ISO 17025 LABORATORY
TESTING CERT # 2937.01

*Hawaii Department of Transportation*
*Research Project Number 67167*

# CRASH TESTING AND EVALUATION OF THE HAWAII THRIE BEAM APPROACH GUARDRAIL TRANSITION: MASH TEST NOS. 3-20 AND 3-21

Submitted by


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

Samuel E. Hovde, B.S.C.E., E.I.T.
Graduate Research Assistant

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

Erin L. Urbank, B.A.
Research Communication Specialist

**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

**Hawaii Department of Transportation**
Aliiaimoku Building
869 Punchbowl Street
Honolulu, Hawaii 96813


MwRSF Research Report No. TRP-03-425-20

March 20, 2020

# TECHNICAL REPORT DOCUMENTATION PAGE

| | | |
|---|---|---|
| 1. Report No.<br>TRP-03-425-20 | 2. | 3. Recipient's Accession No. |
| 4. Title and Subtitle<br>Crash Testing and Evaluation of the Hawaii Thrie Beam Approach Guardrail Transition: MASH Test Nos. 3-20 and 3-21 | | 5. Report Date<br>March 20, 2020<br>6. |
| 7. Author(s)<br>Rosenbaugh, S.K., Hovde, S.E., Faller, R.K., and Urbank, E.L. | | 8. Performing Organization Report No.<br>TRP-03-425-20 |
| 9. Performing Organization Name and Address<br>Midwest Roadside Safety Facility (MwRSF)<br>Nebraska Transportation Center<br>University of Nebraska-Lincoln<br>Main Office:<br>Prem S. Paul Research Center at Whittier School<br>Room 130, 2200 Vine Street<br>Lincoln, Nebraska 68583-0853<br>Outdoor Test Site:<br>4630 N.W. 36th Street<br>Lincoln, Nebraska 68524 | | 10. Project/Task/Work Unit No.<br>11. Contract © or Grant (G) No.<br>Research Project 67167 |
| 12. Sponsoring Organization Name and Address<br>Hawaii Department of Transportation<br>Aliiaimoku Building<br>869 Punchbowl Street<br>Honolulu, Hawaii 96813 | | 13. Type of Report and Period Covered<br>Final Report: 2018-2020<br>14. Sponsoring Agency Code |

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

16. Abstract

The Hawaii Department of Transportation's (HDOT's) Thrie Beam Approach Guardrail Transition (AGT) was designed to safely transition from W-beam guardrail to a rigid concrete parapet. However, the AGT had not yet been evaluated under the current safety standards of the American Association of State Highway and Transportation Official (AASHTO) *Manual for Assessing Safety Hardware, 2nd Edition* (MASH 2016). The AGT consisted of nested thrie beam supported by W6x15 and W6x9/W6x8.5 steel posts and was attached to HDOT's specially-designed reinforced concrete end post, the Type D2 End Post. The AGT was also designed for use with a vertical 6-in. curb placed below the thrie beam. Although not originally part of HDOT's AGT design, the upstream section was modified to include the MGS stiffness transition utilizing an asymmetrical W-to-thrie transition segment to ensure a crashworthy connection between the upstream W-beam and the downstream nested thrie beam.

Within this research study, two full-scale crash tests were conducted on the HDOT AGT to investigate the safety performance according to Test Level 3 (TL-3) criteria in MASH 2016. Test nos. HWTT-1 and HWTT-2 were conducted in accordance with MASH 2016 test designation nos. 3-20 and 3-21, respectively. In both tests, the transition successfully contained and safely redirected the vehicles. All occupant risk measurements were found to be within the established MASH 2016 limits. Therefore, test nos. HWTT-1 and HWTT-2 were deemed to have satisfied all safety performance criteria, and the modified HDOT thrie beam AGT to concrete parapet was determined to be crashworthy to MASH 2016 TL-3.

| | | | |
|---|---|---|---|
| 17. Document Analysis/Descriptors<br>Highway Safety, Crash Test, Roadside Appurtenances, Compliance Test, MASH 2016, Approach Guardrail Transition, AGT, Concrete Parapet, and Thrie Beam | | 18. Availability Statement<br>No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161 | |
| 19. Security Class (this report)<br>Unclassified | 20. Security Class (this page)<br>Unclassified | 21. No. of Pages<br>213 | 22. Price |

## DISCLAIMER STATEMENT

This report was completed with funding from the Hawaii Department of Transportation. 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 Hawaii Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of 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 for the data contained herein was Dr. Mojdeh Asadollahi Pajouh, Research Assistant Professor.

## ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) Hawaii Department of Transportation and (2) MwRSF personnel for constructing the barriers and conducting the crash tests.

Acknowledgement is also given to the following individuals who made a contribution 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
R.W. Bielenberg, M.S.M.E., E.I.T., Research Engineer
J.D. Rasmussen, Ph.D., P.E., Research Assistant Professor
C.S. Stolle, Ph.D., E.I.T., Research Assistant Professor
J.S. Steelman, Ph.D., P.E., 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
C.I. Sims, Construction and Testing Technician I
J.E. Kohtz, B.S.M.E., CAD Technician
Z.Z. Jabr, Engineering Technician
Undergraduate and Graduate Research Assistants

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

# TABLE OF CONTENTS

TECHNICAL REPORT DOCUMENTATION PAGE ..... i

DISCLAIMER STATEMENT ..... ii

UNCERTAINTY OF MEASUREMENT STATEMENT ..... ii

INDEPENDENT APPROVING AUTHORITY ..... ii

ACKNOWLEDGEMENTS ..... ii

TABLE OF CONTENTS ..... iii

LIST OF FIGURES ..... v

LIST OF TABLES ..... x

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

2 DESIGN DETAILS ..... 12
- 2.1 Design Modifications ..... 12
- 2.2 Test Article Details – Modified HDOT AGT ..... 15

3 TEST REQUIREMENTS AND EVALUATION CRITERIA ..... 49
- 3.1 Test Requirements ..... 49
- 3.2 Evaluation Criteria ..... 50
- 3.3 Soil Strength Requirements ..... 51

4 TEST CONDITIONS ..... 52
- 4.1 Test Facility ..... 52
- 4.2 Vehicle Tow and Guidance System ..... 52
- 4.3 Test Vehicles ..... 52
- 4.4 Simulated Occupant ..... 59
- 4.5 Data Acquisition Systems ..... 59
  - 4.5.1 Accelerometers ..... 59
  - 4.5.2 Rate Transducers ..... 62
  - 4.5.3 Retroreflective Optic Speed Trap ..... 62
  - 4.5.4 Digital Photography ..... 62

5 FULL-SCALE CRASH TEST NO. HWTT-1 ..... 65
- 5.1 Static Soil Test ..... 65
- 5.2 Weather Conditions ..... 65
- 5.3 Test Description ..... 65
- 5.4 Barrier Damage ..... 72
- 5.5 Vehicle Damage ..... 76

5.6 Occupant Risk ..... 81
5.7 Discussion ..... 82

6 FULL-SCALE CRASH TEST NO. HWTT-2 ..... 84
6.1 Static Soil Test ..... 84
6.2 Weather Conditions ..... 84
6.3 Test Description ..... 84
6.4 Barrier Damage ..... 91
6.5 Vehicle Damage ..... 95
6.6 Occupant Risk ..... 100
6.7 Discussion ..... 101

7 SUMMARY AND CONCLUSIONS ..... 103

8 REFERENCES ..... 105

9 APPENDICES ..... 107
Appendix A. Material Specifications ..... 108
Appendix B. Vehicle Center of Gravity Determination ..... 157
Appendix C. Static Soil Tests ..... 160
Appendix D. Vehicle Deformation Records ..... 165
Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. HWTT-1 ..... 179
Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. HWTT-2 ..... 196

# LIST OF FIGURES

Figure 1. HDOT AGT to 34-in. Tall Bridge Rail Details ..... 2
Figure 2. HDOT AGT to 34-in. Tall Bridge Rail Details, Continued ..... 3
Figure 3. HDOT AGT to 34-in. Tall Bridge Rail Details, Bridge Rail Cross Sections ..... 4
Figure 4. HDOT AGT to 34-in. Tall Bridge Rail Details, AGT and End Post Cross Sections ..... 5
Figure 5. HDOT AGT to 42-in. Tall Bridge Rail Details ..... 6
Figure 6. HDOT AGT to 42-in. Tall Bridge Rail Details, Continued ..... 7
Figure 7. HDOT AGT to 42-in. Tall Bridge Rail Details, Bridge Rail Cross Sections ..... 8
Figure 8. HDOT AGT to 42-in. Tall Bridge Rail Details, AGT and End Post Cross Sections ..... 9
Figure 9. HDOT AGT Details, Material Specifications and Notes ..... 10
Figure 10. HDOT AGT Details, Guardrail and Connection Hardware ..... 11
Figure 11. Modified HDOT AGT with Inclusion of MGS Upstream Stiffness Transition ..... 14
Figure 12. Modified HDOT AGT with Inclusion of MGS Upstream Stiffness Transition ..... 15
Figure 13. System Layout, Test No. HWTT-1 ..... 17
Figure 14. System Layout, Test No. HWTT-2 ..... 18
Figure 15. Post Nos. 3 through 10 Details, Test Nos. HWTT-1 and HWTT-2 ..... 19
Figure 16. Post Nos. 11 through 19 Details, Test Nos. HWTT-1 and HWTT-2 ..... 20
Figure 17. Type D2 End Post and Terminal Connector, Test Nos. HWTT-1 and HWTT-2 ..... 21
Figure 18. Guardrail End Section and Splice Detail, Test Nos. HWTT-1 and HWTT-2 ..... 22
Figure 19. BCT Anchor Details, Test Nos. HWTT-1 and HWTT-2 ..... 23
Figure 20. Post Nos. 16 through 19 Components, Test Nos. HWTT-1 and HWTT-2 ..... 24
Figure 21. Post Nos. 10 through 15 Components, Test Nos. HWTT-1 and HWTT-2 ..... 25
Figure 22. Post Nos. 3 through 7 Components, Test Nos. HWTT-1 and HWTT-2 ..... 26
Figure 23. Post Nos. 8 and 9 Blockout Details, Test Nos. HWTT-1 and HWTT-2 ..... 27
Figure 24. BCT Timber Post and Foundation Tube Details, Test Nos. HWTT-1 and HWTT-2 ..... 28
Figure 25. Ground Strut Details, Test Nos. HWTT-1 and HWTT-2 ..... 29
Figure 26. BCT Anchor Cable Details, Test Nos. HWTT-1 and HWTT-2 ..... 30
Figure 27. Cable Assembly and Anchor Components, Test Nos. HWTT-1 and HWTT-2 ..... 31
Figure 28. End Post Rebar Details, Test Nos. HWTT-1 and HWTT-2 ..... 32
Figure 29. End Post Sections, Test Nos. HWTT-1 and HWTT-2 ..... 33
Figure 30. End Post Details, Test Nos. HWTT-1 and HWTT-2 ..... 34
Figure 31. Curb Reinforcement Details, Test Nos. HWTT-1 and HWTT-2 ..... 35
Figure 32. Curb Details, Test Nos. HWTT-1 and HWTT-2 ..... 36
Figure 33. End Post Reinforcement Details, Test Nos. HWTT-1 and HWTT-2 ..... 37
Figure 34. End Post Reinforcement Details, Test Nos. HWTT-1 and HWTT-2 ..... 38
Figure 35. Longitudinal End Post and Curb Reinforcement Details, Test Nos. HWTT-1 and HWTT-2 ..... 39
Figure 36. Guardrail Section Details, Test Nos. HWTT-1 and HWTT-2 ..... 40
Figure 37. Asymmetric Transition Rail and Terminal Connector Details, Test Nos. HWTT-1 and HWTT-2 ..... 41
Figure 38. Hardware, Test Nos. HWTT-1 and HWTT-2 ..... 42
Figure 39. Bill of Materials, Test Nos. HWTT-1 and HWTT-2 ..... 43
Figure 40. Bill of Materials, Continued, Test Nos. HWTT-1 and HWTT-2 ..... 44
Figure 41. Bill of Materials, Continued, Test Nos. HWTT-1 and HWTT-2 ..... 45
Figure 42. Test Installation Photographs, Test Nos. HWTT-1 and HWTT-2 ..... 46

Figure 43. Test Installation Photographs, Test Nos. HWTT-1 and HWTT-2 .....47
Figure 44. Test Installation Photographs, Test Nos. HWTT-1 and HWTT-2 .....48
Figure 45. Test Vehicle Photographs, Test No. HWTT-1 .....53
Figure 46. Test Vehicle Interior Floorboards and Undercarriage, Test No. HWTT-2 .....54
Figure 47. Vehicle Dimensions, Test No. HWTT-1 .....55
Figure 48. Test Vehicle Photographs, Test No. HWTT-2 .....56
Figure 49. Test Vehicle Interior Floorboards and Undercarriage, Test No. HWTT-2 .....57
Figure 50. Vehicle Dimensions, Test No. HWTT-2 .....58
Figure 51. Target Geometry, Test No. HWTT-1 .....60
Figure 52. Target Geometry, Test No. HWTT-2 .....61
Figure 53. Camera Locations, Speeds, and Lens Settings, Test No. HWTT-1 .....63
Figure 54. Camera Locations, Speeds, and Lens Settings, Test No. HWTT-2 .....64
Figure 55. Impact Location, Test No. HWTT-1 .....66
Figure 56. Sequential Photographs, Test No. HWTT-1 .....68
Figure 57. Additional Sequential Photographs, Test No. HWTT-1 .....69
Figure 58. Documentary Photographs, Test No. HWTT-1 .....70
Figure 59. Vehicle Final Position and Trajectory Marks, Test No. HWTT-1 .....71
Figure 60. System Damage, Test No. HWTT-1 .....73
Figure 61. Thrie Beam Damage, Test No. HWTT-1 .....74
Figure 62. Rail Connection Terminal, Buttress and Post Damage, Test No. HWTT-1 .....75
Figure 63. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. HWTT-1 .....76
Figure 64. Vehicle Damage, Test No. HWTT-1 .....78
Figure 65. Vehicle Damage, Test No. HWTT-1 .....79
Figure 66. Interior and Undercarriage Damage, Test No. HWTT-1 .....80
Figure 67. Summary of Test Results and Sequential Photographs, Test No. HWTT-1 .....83
Figure 68. Impact Location, Test No. HWTT-2 .....85
Figure 69. Sequential Photographs, Test No. HWTT-2 .....87
Figure 70. Additional Sequential Photographs, Test No. HWTT-2 .....88
Figure 71. Documentary Photographs, Test No. HWTT-2 .....89
Figure 72. Vehicle Final Position and Trajectory Marks, Test No. HWTT-2 .....90
Figure 73. System Damage, Test No. HWTT-2 .....92
Figure 74. Thrie Beam Damage, Test No. HWTT-2 .....93
Figure 75. Buttress Damage, Test No. HWTT-2 .....94
Figure 76. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. HWTT-2 .....95
Figure 77. Vehicle Damage, Test No. HWTT-2 .....97
Figure 78. Vehicle Damage, Test No. HWTT-2 .....98
Figure 79. Interior and Undercarriage Damage, Test No. HWTT-2 .....99
Figure 80. Summary of Test Results and Sequential Photographs, Test No. HWTT-2 .....102
Figure A-1. 12 ft – 6 in. 12-gauge Thrie Beam Section, Test Nos. HWTT-1 and HWTT-2 .....112
Figure A-2. 6 ft. – 3 in. 12-gauge Thrie Beam Section, Test Nos. HWTT-1 and HWTT-2 .....113
Figure A-3. 6 ft – 3 in. 10-gauge W-Beam to Thrie-Beam Asymmetric Transition Section, Test Nos. HWTT-1 and HWTT-2 .....114
Figure A-4. 12 ft – 6 in. 12-gauge W-Beam MGS Section, Test Nos. HWTT-1 and HWTT-2 .....115

Figure A-5. 12 ft – 6 in. 12-gauge W-Beam MGS End Section, Test Nos. HWTT-1 and HWTT-2 ..... 116
Figure A-6. 10-gauge Thrie Beam Terminal Connector, Test Nos. HWTT-1 and HWTT-2 ..... 117
Figure A-7. Reinforced Concrete Buttress, Test Nos. HWTT-1 and HWTT-2 ..... 118
Figure A-8. Reinforced Concrete Buttress, Test Nos. HWTT-1 and HWTT-2 ..... 119
Figure A-9. Reinforced Concrete Curb, Test Nos. HWTT-1 and HWTT-2 ..... 120
Figure A-10. BCT Timber Posts, Test Nos. HWTT-1 and HWTT-2 ..... 121
Figure A-11. BCT Timber Posts, Test Nos. HWTT-1 and HWTT-2 ..... 122
Figure A-12. 72-in. Long Foundation Tube, Test Nos. HWTT-1 and HWTT-2 ..... 123
Figure A-13. Ground Strut Assembly, Test Nos. HWTT-1 and HWTT-2 ..... 124
Figure A-14. BCT Anchor Cable Swaged Fitting and 0.75 in. Dia. 6x19 IWRC Wire Rope, Test Nos. HWTT-1 and HWTT-2 ..... 125
Figure A-15. 8-in. x 8-in. x ⅝-in. Anchor Bearing Plate, Test Nos. HWTT-1 and HWTT-2 ..... 126
Figure A-16. 2⅜-in. O.D. by 6-in. Long BCT Post Sleeve, Test Nos. HWTT-1 and HWTT-2 ..... 127
Figure A-17. Anchor Bracket Assembly, Test Nos. HWTT-1 and HWTT-2 ..... 128
Figure A-18. W6x8.5 72-in. Long Steel Post, Test Nos. HWTT-1 and HWTT-2 ..... 129
Figure A-19. W6x15 78-in. Long Steel Post, Test Nos. HWTT-1 and HWTT-2 ..... 130
Figure A-20. 17½-in. Long, 8-in. x 6-in. x ¼-in. Steel Blockout, Test Nos. HWTT-1 and HWTT-2 ..... 131
Figure A-21. 17½-in. Long, 12-in. x 4-in. x ¼-in. Steel Blockout, Test Nos. HWTT-1 and HWTT-2 ..... 132
Figure A-22. $14^{3}/_{16}$-in. x 12-in. x ⅛-in. Composite Recycle Blockout, Test Nos. HWTT-1 and HWTT-2 ..... 133
Figure A-23. $14^{3}/_{16}$-in. x 8-in. x ⅛-in. Composite Recycle Blockout, Test Nos. HWTT-1 and HWTT-2 ..... 134
Figure A-24. 16 D Double Head Nails, Test Nos. HWTT-1 and HWTT-2 ..... 135
Figure A-25. ¾-in. Dia. Unbent Rebar, Test Nos. HWTT-1 and HWTT-2 ..... 136
Figure A-26. ½-in. Dia. Rebar, Test Nos. HWTT-1 and HWTT-2 ..... 137
Figure A-27. ½-in. Dia. Rebar, Test Nos. HWTT-1 and HWTT-2 ..... 138
Figure A-28. ⅝-in. Dia. Rebar, Test Nos. HWTT-1 and HWTT-2 ..... 139
Figure A-29. ⅝-in. Dia. 11 UNC, 14-in. Long Guardrail Bolts, Test Nos. HWTT-1 and HWTT-2 ..... 140
Figure A-30. ⅝-in. Dia. 11 UNC, 10-in. Long Guardrail Bolts, Test Nos. HWTT-1 and HWTT-2 ..... 141
Figure A-31. ⅝-in. Dia. 11 UNC, 1¼-in. Long Guardrail Bolts, Test Nos. HWTT-1 and HWTT-2 ..... 142
Figure A-32. ⅝-in. Dia. 11 UNC, 10-in. Long Hex Head Bolts, Test Nos. HWTT-1 and HWTT-2 ..... 143
Figure A-33. ⅝-in. Dia. 11 UNC, 1½-in. Long Hex Head Bolts, Test Nos. HWTT-1 and HWTT-2 ..... 144
Figure A-34. ⅞-in. Dia. 9 UNC, 16-in. Long Heavy Hex Head Bolts, Test Nos. HWTT-1 and HWTT-2 ..... 145
Figure A-35. ⅞-in. Dia. 9 UNC, 8-in. Long Hex Head Bolts, Test Nos. HWTT-1 and HWTT-2 ..... 146
Figure A-36. ⅝-in. Dia. 11 UNC, 2-in. Long Guardrail Bolts, Test Nos. HWTT-1 and HWTT-2 ..... 147

Figure A-37. ⅝-in. Dia. 11 UNC, Heavy Hex Nuts, Test Nos. HWTT-1 and HWTT-2.....148
Figure A-38. ⅞-in. Dia. 9 UNC, Hex Nuts, Test Nos. HWTT-1 and HWTT-2.....149
Figure A-39. ⅞-in. Dia. 9 UNC, Heavy Hex Nuts, Test Nos. HWTT-1 and HWTT-2.....150
Figure A-40. 1-in. Dia. 8 UNC, Heavy Hex Nuts, Test Nos. HWTT-1 and HWTT-2.....151
Figure A-41. ⅝-in. Dia. Hex Nuts, Test Nos. HWTT-1 and HWTT-2.....152
Figure A-42. ⅞-in. Plain USS Washers, Test Nos. HWTT-1 and HWTT-2.....153
Figure A-43. 1-in. Plain USS Washers, Test Nos. HWTT-1 and HWTT-2.....154
Figure A-44. 3-in. x 3-in. x ¼-in. Square Washer Plate, Test Nos. HWTT-1 and HWTT-2.....155
Figure A-45. Hilti HIT RE-500 V3 Epoxy Adhesive, Test Nos. HWTT-1 and HWTT-2.....156
Figure B-1. Vehicle Mass Distribution, Test No. HWTT-1.....158
Figure B-2. Vehicle Mass Distribution, Test No. HWTT-2.....159
Figure C-1. Soil Strength, Initial Calibration Tests.....161
Figure C-2. Static Soil Test, Test No. HWTT-1.....162
Figure C-3. Soil Strength, Initial Calibration Tests.....163
Figure C-4. Static Soil Test, Test No. HWTT-2.....164
Figure D-1. Floor Pan Deformation Data – Set 1, Test No. HWTT-1.....166
Figure D-2. Occupant Compartment Deformation Data – Set 1, Test No. HWTT-1.....167
Figure D-3. Windshield Deformation, Test No. HWTT-1.....168
Figure D-4. Maximum Occupant Compartment Deformations by Location, Test No. HWTT-1.....169
Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. HWTT-1.....170
Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. HWTT-1.....171
Figure D-7. Floor Pan Deformation Data – Set 1, Test No. HWTT-2.....172
Figure D-8. Occupant Compartment Deformation Data – Set 1, Test No. HWTT-2.....173
Figure D-9. Floor Pan Deformation Data – Set 2, Test No. HWTT-2.....174
Figure D-10. Occupant Compartment Deformation Data – Set 2, Test No. HWTT-2.....175
Figure D-11. Maximum Occupant Compartment Deformations by Location, Test No. HWTT-2.....176
Figure D-12. Exterior Vehicle Crush (NASS) - Front, Test No. HWTT-2.....177
Figure D-13. Exterior Vehicle Crush (NASS) - Side, Test No. HWTT-2.....178
Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. HWTT-1.....180
Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. HWTT-1.....181
Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. HWTT-1.....182
Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. HWTT-1.....183
Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. HWTT-1.....184
Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. HWTT-1.....185
Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. HWTT-1.....186
Figure E-8. Acceleration Severity Index (SLICE-1), Test No. HWTT-1.....187
Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. HWTT-1.....188
Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. HWTT-1.....189
Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. HWTT-1.....190
Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. HWTT-1.....191
Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. HWTT-1.....192
Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. HWTT-1.....193
Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. HWTT-1.....194
Figure E-16. Acceleration Severity Index (SLICE-2), Test No. HWTT-1.....195
Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. HWTT-2.....197

Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. HWTT-2 .....198
Figure F-3. Longitudinal Occupant Displacement (SLICE-2), Test No. HWTT-2 .....199
Figure F-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. HWTT-2 .....200
Figure F-5. Lateral Occupant Impact Velocity (SLICE-2), Test No. HWTT-2 .....201
Figure F-6. Lateral Occupant Displacement (SLICE-2), Test No. HWTT-2 .....202
Figure F-7. Vehicle Angular Displacements (SLICE-2), Test No. HWTT-2 .....203
Figure F-8. Acceleration Severity Index (SLICE-2), Test No. HWTT-2 .....204
Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. HWTT-2 .....205
Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. HWTT-2 .....206
Figure F-11. Longitudinal Occupant Displacement (SLICE-1), Test No. HWTT-2 .....207
Figure F-12. 10-ms Average Lateral Deceleration (SLICE-1), Test No. HWTT-2 .....208
Figure F-13. Lateral Occupant Impact Velocity (SLICE-1), Test No. HWTT-2 .....209
Figure F-14. Lateral Occupant Displacement (SLICE-1), Test No. HWTT-2 .....210
Figure F-15. Vehicle Angular Displacements (SLICE-1), Test No. HWTT-2 .....211
Figure F-16. Acceleration Severity Index (SLICE-1), Test No. HWTT-2 .....212

# LIST OF TABLES

Table 1. MASH 2016 TL-3 Crash Test Conditions for Longitudinal Barrier Transitions .....49
Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barriers .....50
Table 3. Weather Conditions, Test No. HWTT-1.....65
Table 4. Sequential Description of Impact Events, Test No. HWTT-1.....67
Table 5. Maximum Occupant Compartment Intrusion by Location.....81
Table 6. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. HWTT-1 .....82
Table 7. Weather Conditions, Test No. HWTT-2.....84
Table 8. Sequential Description of Impact Events, Test No. HWTT-2.....86
Table 9. Maximum Occupant Compartment Intrusion by Location.....100
Table 10. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. HWTT-2 .....101
Table 11. Summary of Safety Performance Evaluation, Test Nos. HWTT-1 and HWTT-2.....104
Table A-1. Bill of Materials for Test Nos. HWTT-1 and HWTT-2 .....109
Table A-2. Bill of Materials for Test Nos. HWTT-1 and HWTT-2, Continued.....110
Table A-3. Bill of Materials for Test Nos. HWTT-1 and HWTT-2, Continued.....111

# 1 INTRODUCTION

## 1.1 Background

The Hawaii Department of Transportation (HDOT) utilizes a thrie beam approach guardrail transition (AGT) to connect W-beam guardrail to concrete barriers and bridge rails. However, the crashworthiness of this AGT under current impact safety standards has not been demonstrated. This report documents the system modifications and full-scale crash testing conducted to evaluate the safety performance of the HDOT thrie beam AGT to concrete parapet in accordance with the American Association of State Highway and Transportation (AASHTO) *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [1].

HDOT's AGT consisted of nested thrie beam supported by W6x15 posts with a 6-in. tall, vertical curb located below the thrie beam guardrail, as shown in Figures 1 through 10. The downstream end of the guardrail is connected to a specialized concrete end post, HDOT's Type 2 End Post. The end post can be configured to match up with either HDOT's 34-in. tall vertical concrete bridge rail, as shown in Figures 1 through 4, or HDOT's 42-in. tall vertical concrete bridge rail, as shown in Figures 5 through 8. Note, that both of these bridge rails have previously been evaluated to the Test Level 3 (TL-3) criteria of MASH 2016 [2-3].

The upstream end of the AGT was originally transitioned to W-beam guardrail utilizing a symmetric W-to-thrie transition segment, as shown in Figures 2, 6, and 10. However, HDOT recently adopted the Midwest Guardrail System (MGS), which raised the top-mounting height of the W-beam guardrail to 31 in. Subsequently, the upstream end of the transition needed to be redesigned to connect the taller W-beam systems to the AGT. Additionally, modifying the upstream end of the AGT to replicate previously MASH evaluated upstream stiffness transitions would reduce the number of crash tests necessary to evaluate the entire AGT. Therefore, the AGT system was to be modified as part of this research study, in addition to evaluating the HDOT AGT to concrete parapet to the MASH 2016 TL-3 criteria.

## 1.2 Objective

The objective of this report was to evaluate the safety performance of the modified HDOT Thrie Beam AGT between MGS and concrete parapet. The system was evaluated according to the TL-3 criteria of MASH 2016 [1].

## 1.3 Scope

The research objective was achieved through the completion of several tasks. The first task included a review of the existing HDOT AGT to concrete parapet, the identification of potential safety issues, and the recommendation of system modifications to improve the crashworthiness of the AGT. The modified system was then constructed and subjected to two full-scale crash tests in accordance with MASH 2016 test designation nos. 3-20 and 3-21. The full-scale vehicle crash test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made pertaining to the safety performance of the HDOT AGT to concrete parapet.

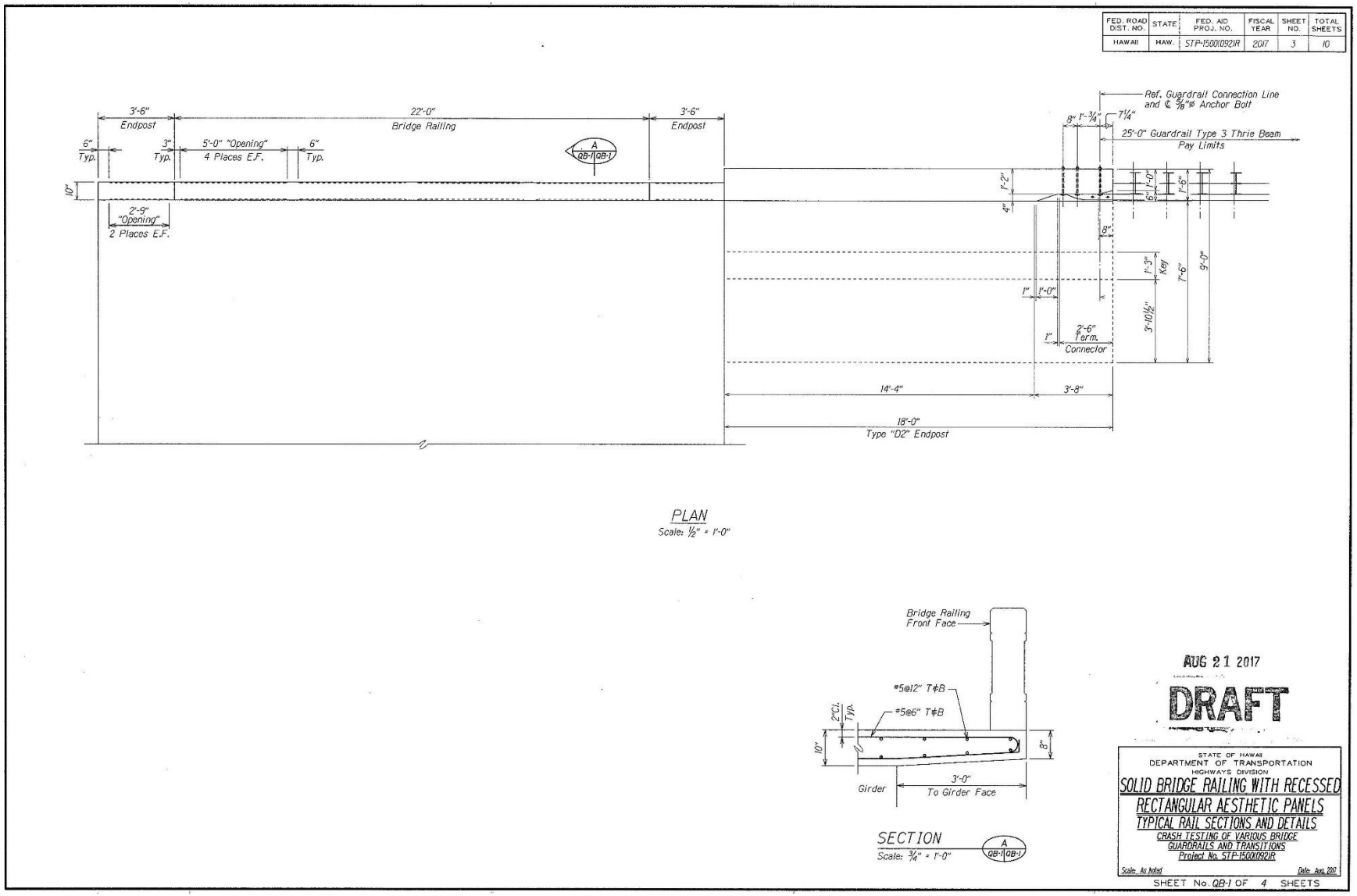



Figure 1. HDOT AGT to 34-in. Tall Bridge Rail Details

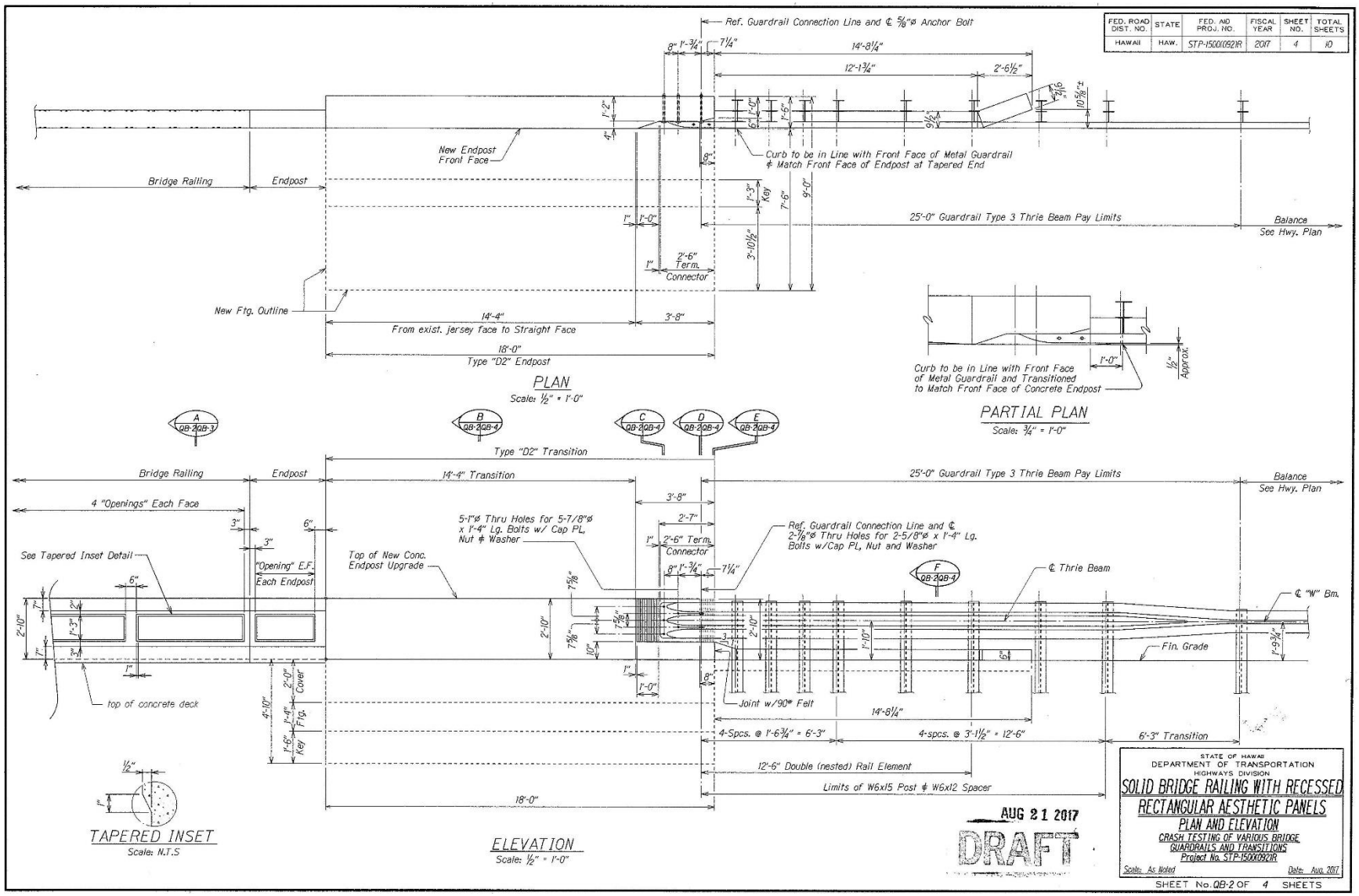



Figure 2. HDOT AGT to 34-in. Tall Bridge Rail Details, Continued

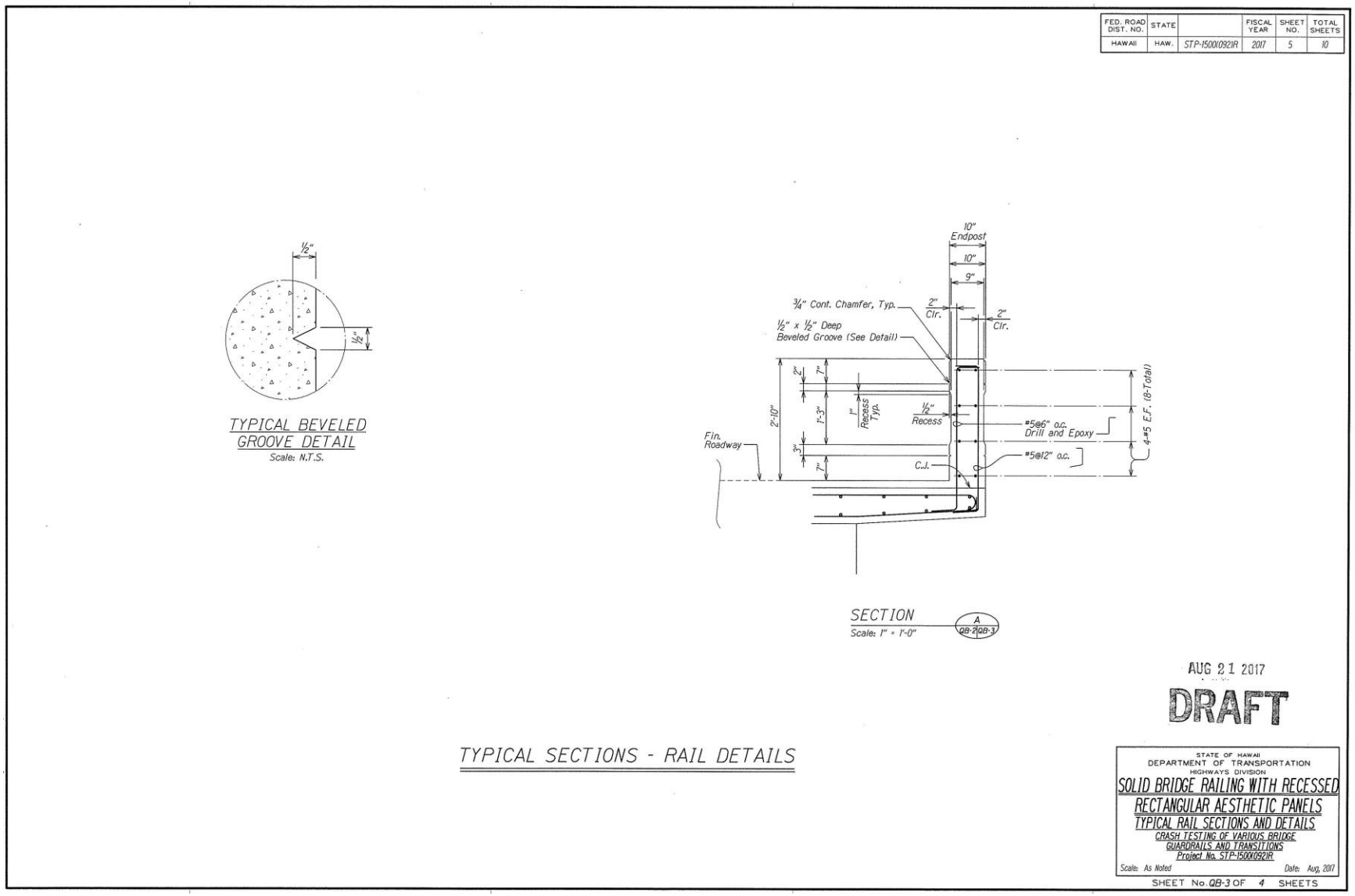



Figure 3. HDOT AGT to 34-in. Tall Bridge Rail Details, Bridge Rail Cross Sections

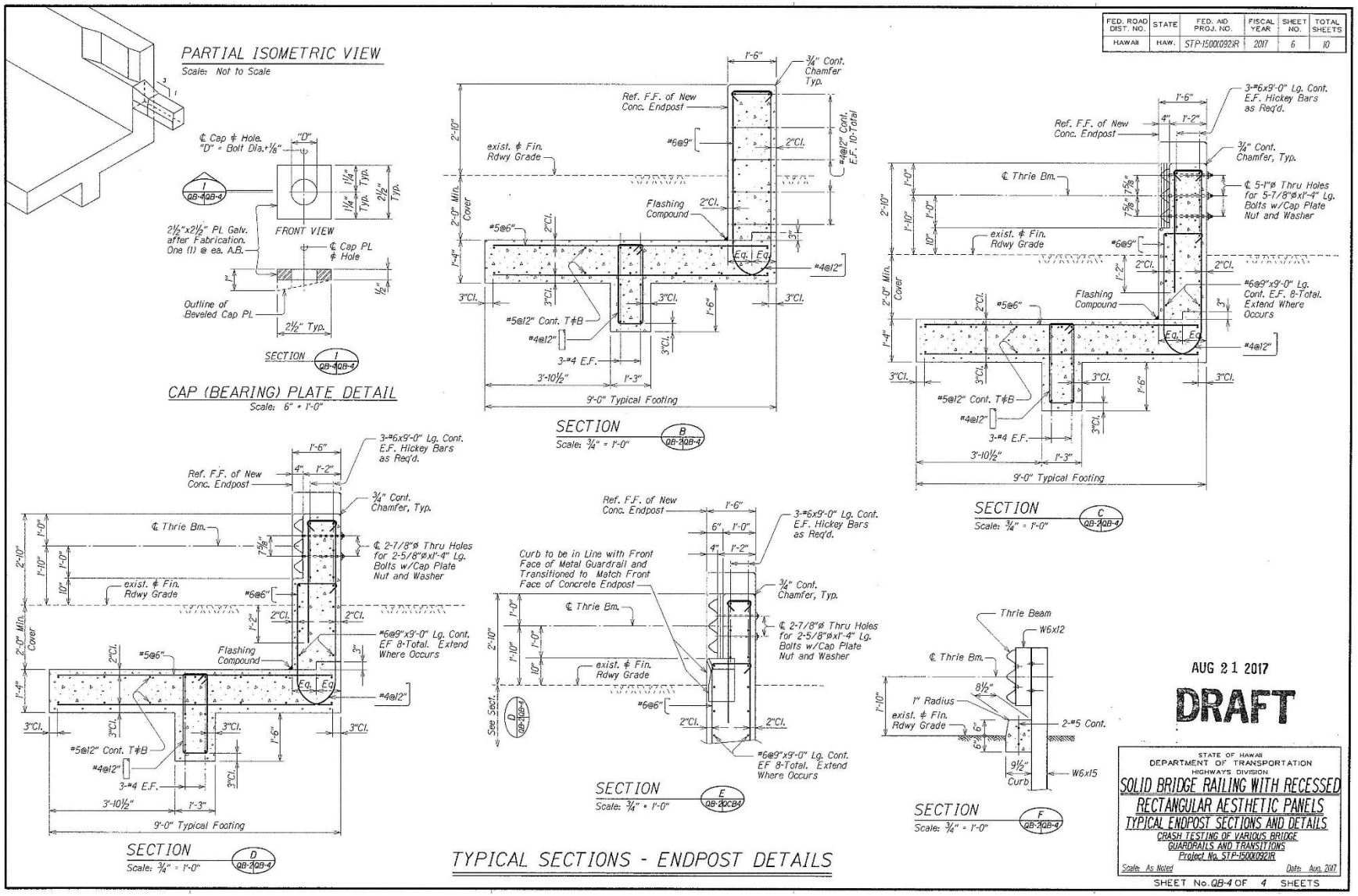



Figure 4. HDOT AGT to 34-in. Tall Bridge Rail Details, AGT and End Post Cross Sections

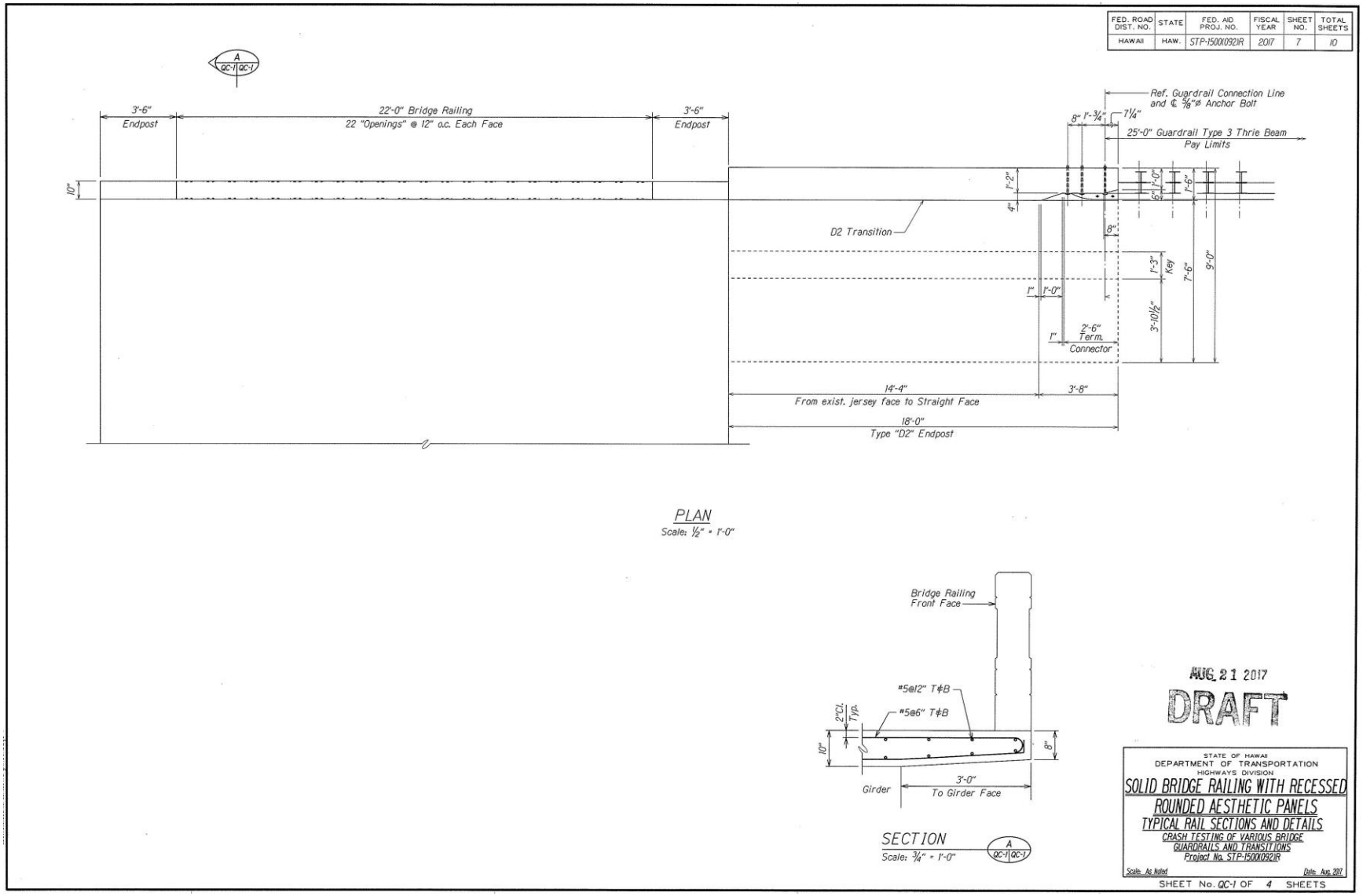



Figure 5. HDOT AGT to 42-in. Tall Bridge Rail Details

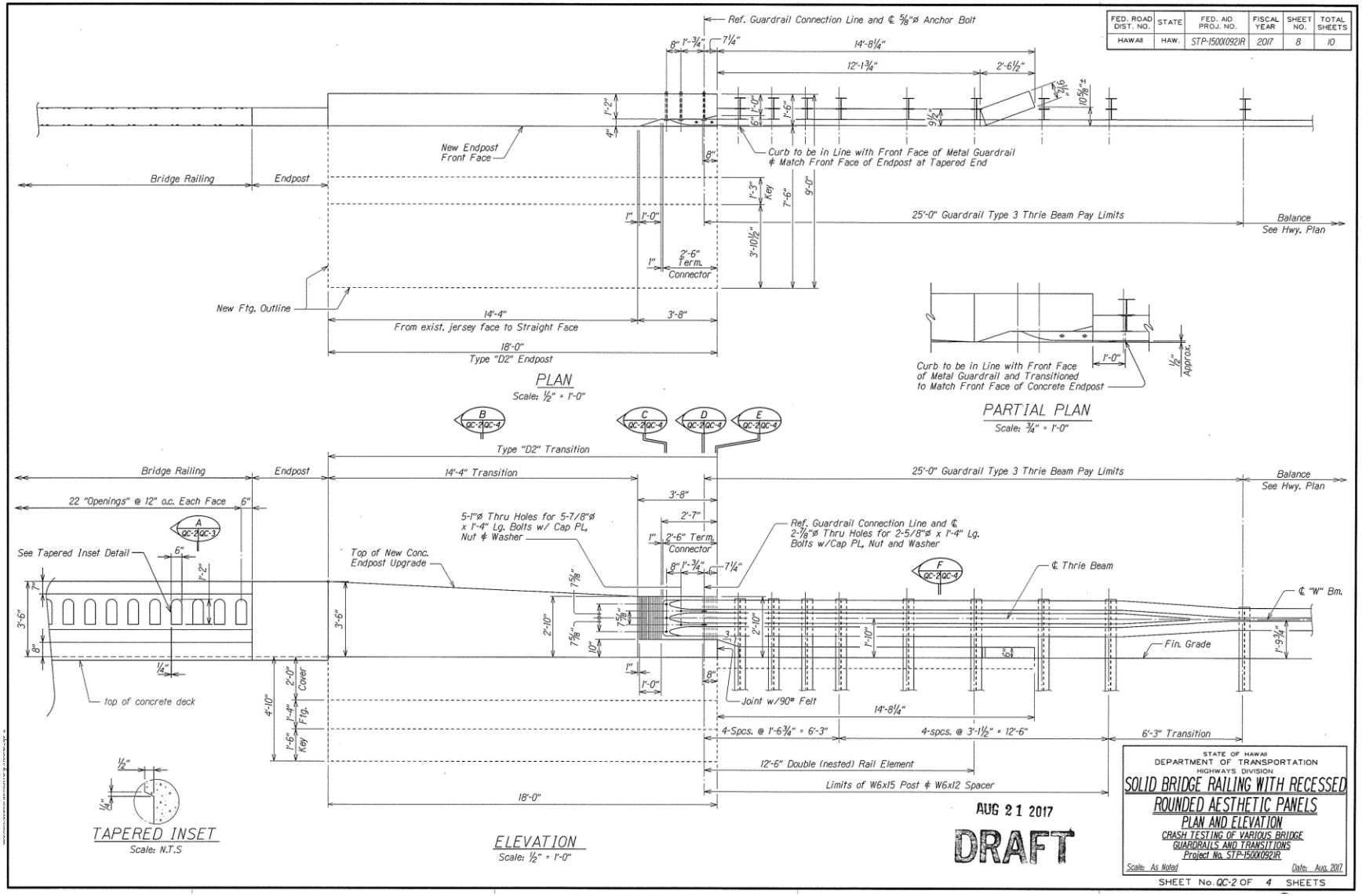



Figure 6. HDOT AGT to 42-in. Tall Bridge Rail Details, Continued

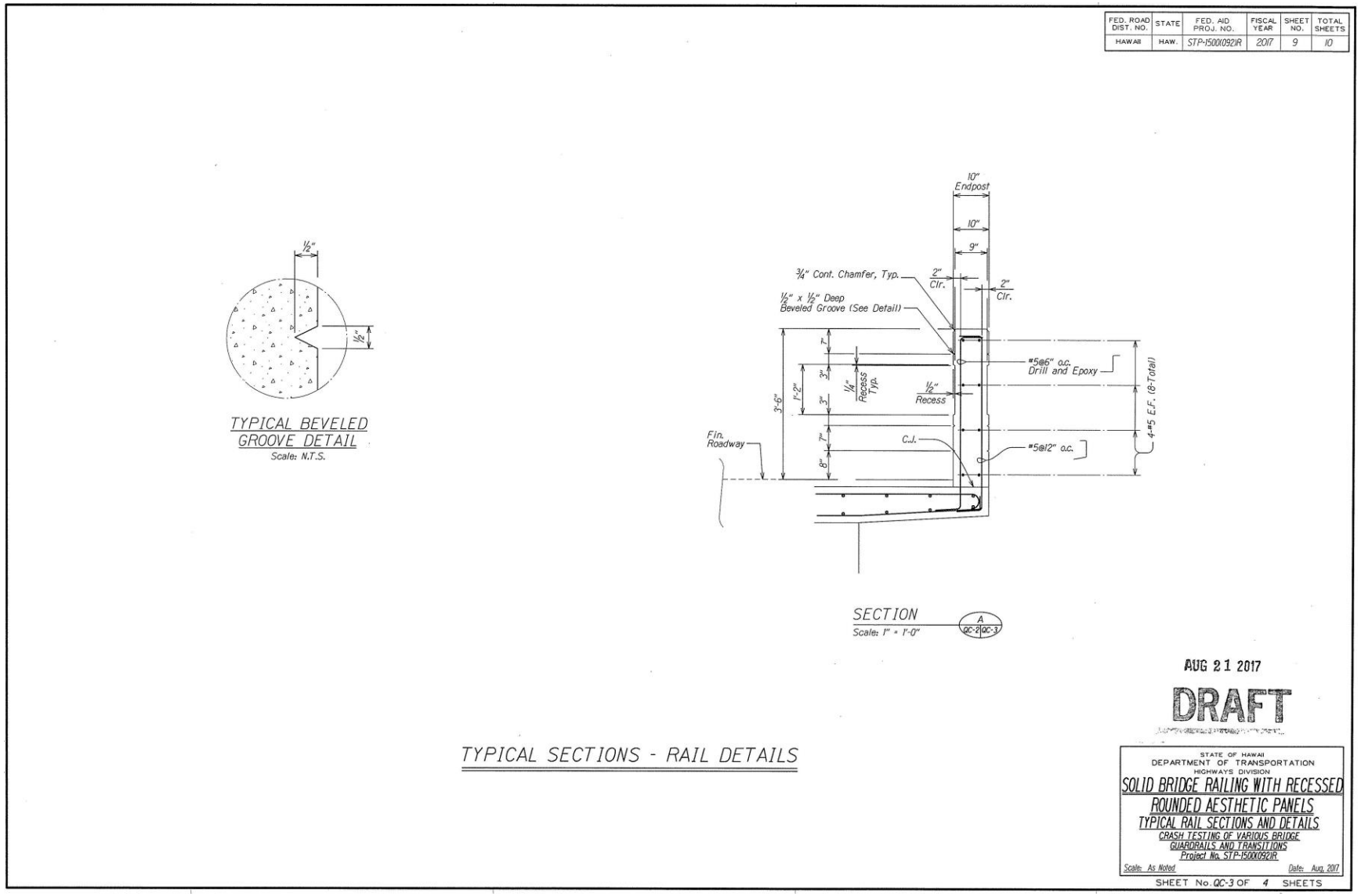



Figure 7. HDOT AGT to 42-in. Tall Bridge Rail Details, Bridge Rail Cross Sections

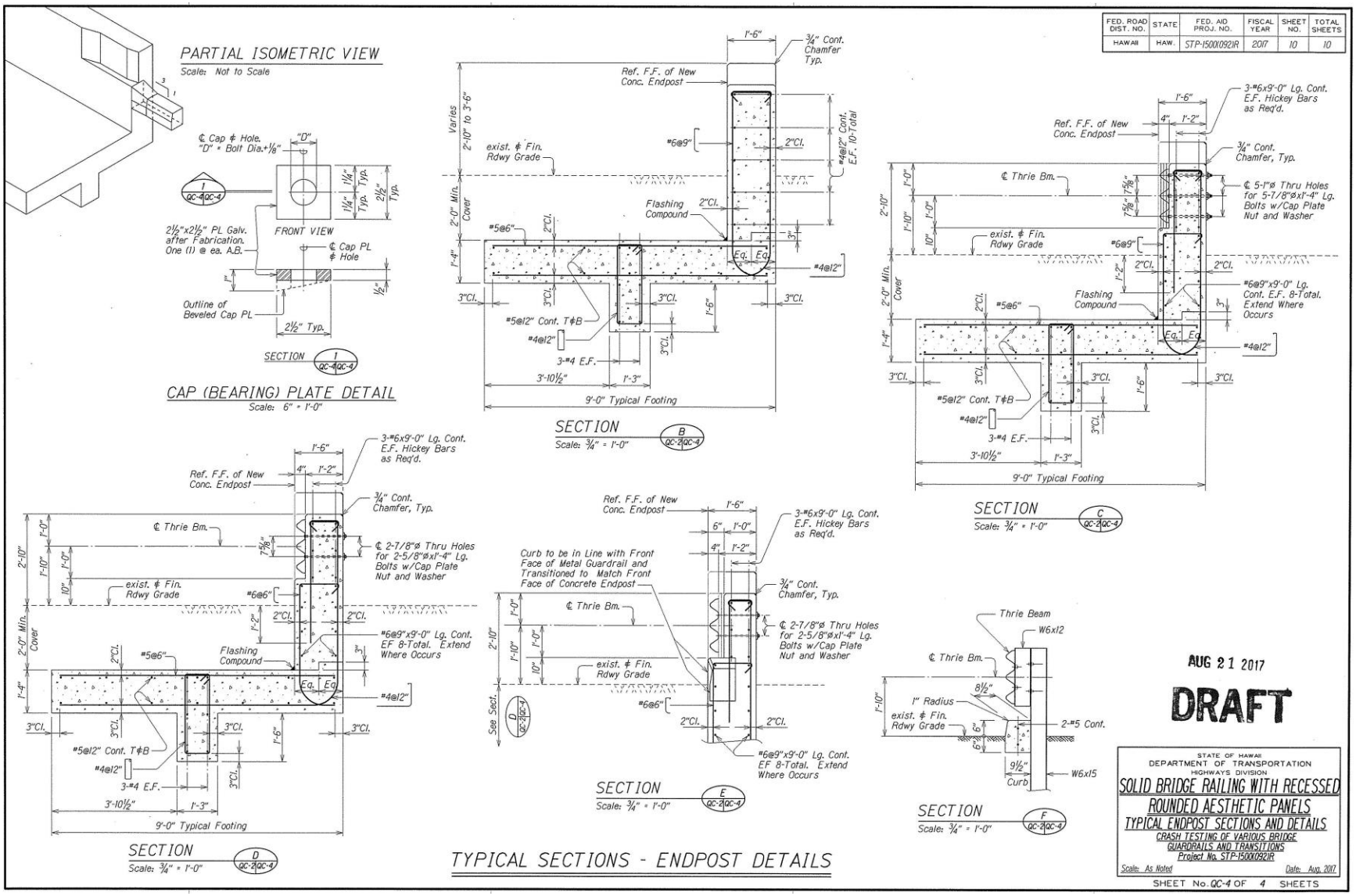
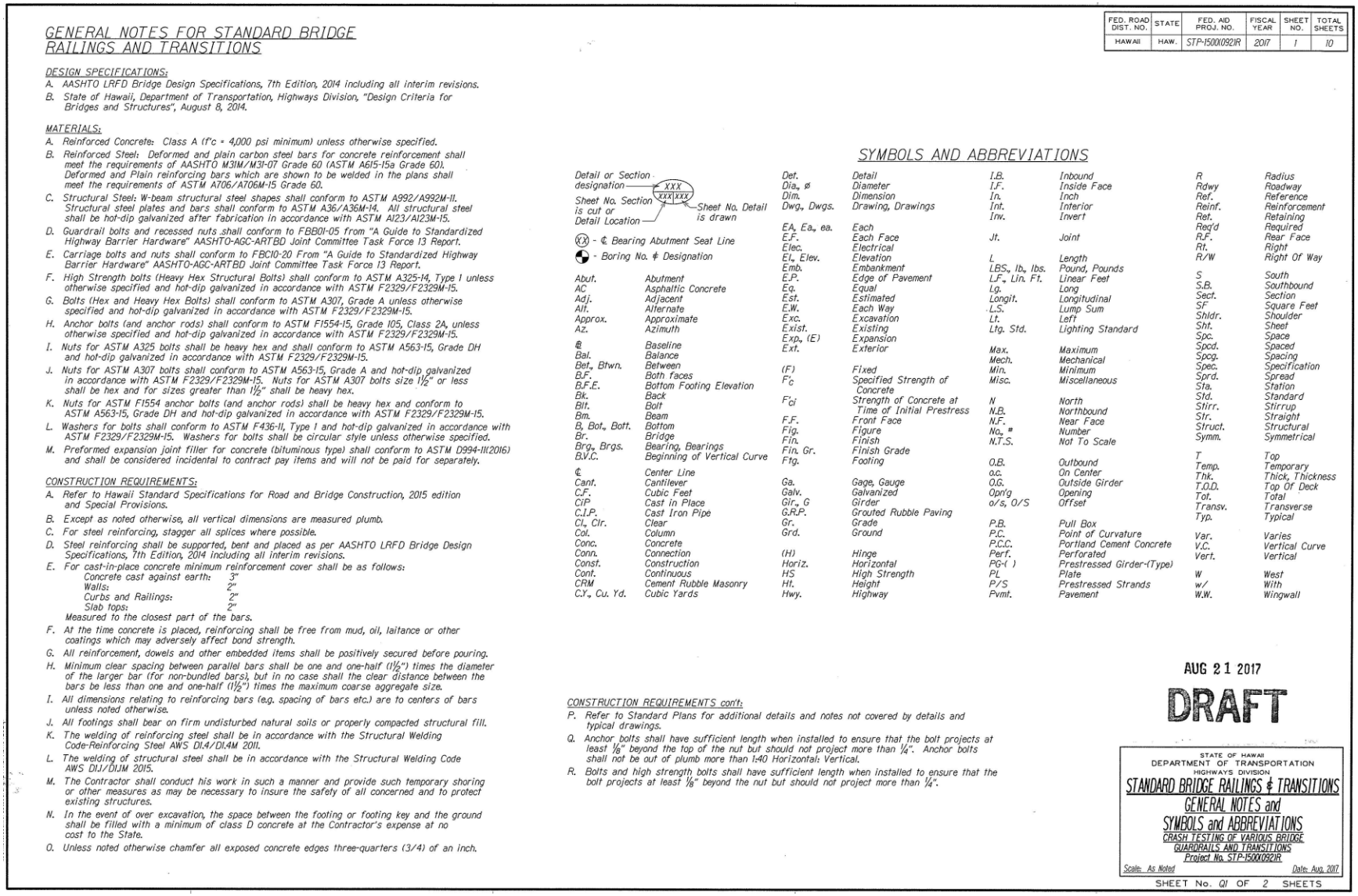



Figure 8. HDOT AGT to 42-in. Tall Bridge Rail Details, AGT and End Post Cross Sections



## GENERAL NOTES FOR STANDARD BRIDGE RAILINGS AND TRANSITIONS

| FED. ROAD DIST. NO. | STATE | FED. AID PROJ. NO. | FISCAL YEAR | SHEET NO. | TOTAL SHEETS |
|---|---|---|---|---|---|
| HAWAII | HAW. | STP-1500(092)R | 2017 | 1 | 10 |

**DESIGN SPECIFICATIONS:**

A. AASHTO LRFD Bridge Design Specifications, 7th Edition, 2014 including all interim revisions.
B. State of Hawaii, Department of Transportation, Highways Division, "Design Criteria for Bridges and Structures", August 8, 2014.

**MATERIALS:**

A. Reinforced Concrete: Class A (f'c = 4,000 psi minimum) unless otherwise specified.
B. Reinforced Steel: Deformed and plain carbon steel bars for concrete reinforcement shall meet the requirements of AASHTO M31M/M31-07 Grade 60 (ASTM A615-15a Grade 60). Deformed and Plain reinforcing bars which are shown to be welded in the plans shall meet the requirements of ASTM A706/A706M-15 Grade 60.
C. Structural Steel: W-beam structural steel shapes shall conform to ASTM A992/A992M-11. Structural steel plates and bars shall conform to ASTM A36/A36M-14. All structural steel shall be hot-dip galvanized after fabrication in accordance with ASTM A123/A123M-15.
D. Guardrail bolts and recessed nuts shall conform to FBB01-05 from "A Guide to Standardized Highway Barrier Hardware" AASHTO-AGC-ARTBD Joint Committee Task Force 13 Report.
E. Carriage bolts and nuts shall conform to FBC10-20 From "A Guide to Standardized Highway Barrier Hardware" AASHTO-AGC-ARTBD Joint Committee Task Force 13 Report.
F. High Strength bolts (Heavy Hex Structural Bolts) shall conform to ASTM A325-14, Type 1 unless otherwise specified and hot-dip galvanized in accordance with ASTM F2329/F2329M-15.
G. Bolts (Hex and Heavy Hex Bolts) shall conform to ASTM A307, Grade A unless otherwise specified and hot-dip galvanized in accordance with ASTM F2329/F2329M-15.
H. Anchor bolts (and anchor rods) shall conform to ASTM F1554-15, Grade 105, Class 2A, unless otherwise specified and hot-dip galvanized in accordance with ASTM F2329/F2329M-15.
I. Nuts for ASTM A325 bolts shall be heavy hex and shall conform to ASTM A563-15, Grade DH and hot-dip galvanized in accordance with ASTM F2329/F2329M-15.
J. Nuts for ASTM A307 bolts shall conform to ASTM A563-15, Grade A and hot-dip galvanized in accordance with ASTM F2329/F2329M-15. Nuts for ASTM A307 bolts size 1½" or less shall be hex and for sizes greater than 1½" shall be heavy hex.
K. Nuts for ASTM F1554 anchor bolts (and anchor rods) shall be heavy hex and conform to ASTM A563-15, Grade DH and hot-dip galvanized in accordance with ASTM F2329/F2329M-15.
L. Washers for bolts shall conform to ASTM F436-11, Type 1 and hot-dip galvanized in accordance with ASTM F2329/F2329M-15. Washers for bolts shall be circular style unless otherwise specified.
M. Preformed expansion joint filler for concrete (bituminous type) shall conform to ASTM D994-11(2016) and shall be considered incidental to contract pay items and will not be paid for separately.

**CONSTRUCTION REQUIREMENTS:**

A. Refer to Hawaii Standard Specifications for Road and Bridge Construction, 2015 edition and Special Provisions.
B. Except as noted otherwise, all vertical dimensions are measured plumb.
C. For steel reinforcing, stagger all splices where possible.
D. Steel reinforcing shall be supported, bent and placed as per AASHTO LRFD Bridge Design Specifications, 7th Edition, 2014 including all interim revisions.
E. For cast-in-place concrete minimum reinforcement cover shall be as follows:
   Concrete cast against earth: 3"
   Walls: 2"
   Curbs and Railings: 2"
   Slab tops: 2"
   Measured to the closest part of the bars.
F. At the time concrete is placed, reinforcing shall be free from mud, oil, laitance or other coatings which may adversely affect bond strength.
G. All reinforcement, dowels and other embedded items shall be positively secured before pouring.
H. Minimum clear spacing between parallel bars shall be one and one-half (1½") times the diameter of the larger bar (for non-bundled bars), but in no case shall the clear distance between the bars be less than one and one-half (1½") times the maximum coarse aggregate size.
I. All dimensions relating to reinforcing bars (e.g. spacing of bars etc.) are to centers of bars unless noted otherwise.
J. All footings shall bear on firm undisturbed natural soils or properly compacted structural fill.
K. The welding of reinforcing steel shall be in accordance with the Structural Welding Code-Reinforcing Steel AWS D1.4/D1.4M 2011.
L. The welding of structural steel shall be in accordance with the Structural Welding Code AWS D1.1/D1.1M 2015.
M. The Contractor shall conduct his work in such a manner and provide such temporary shoring or other measures as may be necessary to insure the safety of all concerned and to protect existing structures.
N. In the event of over excavation, the space between the footing or footing key and the ground shall be filled with a minimum of class D concrete at the Contractor's expense at no cost to the State.
O. Unless noted otherwise chamfer all exposed concrete edges three-quarters (3/4) of an inch.

## SYMBOLS AND ABBREVIATIONS

Detail or Section designation — XXX / XXX|XXX — Sheet No. Detail is drawn
Sheet No. Section is cut or Detail Location

(XX) - ℄ Bearing Abutment Seat Line
- Boring No. # Designation

| | |
|---|---|
| Abut. | Abutment |
| AC | Asphaltic Concrete |
| Adj. | Adjacent |
| Alt. | Alternate |
| Approx. | Approximate |
| Az. | Azimuth |
| ℄ | Baseline |
| Bal. | Balance |
| Bet., Btwn. | Between |
| B.F. | Both faces |
| B.F.E. | Bottom Footing Elevation |
| Bk. | Back |
| Blt. | Bolt |
| Bm. | Beam |
| B, Bot., Bott. | Bottom |
| Br. | Bridge |
| Brg., Brgs. | Bearing, Bearings |
| B.V.C. | Beginning of Vertical Curve |
| ℄ | Center Line |
| Cant. | Cantilever |
| C.F. | Cubic Feet |
| CIP | Cast in Place |
| C.I.P. | Cast Iron Pipe |
| Cl., Clr. | Clear |
| Col. | Column |
| Conc. | Concrete |
| Conn. | Connection |
| Const. | Construction |
| Cont. | Continuous |
| CRM | Cement Rubble Masonry |
| C.Y., Cu. Yd. | Cubic Yards |
| Det. | Detail |
| Dia., ø | Diameter |
| Dim. | Dimension |
| Dwg., Dwgs. | Drawing, Drawings |
| EA, Ea., ea. | Each |
| E.F. | Each Face |
| Elec. | Electrical |
| El., Elev. | Elevation |
| Emb. | Embankment |
| E.P. | Edge of Pavement |
| Eq. | Equal |
| Est. | Estimated |
| E.W. | Each Way |
| Exc. | Excavation |
| Exist. | Existing |
| Exp., (E) | Expansion |
| Ext. | Exterior |
| (F) | Fixed |
| $F'_C$ | Specified Strength of Concrete |
| $F'_{Ci}$ | Strength of Concrete at Time of Initial Prestress |
| F.F. | Front Face |
| Fig. | Figure |
| Fin. | Finish |
| Fin. Gr. | Finish Grade |
| Ftg. | Footing |
| Ga. | Gage, Gauge |
| Galv. | Galvanized |
| Gir., G | Girder |
| G.R.P. | Grouted Rubble Paving |
| Gr. | Grade |
| Grd. | Ground |
| (H) | Hinge |
| Horiz. | Horizontal |
| HS | High Strength |
| Ht. | Height |
| Hwy. | Highway |
| I.B. | Inbound |
| I.F. | Inside Face |
| In. | Inch |
| Int. | Interior |
| Inv. | Invert |
| Jt. | Joint |
| L | Length |
| LBS., lb., lbs. | Pound, Pounds |
| L.F., Lin. Ft. | Linear Feet |
| Lg. | Long |
| Longit. | Longitudinal |
| L.S. | Lump Sum |
| Lt. | Left |
| Ltg. Std. | Lighting Standard |
| Max. | Maximum |
| Mech. | Mechanical |
| Min. | Minimum |
| Misc. | Miscellaneous |
| N | North |
| N.B. | Northbound |
| N.F. | Near Face |
| No., # | Number |
| N.T.S. | Not To Scale |
| O.B. | Outbound |
| o.c. | On Center |
| O.G. | Outside Girder |
| Opn'g | Opening |
| o/s, O/S | Offset |
| P.B. | Pull Box |
| P.C. | Point of Curvature |
| P.C.C. | Portland Cement Concrete |
| Perf. | Perforated |
| PG-( ) | Prestressed Girder-(Type) |
| PL | Plate |
| P/S | Prestressed Strands |
| Pvmt. | Pavement |
| R | Radius |
| Rdwy | Roadway |
| Ref. | Reference |
| Reinf. | Reinforcement |
| Ret. | Retaining |
| Req'd | Required |
| R.F. | Rear Face |
| Rt. | Right |
| R/W | Right Of Way |
| S | South |
| S.B. | Southbound |
| Sect. | Section |
| SF | Square Feet |
| Shldr. | Shoulder |
| Sht. | Sheet |
| Spc. | Space |
| Spcd. | Spaced |
| Spcg. | Spacing |
| Spec. | Specification |
| Sprd. | Spread |
| Sta. | Station |
| Std. | Standard |
| Stirr. | Stirrup |
| Str. | Straight |
| Struct. | Structural |
| Symm. | Symmetrical |
| T | Top |
| Temp. | Temporary |
| Thk. | Thick, Thickness |
| T.O.D. | Top Of Deck |
| Tot. | Total |
| Transv. | Transverse |
| Typ. | Typical |
| Var. | Varies |
| V.C. | Vertical Curve |
| Vert. | Vertical |
| W | West |
| w/ | With |
| W.W. | Wingwall |

**CONSTRUCTION REQUIREMENTS cont:**

P. Refer to Standard Plans for additional details and notes not covered by details and typical drawings.
Q. Anchor bolts shall have sufficient length when installed to ensure that the bolt projects at least ⅛" beyond the top of the nut but should not project more than ¼". Anchor bolts shall not be out of plumb more than 1:40 Horizontal: Vertical.
R. Bolts and high strength bolts shall have sufficient length when installed to ensure that the bolt projects at least ⅛" beyond the nut but should not project more than ¼".

AUG 21 2017

DRAFT

STATE OF HAWAII
DEPARTMENT OF TRANSPORTATION
HIGHWAYS DIVISION
STANDARD BRIDGE RAILINGS & TRANSITIONS
GENERAL NOTES and
SYMBOLS and ABBREVIATIONS
CRASH TESTING OF VARIOUS BRIDGE GUARDRAILS AND TRANSITIONS
Project No. STP-1500(092)R
Scale: As Noted Date: Aug. 2017

SHEET No. 01 OF 2 SHEETS

Figure 9. HDOT AGT Details, Material Specifications and Notes

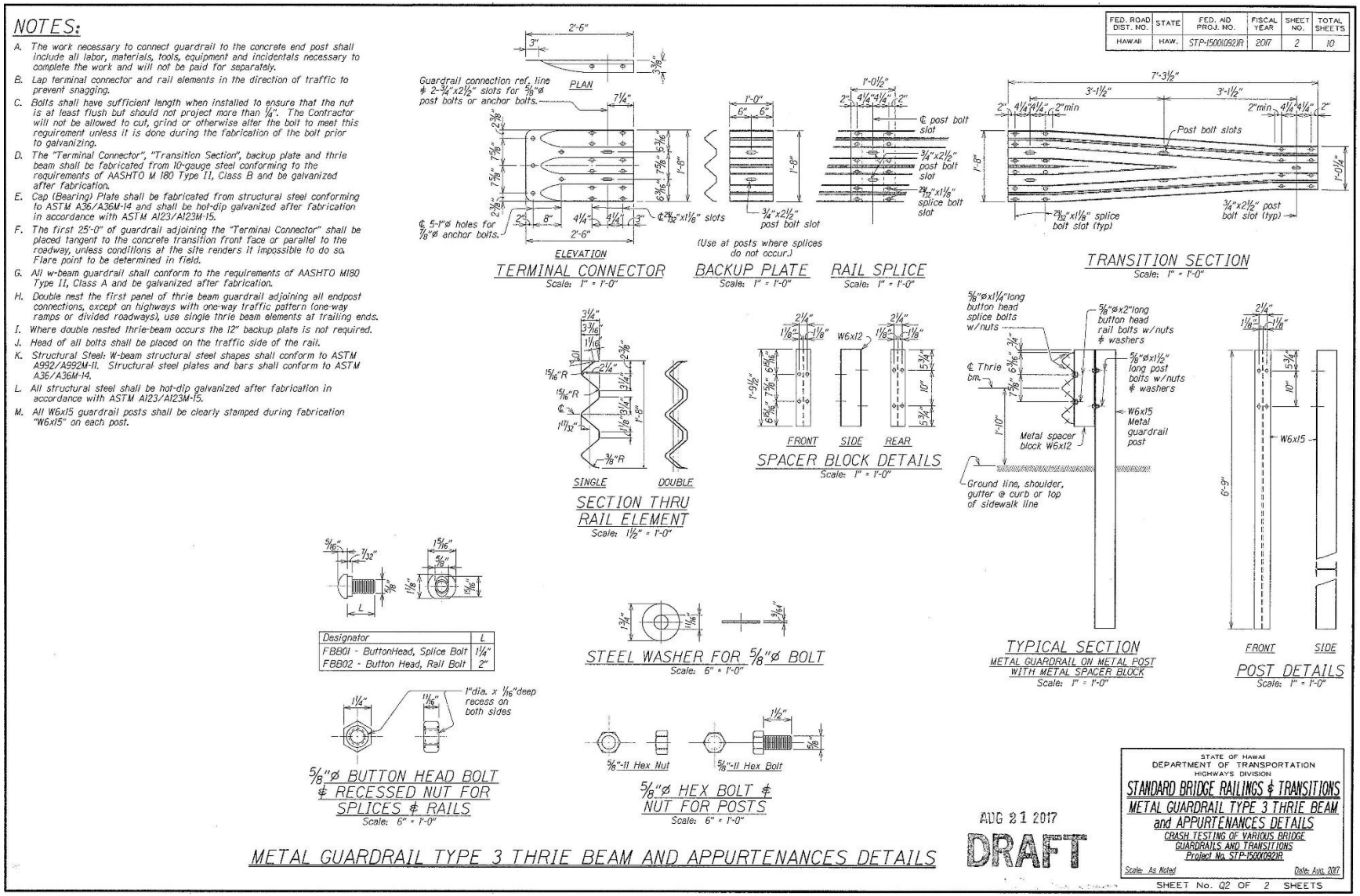



Figure 10. HDOT AGT Details, Guardrail and Connection Hardware

# 2 DESIGN DETAILS

## 2.1 Design Modifications

As described previously, the upstream region of the HDOT thrie beam AGT was modified to include the MGS with a top rail mounting height of 31 in. Specifically, the MGS upstream stiffness transition, which was successfully evaluated and crash tested to MASH TL-3, was incorporated into the HDOT AGT design. The MGS upstream stiffness transition was designed to transition from 31-in. tall W-beam guardrail to the stiffened thrie beam regions of AGTs using an asymmetrical W-to-thrie transition rail segment and standard 6-ft long W6x8.5 or W6x9 guardrail posts [4]. The MGS stiffness transition was designed to be compatible with a variety of thrie beam AGTs. Thus, its inclusion within the HDOT AGT would only require modifications to a few components, all of which were discussed with HDOT prior to the finalization of the new AGT design.

Merging the HDOT AGT and the MGS upstream stiffness transition required the use of the asymmetrical W-to-thrie rail segment and a rearrangement of the posts. The top of Figure 11 shows the original HDOT AGT, while the bottom of the figure shows the as-tested MGS upstream stiffness transition. The middle of Figure 11 depicts the merging of the two transitions to create a modified HDOT AGT. Note that the length of the thrie beam and transition rail segments remained the same. The modified HDOT AGT incorporated two more posts than the original HDOT AGT, but the additional posts located within the upstream stiffness transition were deemed necessary to provide a smooth transition between standard MGS and the stiffened, nested thrie beam region of the AGT. Further elimination of posts in this region of the system would require additional tests to evaluate the safety performance in this region. Additionally, the number of the larger W6x15 transition posts was reduced from eight to four, and only post nos. 1 and 2 were spaced 18.75 in. apart. The rest of the W6x15 posts were spaced at 37.5 in. on-center.

HDOT's original AGT was detailed with a top rail height of 32 in., as noted in Figure 11. However, most thrie beam AGTs, the MGS stiffness transition, and the MGS itself have nominal rail mounting heights of 31 in. Therefore, the top-mounting height of the thrie beam was reduced from 32 in. to 31 in. within the modified transition.

HDOT's Type D2 End Post is 34 in. tall, so the end post extended 3 in. above the 31-in. thrie beam. Due to concerns of vehicle snag on the upstream end of the end post above the rail, a vertical taper measuring 2 in. vertically and 12 in. longitudinally was placed on the upstream end of the parapet. Note, this taper was not included in the sketches in Figure 11 as it would be too small to see clearly, but it was incorporated into the test article's detailed drawings.

The original HDOT AGT used W6x12 steel blockouts between the W6x15 posts and the guardrail segments. However, wide-flange steel blockouts have been associated with multiple performance issues. First, the thin, single web of wide-flange sections make the blockout more vulnerable to buckling, which allows for increased lateral displacements and increases the risk of vehicle snag. Second, the flange edges of wide-flange sections represent relatively sharp, hard points that induce stress concentrations that can lead to tearing in the rail. Previously, rectangular HSS tube blockouts have been developed for use within AGTs as they are much less likely to buckle/fail under lateral loading and have rounded edges that greatly reduce the risk of rail tearing

[5]. Therefore, the modified HDOT AGT incorporated rectangular HSS tube blockouts instead of the previous-used W6x12 blockouts.

The original HDOT also specified 12-in. backup plates for use behind the guardrail except for post locations adjacent to nested rail sections or at rail splices. The modified HDOT AGT design limited the amount of backup plates to only two post locations within the entire AGT. Further, the risk of rail tearing was reduced by the switch to HSS tube blockouts. Subsequently, backup plates were deemed unnecessary and were removed from the modified HDOT AGT.

A total of seven bolts were used in the original HDOT AGT to anchor the thrie beam to the Type D2 End Post, five ⅞-in. diameter bolts in the terminal connector and two ⅝-in. diameter bolts through the center of the splice between the terminal connector and the nested thrie beam. Previous MASH crash testing of thrie beam transitions has shown that the five ⅞-in. diameter bolts are sufficient to anchor the rail [6-9]. Thus, the extra two bolts in the center of the splice were removed from the modified HDOT AGT.

Finally, the 6-in. curb located beneath the thrie beam rails was flared away from the roadway to mitigate wheel snag in the original HDOT AGT design. However, the same flared curb would interfere with the placement of post no. 7 in the modified HDOT AGT, as shown in Figure 12. Multiple options were investigated to alleviate this issue, including reducing the lateral flare of the curb and reducing the length of the curb such that it terminates within the 37.5-in. spacing of the W6x15 transition posts. Ultimately, HDOT decided to eliminate the flare and instead terminate the curb with a vertical taper, as shown at the bottom of Figure 12. Note, the longitudinal length of the tangent curb in the modified HDOT AGT remained the same as the flared curb in the original HDOT AGT.

