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DEVELOPMENT OF A SOCKETED FOUNDATION FOR THE MIDWEST WEAK POST (MWP) V1

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16. Abstract (Limit: 200 words) A socketed foundation was designed and evaluated for use with the Midwest Weak Post (MWP), Version 1. Dynamic component testing was conducted on five different design configurations with varying embedment depths, steel reinforcement, and soil conditions. The low strength of the MWPs limited the force transferred into the foundations and prevented damage in the form of concrete cracking or fracture. Additionally, the lateral movements of the socketed foundations were all within the 1-in. (25-mm) limit established to ensure reuse of the foundations without resetting. The selected design consisted of a 12-in. (305-mm) diameter concrete shaft reinforced with four vertical bars and transverse hoop steel spaced at 6½ in. (165 mm) on center. A 4-in. x 3-in. x ¼-in. (102-mm x 76-mm x 6-mm) steel tube socket was placed in the middle of the shaft. Finally, guidelines were given for the length, or embedment depth, of the foundation based on surrounding soil conditions and risk of frost heave.			
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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

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1 INTRODUCTION

1.1 Background

Thousands of miles of cable guardrail have been installed on highways across the United States. Often, these installations incorporate socketed post foundations as opposed to simply driving barrier posts into the surrounding soil. Socketed foundation designs allow the posts to slide in and out of a ground socket for easy replacement in the event of system damage during a crash. Thus, the time and cost of system repairs can be minimized. However, multiple State DOTs have reported that real-world crashes into cable barrier installations have resulted in damage to their 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 component. Either situation defeats the purpose of using sockets, greatly increases the time necessary to restore a damaged barrier, and results in higher maintenance costs and increased risk to repair crews working adjacent to high-speed facilities.

The majority of existing socketed post foundation designs are constructed by coring a hole in the soil, placing a steel sleeve in the hole, and backfilling the hole with Portland cement concrete. Many of these designs do not have sufficient 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 foundation designs that perform as intended in the field.

Phase I of this project aimed to develop a socketed foundation design that would be compatible with a wide variety of cable barrier systems [1]. Years ago, the S4x7.7 (S102x11.5) was the strongest post used in cable barrier systems, and the 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.

Phase II has focused on designing socketed foundations for S3x5.7 (S76x8.5) steel posts utilized within most non-proprietary, cable median barrier systems [2]. Similar to Phase I, dynamic impact testing was utilized to evaluate the strength of various foundation configurations. Additionally, the foundations were evaluated in both weak, sandy soils and strong, stiff soils. Design recommendations were developed based on soil strength, allowable foundation damage levels, and risk of frost heave. This study remains in progress at this time.

For several years, the Midwest Roadside Safety Facility (MwRSF) has been developing a non-proprietary, high-tension, cable barrier system according to the *Manual for Assessing Safety Hardware* (MASH) [3]. As part of the study, the Midwest Weak Post (MWP) Version No. 1 V1, as shown in Figure 1, was developed [4]. The MWP V1 was fabricated from 7-gauge (4.6-mm thick) sheet steel and designed to be significantly weaker under strong axis bending than the previous S3x5.7 (S76x8.5) post. The future Phase II socketed-foundation design guidelines could be used in conjunction with the MWP. However, the resulting foundation would be conservatively designed in terms of cross-section size, embedment depth, and reinforcement. Thus, a need exists to develop an optimized socketed foundation for the MWP V1.

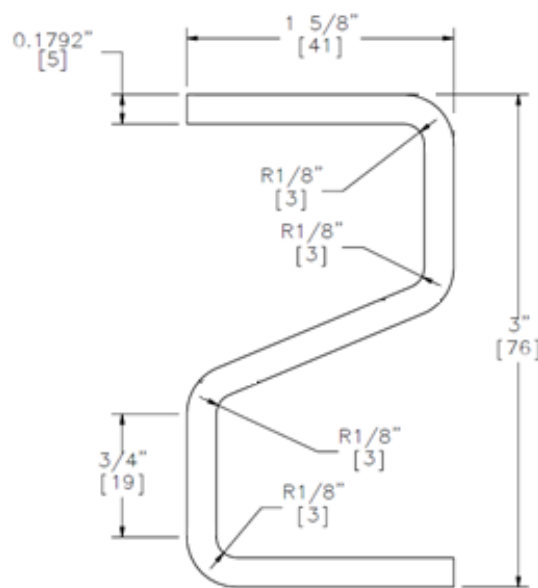


Figure 1. MWP Version No. 1 Cross-Section

1.2 Objective

The objective of this research project was to develop an optimized socketed foundation for use with the new MWP V1. The foundation was to sustain minimal damage and displacement during impacts, thus keeping repair costs to a minimum. Foundation designs were to remain focused on placing a steel socket within a cylindrical, reinforced concrete shaft.

1.3 Research Approach

Design configurations for the MWP socketed foundation would be derived from the previously recommended designs for S3x5.7 (S76x8.5) posts. The MWP V1 has only about half the strong axis bending strength of an S3x5.7 (S76x8.5). Thus, design variations were developed with reduced embedment depths and reduced internal steel reinforcement. The new configurations were evaluated with the same type of dynamic bogie tests conducted during the previous phases of the project. Tests were also conducted in both strong and weak soils to gain an understanding of the embedment requirements for various soil types. Finally, conclusions and recommendations were formulated and documented herein.

2 DESIGN DETAILS

Five different socketed foundations were designed and fabricated for evaluation through dynamic component testing. The same cross-section size and reinforcement pattern was utilized for all five configurations, but the embedment depth and the spacing between steel hoop stirrups varied, as shown in Figures 2 through 11. Fabrication and installation photographs are shown in Figure 12. 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. The foundation lengths, or embedment depths, varied between 24 in., 30 in., and 36 in. (610 mm, 762 mm, and 914 mm). The concrete was specified to have a minimum 28-day compressive strength of 3,500 psi (24 MPa).

The socketed foundations were reinforced with both circumferential and vertical Grade 60 steel rebar. The circumferential rebar was No. 4 (12.7 mm) bars bent into a loop with an inner diameter of 8 in. (203 mm). The spacing of the circumferential steel varied between 2½ in. (64 mm) and 6½ in. (165 mm), as shown in Figures 3 through 5. Finally, four No. 4 (12.7 mm) vertical bars were spaced equally around the inside of the circumferential steel.

A 16-in. (406-mm) long, 4-in. x 3-in. x ¼-in. (102-mm x 76-mm x 6-mm) steel tube was located at the top-center of each foundation. A 4-in. x 3-in. x ¼-in. (102-mm x 76-mm x 6-mm) steel plate was tack-welded to the bottom of the steel tube to enclose the socket void during concrete casting. The socket sleeve assembly was then cast into the top of the concrete foundation with the open end of the tube flush with the top surface of the post base.

As stated previously, these socketed foundations were designed specifically for use with the new MWP V1. For testing purposes, a 49-in. (1,245-mm) long MWP was placed into each socketed foundation. All posts were fabricated using hot-rolled ASTM A1011 HSLA Gr. 50

steel, a typical sheet steel material. Details concerning the development of the MWP V1 can be found in reference [4], while detailed dimensions for the MWP V1 are shown in Figure 7.

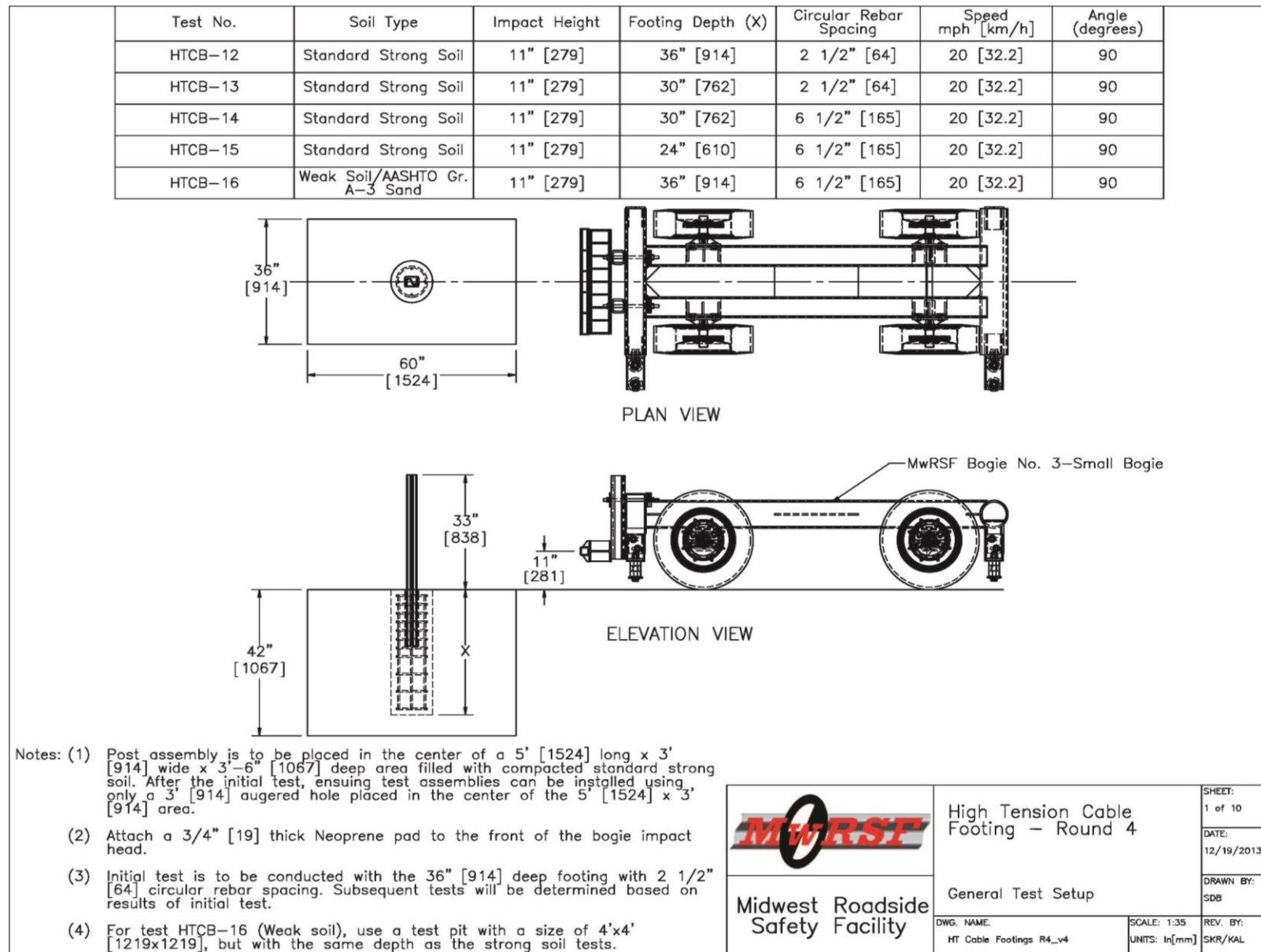


Figure 2. Bogie Testing Matrix and Setup, Test Nos. HTCB-12 through HTCB-16

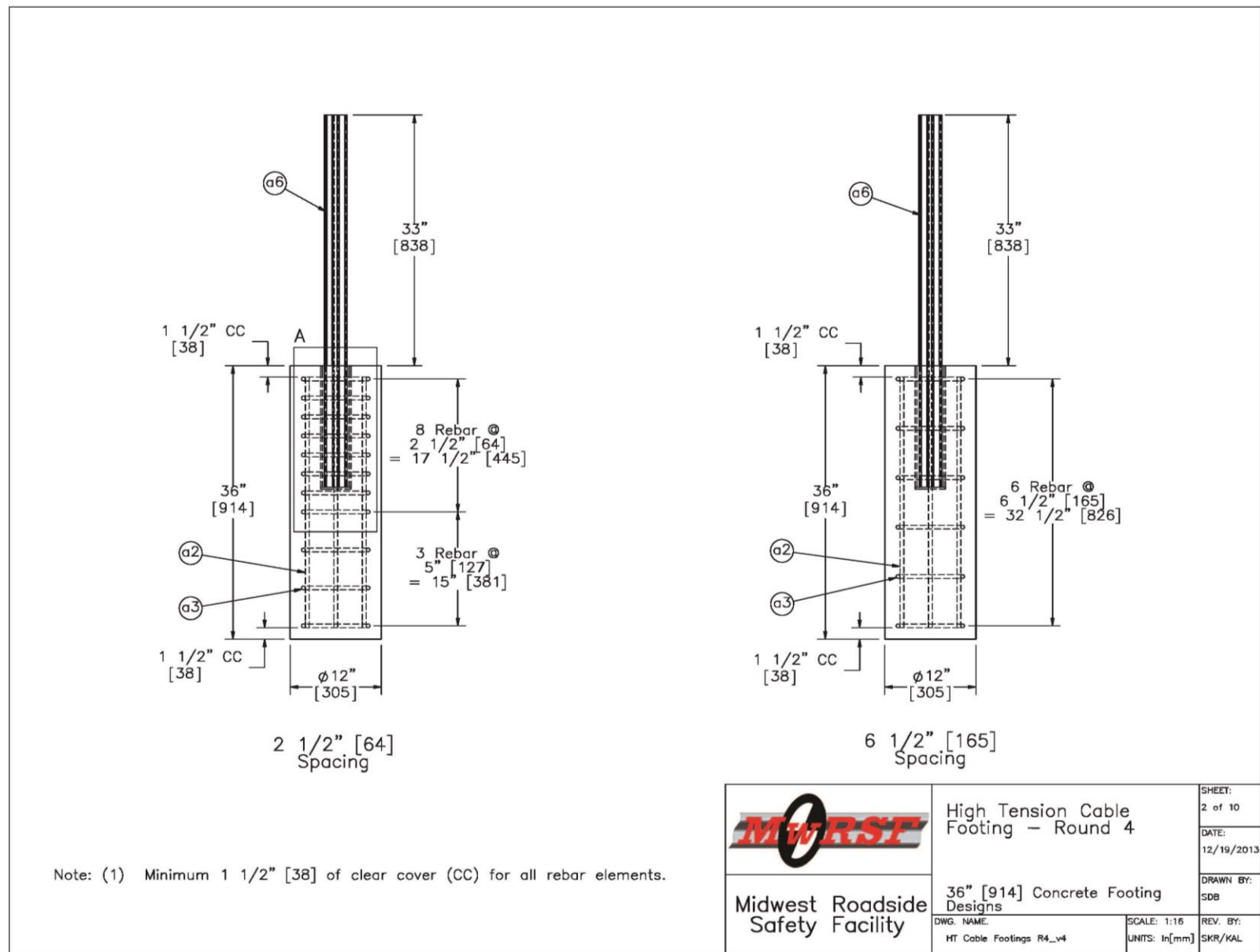


Figure 3. Assemblies and Reinforcement Configurations, Test Nos. HTCB-12 and HTCB-16

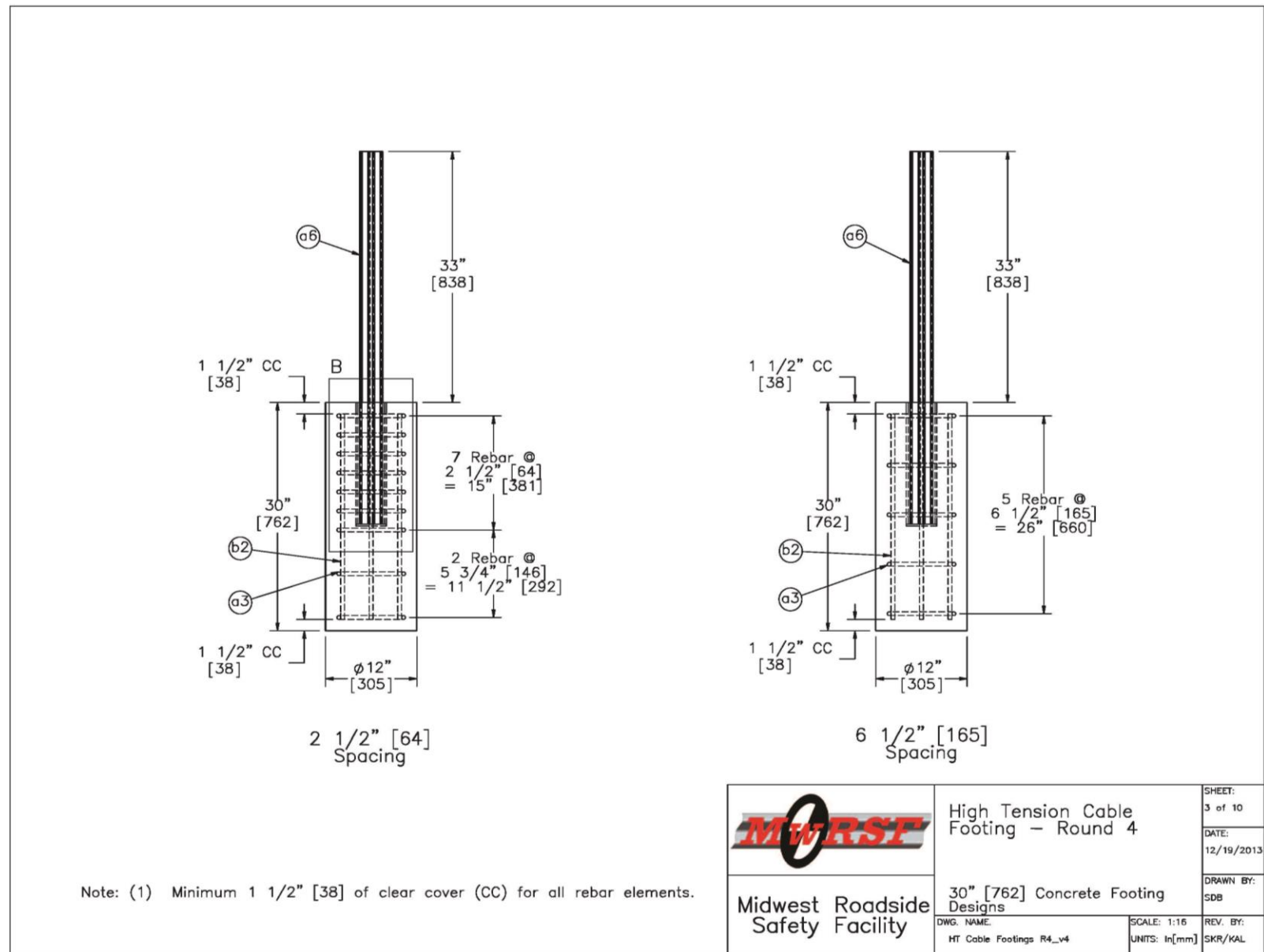


Figure 4. Assemblies and Reinforcement Configurations, Test Nos. HTCB-13 and HTCB-14



