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DESIGN AND EVALUATION OF A HIGH-TENSION CABLE MEDIAN BARRIER ATTACHMENT

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16. Abstract (Limit: 200 words)

Dynamic testing of a cable-to-post attachment for a high-tension cable median barrier design is described in this report. Many variations of a keyway bolt that connected a high-tension cable to an S-shaped steel post were designed and tested. This attachment was found capable of sustaining a target load of approximately 8.00 kips (35.59 kN) when loaded laterally, while releasing the cable vertically at a load close to 1.00 kips (4.45 kN). These loads were selected to develop the full moment capacity of the posts in cable median barriers while ensuring that the cables are not pulled down as the posts deflect.

Six full scale dynamic bogie tests were conducted to test the behavior of the keyway bolt attachments when loaded in a manner similar to an actual crash. These tests showed favorable results and the cable clip developed was recommended for use in the high-tension cable barrier system.

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1 INTRODUCTION

1.1 Background

The Midwest Roadside Safety Facility (MwRSF) was contracted to develop a non-proprietary, high-tension, cable median barrier. This barrier was to be developed for use at any location within a median with up to a 4:1 sloped V-ditch. Cable-to-post attachments desired for low-tension cable barriers were disadvantageous because they were designed for impacts from only one direction. It is necessary for cable median barrier attachment hardware to develop the full moment capacity when loaded laterally while releasing vertically at much lower loads to avoid pulling the cable toward the ground with the deformed posts. In addition, the low vertical release load is also necessary to prevent the cable from locking down on the A-pillar of the vehicle of small passenger cars, which could cause the cable to penetrate the occupant compartment. Since cable median barrier crashes may occur from either direction of traffic, the attachment hardware must develop similar strength and release with similar behavior when loaded from either side of the barrier. Therefore, a new connection design was needed to ensure the safety and functionality of the high-tension cable median barrier.

MwRSF designed and tested a keyway bolt connection that was engineered to perform satisfactorily in conjunction with the high-tension cable median barrier. Dynamic tests were performed on cable attachment hardware at various orientations to simulate different stages of the deformed post during a crash [1].

MwRSF previously conducted three full-scale crash tests on the four cable high-tension cable median barrier that utilized a curved keyway bracket cable clip to attach the cables to the posts of the barrier (test nos. 4CMB-1 through 4CMB-3) [2]. The full-scale crash test no. 4CMB-3 consisted of an 1100C vehicle impacting the cable barrier at a speed of approximately 62.0 mph (99.8 km/h) and at an impact angle of 26.7 degrees. This crash test was considered

unacceptable according to the *Manual for Assessing Safety Hardware* (MASH) standards because the cable caused deformations and intrusion into the occupant compartment that could have caused serious injuries. The cause of the failed test was that the cable snagged on the cable-to-post attachments, which caused the cables to be pulled down on the A-pillar of the vehicle.

1.2 Objective

The project had three main objectives: (1) meet/maintain the cable release behavior from the curved keyway bracket design that was previously crash tested by MwRSF, (2) prevent the cable snagging problems that were present in test no. 4CMB-3 as the cables moved up the posts, and (3) simplify and minimize the number of connecting parts in the cable-to-post connection. The attachment needed to satisfy the targeted strength and cable release behavior for lateral and vertical loads. Initially, a minimum lateral pullout load of 6.00 kips (26.69 kN) was required, with a maximum vertical pullout load of 1.00 kips (4.45 kN). However, upon further investigation, it was decided that the lateral load capacity needed to be increased to 8.00 kips (35.59 kN).

Other factors included in the design were affordability and constructability. The newly developed cable attachment needed to be designed without infringing on current cable-to-post connection patents.

1.3 Scope

Because of the unacceptable behavior of the cable bracket attachments used in test no. 4CMB-3, a new cable-to-post attachment needed to be developed that would release the cable vertically to prevent the cable from being pulled down over the A-pillar of the vehicle. A series of component level tests were conducted to evaluate and fine tune the cable-to-post attachment design. The initial design had several variations that were tested and modified in the field tests. The different variations were tested with lateral, vertical, and angled dynamic loads. After the

cable-to-post attachment were determined to exhibit the correct release requirements, a series of dynamic bogie tests were conducted to evaluate the performance of the attachment in the actual cable barrier system.

2 LITERATURE REVIEW

MwRSF investigated high-tension cable barrier connection design patents in previous research [1]. The current patents include: the Cable Safety System (CASS) produced by Trinity Highway Systems, the Gibraltar Cable Barrier System, the U.S. High Tension Cable Barrier System produced by Nucor Marion Steel, Inc., the Safence Barrier developed by Blue Systems AB, and the Wire Rope Safety Fence (WRSF) produced by Brifen USA, Inc. Detailed descriptions of these high-tension cable median barrier attachments can be found in MwRSF report no. TRP-03-200-08, *Design and Evaluation of High-Tension Cable Median Barrier Hardware*.

Component level tests were conducted on the curved keyway brackets that were used in the high-tension cable barrier for test nos. 4CMB-1 through 4CMB-3. The bracket failed at a lateral load of 5.72 kips (25.44 kN). The bracket test with shoulder bolts allowed the cable to release near the target load of 1.00 kips (4.45 kN) [1].

The full scale crash test no. 4CMB-3 consisted of an 1100C vehicle impacting the cable barrier at a speed of approximately 62.0 mph (99.8 km/h) and at an impact angle of 26.7 degrees. This test failed the MASH 3-10 test criteria because the cables were pulled down on the A-pillar of the vehicle which caused deformations and intrusion into the occupant compartment that could have caused serious injuries [2]. In this test, the cables snagged on the shoulder bolts that attached the curved keyway brackets to the posts. Therefore, the cables were not released vertically and locked down on the A-pillar of the vehicle.

3 CABLE ATTACHMENT DESIGN DETAILS

3.1 Introduction

In previous research, MwRSF conducted numerous dynamic bogie tests on cable attachments for the high-tension cable median barrier. Those tests included curved keyway brackets and keyway bolt attachments [1]. The cable attachments were initially required to develop a minimum of 6.00 kips (26.69 kN) of load laterally and a maximum of 1.00 kips (4.45 kN) vertically to fully develop the lateral resistance of the line posts and to prevent the cable from being pulled down by the deformed posts, respectively.

MwRSF conducted component level tests in a load cell jig on a keyway bolt with a button end to improve the design of the cable attachment. The keyway bolt cable-to-post attachment tests were conducted with three main goals: (1) maintain the vertical and horizontal release loads as the curved keyway bracket used in test nos. 4CMB-1 through 4CMB-3, (2) prevent the cable from snagging on the attachment, and (3) simplify the attachment design. After satisfactory test results were obtained, bogie tests with the keyway bolt attachment mounted in the actual high-tension cable barrier system were conducted to verify the dynamic performance of the bolts.

3.2 S3x5.7 Post Jigs

The standard post used in the high-tension cable median barrier was an S3x5.7 (S76x8.5) section. The post was manufactured from ASTM A36 steel and has a cross section in accordance with A6M standards. The post primarily consisted of three major components: two flanges and the connecting web. The flanges were 2.33 in. (59 mm) wide and 0.26 in. (7 mm) thick, while the web was 0.17 in. (4 mm) thick. All testing described herein used S3x5.7 (S76x8.5) posts or sections of S3x5.7 (S76x8.5) posts for mounting the cable attachments.

3.3 Test Configuration

The keyway bolt attachments were tested at different angles to determine the connection strength at different stages of the deformed post. The angle of the test was measured as the angle from the face of the flange of the post to the direction of the force. A 90 degree test was analogous to a lateral load while a 0 degree test was analogous to a vertical load. Any test with an angle between 0 and 90 degrees simulated the loading condition of a partially deformed post. A summary of the tests and conditions are shown in Tables 1 through 3.

Two different keyway designs were used in the tests. The first design, denoted slot and keyway design type 1, consisted of a slot to hold the threaded end of the keyway bolt and a keyway to hold the button end as shown in the top of Figure 1. This design was modified for several tests by grinding off some of the steel around the slot. The "elongated" remark in Tables 1 through 3 indicates that the slot was modified in the field to slightly enlarge the slot. The second design, denoted slot and keyway design type 2, consisted of a hole slightly larger than the diameter of the keyway bolt to hold the threaded end and a keyway to hold the button end as shown in the bottom of Figure 1. Detailed drawings of both keyway designs are shown in Appendix A.

The tests included several variations of nut connections that ranged from using single or double nuts with loose or tight configurations. Tests conducted with the nuts in the "loose" condition were configured with a small gap between the nut(s) and the flange. Tests conducted with the nuts in the "tight" condition were configured with the nut(s) tightened to the flange with a wrench. All other tests were conducted with the nut(s) tightened by hand. The following test configurations were used: 1 single grade 2 nut, 2 grade 2 nuts, 1 grade 5 nut, and 1 grade 8 high-topped nut.

Figure 1. Slot and Keyway Designs (Top=Type 1, Bottom=Type 2)

3.4 Keyway Bolt Attachments

The basic design of the cable-to-post connection tested consisted of a U-shaped bolt with a button on one end and a shoulder and threaded stud on the other end. The threaded end of the keyway bolt was inserted into a slot below the button and fastened to the flange with a nut. The button head was inserted into a keyway that allowed the keyway bolt to straighten and release the cable when subjected to vertical pullout loads. Detailed drawings of the keyway bolt designs are shown in Appendix A. Material specifications for the hardware used in the bogie tests are shown in Appendix B. There were three basic keyway bolt designs that were tested: (1) the C1018 keyway bolt, (2) the modified C1018 keyway bolt, and (3) the A449 keyway bolt.

3.4.1 C1018 Keyway Bolt

For test nos. HTCUB-1 through HTCUB-26, the keyway bolt was made from C1018 galvanized steel. The shaft of the keyway bolt had a diameter of ¼ in. (6 mm). The C1018 keyway bolt is shown in Figure 2. The test matrix for the C1018 keyway bolt is shown in Table 1.

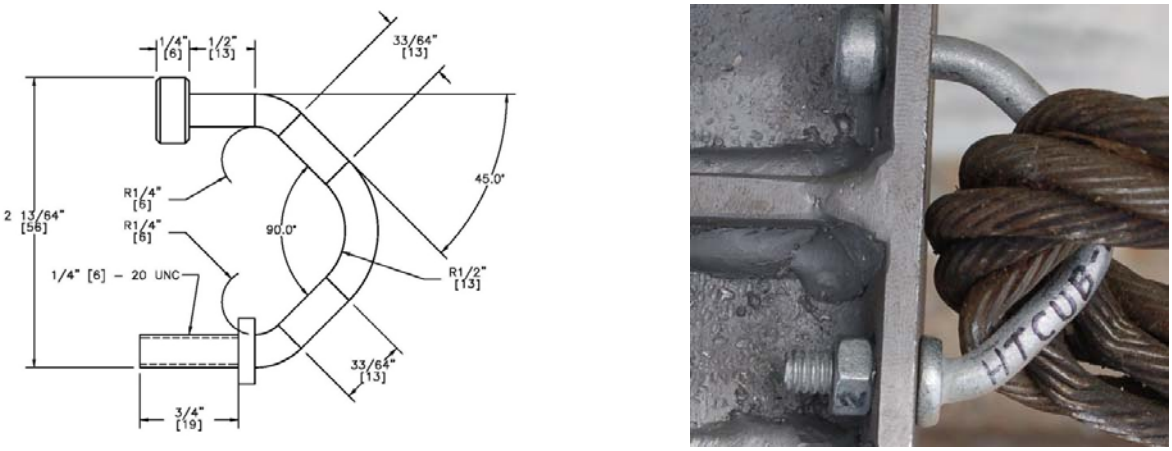


Figure 2. C1018 Keyway Bolt

Table 1. C1018 Keyway Bolt Test Summary

Test	Angle	Nuts	Keyway Bolt	Remarks
HTCUB-1	90°	Grade 2 - Single - Hand	C1018	Position in Slot=Center
HTCUB-2	90°	Grade 2 - Single - Hand	C1018	Position in Slot=Center
HTCUB-3	90°	Grade 2 - Double - Hand	C1018	Position in Slot=Center
HTCUB-4	90°	Grade 2 - Double - Hand	C1018	Position in Slot=Center
HTCUB-5	0°	Grade 2 - Double - Hand	C1018	Position in Slot=Bottom
HTCUB-6	0°	Grade 2 - Double - Hand	C1018	Position in Slot=Upper-Center
HTCUB-7	0°	Grade 2 - Double - Loose	C1018	Position in Slot=Lower-Center
HTCUB-8	0°	Grade 2 - Double - Loose	C1018	Position in Slot=Lower-Center
HTCUB-9	0°	Grade 2 - Double - Loose	C1018	Position in Slot =Lower-Center
HTCUB-10	0°	Grade 2 - Double - Loose	C1018	Position in Slot=Bottom, Slot Elongated
HTCUB-11	0°	Grade 2 - Double - Hand	C1018	Position in Slot=Center, No Shoulder on Keyway Bolt
HTCUB-12	0°	Grade 2 - Double - Tight	C1018	Position in Slot=Top, Slot Elongated
HTCUB-13	0°	Grade 2 - Double - Tight	C1018	Position in Slot=Bottom, Slot Elongated
HTCUB-14	0°	Grade 2 - Double - Tight	C1018	Position in Slot=Bottom, Slot Elongated
HTCUB-15	0°	Grade 2 - Double - Tight	C1018	Position in Slot=Bottom, Slot Elongated, Reduced Button
HTCUB-16	0°	Grade 2 - Double - Tight	C1018	Position in Slot=Bottom, Slot Elongated, Reduced Button
HTCUB-17	90°	Grade 5 - Single - Loose	C1018	Position in Slot=Top, Slot Elongated
HTCUB-18	15°	Grade 5 - Single - Loose	C1018	Position in Slot=Lower-Center, Slot Elongated
HTCUB-19	30°	Grade 5 - Single - Loose	C1018	Position in Slot=Center, Slot Elongated
HTCUB-20	45°	Grade 5 - Single - Loose	C1018	Position in Slot=Bottom, Slot Elongated
HTCUB-21	0°	Grade 2 - Double - Tight	C1018	Position in Slot=Top, Slot Elongated

Table 1. C1018 Keyway Bolt Test Summary (Continued)

Test	Angle	Nuts	Keyway Bolt	Remarks
HTCUB-22	0°	Grade 2 - Double - Tight	C1018	Position in Slot=Top, Slot Elongated
HTCUB-23	90°	Grade 2 - Double - Tight	C1018	Position in Slot=Top, Slot Elongated
HTCUB-24	45°	Grade 2 - Double - Tight	C1018	Position in Slot=Top, Slot Elongated
HTCUB-25	60°	Grade 2 - Double - Tight	C1018	Position in Slot=Top, Slot Elongated
HTCUB-26	60°	Grade 2 - Double - Tight	C1018	Position in Slot=Top, Slot Elongated

*All tests utilized the type 1 slot and keyway design

3.4.2 Modified C1018 Keyway Bolt

For test nos. HTCUB-27 through HTCUB-30, the keyway bolt was made from C1018 galvanized steel, but the shape of the bolt was modified from the design used in test nos. HTCUB-1 through HTCUB-26. The modified C1018 keyway bolt only contained two bends and had a longer shaft attached to the button end. The modified C1018 keyway bolt is shown in Figure 3. The test matrix for the modified C1018 keyway bolt is shown in Table 2

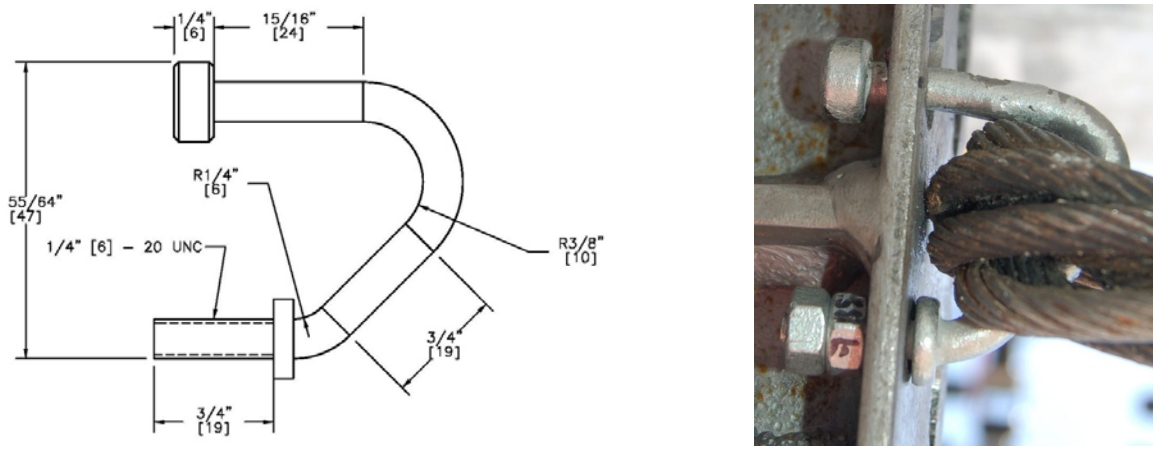


Figure 3. Modified C1018 Keyway Bolt

Table 2. Modified C1018 Keyway Bolt Test Summary

Test	Angle	Nuts	Keyway Bolt	Remarks
HTCUB-27	45°	Grade 2 - Double - Tight	C1018	Type 2 Slot and Keyway, Modified Keyway Bolt
HTCUB-28	90°	Grade 2 - Double - Tight	C1018	Type 2 Slot and Keyway, Modified Keyway Bolt
HTCUB-29	60°	Grade 2 - Double - Tight	C1018	Type 2 Slot and Keyway, Modified Keyway Bolt
HTCUB-30	0°	Grade 2 - Double - Tight	C1018	Type 2 Slot and Keyway, Modified Keyway Bolt

3.4.3 A449 Keyway Bolt

For test nos. HTCUB-31 through HTCUB-37, the keyway bolt was made from ASTM A449 galvanized steel and had a similar shape as the C1018 keyway bolt design. However, the threads were terminated 3/32 in. (2.38 mm) from the shoulder of the keyway bolt. The A449 keyway bolt is shown in Figure 4. The test matrix for the A449 keyway bolt is shown in Table 3

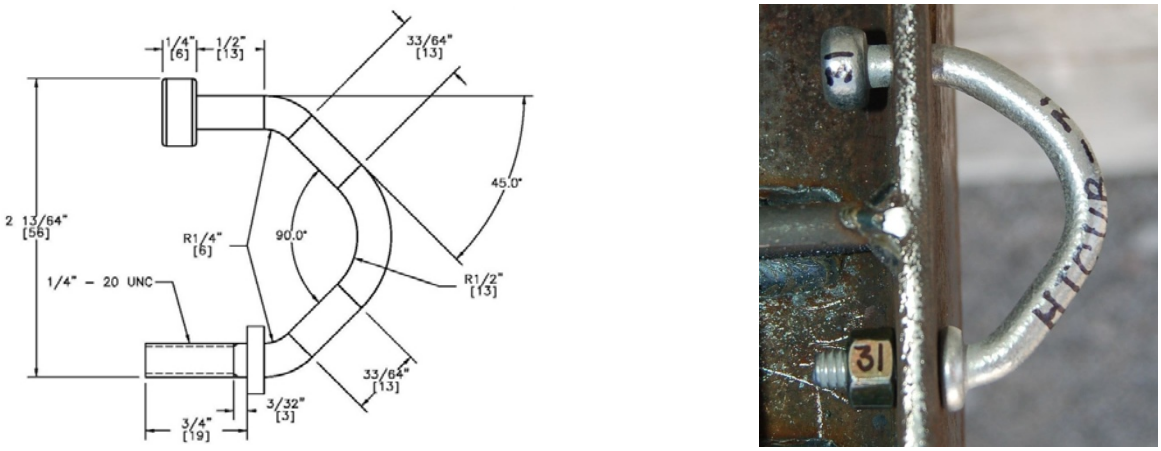


Figure 4. A449 Keyway Bolt

Table 3. A449 Keyway Bolt Test Summary

Test	Angle	Nuts	Keyway Bolt	Remarks
HTCUB-31	0°	Grade 8 - Single - Tight	A449	Type 2 Slot and Keyway, High-Topped Nut
HTCUB-32	0°	Grade 8 - Single - Tight	A449	Type 2 Slot and Keyway, High-Topped Nut
HTCUB-33	90°	Grade 8 - Single - Tight	A449	Type 2 Slot and Keyway, High-Topped Nut
HTCUB-34	90°	Grade 8 - Single - Tight	A449	Type 2 Slot and Keyway, High-Topped Nut
HTCUB-35	0°	Grade 8 - Single - Tight	A449	Type 2 Slot and Keyway, High-Topped Nut
HTCUB-36	0°	Grade 8 - Single - Tight	A449	Type 2 Slot and Keyway, High-Topped Nut
HTCUB-37	0°	Grade 8 - Single - Tight	A449	Type 2 Slot and Keyway, High-Topped Nut

4 CABLE ATTACHMENT DYNAMIC COMPONENT TESTING

4.1 Purpose

Dynamic performance of the keyway bolts was evaluated with bogie tests before implementation in a full-scale test. These tests were designed to demonstrate the performance of the keyway bolt design when subjected to cable loads at dynamic speeds and to measure the fracture and release loads of the attachment. In addition, the behavior of the keyway bolt connection was observed when loaded at angles that simulated different stages of the deformed post. It should be noted that cable size used in the dynamic bogie tests was ¾"-6x19, and the actual cable size utilized in the high-tension cable barrier system was ¾"-3x7, which is much stiffer in bending.

4.2 Scope

A series of 37 bogie tests were conducted on the keyway bolt connection. These tests consisted of attaching one end of a cable to a bogie and the other end to the keyway bolt which was mounted to the post section and attached to an adjustable plate. The bogie was then set in motion, away from the bracket, placing a dynamic load on the connection until fracture or release of the attachment through the keyway occurred. The target cable speed was 5.0 mph (8.0 km/h) and the cables were loaded at a range of angles between 0 and 90 degrees (0 degrees = parallel to the post flange, 90 degrees = perpendicular to the post flange).

4.3 Test Facility

Physical testing of the keyway bolt attachment was conducted at the MwRSF testing facility 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) from the University of Nebraska-Lincoln's city campus.

4.4 Equipment and Instrumentation

A variety of equipment and instrumentation was utilized to collect and record data during the dynamic bogie tests including:

- Bogie
- Load Cell
- Accelerometers
- Photography Cameras
- Test Jig

4.4.1 Bogie

A rigid frame bogie was used to pull a cable attached to the keyway bolt attachment as shown in Figure 5. The weight of the bogie was 1,831 lb (831 kg) for test nos. HTCUB-1 through HTCUB-6, 1,827 lb (829 kg) for test nos. HTCUB-7 through HTCUB-10, 1,819 lb (825 kg) for tests nos. HTCUB-11 through HTCUB-20, 1,727 lb (783 kg) for test nos. HTCUB-21 through HTCUB-30, and 1,816 lb (824 kg) for test nos. HTCUB-31 through HTCUB-37.

The bogie guidance track used in test nos. HTCUB-1 through HTCUB-37 consisted of a corrugated steel beam railing to guide the right-side tires of the bogie. A pickup truck was attached to the bogie by a cable and was used to pull the bogie to a target speed of approximately 5.0 mph (8.0 km/h). When the bogie approached the end of the guidance system, the pickup truck braked allowing the bogie to be free rolling when it applied the load to the keyway bolt.

Figure 5. Rigid Frame Bogie on Guidance Track

4.4.2 Accelerometer

An accelerometer system was mounted on the bogie vehicle near its center of gravity to measure the acceleration in the longitudinal, lateral, and vertical directions for test nos. HTCUB-1 through HTCUB-20 and test nos. HTCUB-31 through HTCUB-35. The accelerometer data used only as a backup if the force history could not be determined from the load cell transducer. The accelerometer was not utilized in test nos. HTCUB-21 through HTCUB-30 and HTCUB-36 through HTCUB-37.

The accelerometer, Model EDR-3, was a triaxial piezoresistive accelerometer system developed by Instrumented Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM memory, 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.

4.4.3 Load Cell

A load cell was placed within the testing apparatus to measure the force exerted on the keyway bolt until failure. This load cell was placed in tension between the attachment and the stationary barrier and had a maximum capacity of 50 kips (222 kN).

4.4.4 High-Speed Digital Photography

Two high-speed AOS VITcam digital video cameras with operating speeds of 500 frames/sec were used to record video imagery of the dynamic testing. One camera was placed above the attachment, facing downward, while the other camera was placed at the same height as the attachment, perpendicular to the test jig.

4.4.5 Digital Photography

Two JVC digital video cameras were used to film the dynamic tests. There cameras operated at a speed of 29.97 frames/sec. One camera was placed above the attachment, facing downward, while the other camera was placed at the same height as the attachment, perpendicular to the test jig.

A Nikon D50 digital still camera was also used to record pre- and post-test images of the dynamic tests.

4.4.6 Test Jig

The test jig consisted of a small section of an S3x5.7 (S76x8.5) post that was connected to an adjustable plate and had a slot and keyway cut into the flange. The adjustable plate was connected through a steel tube to a stationary barrier. The steel tube was attached to the mounting plate by a cylindrical joint which allowed a tension load cell to be used to measure the loads. The keyway bolt was attached to the post section with either 1 or 2 nuts. A cable was then looped through the keyway bolt and tied to a bogie that was set in motion, away from the

attachment, at a speed of approximately 5 mph (8 km/h). Drawings of the test setup are shown in Figure 6 and detailed drawings of the test jig are shown in Appendix A.

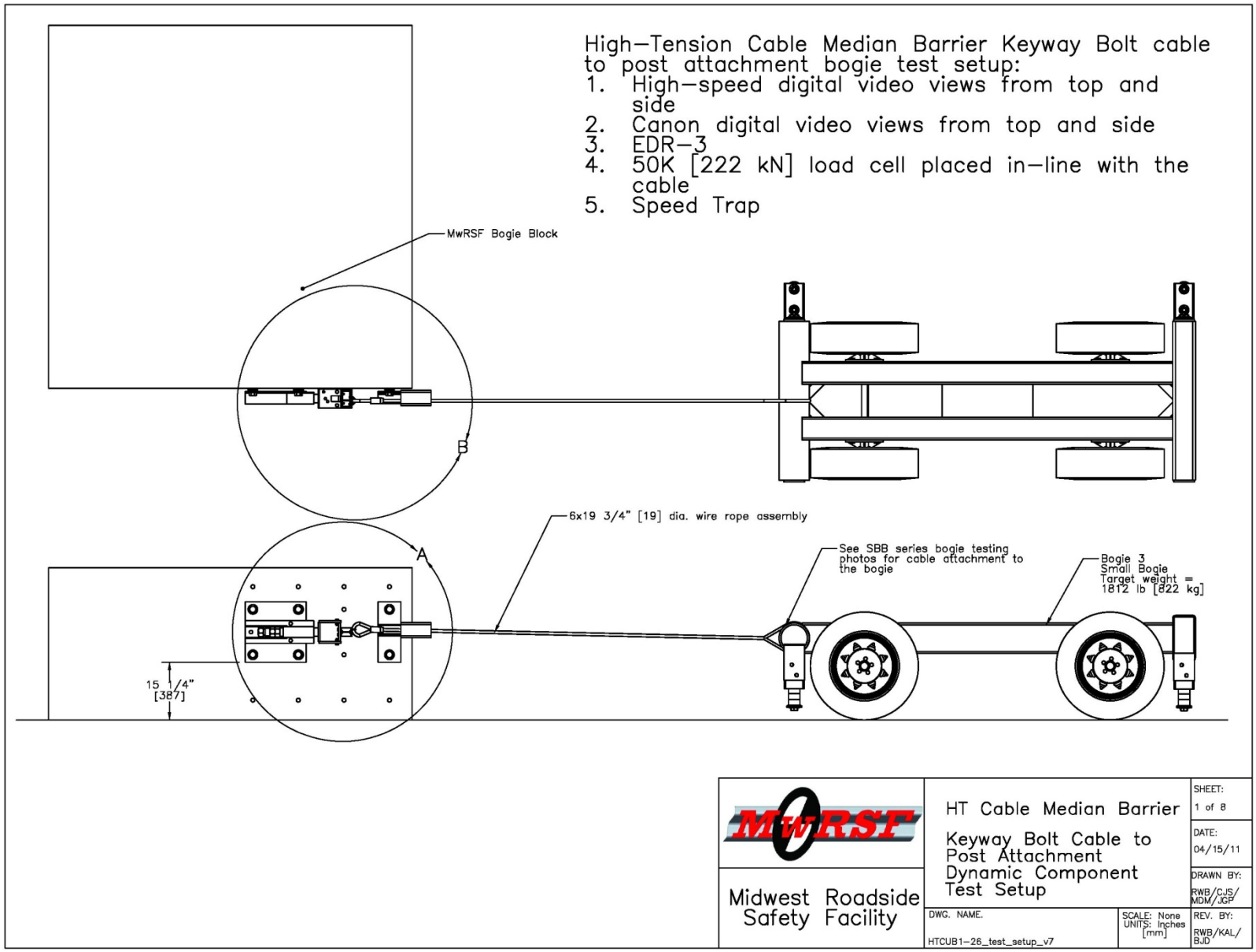


Figure 6. Setup for Test Nos. HTCUB-1 through HTCUB-37

5 COMPONENT DYNAMIC TESTING RESULTS AND DISCUSSION

5.1 Results

A series of 37 dynamic tests were performed on the keyway bolt connection. Vertical, lateral, and inclined loads were applied by varying the angle of the applied load to test its load capacity under different load orientations. The type 1 slot and keyway design was used for the first 26 tests while the type 2 slot and keyway design was used for the last 11. The summary of all test results are shown in Table 4.

Table 4. Dynamic Testing Results Summary

Test	Angle	Nuts	Keyway Bolt	Peak Load	Results
HTCUB-1	90°	Grade 2 - Single - Hand	C1018	5.34 kips (23.75 kN)	Bolt Threads Stripped
HTCUB-2	90°	Grade 2 - Single - Hand	C1018	4.87 kips (21.66 kN)	Bolt Threads Stripped
HTCUB-3	90°	Grade 2 - Double - Hand	C1018	6.71 kips (29.85 kN)	Bolt Fracture Through Threads
HTCUB-4	90°	Grade 2 - Double - Hand	C1018	5.74 kips (25.53 kN)	Bolt Fracture Through Threads
HTCUB-5	0°	Grade 2 - Double - Hand	C1018	2.25 kips (10.01 kN)	Released - Button Through Keyway
HTCUB-6	0°	Grade 2 - Double - Hand	C1018	1.71 kips (7.61 kN)	Released - Button Through Keyway
HTCUB-7	0°	Grade 2 - Double - Loose	C1018	N/A	Released - Button Through Keyway
HTCUB-8	0°	Grade 2 - Double - Loose	C1018	1.04 kips (4.63 kN)	Released - Button Through Keyway
HTCUB-9	0°	Grade 2 - Double - Loose	C1018	1.02 kips (4.54 kN)	Released - Button Through Keyway
HTCUB-10	0°	Grade 2 - Double - Loose	C1018	0.49 kips (2.18 kN)	Released - Button Through Keyway
HTCUB-11	0°	Grade 2 - Double - Hand	C1018	2.12 kips (9.43 kN)	Released - Button Through Keyway
HTCUB-12	0°	Grade 2 - Double - Tight	C1018	0.56 kips (2.49 kN)	Released - Button Through Keyway Button Snag Load of 0.58 kips (2.58 kN)
HTCUB-13	0°	Grade 2 - Double - Tight	C1018	0.85 kips (3.78 kN)	Released - Button Through Keyway Button Snag Load of 1.56 kips (6.94 kN)
HTCUB-14	0°	Grade 2 - Double - Tight	C1018	1.42 kips (6.32 kN)	Released - Button Through Keyway
HTCUB-15	0°	Grade 2 - Double - Tight	C1018	0.88 kips (3.91kN)	Released - Button Through Keyway Button Snag Load of 1.00 kips (4.45 kN)
HTCUB-16	0°	Grade 2 - Double - Tight	C1018	1.14 kips (5.07 kN)	Released - Button Through Keyway
HTCUB-17	90°	Grade 5 - Single - Loose	C1018	6.22 kips (27.67 kN)	Bolt Fracture Through Threads
HTCUB-18	15°	Grade 5 - Single - Loose	C1018	0.93 kips (4.14 kN)	Released - Button Through Keyway Button Snag Load of 1.27 kips (5.65 kN)
HTCUB-19	30°	Grade 5 - Single - Loose	C1018	0.67 kips (2.98 kN)	Released - Button Through Keyway Button Snag Load of 1.35 kips (6.01 kN)
HTCUB-20	45°	Grade 5 - Single - Loose	C1018	0.66 kips (2.94 kN)	Released - Button Through Keyway Button Snag Load of 0.68 kips (3.02 kN)
HTCUB-21	0°	Grade 2 - Double - Tight	C1018	0.94 kips (4.18 kN)	Released - Button Through Keyway

Table 4. Dynamic Testing Results Summary (Continued)

Test	Angle	Nuts	Keyway Bolt	Peak Load	Results
HTCUB-22	0°	Grade 2 - Double - Tight	C1018	0.90 kips (4.00 kN)	Released - Button Through Keyway
HTCUB-23	90°	Grade 2 - Double - Tight	C1018	6.19 kips (27.53 kN)	Bolt Fracture Through Threads
HTCUB-24	45°	Grade 2 - Double - Tight	C1018	0.74 kips (3.29 kN)	Released - Button Through Keyway Button Snag Load of 1.61 kips (7.16 kN)
HTCUB-25	60°	Grade 2 - Double - Tight	C1018	3.99 kips (17.75 kN)	Bolt Fracture Through Threads
HTCUB-26	60°	Grade 2 - Double - Tight	C1018	3.90 kips (17.35 kN)	Bolt Fracture Through Threads
HTCUB-27	45°	Grade 2 - Double - Tight	C1018	0.47 kips (2.09 kN)	Released - Button Through Keyway Button Snag Load of 0.49 kips (2.18 kN)
HTCUB-28	90°	Grade 2 - Double - Tight	C1018	6.75 kips (30.03 kN)	Bolt Fracture Through Threads
HTCUB-29	60°	Grade 2 - Double - Tight	C1018	0.53 kips (2.36 kN)	Released - Button Through Keyway
HTCUB-30	0°	Grade 2 - Double - Tight	C1018	0.58 kips (2.58 kN)	Released - Button Through Keyway Button Snag Load of 0.68 kips (3.02 kN)
HTCUB-31	0°	Grade 8 - Single - Tight	A449	N/A	Released - Button Through Keyway
HTCUB-32	0°	Grade 8 - Single - Tight	A449	1.11 kips (4.94 kN)	Released - Button Through Keyway
HTCUB-33	90°	Grade 8 - Single - Tight	A449	8.04 kips (35.76 kN)	Bolt Fracture Through Threads
HTCUB-34	90°	Grade 8 - Single - Tight	A449	8.80 kips (39.14 kN)	Bolt Fracture Through Threads
HTCUB-35	0°	Grade 8 - Single - Tight	A449	1.41 kips (6.27 kN)	Released - Button Through Keyway
HTCUB-36	0°	Grade 8 - Single - Tight	A449	1.27 kips (5.65 kN)	Released - Button Through Keyway
HTCUB-37	0°	Grade 8 - Single - Tight	A449	0.92 kips (4.09 kN)	Released - Button Through Keyway

5.1.1 Test No. HTCUB-1

For test no. HTCUB-1, the cable applied a load to the keyway bolt at an angle of 90 degrees from the face of the flange. The keyway bolt was attached with one grade 2 nut positioned at the center of the slot. Force data was measured with the load cell transducer and the data was processed with the Channel Frequency Class (CFC) 60 filter in accordance with the Society of Automotive Engineers (SAE) J211. The start of the test was determined as the first data point opposite in sign from the polarity of the main acceleration signal. The cable released at a load of 5.34 kips (23.75 kN). The nut stripped off the threads and the keyway bolt straightened out. The force versus time plot is shown in Figure 7. Pre- and post-test photographs are shown in Figure 8. Sequential photographs are shown in Figure 9.

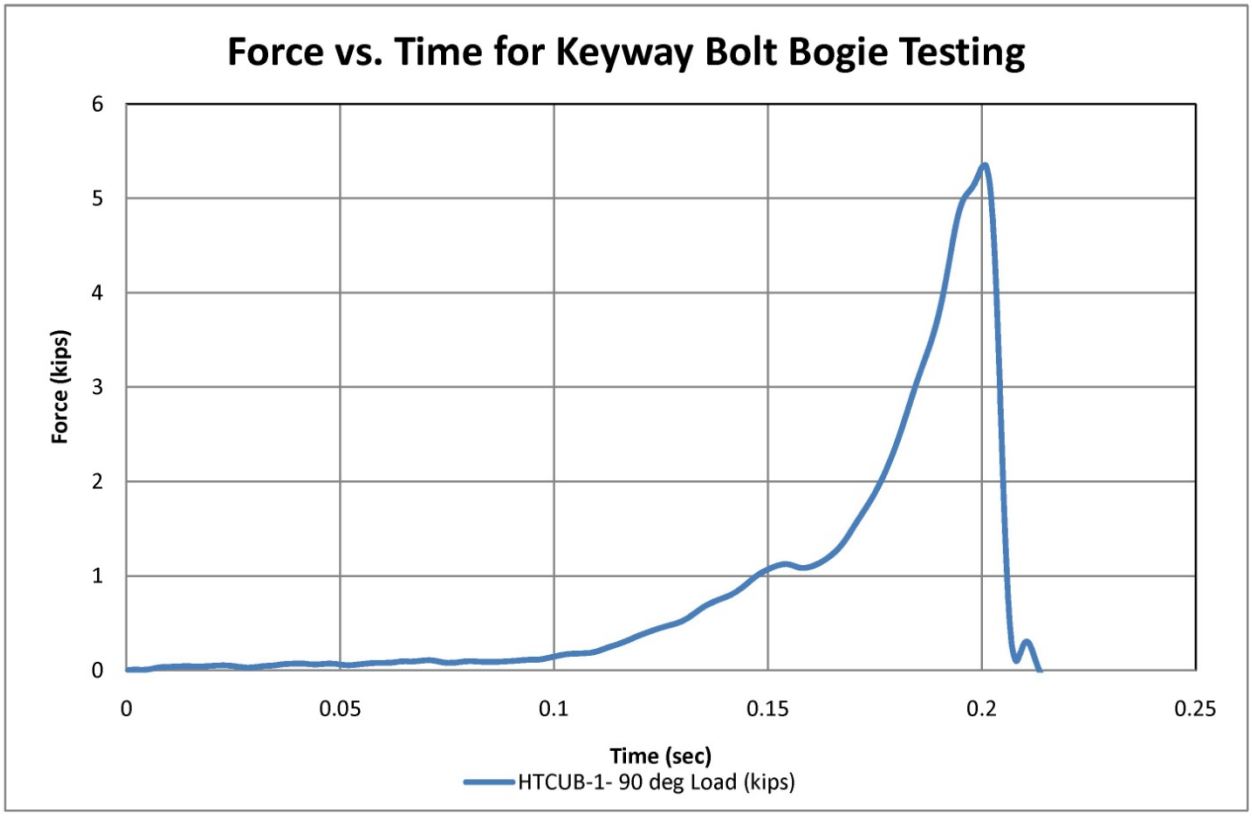
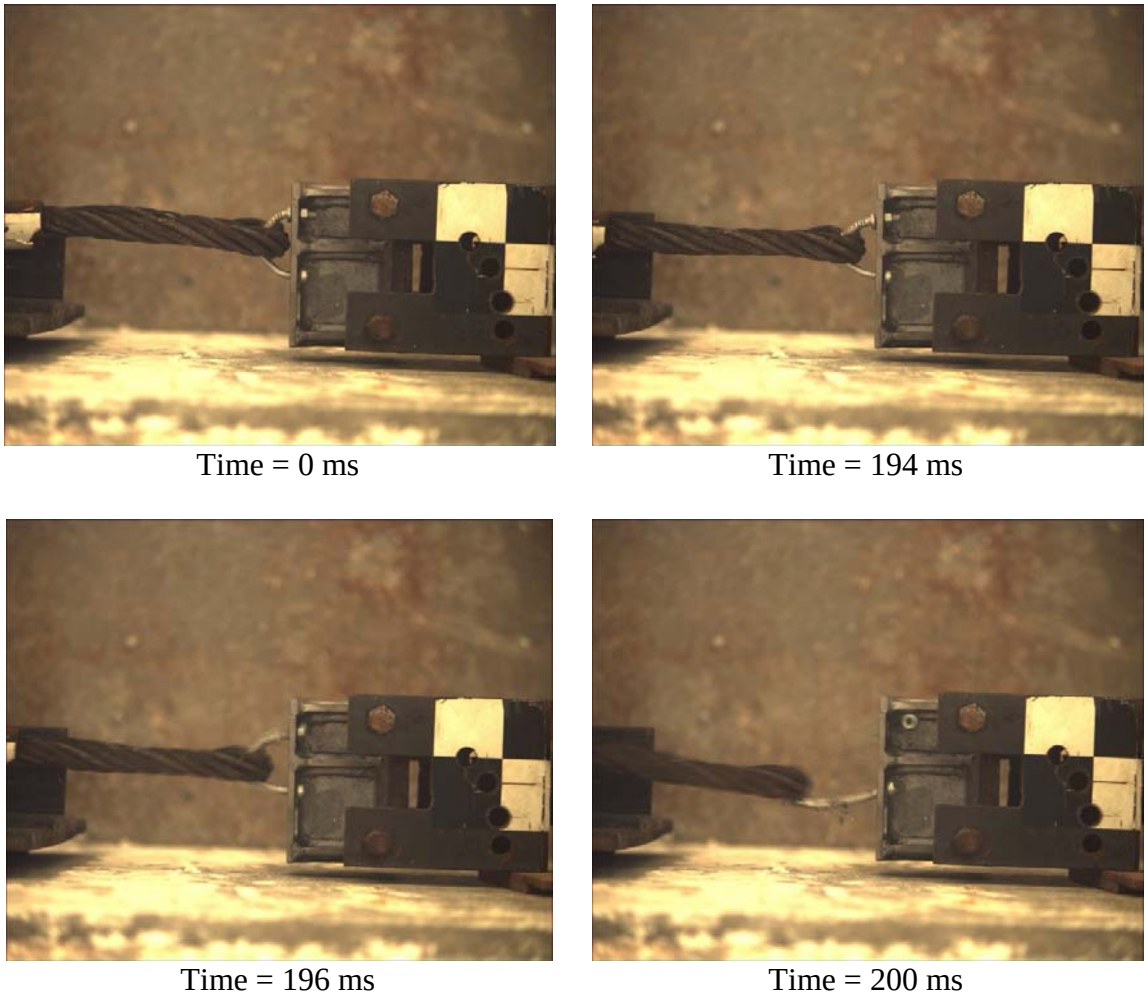


Figure 7. Force-Time Data, Test No. HTCUB-1

Pre-Test Post-Test

Figure 8. Pre-Test and Post-Test Photographs, Test No. HTCUB-1



Time = 0 ms Time = 194 ms

Time = 196 ms Time = 200 ms

Figure 9. Sequential Photographs, Test No. HTCUB-1

5.1.2 Test No. HTCUB-2

For test no. HTCUB-2, the cable applied a load the keyway bolt at an angle of 90 degrees from the face of the flange. The keyway bolt was attached with one grade 2 nut positioned at the center of the slot. The cable released at a load of 4.87 kips (21.66 kN). The nut stripped off the threads and the keyway bolt straightened out. The force versus time plot is shown in Figure 10. Pre- and post-test photographs are shown in Figure 11. Sequential photographs are shown in Figure 12.

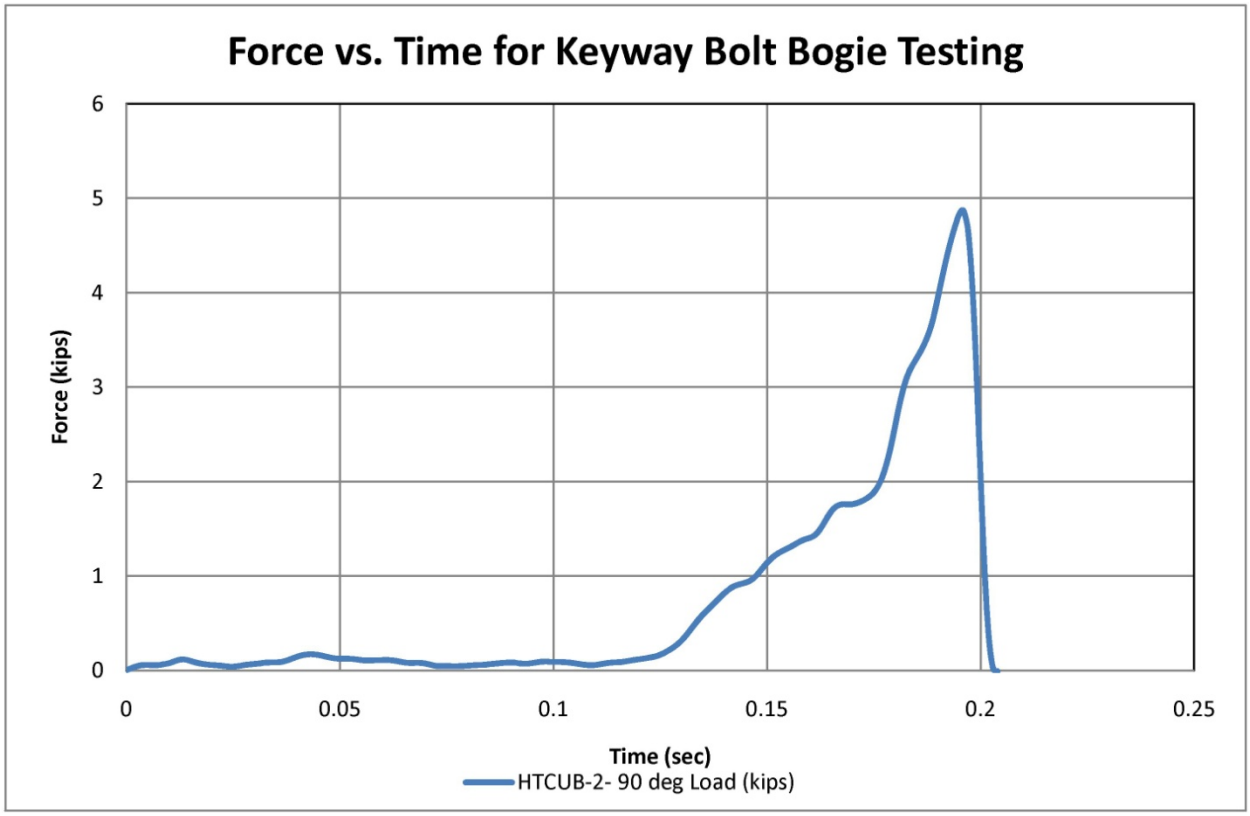
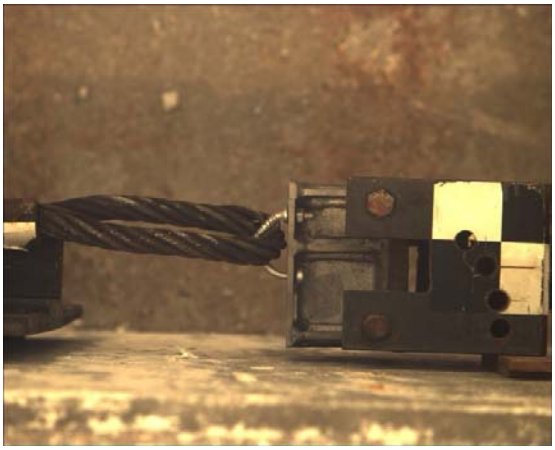


Figure 10. Force-Time Data, Test No. HTCUB-2

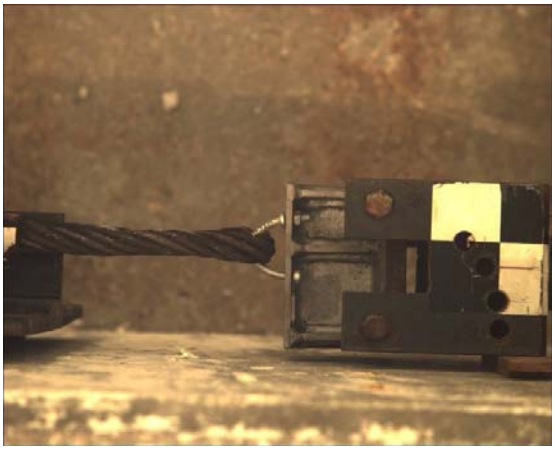
Pre-Test

Post-Test

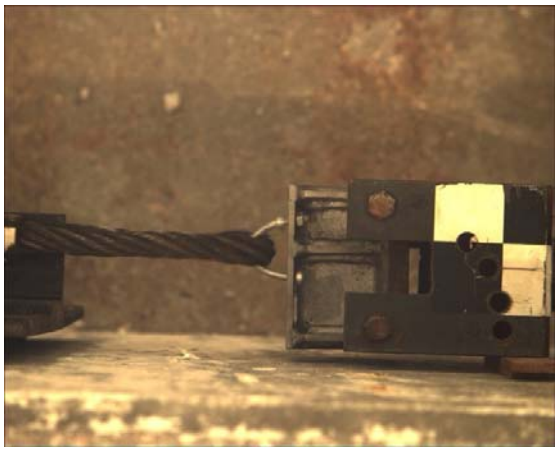
Figure 11. Pre-Test and Post-Test Photographs, Test No. HTCUB-2



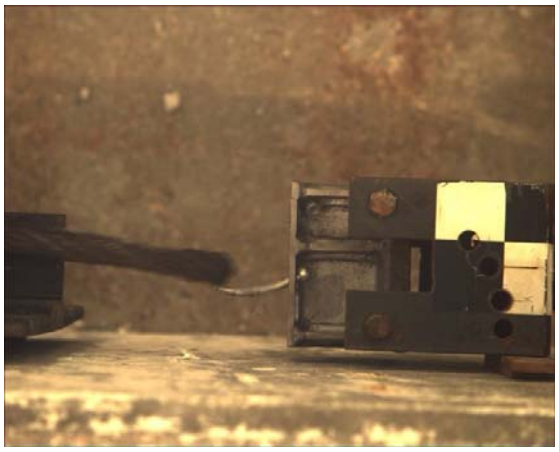
Time = 0 ms



Time = 190 ms



Time = 192 ms



Time = 196 ms

Figure 12. Sequential Photographs, Test No. HTCUB-2

5.1.3 Test No. HTCUB-3

For test no. HTCUB-3, the cable applied a load to the keyway bolt at an angle of 90 degrees from the face of the flange. The keyway bolt was attached with two grade 2 nuts positioned at the center of the slot. The cable released at a load of 6.71 kips (29.85 kN). The keyway bolt fractured through the threads and straightened out. The force versus time plot is shown in Figure 13. Pre- and post-test photographs are shown in Figure 14. Sequential photographs are shown in Figure 15.

