Midwest Pooled Fund Research Program
Fiscal Years 2017-2019 (Years 27 through 29)
Research Project Number TPF-5 (193) Supplement #106
NDOT Sponsoring Agency Code RPFP-17-MGS-2

EVALUATION OF THE MGS PLACED 6 IN. BEHIND A 6-IN. TALL AASHTO TYPE-B CURB TO MASH TL-3

Submitted by

Kellon Ronspies, M.S.M.E.
Former Graduate Research Assistant

Scott Rosenbaugh, M.S.C.E., E.I.T.
Research Engineer

Robert W. Bielenberg, M.S.M.E., E.I.T.
Research Engineer

Ronald K. Faller, Ph.D., P.E.
Research Professor & MwRSF Director

Cody S. Stolle, Ph.D., E.I.T.
Research Assistant Professor

MIDWEST ROADSIDE SAFETY FACILITY
Nebraska Transportation Center
University of Nebraska-Lincoln

Main Office
Prem S. Paul Research Center at Whittier School
Room 130, 2200 Vine Street
Lincoln, Nebraska 68583-0853
(402) 472-0965

Outdoor Test Site
4630 N.W. 36th Street
Lincoln, Nebraska 68524

Submitted to

MIDWEST POOLED FUND PROGRAM
Nebraska Department of Transportation
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

MwRSF Research Report No. TRP-03-390-20

August 27, 2020

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. TRP-03-390-20	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Evaluation of the MGS Placed 6 in. behind a 6-in. tall AASHTO Type B Curb to MASH TL-3		**5. Report Date** August 27, 2020 **6.Performing Organization Code**
7. Author(s) Ronspies, K.B., Rosenbaugh, S.K., Bielenberg, R.W., Faller, R.K., and Stolle, C.S.		**8. Performing Organization Report No.** TRP-03-390-20
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) Nebraska Transportation Center University of Nebraska-Lincoln Main Office: Prem S. Paul Research Center at Whittier School Room 130, 2200 Vine Street Lincoln, Nebraska 68583-0853 Outdoor Test Site: 4630 N.W. 36th Street Lincoln, Nebraska 68524		**10. Work Unit No.** **11. Contract** TPF-5 (193) Supplement #106
12. Sponsoring Organization Name and Address Midwest Pooled Fund Program Nebraska Department of Transportation 1500 Nebraska Highway 2 Lincoln, Nebraska 68502		**13. Type of Report and Period Covered** Final Report: 2017-2020 **14. Sponsoring Agency Code** RPFP-17-MGS-2

15. Supplementary Notes
Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration.

16. **Abstract**

The use of curbs along roads is often required for certain functions such as drainage control, right-of-way reduction and sidewalk separation. However, curbs along roadways can adversely affect the interaction of errant vehicles with roadside barriers. Curbs placed near guardrail systems increase the propensity for vehicle override, vehicle underride, vehicle instability, and excessive rail loading during impact events. The Midwest Guardrail System (MGS) installed behind curbs was evaluated under National Cooperative Highway Research Program (NCHRP) Report 350 Test Level 3 (TL-3) criteria but has not been evaluated to American Association of State Highway Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (MASH) TL-3.

Test nos. MGSC-7 and MGSC-8 were conducted on the MGS offset by 6 in. behind a 6-in. tall AASHTO Type B curb in accordance with MASH 2016 test designation nos. 3-10 and 3-11, respectively. During test no. MGSC-7, the 1100C vehicle impacted the system at 63.6 mph at an angle of 25.0 degrees and was successfully contained and redirected by the system. The system was rebuilt and tested again according to MASH test designation no. 3-11. In test MGSC-8, the 2270P vehicle impacted the system at 63.4 mph at an angle of 25.7 degrees and was successfully contained and redirected by the system. Upon the successful completion of the two full-scale crash tests, the MGS was deemed crashworthy to MASH 2016 TL-3 when placed within 6 in. behind a curb. Installation guidelines were presented to address implementation of the MGS with curb in various barrier configurations as well as in conjunction with a number of roadside features and special applications.

17. Key Words Highway Safety, Crash Test, Roadside Appurtenances, Compliance Test, MASH 2016, Midwest Guardrail System (MGS), Curb, Test Level 3 (TL_3)		**18. Distribution Statement** No restrictions. Document available from: National Technical Information Service. 5285 Port Royal Road Springfield, Virginia 22161	
19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 214	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DISCLAIMER STATEMENT

This material is based upon work supported by the Federal Highway Administration, U.S. Department of Transportation and the Midwest Pooled Fund Program under TPF-5(193) Supplement #106. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the University of Nebraska-Lincoln, state highway departments participating in the Midwest Pooled Fund Program, nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names, which may appear in this report, are cited only because they are considered essential to the objectives of the report. The United States (U.S.) government and the State of Nebraska do not endorse products or manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Dr. Jennifer Rasmussen, Research Associate Professor.

ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the Midwest Pooled Fund Program funded by the California Department of Transportation, Florida Department of Transportation, Georgia Department of Transportation, Hawaii Department of Transportation, Illinois Department of Transportation, Indiana Department of Transportation, Iowa Department of Transportation, Kansas Department of Transportation, Kentucky Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Nebraska Department of Transportation, New Jersey Department of Transportation, North Carolina Department of Transportation, Ohio Department of Transportation, South Carolina Department of Transportation, South Dakota Department of Transportation, Utah Department of Transportation, Virginia Department of Transportation, Wisconsin Department of Transportation, and Wyoming Department of Transportation for sponsoring this project; and (2) MwRSF personnel for constructing the barriers and conducting the crash tests.

Acknowledgement is also given to the following individuals who contributed to the completion of this research project.

Midwest Roadside Safety Facility

J.D. Reid, Ph.D., Professor
J.C. Holloway, M.S.C.E., E.I.T., Research Engineer & Assistant Director –Physical Testing Division
K.A. Lechtenberg, M.S.M.E., E.I.T., Research Engineer
J.D. Rasmussen, Ph.D., P.E., Research Associate Professor
J.S. Steelman, Ph.D., P.E., Associate Professor
M. Pajouh, Ph.D., P.E., Research Assistant Professor
A.T. Russell, B.S.B.A., Testing and Maintenance Technician II
E.W. Krier, B.S., Construction and Testing Technician II
S.M. Tighe, Construction and Testing Technician I
D.S. Charroin, Construction and Testing Technician I
R.M. Novak, Construction and Testing Technician I
T.C. Donahoo, Construction and Testing Technician I
J.T. Jones, Construction and Testing Technician I
J.E. Kohtz, B.S.M.E., CAD Technician
E.L. Urbank, B.A., Research Communication Specialist
Z.Z. Jabr, Engineering Technician
Undergraduate and Graduate Research Assistant

California Department of Transportation
Bob Meline, Chief, Roadside Safety Research Branch
David Whitesel, P.E., Transportation Engineer
John Jewell, P.E., Senior Transportation Engineer, Specialist

Florida Department of Transportation
Derwood C. Sheppard, Jr., P.E., Design Standards Publication Manager, Roadway Design Engineer

Georgia Department of Transportation
Brent Story, P.E., State Design Policy Engineer
Frank Flanders IV, P.E., Assistant State Design Policy Engineer

Hawaii Department of Transportation
James Fu, P.E., State Bridge Engineer
Dean Takiguchi, P.E., Engineer, Bridge Design Section
Kimberly Okamura, Engineer, Bridge Design Section

Illinois Department of Transportation
Filiberto Sotelo, Safety Evaluation Engineer
Martha Brown, P.E., Safety Evaluation Unit Chief

Indiana Department of Transportation
Katherine Smutzer, P.E., Standards Engineer
Elizabeth Phillips, P.E., Standards and Policy Manager

Iowa Department of Transportation
Chris Poole, P.E., Roadside Safety Engineer
Brian Smith, P.E., Methods Engineer
Daniel Harness, P.E., Transportation Engineer Specialist
Stuart Nielsen, P.E., Transportation Engineer Administrator, Design
Elijah Gansen, P.E., Geometrics Engineer

Kansas Department of Transportation
Ron Seitz, P.E., Director of Design
Scott King, P.E., Road Design Bureau Chief
Thomas Rhoads, P.E., Road Design Leader, Bureau of Road Design
Brian Kierath Jr., Engineering Associate III, Bureau of Road Design

Kentucky Department of Transportation
Jason J. Siwula, P.E., Assistant State Highway Engineer
Kevin Martin, P.E., Transportation Engineer Specialist
Gary Newton, Engineering Tech III, Design Standards

Minnesota Department of Transportation
Michael Elle, P.E., Design Standards Engineer
Michelle Moser, P.E., Assistant Design Standards Engineer

Missouri Department of Transportation
Sarah Kleinschmit, P.E., Policy and Innovations Engineer

Nebraska Department of Transportation
Phil TenHulzen, P.E., Design Standards Engineer
Jim Knott, P.E., Construction Engineer
Mike Owen, P.E., State Roadway Design Engineer
Mick Syslo, P.E., Materials and Research Engineer & Division Head
Mark Fischer, P.E., Research Program Manager
Lieska Halsey, Assistant Materials Engineer
Angela Andersen, Research Coordinator
David T. Hansen, Internal Research Coordinator
Jodi Gibson, Former Research Coordinator

New Jersey Department of Transportation
Hung Tang, Senior Engineer, Transportation
Joseph Warren, Assistant Engineer, Transportation

North Carolina Department of Transportation
Neil Mastin, P.E., Manager, Transportation Program Management – Research and Development
D. D. "Bucky" Galloway, P.E., CPM, Field Operations Engineer
Brian Mayhew, P.E., State Traffic Safety Engineer
Joel Howerton, P.E., Plans and Standards Engineer

Ohio Department of Transportation
Don Fisher, P.E., Roadway Standards Engineer

South Carolina Department of Transportation
J. Adam Hixon, P.E., Design Standards Associate
Mark H. Anthony, P.E., Letting Preparation Engineer
Henry Cross, P.E., Design Standards Engineer
Jason Hall, P.E., Engineer

South Dakota Department of Transportation
David Huft, P.E., Research Engineer
Bernie Clocksin, P.E., Standards Engineer

Utah Department of Transportation
Shawn Debenham, Traffic and Safety Specialist
Glenn Blackwelder, Operations Engineer

Virginia Department of Transportation
Charles Patterson, P.E., Standards/Special Design Section Manager
Andrew Zickler, P.E., Complex Bridge Design and ABC Support Program Manager

Wisconsin Department of Transportation
Erik Emerson, P.E., Standards Development Engineer
Rodney Taylor, P.E., Roadway Design Standards Unit Supervisor

Wyoming Department of Transportation
William Wilson, P.E., Architectural and Highway Standards Engineer

Federal Highway Administration
David Mraz, Division Bridge Engineer, Nebraska Division Office

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 yard	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 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short ton (2,000 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
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE & 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 yard	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliter	0.034	fluid ounces	fl 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 ton (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE & PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

TABLE OF CONTENTS

TECHNICAL REPORT DOCUMENTATION PAGE ... i

DISCLAIMER STATEMENT ... ii

UNCERTAINTY OF MEASUREMENT STATEMENT ... ii

INDEPENDENT APPROVING AUTHORITY ... ii

ACKNOWLEDGEMENTS ... iii

1 INTRODUCTION ... 1
- 1.1 Background ... 1
- 1.2 Objective ... 2
- 1.3 Scope ... 2

2 TEST REQUIREMENTS AND EVALUATION CRITERIA ... 3
- 2.1 Test Requirements ... 3
- 2.2 Evaluation Criteria ... 3
- 2.3 Soil Strength Requirements ... 4

3 DESIGN DETAILS ... 5
- 3.1 Test No. MGSC-7 ... 5
- 3.2 Test No. MGSC-8 ... 21

4 TEST CONDITIONS ... 37
- 4.1 Test Facility ... 37
- 4.2 Vehicle Tow and Guidance System ... 37
- 4.3 Test Vehicles ... 37
- 4.4 Simulated Occupant ... 47
- 4.5 Data Acquisition Systems ... 47
  - 4.5.1 Accelerometers ... 47
  - 4.5.2 Rate Transducers ... 47
  - 4.5.3 Retroreflective Optic Speed Trap ... 47
  - 4.5.4 Digital Photography ... 48

5 FULL-SCALE CRASH TEST NO. MGSC-7 ... 51
- 5.1 Static Soil Test ... 51
- 5.2 Weather Conditions ... 51
- 5.3 Test Description ... 51
- 5.4 Barrier Damage ... 62
- 5.5 Vehicle Damage ... 73
- 5.6 Occupant Risk ... 78
- 5.7 Discussion ... 79

6 FULL-SCALE CRASH TEST NO. MGSC-8 ... 81

6.1 Static Soil Test 81
6.2 Weather Conditions 81
6.3 Test Description 81
6.4 Barrier Damage 91
6.5 Vehicle Damage 102
6.6 Occupant Risk 108
6.7 Discussion 109

7 SUMMARY AND CONCLUSIONS 112

8 RECOMMENDATIONS AND IMPLEMENTATION GUIDANCE 114
8.1 MGS to Curb Offset 114
8.2 Applicable Curb Shapes and Heights 114
8.3 MGS Height Tolerances 115
8.4 Approach Slopes and Gutters 115
8.5 MGS Configurations and Special Applications 116
8.5.1 Wood Post MGS 116
8.5.2 MGS without Blockouts 116
8.5.3 MGS with 8-in. Deep Blockouts 117
8.5.4 MGS with an Omitted Post 117
8.5.5 Roadside Slopes 117
8.5.6 Guardrail Stiffness Transitions 118
8.5.7 Guardrail End Terminals and Anchorages 118

9 MASH EVALUATION 119

10 REFERENCES 120

11 APPENDICES 124
Appendix A. Material Specifications 125
Appendix B. Vehicle Center of Gravity Determination 160
Appendix C. Static Soil Tests 163
Appendix D. Vehicle Deformation Records 167
Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. MGSC-7 180
Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. MGSC-8 197

LIST OF FIGURES

Figure 1. System Layout, Test No. MGSC-7 6
Figure 2. Post Detail, Test No. MGSC-7 7
Figure 3. Splice and Post Detail, Test No. MGSC-7 8
Figure 4. End Section Detail, Test No. MGSC-7 9
Figure 5. BCT Anchor Detail, Test No. MGSC-7 10
Figure 6. Post Nos. 3 through 27 Components, Test No. MGSC-7 11
Figure 7. BCT Timber Post and Foundation Tube Detail, Test No. MGSC-7 12
Figure 8. BCT Anchor Cable, Test No. MGSC-7 13
Figure 9. BCT Post Components and Anchor Bracket, Test No. MGSC-7 14
Figure 10. Ground Strut Details, Test No. MGSC-7 15
Figure 11. Rail Section Details, Test No. MGSC-7 16
Figure 12. Hardware, Test No. MGSC-7 17
Figure 13. Bill of Materials, Test No. MGSC-7 18
Figure 14. Test Installation Photographs, Test No. MGSC-7 19
Figure 15. Test Installation Photographs, Test No. MGSC-7 20
Figure 16. System Layout, Test No. MGSC-8 22
Figure 17. Post Detail, Test No. MGSC-8 23
Figure 18. Splice and Post Detail, Test No. MGSC-8 24
Figure 19. End Section Detail, Test No. MGSC-8 25
Figure 20. BCT Anchor Detail, Test No. MGSC-8 26
Figure 21. Post Nos. 3 through 27 Components, Test No. MGSC-8 27
Figure 22. BCT Timber Post and Foundation Tube Detail, Test No. MGSC-8 28
Figure 23. BCT Anchor Cable, Test No. MGSC-8 29
Figure 24. BCT Post Components and Anchor Bracket, Test No. MGSC-8 30
Figure 25. Ground Strut Details, Test No. MGSC-8 31
Figure 26. Rail Section Details, Test No. MGSC-8 32
Figure 27. Hardware, Test No. MGSC-8 33
Figure 28. Bill of Materials, Test No. MGSC-8 34
Figure 29. Test Installation Photographs, Test No. MGSC-8 35
Figure 30. Test Installation Photographs, Test No. MGSC-8 36
Figure 31. Test Vehicle, Test No. MGSC-7 39
Figure 32. Test Vehicle’s Undercarriage and Interior Floorboards, Test No. MGSC-7 40
Figure 33. Vehicle Dimensions, Test No. MGSC-7 41
Figure 34. Test Vehicle, Test No. MGSC-8 42
Figure 35. Test Vehicle’s Undercarriage, Test No. MGSC-8 43
Figure 36. Vehicle Dimensions, Test No. MGSC-8 44
Figure 37. Target Geometry, Test No. MGSC-7 45
Figure 38. Target Geometry, Test No. MGSC-8 46
Figure 39. Camera Locations, Speeds, and Lens Settings, Test No. MGSC-7 49
Figure 40. Camera Locations, Speeds, and Lens Settings, Test No. MGSC-8 50
Figure 41. Impact Location, Test No. MGSC-7 54
Figure 42. Sequential Photographs, Test No. MGSC-7 55
Figure 43. Sequential Photographs, Test No. MGSC-7 56
Figure 44. Sequential Photographs, Test No. MGSC-7 57
Figure 45. Documentary Photographs, Test No. MGSC-7 58

Figure 46. Documentary Photographs, Test No. MGSC-7 59
Figure 47. Documentary Photographs, Test No. MGSC-7 60
Figure 48. Vehicle Final Position and Trajectory Marks, Test No. MGSC-7 61
Figure 49. System Damage, Test No. MGSC-7 63
Figure 50. Guardrail Damage, Post Nos. 13 through 15, Test No. MGSC-7 64
Figure 51. Guardrail Damage, Post Nos. 15 through 18 Test No. MGSC-7 65
Figure 52. Backside Guardrail Damage, Post Nos. 13 through 16, Test No. MGSC-7 66
Figure 53. Backside Guardrail Damage, Post Nos. 16 through 18, Test No. MGSC-7 67
Figure 54. Post Nos. 14 and 15 Damage, Test No. MGSC-7 68
Figure 55. Post Nos. 16 and 17 Damage, Test No. MGSC-7 69
Figure 56. Partial Rail Tearing, Test No. MGSC-7 70
Figure 57. Curb Damage, Test No. MGSC-7 71
Figure 58. Permanent Deflection, Dynamic Deflection, and Working Width, Test No. MGSC-7 72
Figure 59. Vehicle Damage, Test No. MGSC-7 74
Figure 60. Vehicle Damage, Test No. MGSC-7 75
Figure 61. Occupant Compartment Damage, Test No. MGSC-7 76
Figure 62. Vehicle Undercarriage Damage, Test No. MGSC-7 77
Figure 63. Summary of Test Results and Sequential Photographs, Test No. MGSC-7 80
Figure 64. Impact Location, Test No. MGSC-8 84
Figure 65. Sequential Photographs, Test No. MGSC-8 85
Figure 66. Sequential Photographs, Test No. MGSC-8 86
Figure 67. Sequential Photographs, Test No. MGSC-8 87
Figure 68. Documentary Photographs, Test No. MGSC-8 88
Figure 69. Additional Documentary Photographs, Test No. MGSC-8 89
Figure 70. Vehicle Final Position and Trajectory Marks, Test No. MGSC-8 90
Figure 71. System Damage, Test No. MGSC-8 92
Figure 72. System Damage, Guardrail at Post Nos. 12 through 14, Test No. MGSC-8 93
Figure 73. System Damage, Guardrail at Post Nos. 14 through 17, Test No. MGSC-8 94
Figure 74. System Damage, Guardrail at Post Nos. 17 through 19, Test No. MGSC-8 95
Figure 75. System Damage, Backside Rail at Post Nos. 12 through 15, Test No. MGSC-8 96
Figure 76. System Damage, Backside Rail at Post Nos. 16 through 19, Test No. MGSC-8 97
Figure 77. System Damage, Post Nos. 12 through 15, Test No. MGSC-8 98
Figure 78. System Damage, Post Nos. 16 through 19, Test No. MGSC-8 99
Figure 79. System Damage, Post Nos. 25 through 29, Test No. MGSC-8 100
Figure 80. Permanent Deflection, Dynamic Deflection, and Working Width, Test No. MGSC-8 101
Figure 81. Vehicle Damage, Test No. MGSC-8 103
Figure 82. Vehicle Damage, Test No. MGSC-8 104
Figure 83. Vehicle Windshield Damage, Test No. MGSC-8 105
Figure 84. Occupant Compartment Damage, Test No. MGSC-8 106
Figure 85. Vehicle Undercarriage Damage, Test No. MGSC-8 107
Figure 86. Summary of Test Results and Sequential Photographs, Test No. MGSC-8 111
Figure 87. Standard AASHTO Curb Shapes 115
Figure 88. Minimum Recommended Distance between Omitted Posts 117
Figure A-1. 12-ft 6-in. W-Beam MGS Interior and End Sections, Test Nos. MGSC-7 and MGSC-8 127

Figure A-2. 6-ft 3-in. W-Beam MGS Section, Test Nos. MGSC-7 and MGSC-8 128
Figure A-3. 72-in. Long Steel Post, Test Nos. MGSC-7 and MGSC-8......................................129
Figure A-4. 72-in. Long Steel Post, Test Nos. MGSC-7 and MGSC-8......................................130
Figure A-5. Timber Blockouts for Steel Posts, Test Nos. MGSC-7 and MGSC-8 131
Figure A-6. Timber Blockouts for Steel Posts, Test Nos. MGSC-7 and MGSC-8 132
Figure A-7. Timber Blockouts for Steel Posts, Test Nos. MGSC-7 and MGSC-8 133
Figure A-8. 16D Double-Headed Nail, Test Nos. MGSC-7 and MGSC-8 134
Figure A-9. BCT Timber Post, Test Nos. MGSC-7 and MGSC-8...135
Figure A-10. Foundation Tube, Test Nos. MGSC-7 and MGSC-8..136
Figure A-11. Ground Strut Assembly, Test Nos. MGSC-7 and MGSC-8 137
Figure A-12. Ground Strut Assembly, Test Nos. MGSC-7 and MGSC-8 138
Figure A-13. BCT Post Sleeve, Test Nos. MGSC-7 and MGSC-8..139
Figure A-14. Anchor Bearing Plate, Test Nos. MGSC-7 and MGSC-8.....................................140
Figure A-15. Anchor Bracket Assembly, Test Nos. MGSC-7 and MGSC-8.............................141
Figure A-16. BCT Anchor Cable, Test Nos. MGSC-7 and MGSC-8 142
Figure A-17. BCT Cable Nuts, Test Nos. MGSC-7 and MGSC-8...143
Figure A-18. BCT Washers, Test Nos. MGSC-7 and MGSC-8...144
Figure A-19. ⅝-in. by 14-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8 145
Figure A-20. ⅝-in. by 14-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8 146
Figure A-21. ⅝-in. Diameter Guardrail Nut, Test Nos. MGSC-7 and MGSC-8........................147
Figure A-22. ⅝-in. by 10-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8 148
Figure A-23. ⅝-in. by 10-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8 149
Figure A-24. ⅝-in. by 10-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8 150
Figure A-25. ⅝-in. by 1¼-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8 151
Figure A-26. ⅝-in. by 10-in. Long Hex Bolt, Test Nos. MGSC-7 and MGSC-8.......................152
Figure A-27. ⅝-in. Hex Nuts, Test Nos. MGSC-7 and MGSC-8...153
Figure A-28. ⅝-in. by 1½-in. Long Hex Bolts, Test Nos. MGSC-7 and MGSC-8....................154
Figure A-29. ⅞-in. Dia. by 8-in. Long Hex Bolts, Test Nos. MGSC-7 and MGSC-8 155
Figure A-30. ⅞-in. Diameter Nuts, Test Nos. MGSC-7 and MGSC-8......................................156
Figure A-31. Curb Concrete Strength, Test Nos. MGSC-7 and MGSC-8 157
Figure A-32. 819-in. Long Rebar, Test Nos. MGSC-7 and MGSC-8..158
Figure A-33. 16-in. Long Rebar, Test Nos. MGSC-7 and MGSC-8..159
Figure B-1. Vehicle Mass Distribution, Test No. MGSC-7 161
Figure B-2. Vehicle Mass Distribution, Test No. MGSC-8 162
Figure C-1. Soil Strength, Initial Calibration Tests 164
Figure C-2. Static Soil Test, Test No. MGSC-7 165
Figure C-3. Static Soil Test, Test No. MGSC-8 166
Figure D-1. Floor Pan Deformation Data – Set 1, Test No. MGSC-7..168
Figure D-2. Floor Pan Deformation Data – Set 2, Test No. MGSC-7..169
Figure D-3. Interior Crush Deformation Data – Set 1, Test No. MGSC-7.................................170
Figure D-4. Interior Crush Deformation Data – Set 2, Test No. MGSC-7.................................171
Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. MGSC-7 172
Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. MGSC-7....................................173
Figure D-7. Floor Pan Deformation Data – Set 1, Test No. MGSC-8..174
Figure D-8. Floor Pan Deformation Data – Set 2, Test No. MGSC-8..175
Figure D-9. Interior Crush Deformation Data – Set 1, Test No. MGSC-8.................................176
Figure D-10. Interior Crush Deformation Data – Set 2, Test No. MGSC-8...............................177

Figure D-11. Exterior Vehicle Crush (NASS) - Front, Test No. MGSC-8 178
Figure D-12. Exterior Vehicle Crush (NASS) - Side, Test No. MGSC-8 179
Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSC-7 181
Figure E-2. Longitudinal Occupant Velocity (SLICE-1), Test No. MGSC-7 182
Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSC-7 183
Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSC-7 184
Figure E-5. Lateral Occupant Velocity (SLICE-1), Test No. MGSC-7 185
Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. MGSC-7 186
Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. MGSC-7 187
Figure E-8. Acceleration Severity Index (SLICE-1), Test No. MGSC-7 188
Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSC-7 189
Figure E-10. Longitudinal Occupant Velocity (SLICE-2), Test No. MGSC-7 190
Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSC-7 191
Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSC-7 192
Figure E-13. Lateral Occupant Velocity (SLICE-2), Test No. MGSC-7 193
Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. MGSC-7 194
Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. MGSC-7 195
Figure E-16. Acceleration Severity Index (SLICE-2), Test No. MGSC-7 196
Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSC-8 198
Figure F-2. Longitudinal Occupant Velocity (SLICE-2), Test No. MGSC-8 199
Figure F-3. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSC-8 200
Figure F-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSC-8 201
Figure F-5. Lateral Occupant Velocity (SLICE-2), Test No. MGSC-8 202
Figure F-6. Lateral Occupant Displacement (SLICE-2), Test No. MGSC-8 203
Figure F-7. Vehicle Angular Displacements (SLICE-2), Test No. MGSC-8 204
Figure F-8. Acceleration Severity Index (SLICE-2), Test No. MGSC-8 205
Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSC-8 206
Figure F-10. Longitudinal Occupant Velocity (SLICE-1), Test No. MGSC-8 207
Figure F-11. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSC-8 208
Figure F-12. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSC-8 209
Figure F-13. Lateral Occupant Velocity (SLICE-1), Test No. MGSC-8 210
Figure F-14. Lateral Occupant Displacement (SLICE-1), Test No. MGSC-8 211
Figure F-15. Vehicle Angular Displacements (SLICE-1), Test No. MGSC-8 212
Figure F-16. Acceleration Severity Index (SLICE-1), Test No. MGSC-8 213

LIST OF TABLES

Table 1. MASH 2016 TL-3 Crash Test Conditions for Longitudinal Barriers................................3
Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barrier..4
Table 3. Weather Conditions, Test No. MGSC-7...51
Table 4. Sequential Description of Impact Events, Test No. MGSC-7 52
Table 5. Sequential Description of Impact Events, Test No. MGSC-7, Cont. 53
Table 6. Maximum Occupant Compartment Intrusion by Location, Test No. MGSC-7 78
Table 7. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSC-7...................79
Table 8. Weather Conditions, Test No. MGSC-8...81
Table 9. Sequential Description of Impact Events, Test No. MGSC-8 82
Table 10. Sequential Description of Impact Events, Test No. MGSC-8, Cont. 83
Table 11. Maximum Occupant Compartment Intrusions by Location, Test No. MGSC-8.........108
Table 12. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSC-8...............109
Table 13. Summary of Safety Performance Evaluation...113
Table A-1. Bill of Materials, Test Nos. MGSC-7 and MGSC-8 126

1 INTRODUCTION

1.1 Background

The use of curbs along roads is often required for certain functions such as drainage control, right-of-way reduction, and sidewalk separation. However, curbs along roadways can adversely affect the interaction of errant vehicles with roadside barriers. When curbs are placed near guardrail systems, the propensity increases for vehicle override, vehicle underride, vehicle instability, and excessive rail loading.

During the initial development and evaluation of the Midwest Guardrail System (MGS), the guardrail was tested in combination with a 6-in. tall concrete curb [1]. The MGS was positioned with the face of the rail offset 6 in. behind a 6-in. tall American Association of State Highway and Transportation Officials (AASHTO) Type B curb, and a full-scale crash test was successfully conducted with the 2000P pickup truck in accordance with test designation no. 3-11 of *National Cooperative Highway Research Program (NCHRP) Report 350* [2] criteria. However, no small car tests were conducted with the MGS adjacent to curbs.

Since 2009, AASHTO has improved the criteria for the evaluation of roadside hardware beyond the previous NCHRP Report 350 standard. The new standard, entitled the *Manual for Assessing Safety Hardware* (MASH) [3], enforced updates to test vehicles, test matrices, and impact conditions. A second edition of MASH was released in 2016 [4], but very little was changed in the evaluation of longitudinal guardrail systems. In an effort to encourage state departments of transportation and hardware developers to advance hardware designs, the Federal Highway Administration (FHWA) and AASHTO collaborated to develop a MASH implementation policy that includes sunset dates for various roadside categories. To date, the MGS installed adjacent to curbs has not been evaluated to the MASH evaluation criteria.

In the late 2000s, the Midwest Pooled Fund Program conducted research to investigate the safety performance of the MGS installed at increased offsets behind a 6-in. AASHTO Type B concrete curb. In the initial phase of the research, a series of vehicle-curb traversal tests, including the 2270P pickup truck, the 1100C small car, and the 2000P pickup truck, were performed at Test Level 3 (TL-3) impact conditions [5]. The results of those vehicle tests combined with computer simulations were used to establish critical MGS-to-curb offset distances. For the second phase of the research, a full-scale crash test was performed on the MGS offset 8 ft behind a 6-in. Type B curb with a top mounting height of 31 in. relative to the ground, or 37 in. relative to the roadway [6]. In the test, the vehicle was contained by the guardrail, but became unstable and rolled over. High-speed video revealed that the right-front tire snagged on a post and detached. The right-rear tire of the pickup truck traversed over the detached tire, causing the rear of the vehicle to pitch upward. The vehicle subsequently became unstable and rolled over. Thus, the MGS offset 8 ft behind a 6-in. high curb was deemed to be unacceptable according to TL-3 of MASH. The final phase of the research consisted of a MASH TL-2 full-scale crash test performed on the MGS offset 6 ft behind a 6-in. high Type B curb with a top mounting height of 31 in. relative to the ground [7]. In the test, the 2270P vehicle was redirected by the guardrail and all safety performance criteria were met. Thus, the MGS offset 6 ft behind a 6-in. tall Type-B curb was deemed to be acceptable according to MASH TL-2.

More recently, testing of the MGS stiffness transition to a thrie-beam approach guardrail transition revealed possible issues with small cars impacting W-beam guardrail over curbs. During testing of the MGS stiffness transition on level terrain (i.e., without a curb present), the 1100C vehicle was contained and redirected [8]. However, when a 4-in. tall wedge shaped curb was placed underneath the stiffness transition and the test was repeated, the system failed as the W-beam segment adjacent to the transition tore and the 1100C vehicle snagged on the downstream posts [9]. Subsequent testing of the stiffness transition incorporating nested W-beam rail adjacent to the W-to-thrie transition segment satisfied all MASH criteria and showed no signs of rail tearing.

Finally, the MGS was recently full-scale crash tested placed 6 in. behind a 6-in. tall curb and with an omitted post located just downstream from the impact point. During MASH test designation no. 3-10 with the 1100C small car, the W-beam rail tore at the splice located within the elongated span length allowing the vehicle to penetrate the system and ultimately roll over [10]. Lateral impact loads combined with vertical loads from the vehicle's bumper pushing upward as the front wheel overrode the curb were believed to cause the premature rail rupture. Similar to the modification made to the transition with curb system, when nested W-beam was placed around the location of the omitted post, the system satisfied MASH TL-3 criteria.

Based on the crash testing results of these previous research studies, full-scale crash testing of the standard MGS installed over a 6-in. tall, AASHTO Type B curb was recommended to verify the crashworthiness of the system according to MASH TL-3 evaluation criteria.

1.2 Objective

The objective of this research is to conduct full-scale vehicle crash testing according to MASH 2016 TL-3 conditions on the MGS installed with the face of rail offset 6 in. behind a 6-in. tall AASHTO Type B curb.

1.3 Scope

The research objective was achieved through the completion of several tasks. Design drawings of the MGS installed with the face of the rail located 6 in. behind a 6-in. tall AASHTO Type B curb were developed. The system was constructed at the MwRSF outdoor test site, and two full-scale crash tests were conducted on the system according to MASH 2016 test designation nos. 3-10 and 3-11. Full-scale crash test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made pertaining to the safety performance of the MGS guardrail installed in combination with a 6-in. tall AASHTO Type B Curb.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as W-beam guardrails, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the FHWA for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [4]. Note that there is no difference between MASH 2009 [3] and MASH 2016 for longitudinal barriers, such as the MGS, except that additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016. According to TL-3 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1. Critical impact points for the tests were selected using the plots in Section 2.3.2.1 of MASH 2016.

Table 1. MASH 2016 TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight (lb)	Impact Conditions		Evaluation Criteria [1]
				Speed (mph)	Angle (deg.)	
Longitudinal Barrier	3-10	1100C	2,425	62	25	A,D,F,H,I
	3-11	2270P	5,000	62	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

2.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the W-beam guardrail with curb system to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH 2016. The full-scale vehicle crash test documented herein was conducted and reported in accordance with the procedures provided in MASH 2016.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported. Additional discussion on PHD, THIV and ASI is provided in MASH 2016.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="11">Occupant Risk</td><td>D.</td><td colspan="3">1. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.
2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s</td><td>40 ft/s</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

2.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, W6x16 posts are installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips at post deflections between 5 and 20 in. measured at a height of 25 in. above the ground line. If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted instead and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90% of the static baseline test at deflections of 5, 10, and 15 in. Further details can be found in Appendix B of MASH 2016.

3 DESIGN DETAILS

3.1 Test No. MGSC-7

The test installation for test no. MGSC-7 consisted of 182 ft – 3½ in. of standard W-beam guardrail positioned 6 in. behind a 6-in. tall curb. Installation details are shown in Figures 1 through 13, and photographs of the test installations are shown in Figures 14 and 15. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The nominal top rail mounting height for the system was 31 in. However, to evaluate small car underride and snag on the guardrail posts, the guardrail for test no. MGSC-7 was installed at a height of 32 in. above the roadway surface. The 12-gauge W-beam rail segments were spliced in an orientation to reduce vehicle snag potential and supported by twenty-nine guardrail posts. Post nos. 3 through 27 were 72-in. long, galvanized, ASTM A992, W6x8.5 steel sections spaced at 75 in. on center. Because the rail height was increased 1 in. over nominal, the posts were embedded 45 in. into the crushed limestone soil instead of the nominal 46 in. embedment depth. Southern Yellow Pine wood blockouts that measured 6 in. x 12 in. x 14¼ in. were used to offset the guardrail from the face of the posts.

The 6-in. tall, AASHTO Type B curb extended between post nos. 9 and 20 and was located with the center of the face of the curb 6 in. in front of the face edge of the W-beam. Soil backfill was added behind the curb such that the ground line was flush with the top of the curb. The curb was poured with a 4-ft wide by 4-in. thick approach slab. All concrete components had a minimum compressive strength of 4,000 psi. The curb was reinforced by a single #4 rebar.

The upstream and downstream ends of the guardrail installation were configured with a non-proprietary end anchorage system [11-14]. The guardrail anchorage system had a comparable strength to other crashworthy end terminals. The anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts.