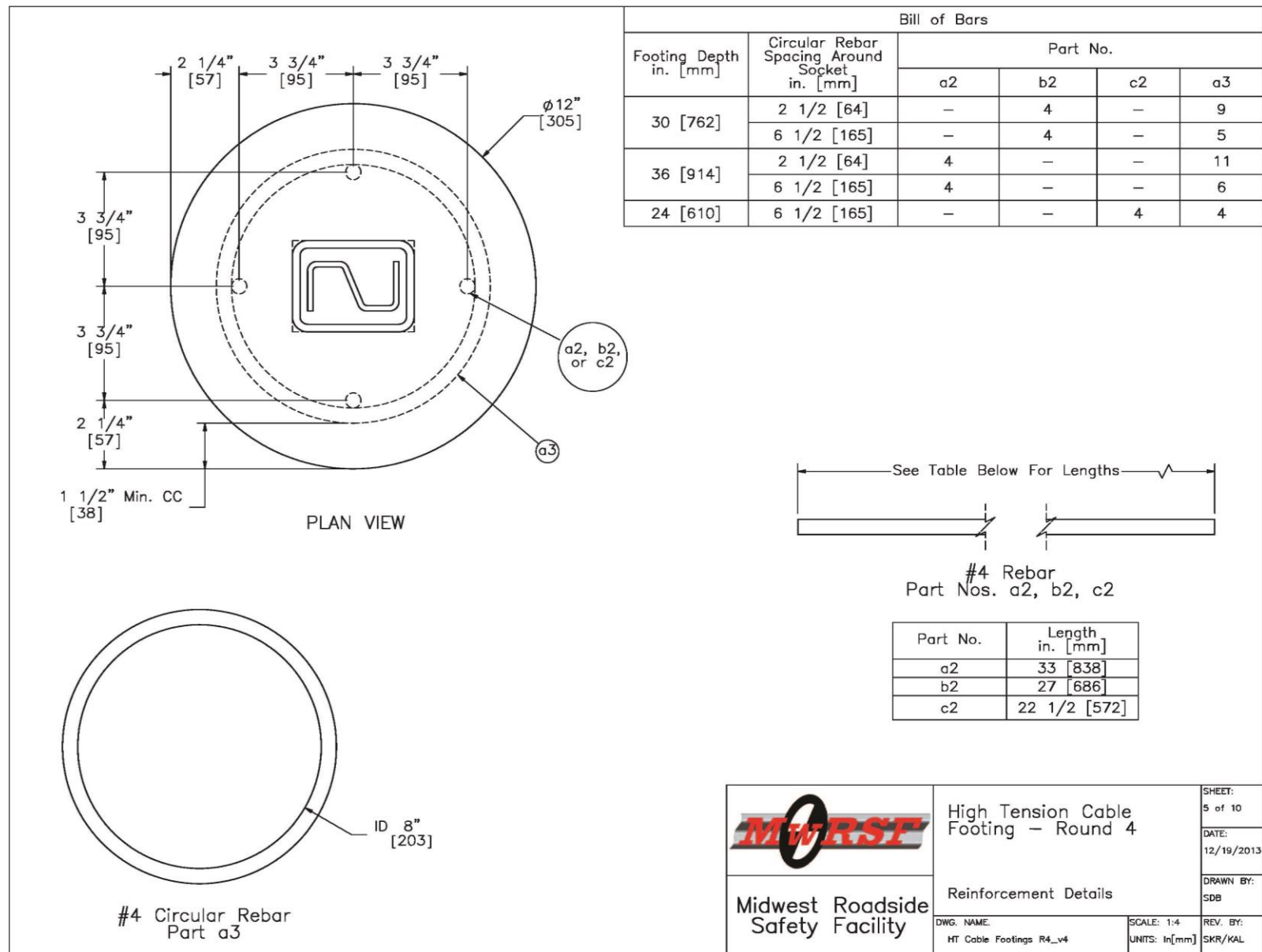


Figure 6. Steel Reinforcement Details, Test Nos. HTCB-12 through HTCB-16

Figure 7. Steel Post and Socket Details, Test Nos. HTCB-12 through HTCB-16

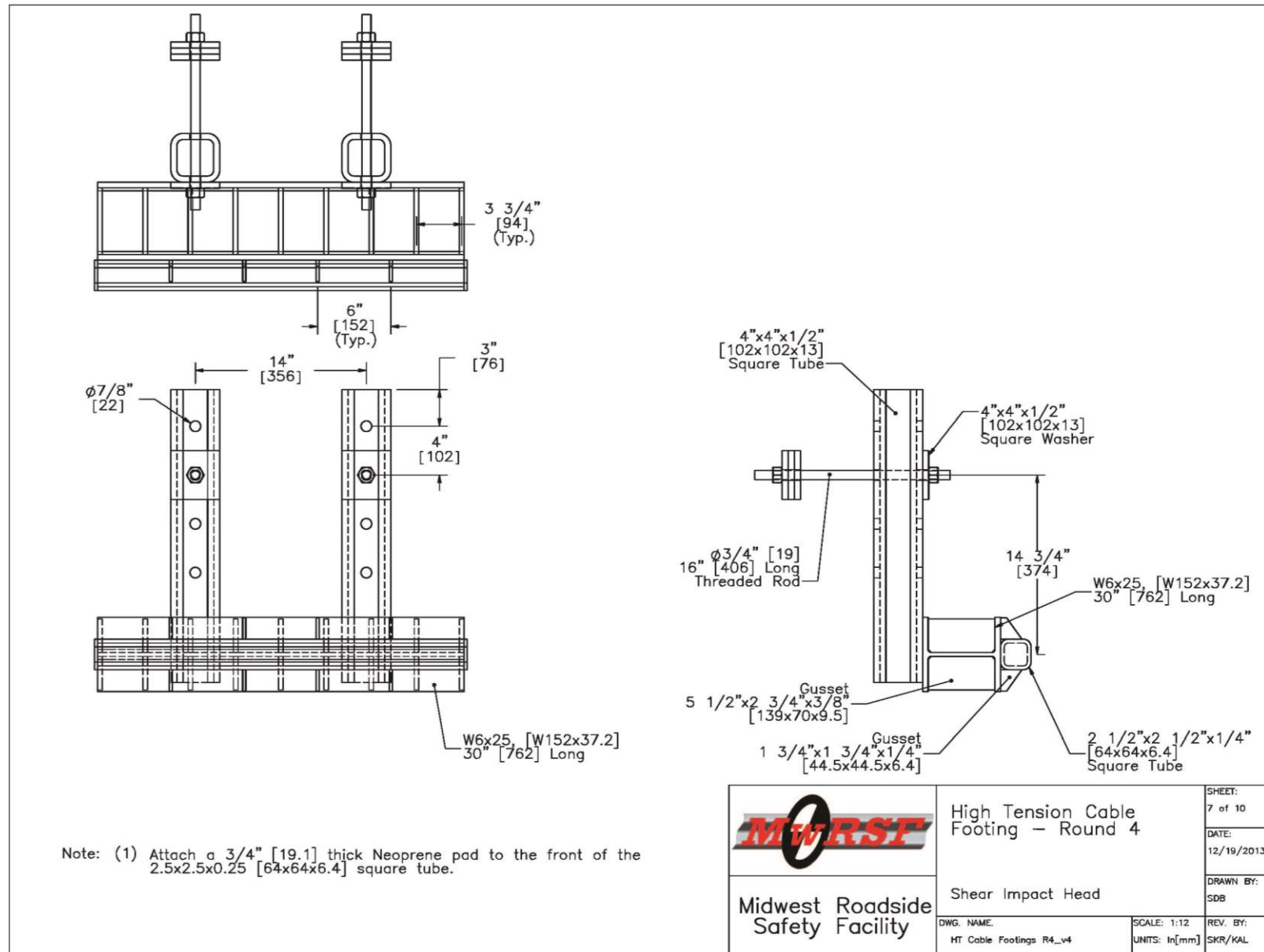


Figure 8. Bogie Head Details, Test Nos. HTCB-12 through HTCB-16

36" [914] Concrete Footing, 2 1/2" [64] Circular Rebar Spacing Around Socket				
Item No.	QTY.	Description	Material Specifications	Hardware Guide
a1	1	Concrete Shaft 36" [914] Long	Min 3500 psi [24 MPa] Comp. Strength	—
a2	4	#4 Rebar 33" [838] Long	Gr. 60	—
a3	11	#4 Circular Rebar 8" [203] ID	Gr. 60	—
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	—
a5	1	HSS 4x3x1/4" [HSS 102x76x6], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	—
a6	1	3"x1–5/8"x7 Gauge [76x41x5], 49" [1245] Long Bent Z–Section Post	Hot–Rolled ASTM A1011 HSLA Gr. 50	—
36" [914] Concrete Footing, 6 1/2" [165] Circular Rebar Spacing Around Socket				
Item No.	QTY.	Description	Material Specifications	Hardware Guide
a1	1	Concrete Shaft 36" [914] Long	Min 3500 psi [24 MPa] Comp. Strength	—
a2	4	#4 Rebar 33" [838] Long	Gr. 60	—
a3	6	#4 Circular Rebar 8" [203] ID	Gr. 60	—
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	—
a5	1	HSS 4x3x1/4" [HSS 102x76x6], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	—
a6	1	3"x1–5/8"x7 Gauge [76x41x5], 49" [1245] Long Bent Z–Section Post	Hot–Rolled ASTM A1011 HSLA Gr. 50	—



Midwest Roadside
Safety Facility

High Tension Cable
Footing – Round 4

Bill of Materials – 36" [914]
Footing Designs

DWG. NAME:
HT Cable Footings R4_v4

SHEET:
8 of 10

DATE:
12/19/2013

DRAWN BY:
SDB

REV. BY:
SKR/KAL

SCALE: 1:16
UNITS: In[mm]

Figure 9. Bill of Materials, Test Nos. HTCB-12 and HTCB-16

30" [762] Concrete Footing, 2 1/2" [64] Circular Rebar Spacing Around Socket				
Item No.	QTY.	Description	Material Specifications	Hardware Guide
b1	1	Concrete Shaft 30" [762] Long	Min 3500 psi [24 MPa] Comp. Strength	—
b2	4	#4 Rebar 27" [686] Long	Gr. 60	—
a3	9	#4 Circular Rebar 8" [203] ID	Gr. 60	—
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	—
a5	1	HSS 4x3x1/4" [HSS 102x76x6], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	—
a6	1	3"x1-5/8"x7 Gauge [76x41x5], 49" [1245] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	—
30" [762] Concrete Footing, 6 1/2" [165] Circular Rebar Spacing Around Socket				
Item No.	QTY.	Description	Material Specifications	Hardware Guide
b1	1	Concrete Shaft 30" [762] Long	Min 3500 psi [24 MPa] Comp. Strength	—
b2	4	#4 Rebar 27" [686] Long	Gr. 60	—
a3	5	#4 Circular Rebar 8" [203] ID	Gr. 60	—
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	—
a5	1	HSS 4x3x1/4" [HSS 102x76x6], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	—
a6	1	3"x1-5/8"x7 Gauge [76x41x5], 49" [1245] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	—



Midwest Roadside
Safety Facility

High Tension Cable
Footing – Round 4

Bill of Materials – 30" [762]
Footing Designs

DWG. NAME:
HT Cable Footings R4_v4

SCALE: 1:16
UNITS: In[mm]

SHEET:
9 of 10
DATE:
12/19/2013
DRAWN BY:
SDB
REV. BY:
SKR/KAL

Figure 10. Bill of Materials, Test Nos. HTCB-13 and HTCB-14

24" [610] Concrete Footing, 6 1/2" [165] Circular Rebar Spacing Around Socket				
Item No.	QTY.	Description	Material Specifications	Hardware Guide
c1	1	Concrete Shaft 24" [610] Long	Min 3500 psi [24 MPa] Comp. Strength	—
c2	4	#4 Rebar 22 1/2" [572] Long	Gr. 60	—
a3	4	#4 Circular Rebar 8" [203] ID	Gr. 60	—
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	—
a5	1	HSS 4x3x1/4" [HSS 102x76x6], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	—
a6	1	3"x1-5/8"x7 Gauge [76x41x5], 49" [1245] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	—
 High Tension Cable Footing — Round 4 Bill of Materials — 24" [610] Footing Designs				

Figure 11. Bill of Materials, Test No. HTCB-15



Figure 12. Fabrication and Installation Photographs

3 COMPONENT TEST CONDITIONS

3.1 Purpose

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

3.2 Scope

Five bogie tests were conducted on MWPs inserted into the reinforced concrete, socketed foundations. Similar to the impact conditions of the previous phases 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 to the bottom of a bumper on a small car, which would cause high shear and bending loads to be imparted to the top of the socketed foundations.

For test nos. HTCB-12 through HTCB-15, the socketed foundations were placed in a strong soil conforming to American Association of State Highway and Transportation Officials (AASHTO) Grade B material. This soil is considered a strong soil that has been utilized during the evaluation of roadside safety hardware. However, the displacement of a foundation in weaker soils was also desired. Thus, the socketed foundation for test no. HTCB-16 was placed in a soil pit consisting of AASHTO Grade A-3 sand material. The details pertaining to each individual test are shown in Table 1.

As stated previously, the main evaluation criteria for these socketed foundations were structural integrity and displacement through the soil. Previous component testing of S3x5.7 (S76x8.5) posts in similar sized socketed foundations revealed both concrete fracture and excessive movement of the foundations [2]. Thus, testing with the MWP V1 began with the

strongest and deepest foundation and then continued with an attempt to optimize the reinforcement and embedment depth.

Table 1. Bogie Testing Matrix – Socketed Foundations for MWP

Test No.	Soil Type	Impact Height in. (mm)	Footing Depth in. (mm)	Circular Rebar Spacing in. (mm)	Target Speed mph (km/h)	Target Impact Angle deg.
HTCB-12	Grade B - Strong	11 (279)	36 (914)	2.5 (64)	20 (32.2)	90
HTCB-13	Grade B - Strong	11 (279)	30 (762)	2.5 (64)	20 (32.2)	90
HTCB-14	Grade B - Strong	11 (279)	30 (762)	6.5 (165)	20 (32.2)	90
HTCB-15	Grade B - Strong	11 (279)	24 (610)	6.5 (165)	20 (32.2)	90
HTCB-16	Grade A3 Sand - Weak	11 (279)	36 (914)	6.5 (165)	20 (32.2)	90

3.3 Test Facility

Physical testing of the socketed foundations for cable barrier 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 city's campus.

3.4 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 digital video, and still cameras.

3.4.1 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 $\frac{3}{4}$ -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) for test nos. HTCB-12 through HTCB-16. The bogie with the impact head is shown in Figure 13. The weight of the bogie with the addition of the mountable impact head and accelerometers was 1,888 lb (856 kg).



Figure 13. Rigid-Frame Bogie on Guidance Track

A pickup truck with a 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 braking system was installed on the bogie, thus allowing it to be brought safely to rest after the test.

3.4.2 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. However, only the longitudinal accelerations were reported. Both accelerometers were mounted near the center of gravity of the bogie vehicle.

The first system, SLICE 6DX, was a modular data acquisition system manufactured by DTS of Seal Beach, California. The acceleration sensors were mounted inside the body of the custom built SLICE 6DX event data recorder and recorded data at 10,000 Hz to the onboard microprocessor. The SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ± 500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The second system, Model EDR-3, was a triaxial piezoresistive accelerometer system manufactured by 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.

3.4.3 Retroreflective Optic Speed Trap

The 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 emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, 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 are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

3.4.4 Digital Photography

One AOS X-PRI high-speed digital video camera and two JVC digital video camera were used to document each test. The AOS high-speed camera had a frame rate of 500 frames per second and the JVC digital video camera had a frame rate of 29.97 frames per second. The AOS high-speed camera and one of the JVC digital cameras were placed laterally from the post, with a view perpendicular to the bogie's direction of travel. The second JVC digital camera was placed above the post, with a view down toward the top surface of the foundation. A Nikon D50 digital still camera was also used to document pre- and post-test conditions for all tests.

3.5 End of Test Determination

During standard bogie-post impact events, the desired test results have been based on force-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 criteria for end of test were discarded, and the true end of test was defined as the time when the bogie vehicle overrode or lost contact with the post.

3.6 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 [5]. 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.

4 DYNAMIC TESTING RESULTS

4.1 Results

Through component testing, the performance of each socketed foundation was evaluated in terms of both structural integrity and displacement of the foundation. A foundation system 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 position. Although not ideal for new installations, these displacements were believed to 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 ground line. The combination of these criteria would ensure that a socketed foundation could be reused in the same system without repairs or resetting. These criteria match those utilized during the evaluation of the socketed foundations for S3x5.7 (S76x8.5) posts in a previous phase of this project [2].

Accelerometer data was used to find the resistance force supplied by the cable barrier 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. Due to the plastic deformation of the posts, foundation displacements had to be measured from the high-speed video.

4.1.1 Test No. HTC B-12

Test no. HTC B-12 was conducted on July 19, 2013 at approximately 1:00 pm. The weather conditions as per the National Oceanic and Atmosphere Administration (station 14939/LNK) were reported and are shown in Table 2.

