Midwest States Regional Pooled Fund Research Program
Fiscal Years 2008-2009 (Years 19 and 20)
Research Project Number TPF-5(091) Supplement #2 and TPF-5(193) Supplement #19
NDOR Sponsoring Agency Code RPFP-09-02 and RPFP-10-CABLE-1

DEVELOPMENT OF SOCKETED FOUNDATIONS FOR S3X5.7 POSTS

Submitted by

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

Tyler L. Schmidt, B.S.C.E.
Graduate Research Assistant

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

John D. Reid, Ph.D.
Professor

MIDWEST ROADSIDE SAFETY FACILITY
Nebraska Transportation Center
University of Nebraska-Lincoln
130 Whittier Research Center
2200 Vine Street
Lincoln, Nebraska 68583-0853
(402) 472-0965

Submitted to

Midwest States Regional Pooled Fund Program
Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

MwRSF Research Report No. TRP-03-293-15

April 28, 2015

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. TRP-03-293-15	2.	3. Recipient's Accession No.
4. Title and Subtitle Development of Socketed Foundations for S3x5.7 Posts		5. Report Date April 28, 2015 6.
7. Author(s) Rosenbaugh, S.K., Schmidt, T.L., Faller, R.K., and Reid, J.D.		8. Performing Organization Report No. TRP-03-293-15
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) Nebraska Transportation Center University of Nebraska-Lincoln 130 Whittier Research Center 2200 Vine Street Lincoln, Nebraska 68583-0853		10. Project/Task/Work Unit No. 11. Contract © or Grant (G) No. TPF-5(091) Supplement #2 TPF-5(193) Supplement #19
12. Sponsoring Organization Name and Address Midwest States Regional Pooled Fund Program Nebraska Department of Roads 1500 Nebraska Highway 2 Lincoln, Nebraska 68502		13. Type of Report and Period Covered Final Report: 2008 – 2015 14. Sponsoring Agency Code RPFP-09-02 RPFP-10-CABLE-1
15. Supplementary Notes Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration.		

16. Abstract (Limit: 200 words)

The objective of this study was to develop a socketed foundation for use with the S3x5.7 (S76x8.5) weak post. The design focused on cylindrical, reinforced concrete foundations with a steel tube placed in the center for use as the socket. The foundation was to prevent both damage and displacements exceeding 1 in. (25 mm), as measured at groundline, during an impact event. To evaluate various foundation designs, ten dynamic bogie tests were conducted over three separate rounds of testing. Round 1 was conducted in a weak, sandy soil; Round 2 was conducted in a strong, stiff soil; and Round 3 was conducted within a 4-in. (102-mm) thick asphalt pad.

The results of the bogie testing led to the development of three socketed foundation design options. Option 1 consisted of a 12-in. (305-mm) diameter foundation; Option 2 was a 15-in. (381-mm) diameter foundation; and Option 3 was a foundation installed within an asphalt mow strip. Option 1 carried a risk of concrete damage during severe impacts, but it was included for those agencies wishing to be more aggressive and accept the risks of damage. Each design option had a unique reinforcement configuration and minimum embedment depth. Further, the recommended minimum embedment depths were also a function of the surrounding soil conditions and the frost line depth of the installation site.

17. Document Analysis/Descriptors Highway Safety, Roadside Appurtenances, Bogie Test, Cable Barrier Posts, Socketed Foundation, S3x5.7, Concrete Foundation, Cylindrical Foundation		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 143	22. Price

DISCLAIMER STATEMENT

This report was completed with funding from the Federal Highway Administration, U.S. 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 state highway departments participating in the Midwest States Regional Pooled Fund Program nor the Federal Highway Administration, U.S. 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 (IAA) for the data contained herein was Ms. Karla Lechtenberg, Research Associate Engineer.

ACKNOWLEDGEMENTS

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

Acknowledgement is also given to the following individuals who made a contribution to the completion of this research project.

Midwest Roadside Safety Facility

J.C. Holloway, M.S.C.E., E.I.T., Test Site Manager
K.A. Lechtenberg, M.S.M.E., E.I.T., Research Associate Engineer
R.W. Bielenberg, M.S.M.E., E.I.T., Research Associate Engineer
C.S. Stolle, Ph.D., E.I.T., Post-Doctoral Research Assistant
J.D. Schmidt, Ph.D., P.E, Post-Doctoral Research Assistant
A.T. Russell, B.S.B.A., Shop Manager
K.L. Krenk, B.S.M.A., Maintenance Mechanic (retired)
S.M. Tighe, Laboratory Mechanic
D.S. Charroin, Laboratory Mechanic
Undergraduate and Graduate Research Assistants

Illinois Department of Transportation

Priscilla A. Tobias, P.E., State Safety Engineer/Bureau Chief
Tim Sheehan, P.E., Safety Design Engineer
Paul L. Lorton, P.E., Safety Programs Unit Chief

Indiana Department of Transportation

Todd Shields, P.E., Maintenance Field Support Manager

Iowa Department of Transportation

Chris Poole, P.E., Roadside Safety Engineer
Brian Smith, P.E., Methods Engineer

Kansas Department of Transportation

Scott King, P.E., Road Design Bureau Chief
Kelly Cool, P.E., Road Design Leader
Thomas Rhoads, P.E., Engineering Associate III, Bureau of Road Design

Minnesota Department of Transportation

Michael Elle, P.E., Design Standard Engineer

Missouri Department of Transportation

Joseph G. Jones, P.E., Engineering Policy Administrator

Nebraska Department of Roads

Phil TenHulzen, P.E., Design Standards Engineer
Jim Knott, P.E., State Roadway Design Engineer
Jodi Gibson, Research Coordinator

New Jersey Department of Transportation

Dave Bizuga, P.E., Manager 2, Roadway Design Group 1

Ohio Department of Transportation

Maria E. Ruppe, P.E., Roadway Standards Engineer

South Dakota Department of Transportation

David Huft, Research Engineer
Bernie Clocksin, Lead Project Engineer

Wisconsin Department of Transportation

Jerry Zogg, P.E., Chief Roadway Standards Engineer
Erik Emerson, P.E., Standards Development Engineer
Rodney Taylor, P.E., Roadway Design Standards Unit Supervisor

Wyoming Department of Transportation

William Wilson, P.E., Architectural and Highway Standards Engineer

Federal Highway Administration

John Perry, P.E., Nebraska Division Office
Danny Briggs, Nebraska Division Office

TABLE OF CONTENTS

TECHNICAL REPORT DOCUMENTATION PAGE ... i

DISCLAIMER STATEMENT ... ii

UNCERTAINTY OF MEASUREMENT STATEMENT ... ii

INDEPENDENT APPROVING AUTHORITY ... ii

ACKNOWLEDGEMENTS ... iii

TABLE OF CONTENTS ... vi

LIST OF FIGURES ... viii

LIST OF TABLES ... xi

1 INTRODUCTION ... 1
1.1 Background ... 1
1.2 Objective ... 2
1.3 Research Approach ... 3

2 COMPONENT TEST CONDITIONS ... 4
2.1 Purpose ... 4
2.2 Scope ... 4
2.3 Test Facility ... 5
2.4 Equipment and Instrumentation ... 5
2.4.1 Bogie ... 5
2.4.2 Accelerometers ... 6
2.4.3 Retroreflective Optic Speed Trap ... 8
2.4.4 Digital Photography ... 9
2.5 End-of-Test Determination ... 9
2.6 Data Processing ... 10

3 DESIGN DETAILS – ROUND 1, WEAK SOIL ... 11

4 COMPONENT TESTING – ROUND 1, WEAK SOIL ... 22
4.1 Purpose ... 22
4.2 Scope ... 22
4.3 Weak-Soil Test Results ... 23
4.3.1 Test No. HTCB-5 (Design D) ... 24
4.3.2 Test No. HTCB-6 (Design D) ... 28
4.3.3 Test No. HTCB-7 (Design E) ... 31
4.3.4 Test No. HTCB-8 (Design F) ... 34
4.3.5 Test No. HTCB-9 (Design G) ... 37
4.4 Weak-Soil Testing Discussion ... 40

5 DESIGN DETAILS – ROUND 2, STRONG SOIL ... 45

6 COMPONENT TESTING – ROUND 2, STRONG SOIL 58
6.1 Purpose 58
6.2 Scope 58
6.3 Strong-Soil Results 59
6.3.1 Test No. HTCB-10 (Design J) 60
6.3.2 Test No. HTCB-11 (Design K) 64
6.3.1 Test No. HTCB-17 (Design M) 67
6.3.1 Test No. HTCB-18 (Design L) 70
6.4 Strong-Soil Testing Discussion 73

7 DESIGN DETAILS – ROUND 3, ASPHALT 78

8 COMPONENT TESTING – ROUND 3, ASPHALT 86
8.1 Purpose 86
8.2 Scope 86
8.3 Asphalt Pad Test Results 87
8.3.1 Test No. HTCB-19 (Design O) 88
8.4 Asphalt Pad Testing Discussion 91

9 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS 94
9.1 Summary and Conclusions 94
9.2 Recommendations 96

10 REFERENCES 105

11 APPENDICES 106
Appendix A. Material Specifications 107
Appendix B. Bogie Test Results 127

LIST OF FIGURES

Figure 1. Rigid-Frame Bogie on Guidance Track 6
Figure 2. Bogie Testing Matrix and Setup, Test Nos. HTCB-5 through HTCB-9 13
Figure 3. Bogie Pit Setup, Test Nos. HTCB-5 through HTCB-9 14
Figure 4. Post Assemblies and Reinforcement Configurations, Test Nos. HTCB-5 through HTCB-9 15
Figure 5. Reinforcement Details, Test Nos. HTCB-5 through HTCB-9 16
Figure 6. Steel Post and Socket Details, Test Nos. HTCB-5 through HTCB-9 17
Figure 7. Steel Tube Details, Test Nos. HTCB-5 through HTCB-9........18
Figure 8. Bogie Shear Impact Head Details, Test Nos. HTCB-5 through HTCB-9........19
Figure 9. Bill of Materials, Test Nos. HTCB-5 through HTCB-9........20
Figure 10. Weak Soil Foundation Construction and Installation Photographs........21
Figure 12. Time-Sequential and Post-Impact Photographs, Test No. HTCB-5........27
Figure 13. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-6........29
Figure 14. Time-Sequential and Post-Impact Photographs, Test No. HTCB-6........30
Figure 15. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-7........32
Figure 16. Time-Sequential and Post-Impact Photographs, Test No. HTCB-7........33
Figure 17. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-8........35
Figure 18. Time-Sequential and Post-Impact Photographs, Test No. HTCB-8........36
Figure 19. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-9........38
Figure 20. Time-Sequential and Post-Impact Photographs, Test No. HTCB-9........39
Figure 21. Force vs. Deflection, Foundations Installed in Weak Soil 43
Figure 22. Energy vs. Deflection, Foundations Installed in Weak Soil........44
Figure 23. Bogie Testing Matrix and Setup, Test Nos. HTCB-10, HTCB-11, HTCB-17, and HTCB-18........47
Figure 24. Foundation Configurations with 12-in. (305-mm) Diameters, Test Nos. HTCB-10 and HTCB-11 48
Figure 25. Foundation Configurations with Increased Diameter Foundations, Test Nos. HTCB-17 and HTCB-18 49
Figure 26. Reinforcement Details for 12-in. (305-mm) Diameter Foundations, Test Nos. HTCB-10 and HTCB-11 50
Figure 27. Reinforcement Details for 12-in. (305-mm) Diameter Foundations, Test Nos. HTCB-10 and HTCB-11 51
Figure 28. Reinforcement Details for Increased Diameter Foundations, Test Nos. HTCB-17 and HTCB-18 52
Figure 29. Steel Post and Socket Details, Test Nos. HTCB-10, HTCB-11, HTCB-17, and HTCB-18........53
Figure 30. Bogie Shear Impact Head Details, Test Nos. HTCB-10, HTCB-11, HTCB-17, and HTCB-18........54
Figure 31. Bill of Materials for 12-in. (305-mm) Diameter Foundations, Test Nos. HTCB-10 and HTCB-11 55
Figure 32. Bill of Materials for Increased Diameter Foundations, Test Nos. HTCB-17, and HTCB-18........56
Figure 33. Test Article Installation Photographs 57
Figure 34. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-10........62
Figure 35. Time-Sequential and Post-Impact Photographs, Test No. HTCB-10........63

Figure 36. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-11 65
Figure 37. Time-Sequential and Post-Impact Photographs, Test No. HTCB-11....66
Figure 38. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-17 68
Figure 39. Time-Sequential and Post-Impact Photographs, Test No. HTCB-17....69
Figure 40. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-18 71
Figure 41. Time-Sequential and Post-Impact Photographs, Test No. HTCB-18....72
Figure 42. Force vs. Deflection, Foundations Installed in Strong Soil 76
Figure 43. Energy vs. Deflection, Foundations Installed in Strong Soil 77
Figure 44. Bogie Testing Matrix and Setup, Test No. HTCB-19 80
Figure 45. Foundation Configurations, Test No. HTCB-19 81
Figure 46. Reinforcement Details, Test No. HTCB-19 82
Figure 47. Steel Post and Socket Details, Test No. HTCB-19 83
Figure 48. Bill of Materials, Test No. HTCB-19 84
Figure 49. Test Installation, Test No. HTCB-19 85
Figure 50. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-19 89
Figure 51. Time-Sequential and Post-Impact Photographs, Test No. HTCB-19....90
Figure 52. Socketed Foundations for S3x5.7 Posts 98
Figure 53. Socketed Foundation for S3x5.7 Posts, Option 1 Details 99
Figure 54. Socketed Foundation for S3x5.7 Posts, Option 2 Details 100
Figure 55. Socketed Foundation for S3x5.7 Posts, Option 3 Details 101
Figure 56. Socketed Foundations for S3x5.7 Posts, Steel Component Details 102
Figure 57. Socketed Foundations for S3x5.7 Posts, Bill of Materials 103
Figure 58. Placement of Foundation on Slope 104
Figure A-1. Bill of Materials, Test Nos. HTCB-5 through HTCB-9....108
Figure A-2. Bill of Materials, Test Nos. HTCB-10 and HTCB-11 109
Figure A-3. Bill of Materials, Test Nos. HTCB-17 through HTCB-19....110
Figure A-4. Concrete Material Specification, Test Nos. HTCB-5 through HTCB-9 111
Figure A-5. Rebar Material Specification, Test Nos. HTCB-5 through HTCB-9....112
Figure A-6. Rebar Material Test Report, Test Nos. HTCB-5 through HTCB-9 113
Figure A-7. Additional Rebar Material Test Report, Test No. HTCB-9 114
Figure A-8. Steel Socket Material Specification, Test Nos. HTCB-5 through HTCB-7 and HTCB-9 115
Figure A-9. Steel Socket Material Specification, Test No. HTCB-8....116
Figure A-10. Steel Plate Material Specification, Test Nos. HTCB-5 through HTCB-9 117
Figure A-11. Steel Material Specification, Test Nos. HTCB-10 and HTCB-11 118
Figure A-12. Steel Socket Material Specification, Test Nos. HTCB-10 and HTCB-11 119
Figure A-13. Steel Posts, Test Nos. HTCB-10, HTCB-11, and HCTB-17 through HTCB-19...120
Figure A-14. Concrete Material Specification, Test Nos. HTCB-10 and HTCB-11....121
Figure A-15. Concrete Material Specification, Test Nos. HTCB-17 through HTCB-19 122
Figure A-16. Transverse Hoop Rebar, Test Nos. HTCB-17 through HTCB-19 123
Figure A-17. Vertical Rebar, Test Nos. HTCB-17 through HTCB-19....124
Figure A-18. Steel Tube Socket, Test Nos. HTCB-17 through HTCB-19 125
Figure A-19. Asphalt Mix, Test No. HTCB-19 126
Figure B-1. Test No. HTCB-5 Results (DTS) 128
Figure B-2. Test No. HTCB-5 Results (EDR-3)....129
Figure B-3. Test No. HTCB-6 Results (EDR-3)....130
Figure B-4. Test No. HTCB-7 Results (EDR-3)....131

Figure B-5. Test No. HTCB-8 Results (EDR-3)..132
Figure B-6. Test No. HTCB-9 Results (EDR-3)..133
Figure B-7. Test No. HTCB-10 Results (EDR-3)..134
Figure B-8. Test No. HTCB-11 Results (DTS SLICE) 135
Figure B-9. Test No. HTCB-11 Results (EDR-3)..136
Figure B-10. Test No. HTCB-17 Results (SLICE-1) 137
Figure B-11. Test No. HTCB-17 Results (SLICE-2) 138
Figure B-12. Test No. HTCB-18 Results (SLICE-1) 139
Figure B-13. Test No. HTCB-18 Results (SLICE-2) 140
Figure B-14. Test No. HTCB-19 Results (SLICE-1) 141
Figure B-15. Test No. HTCB-19 Results (SLICE-2) 142

LIST OF TABLES

Table 1. Accelerometers Utilized During Each Dynamic Component Test....................................8
Table 2. Bogie Testing Matrix – Test Nos. HTCB-5 through HTCB-9 23
Table 3. Weather Conditions, Test No. HTCB-5..24
Table 4. Weather Conditions, Test No. HTCB-6..28
Table 5. Weather Conditions, Test No. HTCB-7..31
Table 6. Weather Conditions, Test No. HTCB-8..34
Table 7. Weather Conditions, Test No. HTCB-9..37
Table 8. Dynamic Testing Summary, Foundations Installed in Weak Soil...................................42
Table 9. Bogie Testing Matrix, Foundations in Strong Soil 59
Table 10. Weather Conditions, Test No. HTCB-10..60
Table 11. Weather Conditions, Test No. HTCB-11..64
Table 12. Weather Conditions, Test No. HTCB-17..67
Table 13. Weather Conditions, Test No. HTCB-18..70
Table 14. Dynamic Testing Summary, Foundations Installed in Strong Soil 75
Table 15. Bogie Testing Matrix, Foundation in Asphalt 87
Table 16. Weather Conditions, Test No. HTCB-19..88
Table 17. Dynamic Testing Summary, Foundation Installed in Asphalt.......................................93

1 INTRODUCTION

1.1 Background

Thousands of miles of cable guardrail have been installed on highways across the United States. Often, these installations include socketed post foundations as opposed to simply driving barrier posts into the surrounding soil. Socketed foundations allow posts to slide in and out of ground sockets for easy replacement in the event of system damage during a crash. Thus, the time and cost of system repairs can be reduced. However, several state Departments of Transportation (DOTs) have reported that real-world crashes into cable barrier installations have resulted in damage to existing socketed foundation designs. Unfortunately, foundation damage requires repair crews to either replace the socketed foundation itself or drive a post into the soil adjacent to the damaged socket. Either situation defeats the purpose of using sockets, increases the time necessary to restore a damaged barrier, results in higher maintenance costs, and leads to increased risk to repair crews working adjacent to high-speed facilities.

The majority of existing socketed post foundations are constructed by coring a hole in the soil, placing a steel sleeve in the hole, and backfilling the hole with Portland cement concrete. However, many of these designs have insufficient reinforcement to resist impact loads that are transmitted through the post and into the socket. Further, many of the foundations are too shallow to resist translation and rotation displacements when a post is impacted. Thus, a need exists to develop socketed foundations for cable guardrail posts that perform as intended in the field.

Phase I of this project aimed to develop a socketed foundation that would be compatible with a wide variety of cable barrier systems [1]. Years ago, the S4x7.7 (S102x11.5) steel section was the strongest post used in cable barrier systems, and these prior socketed foundations were designed and evaluated in combination with this strong post. Four dynamic impact tests were conducted on various foundation designs, all of which resulted in concrete cracking and fracture.

As a result of this first round of component testing, the S4x7.7 (S102x11.5) post was viewed as a strong cable post that may not be suitable for use in rigid foundations. Thus, the weaker S3x5.7 (S76x8.5) post, which is the standard post for current nonproprietary cable barrier systems, was selected for continued development and testing of the socketed foundation. Although the S3x5.7 (S76x8.5) post is weaker than the S4x7.7 (S102x11.5) post, it still provides greater strength than the majority of cable system posts. Thus, a foundation designed to support S3x5.7 (S76x8.5) posts would have sufficient strength to support most other cable barrier posts as well.

It should be noted that a third research and development effort dedicated to the design of socketed foundations for cable posts was conducted in parallel to the study described herein. The development of the Midwest Weak Post (MWP) has been ongoing and is intended for use in non-proprietary cable barrier systems [2]. As such, optimized socketed foundations were desired for these significantly weaker MWP posts. The design and evaluation of these optimized socketed foundations is described in a separate research report [3].

1.2 Objective

The objective of this research project was to develop a socketed foundation for use with the S3x5.7 (S76x8.5) post. Foundation designs were to remain focused on placing a steel socket within a cylindrical, reinforced concrete shaft. The foundation was to sustain minimal damage and displacements during impacts, thus keeping repair costs to a minimum. This component testing program was conducted to determine foundation designs for cable barrier systems that have satisfied the safety standards published in the National Cooperative Highway Research

Program (NCHRP) Report No. 350 [4] or the Manual for Assessing Safety Hardware (MASH) [5].

1.3 Research Approach

Development of the socketed foundations for S3x5.7 (S76x8.5) posts was initially based on the recommendations made at the conclusion of Phase I of this project [1]. From those recommendations, new foundations were designed with various reinforcement configurations, cross section dimensions, and embedment depths. The new foundation designs were evaluated with the same type of dynamic bogie tests conducted during the previous phases of the project. However, testing was completed in three different soils to determine the necessary foundation strengths and embedment depths associated with the various roadside conditions. Round 1 of dynamic testing was conducted with the concrete foundations installed in a weak, sandy soil. Round 2 of testing was conducted with the foundations installed in a standard, strong soil typically utilized during full-scale crash testing of roadside barrier hardware. Finally, Round 3 of testing was conducted with the foundations installed in a strong soil with a 4-in. (102-mm) asphalt overlay. Conclusions and recommendations were formulated for each of these soil conditions and were documented herein.

2 COMPONENT TEST CONDITIONS

2.1 Purpose

Dynamic bogie testing of various socketed foundation designs was conducted to evaluate the structural integrity of the foundations and to quantify the lateral deflections of the foundations during impact events.

2.2 Scope

Ten bogie tests were conducted on S3x5.7 (S76x8.5) posts inserted into the reinforced concrete, socketed foundations. Similar to the impact conditions used in the previous phase of this project, the targeted impact conditions were a speed of 20 mph (32 km/h), an angle of 90 degrees (creating strong-axis bending), and an impact height of 11 in. (279 mm). This impact height was chosen to replicate the height of the bumper on a small car, which would cause high shear and bending loads to be imparted to the top of the socketed foundations.

A foundation had to resist the impact loads without fracture or cracking of the concrete in order to be deemed adequate. Additionally, the displacements of the foundation had to be limited, such that a new post could be dropped into place without having to reset the foundation. Utilizing a 1-in. (25-mm) displacement would result in a replacement post being installed 3.5 degrees from plumb, and the top of the post would be about 2¾ in. (70 mm) from its original, plumb position. Although not ideal for new installations, it was felt that these displacements would be acceptable for replacement posts after a severe impact to the system. Thus, displacements of the foundation were desired to be less than 1 in. (25 mm), measured at groundline. The combination of these criteria would ensure that a socketed foundation could be reused in the same system without repairs or resetting.

Evaluation of the socketed foundation configurations was completed in three rounds of dynamic component testing. During the first round, five tests were conducted on foundations installed in a weak, sandy soil. Round 2 consisted of four tests on foundations installed in standard strong soils, while Round 3 consisted of one test on a foundation installed within a 4-in. (102-mm) asphalt pavement. Further details on individual tests are included at the beginning of each respective testing chapter. Combining the results from all three rounds of testing allowed for the development of foundation design guidelines based on site-specific soil conditions.

2.3 Test Facility

Physical testing on the socketed foundations for cable posts was conducted at the Midwest Roadside Safety Facility (MwRSF) outdoor proving grounds, which is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport. The facility is approximately 5 miles (8 km) northwest from the University of Nebraska-Lincoln's city campus.

2.4 Equipment and Instrumentation

Equipment and instrumentation utilized to collect and record data during the dynamic bogie tests included a bogie, accelerometers, a retroreflective optic speed trap, high-speed and standard-speed digital video, and still cameras.

2.4.1 Bogie

A rigid-frame bogie was used to impact the posts. A variable-height, detachable impact head was used in the testing. The bogie impact head consisted of a 2½-in. x 2½-in. x ¼-in. (64-mm x 64-mm x 6-mm) square tube mounted onto the outside flange of a W6x25 (W152x37.2) steel beam with reinforcing gussets. A ¾-in. (19-mm) neoprene pad was attached to the front of the square tube to prevent local damage to the post from the impact. The impact head was bolted to the bogie vehicle, creating a rigid frame with an impact height of 11 in. (279 mm), except for test no. HTCB-5 when the impact height was 15 in. (381 mm). The bogie with the impact head is shown in Figure 1. The weight of the bogie with the addition of the mountable impact head and accelerometers was approximately 1,800 lb (816 kg).

A pickup truck with a reverse cable tow system was used to propel the bogie to a target impact speed of 20 mph (32 km/h). When the bogie approached the end of the guidance system, it was released from the tow cable, allowing it to be free-rolling when it impacted the post. A remote-control braking system was installed on the bogie, allowing it to be brought safely to rest after the test.

Figure 1. Rigid-Frame Bogie on Guidance Track

2.4.2 Accelerometers

A combination of four different environmental shock and vibration sensor/recorder systems was used to measure the longitudinal accelerations during the bogie tests. All of the accelerometers were mounted near the center of gravity of the bogie vehicle. Table 1 contains the specific accelerometers utilized during each bogie test.

The first 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 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 program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The third accelerometer system was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. The accelerometers were configured and controlled using a system developed and manufactured by DTS. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The fourth system, Model EDR-3, was a triaxial piezoresistive accelerometer system manufactured by Instrumented Sensor Technology, Inc. (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM, a range of ±200 g's, a sample rate of 3,200 Hz, and a 1,120 Hz low-pass filter. The "DynaMax 1 (DM-1)" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

At the time of these tests, the EDR-3 was not calibrated by an ISO 17025 approved laboratory due to the lack of an ISO 17025 calibration laboratory with the capabilities of calibrating the unit. However, the EDR-3 was calibrated by IST, which provided traceable documentation for the calibration. Further, MwRSF recognizes that the EDR-3 transducer does not satisfy the minimum 10,000 Hz sample frequency recommended by MASH. Following numerous test comparisons, the EDR-3 has been shown to provide equivalent results to the DTS unit, which does satisfy all MASH criteria and has ISO 17025 calibration traceability. Therefore, MwRSF has continued to use the EDR-3 during physical impact testing.

Table 1. Accelerometers Utilized During Each Dynamic Component Test

Test No.	SLICE-1	SLICE-2	DTS-TDAS	EDR-3
HTCB-5			X	X
HTCB-6				X
HTCB-7				X
HTCB-8				X
HTCB-9				X
HTCB-10				X
HTCB-11	X			X
HTCB-17	X	X		
HTCB-18	X	X		
HTCB-19	X	X		

2.4.3 Retroreflective Optic Speed Trap

A retroreflective optic speed trap was used to determine the speed of the bogie vehicle before impact. Three retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the vehicle. When the beam of light emitted by the Emitter/Receiver was reflected back by the targets, a signal was sent to the data acquisition computer recording at 10,000 Hz and activated the external LED box. 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 were only used as a backup in the event that vehicle speeds could not be determined from the electronic data.

2.4.4 Digital Photography

At a minimum, one AOS high-speed digital video camera and one JVC standard-speed digital video camera were used to document each test. The AOS camera had a frame rate of 500 frames per second, and the JVC camera had a frame rate of 29.97 frames per second. The cameras were placed laterally from the posts, with a view perpendicular to the bogie's direction of travel. For test nos. HTCB-10 and HTCB-11, a second JVC digital camera was placed on the opposite side of the posts and elevated such that it had a downward view to the top surface of the foundation. For test nos. HTCB-17 through HTCB-19, two GoPro digital cameras, with a frame rate of 120 frames per second, were utilized in place of the JVC cameras. A Nikon D50 digital still camera was also used to document pre- and post-test conditions for all tests.

2.5 End-of-Test Determination

During standard bogie–post impact events, the desired test results have been based on force vs. deflection characteristics. Subsequently, the end-of-test has typically been defined as the first of three occurrences: (1) fracture of the test article; (2) excessive rotation of the test article; or (3) the bogie vehicle overriding or losing contact with the test article. However, the focus of the bogie tests conducted herein was to evaluate the structural adequacy of the socketed foundations and to measure the maximum deflections or rotations of the foundations. Since the maximum resistive forces for the post assembly were restricted by the material and section properties of the post, the data recorded by the accelerometers would only be important in measuring the load at fracture. Therefore, the first two end-of-test criteria were discarded, and the true end-of-test was defined as the time when the bogie vehicle overrode or lost contact with the post.

2.6 Data Processing

The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 Butterworth filter, conforming to the SAE J211/1 specifications [6]. The pertinent acceleration signal was extracted from the bulk of the data signals. The processed acceleration data was then multiplied by the mass of the bogie to get the impact force using Newton's Second Law. Next, the acceleration trace was integrated to find the change in velocity versus time. Initial velocity of the bogie, calculated from the pressure tape switch data, was then used to determine the bogie velocity, and the calculated velocity trace was integrated to find the bogie's displacement. Combining the previous results, a force vs. deflection curve was plotted for each test. Finally, integration of the force vs. deflection curve provided the energy vs. deflection curve for each test.

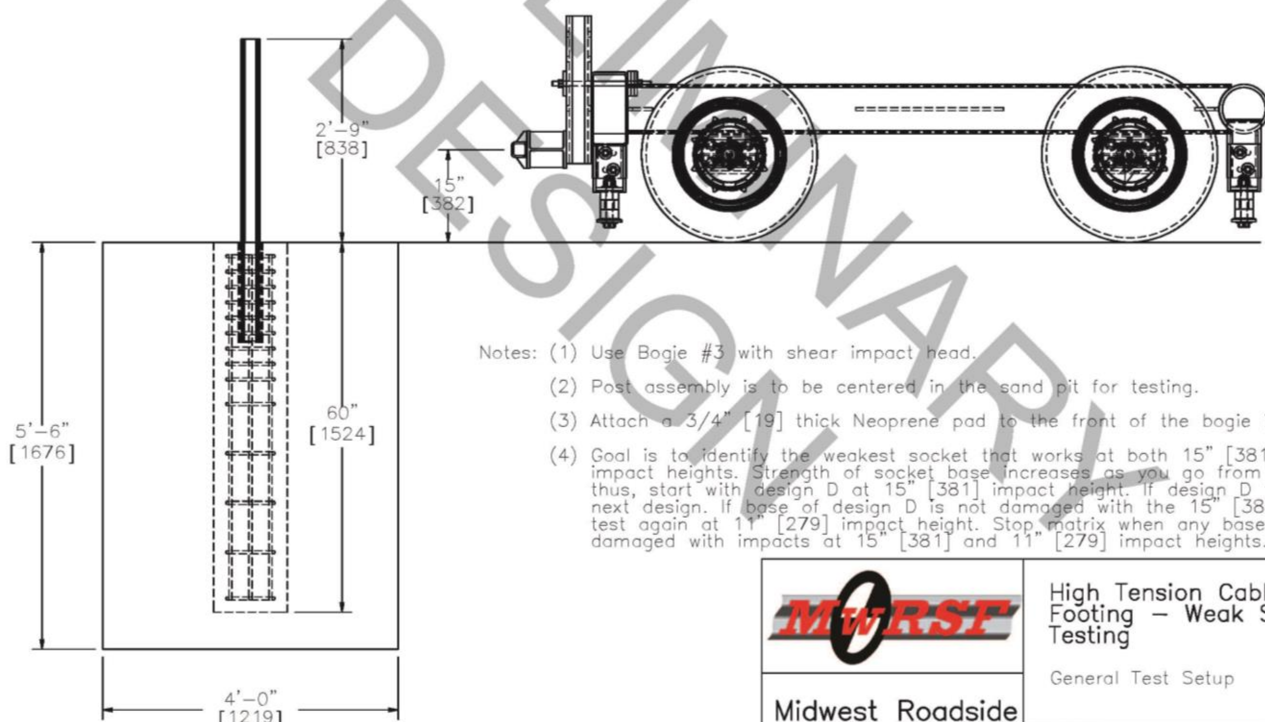
3 DESIGN DETAILS – ROUND 1, WEAK SOIL

Following the poor performance of the initial foundation designs tested in Phase I (Designs A through C), four additional foundation designs (Designs D through G) were fabricated and evaluated through the first round of dynamic component testing with S3x5.7 (S76x8.5) posts. Similar to the designs of Phase I, each socketed foundation consisted of a steel socket placed in the middle of a cylindrical, reinforced concrete foundation. However, each of the new foundations evaluated herein incorporated increased shear strength to prevent concrete failure. Design details for each of the foundations are shown in Figures 2 through 9, and photographs documenting the construction and installation of the foundations are shown in Figure 10. Material specifications, mill certifications, and certificates of conformity for the reinforced concrete, socketed foundations are shown in Appendix A.

Each socketed foundation consisted of a 12-in. (305-mm) diameter concrete cylinder and had a 60-in. (1,524-mm) embedment depth. The concrete was specified to a minimum 28-day compressive strength of 3,500 psi (24 MPa). All of the foundations were reinforced with both circumferential and vertical grade 60 steel rebar. However, the quantity and spacing of the steel reinforcement varied between designs. A 16-in. (406-mm) long, 4-in. x 4-in. x ¼-in. (102-mm x 102-mm x 6-mm) steel tube was located at the top-center of each foundation to act as a socket for the S3x5.7 (S76x8.5) posts. Finally, all of the foundations were installed within a test pit filled with a weak soil material conforming to the AASHTO Grade A-3 sand requirements [7].

Each foundation design had a unique mechanism for increasing the shear capacity of the foundation, and the designs were labeled and tested in order of increasing strength (from Design D to Design G). Design D utilized 4½-in. (114-mm) spacings between transverse steel hoops throughout the top portion of the foundation, while Design E utilized a reduced spacing of 2½ in. (64 mm). The foundation of Design F was nearly identical to that of Design E, execpt Design F incorporated ¼-in. (6-mm) thick shim plates welded on the outside of the post flanges. These plates were intended to bear against the inside of the sockets below the surface of the foundation, thus reducing the propensity for shear cracking at the top of the foundation. Additionally, the moment arm of the post is increased, resulting in a decrease in shear load and further reducing the propensity of concrete cracking. Note, the socket thickness had to be reduced from ¼ in. (6 mm) to ⅛ in. (3 mm) in order to accommodate the shear plates in Design F. Finally, Design G utilized 4-in. (102-mm) spacings between transverse steel hoops and incorporated no. 4 vertical bars welded to the front and back faces of the socket. These additional vertical bars would provide extra strength and stiffness to the socket against rotational displacements.

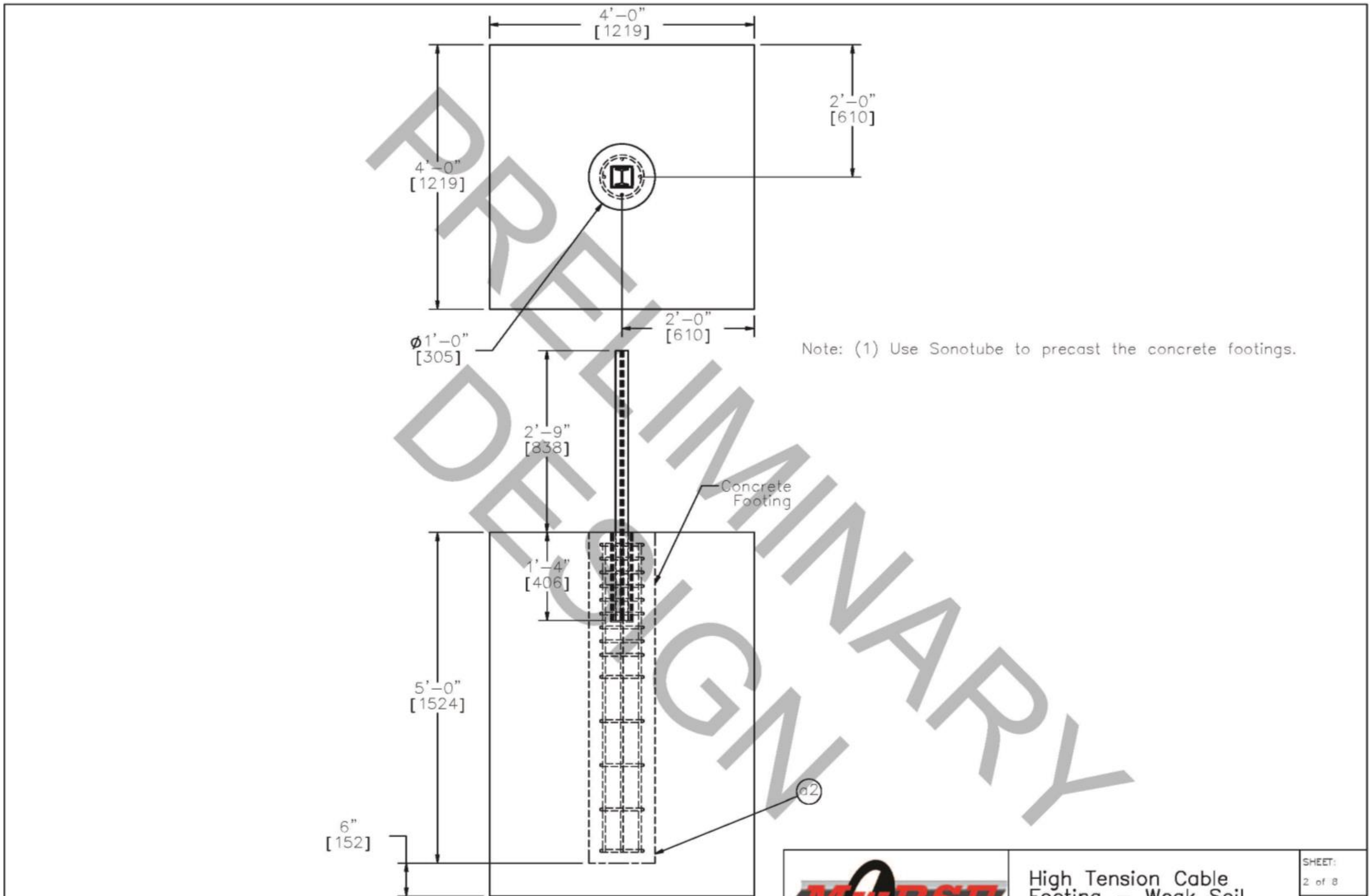
Test No.	Design	Soil Type	Impact Height	Footing Depth	Speed mph [km/h]	Angle (degrees)
HTCB-5	D	A-3 Sand	15" [381]	60" [1524]	20 [32.2]	90
HTCB-6	(See Note 4)	A-3 Sand	(See Note 4)	60" [1524]	20 [32.2]	90
HTCB-7	(See Note 4)	A-3 Sand	(See Note 4)	60" [1524]	20 [32.2]	90
HTCB-8	(See Note 4)	A-3 Sand	(See Note 4)	60" [1524]	20 [32.2]	90
HTCB-9	(See Note 4)	A-3 Sand	(See Note 4)	60" [1524]	20 [32.2]	90



Notes: (1) Use Bogie #3 with shear impact head.
(2) Post assembly is to be centered in the sand pit for testing.
(3) Attach a 3/4" [19] thick Neoprene pad to the front of the bogie impact head.
(4) Goal is to identify the weakest socket that works at both 15" [381] and 11" [279] impact heights. Strength of socket base increases as you go from design D to G; thus, start with design D at 15" [381] impact height. If design D fails, move on to next design. If base of design D is not damaged with the 15" [381] impact height, test again at 11" [279] impact height. Stop matrix when any base design is not damaged with impacts at 15" [381] and 11" [279] impact heights.