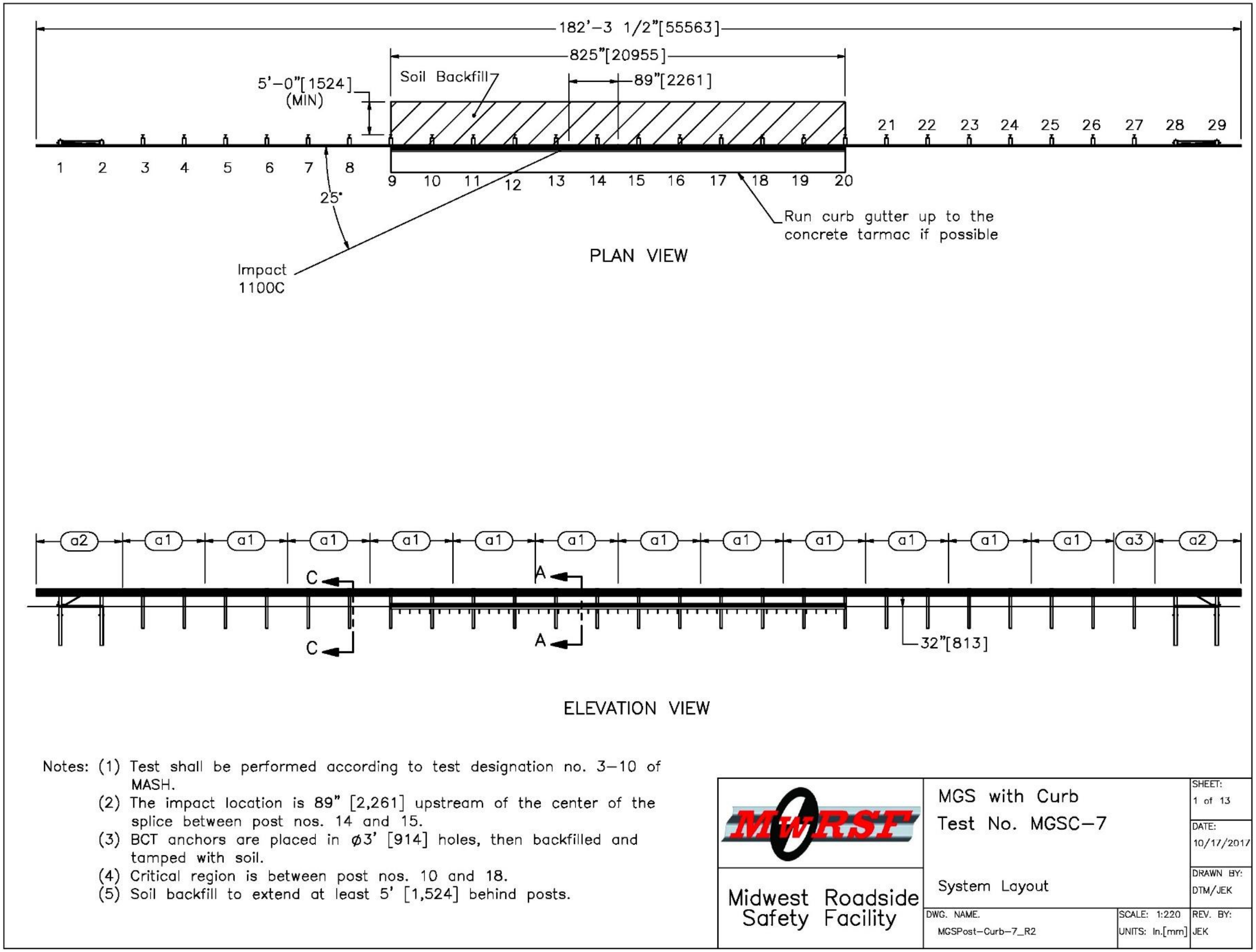


Figure 1. System Layout, Test No. MGSC-7

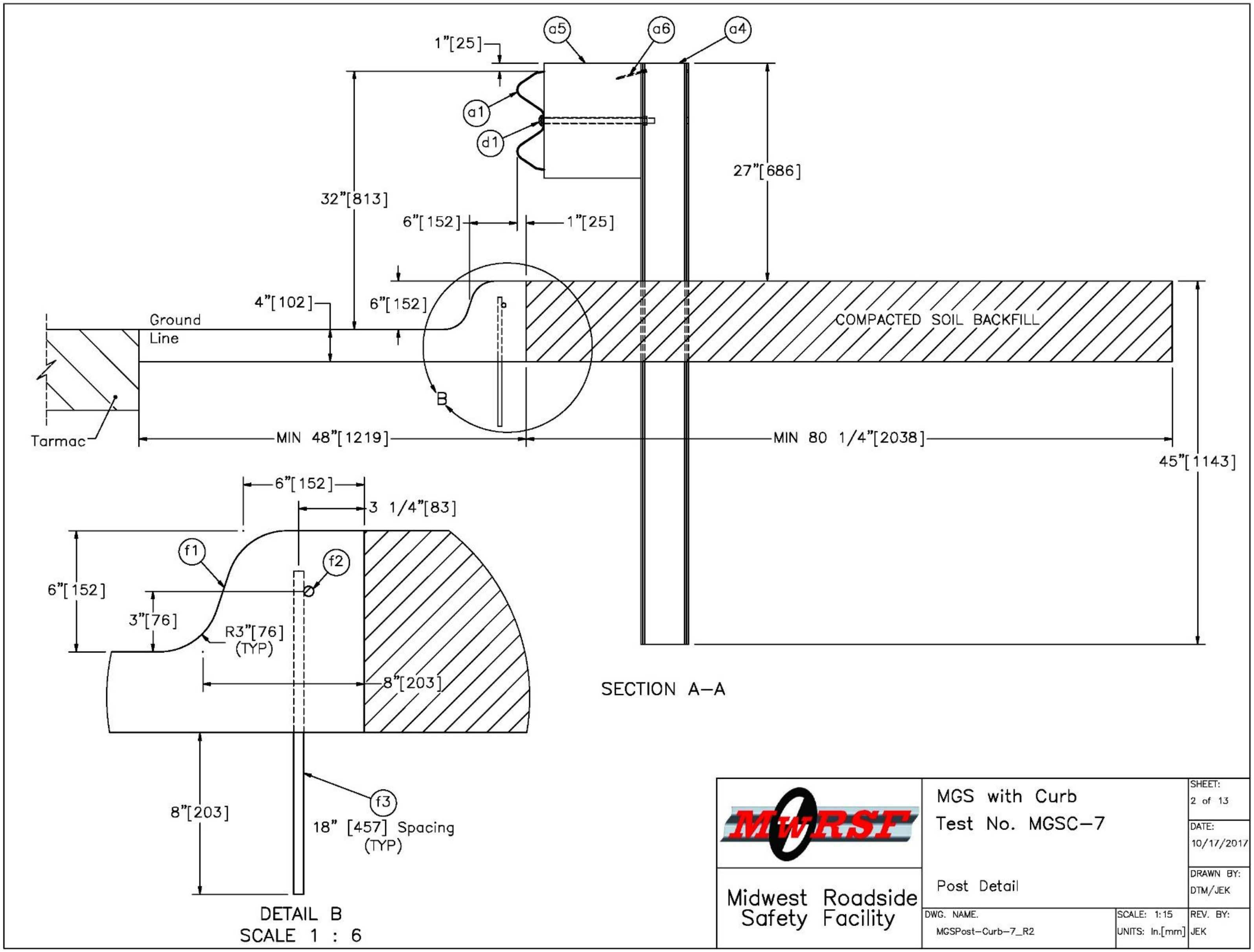


Figure 2. Post Detail, Test No. MGSC-7

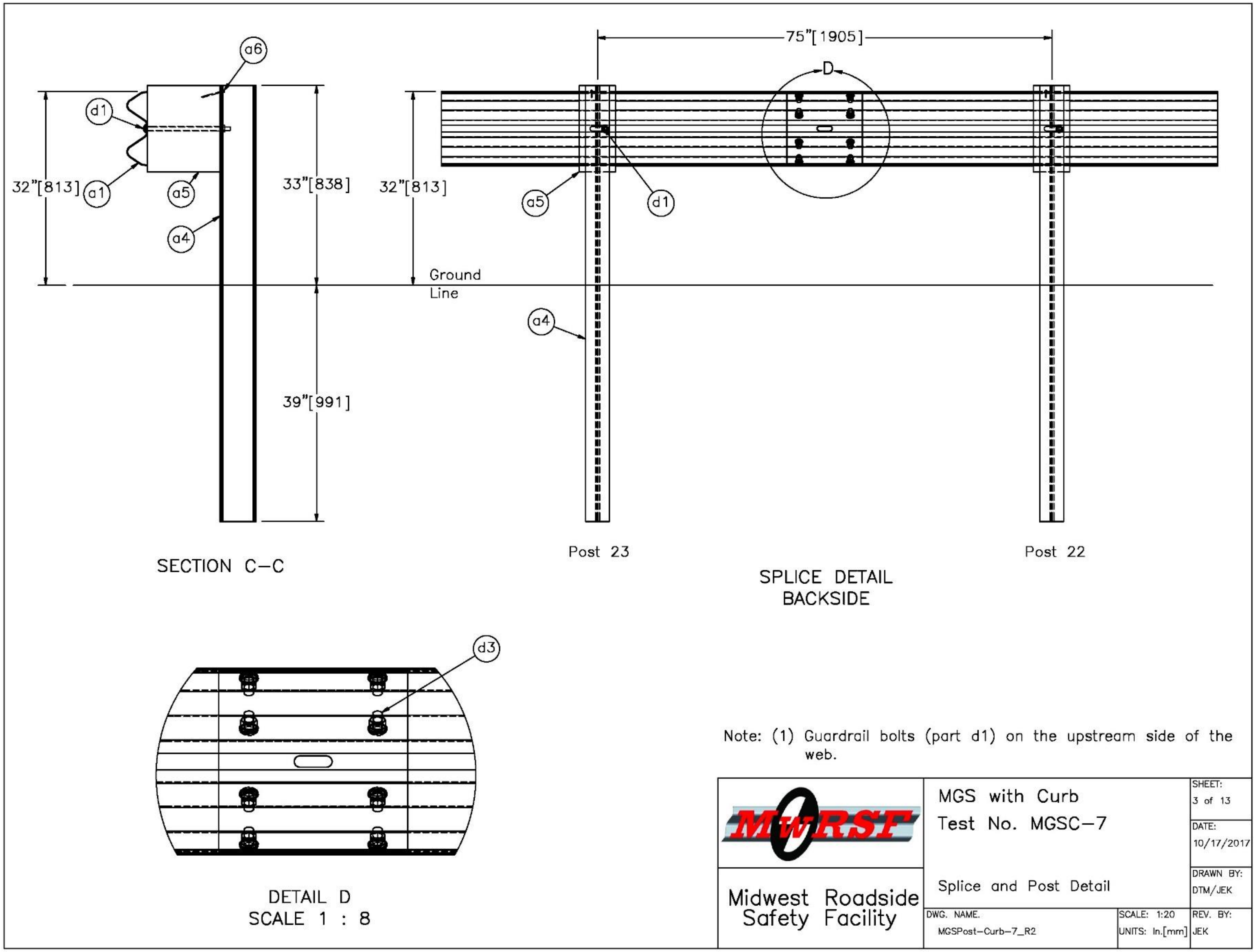


Figure 3. Splice and Post Detail, Test No. MGSC-7

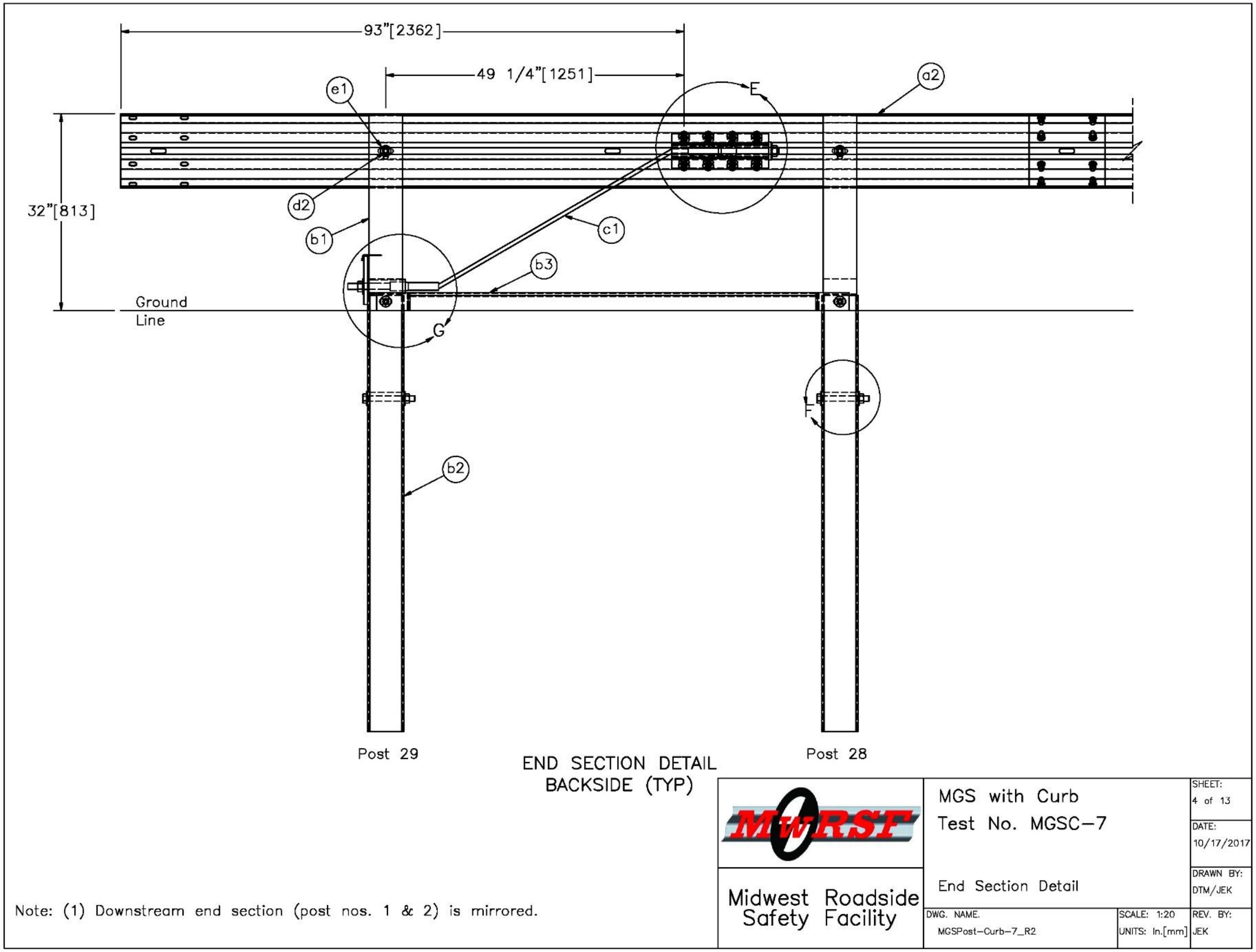


Figure 4. End Section Detail, Test No. MGSC-7

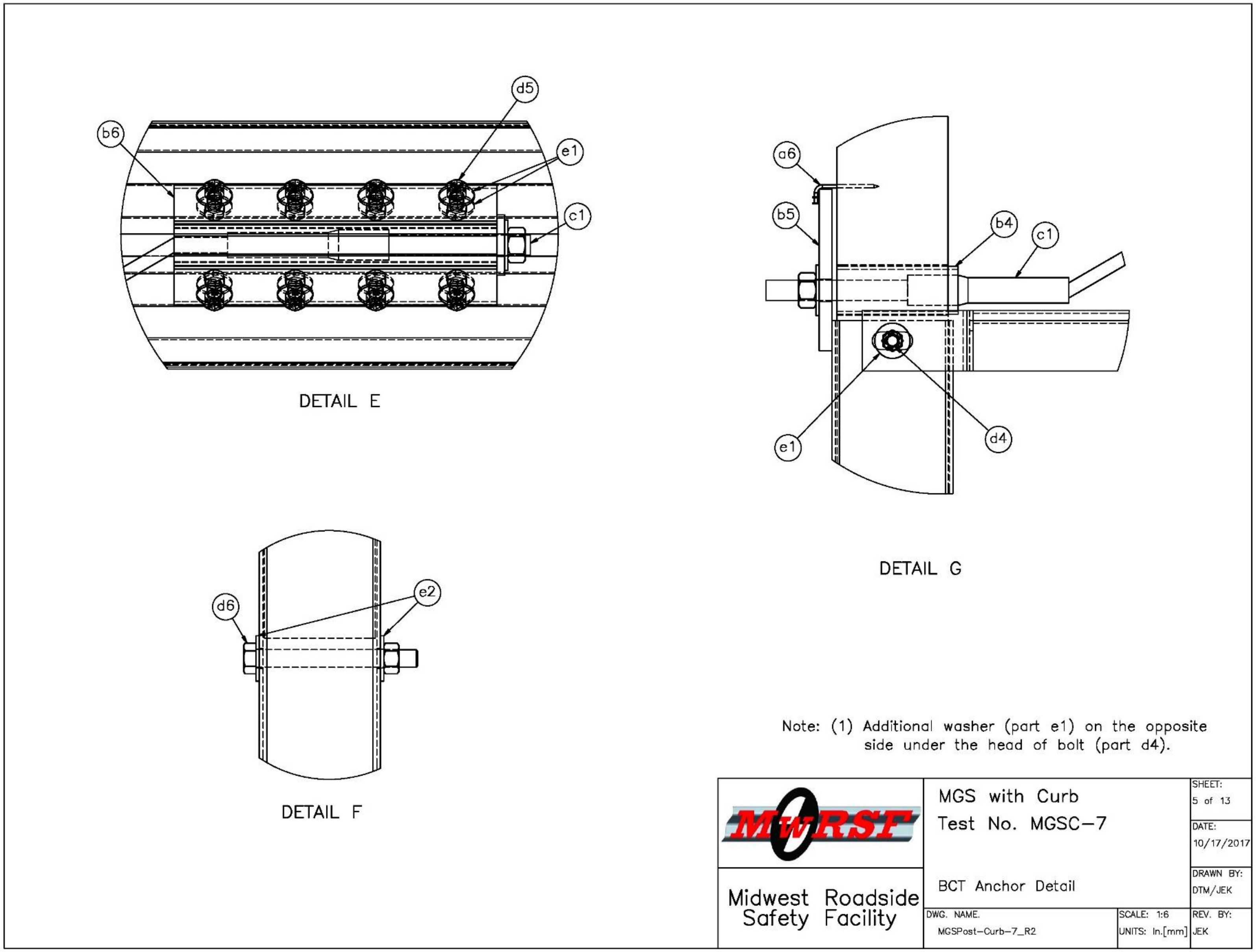


Figure 5. BCT Anchor Detail, Test No. MGSC-7

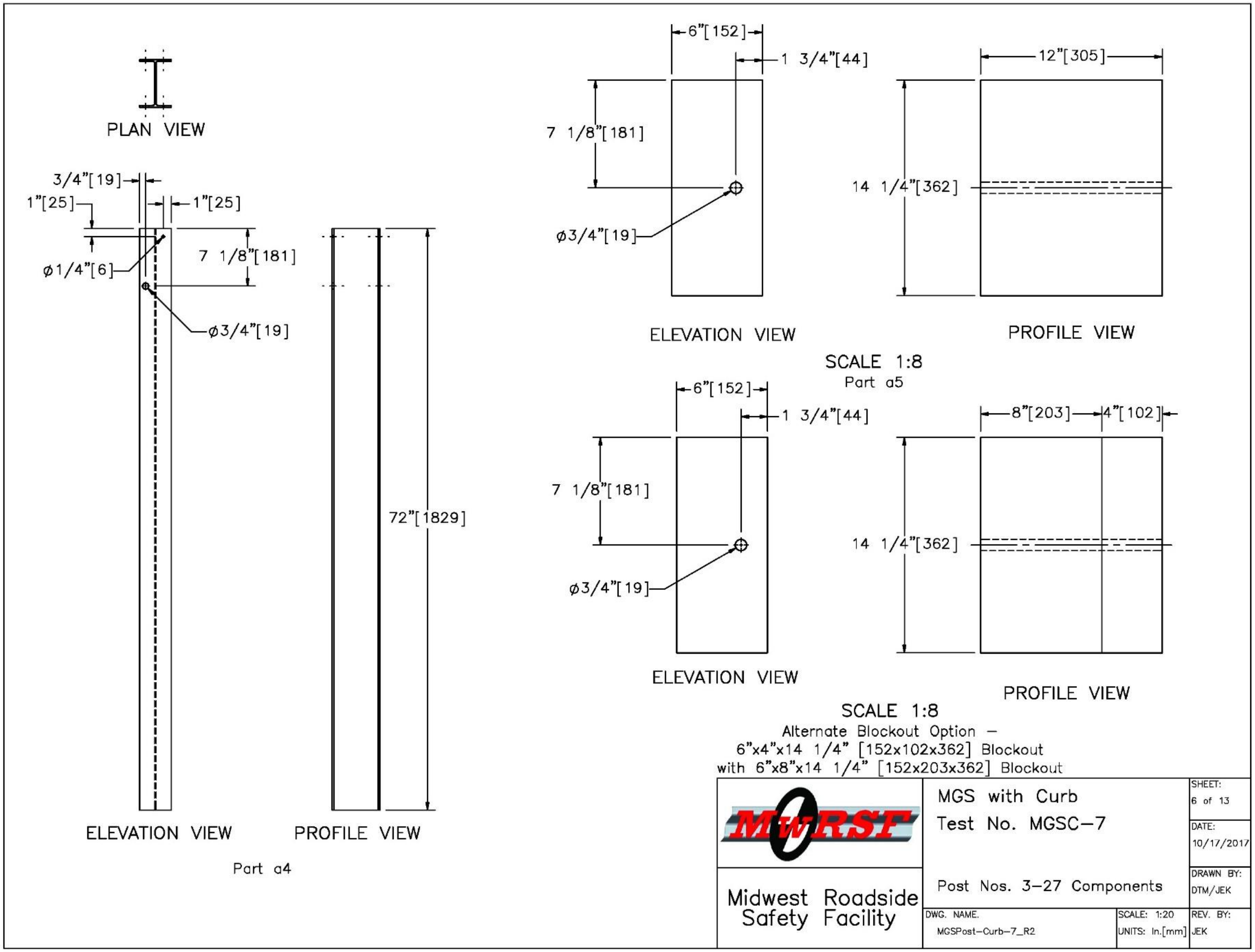


Figure 6. Post Nos. 3 through 27 Components, Test No. MGSC-7

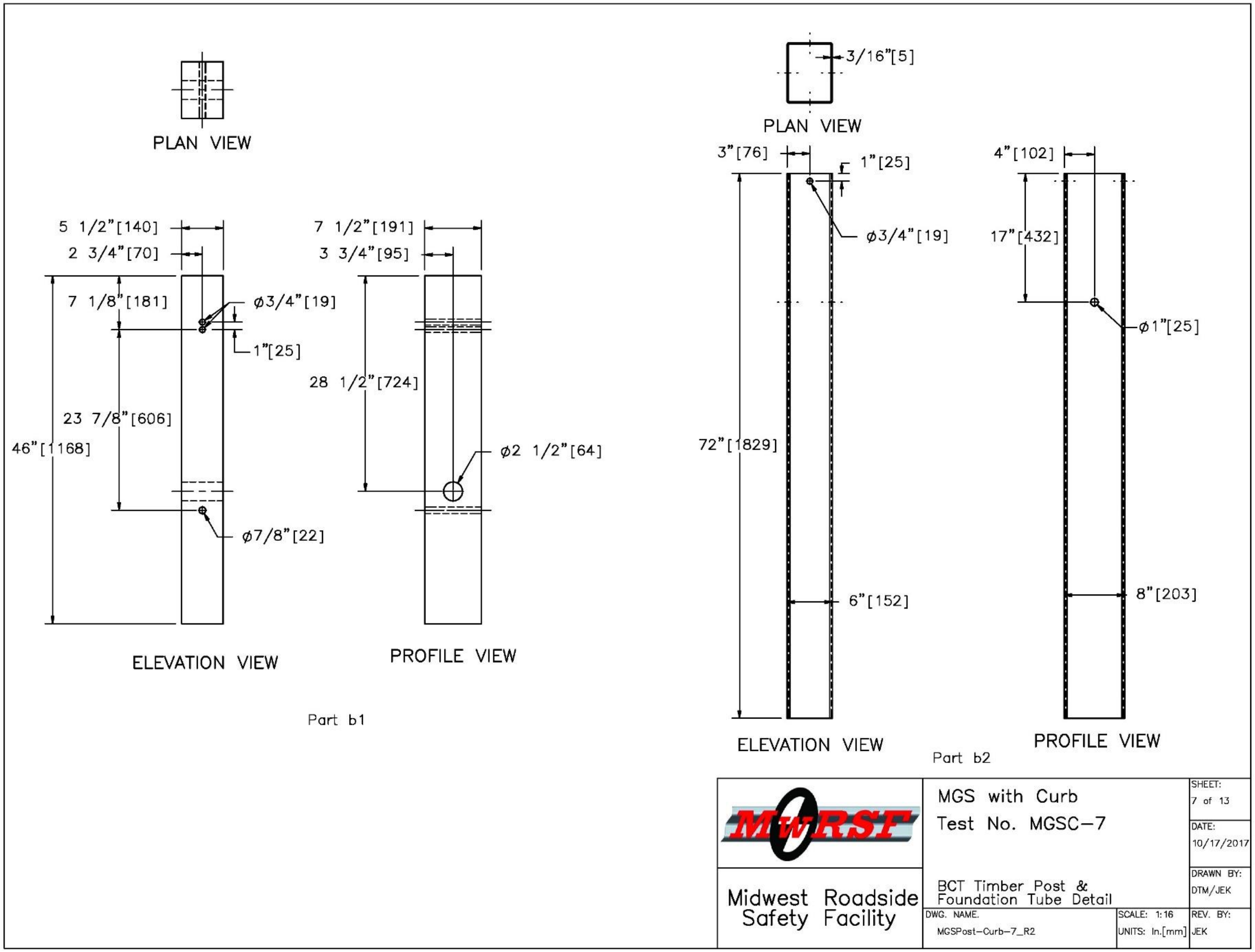


Figure 7. BCT Timber Post and Foundation Tube Detail, Test No. MGSC-7

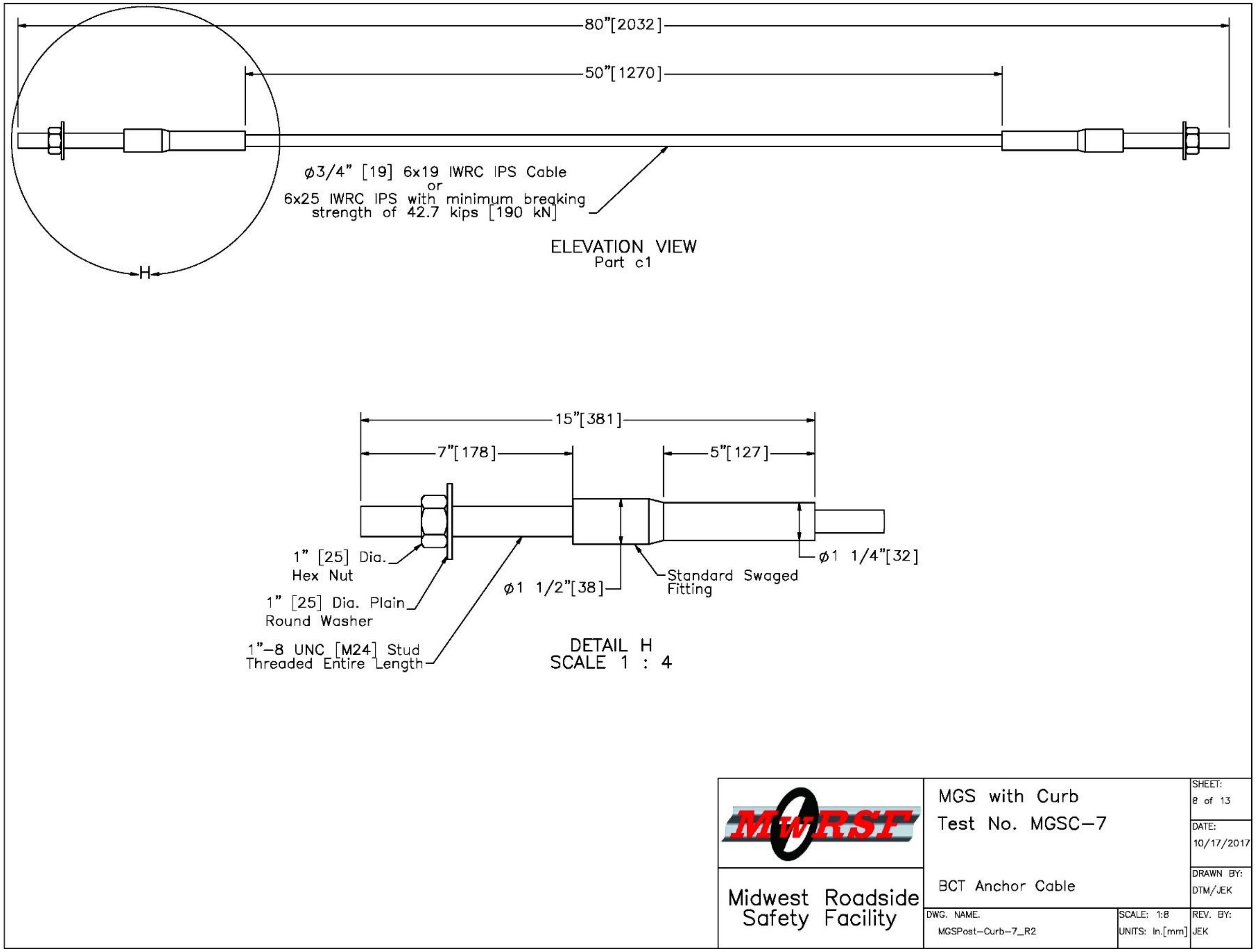


Figure 8. BCT Anchor Cable, Test No. MGSC-7

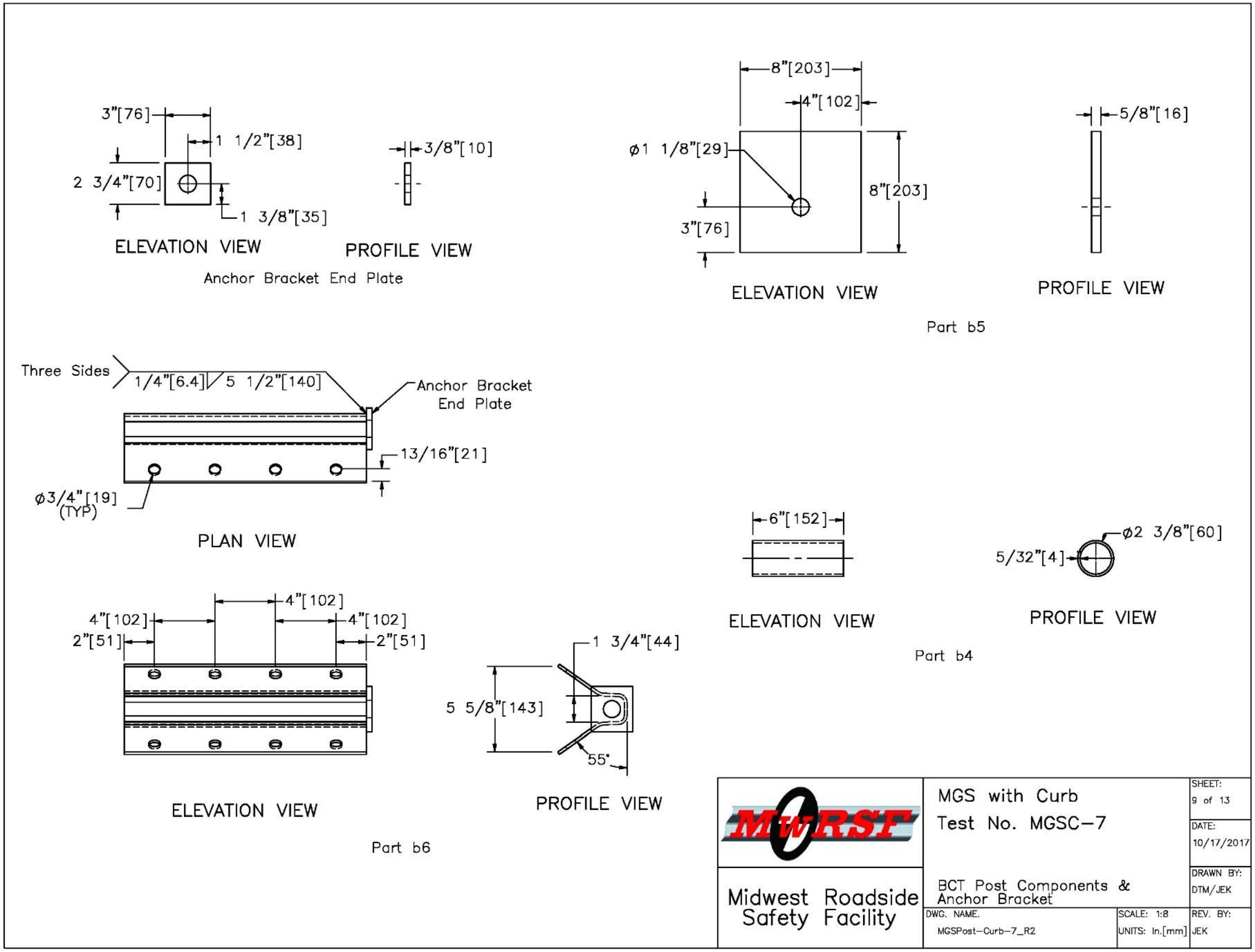


Figure 9. BCT Post Components and Anchor Bracket, Test No. MGSC-7

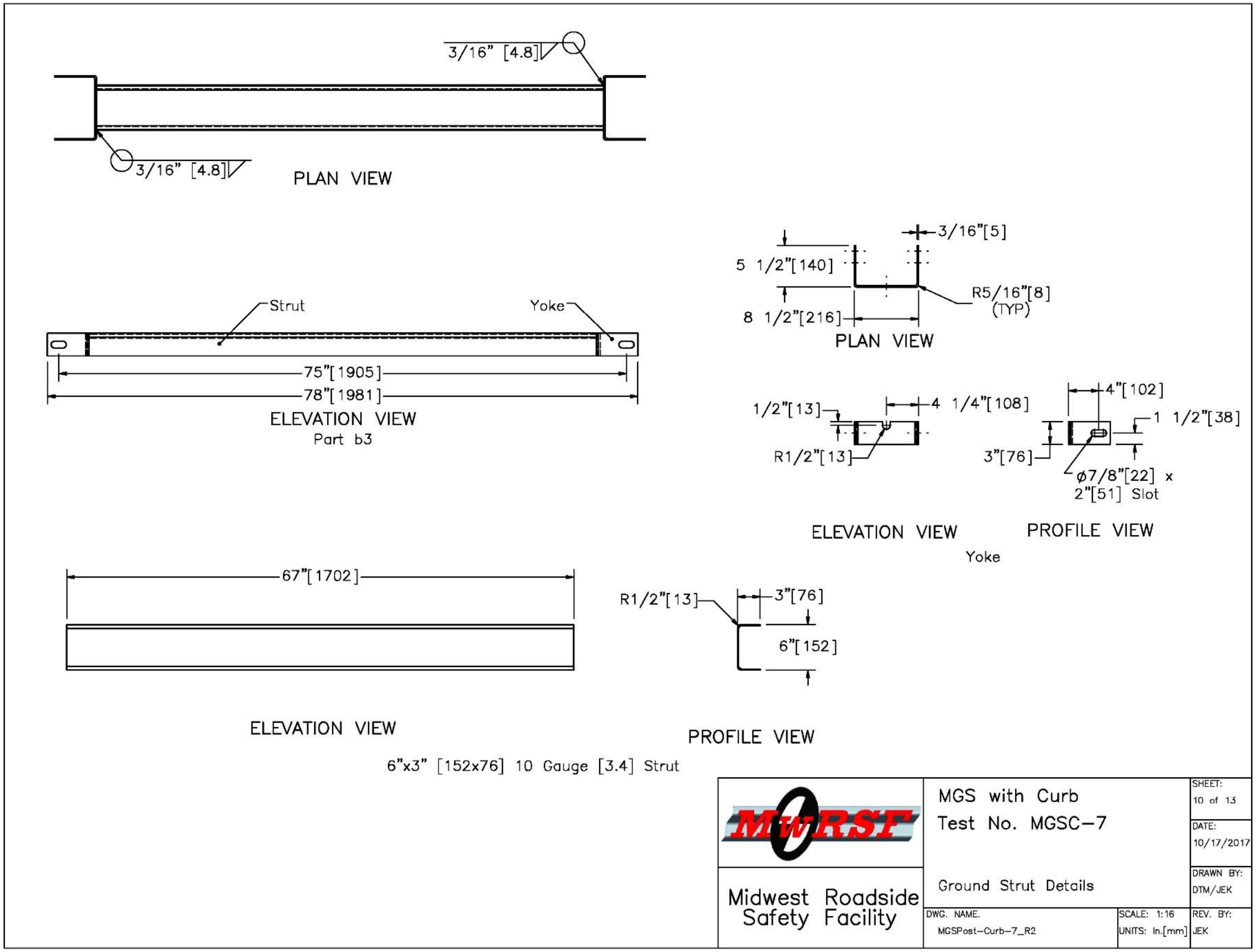


Figure 10. Ground Strut Details, Test No. MGSC-7

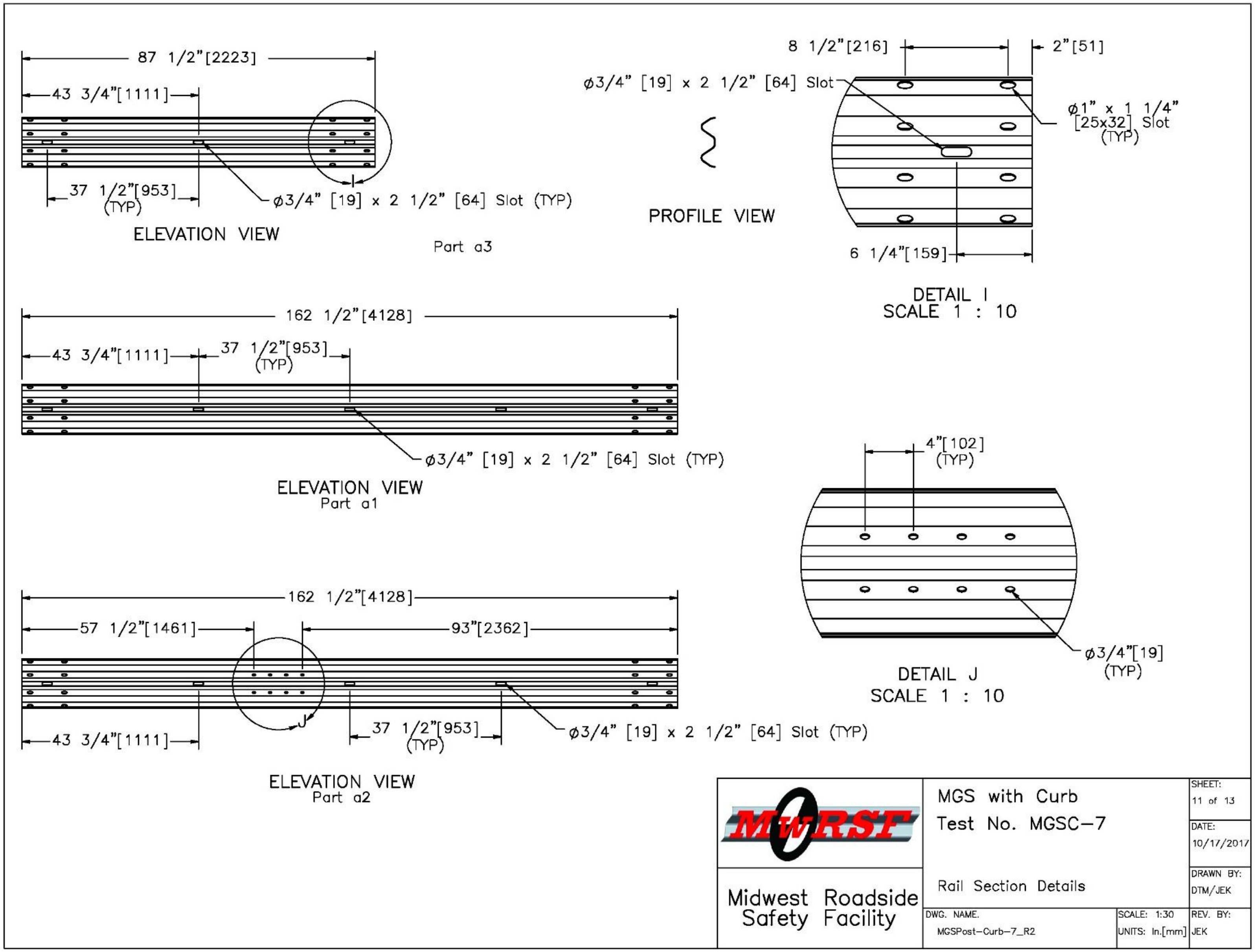


Figure 11. Rail Section Details, Test No. MGSC-7

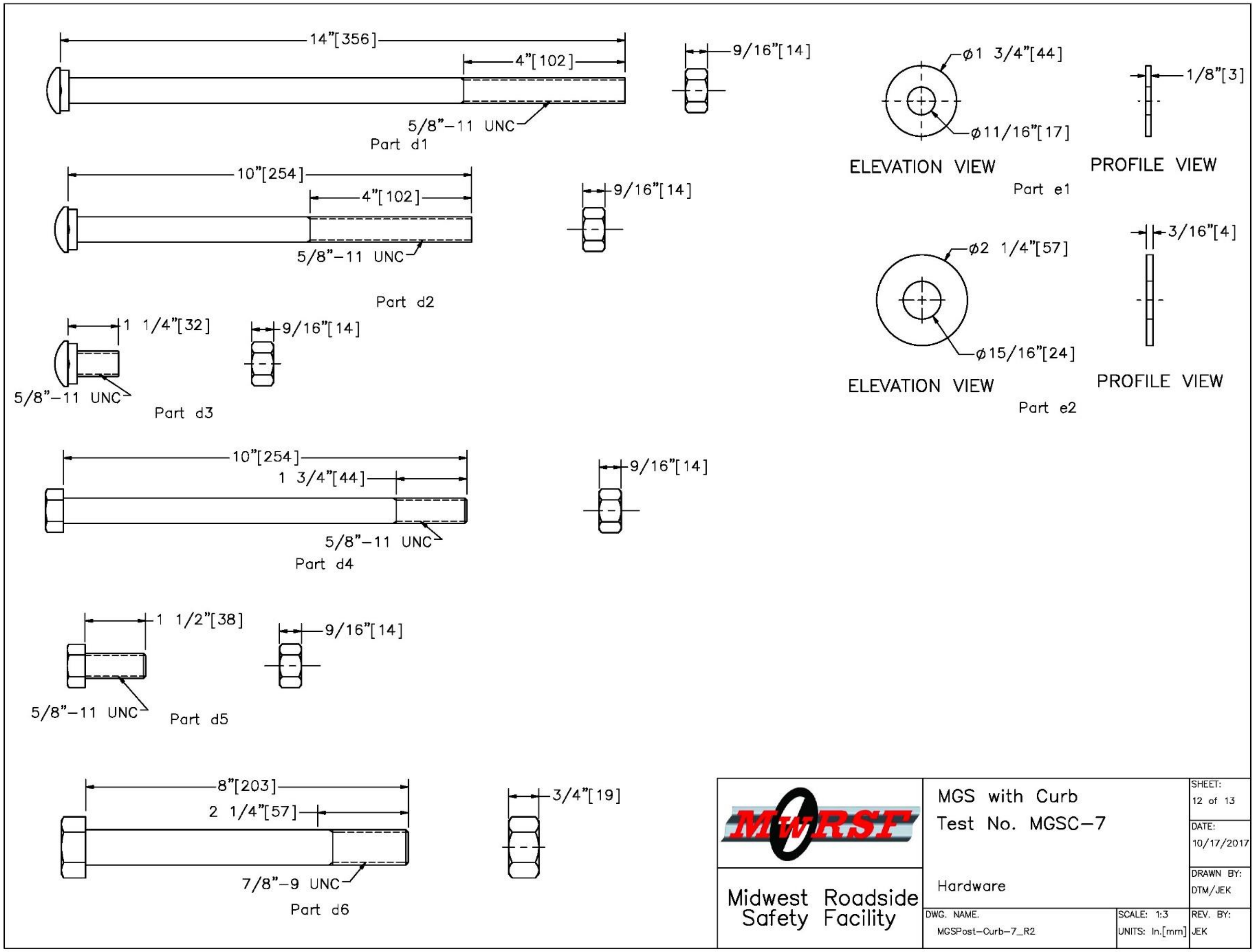


Figure 12. Hardware, Test No. MGSC-7

Item No.	QTY.	Description	Material Specification	Galvanization Specification	Hardware Guide
a1	12	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a2	2	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A123 or A653	RWM14a
a3	1	6'–3" [1,905] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a4	25	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa]	ASTM A123	PWE06
a5	25	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
a6	25	16D Double Head Nail	–	–	–
b1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	–	PDF01
b2	4	72" [1829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	PTE06
b3	2	Ground Strut Assembly	ASTM A36	ASTM A123	PFP02
b4	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	FMM02
b5	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
b6	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
c1	2	BCT Anchor Cable	–	–	FCA01
d1	25	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB06
d2	4	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB03
d3	112	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB01
d4	4	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
d5	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
d6	4	7/8" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	–
e1	44	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
e2	8	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
f1	1	Curb	f'c = 4,000 psi [27.6 MPa]	–	–
f2	1	#4 Rebar 819" [20,803] Long	ASTM A615 Gr. 60	–	–
f3	45	#4 Rebar 16" [406] Long	ASTM A615 Gr. 60	–	–

Midwest Roadside Safety Facility

MGS with Curb
Test No. MGSC–7

Bill of Materials

SHEET: 13 of 13
DATE: 10/17/2017
DRAWN BY: DTM/JEK
REV. BY: JEK
DWG. NAME. MGSPost–Curb–7_R2
SCALE: None
UNITS: In.[mm]

Figure 13. Bill of Materials, Test No. MGSC-7

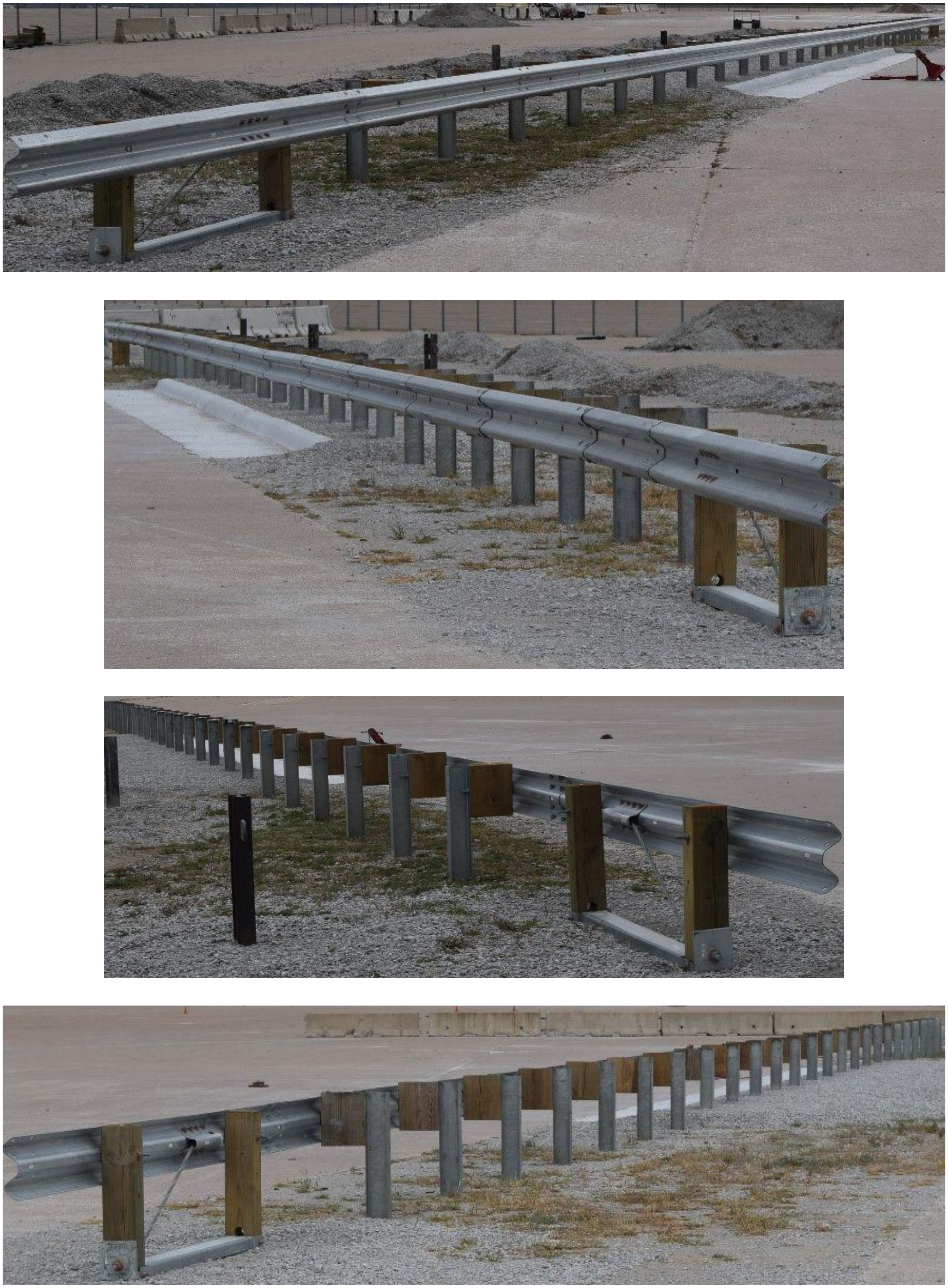


Figure 14. Test Installation Photographs, Test No. MGSC-7

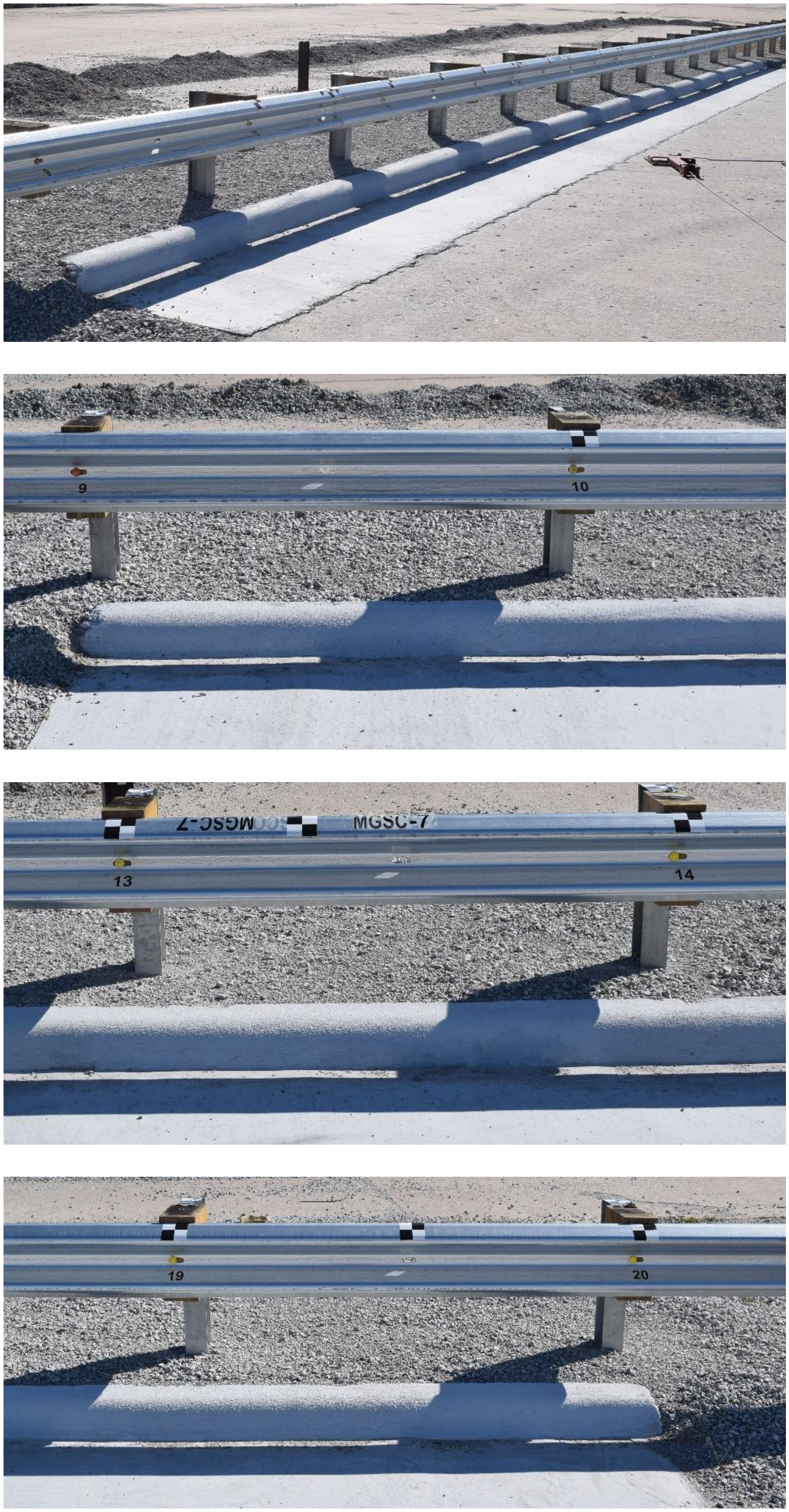


Figure 15. Test Installation Photographs, Test No. MGSC-7

3.2 Test No. MGSC-8

The test article for test no. MGSC-8 was nearly identical to that of test no. MGSC-7. The only differences were that in test no. MGSC-8 the rail was mounted at its nominal 31-in. height and the posts were at their nominal embedment depth of 46 in. All components remained identical between the two test installations. Installation details for test no. MGSC-8 are shown in Figures 16 through 28, and photographs of the test installations are shown in Figures 29 and 30. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

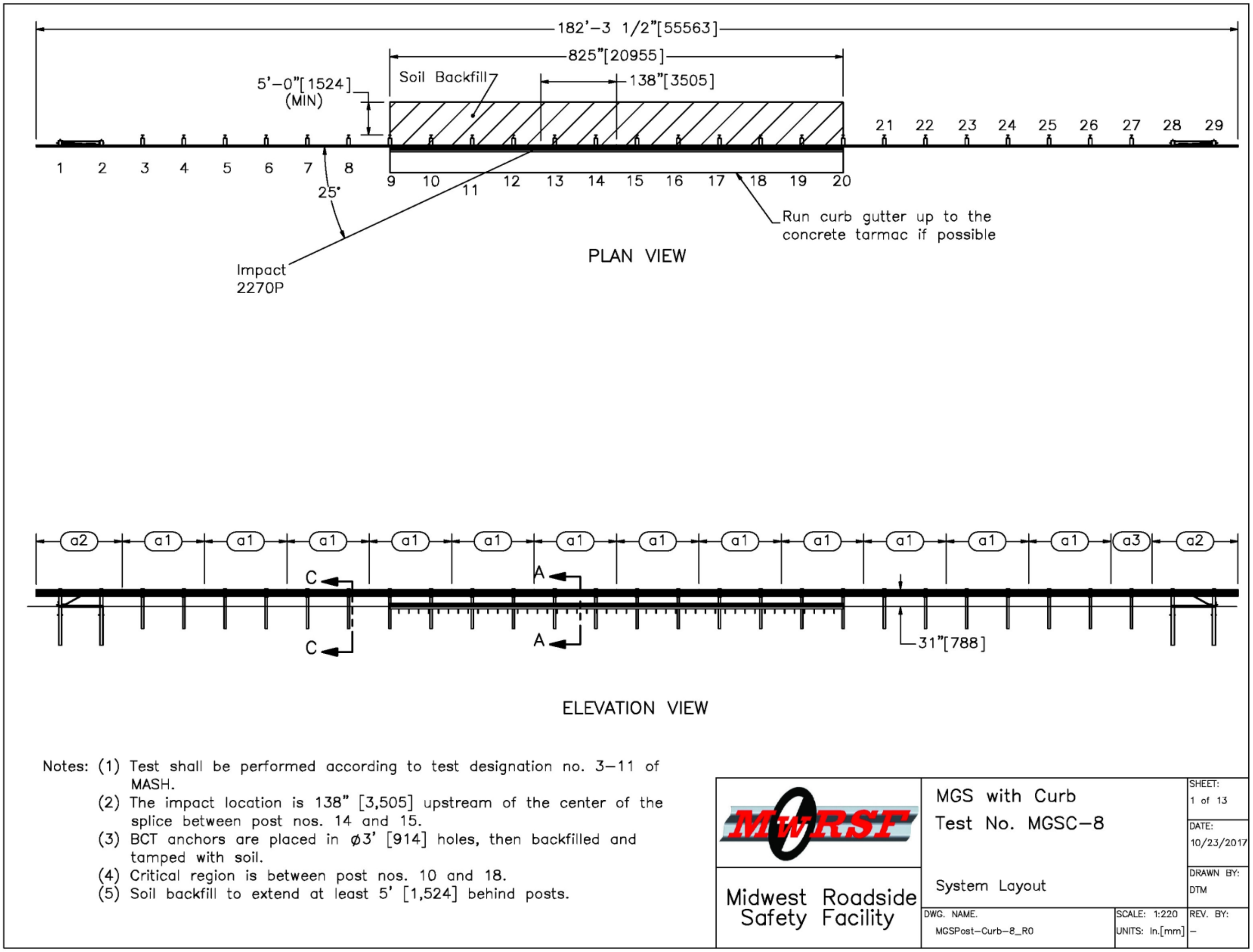


Figure 16. System Layout, Test No. MGSC-8

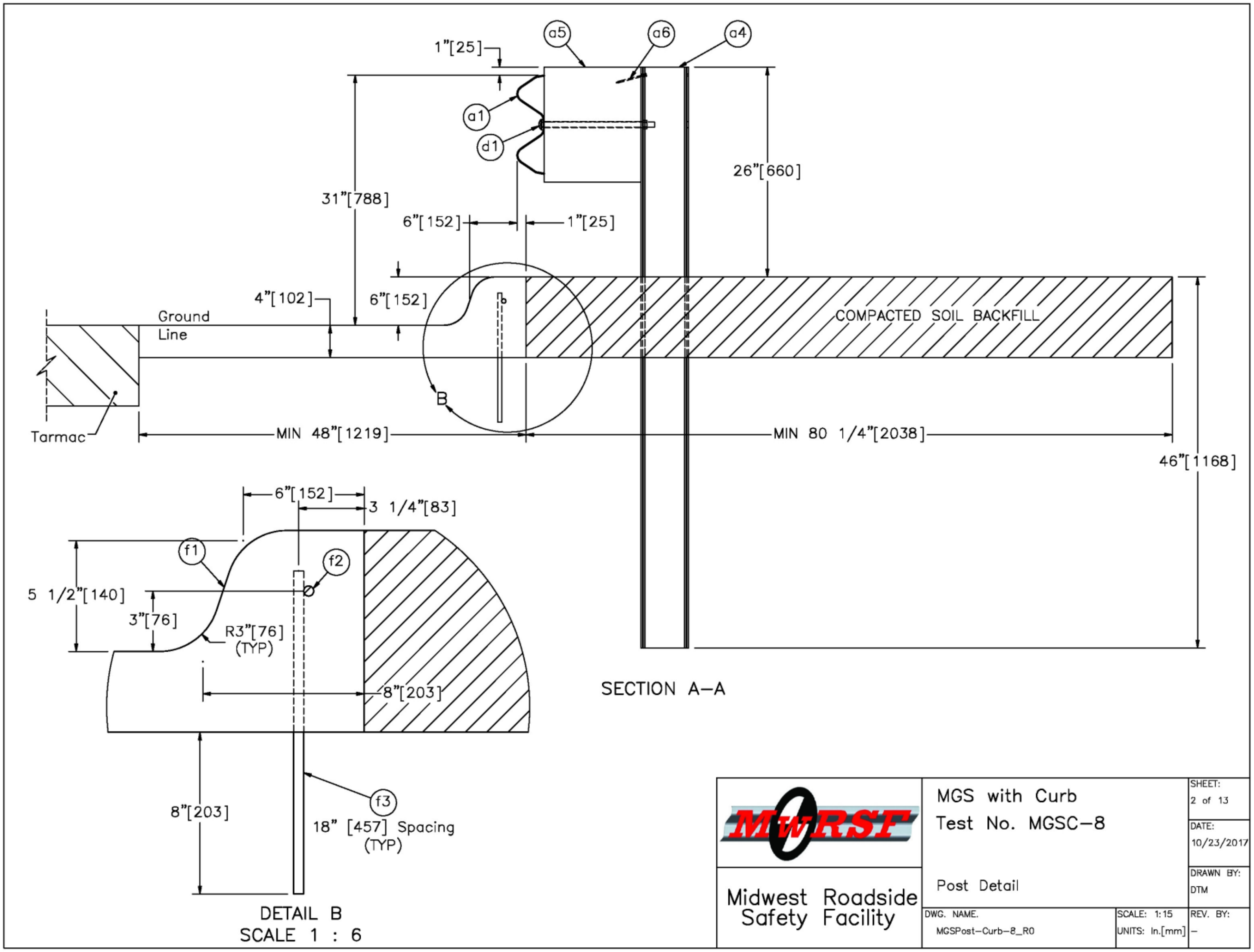


Figure 17. Post Detail, Test No. MGSC-8

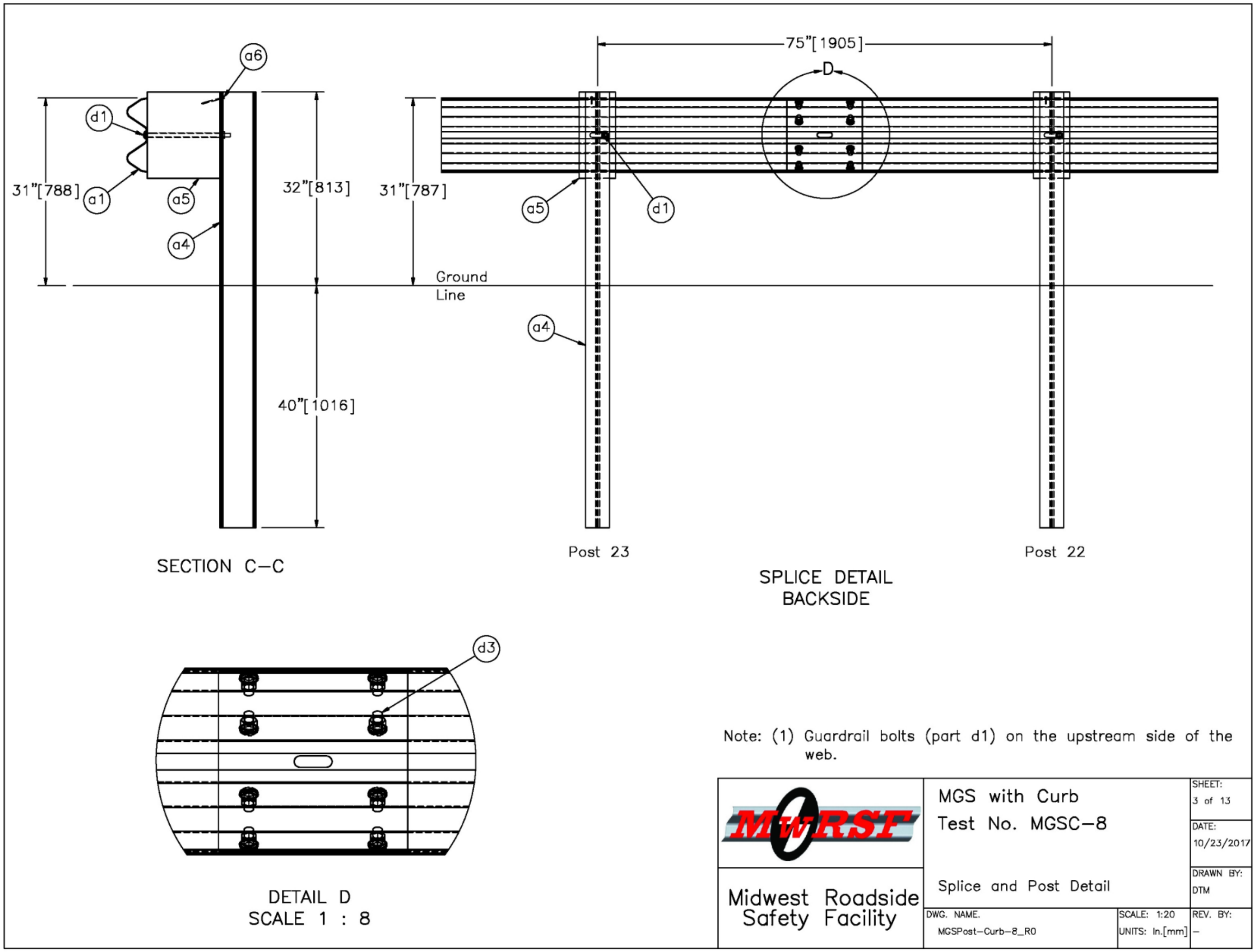


Figure 18. Splice and Post Detail, Test No. MGSC-8

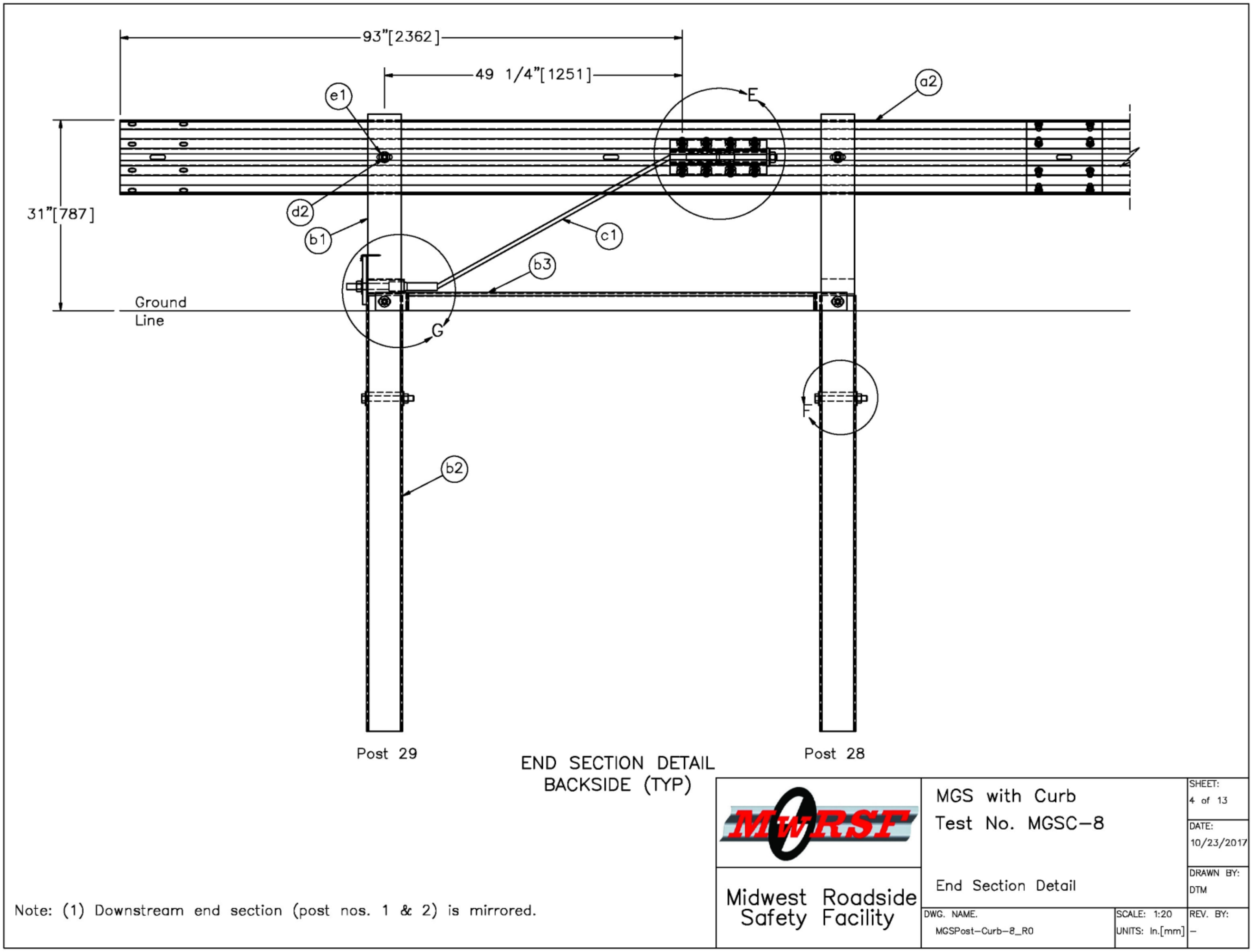


Figure 19. End Section Detail, Test No. MGSC-8

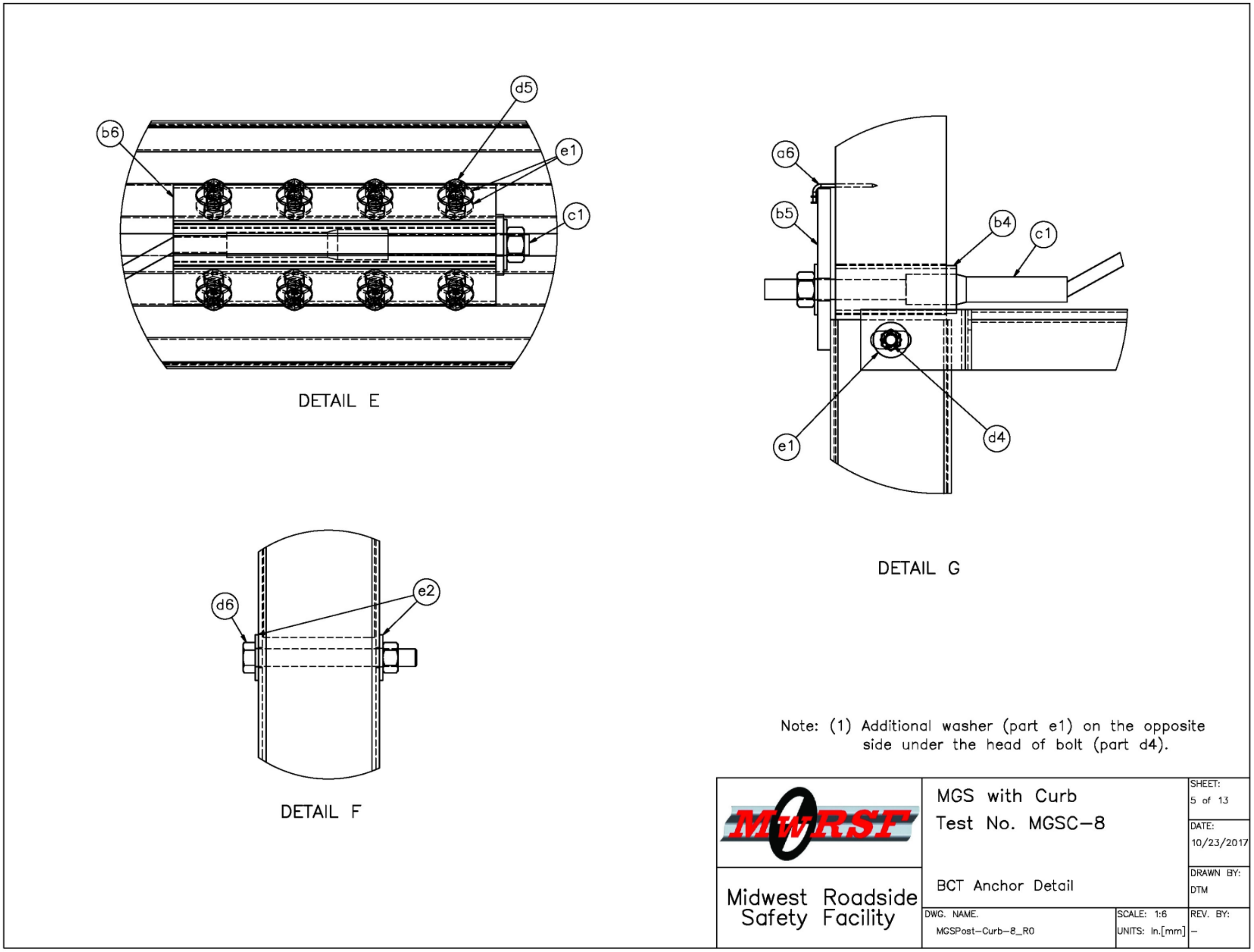


Figure 20. BCT Anchor Detail, Test No. MGSC-8

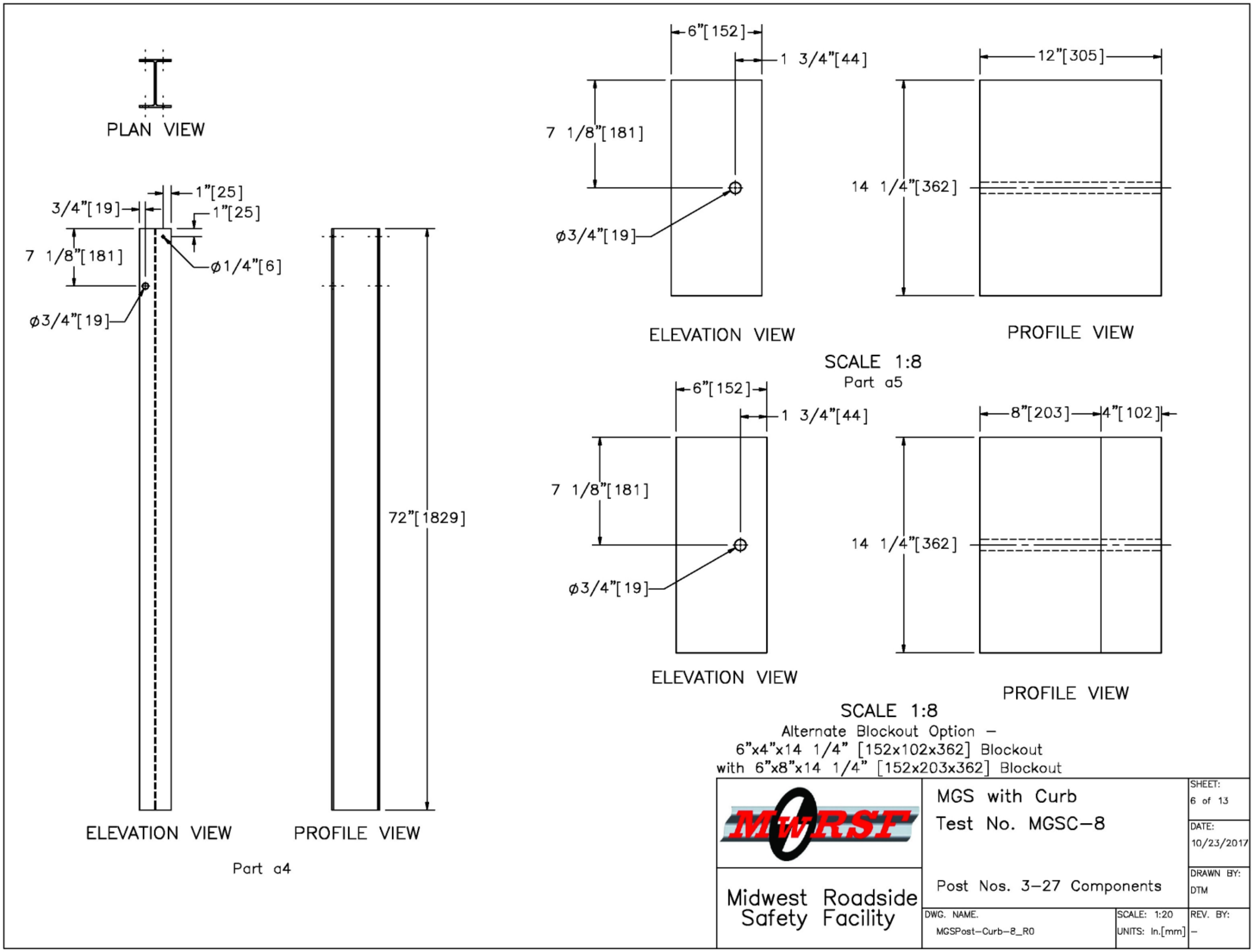


Figure 21. Post Nos. 3 through 27 Components, Test No. MGSC-8

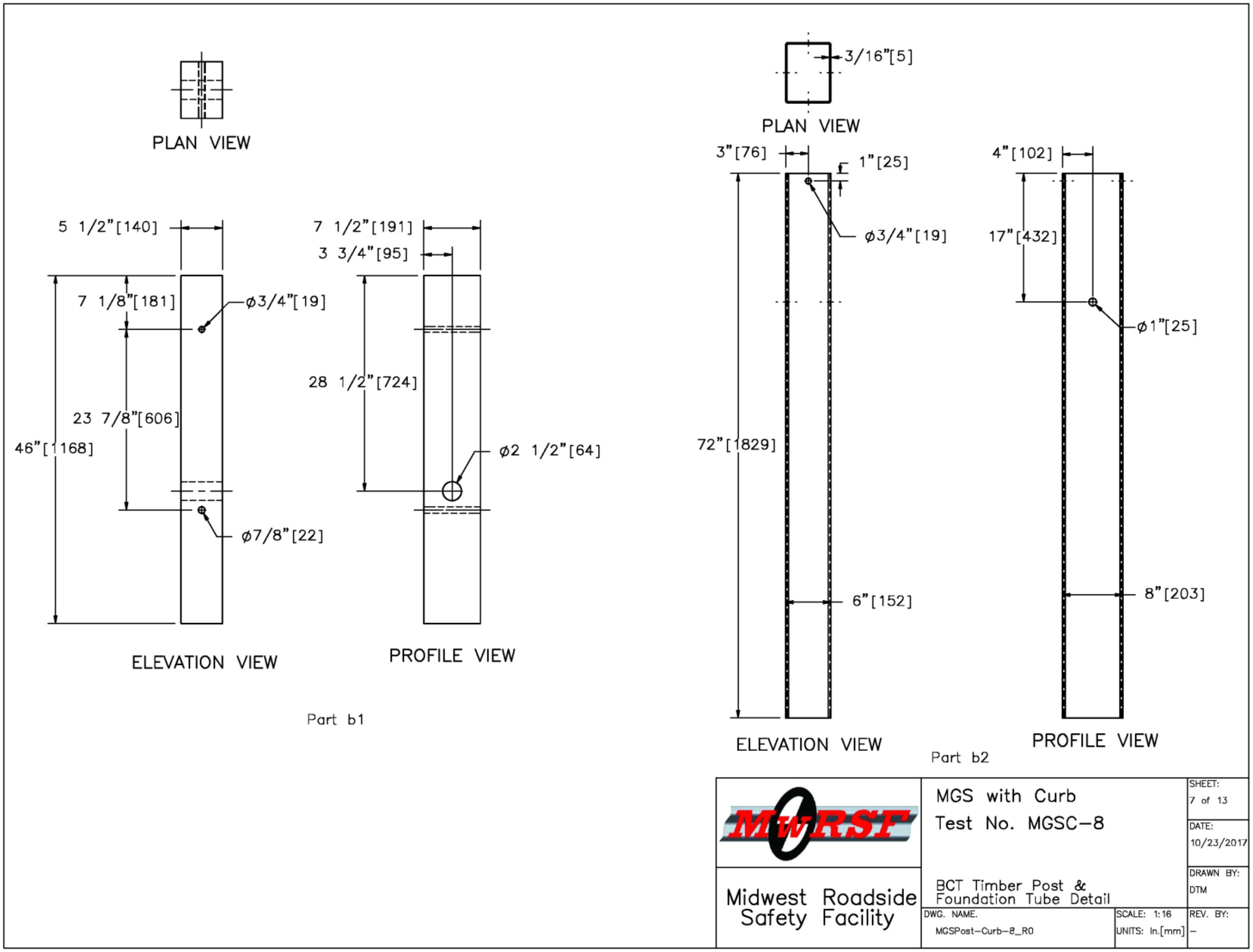


Figure 22. BCT Timber Post and Foundation Tube Detail, Test No. MGSC-8

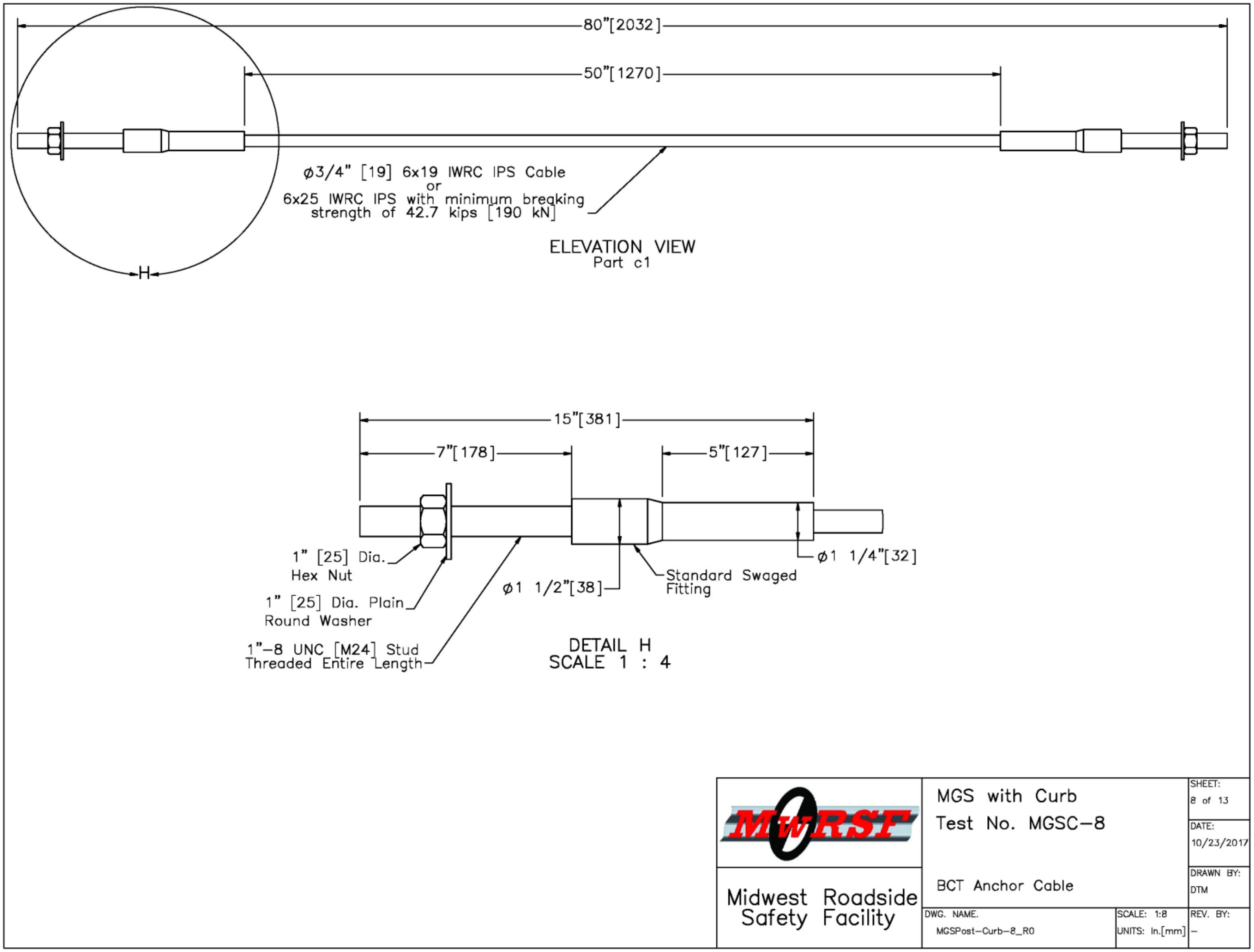


Figure 23. BCT Anchor Cable, Test No. MGSC-8

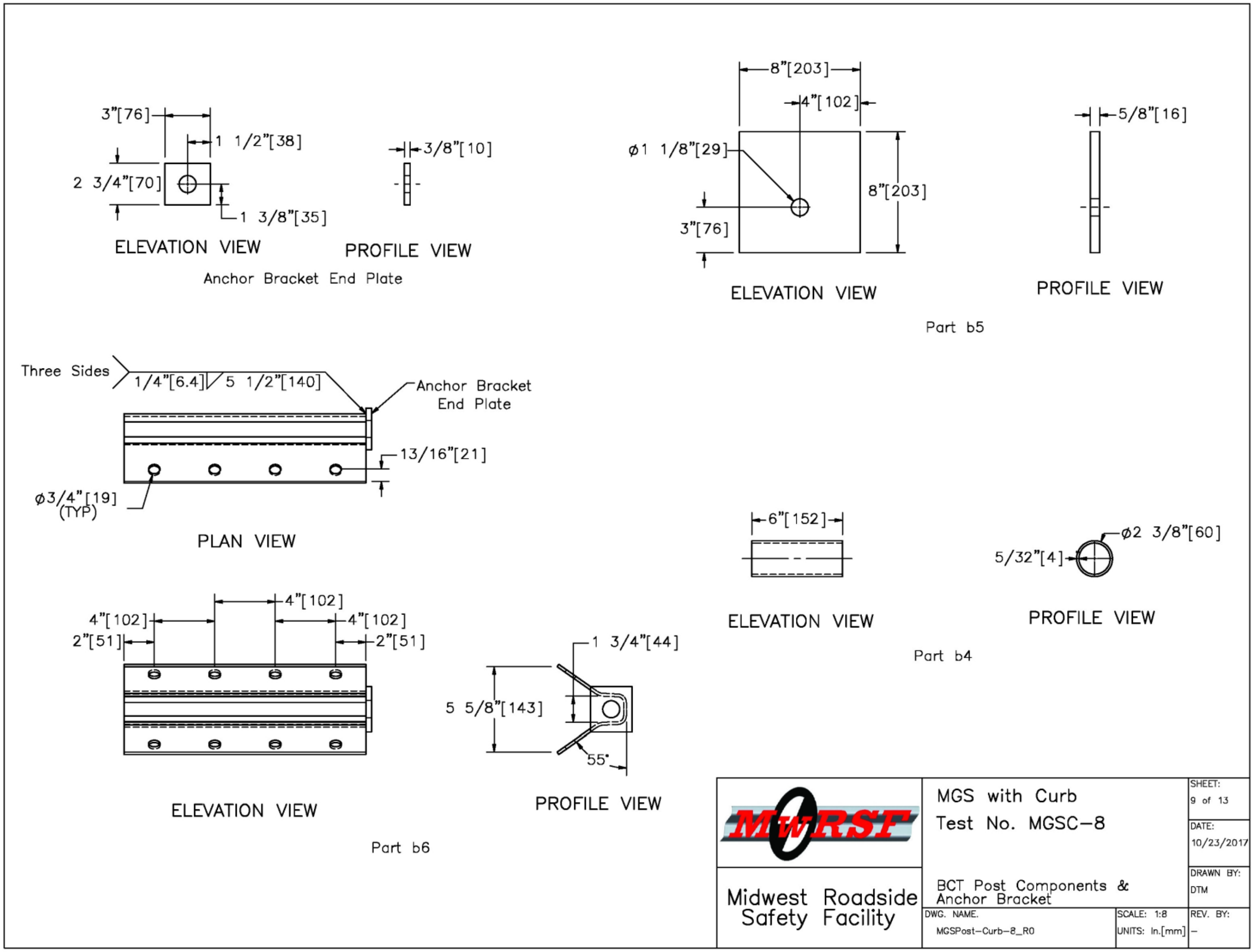


Figure 24. BCT Post Components and Anchor Bracket, Test No. MGSC-8

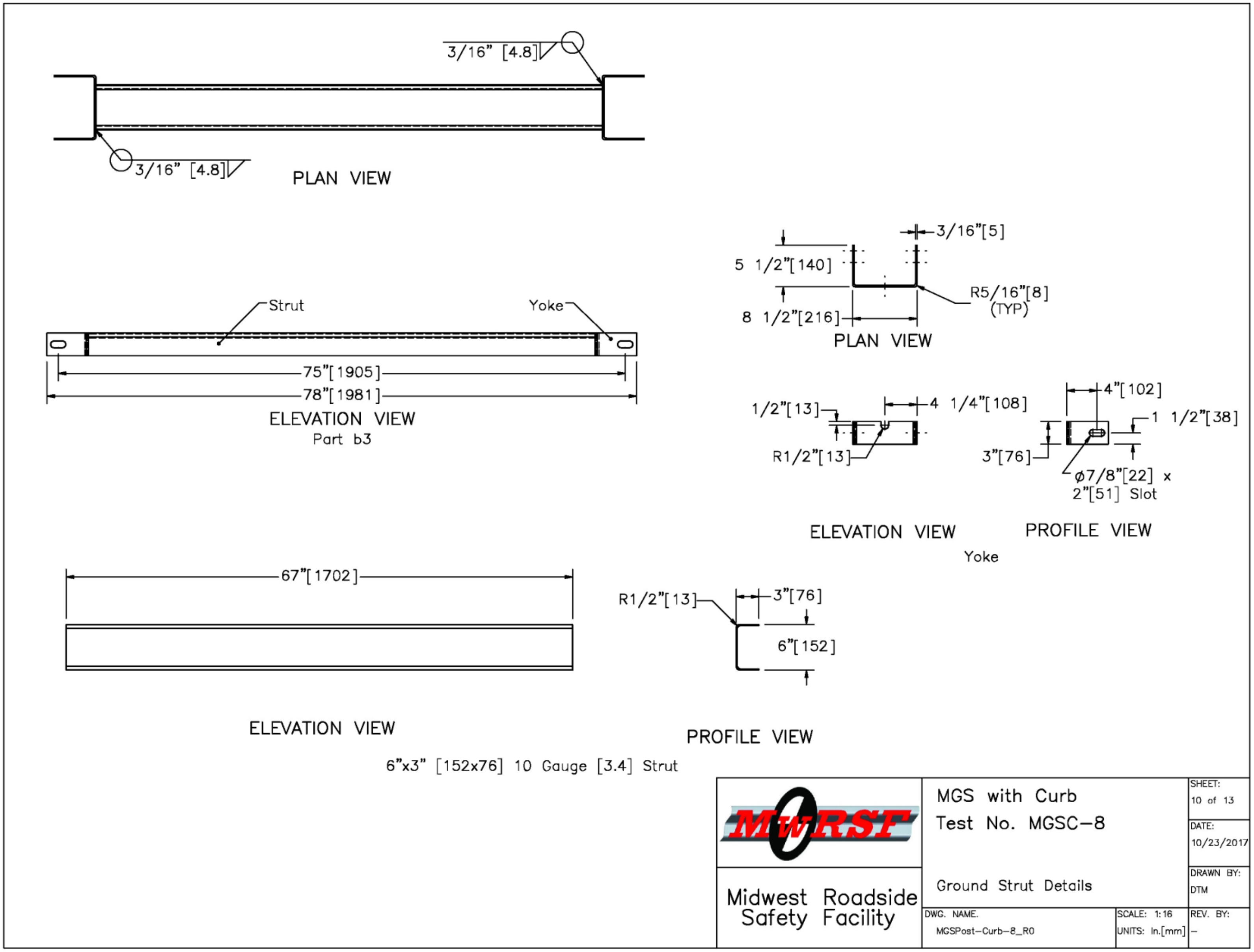


Figure 25. Ground Strut Details, Test No. MGSC-8

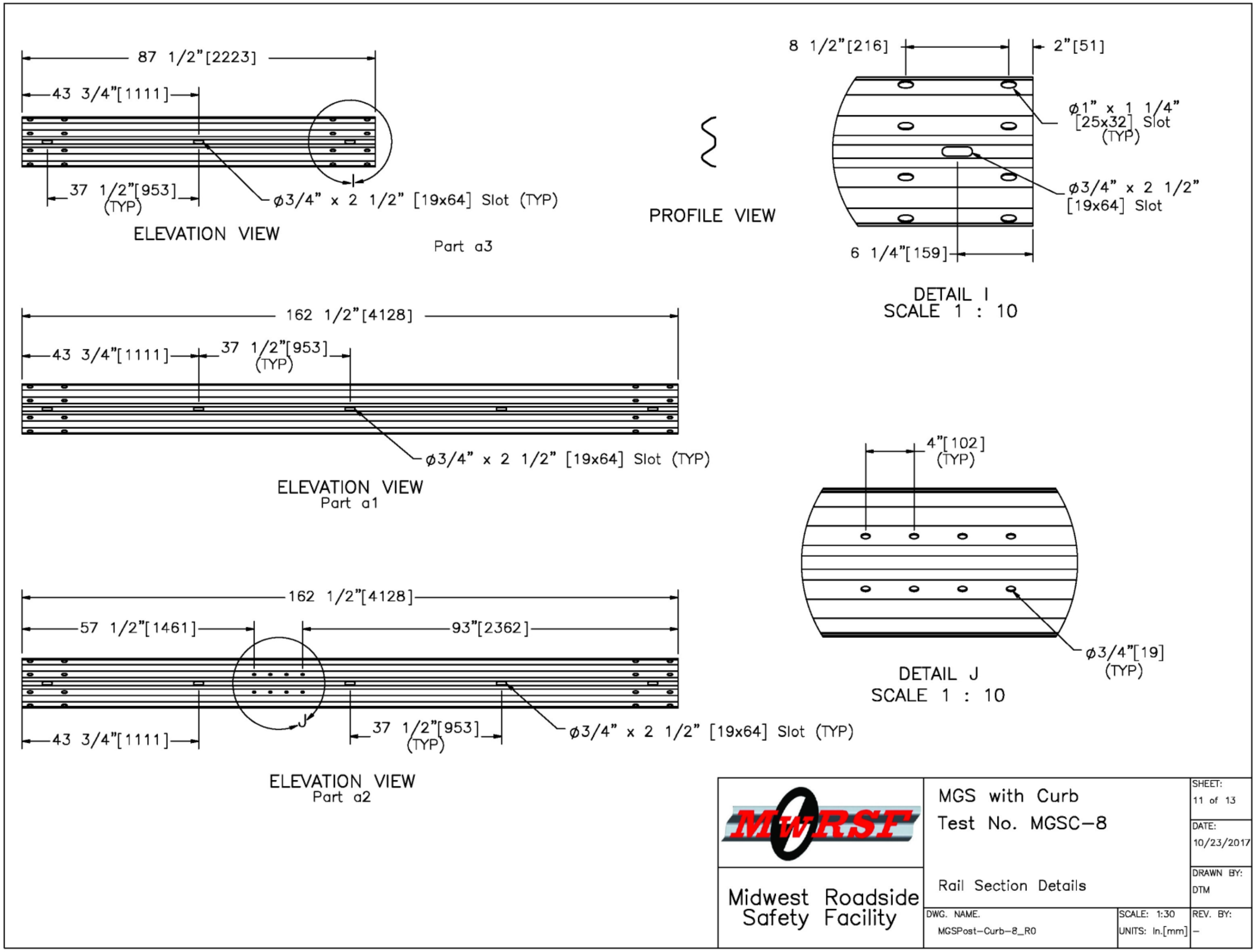


Figure 26. Rail Section Details, Test No. MGSC-8

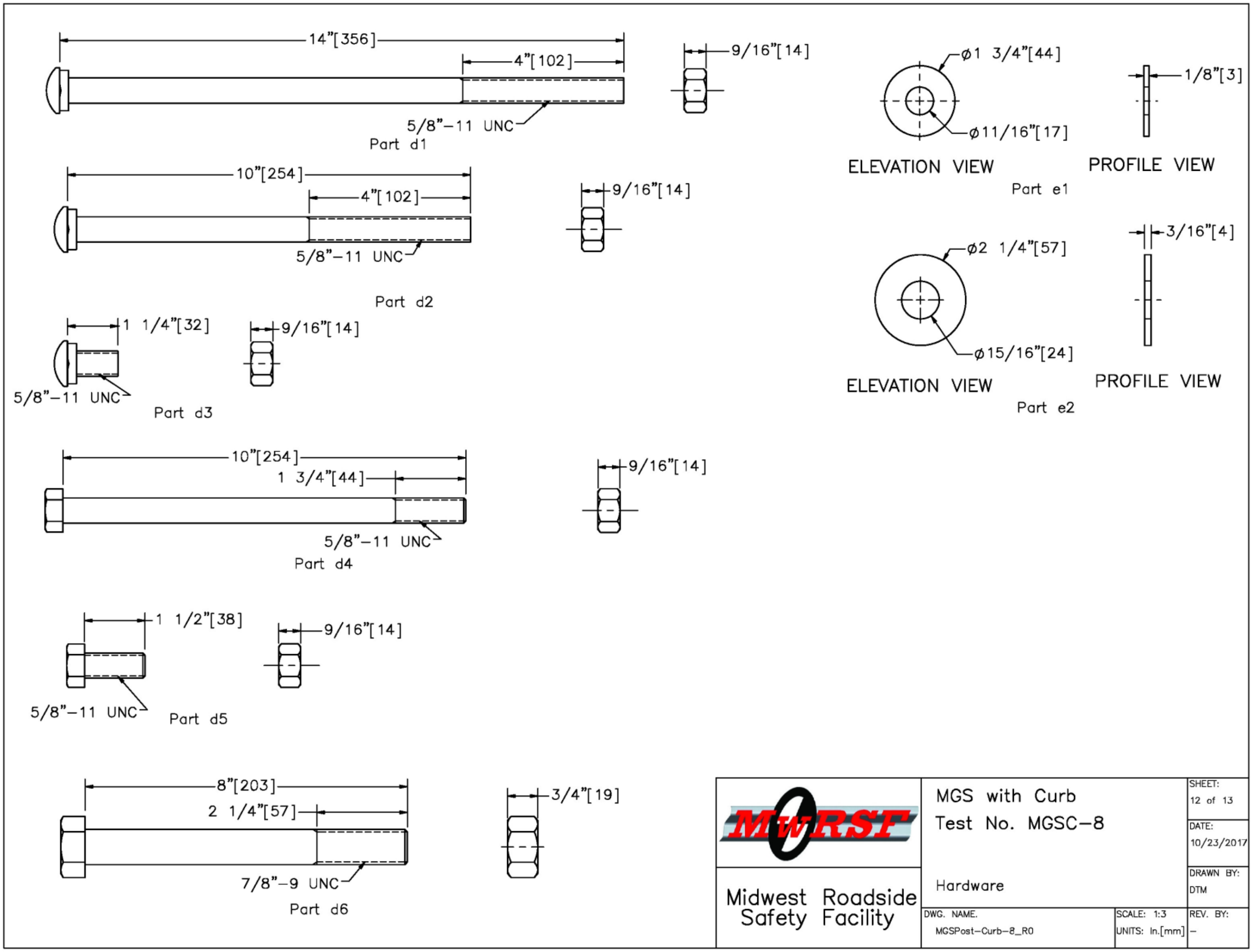


Figure 27. Hardware, Test No. MGSC-8

Item No.	QTY.	Description	Material Specification	Galvanization Specification	Hardware Guide
a1	12	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a2	2	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A123 or A653	RWM14a
a3	1	6'–3" [1,905] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a4	25	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa]	ASTM A123	PWE06
a5	25	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
a6	25	16D Double Head Nail	–	–	–
b1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	–	PDF01
b2	4	72" [1829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	PTE06
b3	2	Ground Strut Assembly	ASTM A36	ASTM A123	PFP02
b4	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	FMM02
b5	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
b6	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
c1	2	BCT Anchor Cable	–	–	FCA01
d1	25	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB06
d2	4	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB03
d3	112	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB01
d4	4	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
d5	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
d6	4	7/8" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	–
e1	44	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
e2	8	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
f1	1	Curb	f'c = 4,000 psi [27.6 MPa]	–	–
f2	1	#4 Rebar 819" [20,803] Long	ASTM A615 Gr. 60	–	–
f3	45	#4 Rebar 16" [406] Long	ASTM A615 Gr. 60	–	–

Midwest Roadside Safety Facility

MGS with Curb
Test No. MGSC–8

Bill of Materials

SHEET: 13 of 13
DATE: 10/23/2017
DRAWN BY: DTM
DWG. NAME. MGSPost–Curb–8_R0
SCALE: None
UNITS: In.[mm]
REV. BY: –

Figure 28. Bill of Materials, Test No. MGSC-8

Figure 29. Test Installation Photographs, Test No. MGSC-8

Figure 30. Test Installation Photographs, Test No. MGSC-8

4 TEST CONDITIONS

4.1 Test Facility

The Outdoor Test Site is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles northwest of the University of Nebraska-Lincoln.