Table 2. Weather Conditions, Test No. HTC B-12

Temperature	93° F
Humidity	43%
Wind Speed	3 mph
Wind Direction	Varied
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. HTC B-12, the bogie impacted the post 11 in. (279 mm) above ground line at a speed of 20.6 mph (33.2 km/h), causing strong-axis bending in the post. Upon impact, the foundation experienced $\frac{1}{8}$ in. (3 mm) of dynamic deflection, and a plastic hinge formed in the post. The steel post continued to bend over until the bogie overrode the top of the post 0.120 seconds after impact and at a deflection of 39.4 in. (1,001 mm). Field measurements concluded that the top of the concrete foundation had no visible permanent displacement after the impact event.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 14. Inertial effects resulted in a high peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a peak of 9.0 kips (40.0 kN) at 7.4 in. (188 mm) of deflection. Following this second peak, the force never exceeded 4 kips

(17.8 kN) and gradually decreased over the remainder of the impact event. At a maximum deflection of 39.4 in. (1,001 mm), the post assembly had absorbed 67.1 k-in. (7.5 kJ) of energy.

Damage to the test article consisted of plastic deformations to the MWP at ground line. The concrete foundation experienced no significant damage, only minor scrapes on the back side of the socket. Time-sequential and post-impact photographs are shown in Figure 15.

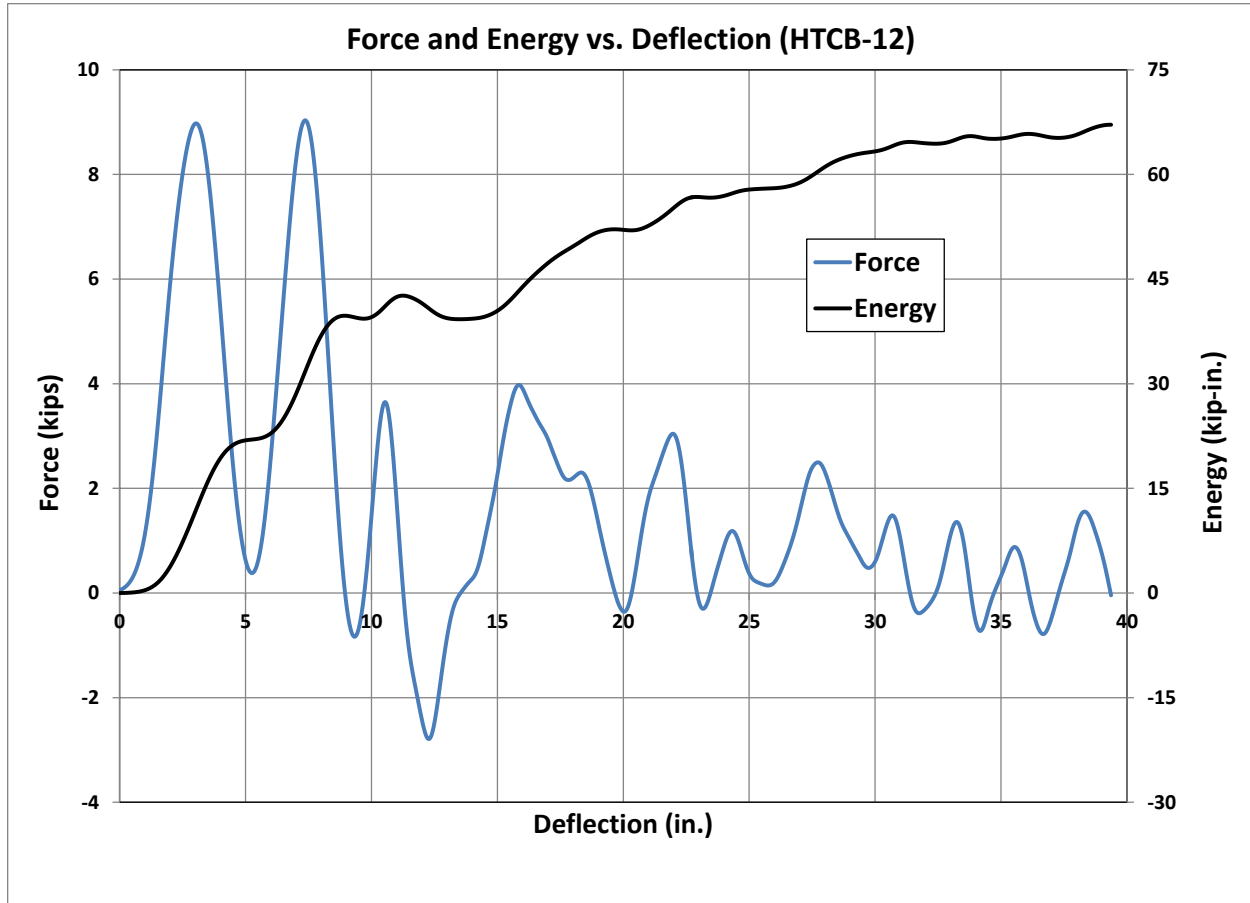


Figure 14. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-12



IMPACT



0.030 sec



0.060 sec



0.090 sec



0.120 sec



0.150 sec



Figure 15. Time-Sequential and Post-Impact Photographs, Test No. HTC B-12

4.1.2 Test No. HTCB-13

Test no. HTCB-13 was conducted on July 26, 2013 at approximately 10:30 am. 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-13

Temperature	76° F
Humidity	47%
Wind Speed	24 mph
Wind Direction	0° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

During test no. HTCB-13, the bogie impacted the post 11 in. (279 mm) above ground line at a speed of 21.1 mph (34.0 km/h), causing strong-axis bending in the post. Upon impact, the foundation experienced $\frac{1}{8}$ in. (3 mm) of dynamic deflection, and a plastic hinge formed in the post. The steel post continued to bend over until the bogie overrode the top of the post at 0.110 sec after impact and a deflection of 37.3 in. (947 mm). Field measurements concluded that the top of the concrete foundation had no visible permanent displacement after the impact event.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 16. Inertial effects resulted in a high peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a peak of 9.1 kips (40.5 kN) at 7.1 in. (180 mm) of deflection. Following this second peak, the forces quickly decreased and remained below 4.5 kips (20.0 kN) for the remainder of the impact event. At a deflection of 37.3 in. (947 mm), the post assembly had absorbed 64.7 k-in. (7.3 kJ) of energy.

Damage to the test article was confined to plastic deformations in the post at ground line. The concrete foundation experienced no significant damage, only minor scrapes on the back side of the socket. Time-sequential and post-impact photographs are shown in Figure 17.

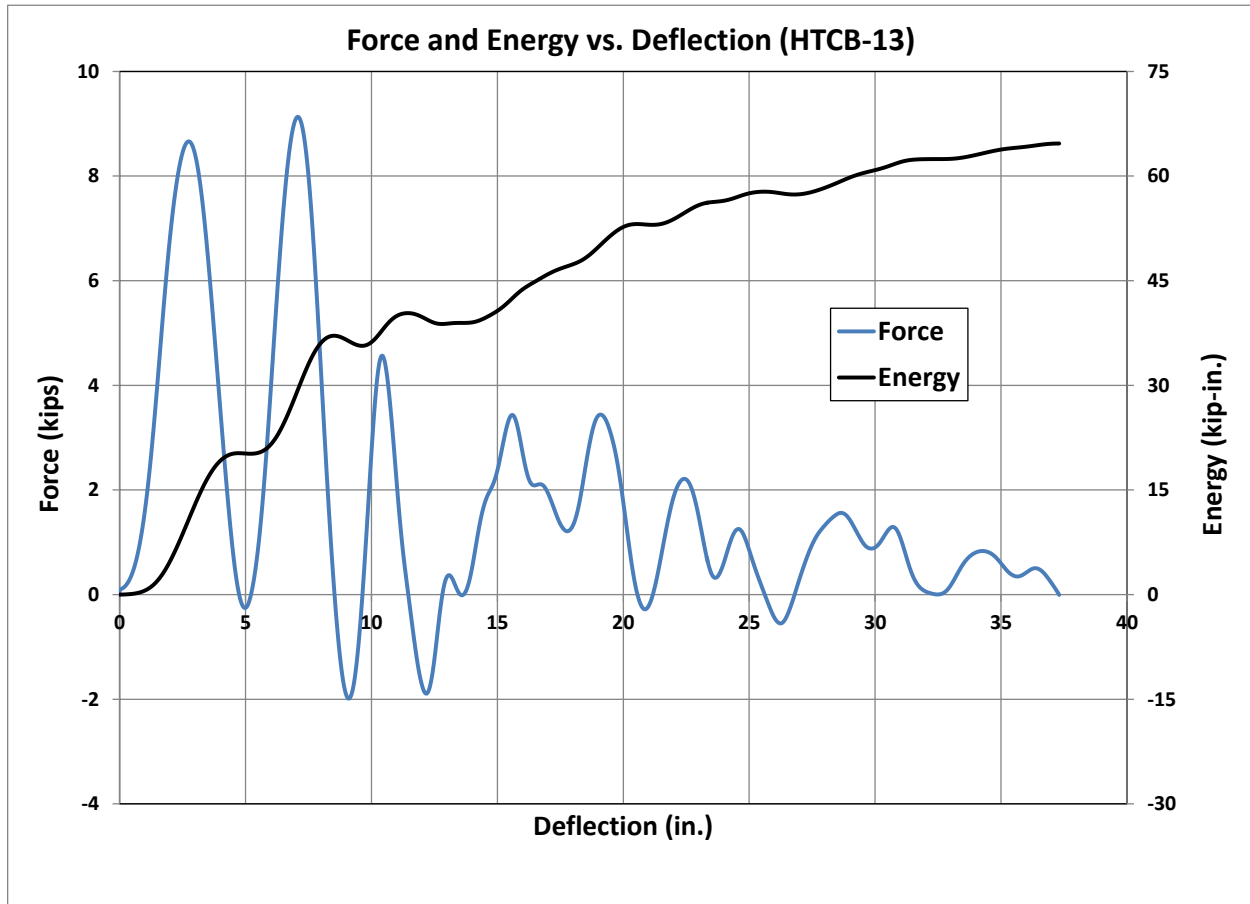


Figure 16. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-13

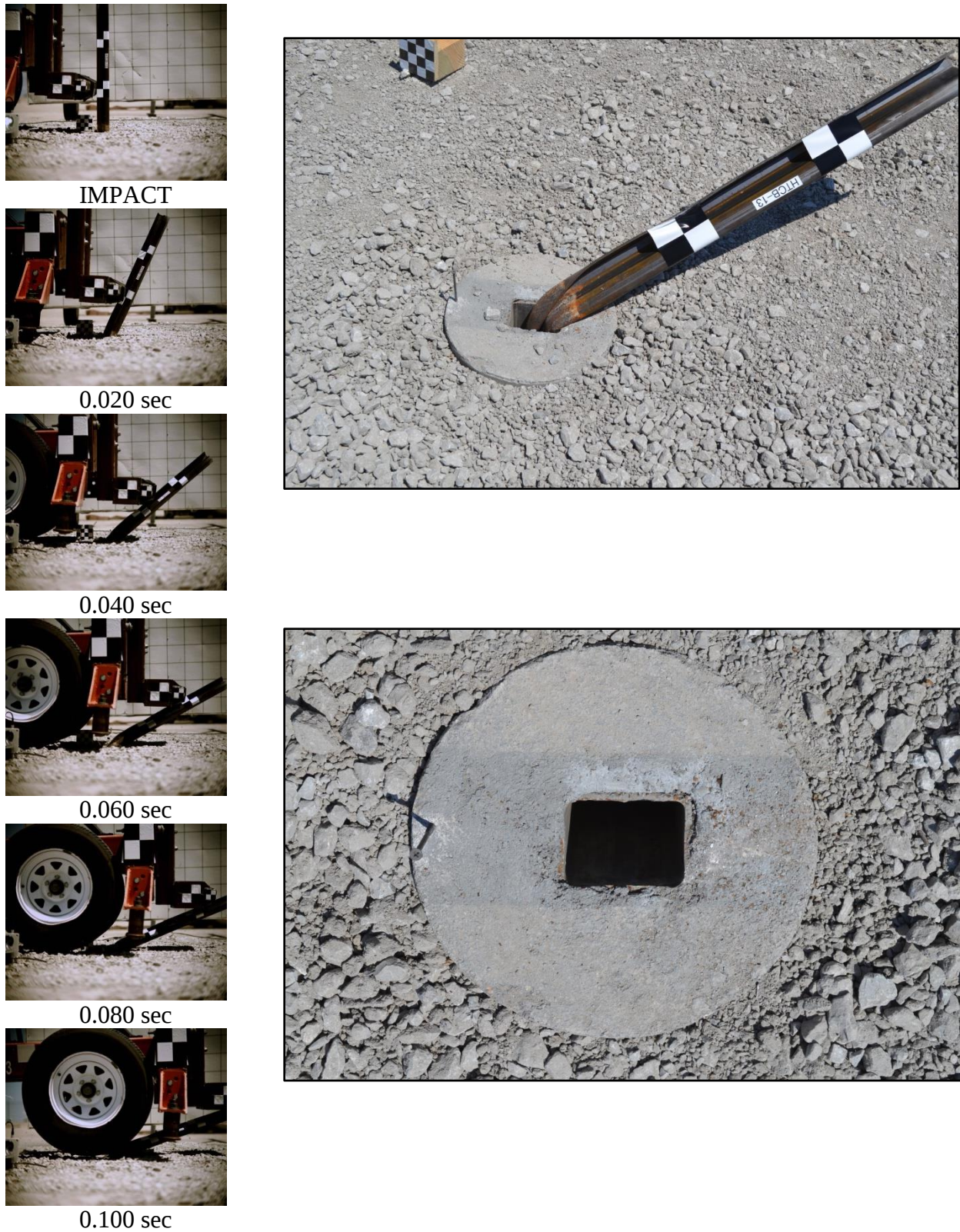


Figure 17. Time-Sequential and Post-Impact Photographs, Test No. HTCB-13

4.1.3 Test No. HTCB-14

Test no. HTCB-14 was conducted on August 5, 2013 at approximately 4:00 pm. 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-14

Temperature	85° F
Humidity	63%
Wind Speed	7 mph
Wind Direction	260° 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-14, the bogie impacted the post 11 in. (279 mm) above ground line at a speed of 19.3 mph (31.1 km/h), causing strong-axis bending in the post. Upon impact, the foundation experienced ¼ in. (6 mm) of dynamic deflection, and a plastic hinge formed in the post. The steel post continued to bend over until the bogie overrode the post 0.120 sec after impact and at a deflection of 35.9 in. (912 mm). Field measurements concluded that the top of the concrete foundation had no visible permanent displacement after the impact event.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 18. Inertial effects resulted in a high peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a peak of 9.5 kips (42.3 kN) at 6.5 in. (165 mm) of deflection. Following this second peak, the force decreased quickly and remained below 4.1 kips (18.2 kN) for the remainder of the impact event. At a deflection of 35.9 in. (912 mm), the post assembly had absorbed 61.3 k-in. (6.9 kJ) of energy.

Damage to the test article was confined to plastic deformations of the post near ground line. The concrete foundation experienced only minor scrapes on the back side of the socket. Time-sequential and post-impact photographs are shown in Figure 19.

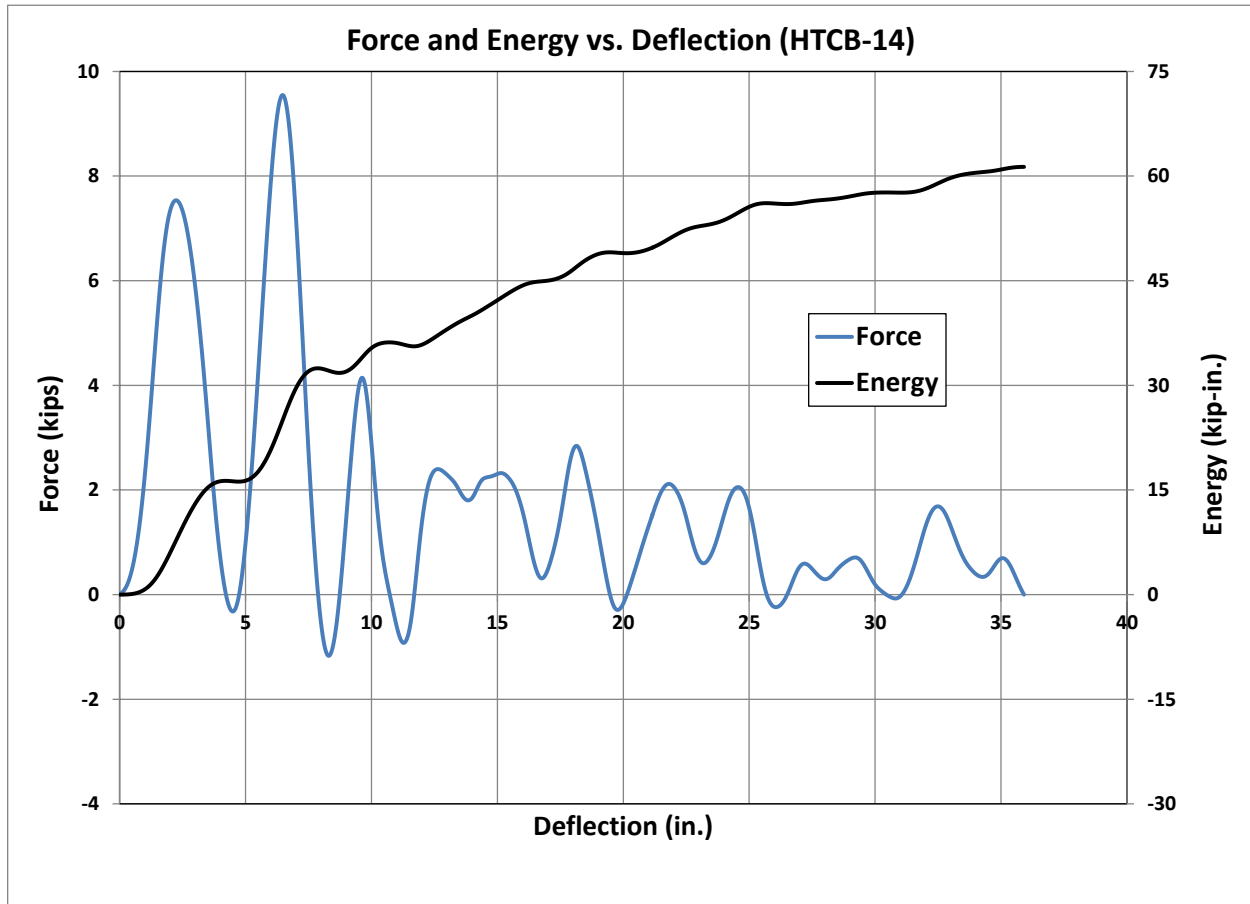


Figure 18. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-14



IMPACT



0.030 sec



0.060 sec



0.090 sec



0.120 sec



0.150 sec



Figure 19. Time-Sequential and Post-Impact Photographs, Test No. HTCB-14

4.1.4 Test No. HTCB-15

Test no. HTCB-15 was conducted on August 9, 2013 at approximately 2:30 pm. 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-15

Temperature	82° F
Humidity	46%
Wind Speed	11 mph
Wind Direction	40° 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-15, the bogie impacted the post 11 in. (279 mm) above ground line at a speed of 22.5 mph (36.2 km/h), causing strong-axis bending in the post. Upon impact, a plastic hinge formed in the post. The steel post continued to bend over until the bogie overrode the assembly at 0.090 sec after impact and a deflection of 33.6 in. (853 mm). Unfortunately, technical difficulties with the high-speed camera prevented dynamic deflections of the foundation from being quantified. Field measurements concluded that the top of the concrete foundation had ¼ in. (6 mm) of permanent displacement after the impact event.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 20. Inertial effects resulted in a high peak force over the first few inches of deflection. After a brief decrease, the force rebounded to a peak of 6.4 kips (28.5 kN) at 7.2 in. (183 mm) of deflection. Following this second peak, the force remained below 3.5 kips

(15.6 kN) for the remainder of the test. At a deflection of 33.6 in. (853 mm), the post assembly had absorbed 55.1 k-in. (6.2 kJ) of energy.

