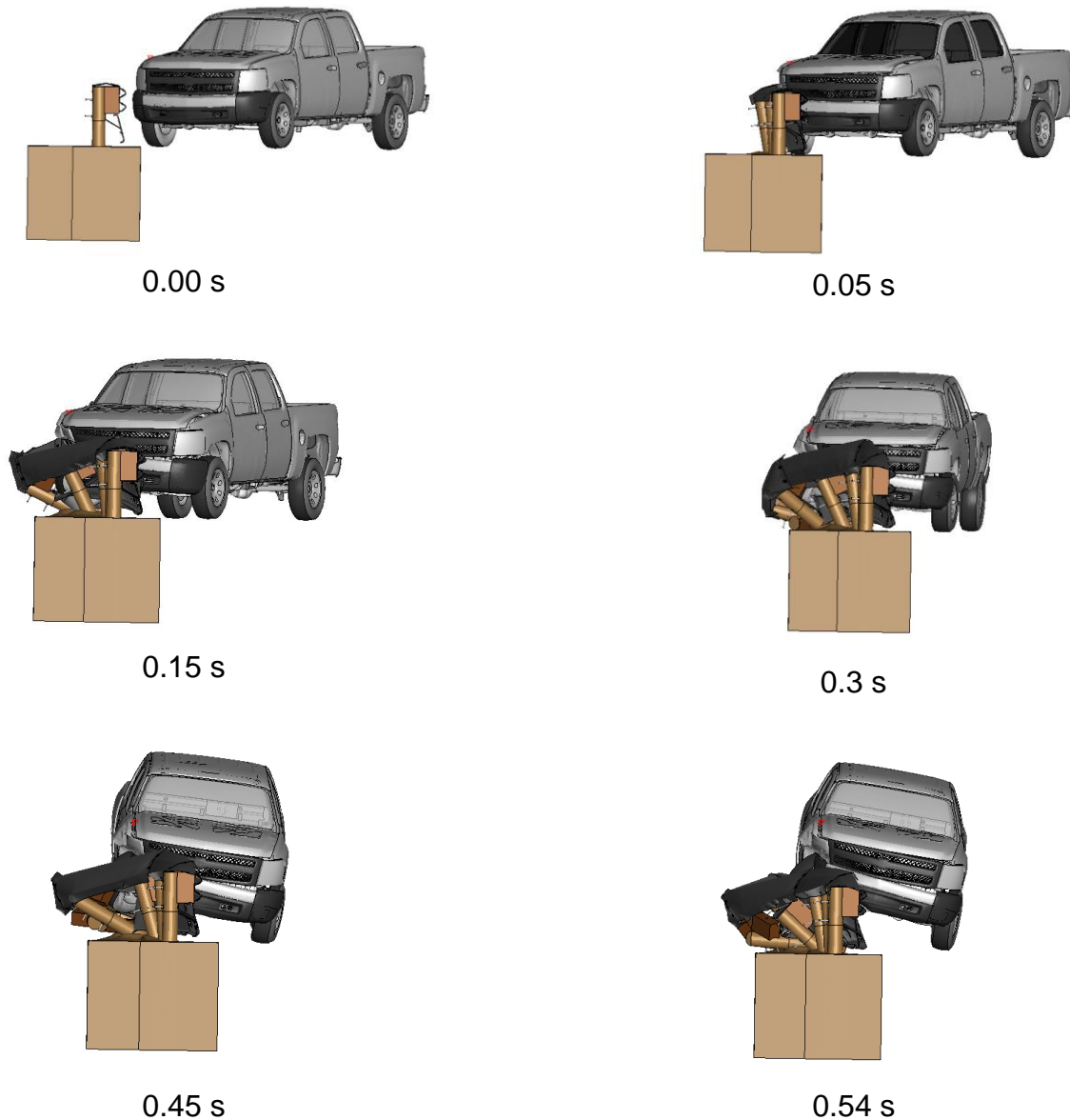


Figure 5.4. Sequential Images of *MASH* Test 3-11 Impact with Barrier.

The pickup truck was successfully contained and redirected during impact with the guardrail system. The vehicle remained stable throughout the event, and the occupant risk values were below the *MASH* limit. During the impact event, however, it was noted that the pickup truck pushed down on the rubrail element and seemed to keep riding on top of it. Although it appeared that riding on top of the rubrail did not

interfere with the vehicle stability and overall integrity of the system, additional design modifications were investigated to improve the crashworthiness of the system.

5.3. DESIGN MODIFICATION

A modification was made to the system to attach the rubrail with minimal offset from the wood posts to reduce some of the noted pickup truck interaction with the rubrail. Figure 5.5 shows a cross-section view of the modified system.

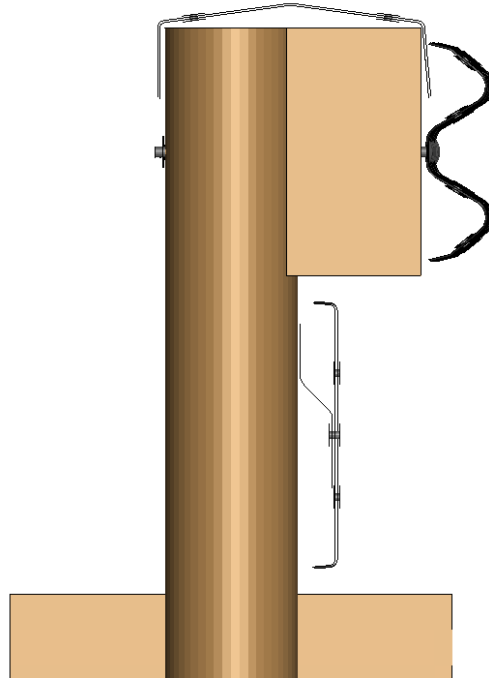


Figure 5.5. FE Model of Modified Retrofit Guardrail System.

After the system was modified, simulations were conducted with the ATD model sliding into the system at a speed of 37 mi/h and an angle of 30 degrees. Figure 5.6 shows a layout of the simulation event with the ATD impacting in line with the wood post. The rubrail indicated the ability to contain and redirect the ATD during impact, and no snagging of limbs on discrete elements was observed.

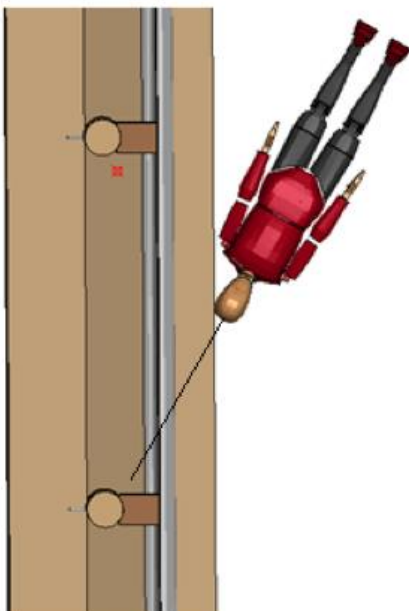


Figure 5.6. ATD Sliding Impact with System.

Based on the results of the FE simulations conducted, the retrofit guardrail system with a top rail and lower rubrail element indicated satisfactory performance for *MASH* impact and motorcyclist impacts. The next step was to evaluate the system with full-scale crash testing.

Chapter 6. SYSTEM DETAILS

6.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation was 181 ft 3 inches long, with a DAT terminal at each end. It consisted of 156 ft 3 inches of timber posts and 14-inch tall blockouts, spaced at 75 inches, which supported a W-beam traffic rail, a rubrail below the W-beam, and a cap rail that covered the top of the posts and blockouts. The top edge of the W-beam was at 31 inches above grade. The 7½-inch diameter timber posts were 68 inches long, with a flat top instead of domed.

The bottom edge of the rubrail was 1½ inches above grade for the 469940 tests and 1 inch above grade for the 469942 and 466943 tests. A bracket made of a bent plate secured the rubrail to the posts. The rubrail was parallel to the posts for the 469940 tests, at 10 degrees for the 469942 test, and at 20 degrees for the 469943 tests.

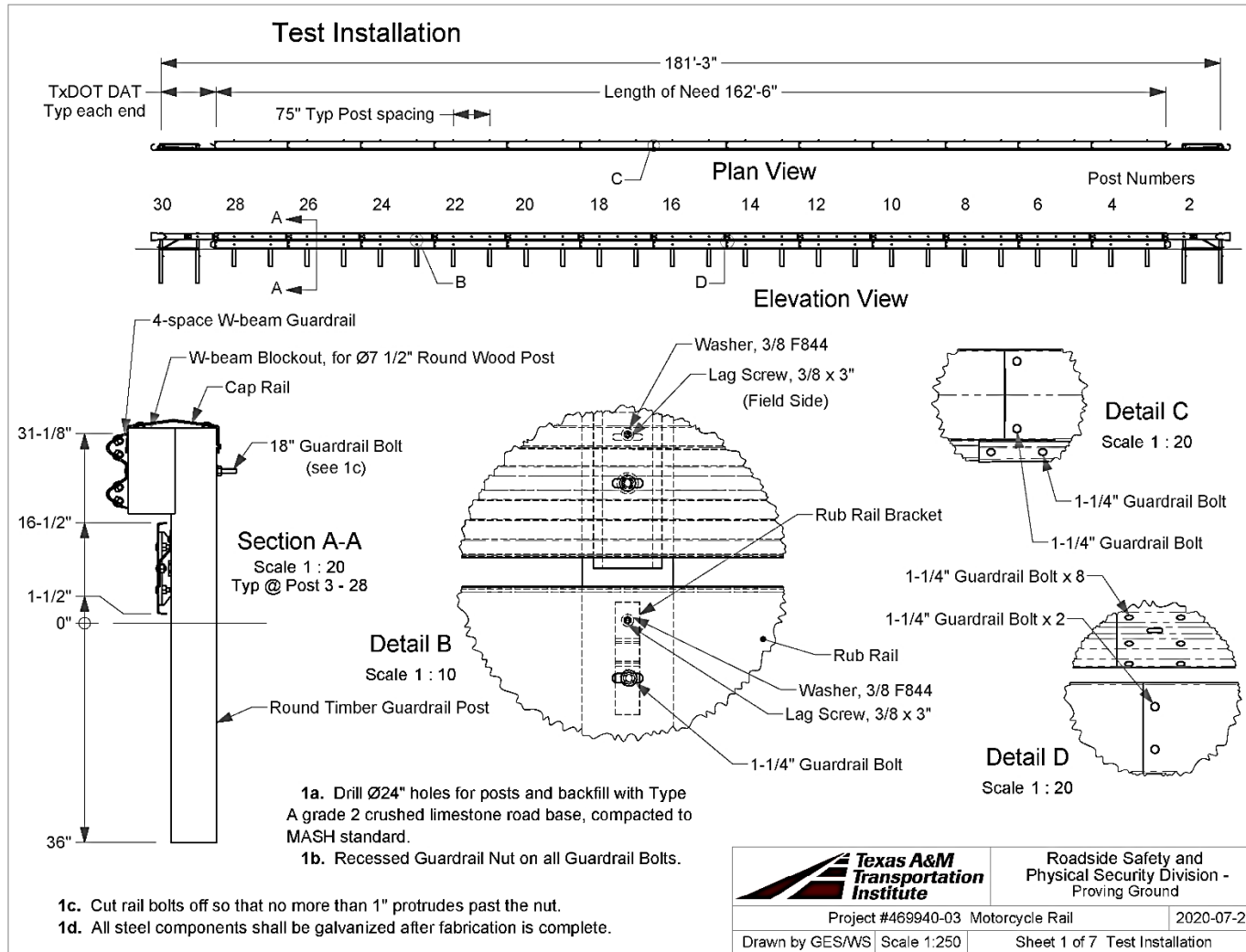
The rubrails for the 469940 tests were 12 ft 10 inches long, with two bolts at each joint. The rubrails for the 469942 and 469943 tests were 13 ft 2 inches long, with four bolts at each joint. They were 14¾ inches wide for all tests.

Figure 6.1 presents the overall information on the enhanced motorcycle guard fence system installed for the 469940 tests, and Figure 6.2 through Figure 6.7 provide photographs of the installation. Figure 6.8 presents the overall information on the enhanced motorcycle guard fence system installed for the 469942 test, and Figure 6.9 and Figure 6.10 provide photographs of the installation. Figure 6.11 presents the overall information on the enhanced motorcycle guard fence system installed for the 469943 tests, and Figure 6.12 and Figure 6.13 provide photographs of the installation.

Appendix A provides further details on the enhanced motorcycle guard fence system. Drawings were provided by the TTI Proving Ground, and construction was performed by an approved vendor and supervised by TTI Proving Ground personnel.

6.2. DESIGN MODIFICATIONS DURING TESTS

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



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Figure 6.1. Details of Enhanced Motorcycle Guard Fence System for Crash Tests 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.



Figure 6.2. Enhanced Motorcycle Guard Fence System prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.



Figure 6.3. Enhanced Motorcycle Guard Fence System Rail Detail prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.



Figure 6.4. Field-Side View of the Enhanced Motorcycle Guard Fence System prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.



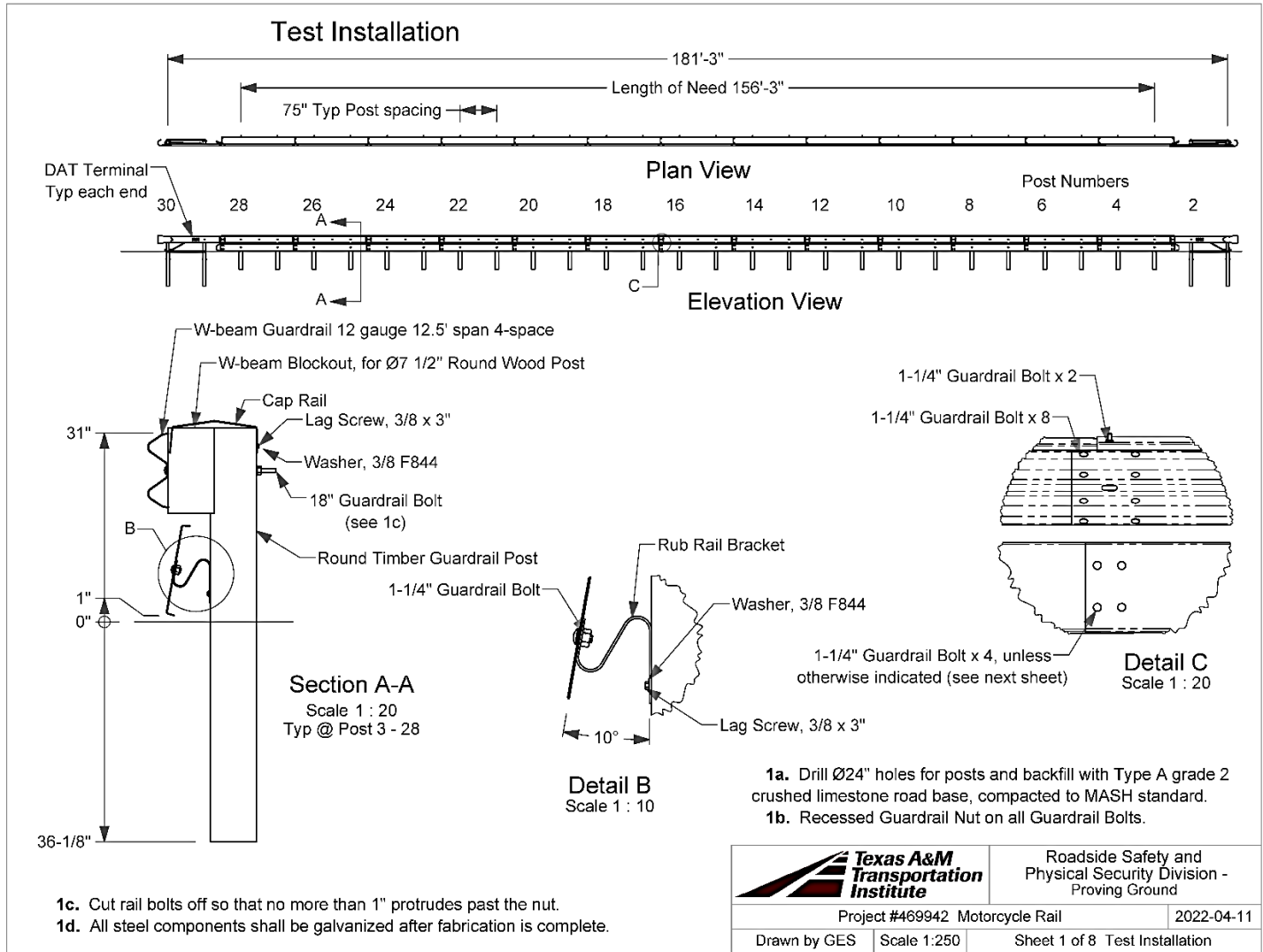
Figure 6.5. Enhanced Motorcycle Guard Fence System Rubrail Bracket Detail prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.



Figure 6.6. Enhanced Motorcycle Guard Fence System W-Beam Hardware Detail prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.



Figure 6.7. Enhanced Motorcycle Guard Fence System Cap Rail Hardware Detail prior to Testing for 469940-03-1, 469940-03-2, 469940-03-3, and 469940-03-4A.



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Figure 6.8. Details of Enhanced Motorcycle Guard Fence System for Crash Test 469942-01-1.



Figure 6.9. Field-Side View of the Enhanced Motorcycle Guard Fence System prior to Testing for 469942-01-1.



Figure 6.10. Enhanced Motorcycle Guard Fence System Rubrail Bracket Detail prior to Testing for 469942-01-1.

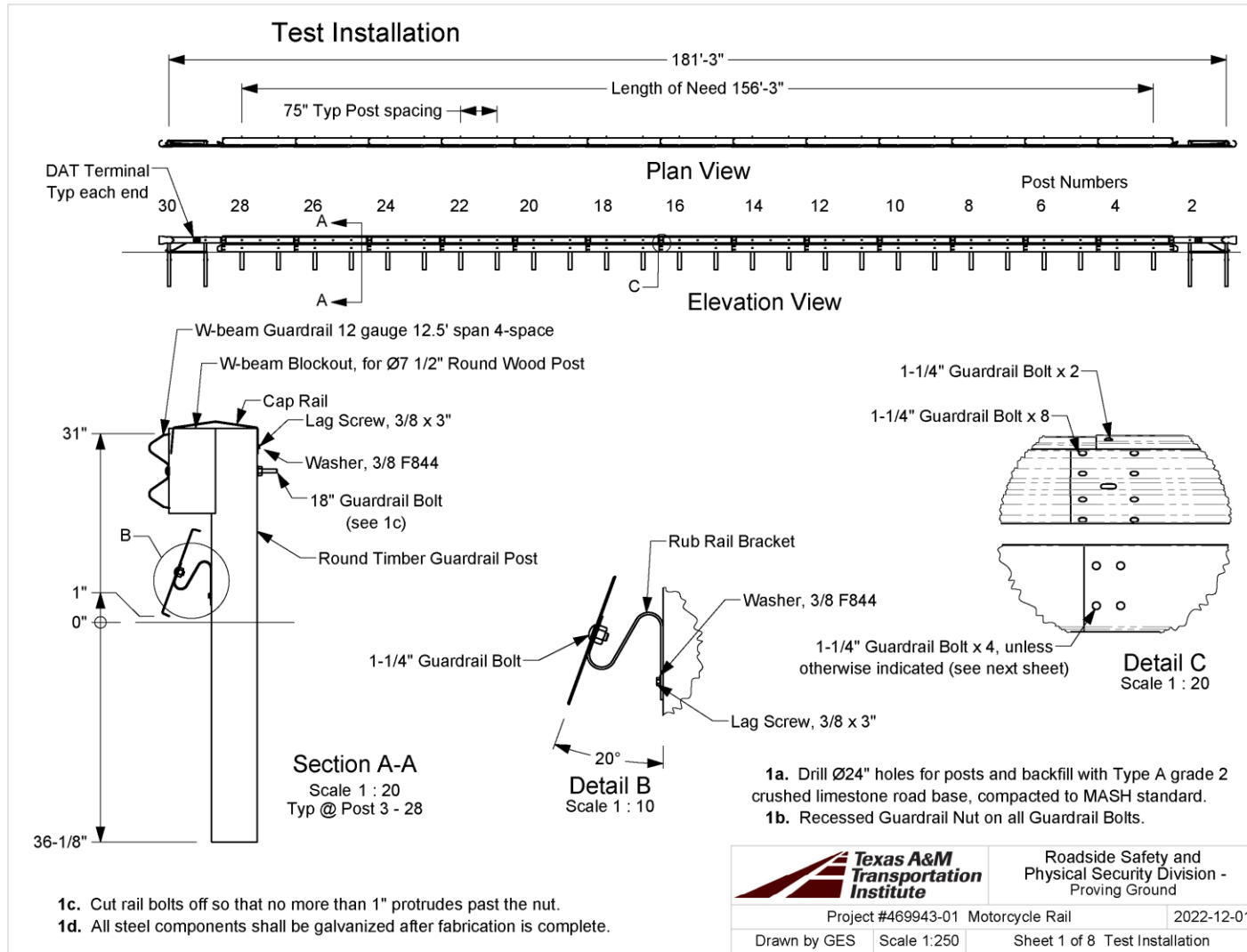


Figure 6.11. Details of Enhanced Motorcycle Guard Fence System for Crash Tests 469943-01-1A, 469943-01-2, 469943-01-3, and 469943-01-4.

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Figure 6.12. Field-Side View of the Enhanced Motorcycle Guard Fence System prior to Testing for 469943-01-1A, 469943-01-2, 469943-01-3, and 469943-01-4.



Figure 6.13. Enhanced Motorcycle Guard Fence System Rubrail Detail prior to Testing for 469943-01-1A, 469943-01-2, 469943-01-3, and 469943-01-4.

6.3. MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the enhanced motorcycle guard fence system.

The test installation was installed in standard soil meeting Type 1 Grade D of AASHTO standard specification M147-17 “Materials for Aggregate and Soil Aggregate Subbase, Base, and Surface Courses.”

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

On the day of Test 469940-03-1, August 5, 2020, loads on the post at deflections were as shown in Table 6.1. The backfill material in which the enhanced motorcycle guard fence system was installed met minimum *MASH* requirements for soil strength.

Table 6.1. Soil Strength for Test 469940-03-1.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	3940	6313
10	5500	6616
15	6540	7727

On the day of Test 469940-03-2, August 7, 2020, loads on the post at deflections were as shown in Table 6.2. The backfill material in which the enhanced motorcycle guard fence system was installed met minimum *MASH* requirements for soil strength.

Table 6.2. Soil Strength for Test 469940-03-2.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	3940	7323
10	5500	8181
15	6540	8383

On the day of Test 469940-03-3, August 14, 2020, loads on the post at deflections were as shown in Table 6.3. The backfill material in which the enhanced motorcycle guard fence system was installed met minimum *MASH* requirements for soil strength.

Table 6.3. Soil Strength for Test 469940-03-3.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	3940	9191
10	5500	9747
15	6540	9848

On the day of Test 469943-01-3, January 3, 2023, loads on the post at deflections were as shown in Table 6.4. The backfill material in which the enhanced motorcycle guard fence system was installed met minimum *MASH* requirements for soil strength.

Table 6.4. Soil Strength for Test 469943-01-3.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	5484
10	4981	6090
15	5282	6121

On the day of Test 469943-01-4, May 18, 2023, loads on the post at deflections were as shown in Table 6.5. The backfill material in which the enhanced motorcycle guard fence system was installed met minimum *MASH* requirements for soil strength.

Table 6.5. Soil Strength for Test 469943-01-4.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	4727
10	4981	5606
15	5282	6000

Chapter 7. TEST REQUIREMENTS AND EVALUATION CRITERIA

7.1. CRASH TEST PERFORMED/MATRIX

Table 7.1 shows the test conditions and evaluation criteria for the crash tests conducted on the enhanced motorcycle guard fence system. The target critical impact points (CIPs) for Tests 469940-03-1, 469940-03-2, 469943-01-3, and 469943-01-4 were determined using the information provided in *MASH* Section 2.2.1 and Section 2.3.2. The test condition for Test 469940-03-3 was for research purposes and was not based on any standard or specification. Test conditions for Tests 469940-03-4A, 469942-01-1, 469943-01-1A, and 469943-01-2 were based on criteria from EN 1317-8. Figure 7.1 through Figure 7.6 show the target CIPs for the various tests conducted on the enhanced motorcycle guard fence system.

Table 7.1. Test Conditions and Evaluation Criteria Specified for the Crash Tests on Enhanced Motorcycle Guard Fence System.

Test Number	Test Designation	Test Vehicle	Impact Speed	Impact Angle	Evaluation Criteria
469940-03-1 & 469943-01-3	<i>MASH</i> 3-10	1100C	62 mi/h	25°	A, D, F, H, I
469940-03-2 & 469943-01-4	<i>MASH</i> 3-11	2270P	62 mi/h	25°	A, D, F, H, I
469940-03-3	N/A	Motorcycle and ATD	37.3 mi/h	15°	N/A
469940-03-4A, 469942-01-1, 469943-01-1A, & 469943-01-2	EN 1317-8 (Modified)	ATD	37.3 mi/h	30°	N/A

Note: N/A = not applicable.

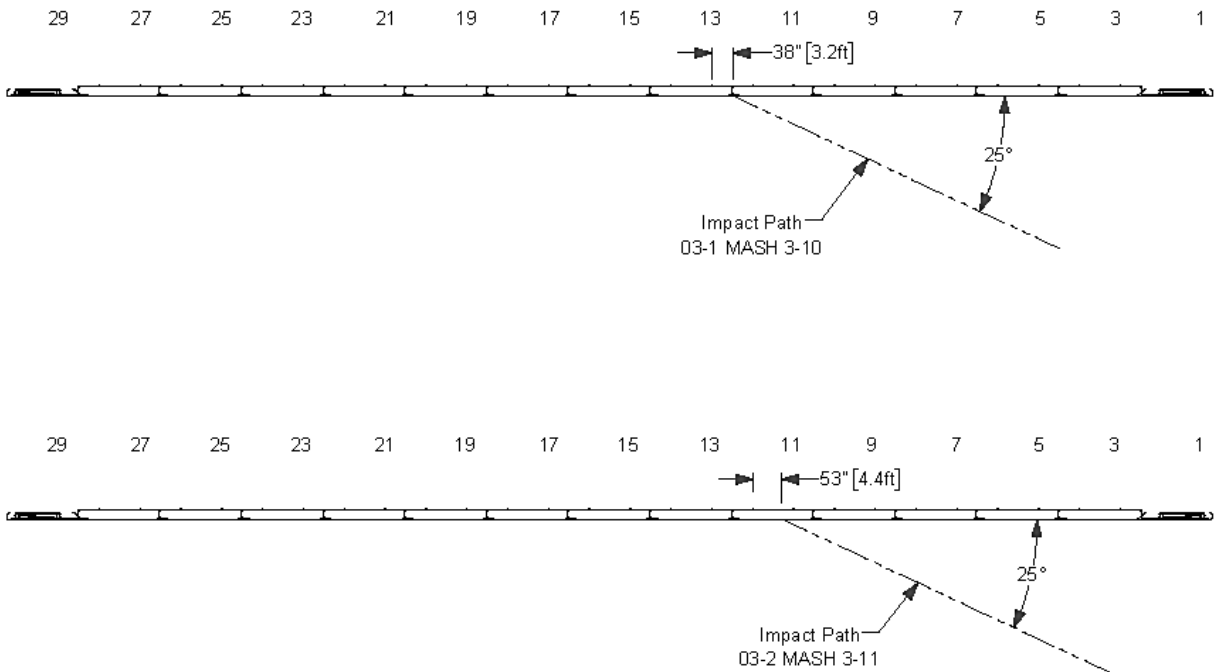


Figure 7.1. Target CIP for 469940-03-1 and 469940-03-2 Crash Tests on Enhanced Motorcycle Guard Fence System.

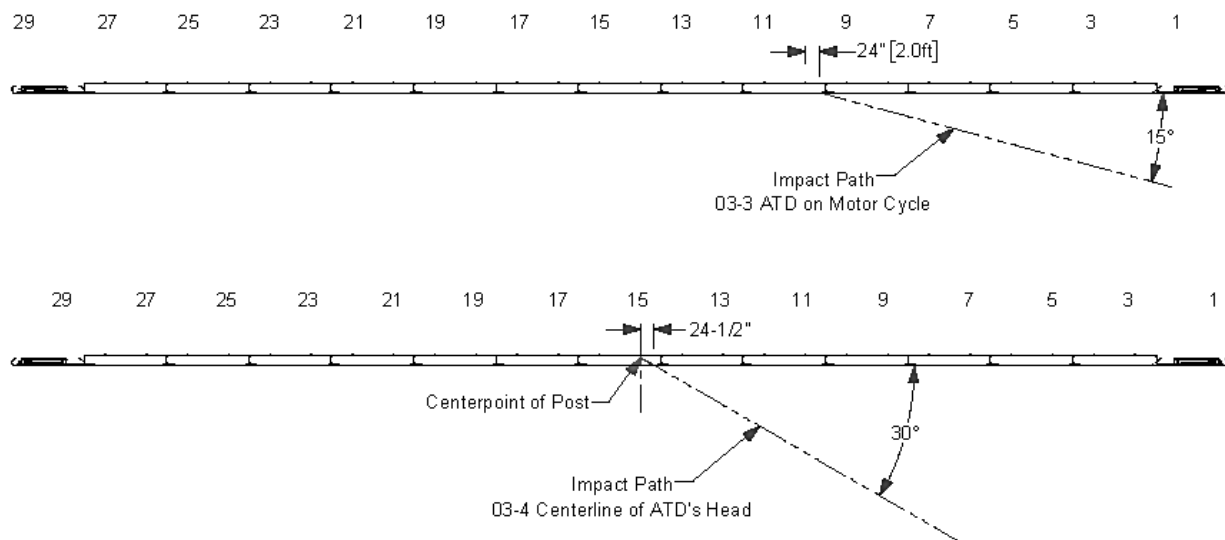


Figure 7.2. Target CIP for 469940-03-3 and 469940-03-4A Crash Tests on Enhanced Motorcycle Guard Fence System.

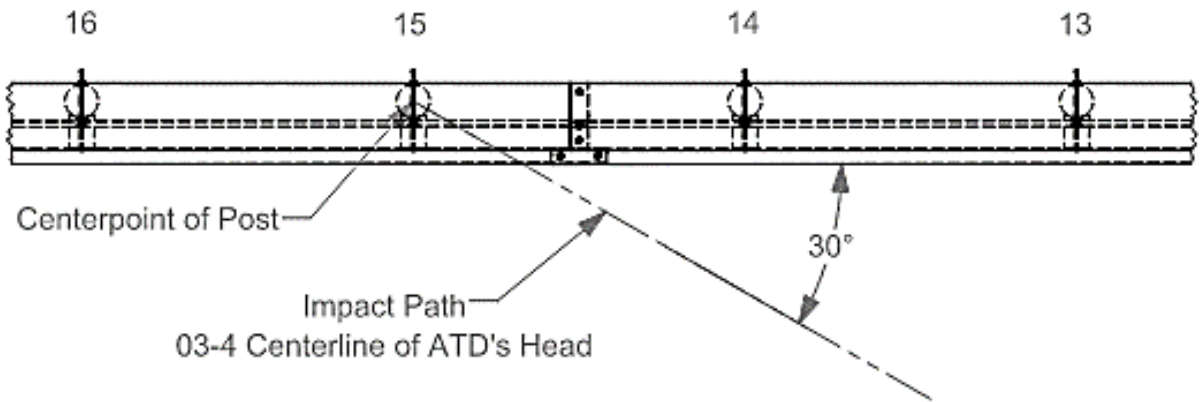


Figure 7.3. Target CIP for 469942-01-1 Crash Test on Enhanced Motorcycle Guard Fence System.

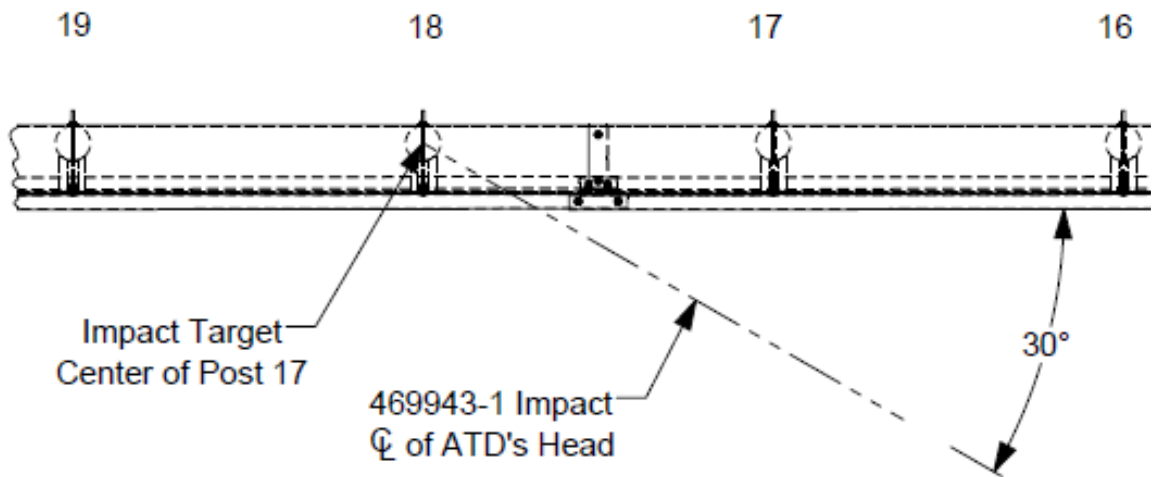


Figure 7.4. Target CIP for 469943-01-1A Crash Test on Enhanced Motorcycle Guard Fence System.

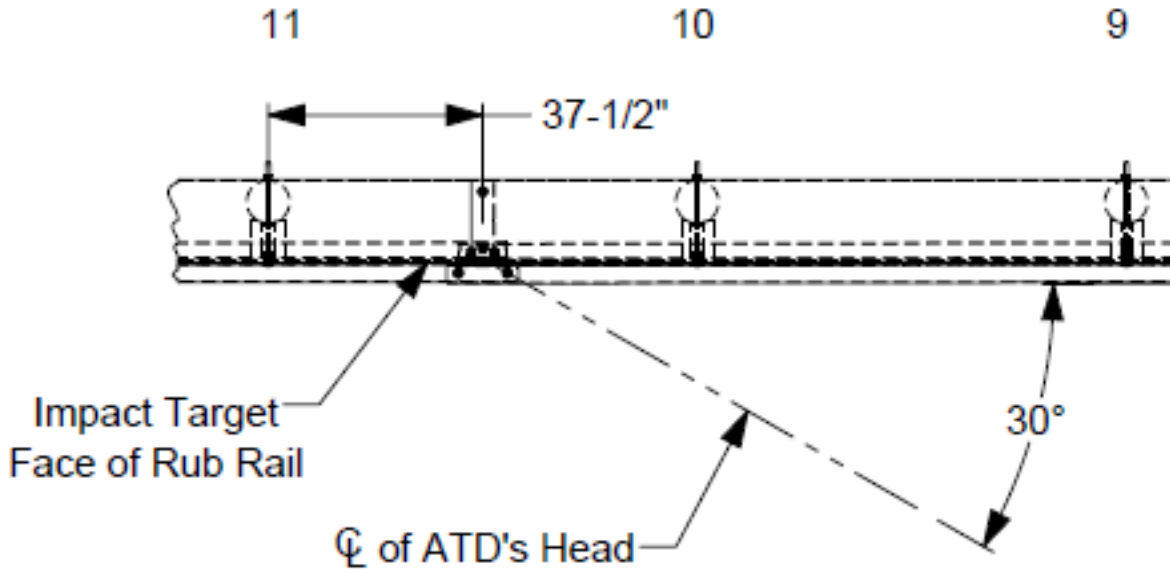


Figure 7.5. Target CIP for 469943-01-2 Crash Test on Enhanced Motorcycle Guard Fence System.

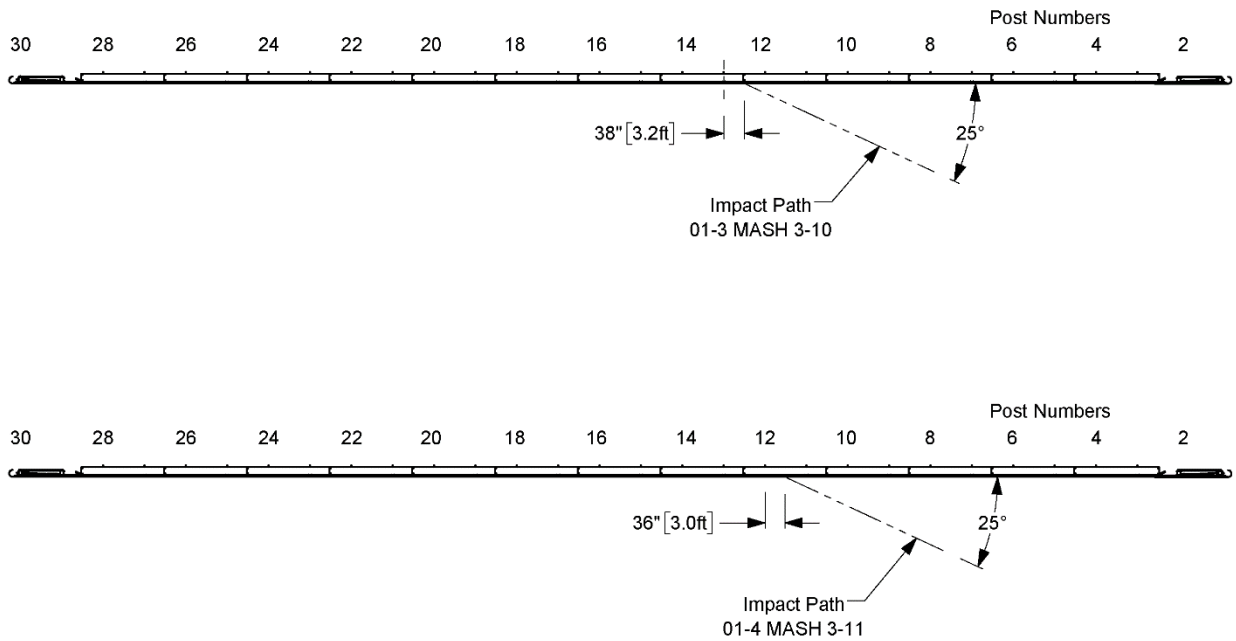


Figure 7.6. Target CIP for 469943-01-3 and 469943-01-4 Crash Tests on Enhanced Motorcycle Guard Fence System.

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 8 presents brief descriptions of these procedures.

7.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2.2 and 5.1 of *MASH* were used to evaluate the 469940-03-1, 469940-03-2, 469943-01-3, and 469943-01-4 crash tests reported herein. Table 7.1 lists the test conditions and evaluation criteria required for *MASH* TL-3, and Table 7.2 provides detailed information on the evaluation criteria.

Table 7.2. Evaluation Criteria Required for *MASH* Testing.

Evaluation Factors	Evaluation Criteria
A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the test article is acceptable.
D.	Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of <i>MASH</i> .
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.
H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.
I.	The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.

For crash tests 469940-03-4A, 469942-01-1, 469943-01-1A, and 469943-01-2, tables are presented in their respective chapters to show the measured injury indices for the head and neck of the ATD. These values were compared to the maximum injury criteria values described in EN 1317-8 protocols.

Chapter 8. TEST CONDITIONS

8.1. TEST FACILITY

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

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

8.2. 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.

8.3. DATA ACQUISITION SYSTEMS

8.3.1. 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/compartiment impact velocities, time of occupant/compartiment impact after vehicle impact, and highest 10-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 ($k = 2$).

8.3.2. Anthropomorphic Dummy Instrumentation

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

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

A Humanetics Hybrid III 50th percentile male anthropomorphic dummy was used for the upright motorcycle crash test, Test 469940-03-3, and the sliding ATD crash tests, Tests 469940-03-4A, 469942-01-1, 469943-01-1A, and 469943-01-2. The dummy was instrumented and equipped with standard motorcyclist clothing, gear, and a U.S. Department of Transportation–approved helmet.

8.3.3. 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 enhanced motorcycle guard fence system. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

Chapter 9. MASH TEST 3-10 (CRASH TEST 469940-03-1)

9.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 9.1 for the *MASH* impact conditions and Table 9.2 for the exit parameters for Test 469940-03-1. Figure 9.1 and Figure 9.2 depict the target impact setup.

Table 9.1. Impact Conditions for *MASH* Test 3-10, Crash Test 469940-03-1.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	63.1
Impact Angle (deg)	25	±1.5°	25.1
Impact Severity (kip-ft)	51	≥51 kip-ft	58.4
Impact Location	38 inches upstream from the centerline of post 13	±12 inches	35.2 inches upstream from the centerline of post 13

Table 9.2. Exit Parameters for *MASH* Test 3-10, Crash Test 469940-03-1.

Exit Parameter	Measured
Speed (mi/h)	43.4
Trajectory (deg)	17.0
Heading (deg)	13.2
Brakes applied post impact (s)	3.7
Vehicle at rest position	219 ft downstream of impact point 130 ft to the traffic side 80° left
Comments:	Vehicle remained upright and stable. Vehicle crossed exit box ^a 29 ft downstream from loss of contact.

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



Figure 9.1. Enhanced Motorcycle Guard Fence System/Test Vehicle Geometrics for Test 469940-03-1.



Figure 9.2. Enhanced Motorcycle Guard Fence System/Test Vehicle Impact Location for Test 469940-03-1.

9.2. WEATHER CONDITIONS

Table 9.3 provides the weather conditions for Test 469940-03-1.

Table 9.3. Weather Conditions for Test 469940-03-1.

Date of Test	2020-08-05 AM
Wind Speed (mi/h)	7
Wind Direction (deg)	198
Temperature (°F)	85
Relative Humidity (%)	75
Vehicle Traveling (deg)	15

9.3. TEST VEHICLE

Figure 9.3 and Figure 9.4 show the 2014 Nissan Versa used for the crash test. Table 9.4 shows the vehicle measurements. Figure C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.



Figure 9.3. Impact Side of Test Vehicle before Test 469940-03-1.



Figure 9.4. Opposite Impact Side of Test Vehicle before Test 469940-03-1.

Table 9.4. Vehicle Measurements for Test 469940-03-1.

Test Parameter	Specification	Tolerance	Measured
Dummy (if applicable) ^a (lb)	165	N/A	165
Inertial Weight (lb)	2420	±55	2440
Gross Static ^a (lb)	2585	±55	2605
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	40.2
CG above Ground ^{c,d} (inches)	N/A	N/A	N/A

Note: N/A = not applicable; CG = center of gravity.

^a If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.

^b Average of front and rear axles.

^c For test inertial mass.

^d 2270P vehicle must meet minimum CG height requirement.

9.4. TEST DESCRIPTION

Table 9.5 lists events that occurred during Test 469940-03-1. Figures C.4, C.5, and C.6 in Appendix C.2 present sequential photographs during the test.

Table 9.5. Events during Test 469940-03-1.

Time (s)	Events
0.000	Vehicle contacted the installation
0.047	Top cover began to lift off rail
0.048	Vehicle began to redirect
0.182	Right rear quarter panel impacted rail
0.210	Vehicle was parallel with guardrail
0.379	Vehicle exited guardrail at 43.4 mi/h, with a trajectory of 17.0 degrees and heading of 13.2 degrees

9.5. DAMAGE TO TEST INSTALLATION

There was no movement at the end terminals. Post 13 was cracked at grade, the blockout was missing from post 14, and the lower channel was detached from post 14. Table 9.6 details the soil gap and post lean information.

Table 9.7 describes the deflection and working width of the enhanced motorcycle guard fence system. Figure 9.5 and Figure 9.6 show the damage to the enhanced motorcycle guard fence system.

Table 9.6. Soil Gap and Post Lean after Test 469940-03-1.

Post #	Soil Gap	Post Lean (from Vertical)
12	Soil disturbed	0.0°
13	1 inch f/s	9.2°
14	3 inches t/s; 1.75 inches f/s	11.3°
15	0.75 inch t/s and f/s	2.0°

Note: f/s = field side; t/s = traffic side.

Table 9.7. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469940-03-1.

Test Parameter	Measured
Permanent Deflection/Location	10.5 inches toward field side, 1 ft upstream from the centerline of post 14
Dynamic Deflection	19.5 inches toward field side at the midspan between posts 13 and 14
Working Width ^a and Height	37.3 inches, at a height of 36.8 inches, at the top rail at the midspan of posts 12 and 13

^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 9.5. Enhanced Motorcycle Guard Fence System at Impact Location after Test 469940-03-1.



Figure 9.6. Enhanced Motorcycle Guard Fence System at the Rubrail at Impact after Test 469940-03-1.

9.6. DAMAGE TO TEST VEHICLE

Figure 9.7 and Figure 9.8 show the damage sustained by the vehicle. Figure 9.9 and Figure 9.10 show the interior of the test vehicle. Table 9.8 and Table 9.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figures C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.



Figure 9.7. Impact Side of Test Vehicle after Test 469940-03-1.



Figure 9.8. Rear Impact Side of Test Vehicle after Test 469940-03-1.



Figure 9.9. Overall Interior of Test Vehicle after Test 469940-03-1.



Figure 9.10. Interior of Test Vehicle on Impact Side after Test 469940-03-1.

Table 9.8. Occupant Compartment Deformation for Test 469940-03-1.

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

Table 9.9. Exterior Vehicle Damage for Test 469940-03-1.

Side Windows	Side windows remained intact
Maximum Exterior Deformation	8 inches in the right plane at the right front corner at bumper height
VDS	01RFQ2
CDC	01FREW1
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, right front fender and headlight, radiator support, right front strut and tower, right front control arm, right front tire and rim, right front door, right rear door, and right rear fender and bumper were damaged. The right front door had a 2-inch gap at the top.

9.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 9.10. Figure C.7 in Appendix C.3 shows the vehicle angular displacements, and Figures C.8 through C.10 in Appendix C.4 show acceleration versus time traces.

Table 9.10. Occupant Risk Factors for Test 469940-03-1.

Test Parameter	Specification ^a	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 <i>30.0</i>	19.2	0.1092 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 <i>30.0</i>	21.7	0.1092 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 <i>15.0</i>	8	0.1297–0.1397 seconds
Ridedown, Lateral (g)	≤20.49 <i>15.0</i>	9.9	0.1121–0.1221 seconds
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	9.5	0.1147 seconds on right side of interior
Acceleration Severity Index (ASI)	N/A	1.16	0.0537–0.1037 seconds
50-ms Moving Avg. Accelerations (MA) Longitudinal (g)	N/A	-7.4	0.0396–0.0896 seconds
50-ms MA Lateral (g)	N/A	-8.8	0.0267–0.0767 seconds
50-ms MA Vertical (g)	N/A	2.4	0.0600–0.1100 seconds
Roll (deg)	≤75	8.1	0.1694 seconds
Pitch (deg)	≤75	3.3	0.7063 seconds
Yaw (deg)	N/A	62.1	2.0000 seconds

Note: N/A = not applicable.

^a Values in italics are the preferred *MASH* values.

9.8. TEST SUMMARY

Figure 9.11 summarizes the results of *MASH* Test 469940-03-1.





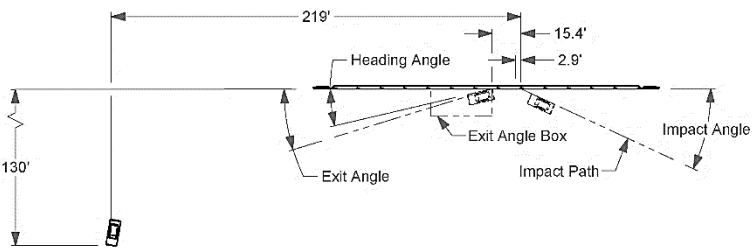
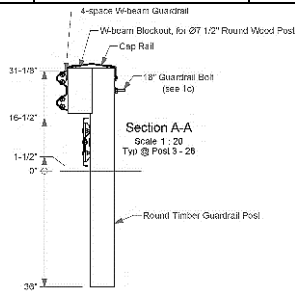
 <p style="text-align: center;">0.000 s</p>	Test Agency	Texas A&M Transportation Institute (TTI)					
	Test Standard/Test No.	MASH 2016, Test 3-10					
	TTI Project No.	469940-03-1					
	Test Date	2020-08-05					
 <p style="text-align: center;">0.200 s</p>	TEST ARTICLE						
	Type	Longitudinal Barrier					
	Name	Enhanced Motorcycle Guard Fence System					
	Length	181 ft 3 inches					
 <p style="text-align: center;">0.400 s</p>	Key Materials	Round timber posts, cap rail, W-beam guardrail, rubrail					
	Soil Type and Condition	Type A Grade 2 crushed limestone					
	TEST VEHICLE						
	Type/Designation	1100C					
 <p style="text-align: center;">0.600 s</p>	Year, Make and Model	2014 Nissan Versa					
	Inertial Weight (lb)	2440					
	Dummy (lb)	165					
	Gross Static (lb)	2605					
IMPACT CONDITIONS							
Impact Speed (mi/h)	63.1						
Impact Angle (deg)	25.1						
Impact Location	35.2 inches upstream from the centerline of post 13						
Impact Severity (kip-ft)	58.4						
EXIT CONDITIONS							
Exit Speed (mi/h)	43.4						
Trajectory/Heading Angle (deg)	17.0/13.2						
Exit Box Criteria	Vehicle crossed exit box 29 ft downstream						
Stopping Distance	219 ft downstream 130 ft to the traffic side						
TEST ARTICLE DEFLECTIONS							
Dynamic (inches)	19.5						
Permanent (inches)	10.5						
Working Width/Height (inches)	37.25/36.8						
VEHICLE DAMAGE							
VDS	01RFQ2						
CDC	01FREW1						
Max. Ext. Deformation (inches)	8						
Max Occupant Compartment Deformation	None						
OCCUPANT RISK VALUES							
Long. OIV (ft/s)	19.2	Long. Ridedown (g)	8	Max 50-ms Long. (g)	-7.4	Max Roll (deg)	8.1
Lat. OIV (ft/s)	21.7	Lat. Ridedown (g)	9.9	Max 50-ms Lat. (g)	-8.8	Max Pitch (deg)	3.3
THIV (m/s)	9.5	ASI	1.16	Max 50-ms Vert. (g)	2.4	Max Yaw (deg)	62.1
							

Figure 9.11. Summary of Results for MASH Test 3-10 on Enhanced Motorcycle Guard Fence System.

Chapter 10. MASH TEST 3-11 (CRASH TEST 469940-03-2)

10.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 10.1 for the *MASH* impact conditions and Table 10.2 for the exit parameters for Test 469940-03-2. Figure 10.1 and Figure 10.2 depict the target impact setup.

Table 10.1. Impact Conditions for *MASH* Test 3-11, Crash Test 469940-03-2.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	63.4
Impact Angle (deg)	25	±1.5°	24.4
Impact Severity (kip-ft)	106	≥106 kip-ft	115.3
Impact Location	13.2 inches downstream from the centerline of post 12	±12 inches	16.1 inches downstream from the centerline of post 12

Table 10.2. Exit Parameters for *MASH* Test 3-11, Crash Test 469940-03-2.

Exit Parameter	Measured
Speed (mi/h)	42.1
Trajectory (deg)	15.2
Heading (deg)	4.7
Brakes applied post impact (s)	2.8
Vehicle at rest position	216 ft downstream of impact point In line with the installation 90° right
Comments:	Vehicle remained upright and stable. Vehicle crossed exit box ^a 59 ft downstream from loss of contact.

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



Figure 10.1. Enhanced Motorcycle Guard Fence System/Test Vehicle Geometrics for Test 469940-03-2.



Figure 10.2. Enhanced Motorcycle Guard Fence System/Test Vehicle Impact Location for Test 469940-03-2.

10.2. WEATHER CONDITIONS

Table 10.3 provides the weather conditions for Test 469940-03-2.

Table 10.3. Weather Conditions for Test 469940-03-2.

Date of Test	2020-08-07 AM
Wind Speed (mi/h)	10
Wind Direction (deg)	199
Temperature (°F)	88
Relative Humidity (%)	70
Vehicle Traveling (deg)	15

10.3. TEST VEHICLE

Figure 10.3 and Figure 10.4 show the 2014 RAM 1500 used for the crash test. Table 10.4 shows the vehicle measurements. Figure D.1 in Appendix D.1 gives additional dimensions and information on the vehicle.



Figure 10.3. Impact Side of Test Vehicle before Test 469940-03-2.



Figure 10.4. Opposite Impact Side of Test Vehicle before Test 469940-03-2.

Table 10.4. Vehicle Measurements for Test 469940-03-2.

Test Parameter	Specification	Tolerance	Measured
Dummy (if applicable) ^a (lb)	165	N/A	N/A
Inertial Weight (lb)	5000	±110	5026
Gross Static ^a (lb)	5000	±110	5026
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	61.4
CG above Ground ^{c,d} (inches)	28	≥28	28.8

Note: N/A = not applicable; CG = center of gravity.

^a If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.

^b Average of front and rear axles.

^c For test inertial mass.

^d 2270P vehicle must meet minimum CG height requirement.

10.4. TEST DESCRIPTION

Table 10.5 lists events that occurred during Test 469940-03-2. Figures D.4, D.5, and D.6 in Appendix D.2 present sequential photographs during the test.

Table 10.5. Events during Test 469940-03-2.

Time (s)	Events
0.0000	Vehicle contacted the installation
0.0190	Posts 12 and 13 began to tilt back toward field side
0.0360	Vehicle began to redirect
0.0400	Top cover began to lift off rail
0.0900	Top cover parted at joint near impact
0.1930	Right rear quarter panel impacted rail
0.2520	Vehicle was parallel with guardrail
0.5310	Top cover section over posts 11 and 12 separated from upstream section
0.5450	Vehicle exited guardrail at 42.1 mi/h, with a trajectory of 15.2 degrees and heading of 4.7 degrees

10.5. DAMAGE TO TEST INSTALLATION

Table 10.6 describes the deflection and working width of the enhanced motorcycle guard fence system. Figure 10.5 and Figure 10.6 show the damage to the enhanced motorcycle guard fence system.

Table 10.6. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469940-03-2.

Test Parameter	Measured
Permanent Deflection/Location	27.3 inches toward field side, 2.5 ft upstream from the centerline of post 14
Dynamic Deflection	32.4 inches toward field side at the midspan between posts 13 and 14
Working Width ^a and Height	113.8 inches, at a height of 1.0 inch, at the top rail at the midspan of posts 12 and 13

^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 10.5. Enhanced Motorcycle Guard Fence System at Impact Location on the Traffic Side after Test 469940-03-2.



Figure 10.6. Enhanced Motorcycle Guard Fence System at Impact Location on the Field Side after Test 469940-03-2.

10.6. DAMAGE TO TEST VEHICLE

Figure 10.7 and Figure 10.8 show the damage sustained by the vehicle. Figure 10.9 and Figure 10.10 show the interior of the test vehicle. Table 10.7 and Table 10.8 provide details on the occupant compartment deformation and exterior vehicle damage. Figures D.2 and D.3 in Appendix D.1 provide exterior crush and occupant compartment measurements.



Figure 10.7. Impact Side of Test Vehicle after Test 469940-03-2.



Figure 10.8. Rear Impact Side of Test Vehicle after Test 469940-03-2.



Figure 10.9. Overall Interior of Test Vehicle after Test 469940-03-2.



Figure 10.10. Interior of Test Vehicle on Impact Side after Test 469940-03-2.

Table 10.7. Occupant Compartment Deformation for Test 469940-03-2.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0.0 inches
Windshield	≤3.0 inches	0.0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0.0 inches
Foot Well/Toe Pan	≤9.0 inches	2.0 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0.0 inches
Side Front Panel	≤12.0 inches	0.0 inches
Front Door (above Seat)	≤9.0 inches	0.0 inches
Front Door (below Seat)	≤12.0 inches	0.0 inches

Table 10.8. Exterior Vehicle Damage for Test 469940-03-2.

Side Windows	The side windows remained intact
Maximum Exterior Deformation	8 inches in the front and side plane at the right front corner at bumper height
VDS	01RFQ3
CDC	01FREW2
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, right headlight, right front fender, right front upper and lower control arms, right front tire and rim, right front door, right rear door, right rear fender, right rear tire and rim, and rear bumper were damaged. The right front door had a 1.5-inch gap at the top.

10.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 10.9. Figure D.7 in Appendix D.3 shows the vehicle angular displacements, and Figures D.8 through D.10 in Appendix D.4 show acceleration versus time traces.

Table 10.9. Occupant Risk Factors for Test 469940-03-2.

Test Parameter	Specification ^a	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 <i>30.0</i>	18.2	0.1477 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 <i>30.0</i>	14.4	0.1477 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 <i>15.0</i>	9.7	0.1726–0.1826 seconds
Ridedown, Lateral (g)	≤20.49 <i>15.0</i>	10	0.1576–0.1676 seconds
THIV (m/s)	N/A	8	0.1618 seconds on right side of interior
ASI	N/A	0.82	0.1670–0.2170 seconds
50-ms MA Longitudinal (g)	N/A	-6.1	0.0873–0.1373 seconds
50-ms MA Lateral (g)	N/A	-6.4	0.1437–0.1937 seconds
50-ms MA Vertical (g)	N/A	-4.8	1.6476–1.6976 seconds
Roll (deg)	≤75	27.3	1.6496 seconds
Pitch (deg)	≤75	25.3	2.1395 seconds
Yaw (deg)	N/A	32.7	0.3565 seconds

Note: N/A = not applicable.

^a Values in italics are the preferred *MASH* values.

10.8. TEST SUMMARY

Figure 10.11 summarizes the results of *MASH* Test 469940-03-2.