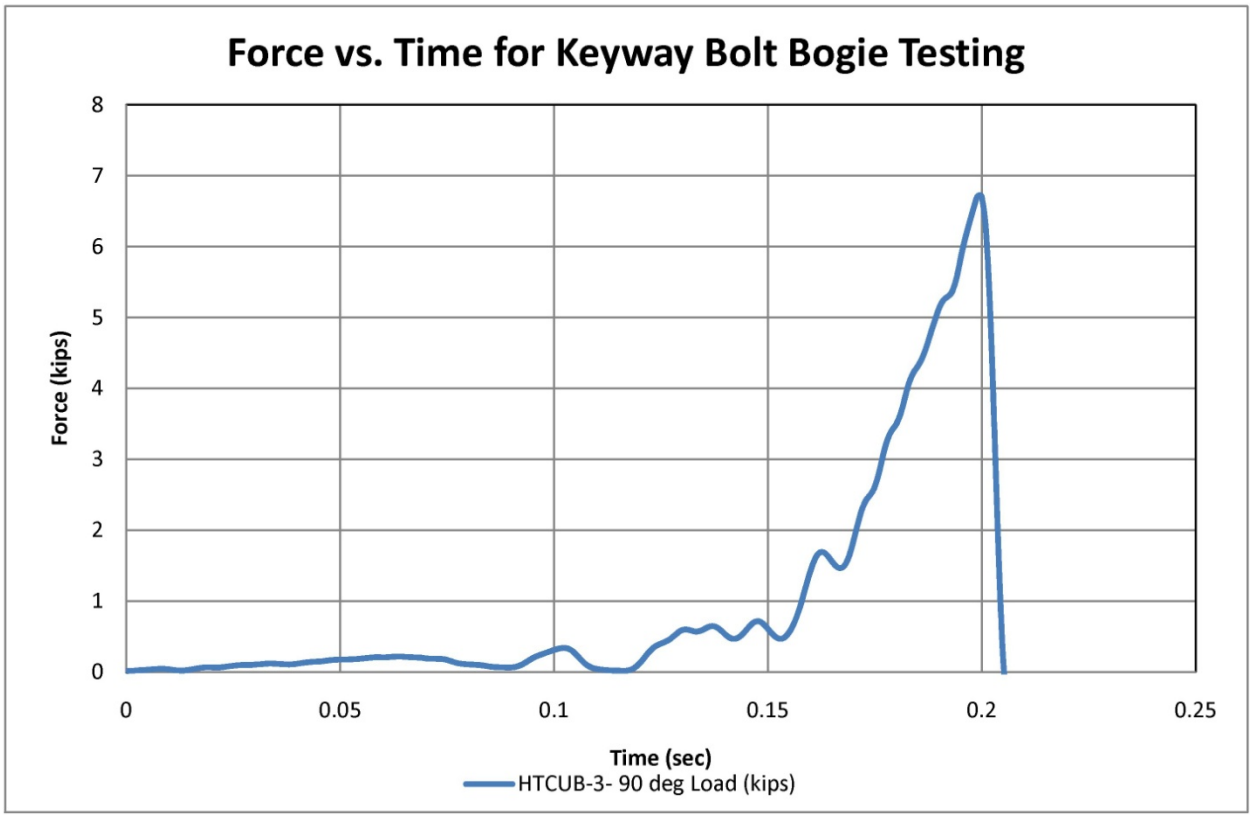
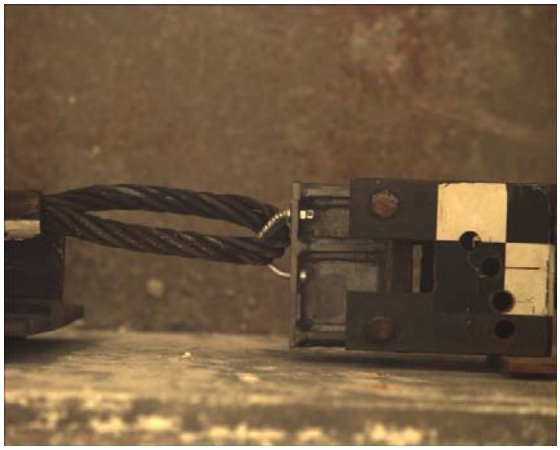


Figure 13. Force-Time Data, Test No. HTCUB-3

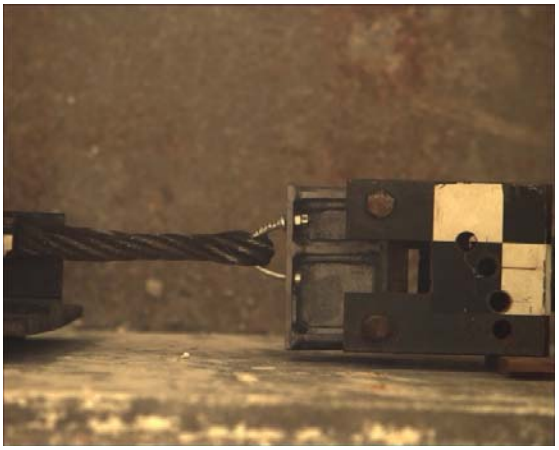
Pre-Test

Post-Test

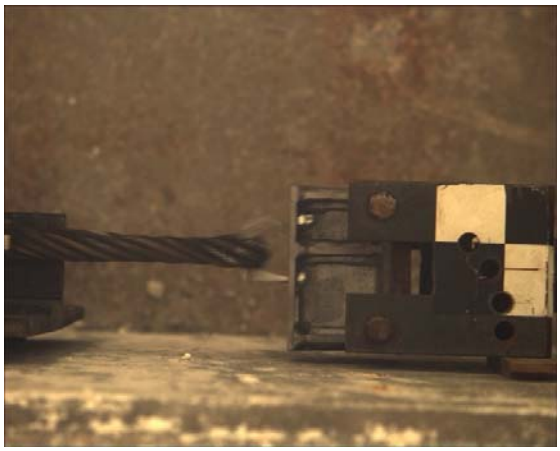
Figure 14. Pre-Test and Post-Test Photographs, Test No. HTCUB-3



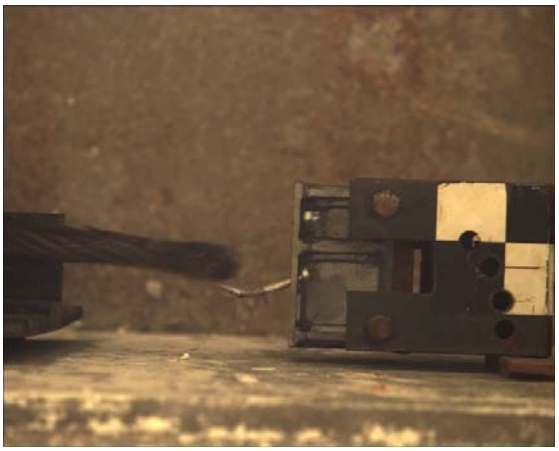
Time = 0 ms



Time = 192 ms



Time = 196 ms



Time = 198 ms

Figure 15. Sequential Photographs, Test No. HTCUB-3

5.1.4 Test No. HTCUB-4

For test no. HTCUB-4, the cable applied a load to the keyway bolt at an angle of 90 degrees from the face of the flange. The keyway bolt was attached with two grade 2 nuts positioned at the center of the slot. The cable released at a load of 5.74 kips (25.53 kN). The keyway bolt fractured through the threads and straightened out. The force versus time plot is shown in Figure 16. Pre- and post-test photographs are shown in Figure 17. Sequential photographs are shown in Figure 18.

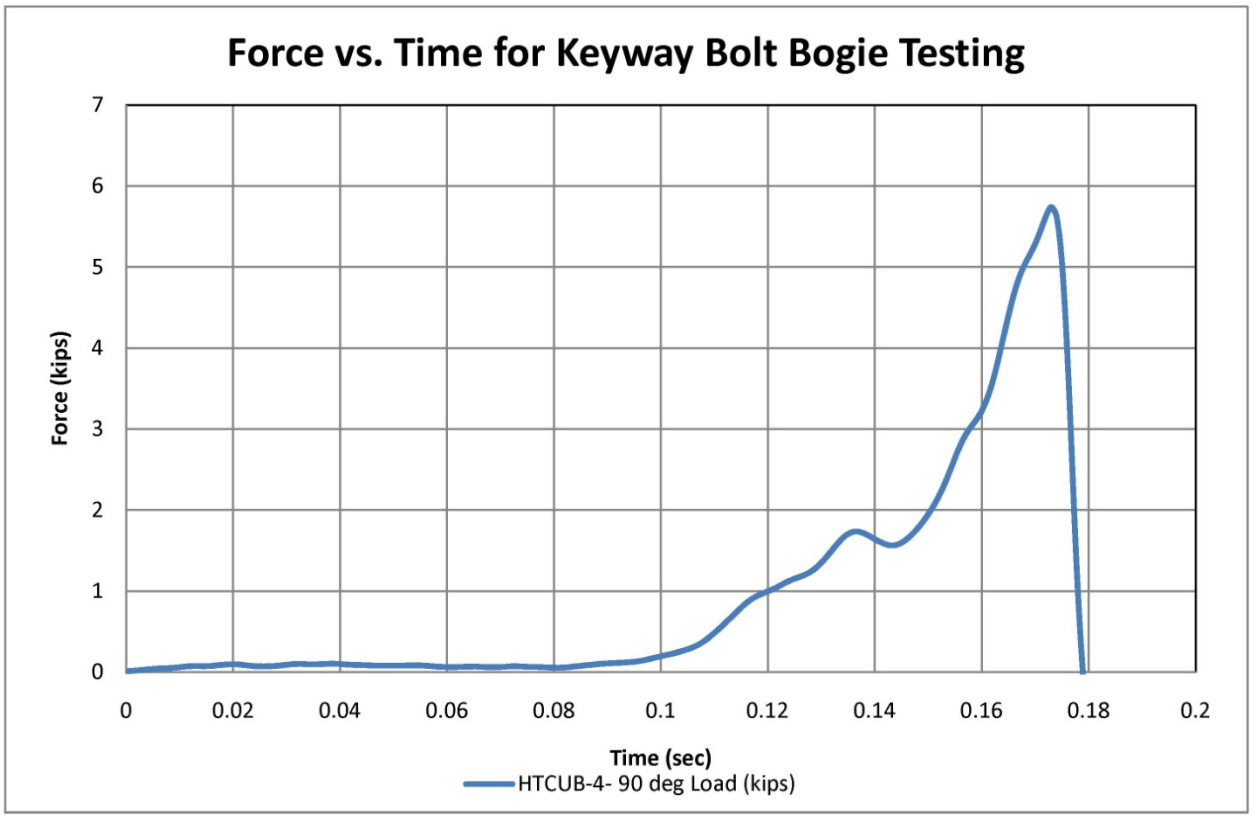
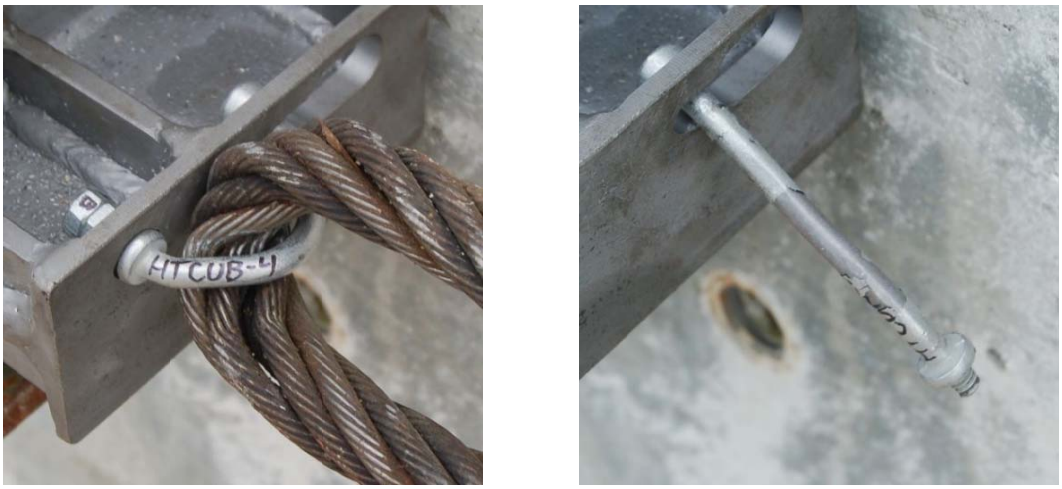
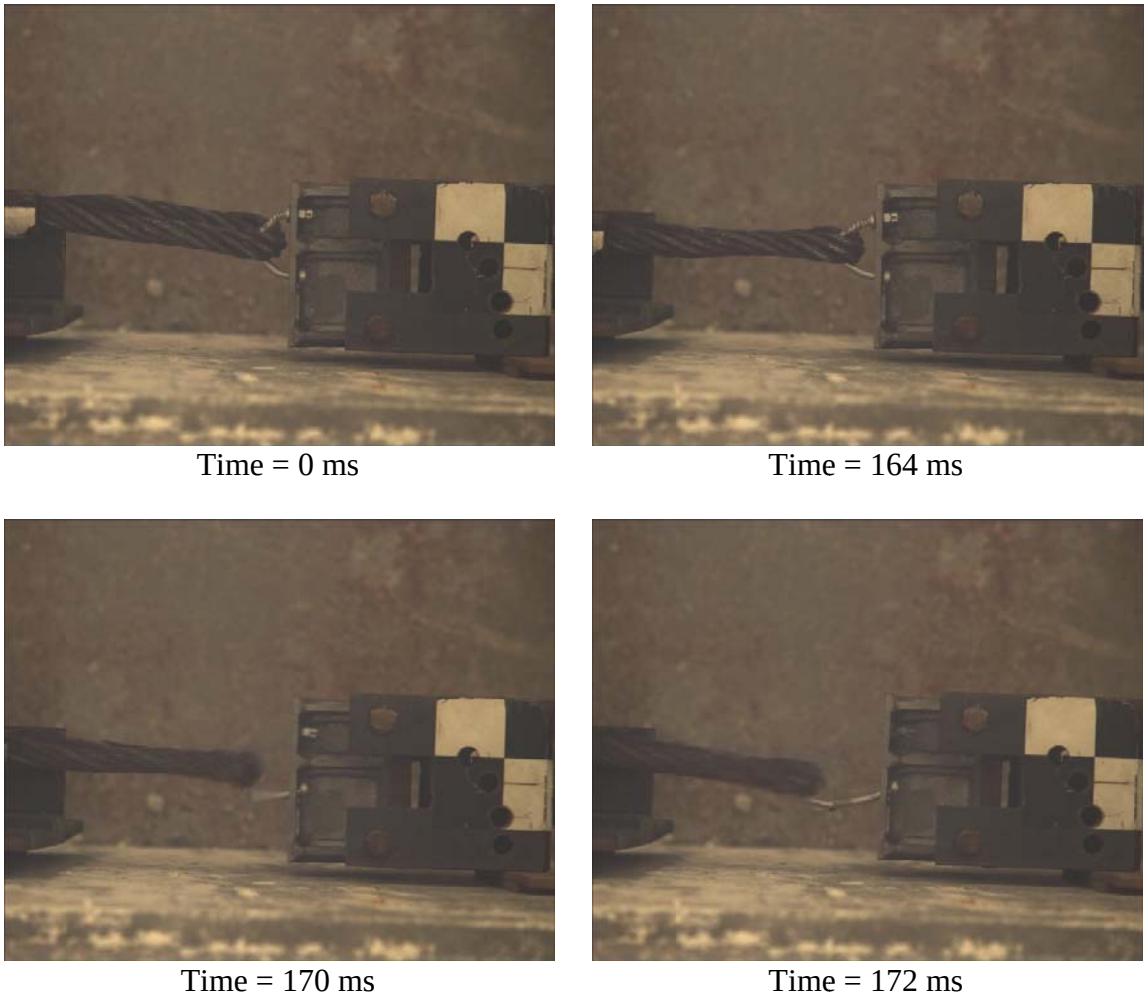


Figure 16. Force-Time Data, Test No. HTCUB-4



Pre-Test Post-Test

Figure 17. Pre-Test and Post-Test Photographs, Test No. HTCUB-4



Time = 0 ms Time = 164 ms

Time = 170 ms Time = 172 ms

Figure 18. Sequential Photographs, Test No. HTCUB-4

5.1.5 Test No. HTCUB-5

For test no. HTCUB-5, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts positioned at the bottom of the slot and the button head of the bolt was at the lowest position in the keyway. The cable released at a load of 2.25 kips (10.01 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 19. Pre- and post-test photographs are shown in Figure 20. Sequential photographs are shown in Figure 21.

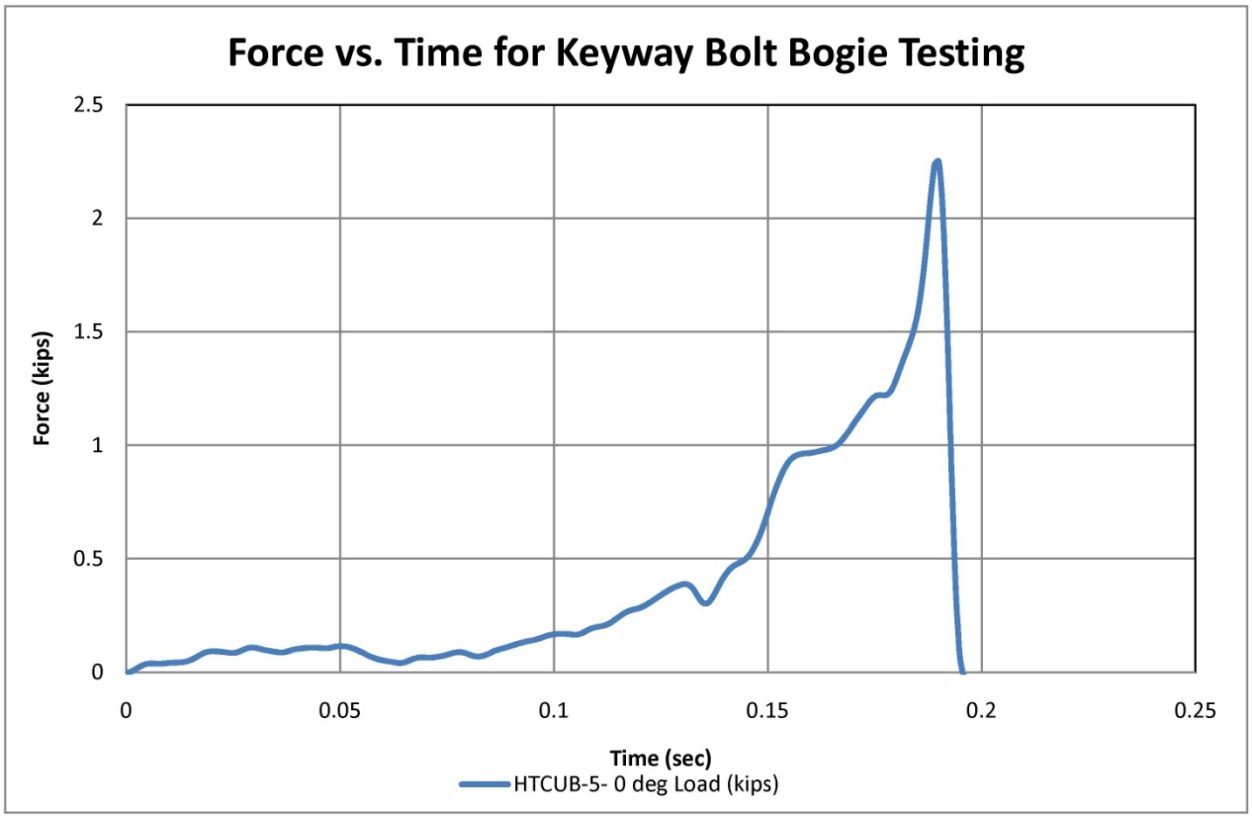
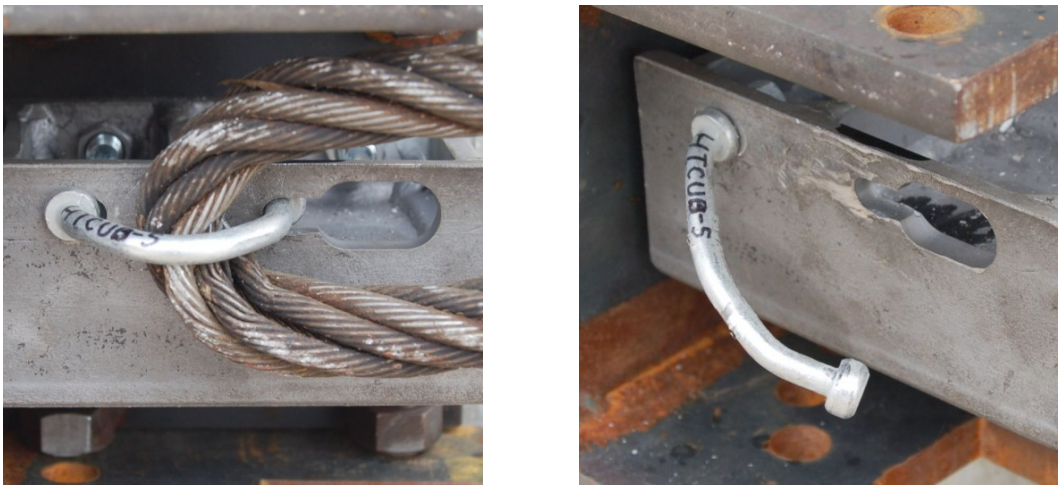
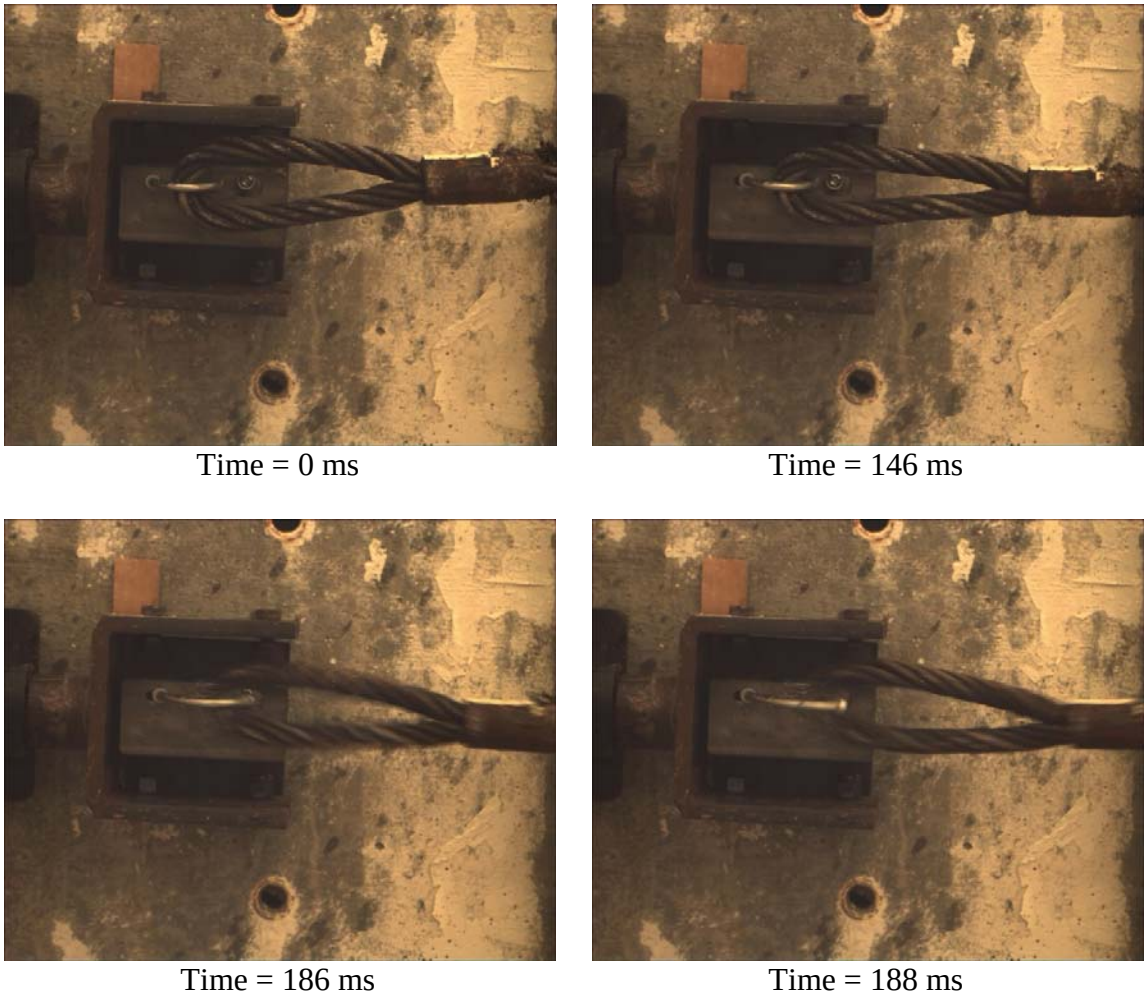


Figure 19. Force-Time Data, Test No. HTCUB-5



Pre-Test Post-Test

Figure 20. Pre-Test and Post-Test Photographs, Test No. HTCUB-5



Time = 0 ms Time = 146 ms

Time = 186 ms Time = 188 ms

Figure 21. Sequential Photographs, Test No. HTCUB-5

5.1.6 Test No. HTCUB-6

For test no. HTCUB-6, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts positioned at the upper-center of the slot. The cable released at a load of 1.71 kips (7.61 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 22. Pre- and post-test photographs are shown in Figure 23. Sequential photographs are shown in Figure 24.

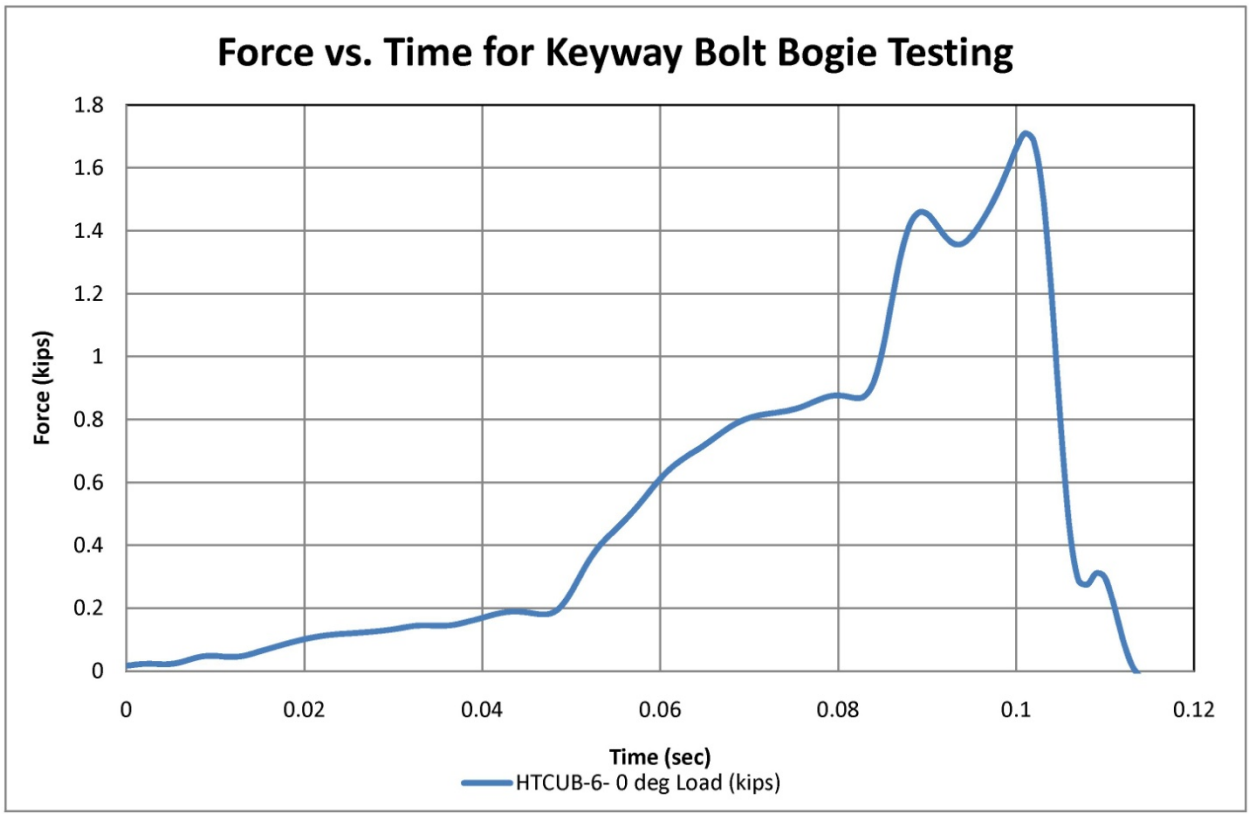
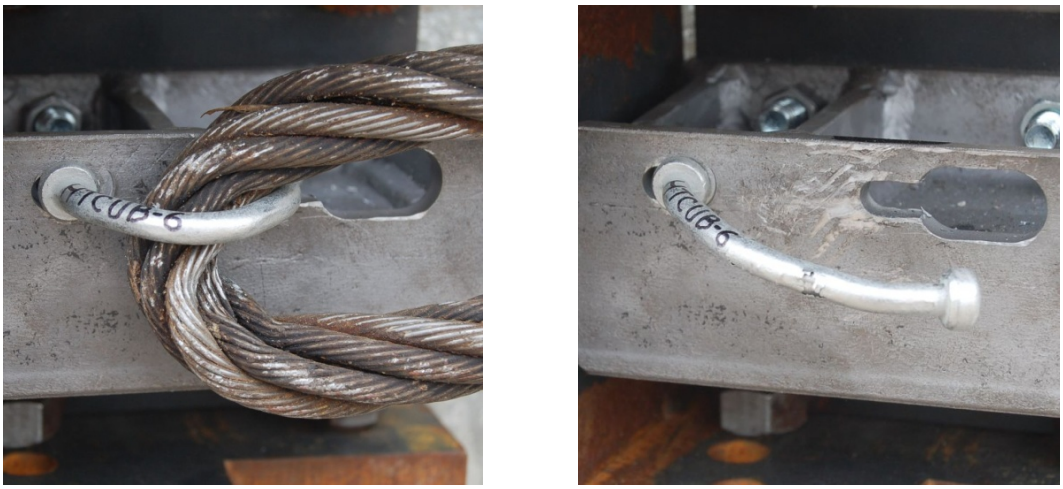
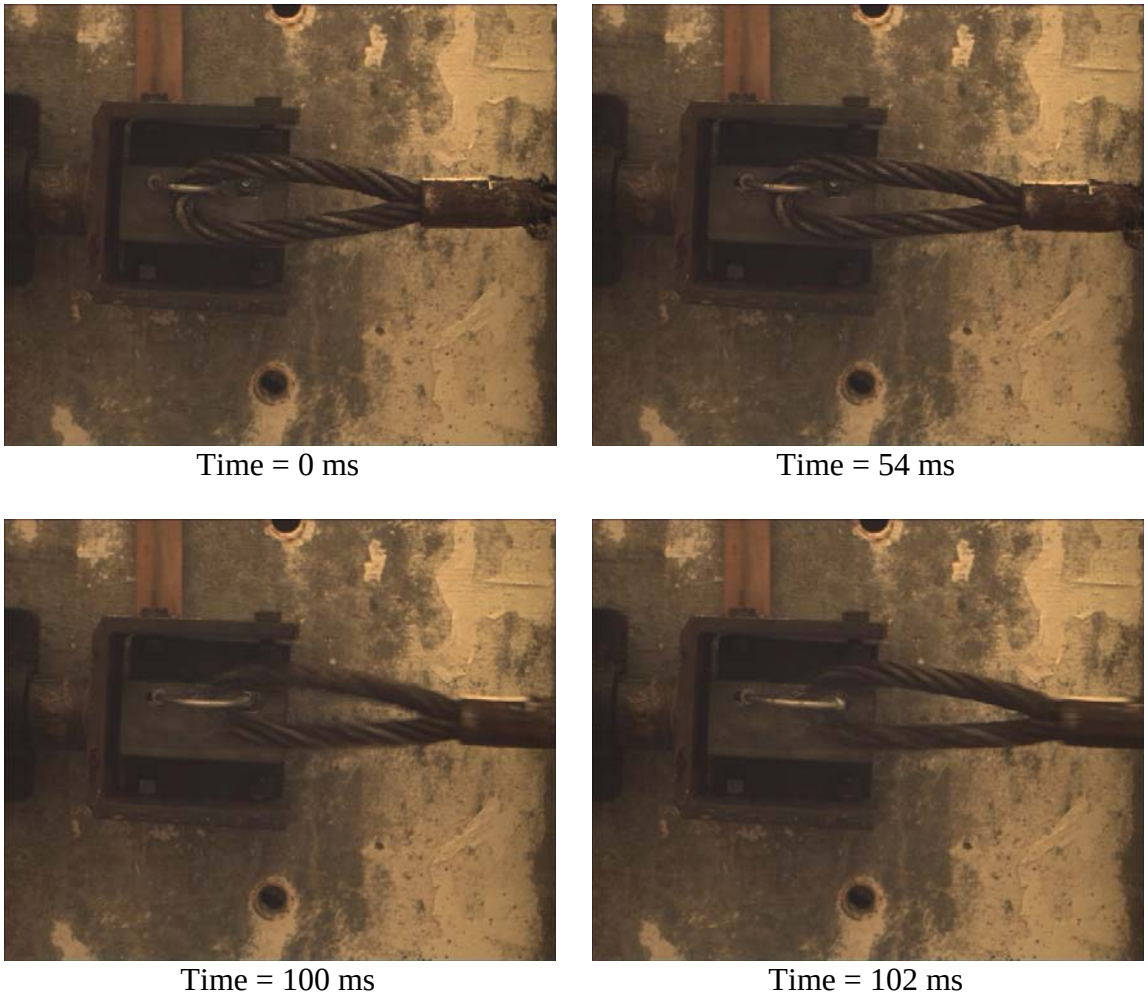


Figure 22. Force-Time Data, Test No. HTCUB-6



Pre-Test Post-Test

Figure 23. Pre-Test and Post-Test Photographs, Test No. HTCUB-6



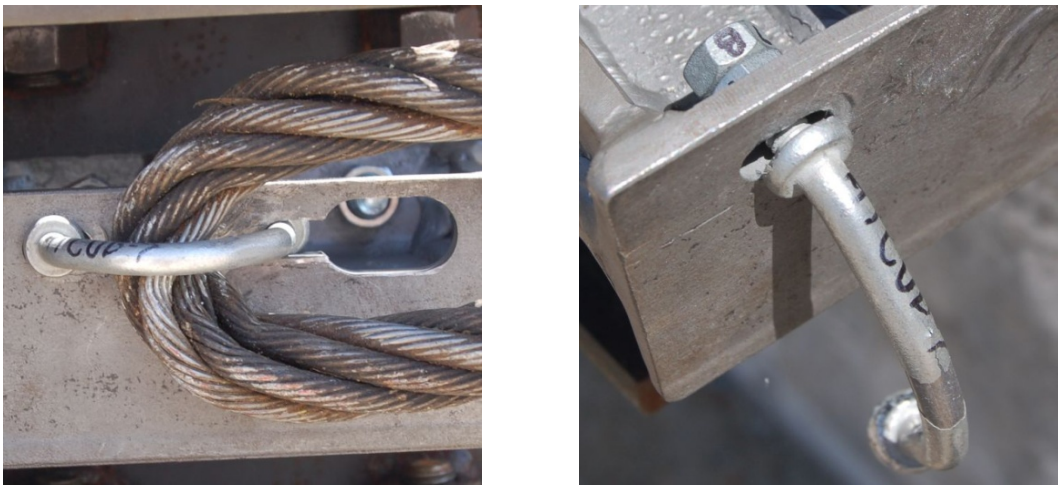
Time = 0 ms Time = 54 ms

Time = 100 ms Time = 102 ms

Figure 24. Sequential Photographs, Test No. HTCUB-6

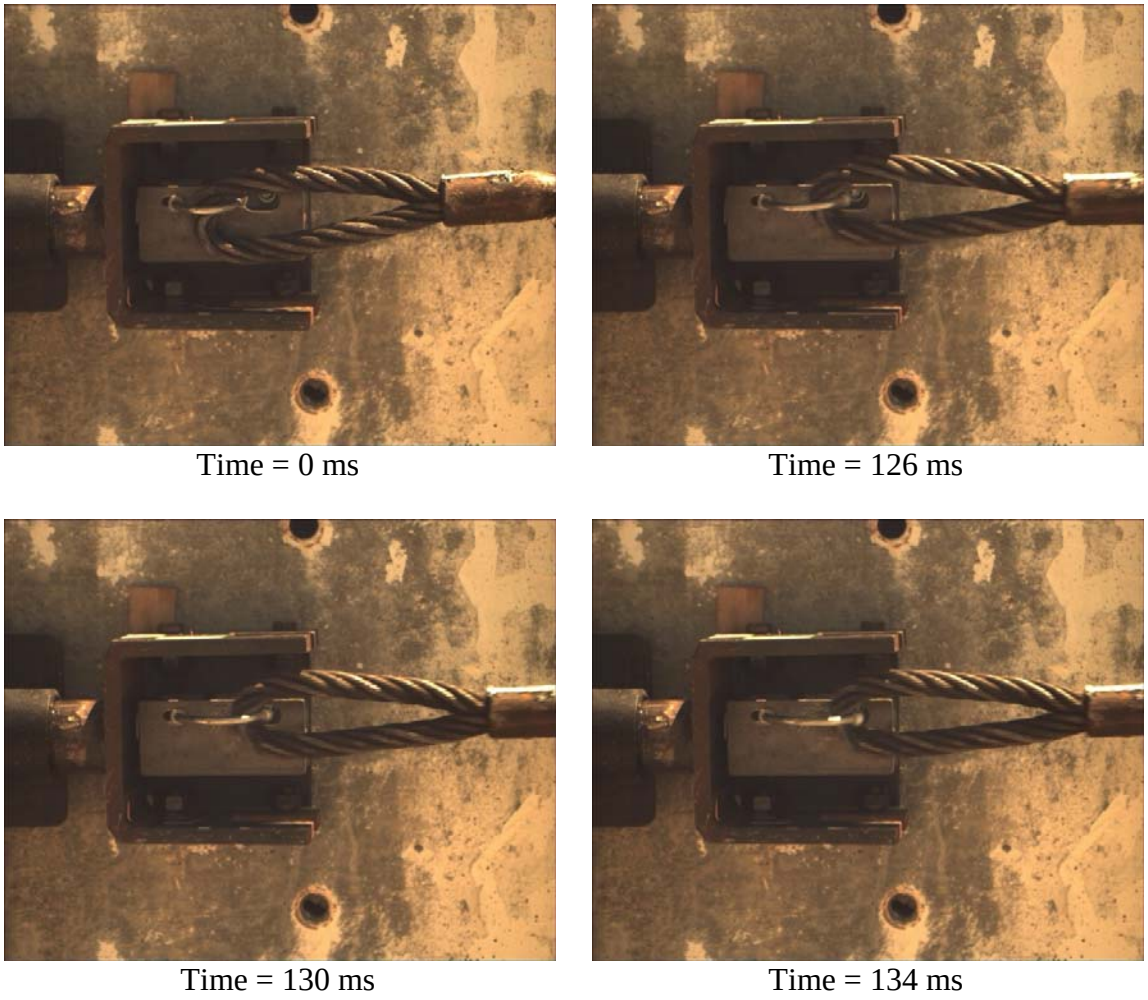
5.1.7 Test No. HTCUB-7

For test no. HTCUB-7, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with a small gap between the two grade 2 nuts and the flange. The threaded end was positioned at the lower-center of the slot. Due to technical difficulties, the load cell did not collect load data. The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. Pre- and post-test photographs are shown in Figure 25. Sequential photographs are shown in Figure 26.



Pre-Test Post-Test

Figure 25. Pre-Test and Post-Test Photographs, Test No. HTCUB-7



Time = 0 ms Time = 126 ms

Time = 130 ms Time = 134 ms

Figure 26. Sequential Photographs, Test No. HTCUB-7

5.1.8 Test No. HTCUB-8

For test no. HTCUB-8, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with a small gap between the two grade 2 nuts and the flange. The threaded end was positioned at the lower-center of the slot. The cable released at a load of 1.04 kips (4.63 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 27. Pre- and post-test photographs are shown in Figure 28. Sequential photographs are shown in Figure 29.

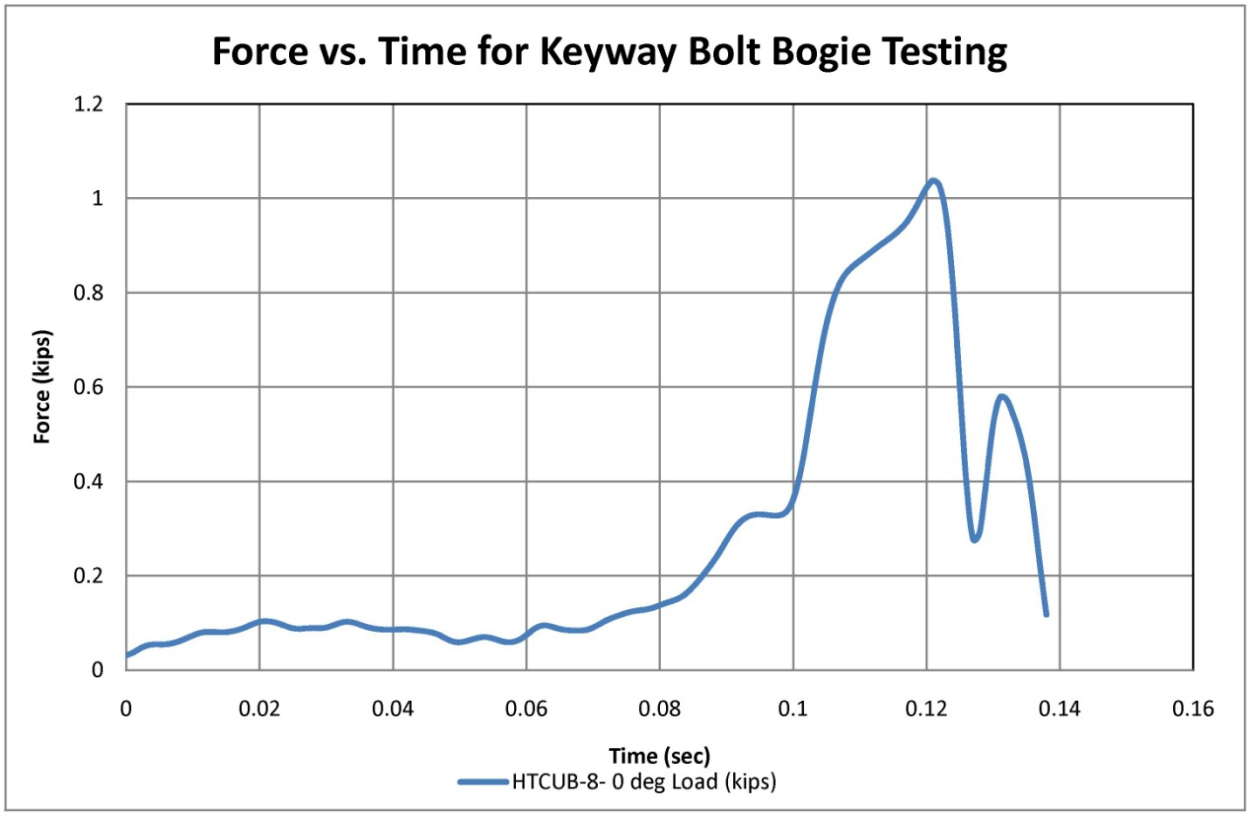
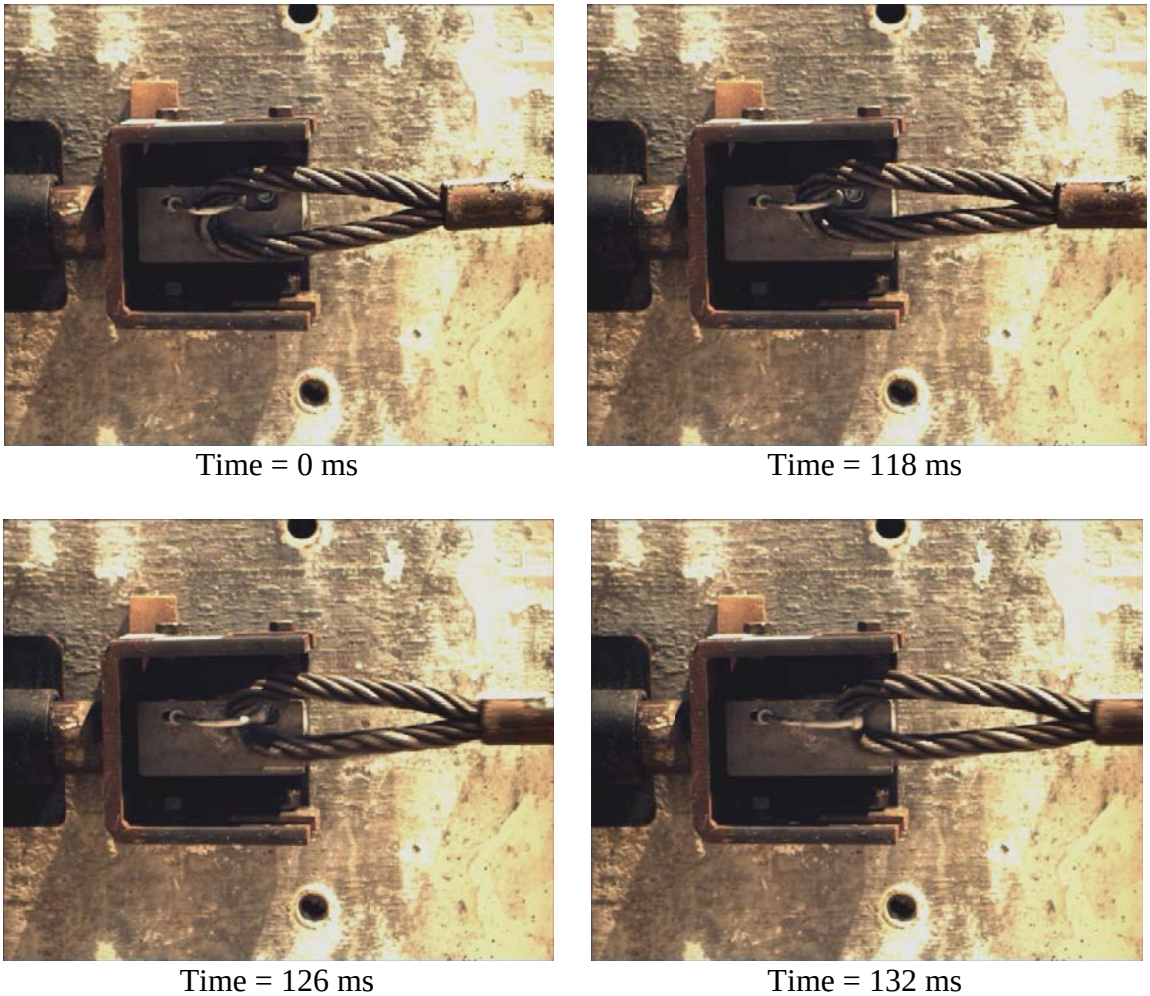


Figure 27. Force-Time Data, Test No. HTCUB-8

Pre-Test Post-Test

Figure 28. Pre-Test and Post-Test Photographs, Test No. HTCUB-8



Time = 0 ms Time = 118 ms

Time = 126 ms Time = 132 ms

Figure 29. Sequential Photographs, Test No. HTCUB-8

5.1.9 Test No. HTCUB-9

For test no. HTCUB-9, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel the face of the flange. The keyway bolt was attached with a small gap between the two grade 2 nuts and the flange. The threaded end was positioned at the lower-center of the slot. The cable released at a load of 1.02 kips (4.54 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 30. Pre- and post-test photographs are shown in Figure 31. Sequential photographs are shown in Figure 32.

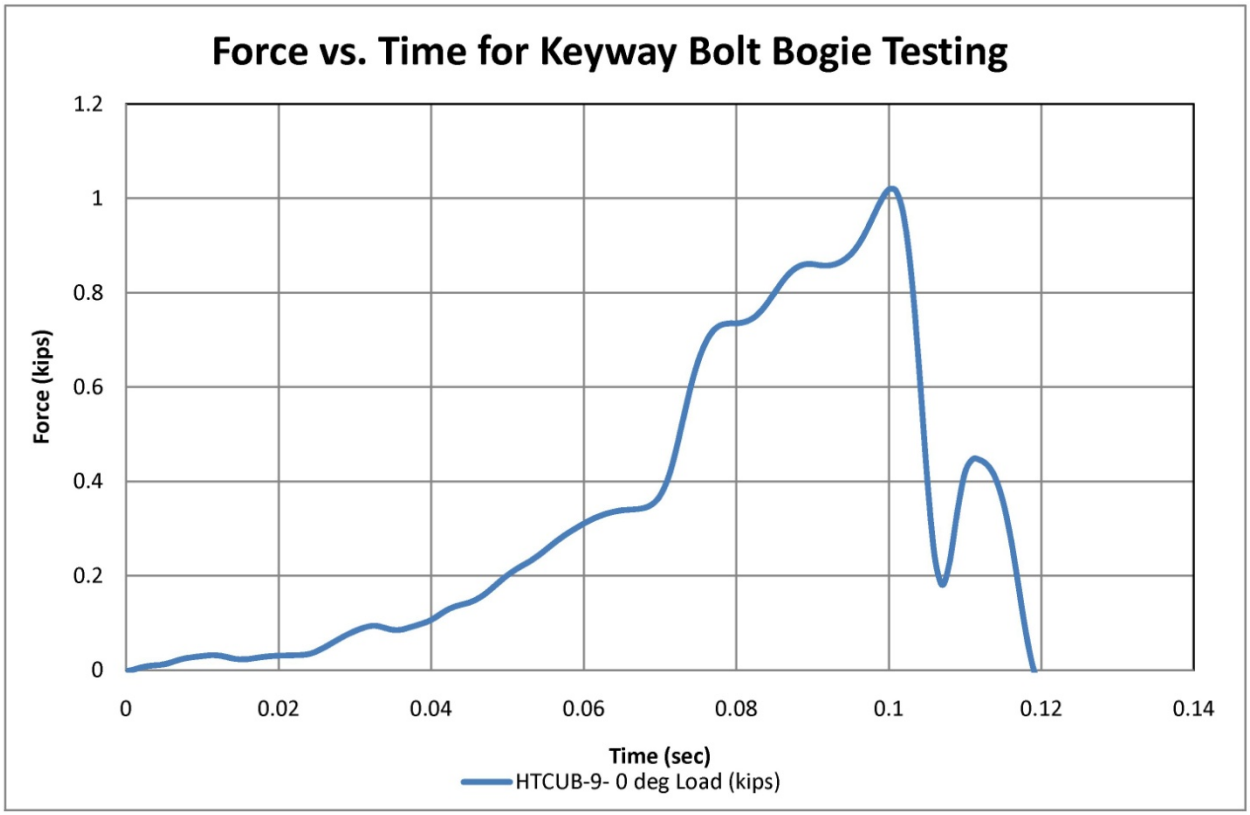
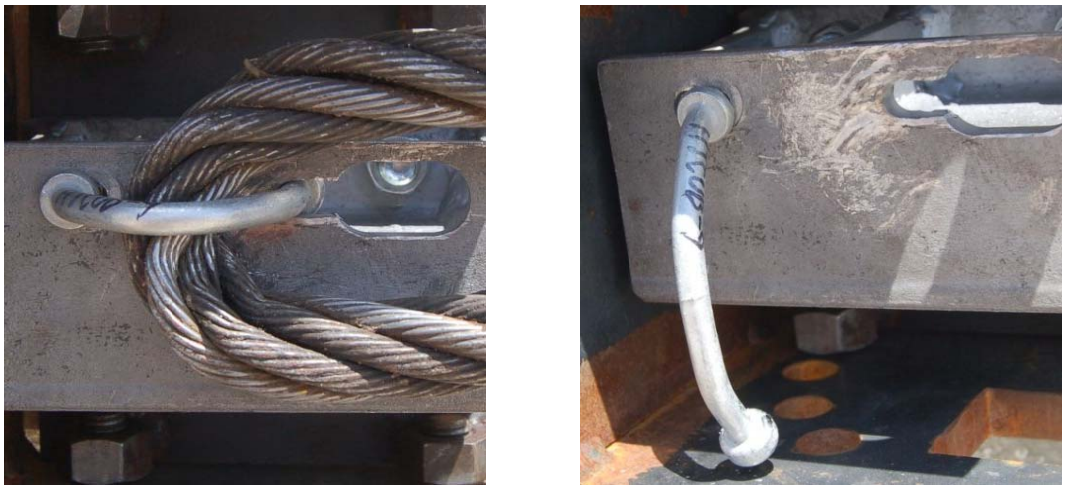
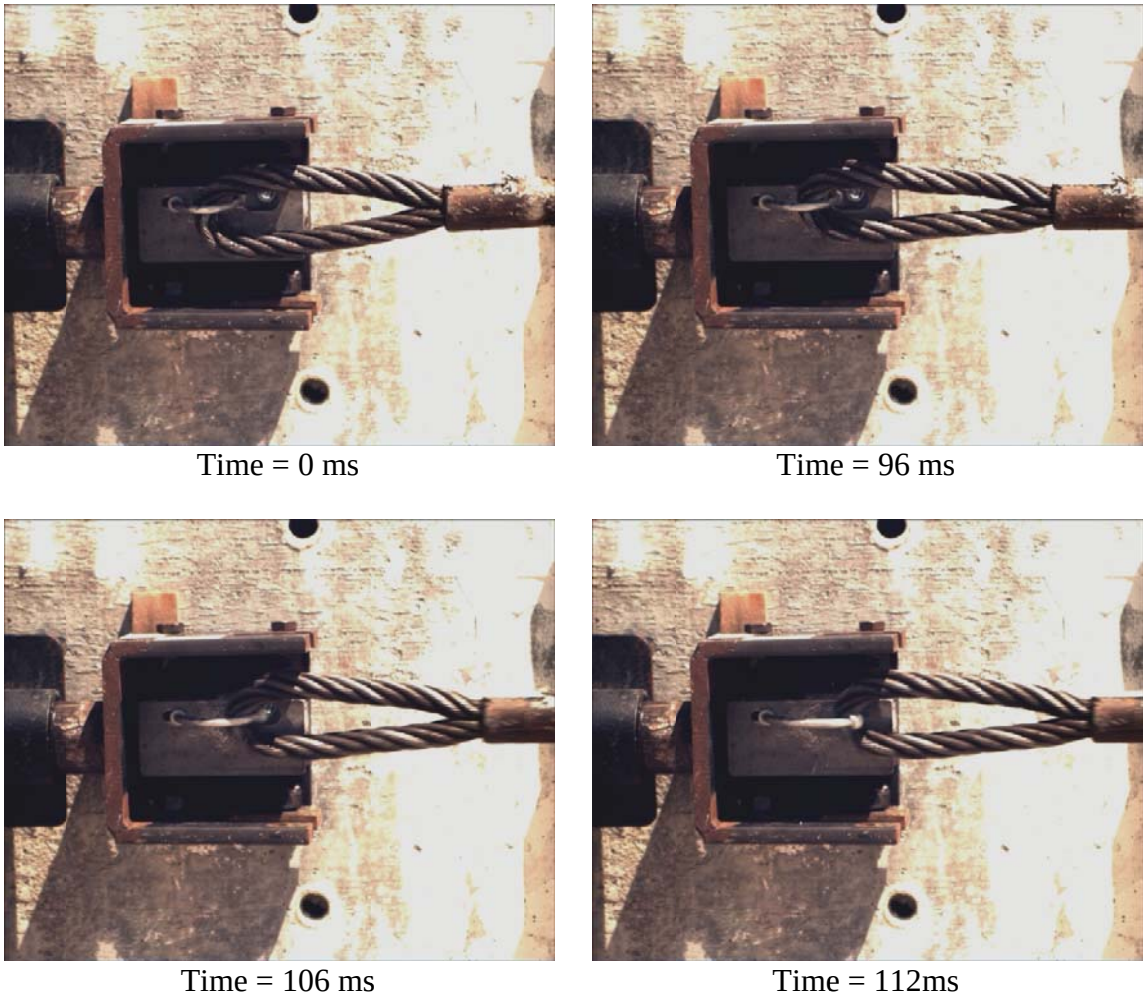


Figure 30. Force-Time Data, Test No. HTCUB-9



Pre-Test Post-Test

Figure 31. Pre-Test and Post-Test Photographs, Test No. HTCUB-9



Time = 0 ms Time = 96 ms

Time = 106 ms Time = 112ms

Figure 32. Sequential Photographs, Test No. HTCUB-9

5.1.10 Test No. HTCUB-10

For test no. HTCUB-10, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with a small gap between the two grade 2 nuts and the flange. The threaded end was positioned at the bottom of the lower slot in the post, which was slightly elongated towards the keyway. The elongation of the slot was done to allow for the button to release more easily. The cable released at a load of 0.49 kips (2.18 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 33. Pre- and post-test photographs are shown in Figure 34. Sequential photographs are shown in Figure 35.