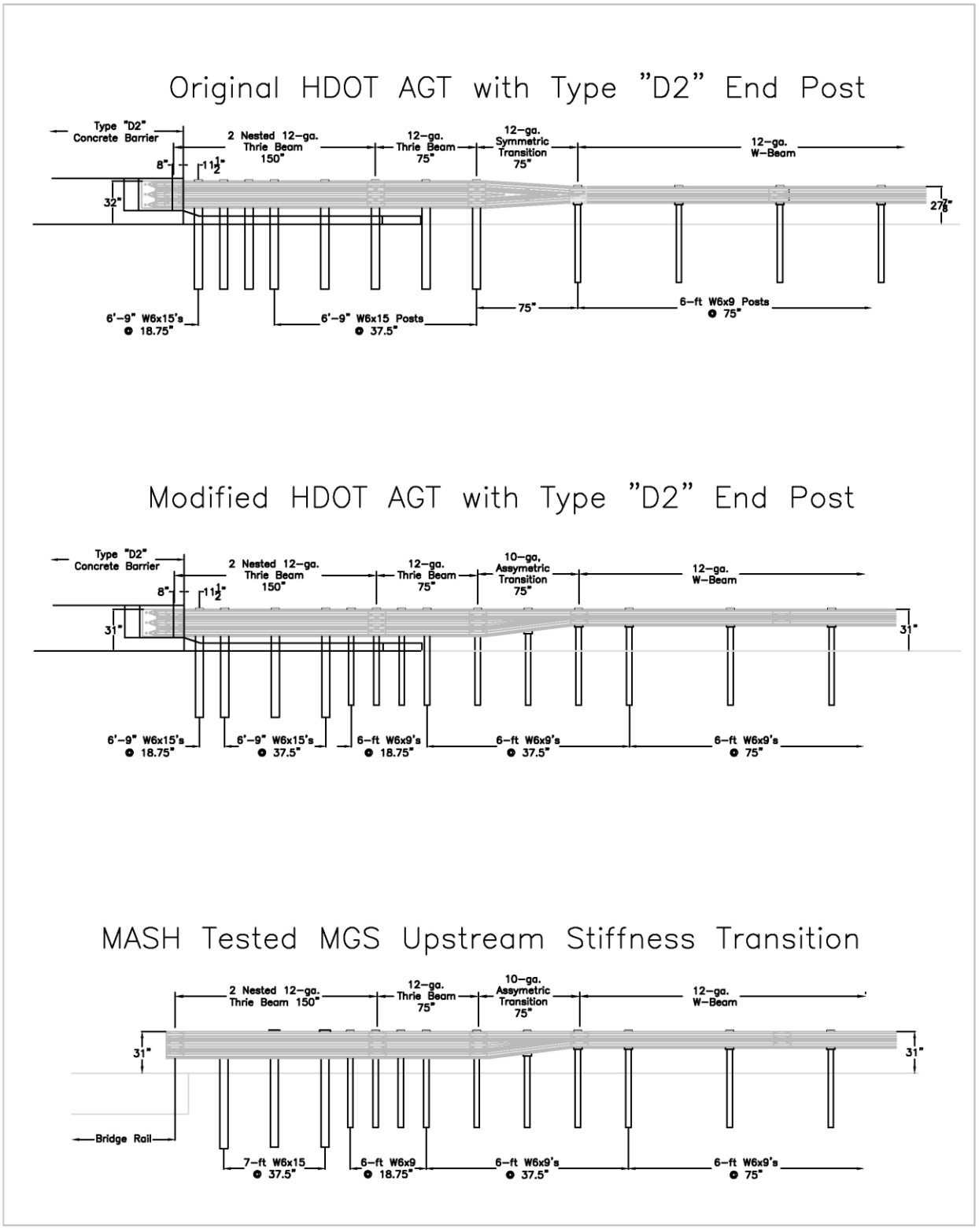



Figure 11. Modified HDOT AGT with Inclusion of MGS Upstream Stiffness Transition

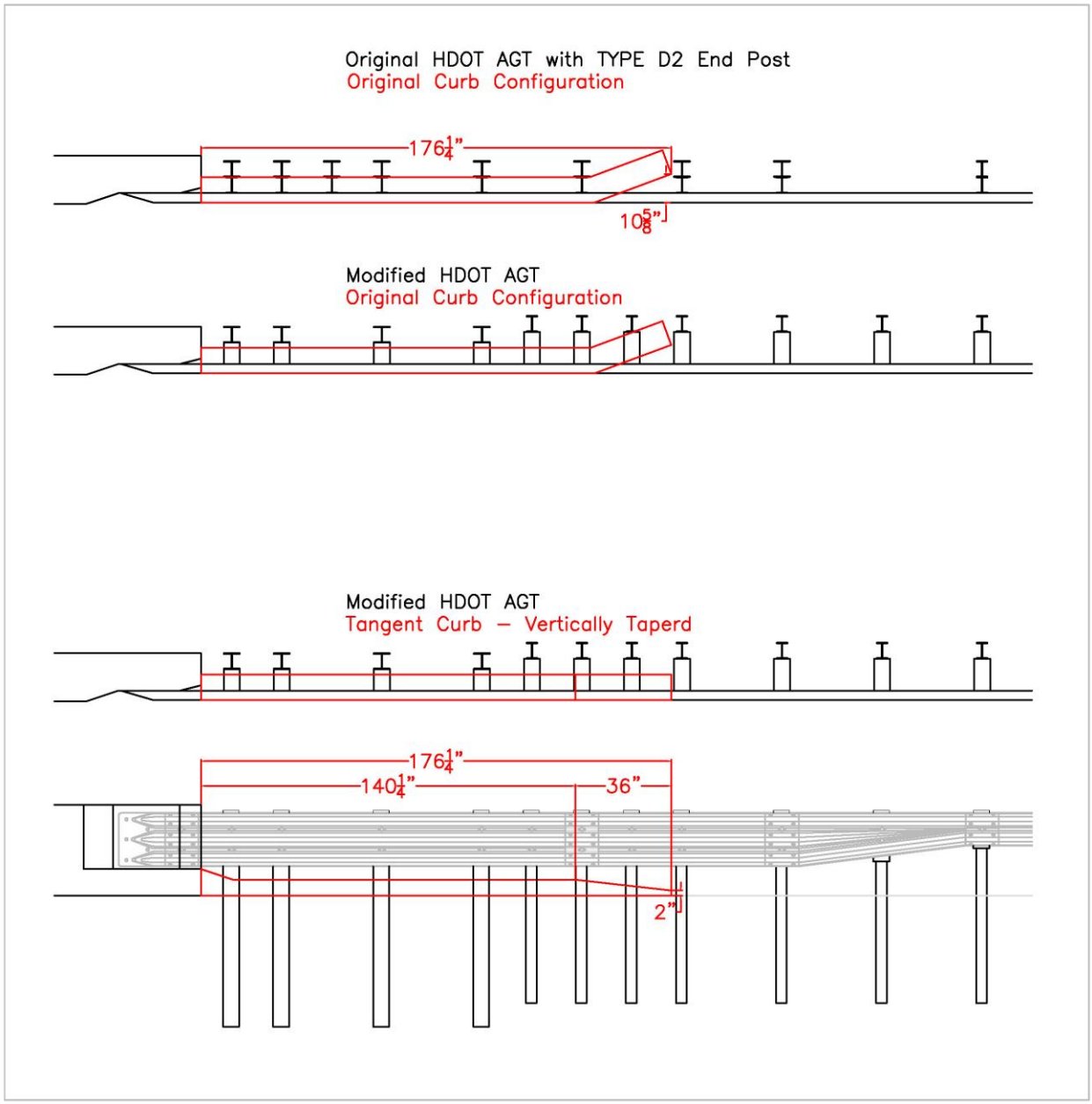



Figure 12. Modified HDOT AGT with Inclusion of MGS Upstream Stiffness Transition

## 2.2 Test Article Details – Modified HDOT AGT

The modified HDOT AGT test installation was approximately 83 ft long and consisted of a concrete parapet, transition, a thrie beam AGT, MGS, and a guardrail anchorage system, as shown in Figures 13 through 41. Photographs of the test installation are shown in Figures 42 through 44. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

At the downstream end of the test installation, there existed an 8-ft long version of HDOT's Type D2 End Post. Since the downstream half of the end post was not expected to interact with

the test vehicles, the length of the end post was reduced from its standard 18-ft length to reduce installation costs. The test installation end post was 34 in. tall, 18 in. wide, and was reinforced with a combination of longitudinal and lateral steel rebar. The vertical steel bars of the end post were anchored directly to the non-reinforced existing concrete tarmac using a chemical epoxy with a minimum bond strength of 1,450 psi. The upstream end of the end post was sloped vertically with a 2-in. x 12-in. taper. The face of the end post was recessed 4 in. at the location of the guardrail terminal connector so that the face of the thrie beam was nearly flush with the face of the concrete parapet. The concrete was found to have a compressive strength of approximately 4,900 psi prior to crash testing.

The downstream end of the AGT was comprised of 12.5 ft of nested thrie beam rail supported by W6x15 steel posts at various spacings, while the upstream end of the AGT incorporated the previously MASH tested MGS upstream stiffness transition [4] to connect the AGT to the adjacent MGS. All guardrail segments had a top mounting height of 31 in. Blockouts within the AGT consisted of rectangular HSS steel tubes. The W6x15 posts were 7 ft long, while the W6x8.5/W6x9 posts were 6 ft long. To ensure the width of the blockouts matched the width of the posts, 6-in. wide blockouts were used with W6x15 posts, and 4-in. wide blockouts were used with W6x8.5/W6x9 posts.

A 6-in. tall concrete curb was placed below the AGT with its front face flush with the face of the guardrail. The curb began at the upstream end of the concrete end posts and extended 176.25 in. upstream. The curb was terminated with a vertical taper measuring 4 in. vertically by 36 in. longitudinally prior to extending below the asymmetrical W-to-thrie transition segment. A 4-in. x 12-in. vertical taper was applied to the downstream end of the curb adjacent to the concrete end post to mitigate wheel snag on the end post.

Approximately 37.5 ft of MGS extended from the upstream end of the AGT. This MGS region of the test installation utilized plastic blockouts manufactured by Mondo Polymer Technologies.

Finally, a guardrail anchorage system typically utilized as a trailing end terminal was utilized to anchor the upstream end of the test installation. The guardrail anchorage system was originally designed to simulate the strength of other crashworthy end terminals. The anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts, which closely resembled the hardware used in the Modified Breakaway Cable Terminal (BCT) system. The guardrail anchorage system has been MASH TL-3 crash tested as a downstream trailing end terminal [10-13].

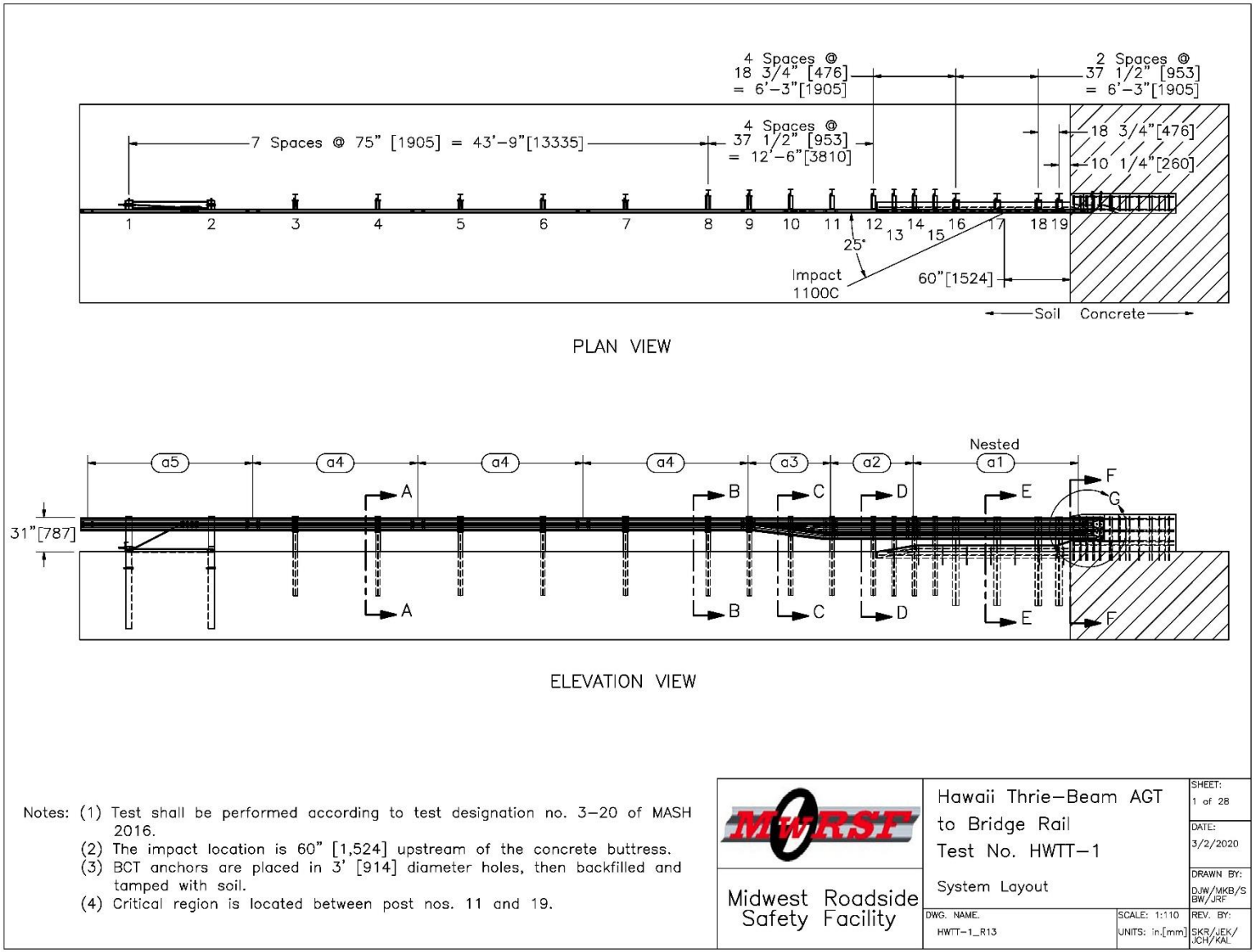



Figure 13. System Layout, Test No. HWTT-1

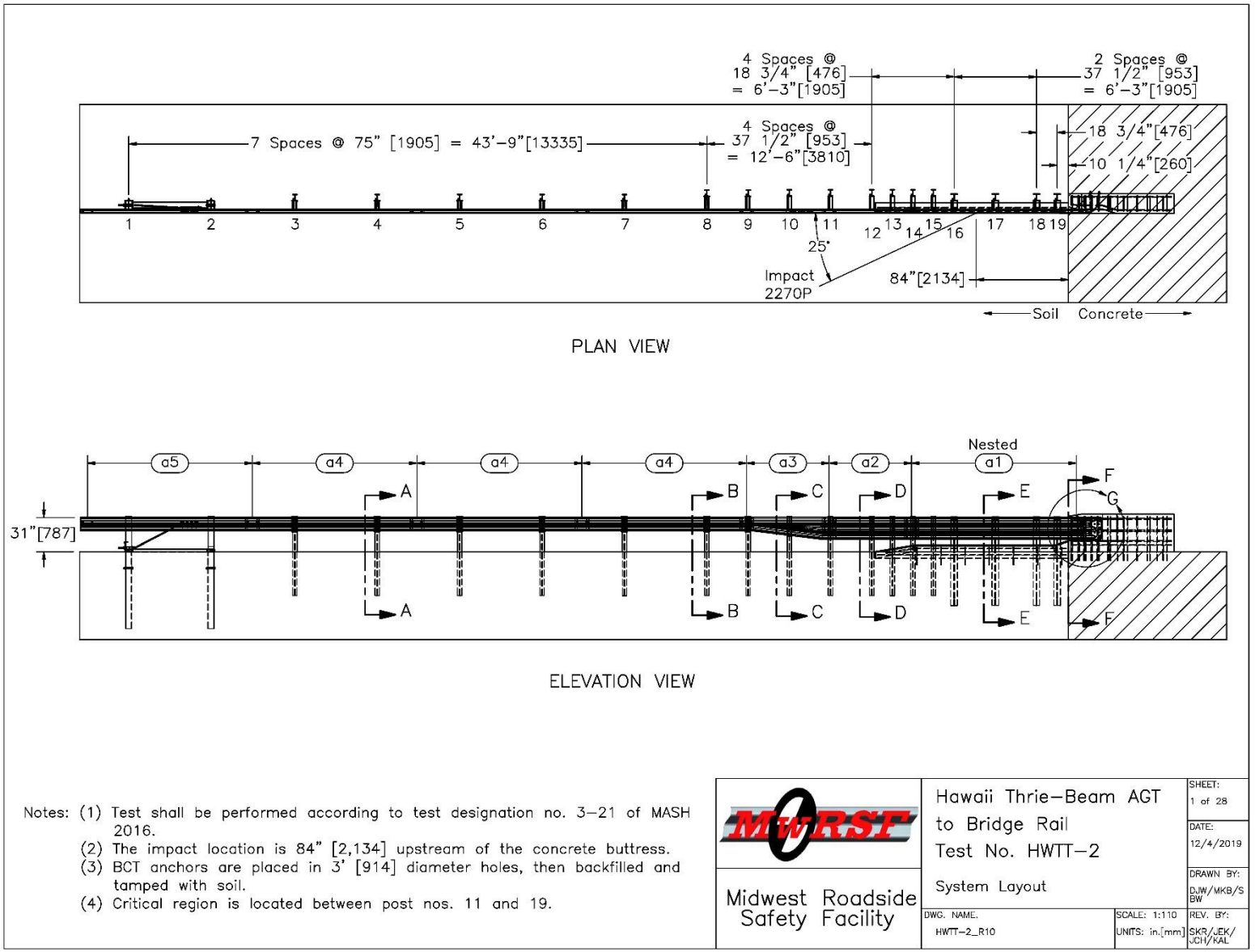



Figure 14. System Layout, Test No. HWTT-2

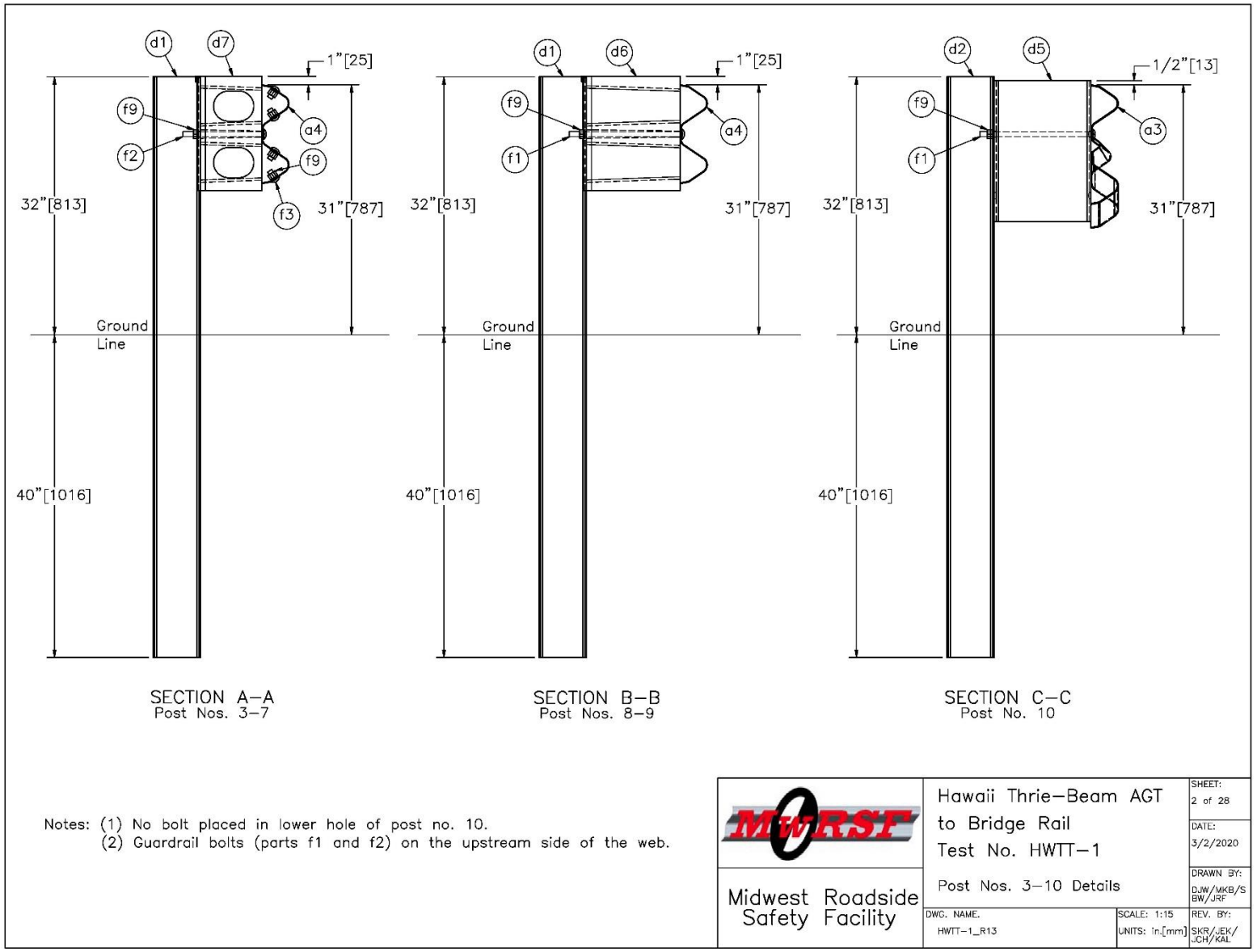



Figure 15. Post Nos. 3 through 10 Details, Test Nos. HWTT-1 and HWTT-2

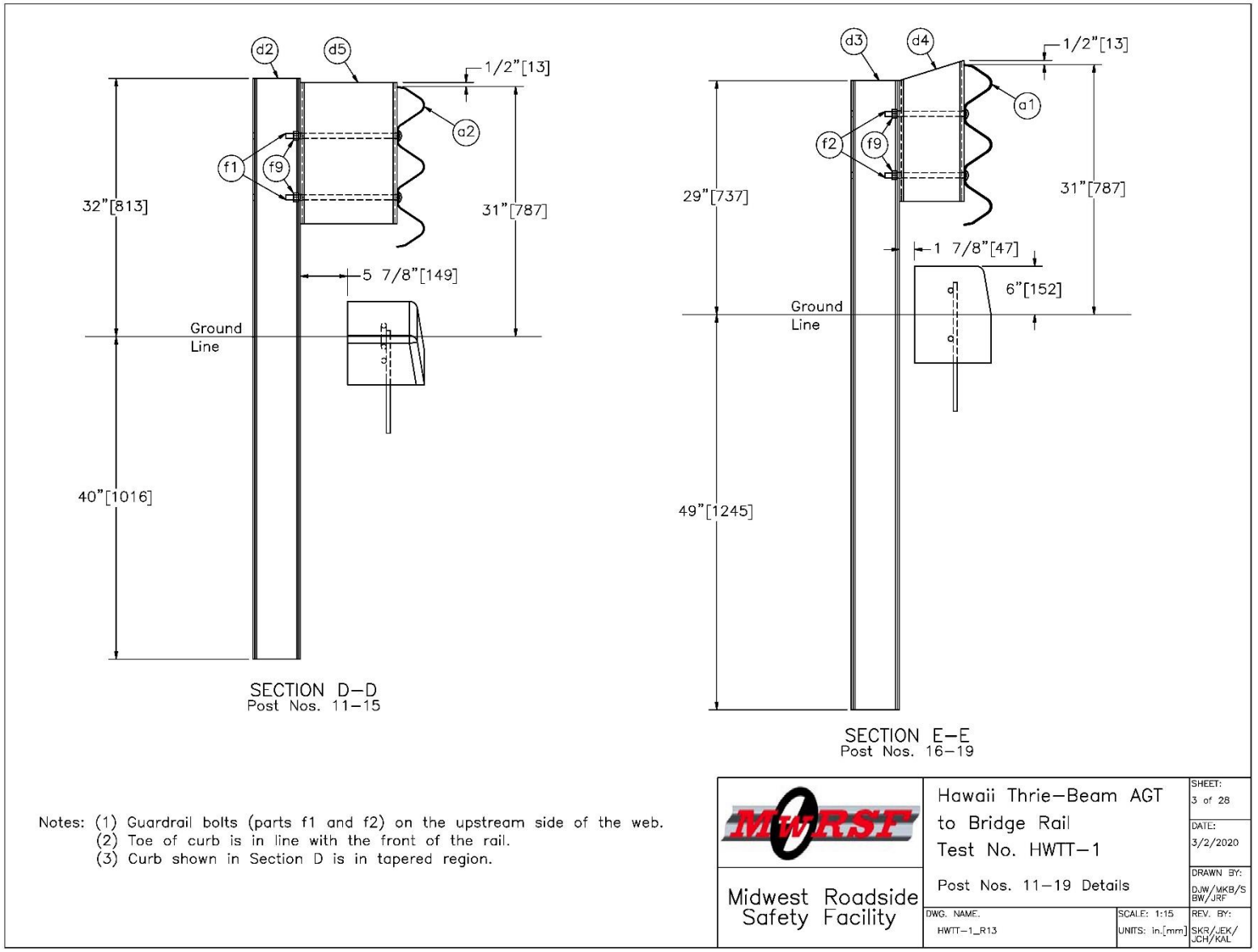



Figure 16. Post Nos. 11 through 19 Details, Test Nos. HWTT-1 and HWTT-2

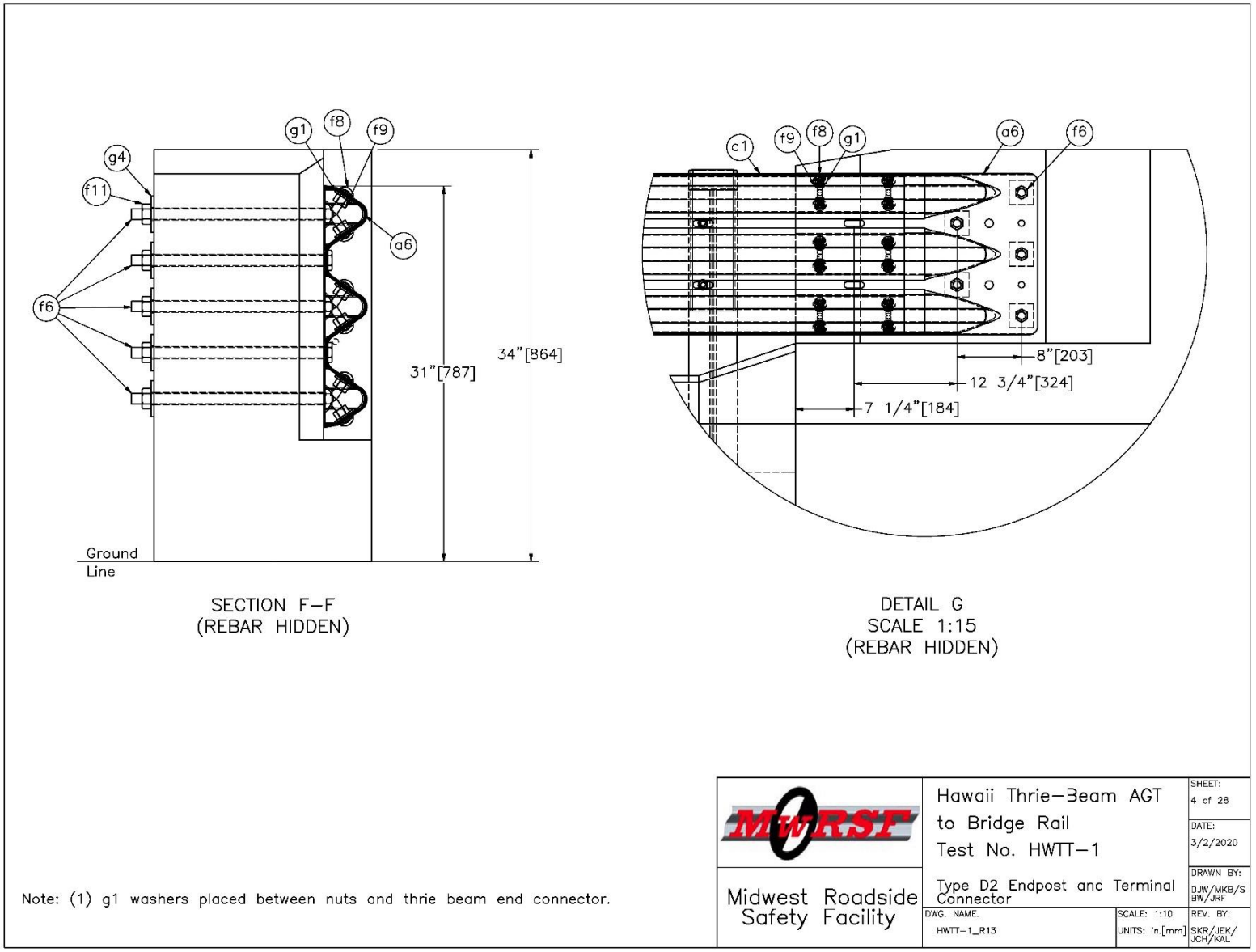



Figure 17. Type D2 End Post and Terminal Connector, Test Nos. HWTT-1 and HWTT-2

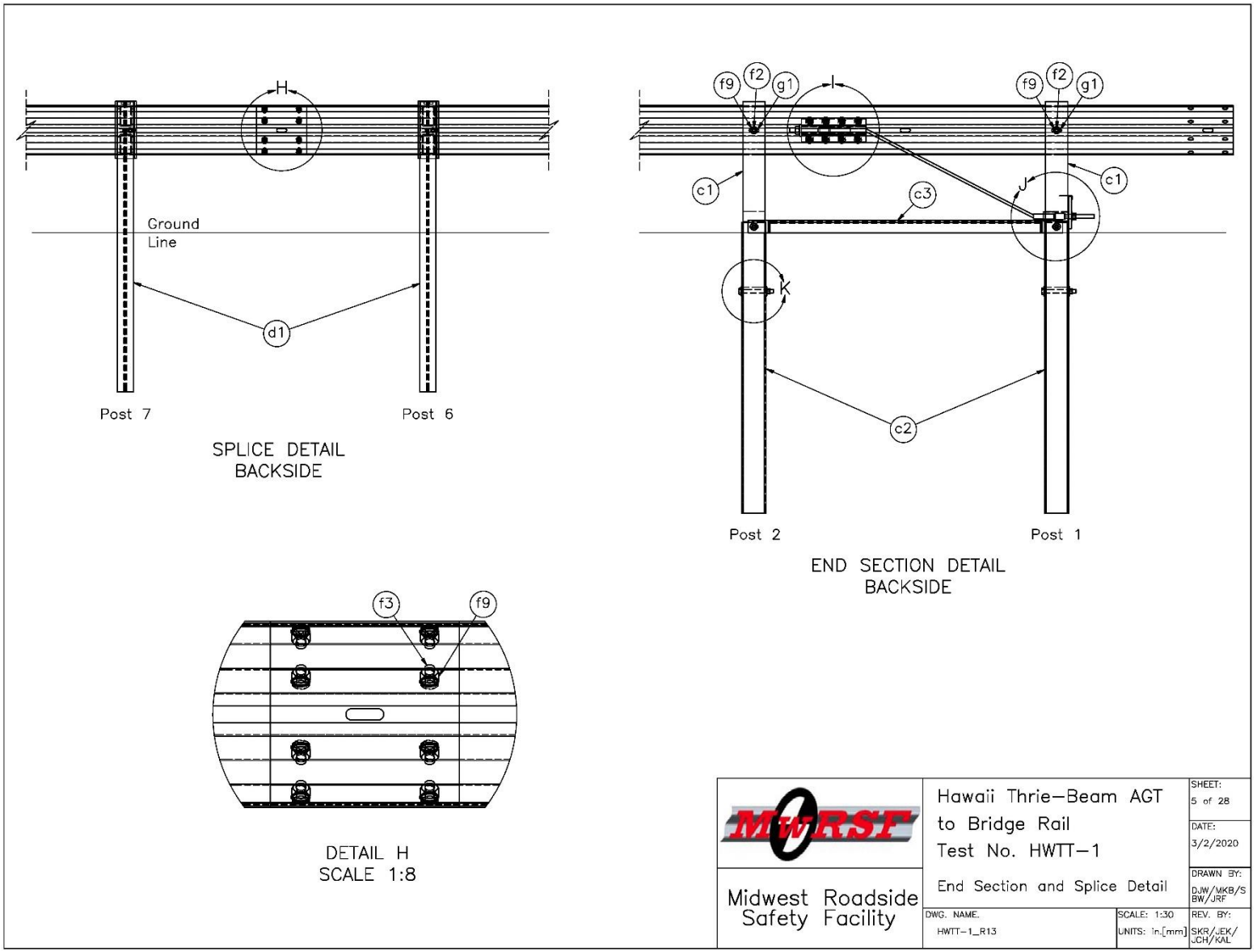



Figure 18. Guardrail End Section and Splice Detail, Test Nos. HWTT-1 and HWTT-2

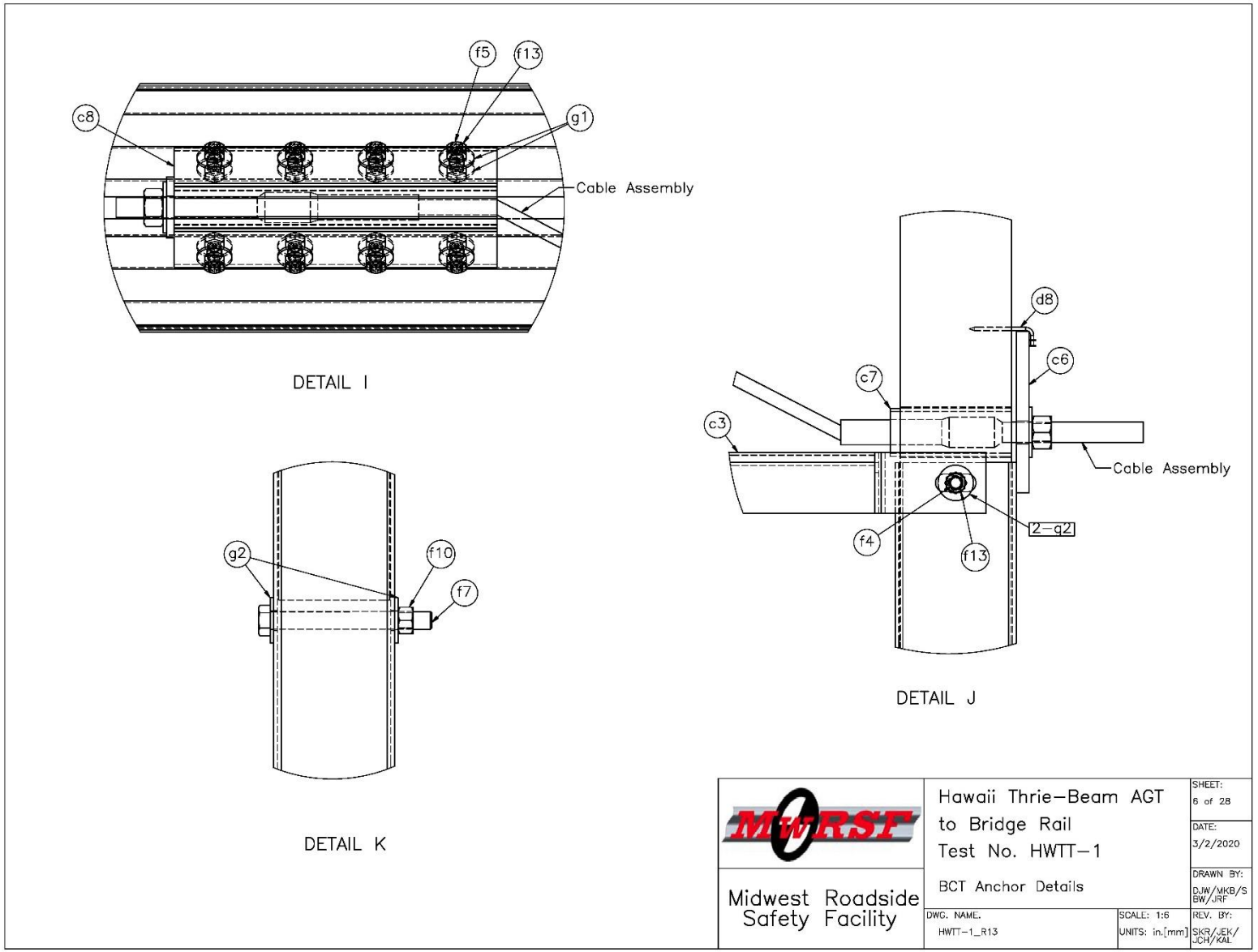



Figure 19. BCT Anchor Details, Test Nos. HWTT-1 and HWTT-2

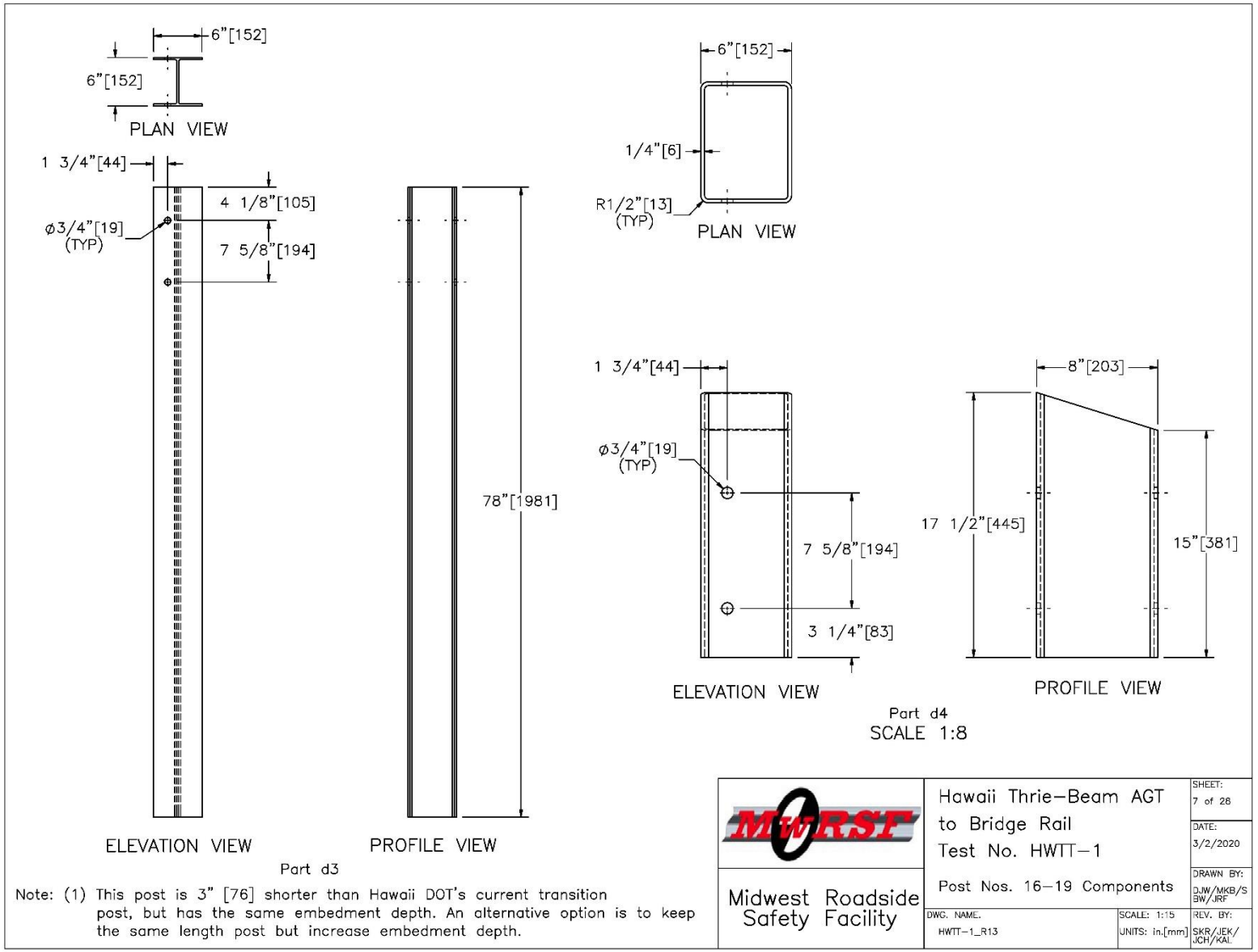



Figure 20. Post Nos. 16 through 19 Components, Test Nos. HWTT-1 and HWTT-2

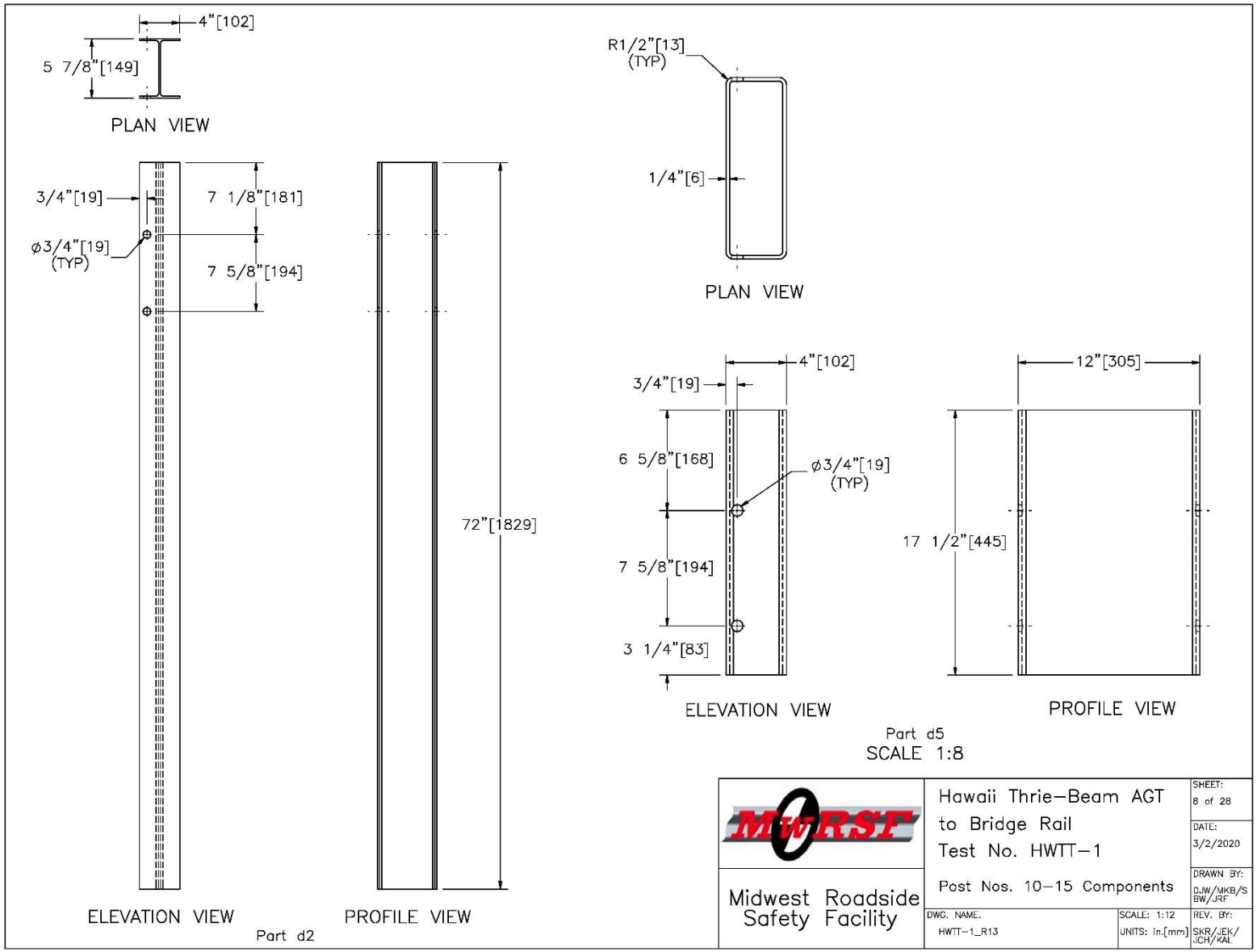



Figure 21. Post Nos. 10 through 15 Components, Test Nos. HWTT-1 and HWTT-2

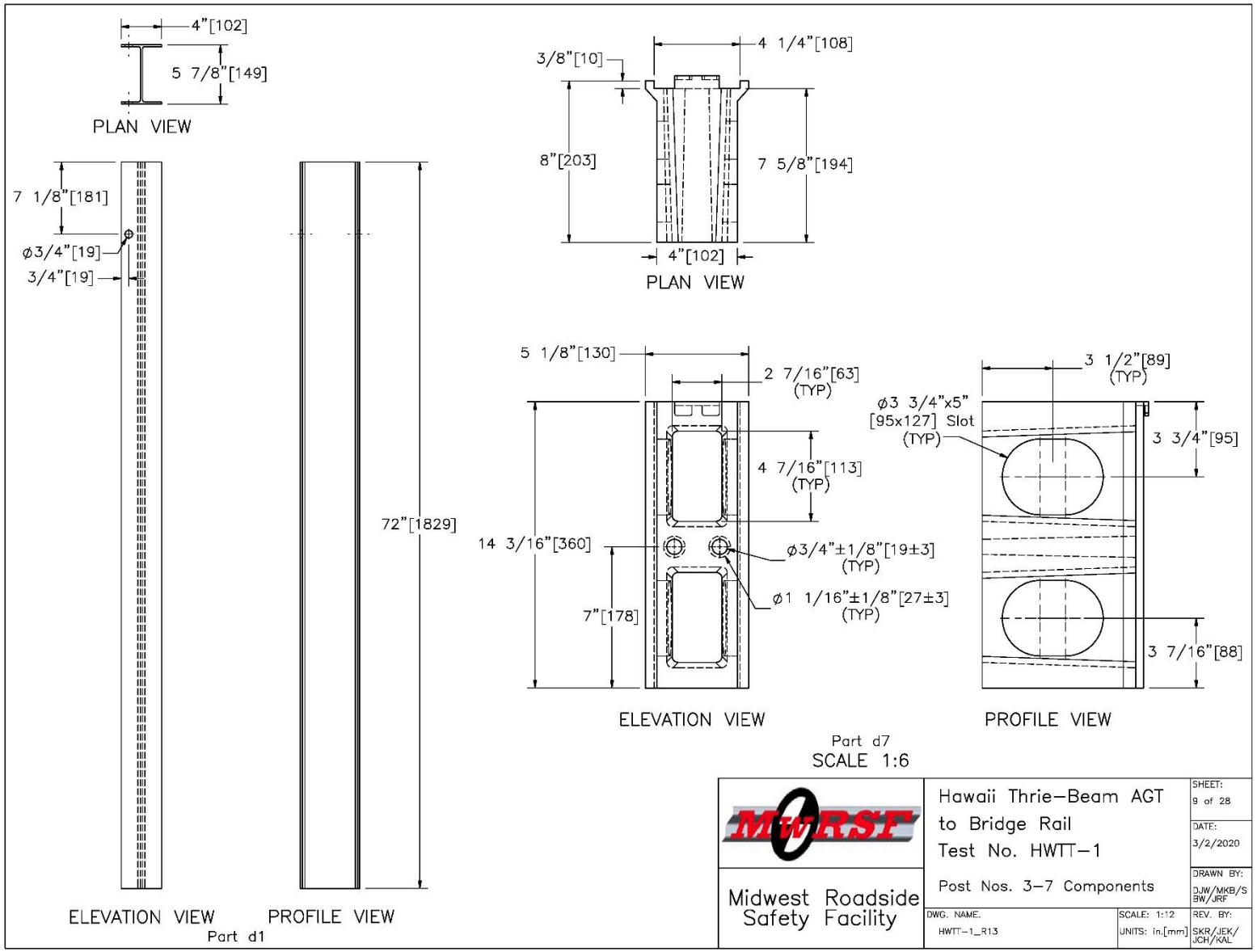



Figure 22. Post Nos. 3 through 7 Components, Test Nos. HWTT-1 and HWTT-2

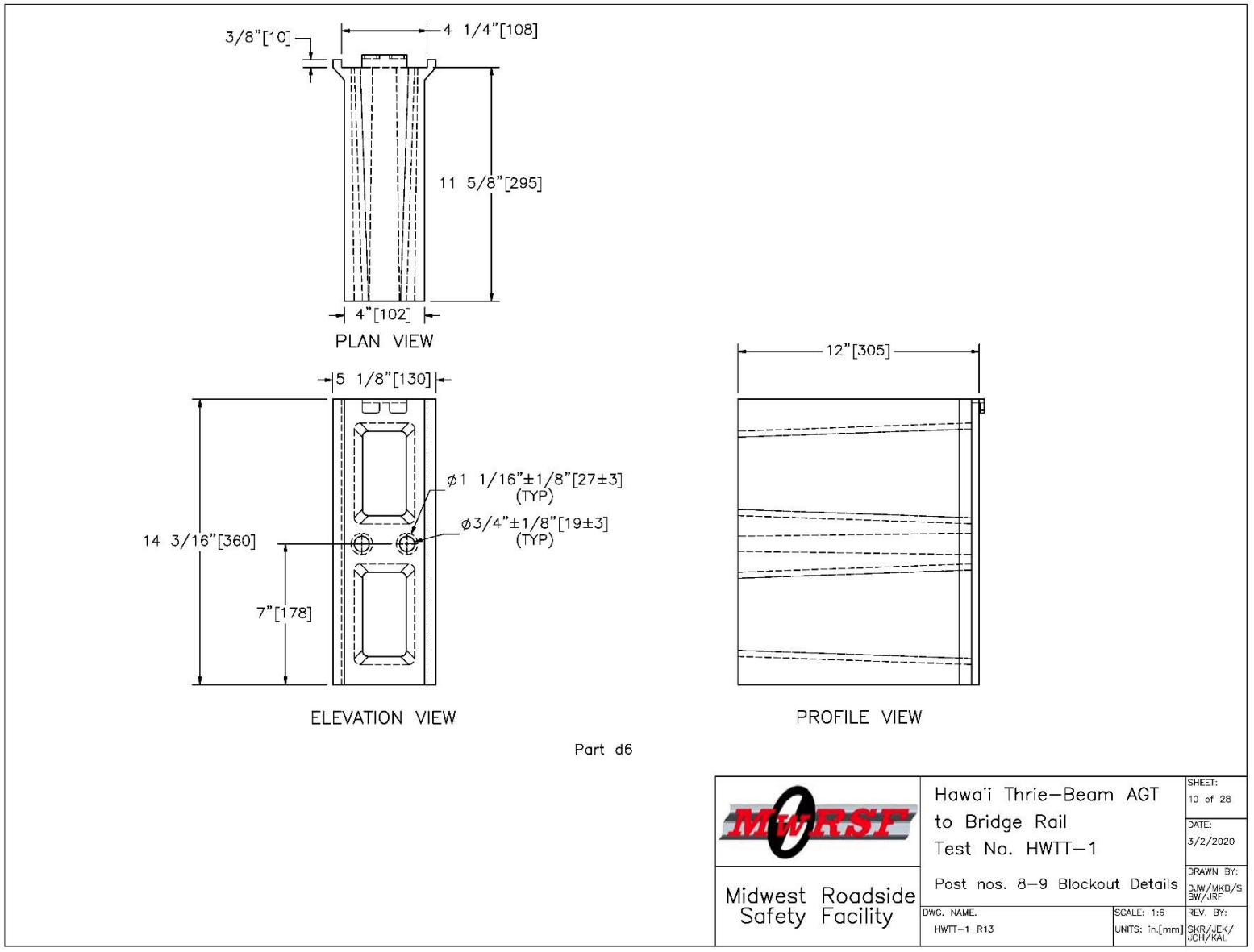



Figure 23. Post Nos. 8 and 9 Blockout Details, Test Nos. HWTT-1 and HWTT-2

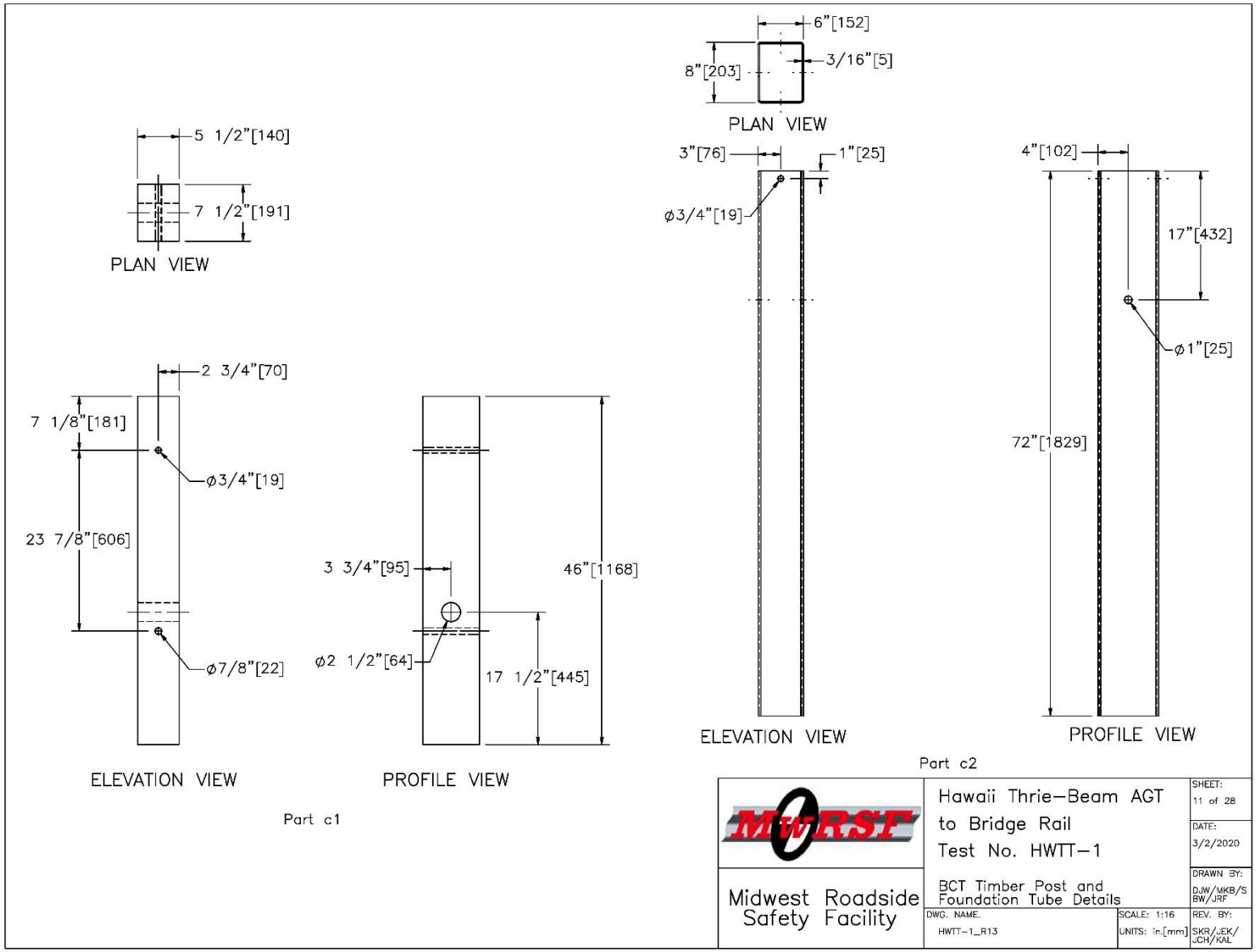



Figure 24. BCT Timber Post and Foundation Tube Details, Test Nos. HWTT-1 and HWTT-2

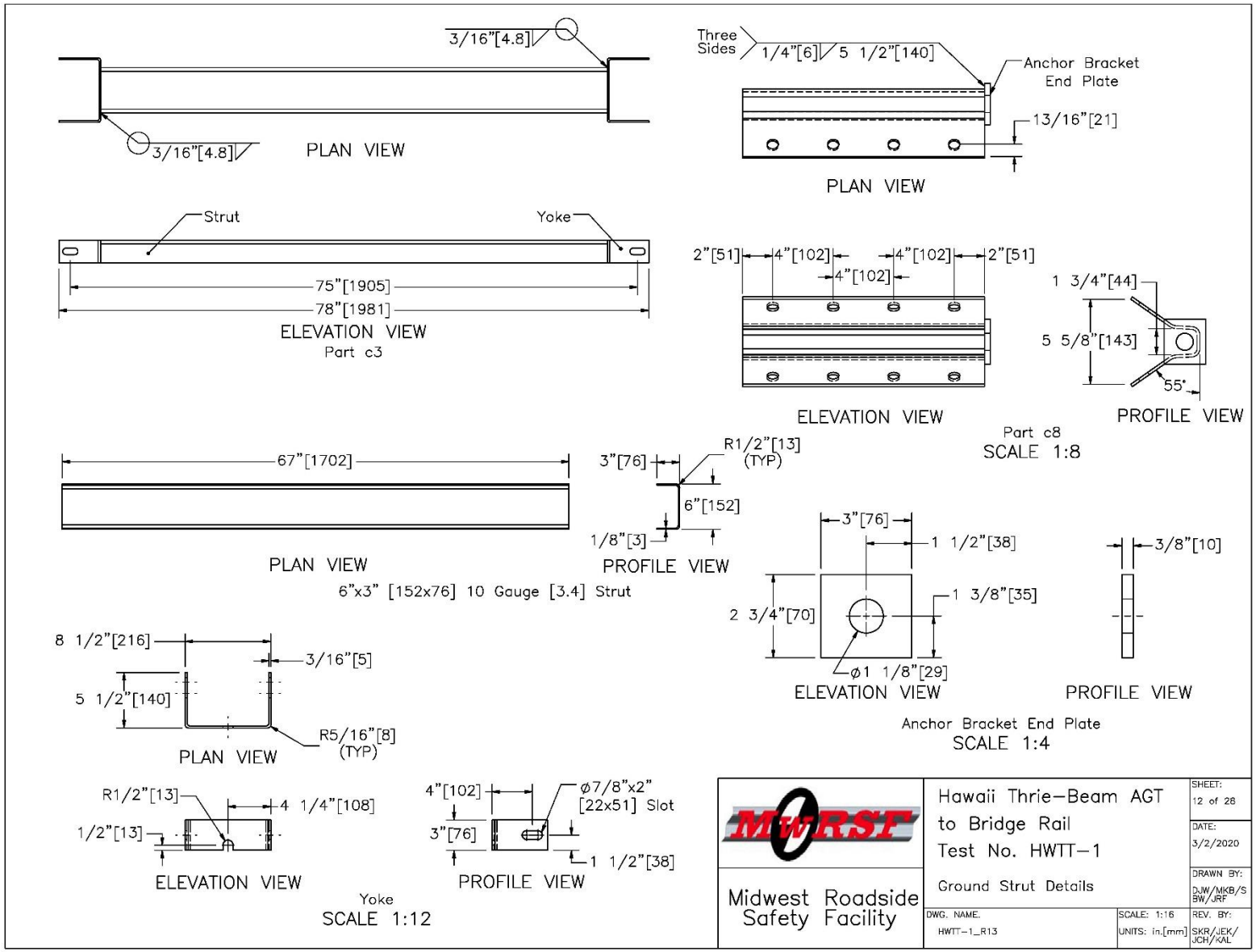
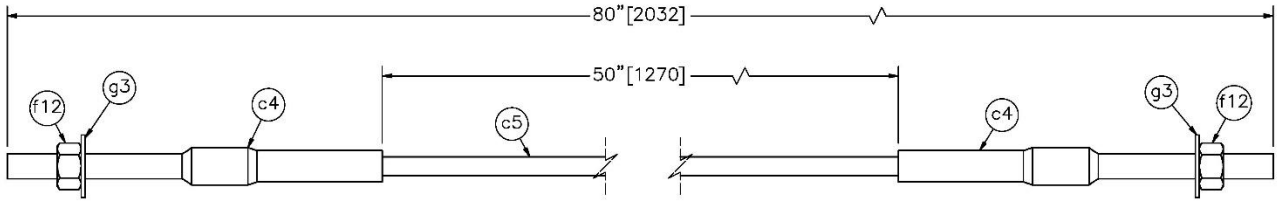



Figure 25. Ground Strut Details, Test Nos. HWTT-1 and HWTT-2




Cable Assembly

| Item No. | QTY. | Description | Material Specification | Treatment Specification | Hardware Guide |
|---|---|---|---|---|---|
| – | 1 | Cable Assembly | – | – | FCA01 |
| c4 | 2 | BCT Anchor Cable End Swaged Fitting | Fitting – ASTM A576 Gr. 1035<br>Stud – ASTM F568 Class C | Fitting – ASTM A153<br>Stud – ASTM A153 or B695 | – |
| c5 | 1 | 3/4" [19] Dia. 6x19 IWRC IPS Wire Rope | ASTM A741 Type 2 | Class A Coating | – |
| f12 | 2 | 1"–8 UNC [M24x3] Heavy Hex Nut | ASTM A563DH or equivalent | ASTM A153 or B695 Class 55 or F2329 | FNX24b |
| g3 | 2 | 1" [25] Dia. Plain USS Washer | ASTM F844 | ASTM A123 or A153 or F2329 | FWC24a |

Midwest Roadside Safety Facility

Hawaii Thrie–Beam AGT to Bridge Rail
Test No. HWTT–1
BCT Anchor Cable

DWG. NAME. HWTT–1_R13
SCALE: 1:6
UNITS: in.[mm]

SHEET: 13 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL

Figure 26. BCT Anchor Cable Details, Test Nos. HWTT-1 and HWTT-2

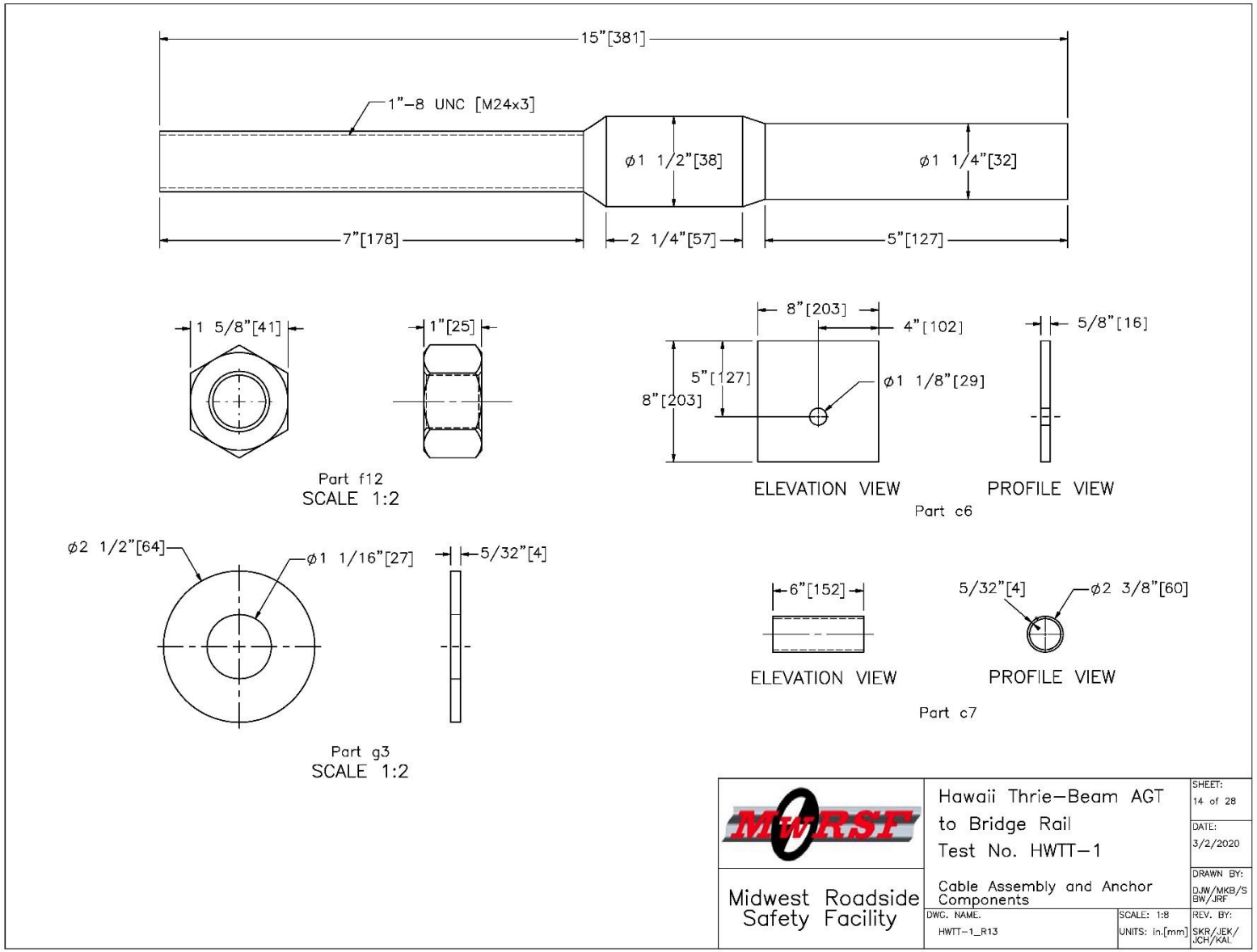



Figure 27. Cable Assembly and Anchor Components, Test Nos. HWTT-1 and HWTT-2

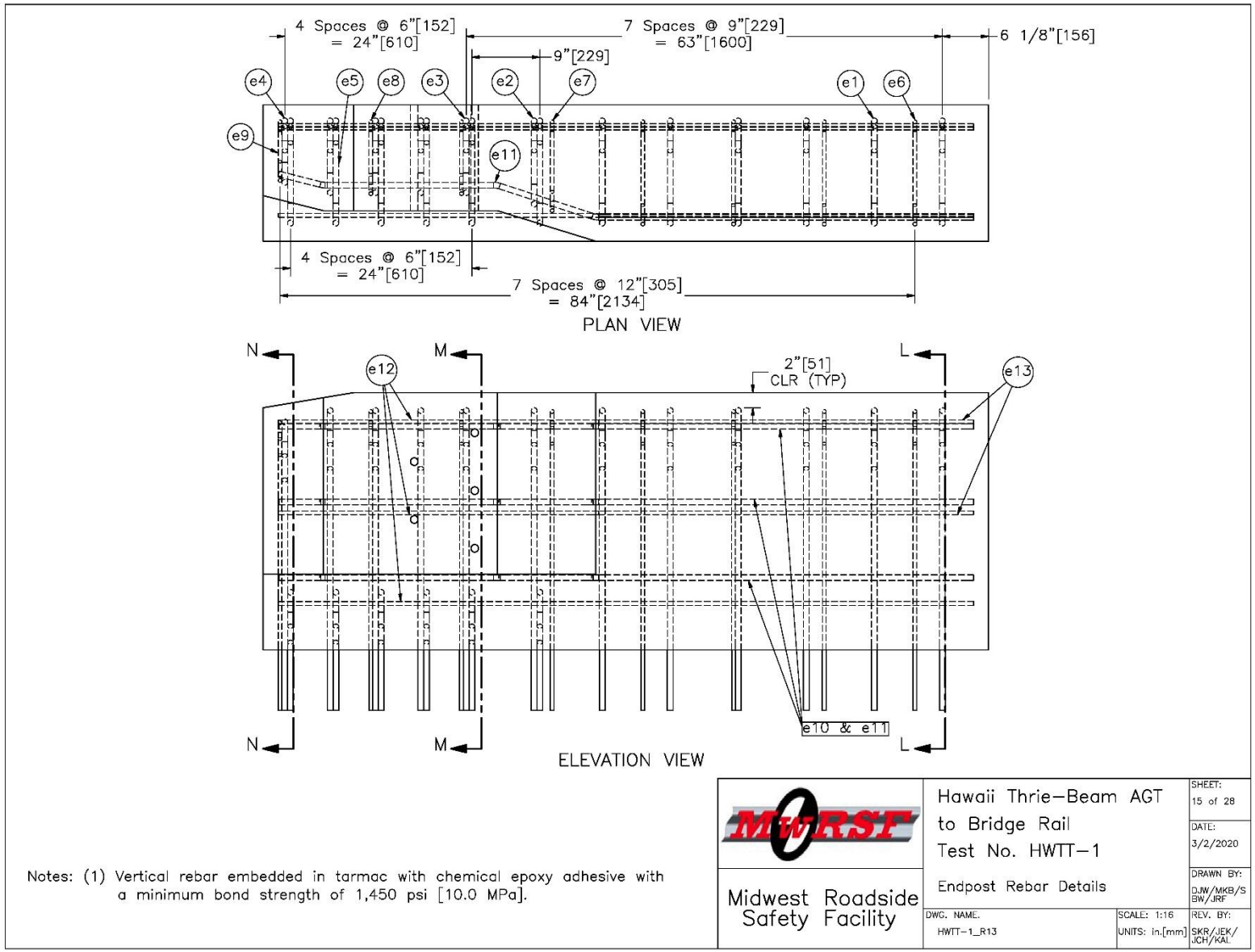



Figure 28. End Post Rebar Details, Test Nos. HWTT-1 and HWTT-2

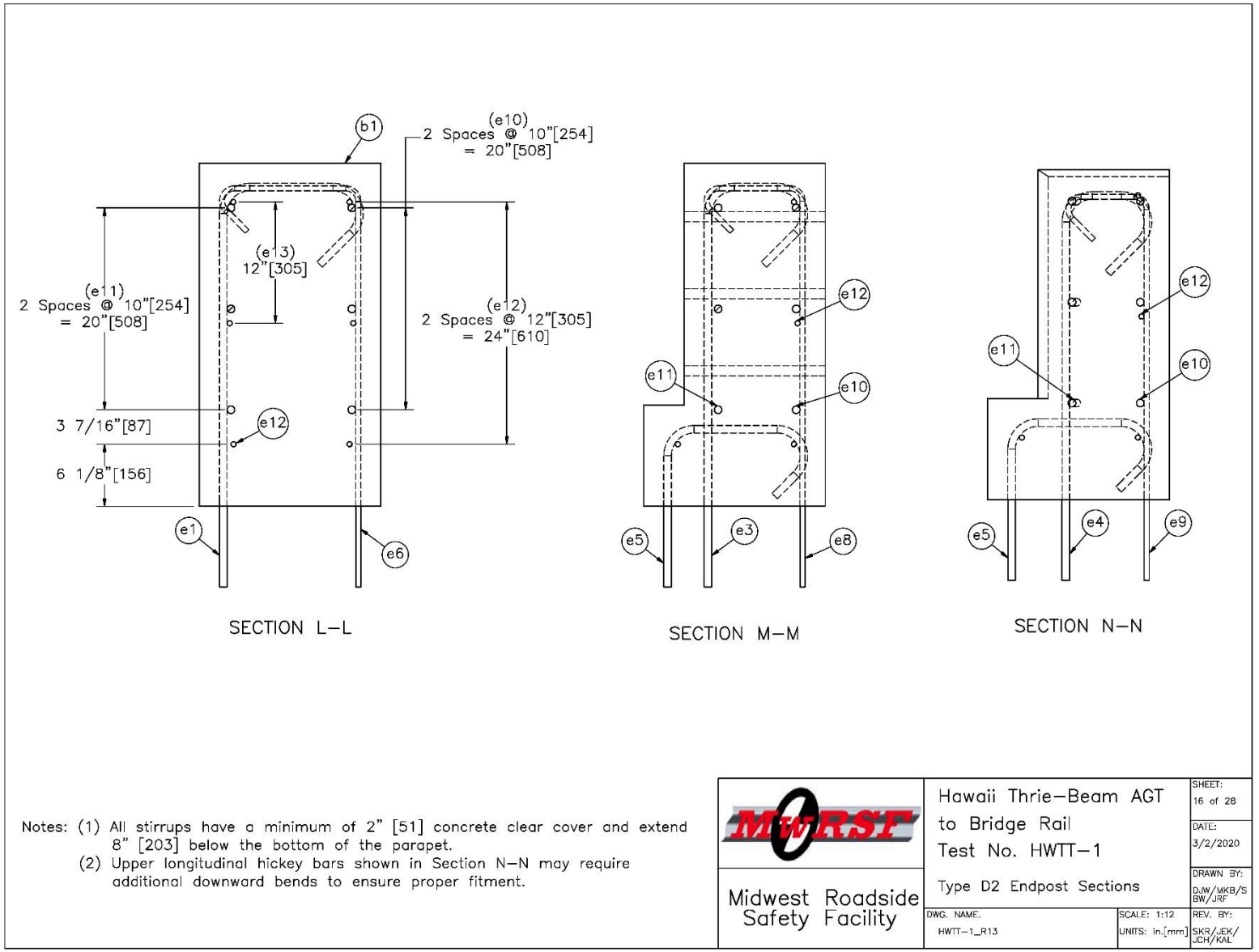



Figure 29. End Post Sections, Test Nos. HWTT-1 and HWTT-2

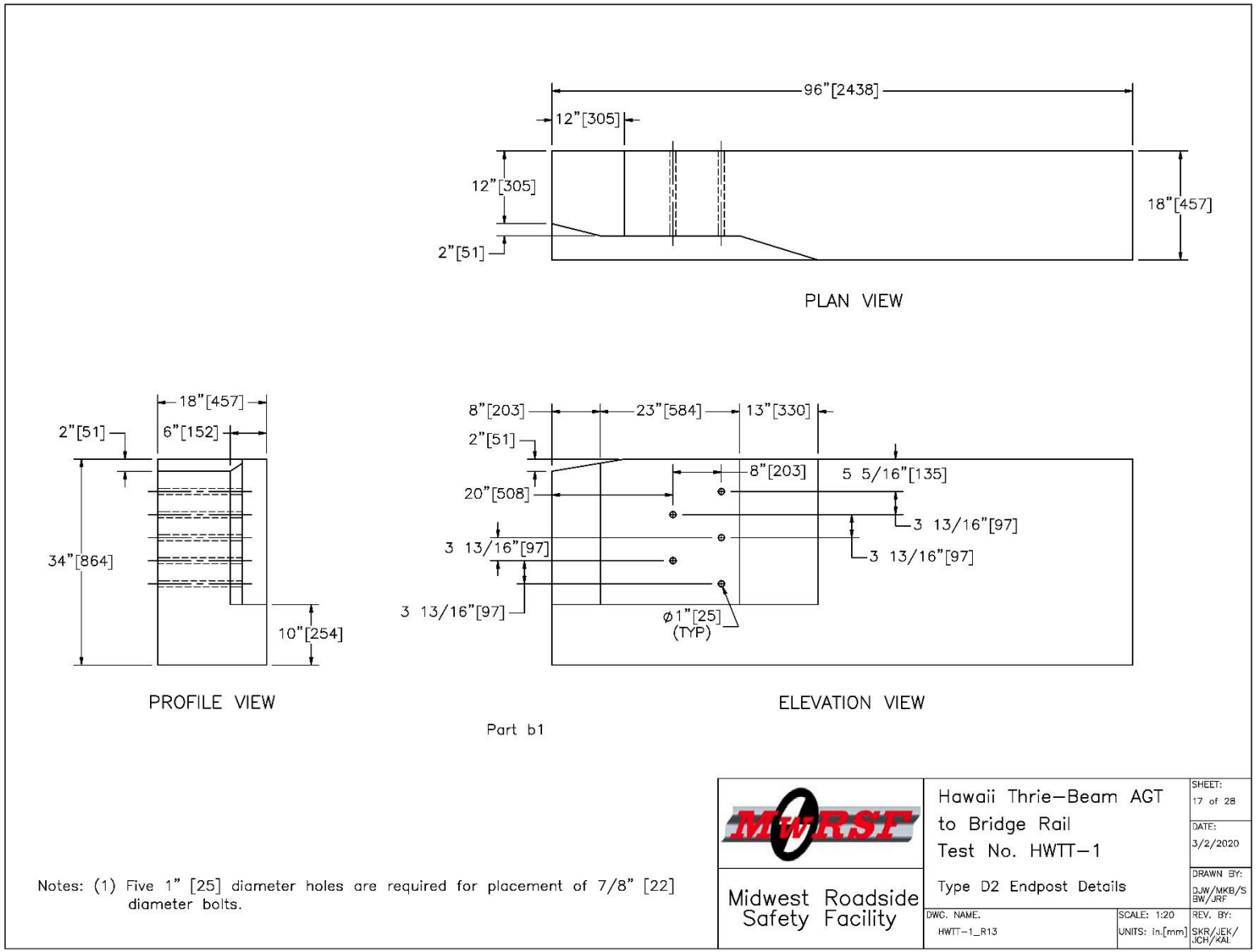



Figure 30. End Post Details, Test Nos. HWTT-1 and HWTT-2

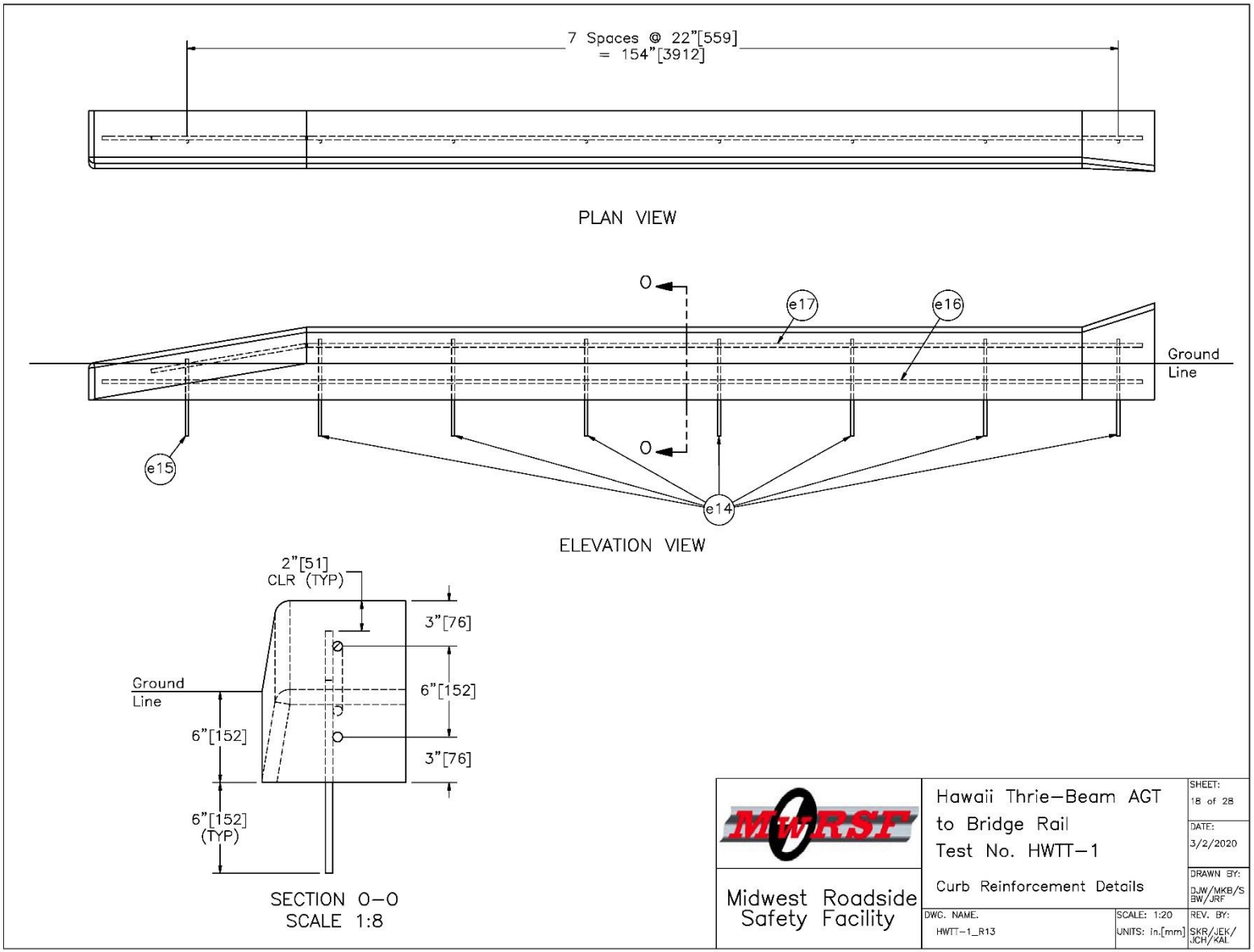



Figure 31. Curb Reinforcement Details, Test Nos. HWTT-1 and HWTT-2

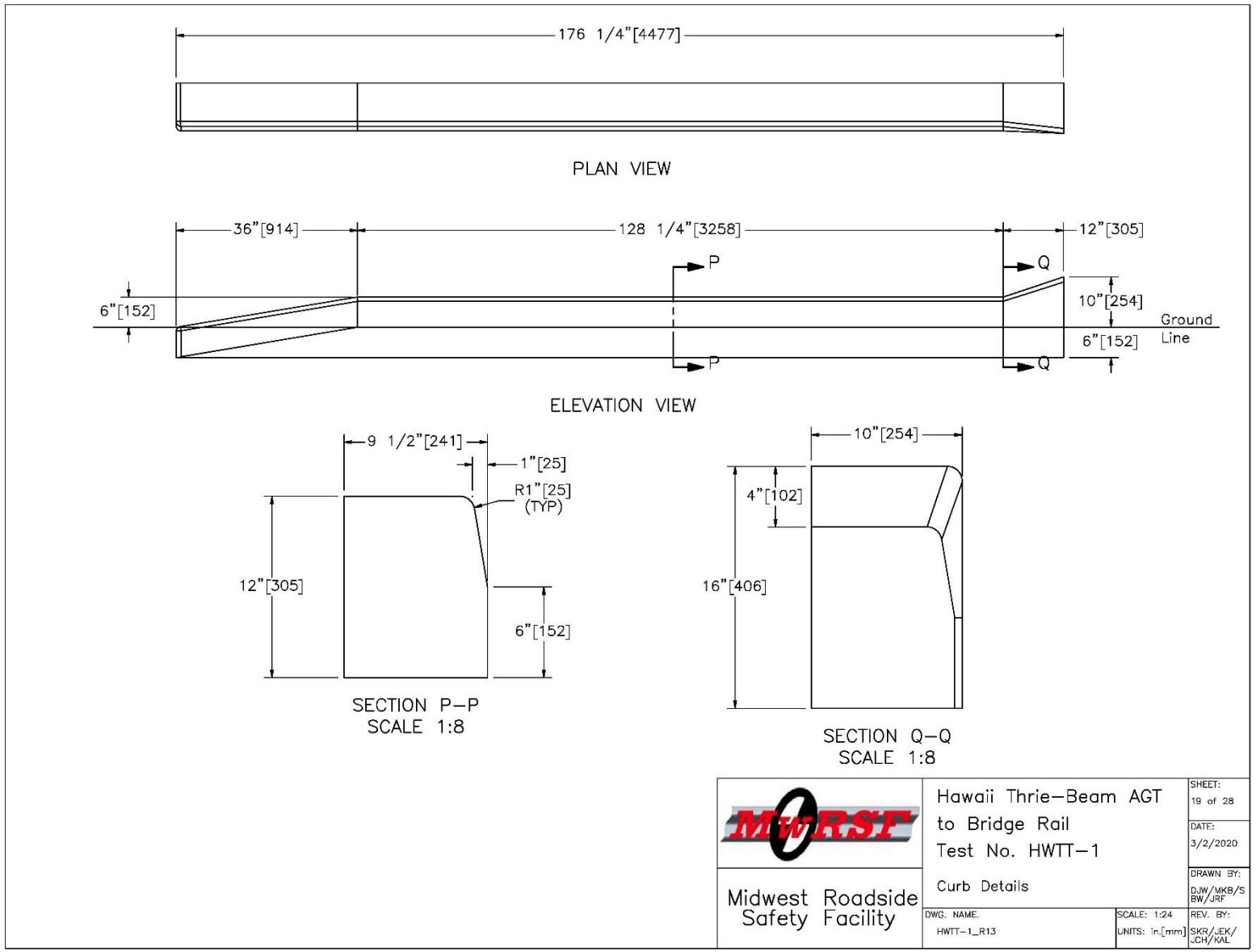



Figure 32. Curb Details, Test Nos. HWTT-1 and HWTT-2

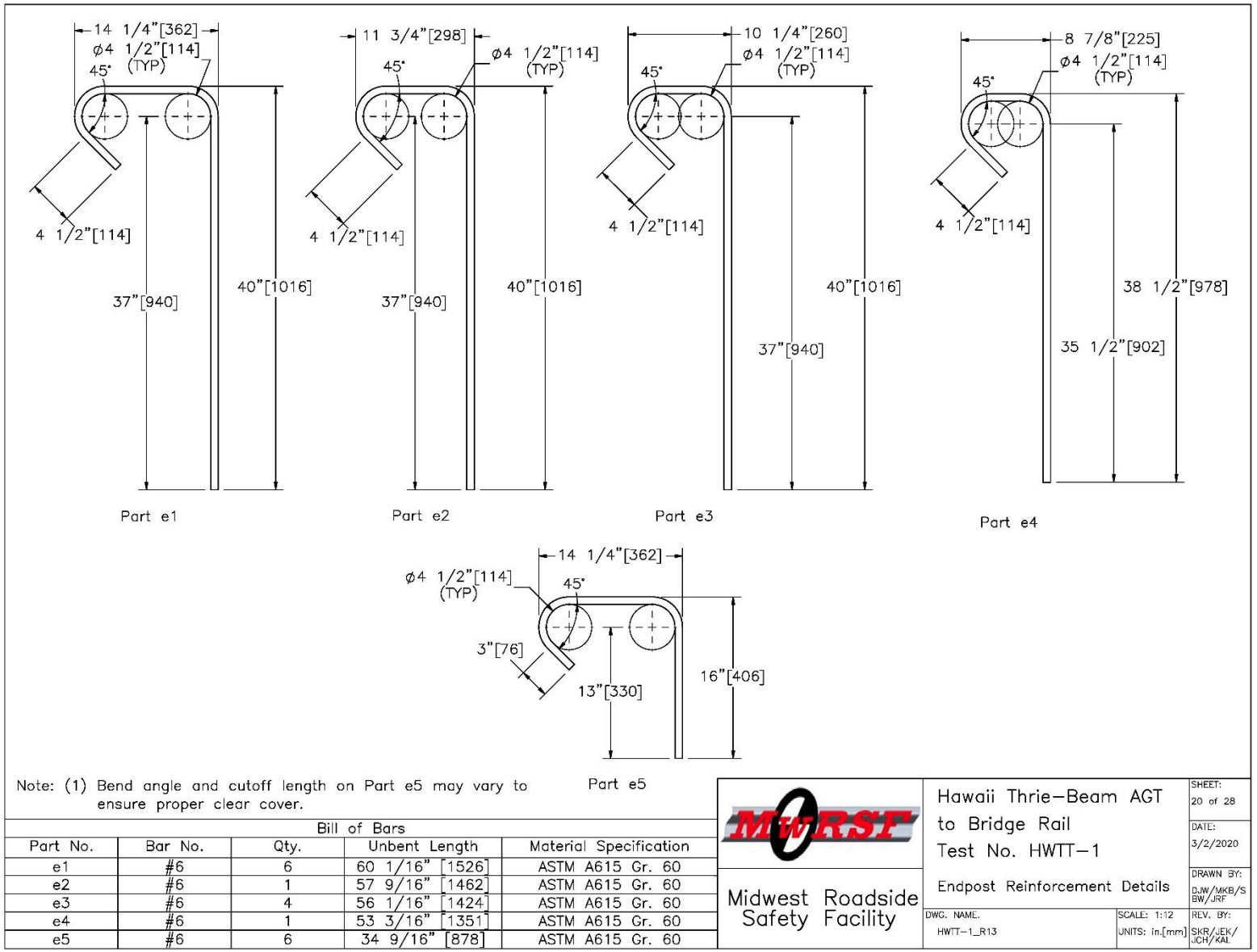
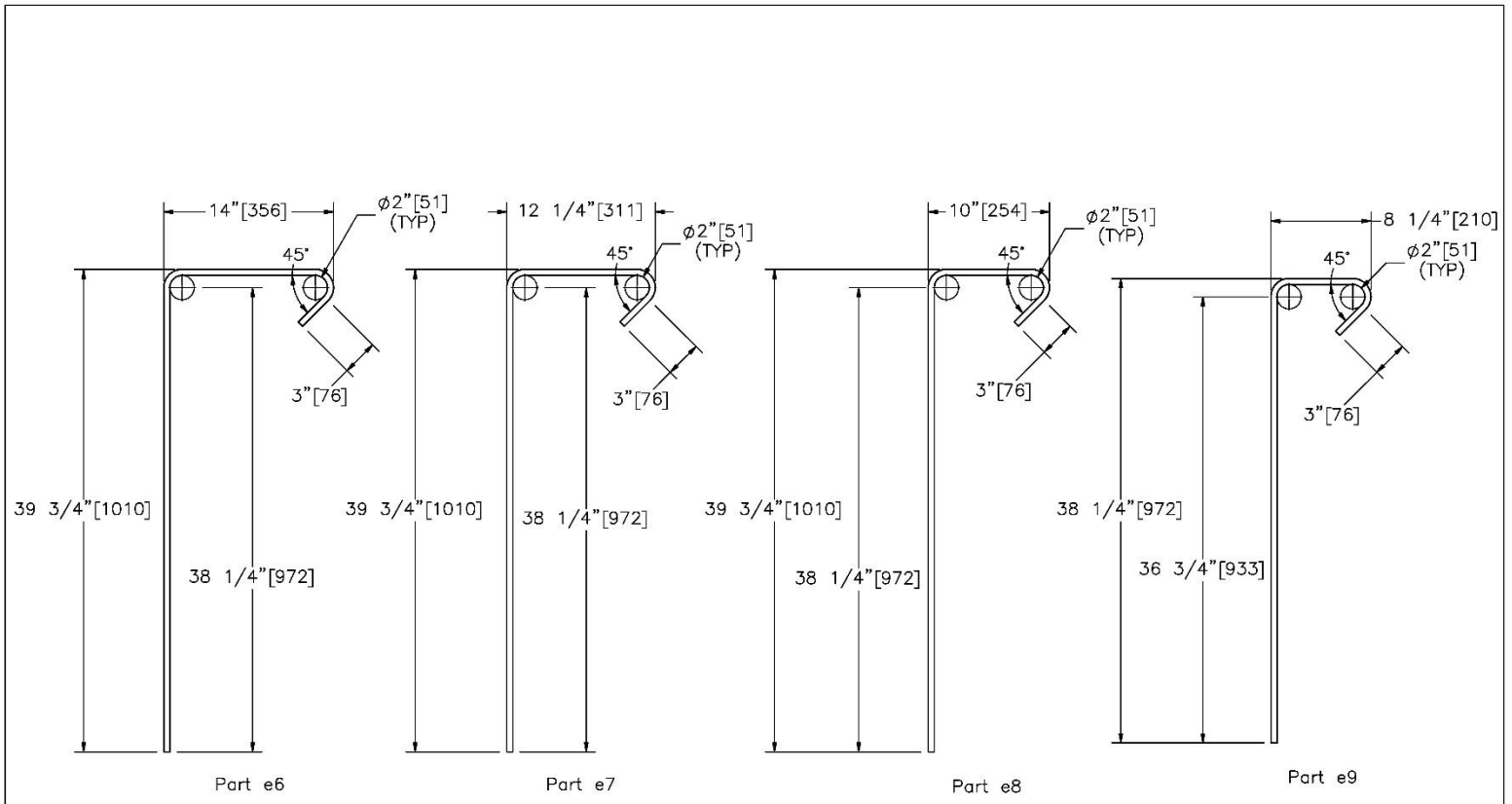