Damage to the test article was confined to plastic deformations of the post at ground line. The concrete foundation experienced no significant damage. Time-sequential and post-impact photographs are shown in Figure 21. Due to technical difficulties with the high-speed camera, time-sequential photographs were taken from the JVC digital camera.

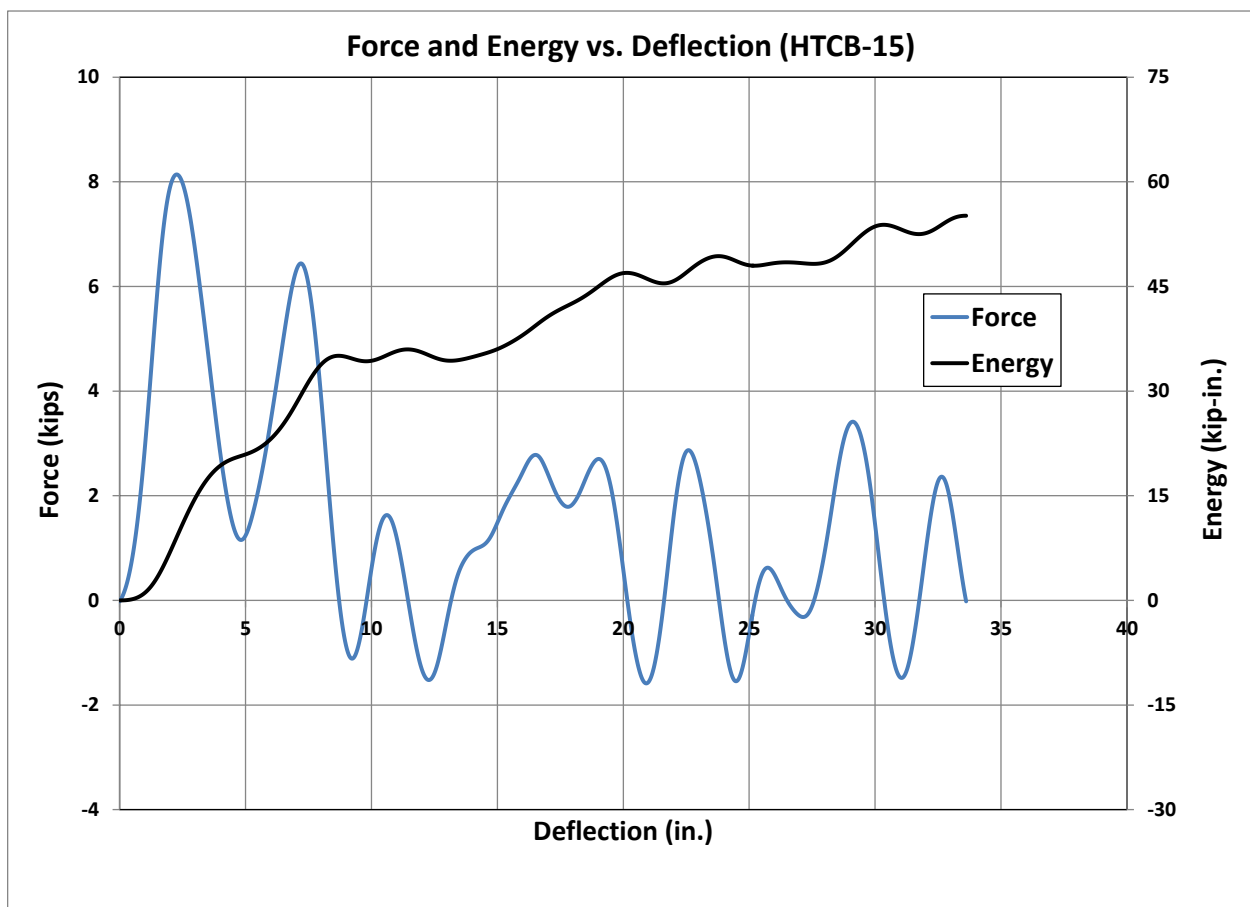


Figure 20. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-15



IMPACT



0.025 sec



0.050 sec



0.076 sec



0.101 sec



0.226 sec



Figure 21. Post-Impact Photographs, Test No. HTCB-15

4.1.5 Test No. HTCB-16

Test no. HTCB-16 was conducted on August 9, 2013 at approximately 3:30 pm. 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-16

Temperature	82° F
Humidity	43%
Wind Speed	13 mph
Wind Direction	30° From True North
Sky Conditions	Clear
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-16, the bogie impacted the post 11 in. (279 mm) above ground line at a speed of 22.2 mph (35.7 km/h), causing strong-axis bending in the post. Upon impact, the concrete foundation experienced 1 in. (25 mm) of dynamic deflection as the post bent plastically. The steel post continued to bend over until the bogie overrode the post 0.090 sec after impact at a deflection of 34.2 in. (869 mm). Field measurements concluded that the top of the concrete foundation had ½ in. (13 mm) of permanent displacement after the impact event.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 22. Inertial effects resulted in a high force over the first few inches of deflection. After a brief decrease, the force rebounded to a peak of 6.4 kips (28.5 kN) at 6.8 in. (173 mm) of deflection. Following this second peak, the force remained below 4 kips (17.8 kN) for the remainder of the test. At a deflection of 34.2 in. (869 mm), the post assembly had absorbed 69.9 k-in. (7.9 kJ) of energy.

Damage to the test article was confined to plastic deformations of the MWP at ground line. The concrete foundation experienced only minor scrapes. Time-sequential and post-impact photographs are shown in Figure 23.

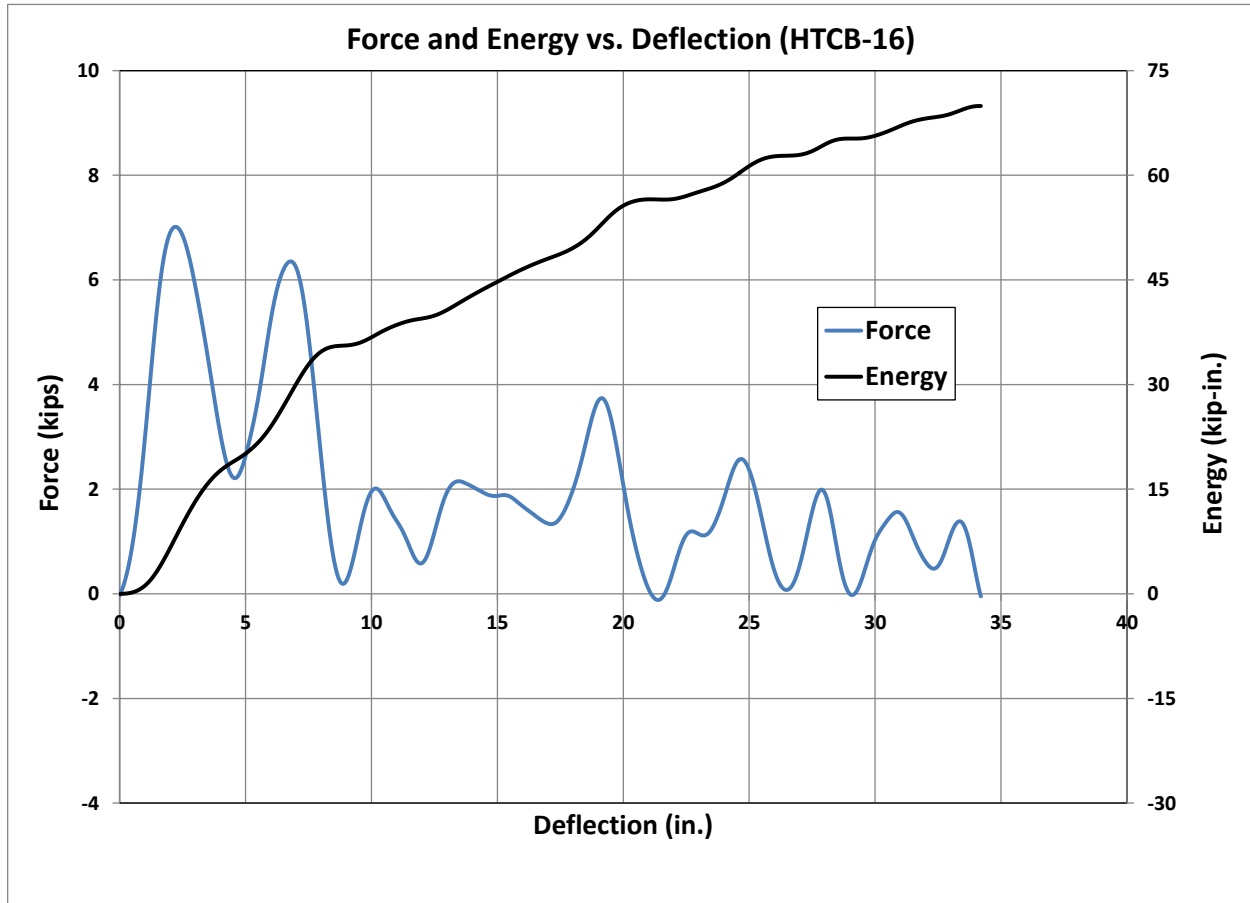


Figure 22. Force vs. Deflection and Energy vs. Deflection, Test No. HTCB-16



IMPACT



0.030 sec



0.060 sec



0.090 sec



0.120 sec



0.150 sec

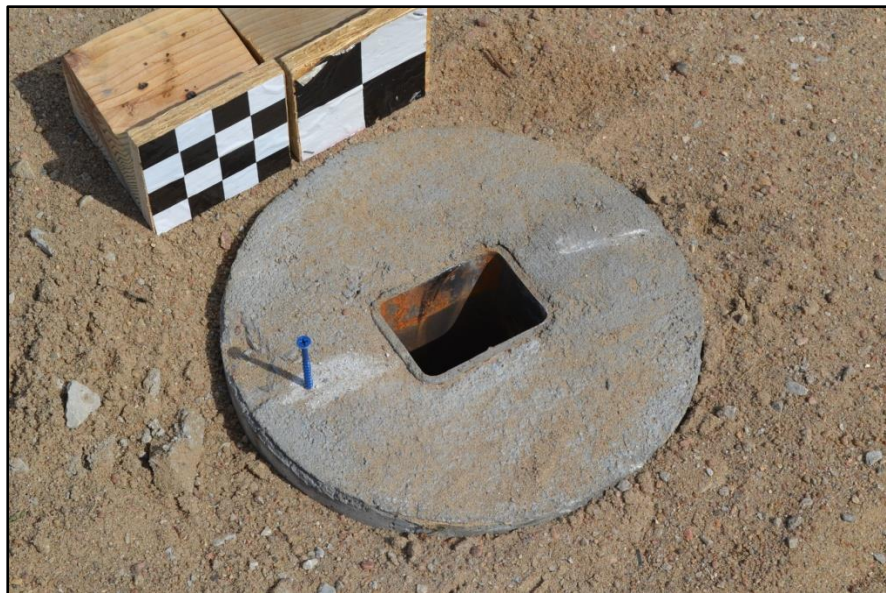


Figure 23. Time-Sequential and Post-Impact Photographs, Test No. HTCB-16

4.2 Discussion

The results from the dynamic component testing are summarized in Table 7. The socketed foundations evaluated in combination with MWPs were not damaged during the component tests. Additionally, the permanent set deflections of the socketed foundations were all within the 1-in. (25-mm) limit. If the test article had been part of a full-scale system installation, the damaged post could have been removed and replaced with a new MWP without any repairs or resetting to the socketed foundation. Therefore, all of the dynamic component tests were deemed successful.

Force vs. deflection and energy vs. deflection comparisons for every test are shown in Figures 24 and 25, respectively. The force plots were similar for all five test articles. Each curve consisted of an initial inertial spike within the first few inches of deflection, followed by a second force spike at approximately 7 in. (178 mm) of deflection. After this second force spike, all the curves fluctuated at lower magnitudes, typically below 4 kips (18 kN), until the bogie overrode the top of the post. Subsequently, the energy absorbed during each test was also similar. The peak forces recorded after the inertial spike during test nos. HTCB-15 and HTCB-16 were significantly lower than the peak forces record from the other three tests. This was most likely the result of the larger dynamic displacements of the foundations observed during these two tests, which allowed for more post rotations with slightly less plastic bending of the MWPs.

Utilizing the weaker MWPs instead of S3x5.7 (S76x8.5) posts, as tested previously [2], resulted in lower impact forces transferred to the socketed foundations, and thus, less foundation damage. In fact, the peak forces were reduced by 30 percent, and the average forces at 10 in. and 20 in. (254 mm and 508 mm) of displacement were reduced by 60 percent when compared to the S3x5.7 (S76x8.5) post. These reduced impact forces also resulted in a reduction in foundation displacements and a reduction to the amount of internal reinforcement required to resist concrete

cracking. Thus, the size, embedment depth, and strength requirements for socketed foundations are significantly less when used in combination with MWP V1 as opposed to standard S3x5.7 (S76x8.5) posts.

Table 7. Component Testing Results Summary, Test Nos. HTCB-12 through HTCB-16

Test No.	Embedment Depth in. (mm)	Hoop Rebar Spacing in. (mm)	Impact Velocity mph (km/h)	Average Force kips (kN)				Peak Force kips (kN)	Total Energy kip-in. (kJ)	Foundation Dynamic Deflection in. (mm)	Foundation Permanent Deflection in. (mm)	Foundation Damage
				@ 5"	@10"	@15"	@20"					
HTCB-12	36 (914)	2.5 (64)	20.6 (33.2)	4.4 (19.6)	4.0 (17.8)	2.7 (12.0)	2.6 (11.6)	9.0 (40.0)	67.1 (7.6)	⅛ (3)	0 (0)	None
HTCB-13	30 (762)	2.5 (64)	21.1 (34.0)	4.1 (18.2)	3.6 (16.0)	2.7 (12.0)	2.6 (11.6)	9.1 (40.5)	64.7 (7.3)	⅛ (3)	0 (0)	None
HTCB-14	30 (762)	6.5 (165)	19.3 (31.1)	3.3 (14.7)	3.5 (15.6)	2.8 (12.5)	2.5 (11.1)	9.5 (42.3)	61.3 (6.9)	¼ (6)	0 (0)	None
HTCB-15	24 (610)	6.5 (165)	22.5 (36.2)	4.2 (18.7)	3.4 (15.1)	2.4 (10.7)	2.3 (10.2)	8.1 (36.0)	55.1 (6.2)	NA	¼ (6)	None
HTCB-16	36 (914)	6.5 (165)	22.2 (35.7)	4.0 (17.8)	3.7 (16.5)	3.0 (13.3)	2.8 (12.5)	7.0 (31.1)	69.9 (7.9)	1 (25)	½ (13)	None