4.2 Vehicle Tow and Guidance System

A reverse-cable, tow system with a 1:2 mechanical advantage was used to propel the test vehicles. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicles. The test vehicles were released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [15] was used to steer the test vehicles. A guide flag, attached to the right-front wheel and the guide cable for each test, was sheared off before impact with the barrier system. The ⅜-in. diameter guide cable was tensioned to approximately 3,500 lb and supported both laterally and vertically every 100 ft by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicles were towed down the line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicles

For test no. MGSC-7, a 2009 Hyundai Accent was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,448 lb, 2,423 lb, and 2,584 lb, respectively. The test vehicle is shown in Figures 31 and 32, and vehicle dimensions are shown in Figure 33.

MASH 2016 requires test vehicles used in crash testing to be no more than six model years old. A 2009 model was used for this test because the vehicle geometry of newer models did not comply with recommended vehicle dimension ranges specified in Table 4.1 of MASH 2016. The use of older test vehicles due to recent small car vehicle properties falling outside of MASH 2016 recommendations was allowed by FHWA and AASHTO in MASH implementation guidance dated May of 2018 [16].

For test no. MGSC-8, a 2010 Dodge Ram 1500 quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,092 lb, 5,000 lb, and 5,162 lb, respectively. The test vehicle is shown in Figures 34 and 35, and vehicle dimensions are shown in Figure 36. Pre-test photographs of the vehicle's interior floorboards were not available.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. For test no. MGSC-7, the vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [17]. The location of the final c.g. is shown in Figures 33 and 37. For test no. MGSC-8, the Suspension Method [18] was used to determine the vertical component of the c.g. of the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g.

location for the test inertial condition. The location of the final c.g. is shown in Figures 36 and 38. For both tests, data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 37 and 38. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

The front wheels of the test vehicles were aligned to vehicle standards except the toe-in value was adjusted to zero such that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted at the center and the front-right center of the vehicles' dashes for test nos. MGSC-7 and MGSC-8, respectively. The bulb was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A remote-controlled brake system was installed in the test vehicles so the vehicles could be brought safely to a stop after the test.

Figure 31. Test Vehicle, Test No. MGSC-7

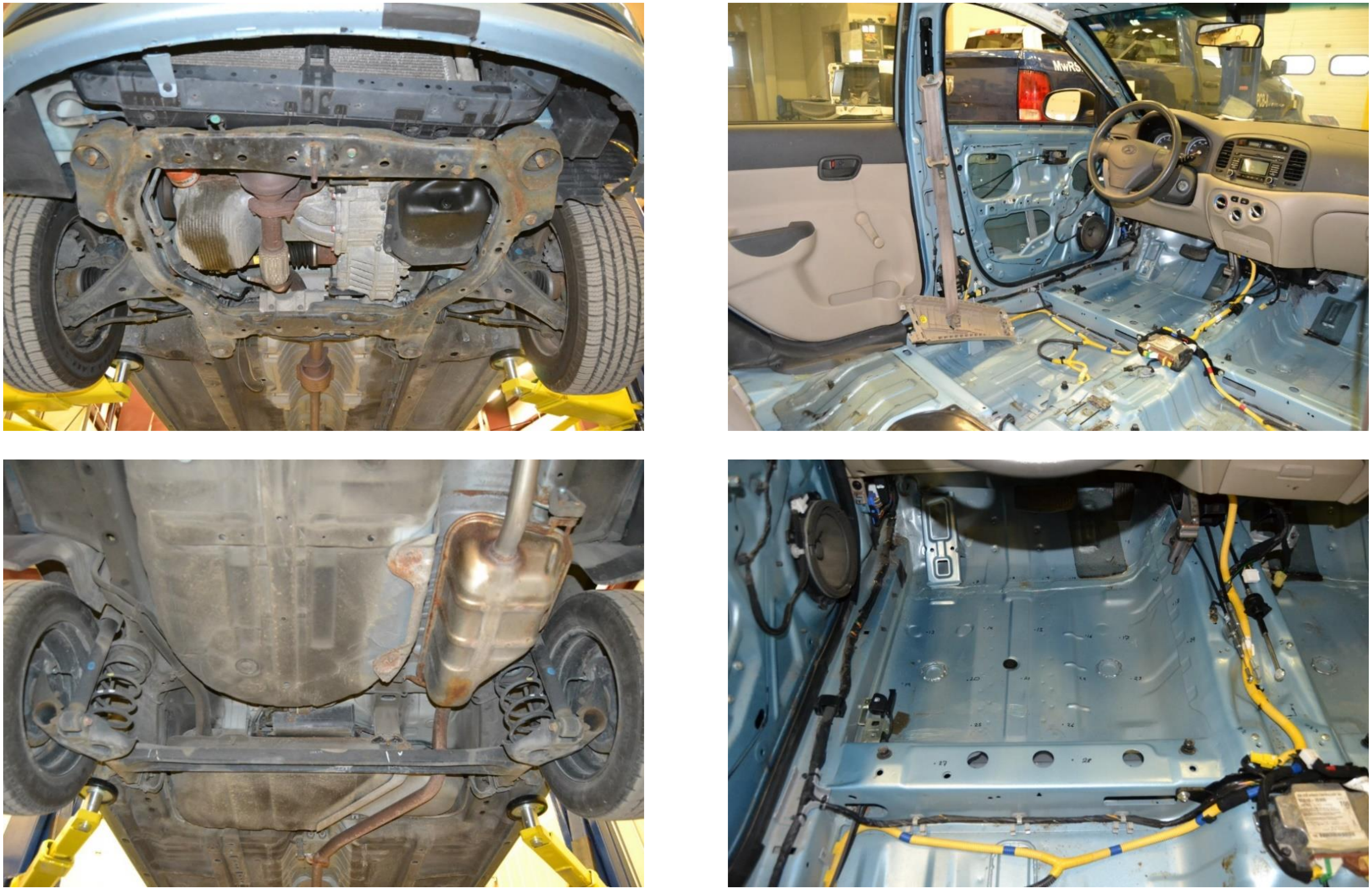
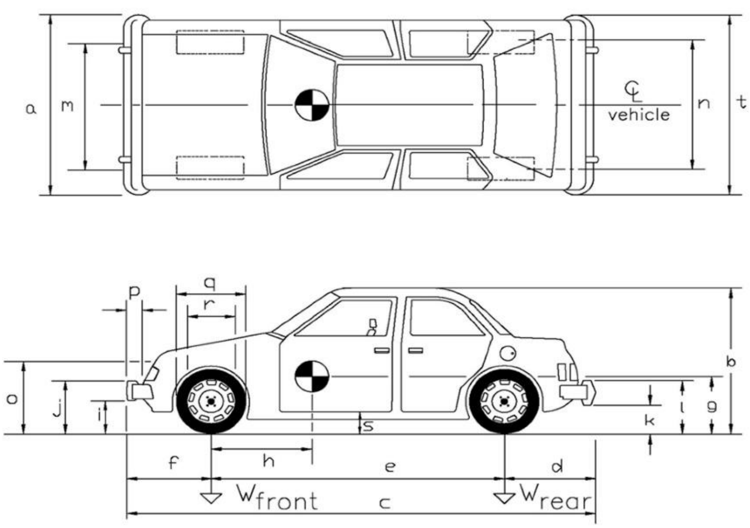


Figure 32. Test Vehicle’s Undercarriage and Interior Floorboards, Test No. MGSC-7

Date:	11/7/2017	Test Number:	MGSC-7	VIN:	KMHCN4AC4AU460931
Year:	2009	Make:	Hyundai	Model:	Accent
Tire Size:	P185/65 R14	Tire Inflation Pressure:	32 Psi	Odometer:	142110



Vehicle Geometry - in. (mm)
Target Ranges listed below

a:	66	(1676)	b:	57 1/4	(1454)
	65±3 (1650±75)				
c:	168 1/2	(4280)	d:	36 1/2	(927)
	169±8 (4300±200)				
e:	98 1/4	(2496)	f:	33 3/4	(857)
	98±5 (2500±125)			35±4 (900±100)	
g:	22 13/16	(579)	h:	36 5/16	(922)
				39±4 (990±100)	
i:	15 1/2	(394)	j:	21 1/2	(546)
k:	15 3/4	(400)	l:	22 3/4	(578)
m:	57 1/2	(1461)	n:	57 1/2	(1461)
	56±2 (1425±50)			56±2 (1425±50)	
o:	28	(711)	p:	4	(102)
	24±4 (600±100)				
q:	23 1/2	(597)	r:	15 1/2	(394)
s:	11 1/2	(292)	t:	64 1/8	(1629)

Mass Distribution lb (kg)

Gross Static	LF	808 (367)	RF	800 (363)	
	LR	528 (239)	RR	448 (203)	

Top of radiator core support:	29	(737)
Wheel Center Height (Front):	10 3/4	(273)
Wheel Center Height (Rear):	10 3/4	(273)
Wheel Well Clearance (Front):	25	(635)
Wheel Well Clearance (Rear):	24 1/2	(622)
Bottom Frame Height (Front):	6 1/4	(159)
Bottom Frame Height (Rear):	15 1/4	(387)
Engine Type:	4cyl. Gas	
Engine Size:	1.6L	
Transmission Type:	Automatic	
Drive Type:	FWD	

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1567 (711)	1528 (693)	1608 (729)
W-rear	881 (400)	895 (406)	976 (443)
W-total	2448 (1110)	2423 (1099) 2420±55 (1100±25)	2584 (1172) 2585±55 (1175±50)

GVWR Ratings lb		Dummy Data	
Front:	1918	Type:	Hybrid II
Rear:	1874	Mass:	161 lb
Total:	3638	Seat Position:	Driver

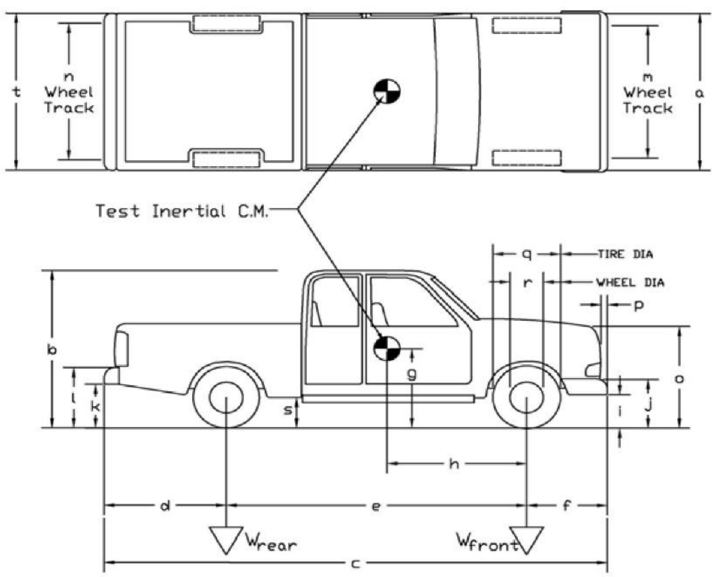
Note any damage prior to test: NONE

Figure 33. Vehicle Dimensions, Test No. MGSC-7

Figure 34. Test Vehicle, Test No. MGSC-8

Figure 35. Test Vehicle's Undercarriage, Test No. MGSC-8

Date:	7/28/2017	Test Name:	MGSC-8	VIN No:	1D7RB1GT8AS118297
Year:	2010	Make:	Dodge	Model:	Ram 1500
Tire Size:	P265/70R17	Tire Inflation Pressure:	40 Psi	Odometer:	280647



Vehicle Geometry - in. (mm)
Target Ranges listed below

a:	73	(1854)	b:	74 3/4	(1899)
	78±2 (1950±50)				
c:	229 1/4	(5823)	d:	48 1/5	(1224)
	237±13 (6020±325)				
e:	140 1/2	(3569)	f:	40 3/8	(1026)
	148±12 (3760±300)			39±3 (1000±75)	
g:	28 1/16	(713)	h:	60	(1524)
	min: 28 (710)			63±4 (1575±100)	
i:	13 3/8	(340)	j:	25 3/8	(645)
k:	21 1/8	(537)	l:	28 3/4	(730)
m:	67	(1702)	n:	67 5/8	(1718)
	67±1.5 (1700±38)			67±1.5 (1700±38)	
o:	46 1/8	(1172)	p:	3 1/2	(89)
	43±4 (1100±75)				
q:	31 3/4	(806)	r:	18 1/2	(470)
s:	15 1/8	(384)	t:	78 7/8	(2003)

Wheel Center Height (Front):	14 3/4	(375)
Wheel Center Height (Rear):	15	(381)
Wheel Well Clearance (Front):	35 7/8	(911)
Wheel Well Clearance (Rear):	38 3/8	(975)
Bottom Frame Height (Front):	18 5/8	(473)
Bottom Frame Height (Rear):	26 1/8	(664)
Engine Type:	Gasoline	
Engine Size:	5.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	
Cab Style:	Quad Cab	
Bed Length:	76"	

Mass Distribution lb (kg)

Gross Static	LF	1524	(691)	RF	1444	(655)
	LR	1080	(490)	RR	1114	(505)

Weights lb (kg)	Curb		Test Inertial		Gross Static	
W-front	2923	(1326)	2864	(1299)	2968	(1346)
W-rear	2169	(984)	2136	(969)	2194	(995)
W-total	5092	(2310)	5000	(2268)	5162	(2341)
			5000±110 (2270±50)		5165±110 (2343±50)	

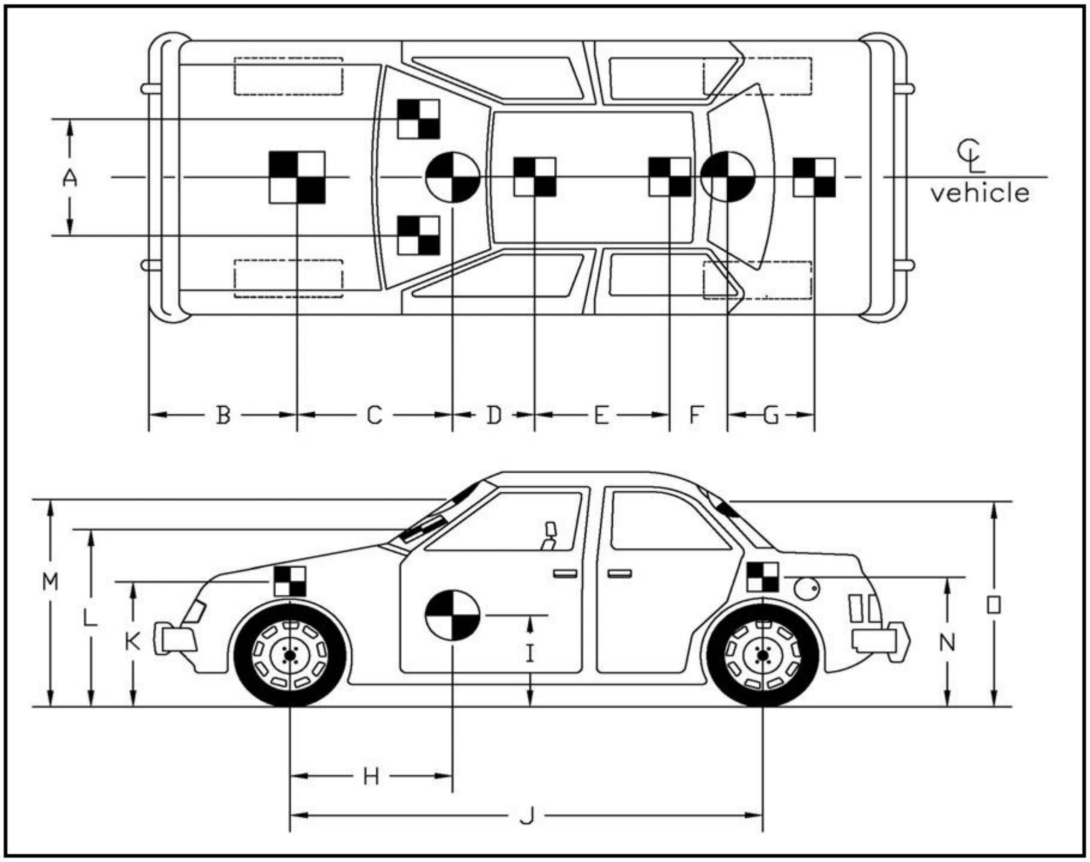
GVWR Ratings lb	
Front	3700
Rear	3900
Total	6700

Dummy Data	
Type:	Hybrid II
Mass:	162 lb
Seat Position:	Driver

Note any damage prior to test: Slightly dented and discolored front right fender. Minor scraping on various parts.

Figure 36. Vehicle Dimensions, Test No. MGSC-8

Date:	11/7/2017	Test Name:	MGSC-7	VIN:	KMHCN4AC4AU460931
Year:	2009	Make:	Hyundai	Model:	Accent

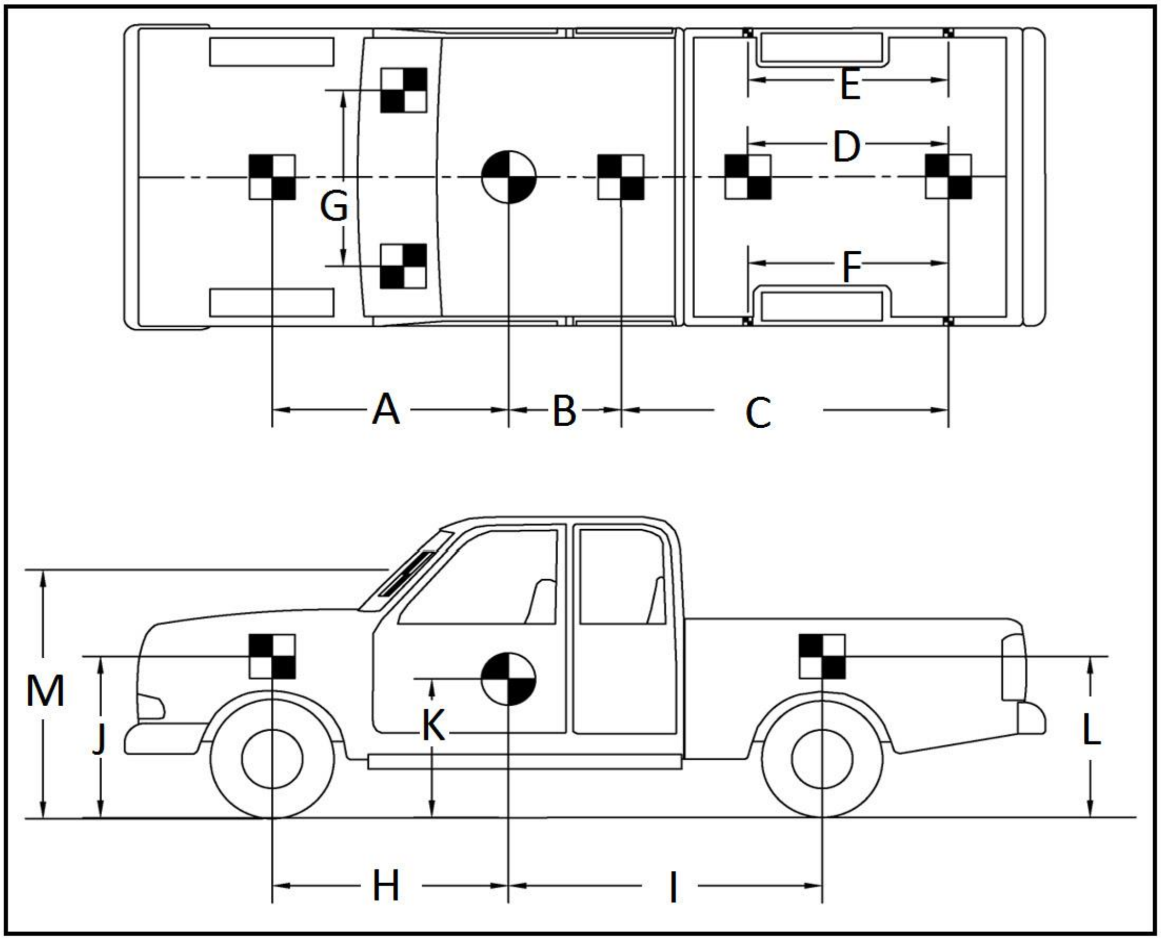


TARGET GEOMETRY - in. (mm)

A	29 3/4	(756)	F	17	(432)	K	28 3/4	(730)
B	22 1/8	(562)	G	23	(583)	L	47 1/4	(1200)
C	47	(1194)	H	36 1/8	(918)	M	53	(1346)
D	10 1/4	(260)	I	22 3/4	(578)	N	28 3/8	(721)
E	34	(864)	J	98 1/2	(2502)	O	52 3/4	(1340)

Figure 37. Target Geometry, Test No. MGSC-7

Date:	11/28/2017	Test Name:	MGSC-8	VIN:	1D7RB1GT8AS118297
Year:	2010	Make:	Dodge	Model:	Ram 1500



TARGET GEOMETRY-- in. (mm)

A:	78 3/4 (2000)	E:	63 1/8 (1603)	J:	39 1/16 (992)
B:	29 (737)	F:	63 3/16 (1605)	K:	28 (711)
C:	76 7/8 (1953)	G:	34 3/8 (873)	L:	42 3/8 (1076)
D:	40 7/16 (1027)	H:	60 (1524)	M:	65 9/16 (1665)
		I:	80 3/8 (2042)		

Figure 38. Target Geometry, Test No. MGSC-8

4.4 Simulated Occupant

For test nos. MGSC-7 and MGSC-8, a Hybrid II 50th-Percentile, Adult Male Dummy equipped with footwear was placed in the left-front seat of the test vehicles with the seat belt fastened. The simulated occupant had a final weight of 161 lb for test no. MGSC-7 and 162 lb for test no. MGSC-8. As recommended by MASH 2016, the simulated occupant weight was not included in calculating the c.g. location.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometer systems were mounted near the c.g. of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [19].

The SLICE-1 and SLICE-2 units were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-1 unit was designated as the primary system for test no. MGSC-7, and the SLICE-2 unit was designated as the primary system for test no. MGSC-8. The acceleration sensors were mounted inside the bodies of custom-built, SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

Two identical angular rate sensor systems mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders were used to measure the rates of rotation of the test vehicle. Each SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessors. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

4.5.3 Retroreflective Optic Speed Trap

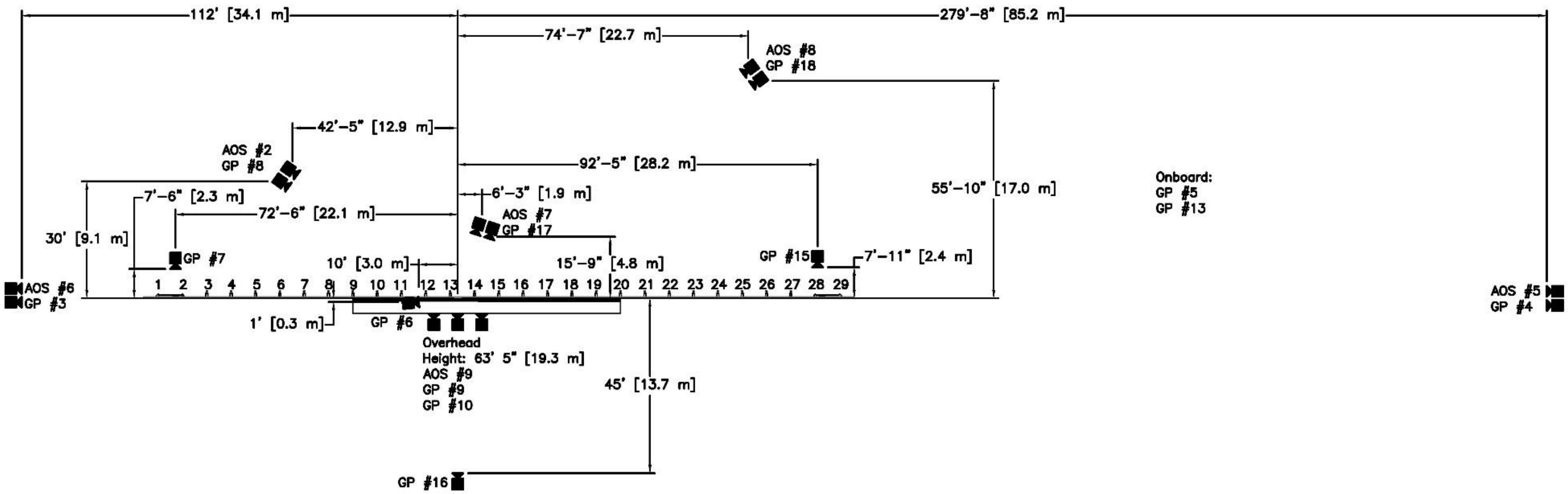
The retroreflective optic speed trap was used to determine the speed of the test vehicles before impact. Five retroreflective targets, spaced at approximately 18-in. intervals, were applied to the sides of the vehicles. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

4.5.4 Digital Photography

Six AOS high-speed digital video cameras and thirteen GoPro digital video cameras were utilized to film test no. MGSC-7. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 39.

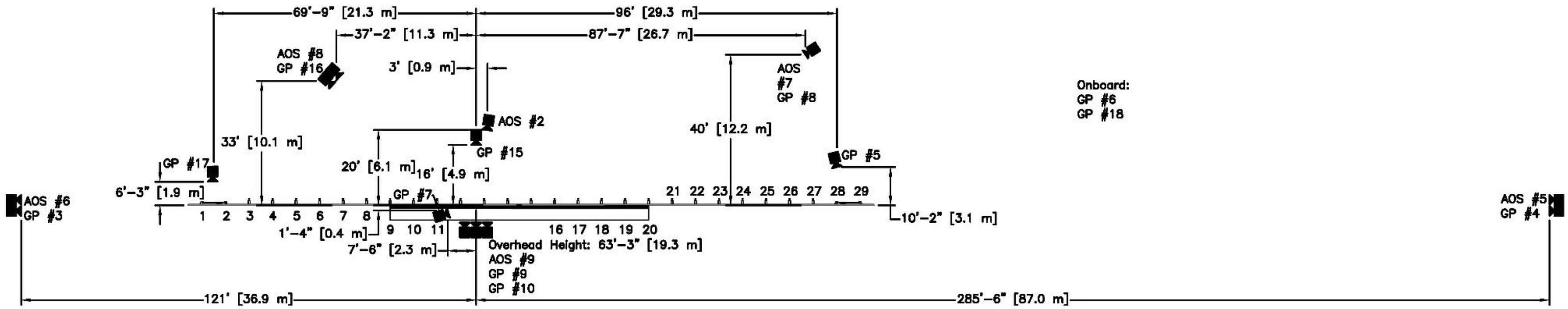
Six AOS high-speed digital video cameras and twelve GoPro digital video cameras were utilized to film test no. MGSC-8. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 40.

The high-speed videos were analyzed using TEMA Motion and Redlake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A digital still camera was also used to document pre- and post-test conditions for the test.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam	500	KOWA 25 mm	
AOS-5	AOS X-PRI	500	Telesar 135 mm Fixed	
AOS-6	AOS X-PRI	500	Fuji 50 mm Fixed	
AOS-7	AOS X-PRI	500	Kowa 16 mm Fixed	
AOS-8	AOS S-VIT 1531	500	Sigma 28-70 (#2)	50 (zoom)
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12 mm Fixed	
GP-3	GoPro Hero 3+ w/ Cosmicar 12.5 mm	120		720 N
GP-4	GoPro Hero 3+ w/ Cosmicar 12.5 mm	120		720 N
GP-5	GoPro Hero 3+	120		720 N
GP-6	GoPro Hero 3+	120		720 M
GP-7	GoPro Hero 4	120		720 W
GP-8	GoPro Hero 4	240		720 N
GP-9	GoPro Hero 4	120		1080W
GP-10	GoPro Hero 4	240		720 N
GP-13	GoPro Hero 4	120		720 M
GP-15	GoPro Hero 4	120		720 M
GP-16	GoPro Hero 4	120		720 M
GP-17	GoPro Hero 4	240		720 N
GP-18	GoPro Hero 4	240		720 N

Figure 39. Camera Locations, Speeds, and Lens Settings, Test No. MGSC-7



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam	500	KOWA 16 mm	
AOS-5	AOS X-PRI	500	Telesar 135 mm	
AOS-6	AOS X-PRI	500	Fujinon 50 mm	
AOS-7	AOS X-PRI	500	Fujinon 35 mm	
AOS-8	AOS S-VIT 1531	500	Sigma 28-70 DG #2	35 (zoom)
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12 mm Fixed	
GP-3	GoPro Hero 3+ w/ Cosmicar 12.5 mm	120		
GP-4	GoPro Hero 3+ w/ Cosmicar 12.5 mm	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
GP-15	GoPro Hero 4	240		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 4	240		

Figure 40. Camera Locations, Speeds, and Lens Settings, Test No. MGSC-8

5 FULL-SCALE CRASH TEST NO. MGSC-7

5.1 Static Soil Test

Before full-scale crash test no. MGSC-7 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

5.2 Weather Conditions

Test no. MGSC-7 was conducted on November 7, 2017 at approximately 2:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

Table 3. Weather Conditions, Test No. MGSC-7

Temperature	43° F
Humidity	37%
Wind Speed	9 mph
Wind Direction	40° from True North
Sky Conditions	Scattered
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.01 in.

5.3 Test Description

The critical impact point for test no. MGSC-7 was selected using the CIP plots found in Section 2.3 of MASH. The critical impact point was determined to be 89 in. upstream from the splice located between post nos. 14 and 15, as shown in Figure 41.

The 2,423-lb small car impacted the MGS 2.7 in. upstream from targeted impact point at a speed of 63.6 mph and at an angle of 25.0 degrees. The vehicle was contained and redirected with exit speed and angle of 21.3 mph and -10.5 degrees, respectively. The vehicle remained stable throughout the impact event with maximum roll and pitch angular displacements of 11 degrees and -5 degrees, respectively. During the test, the left-front corner of the vehicle and the left-front wheel extended below the W-beam rail and snagged on three of the guardrail support posts, which caused the vehicle to yaw back toward the barrier after reaching a maximum yaw displacement of 19.7 degrees. However, the snag was not severe enough to cause excessive decelerations. Additionally, the combined lateral and vertical loads being applied to the rail as the front end of the vehicle extended below the rail caused a partial tear in the guardrail at the splice between post nos. 14 and 15, which extended from the bottom of the W-beam rail to the middle of the rail. After exiting the system, the vehicle continued to yaw toward the barrier, and the vehicle’s front bumper contacted the MGS for a second time. The vehicle ultimately came to rest 50 ft – 3 in. downstream from impact and 10 ft – 8 in. laterally in front of the system after brakes were applied.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 42 through 44. Documentary photographs of the crash test are shown in Figures 45 through 47. The vehicle trajectory and final position are shown in Figure 48.

Table 4. Sequential Description of Impact Events, Test No. MGSC-7

TIME (sec)	EVENT
-0.004	Vehicle’s left-front tire contacted curb.
0.004	Vehicle’s front bumper contacted rail upstream from the splice located between post nos. 14 and 15..
0.004	Vehicle’s front bumper deformed and cracked. Vehicle’s left headlight contacted rail.
0.010	Post no. 13 deflected backward. Vehicle’s left fender contacted rail.
0.016	Vehicle’s hood contacted rail.
0.018	Post no. 14 deflected backward.
0.040	Vehicle’s left-front door contacted rail.
0.042	Vehicle’s front bumper contacted blockout no. 14.
0.046	Vehicle’s front bumper contacted post no. 14. Vehicle began to yaw away from the barrier.
0.048	Post no. 14 twisted counterclockwise.
0.050	Vehicle’s grille disengaged. Blockout no. 14 fractured.
0.068	Vehicle’s left-front tire contacted post no. 14. Rail disengaged from bolt at post no. 14.
0.072	Blockout disengaged from post no. 14.
0.080	Vehicle’s left-front door deformed.
0.084	Vehicle’s left-rear tire contacted curb.
0.102	Post no. 15 twisted clockwise.
0.108	Vehicle’s front bumper contacted post no. 15. Post no. 15 bent downstream.
0.124	Vehicle’s left-rear tire became airborne.
0.126	Blockout disengaged from post no. 15.
0.198	Vehicle’s front bumper contacted post no. 16.
0.224	Rail disengaged from bolt at post no. 16.
0.228	Blockout disengaged from post no. 16.
0.234	Blockout no. 16 fractured.
0.338	Blockout fractured and disengaged from post no. 17.

Table 5. Sequential Description of Impact Events, Test No. MGSC-7, Cont.

TIME (sec)	EVENT
0.342	Rail disengaged from bolt at post no. 17. Vehicle’s front frame contacted post no. 17.
0.416	Vehicle reached a maximum yaw displacement of 19.7 degrees and began to yaw toward the barrier.
0.662	Vehicle exited the system with a speed of 21.3 mph, a c.g. angle of -10.5 degrees, and a heading angle of 25.0 degrees.
0.686	Vehicle’s left-rear tire regained contact with ground.
0.976	Vehicle’s front bumper contacted the rail for a second time as vehicle continued to yaw toward the barrier.
1.200	Vehicle’s right headlight contacted rail.
1.650	Vehicle exited the system for a second time.

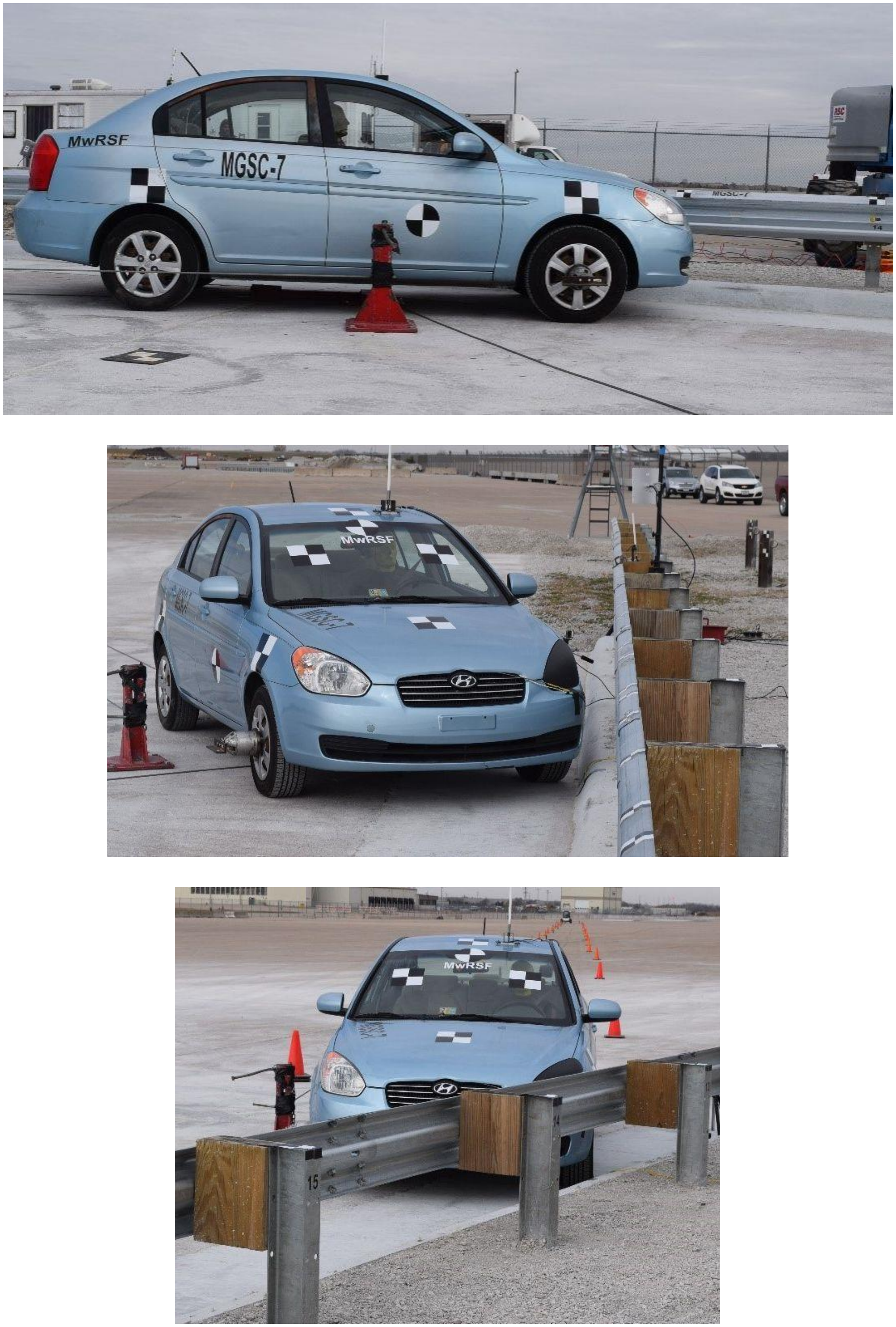
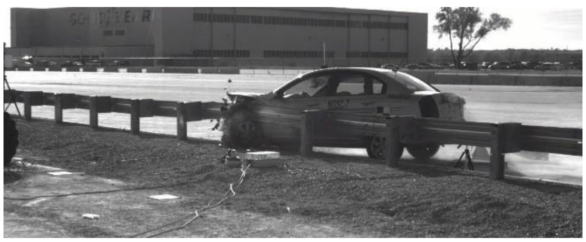


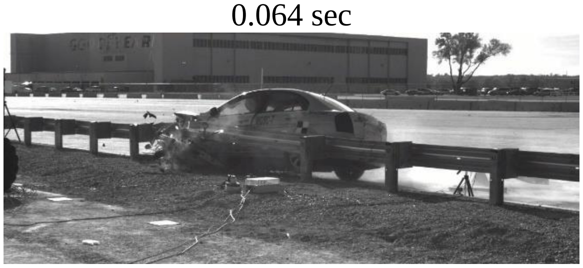
Figure 41. Impact Location, Test No. MGSC-7

0.000 sec

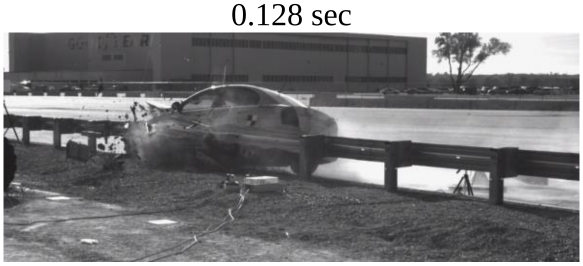
0.028 sec



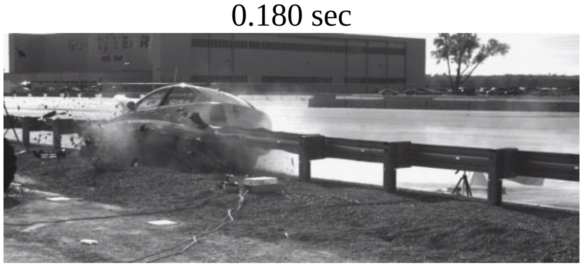
0.064 sec



0.128 sec



0.180 sec



0.300 sec

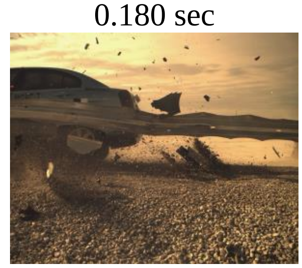
0.000 sec

0.028 sec

0.064 sec

0.128 sec

0.180 sec



0.300 sec

Figure 42. Sequential Photographs, Test No. MGSC-7

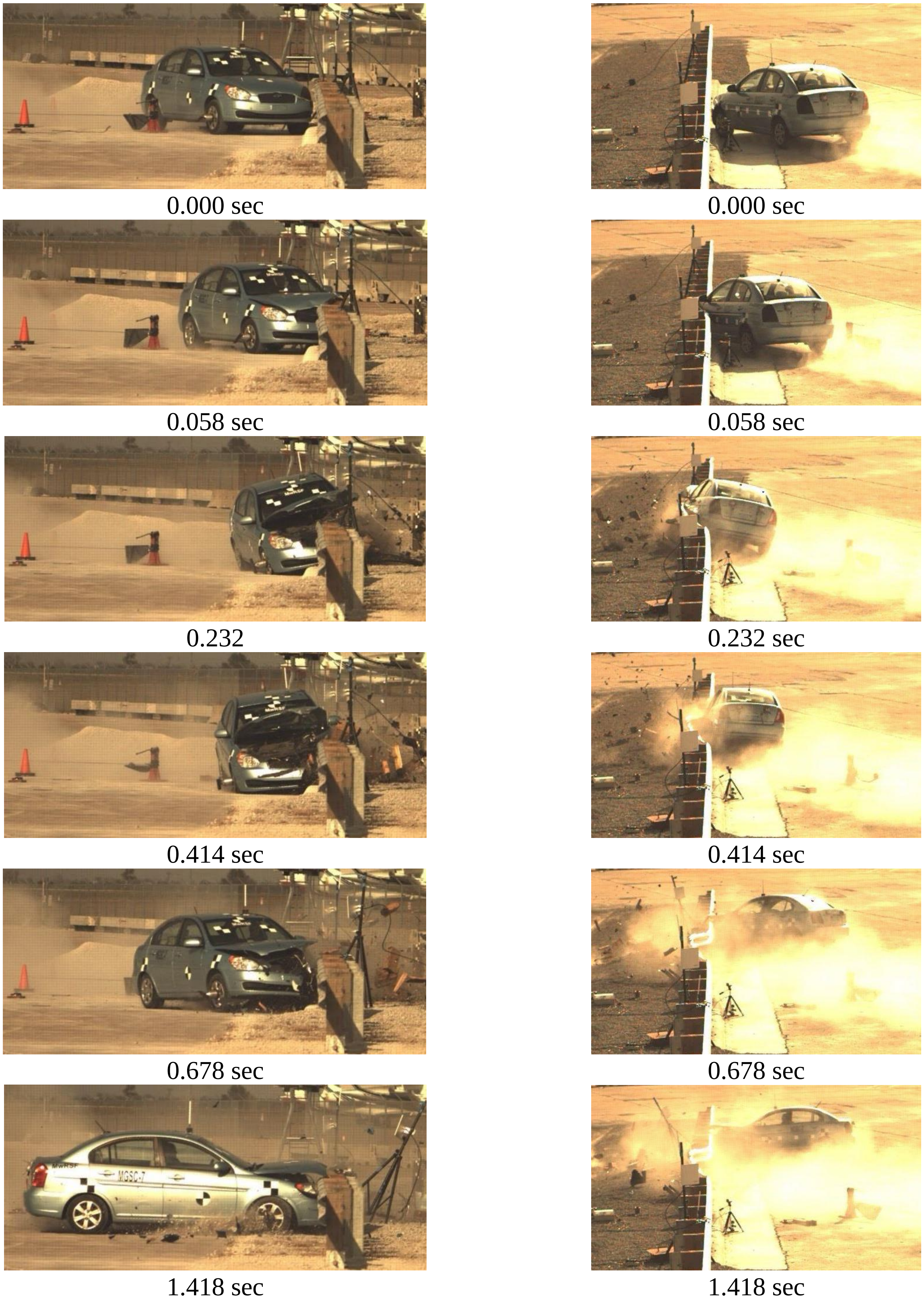


Figure 43. Sequential Photographs, Test No. MGSC-7

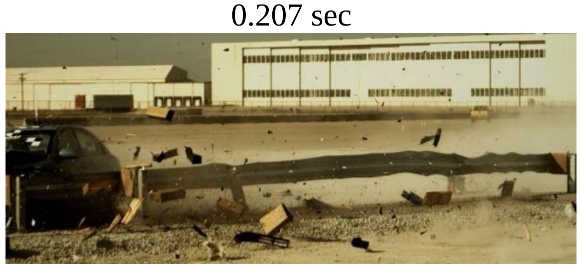
0.000 sec

0.030 sec

0.090 sec

0.160 sec

0.207 sec



0.374 sec

Figure 44. Sequential Photographs, Test No. MGSC-7

Figure 45. Documentary Photographs, Test No. MGSC-7

Figure 46. Documentary Photographs, Test No. MGSC-7

Figure 47. Documentary Photographs, Test No. MGSC-7

Figure 48. Vehicle Final Position and Trajectory Marks, Test No. MGSC-7

5.4 Barrier Damage

Damage to the W-beam guardrail with curb system was moderate, as shown in Figures 49 through 57. Damage consisted of contact marks on various MGS components, as well as bending, kinking, tearing, and twisting of the posts and guardrail. The length of vehicle contact along the barrier was approximately 25 ft – 7 in., which spanned from 12 in. downstream from post no. 13 to 19 in. downstream from post no. 17.

The W-beam guardrail was laterally displaced between post nos. 13 and 17 and was disengaged from post nos. 14 through 17. Rail kinking and flatting was observed at multiple locations along the rail between post nos. 13 and 17. The bottom of the rail was bent upward from post no. 14 to post no. 17. The rail was partially torn at the splice location between post nos. 14 and 15. The tear extended from the bottom edge of the rail, through the lower-upstream bolt holes, and stopped near the middle of the W-beam valley.

Post nos. 14 through 16 were bent back and downstream at ground line. Post no. 17 was bent slightly downstream and twisted to face downstream. Soil heaves and craters formed at the bases of post nos. 14 through 17. Contact marks were found on the upstream edge of post nos. 14 through 17. Post nos. 3 through 14, 16, and 17 were twisted to face downstream. Post nos. 1, 2, and 19 through 29 did not deflect and were not damaged.

Blockouts disengaged from post nos. 14 through 17. The attachment bolt of post no. 15 tore out of the upstream flange web. The blockout of post no. 18 was slightly rotated such that the top of blockout angled upstream. Minor blockout splitting was observed on post nos. 3 through 5, 7, 8, and 12. Curb damage consisted of contact marks which spanned from post nos. 13 to 15.

Figure 49. System Damage, Test No. MGSC-7

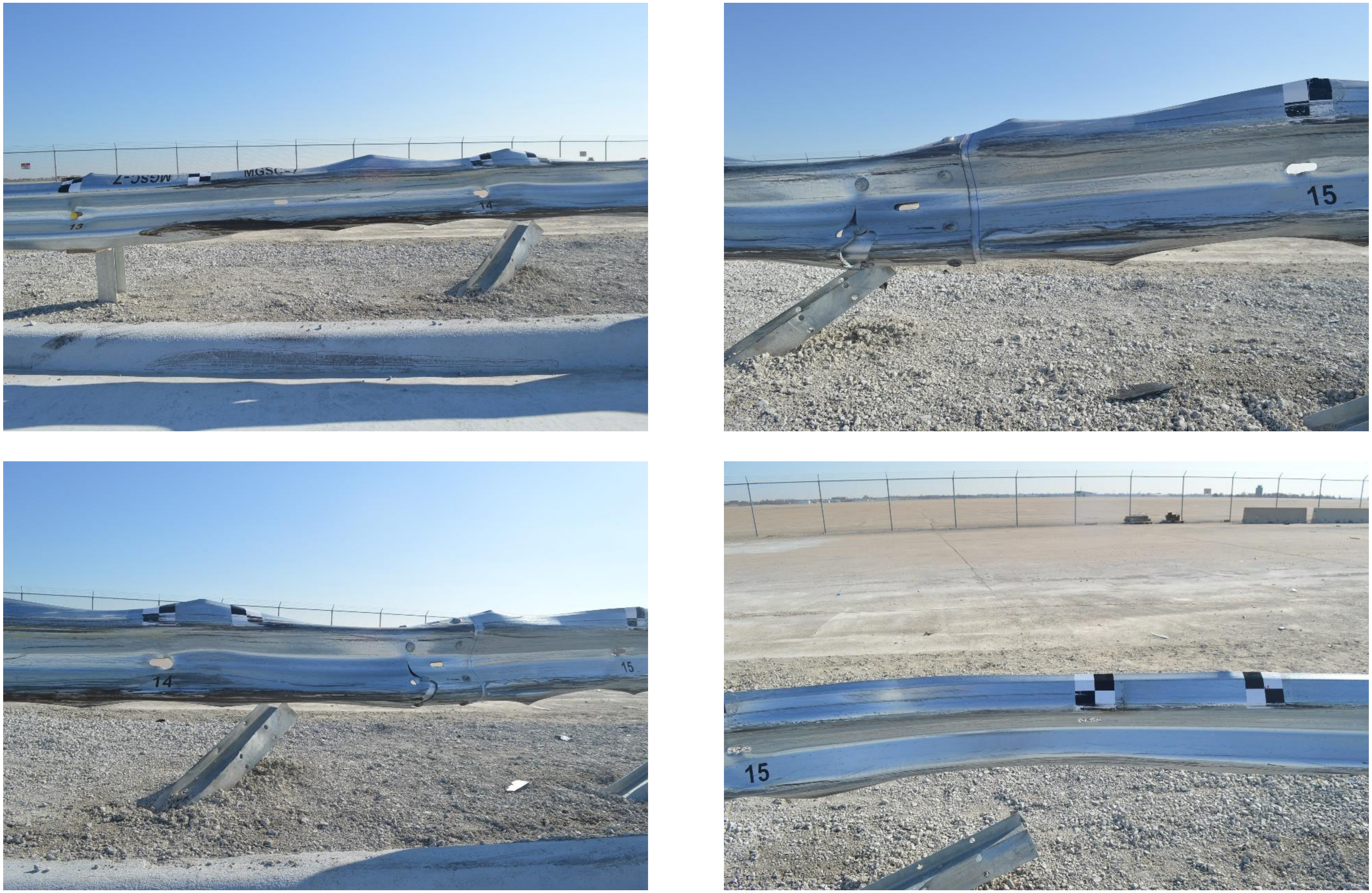


Figure 50. Guardrail Damage, Post Nos. 13 through 15, Test No. MGSC-7

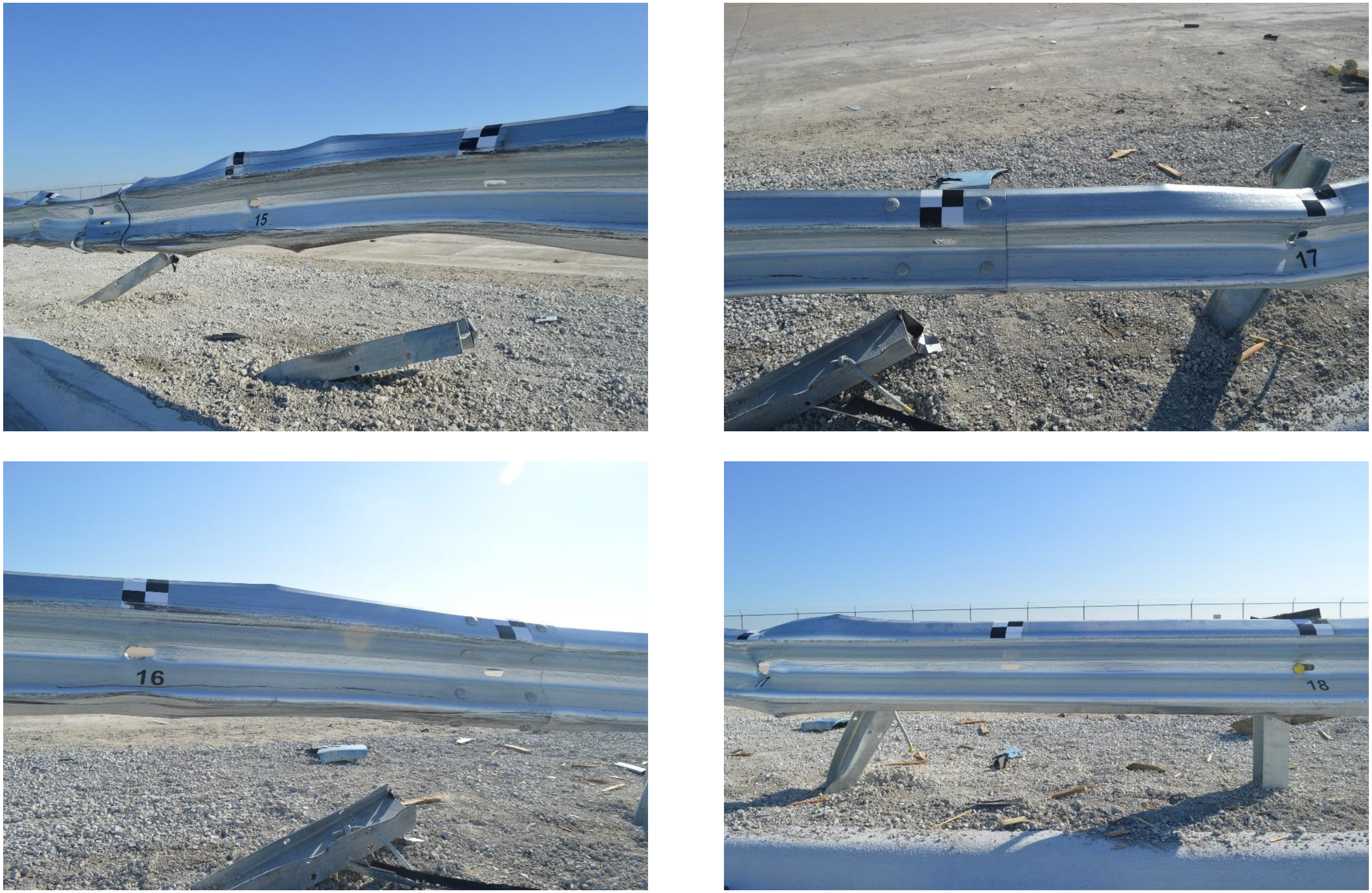


Figure 51. Guardrail Damage, Post Nos. 15 through 18 Test No. MGSC-7

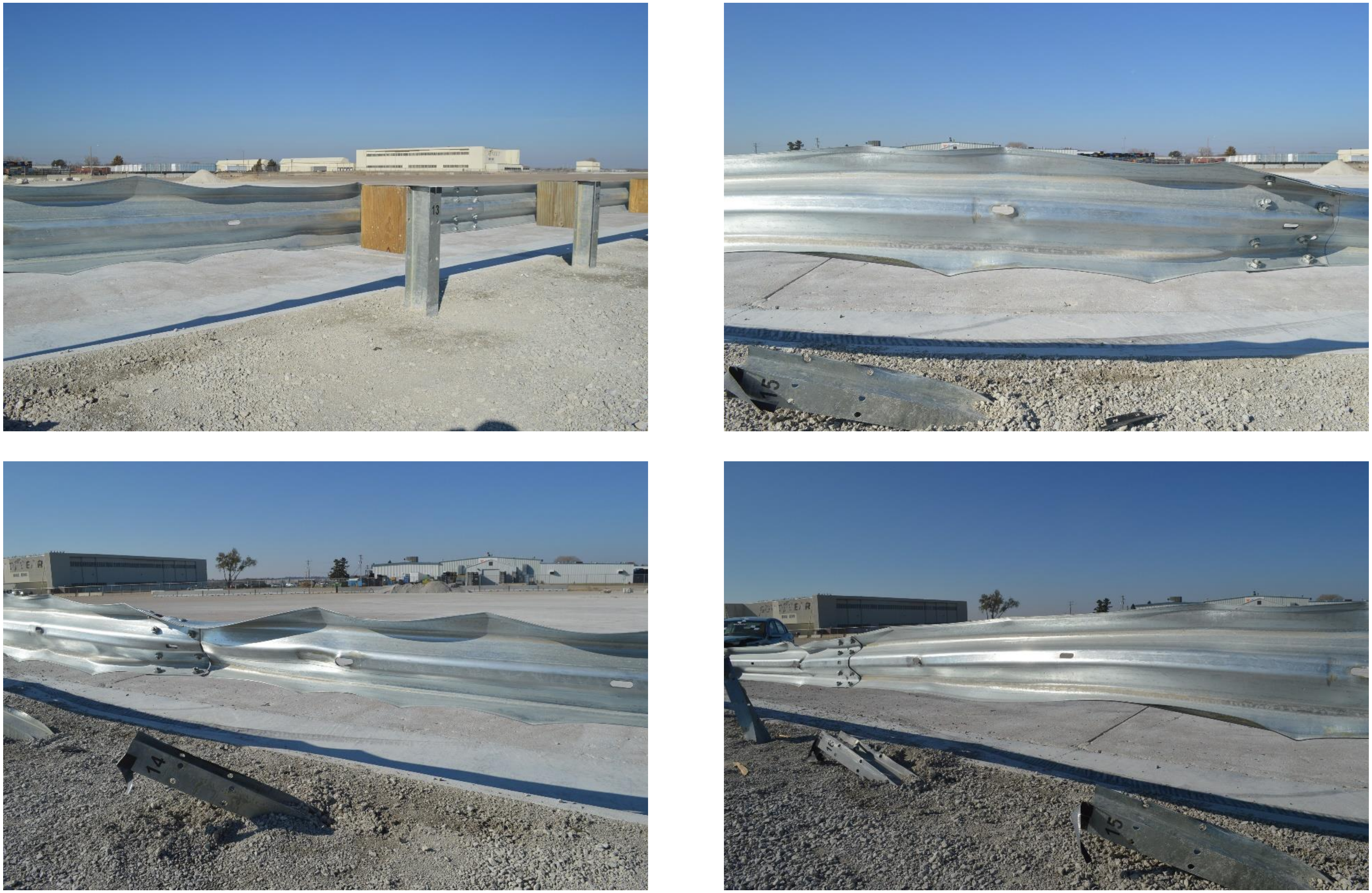


Figure 52. Backside Guardrail Damage, Post Nos. 13 through 16, Test No. MGSC-7

Figure 53. Backside Guardrail Damage, Post Nos. 16 through 18, Test No. MGSC-7

Figure 54. Post Nos. 14 and 15 Damage, Test No. MGSC-7

Figure 55. Post Nos. 16 and 17 Damage, Test No. MGSC-7

Figure 56. Partial Rail Tearing, Test No. MGSC-7

Figure 57. Curb Damage, Test No. MGSC-7

The maximum lateral permanent set of the barrier system was 19.0 in. which occurred at post no. 14, as measured in the field. The maximum lateral dynamic barrier deflection, including deformation of the guardrail along the top surface, was 23.5 in. of the rail at post no. 15, as determined from high-speed digital video analysis. The working width of the system was found to be 40.3 in., determined from video and measurements in the field. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 58.