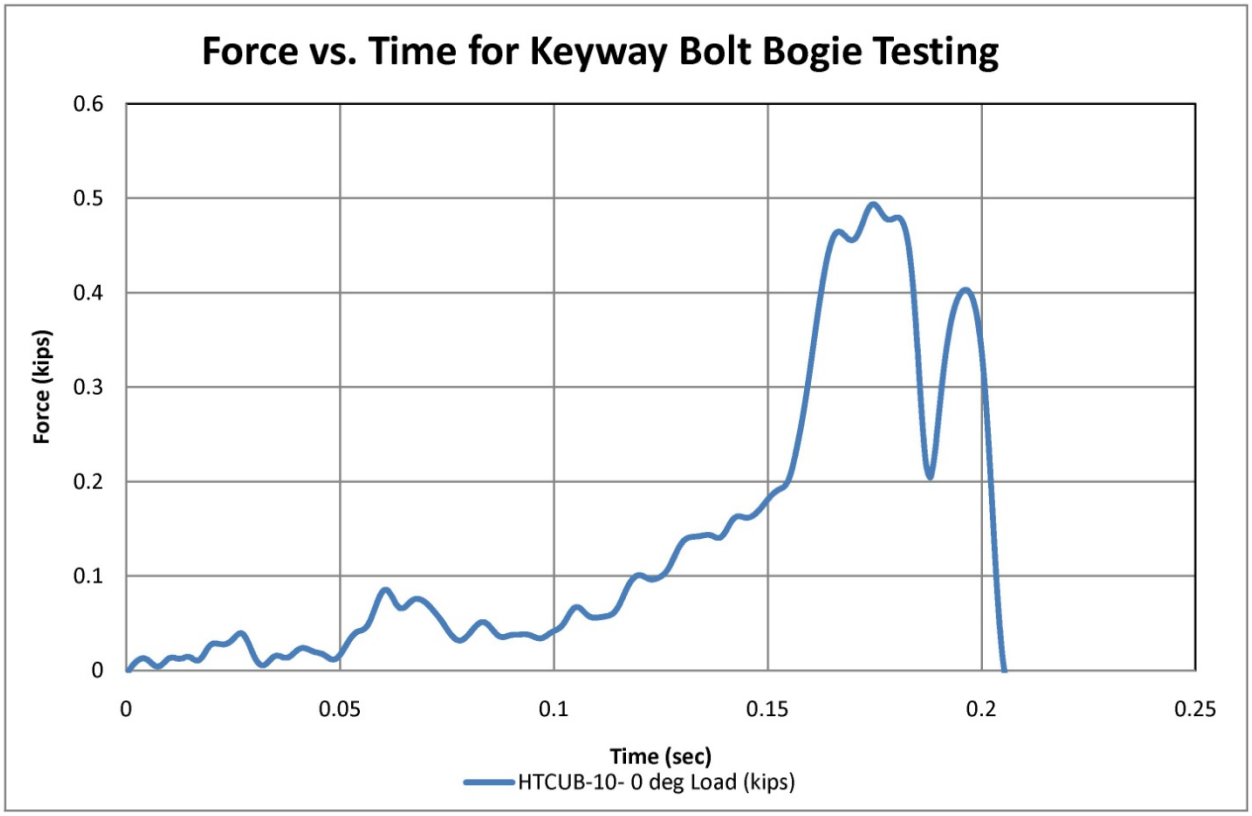
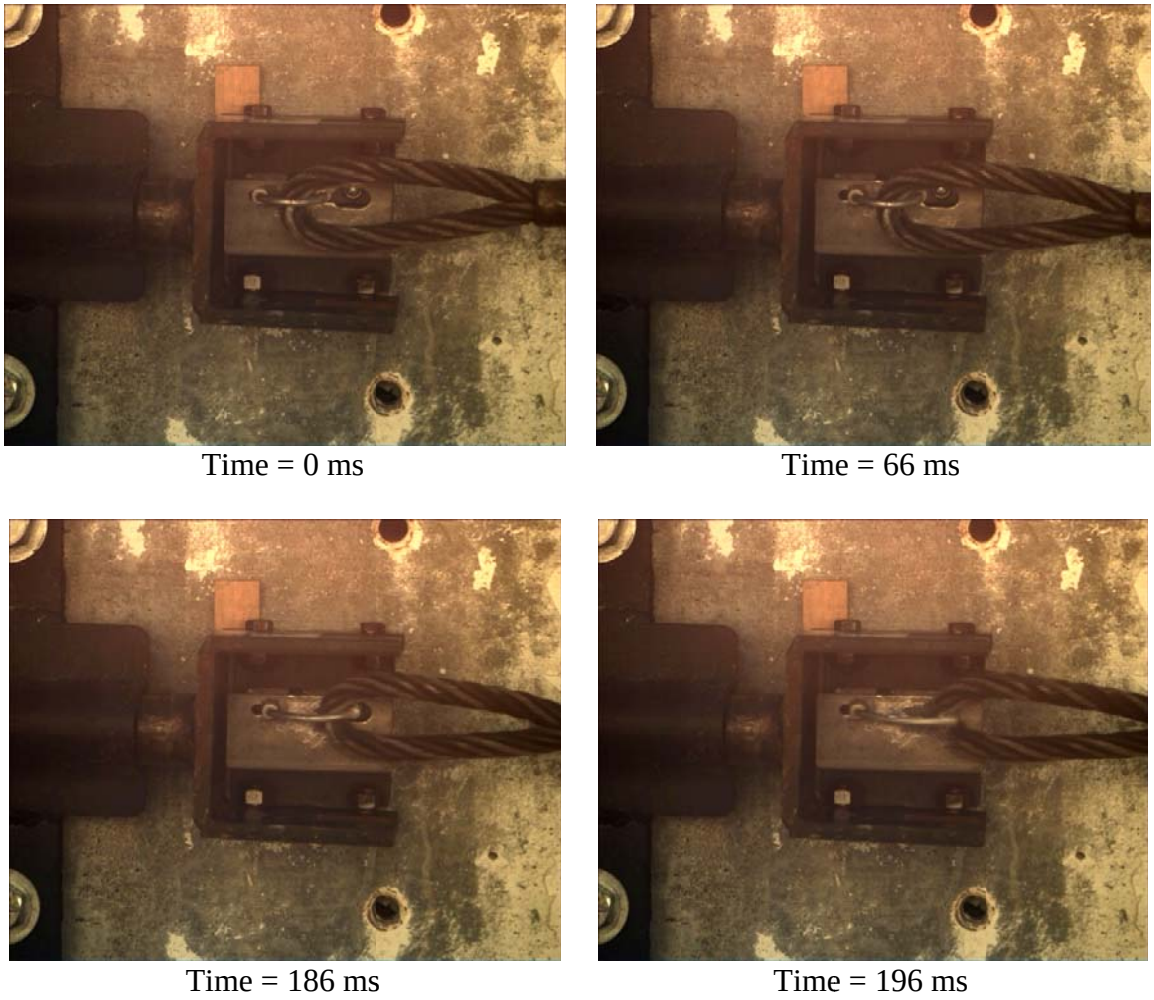


Figure 33. Force-Time Data, Test No. HTCUB-10

Pre-Test Post-Test

Figure 34. Pre-Test and Post-Test Photographs, Test No. HTCUB-10



Time = 0 ms Time = 66 ms

Time = 186 ms Time = 196 ms

Figure 35. Sequential Photographs, Test No. HTCUB-10

5.1.11 Test No. HTCUB-11

For test no. HTCUB-11, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts positioned at the center of the lower slot. The shoulder of the keyway bolt was ground off. The cable released at a load of 2.12 kips (9.43 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 36. Pre- and post-test photographs are shown in Figure 37. Sequential photographs are shown in Figure 38.

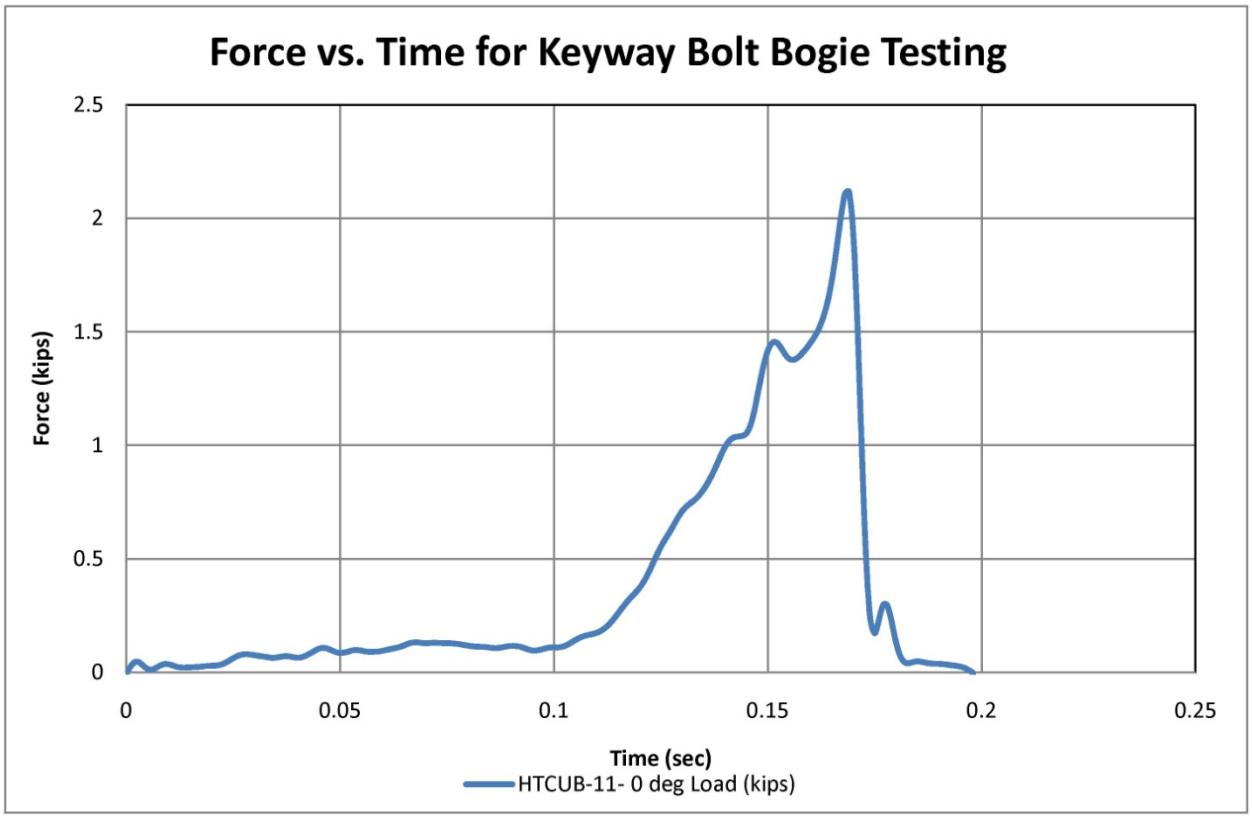
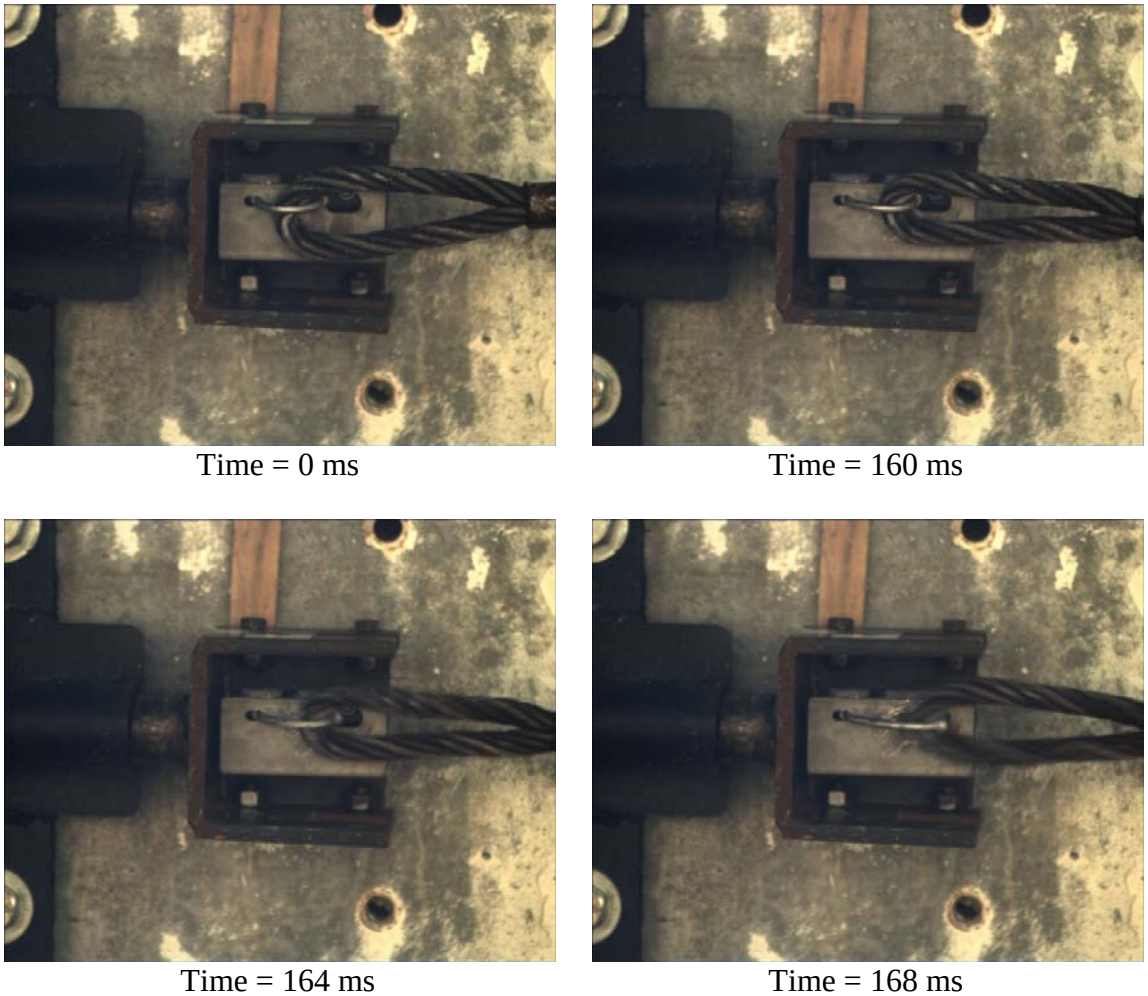


Figure 36. Force-Time Data, Test No. HTCUB-11

Pre-Test Post-Test

Figure 37. Pre-Test and Post-Test Photographs, Test No. HTCUB-11



Time = 0 ms Time = 160 ms

Time = 164 ms Time = 168 ms

Figure 38. Sequential Photographs, Test No. HTCUB-11

5.1.12 Test No. HTCUB-12

For test no. HTCUB-12, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the top of the elongated, lower slot. The slot that held the threaded end of the keyway bolt was slightly elongated. The cable released at a load of 0.56 kips (2.49 kN), but the cable snagged on the button and released at a load of 0.58 kips (2.58 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 39. Pre- and post-test photographs are shown in Figure 40. Sequential photographs are shown in Figure 41.

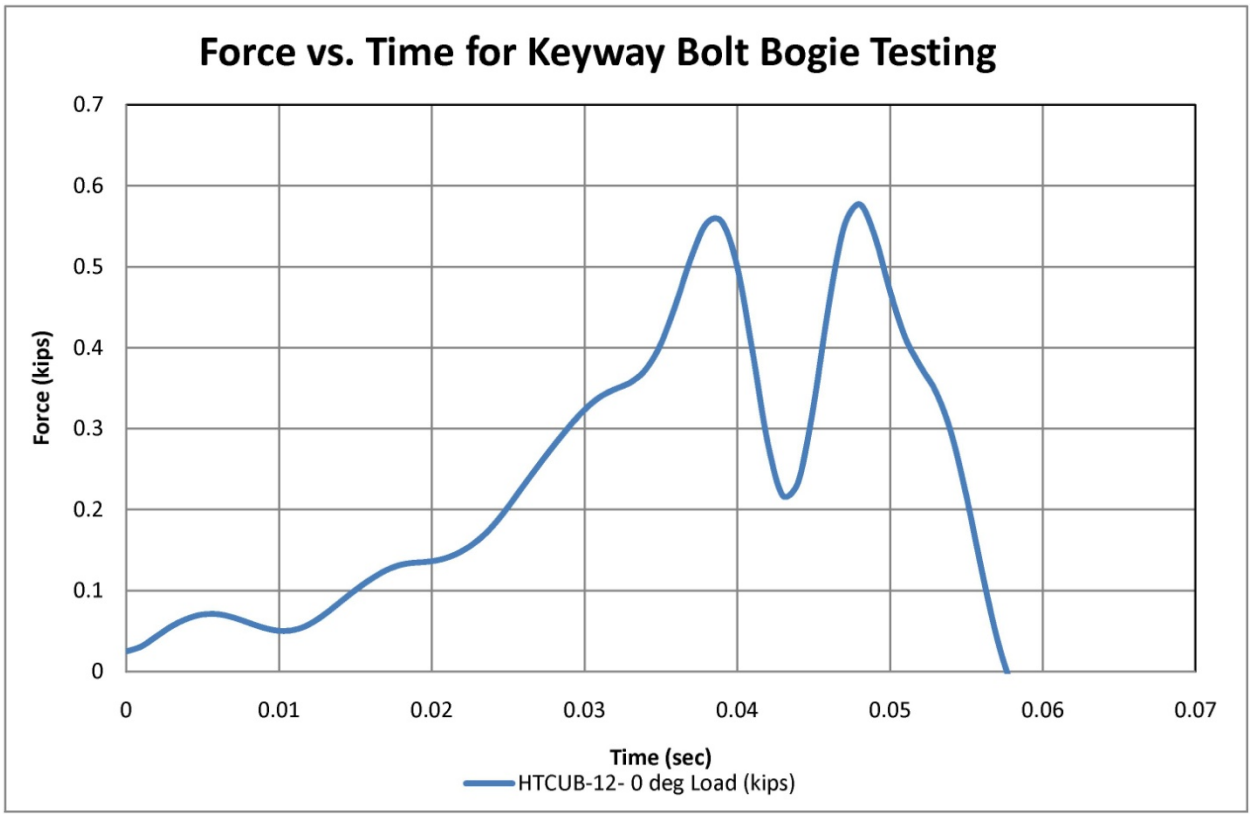
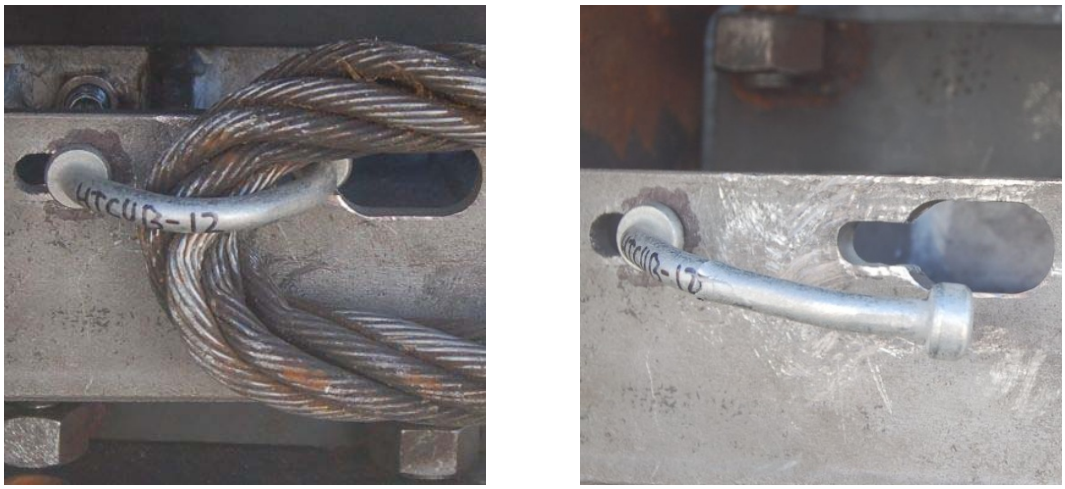
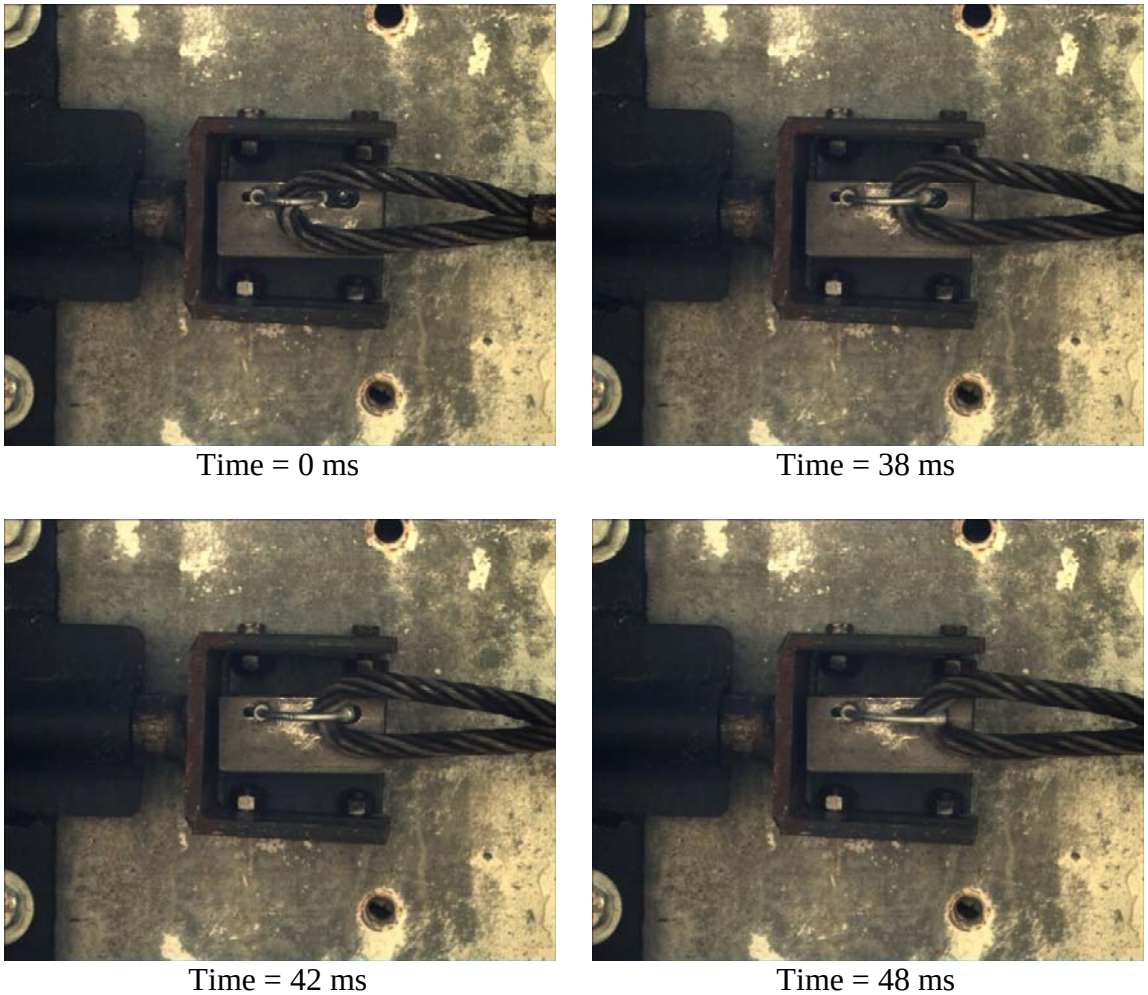


Figure 39. Force-Time Data, Test No. HTCUB-12



Pre-Test Post-Test

Figure 40. Pre-Test and Post-Test Photographs, Test No. HTCUB-12



Time = 0 ms Time = 38 ms

Time = 42 ms Time = 48 ms

Figure 41. Sequential Photographs, Test No. HTCUB-12

5.1.13 Test No. HTCUB-13

For test no. HTCUB-13, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the bottom of the slot. The slot that held the threaded end of the keyway bolt was slightly elongated. The cable released at a load of 0.85 kips (3.78 kN), but the cable snagged on the button and released at a load of 1.56 kips (6.94 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 42. Pre- and post-test photographs are shown in Figure 43. Sequential photographs are shown in Figure 44.

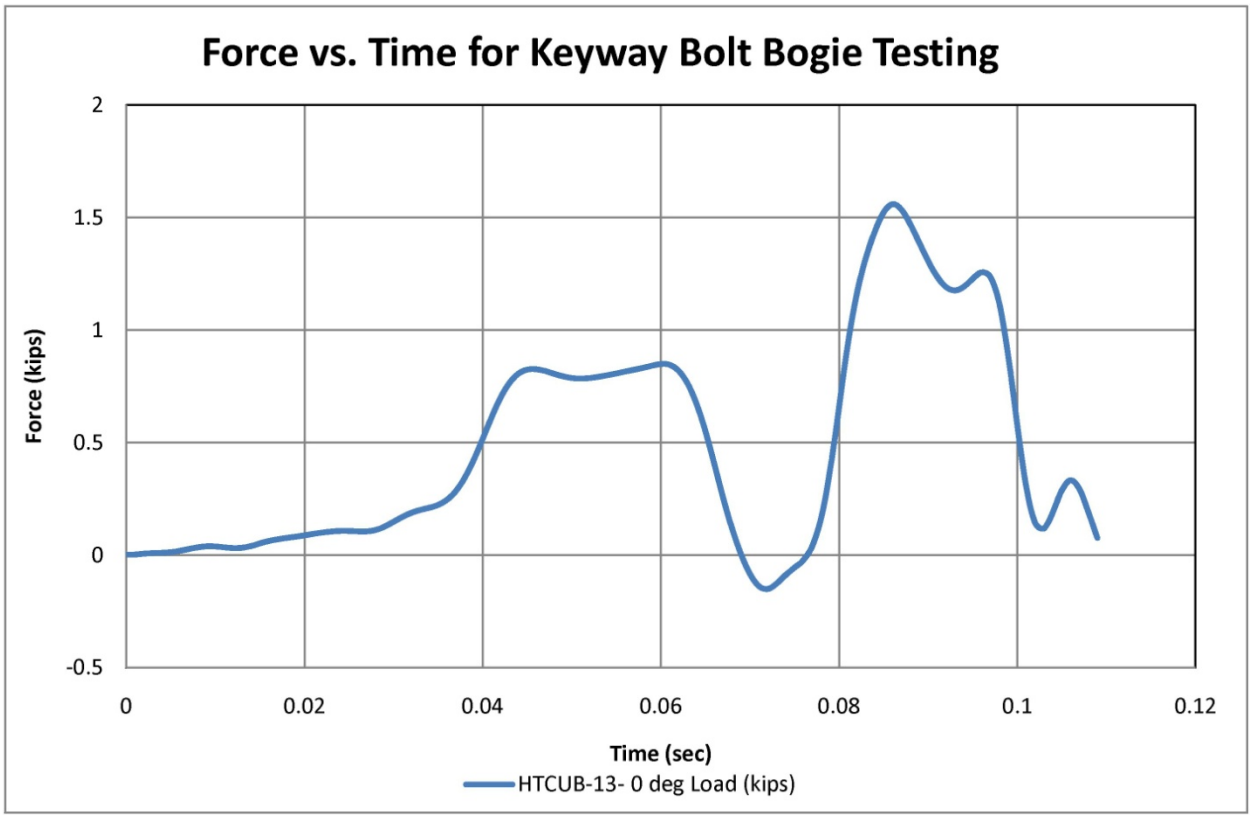
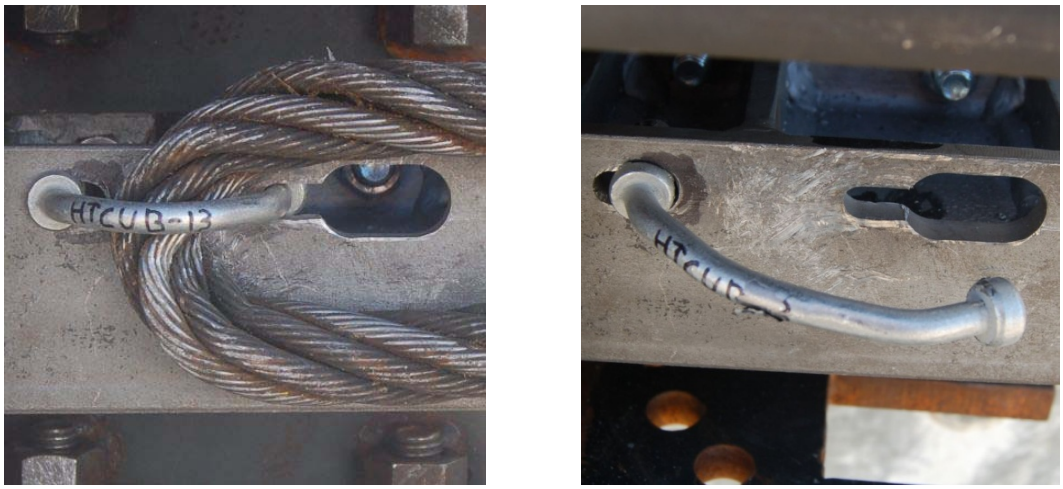
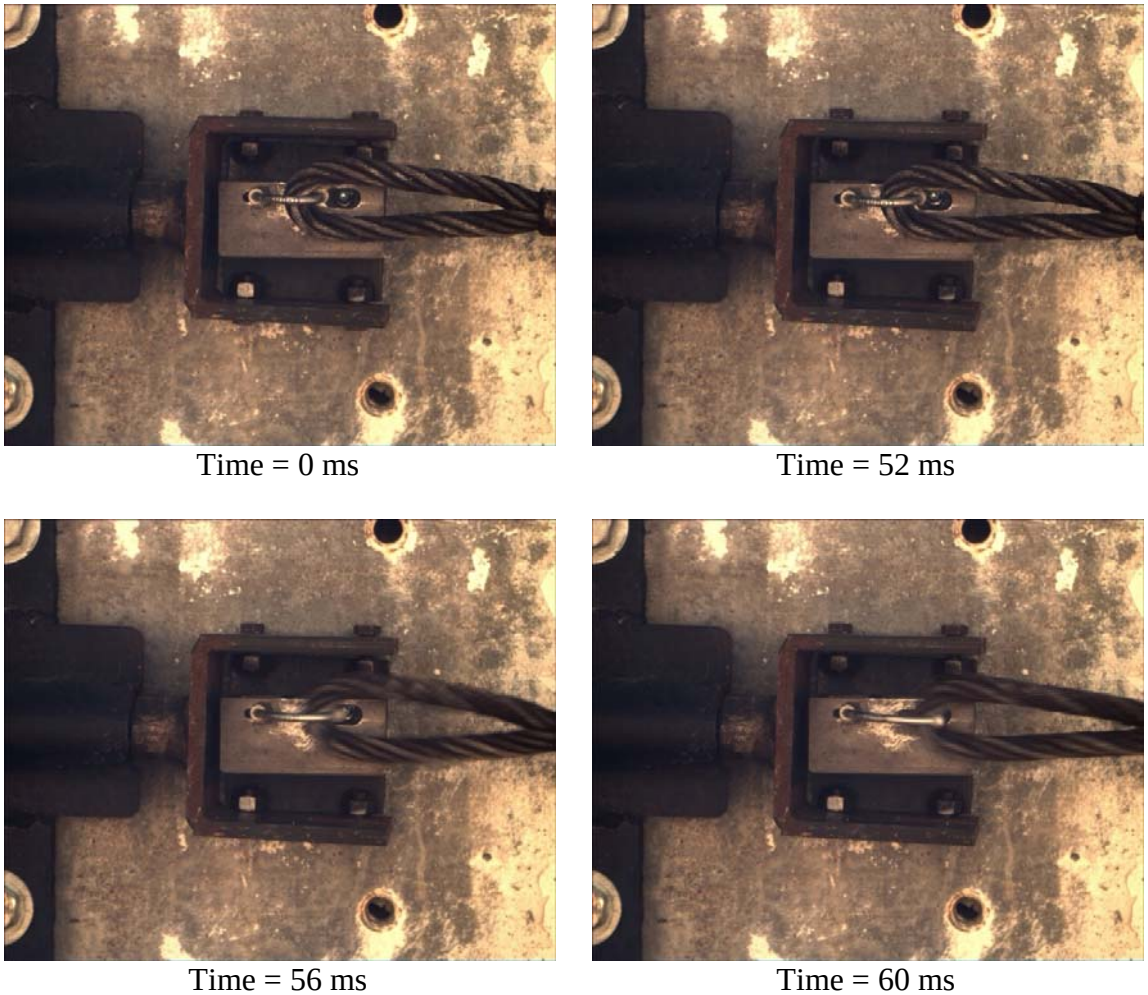


Figure 42. Force-Time Data, Test No. HTCUB-13



Pre-Test Post-Test

Figure 43. Pre-Test and Post-Test Photographs, Test No. HTCUB-13



Time = 0 ms Time = 52 ms

Time = 56 ms Time = 60 ms

Figure 44. Sequential Photographs, Test No. HTCUB-13

5.1.14 Test No. HTCUB-14

For test no. HTCUB-14, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the bottom of the slot. The slot that held the threaded end of the keyway bolt was slightly elongated. The cable released at a load of 1.42 kips (6.32 kN). The button of the keyway bolt slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 45. Pre- and post-test photographs are shown in Figure 46. Sequential photographs are shown in Figure 47.

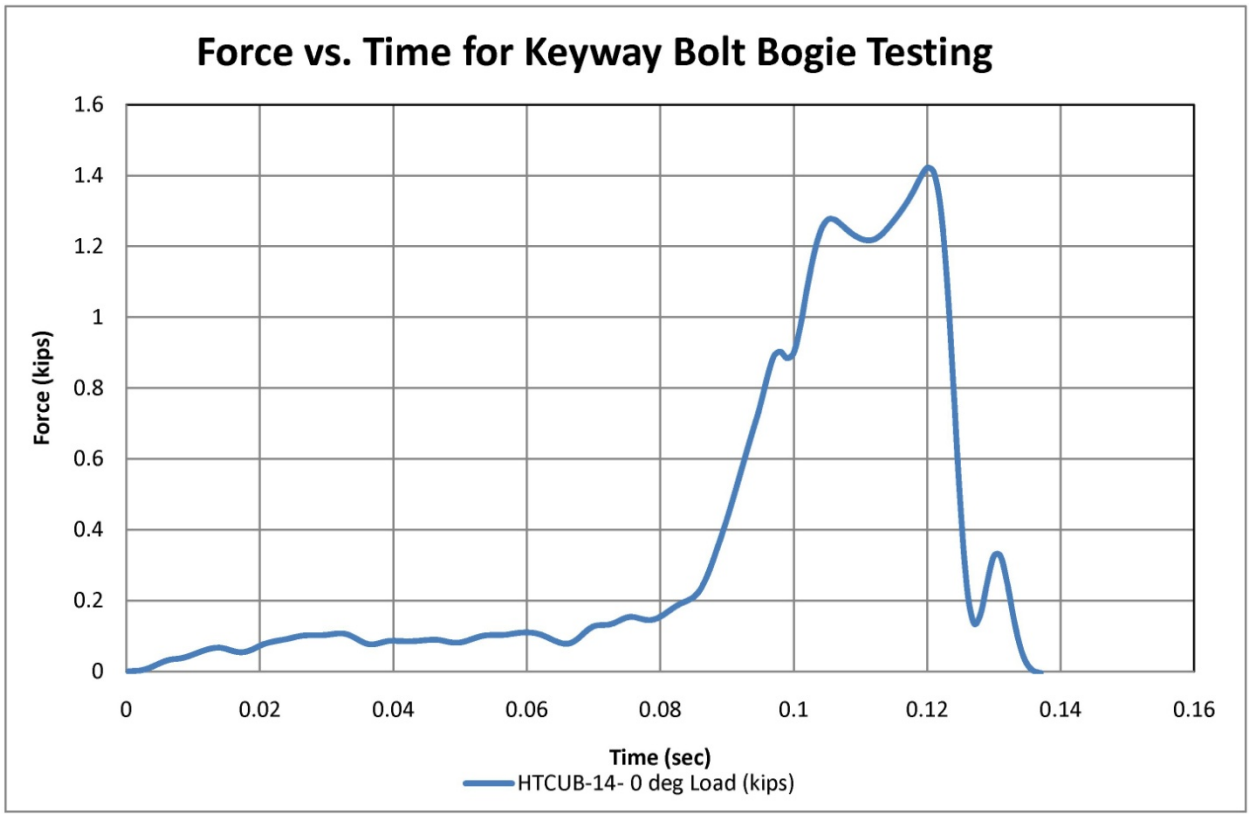
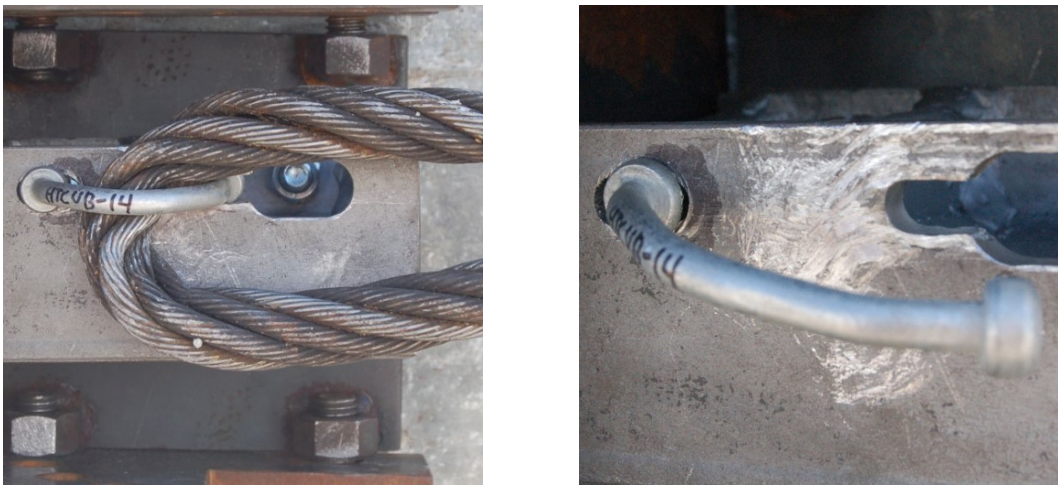
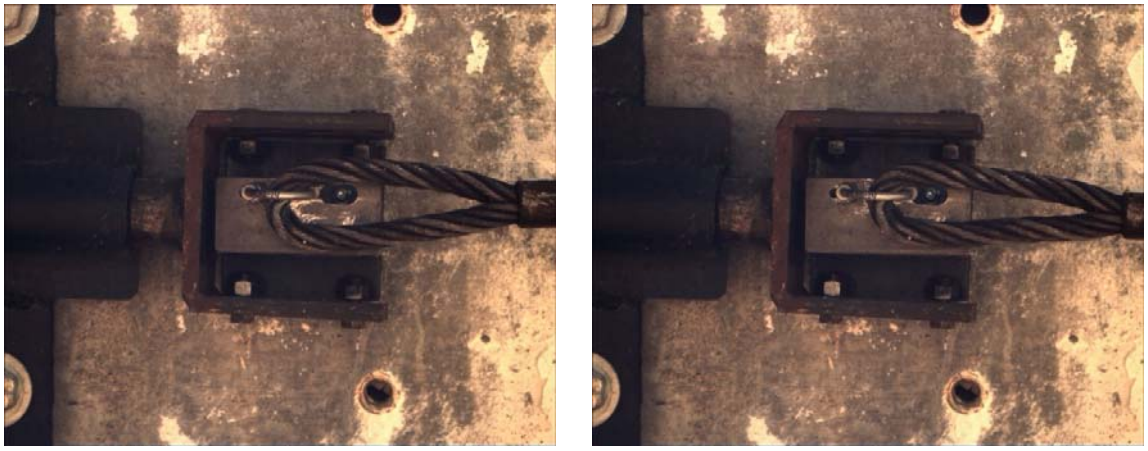


Figure 45. Force-Time Data, Test No. HTCUB-14



Pre-Test Post-Test

Figure 46. Pre-Test and Post-Test Photographs, Test No. HTCUB-14



Time = 0 ms Time = 88 ms

Time = 126 ms Time = 130 ms

Figure 47. Sequential Photographs, Test No. HTCUB-14

5.1.15 Test No. HTCUB-15

For test no. HTCUB-15, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the bottom of the slot. The slot that held the threaded end of the keyway bolt was slightly elongated and the size of the button was slightly reduced. The cable released at a load of 0.88 kips (3.91 kN), but the cable snagged on the button an released at a load of of 1.00 kips (4.45 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 48. Pre- and post-test photographs are shown in Figure 49. Sequential photographs are shown in Figure 50.

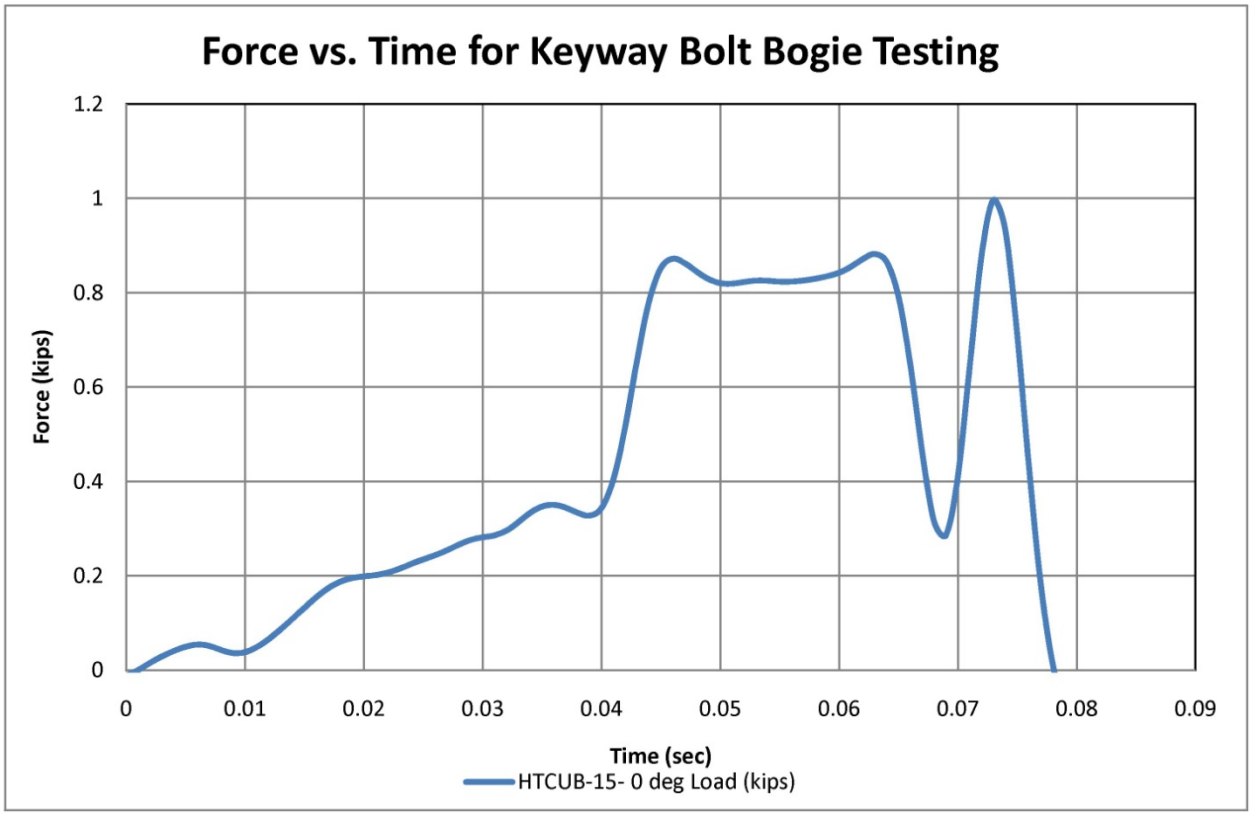
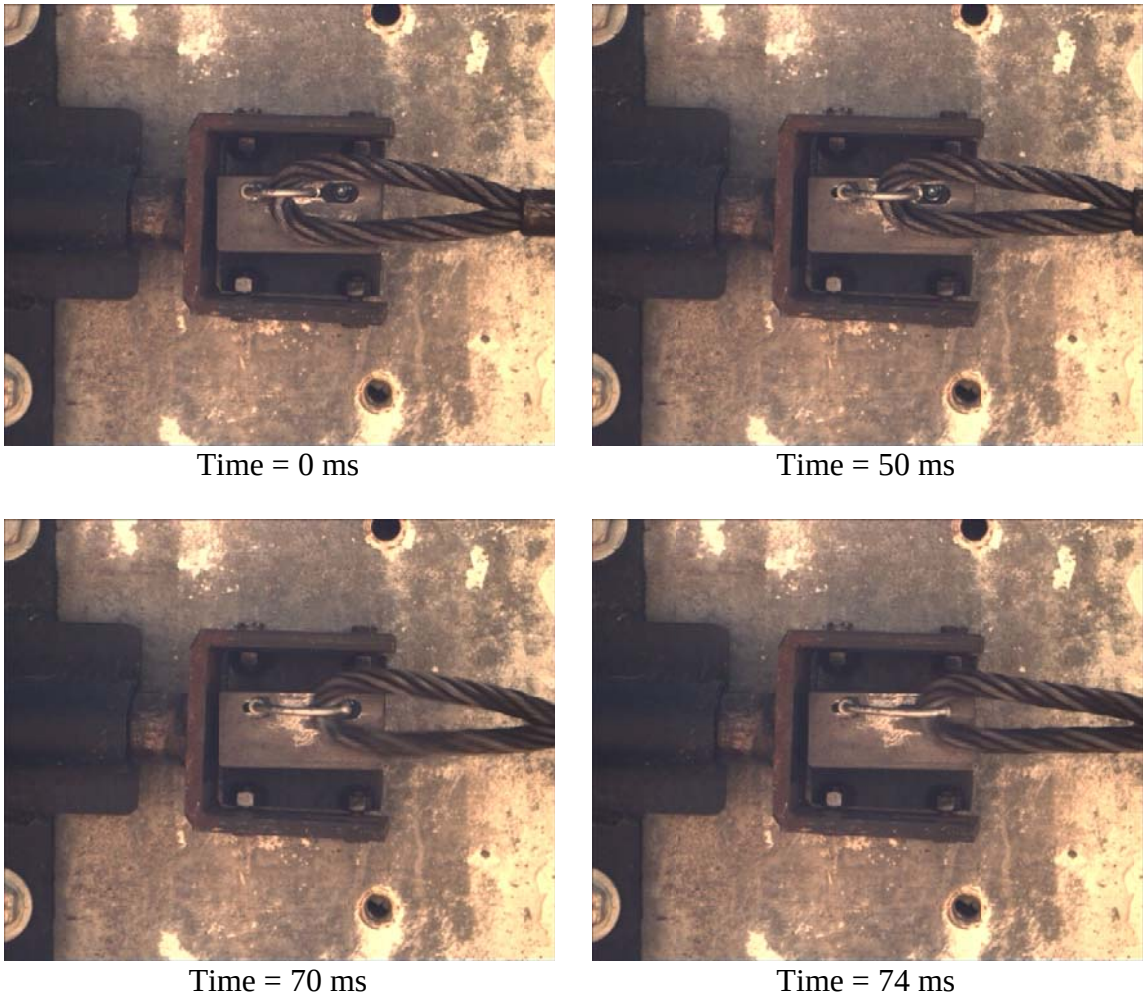


Figure 48. Force-Time Data, Test No. HTCUB-15

Pre-Test Post-Test

Figure 49. Pre-Test and Post-Test Photographs, Test No. HTCUB-15



Time = 0 ms Time = 50 ms

Time = 70 ms Time = 74 ms

Figure 50. Sequential Photographs, Test No. HTCUB-15

5.1.16 Test No. HTCUB-16

For test no. HTCUB-16, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the bottom of the slot. The slot that held the threaded end of the keyway bolt was slightly elongated and the size of the button was slightly reduced. The cable released at a load of 1.14 kips (5.07 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 51. Pre- and post-test photographs are shown in Figure 52. Sequential photographs are shown in Figure 53.