Figure 33. End Post Reinforcement Details, Test Nos. HWTT-1 and HWTT-2




Bill of Bars

| Part No. | Bar No. | Qty. | Unbent Length | Material Specification |
|---|---|---|---|---|
| e6 | #4 | 4 | 57 3/16" [1453] | ASTM A615 Gr. 60 |
| e7 | #4 | 1 | 55 7/16" [1408] | ASTM A615 Gr. 60 |
| e8 | #4 | 2 | 53 3/16" [1351] | ASTM A615 Gr. 60 |
| e9 | #4 | 1 | 49 7/8" [1267] | ASTM A615 Gr. 60 |

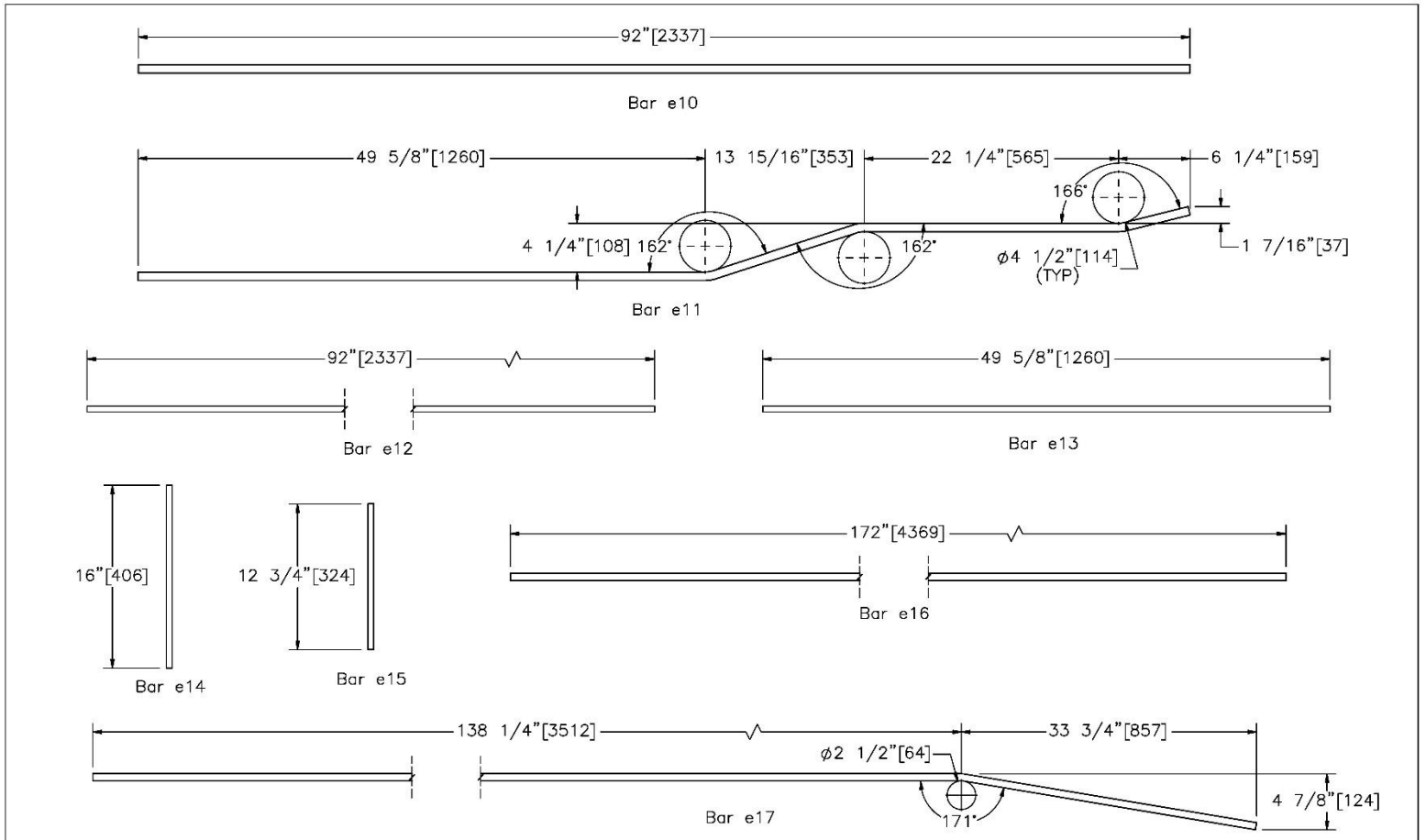
Midwest Roadside Safety Facility

Hawaii Thrie-Beam AGT to Bridge Rail Test No. HWTT-1

Endpost Reinforcement Details

SHEET: 21 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL
DWG. NAME. HWTT-1_R13
SCALE: 1:12
UNITS: in.[mm]

Figure 34. End Post Reinforcement Details, Test Nos. HWTT-1 and HWTT-2




| Bill of Bars | | | | |
|---|---|---|---|---|
| Part No. | Bar No. | Qty. | Unbent Length | Material Specification |
| e10 | #6 | 3 | 92" [2337] | ASTM A615 Gr. 60 |
| e11 | #6 | 3 | 92 7/8" [2359] | ASTM A615 Gr. 60 |
| e12 | #4 | 4 | 92" [2337] | ASTM A615 Gr. 60 |
| e13 | #4 | 2 | 49 5/8" [1260] | ASTM A615 Gr. 60 |
| e14 | #4 | 7 | 16" [406] | ASTM A615 Gr. 60 |
| e15 | #4 | 1 | 12 3/4" [324] | ASTM A615 Gr. 60 |
| e16 | #5 | 1 | 172" [4369] | ASTM A615 Gr. 60 |
| e17 | #5 | 1 | 164 1/4" [4172] | ASTM A615 Gr. 60 |

Midwest Roadside Safety Facility

Hawaii Thrie-Beam AGT to Bridge Rail
Test No. HWTT-1
Longitudinal Endpost and Curb Reinforcement Details

DWG. NAME: HWTT-1_R13
SCALE: 1:12
UNITS: in.[mm]
SHEET: 22 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL

Figure 35. Longitudinal End Post and Curb Reinforcement Details, Test Nos. HWTT-1 and HWTT-2

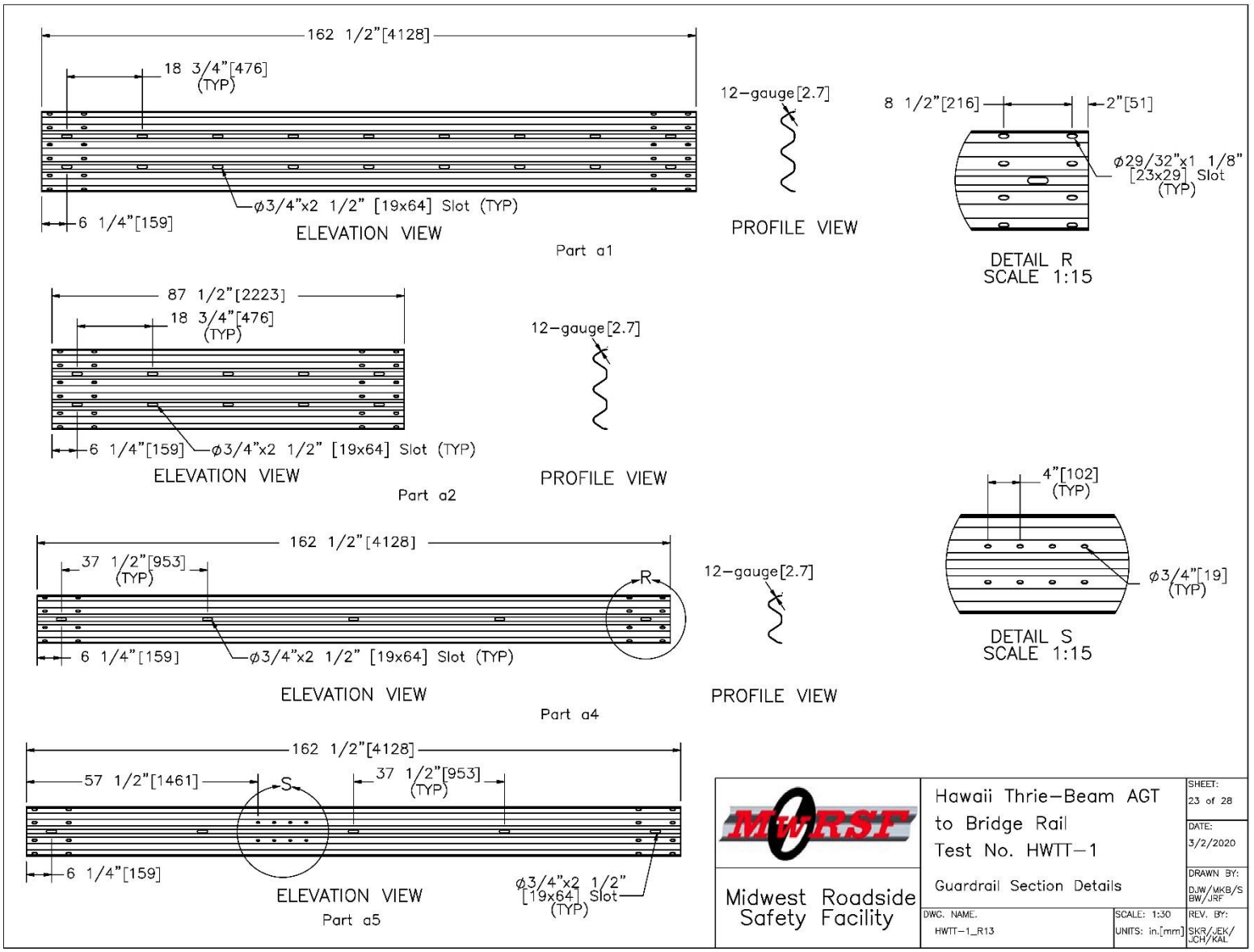



Figure 36. Guardrail Section Details, Test Nos. HWTT-1 and HWTT-2

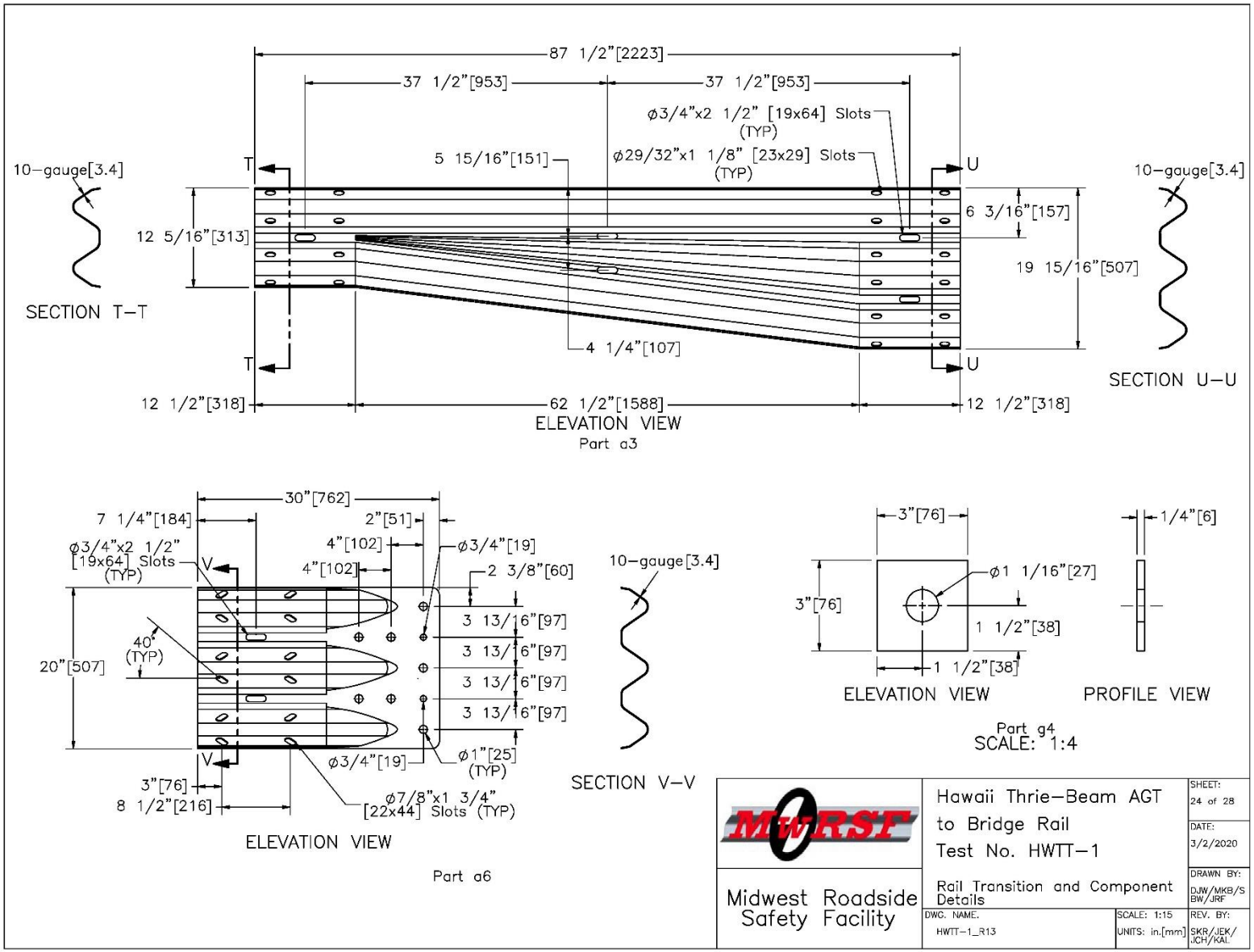



Figure 37. Asymmetric Transition Rail and Terminal Connector Details, Test Nos. HWTT-1 and HWTT-2

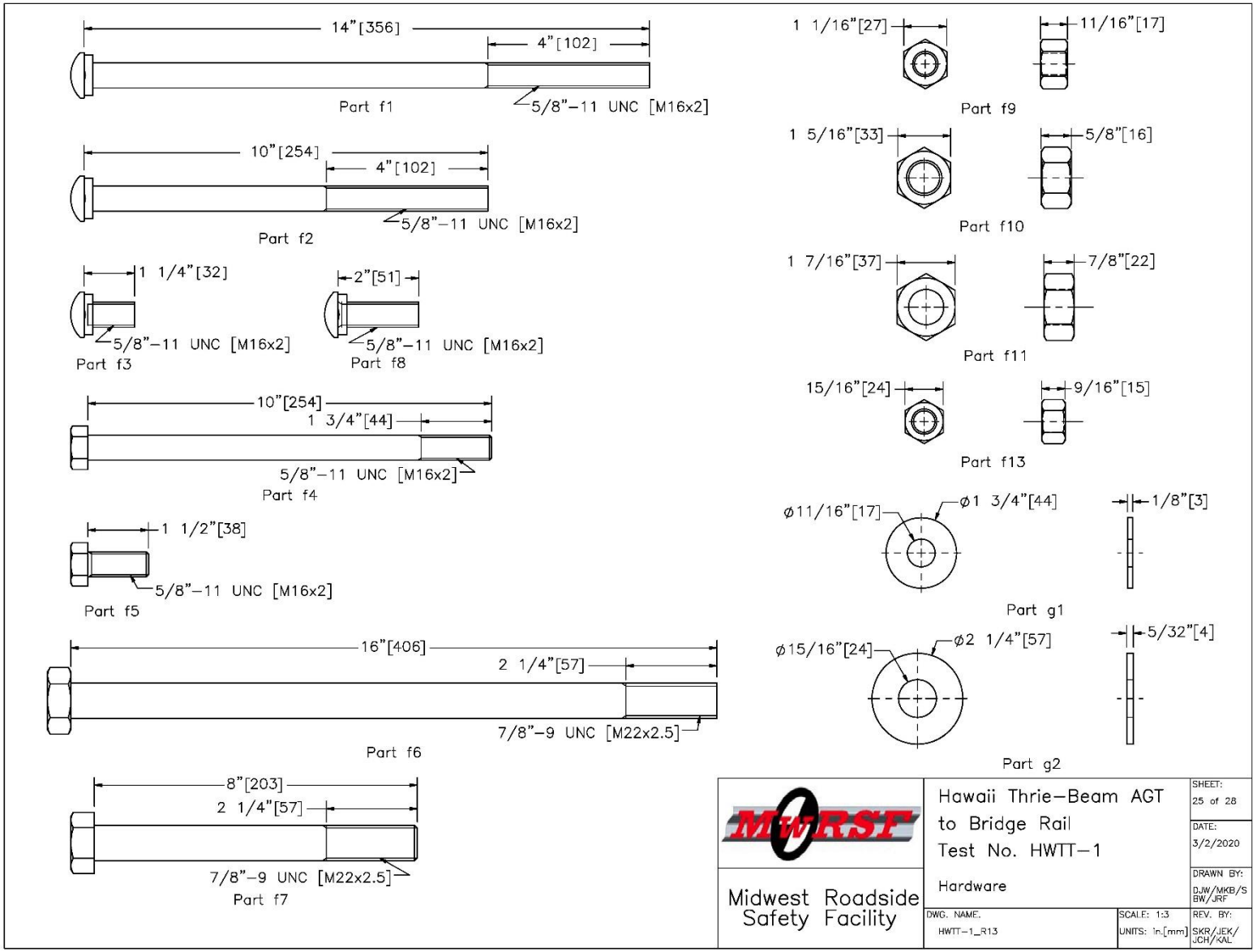



Figure 38. Hardware, Test Nos. HWTT-1 and HWTT-2

| Item No. | QTY. | Description | Material Specification | Treatment Specification | Hardware Guide |
|---|---|---|---|---|---|
| a1 | 2 | 12'–6" [3,810] 12–gauge [2.7] Thrie Beam Section | AASHTO M180 | ASTM A123 or A653 | RTM08a |
| a2 | 1 | 6'–3" [1,905] 12–gauge [2.7] Thrie Beam Section | AASHTO M180 | ASTM A123 or A653 | RTM19a |
| a3 | 1 | 6'–3" [1,905] 10–gauge [3.4] W–Beam to Thrie–Beam Asymmetric Transition Section | AASHTO M180 | ASTM A653 | RWT02 |
| a4 | 3 | 12'–6" [3,810] 12–gauge [2.7] W–Beam MGS Section | AASHTO M180 | ASTM A123 or A653 | RWM04a |
| a5 | 1 | 12'–6" [3,810] 12–gauge [2.7] W–Beam MGS End Section | AASHTO M180 | ASTM A123 or A653 | RWM14a |
| a6 | 1 | 10–gauge [3.4] Thrie Beam Terminal Connector | AASHTO M180<br>Min. yield strength = 50 ksi [345 MPa]<br>Min. ultimate strength = 70 ksi [483 MPa] | ASTM A123 or A653 | RTE01b |
| b1 | 1 | Reinforced Concrete | Min. f'c = 4,000 psi [27.6 MPa]<br>NE Mix 47BD | | – |
| c1 | 2 | BCT Timber Post – MGS Height | SYP Grade No. 1 or better (No knots +/– 18" [457] from ground on tension face) | – | PDF01 |
| c2 | 2 | 72" [1,829] Long Foundation Tube | ASTM A500 Gr. B | ASTM A123 | PTE06 |
| c3 | 1 | Ground Strut Assembly | ASTM A36 | ASTM A123 | PFP02 |
| c4 | 2 | BCT Anchor Cable End Swaged Fitting | Fitting – ASTM A576 Gr. 1035<br>Stud – ASTM F568 Class C | Fitting – ASTM A153<br>Stud – ASTM A153 or B695 | – |
| c5 | 1 | 3/4" [19] Dia. 6x19 IWRC IPS Wire Rope | ASTM A741 Type 2 | Class A Coating | – |
| c6 | 1 | 8"x8"x5/8" [203x203x16] Anchor Bearing Plate | ASTM A36 | ASTM A123 | FPB01 |
| c7 | 1 | 2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve | ASTM A53 Gr. B Schedule 40 | ASTM A123 | FMM02 |
| c8 | 1 | Anchor Bracket Assembly | ASTM A36 | ASTM A123 | FPA01 |
| d1 | 7 | W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post | ASTM A992 | *ASTM A123 | PWE06 |
| d2 | 6 | W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post | ASTM A992 | *ASTM A123 | PWE06 |
| d3 | 4 | W6x15 [W152x22.5], 78" [1,981] Long Steel Post | ASTM A992 | *ASTM A123 | – |
| d4 | 4 | 17 1/2" [445] Long, 8"x6"x1/4" [203x152x6] Steel Blockout | ASTM A500 Gr. B | *ASTM A123 | – |
| d5 | 6 | 17 1/2" [445] Long, 12"x4"x1/4" [305x102x6] Steel Blockout | ASTM A500 Gr. B | *ASTM A123 | – |

* Component does not need to be galvanized for testing purposes.

Midwest Roadside Safety Facility

Hawaii Thrie–Beam AGT to Bridge Rail
Test No. HWTT–1
Bill of Materials

SHEET: 26 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL
DWG. NAME. HWTT–1_R13
SCALE: None
UNITS: In.[mm]

Figure 39. Bill of Materials, Test Nos. HWTT-1 and HWTT-2

| Item No. | QTY. | Description | Material Specification | Treatment Specification | Hardware Guide |
|---|---|---|---|---|---|
| d6 | 2 | 14 3/16"x12"x5 1/8" [360x305x130] Composite Recycled Blockout | Mondo Polymer MGS14SH or Equivalent | – | – |
| d7 | 5 | 14 3/16"x8"x5 1/8" [360x203x130] Composite Recycled Blockout | Mondo Polymer GB14SH2 or Equivalent | – | – |
| d8 | 1 | 16D Double Head Nail | – | – | – |
| e1 | 6 | #6 [19] Rebar, 60 1/16" [1526] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e2 | 1 | #6 [19] Rebar, 57 9/16" [1462] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e3 | 4 | #6 [19] Rebar, 56 1/16" [1424] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e4 | 1 | #6 [19] Rebar, 53 3/16" [1351] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e5 | 6 | #6 [19] Rebar, 34 9/16" [878] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e6 | 4 | #4 [13] Rebar, 57 3/16" [1453] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e7 | 1 | #4 [13] Rebar, 55 7/16" [1408] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e8 | 2 | #4 [13] Rebar, 53 3/16" [1351] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e9 | 1 | #4 [13] Rebar, 49 7/8" [1267] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e10 | 3 | #6 [19] Rebar, 92" [2337] Total Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e11 | 3 | #6 [19] Rebar, 92 7/8" [2359] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e12 | 4 | #4 [13] Rebar, 92" [2337] Total Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e13 | 2 | #4 [13] Rebar, 49 5/8" [1260] Total Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e14 | 7 | #4 [13] Rebar, 16" [406] Total Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e15 | 1 | #4 [13] Rebar, 12 3/4" [324] Total Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e16 | 1 | #5 [16] Rebar, 172" [4369] Total Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |
| e17 | 1 | #5 [16] Rebar, 164 1/4" [4172] Total Unbent Length | ASTM A615 Gr. 60 | **Epoxy–Coated (ASTM A775 or A934) | – |

** Rebar does not need to be epoxy–coated for testing purposes.

Midwest Roadside Safety Facility

Hawaii Thrie–Beam AGT to Bridge Rail
Test No. HWTT–1
Bill of Materials

SHEET: 27 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL
DWG. NAME. HWTT–1_R13
SCALE: None
UNITS: in.[mm]

Figure 40. Bill of Materials, Continued, Test Nos. HWTT-1 and HWTT-2

| Item No. | QTY. | Description | Material Specification | Treatment Specification | Hardware Guide |
|---|---|---|---|---|---|
| f1 | 13 | 5/8"–11 UNC [M16x2], 14" [356] Long Guardrail Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F2329 | FBB06 |
| f2 | 15 | 5/8"–11 UNC [M16x2], 10" [254] Long Guardrail Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F2329 | FBB03 |
| f3 | 44 | 5/8"–11 UNC [M16x2], 1 1/4" [32] Long Guardrail Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F2329 | FBB01 |
| f4 | 2 | 5/8"–11 UNC [M16x2], 10" [254] Long Hex Head Bolt | ASTM A307 Gr. A or equivalent | ASTM A153 or B695 Class 55 or F2329 | FBX16a |
| f5 | 8 | 5/8"–11 UNC [M16x2], 1 1/2" [38] Long Hex Head Bolt | ASTM A307 Gr. A or equivalent | ASTM A153 or B695 Class 55 or F2329 | FBX16a |
| f6 | 5 | 7/8"–9 UNC [M22x2.5], 16" [406] Long Heavy Hex Head Bolt | ASTM F3125 Gr. A325 or equivalent | ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 or F2833 Gr. 1 | FBX22b |
| f7 | 2 | 7/8"–9 UNC [M22x2.5], 8" [203] Long Hex Head Bolt | ASTM A307 Gr. A or equivalent | ASTM A153 or B695 Class 55 or F2329 | – |
| f8 | 24 | 5/8"–11 UNC [M16x2], 2" [51] Long Guardrail Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F2329 | FBB02 |
| f9 | 96 | 5/8"–11 UNC [M16x2] Heavy Hex Nut | ASTM A563A or equivalent | ASTM A153 or B695 Class 55 or F2329 | FNX16b |
| f10 | 2 | 7/8"–9 UNC [M22x2.5] Hex Nut | ASTM A563A or equivalent | ASTM A153 or B695 Class 55 or F2329 | – |
| f11 | 5 | 7/8"–9 UNC [M22x2.5] Heavy Hex Nut | ASTM A563DH | ASTM A153 or B695 Class 55 or F2329 | FNX22b |
| f12 | 2 | 1"–8 UNC [M24x3] Heavy Hex Nut | ASTM A563DH or equivalent | ASTM A153 or B695 Class 55 or F2329 | FNX24b |
| f13 | 10 | 5/8"–11 UNC [M16x2] Hex Nut | ASTM A563A or equivalent | ASTM A153 or B695 Class 55 or F2329 | FNX16a |
| g1 | 46 | 5/8" [16] Dia. Plain USS Washer | ASTM F844 | ASTM A123 or A153 or F2329 | FWC16a |
| g2 | 4 | 7/8" [22] Dia. Plain Round Washer | ASTM F844 | ASTM A123 or A153 or F2329 | – |
| g3 | 2 | 1" [25] Dia. Plain USS Washer | ASTM F844 | ASTM A123 or A153 or F2329 | FWC24a |
| g4 | 5 | 3"x3"x1/4" [76x76x6] or 3 1/2"x3 1/2"x1/4" [89x89x6] Square Washer Plate | ASTM A572 Gr. 50 | ASTM A123 | – |
| – | – | Epoxy Adhesive | Hilti HIT RE–500 V3 | – | – |

Midwest Roadside Safety Facility

Hawaii Thrie–Beam AGT to Bridge Rail
Test No. HWTT–1
Bill of Materials

SHEET: 28 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL
DWG. NAME. HWTT–1_R13
SCALE: None
UNITS: in.[mm]

Figure 41. Bill of Materials, Continued, Test Nos. HWTT-1 and HWTT-2

Figure 42. Test Installation Photographs, Test Nos. HWTT-1 and HWTT-2

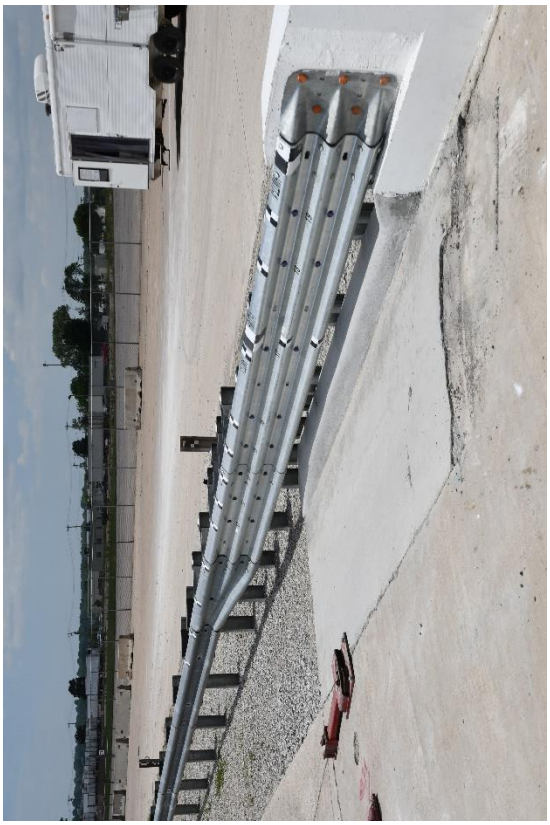




Figure 43. Test Installation Photographs, Test Nos. HWTT-1 and HWTT-2




Figure 44. Test Installation Photographs, Test Nos. HWTT-1 and HWTT-2

# 3 TEST REQUIREMENTS AND EVALUATION CRITERIA

## 3.1 Test Requirements

Longitudinal barriers, such as approach guardrail transitions, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (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 [1]. According to TL-3 of MASH 2016, longitudinal barrier transition systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1. Note that there is no difference between MASH 2009 [14] and MASH 2016 for longitudinal barriers such as the system tested in this project, except that additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016.

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

| Test Article | Test Designation No. | Test Vehicle | Vehicle Weight, lb | Impact Conditions | | Evaluation Criteria [1] |
|---|---|---|---|---|---|---|
| | | | | Speed, mph | Angle, deg. | |
| Longitudinal Barrier | 3-20 | 1100C | 2,425 | 62 | 25 | A,D,F,H,I |
| | 3-21 | 2270P | 5,000 | 62 | 25 | A,D,F,H,I |

[1] Evaluation criteria explained in Table 2.

Recent testing of AGTs has illustrated the importance of evaluating two different transition regions along the length of the AGT: (1) the downstream transition where the thrie beam connects to the rigid parapet and (2) the upstream stiffness transition where the W-beam guardrail transitions to a stiffer thrie beam barrier. However, the upstream stiffness transition of the modified HDOT AGT was specifically designed to replicate the MASH-crashworthy MGS stiffness transition [4]. Therefore, crash testing of the upstream stiffness transition was deemed non-critical.

It should be noted that the test matrix detailed herein represents the researchers' best engineering judgement with respect to the MASH 2016 safety requirements and their internal evaluation of critical tests necessary to evaluate the crashworthiness of the guardrail transition system. However, these opinions may change in the future due to the development of new knowledge (crash testing, real-world performance, etc.) or changes to the evaluation criteria. Thus, any tests within the evaluation matrix deemed non-critical may eventually need to be evaluated based on additional knowledge gained over time or revisions to the MASH 2016 criteria.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barriers

<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="6">Occupant Risk</td><td>D.</td><td colspan="3">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. 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="3">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"><table><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<br>(9.1 m/s)</td><td>40 ft/s<br>(12.2 m/s)</td></tr></table></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="3">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"><table><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></td></tr>
<tr><td></td><td></td></tr>
</table>

## 3.2 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 thrie beam guardrail transition 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 tests documented herein were 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.

### 3.3 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.

# 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 vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was 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 vehicle. A guide flag, attached to the right-front wheel and the guide cable, 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 vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

## 4.3 Test Vehicles

For test no. HWTT-1, a 2010 Hyundai Accent passenger car was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,475 lb, 2,407 lb, and 2,571 lb, respectively. The test vehicle is shown in Figures 45 and 46, and vehicle dimensions are shown in Figure 47. MASH 2016 describes that vehicles used in crash testing should be no more than six model years old. A 2010 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 in MASH 2016 [1].

For test no. HWTT-2, a 2014 Dodge Ram QuadCab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 4,953 lb, 5,000 lb, and 5,160 lb, respectively. The test vehicle is shown in Figures 48 and 49, and vehicle dimensions are shown in Figure 50. Note, the windshield was cracked prior to full-scale crash testing. Since the barrier system was not expected to make contact with the windshield, this pre-existing damage was not expected to affect the evaluation of the AGT.


Figure 45. Test Vehicle Photographs, Test No. HWTT-1

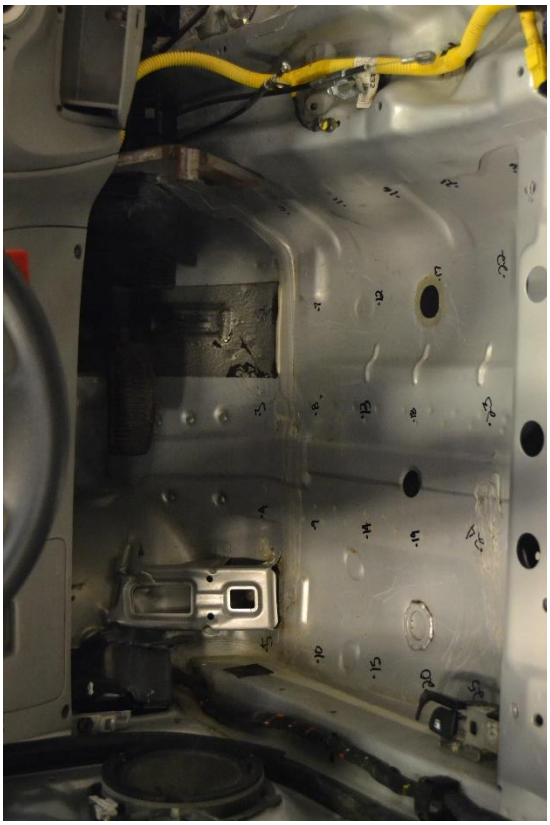
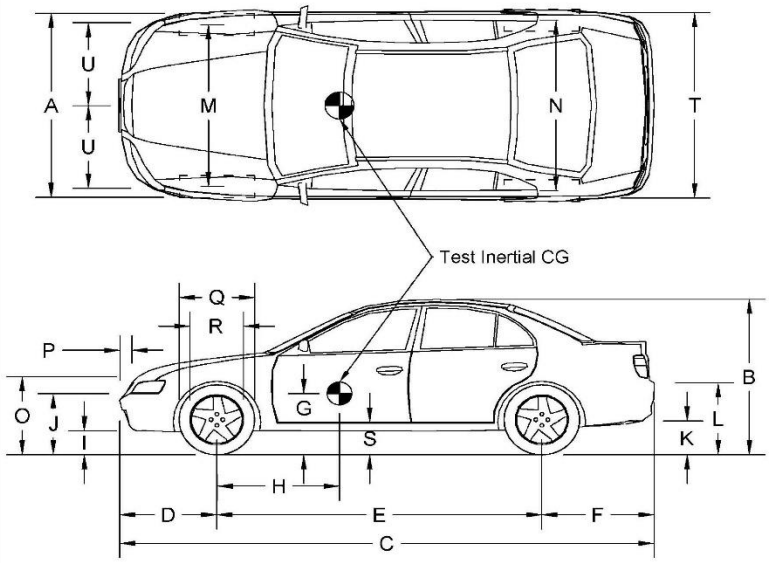


Figure 46. Test Vehicle Interior Floorboards and Undercarriage, Test No. HWTT-2

| | | | | | |
|---|---|---|---|---|---|
| **Date:** | 7/1/2019 | **Test Name:** | HWTT-1 | **VIN No:** | KMHCN4AC8BU608788 |
| **Year:** | 2010 | **Make:** | Hyundai | **Model:** | Accent |
| **Tire Size:** | 185/65R14 | **Tire Inflation Pressure:** | 32 psi | **Odometer:** | 174272 |




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

| | | | |
|---|---|---|---|
| **A:** | 65 1/2 (1664)<br>65±3 (1650±75) | **B:** | 57 3/4 (1467) |
| **C:** | 168 1/2 (4280)<br>169±8 (4300±200) | **D:** | 32 3/4 (832)<br>35±4 (900±100) |
| **E:** | 98 3/4 (2508)<br>98±5 (2500±125) | **F:** | 37 (940) |
| **G:** | 22 7/8 (581) | **H:** | 36 1/4 (921)<br>39±4 (990±100) |
| **I:** | 14 1/2 (368) | **J:** | 21 (533) |
| **K:** | 14 3/4 (375) | **L:** | 23 (584) |
| **M:** | 58 (1473)<br>56±2 (1425±50) | **N:** | 57 3/4 (1467)<br>56±2 (1425±50) |
| **O:** | 28 (711)<br>24±4 (600±100) | **P:** | 3 1/2 (89) |
| **Q:** | 23 (584) | **R:** | 15 3/8 (391) |
| **S:** | 7 1/2 (191) | **T:** | 65 (1651) |
| **U (impact width):** | 29 1/8 (740) | | |

**Mass Distribution - lb (kg)**

| | | | | |
|---|---|---|---|---|
| **Gross Static** | **LF** | 807 (366) | **RF** | 798 (362) |
| | **LR** | 510 (231) | **RR** | 456 (207) |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Top of radiator core support:** | 30 1/2 | (775) | | | | |
| **Wheel Center Height (Front):** | 11 | (279) | | | | |
| **Wheel Center Height (Rear):** | 10 3/4 | (273) | | | | |
| **Wheel Well Clearance (Front):** | 26 1/4 | (667) | | | | |
| **Wheel Well Clearance (Rear):** | 25 5/8 | (651) | | | | |
| **Bottom Frame Height (Front):** | 7 | (178) | | | | |
| **Bottom Frame Height (Rear):** | 5 1/2 | (140) | | | | |

| **Weights lb (kg)** | **Curb** | **Test Inertial** | **Gross Static** |
|---|---|---|---|
| **W-front** | 1573 (714) | 1523 (691) | 1605 (728) |
| **W-rear** | 902 (409) | 884 (401) | 966 (438) |
| **W-total** | 2475 (1123) | 2407 (1092)<br>2420±55 (1100±25) | 2571 (1166)<br>2585±55 (1175±50) |

| | |
|---|---|
| **Engine Type:** | Gasoline |
| **Engine Size:** | 1.6L 4 cyl |
| **Transmission Type:** | Automatic |
| **Drive Type:** | FWD |

**GVWR Ratings lb**

| | |
|---|---|
| **Front** | 1918 |
| **Rear** | 1874 |
| **Total** | 3638 |

**Surrogate Occupant Data**

| | |
|---|---|
| **Type:** | Hybrid II |
| **Mass:** | 164 lb |
| **Seat Position:** | Left/Driver |

**Note any damage prior to test:** down left/driver's side rear door and quarter panel.Two small dents on right/passenger's side

Figure 47. Vehicle Dimensions, Test No. HWTT-1


Figure 48. Test Vehicle Photographs, Test No. HWTT-2

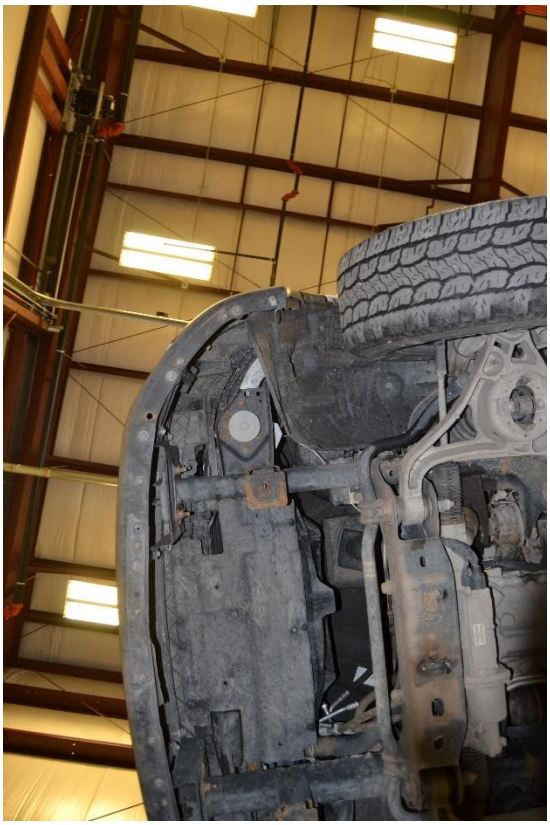
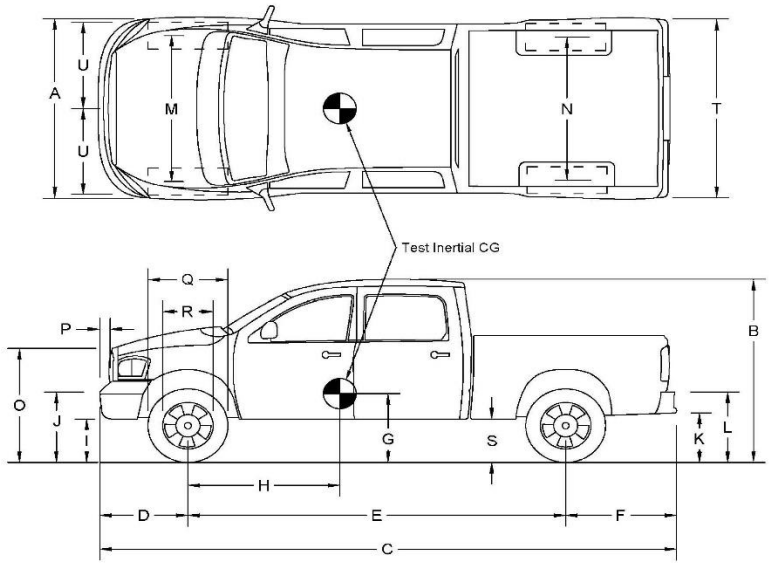


Figure 49. Test Vehicle Interior Floorboards and Undercarriage, Test No. HWTT-2

| | | | | | |
|---|---|---|---|---|---|
| **Date:** | 7/19/2019 | **Test Name:** | HWTT-2 | **VIN No:** | 1C6RR6FG1ES237040 |
| **Year:** | 2014 | **Make:** | Dodge | **Model:** | RAM 1500 |
| **Tire Size:** | 265/70R17 | **Tire Inflation Pressure:** | 40 psi | **Odometer:** | 251198 |




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

| | | | |
|---|---|---|---|
| **A:** | 77 1/2 (1969)<br>78±2 (1950±50) | **B:** | 64 1/4 (1632) |
| **C:** | 229 1/8 (5820)<br>237±13 (6020±325) | **D:** | 39 7/8 (1013)<br>39±3 (1000±75) |
| **E:** | 140 5/8 (3572)<br>148±12 (3760±300) | **F:** | 48 3/8 (1229) |
| **G:** | 28 (711)<br>min: 28 (710) | **H:** | 65 5/16 (1659)<br>63±4 (1575±100) |
| **I:** | 12 (305) | **J:** | 25 1/4 (641) |
| **K:** | 20 1/2 (521) | **L:** | 29 1/4 (743) |
| **M:** | 68 1/8 (1730)<br>67±1.5 (1700±38) | **N:** | 68 1/8 (1730)<br>67±1.5 (1700±38) |
| **O:** | 42 3/4 (1086)<br>43±4 (1100±75) | **P:** | 4 1/2 (114) |
| **Q:** | 30 (762) | **R:** | 18 1/2 (470) |
| **S:** | 14 1/4 (362) | **T:** | 77 1/4 (1962) |
| | | **U (impact width):** | 36 7/8 (937) |

**Mass Distribution - lb (kg)**

| | | | | |
|---|---|---|---|---|
| **Gross Static** | **LF** | 1440 (653) | **RF** | 1330 (603) |
| | **LR** | 1221 (554) | **RR** | 1169 (530) |

| **Weights lb (kg)** | **Curb** | **Test Inertial** | **Gross Static** |
|---|---|---|---|
| **W-front** | 2707 (1228) | 2677 (1214) | 2770 (1256) |
| **W-rear** | 2246 (1019) | 2323 (1054) | 2390 (1084) |
| **W-total** | 4953 (2247) | 5000 (2268)<br>5000±110 (2270±50) | 5160 (2341)<br>5165±110 (2343±50) |

| | |
|---|---|
| **Wheel Center Height (Front):** | 14 7/8 (378) |
| **Wheel Center Height (Rear):** | 15 1/8 (384) |
| **Wheel Well Clearance (Front):** | 35 1/4 (895) |
| **Wheel Well Clearance (Rear):** | 37 3/4 (959) |
| **Bottom Frame Height (Front):** | 11 1/4 (286) |
| **Bottom Frame Height (Rear):** | 13 (330) |
| **Engine Type:** | Gasoline |
| **Engine Size:** | 3.6L V6 |
| **Transmission Type:** | Automatic |
| **Drive Type:** | RWD |
| **Cab Style:** | Quad Cab |
| **Bed Length:** | 76" |

| | | | | | |
|---|---|---|---|---|---|
| **GVWR Ratings - lb** | | **Surrogate Occupant Data** | | | |
| **Front** | 3700 | **Type:** | Hybrid II | | |
| **Rear** | 3900 | **Mass:** | 160 lb | | |
| **Total** | 6800 | **Seat Position:** | Left/Driver | | |

**Note any damage prior to test:**

Figure 50. Vehicle Dimensions, Test No. HWTT-2

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [16]. The location of the final c.g. for the passenger car is shown in Figures 47 and 51. The Suspension Method [17] was used to determine the vertical component of the c.g. for 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 50 and 52. Data used to calculate the locations of the vehicles' c.g. and ballast information for both vehicles 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 51 and 52. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

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 under the vehicle's left windshield wiper for both test nos. HWTT-1 and HWTT-2. The flash 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 vehicle could be brought safely to a stop after the test.

## 4.4 Simulated Occupant

For test nos. HWTT-1 and HWTT-2, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and 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 164 lb and 160 lb for test nos. HWTT-1 and HWTT-2, respectively. As recommended by MASH 2016, the simulated occupant 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 [18].

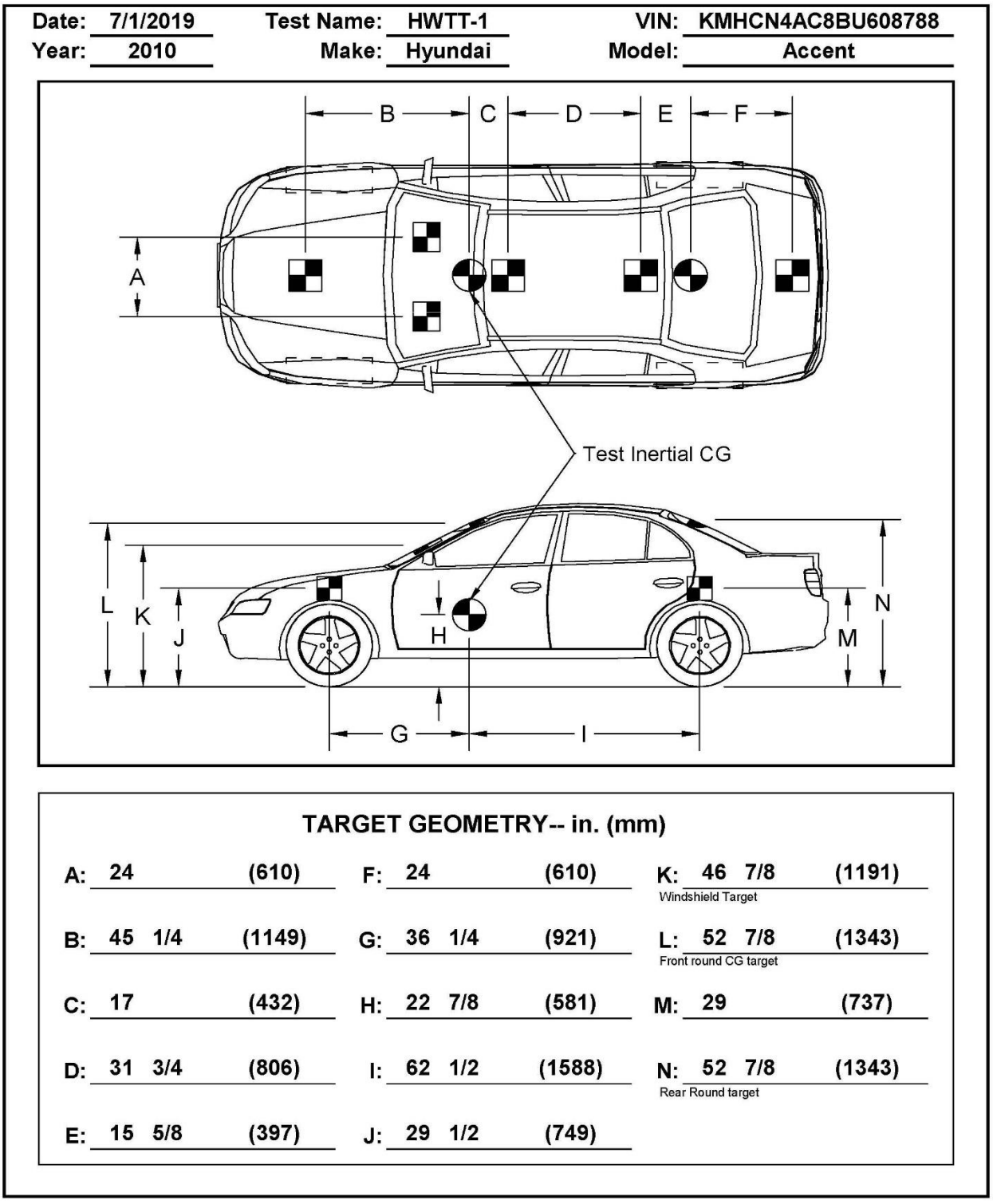



Figure 51. Target Geometry, Test No. HWTT-1

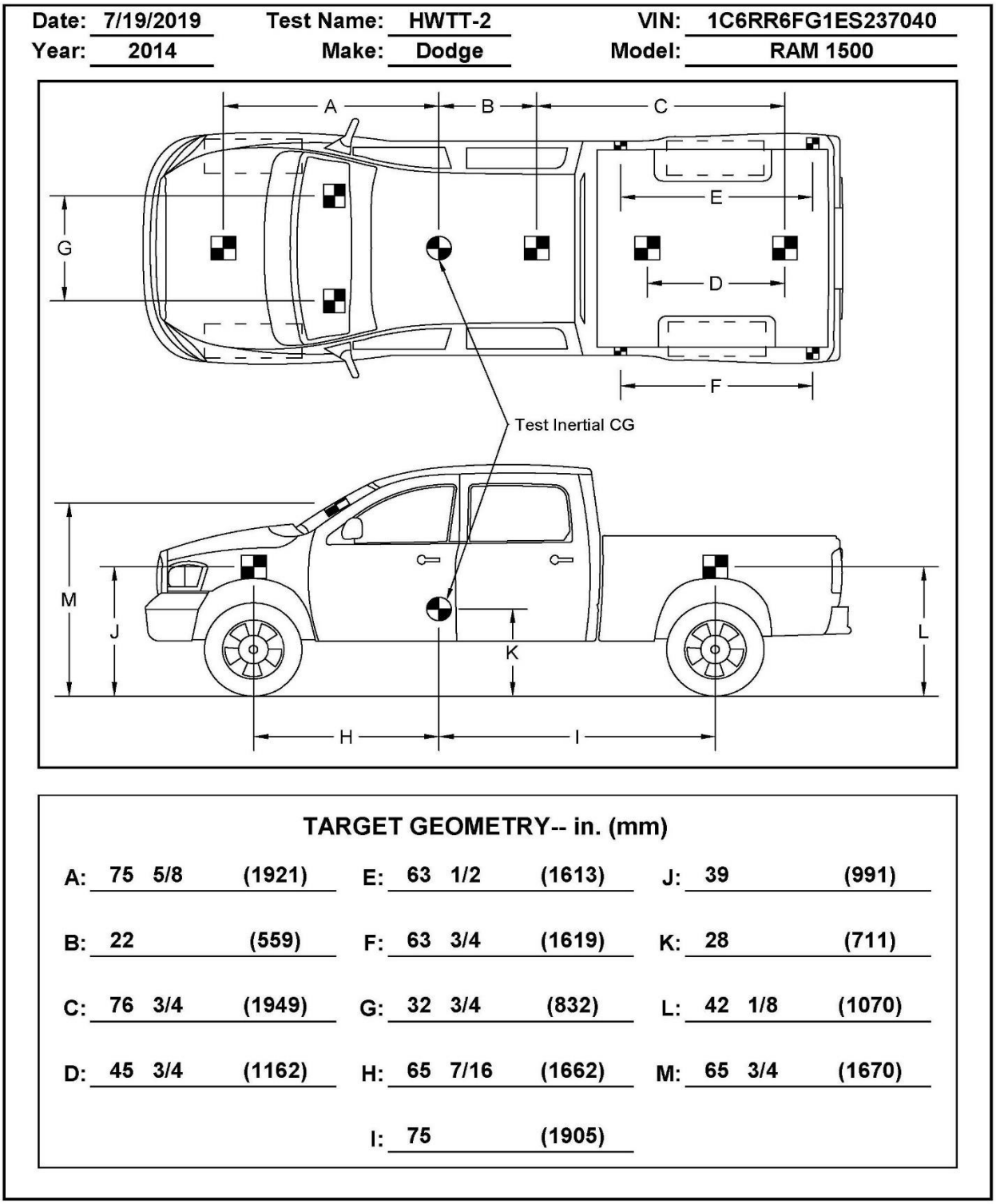



Figure 52. Target Geometry, Test No. HWTT-2

The two systems, 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. HWTT-1, and the SLICE-2 unit was designated as the primary system for test no. HWTT-2. 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 vehicles. 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.

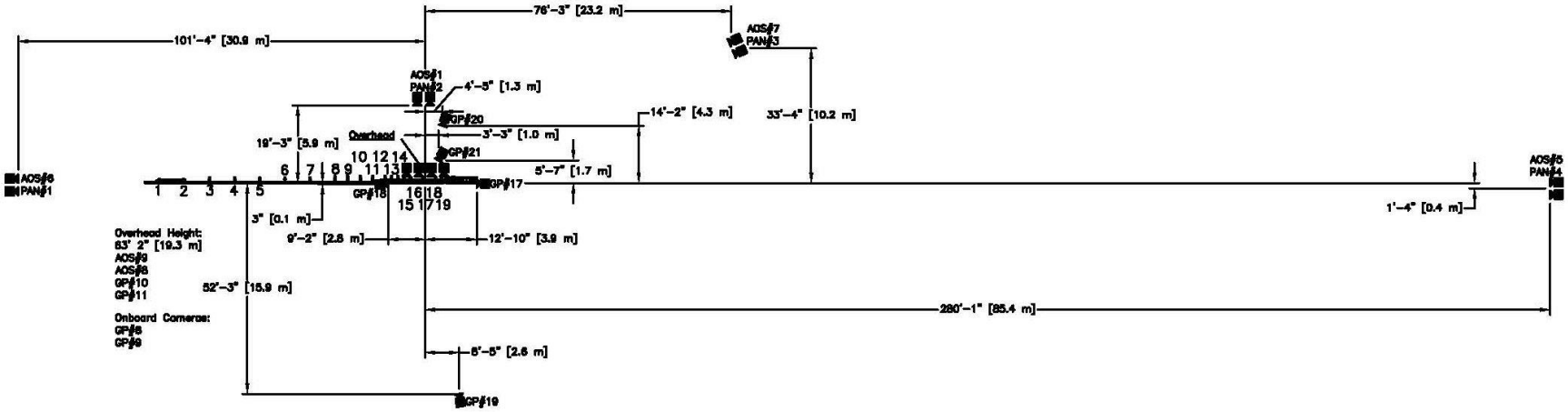
### 4.5.3 Retroreflective Optic Speed Trap

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

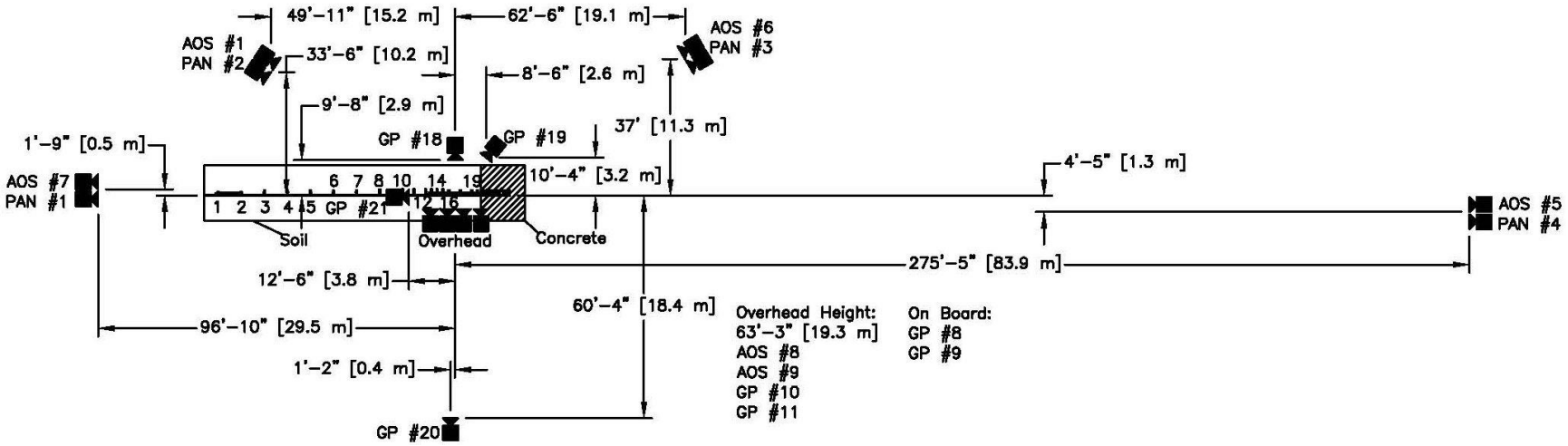
Six AOS high-speed digital video cameras, nine GoPro digital video cameras, and four Panasonic digital video cameras were utilized to film test no. HWTT-1. For test no. HWTT-2, six AOS high speed digital video cameras, eight GoPro digital video cameras, and four Panasonic digital video cameras were used. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system for test nos. HWTT-1 and HWTT-2 are shown in Figures 53 and 54, respectively.

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 tests.




| No. | Type | Operating Speed (frames/sec) | Lens | Lens Setting |
|---|---|---|---|---|
| AOS-1 | AOS Vitcam CTM | 500 | Sigma 28-70 | 28 |
| AOS-5 | AOS X-PRI Gigabit | 500 | 100 mm Fixed | - |
| AOS-6 | AOS X-PRI Gigabit | 500 | Sigma 28-70 | 70 |
| AOS-7 | AOS X-PRI Gigabit | 500 | Fujinon 50 mm Fixed | - |
| AOS-8 | AOS S-VIT 1531 | 500 | Kowa 16 mm Fixed | - |
| AOS-9 | AOS TRI-VIT 2236 | 500 | Kowa 12 mm Fixed | - |
| GP-8 | GoPro Hero 4 | 120 | | |
| GP-9 | GoPro Hero 4 | 120 | | |
| GP-10 | GoPro Hero 4 | 120 | | |
| GP-11 | GoPro Hero 4 | 240 | | |
| GP-17 | GoPro Hero 4 | 240 | | |
| GP-18 | GoPro Hero 6 | 240 | | |
| GP-19 | GoPro Hero 6 | 240 | | |
| GP-20 | GoPro Hero 6 | 240 | | |
| GP-21 | GoPro Hero 6 | 240 | | |
| PAN-1 | Panasonic HC-V770 | 120 | | |
| PAN-2 | Panasonic HC-V770 | 120 | | |
| PAN-3 | Panasonic HC-V770 | 120 | | |
| PAN-4 | Panasonic HC-V770 | 120 | | |

Figure 53. Camera Locations, Speeds, and Lens Settings, Test No. HWTT-1




| No. | Type | Operating Speed (frames/sec) | Lens | Lens Setting |
|---|---|---|---|---|
| AOS-1 | AOS Vitcam CTM | 500 | Minolta 70-120 | 70 |
| AOS-5 | AOS X-PRI Gigabit | 500 | 100 mm Fixed | - |
| AOS-6 | AOS X-PRI Gigabit | 500 | Fujinon 75 mm Fixed | - |
| AOS-7 | AOS X-PRI Gigabit | 500 | Fujinon 50 mm Fixed | - |
| AOS-8 | AOS S-VIT 1531 | 500 | Kowa 16 mm Fixed | - |
| AOS-9 | AOS TRI-VIT 2236 | 500 | Kowa 12 mm Fixed | - |
| GP-8 | GoPro Hero 4 | 120 | | |
| GP-9 | GoPro Hero 4 | 120 | | |
| GP-10 | GoPro Hero 4 | 120 | | |
| GP-11 | GoPro Hero 4 | 240 | | |
| GP-18 | GoPro Hero 6 | 240 | | |
| GP-19 | GoPro Hero 6 | 240 | | |
| GP-20 | GoPro Hero 6 | 240 | | |
| GP-21 | GoPro Hero 6 | 240 | | |
| PAN-1 | Panasonic HC-V770 | 120 | | |
| PAN-2 | Panasonic HC-V770 | 120 | | |
| PAN-3 | Panasonic HC-V770 | 120 | | |
| PAN-4 | Panasonic HC-V770 | 120 | | |

Figure 54. Camera Locations, Speeds, and Lens Settings, Test No. HWTT-2

# 5 FULL-SCALE CRASH TEST NO. HWTT-1

## 5.1 Static Soil Test

Before full-scale crash test no. HWTT-1 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. HWTT-1 was conducted on July 1, 2019 at approximately 3:30 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. HWTT-1

| | |
|---|---|
| Temperature | 91° F |
| Humidity | 45% |
| Wind Speed | 17 mph |
| Wind Direction | 190° from True North |
| Sky Conditions | Sunny/Partly Cloudy |
| Visibility | 10 Statute Miles |
| Pavement Surface | Dry |
| Previous 3-Day Precipitation | 0.00 in. |
| Previous 7-Day Precipitation | 0.40 in. |

## 5.3 Test Description

Initial vehicle impact was to occur 60 in. upstream from the upstream end of the concrete end post, as shown in Figure 55, which was selected using the CIP plot found in Figure 2-14 of MASH 2016 to maximize the probability of pocketing and vehicle snag on the concrete parapet. The 2,407-lb passenger car impacted the modified HDOT AGT at a speed of 61.8 mph and at an angle of 25.2 deg. The actual point of impact was 4.9 in. upstream from the targeted impact location. The vehicle was contained and redirected with only minor system deflections. The curb prevented the front tire from traveling underneath the rail, thereby mitigating vehicle snag. Only the plastic bumper cover of the vehicle protruded between the curb and the bottom of the guardrail and snagged on the buttress. During the redirection of the vehicle, the simulated occupant's head contacted the side window thus causing the window to shatter, but did not strike any component of the barrier. All measured accelerations resulted in occupant risk values (OIV and ORA) within the MASH allowed limits. The vehicle remained stable throughout the impact event. After exiting the system, the vehicle continued traveling downstream before the remote brakes were applied and the vehicle came to a stop 124 ft downstream and 34 ft – 10 in. in front of the system.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 56 and 57. Documentary photographs of the crash test are shown in Figure 58. The vehicle trajectory and final position are shown in Figure 59.

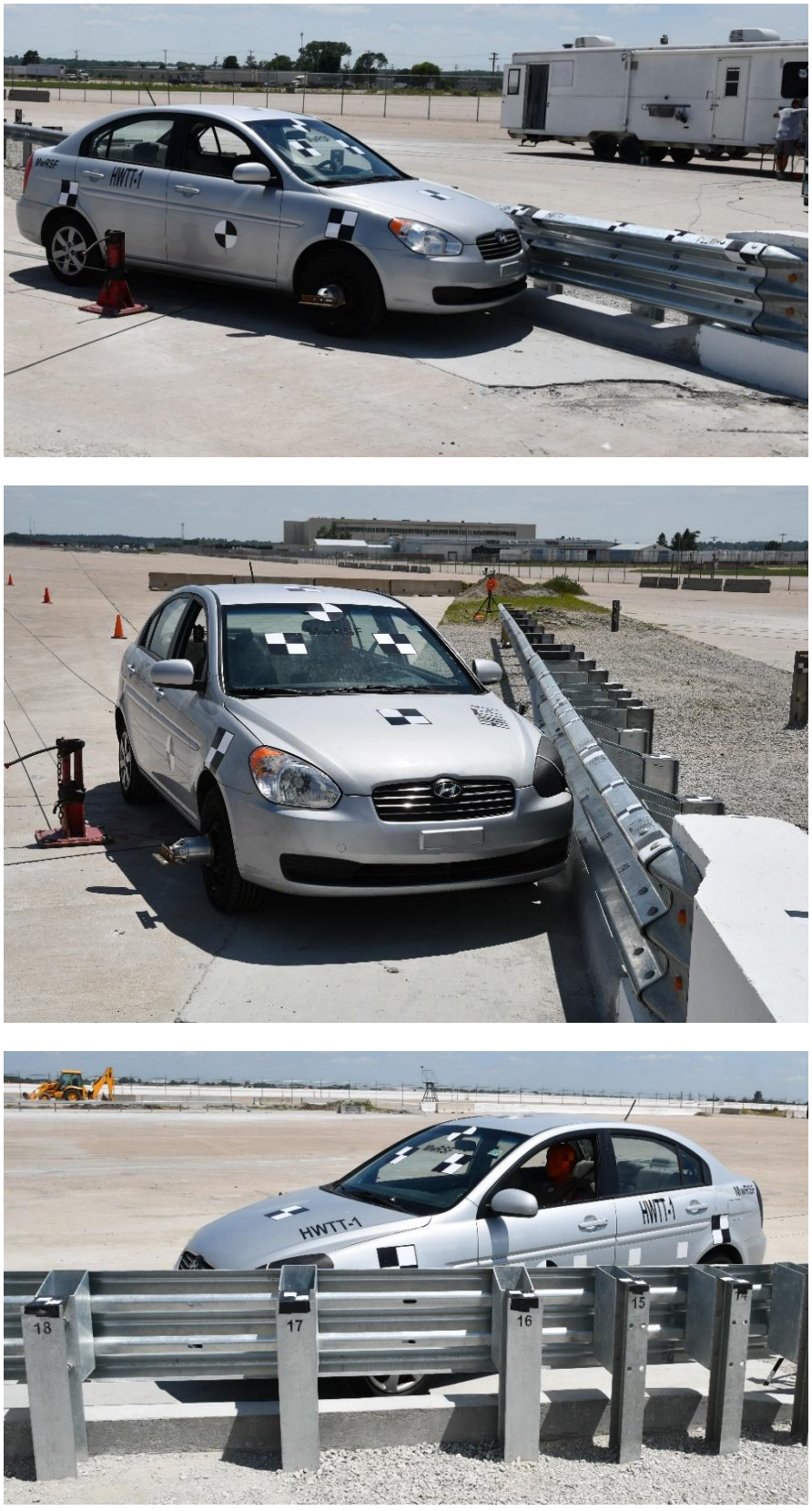



Figure 55. Impact Location, Test No. HWTT-1

Table 4. Sequential Description of Impact Events, Test No. HWTT-1

| TIME (sec) | EVENT |
|---|---|
| 0.000 | Vehicle's front bumper contacted rail 64⅞ in. upstream from parapet. |
| 0.004 | Vehicle's front bumper deformed. |
| 0.010 | Vehicle's hood deformed, vehicle's left headlight deformed, vehicle's left fender contacted rail and vehicle's hood and left headlight deformed. |
| 0.012 | Post no. 17 deflected backward. |
| 0.014 | Post no. 16 deflected backward and vehicle's left fender deformed. |
| 0.016 | Post nos. 18 and 19 deflected backward. |
| 0.030 | Vehicle's grille contacted rail and vehicle rolled toward system. |
| 0.034 | Vehicle's grille deformed and vehicle's left-front door contacted rail. |
| 0.038 | Vehicle's front bumper and grille partially detached. |
| 0.048 | Vehicle's windshield cracked. |
| 0.054 | Vehicle yawed away from system. |
| 0.060 | Vehicle's front bumper contacted parapet. |
| 0.064 | AGT components reached their maximum lateral deflection. |
| 0.068 | Vehicle pitched downward. |
| 0.076 | Vehicle's left-front tire contacted parapet. |
| 0.082 | Vehicle's right-rear tire became airborne occupant's head impacted and shattered left-front window. |
| 0.120 | System came to a rest. |
| 0.176 | Vehicle was parallel to system at a speed of 39.0 mph. |
| 0.230 | Vehicle's left-rear door contacted parapet. |
| 0.236 | Vehicle's left quarter panel deformed and vehicle's rear bumper contacted parapet. |
| 0.264 | Vehicle's left-rear tire contacted buttress. |
| 0.344 | Vehicle exited system at a speed of 37.2 mph. |
| 0.346 | Vehicle rolled away from system. |
| 0.714 | Vehicle's right-rear tire regained contact with ground. |
| 3.500 | Vehicle came to rest 124 ft downstream from impact. |


0.000 sec


0.000 sec


0.100 sec


0.100 sec


0.200 sec


0.200 sec


0.300 sec


0.300 sec


0.500 sec


0.500 sec


0.800 sec


0.800 sec

Figure 56. Sequential Photographs, Test No. HWTT-1

0.000 sec


0.000 sec

0.050 sec

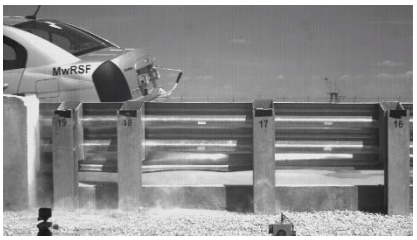

0.050 sec

0.100 sec


0.100 sec

0.150 sec


0.200 sec



0.200 sec


0.300 sec


0.250 sec


0.400 sec

Figure 57. Additional Sequential Photographs, Test No. HWTT-1

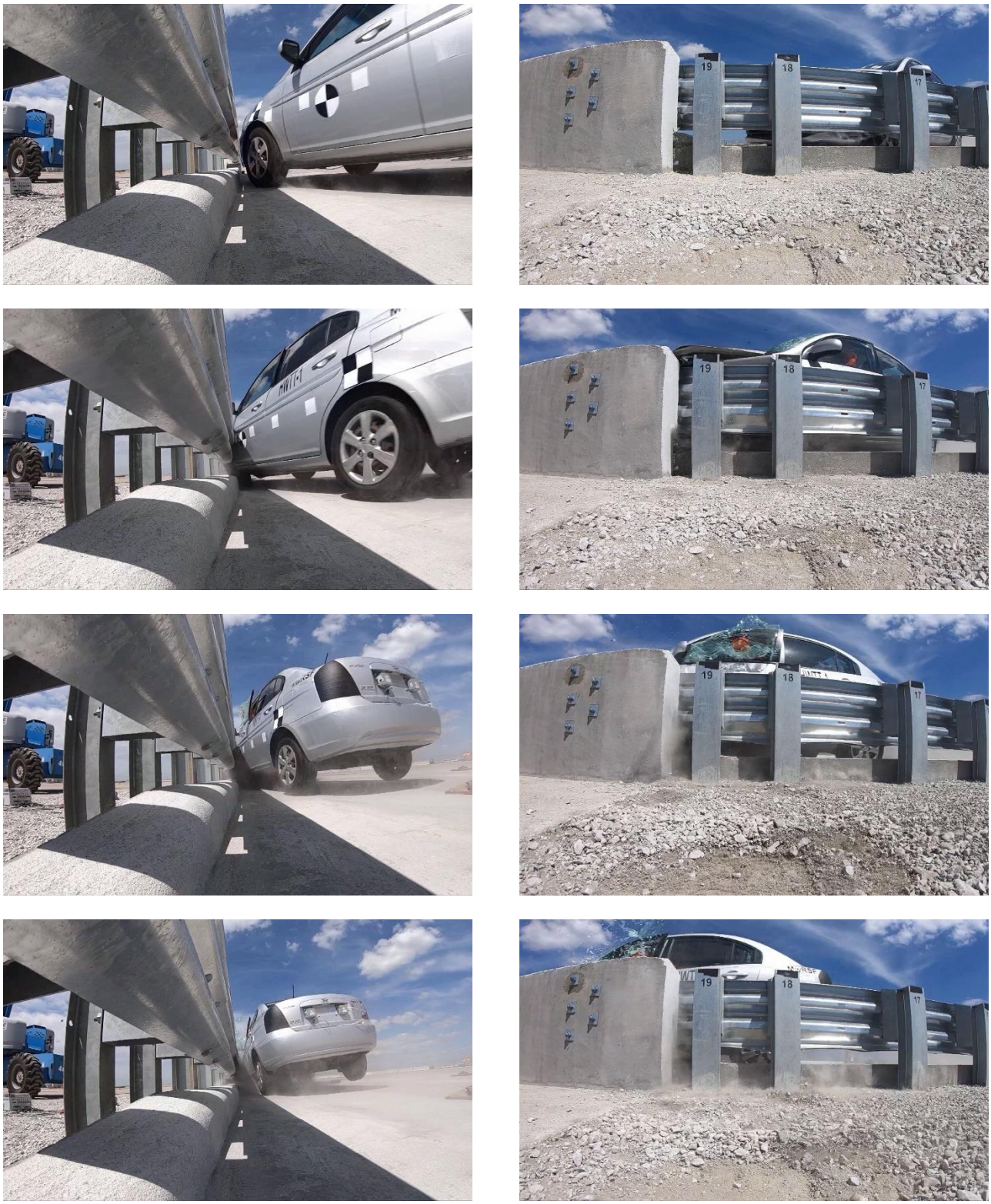


Figure 58. Documentary Photographs, Test No. HWTT-1

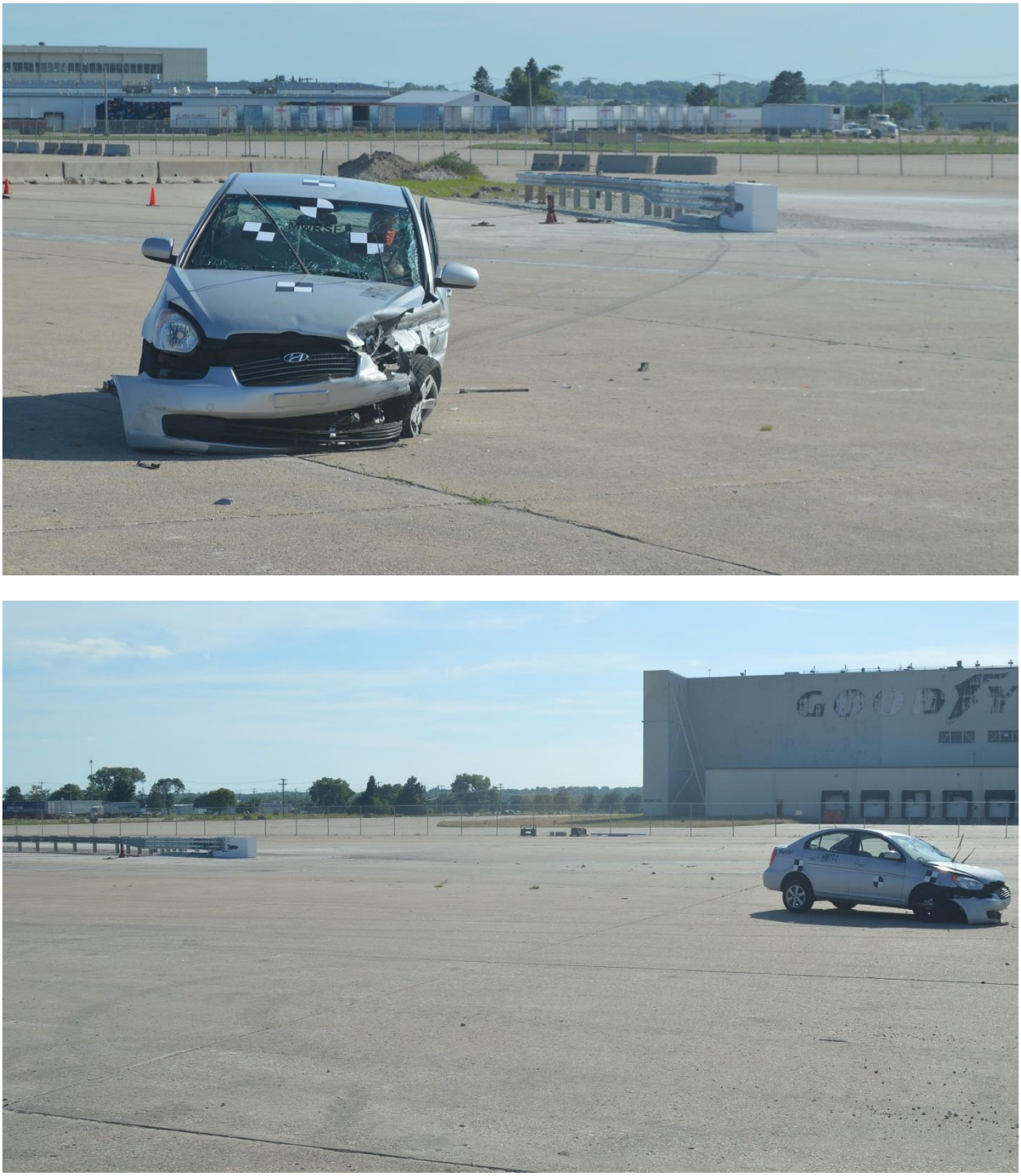


Figure 59. Vehicle Final Position and Trajectory Marks, Test No. HWTT-1

## 5.4 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 60 through 62. Barrier damage consisted of contact marks and kinks of the thrie beam sections, contact marks on the front face of the concrete end post, and minor spalling of the concrete. The length of vehicle contact along the barrier was approximately 13 ft – 7½ in., which began 23½ in. upstream from the center line of post no. 17.

Contact marks on the thrie beam began 23½ in. upstream from the centerline of post no. 17 and continued downstream through to the concrete end post. The bottom corrugation sustained various degrees of flattening damage beginning 23 in. upstream from post no. 18 and continued downstream. Multiple kinks were found on the top and bottom of the thrie beam around post nos. 17 and 18. Post nos. 18 and 19 slightly rotated counterclockwise and sustained minor damage to the top front upstream corner of the blockouts. Post nos.17 through 19 had soil gaps between ⅛ in. and ¼ in. in front of the posts. A ½-in. soil gap was observed behind the back of curb. No movement was observed in the upstream anchorage system.

A contact mark was found on the concrete curb starting 3¼ in. upstream from post no. 17 and extending to the concrete end post. The curb also sustained minor spalling along its top edge beginning 1 in. upstream from post no. 19 and continued downstream onto the Type D2 End Post.

Minor spalling on the top edge of the end post below the rail extended from the upstream extended 12½ in. downstream. Contact marks were found on lower face of the Type D2 End Post below the thrie beam terminal connector. Additional contact marks were found on the angled portion of the end post recess that extended downstream approximately 2 ft.

The maximum lateral permanent set of the barrier system was 1.4 in. which occurred in the thrie beam between post nos. 17 and 18, as measured in the field. The maximum lateral dynamic barrier deflection was 2.6 in. at post no. 18, as determined from high-speed digital video analysis. The working width of the system was found to be 20.0 in. at post no. 18, also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 63.