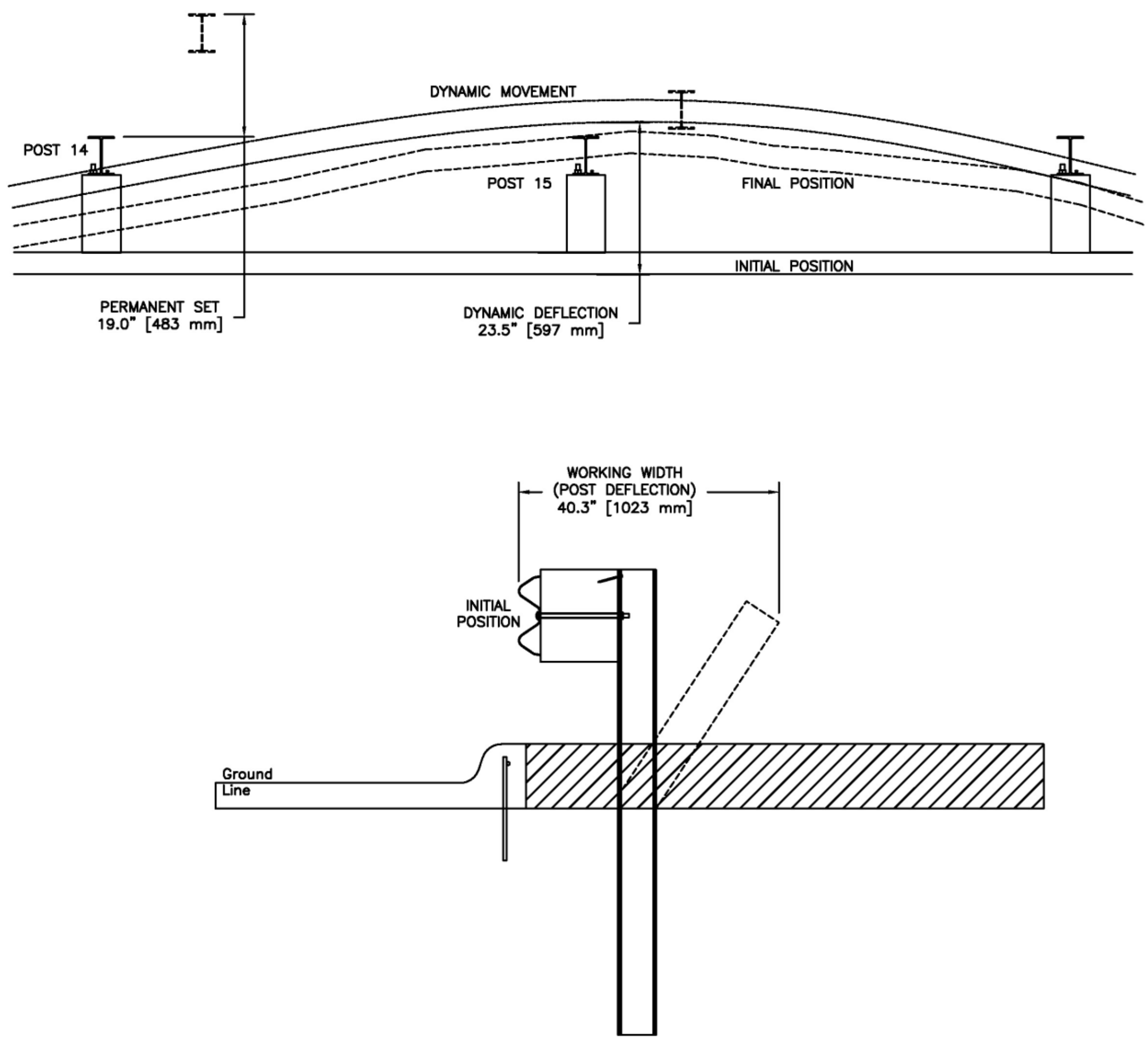


Figure 58. Permanent Deflection, Dynamic Deflection, and Working Width, Test No. MGSC-7

5.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 59 through 62. The maximum occupant compartment deformations are listed in Table 6 along with the deformation limits established in MASH 2016 for various areas of the occupant compartment. Note that none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

The majority of the damage was concentrated at the left-front corner and front end of the vehicle where the impact had occurred. The left-side of the bumper cover was ripped and detached starting 8 in. left of bumper center. The left-front bumper corner was crushed inward and down. The left-side of the radiator core support was displaced. The left-front hood was folded under and pushed in. The left-front fender was bent inward 10 in., and the bottom of the fender protruded outward 5 in. The left-front frame rail was split and crushed backward. The left-front tire was torn, and the wheel rim was bent at three locations. The left-front door was dented near the front and the latch was damaged. The windshield was cracked at the bottom left-front corner, but the roof and remaining window glass were undamaged.

The left-front sway bar was bent upward approximately 2 in. and was in contact with the lower control arm. The left lower control arm was torn 6 in. from the center of the king pin and pulled outward 3 in. The left tie-rod was in contact with the left-front tire rim. A 2¾-in. by 6-in. scrape was found on the oil pan. Scrapes were found at multiple locations on the engine and transmission cross members. The left frame horn was crushed inward 6 in. and pushed down.

Figure 59. Vehicle Damage, Test No. MGSC-7

Figure 60. Vehicle Damage, Test No. MGSC-7

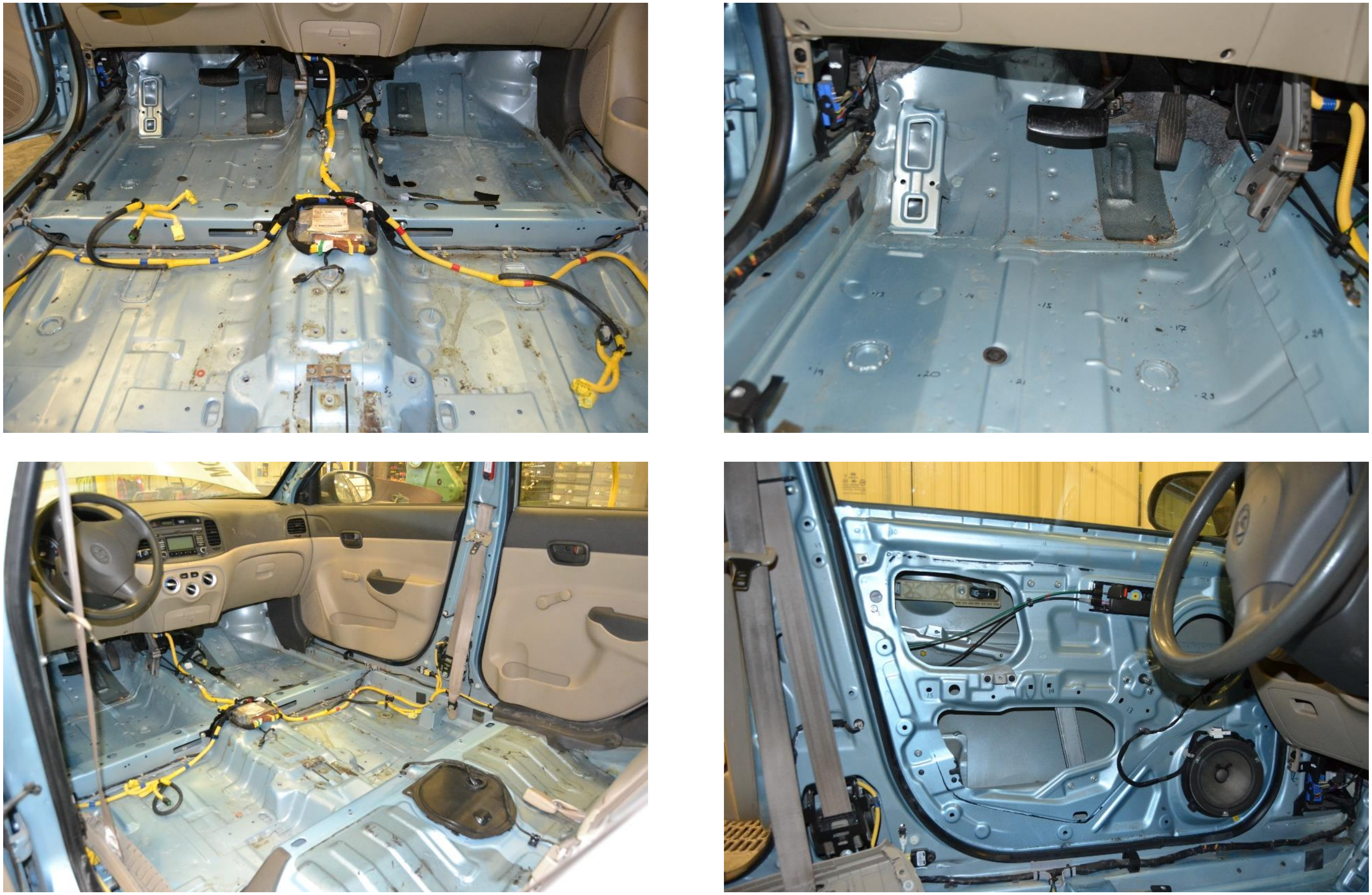


Figure 61. Occupant Compartment Damage, Test No. MGSC-7

Figure 62. Vehicle Undercarriage Damage, Test No. MGSC-7

Table 6. Maximum Occupant Compartment Intrusion by Location, Test No. MGSC-7

LOCATION	MAXIMUM INTRUSION (in.)	MASH 2016 ALLOWABLE INTRUSION (in.)
Wheel Well & Toe Pan	¾	≤ 9
Floor Pan & Transmission Tunnel	⅝	≤ 12
A- and B-Pillars	¾	≤ 5
A- and B-Pillars (Lateral)	¾	≤ 3
Side Front Panel (in Front of A-Pillar)	⅝	≤ 12
Side Door (Above Seat)	⅞	≤ 9
Side Door (Below Seat)	¾	≤ 12
Roof	½	≤ 4
Windshield	0	≤ 3
Side Windows	Intact	No shattering resulting from contact with structural member of test article
Dash	½	N/A

*N/A – No MASH 2016 criteria exist for this location

5.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 7. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 7. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 7. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSC-7

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	SLICE-2	
OIV (ft/s)	Longitudinal	-32.87	-32.49	±40 (12.2)
	Lateral	19.24	19.01	±40 (12.2)
ORA (g's)	Longitudinal	-13.44	-12.50	±20.49
	Lateral	7.03	6.64	±20.49
MAX. ANGULAR DISPL. (deg.)	Roll	11.0	13.1	±75
	Pitch	-5.0	-4.3	±75
	Yaw	-70.8	-72.1	not required
THIV (ft/s)		30.54	32.22	not required
PHD (g's)		16.77	12.58	not required
ASI		1.08	1.03	not required

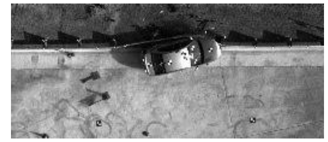
5.7 Discussion

The analysis of the test results for test no. MGSC-7 showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate or ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. As the vehicle exited the barrier, its trajectory did not violate the bounds of the exit box. Therefore, test no. MGSC-7 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-10. A summary of the results from test no. MGSC-7 are shown in Figure 63.

0.000 sec

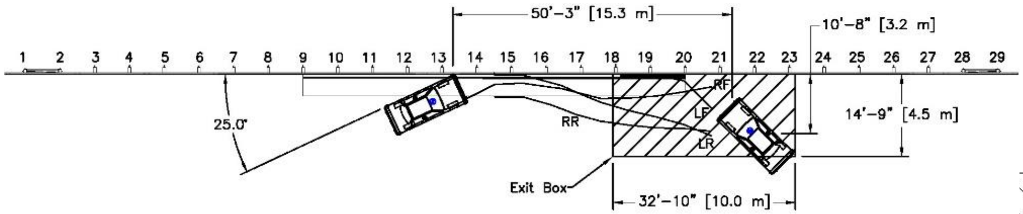
0.028 sec

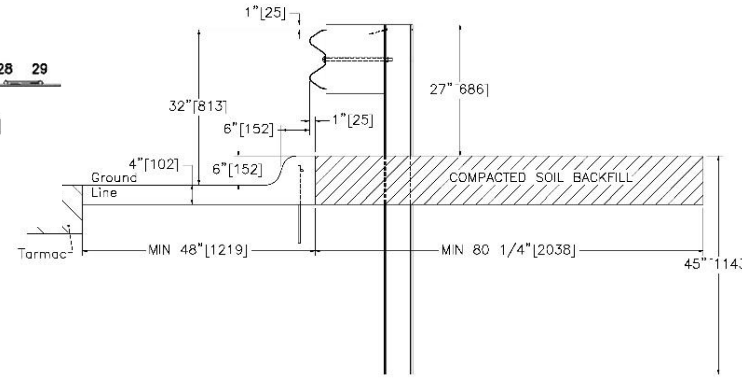
0.067 sec



0.208 sec

0.616 sec





- Test Agency .... MwRSF
- Test Number MGSC-7
- Date 11/7/2017
- MASH 2016 Test Designation No. 3-10
- Test Article .... MGS with Curb
- Total Length .... 182 ft - 3½ in.
- Key Component – Steel W-Beam Guardrail
  - Thickness .... 12 gauge
  - Top Mounting Height .... 32 in. from roadway surface
- Key Component – Steel Post
  - Shape W6x8.5
  - Length .... 72 in.
  - Spacing .... 75 in.
  - Embedment Depth .... 45 in.
- Key Component – Wood Blockout
  - Post Nos. 3-27 .... 6 x 12 x 14¼ in.
- Key Component – Curb .... 6-in. tall AASHTO Type B
- Vehicle Make /Model .... 2009 Hyundai Accent
  - Curb .... 2,448 lb
  - Test Inertial .... 2,423 lb
  - Gross Static .... 2,584 lb
- Impact Conditions
  - Speed .... 63.6 mph
  - Angle .... 25.0 deg.
  - Impact Location .... 91.7 in. US from splice between post nos. 14 and 15
- Impact Severity .... 58.5 kip-ft > 51 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 21.3 mph
  - Angle .... -10.5 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 50 ft – 3 in. DS from impact location
  14 ft – 9 in. laterally in front of system
- Vehicle Damage .... Moderate
  - VDS [20] 11-FL-5
  - CDC [21] 11-LYEW-3
  - Maximum Interior Deformation .... ⅞ in.
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 19.0 in.
  - Dynamic .... 23.5 in.
  - Working Width .... 40.3 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1 (primary)	SLICE-2	
OIV (ft/s)	Longitudinal	-32.87	-32.49	±40
	Lateral	19.24	19.01	±40
ORA (g's)	Longitudinal	-13.44	-12.50	±20.49
	Lateral	7.03	6.64	±20.49
MAX ANGULAR DISP. (deg.)	Roll	11.0	13.1	±75
	Pitch	-5.0	-4.3	±75
	Yaw	19.7 / -70.8	18.7 / -72.1	not required
THIV (ft/s)		30.54	32.22	not required
PHD (g's)		16.77	12.58	not required
ASI		1.08	1.03	not required

Figure 63. Summary of Test Results and Sequential Photographs, Test No. MGSC-7

6 FULL-SCALE CRASH TEST NO. MGSC-8

6.1 Static Soil Test

Before full-scale crash test no. MGSC-8 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

6.2 Weather Conditions

Test no. MGSC-8 was conducted on November 28, 2017 at approximately 2:30 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 8.

Table 8. Weather Conditions, Test No. MGSC-8

Temperature	57° F
Humidity	27%
Wind Speed	21 mph
Wind Direction	0° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

6.3 Test Description

The test installation for test no. MGSC-8 was nearly identical to that from test no. MGSC-7, except the rail height was lowered 1 in. to its nominal 31-in. top mounting height. The critical impact point for test no. MGSC-8 was selected using the CIP plots found in Section 2.3 of MASH. The critical impact point was determined to be 138 in. upstream from the splice located between post nos. 14 and 15, as shown in Figure 64.

The 5,000-lb quad cab pickup truck impacted the MGS 4.4 in. downstream from the targeted impact point at a speed of 63.4 mph and at an angle of 25.7 degrees. The vehicle was contained and redirected with exit speed and angle of 38.2 mph and -4.0 degrees, respectively. The vehicle remained stable throughout the impact event with maximum roll and pitch angular displacements of only -5 degrees and -4 degrees, respectively. During the impact event, the W-beam detached from the posts downstream from impact. The cable anchorage remained intact throughout the entire impact event. After exiting the system, the vehicle turned back into the system, impacted the barrier a second time near the downstream end of the test installation, rolled over the guardrail, and ultimately came rest on top of the guardrail near the downstream anchorage, or 95 ft – 9 in. downstream from impact.

A detailed description of the sequential impact events is contained in Table 9. Sequential photographs are shown in Figures 65 through 67. Documentary photographs of the crash test are shown in Figures 68 and 69. The vehicle trajectory and final position are shown in Figure 70.

Table 9. Sequential Description of Impact Events, Test No. MGSC-8

TIME (sec)	EVENT
0.000	Vehicle’s front bumper contacted rail 133.6 in. upstream from the splice located between post nos. 14 and 15.
0.002	Vehicle’s left-front tire contacted curb.
0.016	Post no. 13 rotated backward.
0.020	Vehicle’s left fender deformed. Vehicle’s grille contacted rail and deformed. Vehicle’s left-front tire contacted rail.
0.026	Vehicle’s left fender contacted rail.
0.044	Vehicle’s left-front tire became airborne. Vehicle’s front airbags deployed.
0.046	Post no. 13 deflected upstream. Vehicle rolled away from barrier. Vehicle’s windshield cracked from airbag deployment.
0.064	Post no. 14 deflected backward.
0.066	Vehicle’s left-front tire regained contact with ground.
0.074	Post no. 14 bent downstream.
0.082	Rail disengaged from bolt at post no. 14.
0.084	Vehicle rolled toward barrier.
0.088	Blockout disengaged from post no. 14.
0.090	Post no. 15 deflected backward and downstream.
0.124	Vehicle’s left-front tire contacted post no. 14.
0.140	Vehicle’s left-rear tire contacted curb.
0.142	Rail disengaged from bolt at post no. 15.
0.156	Vehicle’s front bumper contacted post no. 15.
0.162	Rail disengaged from post bolts at post nos. 21 through 27.
0.163	Vehicle’s left-rear door contacted rail.
0.190	Vehicle’s left-rear tire became airborne.
0.192	Post no. 16 bent downstream.
0.208	Rail disengaged from bolt at post no. 16.
0.210	Vehicle’s rear bumper contacted rail and deformed.
0.213	Vehicle’s left quarter panel contacted rail.
0.234	Blockout disengaged from post no. 16.
0.242	Vehicle’s left-rear tire regained contact with ground.
0.258	Vehicle’s front bumper contacted post no. 16.
0.268	Rail disengaged from post bolt at post no. 28.

Table 10. Sequential Description of Impact Events, Test No. MGSC-8, Cont.

TIME (sec)	EVENT
0.316	Post no. 17 bent downstream.
0.330	Vehicle’s front bumper contacted post no. 17.
0.336	Rail disengaged from bolt at post no. 17.
0.342	Vehicle was parallel to system at a speed of 39.5 mph.
0.348	Rail disengaged from post bolt at post no. 29.
0.364	Blockout disengaged from post no. 17.
0.458	Rail disengaged from bolt at post no. 18.
0.498	Post no. 18 bent downstream.
0.924	Vehicle exited system at a speed of 38.2 mph and an angle of -4.0 degrees.
1.010	Vehicle began to yaw and veer back toward the barrier.
1.766	Vehicle’s front bumper contacted the system near post no. 26.
1.806	Post no. 26 deflected backward.
1.824	Vehicle’s left-front tire overrode rail.
1.986	Vehicle’s front bumper contacted blockout no. 27.
2.024	Post no. 27 deflected backward.
2.302	Vehicle’s front bumper contacted post no. 28.
2.324	Post no. 28 deflected downstream.
2.464	Vehicle’s right-front tire overrode rail.
3.500	Vehicle came to rest on top of downstream anchorage.

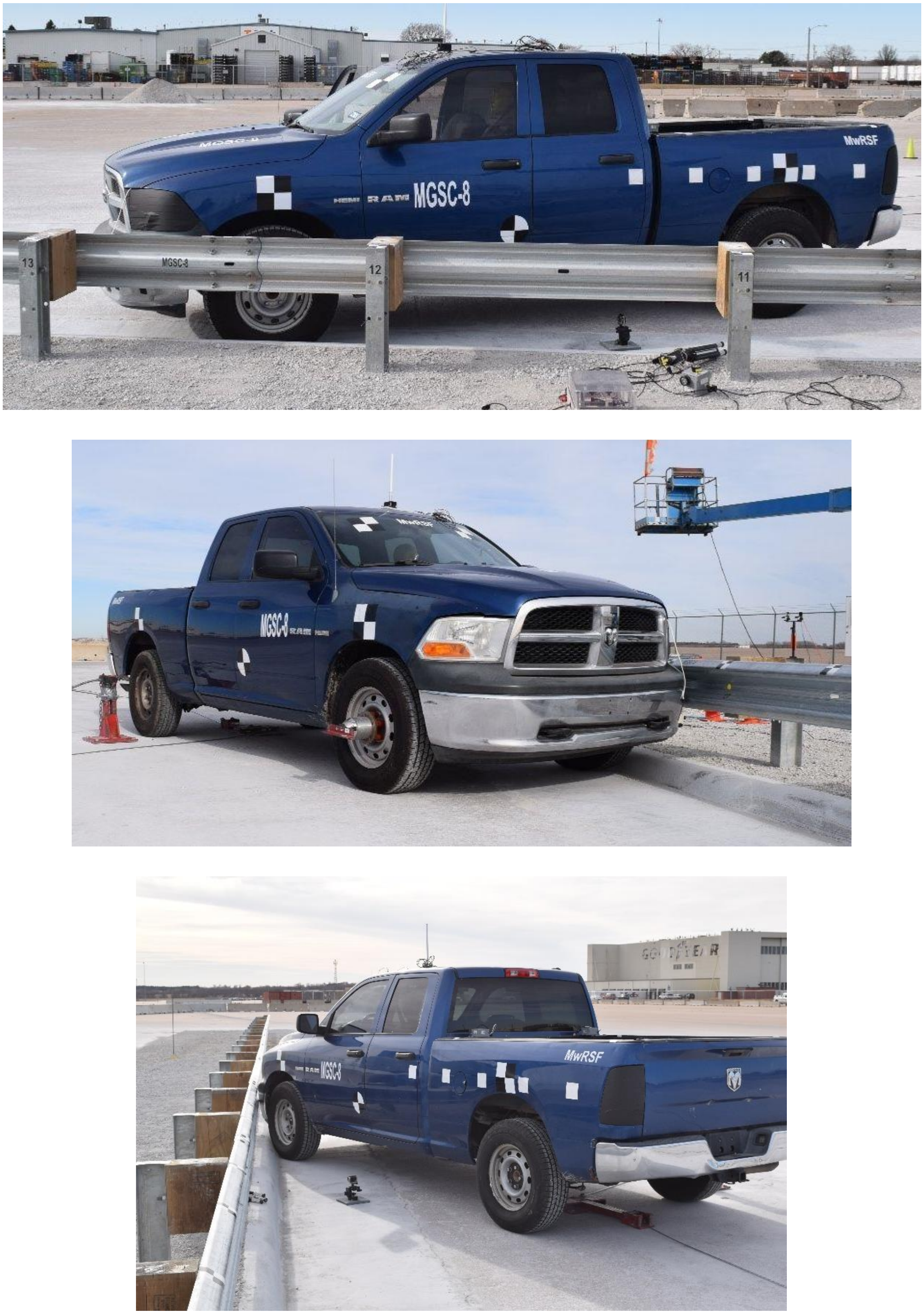


Figure 64. Impact Location, Test No. MGSC-8

0.000 sec

0.000 sec

0.100 sec

0.100 sec

0.300 sec

0.300

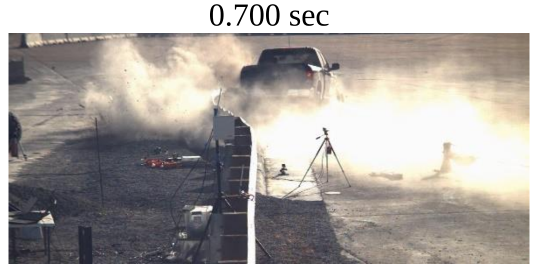
0.500 sec

0.500 sec

0.700 sec

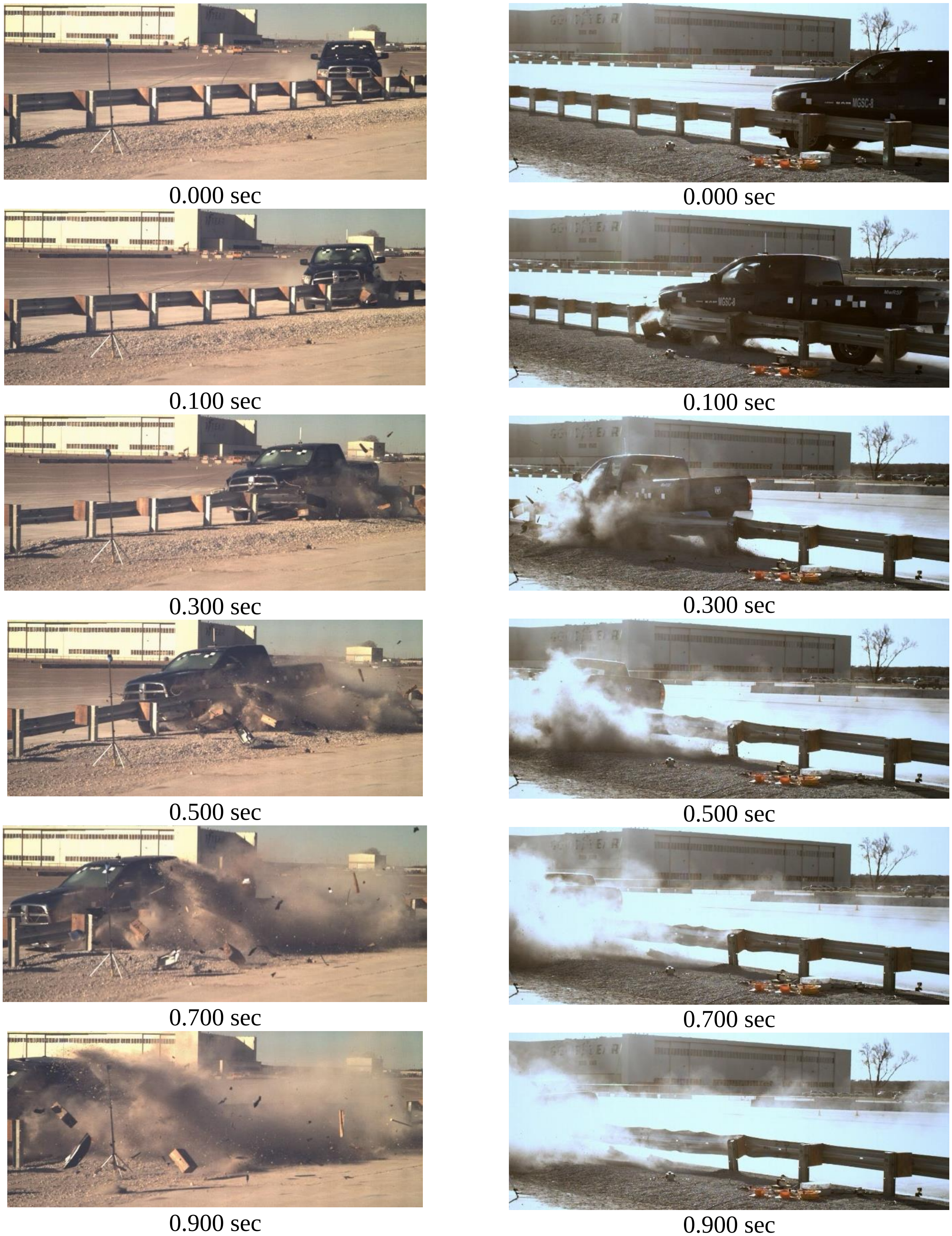
0.700 sec

0.900 sec



0.900 sec

Figure 65. Sequential Photographs, Test No. MGSC-8



0.000 sec | 0.000 sec

0.100 sec | 0.100 sec

0.300 sec | 0.300 sec

0.500 sec | 0.500 sec

0.700 sec | 0.700 sec

0.900 sec | 0.900 sec

Figure 66. Sequential Photographs, Test No. MGSC-8

0.000 sec

0.050 sec

0.100 sec

0.150 sec

0.200 sec

0.250 sec

Figure 67. Sequential Photographs, Test No. MGSC-8

Figure 68. Documentary Photographs, Test No. MGSC-8

Figure 69. Additional Documentary Photographs, Test No. MGSC-8

Figure 70. Vehicle Final Position and Trajectory Marks, Test No. MGSC-8

6.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 71 through 79. Damage to the barrier spanned from post no. 12 through the downstream anchorage of the test installation. The initial contact region spanned from 50 in. downstream from post no. 12 to 5 in. downstream from post no. 18, and the secondary impact was between post nos. 26 and 29.

Curb damage consisted of intermittent tire marks between post nos. 12 and 14. A 68-in. long tire mark was found on the top face of the curb 33 in. downstream from post no. 18. Gouges measuring 7 in., 8 in., and 23 in. were observed near post nos. 13 and 14.

Guardrail damage and deformations were observed along the entire length of the test installation. The rail between post nos. 1 and 2 was slightly bent toward the back side of the system due to tension at the anchorage cable connection. Bolt-slot deformation occurred at post nos. 1, 3, 5 through 7, 12, and 13, and bolt pullout occurred at post nos. 2, 4, 8 through 11, and 14 through 29. A small kink in the W-beam guardrail was observed at post no. 12. Various kinking, flattening, and bending of the guardrail was found continuously between post nos. 13 and 18. The rail was folded under along its bottom edge at the center of post no. 13 and 74½ in. downstream from post no. 13. The rail was flattened beginning 3¾ in. downstream from post no. 13 spanning to the center of post no. 16. Kinking occurred at many locations at the top and bottom edges of the rail between post nos. 13 and 19. The rail buckled 6¼ in., 3¼ in. downstream from post no. 17. Additional flattening occurred along the base of the rail 1½ in. downstream from post no. 17 for a length of 41 in. The rail was bent 5¼ in. upstream and 5¼ in. downstream from post no. 18. The rail buckled 4¼ in and 5⅛ in. downstream from post no. 18. Several additional kinks were found along the rail from post no. 22 to the end of the system.

The most significant post displacements and deformations spanned from post no. 13 to post no. 18. Soil gaps formed at the bases of post nos. 6 through 8, 10, 12, and 22. Soil heaves and craters formed at the bases of post nos. 14 through 19, and additional soil heaves were found at post nos. 26 and 27. Post no. 13 was bent backward and twisted downstream. Blockouts disengaged from post nos. 14 through 17. Each post in this range was bent backward and downstream in addition to being twisted to face upstream. Post no. 18 was bent backward and downstream while being twisted to face downstream. The blockouts of post nos. 18 through 23 had rotated about the attachment bolt. Post nos. 26 and 17 were bent backward and downstream, and post no. 28, which was a BCT post within the downstream anchorage, fractured off at ground level.

The maximum lateral permanent set of the barrier system was 26¾ in., which occurred on the guardrail located at post no. 15, as measured in the field. The maximum lateral dynamic barrier deflection was 39.4 in. measured on the guardrail at post no. 16, as determined from high-speed digital video analysis. The working width of the system was found to be 48.5 in., also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 80.

Figure 71. System Damage, Test No. MGSC-8

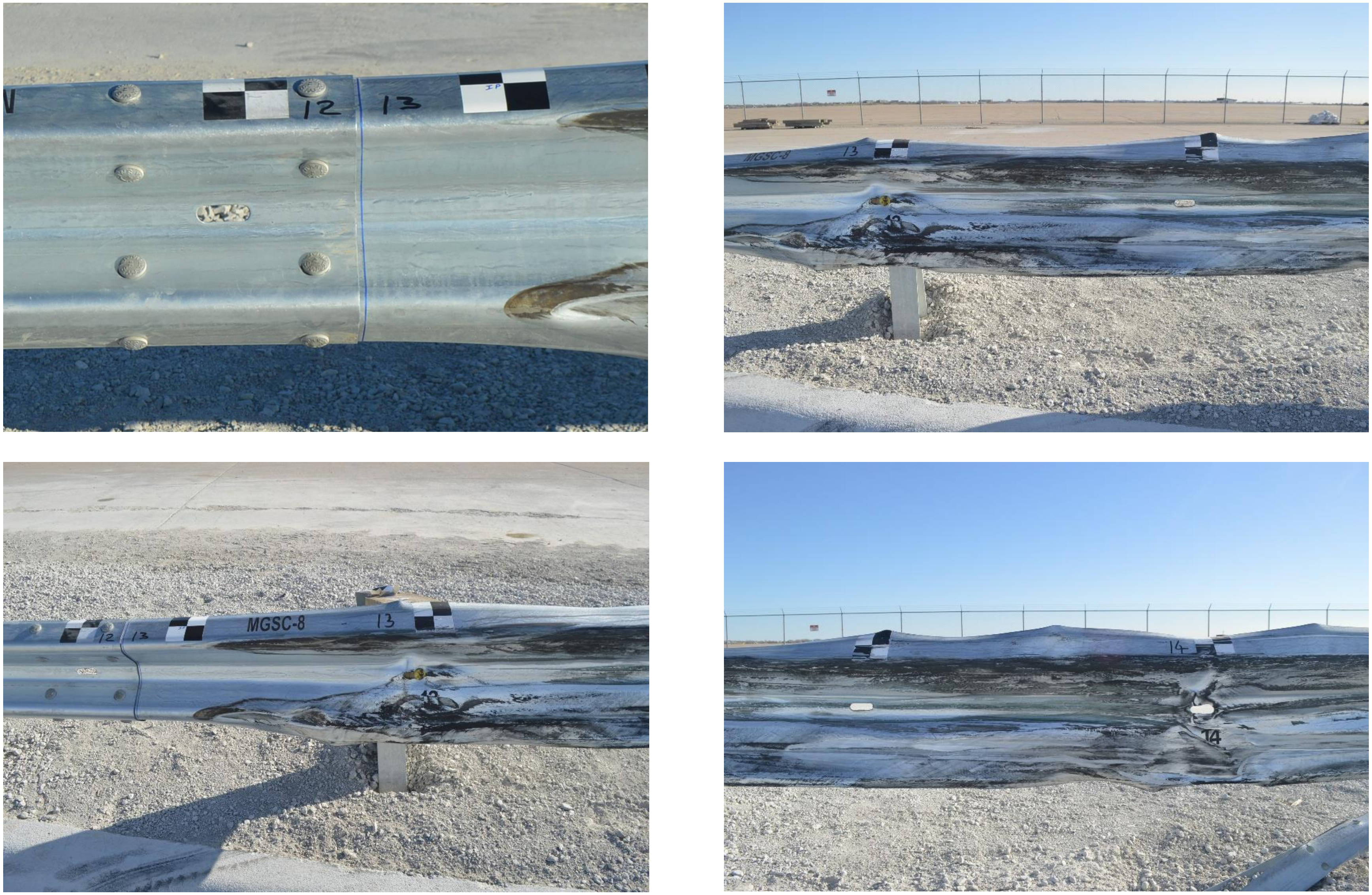


Figure 72. System Damage, Guardrail at Post Nos. 12 through 14, Test No. MGSC-8

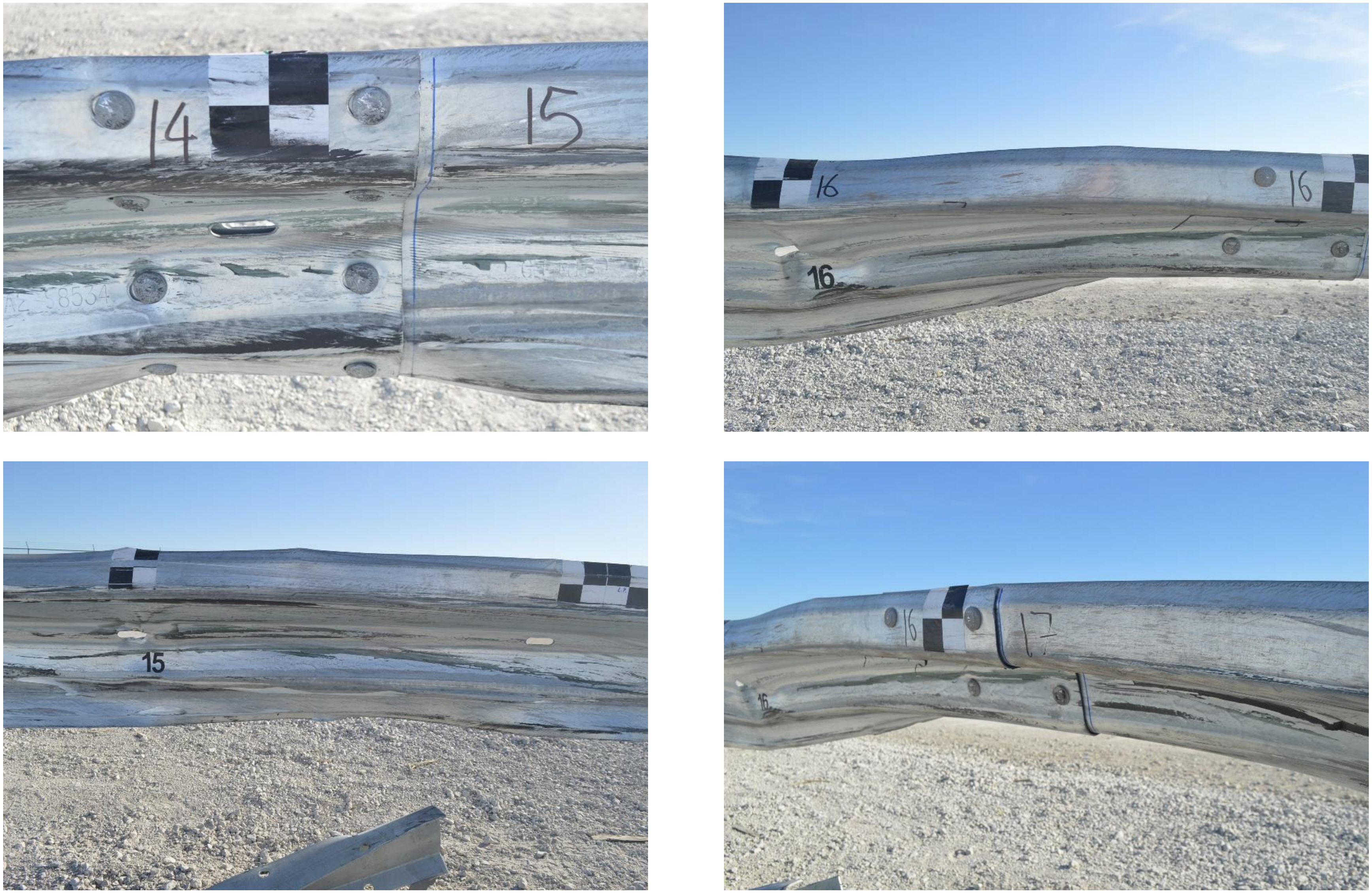


Figure 73. System Damage, Guardrail at Post Nos. 14 through 17, Test No. MGSC-8

Figure 74. System Damage, Guardrail at Post Nos. 17 through 19, Test No. MGSC-8

Figure 75. System Damage, Backside Rail at Post Nos. 12 through 15, Test No. MGSC-8

Figure 76. System Damage, Backside Rail at Post Nos. 16 through 19, Test No. MGSC-8

Figure 77. System Damage, Post Nos. 12 through 15, Test No. MGSC-8

Figure 78. System Damage, Post Nos. 16 through 19, Test No. MGSC-8

Figure 79. System Damage, Post Nos. 25 through 29, Test No. MGSC-8

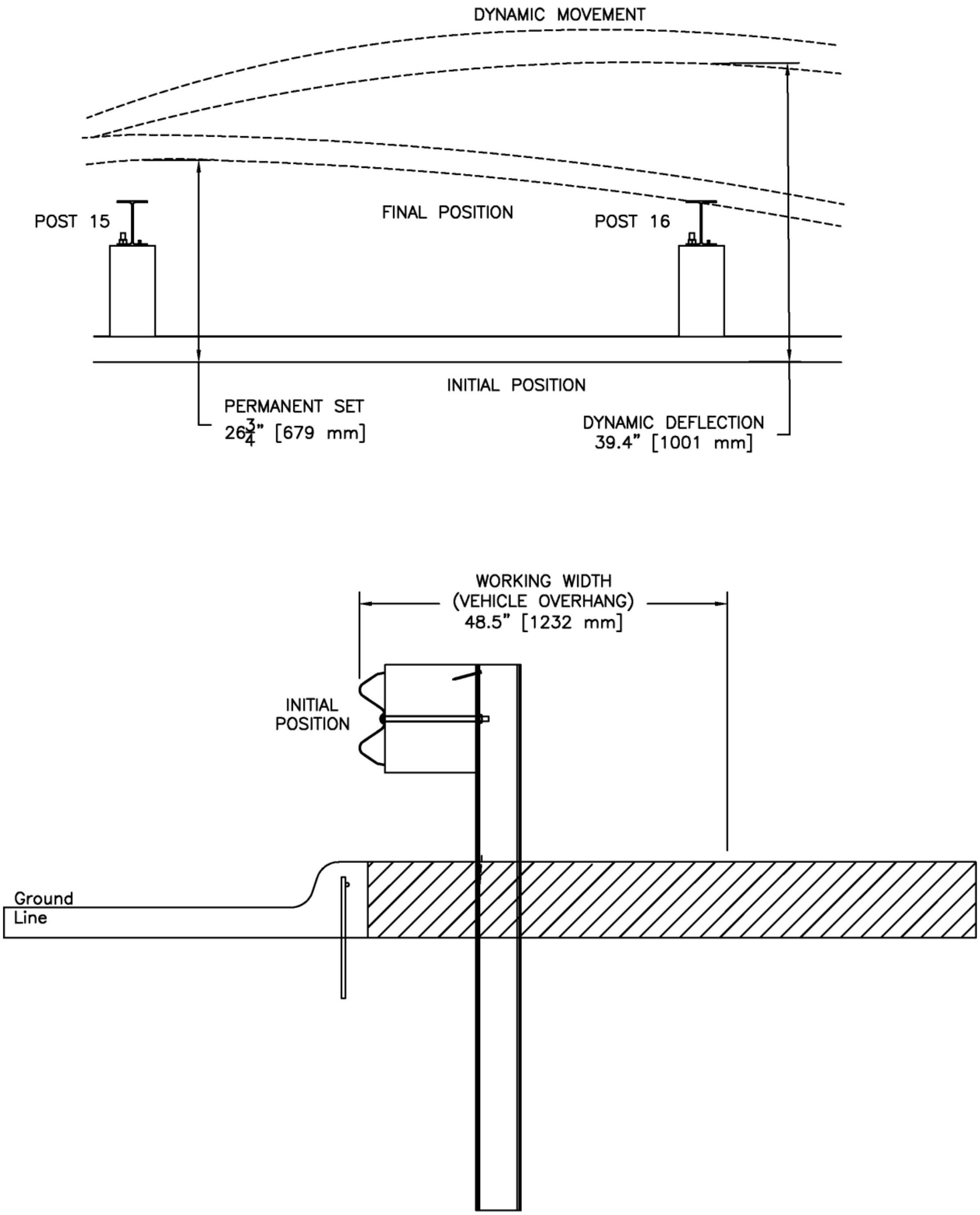


Figure 80. Permanent Deflection, Dynamic Deflection, and Working Width, Test No. MGSC-8

6.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 81 through 85. The maximum occupant compartment deformations are listed in Table 11 along with the deformation limits established in MASH 2016 for various areas of the occupant compartment. Note that none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

The majority of the damage was concentrated at the left-front corner of the vehicle where impact occurred. The left-front bumper was deformed inward toward the engine, and the grille was partially fractured and disengaged from the vehicle. Both front headlights were disengaged. The left-front fender was bent and torn, and the left-front tire sidewall was torn. The wheel rim was bent at several locations. Several minor dents were found on both the left-front and left-rear vehicle doors. Scrapes extended from the left-front fender to the rear bumper along the left side of the vehicle. The left-rear bumper was dented inward. The windshield was cracked at mid-height on the right side due to contact from the vehicle airbag. Additional cracks in the windshield extended outward from the bottom left corner of the windshield. The roof and remaining windows were undamaged.

Damage to the vehicle's undercarriage was minimal. The right-side lower control arm was bent in approximately ½ in. and disengaged from the front mounting point, and the right-front bumper mounting plate was bent.

Figure 81. Vehicle Damage, Test No. MGSC-8

Figure 82. Vehicle Damage, Test No. MGSC-8

Figure 83. Vehicle Windshield Damage, Test No. MGSC-8

Figure 84. Occupant Compartment Damage, Test No. MGSC-8

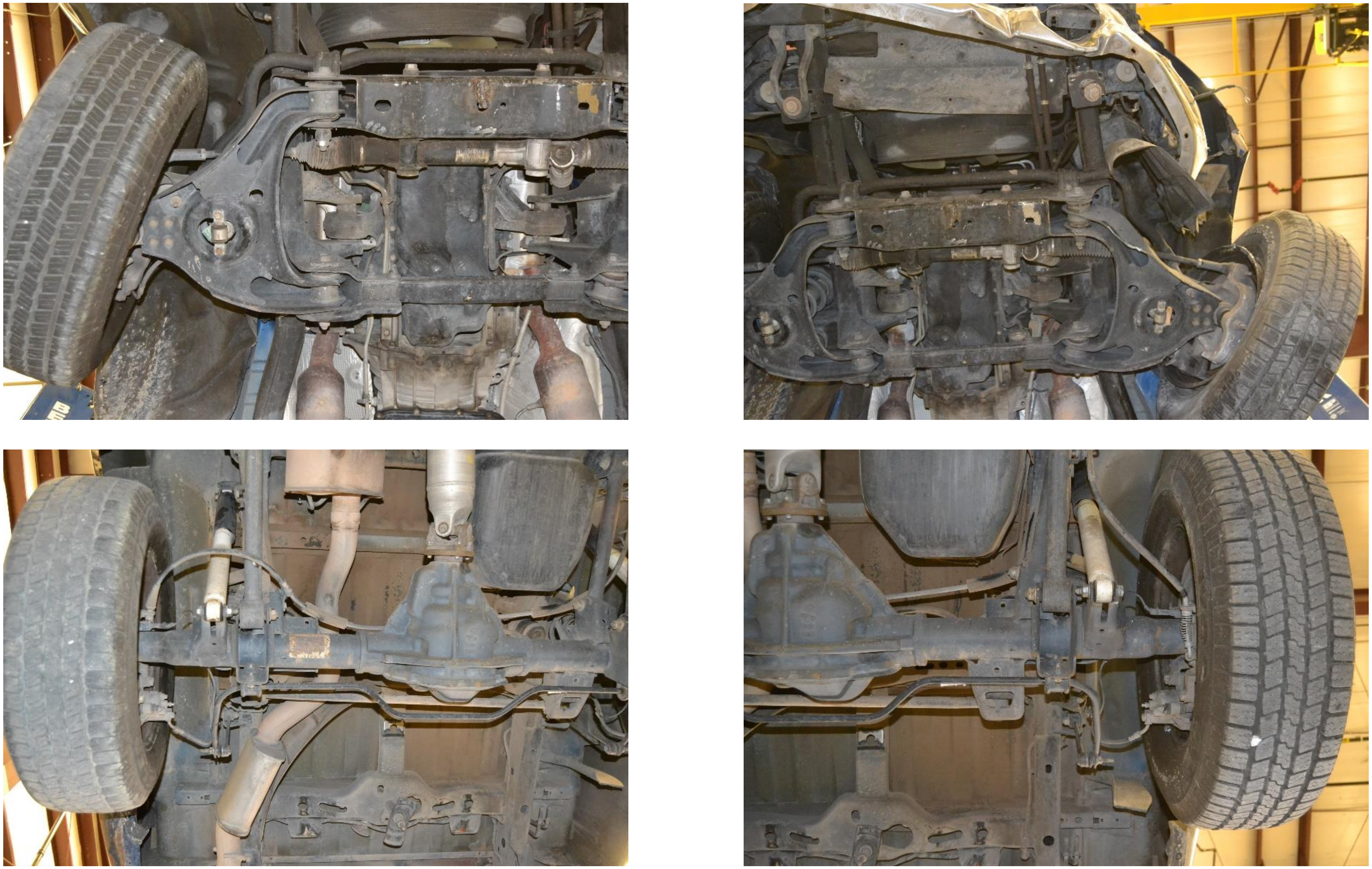


Figure 85. Vehicle Undercarriage Damage, Test No. MGSC-8

Table 11. Maximum Occupant Compartment Intrusions by Location, Test No. MGSC-8

LOCATION	MAXIMUM INTRUSION (in.)	MASH 2016 ALLOWABLE INTRUSION (in.)
Wheel Well & Toe Pan	⅜	≤ 9
Floor Pan & Transmission Tunnel	⅜	≤ 12
A- and B-Pillars	⅜	≤ 5
A- and B-Pillars (Lateral)	¼	≤ 3
Side Front Panel (in Front of A-Pillar)	½	≤ 12
Side Door (Above Seat)	⅜	≤ 9
Side Door (Below Seat)	½	≤ 12
Roof	½	≤ 4
Windshield	0	≤ 3
Side Windows	Intact	No shattering resulting from contact with structural member of test article
Dash	⅜	N/A

*N/A – No MASH 2016 criteria exist for this location

6.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 12. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 12. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

Table 12. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSC-8

Evaluation Criteria		Transducer SLICE-1	Transducer SLICE-2 (primary)	MASH 2016 Limits
OIV (ft/s)	Longitudinal	-21.63	-21.68	±40
	Lateral	13.80	15.06	±40
ORA (g's)	Longitudinal	-6.67	-6.74	±20.49
	Lateral	8.09	8.78	±20.49
MAX. ANGULAR DISPL. (deg.)	Roll	-8.7	-5.3	±75
	Pitch	-3.9	-4.0	±75
	Yaw	38.5	37.3	not required
THIV (ft/s)		22.64	22.90	not required
PHD (g's)		9.23	9.59	not required
ASI		0.69	0.66	not required

6.7 Discussion

The analysis of the test results for test no. MGSC-8 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix F, were deemed acceptable as the vehicle remained upright during and after the collision. The vehicle exited the barrier at an angle of -4.0 degrees, and its trajectory did not violate the bounds of the exit box.

After exiting the system, the vehicle turned back toward the system and impacted the test installation for a second time near post no. 26. The vehicle rolled over the detached W-beam, which had been pulled free from the attachment bolts and was laying on the ground, and came to rest straddling the W-beam guardrail over the downstream anchorage of the test installation. In the MASH evaluation of the system, this phenomenon was not considered to be an override of the guardrail installation for a number of reasons:

- The override occurred as a result of a secondary impact into the system. The vehicle had already been contained, redirected, and exited the system during the initial MASH-specified impact. The evaluation criteria in MASH are not intended for use on secondary impacts that occur after the vehicle exits the system.

- The secondary impact was into a system that had already been damaged by the initial impact. Specifically, the guardrail had been pulled from the downstream posts during the initial impact and was on the ground at the time of the secondary impact, thus allowing the vehicle's front tires to traverse over the rail.

- Although the rail had detached from the posts, the cable anchorage was still intact, so the guardrail anchorage had not failed.

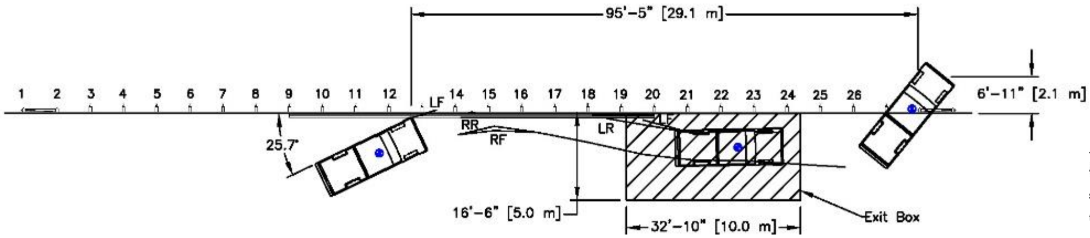
- The secondary impact occurred four posts from the end of the system. Previous research on the downstream anchorage used in the test installation showed that the end of length-of-need (i.e., the farthest downstream point in which a vehicle would be redirected) was six posts from the end [11-14]. Thus, impacts downstream from the sixth post from the end, such as the secondary impact witnessed during test no. MGSC-8, would be expected to result in the guardrail gating and the vehicle traveling behind the system.

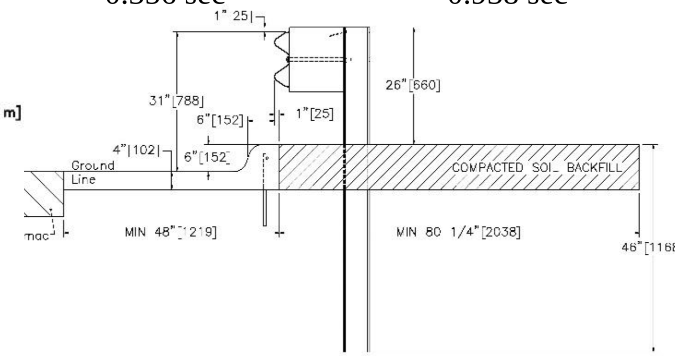
- Multiple other tests on other W-beam guardrail installations have also resulted in the rail being detached from every post between the impact region and the end of the test installation while the cable anchorage remained intact [22-24]. However, in these previous tests, the vehicle never impacted the test installation a second time. Instead, the vehicles either stayed in front of the system or hooked around the system and crossed behind the system downstream from the guardrail anchorages. These previous tests were all determined to pass MASH TL-3 criteria.

- The test installation was a relatively short guardrail installation built for testing purposes only. The relatively short distance from the impact region to the anchorage system may have contributed to the W-beam pulling off of all posts downstream from impact. If the system length had been significantly longer, as most real-world guardrail installations are, it is unlikely that the guardrail detachment would have continued all the way to the anchorage.

Therefore, the secondary impact into the test installation was not considered part of the MASH evaluation of the system, and test no. MGSC-8 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11. A summary of the test results for test no. MGSC-8 are shown in Figure 86.

0.000 sec | 0.044 sec | 0.146 sec | 0.356 sec | 0.938 sec





- Test Agency .... MwRSF
- Test Number MGSC-8
- Date 11/28/2017
- MASH 2016 Test Designation No. 3-11
- Test Article .... MGS with Curb
- Total Length .... 182 ft – 3½ in.
- Key Component – Steel W-Beam Guardrail
  - Thickness .... 12 gauge
  - Top Mounting Height .... 31 in. from roadway
- Key Component – Steel Post
  - Shape W6x8.5
  - Length .... 72 in.
  - Spacing .... 75 in.
  - Embedment Depth .... 46 in.
- Key Component – Wood Blockout
  - Post Nos. 3-27 .... 6 x 12 x 14¼ in.
- Key Component – Curb .... 6-in. tall AASHTO Type B
- Vehicle Make /Model .... 2010 Dodge Ram 1500 Quad Cab Pickup Truck
  - Curb .... 5,092 lb
  - Test Inertial .... 5,000 lb
  - Gross Static .... 5,162 lb
- Impact Conditions
  - Speed .... 63.4 mph
  - Angle .... 25.7 deg.
  - Impact Location .... 133.6 in. US from splice between post nos. 14 and 15
- Impact Severity .... 126.4 kip-ft > 106 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 38.2 mph
  - Angle .... -4.0 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 95 ft – 9 in. DS from impact location
- Vehicle Damage .... Moderate
  - VDS [20] 11-LFQ-2
  - CDC [21] 11-LYEW-1
  - Maximum Interior Deformation .... ½ in.
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 26⅝ in.
  - Dynamic .... 39.4 in.
  - Working Width .... 48.5 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV (ft/s)	Longitudinal	-21.63	-21.68	±40
	Lateral	13.80	15.06	±40
ORA (g's)	Longitudinal	-6.67	-6.74	±20.49
	Lateral	8.09	8.78	±20.49
MAX ANGULAR DISP. (deg.)	Roll	-8.7	-5.3	±75
	Pitch	-3.9	-4.0	±75
	Yaw	38.5	37.3	not required
THIV ft/s		22.64	22.90	not required
PHD (g's)		9.23	9.59	not required
ASI		0.69	0.66	not required

Figure 86. Summary of Test Results and Sequential Photographs, Test No. MGSC-8

7 SUMMARY AND CONCLUSIONS

The objective of the research project described herein was to evaluate the MGS offset 6 in. from a 6-in. tall, AASHTO Type B curb in accordance with MASH 2016 TL-3 criteria. A 182-ft long test installation was constructed at the MwRSF outdoor test site, and test nos. MGSC-7 and MGSC-8 were conducted according to MASH 2016 test designation nos. 3-10 and 3-11, respectively. A summary of the test evaluation for both tests is shown in Table 13.

For test no. MGSC-7, the MGS was installed with a 32-in. top mounting height, 1 in. above nominal, in an effort to evaluate an upper installation tolerance and maximize the risk of vehicle snag below the rail. The 1100C vehicle impacted the system at 63.6 mph and an angle of 25.0 degrees, resulting in an impact severity of 58.5 kip-ft (79.3 kJ). The vehicle was successfully contained and redirected by the system and exited the system at a speed of 21.3 mph and at an angle of -10.5 degrees. A partial tear covering the lower half of the W-beam was found at the critical guardrail splice location within the impact region, but the guardrail remained intact throughout the test. A maximum dynamic deflection of 23.5 in. and a working width of 32.0 in. were observed during the test. All occupant risk values were found to be within limits, and the occupant compartment deformation were also deemed acceptable. Therefore, test no. MGSC-7 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 3-10.

For test no. MGSC-8, the MGS was installed at its nominal height of 31 in. above the roadway surface. The 2270P vehicle impacted the system at 63.4 mph and an angle of 25.7 degrees, resulting in an impact severity of 126.4 kip-ft. The vehicle was successfully contained and redirected by the system and exited the system at a speed of 38.2 mph and an angle of -4.0 degrees. Although the initial contact region spanned approximately 33 ft of guardrail near the middle of the system, the guardrail was detached from all posts downstream from impact. The cable anchorage hardware remained intact. A secondary impact to the damaged test installation, which was not considered part of the MASH evaluation, resulted in the vehicle coming to rest straddling the rail over the downstream anchorage hardware. A maximum dynamic deflection of 39.4 in. and a working width of 48.5 in. were observed during the initial impact event. All occupant risk values were found to be within limits, and occupant compartment deformations were also deemed acceptable. Therefore, test no. MGSC-8 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 3-11.

The two crash tests conducted as part of this project represent both tests listed within the MASH 2016 testing matrix for TL-3 longitudinal barriers. Therefore, the MGS placed 6 in. behind a 6-in. tall AASHTO Type B curb has satisfied all evaluation criteria and has been determined to be crashworthy to MASH 2016 TL-3. Recommendations and general installation guidance for the MGS placed adjacent to curbs is contained in the following chapter.

Table 13. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. MGSC-7</th><th>Test No. MGSC-8</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="5">Occupant Risk</td><td rowspan="2">D.</td><td>1. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</td><td>S</td><td>S</td></tr>
<tr><td>2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Impact Velocity Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td colspan="3">MASH 2016 Test Designation No.</td><td>3-10</td><td>3-11</td></tr>
<tr><td colspan="3">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

8 RECOMMENDATIONS AND IMPLEMENTATION GUIDANCE

The following sections provide implementation guidance and/or recommendations regarding the placement of the MGS adjacent to curbs. These recommendations are intended to ensure comparable safety performance of the guardrail systems and are based on the full-scale testing and any associated research available at the conclusion of this project. Although some installation sites will require systems outside the bounds of these recommendations, the reasoning behind these recommendations should be considered along with other roadside treatments when selecting the final site specific design.

8.1 MGS to Curb Offset

Placement of the MGS closer to the face of the curb has typically been considered to enhance system performance. As the MGS is moved closer to the curb, the vehicle interacts sooner with the guardrail and the effects of the vehicle wheels overriding the curb are reduced. Therefore, the MGS should be considered crashworthy with the face of the rail offset between 0 and 6 in. from the face of the curb. This guidance is in conformance with the results and recommendations from previous NCHRP Report 350 TL-3 and MASH TL-2 studies involving the MGS and curbs [1, 7].

8.2 Applicable Curb Shapes and Heights

Shorter curbs would be expected to result in less vehicle vaulting or less vertical motion of the bumper as the vehicle traverses over the curb. Additionally, curb shapes with a sloped face geometry are likely to reduce the severity of vertical vehicle motion as compared to vertical shaped curbs. Note, the AASHTO Type B curb can be considered a near vertical curb with rounded top and bottom edges, so a 6-in. tall AASHTO Type A curb (vertical shape) is expected to produce vehicle trajectories very similar to those of the 6-in. AASHTO Type B curb tested herein. Thus, the MGS should be considered crashworthy in combination with any standard curb shape up to 6 in. in height. Examples of other AASHTO curb shapes are shown in Figure 87.

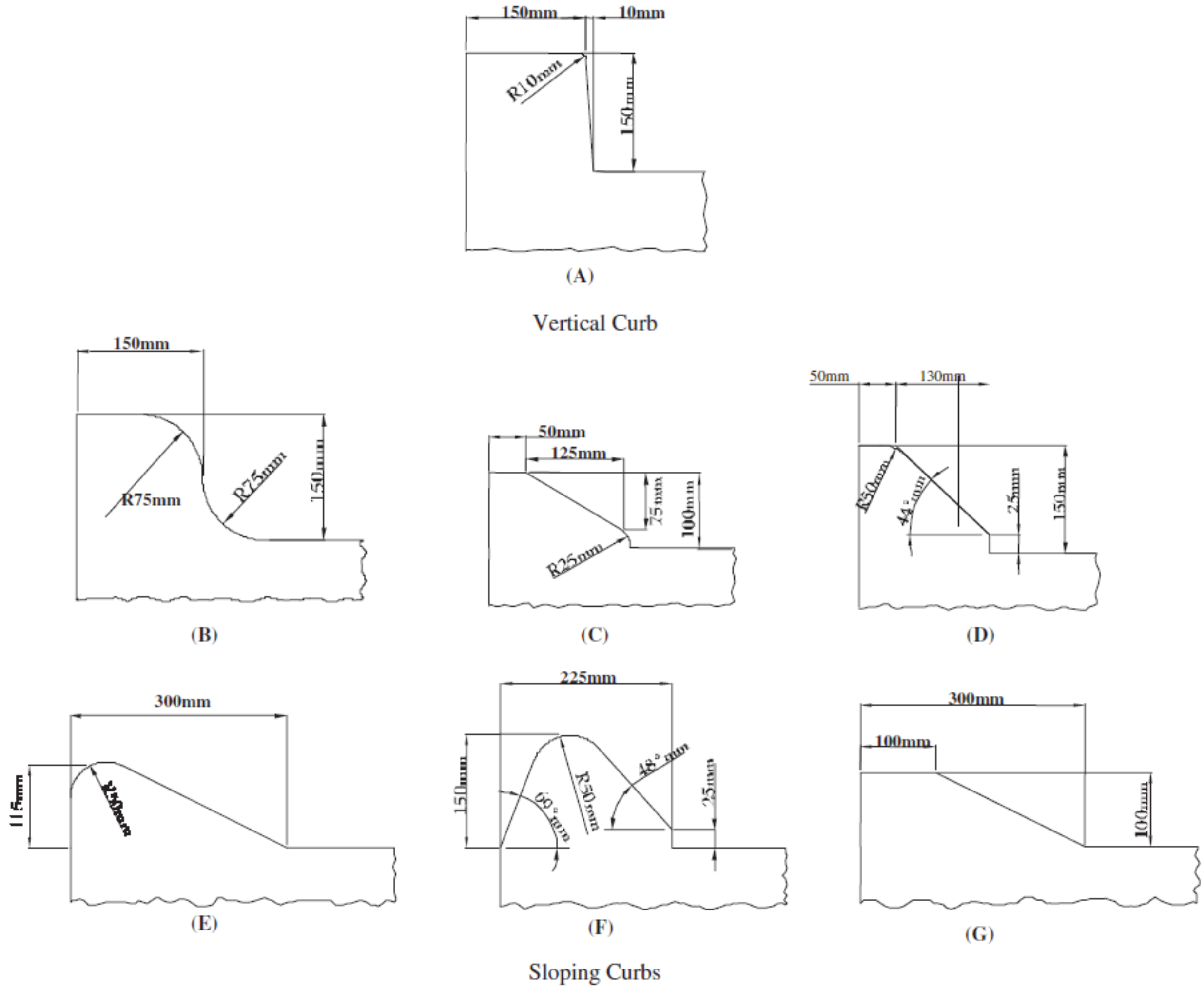


Figure 87. Standard AASHTO Curb Shapes

8.3 MGS Height Tolerances

Test no. MGSC-7 demonstrated the ability of the MGS to safely redirect small vehicles with an increased rail height of 32 in. Unfortunately, the lower bound rail height tolerance of the MGS installed adjacent to curb has not yet been evaluated. Thus, it is not recommended to install the MGS adjacent to curb at heights lower than 31 in. or higher than 32 in. (relative to the roadway surface) until further investigation has been conducted to evaluate the height tolerances of the MGS placed adjacent to curb.