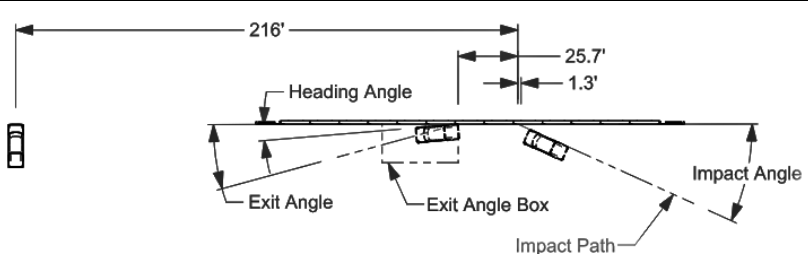
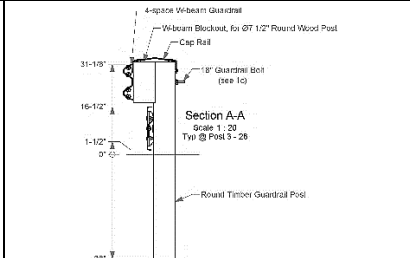
 <p style="text-align: center;">0.000 s</p>	Test Agency	Texas A&M Transportation Institute (TTI)							
	Test Standard/Test No.	MASH 2016, Test 3-11							
	TTI Project No.	469940-03-2							
	Test Date	2020-08-07							
TEST ARTICLE									
		Type	Longitudinal Barrier						
		Name	Enhanced Motorcycle Guard Fence System						
		Length	181 ft 3 inches						
		Key Materials	Round timber posts, cap rail, W-beam guardrail, rubrail						
		Soil Type and Condition	Type A Grade 2 crushed limestone						
 <p style="text-align: center;">0.200 s</p>	TEST VEHICLE								
			Type/Designation	2270P					
			Year, Make and Model	2014 RAM 1500					
			Inertial Weight (lb)	5026					
			Dummy (lb)	N/A					
		Gross Static (lb)	5026						
IMPACT CONDITIONS									
		Impact Speed (mi/h)	63.4						
		Impact Angle (deg)	24.4						
		Impact Location	16.1 inches downstream from the centerline of post 12						
		Impact Severity (kip-ft)	115.3						
 <p style="text-align: center;">0.400 s</p>	EXIT CONDITIONS								
			Exit Speed (mi/h)	42.1					
			Trajectory/Heading Angle (deg)	15.2/4.7					
			Exit Box Criteria	Vehicle crossed exit box 59 ft downstream from loss of contact					
			Stopping Distance	216 ft downstream In line with the installation					
 <p style="text-align: center;">0.600 s</p>	TEST ARTICLE DEFLECTIONS								
			Dynamic (inches)	32.4					
			Permanent (inches)	27.25					
			Working Width/Height (inches)	113.8/1.0					
	VEHICLE DAMAGE								
		VDS	01RFQ3						
		CDC	01FREW2						
		Max. Ext. Deformation (inches)	8						
		Max Occupant Compartment Deformation	2.0 inches in the right foot well						
OCCUPANT RISK VALUES									
Long. OIV (ft/s)	18.2	Long. Ridedown (g)	9.7	Max 50-ms Long. (g)	-6.1	Max Roll (deg)	27.3		
Lat. OIV (ft/s)	14.4	Lat. Ridedown (g)	10	Max 50-ms Lat. (g)	-6.4	Max Pitch (deg)	25.3		
THIV (m/s)	8	ASI	0.82	Max 50-ms Vert. (g)	-4.8	Max Yaw (deg)	32.7		
									

Figure 10.11. Summary of Results for MASH Test 3-11 on Enhanced Motorcycle Guard Fence System.

Chapter 11. UPRIGHT MOTORCYCLE TEST (CRASH TEST 469940-03-3)

11.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 11.1 for the impact conditions and Table 11.2 for the exit parameters for Test 469940-03-3. Figure 11.1 and Figure 11.2 depict the target impact setup.

Table 11.1. Impact Conditions for Crash Test 469940-03-3.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	37.3	±2.5 mi/h	38.2
Impact Angle (deg)	15	±1.5°	14.8
Impact Location	24 inches upstream from the centerline of post 10	±12 inches	24 inches upstream from the centerline of post 10

Table 11.2. Exit Parameters for Crash Test 469940-03-3.

Exit Parameter	Measured
Speed (mi/h)	32.4
Trajectory (deg)	7.0
Heading (deg)	1.5
Brakes applied post impact (s)	Brakes not applied
Vehicle at rest position	109 ft downstream of impact point 14 ft to the traffic side 10° left on its side
Comments:	The dummy landed 81 ft downstream from impact and 8 ft toward the traffic side



Figure 11.1. Enhanced Motorcycle Guard Fence System/Test Vehicle Geometrics for Test 469940-03-3.



Figure 11.2. Enhanced Motorcycle Guard Fence System/Test Vehicle Impact Location for Test 469940-03-3.

11.2. WEATHER CONDITIONS

Table 11.3 provides the weather conditions for Test 469940-03-3.

Table 11.3. Weather Conditions for Test 469940-03-3.

Date of Test	2020-08-04 PM
Wind Speed (mi/h)	5
Wind Direction (deg)	82
Temperature (°F)	99
Relative Humidity (%)	47
Vehicle Traveling (deg)	10

11.3. TEST VEHICLE

Figure 11.3 and Figure 11.4 show the 2012 Kawasaki 250 Ninja used for the crash test. Table 11.4 shows the vehicle measurements. Figure E.1 in Appendix E.1 gives additional dimensions and information on the vehicle.



Figure 11.3. Impact Side of Test Vehicle before Test 469940-03-3.



Figure 11.4. Opposite Impact Side of Test Vehicle before Test 469940-03-3.

Table 11.4. Vehicle Measurements for Test 469940-03-3.

Test Parameter	Specification	Tolerance	Measured
Dummy (if applicable) ^a (lb)	200	N/A	200
Vehicle Inertial Weight (lb)	N/A	N/A	400
Gross Weight (lb)	N/A	N/A	600

Note: N/A = not applicable.

^a If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.

11.4. TEST DESCRIPTION

Table 11.5 lists events that occurred during Test 469940-03-3. Figures E.2, E.3, and E.4 in Appendix E.2 present sequential photographs during the test.

Table 11.5. Events during Test 469940-03-3.

Time (s)	Events
0.0000	Vehicle contacted rail
0.0120	Vehicle began to redirect
0.1020	Vehicle was parallel with rail
0.1590	Dummy's right arm elbow contacted top cover of rail
0.2190	Vehicle exited the guardrail at 32.4 mi/h, with a trajectory of 7.0 degrees and heading of 1.5 degrees
0.4260	Dummy's side and right arm contacted top cover of rail
0.8860	Dummy's right foot contacted the ground
0.9620	Dummy's left foot contacted the ground
1.2660	Dummy's rear contacted the ground
1.3020	Dummy's head contacted the ground

11.5. DAMAGE TO TEST INSTALLATION

There was some scuffing on the rail at impact. Table 11.6 describes the deflection and working width of the enhanced motorcycle guard fence system. Figure 11.5 and Figure 11.6 show the damage to the enhanced motorcycle guard fence system.

Table 11.6. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469940-03-3.

Test Parameter	Measured
Permanent Deflection/Location	None
Dynamic Deflection	0.28 inches toward field side
Working Width ^a and Height	18.5 inches, at a height of 31.1 inches, at the field side of the top of the post.

^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 11.5. Isometric View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469940-03-3.



Figure 11.6. Elevation View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469940-03-3.

11.6. DAMAGE TO TEST VEHICLE

The front fairing, right and left side fairings, and right turn signal were damaged. No damage to the fuel tank was observed.

Figure 11.7, Figure 11.8, and Figure 11.9 show the damage sustained by the vehicle.

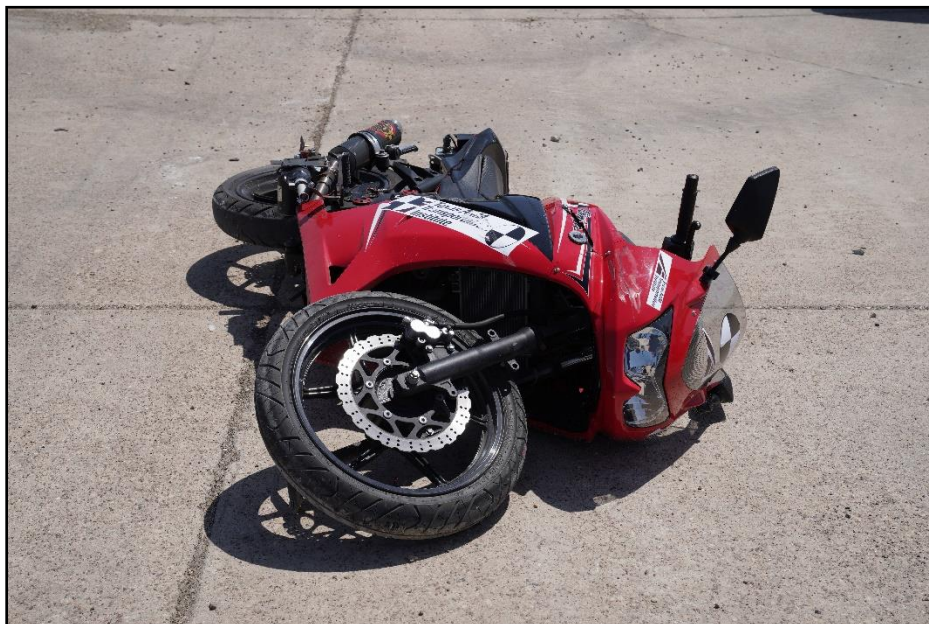


Figure 11.7. Impact Side of Test Vehicle after Test 469940-03-3.



Figure 11.8. Rear Impact Side of Test Vehicle after Test 469940-03-3.



Figure 11.9. Opposite Impact Side of Test Vehicle after Test 469940-03-3.

11.7. TEST SUMMARY

Figure 11.10 summarizes the results of Test 469940-03-3.





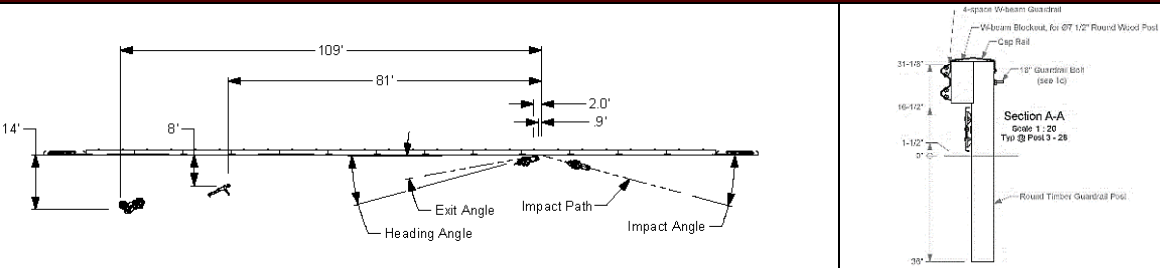
 <p style="text-align: center;">0.000 s</p>	<table border="1"> <tr> <td>Test Agency</td> <td>Texas A&M Transportation Institute (TTI)</td> </tr> <tr> <td>Test Standard/Test No.</td> <td>N/A</td> </tr> <tr> <td>TTI Project No.</td> <td>469940-03-3</td> </tr> <tr> <td>Test Date</td> <td>2020-08-04</td> </tr> </table>	Test Agency	Texas A&M Transportation Institute (TTI)	Test Standard/Test No.	N/A	TTI Project No.	469940-03-3	Test Date	2020-08-04				
	Test Agency	Texas A&M Transportation Institute (TTI)											
	Test Standard/Test No.	N/A											
	TTI Project No.	469940-03-3											
Test Date	2020-08-04												
TEST ARTICLE													
<table border="1"> <tr> <td>Type</td> <td>Longitudinal Barrier</td> </tr> <tr> <td>Name</td> <td>Enhanced Motorcycle Guard Fence System</td> </tr> <tr> <td>Length</td> <td>181 ft 3 inches</td> </tr> <tr> <td>Key Materials</td> <td>Round timber posts, cap rail, W-beam guardrail, rubrail</td> </tr> </table>	Type	Longitudinal Barrier	Name	Enhanced Motorcycle Guard Fence System	Length	181 ft 3 inches	Key Materials	Round timber posts, cap rail, W-beam guardrail, rubrail					
Type	Longitudinal Barrier												
Name	Enhanced Motorcycle Guard Fence System												
Length	181 ft 3 inches												
Key Materials	Round timber posts, cap rail, W-beam guardrail, rubrail												
Soil Type and Condition: AASHTO M147-65(2004), Type 1, Grade D crushed concrete													
 <p style="text-align: center;">0.100 s</p>	<table border="1"> <tr> <td colspan="2" style="background-color: #800000; color: white; text-align: center;">TEST VEHICLE</td> </tr> <tr> <td>Type/Designation</td> <td>Motorcycle</td> </tr> <tr> <td>Year, Make and Model</td> <td>2012 Kawasaki 250 Ninja</td> </tr> <tr> <td>Inertial Weight (lb)</td> <td>400</td> </tr> <tr> <td>Dummy (lb)</td> <td>200</td> </tr> <tr> <td>Gross Static (lb)</td> <td>600</td> </tr> </table>	TEST VEHICLE		Type/Designation	Motorcycle	Year, Make and Model	2012 Kawasaki 250 Ninja	Inertial Weight (lb)	400	Dummy (lb)	200	Gross Static (lb)	600
	TEST VEHICLE												
	Type/Designation	Motorcycle											
	Year, Make and Model	2012 Kawasaki 250 Ninja											
Inertial Weight (lb)	400												
Dummy (lb)	200												
Gross Static (lb)	600												
IMPACT CONDITIONS													
<table border="1"> <tr> <td>Impact Speed (mi/h)</td> <td>38.2</td> </tr> <tr> <td>Impact Angle (deg)</td> <td>14.8</td> </tr> <tr> <td>Impact Location</td> <td>24 inches upstream from the centerline of post 10</td> </tr> </table>	Impact Speed (mi/h)	38.2	Impact Angle (deg)	14.8	Impact Location	24 inches upstream from the centerline of post 10							
Impact Speed (mi/h)	38.2												
Impact Angle (deg)	14.8												
Impact Location	24 inches upstream from the centerline of post 10												
EXIT CONDITIONS													
<table border="1"> <tr> <td>Exit Speed (mi/h)</td> <td>32.4</td> </tr> <tr> <td>Trajectory/Heading Angle (deg)</td> <td>7.0/1.5</td> </tr> <tr> <td>Stopping Distance</td> <td>109 ft downstream 14 ft to the traffic side</td> </tr> </table>	Exit Speed (mi/h)	32.4	Trajectory/Heading Angle (deg)	7.0/1.5	Stopping Distance	109 ft downstream 14 ft to the traffic side							
Exit Speed (mi/h)	32.4												
Trajectory/Heading Angle (deg)	7.0/1.5												
Stopping Distance	109 ft downstream 14 ft to the traffic side												
 <p style="text-align: center;">0.200 s</p>	<table border="1"> <tr> <td colspan="2" style="background-color: #800000; color: white; text-align: center;">TEST ARTICLE DEFLECTIONS</td> </tr> <tr> <td>Dynamic (inches)</td> <td>0.28</td> </tr> <tr> <td>Permanent (inches)</td> <td>None</td> </tr> <tr> <td>Working Width/Height (inches)</td> <td>18.5/31.1</td> </tr> </table>	TEST ARTICLE DEFLECTIONS		Dynamic (inches)	0.28	Permanent (inches)	None	Working Width/Height (inches)	18.5/31.1				
	TEST ARTICLE DEFLECTIONS												
	Dynamic (inches)	0.28											
	Permanent (inches)	None											
Working Width/Height (inches)	18.5/31.1												
 <p style="text-align: center;">0.300 s</p>													
													

Figure 11.10. Summary of Results for Upright Motorcycle Test on Enhanced Motorcycle Guard Fence System.

Chapter 12. SLIDING ATD (CRASH TEST 469940-03-4A)

12.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 12.1 for the impact conditions and Table 12.2 for the exit parameters for Test 469940-03-4A. Figure 12.1 and Figure 12.2 show the ATD prior to impact.

Table 12.1. Impact Conditions for Crash Test 469940-03-4A.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	37.3	+2.2, -0 mi/h	37.2
Impact Angle (deg)	30	$\pm 2^\circ$	30.2
Dummy Weight (lb)	200	200	200
Impact Location	Centerline of the ATD's head aligned with the center of post 9	± 2.4 inches	0.85 inch to the left of the centerline of post 9

Table 12.2. Exit Parameters for Crash Test 469940-03-4A.

Exit Parameter	Measured
Speed (mi/h)	N/A
Trajectory (deg)	N/A
Heading (deg)	N/A
ATD at Rest Position	17 ft downstream of impact point 8.3 ft to the traffic side 90° left



Figure 12.1. Right Side of the ATD prior to Test 469940-03-4A.



Figure 12.2. Left Side of the ATD prior to Test 469940-03-4A.

12.2. WEATHER CONDITIONS

Table 12.3 provides the weather conditions for Test 469940-03-4A.

Table 12.3. Weather Conditions for Test 469940-03-4A.

Date of Test	2020-11-20 AM
Wind Speed (mi/h)	10
Wind Direction (deg)	129
Temperature (°F)	88
Relative Humidity (%)	87
ATD Traveling (deg)	20

12.3. TEST DESCRIPTION

Table 12.4 lists events that occurred during Test 469940-03-4A. Figures F.1, F.2, and F.3 in Appendix F.1 present sequential photographs during the test.

Table 12.4. Events during Test 469940-03-4A.

Time (s)	Events
0.0000	Dummy impacted the installation
0.0040	Dummy began to redirect
0.0940	Dummy traveled parallel to the installation
0.2210	Dummy exited the installation

12.4. DAMAGE TO TEST INSTALLATION

The rubrail was deformed and scuffed at impact. Table 12.5 describes the deflection and working width of the enhanced motorcycle guard fence system. Figure 12.3 and Figure 12.4 show the damage to the enhanced motorcycle guard fence system.

Table 12.5. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469940-03-4A.

Test Parameter	Measured
Permanent Deflection/Location	2.4 inches toward field side, 13 inches upstream from the centerline of post 9
Dynamic Deflection	4 inches toward field side, 13 inches upstream from the centerline of post 9
Working Width ^a and Height	18.6 inches, at a height of 31.1 inches, at the guardrail bolt on the field side of post 9

^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 12.3. Enhanced Motorcycle Guard Fence System at Impact Location on the Traffic Side after Test 469940-03-4A.



Figure 12.4. Enhanced Motorcycle Guard Fence System at Impact Location on the Field Side after Test 469940-03-4A.

12.5. DAMAGE TO ATD

Figure 12.5 and Figure 12.6 show the overall damage sustained by the ATD. Figure 12.7 and Figure 12.8 show the helmet and neck damage sustained by the ATD. Table 12.6 provides details on the calculated injury criteria for the head and neck of the ATD.



Figure 12.5. Backside of the ATD after Test 469940-03-4A.



Figure 12.6. Front of the ATD after Test 469940-03-4A.



Figure 12.7. Back Helmet and ATD Neck Damage after Test 469940-03-4A.



Figure 12.8. ATD Neck Damage after Test 469940-03-4A.

Table 12.6. ATD Head and Neck Injury Criteria for Test 469940-03-4A.

Body Region	Injury Criterion	EN 1317-8 Limit	Measured
Head	HIC ₃₆	1000	679
Neck	F _x (N)	1100	846
	F _z —Tension (N)	3300	4649
	F _z —Compression (N)	4000	4203
	Moc _x (Nm)	134	111
	Moc _y —Flexion (Nm)	190	23
	Moc _y —Extension (Nm)	57	22

12.6. TEST SUMMARY

Figure 12.9 summarizes the results of Test 469940-03-4A.

12.7. DISCUSSION

The enhanced motorcycle guard fence system successfully redirected the ATD during impact. There was no snagging of the ATD limbs with the wood posts or other elements of the longitudinal barrier. The ATD neck axial tension and compression forces measured during the impact did exceed the EN 1317-8 limits. Modifications were investigated, as described in Chapter 13, to potentially reduce the injury criteria for the sliding ATD impact.

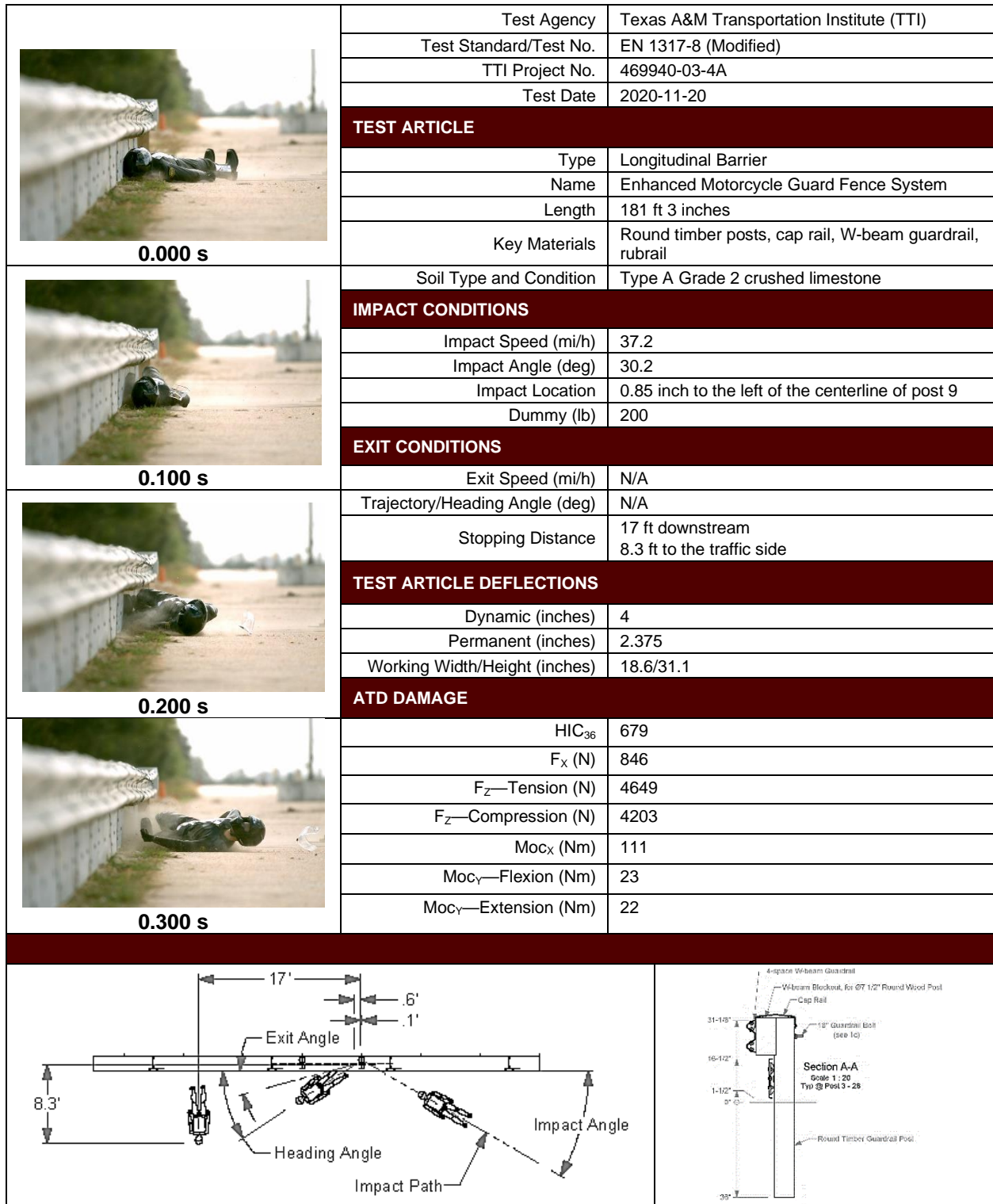


Figure 12.9. Summary of Results for Modified EN 1317-8 Test on Enhanced Motorcycle Guard Fence System.

Chapter 13. COMPUTER SIMULATIONS—REDESIGN

Finite element models of various new design options were developed, and LS-DYNA was used to perform impact simulations with inclusion of the developed models, available Hybrid III 50th percentile ATD (dummy) model (Figure 13.1), and available rider helmet model. To allow for a sliding position of the dummy, the seated pelvis was removed from the model and the legs were straightened. The developed model was calibrated by comparing results of the developed FE barrier system model against available full-scale crash test data. Once the FE model was calibrated, the same model was used to apply the proposed design retrofit changes and conduct predictive simulations.

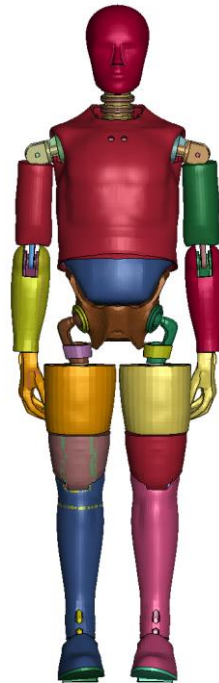


Figure 13.1. ATD Finite Element Model.

13.1. MODEL CALIBRATION

Previous testing was conducted with a sliding motorcyclist into a guardrail system with a vertical rubrail attachment (Chapter 12). To validate the dummy and helmet FE models, a computer simulation was conducted with impact conditions that replicated the full-scale crash test. Figure 13.2 shows the dummy model at impact with the system.

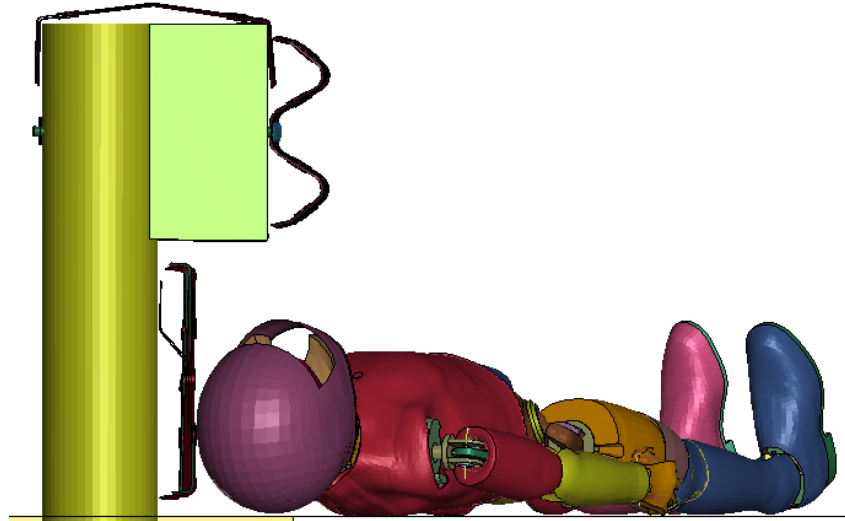


Figure 13.2. Computer Simulation of Sliding Dummy Impact.

The overall behavior of the dummy model was similar to the crash test. A quantitative comparison was conducted by comparing the injury criteria values from the full-scale crash test and the computer simulation. Table 13.1 shows the injury criteria values.

Table 13.1. Injury Criteria Comparison.

Criteria	Crash Test	Validation Simulation	Limit
HIC	679	861	1000
Neck X (Shear) Force (+)	776	631	1100
Neck X (Shear) Force (-)	-846	-1300	1100
Neck Z (Axial) Force (+)	4649	5268	3300
Neck Z (Axial) Force (-)	-4203	-3983	4000
Neck Moment—Mx	111	159	134
Neck Moment—My (Flexion)	23	46	190
Neck Moment—My (Extension)	-22	-61	-57

Some of the injury criteria values were comparable. The neck shear force and neck axial force were higher in the simulation than in the crash test. Also, the Mx and My moments were higher in the simulation than in the crash test. The dummy and helmet models used in the validation simulation were used in the design evaluation simulations discussed in the next section. Researchers noted that the models may overpredict certain injury criteria values.

13.2. DESIGN EVALUATIONS

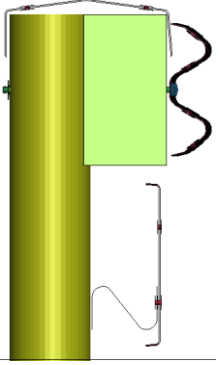
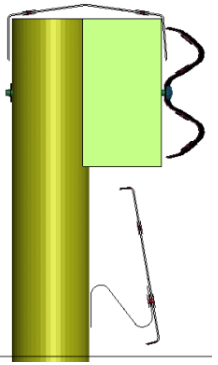
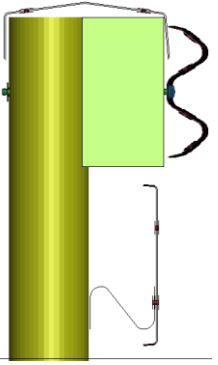
Different design options to reduce possible injury to a sliding motorcyclist were developed and evaluated. It was necessary to reduce the high neck axial forces observed in the crash test with the vertical rubrail design. These design options are discussed in the following subsections.

13.2.1. Channel Rubrail

Modifications were made to the original vertical channel rubrail by inclusion of an energy-absorbing S-shape bracket offsetting the rubrail from the post. In addition, design variations with a different rubrail thickness and rubrail inclination were investigated.

The dummy injury criteria results for the key channel rubrail design options are shown in Table 13.2. Design 2 resulted in injury criteria values below all the limits. The other designs had injury criteria values above the limits.

Table 13.2. Injury Criteria for Channel Rubrail Designs.

Design Notes	Design 1	Design 2	Design 3
	S-shape bracket and rubrail offset	10° incline	14-gauge rubrail
Cross-Section View			
HIC (Limit = 1000)	482	360	490
Neck Force (X-Shear) (+) (Limit = 1100)	556	457	428
Neck Force (X-Shear) (-) (Limit = -1100)	-570	-893	-923
Neck Force (Z-Axial) (+) (Limit = 3300)	2962	2739	4869
Neck Force (Z-Axial) (-) (Limit = -4000)	<i>-4144</i>	<i>-3423</i>	<i>-3606</i>
Neck Moment (Mx) (Limit = 134)	76	63	89
Neck Moment (My—Flexion) (+) (Limit = 190)	22	44	23
Neck Moment (My—Extension) (-) (Limit = -57)	-30	-43	-35
Dummy Interaction with Guardrail Components?	No	No	No
Dummy Rollover?	No	No	No

Note: Numbers in italics indicate values above the limits.

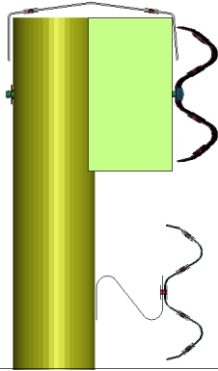
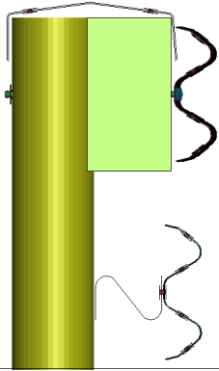
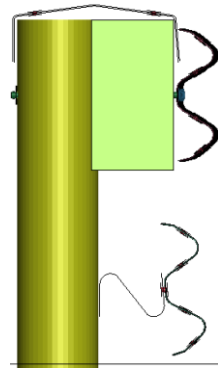
13.2.2. W-Beam Rubrail

A design option with a standard 12-gauge W-beam guardrail was developed. The W-beam rubrail was attached with an S-shape bracket offsetting it from the guardrail posts. Different variations with the W-beam rubrail were considered as follows:

- 14-gauge W-beam.
- 16-gauge W-beam.
- Reduced thickness of S-shape bracket.
- S-shape brackets attached at every other wood post.
- Raised height of W-beam rubrail.
- 5-degree and 10-degree incline of W-beam rubrail.

A total of eight design variations were evaluated with the dummy model. The injury criteria results for some of the most promising W-beam rubrail design options are shown in Table 13.3. Design 3 resulted in injury criteria values below all the limits. The other designs had injury criteria values above the limits.

Table 13.3. Injury Criteria for W-Beam Rubrail Designs.

Design Notes	Design 1	Design 2	Design 3
	12-gauge W-beam and S-shape bracket	14-gauge W-beam	14-gauge W-beam and 5° incline
Cross-Section View			
HIC (Limit = 1000)	<i>1001</i>	733	635
Neck Force (X-Shear) (+) (Limit = 1100)	964	778	814
Neck Force (X-Shear) (-) (Limit = -1100)	-608	-729	-667
Neck Force (Z-Axial) (+) (Limit = 3300)	2242	1899	1867
Neck Force (Z-Axial) (-) (Limit = -4000)	<i>-4507</i>	<i>-4035</i>	<i>-3694</i>
Neck Moment (Mx) (Limit = 134)	132	117	95
Neck Moment (My—Flexion) (+) (Limit = 190)	65	56	84
Neck Moment (My—Extension) (-) (Limit = -57)	-65	-57	-53
Dummy Interaction with Guardrail Components?	No	No	No
Dummy Rollover?	No	No	No

Note: Numbers in italics indicate values above the limits.

13.2.3. Inward V-Shape Rubrail

A modified version of the vertical channel rubrail that had a V-shape profile with attachment to an S-shape bracket was developed. Figure 13.3 shows a cross-section view of the rubrail shape.

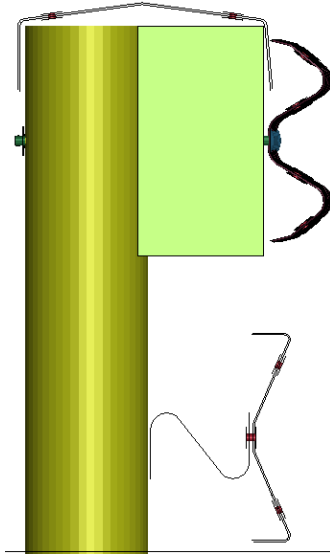


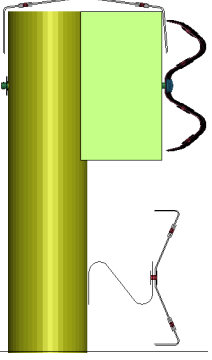
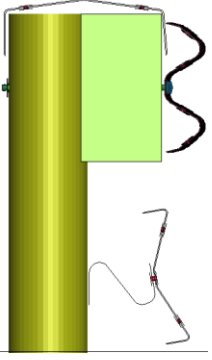
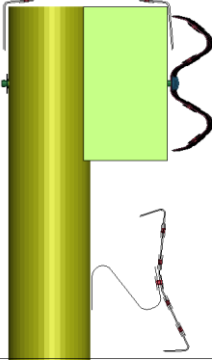
Figure 13.3. V-Shape Rubrail Design Option.

Different variations with the V-shape rubrail were considered as follows:

- Raised height of V-shape rubrail.
- 10-degree incline of rubrail.
- 20-degree incline of rubrail.
- Modification of V-shape profile through steeper and shallower slopes of the V-shape.

A total of 11 design variations were evaluated with the dummy model. The injury criteria results for some of the most promising V-shape design options are shown in Table 13.4. Designs 2 and 3 resulted in injury criteria values below all the limits. However, there was significant contact between the dummy arm and components of the guardrail system for these systems. Additionally, as the dummy exited the system, it rolled over onto the chest. Thus, this design option was not considered for further investigation.

Table 13.4. Injury Criteria for V-Shape Rubrail Designs.

Design Notes	Design 1	Design 2	Design 3
	V-shape rubrail and S-shape bracket	10° incline	Modified V-shape profile
Cross-Section View			
HIC (Limit = 1000)	446	412	433
Neck Force (X-Shear) (+) (Limit = 1100)	799	487	558
Neck Force (X-Shear) (-) (Limit = -1100)	-393	-491	-468
Neck Force (Z-Axial) (+) (Limit = 3300)	2371	1795	1853
Neck Force (Z-Axial) (-) (Limit = -4000)	<i>-4453</i>	<i>-2855</i>	<i>-3431</i>
Neck Moment (Mx) (Limit = 134)	106	93	81
Neck Moment (My—Flexion) (+) (Limit = 190)	26	62	49
Neck Moment (My—Extension) (-) (Limit = -57)	-38	-21	-41
Dummy Interaction with Guardrail Components?	<i>Hand contacts blackout and W-beam guardrail</i>	<i>Arm contacts blackout and W-beam guardrail</i>	<i>Arm contacts blackout and W-beam guardrail</i>
Dummy Rollover?	Yes	Yes	Yes

Note: Numbers/details in italics indicate values above the limits or other design performance issues.

13.2.4. Summary

Two design options were identified through FE simulations that were successful in reducing all the injury criteria severity values for a sliding motorcyclist impacting the modified guardrail system. The options consisted of a channel rubrail and W-beam rubrail inclined at 10 degrees. Both options were connected to an S-shape bracket and offset from the guardrail posts.

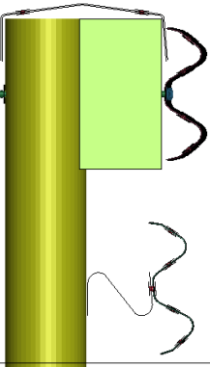
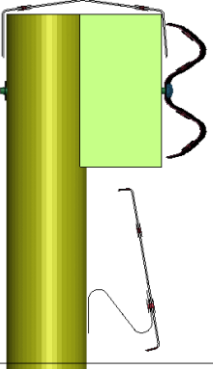
These two design options were further evaluated via impact with the sliding dummy aligned at the midspan of the guardrail system, which is one of the impact conditions required by EN 1317.

13.3. DESIGN EVALUATIONS—SECONDARY IMPACT LOCATION

Computer simulations were conducted with the inclined W-beam rubrail and channel rubrail design options. The sliding dummy impacted the guardrail system at the midspan between the two posts. The critical impact location consisted of impacting the midspan with a splice connection.

The injury criteria results for these two design options are shown in Table 13.5. The 14-gauge W-beam rubrail with a 5-degree incline had dummy injury criteria values below the limits. However, discussions with steel suppliers have shown the 14-gauge W-beam will be costly, and thus it is not likely a feasible design option. The channel rubrail with a 10-degree incline has one injury criteria above the limit. The predicted neck axial compressive force is 4776 N, which is well above the 4000 N injury limit.

Table 13.5. Impact at Splice—Rubrail Design Comparison.

Design Notes	Design 1	Design 2
	14-gauge W-beam and 5° incline	Channel rubrail and 10° incline
Cross-Section View		
HIC (Limit = 1000)	851	625
Neck Force (X-Shear) (+) (Limit = 1100)	1056	771
Neck Force (X-Shear) (-) (Limit = -1100)	-711	-630
Neck Force (Z-Axial) (+) (Limit = 3300)	1618	2743
Neck Force (Z-Axial) (-) (Limit = -4000)	-3539	-4776
Neck Moment (Mx) (Limit = 134)	106	64
Neck Moment (My—Flexion) (+) (Limit = 190)	72	45
Neck Moment (My—Extension) (-) (Limit = -57)	-41	-22
Dummy Interaction with Guardrail Components?	No	No
Dummy Rollover?	No	No

Note: Numbers in italics indicate values above the limits.

13.4. SUMMARY

Full-scale crash testing of a sliding dummy impacting a guardrail system with a rubrail attached to the posts showed neck injury criteria values above the EN 1317 limits. Design modifications were explored using FE computer simulations to reduce the injury forces for a sliding motorcyclist impacting a guardrail system. The three concepts consisted of a channel rubrail, W-beam rubrail, and V-shape rubrail. A channel rubrail with 10-degree inclination and a 14-gauge W-beam with 5-degree inclination were found to help reduce the injury criteria for a sliding motorcyclist.

Both design options were investigated with the sliding dummy impacting at the midspan splice between the posts. The 14-gauge W-beam performed well and resulted in injury criteria values below the limit. However, the cost to manufacture a 14-gauge W-beam was found to be significant and made this option impractical. The channel rubrail resulted in neck compressive force injury criteria above the limit when impacted at the midspan splice. Further modifications were made to this design to help reduce the neck forces in the dummy. However, no design modifications were identified that helped reduce the neck compressive forces and did not cause injury criteria values above the limit for other indices.

After consultation with the TxDOT project team panel, the channel rubrail with a 10-degree incline was selected for further evaluation through full-scale crash testing. The results of the sliding ATD crash test are presented in the next chapter.

Chapter 14. SLIDING ATD (CRASH TEST 469942-01-1)

14.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 14.1 for the impact conditions and Table 14.2 for the exit parameters for Test 469942-01-1. Figure 14.1 and Figure 14.2 depict the ATD prior to testing.

Table 14.1. Impact Conditions for Crash Test 469942-01-1.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	37.3	+2.2, -0 mi/h	41.4
Impact Angle (deg)	30	±2°	29.7
Dummy Weight (lb)	200	200	200
Impact Location	Centerline of the ATD's head aligned with the center of post 15	±2.4 inches	Centerline of the ATD's head aligned with the center of post 15

Table 14.2. Exit Parameters for Crash Test 469942-01-1.

Exit Parameter	Measured
Speed (mi/h)	N/A
Trajectory (deg)	N/A
Heading (deg)	N/A
Vehicle at rest position	16 ft downstream of impact point 106 inches to the traffic side 135° left



Figure 14.1. Side View of the ATD on the Sled Delivery System Prior to Test 469942-01-1.

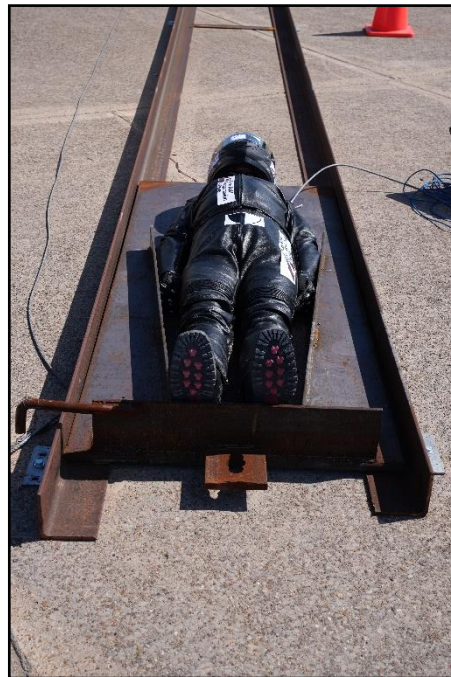


Figure 14.2. In-Line View of the ATD on the Sled Delivery System Prior to Test 469942-01-1.

14.2. WEATHER CONDITIONS

Table 14.3 provides the weather conditions for Test 469942-01-1.

Table 14.3. Weather Conditions for Test 469942-01-1.

Date of Test	2022-04-27 AM
Wind Speed (mi/h)	5
Wind Direction (deg)	219
Temperature (°F)	73
Relative Humidity (%)	54
Vehicle Traveling (deg)	20

14.3. TEST DESCRIPTION

Table 14.4 lists events that occurred during Test 469942-01-1. Figures G.1, G.2, and G.3 in Appendix G.1 present sequential photographs during the test.

Table 14.4. Events during Test 469942-01-1.

Time (s)	Events
0.0000	ATD impacted the installation
0.0030	ATD began to redirect
0.1040	ATD was parallel with installation
0.4180	ATD exited the installation

14.4. DAMAGE TO TEST INSTALLATION

The rubrail was deformed and scuffed at impact, and there were also scuffs on the W-beam at impact. Table 14.5 describes the deflection and working width of the enhanced motorcycle guard fence system. Figure 14.3 and Figure 14.4 show the damage to the enhanced motorcycle guard fence system.

Table 14.5. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469942-01-1.

Test Parameter	Measured
Permanent Deflection/Location	5.5 inches toward field side, 15 inches upstream from the centerline of post 15
Dynamic Deflection	9.3 inches toward field side, 15 inches upstream from the centerline of post 15
Working Width ^a and Height	19.5 inches, at a height of 30.0 inches, at the guardrail bolt on the field side of post 15

^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 14.3. Enhanced Motorcycle Guard Fence System at Impact Location after Test 469942-01-1.



Figure 14.4. Enhanced Motorcycle Guard Fence System Rubrail at Impact Location after Test 469942-01-1.

14.5. DAMAGE TO ATD

Figure 14.5 and Figure 14.6 show the damage sustained by the front of the ATD. Figure 14.7 and Figure 14.8 show the damage sustained by the back of the ATD. Table 14.6 provides details on the calculated injury criteria for the head and neck of the ATD.



Figure 14.5. Left Side of ATD after Test 469942-01-1.



Figure 14.6. Upper Torso Detail of the ATD after Test 469942-01-1.



Figure 14.7. Backside of the ATD after Test 469942-01-1.



Figure 14.8. Backside Detail of the ATD Helmet after Test 469942-01-1.

Table 14.6. ATD Head and Neck Injury Criteria for Test 469942-01-1.

Body Region	Injury Criterion	EN 1317-8 Limit	Measured
Head	HIC ₃₆	1000	344
Neck	F _x (N)	1100	568
	F _z —Tension (N)	3300	1993
	F _z —Compression (N)	4000	4709
	Moc _x (Nm)	134	72
	Moc _y —Flexion (Nm)	190	29
	Moc _y —Extension (Nm)	57	32

14.6. TEST SUMMARY

Figure 14.9 summarizes the results of Test 469942-01-1.

14.7. DISCUSSION

The enhanced motorcycle guard fence system successfully redirected the ATD during impact. There was no snagging of the ATD limbs with the wood posts or other elements of the longitudinal barrier. The ATD neck axial tension was significantly reduced with the modified design and was below the specified limit. However, the ATD neck compression forces still exceeded the EN 1317-8 limit. Modifications were investigated, as described in Chapter 15, to potentially reduce the neck compression force for the sliding ATD impact.






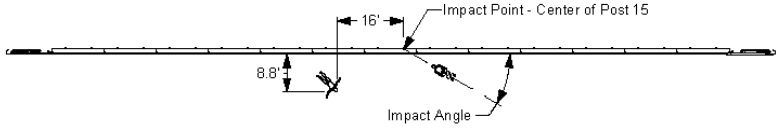
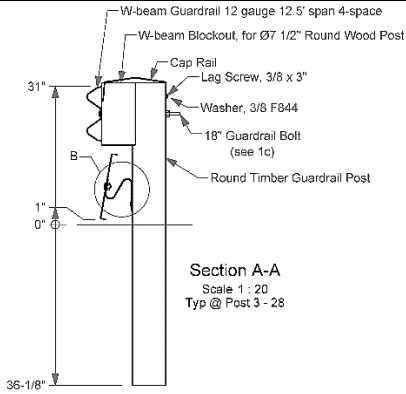
 <p style="text-align: center;">0.000 s</p>	Test Agency	Texas A&M Transportation Institute (TTI)
	Test Standard/Test No.	EN 1317-8 (Modified)
	TTI Project No.	469942-01-1
	Test Date	2022-04-27
TEST ARTICLE		
	Type	Longitudinal Barrier
	Name	Enhanced Motorcycle Guard Fence System
	Length	181 ft 3 inches
	Key Materials	Round timber posts, cap rail, W-beam guardrail, rubrail
	Soil Type and Condition	Type A Grade 2 crushed limestone
 <p style="text-align: center;">0.100 s</p>	IMPACT CONDITIONS	
	Impact Speed (mi/h)	41.4
	Impact Angle (deg)	29.7
	Impact Location	Centerline of the ATD's head aligned with the center of post 15
	Dummy (lb)	200
 <p style="text-align: center;">0.200 s</p>	EXIT CONDITIONS	
	Exit Speed (mi/h)	N/A
	Trajectory/Heading Angle (deg)	N/A
	Stopping Distance	16 ft downstream 106 inches to the traffic side
 <p style="text-align: center;">0.300 s</p>	TEST ARTICLE DEFLECTIONS	
	Dynamic (inches)	9.25
	Permanent (inches)	5.5
	Working Width/Height (inches)	19.5/30.0
 <p style="text-align: center;">0.300 s</p>	ATD DAMAGE	
	HIC ₃₆	344
	F _x (N)	568
	F _z —Tension (N)	1993
	F _z —Compression (N)	4709
	Moc _x (Nm)	72
	Moc _y —Flexion (Nm)	29
	Moc _y —Extension (Nm)	32
		 <p style="text-align: center;">Section A-A Scale 1 : 20 Typ @ Post 3 - 28</p>

Figure 14.9. Summary of Results for Modified EN 1317-8 Test on Enhanced Motorcycle Guard Fence System.

Chapter 15. COMPUTER SIMULATIONS—REDESIGN NO. 2

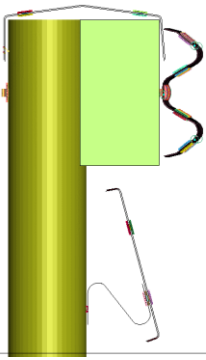
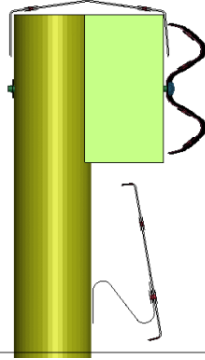
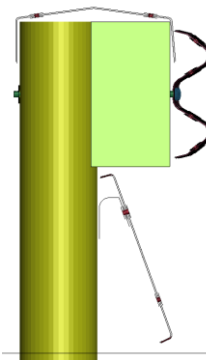
Additional design options to reduce possible injury to a sliding motorcyclist were developed and evaluated. The objective of the design concepts was to reduce the high neck axial compression forces observed in the crash tests. These design options are discussed below.

Design variations were developed to reduce neck axial compression forces for a sliding motorcyclist impacting a guardrail system. Many of the design concepts were variations of the previously crash-tested incline rubrail with the S-shape bracket design. The evaluated designs consisted of the following concepts:

- Increasing rubrail incline to 15 degrees and 20 degrees.
- Moving the S-shape bracket to attach higher on the post.
- Attaching the bracket to the top of the rubrail.
- Attaching the rubrail to the upper W-beam rail.
- Raising the height of the rubrail.
- Placing brackets at every other post.

Combinations of some of the design concepts were also evaluated. Table 15.1 shows the dummy injury criteria results for the key design concepts that significantly reduced the neck compression force value. The design concepts not shown in the table indicated only minor reduction in neck compression forces.

Table 15.1. Injury Criteria for Rubrail Designs.

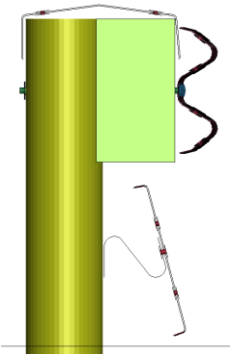
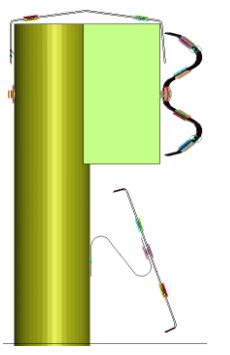
Design Notes	Design 1	Design 2	Design 3
	15° incline	20° incline	High bracket
Cross-Section View			
Neck Force (X-Shear) (+) (Limit = 1100)	473	591	672
Neck Force (X-Shear) (-) (Limit = -1100)	-433	-460	-448
Neck Force (Z-Axial) (+) (Limit = 3300)	2134	1555	1612
Neck Force (Z-Axial) (-) (Limit = -4000)	-3048	-2808	-2850
Neck Moment (Mx) (Limit = 134)	66	84	60
Neck Moment (My—Flexion) (+) (Limit = 190)	21	24	33
Neck Moment (My—Extension) (-) (Limit = -57)	-59	-25	-48
Dummy Interaction with Guardrail Components?	No	Yes	Yes
Dummy Rollover?	No	Yes	No

Note: Numbers/details in italics indicate values above the limits or other design performance issues.

The rubrail design concepts with an S-shape bracket and inclined rubrail of 15 degrees and 20 degrees showed a significant reduction in neck compression forces. However, the increased incline resulted in the dummy ramping up the rubrail and interacting with the W-beam guardrail and blockout elements. To mitigate this ramping effect, the S-shape bracket was raised to attach at the middle of the rubrail.

The injury criteria results for the two increased incline designs with a raised S-shape bracket are shown in Table 15.2. Both designs indicated injury criteria results below the limits and a stable redirection of the dummy with no W-beam guardrail or blockout interaction. The 20-degree incline resulted in the lowest neck compression force. Thus, this design option was recommended for further evaluation through full-scale crash testing.

Table 15.2. Injury Criteria for Modified Rubrail Designs.

Design Notes	Design 1	Design 2
	15° incline and raised bracket	20° incline and raised bracket
Cross-Section View		
HIC (Limit = 1000)	292	234
Neck Force (X-Shear) (+) (Limit = 1100)	451	423
Neck Force (X-Shear) (-) (Limit = -1100)	-449	-448
Neck Force (Z-Axial) (+) (Limit = 3300)	2000	2251
Neck Force (Z-Axial) (-) (Limit = -4000)	-2986	-2684
Neck Moment (Mx) (Limit = 134)	54	53
Neck Moment (My—Flexion) (+) (Limit = 190)	60	41
Neck Moment (My—Extension) (-) (Limit = -57)	-39	-28
Dummy Interaction with Guardrail Components?	No	No
Dummy Rollover?	No	No

Chapter 16. SLIDING ATD (CRASH TEST 469943-01-1A)

16.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 16.1 for the impact conditions and Table 16.2 for the exit parameters for Test 469943-01-1A. Figure 16.1 and Figure 16.2 depict the ATD prior to testing.

Table 16.1. Impact Conditions for Crash Test 469943-01-1A.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	37.3	± 2.5 mi/h	38.5
Impact Angle (deg)	30	$\pm 1.5^\circ$	30.3
Impact Location	Centerline of the ATD's head aligned with the center of post 15	± 2.4 inches	1.8 inches to the right of the center of post 19

Table 16.2. Exit Parameters for Crash Test 469943-01-1A.

Exit Parameter	Measured
Speed (mi/h)	N/A
Trajectory (deg)	N/A
Heading (deg)	N/A
Vehicle at rest position	16 ft downstream of impact point 9 ft to the traffic side 90° left



Figure 16.1. Side View of the ATD on the Sled Delivery System prior to Test 469943-01-1A.

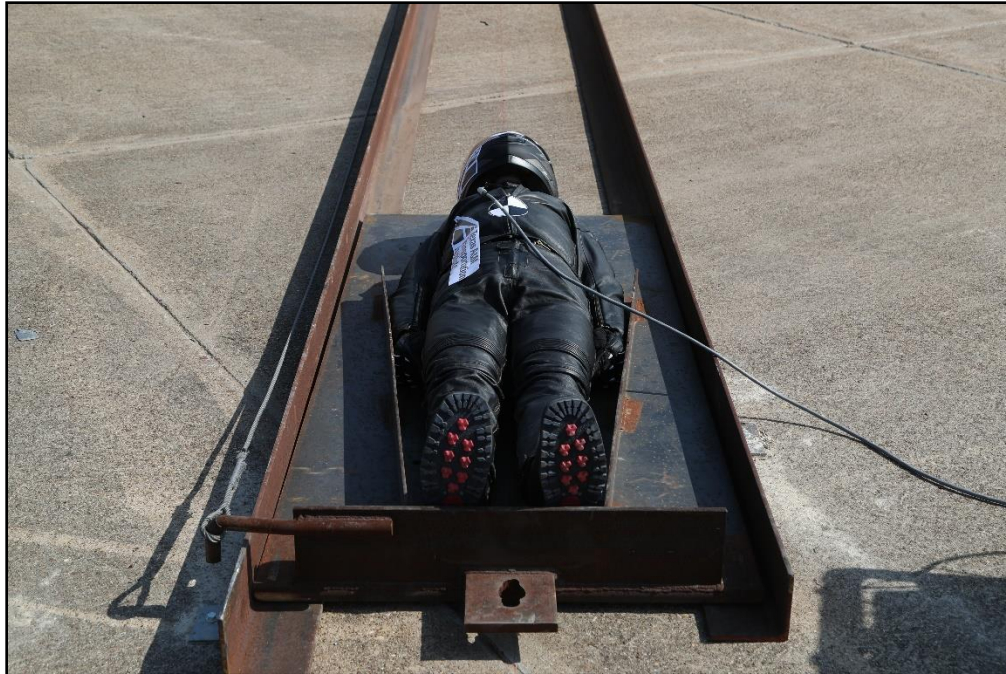


Figure 16.2. In-Line View of the ATD on the Sled Delivery System prior to Test 469943-01-1A.

16.2. WEATHER CONDITIONS

Table 16.3 provides the weather conditions for Test 469943-01-1A.

Table 16.3. Weather Conditions for Test 469943-01-1A.

Date of Test	2023-03-29 AM
Wind Speed (mi/h)	10
Wind Direction (deg)	347
Temperature (°F)	61
Relative Humidity (%)	65
Vehicle Traveling (deg)	20

16.3. TEST DESCRIPTION

Table 16.4 lists events that occurred during Test 469943-01-1A. Figures H.1, H.2, and H.3 in Appendix H.1 present sequential photographs during the test.

Table 16.4. Events during Test 469943-01-1A.

Time (s)	Events
0.0000	Dummy helmet impacted the installation
0.0020	Rubrail began to lean toward field side
0.0030	Dummy helmet began to redirect
0.0150	Dummy left shoulder impacted rubrail
0.1050	Dummy was parallel with installation
0.6750	Dummy lost contact with rubrail

16.4. DAMAGE TO TEST INSTALLATION

The rubrail was deformed and scuffed at impact. Table 16.5 describes the deflection and working width of the enhanced motorcycle guard fence system. Figure 16.3 and Figure 16.4 show the damage to the enhanced motorcycle guard fence system.

Table 16.5. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469943-01-1A.

Test Parameter	Measured
Permanent Deflection/Location	5.3 inches toward field side, 20 inches upstream from the centerline of post 19
Dynamic Deflection	8.3 inches toward field side, 20 inches upstream from the centerline of post 19
Working Width ^a and Height	17.3 inches, at a height of 31 inches, at the guardrail bolt on the field side of post 15

^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 16.3. Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-1A.



Figure 16.4. Enhanced Motorcycle Guard Fence System Rubrail at Impact Location after Test 469943-01-1A.