MwRSF Midwest Roadside Safety Facility	High Tension Cable Footing – Weak Soil Testing General Test Setup	SHEET: 1 of 8 DATE: 08/12/2014 DRAWN BY: RJT/MDM/DMH/SDB/JEK
	DWG. NAME. HT Cable Footings R2_v10 · SCALE: 1:25 · UNITS: in[mm]	REV. BY: KAL/SKR

Figure 2. Bogie Testing Matrix and Setup, Test Nos. HTCB-5 through HTCB-9



Part No.	Soil Type	Spec.
a1	AASHTO A–3 Sand	No. 40 Sieve–51% min. pass No. 200 Sieve–10% max. pass Plasticity Index–NP Fine Sand

Figure 3. Bogie Pit Setup, Test Nos. HTCB-5 through HTCB-9

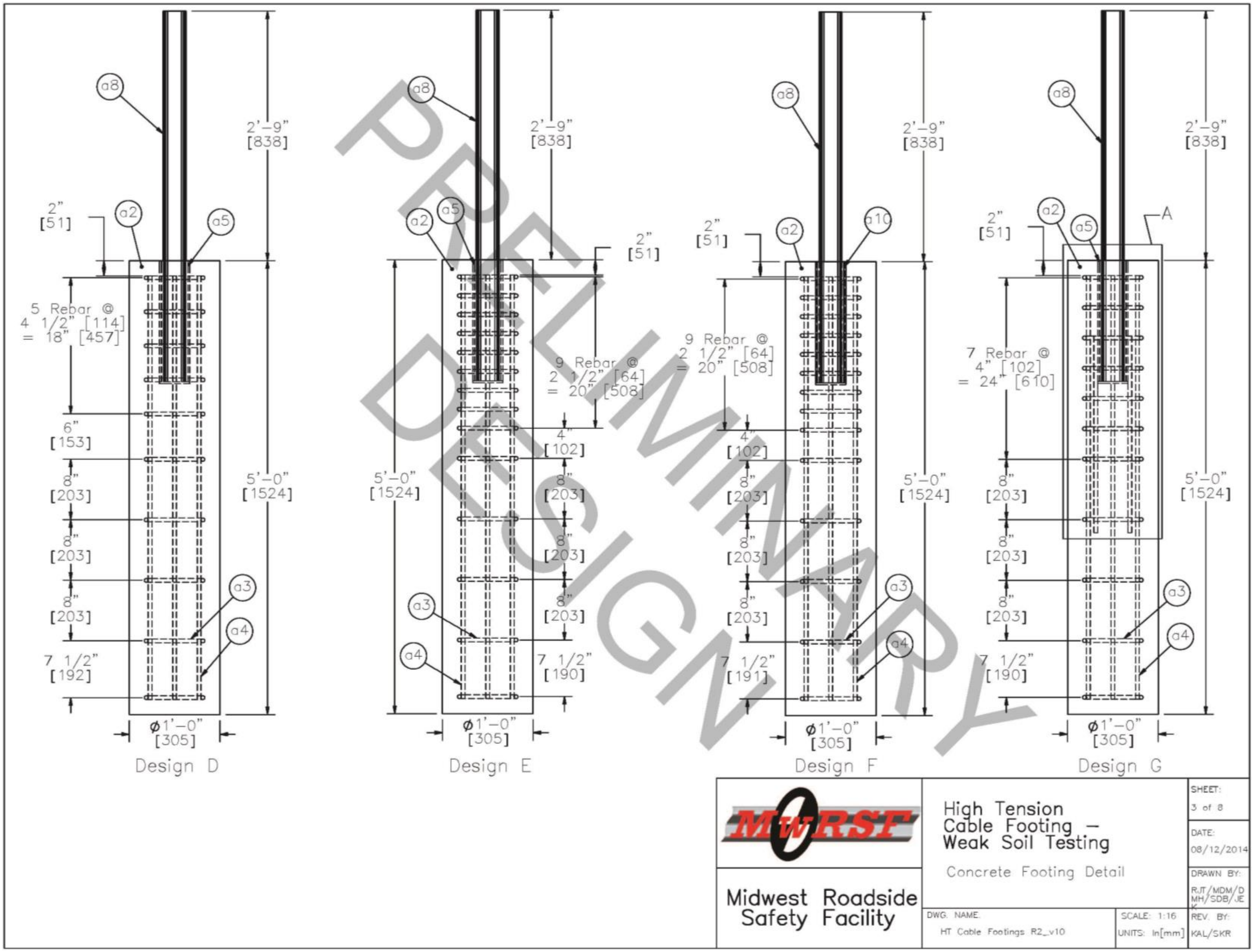


Figure 4. Post Assemblies and Reinforcement Configurations, Test Nos. HTCB-5 through HTCB-9

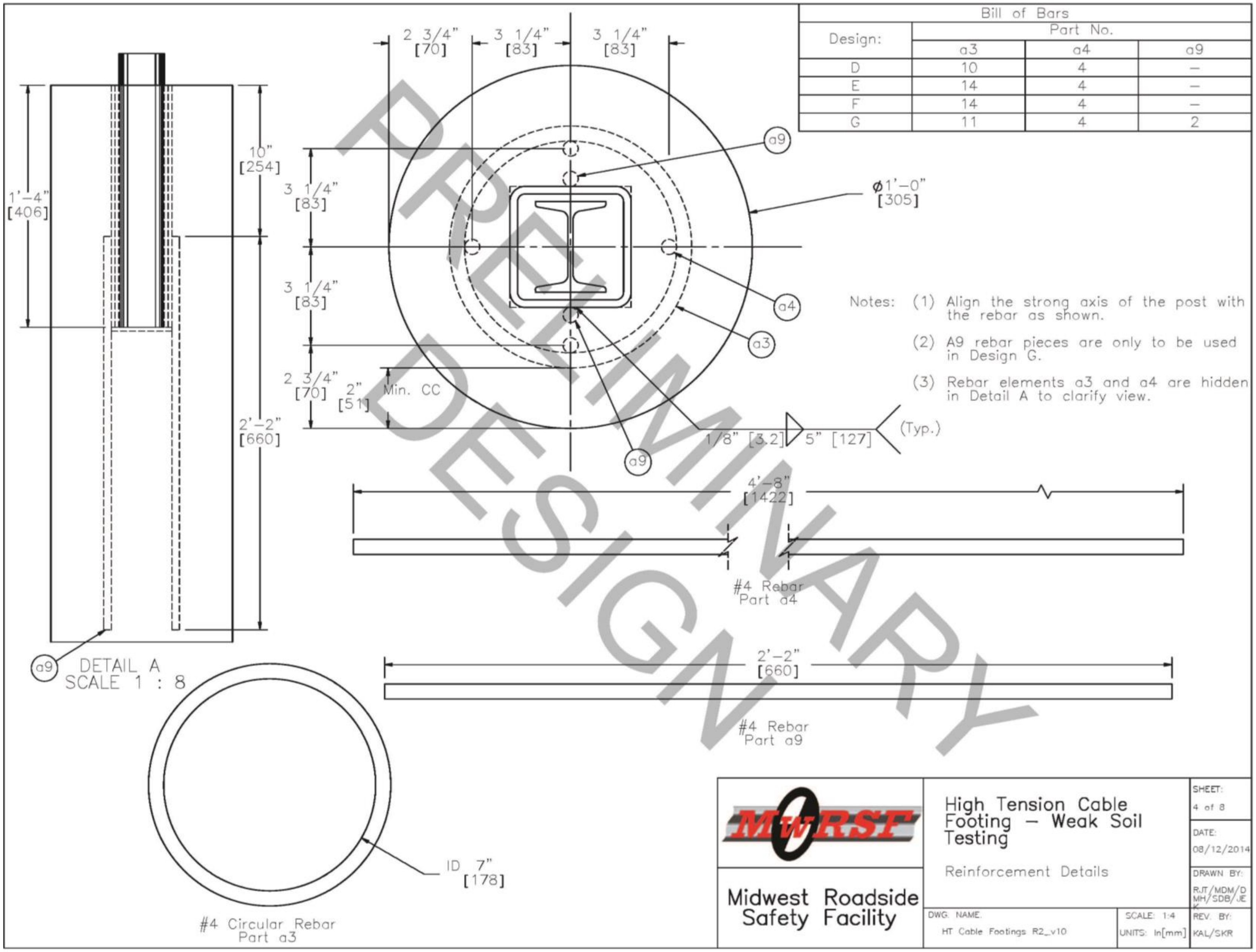


Figure 5. Reinforcement Details, Test Nos. HTCB-5 through HTCB-9

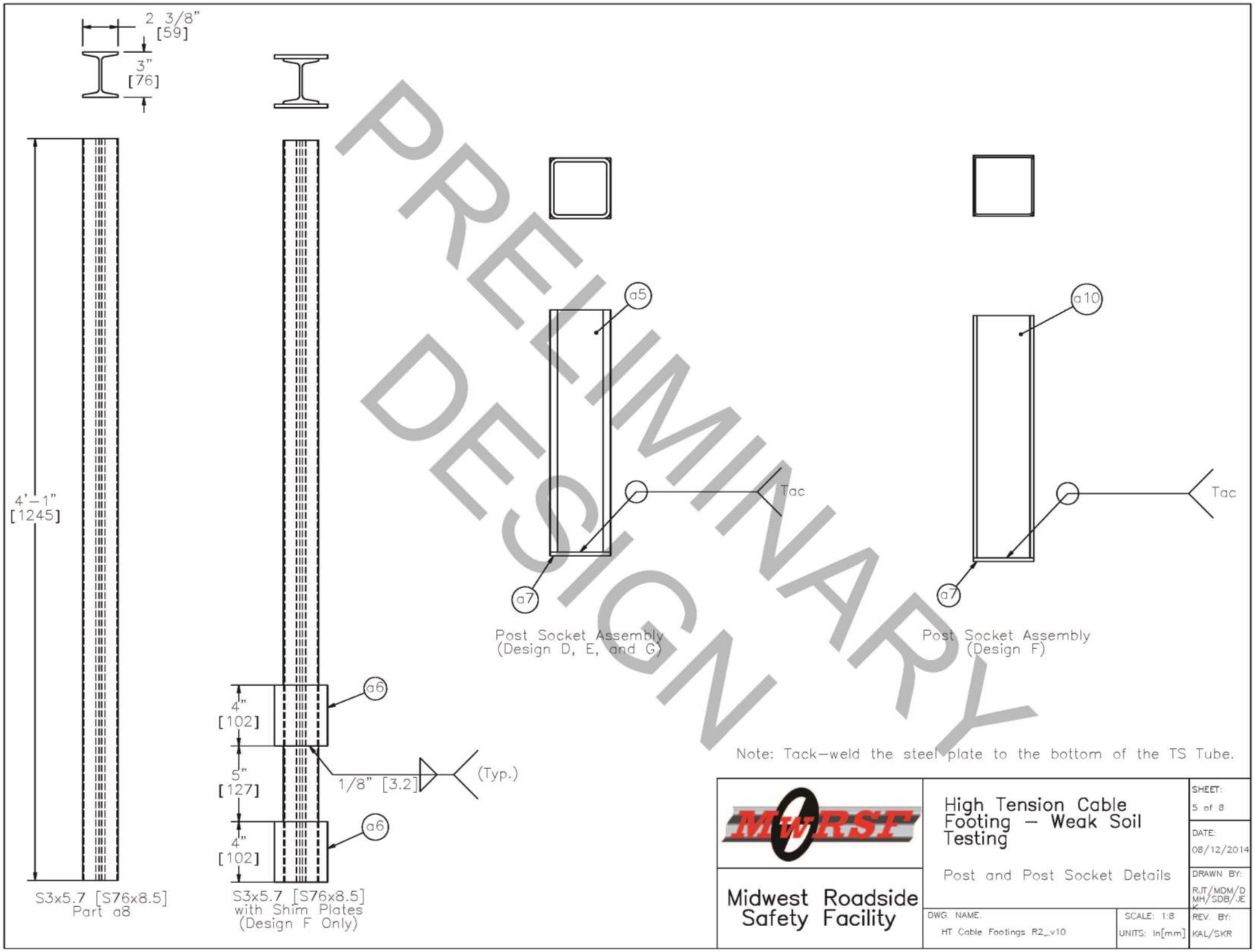


Figure 6. Steel Post and Socket Details, Test Nos. HTCB-5 through HTCB-9

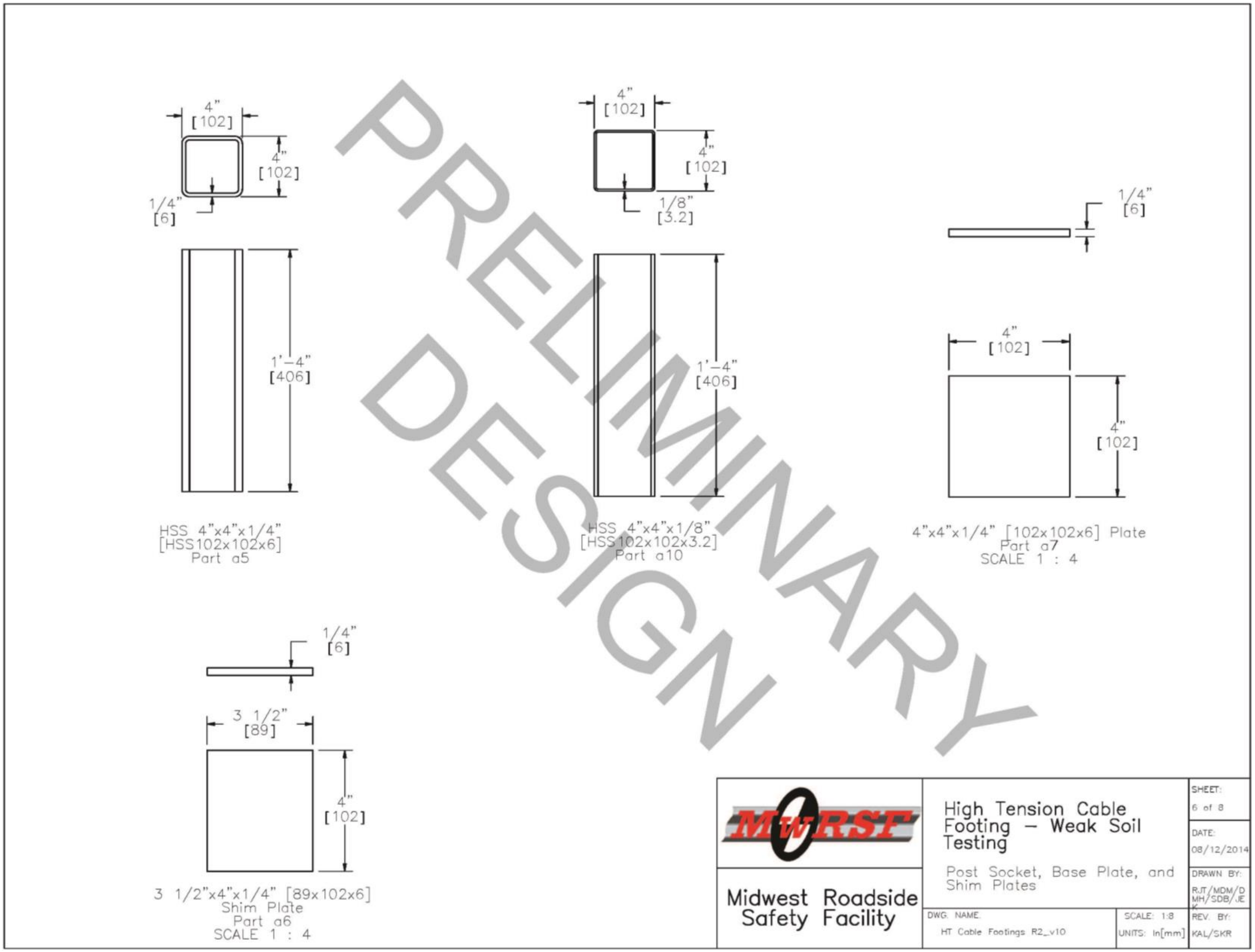


Figure 7. Steel Tube Details, Test Nos. HTCB-5 through HTCB-9

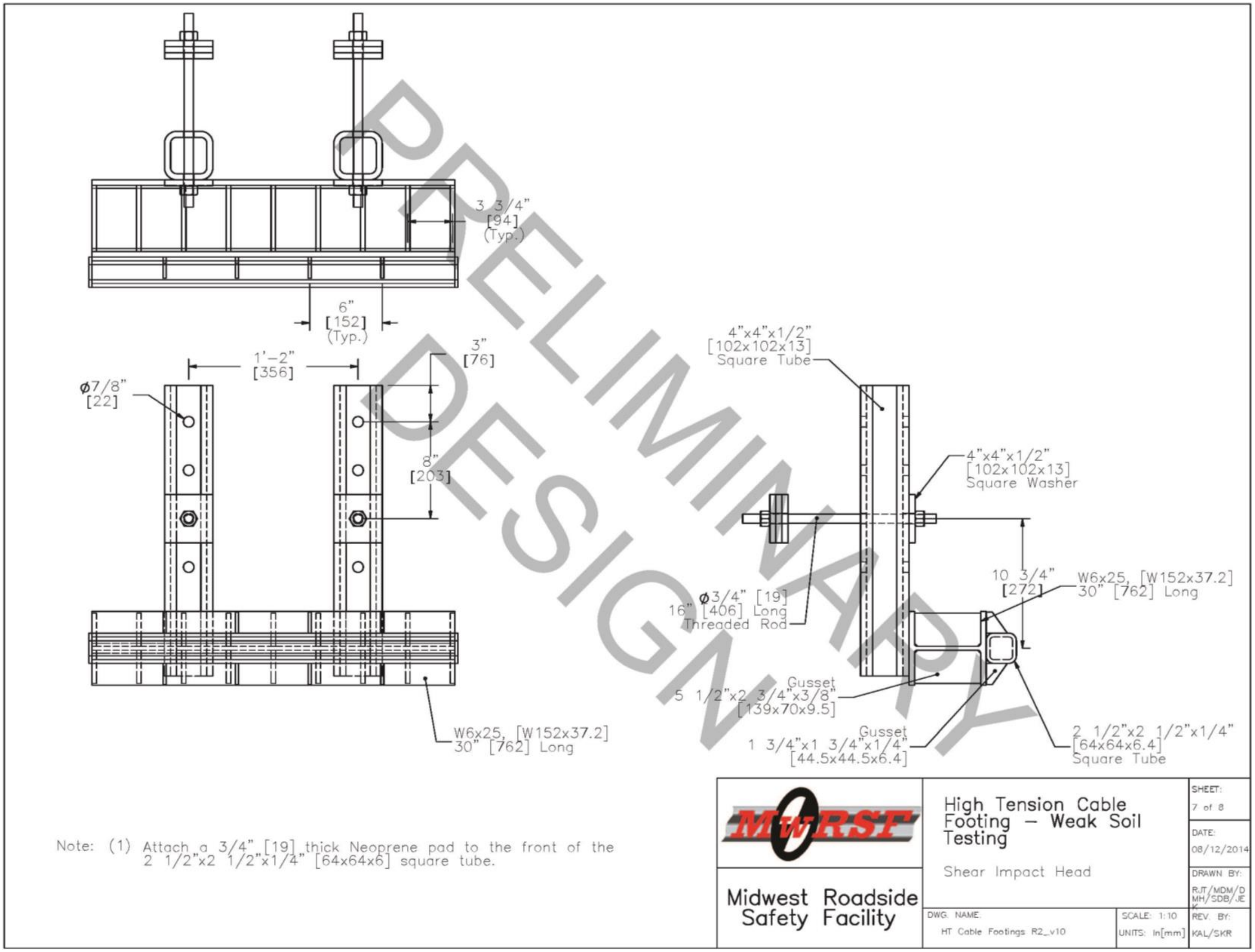


Figure 8. Bogie Shear Impact Head Details, Test Nos. HTCB-5 through HTCB-9

Item No.	QTY.	Description	Material Specification	Comments
a1	1	AASHTO A-3 Sand	See Page 2	–
a2	1	Concrete	Min 3500 psi [24 MPa] Comp. Strength	–
a3	(see pg. 3)	#4 Circular Rebar 7" [178] ID	Gr. 60	–
a4	(see pg. 3)	#4 Rebar 56" [1422] Long	Gr. 60	–
a5	3	HSS 4x4x1/4" [HSS 102x102x6], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [289 MPa] Yield Strength)	–
a6	4	Shim Plate	ASTM A36	Design F Only
a7	4	4x4x1/4" [102x102x6] Steel Plate	ASTM A36	–
a8	4	S3x5.7 [S76x8.5], 49" [1245] Long	Min 50 ksi [344.7 MPa] Yield Strength	–
a9	2	#4 Rebar 26" [660] Long	Gr. 60	Design G Only
a10	1	HSS 4x4x1/8" [HSS 102x102x3.2], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [289 MPa] Yield Strength)	Design F Only

Midwest Roadside Safety Facility	High Tension Cable Footing – Weak Soil Testing Bill of Materials		SHEET: 8 of 8 DATE: 08/12/2014 DRAWN BY: RJT/MDM/DMH/SDB/JEK
	DWG. NAME. HT Cable Footings R2_v10	SCALE: None UNITS: in[mm]	REV. BY: KAL/SKR

Figure 9. Bill of Materials, Test Nos. HTCB-5 through HTCB-9

Figure 10. Weak Soil Foundation Construction and Installation Photographs

4 COMPONENT TESTING – ROUND 1, WEAK SOIL

4.1 Purpose

Socketed foundations are required to resist displacement within the ground while maintaining structural integrity. Obviously, the surrounding soil conditions are directly related to the displacement expected for a given foundation during an impact. A stiff, strong soil would provide greater resistance to translation and rotation than a weaker soil. Since cable barriers are frequently placed in depressed medians where saturated soils are common, the performance of socketed foundations in weak soils is critical. Thus, the first round of dynamic component testing was conducted within a weak, sandy soil in order to establish the required embedment depth for socketed foundations supporting S3x5.7 (S76x8.5) posts.

4.2 Scope

Five bogie tests were conducted on socketed foundations placed in a sand pit satisfying AASHTO A-3 sand material requirements. For test nos. HTCB-5 through HTCB-9, the target impact conditions were a speed of 20 mph (32 km/h) and an angle of 90 degrees, creating a classical "head-on" or full-frontal impact with the strong axis of the S3x5.7 (S76x8.5) post, as shown in Table 2.

The goal of the testing program was to identify the weakest concrete foundation that maintained its structural integrity while also resisting lateral displacements. Note that the strength of each socketed foundation designs increases incrementally from Design D to Design G. Thus, testing began with Design D. The critical impact height was selected as 11 in. (279 mm) to represent the lower height of a small car bumper or the height to the center of a small car wheel. However, due to the excessive displacements and foundation fractures observed during Phase I of this research effort [1], impacts began at a height of 15 in. (381 mm). If a socketed foundation was not damaged under this loading condition, the corresponding design was again tested with an 11-in. (279-mm) impact height. However, if a design failed at either impact height, testing continued with the next foundation design.

Table 2. Bogie Testing Matrix – Test Nos. HTCB-5 through HTCB-9

Test No.	Design	Soil Type	Impact Height in. (mm)	Embedment Depth in. (mm)	Target Impact Speed mph (km/h)	Target Impact Angle deg.
HTCB-5	D	A-3 Sand	15 (381)	60 (1,524)	20 (32)	90
HTCB-6	D	A-3 Sand	11 (279)	60 (1,524)	20 (32)	90
HTCB-7	E	A-3 Sand	11 (279)	60 (1,524)	20 (32)	90
HTCB-8	F	A-3 Sand	11 (279)	60 (1,524)	20 (32)	90
HTCB-9	G	A-3 Sand	11 (279)	60 (1,524)	20 (32)	90

4.3 Weak-Soil Test Results

Through component testing, the performance of each socketed foundation was evaluated in terms of both structural integrity and displacement of the foundation in weak soils. A foundation system had to resist the impact loads without fracture to be deemed adequate. Additionally, the researchers desired to limit the displacements of the foundation to less than 1 in. (25 mm), as measured at groundline. The combination of these criteria would ensure that a socketed foundation could be reused in the same system without repairs or resetting.

Accelerometer data was used to find the resistance force supplied by the S3x5.7 (S76x8.5) post and foundation assembly. Since the accelerometers were mounted on the bogie vehicle, the forces and displacements calculated from the acceleration data were related to the motion of the bogie and the forces applied to it from the posts. These forces and displacements did not directly reflect the force applied to the top of the foundations or the displacement of the foundation. However, the recorded forces can be used to indicate approximate force magnitudes imparted to the sockets. Individual results for all accelerometers utilized during each test are shown in Appendix B. Due to the plastic deformation of the posts, foundation displacements were measured from the high-speed video and post-test field measurements.

4.3.1 Test No. HTCB-5 (Design D)

Test no. HTCB-5 was conducted on December 21, 2011 at approximately 10:00 a.m. The weather conditions, as per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 3.

Table 3. Weather Conditions, Test No. HTCB-5

Temperature	30° F
Humidity	75%
Wind Speed	9 mph
Wind Direction	260° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

During test no. HTCB-5, the bogie impacted the post 15 in. (381 mm) above the groundline at a speed of 20.8 mph (33.5 km/h), causing strong-axis bending in the post. Upon impact, the foundation began to rotate through the soil, and a plastic hinge formed in the post at groundline. By 0.006 seconds after impact, a concrete crack had formed across the top of the foundation adjacent to the back edge of the socket. The foundation assembly reached a maximum dynamic deflection of 0.8 in. (20 mm) at 0.030 seconds. The post continued to bend over until the bogie head overrode the top of the post at 0.100 seconds after impact and at a deflection of 29.5 in. (749 mm). The top of the foundation had permanently displaced 0.3 in. (8 mm) laterally during the impact event.

Force vs. deflection and energy vs. deflection curves created from the EDR-3 accelerometer data are shown in Figure 11. Inertial effects resulted in a high peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a maximum of 13.3 kips (59.2 kN) near 5.8 in. (147 mm) of deflection. Following this peak, the force gradually began to decrease until approximately 17 in. (432 mm), where a relatively steady force of approximately 2 kips (8.9 kN) was observed for the rest of the impact event. At a maximum deflection of 29.5 in. (749 mm), the post and socketed foundation had absorbed 140.3 kip-in. (15.9 kJ) of energy.

Damage to the test article consisted of plastic bending to the steel post and cracking to the back side of the concrete foundation. Concrete shear cracking resulted in a 7-in. (178-mm) deep piece of concrete fracturing off the top-back edge of the concrete foundation. Subsequently, a portion of the steel socket and one transverse steel stirrup were exposed. Time-sequential and post-impact photographs are shown in Figure 12. Based on these results with a 15-in. (381-mm) impact height, the rest of the tests were to be conducted with an impact height of 11 in. (279 mm).

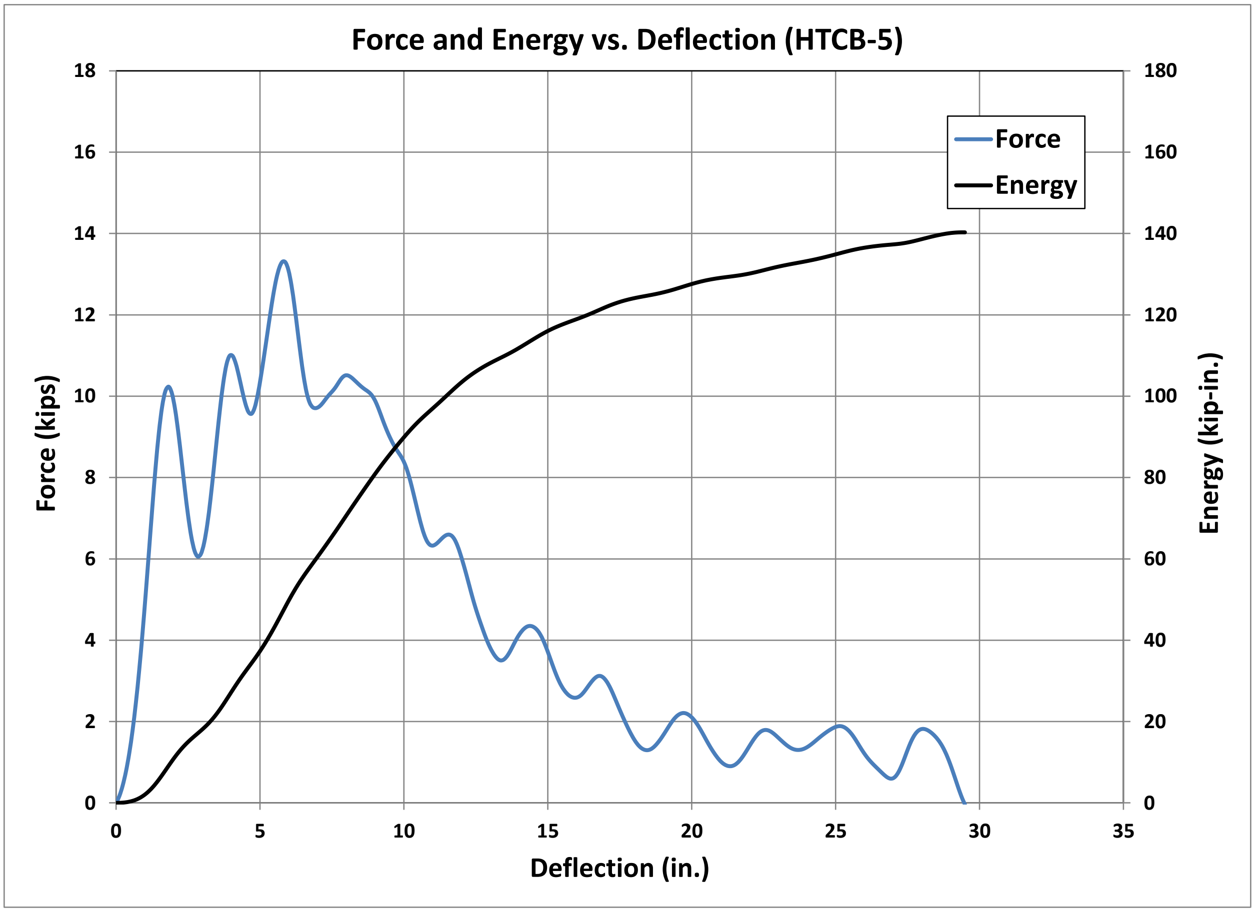
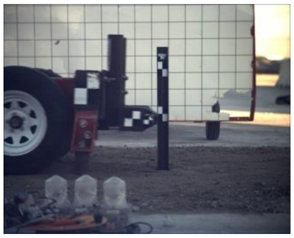


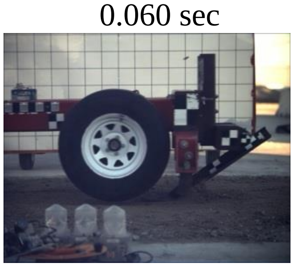
Figure 11. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-5


IMPACT


0.020 sec


0.040 sec


0.060 sec


0.080 sec

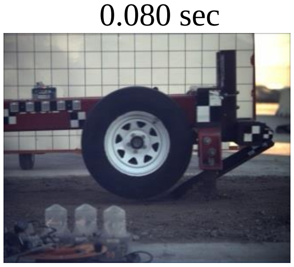

0.100 sec

Figure 12. Time-Sequential and Post-Impact Photographs, Test No. HTCB-5

4.3.2 Test No. HTCB-6 (Design D)

Test no. HTCB-6 was conducted on January 4, 2012 at approximately 12:15 p.m. The weather conditions, as per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 4.

Table 4. Weather Conditions, Test No. HTCB-6

Temperature	50° F
Humidity	41%
Wind Speed	6 mph
Wind Direction	270° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

The concrete foundation assembly from test no. HTCB-5 was rotated 180 degrees and re-used for test no. HTCB-6. During test no. HTCB-6, the bogie impacted the post 11 in. (279 mm) above the groundline at a speed of 20.0 mph (32.2 km/h), causing strong-axis bending in the post. Upon impact, the foundation rotated back through the soil, and a plastic hinge formed in the post at groundline. At 0.036 seconds, the top of the concrete foundation fractured, and the steel socket began to bend. Both the socket and post continued to bend backward until the bogie head overrode the top of the post at 0.148 seconds after impact. Due to the concrete fracturing apart, foundation displacements could not be measured for this test.

Force vs. deflection and energy vs. deflection curves created from the EDR-3 accelerometer data are shown in Figure 13. Inertial effects resulted in a high peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a maximum of 15.8 kips (70.3 kN) near 5.8 in. (147 mm) of deflection. Following this second peak, a relatively steady force of 12 kips (53.4 kN) was observed until approximately 10 in. (254 mm), when the concrete fractured and the force rapidly decreased. At a deflection of 25.7 in. (653 mm), the post and socketed foundation had absorbed 156.2 kip-in. (17.6 kJ) of energy.

Damage to the test article consisted of plastic bending in the post and fracturing of the foundation. The post was bent at groundline, but not to the extent observed during test no. HTCB-5. The top 16 in. (406 mm) of the concrete foundation was fractured, and chunks of concrete were scattered around the impact location. The steel socket and several reinforcing bars were exposed and bent backward. Time-sequential and post-impact photographs are shown in Figure 14.

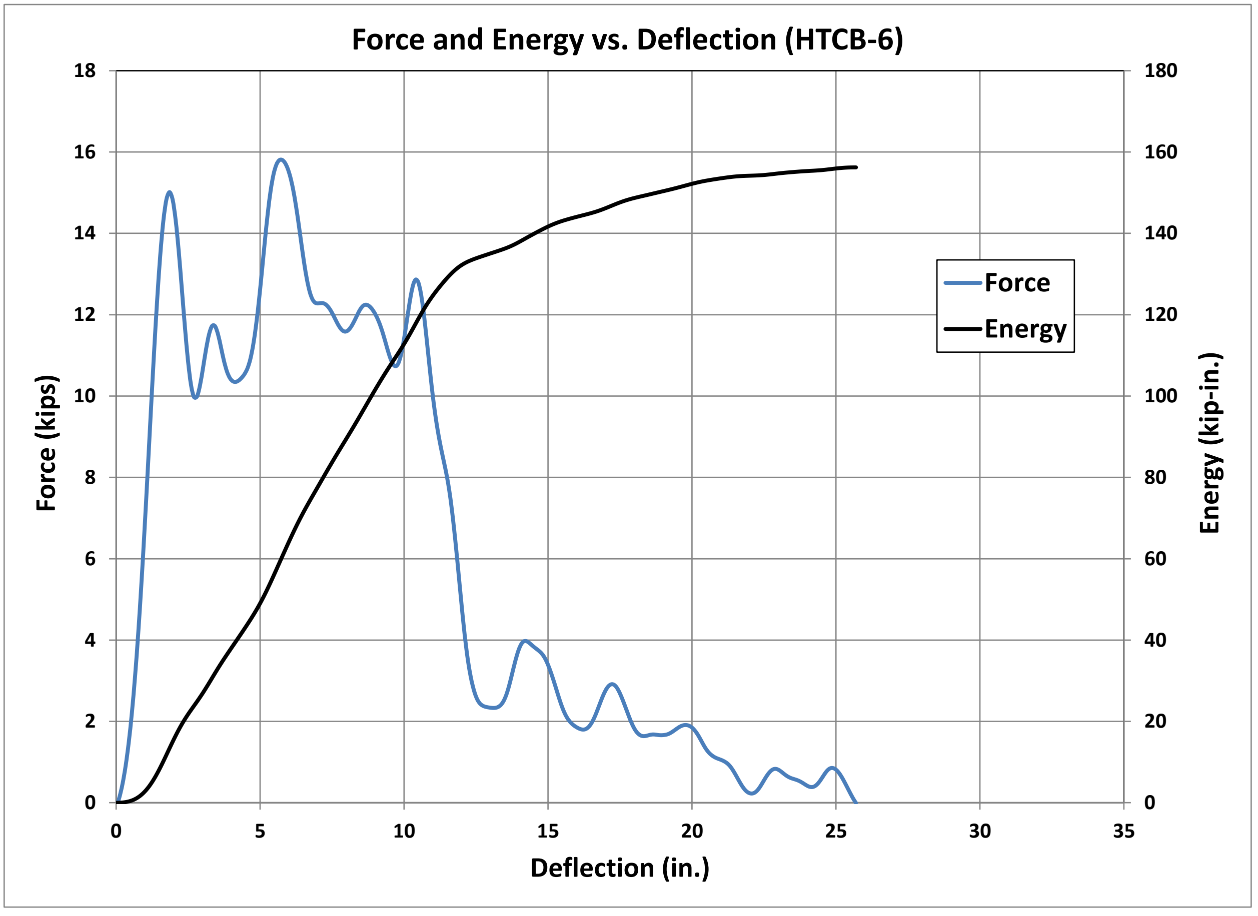
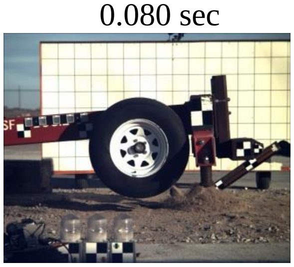


Figure 13. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-6

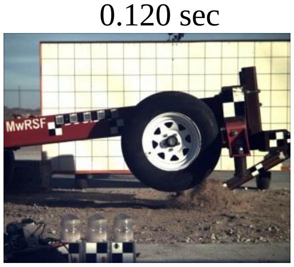
IMPACT

0.040 sec

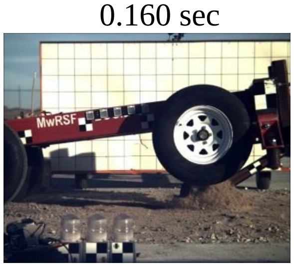
0.080 sec



0.120 sec



0.160 sec



0.200 sec

Figure 14. Time-Sequential and Post-Impact Photographs, Test No. HTCB-6

4.3.3 Test No. HTCB-7 (Design E)

Test no. HTCB-7 was conducted on January 5, 2012 at approximately 10:00 a.m. The weather conditions, as per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 5.

Table 5. Weather Conditions, Test No. HTCB-7

Temperature	40° F
Humidity	55%
Wind Speed	3 mph
Wind Direction	230° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

During test no. HTCB-7, the bogie impacted the post 11 in. (279 mm) above the groundline at a speed of 20.7 mph (33.3 km/h), causing strong-axis bending in the post. Upon impact, the foundation began to rotate through the soil, and a plastic hinge formed in the post at groundline. The foundation assembly reached a maximum dynamic deflection of 1.1 in. (28 mm) at 0.040 seconds. The post continued to bend over until the bogie head overrode the top of the post at 0.110 seconds after impact and at a deflection of 30.2 in. (767 mm). The top of the concrete foundation had permanently displaced 0.8 in. (20 mm) laterally during the impact event, as measured through video analysis.

Force vs. deflection and energy vs. deflection curves created from the EDR-3 accelerometer data are shown in Figure 15. Inertial effects resulted in a high peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a maximum of 13.6 kips (60.5 kN) at 5.9 in. (150 mm) of deflection. Following this peak, the force gradually decreased for the remainder of the impact event. At a maximum deflection of 30.2 in. (767 mm), the post and socketed foundation had absorbed 144.6 kip-in. (16.3 kJ) of energy.

Damage to the test article consisted of plastic bending to the steel post at groundline and concrete cracking. The foundation experienced concrete shear cracking, which caused a 5.3-in. (135-mm) deep piece of concrete to fracture off the top-back edge of the foundation. Subsequently, a portion of the steel socket and one transverse steel stirrup were exposed. Time-sequential and post-impact photographs are shown in Figure 16.

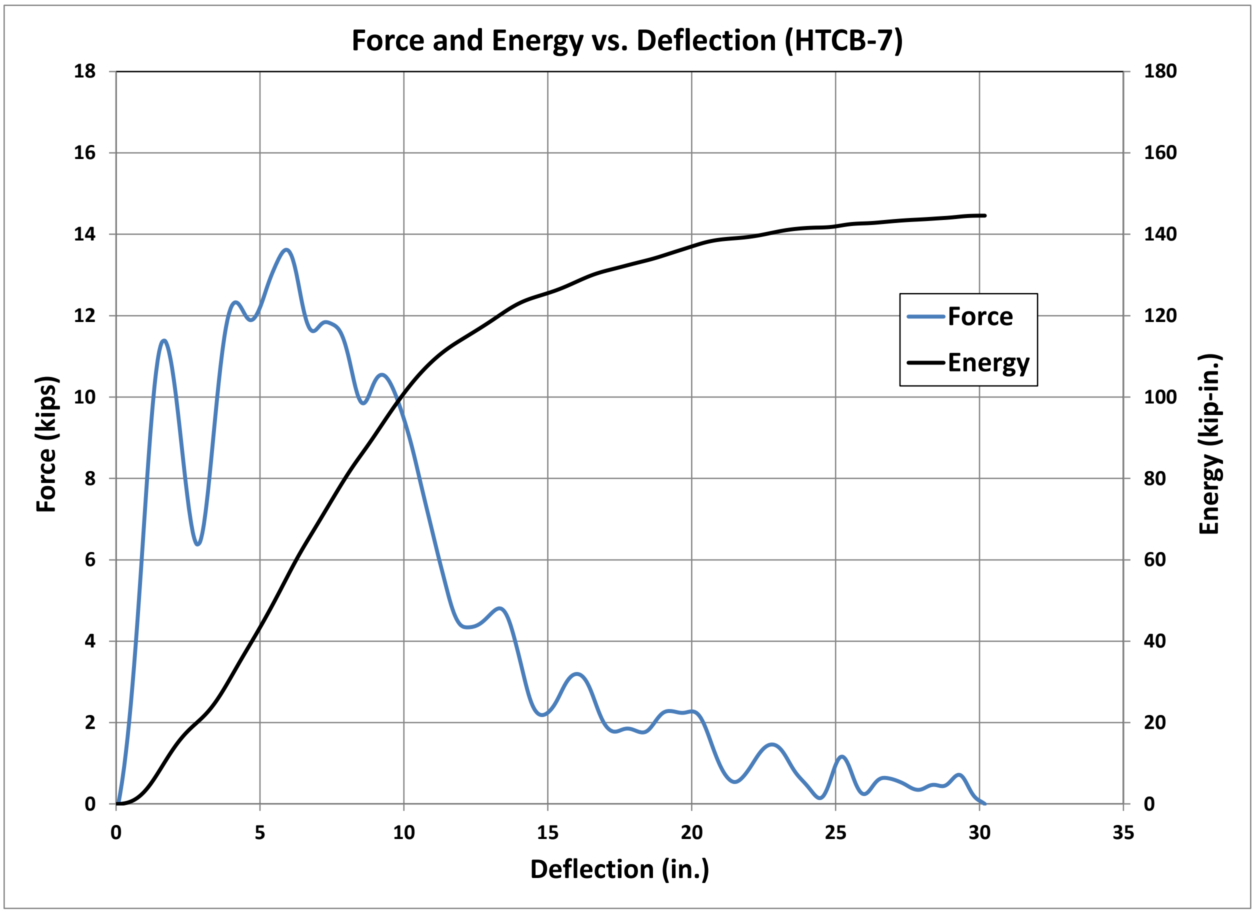


Figure 15. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-7

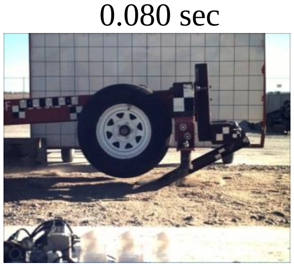
IMPACT

0.020 sec

0.040 sec

0.060 sec

0.080 sec



0.100 sec

Figure 16. Time-Sequential and Post-Impact Photographs, Test No. HTCB-7

4.3.4 Test No. HTCB-8 (Design F)

Test no. HTCB-8 was conducted on January 5, 2012 at approximately 1:15 p.m. The weather conditions, as per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 6.

Table 6. Weather Conditions, Test No. HTCB-8

Temperature	60° F
Humidity	27%
Wind Speed	13 mph
Wind Direction	240° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

During test no. HTCB-8, the bogie impacted the post 11 in. (279 mm) above the groundline at a speed of 20.9 mph (33.6 km/h), causing strong-axis bending in the post. Upon impact, the foundation began to rotate through the soil, and a plastic hinge formed in the post at groundline. The foundation reached a maximum dynamic deflection of 1.0 in. (25 mm) at 0.042 seconds. The post continued to bend over until the bogie head overrode the top of the post at 0.112 seconds after impact and at a deflection of 31.1 in. (790 mm). The top of the concrete foundation had permanently displaced 0.8 in. (20 mm) laterally during the impact event, as determined from video analysis.

Force vs. deflection and energy vs. deflection curves created from the EDR-3 accelerometer data are shown in Figure 17. Inertial effects resulted in a high peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a maximum of 13.3 kips (59.2 kN) at 6 in. (152 mm) of deflection. Following this second peak, the force gradually decreased until approximately 14 in. (356 mm) of deflection. A relatively steady force of approximately 2 kips (8.9 kN) was observed for the remainder of the impact event. At the maximum deflection of 31.1 in. (790 mm), the post assembly had absorbed 143.9 kip-in. (16.3 kJ) of energy.

Damage to the test article consisted of plastic bending of the post at groundline and concrete cracking. The foundation experienced concrete shear cracking, which caused a 4.8-in. (122-mm) deep chunk of concrete to fracture off the top-back edge of the foundation. Subsequently, a small portion of the steel socket and one transverse steel stirrup were exposed. Time-sequential and post-impact photographs are shown in Figure 18.

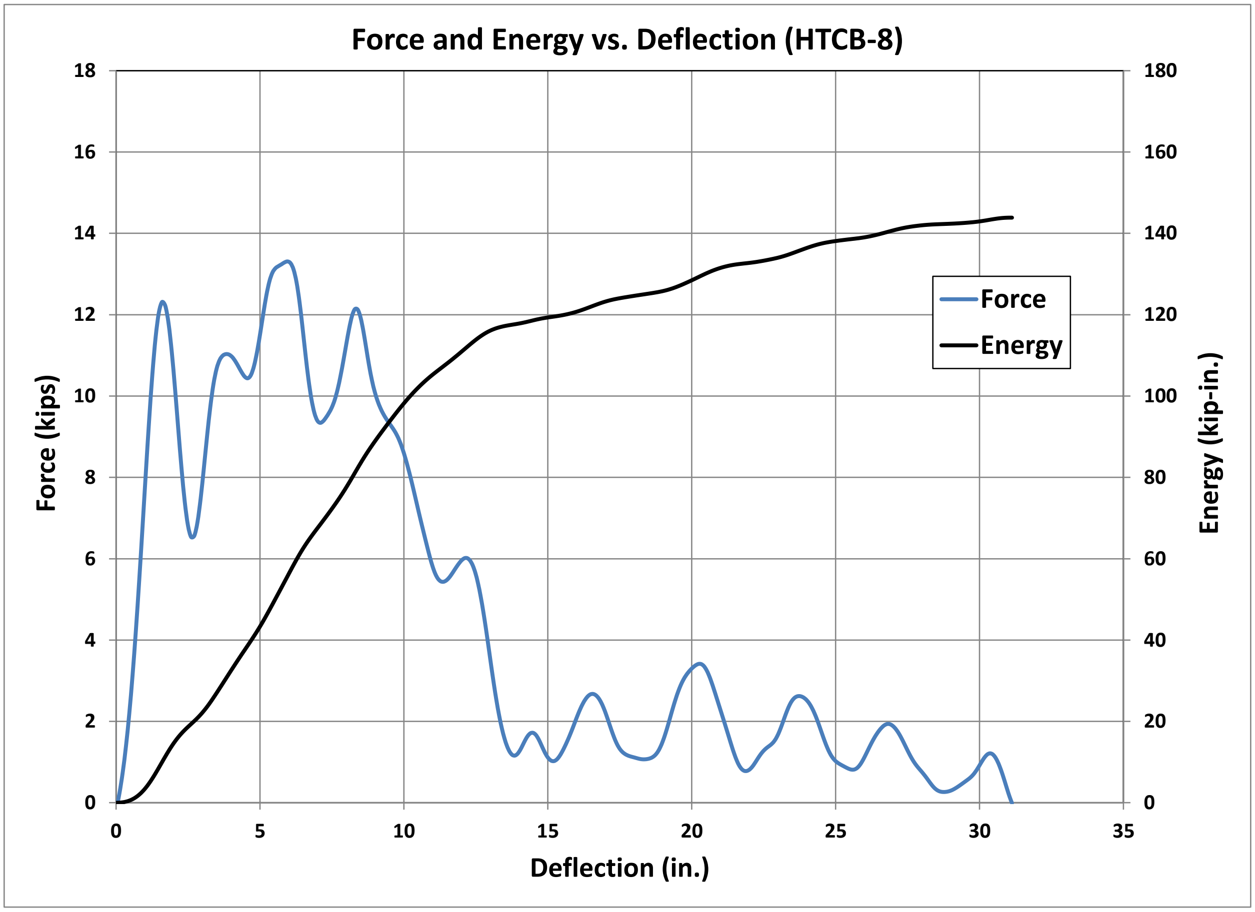


Figure 17. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-8

IMPACT

0.020 sec

0.040 sec

0.060 sec

0.080 sec

0.100 sec

Figure 18. Time-Sequential and Post-Impact Photographs, Test No. HTCB-8

4.3.5 Test No. HTCB-9 (Design G)

Test no. HTCB-9 was conducted on January 6, 2012 at approximately 10:00 a.m. The weather conditions, as per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 7.

Table 7. Weather Conditions, Test No. HTCB-9

Temperature	46° F
Humidity	43%
Wind Speed	20 mph
Wind Direction	360° From True North
Sky Conditions	Cloudy
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

During test no. HTCB-9, the bogie impacted the post 11 in. (279 mm) above the groundline at a speed of 20.8 mph (33.5 km/h), causing strong-axis bending in the post. Upon impact, the foundation began to rotate through the soil, and a plastic hinge formed in the post at groundline. The foundation reached a maximum dynamic deflection of 1.2 in. (30 mm) at 0.038 seconds. The post continued to bend over until the bogie head overrode the top of the post at 0.112 seconds after impact. The top of the concrete foundation had permanently displaced 1.1 in. (28 mm) laterally during the impact event, as determined from video analysis.

Force vs. deflection and energy vs. deflection curves created from the EDR-3 accelerometer data are shown in Figure 19. Inertial effects resulted in a high peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a maximum of 13.7 kips (60.9 kN) at 5.9 in. (150 mm) of deflection. Following this second peak, the force gradually decreased until approximately 13 in. (330 mm) of deflection. A relatively steady force of approximately 2 kips (8.9 kN) was observed for the rest of the impact event. At the maximum deflection of 26.8 in. (681 mm), the post assembly had absorbed 130.2 kip-in. (14.7 kJ) of energy.

Damage to the test article consisted of plastic bending of the post at groundline and concrete cracking. The foundation experienced concrete shear cracking, which caused a 4.8-in. (122-mm) deep chunk of concrete to fracture off the top-back edge of the foundation. Subsequently, a small portion of the steel socket and one transverse steel stirrup were exposed. Time-sequential and post-impact photographs are shown in Figure 20.