8.4 Approach Slopes and Gutters

Curbs are typically installed at the edge of a roadway along the shoulder, so any approach slopes to the curb and MGS would be restricted to typical roadway crowns and grading. As such, approach slopes are not expected to exceed 10H:1V, and therefore, would not affect the performance of the MGS adjacent to curb. Additionally, curbs are commonly placed in combination with shallow gutters to collect and drain water from the roadway. However, these gutters are seldom wider than 1-2 ft and consist of gentle slopes leading into the curb. It is unlikely that these shallow gutters would alter the trajectory of an errant vehicle traveling at speeds and departure angles near MASH TL-3 limits, so common shallow gutters are also not expected to affect the safety performance of the MGS placed adjacent to curbs.

8.5 MGS Configurations and Special Applications

The research and testing detailed herein demonstrated that the MGS installed 6 in. behind the face of a 6-in. tall, AASHTO Type B curb was crashworthy according to the TL-3 safety standards of MASH 2016. However, variations of the MGS developed for special applications may be sensitive to the addition of a curb adjacent to the guardrail. Subsequently, recommendations regarding the placement of various MGS applications adjacent to curbs may vary depending on the nature and behavior of the specific MGS configuration. The following sections provide implementation guidance and/or recommendations regarding various MGS configurations and special applications placed adjacent to curbs.

8.5.1 Wood Post MGS

Wood post versions of the MGS utilizing 6-in. x 8-in. posts of both Southern Yellow Pine and White Pine timber species were previously tested in accordance with MASH safety performance standards [25-26]. The full-scale testing illustrated that the MGS performed similarly when utilizing either 6-in. x 8-in. wood posts or W6x8.5 steel posts [27-28]. System deflections, working widths, and vehicle decelerations were all similar between these MGS configurations. As such, a wood post MGS system placed adjacent to curbs should result in similar behavior and performance to the system evaluated herein.

8.5.2 MGS without Blockouts

Previously, full-scale crash testing was successfully performed on the MGS without blockouts. The installation utilized standard steel guardrail posts and 12-in. long backup plates to prevent contact between the rail and the posts and reduce the probability of rail tearing. The system was successfully crash tested to MASH TL-3 [29]. However, vehicular impacts into guardrail placed adjacent to curbs may contact the barrier face with an increased bumper height and trajectory, especially when the front bumper and impact-side wheels become airborne early in the impact event. Guardrail blockouts help maintain rail height during system deflections as the lateral dimension of the blockout gains a vertical component as the post rotates back. Thus, the loss in height produced by the post rotating backward is offset by the vertical contribution of the blockout depth. Non-blocked MGS will allow the top rail height to decrease more rapidly as the post rotates back. Additionally, the increased embedment depth from the soil backfill behind the curb moves the post rotation point upward, reduces the distance between the rail and the post rotation point, and results in the rail height dropping more rapidly compared to an MGS installation on level terrain. Therefore, placement of a non-blocked MGS adjacent to curb is not recommended for use without further analysis and/or crash testing.

8.5.3 MGS with 8-in. Deep Blockouts

The concerns raised in the previous section discussing non-blocked MGS installations may apply to other configurations utilizing a blockout depth less than the 12-in. depth tested herein. However, it is also recognized that there are blockout depths less than 12 in. that would likely satisfy MASH TL-3 when used in MGS installations adjacent to a curb. Unfortunately, the minimum blockout depth required to ensure proper performance for the MGS adjacent to curb remains unknown until further evaluation is conducted. However, the performance of 8-in. and 12-in. blockouts have been shown to be similar for installations on level terrain [30], so the performance of either blockout type should also be similar with the presence of a curb. Thus, it is recommended to utilize the same implementation guidelines and restrictions presented herein for MGS installations incorporating 8-in. blockouts adjacent to curbs.

8.5.4 MGS with an Omitted Post

Previous crash testing on an MGS installation with an omitted post was successful to MASH TL-3 criteria [24]. However, when the system was tested with MGS placed 6 in. behind a 6-in. tall AASHTO Type B curb, the W-beam ruptured, the vehicle penetrated behind the system, and the 1100C vehicle ultimately rolled over [31]. To prevent premature rail failure, 37.5 ft of nested W-beam was placed around the location of the omitted post. Crashing testing on the nested MGS system with an omitted post was successfully conducted to both MASH 2016 test designation nos. 3-10 and 3-11 [31-32]. Therefore, if the omission of a post is required within an MGS installation placed adjacent to a curb, 37.5 ft of nested W-beam guardrail should be placed around the omitted post to ensure MASH TL-3 crashworthiness.

The omission of multiple posts within an MGS installation may lead to increased deflections, increased rail loads, and increased pocketing, all of which may lead to failure of the guardrail system. Therefore, sufficient distance between omitted posts within an MGS installation is necessary to ensure proper system performance. Keeping in line with the recommendations set for the MGS on level terrain [24], the distance between omitted posts is recommended to be at least 56.25 ft, as shown in Figure 88. This distance is equivalent to omitting a single post at every ninth post along an MGS installation

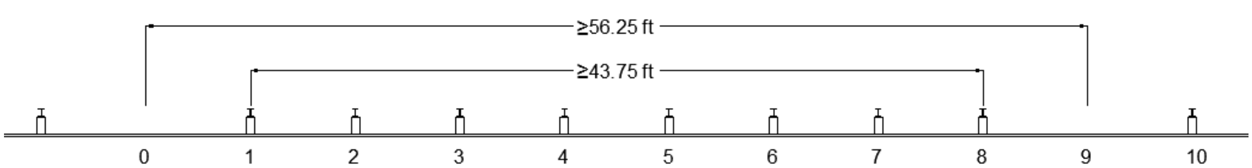


Figure 88. Minimum Recommended Distance between Omitted Posts

8.5.5 Roadside Slopes

The MGS with curb was tested on a level surface with level grading behind the curb and guardrail posts. Although steep roadside slopes are not commonly located adjacent to curbs, it is possible that a slope may be located behind the surface of the curb. Previously, the MGS without curb was successfully full-scale crash tested to MASH TL-3 with the posts located at the slope break point of a 2H:1V slope [23]. The sloped terrain resulted in a reduced soil resistance to guardrail post rotations, and the system deflections were greatly increased as compared to the deflections of the MGS on level terrain. The additional embedment depth associated with the soil backfill behind the curb would increase the soil resistance back toward that of a post on level terrain. However, it is difficult to predict the soil-post resistance forces and the effective system stiffness that would result from the combination of sloped terrain and soil backfill behind the curb. Thus, placement of the MGS with curb adjacent to roadside slopes is not recommended until further evaluation is completed.

8.5.6 Guardrail Stiffness Transitions

Multiple thrie beam approach guardrail transitions (AGTs) have been developed and successfully crash tested with a curb placed below the thrie beam. The curbs geometries within these AGTs range in shape from a 4-in. tall triangular shape to a 6-in. vertical shape. However, the upstream stiffness transition, which connects standard MGS to the stiffened thrie beam regions of AGTs, has only been evaluated in combination with a 4-in. tall triangular shaped curb. Full-scale testing on the upstream stiffness transition with a 4-in. tall curb resulted in the 1100C small car wedging underneath the rail and causing rail rupture of the W-beam adjacent to the W-to-thrie transition segment [33]. To prevent premature rail failure, 12.5 ft of nested W-beam was added just upstream of the W-to-thrie transition segment. The modified upstream stiffness transition satisfied all evaluation criteria of MASH TL-3. However, there are still concerns that taller curbs may accentuate vehicle wedging below the rail and lead to premature rail failure. Thus, it is recommended that curbs placed adjacent to the upstream stiffness transition be limited to a maximum height of 4 in. until further evaluation is conducted.

8.5.7 Guardrail End Terminals and Anchorages

Multiple W-beam guardrail end terminals have been developed for use with the MGS. However, to date, no upstream guardrail end terminations have been evaluated to MASH criteria when placed adjacent to curbs. Thus, guardrail terminals installed adjacent to curbed roadways should follow manufacturer recommendations. If no evaluations or recommendations can be found, it may be beneficial to place upstream guardrail terminals an adequate distance upstream from the start of a curb to avoid negatively affecting the system’s safety performance.

A non-proprietary, downstream anchorage system was previously developed for use at the trailing-end of guardrail installations which are not subject to reverse direction impacts. The system was successfully crash tested on level terrain to MASH TL-3 criteria [11-14]. However, the downstream anchorage was designed for a 31-in. rail height relative to ground line adjacent to the BCT posts. The presence of a curb and soil backfill, as evaluated herein, effectively reduces the rail to ground distance to 25 in. The downstream anchorage system components were not designed for this configuration and would not fit properly. Therefore, the downstream end anchorage system should not be placed adjacent to curbed roadways until further evaluation and testing are conducted.

9 MASH EVALUATION

The evaluation of the MGS placed adjacent to curb was conducted with the face of the W-beam guardrail offset 6-in. laterally from the face of a 6-in. tall AASHTO Type B curb. The MGS was given a nominal rail height of 31 in. measured from the roadway surface, and soil backfill was placed behind the curb to maintain a ground line even with the top of the curb. As such, the nominal post embedment depth was increased by 6 in. to 46 in.

The MGS placed adjacent to curb was subjected to two full-scale crash tests in accordance with MASH 2016 TL-3 evaluation criteria. In test no. MGSC-7, the 1100C small car was contained and safely redirected. Partial tearing of the W-beam occurred at a splice location within the contact region, but the rail did not fully rupture. All occupant risk criteria was satisfied, and the test was determined to pass MASH test designation no. 3-10. During test no. MGSC-8, the 2270P pickup was captured and smoothly redirected, and all occupant risk values were below MASH limits. Thus, test no. MGSC-8 was determined to satisfy MASH test designation no. 3-11.

With the successful completion of both crash tests within the TL-3 testing matrix, the MGS placed 6 in. from a 6-in. tall AASHTO Type B curb was determined to be crashworthy to MASH 2016 TL-3 criteria. Barrier placement closer to the face of the curb is generally considered to improve system performance as it reduces the curb's effect on vehicle trajectory. Thus, the MGS should be considered crashworthy for curb-to-guardrail offsets between 0 in. and 6 in. Lower height curbs and curbs with sloped faces are also expected to reduce the vertical trajectory of impacting vehicles. Since the MGS was evaluated with a critical curb shape, the MGS is expected to remain crashworthy in combination with any standard curb shape at or below a maximum height of 6 in.

10 REFERENCES

1. Polivka, K.A., Faller, R.K., Sicking, D.L., Reid, J.D., Rohde, J.R., Holloway, J.C., Bielenberg, R.W., and Kuipers, B.D., *Development of the Midwest Guardrail System (MGS) for Standard and Reduced Post Spacing and in Combination with Curbs*, Report No. TRP-03-139-04, Project No. SPR-3(017), Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, September 2004.

2. Ross, H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Research Program (NCHRP) Report No. 350, Transportation Research Board, Washington, D.C., 1993.

3. *Manual for Assessing Safety Hardware,* American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.

4. *Manual for Assessing Safety Hardware*, *Second Edition,* American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2016.

5. Zhu, L., Faller, R.K., Reid, J.D., Sicking, D.L., Bielenberg, R.W., Lechtenberg, K.A., and Benner, C.D., *Performance Limits for 152-mm (6-In.) High Curbs Placed in Advance of the MGS Using MASH-08 Vehicles - Part I: Vehicle-Curb Testing and LS-DYNA Analysis*, Report No. TRP-03-205-09, Project No.: SPR-3(017), Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, May 2009.

6. Thiele, J.C., Lechtenberg, K.A., Reid, J.D., Faller, R.K., Sicking, D.L., and Bielenberg, R.W., *Performance Limits for 6-In. (152-mm) High Curbs Placed in Advance of the MGS Using MASH-08 Vehicles - Part II: Full-Scale Crash Testing*, Report No. TRP-03-221-09, Project No.: SPR-3(017), Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 2009.

7. Thiele, J.C., Reid, J.D., Lechtenberg, K.A., Faller, R.K., Sicking, D.L., and Bielenberg, R.W., *Performance Limits for 6-In. (152-mm) High Curbs Placed in Advance of the MGS Using MASH Vehicles - Part III: Full-Scale Crash Testing (TL-2)*, Report No. TRP-03-237-10, Project No.: SPR-3(017), Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, November 2010.

8. Rosenbaugh, S.K., Lechtenberg, K.A., Faller, R.K., Sicking, D.L., Bielenberg, R.W., and Reid, J.D., *Development of the MGS Approach Guardrail Transition Using Standardized Steel Posts*, Report No. TRP-03-210-10, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, December 2010.

9. Winkelbauer, B.J., Putjenter, J.G., Rosenbaugh, S.K., Lechtenberg, K.A., Bielenberg, R.W., Faller, R.K., and Reid, J.D., *Dynamic Evaluation of MGS Stiffness Transition with Curb*, Report No. TRP 03-291-14, Midwest Roadside Safety Facility, University of Nebraska Lincoln, Lincoln, Nebraska, June 2014.

10. Rosenbaugh, S.K., Stolle, C.S., and Ronspies, K.B., *MGS with Curb and Omitted Post: Evaluation to MASH 2016 Test Designation No. 3-10*, Report No. TRP-03-393-19, Midwest Roadside Safety Facility, University of Nebraska Lincoln, Lincoln, Nebraska, April 2019.

11. Mongiardini, M., Faller, R.K., Reid, J.D., Sicking, D.L., Stolle, C.S., and Lechtenberg, K.A., *Downstream Anchoring Requirements for the Midwest Guardrail System*, Report No. TRP-03-279-13, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 28, 2013.

12. Mongiardini, M., Faller, R.K., Reid, J.D., and Sicking, D.L., *Dynamic Evaluation and Implementation Guidelines for a Non-Proprietary W-Beam Guardrail Trailing-End Terminal*, Paper No. 13-5277, Transportation Research Record No. 2377, Journal of the Transportation Research Board, TRB AFB20 Committee on Roadside Safety Design, Transportation Research Board, Washington D.C., January 2013, pages 61-73.

13. Stolle, C.S., Reid, J.D., Faller, R.K., and Mongiardini, M., *Dynamic Strength of a Modified W-Beam BCT Trailing-End Termination*, Paper No. IJCR 886R1, Manuscript ID 1009308, International Journal of Crashworthiness, Taylor & Francis, Vol. 20, Issue 3, Published online February 23, 2015, pages 301-315.

14. Griffith, M.S., Federal Highway Administration (FHWA), *Eligibility Letter HSST/B-256 for: Trailing-End Anchorage for 31" Tall Guardrail*, December 18, 2015.

15. Hinch, J., Yang, T.L., and Owings, R., *Guidance Systems for Vehicle Testing,* ENSCO, Inc., Springfield, Virginia, 1986.

16. *Clarifications on Implementing the AASHTO Manual for Assessing Safety Hardware*, 2016, FHWA and AASHTO, https://design.transportation.org/wp-content/uploads/sites/21/2019/11/Clarifications-on-Implementing-MASH-2016-aka-MASH-QA-Updated-Nov-19-2019.pdf, November 2019.

17. MacInnis, D., Cliff, W., and Ising, K., *A Comparison of the Moment of Inerita Estimation Techniques for Vehicle Dynamics Simulation*, SAE Technical Paper Series – 970951, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1997.

18. *Center of Gravity Test Code - SAE J874 March 1981*, SAE Handbook Vol. 4, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1986.

19. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, NY, July, 2007.

20. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

21. *Collision Deformation Classification – Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

22. Meyer, D.T., Reid, J.D., Lechtenberg, K.A., Bielenberg, R.W., and Faller, R.K., *Increased Span Length for the MGS Long-Span Guardrail System Part II: Full-Scale Crash Testing*, Report No. TRP 03-339-17, Project No.: TPF-5(193) Supplement #56, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, April 7, 2017.

23. Haase, A.J., Kohtz, J.E., Lechtenberg, K.A., Bielenberg, R.W., Reid, J.D., and Faller, R.K., *Midwest Guardrail System (MGS) with 6-ft Posts Placed Adjacent to a 1V:6H Fill Slope*, Report No. TRP 03-320-16, Project No.: TPF-5(193) Supplement #68, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, August 22, 2016.

24. Lingenfelter, J.L., Rosenbaugh, S.K., Bielenberg, R.W., Lechtenberg, K.A., Faller, R.K., and Reid, J.D., *Midwest Guardrail System (MGS) with an Omitted Post, Final Report to the Midwest State's Pooled Fund Program*, Report No. TRP 03-326-16, Project No.: TPF-5(193) Supplement #80, Midwest Roadside Safety Facility, University of Nebraska Lincoln, Lincoln, Nebraska, February 22, 2016.

25. Stolle, C.J., Lechtenberg, K.A., Faller, R.K., Rosenbaugh, S.K., Sicking, D.L., and Reid, J.D., *Evaluation of the Midwest Guardrail System (MGS) with White Pine Wood Posts*, Report No. TRP-03-241-11, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, March 28, 2011.

26. Gutierrez, D.A., Lechtenberg, K.A., Bielenberg, R.W., Faller, R.K., Reid, J.D., and Sicking, D.L., *Midwest Guardrail System (MGS) with Southern Yellow Pine Posts*, Report No. TRP 03-272-13, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, September 4, 2013.

27. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, B.W., and Reid, J.D., *Performance Evaluation of the Midwest Guardrail System - Update to NCHRP 350 Test No. 3-11 (2214MG-1)*, Final Report to the National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Report No. TRP-03-170-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln Nebraska, October 10, 2006.

28. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, B.W., and Reid, J.D., *Performance Evaluation of the Midwest Guardrail System - Update to NCHRP 350 Test No. 3-11 with 28" C.G. Height (2214MG-2)*, Final Report to the National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Report No. TRP-03-171-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 11, 2006.

29. Schrum, K.D., Lechtenberg, K.A., Bielenberg, R.W., Rosenbaugh, S.K., Faller, R.K., Reid, J.D., and Sicking, D.L., *Safety Performance Evaluation of the Non-Blocked Midwest Guardrail System (MGS)*, Report No. TRP-03-262-12, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, January 24, 2013.

30. Dobrovolny, C.S., White, K.M., and Bligh, R.P., *Synthesis of System/Vehicle Interaction Similarities/Dissimilarities with 12-Inch vs 8-Inch Blockouts with 31-Inch Mounting Height, Mid-Span Splices*, Program Report No. 601621, Texas Transportation Institute, Texas A&M University, College Station, Texas, July 2014.

31. Rosenbaugh, S.K., Stolle, C.S., and Ronspies, K.B., *MGS with Curb and Omitted Post: Evaluation to MASH 2016 Test Designation No. 3-10*, Research Report No. TRP-03-393-19, Project No.: TPF(193) Supplement #105, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, July 2, 2019.

32. Rosenbaugh, S.K., et al., *MGS with Curb and Omitted Post: Evaluation to MASH 2016 Test Designation No. 3-11*, DRAFT Report No. TRP-03-433-20, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, **DRAFT IN PROGRESS**.

33. Winkelbauer, B.J., Putjenter, J.G., Rosenbaugh, S.K., Lechtenberg, K.A., Faller, R.K., Bielenberg, R.W., and Reid, J.D., *Dynamic Evaluation of MGS Stiffness Transition with Curb*, Report No. TRP-03-291-14, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, June 30, 2014.

11 APPENDICES

Appendix A. Material Specifications

Table A-1. Bill of Materials, Test Nos. MGSC-7 and MGSC-8

Item No.	Description	Material Spec	Reference
a1	12'-6" 12 ga. W-Beam MGS Section	AASHTO M180	H#9411949
a2	12'-6" 12 ga. W-Beam MGS End Section	AASHTO M180	H#9411949
a3	6'-3" 12 ga. W-Beam MGS Section	AASHTO M180	H#515691
a4	W6x8.5, 72" Long Steel Post	ASTM A992 Min. 50 ksi	H#55044258 H#55044251
a5	6"x12"x14¼" Timber Blockout for Steel Posts	SYP Grade No. 1 or better	CoC: 10/29/15 CoC: 4/23/14 CoC: 7/26/16
a6	16D Double Head Nail	-	CoC: Order#E000357170
b1	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (no knots +/- 18" of ground on tension face)	CoC 3/2/17
b2	72" Long Foundation Tube	ASTM A500 Gr. B	H#0173175
b3	Ground Strut Assembly	ASTM A36	South: H#163375 North: BOL#43073
b4	2⅜" O.D. x 6" Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	H#A79999
b5	8"x8"x⅝" Anchor Bearing Plate	ASTM A36	H#DL15103543
b6	Anchor Bracket Assembly	ASTM A36	H#JK16101488
c1	BCT Anchor Cable	-	Cable: H#DL15103032 Nut: H#15105591 Washer: L#16H-168236-30
d1	⅝" Dia. UNO, 14" Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolt:H#NF16202178 H#NF16100453 Nut: H#20479830
d2	⅝" Dia. UNO, 10" Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolt: H#20351510 H#10240100 H#20297970 Nut: H#20479830
d3	⅝" Dia. UNO, 1¼" Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolt: H#20460760 Nut: H#20479830
d4	⅝" Dia. UNO, 10" Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolt:H#DL15107048 Nut: CoC 129980
d5	⅝" Dia. UNO, 1½" Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolt: H#816070039 Nut: CoC 129980
d6	⅞" Dia. UNO, 8" Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolt: H#2038622 Nut: H#12101054
e1	⅝" Dia. Plain Round Washer	ASTM F844	n/a
e2	⅞"] Dia. Plain Round Washer	ASTM F844	n/a
f1	Curb Concrete	f'c – 4,000 psi	R#2147369335
f2	#4 Rebar 819" Long	ASTM A615 Gr. 60	H#JW16104719
f3	#4 Rebar 16" Long	ASTM A615 Gr. 60	H#58028856

Gregory Industries 13:54:11 Jun 24 2015 Page 1

H E A T   M A S T E R   L I S T I N G

Heat No.	Mill#	Name	YR	Primary Grade	Secondary Grade	CODE	Original Heat Number
9411949	ARC03	ARCELOR MITTAL USA, LLC	15	1021		8534	

******* Chemistry *******

Cr	Si	P	C	Mn	S	Cu	Ni	Mo	Sn	Al	V	Cb	N	Ti
0.0400	0.0100	0.0100	0.2100	0.7500	0.0060	0.0200	0.0100	0.0100	0.0020	0.0580	0.0020	0.0020	0.0042	0.0020

Ca
0.0003

******* Mechanical Test *******

YIELD	TENSILE	ELONGATION	ROCKWELL
56527	75774	27.15	78

Guardrail W-Beam
20ct/25'
100ct/12'
10ct/25ft w/MGS Anchor Panel
July 2015 SMT

Figure A-1. 12-ft 6-in. W-Beam MGS Interior and End Sections, Test Nos. MGSC-7 and MGSC-8

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1164746
Customer PO: 2563
BOL Number: 69500
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/16/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
50	6G	12/6'3/S	M-180	A	2	515691	64,000	72,300	27.0	0.060	0.740	0.009	0.008	0.010	0.021	0.04	0.032	0.000	4
			M-180	A	2	4111321	63,100	80,200	29.0	0.210	0.710	0.009	0.007	0.010	0.030	0.000	0.030	0.000	4
			M-180	A	2	515659	67,000	75,200	26.0	0.064	0.790	0.012	0.008	0.008	0.022	0.000	0.025	0.000	4
			M-180	A	2	515660	66,800	74,300	27.0	0.064	0.740	0.012	0.006	0.009	0.017	0.000	0.025	0.000	4
			M-180	A	2	515662	63,900	72,900	28.0	0.064	0.770	0.010	0.006	0.009	0.016	0.000	0.025	0.000	4
			M-180	A	2	515663	64,900	76,500	21.0	0.064	0.740	0.009	0.007	0.007	0.023	0.000	0.026	0.000	4
			M-180	A	2	515668	66,700	75,500	27.0	0.063	0.770	0.014	0.007	0.010	0.024	0.000	0.030	0.000	4
			M-180	A	2	515668	70,200	80,800	21.0	0.063	0.770	0.014	0.007	0.010	0.024	0.000	0.030	0.000	4
			M-180	A	2	515669	64,500	74,100	26.0	0.063	0.790	0.014	0.007	0.009	0.017	0.000	0.028	0.000	4
			M-180	A	2	515687	63,400	74,100	30.0	0.068	0.750	0.012	0.010	0.008	0.025	0.000	0.060	0.000	4
			M-180	A	2	515687	65,100	74,400	28.0	0.068	0.750	0.012	0.010	0.008	0.025	0.000	0.060	0.000	4
			M-180	A	2	515690	63,000	71,800	27.0	0.059	0.720	0.010	0.008	0.013	0.024	0.000	0.042	0.000	4
			M-180	A	2	515696	62,900	72,500	28.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515696	63,900	73,400	29.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515700	67,800	77,700	28.0	0.065	0.800	0.013	0.009	0.012	0.036	0.000	0.035	0.000	4
			M-180	A	2	616068	62,900	71,600	27.0	0.061	0.740	0.013	0.010	0.012	0.027	0.000	0.064	0.000	4
			M-180	A	2	616068	66,700	74,200	30.0	0.061	0.740	0.013	0.010	0.012	0.027	0.000	0.064	0.000	4
			M-180	A	2	616071	64,000	74,000	28.0	0.061	0.760	0.016	0.007	0.011	0.021	0.000	0.028	0.000	4
			M-180	A	2	616072	63,800	74,200	29.0	0.066	0.750	0.014	0.009	0.010	0.026	0.000	0.039	0.000	4
			M-180	A	2	616073	63,900	73,300	27.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
			M-180	A	2	616073	65,000	74,500	28.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
30	60G	12/25/6'3/S	M-180	A	2	4111321	63,100	80,200	29.0	0.210	0.710	0.009	0.007	0.010	0.030	0.00	0.030	0.000	4
			M-180	A	2	515656	63,600	73,600	27.0	0.066	0.720	0.012	0.006	0.011	0.021	0.000	0.026	0.000	4
			M-180	A	2	515658	64,800	74,300	26.0	0.069	0.740	0.010	0.006	0.011	0.022	0.000	0.021	0.000	4
			M-180	A	2	515659	67,000	75,200	26.0	0.064	0.790	0.012	0.008	0.008	0.022	0.000	0.025	0.000	4
			M-180	A	2	515663	64,900	76,500	21.0	0.064	0.740	0.009	0.007	0.007	0.023	0.000	0.026	0.000	4

1 of 4

Figure A-2. 6-ft 3-in. W-Beam MGS Section, Test Nos. MGSC-7 and MGSC-8

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
HIGHWAY SAFETY CORP 473 W FAIRGROUND ST MARION,OH 43302-1701 USA	HIGHWAY SAFETY CORP GLASTONBURY,CT 06033-0358 USA	A992/A709-36	Wide Flange Beam / 6 X 8.5# / 150 X 13.0	0000000000
		LENGTH 42'00"	WEIGHT 44,982 LB	HEAT / BATCH 55044258/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
3399484/000010		ASTM A6-14 ASTM A709-13A ASTM A992-11 CSA G40.21-13 345WM

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
0001677045 IB-B0600800	1323-0000067091	03/30/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %
0.13	0.90	0.010	0.028	0.18	0.29	0.10	0.06	0.031	0.016	0.016	0.000

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	G/L Inch	Elong. %
52000	71200	359	491	8.000	20.50
51600	69800	356	481	8.000	23.40

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure A-3. 72-in. Long Steel Post, Test Nos. MGSC-7 and MGSC-8

CERTIFIED MATERIAL TEST REPORT

Page 1/1

GERDAU

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
HIGHWAY SAFETY CORP 473 W FAIRGROUND ST MARION,OH 43302-1701 USA	HIGHWAY SAFETY CORP GLASTONBURY,CT 06033-0358 USA	A992/A709-36	Wide Flange Beam / 6 X 8.5# / 150 X 13.0	0000006197

LENGTH	WEIGHT	HEAT / BATCH
42'00"	44,982 LB	55044251/02

SALES ORDER	CUSTOMER MATERIAL Nº
3399484/000010	IB-B0600800

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
000167 PO#1677003	1323-0000066391	03/16/2016

SPECIFICATION / DATE or REVISION
ASTM A6-14
ASTM A709-13A
ASTM A992-11
CSA G40.21-13 345WM

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %
0.14	0.90	0.014	0.019	0.19	0.28	0.08	0.09	0.023	0.012	0.017	0.000

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	G/L Inch	Elong. %
56700	77700	391	536	8.000	21.30
54800	75700	378	522	8.000	22.60

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure A-4. 72-in. Long Steel Post, Test Nos. MGSC-7 and MGSC-8

CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

R#16-692 6x12x14 Timber Blockouts
COC June2016 SMT Black Paint Tags

Date: 10/29/15

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery. BOL# 18052937

Customer PO# 3161 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
	6x12 – 14" ocd Block	84	21327	.658 pcf

I certify the above referenced material has been produced, treated and tested in accordance with AWPA standards and conforms to AASHTO M133 & M168.

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

[signature] G.M
Nick Sowl, General Counsel

10/29/15
Date

Figure A-5. Timber Blockouts for Steel Posts, Test Nos. MGSC-7 and MGSC-8

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

CWNP Invoice 10048570
Shipped To MIDWEST-MILFORD
Customer PO 2892

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Date: 4/23/14

Specifications: Highway Construction Use

Preservative: CCA – C 0.60 pcf

Charge #	Date Treated	Grade	Material Size, Length & Dressing	# Pieces	White Moisture Readings	Penetration # of Borings & % Conforming	Actual Retentions % Conforming
18379	4/16/14	#1	6x12-14" Blocks	756	19	1/20 95%	.651 pcf
18379	4/16/14	#1	6x8-22" Blocks	84	19	1/20 95%	.651 pcf

Number of pieces rejected and reason for rejection:
None

Statement: The above reference material was treated and inspected in accordance with the above referenced specifications.

Kurt Andres, General Manager

4/23/14
Date

MGS Wood Blockouts 6x12x14" R#14-0554
GREEN TAGS don't mistaken these for the 2part blockouts because they are also GREEN. July 2014 SMT

Figure A-6. Timber Blockouts for Steel Posts, Test Nos. MGSC-7 and MGSC-8

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

6x12x14 B/O
Orange Paint
R#17-395
Purchased for Thrie Buttress

Date: 7/26/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10054605

Customer PO# 3292 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
40756	6x8-14" BLK	126	22416	.676
GR61214BLK	6x12-14" OCD BLK	84	21292	.623
)	)	84	22397	.607
		168	22421	.733

I certify the above referenced material has been produced, treated and tested in accordance with AWPA standards and conforms to AASHTO M133 & M168.

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

7/26/16
Date

Figure A-7. Timber Blockouts for Steel Posts, Test Nos. MGSC-7 and MGSC-8

McMASTER-CARR

Certificate of Compliance

600 N County Line Rd
Elmhurst IL 60126-2081
630-600-3600
chi.sales@mcmaster.com

University of Nebraska
Midwest Roadside Safety Facility
M W R S F
4630 Nw 36TH St
Lincoln NE 68524-1802
Attention: Shaun M Tighe
Midwest Roadside Safety Facility

Purchase Order
E000357170

Order Placed By
Shaun M Tighe

McMaster-Carr Number
2098331-01

Page 1 of 1

Line		Product	Ordered	Shipped
1	**97812A109**	Steel Double-Headed Nail Size 16D, 3" Length, .16" Shank Diameter, 200 Pieces/Pack, Packs of 5	**5 Packs**	**5**

Certificate of compliance

This is to certify that the above items were supplied in accordance with the description and as illustrated in the catalog. Your order is subject only to our terms and conditions, available at www.mcmaster.com or from our Sales Department.

Sarah Weinberg
Compliance Manager

Figure A-8. 16D Double-Headed Nail, Test Nos. MGSC-7 and MGSC-8

CENTRAL NEBRASKA WOOD PRESERVERS, INC.
P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

R#17-505
BCT Posts
Orange Paint March 2017 SMT

Date: 3/2/17

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10056187

Customer PO# 3396 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
65680b.5PST	6x8-6.5 Rub PosT	168	23489	.649
656806.5PST	6x8-6.5' Rub Post	42	23490	.724
6568065PST	6x8.5-CRT PST	42	23490	.724
656846PST	6x8-46" BCT	42	23491	.651

I certify the above referenced material has been produced, treated and tested in accordance with AWPA standards and conforms to AASHTO M133 & M168.

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

3/2/17
Date

Figure A-9. BCT Timber Post, Test Nos. MGSC-7 and MGSC-8

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405

Project: STOCK

Order Number: 1215324 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2884
BOL Number: 80821 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/14/14

Foundation Tubes Green Paint
R#15-0157 September 2014 SMT

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	701A	.25X11.75X16 CAB ANC	A-36			A3V3361	48,600	69,000	29.1	0.180	0.410	0.010	0.005	0.040	0.270	0.000	0.070	0.001	4
	701A		A-36			JJ4744	50,500	71,900	30.0	0.150	1.060	0.010	0.035	0.240	0.270	0.002	0.090	0.021	4
12	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
15	736G	5'/TUBE SL/.188"X6"X8"FLA	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
12	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
5	783A	5/8X8X8 BEAR PL 3/16 STP	A-36			10903960	56,000	79,500	28.0	0.180	0.810	0.009	0.005	0.020	0.100	0.012	0.030	0.000	4
	783A		A-36			DL13106973	57,000	72,000	22.0	0.160	0.720	0.012	0.022	0.190	0.360	0.002	0.120	0.050	4
20	3000G	CBL 3/4X6'6/DBL	HW			99692													
25	4063B	WD 6'0 POST 6X8 CRT	HW			43360													
15	4147B	WD 3'9 POST 5.5"X7.5"	HW			2401													
20	15000G	6'0 SYT PST/8.5/31" GR HT	A-36			34940	46,000	66,000	25.3	0.130	0.640	0.012	0.043	0.220	0.310	0.001	0.100	0.002	4
10	19948G	.135(10Ga)X1.75X1.75	HW			P34744													
2	33795G	SYT-3"AN STRT 3-HL 6'6	A-36			JJ6421	53,600	73,400	31.3	0.140	1.050	0.009	0.028	0.210	0.280	0.000	0.100	0.022	4
4	34053A	SRT-31 TRM UP PST 2'6.625	A-36			JJ5463	56,300	77,700	31.3	0.170	1.070	0.009	0.016	0.240	0.220	0.002	0.080	0.020	4

1 of 3

Figure A-10. Foundation Tube, Test Nos. MGSC-7 and MGSC-8

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405

Project: STOCK

Order Number: 1214903 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2878
BOL Number: 80278 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 3/7/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
36	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
20	3000G	CBL 3/4X6'6/DBL	HW			98790													
22	9852A	STRUT & YOKE ASSY	A-1011-SS			163375	48,380	64,020	32.9	0.190	0.520	0.011	0.003	0.030	0.110	0.000	0.050	0.000	4
	9852A		A-36			11237730	45,500	70,000	30.0	0.170	0.500	0.010	0.008	0.020	0.080	0.000	0.070	0.001	4

Ground Strut Green Paint
R#15-0157 September 2014 SMT

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
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

1 of 2

Figure A-11. Ground Strut Assembly, Test Nos. MGSC-7 and MGSC-8

425 E. O'Connor
Lima, OH

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

Pieces	Description
64	5/8"X10" GR BOLT A307
192	5/8"X18" GR BOLT A307
32	1" ROUND WASHER F844
64	1" HEX NUT A563
192	WD 6'0 POST 6X8 CRT
192	WD BLK 6X8X14 DR
64	NAIL 16d SRT
64	WD 3'9 POST 5.5X7.5 BAND
32	STRUT & YOKE ASSY
128	SLOT GUARD '98
32	3/8 X 3 X 4 PL WASHER

MGSBR

Ground Strut

090453-8

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
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.
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 – 49100 LB
State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

2 of 4

Figure A-12. Ground Strut Assembly, Test Nos. MGSC-7 and MGSC-8

EXLTUBE

1000 BURLINGTON STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

Customer:	Size:	Customer Order No:	Date:
SPS - New Century 401 New Century Parkway NEW CENTURY KS 66031-1127	02.375	4500269918	07/25/2016
	Gauge: .154	Delivery No: 82799116 Load No. 3774661	
	Specification: ASTM A500-13 Gr.B/C, ASTM A53-12 Gr.B BNT*, ASME SA53 Gr.B BNT*		

Heat No	Yield KSI	Tensile KSI	Elongation % 2 inch
A79999	63.2	67.3	31.00

R#17-175 H#A79999
BCT Post Sleeves QTY 8
Oct 2016 SMT

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
A79999	0.0700	0.8400	0.0110	0.0040	0.0200	0.1500	0.0500	0.0600	0.0200	0.0010

This material was melted & manufactured in the U.S.A.
We hereby certify that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above. This product was manufactured in accordance with your purchase order requirements.
BNT=Grade B not pressure tested - meets tensile & chemical properties ONLY.

This material has not come into direct contact with mercury, any of its compounds, or any mercury bearing devices during our manufacturing process, testing, or inspections.

This material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

This material has passed NDE (eddy current, A309) testing. This material has passed flattening tests.

Tensile test completed using test specimen with 3/4" reduced area.

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe
Quality Assurance Manager

Figure A-13. BCT Post Sleeve, Test Nos. MGSC-7 and MGSC-8

NUCOR
NUCOR CORPORATION
NUCOR STEEL SOUTH CAROLINA

Mill Certification
7/30/2015

MTR #: 0000087896
300 Steel Mill Road
DARLINGTON, SC 29540
(843) 393-5841
Fax: (843) 395-8701

Sold To: TRINITY INDUSTRIES INC
ROLLFORM ACCOUNTING-4TH FLOOR
PO BOX 568887
DALLAS, TX 75356-8887
(214) 689-0847
Fax: (214) 589-8535

Ship To: TRINITY INDUSTRIES LIMA
550 E. ROBB AVENUE
PLANT 55
LIMA, OH 45801-0000
(214) 589-8407
Fax: (214) 589-8420

Customer P.O.	171075	Sales Order	229472.1
Product Group	Merchant Bar Quality	Part Number	5362580024010W0
Grade	NUCOR MULTIGRADE	Lot #	DL1510354303
Size	5/8x8" Flat	Heat #	DL15103543
Product	5/8x8" Flat 20' NUCOR MULTIGRADE	B.L. Number	C1-668702
Description	NUCOR MULTIGRADE	Load Number	C1-347435
Customer Spec		Customer Part #	100395B

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

Roll Date: 6/22/2015 Melt Date: 6/18/2015 Qty Shipped LBS: 45,929 Qty Shipped Pcs: 135

Melt Date: 6/18/2015

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.15%	0.75%	0.013%	0.025%	0.20%	0.36%	0.09%	0.09%	0.021%	0.0500%	0.003%	0.016%
Ti	CE4020										
0.001%	0.34%										

CE4020: C. E. CSA G4020, AASHTO M270

Roll Date: 6/22/2015

Yield 1: 58,000psi	Tensile 1: 74,000psi	Elongation: 25% in 8"(% in 203.3mm)
Yield 2: 58,000psi	Tensile 2: 74,000psi	Elongation 25% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/A36M-12, A529/529M-05(2009) GR50(345), A572/572M-13A GR50(345), A709/709M-13A GR36(250) & GR50(345), CSA G40.21-04 GR44W(300W) & GR50W(350W) AASHTO M270/M270M-10 GR36(270) & GR50(345), ASME SA36/SA36M-07, QQ-S-741D, KILLED FG PRACTICE

1. WELDING OR WELD REPAIR WAS NOT PERFORMED ON THIS MATERIAL
2. MELTED AND MANUFACTURED IN THE USA
3. MERCURY, RADIUM, OR ALPHA SOURCE MATERIALS IN ANY FORM HAVE NOT BEEN USED IN THE PRODUCTION OF THIS MATERIAL

James H. Blew
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 1

Figure A-14. Anchor Bearing Plate, Test Nos. MGSC-7 and MGSC-8

NUCOR
NUCOR STEEL JACKSON, INC.

Mill Certification
7/27/2016

MTR #: M1-150903
NUCOR STEEL JACKSON, INC.
3630 Fourth Street
Flowood, MS 39232
(601) 939-1623
Fax: (601) 936-6202

Sold To: O'NEAL STEEL INC
ATTN ACCOUNTS PAYABLE
PO BOX 98
BIRMINGHAM, AL 35202-0098
(205) 599-8000
Fax: (205) 599-8052

Ship To: O'NEAL STEEL INC
4530 MESSER-AIRPORT HWY
BIRMINGHAM, AL 35222
(205) 599-8000
Fax: (205) 599-8052

Customer P.O.	00771356	Sales Order	343125.6
Product Group	Merchant Bar Quality	Part Number	5350030024010W0
Grade	NUCOR MULTIGRADE	Lot #	JK1610148801
Size	1/2x3" Flat	Heat #	JK16101488
Product	1/2x3" Flat 20' NUCOR MULTIGRADE	B.L. Number	M1-429898
Description	NUCOR MULTIGRADE	Load Number	M1-150903
Customer Spec		Customer Part #	00777557

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

Roll Date: 4/5/2016 Melt Date: 3/30/2016 Qty Shipped LBS: 4,900 Qty Shipped Pcs: 48

Melt Date: 3/30/2016

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.16%	0.78%	0.017%	0.028%	0.20%	0.28%	0.09%	0.14%	0.020%	0.0280%	0.001%	0.010%
CE4020	CEA529										
0.35%	0.39%										

CE4020: C. E. CSA G4020, AASHTO M270
CEA529: A529 CARBON EQUIVALENT

Roll Date: 4/5/2016

Yield 1: 56,172psi	Tensile 1: 75,460psi	Elongation: 25% in 8"(% in 203.3mm)
Yield 2: 56,126psi	Tensile 2: 76,500psi	Elongation 25% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/36M, ASTM A529/529M GR50 ASTM A572/572M GR50 ASTM709/709M GR36/GR50 CSA G40.21 GR44W(300W)/GR50W(350W) AASHTO M270/M270M GR36/GR50 ASME SA36/SA36M MEETS EN10204 SEC 3.1 REPORTING REQUIREMENTS

ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT, INCLUDING MELTING, HAVE OCCURRED WITHIN THE UNITED STATES. ALL PRODUCTS PRODUCED ARE WELD FREE. MERCURY, IN ANY FORM, HAS NOT BEEN USED IN THE PRODUCTION OR TESTING OF THIS MATERIAL.

QA Approved
SI# 777557

Christopher Smith
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 1

Figure A-15. Anchor Bracket Assembly, Test Nos. MGSC-7 and MGSC-8

300608

NUCOR
NUCOR CORPORATION
NUCOR STEEL SOUTH CAROLINA

Mill Certification
6/13/2015

MTR #: 0000080529
300 Steel Mill Road
DARLINGTON, SC 29540
(843) 393-5841
Fax: (843) 395-8701

Sold To: NUCOR FASTENER INDIANA
PO BOX 6100
ST JOE, IN 46785-0000
(800) 955-6826
Fax: (219) 337-1726

Ship To: NUCOR FASTENER
6730 COUNTY ROAD 60
ST JOE, IN 46785
(800) 955-6826
Fax: (219) 337-1722

Customer P.O.	153148	Sales Order	225393.3
Product Group	Special Bar Quality	Part Number	30001281480V780
Grade	1045L	Lot #	DL1510303201
Size	1-9/32" (1.2813) Round	Heat #	DL15103032
Product	1-9/32" (1.2813) Round 40' 1045L	B.L. Number	C1-664767
Description	1045L	Load Number	C1-344378
Customer Spec		Customer Part #	025016

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

Roll Date: 6/3/2015 **Melt Date: 5/26/2015** **Qty Shipped LBS: 65,291** **Qty Shipped Pcs: 372**

Melt Date: 5/26/2015

C	Mn	V	Si	S	P	Cu	Cr	Ni	Mo	Al	Cb
0.45%	0.67%	0.003%	0.20%	0.019%	0.003%	0.17%	0.07%	0.06%	0.01%	0.002%	0.004%
Pb	Sn	Ca	B	Ti	NICUMO						
0.005%	0.009%	0.0023%	0.0004%	0.001%	0.24						

NICUMO: Cu+Ni+Mo

Roll Date: 6/3/2015

Reduction Ratio 38 :1

ASTM E381
Surface: 2 Mid Radius: 2 Center: 2

Specification Comments:

1. WELDING OR WELD REPAIR WAS NOT PERFORMED ON THIS MATERIAL
2. MELTED AND MANUFACTURED IN THE USA
3. MERCURY, RADIUM, OR ALPHA SOURCE MATERIALS IN ANY FORM HAVE NOT BEEN USED IN THE PRODUCTION OF THIS MATERIAL

Chemistry Verification Checks

Part# 25016 RM# 300608

	Checked By	Date
Receiving OK:	297	6-22-15
Certifications OK:	375	6-22-15

James H. Blew
Division Metallurgist

Page 3 of 4

NBMG-10 January 1, 2012

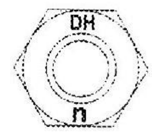
Figure A-16. BCT Anchor Cable, Test Nos. MGSC-7 and MGSC-8

NUCOR
FASTENER DIVISION

LOT NO.
371123B

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
8001 FASTENAL COMPANY-KS
NUCOR ORDER # 978943
TEST REPORT SERIAL# FB488556
CUST PART # 38210
TEST REPORT ISSUE DATE 3/04/16
DATE SHIPPED 8/17/16
CUSTOMER P.O. # 210117217
NAME OF LAB SAMPLER: SANDRA NEUMANN-PLUMMER, LAB TECHNICIAN



*****************CERTIFIED MATERIAL TEST REPORT*****************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175647	3600	371123B	1-8 GR DH HV H.D.G.

MANUFACTURE DATE 1/07/16 HEX NUT H.D.G./GREEN LUBE

--CHEMISTRY MATERIAL GRADE -1045L

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER NUCOR STEEL - SOUTH CAROL

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM030412	DL15105591	.44	.64	.005	.020	.20

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-07a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	26.6	PASS	N/A	N/A
N/A	27.0	PASS	N/A	N/A
N/A	27.6	PASS	N/A	N/A
N/A	28.9	PASS	N/A	N/A
N/A	26.7	PASS	N/A	N/A

AVERAGE VALUES FROM TESTS
27.4
PRODUCTION LOT SIZE 90800 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a 80 PCS. SAMPLED LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-13 - GALVANIZING PERFORMED IN THE U.S.A.
1. 0.00294 2. 0.00311 3. 0.00346 4. 0.00235 5. 0.00218 6. 0.00270 7. 0.00353
8. 0.00322 9. 0.00406 10. 0.00269 11. 0.00275 12. 0.00315 13. 0.00487 14. 0.00253
15. 0.00416
AVERAGE THICKNESS FROM 15 TESTS .00318
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.824	1.844
Thickness	32	0.980	1.001

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/17

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Figure A-17. BCT Cable Nuts, Test Nos. MGSC-7 and MGSC-8

Certified Material Test Report to BS EN ISO 10204-2004 3.1

FOR USS FLAT WASHER HDG

COUNTRY OF ORIGIN: CHINA
CUSTOMER: FASTENAL
FACTORY NAME: IFI & MORGAN LTD.
FACTORY ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China

DESCRIPTION: 1
INVOICE NBR: TD16680155
PART NBR.: 33188
LOT NO.: 16H-168236-30

DATE: 2016-10-08
ORDER NBR. 210114135
QUANTITY:3240PCS

DIMENSIONS (UNIT:INCH)

	STANDARD	RESULT				
		1	2	3	4	5
INSIDE DIA	1.055-1.092	1.068	1.068	1.067	1.069	1.068
OUTSIDE DIA	2.493-2.530	2.514	2.513	2.514	2.514	2.511
THICKNESS	0.136-0.192	0.146	0.149	0.152	0.152	0.147

WE HEREBY CERTIFY THAT THIS WAS PRODUCED AS PER CUSTOMER'S REQUIREMENT.

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
HOT DIP GALVANIZED ASTM F2329				
	Min 43 um	48-64um	8	0

NOTE

1. QUANTITY OF SAMPLES: 5 PCS

2. JUDGEMENT: GOOD

3. CHIEF INSPECTOR:

IFI & MORGAN LTD.
检验专用章
QUANLITY CONTROL

Figure A-18. BCT Washers, Test Nos. MGSC-7 and MGSC-8

King Steel Corporation
King Steel
5225 East Cook Rd.
Grand Blanc, MI 48439
Tel 810-953-7637
Fax 810-953-1718

Material Certification

Heat: NF16202178
Grade: 1010
Note: Processed in the USA
Rockford Bolt Rockford, IL
PO# P36771
Weight: 16,400

Material Specification Type	Material Specification	Actual
Chemical	C	.12 %
	Mn	.54 %
	P	.007 %
	S	.035 %
	Si	.17 %
	Ni	.07 %
	Cr	.07 %
	Mo	.02 %
	B	.0001 %
	Cu	.20 %
	V	.003 %
	Nb	.003 %
	Sn	.009 %
	Ca	.0003 %
Physical	Tensile Full-Size (PSI)	64654 psi
	Yield Full-Size (PSI)	47066 psi
	% Elongation	24 %
	Reduction Ratio:	158.8:1
	Melted & Manufactured in:	USA

We hereby certify that chemical analysis and/or physical characteristics shown are a true copy of orignal test reports on file with us from the producing source covering the heat or lot from which this material was taken.

Plex 6/7/16 3:34 PM chetherington Page 1

35406

Figure A-19. ⅝-in. by 14-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8

NUCOR
NSNE-NORFOLK, NE

MILL CERTIFICATION DETAILS

354d

Purchase Order #: 14404
Customer: KRUEGER & CO - ELMHURST
Bill of Lading : 319723
Certified By : Jim Hill
Lot #: NF1610045312
Grade: 1010
Melt Date : 02/05/2016
Qty Shipped LBS: 45350
Comments:

Heat #: NF16100453
Customer Part #: 593R1010IQH
Length: 0'0"
Date: 02/11/2016
Tag #: NF1611016424
Size : 19/32 WRC
Divison : NSNE-Norfolk, NE
Qty Shipped PCS : 11
Roll Date : 02/11/2016

hemical Properties -Wt.%

C	Mn	Si	S	P	Cu	Cr	Ni	Mo
0.12	0.56	0.19	0.030	0.006	0.23	0.06	0.08	0.02
Al	**V**	**Nb**	**Pb**	**Sn**	**Ca**	**B**	**Ti**	
0.002	0.003	0.004	0.000	0.009	0.0004	0.0002	0.001	

Physical Properties

	Imperial-psi
Tensile:	65642
Yield:	51554
Elongation (in 8 inches):	
Elongation (in 2 inches):	

arbon Equiv:

hereby certify that the material described herein has been manufactured in accordance with the specification and standards listed above and that it satisfies iose requirements. All melting and manufacturing process were performed in the United States of America unless otherwise noted on the mill test report.

Jim Hill
Division Metallurgist

Figure A-20. ⅝-in. by 14-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8

CHARTER STEEL
A Division of Charter Manufacturing Company, Inc.

EMAIL

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
Fax (262) 268-2570

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Cust P.O.	91893
Customer Part #	AXA18CB-5/16
Charter Sales Order	30124802
Heat #	20479830
Ship Lot #	2117839
Grade	1018 X AK FG RHQ 5/16
Process	HR
Finish Size	5/16
Ship date	13-JAN-17

Johnstown Wire Technologies
124 Laurel Ave.
Johnstown,PA-15906

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 20479830

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.16	.84	.008	.004	.060	.03	.05	.01	.04	.003	.001
	AL	N	B	TI	NB						
	.051	.0050	.0001	.001	.001						

CAT DI=.35

Test results of Rolling Lot # 2117839

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE (KSI)	1	68.6	68.6	68.6	TENSILE LAB = 0358-04
REDUCTION OF AREA (%)	1	72	72	72	RA LAB = 0358-04

NUM DECARB=1
REDUCTION RATIO=637:1

AVE DECARB (Inch)=.000

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 12/12/13
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = RW007-RW100 Revision = Dated = 08-NOV-13

Additional Comments:

Melt Source:
Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1,Fax0,Mail0

ACCREDITED Testing Laboratory

Page 1 of 2

This MTR supersedes all previously dated MTRs for this order
Janice Barnard Division Mgr. of Quality Assurance
barnardJ@chartersteel.com
Printed Date : 01/13/2017

Figure A-21. ⅝-in. Diameter Guardrail Nut, Test Nos. MGSC-7 and MGSC-8

R#16-692 5/8"x10" GR Bolt
Orange Paint H#20351510 L#150424L

3500G

TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

MATERIAL CERTIFICATION

Customer: Stock

Date: December 16, 2015
Invoice Number:
Lot Number: 150424L

Part Number: 3500G
Quantity: 16,702 Pcs.

Description: 5/8" x 10" G.R. Bolt
Heat Numbers: 20351510 16,702

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20351510	.09	.33	.007	.002	.06	.04	.05	.01	.06	.004	.001	.028	.007	.0001	.001	.001

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.52 (2.0 Mils Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 12-17-15

NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 419-227-1296

MONIQUE HOLMES
Notary Public, State of Ohio
My Commission Expires
July 5, 2020

Figure A-22. ⅝-in. by 10-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8

5/8x10" post bolt
R#14-0207 Green Paint

8/26/13
3500G

TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

MATERIAL CERTIFICATION

Customer: Stock
Date: August 16, 2013
Invoice Number:
Lot Number: 130809L
Part Number: 3500G
Quantity: 16,233 Pcs.
Description: 5/8" x 10" G.R. Bolt

Heat Numbers:	
10240100	10,820
10231650	5,413

PASSED & CERTIFIED
AUG 20 2013
Trinity Highway Products, LLC
Dallas, Texas Plant 99

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
10240100	.09	.49	.01	.007	.09	.04	.09	.02	.08	.008	.002	.023	.005	.0001	.001	.001
10231650	.09	.49	.008	.011	.09	.05	.08	.02	.09	.006	.002	.023	.007	.0001	.001	.001

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.51 (2.0 Mils Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A
WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 19th day of Aug 2013

Sheri Brown NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296

STATE OF OHIO NOTARY PUBLIC ID# 2009NT0139 Commission Expires April 20, 2014 ALLEN COUNTY

Figure A-23. ⅝-in. by 10-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8

R#15-0627 H#20297970 L#140530L
5/8x10" Guardrail Bolt
June 2015 SMT White Paint 3500G

TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

7/31/14

MATERIAL CERTIFICATION

Customer: Stock

Date: June 25,2014

Invoice Number:

Lot Number: 140530L

Part Number: 3500G

Quantity: 17,173 Pcs.

Description: 5/8" x 10" G.R. Bolt

Heat Numbers: 20297970 17,173

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20297970	.09	.33	.006	.001	.06	.03	.04	.01	.08	.002	.001	.026	.008	.0001	.001	.002

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.54 (2.0 Mils Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A
WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 11th day of July 2014

Sherri Braun NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296.

SHERRI BRAUN
Notary Public, State of Ohio
My Commission Expires
April 20, 2019

RECEIVED
JUL 11 2014
Trinity Highway Products, LLC
Dallas, Texas Plant 99

Figure A-24. ⅝-in. by 10-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8

CHARTER STEEL
A Division of Charter Manufacturing Company, Inc.

LOAD

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
Fax (262) 268-2570

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Rockford Bolt & Steel
126 Mill St.
Rockford,IL-61101
Kind Attn :Linda McComas

Cust P.O.	P37098
Customer Part #	100905
Charter Sales Order	70075879
Heat #	20460760
Ship Lot #	3242161
Grade	1010 A AK FG RHQ 19/32
Process	HRSA
Finish Size	19/32
Ship date	01-NOV-16

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 20460760

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.09	.33	.006	.003	.060	.03	.06	.01	.08	.006	.001

	AL	N	B	TI	NB
	.025	.0070	.0001	.001	.001

Test results of Rolling Lot # 2110397

REDUCTION RATIO=177:1

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 12/12/13
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M Revision = 15 Dated = 01-NOV-15

Additional Comments: MELTED AND ROLLED IN THE USA

Melt Source:
Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1,Fax0,Mail0

ACCREDITED
Testing Laboratory

This MTR supersedes all previously dated MTRs for this order

Janice Barnard Division Mgr. of Quality Assurance
barnardJ@chartersteel.com
Printed Date : 11/01/2016

Page 1 of 2

Figure A-25. ⅝-in. by 1¼-in. Long Guardrail Bolts, Test Nos. MGSC-7 and MGSC-8

Birmingham Fastener Manufacturing

P.O. Box 10323
Birmingham, Alabama 35202
(205) 595-3512

Pg 1 of 1

Certificate of Compliance

Customer :	Midwest Machinery & Supply	**BFM # :**	1338859
P.O. # :	3275	**Date Shipped :**	6/16/2016

	Quantity	Description	Lot#	Heat #	Specification	Finish
1	104	5/8"-11 x 8" HEX BOLT	208976	DL15107048	ASTM A307 Gr A	HDG
2	157	5/8"-11 x 10" HEX BOLT	208977	DL15107048	ASTM A307 Gr A	HDG
3	402	7/8"-9 x 16" Hex Bolt	208978	JK15100276	ASTM A307 Gr A	HDG
4	67	7/8"-9 X 26" Hex Bolt	208979	JK15100276	ASTM A307 Gr A	HDG

Birmingham Fastener Manufacturing. hereby certifies that the material furnished in reference to the above purchase order number will meet or exceed the above assigned specifications.

Signed: [signature] ***Date:*** ***06/15/2016***

Brian Hughes

R#16-692 5/8"x10" BCT Hex Bolts
Orange Paint H#DL15107048
June2016 SMT

Figure A-26. ⅝-in. by 10-in. Long Hex Bolt, Test Nos. MGSC-7 and MGSC-8

R#16-0217
BCT Hex Nuts
December 2015 SMT
Fastenal part#36713
Control# 210101523

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 129980
- Part No: AFH2G0625C
- Cust Part No: 36713
- Quantity (PCS): 1200
- Description: 5/8-11 Fin Hx Nut Gr2 HDG/TOS 0.020
- Specification: SAE J995(99) - GRADE 2 / ANSI B18.2.2
- Stelfast I.D. NO: 595689-O201087
- Customer PO: 210101523
- Warehouse: DAL

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

This document may only be reproduced unaltered and only for certifying the same or lesser quantity of the product specified herein. Reproduction or alteration of this document for any other purpose is prohibited.

Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

December 07, 2015

Page 1 of 1

Figure A-27. ⅝-in. Hex Nuts, Test Nos. MGSC-7 and MGSC-8

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

FACTORY: NINGBO ECONOMIC & TECHNICAL DEVELOPMENT ZONE YONGGANG FASTENERS CO., LTD.
REPORT DATE:2016/12/29
R#17-507 H#816070039
ADDRESS: FuShan South Road No.17,BeiLun NingBo China
BCT Cable Bracket Bolts
MANUFACTURE DATE:2016/12/2
TEL#(852)25423366
CUSTOMER: FASTENAL
MFG LOT NUMBER:M-2016HT927-9
SAMPE SIZE: ACC.TO Dimension:ASME B18.18-11;Mechanical Properties:ASTM F1470-12
MANU QTY: 4800PCS
SHIPPED QTY: 4800PCS
SIZE: 5/8-11X1 1/2 HDG
HEADMARKS: 307A PLUS NY
PO NUMBER:220023115
PART NO:1191919

STEEL PROPERTIES:
MATERIAL TYPE:Q195
HEAT NUMBER: 816070039

CHEMISTRY SPEC:	C %*100	Mn%*100	P %*1000	S %*1000
Grade A ASTM A307-12	0.29max	1.20 max	0.04max	0.15max
TEST:	0.07	0.28	0.016	0.003

DIMENSIONAL INSPECTIONS Unit:inch SPECIFICATION: ASME B18.2.1 - 2012

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
VISUAL	ASTM F788-2013	PASSED	22	0
THREAD	ASME B1.1-2003,3A GO,2A NOGO	PASSED	15	0
WIDTH FLATS	0.906-0.938	0.915-0.928	4	0
WIDTH A/C	1.033-1.083	1.048-1.057	4	0
HEAD HEIGHT	0.378-0.444	0.394-0.424	4	0
THREAD LENGTH	1.420-1.560	1.435-1.541	15	0
LENGTH	1.420-1.560	1.435-1.541	15	0

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307-2012 GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS :	ASTM F606-2014	69-100 HRB	76-79 HRB	4	0
WEDGE TENSILE:	ASTM F606-2014	Min 60 KSI	65-69 KSI	4	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
COATINGS OF ZINC:		SPECIFIATION:ASTM F2329-2013			
HOT DIP GALVANIZED	ASTM B568-98(2104)	Min 0.0017"	0.0017" -0.0018"	4	0

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

Maker's ISO# 00109Q16722R3M/3302

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

Figure A-28. ⅝-in. by 1½-in. Long Hex Bolts, Test Nos. MGSC-7 and MGSC-8

Heat Number	Shipper No	Invoice No	Customer PO#	Customer Name
2038622	680907	701917	5-7-2015 MIKE	GAFFNEY BOLT CO.

CMC STEEL SOUTH CAROLINA
310 New State Road
Cayce SC 29033-3704

1SERIES-BPS ®

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

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

Richard S. Ray
Richard S. Ray - CMC Steel SC
Quality Assurance Manager

	SOLD TO	SHIP TO	
HEAT NO.:2038622 SECTION: ROUND 7/8 x 40'0" A36/52950 GRADE: ASTM A36-12/A529-05 Gr 50 ROLL DATE: 09/09/2014 MELT DATE: 09/08/2014	Infra-Metals - Mars 1601 Broadway St Marseilles IL US 61341-9326 8009875283	Infra-Metals - Mars 1601 Broadway St Marseilles IL US 61341-9326 8009875283	Delivery#: 81471569 BOL#: 70533247 CUST PO#: CE-485729 CUST P/N: DLVRY LBS / HEAT: 9075.000 LB DLVRY PCS / HEAT: 111 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.16%	Elongation Gage Lgth test 1	8IN		
Mn	0.73%	Reduction of Area test 1	58%		
P	0.013%	Yield to tensile ratio test1	0.75		
S	0.021%	Yield Strength test 2	56.9ksi		
Si	0.22%	Tensile Strength test 2	76.5ksi		
Cu	0.32%	Elongation test 2	25%		
Cr	0.13%	Elongation Gage Lgth test 2	8IN		
Ni	0.10%	Reduction of Area test 2	57%		
Mo	0.027%	Yield to tensile ratio test2	0.74		
V	0.000%	C+(Mn/6)	0.28%		
Cb	0.026%				
Sn	0.010%				
Al	0.000%				
Ti	0.001%				
N	0.0084%				
Carbon Eq A529	0.38%				
Yield Strength test 1	57.1ksi				
Tensile Strength test 1	76.3ksi				
Elongation test 1	23%				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

ALSO MEETS ASTM GRADE A36 REV-03A, A529 GR.50, A572-2013A GR.50, A709 GR.36, A709 GR.50, A992, AASHTO GRADE M270 GR.36, M270 GR.50, CSA G40.21-04 GRADE 44W, 50WASME SA-36 2008A ADDEND A.