16.5. DAMAGE TO ATD

Figure 16.5 and Figure 16.6 show the damage sustained by the front of the ATD. Figure 16.7 and Figure 16.8 show the damage sustained by the back of the ATD. Table 16.6 provides details on the calculated injury criteria for the head and neck of the ATD.



Figure 16.5. Right Side of ATD after Test 469943-01-1A.

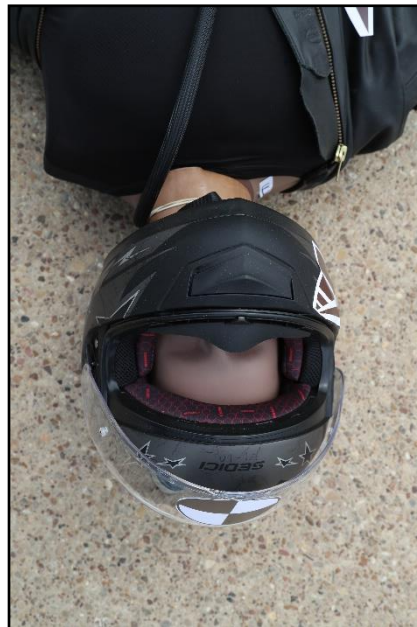


Figure 16.6. ATD Head and Helmet after Test 469943-01-1A.



Figure 16.7. ATD after Test 469943-01-1A.



Figure 16.8. Rear Side of ATD after Test 469943-01-1A.

Table 16.6. ATD Head and Neck Injury Criteria for Test 469943-01-1A.

Body Region	Injury Criterion	EN 1317-8 Limit	Measured
Head	HIC ₃₆	1000	185
Neck	F _x (N)	1100	518
	F _z —Tension (N)	3300	2206
	F _z —Compression (N)	4000	4181
	Moc _x (Nm)	134	82
	Moc _y —Flexion (Nm)	190	26
	Moc _y —Extension (Nm)	57	30

16.6. TEST SUMMARY

Figure 16.9 summarizes the results of Test 469943-01-1A.

16.7. DISCUSSION

The enhanced motorcycle guard fence system successfully redirected the ATD during impact. There was no snagging of the ATD limbs with the wood posts or other elements of the longitudinal barrier. The ATD neck compression forces still exceeded the EN 1317-8 limit by about 5 percent. After discussion with the TxDOT project team panel, it was decided to continue with evaluating the design according to the other impact configurations.

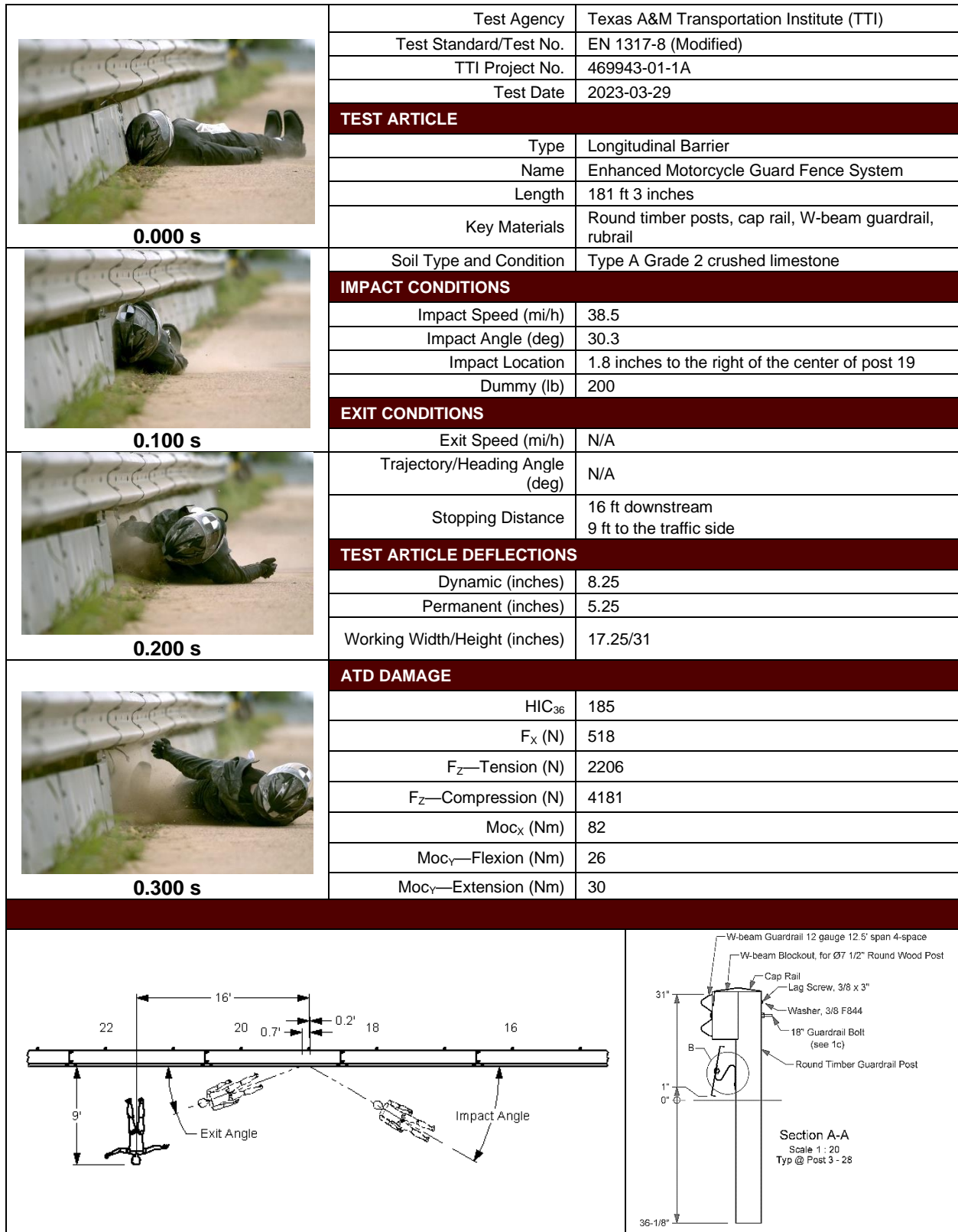


Figure 16.9. Summary of Results for Modified EN 1317-8 Test on Enhanced Motorcycle Guard Fence System.

Chapter 17. SLIDING ATD (CRASH TEST 469943-01-2)

17.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 17.1 for the impact conditions and Table 17.2 for the exit parameters for Test 469943-01-2. Figure 17.1 and Figure 17.2 depict the target impact setup.

Table 17.1. Impact Conditions for Crash Test 469943-01-2.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	37.3	±2.5 mi/h	37.9
Impact Angle (deg)	30	±1.5°	29.7
Impact Location	Centerline of ATD's head aligned with centerline of the rubrail joint	±2.4 inches	1.1 inches upstream from the center of the joint in the rubrail

Table 17.2. Exit Parameters for Crash Test 469943-01-2.

Exit Parameter	Measured
Speed (mi/h)	N/A
Trajectory (deg)	N/A
Heading (deg)	N/A
Vehicle at rest position	20 ft downstream of impact point 9 ft to the traffic side 90° left



Figure 17.1. Side View of the ATD on the Sled Delivery System prior to Test 469943-01-2.



Figure 17.2. In-Line View of the ATD on the Sled Delivery System prior to Test 469943-01-2.

17.2. WEATHER CONDITIONS

Table 17.3 provides the weather conditions for Test 469943-01-2.

Table 17.3. Weather Conditions for Test 469943-01-2.

Date of Test	2023-04-14 AM
Wind Speed (mi/h)	19
Wind Direction (deg)	80
Temperature (°F)	72
Relative Humidity (%)	80
Vehicle Traveling (deg)	20

17.3. TEST DESCRIPTION

Table 17.4 lists events that occurred during Test 469943-01-2. Figures I.1, I.2, and I.3 in Appendix I.1 present sequential photographs during the test.

Table 17.4. Events during Test 469943-01-2.

Time (s)	Events
0.0000	Dummy helmet impacted the installation
0.0010	Rubrail began to lean toward field side and dummy helmet began to deform
0.0090	Dummy left shoulder impacted rubrail
0.1020	Dummy was parallel with installation
0.3150	Dummy lost contact with rubrail

17.4. DAMAGE TO TEST INSTALLATION

There was some scuffing on the rubrail at impact, and the rail was deformed. Table 17.5 describes the deflection and working width of the enhanced motorcycle guard fence system. Figure 17.3 and Figure 17.4 show the damage to the enhanced motorcycle guard fence system.

Table 17.5. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469943-01-2.

Test Parameter	Measured
Permanent Deflection/Location	4.5 inches toward field side, 4 inches downstream from the center of the joint
Dynamic Deflection	8.5 inches toward field side, 4 inches downstream from the center of the joint
Working Width ^a and Height	17.3 inches, at a height of 31 inches, at the guardrail bolt on the field side of post 15

^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 17.3. Traffic Side of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-2.



Figure 17.4. Field Side of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-2.

17.5. DAMAGE TO ATD

Figure 17.5 and Figure 17.6 show the damage sustained by the front of the ATD. Figure 17.7 and Figure 17.8 show detailed damage of the head and shoulder of the ATD. Table 17.6 provides details on the calculated injury criteria for the head and neck of the ATD.



Figure 17.5. Left Side of the ATD after Test 469943-01-2.



Figure 17.6. Front of the ATD after Test 469943-01-2.



Figure 17.7. Helmet Damage after Test 469943-01-2.



Figure 17.8. Shoulder Damage after Test 469943-01-2.

Table 17.6. ATD Head and Neck Injury Criteria for Test 469943-01-2.

Body Region	Injury Criterion	EN 1317-8 Limit	Measured
Head	HIC ₃₆	1000	420
Neck	F _x (N)	1100	430
	F _z —Tension (N)	3300	2236
	F _z —Compression (N)	4000	4003
	Moc _x (Nm)	134	74
	Moc _y —Flexion (Nm)	190	18
	Moc _y —Extension (Nm)	57	24

17.6. TEST SUMMARY

Figure 17.9 summarizes the results of Test 469943-01-2.





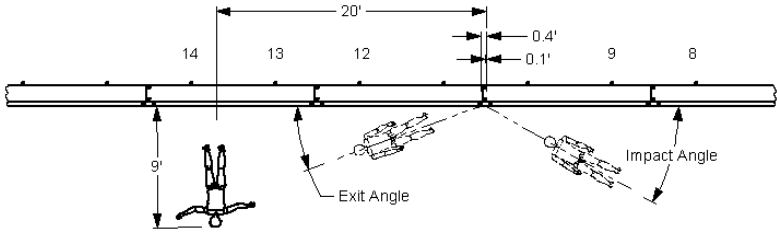
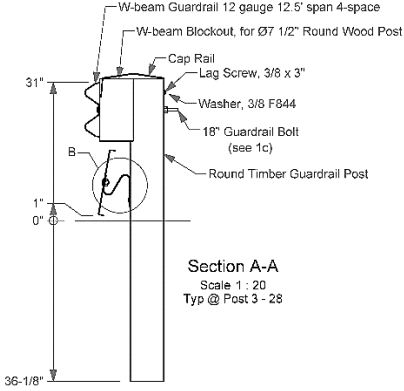
 <p style="text-align: center;">0.000 s</p>	Test Agency	Texas A&M Transportation Institute (TTI)
	Test Standard/Test No.	EN 1317-8 (Modified)
	TTI Project No.	469943-01-2
	Test Date	2023-04-14
Test ARTICLE		
	Type	Longitudinal Barrier
	Name	Enhanced Motorcycle Guard Fence System
	Length	181 ft 3 inches
	Key Materials	Round timber posts, cap rail, W-beam guardrail, rubrail
	Soil Type and Condition	Type A Grade 2 crushed limestone
 <p style="text-align: center;">0.100 s</p>	IMPACT CONDITIONS	
	Impact Speed (mi/h)	37.9
	Impact Angle (deg)	29.7
	Impact Location	1.1 inches upstream from the center of the joint in the rubrail
	Dummy (lb)	200
 <p style="text-align: center;">0.200 s</p>	EXIT CONDITIONS	
	Exit Speed (mi/h)	N/A
	Trajectory/Heading Angle (deg)	N/A
	Stopping Distance	20 ft downstream 9 ft to the traffic side
 <p style="text-align: center;">0.300 s</p>	Test ARTICLE DEFLECTIONS	
	Dynamic (inches)	8.5
	Permanent (inches)	4.5
	Working Width/Height (inches)	17.25/31
ATD DAMAGE		
	HIC ₃₆	420
	F _x (N)	430
	F _z —Tension (N)	2236
	F _z —Compression (N)	4003
	Moc _x (Nm)	74
	Moc _y —Flexion (Nm)	18
	Moc _y —Extension (Nm)	24
		 <p style="text-align: center;">Section A-A Scale 1 : 20 Typ @ Post 3 - 28</p>

Figure 17.9. Summary of Results for Modified EN 1317-8 Test on Enhanced Motorcycle Guard Fence System.

Chapter 18. MASH TEST 3-10 (CRASH TEST 469943-01-3)

18.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 18.1 for the *MASH* impact conditions and Table 18.2 for the exit parameters for Test 469943-01-3. Figure 18.1 and Figure 18.2 depict the target impact setup.

Table 18.1. Impact Conditions for *MASH* Test 3-10, Crash Test 469943-01-3.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	62.2
Impact Angle (deg)	25	±1.5°	24.7
Impact Severity (kip-ft)	51	≥51 kip-ft	55.0
Impact Location	38 inches upstream from the centerline of post 13	±12 inches	36.4 inches upstream from the centerline of post 13

Table 18.2. Exit Parameters for *MASH* Test 3-10, Crash Test 469943-01-3.

Exit Parameter	Measured
Speed (mi/h)	41.4
Trajectory (deg)	11.6
Heading (deg)	11.2
Brakes applied post impact (s)	2.7
Vehicle at rest position	206 ft downstream of impact point 27 ft to the traffic side 0°
Comments:	The vehicle remained upright and stable. Vehicle crossed the exit box ^a 31 ft downstream from loss of contact.

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



Figure 18.1. Enhanced Motorcycle Guard Fence System/Test Vehicle Geometrics for Test 469943-01-3.



Figure 18.2. Enhanced Motorcycle Guard Fence System/Test Vehicle Impact Location for Test 469943-01-3.

18.2. WEATHER CONDITIONS

Table 18.3 provides the weather conditions for Test 469943-01-3.

Table 18.3. Weather Conditions for Test 469943-01-3.

Date of Test	2023-04-18 AM
Wind Speed (mi/h)	4
Wind Direction (deg)	145
Temperature (°F)	66
Relative Humidity (%)	91
Vehicle Traveling (deg)	15

18.3. TEST VEHICLE

Figure 18.3 and Figure 18.4 show the 2017 Nissan Versa used for the crash test. Table 18.4 shows the vehicle measurements. Figure J.1 in Appendix J.1 gives additional dimensions and information on the vehicle.



Figure 18.3. Impact Side of Test Vehicle before Test 469943-01-3.



Figure 18.4. Opposite Impact Side of Test Vehicle before Test 469943-01-3.

Table 18.4. Vehicle Measurements for Test 469943-01-3.

Test Parameter	Specification	Tolerance	Measured
Dummy (if applicable) ^a (lb)	165	N/A	165
Inertial Weight (lb)	2420	±55	2434
Gross Static ^a (lb)	2585	±55	2599
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	41.2
CG above Ground ^{c,d} (inches)	N/A	N/A	N/A

Note: N/A = not applicable; CG = center of gravity.

^a If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.

^b Average of front and rear axles.

^c For test inertial mass.

^d 2270P vehicle must meet minimum CG height requirement.

18.4. TEST DESCRIPTION

Table 18.5 lists events that occurred during Test 469943-01-3. Figures J.4, J.5, and J.6 in Appendix J.2 present sequential photographs during the test.

Table 18.5. Events during Test 469943-01-3.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0330	Vehicle began to redirect
0.0630	Top rail came free from test article
0.1910	Rear passenger bumper contacted rail
0.1980	Front passenger-side tire impacted post 15
0.2020	Vehicle was parallel with installation
0.3980	Vehicle exited the installation at 41.4 mi/h with a heading of 11.2 degrees and a trajectory of 11.6 degrees

18.5. DAMAGE TO TEST INSTALLATION

The top rail pulled away starting at post 8 and continuing to post 20. The rail released from posts 10 through 19. The W-beam was scuffed and deformed at impact and released from posts 14 and 15. The rubrail was scuffed and deformed at impact and released from the bracket at post 15, while the rubrail bracket released from post 14. Table 18.6 describes the soil gap and post lean of the enhanced motorcycle guard fence system.

Table 18.7 describes the deflection and working width of the enhanced motorcycle guard fence system. Figure 18.5 and Figure 18.6 show the damage to the enhanced motorcycle guard fence system.

Table 18.6. Soil Gap and Post Lean for Test 469943-01-3.

Post	Soil Gap	Post Lean from Vertical
11	Soil disturbed	—
12	1 inch t/s	3.6° f/s
13	—	26.0° f/s
15	—	15.7° f/s; 30.0° t/s
16	0.25 inch t/s; 0.125 inch f/s	3.5° f/s

Note: f/s = field side; t/s = traffic side; — = none.

Table 18.7. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469943-01-3.

Test Parameter	Measured
Permanent Deflection/Location	15.4 inches toward field side at post 14
Dynamic Deflection	22.8 inches toward field side at the main rail 1 ft downstream of post 14
Working Width ^a and Height	51.9 inches, at a height of 39.4 inches, at the top rail cover joint between posts 14 and 15

^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 18.5. Traffic-Side View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-3.



Figure 18.6. Field-Side View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-3.

18.6. DAMAGE TO TEST VEHICLE

Figure 18.7 and Figure 18.8 show the damage sustained by the vehicle. Figure 18.9 and Figure 18.10 show the interior of the test vehicle. Table 18.8 and Table 18.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figures J.2 and J.3 in Appendix J.1 provide exterior crush and occupant compartment measurements.



Figure 18.7. Impact Side of Test Vehicle after Test 469943-01-3.



Figure 18.8. Rear Impact Side of Test Vehicle after Test 469943-01-3.



Figure 18.9. Overall Interior of Test Vehicle after Test 469943-01-3.



Figure 18.10. Interior of Test Vehicle on Impact Side after Test 469943-01-3.

Table 18.8. Occupant Compartment Deformation for Test 469943-01-3.

Test Parameter	Specification (inches)	Measured (inches)
Roof	≤4.0	0.0
Windshield	≤3.0	0.0
A and B Pillars	≤5.0 overall/≤3.0 lateral	0.0
Foot Well/Toe Pan	≤9.0	1.0
Floor Pan/Transmission Tunnel	≤12.0	0.0
Side Front Panel	≤12.0	1.0
Front Door (above Seat)	≤9.0	0.0
Front Door (below Seat)	≤12.0	0.0

Table 18.9. Exterior Vehicle Damage for Test 469943-01-3.

Side Windows	The side windows remained intact
Maximum Exterior Deformation	8 inches in the front plane at the right front corner above bumper height
VDS	01RFQ2
CDC	01FREW1
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, grill, right front headlight, right front fender, right front frame rail, right front tire, wheel, strut, right front drive axle, right front door, right rear door, right rear quarter panel, and rear bumper were damaged. The lower portion of the right front door was pulled up 3 inches, and there was a 5-inch long, 1.5-inch wide hole in the front right door. The right front door had a 1.25-inch gap at the top.

18.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 18.10. Figure J.7 in Appendix J.3 shows the vehicle angular displacements, and Figures J.8 through J.10 in Appendix J.4 show acceleration versus time traces.

Table 18.10. Occupant Risk Factors for Test 469943-01-3.

Test Parameter	Specification ^a	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 <i>30.0</i>	14.5	0.1086 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 <i>30.0</i>	18.8	0.1086 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 <i>15.0</i>	10.6	0.2030–0.2130 seconds
Ridedown, Lateral (g)	≤20.49 <i>15.0</i>	10.1	0.2243–0.2343 seconds
THIV (m/s)	N/A	7.2	0.1048 seconds on right side of interior
ASI	N/A	1.24	0.0505–0.1005 seconds
50-ms MA Longitudinal (g)	N/A	-7.1	0.0154–0.0654 seconds
50-ms MA Lateral (g)	N/A	-9.3	0.0221–0.0721 seconds
50-ms MA Vertical (g)	N/A	-2.7	0.1841–0.2341 seconds
Roll (deg)	≤75	17.8	1.1179 seconds
Pitch (deg)	≤75	5.4	1.1134 seconds
Yaw (deg)	N/A	49.2	1.0968 seconds

Note: N/A = not applicable.

^a Values in italics are the preferred *MASH* values.

18.8. TEST SUMMARY

Figure 18.11 summarizes the results of *MASH* Test 469943-01-3.



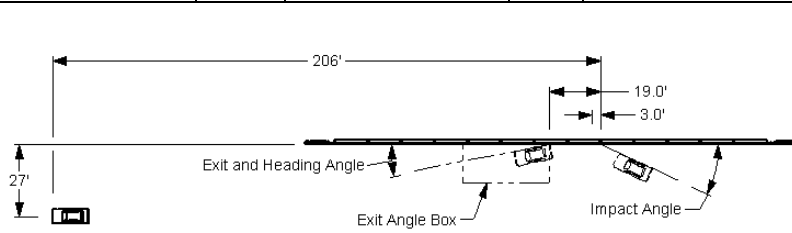
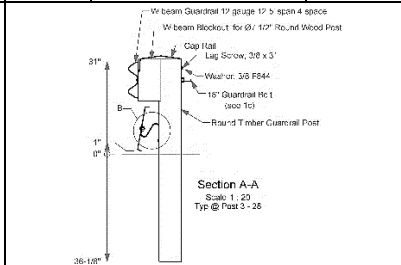
 <p>0.000 s</p>	Test Agency	Texas A&M Transportation Institute (TTI)					
	Test Standard/Test No.	MASH 2016, Test 3-10					
	TTI Project No.	469943-01-3					
	Test Date	2023-04-18					
 <p>0.200 s</p>	TEST ARTICLE						
	Type	Longitudinal Barrier					
	Name	Enhanced Motorcycle Guard Fence System					
	Length	181 ft 3 inches					
 <p>0.400 s</p>	Key Materials	Round timber posts, cap rail, W-beam guardrail, rubrail					
	Soil Type and Condition	Type A Grade 2 crushed limestone					
	TEST VEHICLE						
	Type/Designation	1100C					
 <p>0.600 s</p>	Year, Make and Model	2017 Nissan Versa					
	Inertial Weight (lb)	2434					
	Dummy (lb)	165					
	Gross Static (lb)	2599					
IMPACT CONDITIONS							
Impact Speed (mi/h)	62.2						
Impact Angle (deg)	24.7						
Impact Location	36.4 inches upstream from the centerline of post 13						
Impact Severity (kip-ft)	55.0						
EXIT CONDITIONS							
Exit Speed (mi/h)	41.4						
Trajectory/Heading Angle (deg)	11.6/11.2						
Exit Box Criteria	Vehicle crossed the exit box 31 ft downstream from loss of contact						
Stopping Distance	206 ft downstream 27 ft to the traffic side						
TEST ARTICLE DEFLECTIONS							
Dynamic (inches)	22.8						
Permanent (inches)	15.4						
Working Width/Height (inches)	51.9/39.4						
VEHICLE DAMAGE							
VDS	01RFQ2						
CDC	01FREW1						
Max. Ext. Deformation (inches)	8						
Max Occupant Compartment Deformation	1 inch in the right foot well and in the front side panel						
OCCUPANT RISK VALUES							
Long. OIV (ft/s)	14.5	Long. Ridedown (g)	10.6	Max 50-ms Long. (g)	-7.1	Max Roll (deg)	17.8
Lat. OIV (ft/s)	18.8	Lat. Ridedown (g)	10.1	Max 50-ms Lat. (g)	-9.3	Max Pitch (deg)	5.4
THIV (m/s)	7.2	ASI	1.24	Max 50-ms Vert. (g)	-2.7	Max Yaw (deg)	49.2
							

Figure 18.11. Summary of Results for MASH Test 3-10 on Enhanced Motorcycle Guard Fence System.

Chapter 19. MASH TEST 3-11 (CRASH TEST 469943-01-4)

19.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 19.1 for the *MASH* impact conditions and Table 19.2 for the exit parameters for Test 469943-01-4. Figure 19.1 and Figure 19.2 depict the target impact setup.

Table 19.1. Impact Conditions for *MASH* Test 3-11, Crash Test 469943-01-4.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	65.0
Impact Angle (deg)	25	±1.5°	24.7
Impact Severity (kip-ft)	106	≥106 kip-ft	124.1
Impact Location	13 ³ / ₁₆ inches upstream of centerline of post 12	±12 inches	13 ³ / ₁₆ inches upstream of centerline of post 12

Table 19.2. Exit Parameters for *MASH* Test 3-11, Crash Test 469943-01-4.

Exit Parameter	Measured
Speed (mi/h)	Not measurable. Exit was out of camera frame.
Trajectory (deg)	Not measurable. Exit was out of camera frame.
Heading (deg)	Not measurable. Exit was out of camera frame.
Brakes applied post impact (s)	2.6
Vehicle at rest position	171 ft downstream of impact point 6 ft to the field side 15° right
Comments:	The vehicle remained upright and stable. Vehicle did not cross the exit box.



Figure 19.1. Enhanced Motorcycle Guard Fence System/Test Vehicle Geometrics for Test 469943-01-4.



Figure 19.2. Enhanced Motorcycle Guard Fence System/Test Vehicle Impact Location for Test 469943-01-4.

19.2. WEATHER CONDITIONS

Table 19.3 provides the weather conditions for Test 469943-01-4.

Table 19.3. Weather Conditions for Test 469943-01-4.

Date of Test	2023-05-18 PM
Wind Speed (mi/h)	3
Wind Direction (deg)	10
Temperature (°F)	88
Relative Humidity (%)	56
Vehicle Traveling (deg)	15

19.3. TEST VEHICLE

Figure 19.3 and Figure 19.4 show the 2017 RAM 1500 used for the crash test. Table 19.4 shows the vehicle measurements. Figure K.1 in Appendix K.1 gives additional dimensions and information on the vehicle.



Figure 19.3. Impact Side of Test Vehicle before Test 469943-01-4.



Figure 19.4. Opposite Impact Side of Test Vehicle before Test 469943-01-4.

Table 19.4. Vehicle Measurements for Test 469943-01-4.

Test Parameter	Specification	Tolerance	Measured
Dummy (if applicable) ^a (lb)	165	N/A	N/A
Inertial Weight (lb)	5000	±110	5032
Gross Static ^a (lb)	5000	±110	5032
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46
Track Width ^b (inches)	67	±1.5	68.25
CG aft of Front Axle ^c (inches)	63	±4	61.06
CG above Ground ^{c,d} (inches)	28	28	28.6

Note: N/A = not applicable; CG = center of gravity.

^a If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.

^b Average of front and rear axles.

^c For test inertial mass.

^d 2270P vehicle must meet minimum CG height requirement.

19.4. TEST DESCRIPTION

Table 19.5 lists events that occurred during Test 469943-01-4. Figures K.4, K.5, and K.6 in Appendix K.2 present sequential photographs during the test.

Table 19.5. Events during Test 469943-01-4.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0170	Posts 11 and 12 began to lean toward field side
0.0270	Post 13 began to lean toward field side
0.0320	Vehicle began to redirect
0.0562	Front passenger-side tire impacted post 12
0.1370	Front driver-side tire lifted off pavement
0.2760	Vehicle was parallel with installation

19.5. DAMAGE TO TEST INSTALLATION

The W-beam rail released from posts 1, 2, and 4 through 15. The cap rail was pushed up on the traffic side from posts 4 through 21, and it released from posts 9 through 18. The rubrail released from posts 12 through 16, and the rubrail bracket was significantly deformed but still attached to the rail at posts 11 and 17. Posts 13 and 15 broke off at grade, and post 14 pulled out of the soil. Table 19.6 describes the soil gap and post lean of the enhanced motorcycle guard fence system.

Table 19.7 describes the deflection and working width of the enhanced motorcycle guard fence system. Figure 19.5 and Figure 19.6 show the damage to the enhanced motorcycle guard fence system.

Table 19.6. Soil Gap and Post Lean for Test 469943-01-4.

Post	Soil Gap	Post Lean from Vertical
11	1 inch t/s; 0.25 inch f/s	6.6 degrees
12	Soil filled back in t/s; 3 inches f/s	6.6 degrees
16	1.5 inches t/s & f/s	1.0 degree
17	Soil disturbed	—

Note: f/s = field side; t/s = traffic side; — = none.

Table 19.7. Deflection and Working Width of the Enhanced Motorcycle Guard Fence System for Test 469943-01-4.

Test Parameter	Measured
Permanent Deflection/Location	32 inches toward field side at post 14
Dynamic Deflection	41.4 inches toward field side at the main rail at post 14
Working Width ^a and Height	57.3 inches, at a height of 34.0 inches, at the top rail cover between posts 13 and 14

^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 19.5. Traffic-Side View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-4.



Figure 19.6. In-Line View of the Enhanced Motorcycle Guard Fence System at Impact Location after Test 469943-01-4.

19.6. DAMAGE TO TEST VEHICLE

Figure 19.7 and Figure 19.8 show the damage sustained by the vehicle. Figure 19.9 and Figure 19.10 show the interior of the test vehicle. Table 19.8 and Table 19.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figures K.2 and K.3 in Appendix K.1 provide exterior crush and occupant compartment measurements.

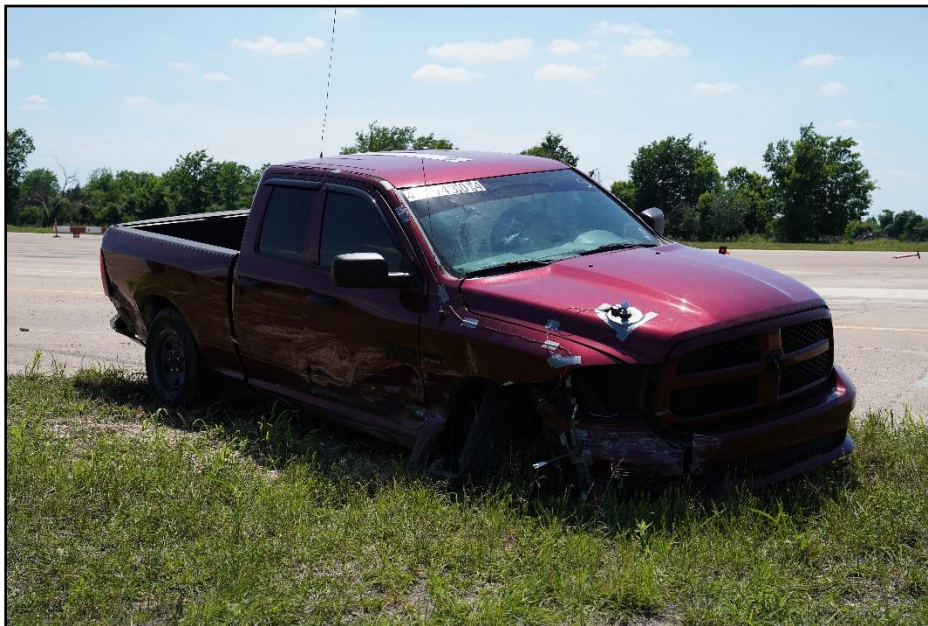


Figure 19.7. Impact Side of Test Vehicle after Test 469943-01-4.



Figure 19.8. Rear Impact Side of Test Vehicle after Test 469943-01-4.

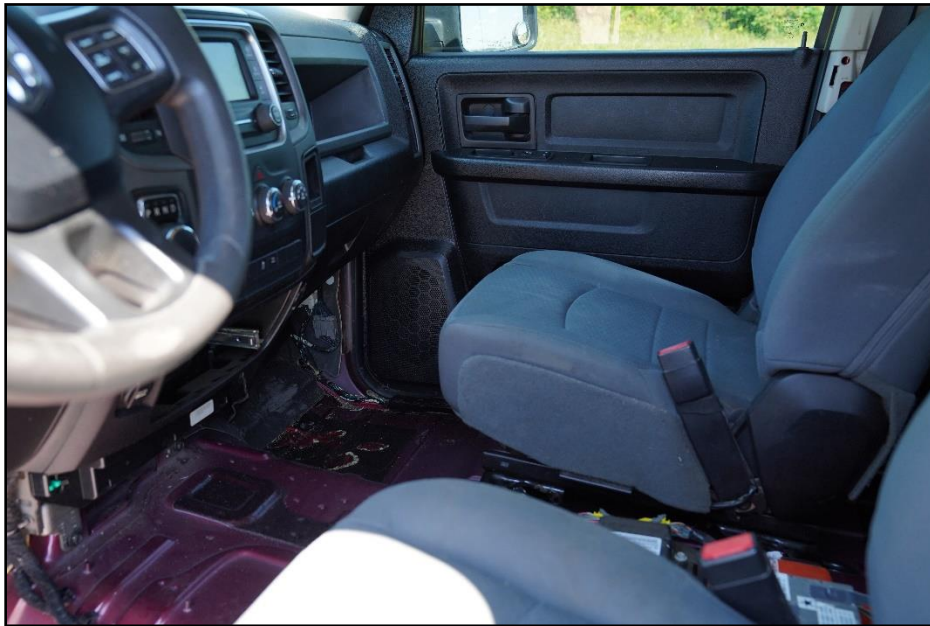


Figure 19.9. Overall Interior of Test Vehicle after Test 469943-01-4.



Figure 19.10. Interior of Test Vehicle on Impact Side after Test 469943-01-4.

Table 19.8. Occupant Compartment Deformation for Test 469943-01-4.

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

Table 19.9. Exterior Vehicle Damage for Test 469943-01-4.

Side Windows	The side windows remained intact
Maximum Exterior Deformation	10 inches in the front plane at the right front corner above bumper height
VDS	01RFQ3
CDC	01FREW2
Fuel Tank Damage	None
Description of Damage to Vehicle:	The right front bumper, right headlight, right front lower A arm, right front tire and wheel, right front fender, right side quarter panels, and rear bumper were damaged. The right front door had a 1-inch gap at the top.

19.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 19.10. Figure K.7 in Appendix K.3 shows the vehicle angular displacements, and Figures K.8 through K.10 in Appendix K.4 show acceleration versus time traces.

Table 19.10. Occupant Risk Factors for Test 469943-01-4.

Test Parameter	Specification ^a	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 <i>30.0</i>	14.7	0.1481 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 <i>30.0</i>	15	0.1481 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 <i>15.0</i>	8.7	0.2356–0.2456 seconds
Ridedown, Lateral (g)	≤20.49 <i>15.0</i>	8.6	0.2355–0.2455 seconds
THIV (m/s)	N/A	5.9	0.1417 seconds on right side of interior
ASI	N/A	0.76	0.2332–0.2832 seconds
50-ms MA Longitudinal (g)	N/A	-5.1	0.1952–0.2452 seconds
50-ms MA Lateral (g)	N/A	-6.2	0.2360–0.2860 seconds
50-ms MA Vertical (g)	N/A	3	0.3293–0.3793 seconds
Roll (deg)	≤75	13.9	0.6564 seconds
Pitch (deg)	≤75	9.4	0.6462 seconds
Yaw (deg)	N/A	40.5	0.6434 seconds

Note: N/A = not applicable.

^a Values in italics are the preferred *MASH* values.

19.8. TEST SUMMARY

Figure 19.11 summarizes the results of *MASH* Test 469943-01-4.





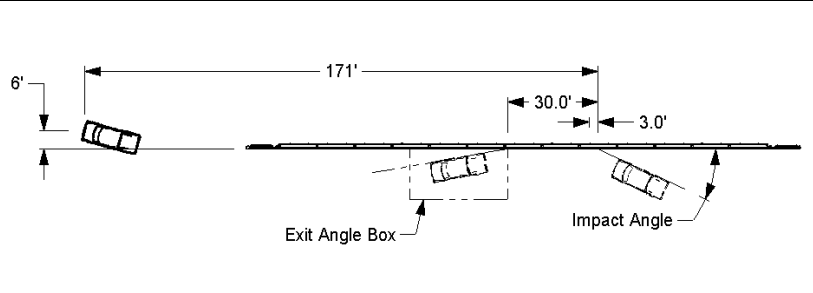
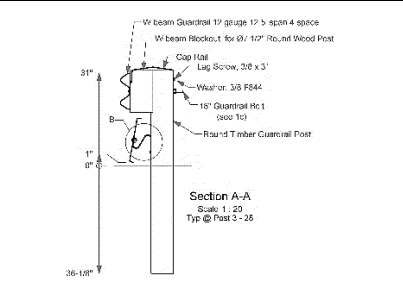
 <p style="text-align: center;">0.000 s</p>	Test Agency	Texas A&M Transportation Institute (TTI)					
	Test Standard/Test No.	MASH 2016, Test 3-11					
	TTI Project No.	469943-01-4					
	Test Date	2023-05-18					
 <p style="text-align: center;">0.200 s</p>	Test ARTICLE						
	Type	Longitudinal Barrier					
	Name	Enhanced Motorcycle Guard Fence System					
	Length	181 ft 3 inches					
 <p style="text-align: center;">0.400 s</p>	Key Materials	Round timber posts, cap rail, W-beam guardrail, rubrail					
	Soil Type and Condition	Type A Grade 2 crushed limestone					
	Test VEHICLE						
	Type/Designation	2270P					
 <p style="text-align: center;">0.600 s</p>	Year, Make and Model	2017 RAM 1500					
	Inertial Weight (lb)	5032					
	Dummy (lb)	N/A					
	Gross Static (lb)	5032					
IMPACT CONDITIONS							
Impact Speed (mi/h)	65.0						
Impact Angle (deg)	24.7						
Impact Location	13 ³ / ₁₆ inches upstream of centerline of post 12						
Impact Severity (kip-ft)	124.1						
EXIT CONDITIONS							
Exit Speed (mi/h)	Not measurable. Exit was out of camera frame.						
Trajectory/Heading Angle (deg)	Not measurable. Exit was out of camera frame.						
Exit Box Criteria	Vehicle did not cross the exit box						
Stopping Distance	171 ft downstream 6 ft to the field side						
Test ARTICLE DEFLECTIONS							
Dynamic (inches)	41.4						
Permanent (inches)	32						
Working Width/Height (inches)	57.3/34.0						
VEHICLE DAMAGE							
VDS	01RFQ3						
CDC	01FREW2						
Max. Ext. Deformation (inches)	10						
Max Occupant Compartment Deformation	No occupant compartment deformation						
OCCUPANT RISK VALUES							
Long. OIV (ft/s)	14.7	Long. Ridedown (g)	8.7	Max 50-ms Long. (g)	-5.1	Max Roll (deg)	13.9
Lat. OIV (ft/s)	15	Lat. Ridedown (g)	8.6	Max 50-ms Lat. (g)	-6.2	Max Pitch (deg)	9.4
THIV (m/s)	5.9	ASI	0.76	Max 50-ms Vert. (g)	3	Max Yaw (deg)	40.5
							

Figure 19.11. Summary of Results for MASH Test 3-11 on Enhanced Motorcycle Guard Fence System.

Chapter 20. PLACEMENT GUIDANCE

It was desired to develop placement guidance for installing the guardrails to decrease the severity of roadway departure (RwD) motorcycle crashes involving fixed objects. RwD crashes are single-vehicle crashes that can be divided into three groups: (1) fixed object, (2) opposing direction, and (3) rollover crashes. For the purposes of this project, the researchers selected the RwD motorcycle crashes that involved fixed objects (roadway departure involving fixed objects [RDFO]). After identifying these crashes, the researchers conducted a statistical analysis to identify the roadway and roadside factors associated with fatal and injury motorcycle crashes involving fixed objects. Finally, the researchers conducted a data mining analysis to select the sites with low, medium, and high risk of RDFO motorcycle crashes that can benefit from the retrofit guardrail.

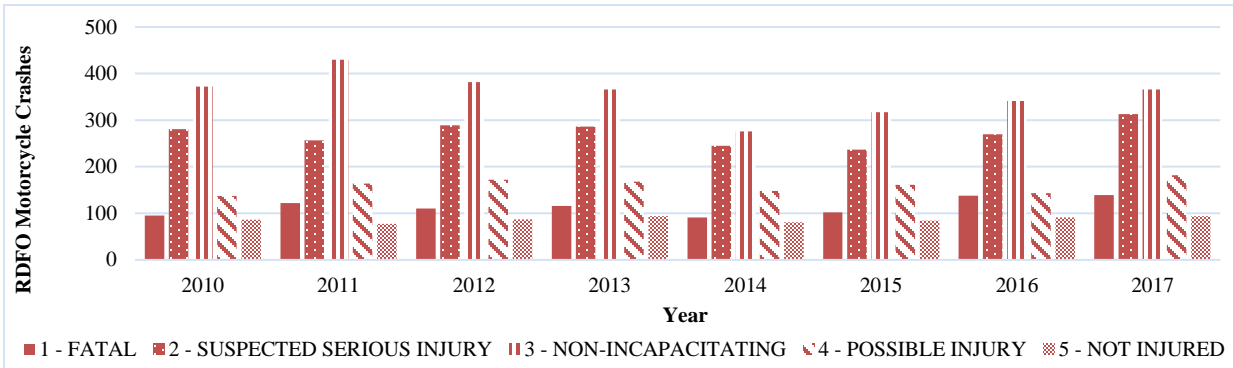
20.1. RDFO MOTORCYCLE CRASHES

CRIS contains 68,838 TxDOT reportable motorcycle-involved crashes that occurred between 2010 and 2017, out of which 7,910 were reported to be RDFO. Table 20.1 shows the frequency and severity of these crashes for this period. As can be observed, the majority of RDFO motorcycle crashes resulted in fatal and injury crashes.

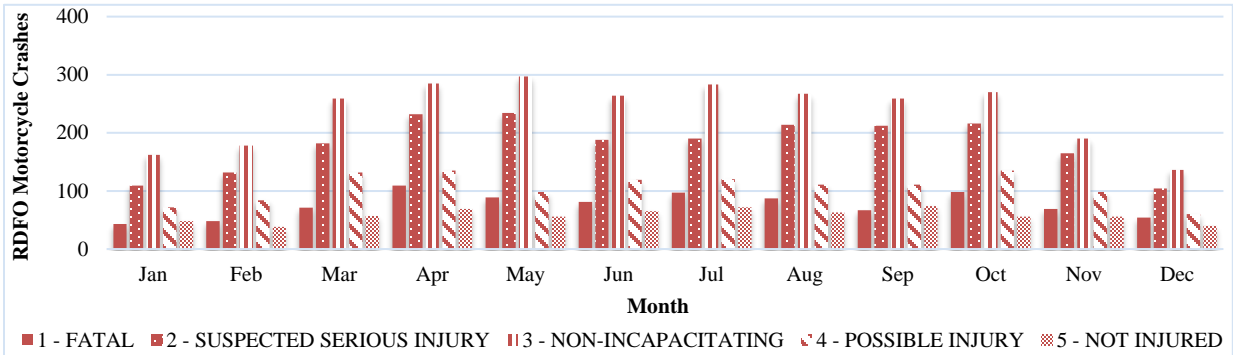
Table 20.1. Number and Percentage of RDFO Motorcycle Crash Severities.

Crash Injury Level	Number of Crashes	Percentage
Fatal	913	12%
Suspected Serious Injury	2,178	28%
Non-incapacitating	2,850	36%
Possible Injury	1,275	16%
No Injury	694	9%
Total	7,910	100%

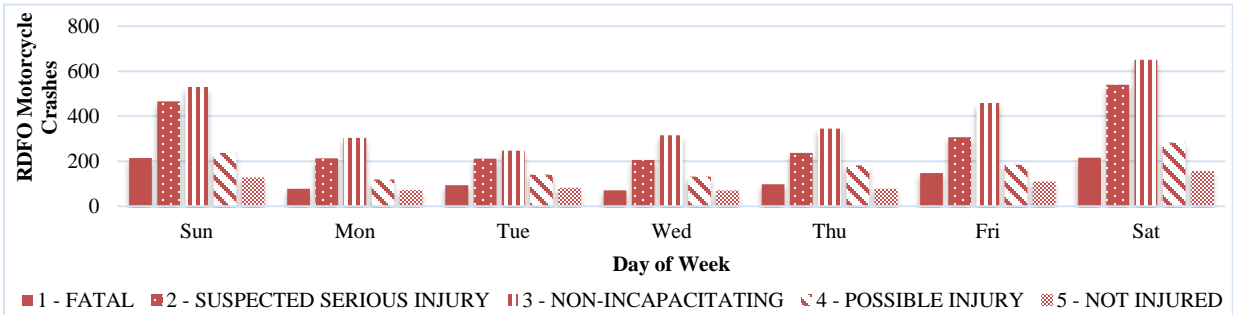
Figure 20.1 depicts the temporal features of RDFO motorcycle crashes that resulted in a fatality or injury (FI, or KABC). As the figure shows, FI crashes, particularly fatal and suspected serious injury RDFO motorcycle crashes, have been increasing in past years (Figure 20.1[a]). The crashes from 2010 to 2017 occurred mainly during summer months (Figure 20.1[b]) and on the weekends (Figure 20.1[c]), indicating high recreational activity. The RDFO FI motorcycle crashes also tended to occur during peak hours (Figure 20.1[d]). However, unlike the vehicle crashes, the crash frequency and severity of RDFO motorcycle crashes remained high until 2:00 a.m.



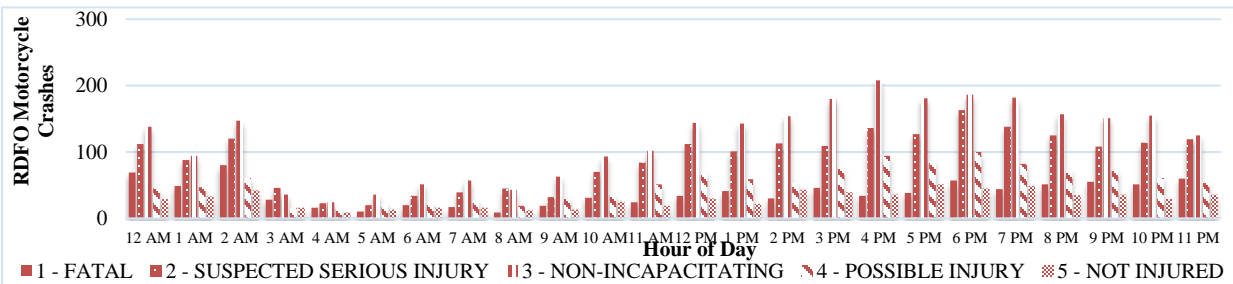
a) Year



b) Month



c) Day of Week



d) Hour of Day

Figure 20.1. Temporal Distribution of RDFS Motorcycle Crashes.

These crashes involved over 28 types of fixed objects. For modeling purposes, the fixed objects found in the crash database were categorized into seven groups, as shown in Table 20.2.

Table 20.2. Fixed Object Types.

Roadside Safety Device and Fixed Object Name	Fixed Object Group	Roadside Safety Device and Fixed Object Name	Fixed Object Group
Curb	Concrete	Jack-Knifed	Other
Concrete Traffic Barrier	Concrete	Highway Sign	Poles
Retaining Wall	Concrete	Tree Shrub Landscaping	Poles
Culvert-Headwall	Concrete	Mailbox	Poles
Embankment	Concrete	Delineator or Marker Post	Poles
End of Bridge (Abutment or Rail End)	Bridge	Fire Hydrant	Poles
Side of Bridge (Bridge Rail)	Bridge	Utility Pole	Poles
Pier or Support at Underpass Tunnel or Overhead Sign Bridge	Bridge	Luminaire Pole	Poles
House Building or Building Fixture	Building	Traffic Signal Pole or Post	Poles
Bus Stop Structure (Bench)	Building	Commercial Sign	Poles
Fence	Guardrail and Fence	Fallen Trees or Debris on Road	Poles
Guardrail	Guardrail and Fence	Not Applicable	Other
Attenuation Device	Guardrail and Fence	Work Zone Barricade, Cones, Signs, or Material	Work Zone Elements
Other Fixed Object	Other	Work Zone Machinery or Stockpiled Materials	Work Zone Elements

In addition to the fixed objects listed above, the research team also considered other roadway and roadside elements, as well as operational and environmental crash-contributing factors, for developing the severity models:

- Roadside elements and safety systems (e.g., fixed objects, curb, shoulder type and width).
- Roadway characteristics (e.g., highway system, alignment, number of lanes).
- Operational factors (e.g., speed limit, average annual daily traffic [AADT]).
- Temporal factors (e.g., crash hour, lighting conditions).

Table 20.3 and Table 20.4 present the descriptive statistics of the quantitative and qualitative variables used in the analysis.

Table 20.3. Descriptive Statistics of Quantitative Variables.

Variable	Min	Max	Mean	St. D.
Average Annual Daily Traffic (number of vehicles)	10	277,883	23,467.03	45,346.9
Curve Length (mi)	0	2,007	19.85	316.62
K-Factor	5	29	10.4133	1.61
Lane Width (ft)	9	14	11.0293	1.457
Segment Length (mi)	0.01	21.88	1.32	1.71
Median Width (ft)	0	50	6.47	20.27
Number of Lanes	1	14	3.27530	1.85
Radius (ft)	0	7,237	42.75	243.82
Shoulder Width (ft)	0	<10	5.27602	8.08
Speed Limit (mi/h)	10	80	43.5138	14.97
Surface Treatment Thickness (inches)	0	3	0.00126	3

Table 20.4. Description of Qualitative Variables.

Variable	Description	
Alignment, Horizontal	Curve, Tangent	
Alignment, Vertical	Level, Grade, Hillcrest	
Crash Severity	K=Fatal A=Suspected Serious Injury B=Non-Incapacitating	C=Possible Injury O=No Injury
Functional Class	<u>Rural:</u> 01=Interstate 02=Other Principal Arterial 06=Minor Arterial 07=Major Collector 08=Minor Collector 09=Local	<u>Urban:</u> 11=Interstate 12=Other Freeway and Expressway 14=Other Principal Arterial 16=Minor Arterial 17=Collector 19=Local
Fixed Object	Concrete Poles Guardrail	Work Zone Bridge Building
Highway System	<u>On-System:</u> BF=Business FM BI=Business IH BS=Business State BU=Business US FM=Farm to Market FS=FM Spur IH=Interstate PA=Principal Arterial PR=Park Road RE=Rec Road RM=Ranch to Market	<u>Off-System:</u> CR=County Road FC=Func. Classified City Street FD=Federal Road RP=Rec Road Spur RR=Ranch Road RS=RM Spur RU=RR Spur SA=State Alternate SH=State Highway SL=State Loop SS=State Spur UA=US Alternate UP=US Spur US=US Highway LS=Local Street TL=Off-System Toll Road
Light Conditions	Dark Lighted Dark Not Lighted	Dawn Daylight Dusk
Median Type	0=No Median 1=Curbed 2=Positive Barrier 3=Unprotected	4=One-Way Pair 5=Positive Barrier Flexible 6=Positive Barrier Semi-Rigid 7=Positive Barrier Rigid
Shoulder Type	1=None (unpaved) 2=Surfaced (paved) 3=Stabilized-Surfaced with Flex (unpaved)	4=Combination—Surface/Stabilized (unpaved) 5=Earth—with or without turf (unpaved)

20.2. CRASH SEVERITY MODELS

To develop the placement guidance, the researchers also developed crash severity models using multinomial logistic regression models to identify the roadway, roadside, and operational and environmental factors associated with severe motorcycle crashes involving fixed objects. The objective of the multinomial logit regression analysis was to identify the contributing factors affecting the severity of RDFO motorcycle crashes. The goal was to determine how different roadway and roadside factors affect the severity of the crash. Therefore, the model was developed by assuming that the crashes with possible injury were the base condition. Thus, the results obtained for fatal (K), suspected serious (A), non-incapacitating injury (B), and possible injury (C) are presented in terms of these crashes. The results of the multinomial logit regression are shown in Table 20.5. The odds ratio (or risk ratio) indicates that the following variables are associated with higher severity of RDFO motorcycle crashes: fixed objects, roadway alignment, segment length, urban roadways, number of lanes, lane width, speed limit, AADT, K-factor, daylight, and crash hour.

Table 20.5. Multinomial Logit Estimation Results.

Variable		Fatal		Suspected Serious Injury		Non-Incapacitating Injury	
		Odds Ratio	St. D.	Odds Ratio	St. D.	Odds Ratio	St. D.
Model	Intercept	0.74	0.18	5.86	0.21	7.65	0.23
Roadside Safety Devices and Fixed Objects	Bridge	2.23	0.04	4.50	0.01	1.71	0.01
	Building	1.08	0.01	1.22	0.01	0.58	0.01
	Concrete	2.05	0.07	1.69	0.14	1.30	0.16
	Guardrail	3.35	0.04	2.21	0.03	1.66	0.04
	Poles	2.34	0.05	1.63	0.05	1.17	0.05
	Work Zone	2.38	0.01	1.94	0.01	1.67	0.01
Roadway Design Characteristics	Curve, Grade	3.17	0.04	2.52	0.04	1.79	0.05
	Curve, Level	2.24	0.07	1.40	0.06	1.16	0.06
	Curve, Hillcrest	2.98	0.01	1.41	0.00	1.61	0.01
	Tangent, Grade	3.37	0.01	2.44	0.02	2.16	0.02
	Tangent, Hillcrest	1.37	0.03	0.51	0.01	0.75	0.01
	Urban (1 if urban, 0 otherwise)	0.45	0.11	0.47	0.19	0.77	0.23
	Shoulder Width	1.03	0.93	1.01	0.62	1.01	0.00
	Lane Width	0.98	0.19	0.94	0.24	0.96	0.00
	Length	1.05	0.27	1.02	0.22	1.02	0.19
	Number of Lanes	1.01	0.45	0.94	0.60	0.95	0.68
Operational	Speed Limit	1.00	0.24	1.00	0.10	1.00	0.11
	AADT	1.00	0.01	1.00	0.01	1.00	0.01
	K-Factor	1.02	0.19	0.96	0.23	0.95	0.24
Temporal	Daylight (1 if daylight, 0 otherwise)	0.45	0.09	0.77	0.26	0.99	0.30

Bridges and guardrails were found to have a higher association with fatal crashes than with possible injury crashes; the relative risk ratio of fatality by hitting a bridge and guardrail was 2.2 and 3.3, respectively, compared to other types of fixed objects. These two roadside elements were also associated with a higher number of suspected serious injury and non-incapacitating injury crashes.

As for the roadway alignment characteristics, a vertical curve was estimated to affect the RDFO motorcycle crash severity more than a horizontal curve. Compared to tangent segments with no grade, segments with grade (both curve and tangent) were found to be associated with more fatalities and suspected serious injury crashes; the relative risk ratios for fatalities were 3.4 (tangent, grade) and 3.2 (curve, grade).

Urban highways were found to be associated with higher motorcycle crash severities; the risk ratio of crash severity decreased when moving from urban roadway to rural roadway. Increasing segment length and shoulder width were also found to be associated with higher crash severity. Lane width, on the other hand, was found to

lower the crash severity. As can be observed, the risk ratio of fatal and suspected serious injury crashes decreased by 0.98 and 0.94 as the lane width increased 1 ft. Increasing the number of lanes was found to be associated with more fatal crashes (1.01) than suspected serious (0.94) and non-incapacitating injury crashes (0.95). However, this difference was marginal.

Finally, the effects of temporal factors indicated that crash severity of RDFO motorcycle crashes in daylight increase when compared to no daylight (dark with or without light).

20.3. SELECTION OF HIGH-RISK LOCATIONS

20.3.1. Random Forests to Select Important Factors

To assess how external roadway and roadside factors affect the crash severity of motorcycle crashes, the researchers used random forests. Figure 20.2 shows the importance of the crash-contributing variables in determining the severity outcome of a crash. As the figure illustrates, the most important variables associated with the RDFO motorcycle crash severity are segment length, AADT, crash hour, speed limit, fixed object, road alignment, K-factor, highway system, rural-urban (RU) classification, lane width, lighting conditions, surface type, and shoulder width. The variables of segment length and AADT are related to exposure, while all the others are related to risk.