Figure 60. System Damage, Test No. HWTT-1

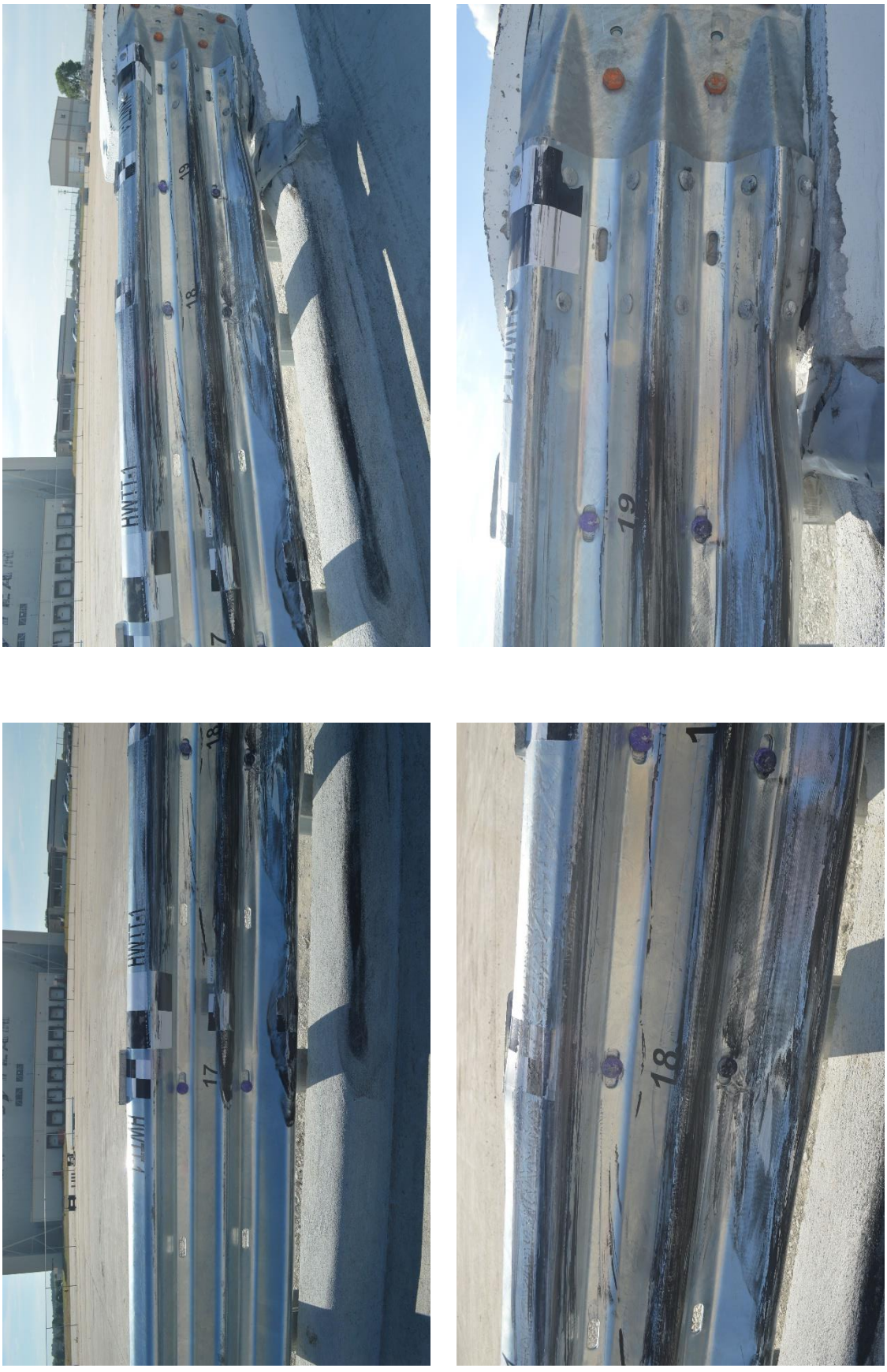



Figure 61. Thrie Beam Damage, Test No. HWTT-1


Figure 62. Rail Connection Terminal, Buttress and Post Damage, Test No. HWTT-1

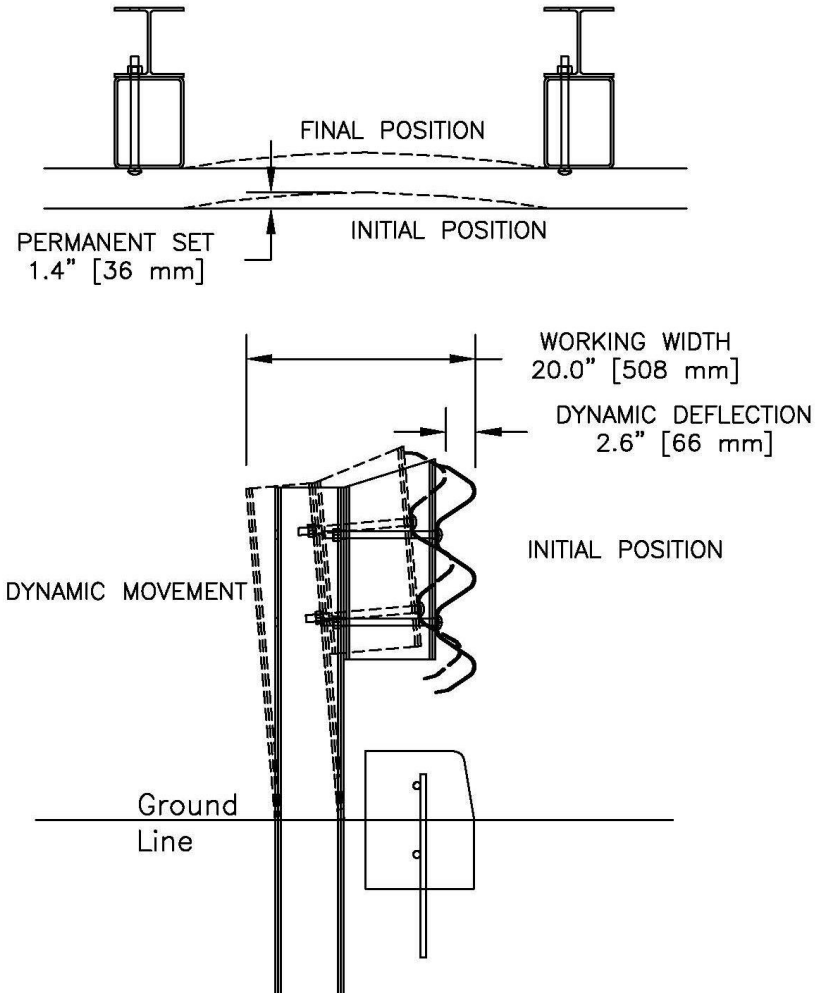



Figure 63. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. HWTT-1

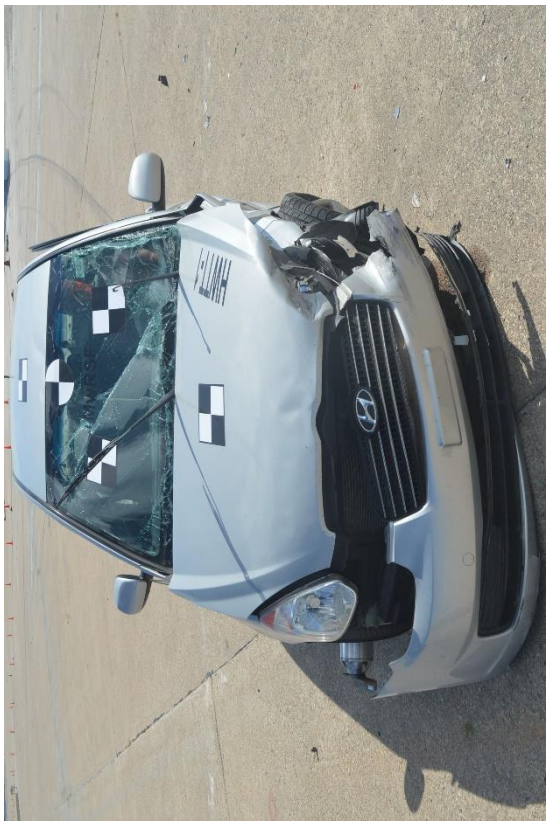
## 5.5 Vehicle Damage

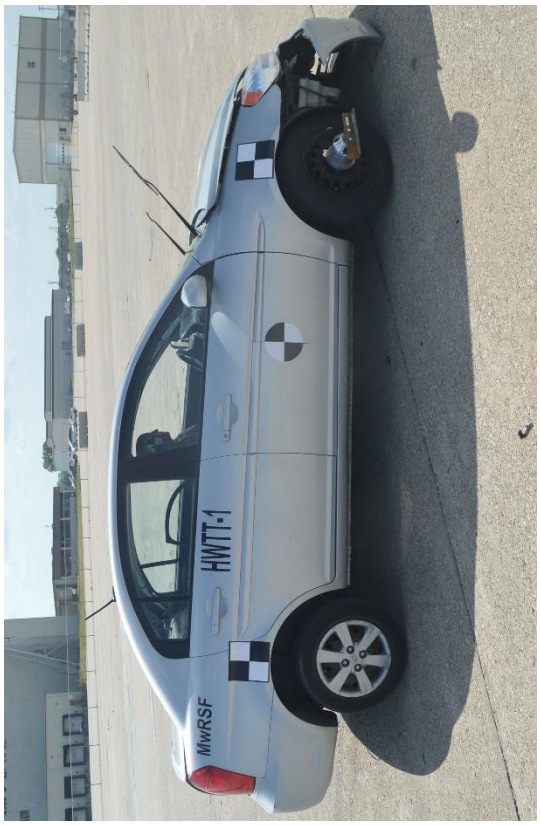
The damage to the vehicle was moderate, as shown in Figures 64 through 66. The majority of the damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The left side of the vehicle hood was crushed inward toward the engine compartment. Scraping and inward crushing was recorded on the left-side bumper and left-front fender. The front bumper cover was disengaged on the right side. A piece of the bumper cover disengaged after snagging between the thrie beam and curb. The left-front headlight shattered, and the left-front door was scraped and crushed inward behind the front fender, causing the middle section of the door to be forced outward. The left-rear door was dented and scraped, starting at the door handle and ending at the door seam. The left-rear quarter panel was scraped and crushed along the entirety of its length, and it was cut from the bottom of the fuel fill door to the rear panel. The fuel door was disengaged from the vehicle. The left-rear taillight was shattered, and the rear bumper was crushed inward. Contact with the head of the test dummy caused the left-front window to shatter.

Undercarriage damage was minimal. The left control arm was bent toward the rear of the test vehicle. The left-outer tie rod was bent toward the center of the test vehicle. The transmission and oil pan had scrapes in the middle and along the bottom, and on the left side, respectively. The frame rail on the left side twisted slightly, and it was bent up in front of the rear axle. The front cross member folded and twisted, while the rear cross member compressed in on itself. The left cross member bent toward the middle, and the right cross member showed indicators of beginning to fold. The frame horn was pushed rearward and inward toward the engine compartment. A wrinkle also occurred across the entire length of the floor pan.

The windshield was significantly deformed and a large tear in the windshield stretched from the lower left corner to the upper right side of the windshield. However, the system never contacted the windshield. This tear was caused by deformations to the vehicle's front-left side, quarter panel, and lower A-frame. Additionally, the tearing and cracking of the windshield allowed the glass to sag adjacent to the tear. This behavior resulted in a maximum of 3.5 in. of deformation to the windshield adjacent to the tear, which would violate the MASH accepted limit. However, since the system never contacted the windshield and the tearing and deformations were the result of vehicle deformations, this windshield damage did not result in test failure. Similar windshield damage has been observed in other recent MASH 1100C tests into rigid barriers, including testing of the Hawaii 34-in. tall concrete bridge rail [2]. Windshield damages in the form of tearing and deformations have been allowed for these other systems/tests when the barrier does not make direct contact with the system.

The maximum occupant compartment intrusions are listed in Table 5 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. Complete occupant compartment and vehicle intrusions and the corresponding locations are provided in Appendix D. MASH 2016 defines intrusion as the occupant compartment being deformed and reduced in size with no penetration. Outward deformations, which are denoted as negative numbers in Appendix D, are not considered as crush toward the occupant, and are not subject to evaluation by MASH 2016 criteria. It should be noted only one reference set was used to measure the occupant compartment intrusions due to shifting of the second reference set during testing.





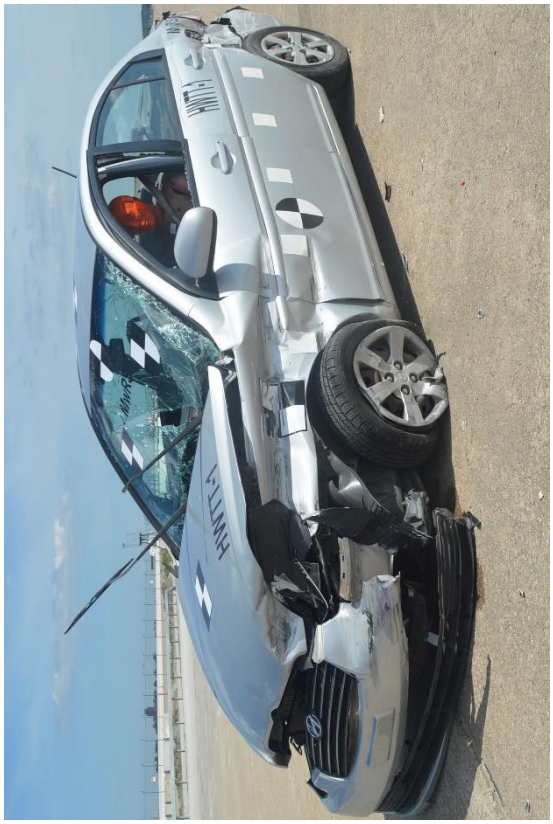




Figure 64. Vehicle Damage, Test No. HWTT-1


Figure 65. Vehicle Damage, Test No. HWTT-1

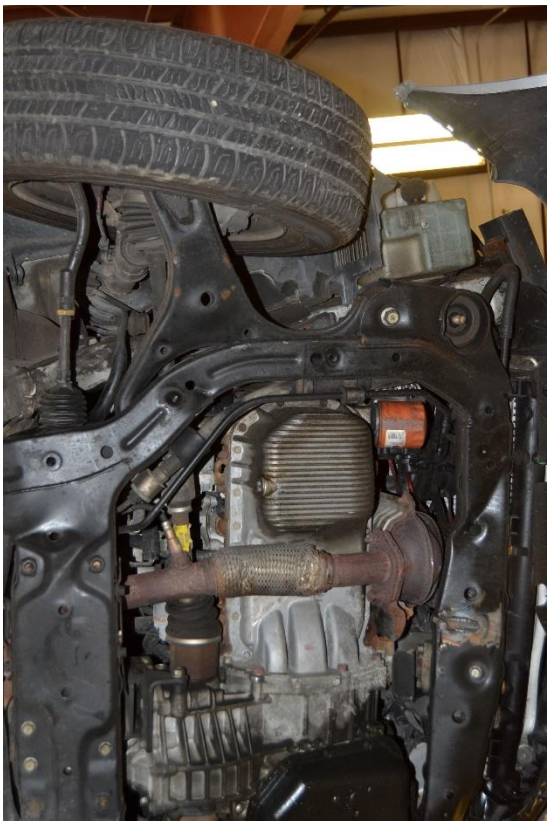


Figure 66. Interior and Undercarriage Damage, Test No. HWTT-1

Table 5. Maximum Occupant Compartment Intrusion by Location

| LOCATION | MAXIMUM INTRUSION (in.) | MASH 2016 ALLOWABLE INTRUSTION (in.) |
|---|---|---|
| Wheel Well & Toe Pan | 0.6 | ≤ 9 |
| Floor Pan & Transmission Tunnel | 1.4 | ≤ 12 |
| A-Pillar | 0.4 | ≤ 5 |
| A-Pillar (Lateral) | 0.0 | ≤ 3 |
| B-Pillar | 0.4 | ≤ 5 |
| B-Pillar (Lateral) | 0.0 | ≤ 3 |
| Side Front Panel (in Front of A-Pillar) | 1.7 | ≤ 12 |
| Side Door (Above Seat) | 0.0 | ≤ 9 |
| Side Door (Below Seat) | 0.0 | ≤ 12 |
| Roof | 0.1 | ≤ 4 |
| Windshield | 3.5 | ≤ 3 |
| Side Window | Shattered due to contact with simulated occupant's head | No shattering resulting from contact with structural member of test article |
| Dash | 0.5 | N/A |

N/A – Not applicable

## 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, as determined by accelerometer data, are shown in Table 6. 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 6. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 6. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. HWTT-1

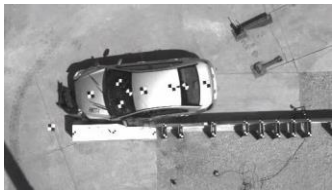
| Evaluation Criteria | | Transducer | | MASH 2016 Limits |
|---|---|---|---|---|
| | | SLICE-1 (primary) | SLICE-2 (backup) | |
| OIV ft/s | Longitudinal | -30.34 | -30.85 | ±40 |
| | Lateral | 34.36 | 32.49 | ±40 |
| ORA g's | Longitudinal | -8.41 | -5.78 | ±20.49 |
| | Lateral | 5.94 | 6.77 | ±20.49 |
| MAX. ANGULAR DISPL. deg. | Roll | -17.4 | -13.2 | ±75 |
| | Pitch | -6.5 | -9.0 | ±75 |
| | Yaw | 57.6 | 56.7 | not required |
| THIV ft/s | | 0.11 | 0.12 | not required |
| PHD g's | | 39.49 | 39.12 | not required |
| ASI | | 2.64 | 2.53 | not required |

## 5.7 Discussion

The analysis of the test results for test no. HWTT-1 showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 67. 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 nor override 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 as they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 12.8 deg., and its trajectory did not violate the bounds of the exit box. Shattering of the side window was due to impact with the dummy's head and not a barrier component. Further, the dummy's head did not contact any barrier component as it extended out the side window. Deformations and tearing of the windshield were caused by vehicle deformations as the windshield was never in contact with the barrier. Thus, there was no potential for the test article to penetrate into the vehicle, and there was no perceived risk to the occupant. Therefore, test no. HWTT-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-20.

0.000 sec

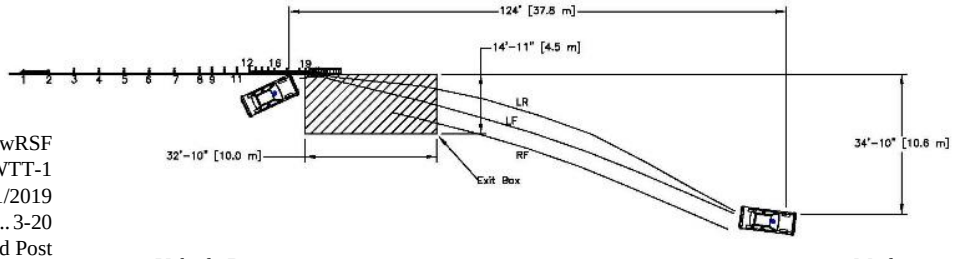
0.050 sec



0.150 sec

0.250 sec

0.350 sec




- Test Agency ..... MwRSF
- Test Number ..... HWTT-1
- Date ..... 7/1/2019
- MASH 2016 Test Designation No. ..... 3-20
- Test Article ..... Modified HDOT AGT to Type D2 End Post
- Total Length ..... 79 ft – 2 in.
- Key Component – Thrie beam Guardrail
  - Thickness ..... 12 ga.
  - Mounting Height ..... 31 in.
- Key Component – ASTM A992 W6x15 Steel Post
  - Length ..... 78 in.
  - Embedment Depth ..... 49 in.
  - Spacing ..... 37½ in.
- Key Component – Type D2 End Post (Concrete Parapet)
  - Length ..... 96 in.
  - Width ..... 18 in.
  - Height ..... 34 in.
- Soil Type ..... Crushed Limestone
- Vehicle Make /Model ..... Hyundai Accent
  - Curb ..... 2,475 lb
  - Test Inertial ..... 2,407 lb
  - Gross Static ..... 2,571 lb
- Impact Conditions
  - Speed ..... 61.8 mph
  - Angle ..... 25.2 deg.
  - Impact Location ..... 64.9 in. upstream from parapet
- Impact Severity ..... 55.7 kip-ft > 51 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed ..... 37.2 mph
  - Angle ..... 12.8 deg.
- Exit Box Criterion ..... Pass
- Vehicle Stability ..... Satisfactory
- Vehicle Stopping Distance ..... 124 ft downstream and 34 ft – 10 in. in front
- Vehicle Damage ..... Moderate
  - VDS [19] ..... 10-LFQ-5
  - CDC [20] ..... 10-LFEW-3
  - Maximum Interior Deformation ..... 3½ in.
- Test Article Damage ..... Minimal
- Maximum Test Article Deflections
  - Permanent Set ..... 1.4 in.
  - Dynamic ..... 2.6 in.
  - Working Width ..... 20.0 in.
- Transducer Data

| Evaluation Criteria | | Transducer | | MASH 2016 Limit |
|---|---|---|---|---|
| | | SLICE-1 (primary) | SLICE-2 (backup) | |
| OIV ft/s | Longitudinal | -30.34 | -30.85 | ±40 |
| | Lateral | 34.36 | 32.49 | ±40 |
| ORA g's | Longitudinal | -8.41 | -5.78 | ±20.49 |
| | Lateral | 5.94 | 6.77 | ±20.49 |
| MAX ANGULAR DISP. deg. | Roll | -17.4 | -13.2 | ±75 |
| | Pitch | -6.5 | -9.0 | ±75 |
| | Yaw | 57.6 | 56.7 | not required |
| THIV – ft/s | | 0.11 | 0.12 | not required |
| PHD – g's | | 39.49 | 39.12 | not required |
| ASI | | 2.64 | 2.53 | not required |

Figure 67. Summary of Test Results and Sequential Photographs, Test No. HWTT-1

# 6 FULL-SCALE CRASH TEST NO. HWTT-2

## 6.1 Static Soil Test

Before full-scale crash test no. HWTT-2 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. HWTT-2 was conducted on July 19, 2019 at approximately 1:15 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 7.

Table 7. Weather Conditions, Test No. HWTT-2

| | |
|---|---|
| Temperature | 97° F |
| Humidity | 46% |
| Wind Speed | 18 mph |
| Wind Direction | 190° from True North |
| Sky Conditions | Sunny |
| Visibility | 10 Statute Miles |
| Pavement Surface | Dry |
| Previous 3-Day Precipitation | 0.33 in. |
| Previous 7-Day Precipitation | 0.35 in. |

## 6.3 Test Description

Initial vehicle impact was to occur 84 in. upstream from the upstream end of the concrete end post, as shown in Figure 68, which was selected using the CIP plot found in Figure 2-17 of MASH 2016 to maximize the probability of pocketing and vehicle snag on the concrete parapet. The 5,000-lb pickup truck impacted the modified HDOT AGT at a speed of 63.0 mph and at an angle of 25.2 deg. The actual point of impact was 5.7 in. upstream from the targeted impact location. The vehicle was captured and redirected by the modified HDOT AGT with minor deflections to the system. The front-left tire rode up on top of the curb but did not snag on the concrete end post. The vehicle remained stable throughout the impact event. During the redirection of the vehicle, the dummy's head contacted the side window, thus causing the window to shatter. However, the head did not strike any component of the barrier. All measured accelerations resulted in occupant risk values (OIV and ORA) within the MASH allowed limits. After exiting the system, the vehicle continued traveling downstream before the remote brakes were applied and the vehicle came to a stop 165 ft – 8in. downstream from impact and 6 ft – 6 in. behind the system.

A detailed description of the sequential impact events is contained in Table 8. Sequential photographs are shown in Figures 69 and 70. Documentary photographs of the crash test are shown in Figure 71. The vehicle trajectory and final position are shown in Figure 72.



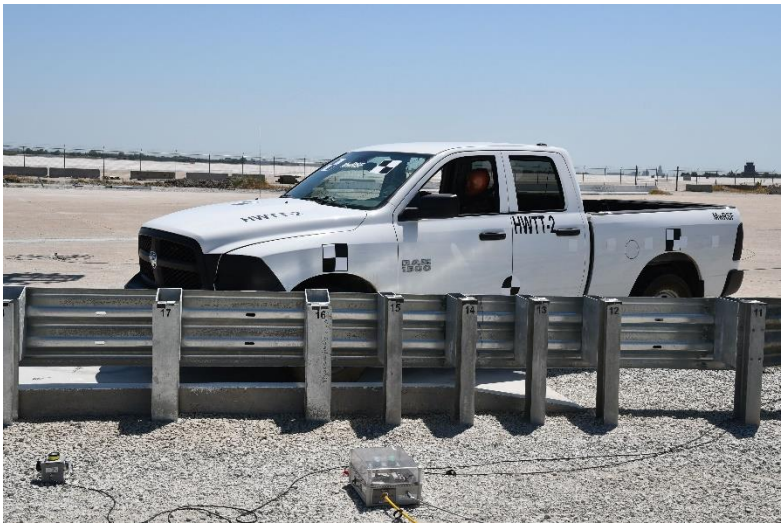



Figure 68. Impact Location, Test No. HWTT-2

Table 8. Sequential Description of Impact Events, Test No. HWTT-2

| TIME (sec) | EVENT |
|---|---|
| 0.000 | Vehicle's front bumper contacted rail 89¾ in. upstream from concrete parapet. |
| 0.002 | Vehicle's front bumper deformed and vehicle's left headlight contacted rail. |
| 0.008 | Vehicle's left fender contacted rail and deformed. |
| 0.010 | Vehicle's left-front tire contacted rail. |
| 0.016 | Post no. 17 deflected backward. |
| 0.018 | Post no. 16 deflected backward. |
| 0.020 | Post nos. 15 and 18 deflected backward, and vehicle's grille contacted rail. |
| 0.024 | Post no. 19 deflected downstream. |
| 0.026 | Post no. 14 deflected backward. |
| 0.030 | Post no. 13 deflected backward. |
| 0.042 | Vehicle's left-front door contacted rail. |
| 0.044 | Vehicle yawed away from system. |
| 0.046 | Vehicle's left-front door deformed. |
| 0.056 | Vehicle pitched downward. |
| 0.062 | Vehicle rolled toward system. |
| 0.086 | Occupant's head shattered left-front side window and exited vehicle. |
| 0.104 | Vehicle's right-front tire became airborne. |
| 0.116 | Vehicle's windshield cracked. |
| 0.130 | Vehicle's left-rear door contacted rail. |
| 0.182 | Vehicle's grille became disengaged. |
| 0.184 | Vehicle was parallel to system at a speed of 42.4 mph. |
| 0.186 | Occupant's head re-entered vehicle. |
| 0.188 | Vehicle's left-rear tire contacted rail and vehicle's right-rear tire became airborne. |
| 0.206 | Vehicle's rear bumper deformed. |
| 0.310 | System came to a rest. |
| 0.368 | Vehicle exited system at a speed of 41.0 mph. |
| 0.444 | Vehicle rolled away from system. |
| 0.456 | Vehicle yawed toward system. |
| 0.784 | Vehicle's right-front tire regained contact with ground. |
| 0.878 | Vehicle's right-rear tire regained contact with ground. |
| 4.600 | Vehicle came to rest 165 ft – 8 in. downstream from impact and 6 ft – 6 in. behind the system. |


0.000 sec


0.000 sec


0.100 sec


0.050 sec


0.200 sec


0.150 sec


0.300 sec


0.300 sec


0.400 sec


0.500 sec


0.500 sec


0.850 sec

Figure 69. Sequential Photographs, Test No. HWTT-2

0.000 sec


0.000 sec

0.050 sec


0.050sec

0.100 sec


0.100 sec

0.150 sec


0.150 sec


0.250 sec


0.200 sec


0.350 sec


0.250 sec

Figure 70. Additional Sequential Photographs, Test No. HWTT-2


Figure 71. Documentary Photographs, Test No. HWTT-2


Figure 72. Vehicle Final Position and Trajectory Marks, Test No. HWTT-2

### 6.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 73 through 75. Barrier damage consisted of contact marks, post deflection, rail kinking, and gouging and spalling to the concrete parapet and curb. The length of vehicle contact along the barrier was approximately 13 ft – 8 in., which began 6 in. downstream from the center of post no. 16 and extended 5 ft – 6 in. onto the concrete end post.

Contact marks were found on the thrie beam and were mostly concentrated on the upper and middle corrugations. The marks started 6 in. downstream from post no. 16 and onto the terminal connector. The upper half of the thrie beams between post nos. 17 and 19 were flattened. Various rail kinking was found on the guardrail spanning from post no. 14 to post no. 19. The largest rail kinks were found around post nos. 17 and 18. The lower corrugation was also folded upward between post nos. 17 and 19.

Post no. 1 had a ⅛ in. soil gap on the upstream side, but no other damage was documented to the upstream anchorage. Post nos. 3 through 17 all experienced slight counterclockwise rotation around the vertical axis. Post nos. 15 through 19 rotated backward leaving soil gaps adjacent to the front flange, the largest of which were measure to be around 2½ in. at post nos. 17 and 18. In addition to being deflected backward, post nos. 18 and 19 experienced clockwise rotation resulting in minor localized deformations to the upstream sides of the front flanges adjacent to the blockouts.

The concrete curb had tire marks on the top and face starting 15½ in. downstream from post no. 16 and continuing 44 in. onto the lower face of the Type D2 End Post. Another tire mark was found on the angled section at the downstream end of the lateral recess on the end post. Scratches were also recorded on the top of the barrier starting at the upstream end and continuing for 71 in. Concrete spalling was found on the top-front edge of the end post behind the nested thrie beam, as shown in Figure 75. Minor concrete spalling also occurred at the joint between the curb and the concrete end post.

The maximum lateral permanent set of the barrier system was 6.2 in., which occurred in the thrie beam between post nos. 18 and 19, as measured in the field. The maximum lateral dynamic barrier deflection was 9 in. at post no. 18, as determined from high-speed digital video analysis. The working width of the system was found to be 23 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 76.

Figure 73. System Damage, Test No. HWTT-2



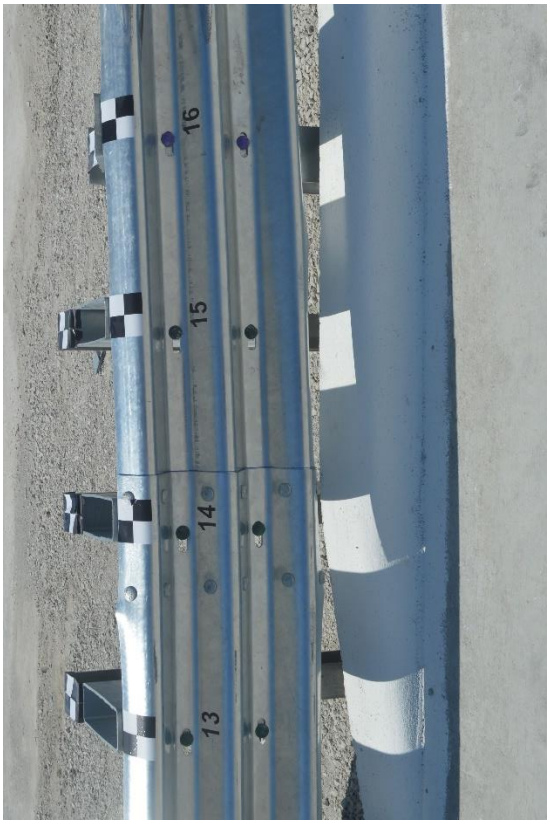




Figure 74. Thrie Beam Damage, Test No. HWTT-2

Figure 75. Buttress Damage, Test No. HWTT-2

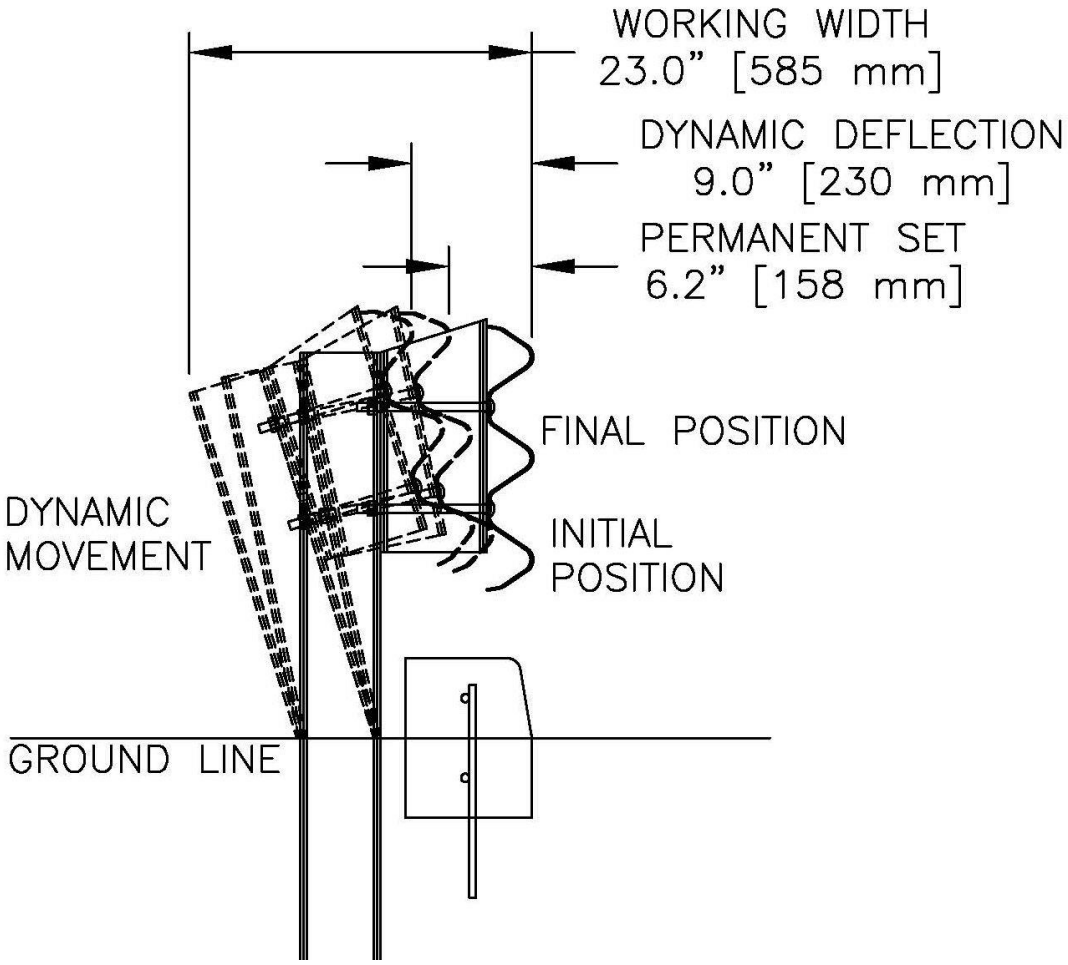



Figure 76. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. HWTT-2

### 6.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 77 through 79. The majority of the damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The grille disengaged from the vehicle, and the front bumper crushed inward. The vehicle's headlights detached, and the hood was slightly bent inward on the left side. Significant damage was imparted to the left-front fender including being crushed inward and rearward. The left-front door was scraped and crushed inward along the entirety of its length causing the door to bow outward near the top. The left-rear door experienced scraping down its entire length and was crushed in the middle. Similarly, the left-rear fender was scraped and crushed, and the rear bumper bowed outward in the middle due to crushing of the left corner. The windshield was cracked prior to testing, but the impact caused further cracking to the left side of the windshield.

The left-front shock and spring were bent into an L-shape, and the bump stop was detached from the vehicle. The sway and anti-roll bar linkage was deformed on the left-front side. The left-front steering knuckle was scraped due to contact with the lower control arm. The left lower control

arm was broken off both mounts, and the upper control arm was bent. The right-lower control arm was scraped on the leading edge. The left-front outer tie rod was bent, and the steering gear box was scraped on the bottom. The engine and transmission mounts on the left-front side was slightly twisted on the bushing. The vehicle frame bent near the left-front wheel assembly. The front cross member had several scrapes and dents, and the middle cross member buckled in the middle. On the left side, the frame horn was pushed toward the centerline of the vehicle.

The maximum occupant compartment intrusions are listed in Table 9 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. Complete occupant compartment and vehicle intrusions and the corresponding locations are provided in Appendix D. MASH 2016 defines intrusion as the occupant compartment being deformed and reduced in size with no penetration. Outward deformations, which are denoted as negative numbers in Appendix D, are not considered as crush toward the occupant, and are not subject to evaluation by MASH 2016 criteria. Note that none of the established MASH 2016 intrusion limits were violated.

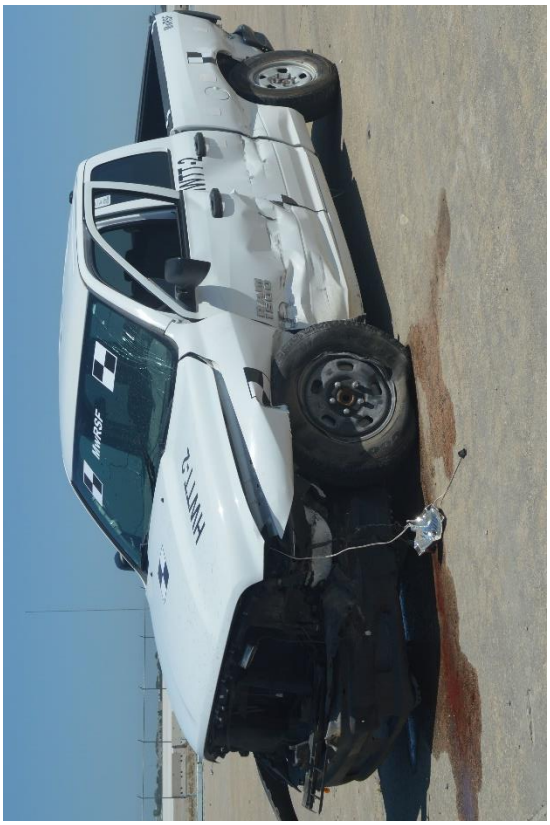






Figure 77. Vehicle Damage, Test No. HWTT-2



Figure 78. Vehicle Damage, Test No. HWTT-2

Figure 79. Interior and Undercarriage Damage, Test No. HWTT-2

Table 9. Maximum Occupant Compartment Intrusion by Location

| LOCATION | MAXIMUM INTRUSION (in.) | MASH 2016 ALLOWABLE INTRUSION in. |
|---|---|---|
| Wheel Well & Toe Pan | 6.5 | ≤ 9 |
| Floor Pan & Transmission Tunnel | 0.1 | ≤ 12 |
| A-Pillar | 0.2 | ≤ 5 |
| A-Pillar (Lateral) | 0.0 | ≤ 3 |
| B-Pillar | 0.6 | ≤ 5 |
| B-Pillar (Lateral) | 0.0 | ≤ 3 |
| Side Front Panel (in Front of A-Pillar) | 2.9 | ≤ 12 |
| Side Door (Above Seat) | 0.0 | ≤ 9 |
| Side Door (Below Seat) | 0.0 | ≤ 12 |
| Roof | 0.3 | ≤ 4 |
| Windshield | 0.0 | ≤ 3 |
| Side Window | Shattered due to contact with dummy's head | No shattering resulting from contact with structural member of test article |
| Dash | 0.7 | N/A |

N/A – Not applicable

### 6.6 Occupant Risk

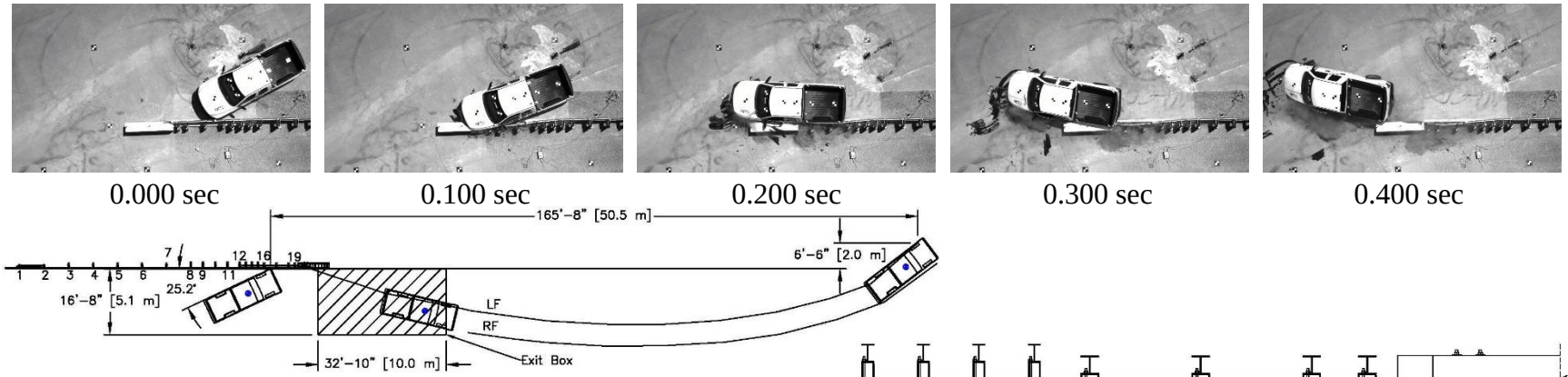
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from accelerometer data, are shown in Table 10. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 10. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

Table 10. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. HWTT-2

| Evaluation Criteria | | Transducer | | MASH 2016 Limits |
|---|---|---|---|---|
| | | SLICE-2 (primary) | SLICE-1 (backup) | |
| OIV ft/s | Longitudinal | -23.47 | -24.67 | ±40 |
| | Lateral | 26.73 | 25.90 | ±40 |
| ORA g's | Longitudinal | -13.77 | -11.47 | ±20.49 |
| | Lateral | 9.90 | 11.35 | ±20.49 |
| MAX. ANGULAR DISPL. deg. | Roll | -23.0 | -27.2 | ±75 |
| | Pitch | -9.1 | -6.9 | ±75 |
| | Yaw | 40.3 | 41.3 | not required |
| THIV ft/s | | 34.49 | 34.00 | not required |
| PHD g's | | 16.64 | 16.37 | not required |
| ASI | | 1.58 | 1.50 | not required |

## 6.7 Discussion

The analysis of the test results for test no. HWTT-2 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 80. 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 nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix F, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. Shattering of the side window was due to impact with the dummy's head and not a barrier component. Further, the dummy's head did not contact any barrier component as it extended out the side window. After impact, the vehicle exited the barrier at an angle of 11.1 deg., and its trajectory did not violate the bounds of the exit box. Therefore, test no. HWTT-2 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-21.




- Test Agency ..... MwRSF
- Test Number ..... HWTT-2
- Date ..... 7/19/2019
- MASH 2016 Test Designation No. ..... 3-21
- Test Article ..... Modified HDOT AGT with Type D2 End Post
- Total Length ..... 79 ft – 2 in.
- Key Component – Thrie beam Guardrail
  - Thickness ..... 12 ga.
  - Mounting Height ..... 31 in.
- Key Component – ASTM A992 W6x15 Steel Post
  - Length ..... 78 in.
  - Embedment Depth ..... 49 in.
  - Spacing ..... 37½ in.
- Key Component – Type D2 End Post (Concrete Buttress)
  - Length ..... 96 in.
  - Width ..... 18 in.
  - Height ..... 34 in.
- Soil Type ..... Crushed Limestone
- Vehicle Make /Model ..... Dodge Ram 1500
  - Curb ..... 4,953 lb
  - Test Inertial ..... 5,000 lb
  - Gross Static ..... 5,160 lb
- Impact Conditions
  - Speed ..... 63.0 mph
  - Angle ..... 25.2 deg.
  - Impact Location ..... 89.7 in. upstream from concrete parapet
- Impact Severity ..... 120.6 kip-ft > 106 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed ..... 41.0 mph
  - Angle ..... 11.1 deg.
- Exit Box Criterion ..... Pass
- Vehicle Stability ..... Satisfactory
- Vehicle Stopping Distance ..... 165 ft 8 in. downstream and 6 ft 6 in. behind
- Vehicle Damage ..... Moderate
  - VDS [19] ..... 10-LFQ-5
  - CDC [20] ..... 11-LFEW-4
  - Maximum Interior Deformation ..... 6.5 in.
- Test Article Damage ..... Moderate
- Maximum Test Article Deflections
  - Permanent Set ..... 6.2 in.
  - Dynamic ..... 9.0 in.
  - Working Width ..... 23.0 in.
- Transducer Data

| Evaluation Criteria | | Transducer SLICE-2 (primary) | Transducer SLICE-1 (backup) | MASH 2016 Limit |
|---|---|---|---|---|
| OIV ft/s | Longitudinal | -23.47 | -24.67 | ±40 |
| | Lateral | 26.73 | 25.90 | ±40 |
| ORA g's | Longitudinal | -13.77 | -11.47 | ±20.49 |
| | Lateral | 9.90 | 11.35 | ±20.49 |
| MAX ANGULAR DISP. deg. | Roll | -23.0 | -27.2 | ±75 |
| | Pitch | -9.1 | -6.9 | ±75 |
| | Yaw | 40.3 | 41.3 | not required |
| THIV – ft/s | | 34.49 | 34.00 | not required |
| PHD – g's | | 16.64 | 16.37 | not required |
| ASI | | 1.58 | 1.50 | not required |

Figure 80. Summary of Test Results and Sequential Photographs, Test No. HWTT-2

# 7 SUMMARY AND CONCLUSIONS

HDOT desired to test and evaluate their thrie beam guardrail transition to a specialized concrete parapet, the HDOT Type D2 End Post, according to MASH 2016 TL-3 criteria. Prior to full-scale crash testing, the HDOT AGT was modified to improve its performance and connect with 31-in. tall MGS guardrail. The upstream end of the HDOT was altered to include the MASH crashworthy MGS upstream stiffness transition, and multiple W6x15 posts were removed from the downstream end of the AGT based on MASH testing of similar transitions. The height of the system was reduced from 32 in. to 31 in. to match the adjacent MGS, and the top edge of the Type D2 End Post was given a 2-in. x 12-in. vertical taper to mitigate the potential for vehicle snag on the concrete parapet above the rail. The W6x12 blockouts were replaced with rectangular HSS sections to improve strength and prevent premature collapse. Finally, the flare at the upstream end of the curb was eliminated, and a vertical taper was used to terminate the curb while minimizing wheel snag.

The modified HDOT AGT was then subjected to full-scale crash testing in accordance with the TL-3 evaluation criteria of MASH 2016. Test nos. HWTT-1 and HWTT-2 were conducted to MASH 2016 test designations nos. 3-20 and 3-21, respectively. Summaries of the test evaluations are shown in Table 11.

In test no. HWTT-1, the 1100C vehicle impacted the modified HDOT AGT at a speed of 61.8 mph, an angle of 25.2 deg., and at a location 64.9 in. upstream from the Type D2 End Post. The vehicle was captured and safely redirected by the barrier system. The vehicle exited the system at a speed of 37.2 mph and an angle of 12.8 deg., which did not violate the bounds of the exit box, and came to rest 124 ft downstream from impact and 34 ft – 10 in. in front of the barrier. All vehicle decelerations, ORA's, and OIV's fell within the recommended safety limits established in MASH 2016. Therefore, test no. HWTT-1 was successful according to the safety criteria of MASH 2016 test designation no. 3-20.

In test no. HWTT-2, the 2270P vehicle impacted the modified HDOT AGT at a speed of 63.0 mph, an angle of 25.2 deg., and at a location of 89.7 in. upstream from the Type D2 End Post. The vehicle was captured and safely redirected by the barrier system. The vehicle exited the system at a speed of 41.0 mph and an angle of 11.1 deg, which did not violate the bounds of the exit box, and came to rest 165 ft – 8 in. downstream from impact and 6 ft – 6 in. behind the barrier system. All vehicle decelerations, ORA's, and OIV's fell within the recommended safety limits established in MASH 2016. Therefore test no. HWTT-2 was successful according to the safety criteria of MASH 2016 test designation no. 3-21.

Although MASH 2016 only specifies two full-scale crash tests to evaluate longitudinal transitions, recent research has illustrated the importance of evaluating two different regions within approach guardrail transitions: (1) the upstream stiffness transition where W-beam connects to stiffened thrie beam and (2) the downstream end of an AGT where the guardrail attaches to the rigid parapet. The upstream region of the modified HDOT AGT includes the MGS upstream stiffness transition, which has already been successfully crash tested to MASH TL-3 [4]. With the successful crash tests documented herein, the downstream region of the AGT has also been proven crashworthy. Therefore, the modified HDOT AGT meets the safety performance criteria for MASH 2016 TL-3.

Table 11. Summary of Safety Performance Evaluation, Test Nos. HWTT-1 and HWTT-2

<table>
<tr><th>Evaluation Factors</th><th>Evaluation Criteria</th><th>Test No. HWTT-1</th><th>Test No. HWTT-2</th></tr>
<tr><td>Structural Adequacy</td><td>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D. 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. 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. 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</td><td>40 ft/s</td></tr>
</table></td><td>S</td><td>S</td></tr>
<tr><td>I. 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="2">MASH 2016 Test Designation No.</td><td>3-20</td><td>3-21</td></tr>
<tr><td colspan="2">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

# 8 REFERENCES

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

2. Bielenberg, R.W., Yoo, S.H., Faller, R.K., and Urbank, E.L., *Crash Testing and Evaluation of the HDOT 34-in. Tall Aesthetic Concrete Bridge Rail: MASH Test Designation Nos. 3-10 and 3-11*, Report No. TRP-03-420-19, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, October 2019.

3. Bielenberg, R.W., Dowler, N.T., Faller, R.K., and Urbank, E.L., *Crash Testing and Evaluation of the HDOT 42-in. Tall Aesthetic Concrete Bridge Rail: MASH Test Designation Nos. 3-10 and 3-11*, Report No. TRP-03-424-20, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, January 2020.

4. 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 21, 2010.

5. Rosenbaugh, S.K., *Equivalent Steel Blockouts for Approach Guardrail Transitions*, Technical Memorandum to Central Federal Lands Highway Division, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 26, 2018.

6. Rosenbaugh, S.K., Schmidt, J.D., and Faller, R.K., Development of a Standardized Buttress for Approach Guardrail Transitions, *Transportation Research Record: Journal of the Transportation Research Board*, 2018. https://doi.org/10.1177%2F0361198118758676.

7. Rosenbaugh, S.K., et al. *Development and Evaluation of Standardized Concrete End Buttress*, Draft Report No. TRP-03-369-20 (in progress), Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, 2020.

8. Rosenbaugh, S.K., Fallet, W.G., Faller, R.K., Bielenberg, R.W., and Schmidt, J.D. *34-in. Tall Thrie Beam Transition to Concrete Buttress*, Report No. TRP-03-367-19-R1, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, July 2019.

9. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, R.W., Reid, J.D., and Coon, B.A., *Performance Evaluation of the Guardrail to Concrete Barrier Transition – Update to NCHRP 350 Test No. 3-21 with 28 in. C.G. Height (2214T-1)*, Report No. TRP-03-175-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, 2006.

10. 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.

11. 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.

12. 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.

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

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

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

16. 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.

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

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

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

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

# 9 APPENDICES

# Appendix A. Material Specifications

Table A-1. Bill of Materials for Test Nos. HWTT-1 and HWTT-2

| Item No. | Description | Material Specification | Reference |
|---|---|---|---|
| a1 | 12'-6" [3,810] 12-gauge [2.7] Thrie Beam Section | AASHTO M180 | #L30719 |
| a2 | 6'-3" [1,905] 12-gauge [2.7] Thrie Beam Section | AASHTO M180 | #L34518 |
| a3 | 6'-3" [1905] 10-gauge [3.4] W-Beam to Thrie-Beam Asymmetric Transition Section | AASHTO M180 | H#A80436 |
| a4 | 12'-6" [3,810] 12-gauge [2.7] W-Beam MGS Section | AASHTO M180 | V1207 H#C85187 |
| a5 | 12'-6" [3,810] 12-gauge [2.7] W-Beam MGS End Section | AASHTO M180 | S8534 H#9411949 |
| a6 | 10-gauge [3.4] Thrie Beam Terminal Connector | AASHTO M180<br>Min. yield strength = 50 ksi [345 MPa]<br>Min. ultimate strength = 70 ksi [483 MPa] | H#A81568 |
| b1b | Reinforced Concrete: Buttress | Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD | Ticket#1235879<br>ProCode#470031PF<br>ID#URR-123<br>ID#URR-124 |
| b1c | Reinforced Concrete: Curb | Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD | Ticket#4215635<br>ProCode#470031PF |
| c1 | BCT Timber Post - MGS Height | SYP Grade No. 1 or better (No knots +/- 18" [457] from ground on tension face) | Ch#25729 White Paint |
| c2 | 72" [1,829] Long Foundation Tube | ASTM A500 Gr. B | H#821T08220 |
| c3 | Ground Strut Assembly | ASTM A36 | Yoke: H#645887<br>Strut: H#195070<br>H#A82292<br>Welded<br>Wire:H#15056184 |
| c4 | BCT Anchor Cable End Swaged Fitting | Fitting - ASTM A576 Gr. 1035<br>Stud - ASTM F568 Class C | PO#40299<br>ASPI#122160 |
| c5 | 3/4" [19] Dia. 6x19 IWRC IPS Wire Rope | ASTM A741 Type 2 | PO#40299<br>ASPI#122160 |
| c6 | 8"x8"x5/8" [203x203x16] Anchor Bearing Plate | ASTM A36 | H#4181496 |
| c7 | 2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve | ASTM A53 Gr. B Schedule 40 | H#B712810 |
| c8 | Anchor Bracket Assembly | ASTM A36 | H#JK16101488 |
| d1 | W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post | ASTM A992 | H#55044251 |

Table A-2. Bill of Materials for Test Nos. HWTT-1 and HWTT-2, Continued

| Item No. | Description | Material Specification | Reference |
|---|---|---|---|
| d2 | W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post | ASTM A992 | H#55044251 |
| d3 | W6x15 [W152x22.5], 78" [1,981] Long Steel Post | ASTM A992 MTR says A572 instead | H#2815472 |
| d4 | 17 1/2" [445] Long, 8"x6"x1/4" [203x152x6] Steel Blockout | ASTM A500 Gr. B | H#17156541 |
| d5 | 17 1/2" [445] Long, 12"x4"x1/4" [305x102x6] Steel Blockout | ASTM A500 Gr. B | H#B46771 |
| d6 | 14 3/16"x12"x5 1/8" [360x305x130] Composite Recycled Blockout | Mondo Polymer MGS14SH or Equivalent | L#1904/1000 |
| d7 | 14 3/16"x8"x5 1/8" [360x203x130] Composite Recycled Blockout | Mondo Polymer GB14SH2 or Equivalent | L#1804/1000 |
| d8 | 16D Double Head Nail | - | PO E000548963 COC |
| e1 | #6 [19] Rebar, 57 7/8" [1470] Total Unbent Length | ASTM A615 Gr. 60 | H#6005053 |
| e2 | #6 [19] Rebar, 55 3/8" [1407] Total Unbent Length | ASTM A615 Gr. 60 | H#6005053 |
| e3 | #6 [19] Rebar, 53 7/8" [1368] Total Unbent Length | ASTM A615 Gr. 60 | H#6005053 |
| e4 | #6 [19] Rebar, 51" [1295] Total Unbent Length | ASTM A615 Gr. 60 | H#6005053 |
| e5 | #6 [19] Rebar, 33 7/8" [860] Total Unbent Length | ASTM A615 Gr. 60 | H#6005053 |
| e6 | #4 [13] Rebar, 56 3/4" [1441] Total Unbent Length | ASTM A615 Gr. 60 | H#605061 |
| e7 | #4 [13] Rebar, 55" [1397] Total Unbent Length | ASTM A615 Gr. 60 | H#605061 |
| e8 | #4 [13] Rebar, 52 3/4" [1340] Total Unbent Length | ASTM A615 Gr. 60 | H#605061 |
| e9 | #4 [13] Rebar, 49 1/2" [1257] Total Unbent Length | ASTM A615 Gr. 60 | H#605061 |
| e10 | #6 [19] Rebar, 92" [2337] Total Length | ASTM A615 Gr. 60 | H#6005053 |
| e11 | #6 [19] Rebar, 92 7/8" [2359] Total Unbent Length | ASTM A615 Gr. 60 | H#6005053 |
| e12 | #4 [13] Rebar, 92" [2337] Total Length | ASTM A615 Gr. 60 | H#58035268 |
| e13 | #4 [13] Rebar, 49 5/8" [1260] Total Length | ASTM A615 Gr. 60 | H#58035268 |
| e14 | #4 [13] Rebar, 16" [406] Total Length | ASTM A615 Gr. 60 | H#605061 |
| e15 | #4 [13] Rebar, 12 3/4" [324] Total Length | ASTM A615 Gr. 60 | H#605061 |

Table A-3. Bill of Materials for Test Nos. HWTT-1 and HWTT-2, Continued

| Item No. | Description | Material Specification | Reference |
|---|---|---|---|
| e16 | #5 [16] Rebar, 172" [4369] Total Length | ASTM A615 Gr. 60 | H#6005295 |
| e17 | #5 [16] Rebar, 164 1/4" [4172] Total Unbent Length | ASTM A615 Gr. 60 | H#6005295 |
| f1 | 5/8"-11 UNC [M16x2], 14" [356] Long Guardrail Bolt | ASTM A307 Gr. A | H#DL17100590 L#30361-P |
| f2 | 5/8"-11 UNC [M16x2], 10" [254] Long Guardrail Bolt | ASTM A307 Gr. A | H#1721198 R#19-255 |
| f3 | 5/8"-11 UNC [M16x2], 1 1/4" [32] Long Guardrail Bolt | ASTM A307 Gr. A | H#10553090 |
| f4 | 5/8"-11 UNC [M16x2], 10" [254] Long Hex Head Bolt | ASTM A307 Gr. A or equivalent | H#JK110419701 |
| f5 | 5/8"-11 UNC [M16x2], 1 1/2" [38] Long Hex Head Bolt | ASTM A307 Gr. A or equivalent | H#14300105-3 L#1B1450923 P#1191919 |
| f6 | 7/8”-9 UNC [M22x2.5], 16” [356] Long Heavy Hex Head Bolt | ASTM F3125 Gr. A325 or equivalent | H#75071284 |
| f7 | 7/8"-9 UNC [M22x2.5], 8" [203] Long Hex Head Bolt | ASTM A307 Gr. A or equivalent | P#92005 C#llne35042_COC ONLY |
| f8 | 5/8"-11 UNC [M16x2], 2" [51] Long Guardrail Bolt | ASTM A307 Gr. A | H#10439100 |
| f9 | 5/8"-11 UNC [M16x2] Heavy Hex Nut | ASTM A563DH or equivalent | H#10470360 L#17-35-017 |
| f10 | 7/8"-9 UNC [M22x2.5] Hex Nut | ASTM A563A or equivalent | H#331704677 L#1N1810005 P#36717 |
| f11 | 7/8"-9 UNC [M22x2.5] Heavy Hex Nut | ASTM A563DH | H#189069 |
| f12 | 1"-8 UNC [M24x3] Heavy Hex Nut | ASTM A563DH or equivalent | COC Only P#38210 T#210157128 |
| f13 | 5/8" [16] Dia. Hex Nut | ASTM A563A | H#331608011 P#36713 L#1N1680027 |
| g1 | 5/8" [16] Dia. Plain USS Washer | ASTM F844 | n/a |
| g2 | 7/8" [22] Dia. Plain Round Washer | ASTM F844 | P#33187 PO#170077928 COC |
| g3 | 1" [25] Dia. Plain USS Washer | ASTM F844 | P#33188 PO#210151571 |
| g4 | 3"x3"x1/4" [76x76x6] or 3 1/2"x3 1/2"x1/4" [89x89x6] Square Washer Plate | ASTM A572 Gr. 50 | H#E8I347 |
| - | Epoxy Adhesive | Hilti HIT RE-500 V3 | Hilti COC |

# Certified Analysis

Trinity Highway Products LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH & SUPPLY CO
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

Order Number: 1305851 Prod Ln Grp: 0-OE2.0
Customer PO: 3693
BOL Number: 107841 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

Asof: 2/28/19

| Qty | Part # | Description | Spec | CL | TY | Heat Code/Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | 12173G | T12/6'3/4@1'6.75"/S | | | 2 | L34518 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | C88581 | 59,000 | 79,100 | 16.3 | 0.210 | 0.690 | 0.009 | 0.002 | 0.030 | 0.110 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 232897 | 64,140 | 82,950 | 26.2 | 0.190 | 0.730 | 0.012 | 0.000 | 0.030 | 0.100 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 232898 | 61,510 | 80,400 | 26.7 | 0.019 | 0.720 | 0.010 | 0.003 | 0.020 | 0.100 | 0.000 | 0.070 | 0.002 | 4 |
| 160 | 12365G | T12/12'6/8@1'6.75/S | | | 2 | L30719 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | C88581 | 59,000 | 79,100 | 16.3 | 0.210 | 0.690 | 0.009 | 0.002 | 0.030 | 0.110 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 232897 | 64,140 | 82,950 | 26.2 | 0.190 | 0.730 | 0.012 | 0.000 | 0.030 | 0.100 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 232898 | 61,510 | 80,400 | 26.7 | 0.019 | 0.720 | 0.010 | 0.003 | 0.020 | 0.100 | 0.000 | 0.070 | 0.002 | 4 |
| 4 | 12447G | T12/25/8@1'6.75:4@3'1.5/S | | | 2 | L30719 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | 233580 | 62,360 | 81,100 | 25.2 | 0.190 | 0.720 | 0.011 | 0.004 | 0.020 | 0.100 | 0.000 | 0.050 | 0.001 | 4 |
| | | | M-180 | A | 2 | 233581 | 61,600 | 79,750 | 24.6 | 0.180 | 0.720 | 0.011 | 0.004 | 0.020 | 0.130 | 0.000 | 0.060 | 0.002 | 4 |
| 75 | 54043G | 7'0 PST/6X15/DB:3HI | A-572 | | | 2815472 | 62,500 | 75,700 | 23.0 | 0.070 | 0.840 | 0.008 | 0.025 | 0.220 | 0.280 | 0.029 | 0.090 | 0.004 | 4 |

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED I NUSA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDI NGIN SUFFIX B,P, OR S, ARE UNCOATED

2 of 3

Figure A-1. 12 ft – 6 in. 12-gauge Thrie Beam Section, Test Nos. HWTT-1 and HWTT-2

# Certified Analysis

Trinity Highway Products LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH & SUPPLY CO
P. O. BOX 703
MILFORD, NE 68405
Project: STOCK

Order Number: 1305851 Prod Ln Grp: 0-OE2.0
Customer PO: 3693
BOL Number: 107841 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

Asof: 2/28/19

| Qty | Part # | Description | Spec | CL | TY | Heat Code/Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | 12173G | T12/6'3/4@1'6.75"/S | | | 2 | L34518 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | C88581 | 59,000 | 79,100 | 16.3 | 0.210 | 0.690 | 0.009 | 0.002 | 0.030 | 0.110 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 232897 | 64,140 | 82,950 | 26.2 | 0.190 | 0.730 | 0.012 | 0.000 | 0.030 | 0.100 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 232898 | 61,510 | 80,400 | 26.7 | 0.019 | 0.720 | 0.010 | 0.003 | 0.020 | 0.100 | 0.000 | 0.070 | 0.002 | 4 |
| 160 | 12365G | T12/12'6/8@1'6.75/S | | | 2 | L30719 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | C88581 | 59,000 | 79,100 | 16.3 | 0.210 | 0.690 | 0.009 | 0.002 | 0.030 | 0.110 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 232897 | 64,140 | 82,950 | 26.2 | 0.190 | 0.730 | 0.012 | 0.000 | 0.030 | 0.100 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 232898 | 61,510 | 80,400 | 26.7 | 0.019 | 0.720 | 0.010 | 0.003 | 0.020 | 0.100 | 0.000 | 0.070 | 0.002 | 4 |
| 4 | 12447G | T12/25/8@1'6.75:4@3'1.5/S | | | 2 | L30719 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | 233580 | 62,360 | 81,100 | 25.2 | 0.190 | 0.720 | 0.011 | 0.004 | 0.020 | 0.100 | 0.000 | 0.050 | 0.001 | 4 |
| | | | M-180 | A | 2 | 233581 | 61,600 | 79,750 | 24.6 | 0.180 | 0.720 | 0.011 | 0.004 | 0.020 | 0.130 | 0.000 | 0.060 | 0.002 | 4 |
| 75 | 54043G | 7'0 PST/6X15/DB:3HI | A-572 | | | 2815472 | 62,500 | 75,700 | 23.0 | 0.070 | 0.840 | 0.008 | 0.025 | 0.220 | 0.280 | 0.029 | 0.090 | 0.004 | 4 |

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED I NUSA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDI NGIN SUFFIX B,P, OR S, ARE UNCOATED

2 of 3

Figure A-2. 6 ft. – 3 in. 12-gauge Thrie Beam Section, Test Nos. HWTT-1 and HWTT-2

NUCOR
NUCOR STEEL GALLATIN

**Nucor Steel Gallatin**
4831 U.S. Highway 42 West
Ghent, KY 41045-9704
Phone: 1(800)581-3853 Fax: (859)567-3165

## METALLURGICAL TEST REPORT

**Invoice To:** Triamerica Steel Resources, LLC
1617 Akron Peninsula Rd #103
akron, OH 44313

**Ship To:** Triamerica Steel Resources, LLC
Pick Up

**Date:** 6/28/2016
**Customer No:** 30932
**Customer P.O.:** 074532

**Mill Order No:** 200612-5 **Customer Reference No:** NA **Load No:** 668737

**This product was melted and manufactured in the USA to meet the requirements of:** Excess
Excess HR Sheet Steel Bands

**Coil Number(s):** 1359677

**Ordered Size:** Nom 0.132 (In.) X 62.58 (In.) X Coil
Nom 3.353 (mm) X 1590 (mm) X Coil

**CHEMICAL ANALYSIS (Weight %)**

| Heat No | C | Mn | P | S | Si | Cu | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|---|---|
| A80436 | 0.05 | 0.46 | 0.011 | 0.004 | 0.03 | 0.14 | 0.05 | 0.06 | 0.02 |
| | Al | Ca | Nb | V | B | Ti | N | Sn | |
| | 0.022 | 0.0020 | 0.020 | 0.001 | 0.0001 | 0.002 | 0.0078 | 0.008 | |

**MECHANICAL PROPERTIES**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Coil Tested | | | | | | | | |
| Yield Strength(ksi) | | | | | | | | |
| Yield Strength(mpa) | | | | | | | | |
| Tensile Strength(ksi) | | | | | | | | |
| Tensile Strength(mpa) | | | | | | | | |
| % Elongation | | | | | | | | |
| N-Value | | | | | | | | |
| N-Value Range | | | | | | | | |
| Hardness(HRBW) | | | | | | | | |
| Test Section | | | | | | | | |
| Orientation | | | | | | | | |
| Test Method | | | | | | | | |

**BEND TEST RESULTS**

| Coil ID # | Orientation | Diameter/radius of mandrel | No. of cracks | Size of cracks | Pass/ Fail |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

Hot rolled coils manufactured through Nucor Steel Gallatin do not contain welds or weld repairs at the time of shipment (fca mill). Mercury was not added during production of this material. The material was produced using a fully killed fine grain practice.

This product is in compliance with DFARS 252.225, the Buy American Act.

Above tests performed in accordance to ASTM standards E8 (yield strength determined using 0.2% offset method and elongation determined using after fracture method) or JIS Z2241, E18, E415, and E1019 and are correct as contained in the records of the company.

The elongation original gauge length is 2 inches for ASTM test method and 1.97 inches for JIS test method. Above test results were performed in accordance to EN 10204 3.1

Bend tests were conducted in accordance with ISO 7438, ASTM E290, or JIS Z2248 using the press, guided, two support and a mandrel bend method at a 180 degree bend. Bend test specimen is longer than 6" and wider than 0.8"

This report shall not be reproduced, except in full, without written approval of the undersigned laboratory managers.
* This mechanical property has been tested at a subcontractor's laboratory.

Stephen S. Sipple
Chemical Laboratory
Mechanical Laboratory
steve.sipple@nucor.com



Page 1 of 1

X 157867

Figure A-3. 6 ft – 3 in. 10-gauge W-Beam to Thrie-Beam Asymmetric Transition Section, Test Nos. HWTT-1 and HWTT-2

NUCOR
NUCOR STEEL GALLATIN

**Nucor Steel Gallatin**
4831 U.S. Highway 42 West
Ghent, KY 41045-9704
Phone: 1(800)581-3853 Fax: (859)567-3165

## METALLURGICAL TEST REPORT

**Invoice To:** Gregory Industries
4100 13th Street SW
Canton, OH 44710

**Ship To:** Gregory Industries
4100 13th Street SW
Canton, OH 44710

**Date:** 1/21/2018
**Customer No:** 10019
**Customer P.O.:** 39620

**Mill Order No:** 214078-1 **Customer Reference No:** 39620 **Load No:** 736148

**This product was melted and manufactured in the USA to meet the requirements of:** 1020 steel for SS 50 grade for Guard Rails - 50 ksi min yield, 70 ksi min tensile, 0.10% max Si, and 0.06% Cr max
HR Sheet Steel Bands

**Ordered Size:** Min 0.095 (In.) X 56.88 (In.) X Coil
Min 2.413 (mm) X 1445 (mm) X Coil

**Coil Number(s):** 1465177

**CHEMICAL ANALYSIS (Weight %)**

| Heat No | C | Mn | P | S | Si | Cu | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|---|---|
| C85187 | 0.20 | 0.48 | 0.008 | 0.003 | 0.03 | 0.06 | 0.02 | 0.05 | 0.01 |
| | Al | Ca | Nb | V | B | Ti | N | Sn | |
| | 0.029 | 0.0017 | 0.000 | 0.001 | 0.0001 | 0.001 | 0.0080 | 0.003 | |

**MECHANICAL PROPERTIES**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Coil Tested | | | | | | | | |
| Yield Strength(ksi) | | | | | | | | |
| Yield Strength(mpa) | | | | | | | | |
| Tensile Strength(ksi) | | | | | | | | |
| Tensile Strength(mpa) | | | | | | | | |
| % Elongation | | | | | | | | |
| N-Value | | | | | | | | |
| N-Value Range | | | | | | | | |
| Hardness(HRBW) | | | | | | | | |
| Test Section | | | | | | | | |
| Orientation | | | | | | | | |
| Test Method | | | | | | | | |

**BEND TEST RESULTS**

| Coil ID # | Orientation | Diameter/radius of mandrel | No. of cracks | Size of cracks | Pass/ Fail |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

Ht code
1207

Hot rolled coils manufactured through Nucor Steel Gallatin do not contain welds or weld repairs at the time of shipment (fca mill). Mercury was not added during production of this material. The material was produced using a fully killed fine grain practice with a grain size of 6 or finer according to ASTM E112.

This product is in compliance with DFARS 252.225, the Buy American Act.

Above tests performed in accordance to ASTM standards E8 (yield strength determined using 0.2% offset method and elongation determined using at fracture method) or JIS Z2241, E18, E415, and E1019 and are correct as contained in the records of the company.

The elongation original gauge length is 2 inches for ASTM test method and 1.97 inches for JIS test method. Above test results were performed in accordance to EN 10204 3.1

Bend tests were conducted in accordance with ISO 7438, ASTM E290, or JIS Z2248 using the press, guided, two support and a mandrel bend method at a 180 degree bend. Bend test specimen is longer than 6" and wider than 0.8"

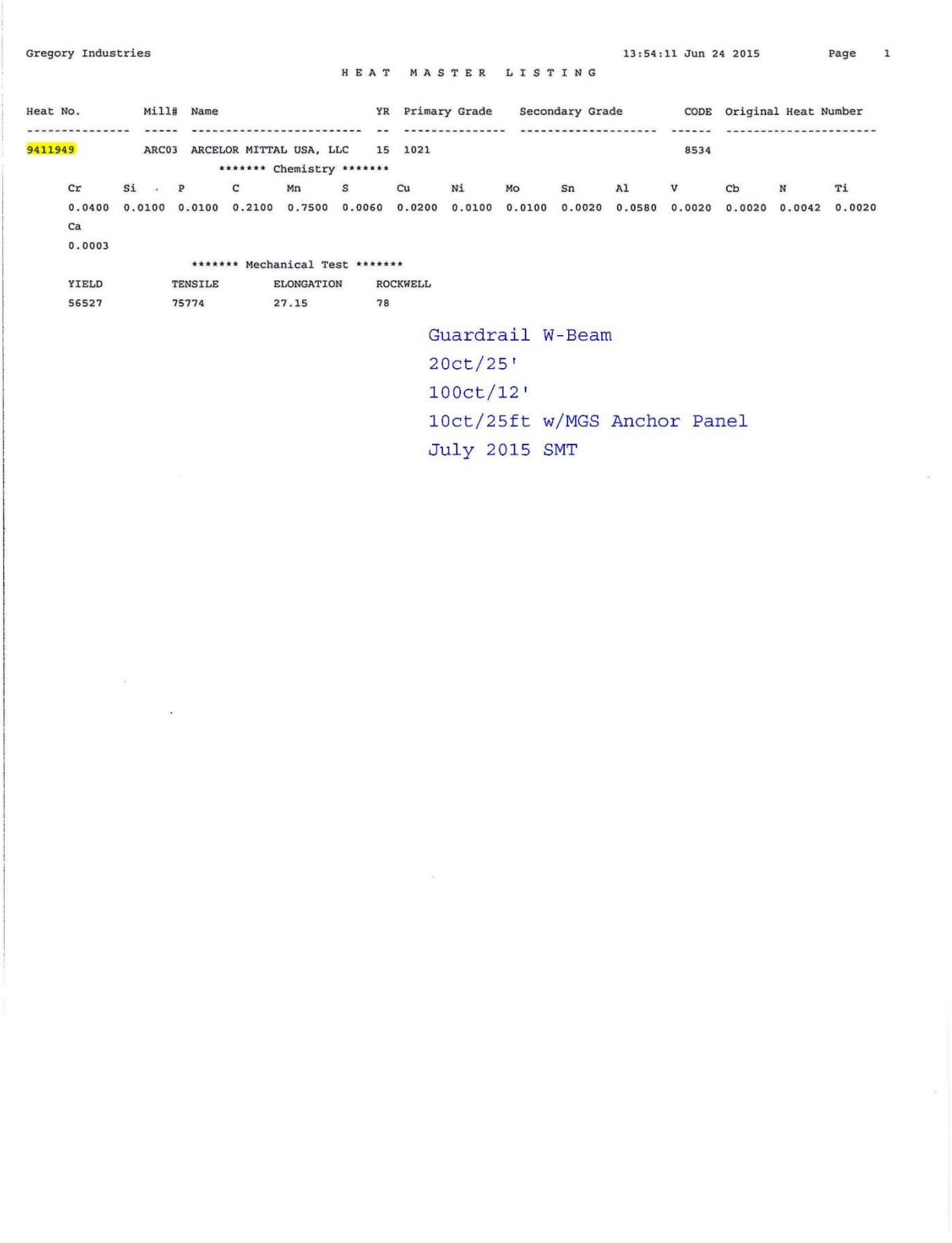
This report shall not be reproduced, except in full, without written approval of the undersigned laboratory managers.
* This mechanical property has been tested at a subcontractor's laboratory.

Stephen S. Sipple
Chemical Laboratory
Mechanical Laboratory
steve.sipple@nucor.com





Figure A-4. 12 ft – 6 in. 12-gauge W-Beam MGS Section, Test Nos. HWTT-1 and HWTT-2



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 | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 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-5. 12 ft – 6 in. 12-gauge W-Beam MGS End Section, Test Nos. HWTT-1 and HWTT-2

Roadway Construction Productions
511 West Main Street
Clarkson, Ky 42726

**********
MILL CERTIFICATION REPORT
**********

Invoice No.: 85194 Page
Date: 07/11/2018 1
Purchase Order: VERBAL
County:
Project No.:
Bill of Lading: 85194

Sold to:
MIDWEST ROADSIDE SAFETY FAC

Tested in accordance with ASTM A36.
All structural steel meets AASHTO-111.
All steel used in MFG. is of domestic orgin.
Galv. material conforms with ASTM-123 & AASHTO M 232-82
All guardrail & terminal sections meets AASHTO M-180.
Bolts, nuts & washers comply with ASTM-307 and/or A325 specifications.
Hereby certify that the material test results presented here are from the reported heat and are correct. All test were reported accordance to the specifications reported above. All steel is electric furnace melted, manufactured, processed and tested in the U.S.A. with satisfactory results, and is free from mercury contamination in the product.

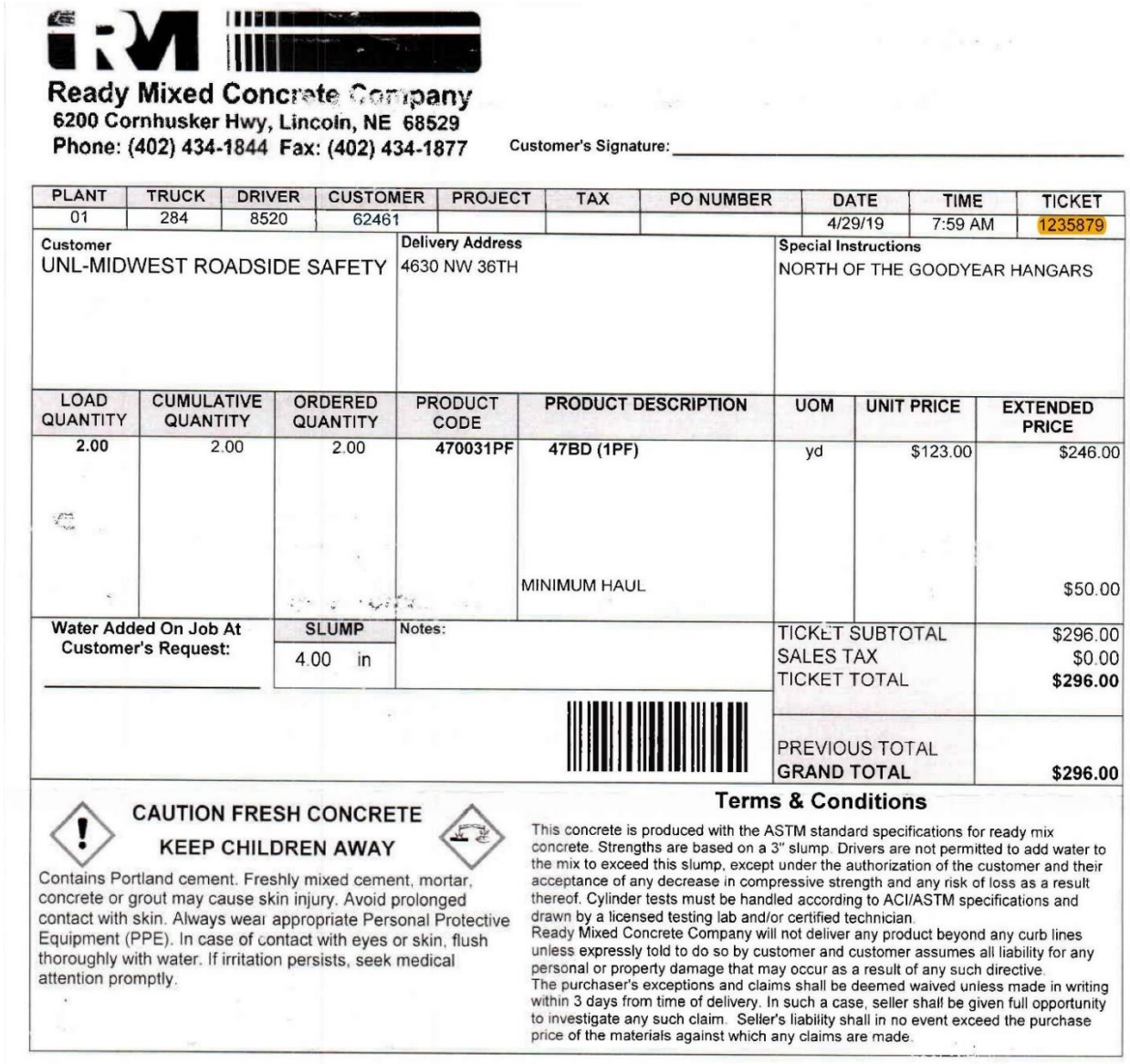
STATE OF KENTUCKY, COUNTY OF STATE AT LARGE
Sworn and Subscribed Before Me This 11 day of JULY , 2018
Notary Public:
My Commission expires: 6/16/21

LABETTA NOTARY PUBLIC ID NO. MY COMMISSION EXPIRES STATE AT LARGE

| QTY | HEAT NO | PART NO | DESCRIPTION | YIELD | TENSILE | ELONGATION % LENGTH |
|---|---|---|---|---|---|---|
| 4 | A81568 | G20055BF-G | 10GA.THRI.END G | 56.1 | 78.8 | 26.8 #1 #2 |

| C | MN | P | S | SI | CU | NI | CR | MO | CB | V | AL | TEST |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .20 | .70 | .010 | .002 | .03 | .11 | .03 | .04 | .02 | | .001 | .025 | |

Figure A-6. 10-gauge Thrie Beam Terminal Connector, Test Nos. HWTT-1 and HWTT-2



**Ready Mixed Concrete Company**
6200 Cornhusker Hwy, Lincoln, NE 68529
Phone: (402) 434-1844 Fax: (402) 434-1877

Customer's Signature: _____

| PLANT | TRUCK | DRIVER | CUSTOMER | PROJECT | TAX | PO NUMBER | DATE | TIME | TICKET |
|---|---|---|---|---|---|---|---|---|---|
| 01 | 284 | 8520 | 62461 | | | | 4/29/19 | 7:59 AM | 1235879 |

| Customer | Delivery Address | Special Instructions |
|---|---|---|
| UNL-MIDWEST ROADSIDE SAFETY | 4630 NW 36TH | NORTH OF THE GOODYEAR HANGARS |

| LOAD QUANTITY | CUMULATIVE QUANTITY | ORDERED QUANTITY | PRODUCT CODE | PRODUCT DESCRIPTION | UOM | UNIT PRICE | EXTENDED PRICE |
|---|---|---|---|---|---|---|---|
| 2.00 | 2.00 | 2.00 | 470031PF | 47BD (1PF) | yd | $123.00 | $246.00 |
| | | | | MINIMUM HAUL | | | $50.00 |

| Water Added On Job At Customer's Request: | SLUMP | Notes: | | |
|---|---|---|---|---|
| _____ | 4.00 in | | TICKET SUBTOTAL | $296.00 |
| | | | SALES TAX | $0.00 |
| | | | TICKET TOTAL | **$296.00** |
| | | | PREVIOUS TOTAL | |
| | | | **GRAND TOTAL** | **$296.00** |

**CAUTION FRESH CONCRETE**
**KEEP CHILDREN AWAY**

Contains Portland cement. Freshly mixed cement, mortar, concrete or grout may cause skin injury. Avoid prolonged contact with skin. Always wear appropriate Personal Protective Equipment (PPE). In case of contact with eyes or skin, flush thoroughly with water. If irritation persists, seek medical attention promptly.

**Terms & Conditions**

This concrete is produced with the ASTM standard specifications for ready mix concrete. Strengths are based on a 3" slump. Drivers are not permitted to add water to the mix to exceed this slump, except under the authorization of the customer and their acceptance of any decrease in compressive strength and any risk of loss as a result thereof. Cylinder tests must be handled according to ACI/ASTM specifications and drawn by a licensed testing lab and/or certified technician.
Ready Mixed Concrete Company will not deliver any product beyond any curb lines unless expressly told to do so by customer and customer assumes all liability for any personal or property damage that may occur as a result of any such directive.
The purchaser's exceptions and claims shall be deemed waived unless made in writing within 3 days from time of delivery. In such a case, seller shall be given full opportunity to investigate any such claim. Seller's liability shall in no event exceed the purchase price of the materials against which any claims are made.

Figure A-7. Reinforced Concrete Buttress, Test Nos. HWTT-1 and HWTT-2

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
**Project Name:** Miscellaneous Concrete Testing
**Placement Location:** HWTT Buttress
**Date** 17-May-19

**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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| URR-123 | C | 4/29/2019 | 5/17/2019 | 5/17/2019 | 18 | 0 | 18 | 12 | 5.99 | 28.18 | 140,473 | 4,980 | | 5 | C 1231 |
| URR-124 | D | 4/29/2019 | 5/17/2019 | 5/17/2019 | 18 | 0 | 18 | 12 | 5.99 | 28.18 | 134,987 | 4,790 | | 5 | C 1231 |

1 cc: Ms. Karla Lechtenberg
Midwest Roadside Safety Facility

**Remarks:**

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



Report Number 2147371194
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

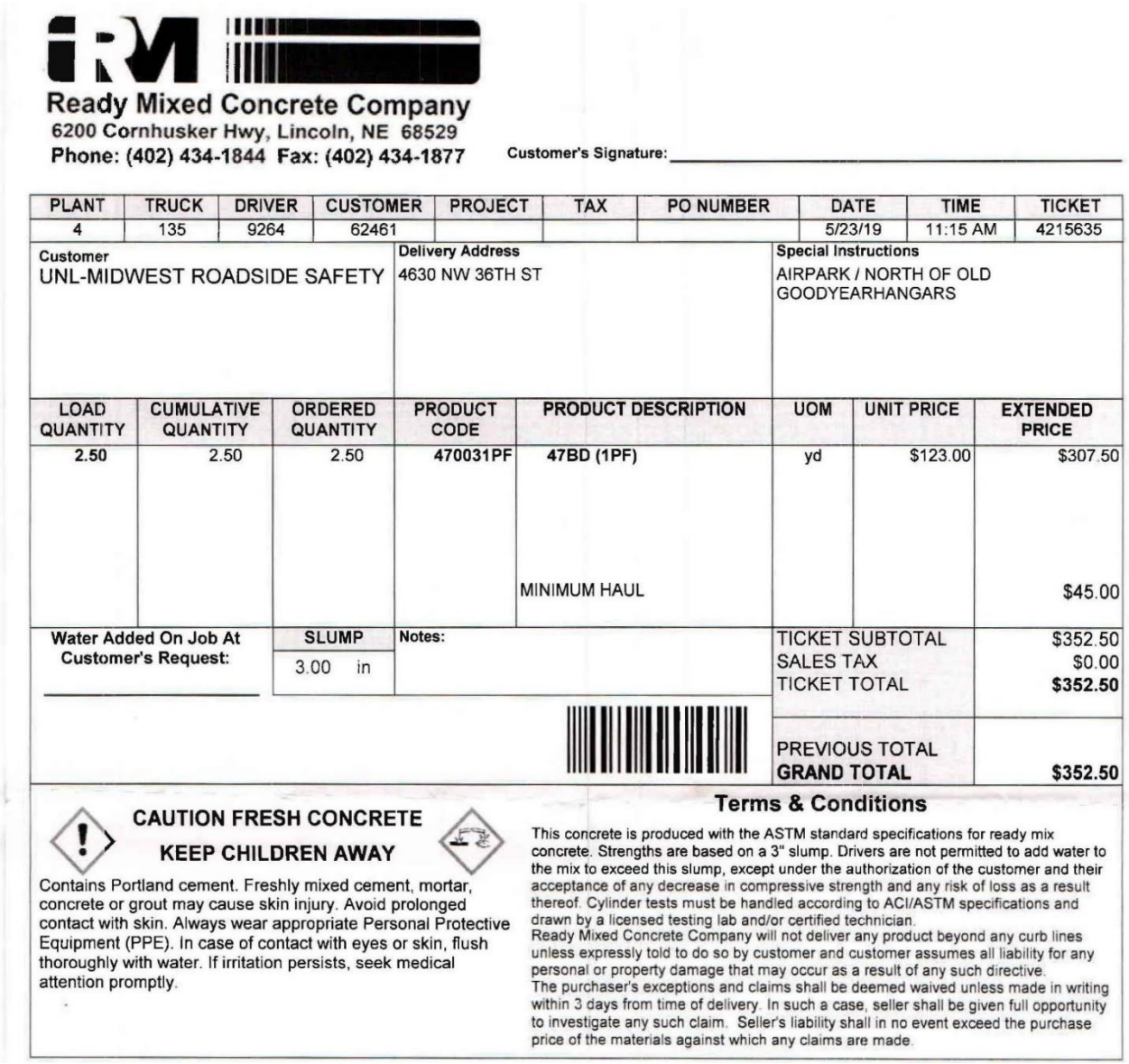
ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By Matt Rowler





Figure A-8. Reinforced Concrete Buttress, Test Nos. HWTT-1 and HWTT-2



**Ready Mixed Concrete Company**
6200 Cornhusker Hwy, Lincoln, NE 68529
Phone: (402) 434-1844 Fax: (402) 434-1877

Customer's Signature: _____

| PLANT | TRUCK | DRIVER | CUSTOMER | PROJECT | TAX | PO NUMBER | DATE | TIME | TICKET |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 135 | 9264 | 62461 | | | | 5/23/19 | 11:15 AM | 4215635 |

| Customer | Delivery Address | Special Instructions |
|---|---|---|
| UNL-MIDWEST ROADSIDE SAFETY | 4630 NW 36TH ST | AIRPARK / NORTH OF OLD GOODYEARHANGARS |

| LOAD QUANTITY | CUMULATIVE QUANTITY | ORDERED QUANTITY | PRODUCT CODE | PRODUCT DESCRIPTION | UOM | UNIT PRICE | EXTENDED PRICE |
|---|---|---|---|---|---|---|---|
| 2.50 | 2.50 | 2.50 | 470031PF | 47BD (1PF) | yd | $123.00 | $307.50 |
| | | | | MINIMUM HAUL | | | $45.00 |

| Water Added On Job At Customer's Request: | SLUMP | Notes: | | |
|---|---|---|---|---|
| _____ | 3.00 in | | TICKET SUBTOTAL | $352.50 |
| | | | SALES TAX | $0.00 |
| | | | TICKET TOTAL | **$352.50** |
| | | | PREVIOUS TOTAL | |
| | | | **GRAND TOTAL** | **$352.50** |

**CAUTION FRESH CONCRETE**
**KEEP CHILDREN AWAY**

Contains Portland cement. Freshly mixed cement, mortar, concrete or grout may cause skin injury. Avoid prolonged contact with skin. Always wear appropriate Personal Protective Equipment (PPE). In case of contact with eyes or skin, flush thoroughly with water. If irritation persists, seek medical attention promptly.