03/18/2015 14:05:35
Page 1 OF 1

Figure A-29. ⅞-in. Dia. by 8-in. Long Hex Bolts, Test Nos. MGSC-7 and MGSC-8

INSPECTION CERTIFICATE

Customer	Specification	Size	Lot No.	Date
	ASTM A-563 GRADE DH HEAVY HEX NUT	7/8- 9 UNC	WA651	Jun. 29,'12

UNYTITE, INC.
One Unytite Drive
Peru, Illinois 61354
815-224-2221 — FAX# 815-224-3434

Mechanical properties tested in accordance to ASTM F606/F606M, ASTM A370, ASTM E18

Chemical Composition (%)

Mill Maker	Material Size	Heat No.	Spec.	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	
NUCOR	CARBON			0.20 0.55	-	MIN. 0.60	MAX. 0.040	MAX. 0.050	-	-	-	-	-
STEEL	STEEL	12101054		0.43	0.24	0.87	0.015	0.020	0.09	0.04	0.08	-	-

Shape & Dimension	
Inspection	ANSI B18.2.2 GOOD
Thread Precision Inspection	ANSI B1.1 CLASS 2B GOOD
Appearance Inspection	GOOD

Mechanical Property Inspection

Item	Proof Load	Cone stripping	Hardness	After Heat Treatment Hardness	Absorbed Energy	Heat Treatment
Spec.	80,850 lbf	- kN·kgf·lbf	24-38 HrC	HrB·HB	j·kgfm·ftlbf	T:MIN.800 F
Results	n 5 Results GOOD	n - Results -	29.4 28.9 29.7 29.7 29.5 29.4	5 Piece Average After Heat Treament Hardness Treatment After 24 Hr.X °F(°C)	at °F(°C)	Q:FORGING Q (W.Q.) T:1058 F/45M. (W.C. Q: Quenching T: Tempering ST: Solution Treatment

OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/18/13
07-10-13

Remarks:

"DH U"

Production Quantity
22,391 pcs.

BCT Foundation Tube
Keeper Bolt Nuts
R#15-0600 June 2015 SMT

Material used for the nut was melted and manufactured in the USA. The nut was manufactured in the USA to the above specification.

We hereby certify that the material described has been manufactured and inspected satisfactorily with the requirement of the above specification.

Chief of Quality Assurance Section

Figure A-30. ⅞-in. Diameter Nuts, Test Nos. MGSC-7 and MGSC-8

benesch
engineers · scientists · planners

LINCOLN OFFICE
825 "M" Street Suite 100
Lincoln, NE 68508
Phone: (402) 479-2200
Fax: (402) 479-2276

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 6x12

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility **Date** 21-Jul-17
Project Name: Omitted Post
Placement Location: Curb A and Curb B

Mix Designation: **Required Strength:**

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area, sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
MPP- 1	A	7/7/2017	7/21/2017	7/21/2017	14	0	14	12	6.01	28.37	165,056	5,820		2	C 1231
MPP- 2	B	7/7/2017	7/21/2017	7/21/2017	14	0	14	12	6.01	28.37	170,033	5,990		2	C 1231

Remarks: Curb A and Curb B Retest

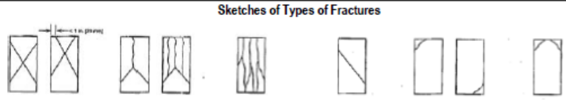
Concrete test specimens along with documentation and test data were submitted by Midwest Roadside Safety Facility.

Test results presented relate only to the concrete specimens as received from Midwest Roadside Safety

This report shall not be reproduced except in full, without the written approval of Alfred Benesch & Company.

Report Number 2147369335
Page 1

Sketches of Types of Fractures



Type 1 Reasonably well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2 Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3 Columnar vertical cracking through both ends, no well-formed cones

Type 4 Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1

Type 5 Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6 Similar to Type 5 but end of cylinder is pointed

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By____________________
Brant Wells, Field/Lab Operations Manager

Figure A-31. Curb Concrete Strength, Test Nos. MGSC-7 and MGSC-8

NUCOR
NUCOR CORPORATION
NUCOR STEEL TEXAS

Mill Certification
8/2/2016

MTR #: J1-347424
8812 Hwy 79 W
Jewett, TX 75846
(903) 626-4461
Fax: (903) 626-6290

Sold To: ADELPHIA METALS I LLC
1930 E MARLTON PIKE M-66
CHERRY HILL, NJ 08003
(856) 988-8889
Fax: (856) 988-8090

Ship To: ADELPHIA METALS-CUST PU
N/A
JEWETT, TX 75846
(856) 988-8889
Fax: (856) 988-8163

Customer P.O.	818359	Sales Order	236478.5
Product Group	Rebar	Part Number	900000132404200
Grade	ASTM A615/A615M-14 GR 60[420] AASHTO M31-07	Lot #	JW1610471901
Size	13/#4 Rebar	Heat #	JW16104719
Product	13/#4 Rebar 20' A615M GR420 (Gr60)	B.L. Number	J1-745944
Description	A615M GR 420 (Gr60)	Load Number	J1-347424
Customer Spec		Customer Part #	

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

Roll Date: 6/22/2016 Melt Date: 6/18/2016 Qty Shipped LBS: 48,096 Qty Shipped Pcs: 3,600

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb
0.38%	0.98%	0.011%	0.021%	0.19%	0.30%	0.15%	0.16%	0.042%	0.0032%	0.000%

Yield 1: 63,900psi Tensile 1: 101,000psi Elongation: 15% in 8"(% in 203.3mm)

Bend OK

Specification Comments:

Comments: E-mail: websales@nstexas.com

1. All manufacturing processes of the steel, including melting, casting & hot rolling, have been performed in U.S.A
2. Mercury in any form has not been used in the production or testing of this product.
3. Welding or weld repair was not perfomed on this material.
4. This material conforms to the specifications described on this document and may not be reproduced, except in full, without written approval of Nucor Corporation.
5. Results reported for ASTM E45 (Inclusion content) and ASTM E381 (Macro-etch) are provided as interpretation of ASTM procedures.

Bhargava R Vantari
Division Metallurgist

Page 1 of 1

NBMG-10 January 1, 2012

Figure A-32. 819-in. Long Rebar, Test Nos. MGSC-7 and MGSC-8

GERDAU

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

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
NEBCO INC STEEL DIVISION HAVELOCK,NE 68529 USA	CONCRETE INDUSTRIES INC LINCOLN,NE 68529-0529 USA	60 (420)	Rebar / #4 (13MM)	0000000000

LENGTH	WEIGHT	HEAT / BATCH
60'00"	46,534 LB	**58028856**/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
4777299/000010		ASTM A615/A615M-15 E1

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
123808	1327-0000226793	02/28/2017

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.46	0.91	0.016	0.031	0.26	0.31	0.12	0.20	0.026	0.006	0.004	0.000	0.003

CHEMICAL COMPOSITION

CEqyA706 %
0.65

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
69462	479	110140	759	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
13.90	OK

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

Phone: (409) 769-1014 Email: Bhaskar.Yalamanchili@gerdau.com

TOM HARRINGTON
QUALITY ASSURANCE MGR.

Phone: 972-779-1872 Email: Tommy.Harrington@gerdau.com

Figure A-33. 16-in. Long Rebar, Test Nos. MGSC-7 and MGSC-8

Appendix B. Vehicle Center of Gravity Determination

Date:	11/7/2017	Test Name:	MGSC-7	VIN:	KMHCN4AC4AU460931
Year:	2009	Make:	Hyundai	Model:	Accent

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)
+	Unbalasted Car (Curb)	2448
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	22
+	Strobe/Brake Battery	5
+	Brake Reciever/Wires	6
+	CG Plate including DAS	13
-	Battery	-32
-	Oil	-10
-	Interior	-57
-	Fuel	-7
-	Coolant	-5
-	Washer fluid	-2
+	Water Ballast (In Fuel Tank)	0
+	Onboard Battery	12

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

Estimated Total Weight (lb) 2419

Vehicle Dimensions for C.G. Calculations

Roof Height:	57 1/4	in.	Front Track Width:	57 1/2	in.
Wheel Base:	98 1/4	in.	Rear Track Width:	57 1/2	in.

Center of Gravity	**1100C MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	2420 ± 55	2423	3
Longitudinal CG (in.)	39 ± 4	36.29127	-2.7087288
Lateral CG (in.)	NA	0.083058	NA
Vertical CG (in.)	NA	22.79608	NA

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb)

	Left	Right
Front	786	781
Rear	459	422

FRONT	1567	lb
REAR	881	lb
TOTAL	2448	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	743	785
Rear	465	430

FRONT	1528	lb
REAR	895	lb
TOTAL	2423	lb

Figure B-1. Vehicle Mass Distribution, Test No. MGSC-7

Date:	7/28/2017	Test Name:	MGSC-8	VIN:	1D7RB1GT8AS118297
Year:	2010	Make:	Dodge	Model:	Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5092	28 1/3	144167.25
+	Hub	19	14 3/4	280.25
+	Brake activation cylinder & frame	7	24 1/2	171.5
+	Pneumatic tank (Nitrogen)	27	25 1/2	688.5
+	Strobe/Brake Battery	5	24 3/4	123.75
+	Brake Receiver/Wires	5	51 3/4	258.75
+	CG Plate including DAS	42	29 1/4	1228.5
-	Battery	-45	43	-1935
-	Oil	-9	26 1/2	-238.5
-	Interior	-85	35 1/2	-3017.5
-	Fuel	-162	19 1/2	-3159
-	Coolant	-2	33 1/2	-67
-	Washer fluid	-7	33	-231
+	Water Ballast (In Fuel Tank)	89	16 1/2	1468.5
+	Onboard Supplemental Battery	12	25	300
				0
				140039

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

Estimated Total Weight (lb)	4988
Vertical CG Location (in.)	28.0752

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140 1/2 in.

Front Track Width: 67 in.

Rear Track Width: 67 5/8 in.

Center of Gravity	**2270P MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	5000 ± 110	5000	0.0
Longitudinal CG (in.)	63 ± 4	60.0216	-2.97840
Lateral CG (in.)	NA	0.3634875	NA
Vertical CG (in.)	28 or greater	28.08	0.07518

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb)

	Left	Right
Front	1510	1413
Rear	1065	1104

FRONT	2923	lb
REAR	2169	lb
TOTAL	5092	lb

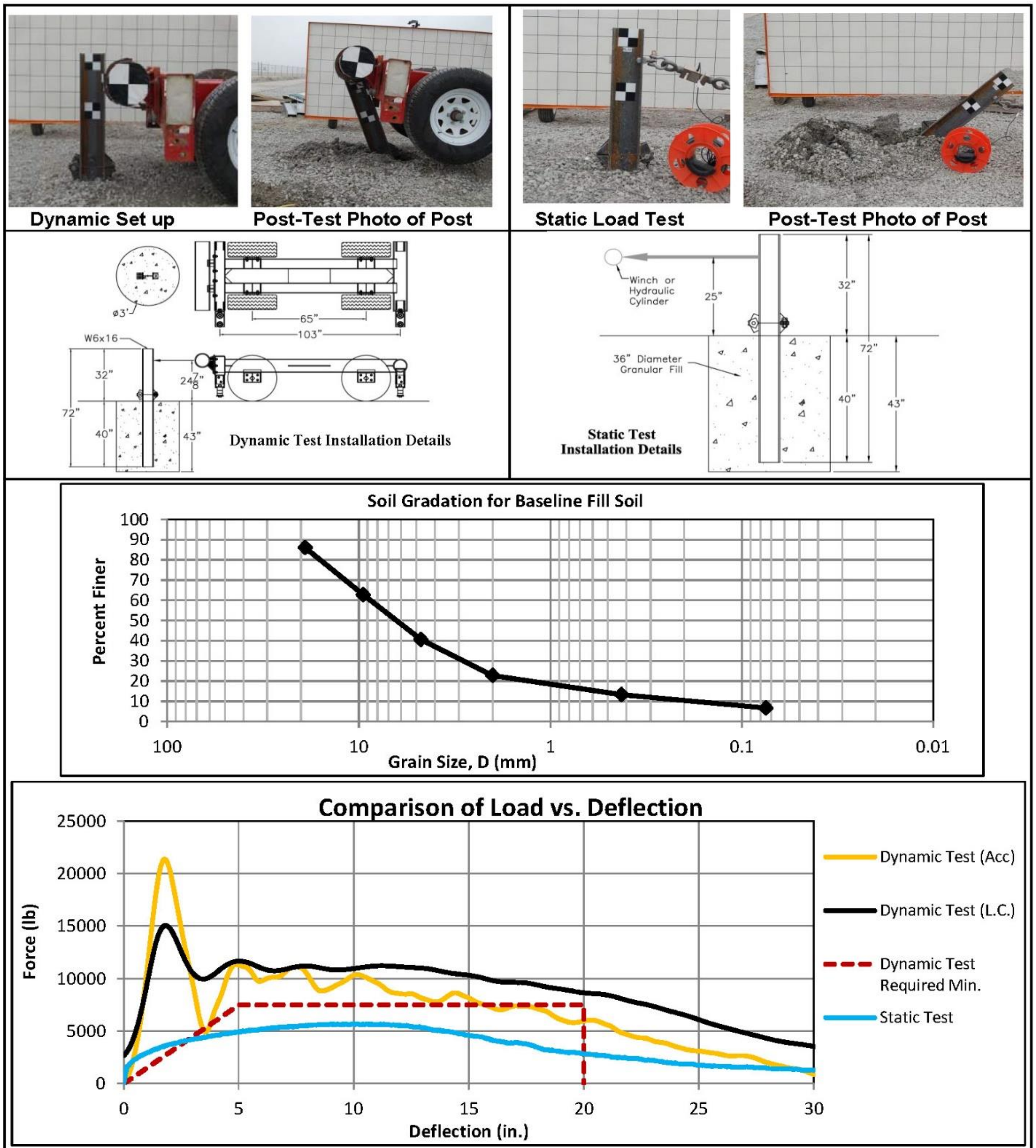
TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	1420	1444
Rear	1053	1083

FRONT	2864	lb
REAR	2136	lb
TOTAL	5000	lb

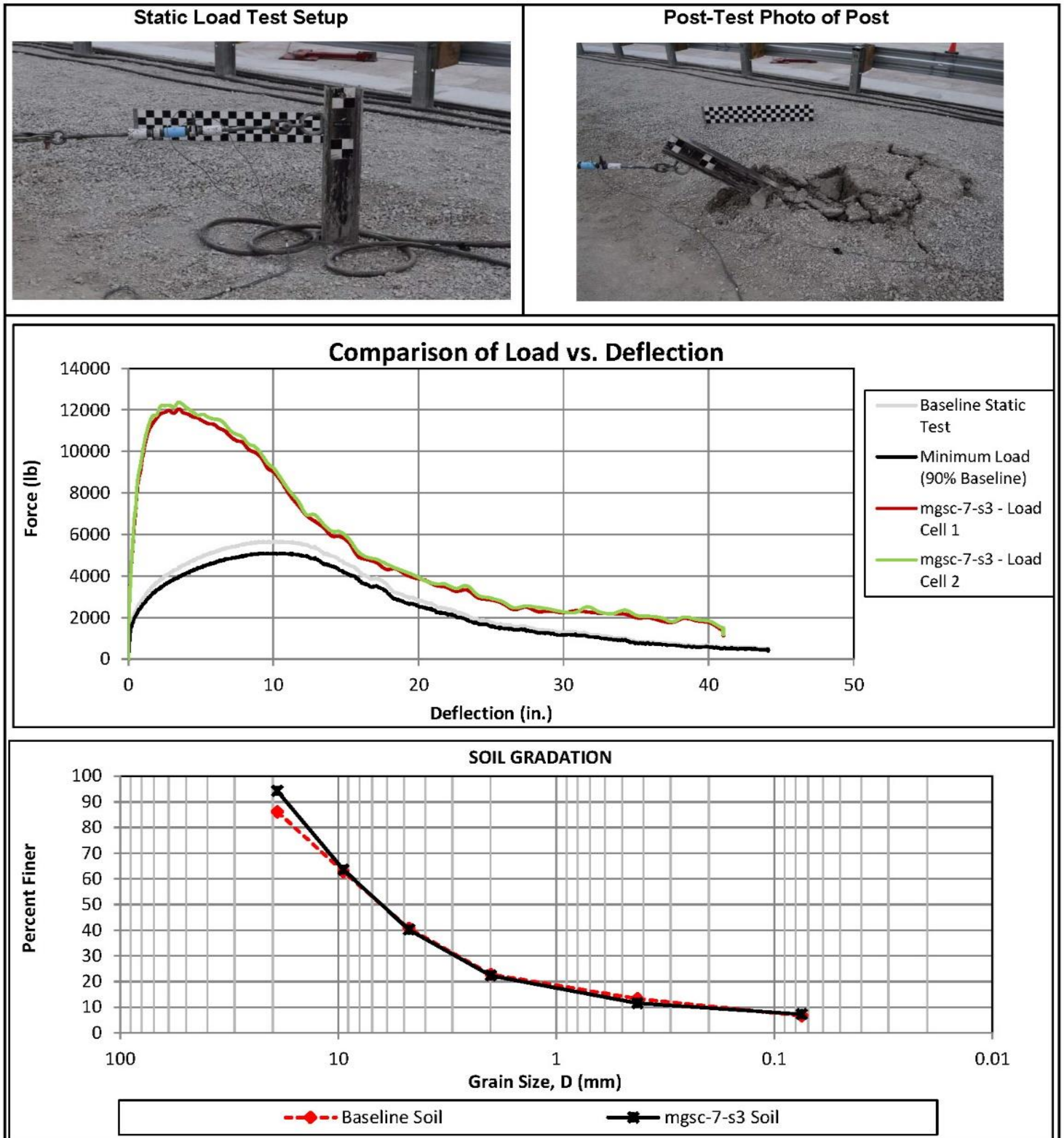
Figure B-2. Vehicle Mass Distribution, Test No. MGSC-8

Appendix C. Static Soil Tests



Date..	5/17/2013
Test Facility & Site Location......................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)..........	Well-Graded Gravel (GW)
Fill material description (ASTM D2487).........	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure........	H.E.-8
Bogie Weight...	1857 lb — 842 kg
Impact Velocity..	20.6 mph — 33.2 km/h

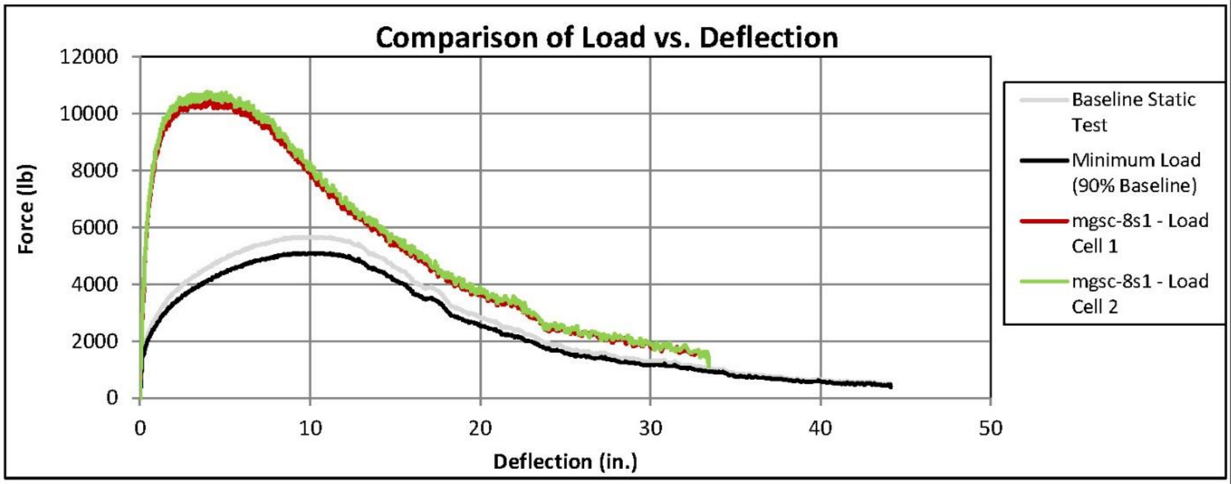
Figure C-1. Soil Strength, Initial Calibration Tests

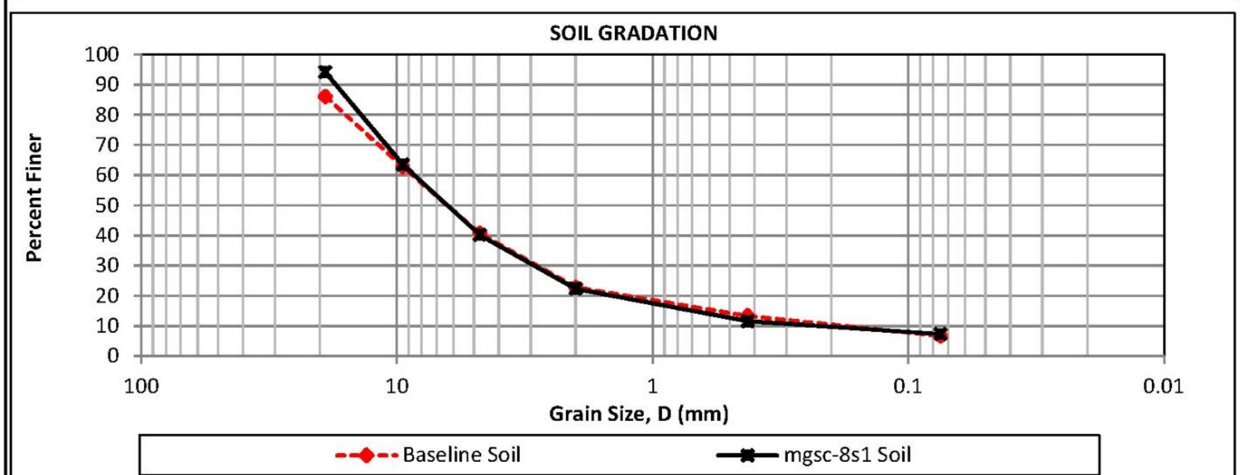


Date..	11/7/2017
Test Facility & Site Location.......................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)...........	Well-Graded Gravel (GW)
Fill material description (ASTM D2487).........	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure........	8-inch lifts tamped with a pneumatic compactor

Figure C-2. Static Soil Test, Test No. MGSC-7

Static Load Test Setup	Post-Test Photo of Post
	





Date………………………………………………	11/28/2017
Test Facility & Site Location……………………	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)………..	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)………	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure……..	8-inch lifts tamped with a pneumatic compactor

Figure C-3. Static Soil Test, Test No. MGSC-8

Appendix D. Vehicle Deformation Records

Date: 11/7/2017 Test Name: MGSC-7 VIN: KMHCN4AC4AU460931
Year: 2009 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	26.678	-24.554	3.274	26.264	-24.418	3.475	-0.414	0.137	0.202	0.480
2	29.124	-21.757	2.076	28.764	-21.551	2.209	-0.360	0.205	0.133	0.436
3	30.918	-18.126	0.002	30.888	-18.321	-0.051	-0.030	-0.195	-0.053	0.204
4	24.331	-8.747	-3.952	24.310	-8.954	-3.920	-0.021	-0.206	0.032	0.210
5	21.654	-6.186	-0.984	21.564	-6.393	-0.860	-0.091	-0.207	0.124	0.257
6	15.175	-4.946	0.540	15.194	-5.203	0.557	0.020	-0.257	0.017	0.259
7	19.982	-22.432	-5.321	20.004	-22.637	-5.261	0.022	-0.205	0.060	0.215
8	20.321	-19.102	-5.090	20.338	-19.355	-5.036	0.016	-0.253	0.054	0.259
9	20.436	-16.298	-5.249	20.433	-16.481	-5.188	-0.003	-0.183	0.061	0.193
10	20.645	-13.882	-5.332	20.640	-14.085	-5.280	-0.005	-0.203	0.052	0.210
11	19.351	-10.514	-5.299	19.353	-10.768	-5.231	0.002	-0.254	0.068	0.262
12	17.482	-7.166	-3.040	17.583	-7.392	-3.031	0.100	-0.226	0.009	0.247
13	13.971	-25.590	-5.640	13.982	-25.807	-5.606	0.011	-0.217	0.034	0.220
14	14.067	-20.844	-5.157	14.001	-20.990	-5.100	-0.067	-0.146	0.058	0.171
15	13.875	-16.739	-5.216	13.844	-16.897	-5.164	-0.031	-0.158	0.052	0.169
16	13.675	-12.552	-5.668	13.715	-12.754	-5.454	0.040	-0.202	0.214	0.297
17	13.520	-9.891	-5.727	13.568	-10.089	-5.653	0.049	-0.197	0.074	0.216
18	12.935	-6.434	-1.706	12.943	-6.653	-1.663	0.008	-0.219	0.043	0.223
19	8.218	-26.283	-5.354	8.191	-26.480	-5.264	-0.028	-0.197	0.090	0.218
20	8.398	-21.457	-5.192	8.420	-21.666	-5.139	0.023	-0.208	0.053	0.216
21	8.595	-17.472	-5.100	8.592	-17.638	-5.065	-0.003	-0.166	0.035	0.170
22	8.923	-13.205	-5.335	8.958	-13.442	-5.230	0.036	-0.237	0.105	0.262
23	9.145	-9.341	-5.646	9.156	-9.547	-5.598	0.011	-0.206	0.048	0.212
24	8.606	-6.110	-1.354	8.677	-6.330	-1.300	0.070	-0.220	0.054	0.237
25	4.141	-20.548	-4.845	4.105	-20.764	-4.798	-0.036	-0.217	0.047	0.225
26	4.344	-14.326	-4.869	4.308	-14.561	-4.859	-0.036	-0.235	0.010	0.238
27	-1.112	-21.454	-1.134	-1.153	-21.623	-1.051	-0.041	-0.169	0.082	0.192
28	-0.679	-13.768	-1.169	-0.753	-13.954	-1.138	-0.074	-0.186	0.031	0.203

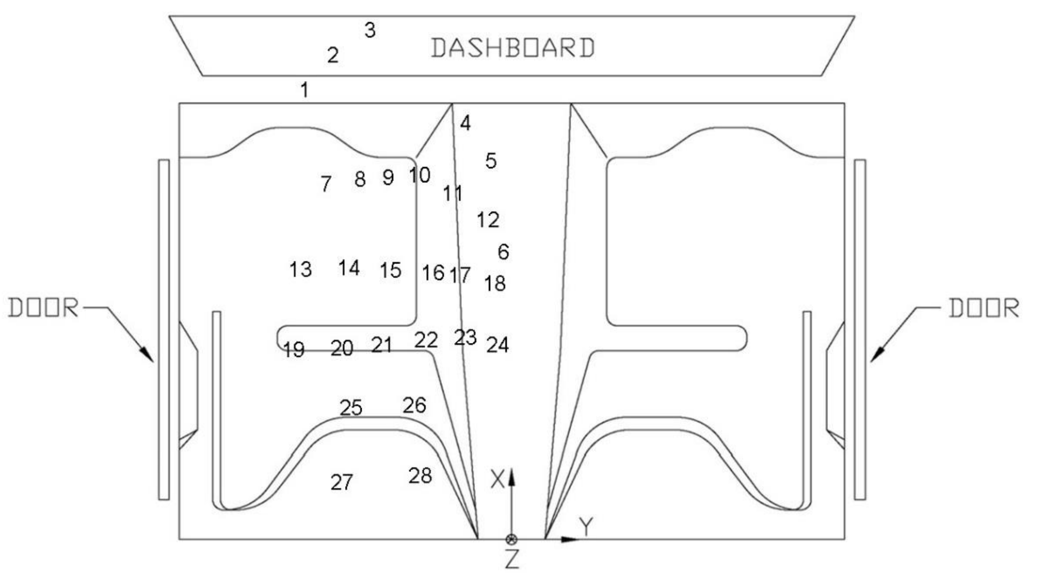


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. MGSC-7

Date: 11/7/2017 Test Name: MGSC-7 VIN: KMHCN4AC4AU460931
Year: 2009 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	51.668	-28.384	6.459	51.287	-28.030	6.054	-0.382	0.354	-0.405	0.659
2	54.405	-25.675	5.450	54.015	-25.231	4.954	-0.390	0.445	-0.496	0.772
3	56.425	-22.144	3.428	56.449	-22.057	2.829	0.023	0.087	-0.600	0.606
4	50.565	-12.412	-0.669	50.615	-12.342	-1.039	0.050	0.071	-0.369	0.379
5	47.905	-9.685	2.227	47.862	-9.657	1.924	-0.043	0.028	-0.304	0.308
6	41.423	-8.154	3.470	41.414	-8.106	3.125	-0.009	0.048	-0.345	0.349
7	45.471	-25.826	-2.336	45.551	-25.700	-2.845	0.080	0.126	-0.509	0.530
8	46.008	-22.522	-2.062	46.076	-22.488	-2.546	0.068	0.035	-0.484	0.489
9	46.317	-19.704	-2.187	46.303	-19.618	-2.641	-0.014	0.086	-0.454	0.462
10	46.683	-17.273	-2.247	46.673	-17.226	-2.671	-0.010	0.047	-0.424	0.427
11	45.552	-13.885	-2.238	45.592	-13.796	-2.592	0.039	0.089	-0.354	0.367
12	43.838	-10.408	0.017	43.892	-10.386	-0.405	0.054	0.022	-0.422	0.426
13	39.348	-28.611	-2.922	39.405	-28.454	-3.478	0.057	0.157	-0.556	0.581
14	39.637	-23.819	-2.398	39.717	-23.751	-2.887	0.079	0.068	-0.489	0.500
15	39.699	-19.757	-2.428	39.716	-19.694	-2.886	0.017	0.063	-0.458	0.462
16	39.772	-15.581	-2.855	39.840	-15.501	-3.091	0.068	0.080	-0.237	0.259
17	39.806	-12.946	-2.897	39.833	-12.817	-3.244	0.027	0.129	-0.347	0.371
18	39.260	-9.459	1.116	39.240	-9.403	0.814	-0.020	0.056	-0.303	0.309
19	33.545	-29.015	-2.862	33.592	-28.905	-3.392	0.047	0.111	-0.531	0.544
20	34.064	-24.196	-2.668	34.039	-24.050	-3.148	-0.025	0.146	-0.481	0.503
21	34.411	-20.140	-2.528	34.409	-20.122	-3.012	-0.002	0.018	-0.484	0.484
22	35.016	-16.074	-2.615	35.039	-15.935	-3.046	0.023	0.138	-0.431	0.453
23	35.456	-12.128	-2.988	35.436	-12.072	-3.357	-0.020	0.056	-0.370	0.374
24	34.957	-8.870	1.359	34.986	-8.855	1.017	0.028	0.016	-0.343	0.344
25	29.788	-23.017	-2.482	29.802	-22.977	-2.973	0.014	0.040	-0.492	0.494
26	30.313	-16.817	-2.443	30.328	-16.800	-2.900	0.015	0.017	-0.456	0.457
27	24.281	-23.630	1.011	24.343	-23.601	0.550	0.062	0.029	-0.461	0.466
28	25.166	-16.024	1.054	25.178	-15.966	0.637	0.012	0.058	-0.417	0.422

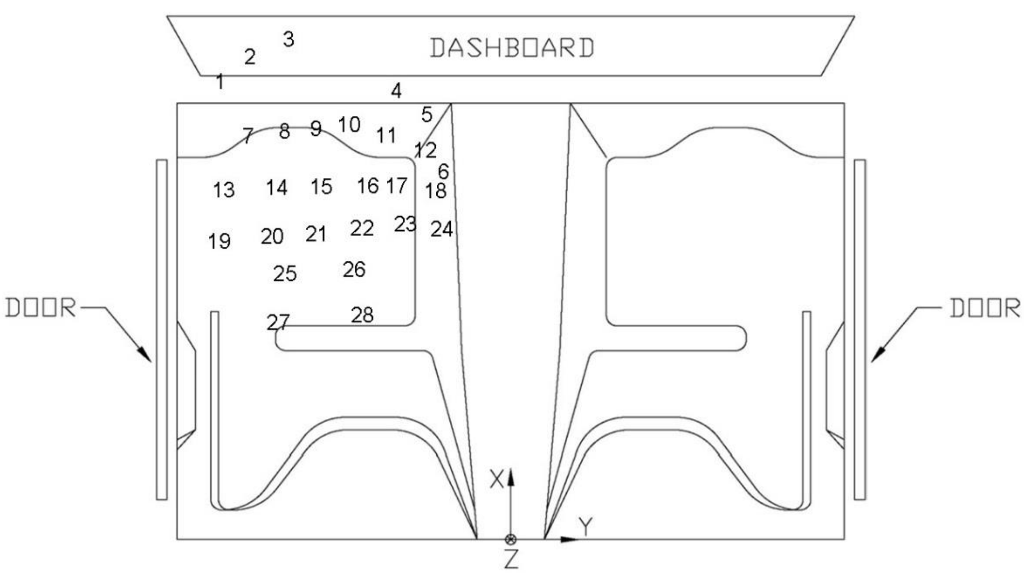


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. MGSC-7

Date: 11/7/2017 Test Name: MGSC-7 VIN: KMHCN4AC4AU460931
Year: 2009 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	13.191	-26.452	22.489	13.569	-26.523	22.644	0.378	-0.071	0.155	0.415
	2	11.227	-16.069	26.281	11.633	-16.067	26.388	0.406	0.002	0.107	0.420
	3	15.383	-7.609	23.467	15.763	-7.641	23.547	0.380	-0.032	0.080	0.389
	4	13.427	-2.011	23.617	13.950	-2.001	23.674	0.523	0.010	0.057	0.527
	5	9.356	-2.212	17.230	9.741	-2.255	17.330	0.385	-0.043	0.100	0.400
	6	10.981	-1.680	8.515	11.213	-1.808	8.622	0.232	-0.129	0.108	0.286
SIDE PANEL	7	17.163	-29.228	3.229	17.370	-29.295	3.413	0.207	-0.068	0.184	0.285
	8	16.577	-29.205	0.930	16.729	-29.217	1.031	0.152	-0.012	0.101	0.183
	9	20.084	-29.209	0.585	20.161	-29.056	0.725	0.077	0.153	0.140	0.221
IMPACT SIDE DOOR	10	-13.756	-28.753	23.562	-13.488	-29.458	23.832	0.267	-0.704	0.270	0.800
	11	-3.424	-29.190	22.598	-3.165	-29.629	22.819	0.259	-0.439	0.221	0.556
	12	8.894	-29.712	21.263	9.161	-29.914	21.364	0.267	-0.203	0.101	0.350
	13	2.845	-30.018	10.484	3.037	-30.641	10.635	0.192	-0.623	0.152	0.670
	14	-3.324	-29.773	12.085	-3.131	-30.442	12.286	0.194	-0.669	0.200	0.724
	15	-12.082	-29.524	12.433	-11.854	-30.047	12.737	0.228	-0.524	0.304	0.647
ROOF	16	0.001	-21.123	38.629	0.522	-21.110	38.755	0.521	0.012	0.126	0.536
	17	0.971	-16.237	38.942	1.487	-16.126	39.041	0.517	0.111	0.099	0.538
	18	1.730	-10.709	39.139	2.202	-10.720	39.208	0.473	-0.010	0.068	0.478
	19	2.195	-6.041	39.195	2.658	-6.022	39.239	0.463	0.020	0.044	0.465
	20	2.466	-1.797	39.167	2.949	-1.854	39.180	0.483	-0.057	0.013	0.486
	21	-5.355	-19.768	41.089	-4.843	-19.744	41.221	0.512	0.024	0.132	0.530
	22	-4.704	-15.913	41.351	-4.169	-15.865	41.456	0.534	0.047	0.105	0.547
	23	-4.039	-10.558	41.599	-3.536	-10.491	41.671	0.503	0.067	0.073	0.512
	24	-3.808	-5.965	41.746	-3.281	-5.909	41.792	0.527	0.056	0.046	0.532
	25	-3.967	-1.622	41.861	-3.453	-1.612	41.893	0.514	0.011	0.032	0.515
	26	-8.668	-18.221	41.966	-8.162	-18.139	42.095	0.506	0.082	0.129	0.528
	27	-8.493	-15.437	42.208	-8.039	-15.369	42.329	0.455	0.068	0.121	0.475
	28	-7.906	-10.643	42.446	-7.377	-10.546	42.530	0.529	0.096	0.084	0.544
	29	-7.565	-5.820	42.588	-7.017	-5.720	42.641	0.548	0.100	0.053	0.559
	30	-7.043	-1.542	42.552	-6.537	-1.509	42.585	0.506	0.033	0.033	0.508
A PILLAR	31	0.452	-23.951	35.962	0.939	-23.947	36.157	0.487	0.004	0.195	0.524
	32	3.837	-24.652	34.547	4.343	-24.694	34.658	0.506	-0.043	0.112	0.520
	33	8.471	-25.901	31.804	8.976	-25.975	31.942	0.505	-0.074	0.138	0.529
	34	12.637	-27.001	28.963	13.065	-27.090	29.143	0.428	-0.089	0.180	0.473
B PILLAR	35	-18.322	-27.384	22.476	-17.905	-27.409	22.747	0.417	-0.025	0.271	0.498
	36	-22.116	-27.274	22.351	-21.790	-27.289	22.592	0.326	-0.015	0.241	0.406
	37	-18.587	-26.619	27.697	-18.216	-26.610	27.936	0.371	0.010	0.239	0.441
	38	-22.632	-26.572	27.493	-22.190	-26.561	27.672	0.441	0.011	0.179	0.476
	39	-19.766	-24.437	34.270	-19.317	-24.370	34.519	0.448	0.067	0.249	0.517
	40	-22.997	-24.529	33.900	-22.566	-24.478	34.100	0.431	0.052	0.200	0.477

Figure D-3. Interior Crush Deformation Data – Set 1, Test No. MGSC-7

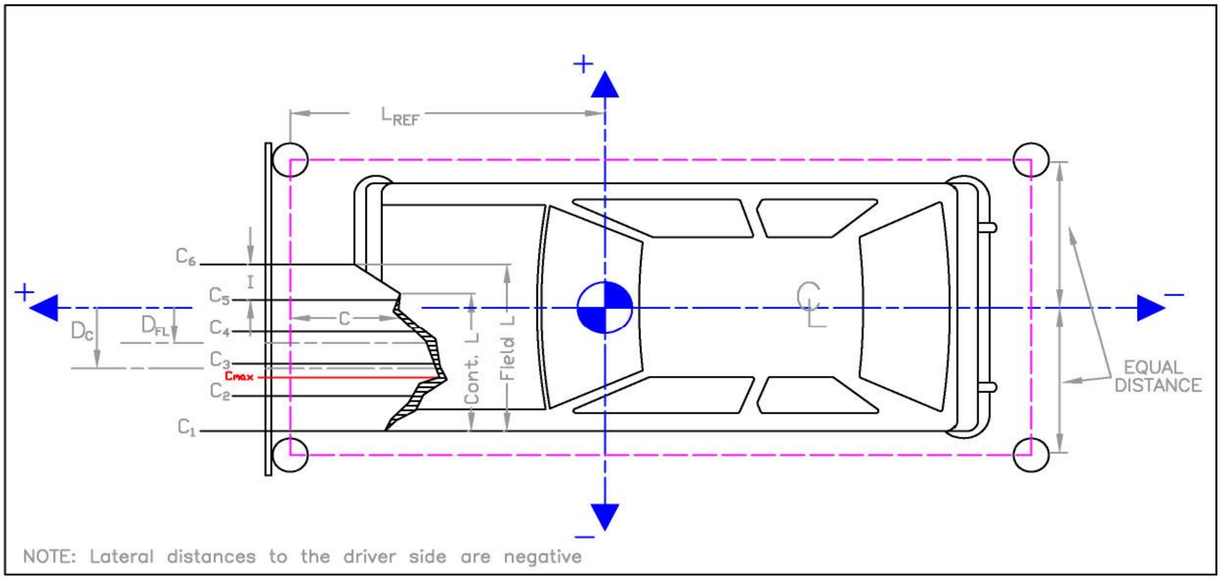
Date: 11/7/2017 Test Name: MGSC-7 VIN: KMHCN4AC4AU460931
Year: 2009 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	37.585	-29.643	25.175	37.750	-29.743	24.705	0.165	-0.101	-0.470	0.508
	2	36.046	-19.143	28.955	36.183	-19.255	28.584	0.138	-0.113	-0.371	0.411
	3	40.836	-10.907	26.406	40.927	-10.994	26.079	0.092	-0.088	-0.327	0.351
	4	39.246	-5.202	26.523	39.360	-5.292	26.236	0.115	-0.089	-0.287	0.322
	5	35.349	-5.135	19.965	35.430	-5.239	19.714	0.081	-0.104	-0.251	0.284
	6	37.303	-4.645	11.370	37.341	-4.696	11.071	0.038	-0.051	-0.300	0.306
SIDE PANEL	7	42.219	-32.523	6.095	42.206	-32.356	5.593	-0.014	0.167	-0.502	0.529
	8	41.711	-32.453	3.717	41.669	-32.201	3.181	-0.042	0.252	-0.536	0.594
	9	45.171	-32.683	3.465	45.163	-32.222	3.022	-0.008	0.461	-0.443	0.639
IMPACT SIDE DOOR	10	10.569	-30.384	25.205	10.503	-31.198	24.771	-0.066	-0.813	-0.434	0.924
	11	20.884	-31.402	24.592	20.856	-31.914	24.144	-0.028	-0.512	-0.448	0.681
	12	33.221	-32.629	23.732	33.209	-32.848	23.206	-0.011	-0.219	-0.526	0.569
	13	27.546	-32.502	12.762	27.505	-33.045	12.224	-0.041	-0.543	-0.538	0.765
	14	21.311	-31.923	14.115	21.297	-32.538	13.608	-0.014	-0.616	-0.506	0.797
	15	12.606	-31.180	14.135	12.626	-31.677	13.750	0.020	-0.497	-0.385	0.629
ROOF	16	24.141	-23.607	40.803	24.248	-23.868	40.415	0.107	-0.262	-0.389	0.481
	17	25.319	-18.770	41.207	25.481	-19.013	40.824	0.161	-0.243	-0.383	0.482
	18	26.377	-13.336	41.474	26.502	-13.597	41.128	0.125	-0.261	-0.345	0.450
	19	27.080	-8.635	41.595	27.228	-8.947	41.265	0.147	-0.312	-0.329	0.477
	20	27.587	-4.468	41.608	27.760	-4.793	41.296	0.173	-0.325	-0.312	0.483
	21	18.726	-21.973	43.071	18.893	-22.249	42.681	0.166	-0.276	-0.390	0.506
	22	19.573	-18.159	43.392	19.773	-18.428	43.019	0.200	-0.268	-0.373	0.501
	23	20.480	-12.847	43.717	20.662	-13.103	43.371	0.182	-0.256	-0.346	0.467
	24	21.019	-8.289	43.896	21.179	-8.579	43.592	0.160	-0.289	-0.304	0.449
	25	21.034	-3.938	44.050	21.225	-4.215	43.777	0.191	-0.277	-0.273	0.434
	26	15.436	-20.248	43.833	15.587	-20.509	43.463	0.151	-0.261	-0.370	0.477
	27	15.735	-17.458	44.108	15.890	-17.780	43.748	0.154	-0.322	-0.359	0.507
	28	16.641	-12.791	44.391	16.797	-13.040	44.071	0.155	-0.249	-0.320	0.434
	29	17.231	-7.868	44.591	17.411	-8.212	44.295	0.180	-0.345	-0.296	0.489
	30	17.969	-3.687	44.610	18.131	-4.008	44.345	0.162	-0.321	-0.266	0.447
A PILLAR	31	24.486	-26.466	38.150	24.640	-26.698	37.759	0.154	-0.232	-0.391	0.480
	32	27.905	-27.368	36.819	28.082	-27.606	36.382	0.177	-0.238	-0.438	0.529
	33	32.612	-28.874	34.273	32.774	-29.096	33.816	0.162	-0.222	-0.457	0.533
	34	36.754	-30.180	31.606	36.905	-30.377	31.177	0.150	-0.197	-0.430	0.496
B PILLAR	35	6.158	-28.746	23.969	6.259	-28.888	23.534	0.100	-0.142	-0.435	0.469
	36	2.339	-28.416	23.647	2.421	-28.553	23.233	0.083	-0.137	-0.414	0.444
	37	5.650	-27.446	28.958	5.803	-28.169	28.752	0.153	-0.724	-0.206	0.768
	38	1.704	-27.712	28.738	1.803	-27.891	28.322	0.099	-0.179	-0.416	0.464
	39	4.357	-25.774	35.664	4.521	-26.003	35.276	0.164	-0.230	-0.388	0.480
	40	1.171	-25.680	35.161	1.324	-25.890	34.813	0.153	-0.210	-0.348	0.434

Figure D-4. Interior Crush Deformation Data – Set 2, Test No. MGSC-7

Date:	11/7/2018	Test Number:	MGSC-7		
Year:	2009	Make:	Hyundai	Model:	Accent



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	83 5/8	(2124)
Total Width of Vehicle:	53 1/8	(1349)
Width of contact and induced crush - Field L:	66	(1676)
Crush measurement spacing interval (L/5) - I:	13 1/4	(337)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	27	(686)
Distance from center of vehicle to center of contact damage - D_C:	19 1/2	(495)

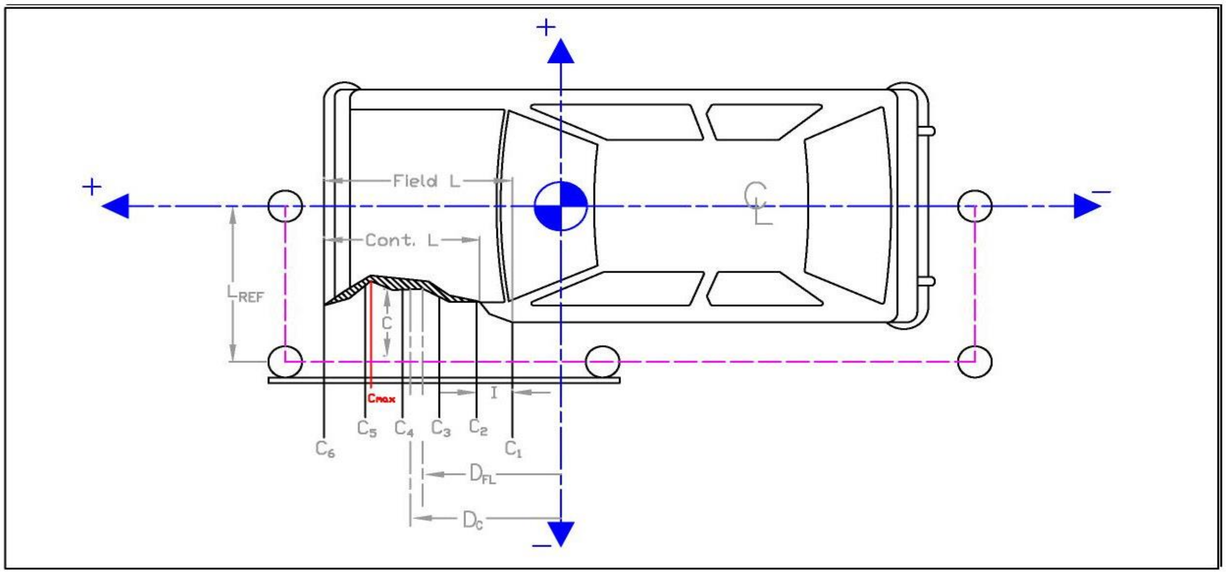
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

Crush Measurement			Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	27 3/4	(705)	-33	-(838)	20 1/4	(514)	11 4/5	(300)	-4 1/3	-(110)
C_2	14 7/8	(378)	-19 3/4	-(502)	4 3/4	(121)			-1 2/3	-(43)
C_3	12 1/4	(311)	-6 1/2	-(165)	2 3/8	(60)			-2	-(49)
C_4	12 3/8	(314)	6 3/4	(171)	2 3/8	(60)			-1 4/5	-(46)
C_5	27 5/8	(702)	20	(508)	4 7/8	(124)			11	(278)
C_6	NA	NA	33 1/4	(845)	19 7/8	(505)			NA	NA
C_{MAX}	38	(965)	24 1/4	(616)	6 3/4	(171)			19 4/9	(494)

Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. MGSC-7

Date: 11/7/2018 Test Number: MGSC-7

Year: 2009 Make: Hyundai Model: Accent



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	36	(914)
Total Vehicle Length:	168 1/2	(4280)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-14 1/5	-(360)
Width of contact and induced crush - Field L:	67	(1702)
Crush measurement spacing interval (L/5) - I:	13 3/8	(340)
Distance from vehicle c.g. to center of Field L - D_{FL}:	36 1/2	(927)
Width of Contact Damage:	67	(1702)
Distance from vehicle c.g. to center of contact damage - D_C:	36 1/2	(927)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	3 1/2	(89)	3	(76)	3 1/4	(83)	0	()	1/4	(6)
C_2	4 5/8	(117)	16 3/8	(416)	3 1/4	(83)			1 3/8	(35)
C_3	3 3/4	(95)	29 3/4	(756)	3 5/8	(92)			1/8	(3)
C_4	16 7/8	(429)	43 1/8	(1095)	3 3/8	(86)			13 1/2	(343)
C_5	13 7/8	(352)	56 1/2	(1435)	5 1/2	(140)			8 3/8	(213)
C_6	27	(686)	69 7/8	(1775)	31 7/8	(810)			-4 7/8	-(124)
C_{MAX}	16 7/8	(429)	43 1/8	(1095)	3 3/8	(86)			13 1/2	(343)

Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. MGSC-7

Date: 7/28/2017 Test Name: MGSC-8 VIN: 1D7RB1GT8AS118297
Year: 2010 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	29.805	-33.499	1.915	30.044	-33.247	1.951	0.240	0.252	0.036	0.349
2	30.762	-30.254	0.257	31.000	-30.010	0.215	0.238	0.244	-0.042	0.343
3	30.984	-25.606	-0.927	31.219	-25.391	-0.946	0.235	0.216	-0.020	0.320
4	29.565	-21.154	-1.198	29.779	-20.849	-1.197	0.214	0.305	0.001	0.372
5	27.392	-34.118	-1.257	27.671	-33.792	-1.294	0.279	0.327	-0.037	0.431
6	28.280	-30.452	-2.397	28.582	-30.164	-2.390	0.302	0.287	0.006	0.417
7	28.051	-26.309	-2.464	28.318	-26.106	-2.468	0.267	0.203	-0.005	0.336
8	27.535	-21.110	-2.612	27.810	-20.858	-2.598	0.275	0.252	0.014	0.373
9	24.181	-34.477	-4.475	24.410	-34.299	-4.512	0.229	0.177	-0.037	0.292
10	24.045	-30.354	-4.457	24.321	-30.120	-4.459	0.275	0.234	-0.002	0.361
11	24.225	-26.138	-4.497	24.409	-25.949	-4.542	0.184	0.189	-0.046	0.268
12	24.383	-21.218	-4.439	24.639	-20.979	-4.441	0.257	0.239	-0.002	0.351
13	20.015	-34.794	-6.453	20.271	-34.600	-6.481	0.256	0.194	-0.028	0.323
14	19.673	-30.689	-6.488	19.968	-30.458	-6.488	0.296	0.231	0.000	0.375
15	19.658	-26.381	-6.495	19.904	-26.087	-6.499	0.246	0.295	-0.004	0.384
16	19.798	-20.830	-6.472	20.002	-20.540	-6.488	0.204	0.290	-0.016	0.355
17	14.920	-35.233	-6.862	15.203	-34.973	-6.888	0.284	0.260	-0.026	0.386
18	14.818	-31.216	-6.815	15.079	-30.953	-6.831	0.261	0.264	-0.016	0.372
19	15.722	-26.717	-6.608	16.003	-26.408	-6.619	0.281	0.310	-0.011	0.418
20	15.969	-20.466	-6.633	16.224	-20.192	-6.651	0.255	0.274	-0.019	0.375
21	9.055	-35.041	-6.866	9.255	-34.705	-6.900	0.200	0.336	-0.034	0.393
22	8.432	-30.837	-6.792	8.665	-30.584	-6.821	0.234	0.253	-0.029	0.345
23	8.241	-26.861	-6.790	8.434	-26.609	-6.801	0.193	0.252	-0.011	0.318
24	8.355	-20.777	-6.831	8.602	-20.505	-6.845	0.247	0.272	-0.014	0.367
25	-0.135	-31.443	-2.841	0.103	-31.159	-2.866	0.237	0.284	-0.025	0.371
26	-0.009	-27.898	-2.838	0.175	-27.589	-2.864	0.184	0.309	-0.026	0.360
27	-0.153	-25.218	-2.909	0.119	-24.932	-2.915	0.273	0.286	-0.006	0.395
28	-0.112	-20.762	-2.877	0.160	-20.514	-2.888	0.272	0.249	-0.011	0.368

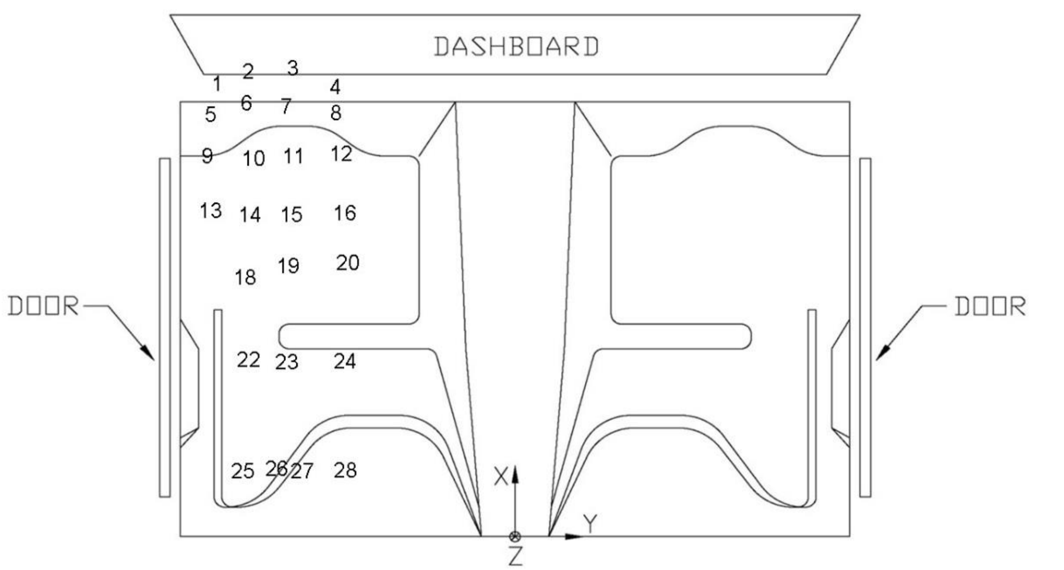


Figure D-7. Floor Pan Deformation Data – Set 1, Test No. MGSC-8

Date: 7/28/2017 Test Name: MGSC-8 VIN: 1D7RB1GT8AS118297
Year: 2010 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	57.280	-32.390	4.271	57.231	-32.637	4.182	-0.049	-0.247	-0.088	0.267
2	58.182	-29.164	2.628	58.149	-29.384	2.456	-0.033	-0.220	-0.171	0.281
3	58.337	-24.543	1.417	58.307	-24.761	1.302	-0.030	-0.218	-0.116	0.249
4	56.819	-20.040	1.112	56.800	-20.241	1.045	-0.019	-0.201	-0.067	0.212
5	54.858	-32.962	0.944	54.888	-33.214	0.921	0.031	-0.251	-0.023	0.254
6	55.703	-29.349	-0.095	55.752	-29.572	-0.165	0.048	-0.223	-0.070	0.238
7	55.423	-25.254	-0.156	55.427	-25.518	-0.241	0.004	-0.265	-0.085	0.278
8	54.856	-20.102	-0.312	54.841	-20.278	-0.369	-0.015	-0.177	-0.057	0.186
9	51.693	-33.481	-2.201	51.657	-33.767	-2.320	-0.036	-0.286	-0.118	0.311
10	51.491	-29.336	-2.183	51.504	-29.589	-2.263	0.014	-0.254	-0.080	0.267
11	51.522	-25.149	-2.266	51.531	-25.417	-2.342	0.009	-0.268	-0.076	0.279
12	51.698	-20.209	-2.154	51.685	-20.444	-2.233	-0.012	-0.235	-0.079	0.249
13	47.540	-33.879	-4.217	47.537	-34.127	-4.317	-0.003	-0.249	-0.100	0.268
14	47.191	-29.743	-4.238	47.172	-29.991	-4.323	-0.019	-0.248	-0.084	0.263
15	47.057	-25.385	-4.259	47.042	-25.620	-4.329	-0.015	-0.236	-0.070	0.247
16	47.069	-19.879	-4.246	47.056	-20.073	-4.312	-0.013	-0.194	-0.067	0.206
17	42.471	-34.297	-4.667	42.478	-34.577	-4.759	0.007	-0.280	-0.092	0.295
18	42.287	-30.347	-4.622	42.293	-30.558	-4.699	0.006	-0.211	-0.077	0.225
19	43.133	-25.808	-4.408	43.146	-26.000	-4.476	0.014	-0.192	-0.068	0.205
20	43.254	-19.552	-4.431	43.274	-19.782	-4.501	0.020	-0.230	-0.070	0.241
21	36.515	-34.210	-4.716	36.526	-34.398	-4.811	0.011	-0.188	-0.095	0.211
22	35.873	-30.083	-4.646	35.874	-30.286	-4.732	0.001	-0.203	-0.086	0.220
23	35.601	-26.076	-4.645	35.583	-26.315	-4.710	-0.018	-0.239	-0.065	0.249
24	35.651	-19.932	-4.686	35.659	-20.209	-4.747	0.008	-0.276	-0.061	0.283
25	27.277	-30.782	-0.764	27.294	-30.994	-0.837	0.017	-0.213	-0.073	0.225
26	27.308	-27.224	-0.765	27.313	-27.424	-0.831	0.005	-0.199	-0.066	0.210
27	27.169	-24.571	-0.830	27.218	-24.767	-0.879	0.048	-0.197	-0.050	0.208
28	27.161	-20.143	-0.802	27.192	-20.349	-0.848	0.031	-0.206	-0.047	0.214

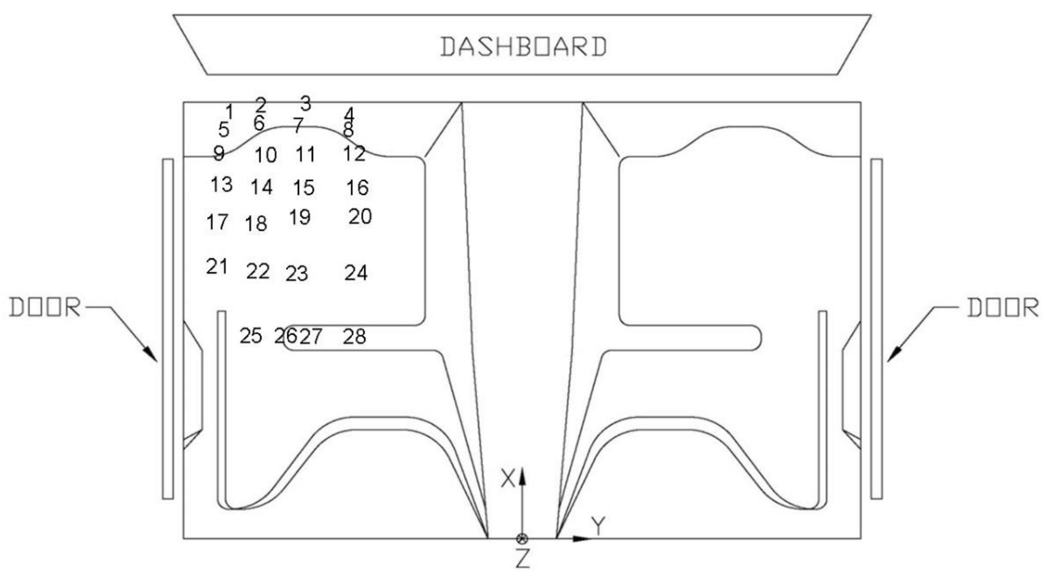


Figure D-8. Floor Pan Deformation Data – Set 2, Test No. MGSC-8

Date: 7/28/2017 Test Name: MGSC-8 VIN: 1D7RB1GT8AS118297
Year: 2010 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	14.593	-34.864	24.614	14.897	-34.627	24.577	0.305	0.238	-0.037	0.388
	2	14.309	-16.761	25.473	14.602	-16.470	25.449	0.293	0.291	-0.024	0.413
	3	11.183	-6.189	25.113	11.475	-5.886	25.063	0.292	0.303	-0.050	0.424
	4	11.136	-32.294	13.789	11.419	-32.022	13.756	0.283	0.272	-0.033	0.394
	5	10.442	-18.332	13.405	10.746	-18.111	13.315	0.303	0.221	-0.090	0.386
	6	8.369	-6.719	13.838	8.641	-6.524	13.840	0.272	0.195	0.002	0.335
SIDE PANEL	7	20.221	-38.732	3.617	20.413	-38.453	3.644	0.192	0.280	0.026	0.340
	8	22.108	-38.700	0.210	22.357	-38.430	0.167	0.249	0.270	-0.043	0.370
	9	26.433	-38.489	2.584	26.818	-38.227	2.455	0.385	0.262	-0.128	0.483
IMPACT SIDE DOOR	10	-13.199	-40.475	21.396	-13.065	-40.399	21.373	0.134	0.076	-0.023	0.156
	11	-2.357	-40.293	21.281	-2.101	-40.160	21.227	0.256	0.133	-0.054	0.293
	12	8.726	-40.113	20.972	8.959	-39.889	21.087	0.234	0.223	0.115	0.343
	13	-10.666	-41.206	1.244	-10.513	-40.934	1.194	0.153	0.272	-0.050	0.316
	14	-0.214	-41.913	2.071	0.005	-41.547	2.084	0.218	0.366	0.013	0.427
	15	6.743	-41.455	1.676	6.935	-41.053	1.671	0.192	0.402	-0.005	0.446
ROOF	16	3.599	-29.619	40.593	3.897	-29.423	40.551	0.297	0.196	-0.042	0.358
	17	5.098	-24.716	40.747	5.292	-24.499	40.761	0.194	0.216	0.014	0.291
	18	5.878	-20.799	40.877	6.189	-20.585	40.836	0.310	0.214	-0.041	0.379
	19	6.675	-14.548	41.046	7.069	-14.295	40.972	0.394	0.253	-0.074	0.474
	20	7.105	-6.736	41.082	7.369	-6.454	41.073	0.264	0.282	-0.009	0.386
	21	-4.601	-29.263	43.723	-4.360	-29.015	43.683	0.242	0.249	-0.040	0.349
	22	-3.743	-22.677	44.175	-3.534	-22.452	44.139	0.209	0.225	-0.037	0.309
	23	-3.220	-16.980	44.396	-2.903	-16.761	44.341	0.318	0.219	-0.054	0.390
	24	-2.625	-12.779	44.440	-2.254	-12.635	44.384	0.371	0.144	-0.056	0.402
	25	-1.982	-7.056	44.417	-1.722	-6.877	44.375	0.261	0.179	-0.042	0.319
	26	-9.237	-28.779	44.304	-9.017	-28.633	44.251	0.220	0.146	-0.054	0.269
	27	-8.313	-22.936	44.663	-8.007	-22.700	44.609	0.307	0.236	-0.053	0.390
	28	-6.959	-16.997	44.834	-6.733	-16.909	44.787	0.227	0.088	-0.047	0.248
	29	-6.846	-12.574	44.944	-6.478	-12.361	44.885	0.368	0.213	-0.059	0.429
	30	-6.473	-7.476	44.964	-6.155	-7.335	44.917	0.317	0.141	-0.047	0.350
A PILLAR	31	4.422	-34.084	37.971	4.714	-33.849	38.020	0.293	0.236	0.050	0.379
	32	11.290	-35.596	33.964	11.624	-35.364	33.912	0.334	0.233	-0.052	0.410
	33	14.870	-36.382	31.422	15.113	-36.134	31.474	0.242	0.248	0.052	0.350
	34	16.777	-36.700	29.516	16.973	-36.436	29.592	0.196	0.265	0.077	0.338
B PILLAR	35	-23.345	-38.497	21.768	-23.070	-38.285	21.762	0.275	0.212	-0.006	0.347
	36	-19.734	-38.428	22.197	-19.486	-38.212	22.197	0.248	0.216	0.000	0.329
	37	-23.485	-37.780	27.927	-23.190	-37.562	27.941	0.295	0.218	0.014	0.367
	38	-20.264	-37.808	27.550	-19.940	-37.593	27.526	0.324	0.214	-0.024	0.389
	39	-24.017	-34.465	37.590	-23.688	-34.245	37.594	0.329	0.220	0.004	0.396
	40	-21.348	-34.440	37.617	-21.033	-34.211	37.654	0.314	0.230	0.036	0.391