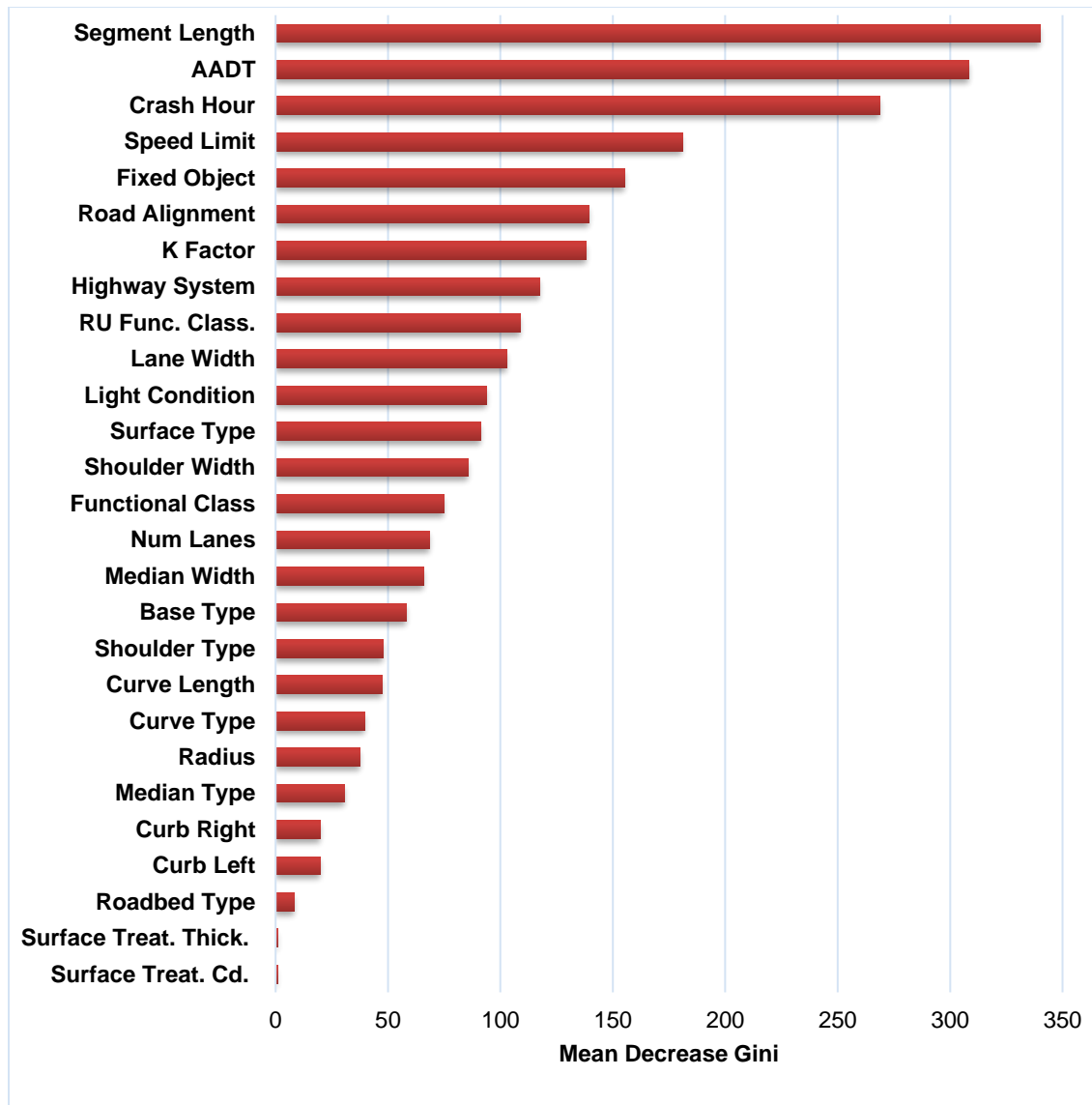


Figure 20.2. Important Variables Associated with Motorcycle Crash Severity.

20.3.2. Risk Factor Groups

The researchers then used the most important crash-contributing factors identified from random forests and multinomial logit models to create risk factor groups (RFGs) to determine the list of potential sites for improvement. RFG, in this context, refers to the group of roadway and roadside design elements, as well as operational factors that are associated with high-severity (KA) and low-severity (BC) motorcycle crashes. Because temporal factors such as crash hour or daylight conditions cannot be altered by engineering decisions, these variables were not considered for creating the RFGs. Researchers used 80 percent of the observations to train the decision tree and 20 percent to test it. Results of the decision tree are shown in Figure 20.3.

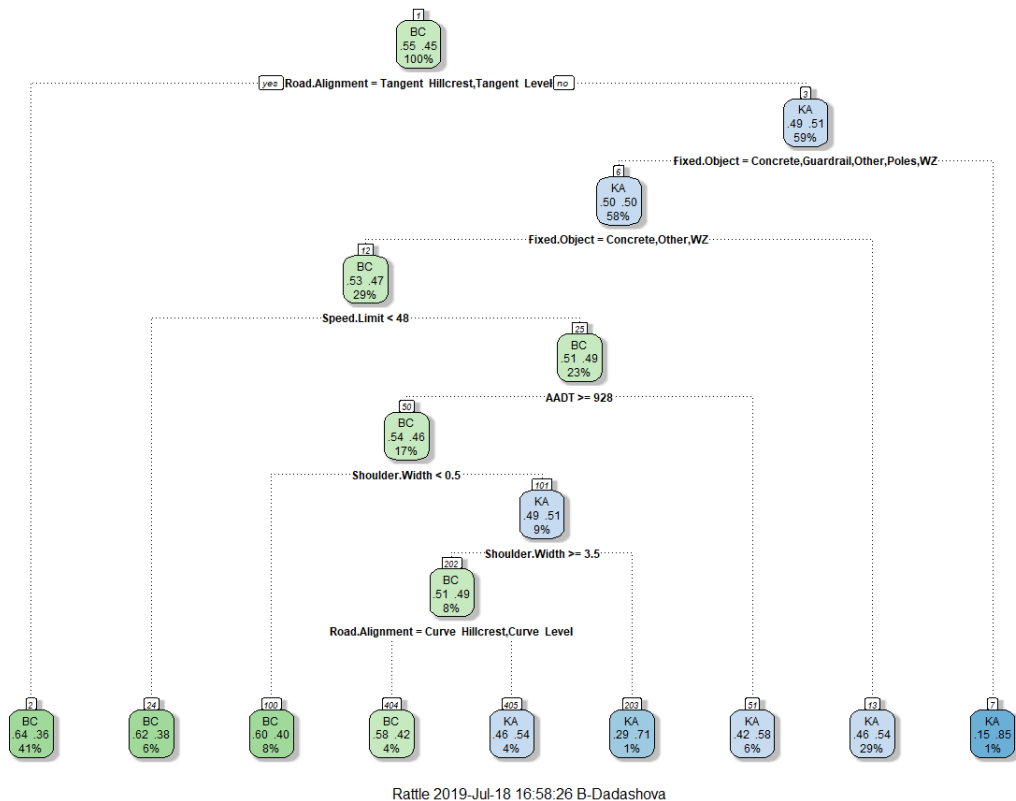


Figure 20.3. Decision Tree for Identifying Risk Factor Groups.

This decision tree has nine nodes, or RFGs. The first RFG is created by the first split of the tree: roadway alignment. This node, or RFG, indicates that when a motorcycle crash occurs on a tangent hillcrest and level road, the probability of a crash resulting in a KA and BC injury is 36 and 64 percent, respectively, indicating that the severity of this RFG is relatively low. The second split is caused by the fixed object type. This split shows that if a motorcyclist hits a bridge and barrier on a curve (level, grade, and hillcrest) and tangent with the grade, the crash has an 85 percent probability of resulting in a fatality or serious injury. This combination of roadway (i.e., alignment) and roadside (i.e., fixed object type) factors creates RFG #9, which is a high-risk roadway segment group. If the motorcyclist hits a guardrail and pole on a segment with a similar roadway alignment, the crash has a 54 percent probability of resulting in a KA crash (RFG #8). On the other hand, if a motorcyclist hits a concrete, work zone, or other roadside structure, the severity of the crash will depend on a combination of roadway (shoulder width), roadside, and operational (posted speed limit [PSL] and AADT) elements. For example, hitting a concrete barrier or work zone element on the roadway with less than a 48 mi/h (e.g., 45 mi/h) PSL would result in a less severe crash (RFG #2). Note that 48 mi/h is a cutoff or threshold value determined by the decision tree. If the PSL is more than this threshold, AADT is more than 928, and shoulder width is less than 3.5 ft (and more than 0.5), a crash could result in a KA crash with a 71 percent probability (RFG #6).

Overall, the risk groups can be classified into three groups: high risk (RFG #6 and #9), moderate risk (RFG #5, #7, and #8), and low risk (RFG #1, #2, #3, and #4). Table 20.6 depicts the list of RFGs together with the risk level and the roadway, roadside, and operational characteristics of each risk group. According to these results, bridge and building structures on horizontal and vertical curves may present a very high risk for motorcyclist safety. Although curve and tangent grades were found to be associated with more severe crashes, the RFG indicates that not all the segments with these roadway alignment characteristics are high risk; for example, hitting a concrete or work zone device on a horizontal curve with less than a 48 mi/h PSL will have a 38 percent probability of resulting in a fatality or suspected serious injury. The probability starts increasing for the roadways where the PSL is higher than this threshold.

Table 20.6. Roadway Characteristics of Low-, Moderate-, and High-Risk Sites.

Risk Factors Characteristics		Probability of Crash Severity		Risk Factor Characteristics				
Risk Level	RFG	KA	BC	Roadway Alignment	Fixed Object	Speed Limit	AADT	Shoulder Width
Low	#1	36%	64%	Tangent Hillcrest, Tangent Level	N/A	N/A	N/A	N/A
Low	#2	38%	62%	Curve Level, Curve Grade, Curve Hillcrest, Tangent Grade	Concrete and Work Zone	<48	N/A	N/A
Low	#3	40%	60%	Curve Level, Curve Grade, Curve Hillcrest, Tangent Grade	Concrete and Work Zone	≥48	≥928	<0.5
Low	#4	42%	58%	Curve Level and Curve Hillcrest	Concrete and Work Zone	≥48	≥928	≥3.5
Moderate	#5	54%	46%	Curve Grade and Tangent Grade	Concrete and Work Zone	≥48	≥928	≥3.5
Moderate	#8	54%	46%	Curve Level, Curve Grade, Curve Hillcrest, Tangent Grade	Guardrail and Pole	N/A	N/A	N/A
Moderate	#7	58%	42%	Curve Level, Curve Grade, Curve Hillcrest, Tangent Grade	Concrete and Work Zone	≥48	<928	N/A
High	#6	71%	29%	Curve Level, Curve Grade, Curve Hillcrest, Tangent Grade	Concrete and Work Zone	≥48	≥928	0.5≤SW<3.5
High	#9	85%	15%	Curve Level, Curve Grade, Curve Hillcrest, Tangent Grade	Bridge and Building	N/A	N/A	N/A

Note: N/A = not applicable.

20.3.3. Site Selection

The RDFO motorcycle crashes identified in CRIS occurred at 7,101 sites (Table 20.7). Based on the results of the risk factor group analysis, 5,539 of these sites were low risk, indicating that there were fewer high-severity RDFO motorcycle crashes at these sites with respect to others. Meanwhile, 1,467 segments were found to be moderate risk, while 95 segments were found to be high risk, with a total of 101 crashes, out of which 66 were fatal and suspected serious injury crashes.

Table 20.7. Number of Sites and Crashes per Risk Level.

Risk Level	Number of Sites	Number of RDFO Motorcycle Crashes					Grand Total
		Fatal (K)	Suspected Serious Injury (A)	Non-Incapacitating Injury (B)	Possible Injury (C)	No Injury (PDO)	
High	95	34	32	21	8	6	101
Moderate	1,467	316	555	497	161	144	1,673
Low	5,539	530	1,537	2,457	1,183	644	6,351
Grand Total	7,101	880	2,124	2,975	1,352	794	8,125

Figure 20.4 shows the number of crashes per crash severity and year at high-risk sites. As shown, the number of fatal and injury crashes at the high-risk sites was higher than the possible and non-injury crashes. Thus, these sites have the potential for safety improvement and were the candidate sites for installing the retrofit guardrails. Figure 20.5 shows the low- to high-risk locations where the RDFO motorcycle crashes occurred.

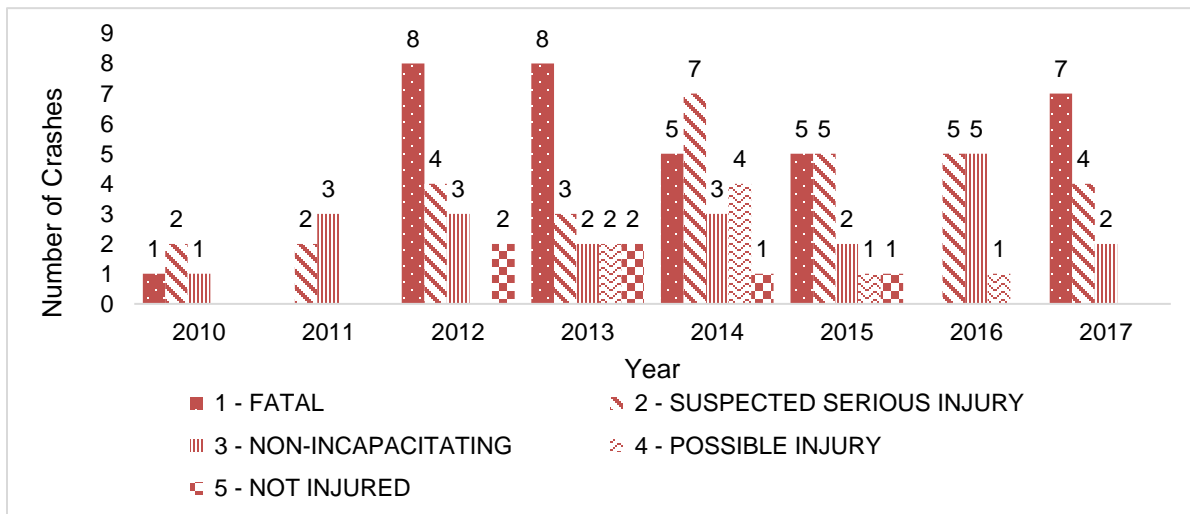


Figure 20.4. Number of Severe Crashes at High-Risk Sites.

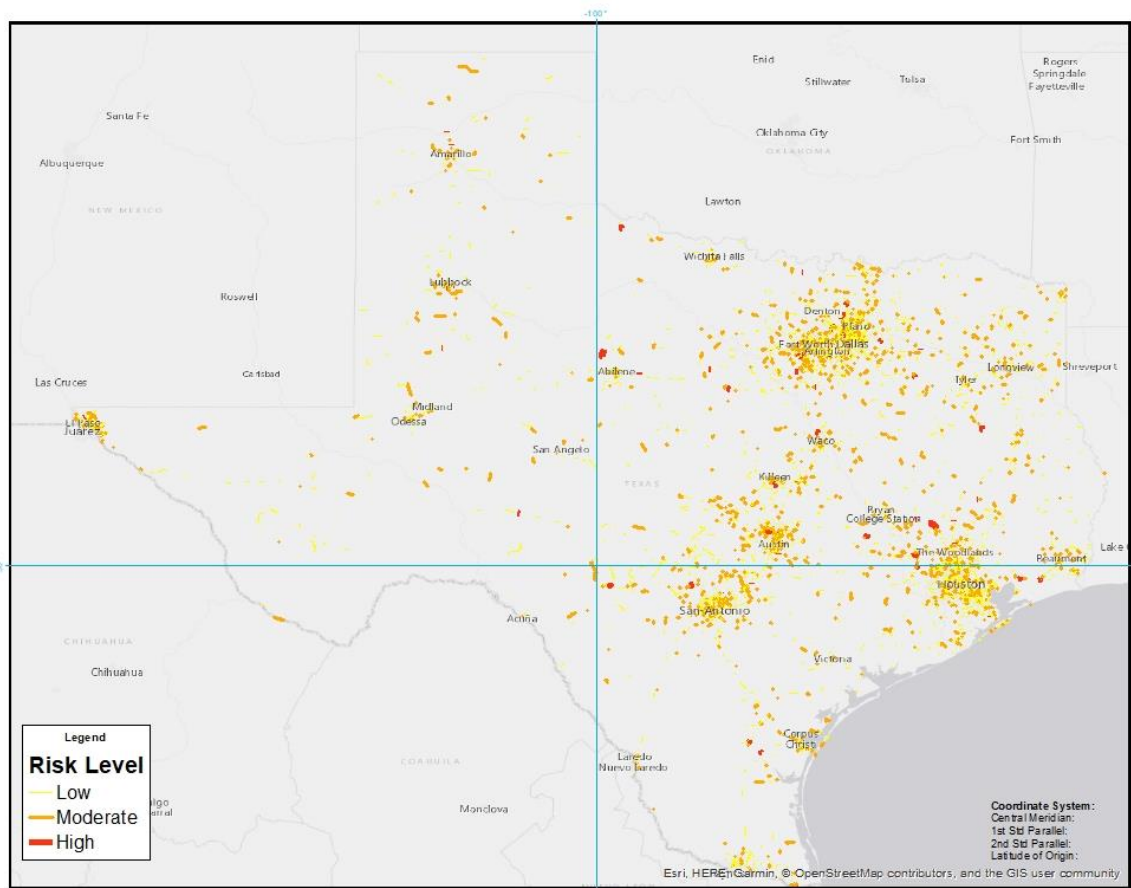


Figure 20.5. Low- to High-Risk Sites.

20.4. CONCLUSIONS

In this analysis, the research team identified the roadside safety devices and fixed objects associated with severe RDFO motorcyclist crashes in Texas from 2010 to 2017. The researchers first used the multinomial logit regression model to estimate the effect of the various roadway, roadside, operational, and temporal factors on the severity of motorcycle crashes involving a fixed object. Results show that roadside elements have a significant impact on crash severity. After conducting the regression analysis, researchers developed a framework for identifying the high-risk locations for motorcycle crashes using random forests and decision trees. The results of data mining were later used to identify the sites for installing the retrofit guardrails for improving motorcyclist safety.

Chapter 21. SUMMARY AND CONCLUSIONS

21.1. ASSESSMENT OF MASH TEST RESULTS

The *MASH* crash tests reported herein were performed in accordance with *MASH* TL-3, which involves two tests, on the enhanced motorcycle guard fence system.

Table 21.1 shows that the enhanced motorcycle guard fence system met the performance criteria for *MASH* TL-3 longitudinal barriers.

Table 21.1. Assessment Summary for *MASH* TL-3 Tests on Enhanced Motorcycle Guard Fence System.

Evaluation Criteria ^a	Description	Test 469943-01-3	Test 469943-01-4
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

Note: S = Satisfactory.

^a See Table 7.2 for details.

21.2. ASSESSMENT OF MOTORCYCLE TEST RESULTS

The performance of the enhanced motorcycle guard fence system was also evaluated with an upright motorcycle and ATD and sliding ATD impact configuration. The sliding ATD tests were based on the standards set forth in EN 1317-8.

For the upright motorcycle and ATD crash test (Test 469940-03-3), there was no observed snagging of the ATD on discrete elements of the enhanced motorcycle guard fence system. The ATD slid along the system and eventually came to rest on the traffic side of the system.

For the sliding ATD crash tests (Test 469943-01-1A and 469943-01-2), there was no observed snagging of the ATD on discrete elements of the enhanced motorcycle guard fence system. The ATD was redirected and came to rest on the traffic side of the system. Injury criteria for the ATD were measured for both crash tests. All the injury criteria were below the limits specified in EN 1317-8 except the neck axial compression force. This criterion exceeded the limit by approximately 5 percent in Test 469943-01-1A and 0.1 percent in Test 469943-01-2.

21.3. CONCLUSIONS

The objective of this project was to develop and evaluate a retrofit guard fence system for consideration of motorcycle-related impacts. The system was evaluated through full-scale crash testing with motorcyclist and vehicle impacts. The enhanced motorcycle guard fence system was found to be compliant for *MASH* TL-3 and indicated the ability to prevent motorcyclist interaction with discrete elements of a guard fence system during upright and sliding impacts.

Chapter 22. IMPLEMENTATION*

The enhanced motorcycle guard fence system was evaluated through full-scale crash testing. This system is ready for implementation as a longitudinal barrier system. Specifically, this system can be considered for roadway sections at high risk for motorcycle fatalities.

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

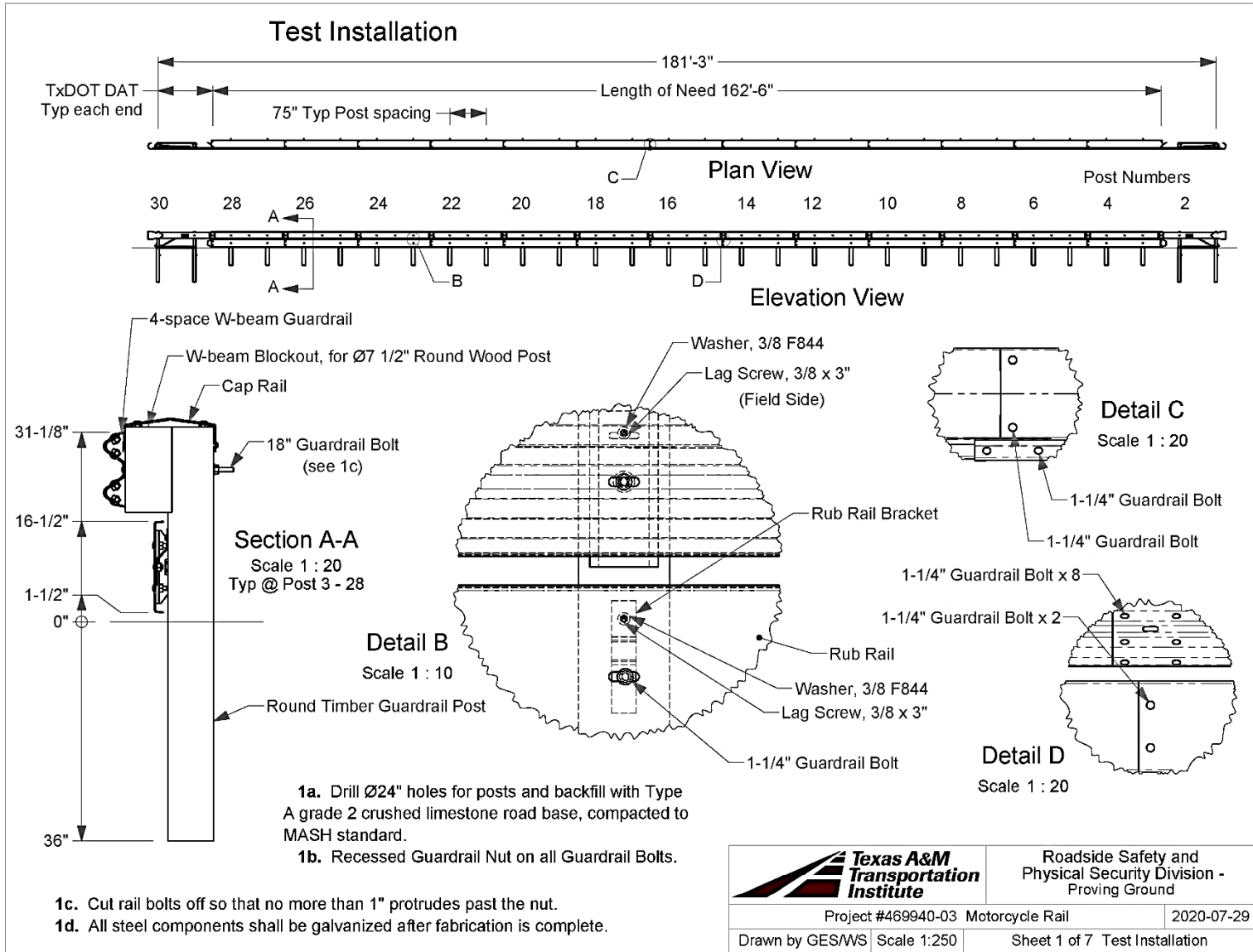
REFERENCES

1. Gabler, C., Daniello, A., Tatem, W., Tsoi, Gabauer, D., Stitzel, J., Sink, J., and Barnard, R. *Motorcycle Crashes with Traffic Barriers: Factors Related to Serious Injury and Fatal*. NCHRP Report 1005, National Academies of Science, TRB, Washington, DC, 2022.
2. AASHTO. *Manual for Assessing Safety Hardware, Second Edition*. American Association of State Highway and Transportation Officials, Washington, DC, 2016.
3. European Commission. *Road Safety in the European Union*. Brussels, Belgium, 2015.
4. Stock, R., Follman, J., Frieling, R., Kuschefski, A., Lipphard, D., Nikolaus, H., Lenzen, M., Heuber, A., and Ritz, T. *Motorbiking—on Safe Roads, Practical Guidelines*. Allgemeiner Deutscher Automobil-Club e.V. Transport Affairs, München, Deutschland, 2001.
5. National Highway Traffic Safety Administration. *Traffic Safety Facts 2013 Data*. NHTSA, Washington, DC, 2015.
6. Nazemetz, J., Dents, F., Perry, J., Thor, C., and Mohamedshah, Y. *Motorcycle Crash Causation Study*. Report No. FHWA-HRT-18-064. Federal Highway Administration, McLean, VA, 2017.
7. Nabors, D., Goughnour, E., and Soika, J. *Motorcycle Road Safety Audit Case Studies, Roadside Safety Audits (RSAs)*. Federal Highway Administration, Vienna, VA, 2016.
8. Milling, D., Affum, J., Chong, L., and Taylor, S. *Infrastructure Improvements to Reduce Motorcycle Casualties*. Austroads Research Report AP-R515-16, Austroads Ltd, Sydney, Australia, 2016.
9. Berg, F., Rucker, P., Gartner, M., Konig, J., Grzebieta, R., and Zou, R. *Motorcycle Impacts into Roadside Barriers—Real-World Accident Studies, Crash Tests and Simulations Carried Out in Germany and Australia*. 19th International Technical Conference on the Enhanced Safety of Vehicles, Washington DC, 2005.
10. Peldschus, S., Schuller, E., Koenig, J., Gaertner, M., García, D., and Mansilla, A. *Technical Bases for the Development of a Test Standard for Impacts of Powered Two-Wheelers on Roadside Barriers*. Proceedings of the 20th International Conference on the Enhanced Safety of Vehicles Conference, Lyon, France, 2007.
11. ISO 13232. *Motorcycles—Test and Analysis Procedures for Research Evaluation of Rider Crash Protection Devices Fitted to Motorcycles*. International Organization for Standardization, Geneva, Switzerland, 1996.
12. Rogers, N., and Zellner, J. *An Overall Evaluation of UKDS Motorcyclist Leg Protectors Based on ISO 13232*. 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Paper Number 98-S 10-0-13, Windsor, Ontario, Canada, 1998.
13. L.I.E.R. *Protocol: Motorcyclist Safety Evaluation Regarding Safety Barriers*. France, 1998.
14. Page, M., and Bloch, J. *Evaluation Procedures of Motorcyclist Protection Devices*. Europeanroads Review, ERR 16, 16th IRF World Meeting Sharing the Road, Portugal, 2010.
15. AENOR. Standard UNE 135900:2008rev.01. Spain, 2008.

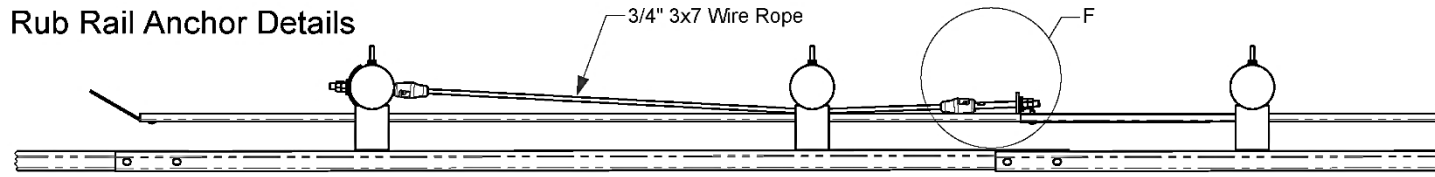
16. EN 1317-8. Road Restraint Systems—Part 8: Motorcycle Road Restraint Systems Which Reduce the Impact Severity of Motorcyclist Collisions with Safety Barriers. Technical Specification, Final Draft FprCEN/TS 1317-8, European Committee for Standardization, Brussels, Belgium, 2011.
17. FEMA. *Final Report of the Motorcyclists & Crash Barriers Project*. Federation of European Motorcyclist's Associations, 2010. http://www.fema-online.eu/uploads/documents/guardrails/Motorcyclists_and_crash_barriers.pdf.
18. Standards Australia. *AS/NZS 3845:2015 – Road Safety Barrier Systems and Devices*. Homebush, NSW, Australia, 2015.
19. Quincy, R., Vulin, D., and Mounier, B. *Motorcycle Impacts with Guardrail*. Institute National de Recherche sur les Transports et leur Securite, INRETS, France, 1988.
20. Nieboer, J., Wismans, J., Versmissen, A., van Slagmaat, M., Kurawaki, I., and Ohara, N. *Motorcycle Crash Test Modelling*. Proceedings of 37th Stapp Car Crash Conference, pp. 273–288, SAE Paper 933133, San Antonio, TX, 1993.
21. Adamson, K., Alexander, P., Robinson, E., Johnson, G., Burkhead, C., McManus, J., Anderson, G., Aronberg, R., Kinney, J., and Sallmann, D. W. *Seventeen Motorcycle Crash Tests into Vehicles and a Barrier*. SAE Technical Paper Series 2002-01-0551, SAE 2002 World Congress, Detroit, MI, 2002.
22. Dobrovolny, C., Shi, S., Kovar, J., Bligh, R., Kuhn, D., and Griffith, B. *Development and Evaluation of Concrete Barrier Containment Options for Errant Motorcycle Riders*. Texas A&M Transportation Institute, College Station, TX, 2018.
23. Franco, A., Anghileri, M., and Dobrovolny, C. *Design and Assessment of a New Roadside Safety Barrier System for Consideration and Mitigation of Upright Motorcycle Impacts*. Texas A&M Transportation Institute, College Station, TX, 2018.
24. Shaffer, R., Heuer, D., Bents, F., Foglietta III, J., Wieder, D., Jordan, M., and Tiwari, P. *Scan 09-04: Leading Practices for Motorcyclist Safety*. Arora and Associates, P.C., Lawrenceville, NJ, 2001.
25. Nicol, D., Heuer, D., Chrysler, S., Baron, J., Bloschock, M., Cota, K., Paul, D., Garber, N., Kolb, J., McGrath, M., Moreland, M., and Tan, C. *Infrastructure Countermeasures to Mitigate Motorcycle Crashes in Europe*. International Technology Scanning Program, Stafford, VA, 2012.
26. National Highway Traffic Safety Administration. *Vehicle API*. NHTSA, Washington, DC, 2023. <https://vpic.nhtsa.dot.gov/api/>
27. Motorcycle Safety Foundation. *National Agenda for Motorcycle Safety*. NHTSA, Washington, DC. <https://one.nhtsa.gov/people/injury/pedbimot/motorcycle/00-nht-212-motorcycle/motorcycle39-41.html>

**APPENDIX A. DETAILS OF ENHANCED MOTORCYCLE GUARD
FENCE SYSTEM**

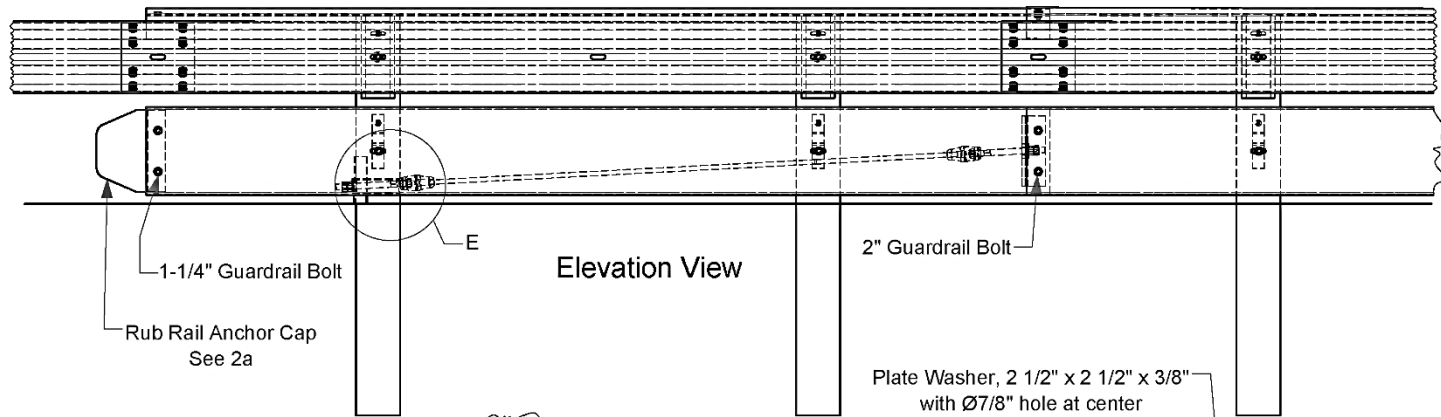
**A.1. DETAILS FOR CRASH TESTS 469940-03-1, 469940-03-2, 469940-03-3,
AND 469940-03-4A**



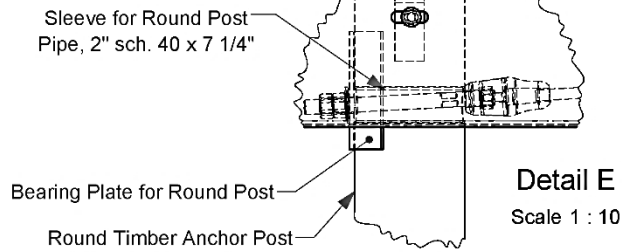
Rub Rail Anchor Details



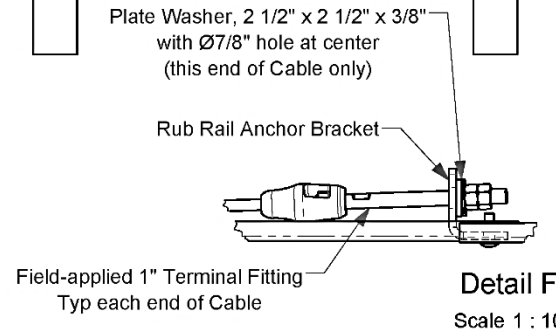
Plan View
Cap Rail not shown for clarity



Elevation View



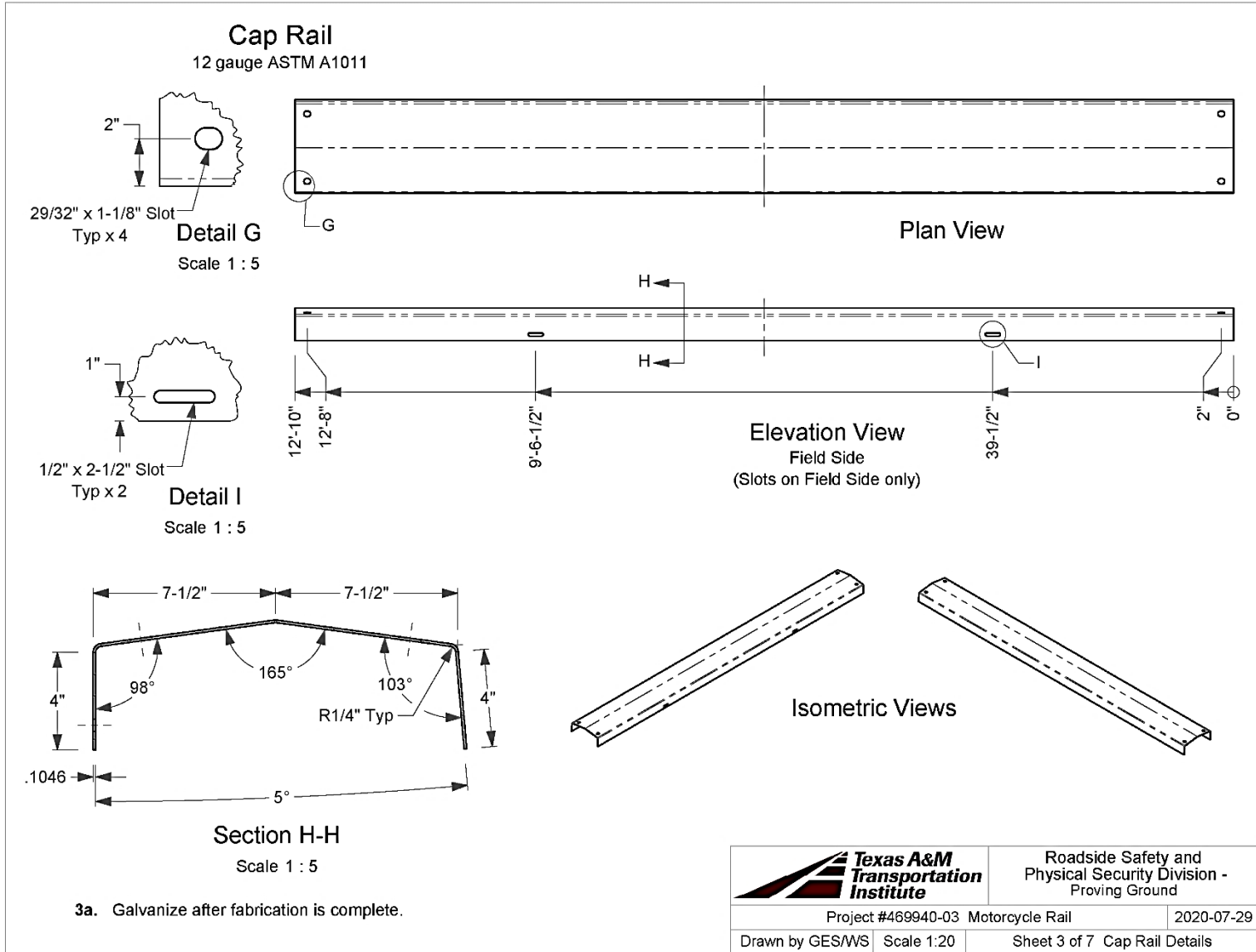
Detail E
Scale 1 : 10



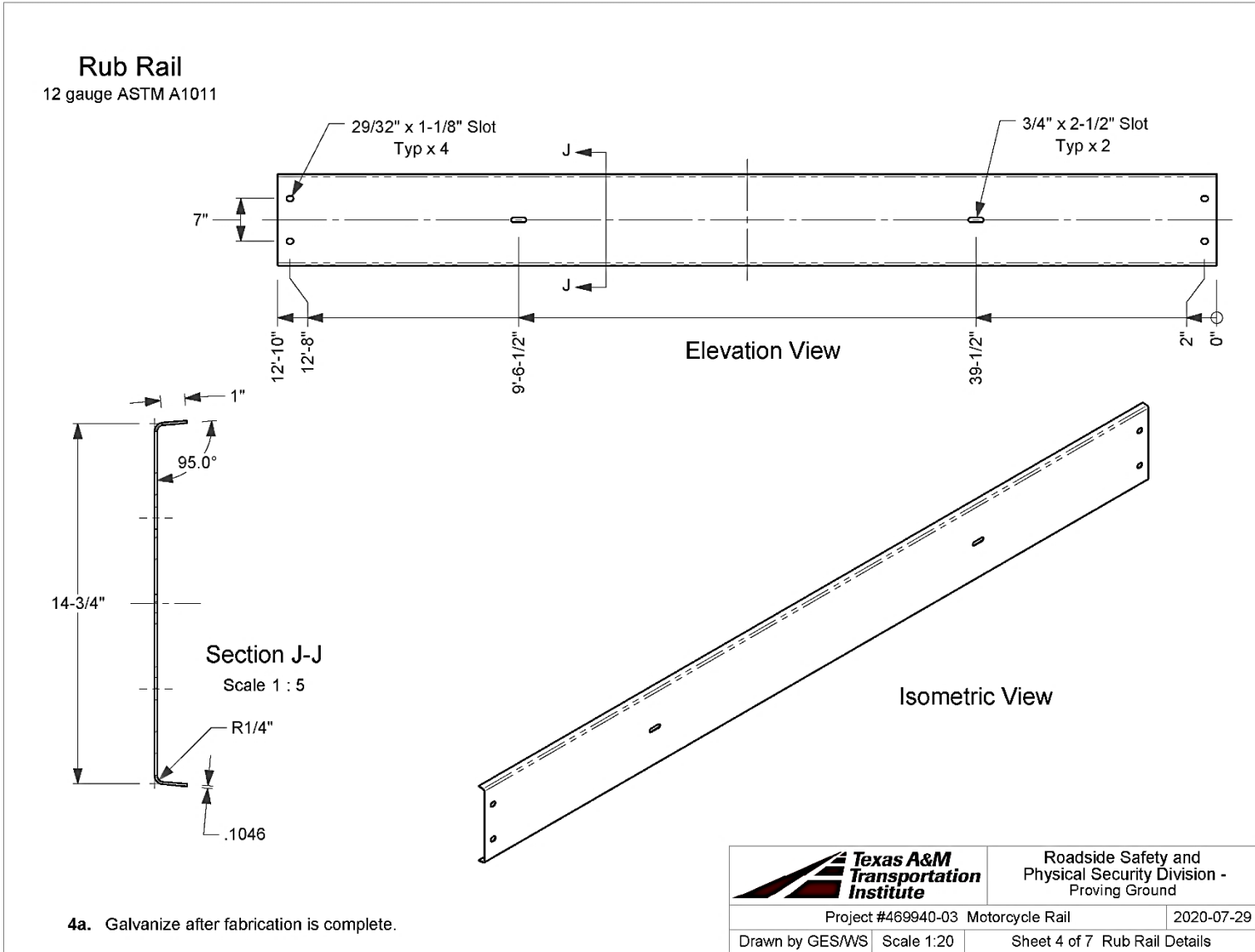
Detail F
Scale 1 : 10

2a. Rub Rail Anchor Cap is placed on field side of Rub Rail in this location. It will be on the traffic side on the upstream end of the installation to minimize snagging.

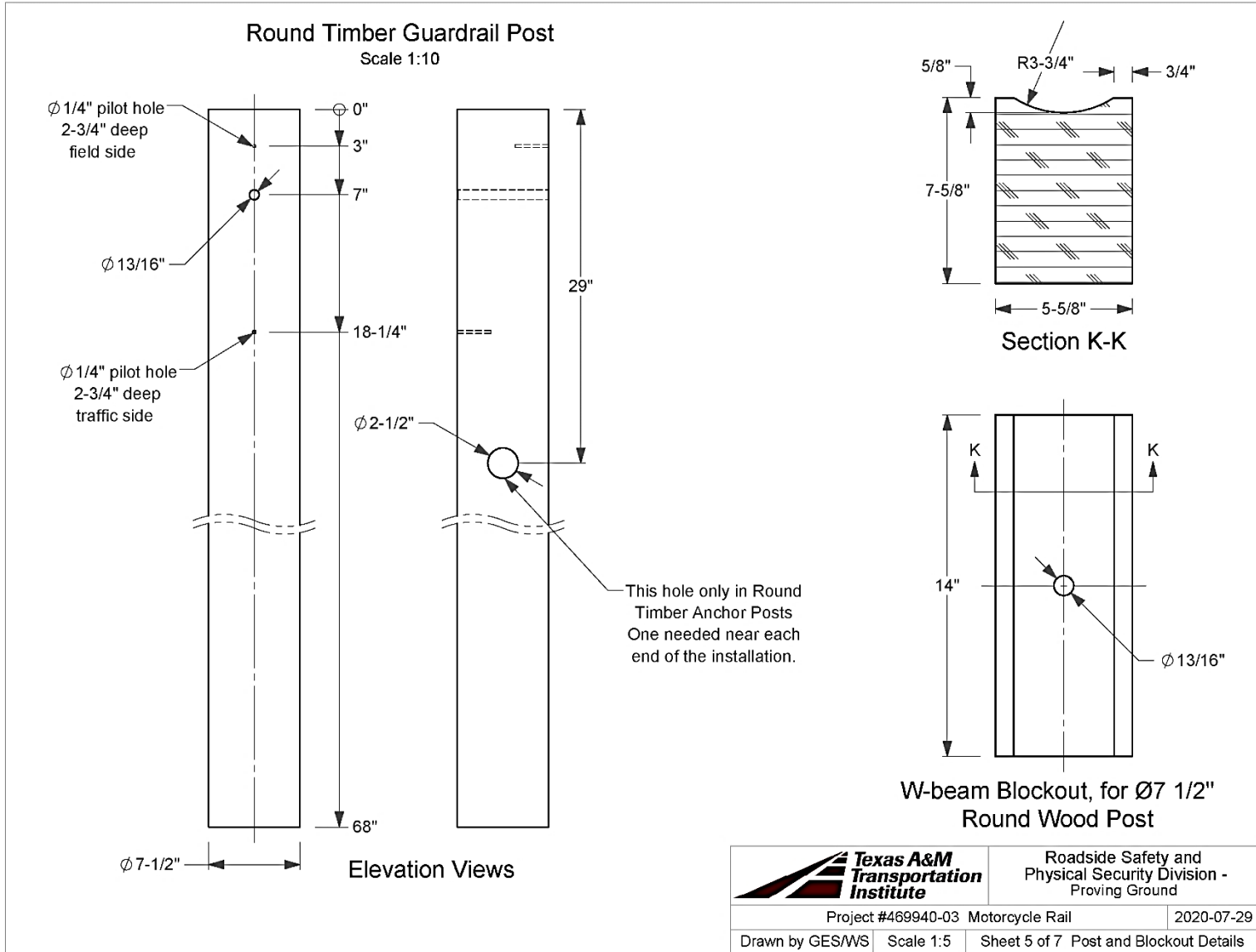
		Roadside Safety and Physical Security Division - Proving Ground
Project #469940-03 Motorcycle Rail		2020-07-29
Drawn by GES/WVS	Scale 1:25	Sheet 2 of 7 Rub Rail Anchor Details



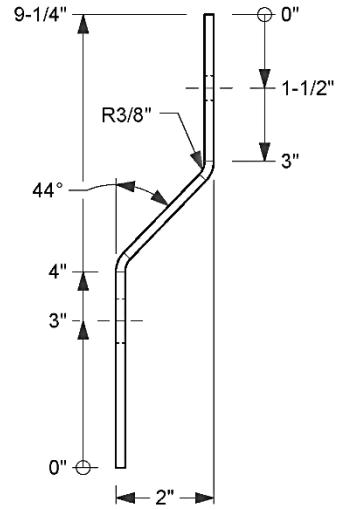
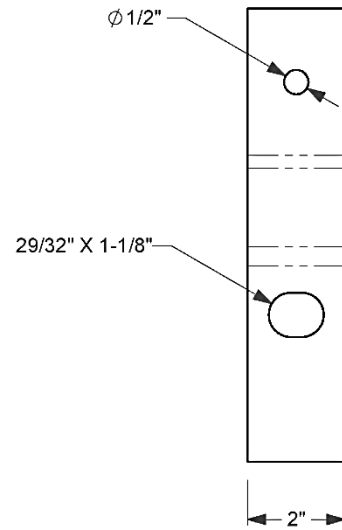
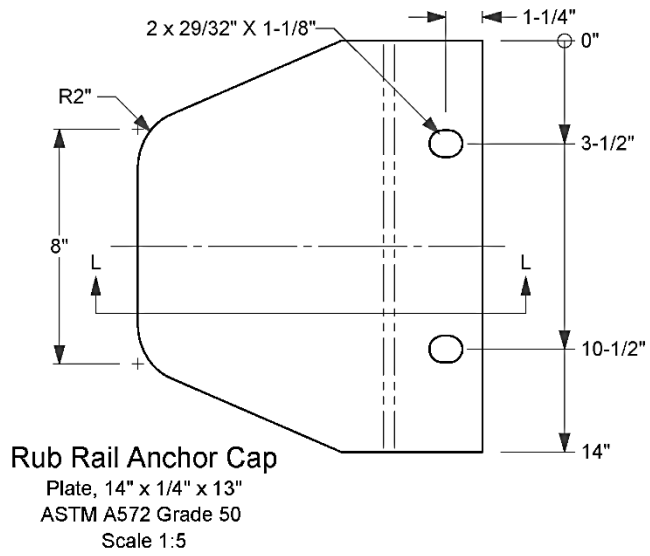
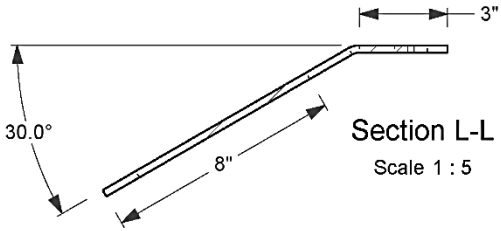
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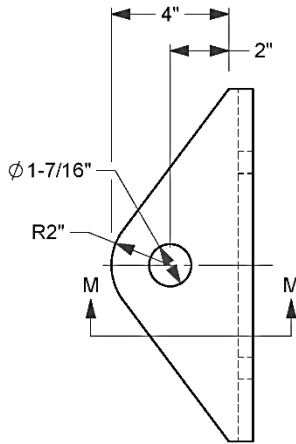
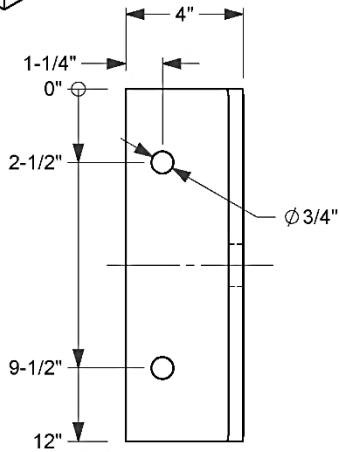
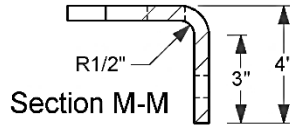
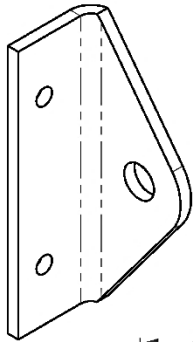
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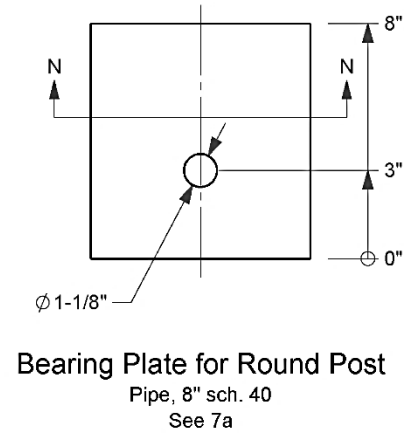
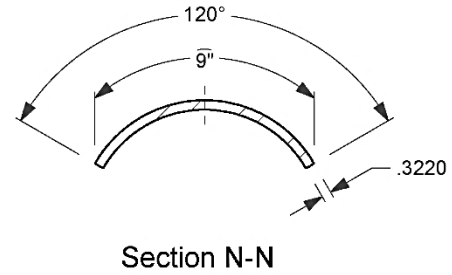
Rub Rail Bracket
Plate, 2" x 3/16" ASTM A36

		Roadside Safety and Physical Security Division - Proving Ground	
Project #469940-03 Motorcycle Rail		2020-07-29	
Drawn by GES/WS	Scale 1:3	Sheet 6 of 7 Parts-1	

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Rub Rail Anchor Bracket
 Plate, 12" x 1/2" x 8"
 ASTM A572 Grade 50

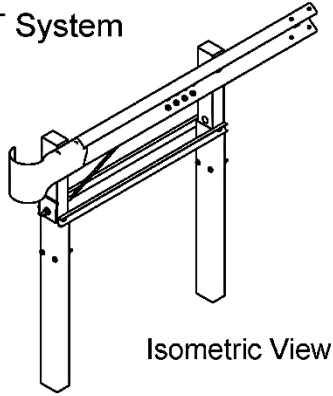


Bearing Plate for Round Post
 Pipe, 8" sch. 40
 See 7a

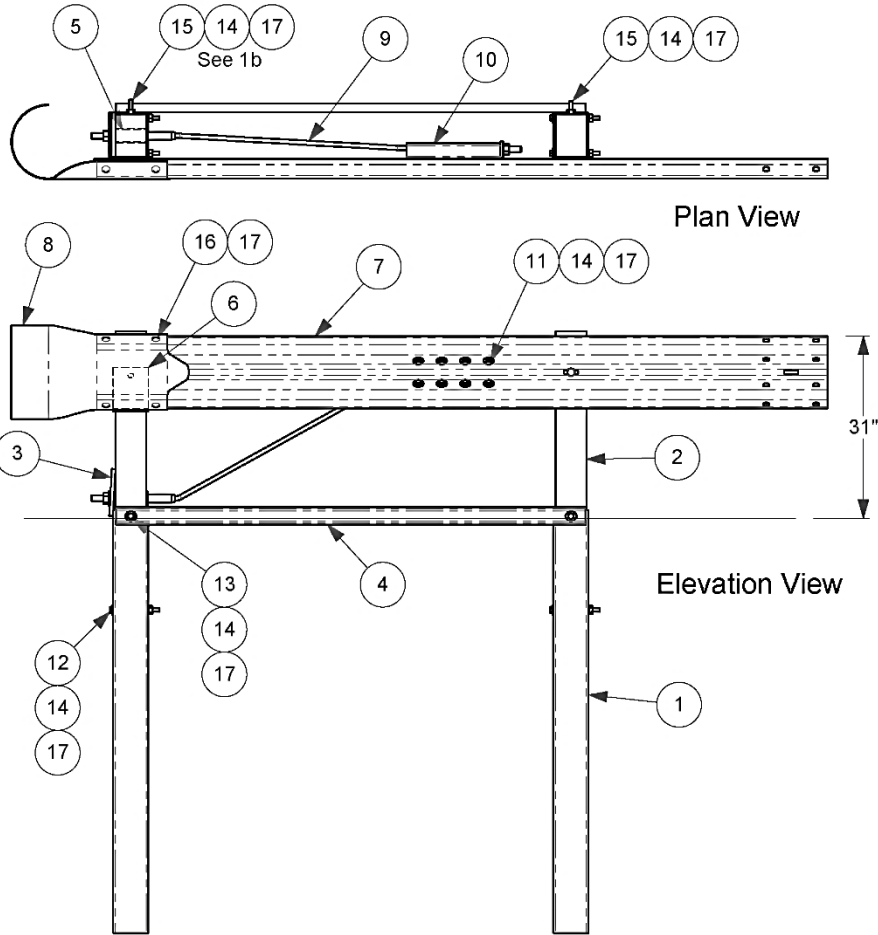
7a. Bearing Plate for Round Post may be fabricated from schedule 40 pipe, as indicated, or 3/8" plate at contractor's discretion. Contractor shall specify which option was used for the installation and provide material certs.