**Terms & Conditions**

This concrete is produced with the ASTM standard specifications for ready mix concrete. Strengths are based on a 3" slump. Drivers are not permitted to add water to the mix to exceed this slump, except under the authorization of the customer and their acceptance of any decrease in compressive strength and any risk of loss as a result thereof. Cylinder tests must be handled according to ACI/ASTM specifications and drawn by a licensed testing lab and/or certified technician.
Ready Mixed Concrete Company will not deliver any product beyond any curb lines unless expressly told to do so by customer and customer assumes all liability for any personal or property damage that may occur as a result of any such directive.
The purchaser's exceptions and claims shall be deemed waived unless made in writing within 3 days from time of delivery. In such a case, seller shall be given full opportunity to investigate any such claim. Seller's liability shall in no event exceed the purchase price of the materials against which any claims are made.

Figure A-9. Reinforced Concrete Curb, Test Nos. HWTT-1 and HWTT-2

PO 3616

CNWP

1098 East Maple St
Sutton, NE 68979
Phone: 402.773.4319
Email: nick@nebraskawood.com

## CERTIFICATE OF COMPLIANCE

**Shipped To:** Midwest Machinery and Supply
**BOL#** N05656
**Customer PO#** 3616
**Preservative:** CCA – C 0.60D pcf AWPA UC4B

| Part # | Physical Description | # of Pieces | Charge # | Tested Retention |
|---|---|---|---|---|
| GS6846 PST | 5.5x7.5-46" BCT | 42 | 25729 | .680 |
| 6118b | 6x8-14" Tapered Block | 126 | 25729 | .680 |
| GR6822 BLK | 6x8-22" CH Block | 168 | 25702 | .694 |
| GR6819 BLK | 6x8-19" OCD Block | 168 | 25702 | .694 |
| GR61219 BLK | 6x12-19" OCD Thrie | 168 | 25698 | .686 |
| | | | | |
| | | | | |
| | | | | |

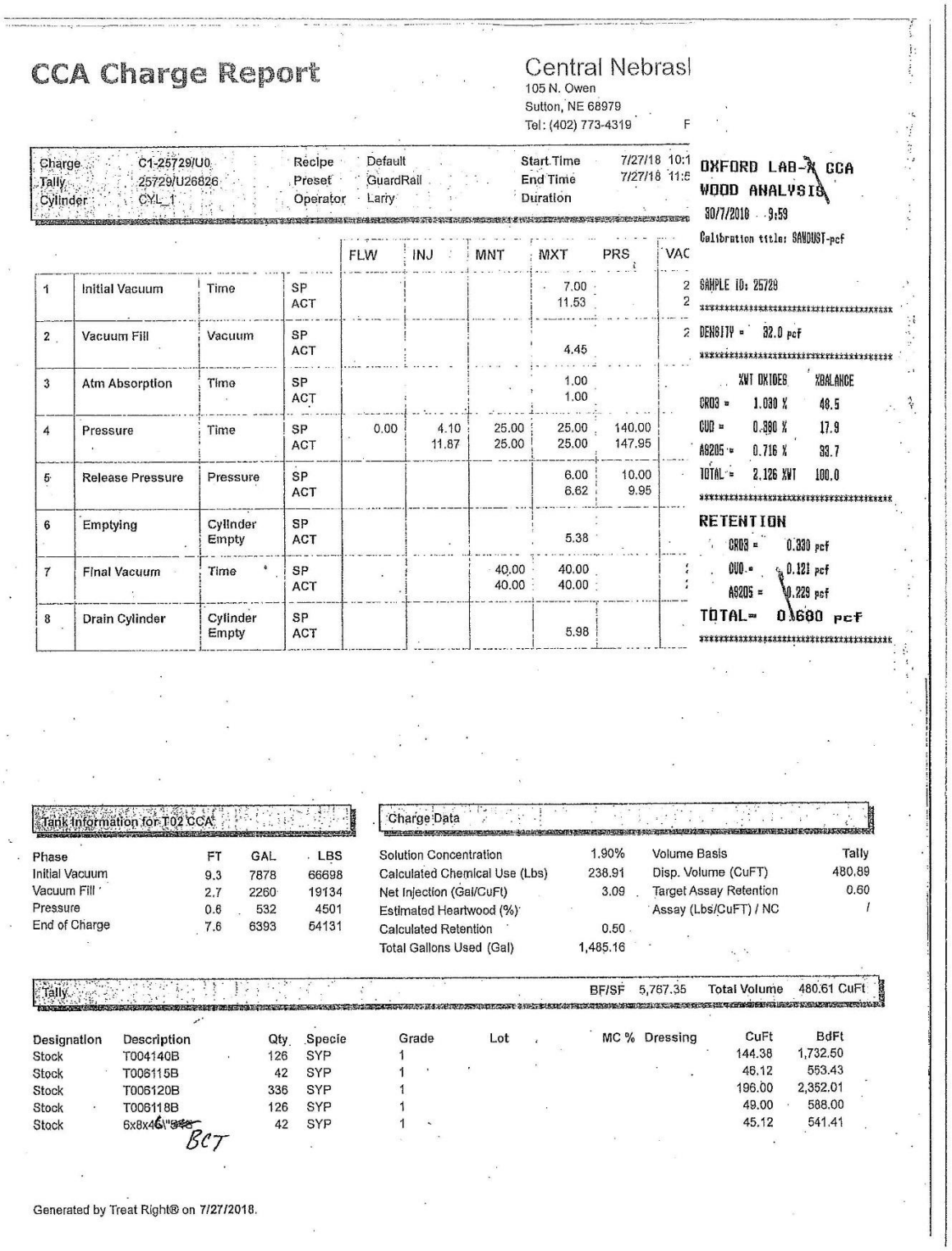
I certify the above referenced material has been produced, treated and tested in accordance with and conforms to AASHTO M133 & M168 standards.

VA: Iowa 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

7/31/18
Date

Figure A-10. BCT Timber Posts, Test Nos. HWTT-1 and HWTT-2



# CCA Charge Report

Central Nebrasl
105 N. Owen
Sutton, NE 68979
Tel: (402) 773-4319 F

| | | | | | |
|---|---|---|---|---|---|
| Charge | C1-25729/U0 | Recipe | Default | Start Time | 7/27/18 10:1 |
| Tally | 25729/U26826 | Preset | GuardRail | End Time | 7/27/18 11:5 |
| Cylinder | CYL_1 | Operator | Larry | Duration | |

OXFORD LAB-X CCA
WOOD ANALYSIS
30/7/2018 9:59
Calibration title: SAWDUST-pcf

SAMPLE ID: 25729
**********
DENSITY = 32.0 pcf
**********

| | %WT OXIDES | %BALANCE |
|---|---|---|
| CR03 = | 1.030 % | 48.5 |
| CUO = | 0.390 % | 17.9 |
| AS205 = | 0.716 % | 33.7 |
| TOTAL = | 2.126 %WT | 100.0 |

**********
RETENTION
CR03 = 0.330 pcf
CUO = 0.121 pcf
AS205 = 0.229 pcf
TOTAL= 0.680 pcf
**********

| | | | | FLW | INJ | MNT | MXT | PRS | VAC |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Initial Vacuum | Time | SP | | | | 7.00 | | 2 |
| | | | ACT | | | | 11.53 | | 2 |
| 2 | Vacuum Fill | Vacuum | SP | | | | | | 2 |
| | | | ACT | | | | 4.45 | | |
| 3 | Atm Absorption | Time | SP | | | | 1.00 | | |
| | | | ACT | | | | 1.00 | | |
| 4 | Pressure | Time | SP | 0.00 | 4.10 | 25.00 | 25.00 | 140.00 | |
| | | | ACT | | 11.87 | 25.00 | 25.00 | 147.95 | |
| 5 | Release Pressure | Pressure | SP | | | | 6.00 | 10.00 | |
| | | | ACT | | | | 6.62 | 9.95 | |
| 6 | Emptying | Cylinder Empty | SP | | | | | | |
| | | | ACT | | | | 5.38 | | |
| 7 | Final Vacuum | Time | SP | | | 40.00 | 40.00 | | |
| | | | ACT | | | 40.00 | 40.00 | | |
| 8 | Drain Cylinder | Cylinder Empty | SP | | | | | | |
| | | | ACT | | | | 5.98 | | |

**Tank Information for T02 CCA**

| Phase | FT | GAL | LBS |
|---|---|---|---|
| Initial Vacuum | 9.3 | 7878 | 66698 |
| Vacuum Fill | 2.7 | 2260 | 19134 |
| Pressure | 0.6 | 532 | 4501 |
| End of Charge | 7.6 | 6393 | 54131 |

**Charge Data**

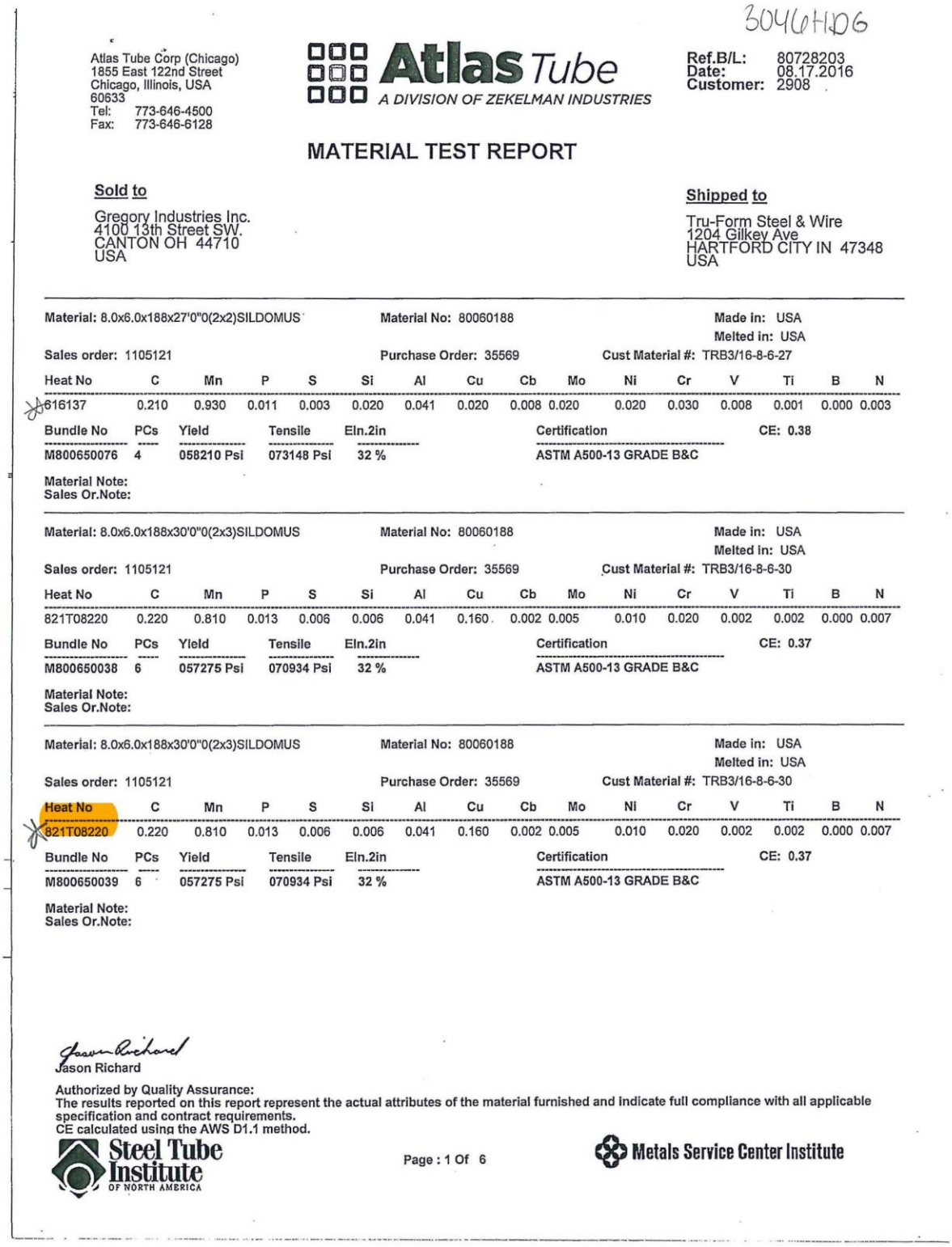
| | | | |
|---|---|---|---|
| Solution Concentration | 1.90% | Volume Basis | Tally |
| Calculated Chemical Use (Lbs) | 238.91 | Disp. Volume (CuFT) | 480.89 |
| Net Injection (Gal/CuFt) | 3.09 | Target Assay Retention | 0.60 |
| Estimated Heartwood (%) | | Assay (Lbs/CuFT) / NC | / |
| Calculated Retention | 0.50 | | |
| Total Gallons Used (Gal) | 1,485.16 | | |

**Tally** BF/SF 5,767.35 Total Volume 480.61 CuFt

| Designation | Description | Qty | Specie | Grade | Lot | MC % | Dressing | CuFt | BdFt |
|---|---|---|---|---|---|---|---|---|---|
| Stock | T004140B | 126 | SYP | 1 | | | | 144.38 | 1,732.50 |
| Stock | T006115B | 42 | SYP | 1 | | | | 46.12 | 553.43 |
| Stock | T006120B | 336 | SYP | 1 | | | | 196.00 | 2,352.01 |
| Stock | T006118B | 126 | SYP | 1 | | | | 49.00 | 588.00 |
| Stock | 6x8x46" ~~S4S~~ BCT | 42 | SYP | 1 | | | | 45.12 | 541.41 |

Generated by Treat Right® on 7/27/2018.

Figure A-11. BCT Timber Posts, Test Nos. HWTT-1 and HWTT-2



3046HD6

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

Atlas Tube
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80728203
Date: 08.17.2016
Customer: 2908

MATERIAL TEST REPORT

Sold to

Gregory Industries Inc.
4100 13th Street SW.
CANTON OH 44710
USA

Shipped to

Tru-Form Steel & Wire
1204 Gilkey Ave
HARTFORD CITY IN 47348
USA

Material: 8.0x6.0x188x27'0"0(2x2)SILDOMUS Material No: 80060188 Made in: USA
Melted in: USA
Sales order: 1105121 Purchase Order: 35569 Cust Material #: TRB3/16-8-6-27

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 616137 | 0.210 | 0.930 | 0.011 | 0.003 | 0.020 | 0.041 | 0.020 | 0.008 | 0.020 | 0.020 | 0.030 | 0.008 | 0.001 | 0.000 | 0.003 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.38 |
|---|---|---|---|---|---|---|
| M800650076 | 4 | 058210 Psi | 073148 Psi | 32 % | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Material: 8.0x6.0x188x30'0"0(2x3)SILDOMUS Material No: 80060188 Made in: USA
Melted in: USA
Sales order: 1105121 Purchase Order: 35569 Cust Material #: TRB3/16-8-6-30

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 821T08220 | 0.220 | 0.810 | 0.013 | 0.006 | 0.006 | 0.041 | 0.160 | 0.002 | 0.005 | 0.010 | 0.020 | 0.002 | 0.002 | 0.000 | 0.007 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.37 |
|---|---|---|---|---|---|---|
| M800650038 | 6 | 057275 Psi | 070934 Psi | 32 % | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Material: 8.0x6.0x188x30'0"0(2x3)SILDOMUS Material No: 80060188 Made in: USA
Melted in: USA
Sales order: 1105121 Purchase Order: 35569 Cust Material #: TRB3/16-8-6-30

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 821T08220 | 0.220 | 0.810 | 0.013 | 0.006 | 0.006 | 0.041 | 0.160 | 0.002 | 0.005 | 0.010 | 0.020 | 0.002 | 0.002 | 0.000 | 0.007 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.37 |
|---|---|---|---|---|---|---|
| M800650039 | 6 | 057275 Psi | 070934 Psi | 32 % | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Jason Richard

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

Steel Tube Institute OF NORTH AMERICA

Page : 1 Of 6

Metals Service Center Institute

Figure A-12. 72-in. Long Foundation Tube, Test Nos. HWTT-1 and HWTT-2

# Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1275017 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3400
BOL Number: 99202 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 3/22/17

| Qty | Part # | Description | Spec | CL | TY | Heat Code/ Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 3380G | 5/8"X1.5" HEX BOLT A307 | HW | | | 0052429-113200 | | | | | | | | | | | | | |
| 600 | 3400G | 5/8"X2" GR BOLT | HW | | | 29221 | | | | | | | | | | | | | |
| 500 | 3480G | 5/8"X8" GR BOLT A307 | HW | | | 29369 | | | | | | | | | | | | | |
| 450 | 3500G | 5/8"X10" GR BOLT A307 | HW | | | 29550-B | | | | | | | | | | | | | |
| 700 | 3540G | 5/8"X14" GR BOLT A307 | HW | | | 29567 | | | | | | | | | | | | | |
| 300 | 3580G | 5/8"X18" GR BOLT A307 | HW | | | 29338 | | | | | | | | | | | | | |
| 600 | 4235G | 3/16"X1.75"X3" WSHR | HW | | | C7001 | | | | | | | | | | | | | |
| 10 | 9852A | STRUT & YOKE ASSY | A-36 | | | 195070 | 52,940 | 69,970 | 31.1 | 0.190 | 0.520 | 0.014 | 0.004 | 0.020 | 0.110 | 0.000 | 0.050 | 0.000 | 4 |
| | 9852A | | A-36 | | | A82292 | 54,000 | 73,300 | 31.0 | 0.200 | 0.460 | 0.010 | 0.003 | 0.020 | 0.150 | 0.000 | 0.060 | 0.001 | 4 |
| | 9852A | | A-36 | | | 645887 | 39,900 | 62,500 | 32.0 | 0.190 | 0.400 | 0.009 | 0.015 | 0.009 | 0.054 | 0.001 | 0.038 | 0.001 | 4 |
| | 9852A | | A-36 | | | 645887 | 39,900 | 62,500 | 32.0 | 0.190 | 0.400 | 0.009 | 0.015 | 0.009 | 0.054 | 0.001 | 0.038 | 0.001 | 4 |
| | 9852A | | HW | | | 15056184 | | | | | | | | | | | | | |
| 20 | 12173G | T12/6'3/4@1'6.75"/S | | | 2 | L35216 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | 209331 | 62,090 | 81,500 | 28.1 | 0.190 | 0.720 | 0.013 | 0.002 | 0.020 | 0.110 | 0.000 | 0.070 | 0.002 | 4 |
| | | | M-180 | A | 2 | 209332 | 61,400 | 81,290 | 25.3 | 0.190 | 0.730 | 0.014 | 0.003 | 0.020 | 0.120 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 209333 | 61,200 | 80,050 | 25.8 | 0.200 | 0.740 | 0.016 | 0.005 | 0.010 | 0.120 | 0.000 | 0.070 | 0.002 | 4 |

2 of 4

Figure A-13. Ground Strut Assembly, Test Nos. HWTT-1 and HWTT-2

ASSEMBLY SPECIALTY PRODUCTS INC

PH 216.676.5600
FX 216.676.6761
www.assemblyspecialty.com

ISO 9001:2008

14700 Brookpark Rd
Cleveland, OH 44135-5166
customerservice@assemblyspecialty.com

## Certificate of Conformance

**Date:** September 24, 2018

**To:** Gregory Industries, Inc.
Gregory Galv. & Metal Processing
4100 13th St. SW
Canton, OH 44710

We certify that our system and procedures for the control of quality assures that all items furnished on the order will meet applicable tests, requirements and inspection requirements as required by the purchase order and applicable specifications and drawings.

**PURCHASE ORDER #:** 40299
**DATE SHIPPED:** 09/24/18
**ASPI SALES ORDER #:** 122160
**MANUFACTURER:** ASSEMBLY SPECIALTY PRODUCTS, INC.

| QTY | CUST P/N | ASPI P/N | ASPI LOT# | DESCRIPTION |
|---|---|---|---|---|
| 250 | 3012G | C-2028 | 89315 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89316 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89318 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89864 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89865 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89866 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89929 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89930 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89931 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89932 | 6' 6" BCT Cable Assembly |

**REMARKS:** NOMINAL BREAKING STRENGTH: 46,000 lbs
WIRE ROPE MANUFACTURED IN ACCORDANCE WITH AASHTO DESIGNATION: M30-02 and ASTM A741 TYPE 2, CLASS A
FITTINGS GALVANIZED IN ACCORDANCE WITH ASTM A-153 CLASS C.

STEEL USED TO MANUFACTURE THESE ITEMS WAS MELTED AND MANUFACTURED IN THE U.S.A
ALL MANUFACTURING PROCESSES SUPPLIED OR PERFORMED BY ASSEMBLY SPECIALTY PRODUCTS, INC. TOOK PLACE IN THE U.S.A.

Signature:

Certification and Compliance Manager

Figure A-14. BCT Anchor Cable Swaged Fitting and 0.75 in. Dia. 6x19 IWRC Wire Rope, Test Nos. HWTT-1 and HWTT-2

**GREGORY HIGHWAY PRODUCTS, INC.**
**4100 13th St. SW**
**Canton, Ohio 44710**

MIDWEST MACHINERY & SUPPLY CO.
P. O. BOX 703

MILFORD,NE,68405

Test Report
Ship Date: 11/17/2017
Customer P.O.: 3515
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
PROJECT:
GHP Order No: 128AA

| HT CODE | Lot # | C. | Mn. | P. | S. | Si. | Tensile | Yield | Elong. | Quantity | Class | Type | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A74070 | | 0.21 | 0.46 | 0.012 | 0.002 | 0.03 | 76100 | 58800 | 25.2 | 4 | A | 2 | 12GA TB TRANS. |
| 4181496 | | 0.24 | 0.84 | 0.014 | 0.01 | 0.01 | 72400 | 44800 | 34 | 4 | | 2 | 5/8IN X 8IN X 8IN BRG. PL. |
| 4181489 | | 0.09 | 0.45 | 0.012 | 0.004 | 0.01 | 58000 | 43100 | 27 | 4 | | 2 | 350 STRUT & YOKE |
| 196828BM | | 0.04 | 0.84 | 0.014 | 0.003 | 0.02 | 76000 | 74000 | 25 | | | 2 | 350 STRUT & YOKE |
| E22985 | | 0.17 | 0.51 | 0.013 | 0.008 | 0.008 | 72510 | 64310 | 29.5 | 4 | | 2 | 2IN X 5 1/2IN PIPE SLEEVE |
| 821T08220 | | 0.22 | 0.81 | 0.013 | 0.006 | 0.006 | 70934 | 57275 | 32 | 8 | | 2 | 3/16IN X 6IN X 8IN X 6FT0IN TUBE SLEEVE |

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.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All sheet, zinc-coated or zinc-iron alloy-coated by the hot dip process that meets ASTM Specifications A653

Jeffery L Grover

By:_____
Jeffery L Grover, VP of Highway Products Sales & Marketing
Gregory Highway Products, Inc.

Figure A-15. 8-in. x 8-in. x ⅝-in. Anchor Bearing Plate, Test Nos. HWTT-1 and HWTT-2

Atlas Tube (Alabama), Inc.
171 Cleage Dr
Birmingham, Alabama, USA
35217
Tel:
Fax:

**Atlas Tube**
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80791452
Date: 11.10.2017
Customer: 179

## MATERIAL TEST REPORT

**Sold to**

Steel & Pipe Supply Compan
PO Box 1688
MANHATTAN KS 66505
USA

**Shipped to**

Steel & Pipe Supply Compan
401 New Century Parkway
NEW CENTURY KS 66031
USA

Material: 3.0x2.0x188x40'0"0(5x4). Material No: 0300201884000-B Made in: USA
Melted in: USA
Sales order: 1226976 Purchase Order: 4500296656 Cust Material #: 6630020018840

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B704212 | 0.200 | 0.450 | 0.010 | 0.004 | 0.020 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.28 |
|---|---|---|---|---|---|---|
| 40867002 | 20 | 064649 Psi | 087652 Psi | 24 % | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Material: 2.375x154x42'0"0(34x1). Material No: R023751544200 Made in: USA
Melted in: USA
Sales order: 1226976 Purchase Order: 4500296656 Cust Material #: 642004042

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B712810 | 0.210 | 0.460 | 0.012 | 0.002 | 0.020 | 0.024 | 0.100 | 0.002 | 0.020 | 0.030 | 0.060 | 0.004 | 0.002 | 0.000 | 0.008 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Rb | Certification | CE: 0.32 |
|---|---|---|---|---|---|---|---|
| MC00006947 | 34 | 063688 Psi | 083220 Psi | 25 % | 91 | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Material: 2.375x154x42'0"0(34x1). Material No: R023751544200 Made in: USA
Melted in: USA
Sales order: 1226976 Purchase Order: 4500296656 Cust Material #: 642004042

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17037261 | 0.210 | 0.810 | 0.005 | 0.004 | 0.020 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.35 |
|---|---|---|---|---|---|---|
| 41532001 | 34 | 066144 Psi | 082159 Psi | 27 % | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

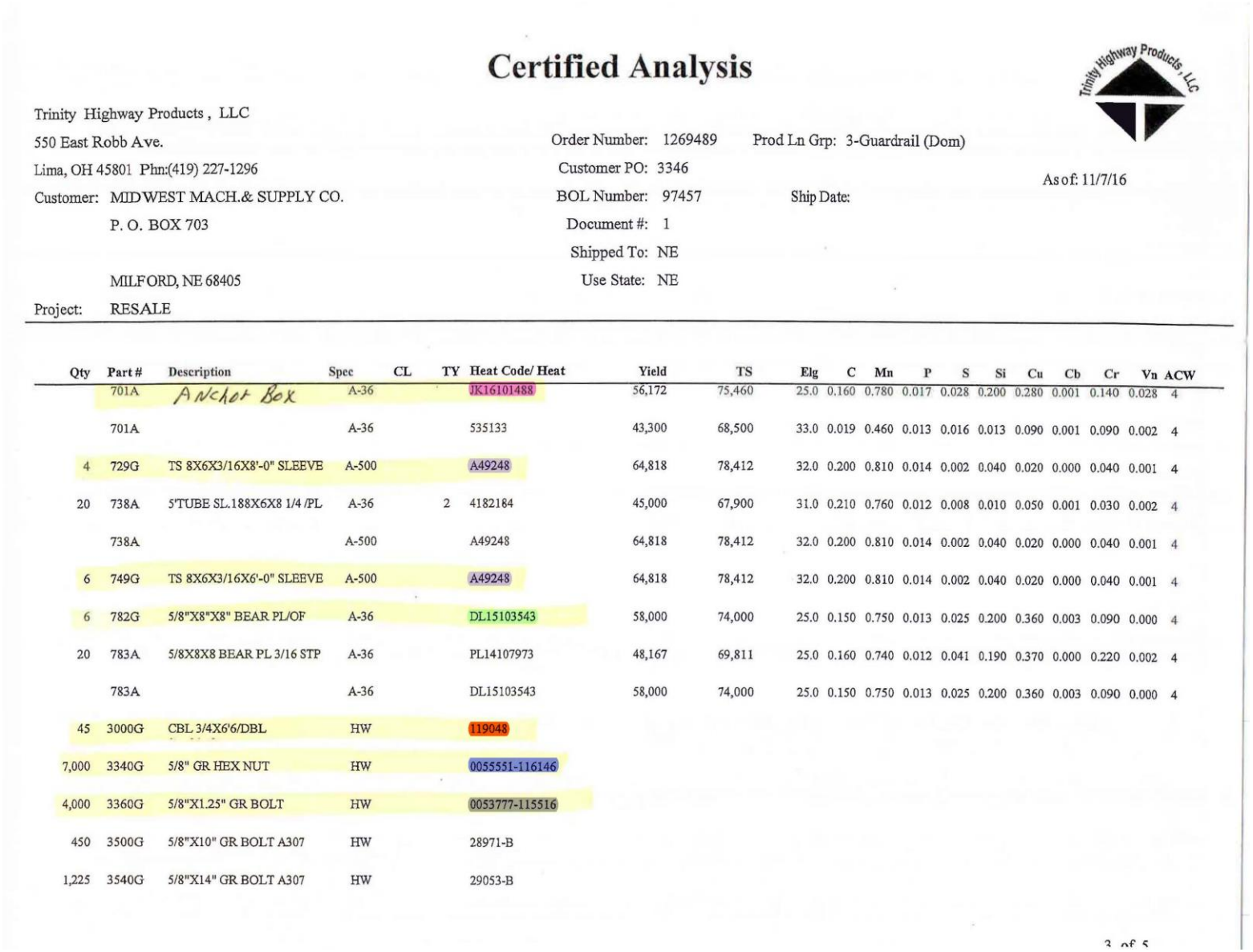
Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
Ca[illegible] using the AWS D1.1 method.

Steel Tube Institute

Page : 3 Of 4

Metals Service Center Institute

Figure A-16. 2⅜-in. O.D. by 6-in. Long BCT Post Sleeve, Test Nos. HWTT-1 and HWTT-2



# Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

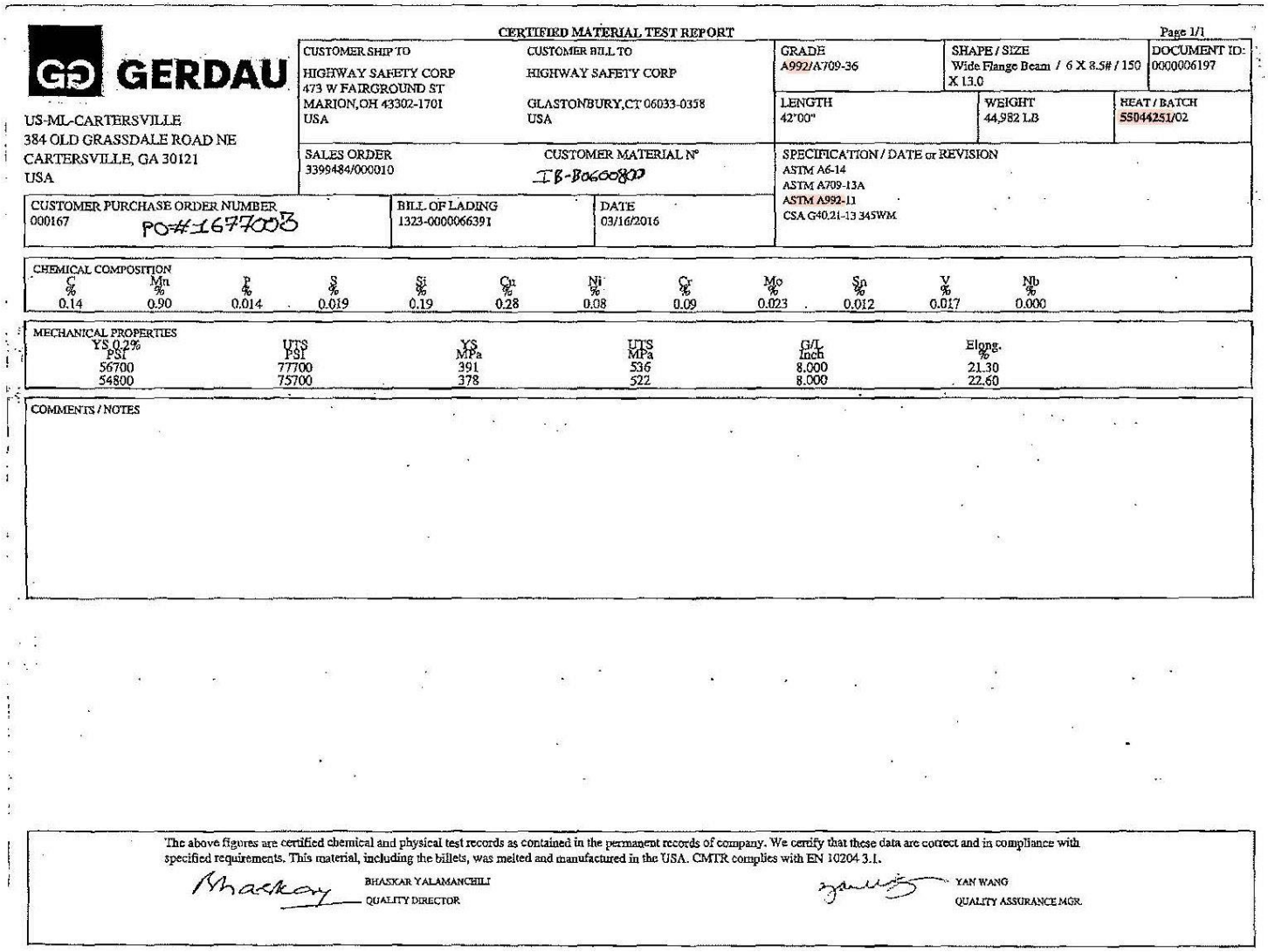
Order Number: 1269489 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3346
BOL Number: 97457 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 11/7/16

| Qty | Part # | Description | Spec | CL | TY | Heat Code/ Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 701A | Anchor Box | A-36 | | | JK16101488 | 56,172 | 75,460 | 25.0 | 0.160 | 0.780 | 0.017 | 0.028 | 0.200 | 0.280 | 0.001 | 0.140 | 0.028 | 4 |
| | 701A | | A-36 | | | 535133 | 43,300 | 68,500 | 33.0 | 0.019 | 0.460 | 0.013 | 0.016 | 0.013 | 0.090 | 0.001 | 0.090 | 0.002 | 4 |
| 4 | 729G | TS 8X6X3/16X8'-0" SLEEVE | A-500 | | | A49248 | 64,818 | 78,412 | 32.0 | 0.200 | 0.810 | 0.014 | 0.002 | 0.040 | 0.020 | 0.000 | 0.040 | 0.001 | 4 |
| 20 | 738A | 5'TUBE SL.188X6X8 1/4 /PL | A-36 | | 2 | 4182184 | 45,000 | 67,900 | 31.0 | 0.210 | 0.760 | 0.012 | 0.008 | 0.010 | 0.050 | 0.001 | 0.030 | 0.002 | 4 |
| | 738A | | A-500 | | | A49248 | 64,818 | 78,412 | 32.0 | 0.200 | 0.810 | 0.014 | 0.002 | 0.040 | 0.020 | 0.000 | 0.040 | 0.001 | 4 |
| 6 | 749G | TS 8X6X3/16X6'-0" SLEEVE | A-500 | | | A49248 | 64,818 | 78,412 | 32.0 | 0.200 | 0.810 | 0.014 | 0.002 | 0.040 | 0.020 | 0.000 | 0.040 | 0.001 | 4 |
| 6 | 782G | 5/8"X8"X8" BEAR PL/OF | A-36 | | | DL15103543 | 58,000 | 74,000 | 25.0 | 0.150 | 0.750 | 0.013 | 0.025 | 0.200 | 0.360 | 0.003 | 0.090 | 0.000 | 4 |
| 20 | 783A | 5/8X8X8 BEAR PL 3/16 STP | A-36 | | | PL14107973 | 48,167 | 69,811 | 25.0 | 0.160 | 0.740 | 0.012 | 0.041 | 0.190 | 0.370 | 0.000 | 0.220 | 0.002 | 4 |
| | 783A | | A-36 | | | DL15103543 | 58,000 | 74,000 | 25.0 | 0.150 | 0.750 | 0.013 | 0.025 | 0.200 | 0.360 | 0.003 | 0.090 | 0.000 | 4 |
| 45 | 3000G | CBL 3/4X6'6/DBL | HW | | | 119048 | | | | | | | | | | | | | |
| 7,000 | 3340G | 5/8" GR HEX NUT | HW | | | 0055551-116146 | | | | | | | | | | | | | |
| 4,000 | 3360G | 5/8"X1.25" GR BOLT | HW | | | 0053777-115516 | | | | | | | | | | | | | |
| 450 | 3500G | 5/8"X10" GR BOLT A307 | HW | | | 28971-B | | | | | | | | | | | | | |
| 1,225 | 3540G | 5/8"X14" GR BOLT A307 | HW | | | 29053-B | | | | | | | | | | | | | |

3 of 5

Figure A-17. Anchor Bracket Assembly, Test Nos. HWTT-1 and HWTT-2



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 |
|---|---|
| HIGHWAY SAFETY CORP<br>473 W FAIRGROUND ST<br>MARION,OH 43302-1701<br>USA | HIGHWAY SAFETY CORP<br><br>GLASTONBURY,CT 06033-0358<br>USA |

| GRADE | SHAPE / SIZE | DOCUMENT ID: |
|---|---|---|
| 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 N° |
|---|---|
| 3399484/000010 | IB-B0600800 |

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

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

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-18. W6x8.5 72-in. Long Steel Post, Test Nos. HWTT-1 and HWTT-2

# Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH & SUPPLY CO
P. O. BOX 703
MILFORD, NE 68405
Project: STOCK

Order Number: 1302452 Prod Ln Grp: 0-OE2.0
Customer PO: 3656
BOL Number: 107001 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 11/13/18

| Qty | Part # | Description | Spec | CL | TY | Heat Code/ Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | M-180 | A | 2 | 222038 | 63,780 | 82,280 | 22.9 | 0.190 | 0.750 | 0.012 | 0.002 | 0.030 | 0.100 | 0.000 | 0.070 | 0.001 | 4 |
| | | | M-180 | A | 2 | 222878 | 64,680 | 81,820 | 25.2 | 0.180 | 0.740 | 0.012 | 0.003 | 0.020 | 0.130 | 0.000 | 0.070 | 0.002 | 4 |
| | | | M-180 | A | 2 | 222038 | 63,780 | 82,280 | 22.9 | 0.190 | 0.750 | 0.012 | 0.002 | 0.030 | 0.100 | 0.000 | 0.070 | 0.001 | 4 |
| | | | M-180 | A | 2 | 222878 | 64,680 | 81,820 | 25.2 | 0.180 | 0.740 | 0.012 | 0.003 | 0.020 | 0.130 | 0.000 | 0.070 | 0.002 | 4 |
| 75 | 54043G | 7'0 PST/6X15/DB:3HI | A-572 | | | 2815472 | 62,500 | 75,700 | 23.0 | 0.070 | 0.840 | 0.008 | 0.025 | 0.220 | 0.280 | 0.029 | 0.090 | 0.004 | 4 |

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED

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

State of Ohio, County of Allen. Sworn and subscribed before me this 13rd day of November, 2018 .

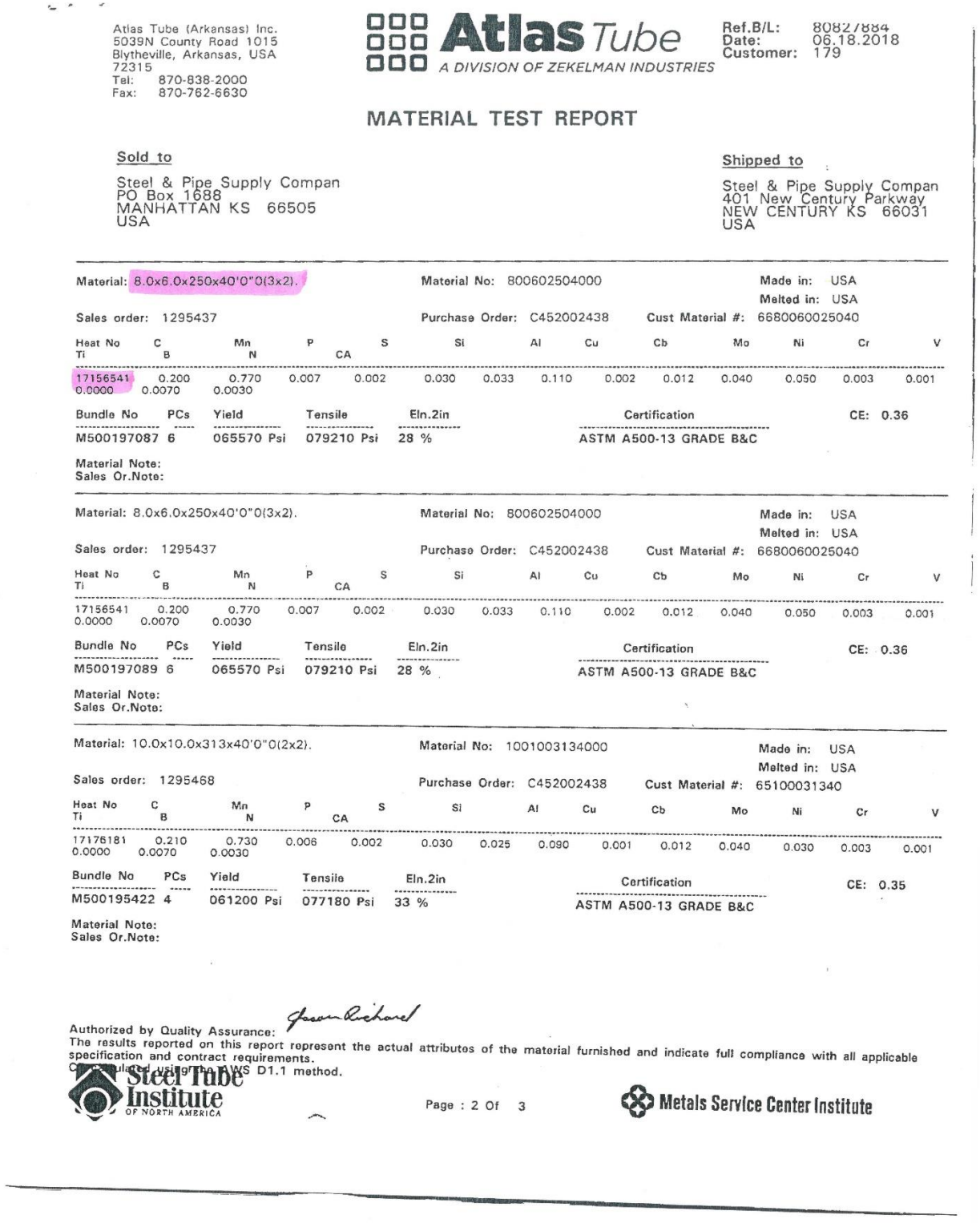
Notary Public: Jamie L Davis
Commission Expires: 3/22/2021

NOTARIAL SEAL STATE OF OHIO
JAMIE L DAVIS
Notary Public, State of Ohio
My Commission Expires
March 22, 2021

Trinity Highway Products, LLC
Certified By: Heather L. Painter
Quality Assurance

2 of 2

Figure A-19. W6x15 78-in. Long Steel Post, Test Nos. HWTT-1 and HWTT-2



Atlas Tube (Arkansas) Inc.
5039N County Road 1015
Blytheville, Arkansas, USA
72315
Tel: 870-838-2000
Fax: 870-762-6630

Atlas Tube
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 8082/884
Date: 06.18.2018
Customer: 179

MATERIAL TEST REPORT

Sold to

Steel & Pipe Supply Compan
PO Box 1688
MANHATTAN KS 66505
USA

Shipped to

Steel & Pipe Supply Compan
401 New Century Parkway
NEW CENTURY KS 66031
USA

Material: 8.0x6.0x250x40'0"0(3x2). Material No: 800602504000 Made in: USA
Melted in: USA
Sales order: 1295437 Purchase Order: C452002438 Cust Material #: 6680060025040

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ti | B | N | CA | | | | | | | | | |
| 17156541 | 0.200 | 0.770 | 0.007 | 0.002 | 0.030 | 0.033 | 0.110 | 0.002 | 0.012 | 0.040 | 0.050 | 0.003 | 0.001 |
| 0.0000 | 0.0070 | 0.0030 | | | | | | | | | | | |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.36 |
|---|---|---|---|---|---|---|
| M500197087 | 6 | 065570 Psi | 079210 Psi | 28 % | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Material: 8.0x6.0x250x40'0"0(3x2). Material No: 800602504000 Made in: USA
Melted in: USA
Sales order: 1295437 Purchase Order: C452002438 Cust Material #: 6680060025040

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ti | B | N | CA | | | | | | | | | |
| 17156541 | 0.200 | 0.770 | 0.007 | 0.002 | 0.030 | 0.033 | 0.110 | 0.002 | 0.012 | 0.040 | 0.050 | 0.003 | 0.001 |
| 0.0000 | 0.0070 | 0.0030 | | | | | | | | | | | |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.36 |
|---|---|---|---|---|---|---|
| M500197089 | 6 | 065570 Psi | 079210 Psi | 28 % | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Material: 10.0x10.0x313x40'0"0(2x2). Material No: 1001003134000 Made in: USA
Melted in: USA
Sales order: 1295468 Purchase Order: C452002438 Cust Material #: 65100031340

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ti | B | N | CA | | | | | | | | | |
| 17176181 | 0.210 | 0.730 | 0.006 | 0.002 | 0.030 | 0.025 | 0.090 | 0.001 | 0.012 | 0.040 | 0.030 | 0.003 | 0.001 |
| 0.0000 | 0.0070 | 0.0030 | | | | | | | | | | | |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.35 |
|---|---|---|---|---|---|---|
| M500195422 | 4 | 061200 Psi | 077180 Psi | 33 % | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Authorized by Quality Assurance: Jason Richard
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
Calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 2 Of 3

Metals Service Center Institute

Figure A-20. 17½-in. Long, 8-in. x 6-in. x ¼-in. Steel Blockout, Test Nos. HWTT-1 and HWTT-2

MARUICHI LEAVITT PIPE AND TUBE

**MATERIAL TEST REPORT**

**ORIGINAL**

M/C No. MC0000056391
Date 03/01/2019

BL No. SH0000065644
Destination STEEL & PIPE SUPPLY-NEW CENTURY
Supplier STEEL & PIPE SUPPLY CO., INC. - BILL TO

**MARUICHI LEAVITT PIPE & TUBE, LLC**
1717 W. 115th St.
Chicago, IL 60643
TEL: (773) 239-7700 FAX: (773) 239-1023

| | SPEC / SIZE / Customer PO No. / Customer Item No. | No of PCS / Calculated Wt(LBS) | Heat No | Chemical Composition(Ladle Analysis) C (%) X 100 | Si (%) X 100 | Mn (%) X 100 | P (%) X 1000 | S (%) X 1000 | Cu (%) X 1000 | Ni (%) X 1000 | Cr (%) X 1000 | Mo (%) X 1000 | V (%) X 1000 | Tensile Test Yield Strength (PSI) | Tensile Strength (PSI) | Elongation (%) | Hydrostatic Test Pressure (PSI) / Result | Bending Test / Flattening Test | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ASTM A500/A500M-13 GRADE B ERW TUBING<br>6IN x 3IN x 0.188IN x 20FT HRB<br>4500324823 / 6660030018820 | 48<br>10,272 | A59120 | 18 | 4 | 69 | 9 | 2 | 30 | 20 | 40 | 6 | 5 | 61,851 | 72,499 | 26 | | | SA0000158644 |
| 2 | ASTM A500/A500M-13 GRADE B ERW TUBING<br>6IN x 3IN x 0.375IN x 20FT HRB<br>4500324823 / 6660030037520 | 16<br>6,344 | A58347 | 6 | 4 | 114 | 9 | 2 | 30 | 20 | 40 | 8 | 7 | 60,461 | 66,694 | 28 | | | SA0000158644 |
| 3 | ASTM A500/A500M-13 GRADE B ERW TUBING<br>7IN x 5IN x 0.250IN x 40FT HRB<br>4500324823 / 6670050025040 | 9<br>6,848 | 821C10790 | 19 | 1 | 80 | 13 | 4 | 15 | 10 | 30 | 4 | 1 | 57,856 | 74,471 | 32 | | | SA0000158644 |
| 4 | ASTM A500/A500M-13 GRADE B ERW TUBING<br>8IN x 3IN x 0.188IN x 20FT HRB<br>4500324823 / 6680030018820 | 12<br>3,180 | 821C10780 | 18 | 1 | 76 | 11 | 5 | 19 | 10 | 30 | 6 | 1 | 58,686 | 68,054 | 33 | | | SA0000158644 |
| 5 | ASTM A500/A500M-13 GRADE B ERW TUBING<br>12IN x 4IN x 0.250IN x 40FT HRB<br>4500324823 / 66120040025040 | 6<br>6,196 | B46771 | 18 | 3 | 70 | 8 | 2 | 20 | 10 | 40 | 8 | 1 | 64,078 | 74,433 | 30 | | | SA0000158644 |
| 6 | ASTM A500/A500M-13 GRADE B ERW TUBING<br>5IN x 5IN x 0.250IN x 40FT HRB<br>4500324845 / 6550025040 | 5<br>3,124 | B49151 | 20 | 2 | 66 | 9 | 6 | 20 | 10 | 40 | 3 | 1 | 56,484 | 75,312 | 25 | | | SA0000158646 |

**Made and Melted in The U.S.A.**
This material has not come in direct contact with mercury during the manufacturing or testing processes. No Weld Repair.

Remarks:

We hereby certify that the material described herein conforms fully to the said specification.

Maruichi Leavitt Pipe & Tube, LLC

F-824-101 - Rev. 0

Figure A-21. 17½-in. Long, 12-in. x 4-in. x ¼-in. Steel Blockout, Test Nos. HWTT-1 and HWTT-2

**MONDO POLYMER TECHNOLOGIES INC.**
Plastics From Today for Tomorrow...

**P.O. BOX 250**
**27620 ST. RT. 7 NORTH**
**RENO, OH 45773**

**Phone: 740-376-9396**
**Fax: 740-376-9960**
**(888) 607-4790**

## MATERIAL CERTIFICATE

SHIPMENT NUMBER: 34545
PURCHASE ORDER HWTT
SHIPMENT DATE: 4/4/2019

PAGE: 2

**CONSIGNED TO**

Midwest Roadside Safety
4630 NV 36th Street
Lincoln, NE 68524

**SHIP TO**

Midwest Roadside Safety

4630 NW 36th Street
Lincoln, NE 68524

| CONSIGNED | ITEM NUMBER | DESCRIPTION | LOT # | SHIP VIA |
|---|---|---|---|---|
| 4 | MGS14SH | Midwest Composite Block 14" h x 12" d for Steel Post | 1904/1000 | FedEx Freight |

**MADE IN USA**

**The composite guardrail blocks for the Midwest Guardrail System are manufactured by Mondo Polymer Technologies, Inc., and are of the same formulation, composition, and test properties as those which were MASH qualified and and eligible for reimbursement by the Federal Highway Administration under the Federal-aid highway program, Approval #HSST/B-39C.**

**All materials meet required specifications.**

**Approved by:** Maggie Ellis **Date:** 4/4/2019

**Print Name:** Maggie Ellis **Position:** General Manager

Figure A-22. $14^{3}/_{16}$-in. x 12-in. x ⅛-in. Composite Recycle Blockout, Test Nos. HWTT-1 and HWTT-2

MONDO POLYMER TECHNOLOGIES INC.
Plastics From Today for Tomorrow...

P.O. BOX 250
27620 ST. RT. 7 NORTH
RENO, OH 45773

Phone: 740-376-9396
Fax: 740-376-9960
(888) 607-4790

## MATERIAL CERTIFICATE

SHIPMENT NUMBER: 34545
PURCHASE ORDER HWTT
SHIPMENT DATE: 4/4/2019

PAGE: 1

**CONSIGNED TO**

Midwest Roadside Safety
4630 NV 36th Street
Lincoln, NE 68524

**SHIP TO**

Midwest Roadside Safety

4630 NW 36th Street
Lincoln, NE 68524

| CONSIGNED | ITEM NUMBER | DESCRIPTION | LOT # | SHIP VIA |
|---|---|---|---|---|
| 10 | GB14SH2 | Composite Guardrial Block 14" for Steel Post w/hanger CO | 1804/1000 | FedEx Freight |

**MADE IN USA**

**The composite guardrail offset blocks for the Midwest Guardrail System (MGS), are manufactured by Mondo Polymer Technologies, Inc., and are of the same formulation, composition, and test properties as those which were MASH qualified and eligible for reimbursement by the Federal Highway Administration under the Federal-aid highway program, Approval No. HSST-1/B-278A.**

**All materials meet required specifications.**

Approved by: Maggie Ellis Date: 4/4/2019

Print Name: Maggie Ellis Position: General Manager

Figure A-23. $14^{3}/_{16}$-in. x 8-in. x ⅛-in. Composite Recycle Blockout, Test Nos. HWTT-1 and HWTT-2

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
**E000548963**

Order Placed By
**Shaun M Tighe**

McMaster-Carr Number
**7204107-01**

Page 1 of 1

08/02/2018

| Line | | Product | Ordered | Shipped |
|---|---|---|---|---|
| 1 | **97812A109** | Raised-Head Removable Nails, 16D Penny Size, 3" Long, 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-24. 16 D Double Head Nails, Test Nos. HWTT-1 and HWTT-2

CMC STEEL OKLAHOMA
584 Old Highway 70
Durant OK 74701-0000

**CERTIFIED MILL TEST REPORT**
For additional copies call
830-372-8771

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

Jacob Selzer – CMC Steel
Quality Assurance Manager

| | | | | | |
|---|---|---|---|---|---|
| HEAT NO.:6005053<br>SECTION: REBAR 19MM (#6) 60'0" 420/60<br>GRADE: ASTM A615-18e1 Gr 420/60<br>ROLL DATE: 01/27/2019<br>MELT DATE: 01/27/2019<br>Cert. No.: 82626070 / 005053J053 | SOLD TO | Concrete Industries Inc<br><br>6300 Cornhusker Hwy<br>Lincoln NE<br>US 68529-0529<br>4024341899<br>4024341899 | SHIP | Nebco Inc<br><br>Steel Division<br>Havelock NE<br>US 68529-0000<br>4024341800 | Delivery#: 82626070<br>BOL#: 1731410<br>CUST PO#: 135110<br>CUST P/N:<br>DLVRY LBS / HEAT: 61280.000 LB<br>DLVRY PCS / HEAT: 680 EA |

| Characteristic | Value | Characteristic | Value |
|---|---|---|---|
| C | 0.26% | Elongation Gage Lgth test 1 | 8IN |
| Mn | 0.90% | Bend Test 1 | Passed |
| P | 0.010% | Rebar Deformation Avg. Spaci | 0.500IN |
| S | 0.036% | Rebar Deformation Avg. Heigh | 0.043IN |
| Si | 0.26% | Rebar Deformation Max. Gap | 0.116IN |
| Cu | 0.33% | Bend Test Diameter | 3.750IN |
| Cr | 0.11% | Uniform Elongation | 7.3% |
| Ni | 0.10% | | |
| Mo | 0.033% | | |
| V | 0.006% | | |
| Sn | 0.013% | | |
| Al | 0.004% | | |
| NB | 0.001% | | |
| N | 0.0081% | | |
| Carbon Eq A6 | 0.47% | | |
| Yield Strength test 1 | 85.2ksi | | |
| Yield Strength test 1 (metri | 588MPa | | |
| Tensile Strength test 1 | 101.7ksi | | |
| Tensile Strength 1 (metric) | 702MPa | | |
| Elongation test 1 | 14% | | |

**The Following is true of the material represented by this MTR:**

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

**REMARKS :**

03/12/2019 11:54:14
Page 1 OF 1

Figure A-25. ¾-in. Dia. Unbent Rebar, Test Nos. HWTT-1 and HWTT-2

EVRAZ ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

3100 S. Freeway
Pueblo, CO 81004 USA

# MATERIAL TEST REPORT

Date Printed: 19–MAR–19

Date Shipped: 19–MAR–19 | Product: DEF #4 (1/2") | Specification: ASTM A706/A615 GR 60

FWIP: 52815348 | Customer: CONCRETE INDUSTRIES INC | Cust. PO: 135424

P O BOX 29529
LINCOLN, NE 68529

## CHEMICAL ANALYSIS (In Weight %, uncertainty of measurement 0.005%)

(Heat cast 01/03/19)

| Heat Number | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | Al | V | B | Cb | Sn | N | Ti |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 605061 | 0.27 | 1.24 | 0.014 | 0.025 | 0.23 | 0.27 | 0.07 | 0.18 | 0.017 | 0.002 | 0.038 | 0.0003 | 0.000 | 0.010 | 0.0090 | 0.001 |

Carbon Equivalent = 0.501

## MECHANICAL PROPERTIES (Tensiles test date 01/04/19)

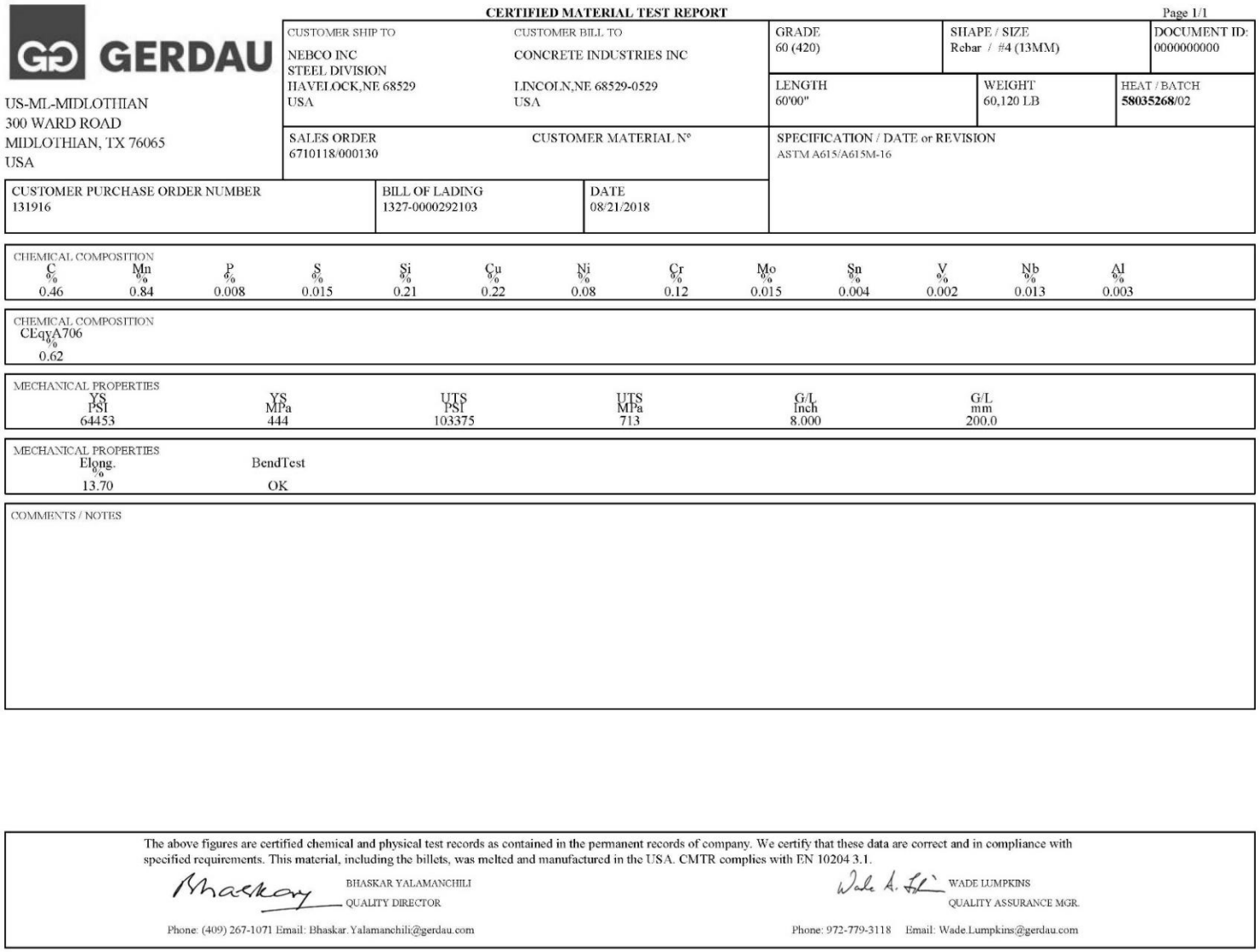
| Heat Number | Sample No. | | Yield (Psi) | Ultimate (Psi) | Elongation (%) | Reduction (%) | Bend | Wt/ft |
|---|---|---|---|---|---|---|---|---|
| 605061 | 01 | | 67853 | 967930 | 15.1 | | ok | 0.662 |
| | | (MPa) | 467.8 | ****** | | | | |
| 605061 | 02 | | 65649 | 94460 | 15.3 | | ok | 0.662 |
| | | (MPa) | 452.6 | 651.3 | | | | |

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.
ERMS also certifies this material to be free from Mercury contamination.

This material has been produced, tested and conforms to the requirements of the applicable specifications. We hereby certify that the above test results represent those contained in the records of the Company.

Bryce Lakamp
Process Control Engineer

Figure A-26. ½-in. Dia. Rebar, Test Nos. HWTT-1 and HWTT-2



**CERTIFIED MATERIAL TEST REPORT** Page 1/1

GERDAU

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

| CUSTOMER SHIP TO | CUSTOMER BILL TO |
|---|---|
| NEBCO INC<br>STEEL DIVISION<br>HAVELOCK,NE 68529<br>USA | CONCRETE INDUSTRIES INC<br><br>LINCOLN,NE 68529-0529<br>USA |

| GRADE | SHAPE / SIZE | DOCUMENT ID: |
|---|---|---|
| 60 (420) | Rebar / #4 (13MM) | 0000000000 |

| LENGTH | WEIGHT | HEAT / BATCH |
|---|---|---|
| 60'00" | 60,120 LB | **58035268**/02 |

| SALES ORDER | CUSTOMER MATERIAL N° | SPECIFICATION / DATE or REVISION |
|---|---|---|
| 6710118/000130 | | ASTM A615/A615M-16 |

| CUSTOMER PURCHASE ORDER NUMBER | BILL OF LADING | DATE |
|---|---|---|
| 131916 | 1327-0000292103 | 08/21/2018 |

CHEMICAL COMPOSITION

| C % | Mn % | P % | S % | Si % | Cu % | Ni % | Cr % | Mo % | Sn % | V % | Nb % | Al % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.46 | 0.84 | 0.008 | 0.015 | 0.21 | 0.22 | 0.08 | 0.12 | 0.015 | 0.004 | 0.002 | 0.013 | 0.003 |

CHEMICAL COMPOSITION

| CEqvA706 % |
|---|
| 0.62 |

MECHANICAL PROPERTIES

| YS PSI | YS MPa | UTS PSI | UTS MPa | G/L Inch | G/L mm |
|---|---|---|---|---|---|
| 64453 | 444 | 103375 | 713 | 8.000 | 200.0 |

MECHANICAL PROPERTIES

| Elong. % | BendTest |
|---|---|
| 13.70 | 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) 267-1071 Email: Bhaskar.Yalamanchili@gerdau.com

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

Figure A-27. ½-in. Dia. Rebar, Test Nos. HWTT-1 and HWTT-2

CMC STEEL OKLAHOMA
584 Old Highway 70
Durant OK 74701-0000

**CERTIFIED MILL TEST REPORT**
For additional copies call
830-372-8771

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

Jacob Selzer – CMC Steel
Quality Assurance Manager

| | | | | | |
|---|---|---|---|---|---|
| HEAT NO.:6005295<br>SECTION: REBAR 16MM (#5) 60'0" 420/60<br>GRADE: ASTM A615-18e1 Gr 420/60<br>ROLL DATE: 02/10/2019<br>MELT DATE: 02/10/2019<br>Cert. No.: 82631779 / 005295J002 | SOLD TO | Concrete Industries Inc<br><br>6300 Cornhusker Hwy<br>Lincoln NE<br>US 68529-0529<br>4024341899<br>4024341899 | SHIP TO | Nebco Inc<br><br>Steel Division<br>Havelock NE<br>US 68529-0000<br>4024341800 | Delivery#: 82631779<br>BOL#: 1736610<br>CUST PO#: 135113<br>CUST P/N:<br>DLVRY LBS / HEAT: 110394.000 LB<br>DLVRY PCS / HEAT: 1764 EA |

| Characteristic | Value | Characteristic | Value |
|---|---|---|---|
| C | 0.28% | Elongation Gage Lgth test 1 | 8IN |
| Mn | 0.95% | Bend Test 1 | Passed |
| P | 0.013% | Rebar Deformation Avg. Spaci | 0.421IN |
| S | 0.037% | Rebar Deformation Avg. Heigh | 0.040IN |
| Si | 0.19% | Rebar Deformation Max. Gap | 0.113IN |
| Cu | 0.37% | Bend Test Diameter | 2.188IN |
| Cr | 0.10% | Uniform Elongation | 10.9% |
| Ni | 0.12% | | |
| Mo | 0.031% | | |
| V | 0.005% | | |
| Sn | 0.014% | | |
| Al | 0.000% | | |
| NB | 0.000% | | |
| N | 0.0108% | | |
| Carbon Eq A6 | 0.50% | | |
| Yield Strength test 1 | 83.0ksi | | |
| Yield Strength test 1 (metri | 573MPa | | |
| Tensile Strength test 1 | 100.0ksi | | |
| Tensile Strength 1 (metric) | 690MPa | | |
| Elongation test 1 | 15% | | |

**The Following is true of the material represented by this MTR:**

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

**REMARKS :**

03/12/2019 13:12:40
Page 1 OF 1

Figure A-28. ⅝-in. Dia. Rebar, Test Nos. HWTT-1 and HWTT-2

**CERTIFICATE OF COMPLIANCE**

**ROCKFORD BOLT & STEEL CO.**
**126 MILL STREET**
**ROCKFORD, IL 61101**
**815-968-0514 FAX# 815-968-3111**

**CUSTOMER NAME:** TRINITY INDUSTRIES

**CUSTOMER PO:** 187087

**SHIPPER #:** 061972
**DATE SHIPPED:** 11/06/2017

**LOT#:** 30361-P

**SPECIFICATION:** ASTM A307, GRADE A MILD CARBON STEEL BOLTS

| | | | | |
|---|---|---|---|---|
| **TENSILE:** | SPEC: | 60,000 psi*min | RESULTS: | 66,566<br>66,832 |
| **HARDNESS:** | | 100 max | | 82.60<br>82.70 |

*Pounds Per Square Inch.

**COATING:** ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
**ROGERS GALVANIZE:** 30361-P

**CHEMICAL COMPOSITION**

| MILL | GRADE | HEAT# | C | Mn | P | S | Si |
|---|---|---|---|---|---|---|---|
| NUCOR | 1010 | DL17100590 | .10 | .41 | .005 | .005 | .05 |

**QUANTITY AND DESCRIPTION:**

4,825 PCS 5/8" X 14" GUARD RAIL BOLT
P/N 3540G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENT PER ABOVE SPECIFICATION.

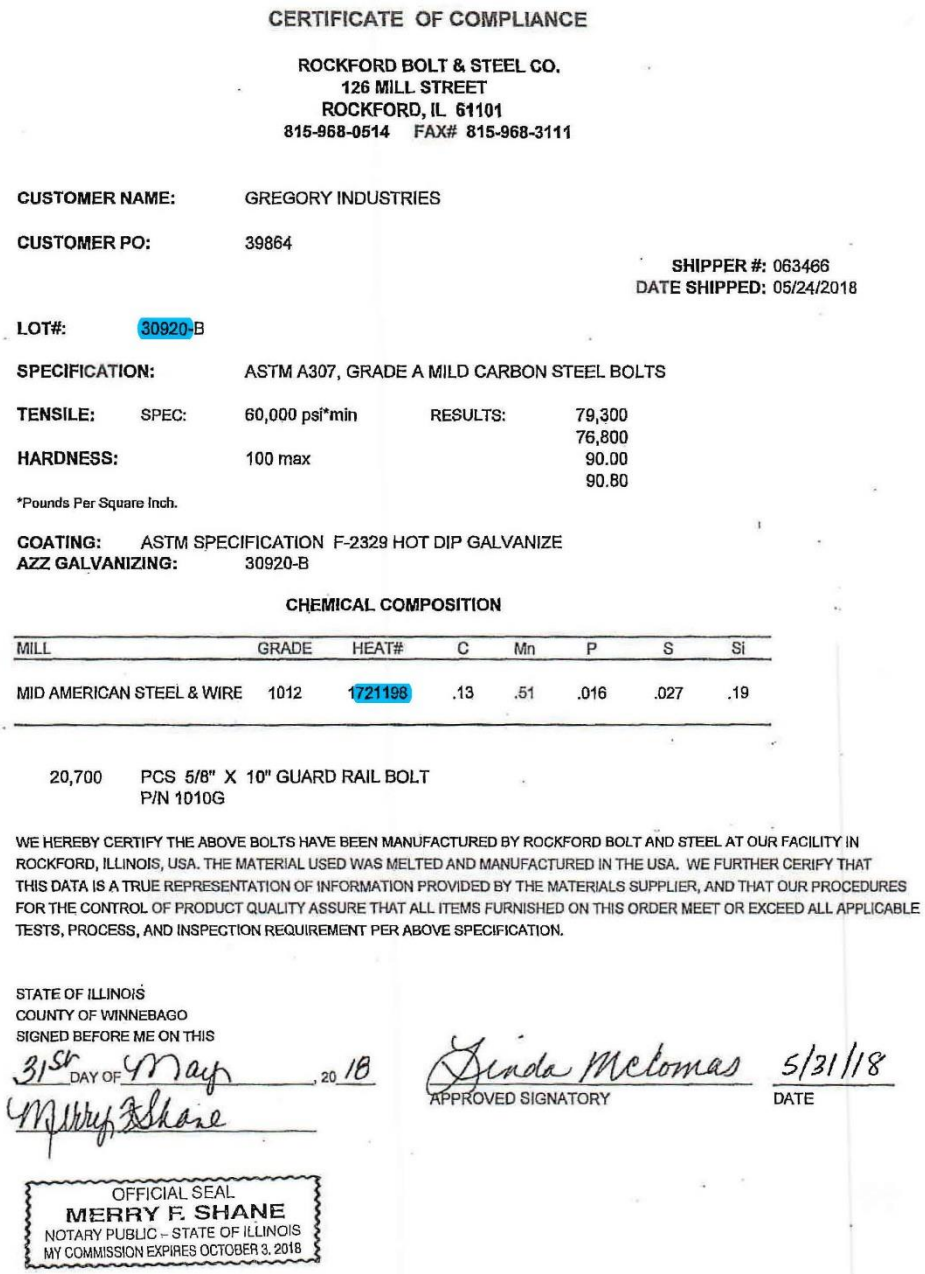
STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
16th DAY OF November 2017

Linda McComas — APPROVED SIGNATORY
11/6/17 — DATE

Merry F. Shane

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Figure A-29. ⅝-in. Dia. 11 UNC, 14-in. Long Guardrail Bolts, Test Nos. HWTT-1 and HWTT-2



CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

**CUSTOMER NAME:** GREGORY INDUSTRIES

**CUSTOMER PO:** 39864

**SHIPPER #:** 063466
**DATE SHIPPED:** 05/24/2018

**LOT#:** 30920-B

**SPECIFICATION:** ASTM A307, GRADE A MILD CARBON STEEL BOLTS

| | | | | |
|---|---|---|---|---|
| **TENSILE:** | SPEC: | 60,000 psi*min | RESULTS: | 79,300<br>76,800 |
| **HARDNESS:** | | 100 max | | 90.00<br>90.80 |

*Pounds Per Square Inch.

**COATING:** ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
**AZZ GALVANIZING:** 30920-B

**CHEMICAL COMPOSITION**

| MILL | GRADE | HEAT# | C | Mn | P | S | Si |
|---|---|---|---|---|---|---|---|
| MID AMERICAN STEEL & WIRE | 1012 | 1721198 | .13 | .51 | .016 | .027 | .19 |

20,700 PCS 5/8" X 10" GUARD RAIL BOLT
P/N 1010G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENT PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
31st DAY OF May, 20 18

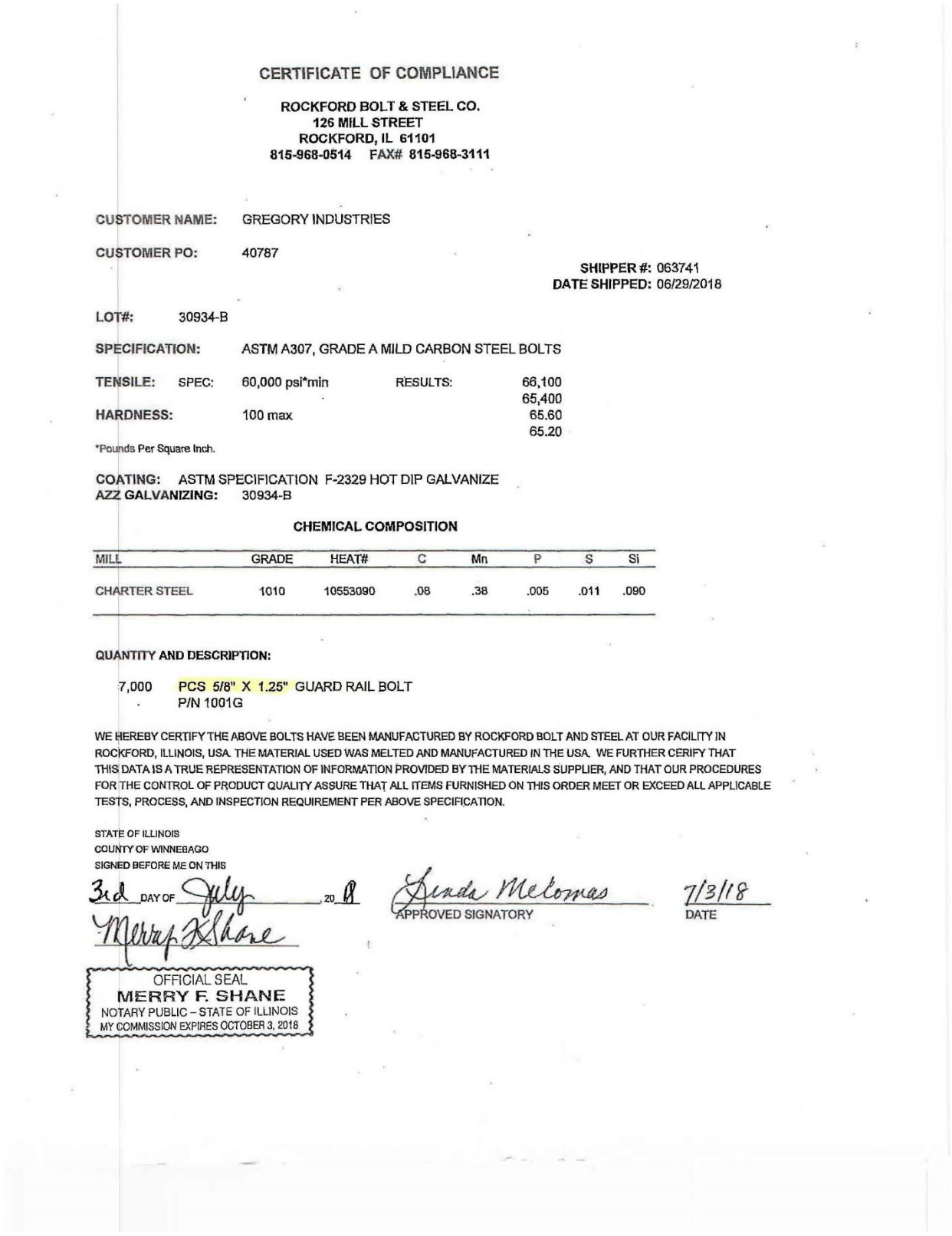
Merry F Shane

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Linda McComas
APPROVED SIGNATORY

5/31/18
DATE

Figure A-30. ⅝-in. Dia. 11 UNC, 10-in. Long Guardrail Bolts, Test Nos. HWTT-1 and HWTT-2



CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: GREGORY INDUSTRIES

CUSTOMER PO: 40787

SHIPPER #: 063741
DATE SHIPPED: 06/29/2018

LOT#: 30934-B

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

| | | | | |
|---|---|---|---|---|
| TENSILE: | SPEC: | 60,000 psi*min | RESULTS: | 66,100<br>65,400 |
| HARDNESS: | | 100 max | | 65.60<br>65.20 |

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
AZZ GALVANIZING: 30934-B

CHEMICAL COMPOSITION

| MILL | GRADE | HEAT# | C | Mn | P | S | Si |
|---|---|---|---|---|---|---|---|
| CHARTER STEEL | 1010 | 10553090 | .08 | .38 | .005 | .011 | .090 |

QUANTITY AND DESCRIPTION:

7,000 PCS 5/8" X 1.25" GUARD RAIL BOLT
P/N 1001G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENT PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
3rd DAY OF July, 20 18

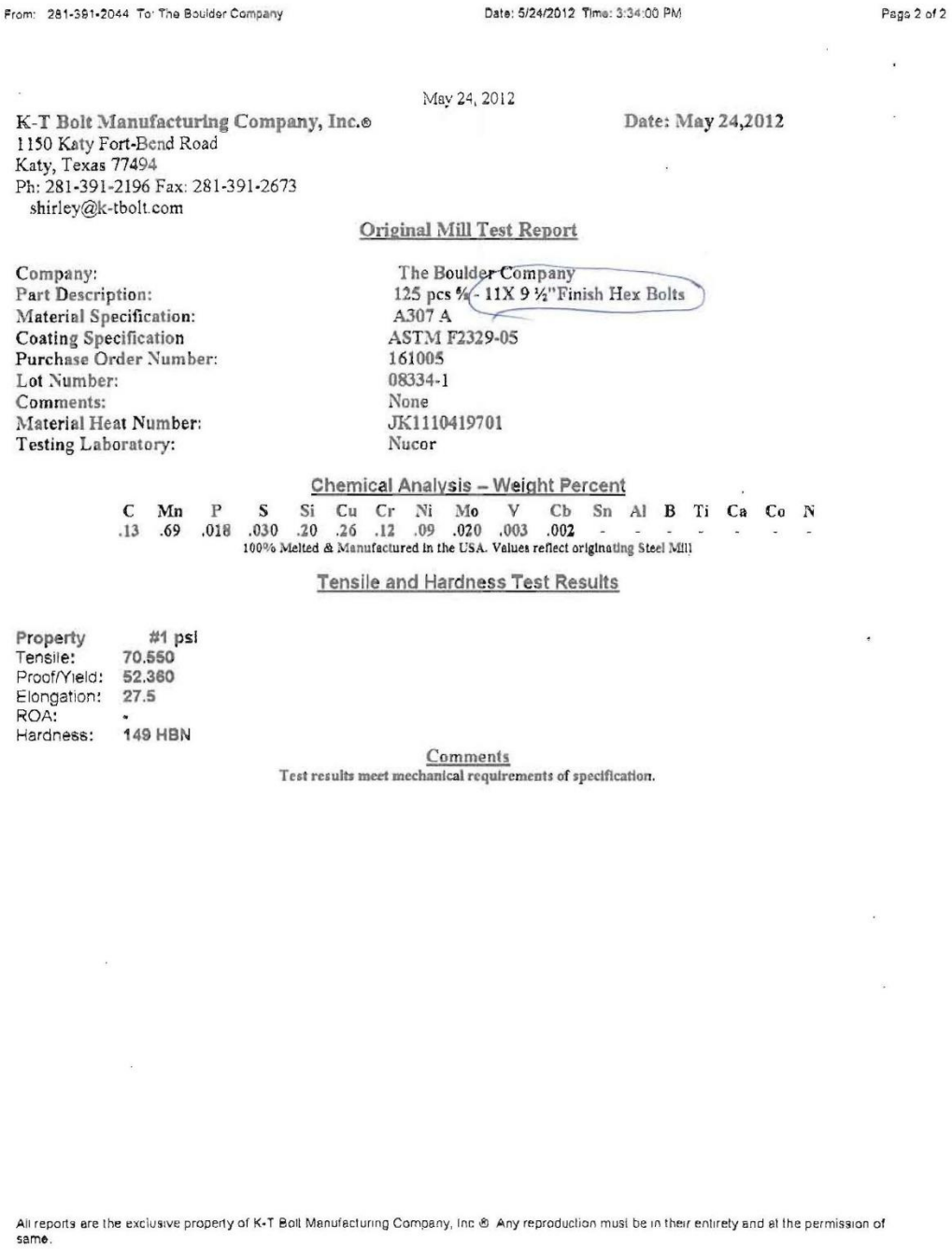
Merry F Shane

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Linda Melomas
APPROVED SIGNATORY

7/3/18
DATE

Figure A-31. ⅝-in. Dia. 11 UNC, 1¼-in. Long Guardrail Bolts, Test Nos. HWTT-1 and HWTT-2



From: 281-391-2044 To: The Boulder Company Date: 5/24/2012 Time: 3:34:00 PM Page 2 of 2

May 24, 2012

K-T Bolt Manufacturing Company, Inc.®
1150 Katy Fort-Bend Road
Katy, Texas 77494
Ph: 281-391-2196 Fax: 281-391-2673
shirley@k-tbolt.com

Date: May 24,2012

Original Mill Test Report

| | |
|---|---|
| Company: | The Boulder Company |
| Part Description: | 125 pcs ⅝ - 11X 9 ½"Finish Hex Bolts |
| Material Specification: | A307 A |
| Coating Specification | ASTM F2329-05 |
| Purchase Order Number: | 161005 |
| Lot Number: | 08334-1 |
| Comments: | None |
| Material Heat Number: | JK1110419701 |
| Testing Laboratory: | Nucor |

Chemical Analysis – Weight Percent

| C | Mn | P | S | Si | Cu | Cr | Ni | Mo | V | Cb | Sn | Al | B | Ti | Ca | Co | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .13 | .69 | .018 | .030 | .20 | .26 | .12 | .09 | .020 | .003 | .002 | - | - | - | - | - | - | - |

100% Melted & Manufactured in the USA. Values reflect originating Steel Mill

Tensile and Hardness Test Results

| Property | #1 psi |
|---|---|
| Tensile: | 70,550 |
| Proof/Yield: | 52,360 |
| Elongation: | 27.5 |
| ROA: | - |
| Hardness: | 149 HBN |

Comments
Test results meet mechanical requirements of specification.

All reports are the exclusive property of K-T Bolt Manufacturing Company, Inc ® Any reproduction must be in their entirety and at the permission of same.

Figure A-32. ⅝-in. Dia. 11 UNC, 10-in. Long Hex Head Bolts, Test Nos. HWTT-1 and HWTT-2

IATF 16949:2016 BUREAU VERITAS Certification

## GEM-YEAR TESTING LABORATORY
### CERTIFICATE OF INSPECTION

MANUFACTURER : GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA
Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2019/04/18

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 110161336
COMMODITY : HEX MACHINE BOLT GR-A
SIZE : 5/8-11X1-1/2 NC
LOT NO : 1B1450923
SHIP QUANTITY : 2,400 PCS
LOT QUANTITY 14,959 PCS
HEADMARKS : CYI & 307A

PACKING NO : GEM140901009
INVOICE NO : GEM/FNL-140917WI-2
PART NO : 1191919
SAMPLING PLAN : ASME B18.18-2017(Catcgory.2)/ASTM F1470-2018
HEAT NO : 14300105-3
MATERIAL : X1008A
FINISH : HOT DIP GALVANIZED PER ASTM A153-2009/ASTM F2329-2013

MANUFACTURE DATE : 2014/08/11
COUNTRY OF ORIGIN : CHINA

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A307-2014

| Chemistry | AL% | C% | MN% | P% | S% | SI% |
|---|---|---|---|---|---|---|
| Spec. : MIN. | | | | | | |
| MAX. | | 0.3300 | 1.2500 | 0.0410 | | |
| Test Value | 0.0340 | 0.1000 | 0.3400 | 0.0120 | 0.0090 | 0.0300 |

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.1-2012

SAMPLED BY : TAO JIA MIN

| INSPECTIONS ITEM | SAMPLE | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|
| MAJOR DIAMETER | 4 PCS | 0.6130-0.6250 inch | 0.6190-0.6210 inch | 4 | 0 |
| WIDTH ACROSS CORNERS | 4 PCS | 1.0330-1.0830 inch | 1.0540-1.0610 inch | 4 | 0 |
| HEIGHT | 4 PCS | 0.3780-0.4440 inch | 0.3940-0.3980 inch | 4 | 0 |
| NOMINAL LENGTH | 15 PCS | 1.4200-1.5600 inch | 1.4610-1.4680 inch | 15 | 0 |
| WIDTH ACROSS FLATS | 4 PCS | 0.9060-0.9380 inch | 0.9260-0.9290 inch | 4 | 0 |
| SURFACE DISCONTINUITIES | 29 PCS | ASTM F788-2013 | PASSED | 29 | 0 |
| THREAD | 4 PCS | ASME B1.1-2003 nut | PASSED | 4 | 0 |

MECHANICAL PROPERTIES : ACCORDING TO ASTM A 307-2014

SAMPLED BY : GDAN LIAN

| INSPECTIONS ITEM | SAMPLE | TEST METHOD | REF | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|---|
| CORE HARDNESS | 13 PCS | ASTM F606-2016 | | 69-100 HRB | 82-84 HRB | 13 | 0 |
| TENSILE STRENGTH | 3 PCS | ASTM F606-2016 | | Min. 60 KSI | 76-78 KSI | 3 | 0 |
| PLATING THICKNESS( μm) | 5 PCS | ASTM B568-1998 | | >=53 | 62.76-69.38 | 5 | 0 |

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER
WE CERTIFY THAT ALL PRODUCTS WE SUPPLIED ARE IN COMPLIANCE WITH DIN EN 10204 3.1 CONTENT

Quality Supervisor:

page 1 of 1

Figure A-33. ⅝-in. Dia. 11 UNC, 1½-in. Long Hex Head Bolts, Test Nos. HWTT-1 and HWTT-2

Portland Bolt
& MANUFACTURING COMPANY

Phone: 800-547-6758 | Fax: 503-227-4634
3441 NW Guam Street, Portland, OR 97210
Web: www.portlandbolt.com | Email: sales@portlandbolt.com

**CERTIFICATE OF CONFORMANCE**

**For:** MIDWEST ROADSIDE SAFETY FACIL
**PB Invoice#:** 119382
**Cust PO#:** CHAT
**Date:** 4/08/2019
**Shipped:** 4/09/2019

**We certify that the following items were manufactured and tested in accordance with the chemical, mechanical, dimensional and thread fit requirements of the specifications referenced.**

---

**Description:** 7/8 X 16 GALV ASTM F3125 GRADE A325 HEAVY HEX BOLT

**Heat#:** 75071284 **Base Steel:** 4140 **Diam:** 7/8

**Source:** KREHER STEEL CO LLC **Proof Load:** 39,250 LBF

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **C :** | .400 | **Mn:** | .880 | **P :** | .010 | **Hardness:** | 269 HBN |
| **S :** | .018 | **Si:** | .240 | **Ni:** | .140 | **Tensile:** | 59,480 LBF |
| **Cr:** | 1.010 | **Mo:** | .170 | **Cu:** | .210 | **Yield:** | 0 |
| **Pb:** | .000 | **V :** | .003 | **Cb:** | .000 | **Sample Length:** | 0 |
| **N :** | .000 | | | **CE:** | .6562 | **Charpy:** | |

**RA:** .00%
**Elon:** .00%
**CVN Temp:**

---

LOT#18895

---

**Nuts:**
ASTM A563DH HVY HX

**Coatings:**
ITEMS HOT DIP GALVANIZED PER ASTM F2329/A153C

**Other:**
ALL ITEMS MELTED & MANUFACTURED IN THE USA

---

By: _____
Certification Department Quality Assurance
Dane McKinnon

Figure A-34. ⅞-in. Dia. 9 UNC, 16-in. Long Heavy Hex Head Bolts, Test Nos. HWTT-1 and HWTT-2

Apr. 12. 2018 4:32PM Fastenal-NELIN No. 4682 P. 3

FASTENAL®

## Certificate of Compliance

**Sold To:**

UNL TRANSPORTATION

**Purchase Order:**

**Job:** TL-2 and Bullnose

**Invoice Date:** 03/27/2018

THIS IS TO CERTIFY THAT WE HAVE SUPPLIED YOU WITH THE FOLLOWING PARTS.
THESE PARTS WERE PURCHASED TO THE FOLLOWING SPECIFICATIONS.