Figure D-9. Interior Crush Deformation Data – Set 1, Test No. MGSC-8

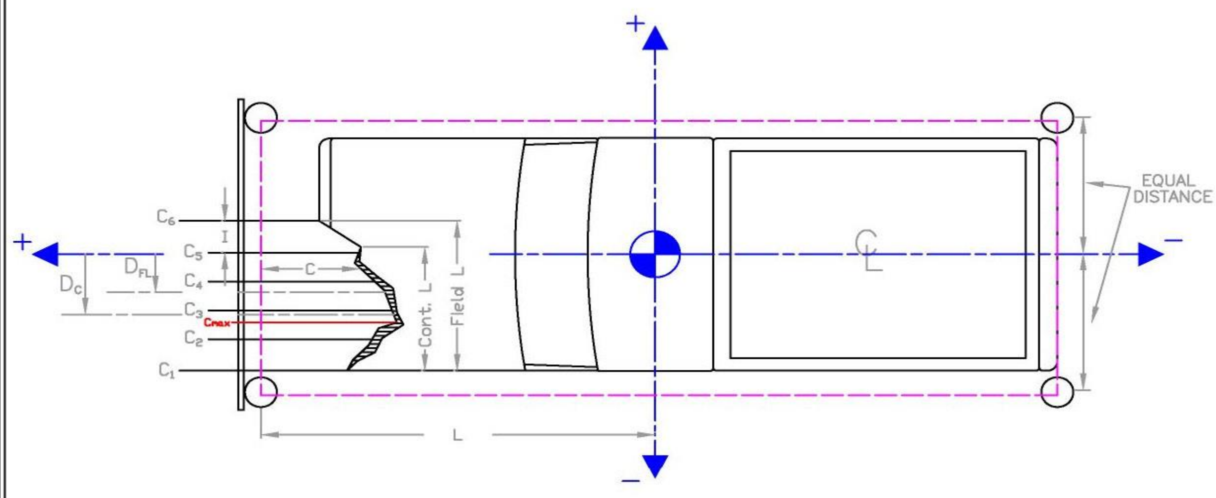
Date: 7/28/2017 Test Name: MGSC-8 VIN: 1D7RB1GT8AS118297
Year: 2010 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	41.867	-34.038	26.794	41.859	-34.221	26.737	-0.008	-0.183	-0.057	0.191
	2	41.323	-15.933	27.691	41.332	-16.123	27.642	0.009	-0.189	-0.049	0.196
	3	38.041	-5.393	27.307	38.090	-5.703	27.233	0.049	-0.310	-0.074	0.322
	4	38.455	-31.486	15.987	38.494	-31.679	15.894	0.039	-0.193	-0.093	0.218
	5	37.527	-17.608	15.624	37.614	-17.803	15.459	0.087	-0.194	-0.166	0.270
	6	35.294	-5.925	15.964	35.337	-6.203	15.883	0.043	-0.277	-0.081	0.292
SIDE PANEL	7	47.746	-37.779	5.881	47.637	-37.990	5.923	-0.110	-0.211	0.042	0.242
	8	49.629	-37.717	2.451	49.563	-37.939	2.428	-0.066	-0.222	-0.023	0.233
	9	53.930	-37.425	4.798	53.900	-37.677	4.832	-0.030	-0.252	0.034	0.256
IMPACT SIDE DOOR	10	14.139	-40.060	23.328	14.182	-40.440	23.328	0.043	-0.380	0.000	0.382
	11	25.108	-39.715	23.239	25.124	-40.044	23.250	0.016	-0.330	0.011	0.330
	12	36.150	-39.341	23.124	36.087	-39.631	23.090	-0.063	-0.290	-0.033	0.298
	13	16.917	-40.732	3.256	16.811	-40.928	3.147	-0.107	-0.196	-0.109	0.249
	14	27.363	-41.279	4.176	27.184	-41.387	4.096	-0.179	-0.107	-0.080	0.224
	15	34.283	-40.715	3.824	34.211	-40.815	3.888	-0.072	-0.100	0.064	0.139
ROOF	16	30.735	-28.983	42.648	30.744	-29.112	42.660	0.009	-0.128	0.012	0.129
	17	32.046	-24.034	42.877	32.066	-24.255	42.862	0.021	-0.220	-0.015	0.222
	18	32.796	-20.045	43.004	32.846	-20.238	42.980	0.050	-0.193	-0.023	0.201
	19	33.514	-13.779	43.174	33.601	-14.110	43.121	0.087	-0.331	-0.053	0.346
	20	33.899	-5.974	43.176	33.990	-6.281	43.122	0.091	-0.308	-0.054	0.325
	21	22.394	-28.610	45.782	22.408	-28.905	45.725	0.013	-0.294	-0.057	0.300
	22	23.205	-22.034	46.227	23.243	-22.413	46.160	0.037	-0.378	-0.067	0.386
	23	23.651	-16.377	46.445	23.696	-16.663	46.382	0.046	-0.286	-0.063	0.297
	24	24.157	-12.211	46.495	24.257	-12.527	46.427	0.100	-0.315	-0.067	0.337
	25	24.633	-6.418	46.483	24.753	-6.687	46.428	0.120	-0.268	-0.055	0.299
	26	17.800	-28.295	46.301	17.898	-28.589	46.239	0.098	-0.294	-0.062	0.316
	27	18.666	-22.444	46.666	18.695	-22.716	46.610	0.029	-0.272	-0.056	0.279
	28	19.856	-16.563	46.850	19.768	-16.856	46.806	-0.088	-0.293	-0.044	0.309
	29	19.865	-12.083	46.964	20.017	-12.360	46.905	0.152	-0.277	-0.059	0.321
	30	20.199	-7.039	46.986	20.259	-7.314	46.942	0.060	-0.275	-0.044	0.285
A PILLAR	31	31.547	-33.372	40.115	31.674	-33.657	40.092	0.126	-0.285	-0.023	0.313
	32	38.498	-34.783	36.139	38.572	-35.044	36.072	0.074	-0.261	-0.066	0.279
	33	42.147	-35.523	33.610	42.211	-35.786	33.582	0.063	-0.263	-0.028	0.272
	34	44.038	-35.798	31.718	44.077	-36.054	31.713	0.039	-0.256	-0.005	0.259
B PILLAR	35	4.001	-38.230	23.655	4.024	-38.477	23.684	0.023	-0.247	0.029	0.250
	36	7.598	-38.098	24.179	7.605	-38.351	24.136	0.008	-0.253	-0.043	0.257
	37	3.831	-37.516	29.808	3.809	-37.762	29.812	-0.022	-0.246	0.004	0.247
	38	7.026	-37.501	29.409	7.059	-37.744	29.427	0.034	-0.243	0.018	0.246
	39	3.213	-34.206	39.478	3.209	-34.459	39.457	-0.004	-0.254	-0.021	0.254
	40	5.823	-34.149	39.510	5.931	-34.378	39.526	0.108	-0.229	0.016	0.254

Figure D-10. Interior Crush Deformation Data – Set 2, Test No. MGSC-8

Date:	1/29/2018	Test Name:	MGSC-8	VIN:	1D7RB1GT8AS118297
Year:	2010	Make:	Dodge	Model:	Ram 1500



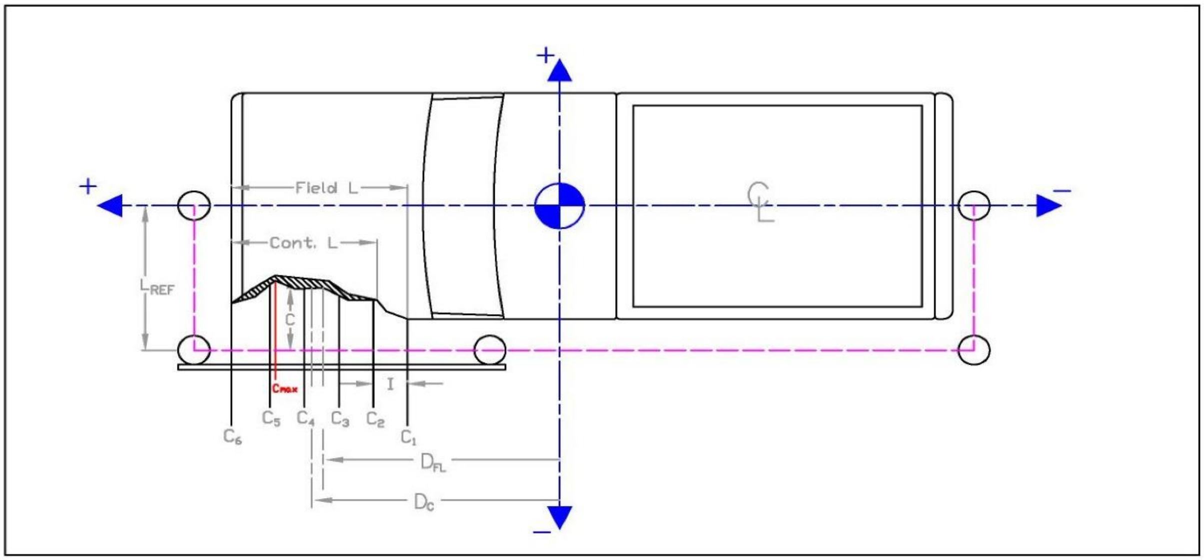
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	115 1/2	(2934)
Total Vehicle Width:	73	(1854)
Width of contact and induced crush - Field L:	58	(1473)
Crush measurement spacing interval (L/5) - I:	11 5/8	(295)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	20 1/2	(521)
Distance from center of vehicle to center of contact damage - D_C:	-26 1/2	-(673)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	35	(889)	-29	-(737)	8 5/8	(219)	11 1/2	(292)	14 7/8	(378)
C_2	20 1/4	(514)	-17 3/8	-(441)	5 1/4	(133)			3 1/2	(89)
C_3	17 1/4	(438)	-5 3/4	-(146)	4 1/8	(105)			1 5/8	(41)
C_4	14 1/2	(368)	5 7/8	(149)	4 1/8	(105)			-1 1/8	-(29)
C_5	15 1/2	(394)	17 1/2	(445)	5 1/4	(133)			-1 1/4	-(32)
C_6	20 1/2	(521)	29 1/8	(740)	8 5/8	(219)			3/8	(10)
C_{MAX}	35	(889)	-29	-(737)	8 5/8	(219)			14 7/8	(378)

Figure D-11. Exterior Vehicle Crush (NASS) - Front, Test No. MGSC-8

Date:	1/29/2018	Test Name:	MGSC-8	VIN:	1D7RB1GT8AS118297
Year:	2010	Make:	Dodge	Model:	Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	49 1/2	(1257)
Total Vehicle Length:	229 1/4	(5823)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-14 1/4	-(362)
Width of contact and induced crush - Field L:	229 1/4	(5823)
Crush measurement spacing interval (L/5) - I:	45 7/8	(1165)
Distance from vehicle c.g. to center of Field L - D_{FL}:	14 1/4	(362)
Width of Contact Damage:	229 1/4	(5823)
Distance from vehicle c.g. to center of contact damage - D_C:	14 1/4	(362)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)

NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	12 1/2	(318)	-100 3/8	-(2550)	5 5/8	(143)	5 1/2	(140)	1 3/8	(35)
C_2	10 3/4	(273)	-54 1/2	-(1384)	5 1/2	(140)			- 1/4	-(6)
C_3	10 1/4	(260)	-8 5/8	-(219)	5	(127)			- 1/4	-(6)
C_4	10 3/4	(273)	37 1/4	(946)	5 1/4	(133)			0	()
C_5	20 7/8	(530)	83 1/8	(2111)	6 1/4	(159)			9 1/8	(232)
C_6	N/A	N/A	129	(3277)	33 1/2	(851)			N/A	N/A
C_{MAX}	20 7/8	(530)	83 1/8	(2111)	6 1/4	(159)			9 1/8	(232)