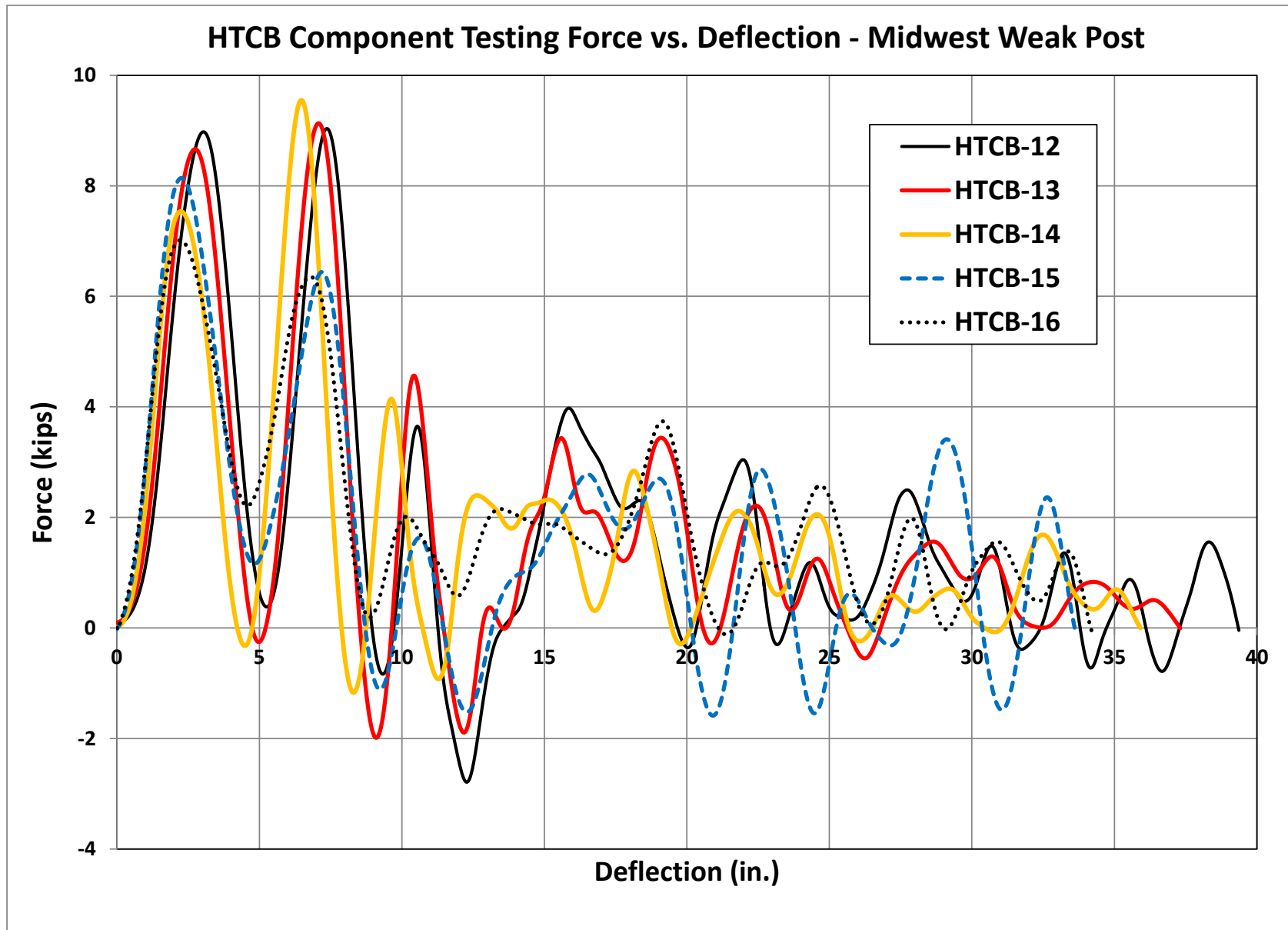


Figure 24. Force vs. Deflection Comparison, Test Nos. HTCB-12 through HTCB-16

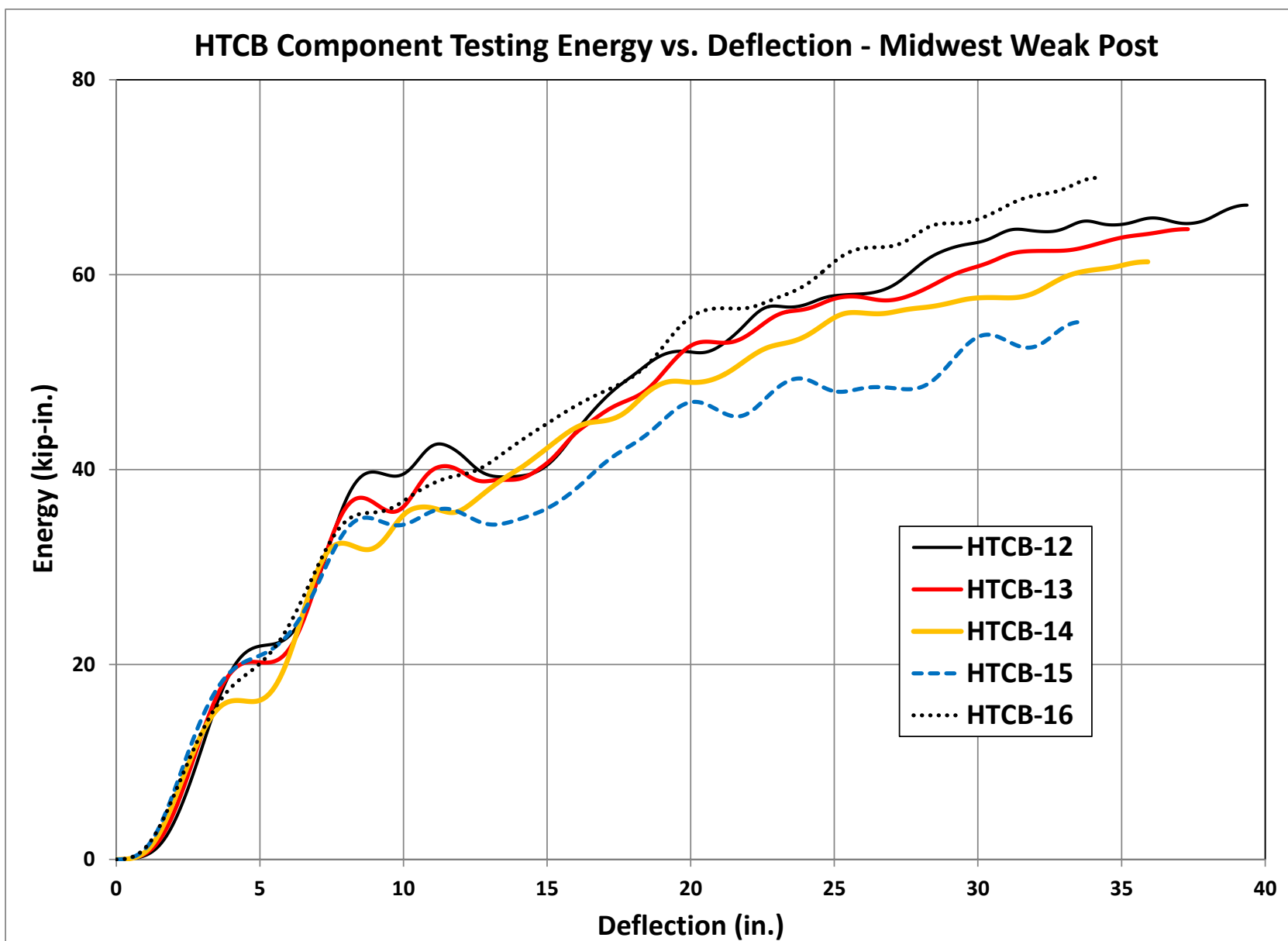


Figure 25. Energy vs. Deflection Comparison, Test Nos. HTCB-12 through HTCB-16

5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this research project was to develop a socketed foundation for use with the MWP V1 developed for MwRSF's new high-tension, cable median barrier. The new socketed foundation was required to remain free of concrete cracking and/or fracture 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.

Five socketed foundations were developed utilizing reinforced concrete configured in a cylindrical geometry. 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. Each design was configured with different combinations of steel reinforcement and embedment depth. The socketed foundations were evaluated through dynamic impact testing utilizing an impact height of 11 in. (279 mm), which was selected to represent the bumper height of a small car.

All five dynamic component tests had similar results. The MWPs bent over, and each foundation remained free of concrete cracking and fracture. As such, the reinforcement configurations with transverse steel hoops spaced at 6½-in. (165-mm) intervals provided adequate strength to resist impact loads and prevent damage to the foundation. Although the reinforcement configurations with more hoop steel at tighter spacing would also prevent foundation damage, these over-reinforced designs may add unnecessary material costs to barrier installations.

The permanent set displacements of the five foundations were all less than the 1-in. (25-mm) limit. However, foundation displacements did vary with changes to the embedment depth. In strong soil, embedment depths of 30 in. (762 mm) or greater resulted in no permanent set

displacements. An embedment depth of 24 in. (610 mm) resulted in a permanent set displacement of $\frac{1}{4}$ in. (6 mm). Testing of embedment depths shallower than 24 in. (610 mm) was not conducted due to concerns for frost heave and the likelihood for softer soils being up near ground line at actual installation sites. Testing of a 36-in. (914-mm) deep foundation in weak, sandy soil resulted in a permanent set displacement of $\frac{1}{2}$ in. (13 mm). It was believed that shortening the embedment to 30 in. (762 mm) in weak soil would have resulted in displacements larger than the 1-in. (25-mm) limit.

Detailed drawings for the final socketed foundation configuration for use with MWP's are shown in Figures 26 through 28. Although the foundation cross section and reinforcement pattern remain constant for all installations, the recommended foundation embedment depth varies according to the following guidelines:

1. A minimum embedment depth of 24 in. (610 mm) for socketed foundations installed in stiff soils, characterized as dry, well graded, heavily compacted soils.
2. A minimum embedment depth of 36 in. (914 mm) for socketed foundations installed in weak soils, typically characterized as sandy, often saturated, or loosely compacted soils.
3. A minimum embedment depth greater than the expected freeze line within the soil in order to prevent frost heave.

Cable guardrail systems are regularly installed within medians and on roadsides with cross slopes. Under these circumstances, the top of the socketed foundation would not lay flush with the surrounding terrain, and may result in the downslope side of the foundation protruding above ground line. 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 29. Additionally, this configuration ensures that the post and cables remain at the correct height.

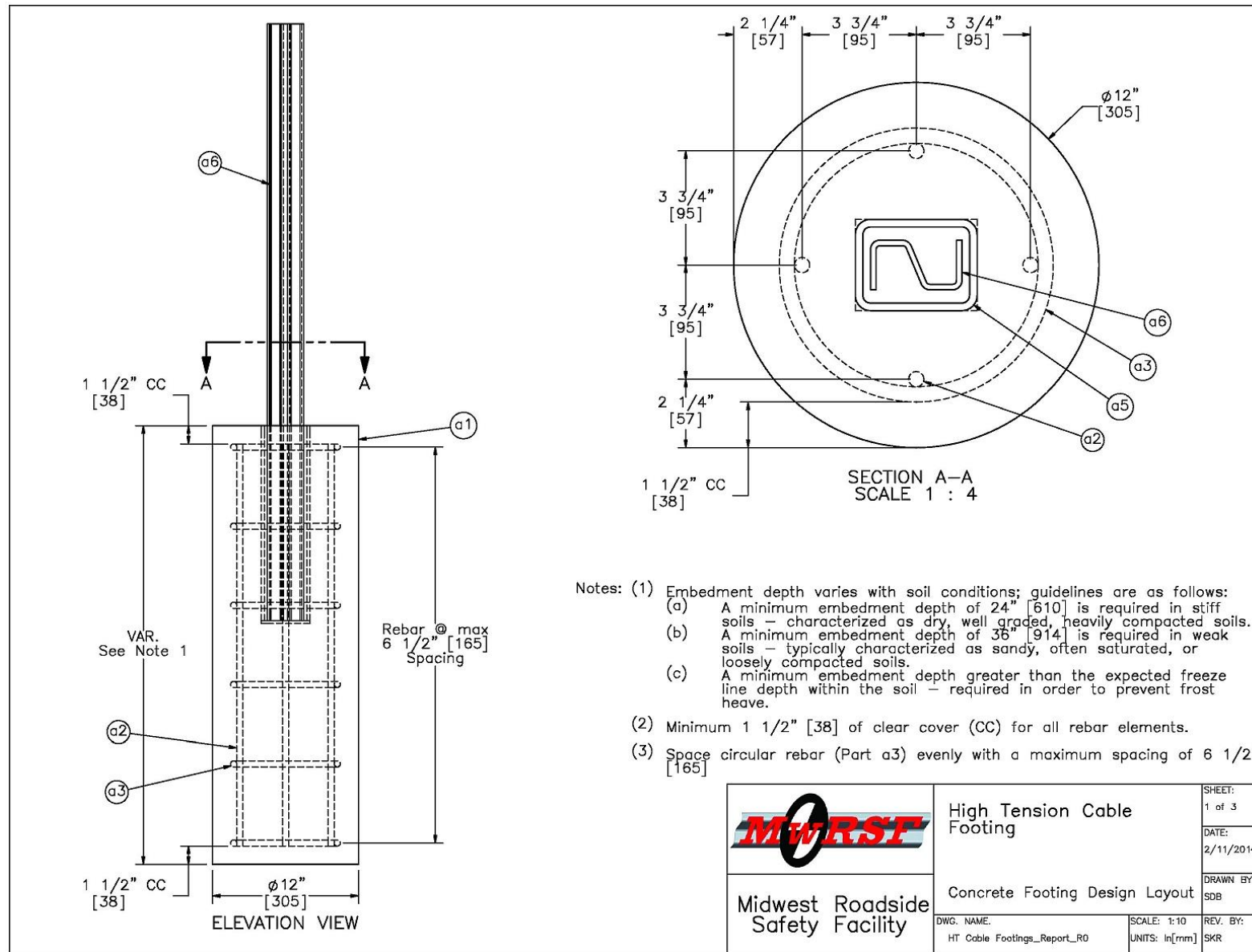


Figure 26. Socketed Foundation for MWPs, Design Details

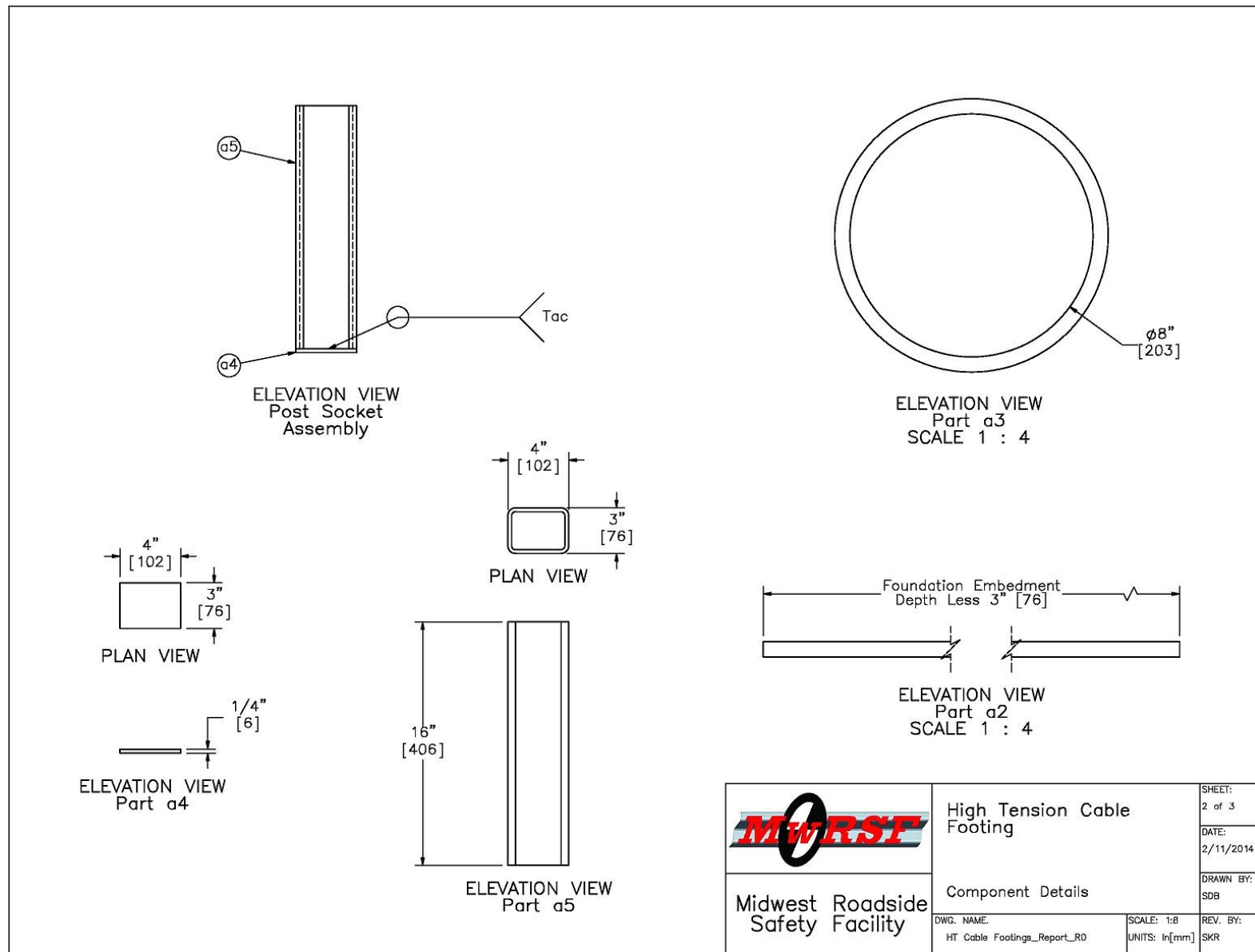


Figure 27. Socketed Foundation for MWPs, Steel Component Details

Item No.	QTY.	Description	Material Spec	Hardware Guide
a1	1	Concrete Shaft	Min 3500 psi [24 MPa] Comp. Strength	—
a2	4	#4 Vertical Rebar	Gr. 60	—
a3	VAR.	#4 Circular Rebar 8" [203] ID	Gr. 60	—
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	—
a5	1	HSS 4x3x1/4" [HSS 102x76x6], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	—
a6	1	7 gauge Midwest Weak Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	—
 High Tension Cable Footing Bill of Materials Midwest Roadside Safety Facility DWG. NAME: HT Cable Footings_Report_R0 SCALE: 1:16 UNITS: In[mm] REV. BY: SKR SHEET: 3 of 3 DATE: 2/11/2014 DRAWN BY: SDB				

Figure 28. Socketed Foundation for MWPs, Bill of Materials

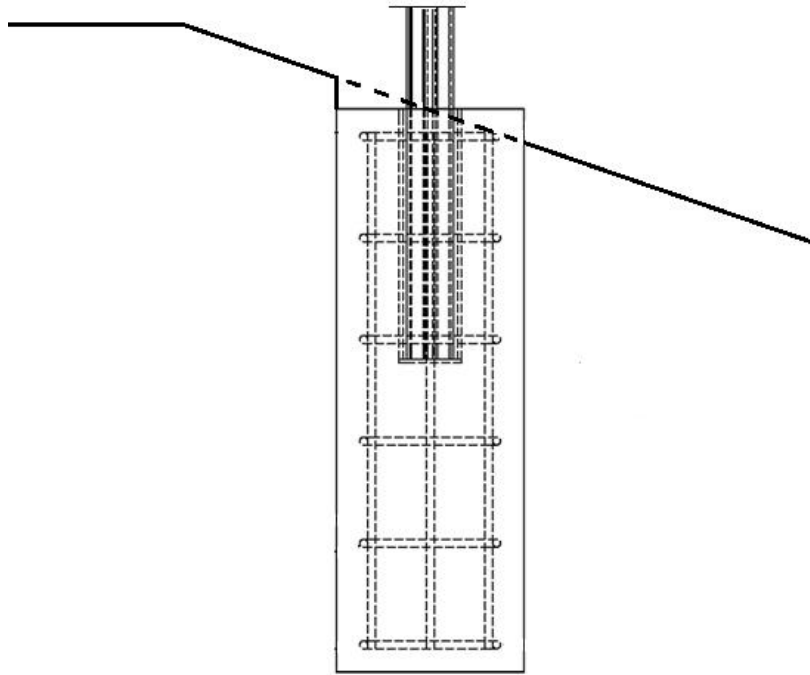


Figure 29. Placement of Foundation on Slope

6 REFERENCES

1. Terpsma, R.J., Zhu, L., Rohde, J., Dickey, B.J., Rosenbaugh, S.K., Faller, R.K., *Development of a Socketed Foundation For Cable Barrier Posts – Phase I*, Final Report to the Midwest States Regional Pooled Fund Program and Mid-America Transportation Center, Report No. TRP-03-232-11, Midwest Roadside Safety Facility, Lincoln, Nebraska, University of Nebraska-Lincoln, February 2012.
2. Schmidt, T.L., Rosenbaugh, S.K., Faller, R.K., Sicking, D.L., Reid, J.D., *Development of a Socketed Foundation for S3x5.7 Posts*, Draft Report to the Midwest States Regional Pooled Fund Program, Report No. TRP-03-293-14, Midwest Roadside Safety Facility, Lincoln, Nebraska, University of Nebraska-Lincoln, In Progress.
3. *Manual for Assessing Safety Hardware (MASH)*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.
4. 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, Report No. TRP-03-286-14, Midwest Roadside Safety Facility, Lincoln, Nebraska, University of Nebraska-Lincoln, In Progress.
5. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, NY, July, 2007.