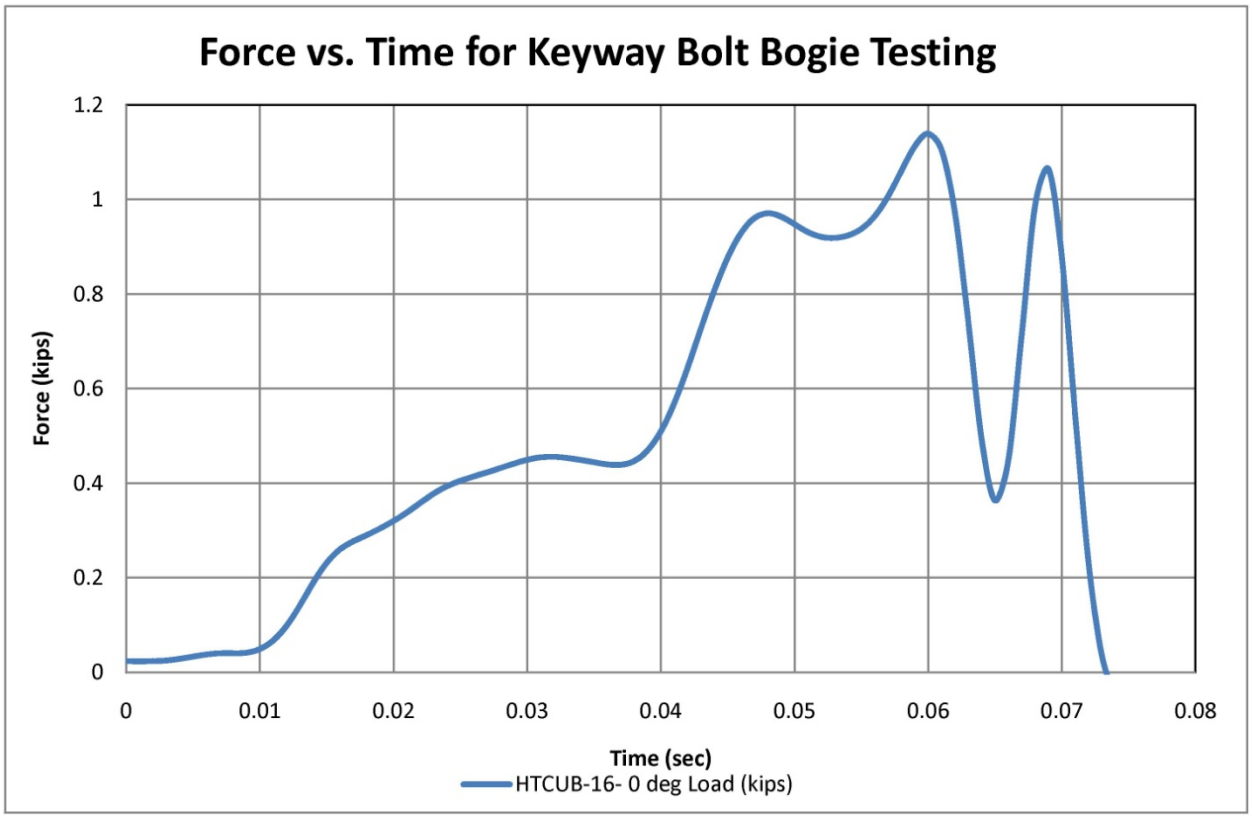
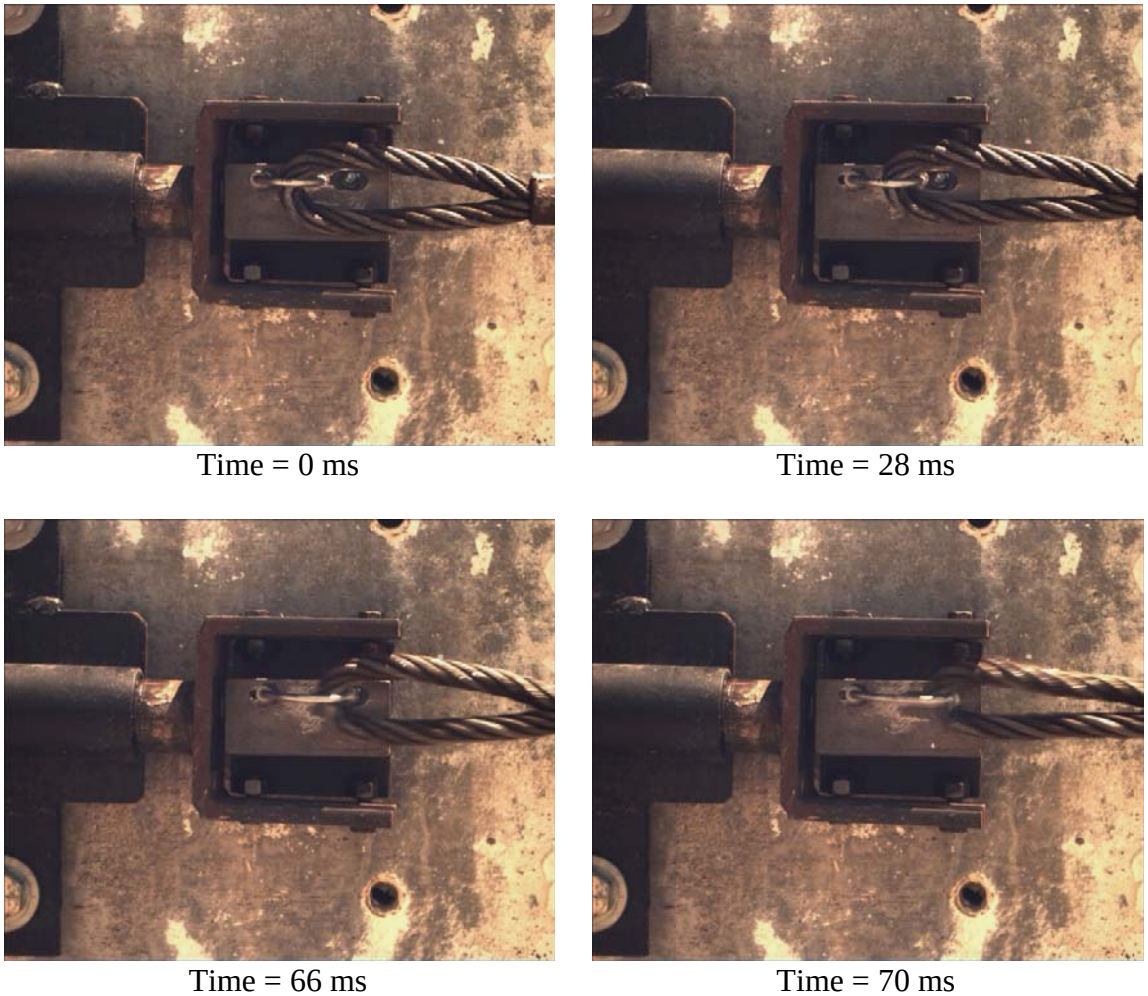


Figure 51. Force-Time Data, Test No. HTCUB-16

Pre-Test Post-Test

Figure 52. Pre-Test and Post-Test Photographs, Test No. HTCUB-16



Time = 0 ms Time = 28 ms

Time = 66 ms Time = 70 ms

Figure 53. Sequential Photographs, Test No. HTCUB-16

5.1.17 Test No. HTCUB-17

For test no. HTCUB-17, the cable applied a load to the keyway bolt at an angle of 90 degrees from the face of the flange. The keyway bolt was attached with a small gap between one grade 5 nut and the flange. The threaded end was positioned at the top of the slot, which was slightly elongated. The cable released at a load of 6.22 kips (27.67 kN). The bolt fractured through the threads and straightened out. The force versus time plot is shown in Figure 54. Pre- and post-test photographs are shown in Figure 55. Sequential photographs are shown in Figure 56.

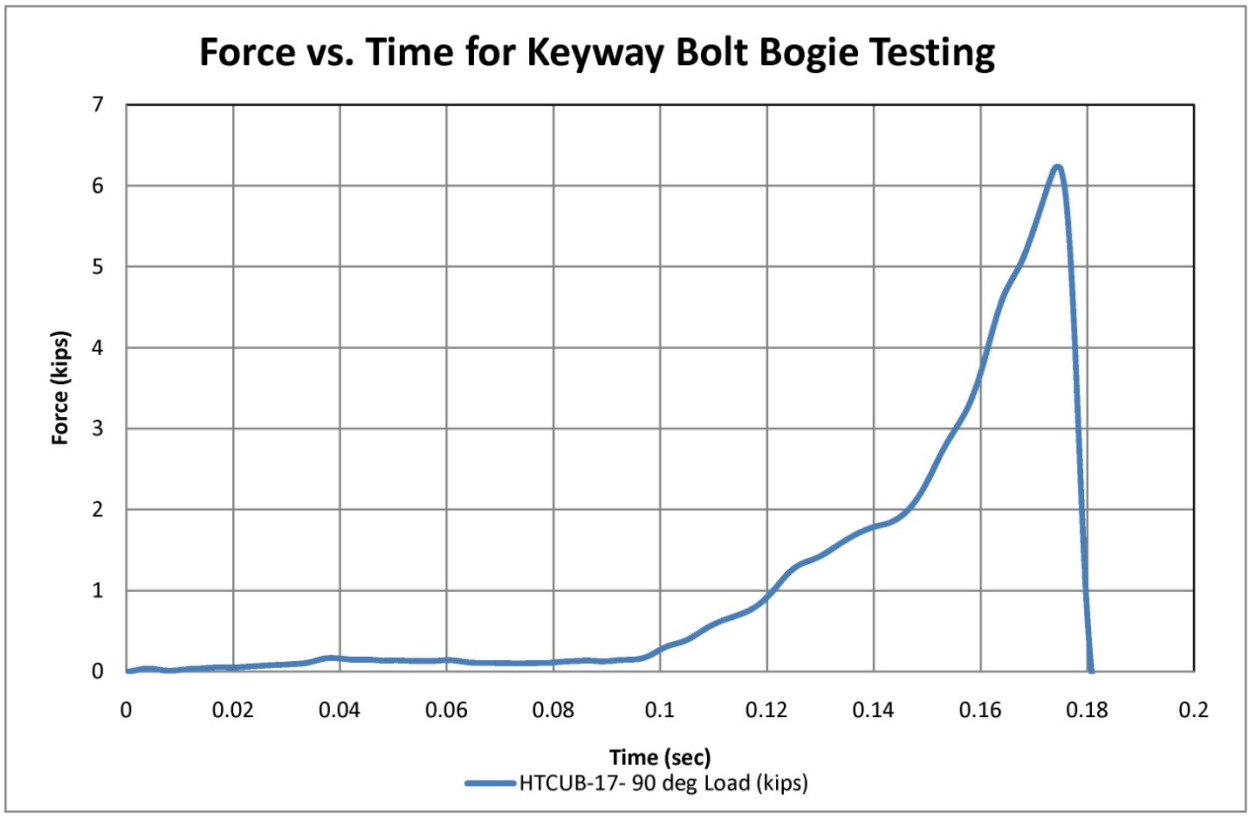
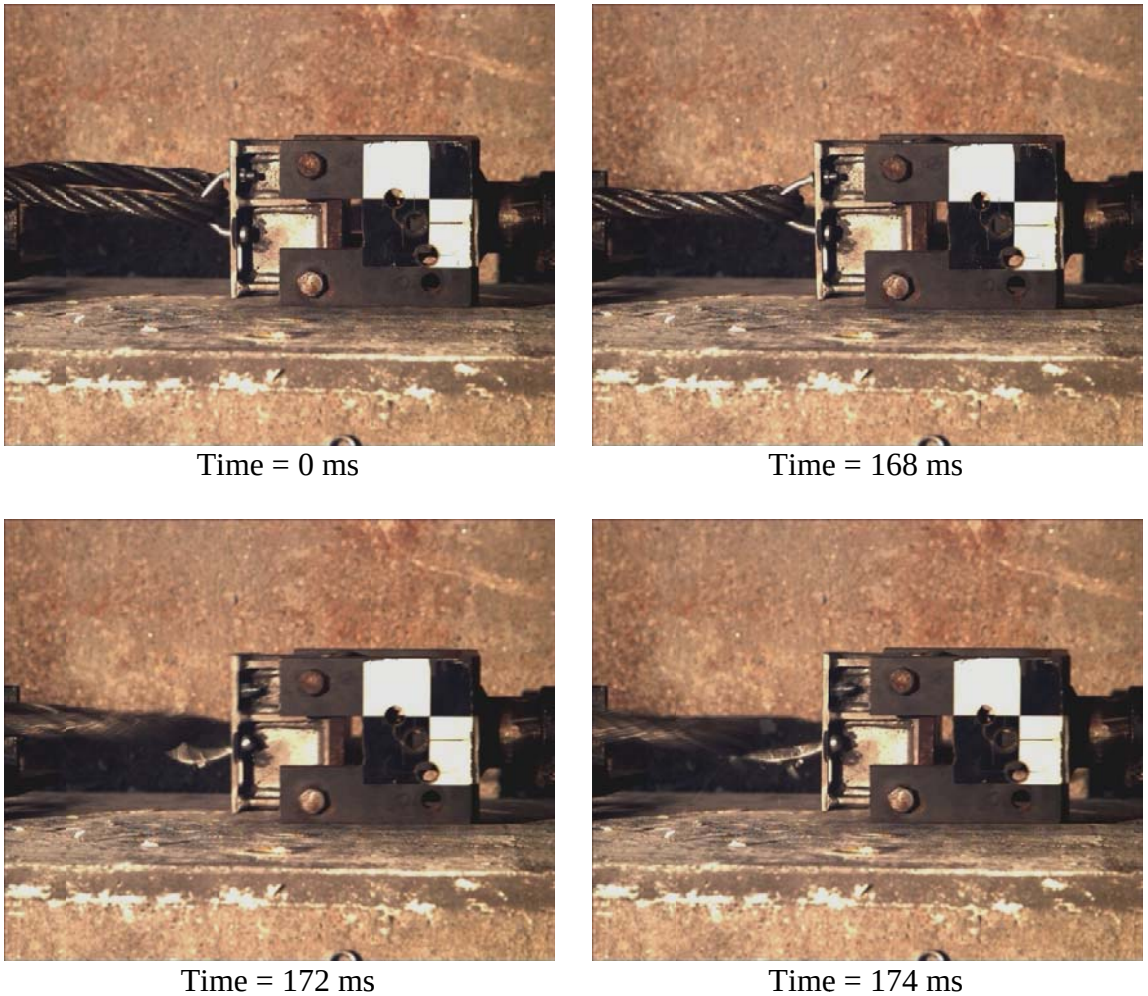


Figure 54. Force-Time Data, Test No. HTCUB-17

Pre-Test Post-Test

Figure 55. Pre-Test and Post-Test Photographs, Test No. HTCUB-17



Time = 0 ms Time = 168 ms

Time = 172 ms Time = 174 ms

Figure 56. Sequential Photographs, Test No. HTCUB-17

5.1.18 Test No. HTCUB-18

For test no. HTCUB-18, the cable applied a load to the keyway bolt at an angle of 15 degrees from the face of the flange. The keyway bolt was attached with a small gap between one grade 5 nut and the flange. The threaded end was positioned at the lower-center of the slot, which was slightly elongated. The cable released at a load of 0.93 kips (4.14 kN), but the cable snagged on the button and released at a load of 1.27 kips (5.65 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 57. Pre- and post-test photographs are shown in Figure 58. Sequential photographs are shown in Figure 59.

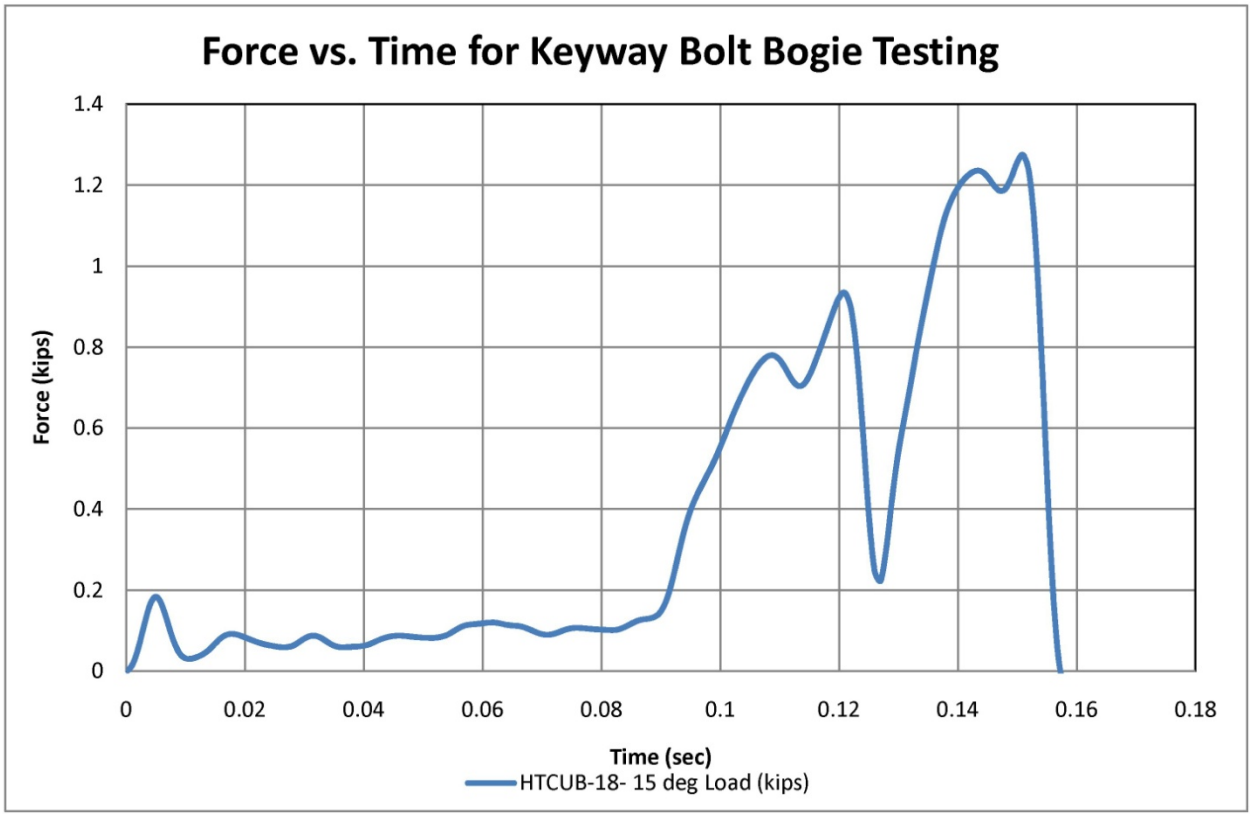
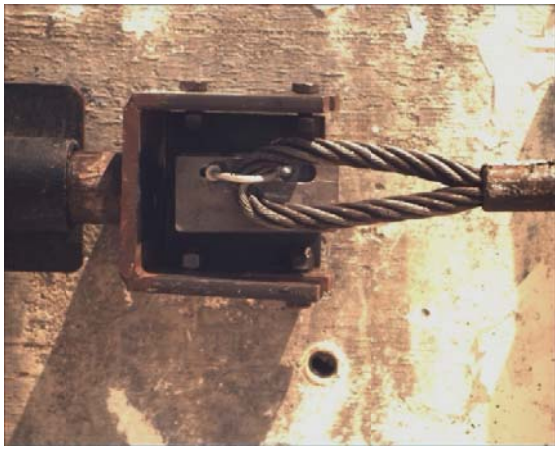


Figure 57. Force-Time Data, Test No. HTCUB-18

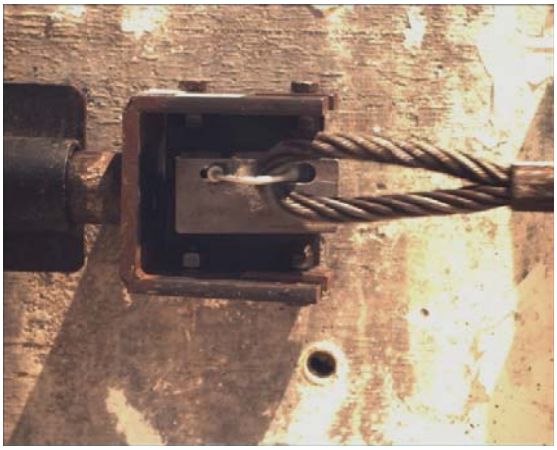
Pre-Test

Post-Test

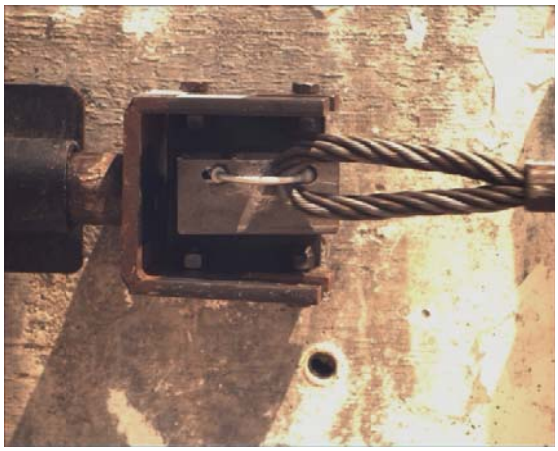
Figure 58. Pre-Test and Post-Test Photographs, Test No. HTCUB-18



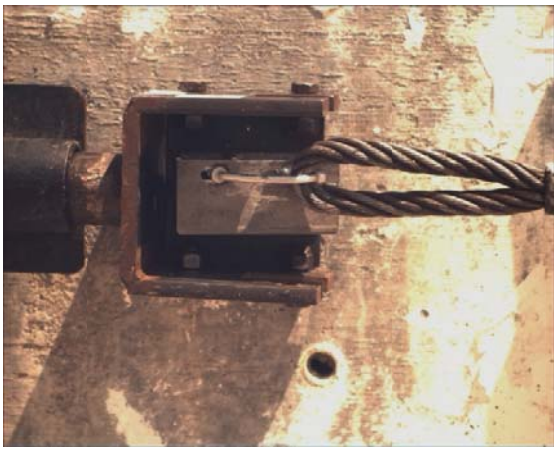
Time = 0 ms



Time = 124 ms



Time = 128 ms



Time = 150 ms

Figure 59. Sequential Photographs, Test No. HTCUB-18

5.1.19 Test No. HTCUB-19

For test no. HTCUB-19, the cable applied a load to the keyway bolt at an angle of 30 degrees from the face of the flange. The keyway bolt was attached with a small gap between one grade 5 nut and the flange. The threaded end was positioned at the center of the slot, which was slightly elongated. The cable released at a load of 0.67 kips (2.98 kN), but the cable snagged on the button and released at a load of 1.35 kips (6.01 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 60. Pre- and post-test photographs are shown in Figure 61. Sequential photographs are shown in Figure 62.

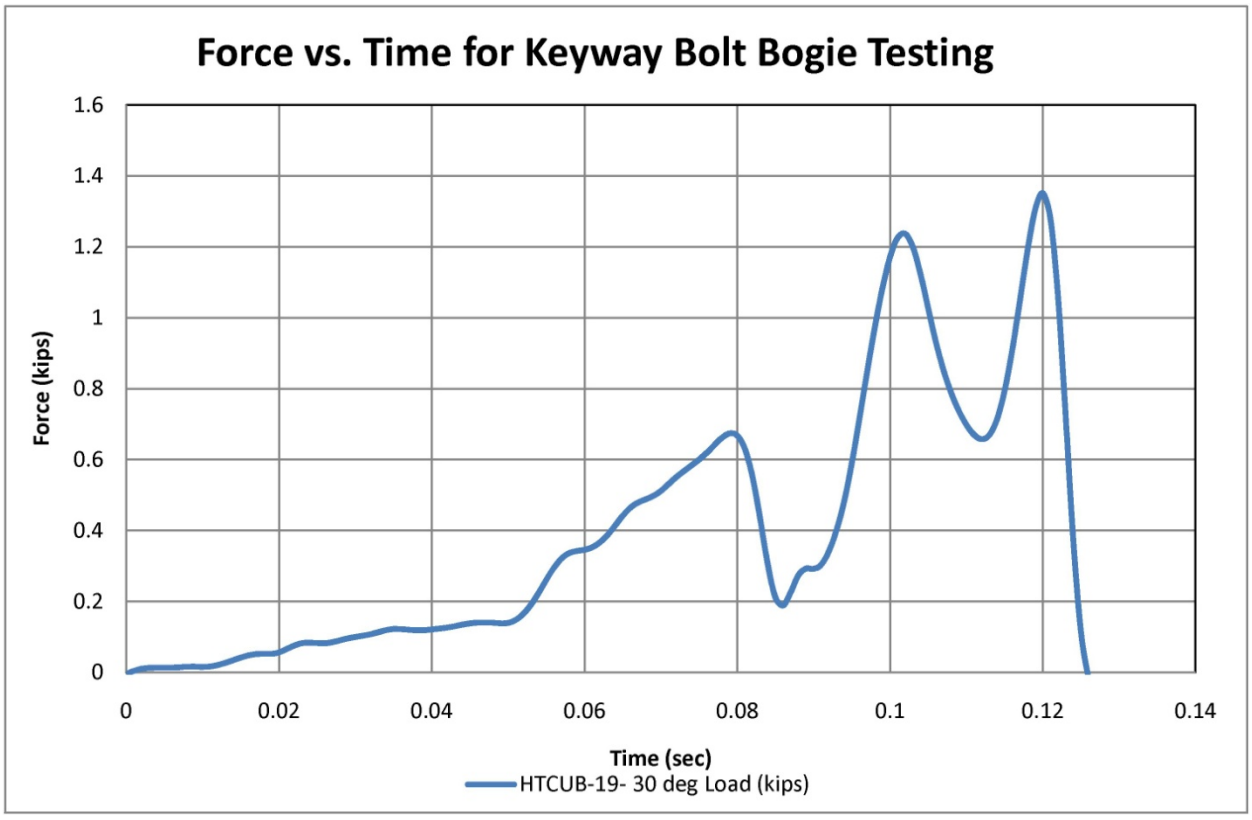
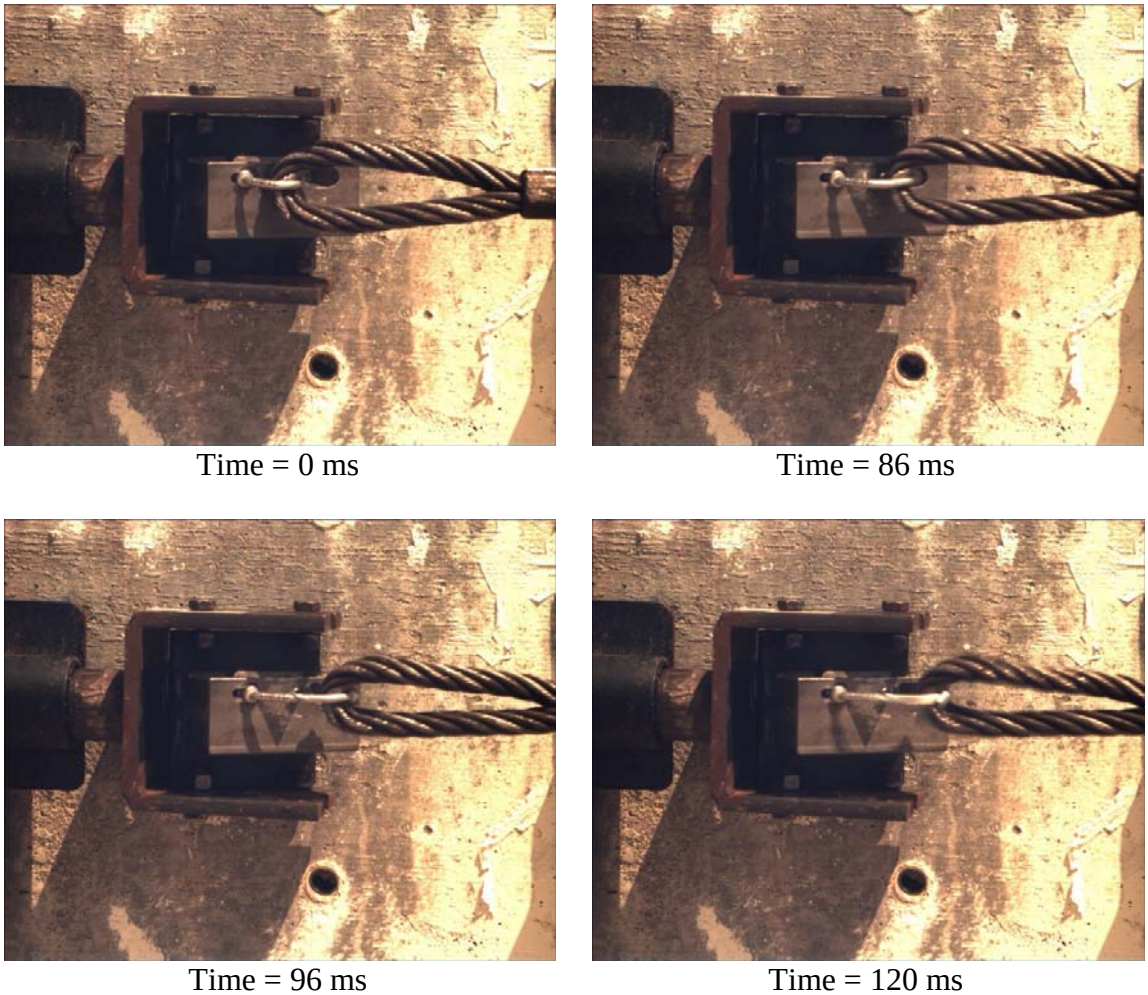


Figure 60. Force-Time Data, Test No. HTCUB-19

Pre-Test Post-Test

Figure 61. Pre-Test and Post-Test Photographs, Test No. HTCUB-19



Time = 0 ms Time = 86 ms

Time = 96 ms Time = 120 ms

Figure 62. Sequential Photographs, Test No. HTCUB-19

5.1.20 Test No. HTCUB-20

For test no. HTCUB-20, the cable applied a load to the keyway bolt at an angle of 45 degrees from the face of the flange. The keyway bolt was attached with a small gap between one grade 5 nut and the flange. The threaded end was positioned at the bottom of the slot, which was slightly elongated. The cable released at a load of 0.66 kips (2.94 kN), but the cable snagged on the button and released at a load of 0.68 kips (3.02 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 63. Pre- and post-test photographs are shown in Figure 64. Sequential photographs are shown in Figure 65.

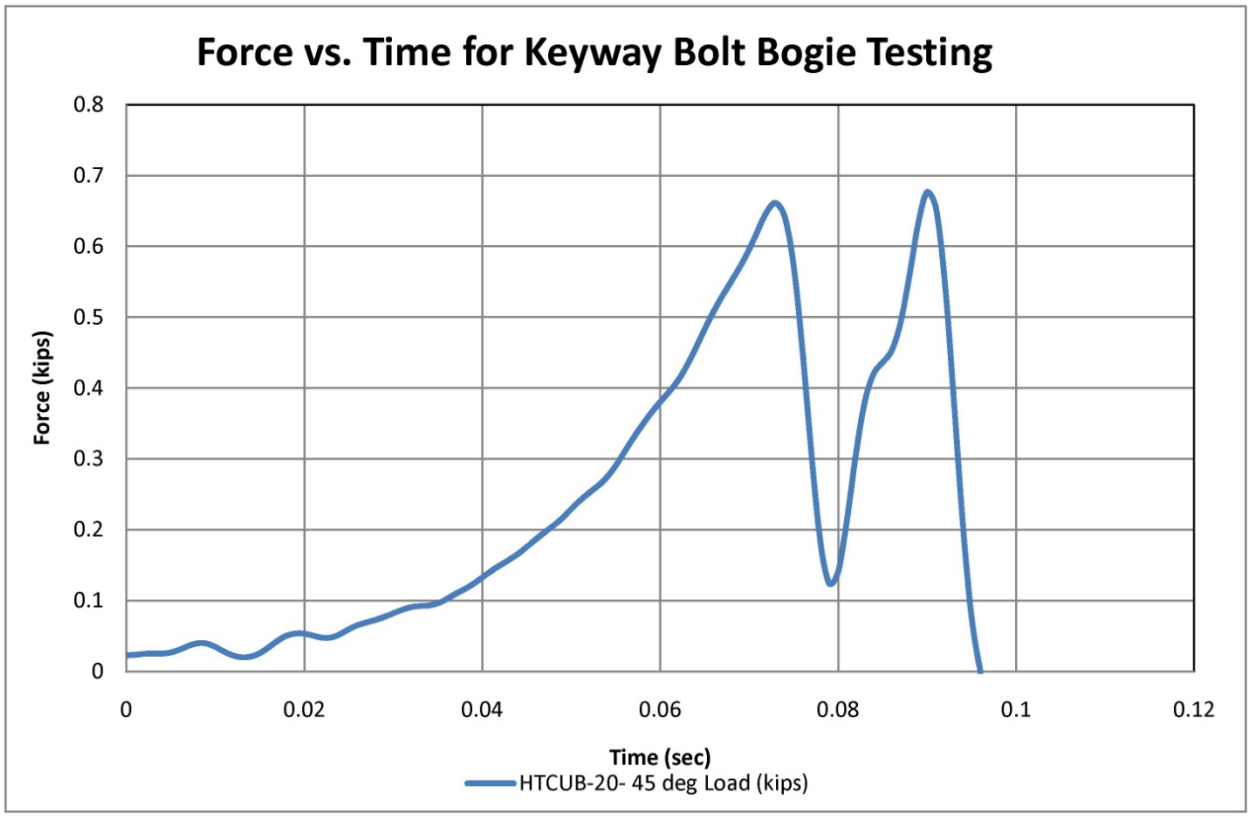
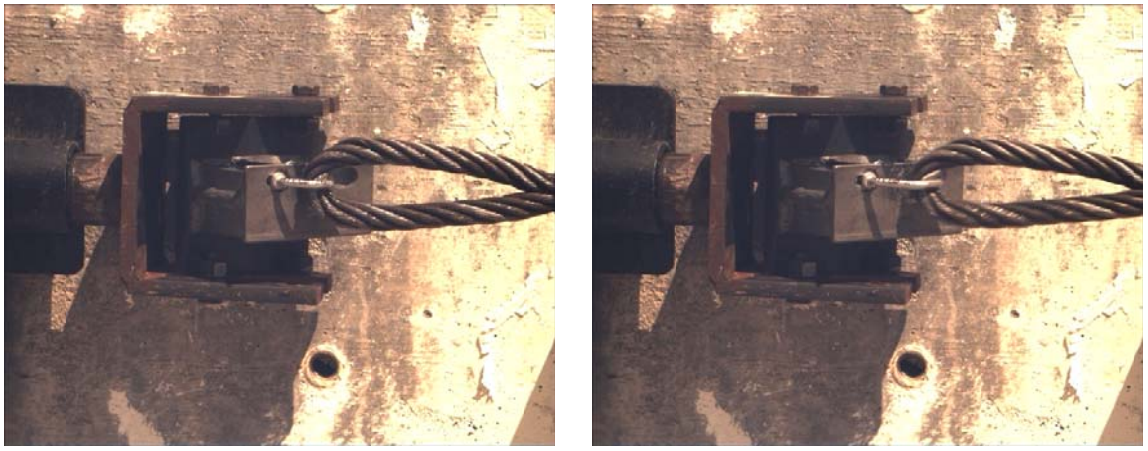


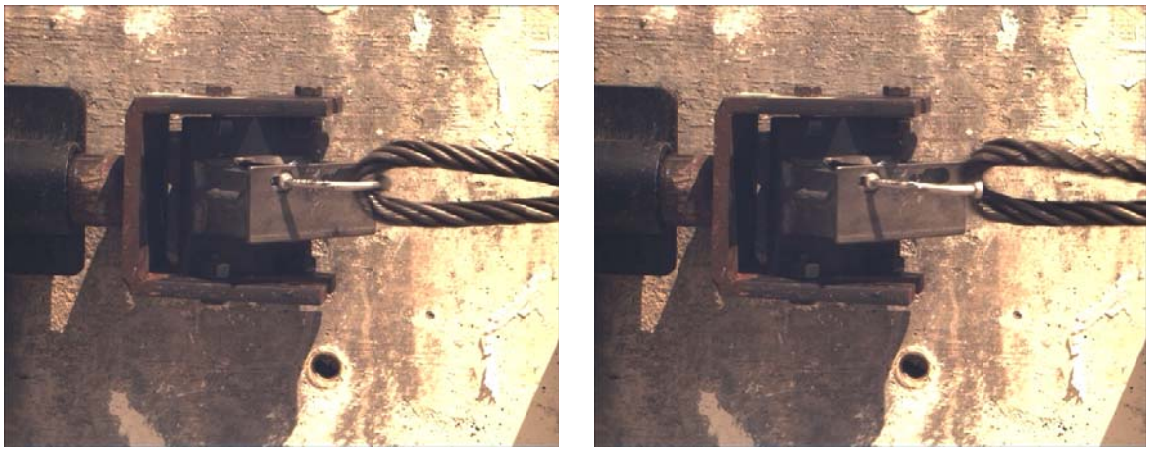
Figure 63. Force-Time Data, Test No. HTCUB-20

Pre-Test | Post-Test

Figure 64. Pre-Test and Post-Test Photographs, Test No. HTCUB-20



Time = 0 ms | Time = 76 ms



Time = 84 ms | Time = 90 ms

Figure 65. Sequential Photographs, Test No. HTCUB-20

5.1.21 Test No. HTCUB-21

For test no. HTCUB-21, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the top of the slot. The slot that held the threaded end of the keyway bolt was slightly elongated. The cable released at a load of 0.94 kips (4.18 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 66. Pre- and post-test photographs are shown in Figure 67. Sequential photographs are shown in Figure 68.

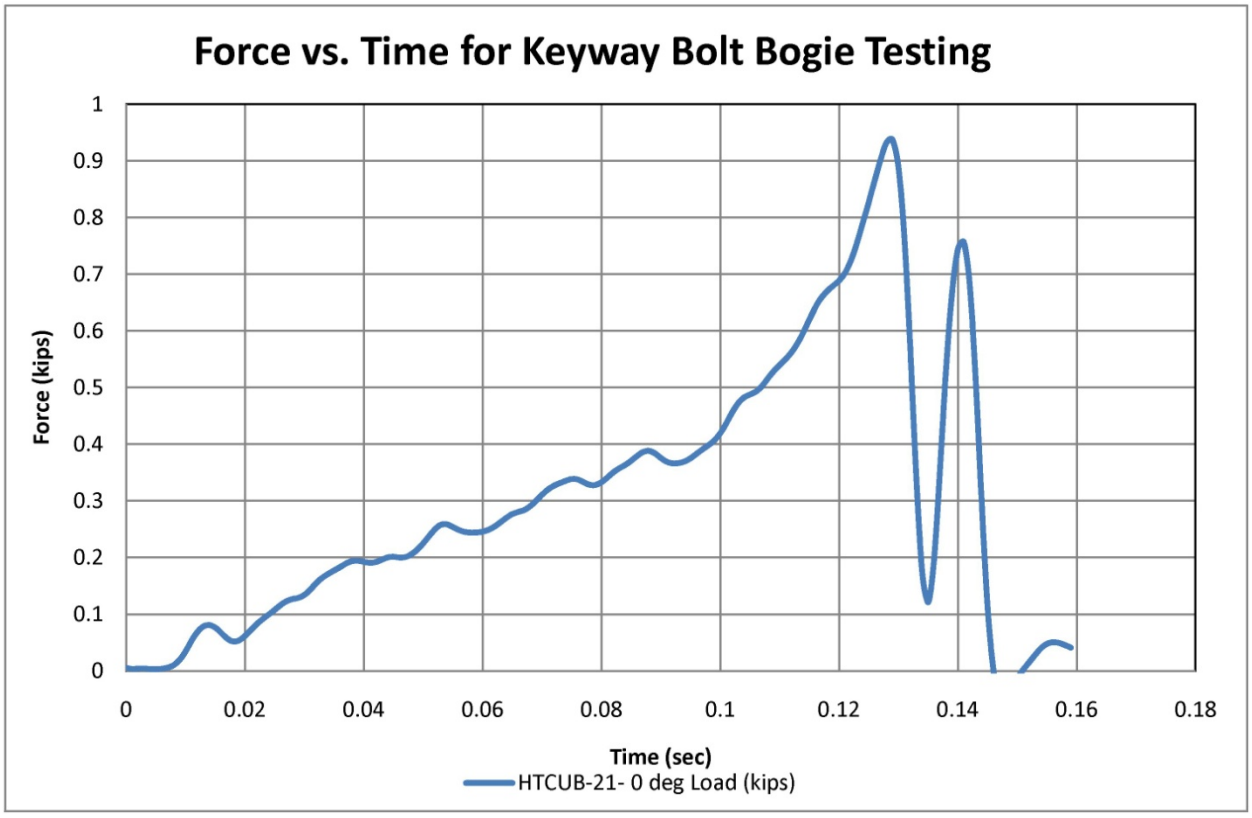
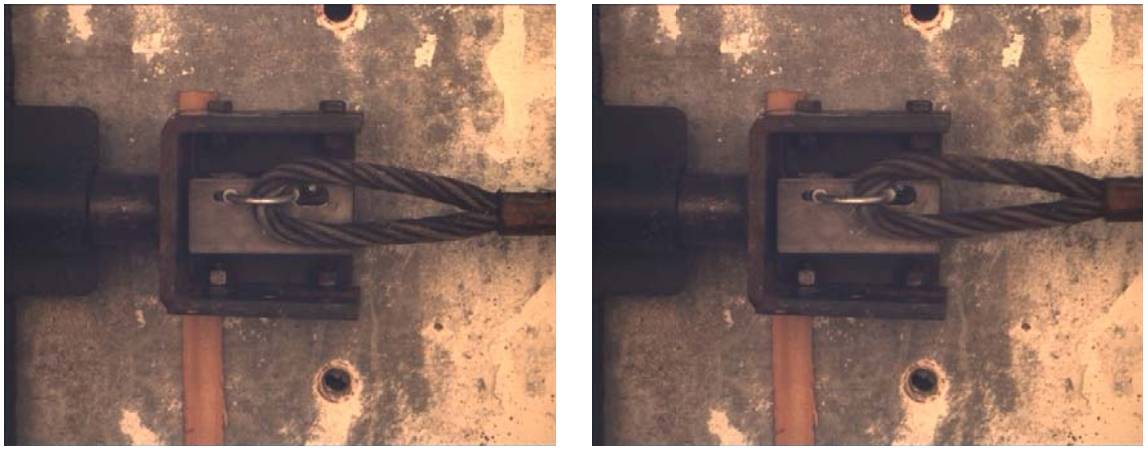


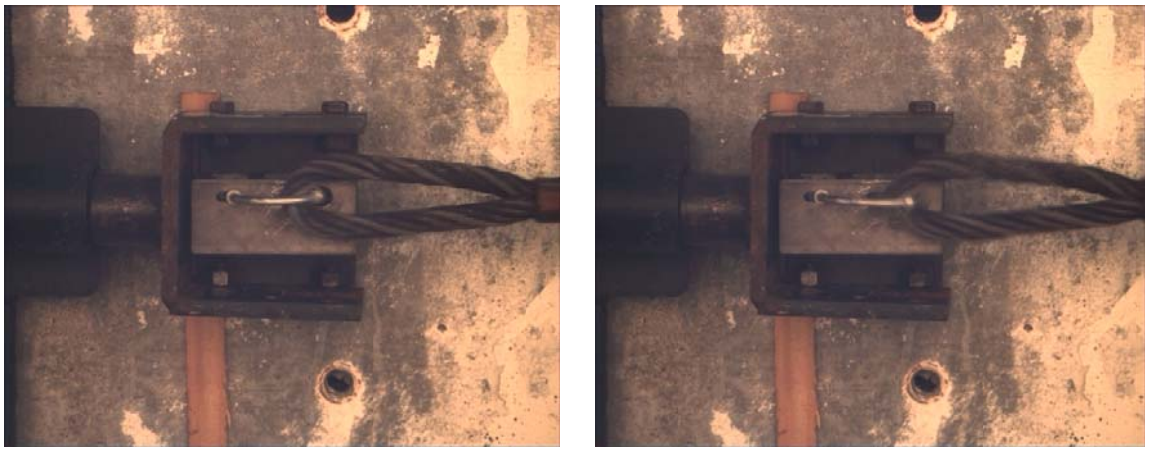
Figure 66. Force-Time Data, Test No. HTCUB-21

Pre-Test | Post-Test

Figure 67. Pre-Test and Post-Test Photographs, Test No. HTCUB-21



Time = 0 ms | Time = 130 ms



Time = 134 ms | Time = 140 ms

Figure 68. Sequential Photographs, Test No. HTCUB-21

5.1.22 Test No. HTCUB-22

For test no. HTCUB-22, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the top of the slot. The slot that held the threaded end of the keyway bolt was slightly elongated. The cable released at a load of 0.90 kips (4.00 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 69. Pre- and post-test photographs are shown in Figure 70. Sequential photographs are shown in Figure 71.

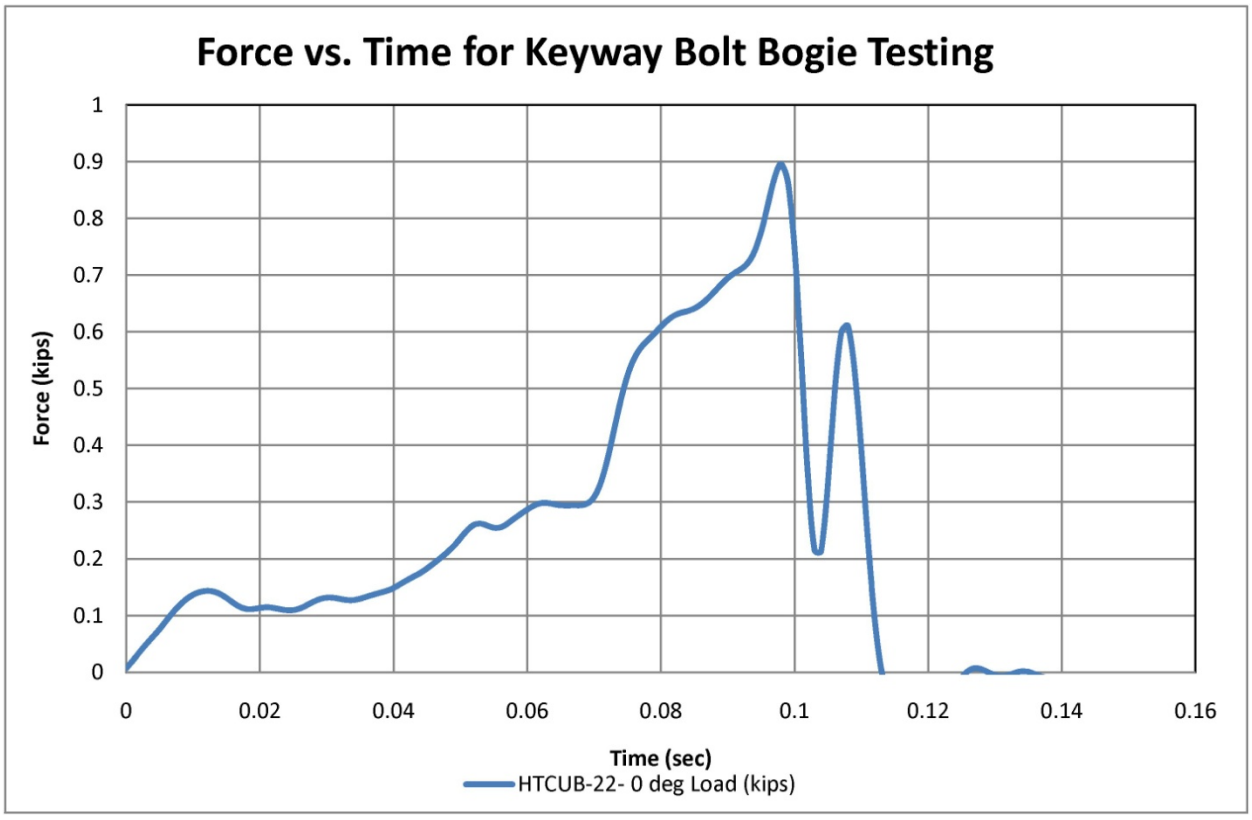
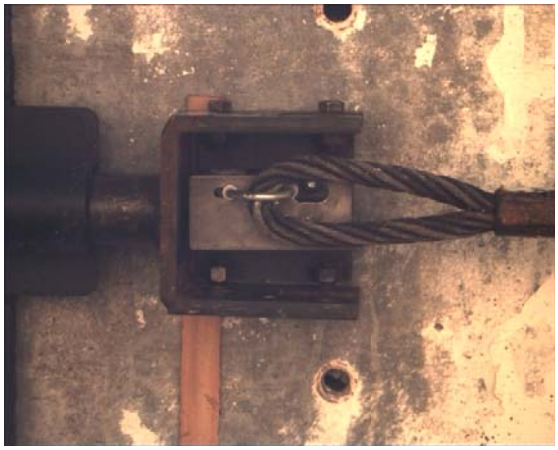


Figure 69. Force-Time Data, Test No. HTCUB-22

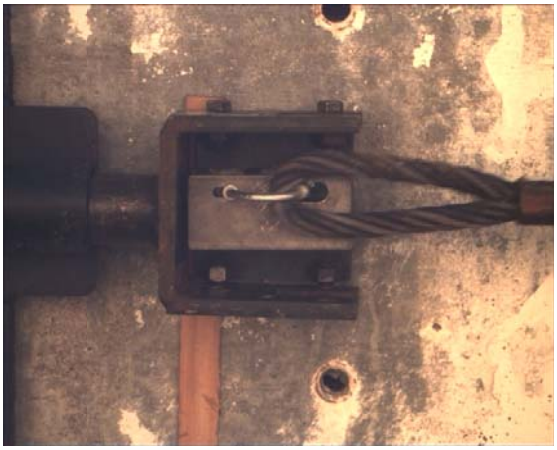
Pre-Test

Post-Test

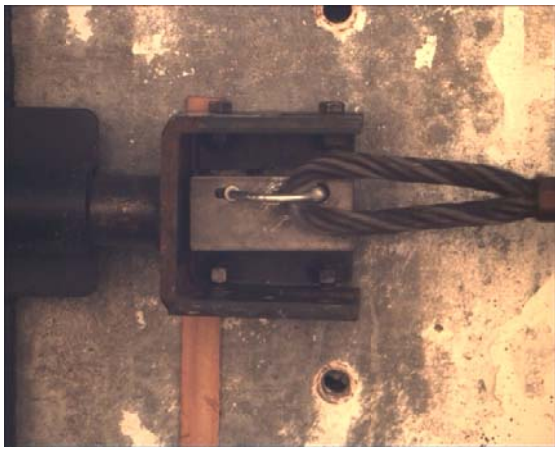
Figure 70. Pre-Test and Post-Test Photographs, Test No. HTCUB-22



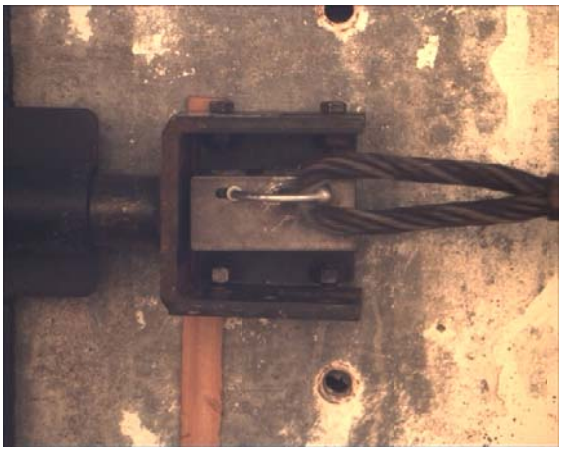
Time = 0 ms



Time = 102 ms



Time = 106 ms



Time = 108 ms

Figure 71. Sequential Photographs, Test No. HTCUB-22

5.1.23 Test No. HTCUB-23

For test no. HTCUB-23, the cable applied a load to the keyway bolt at an angle of 90 degrees from the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the top of the slot. The slot that held the threaded end of the keyway bolt was slightly elongated. The cable released at a load of 6.19 kips (27.53 kN). The keyway bolt fractured through the threads and straightened out. The force versus time plot is shown in Figure 72. Pre- and post-test photographs are shown in Figure 73. Sequential photographs are shown in Figure 74.