	Roadside Safety and Physical Security Division - Proving Ground	
	Project #469940-03 Motorcycle Rail	2020-07-29
Drawn by GES/WVS	Scale 1:5	Sheet 7 of 7 Parts-2

DAT System

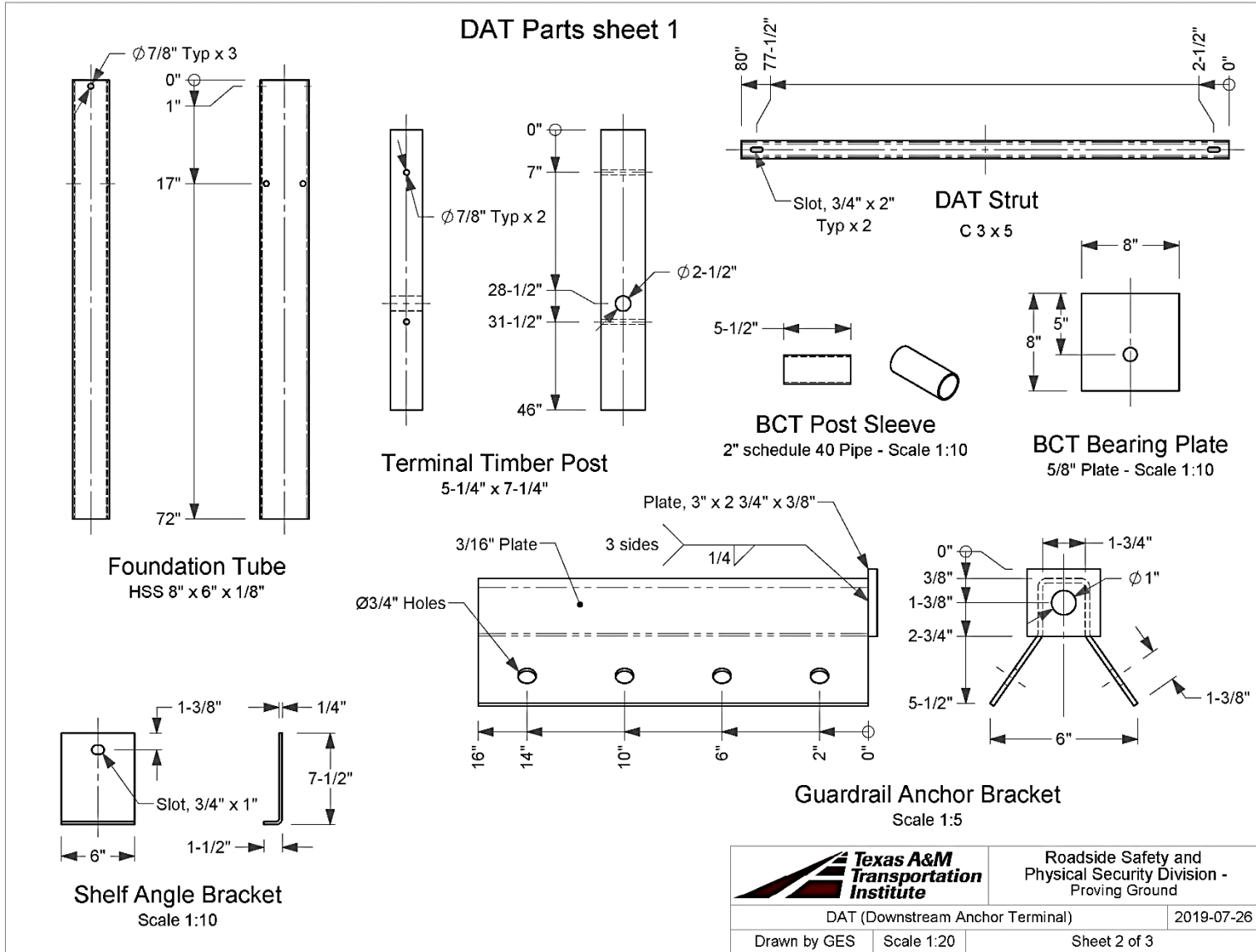


#	Part Name	Qty.
1	Foundation Tube	2
2	Terminal Timber Post	2
3	BCT Bearing Plate	1
4	DAT Strut	2
5	BCT Post Sleeve	1
6	Shelf Angle Bracket	1
7	DAT Terminal Rail	1
8	W-beam End Section	1
9	Anchor Cable Assembly	1
10	Guardrail Anchor Bracket	1
11	Bolt, 5/8 x 2" hex	8
12	Bolt, 5/8 x 8" hex	4
13	Bolt, 5/8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



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

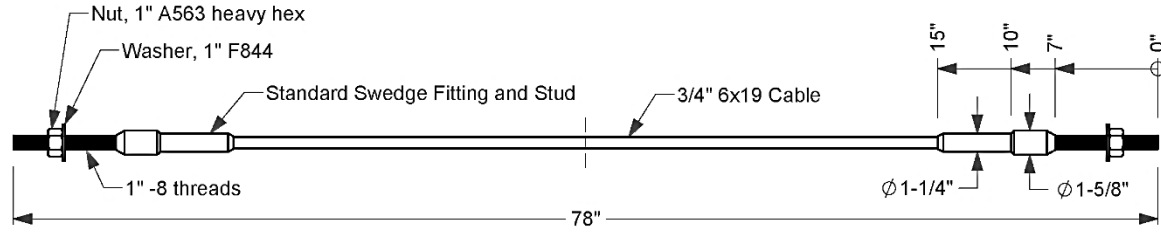
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DAT (Downstream Anchor Terminal)		2019-07-26
Drawn by GES	Scale 1:25	Sheet 1 of 3



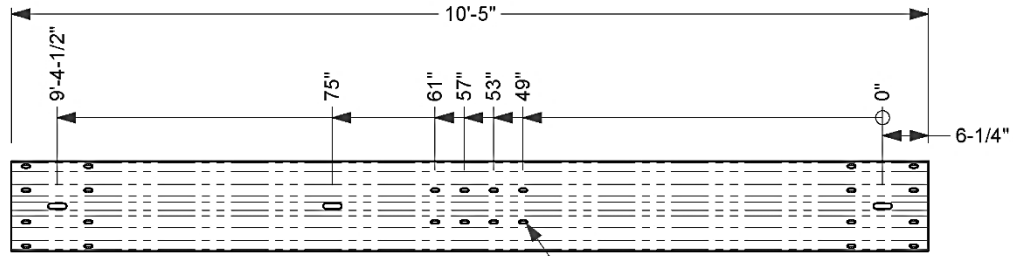
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)		2019-07-26
Drawn by GES	Scale 1:20	Sheet 2 of 3

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DAT Parts sheet 2

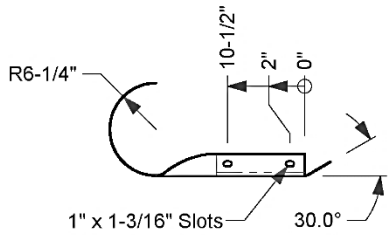


Anchor Cable Assembly



DAT Terminal Rail

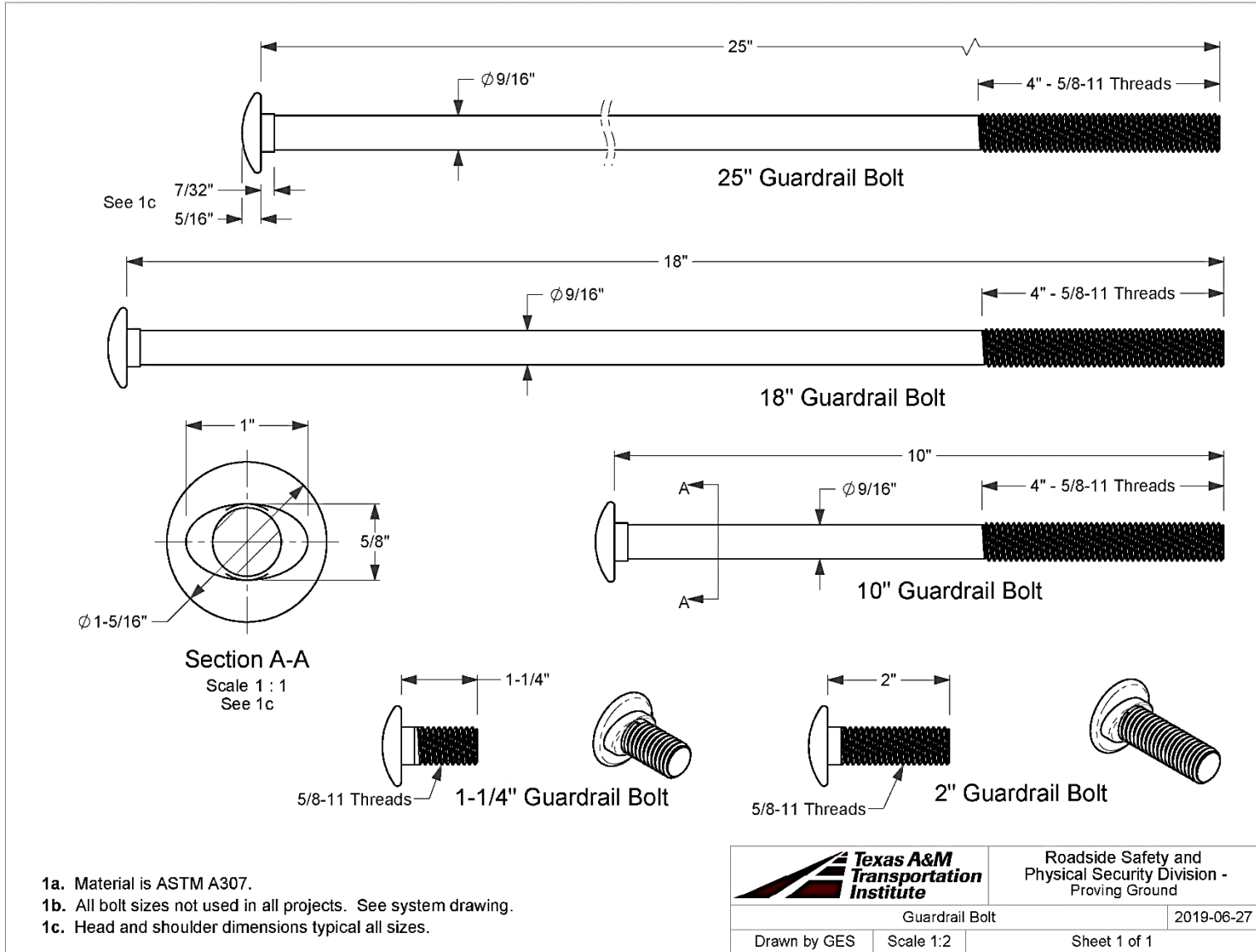
Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.



W-beam End Section

12 gauge steel - Scale 1:20

		Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)		2019-07-26
Drawn by GES	Scale 1:10	Sheet 3 of 3

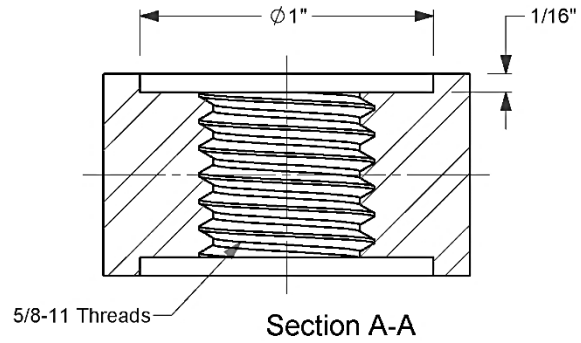
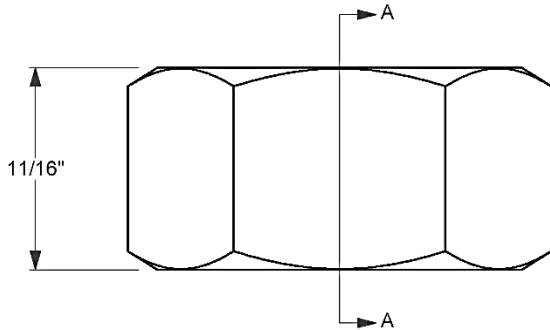
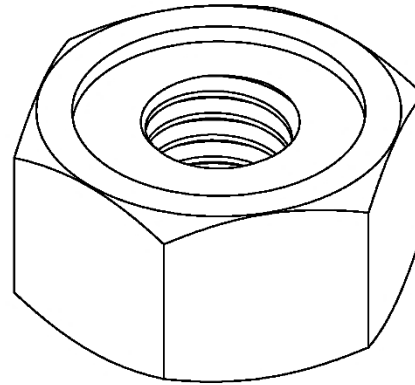
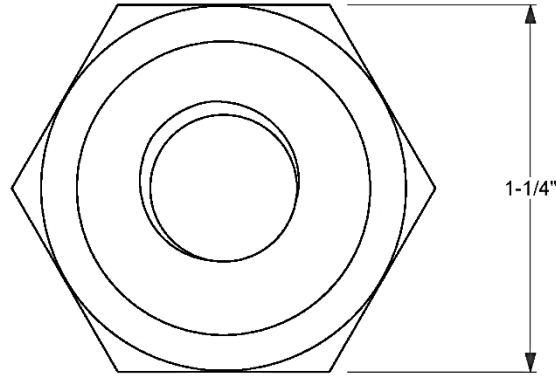


- 1a. Material is ASTM A307.
- 1b. All bolt sizes not used in all projects. See system drawing.
- 1c. Head and shoulder dimensions typical all sizes.


		Roadside Safety and Physical Security Division - Proving Ground
Guardrail Bolt		2019-06-27
Drawn by GES	Scale 1:2	Sheet 1 of 1

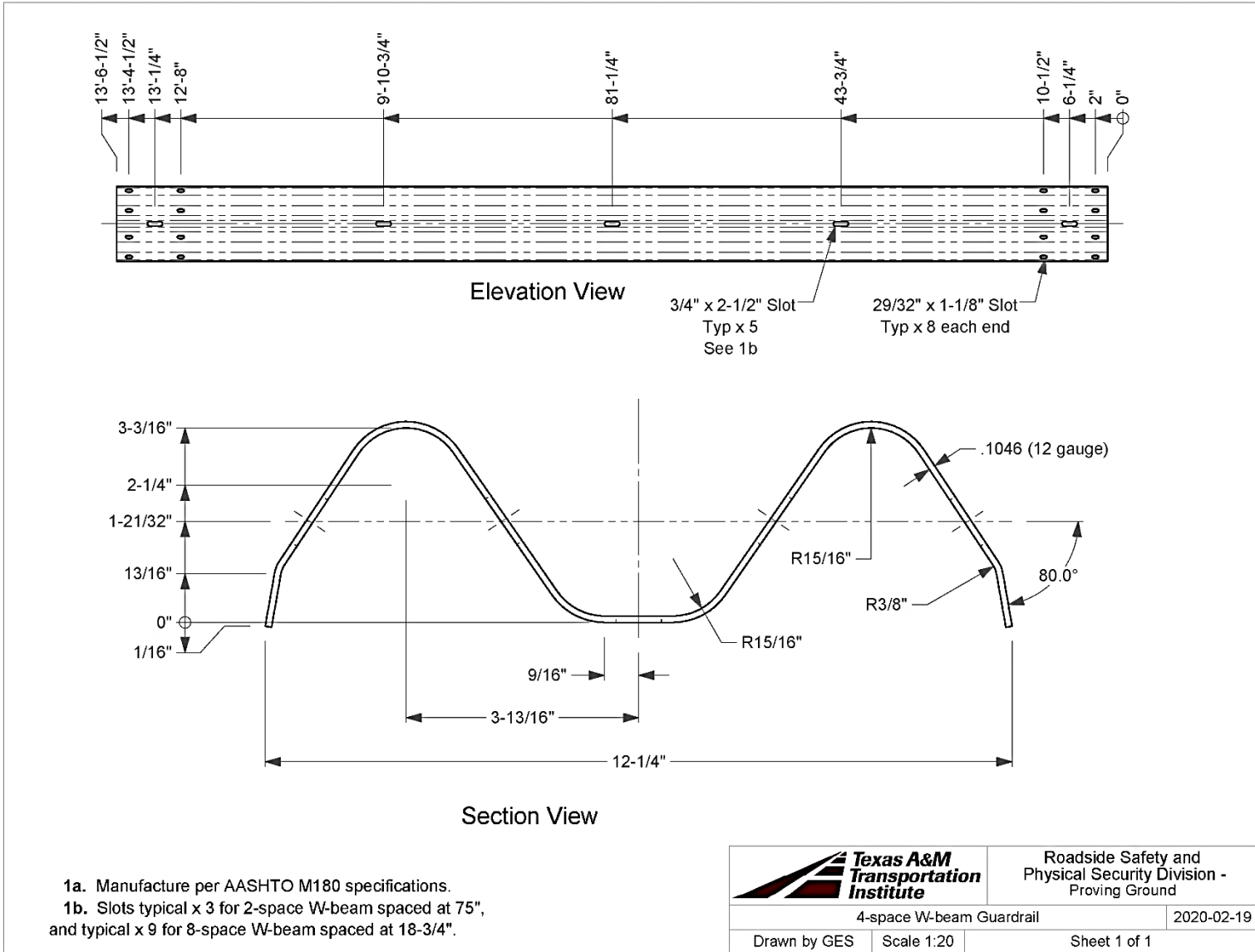
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Recessed Guardrail Nut



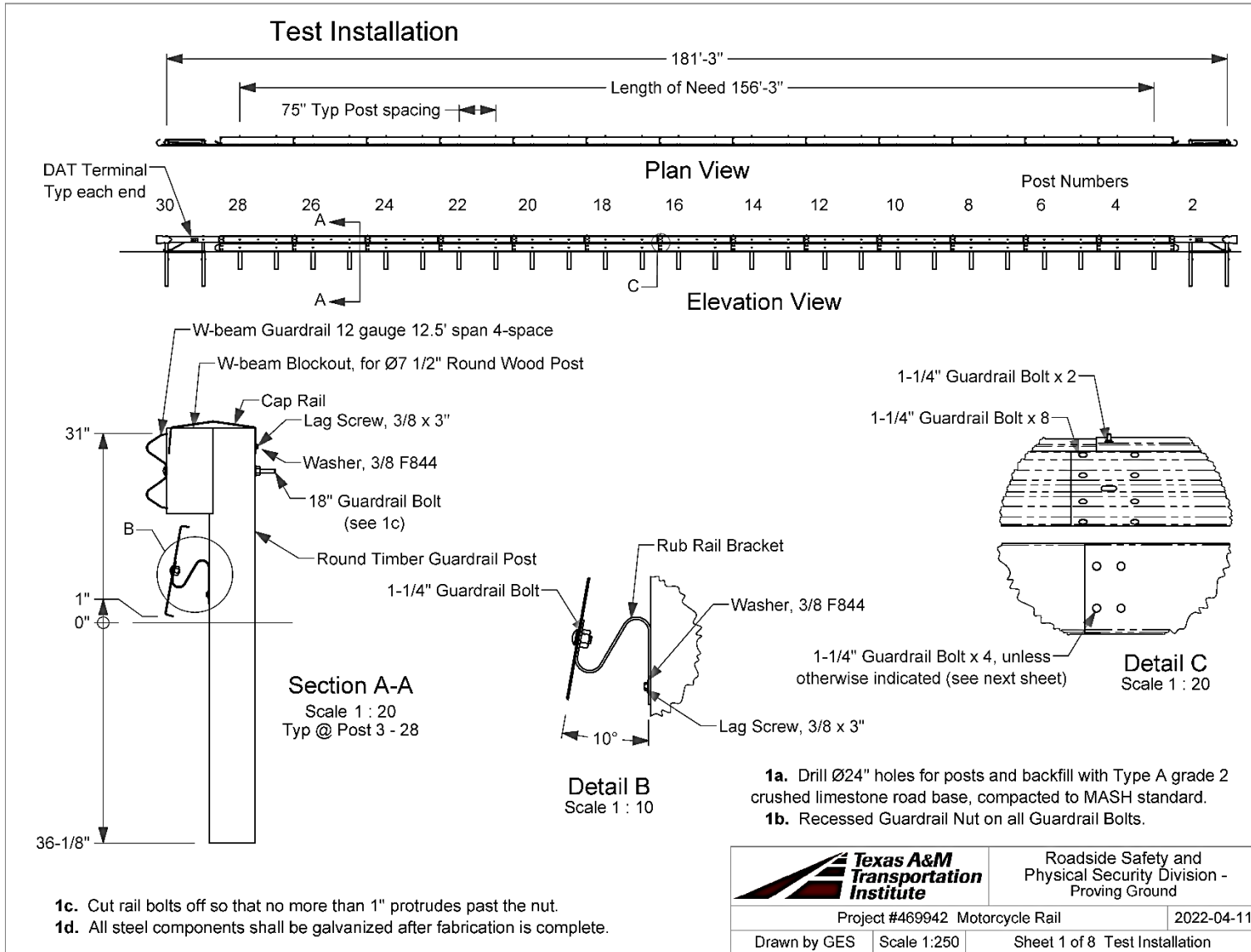
1a. Material is ASTM A 563 Grade A.

		Roadside Safety and Physical Security Division - Proving Ground
Recessed Guardrail Nut		2019-06-27
Drawn by GES	Scale 2:1	Sheet 1 of 1



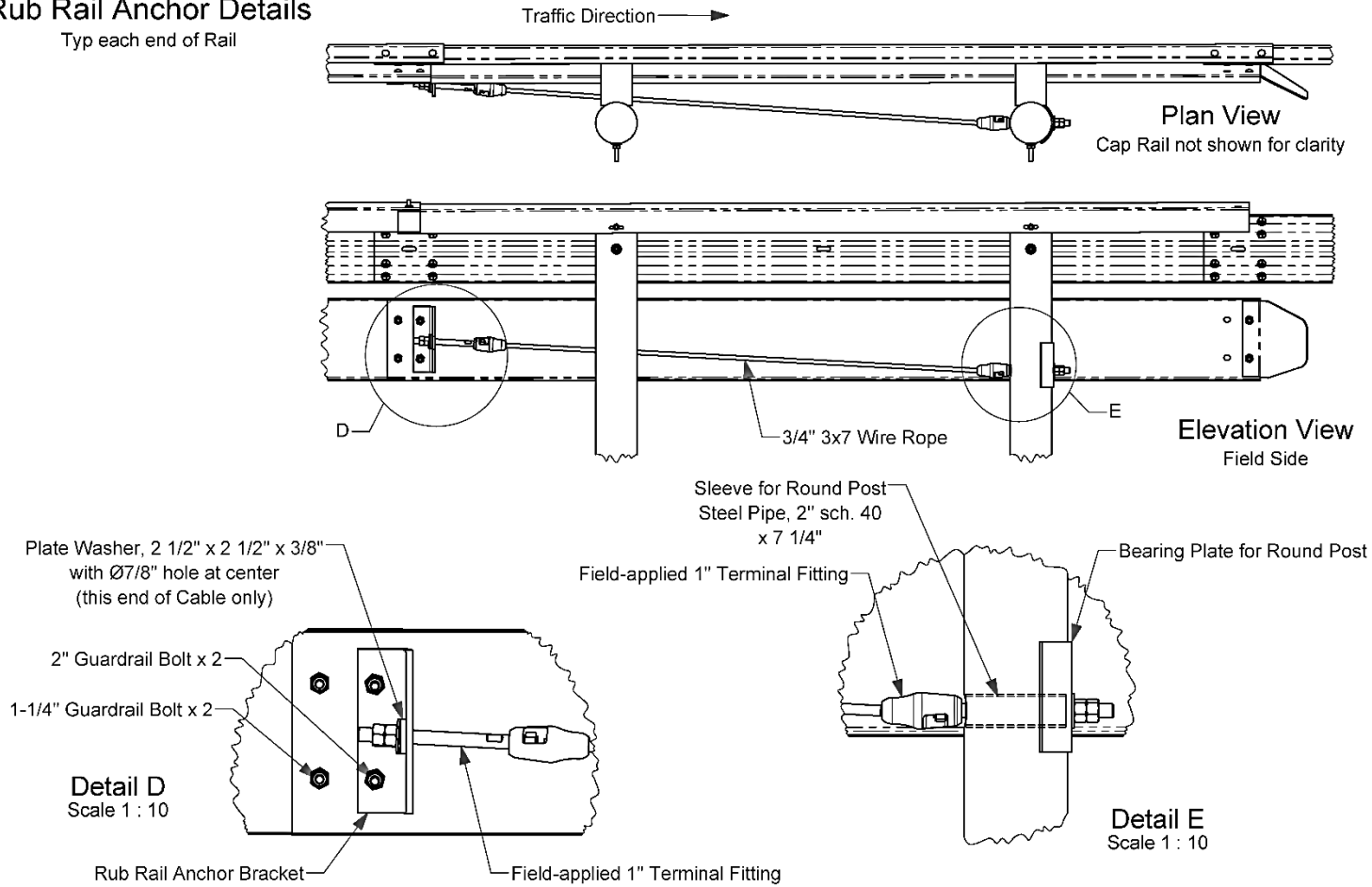
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A.2. DETAILS FOR CRASH TEST 469942-01-1



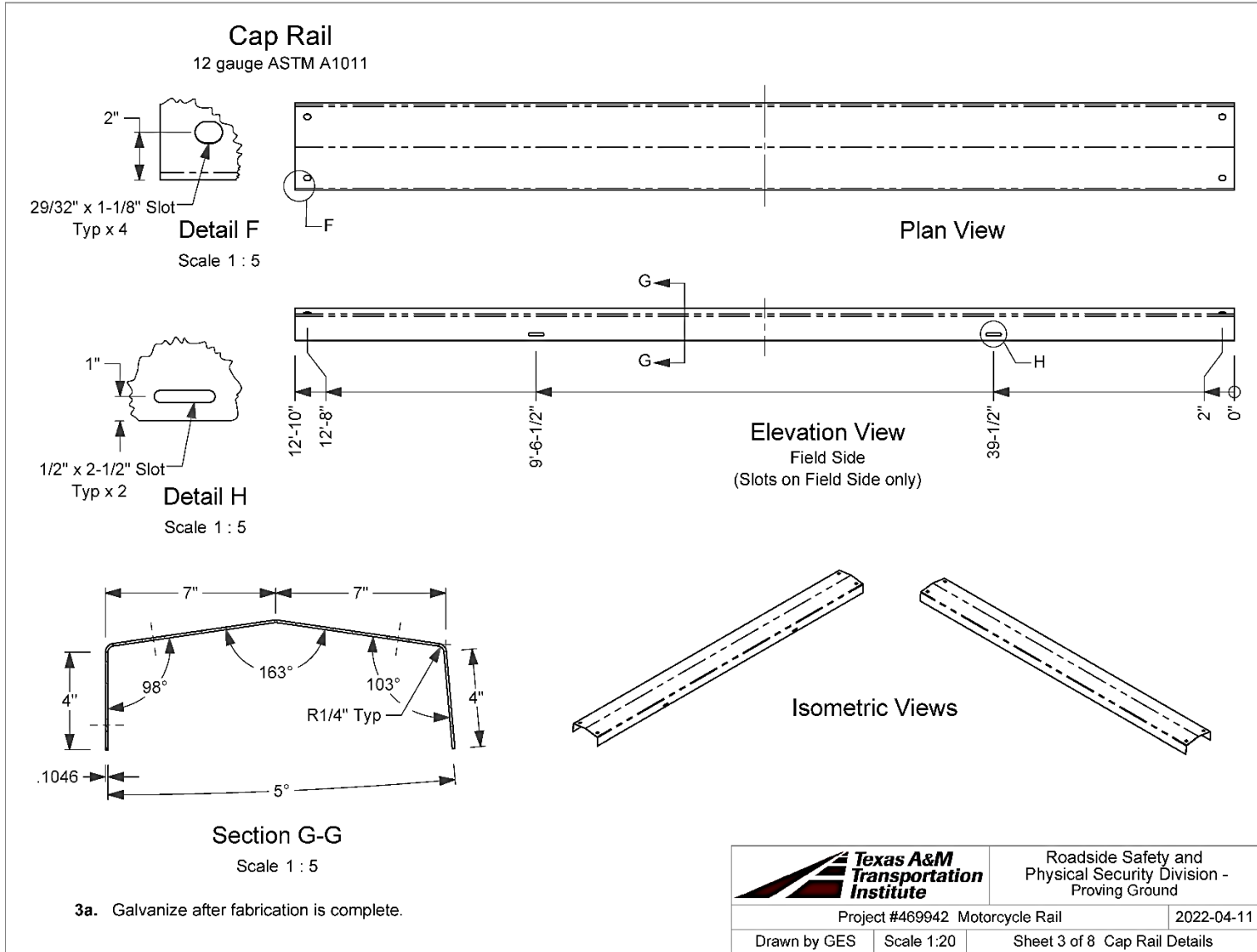
Rub Rail Anchor Details

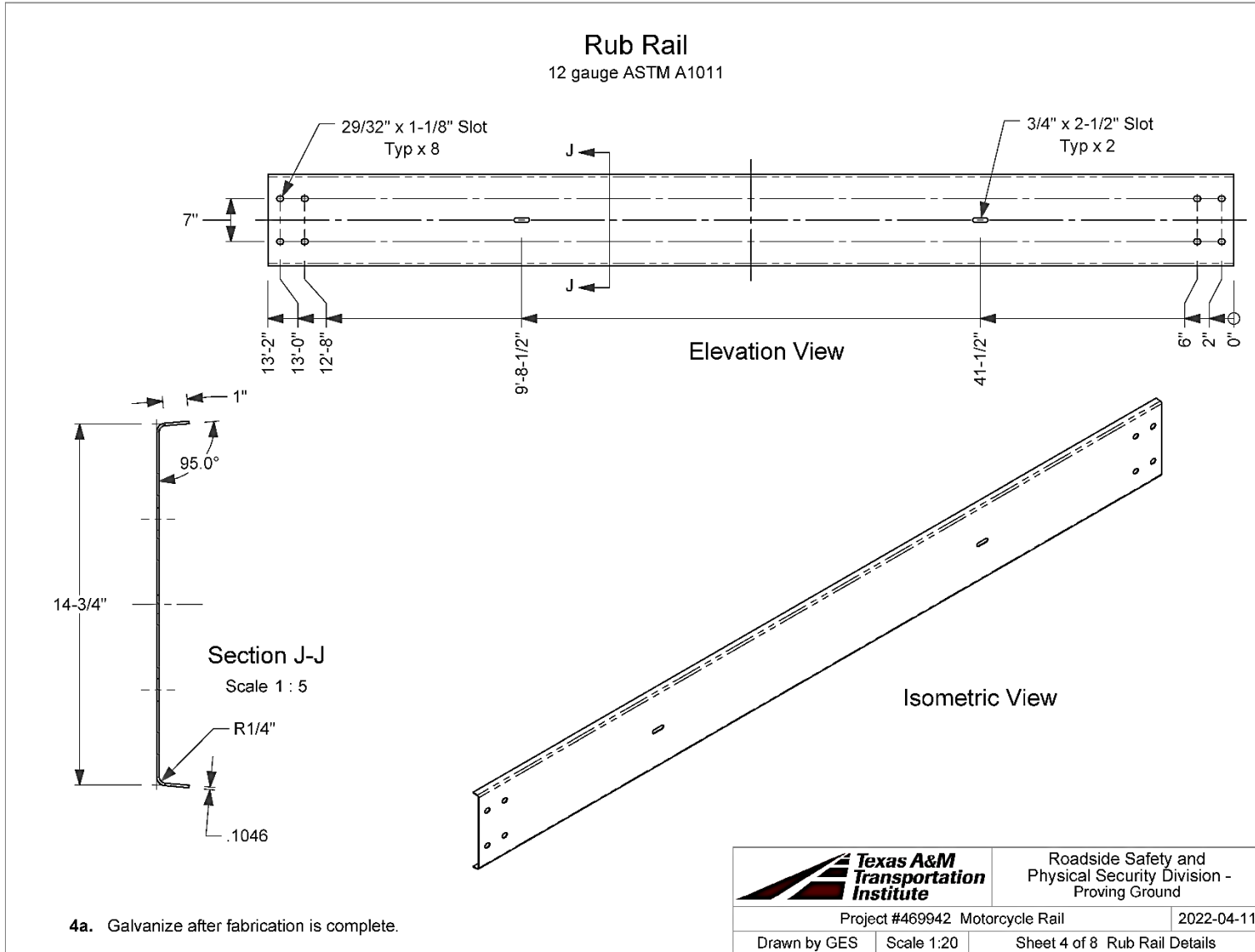
Typ each end of Rail

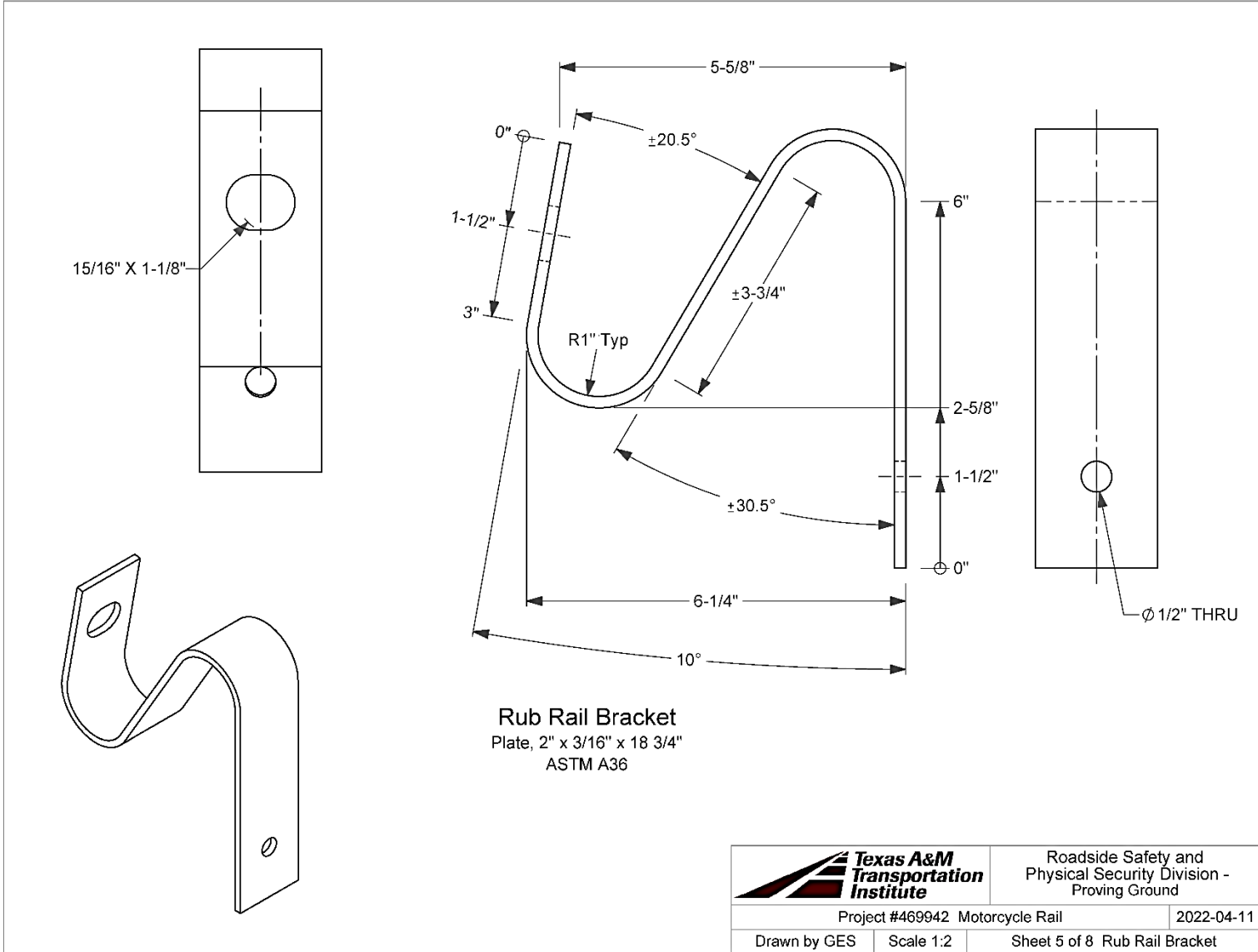


2a. Rub Rail Anchor Cap is placed on field side of Rub Rail in this location. It will be on the traffic side on the upstream end of the installation to minimize snagging.

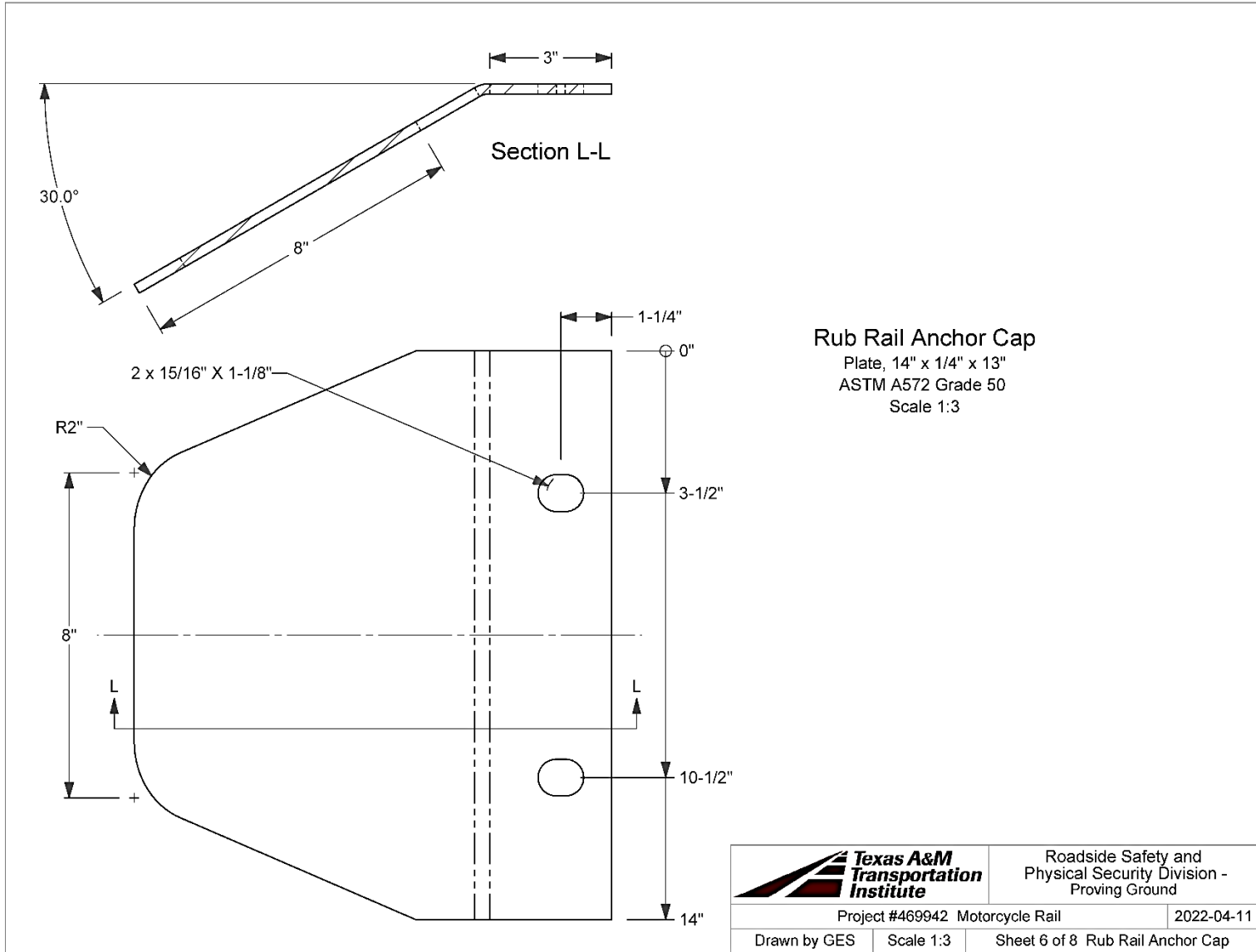
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Project #469942 Motorcycle Rail		2022-04-11
Drawn by GES	Scale 1:25	Sheet 2 of 8 Rub Rail Anchor Details



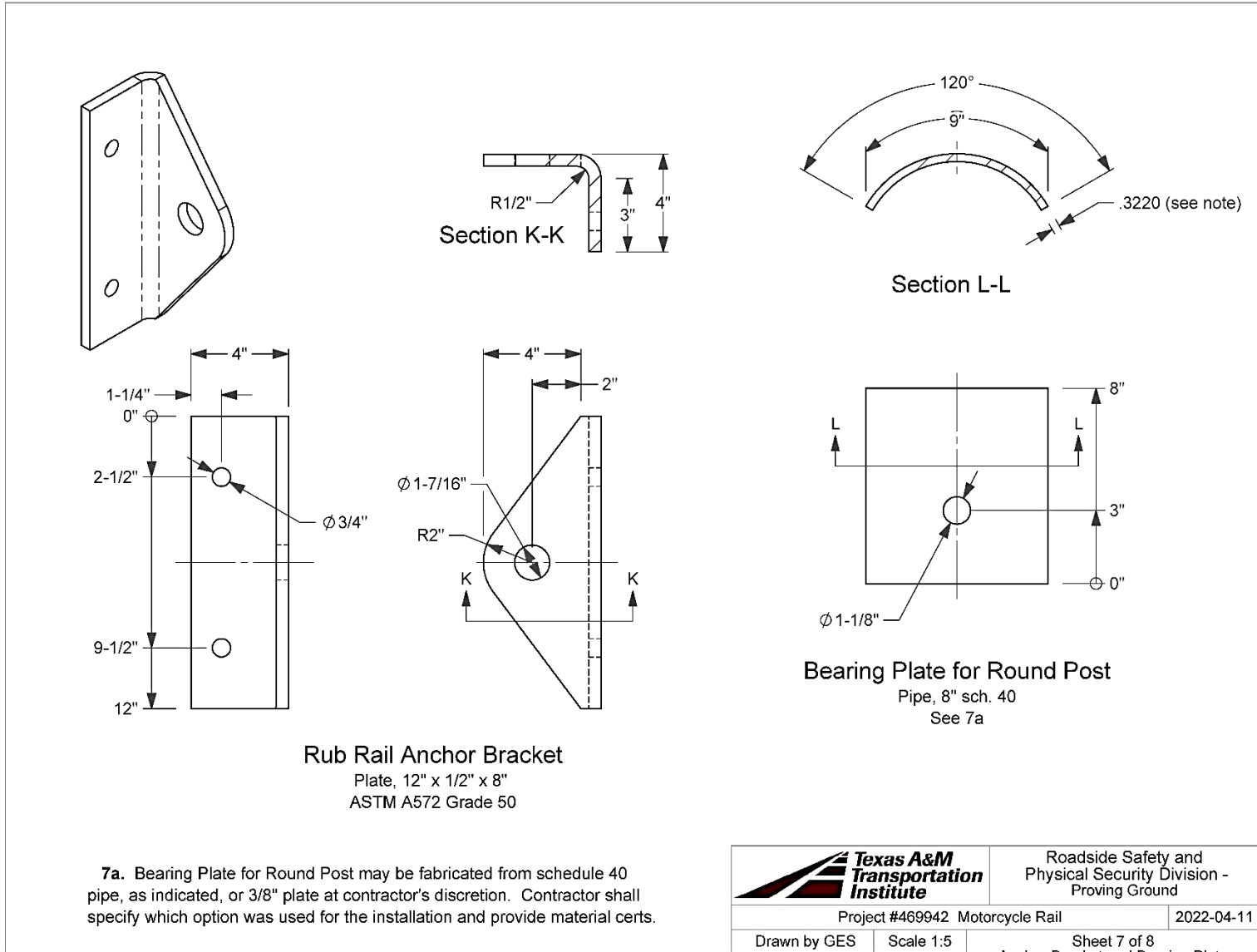




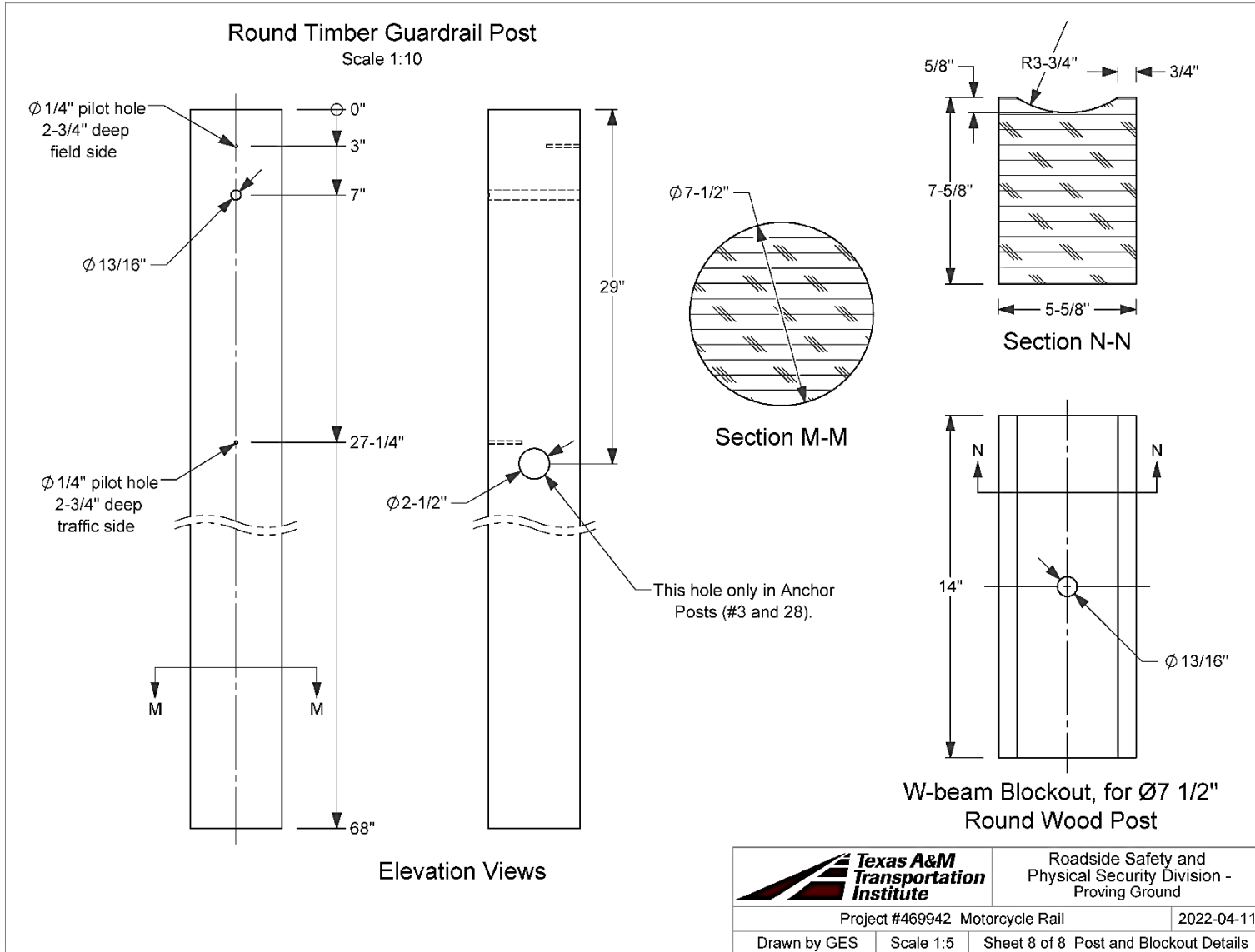
		Roadside Safety and Physical Security Division - Proving Ground
Project #469942 Motorcycle Rail		2022-04-11
Drawn by GES	Scale 1:2	Sheet 5 of 8 Rub Rail Bracket



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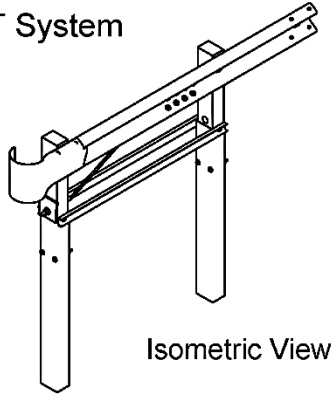


		Roadside Safety and Physical Security Division - Proving Ground
Project #469942 Motorcycle Rail		2022-04-11
Drawn by GES	Scale 1:5	Sheet 7 of 8 Anchor Bracket and Bearing Plate

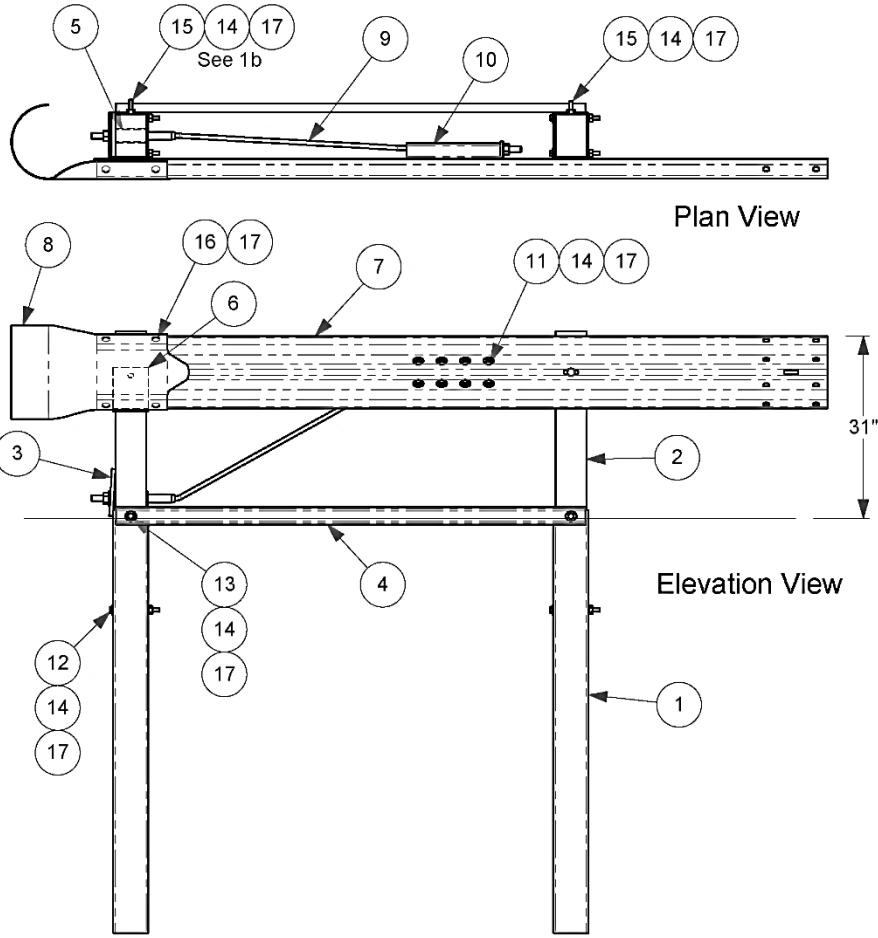


		Roadside Safety and Physical Security Division - Proving Ground
Project #469942 Motorcycle Rail		2022-04-11
Drawn by GES	Scale 1:5	Sheet 8 of 8 Post and Blockout Details

DAT System

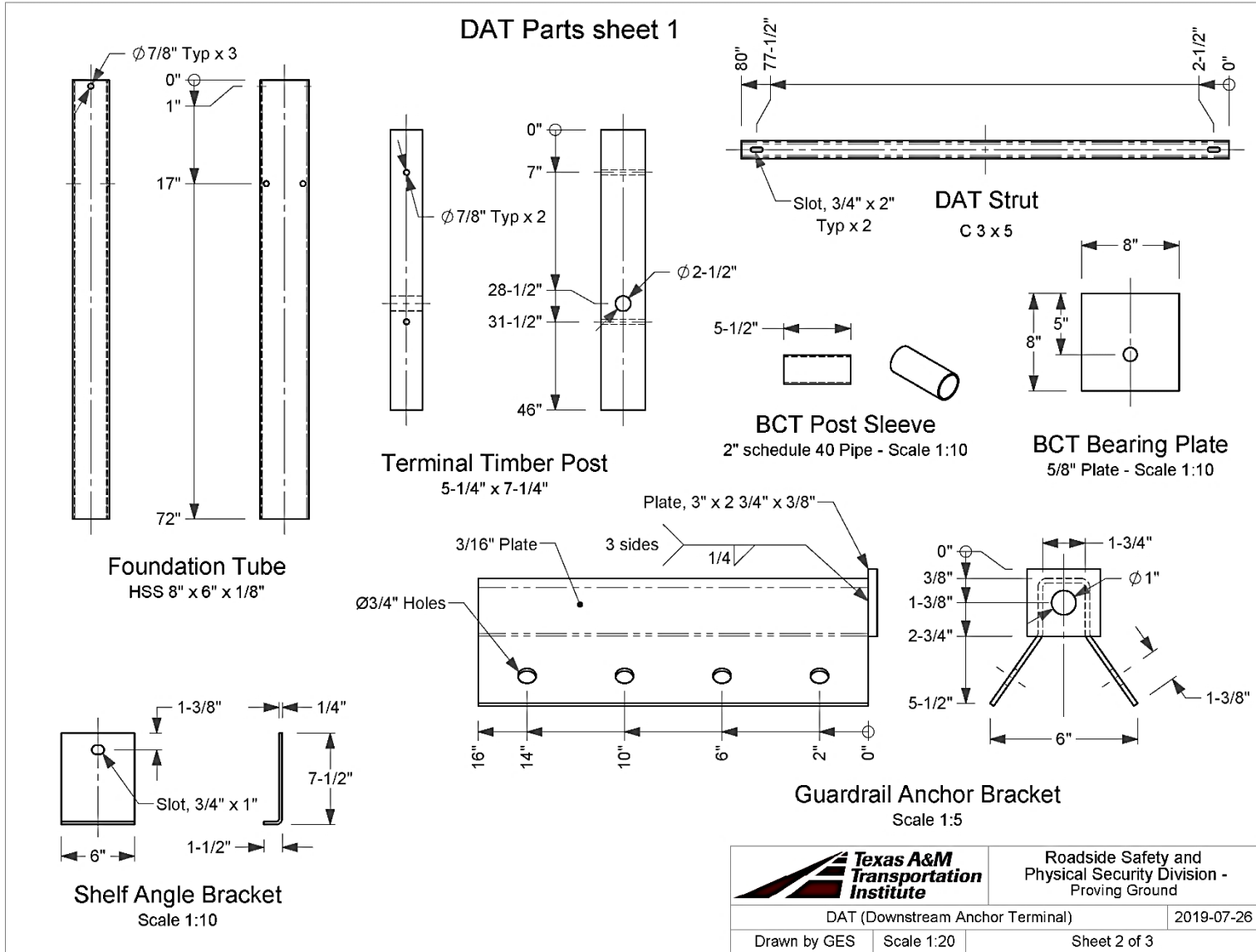


#	Part Name	Qty.
1	Foundation Tube	2
2	Terminal Timber Post	2
3	BCT Bearing Plate	1
4	DAT Strut	2
5	BCT Post Sleeve	1
6	Shelf Angle Bracket	1
7	DAT Terminal Rail	1
8	W-beam End Section	1
9	Anchor Cable Assembly	1
10	Guardrail Anchor Bracket	1
11	Bolt, 5/8 x 2" hex	8
12	Bolt, 5/8 x 8" hex	4
13	Bolt, 5/8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



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

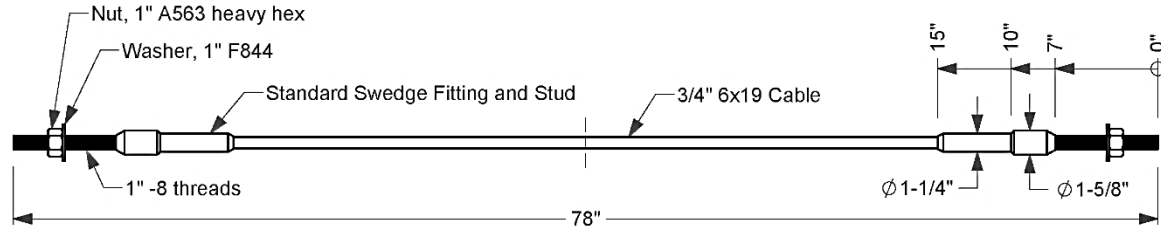
	Roadside Safety and Physical Security Division - Proving Ground	
	DAT (Downstream Anchor Terminal) 2019-07-26	
Drawn by GES	Scale 1:25	Sheet 1 of 3



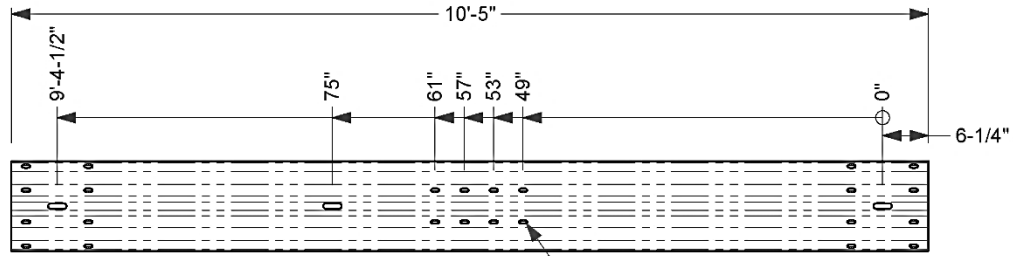
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		Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)		2019-07-26
Drawn by GES	Scale 1:20	Sheet 2 of 3

DAT Parts sheet 2

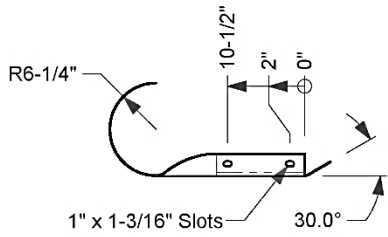


Anchor Cable Assembly



DAT Terminal Rail

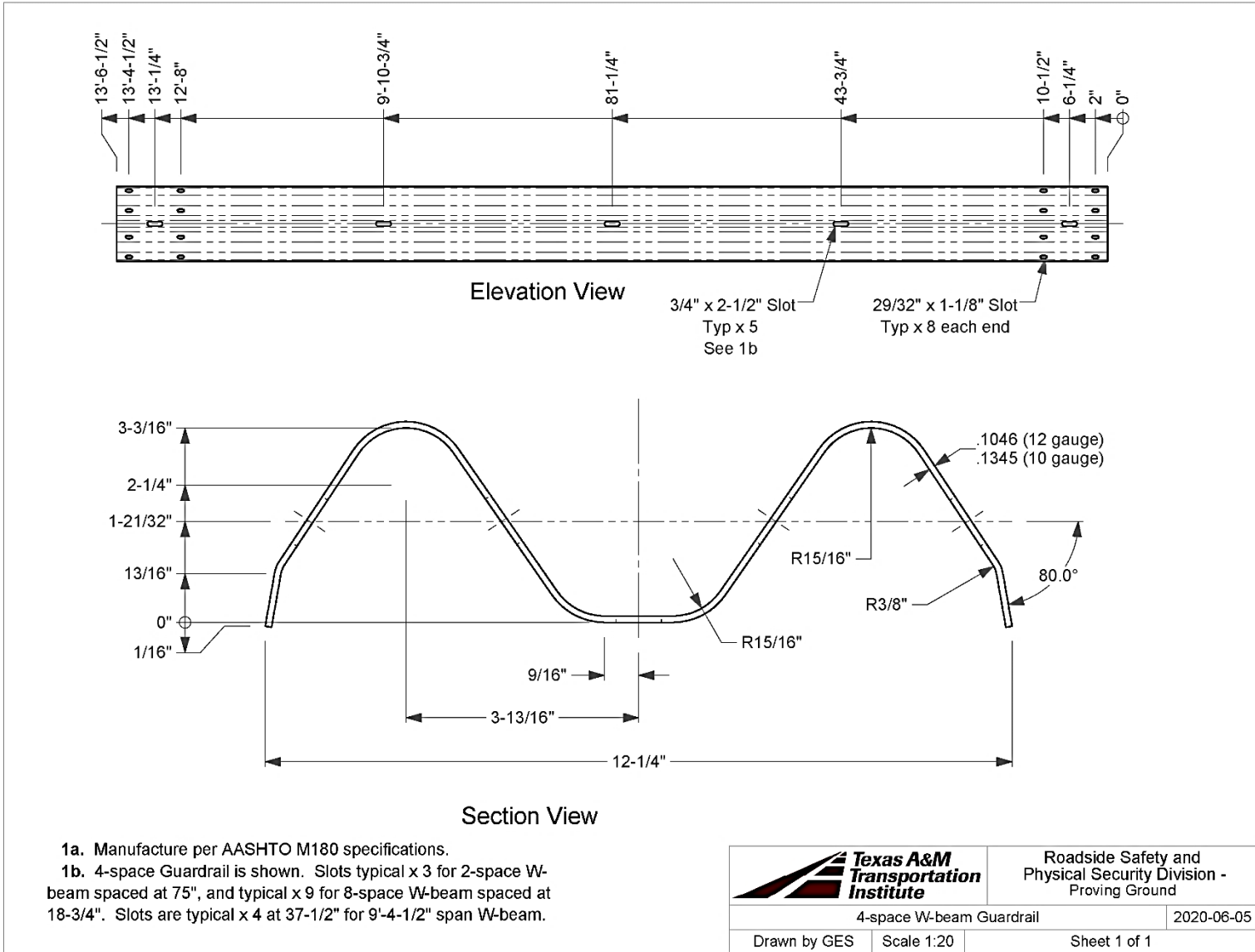
Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.