7 APPENDICES

Appendix A. Material Specifications

Table A-1. Bill of Materials, Test Nos. HTCB-12 and HTCB-16

36" [914] Concrete Footing, 2 1/2" [64] Circular Rebar Spacing Around Socket				
Item No.	QTY.	Description	Material Specifications	Reference:
a1	1	Concrete Shaft 36" [914] Long	Min 3500 psi [24 MPa] Comp. Strength	Mix Code: 24013000
a2	4	#4 Rebar 33" [838] Long	Gr. 60	White Cap R#13-0413 No CERTS available
a3	11	#4 Circular Rebar 8" [203] ID	Gr. 60	White Cap R#13-0413 No CERTS available
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	N/A
a5	1	HSS 4x3x1/4" [HSS 102x76x6.4], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	Heat #B200931 R#13-0175
a6	1	3"x1-5/8"x7 Gauge [76x41x4.6], 49" [1245] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	Heat #53449D R#14-0010

36" [914] Concrete Footing, 6 1/2" [165] Circular Rebar Spacing Around Socket				
Item No.	QTY.	Description	Material Specifications	Reference:
a1	1	Concrete Shaft 36" [914] Long	Min 3500 psi [24 MPa] Comp. Strength	Mix Code: 24013000
a2	4	#4 Rebar 33" [838] Long	Gr. 60	White Cap R#13-0413 No CERTS available
a3	6	#4 Circular Rebar 8" [203] ID	Gr. 60	White Cap R#13-0413 No CERTS available
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	N/A
a5	1	HSS 4x3x1/4" [HSS 102x76x6.4], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	Heat #B200931 R#13-0175
a6	1	3"x1-5/8"x7 Gauge [76x41x4.6], 49" [1245] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	Heat #53449D R#14-0010

Table A-2. Bill of Materials, Test Nos. HTCB-13 and HTCB-14

30" [762] Concrete Footing, 2 1/2" [64] Circular Rebar Spacing Around Socket				
Item No.	QTY.	Description	Material Specifications	Reference:
b1	1	Concrete Shaft 30" [762] Long	Min 3500 psi [24 MPa] Comp. Strength	Mix Code: 24013000
b2	4	#4 Rebar 27" [686] Long	Gr. 60	White Cap R#13-0413 No CERTS available
a3	9	#4 Circular Rebar 8" [203] ID	Gr. 60	White Cap R#13-0413 No CERTS available
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	N/A
a5	1	HSS 4x3x1/4" [HSS 102x76x6.4], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	Heat #B200931 R#13-0175
a6	1	3"x1-5/8"x7 Gauge [76x41x5], 49" [1245] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	Heat #53449D R#14-0010

30" [762] Concrete Footing, 6 1/2" [165] Circular Rebar Spacing Around Socket				
Item No.	QTY.	Description	Material Specifications	Reference:
b1	1	Concrete Shaft 30" [762] Long	Min 3500 psi [24 MPa] Comp. Strength	Mix Code: 24013000
b2	4	#4 Rebar 27" [686] Long	Gr. 60	White Cap R#13-0413 No CERTS available
a3	5	#4 Circular Rebar 8" [203] ID	Gr. 60	White Cap R#13-0413 No CERTS available
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	N/A
a5	1	HSS 4x3x1/4" [HSS 102x76x6.4], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	Heat #B200931 R#13-0175
a6	1	3"x1-5/8"x7 Gauge [76x41x5], 49" [1245] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	Heat #53449D R#14-0010

Table A-3. Bill of Materials, Test No. HTCB-15

24" [610] Concrete Footing, 6 1/2" [165] Circular Rebar Spacing Around Socket				
Item No.	QTY.	Description	Material Specifications	Reference:
c1	1	Concrete Shaft 30" [762] Long	Min 3500 psi [24 MPa] Comp. Strength	Mix Code: 24013000
c2	4	#4 Rebar 21" [533] Long	Gr. 60	White Cap R#13-0413 No CERTS available
a3	5	#4 Circular Rebar 8" [203] ID	Gr. 60	White Cap R#13-0413 No CERTS available
a4	1	4x3x1/4" [102x76x6] Steel Plate	ASTM A36	N/A
a5	1	HSS 4x3x1/4" [HSS 102x76x6.4], 16" [406] Long	ASTM A500 Grade B (Min 42 ksi [290 MPa] Yield Strength)	Heat #B200931 R#13-0175
a6	1	3"x1-5/8"x7 Gauge [76x41x5], 49" [1245] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	Heat #53449D R#14-0010

RM

**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	24013000	1.25	0107		NTE		10:57AM	06/05/13	1164586
CUSTOMER	JOB	CUSTOMER NAME			TAX CODE	PARTIAL	NIGHT R.	LOADS	
00003		CIA---MwRSF							
DELIVERY ADDRESS					SPECIAL INSTRUCTIONS		P.O. NUMBER		
4800 NW 35TH					OFF W. CUMINGS N/OF NORTH GOODY EAR HANGAR		402-450-6250		

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UNIT PRICE	AMOUNT
1.25	1.25	1.25	24013000	14000 MINIMUM HAUL	96.25	120.31
						57.50

WATER ADDED ON JOB
 AT CUSTOMER'S REQUEST 0 GAL

RECEIVED BY J.C. HOLLGEMUTH

SUBTOTAL		177.81
TAX		177.81
TOTAL		177.81

TRUCK	USER LOGIN	DISP	TICKET NUM	TICKET NUM	TICKET ID	TIME	DATE
0107	USER		1164586	183938	36894	10:57	06/05/2013

LOAD SIZE	MIX CODE	SRQ	LOAD ID
1.25 yd	24013000		36962

MATERIAL	SOURCE	DESIGN QTY	REQUIRED	BATCHED	VAR	% VAR	WET MOISTURE	ACTUAL WAT
G47B	47B GRAVEL	2106 lb	2683 lb	2680	-3	-0.1%	1.90 M	5.99 gl
L47B	47B ROCK	916 lb	1152 lb	1140	-12	-1.04%	0.60 M	0.81 gl
CEM1	CEM 1/2	611 lb	764 lb	760	-4	-0.52%		
AIR	MB-AE 90 A	5.50 oz	6.88 oz	8.00	1.12	16.28%		
WATER	WATER	30.0 GL	31.9 GL	32.1	0.2	0.66%		32.12 gl
WATER2	WATER2	0.0 gl	0.0 gl	0.0	0.0	0.00%		

NON-SIMULATED NUM BATCHES: 1

LOAD TOTAL: 4849 lb DESIGN W/C: 0.410 WATER/CEMENT: 0.427A DESIGN WATER: 37.5 gl ACTUAL WATER: 38.9 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

HT Cable Footing/ Mow Strip

2nd COPY

Figure A-1. Concrete Material Specification, Test Nos. HTC12 through HTC16



U.S. Steel Corporation Metallurgical Test Report
Granite City Works
Granite City, IL 62040

ORDER: CQ37275-01 SALES NUM: 1402415 PART: 25237
LOAD: 255005173 INVOICE: 543-851081 SHIP DATE: 05/17/13
PO NBR: 01011330 VEH ID: UP 242055

--- SOLD TO: --- SHIP TO: ---
NORFOLK IRON & METAL CO NORFOLK IRON & METAL CO
PO BOX 1129 3003 N VICTORY RD
NORFOLK, NE 68702-1129 WEST PIT
NORFOLK, NE 68701-0833

MATL ID: HSM 00549853 HEAT: 53449D TEST OR PIECE IDENTITY: HSM 00549853
GAUGE: .1810 IN WIDTH: 60.00 IN LENGTH: COIL 1 PC WEIGHT: 58390 LBS
GAUGE: 4.597 MM WIDTH: 1524 MM LENGTH: COIL 1 PC WEIGHT: 26486 KGS

SPEC: HOT ROLL CARBON ASTM A1011-12B GR 36 TYPE 2 APPROVED SS NON-PICKLE NON-TEMPER ROLLED
HR36SK58 EXPOSED DRY YS MIN 36 KSI TS 58 KSI/80 KSI EL MIN 21 % EL DIST 2 INCHES

INSP: 01 MILL INSPECTION RA/SN ALSO RA/LT, FOR CONVERSION FROM HOT ROLL SHEET TO PLATE
SPECIFICATION ASTM A36 BY PURCHASER. USS HAS NOT PERFORMED TESTING TO THE REFERENCED
PLATE SPECIFICATION. SUCH TESTING IS THE RESPONSIBILITY OF THE PURCHASER.

HEAT: 53449D
C=.22 MN=0.80 P=.011 S=.008 CU=.04 SI=.013 AL=.051 N=.0050 V=.000 CA=.000 MO=.00 CR=.04
NI=.01 SN=.00 CB=.002 TI=.002 B=.0000
Chemical analysis in weight %.

TEST RESULT - 53449D	VALUE	DIRECTION	LOCATION
Yield strength	50500 PSI	Longitudinal	Tail
Tensile strength (UTS)	73000 PSI	Longitudinal	Tail
Elongation %	32%	Longitudinal	Tail
N Value	.190		
Yield strength	56500 PSI	Longitudinal	Tail
Tensile strength (UTS)	79000 PSI	Longitudinal	Tail
Elongation %	29%	Longitudinal	Tail
N Value	.161		

END OF TEST RESULT DATA

THIS IS TO CERTIFY THAT THE PRODUCT DESCRIBED HEREIN WAS MANUFACTURED, TESTED AND/OR INSPECTED
IN ACCORDANCE WITH THE SPECIFICATION AND FULFILLS REQUIREMENTS IN SUCH RESPECT. PREPARED
BY THE OFFICE OF ROBERT J. SNYDER, PROC.TECH MGR. BY: DATE:

*0405 P F 0 0 0 5314000028Z RJS 0 0 1 PAGE 1 OF 2

Z-Posts for HT Cable Footing R# 14-0010 H# 53449D

Figure A-2. Post Material Specification, Test Nos. HTCB-12 through HTCB-16

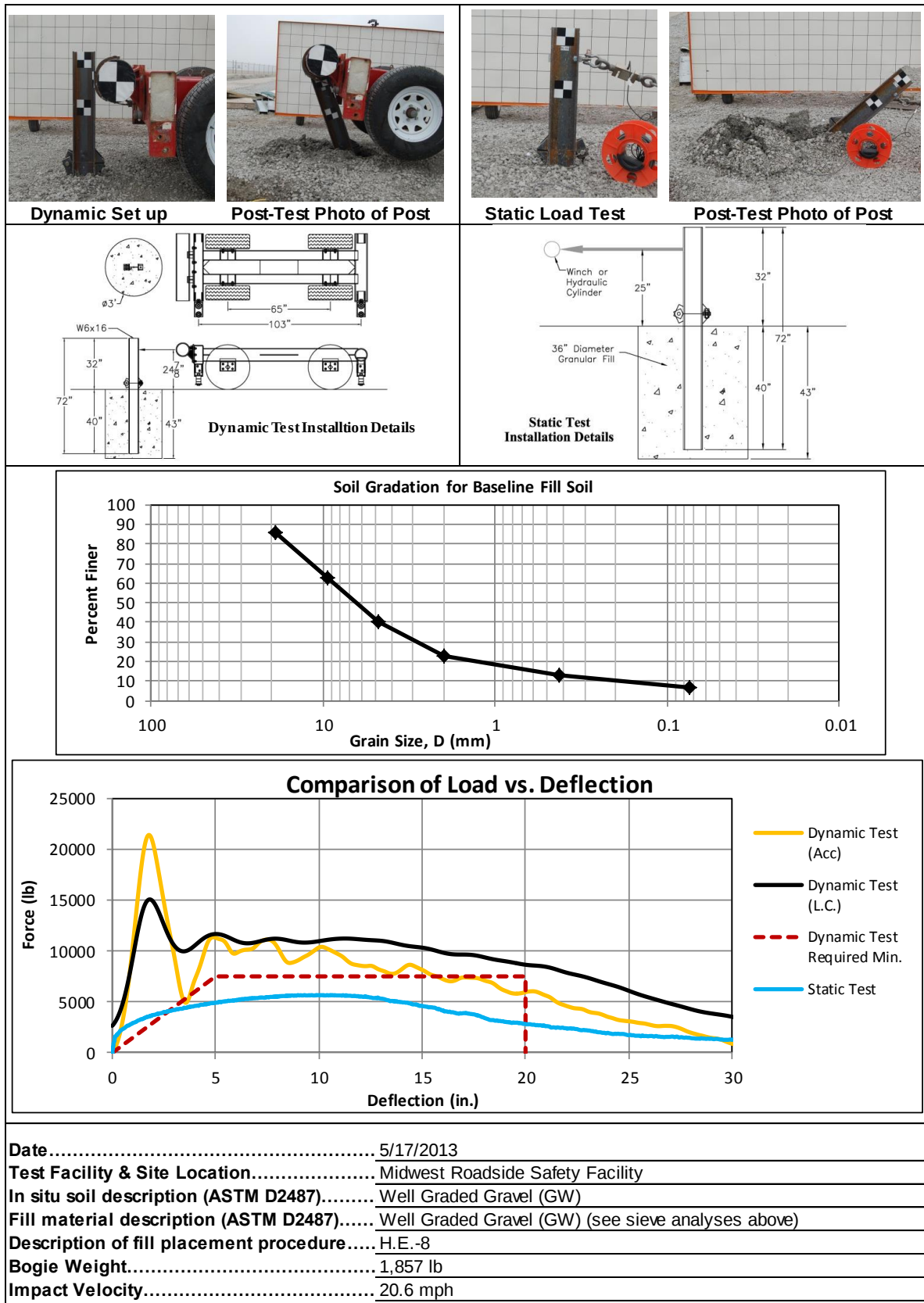


Figure A-4. Strong Soil Specifications, Test Nos. HTCB-12 through HTCB-15

Appendix B. Bogie Test Results

The results of the recorded data from each accelerometer on each 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.