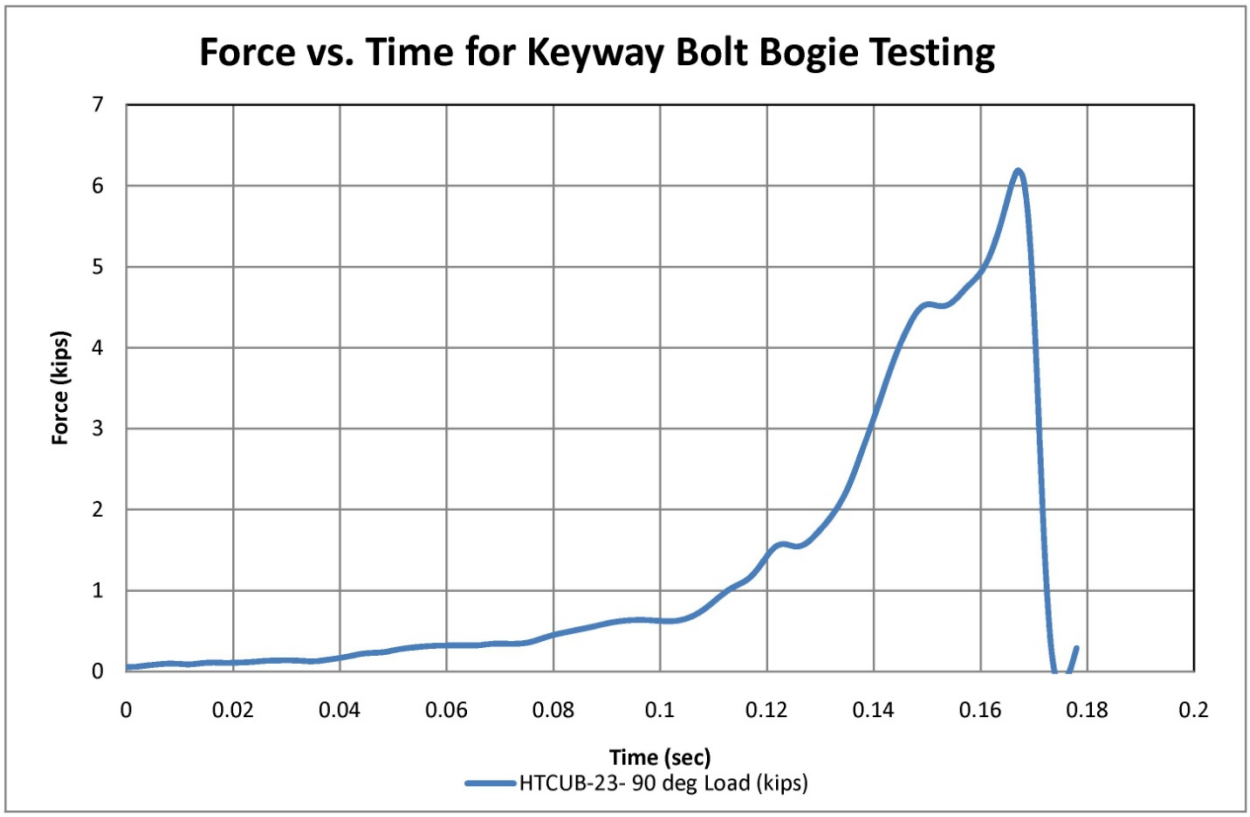
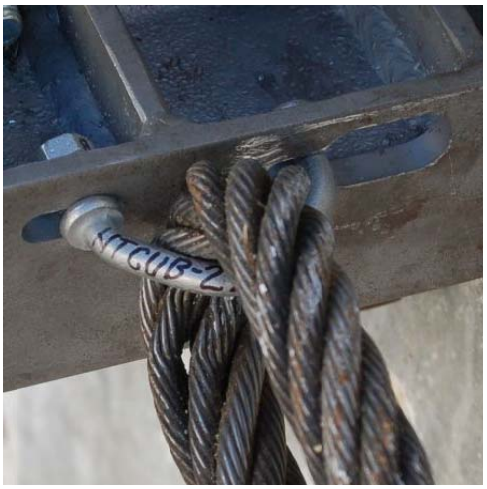


Figure 72. Force-Time Data, Test No. HTCUB-23

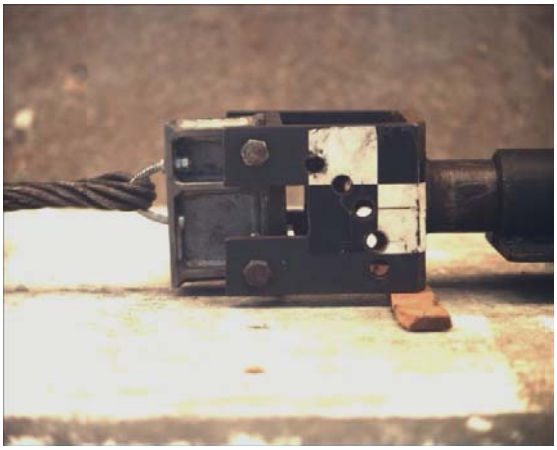


Pre-Test

Post-Test

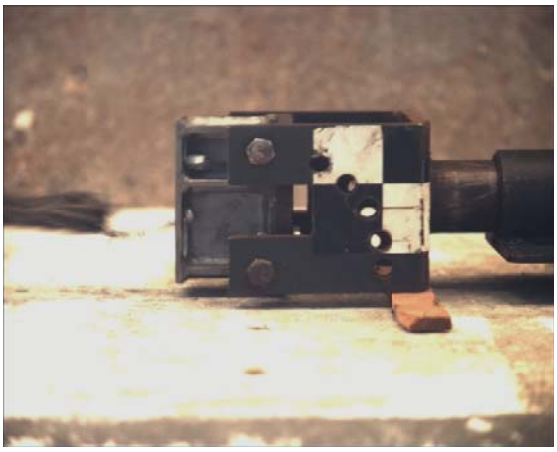
Figure 73. Pre-Test and Post-Test Photographs, Test No. HTCUB-23

Time = 0 ms



Time = 164 ms

Time = 166 ms



Time = 168 ms

Figure 74. Sequential Photographs, Test No. HTCUB-23

5.1.24 Test No. HTCUB-24

For test no. HTCUB-24, the cable applied a load to the keyway bolt at an angle of 45 degrees from the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the top of the slot. The slot that held the threaded end of the keyway bolt was slightly elongated. The cable released at a load of 0.74 kips (3.29 kN), but the cable snagged on the button and released at a load of 1.61 kips (7.16 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 75. Pre- and post-test photographs are shown in Figure 76. Sequential photographs are shown in Figure 77.

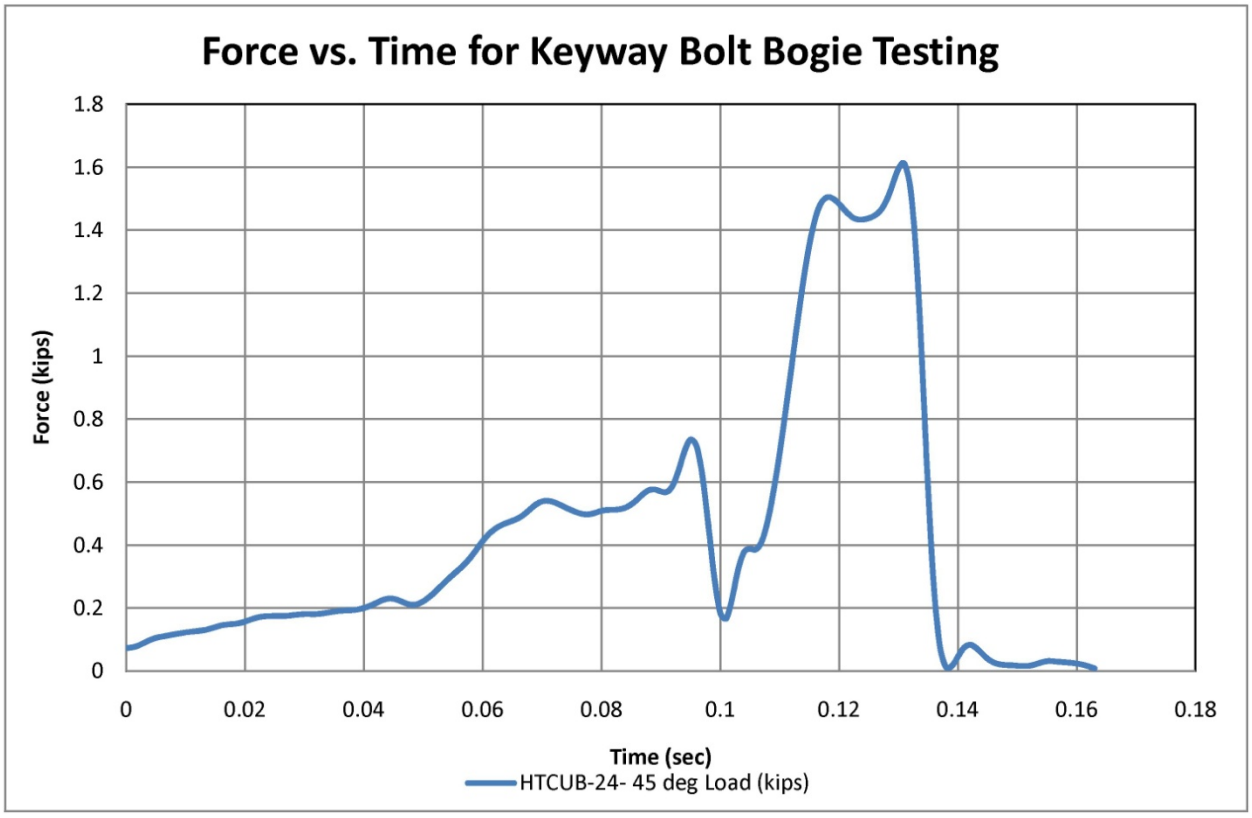
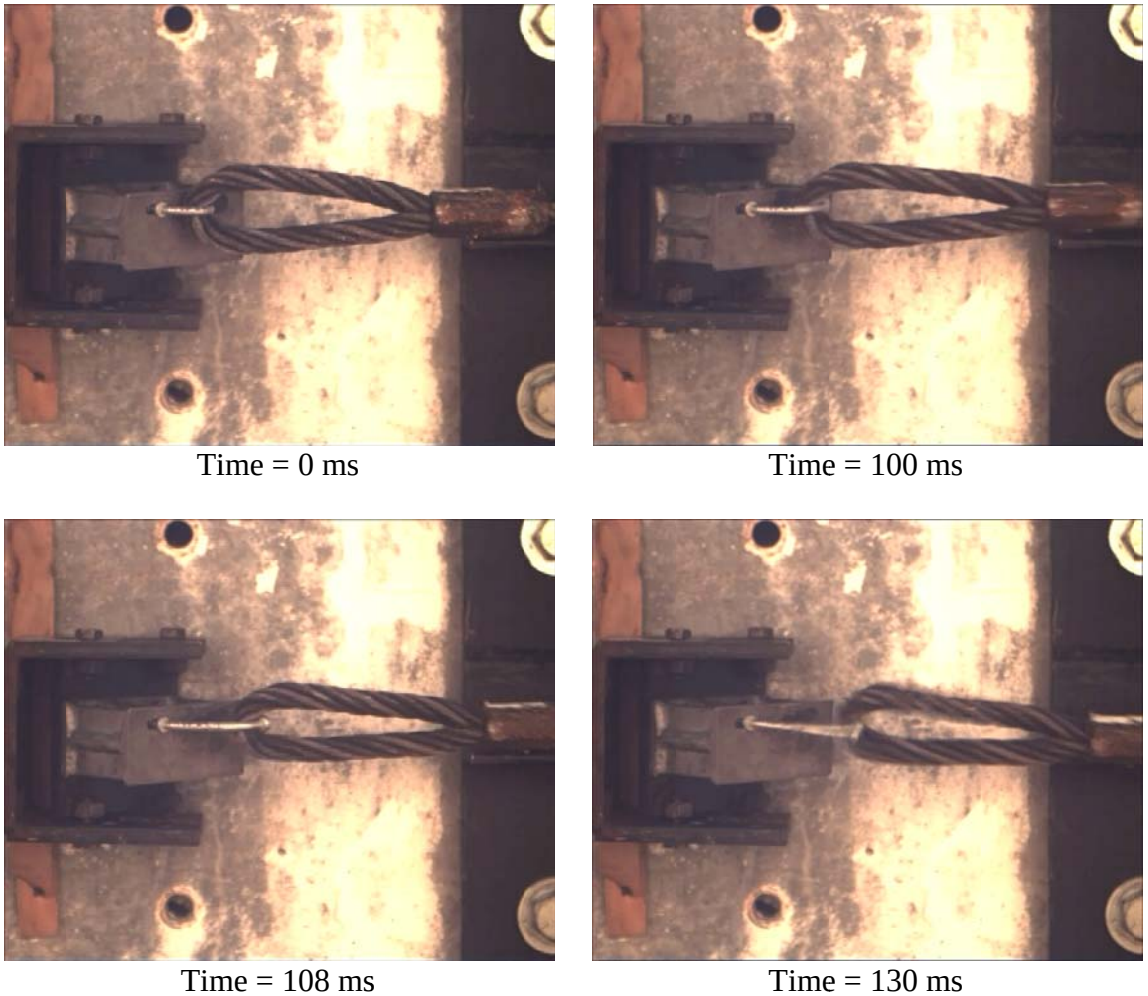


Figure 75. Force-Time Data, Test No. HTCUB-24

Pre-Test Post-Test

Figure 76. Pre-Test and Post-Test Photographs, Test No. HTCUB-24



Time = 0 ms Time = 100 ms

Time = 108 ms Time = 130 ms

Figure 77. Sequential Photographs, Test No. HTCUB-24

5.1.25 Test No. HTCUB-25

For test no. HTCUB-25, the cable applied a load to the keyway bolt at an angle of 60 degrees from the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the top of the slot. The slot that held the threaded end of the keyway bolt was slightly elongated. The cable released at a load of 3.99 kips (17.75 kN). The keyway bolt fractured through the threads and straightened out very slightly. The force versus time plot is shown in Figure 78. Pre- and post-test photographs are shown in Figure 79. Sequential photographs are shown in Figure 80.

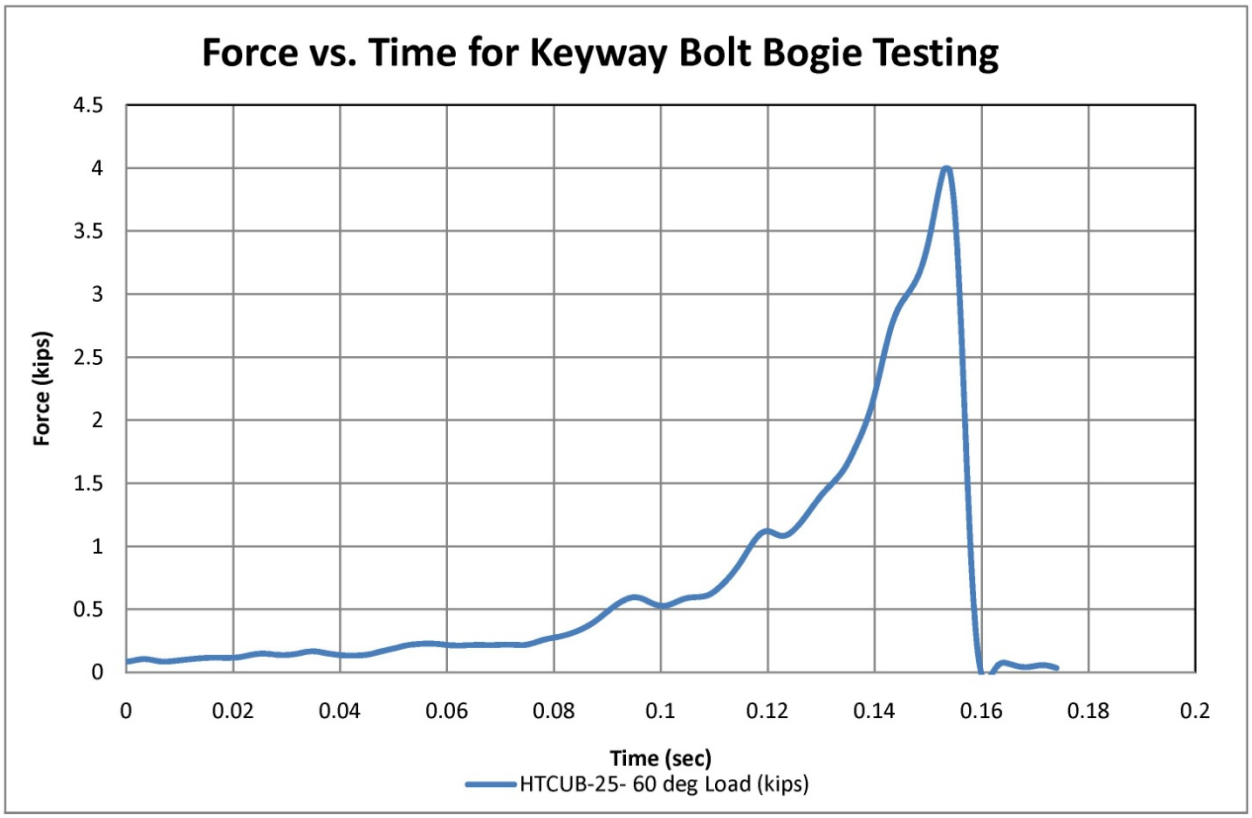
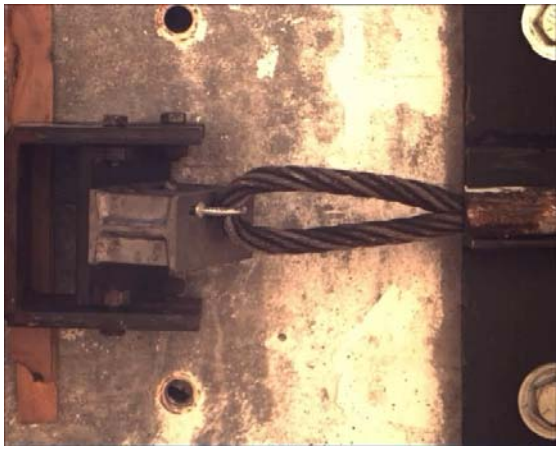


Figure 78. Force-Time Data, Test No. HTCUB-25

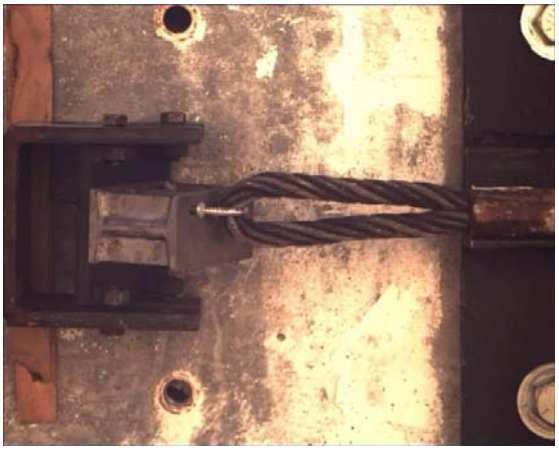
Pre-Test

Post-Test

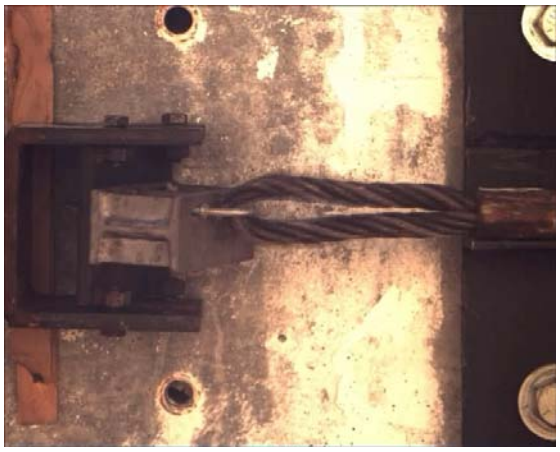
Figure 79. Pre-Test and Post-Test Photographs, Test No. HTCUB-25



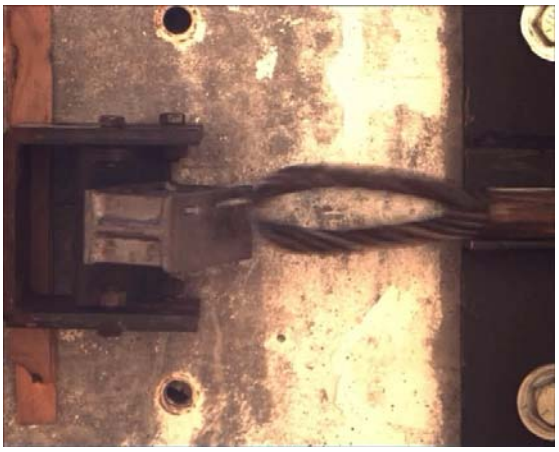
Time = 0 ms



Time = 144 ms



Time = 152 ms



Time = 154 ms

Figure 80. Sequential Photographs, Test No. HTCUB-25

5.1.26 Test No. HTCUB-26

For test no. HTCUB-26, the cable applied a load to the keyway bolt at an angle of 60 degrees from the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench that were positioned at the top of the slot. The slot that held the threaded end of the keyway bolt was slightly elongated. The cable released at a load of 3.90 kips (17.35 kN). The keyway bolt fractured through the threads and straightened out very slightly. The force versus time plot is shown in Figure 81. Pre- and post-test photographs are shown in Figure 82. Sequential photographs are shown in Figure 83.

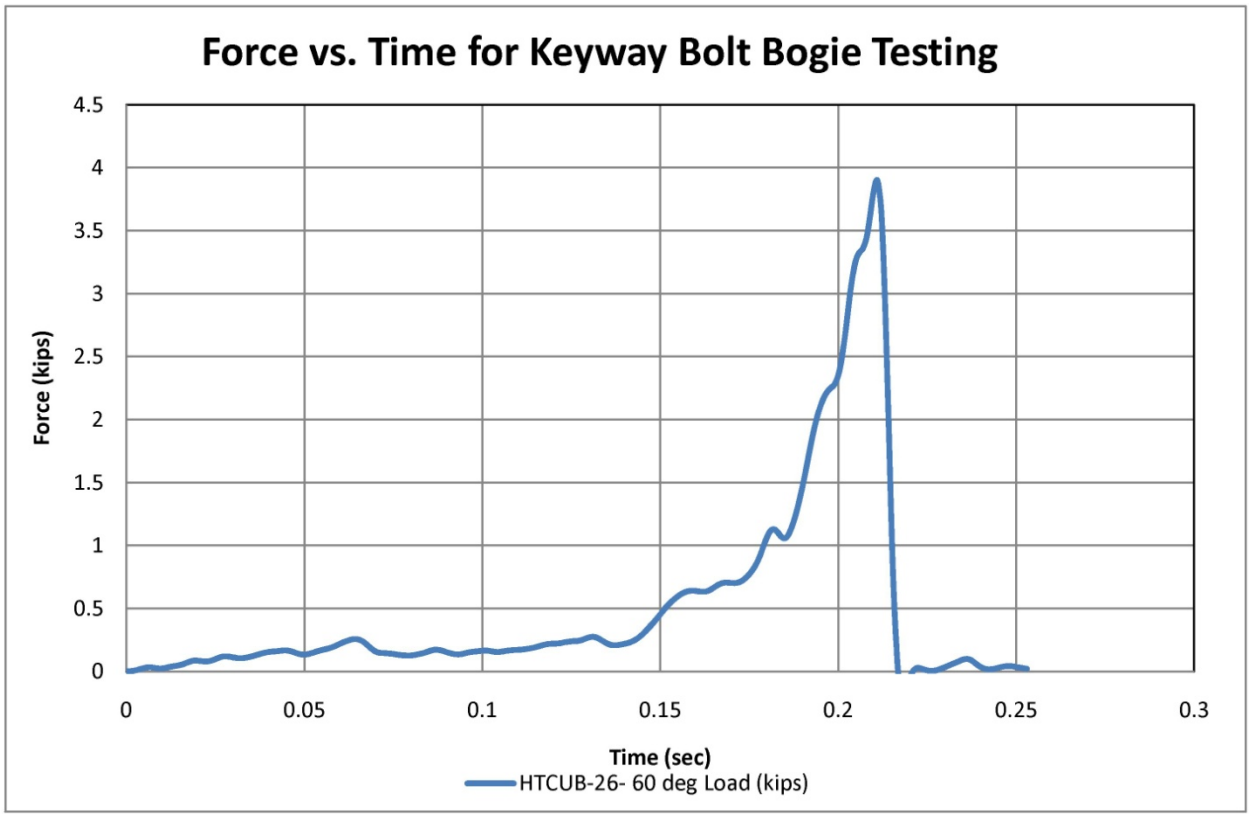
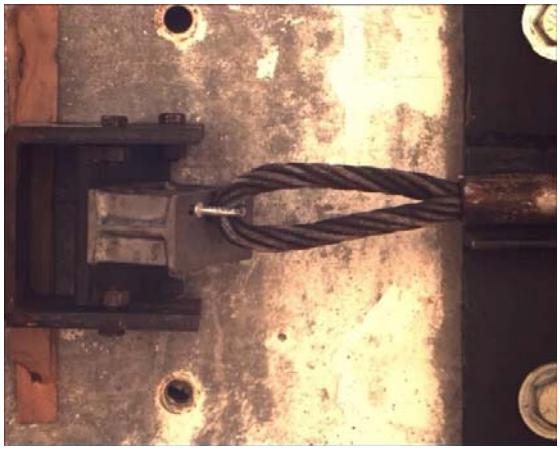


Figure 81. Force-Time Data, Test No. HTCUB-26

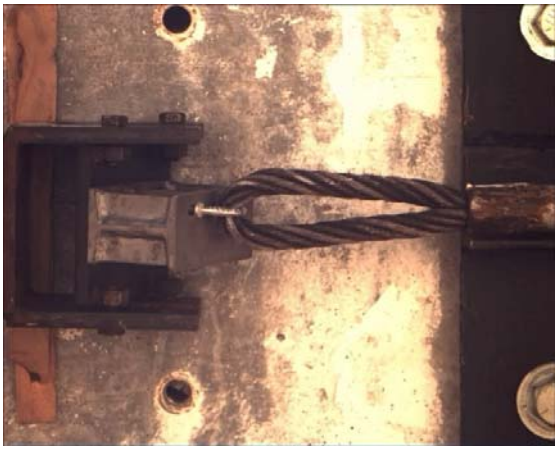
Pre-Test

Post-Test

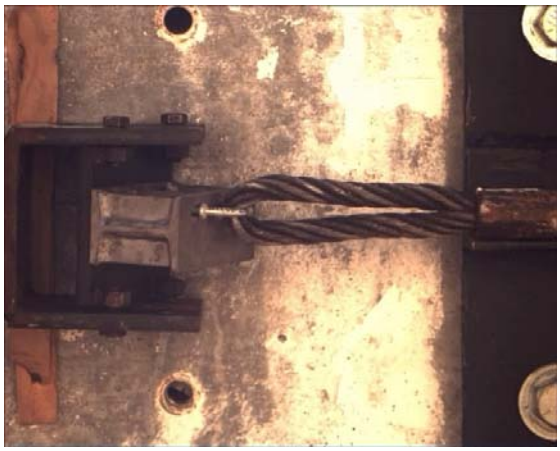
Figure 82. Pre-Test and Post-Test Photographs, Test No. HTCUB-26



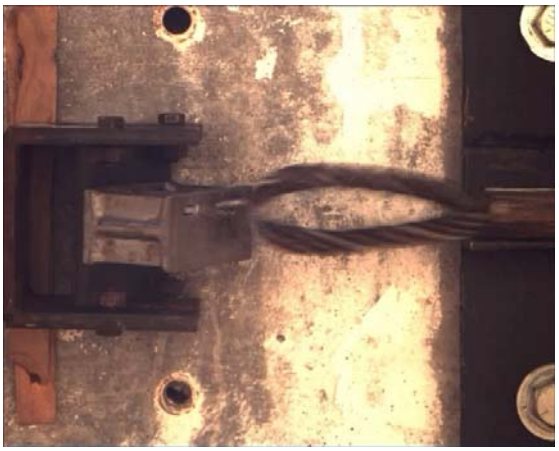
Time = 0 ms



Time = 170 ms



Time = 206 ms



Time = 210 ms

Figure 83. Sequential Photographs, Test No. HTCUB-26

5.1.27 Test No. HTCUB-27

For test no. HTCUB-27, the cable applied a load to the keyway bolt at an angle of 45 degrees from the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench and the slot and keyway design type 2 was used. The cable released at a load of 0.47 kips (2.09 kN), but the cable snagged on the button and released at a load of 0.49 kips (2.18 kN). The button slipped out of the keyway while the threaded end stayed attached and the keyway bolt straightened out. The force versus time plot is shown in Figure 84. Pre- and post-test photographs are shown in Figure 85. Sequential photographs are shown in Figure 86.

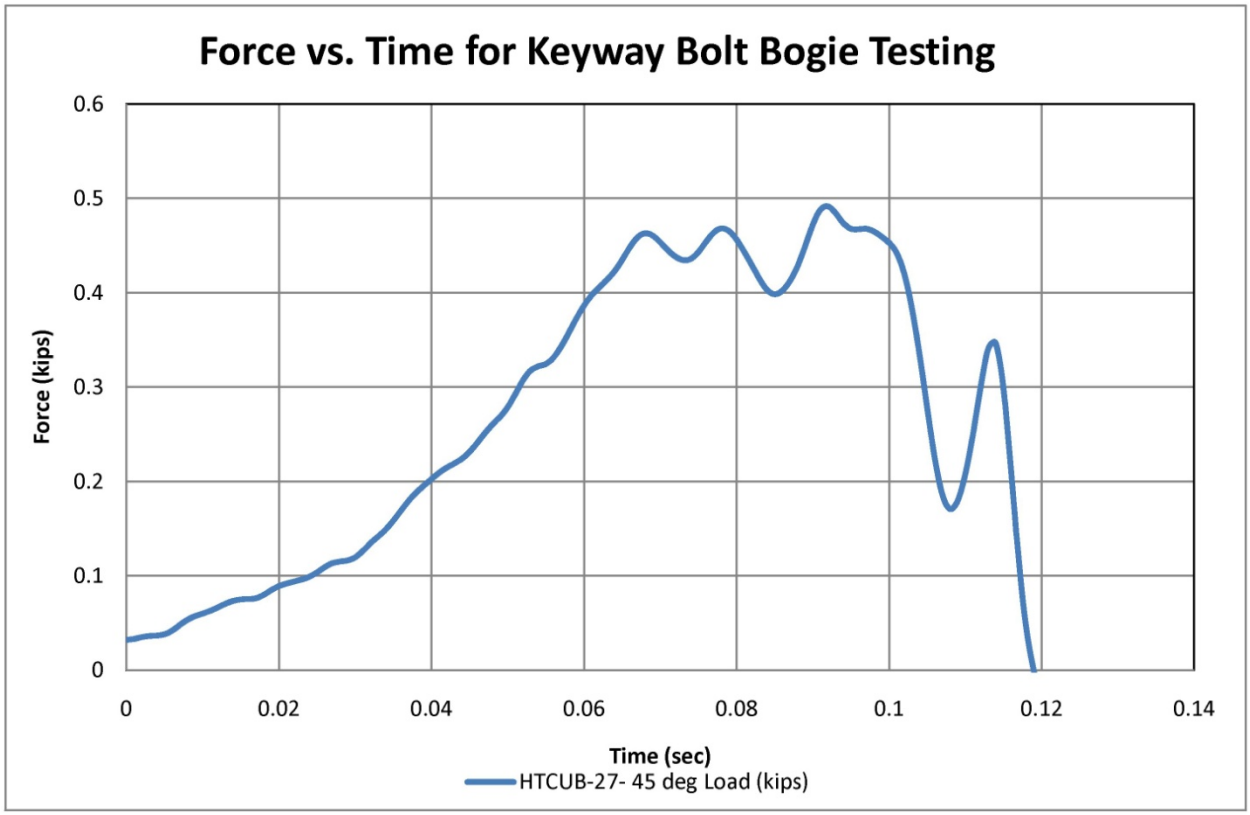
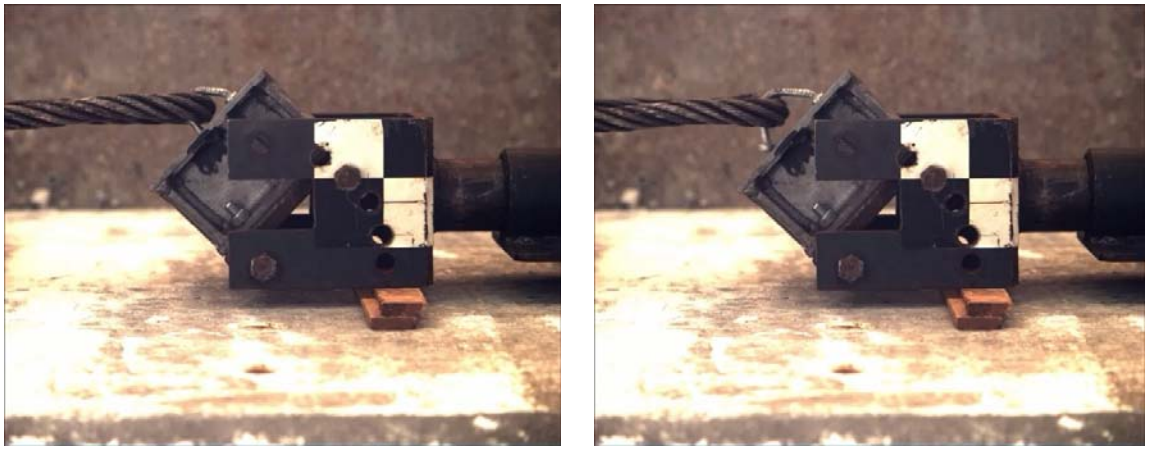


Figure 84. Force-Time Data, Test No. HTCUB-27

Pre-Test Post-Test

Figure 85. Pre-Test and Post-Test Photographs, Test No. HTCUB-27



Time = 0 ms Time = 94 ms

Time = 108 ms Time = 114 ms

Figure 86. Sequential Photographs, Test No. HTCUB-27

5.1.28 Test No. HTCUB-28

For test no. HTCUB-28, the cable applied a load to the keyway bolt at an angle of 90 degrees from the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench and the slot and keyway design type 2 was used. The cable released at a load of 6.75 kips (30.03 kN). The keyway bolt fractured through the threads and straightened out. The force versus time plot is shown in Figure 87. Pre- and post-test photographs are shown in Figure 88. Sequential photographs are shown in Figure 89.

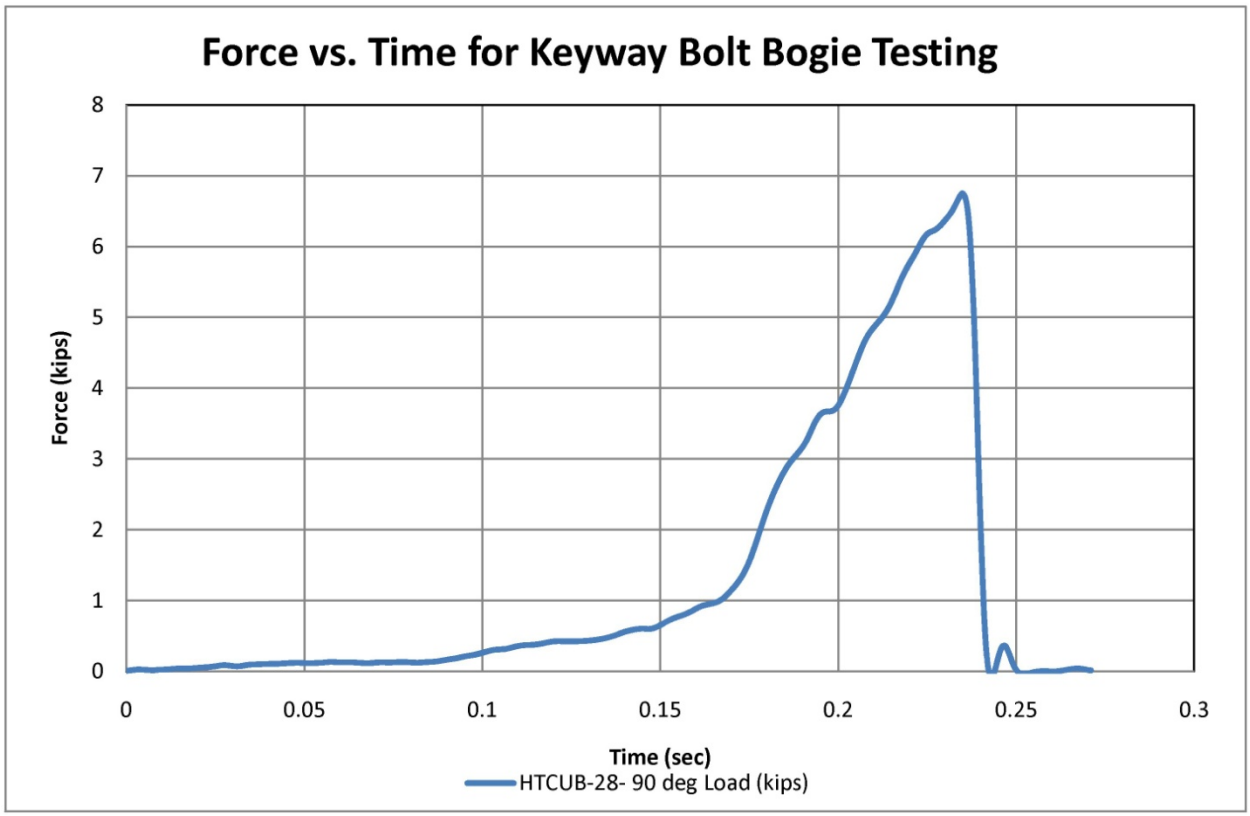
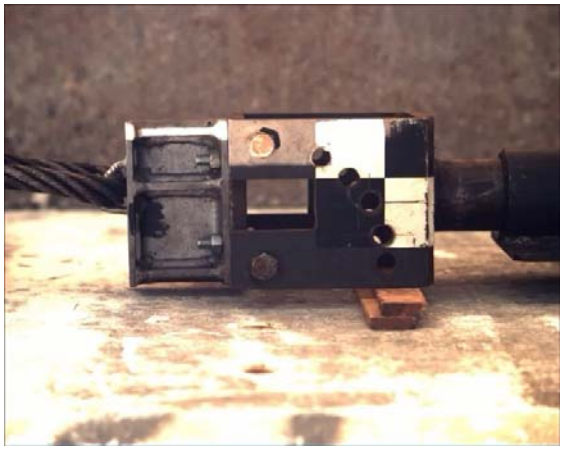


Figure 87. Force-Time Data, Test No. HTCUB-28

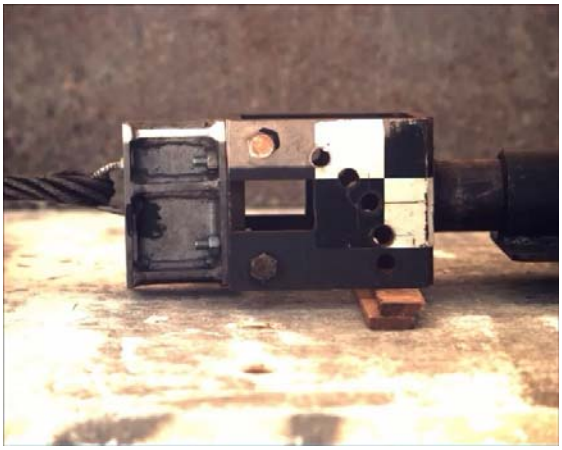
Pre-Test

Post-Test

Figure 88. Pre-Test and Post-Test Photographs, Test No. HTCUB-28

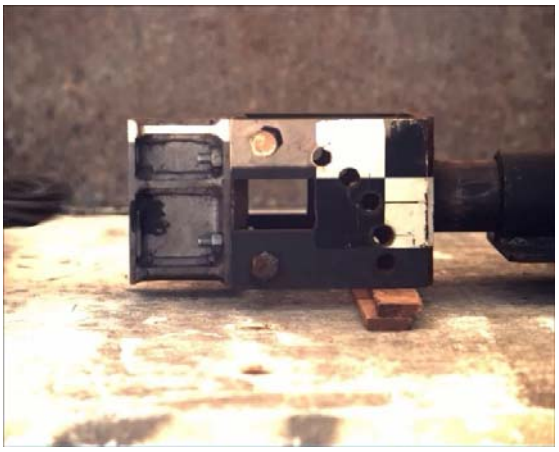


Time = 0 ms



Time = 210 ms

Time = 232 ms



Time = 236 ms

Figure 89. Sequential Photographs, Test No. HTCUB-28

5.1.29 Test No. HTCUB-29

For test no. HTCUB-29, the cable applied a load to the keyway bolt at an angle of 60 degrees from the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench and the slot and keyway design type 2 was used. The cable released at a load of 0.53 kips (2.36 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 90. Pre- and post-test photographs are shown in Figure 91. Sequential photographs are shown in Figure 92.

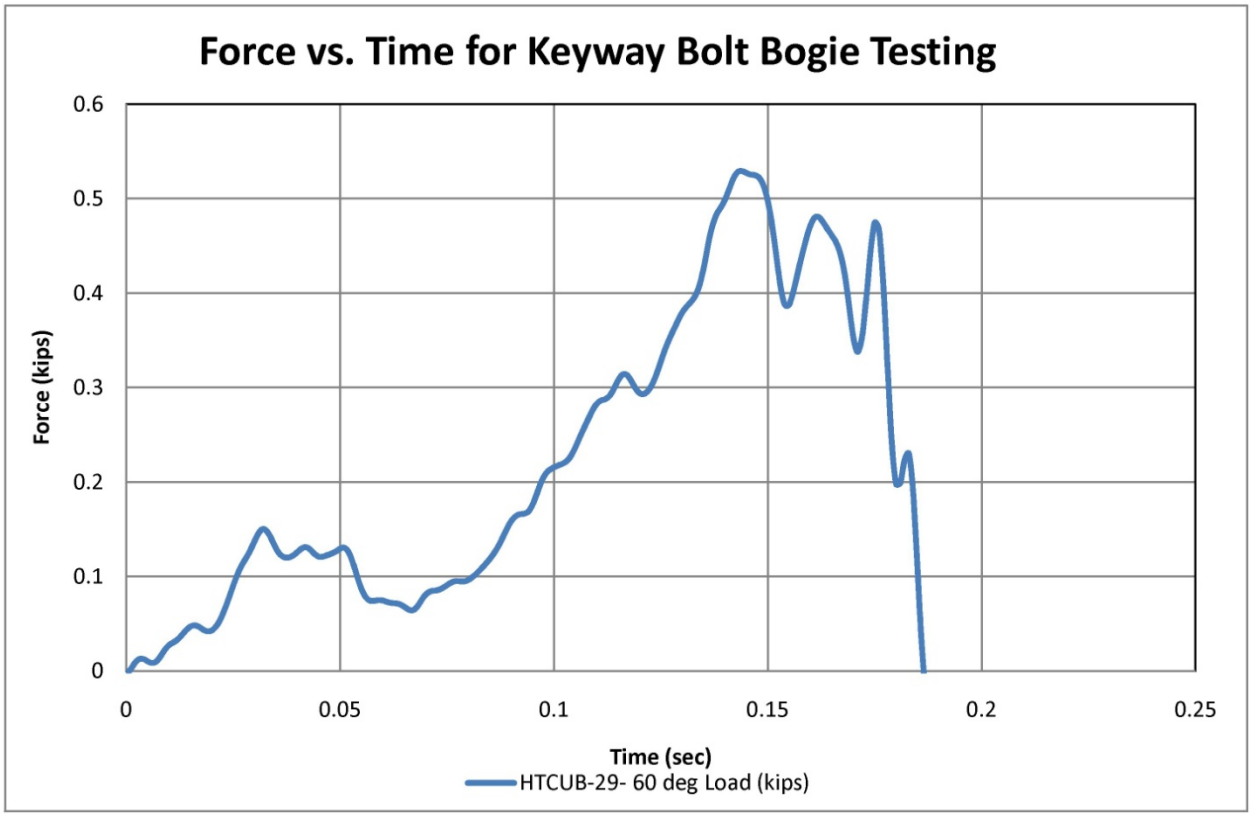
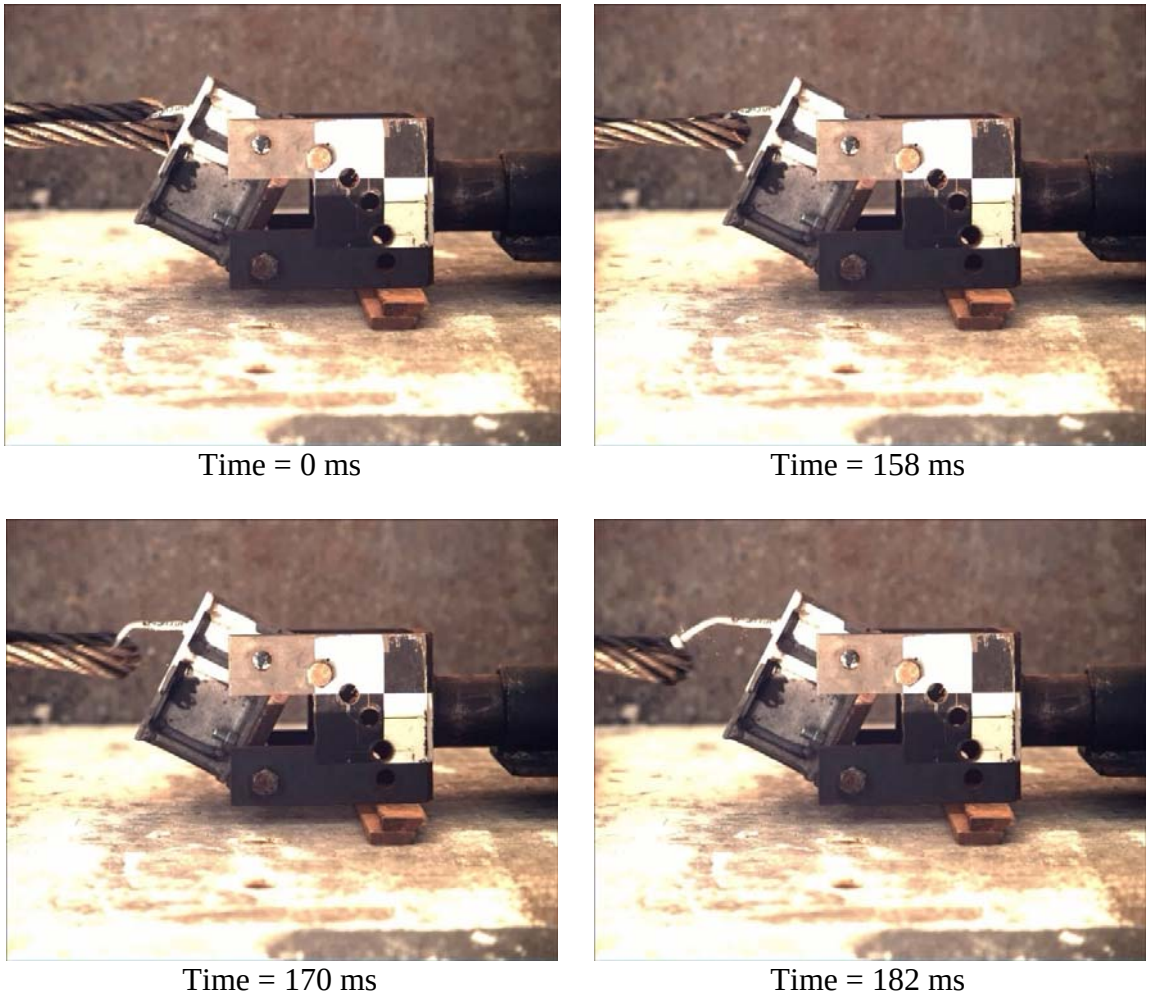


Figure 90. Force-Time Data, Test No. HTCUB-29

Pre-Test Post-Test

Figure 91. Pre-Test and Post-Test Photographs, Test No. HTCUB-29



Time = 0 ms Time = 158 ms

Time = 170 ms Time = 182 ms

Figure 92. Sequential Photographs, Test No. HTCUB-29

5.1.30 Test No. HTCUB-30

For test no. HTCUB-30, the cable applied a load to the keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with two grade 2 nuts tightened with a wrench and the slot and keyway design type 2 was used. The cable released at a load of 0.58 kips (2.58 kN), but the cable snagged on the button and released at a load of 0.68 kips (3.02 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 93. Pre- and post-test photographs are shown in Figure 94. Sequential photographs are shown in Figure 95.