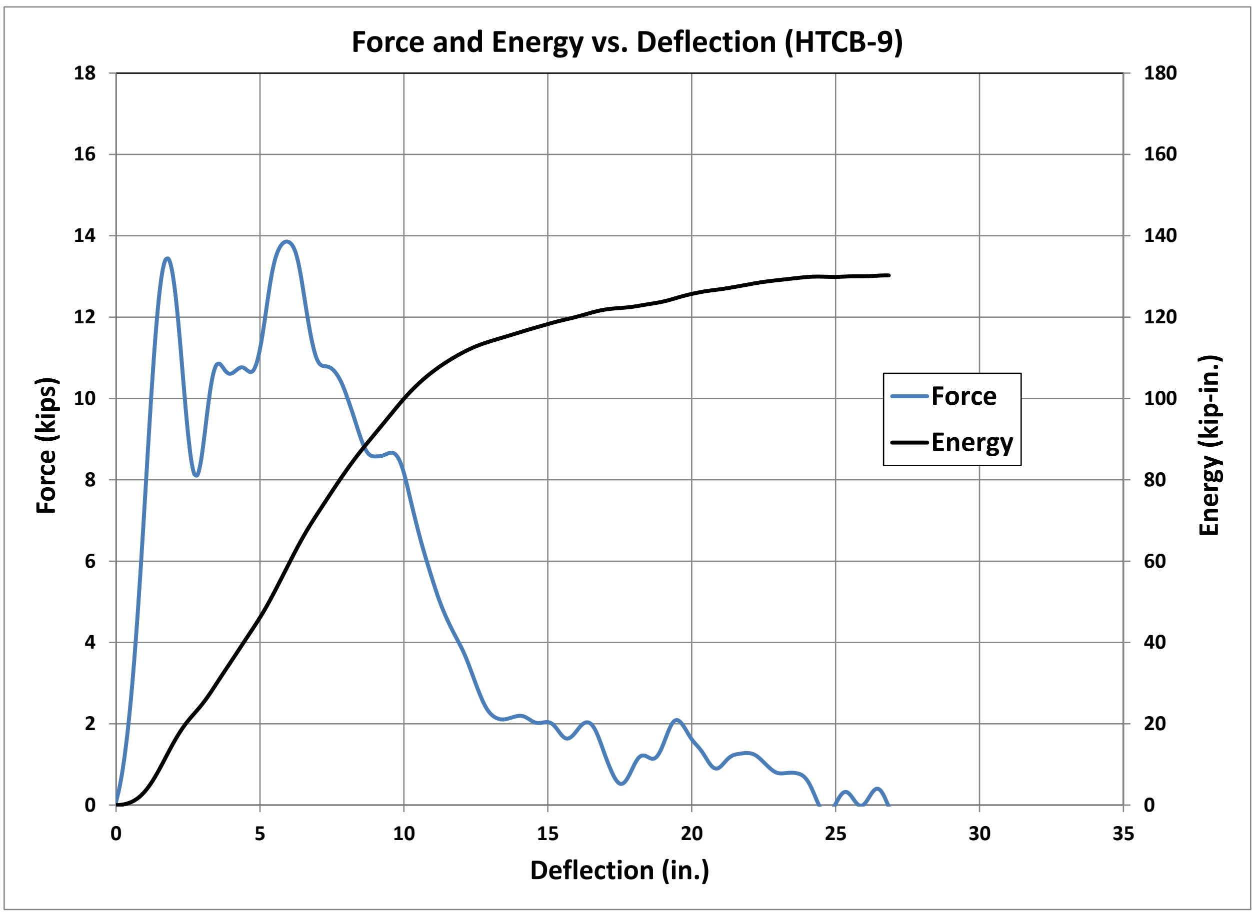
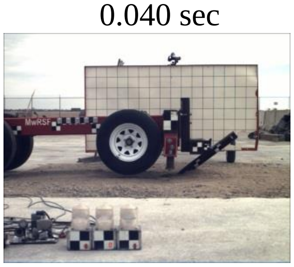


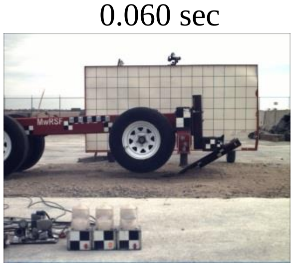
Figure 19. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-9


IMPACT


0.020 sec


0.040 sec


0.060 sec


0.080 sec


0.100 sec

Figure 20. Time-Sequential and Post-Impact Photographs, Test No. HTCB-9

4.4 Weak-Soil Testing Discussion

Results from the dynamic component testing conducted in weak soil are summarized in Table 8. Force vs. deflection and energy vs. deflection plots for each test are shown in Figures 21 and 22, respectively. The forces observed during the tests were similar in magnitude and duration. As expected, test no. HTCB-5 resulted in the lowest forces, since it was the only test conducted with the increased impact height of 15 in. (381 mm). All of the force curves contained an inertial spike within the first 2 in. (51 mm) of deflection, followed by relatively steady force plateaus over 10 kips (45 kN). Upon post yielding between 5 in. and 10 in. (127 mm and 254 mm), the forces dropped rapidly, and the bogie overrode the post. The variations in forces and energies between tests were considered negligible, and the result of small variations in impact speed, material strengths, and soil compaction.

Testing began with the weakest of the foundation configurations, Design D. When impacted at a height of 15 in. (381 mm) above the groundline during test no. HTCB-5, the foundation had a permanent displacement of only 0.3 in. (8 mm), well below the targeted 1-in. (25-mm) limit. Shear loads imparted to the socket from the post resulted in concrete cracking and a piece of concrete spalling off the top-back side of the foundation. Due to the limited displacement and minor damage to the weakest of the foundation designs, the remainder of the tests were conducted with the lower, more critical, impact height of 11 in. (279 mm).

Retesting of foundation Design D with the lower impact height resulted in severe damage to the top of the foundation in the form of concrete fractures and socket bending. Recall that the foundation assembly utilized in test no. HTCB-5 was rotated 180 degrees and reused for test no. HTCB-6. The previously damaged foundation assembly may have attributed to the poor performance of test no. HTCB-6. However, if the test were re-run with a new foundation conforming to Design D details, the damage would be expected to be similar, if not greater, than that observed during test no. HTCB-5.

Designs E through G, evaluated in test nos. HTCB-7 through HTCB-9, respectively, had similar results. All three configurations experienced concrete shear cracking and fracture of the top-back side of the foundation. Thus, none of the incremental design changes intended to increase the shear strength of the foundation were enough to prevent concrete shear failure. Due to the high amount of transverse and vertical steel already present in the foundation configurations, further increasing the internal steel reinforcement likely would not produce better results. Rather, the concrete would need to be confined (e.g., wrapping the foundation with steel or carbon fiber) or the diameter of the foundations would have to be increased to prevent concrete shear failure on the back of the socketed foundation,.

The permanent displacements observed in Designs E through G were similar, measuring 0.8 in. (20 mm), 0.8 in. (20 mm), and 1.1 in. (28 mm), respectively. The minor differences in displacements were attributed to small variations in impact speeds and soil compaction, since these three foundations each had a 12-in. (305-mm) diameter and a 60-in. (1,524-mm) embedment depth. The average displacement for these three foundation designs in weak soil was 0.9 in. (23 mm), which was below the 1-in. (25-mm) displacement limit. Thus, 60 in. (1,524 mm) was deemed the minimum embedment depth for a 12-in. (305-mm) diameter socketed foundation installed in weak, saturated, or sandy soils in order to prevent excessive displacements.

Table 8. Dynamic Testing Summary, Foundations Installed in Weak Soil

Test No.	Design	Impact Height in. (mm)	Impact Velocity mph (km/h)	Average Force kips (kN)			Peak Force kips (kN)	Total Energy kip-in. (kJ)	Permanent Foundation Deflection in. (mm)	Foundation Damage
				@ 10"	@ 15"	@ 20"				
HTCB-5	D	15 (381)	20.8 (33.5)	8.9 (39.6)	7.7 (34.3)	6.4 (28.5)	13.3 (59.2)	140.3 (15.9)	0.3 (8)	shear cracking/fracture
HTCB-6	D	11 (279)	20.0 (32.2)	11.3 (50.3)	9.4 (41.8)	7.6 (33.8)	15.8 (70.3)	156.2 (17.6)	NA	foundation fracture & socket bending
HTCB-7	E	11 (279)	20.7 (33.3)	10.0 (44.5)	8.4 (37.4)	6.8 (30.2)	13.6 (60.5)	144.6 (16.3)	0.8 (20)	shear cracking/fracture
HTCB-8	F	11 (279)	20.9 (33.6)	9.8 (43.6)	8.0 (35.6)	6.4 (28.5)	13.3 (59.2)	143.9 (16.3)	0.8 (20)	shear cracking/fracture
HTCB-9	G	11 (279)	20.8 (33.5)	9.8 (43.6)	7.7 (34.3)	6.1 (27.1)	13.9 (61.9)	130.2 (14.7)	1.1 (28)	shear cracking/fracture

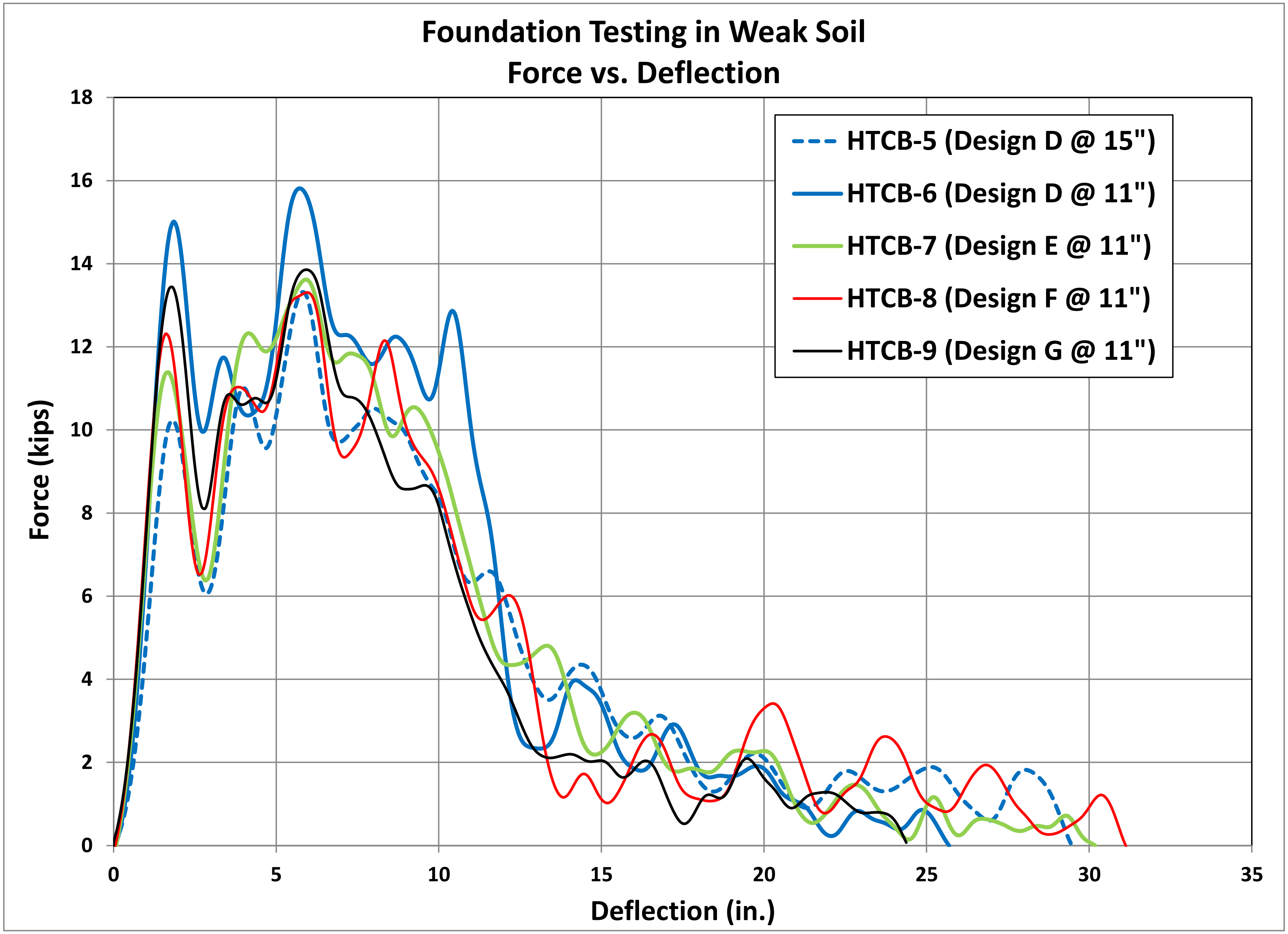


Figure 21. Force vs. Deflection, Foundations Installed in Weak Soil

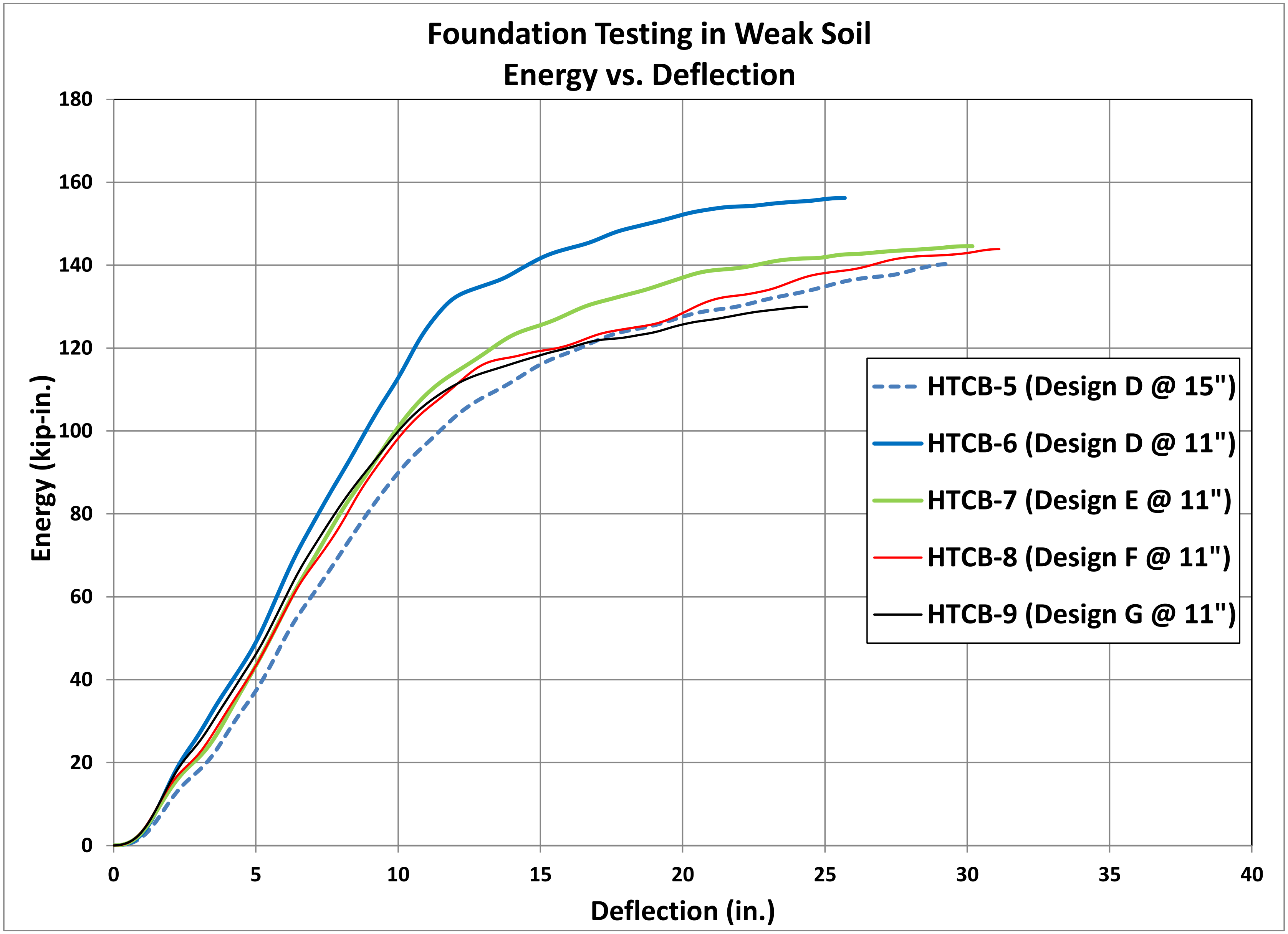


Figure 22. Energy vs. Deflection, Foundations Installed in Weak Soil

5 DESIGN DETAILS – ROUND 2, STRONG SOIL

Round 1 of dynamic component testing evaluated the performance of socketed foundations installed in critically weak soils. However, foundation performance in combination with compacted, stiff soils was also desired. Thus, Round 2 of dynamic component testing was conducted with the foundations placed within a strong, stiff soil satisfying AASHTO Grade B gradation specifications [7] and MASH soil resistance requirements [5]. Design drawings for the socketed foundations evaluated in combination with strong soil are shown in Figures 23 through 32, and photographs of the test installations are shown in Figure 33. Material specifications, mill certifications, and certificates of conformity for the reinforced concrete, socketed foundations are shown in Appendix A.

Results from Round 1 of component testing on 12-in. (305-mm) diameter socketed foundations indicated that in order to prevent concrete shear failure, either the concrete would need to be confined, or the diameter of the foundation would have to be increased. It was unclear whether increasing the strength of the soil surrounding the foundation would be sufficient to confine the concrete and prevent shear cracking. However, providing external reinforcement to the foundations (e.g., sheet steel or carbon fiber wraps) to provide confinement was deemed undesirable by the project sponsors. Thus, various diameters for the socketed foundations were explored during Round 2 testing.

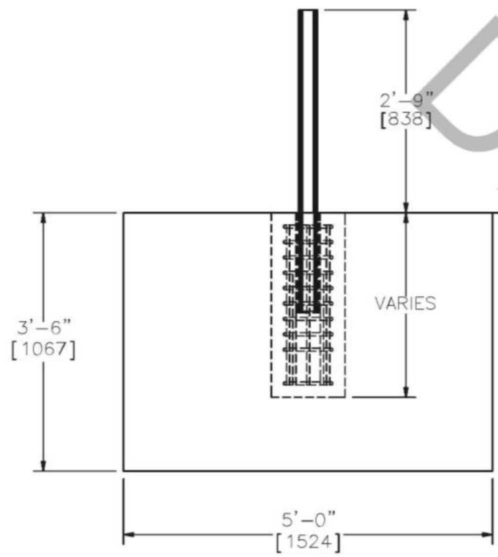
Six different socketed foundation designs were fabricated to evaluate performance in combination with strong soils (though only four of these six were actually tested). Of these foundations, three designs maintained the 12-in. (305-mm) diameter utilized during testing of the foundations in weak soil, while three more designs utilized an increased shaft diameter. The same internal reinforcement pattern was utilized in all three 12-in. (305-mm) diameter foundations, Designs H, J, and K. The reinforcement pattern consisted of a combination of previous Designs E and G to maximize the strength of the foundations against cracking. Specifically, the tight, 2½-in. (64-mm) stirrup spacing of Design E was combined with the extra vertical steel bars of Design G, as shown in Figures 24, 26, and 27. Designs H, J, and K had embedment depths of 24 in. (610 mm), 30 in. (762 mm), and 36 in. (914 mm), respectively.

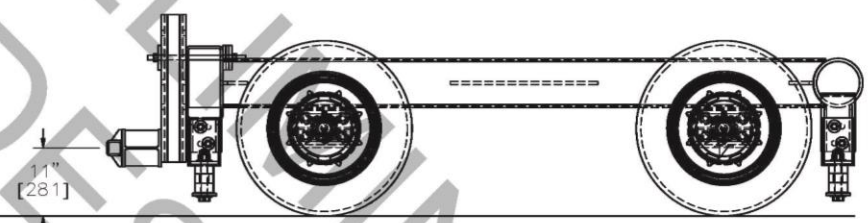
Designs L and M utilized an outside diameter of 15 in. (381 mm), while Design N utilized an outside diameter of 18 in. (457 mm). All three of the increased diameter foundation designs utilized 4-in. (102-mm) spacings between stirrups. The stirrup sizes varied with foundation diameter to maintain a constant concrete clear cover of 1½ in. (38 mm), as shown in Figures 25 and 28. Only four vertical steel bars were utilized within these three foundation designs. The embedment depths for Designs L through N were 24 in. (610 mm), 30 in. (762 mm), and 30 in. (762 mm), respectively.

The S3x5.7 (S76x8.5) steel post and the HSS 4-in. x 4-in. x ¼-in. (HSS 102-mm x 102-mm x 6-mm) steel tube socket remained the same from Round 1 of component testing. Additionally, the minimum concrete strength remained at 3,500 psi (24 MPa). Concrete cylinder testing revealed the actual strength of the concrete to be 4,800 psi (33 MPa).

Although six foundation designs were fabricated for Round 2 testing, only four were actually impacted. After conducting testing on Design J, it was clear that Design H was too shallow to prevent rotation, and after conducting testing on Design M, the increased diameter of Design N was deemed unnecessary. Thus, neither Design H nor Design N was evaluated through dynamic bogie testing.

Test No.	Design	Soil Type	Impact Height	Foundation Diameter	Foundation Depth	Speed mph [km/h]	Angle (degrees)
HTCB–10	J	Standard Strong Soil	11" [279]	12" [305]	30" [762]	20 [32.2]	90
HTCB–11	K	Standard Strong Soil	11" [279]	12" [305]	36" [914]	20 [32.2]	90
HTCB–17	M	Standard Strong Soil	11" [279]	15" [381]	30" [762]	20 [32.2]	90
HTCB–18	L	Standard Strong Soil	11" [279]	15" [381]	24" [610]	20 [32.2]	90





Notes: (1) Use Bogie #3 with shear impact head.

(2) Post assembly is to be placed in the center of a 5' [1524] long x 3' [914] wide x 3'–6" [1067] deep area filled with compacted standard strong soil. After the initial test, ensuing test assemblies can be installed using only a 3' [914] augered hole, placed in the center of the 5' [1524] x 3' [914] area.

(3) Attach a 3/4" [19] thick Neoprene pad to the front of the bogie impact head.

(4) Initial test is to be conducted with the 12" [305] diameter, 30" [762] deep foundation. Based on test results, the PI will select the next foundation for testing.

MwRSF Midwest Roadside Safety Facility	High Tension Cable Footing – Strong Soil Tests	SHEET: 1 of 10
		DATE: 8/12/2014
	General Test Setup	DRAWN BY: RJT/CWP/S DB/ESG/JEK
	DWG. NAME. HT Cable Footings R3&R6_ForReport_R	SCALE: 1:4 UNITS: In[mm]
		REV. BY: KAL/SKR

Figure 23. Bogie Testing Matrix and Setup, Test Nos. HTCB-10, HTCB-11, HTCB-17, and HTCB-18

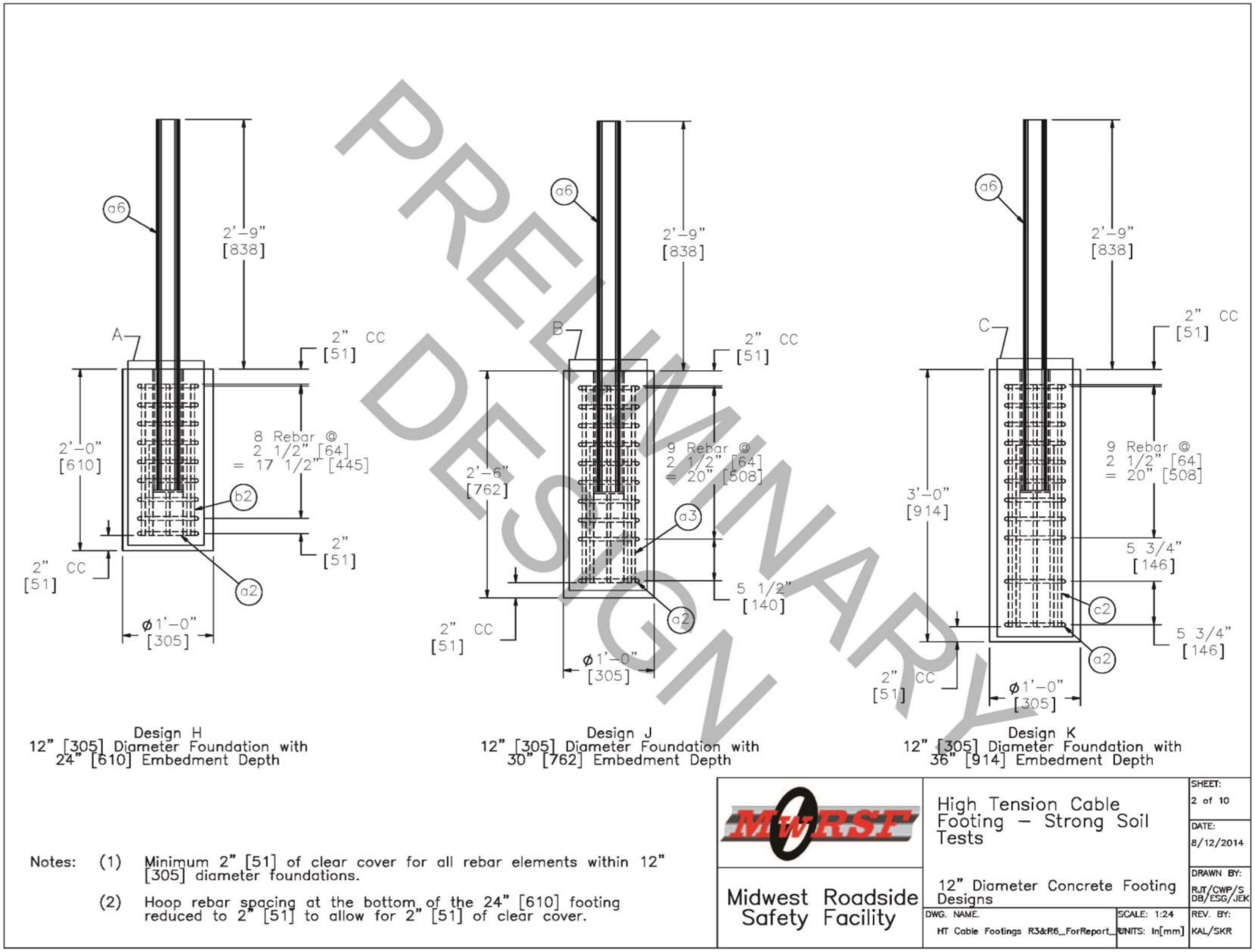


Figure 24. Foundation Configurations with 12-in. (305-mm) Diameters, Test Nos. HTCB-10 and HTCB-11

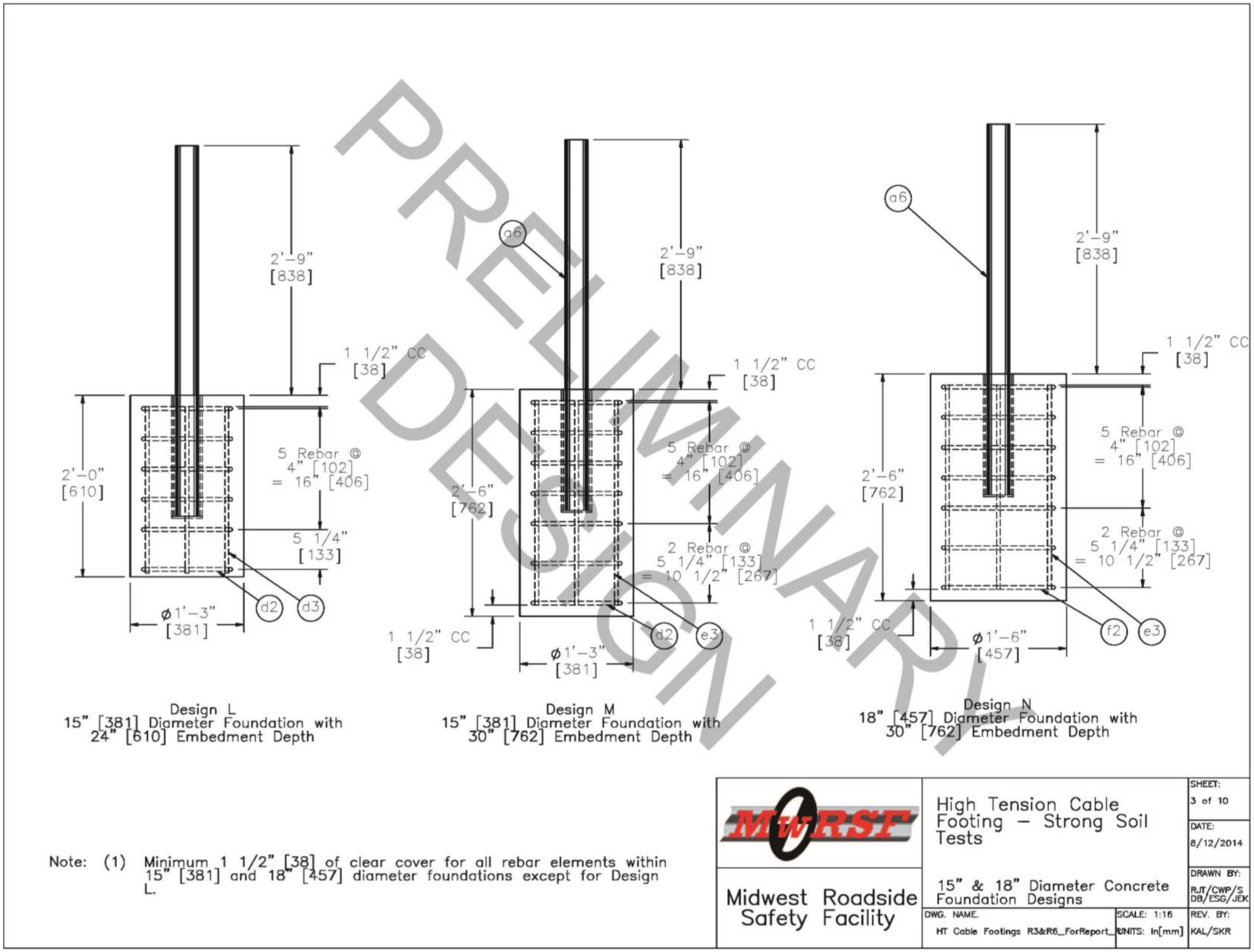


Figure 25. Foundation Configurations with Increased Diameter Foundations, Test Nos. HTCB-17 and HTCB-18

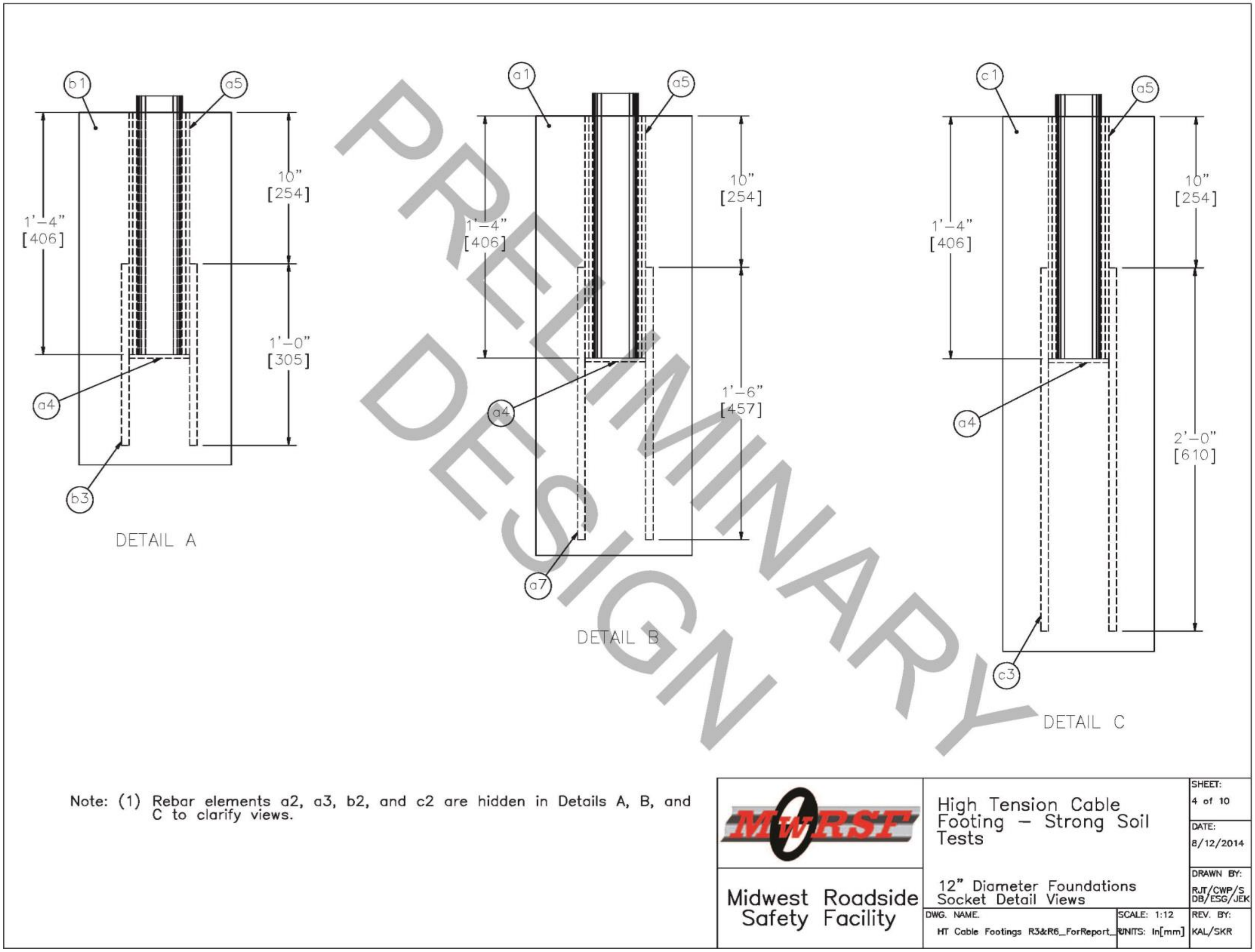
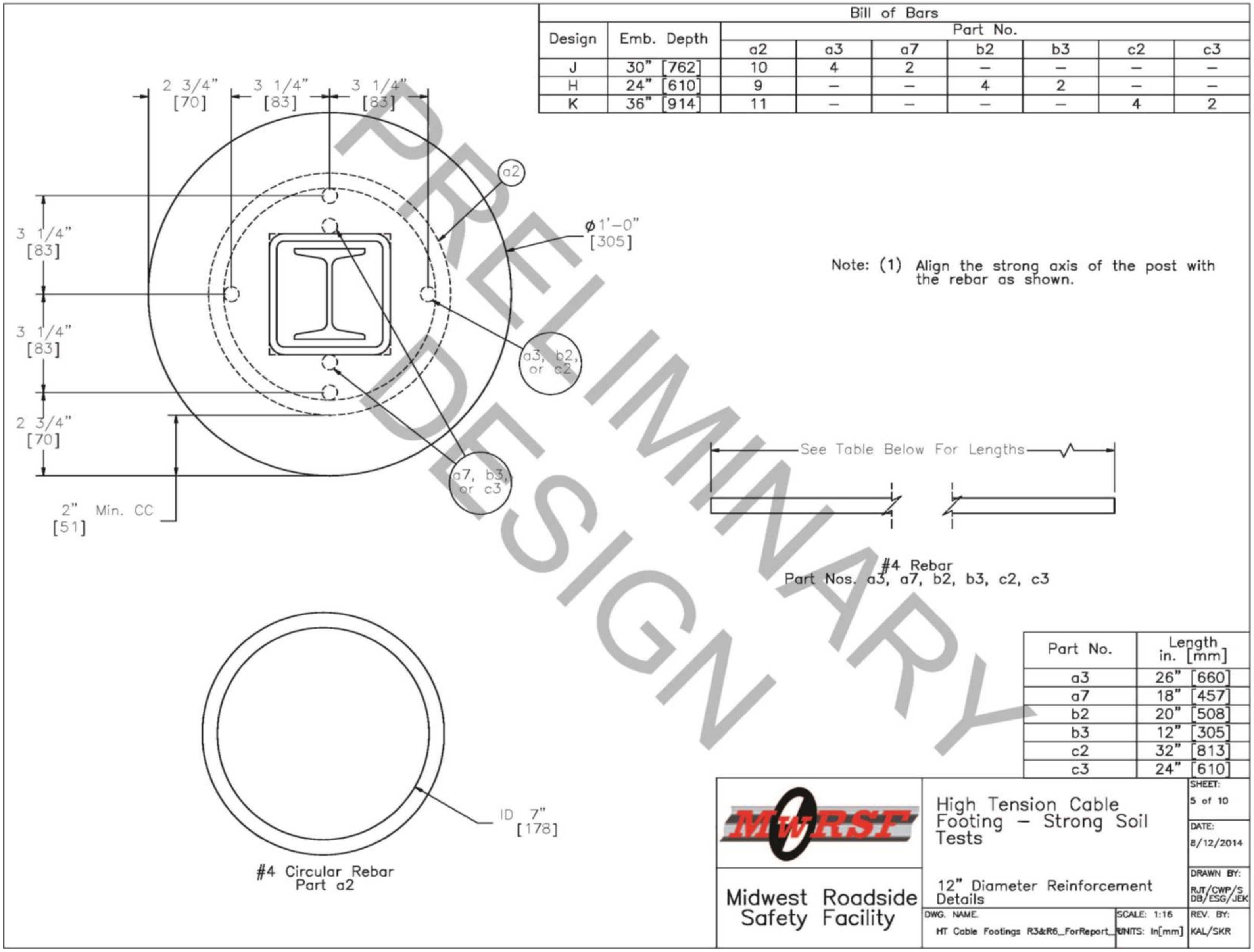


Figure 26. Reinforcement Details for 12-in. (305-mm) Diameter Foundations, Test Nos. HTCB-10 and HTCB-11

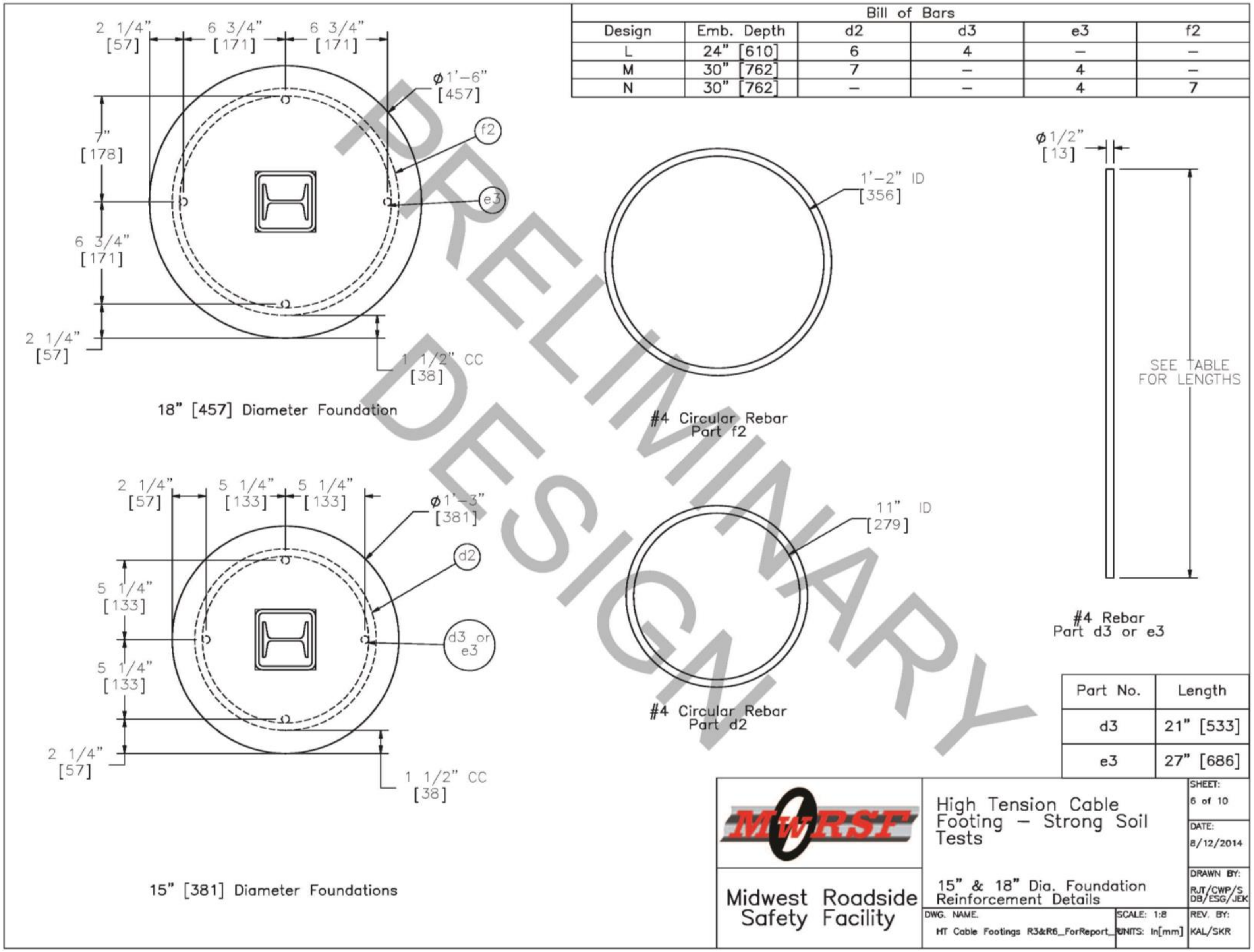


Bill of Bars

Design	Emb. Depth	Part No. a2	a3	a7	b2	b3	c2	c3
J	30" [762]	10	4	2	–	–	–	–
H	24" [610]	9	–	–	4	2	–	–
K	36" [914]	11	–	–	–	–	4	2

Part No.	Length in. [mm]
a3	26" [660]
a7	18" [457]
b2	20" [508]
b3	12" [305]
c2	32" [813]
c3	24" [610]

Figure 27. Reinforcement Details for 12-in. (305-mm) Diameter Foundations, Test Nos. HTCB-10 and HTCB-11



Bill of Bars

Design	Emb. Depth	d2	d3	e3	f2
L	24" [610]	6	4	–	–
M	30" [762]	7	–	4	–
N	30" [762]	–	–	4	7

Part No.	Length
d3	21" [533]
e3	27" [686]

Figure 28. Reinforcement Details for Increased Diameter Foundations, Test Nos. HTCB-17 and HTCB-18

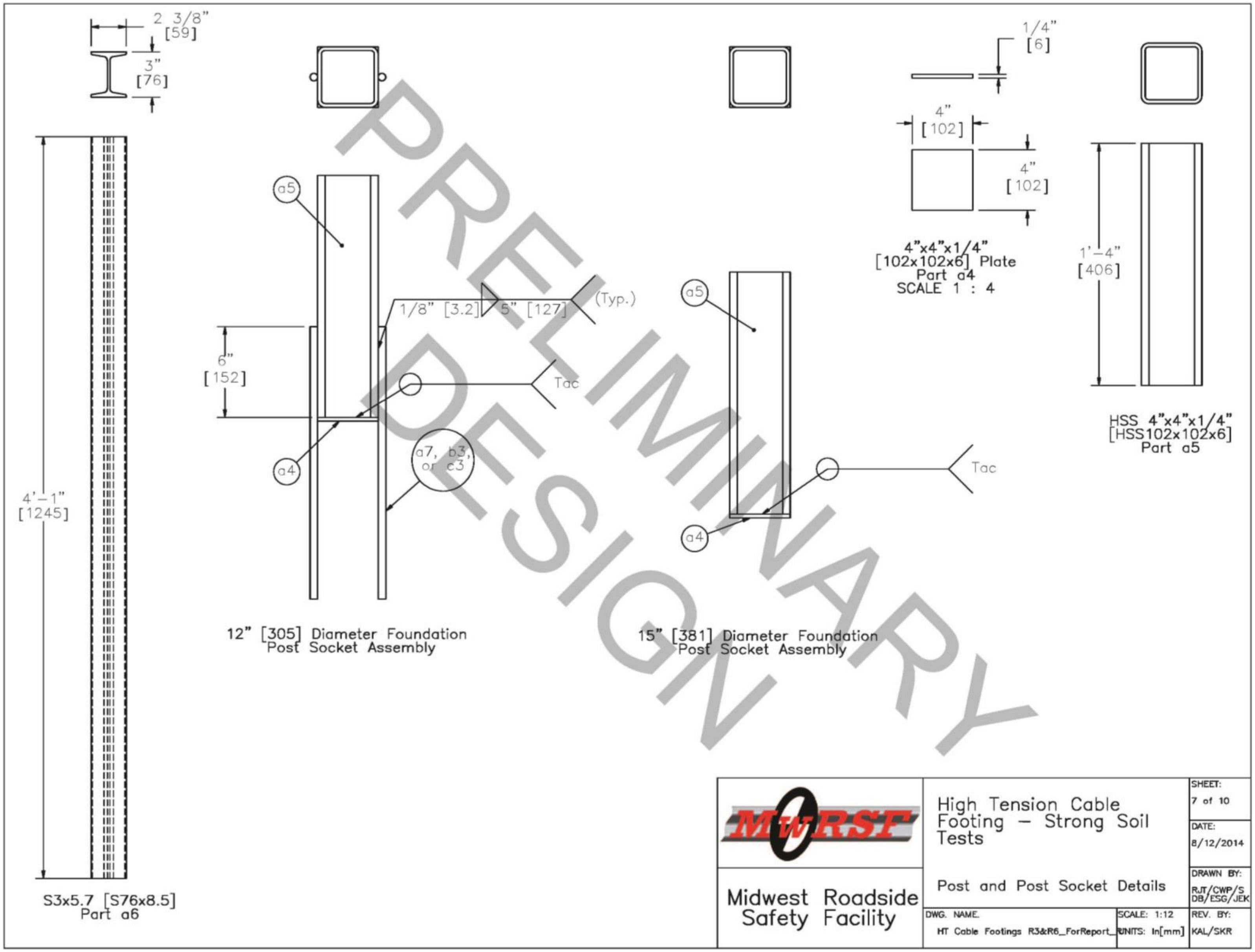


Figure 29. Steel Post and Socket Details, Test Nos. HTCB-10, HTCB-11, HTCB-17, and HTCB-18