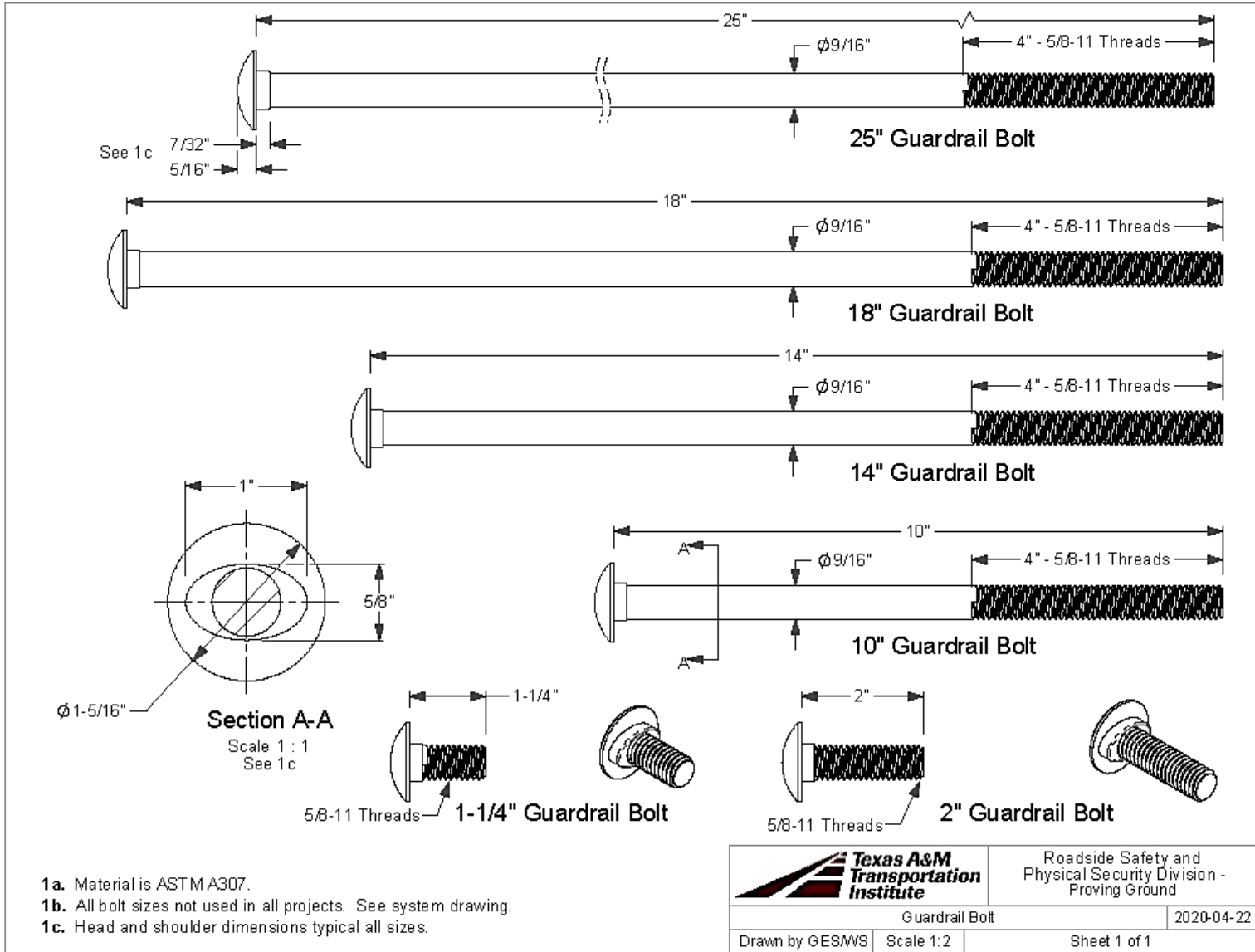
W-beam End Section

12 gauge steel - Scale 1:20

		Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)		2019-07-26
Drawn by GES	Scale 1:10	Sheet 3 of 3

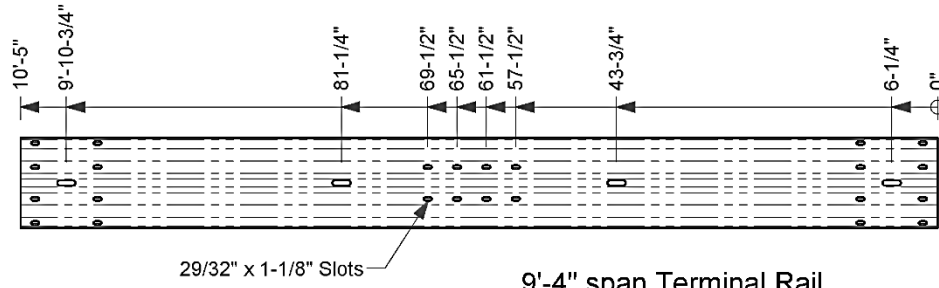


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		Roadside Safety and Physical Security Division - Proving Ground
Guardrail Bolt		2020-04-22
Drawn by GESWS	Scale 1:2	Sheet 1 of 1

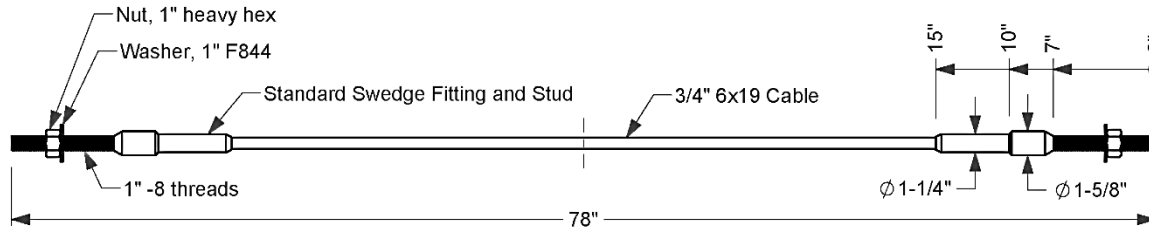
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29/32" x 1-1/8" Slots

9'-4" span Terminal Rail

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

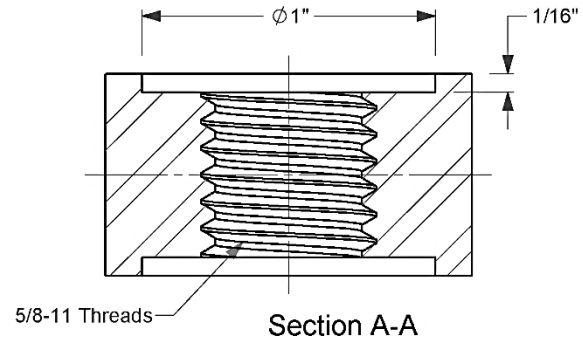
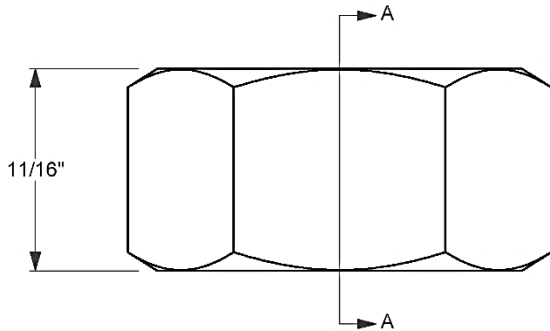
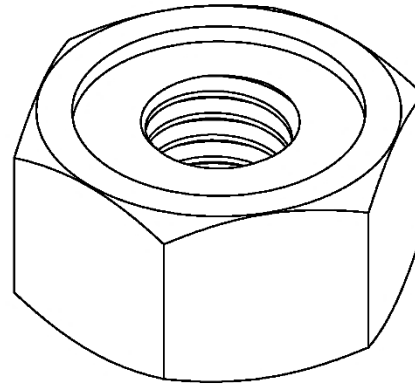
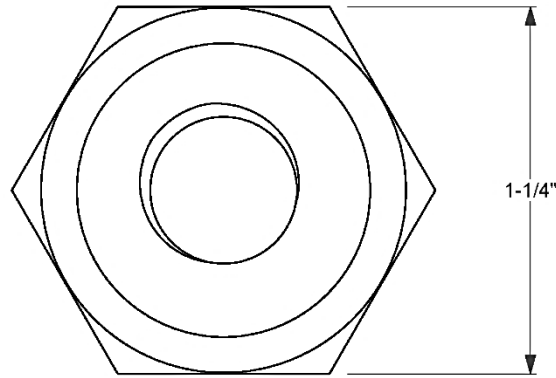


Anchor Cable Assembly


		Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal		2021-06-01
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B

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

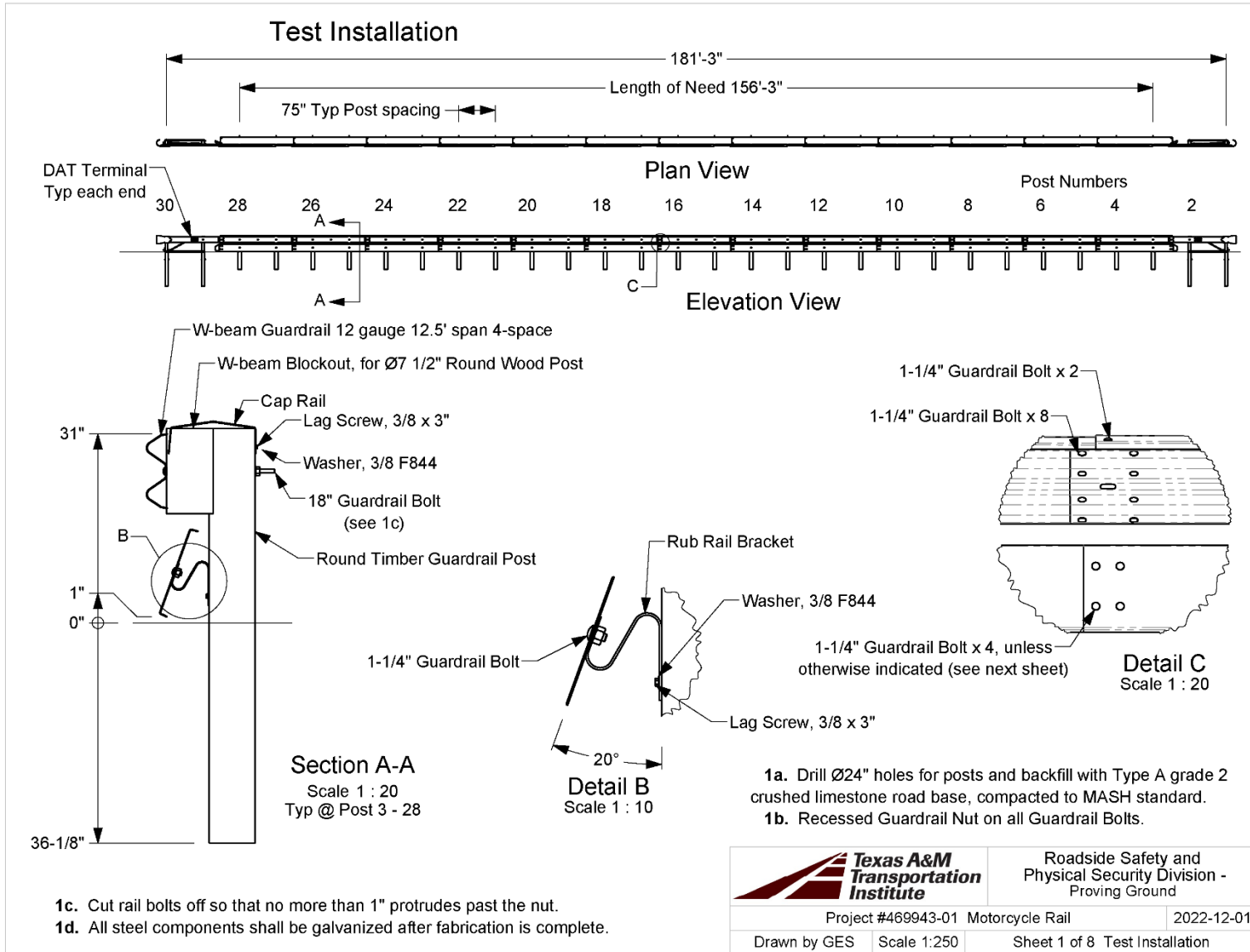
Recessed Guardrail Nut



1a. Material is ASTM A 563 Grade A.

		Roadside Safety and Physical Security Division - Proving Ground
Recessed Guardrail Nut		2019-06-27
Drawn by GES	Scale 2:1	Sheet 1 of 1

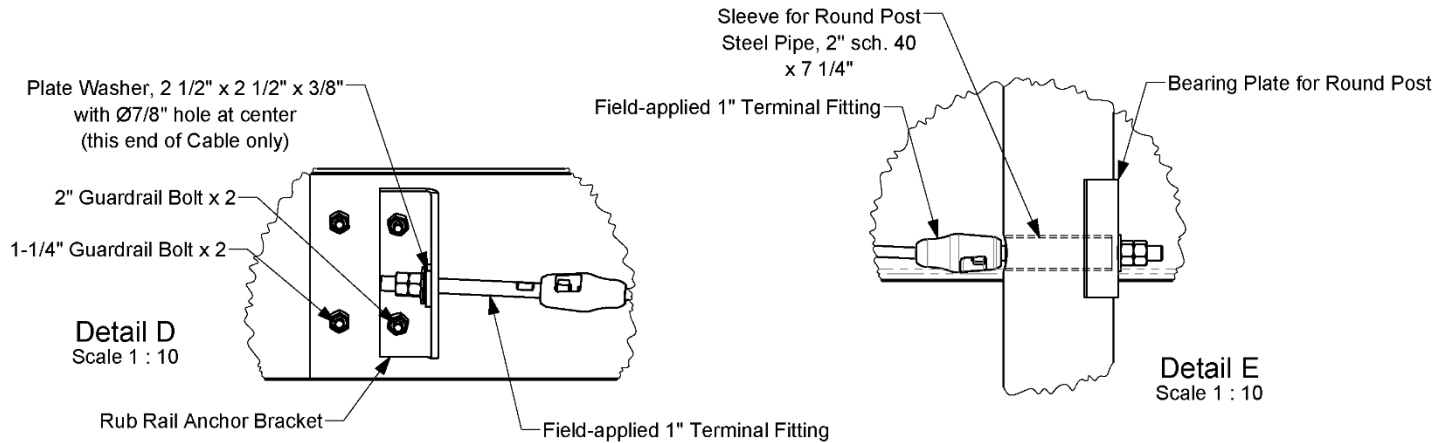
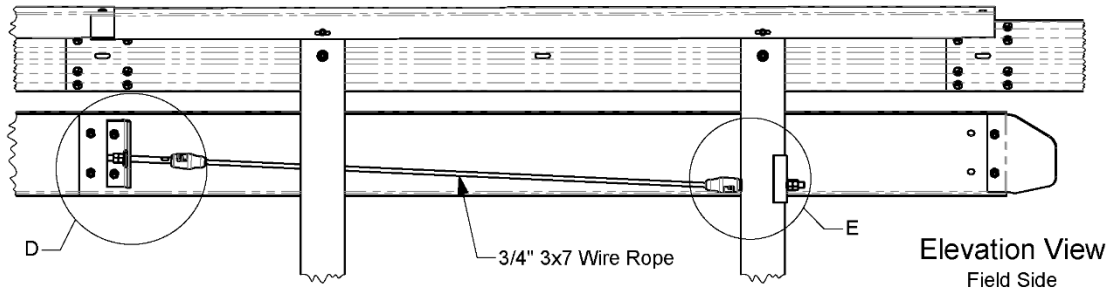
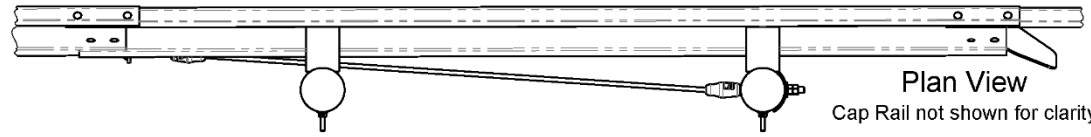
**A.3. DETAILS FOR CRASH TESTS 469943-01-1A, 469943-01-2, 469943-01-3,
AND 469943-01-4**



Rub Rail Anchor Details

Typ each end of Rail

Traffic Direction →

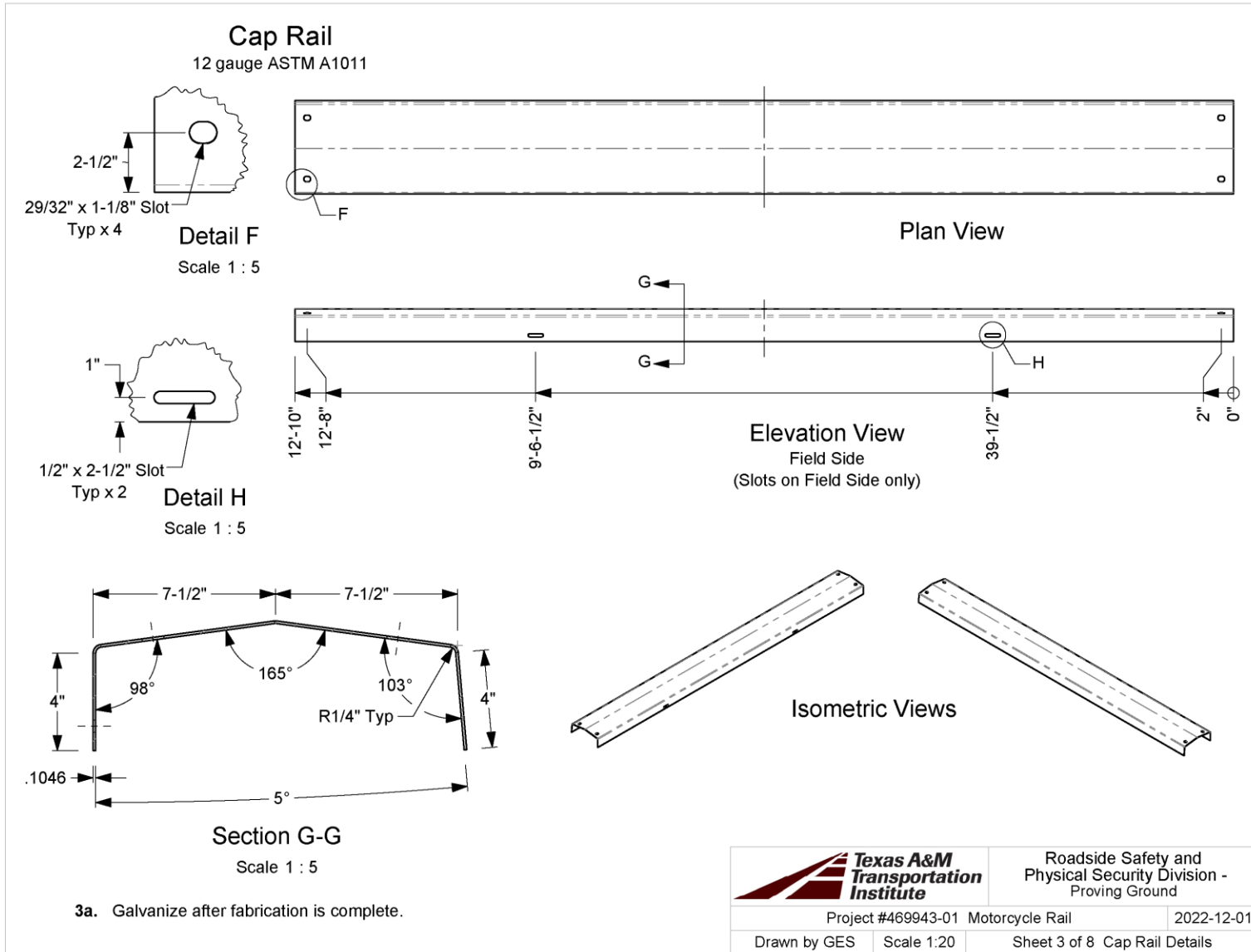


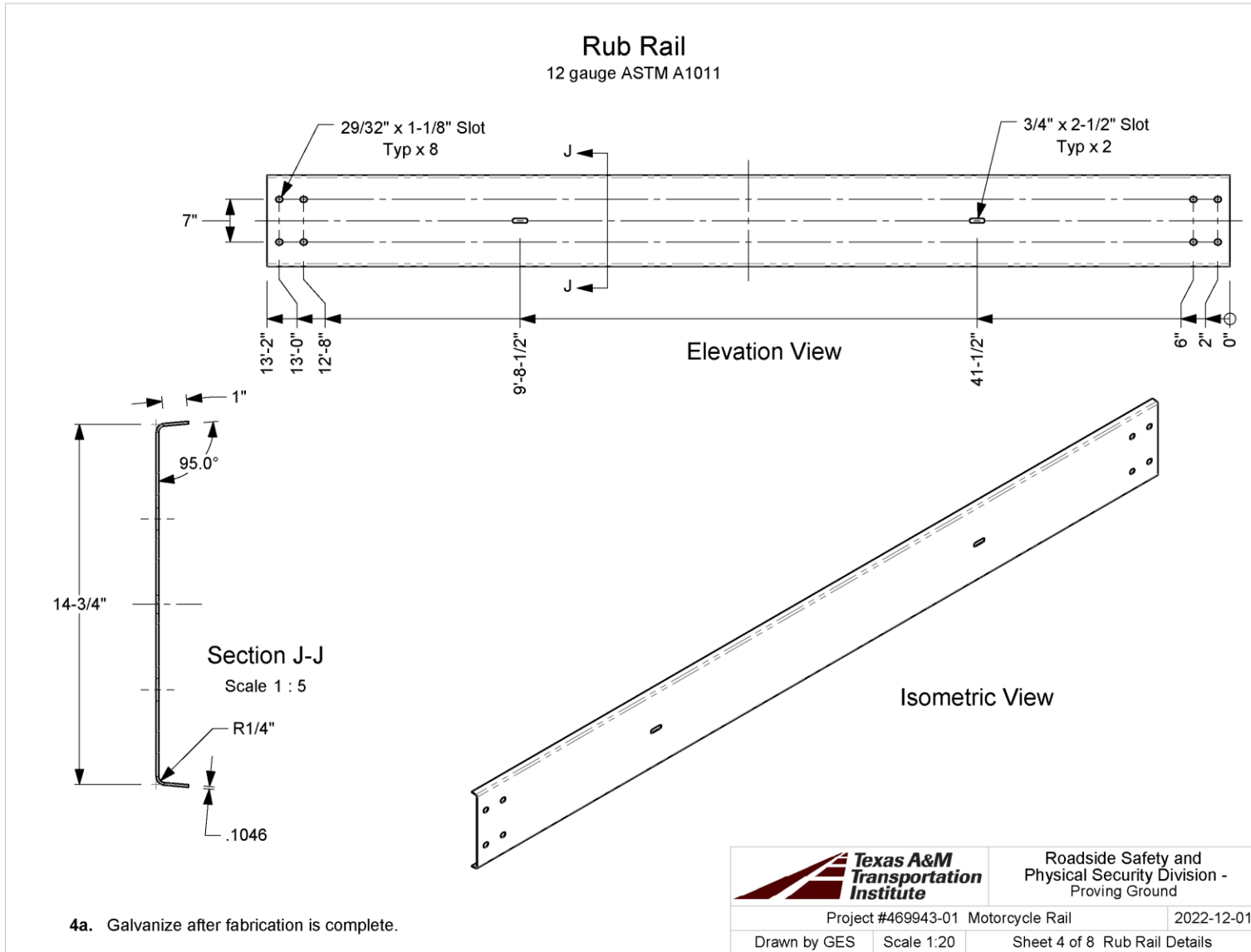
2a. Rub Rail Anchor Cap is placed on field side of Rub Rail in this location. It will be on the traffic side on the upstream end of the installation to minimize snagging.

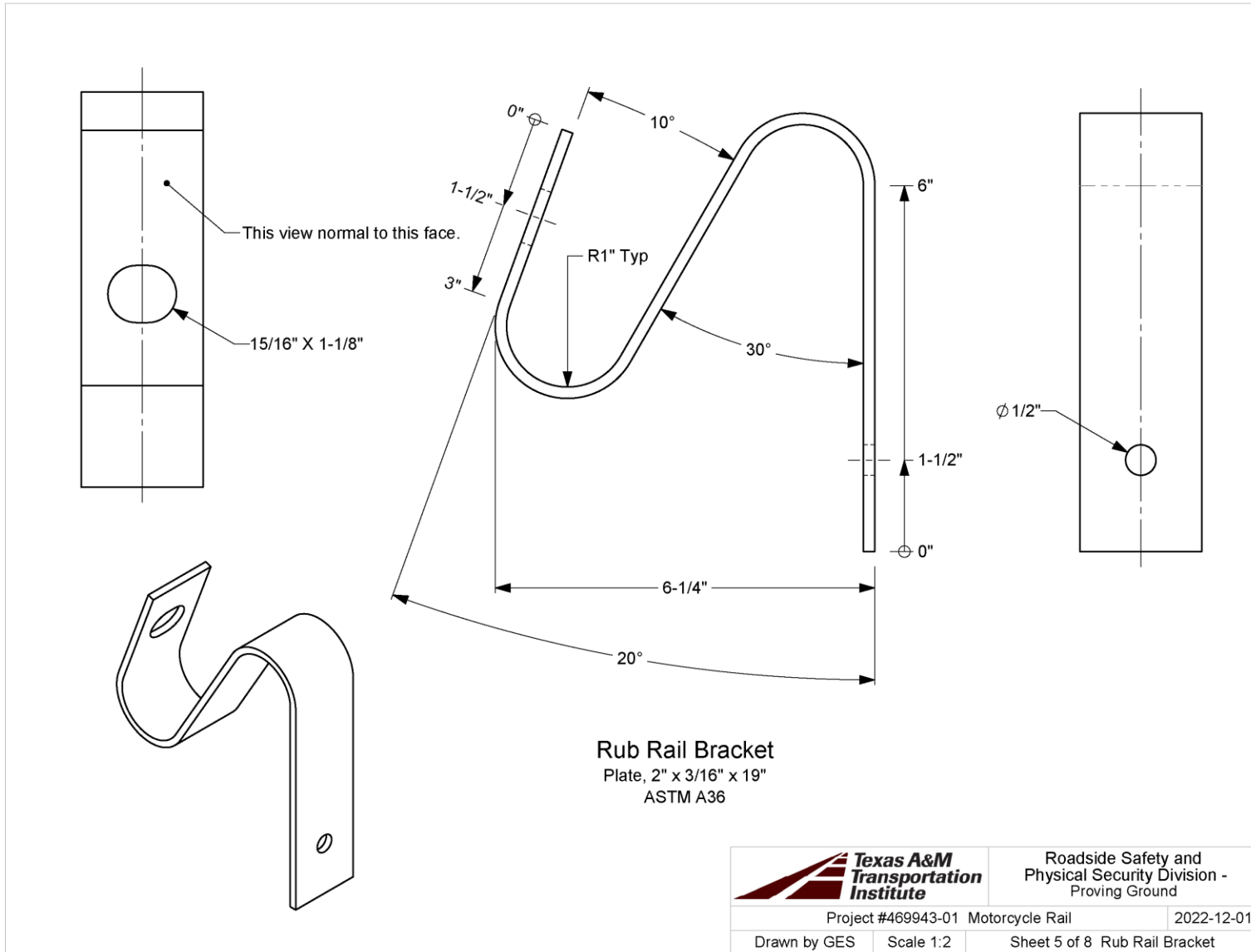


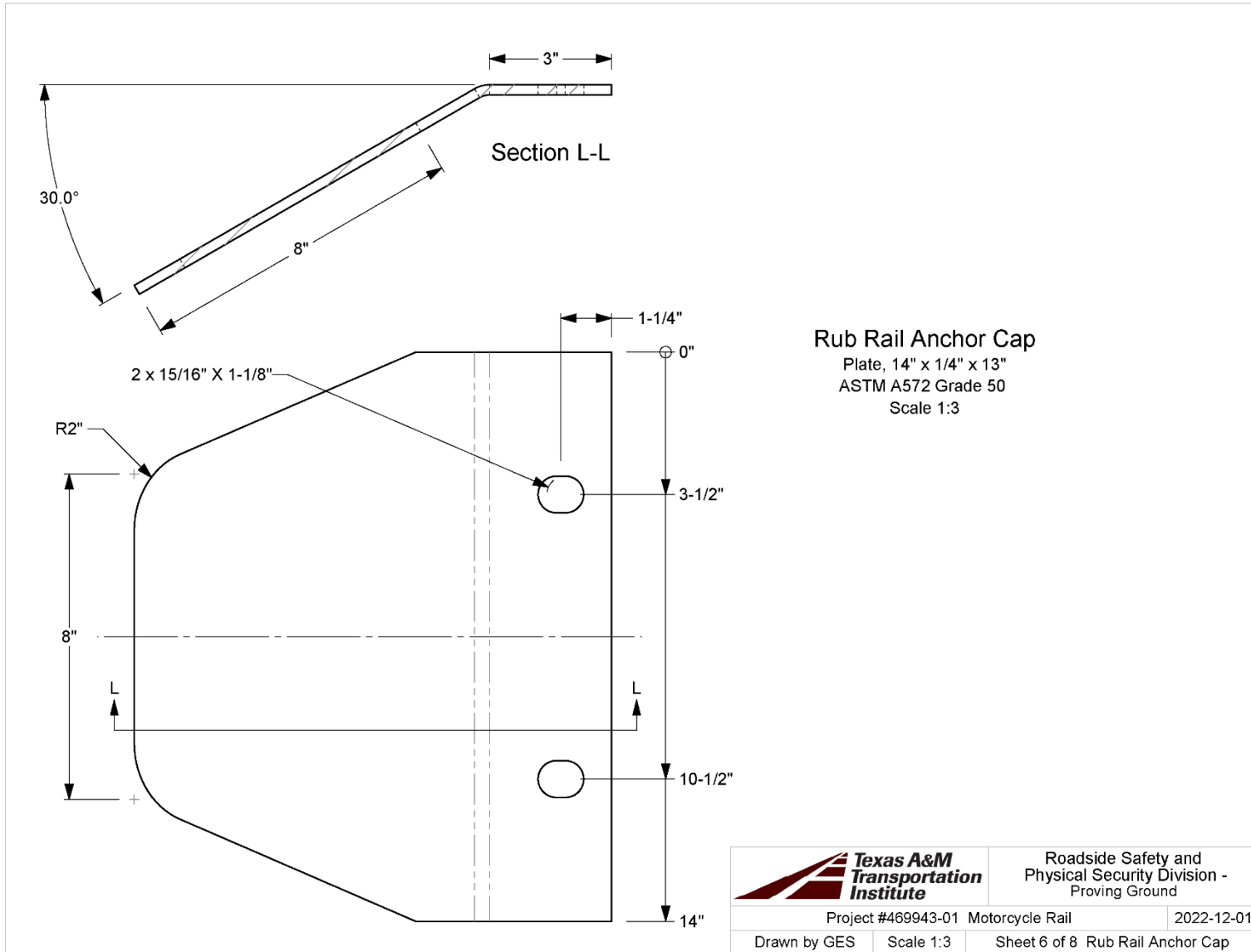
Roadside Safety and Physical Security Division - Proving Ground

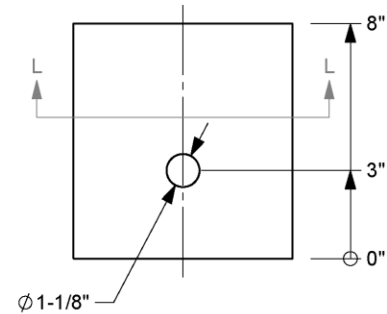
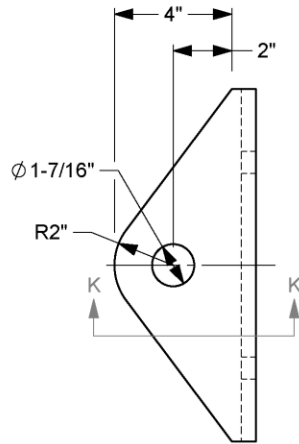
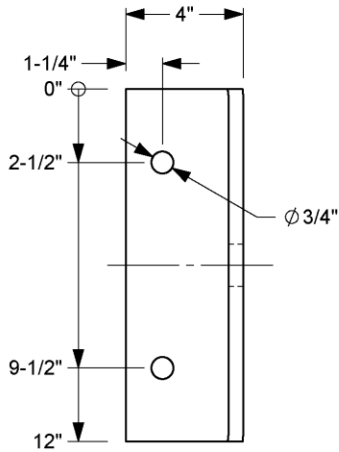
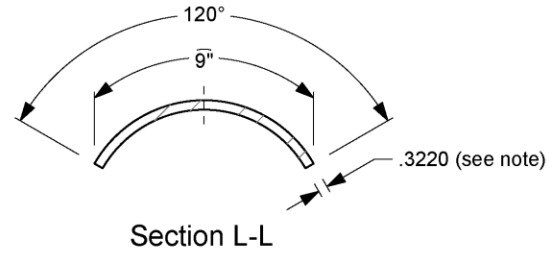
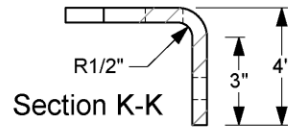
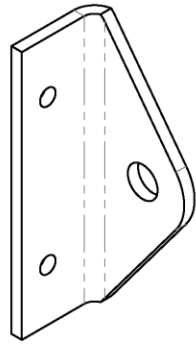
Project #469943-01 Motorcycle Rail		2022-12-01
Drawn by GES	Scale 1:25	Sheet 2 of 8 Rub Rail Anchor Details









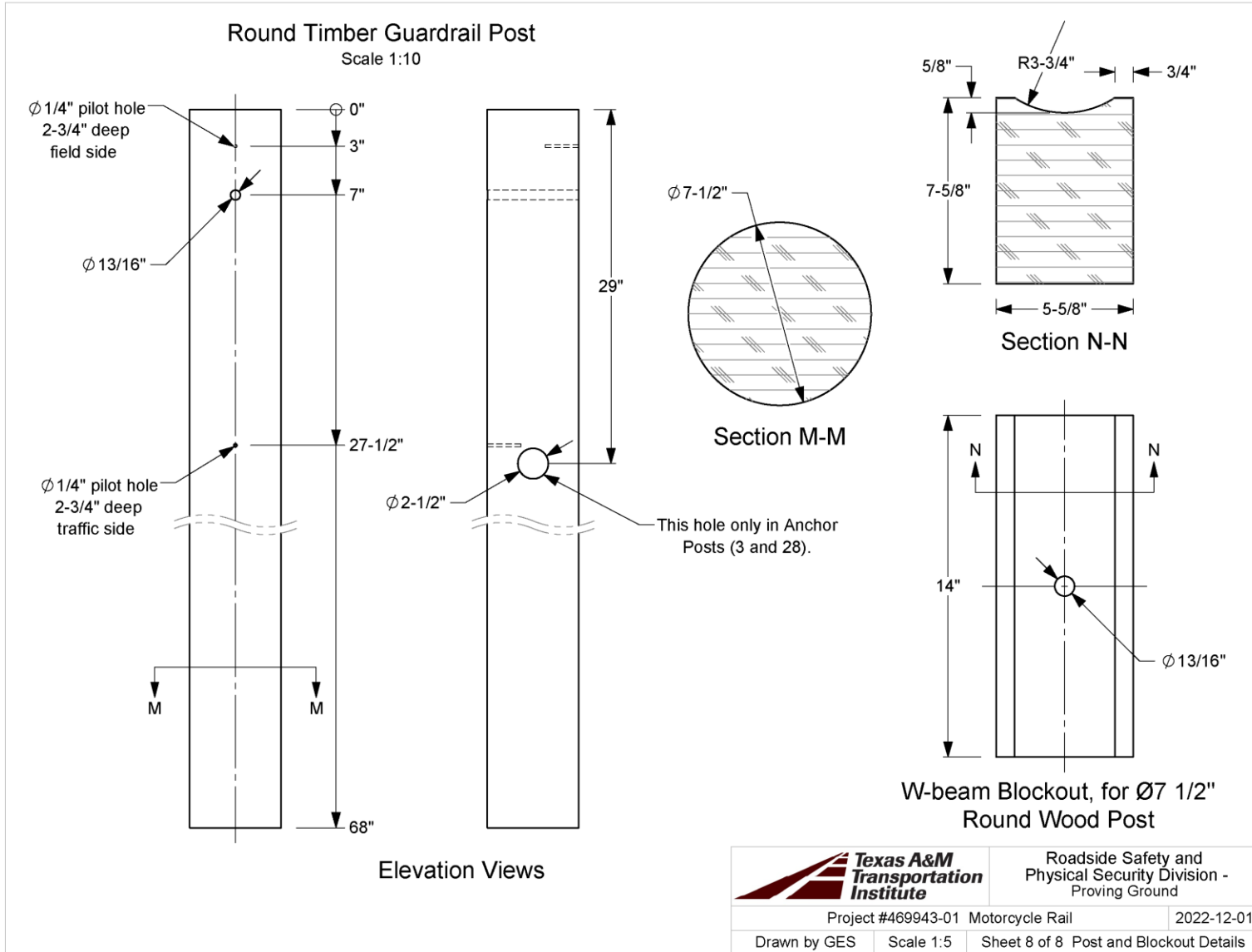


Bearing Plate for Round Post
Pipe, 8" sch. 40
See 7a

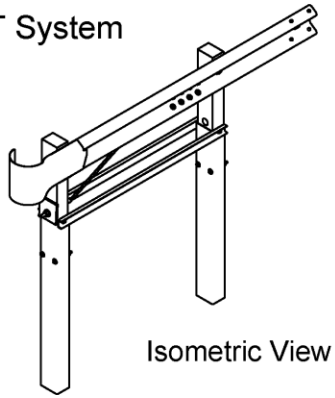
Rub Rail Anchor Bracket
Plate, 12" x 1/2" x 8"
ASTM A572 Grade 50

7a. Bearing Plate for Round Post may be fabricated from schedule 40 pipe, as indicated, or 3/8" plate at contractor's discretion. Contractor shall specify which option was used for the installation and provide material certs.

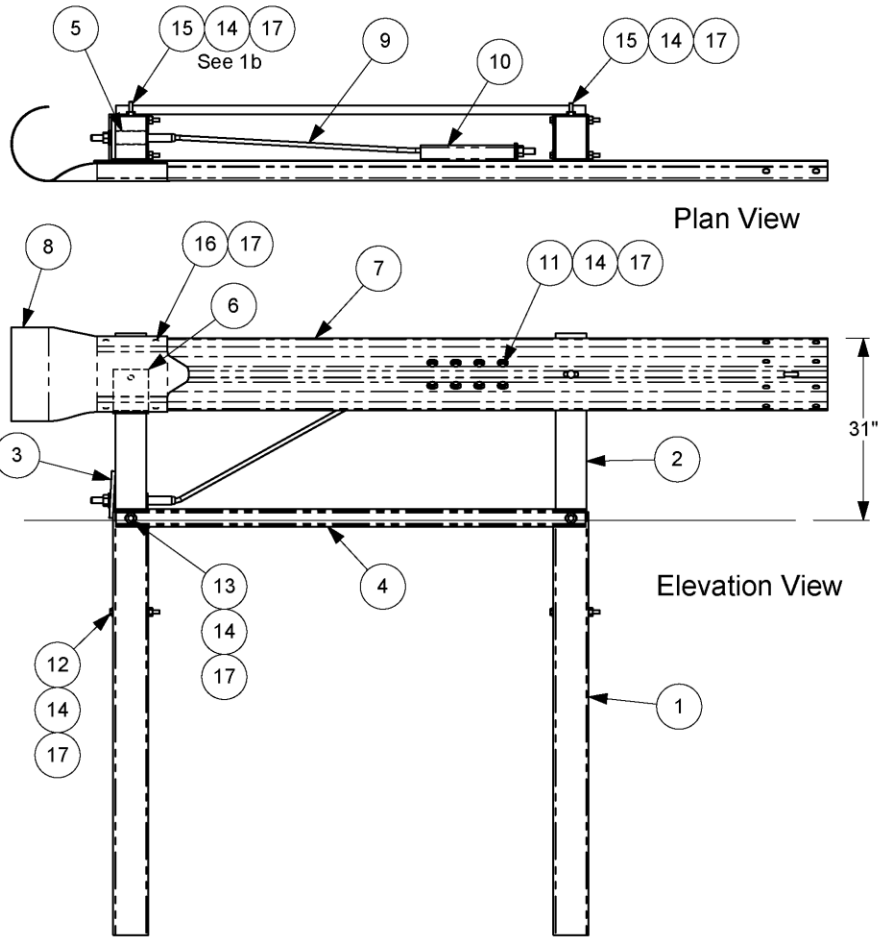
		Roadside Safety and Physical Security Division - Proving Ground	
Project #469943-01 Motorcycle Rail		2022-12-01	
Drawn by GES	Scale 1:5	Sheet 7 of 8 Anchor Bracket and Bearing Plate	



DAT System



#	Part Name	Qty.
1	72" Foundation Tube	2
2	Tube Post	2
3	BCT Bearing Plate	1
4	DAT Strut	2
5	BCT Post Sleeve	1
6	Shelf Angle Bracket	1
7	9'-4" span Terminal Rail	1
8	W-beam End Section	1
9	Anchor Cable Assembly	1
10	Guardrail Anchor Bracket	1
11	Bolt, 5/8 x 2" hex	8
12	Bolt, 5/8 x 8" hex	4
13	Bolt, 5/8 x 10" hex	2
14	Washer, 5/8 F844	16
15	10" Guardrail Bolt	2
16	1-1/4" Guardrail Bolt	4
17	Recessed Guardrail Nut	20



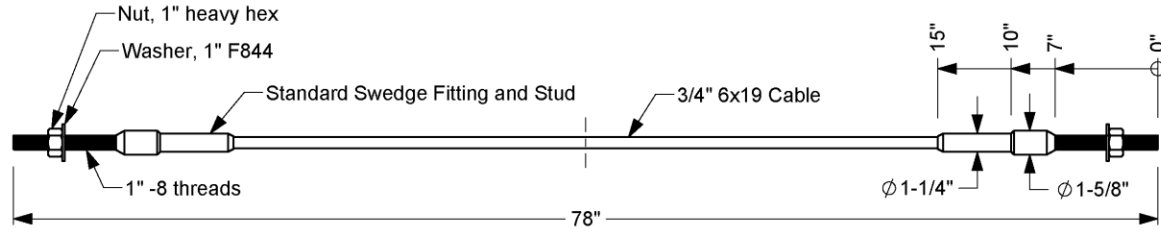
1a. All bolts are ASTM A307.
1b. Hardware secures Shelf Angle Bracket to Post. Rail is supported by Shelf Angle Bracket and does not attach directly to Post.



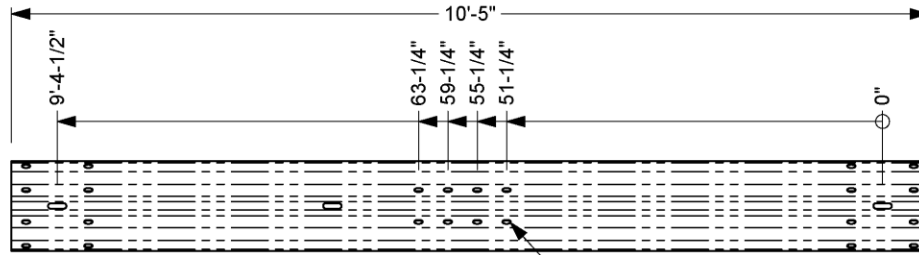
Roadside Safety and Physical Security Division - Proving Ground

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

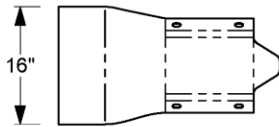
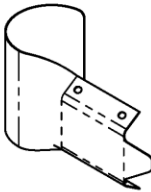
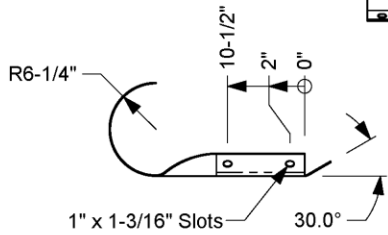
DAT Parts sheet 2



Anchor Cable Assembly



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

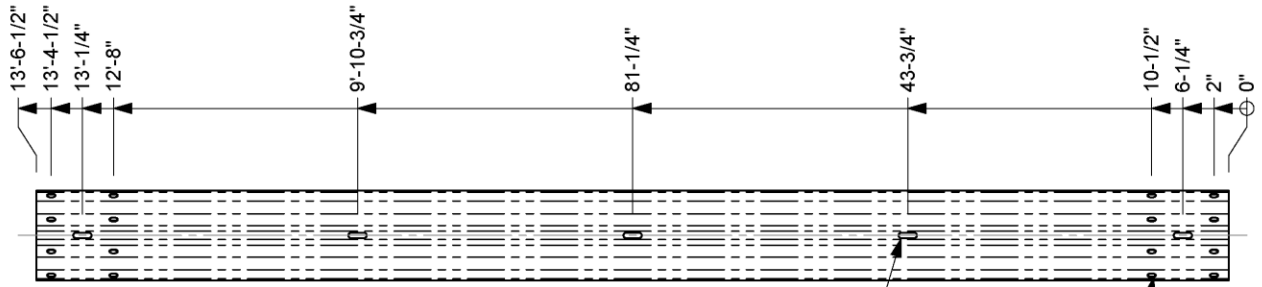


W-beam End Section
12 gauge steel - Scale 1:20



Roadside Safety and
Physical Security Division -
Proving Ground

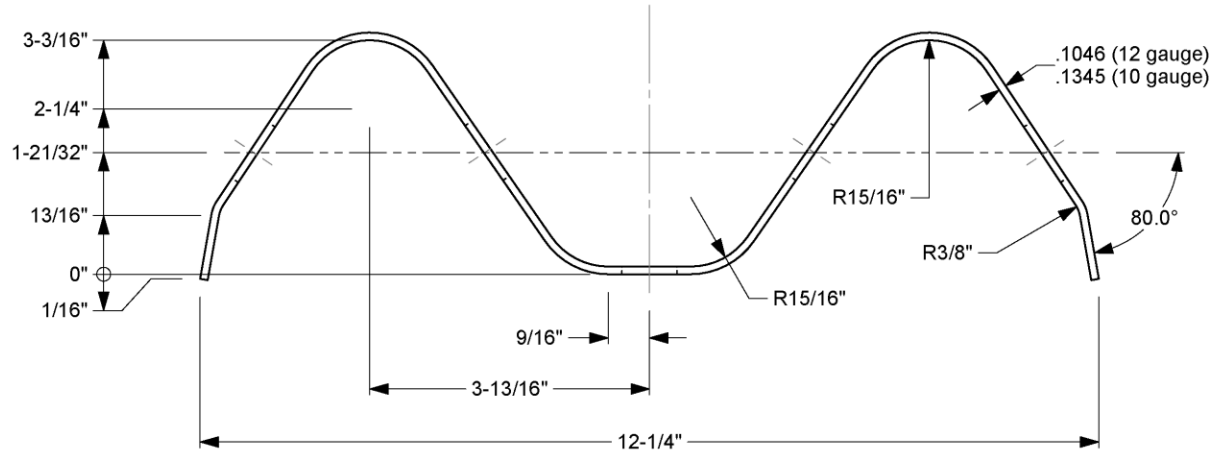
DAT (Downstream Anchor Terminal)		2022-07-13
Drawn by GES	Scale 1:10	Sheet 3 of 3



Elevation View

3/4" x 2-1/2" Slot
Typ x 5
See 1b

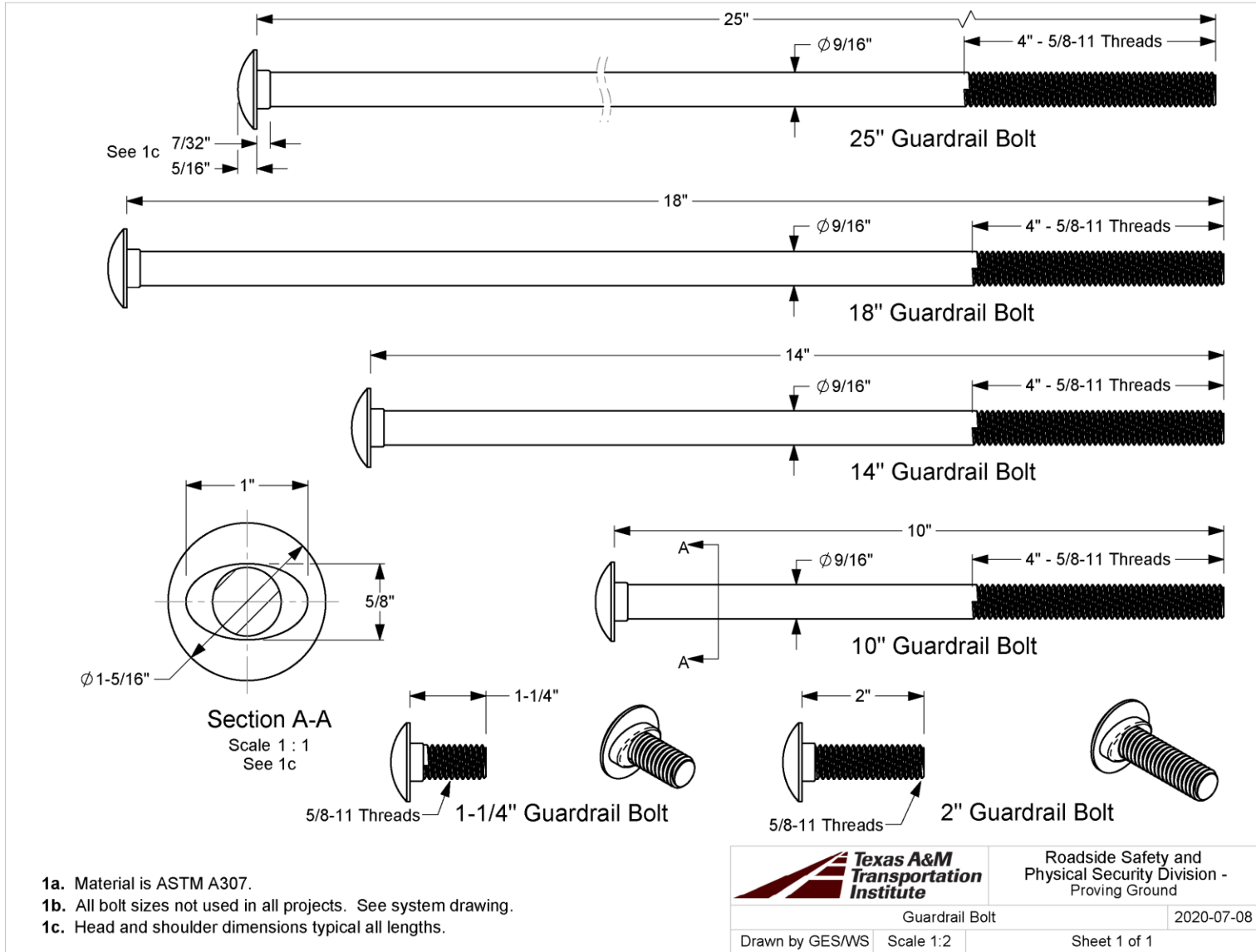
29/32" x 1-1/8" Slot
Typ x 8 each end



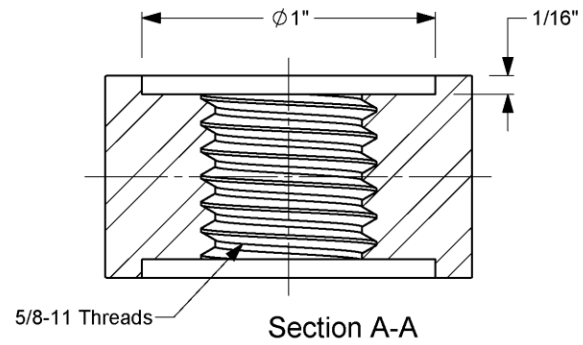
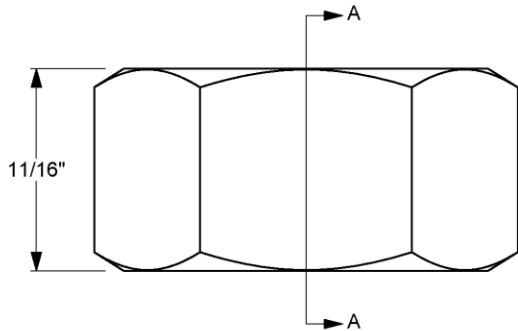
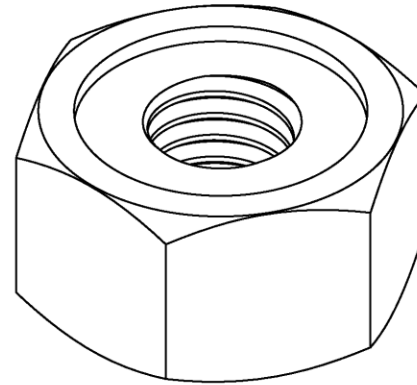
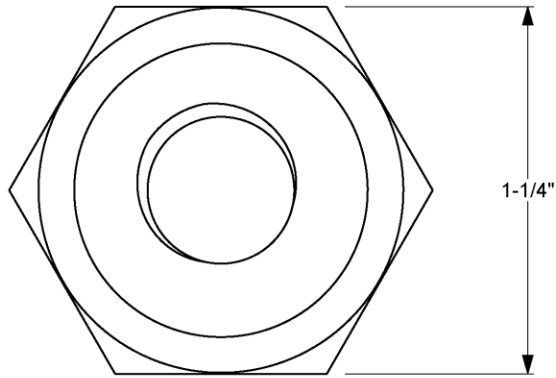
Section View

1a. Manufacture per AASHTO M180 specifications.
 1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

		Roadside Safety and Physical Security Division - Proving Ground
W-beam Guardrail		2022-07-13
Drawn by GES	Scale 1:20	Sheet 1 of 1



Recessed Guardrail Nut



1a. Material is ASTM A 563 Grade A.



Roadside Safety and
Physical Security Division -
Proving Ground

Recessed Guardrail Nut		2022-07-18
Drawn by GES	Scale 2:1	Sheet 1 of 1

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

This Memorandum

is an acknowledgment that a Bill of Lading has been issued and is not the original Bill of Lading, nor a copy or duplicate, covering the property named herein, and is intended solely for filing or record.