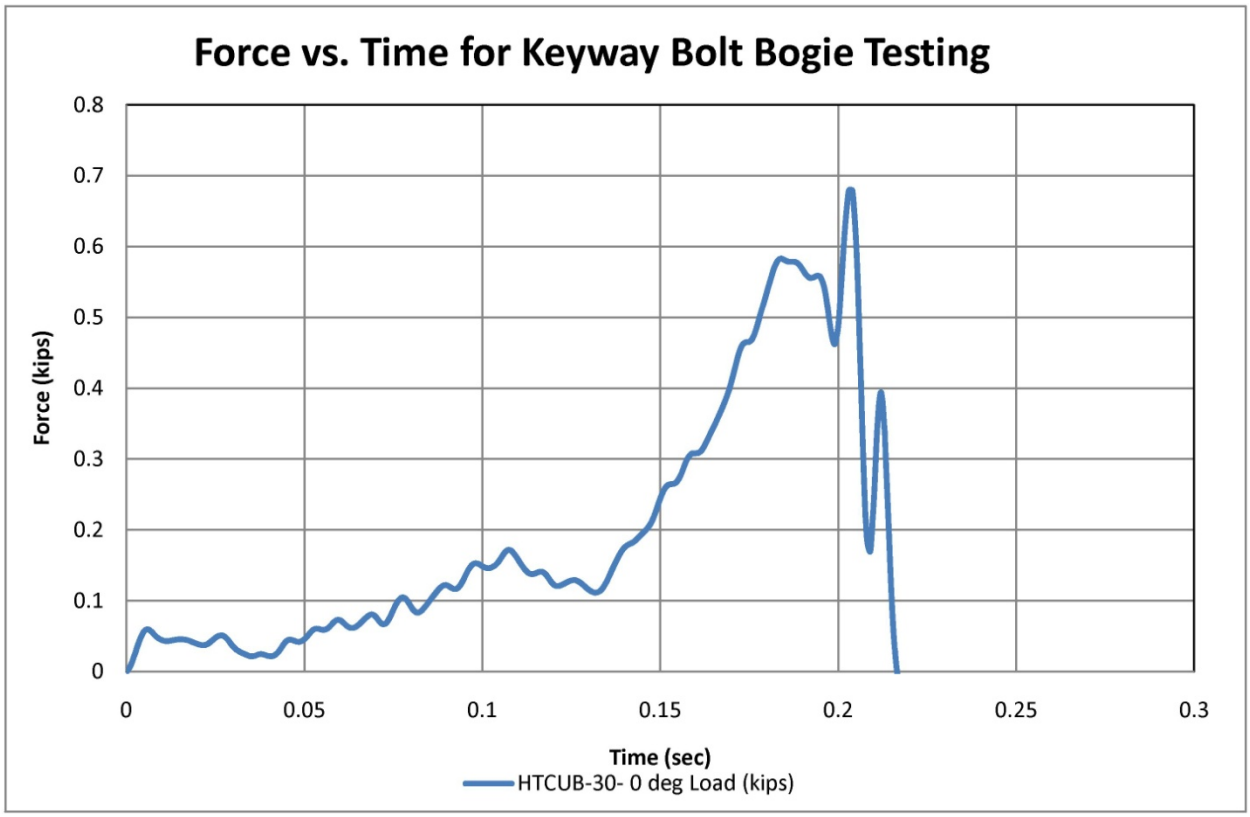
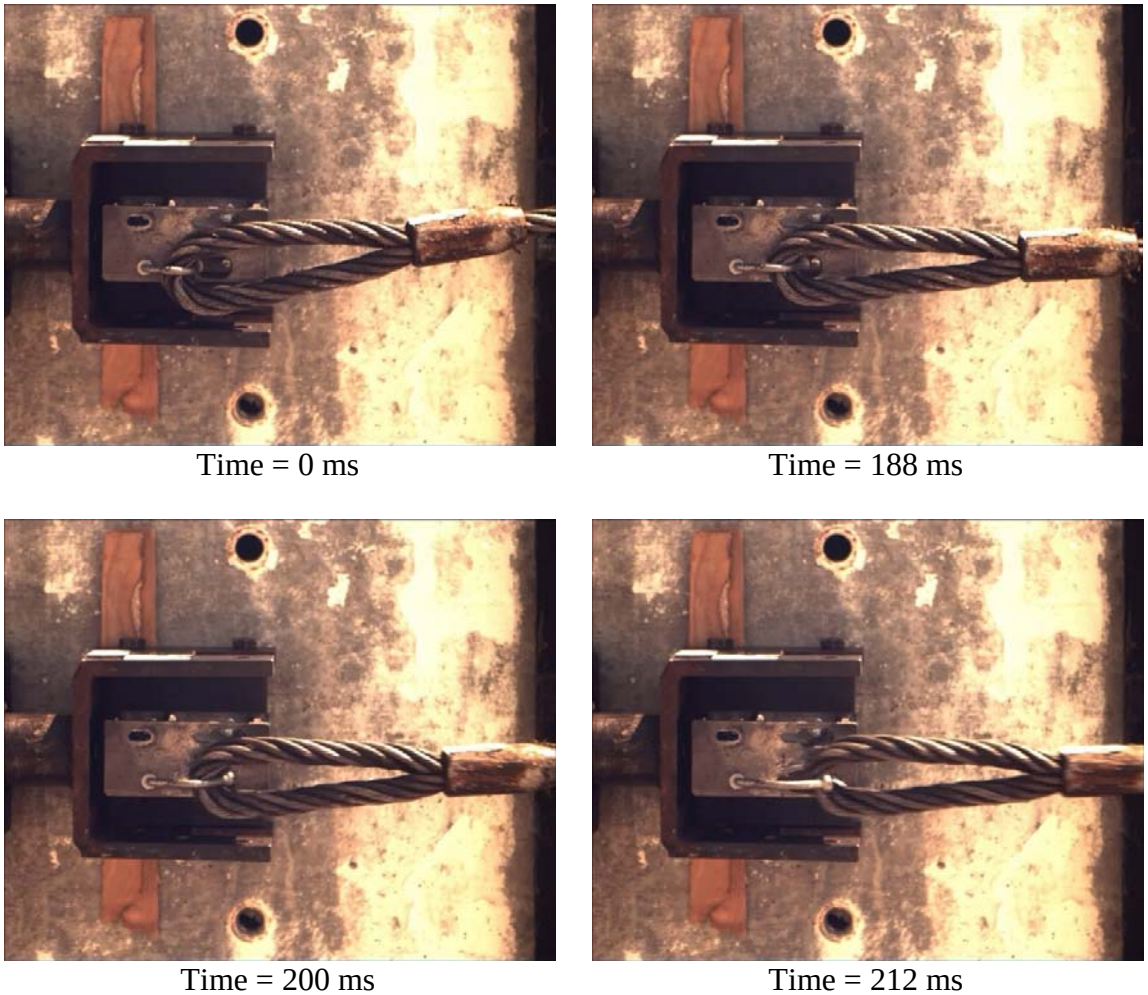


Figure 93. Force-Time Data, Test No. HTCUB-30

Pre-Test | Post-Test

Figure 94. Pre-Test and Post-Test Photographs, Test No. HTCUB-30



Time = 0 ms | Time = 188 ms

Time = 200 ms | Time = 212 ms

Figure 95. Sequential Photographs, Test No. HTCUB-30

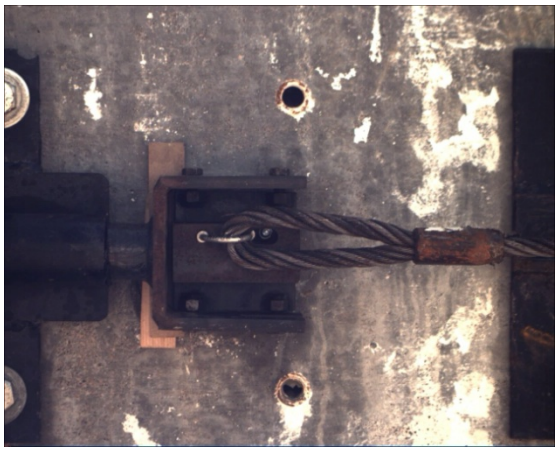
5.1.31 Test No. HTCUB-31

For test no. HTCUB-31, the cable applied a load to the A449 keyway bolt at an angle of 0 degrees, parallel the face of the flange. The keyway bolt was attached with one grade 8 high-topped nut tightened with a wrench and the slot and keyway design type 2 was used. Due to technical difficulties, the load cell did not collect data. The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. Pre- and post-test photographs are shown in Figure 96. Sequential photographs are shown in Figure 97.

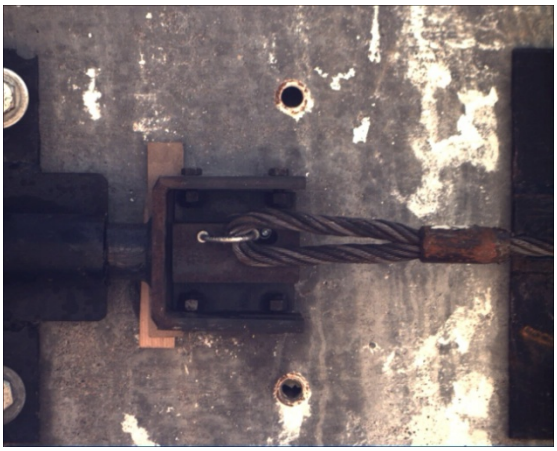
Pre-Test

Post-Test

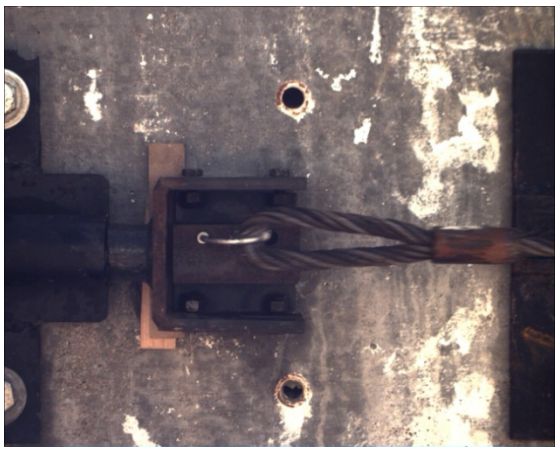
Figure 96. Pre-Test and Post-Test Photographs, Test No. HTCUB-31



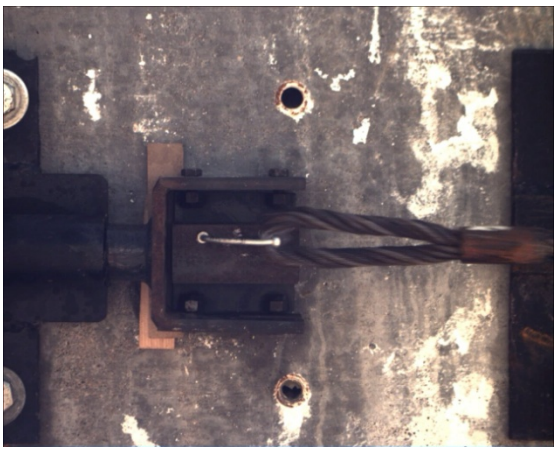
Time = 0 ms



Time = 48 ms



Time = 52 ms



Time = 58 ms

Figure 97. Sequential Photographs, Test No. HTCUB-31

5.1.32 Test No. HTCUB-32

For test no. HTCUB-32, the cable applied a load to the A449 keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with one grade 8 high-topped nut tightened with a wrench and the slot and keyway design type 2 was used. The cable released at a load of 1.11 kips (4.94 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 98. Pre- and post-test photographs are shown in Figure 99. Sequential photographs are shown in Figure 100.

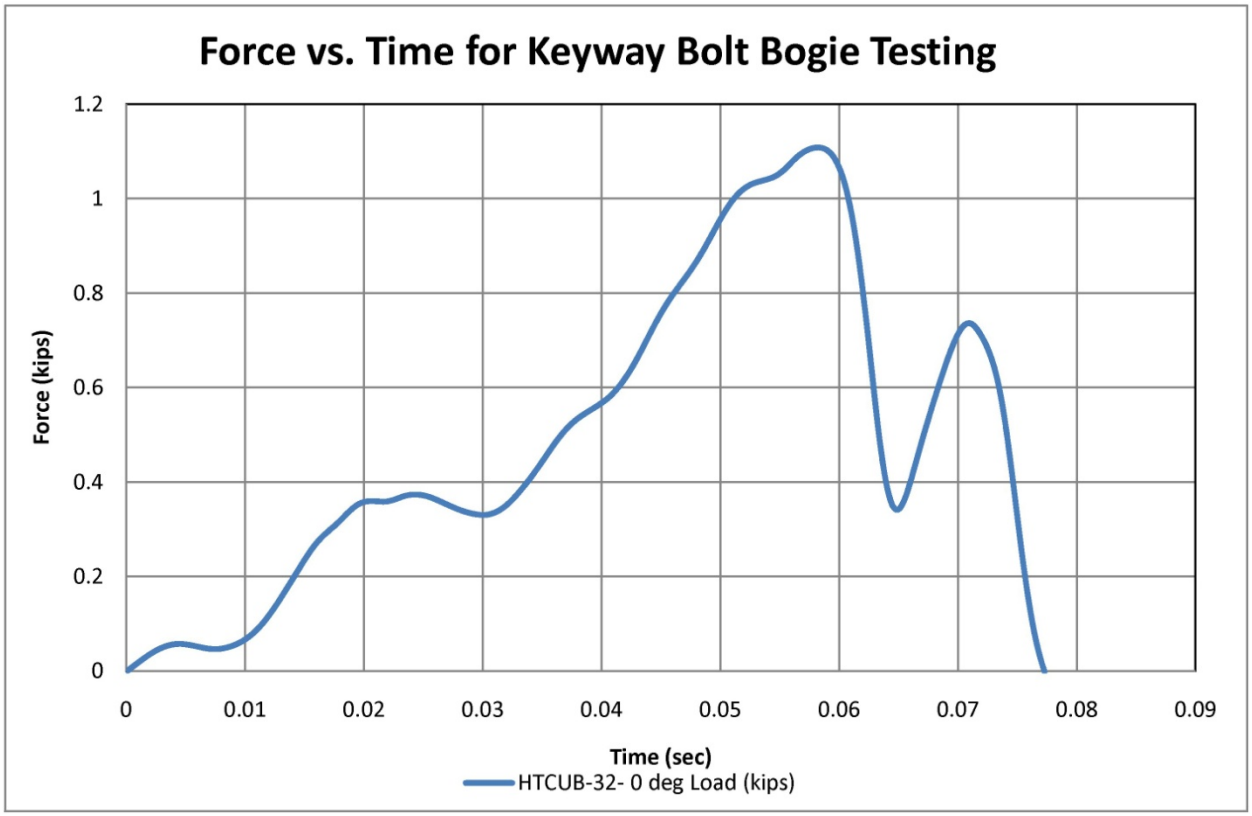
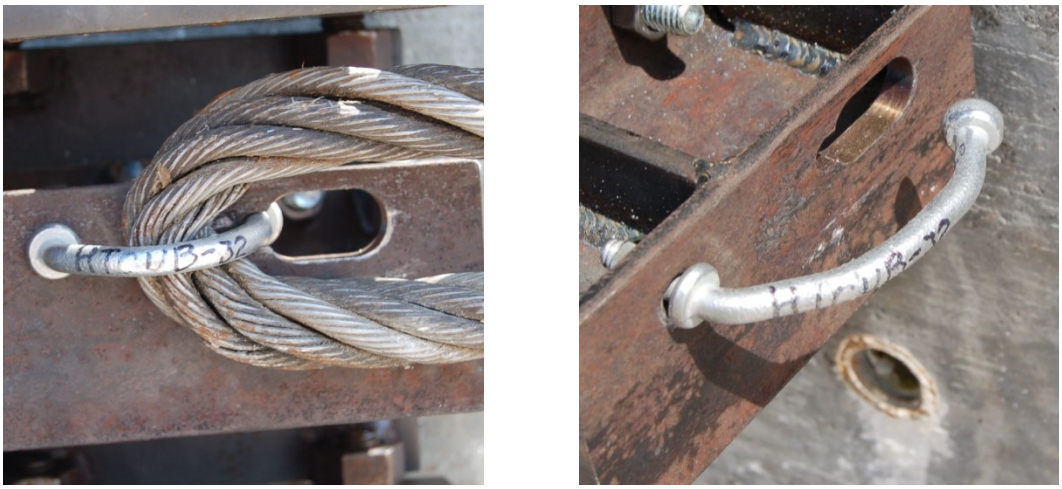
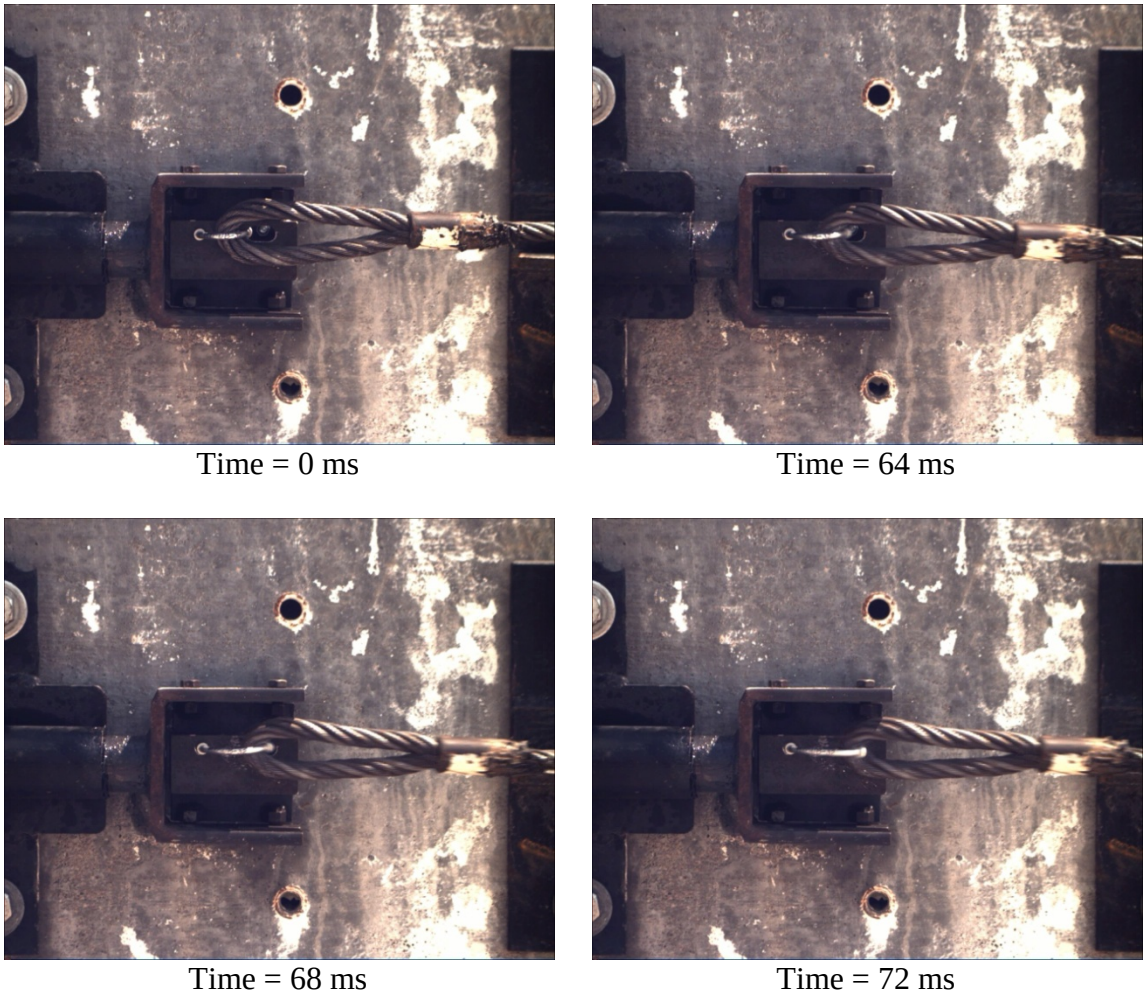


Figure 98. Force-Time Data, Test No. HTCUB-32



Pre-Test Post-Test

Figure 99. Pre-Test and Post-Test Photographs, Test No. HTCUB-32



Time = 0 ms Time = 64 ms

Time = 68 ms Time = 72 ms

Figure 100. Sequential Photographs, Test No. HTCUB-32

5.1.33 Test No. HTCUB-33

For test no. HTCUB-33, the cable applied a load to the A449 keyway bolt at an angle of 90 degrees from the face of the flange. The keyway bolt was attached with one grade 8 high-topped nut tightened with a wrench and the slot and keyway design type 2 was used. The cable released at a load of 8.04 kips (35.76 kN). The keyway bolt fractured through the threads and straightened out. The force versus time plot is shown in Figure 101. Pre- and post-test photographs are shown in Figure 102. Sequential photographs are shown in Figure 103.

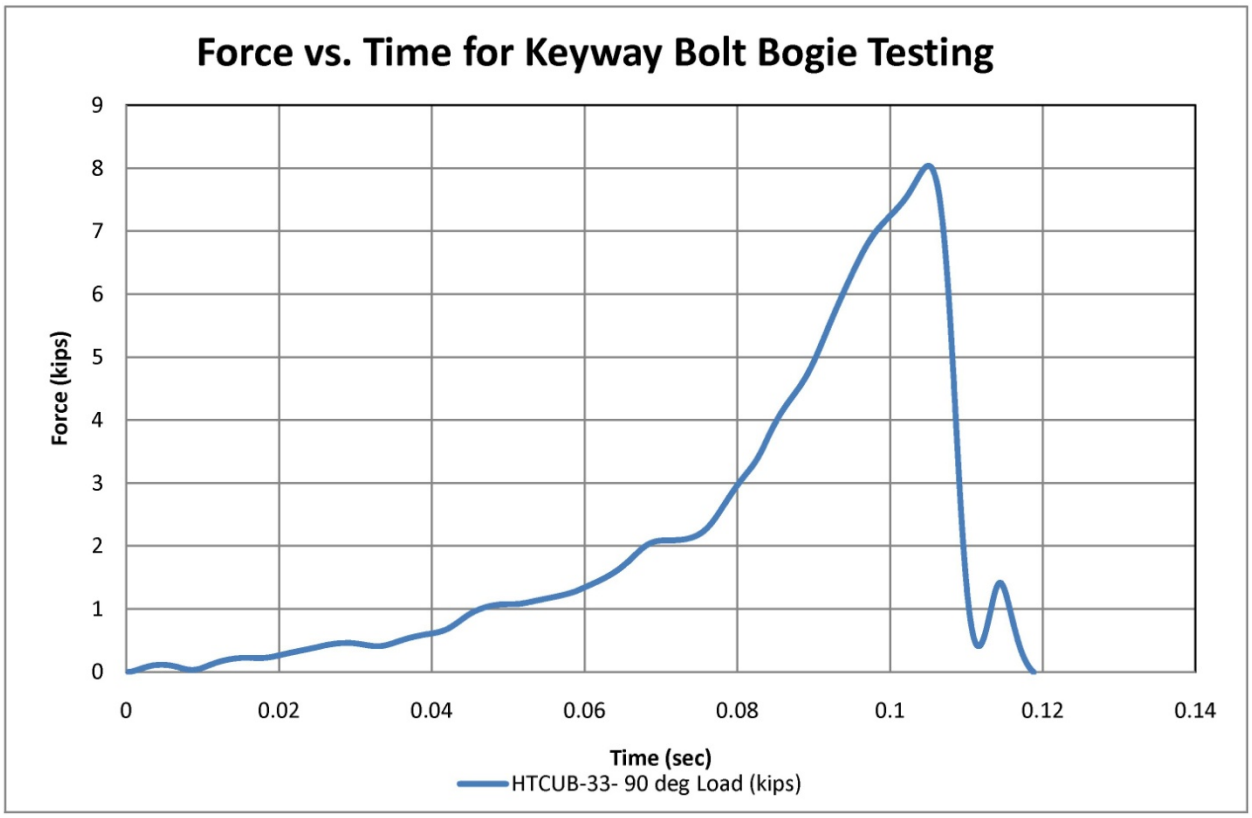
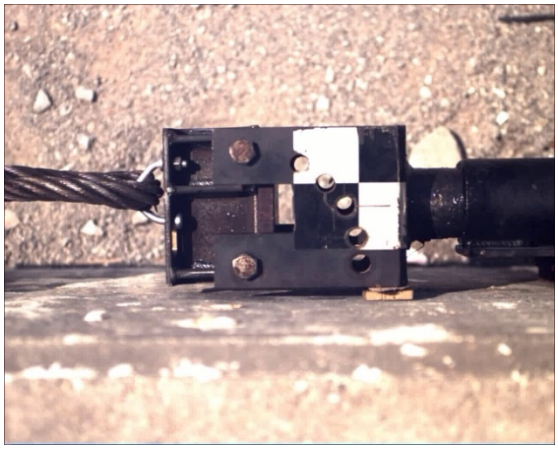


Figure 101. Force-Time Data, Test No. HTCUB-33

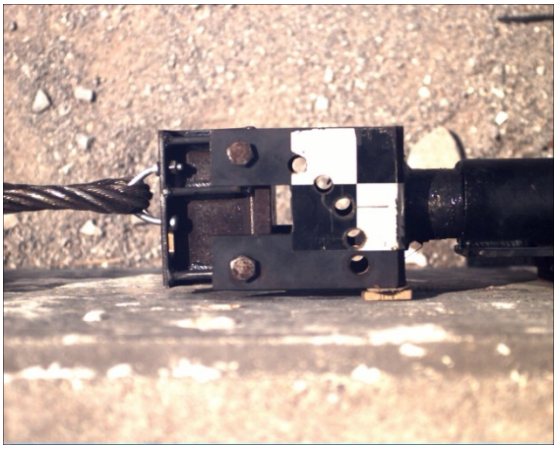
Pre-Test

Post-Test

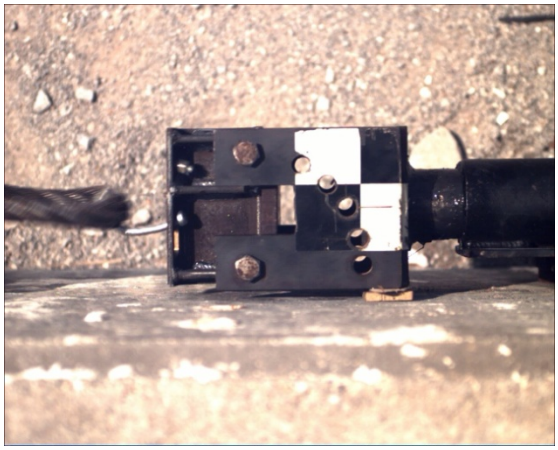
Figure 102. Pre-Test and Post-Test Photographs, Test No. HTCUB-33



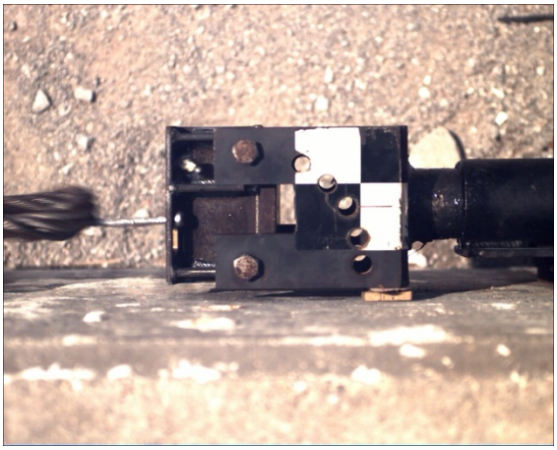
Time = 0 ms



Time = 98 ms



Time = 102 ms



Time = 104 ms

Figure 103. Sequential Photographs, Test No. HTCUB-33

5.1.34 Test No. HTCUB-34

For test no. HTCUB-34, the cable applied a load to the A449 keyway bolt at an angle of 90 degrees from the face of the flange. The keyway bolt was attached with one grade 8 high-topped nut tightened with a wrench and the slot and keyway design type 2 was used. The cable released at a load of 8.80 kips (39.14 kN). The keyway bolt fractured through the threads and straightened out. The force versus time plot is shown in Figure 104. Pre- and post-test photographs are shown in Figure 105. Sequential photographs are shown in Figure 106.

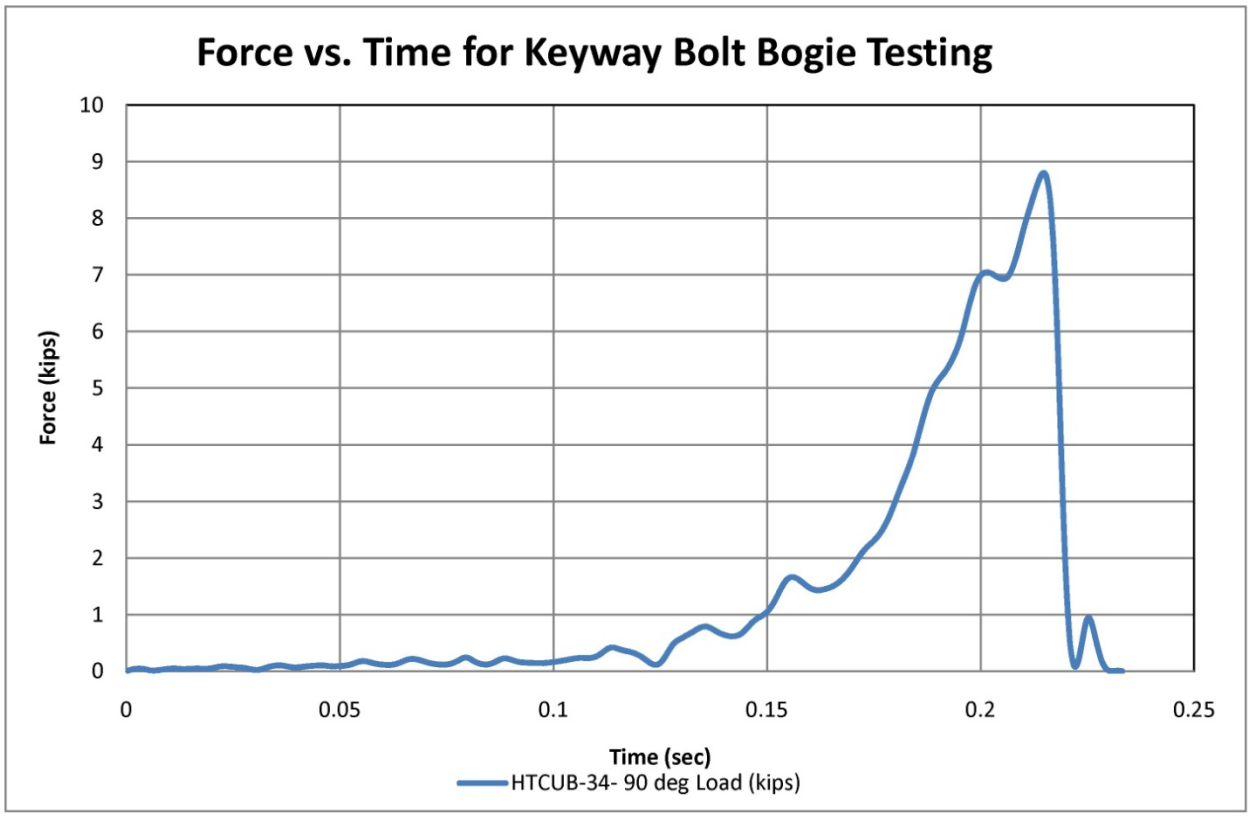
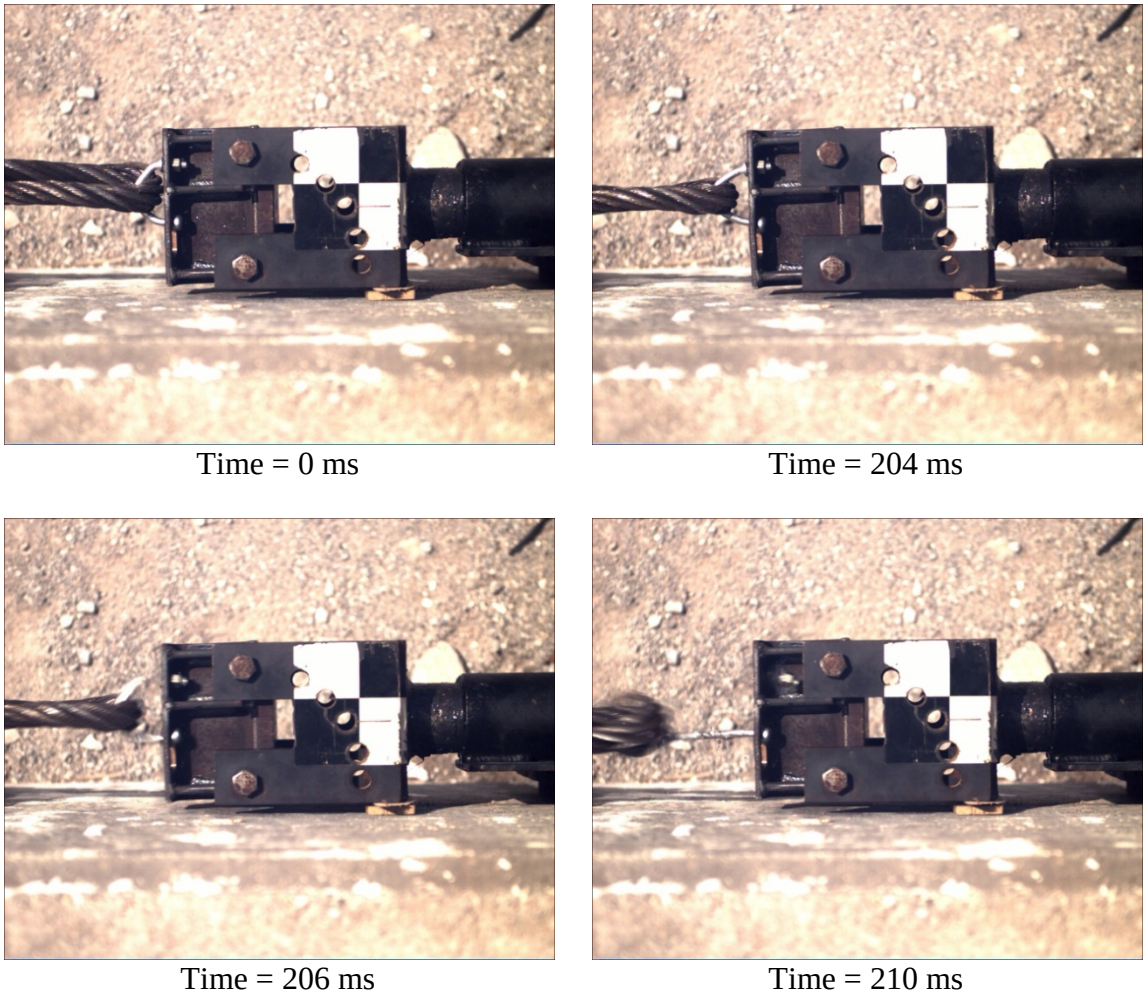


Figure 104. Force-Time Data, Test No. HTCUB-34

Pre-Test | Post-Test

Figure 105. Pre-Test and Post-Test Photographs, Test No. HTCUB-34



Time = 0 ms | Time = 204 ms

Time = 206 ms | Time = 210 ms

Figure 106. Sequential Photographs, Test No. HTCUB-34

5.1.35 Test No. HTCUB-35

For test no. HTCUB-35, the cable applied a load to the A449 keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with one grade 8 high-topped nut tightened with a wrench and the slot and keyway design type 2 was used. The cable released at a load of 1.41 kips (6.27 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 107. Pre- and post-test photographs are shown in Figure 108. Sequential photographs are shown in Figure 109.

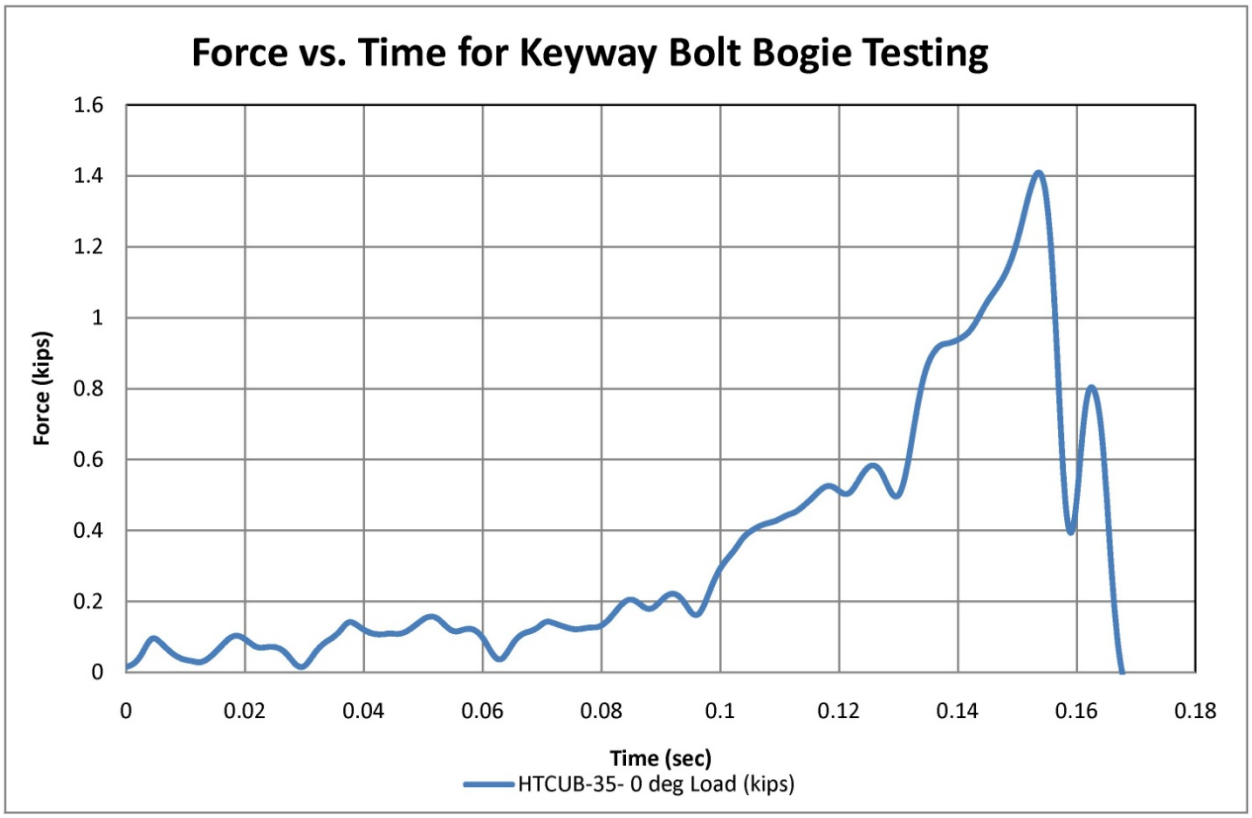
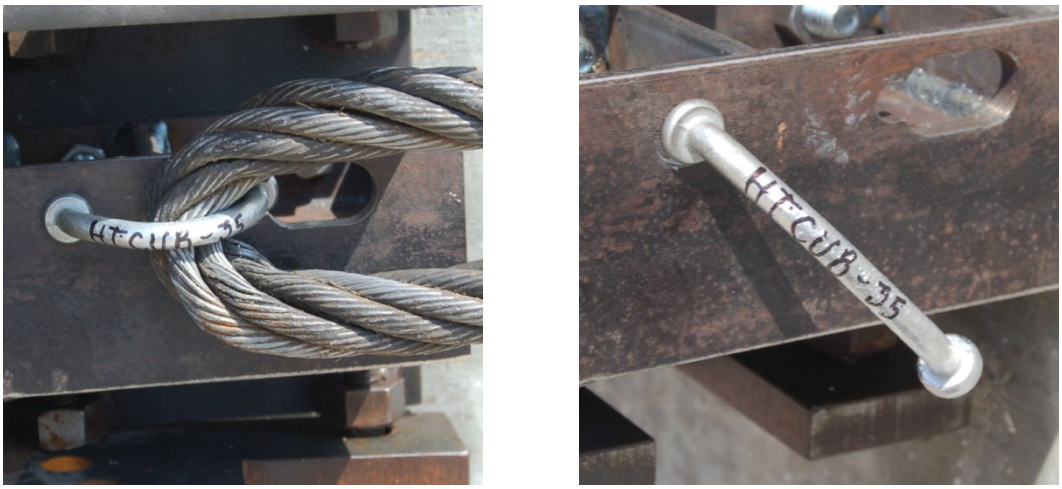
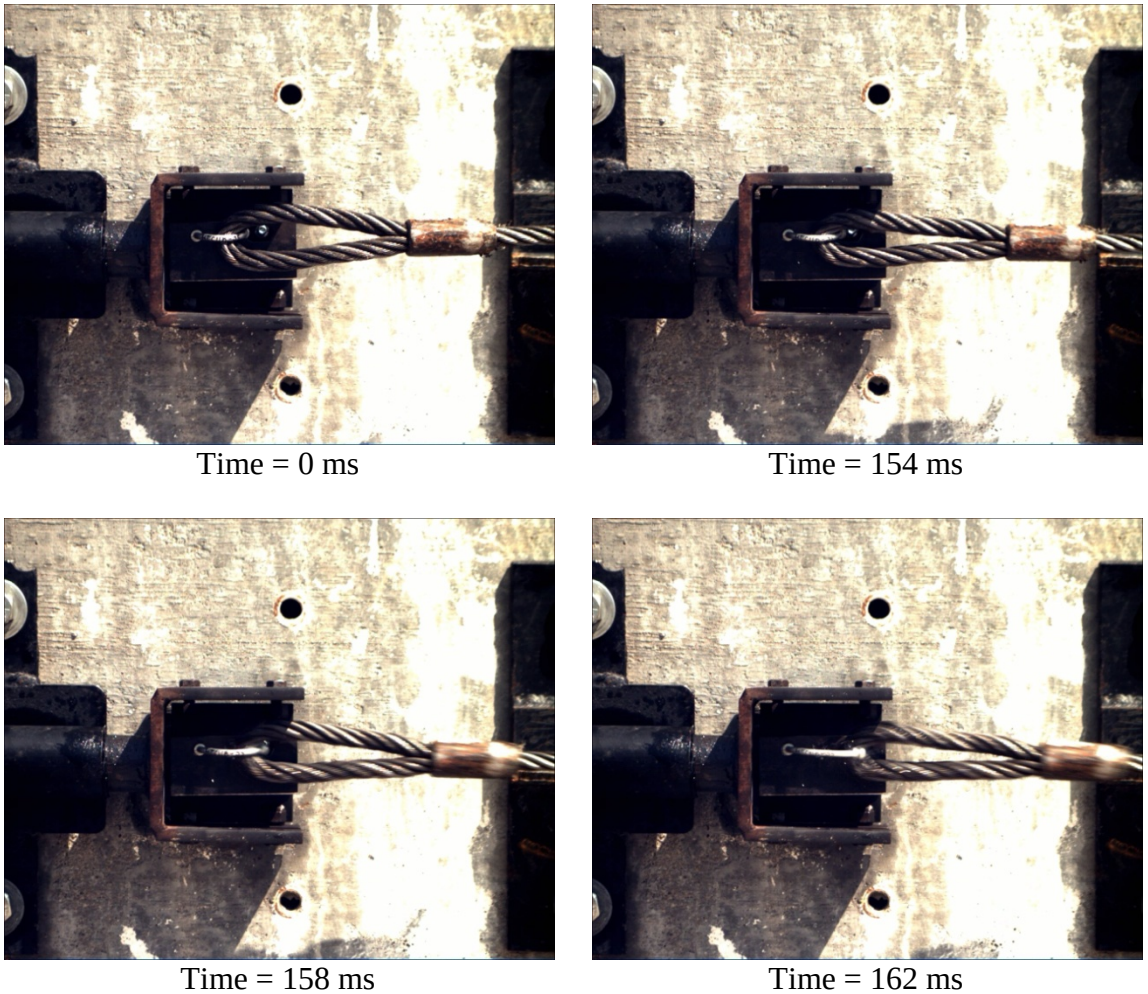


Figure 107. Force-Time Data, Test No. HTCUB-35



Pre-Test Post-Test

Figure 108. Pre-Test and Post-Test Photographs, Test No. HTCUB-35



Time = 0 ms Time = 154 ms

Time = 158 ms Time = 162 ms

Figure 109. Sequential Photographs, Test No. HTCUB-35

5.1.36 Test No. HTCUB-36

For test no. HTCUB-36, the cable applied a load to the A449 keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with one grade 8 high-topped nut tightened with a wrench and the slot and keyway design type 2 was used. The cable released at a load of 1.27 kips (5.65 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 110. Pre- and post- test photographs are shown in Figure 111. Sequential photographs are shown in Figure 112.

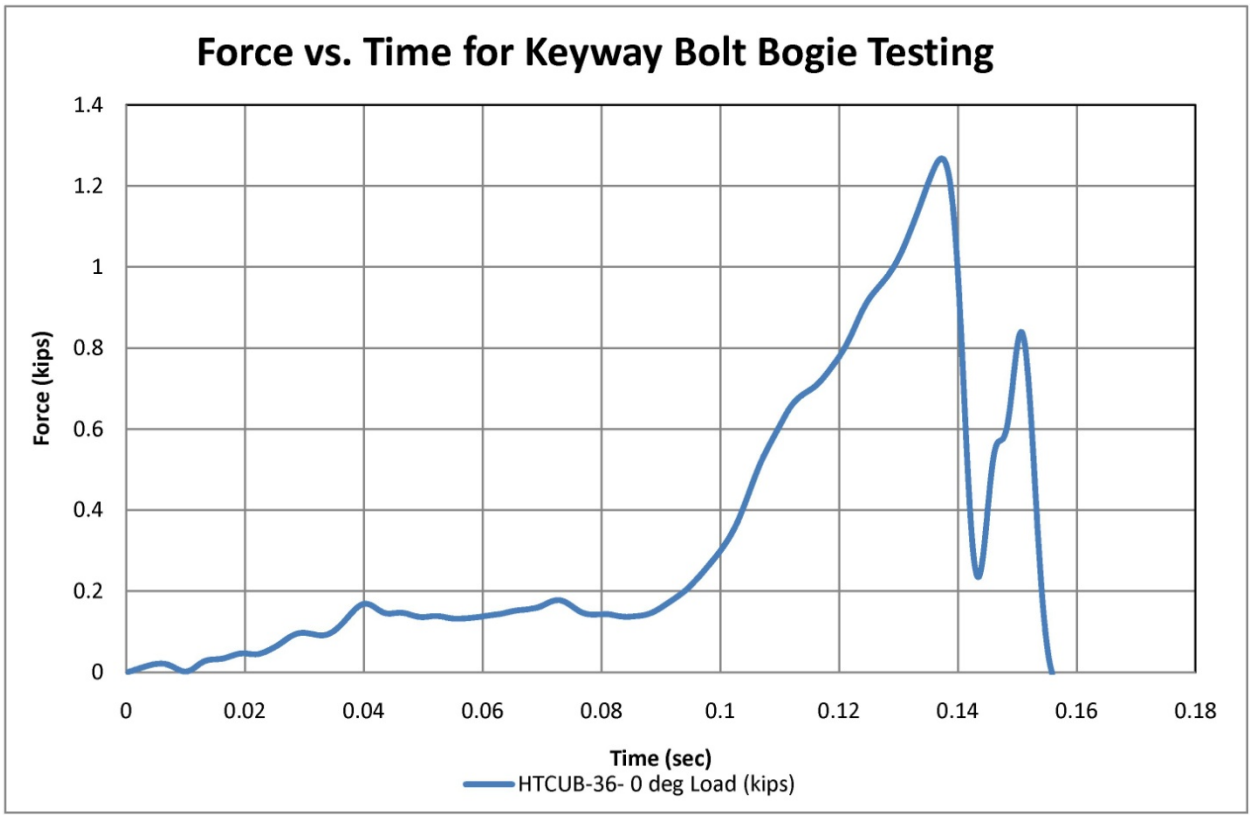
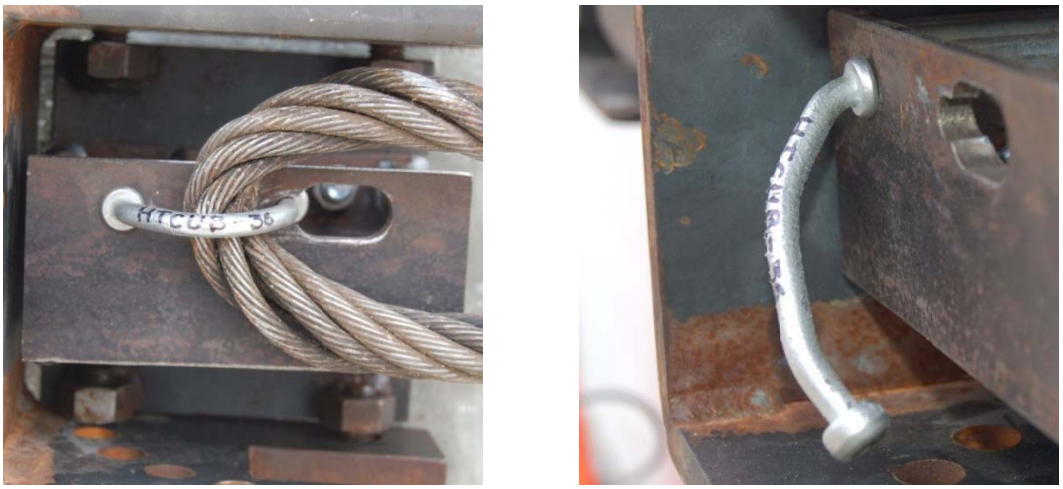
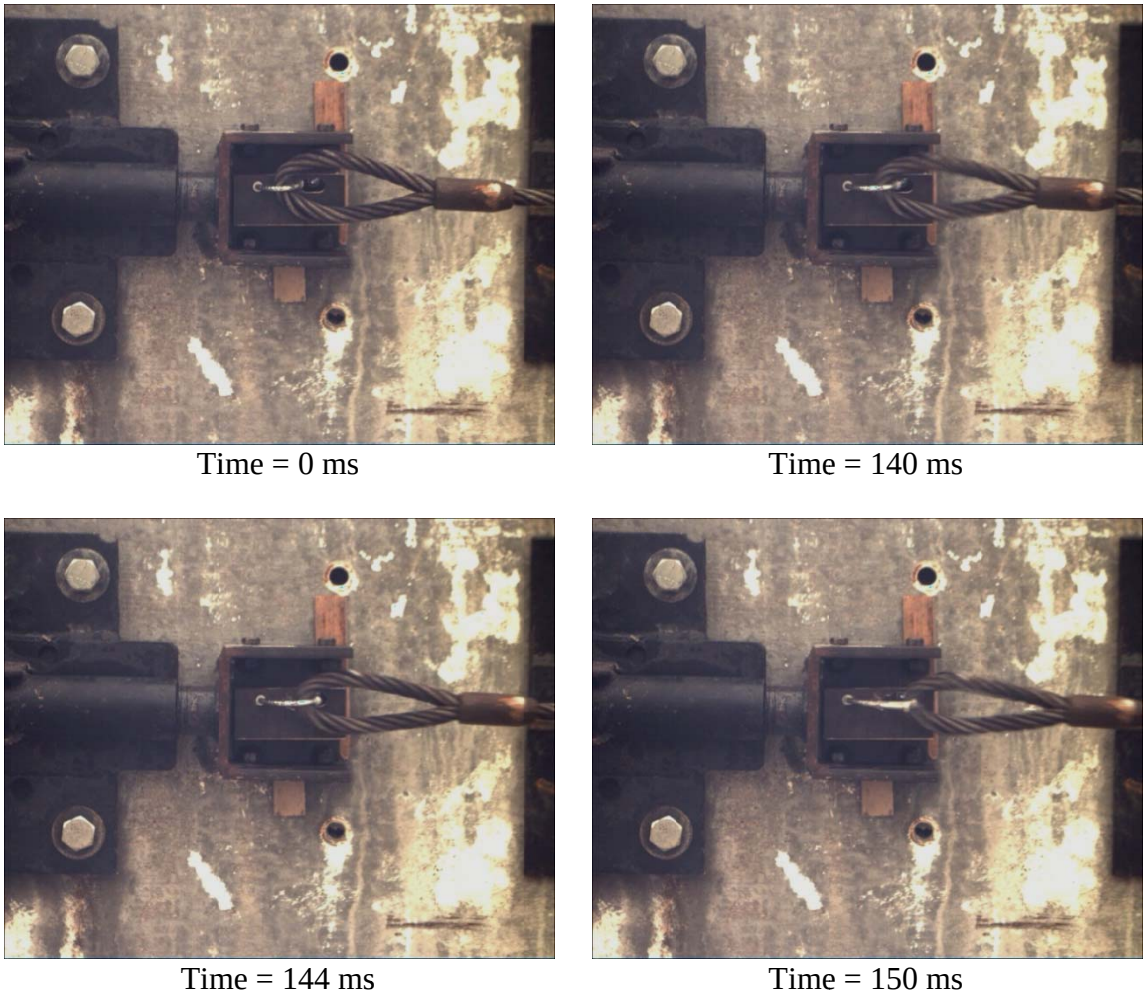


Figure 110. Force-Time Data, Test No. HTCUB-36



Pre-Test | Post-Test

Figure 111. Pre-Test and Post-Test Photographs, Test No. HTCUB-36



Time = 0 ms | Time = 140 ms

Time = 144 ms | Time = 150 ms

Figure 112. Sequential Photographs, Test No. HTCUB-36

5.1.37 Test No. HTCUB-37

For test no. HTCUB-37, the cable applied a load to the A449 keyway bolt at an angle of 0 degrees, parallel to the face of the flange. The keyway bolt was attached with one grade 8 high-topped nut tightened with a wrench and the slot and keyway design type 2 was used. The cable released at a load of 0.92 kips (4.09 kN). The button slipped out of the keyway while the threaded end remained attached to the flange and the keyway bolt straightened out. The force versus time plot is shown in Figure 113. Pre- and post-test photographs are shown in Figure 114. Sequential photographs are shown in Figure 115.