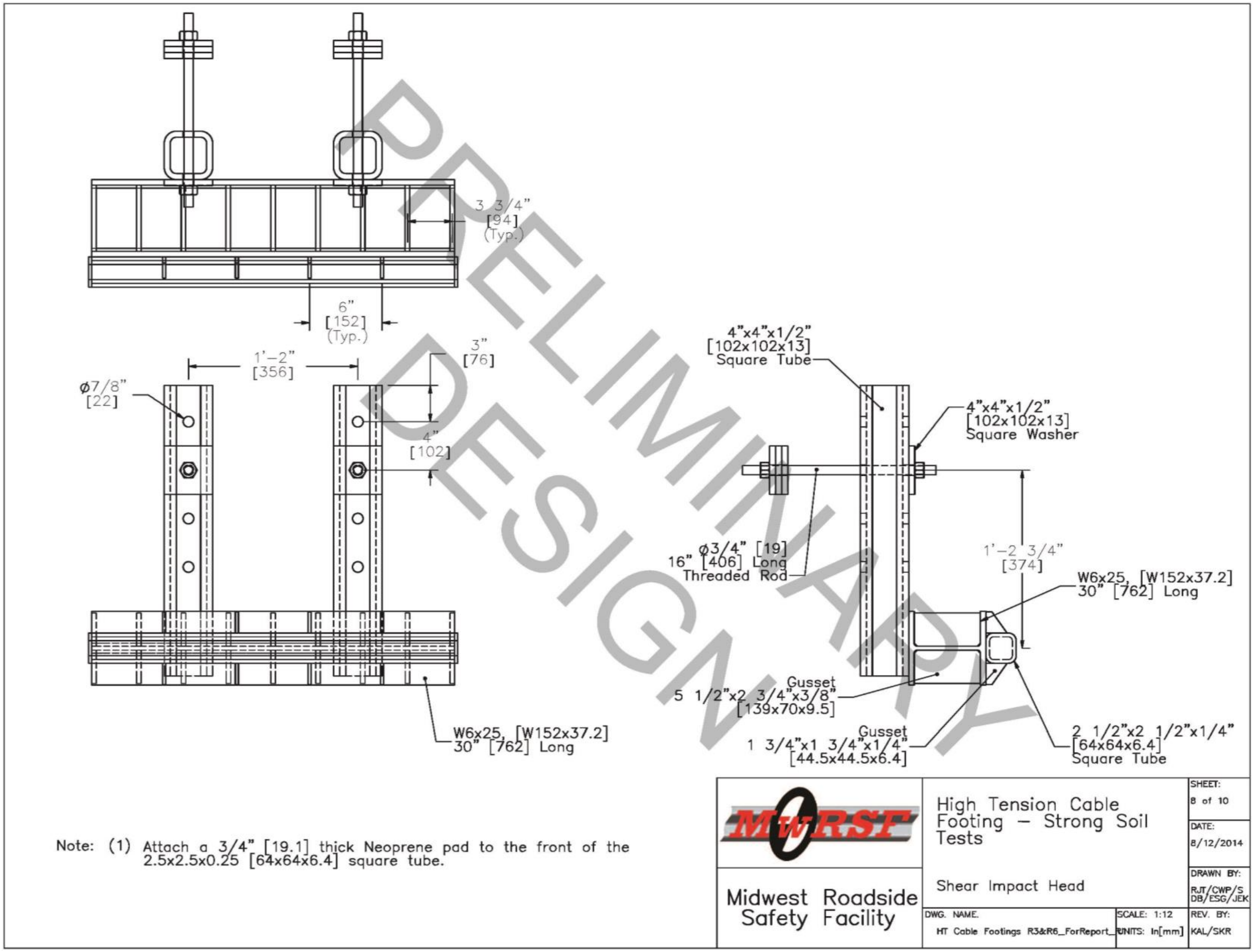


Figure 30. Bogie Shear Impact Head Details, Test Nos. HTCB-10, HTCB-11, HTCB-17, and HTCB-18

Design J Bill of Materials			
Part No.	QTY.	Part Description	Material Specification
a1	1	Concrete Shaft 30" [762] Long	Min 3500 psi [24 MPa] Comp. Strength
a2	10	#4 Circular Rebar 7" [178] ID	Gr. 60
a3	4	#4 Rebar 26" [660] Long	Gr. 60
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
a5	1	HSS 4x4x1/4" [HSS 102x102x6], 16" [406] Long	ASTM A500 Grade B
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50 / ASTM A992 / ASTM A209 Gr. 50
a7	2	#4 Rebar 18" [457] Long	Gr. 60

Design H Bill of Materials			
Part No.	QTY.	Part Description	Material Specification
a2	9	#4 Circular Rebar 7" [178] ID	Gr. 60
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
a5	1	HSS 4x4x1/4" [HSS 102x102x6], 16" [406] Long	ASTM A500 Grade B
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50 / ASTM A992 / ASTM A209 Gr. 50
b1	1	Concrete Shaft 24" [610] Long	Min 3500 psi [24 MPa] Comp. Strength
b2	4	#4 Rebar 20" [508] Long	Gr. 60
b3	2	#4 Rebar 12" [305] Long	Gr. 60

Design K Bill of Materials			
Part No.	QTY.	Part Description	Material Specification
a2	11	#4 Circular Rebar 7" [178] ID	Gr. 60
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
a5	1	HSS 4x4x1/4" [HSS 102x102x6], 16" [406] Long	ASTM A500 Grade B
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50 / ASTM A992 / ASTM A209 Gr. 50
c1	1	Concrete Shaft 36" [914] Long	Min 3500 psi [24 MPa] Comp. Strength
c2	4	#4 Rebar 32" [813] Long	Gr. 60
c3	2	#4 Rebar 24" [610] Long	Gr. 60

MwRSF
Midwest Roadside Safety Facility

High Tension Cable Footing – Strong Soil Tests

Bill of Materials

SHEET: 9 of 10
DATE: 8/12/2014
DRAWN BY: RJT/CWP/SDB/ESG/JEK
DWG. NAME. HT Cable Footings R3&R6_ForReport_R
SCALE: 1:16
UNITS: in[mm]
REV. BY: KAL/SKR

Figure 31. Bill of Materials for 12-in. (305-mm) Diameter Foundations, Test Nos. HTCB-10 and HTCB-11

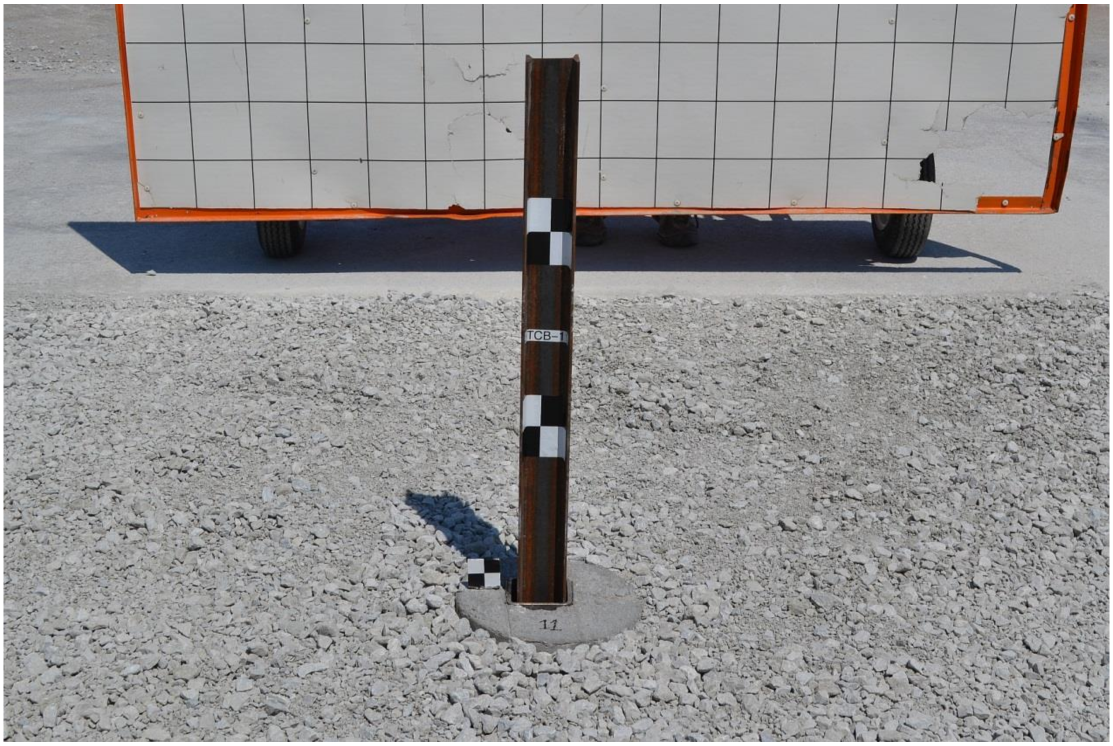
Design L Bill of Materials			
Item No.	QTY.	Description	Material Spec
d1	1	Concrete Shaft 15" [381] Diameter	Min 3500 psi [24 MPa] Compressive Strength
d2	6	#4 Circular Rebar 7" [178] ID	Gr. 60
d3	4	#4 Rebar 22" [559] Long	Gr. 60
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50 / ASTM A992 / ASTM A209 Gr. 50

Design M Bill of Materials			
Item No.	QTY.	Description	Material Specification
e1	1	Concrete Shaft 15" [381] Diameter	Min 3500 psi [24 MPa] Compressive Strength
d2	7	#4 Circular Rebar 7" [178] ID	Gr. 60
e3	4	#4 Rebar 27" [686] Long	Gr. 60
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50 / ASTM A992 / ASTM A209 Gr. 50

Design N Bill of Materials			
Item No.	QTY.	Description	Material Specification
f1	1	Concrete Shaft 18" [457] Diameter	Min 3500 psi [24 MPa] Compressive Strength
f2	7	#4 Circular Rebar 14" [178] ID	Gr. 60
e3	4	#4 Rebar 27" [686] Long	Gr. 60
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50 / ASTM A992 / ASTM A209 Gr. 50

MwRSF Midwest Roadside Safety Facility	High Tension Cable Footing – Strong Soil Tests	SHEET: 10 of 10
		DATE: 8/12/2014
	Bill of Materials	DRAWN BY: RJT/CWP/S DB/ESG/JEK
	DWG. NAME. HT Cable Footings R3&R6_ForReport_	SCALE: 1:24 UNITS: in[mm]
		REV. BY: KAL/SKR

Figure 32. Bill of Materials for Increased Diameter Foundations, Test Nos. HTCB-17, and HTCB-18



12-in. (305-mm) Diameter Foundation

15-in. (381-mm) Diameter Foundation

Figure 33. Test Article Installation Photographs

6 COMPONENT TESTING – ROUND 2, STRONG SOIL

6.1 Purpose

After completing the testing matrix for socketed foundations installed in critically weak soils, it was desired to determine foundation performance in combination with stiff soils similar to those typically used during barrier evaluation under MASH [5]. Thus, Round 2 of dynamic component testing was conducted with the foundations placed within a strong, stiff soil satisfying AASHTO Grade B gradation specifications [7] and MASH soil resistance requirements. During Round 2 testing, the embedment depth of the foundations was varied to determine the minimum depth required to prevent excessive displacements, greater than 1 in. (25 mm), in stiff soils. Additionally, the reinforcement configurations and foundation diameters were varied in an effort to prevent concrete shear cracking on the back side of the foundation.

6.2 Scope

Four bogie tests were conducted on S3x5.7 (S76x8.5) steel posts inserted into reinforced concrete, socketed foundations installed in a strong, stiff soil. Test nos. HTCB-10 and HTCB-11 were conducted on socketed foundations with 12-in. (305-mm) diameters and embedment depths of 30 in. (762 mm) and 36 in. (914 mm), respectively. Test nos. HTCB-17 and HTCB-18 were conducted on socketed foundations with an increased diameter of 15 in. (381 mm) and embedment depths of 30 in. (762 mm) and 24 in. (610 mm), respectively. The target impact conditions for all four tests were an impact height of 11 in. (279 mm), a speed of 20 mph (32 km/h), and an angle of 90 degrees, creating a classic “head-on” impact with the strong axis of the post. The test matrix is shown in Table 9.

As described in Chapter 5, there were six socketed foundation designs fabricated for evaluation during Round 2 of component testing. Designs H, J, and K were 12-in. (305-mm) diameter foundations with varying embedment depths, while Designs L through N had an increased diameter and varying embedment depths. However, in an effort to limit the amount of testing required to determine the necessary foundation strength and embedment depth, the middle-sized foundation from each of these two groups was tested first, and the second test article would be selected depending upon the results. Thus, the 12-in. (305-mm) diameter socket with the middle embedment depth, Design J, was evaluated first. After excessive displacement was observed, testing continued with the larger foundation, Design K, and Design H was never evaluated. Similarly, Design M was evaluated first and resulted in minimal displacement and damage. Thus, Design L was selected for the next test, and Design N was never evaluated.

Table 9. Bogie Testing Matrix, Foundations in Strong Soil

Test No.	Design	Soil Type	Impact Height in. (mm)	Impact Speed mph (km/h)	Impact Angle deg.	Embed. Depth in. (mm)	Foundation Diameter in. (mm)
HTCB-10	J	AASHTO Grade B	11 (279)	20 (32)	90	30 (762)	12 (305)
HTCB-11	K	AASHTO Grade B	11 (279)	20 (32)	90	36 (914)	12 (305)
HTCB-17	M	AASHTO Grade B	11 (279)	20 (32)	90	30 (762)	15 (381)
HTCB-18	L	AASHTO Grade B	11 (279)	20 (32)	90	24 (610)	15 (381)

6.3 Strong-Soil Results

Through component testing, the performance of each socketed foundation was evaluated in terms of both structural integrity and displacement of the foundation in strong soils. A foundation system had to resist the impact loads without fracture to be deemed adequate. Additionally, the researchers desired to limit the displacements of the foundation to less than 1 in. (25 mm), as measured at groundline. The combination of these criteria would ensure that a socketed foundation could be reused in the same system without repairs or resetting.

Accelerometer data was used to find the resistance force supplied by the S3x5.7 (S76x8.5) post and foundation assembly. Since the accelerometers were mounted on the bogie vehicle, the forces and displacements calculated from the acceleration data were related to the motion of the bogie and the forces applied to it from the posts. These forces and displacements did not directly reflect the force applied to the top of the foundations or the displacement of the foundation. However, the recorded forces can be used to indicate approximate force magnitudes imparted to the sockets. Individual results for all accelerometers utilized during each test are shown in Appendix B. Due to the plastic deformation of the posts, foundation displacements were measured from the high-speed video and post-test field measurements.

6.3.1 Test No. HTCB-10 (Design J)

Test no. HTCB-10 was conducted on June 13, 2012 at approximately 12:30 p.m. The weather conditions, as per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 10.

Table 10. Weather Conditions, Test No. HTCB-10

Temperature	85° F
Humidity	30%
Wind Speed	23 mph
Wind Direction	160° From True North
Sky Conditions	Partly Cloudy
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

During test no. HTCB-10, the bogie impacted the S3x5.7 (S76x8.5) steel post 11 in. (279) above the groundline and at a speed of 20.6 mph (33.2 km/h), causing strong-axis bending in the post. Upon impact, the foundation assembly began to rotate through the soil, and a plastic hinge formed in the post at groundline. By 0.008 seconds after impact, a concrete crack had formed across the top of the foundation adjacent to the back edge of the socket. The foundation assembly reached a maximum dynamic deflection of 3.1 in. (79 mm) at 0.052 seconds. The post continued to bend over until the bogie head overrode the top of the post at 0.116 seconds after impact. The top of the concrete foundation had permanently displaced 2.2 in. (56 mm) laterally during the impact event, as determined from video analysis.

Force vs. deflection and energy vs. deflection curves created from the EDR-3 accelerometer data are shown in Figure 34. Inertial effects resulted in a quick peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a maximum of 20.7 kips (92.1 kN) at 5.4 in. (137 mm) of deflection. Following the maximum peak, the force gradually decreased until approximately 11 in. (279 mm) of deflection. The force remained below 5 kips (22 kN) for the remainder of the impact event. At the maximum deflection of 30.2 in. (767 mm), the post assembly had absorbed 149.6 kip-in. (16.9 kJ) of energy.

Damage to the test article consisted of plastic bending of the post at groundline and concrete cracking. The foundation experienced concrete shear cracking, which caused a 5-in. (127-mm) deep chunk of concrete to fracture off the top-back edge of the foundation. Subsequently, a small portion of the steel socket and one transverse steel stirrup were exposed. Time-sequential and post-impact photographs are shown in Figure 35.

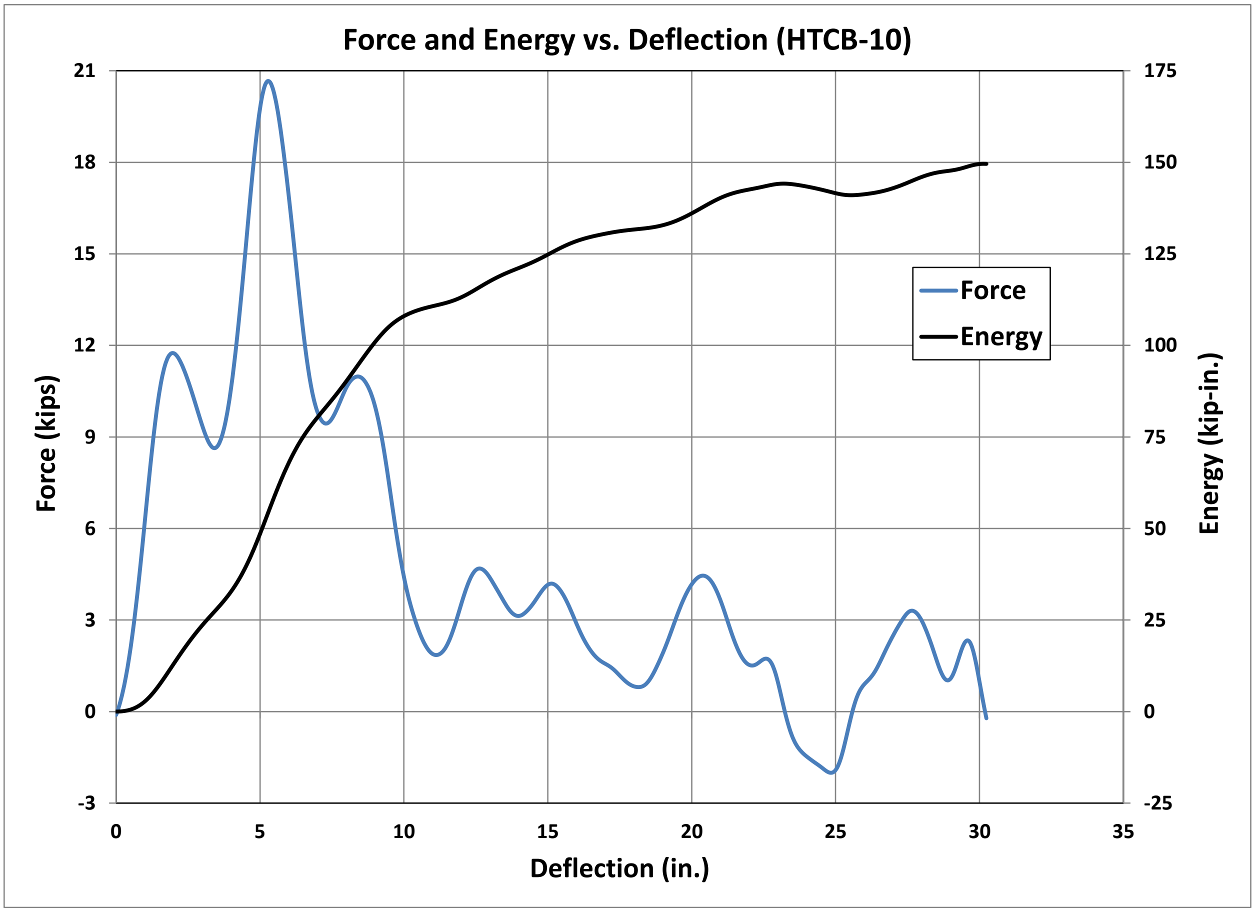


Figure 34. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-10

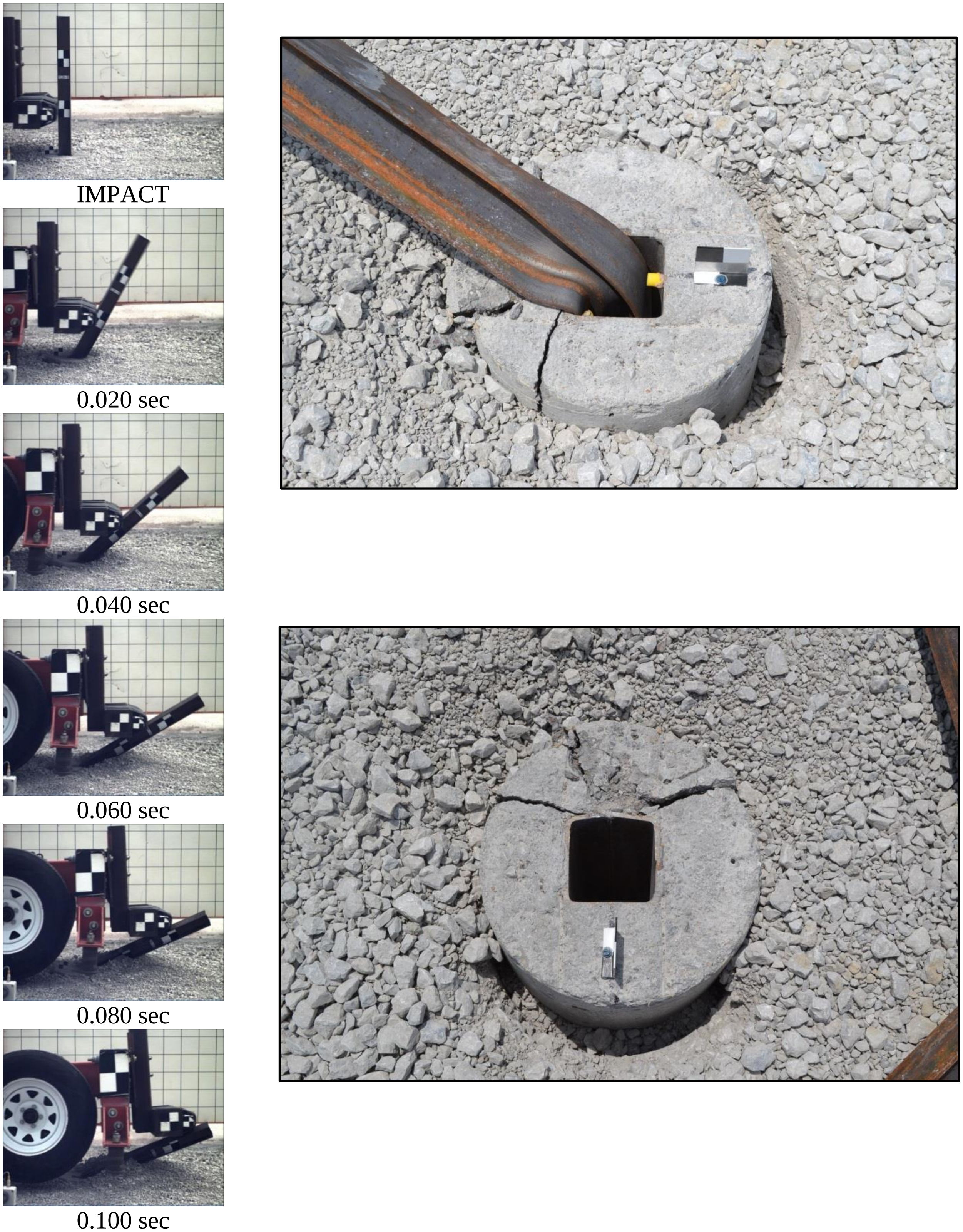


Figure 35. Time-Sequential and Post-Impact Photographs, Test No. HTCB-10

6.3.2 Test No. HTCB-11 (Design K)

Test no. HTCB-11 was conducted on June 13, 2012 at approximately 5:00 p.m. The weather conditions, as per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 11.

Table 11. Weather Conditions, Test No. HTCB-11

Temperature	85° F
Humidity	36%
Wind Speed	22 mph
Wind Direction	160° From True North
Sky Conditions	Partly Cloudy
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

During test no. HTCB-11, the bogie impacted the S3x5.7 (S76x8.5) steel post 11 in. (279) above the groundline and at a speed of 20.0 mph (32.2 km/h), causing strong-axis bending in the post. Upon impact, the foundation assembly began to rotate through the soil, and a plastic hinge formed in the post at groundline. By 0.008 seconds after impact, a concrete crack had formed across the top of the foundation adjacent to the back edge of the socket. The foundation assembly reached a maximum dynamic deflection of 1.1 in. (28 mm) at 0.034 seconds. The post continued to bend over until the bogie head overrode the top of the post at 0.106 seconds after impact. The top of the concrete foundation had permanently displaced 0.8 in. (20 mm) laterally during the impact event, as determined from video analysis.

Force vs. deflection and energy vs. deflection curves created from the SLICE-1 accelerometer data are shown in Figure 36. Inertial effects resulted in a quick peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a maximum of 17.9

kips (79.6 kN) at 4.8 in. (122 mm) of deflection. Following the maximum peak, the force gradually decreased until approximately 10 in. (254 mm) of deflection. The force remained below 5 kips (22 kN) for the remainder of the impact event. At the maximum deflection of 30.1 in. (765 mm), the post assembly had absorbed 120.0 kip-in. (13.6 kJ) of energy.

Damage to the test article consisted of plastic bending of the post at groundline and concrete cracking. The foundation experienced concrete shear cracking on the back side of the foundation, similar to the previously tested 12-in. (305-mm) diameter foundations. However, the concrete on the back edge of the foundation did not fracture away as seen previously. Time-sequential and post-impact photographs are shown in Figure 37.

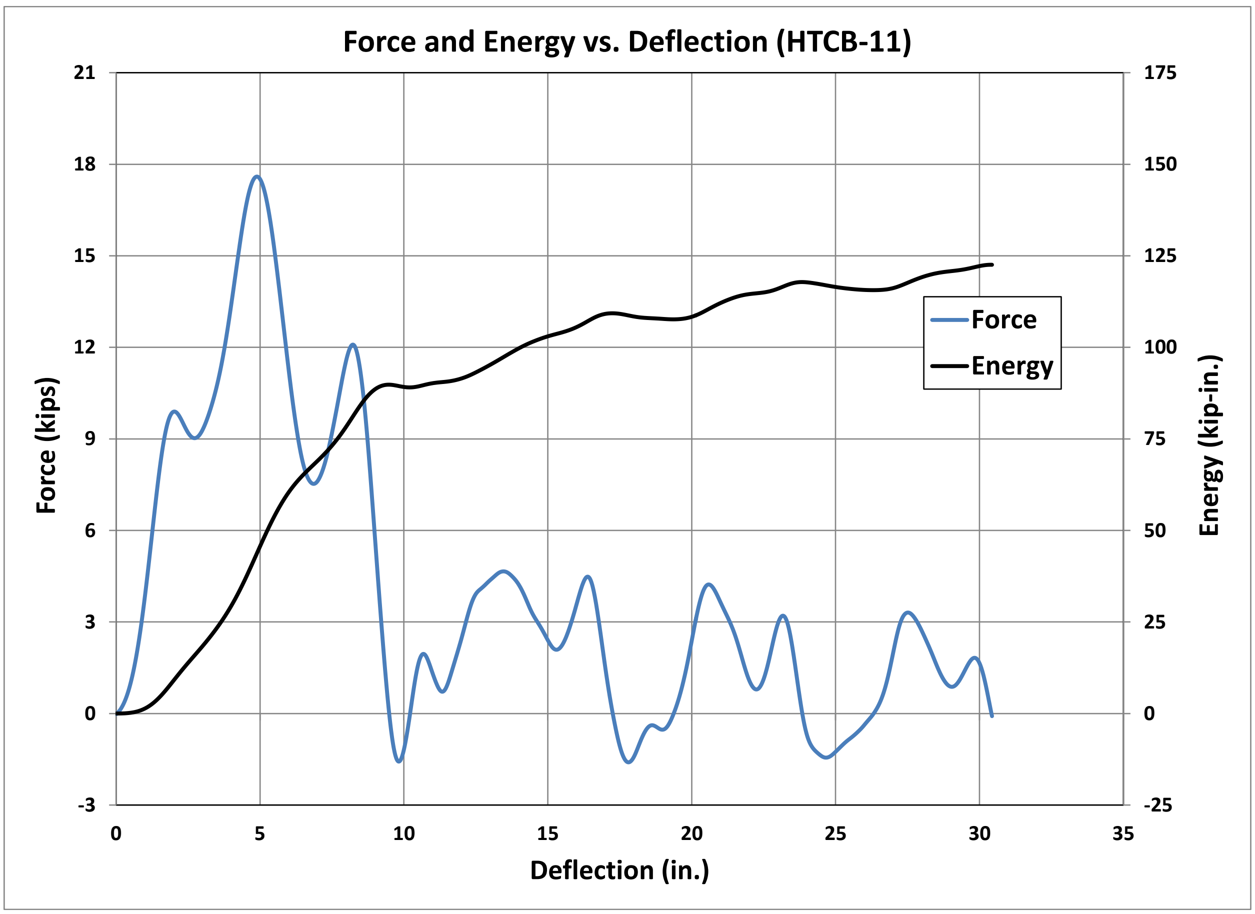
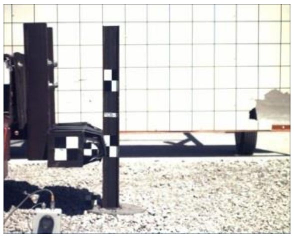
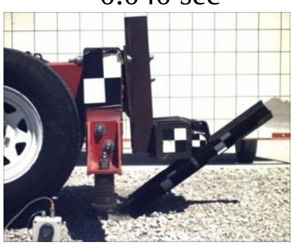


Figure 36. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-11


IMPACT


0.020 sec


0.040 sec


0.060 sec


0.080 sec


0.100 sec

Figure 37. Time-Sequential and Post-Impact Photographs, Test No. HTCB-11

6.3.1 Test No. HTCB-17 (Design M)

Test no. HTCB-17 was conducted on February 26, 2014 at approximately 2:10 p.m. The weather conditions, as per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 12.

Table 12. Weather Conditions, Test No. HTCB-17

Temperature	31° F
Humidity	40%
Wind Speed	23 mph
Wind Direction	230° From True North
Sky Conditions	Clear
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.04 in.
Previous 7-Day Precipitation	0.27 in.

During test no. HTCB-17, the bogie impacted the S3x5.7 (S76x8.5) steel post 11 in. (279) above the groundline and at a speed of 20.8 mph (33.5 km/h), causing strong-axis bending in the post. Upon impact, the foundation assembly began to rotate through the soil, and a plastic hinge formed in the post at groundline. By 0.040 seconds after impact, the foundation assembly reached a maximum dynamic deflection of 1.2 in. (30 mm). The post continued to bend over until the bogie head overrode the top of the post at 0.108 seconds. The top of the concrete foundation had permanently displaced ⅝ in. (16 mm) laterally during the impact event, as determined from post-test measurements.

Force vs. deflection and energy vs. deflection curves created from the SLICE-1 accelerometer data are shown in Figure 38. Initially, inertial effects resulted in a peak force over the first few inches of deflection. After a short decrease, the force rebounded to a maximum of 17.7 kips (78.8 kN) at 3.4 in. (86 mm) of deflection. Following the maximum peak, the force gradually decreased until approximately 14 in. (356 mm) of deflection. The force remained below 5 kips (22 kN) for the remainder of the impact event. At the maximum deflection of 33.9 in. (861 mm), the post assembly had absorbed 141.6 kip-in. (16.0 kJ) of energy.

Damage to the test article consisted of plastic bending of the post at groundline. The concrete foundation remained whole and free of cracks. Only minor scrapes resulting from contact with the post were observed on the top surface of the foundation. Time-sequential and post-impact photographs are shown in Figure 39.

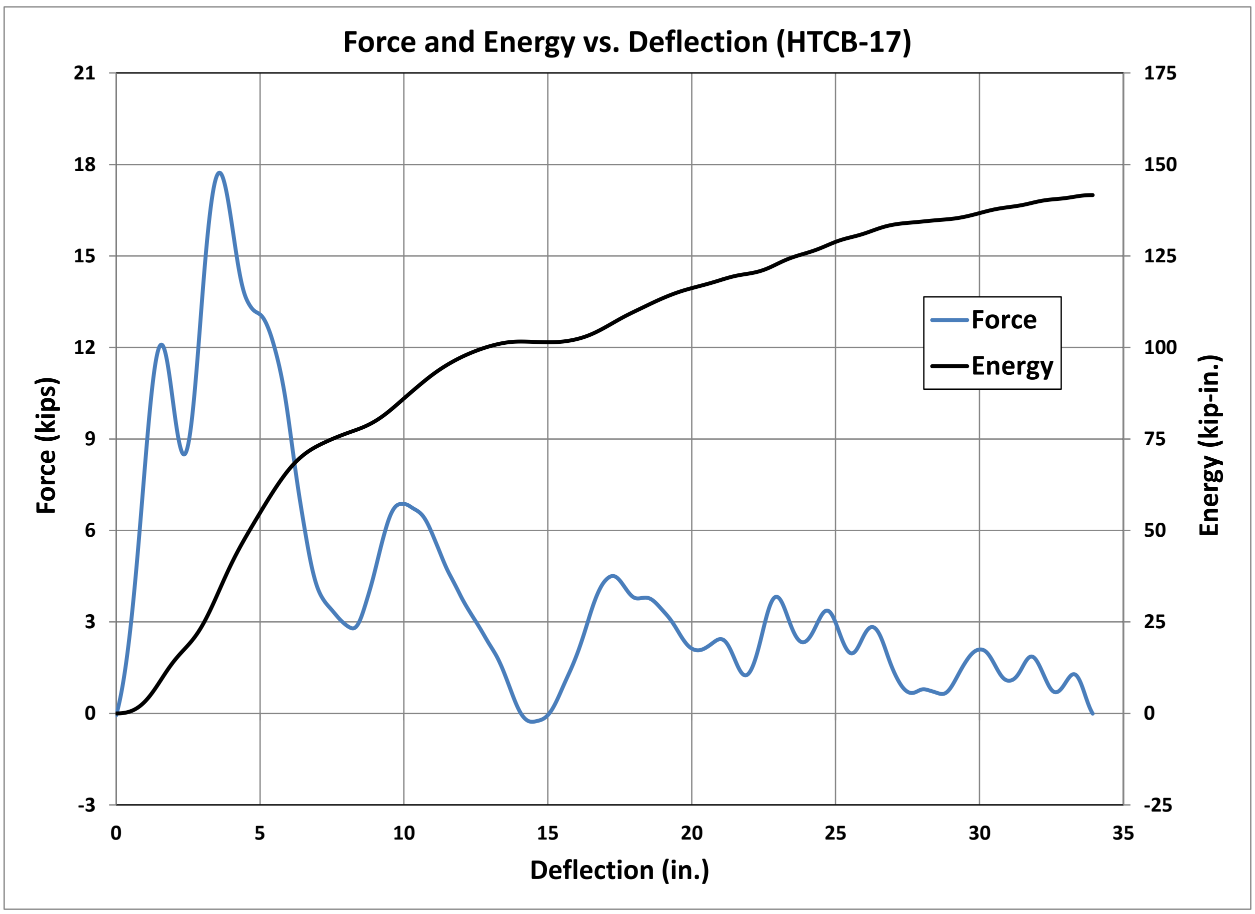


Figure 38. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-17

IMPACT

0.020 sec

0.040 sec

0.060 sec

0.080 sec

0.100 sec

Figure 39. Time-Sequential and Post-Impact Photographs, Test No. HTCB-17

6.3.1 Test No. HTCB-18 (Design L)

Test no. HTCB-18 was conducted on February 26, 2014 at approximately 4:30 p.m. The weather conditions, as per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 13.

Table 13. Weather Conditions, Test No. HTCB-18

Temperature	36° F
Humidity	34%
Wind Speed	20 mph
Wind Direction	260° From True North
Sky Conditions	Clear
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.04 in.
Previous 7-Day Precipitation	0.27 in.

During test no. HTCB-18, the bogie impacted the S3x5.7 (S76x8.5) steel post 11 in. (279) above the groundline and at a speed of 20.3 mph (32.7 km/h), causing strong-axis bending in the post. Upon impact, the foundation assembly began to rotate through the soil, and a plastic hinge formed in the post at groundline. By 0.040 seconds after impact, large foundation displacements caused the soil behind the foundation to heave. At 0.070 seconds, the foundation had reached a deflection of 5 in. (127 mm), and the foundation was continuing to rotate. However, continued motion of the foundation was blocked from view by the bogie wheels and displaced soil. The post continued to bend over until the bogie head overrode the top of the post at 0.138 seconds. The top of the concrete foundation had permanently displaced approximately 6 in. (152 mm) laterally during the impact event, as determined from post-test measurements.

Force vs. deflection and energy vs. deflection curves created from the SLICE-1 accelerometer data are shown in Figure 40. Initially, inertial effects resulted in a peak force over the first few inches of deflection. After a short decrease, the force rebounded to a maximum of 18.7 kips (83.2 kN) at 3.3 in. (84 mm) of deflection. Following the maximum peak, the force gradually decreased until approximately 15 in. (381 mm) of deflection. The force remained below 5 kips (22 kN) for the remainder of the impact event. At the maximum deflection of 35.9 in. (912 mm), the post assembly had absorbed 172.4 kip-in. (20.7 kJ) of energy.

Damage to the test article consisted of plastic bending of the post at groundline, excessive foundation deflection, and significant soil displacements. Aside from the large displacements, the concrete foundation remained whole and free of cracks. Time-sequential and post-impact photographs are shown in Figure 41.

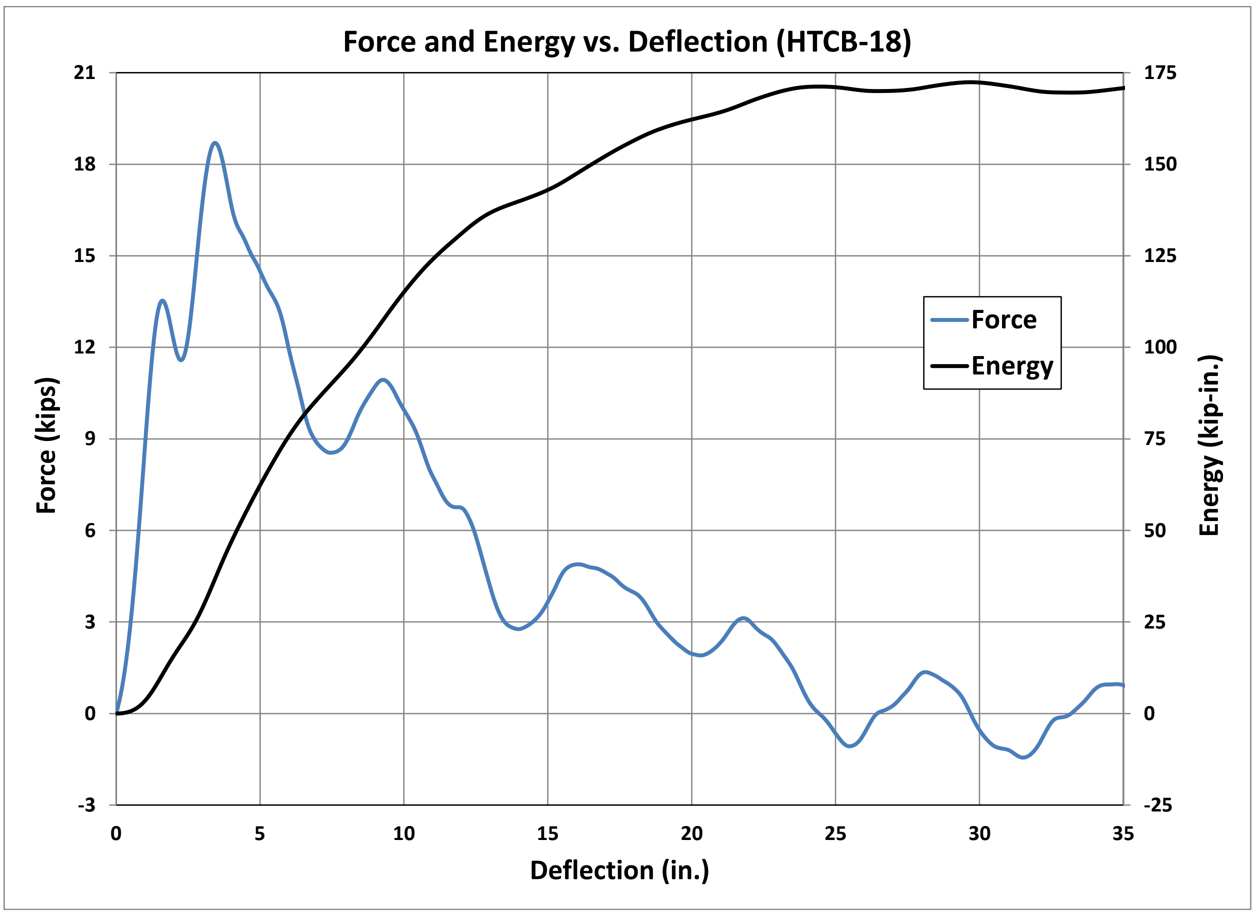
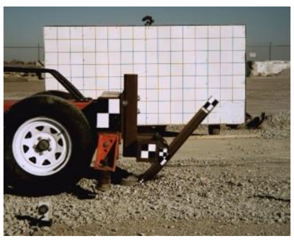


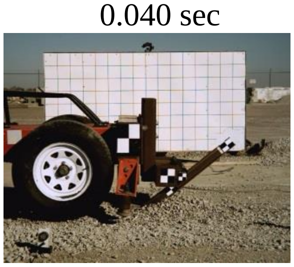
Figure 40. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-18

IMPACT

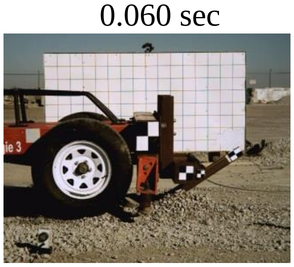
0.020 sec



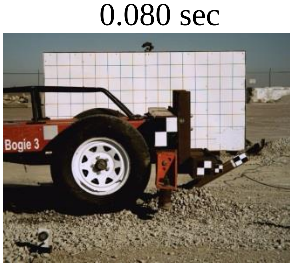
0.040 sec



0.060 sec



0.080 sec



0.100 sec

Figure 41. Time-Sequential and Post-Impact Photographs, Test No. HTCB-18

6.4 Strong-Soil Testing Discussion

The results from the bogie testing matrix are summarized in Table 14. Force vs. deflection and energy vs. deflection comparisons for all four tests are shown in Figures 42 and 43, respectively. All four tests resulted in similar force vs. deflection plots, with peak forces occurring between 3 in. and 6 in. (76 mm and 152 mm), followed by decreased force magnitudes until the bogie overrode the posts. Interestingly, the two tests that resulted in excessive foundation displacement, test nos. HTCB-10 and HTCB-18, absorbed more energy than their similar-sized foundation counterparts. Since the posts yielded in all four tests, this increase was attributed to the energy required to displace the soil surrounding these foundations.

The first two tests, test nos. HTCB-10 and HTCB-11, were conducted on heavily reinforced 12-in. (305-mm) diameter foundations with various embedment depths. During test no. HTCB-10, an embedment depth of 30 in. (762 mm) resulted in a permanent displacement of 2.2 in. (56 mm), which exceeded the limit of 1 in. (25 mm). Thus, 30 in. (762 mm) was too shallow to resist excessive displacements, and the deeper foundation embedment depth was selected for further testing. Test no. HTCB-11 with a 36-in. (914-mm) deep foundation resulted in only 0.8 in. (20 mm) of foundation movement. Subsequently, 36 in. (914 mm) was deemed the minimum embedment depth required to prevent excessive displacements for a 12-in. (305-mm) diameter foundation installed in strong soil.

Although a heavier reinforcement configuration was utilized in Designs J and K, damage to both 12-in. (305-mm) diameter foundations was similar to that experienced during the first round of component testing conducted in weak soil. Test no. HTCB-11 on Design K did not result in concrete fracture on the back side of the foundation, but the concrete cracked along the same shear plane where failure occurred in the other foundations. Thus, the Design K foundation was very near fracture. From these results, it was determined that neither the increased internal steel reinforcement, nor the increased strength of the surrounding soil, could provide enough confinement to the concrete foundation to prevent shear cracking and fracture of 12-in. (305-mm) diameter foundations.

Test nos. HTCB-17 and HTCB-18 were conducted on concrete foundations with 15-in. (381-mm) diameters. During test no. HTCB-17, the 30-in. (762-mm) embedment depth of Design M provided enough resistance to limit the foundation displacement to ⅝ in. (16 mm). However, test no. HTCB-18 on Design L with an embedment depth of 24 in. (610 mm) resulted in an excessive foundation displacement of 6.0 in. (152 mm). Subsequently, 30 in. (762 mm) was deemed the minimum embedment depth required to prevent excessive displacements for a 15-in. (381-mm) diameter foundation.

Contrary to previous test results, Designs L and M were not damaged during testing. The 15-in. (381-mm) diameter concrete foundations remained intact and free of cracks after both tests. Increasing the foundation diameter by 3 in. (76 mm) provided enough increase to the concrete area through the shear fracture plane to prevent failure/cracking. As such, the probability of concrete damage is minimized for foundations with diameters of at least 15 in. (381 mm). Although Design N, with an 18-in. (457-mm) diameter, was never tested, its increased diameter would only further strengthen the foundation and, thus, could also be utilized if so desired.