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading, at 8-12-20 from TTI the property described below in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, consigned and destined as shown below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or route, or within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, including the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

Carrier
Shipper's No. 16-80154
S/O No. 1345229

Consigned to: SAMPLES, TESTING MATERIALS Cust. P.O. TTI MOTORCYCLE Load No.: 45-1
Destination: TTI BLDG 7090 Total Weight: 7,250.04
3100 STATE HWY 47
City: DRIAN State: TX Zip: 75807 Ship: 07/27/20 9:37 AM
Contact: MARY GERSE Phone: 930-843-4001 Arrive: 07/28/20 8:00 AM TRL#
Delivering Carrier: BENNETT Vehicle or Car Initial: TRL# 0610 No. 1610

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.
TRINITY HIGHWAY PRODUCTS, LLC
Per DUREY (Signature of Consignor) LLC
If charges are to be prepaid, write or stamp here, "To be Prepaid."
TO BE PREPAID
Received \$ _____
to apply in prepayment of the charges on the property described hereon.
Agent or Cashier
Per _____
(The signature here acknowledges only the amount prepaid.)
Charges advanced:

Collect On Delivery: \$ _____ and remit to: _____ C.O.D. charge Shipper to be paid by Consignee
Street _____ City _____ State _____

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.	No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. QMS-LG-002											
Project Info: MOTORCYCLE TEST											
LD Comments:											
	52	11G 12/12/6/31.5/5									
	4	850G 12/BUFFER/ROLLED									
	4	3000G CBL 3/4X6/6/DBL SWG/NOHW/D									
	104	3300G WASHER, FLAT, 5/8 R.T.Y B.G									
	804	3340G 5/8" GR HEX NUT									
	700	3360G 5/8"X1.25" GR BOLT									
	104	3580G 5/8"X18" GR BOLT A307									
	12	3900G 1" ROUND WASHER F844									
	24	3910G 1" HEX NUT A563									
	5	5910G CASS STUD CBL ASSY 1" RT									
		*BackOrdered: 7									
	8	10481G C3X5/8X6-8" RUBRAIL									
	4	20207G 12/9/4 5/8-HOLE ANCH/S									
	4	36120A DAT-31-TX-HDW-CAN									
	6	130896G 6/0 TUBE SL/125X8X6									
	8	626079B WD 3/10 POST 5.25X7.25CRT									
<i>GERSE</i>											

SPECIAL INSTRUCTIONS: **SHIPPER LOAD - CONSIGNEE UNLOAD** 16-80154 Total Weight 7,251 **3**

*If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding _____

ORIGIN: SHIPPER OR AGENT I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof. DATE 8/12/20
SIGN HERE Mary Gersé
AGENT OR DRIVER This shipment received subject to exceptions as noted and according to the terms and conditions hereof.
(SIGN HERE) DATE _____

DESTINATION: CONSIGNEE OR AGENT Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions. AM. PM.
SIGN HERE DATE TIME
DRIVER Bennett NO

Permanent post-office address of shipper, FRI 609-RF (R 10/93) (This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.) **CONSIGNEE/CUSTOMER COPY**



Certified Analysis

Trinity Highway Products LLC
 2548 N.E. 28th St.
 Ft Worth (THP), TX 76111 Phn:(817) 665-1499
 Customer: SAMPLES, TESTING MATERIALS
 2525 STEMMONS FRWY
 DALLAS, TX 75207
 Project: MOTORCYCLE TEST

Order Number: 1325977 Prod L.n Grp: 3-Guardrail (Dom)
 Customer PO: TTI - MOTORCYC
 BOL Number: 80154 Ship Date: 6/12/2020
 Document #: 1
 Shipped To: TX
 Use State: TX



Qty	Part #	Description	Spec	CL	TV	Heat Code/Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
52	11G	12/12/63/1.5/S		2	F12120														
	M-180	A	2	2100151		58,800	81,000	25.0	0.190	0.780	0.008	0.002	0.020	0.100	0.000	0.050	0.004	4	
	M-180	A	2	2100151		58,800	81,000	25.0	0.190	0.780	0.008	0.002	0.020	0.100	0.001	0.050	0.004	4	
	M-180	A	2	2101129		56,500	82,100	23.0	0.230	1.010	0.009	0.001	0.030	0.130	0.000	0.050	0.004	4	
	M-180	A	2	2101130		62,400	84,900	25.0	0.230	1.000	0.010	0.001	0.030	0.140	0.000	0.050	0.004	4	
	M-180	A	2	2200773		65,000	85,300	23.0	0.220	0.770	0.012	0.003	0.030	0.160	0.000	0.060	0.003	4	
	M-180	A	2	2201642		57,900	73,200	23.0	0.230	0.980	0.008	0.002	0.020	0.140	0.000	0.050	0.004	4	
4	850G	12/BUFFER/ROLLED	M-180	A	2	216690	65,000	83,340	22.8	0.190	0.730	0.012	0.003	0.020	0.100	0.000	0.070	0.002	4
	850G		M-180	A	2	11719850	51,600	62,400	33.0	0.050	0.520	0.009	0.003	0.040	0.100	0.001	0.050	0.002	4
	850G		M-180	A	2	31847970	48,400	62,300	35.0	0.060	0.450	0.015	0.001	0.030	0.090	0.000	0.070	0.002	4
4	3000G	CBL 3/4X6/6/DBL	WIRE			348066													4
104	3300G	WASHER, FLAT, 5/8 R, TY	F844-3300			P39261 R73305-01													4
804	3340G	5/8" GR HEX NUT	FAST			20-42-004													4
700	3360G	5/8"X1.25" GR BOLT	A307-3360			906581-5													4
104	3580G	5/8"X18" GR BOLT A307	A307-3580			32870													4
12	3900G	1" ROUND WASHER F844	F844-3900			P38875 R71579-01													4
24	3910G	1" HEX NUT A563	A563-3910			P38851 R71907													4
5	5910G	CASS STUD CBL ASSY 1"	WIRE			138656													4



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 Customer PO: TTI-MOTORCYC
 BOL Number: 80154 Ship Date: 6/12/2020
 Document #: 1
 Shipped To: TX
 Use State: TX



Qty	Part #	Description	Spec	CL	TV	Heat Code/Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW	
8	19481G	C3X5#X6-8" RUBRAIL	A-36			3077310	55,400	77,200	32.0	0.170	0.560	0.013	0.039	0.210	0.330	0.002	0.090	0.017	4	
	19481G		A-36			3086787	56,100	76,000	29.0	0.150	0.630	0.013	0.035	0.210	0.320	0.000	0.130	0.000	4	
4	20207G	12/94.5#-HOLE ANCHIS	RHC	2	L13818		62,830	81,430	27.2	0.200	0.750	0.009	0.002	0.020	0.140	0.000	0.050	0.002	4	
			M-180	A	2	230046	62,160	80,260	26.9	0.190	0.720	0.014	0.004	0.010	0.120	0.000	0.070	0.001	4	
			M-180	A	2	230050	57,040	77,590	26.9	0.180	0.720	0.010	0.004	0.020	0.110	0.000	0.060	0.002	4	
			M-180	A	2	231186	55,080	78,060	25.3	0.180	0.720	0.014	0.004	0.010	0.110	0.000	0.070	0.008	4	
			M-180	A	2	231187	59,830	82,260	22.6	0.190	0.740	0.010	0.002	0.020	0.120	0.000	0.050	0.002	4	
			M-180	A	2	231188	59,500	81,190	23.6	0.190	0.700	0.014	0.004	0.010	0.110	0.000	0.060	0.002	4	
			M-180	A	2	231189	64,500	86,000	19.7	0.200	0.720	0.015	0.002	0.030	0.050	0.001	0.060	0.001	4	
			M-180	A	2	A89864	60,600	83,000	22.1	0.200	0.680	0.008	0.003	0.030	0.060	0.001	0.050	0.001	4	
			M-180	A	2	C87743	56,880	76,080	28.9	0.190	0.730	0.013	0.004	0.020	0.120	0.000	0.060	0.008	4	
			M-180	B	2	228145	62,200	79,510	28.2	0.190	0.730	0.012	0.004	0.020	0.100	0.000	0.070	0.000	4	
			M-180	B	2	229086														
			M-180	B	2	F12320														
20207G			M-180	A	2	210130	62,400	84,900	25.0	0.230	1.000	0.010	0.001	0.030	0.140	0.000	0.050	0.004	4	
			M-180	A	2	210131	59,500	83,400	26.0	0.230	1.000	0.010	0.001	0.030	0.140	0.000	0.060	0.004	4	
			M-180	A	2	2200771	65,100	88,400	20.0	0.210	0.750	0.013	0.011	0.040	0.170	0.000	0.060	0.003	4	
			M-180	A	2	2200772	70,000	90,200	22.0	0.220	0.770	0.011	0.001	0.030	0.160	0.000	0.060	0.003	4	
			M-180	A	2	2200773	65,000	85,300	23.0	0.220	0.770	0.012	0.003	0.030	0.160	0.000	0.060	0.003	4	
			M-180	A	2	2201642	57,900	73,200	23.0	0.230	0.960	0.008	0.002	0.020	0.140	0.000	0.050	0.004	4	
			M-180	A	2	2201643	60,400	84,500	24.0	0.230	1.000	0.010	0.001	0.020	0.140	0.000	0.050	0.004	4	
			RHC	2	L12019															
20207G			M-180	A	2	238622	61,950	81,070	23.2	0.180	0.720	0.011	0.004	0.020	0.140	0.000	0.070	0.002	4	



Certified Analysis

Trinity Highway Products LLC
 2548 N.E. 28th St.
 Ft Worth (THP), TX 76111 Phn:(817) 665-1499
 Customer: SAMPLES, TESTING MATERIALS
 2525 STEMMONS FRWY
 DALLAS, TX 75207
 Project: MOTORCYCLE TEST

Order Number: 1325977 Prod Ln Grp: 3-Guardrail (Dom)
 Customer PO: TTI - MOTORCYC
 BOL Number: 80154 Ship Date: 6/12/2020
 Document #: 1
 Shipped To: TX
 Use State: TX

As of: 6/12/20



Qty	Part #	Description	Spec	CL	TY	Heat Code/Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW	
4	36120A	DAT-31-TX-HDW-CAN	A-36	A	2	4178841	50,500	70,300	32.0	0.200	0.400	0.019	0.002	0.030	0.050	0.001	0.060	0.001	4	
	36120A		HW			31654														
	36120A		A307-4500			883669-4														4
	36120A		A-36			1100008623	58,600	60,100	21.0	0.130	0.820	0.022	0.020	0.212	0.310	0.000	0.190	0.057	4	
	36120A		HW			025689														
	36120A		HW			025689														
	36120A		A-36			91639C	43,000	67,000	31.0	0.220	1.000	0.017	0.004	0.009	0.030	0.000	0.050	0.000	4	
	36120A		A-500			B919187	59,000	65,500	28.0	0.070	0.350	0.010	0.004	0.020	0.060	0.000	0.060	0.001	4	
	36120A		A-36			1053561	60,000	77,100	23.0	0.160	0.750	0.018	0.024	0.180	0.330	0.001	0.200	0.032	4	
	36120A		F844-3300			P39261 R73305-01														4
	36120A		FAST			20-42-004														4
	36120A		A307-3360			906581-5														4



Certified Analysis

Trinity Highway Products LLC
 2548 N.E. 28th St.
 Ft Worth (THP), TX 76111 Phn:(817) 665-1499
 Customer: SAMPLES, TESTING MATERIALS
 2525 STEMMONS FRWY
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Order Number: 1325977 Prod Ln Grp: 3-Guardrail (Dom)
 Customer PO: TTI - MOTORCYC
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Qty	Part #	Description	Spec	CL	TV	Heat Code/Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
36120A			A307-3403			848773-8													4
36120A			A307-3500			914488-4													4
36120A			F844-3900			P38875 R71579-01													4
36120A			A563-3910			P38851 R71907													4
36120A			A-36			2064020	56,500	75,300	28.0	0.140	0.640	0.013	0.021	0.210	0.300	0.000	0.150	0.000	4
8	130896G	60 TUBE SL125X8X6	A-500			811100940	62,100	71,300	34.0	0.050	0.630	0.018	0.006	0.021	0.014	0.000	0.040	0.001	4
8	626079B	WD 3"10 POST	WOOD			1694													

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy QMS-LG-002.
 ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
 ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.
 ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
 ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
 ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)
 FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED



Certified Analysis

Trinity Highway Products LLC
 2548 N.E. 28th St.
 Ft Worth (THP), TX 76111 Phn: (817) 665-1499
 Customer: SAMPLES, TESTING MATERIALS
 2525 STEMMONS FRWY

Order Number: 1325977 Prod Ln Grp: 3-Guardrail (Dom)
 Customer PO: TTI - MOTORCYC
 BOL Number: 80154 Ship Date: 6/12/2020
 Document #: 1



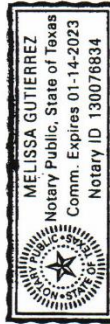
Shipped To: TX
 Use State: TX

Project: MOTORCYCLE TEST

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

State of Texas, County of Tarrant. Sworn and subscribed before me this 12nd day of June, 2020 .

Notary Public: /
 Commission Expires: /



Melissa M. Gutierrez

Trinity Highway Products LLC
 Certified By: *Justin O'Neil*
 Quality Assurance

This Memorandum

is an acknowledgment that a Bill of Lading has been issued and is not the original Bill of Lading, nor a copy or duplicate, covering the property named herein, and is intended solely for filing or record.

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading, at 8-12-20 from TTI the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, classified and destined as shown below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or route, or within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, including the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

Carrier
Shipper's No. 16-80154
S/O No. 16-80154

Consigned to: SAMPLES, TESTING MATERIALS Cust. P.O. TTI MOTORCYCLE Load No.: 45-1
Destination: TTI BLDG 7090 Total Weight: 7,250.04
3100 STATE HWY 47
City: DRIAN State: TX Zip: 77807 Ship: 8/12/2020 9:37:04AM
Arrive: 8/15/20 8:00:00AM TRL#
Contact: MARY GERKE Phone: 930-843-4001 588082
Delivering Carrier: BENNETT Vehicle or Car Initial: TRL# 0610 No. 1610

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.
TRINITY HIGHWAY PRODUCTS, LLC
Per MARY GERKE (Signature of Consignor) LLC
If charges are to be prepaid, write or stamp here, "To Be Prepaid."
TO BE PREPAID
Received \$ _____ to apply in prepayment of the charges on the property described hereon.
Agent or Cashier
Per _____
(The signature here acknowledges only the amount prepaid.)
Charges advanced:

Collect On Delivery: C.O.D. charge Shipper
\$ _____ and remit to: _____ to be paid by Consignee
Street _____ City _____ State _____

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	Col.	No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	Col.
Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. QMS-LG-002.											
Project Info: MOTORCYCLE TEST											
LD Comments:											
52	11G	12/12/6/3/1.5/5									
4	850G	12/BUFFER/ROLLED									
4	3000G	CBL 3/4X6/6/DBL SWG/NOHW									
104	3300G	WASHER, FLAT, 5/8 R, TY B, G									
804	3340G	5/8" GR HEX NUT									
700	3360G	5/8"X1.25" GR BOLT									
104	3580G	5/8"X1.8" GR BOLT A307									
12	3900G	1" ROUND WASHER F844									
24	3910G	1" HEX NUT A.563									
5	5910G	CASS STUD CBL ASSY 1" RT									
*Back Ordered: 7											
8	19481G	3X5/8X6'-8" RUBRAIL									
4	20207G	12/9/4 5/8-HOLE ANCH/S									
4	36120A	DAT-31-TX-HDW-CAN									
6	130896G	6"0 TUBE SL 125X82X6									
8	626079B	WD 3'10 POST 5.25X7.25CRT									

SPECIAL INSTRUCTIONS:
SHIPPER LOAD - CONSIGNEE UNLOAD 16-80154 Total Weight 3
*If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding _____
SHIPPER OR AGENT I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof. 8/12/20 per CONSIGNEE OR AGENT Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions.
ORIGIN SIGN HERE Mary Gerke DATE 8/12/20 DESTINATION SIGN HERE Bennett DATE / / AM. PM.
AGENT OR DRIVER This shipment received subject to exceptions as noted and according to the terms and conditions hereof. (SIGN HERE) DATE DRIVER NO

Permanent post-office address of shipper, FRI 609-RF (R 10/93) (This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.) **CONSIGNEE/CUSTOMER COPY**



Certified Analysis

Trinity Highway Products LLC
 2548 N.E. 28th St.
 Ft Worth (THP), TX 76111 Phn:(817) 665-1499
 Customer: SAMPLES, TESTING MATERIALS
 2525 STEMMONS FRWY
 DALLAS, TX 75207
 Project: MOTORCYCLE TEST

Order Number: 1325977 Prod L.n Grp: 3-Guardrail (Dom)
 Customer PO: TTI - MOTORCYC
 BOL Number: 80154 Ship Date: 6/12/2020
 Document #: 1
 Shipped To: TX
 Use State: TX

As of: 6/12/20



Qty	Part #	Description	Spec	CL	TV	Heat Code/Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW	
52	11G	12/12/63T.5/S		2	F12120															
	M-180	A	2	2100151		58,800	81,000	25.0	0.190	0.780	0.008	0.002	0.020	0.100	0.000	0.050	0.004	4		
	M-180	A	2	2100151		58,800	81,000	25.0	0.190	0.780	0.008	0.002	0.020	0.100	0.001	0.050	0.004	4		
	M-180	A	2	2101129		56,500	82,100	23.0	0.230	1.010	0.009	0.001	0.030	0.130	0.000	0.050	0.004	4		
	M-180	A	2	2101130		62,400	84,900	25.0	0.230	1.000	0.010	0.001	0.030	0.140	0.000	0.050	0.004	4		
	M-180	A	2	2200773		65,000	85,300	23.0	0.220	0.770	0.012	0.003	0.030	0.160	0.000	0.060	0.003	4		
	M-180	A	2	2201642		57,900	73,200	23.0	0.230	0.980	0.008	0.002	0.020	0.140	0.000	0.050	0.004	4		
4	850G	12/BUFFER/ROLLED	M-180	A	2	216690	65,000	83,340	22.8	0.190	0.730	0.012	0.003	0.020	0.100	0.000	0.070	0.002	4	
	850G		M-180	A	2	11719850	51,600	62,400	33.0	0.050	0.520	0.009	0.003	0.040	0.100	0.001	0.050	0.002	4	
	850G		M-180	A	2	31847970	48,400	62,300	35.0	0.060	0.450	0.015	0.001	0.030	0.090	0.000	0.070	0.002	4	
4	3000G	CBL.3/4X6/6/DBL	WIRE			348066													4	
104	3300G	WASHER,FLAT,5/8 R,TY	F844-3300			P39261 R73305-01													4	
804	3340G	5/8" GR HEX NUT	FAST			20-42-004													4	
700	3360G	5/8"X1.25" GR BOLT	A307-3360			906581-5													4	
104	3580G	5/8"X18" GR BOLT A307	A307-3580			32870													4	
12	3900G	1" ROUND WASHER F844	F844-3900			P38875 R71579-01													4	
24	3910G	1" HEX NUT A563	A563-3910			P38851 R71907													4	
5	5910G	CASS STUD CBL ASSY 1"	WIRE			138656													4	



Certified Analysis

Trinity Highway Products LLC
 2548 N.E. 28th St.
 Ft Worth (THP), TX 76111 Phn:(817) 665-1499
 Customer: SAMPLES, TESTING MATERIALS
 2525 STEMMONS FRWY
 DALLAS, TX 75207
 Project: MOTORCYCLE TEST

Order Number: 1325977 Prod Ln Grp: 3-Guardrail (Dom)
 Customer PO: TTI-MOTORCYC
 BOL Number: 80154 Ship Date: 6/12/2020
 Document #: 1
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As of: 6/12/20



Qty	Part #	Description	Spec	CL	TV	Heat Code/Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
8	19481G	C3X5#X6-8" RUBRAIL	A-36			3077310	55,400	77,200	32.0	0.170	0.560	0.013	0.039	0.210	0.330	0.002	0.090	0.017	4
	19481G		A-36			3086787	56,100	76,000	29.0	0.150	0.630	0.013	0.035	0.210	0.320	0.000	0.130	0.000	4
4	20207G	12/94.5/8-HOLE ANCHUS	RHC	2	L13818		62,830	81,430	27.2	0.200	0.750	0.009	0.002	0.020	0.140	0.000	0.050	0.002	4
			M-180	A	2	230046	62,160	80,260	26.9	0.190	0.720	0.014	0.004	0.010	0.120	0.000	0.070	0.001	4
			M-180	A	2	230050	57,040	77,590	26.9	0.180	0.720	0.010	0.004	0.020	0.110	0.000	0.060	0.002	4
			M-180	A	2	231186	55,080	78,060	25.3	0.180	0.720	0.014	0.004	0.010	0.110	0.000	0.070	0.008	4
			M-180	A	2	231187	59,830	82,260	22.6	0.190	0.740	0.010	0.002	0.020	0.120	0.000	0.050	0.002	4
			M-180	A	2	231188	59,500	81,190	23.6	0.190	0.700	0.014	0.004	0.010	0.110	0.000	0.060	0.002	4
			M-180	A	2	231189	64,500	86,000	19.7	0.200	0.720	0.015	0.002	0.030	0.050	0.001	0.060	0.001	4
			M-180	A	2	A89864	60,600	83,000	22.1	0.200	0.680	0.008	0.003	0.030	0.060	0.001	0.050	0.001	4
			M-180	A	2	C87743	56,880	76,080	28.9	0.190	0.730	0.013	0.004	0.020	0.120	0.000	0.060	0.008	4
			M-180	B	2	228145	62,200	79,510	28.2	0.190	0.730	0.012	0.004	0.020	0.100	0.000	0.070	0.000	4
			M-180	B	2	229086													
			M-180	B	2	F12320													
20207G			M-180	A	2	210130	62,400	84,900	25.0	0.230	1.000	0.010	0.001	0.030	0.140	0.000	0.050	0.004	4
			M-180	A	2	210131	59,500	83,400	26.0	0.230	1.000	0.010	0.001	0.030	0.140	0.000	0.060	0.004	4
			M-180	A	2	2200771	65,100	88,400	20.0	0.210	0.750	0.013	0.011	0.040	0.170	0.000	0.060	0.003	4
			M-180	A	2	2200772	70,000	90,200	22.0	0.220	0.770	0.011	0.001	0.030	0.160	0.000	0.060	0.003	4
			M-180	A	2	2200773	65,000	85,300	23.0	0.220	0.770	0.012	0.003	0.030	0.160	0.000	0.060	0.003	4
			M-180	A	2	2201642	57,900	73,200	23.0	0.230	0.960	0.008	0.002	0.020	0.140	0.000	0.050	0.004	4
			M-180	A	2	2201643	60,400	84,500	24.0	0.230	1.000	0.010	0.001	0.020	0.140	0.000	0.050	0.004	4
			RHC	2	L12019														
20207G			M-180	A	2	238622	61,950	81,070	23.2	0.180	0.720	0.011	0.004	0.020	0.140	0.000	0.070	0.002	4



Certified Analysis

Trinity Highway Products LLC
 2548 N.E. 28th St.
 Ft Worth (THP), TX 76111 Phn:(817) 665-1499
 Customer: SAMPLES, TESTING MATERIALS
 2525 STEMMONS FRWY
 DALLAS, TX 75207
 Project: MOTORCYCLE TEST

Order Number: 1325977 Prod Ln Grp: 3-Guardrail (Dom)
 Customer PO: TTI - MOTORCYC
 BOL Number: 80154 Ship Date: 6/12/2020
 Document #: 1
 Shipped To: TX
 Use State: TX

As of: 6/12/20



Qty	Part #	Description	Spec	CL	TY	Heat Code/Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW	
4	36120A	DAT-31-TX-HDW-CAN	A-36	A	2	4178841	50,500	70,300	32.0	0.200	0.400	0.019	0.002	0.030	0.050	0.001	0.060	0.001	4	
	36120A		HW			31654														
	36120A		A307-4500			883669-4														4
	36120A		A-36			1100008623	58,600	60,100	21.0	0.130	0.820	0.022	0.020	0.212	0.310	0.000	0.190	0.057	4	
	36120A		HW			025689														
	36120A		HW			025689														
	36120A		A-36			91639C	43,000	67,000	31.0	0.220	1.000	0.017	0.004	0.009	0.030	0.000	0.050	0.000	4	
	36120A		A-500			B919187	59,000	65,500	28.0	0.070	0.350	0.010	0.004	0.020	0.060	0.000	0.060	0.001	4	
	36120A		A-36			1053561	60,000	77,100	23.0	0.160	0.750	0.018	0.024	0.180	0.330	0.001	0.200	0.032	4	
	36120A		F844-3300			P39261 R73305-01														4
	36120A		FAST			20-42-004														4
	36120A		A307-3360			906581-5														4



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Trinity Highway Products LLC
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Qty	Part #	Description	Spec	CL	TV	Heat Code/Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
36120A			A307-3403			848773-8													4
36120A			A307-3500			914488-4													4
36120A			F844-3900			P38875 R71579-01													4
36120A			A563-3910			P38851 R71907													4
36120A			A-36			2064020	56,500	75,300	28.0	0.140	0.640	0.013	0.021	0.210	0.300	0.000	0.150	0.000	4
8	130896G	60 TUBE SL125X8X6	A-500			811100940	62,100	71,300	34.0	0.050	0.630	0.018	0.006	0.021	0.014	0.000	0.040	0.001	4
8	626079B	WD 3"10 POST	WOOD			1694													

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy QMS-LG-002.
 ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
 ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.
 ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
 ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
 ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)
 FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED



Certified Analysis

Trinity Highway Products LLC
 2548 N.E. 28th St.
 Ft Worth (THP), TX 76111 Phn: (817) 665-1499
 Customer: SAMPLES, TESTING MATERIALS
 2525 STEMMONS FRWY

Order Number: 1325977 Prod Ln Grp: 3-Guardrail (Dom)
 Customer PO: TTI - MOTORCYC
 BOL Number: 80154 Ship Date: 6/12/2020
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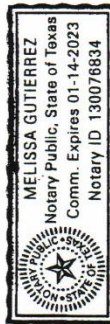
Shipped To: TX
 Use State: TX

Project: MOTORCYCLE TEST
 DALLAS, TX 75207

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

State of Texas, County of Tarrant. Sworn and subscribed before me this 12nd day of June, 2020 .

Notary Public: /
 Commission Expires: /



Melissa M. Gutierrez

Trinity Highway Products LLC
 Certified By: *Justin O'Neil*
 Quality Assurance

APPENDIX C. MASH TEST 3-10 (CRASH TEST 469940-03-1)

C.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2020-08-05 Test No.: 469940-03-1 VIN No.: 3N1CN7AP3EL835901

Year: 2014 Make: NISSAN Model: VERSA

Tire Inflation Pressure: 36 PSI Odometer: 125624 Tire Size: 185 65R 15

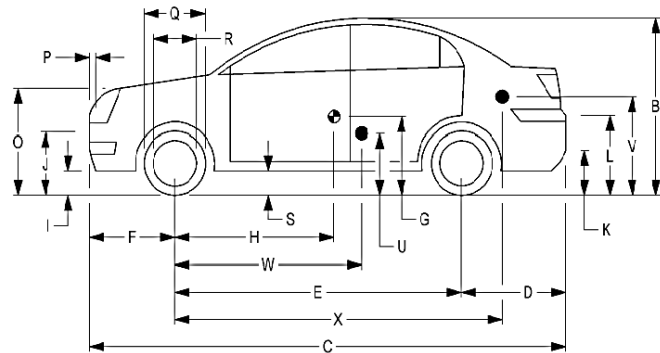
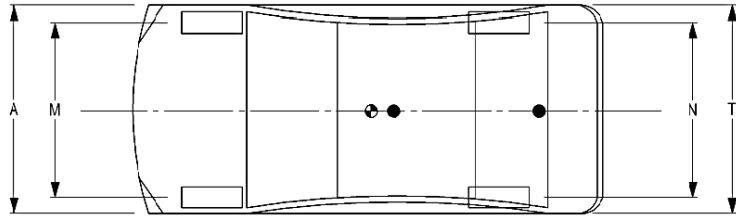
Describe any damage to the vehicle prior to test: None

• 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>40.20</u>	M <u>58.30</u>	R <u>16.25</u>	W <u>40.20</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>22.25</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>0.00</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

GWR Ratings:	Mass: lb	Curb	Test Inertial	Gross Static
Front <u>1750</u>	M _{front} <u>1461</u>	<u>1461</u>	<u>1482</u>	<u>1567</u>
Back <u>1687</u>	M _{rear} <u>964</u>	<u>964</u>	<u>958</u>	<u>1038</u>
Total <u>3389</u>	M _{Total} <u>2425</u>	<u>2425</u>	<u>2440</u>	<u>2605</u>

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

Mass Distribution:
 lb LF: 746 RF: 736 LR: 508 RR: 450

Figure C.1. Vehicle Properties for Test 469940-03-1.

Date: 2020-08-05 Test No.: 469940-03-1 VIN No.: 3N1CNTAP3EL835901
 Year: 2014 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	Front plane at bumper ht	15	5	16	-	-	-	-	-	-	21
2	Side plane at bumper ht	15	8	32	-	-	-	-	-	-	64
	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.

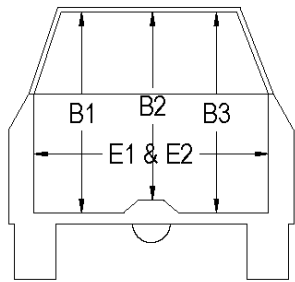
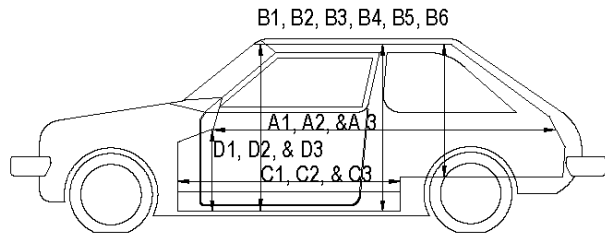
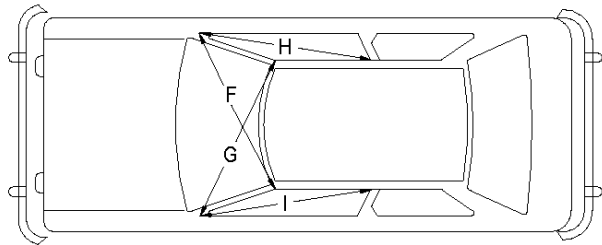
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 469940-03-1.

Date: 2020-08-05 Test No.: 469940-03-1 VIN No.: 3N1CNTAP3EL835901
 Year: 2014 Make: NISSAN Model: VERSA



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	75.00	75.00	0.00
A2	74.00	74.00	0.00
A3	74.00	74.00	0.00
B1	43.00	43.00	0.00
B2	37.00	37.00	0.00
B3	43.00	43.00	0.00
B4	46.50	46.50	0.00
B5	42.50	42.50	0.00
B6	46.50	46.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	12.50	12.50	0.00
D2	0.00	0.00	0.00
D3	10.00	10.00	0.00
E1	45.00	45.00	0.00
E2	48.75	48.75	0.00
F	47.50	47.50	0.00
G	47.50	47.50	0.00
H	39.00	39.00	0.00
I	39.00	39.00	0.00
J*	48.50	48.50	0.00

*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 469940-03-1.

C.2. SEQUENTIAL PHOTOGRAPHS

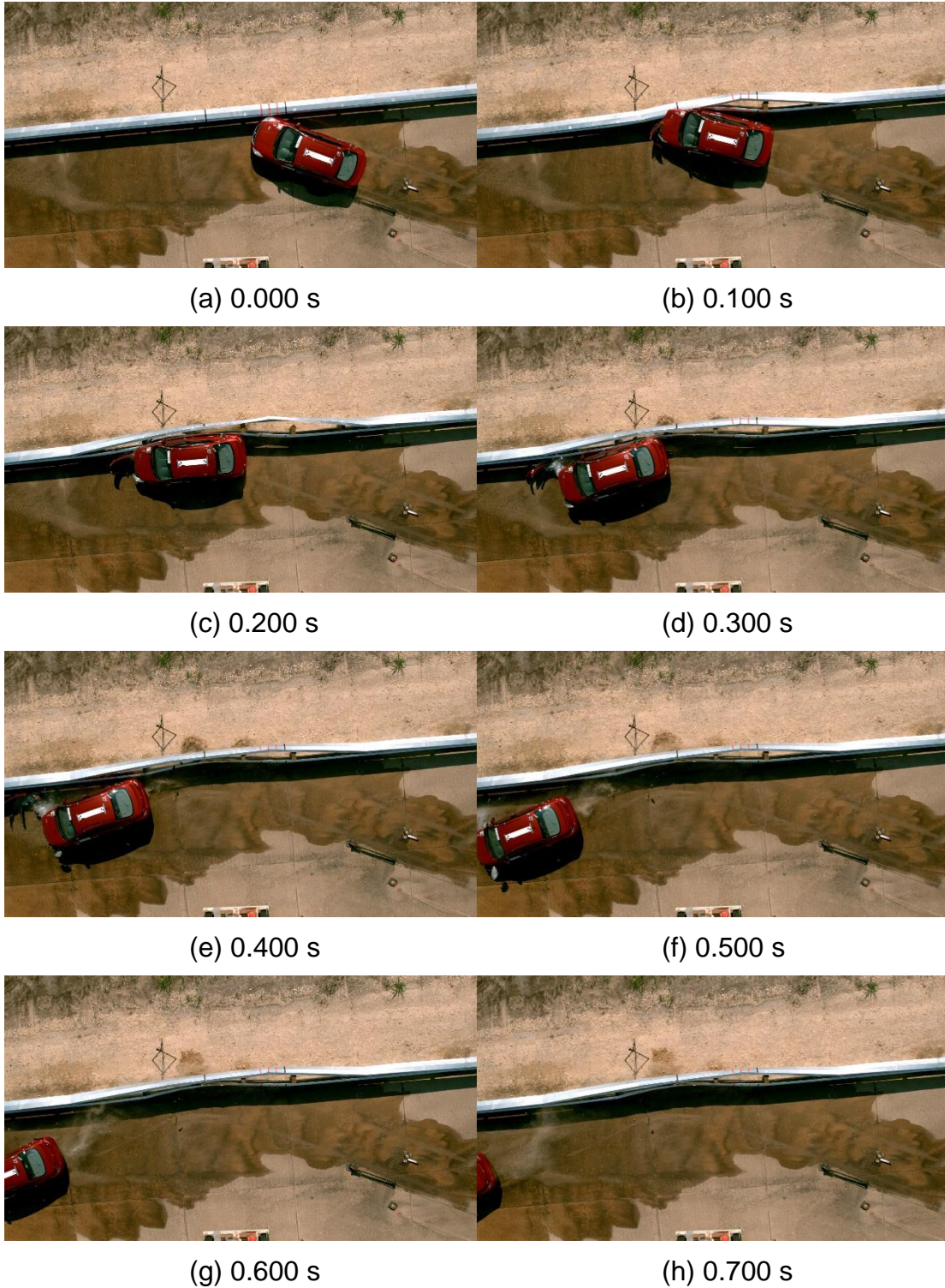


Figure C.4. Sequential Photographs for Test 469940-03-1 (Overhead Views).



(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 469940-03-1 (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

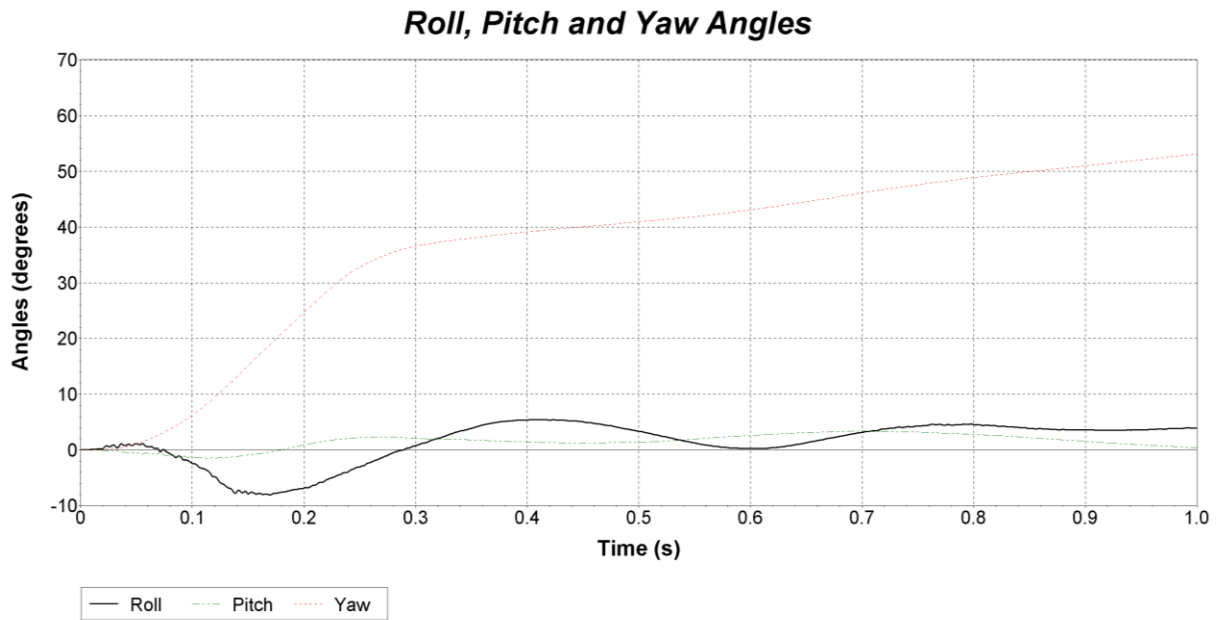


(g) 0.600 s

(h) 0.700 s

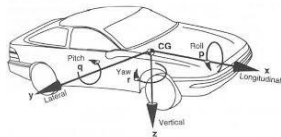
Figure C.6. Sequential Photographs for Test 469940-03-1 (Rear Views).

C.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 469940-03-1
 Test Standard Test Number: *MASH* Test 3-10
 Test Article: Enhanced Motorcycle Guard Fence System
 Test Vehicle: 2014 Nissan Versa
 Inertial Mass: 2440 lb
 Gross Mass: 2605 lb
 Impact Speed: 63.1 mi/h
 Impact Angle: 25.1°

Figure C.7. Vehicle Angular Displacements for Test 469940-03-1.

C.4. VEHICLE ACCELERATIONS

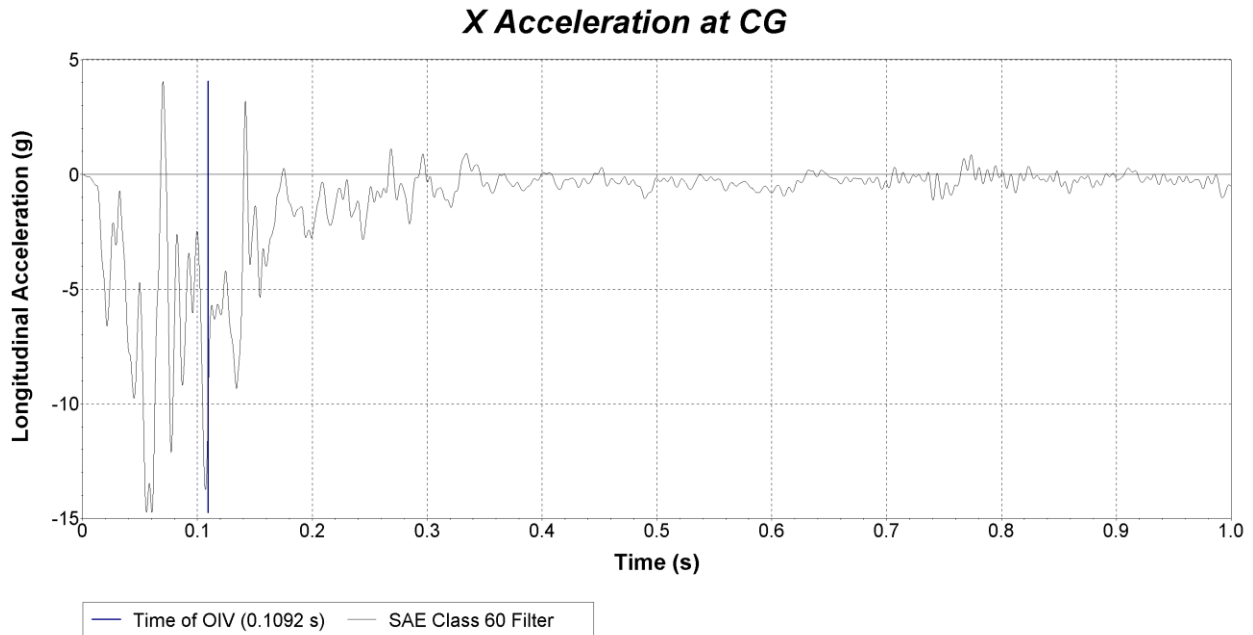


Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test 469940-03-1 (Accelerometer Located at Center of Gravity).

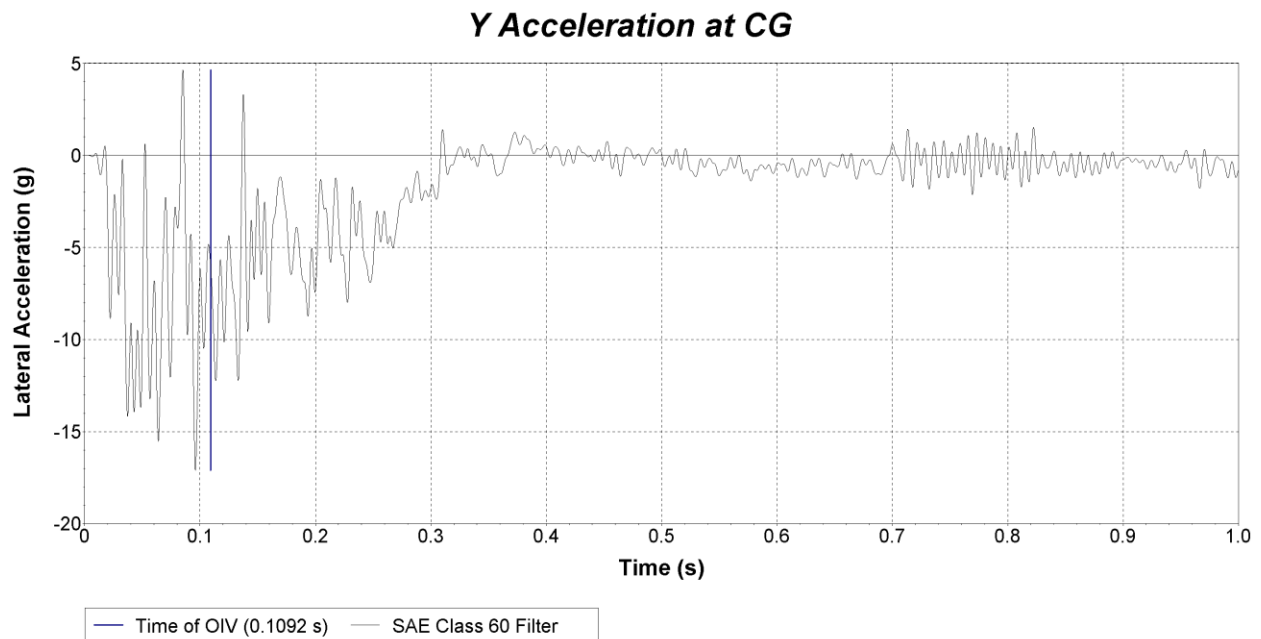


Figure C.9. Vehicle Lateral Accelerometer Trace for Test 469940-03-1 (Accelerometer Located at Center of Gravity).

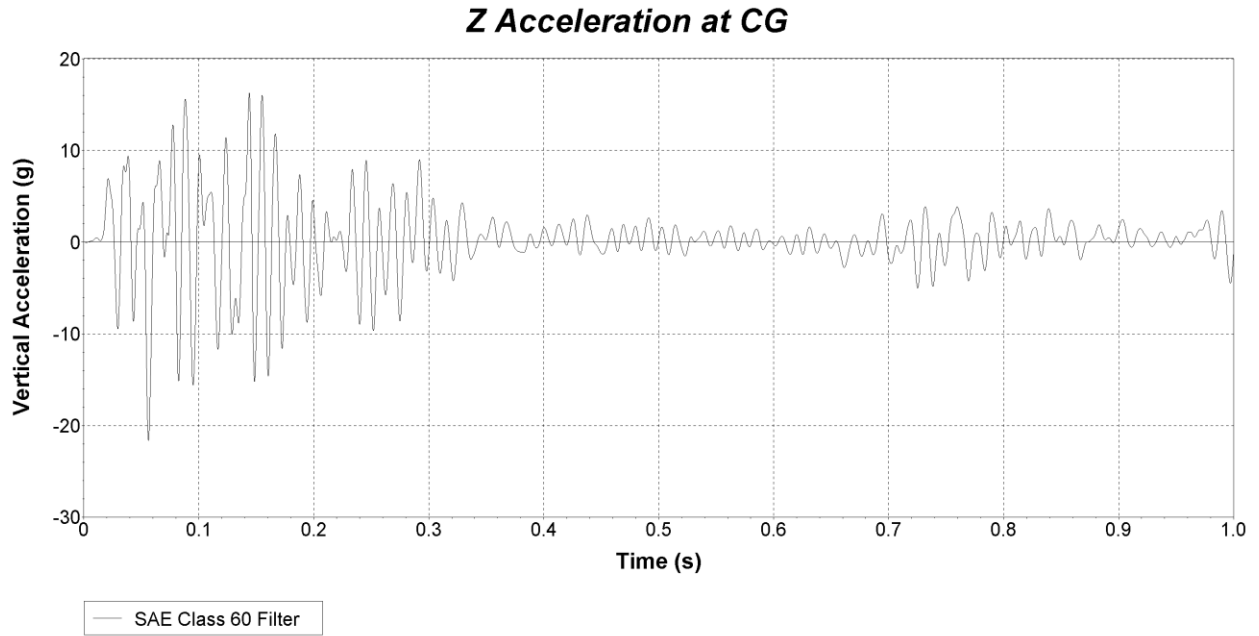


Figure C.10. Vehicle Vertical Accelerometer Trace for Test 469940-03-1 (Accelerometer Located at Center of Gravity).

APPENDIX D. MASH TEST 3-11 (CRASH TEST 469940-03-2)

D.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2020-8-7 Test No.: 469940-03-2 VIN No.: 1C6RR6FTXES122398
 Year: 2014 Make: RAM Model: 1500
 Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi
 Tread Type: Highway Odometer: 164069
 Note any damage to the vehicle prior to test: None

• Denotes accelerometer location.

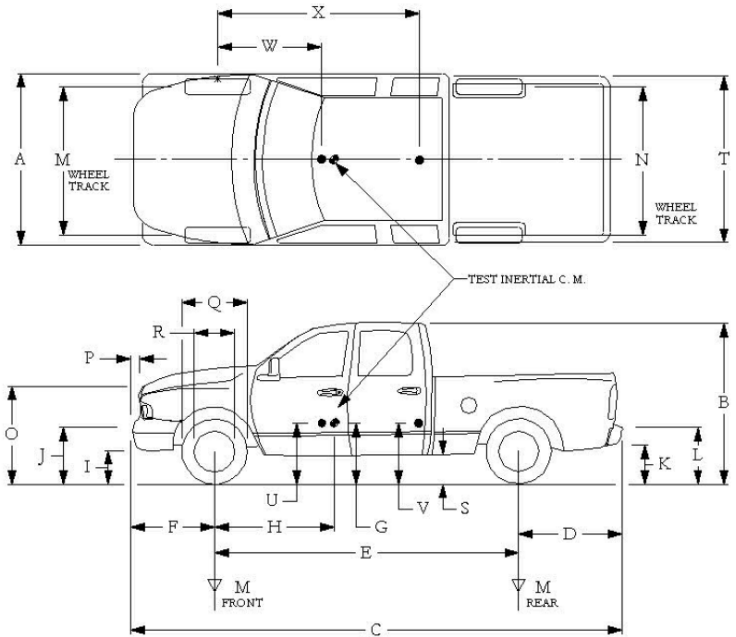
NOTES: None

Engine Type: V-8
 Engine CID: 5.7 L

Transmission Type:
 Auto or Manual
 FWD RWD 4WD

Optional Equipment:
None

Dummy Data:
 Type: NONE
 Mass: 0 lb
 Seat Position: _____



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.80	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.36	M	68.50	R	18.00	W	61.30
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		
Wheel Center Height Front		14.75	Wheel Well Clearance (Front)		6.00	Bottom Frame Height - Front		12.50	
Wheel Center Height Rear		14.75	Wheel Well Clearance (Rear)		9.25	Bottom Frame Height - Rear		22.50	

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

GVWR Ratings:	Mass: lb	Curb	Test Inertial	Gross Static
Front	3700	M _{front}	2906	2831
Back	3900	M _{rear}	2080	2195
Total	6700	M _{Total}	4986	5026

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

Mass Distribution:
 lb LF: 1390 RF: 1441 LR: 1124 RR: 1071

Figure D.1. Vehicle Properties for Test 469940-03-2.

Date: 2020-08-07 Test No.: 469940-03-2 VIN No.: 1C6RR6FTXES122398
 Year: 2014 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	Front plane at bmp ht	18	8	30							-24
2	Side plane at bmp ht	18	8	52							70
	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).

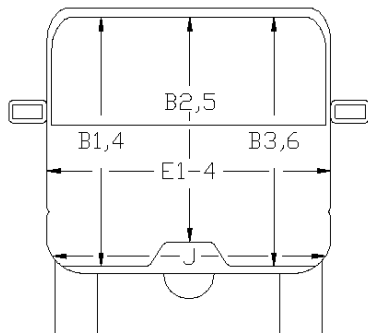
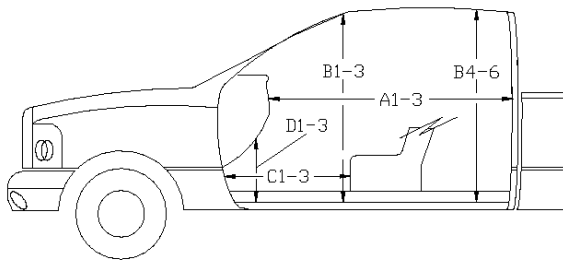
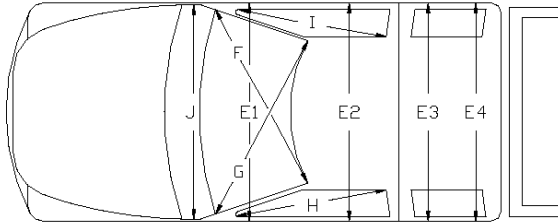
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Figure D.2. Exterior Crush Measurements for Test 469940-03-2.

Date: 2020-08-07 Test No.: 469940-03-2 VIN No.: 1C6RR6FTXES122398
 Year: 2014 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	24.00	-2.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	58.50	0.00
E2	63.50	64.5	1.00
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 469940-03-2.

D.2. SEQUENTIAL PHOTOGRAPHS

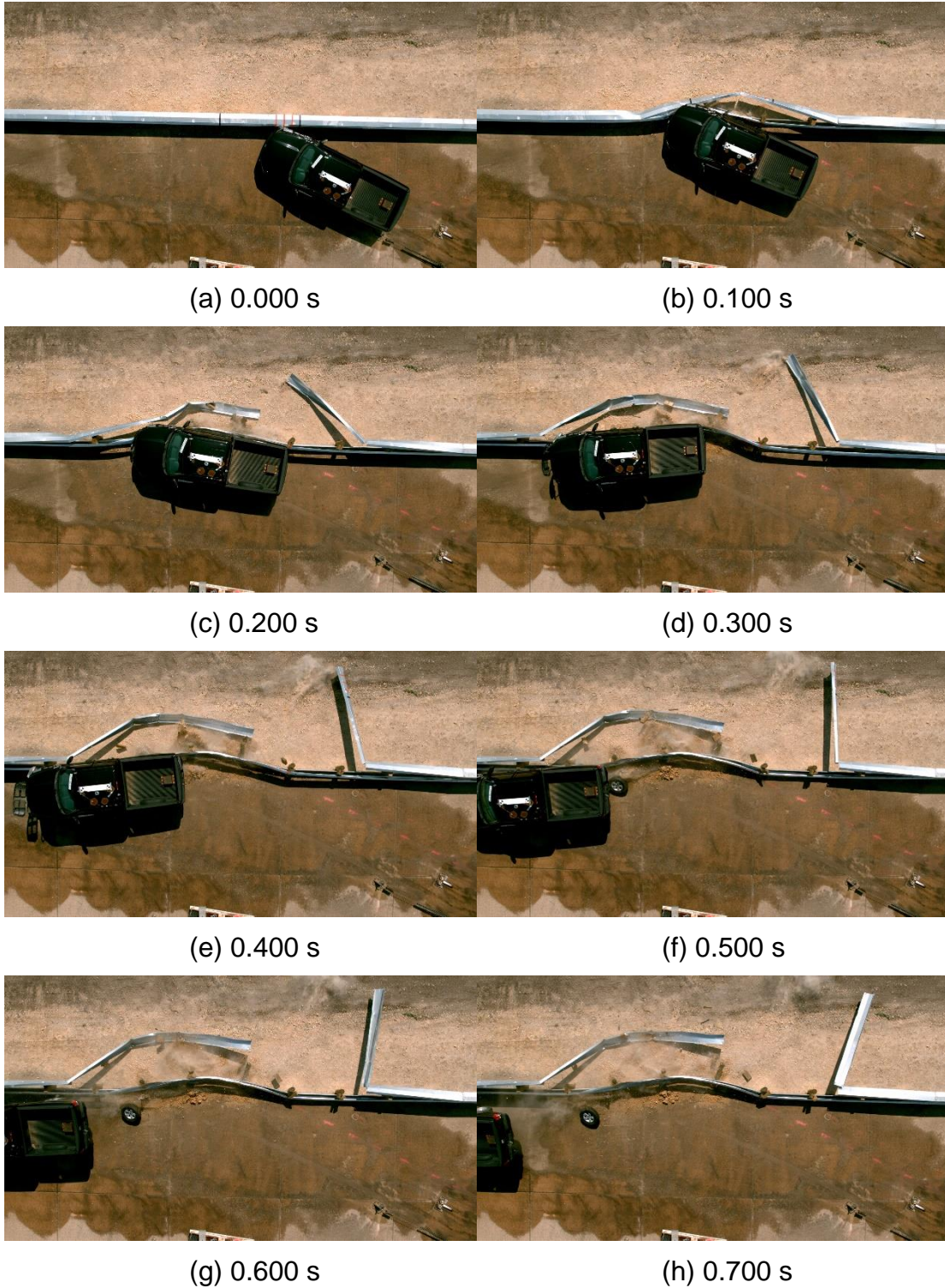


Figure D.4. Sequential Photographs for Test 469940-03-2 (Overhead Views).



(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 469940-03-2 (Frontal Views).



(a) 0.000 s

(b) 0.100 s



(c) 0.200 s

(d) 0.300 s



(e) 0.400 s

(f) 0.500 s

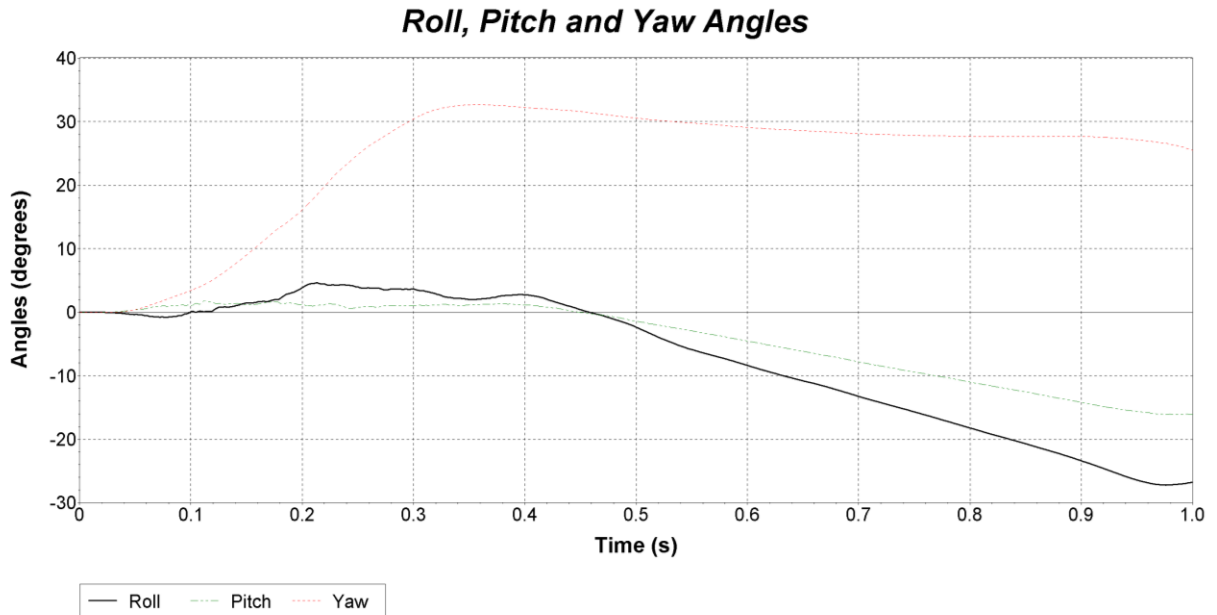


(g) 0.600 s

(h) 0.700 s

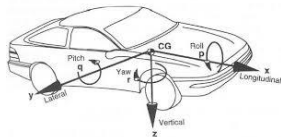
Figure D.6. Sequential Photographs for Test 469940-03-2 (Rear Views).

D.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

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



Test Number: 469940-03-2
 Test Standard Test Number: *MASH* Test 3-11
 Test Article: Enhanced Motorcycle Guard Fence System
 Test Vehicle: 2014 RAM 1500
 Inertial Mass: 5026 lb
 Gross Mass: 5026 lb
 Impact Speed: 63.4 mi/h
 Impact Angle: 24.4°

Figure D.7. Vehicle Angular Displacements for Test 469940-03-2.

D.4. VEHICLE ACCELERATIONS

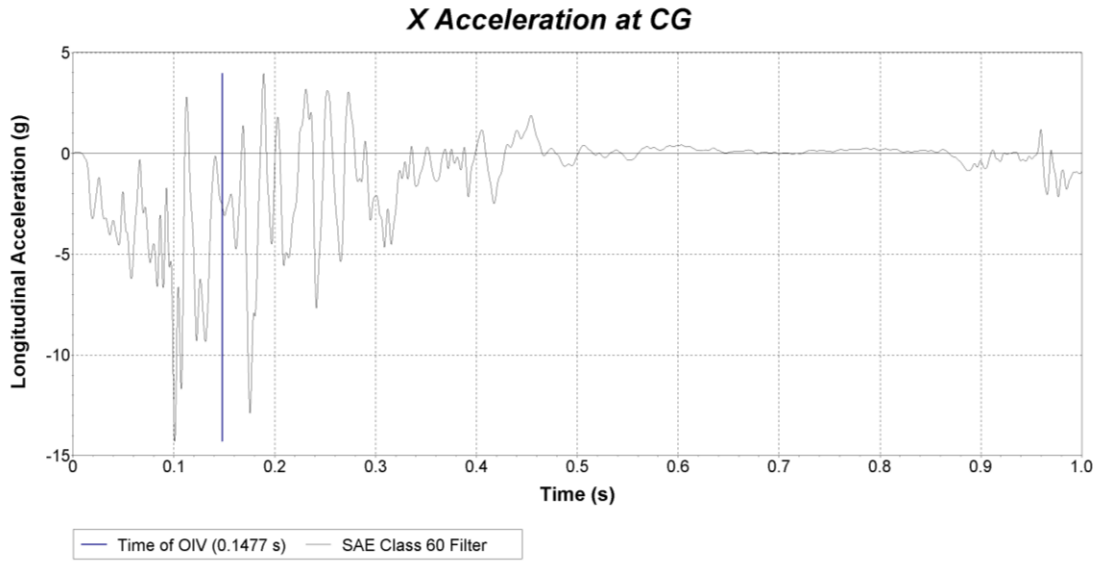


Figure D.8. Vehicle Longitudinal Accelerometer Trace for Test 469940-03-2 (Accelerometer Located at Center of Gravity).

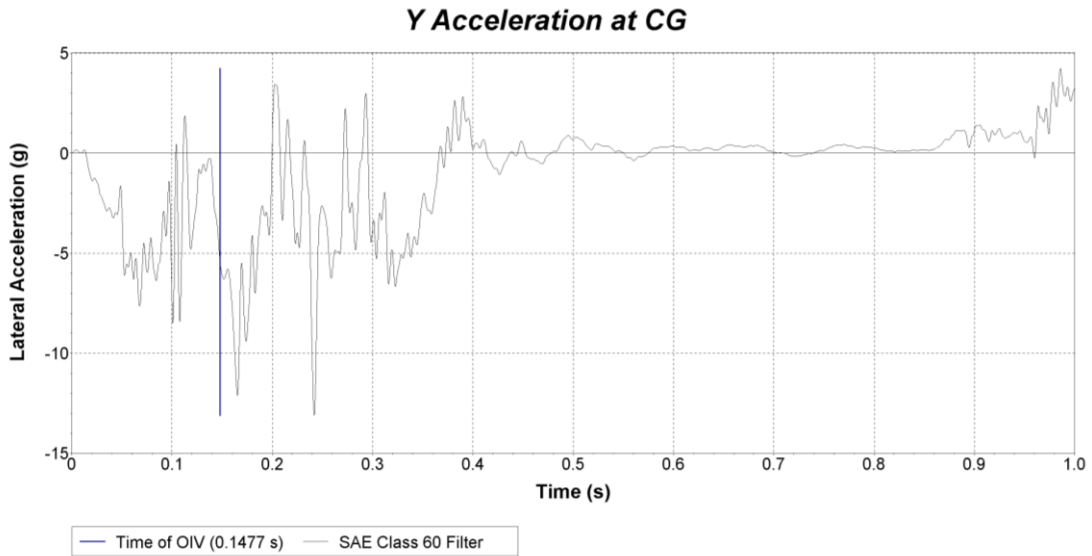


Figure D.9. Vehicle Lateral Accelerometer Trace for Test 469940-03-2 (Accelerometer Located at Center of Gravity).