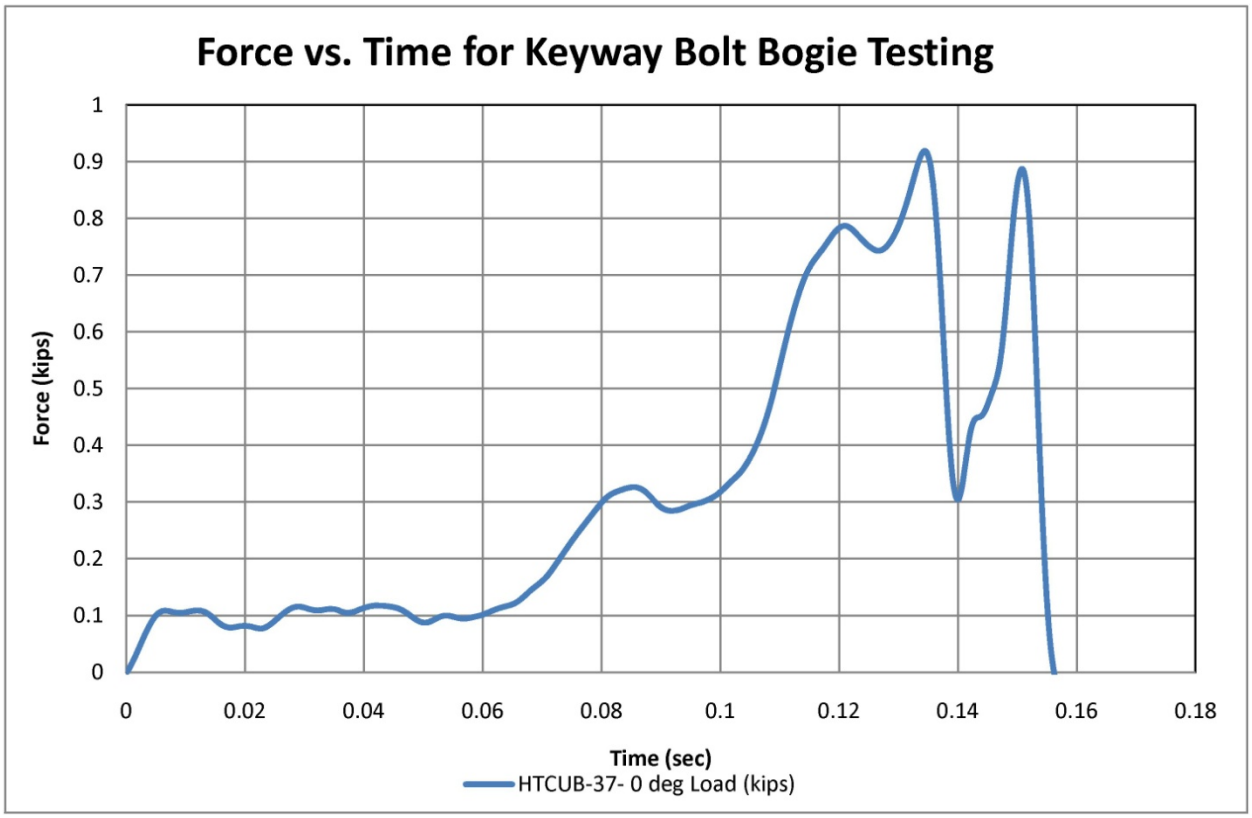
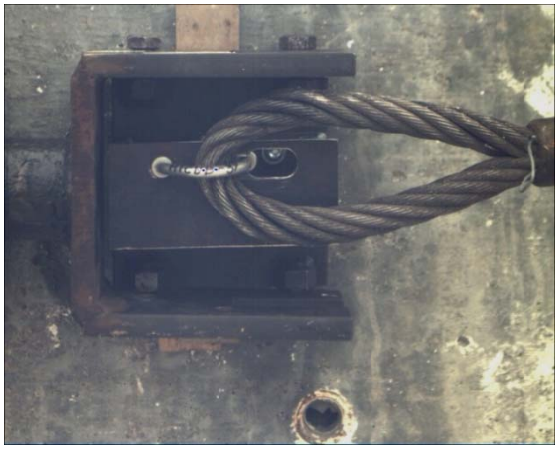


Figure 113. Force-Time Data, Test No. HTCUB-37

Pre-Test

Post-Test

Figure 114. Pre-Test and Post-Test Photographs, Test No. HTCUB-37



Time = 0 ms

Time = 138 ms

Time = 144 ms

Time = 150 ms

Figure 115. Sequential Photographs, Test No. HTCUB-37

5.2 Discussion

The 37 dynamic tests were used to evaluate the cable clip hardware and develop a design that could be utilized in the high-tension cable median barrier. The design objectives required the cable clip to maintain a minimum perpendicular tensile load of 8.00 kips (35.59 kN) while releasing vertically at a maximum pullout load of 1.00 kips (4.45 kN). Several different configurations were tested with different sizes and strengths of nuts, keyway bolts, and slot and keyway designs.

The type 1 slot and keyway was designed for development only and was used to fine tune the bolt attachment. The testing of the type 1 slot and keyway design led to the type 2 design in terms of the depth and position of the keyway relative to the lower hole. The type 2 slot and keyway design showed more consistent behavior and an improvement over the type 1 design. Placement of the top arm of the bolt lower in the keyway led to the upper arm having higher release loads. This led to excessive loads in tests which utilized the type 1 design and the keyway bolt placed near the bottom of the slot. These failed tests included HTCUB-5, HTCUB-6, HTCUB-11, HTCUB-14, and HTCUB-16 because the observed loads were higher than the maximum acceptable vertical pullout load for the C1018 keyway bolt.

Following test nos. HTCUB-1 through HTCUB-30, it was believed that the C1018 keyway bolt with either a single grade 5 nut or double grade 2 nuts installed on the type 2 slot and keyway design would yield the desired behavior. However, after observing the first two cable barrier dynamic bogie tests described in Chapter 7 (HTCC-1 and HTCC-2), the design requirements were considered inadequate because the clips prematurely released the cables due to fracture of the bolt and did not develop the desired deformation of the S3x5.7 (S76x8.5) post. An A449 keyway bolt with a single grade 8 high-topped nut was proposed and tested in order to

increase the strength of the cable clip connection. The selection of the thicker grade 8 nut was to prevent the threads from stripping off of the bolts, as was observed in test nos. HTCUB-1 and HTCUB-2. Both of the 90 degree tests that utilized the A449 keyway bolt and the grade 8 high-topped nut provided a resistance greater than 8.00 kips (35.59 kN) while releasing the cable at an average load of 1.18 kips (5.25 kN) for the 0 degree tests. The increase in vertical pullout loads, although undesirable, was accepted in exchange for greater tensile capacity. This design showed favorable results and was recommended for implementation in the high-tension cable barrier design after verifying its performance when installed on the S3x5.7 (S76x8.5) posts with dynamic bogie testing.

6 CABLE BARRIER DYNAMIC BOGIE TESTING

6.1 Purpose

Six dynamic bogie tests were performed to evaluate the high-tension cable barrier attachments when installed on a series of S3x5.7 (S76x8.5) posts with a high-tension cable and subjected to loads in a similar manner as a full-scale crash. It was desired that the keyway bolts develop the full strength of the post when the posts were in the vertical position, while allowing the cable to release from the posts as the posts deformed and rotated toward the ground. The clips were designed to develop the full moment capacity of the steel posts with specified yield strengths up to 50 ksi (345 MPa). The test was considered successful if the clips developed enough load to deform the post, but released the cable at a similar post rotation to the curved keyway bracket attachment used in full-scale crash test nos. 4CMB-1 through 4CMB-3.

6.2 Scope

The basic test setup consisted of four S3x5.7 (S76x8.5) posts at 16 ft (1.88 m) spacing with a tensioned cable mounted along all four posts, as shown in Figure 116. A bogie was directed toward the cable barrier and at the midpoint between post nos. 4 and 5. The target conditions were 17.0 mph (27.4 km/h) at an angle of 90 degrees to the cable. The cable was set at a height of 34-1/2 in. (876 mm) above the ground surface. A summary of all the cable barrier dynamic bogie tests is shown in Table 5. All of the posts were placed in a compacted coarse, crushed limestone material meeting Grading B of AASHTO M 147-65 as found in MASH.

For test no. HTCC-1, two different types of attachments were used. The two posts adjacent to the impact location utilized C1018 galvanized steel keyway bolts with the type 2 slot and keyway and one grade 5 nut. The test setup drawings used for test no. HTCC-1 are shown in Figures 116 through 119. Post no. 4 was oriented so that the cable was on the non-impact side of the post and post no. 5 was oriented so that the cable was on the impact side of the post. This

allowed for evaluating the performance of the attachment when the cable was pulled away and pushed into the post. Post nos. 3 and 6 utilized a curved keyway bracket with shoulder bolts on the non-impact side of the posts. MwRSF previously performed static and dynamic testing on this clip design [1]. Material specifications for all hardware used in the bogie tests are shown in Appendix B.

Test no. HTCC-2 was set up with a similar configuration as test no. HTCC-1. The test setup for test no. HTCC-2 is shown in Appendix A. Both post nos. 4 and 5 had the cable connected to the non-impact side of the post with C1018 galvanized steel keyway bolts. Post no. 4 had one grade 5 nut attached to the keyway bolt while post no. 5 had two grade 2 nuts attached to the keyway bolt. Post nos. 3 and 6 utilized curved keyway brackets with shoulder bolts installed on the non-impact side of the posts.

Test nos. HTCC-3 and HTCC-4 were set up with a similar configuration as test no. HTCC-1. The test setup used in test nos. HTCC-3 and HTCC-4 is shown in Appendix A. Test no. HTCC-3 utilized C1018 galvanized steel keyway bolts with grade 8 high-topped nuts on post nos. 4 and 5. Test no. HTCC-4 utilized A449 galvanized steel keyway bolts with grade 8 high-topped nuts on post nos. 4 and 5. For both test nos. HTCC-3 and HTCC-4, post nos. 3 and 6 utilized curved keyway brackets with shoulder bolts installed on the non-impact side of the posts. Test no. HTCC-5 was a repeat test of test no. HTCC-4. The keyway bolts used in test nos. HTCC-3, HTCC-4, and HTCC-5 had the threads terminated 3/32 in. (2.38 mm) from the shoulder of the keyway bolt.

Test no. HTCC-6 was set up with a similar configuration to the previous tests except that the curved keyway brackets with shoulder bolts were utilized at every post connection. The test setup drawings for test no. HTCC-6 are shown in Appendix A. Post nos. 3, 4, and 6 had the

curved keyway brackets installed on the non-impact side of the post while post no. 5 had the curved keyway bracket installed in the impact side of the post.

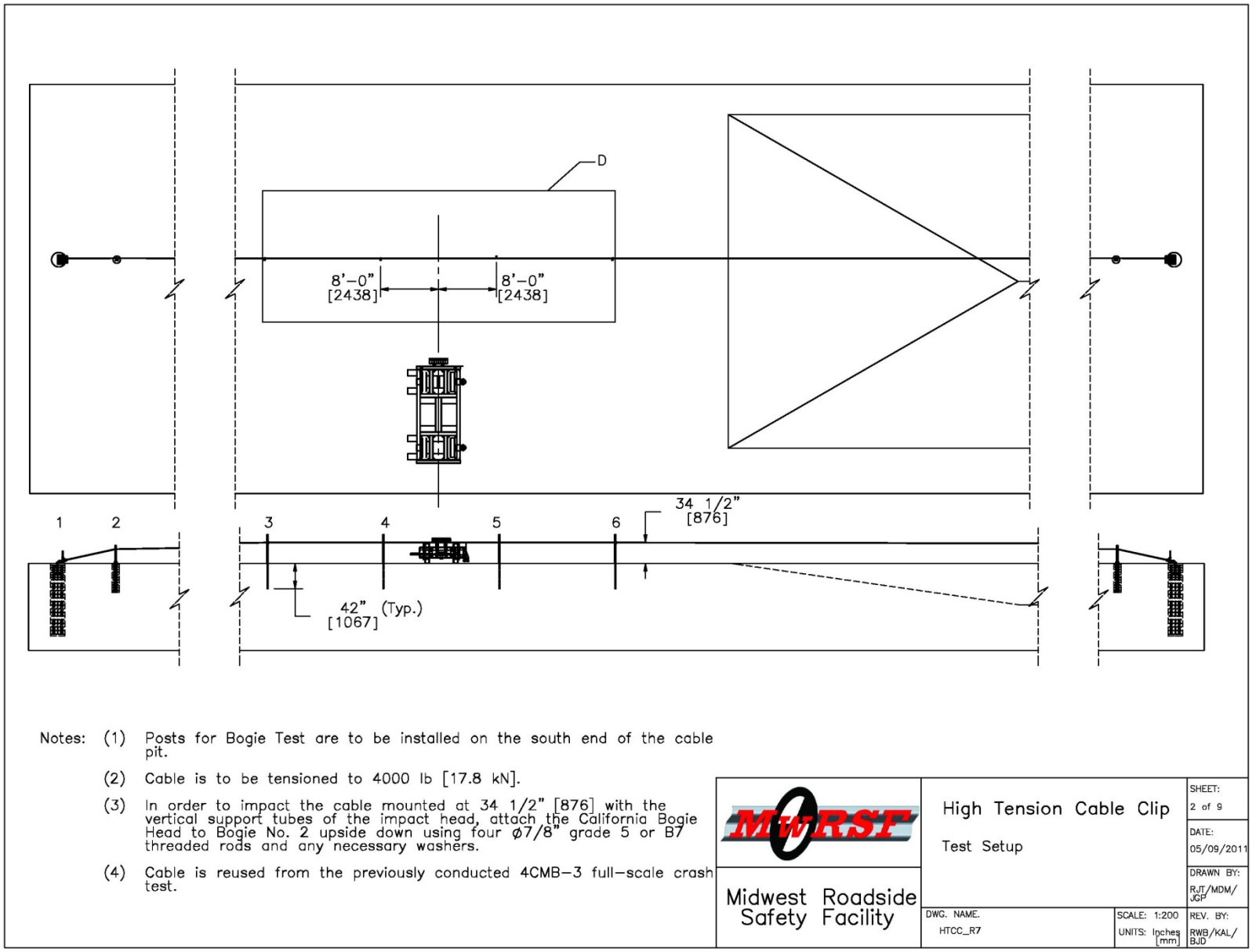


Figure 116. Test No. HTCC-1 Setup

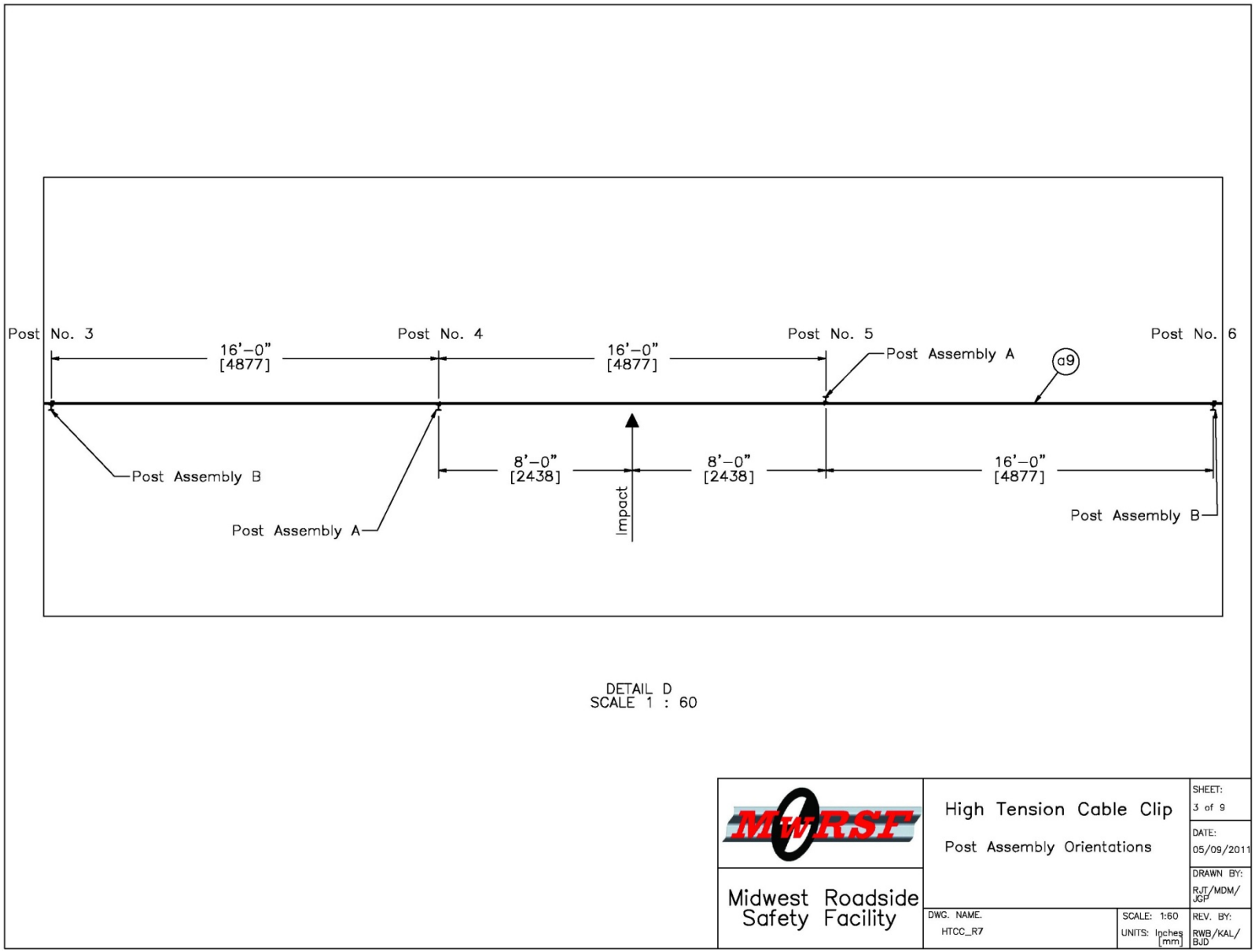


Figure 117. Detail D, Test No. HTCC-1

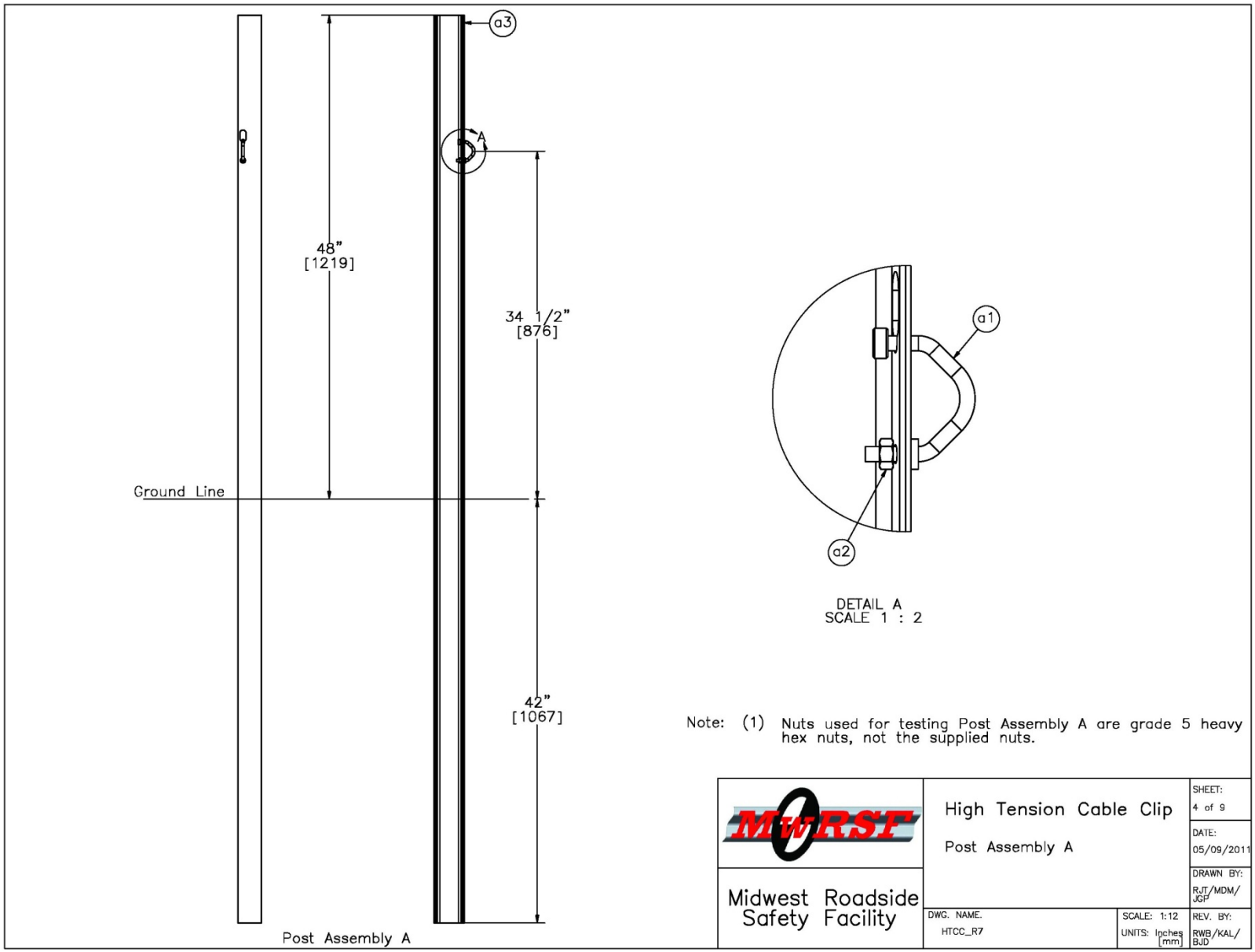


Figure 118. Post Assembly A, Test No. HTCC-1

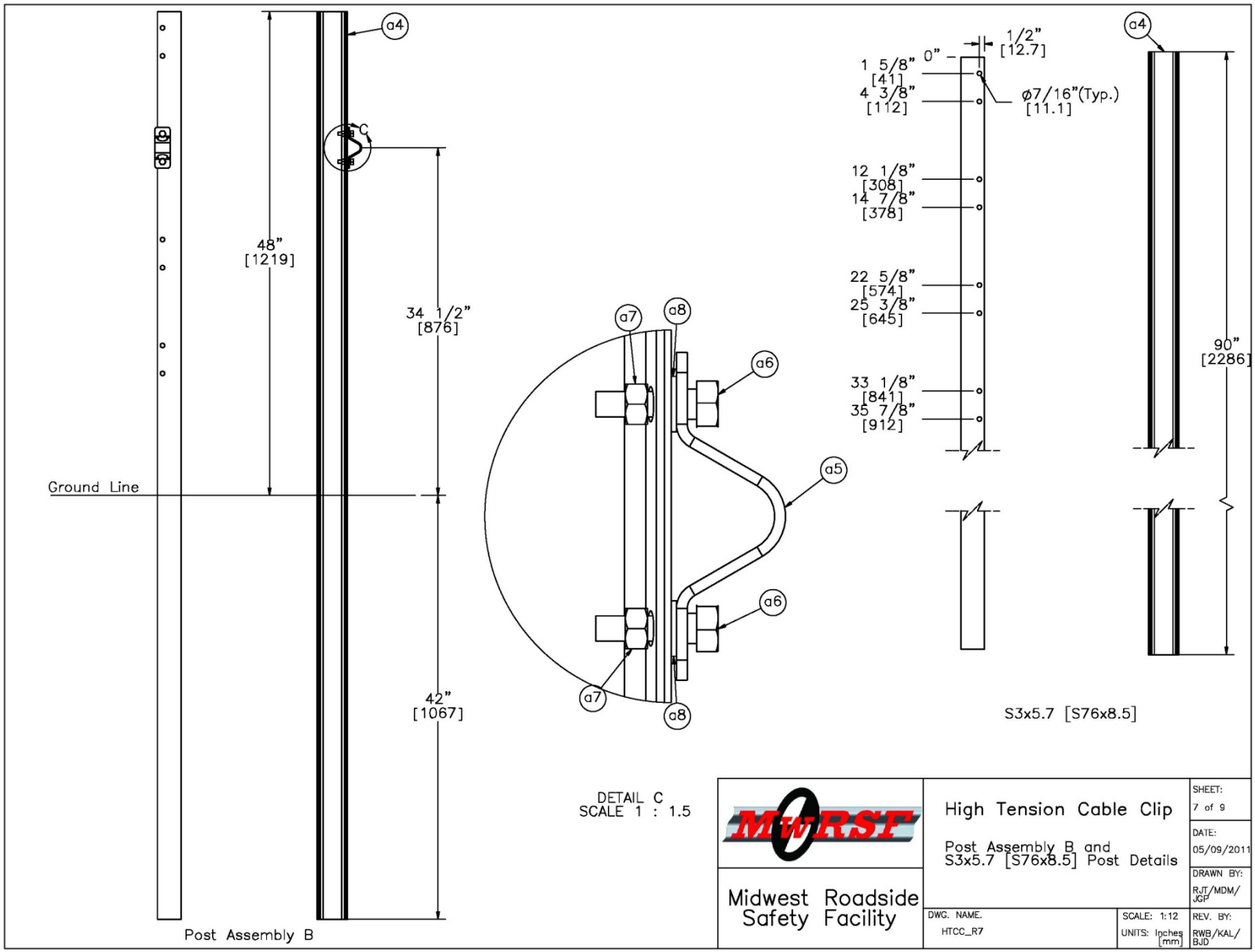


Figure 119. Post Assembly B, Test No. HTCC-1

6.3 Test Facility

Physical testing of the high-tension cable barrier was conducted at the MwRSF testing facility 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) from the University of Nebraska-Lincoln's city campus.

Table 5. Summary of Bogie Crash Test Setups

Test No.	Post No. 3	Post No. 4	Post No. 5	Post No. 6	Bogie Speed	Cable Tension
HTCC-1	Curved Keyway Bracket on Non-Impact Side	C1018 Keyway Bolt with Grade 5 Nut on Non-Impact Side	C1018 Keyway Bolt with Grade 5 Nut on Impact Side	Curved Keyway Bracket on Non-Impact Side	19.6 mph (31.5 km/h)	4.12 kips (18.33 kN)
HTCC-2	Curved Keyway Bracket on Non-Impact Side	C1018 Keyway Bolt with Grade 5 Nut on Non-Impact Side	C1018 Keyway Bolt with Two Grade 2 Nuts on Non-Impact Side	Curved Keyway Bracket on Non-Impact Side	18.5 mph (29.8 km/h)	3.98 kips (17.70 kN)
HTCC-3	Curved Keyway Bracket on Non-Impact Side	C1018 Keyway Bolt with Grade 8 High-Topped Nut on Non-Impact Side	C1018 Keyway Bolt with Grade 8 High-Topped Nut on Impact Side	Curved Keyway Bracket on Non-Impact Side	20.1 mph (32.3 km/h)	4.14 kips (18.42 kN)
HTCC-4	Curved Keyway Bracket on Non-Impact Side	A449 Keyway Bolt with Grade 8 High-Topped Nut on Non-Impact Side	A449 Keyway Bolt with Grade 8 High-Topped Nut on Impact Side	Curved Keyway Bracket on Non-Impact Side	21.4 mph (34.4 km/h)	4.10 kips (18.24 kN)
HTCC-5	Curved Keyway Bracket on Non-Impact Side	A449 Keyway Bolt with Grade 8 High-Topped Nut on Non-Impact Side	A449 Keyway Bolt with Grade 8 High-Topped Nut on Impact Side	Curved Keyway Bracket on Non-Impact Side	20.8 mph (33.5 km/h)	4.10 kips (18.24 kN)
HTCC-6	Curved Keyway Bracket on Non-Impact Side	Curved Keyway Bracket on Non-Impact Side	Curved Keyway Bracket on Impact Side	Curved Keyway Bracket on Non-Impact Side	19.8 mph (31.9 km/h)	4.10 kips (18.24 kN)

6.4 Equipment and Instrumentation

A variety of equipment and instrumentation was utilized to collect and record data during the dynamic bogie tests that included:

- Bogie
- Accelerometers
- Pressure Tape Switches
- Photography Cameras

6.4.1 Bogie

A rigid frame bogie with a variable height, detachable head was used to impact the cable barrier. The bogie impact head was attached to the front of the bogie, with the horizontal tube oriented above the cable. A photograph of the bogie with the head in position relative to the height of the cable is shown in Figure 120.

The tests were conducted using a steel corrugated beam guardrail to guide the left-side tires of the bogie vehicle. A pickup truck was used to accelerate the bogie vehicle to the required impact velocity. After reaching the target velocity, the push vehicle braked allowing the bogie to be free rolling as it came off the track.

6.4.2 Accelerometers

An accelerometer system was mounted on the bogie vehicle near its center of gravity to measure the acceleration in the longitudinal, lateral, and vertical directions. The accelerometer, Model EDR-3, was a triaxial piezoresistive accelerometer system developed by Instrumented Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM memory, 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.

Figure 120. Rigid Frame Bogie with Head Attachment and Cable Height

An additional accelerometer system was used to measure the acceleration in the longitudinal and lateral directions at a sample rate of 10,000 Hz. The environmental shock and vibration sensor/recorder system, a two-Arm piezoresistive accelerometer, was developed by Endevco of San Juan Capistrano, California. Two accelerometers were used to measure the longitudinal and lateral accelerations independently. Data was collected using a Sensor Input Module (SIM), Model TDAS3-SIM-16M, which was developed by Diversified Technical Systems, Inc (DTS) of Seal Beach, California. The SIM was configured with 16 MB SRAM memory and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack is configured with isolated

power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal back-up battery. Both the SIM and module rack were crashworthy. The "DTS TDAS Control" and "DADiSP" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

6.4.3 Pressure Tape Switches

Three pressure tape switches, spaced at approximately 18-in. (457-mm) intervals and placed near the end of the bogie track, were used to determine the speed of the bogie before the impact. As the right-front tire of the bogie passed over each tape switch, a strobe light was fired sending an electronic timing signal to the data acquisition system. The system recorded the signals and the time each occurred. The speed was then calculated using the spacing between the sensors and the time between the signals. Strobe lights and high-speed video analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.

6.4.4 Photography Cameras

High-speed AOS VITcam digital video cameras and JVC digital video cameras were used to document each test. All high-speed AOS VITcam digital video cameras had a frame rate of 500 frames per second and all JVC digital video cameras had a frame rate of 29.97 frames per second. A Nikon D50 digital still camera was also used to document pre- and post-test conditions for all tests.

For test nos. HTCC-1 and HTCC-2, two AOS VITcam high-speed digital video cameras were positioned along the cable barrier, with one located downstream of the impact location and the other located upstream of the impact location. Two JVC digital video cameras were also positioned along the cable barrier, with one located downstream of the impact location and the other located upstream of the impact location. Test no. HTCC-2 utilized an additional AOS

VITcam high-speed digital video camera positioned offset of the cable barrier on the non-impact side.

For test nos. HTCC-3, HTCC-4, HTCC-5, and HTCC-6, three AOS VITcam high speed digital video cameras were used with one positioned downstream and offset to the impact side of the impact location, one positioned upstream and offset to the non-impact side of the impact location, and one positioned along the cable barrier on the upstream end. Three JVC digital video cameras were also used and were positioned in the same locations as the AOS VITcam high speed digital cameras.

7 CABLE BARRIER TESTING RESULTS AND DISCUSSION

7.1 Results

Six dynamic bogie tests were performed to evaluate the dynamic performance of the keyway bolt attachment in the vicinity of impact. The tested keyway bolts with the type 2 slot and keyway design and/or the curved keyway bracket with shoulder bolts were installed on posts on both sides of impact. A summary of the test results is shown in Table 6. For each test, a measurement of the maximum strong axis post bend angle was taken from either post no. 4 or 5. The reported bend angle was taken from the post that experienced the least rotation of the two.

7.1.1 Test No. HTCC-1

For test no. HTCC-1, a tensile pre-load of 4.12 kips (18.33 kN) was applied to the cable. The 4,913 lb (2,228 kg) bogie impacted the cable barrier at a speed of 19.6 mph (31.5 km/h) at the midspan between post nos. 4 and 5 at an angle of 90 degrees from the cable. The C1018 keyway bolt that was installed on post no. 4 fractured in tension through the threads at the base of the shoulder while the keyway bolt that was installed on post no. 5 released the cable when the button slipped out of the keyway. All of the posts yielded near the ground line and experienced some slight twisting deformation. Pre- and post-test photographs of the bogie and system are shown in Figure 121. Pre- and post-test photographs of the attachments are shown in Figures 122 and 123, and sequential photographs are shown in Figure 124. There was significant scraping damage to the keyway on post no. 5, as shown in Figure 123. The cable also scraped the edge of the flange from the keyway location to the top of the post. There was no significant damage to the keyway on post no. 4. The maximum angle of rotation of the posts was 18 degrees, as shown in Figure 125.

Table 6. Summary of Bogie Crash Tests

Test No.	Post No. 3	Post No. 4	Post No. 5	Post No. 6	Result	Post Rotation Angle
HTCC-1	Curved Keyway Bracket on Non-Impact Side	C1018 Keyway Bolt with Grade 5 Nut on Non-Impact Side	C1018 Keyway Bolt with Grade 5 Nut on Impact Side	Curved Keyway Bracket on Non-Impact Side	Keyway Bolt on Post No. 4 Fractured, Keyway Bolt on Post No. 5 Released and Remained Attached, Posts Yielded and Experienced Slight Twisting Deformation.	18°
HTCC-2	Curved Keyway Bracket on Non-Impact Side	C1018 Keyway Bolt with Grade 5 Nut on Non-Impact Side	C1018 Keyway Bolt with Two Grade 2 Nuts on Non-Impact Side	Curved Keyway Bracket on Non-Impact Side	Keyway Bolts on Post Nos. 4 and 5 Fractured, Posts Yielded and Experienced Slight Twisting Deformation.	N/A
HTCC-3	Curved Keyway Bracket on Non-Impact Side	C1018 Keyway Bolt with Grade 8 High-Topped Nut on Non-Impact Side	C1018 Keyway Bolt with Grade 8 High-Topped Nut on Impact Side	Curved Keyway Bracket on Non-Impact Side	Keyway Bolt on Post No. 4 Fractured, Keyway Bolt on Post No. 5 Released and Remained Attached, Posts Yielded and Experienced Slight Twisting Deformation.	23°
HTCC-4	Curved Keyway Bracket on Non-Impact Side	A449 Keyway Bolt with Grade 8 High-Topped Nut on Non-Impact Side	A449 Keyway Bolt with Grade 8 High-Topped Nut on Impact Side	Curved Keyway Bracket on Non-Impact Side	Keyway Bolt on Post No. 4 Fractured, Keyway Bolt on Post No. 5 Released and Remained Attached, Posts Yielded and Experienced Twisting Deformation, Post No. 5 Experienced Minor Scraping and a Larger Angle of Bending.	34°
HTCC-5	Curved Keyway Bracket on Non-Impact Side	A449 Keyway Bolt with Grade 8 High-Topped Nut on Non-Impact Side	A449 Keyway Bolt with Grade 8 High-Topped Nut on Impact Side	Curved Keyway Bracket on Non-Impact Side	Keyway Bolt on Post No. 4 Fractured, Keyway Bolt on Post No. 5 Released and Remained Attached, Posts Yielded and Experienced Twisting Deformation.	24°
HTCC-6	Curved Keyway Bracket on Non-Impact Side	Curved Keyway Bracket on Non-Impact Side	Curved Keyway Bracket on Impact Side	Curved Keyway Bracket on Non-Impact Side	Cable Clips on Post Nos. 4 and 5 Straightened Out and Released Cable, Cable Snagged on Shoulder Bolt on Post No. 5, Posts Yielded and Experienced Twisting Deformation.	33°

Pre-Test

Post-Test

Figure 121. Pre-Test and Post Test Photographs, Test No. HTCC-1

Pre-Test

Post-Test

Figure 122. Pre-Test and Post-Test Photographs of Post No. 4, Test No. HTCC-1

Pre-Test

Post-Test

Figure 123. Pre-Test and Post-Test Photographs of Post No. 5, Test No. HTCC-1


0 ms


300 ms


50 ms


350 ms


100 ms


400 ms


150 ms


450 ms


200 ms


500 ms


250 ms


550 ms

Figure 124. Sequential Photographs, Test No. HTCC-1

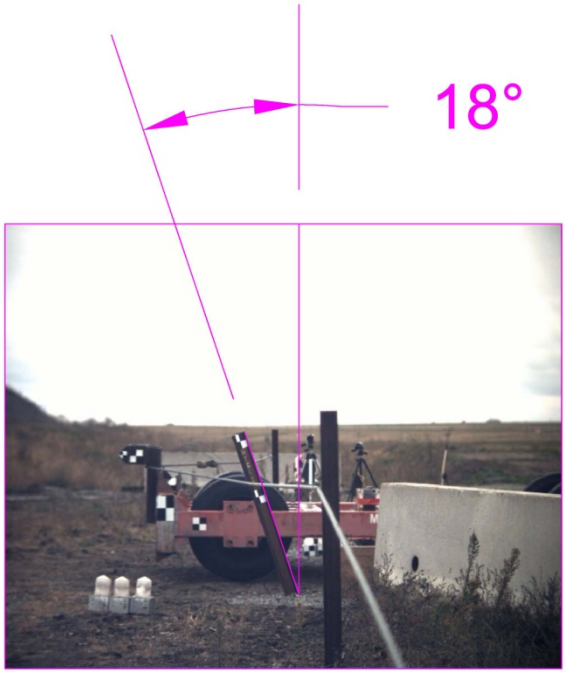


Figure 125. Post Deflection Angle, Test No. HTCC-1

7.1.2 Test No. HTCC-2

For test no. HTCC-2, a tensile pre-load of 3.98 kips (17.70 kN) was applied to the cable. The 4,926 lb (2,234 kg) bogie impacted the cable barrier at a speed of 18.5 mph (29.8 km/h) at the midspan between post nos. 4 and 5 at an angle of 90 degrees from the cable. Both of the C1018 keyway bolts on post nos. 4 and 5 fractured in tension through the threads at the base of the shoulder. All of the posts yielded near the ground line and experienced some slight twisting deformation. There were slight contact marks around the edges of the slots and keyways that were caused by the impact with the keyway bolt. The angle of post rotation was not able to be determined for this test because there was not a camera aligned along the line of the posts. However, the post behavior was very similar to the post deformation observed in test no. HTCC-1. Pre- and post-test photographs of the bogie and system are shown in Figure 126. Pre- and post-test photographs of the attachments are shown in Figures 127 and 128. Sequential photographs are shown in Figure 129.

Pre-Test

Post-Test

Figure 126. Pre-Test and Post-Test Photographs, Test No. HTCC-2

Pre-Test

Post-Test

Figure 127. Pre-Test and Post-Test Photographs of Post No. 4, Test No. HTCC-2

Pre-Test

Post-Test

Figure 128. Pre-Test and Post-Test Photographs of Post No. 5, Test No. HTCC-2


0 ms


150 ms


26 ms


176 ms


50 ms


200 ms


76 ms


226 ms


100 ms


250 ms


126 ms


276 ms

Figure 129. Sequential Photographs, Test No. HTCC-2

7.1.3 Test No. HTCC-3

For test no. HTCC-3, a tensile pre-load of 4.14 kips (18.42 kN) was applied to the cable. The 4,937 lb (2,239 kg) bogie impacted the cable barrier at a speed of 20.1 mph (32.3 km/h) at the midspan between post nos. 4 and 5 at an angle of 90 degrees from the cable. The C1018 keyway bolt that was installed on post no. 4 fractured in tension through the threads while the keyway bolt that was installed on post no. 5 released the cable when the button slipped out of the keyway. All of the posts yielded near the ground line and experienced some slight twisting deformation. Post no. 4 had slight contact marks from the impact with the keyway bolt and post no. 5 had scrape marks from the impact with the cable. The maximum angle of rotation of the posts was 23 degrees, as shown in Figure 130. Pre- and post-test photographs of the bogie and system are shown in Figure 131. Pre- and post-test photographs of the attachments are shown in Figures 132 and 133. Sequential photographs are shown in Figure 134.

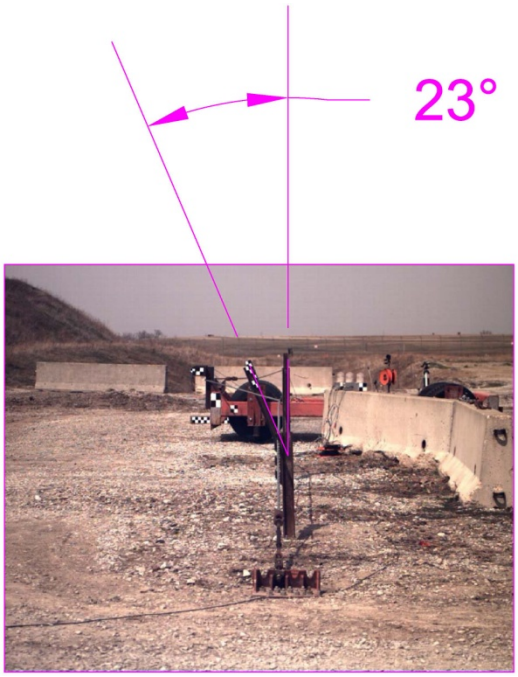
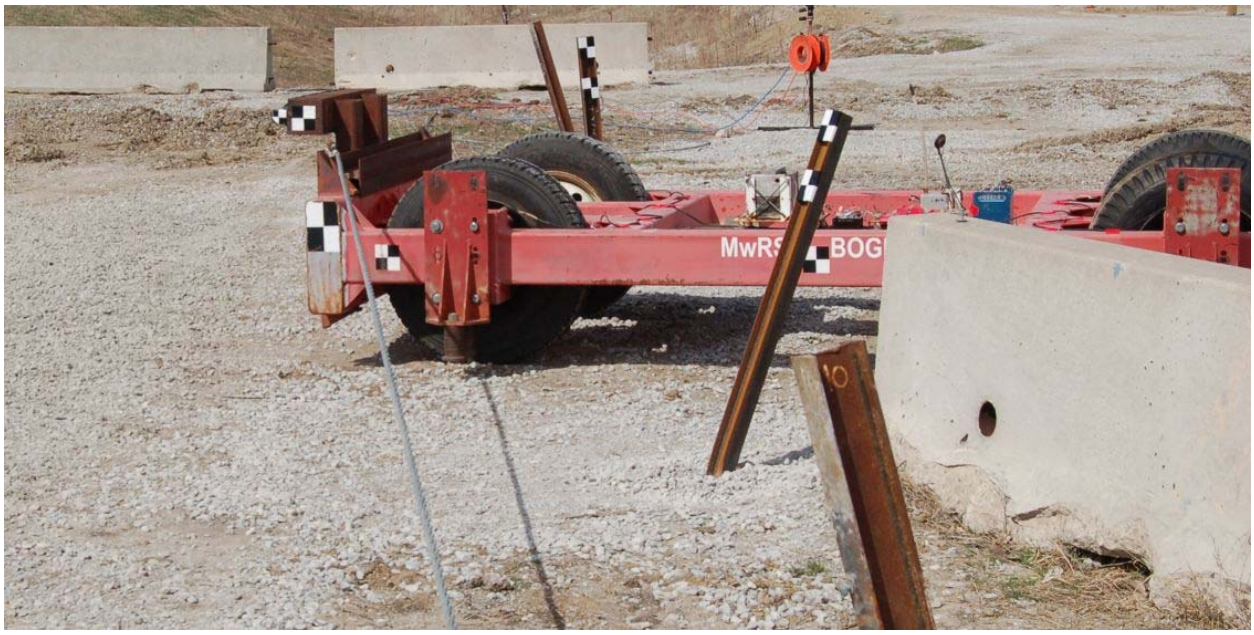


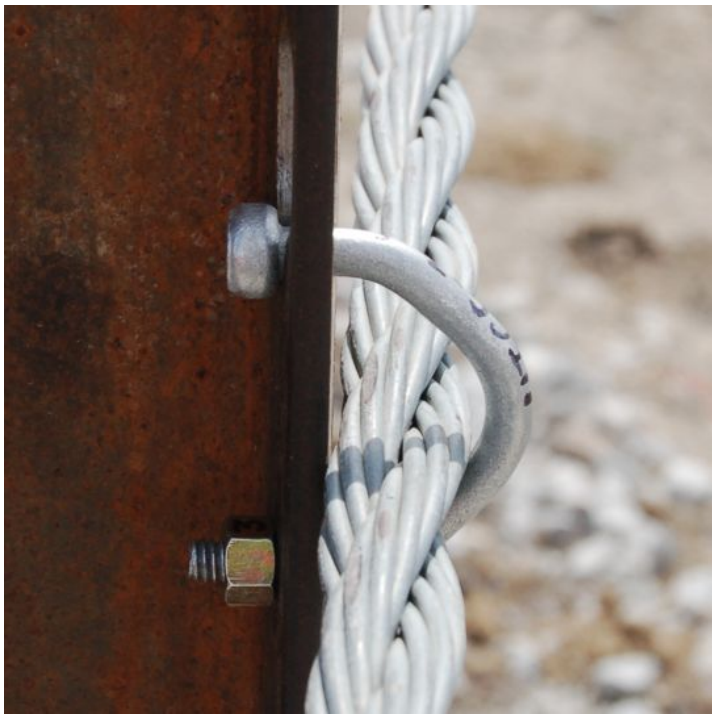
Figure 130. Post Deflection Angle, Test No. HTCC-3

Pre-Test



Post-Test

Figure 131. Pre-Test and Post-Test Photographs, Test No. HTCC-3



Pre-Test

Post-Test

Figure 132. Pre-Test and Post-Test Photographs of Post No. 4, Test No. HTCC-3

Pre-Test

Post-Test

Figure 133. Pre-Test and Post-Test Photographs of Post No. 5, Test No. HTCC-3

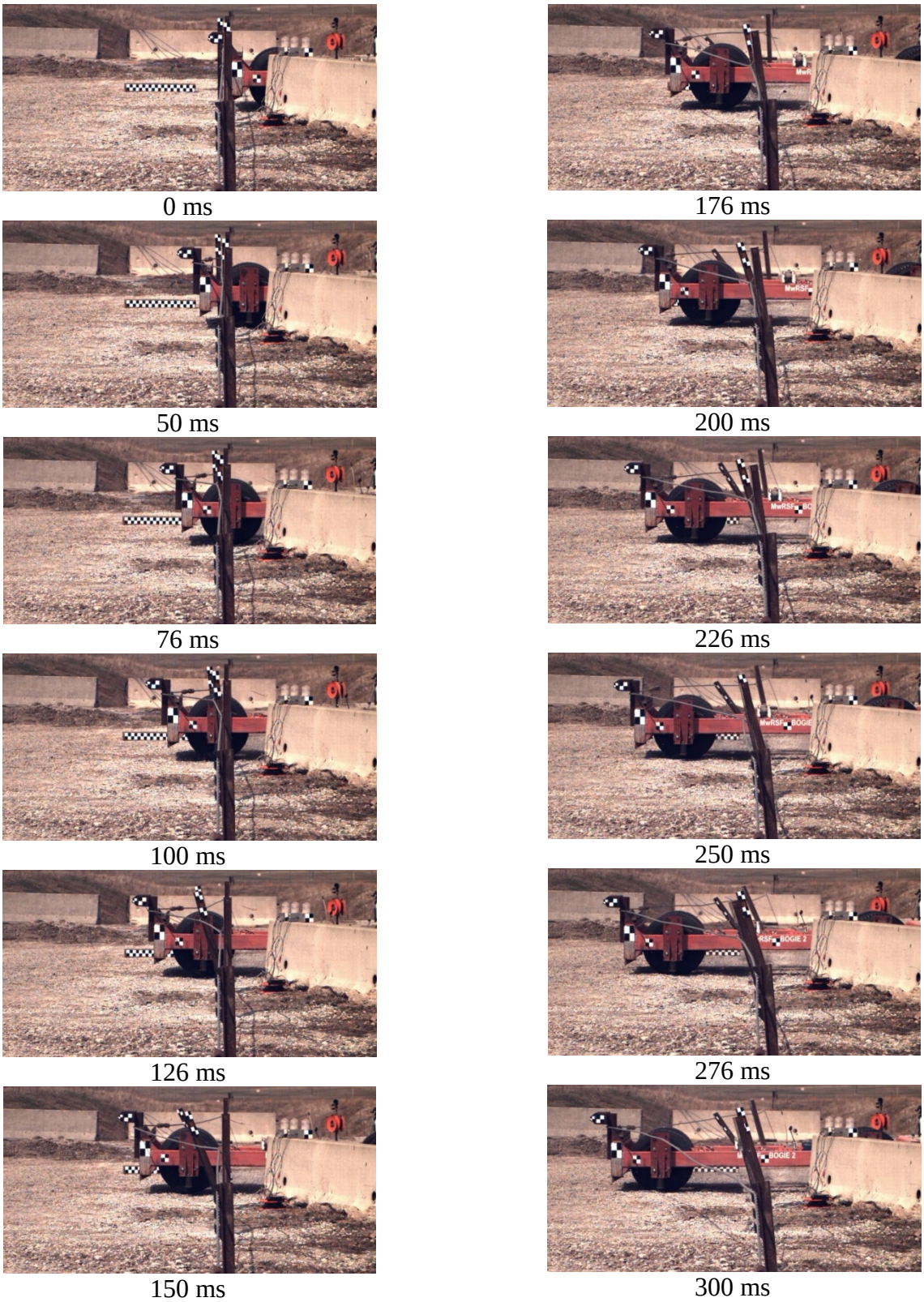


Figure 134. Sequential Photographs, Test No. HTCC-3

7.1.4 Test No. HTCC-4

For test no. HTCC-4, a tensile pre-load of 4.10 kips (18.24 kN) was applied to the cable. The 4,937 lb (2,239 kg) bogie impacted the cable at a speed of 21.4 mph (34.4 km/h) at the midspan between post nos. 4 and 5 at an angle of 90 degrees from the cable. The A449 keyway bolt that was installed on post no. 4 fractured in tension through the threads while the A449 keyway bolt that was installed on post no. 5 released the cable when the button slipped out of the keyway. All of the posts yielded near the ground line and experienced some twisting deformation. However, post no. 5 experienced a larger angle of bending that post no. 4. Post no. 4 had slight contact marks from the impact with the keyway bolt and post no. 5 had scrape marks from the impact with the cable. The maximum angle of rotation of the posts was 34 degrees, as shown in Figure 135. Pre- and post-test photographs of the bogie and system are shown in Figure 136. Pre- and post-test photographs of the attachments are shown in Figures 137 and 138. Sequential photographs are shown in Figure 139.