It should be noted that the cracking and fracture of the top-back corner of the smaller-diameter foundations would not necessarily require replacement. The sockets themselves were not damaged or excessively rotated, so the foundations could be reused. Thus, a 12-in. (305-mm) diameter foundation may still be implemented if there is little concern about this type of concrete damage occurring after severe impacts. However, repeated impacts to a foundation would lead to further damage and eventually compromise the structural integrity of the foundation.

Table 14. Dynamic Testing Summary, Foundations Installed in Strong Soil

Test No.	Design	Diameter in. (mm)	Embed. Depth in. (mm)	Impact Velocity mph (km/h)	Average Force kips (kN)			Peak Force kips (kN)	Total Energy kip-in. (kJ)	Permanent Foundation Deflection in. (mm)	Foundation Damage
					@ 10"	@ 15"	@ 20"				
HTCB-10	J	12 (305)	30 (762)	20.6 (33.2)	10.8 (48.0)	8.3 (36.9)	6.8 (30.2)	20.7 (92.1)	149.6 (16.9)	2.2 (56)	concrete cracking and fracture
HTCB-11	K	12 (305)	36 (914)	20.0 (32.2)	9.3 (41.4)	7.1 (31.6)	5.5 (24.5)	17.9 (79.6)	120.0 (13.6)	0.8 (20)	concrete shear cracking
HTCB-17	M	15 (381)	30 (762)	20.8 (33.5)	8.6 (38.3)	6.8 (30.2)	5.8 (25.8)	17.7 (78.7)	141.6 (16.0)	0.6 (15)	None
HTCB-18	L	15 (381)	24 (610)	20.3 (32.7)	11.5 (51.2)	9.5 (42.3)	8.1 (36.0)	18.7 (83.2)	172.4 (19.5)	6.0 (152)	None

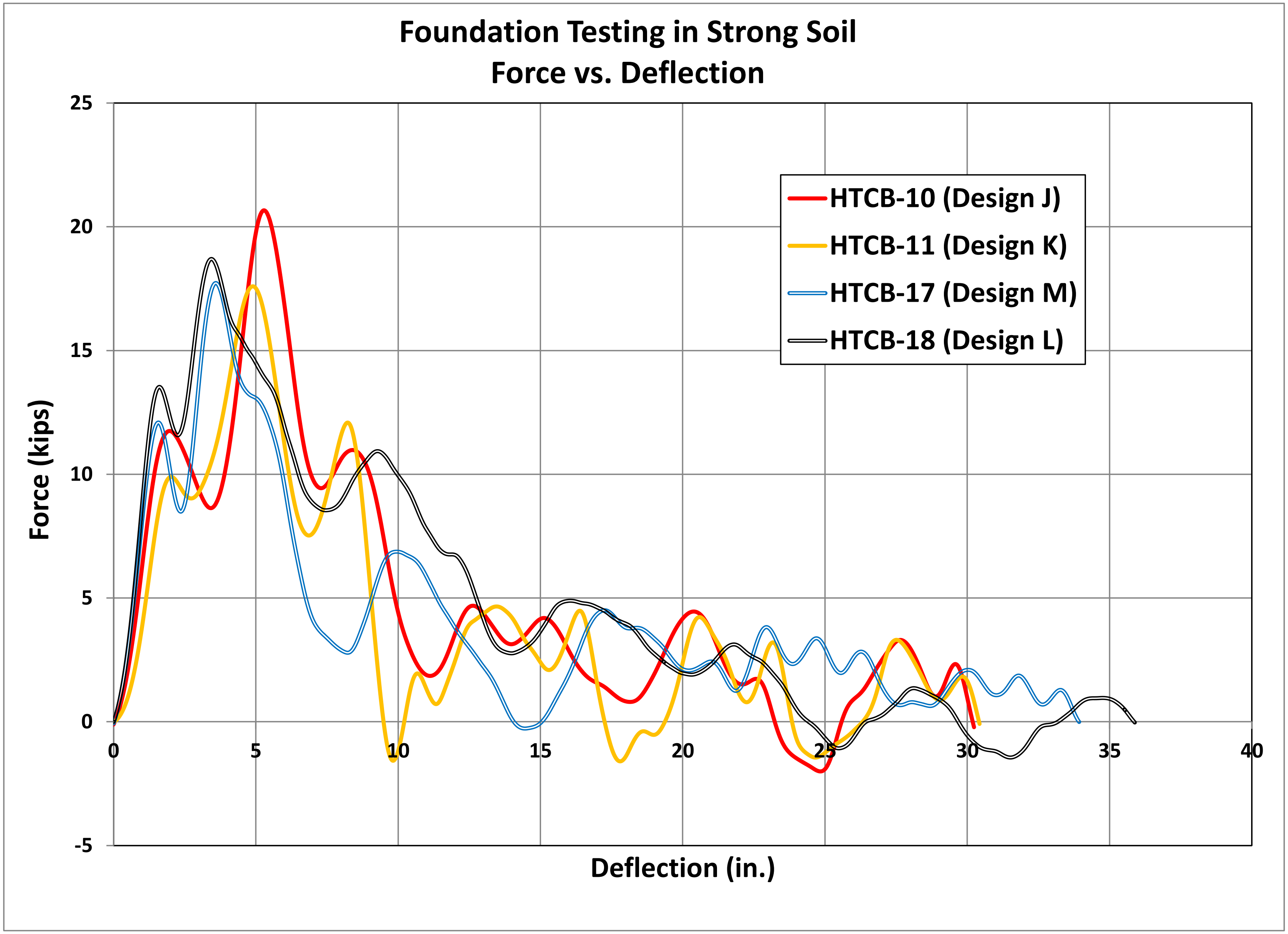


Figure 42. Force vs. Deflection, Foundations Installed in Strong Soil

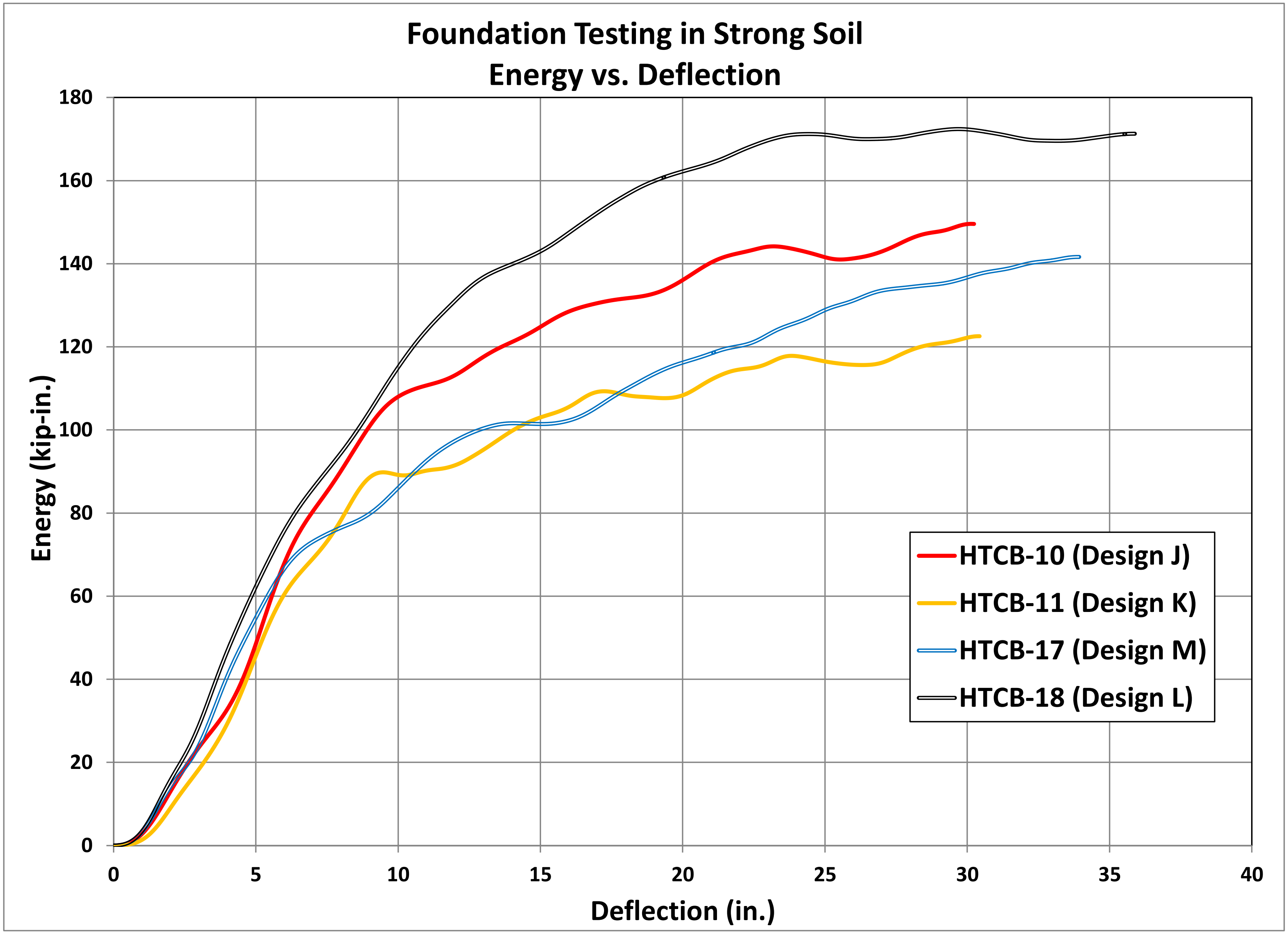


Figure 43. Energy vs. Deflection, Foundations Installed in Strong Soil

7 DESIGN DETAILS – ROUND 3, ASPHALT

Some cable barrier systems are placed within asphalt mow strips to prevent maintenance crews from having to cut the vegetation under the cables and around the posts. Mow strips provide significant strength increases to socketed foundations in which they encase. Reducing the propensity for displacement and concrete cracking allows for the use of smaller and weaker post foundations. Thus, it was desired to conduct component testing on socketed foundations placed within an asphalt mow strip. Design drawings for the socketed foundations evaluated in combination with a 4-in. (102-mm) thick asphalt pad are shown in Figures 44 through 48, and photographs of the test installations are shown in Figure 49. Material specifications, mill certifications, and certificates of conformity for the reinforced concrete, socketed foundations are shown in Appendix A.

Two different socketed foundation designs were fabricated to evaluate performance in combination with asphalt mow strips (only one was actually tested). Both designs had 12-in. (305-mm) diameters and the same internal reinforcement pattern (with a ¼-in. (6 mm) difference between the transverse steel spacing due to continuity within the socket height). However, Design O had an embedment depth of 30 in. (762 mm), while Design P had an embedment depth of 36 in. (914 mm).

The S3x5.7 (S76x8.5) steel post and the HSS 4-in. x 4-in. x ¼-in. (HSS 102-mm x 102-mm x 6-mm) steel tube socket remained the same as those used in the previous two rounds of component testing. Additionally, the minimum concrete strength remained at 3,500 psi (24 MPa). Cylinder testing revealed the actual strength of the concrete was 4,800 psi (33 MPa).

Although two foundation designs were fabricated for testing Round 3, only one was actually impacted. After conducting testing on Design O and achieving successful results, the increased embedment depth of Design P was deemed unnecessary. Thus, Design P was not evaluated through dynamic bogie testing.

Test No.	Design	Soil Type	Impact Height	Embedment Depth "EMB"	Speed mph [km/h]	Angle (degrees)
HTCB-19	O	Standard Strong Soil with 4" [102] Asphalt	11" [279]	30" [762]	20 [32.2]	90 (Strong Axis)
HTCB-20 (Potential)	P	Standard Strong Soil with 4" [102] Asphalt	11" [279]	36" [914]	20 [32.2]	90 (Strong Axis)

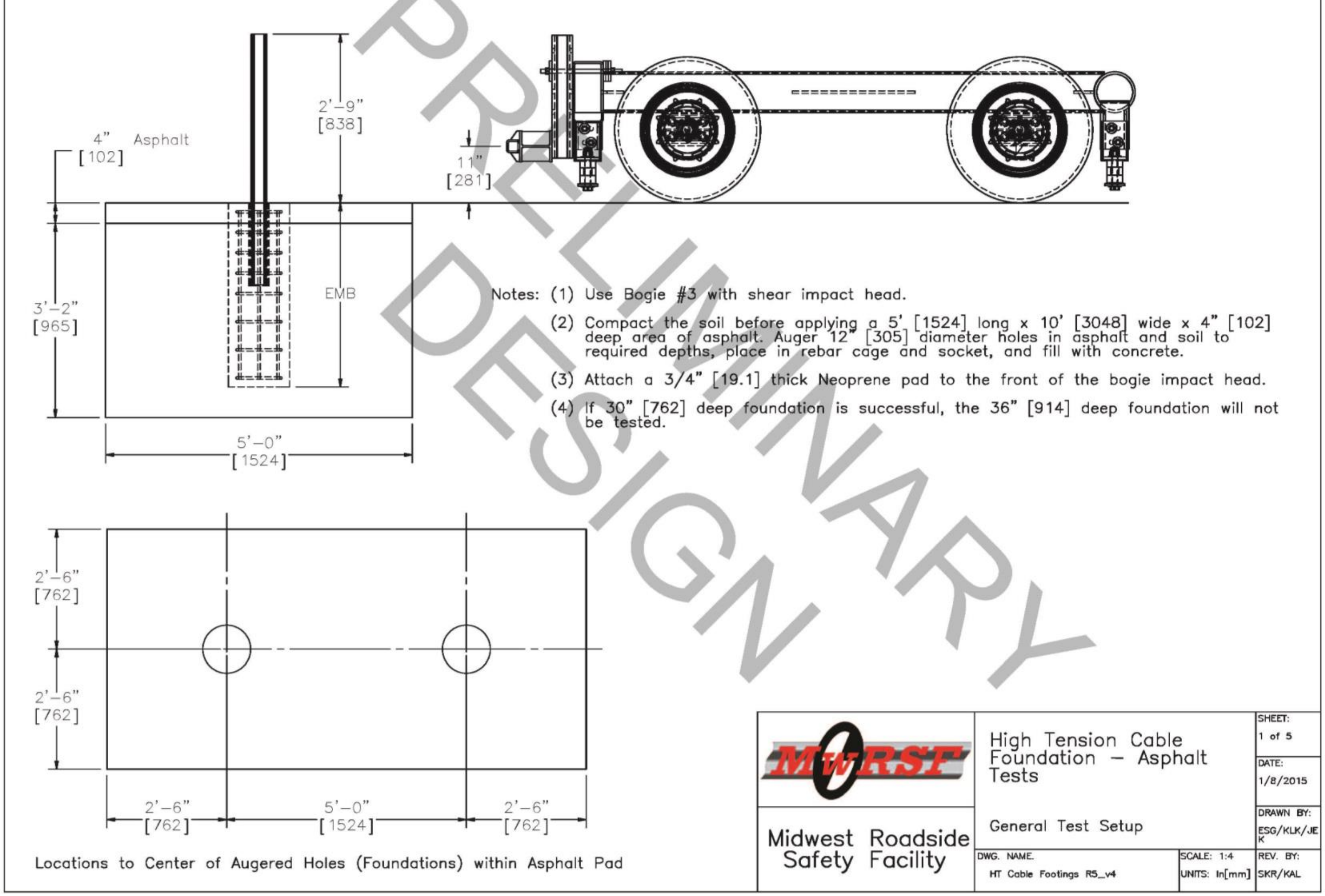


Figure 44. Bogie Testing Matrix and Setup, Test No. HTCB-19

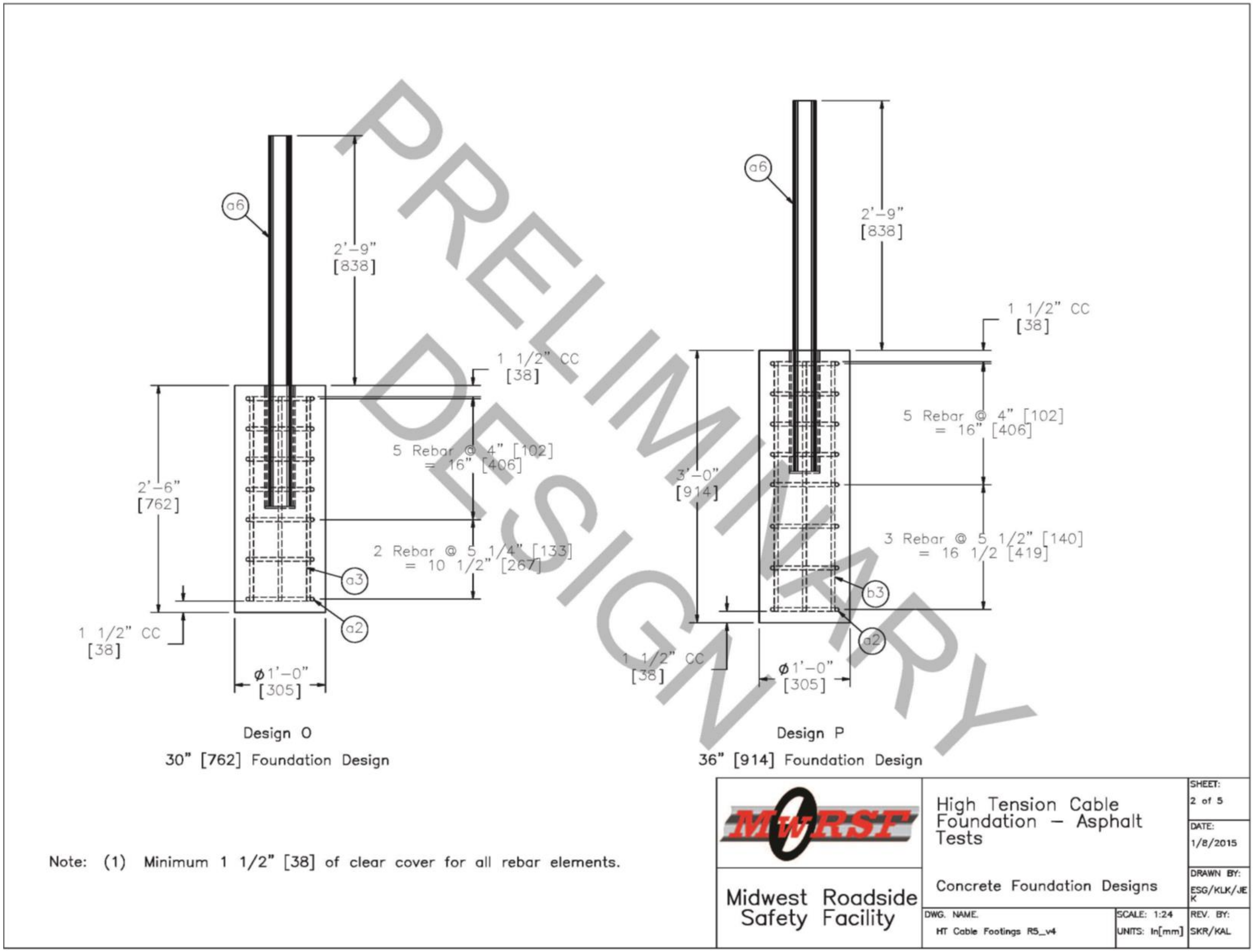
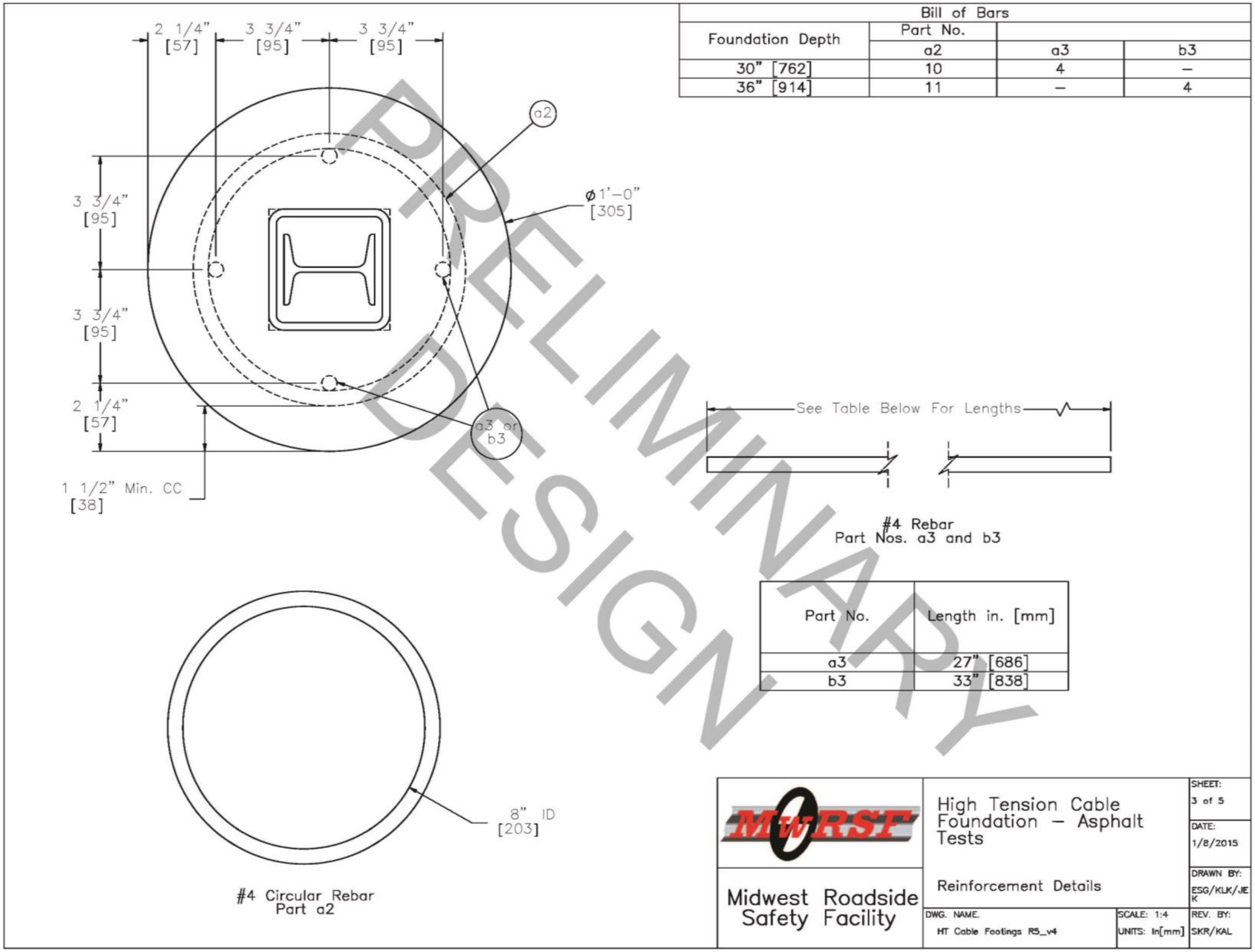


Figure 45. Foundation Configurations, Test No. HTCB-19



Bill of Bars			
Foundation Depth	Part No.		
	a2	a3	b3
30" [762]	10	4	–
36" [914]	11	–	4

Part No.	Length in. [mm]
a3	27" [686]
b3	33" [838]

Figure 46. Reinforcement Details, Test No. HTCB-19

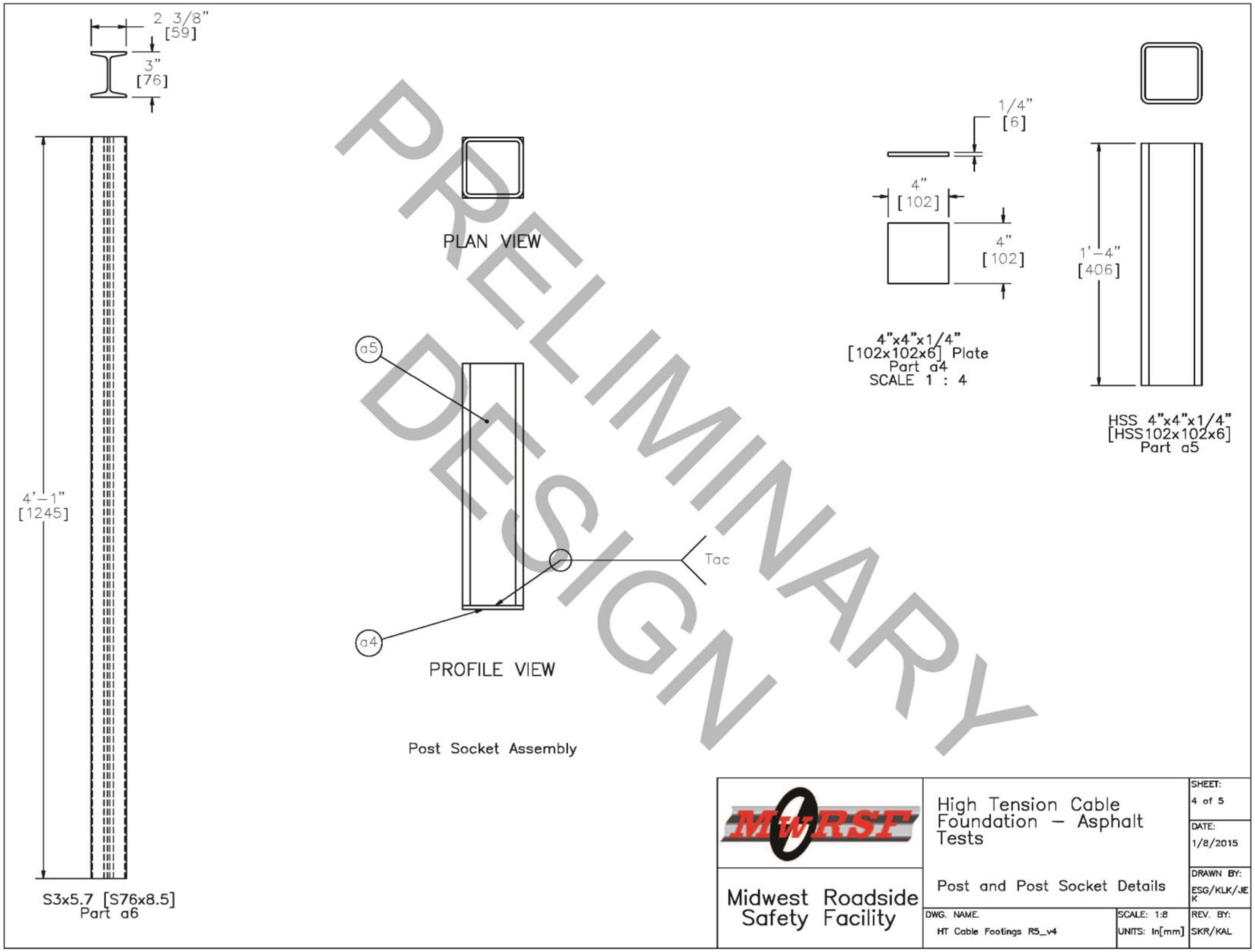


Figure 47. Steel Post and Socket Details, Test No. HTCB-19

Design O Bill of Materials			
Item No.	QTY.	Description	Material Spec
a1	1	Concrete Shaft, 30" [762] Long	Min 3500 psi [24 MPa] Compressive Strength
a2	7	#4 Circular Rebar, 8" [203] ID	Gr. 60
a3	4	#4 Rebar, 27" [686] Long	Gr. 60
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50, ASTM A992, ASTM A209 Gr. 50
a7	1	5'x10'x4" [1524x3048x102] Asphalt	52 – 34 Grade Binder

Design P Bill of Materials			
Item No.	QTY.	Description	Material Spec
a2	8	#4 Circular Rebar, 8" [203] ID	Gr. 60
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50, ASTM A992, ASTM A209 Gr. 50
a7	1	5'x10'x4" [1524x3048x102] Asphalt	52 – 34 Grade Binder
b1	1	Concrete Shaft, 36" [914] Long	Min 3500 psi [24 MPa] Compressive Strength
b3	4	#4 Rebar, 33" [838] Long	Gr. 60

MwRSF Midwest Roadside Safety Facility	High Tension Cable Foundation – Asphalt Tests Bill of Materials	SHEET: 5 of 5 DATE: 1/8/2015 DRAWN BY: ESG/KLK/JEK
DWG. NAME. HT Cable Footings R5_v4	SCALE: 1:32 UNITS: In[mm]	REV. BY: SKR/KAL

Figure 48. Bill of Materials, Test No. HTCB-19

Figure 49. Test Installation, Test No. HTCB-19

8 COMPONENT TESTING – ROUND 3, ASPHALT

8.1 Purpose

The project sponsors desired to investigate the effects of encasing post foundations within asphalt mow strips. Thus, Round 3 dynamic component testing was conducted with the foundations placed within a 4-in. (102-mm) thick asphalt mow strip. During Round 3 testing, the embedment depth of the foundations was to be varied in order to determine the minimum depth required to prevent excessive displacements greater than 1 in. (25 mm). Additionally, the testing would evaluate whether the asphalt surrounding the foundations would prevent concrete shear cracking on the back side of the foundation.

8.2 Scope

One bogie test was conducted on an S3x5.7 (S76x8.5) steel post inserted into a reinforced concrete, socketed foundation installed within a 4-in. (102-mm) thick asphalt mow strip. The soil below the asphalt was classified as an AASHTO Grade B soil [7], but it was not compacted to the strength that was used during Round 2 testing. Test no. HTCB-19 was conducted on a socketed foundation with a diameter of 12 in. (305 mm) and an embedment depth of 30 in. (762 mm). The target impact conditions were an impact height of 11 in. (279 mm), a speed of 20 mph (32 km/h), and an angle of 90 degrees, creating a classic “head-on” impact with the strong axis of the post. The test matrix is shown in Table 15.

As described in Chapter 7, two socketed foundation designs were fabricated for evaluation during Round 2 component testing. However, after a successful test with limited displacement was observed with Design O, testing with the larger configuration, Design P, was deemed unnecessary.

Table 15. Bogie Testing Matrix, Foundation in Asphalt

Test No.	Design	Soil Type	Impact Height in. (mm)	Impact Speed mph (km/h)	Impact Angle deg.	Embed. Depth in. (mm)	Foundation Diameter in. (mm)
HTCB-19	O	4” Asphalt over AASHTO Grade B	11 (279)	20 (32)	90	30 (762)	12 (305)

8.3 Asphalt Pad Test Results

Through component testing, the performance of the socketed foundation was evaluated in terms of both structural integrity and displacement of the foundation within an asphalt pad. A foundation system had to resist the impact loads without fracture to be deemed adequate. Additionally, the researchers desired to limit the displacements of the foundation to less than 1 in. (25 mm), as measured at groundline. The combination of these criteria would ensure that a socketed foundation could be reused in the same system without repairs or resetting.

Accelerometer data was used to find the resistance force supplied by the S3x5.7 (S76x8.5) post and foundation assembly. Since the accelerometers were mounted on the bogie vehicle, the forces and displacements calculated from the acceleration data were related to the motion of the bogie and the forces applied to it from the post. These forces and displacements did not directly reflect the force applied to the top of the foundation or the displacement of the foundation. However, the recorded forces can be used to indicate approximate force magnitudes imparted to the socket. Individual results for all accelerometers utilized during the test are shown in Appendix B. Due to the plastic deformation of the post, foundation displacements were measured from the high-speed video and post-test field measurements.

8.3.1 Test No. HTCB-19 (Design O)

Test no. HTCB-19 was conducted on May 20, 2014 at approximately 2:00 p.m. The weather conditions, as per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 16.

Table 16. Weather Conditions, Test No. HTCB-19

Temperature	83° F
Humidity	49%
Wind Speed	16 mph
Wind Direction	50° From True North
Sky Conditions	Partly Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

During test no. HTCB-19, the bogie impacted the S3x5.7 (S76x8.5) steel post 11 in. (279) above the groundline and at a speed of 22.0 mph (35.4 km/h), causing strong-axis bending in the post. Upon impact, the foundation assembly began to translate back, and a plastic hinge formed in the post at groundline. The foundation reached a maximum dynamic deflection of 0.3 in. (8 mm) at 0.028 seconds. The post continued to bend over until the bogie head overrode the top of the post at 0.096 seconds after impact. The top of the concrete foundation permanently displaced 0.3 in. (8 mm) laterally during the impact event, as determined from video analysis.

Force vs. deflection and energy vs. deflection curves created from the SLICE-1 accelerometer data are shown in Figure 50. Inertial effects resulted in a quick peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a maximum of 14.8 kips (65.9 kN) at 3.7 in. (94 mm) of deflection. Following the maximum peak, the force quickly decreased to near zero at approximately 8 in. (203 mm) of deflection. The force remained below

5 kips (22 kN) for the remainder of the impact event. At the maximum deflection of 31.0 in. (787 mm), the post assembly had absorbed 112.1 kip-in. (12.7 kJ) of energy.

Damage to the test article consisted of only plastic bending of the post at groundline. The foundation experienced no visible damage. Note, the concrete spalling on the top-left side of the foundation had occurred during installation. Time-sequential and post-impact photographs are shown in Figure 51.

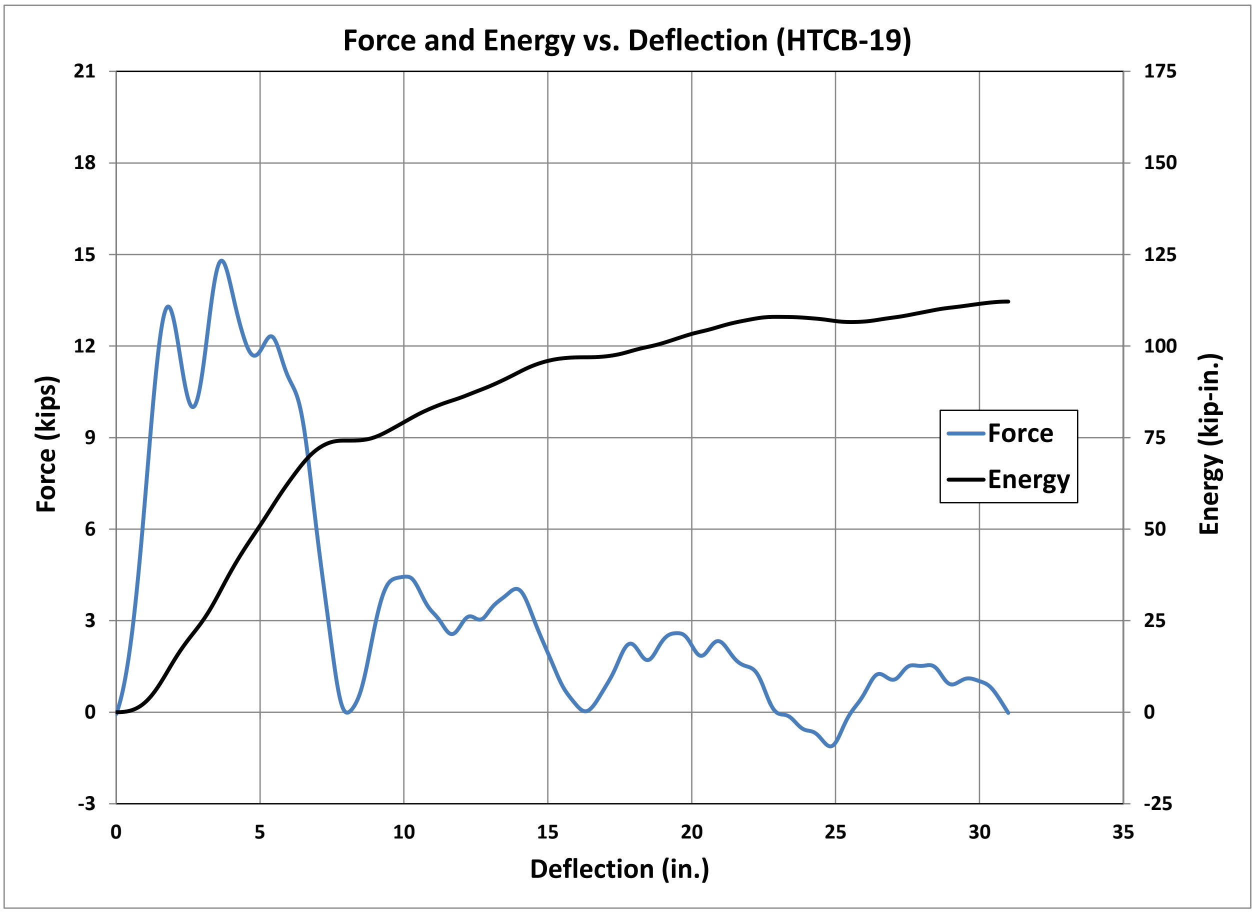
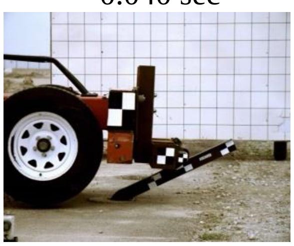


Figure 50. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-19

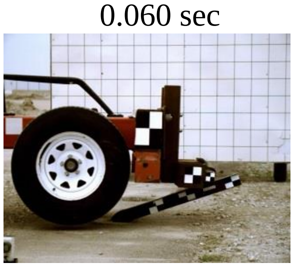
IMPACT

0.020 sec

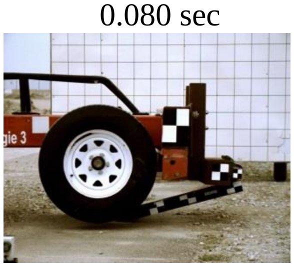
0.040 sec



0.060 sec



0.080 sec



0.100 sec

Figure 51. Time-Sequential and Post-Impact Photographs, Test No. HTCB-19

8.4 Asphalt Pad Testing Discussion

The bogie testing results from a foundation installed within asphalt mow strips are summarized in Table 17. As anticipated, the asphalt pad significantly increased the foundation's resistance to displacement. During test no. HTCB-19, the 30-in. (762-mm) deep foundation limited permanent set displacements to 0.3 in. (8 mm), well within the 1-in. (25-mm) limit. Additionally, the asphalt acted as a bearing surface for the top of the foundation and prevented concrete shear cracks from forming. In comparison, test no. HTCB-10 was previously conducted on the same size foundation installed in strong soil, but resulted in 2.2 in. (56 mm) of displacement and concrete fracture on the back side of the foundation. Due to the success of the 30-in. (762-mm) foundation design, the 36-in. (914-mm) deep foundation, Design P, was deemed overly conservative and, therefore, it was never tested.

The test article for test no. HTCB-19 was fabricated prior to installation. A hole was cored in the asphalt mow strip, and the socketed foundation was dropped into place. This installation method resulted in a small gap between the outside of the foundation and the surrounding asphalt and was determined to be the critical installation method. The socketed foundations may also have been constructed utilizing two other methods: (1) inserting the steel components and pouring concrete directly into a cored hole in the asphalt/ground and (2) inserting the foundation into the soil (leaving the top above the groundline) and then laying the asphalt around the foundation. Either of these two alternative installation practices would result in the elimination of the gap between the concrete and asphalt surfaces, and the foundation's resistance to displacements should be even stronger. Thus, all three of the installation methods described here are acceptable for system construction.

The asphalt mow strip utilized during test no. HTCB-19 was 4-in. (102-mm) thick and 4-ft (1.2-m) wide. In order to maintain stiffness and strength, these dimensions shall be the minimum allowable for real-world system installations. Of course, thicker and/or wider asphalt pads would be acceptable. Similarly, a concrete mow strip would also be acceptable for use with the socketed foundations. Finally, due to a lack of further component testing on foundations installed within pavements, the minimum embedment depth for a foundation should be 30 in. (762 mm) regardless of soil strength below the asphalt.

Table 17. Dynamic Testing Summary, Foundation Installed in Asphalt

Test No.	Design	Diameter in. (mm)	Embed. Depth in. (mm)	Impact Velocity mph (km/h)	Average Force kips (kN)			Peak Force kips (kN)	Total Energy kip-in. (kJ)	Permanent Foundation Deflection in. (mm)	Foundation Damage
					@ 10"	@ 15"	@ 20"				
HTCB-19	O	12 (305)	30 (762)	22.0 (35.4)	7.9 (35.1)	6.4 (28.5)	5.2 (23.1)	14.8 (65.8	112.1 (12.7)	0.3 (8)	None

9 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

9.1 Summary and Conclusions

The objective of this research project was to develop a socketed foundation for use with S3x5.7 (S76x8.5) posts. The new socketed foundation was required to remain undamaged and restrict socket displacements to less than 1 in. (25 mm) during vehicle impacts. If these criteria were satisfied, damaged posts could be removed and replaced without repairs or resetting of the socketed foundation.

A total of ten dynamic component tests were conducted on various reinforced concrete foundation configurations in three separate rounds of testing. Each round of testing was characterized by one of three surrounding soil conditions: weak soil, strong soil, and asphalt pad. Testing in various soils was desired in order to understand the effects that in situ conditions have on foundation performance. Each component test was conducted with a bogie vehicle impacting the post at a height of 11 in. (279 mm) to represent impacts from small car bumpers, except for test no. HTCB-5 which had an impact height of 15 in. (381 mm).

Round 1 testing consisted of five bogie tests conducted on socketed foundations installed in a weak, sandy soil. Each socketed foundation measured 12 in. (305 mm) in diameter and utilized a 4-in. x 3-in. x ¼-in. (102-mm x 76-mm x 6-mm) steel tube as the post socket. However, the internal steel configurations varied between each foundation design evaluated. During the tests, the S3x5.7 (S76x8.5) posts bent over, and the foundations rotated backward slightly. An embedment depth of 60 in. (1,524 mm) was determined to be the minimum depth required to resist excessive displacements for 12-in. (305-mm) diameter foundations in weak soil. However, concrete shear cracks formed on the top-back side of each foundation and caused a wedge-shaped piece of concrete to fracture off. Due to the already extensive steel reinforcement within the foundations, it was determined that the concrete foundation would have to be externally confined, or the diameter would have to be increased, to prevent concrete shear fractures during severe impact events.

Round 2 testing consisted of four bogie tests conducted on socketed foundations installed in a stiff, strong soil. The first two tests involved heavily reinforced, 12-in. (305-mm) diameter foundations, similar to those utilized during Round 1 testing. From these tests, it was determined that a minimum embedment depth of 36 in. (914 mm) was required to prevent excessive displacements in strong soil. Unfortunately, the concrete shear cracking and fracture observed during Round 1 continued during Round 2 testing in the strong soils.

The second two tests of Round 2 were conducted on 15-in. (381-mm) diameter foundations with reduced internal steel compared to the previous designs. The increased cross-sectional area and concrete shear strength resulted in both foundations being free of cracking and/or fracture after the tests. Additionally, 30 in. (762 mm) was found to be the minimum embedment depth required to prevent excessive displacements.

Since the 15-in. (381-mm) diameter foundations were not evaluated in weak soil, the recommended embedment depth for Option 2 in weak soil was determined through additional analysis. When comparing 12-in. (305-mm) diameter tests from both Round 1 and Round 2 component testing, the weak soil strength was found to be 36 percent of the strong soil strength. Using this relation with the common assumption that soil resistance to post rotation is related to the square of the embedment depth, a 50-in. (1,270-mm) embedment depth was conservatively estimated for the 15-in. (381-mm) diameter foundation in weak soils.

Round 3 testing consisted of one bogie test conducted on a 12-in. (305-mm) diameter foundation encased within a 4-in. (102-mm) thick asphalt mow strip. The asphalt proved to be stiff enough to support the concrete on the back side of the foundation, as no visible damage was observed to the foundation or the asphalt mow strip after the test. A minimum embedment depth of 30 in. (762 mm) was found to prevent excessive foundation displacements.

9.2 Recommendations

After the results of the component testing program were presented, some project sponsors noted a desire to utilize a 12-in. (305-mm) diameter foundation and accept the risks of concrete fracture on the back side of the foundations during the rare occurrence of a severe impact event. However, other project sponsors wished to have a socketed foundation design that would remain free of damage, even in the event of a severe impact. Therefore, three socketed foundation design options are recommended for use: (1) a 12-in. (305-mm) diameter foundation; (2) a 15-in. (381-mm) diameter foundation; and (3) a foundation for use within mow strips. Final design details for these socketed foundations for use with S3x5.7 (S76x8.5) posts are shown in Figures 52 through 57.

Testing within various soil conditions proved that foundation performance was highly related to the surrounding soil strength. As such, the depth of the recommended foundation design is variable and should be determined based on the soil conditions at the installation site. In addition, a foundation must also extend beyond the frost line of the specific installation site to prevent frost heave. Thus, the proper embedment depth of a socketed foundation is based on the selected design option, the soil conditions, and the depth to the frost line, as shown by the chart in Figure 52. Note, the top portions of each design option should remain as detailed, and only the bottom hoop reinforcement spacing may change with the various embedment depths.