Figure D-12. Exterior Vehicle Crush (NASS) - Side, Test No. MGSC-8

Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. MGSC-7

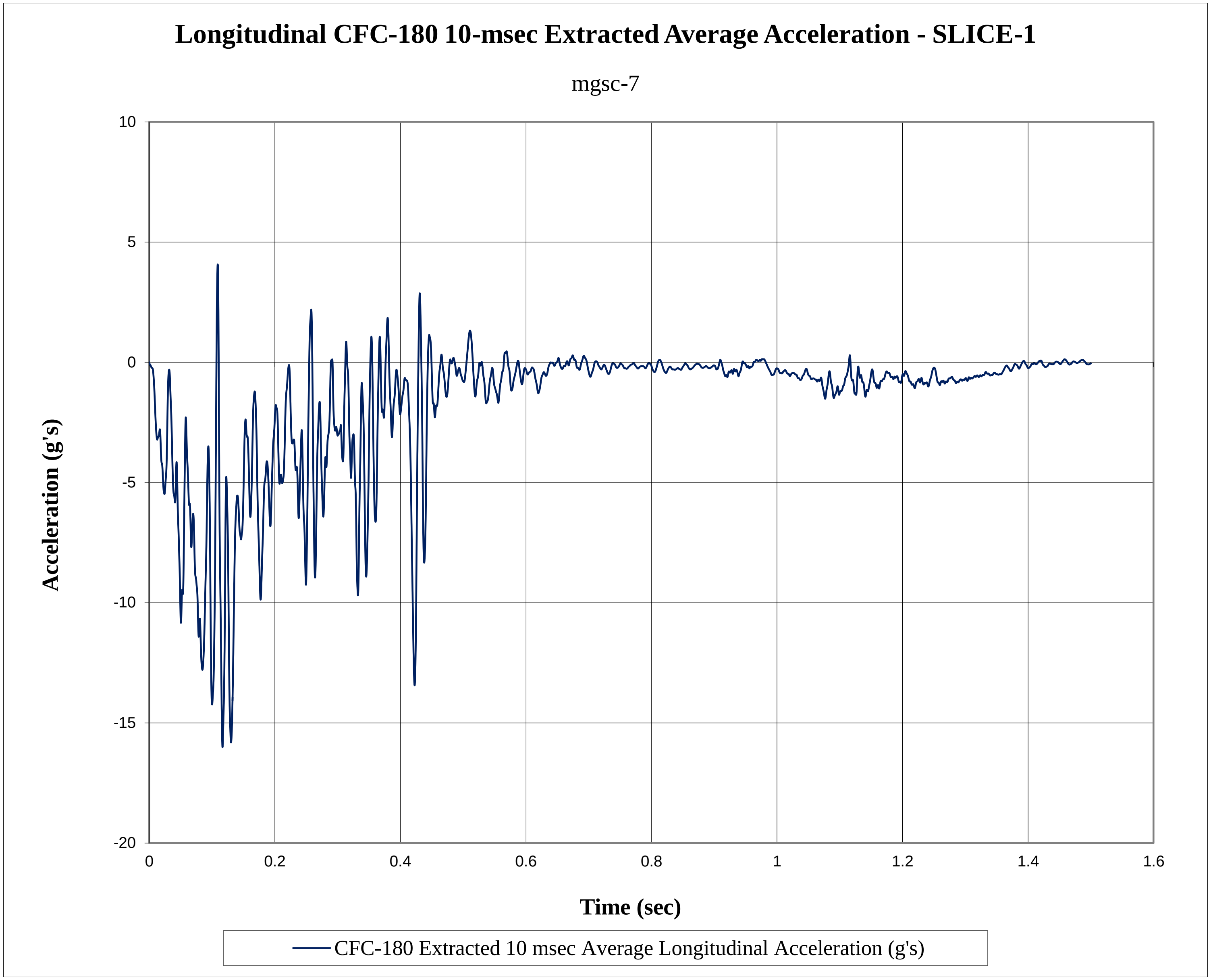


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSC-7

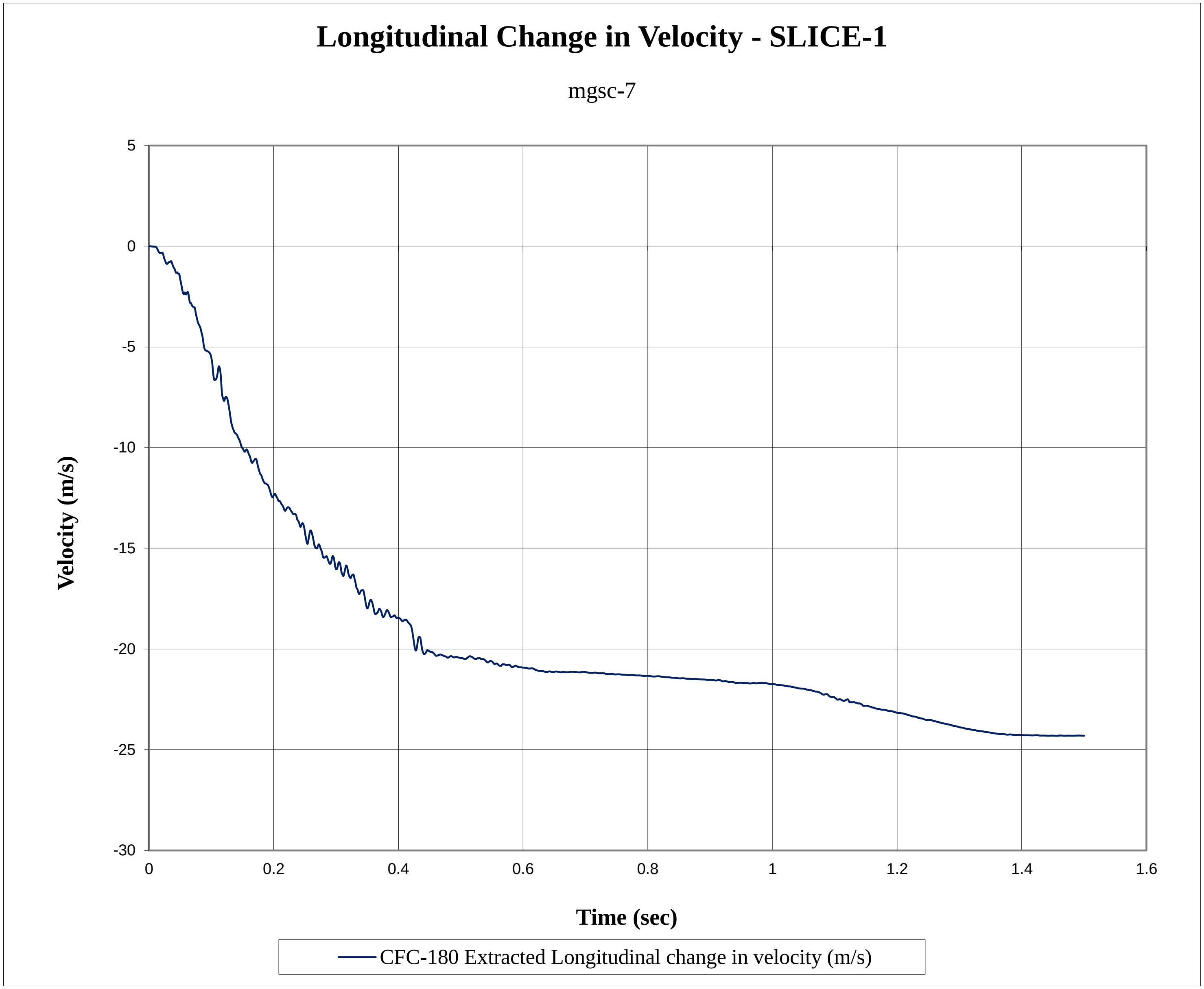


Figure E-2. Longitudinal Occupant Velocity (SLICE-1), Test No. MGSC-7

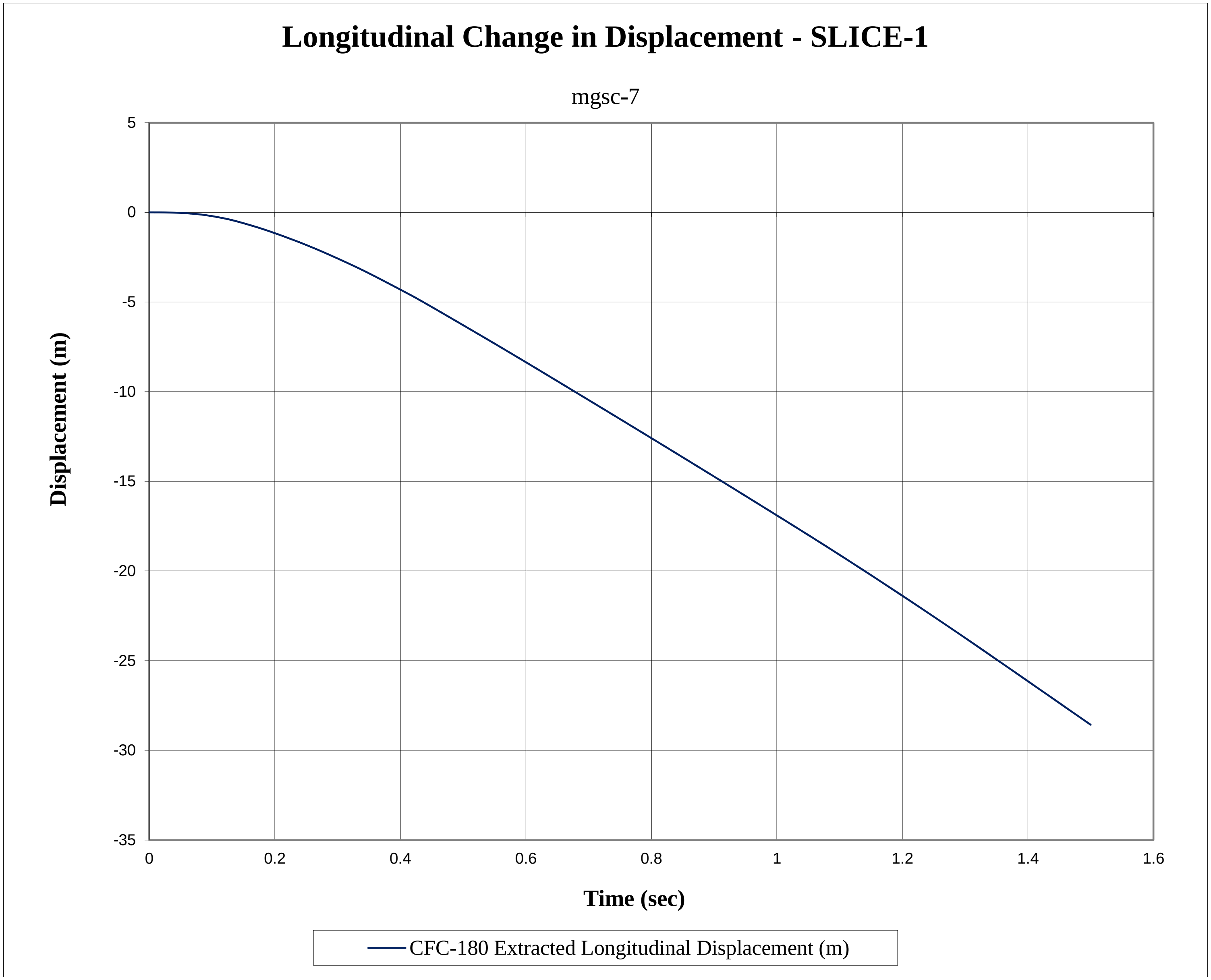


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSC-7

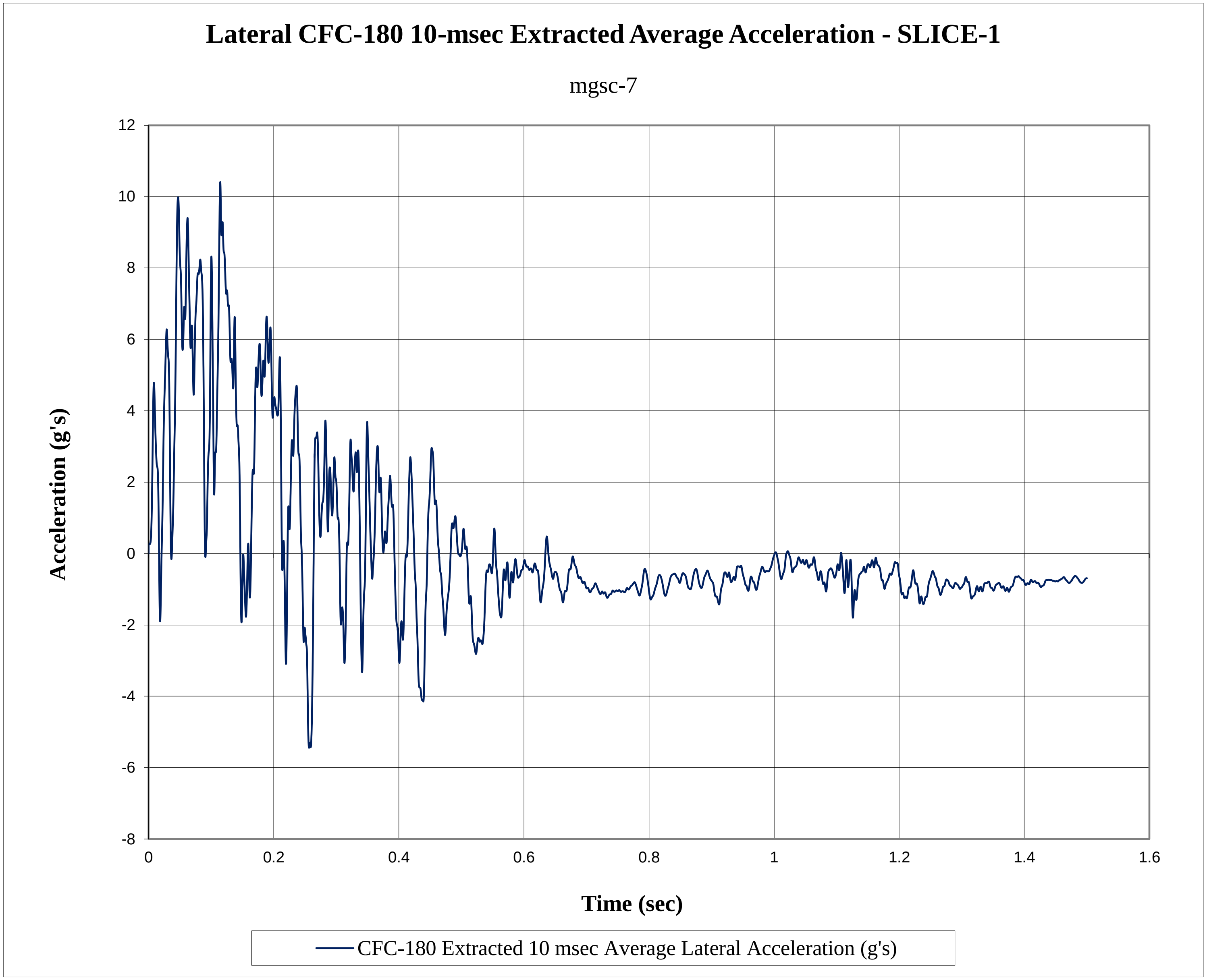


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSC-7

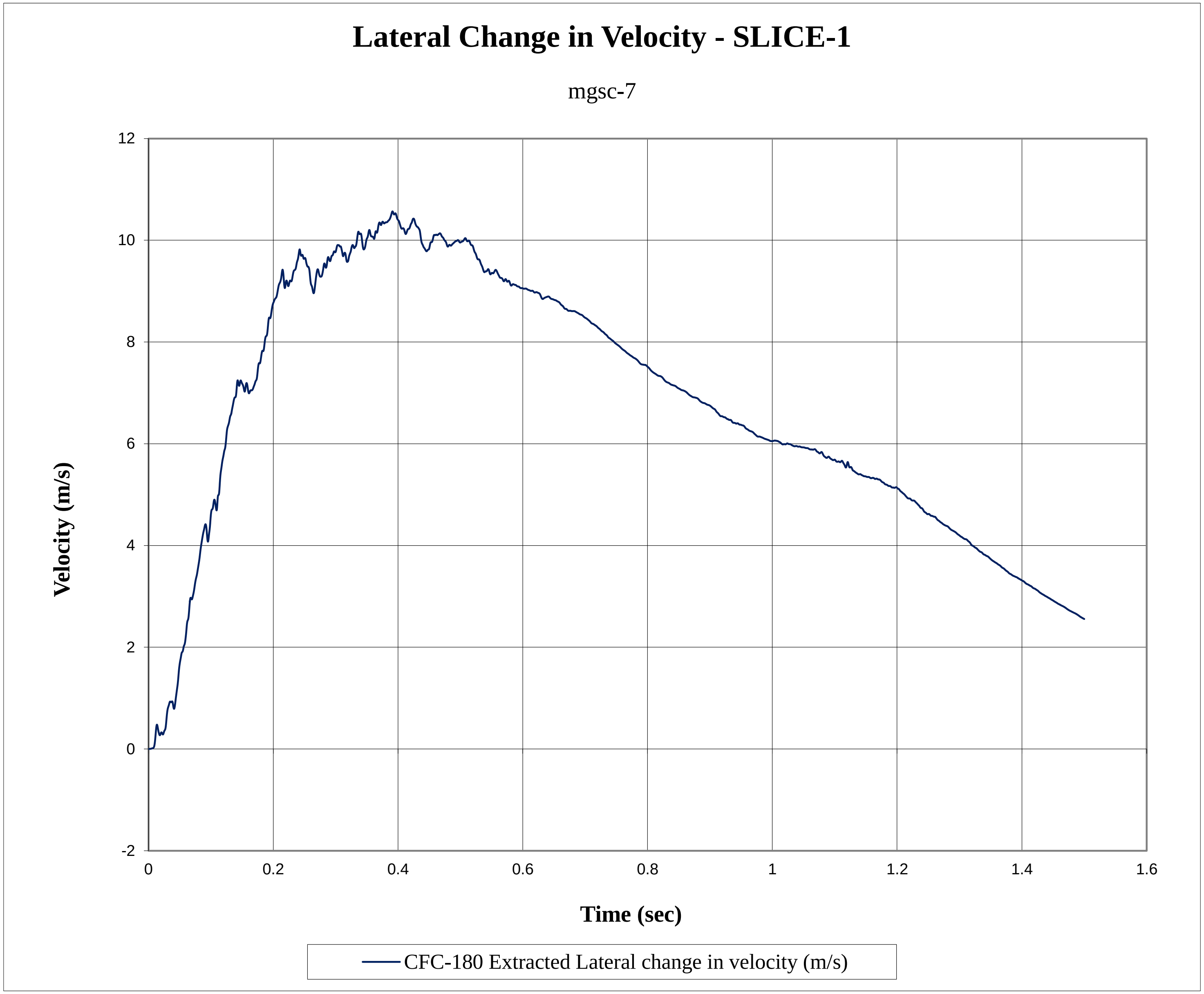


Figure E-5. Lateral Occupant Velocity (SLICE-1), Test No. MGSC-7

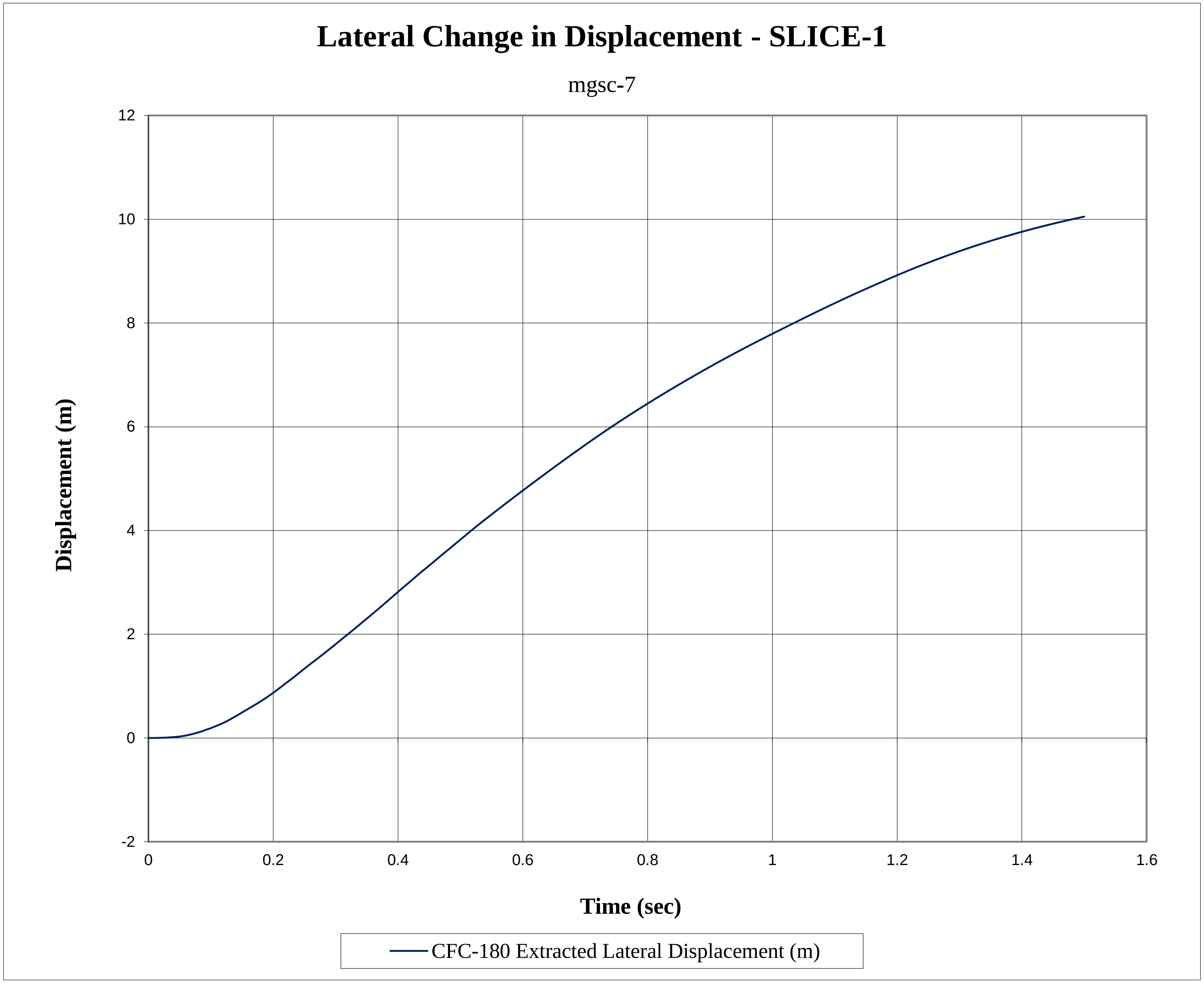


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. MGSC-7

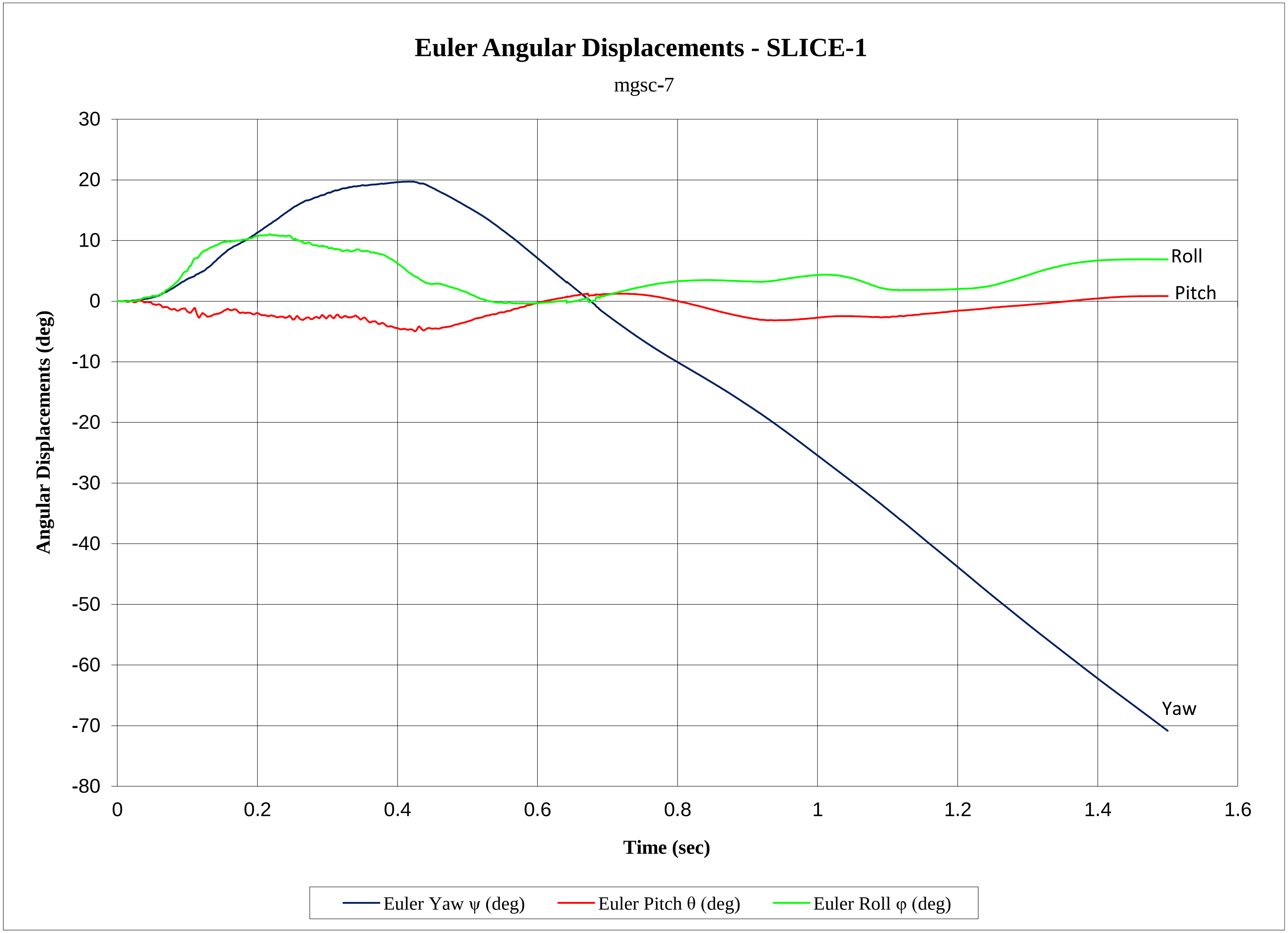


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. MGSC-7

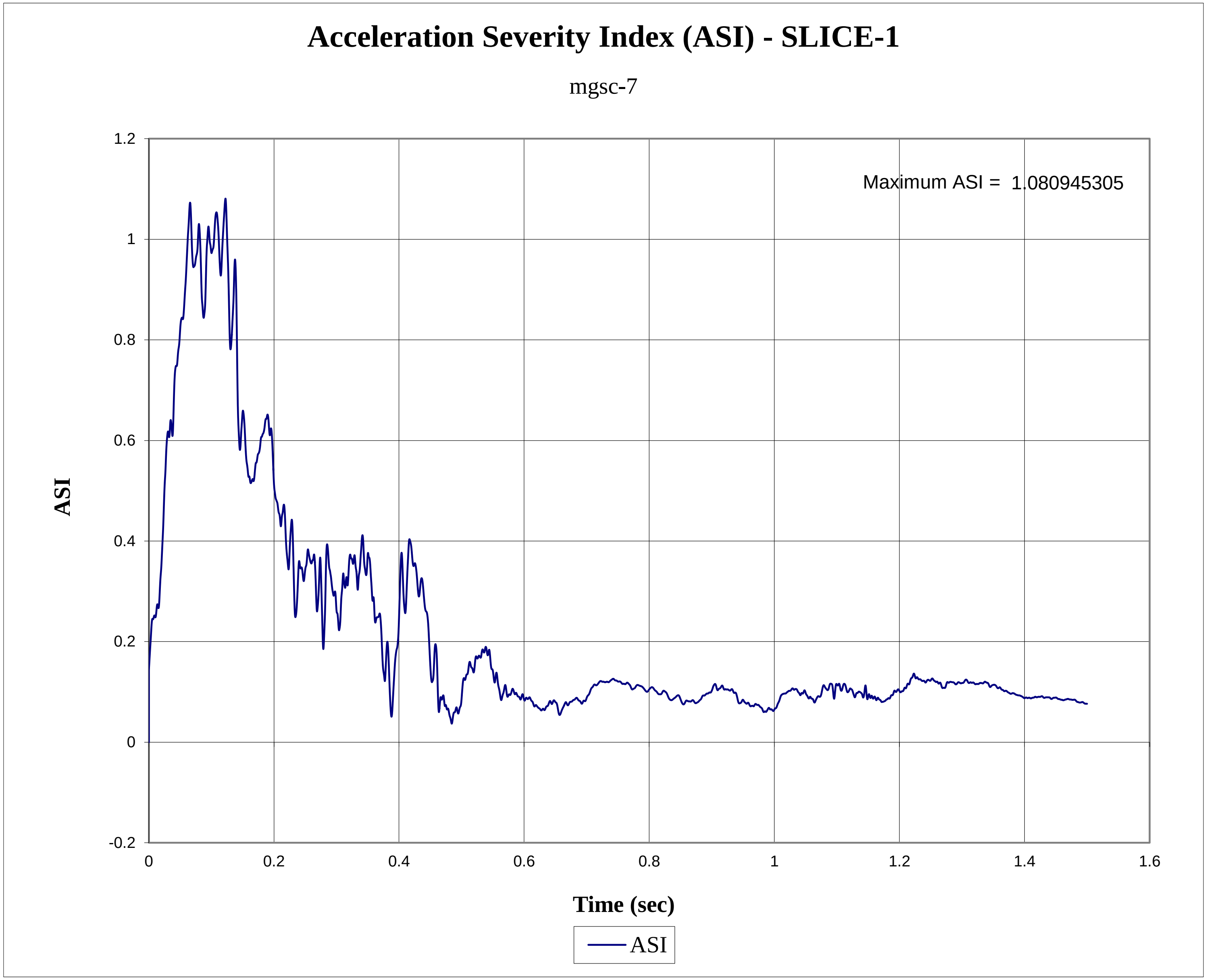


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. MGSC-7

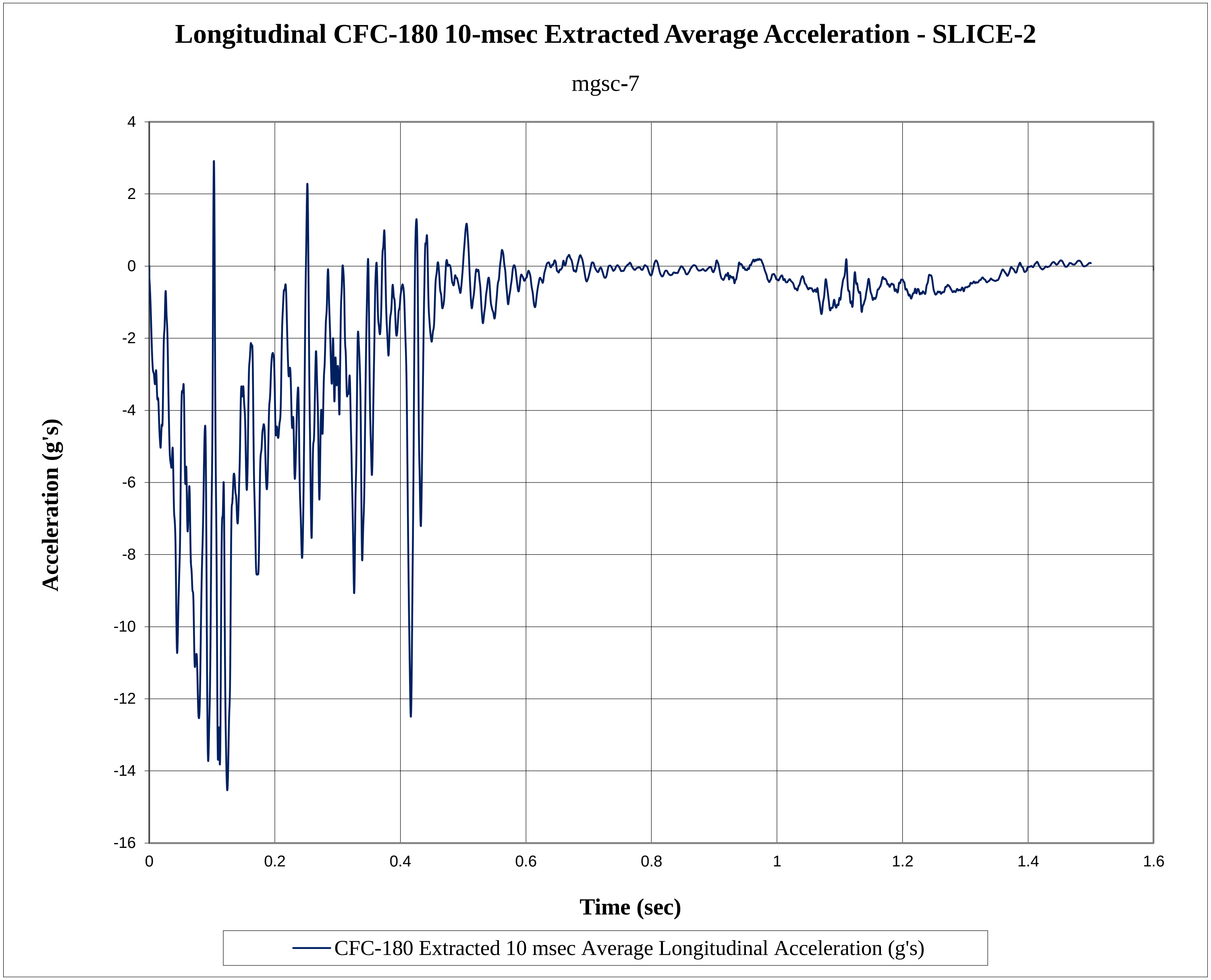


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSC-7

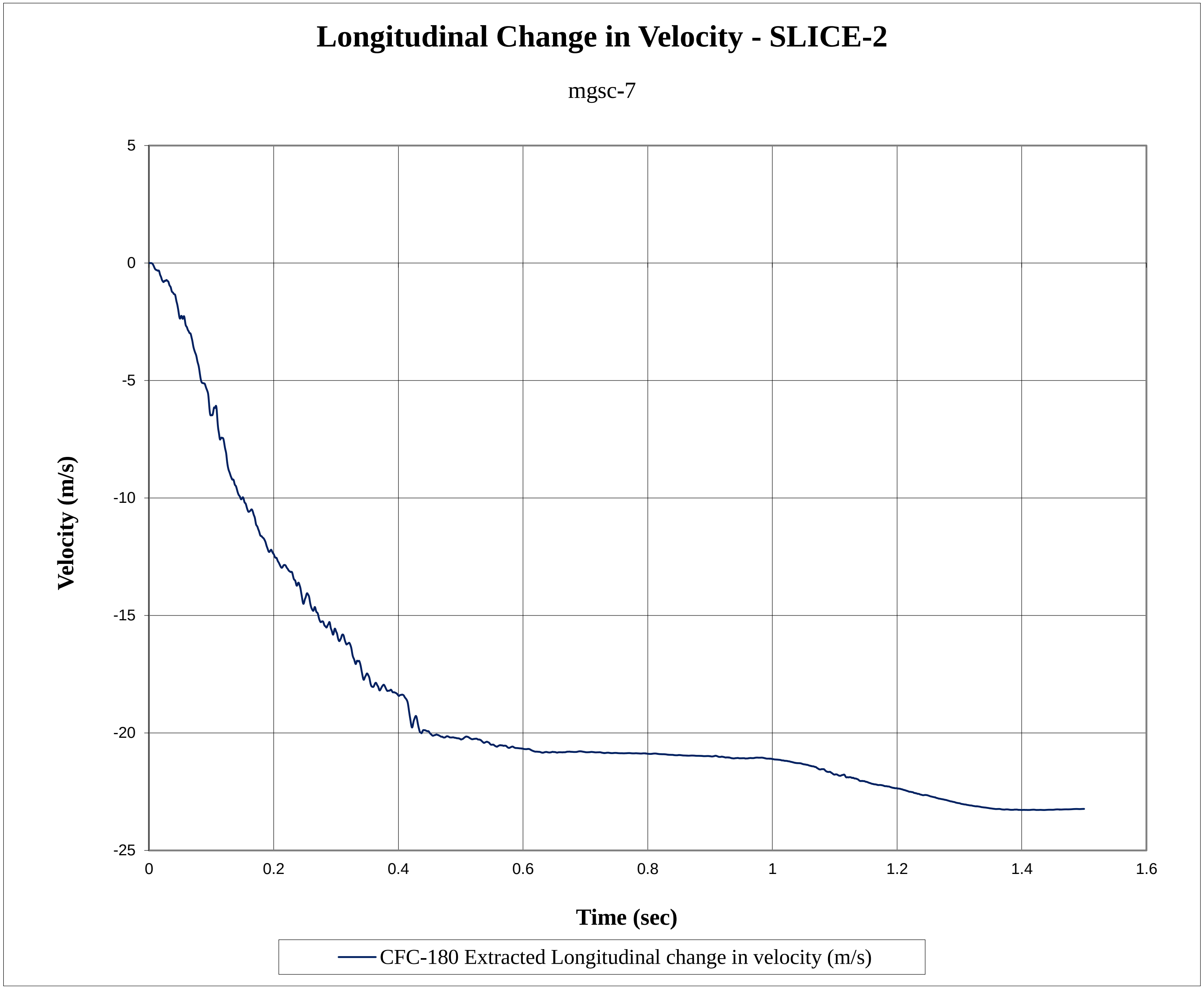


Figure E-10. Longitudinal Occupant Velocity (SLICE-2), Test No. MGSC-7

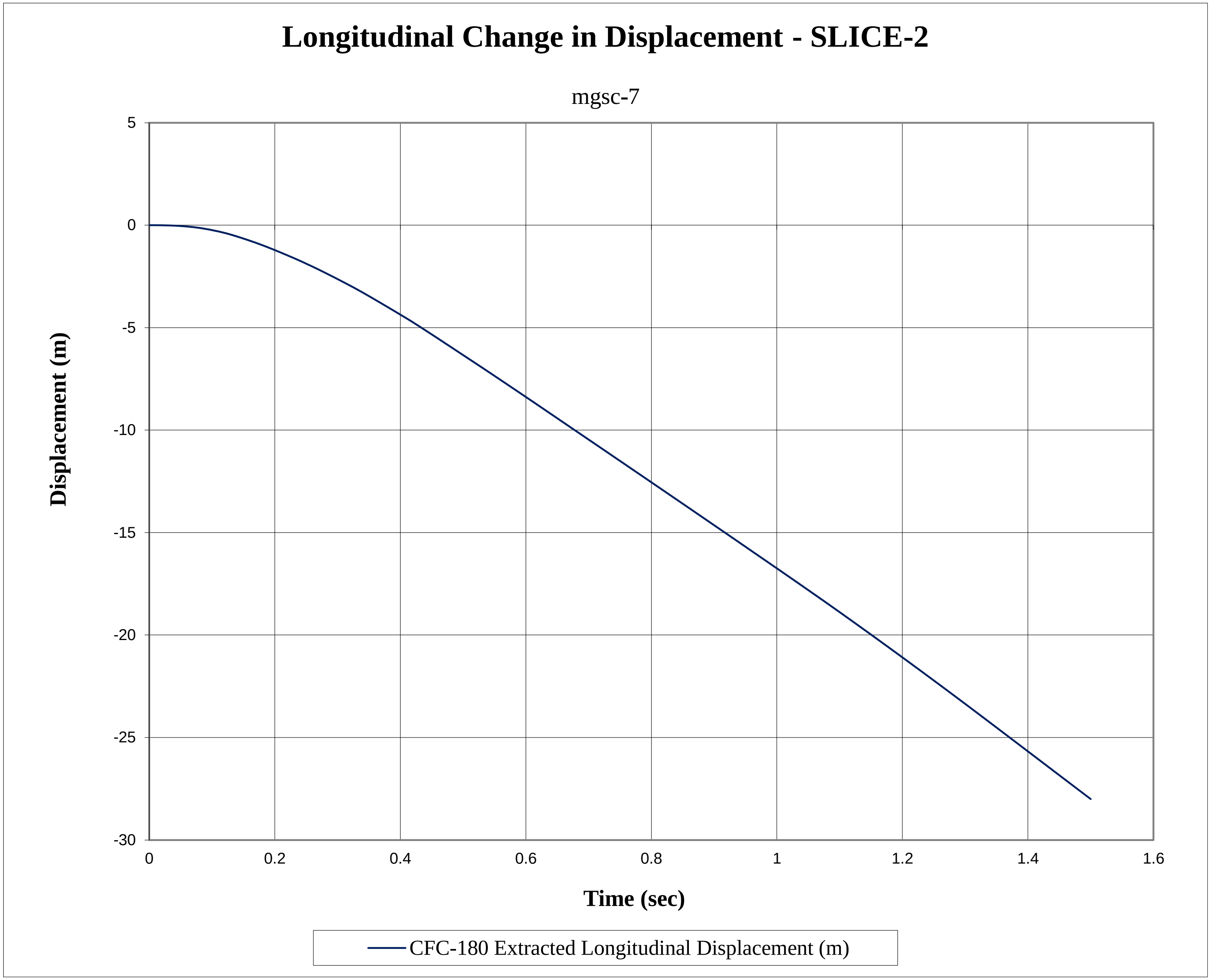


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSC-7

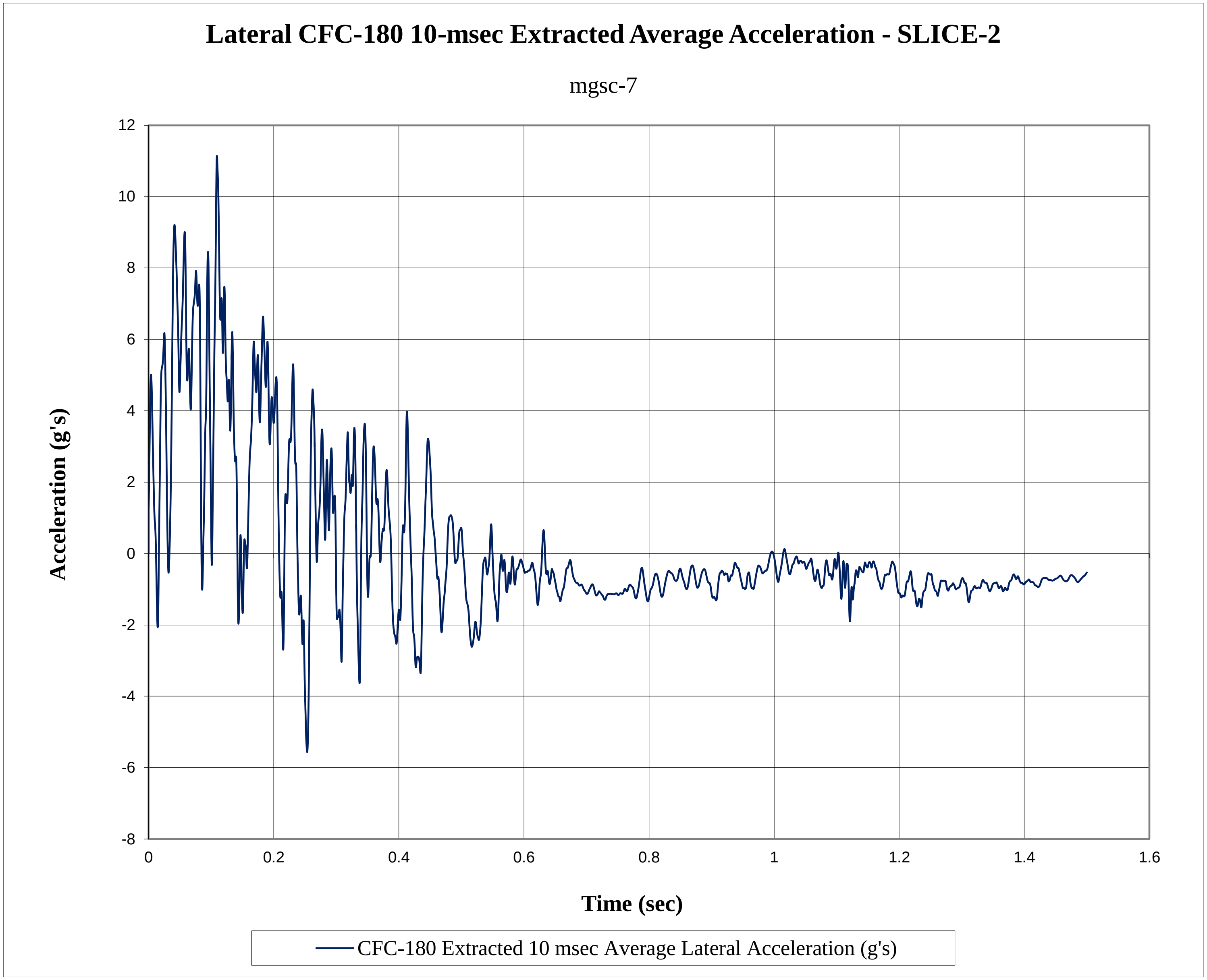


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSC-7

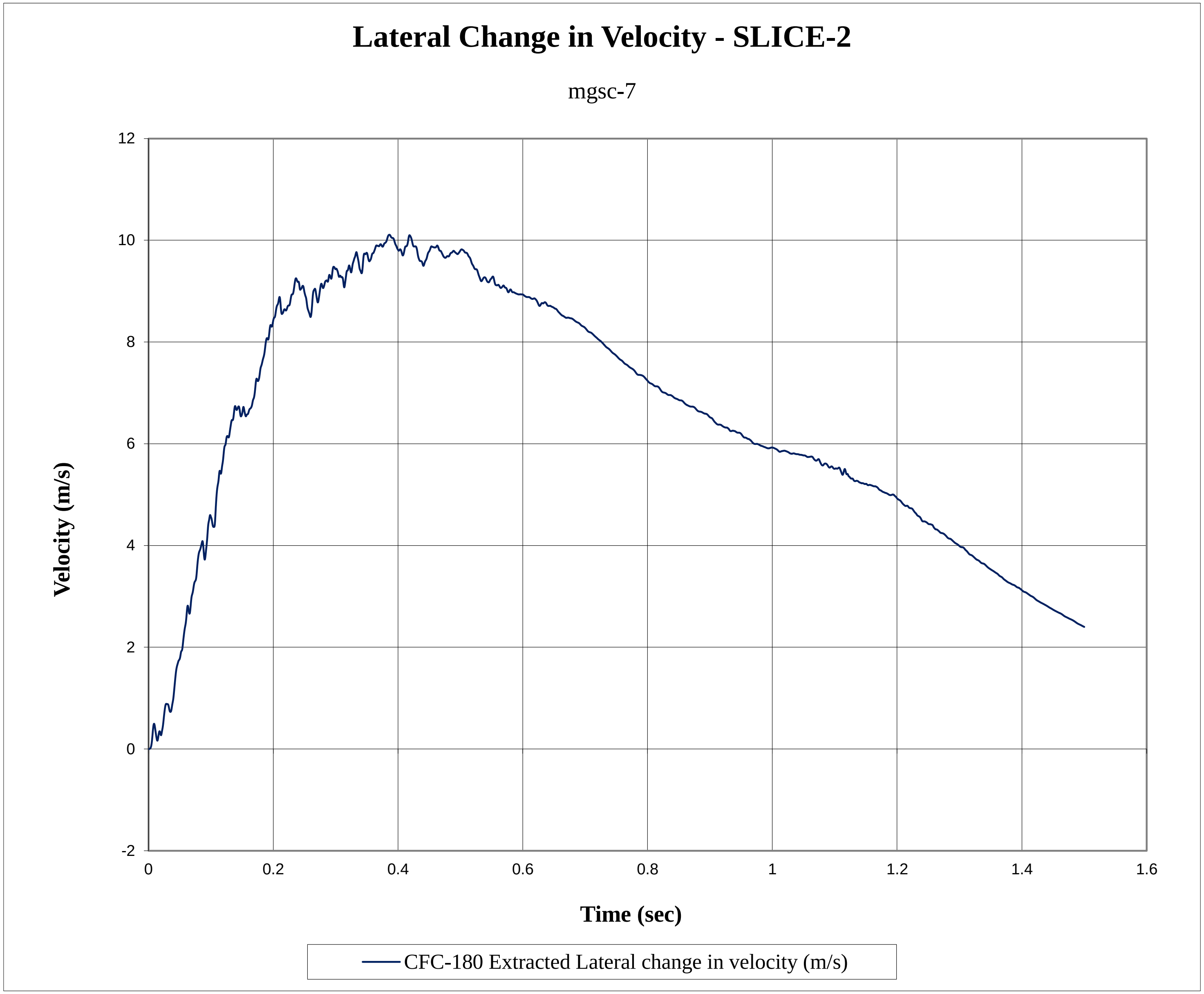


Figure E-13. Lateral Occupant Velocity (SLICE-2), Test No. MGSC-7

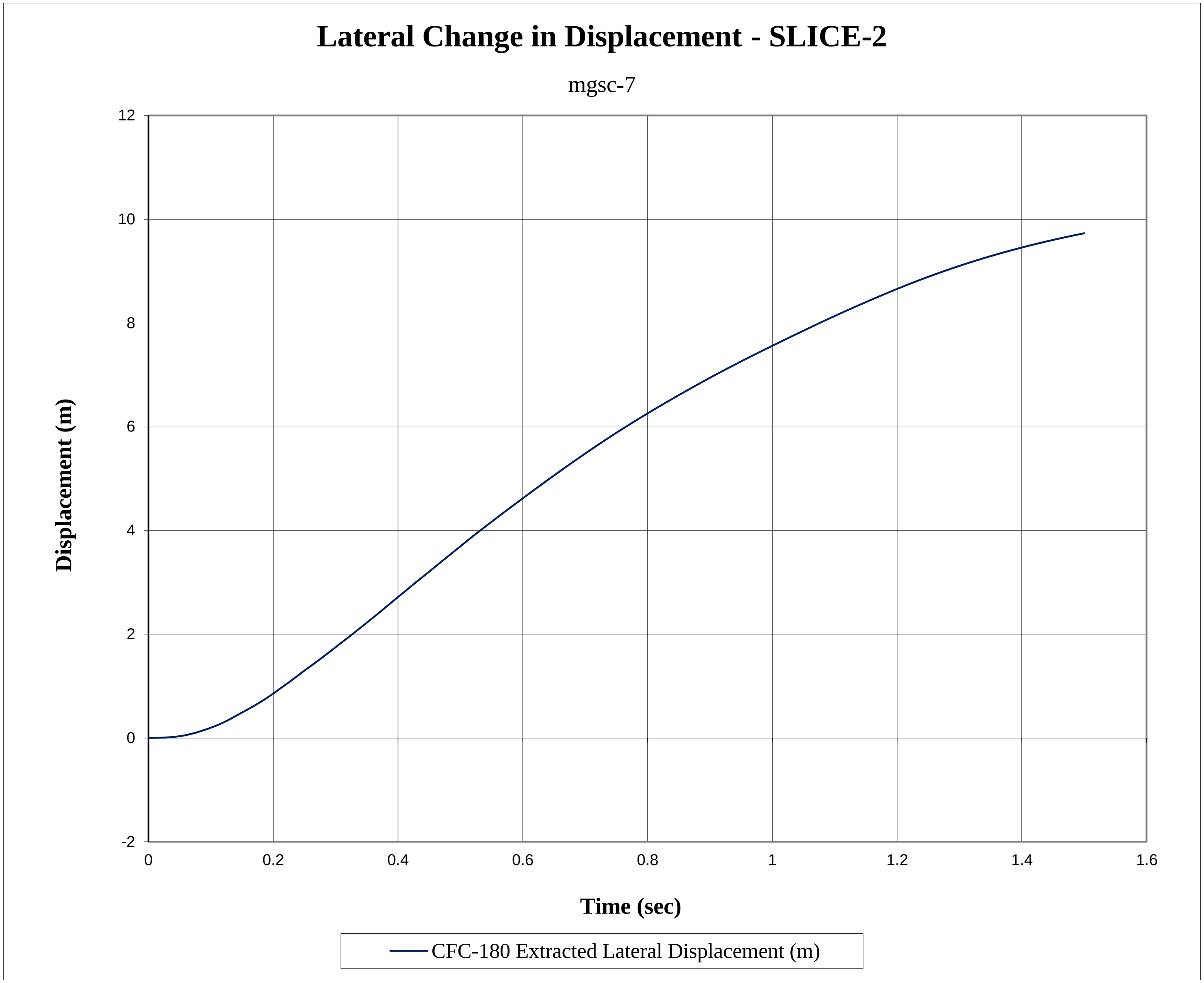


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. MGSC-7

Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. MGSC-7

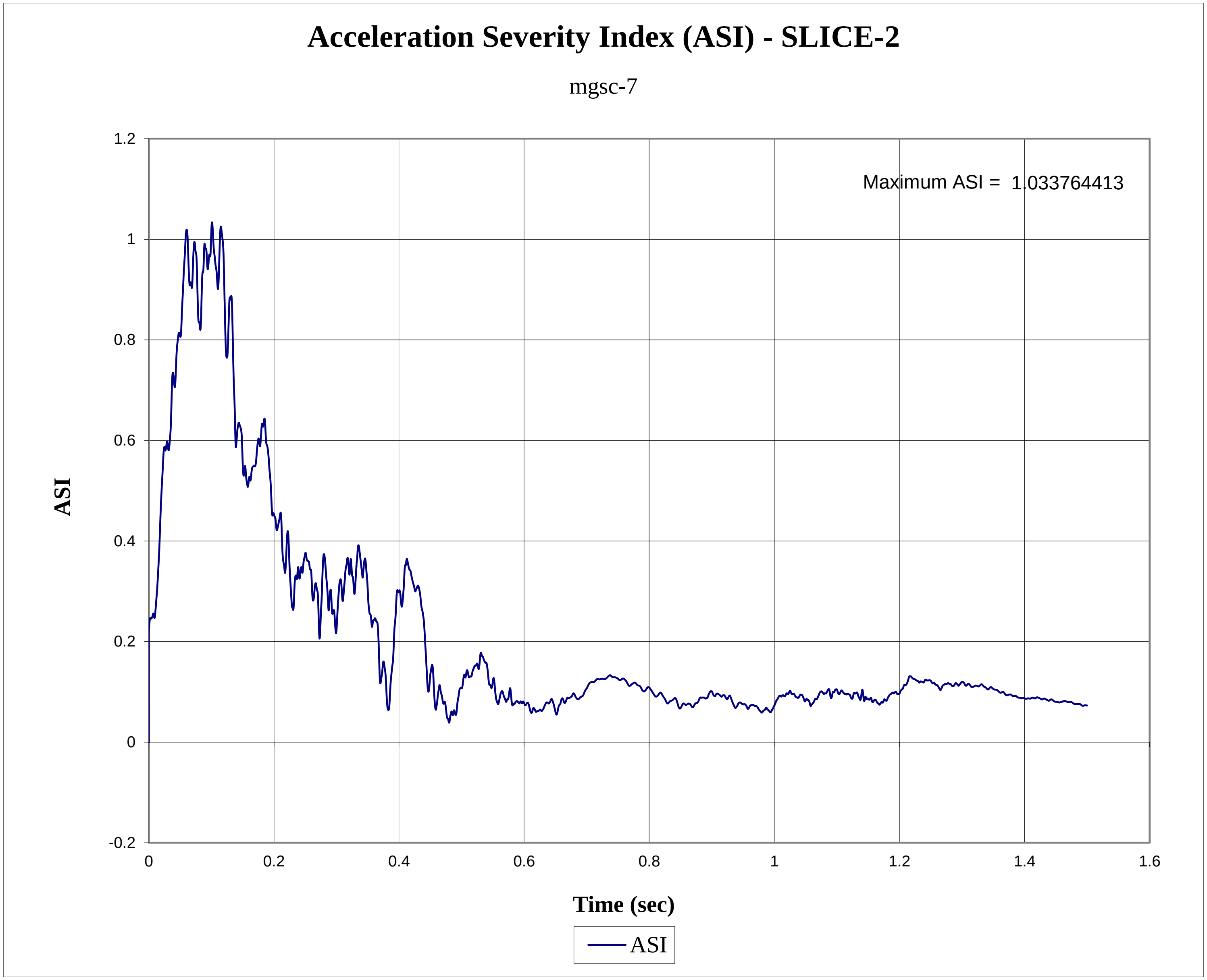


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. MGSC-7

Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. MGSC-8

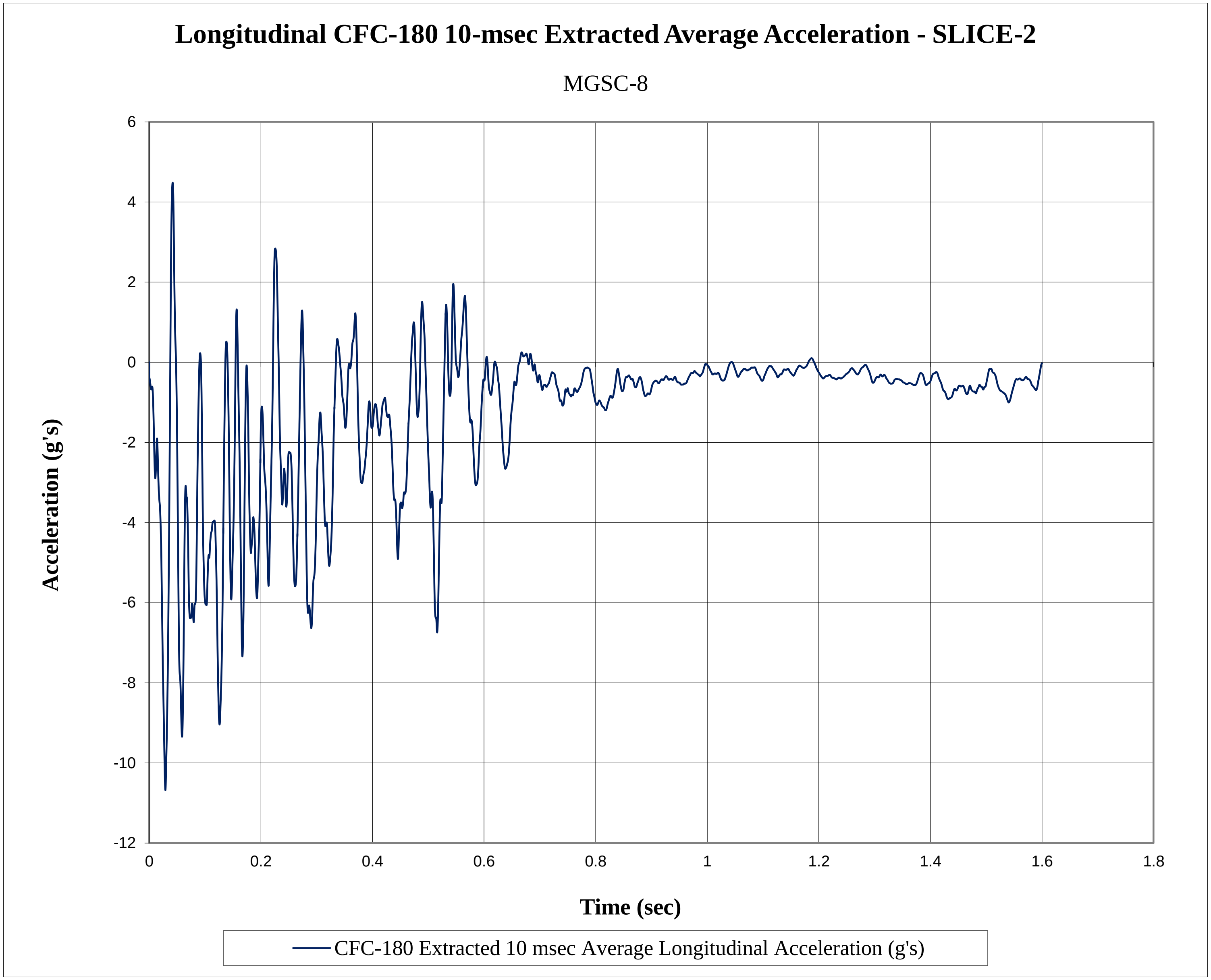


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSC-8

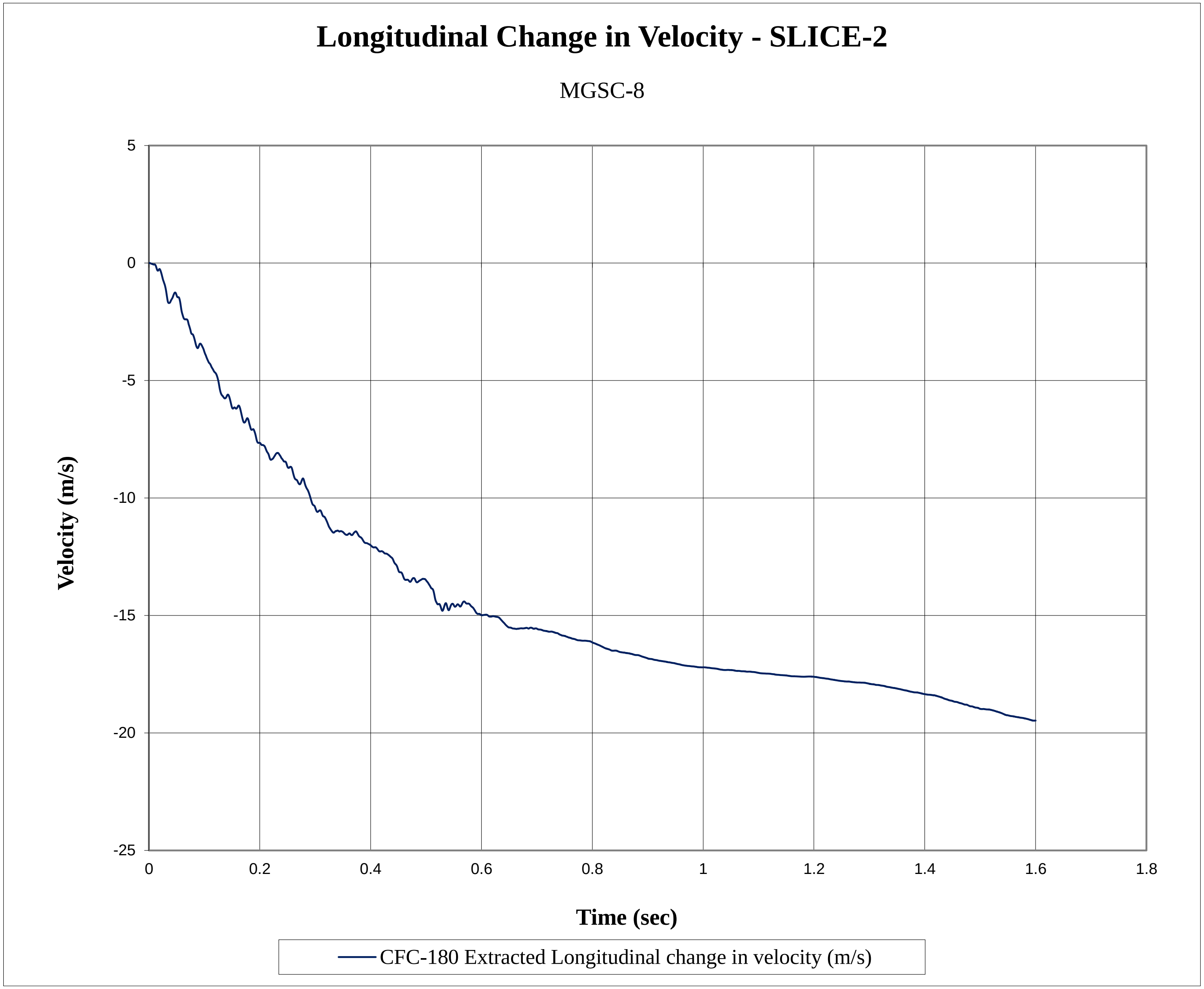


Figure F-2. Longitudinal Occupant Velocity (SLICE-2), Test No. MGSC-8

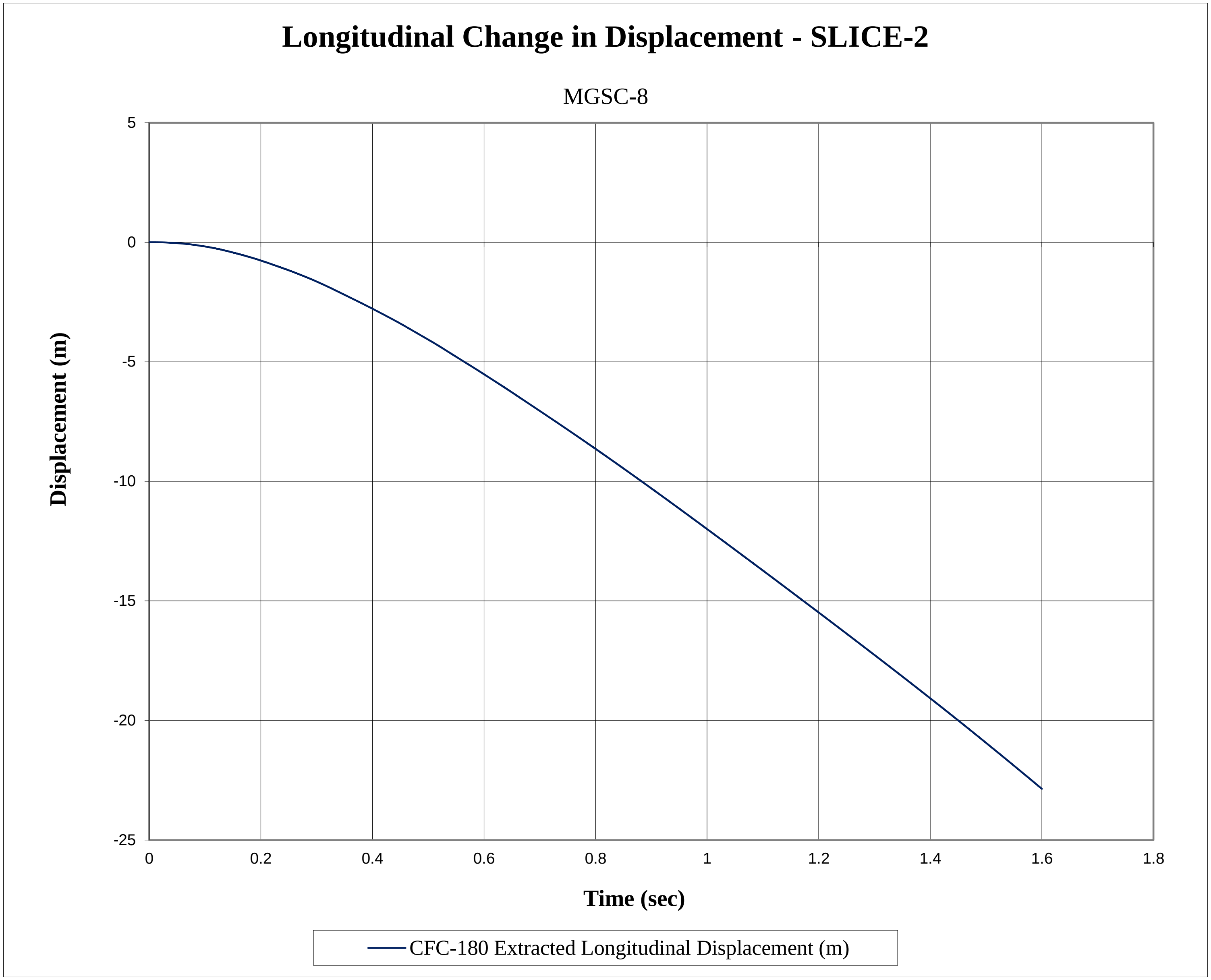


Figure F-3. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSC-8

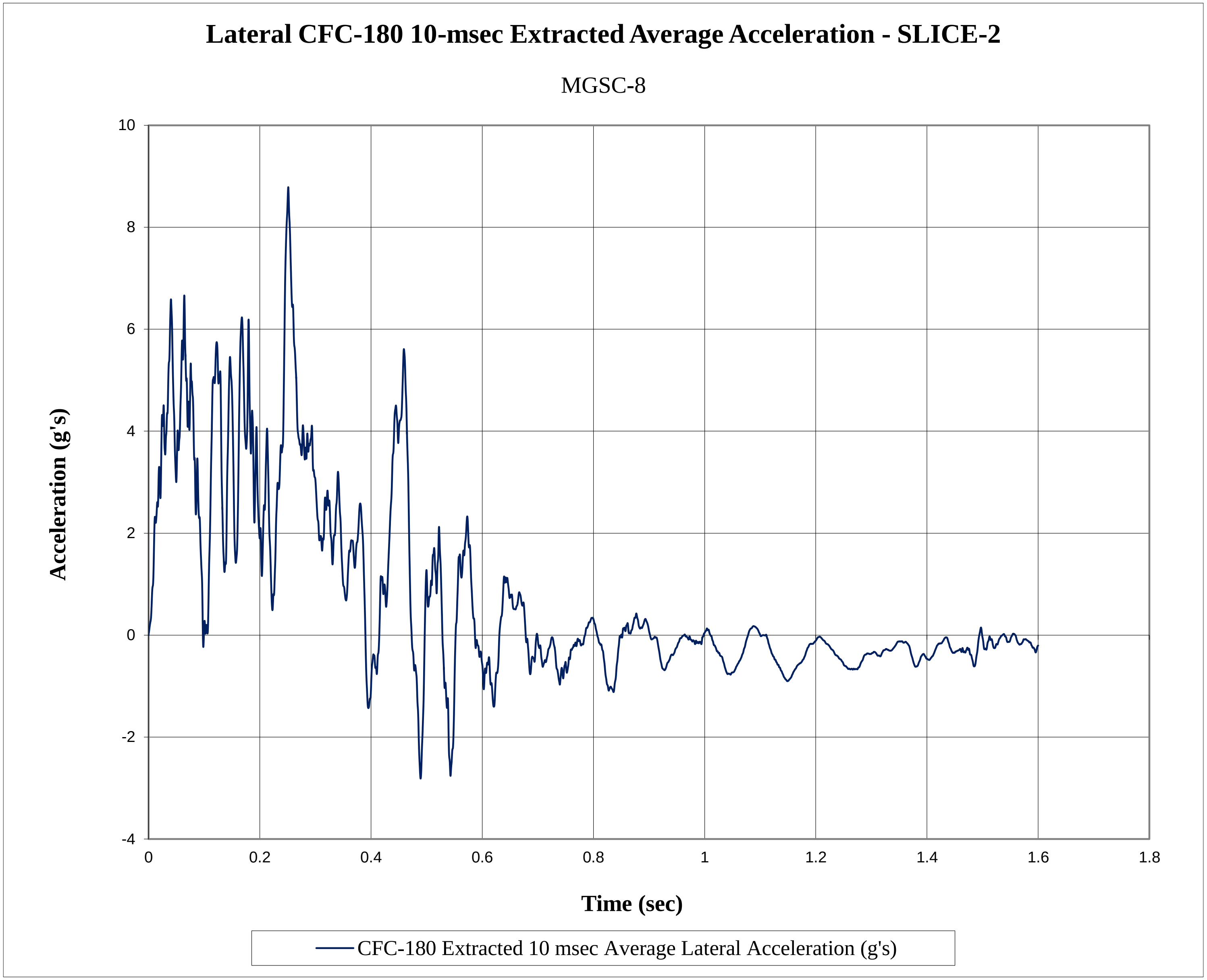


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSC-8

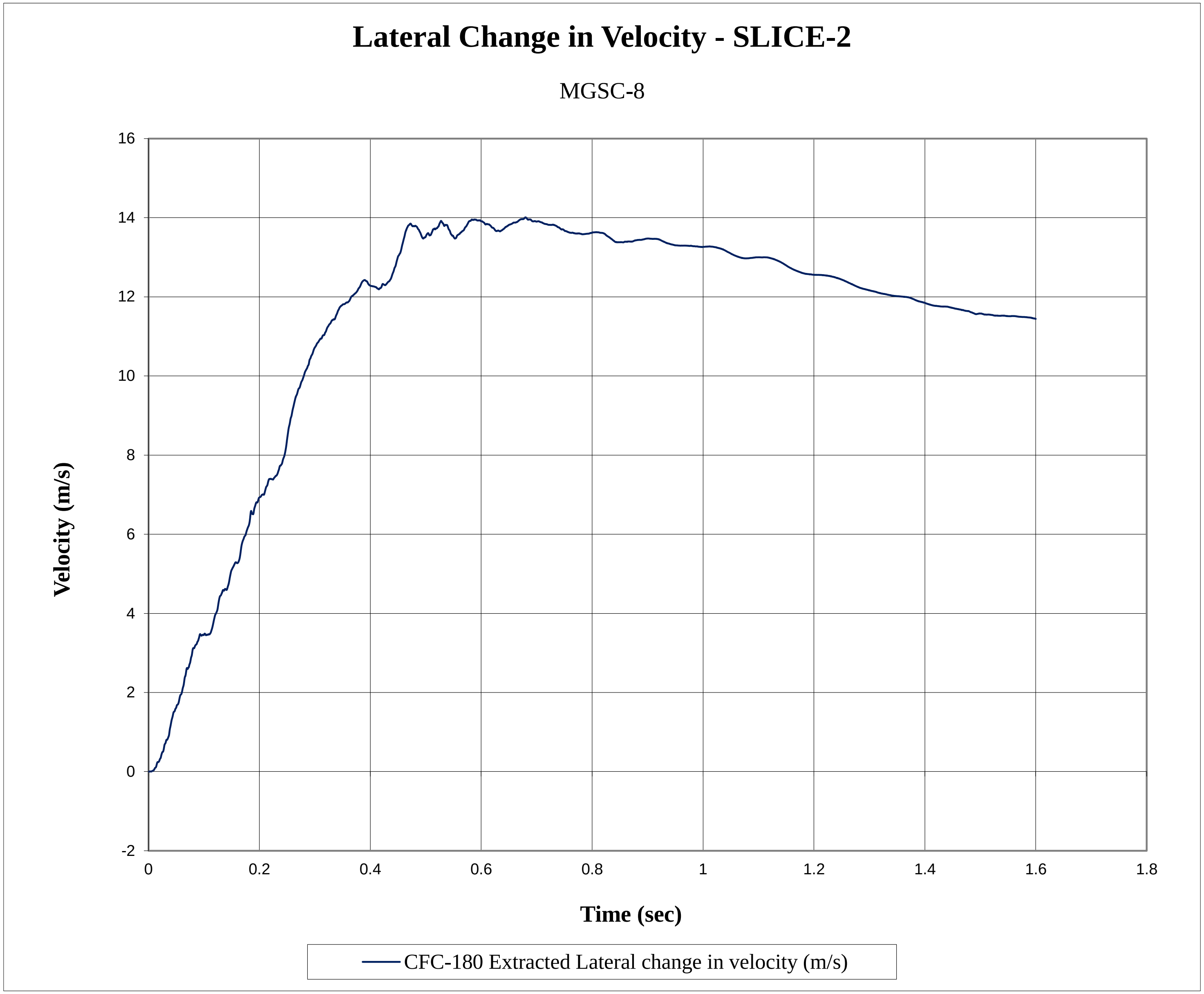


Figure F-5. Lateral Occupant Velocity (SLICE-2), Test No. MGSC-8

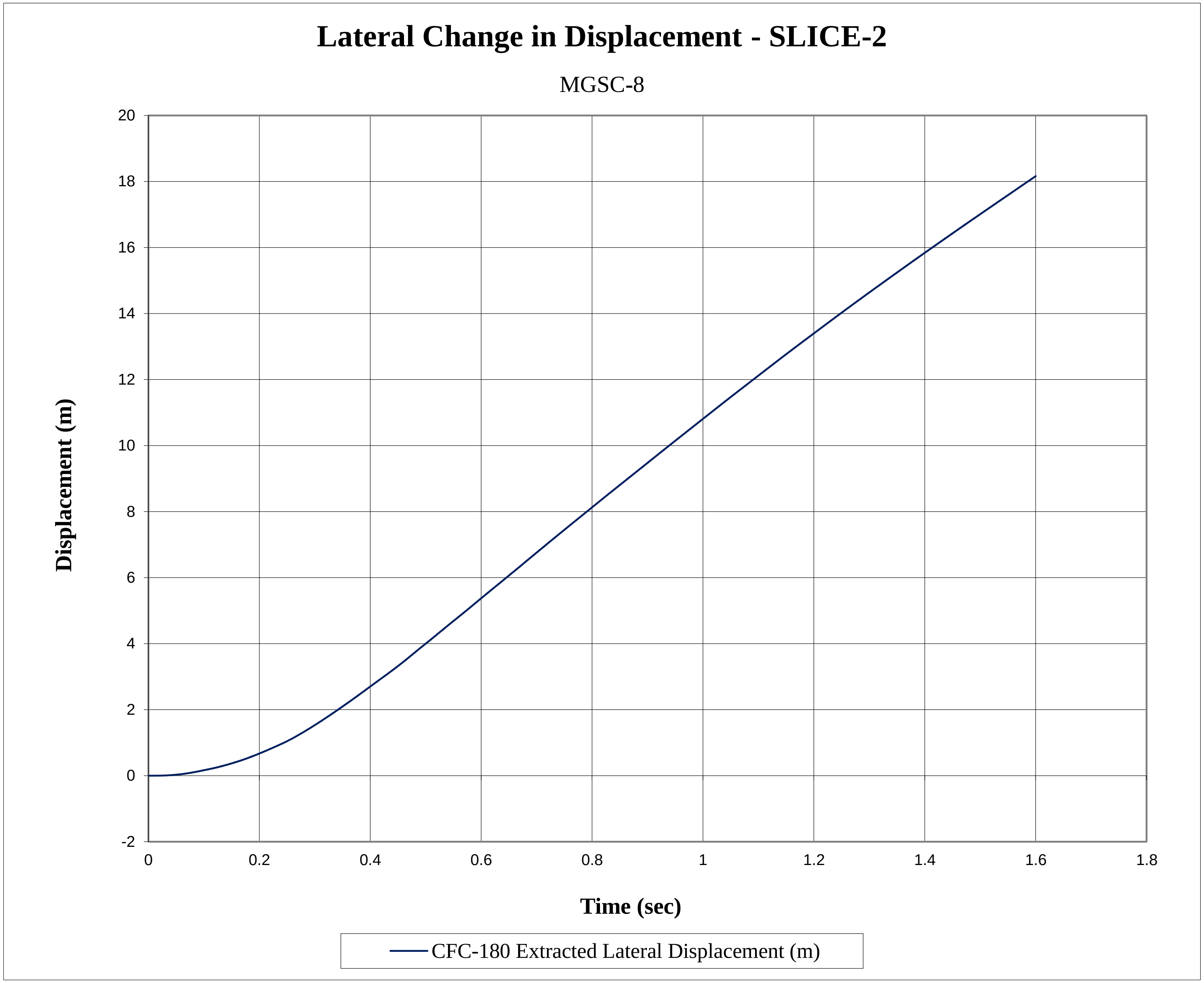


Figure F-6. Lateral Occupant Displacement (SLICE-2), Test No. MGSC-8

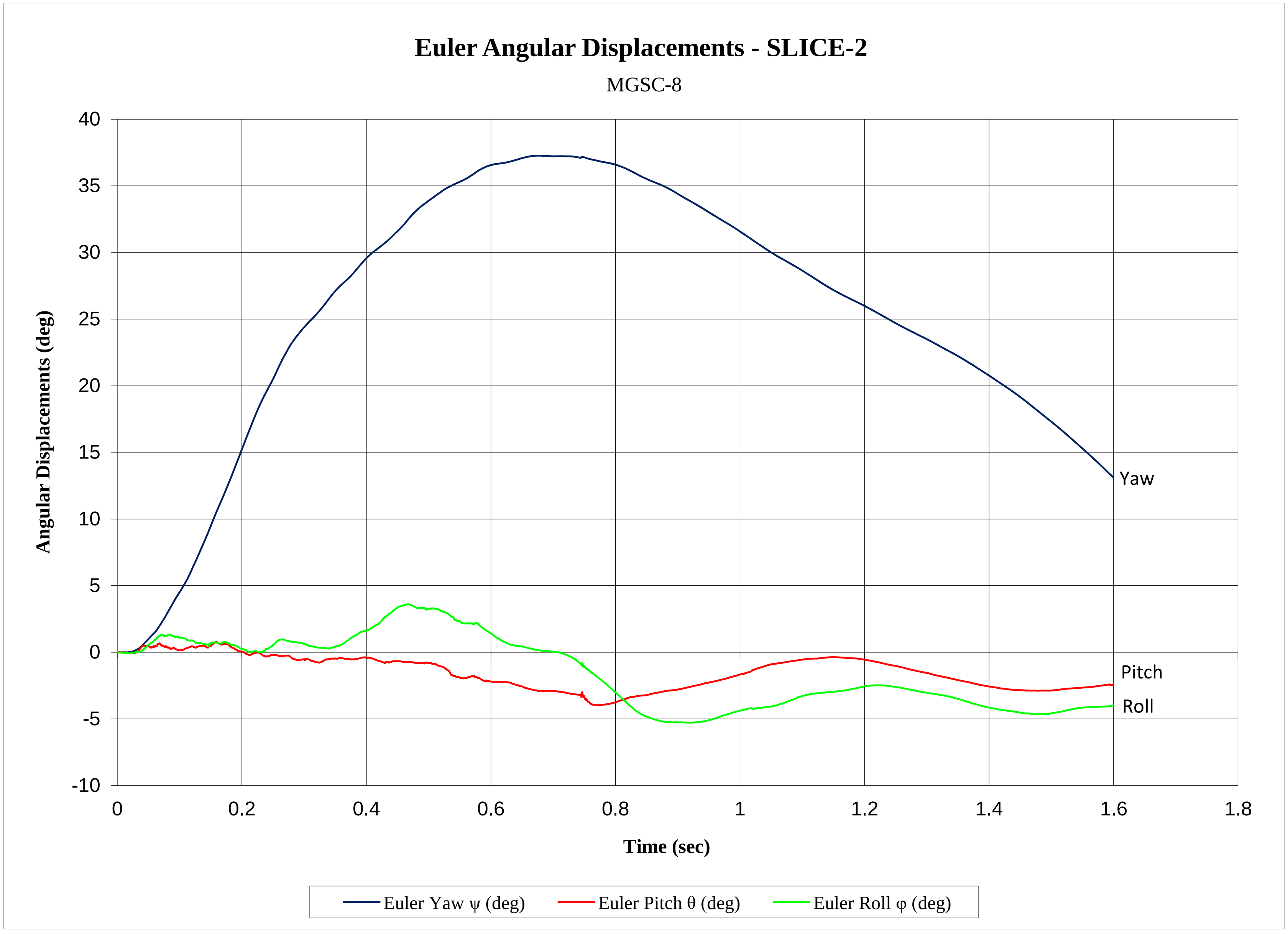


Figure F-7. Vehicle Angular Displacements (SLICE-2), Test No. MGSC-8

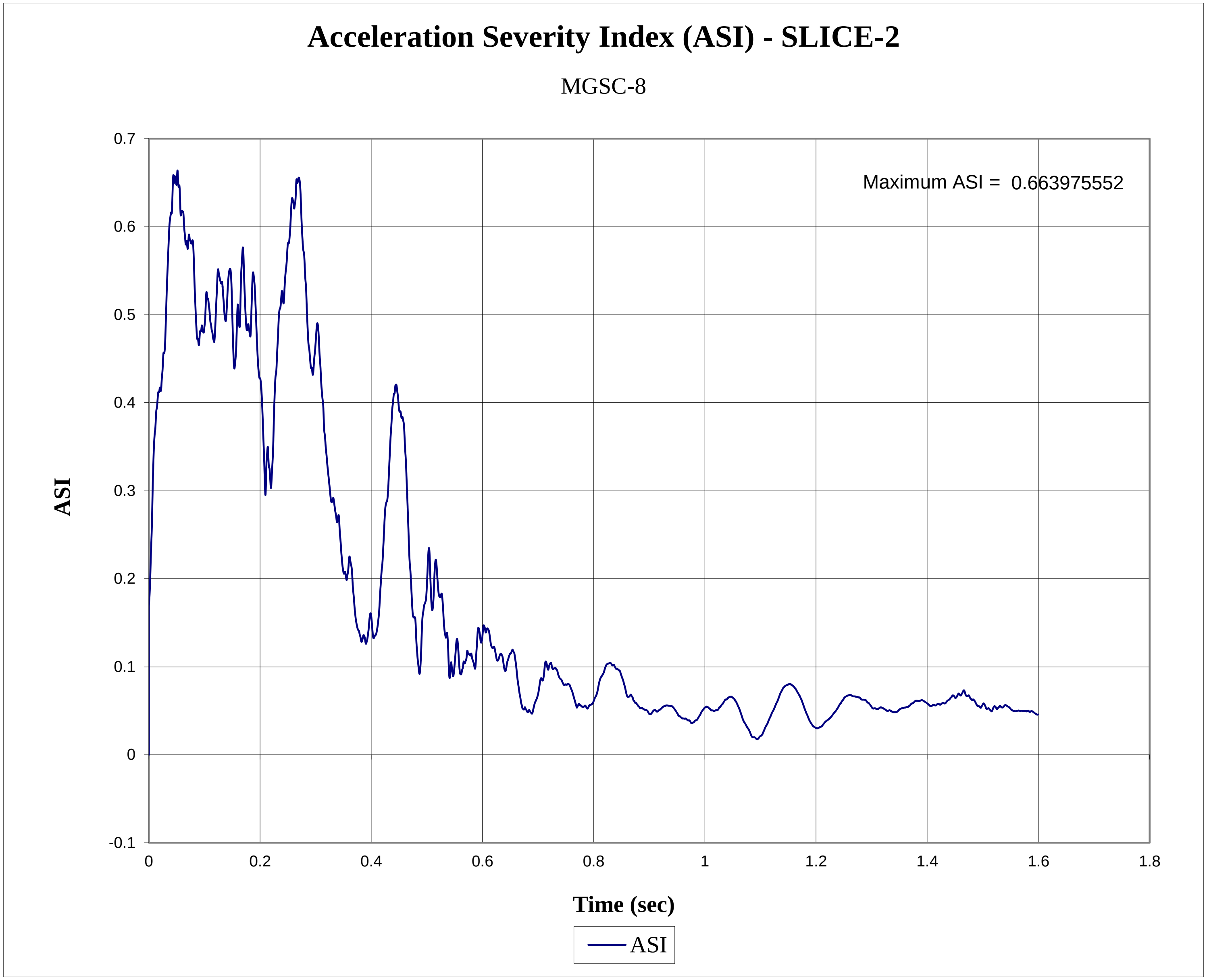


Figure F-8. Acceleration Severity Index (SLICE-2), Test No. MGSC-8

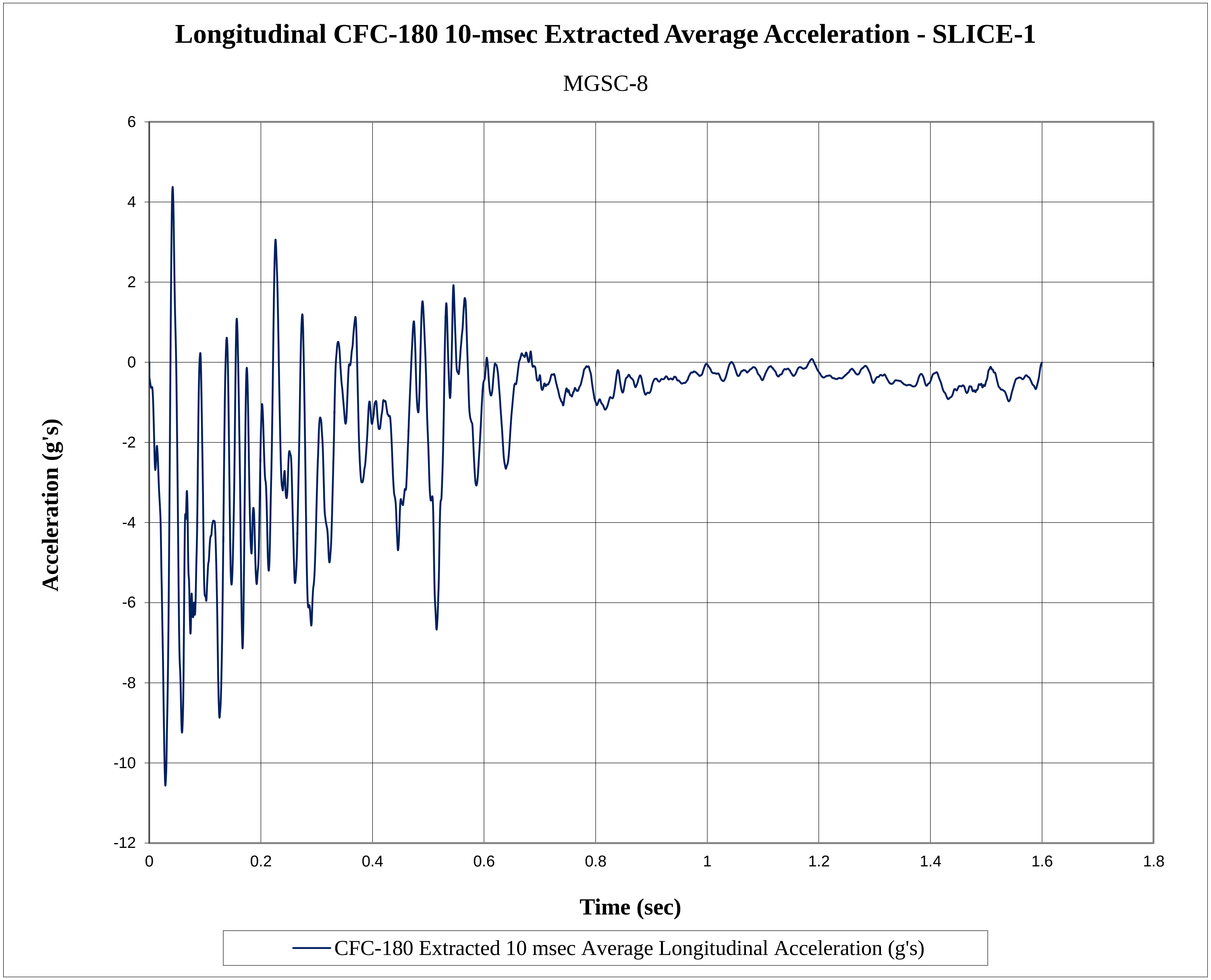


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSC-8

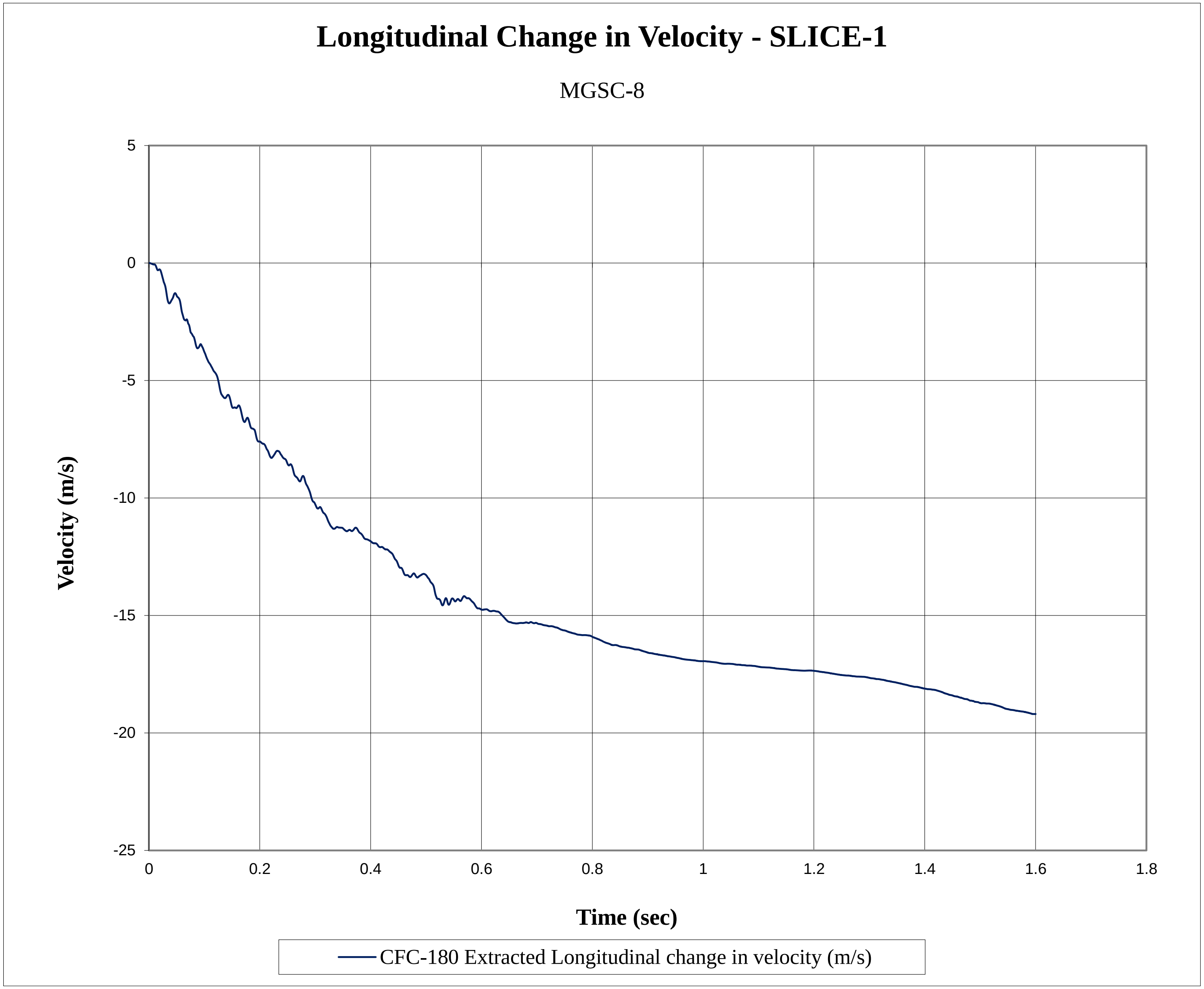


Figure F-10. Longitudinal Occupant Velocity (SLICE-1), Test No. MGSC-8

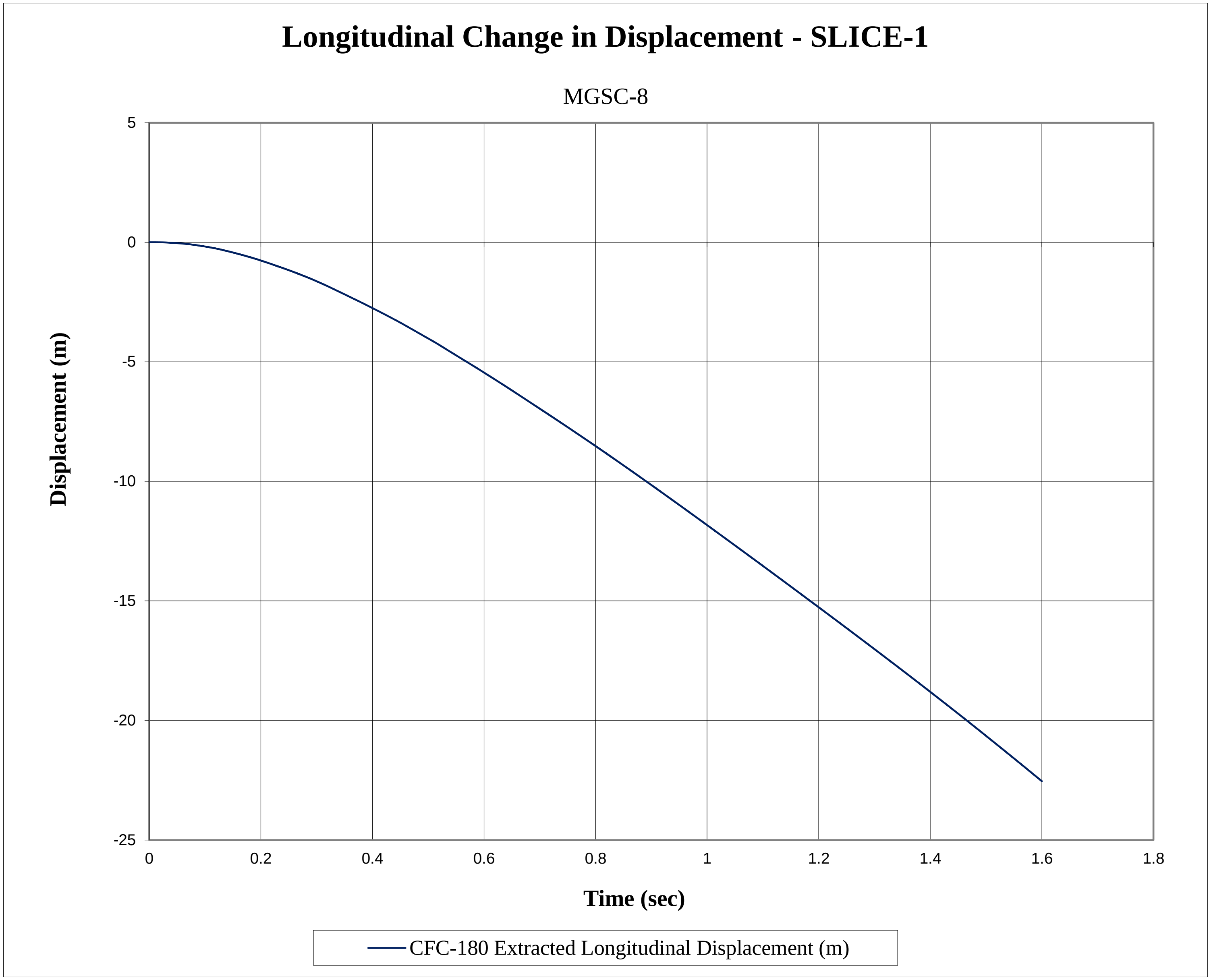


Figure F-11. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSC-8

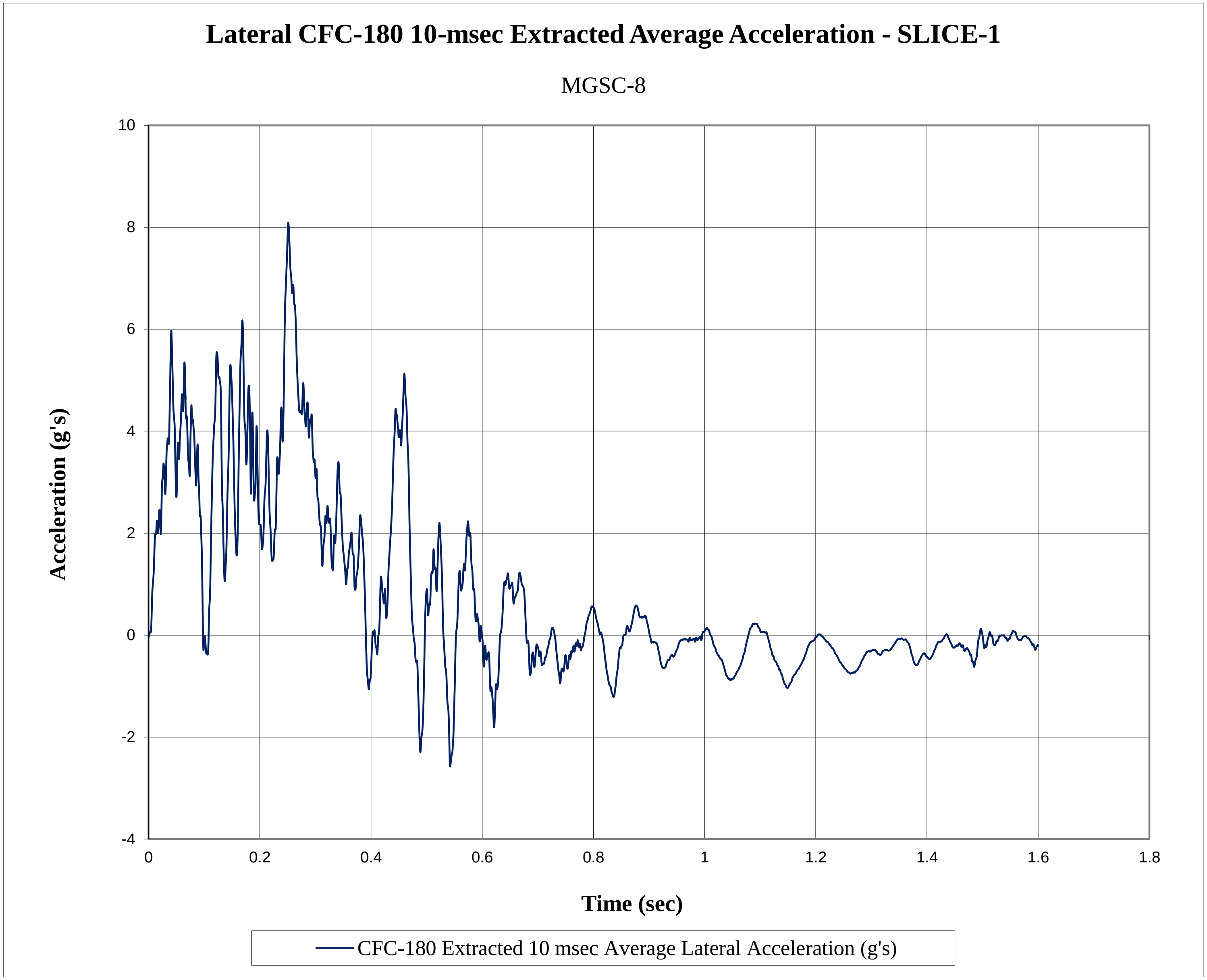


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSC-8

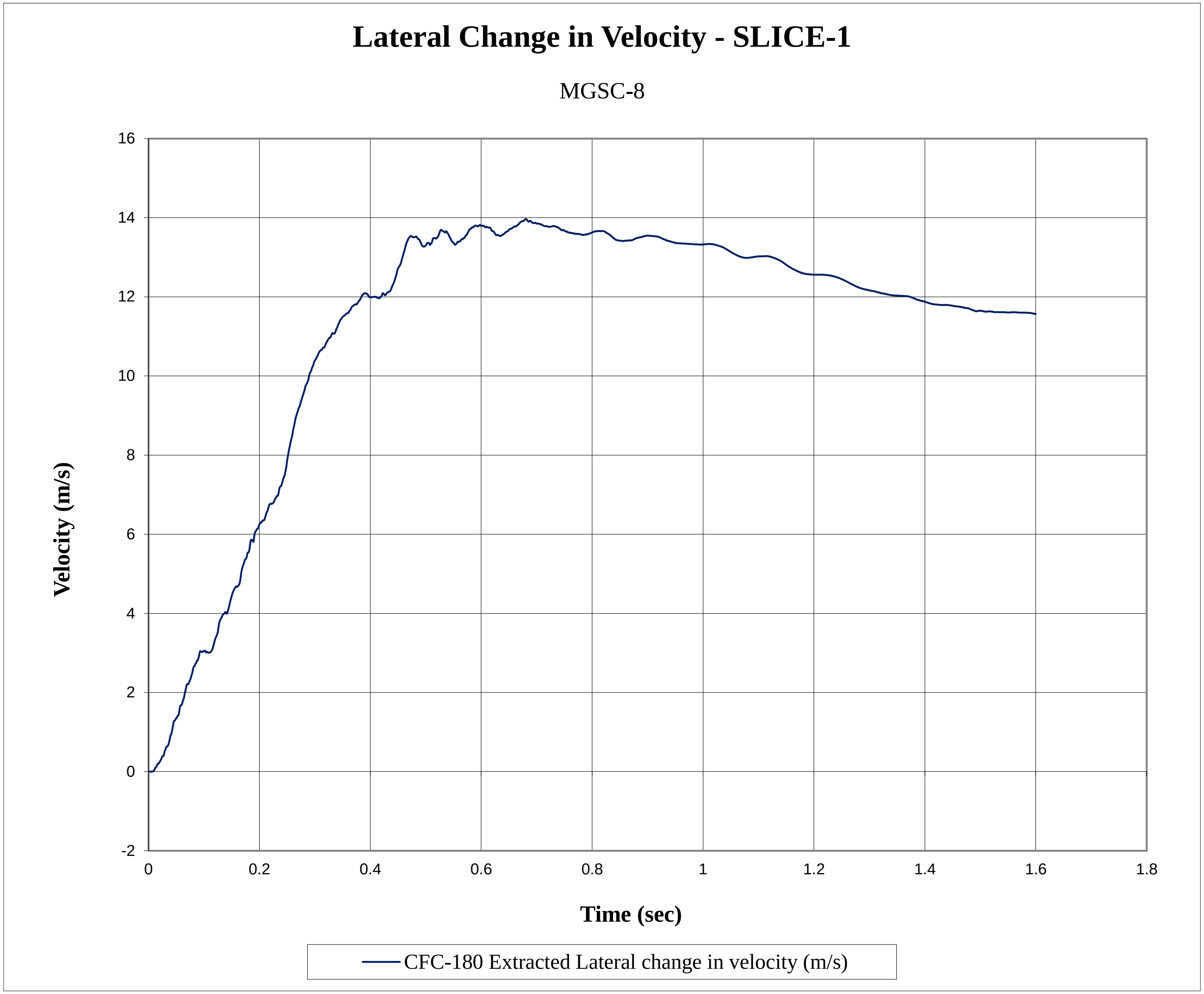


Figure F-13. Lateral Occupant Velocity (SLICE-1), Test No. MGSC-8

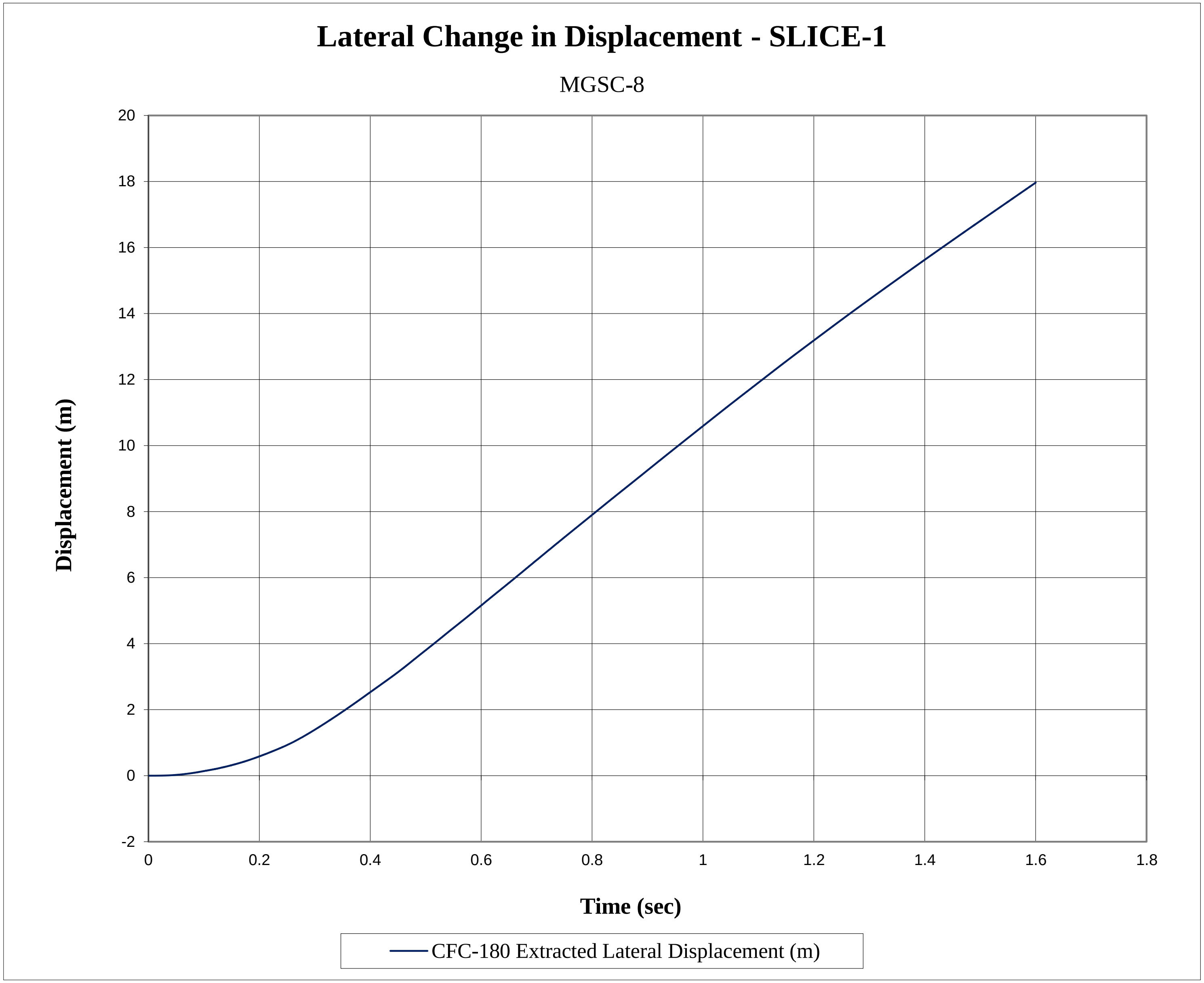


Figure F-14. Lateral Occupant Displacement (SLICE-1), Test No. MGSC-8

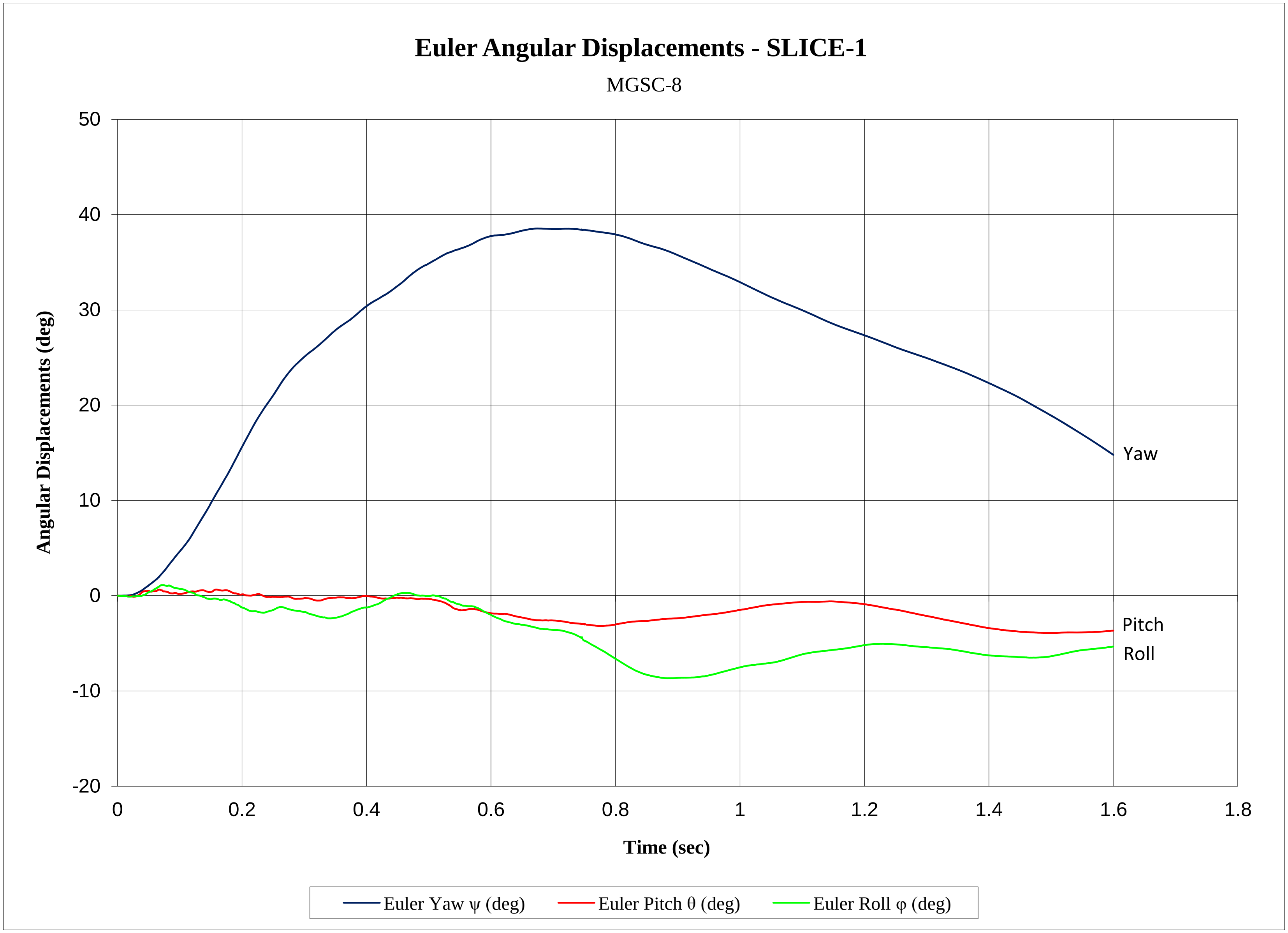


Figure F-15. Vehicle Angular Displacements (SLICE-1), Test No. MGSC-8

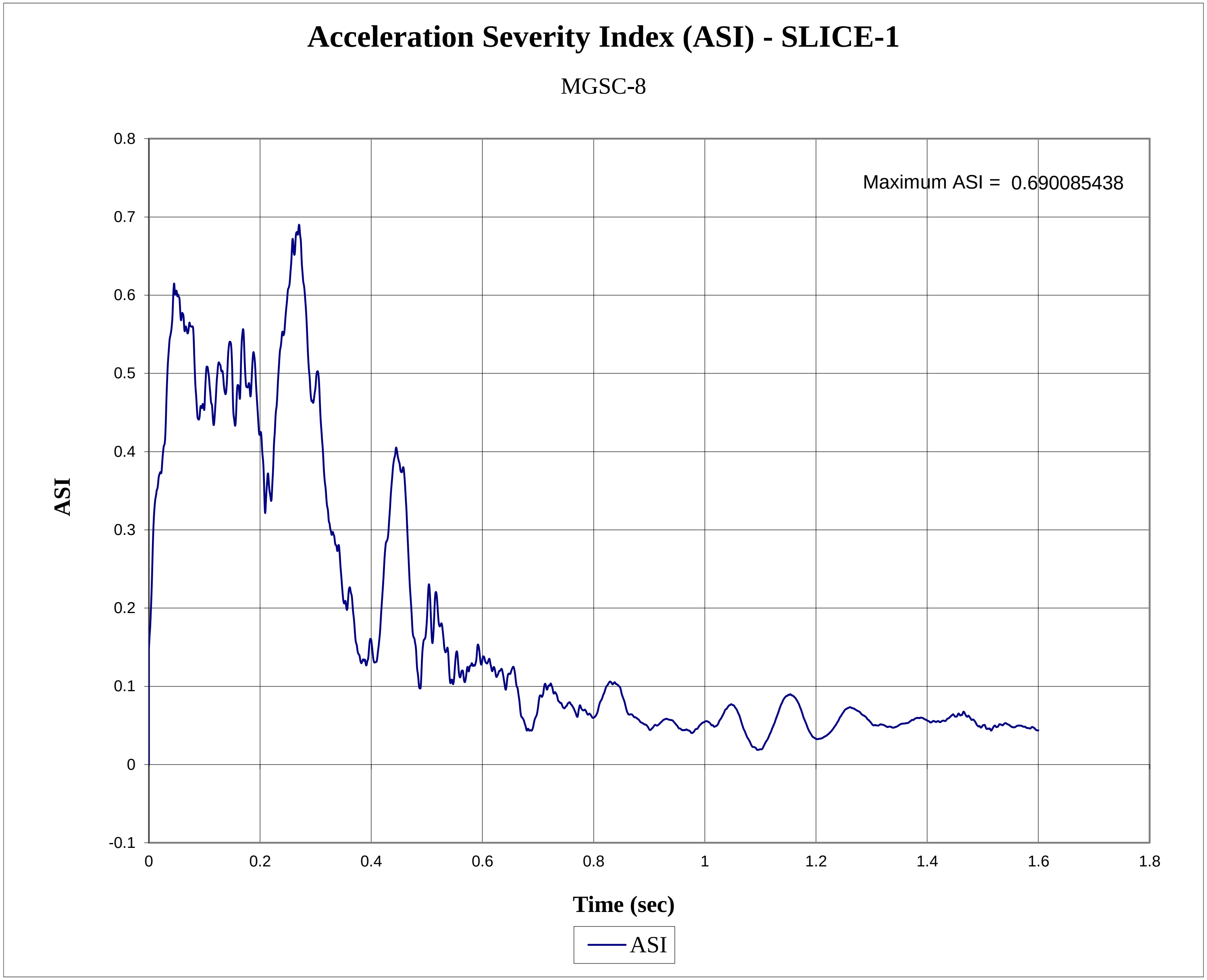


Figure F-16. Acceleration Severity Index (SLICE-1), Test No. MGSC-8

END OF DOCUMENT