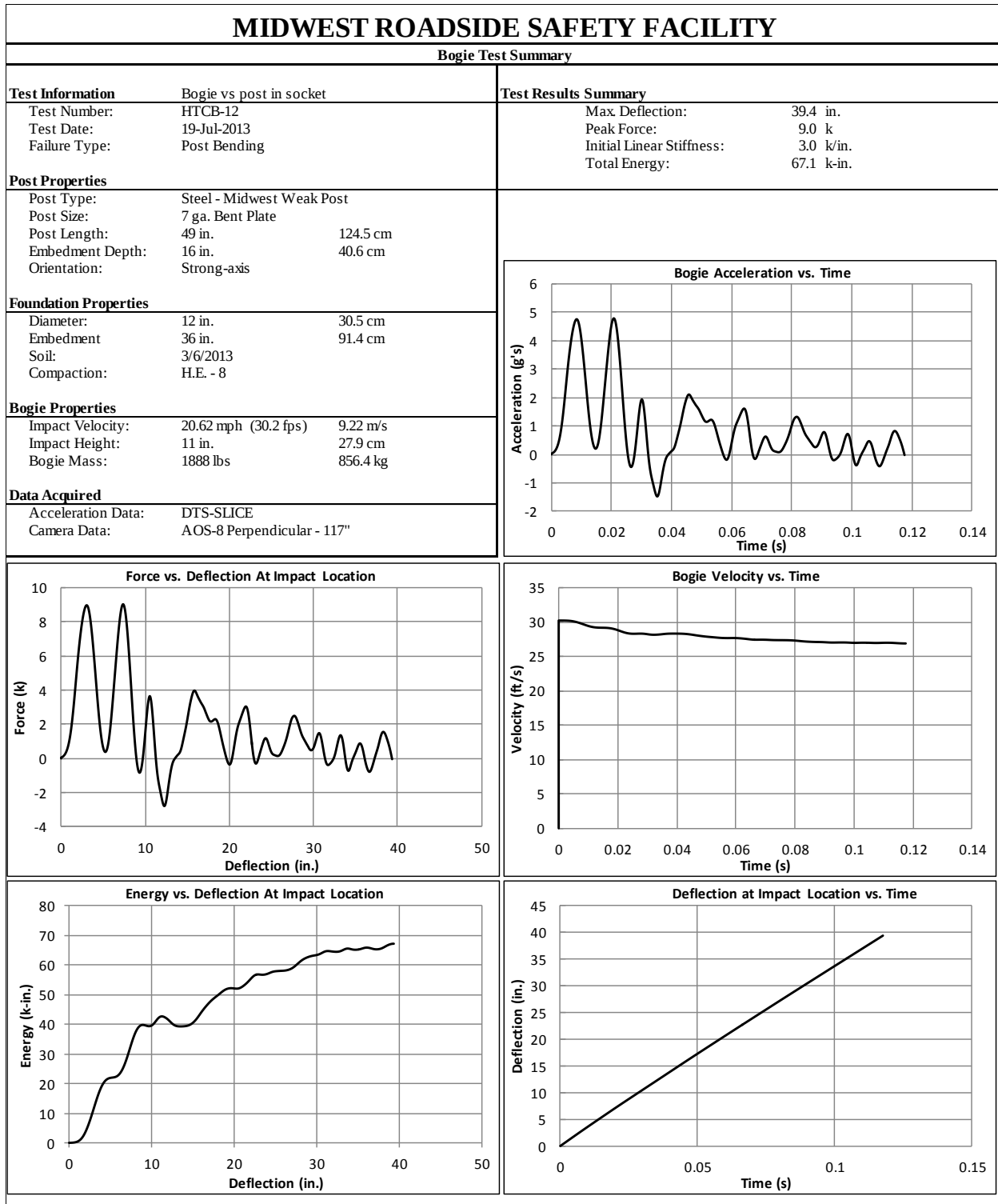


Figure B-1. Test No. HTCB-12 Results (SLICE)

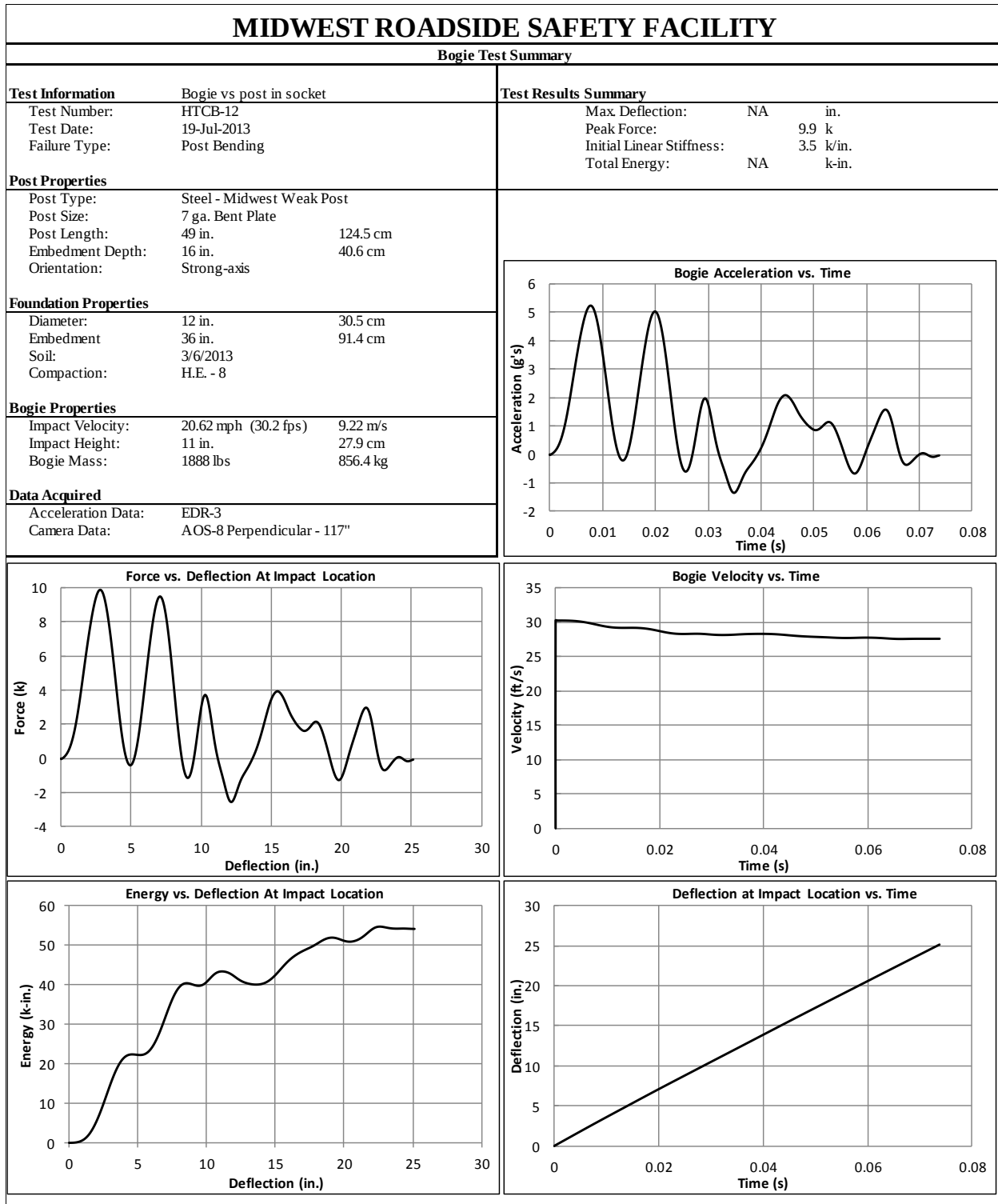


Figure B-2. Test No. HTCB-12 Results (EDR-3)

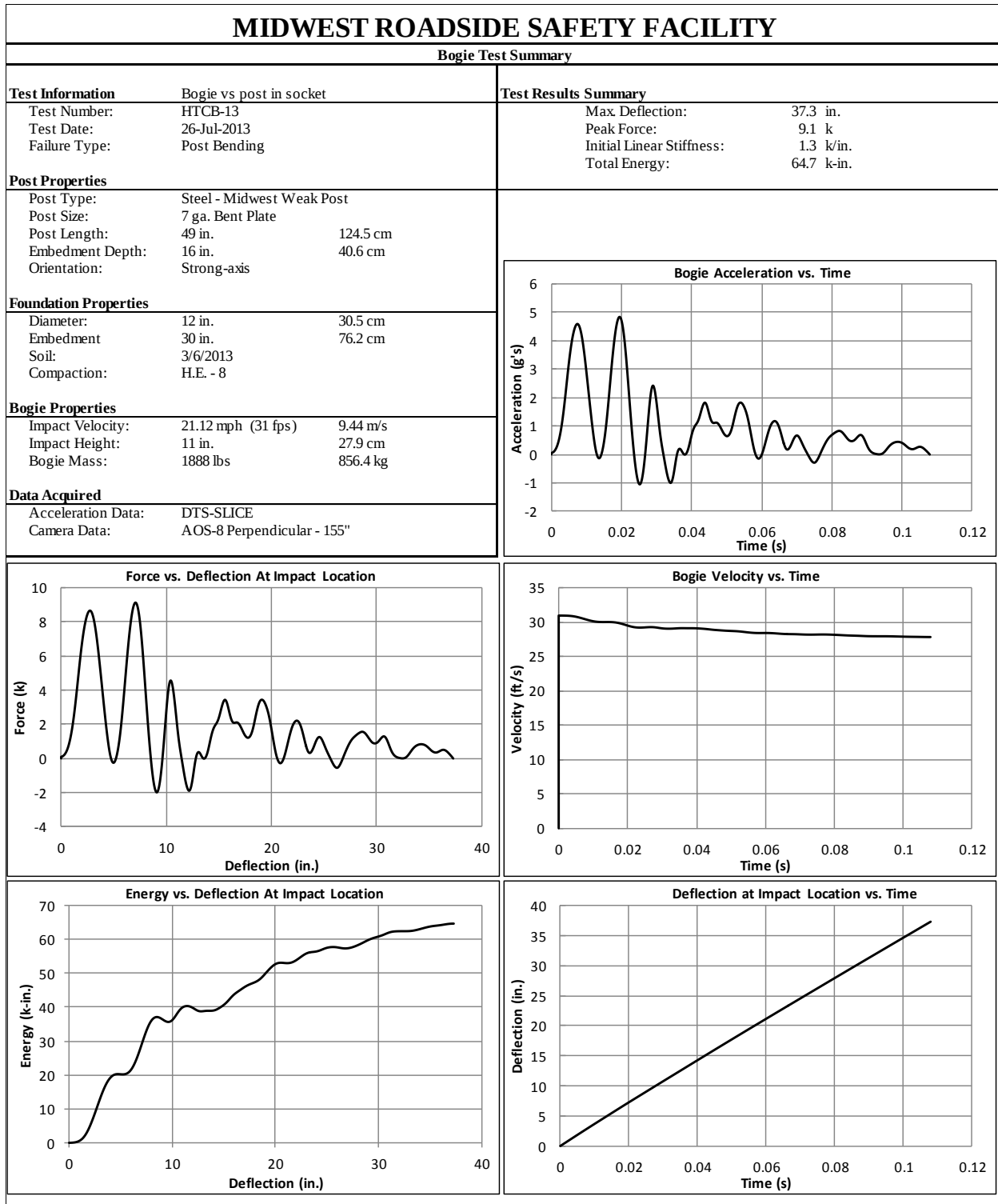


Figure B-3. Test No. HTCB-13 Results (SLICE)

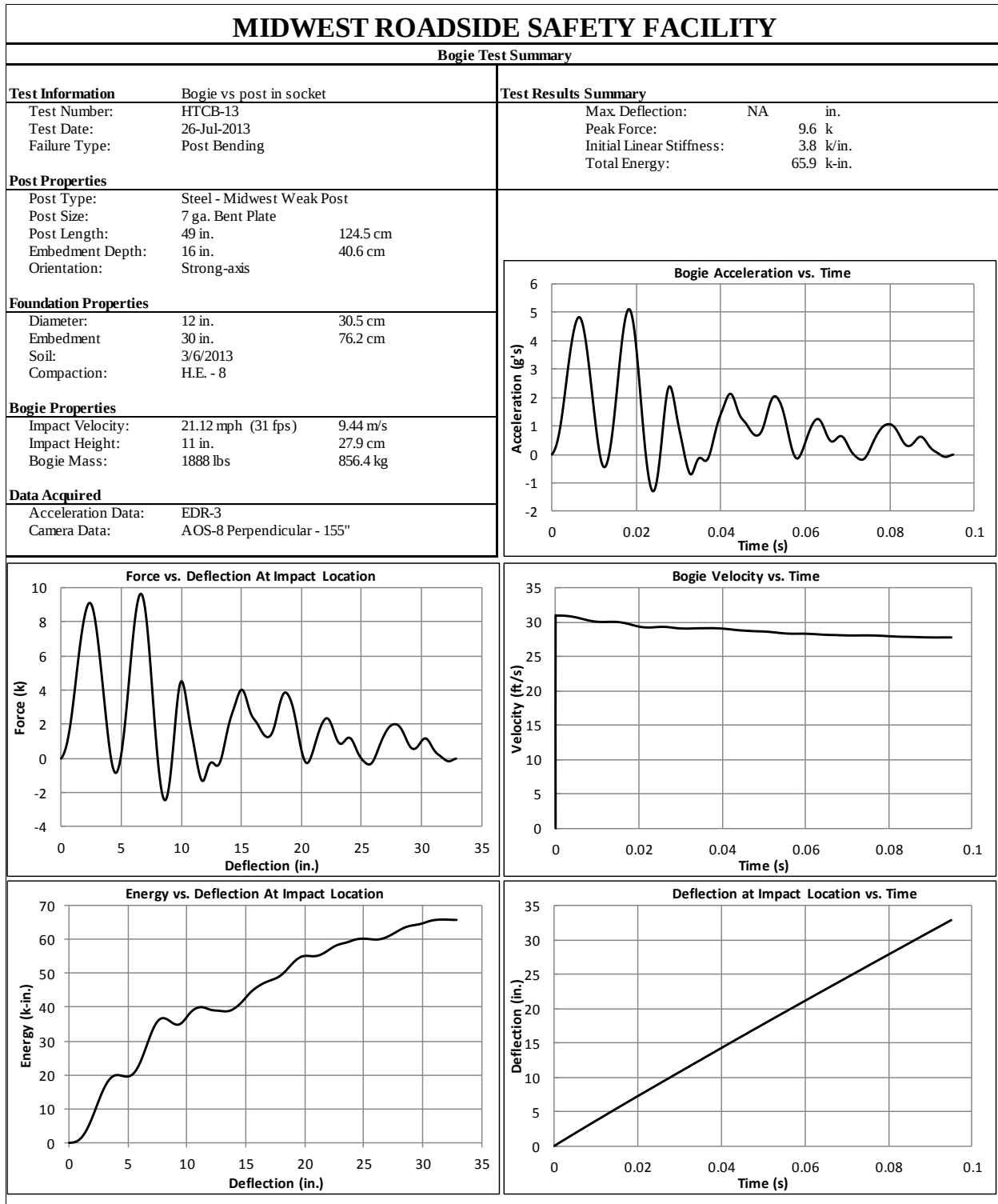


Figure B-4. Test No. HTCB-13 Results (EDR-3)

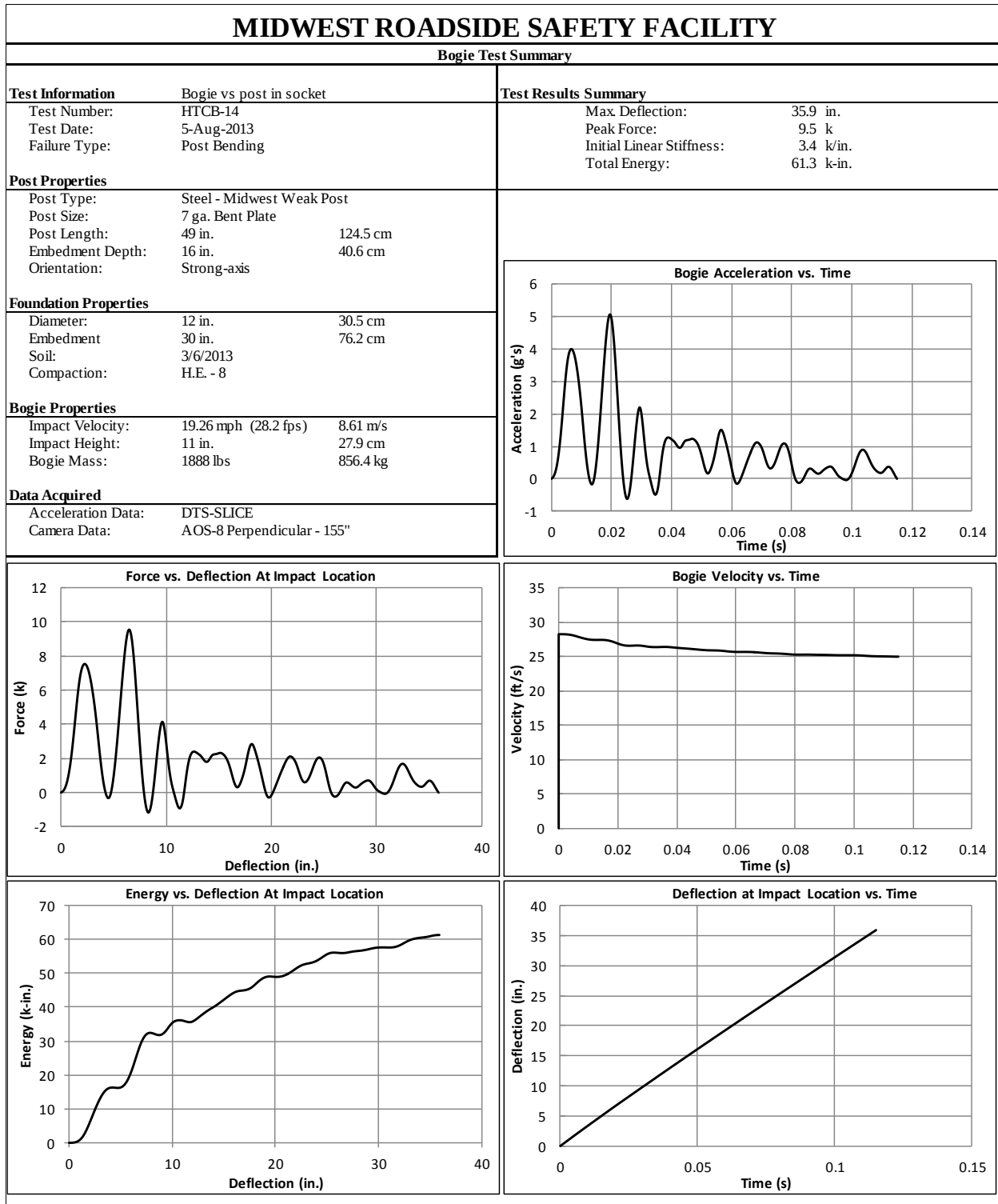


Figure B-5. Test No. HTCB-14 Results (SLICE)