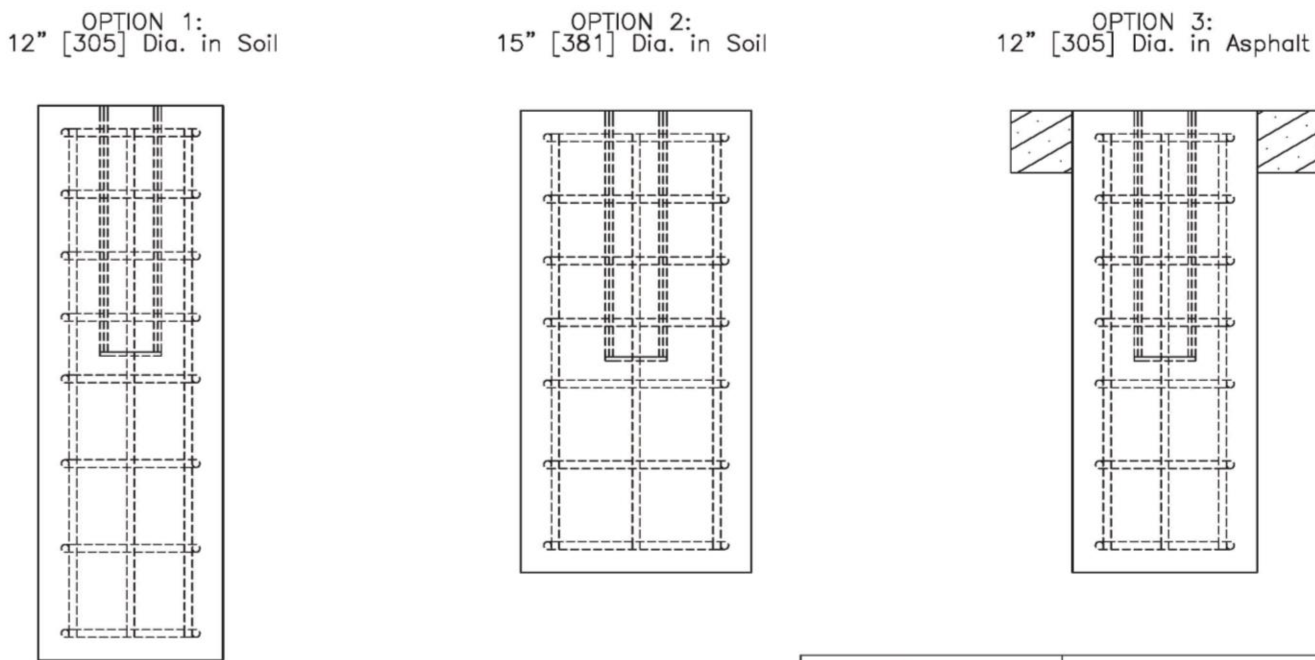
Upon review of the concrete failures observed during the first and second rounds of testing, it was noted that the fracture patterns were all the same, regardless of the reinforcement configuration. All of the concrete cracks occurred behind the socket tube and above the uppermost steel hoop. The additional reinforcement added to strengthen the foundations as the testing program continued did little to prevent the concrete shear cracks. Therefore, the reinforcement recommended for Option 1 has a reduced number of steel bars in comparison to the tested 12-in (305-mm) foundation designs. Additionally, the concrete clear cover for all rebar was decreased from 2 in. (51 mm) to 1½ in. (38 mm) to strengthen the foundation against shear cracking.

The Option 3 design was developed utilizing a 4-in. (102-mm) thick by 4-ft (1.2-m) wide asphalt mow strip. Option 3 foundations should only be installed within mow strips of equal or greater strength. Thus, asphalt mow strips should be at least 4 in. (102 mm) thick, and there should be a minimum of 18 in. (457 mm) between the edge of the foundation and the edge of the asphalt mow strip. Since concrete is stronger than asphalt, utilization of Option 3 foundations within a concrete mow strip is acceptable.

These socketed foundations were developed to support any guardrail system utilizing S3x5.7 (S76x8.5) support posts. Posts with increased size and strength may require increased embedment depth, increased diameters, increased reinforcement, and/or a larger socket tube. On the other hand, these foundation details would be applicable to any post with a bending strength lower than that of the S3x5.7 (S76x8.5) post, given that it fits inside the socket. Reduced-size sockets would also be allowed, as long as the socket remains in the center of the foundation.

Some guardrail systems are installed within medians and on roadsides with cross slopes, e.g., cable barriers. If the top of the socketed foundation is not poured to match the surrounding terrain, it would result in the downslope side of the foundation protruding above the groundline. To minimize the extent of this protrusion, it is recommended to install the top center of the foundation level with the surrounding slope, as shown in Figure 58. Additionally, this configuration ensures that the post and cables remain at the correct height. Casting the foundation on-site to match the surrounding terrain would also be acceptable.

Option No.	Option Description	Minimum Embedment Depths			Possible Damage
		Stiff Soil	Weak Soil	Freeze Line (All Soils)	
1	12" [305] Dia. in Soil	36" [914]	60" [1524]	Must be greater than the expected soil freeze line depth.	Concrete shear fracture
2	15" [381] Dia. in Soil	30" [762]	50" [1270]		None
3	12" [305] Dia. in Asphalt	30" [762]	30" [762]		None



Midwest Roadside Safety Facility

S3x5.7 Post Foundations

Overview of Options

SHEET: 1 of 6

DATE: 1/8/2015

DRAWN BY: KLK/SDB/JEK

DWG. NAME. S3x5.7_Post_Found_R7

SCALE: 1:24

UNITS: in.[mm]

REV. BY: SDB/KAL

Figure 52. Socketed Foundations for S3x5.7 Posts

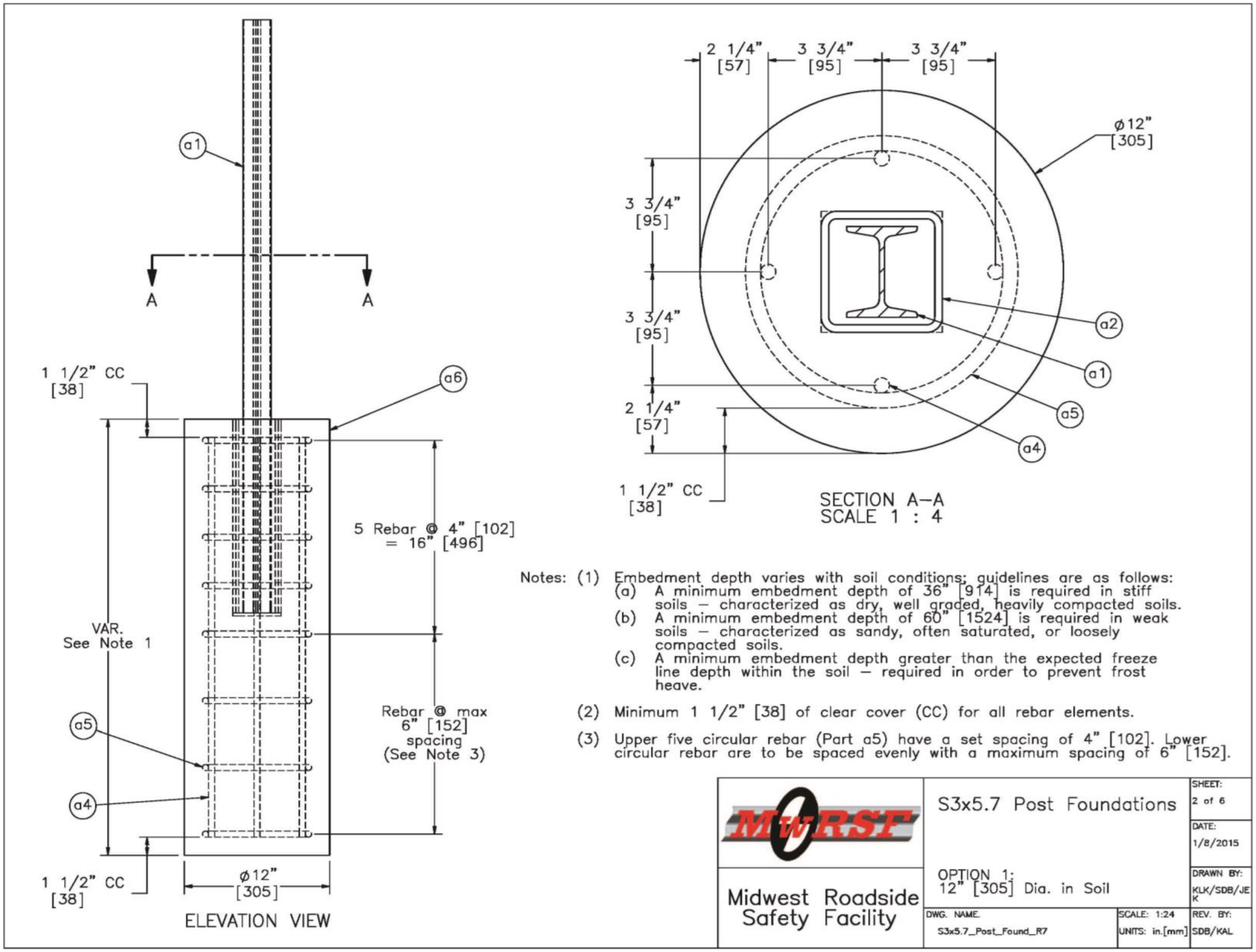


Figure 53. Socketed Foundation for S3x5.7 Posts, Option 1 Details

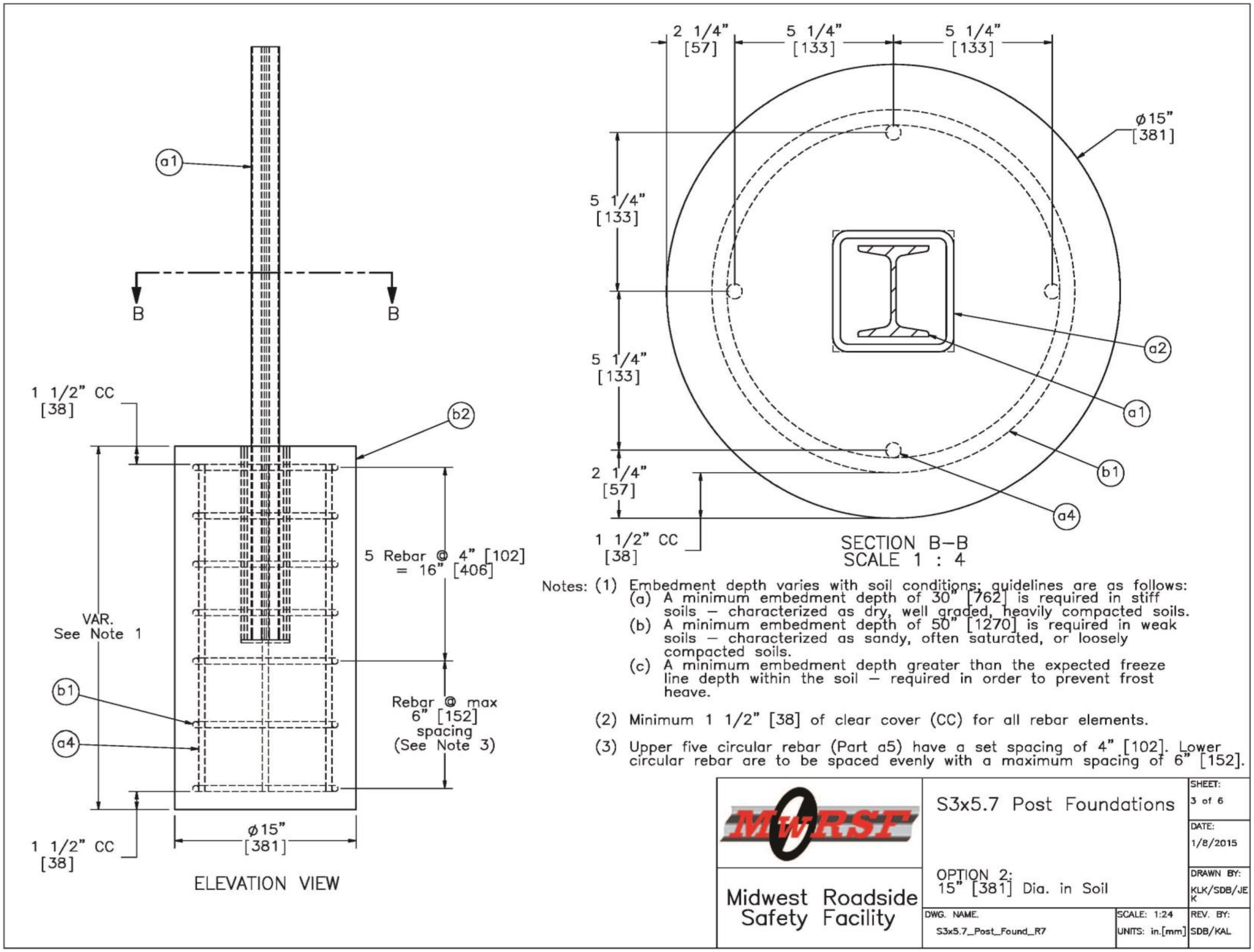


Figure 54. Socketed Foundation for S3x5.7 Posts, Option 2 Details

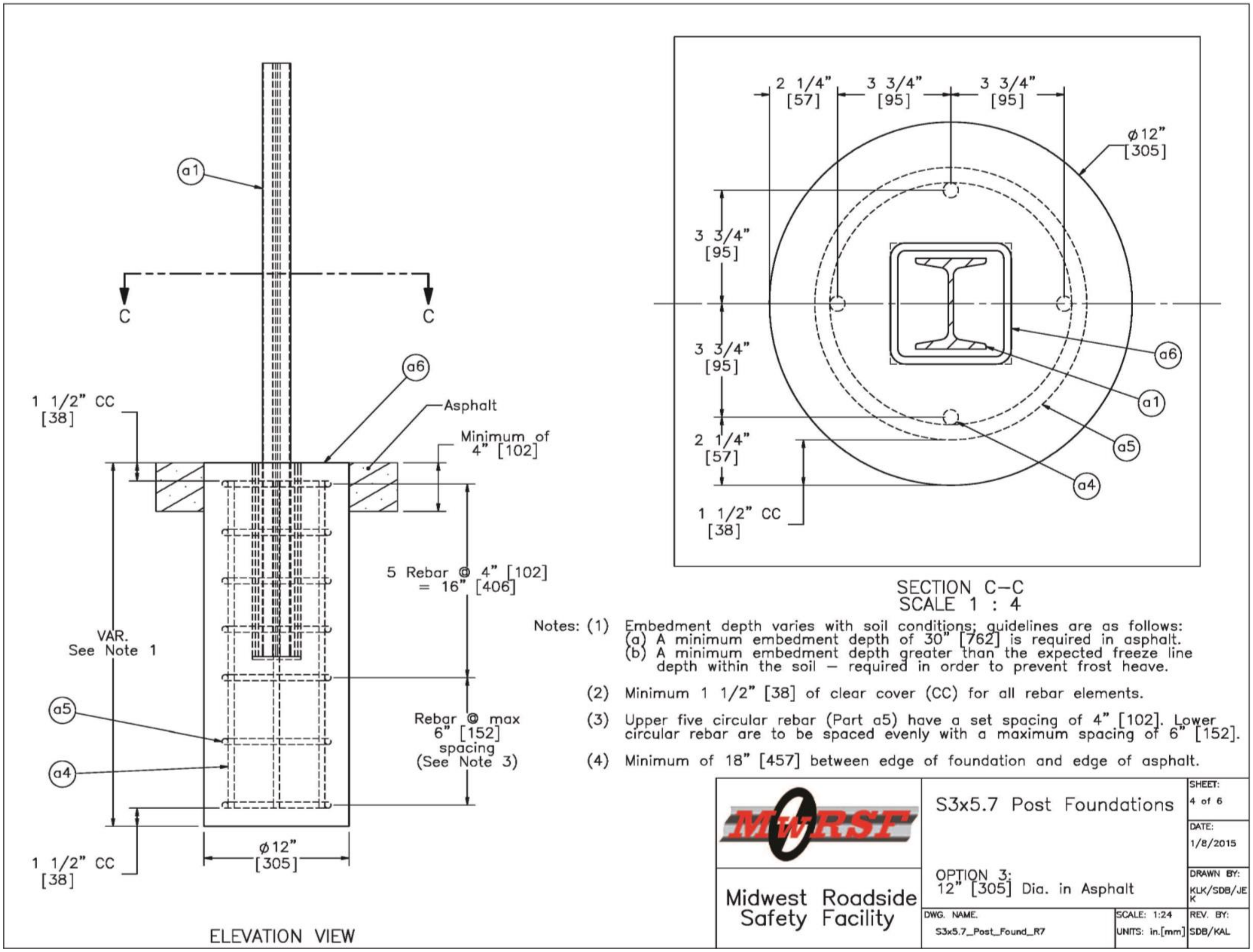


Figure 55. Socketed Foundation for S3x5.7 Posts, Option 3 Details

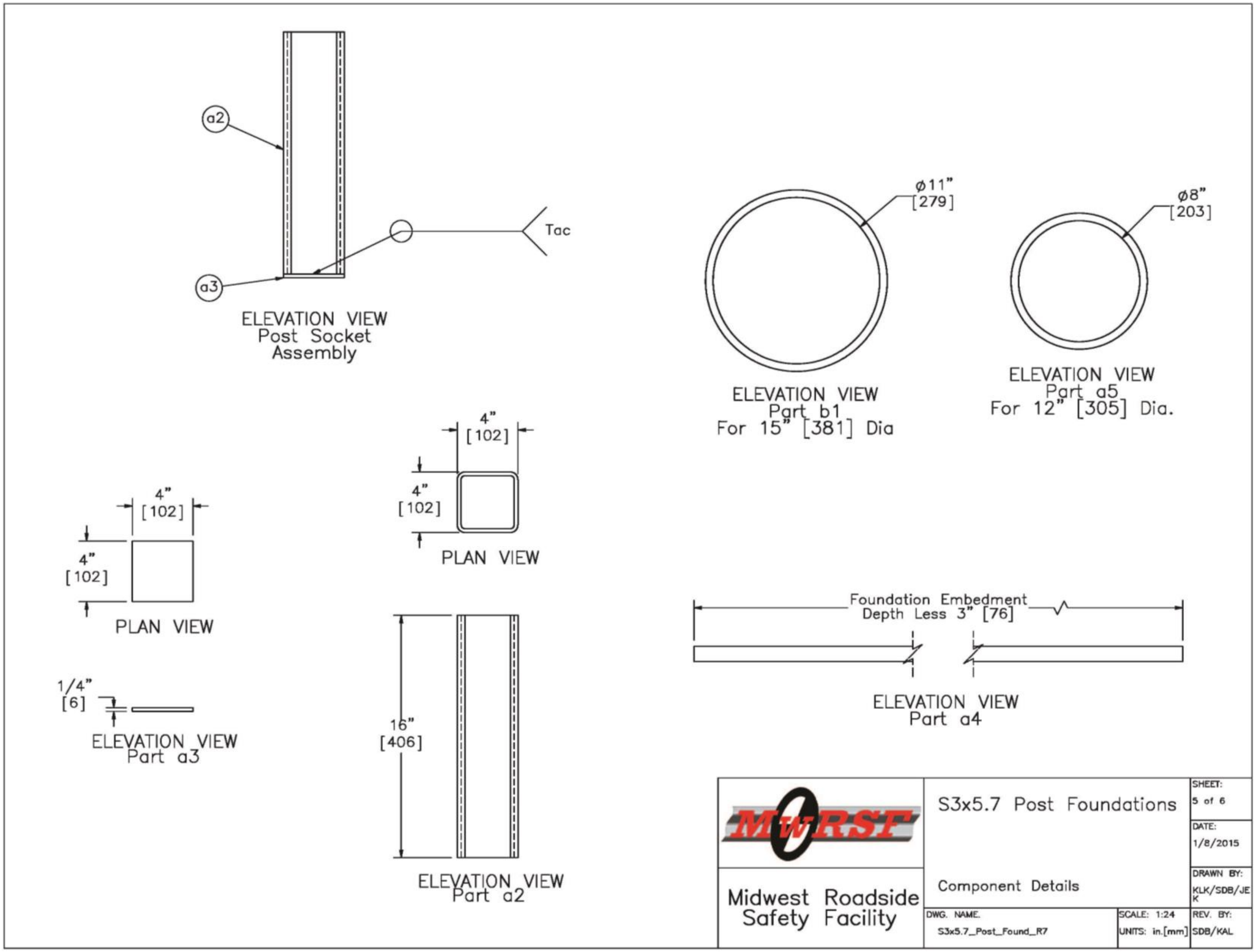


Figure 56. Socketed Foundations for S3x5.7 Posts, Steel Component Details

Option 1: 12" [305] Dia. in Soil			
Item No.	QTY.	Description	Material Specifications
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50, ASTM A992, ASTM A209 Gr. 50
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
b3	4	#4 Rebar, 33" [838] Long	Gr. 60
a2	VAR.	#4 Circular Rebar, 8" [203] ID	Gr. 60
b1	1	Concrete Shaft, 36" [914] Long	Min 3500 psi [24 MPa] Compressive Strength

Option 2: 15" [381] Dia. in Soil			
Item No.	QTY.	Description	Material Specifications
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50 / ASTM A992 / ASTM A209 Gr. 50
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
e3	4	#4 Rebar 27" [660] Long	Gr. 60
d2	VAR.	#4 Circular Rebar 11" [178] ID	Gr. 60
e1	1	Concrete Shaft 15" [381] Diameter	Min 3500 psi [24 MPa] Compressive Strength

Option 3: 12" [305] Dia. in Asphalt			
Item No.	QTY.	Description	Material Specifications
a1	1	Concrete Shaft, 30" [762] Long	Min 3500 psi [24 MPa] Compressive Strength
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50, ASTM A992, ASTM A209 Gr. 50
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36
a3	4	#4 Rebar, 27" [686] Long	Gr. 60
a2	VAR.	#4 Circular Rebar, 8" [203] ID	Gr. 60

MwRSF
Midwest Roadside Safety Facility

S3x5.7 Post Foundations

Bill of Materials

SHEET: 6 of 6
DATE: 1/8/2015
DRAWN BY: KLK/SDB/JEK
DWG. NAME. S3x5.7_Post_Found_R7
SCALE: 1:24
UNITS: in.[mm]
REV. BY: SDB/KAL

Figure 57. Socketed Foundations for S3x5.7 Posts, Bill of Materials

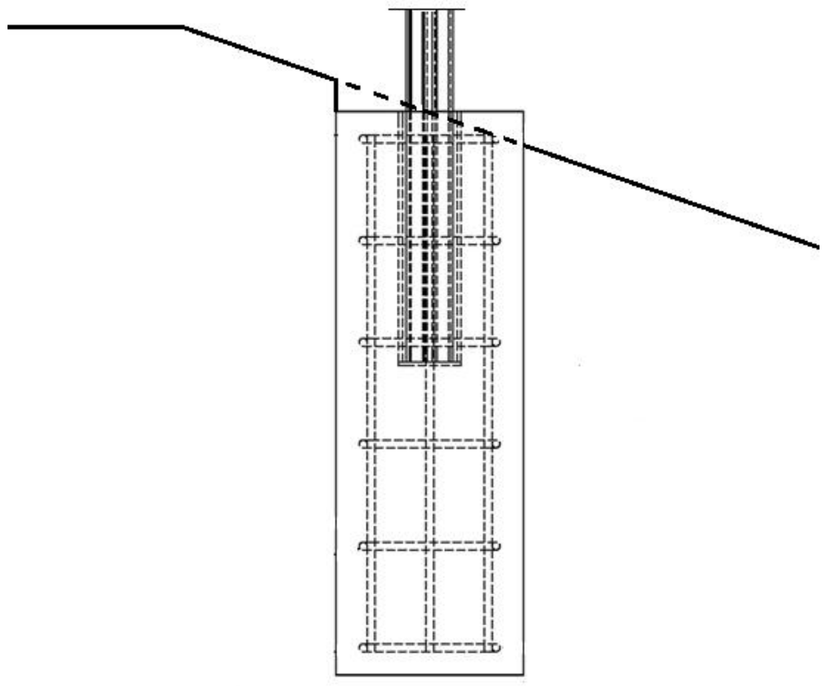


Figure 58. Placement of Foundation on Slope

10 REFERENCES

1. Terpsma, R.J., Zhu, L., Rohde, J., Dickey, B.J., Rosenbaugh, S.K., and Faller, R.K., *Development of a Socketed Foundation For Cable Barrier Posts – Phase I*, Submitted to the Midwest States' Regional Pooled Fund Program and the Mid-America Transportation Center, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Transportation Research Report No. TRP-03-232-11, February 2012.

2. Schmidt, T.L., Faller, R.K., Bielenberg, R.W., Lechtenberg, K.A., Rosenbaugh, S.K., Reid, J.D., and Sicking, D.L., *Design of an Improved Post for Use in a Non-Proprietary, High-Tension, Cable Median Barrier*, Draft Report to the Midwest States' Regional Pooled Fund Program, Transportation Report No. TRP-03-286-14, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, In Progress.

3. Schmidt, T.L., Rosenbaugh, S.K., Faller, R.K., Sicking, D.S., and Reid, J.D., *Development of a Socketed Foundation for the Midwest Weak Post*, Submitted to the Midwest States' Regional Pooled Fund Program, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Transportation Research Report No. TRP-03-298-14, June 2014.

4. Ross, H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program (NCHRP) Report 350, Transportation Research Board, Washington, D.C., 1993.

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

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

7. *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 34th Edition, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2014.

11 APPENDICES

Appendix A. Material Specifications

Item No.	Description	Material Specifications and/or Grade	Reference
a1	AASHTO A-3 Sand	No. 40 Sieve (51% min. pass) No. 200 Sieve (10% min. pass) Plasticity Index (NP) fine sand	"fill" sand
a2	Concrete	Min 3500 psi [24 MPa] Comp. Strength	R# 11-0421 (Ticket 1139274) 24033000
a3	#4 Circular Rebar 7" [178] ID	Gr. 60	R#11-0401 H#M660231 and H#536736
a4	#4 Rebar 56" [1422] Long	Gr. 60	R#11-0401 H#M660231 and H#536736
a5	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [289.6 MPa] Yield Strength)	H# S07068
a6	Shim Plate	ASTM A36	H# V911523
a7	4x4x1/4" [102x102x6] Steel Plate	ASTM A36	H# V911523
a8	S3x5.7 [S76x8.5], 49" [1245] Long	Min 50 ksi [344.7 MPa] Yield Strength	H# G104598/99
a9	#4 Rebar 26" [660] Long	Gr. 60	R#11-0401 H#M660231 and H#536736
a10	HSS 4x4x1/8" [HSS 102x102x3.2], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [289.6 MPa] Yield Strength)	H# U03477

Figure A-1. Bill of Materials, Test Nos. HTCB-5 through HTCB-9

30" [762] Footer Bill of Materials

Part No.	QTY.	Part Description	Material Specifications	Reference
a1	1	Concrete Shaft 30" [762] Long	Min 3500 psi [24 MPa] Comp. Strength	R# 12-0357 (Ticket 4132597) 24013000
a2	10	#4 Circular Rebar 7" [178] ID	Gr. 60	H# M660231
a3	4	#4 Rebar 26" [660] Long	Gr. 60	H# M660231
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36	H# 1042282
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [289.6 MPa] Yield Strength)	H# M44182
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	Min 50 ksi [344.7 MPa] Yield Strength	H# G104598/99
a7	2	#4 Rebar 18" [457] Long	Gr. 60	H# M660231

24" [610] Footer Bill of Materials

Part No.	QTY.	Part Description	Material Specifications	Reference
a2	10	#4 Circular Rebar 7" [178] ID	Gr. 60	H# M660231
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36	H# 1042282
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [289.6 MPa] Yield Strength)	H# M44182
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	Min 50 ksi [344.7 MPa] Yield Strength	H# G104598/99
b1	1	Concrete Shaft 24" [610] Long	Min 3500 psi [24 MPa] Comp. Strength	R# 12-0357 (Ticket 4132597) 24013000
b2	4	#4 Rebar 20" [508] Long	Gr. 60	H# M660231
b3	2	#4 Rebar 12" [305] Long	Gr. 60	H# M660231

36" [914] Footer Bill of Materials

Part No.	QTY.	Part Description	Material Specifications	Reference
a2	10	#4 Circular Rebar 7" [178] ID	Gr. 60	H# M660231
a4	1	4x4x1/4" [102x102x6] Steel Plate	ASTM A36	H# 1042282
a5	1	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [289.6 MPa] Yield Strength)	H# M44182
a6	1	S3x5.7 [S76x8.5], 49" [1245] Long	Min 50 ksi [344.7 MPa] Yield Strength	H# G104598/99
c1	1	Concrete Shaft 36" [914] Long	Min 3500 psi [24 MPa] Comp. Strength	R# 12-0357 (Ticket 4132597) 24013000
c2	4	#4 Rebar 32" [813] Long	Gr. 60	H# M660231
c3	2	#4 Rebar 24" [610] Long	Gr. 60	H# M660231

Figure A-2. Bill of Materials, Test Nos. HTCB-10 and HTCB-11

15" [381] and 18" [457] Diameter Foundations: Bill of Materials			
Item No.	**Description**	**Material Specification**	**Reference**
a1	Concrete Shaft 15 [381] Diameter "	Min 3500 psi [24 MPa] Compressive Strength	Ticket No. 175564
b1	Concrete Shaft 18 [457] Diameter "	Min 3500 psi [24 MPa] Compressive Strength	Ticket No. 175564
a2	#4 Circular Rebar 11 [178] ID "	Gr. 60	H# 564780
b2	#4 Circular Rebar 14 [178] ID "	Gr. 60	H# 564780
a3	#4 Rebar 27 [660] Long "	Gr. 60	H# 57134859
a4	4x4x1/4 [102x102x6] Steel Plate "	ASTM A36	N/A
a5	HSS 4x4x1/4 [HSS 102x102x6.4] 16" [406] Long "	ASTM A500 Grade B	H# R1496
a6	S3x5.7 [S76x8.5], 49 [1245] Long "	ASTM A572 Gr. 50 / ASTM A992 / ASTM A209 Gr. 50	H# G104598/99

12" [305] Diameter Foundation in Asphalt: Bill of Materials			
Item No.	**Description**	**Material Specifications and/or Grade**	**Reference**
a1	Concrete Shaft 30" [762] Long	Min 3500 psi [24 MPa] Compressive Strength	Ticket No. 175564
a2	#4 Circular Rebar 8" [203] ID	Gr. 60	H# 564780
a3	#4 Rebar 27" [686] Long	Gr. 60	H# 57134859
a4	4x4x1/4" [102x102x6] Steel Plate	ASTM A36	N/A
a5	HSS 4x4x1/4" [HSS 102x102x6.4], 16" [406] Long	ASTM A500 Grade B	H# R1496
a6	S3x5.7 [S76x8.5], 49" [1245] Long	ASTM A572 Gr. 50 / ASTM A992 / ASTM A209 Gr. 50	H# G104598/99
a7	5'x10'x4" [1524x3048x102] Asphalt	52 - 34 Grade Binder	R# 13-0434

Figure A-3. Bill of Materials, Test Nos. HTCB-17 through HTCB-19

CAUTION
FRESH CONCRETE

Body and or eye contact with fresh (moist) concrete should be avoided because it contains alkali and is caustic.

Ready Mixed
Concrete Company

6200 Cornhusker Highway, P.O. Box 29288
Lincoln, Nebraska 68529
Telephone 402-434-1844

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
01	24033000	1.50	0112		NTE		10:02AM	05/26/11	1139274

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003		CIA---MRS				1

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4800 NW 35TH	NORTH OF NORTH GOODYEAR HANGER	4024506250 JIM

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION		UNIT PRICE	AMOUNT
1.50	1.50	1.50	24033000	L4000 TYPE 3	4.00	98.89	148.34
				MINIMUM HAUL			55.00
							203.34
						SUBTOTAL	
						TAX	203.34
						TOTAL	203.34

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 1 GAL.

RECEIVED BY

TRUCK	USER LOGIN	DISP TICKET NUM	TICKET NUM	TICKET ID	TIME	DATE
0112	USER	1139274	160788	11534	10:02	05/26/2011

LOAD SIZE	MIX CODE	SEQ	LOAD ID
1.50 yd	24033000	W	11551

MATERIAL	DESIGN QTY	REQUIRED	BATCHED	VAR	% VAR	%MOISTURE	ACTUAL WAT
G47B	2090 lb	3212 lb	3220	8	0.25%	2.46 A	9.26 gl
L47B	909 lb	1384 lb	1380	-4	-.29%	1.50 M	2.44 gl
CEM3	611 lb	916 lb	955 >	39	4.26%		
PROT	1.20 oz	1.80 oz	2.00	0.20	11.11%		
WATER	34.0 GL	40.8 GL	40.7	-0.1	-.25%		40.74 gl
WATER2	0.0 gl #	0.0 gl	0.0	0.0	0.00%		

NON-SIMULATED NUM BATCHES: 1
LOAD TOTAL: 5895 lb DESIGN W/C: 0.464 WATER/CEMENT: 0.458A DESIGN WATER: 51.0 gl ACTUAL WATER: 52.5 gl TO ADD: 0.0 gl
SLUMP: 4.00 "# WATER IN TRUCK: 0.0 gl ADJUST WATER: 0.0 gl /load TRIM WATER: 0.0 gl /yd

ORIGINAL

Figure A-4. Concrete Material Specification, Test Nos. HTCB-5 through HTCB-9

Concrete Industries
6300 Cornhusker Highway
P.O. Box 29529
Lincoln, NE 00006-8529
Phone: (402)434-1800 FAX: (402)434-1899

JOB NUMBER	RELEASE NUMBER	REQ DELIVERY DATE	PAGE
8000MISC.	PATTI-114		1T

JOB NAME	CC
MISC. PROJECT	FREE

CUSTOMER	BY
MIDWEST ROADSIDE SAFETY	PKL

MATERIAL TYPE	REFERENCE	DRAWING ID	DESCRIPTION
Multiple			HIGH TENSION CABLE FOOTING

WEIGHT SUMMARY

SIZE	TOTAL ITEMS	TOTAL PIECES	TOTAL LBS	STRAIGHT ITEMS	STRAIGHT PIECES	STRAIGHT LBS	LIGHT BENDING ITEMS	LIGHT BENDING PIECES	LIGHT BENDING LBS	HEAVY BENDING ITEMS	HEAVY BENDING PIECES	HEAVY BENDING LBS
Rebar, Grade A706, Black												
4	1	2	3	1	2	3	0	0	0	0	0	0
	1	2	3	1	2	3	0	0	0	0	0	0
Rebar, Grade 60, Black												
4	2	71	166	1	16	53	1	55	113	0	0	0
	2	71	166	1	16	53	1	55	113	0	0	0

Total Weight: 169 Lbs

Longest Length: 4-11

v7.20.1826 (T) (LIN)

4/20/2011 7:19 AM

Figure A-5. Rebar Material Specification, Test Nos. HTCB-5 through HTCB-9

GERDAU AMERISTEEL

ST PAUL STEEL MILL
1678 RED ROCK ROAD
ST PAUL MN 55119 USA

Chemical and Physical Test Report

MADE IN UNITED STATES

CUSTOMER: CONCRETE INDUSTRIES INC

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
X13MM REBAR (# 4)	420 (60)	ASTM A615/A615M-09 GR 60/420 A6/A6M-08A		

HEAT I.D.	C	Mn	P	S	SI	Cu	Ni	Cr	Mo	V	Nb	N	Sn	Al	Ti	Ca	Zn	Co
M660231	.45	1.08	.007	.040	.21	.31	.09	.08	.032	.004	.000	.0094	.025	.001	.00000	.00110	.00300	.007

Mechanical Test: Yield 80000 PSI, 551.58 MPA Tensile: 121500 PSI, 837.71 MPA %El: 15.0/8in, 15.0/203.2mm Bend: OK Def HT: .035, .89MM %l/h -1.5L Red R 155.69 ldl
Diam: 1.76 Corrosion Index: 5.5

Customer Requirements SOURCE: GA-STP CASTING: STRAND CAST

Comment: made in the USA
melt shop heat M102441

This material, including the billets, was melted and manufactured in the United States of America

Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

THE ABOVE FIGURES ARE CERTIFIED CHEMICAL AND PHYSICAL TEST RECORDS AS CONTAINED IN THE PERMANENT RECORDS OF COMPANY.

Metallurgical Services Manager
ST PAUL STEEL MILL

Seller warrants that all material furnished shall comply with specifications subject to standard published manufacturing variations. NO OTHER WARRANTIES, EXPRESSED OR IMPLIED, ARE MADE BY THE SELLER, AND SPECIFICALLY EXCLUDED ARE WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.
In no event shall seller be liable for indirect, consequential or punitive damages arising out of or related to the materials furnished by seller.
Any claim for damages for materials that do not conform to specifications must be made from buyer to seller immediately after delivery of same in order to allow the seller the opportunity to inspect the material in question.

Figure A-6. Rebar Material Test Report, Test Nos. HTCB-5 through HTCB-9

Bill To:
CONCRETE INDUSTRIES, INC.
P.O. BOX 29529
LINCOLN NE
68529 US

Ship To: 3
CONCRETE INDUSTRIES, INC (REE
6300 CORNHUSKER HWY
LINCOLN NE
68521 US

Order Date:07/02/2010
PO No:83376
Mill Order No:3750463
Load No:1315770
Manifest No:2014986

CERTIFIED MATERIAL TEST REPORT
GERDAU AMERISTEEL
GERDAU AMERISTEEL
Midlothian Mill
300 Ward Road
Midlothian, TX 76065
(972)775-8241

SPECIFICATIONS	SIZE	GRADE	LENGTH	PRODUCT
ASTM A706/A706M-09	# 4 REBAR/13 MM / 13 MM	A706	60 FT / 18.288 M	REBAR

HEAT NO: 11877680

CHEMICAL ANALYSIS

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	Nb	CE
.25	1.34	.015	.033	.22	.25	.10	.11	.027	.011	.031	.002	.000	.5

PHYSICAL PROPERTIES

Yield Strength KSI	Yield Strength MPa	Tensile Strength KSI	Tensile Strength MPa	Specimen Area Sq In	Specimen Area Sq cm	Elongation %	Gage Length		Bend Test Dia.	Bend Test Result	ROA %
66.5	458.5	91.8	632.9	0.191	1.23	17.3	8 In	200 mm	3.0	PASS	

All manufacturing processes of this product, including electric arc MELTING and continuous CASTING, occurred in the U.S.A.
CMTR complies with EN 10204 3.1

"I hereby certify that the contents of this report are correct and accurate. All tests and operations performed by this material manufacturer or its sub-contractors, when applicable, are in compliance with the requirements of the material specifications and applicable purchaser designated requirements."

Signed: Tom L. Harrington Date: Jul. 07, 2010
Tom L. Harrington: Quality Assurance Manager

Signed: ____________ Date: ________
Notary Public (if applicable)

Page: 1 of 1

Figure A-7. Additional Rebar Material Test Report, Test No. HTCB-9

TEST REPORT

Customer Name: SIOUX CITY FOUNDRY COMPANY
Customer PO No: 130432W

Heat No.:	S07068	Spec/Grade:	A500-10a/B/C
Description:	CARBON STEEL TUBING	Print Date:	1/31/2011
Size/Length:	4" Square 1/4" Wall 24'	Wall Thickness:	0.2500

Carbon (C):	0.2000	Tin (Sn):	0.0040	Vanadium (V):	0.0010
Manganese (Mn):	0.4100	Nickel (Ni):	0.0300	Columbium (Cb):	0.0000
Phosphorus (P):	0.0100	Chromium (Cr):	0.0300	Titanium (Ti):	0.0010
Sulphur (S):	0.0050	Molybdenum (Mo):	0.0100	Boron (B):	0.0001
Silicon (Si):	0.0250	Aluminum (Al):	0.0250	Calcium (Ca):	0.0021
Copper (Cu):	0.0900	Nitrogen (N):	0.0085	Carbon Equiv. (CE):	0.2845

Sample Number	Sample Date	Tensile (psi)	Yield (psi)	Elongation (%)
SL25825	1/19/2011	74,600	68,300	25.00

We hereby certify that the above figures are correct as contained in the records of this company. Tensile testing (if applicable) is performed according to ASTM A370 and ASTM E8 (Yield Strength determined using 0.2% offset method).

Computer Generated Document
Quality Assurance

Melted & Manufactured in the U.S.A.

STI Pickup No: 12TS017 STI Order No: 224492 STI Item No: 4.0S25024

Figure A-8. Steel Socket Material Specification, Test Nos. HTCB-5 through HTCB-7 and HTCB-9

TEST REPORT

Customer Name: SIOUX CITY FOUNDRY COMPANY
Customer PO No: 131033

Heat No.:	U03477	Spec/Grade:	A500-10a/B/C
Description:	CARBON STEEL TUBING	Print Date:	1/26/2011
Size/Length:	4" Square 1/8" Wall 24'	Wall Thickness:	0.1250

Carbon (C):	0.2100	Tin (Sn):	0.0090	Vanadium (V):	0.0010
Manganese (Mn):	0.4100	Nickel (Ni):	0.0100	Columbium (Cb):	0.0000
Phosphorus (P):	0.0060	Chromium (Cr):	0.0300	Titanium (Ti):	0.0000
Sulphur (S):	0.0110	Molybdenum (Mo):	0.0050	Boron (B):	0.0001
Silicon (Si):	0.0100	Aluminum (Al):	0.0280	Calcium (Ca):	0.0000
Copper (Cu):	0.0400	Nitrogen (N):	0.0060	Carbon Equiv. (CE):	0.2889

Sample Number	Sample Date	Tensile (psi)	Yield (psi)	Elongation (%)
SL25809	1/18/2011	69,900	52,300	23.00

We hereby certify that the above figures are correct as contained in the records of this company. Tensile testing (if applicable) is performed according to ASTM A370 and ASTM E8 (Yield Strength determined using 0.2% offset method).

Computer Generated Document
Quality Assurance

Melted & Manufactured in the U.S.A.