5 PCS 7/8"-9 x 8" ASTM A307 Grade A Hot Dipped Galvanized Hex Bolt SUPPLIED UNDER OUR TRACE NUMBER line35042 AND UNDER PART NUMBER 92005

20 PCS 7/8"-9 Hot Dip Galvanized Finish Grade A Finished Hex Nut SUPPLIED UNDER OUR TRACE NUMBER 110254885 AND UNDER PART NUMBER 36717

5 PCS 7/8"-9 x 8" ASTM A307 Grade A Hot Dipped Galvanized Hex Bolt SUPPLIED UNDER OUR TRACE NUMBER line35042 AND UNDER PART NUMBER 92005

5 PCS 7/8"-9 x 8" ASTM A307 Grade A Hot Dipped Galvanized Hex Bolt SUPPLIED UNDER OUR TRACE NUMBER line35042 AND UNDER PART NUMBER 92005

5 PCS 7/8"-9 x 8" ASTM A307 Grade A Hot Dipped Galvanized Hex Bolt SUPPLIED UNDER OUR TRACE NUMBER line35042 AND UNDER PART NUMBER 92005

This is to certify that the above document is true and accurate to the best of my knowledge.

**Fastenal Account Representative Signature**

Jeremiah Moorhead
**Printed Name**

4/12/18
**Date**

Please check current revision to avoid using obsolete copies.

This document was printed on 04/12/2018 and was current at that time.

**Fastenal Store Location/Address**

*3201 N. 23rd Street STE 1*
*LINCOLN, NE 68521*
*Phone #: (402)476-7900*
*Fax #: 402/476-7958*

Page 1 of 1

Figure A-35. ⅞-in. Dia. 9 UNC, 8-in. Long Hex Head Bolts, Test Nos. HWTT-1 and HWTT-2

3400b

**CERTIFICATE OF COMPLIANCE**

**ROCKFORD BOLT & STEEL CO.**
**126 MILL STREET**
**ROCKFORD, IL 61101**
**815-968-0514 FAX# 815-968-3111**

**CUSTOMER NAME:** TRINITY INDUSTRIES

**CUSTOMER PO:** 182402

**SHIPPER #:** 059943
**DATE SHIPPED:** 03/07/2017

**LOT#:** 29221

**SPECIFICATION:** ASTM A307, GRADE A MILD CARBON STEEL BOLTS

| | | | | |
|---|---|---|---|---|
| **TENSILE:** | SPEC: | 60,000 psi*min | RESULTS: | 68,460<br>66,327 |
| **HARDNESS:** | | 100 max | | 71.30<br>71.60 |

*Pounds Per Square Inch.

**COATING:** ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
**ROGERS GALVANIZE:** 29221

**CHEMICAL COMPOSITION**

| MILL | GRADE | HEAT# | C | Mn | P | S | Si |
|---|---|---|---|---|---|---|---|
| CHARTER | 1010 | 10439100 | .09 | .40 | .008 | .011 | .090 |

**QUANTITY AND DESCRIPTION:**

10,400 **PCS 5/8" X 2" GUARD RAIL BOLT**
**P/N 3400G**

**WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY THAT** THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENT PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
7th DAY OF March, 20 17

Merry F. Shane

Linda McComas — APPROVED SIGNATORY
3/7/17 — DATE

OFFICIAL SEAL
**MERRY F. SHANE**
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Figure A-36. ⅝-in. Dia. 11 UNC, 2-in. Long Guardrail Bolts, Test Nos. HWTT-1 and HWTT-2

DECKER
SINCE 1927 www.deckernut.com

DECKER MANUFACTURING CORPORATION
703 N. Clark Street
Albion, Michigan 49224
P: 517.629.9555 • F: 517.629.5535

Printed: 7/28/2017 10:29:02 AM
July 28, 2017

TRINITY HWY PRODUCTS LLC 55
550 E ROBBAVENUE
LIMA, OH 45801

PRODUCT MATERIAL CERTIFICATION

| | | | |
|---|---|---|---|
| CUSTOMER PART NUMBER : | 003340G | INVOICE: | 137831 |
| CUSTOMER P.O. NUMBER : | 184358 B1 | | |

| | | | |
|---|---|---|---|
| LOT NUMBER: | 17-35-017 | DESCRIPTION: | 5/8 GRD RAIL NUT .031 |
| DATE: | Jan 17, 2017 | QUANTITY: | 72,000 |
| HEAT NUMBER: | 10470360 | MATERIAL SUPPLIER: | CHARTER STEEL |
| MATERIAL: | STEEL - C1010 | | |

We certify the product above was manufactured at DECKER MANUFACTURING CORPORATION from the specified raw material and that said product is certified to be manufactured, randomly sampled, tested and/or inspected and conforms to applicable specifications. We additionally certify that said raw material was domestically manufactured in the United States of America and that said raw material was manufactured free of mercury contamination.

The items were processed under the Decker Quality Manual. The current revision is dated January 12, 2005
No welding was performed.

This document accurately represents values and statements provided by our suppliers accredited testing facility. The original metallurgical test report shall be retained on file by DECKER MANUFACTURING CORPORATION for a period of not less than (10) years.

CHEMICAL ANALYSIS BY MATERIAL SUPPLIER

| | | | |
|---|---|---|---|
| CARBON : | 0.090 | PHOSPHOROUS : | 0.006 |
| MANGANESE : | 0.440 | SULFUR : | 0.009 |

DECKER MANUFACTURING CORPORATION

Russel L. Wilson
Quality Assurance Manager

The above results pertain only to the items tested. This report shall not be reproduced except in full without the approval of this testing facility.

Figure A-37. ⅝-in. Dia. 11 UNC, Heavy Hex Nuts, Test Nos. HWTT-1 and HWTT-2

ISO/TS 16949 BUREAU VERITAS Certification

## GEM-YEAR TESTING LABORATORY
### CERTIFICATE OF INSPECTION

MANUFACTURER : GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA
Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2018/03/28

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 110254885
COMMODITY : FINISHED HEX NUT GR-A
SIZE : 7/8-9 NC O/T 0.56MM
LOT NO : 1N1810005
SHIP QUANTITY : 9,000 PCS
LOT QUANTITY 55,748 PCS
HEADMARKS :

PACKING NO : GEM180115010
INVOICE NO : GEM/FNL-180201WI-1
PART NO : 36717
SAMPLING PLAN : ASME B18.18-2011(Category.2)/ASTM F1470-2012
HEAT NO : 331704677
MATERIAL : XGML08
FINISH : HOT DIP GALVANIZED PER ASTM A153-2009/ASTM F2329-2013

MANUFACTURE DATE : 2018/01/05
COUNTRY OF ORIGIN : CHINA

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A563-2015

| Chemistry | AL% | C% | MN% | P% | S% | SI% |
|---|---|---|---|---|---|---|
| Spec. : MIN. | | | | | | |
| MAX. | | 0.5800 | | 0.1300 | 0.2300 | |
| Test Value | 0.0360 | 0.0600 | 0.4500 | 0.0140 | 0.0030 | 0.0300 |

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.2-2015

SAMPLED BY : WDANDAN

| INSPECTIONS ITEM | SAMPLE | SPECIFIED | | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|
| WIDTH ACROSS CORNERS | 5 PCS | | 1.4470-1.5160 inch | 1.4850-1.4930 inch | 5 | 0 |
| FIM | 15 PCS | ASME B18.2.2-2015 | Max. 0.0250 inch | 0.0110-0.0200 inch | 15 | 0 |
| THICKNESS | 5 PCS | | 0.7240-0.7760 inch | 0.7460-0.7570 inch | 5 | 0 |
| WIDTH ACROSS FLATS | 5 PCS | | 1.2690-1.3120 inch | 1.2930-1.2980 inch | 5 | 0 |
| SURFACE DISCONTINUITIES | 29 PCS | | ASTM F812-2012 | PASSED | 29 | 0 |
| THREAD | 15 PCS | | GAGING SYSTEM 21 | PASSED | 15 | 0 |

MECHANICAL PROPERTIES : ACCORDING TO ASTM A563-2015

SAMPLED BY : TANGHAO

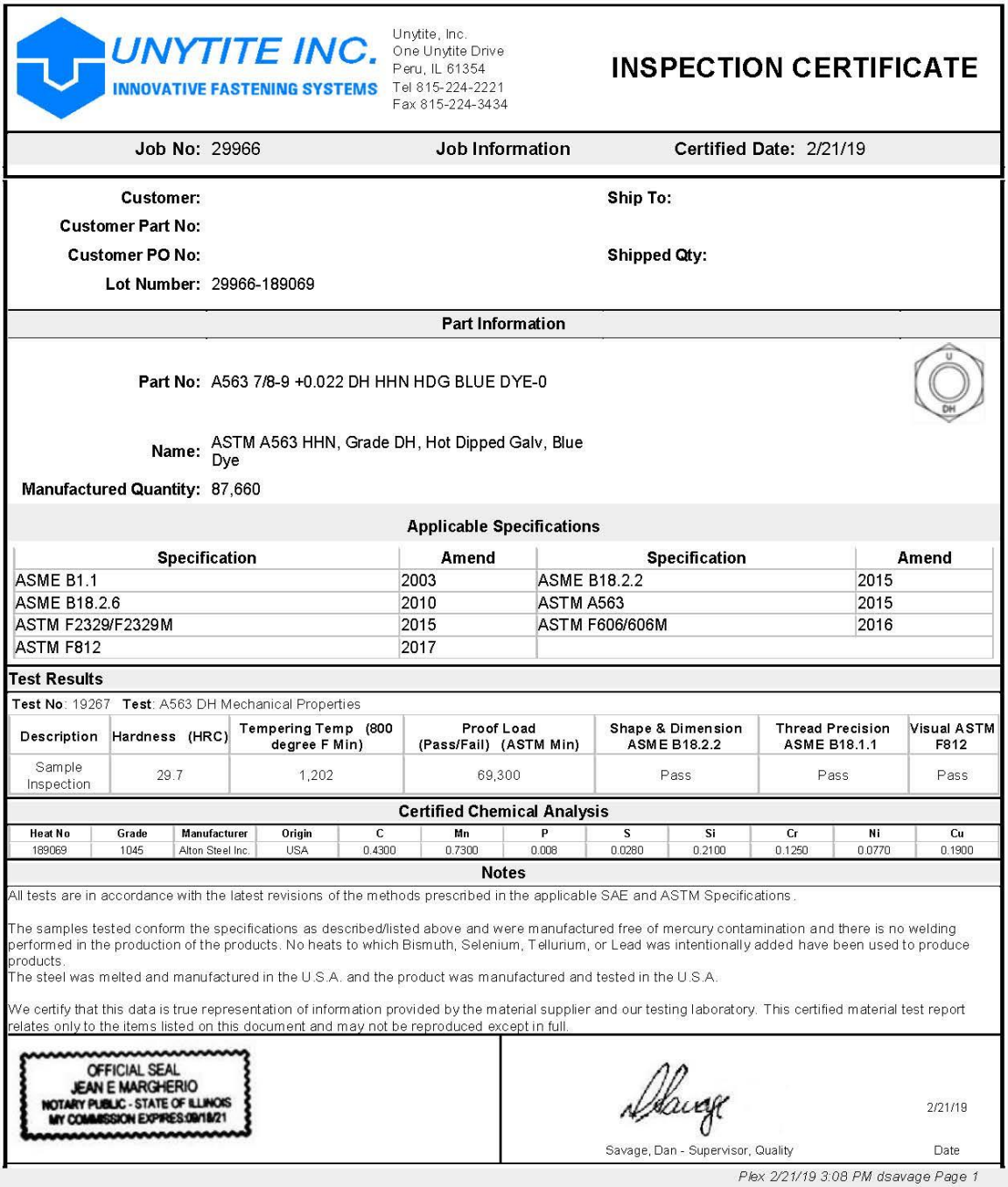
| INSPECTIONS ITEM | SAMPLE | TEST METHOD | REF | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|---|
| CORE HARDNESS | 15 PCS | ASTM F606-2014 | | 68-107 HRB | 86-90 HRB | 15 | 0 |
| PROOF LOAD | 5 PCS | ASTM F606-2014 | | Min. 31,416 LBF | OK | 5 | 0 |
| PLATING THICKNESS( μm) | 29 PCS | ASTM B568-1998 | | >=53 | 62.38-62.57 | 29 | 0 |

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER

Quality Supervisor:

page 1 of 1

Figure A-38. ⅞-in. Dia. 9 UNC, Hex Nuts, Test Nos. HWTT-1 and HWTT-2



UNYTITE INC.
INNOVATIVE FASTENING SYSTEMS

Unytite, Inc.
One Unytite Drive
Peru, IL 61354
Tel 815-224-2221
Fax 815-224-3434

**INSPECTION CERTIFICATE**

**Job No:** 29966 **Job Information** **Certified Date:** 2/21/19

**Customer:**
**Customer Part No:**
**Customer PO No:**
**Lot Number:** 29966-189069

**Ship To:**
**Shipped Qty:**

**Part Information**

**Part No:** A563 7/8-9 +0.022 DH HHN HDG BLUE DYE-0

**Name:** ASTM A563 HHN, Grade DH, Hot Dipped Galv, Blue Dye

**Manufactured Quantity:** 87,660

**Applicable Specifications**

| Specification | Amend | Specification | Amend |
|---|---|---|---|
| ASME B1.1 | 2003 | ASME B18.2.2 | 2015 |
| ASME B18.2.6 | 2010 | ASTM A563 | 2015 |
| ASTM F2329/F2329M | 2015 | ASTM F606/606M | 2016 |
| ASTM F812 | 2017 | | |

**Test Results**

**Test No**: 19267 **Test**: A563 DH Mechanical Properties

| Description | Hardness (HRC) | Tempering Temp (800 degree F Min) | Proof Load (Pass/Fail) (ASTM Min) | Shape & Dimension ASME B18.2.2 | Thread Precision ASME B18.1.1 | Visual ASTM F812 |
|---|---|---|---|---|---|---|
| Sample Inspection | 29.7 | 1,202 | 69,300 | Pass | Pass | Pass |

**Certified Chemical Analysis**

| Heat No | Grade | Manufacturer | Origin | C | Mn | P | S | Si | Cr | Ni | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 189069 | 1045 | Alton Steel Inc. | USA | 0.4300 | 0.7300 | 0.008 | 0.0280 | 0.2100 | 0.1250 | 0.0770 | 0.1900 |

**Notes**

All tests are in accordance with the latest revisions of the methods prescribed in the applicable SAE and ASTM Specifications.

The samples tested conform the specifications as described/listed above and were manufactured free of mercury contamination and there is no welding performed in the production of the products. No heats to which Bismuth, Selenium, Tellurium, or Lead was intentionally added have been used to produce products.
The steel was melted and manufactured in the U.S.A. and the product was manufactured and tested in the U.S.A.

We certify that this data is 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.

OFFICIAL SEAL
JEAN E MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:09/18/21

Savage, Dan - Supervisor, Quality — 2/21/19 Date

*Plex 2/21/19 3:08 PM dsavage Page 1*

Figure A-39. ⅞-in. Dia. 9 UNC, Heavy Hex Nuts, Test Nos. HWTT-1 and HWTT-2

Apr. 17. 2019 2:15PM Fastenal-NELIN No. 6648 P. 2

FASTENAL®

## Certificate of Compliance

**Sold To:**

UNL TRANSPORTATION/Midwest Roadside Safe

**Purchase Order:** 70acct BCTAnchorCableHardware

**Job:**

**Invoice Date:** 10/19/2018

THIS IS TO CERTIFY THAT WE HAVE SUPPLIED YOU WITH THE FOLLOWING PARTS.
THESE PARTS WERE PURCHASED TO THE FOLLOWING SPECIFICATIONS.

200 PCS 1" x 2.500" OD Low Carbon Hot Dipped Galvanized Finish Steel USS General Purpose Flat Washer SUPPLIED UNDER OUR TRACE NUMBER 210151571 AND UNDER PART NUMBER 33188

200 PCS 1"-8 Hot Dipped Galvanized A563 Grade DH Heavy Hex Nut Made In USA SUPPLIED UNDER OUR TRACE NUMBER 210157128 AND UNDER PART NUMBER 38210

This is to certify that the above document is true and accurate to the best of my knowledge.

**Fastenal Account Representative Signature**

Abigail Ferguson

**Printed Name**

4/17/2019

**Date**

Please check current revision to avoid using obsolete copies.

This document was printed on 04/17/2019 and was current at that time.

**Fastenal Store Location/Address**

*3201 N. 23rd Street STE 1*
*LINCOLN, NE 68521*
*Phone #: (402)476-7900*
*Fax #: 402/476-7958*

Page 1 of 1

Figure A-40. 1-in. Dia. 8 UNC, Heavy Hex Nuts, Test Nos. HWTT-1 and HWTT-2

ISO/TS 16949 BUREAU VERITAS Certification

## GEM-YEAR TESTING LABORATORY
### CERTIFICATE OF INSPECTION

MANUFACTURER : GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA
Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2017/03/23

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 110216407
COMMODITY : FINISHED HEX NUT GR-A
SIZE : 5/8-11 NC O/T 0.51MM
LOT NO : 1N1680027
SHIP QUANTITY : 23,400 PCS
LOT QUANTITY 170,278 PCS
HEADMARKS :

PACKING NO : GEM160919007
INVOICE NO : GEM/FNL-160929WI
PART NO : 36713
SAMPLING PLAN : ASME B18.18-2011(Category.2)/ASTM F1470-2012
HEAT NO : 331608011
MATERIAL : ML08
FINISH : HOT DIP GALVANIZED PER ASTM A153-2009/ASTM F2329-2013

MANUFACTURE DATE : 2016/08/26
COUNTRY OF ORIGIN : CHINA

R#17-507 H#331608011
BCT Cable Bracket Nuts

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A563-2007

| Chemistry | AL% | C% | MN% | P% | S% | SI% |
|---|---|---|---|---|---|---|
| Spec. : MIN. | | | | | | |
| MAX. | | 0.5800 | | 0.1300 | 0.2300 | |
| Test Value | 0.0350 | 0.0700 | 0.4100 | 0.0160 | 0.0060 | 0.0500 |

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.2-2010

SAMPLED BY : DWTING

| INSPECTIONS ITEM | SAMPLE | SPECIFIED | | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|
| WIDTH ACROSS CORNERS | 6 PCS | | 1.0510-1.0830 inch | 1.0560-1.0690 inch | 6 | 0 |
| FIM | 15 PCS | ASME B18.2.2-2010 | Max. 0.0210 inch | 0.0020-0.0040 inch | 15 | 0 |
| THICKNESS | 6 PCS | | 0.5350-0.5590 inch | 0.5390-0.5570 inch | 6 | 0 |
| WIDTH ACROSS FLATS | 6 PCS | | 0.9220-0.9380 inch | 0.9240-0.9340 inch | 6 | 0 |
| SURFACE DISCONTINUITIES | 29 PCS | | ASTM F812-2012 | PASSED | 29 | 0 |
| THREAD | 15 PCS | | GAGING SYSTEM 21 | PASSED | 15 | 0 |

MECHANICAL PROPERTIES : ACCORDING TO ASTM A563-2007

SAMPLED BY : GDAN LIAN

| INSPECTIONS ITEM | SAMPLE | TEST METHOD | REF | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|---|
| CORE HARDNESS | 15 PCS | ASTM F606-2014 | | 68-107 HRB | 79-81 HRB | 15 | 0 |
| PROOF LOAD | 4 PCS | ASTM F606-2014 | | Min. 90 KSI | OK | 4 | 0 |
| PLATING THICKNESS( μm) | 5 PCS | ASTM B568-1998 | | >=53 | 70.02-75.81 | 5 | 0 |

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER

Quality Supervisor:

page 1 of 1

Figure A-41. ⅝-in. Dia. Hex Nuts, Test Nos. HWTT-1 and HWTT-2

## CERTIFIED MATERIAL TEST REPORT
## FOR USS FLAT WASHERS HDG

FACTORY: IFI & Morgan Ltd — REPORT DATE: 23/4/2018
ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan,Zhejiang, China

SAMPLING PLAN PER ASME B18.18-11 — PO NUMBER: 170077928
SIZE: USS 7/8 HDG — QNTY(Lot size): 3600PCS
HEADMARKS: NO MARK — PART NO: 33187

DIMENSIONAL INSPECTIONS — SPECIFICATION: ASTM B18.21.1-2011

| CHARACTERISTICS | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|
| APPEARANCE | ASTM F844 | PASSED | 100 | 0 |
| OUTSIDE DIA | 2.243-2.280 | 2.246-2.254 | 10 | 0 |
| INSIDE DIA | 0.931-0.968 | 0.956-0.965 | 10 | 0 |
| THICKNESS | 0.136-0.192 | 0.136-0.157 | 10 | 0 |

| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | | ACC. | REJ. |
|---|---|---|---|---|---|---|
| HOT DIP GALVANIZED | ASTM F2329-13 | Min 0.0017" | 0.0017-0.0020 | in | 8 | 0 |

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD.
检验专用章
QUANLITY CONTROL
(SIGNATURE OF Q.A. LAB MGR.)

Figure A-42. ⅞-in. Plain USS Washers, Test Nos. HWTT-1 and HWTT-2

## CERTIFIED MATERIAL TEST REPORT
## FOR USS FLAT WASHERS HDG

FACTORY: IFI & Morgan Ltd — REPORT DATE: 22/10/2018
ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan,Zhejiang, China

SAMPLING PLAN PER ASME B18.18-11 — PO NUMBER: 210151571
SIZE: USS 1 HDG — QNTY(Lot size): 3240PCS
HEADMARKS: NO MARK — PART NO: 33188

DIMENSIONAL INSPECTIONS — SPECIFICATION: ASTM B18.21.1-2011

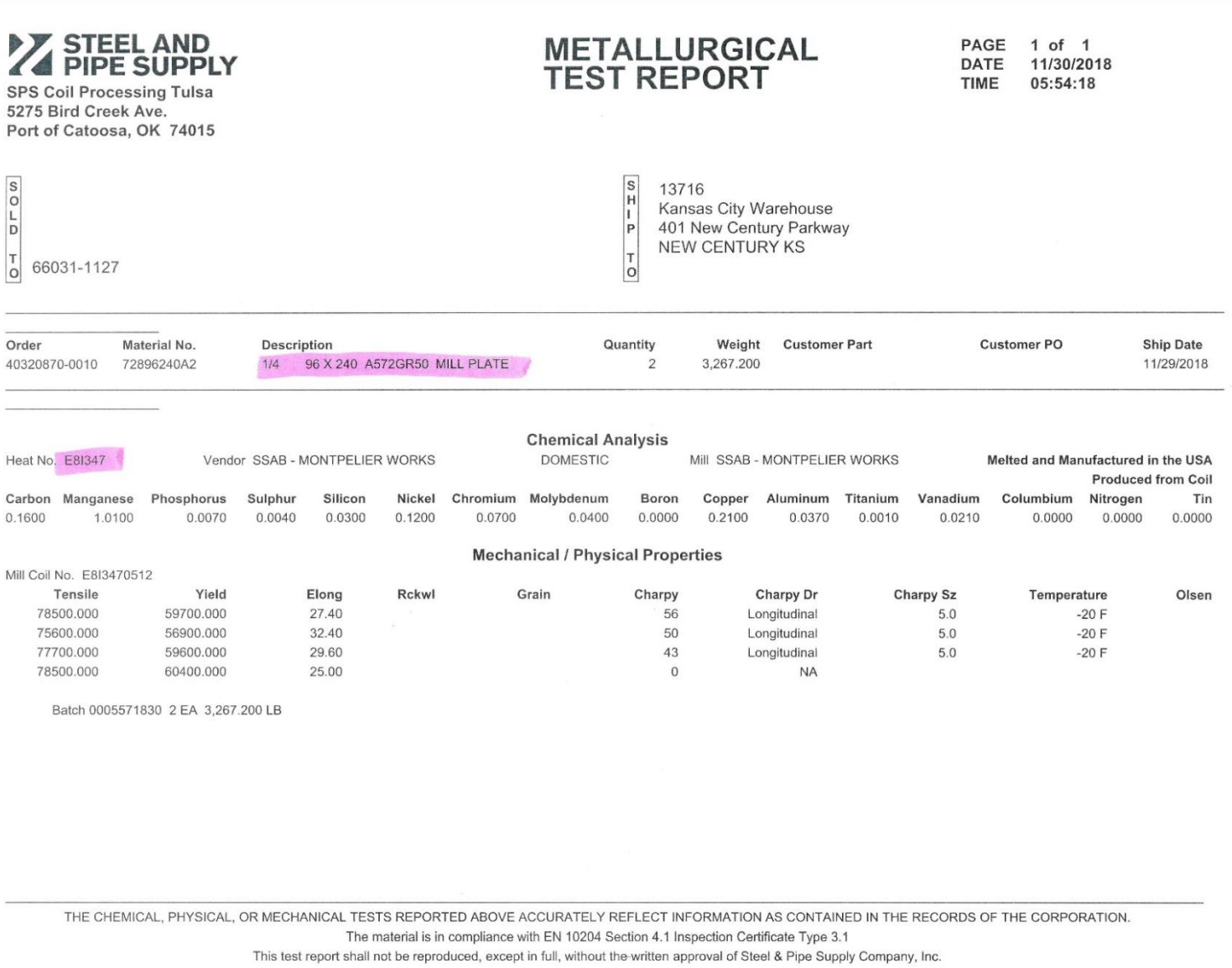
| CHARACTERISTICS | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|
| APPEARANCE | ASTM F844 | PASSED | 100 | 0 |
| OUTSIDE DIA | 2.492-2.529 | 2.496-2.504 | 10 | 0 |
| INSIDE DIA | 1.055-1.092 | 1.080-1.089 | 10 | 0 |
| THICKNESS | 0.135-0.192 | 0.135-0.157 | 10 | 0 |

| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | | ACC. | REJ. |
|---|---|---|---|---|---|---|
| HOT DIP GALVANIZED | ASTM F2329-13 | Min 0.0017" | 0.0017-0.0020 | in | 8 | 0 |

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD.
检验专用章
QUANLITY CONTROL
(SIGNATURE OF Q.A. LAB MGR.)

Figure A-43. 1-in. Plain USS Washers, Test Nos. HWTT-1 and HWTT-2



STEEL AND PIPE SUPPLY

SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

# METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 11/30/2018
TIME 05:54:18

SOLD TO 66031-1127

SHIP TO 13716
Kansas City Warehouse
401 New Century Parkway
NEW CENTURY KS

| Order | Material No. | Description | Quantity | Weight | Customer Part | Customer PO | Ship Date |
|---|---|---|---|---|---|---|---|
| 40320870-0010 | 72896240A2 | 1/4 96 X 240 A572GR50 MILL PLATE | 2 | 3,267.200 | | | 11/29/2018 |

## Chemical Analysis

Heat No. E8I347 Vendor SSAB - MONTPELIER WORKS DOMESTIC Mill SSAB - MONTPELIER WORKS Melted and Manufactured in the USA Produced from Coil

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1600 | 1.0100 | 0.0070 | 0.0040 | 0.0300 | 0.1200 | 0.0700 | 0.0400 | 0.0000 | 0.2100 | 0.0370 | 0.0010 | 0.0210 | 0.0000 | 0.0000 | 0.0000 |

## Mechanical / Physical Properties

Mill Coil No. E8I3470512

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 78500.000 | 59700.000 | 27.40 | | | 56 | Longitudinal | 5.0 | -20 F | |
| 75600.000 | 56900.000 | 32.40 | | | 50 | Longitudinal | 5.0 | -20 F | |
| 77700.000 | 59600.000 | 29.60 | | | 43 | Longitudinal | 5.0 | -20 F | |
| 78500.000 | 60400.000 | 25.00 | | | 0 | NA | | | |

Batch 0005571830 2 EA 3,267.200 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1
This test report shall not be reproduced, except in full, without the written approval of Steel & Pipe Supply Company, Inc.

Figure A-44. 3-in. x 3-in. x ¼-in. Square Washer Plate, Test Nos. HWTT-1 and HWTT-2

P.O. Box 21148
Tulsa, OK 74121
P: 800-879-8000
F: 800-879-7000

Date: 5/15/2019

Customer: UNIVERSITY OF NEBRASKA-LINCOLN

Customer PO: H42BR

**Subject: Certificate of Conformance - HIT RE-500 V3 Adhesive**

Quantity: 20 PCS / 2123404 / Injectable mortar HIT-RE 500 V3/500/1

To Whom it May Concern:

This is to certify that the HIT-RE 500 V3 provided on the above referenced order is a high-strength, slow cure two-part epoxy adhesive contained in two cartridges separating the resin from the hardener.

Additionally, this certifies that the product has been seismically and cracked concrete qualified as represented in ICC-ES report ESR- 3814.

Sincerely,

B. Mitchell

B. Mitchell, Certification Specialist

HILTI, Inc.
cocRE500 V3

Figure A-45. Hilti HIT RE-500 V3 Epoxy Adhesive, Test Nos. HWTT-1 and HWTT-2

# Appendix B. Vehicle Center of Gravity Determination

| Date: | 7/1/2019 | Test Name: | HWTT-1 | VIN: | KMHCN4AC8BU608788 |
|---|---|---|---|---|---|
| Year: | 2010 | Make: | Hyundai | Model: | Accent |

**Vehicle CG Determination**

| | Vehicle Equipment | Weight (lb) |
|---|---|---|
| + | Unballasted Car (Curb) | 2475 |
| + | Hub | 19 |
| + | Brake activation cylinder & frame | 7 |
| + | Pneumatic tank (Nitrogen) | 30 |
| + | Strobe/Brake Battery | 5 |
| + | Brake Receiver/Wires | 6 |
| + | CG Plate including DAQ | 13 |
| - | Battery | -33 |
| - | Oil | -12 |
| - | Interior | -65 |
| - | Fuel | -18 |
| - | Coolant | -5 |
| - | Washer fluid | 0 |
| + | Water Ballast (In Fuel Tank) | 0 |
| + | Onboard Supplemental Battery | 0 |
| | | |
| | | |

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

Estimated Total Weight (lb): 2422

**Vehicle Dimensions for C.G. Calculations**

| | | | | | |
|---|---|---|---|---|---|
| Wheel Base: | 98.75 | in. | Front Track Width: | 58.0 | in. |
| Roof Height: | 57.75 | in. | Rear Track Width: | 57.75 | in. |

| Center of Gravity | 1100C MASH Targets | Test Inertial | Difference |
|---|---|---|---|
| Test Inertial Weight (lb) | 2420 ± 55 | 2407 | -13.0 |
| Longitudinal CG (in.) | 39 ± 4 | 36.267 | -2.733 |
| Lateral CG (in.) | NA | 0.301 | NA |
| Vertical CG (in.) | NA | 22.864 | 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 | 788 | 785 | | |
| Rear | 464 | 438 | | |
| FRONT | 1573 | | lb | |
| REAR | 902 | | lb | |
| TOTAL | 2475 | | lb | |

**TEST INERTIAL WEIGHT (lb)**

| | Left | Right | | |
|---|---|---|---|---|
| Front | 738 | 785 | | |
| Rear | 453 | 431 | | |
| FRONT | 1523 | | lb | |
| REAR | 884 | | lb | |
| TOTAL | 2407 | | lb | |

Figure B-1. Vehicle Mass Distribution, Test No. HWTT-1

| Date: | 7/19/2019 | Test Name: | HWTT-2 | VIN: | 1C6RR6FG1ES237040 |
|---|---|---|---|---|---|
| Year: | 2014 | Make: | Dodge | Model: | RAM 1500 |

**Vehicle CG Determination**

| | Vehicle Equipment | Weight (lb) | Vertical CG (in.) | Vertical M (lb-in.) |
|---|---|---|---|---|
| + | Unballasted Truck (Curb) | 4953 | 28.190339 | 139626.75 |
| + | Hub | 19 | 14.875 | 282.625 |
| + | Brake activation cylinder & frame | 8 | 27 5/8 | 221 |
| + | Pneumatic tank (Nitrogen) | 30 | 26 1/2 | 795 |
| + | Strobe/Brake Battery | 5 | 26 1/4 | 131.25 |
| + | Brake Receiver/Wires | 6 | 52 | 312 |
| + | CG Plate including DAQ | 30 | 31 1/8 | 933.75 |
| - | Battery | -41 | 41 | -1681 |
| - | Oil | -10 | 12 | -120 |
| - | Interior | -84 | 30 | -2520 |
| - | Fuel | -144 | 16 1/2 | -2376 |
| - | Coolant | -12 | 34 1/4 | -411 |
| - | Washer fluid | -7 | 36 | -252 |
| + | Water Ballast (In Fuel Tank) | 229 | 20 | 4580 |
| + | Onboard Supplemental Battery | 13 | 26 1/4 | 341.25 |
| | | | | 0 |
| | | | | 0 |
| | | | | 139863.63 |

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

| | |
|---|---|
| Estimated Total Weight (lb) | 4995 |
| Vertical CG Location (in.) | 28.0007 |

**Vehicle Dimensions for C.G. Calculations**

Wheel Base: 140.625 in. Front Track Width: 68.125 in.
Rear Track Width: 68.125 in.

| Center of Gravity | 2270P MASH Targets | Test Inertial | Difference |
|---|---|---|---|
| Test Inertial Weight (lb) | 5000 ± 110 | 5000 | 0.0 |
| Longitudinal CG (in.) | 63 ± 4 | 65.334375 | 2.33437 |
| Lateral CG (in.) | NA | -0.476875 | NA |
| Vertical CG (in.) | 28 or greater | 28.00 | 0.00073 |

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.)**

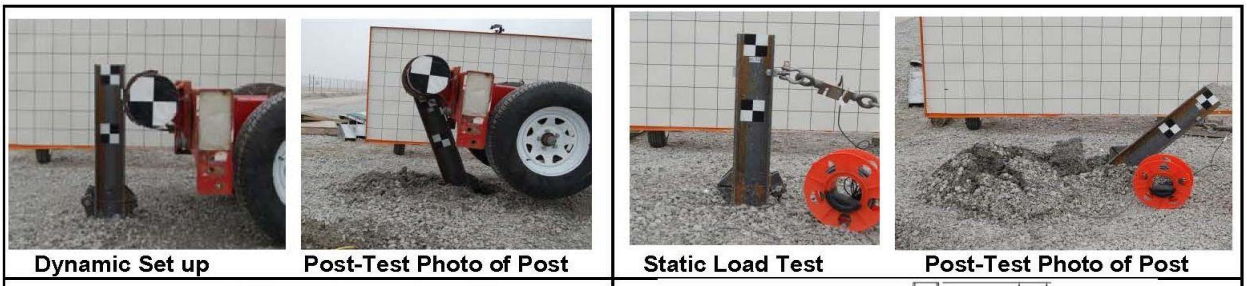
| | Left | Right | |
|---|---|---|---|
| Front | 1373 | 1334 | |
| Rear | 1140 | 1106 | |
| FRONT | 2707 | lb | |
| REAR | 2246 | lb | |
| TOTAL | 4953 | lb | |

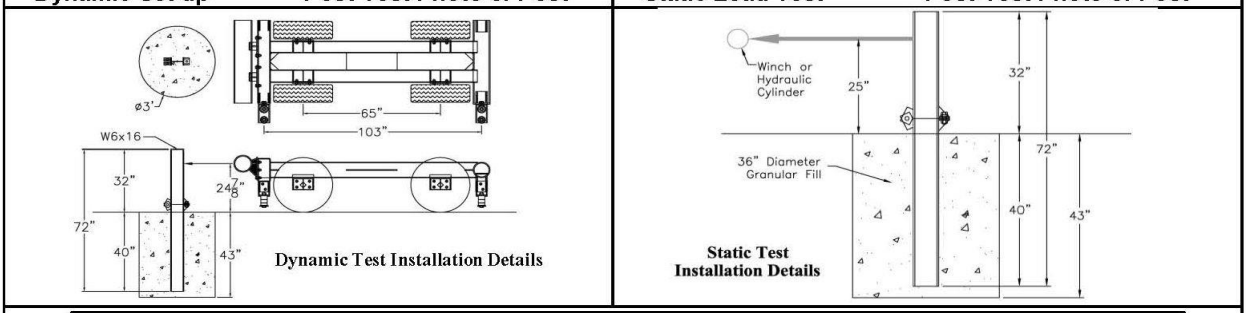
**TEST INERTIAL WEIGHT (lb.)**

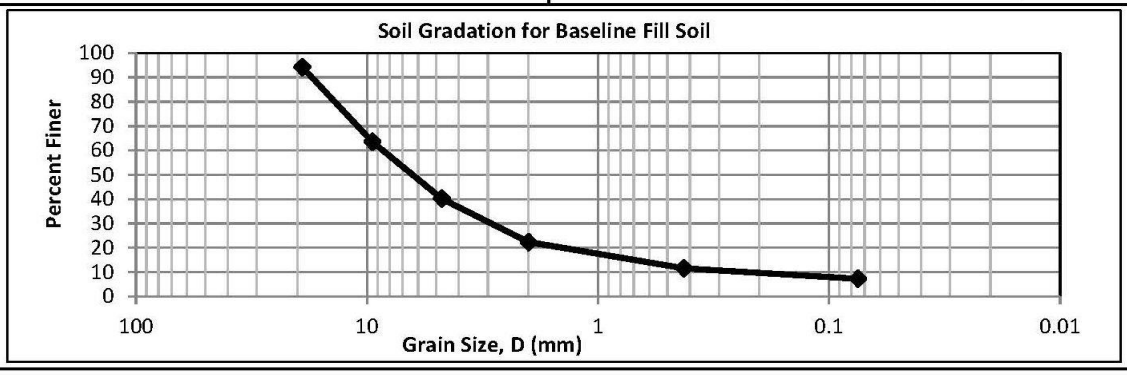
| | Left | Right | |
|---|---|---|---|
| Front | 1356 | 1321 | |
| Rear | 1179 | 1144 | |
| FRONT | 2677 | lb | |
| REAR | 2323 | lb | |
| TOTAL | 5000 | lb | |

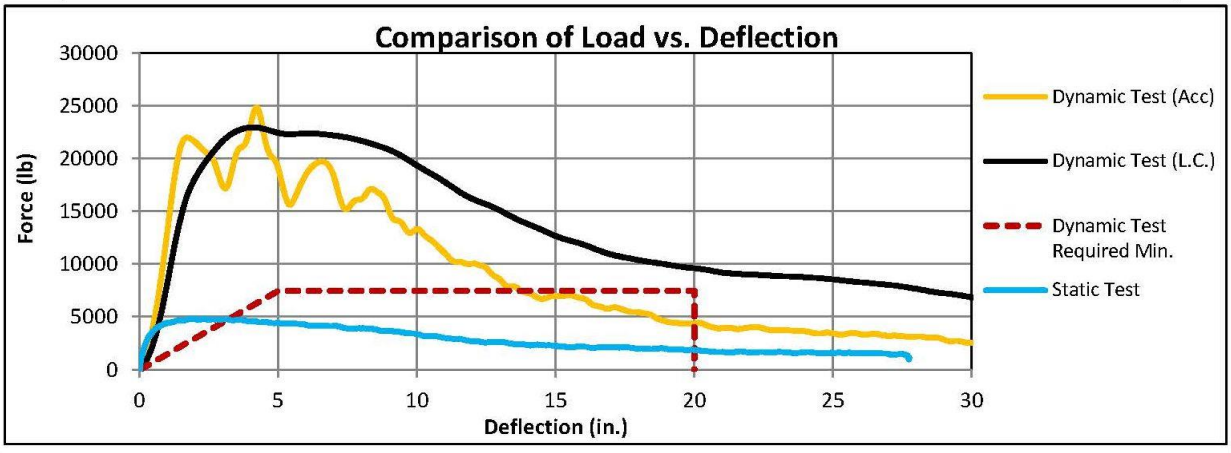
Figure B-2. Vehicle Mass Distribution, Test No. HWTT-2

# Appendix C. Static Soil Tests



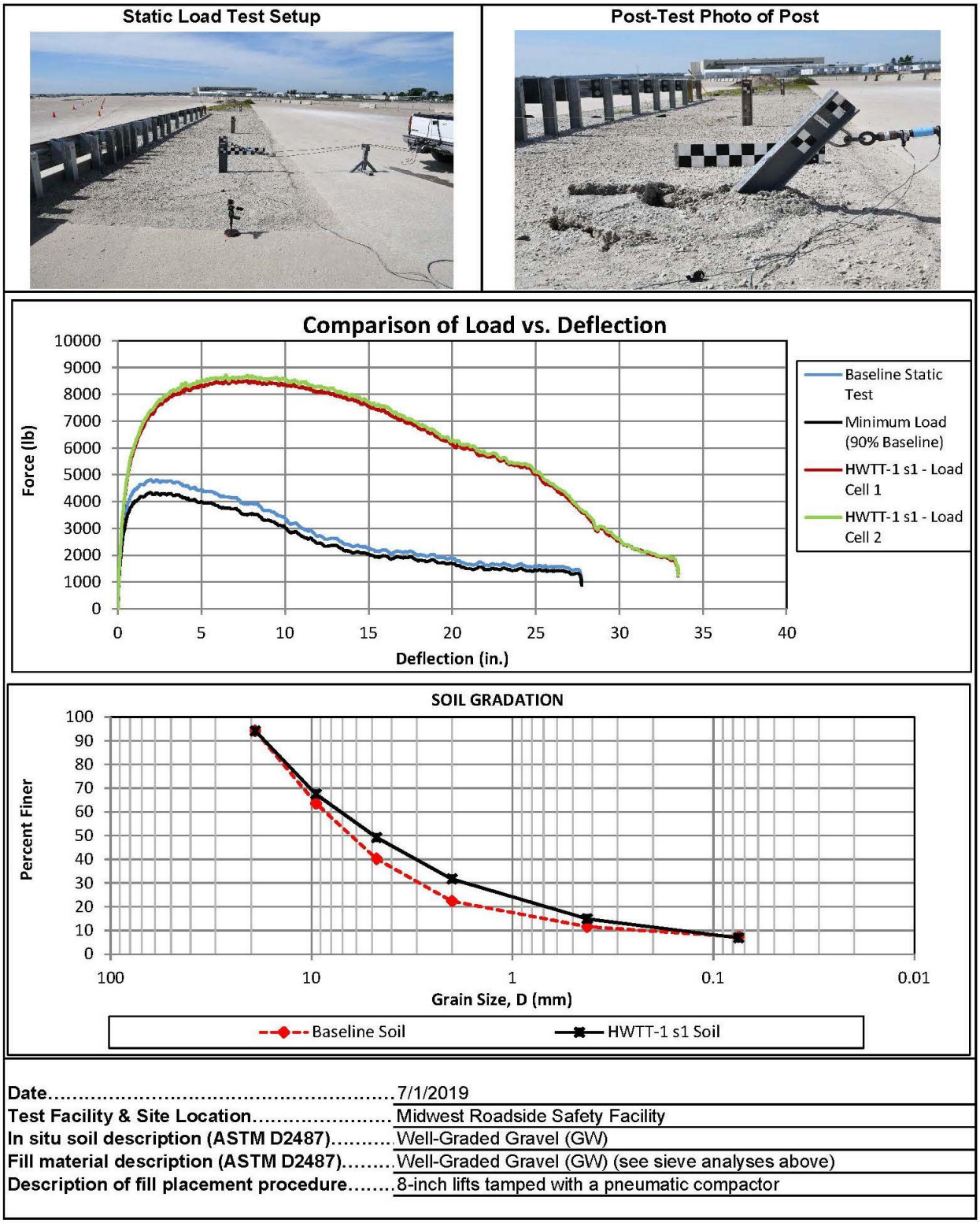



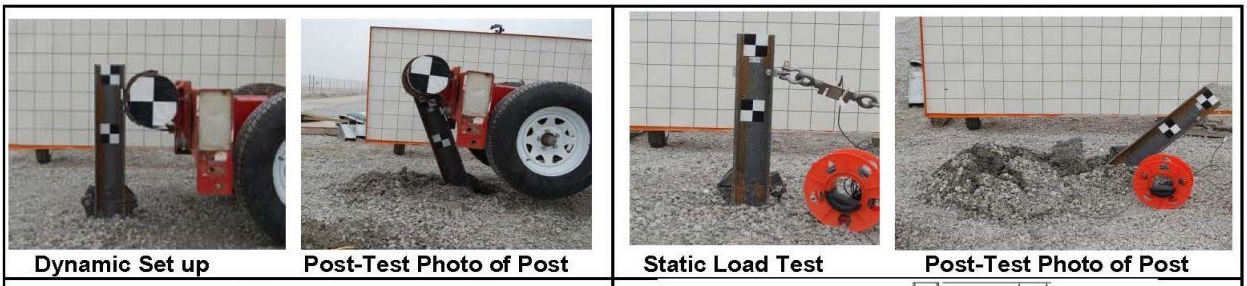

| | | | |
|---|---|---|---|
| **Date** | 2/16/2018 | | |
| **Test Facility & Site Location** | Midwest Roadside Safety Facility | | |
| **In situ soil description (ASTM D2487)** | Well-Graded Gravel (GW) | | |
| **Fill material description (ASTM D2487)** | Well-Graded Gravel (GW) (see sieve analyses above) | | |
| **Description of fill placement procedure** | H.E.-8 | | |
| **Bogie Weight** | 1786 | lb | 810 kg |
| **Impact Velocity** | 20.9 | mph | 33.7 km/h |

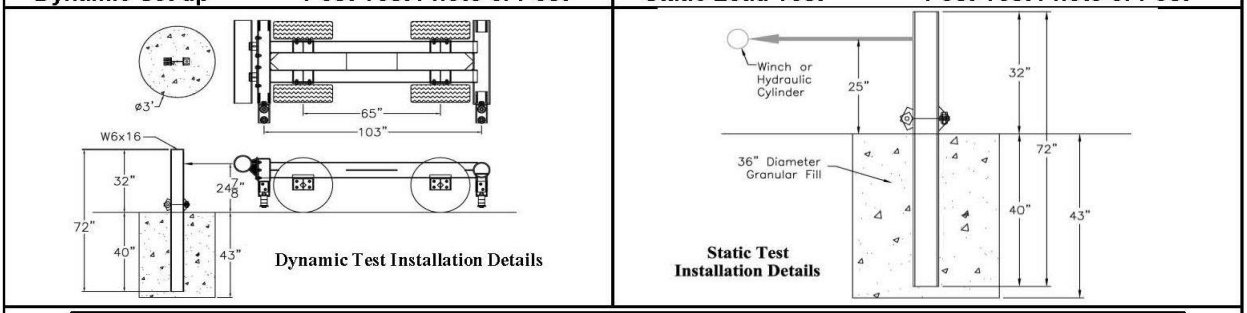
Figure C-1. Soil Strength, Initial Calibration Tests

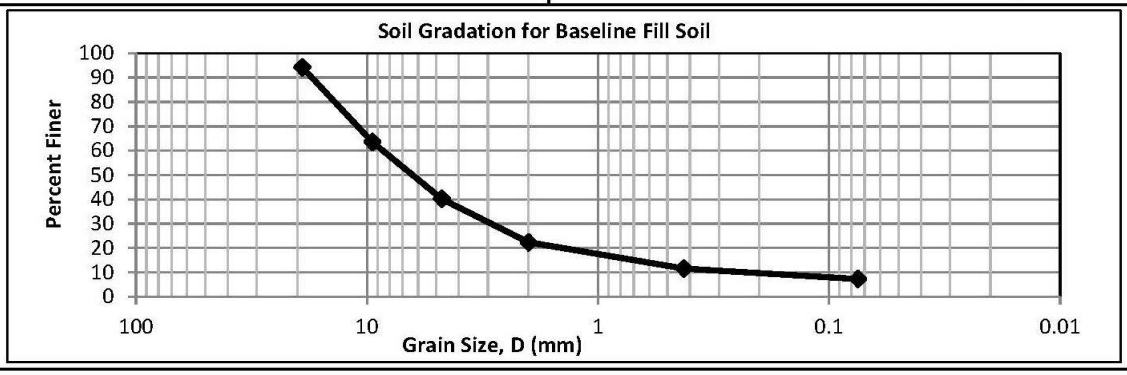


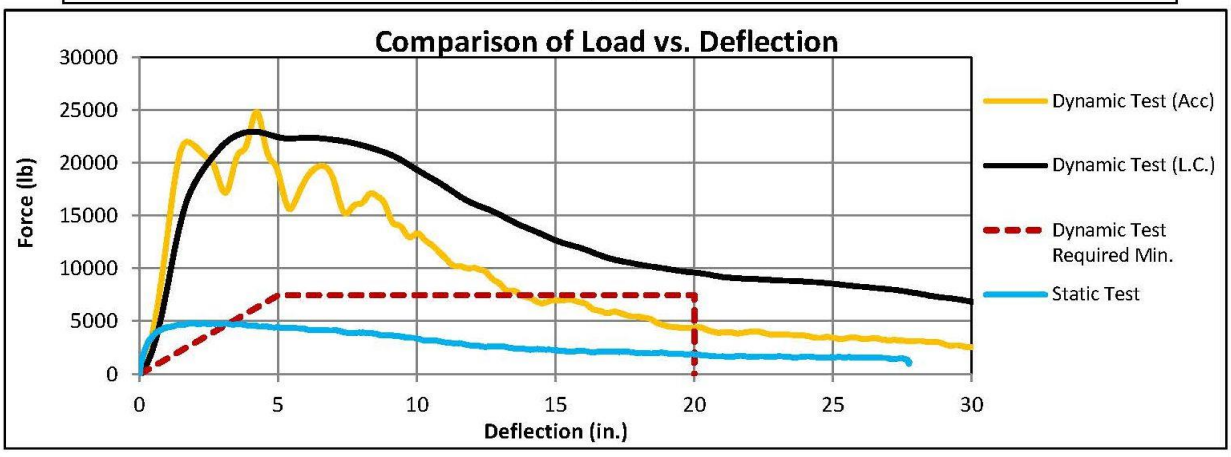

| | |
|---|---|
| **Date** | 7/1/2019 |
| **Test Facility & Site Location** | Midwest Roadside Safety Facility |
| **In situ soil description (ASTM D2487)** | Well-Graded Gravel (GW) |
| **Fill material description (ASTM D2487)** | Well-Graded Gravel (GW) (see sieve analyses above) |
| **Description of fill placement procedure** | 8-inch lifts tamped with a pneumatic compactor |

Figure C-2. Static Soil Test, Test No. HWTT-1



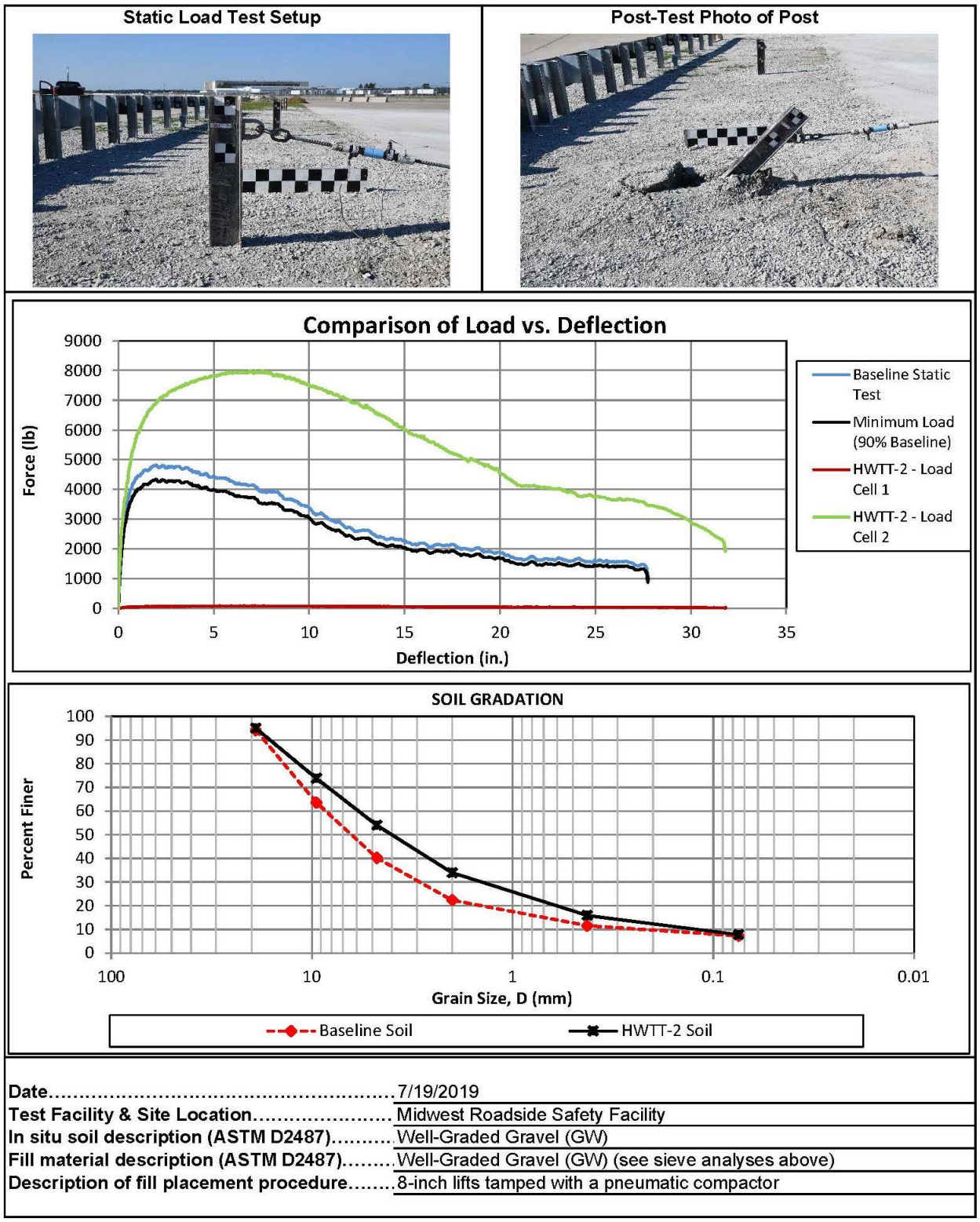




| | | | |
|---|---|---|---|
| **Date** | 2/16/2018 | | |
| **Test Facility & Site Location** | Midwest Roadside Safety Facility | | |
| **In situ soil description (ASTM D2487)** | Well-Graded Gravel (GW) | | |
| **Fill material description (ASTM D2487)** | Well-Graded Gravel (GW) (see sieve analyses above) | | |
| **Description of fill placement procedure** | H.E.-8 | | |
| **Bogie Weight** | 1786 | lb | 810 kg |
| **Impact Velocity** | 20.9 | mph | 33.7 km/h |

Figure C-3. Soil Strength, Initial Calibration Tests




| | |
|---|---|
| **Date** | 7/19/2019 |
| **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-4. Static Soil Test, Test No. HWTT-2

# Appendix D. Vehicle Deformation Records

The following figures and tables describe all occupant compartment measurements taken on the test vehicles used in full-scale crash testing herein. MASH 2016 defines intrusion as the occupant compartment being deformed and reduced in size with no penetration. Outward deformations, which are denoted as negative numbers within this Appendix, are not considered as crush toward the occupant, and are not subject to evaluation by MASH 2016 criteria.

Date: 7/1/2019 Test Name: HWTT-1 VIN: KMHCN4AC8BU608788
Year: 2010 Make: Hyundai Model: Accent

**VEHICLE DEFORMATION**
**DRIVER SIDE FLOOR PAN - SET 1**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOE PAN - WHEEL WELL (X, Z) | 1 | 58.6707 | 4.3715 | 6.0895 | 58.8578 | 5.7432 | 6.5147 | -0.1871 | -1.3717 | -0.4252 | 1.4482 | 0.0000 | NA |
| | 2 | 58.3848 | -0.0174 | 7.6620 | 57.8810 | 1.6783 | 7.3371 | 0.5038 | 1.6957 | 0.3249 | 1.7985 | 0.5995 | X, Z |
| | 3 | 58.1324 | -4.6329 | 7.6552 | 57.5639 | -2.9587 | 7.8523 | 0.5685 | 1.6742 | -0.1971 | 1.7790 | 0.5685 | X |
| | 4 | 57.6246 | -9.5335 | 7.7209 | 57.2715 | -7.7679 | 8.6573 | 0.3531 | 1.7656 | -0.9364 | 2.0295 | 0.3531 | X |
| | 5 | 56.9505 | -15.8906 | 7.9640 | 56.6687 | -14.1675 | 8.6784 | 0.2818 | 1.7231 | -0.7144 | 1.8865 | 0.2818 | X |
| | 6 | 53.6529 | 4.5320 | 6.0907 | 53.9663 | 4.9305 | 5.7238 | -0.3134 | -0.3985 | 0.3669 | 0.6258 | 0.3669 | Z |
| | 7 | 54.1806 | 0.5271 | 8.1781 | 53.5918 | 2.0514 | 7.9522 | 0.5888 | -1.5243 | 0.2259 | 1.6496 | 0.6306 | X, Z |
| | 8 | 53.8229 | -4.1865 | 8.0869 | 53.2696 | -2.6341 | 8.3305 | 0.5533 | 1.5524 | -0.2436 | 1.6660 | 0.5533 | X |
| | 9 | 53.5608 | -9.4734 | 8.1332 | 53.1331 | -7.8125 | 8.5945 | 0.4277 | 1.6609 | -0.4613 | 1.7760 | 0.4277 | X |
| | 10 | 52.8341 | -15.4657 | 8.1606 | 52.5027 | -13.7922 | 8.7733 | 0.3314 | 1.6735 | -0.6127 | 1.8127 | 0.3314 | X |
| FLOOR PAN (Z) | 11 | 49.4446 | 4.6537 | 6.1777 | 49.7034 | 5.2774 | 6.0778 | -0.2588 | -0.6237 | 0.0999 | 0.6826 | 0.0999 | Z |
| | 12 | 50.2568 | 0.7950 | 8.7524 | 49.6320 | 2.2812 | 7.5050 | 0.6248 | -1.4862 | 1.2474 | 2.0384 | 1.2474 | Z |
| | 13 | 50.2325 | -4.1023 | 8.1677 | 49.6817 | -2.5968 | 8.4226 | 0.5508 | 1.5055 | -0.2549 | 1.6232 | -0.2549 | Z |
| | 14 | 49.5604 | -9.2286 | 8.2217 | 49.1299 | -7.7676 | 8.7011 | 0.4305 | 1.4610 | -0.4794 | 1.5968 | -0.4794 | Z |
| | 15 | 48.6413 | -15.0964 | 8.3883 | 48.4316 | -13.6144 | 8.9869 | 0.2097 | 1.4820 | -0.5986 | 1.6120 | -0.5986 | Z |
| | 16 | 45.8218 | 4.7660 | 6.3152 | 46.0623 | 5.5282 | 6.1534 | -0.2405 | -0.7622 | 0.1618 | 0.8155 | 0.1618 | Z |
| | 17 | 46.4199 | 1.7637 | 8.9463 | 46.1969 | 1.9122 | 7.5840 | 0.2230 | -0.1485 | 1.3623 | 1.3884 | 1.3623 | Z |
| | 18 | 46.6802 | -3.9656 | 8.2250 | 46.1153 | -2.6204 | 8.4664 | 0.5649 | 1.3452 | -0.2414 | 1.4788 | -0.2414 | Z |
| | 19 | 46.0586 | -9.0151 | 8.2557 | 45.6463 | -7.6303 | 8.6874 | 0.4123 | 1.3848 | -0.4317 | 1.5080 | -0.4317 | Z |
| | 20 | 45.1986 | -14.8600 | 8.5002 | 44.9537 | -13.4052 | 9.1060 | 0.2449 | 1.4548 | -0.6058 | 1.5948 | -0.6058 | Z |
| | 21 | 42.1481 | 4.9207 | 6.2351 | 42.3986 | 5.4460 | 5.9555 | -0.2505 | -0.5253 | 0.2796 | 0.6457 | 0.2796 | Z |
| | 22 | 42.2281 | 1.9063 | 8.7083 | 42.0777 | 2.2159 | 7.6038 | 0.1504 | -0.3096 | 1.1045 | 1.1569 | 1.1045 | Z |
| | 23 | 42.0301 | -3.7112 | 8.2864 | 41.4427 | -2.5002 | 8.4907 | 0.5874 | 1.2110 | -0.2043 | 1.3614 | -0.2043 | Z |
| | 24 | 42.0817 | -8.5228 | 8.2902 | 41.6434 | -7.2979 | 8.7078 | 0.4383 | 1.2249 | -0.4176 | 1.3663 | -0.4176 | Z |
| | 25 | 41.8735 | -14.5183 | 8.4983 | 41.6230 | -13.2355 | 9.2874 | 0.2505 | 1.2828 | -0.7891 | 1.5268 | -0.7891 | Z |
| | 26 | 38.6822 | 5.1533 | 5.9925 | 38.8713 | 5.8631 | 5.7216 | -0.1891 | -0.7098 | 0.2709 | 0.7829 | 0.2709 | Z |
| | 27 | 38.6807 | 2.0906 | 8.1899 | 38.4965 | 2.7832 | 7.8577 | 0.1842 | -0.6926 | 0.3322 | 0.7899 | 0.3322 | Z |
| | 28 | 38.3977 | -3.0087 | 8.2589 | 37.9748 | -2.0242 | 8.2083 | 0.4229 | 0.9845 | 0.0506 | 1.0727 | 0.0506 | Z |
| | 29 | 38.1612 | -8.1970 | 8.2941 | 37.7966 | -7.1118 | 8.6200 | 0.3646 | 1.0852 | -0.3259 | 1.1903 | -0.3259 | Z |
| | 30 | 38.0473 | -12.8671 | 8.2491 | 37.7668 | -11.7881 | 8.8397 | 0.2805 | 1.0790 | -0.5906 | 1.2616 | -0.5906 | Z |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.
[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.
[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

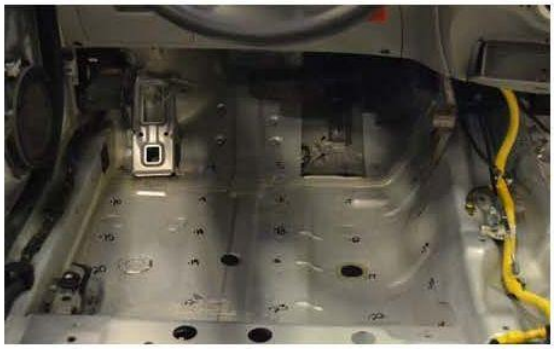
| Pretest Floor Pan | Posttest Floor Pan |
|---|---|
|  |  |

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

Date: 5/9/2019 Test Name: HWTT-1 VIN: KMHCN4AC8BU608788
Year: 2010 Make: Hyundai Model: Accent

**VEHICLE DEFORMATION**
**DRIVER SIDE INTERIOR CRUSH - SET 1**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DASH (X, Y, Z) | 1 | 48.8530 | 9.7381 | -20.7490 | 49.2418 | 9.7036 | -20.8734 | -0.3888 | 0.0345 | -0.1244 | 0.4097 | 0.4097 | X, Y, Z |
| | 2 | 47.2410 | -2.3820 | -23.1113 | 47.5969 | -2.3956 | -23.0829 | -0.3559 | -0.0136 | 0.0284 | 0.3573 | 0.3573 | X, Y, Z |
| | 3 | 49.6462 | -14.7249 | -19.9206 | 49.8976 | -14.7713 | -19.6378 | -0.2514 | -0.0464 | 0.2828 | 0.3812 | 0.3812 | X, Y, Z |
| | 4 | 44.6635 | 7.9567 | -10.2382 | 44.9596 | 8.1707 | -10.3069 | -0.2961 | -0.2140 | -0.0687 | 0.3717 | 0.3717 | X, Y, Z |
| | 5 | 48.5856 | -3.7616 | -8.2512 | 48.7022 | -3.3943 | -8.2144 | -0.1166 | 0.3673 | 0.0368 | 0.3871 | 0.3871 | X, Y, Z |
| | 6 | 48.2240 | -15.3931 | -8.1039 | 47.9793 | -14.9719 | -7.9090 | 0.2447 | 0.4212 | 0.1949 | 0.5247 | 0.5247 | X, Y, Z |
| SIDE PANEL (Y) | 7 | 57.6294 | -17.6397 | -2.6281 | 57.3068 | -15.9554 | -2.2979 | 0.3226 | 1.6843 | 0.3302 | 1.7464 | 1.6843 | Y |
| | 8 | 54.0612 | -17.5796 | -2.4808 | 53.8393 | -16.5608 | -2.0177 | 0.2219 | 1.0188 | 0.4631 | 1.1409 | 1.0188 | Y |
| | 9 | 53.1667 | -17.5100 | 1.3482 | 52.8997 | -16.3811 | 1.8030 | 0.2670 | 1.1289 | 0.4548 | 1.2460 | 1.1289 | Y |
| IMPACT SIDE DOOR (Y) | 10 | 19.8332 | -17.4014 | -18.7944 | 19.7078 | -19.6115 | -18.3884 | 0.1254 | -2.2101 | 0.4060 | 2.2506 | -2.2101 | Y |
| | 11 | 33.8357 | -17.8228 | -17.9753 | 33.5724 | -19.7875 | -17.4847 | 0.2633 | -1.9647 | 0.4906 | 2.0421 | -1.9647 | Y |
| | 12 | 45.1688 | -18.1662 | -17.5839 | 44.8250 | -18.9348 | -17.0526 | 0.3438 | -0.7686 | 0.5313 | 0.9956 | -0.7686 | Y |
| | 13 | 23.8789 | -18.0389 | -1.9913 | 23.8418 | -18.9569 | -1.5687 | 0.0371 | -0.9180 | 0.4226 | 1.0113 | -0.9180 | Y |
| | 14 | 35.5585 | -18.9787 | -0.9449 | 35.3925 | -20.0577 | -0.4992 | 0.1660 | -1.0790 | 0.4457 | 1.1792 | -1.0790 | Y |
| | 15 | 42.2278 | -18.7306 | -1.4053 | 42.1039 | -20.2541 | -0.8770 | 0.1239 | -1.5235 | 0.5283 | 1.6173 | -1.5235 | Y |
| ROOF - (Z) | 16 | 35.2686 | 9.6131 | -35.4092 | 35.6796 | 8.0335 | -35.3037 | -0.4110 | 1.5796 | 0.1055 | 1.6356 | 0.1055 | Z |
| | 17 | 35.1672 | 5.3284 | -35.2961 | 35.4176 | 3.8442 | -35.2963 | -0.2504 | 1.4842 | -0.0002 | 1.5052 | -0.0002 | Z |
| | 18 | 34.6685 | -0.6007 | -35.0918 | 34.8917 | -2.1281 | -35.0707 | -0.2232 | -1.5274 | 0.0211 | 1.5438 | 0.0211 | Z |
| | 19 | 33.9843 | -5.1392 | -34.8405 | 34.2215 | -6.6517 | -34.8105 | -0.2372 | -1.5125 | 0.0300 | 1.5313 | 0.0300 | Z |
| | 20 | 32.8758 | -10.2318 | -34.4082 | 33.0835 | -11.7504 | -34.3834 | -0.2077 | -1.5186 | 0.0248 | 1.5329 | 0.0248 | Z |
| | 21 | 28.7965 | 9.7287 | -38.3741 | 29.1858 | 8.2524 | -38.5406 | -0.3893 | 1.4763 | -0.1665 | 1.5358 | -0.1665 | Z |
| | 22 | 28.5043 | 5.5472 | -38.3370 | 28.8500 | 4.0344 | -38.4691 | -0.3457 | 1.5128 | -0.1321 | 1.5574 | -0.1321 | Z |
| | 23 | 28.0829 | 0.1566 | -38.1450 | 28.4095 | -1.2965 | -38.2140 | -0.3266 | 1.4531 | -0.0690 | 1.4909 | -0.0690 | Z |
| | 24 | 27.9223 | -4.3379 | -37.8112 | 28.1899 | -5.8265 | -37.8180 | -0.2676 | -1.4886 | -0.0068 | 1.5125 | -0.0068 | Z |
| | 25 | 27.1918 | -8.2957 | -37.4982 | 27.5053 | -9.8217 | -37.3849 | -0.3135 | -1.5260 | 0.1133 | 1.5620 | 0.1133 | Z |
| | 26 | 23.0474 | 10.0422 | -39.1167 | 23.4845 | 8.4488 | -39.3010 | -0.4371 | 1.5934 | -0.1843 | 1.6625 | -0.1843 | Z |
| | 27 | 22.9318 | 5.8030 | -39.0555 | 23.3772 | 4.2606 | -39.1688 | -0.4454 | 1.5424 | -0.1133 | 1.6094 | -0.1133 | Z |
| | 28 | 22.7056 | 0.6501 | -38.8467 | 23.1158 | -0.9569 | -38.8708 | -0.4102 | 1.6070 | -0.0241 | 1.6587 | -0.0241 | Z |
| | 29 | 22.2727 | -3.3579 | -38.5926 | 22.6266 | -4.9124 | -38.5554 | -0.3539 | -1.5545 | 0.0372 | 1.5947 | 0.0372 | Z |
| | 30 | 21.9957 | -6.7911 | -38.2874 | 22.2927 | -8.2997 | -38.1586 | -0.2970 | -1.5086 | 0.1288 | 1.5429 | 0.1288 | Z |
| A-PILLAR Maximum (X, Y, Z) | 31 | 54.1728 | -16.7253 | -21.6055 | 54.4088 | -16.9738 | -21.2119 | -0.2360 | -0.2485 | 0.3936 | 0.5219 | 0.3936 | Z |
| | 32 | 51.1993 | -16.1473 | -23.7271 | 51.4429 | -16.5885 | -23.3734 | -0.2436 | -0.4412 | 0.3537 | 0.6157 | 0.3537 | Z |
| | 33 | 47.3002 | -15.2372 | -26.2430 | 47.6060 | -16.0292 | -26.0612 | -0.3058 | -0.7920 | 0.1818 | 0.8682 | 0.1818 | Z |
| | 34 | 44.2481 | -14.4797 | -28.0253 | 44.5944 | -15.4820 | -27.8946 | -0.3463 | -1.0023 | 0.1307 | 1.0685 | 0.1307 | Z |
| | 35 | 40.8354 | -13.5807 | -30.0334 | 41.1589 | -14.7121 | -29.9768 | -0.3235 | -1.1314 | 0.0566 | 1.1781 | 0.0566 | Z |
| | 36 | 35.3729 | -12.3279 | -32.4741 | 35.6155 | -13.7691 | -32.4523 | -0.2426 | -1.4412 | 0.0218 | 1.4616 | 0.0218 | Z |
| A-PILLAR Lateral (Y) | 31 | 54.1728 | -16.7253 | -21.6055 | 54.4088 | -16.9738 | -21.2119 | -0.2360 | -0.2485 | 0.3936 | 0.5219 | -0.2485 | Y |
| | 32 | 51.1993 | -16.1473 | -23.7271 | 51.4429 | -16.5885 | -23.3734 | -0.2436 | -0.4412 | 0.3537 | 0.6157 | -0.4412 | Y |
| | 33 | 47.3002 | -15.2372 | -26.2430 | 47.6060 | -16.0292 | -26.0612 | -0.3058 | -0.7920 | 0.1818 | 0.8682 | -0.7920 | Y |
| | 34 | 44.2481 | -14.4797 | -28.0253 | 44.5944 | -15.4820 | -27.8946 | -0.3463 | -1.0023 | 0.1307 | 1.0685 | -1.0023 | Y |
| | 35 | 40.8354 | -13.5807 | -30.0334 | 41.1589 | -14.7121 | -29.9768 | -0.3235 | -1.1314 | 0.0566 | 1.1781 | -1.1314 | Y |
| | 36 | 35.3729 | -12.3279 | -32.4741 | 35.6155 | -13.7691 | -32.4523 | -0.2426 | -1.4412 | 0.0218 | 1.4616 | -1.4412 | Y |
| B-PILLAR Maximum (X, Y, Z) | 37 | 11.6436 | -10.6098 | -34.0810 | 11.8805 | -11.9197 | -33.9278 | -0.2369 | -1.3099 | 0.1532 | 1.3399 | 0.1532 | Z |
| | 38 | 14.6398 | -12.0149 | -31.5889 | 14.9057 | -13.2976 | -31.3453 | -0.2659 | -1.2827 | 0.2436 | 1.3324 | 0.2436 | Z |
| | 39 | 12.1520 | -13.7201 | -27.3254 | 12.3762 | -14.7986 | -27.0509 | -0.2242 | -1.0785 | 0.2745 | 1.1352 | 0.2745 | Z |
| | 40 | 16.2102 | -14.8585 | -24.1362 | 16.3436 | -15.9102 | -23.7511 | -0.1334 | -1.0517 | 0.3851 | 1.1279 | 0.3851 | Z |
| B-PILLAR Lateral (Y) | 37 | 11.6436 | -10.6098 | -34.0810 | 11.8805 | -11.9197 | -33.9278 | -0.2369 | -1.3099 | 0.1532 | 1.3399 | -1.3099 | Y |
| | 38 | 14.6398 | -12.0149 | -31.5889 | 14.9057 | -13.2976 | -31.3453 | -0.2659 | -1.2827 | 0.2436 | 1.3324 | -1.2827 | Y |
| | 39 | 12.1520 | -13.7201 | -27.3254 | 12.3762 | -14.7986 | -27.0509 | -0.2242 | -1.0785 | 0.2745 | 1.1352 | -1.0785 | Y |
| | 40 | 16.2102 | -14.8585 | -24.1362 | 16.3436 | -15.9102 | -23.7511 | -0.1334 | -1.0517 | 0.3851 | 1.1279 | -1.0517 | Y |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure D-2. Occupant Compartment Deformation Data – Set 1, Test No. HWTT-1

Date: 5/9/2019 Test Name: HWTT-1 VIN: KMHCN4AC8BU608788
Year: 2010 Make: Hyundai Model: Accent

**VEHICLE DEFORMATION**
**WINDSHIELD**

| | POINT | Vertical Reference Length[A] | Vertical Reference Side[B] (Top or Bottom) | Lateral Referece Length[C] | Lateral Reference Side[B] (Driver or Pass.) | Examplar Vehicle Measurement | Test Vehicle Measurment | Crush[D] (in.) |
|---|---|---|---|---|---|---|---|---|
| WINDSHIELD | 1 | 31 3/4 | Top | 12 | Drivers | 5 1/8 | 5 1/4 | 0.125 |
| | 2 | 27 | Top | 37 1/2 | Pass. | 5 1/8 | 8 5/8 | 3.5 |
| | 3 | 21 | Top | 29 3/4 | Pass. | 5 3/8 | 7 | 1.625 |
| | 4 | 15 3/8 | Top | 22 1/2 | Pass. | 5 1/2 | 7 1/4 | 1.75 |
| | 5 | 29 1/8 | Top | 46 | Pass. | 5 1/2 | 6 1/2 | 1 |
| | 6 | 22 5/8 | Top | 39 3/4 | Pass. | 5 1/2 | 7 1/2 | 2 |
| | 7 | 13 1/2 | Top | 30 3/4 | Pass. | 5 3/4 | 7 3/8 | 1.625 |
| | 8 | 12 3/8 | Top | 43 1/2 | Pass. | 6 3/4 | 7 1/8 | 0.375 |
| | | | | | | | | |
| | | | | | | | | |

[A] Length to vertical reference, typically the top or bottom of the windshield frame.
[B] Side of windshield frame, top, bottom, passenger, or driver, in which the reference was measured from.
[C] Length to lateral referene either the driver or passenger side windshield frame.
[D] Crush is the difference between the test vehcile and examplar vehicle that is the intrusion of the windshield deformation. The intrusion is perpendicular to the plane of the windshield which is a resultant of the X & Z directions.

**Examplar Vehicle Description**

Year: 2010 Make: Hyundai Model: Accent VIN: KMHCN4AC9AU498042

**Windshield Deformation Notes:**

The windshield was torn due to movement of the windshield frame not from direct contact with anything. The tearing of the windshield caused the glass to sag from it's weight.

**Test Vehicle Damaged Windshield**


**Examplar Vehicle Windshield**

Figure D-3. Windshield Deformation, Test No. HWTT-1

| | | | | | |
|---|---|---|---|---|---|
| Date: | 5/9/2019 | Test Name: | HWTT-1 | VIN: | KMHCN4AC8BU608788 |
| Year: | 2010 | Make: | Hyundai | Model: | Accent |

**Driver Side Maximum Deformations**

| Reference Set 1 | | | | Reference Set 2 | | | |
|---|---|---|---|---|---|---|---|
| Location | Maximum Deformation[A,B] (in.) | MASH Allowable Deformation (in.) | Directions of Deformation[C] | Location | Maximum Deformation[A,B] (in.) | MASH Allowable Deformation (in.) | Directions of Deformation[C] |
| Roof | 0.1 | ≤ 4 | Z | Roof | 0.0 | ≤ 4 | Z |
| Windshield[D] | 3.5 | ≤ 3 | X, Z | Windshield[D] | NA | ≤ 3 | X, Z |
| A-Pillar Maximum | 0.4 | ≤ 5 | Z | A-Pillar Maximum | 0.0 | ≤ 5 | NA |
| A-Pillar Lateral | -1.4 | ≤ 3 | Y | A-Pillar Lateral | 0.0 | ≤ 3 | Y |
| B-Pillar Maximum | 0.4 | ≤ 5 | Z | B-Pillar Maximum | 0.0 | ≤ 5 | NA |
| B-Pillar Lateral | -1.4 | ≤ 3 | Y | B-Pillar Lateral | 0.0 | ≤ 3 | Y |
| Toe Pan - Wheel Well | 0.6 | ≤ 9 | X, Z | Toe Pan - Wheel Well | 0.0 | ≤ 9 | NA |
| Side Front Panel | 1.7 | ≤ 12 | Y | Side Front Panel | 0.0 | ≤ 12 | Y |
| Side Door (above seat) | -2.2 | ≤ 9 | Y | Side Door (above seat) | 0.0 | ≤ 9 | Y |
| Side Door (below seat) | -1.5 | ≤ 12 | Y | Side Door (below seat) | 0.0 | ≤ 12 | Y |
| Floor Pan | 1.4 | ≤ 12 | Z | Floor Pan | 0.0 | ≤ 12 | Z |
| Dash - no MASH requirement | 0.5 | NA | X, Y, Z | Dash - no MASH requirement | 0.5 | NA | X, Y, Z |

[A] Items highlighted in red do not meet MASH allowable deformations.

[B] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

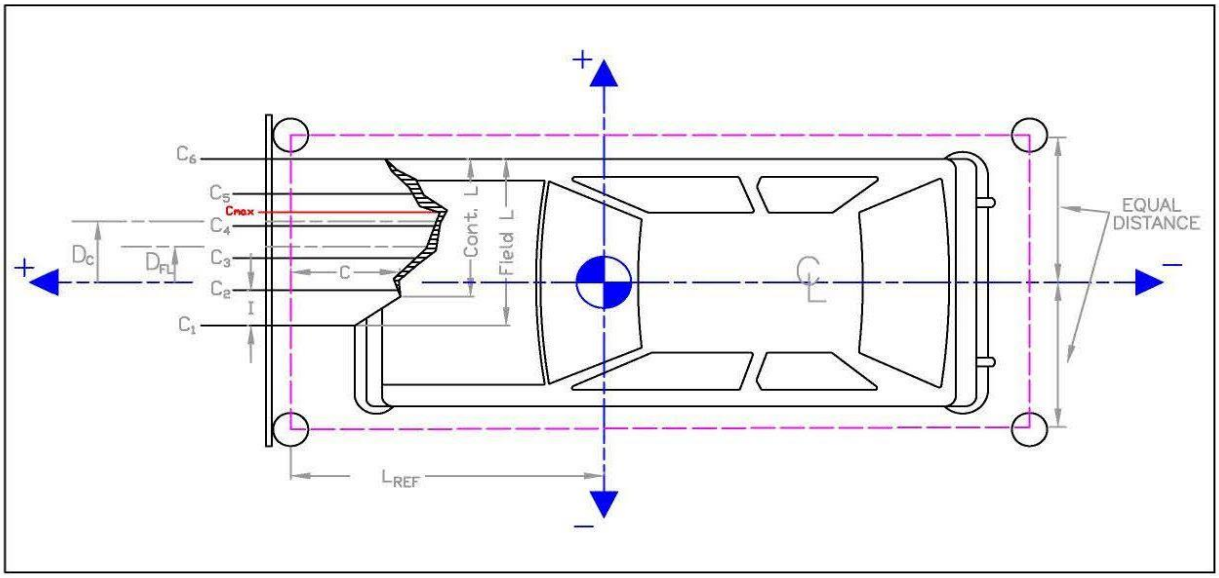
**Notes on vehicle crush:**

Reference Set 2 has been omited due to movement of the references.