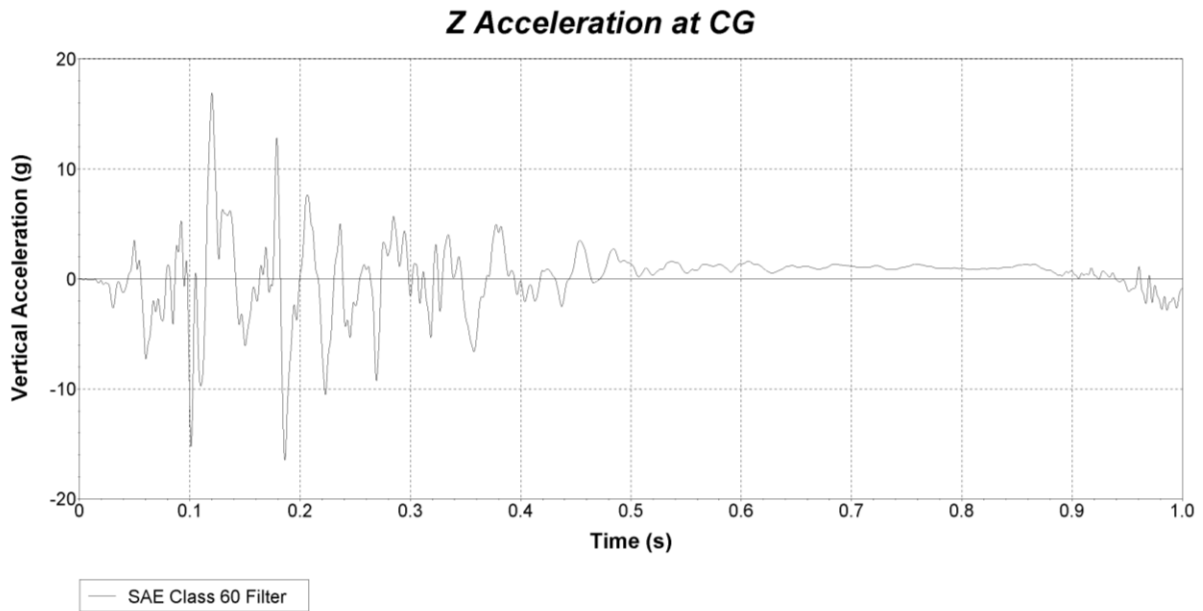


Figure D.10. Vehicle Vertical Accelerometer Trace for Test 469940-03-2 (Accelerometer Located at Center of Gravity).

APPENDIX E. MASH TEST (CRASH TEST 469940-03-3)

E.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2020-8-14 Test No.: 469940-03-3 VIN No.: JKAEXMJ17CDAAO017
 Year: 2012 Make: KAWASAKI Model: 250 NINJA
 Tire Size: FT 110/70 R17 REAR 130 70R17 Tire Inflation Pressure: 28 PSI
 Tread Type: HIGHWAY Odometer: O6772

Note any damage to the vehicle prior to test: _____

• Denotes accelerometer location.

NOTES: _____

Engine Type: 2 CYL
 Engine CID: 249 CC

Transmission Type:
 Auto or Manual
 FWD RWD 4WD

Optional Equipment: _____

Dummy Data:
 Type: _____
 Mass: 190 lb
 Seat Position: _____



Geometry: inches

A	<u>30</u>	C	<u>78.5</u>	E	<u>12.5</u>	G	<u>5</u>
B	<u>45.8</u>		<u>55</u>	F	<u>30.5</u>	H	<u>26.5</u>
Wheel Center Height Front	<u>11.3</u>	Wheel Well Clearance (Front)	<u>1.5</u>	Bottom Frame Height - Front	<u>8</u>		
Wheel Center Height Rear	<u>11.8</u>	Wheel Well Clearance (Rear)	<u>6.75</u>	Bottom Frame Height - Rear	<u>9</u>		

GVWR Ratings:	Mass: lb	Curb	Test Inertial	Gross Static	
Front	<u>265</u>	M_{front}	<u>180</u>	<u>170</u>	<u>240</u>
Back	<u>485</u>	M_{rear}	<u>180</u>	<u>230</u>	<u>360</u>
Total	<u>750</u>	M_{Total}	<u>360</u>	<u>400</u>	<u>600</u>

Mass Distribution:
 lb F: 170 R: 230

Figure E.1. Vehicle Properties for Test 469940-03-3.

E.2. SEQUENTIAL PHOTOGRAPHS

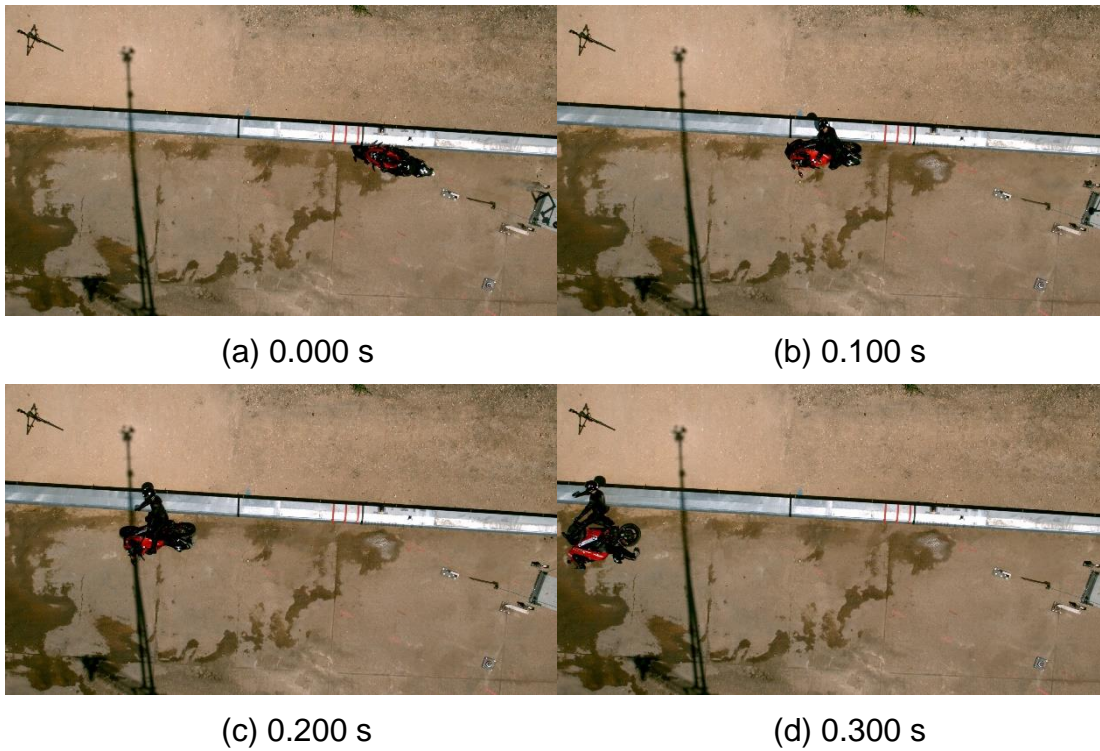


Figure E.2. Sequential Photographs for Test 469940-03-3 (Overhead Views).



(a) 0.000 s

(b) 0.100 s



(c) 0.200 s

(d) 0.300 s



(e) 0.400 s

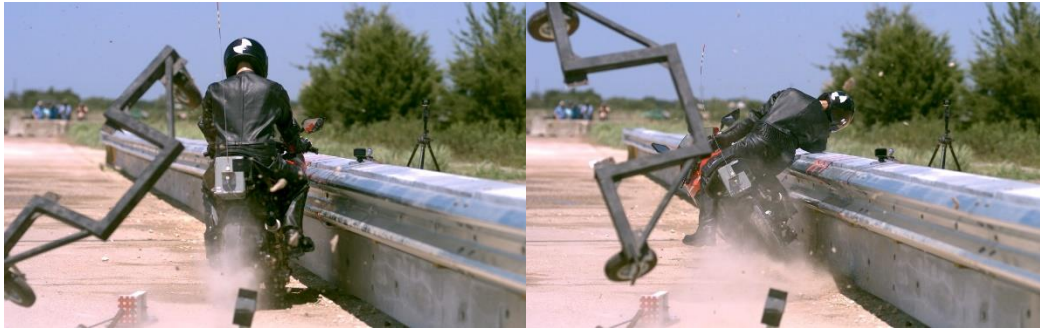
(f) 0.500 s



(g) 0.600 s

(h) 0.700 s

Figure E.3. Sequential Photographs for Test 469940-03-3 (Frontal Views).



(a) 0.000 s

(b) 0.100 s



(c) 0.200 s

(d) 0.300 s



(e) 0.400 s

(f) 0.500 s



(g) 0.600 s

(h) 0.700 s

Figure E.4. Sequential Photographs for Test 469940-03-3 (Rear Views).

APPENDIX F. MASH TEST (CRASH TEST 469940-03-4A)

F.1. SEQUENTIAL PHOTOGRAPHS

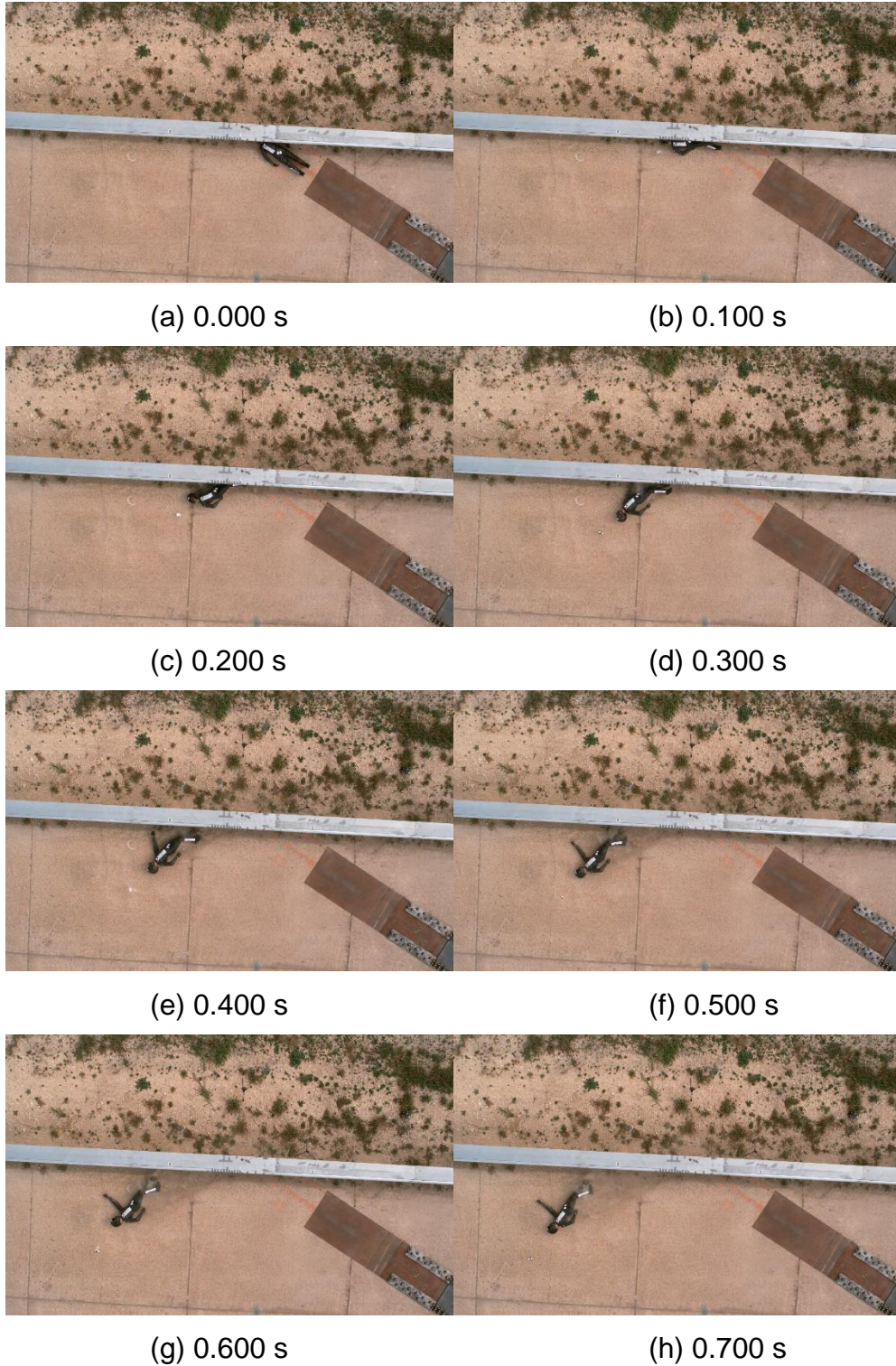


Figure F.1. Sequential Photographs for Test 469940-03-4A (Overhead Views).



(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 F.2. Sequential Photographs for Test 469940-03-4A (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 F.3. Sequential Photographs for Test 469940-03-4A (Rear Views).

APPENDIX G. MASH TEST (CRASH TEST 469942-01-1)

G.1. 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 G.1. Sequential Photographs for Test 469942-01-1 (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 G.2. Sequential Photographs for Test 469942-01-1 (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 G.3. Sequential Photographs for Test 469942-01-1 (Rear Views).

APPENDIX H. MASH TEST (CRASH TEST 469943-01-1A)

H.1. SEQUENTIAL PHOTOGRAPHS

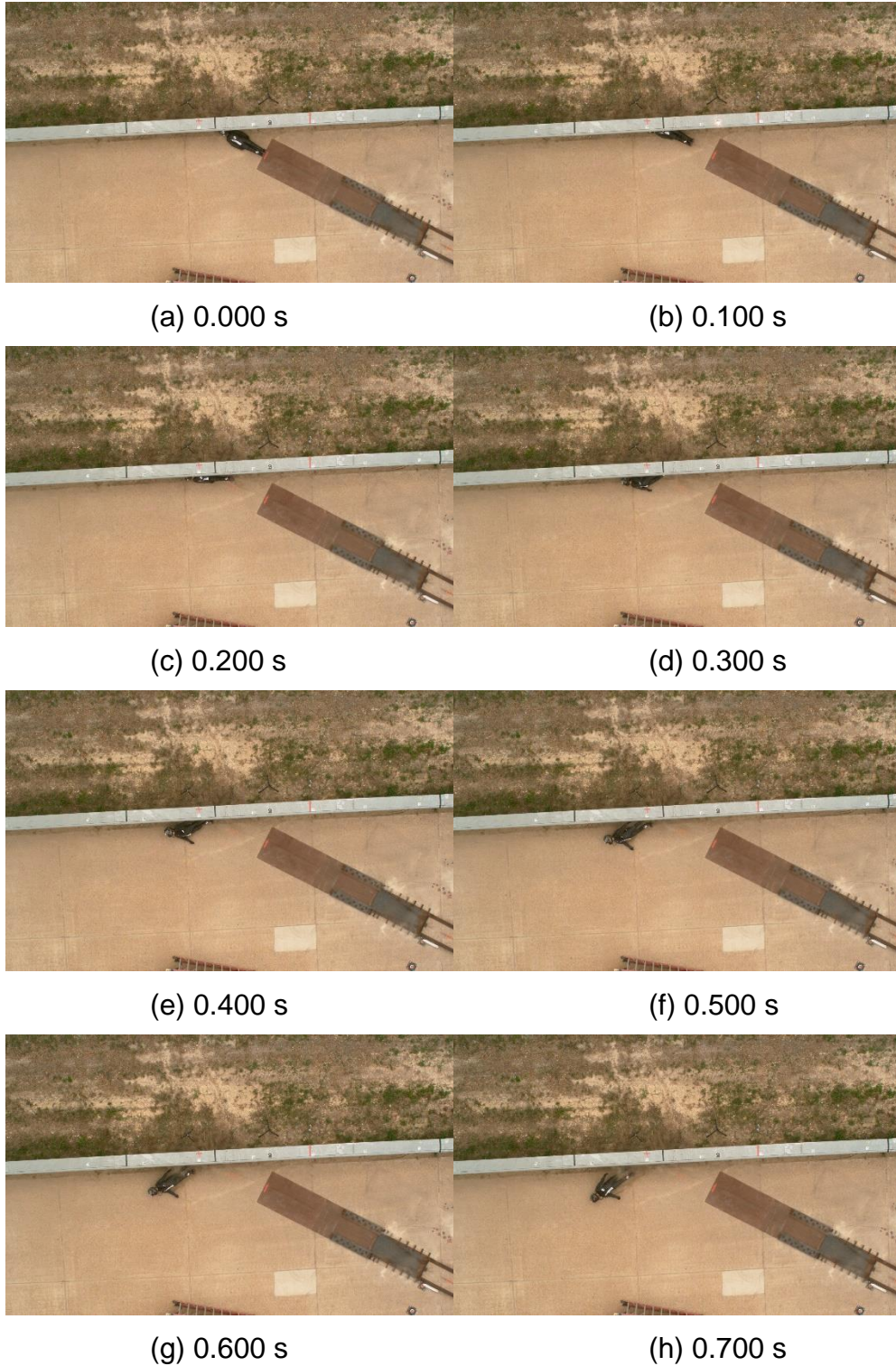


Figure H.1. Sequential Photographs for Test 469943-01-1A (Overhead Views).



(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 H.2. Sequential Photographs for Test 469943-01-1A (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 H.3. Sequential Photographs for Test 469943-01-1A (Rear Views).

APPENDIX I. MASH TEST (CRASH TEST 469943-01-2)

I.1. SEQUENTIAL PHOTOGRAPHS

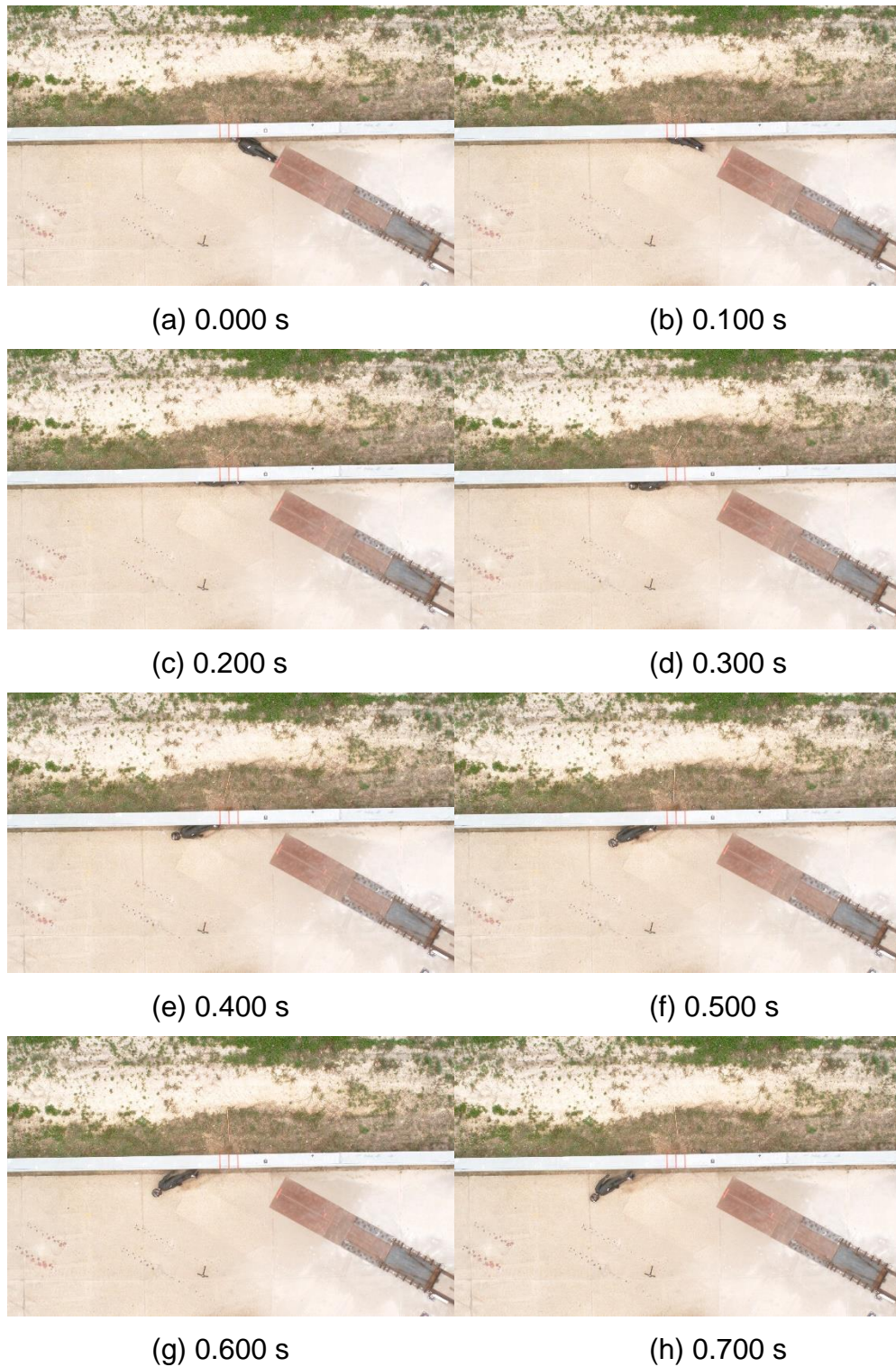


Figure I.1. Sequential Photographs for Test 469943-01-2 (Overhead Views).



(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 I.2. Sequential Photographs for Test 469943-01-2 (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 I.3. Sequential Photographs for Test 469943-01-2 (Rear Views).

APPENDIX J. MASH TEST 3-10 (CRASH TEST 469943-01-3)

J.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2023-04-18 Test No.: 469943-01-3 VIN No.: 3N1CN7APXHL842803

Year: 2017 Make: Nissan Model: Versa

Tire Inflation Pressure: 36 PSI Odometer: 104990 Tire Size: P185/65R15

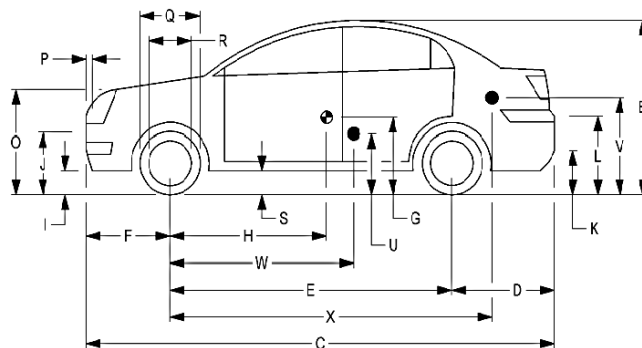
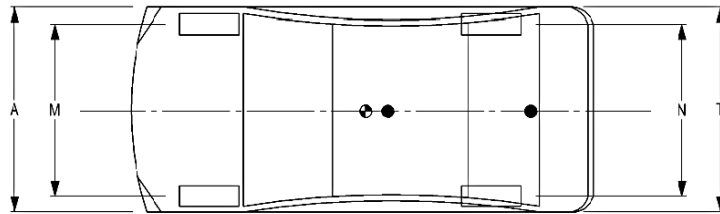
Describe any damage to the vehicle prior to test: None

• 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 <u>0.00</u>	L <u>26.00</u>	Q <u>24.00</u>	V <u>21.25</u>
C <u>175.40</u>	H <u>41.22</u>	M <u>58.30</u>	R <u>16.25</u>	W <u>41.25</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>0.03</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>1430</u>	<u>1454</u>	<u>1539</u>
Back <u>1687</u>	M _{rear}	<u>960</u>	<u>980</u>	<u>1060</u>
Total <u>3389</u>	M _{Total}	<u>2390</u>	<u>2434</u>	<u>2599</u>

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

Mass Distribution:

lb LF: 748 RF: 706 LR: 489 RR: 491

Figure J.1. Vehicle Properties for Test 469943-01-3.

Date: 2023-04-18 Test No.: 469943-01-3 VIN No.: 3N1CN7APXHL842803
 Year: 2017 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 FRONT BUMPER	16	5	50	0	0	0	0	0	0	-5.5
2	ABOVE FRONT BUMPER	16	8	49	0	0	0	0	0	0	52
	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.

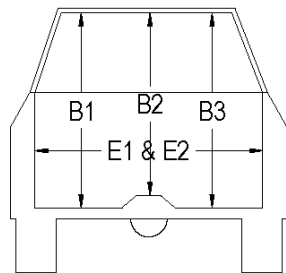
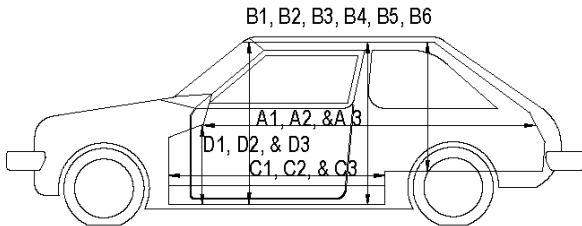
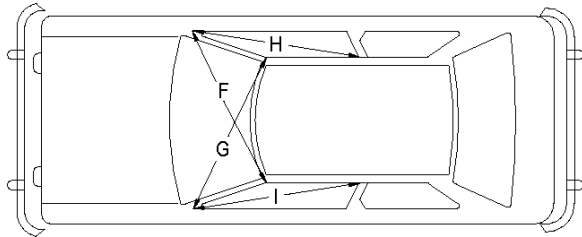
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 J.2. Exterior Crush Measurements for Test 469943-01-3.

Date: 2023-04-18 Test No.: 469943-01-3 VIN No.: 3N1CN7APXHL842803
 Year: 2017 Make: Nissan Model: Versa



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.50	67.50	0.00
A2	67.25	67.25	0.00
A3	67.75	67.75	0.00
B1	40.50	40.50	0.00
B2	39.00	39.00	0.00
B3	40.50	40.50	0.00
B4	36.25	36.25	0.00
B5	36.00	36.00	0.00
B6	36.25	36.25	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	25.00	-1.00
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	9.50	0.00
E1	51.50	51.50	0.00
E2	51.00	51.00	0.00
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	51.00	50.00	-1.00

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

Figure J.3. Occupant Compartment Measurements for Test 469943-01-3.

J.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 J.4. Sequential Photographs for Test 469943-01-3 (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 J.5. Sequential Photographs for Test 469943-01-3 (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

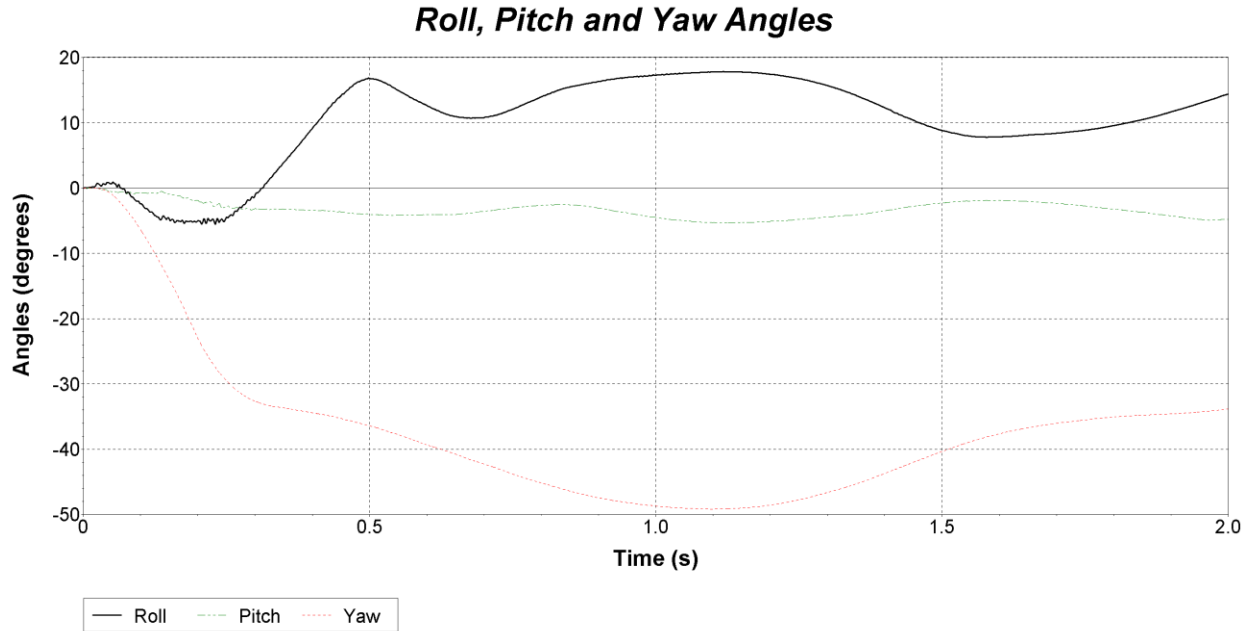


(g) 0.600 s

(h) 0.700 s

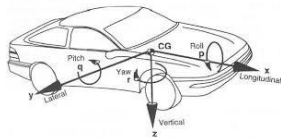
Figure J.6. Sequential Photographs for Test 469943-01-3 (Rear Views).

J.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

7. Yaw.
8. Pitch.
9. Roll.



Test Number: 469943-01-3
 Test Standard Test Number: *MASH* Test 3-10
 Test Article: Enhanced Motorcycle Guard Fence System
 Test Vehicle: 2017 Nissan Versa
 Inertial Mass: 2434 lb
 Gross Mass: 2599 lb
 Impact Speed: 62.2 mi/h
 Impact Angle: 24.7°

Figure J.7. Vehicle Angular Displacements for Test 469943-01-3.

J.4. VEHICLE ACCELERATIONS

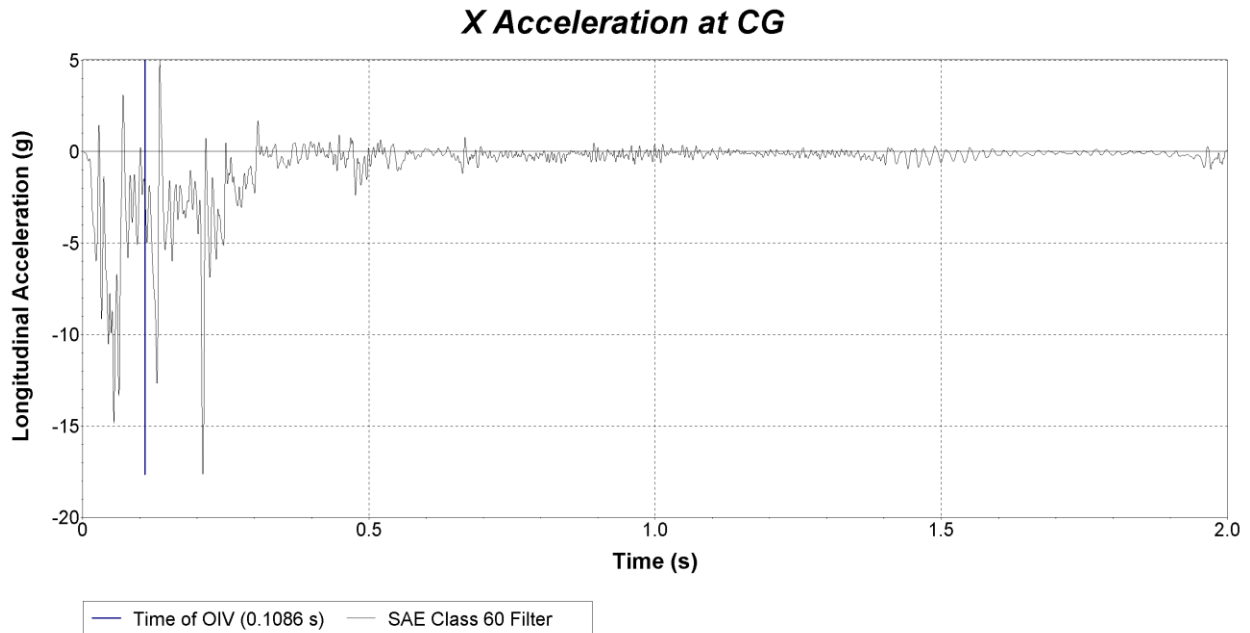


Figure J.8. Vehicle Longitudinal Accelerometer Trace for Test 469943-01-3 (Accelerometer Located at Center of Gravity).

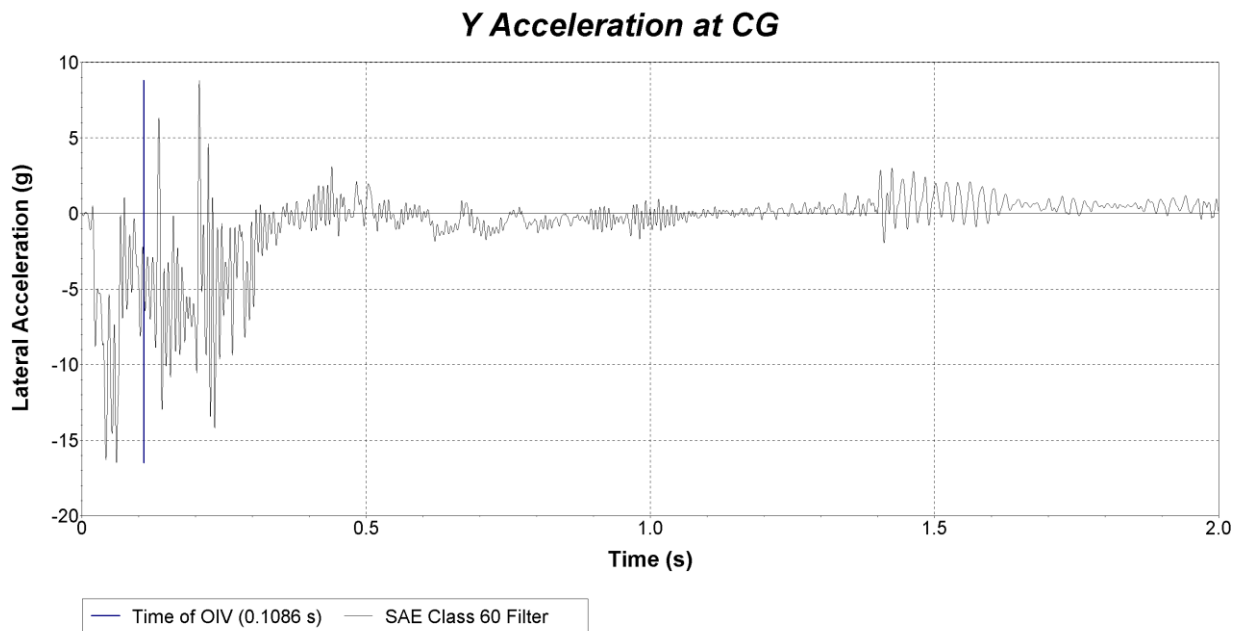
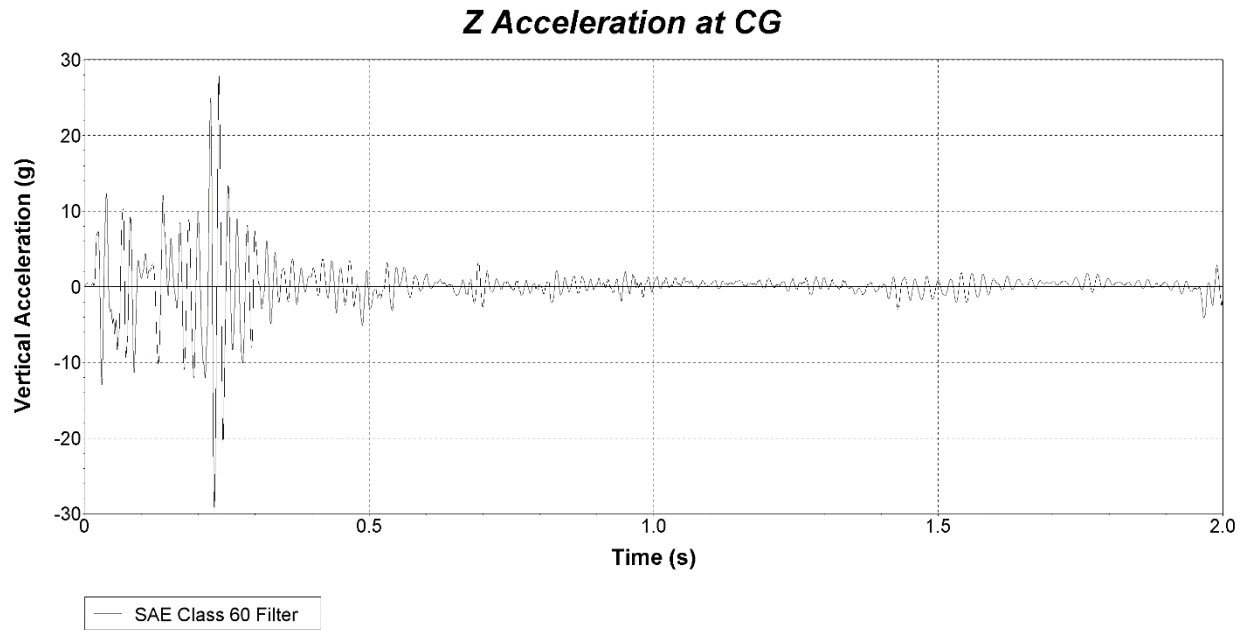


Figure J.9. Vehicle Lateral Accelerometer Trace for Test 469943-01-3 (Accelerometer Located at Center of Gravity).



**Figure J.10. Vehicle Vertical Accelerometer Trace for Test 469943-01-3
(Accelerometer Located at Center of Gravity).**

APPENDIX K. MASH TEST 3-11 (CRASH TEST 469943-01-4)

K.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2023-05-18 Test No.: 469943-01-4 VIN No.: 1C6RR6FT6HS836131
 Year: 2017 Make: RAM Model: 1500
 Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi
 Tread Type: Highway Odometer: 237227
 Note any damage to the vehicle prior to test: None

- Denotes accelerometer location.

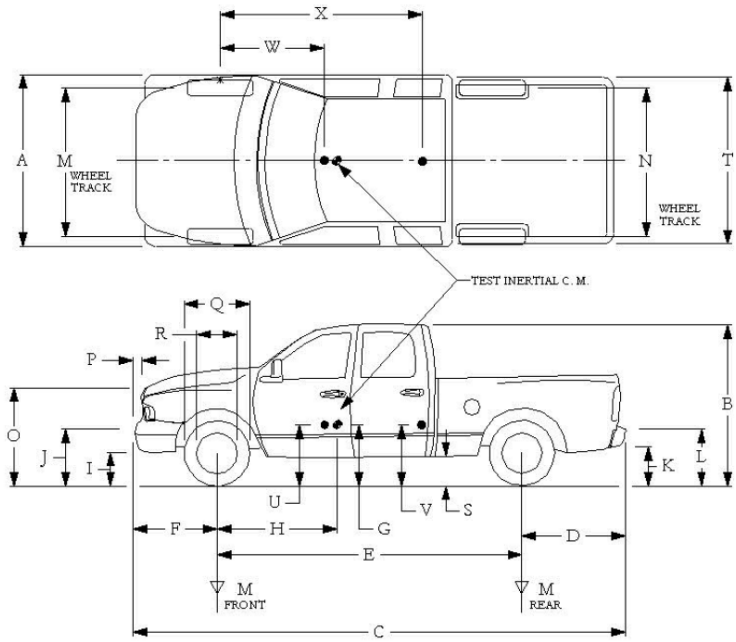
NOTES: None

Engine Type: V-8
 Engine CID: 5.7 liter

Transmission Type:
 Auto or Manual
 FWD RWD 4WD

Optional Equipment:
None

Dummy Data:
 Type: -
 Mass: -
 Seat Position: -



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.62	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.06	M	68.50	R	18.00	W	61.50
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		
Wheel Center Height Front		14.75	Wheel Well Clearance (Front)		6.00	Bottom Frame Height - Front		12.50	
Wheel Center Height Rear		14.75	Wheel Well Clearance (Rear)		9.25	Bottom Frame Height - Rear		22.50	

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

GWWR Ratings:	Mass: lb	Curb	Test Inertial	Gross Static	
Front	3700	M _{front}	2910	2845	0
Back	3900	M _{rear}	2089	2187	0
Total	6700	M _{Total}	4999	5032	5032

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

Mass Distribution:
 lb LF: 1393 RF: 1452 LR: 1137 RR: 1050

Figure K.1. Vehicle Properties for Test 469943-01-4.

Date: 2023-05-18 Test No.: 469943-01-4 VIN No.: 1C6RR6FT6HS836131
 Year: 2017 Make: RAM Model: 1500

VEHICLE CRUSH MEASUREMENT SHEET¹

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

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 FRONT BUMPER	18	9	36	-	-	-	-	-	-	+17
2	ABOVE FT BUMPER	18	10	61	-	-	-	-	-	-	+66
	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).

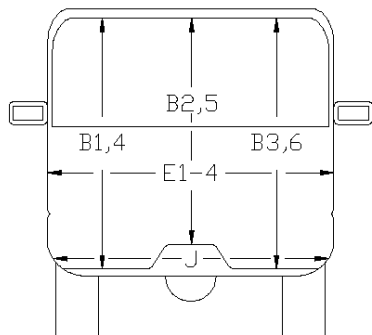
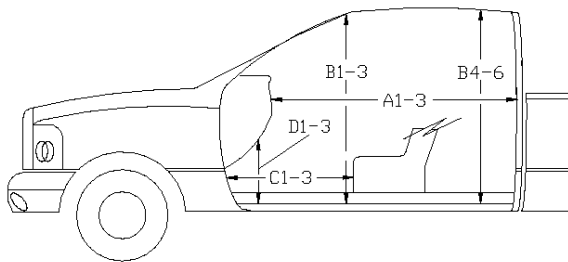
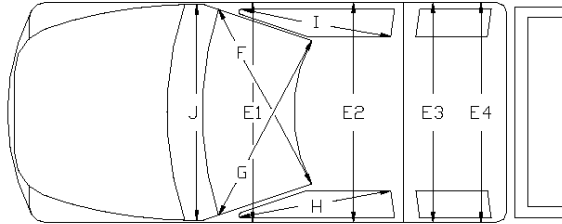
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Figure K.2. Exterior Crush Measurements for Test 469943-01-4.

Date: 2023-05-18 Test No.: 469943-01-4 VIN No.: 1C6RR6FT6HS836131
 Year: 2017 Make: RAM Model: 1500

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT



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

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

Figure K.3. Occupant Compartment Measurements for Test 469943-01-4.

K.2. SEQUENTIAL PHOTOGRAPHS

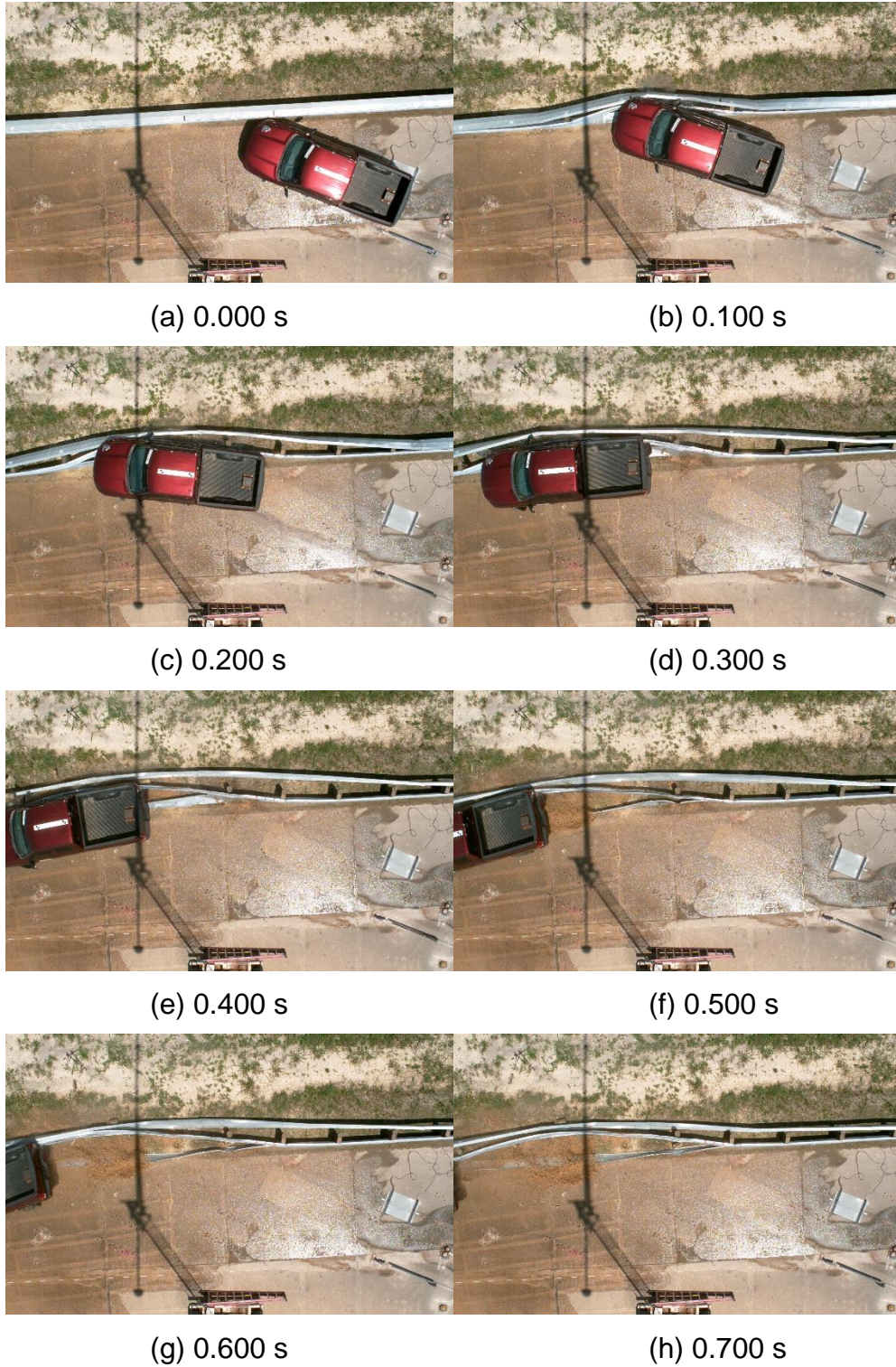


Figure K.4. Sequential Photographs for Test 469943-01-4 (Overhead Views).



(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 K.5. Sequential Photographs for Test 469943-01-4 (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

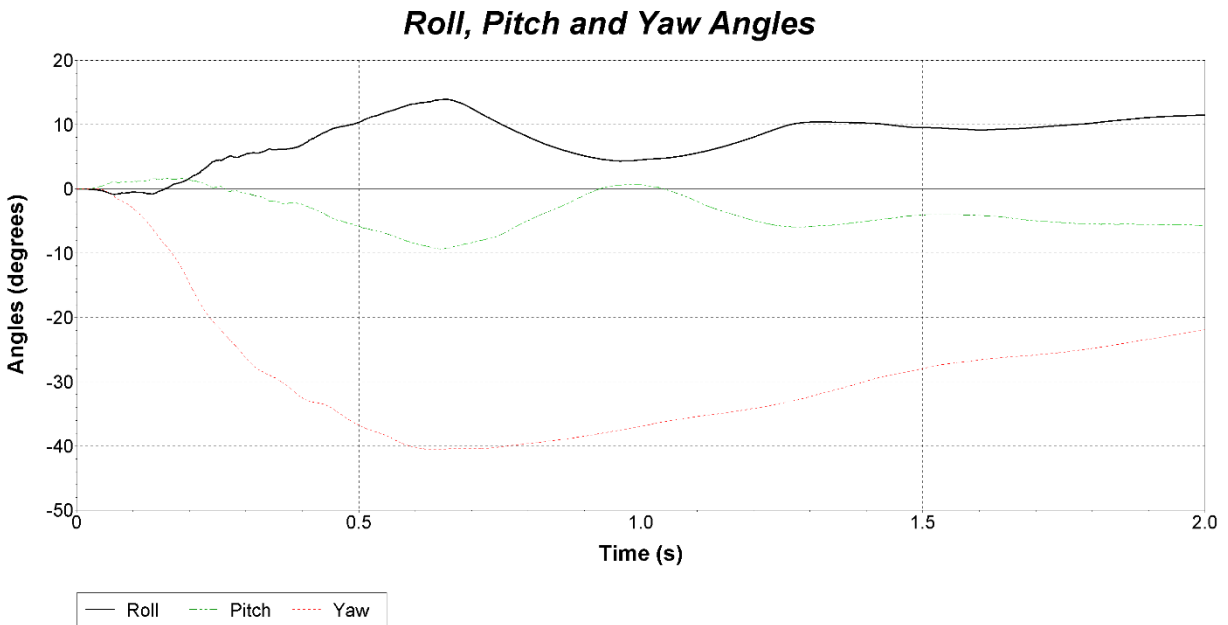


(g) 0.600 s

(h) 0.700 s

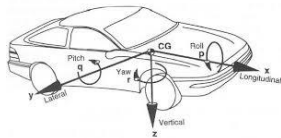
Figure K.6. Sequential Photographs for Test 469943-01-4 (Rear Views).

K.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

10. Yaw.
11. Pitch.
12. Roll.



Test Number: 469943-01-4
 Test Standard Test Number: *MASH* Test 3-11
 Test Article: Enhanced Motorcycle Guard Fence System
 Test Vehicle: 2017 RAM 1500
 Inertial Mass: 5032 lb
 Gross Mass: 5032 lb
 Impact Speed: 65.0 mi/h
 Impact Angle: 24.7

Figure K.7. Vehicle Angular Displacements for Test 469943-01-4.

K.4. VEHICLE ACCELERATIONS

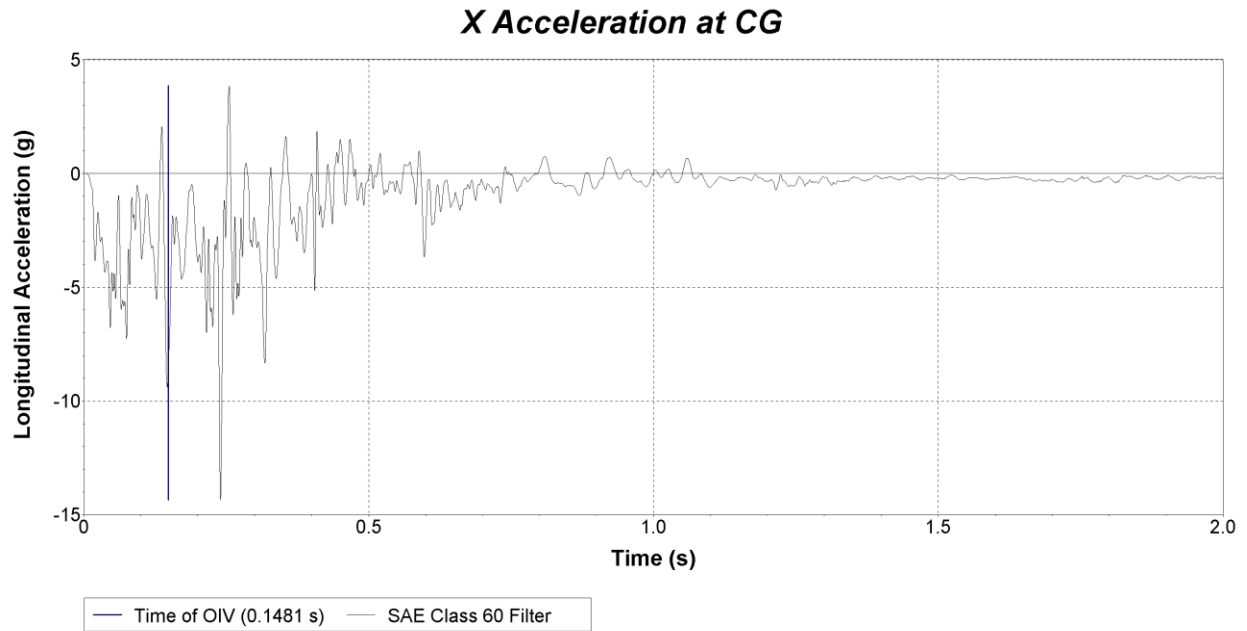


Figure K.8. Vehicle Longitudinal Accelerometer Trace for Test 469943-01-4 (Accelerometer Located at Center of Gravity).

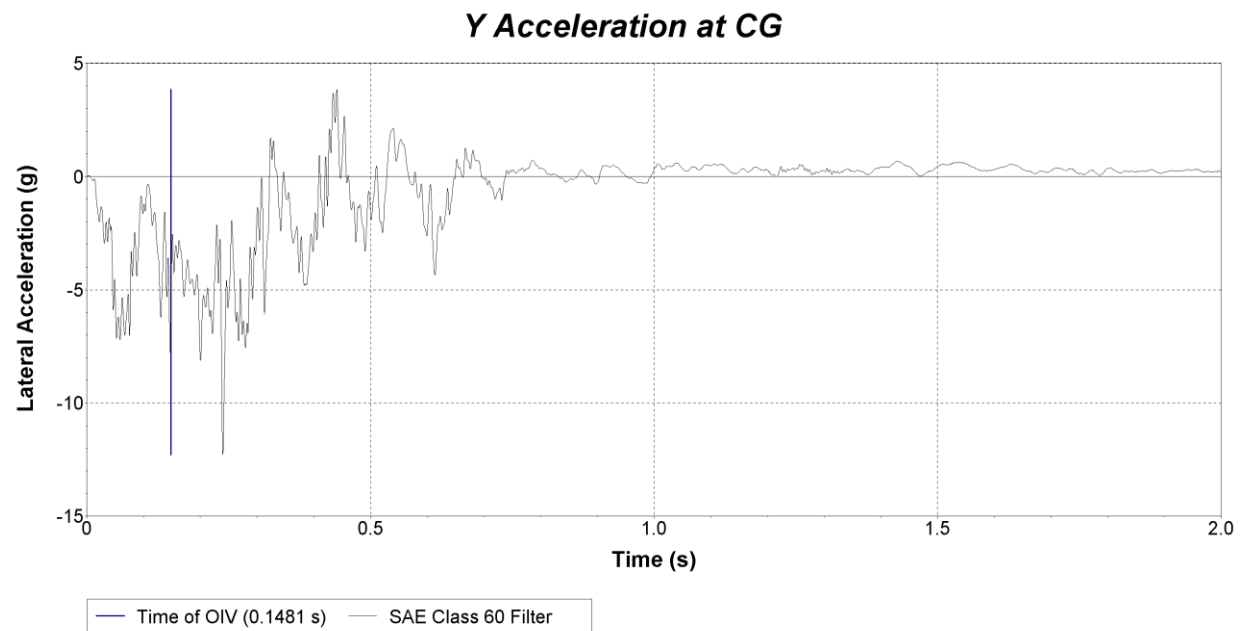
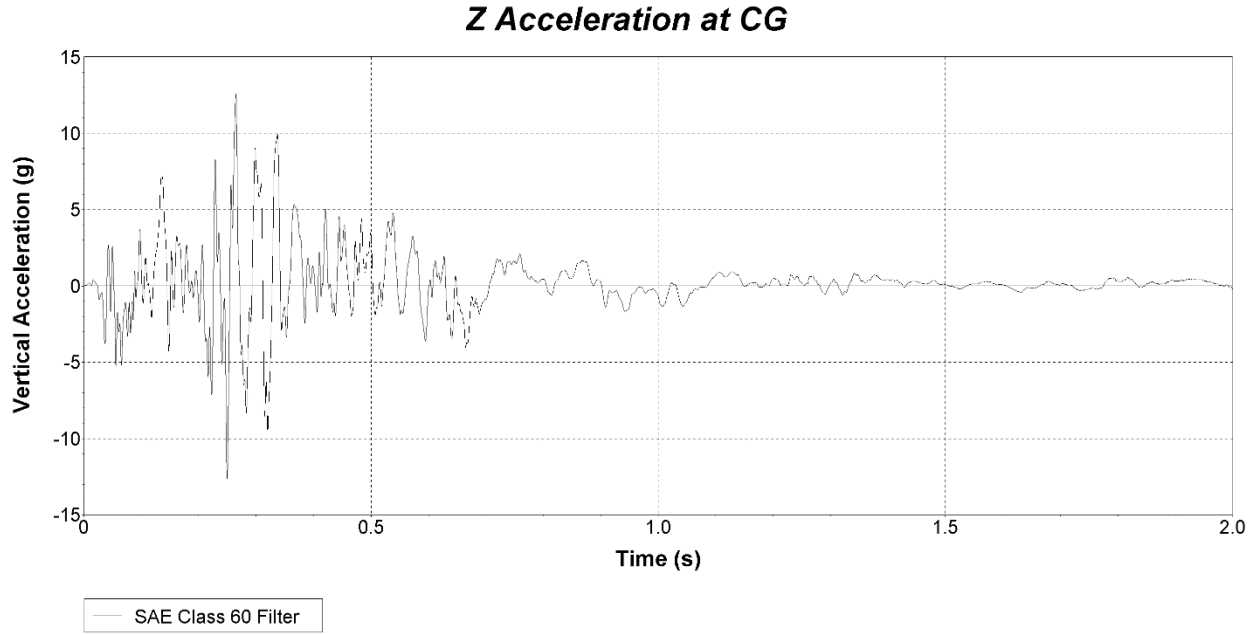


Figure K.9. Vehicle Lateral Accelerometer Trace for Test 469943-01-4 (Accelerometer Located at Center of Gravity).



**Figure K.10. Vehicle Vertical Accelerometer Trace for Test 469943-01-4
(Accelerometer Located at Center of Gravity).**