STI Pickup No: 01TS007 STI Order No: 226852 STI Item No: 4.0S1124

Figure A-9. Steel Socket Material Specification, Test No. HTCB-8

Chemical and Physical Test Report
MADE IN UNITED STATES

V-693577

SHIP TO	INVOICE TO	SHIP DATE
SIOUX CITY FOUNDRY INC 801 DIVISION STREET 800-831-0874 SIOUX CITY, IA 51102	SIOUX CITY FOUNDRY INC ACCTS PAYABLE PO BOX 3067 SIOUX CITY, IA 51102	04/12/11 **CUST. ACCOUNT NO** 60044062

PRODUCED IN: JACKSON TN

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
F1/2 X 5	A36	ASTM A36-08; ASME SA-36-08, ASTM A709-36-08	1026521-02	132999W-02

HEAT I D	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Zr	Ca	C Eqv
V909259	18	76	.010	025	.23	.31	09	.08	.020	.006	001	.0005	0112	.012	002	.00100	.000	.00000	.398

Mechanical Test: Yield 51600 PSI, 355.77 MPA Tensile: 73440 PSI, 506.35 MPA %El: 28.0/8in, 28.0/200MM Def HT: 0, 0MM %I/h 0L Red R 14
Mechanical Test: Yield 49990 PSI, 344.67 MPA Tensile: 72810 PSI, 502.01 MPA %El 27.5/8in, 27.5/200MM Def HT: 0, 0MM %I/h 0L Red R 14

PRODUCED IN: JACKSON TN

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
A2 X 2 X 1/4	A36	ASTM A36-08; ASME SA-36-08, ASTM A709-36-08	0127748-02	129665W-02

HEAT I D	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Zr	Ca	C Eqv
V911326	12	61	018	006	.19	.31	09	.10	021	.004	002	.0003	0000	.012	.001	.00100	000	.00000	.305

Mechanical Test: Yield 49020 PSI, 337.98 MPA Tensile: 67660 PSI, 466.5 MPA %El. 31.0/8in, 31.0/200MM Def HT: 0, 0MM %I/h 0L Red R 28.91
Mechanical Test: Yield 48430 PSI, 333.91 MPA Tensile: 67440 PSI, 464.98 MPA %El. 30.5/8in, 30.5/200MM Def HT: 0, 0MM %I/h 0L Red R 28.91

PRODUCED IN: JACKSON TN

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
F1/4 X 4	A36	ASTM A36-08; ASME SA-36-08; ASTM A709-36-08; C.S.A G40 21-98 44W-04	1026521-01	132999W-01

HEAT I D	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Zr	Ca	C Eqv
V911523	12	75	.014	032	.23	32	09	.08	022	004	.001	.0004	.0000	.011	.001	.00100	.000	.00000	.324

Mechanical Test: Yield 49550 PSI, 341.64 MPA Tensile: 67510 PSI, 465.47 MPA %El: 30.0/8in, 30.0/200MM Def HT: 0, 0MM %I/h 0L Red R 35
Mechanical Test: Yield 48950 PSI, 337.5 MPA Tensile: 67550 PSI, 465.74 MPA %El: 29.5/8in, 29.5/200MM Def HT: 0, 0MM %I/h 0L Red R 35

Customer Notes

NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

This material, including the billets, was melted and manufactured in the United States of America

Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

THE ABOVE FIGURES ARE CERTIFIED CHEMICAL AND PHYSICAL TEST RECORDS AS CONTAINED IN THE PERMANENT RECORDS OF COMPANY

Metallurgical Services Manager
JACKSON STEEL MILL

Figure A-10. Steel Plate Material Specification, Test Nos. HTCB-5 through HTCB-9

06/02/2009 14:49 314-851-9336 TUBULAR STEEL INC PAGE 01

05/06/2009 13:49 3148519338 TUBULAR STEEL INC PAGE 02

05/04/2009 MON 18:24 FAX ☑004/005

Atlas Tube (U.S.) Inc.
13101 Eckles Road
Plymouth, Michigan, USA
48170
Tel: 313-454-5600
Fax: 313-454-1474

Ref.B/L: 80340207
Date: 05.04.2009
Customer: 193

Atlas TUBE

MATERIAL TEST REPORT

Sold to

Tubular Steel
1031 Executive Parkway
ST.LOUIS MO 63141
USA

Shipped to

Tubular Steel
7220 Polson Lane
HAZELWOOD MO 63141
USA

Material: 5.0x4.0x375x40'0"0(3x3). Material No: 500403754000 Made In: Canada
Sales order: 466681 Purchase Order: PO-007724

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti
756227	0.060	0.560	0.010	0.006	0.013	0.036	0.036	0.034	0.003	0.011	0.031	0.000	0.002

Bundle No	Yield	Tensile	Eln.2in	Certification	CE: 0.17
M100853734	073280 Psi	079930 Psi	24.8 %	ASTM A500-07 GRADE B&C	

Material Note:
Sales Or.Note:

09-0391-2

Material: 5.0x4.0x375x40'0"0(3x3). Material No: 500403754000 Made in: Canada
Sales order: 466681 Purchase Order: PO-007724

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti
756227	0.060	0.560	0.010	0.006	0.013	0.036	0.036	0.034	0.003	0.011	0.031	0.000	0.002

Bundle No	Yield	Tensile	Eln.2in	Certification	CE: 0.17
M100853733	073280 Psi	079930 Psi	24.8 %	ASTM A500-07 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 16.0x4.0x313x48'0"0(1x4). Material No: 1600403134800 Made In: Canada
Sales order: 466681 Purchase Order: PO-007724

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti
755882	0.060	0.570	0.007	0.004	0.018	0.035	0.028	0.035	0.003	0.010	0.024	0.000	0.002

Bundle No	Yield	Tensile	Eln.2in	Certification	CE: 0.17
M200589423	068830 Psi	076080 Psi	26.9 %	ASTM A500-07 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 2.0x1.0x188x24'0"0(6x8).-D Material No: 0200101882400-D Made In: USA
Melted & Manufactured In USA
Sales order: 464202 Purchase Order: PO-007562

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti
DB0150	0.160	0.780	0.011	0.007	0.016	0.051	0.020	0.000	0.004	0.010	0.030	0.001	0.001

Bundle No	Yield	Tensile	Eln.2in	Certification	CE: 0.30
M300426419	070460 Psi	077445 Psi	23.3 %	ASTM A500-07 GRADE B&C	

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

Steel Tube Institute OF NORTH AMERICA

Page : 2 Of 3

Metals Service Center Institute

TUBE 5x4x3/8

Figure A-11. Steel Material Specification, Test Nos. HTCB-10 and HTCB-11

Post Sockets
5-2-2012

MATERIAL TEST REPORT

Sold to

SIOUX CITY FOUNDRY
SIOUX CITY IA 51102
USA

Shipped to

Sioux City Foundry
801 Division Street
SIOUX CITY IA 51105
USA

Material: 4.0x4.0x250x24'0"0(5x4). Material No: 400402502400 Made in: USA Melted in: USA

Sales order: 705500 Purchase Order: 140572W

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
M44182	0.200	0.790	0.012	0.008	0.019	0.043	0.040	0.006	0.003	0.010	0.030	0.001	0.001	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M800318647	20	066508 Psi	075859 Psi	33 %	ASTM A500-10A GRADE B&C	

Material Note:
Sales Or.Note:

Material: 4.0x4.0x250x24'0"0(5x4). Material No: 400402502400 Made in: USA Melted in: USA

Sales order: 705500 Purchase Order: 140572W

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
M44182	0.200	0.790	0.012	0.008	0.019	0.043	0.040	0.006	0.003	0.010	0.030	0.001	0.001	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M800318646	20	066508 Psi	075859 Psi	33 %	ASTM A500-10A GRADE B&C	

Material Note:
Sales Or.Note:

Material: 1.0x1.0x083x24'0"0(10x10).A513 Material No: 0100100832400-A513 Made in: USA Melted in: USA

Sales order: 697303 Purchase Order: 139742W

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
36327D	0.060	0.390	0.009	0.010	0.006	0.034	0.050	0.000	0.000	0.020	0.040	0.000	0.000	0.000	0.000

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.14
M600111243	100	000000 Psi	Psi	%	ASTM A513, TYPE 1	

Material Note:
Sales Or.Note:

Authorized by Quality Assurance: M Wheeler
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 : 3 Of 4

Metals Service Center Institute

Figure A-12. Steel Socket Material Specification, Test Nos. HTCB-10 and HTCB-11

48 har Glass - 4-30-2011

[redacted]

Chemical and Physical Test Report
Made and Melted In USA

G-163740

SHIP TO	**INVOICE TO**	**SHIP DATE**
SIOUX CITY FOUNDRY INC 801 DIVISION STREET 800-831-0874 SIOUX CITY, IA 51102	SIOUX CITY FOUNDRY INC ACCTS PAYABLE PO BOX 3067 SIOUX CITY, IA 51102	11/08/10 **CUST. ACCOUNT NO** 60044062

PRODUCED IN: CARTERSVILLE

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
W3 X 5.7# S-BEAM	A57250/992	ASTM A572 GR50-07, ASTM A992 -06A, ASTM A709 GR50-09A	0123380-05	129309W-05

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv						
G104598	14	.91	012	.020	.22	.30	.09	.05	.022	.016	.002	.0003	.0100	.010	.002	.00100	.00030	.00710	.374						

Mechanical Test: Yield 53300 PSI, 367.49 MPA Tensile: 74200 PSI, 511.59 MPA %El: 19.2/8in, 19.2/200MM
Customer Requirements CASTING. STRAND CAST
Comment NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
Mechanical Test: Yield 53900 PSI, 371 63 MPA Tensile: 73300 PSI, 505.39 MPA %El: 20.0/8in, 20.0/200MM
Customer Requirements CASTING: STRAND CAST
Comment NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

PRODUCED IN: CARTERSVILLE

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
W3 X 5.7# S-BEAM	A57250/992	ASTM A572 GR50-07, ASTM A992 -06A, ASTM A709 GR50-09A	0123380-05	129309W-05

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv						
G104599	14	.92	014	.023	.22	.28	.09	.05	025	.016	.002	.0003	.0095	.010	.002	.00100	.00050	.00740	.373						

Mechanical Test: Yield 54800 PSI, 377.83 MPA Tensile: 74700 PSI, 515.04 MPA %El: 19.5/8in, 19.5/200MM
Customer Requirements CASTING: STRAND CAST
Comment NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
Mechanical Test: Yield 53800 PSI, 370.94 MPA Tensile: 73700 PSI, 508.14 MPA %El: 21.3/8in, 21.3/200MM
Customer Requirements CASTING. STRAND CAST
Comment NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

Customer Notes
NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

All manufacturing processes including melt and cast, occurred in USA. MTR complies with EN10204 3.1B

Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

THE ABOVE FIGURES ARE CERTIFIED EXTRACTS FROM THE ORIGINAL CHEMICAL AND PHYSICAL TEST RECORDS AS CONTAINED IN THE PERMANENT RECORDS OF COMPANY.

Metallurgical Services Manager
CARTERSVILLE STEEL MILL

Figure A-13. Steel Posts, Test Nos. HTCB-10, HTCB-11, and HCTB-17 through HTCB-19

CAUTION
FRESH CONCRETE

Body and or eye contact with fresh (moist) concrete should be avoided because it contains alkali and is caustic.

Ready Mixed Concrete Company
6200 Cornhusker Highway, P.O. Box 29288
Lincoln, Nebraska 68529
Telephone 402-434-1844

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
4	24013000	4.50	0203	010	NTE		09:04AM	05/14/12	4132597

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003		CIA---UNL / MWRSF				1

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4800 NW 35TH	NORTH OF GOODYEAR HANGERS	450-6250 JIM

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION		UNIT PRICE	AMOUNT
4.50	4.50	4.50	24013000	L4000	4.00	94.75	426.38
				MINIMUM HAUL			25.00

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 10 GAL

RECEIVED BY -UNL

SUBTOTAL 451.38
TAX
TOTAL 451.38
451.38

TRUCK	USER LOGIN	DISP TICKET NUM	TICKET NUM	TICKET ID	TIME	DATE
0203	USER	4132597	152638	164933	09:04	05/14/2012

LOAD SIZE	MIX CODE	SEQ	LOAD ID
4.50 yd	24013000	W	166617

MATERIAL	DESIGN QTY	REQUIRED	BATCHED	VAR	% VAR	%MOISTURE	ACTUAL WAT
G47B	2113.0 lb	9737.7 lb	9700.0	-37.7	-.39%	2.41 A	27.36 gl
L47B	919.0 lb	4197.5 lb	4180.0	-17.5	-.42%	1.50 M	7.40 gl
CEM1	611.0 lb	2749.5 lb	2785.0 +	35.5	1.29%		
PROT	5.7 oz	25.6 oz	26.0	0.4	1.56%		
WATER	31.5 gl	111.4 gl	111.4	0.0	0.00%		111.44 gl
WATER2	0.0 gl #	0.0 gl	0.0	0.0	0.00%		

NON-SIMULATED NUM BATCHES: 1
LOAD TOTAL: 17597 lb DESIGN W/C: 0.430 WATER/CEMENT: 0.438A DESIGN WATER: 141.7 gl ACTUAL WATER: 146.2 gl
SLUMP: 4.00 "# WATER IN TRUCK: 0.0 gl

ORIGINAL

Figure A-14. Concrete Material Specification, Test Nos. HTCB-10 and HTCB-11

CAUTION
FRESH CONCRETE

Body and or eye contact with fresh (moist) concrete should be avoided because it contains alkali and is caustic.

Ready Mixed Concrete Company

6200 Cornhusker Highway, P.O. Box 29288
Lincoln, Nebraska 68529
Telephone 402-434-1844

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
04	23513000	2.50	0131	075			10:06AM	02/10/14	4155728

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003		CIA--MRS				1

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4630 NW 36TH	N OF GOODYEAR HANGER	4024506250

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION		UNIT PRICE	AMOUNT
2.50	2.50	2.50	23513000	L3500 (47B)	3.00	94.00	235.00
				MINIMUM HAUL			45.00
				WINTER SERVICE			10.00
							290.00
						SUBTOTAL	290.00
						TAX	
						TOTAL	290.00

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 0 GAL. RECEIVED BY

```
TRUCK        USER LOGIN  DISP TICKET NUM TICKET NUM TICKET ID  TIME   DATE
0131         USER               4155728     175564    190035   10:06  02/10/2014
LOAD SIZE    MIX CODE                                          SEQ    LOAD ID
 2.50 yd     23513000                                          W       192017
MATERIAL     SOURCE       DESIGN QTY   REQUIRED    BATCHED       VAR    % VAR   %MOISTURE ACTUAL WAT
G47B         47B GRAVEL   2133.0 lb   5455.1 lb   5440.0       -15.1    -.28%    2.30 M   14.66 gl
L47B         47B ROCK      928.0 lb   2343.2 lb   2340.0        -3.2    -.14%    1.00 M    2.78 gl
CEM1         CEMENT TYP    564.0 lb   1410.0 lb   1410.0         0.0    0.00%
AIR          MB-AE 90 A      5.0 oz     12.5 oz     12.0        -0.5   -4.00%
WATER        WATER          31.0 gl     60.0 gl     61.1   +     1.1    1.83%             61.11 gl
WATER2       RECYCLE WA      0.0 gl #    0.0 gl      0.0         0.0    0.00%
NON-SIMULATED   NUM BATCHES: 1
 LOAD TOTAL:  9701 lb  DESIGN W/C: 0.459  WATER/CEMENT: 0.465A   DESIGN WATER:  77.5 gl   ACTUAL WATER:   78.5 gl
 SLUMP:  3.00 "  WATER IN TRUCK:   0.0 gl
```

ORIGINAL

Figure A-15. Concrete Material Specification, Test Nos. HTCB-17 through HTCB-19

EVRAZ ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

P.O. Box 316
Pueblo, CO 81002 USA

MATERIAL TEST REPORT

Date Printed: 09–OCT–13

Date Shipped: 09–OCT–13	Product: DEF #4 (1/2")	Specification: ASTM–A–615M09b GR 420/ASTM–A–706M09b
FWIP: 52815348	Customer: CONCRETE INDUSTRIES INC	Cust. PO: 103151

CHEMICAL ANALYSIS (Heat cast 09/20/13)

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ti
564780	0.26	1.28	0.010	0.009	0.26	0.30	0.08	0.13	0.019	0.003	0.039	0.0005	0.000	0.012	0.0072	0.001

Carbon Equivalent = 0.494

MECHANICAL PROPERTIES

Heat Number	Sample No.		Yield (Psi)	Ultimate (Psi)	Elongation (%)	Reduction (%)	Bend	Wt/ft
564780	01		66699	98420	15.0		OK	0.681
		(MPa)	459.9	678.6				
564780	02		71527	100780	15.7		OK	0.676
		(MPa)	493.2	694.9				

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 and tested in accordance with the requirements of the applicable specifications. We hereby certify that the above test results represent those contained in the records of the Company.

Mark f Espanex

Quality Assurance Department

Figure A-16. Transverse Hoop Rebar, Test Nos. HTCB-17 through HTCB-19

CERTIFIED MATERIAL TEST REPORT

Page 1/1

GERDAU

US-ML-KNOXVILLE
1919 TENNESSEE AVENUE N. W.
KNOXVILLE, TN 37921
USA

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

LENGTH	WEIGHT	HEAT / BATCH
60'00"	24,287 LB	57134859/03

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
507838/000010		1-ASTM A615/A615M-09

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
101827	1326-0000008529	08/22/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqvA706 %
0.27	0.57	0.020	0.088	0.19	0.43	0.17	0.09	0.031	0.004	0.003	0.39

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
80520	555	96540	666	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
11.30	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.79	0.031	0.105	0.331

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

Bhaskar — BHASKAR YALAMANCHILI, QUALITY DIRECTOR

Lisa K. Churnetski — LISA CHURNETSKI, QUALITY ASSURANCE MGR.

Figure A-17. Vertical Rebar, Test Nos. HTCB-17 through HTCB-19

4x4x1/4" Tube

CERTIFICATE OF TESTING

Page 1

Certificate Number:	224856-1
	Tuesday, July 16, 2013, 1:11:26 PM

Bill of Lading: **188444**

Size: **4.000 X 4.000 in** | Gage: **0.250 in** | Grade: **A500B** | Mill Order No: **51829-06** | Customer PO: **152794W**

Specification: **ASTM A500-01**
PRODUCT MEETS SPECIFICATION REQUIREMENTS
FOR GRADES B AND C.

Customer: **SIOUX CITY FOUNDRY**

Pieces: **40** Length: **24.00** (ft)

Heat	Product ID	Test Type			Orientation				Width (in)		YS (psi)		UTS (psi)		Elong%(2 in)		Y/T	
		Wgt (%)	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Cb	Ti	B	CEQ
R1496	G-776C 5053736/	HEAT QUALIFIER			PIPE LPA				1.500		70700		74300		39.0		0.95	
		Heat:	0.15	0.62	0.006	0.005	0.02	0.13	0.06	0.04	0.020	0.026	0.033	0.002	0.000	0.001	0.0000	0.26

TPA - Transverse Pipe Axis
LPA - Longitudinal Pipe Axis
90° of Weld
TWA - Transverse Weld Axix
FST - Full Section Testing
FBN - Full Body Normalized
Q&T - Quenched and Tempered
SR - Stress Relieve
form CRTR3001

Melted and Manufactured in the USA

We certify that the product described above has been manufactured, sampled, inspected, and tested in accordance to the referenced specification. The product has been found to be in compliance with all requirements.

Tuesday, July 16, 2013, 1:12:15 PM

Figure A-18. Steel Tube Socket, Test Nos. HTCB-17 through HTCB-19

Asphalt Mix R# 13-0434 Mowstrip Project

Shaun Tighe

From: Jim C. Holloway [jholloway1@unl.edu]
Sent: Thursday, July 25, 2013 10:11 AM
To: Shaun Tighe
Subject: FW: Midwest Roadside Safety Invoice

-----Original Message-----
From: Judy Miller [mailto:catherandsons@futuretk.com]
Sent: Thursday, July 11, 2013 3:45 PM
To: Jim Holloway
Subject: RE: Midwest Roadside Safety Invoice

>Jim; This is what my records show for the mixed used on your project...let me know if you need it in a different format...Thanks, Judy

25% - 3A Gravel
28% - 1/4" Dry Chip Limestone
12% - 3/4" Clean Limestone
30% - RAP
5% - RAS
5.6% - PG58-28 asphaltic cement

Figure A-19. Asphalt Mix, Test No. HTCB-19

Appendix B. Bogie Test Results

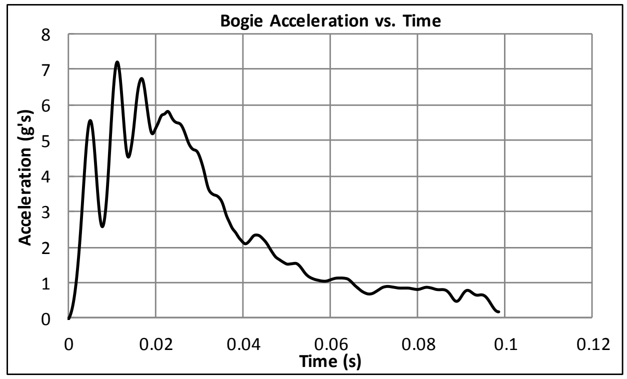
The results of the recorded data from each accelerometer for every dynamic bogie test are provided in the summary sheets found in this appendix. Summary sheets include acceleration, velocity, and deflection vs. time plots, as well as force vs. deflection and energy vs. deflection plots.

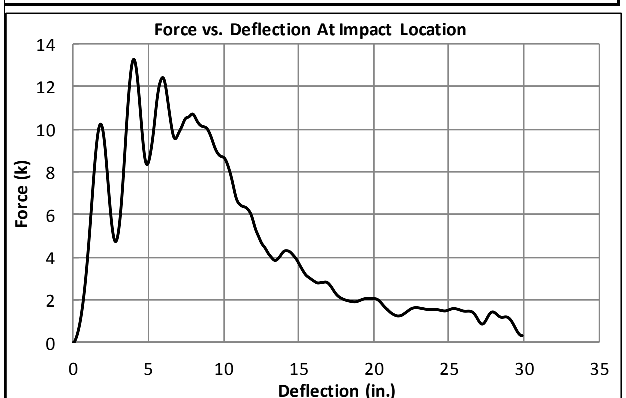
MIDWEST ROADSIDE SAFETY FACILITY

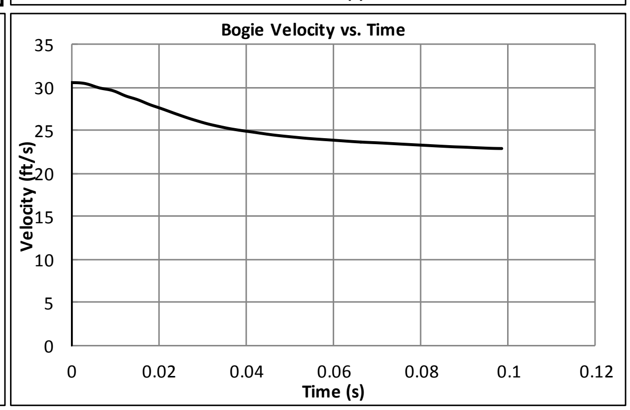
Bogie Test Summary

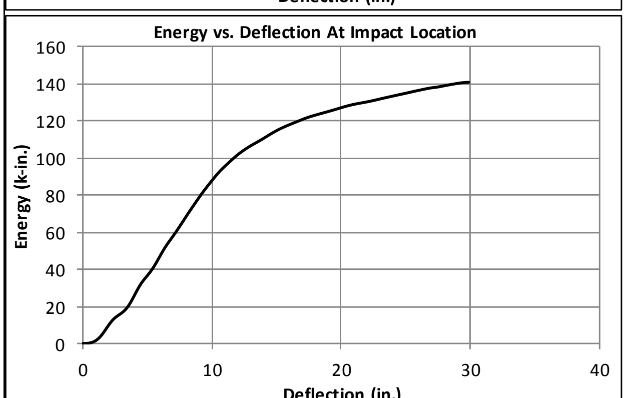
Test Information	Bogie - Post	
Test Number:	HTCB-5	
Test Date:	21-Dec-2011	
Failure Type:	Post Bending	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	49 in.	124.5 cm
Embedment Depth:	16 in.	40.6 cm
Orientation:	strong axis	
Foundation		
Design:	D	
Length:	60 in.	152.4 cm
Embedment:	60 in.	152.4 cm
Diameter:	12 in.	30.5 cm
Bogie Properties		
Impact Velocity:	20.83 mph (30.5 fps)	9.31 m/s
Impact Height:	15 in.	38.1 cm
Bogie Mass:	1843 lbs	836 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-5 Perpendicular - 22'	

Test Results Summary		
Max. Deflection:	29.9	in.
Peak Force:	13.3	k
Initial Linear Stiffness:	3.3	k/in.
Total Energy:	140.7	k-in.









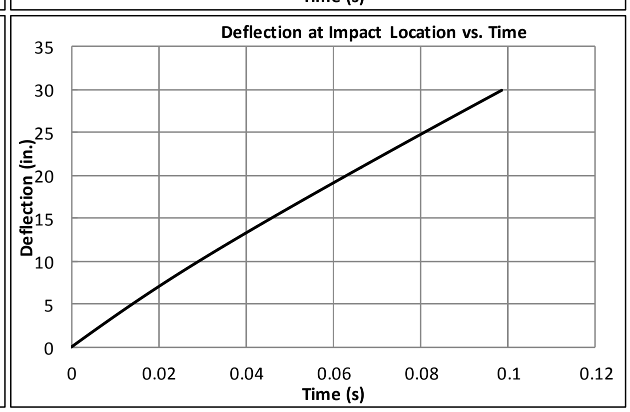


Figure B-1. Test No. HTCB-5 Results (DTS)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information Bogie - Post
Test Number: HTCB-5
Test Date: 21-Dec-2011
Failure Type: Post Bending

Post Properties
Post Type: Steel
Post Size: S3x5.7 S76x8.5
Post Length: 49 in. 124.5 cm
Embedment Depth: 16 in. 40.6 cm
Orientation: strong axis

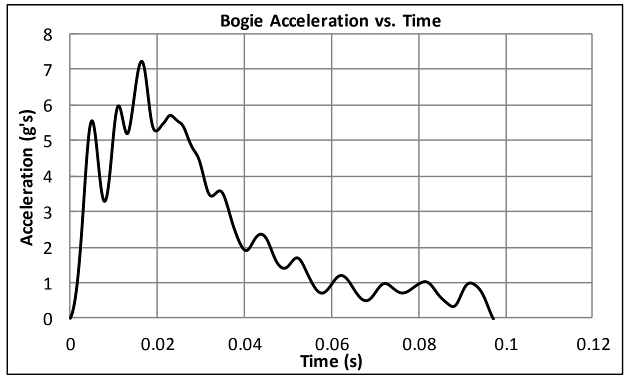
Foundation
Design: D
Length: 60 in. 152.4 cm
Embedment: 60 in. 152.4 cm
Diameter: 12 in. 30.5 cm

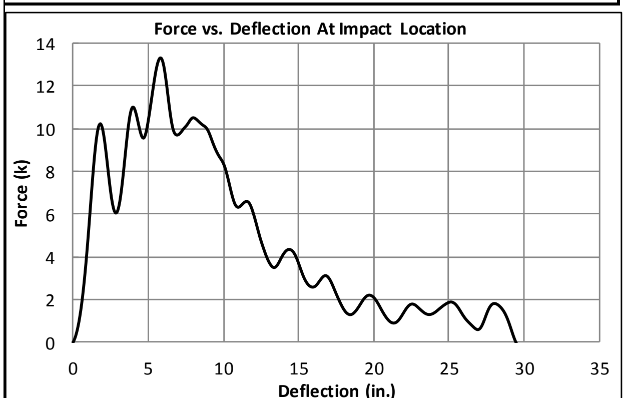
Bogie Properties
Impact Velocity: 20.83 mph (30.5 fps) 9.31 m/s
Impact Height: 15 in. 38.1 cm
Bogie Mass: 1843 lbs 836 kg

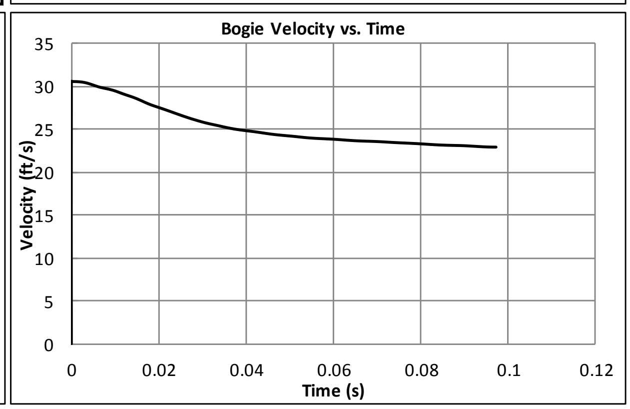
Data Acquired
Acceleration Data: EDR-3
Camera Data: AOS-5 Perpendicular - 22'

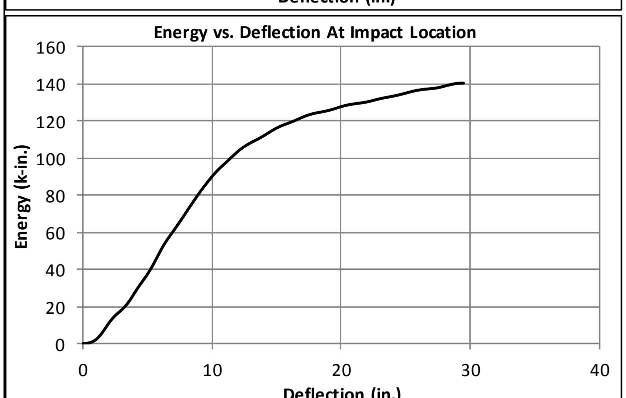
Test Results Summary

Max. Deflection:	29.5	in.
Peak Force:	13.3	k
Initial Linear Stiffness:	2.3	k/in.
Total Energy:	140.3	k-in.









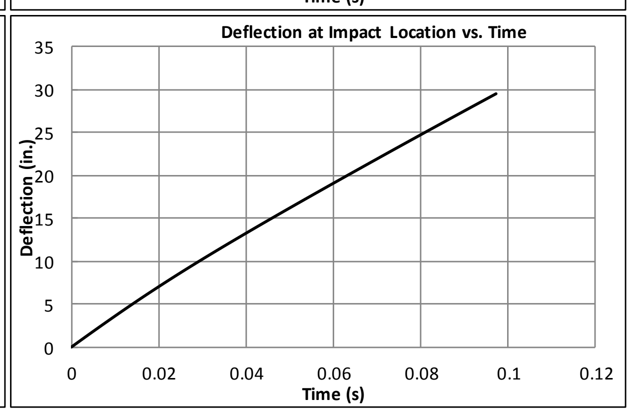


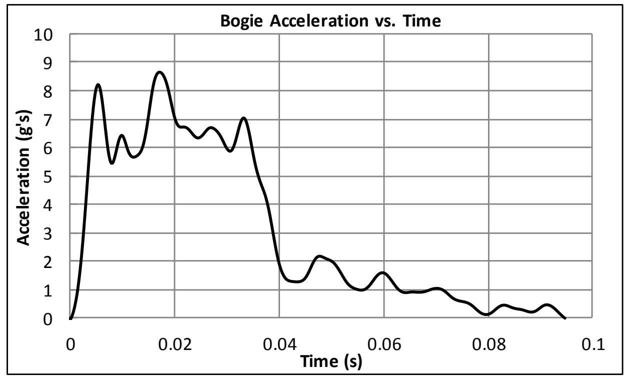
Figure B-2. Test No. HTCB-5 Results (EDR-3)

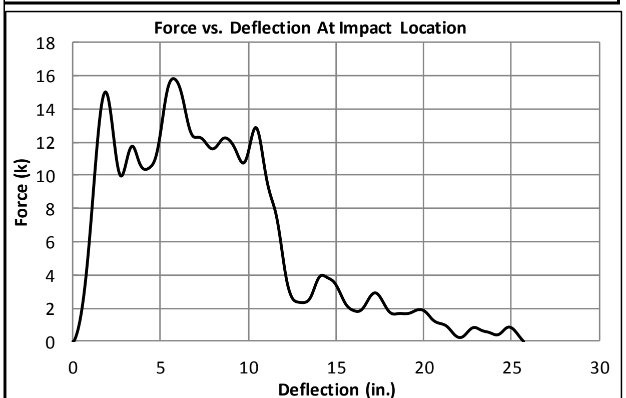
MIDWEST ROADSIDE SAFETY FACILITY

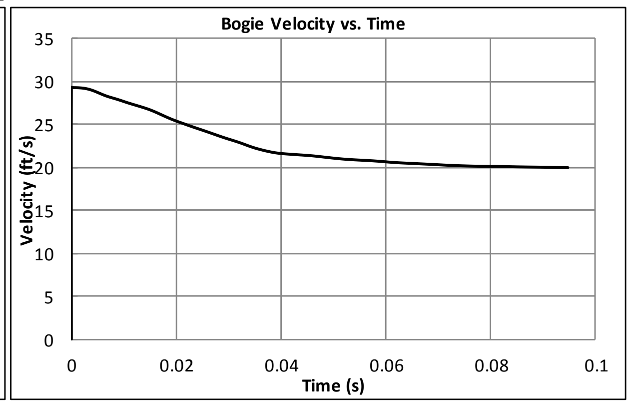
Bogie Test Summary

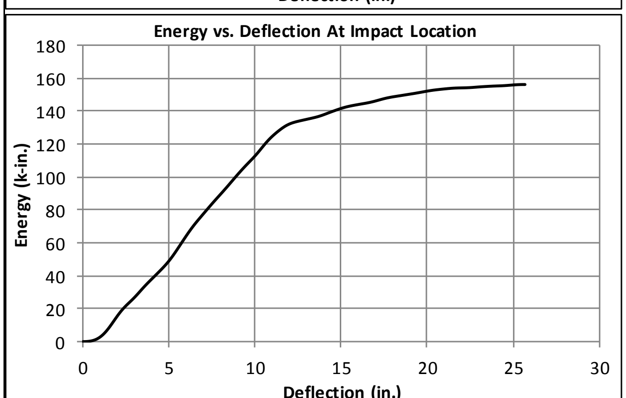
Test Information	Bogie - Post	
Test Number:	HTCB-6	
Test Date:	4-Jan-2012	
Failure Type:	Foundation Fracture	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	49 in.	124.5 cm
Embedment Depth:	16 in.	40.6 cm
Orientation:	strong axis	
Foundation		
Design:	D	
Length:	60 in.	152.4 cm
Embedment:	60 in.	152.4 cm
Diameter:	12 in.	30.5 cm
Bogie Properties		
Impact Velocity:	19.95 mph (29.3 fps)	8.92 m/s
Impact Height:	11 in.	27.9 cm
Bogie Mass:	1828 lbs	829.2 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 22'	

Test Results Summary		
Max. Deflection:	25.7	in.
Peak Force:	15.8	k
Initial Linear Stiffness:	8.1	k/in.
Total Energy:	156.2	k-in.









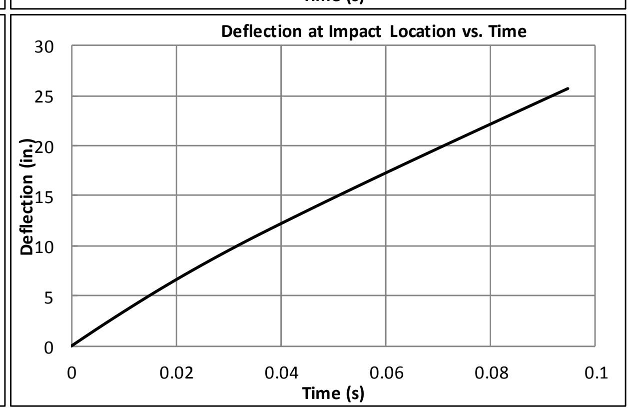


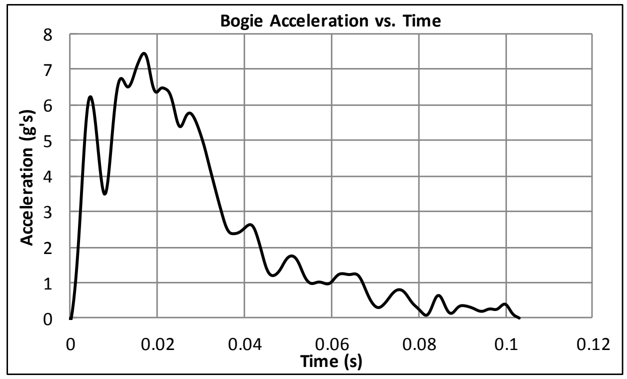
Figure B-3. Test No. HTCB-6 Results (EDR-3)

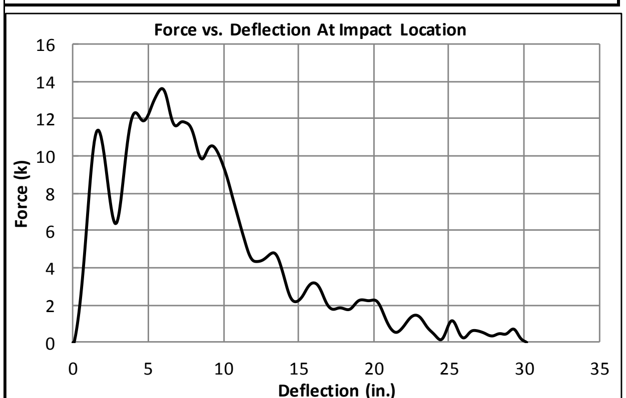
MIDWEST ROADSIDE SAFETY FACILITY

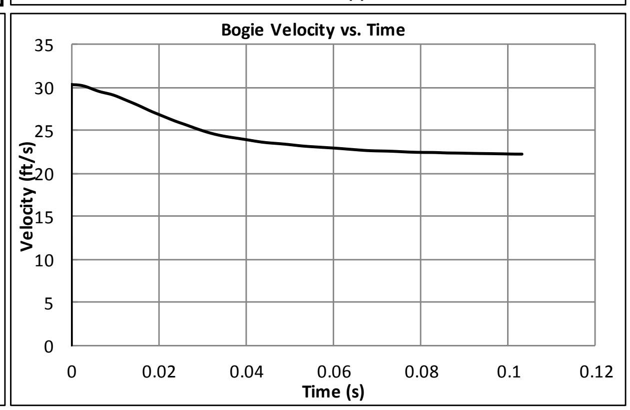
Bogie Test Summary

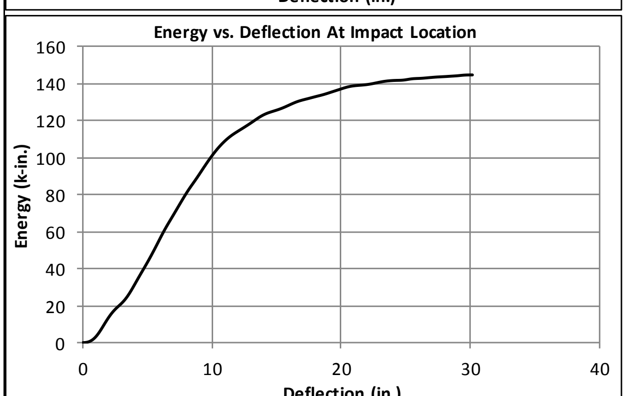
Test Information	Bogie - Post	
Test Number:	HTCB-7	
Test Date:	5-Jan-2012	
Failure Type:	Post Bending & Foundation Fracture	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	49 in.	124.5 cm
Embedment Depth:	16 in.	40.6 cm
Orientation:	strong axis	
Foundation		
Design:	E	
Length:	60 in.	152.4 cm
Embedment:	60 in.	152.4 cm
Diameter:	12 in.	30.5 cm
Bogie Properties		
Impact Velocity:	20.67 mph (30.3 fps)	9.24 m/s
Impact Height:	11 in.	27.9 cm
Bogie Mass:	1828 lbs	829.2 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 20'	

Test Results Summary		
Max. Deflection:	30.2	in.
Peak Force:	13.6	k
Initial Linear Stiffness:	3.0	k/in.
Total Energy:	144.6	k-in.









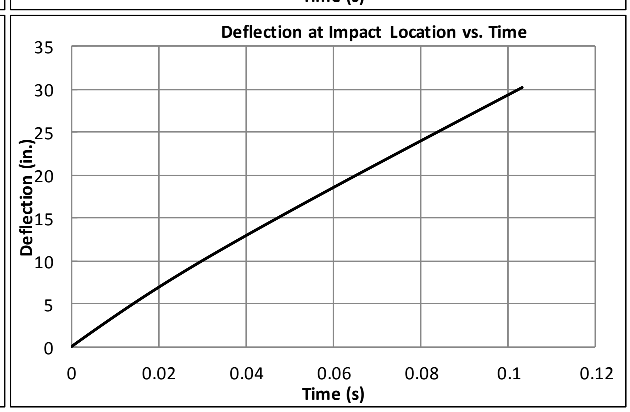


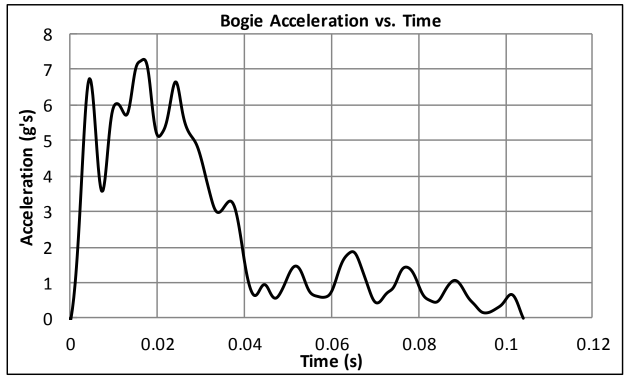
Figure B-4. Test No. HTCB-7 Results (EDR-3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Bogie - Post	
Test Number:	HTCB-8	
Test Date:	5-Jan-2012	
Failure Type:	Post Bending & Foundation Cracking	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	49 in.	124.5 cm
Embedment Depth:	16 in.	40.6 cm
Orientation:	strong axis	
Foundation		
Design:	F	
Length:	60 in.	152.4 cm
Embedment:	60 in.	152.4 cm
Diameter:	12 in.	30.5 cm
Bogie Properties		
Impact Velocity:	20.85 mph (30.6 fps)	9.32 m/s
Impact Height:	11 in.	27.9 cm
Bogie Mass:	1828 lbs	829.2 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 20'	

Test Results Summary		
Max. Deflection:	31.1	in.
Peak Force:	13.3	k
Initial Linear Stiffness:	2.2	k/in.
Total Energy:	143.9	k-in.



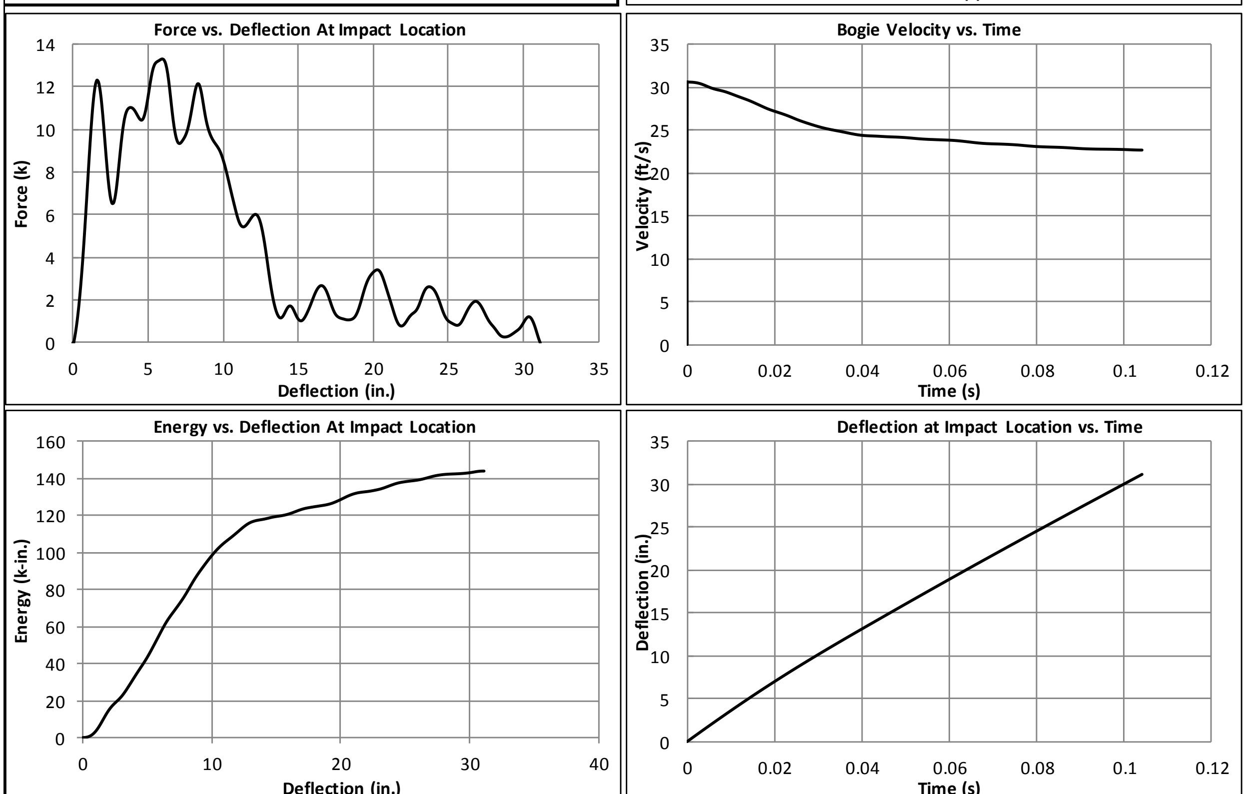


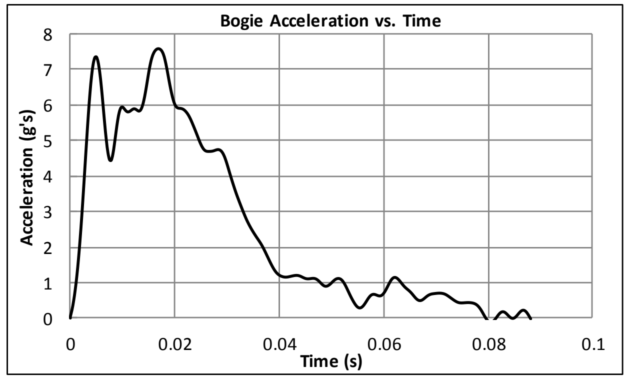
Figure B-5. Test No. HTCB-8 Results (EDR-3)

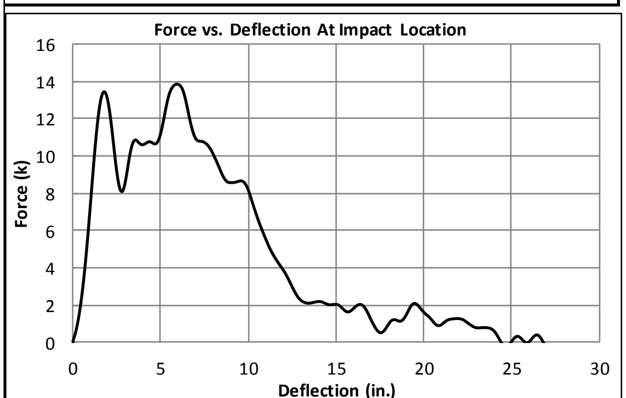
MIDWEST ROADSIDE SAFETY FACILITY

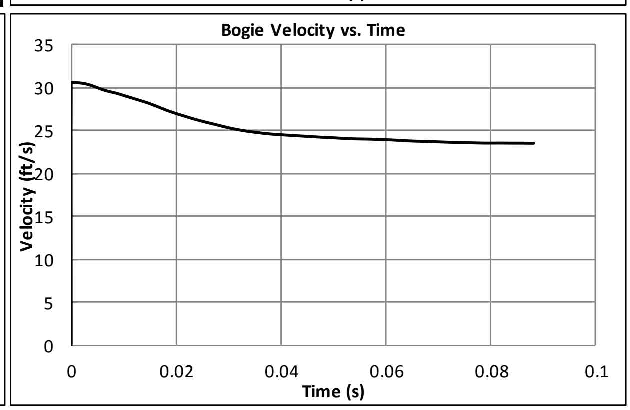
Bogie Test Summary

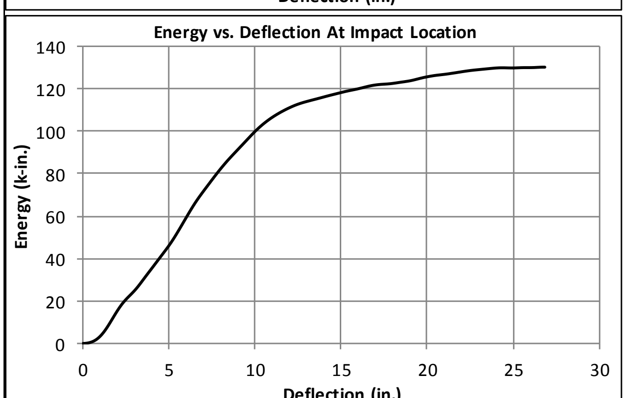
Test Information	Bogie - Post	
Test Number:	HTCB-9	
Test Date:	6-Jan-2012	
Failure Type:	Post Bending - Foundation Cracking	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	49 in.	124.5 cm
Embedment Depth:	16 in.	40.6 cm
Orientation:	strong axis	
Foundation		
Design:	F	
Length:	60 in.	152.4 cm
Embedment:	60 in.	152.4 cm
Diameter:	12 in.	30.5 cm
Bogie Properties		
Impact Velocity:	20.85 mph (30.6 fps)	9.32 m/s
Impact Height:	11 in.	27.9 cm
Bogie Mass:	1828 lbs	829.2 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 20'	

Test Results Summary		
Max. Deflection:	26.8	in.
Peak Force:	13.9	k
Initial Linear Stiffness:	7.4	k/in.
Total Energy:	130.2	k-in.