Figure D-4. Maximum Occupant Compartment Deformations by Location, Test No. HWTT-1

Date: 7/9/2019 Test Name: HWTT-1 VIN: KMHCN4AC8BU608788

Year: 2010 Make: Hyundai Model: Accent




| | in. | (mm) |
|---|---|---|
| Distance from C.G. to reference line - $L_{REF}$: | 76 | (1930) |
| Total Width of Vehicle: | 65 1/2 | (1664) |
| Width of contact and induced crush - Field L: | 65 1/2 | (1664) |
| Crush measurement spacing interval (L/5) - I: | 13 1/8 | (333) |
| Distance from center of vehicle to center of Field L - $D_{FL}$: | 0 | () |
| Width of Contact Damage: | 18 | (457) |
| Distance from center of vehicle to center of contact damage - $D_C$: | 20 | (508) |

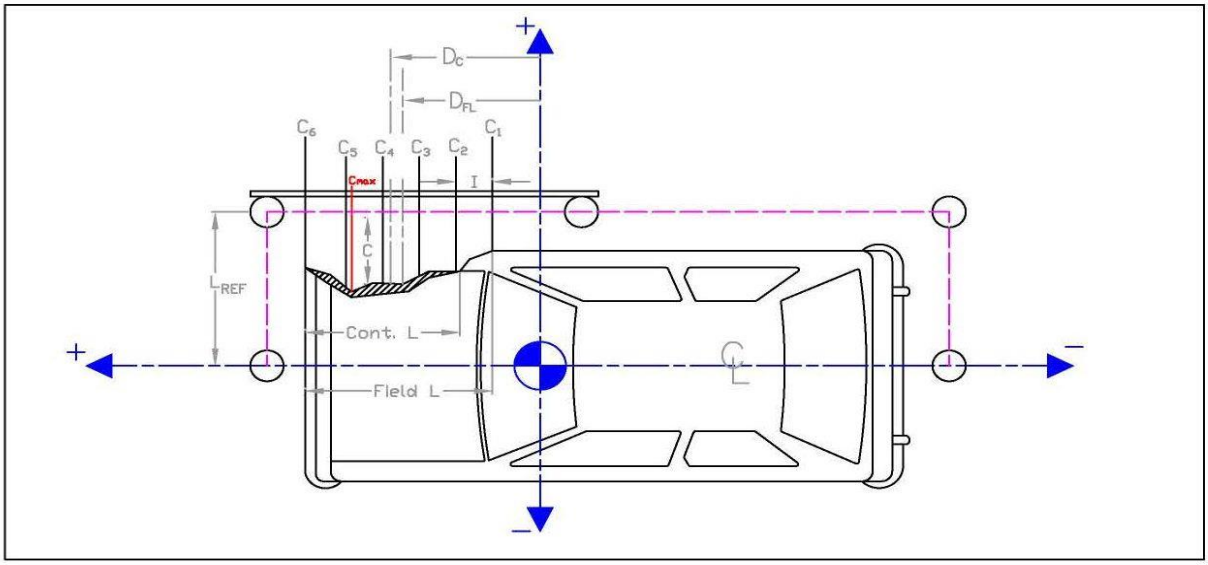
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

| | Crush Measurement | | Lateral Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual Crush | |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | N/A | NA | -32 3/4 | -(832) | 20 1/4 | (514) | 4 3/4 | (121) | NA | NA |
| $C_2$ | 10 | (254) | -19 5/8 | -(498) | 4 3/4 | (121) | | | 1/2 | (13) |
| $C_3$ | 6 | (152) | -6 1/2 | -(165) | 2 3/8 | (60) | | | -1 1/8 | -(29) |
| $C_4$ | 6 1/2 | (165) | 6 5/8 | (168) | 2 3/8 | (60) | | | - 5/8 | -(16) |
| $C_5$ | 10 7/8 | (276) | 19 3/4 | (502) | 4 3/4 | (121) | | | 1 3/8 | (35) |
| $C_6$ | N/A | NA | 32 7/8 | (835) | 19 7/8 | (505) | | | NA | NA |
| $C_{MAX}$ | 10 7/8 | (276) | 19 3/4 | (502) | 4 3/4 | (121) | | | 1 3/8 | (35) |

Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. HWTT-1

Date: 7/9/2019 Test Name: HWTT-1 VIN: KMHCN4AC8BU608788

Year: 2010 Make: Hyundai Model: Accent




| | in. | (mm) |
|---|---|---|
| Distance from centerline to reference line - $L_{REF}$: | 35 | (889) |
| Total Vehicle Length: | 168 1/2 | (4280) |
| Distance from vehicle c.g. to 1/2 of Vehicle total length: | -11 | -(279) |
| Width of contact and induced crush - Field L: | 168 1/2 | (4280) |
| Crush measurement spacing interval (L/5) - I: | 33 3/4 | (857) |
| Distance from vehicle c.g. to center of Field L - $D_{FL}$: | -11 | -(279) |
| Width of Contact Damage: | 168 1/2 | (4280) |
| Distance from vehicle c.g. to center of contact damage - $D_C$: | -11 | -(279) |

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) |
| $C_1$ | 11 | (279) | -95 1/4 | -(2419) | 12 3/8 | (314) | -1 | -(25) | - 3/8 | -(10) |
| $C_2$ | N/A | NA | -61 1/2 | -(1562) | 4 | (102) | | | NA | NA |
| $C_3$ | 2 | (51) | -27 3/4 | -(705) | 3 3/8 | (86) | | | - 3/8 | -(10) |
| $C_4$ | 2 | (51) | 6 | (152) | 3 1/4 | (83) | | | - 1/4 | -(6) |
| $C_5$ | N/A | NA | 39 3/4 | (1010) | 3 1/2 | (89) | | | NA | NA |
| $C_6$ | N/A | NA | 73 1/2 | (1867) | 36 | (914) | | | NA | NA |
| $C_{MAX}$ | 4 1/4 | (108) | 18 1/4 | (464) | 3 1/4 | (83) | | | 2 | (51) |

Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. HWTT-1

Date: 7/19/2019 Test Name: HWTT-2 VIN: 1C6RR6FG1ES237040
Year: 2014 Make: Dodge Model: RAM 1500

**VEHICLE DEFORMATION**
**DRIVER SIDE FLOOR PAN - SET 1**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOE PAN - WHEEL WELL (X, Z) | 1 | 53.9675 | -6.0302 | 2.3141 | 53.6879 | -6.1075 | 3.0709 | 0.2796 | -0.0773 | -0.7568 | 0.8105 | 0.2796 | X |
| | 2 | 54.0989 | -10.0342 | 2.1925 | 53.8048 | -10.1012 | 3.7011 | 0.2941 | -0.0670 | -1.5086 | 1.5385 | 0.2941 | X |
| | 3 | 54.1968 | -14.8396 | 2.1870 | 51.8753 | -13.8721 | 2.1018 | 2.3215 | 0.9675 | 0.0852 | 2.5165 | 2.3231 | X, Z |
| | 4 | 54.8303 | -19.5799 | NA | NA | NA | -21.2671 | #VALUE! | #VALUE! | #VALUE! | NA | NA | #VALUE! |
| | 5 | 55.1412 | -23.0476 | 1.4465 | 49.7917 | -20.6603 | -1.3112 | 5.3495 | 2.3873 | 2.7577 | 6.4747 | 6.0185 | X, Z |
| | 6 | 50.7676 | -5.6608 | 3.9275 | 50.5363 | -5.5155 | 4.6894 | 0.2313 | 0.1453 | -0.7619 | 0.8094 | 0.2313 | X |
| | 7 | 50.6312 | -10.9168 | 4.0593 | 50.3513 | -10.5563 | 5.8339 | 0.2799 | 0.3605 | -1.7746 | 1.8324 | 0.2799 | X |
| | 8 | 50.9659 | -15.4682 | 3.9177 | 49.4549 | -14.6023 | 4.8298 | 1.5110 | 0.8659 | -0.9121 | 1.9659 | 1.5110 | X |
| | 9 | 51.0297 | -20.0052 | 3.9326 | 47.9992 | -18.6335 | 3.4771 | 3.0305 | 1.3717 | 0.4555 | 3.3575 | 3.0645 | X, Z |
| | 10 | 50.9802 | -24.0372 | 4.0052 | 48.1129 | -21.9981 | 3.2504 | 2.8673 | 2.0391 | 0.7548 | 3.5985 | 2.9650 | X, Z |
| FLOOR PAN (Z) | 11 | 46.7043 | -6.3761 | 5.1707 | 46.4166 | -5.9319 | 5.9058 | 0.2877 | 0.4442 | -0.7351 | 0.9058 | -0.7351 | Z |
| | 12 | 46.5814 | -10.1934 | 5.1180 | 46.3159 | -9.6693 | 6.3510 | 0.2655 | 0.5241 | -1.2330 | 1.3658 | -1.2330 | Z |
| | 13 | 46.5549 | -15.0074 | 5.1240 | 46.1315 | -14.4154 | 7.2637 | 0.4234 | 0.5920 | -2.1397 | 2.2601 | -2.1397 | Z |
| | 14 | 46.8679 | -19.1032 | 5.1209 | 46.2563 | -18.3719 | 7.1742 | 0.6116 | 0.7313 | -2.0533 | 2.2638 | -2.0533 | Z |
| | 15 | 46.9472 | -23.1788 | 5.1278 | 45.6523 | -22.2184 | 6.7836 | 1.2949 | 0.9604 | -1.6558 | 2.3110 | -1.6558 | Z |
| | 16 | 42.3304 | -6.4606 | 5.1717 | 42.0686 | -5.9551 | 5.7742 | 0.2618 | 0.5055 | -0.6025 | 0.8289 | -0.6025 | Z |
| | 17 | 42.1807 | -10.5989 | 5.1451 | 41.9091 | -10.0203 | 6.4507 | 0.2716 | 0.5786 | -1.3056 | 1.4537 | -1.3056 | Z |
| | 18 | 42.2506 | -14.9229 | 5.1433 | 42.0171 | -14.3552 | 7.1438 | 0.2335 | 0.5677 | -2.0005 | 2.0926 | -2.0005 | Z |
| | 19 | 41.9286 | -19.0646 | 5.1491 | 41.6706 | -18.4012 | 7.8009 | 0.2580 | 0.6634 | -2.6518 | 2.7457 | -2.6518 | Z |
| | 20 | 41.6927 | -23.2758 | 5.1655 | 41.4297 | -22.5390 | 8.2078 | 0.2630 | 0.7368 | -3.0423 | 3.1413 | -3.0423 | Z |
| | 21 | 36.2799 | -6.5360 | 5.1475 | 36.0379 | -6.1517 | 5.5395 | 0.2420 | 0.3843 | -0.3920 | 0.5999 | -0.3920 | Z |
| | 22 | 36.1905 | -10.4730 | 5.2373 | 35.9517 | -10.0253 | 5.9256 | 0.2388 | 0.4477 | -0.6883 | 0.8551 | -0.6883 | Z |
| | 23 | 36.1953 | -14.5248 | 5.2391 | 36.0004 | -14.0042 | 6.5345 | 0.1949 | 0.5206 | -1.2954 | 1.4096 | -1.2954 | Z |
| | 24 | 36.0714 | -18.0672 | 5.2327 | 35.9074 | -17.5868 | 6.9729 | 0.1640 | 0.4804 | -1.7402 | 1.8127 | -1.7402 | Z |
| | 25 | 36.0750 | -23.1776 | 5.3014 | 35.8994 | -22.6303 | 7.5110 | 0.1756 | 0.5473 | -2.2096 | 2.2831 | -2.2096 | Z |
| | 26 | 32.1944 | -6.6626 | 4.1038 | 31.9530 | -6.3645 | 4.3508 | 0.2414 | 0.2981 | -0.2470 | 0.4562 | -0.2470 | Z |
| | 27 | 32.5286 | -11.1003 | 4.4844 | 32.3557 | -10.7497 | 5.0925 | 0.1729 | 0.3506 | -0.6081 | 0.7229 | -0.6081 | Z |
| | 28 | 32.7865 | -14.7549 | 4.3089 | 32.6449 | -14.4782 | 5.2612 | 0.1416 | 0.2767 | -0.9523 | 1.0017 | -0.9523 | Z |
| | 29 | 32.8050 | -18.1032 | 4.4864 | 32.7399 | -17.7565 | 5.7431 | 0.0651 | 0.3467 | -1.2567 | 1.3053 | -1.2567 | Z |
| | 30 | 32.8991 | -22.5294 | 4.4939 | 32.8303 | -22.2160 | 6.1328 | 0.0688 | 0.3134 | -1.6389 | 1.6700 | -1.6389 | Z |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.
[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.
[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

| Pretest Floor Pan | Posttest Floor Pan |
|---|---|
|  |  |

Figure D-7. Floor Pan Deformation Data – Set 1, Test No. HWTT-2

Date: 7/19/2019 Test Name: HWTT-2 VIN: 1C6RR6FG1ES237040
Year: 2014 Make: Dodge Model: RAM 1500

**VEHICLE DEFORMATION**
**DRIVER SIDE INTERIOR CRUSH - SET 1**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DASH (X, Y, Z) | 1 | 44.5362 | -19.6143 | -28.4488 | 44.7154 | -19.8743 | -28.7483 | -0.1792 | -0.2600 | -0.2995 | 0.4352 | 0.4352 | X, Y, Z |
| | 2 | 44.2214 | -7.5036 | -28.8416 | 44.6434 | -7.7291 | -28.8759 | -0.4220 | -0.2255 | -0.0343 | 0.4797 | 0.4797 | X, Y, Z |
| | 3 | 43.5338 | 5.3393 | -28.0234 | 44.0706 | 5.1064 | -27.9251 | -0.5368 | 0.2329 | 0.0983 | 0.5933 | 0.5933 | X, Y, Z |
| | 4 | 40.1914 | -23.0491 | -16.2515 | 39.7876 | -23.2634 | -16.8143 | 0.4038 | -0.2143 | -0.5628 | 0.7251 | 0.7251 | X, Y, Z |
| | 5 | 39.0525 | -6.7346 | -15.1055 | 38.9462 | -6.8905 | -15.3244 | 0.1063 | -0.1559 | -0.2189 | 0.2890 | 0.2890 | X, Y, Z |
| | 6 | 36.5547 | 5.1177 | -16.7889 | 36.7837 | 4.8827 | -16.8594 | -0.2290 | 0.2350 | -0.0705 | 0.3356 | 0.3356 | X, Y, Z |
| SIDE PANEL (Y) | 7 | 49.2353 | -26.8015 | 2.1652 | 47.7788 | -24.6379 | 2.2155 | 1.4565 | 2.1636 | 0.0503 | 2.6087 | 2.1636 | Y |
| | 8 | 49.3036 | -26.8891 | -3.2563 | 47.8790 | -24.4445 | -3.5136 | 1.4246 | 2.4446 | -0.2573 | 2.8411 | 2.4446 | Y |
| | 9 | 53.5344 | -26.6871 | -2.6633 | 51.4319 | -24.1342 | -3.2701 | 2.1025 | 2.5529 | -0.6068 | 3.3624 | 2.5529 | Y |
| IMPACT SIDE DOOR (Y) | 10 | 38.4212 | -29.4335 | -16.6391 | 37.4368 | -31.7972 | -16.2766 | 0.9844 | -2.3637 | 0.3625 | 2.5860 | -2.3637 | Y |
| | 11 | 27.8086 | -29.9096 | -16.4004 | 27.0426 | -34.1140 | -15.8236 | 0.7660 | -4.2044 | 0.5768 | 4.3124 | -4.2044 | Y |
| | 12 | 15.6769 | -29.8296 | -15.3337 | 15.1005 | -34.0485 | -14.8100 | 0.5764 | -4.2189 | 0.5237 | 4.2902 | -4.2189 | Y |
| | 13 | 39.0831 | -28.2332 | -6.2681 | 37.5623 | -29.7098 | -6.1334 | 1.5208 | -1.4766 | 0.1347 | 2.1240 | -1.4766 | Y |
| | 14 | 31.6166 | -30.4698 | -3.9573 | 31.0016 | -33.1229 | -3.4053 | 0.6150 | -2.6531 | 0.5520 | 2.7788 | -2.6531 | Y |
| | 15 | 19.2115 | -29.8770 | -2.5921 | 18.5444 | -32.3623 | -2.1611 | 0.6671 | -2.4853 | 0.4310 | 2.6091 | -2.4853 | Y |
| ROOF - (Z) | 16 | 25.8200 | -17.2419 | -45.0428 | 26.3166 | -17.9796 | -44.8164 | -0.4966 | -0.7377 | 0.2264 | 0.9176 | 0.2264 | Z |
| | 17 | 26.9013 | -10.2320 | -45.4758 | 27.3753 | -11.0058 | -45.2489 | -0.4740 | -0.7738 | 0.2269 | 0.9354 | 0.2269 | Z |
| | 18 | 27.6848 | -4.5332 | -45.6384 | 28.3165 | -5.2853 | -45.3820 | -0.6317 | -0.7521 | 0.2564 | 1.0151 | 0.2564 | Z |
| | 19 | 27.8273 | 1.9967 | -45.7740 | 28.5236 | 1.1459 | -45.5248 | -0.6963 | 0.8508 | 0.2492 | 1.1273 | 0.2492 | Z |
| | 20 | 27.5169 | 7.4824 | -45.8220 | 28.0268 | 6.7952 | -45.6201 | -0.5099 | 0.6872 | 0.2019 | 0.8792 | 0.2019 | Z |
| | 21 | 17.4933 | -17.2857 | -45.9921 | 18.0099 | -18.0353 | -45.7392 | -0.5166 | -0.7496 | 0.2529 | 0.9448 | 0.2529 | Z |
| | 22 | 18.5188 | -10.6347 | -46.3263 | 19.1787 | -11.3842 | -46.1438 | -0.6599 | -0.7495 | 0.1825 | 1.0151 | 0.1825 | Z |
| | 23 | 18.9401 | -3.3080 | -46.6068 | 19.5031 | -4.1011 | -46.4375 | -0.5630 | -0.7931 | 0.1693 | 0.9872 | 0.1693 | Z |
| | 24 | 17.9909 | 2.4287 | -46.8327 | 18.4965 | 1.6594 | -46.6907 | -0.5056 | 0.7693 | 0.1420 | 0.9315 | 0.1420 | Z |
| | 25 | 18.2003 | 7.0188 | -46.8171 | 18.7469 | 6.2808 | -46.6849 | -0.5466 | 0.7380 | 0.1322 | 0.9278 | 0.1322 | Z |
| | 26 | 9.6666 | -16.6995 | -46.3742 | 10.2382 | -17.4293 | -46.1216 | -0.5716 | -0.7298 | 0.2526 | 0.9608 | 0.2526 | Z |
| | 27 | 9.9446 | -10.8102 | -46.7712 | 10.5342 | -11.6164 | -46.6648 | -0.5896 | -0.8062 | 0.1064 | 1.0044 | 0.1064 | Z |
| | 28 | 9.8568 | -4.0479 | -47.0536 | 10.3708 | -4.7382 | -46.9460 | -0.5140 | -0.6903 | 0.1076 | 0.8673 | 0.1076 | Z |
| | 29 | 9.2382 | 1.8804 | -47.1818 | 9.8462 | 1.1455 | -47.1033 | -0.6080 | 0.7349 | 0.0785 | 0.9570 | 0.0785 | Z |
| | 30 | 8.9442 | 5.5376 | -47.1987 | 9.5071 | 4.8393 | -47.1357 | -0.5629 | 0.6983 | 0.0630 | 0.8991 | 0.0630 | Z |
| A-PILLAR Maximum (X, Y, Z) | 31 | 49.0064 | -25.5687 | -28.8109 | 49.5661 | -26.5023 | -28.7508 | -0.5597 | -0.9336 | 0.0601 | 1.0902 | 0.0601 | Z |
| | 32 | 45.9085 | -24.9629 | -31.1997 | 46.5424 | -25.9122 | -31.2819 | -0.6339 | -0.9493 | -0.0822 | 1.1444 | 0.0000 | NA |
| | 33 | 43.4459 | -24.3003 | -32.6792 | 44.0478 | -25.2088 | -32.6551 | -0.6019 | -0.9085 | 0.0241 | 1.0901 | 0.0241 | Z |
| | 34 | 40.2478 | -23.7086 | -35.0931 | 40.8166 | -24.5862 | -35.0538 | -0.5688 | -0.8776 | 0.0393 | 1.0465 | 0.0393 | Z |
| | 35 | 35.9378 | -23.0838 | -38.5185 | 36.5397 | -23.9713 | -38.4611 | -0.6019 | -0.8875 | 0.0574 | 1.0739 | 0.0574 | Z |
| | 36 | 31.8648 | -22.1790 | -40.5384 | 32.3747 | -23.0003 | -40.3184 | -0.5099 | -0.8213 | 0.2200 | 0.9914 | 0.2200 | Z |
| A-PILLAR Lateral (Y) | 31 | 49.0064 | -25.5687 | -28.8109 | 49.5661 | -26.5023 | -28.7508 | -0.5597 | -0.9336 | 0.0601 | 1.0902 | -0.9336 | Y |
| | 32 | 45.9085 | -24.9629 | -31.1997 | 46.5424 | -25.9122 | -31.2819 | -0.6339 | -0.9493 | -0.0822 | 1.1444 | -0.9493 | Y |
| | 33 | 43.4459 | -24.3003 | -32.6792 | 44.0478 | -25.2088 | -32.6551 | -0.6019 | -0.9085 | 0.0241 | 1.0901 | -0.9085 | Y |
| | 34 | 40.2478 | -23.7086 | -35.0931 | 40.8166 | -24.5862 | -35.0538 | -0.5688 | -0.8776 | 0.0393 | 1.0465 | -0.8776 | Y |
| | 35 | 35.9378 | -23.0838 | -38.5185 | 36.5397 | -23.9713 | -38.4611 | -0.6019 | -0.8875 | 0.0574 | 1.0739 | -0.8875 | Y |
| | 36 | 31.8648 | -22.1790 | -40.5384 | 32.3747 | -23.0003 | -40.3184 | -0.5099 | -0.8213 | 0.2200 | 0.9914 | -0.8213 | Y |
| B-PILLAR Maximum (X, Y, Z) | 37 | 7.8345 | -23.6966 | -37.8181 | 8.2291 | -24.3809 | -37.3341 | -0.3946 | -0.6843 | 0.4840 | 0.9264 | 0.4840 | Z |
| | 38 | 5.5539 | -26.6865 | -29.1461 | 5.7955 | -27.2207 | -28.8014 | -0.2416 | -0.5342 | 0.3447 | 0.6801 | 0.3447 | Z |
| | 39 | 9.6630 | -27.3653 | -21.2717 | 9.9292 | -27.8398 | -20.6915 | -0.2662 | -0.4745 | 0.5802 | 0.7954 | 0.5802 | Z |
| | 40 | 6.0894 | -27.6357 | -14.8778 | 6.2196 | -28.0179 | -14.3763 | -0.1302 | -0.3822 | 0.5015 | 0.6438 | 0.5015 | Z |
| B-PILLAR Lateral (Y) | 37 | 7.8345 | -23.6966 | -37.8181 | 8.2291 | -24.3809 | -37.3341 | -0.3946 | -0.6843 | 0.4840 | 0.9264 | -0.6843 | Y |
| | 38 | 5.5539 | -26.6865 | -29.1461 | 5.7955 | -27.2207 | -28.8014 | -0.2416 | -0.5342 | 0.3447 | 0.6801 | -0.5342 | Y |
| | 39 | 9.6630 | -27.3653 | -21.2717 | 9.9292 | -27.8398 | -20.6915 | -0.2662 | -0.4745 | 0.5802 | 0.7954 | -0.4745 | Y |
| | 40 | 6.0894 | -27.6357 | -14.8778 | 6.2196 | -28.0179 | -14.3763 | -0.1302 | -0.3822 | 0.5015 | 0.6438 | -0.3822 | Y |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure D-8. Occupant Compartment Deformation Data – Set 1, Test No. HWTT-2

Date: 7/19/2019 Test Name: HWTT-2 VIN: 1C6RR6FG1ES237040
Year: 2014 Make: Dodge Model: RAM 1500

**VEHICLE DEFORMATION**
**DRIVER SIDE FLOOR PAN - SET 2**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOE PAN - WHEEL WELL (X, Z) | 1 | 55.2846 | -25.7115 | -1.5439 | 54.7824 | -25.7129 | -1.2515 | 0.5022 | -0.0014 | -0.2924 | 0.5811 | 0.5022 | X |
| | 2 | 55.4009 | -29.7153 | -1.6845 | 54.8894 | -29.7140 | -0.6684 | 0.5115 | 0.0013 | -1.0161 | 1.1376 | 0.5115 | X |
| | 3 | 55.4799 | -34.5210 | -1.7132 | 52.9497 | -33.4609 | -2.3112 | 2.5302 | 1.0601 | 0.5980 | 2.8077 | 2.5999 | X, Z |
| | 4 | 56.0980 | -39.2610 | -2.2788 | NA | NA | NA | #VALUE! | #VALUE! | #VALUE! | NA | NA | #VALUE! |
| | 5 | 56.3965 | -42.7289 | -2.4884 | 50.8476 | -40.2032 | -5.8030 | 5.5489 | 2.5257 | 3.3146 | 6.9395 | 6.4635 | X, Z |
| | 6 | 52.0765 | -25.3373 | 0.0520 | 51.6329 | -25.1319 | 0.3750 | 0.4436 | 0.2054 | -0.3230 | 0.5859 | 0.4436 | X |
| | 7 | 51.9186 | -30.5933 | 0.1570 | 51.4354 | -30.1853 | 1.4602 | 0.4832 | 0.4080 | -1.3032 | 1.4485 | 0.4832 | X |
| | 8 | 52.2362 | -35.1452 | -0.0050 | 50.5283 | -34.2170 | 0.4090 | 1.7079 | 0.9282 | -0.4140 | 1.9874 | 1.7079 | X |
| | 9 | 52.2820 | -39.6825 | -0.0121 | 49.0619 | -38.2282 | -0.9905 | 3.2201 | 1.4543 | 0.9784 | 3.6662 | 3.3655 | X, Z |
| | 10 | 52.2162 | -43.7146 | 0.0403 | 49.1670 | -41.5902 | -1.2568 | 3.0492 | 2.1244 | 1.2971 | 3.9361 | 3.3136 | X, Z |
| FLOOR PAN (Z) | 11 | 48.0030 | -26.0426 | 1.2673 | 47.5125 | -25.5521 | 1.5880 | 0.4905 | 0.4905 | -0.3207 | 0.7642 | -0.3207 | Z |
| | 12 | 47.8654 | -29.8591 | 1.1950 | 47.4025 | -29.2943 | 1.9892 | 0.4629 | 0.5648 | -0.7942 | 1.0789 | -0.7942 | Z |
| | 13 | 47.8199 | -34.6729 | 1.1770 | 47.2063 | -34.0502 | 2.8461 | 0.6136 | 0.6227 | -1.6691 | 1.8842 | -1.6691 | Z |
| | 14 | 48.1167 | -38.7697 | 1.1556 | 47.3210 | -38.0057 | 2.7101 | 0.7957 | 0.7640 | -1.5545 | 1.9061 | -1.5545 | Z |
| | 15 | 48.1800 | -42.8457 | 1.1429 | 46.7071 | -41.8458 | 2.2745 | 1.4729 | 0.9999 | -1.1316 | 2.1094 | -1.1316 | Z |
| | 16 | 43.6289 | -26.1097 | 1.2415 | 43.1645 | -25.5627 | 1.4578 | 0.4644 | 0.5470 | -0.2163 | 0.7494 | -0.2163 | Z |
| | 17 | 43.4630 | -30.2472 | 1.1937 | 42.9948 | -29.6352 | 2.0865 | 0.4682 | 0.6120 | -0.8928 | 1.1793 | -0.8928 | Z |
| | 18 | 43.5159 | -34.5713 | 1.1709 | 43.0920 | -33.9782 | 2.7285 | 0.4239 | 0.5931 | -1.5576 | 1.7198 | -1.5576 | Z |
| | 19 | 43.1775 | -38.7117 | 1.1543 | 42.7355 | -38.0307 | 3.3381 | 0.4420 | 0.6810 | -2.1838 | 2.3298 | -2.1838 | Z |
| | 20 | 42.9249 | -42.9219 | 1.1486 | 42.4842 | -42.1724 | 3.6965 | 0.4407 | 0.7495 | -2.5479 | 2.6922 | -2.5479 | Z |
| | 21 | 37.5784 | -26.1610 | 1.1806 | 37.1332 | -25.7412 | 1.2231 | 0.4452 | 0.4198 | -0.0425 | 0.6134 | -0.0425 | Z |
| | 22 | 37.4729 | -30.0980 | 1.2505 | 37.0373 | -29.6188 | 1.5637 | 0.4356 | 0.4792 | -0.3132 | 0.7194 | -0.3132 | Z |
| | 23 | 37.4618 | -34.1496 | 1.2323 | 37.0761 | -33.6048 | 2.1257 | 0.3857 | 0.5448 | -0.8934 | 1.1152 | -0.8934 | Z |
| | 24 | 37.3239 | -37.6915 | 1.2077 | 36.9741 | -37.1920 | 2.5220 | 0.3498 | 0.4995 | -1.3143 | 1.4489 | -1.3143 | Z |
| | 25 | 37.3070 | -42.8021 | 1.2512 | 36.9535 | -42.2415 | 3.0007 | 0.3535 | 0.5606 | -1.7495 | 1.8708 | -1.7495 | Z |
| | 26 | 33.4988 | -26.2662 | 0.1118 | 33.0474 | -25.9296 | 0.0336 | 0.4514 | 0.3366 | 0.0782 | 0.5685 | 0.0782 | Z |
| | 27 | 33.8132 | -30.7070 | 0.4725 | 33.4392 | -30.3242 | 0.7235 | 0.3740 | 0.3828 | -0.2510 | 0.5911 | -0.2510 | Z |
| | 28 | 34.0578 | -34.3617 | 0.2805 | 33.7189 | -34.0552 | 0.8483 | 0.3389 | 0.3065 | -0.5678 | 0.7288 | -0.5678 | Z |
| | 29 | 34.0620 | -37.7108 | 0.4416 | 33.8058 | -37.3392 | 1.2915 | 0.2562 | 0.3716 | -0.8499 | 0.9623 | -0.8499 | Z |
| | 30 | 34.1385 | -42.1374 | 0.4278 | 33.8849 | -41.8032 | 1.6287 | 0.2536 | 0.3342 | -1.2009 | 1.2721 | -1.2009 | Z |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.
[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.
[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

| Pretest Floor Pan | Posttest Floor Pan |
|---|---|
|  |  |

Figure D-9. Floor Pan Deformation Data – Set 2, Test No. HWTT-2

Date: 7/19/2019 Test Name: HWTT-2 VIN: 1C6RR6FG1ES237040
Year: 2014 Make: Dodge Model: RAM 1500

**VEHICLE DEFORMATION**
**DRIVER SIDE INTERIOR CRUSH - SET 2**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DASH (X, Y, Z) | 1 | 45.9990 | -39.1217 | -32.4743 | 45.7633 | -38.8429 | -33.2518 | 0.2357 | 0.2788 | -0.7775 | 0.8589 | 0.8589 | X, Y, Z |
| | 2 | 45.7385 | -27.0078 | -32.8034 | 45.7246 | -26.6968 | -33.2324 | 0.0139 | 0.3110 | -0.4290 | 0.5301 | 0.5301 | X, Y, Z |
| | 3 | 45.1012 | -14.1666 | -31.9197 | 45.1877 | -13.8723 | -32.1260 | -0.0865 | 0.2943 | -0.2063 | 0.3697 | 0.3697 | X, Y, Z |
| | 4 | 41.5683 | -42.6033 | -20.3212 | 40.8334 | -42.3626 | -21.3565 | 0.7349 | 0.2407 | -1.0353 | 1.2922 | 1.2922 | X, Y, Z |
| | 5 | 40.4928 | -26.2905 | -19.0936 | 40.0380 | -26.0067 | -19.6681 | 0.4548 | 0.2838 | -0.5745 | 0.7858 | 0.7858 | X, Y, Z |
| | 6 | 38.0557 | -14.4186 | -20.7273 | 37.9069 | -14.2098 | -21.0592 | 0.1488 | 0.2088 | -0.3319 | 0.4194 | 0.4194 | X, Y, Z |
| SIDE PANEL (Y) | 7 | 50.4885 | -46.4939 | -1.8729 | 48.8324 | -43.9892 | -2.3499 | 1.6561 | 2.5047 | -0.4770 | 3.0403 | 2.5047 | Y |
| | 8 | 50.5880 | -46.5526 | -7.2943 | 48.9296 | -43.7268 | -8.0763 | 1.6584 | 2.8258 | -0.7820 | 3.3685 | 2.8258 | Y |
| | 9 | 54.8161 | -46.3721 | -6.6756 | 52.4835 | -43.4293 | -7.8313 | 2.3326 | 2.9428 | -1.1557 | 3.9290 | 2.9428 | Y |
| IMPACT SIDE DOOR (Y) | 10 | 39.7731 | -48.9779 | -20.7538 | 38.4594 | -50.8958 | -20.9206 | 1.3137 | -1.9179 | -0.1668 | 2.3307 | -1.9179 | Y |
| | 11 | 29.1573 | -49.4094 | -20.5793 | 28.0592 | -53.1893 | -20.4890 | 1.0981 | -3.7799 | 0.0903 | 3.9372 | -3.7799 | Y |
| | 12 | 17.0201 | -49.2826 | -19.5827 | 16.1179 | -53.1034 | -19.4671 | 0.9022 | -3.8208 | 0.1156 | 3.9276 | -3.8208 | Y |
| | 13 | 40.3796 | -47.8363 | -10.3727 | 38.5969 | -48.9316 | -10.7530 | 1.7827 | -1.0953 | -0.3803 | 2.1266 | -1.0953 | Y |
| | 14 | 32.8902 | -50.0530 | -8.1175 | 32.0284 | -52.3595 | -8.0622 | 0.8618 | -2.3065 | 0.0553 | 2.4629 | -2.3065 | Y |
| | 15 | 20.4800 | -49.4140 | -6.8212 | 19.5742 | -51.5798 | -6.8009 | 0.9058 | -2.1658 | 0.0203 | 2.3477 | -2.1658 | Y |
| ROOF - (Z) | 16 | 27.3903 | -36.5790 | -49.1638 | 27.3599 | -36.7033 | -49.2839 | 0.0304 | -0.1243 | -0.1201 | 0.1755 | -0.1201 | Z |
| | 17 | 28.5042 | -29.5716 | -49.5525 | 28.4376 | -29.7278 | -49.6327 | 0.0666 | -0.1562 | -0.0802 | 0.1878 | -0.0802 | Z |
| | 18 | 29.3131 | -23.8754 | -49.6797 | 29.3945 | -24.0087 | -49.6972 | -0.0814 | -0.1333 | -0.0175 | 0.1572 | -0.0175 | Z |
| | 19 | 29.4844 | -17.3456 | -49.7791 | 29.6191 | -17.5768 | -49.7623 | -0.1347 | -0.2312 | 0.0168 | 0.2681 | 0.0168 | Z |
| | 20 | 29.1978 | -11.8584 | -49.7992 | 29.1378 | -11.9255 | -49.7889 | 0.0600 | -0.0671 | 0.0103 | 0.0906 | 0.0103 | Z |
| | 21 | 19.0692 | -36.5817 | -50.1617 | 19.0526 | -36.7251 | -50.2020 | 0.0166 | -0.1434 | -0.0403 | 0.1499 | -0.0403 | Z |
| | 22 | 20.1252 | -29.9335 | -50.4539 | 20.2394 | -30.0728 | -50.5269 | -0.1142 | -0.1393 | -0.0730 | 0.1944 | -0.0730 | Z |
| | 23 | 20.5795 | -22.6073 | -50.6923 | 20.5836 | -22.7876 | -50.7326 | -0.0041 | -0.1803 | -0.0403 | 0.1848 | -0.0403 | Z |
| | 24 | 19.6562 | -16.8654 | -50.8926 | 19.5928 | -17.0217 | -50.9155 | 0.0634 | -0.1563 | -0.0229 | 0.1702 | -0.0229 | Z |
| | 25 | 19.8852 | -12.2764 | -50.8509 | 19.8559 | -12.4014 | -50.8540 | 0.0293 | -0.1250 | -0.0031 | 0.1284 | -0.0031 | Z |
| | 26 | 11.2474 | -35.9596 | -50.5861 | 11.2823 | -36.0932 | -50.5721 | -0.0349 | -0.1336 | 0.0140 | 0.1388 | 0.0140 | Z |
| | 27 | 11.5530 | -30.0696 | -50.9496 | 11.5940 | -30.2749 | -51.0451 | -0.0410 | -0.2053 | -0.0955 | 0.2301 | -0.0955 | Z |
| | 28 | 11.4959 | -23.3055 | -51.1958 | 11.4493 | -23.3935 | -51.2430 | 0.0466 | -0.0880 | -0.0472 | 0.1102 | -0.0472 | Z |
| | 29 | 10.9035 | -17.3740 | -51.2956 | 10.9408 | -17.5068 | -51.3287 | -0.0373 | -0.1328 | -0.0331 | 0.1419 | -0.0331 | Z |
| | 30 | 10.6253 | -13.7155 | -51.2944 | 10.6119 | -13.8120 | -51.3162 | 0.0134 | -0.0965 | -0.0218 | 0.0998 | -0.0218 | Z |
| A-PILLAR Maximum (X, Y, Z) | 31 | 50.4457 | -45.0933 | -32.8427 | 50.5957 | -45.4836 | -33.3376 | -0.1500 | -0.3903 | -0.4949 | 0.6479 | 0.0000 | NA |
| | 32 | 47.3644 | -44.4612 | -35.2461 | 47.5721 | -44.8547 | -35.8595 | -0.2077 | -0.3935 | -0.6134 | 0.7578 | 0.0000 | NA |
| | 33 | 44.9133 | -43.7800 | -36.7363 | 45.0785 | -44.1278 | -37.2224 | -0.1652 | -0.3478 | -0.4861 | 0.6201 | 0.0000 | NA |
| | 34 | 41.7320 | -43.1615 | -39.1655 | 41.8477 | -43.4674 | -39.6114 | -0.1157 | -0.3059 | -0.4459 | 0.5530 | 0.0000 | NA |
| | 35 | 37.4447 | -42.4997 | -42.6124 | 37.5704 | -42.7995 | -43.0082 | -0.1257 | -0.2998 | -0.3958 | 0.5122 | 0.0000 | NA |
| | 36 | 33.3875 | -41.5663 | -44.6511 | 33.4069 | -41.7948 | -44.8509 | -0.0194 | -0.2285 | -0.1998 | 0.3042 | 0.0000 | NA |
| A-PILLAR Lateral (Y) | 31 | 50.4457 | -45.0933 | -32.8427 | 50.5957 | -45.4836 | -33.3376 | -0.1500 | -0.3903 | -0.4949 | 0.6479 | -0.3903 | Y |
| | 32 | 47.3644 | -44.4612 | -35.2461 | 47.5721 | -44.8547 | -35.8595 | -0.2077 | -0.3935 | -0.6134 | 0.7578 | -0.3935 | Y |
| | 33 | 44.9133 | -43.7800 | -36.7363 | 45.0785 | -44.1278 | -37.2224 | -0.1652 | -0.3478 | -0.4861 | 0.6201 | -0.3478 | Y |
| | 34 | 41.7320 | -43.1615 | -39.1655 | 41.8477 | -43.4674 | -39.6114 | -0.1157 | -0.3059 | -0.4459 | 0.5530 | -0.3059 | Y |
| | 35 | 37.4447 | -42.4997 | -42.6124 | 37.5704 | -42.7995 | -43.0082 | -0.1257 | -0.2998 | -0.3958 | 0.5122 | -0.2998 | Y |
| | 36 | 33.3875 | -41.5663 | -44.6511 | 33.4069 | -41.7948 | -44.8509 | -0.0194 | -0.2285 | -0.1998 | 0.3042 | -0.2285 | Y |
| B-PILLAR Maximum (X, Y, Z) | 37 | 9.3354 | -42.9948 | -42.0788 | 9.2594 | -43.1451 | -41.8680 | 0.0760 | -0.1503 | 0.2108 | 0.2698 | 0.2241 | X, Z |
| | 38 | 6.9915 | -46.0215 | -33.4365 | 6.8232 | -46.0812 | -33.3688 | 0.1683 | -0.0597 | 0.0677 | 0.1910 | 0.1814 | X, Z |
| | 39 | 11.0515 | -46.7605 | -25.5421 | 10.9602 | -46.8098 | -25.2696 | 0.0913 | -0.0493 | 0.2725 | 0.2916 | 0.2874 | X, Z |
| | 40 | 7.4396 | -47.0499 | -19.1707 | 7.2539 | -47.0540 | -18.9547 | 0.1857 | -0.0041 | 0.2160 | 0.2849 | 0.2849 | X, Z |
| B-PILLAR Lateral (Y) | 37 | 9.3354 | -42.9948 | -42.0788 | 9.2594 | -43.1451 | -41.8680 | 0.0760 | -0.1503 | 0.2108 | 0.2698 | -0.1503 | Y |
| | 38 | 6.9915 | -46.0215 | -33.4365 | 6.8232 | -46.0812 | -33.3688 | 0.1683 | -0.0597 | 0.0677 | 0.1910 | -0.0597 | Y |
| | 39 | 11.0515 | -46.7605 | -25.5421 | 10.9602 | -46.8098 | -25.2696 | 0.0913 | -0.0493 | 0.2725 | 0.2916 | -0.0493 | Y |
| | 40 | 7.4396 | -47.0499 | -19.1707 | 7.2539 | -47.0540 | -18.9547 | 0.1857 | -0.0041 | 0.2160 | 0.2849 | -0.0041 | Y |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure D-10. Occupant Compartment Deformation Data – Set 2, Test No. HWTT-2

| | | | | | |
|---|---|---|---|---|---|
| Date: | 7/19/2019 | Test Name: | HWTT-2 | VIN: | 1C6RR6FG1ES237040 |
| Year: | 2014 | Make: | Dodge | Model: | RAM 1500 |

**Driver Side Maximum Deformation**

| Reference Set 1 | | | | Reference Set 2 | | | |
|---|---|---|---|---|---|---|---|
| Location | Maximum Deformation[A,B] (in.) | MASH Allowable Deformation (in.) | Directions of Deformation[C] | Location | Maximum Deformation[A,B] (in.) | MASH Allowable Deformation (in.) | Directions of Deformation[C] |
| Roof | 0.3 | ≤ 4 | Z | Roof | 0.0 | ≤ 4 | Z |
| Windshield[D] | 0.0 | ≤ 3 | X, Z | Windshield[D] | NA | ≤ 3 | X, Z |
| A-Pillar Maximum | 0.2 | ≤ 5 | Z | A-Pillar Maximum | 0.0 | ≤ 5 | NA |
| A-Pillar Lateral | -0.9 | ≤ 3 | Y | A-Pillar Lateral | -0.4 | ≤ 3 | Y |
| B-Pillar Maximum | 0.6 | ≤ 5 | Z | B-Pillar Maximum | 0.3 | ≤ 5 | X, Z |
| B-Pillar Lateral | -0.9 | ≤ 3 | Y | B-Pillar Lateral | -0.2 | ≤ 3 | Y |
| Toe Pan - Wheel Well | 6.0 | ≤ 9 | X, Z | Toe Pan - Wheel Well | 6.5 | ≤ 9 | X, Z |
| Side Front Panel | 2.6 | ≤ 12 | Y | Side Front Panel | 2.9 | ≤ 12 | Y |
| Side Door (above seat) | -4.2 | ≤ 9 | Y | Side Door (above seat) | -3.8 | ≤ 9 | Y |
| Side Door (below seat) | -2.7 | ≤ 12 | Y | Side Door (below seat) | -2.3 | ≤ 12 | Y |
| Floor Pan | -3.0 | ≤ 12 | Z | Floor Pan | 0.1 | ≤ 12 | Z |
| Dash - no MASH requirement | 0.7 | NA | X, Y, Z | Dash - no MASH requirement | 0.7 | NA | X, Y, Z |

[A] Items highlighted in red do not meet MASH allowable deformations.

[B] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

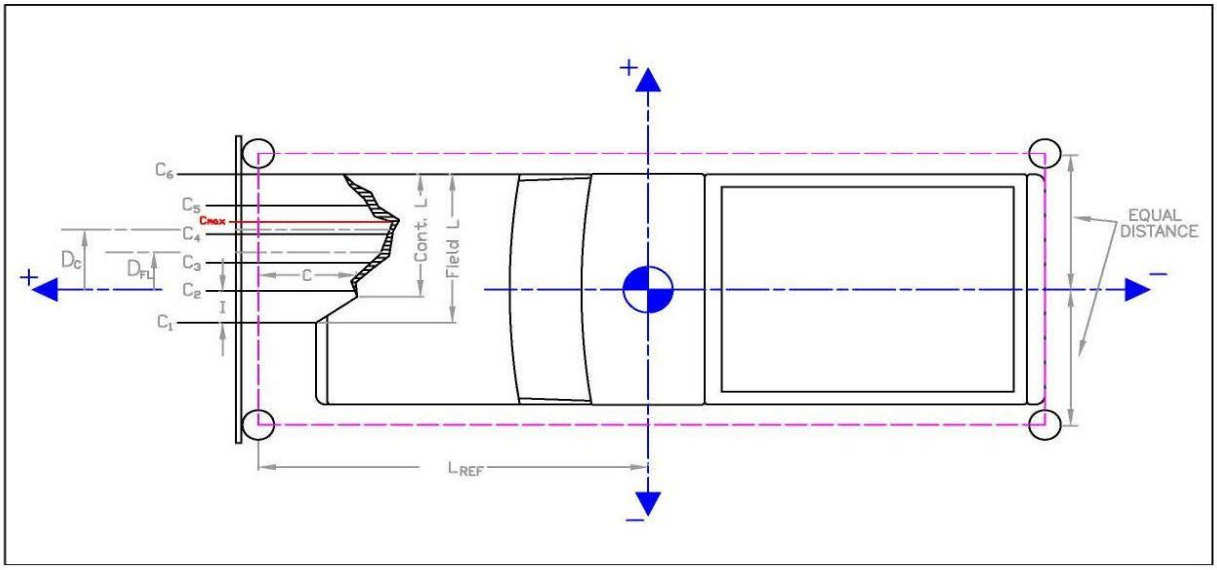
[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

**Notes on vehicle interior crush:**

Figure D-11. Maximum Occupant Compartment Deformations by Location, Test No. HWTT-2

| | | | | | |
|---|---|---|---|---|---|
| Date: | 7/23/2019 | Test Name: | HWTT-2 | VIN: | 1C6RR6FG1ES237040 |
| Year: | 2014 | Make: | Dodge | Model: | RAM 1500 |




| | in. | (mm) |
|---|---|---|
| Distance from C.G. to reference line - $L_{REF}$: | 112 | (2845) |
| Total Vehicle Width: | 77 1/2 | (1969) |
| Width of contact and induced crush - Field L: | 77 1/2 | (1969) |
| Crush measurement spacing interval (L/5) - I: | 15 1/2 | (394) |
| Distance from center of vehicle to center of Field L - $D_{FL}$: | 0 | () |
| Width of Contact Damage: | 19 | (483) |
| Distance from center of vehicle to center of contact damage - $D_C$: | -21 1/4 | -(540) |

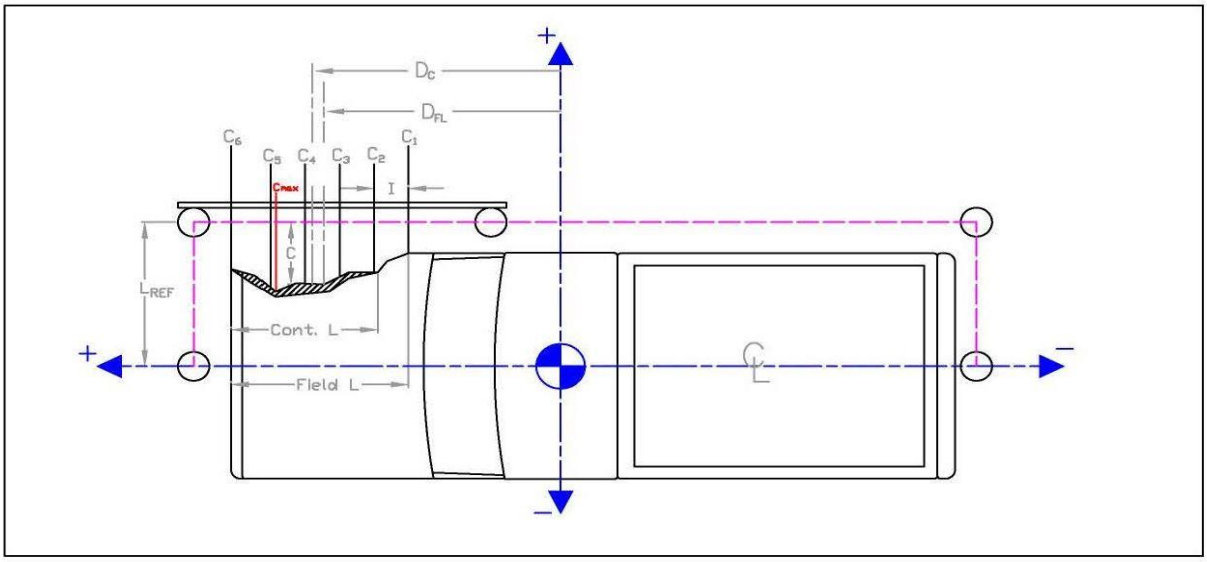
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

| | Crush Measurement | | Lateral Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual Crush | |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | N/A | N/A | -38 3/4 | -(984) | 22 1/2 | (572) | 2 4/5 | (71) | N/A | N/A |
| $C_2$ | N/A | N/A | -23 1/4 | -(591) | 6 1/2 | (165) | | | N/A | N/A |
| $C_3$ | 10 1/2 | (267) | -7 3/4 | -(197) | 4 1/4 | (108) | | | 3 4/9 | (87) |
| $C_4$ | 4 1/4 | (108) | 7 3/4 | (197) | 4 1/4 | (108) | | | -2 4/5 | -(71) |
| $C_5$ | 8 3/8 | (213) | 23 1/4 | (591) | 6 1/4 | (159) | | | - 2/3 | -(17) |
| $C_6$ | N/A | N/A | 38 3/4 | (984) | 20 1/2 | (521) | | | N/A | N/A |
| $C_{MAX}$ | 10 1/2 | (267) | -7 3/4 | -(197) | 4 1/4 | (108) | | | 3 4/9 | (87) |

Figure D-12. Exterior Vehicle Crush (NASS) - Front, Test No. HWTT-2

Date: 7/23/2019 Test Name: HWTT-2 VIN: 1C6RR6FG1ES237040

Year: 2014 Make: Dodge Model: RAM 1500




| | in. | (mm) |
|---|---|---|
| Distance from centerline to reference line - $L_{REF}$: | 43 | (1092) |
| Total Vehicle Length: | 229 1/8 | (5820) |
| Distance from vehicle c.g. to 1/2 of Vehicle total length: | - 7/8 | -(22) |
| Width of contact and induced crush - Field L: | 229 1/8 | (5820) |
| Crush measurement spacing interval (L/5) - I: | 45 7/8 | (1165) |
| Distance from vehicle c.g. to center of Field L - $D_{FL}$: | - 7/8 | -(22) |
| Width of Contact Damage: | 229 1/8 | (5820) |
| Distance from vehicle c.g. to center of contact damage - $D_C$: | - 7/8 | -(22) |

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) |
| $C_1$ | N/A | N/A | -115 1/2 | -(2934) | 33 1/2 | (851) | -1 | -(25) | N/A | N/A |
| $C_2$ | N/A | N/A | -69 5/8 | -(1768) | 5 1/4 | (133) | | | N/A | N/A |
| $C_3$ | 4 5/8 | (117) | -23 3/4 | -(603) | 5 1/2 | (140) | | | 1/8 | (3) |
| $C_4$ | 3 7/8 | (98) | 22 1/8 | (562) | 5 1/8 | (130) | | | - 1/4 | -(6) |
| $C_5$ | N/A | N/A | 68 | (1727) | 5 | (127) | | | N/A | N/A |
| $C_6$ | N/A | N/A | 113 7/8 | (2892) | 33 1/2 | (851) | | | N/A | N/A |
| $C_{MAX}$ | 24 1/2 | (622) | 89 | (2261) | 5 3/4 | (146) | | | 19 3/4 | (502) |