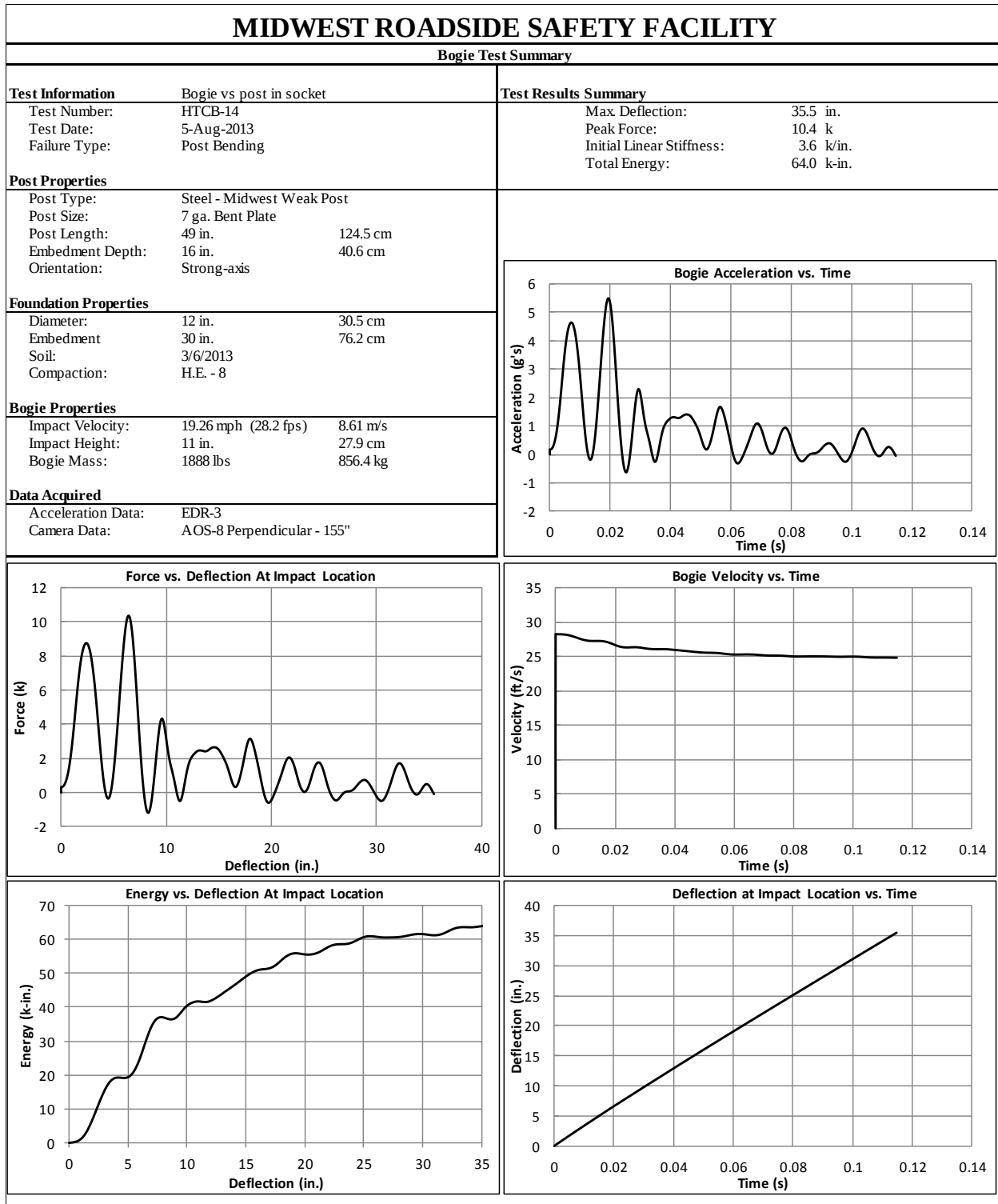


Figure B-6. Test No. HTCB-14 Results (EDR-3)

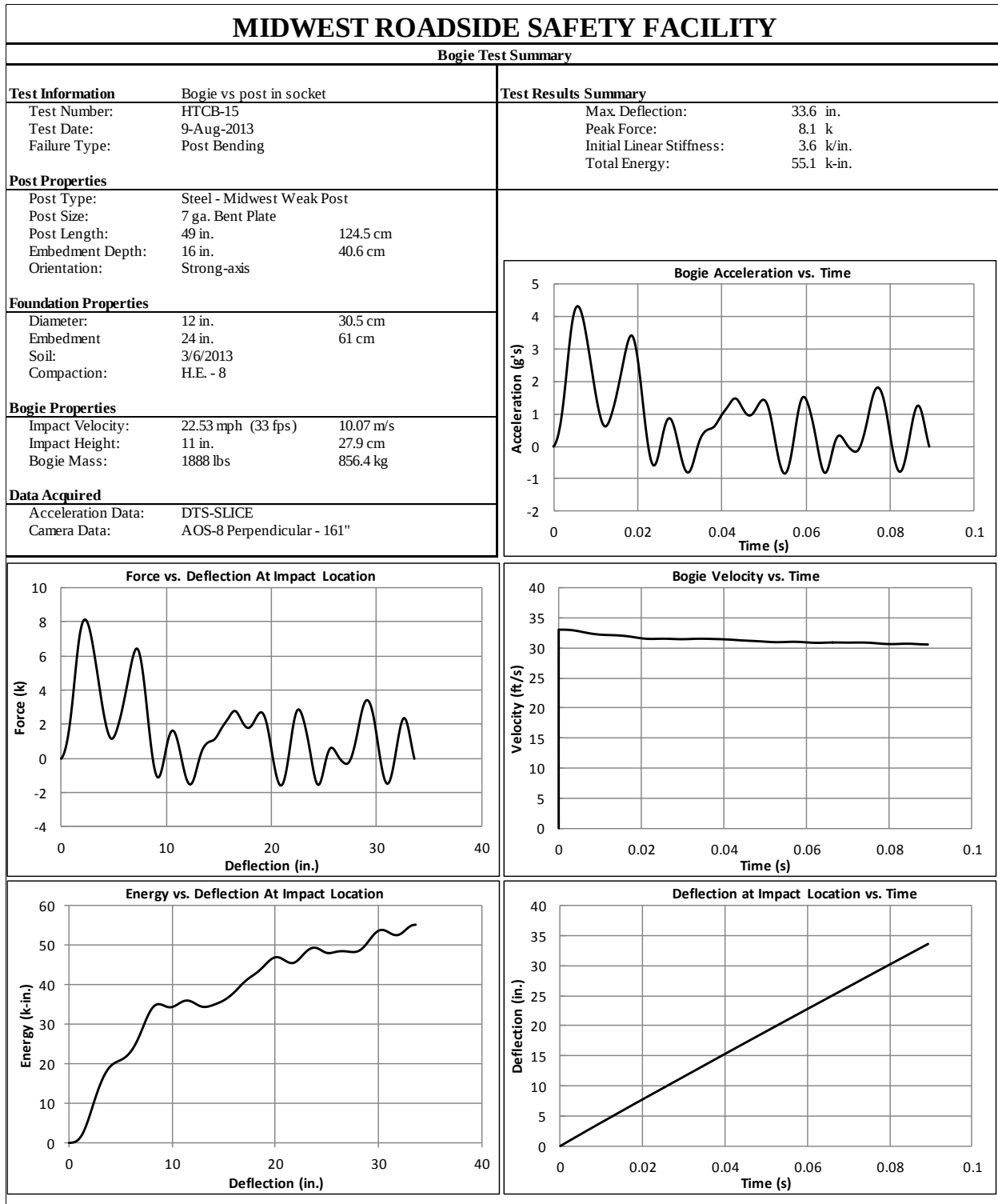


Figure B-7. Test No. HTCB-15 Results (SLICE)

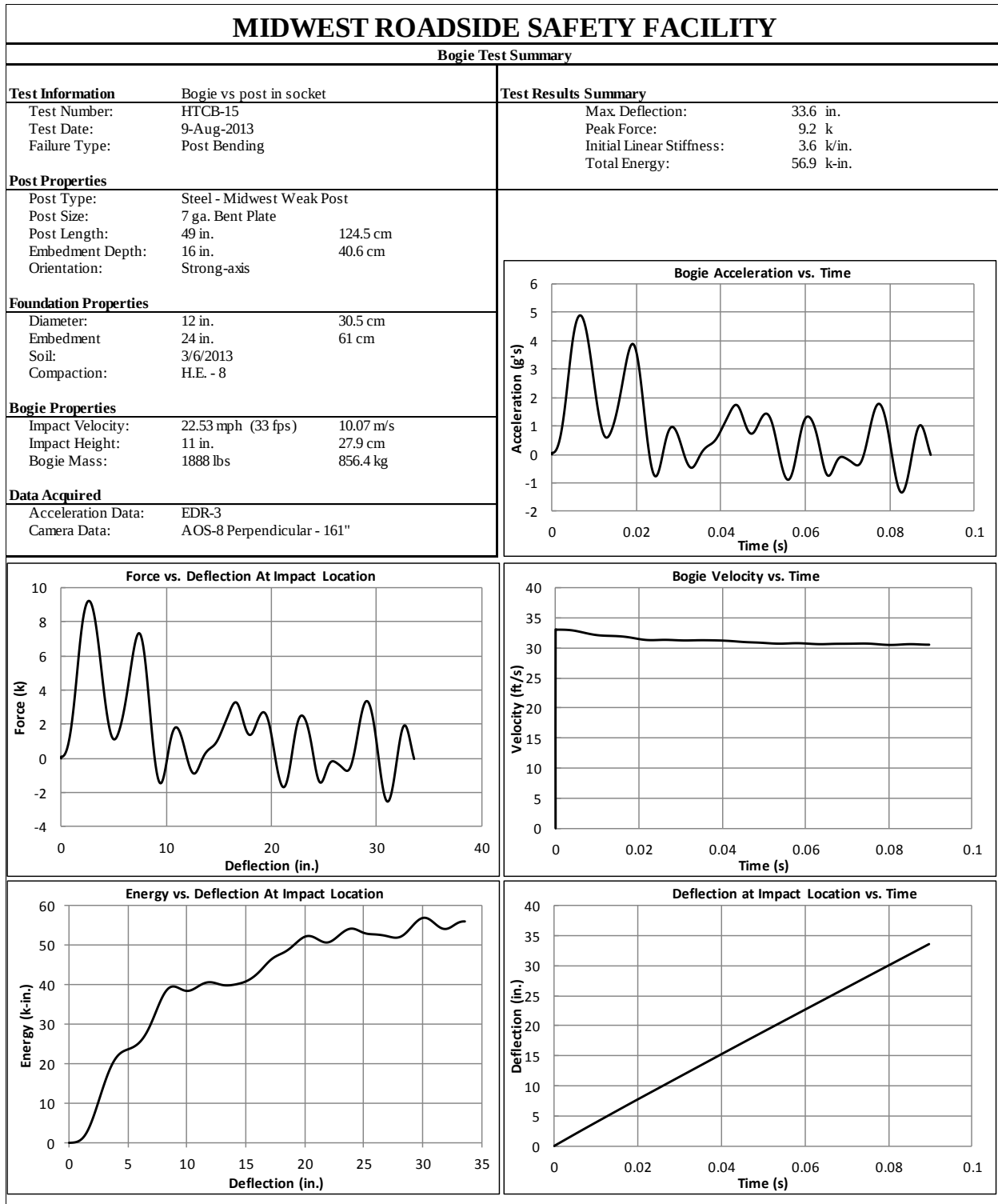


Figure B-8. Test No. HTCB-15 Results (EDR-3)

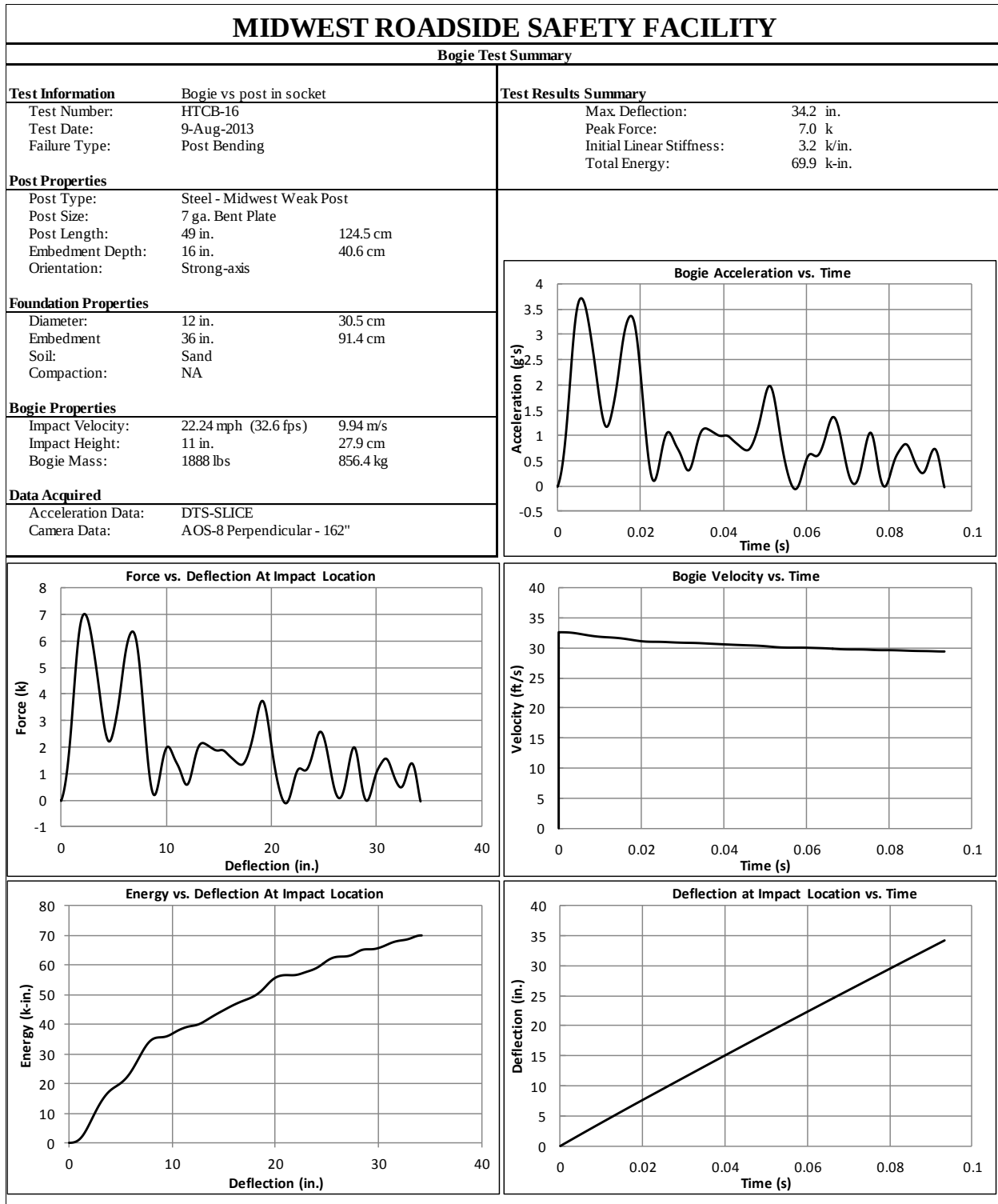


Figure B-9. Test No. HTCB-16 Results (SLICE)

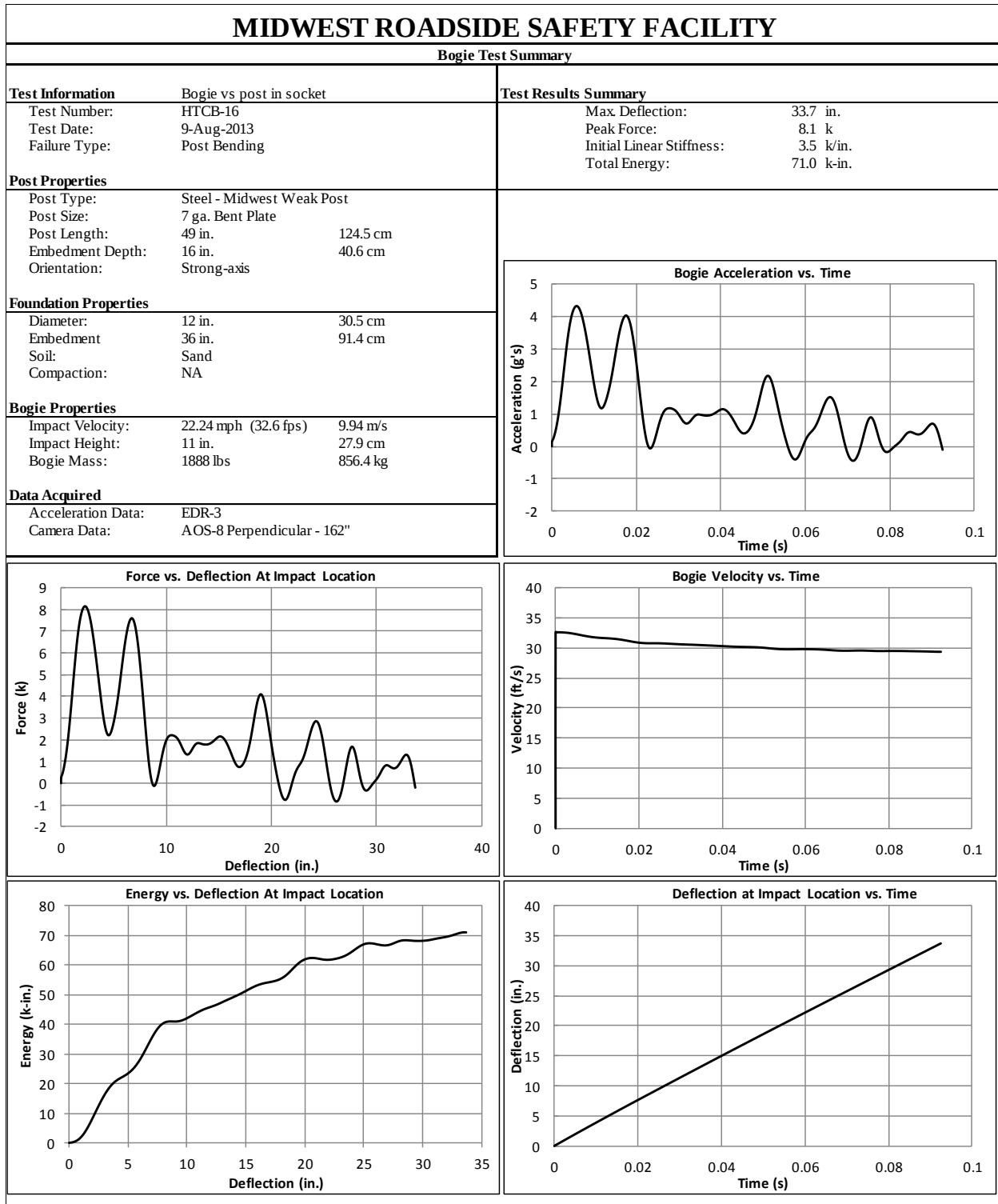


Figure B-10. Test No. HTCB-16 Results (EDR-3)

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