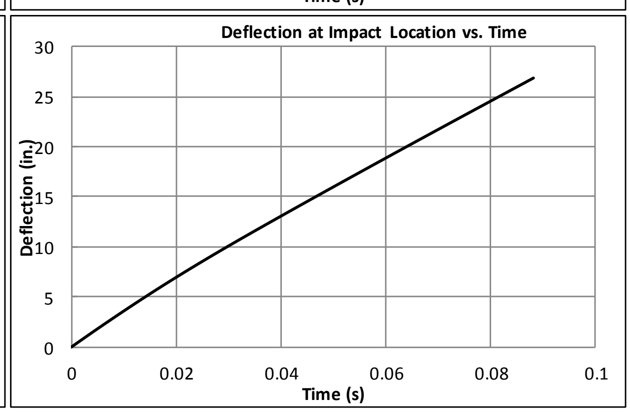


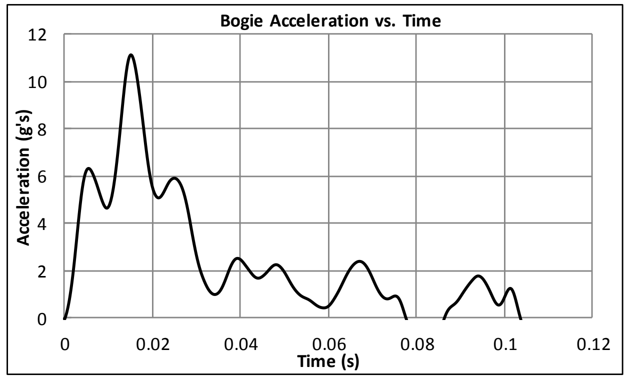
Figure B-6. Test No. HTCB-9 Results (EDR-3)

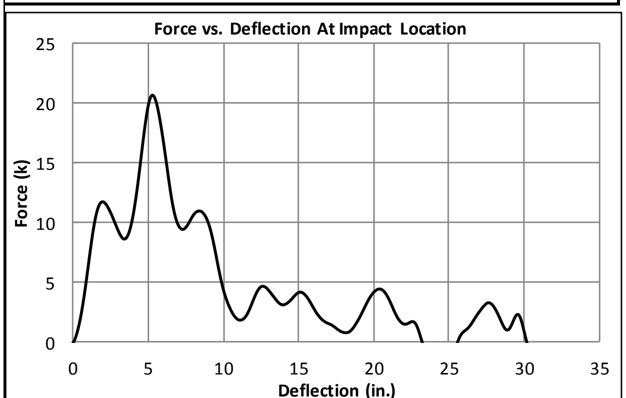
MIDWEST ROADSIDE SAFETY FACILITY

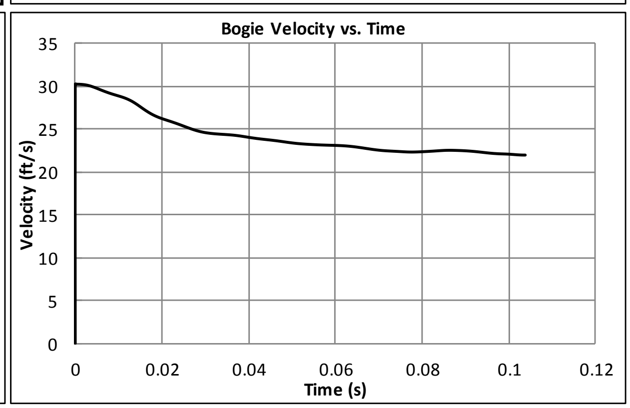
Bogie Test Summary

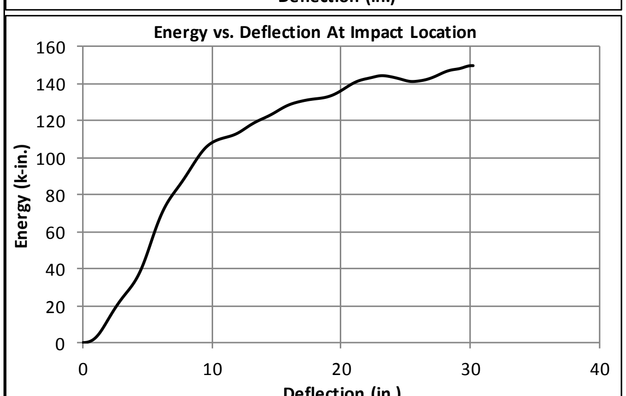
Test Information	Bogie vs post in socket	
Test Number:	HTCB-10	
Test Date:	13-Jun-2012	
Failure Type:	Post Failure - Foundation Cracking	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	49 in.	124.5 cm
Embedment Depth:	16 in.	40.6 cm
Orientation:	Strong	
Foundation Properties		
Design:	J	
Diameter:	12 in.	30.5 cm
Embedment Depth:	30 in.	76.2 cm
Soil:	1/19/2012 H.E. - 8	
Bogie Properties		
Impact Velocity:	20.6 mph (30.2 fps)	9.21 m/s
Impact Height:	11 in.	27.9 cm
Bogie Mass:	1860 lbs	843.7 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 163"	

Test Results Summary		
Max. Deflection:	30.2	in.
Peak Force:	20.7	k
Initial Linear Stiffness:	3.9	k/in.
Total Energy:	149.6	k-in.









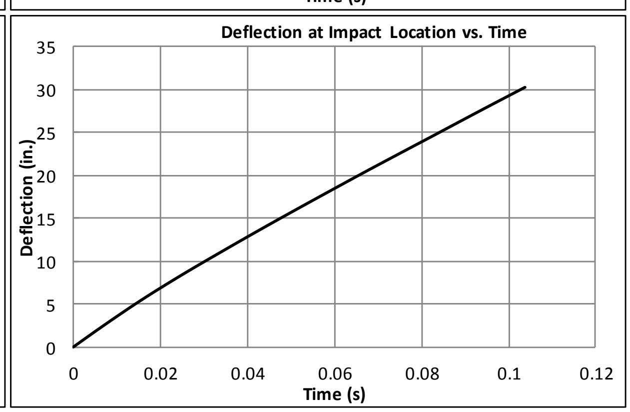


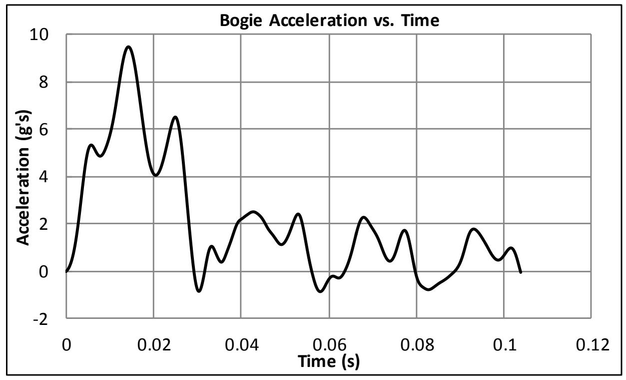
Figure B-7. Test No. HTCB-10 Results (EDR-3)

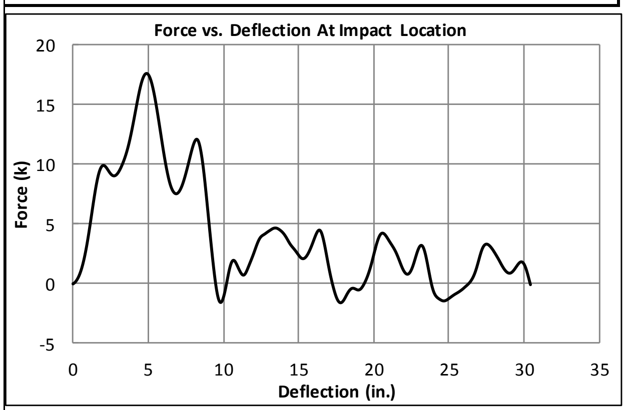
MIDWEST ROADSIDE SAFETY FACILITY

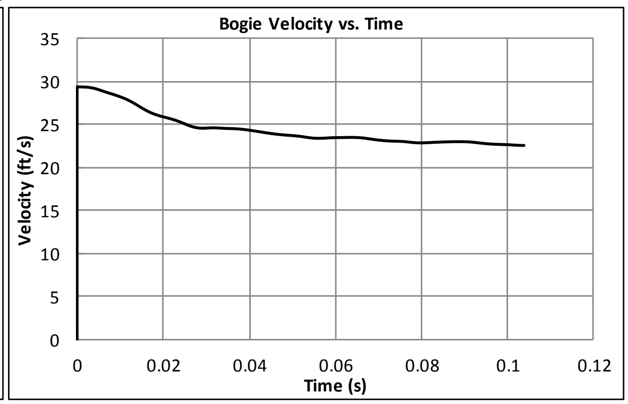
Bogie Test Summary

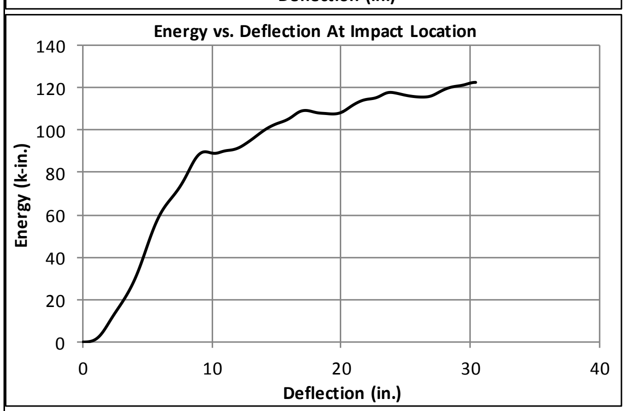
Test Information	Bogie vs post in socket	
Test Number:	HTCB-11	
Test Date:	13-Jun-2012	
Failure Type:	Post Failure	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	49 in.	124.5 cm
Embedment Depth:	16 in.	40.6 cm
Orientation:	Strong	
Foundation Properties		
Design:	K	
Diameter:	12 in.	30.5 cm
Embedment Depth:	36 in.	91.4 cm
Soil:	1/19/2012 H.E. - 8	
Bogie Properties		
Impact Velocity:	20.02 mph (29.4 fps)	8.95 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1860 lbs	843.7 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-5 Perpendicular - 164"	

Test Results Summary		
Max. Deflection:	30.4	in.
Peak Force:	17.6	k
Initial Linear Stiffness:	3.6	k/in.
Total Energy:	122.6	k-in.









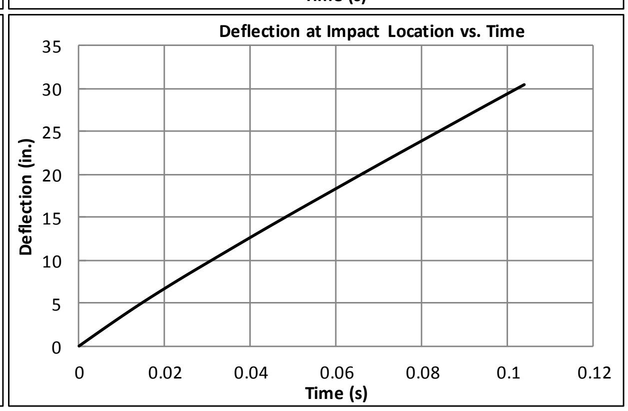


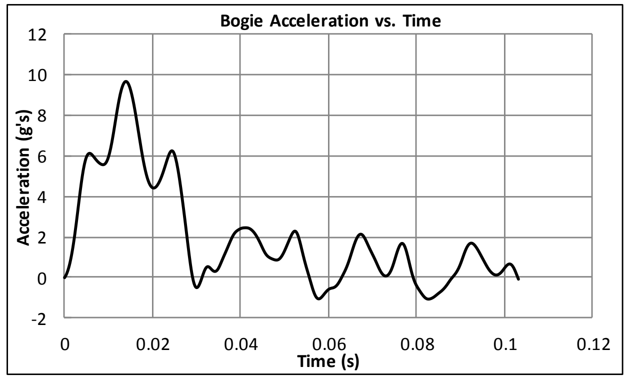
Figure B-8. Test No. HTCB-11 Results (DTS SLICE)

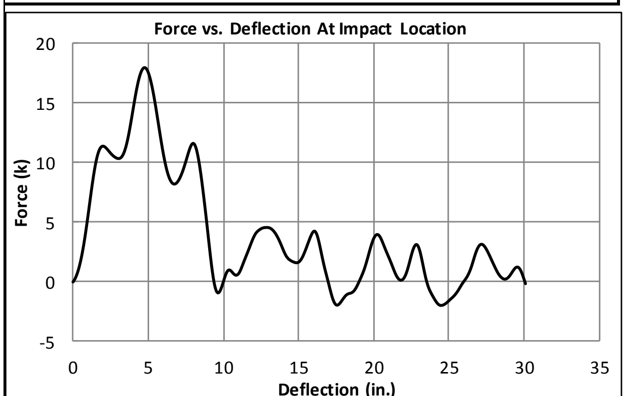
MIDWEST ROADSIDE SAFETY FACILITY

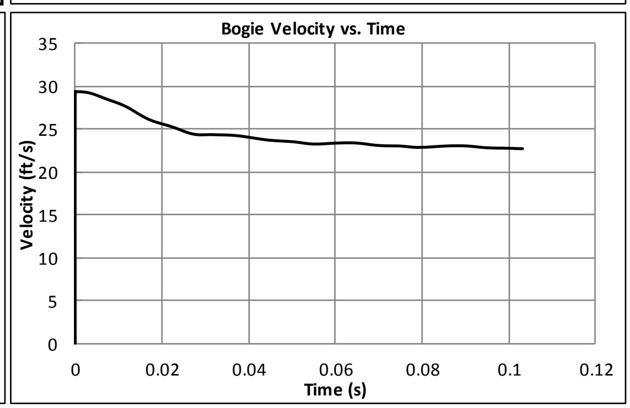
Bogie Test Summary

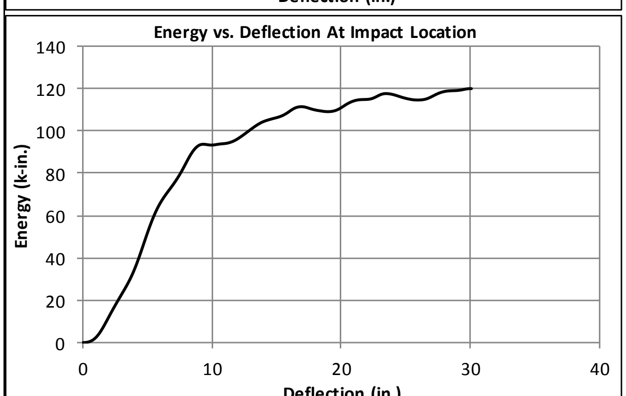
Test Information	Bogie vs post in socket	
Test Number:	HTCB-11	
Test Date:	13-Jun-2012	
Failure Type:	Post Failure	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	49 in.	124.5 cm
Embedment Depth:	16 in.	40.6 cm
Orientation:	Strong	
Foundation Properties		
Design:	K	
Diameter:	12 in.	30.5 cm
Embedment Depth:	36 in.	91.4 cm
Soil:	1/19/2012 H.E. - 8	
Bogie Properties		
Impact Velocity:	20.02 mph (29.4 fps)	8.95 m/s
Impact Height:	11 in.	27.9 cm
Bogie Mass:	1860 lbs	843.7 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 164"	

Test Results Summary		
Max. Deflection:	30.1	in.
Peak Force:	17.9	k
Initial Linear Stiffness:	3.7	k/in.
Total Energy:	120.0	k-in.









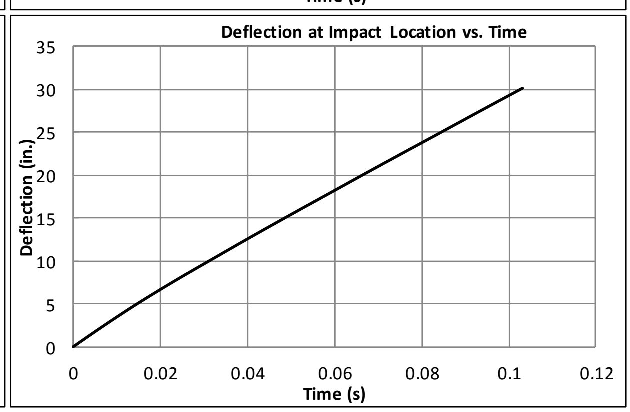


Figure B-9. Test No. HTCB-11 Results (EDR-3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Post in socketed concrete foundation
Test Number:	HTCB-17
Test Date:	2/26/2014
Failure Type:	Post bending

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	49"
Embedment Depth:	16"
Orientation:	90 degrees - Strong Axis

Foundation Properties

Design:	M
Diameter:	15"
Embedment	30"
Soil:	9/6/2013 H.E. 8

Bogie Properties

Impact Velocity:	20.75 mph	(30.43 ft/s)
Impact Height:	11"	
Bogie Mass:	1925 lb	

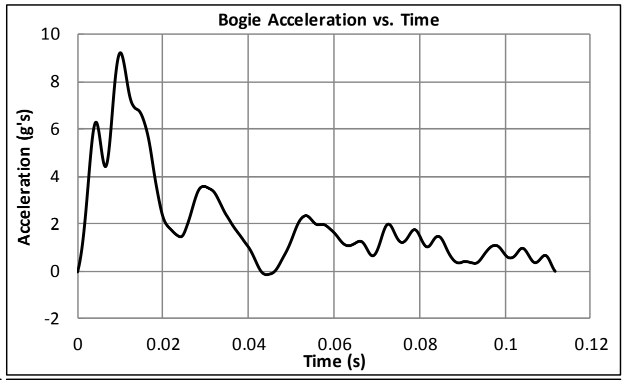
Data Acquired

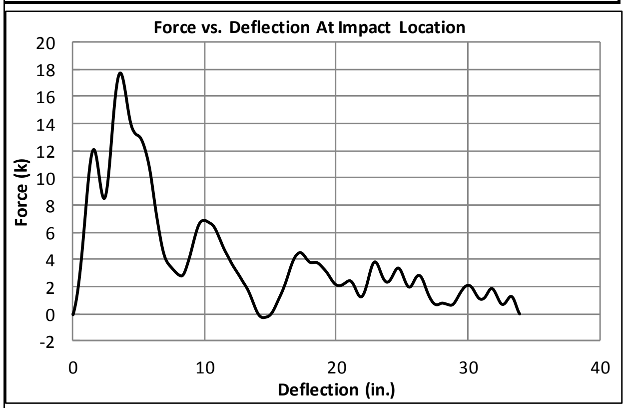
Accelerometer:	SLICE-1
Camera Data:	AOS-8 @ 249"

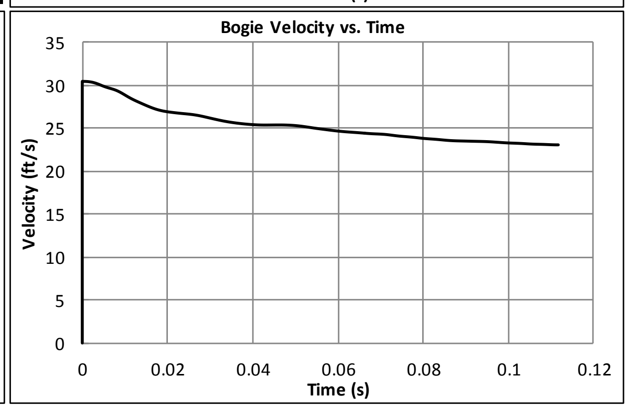
Test Results Summary

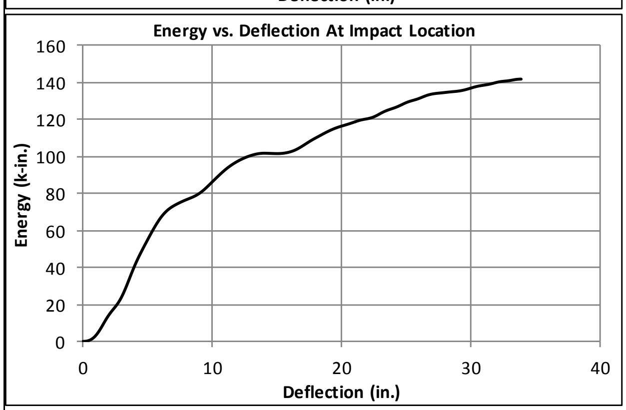
Event Duration:	0.1117	sec
Max. Deflection:	33.9	in.
Peak Force:	17.7	k
Initial Linear Stiffness:	5.0	k/in.
Total Energy:	141.6	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	10.89	8.58	6.76	5.81
Energy (k-in.)	54.4	85.8	101.4	116.2









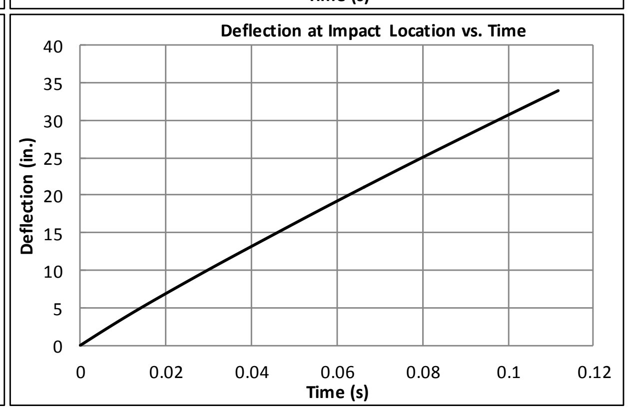


Figure B-10. Test No. HTCB-17 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Post in socketed concrete foundation
Test Number:	HTCB-17
Test Date:	2/26/2014
Failure Type:	Post bending

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	49"
Embedment Depth:	16"
Orientation:	90 degrees - Strong Axis

Foundation Properties

Design:	M
Diameter:	15"
Embedment	30"
Soil:	9/6/2013 H.E. 8

Bogie Properties

Impact Velocity:	20.75 mph	(30.43 ft/s)
Impact Height:	11"	
Bogie Mass:	1925 lb	

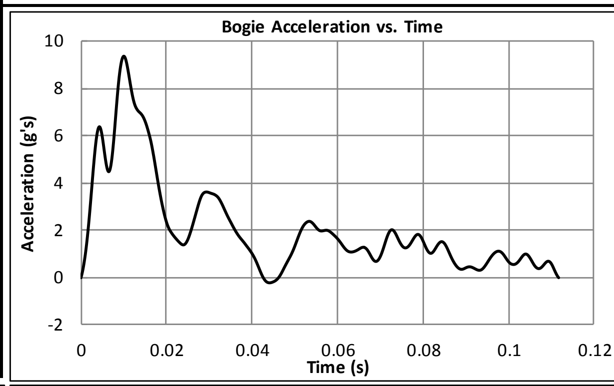
Data Acquired

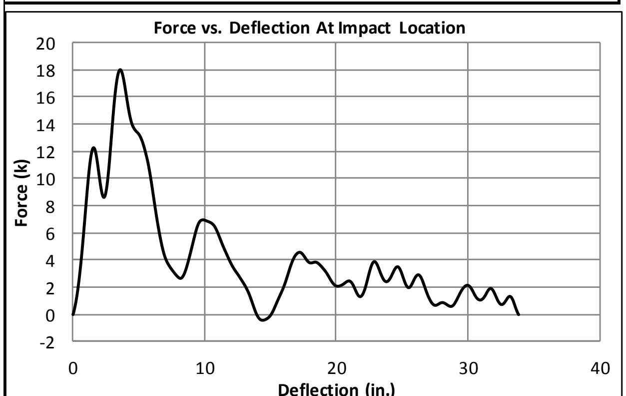
Accelerometer:	SLICE-2
Camera Data:	AOS-8 @ 249"

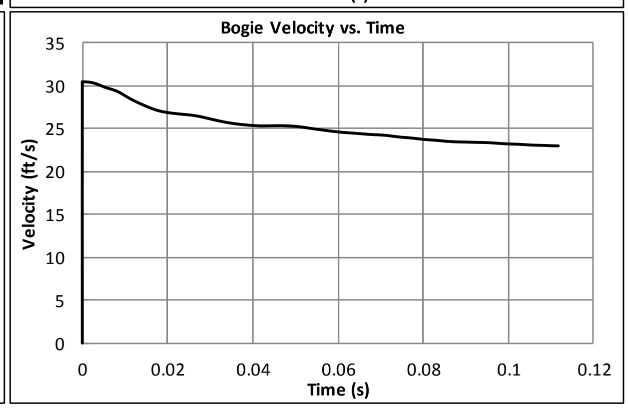
Test Results Summary

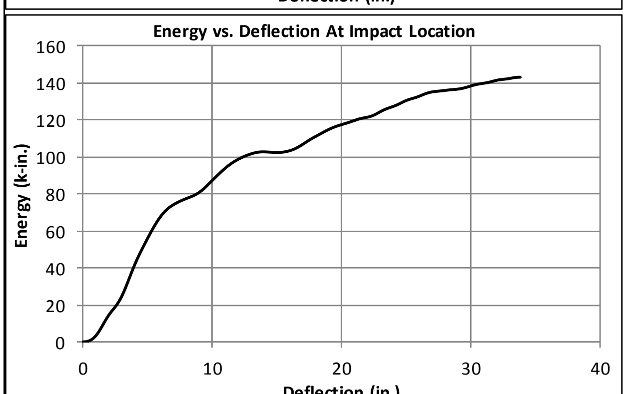
Event Duration:	0.1117	sec
Max. Deflection:	33.9	in.
Peak Force:	18.0	k
Initial Linear Stiffness:	5.0	k/in.
Total Energy:	142.9	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	11.09	8.70	6.82	5.86
Energy (k-in.)	55.4	87.0	102.3	117.2









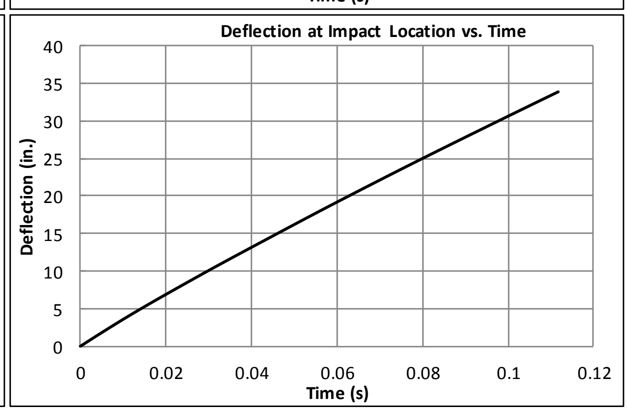


Figure B-11. Test No. HTCB-17 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Post in socketed concrete foundation
Test Number:	HTCB-18
Test Date:	2/26/2014
Failure Type:	Post bending / foundation rotation through soil

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	49"
Embedment Depth:	16"
Orientation:	90 degrees - Strong Axis

Foundation Properties

Design:	L
Diameter:	15"
Embedment	24"
Soil:	9/6/2013 H.E. 8

Bogie Properties

Impact Velocity:	20.29 mph	(29.76 ft/s)
Impact Height:	11"	
Bogie Mass:	1925 lb	

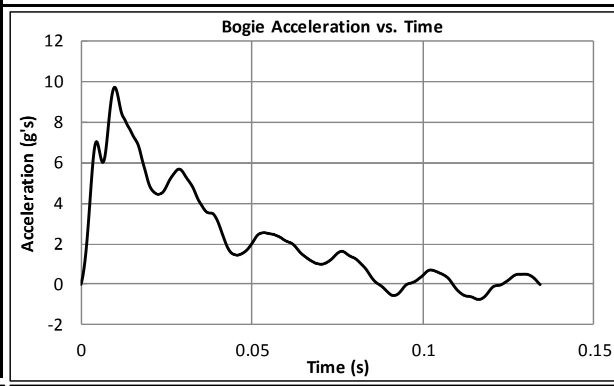
Data Acquired

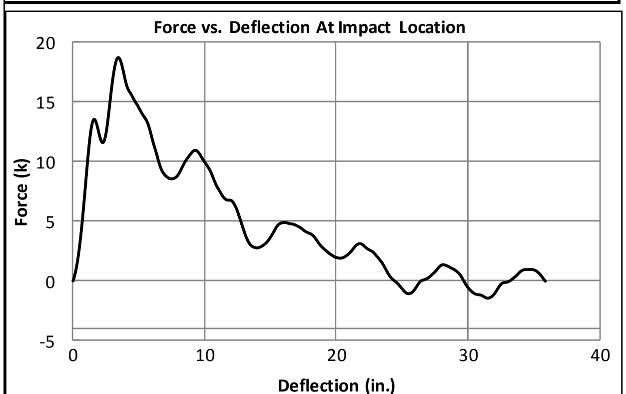
Accelerometer:	SLICE-1
Camera Data:	AOS-8 @ 149.5"

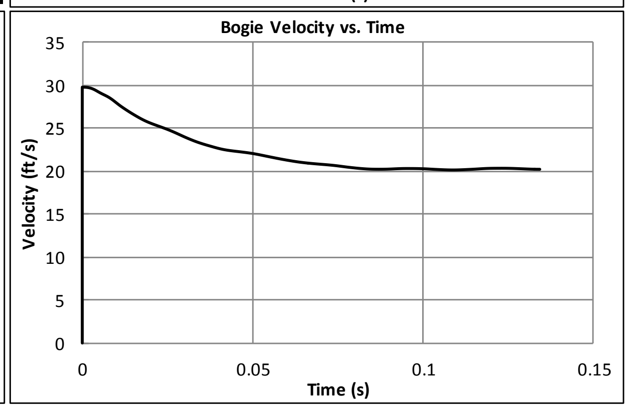
Test Results Summary

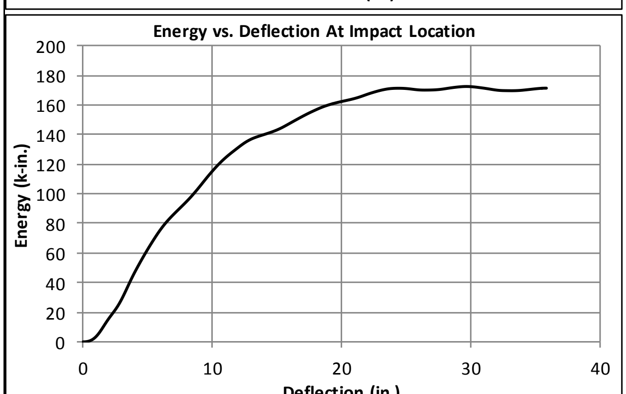
Event Duration:	0.1342	sec
Max. Deflection:	35.9	in.
Peak Force:	18.7	k
Initial Linear Stiffness:	5.5	k/in.
Total Energy:	172.4	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	12.45	11.49	9.53	8.11
Energy (k-in.)	62.2	114.9	143.0	162.2









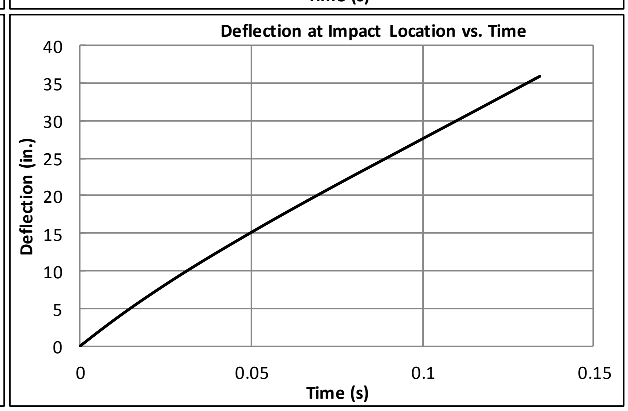


Figure B-12. Test No. HTCB-18 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Post in socketed concrete foundation
Test Number:	HTCB-18
Test Date:	2/26/2014
Failure Type:	Post bending / foundation rotation through soil

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	49"
Embedment Depth:	16"
Orientation:	90 degrees - Strong Axis

Foundation Properties

Design:	L
Diameter:	15"
Embedment	24"
Soil:	9/6/2013 H.E. 8

Bogie Properties

Impact Velocity:	20.29 mph	(29.76 ft/s)
Impact Height:	11"	
Bogie Mass:	1925 lb	

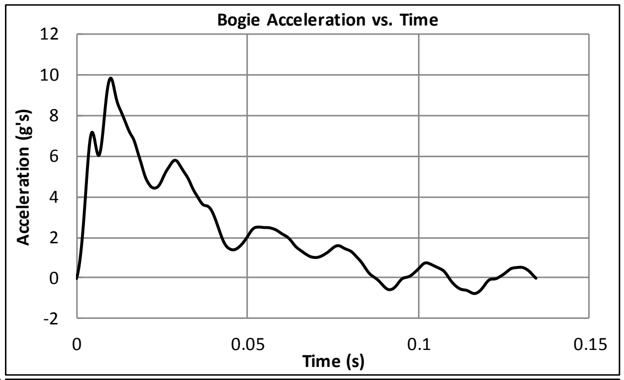
Data Acquired

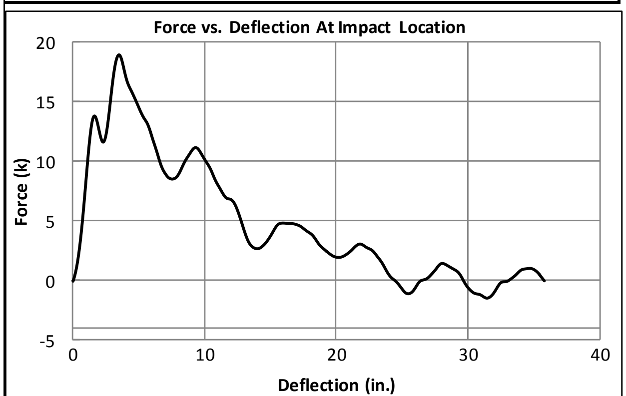
Accelerometer:	SLICE-2
Camera Data:	AOS-8 @ 149.5"

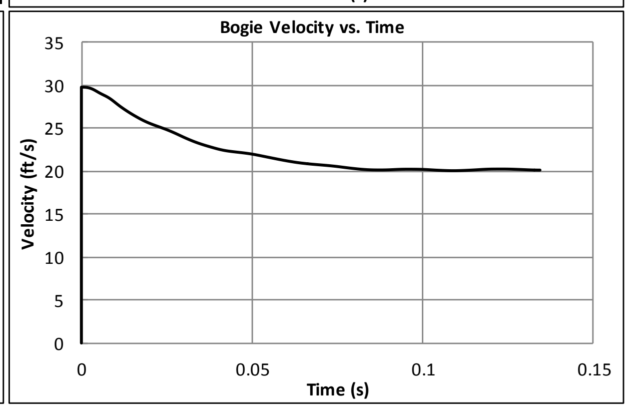
Test Results Summary

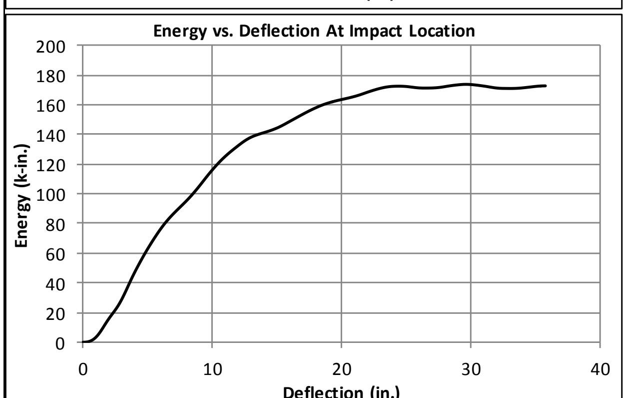
Event Duration:	0.1343	sec
Max. Deflection:	35.8	in.
Peak Force:	18.9	k
Initial Linear Stiffness:	5.4	k/in.
Total Energy:	173.7	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	12.53	11.56	9.61	8.17
Energy (k-in.)	62.7	115.6	144.1	163.4









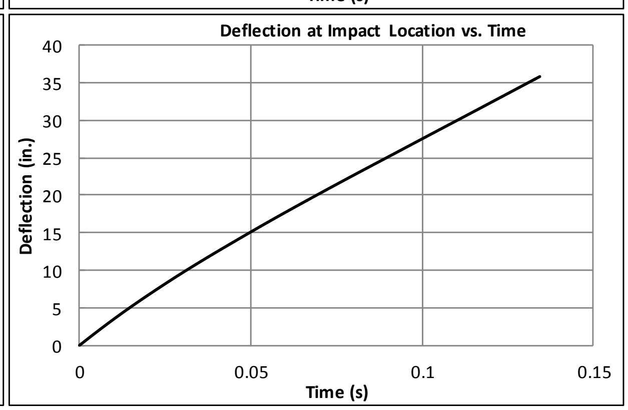


Figure B-13. Test No. HTCB-18 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Post in socketed concrete foundation
Test Number:	HTCB-19
Test Date:	5/20/2014
Failure Type:	Post bending

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	49"
Embedment Depth:	16"
Orientation:	90 degrees - Strong Axis

Foundation Properties

Design:	O
Diameter:	12"
Embedment	30"
Soil:	AASHTO Gr. B under 4" Asphalt Pad

Bogie Properties

Impact Velocity:	21.95 mph	(32.19 ft/s)
Impact Height:	11"	
Bogie Mass:	1838 lb	

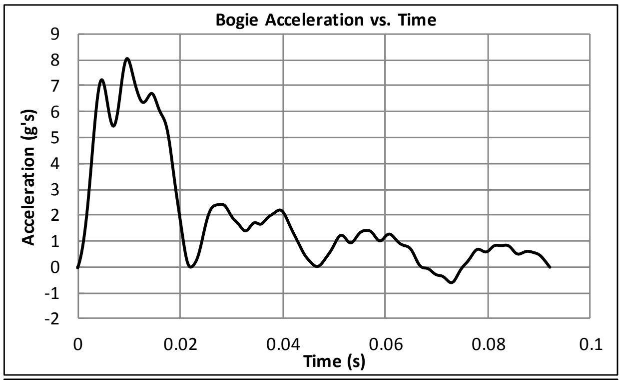
Data Acquired

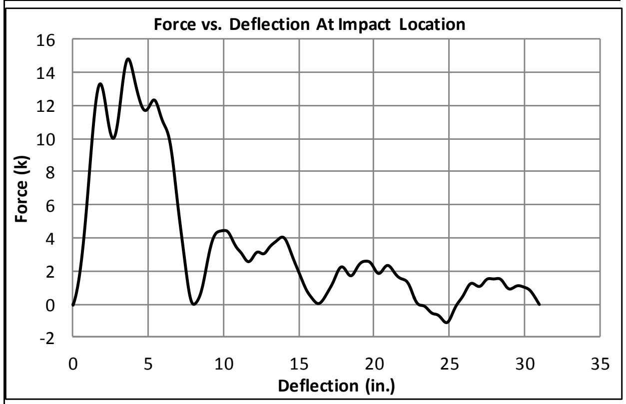
Accelerometer:	SLICE-1
Camera Data:	AOS-8 @ 271"

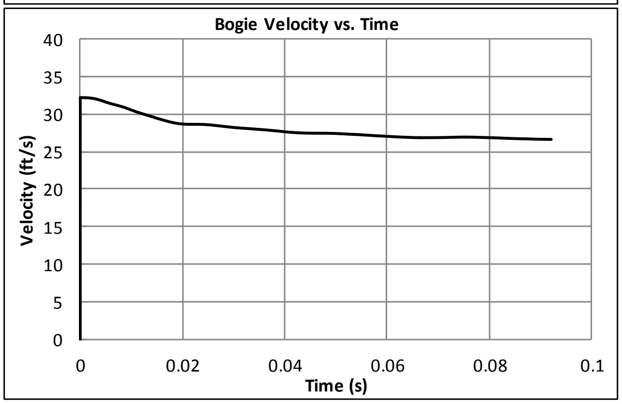
Test Results Summary

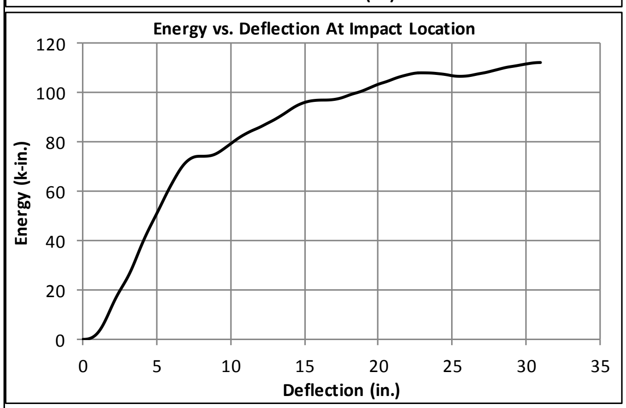
Event Duration:	0.0921	sec
Max. Deflection:	31.0	in.
Peak Force:	14.8	k
Initial Linear Stiffness:	7.4	k/in.
Total Energy:	112.1	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	10.15	7.92	6.39	5.16
Energy (k-in.)	50.7	79.2	95.9	103.3









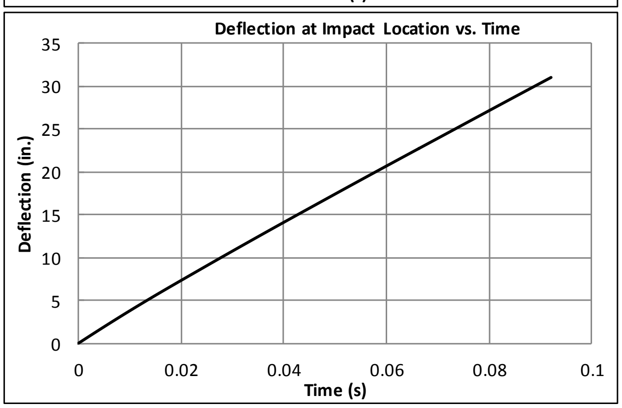


Figure B-14. Test No. HTCB-19 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Post in socketed concrete foundation
Test Number:	HTCB-19
Test Date:	5/20/2014
Failure Type:	Post bending

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	49"
Embedment Depth:	16"
Orientation:	90 degrees - Strong Axis

Foundation Properties

Design:	O
Diameter:	12"
Embedment	30"
Soil:	AASHTO Gr. B under 4" Asphalt Pad

Bogie Properties

Impact Velocity:	21.95 mph	(32.19 ft/s)
Impact Height:	11"	
Bogie Mass:	1838 lb	

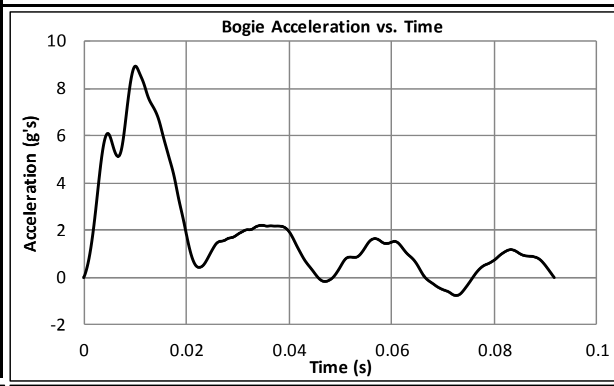
Data Acquired

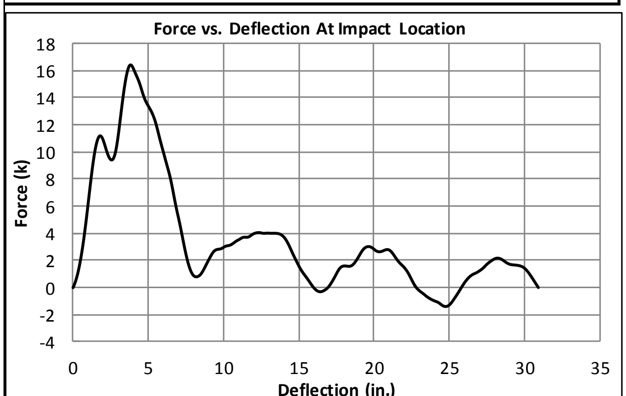
Accelerometer:	SLICE-2
Camera Data:	AOS-8 @ 271"

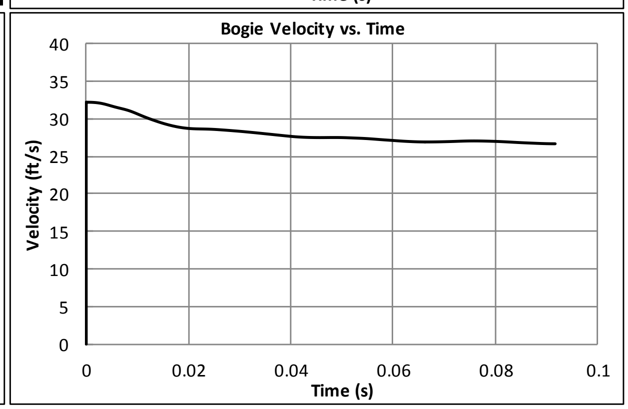
Test Results Summary

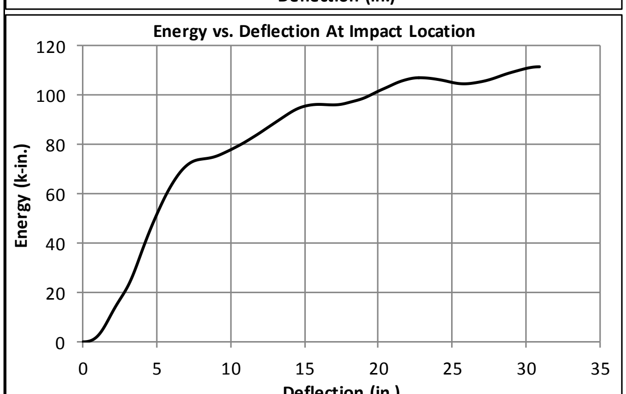
Event Duration:	0.0917	sec
Max. Deflection:	30.9	in.
Peak Force:	16.4	k
Initial Linear Stiffness:	6.4	k/in.
Total Energy:	111.4	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	10.29	7.77	6.36	5.07
Energy (k-in.)	51.5	77.7	95.4	101.5









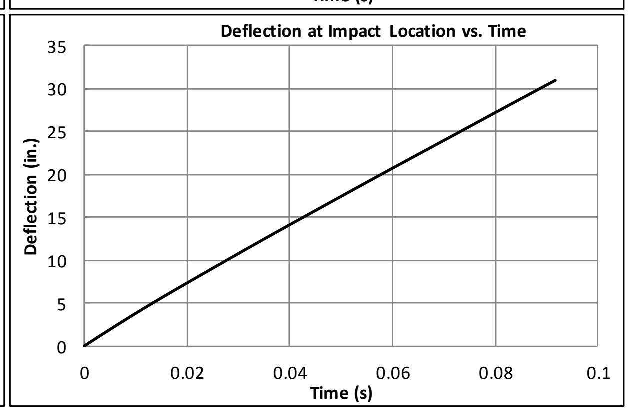


Figure B-15. Test No. HTCB-19 Results (SLICE-2)

END OF DOCUMENT