Figure D-13. Exterior Vehicle Crush (NASS) - Side, Test No. HWTT-2

# Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. HWTT-1

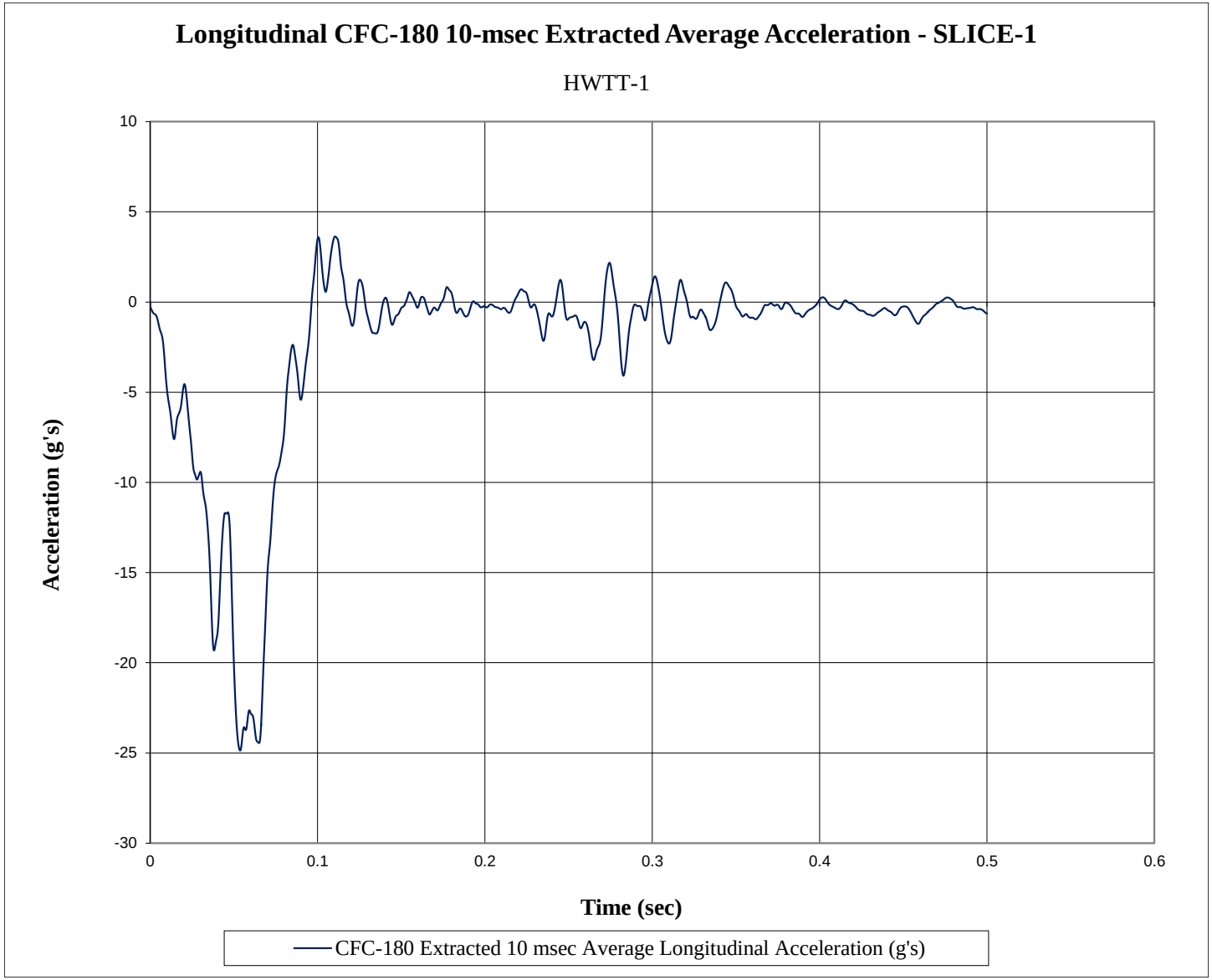



Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. HWTT-1

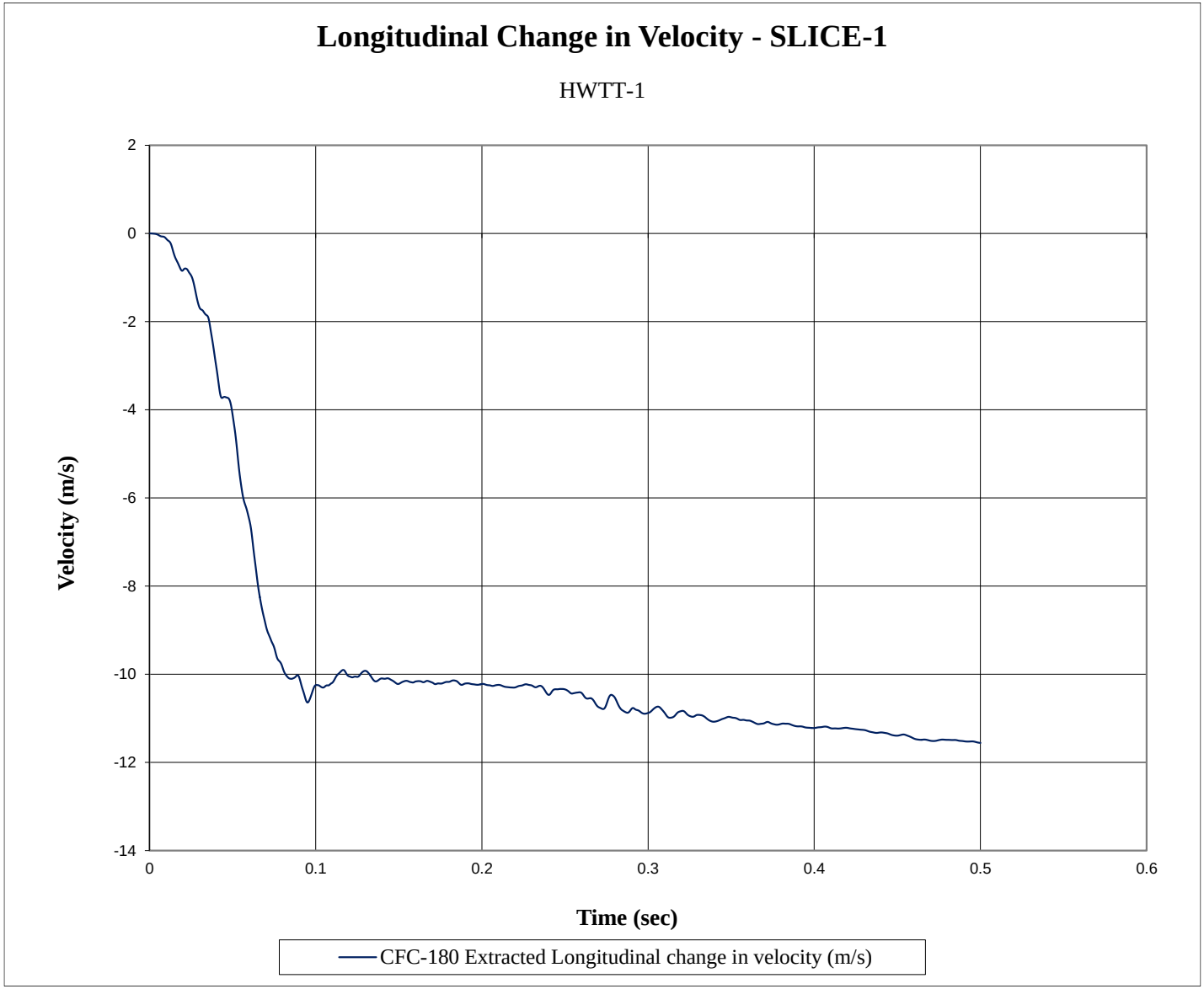



Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. HWTT-1

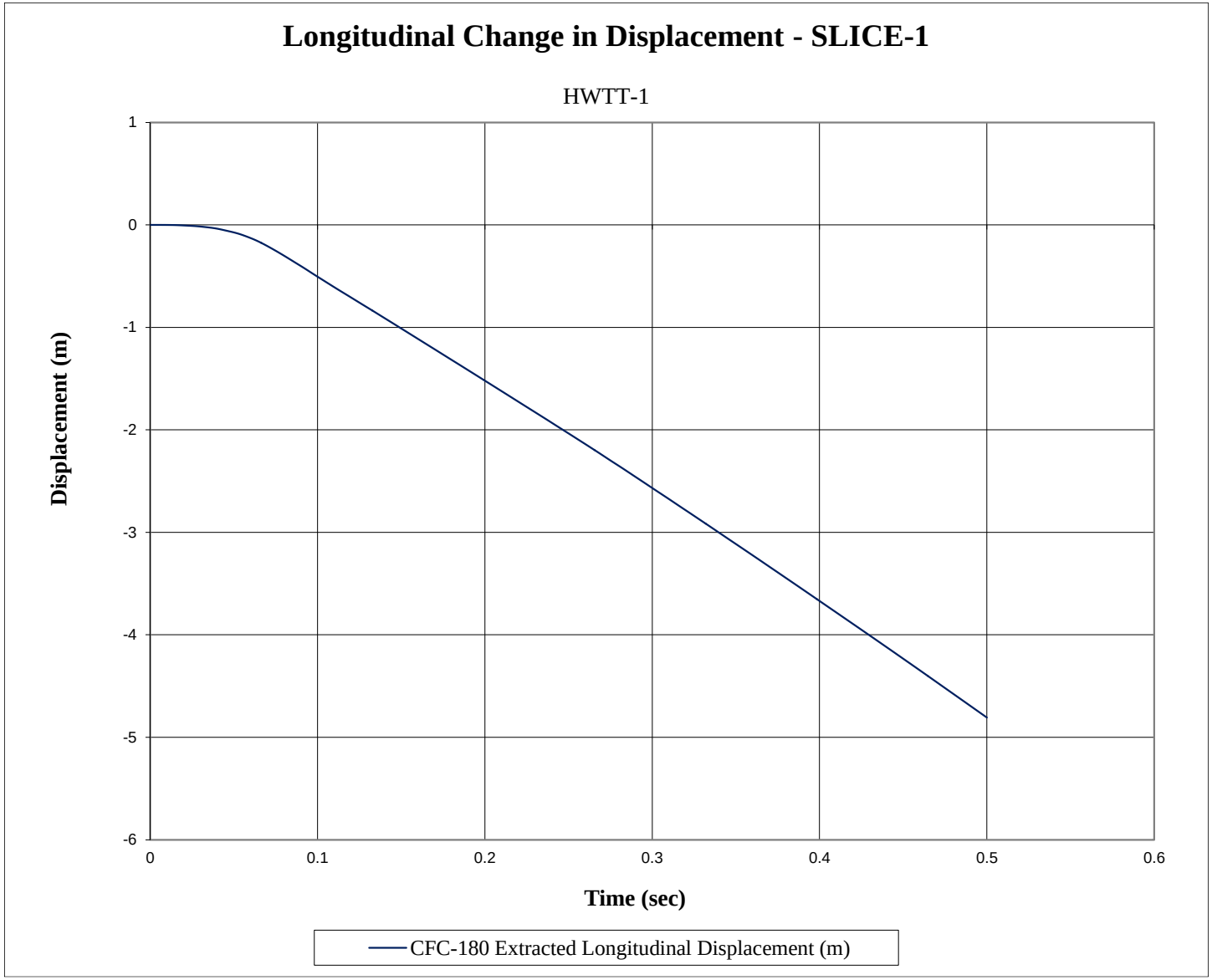



Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. HWTT-1

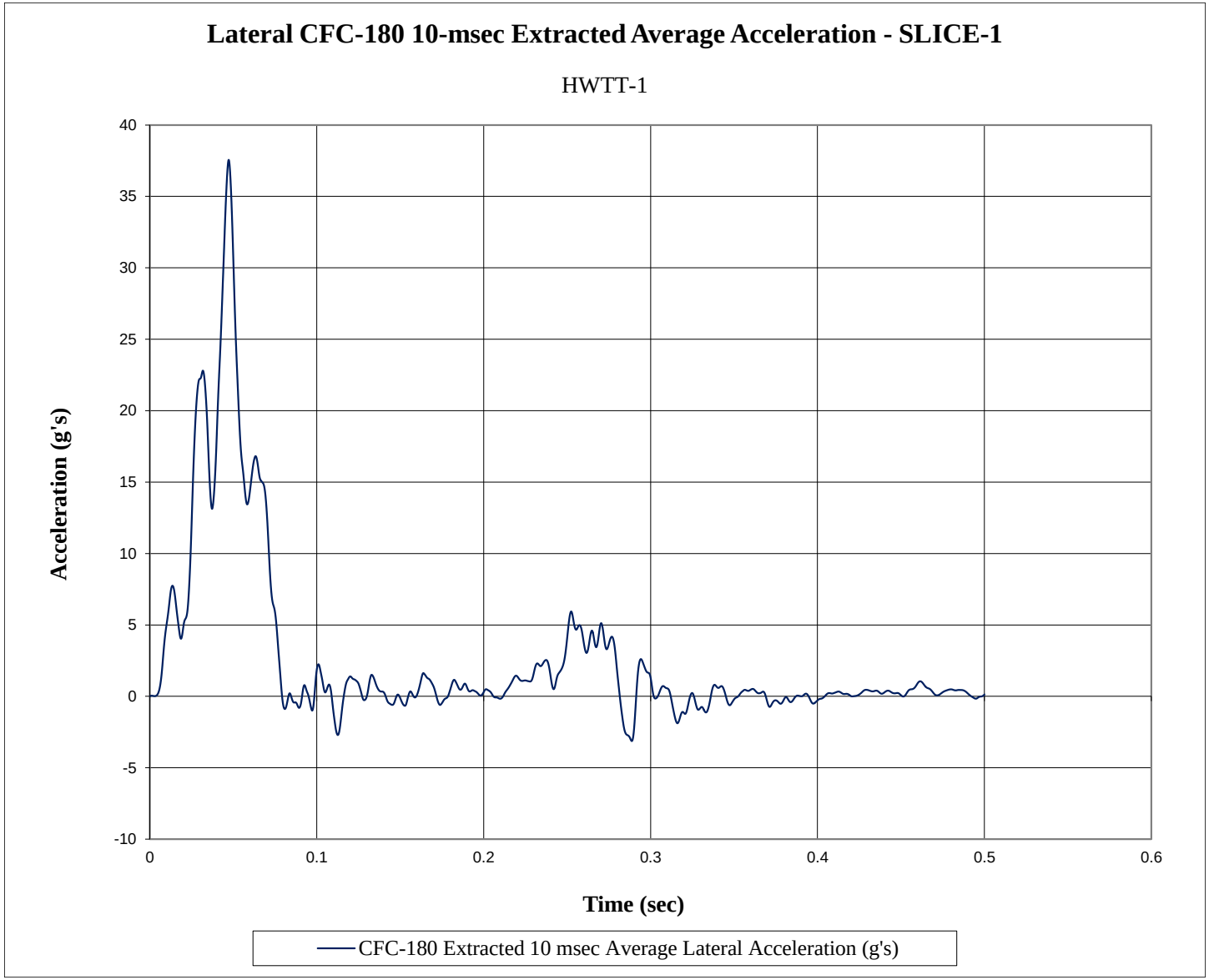



Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. HWTT-1

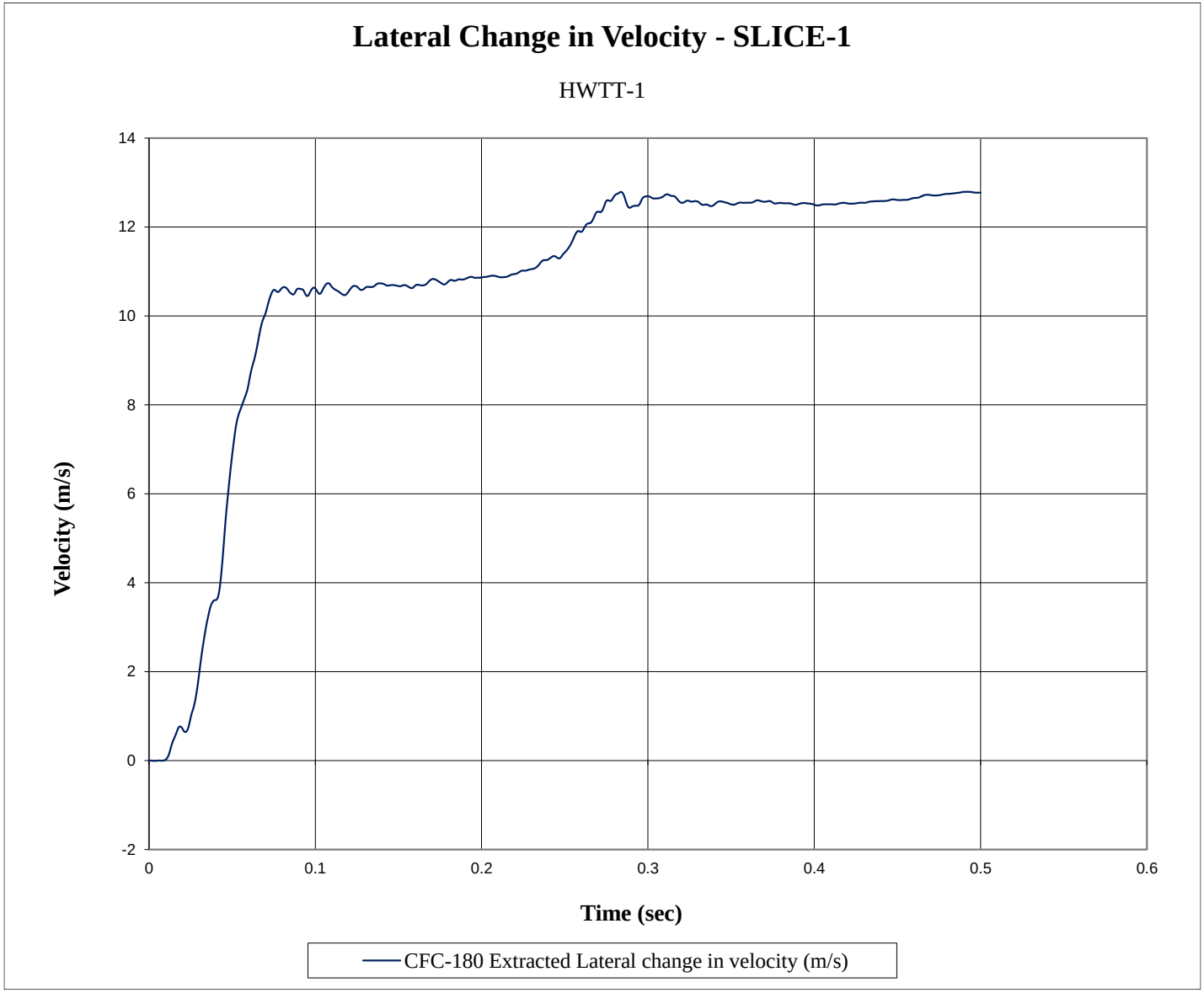



Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. HWTT-1

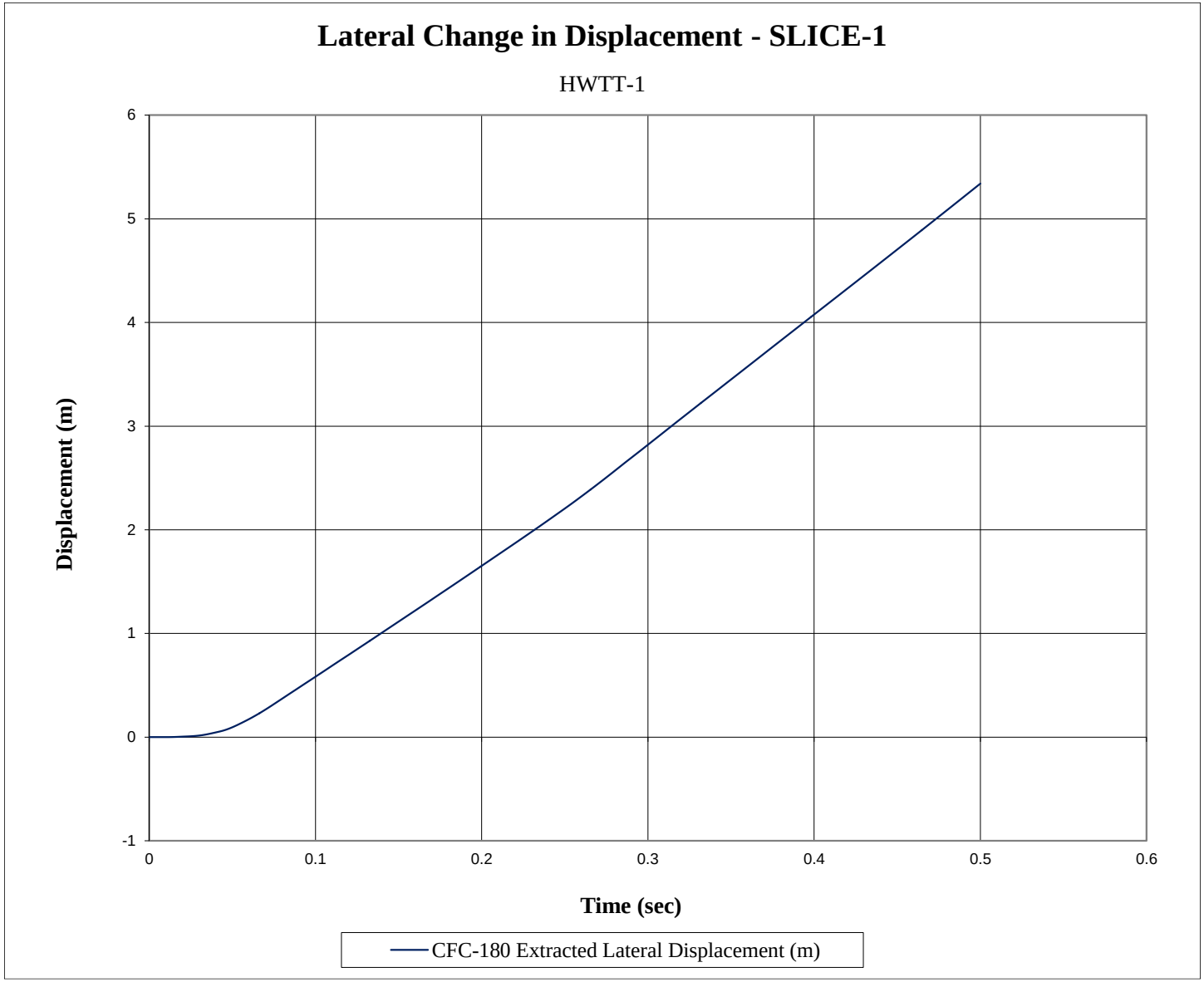



Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. HWTT-1

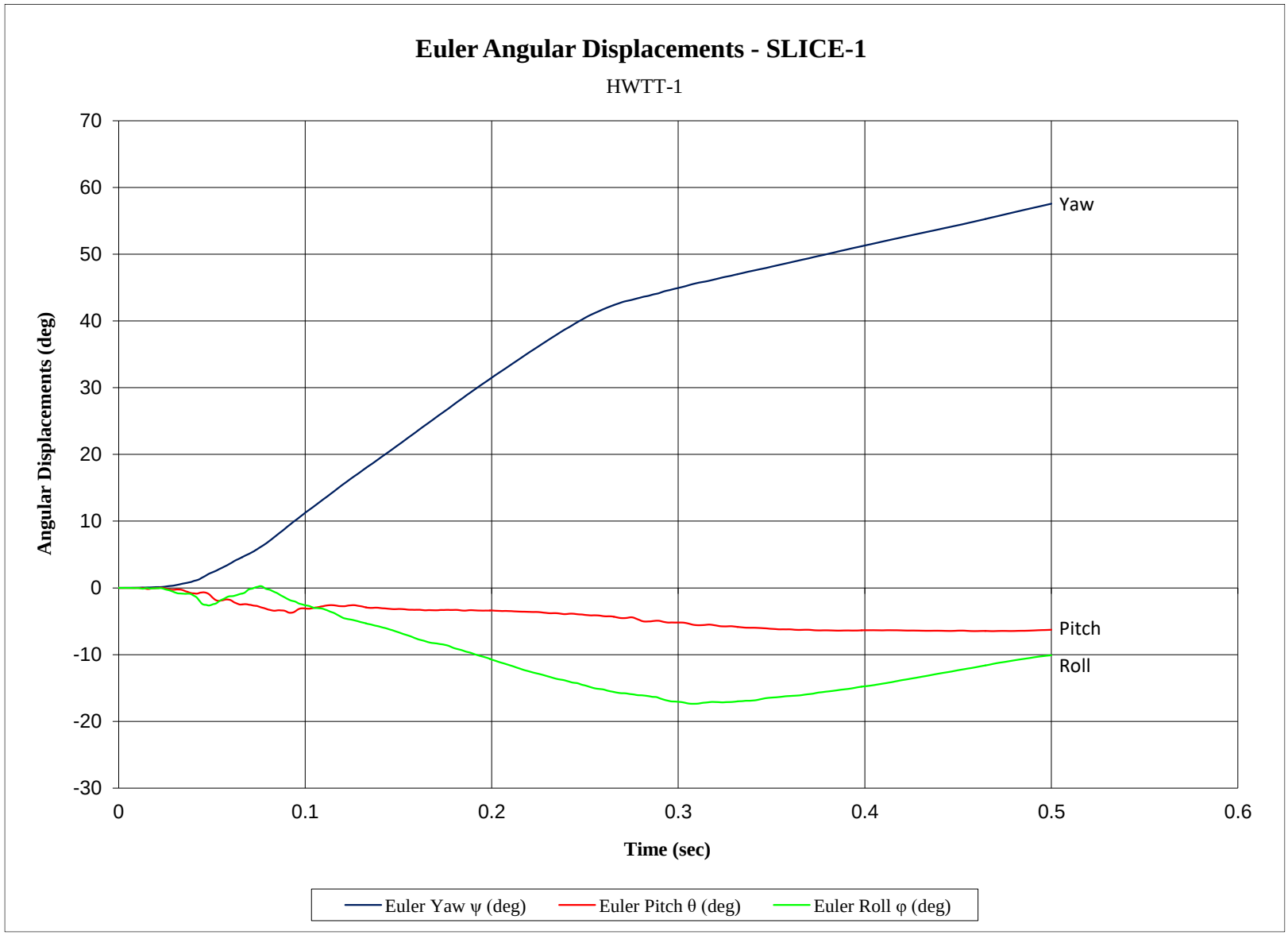



Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. HWTT-1

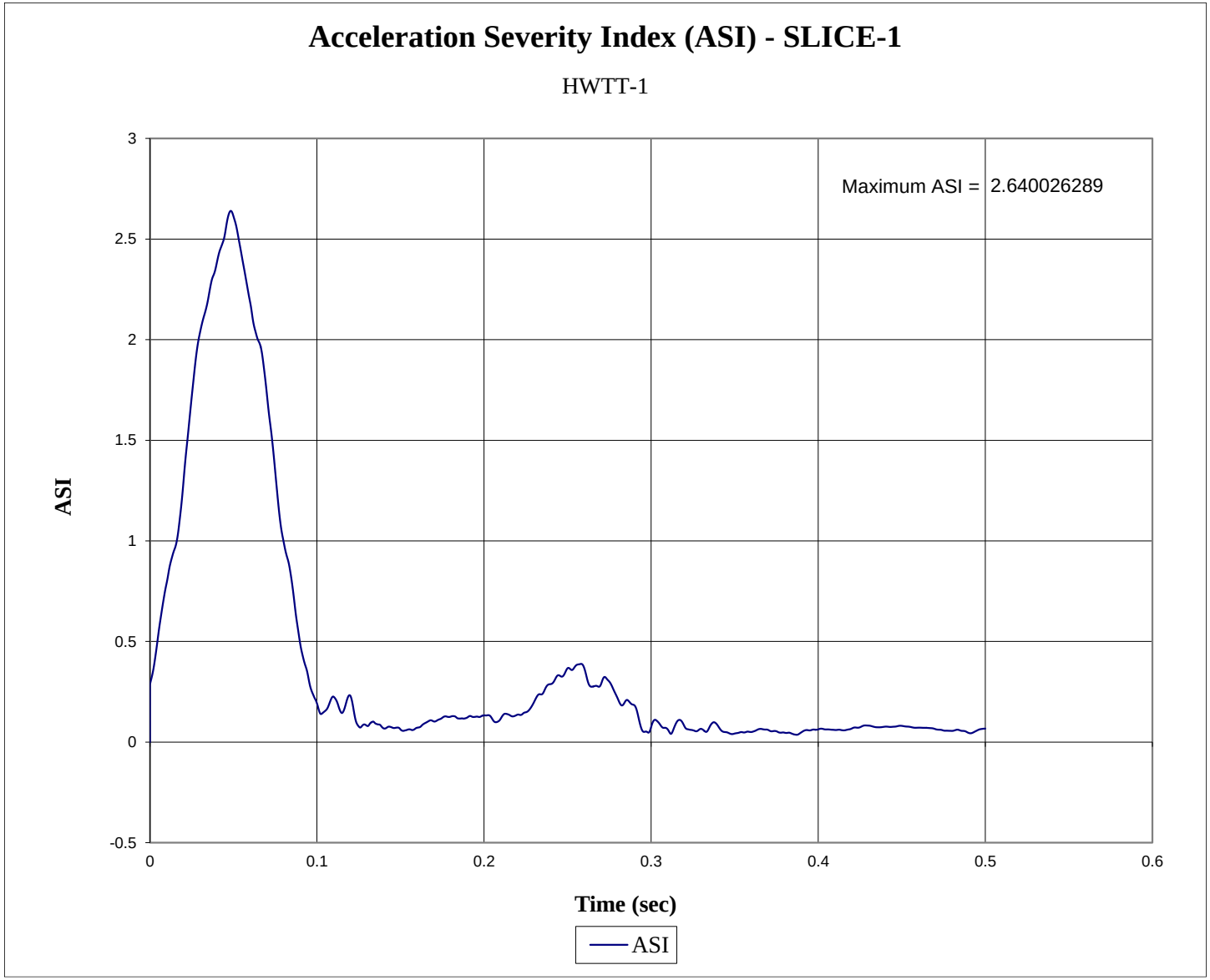



Figure E-8. Acceleration Severity Index (SLICE-1), Test No. HWTT-1

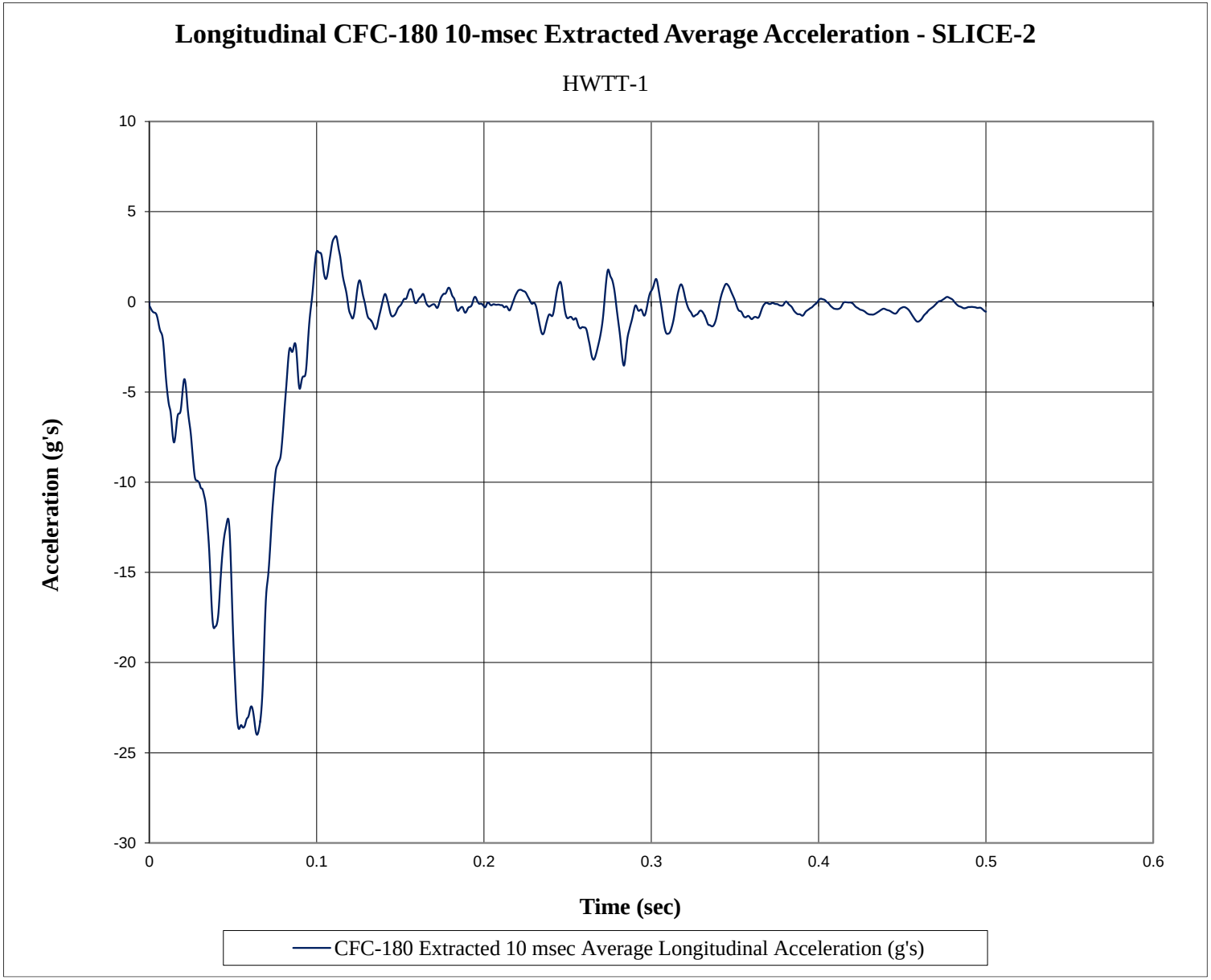



Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. HWTT-1

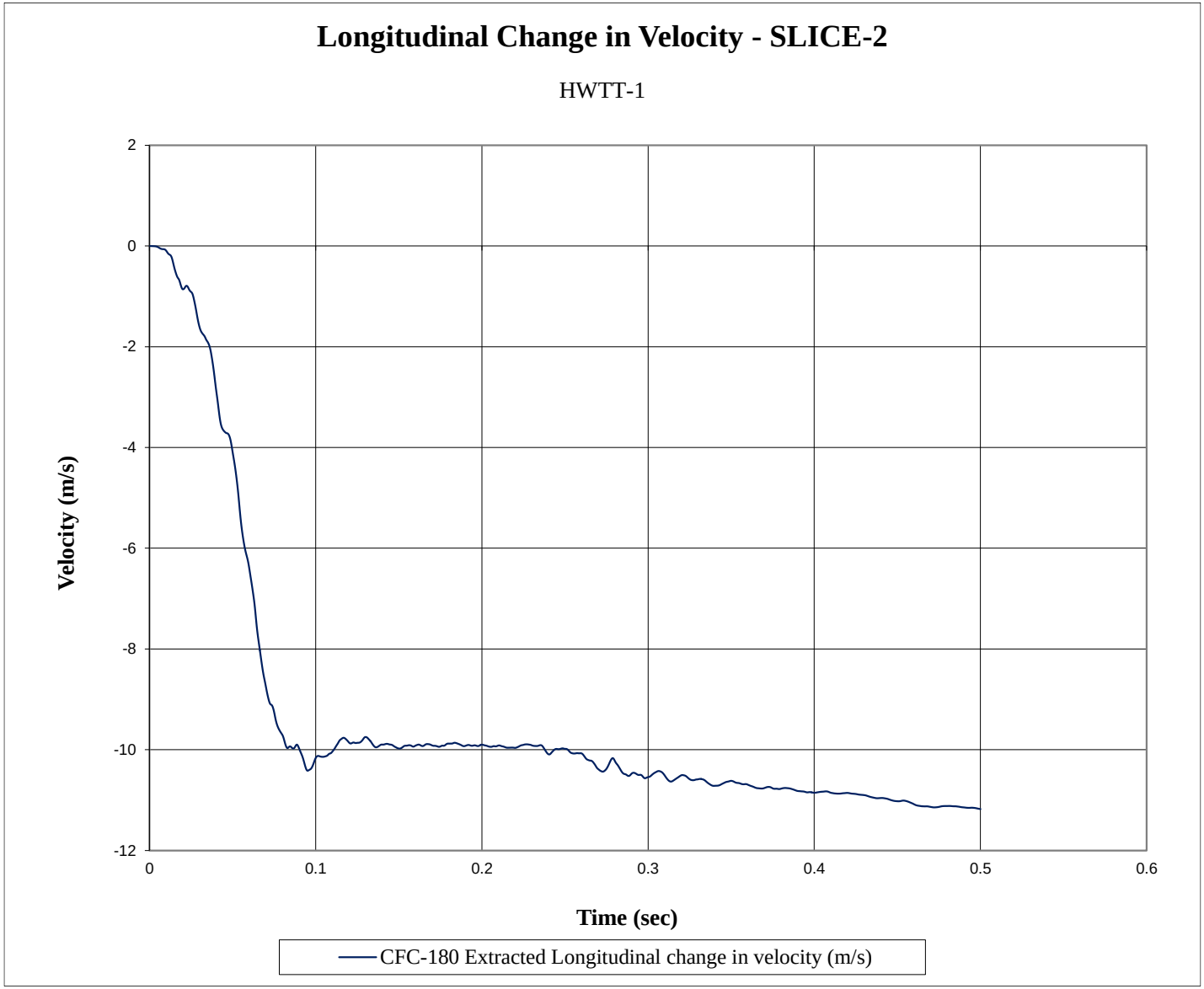



Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. HWTT-1

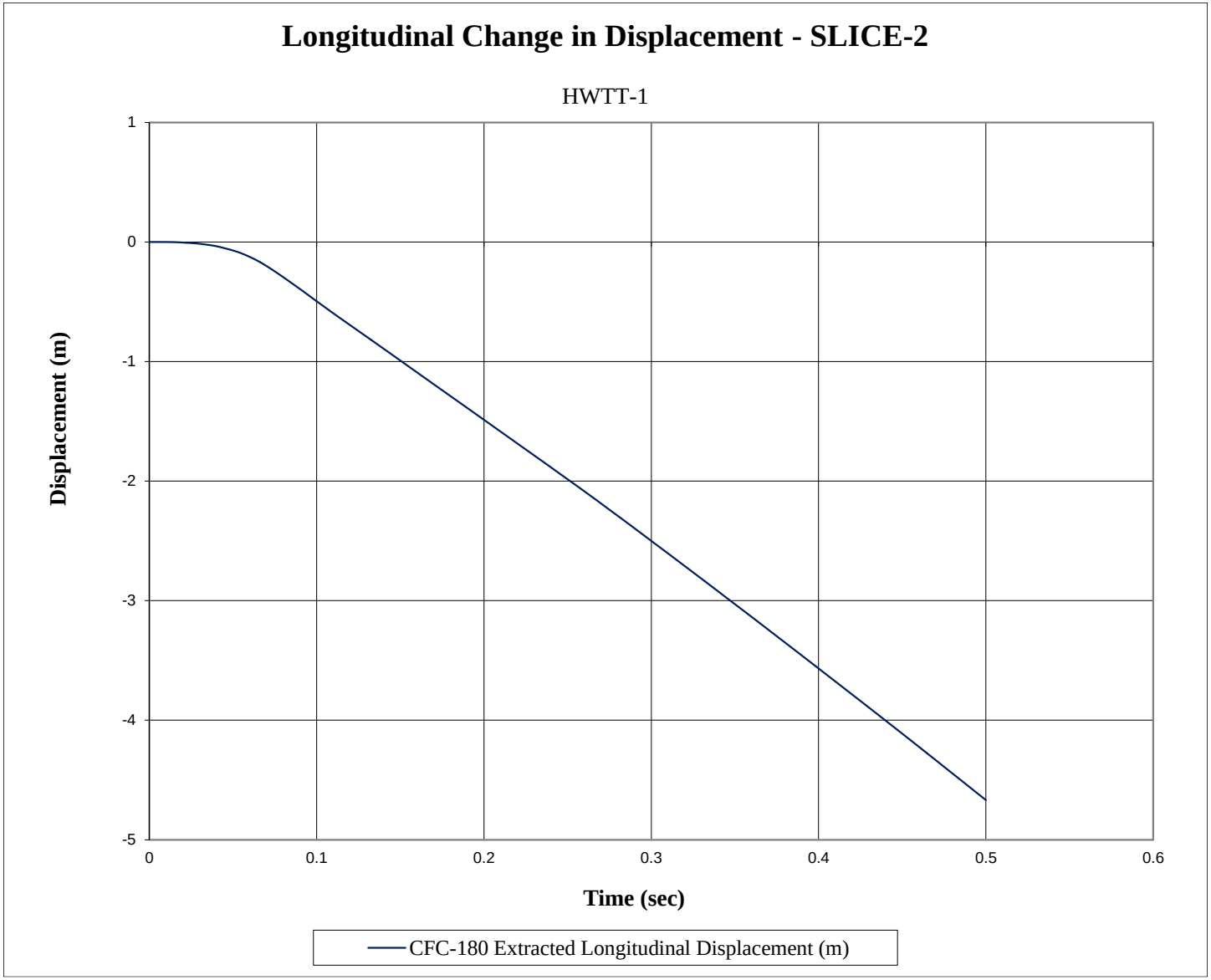



Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. HWTT-1

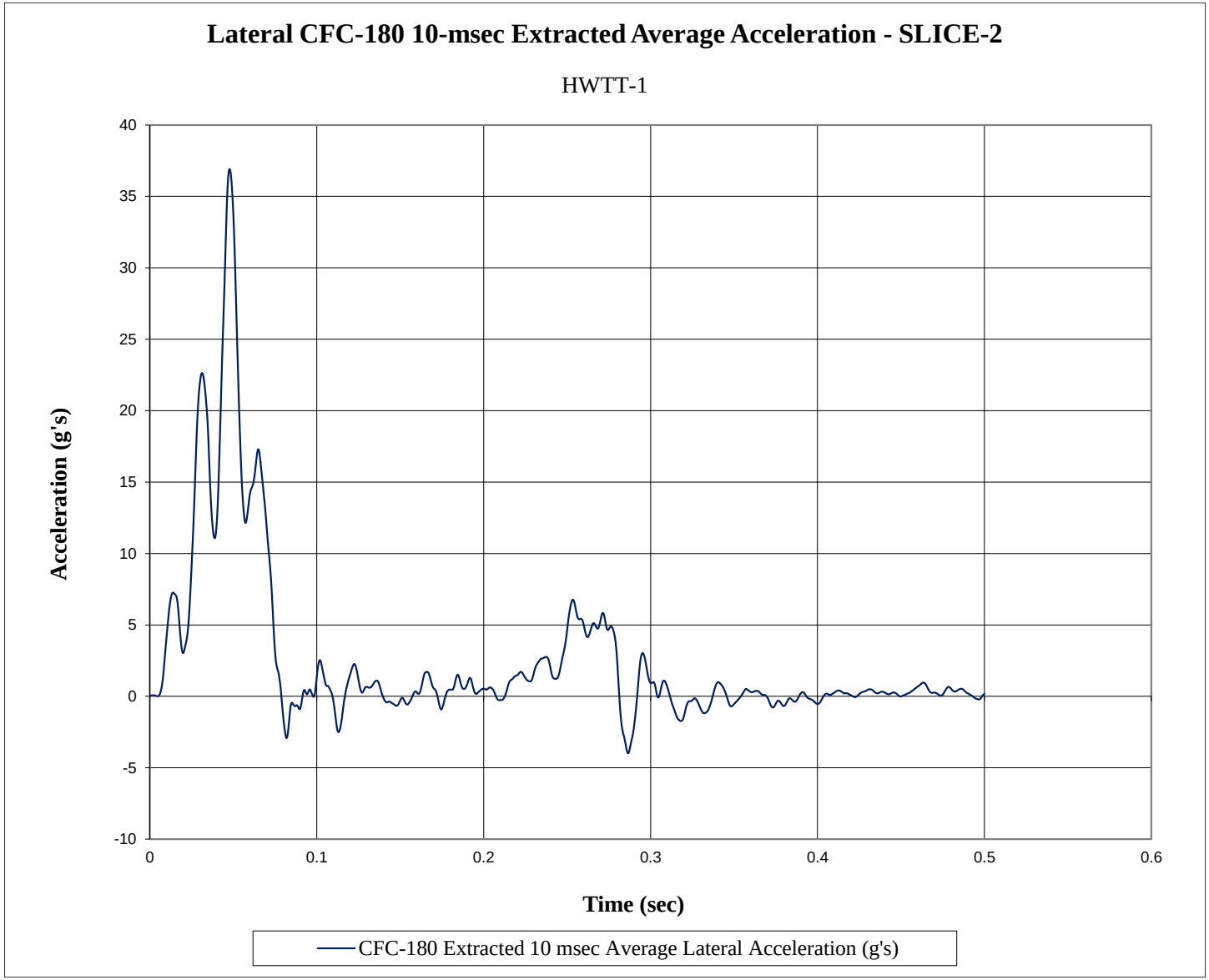



Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. HWTT-1

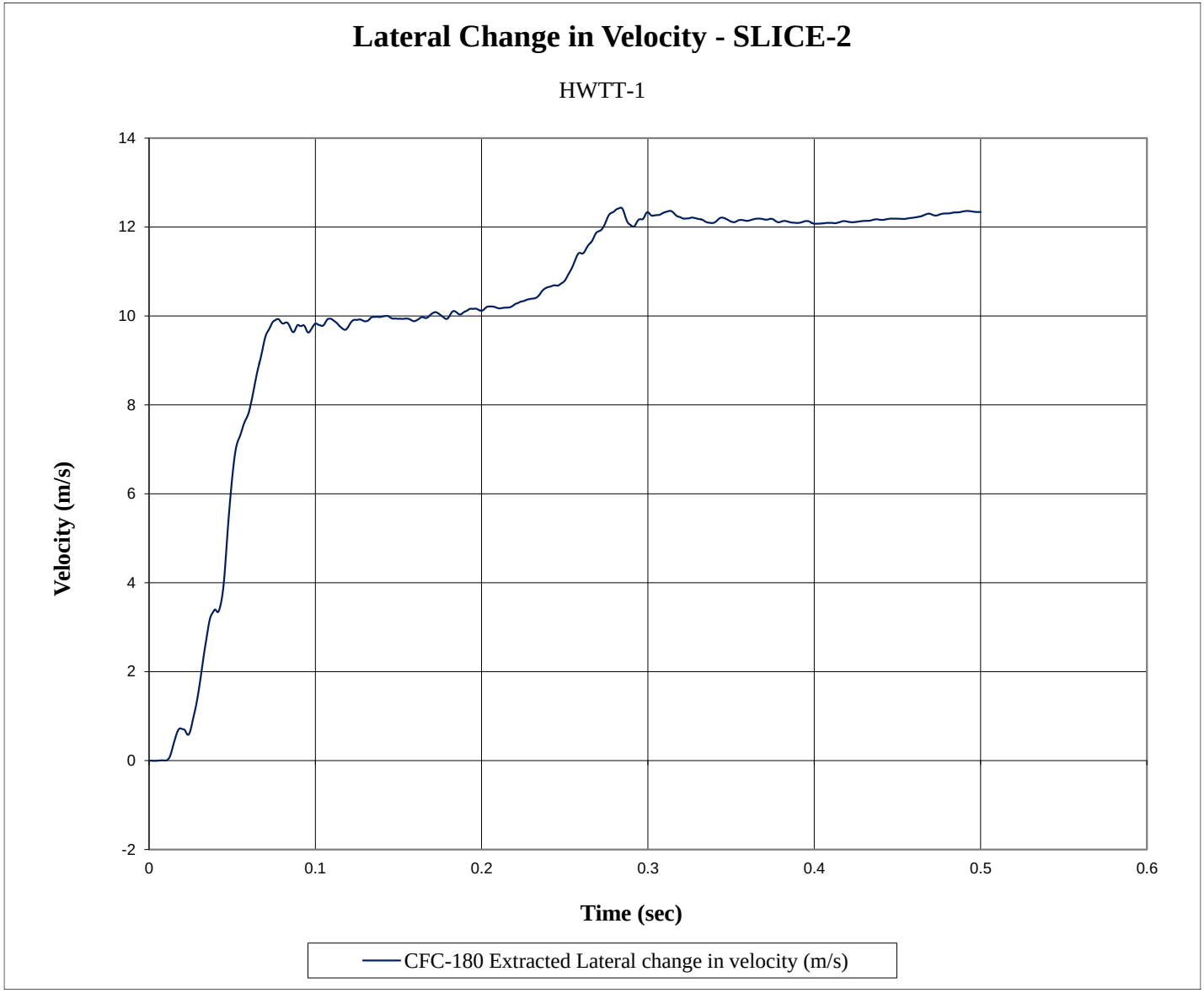



Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. HWTT-1

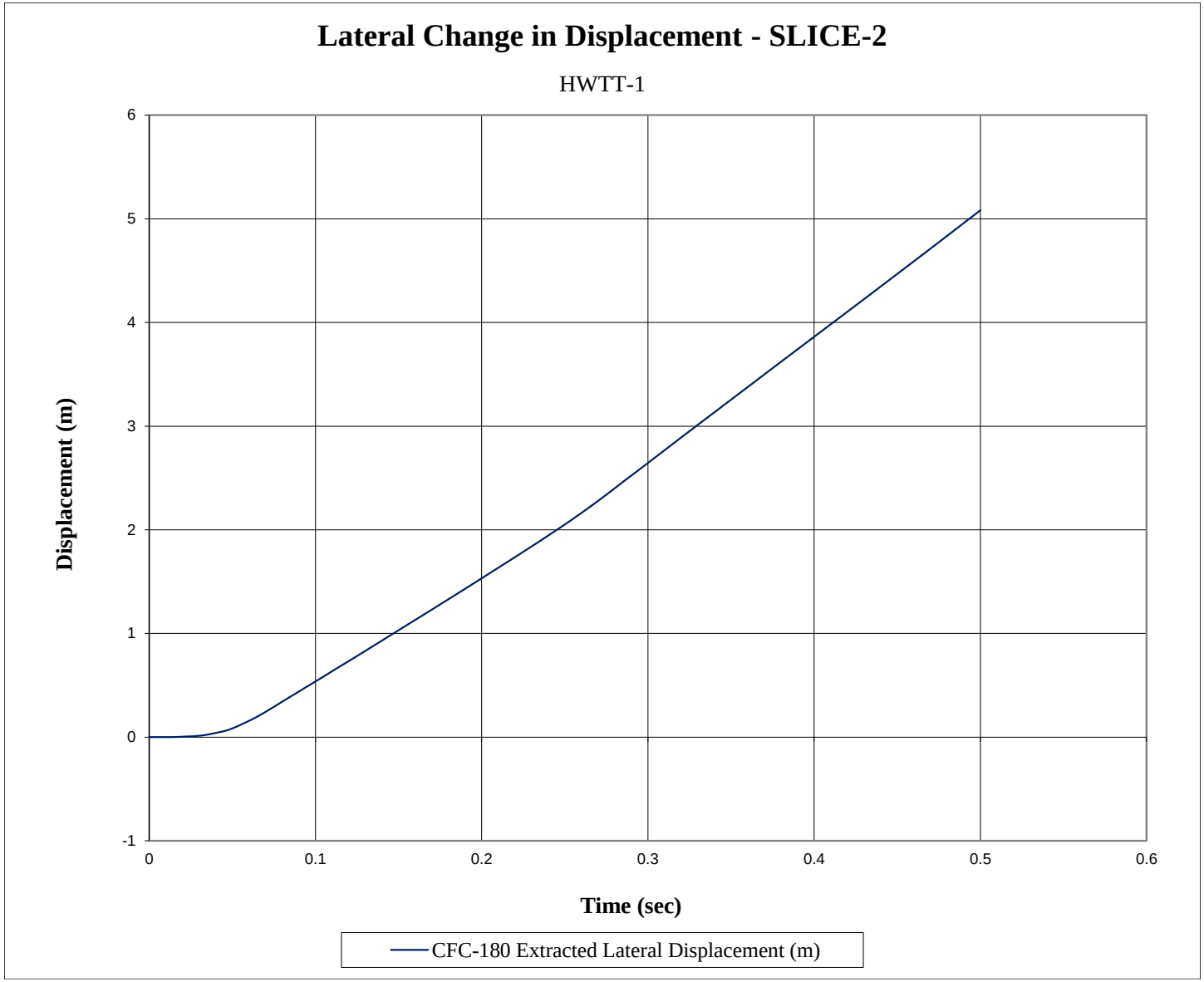



Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. HWTT-1

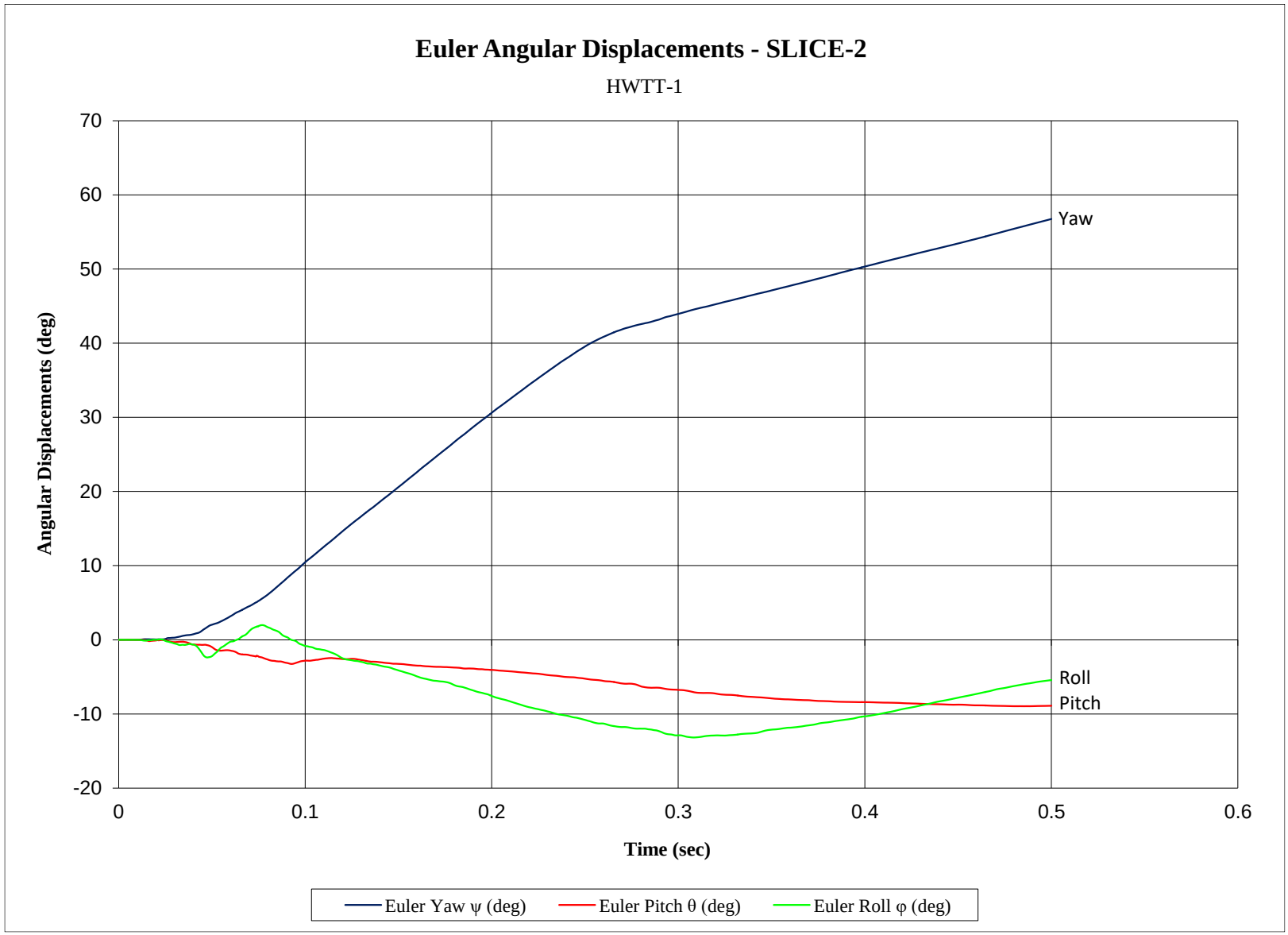



Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. HWTT-1

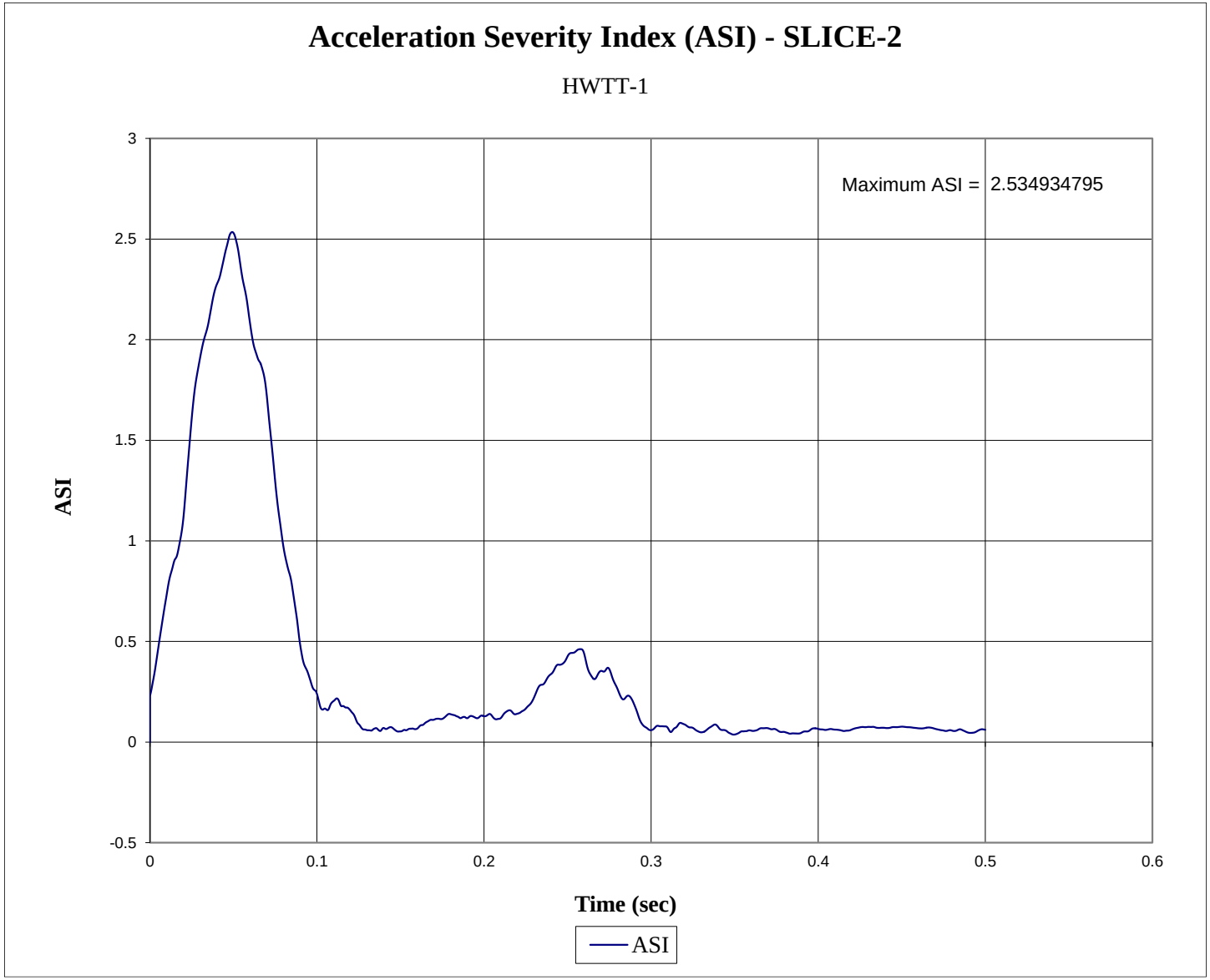



Figure E-16. Acceleration Severity Index (SLICE-2), Test No. HWTT-1

# Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. HWTT-2

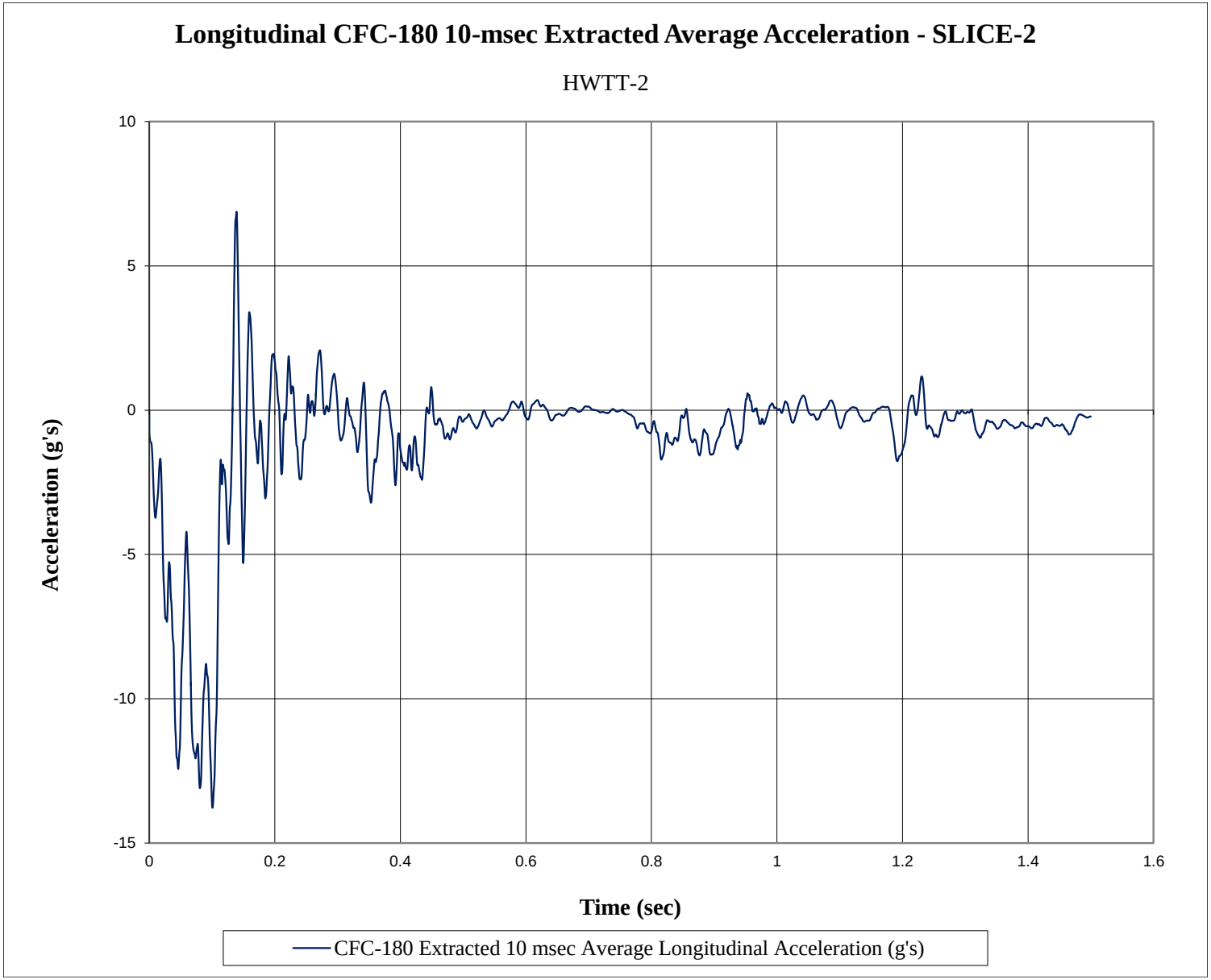



Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. HWTT-2

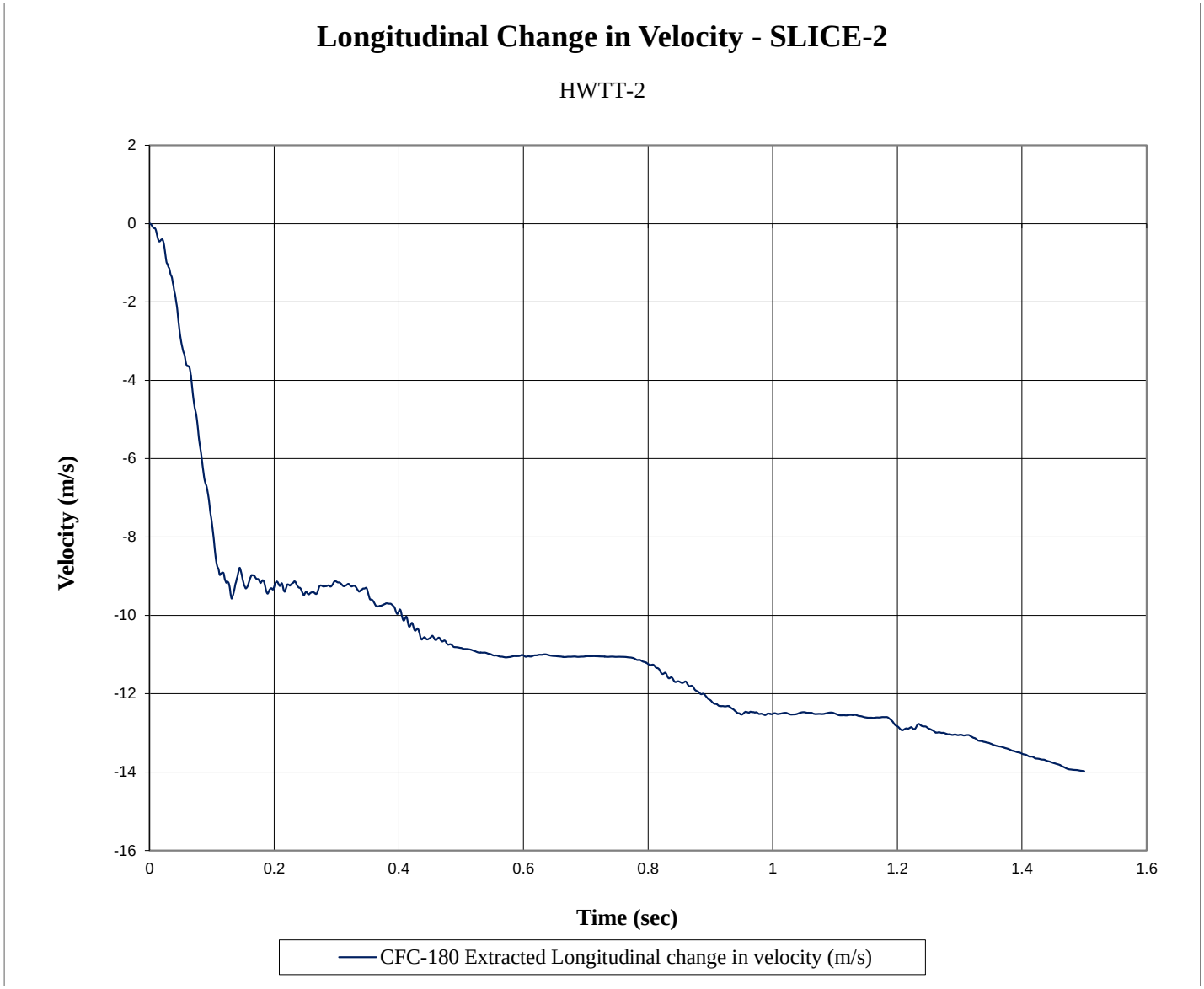



Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. HWTT-2

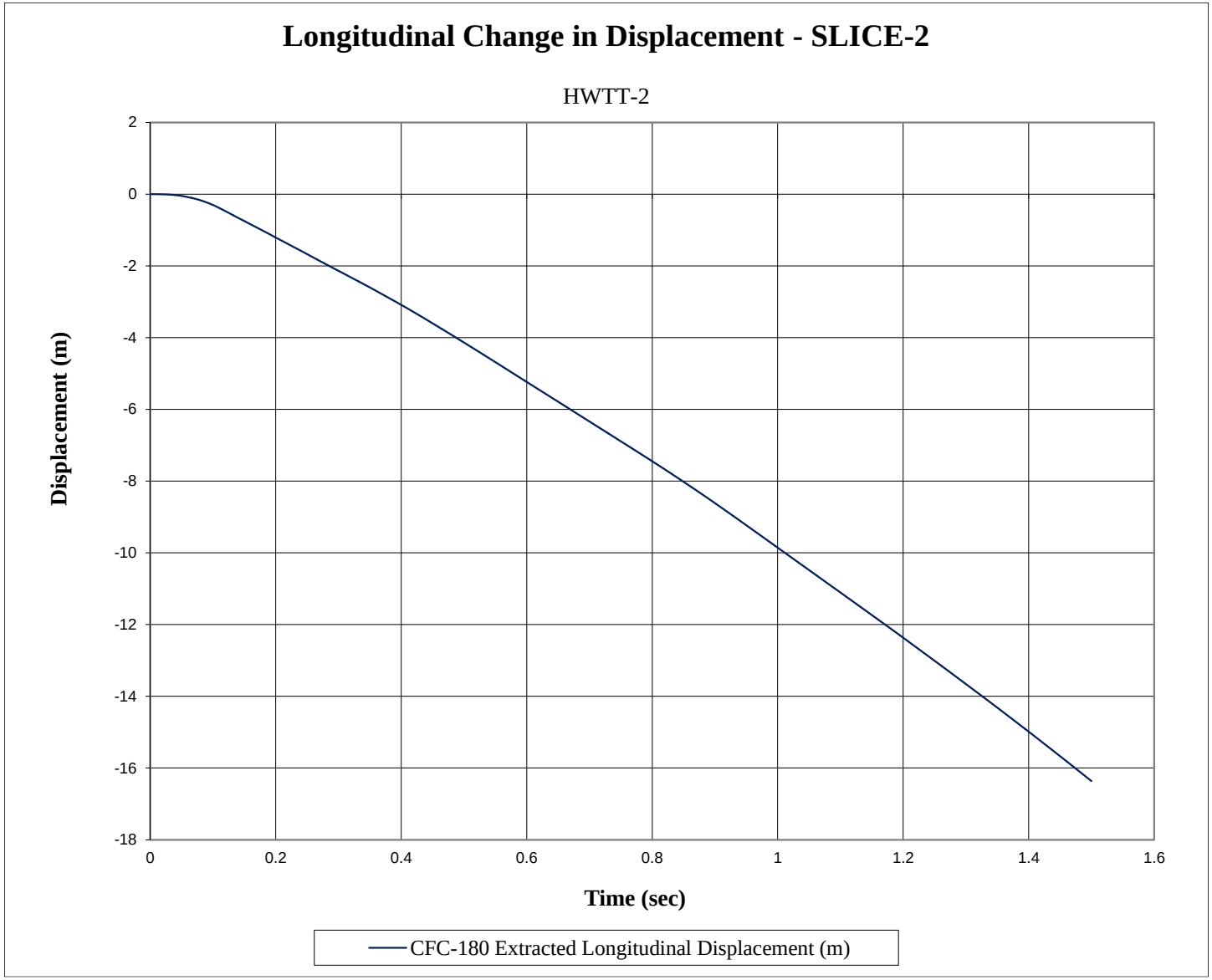



Figure F-3. Longitudinal Occupant Displacement (SLICE-2), Test No. HWTT-2

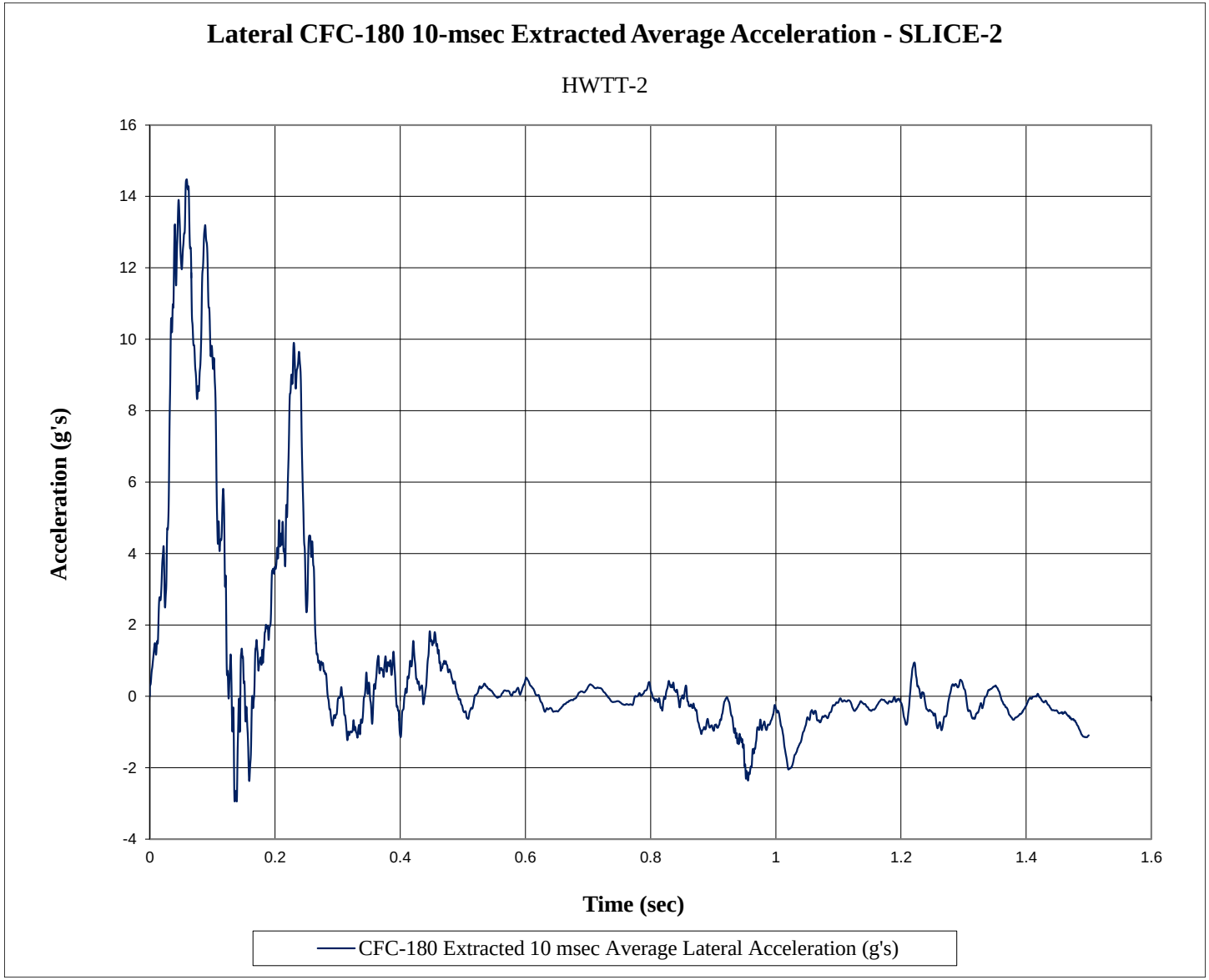



Figure F-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. HWTT-2

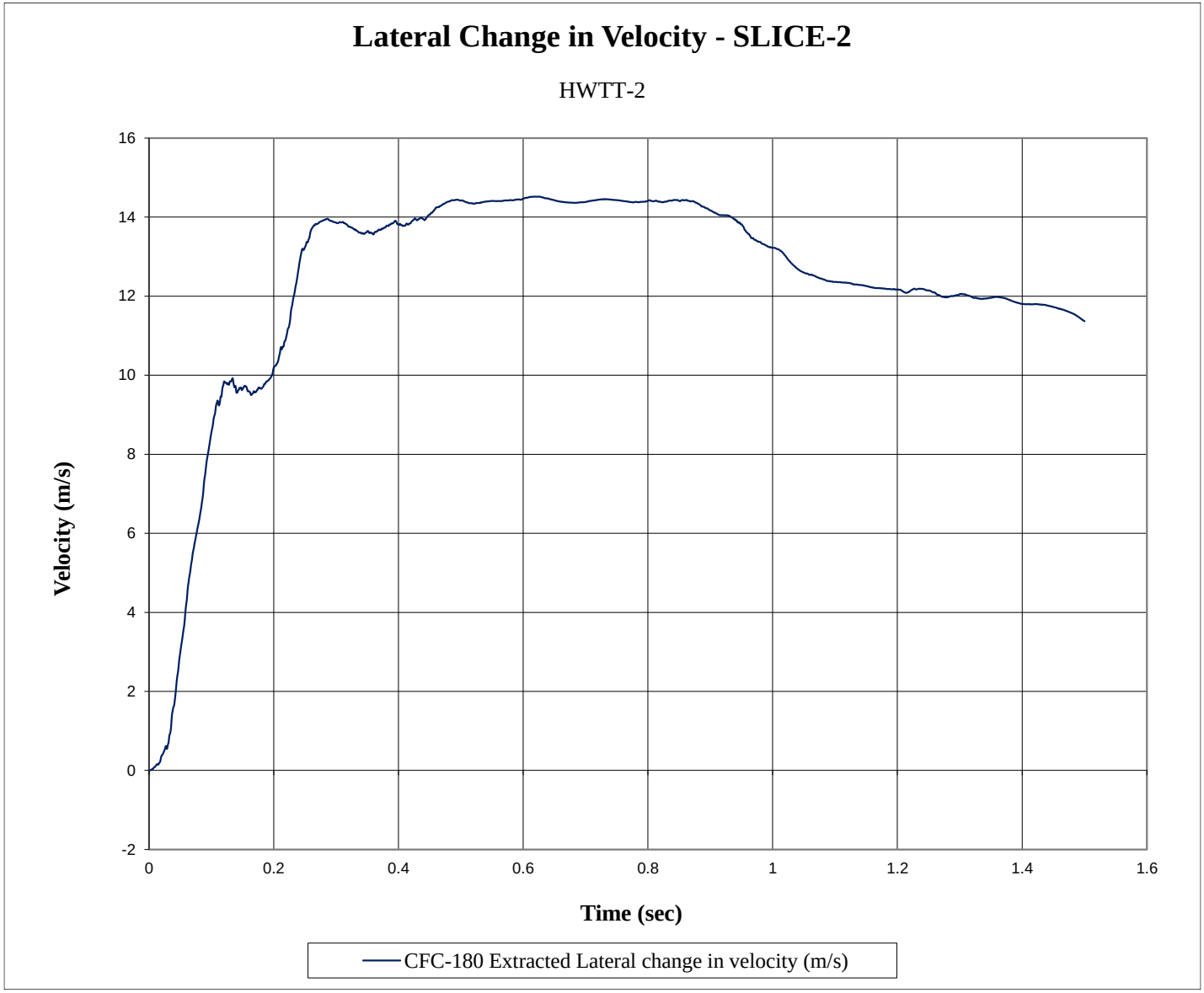



Figure F-5. Lateral Occupant Impact Velocity (SLICE-2), Test No. HWTT-2

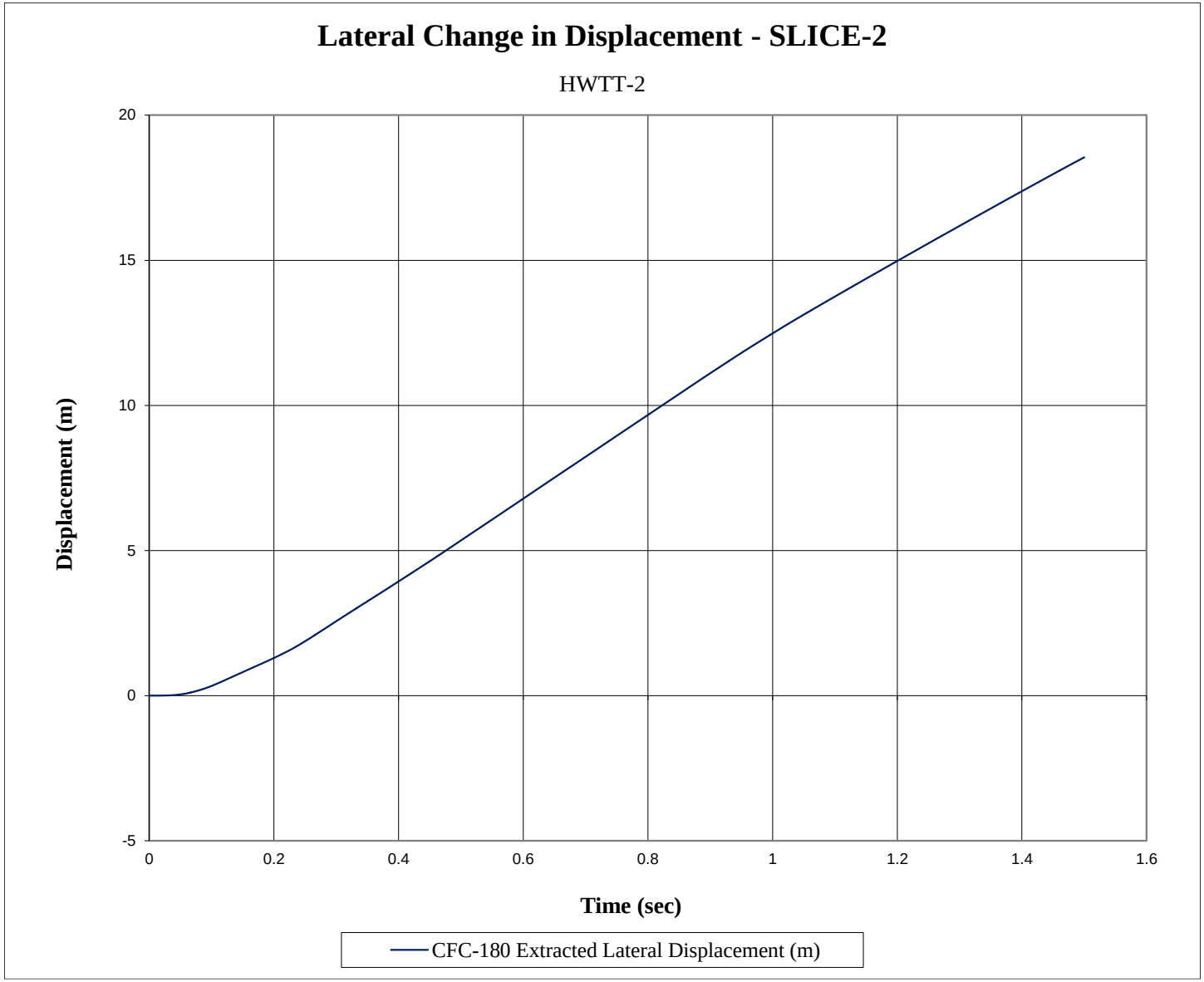



Figure F-6. Lateral Occupant Displacement (SLICE-2), Test No. HWTT-2

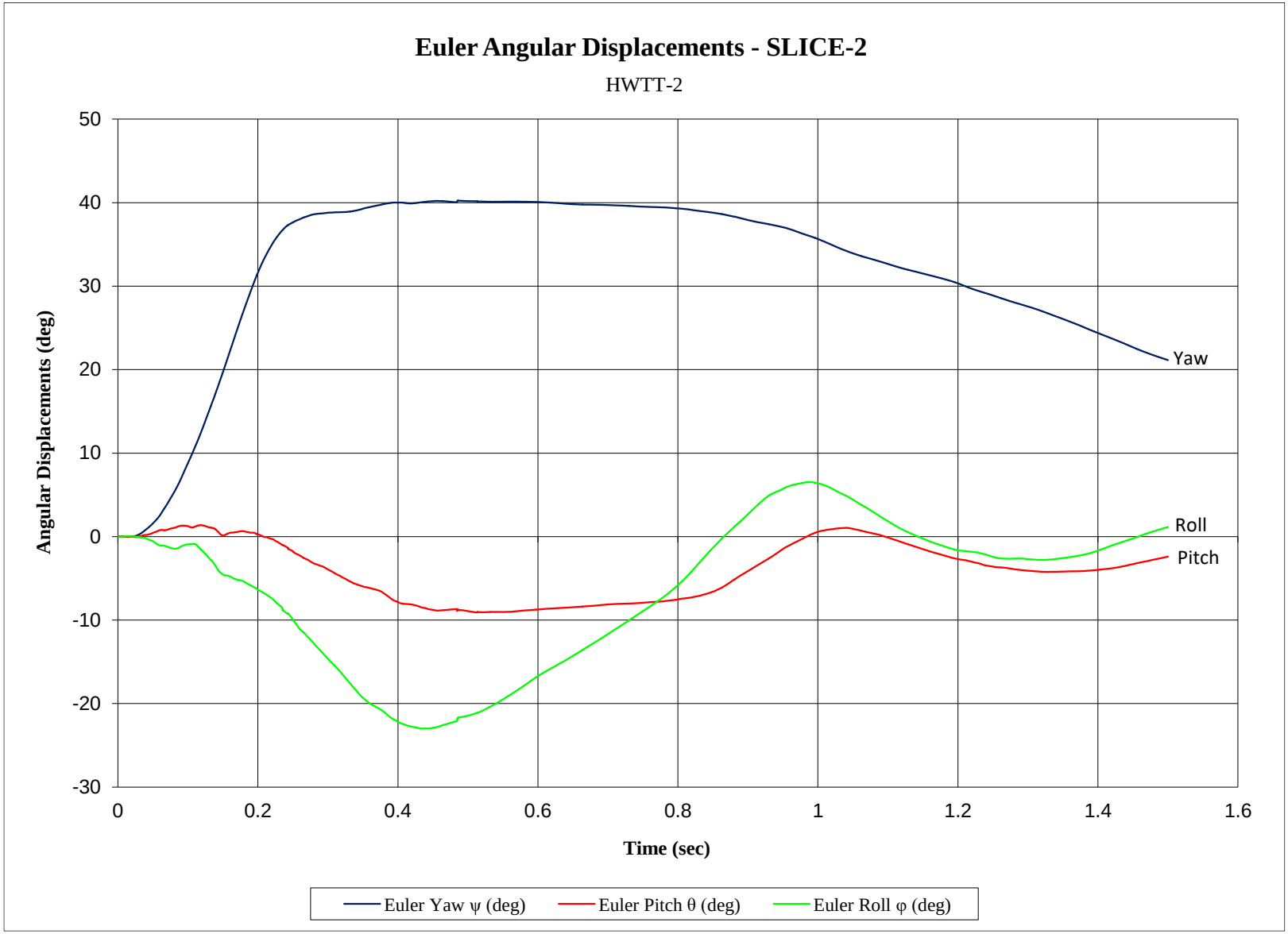



Figure F-7. Vehicle Angular Displacements (SLICE-2), Test No. HWTT-2

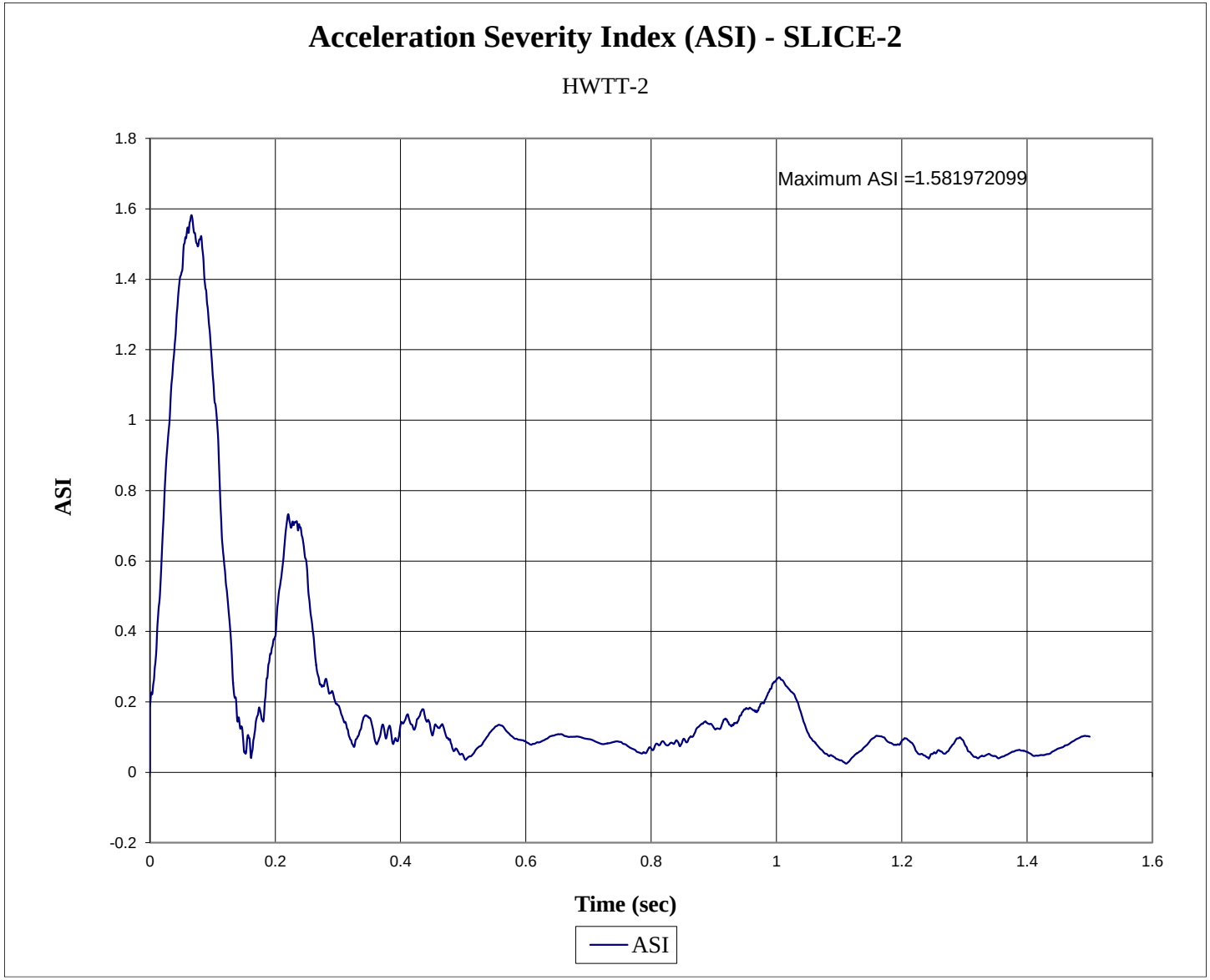



Figure F-8. Acceleration Severity Index (SLICE-2), Test No. HWTT-2

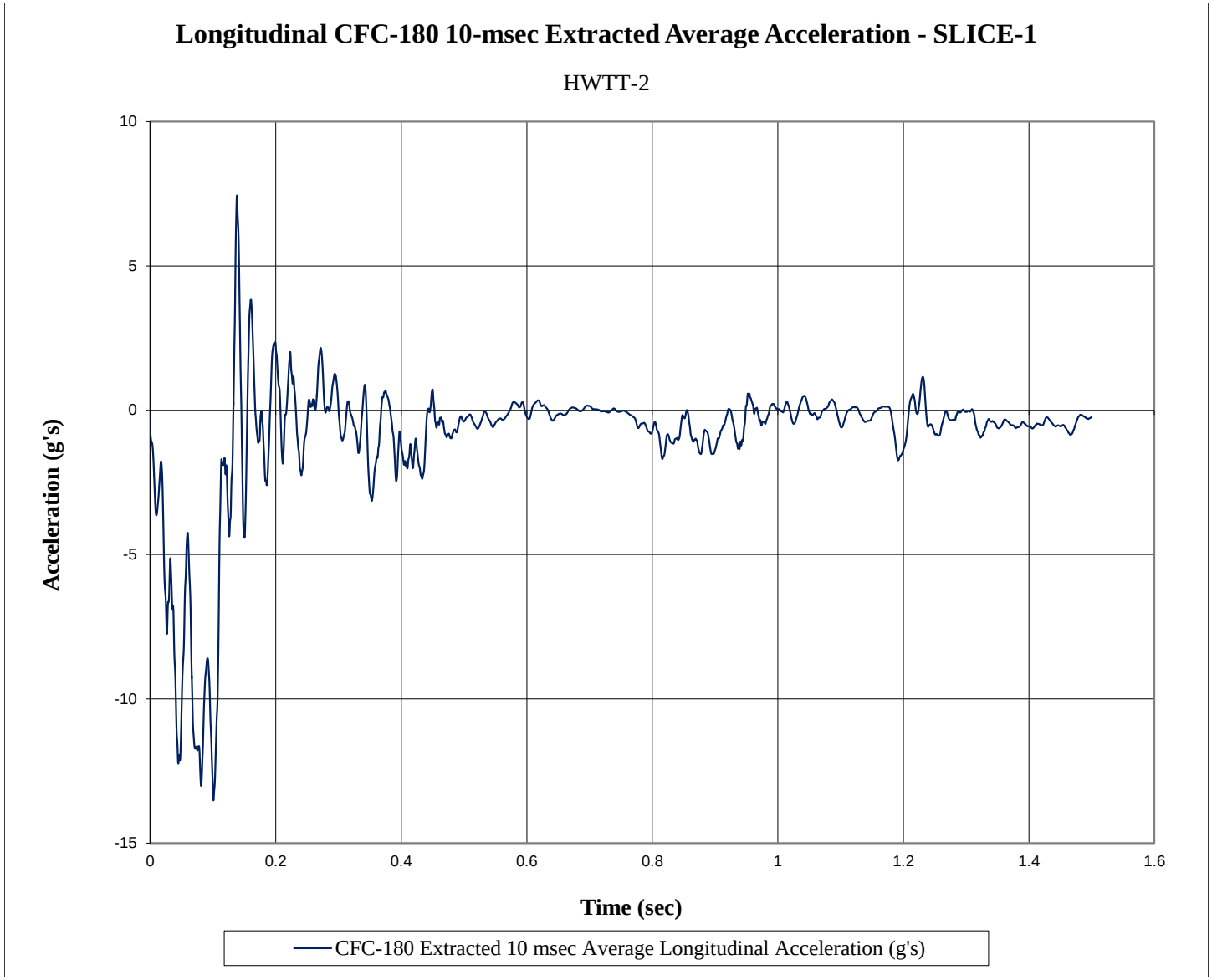



Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. HWTT-2

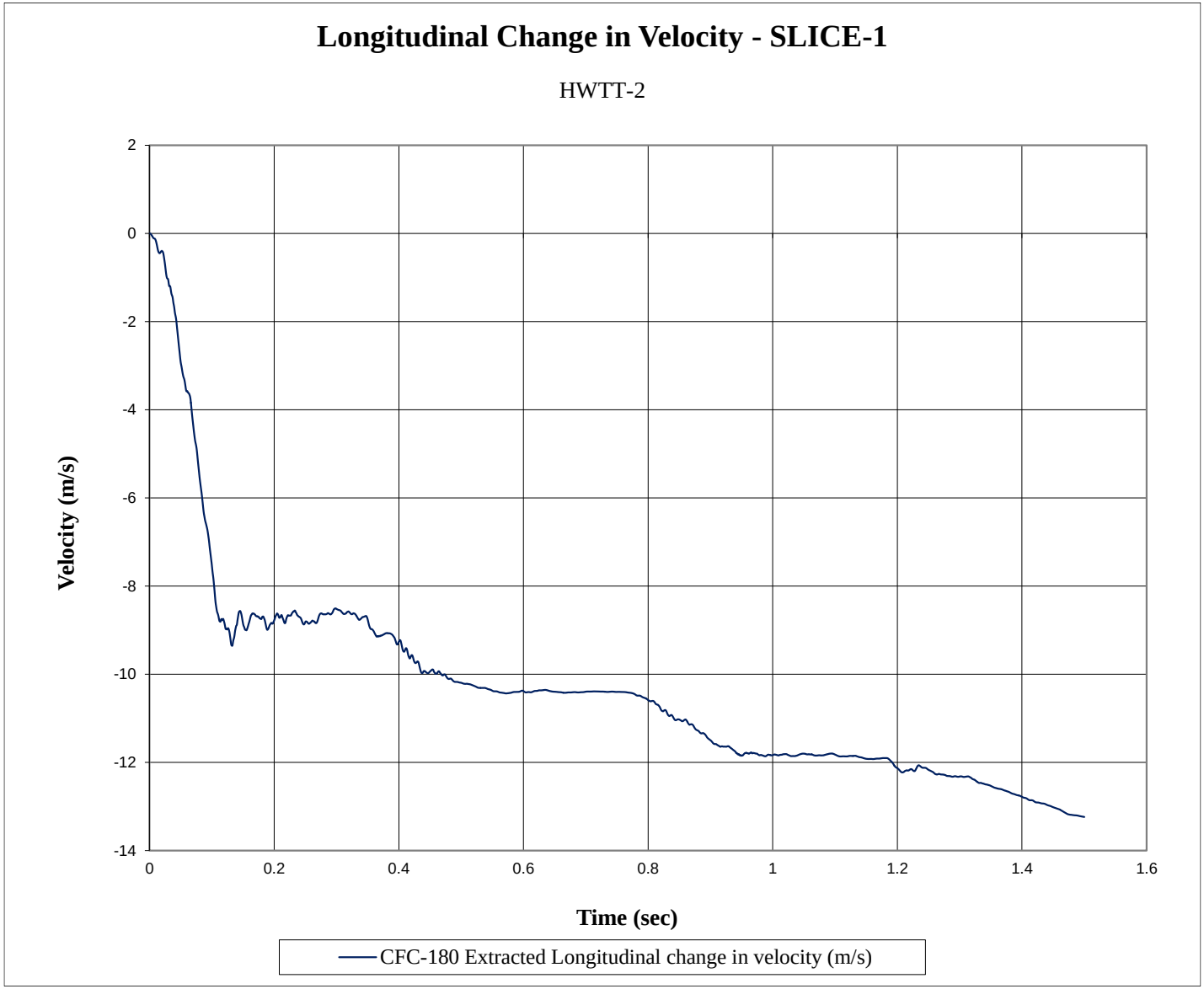



Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. HWTT-2

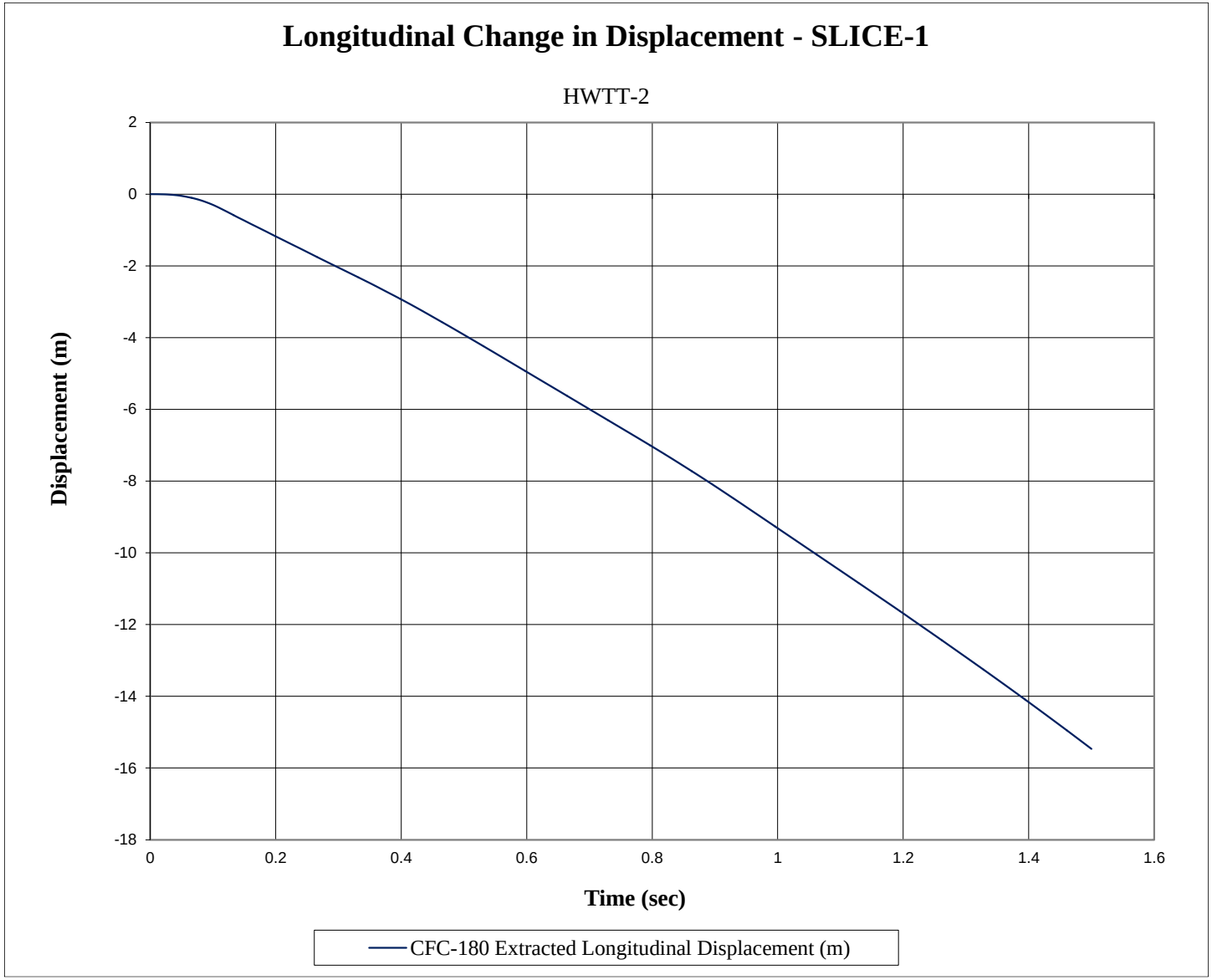



Figure F-11. Longitudinal Occupant Displacement (SLICE-1), Test No. HWTT-2

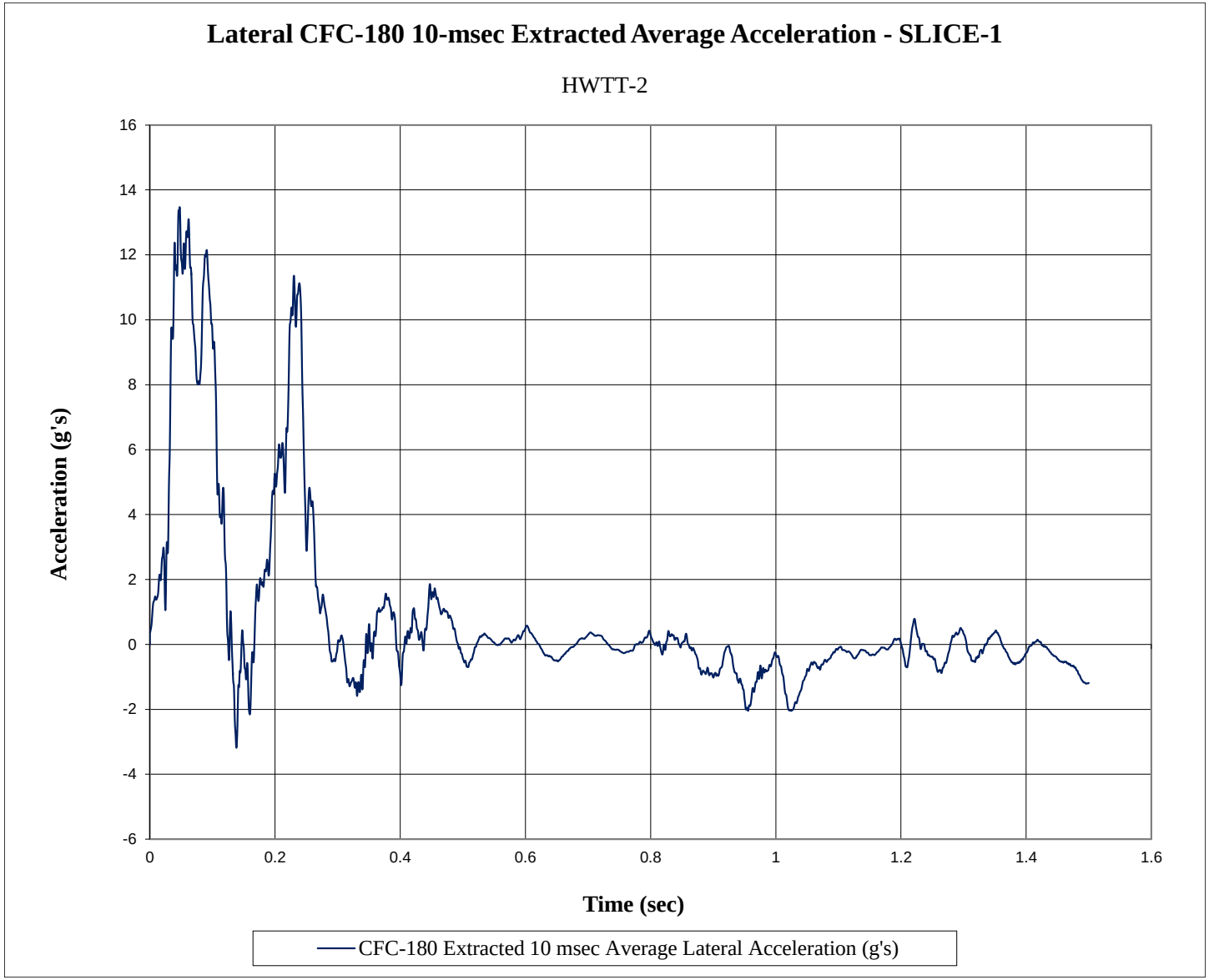



Figure F-12. 10-ms Average Lateral Deceleration (SLICE-1), Test No. HWTT-2

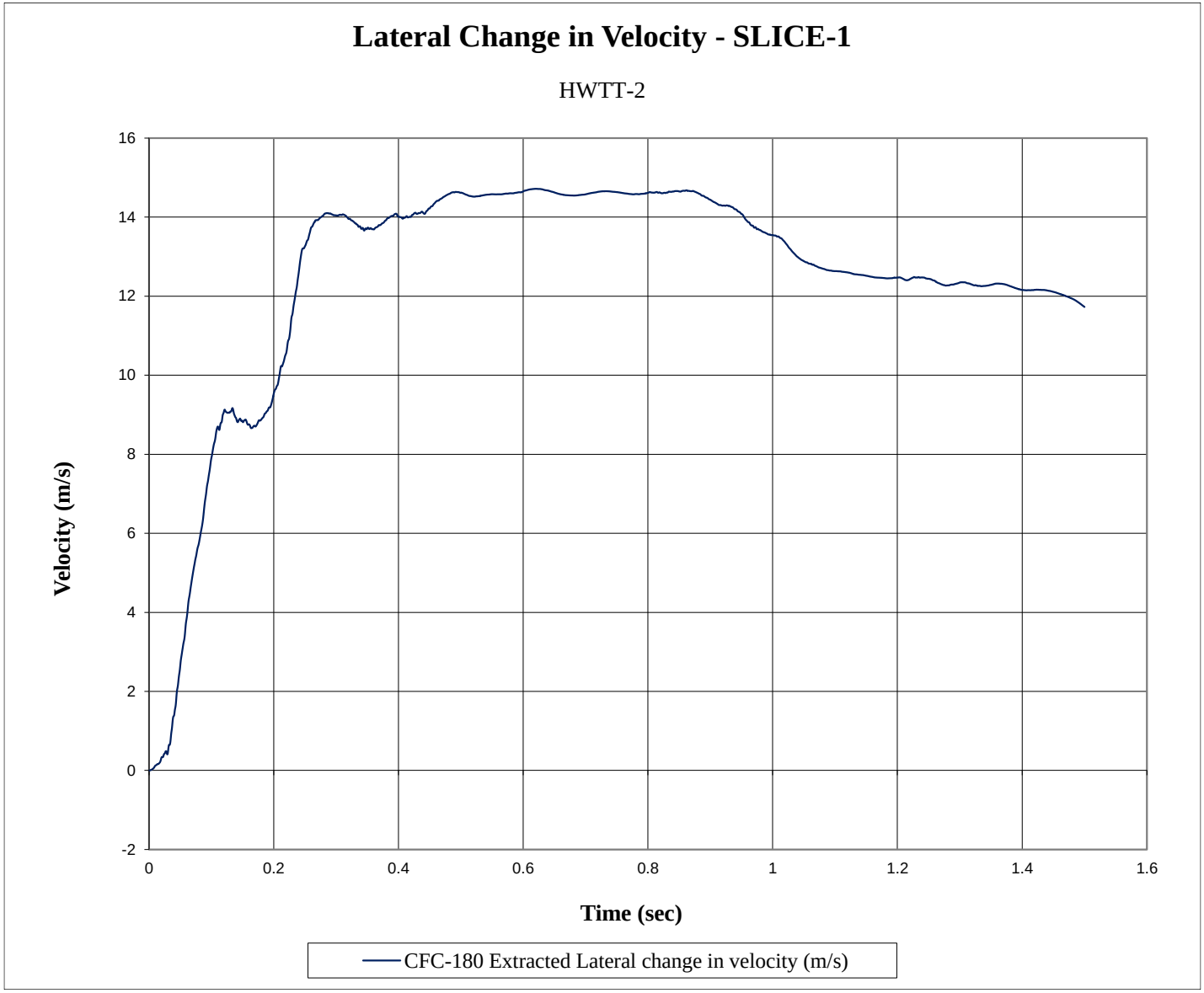



Figure F-13. Lateral Occupant Impact Velocity (SLICE-1), Test No. HWTT-2

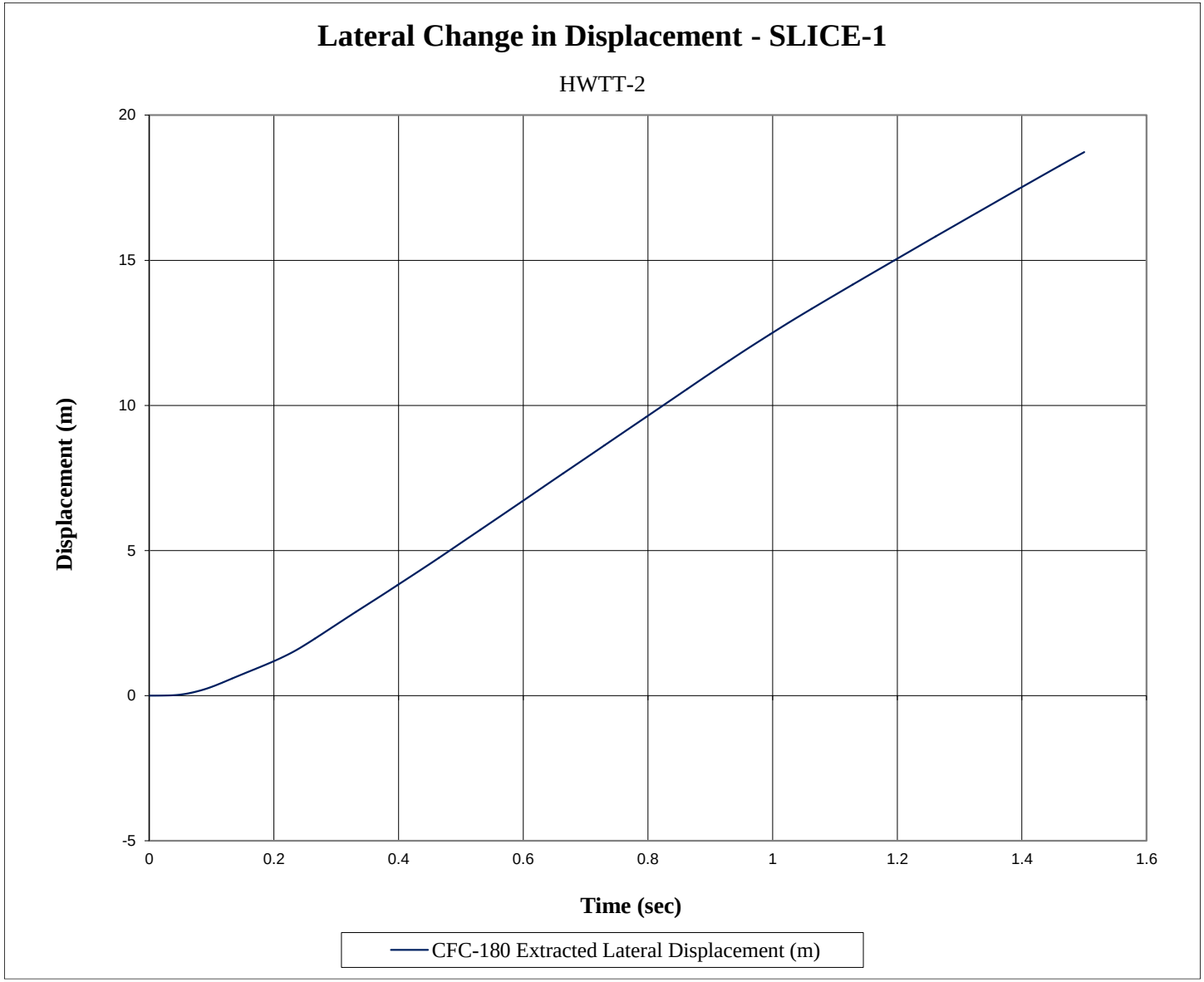



Figure F-14. Lateral Occupant Displacement (SLICE-1), Test No. HWTT-2

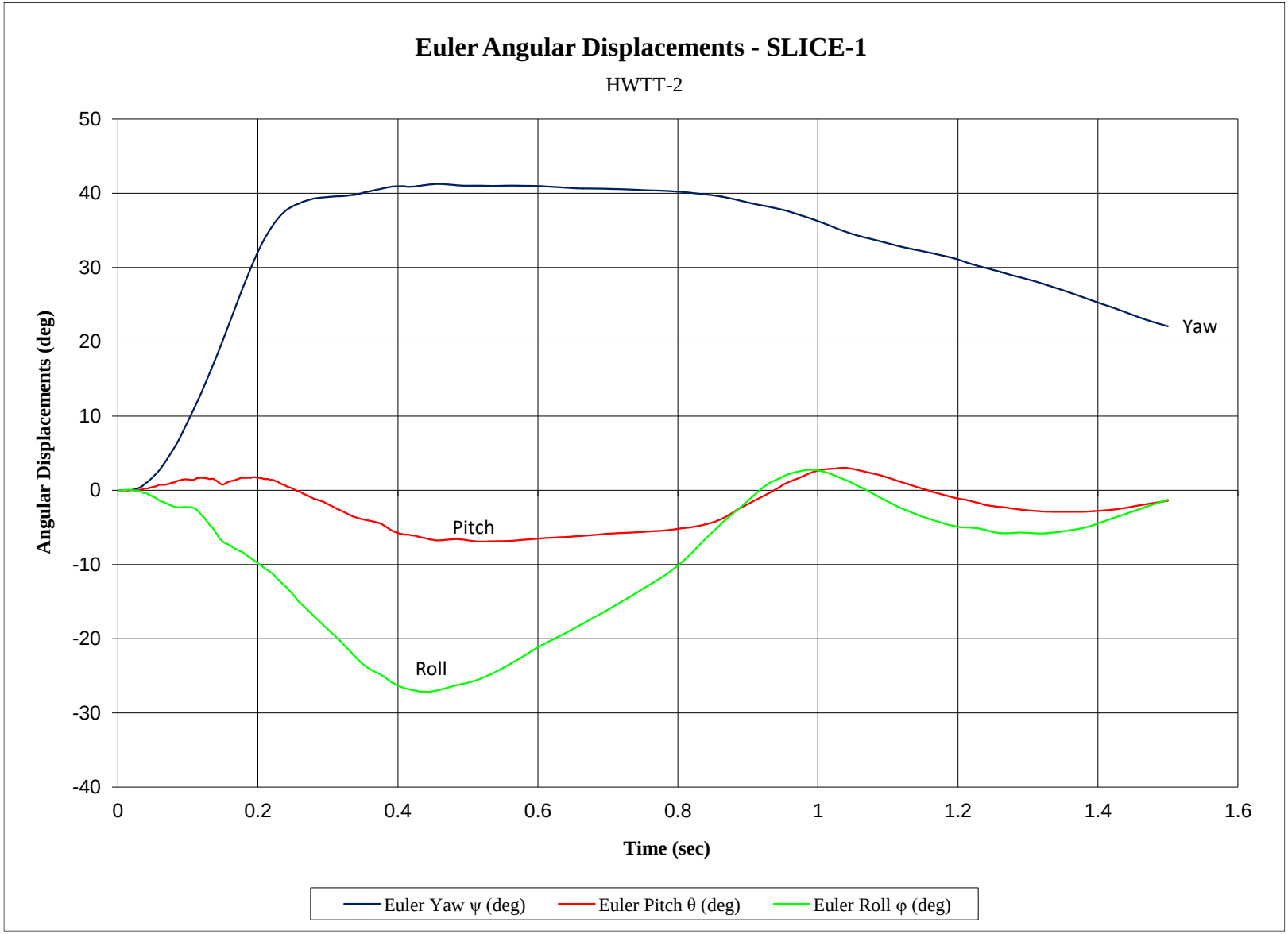



Figure F-15. Vehicle Angular Displacements (SLICE-1), Test No. HWTT-2

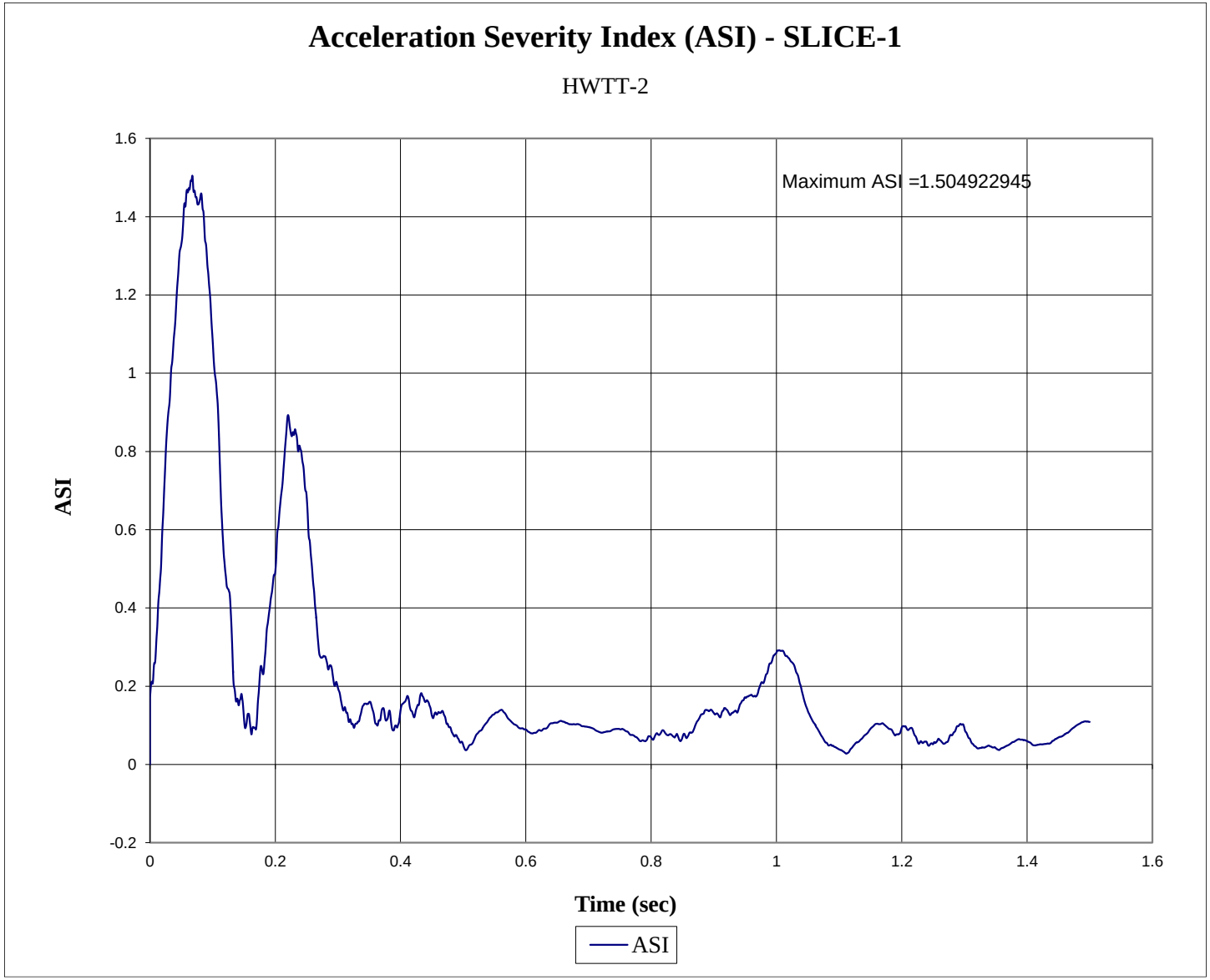



Figure F-16. Acceleration Severity Index (SLICE-1), Test No. HWTT-2

# END OF DOCUMENT