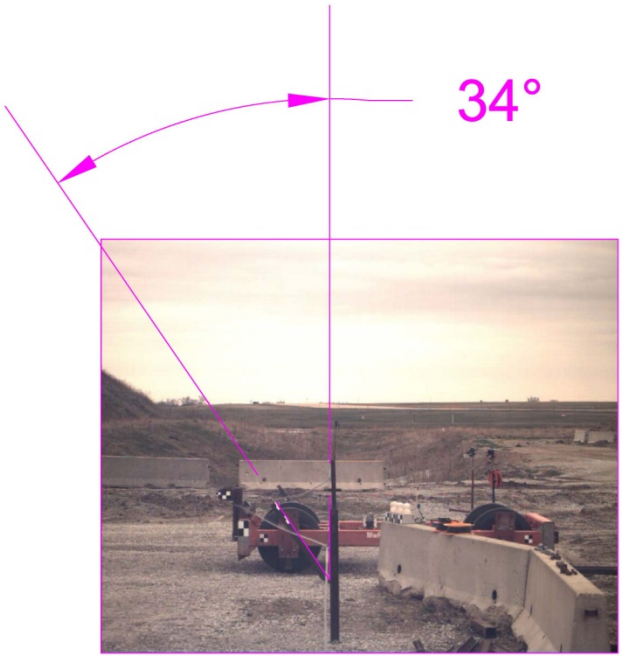


Figure 135. Post Deflection Angle, Test No. HTCC-4

Pre-Test

Post-Test

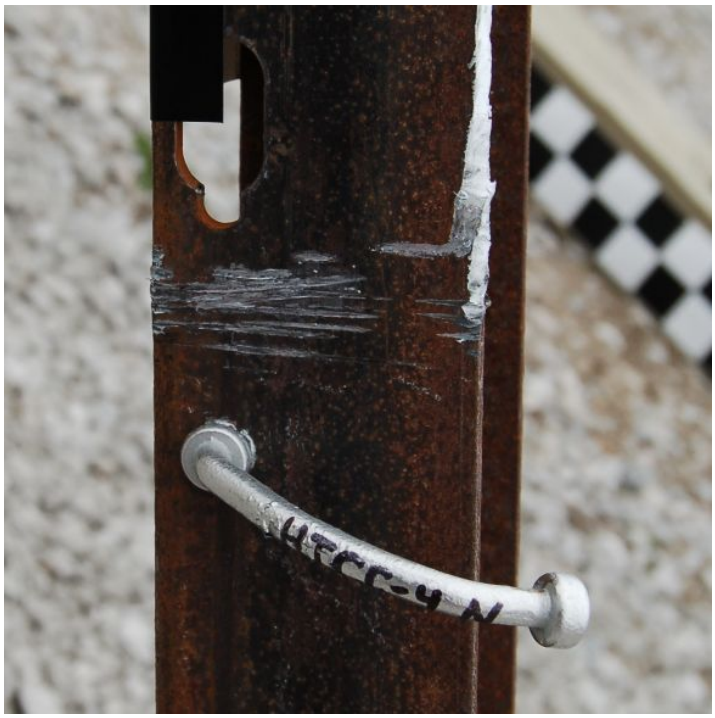
Figure 136. Pre-Test and Post-Test Photographs, Test No. HTCC-4

Pre-Test

Post-Test

Figure 137. Pre-Test and Post-Test Photographs of Post No. 4, Test No. HTCC-4

Pre-Test



Post-Test

Figure 138. Pre-Test and Post-Test Photographs of Post No. 5, Test No. HTCC-4

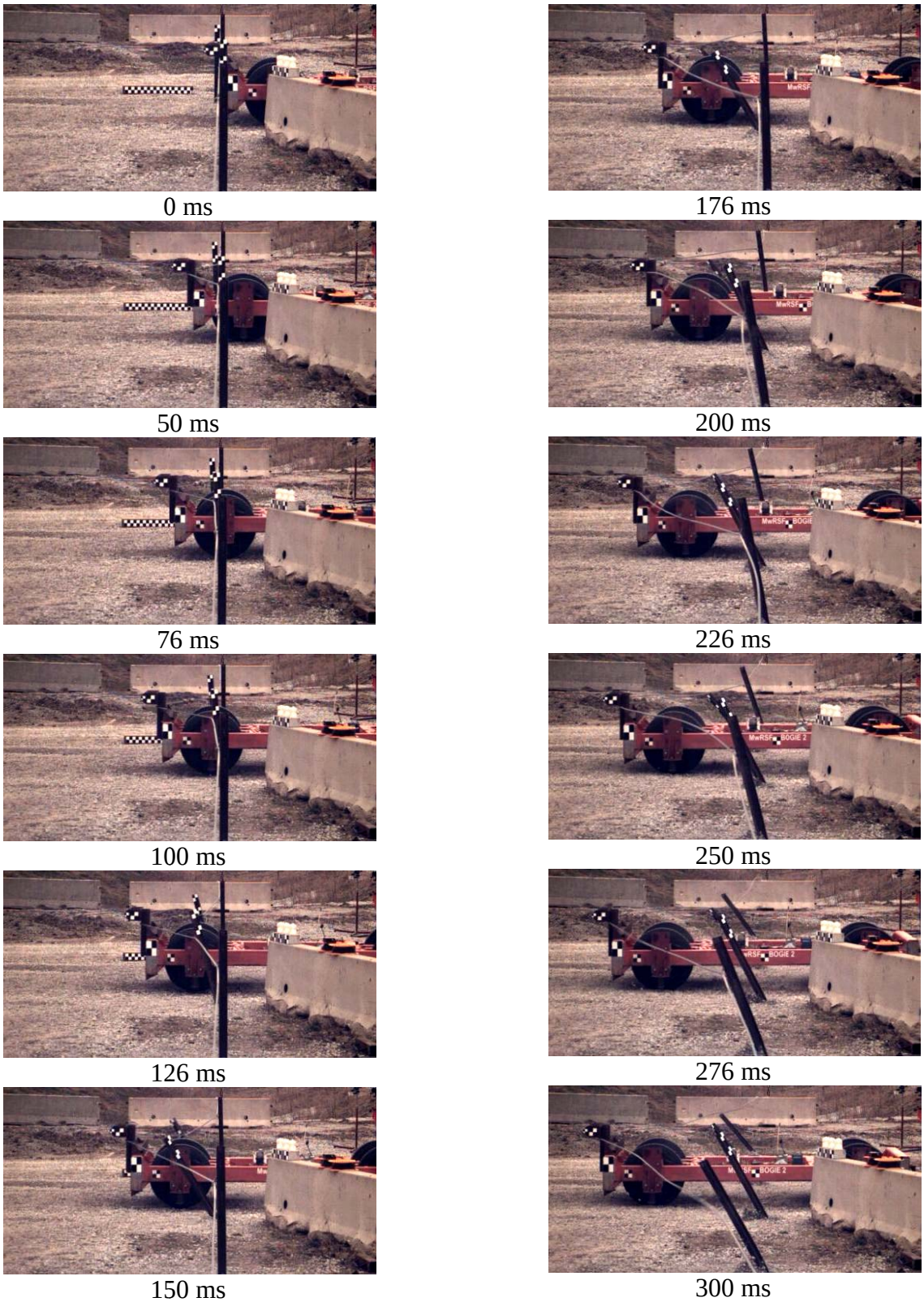


Figure 139. Sequential Photographs, Test No. HTCC-4

7.1.5 Test No. HTCC-5

Test no. HTCC-5 was set up the same as test no. HTCC-4 and experienced similar results. A tensile pre-load of 4.10 kips (18.24 kN) was applied to the cable. The 4,937 lb (2,239 kg) bogie impacted the cable at a speed of 20.8 mph (33.5 km/h) at the midspan between post nos. 4 and 5 at an angle of 90 degrees from the cable. The keyway bolt that was installed on post no. 4 fractured in tension through the threads while the keyway bolt that was installed on post no. 5 released the cable when the button slipped out of the keyway. All of the posts yielded near the ground line and experienced some twisting deformation. Post no. 4 had slight contact marks from the impact with the keyway bolt and post no. 5 had scrape marks from the impact with the cable. A post-test photograph of the bogie and system is shown in Figure 140. Post-test photographs of the attachments are shown in Figures 141 and 142. Sequential photographs are shown in Figure 143. The maximum angle of rotation of the posts was 24 degrees, as shown in Figure 144.

Figure 140. Post-Test Photograph, Test No. HTCC-5

Figure 141. Post-Test Photograph of Post No. 4, Test No. HTCC-5

Figure 142. Post-Test Photograph of Post No. 5, Test No. HTCC-5

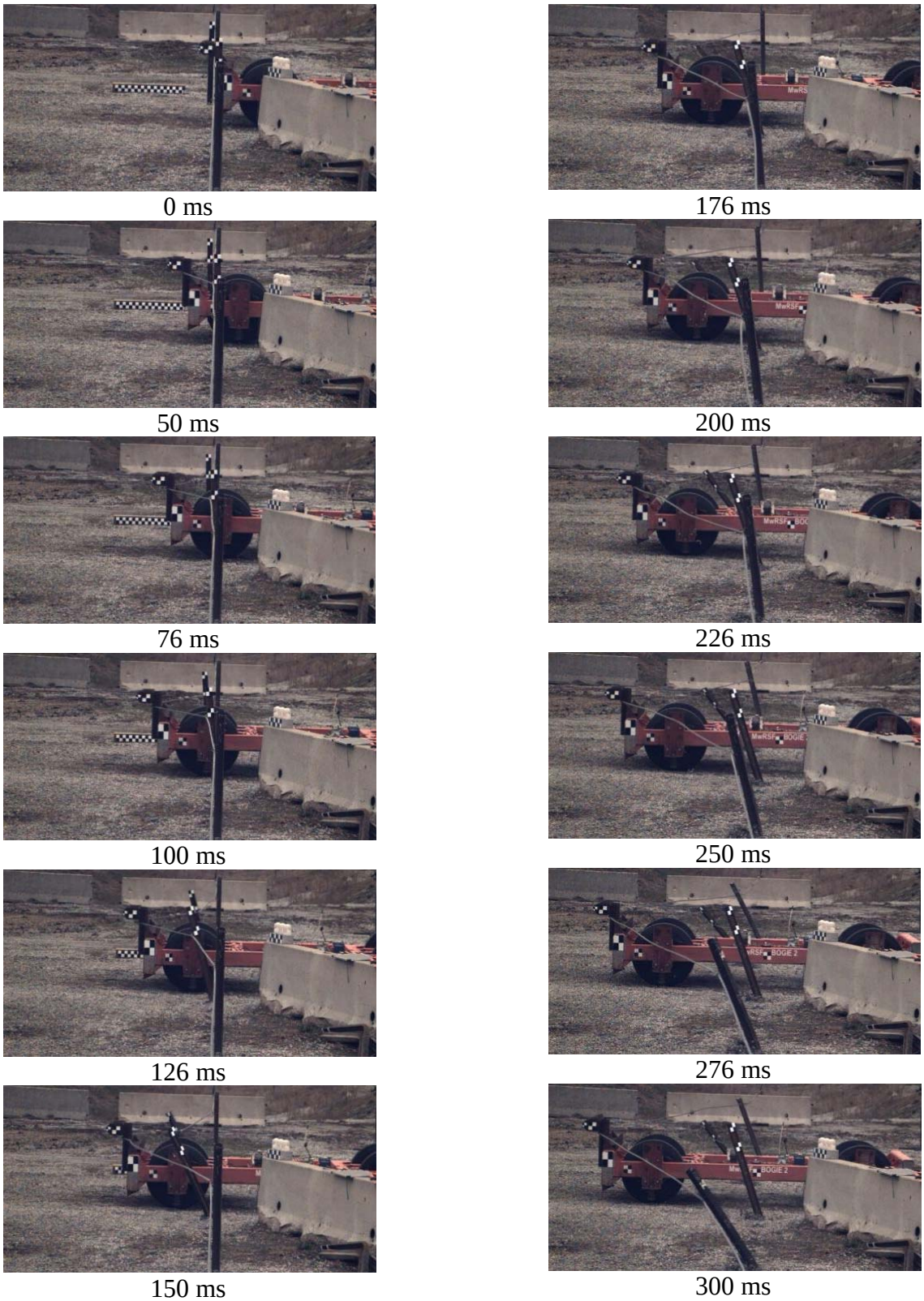


Figure 143. Sequential Photographs, Test No. HTCC-5

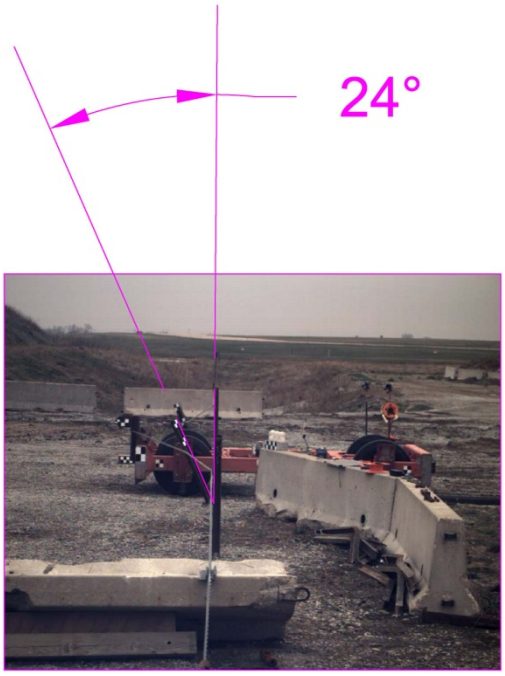


Figure 144. Post Deflection Angle, Test No. HTCC-5

7.1.6 Test No. HTCC-6

For test no. HTCC-6, a tensile pre-load of 4.10 kips (18.24 kN) was applied to the cable. The 4,937 lb (2,239 kg) bogie impacted the cable at a speed of 19.8 mph (31.9 km/h) at the midspan between post nos. 4 and 5 at an angle of 90 degrees from the cable. The clip on post no. 4 straightened out and released the cable as the shoulder bolt slipped through the keyway on the cable clip. The clip on post no. 5 also straightened out and released the clip from the shoulder bolts, but the cable snagged on the top shoulder bolt which fractured in shear and released the cable. All of the posts yielded near the ground line and experienced some twisting deformation. There were scrape marks on post no. 5 from the impact with the cable and the top shoulder bolt was fractured off. The maximum angle of rotation of the posts was 33 degrees, as shown in Figure 145. Pre- and post-test photographs of the system are shown in Figure 146. Pre- and post-test photographs of the attachments are shown in Figures 147 and 148. Sequential photographs are shown in Figure 149. There was little damage around the connection area on post no. 4.

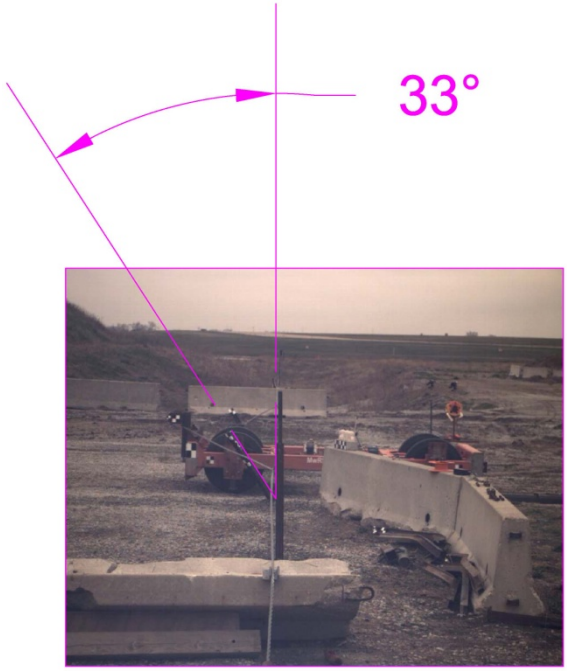
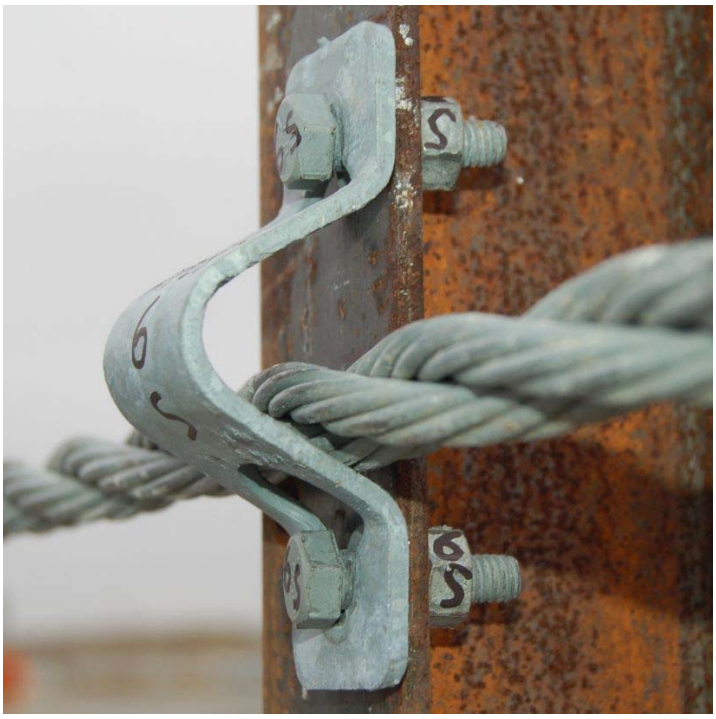


Figure 145. Post Deflection Angle, Test No. HTCC-6

Pre-Test

Post-Test

Figure 146. Pre-Test and Post-Test Photographs, Test No. HTCC-6



Pre-Test

Post-Test

Figure 147. Pre-Test and Post-Test Photographs of Post No. 4, Test No. HTCC-6

Pre-Test

Post-Test

Figure 148. Pre-Test and Post-Test Photographs of Post No. 5, Test No. HTCC-6

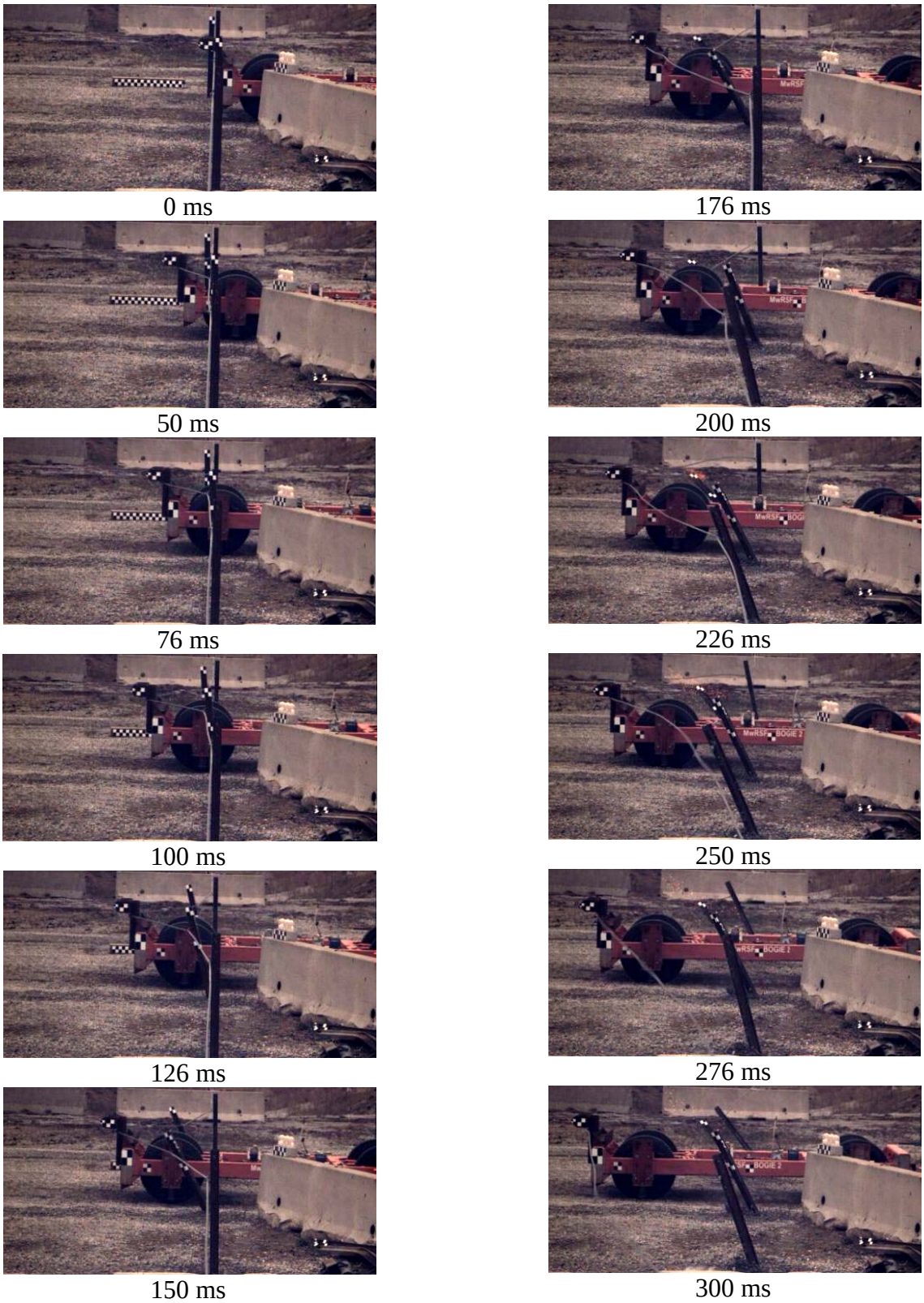


Figure 149. Sequential Photographs, Test No. HTCC-6

7.2 Discussion

Six dynamic bogie tests were conducted to evaluate the performance and behavior of the high-tension cable barrier with the clips developed. The tests were conducted with both C1018 and A449 keyway bolts and the curved keyway bracket design used in the full-scale crash test nos. 4CMB-1 through 4CMB-3. Results from these tests were analyzed to ensure that the keyway bolt cable attachments could safely release the cables while still developing similar levels of post deformation and post energy absorption as the original curved keyway bracket.

Test no. HTCC-6 utilized the curved keyway bracket at every post connection. This test was used as a baseline comparison for the keyway bolt attachments. It should be noted that a cable snag on the shoulder bolt installed on the impact side of the post was observed in this test. This behavior is not desired as it could lead to unacceptable behavior of the system if the cables slip over the hood of a vehicle. This behavior was documented in a previous test report [2].

The results from test nos. HTCC-1 and HTCC-2 showed consistent release of the cable, but the cable released from the posts too quickly and insufficient post deformation and rotation was achieved. Test nos. HTCC-3, HTCC-4, and HTCC-5 utilized higher strength keyway bolts and/or nuts to increase the connection strength. In addition, the threads on the keyway bolt were moved away from the shoulder to remove a stress concentration in that area. The maximum post rotation achieved in test no. HTCC-3 was 23 degrees, which was less than the desired post rotation of 33 degrees that was achieved with the curved keyway bracket design utilized is test no. HTCC-6. This lower rotation angle was caused by the premature fracturing of the C1018 keyway bolt on post no. 4. The maximum post rotation angles achieved in test nos. HTCC-4 and HTCC-5 were 34 and 24 degrees respectively. The use of higher strength hardware enabled the keyway bolts to remain attached to the cable longer and the full strength of the posts were developed. This allowed for the posts located near the impact location to absorb more energy.

The behavior of these tests proved to be satisfactory as the clips released the cables without dragging the posts to the ground or uprooting them, causing excessive twisting. Therefore, the A449 keyway bolt with the grade 8 high-topped nut configuration was considered to behave similar to the curved keyway bracket utilized in test no. HTCC-6 because similar maximum post rotation angles were achieved.

Based on the results from the dynamic cable barrier bogie tests, the A449 keyway bolt with the grade 8 high-topped nut used in conjunction with the type 2 slot and keyway design was recommend for use in a full-scale crash test. Three criteria were used to support this design: (1) the keyway bolt attachment exhibited similar post deflection as the curved keyway bracket used in test no. HTCC-6 and test nos. 4CMB-1 through 4CMB-3, (2) there was no evidence that the keyway bolt would cause significant snagging of the cable that would restrict the cable from releasing, and (3) the keyway bolt attachment design was a simpler, less expensive design as compared to the curved keyway bracket attachment.

8 SUMMARY AND CONLUSIONS

Cable-to-post attachment components for the high-tension cable median barrier were selected through a process of dynamic component tests and dynamic bogie tests of a section of the cable barrier system. These tests were designed to characterize the performance of the attachments and determine the optimal attachment design.

A wide range of component tests were conducted with different keyway bolt materials and shapes, nut configurations, and slot and keyway designs to optimize the performance of the cable-to-post attachment. The size and shape of the slot and keyway were developed and showed consisted release behavior for the keyway bolt. The keyway bolts were tested with C1018 and A449 steel. The A449 keyway bolt was selected as the optimum design which provided a lateral resistance above 8.00 kips (35.59 kN) while releasing the cable vertically at an average load of 1.18 kips (5.25 kN). A grade 8 high-topped nut was selected for the final design to provide adequate thread stripping resistance of the keyway bolt.

Cable barrier bogie tests were conducted to observe the behavior of the newly developed cable-to-post attachments relative to the curved keyway bracket connection design used in full-scale crash test nos. 4CMB-1 through 4CMB-3. The C1018 keyway bolts did not provide enough lateral resistance to achieve the desired post rotation angle of 33 degrees, which was determined from test no. HTCC-6 that utilized the curved keyway brackets to attach the cable to the posts. Two tests that utilized the A449 keyway bolt and grade 8 high-topped nut, test nos. HTCC-4 and HTCC-5, showed maximum post rotation angles of 34 and 24 degrees, respectively, and the behavior of the posts were similar to test no. HTCC-6.

Therefore, the A449 keyway bolt was considered an acceptable design replacement for the curved keyway bracket that performed well in test nos. 4CMB-1 and 4CMB-2. The keyway bolt cable-to-post attachments showed similar cable release behavior as the previous design and

the angle of the keyway bolt arm should preclude cable would snag on the keyway bolts. Further, the design of the keyway bolt should be much simpler and less expensive than the previously used curved keyway bracket design. Details and pictures of the recommended keyway bolt attachments are shown in Figure 150.

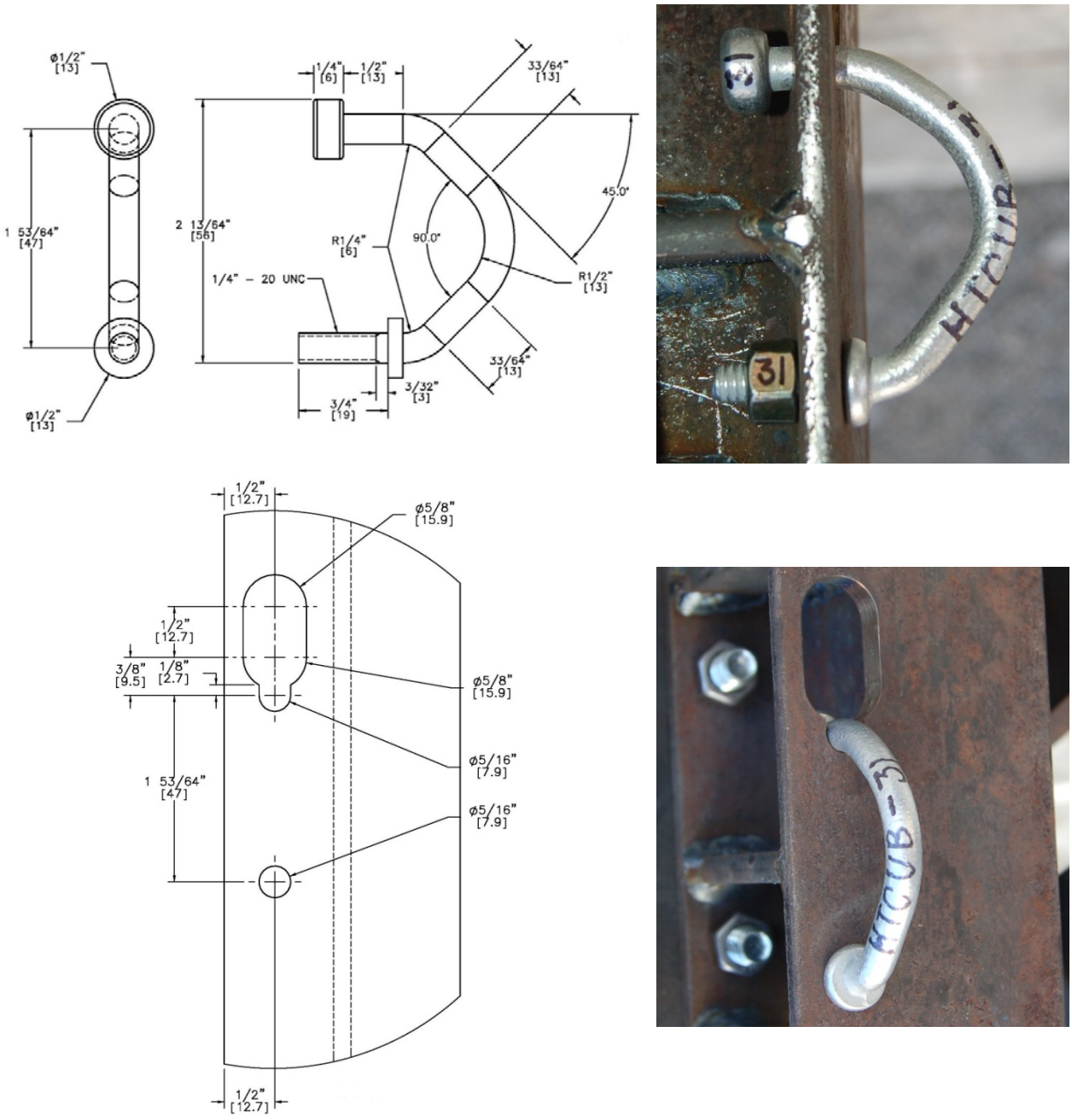


Figure 150. Final A449 Keyway Bolt Connection Design

9 REFERENCES

1. Thiele, J.C., Bielenberg, R.W., Faller, R.K., Sicking, D.L., Rohde, J.R., Reid, J.D., Polivka, K.A., Holloway, J.C., *Design and Evaluation of High-Tension Cable Barrier Hardware*, Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-200-08, Project No.: SPR-3(017), Project Code: RPFP-01-05, RPFP-04-01, RPFP-06, and RPFP-08-02 - Years 11, 14, 16, and 18, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, February 25, 2008.

2. Wiebelhaus, M.J., Johnson, E.A., Sicking, D.L., Faller, R.K., Lechtenberg, K.A., Rohde, J.R., Bielenberg, R.W., Reid, J.D., Rosenbaugh, S.K., *Phase I Development of a Non-Proprietary Four-Cable High Tension Median Barrier*, Draft Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-213-10, Project No.: SPR-3(017), Project Code: RPFP-04-01 and RPFP-08-02 - Years 14, 16, and 18, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, August 25, 2010.

10 APPENDICES

Appendix A. Additional Bogie Testing Details

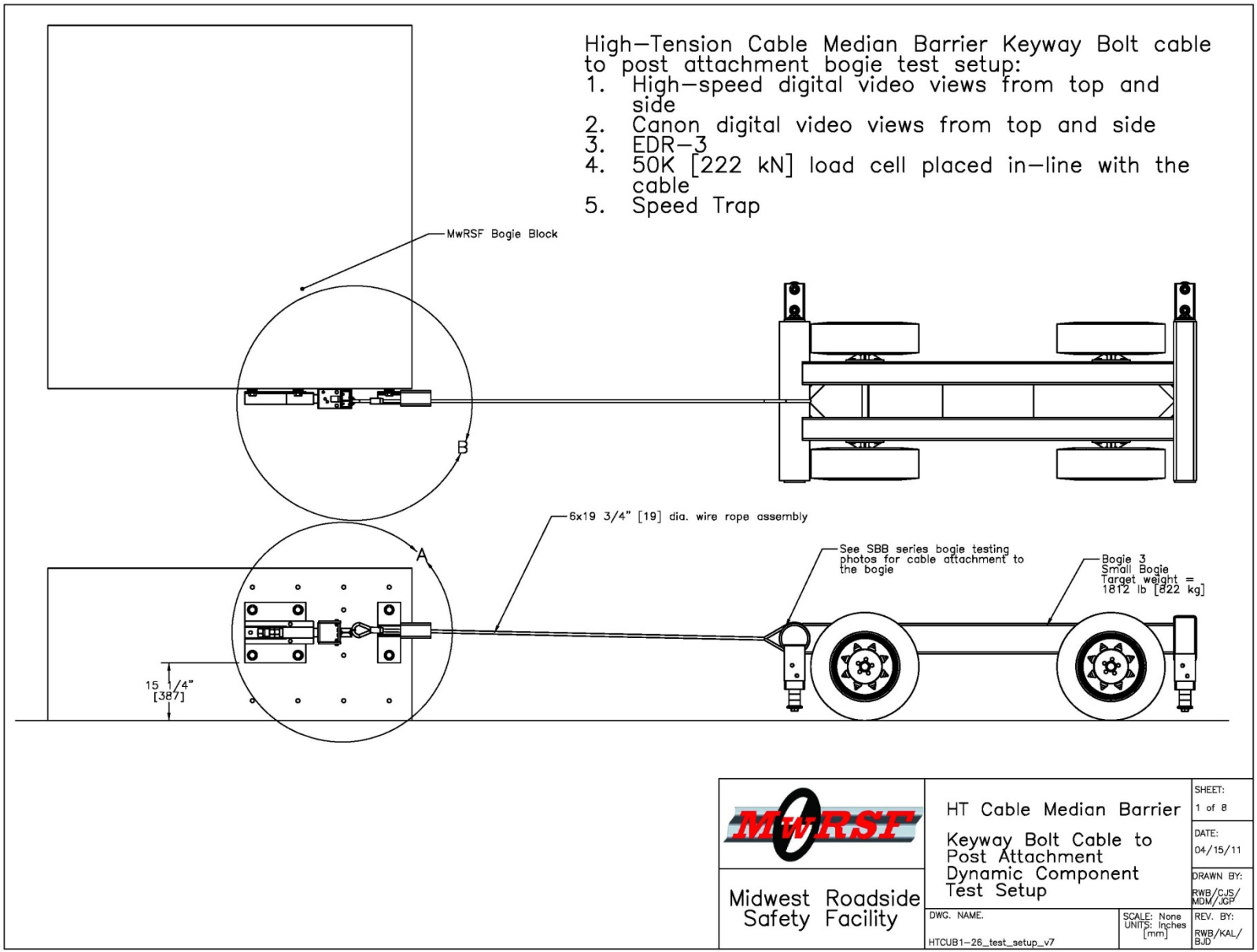
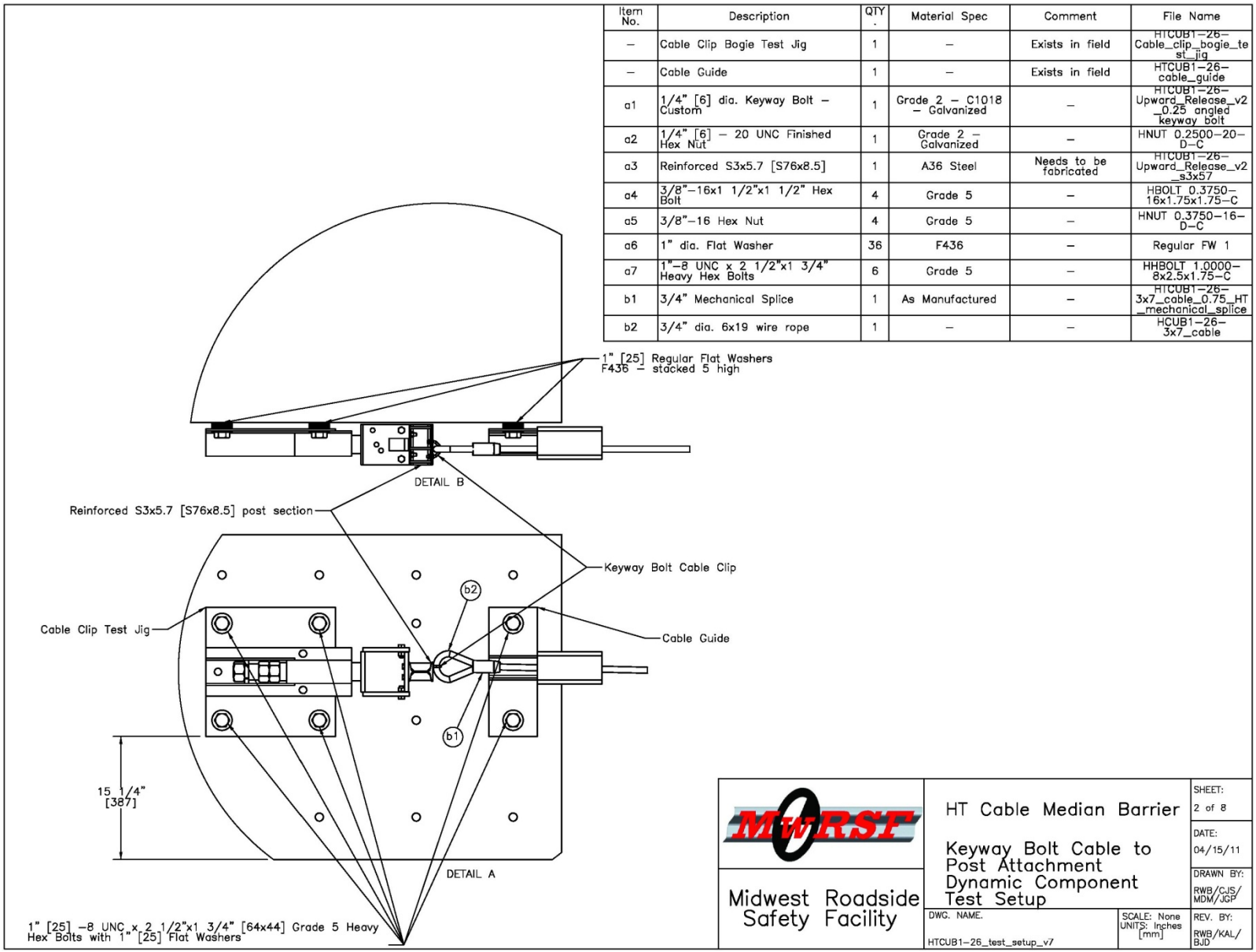


Figure A-1. Test Setup, Test Nos. HTCUB-1 through HTCUB-26



Item No.	Description	QTY.	Material Spec	Comment	File Name
–	Cable Clip Bogie Test Jig	1	–	Exists in field	HTCUB1–26–Cable_clip_bogie_test_jig
–	Cable Guide	1	–	Exists in field	HTCUB1–26–cable_guide
a1	1/4" [6] dia. Keyway Bolt – Custom	1	Grade 2 – C1018 – Galvanized	–	HTCUB1–26–Upward_Release_v2_0.25 angled keyway bolt
a2	1/4" [6] – 20 UNC Finished Hex Nut	1	Grade 2 – Galvanized	–	HNUT 0.2500–20–D–C
a3	Reinforced S3x5.7 [S76x8.5]	1	A36 Steel	Needs to be fabricated	HTCUB1–26–Upward_Release_v2_s3x57
a4	3/8"–16x1 1/2"x1 1/2" Hex Bolt	4	Grade 5	–	HBOLT 0.3750–16x1.75x1.75–C
a5	3/8"–16 Hex Nut	4	Grade 5	–	HNUT 0.3750–16–D–C
a6	1" dia. Flat Washer	36	F436	–	Regular FW 1
a7	1"–8 UNC x 2 1/2"x1 3/4" Heavy Hex Bolts	6	Grade 5	–	HHBOLT 1.0000–8x2.5x1.75–C
b1	3/4" Mechanical Splice	1	As Manufactured	–	HTCUB1–26–3x7_cable_0.75_HT_mechanical_splice
b2	3/4" dia. 6x19 wire rope	1	–	–	HCUB1–26–3x7_cable

Midwest Roadside Safety Facility	HT Cable Median Barrier Keyway Bolt Cable to Post Attachment Dynamic Component Test Setup	SHEET: 2 of 8 DATE: 04/15/11 DRAWN BY: RWB/CJS/MDM/JCP REV. BY: RWB/KAL/BJD
	DWG. NAME. HTCUB1–26_test_setup_v7	SCALE: None UNITS: Inches [mm]

Figure A-2. Test Jig, Test Nos. HTCUB-1 through HTUCB-26

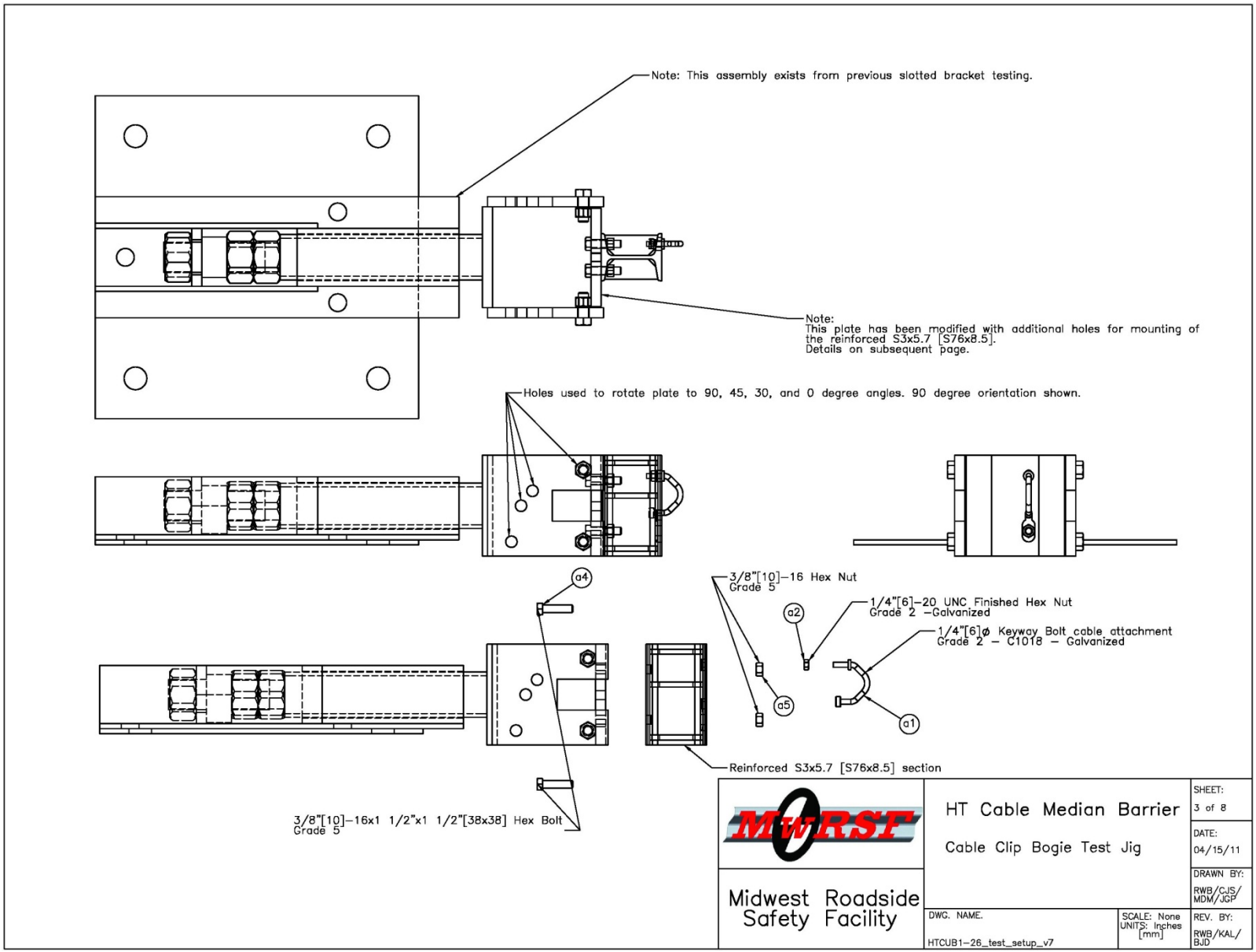


Figure A-3. Test Jig Setup, Test Nos. HTCUB-1 though HTCUB-26

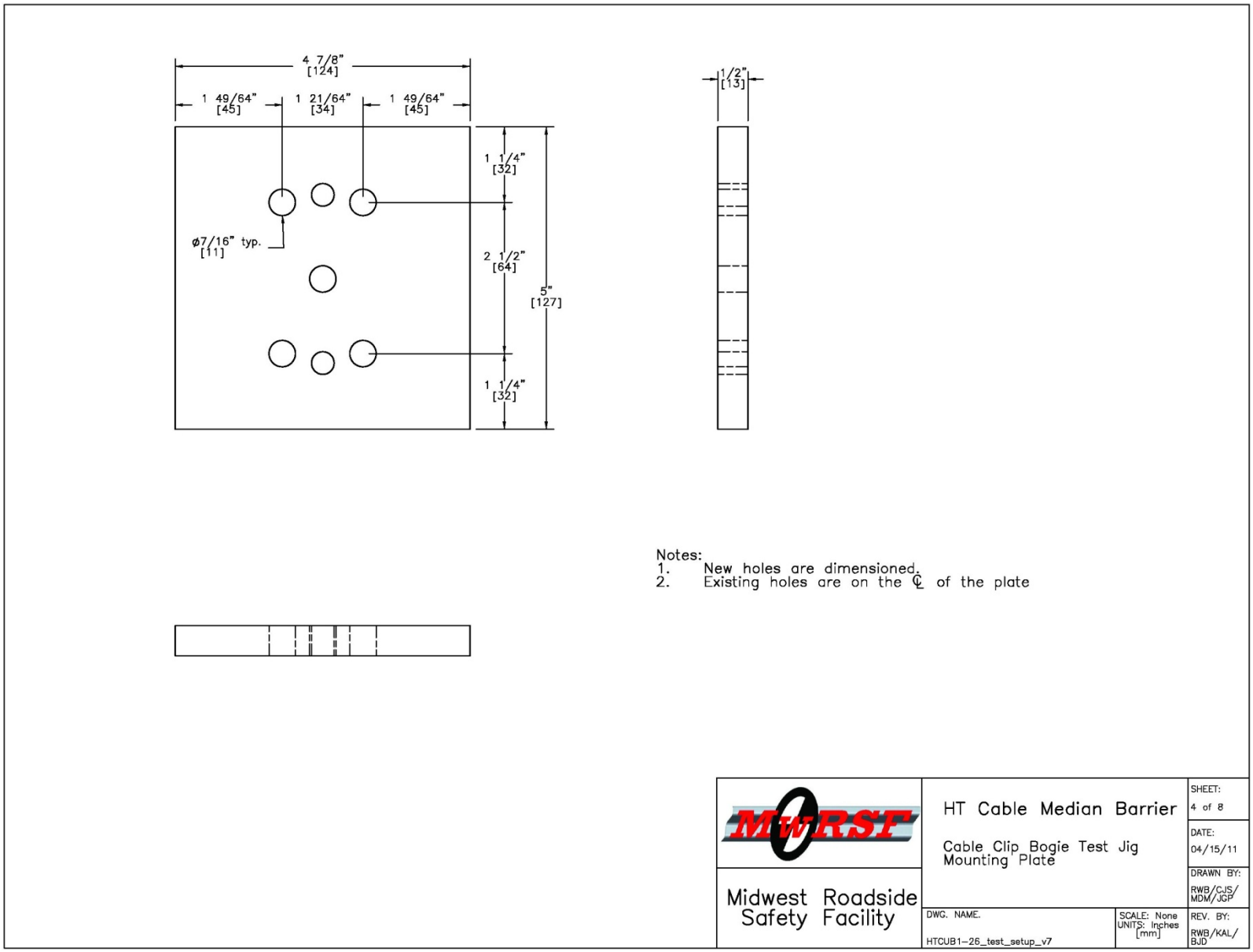


Figure A-4. Test Jig Mounting Plate, Test Nos. HTCUB-1 through HTCUB-26

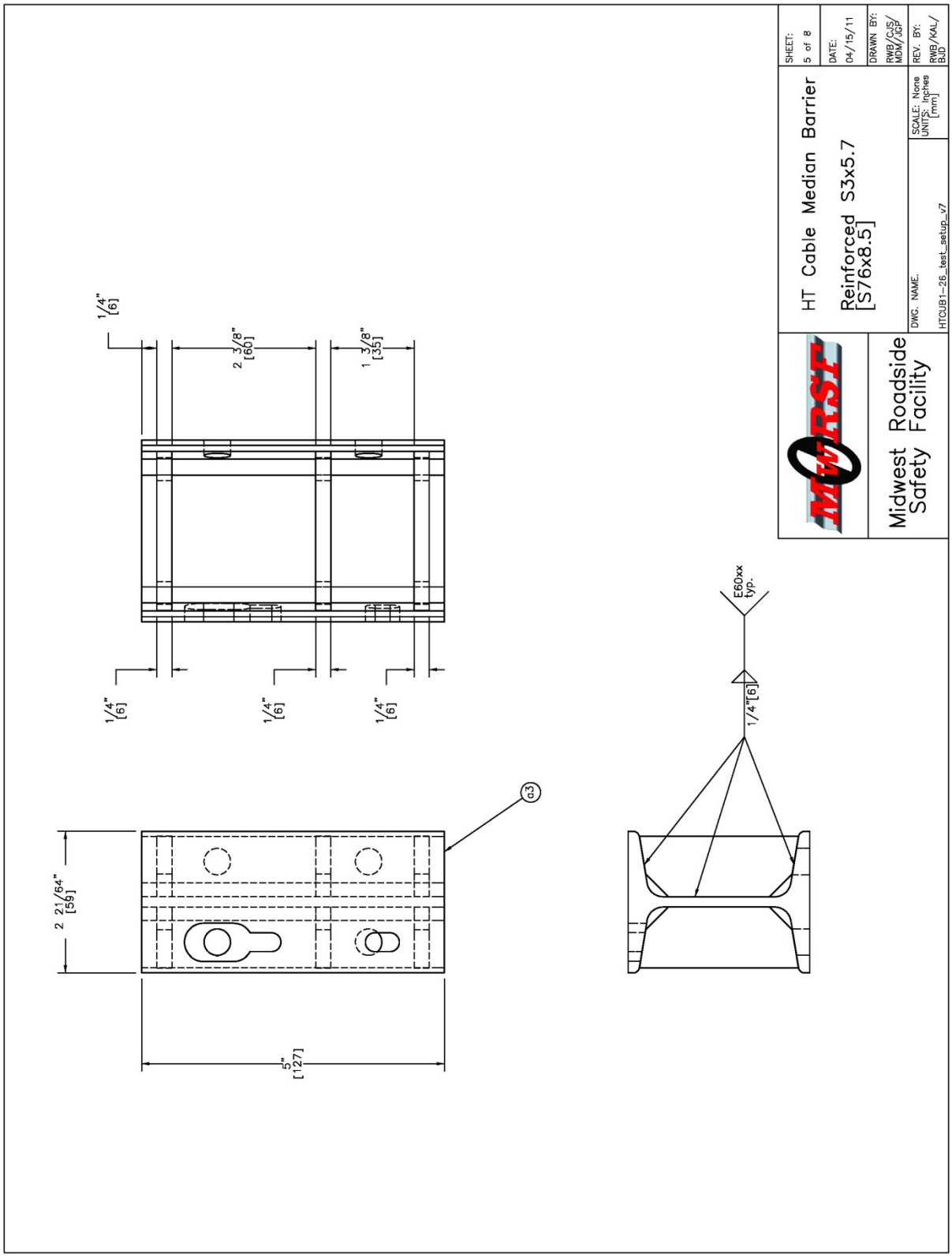


Figure A-5. S3x5.7 Reinforcement, Test Nos. HTCUB-1 through HTCUB-26

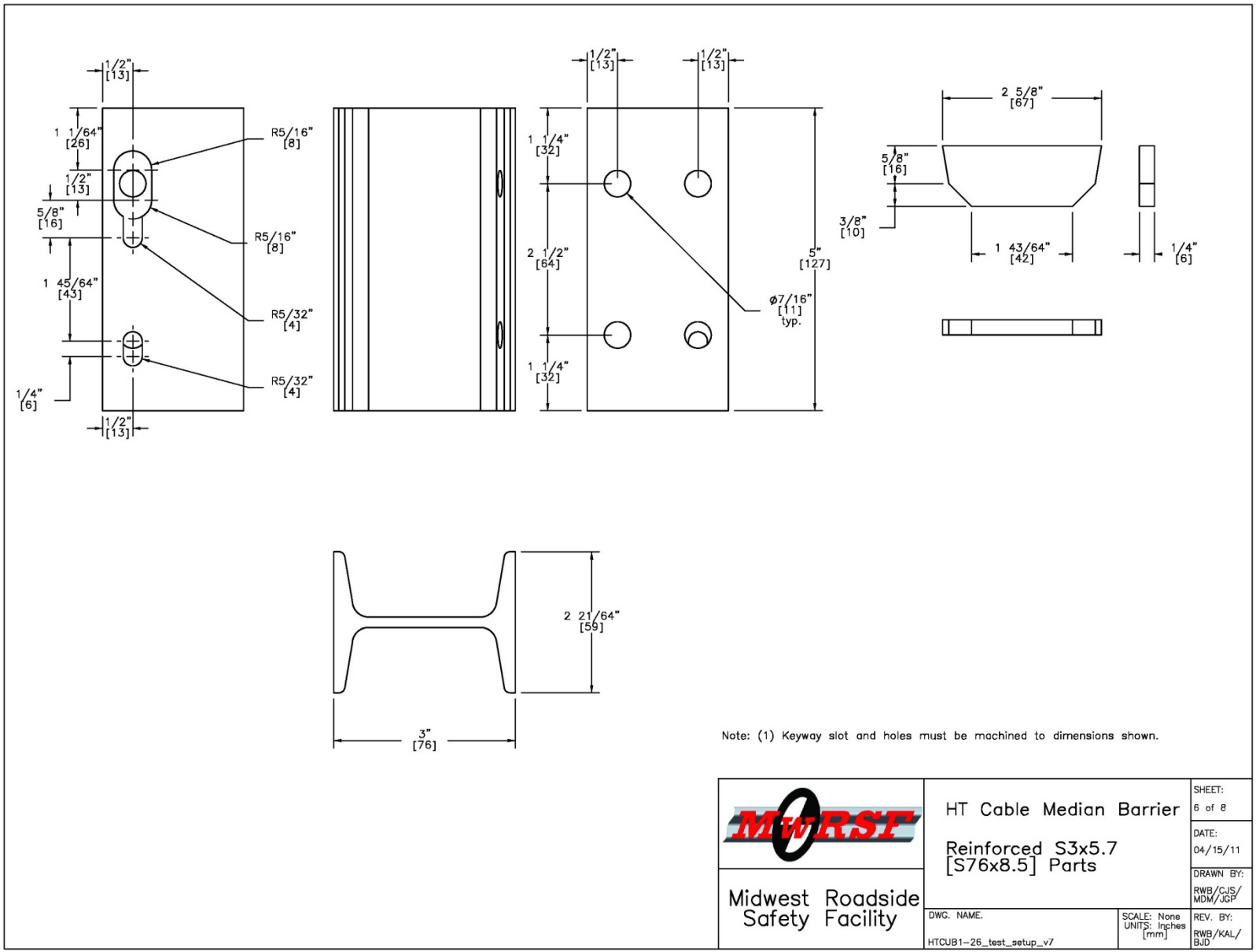
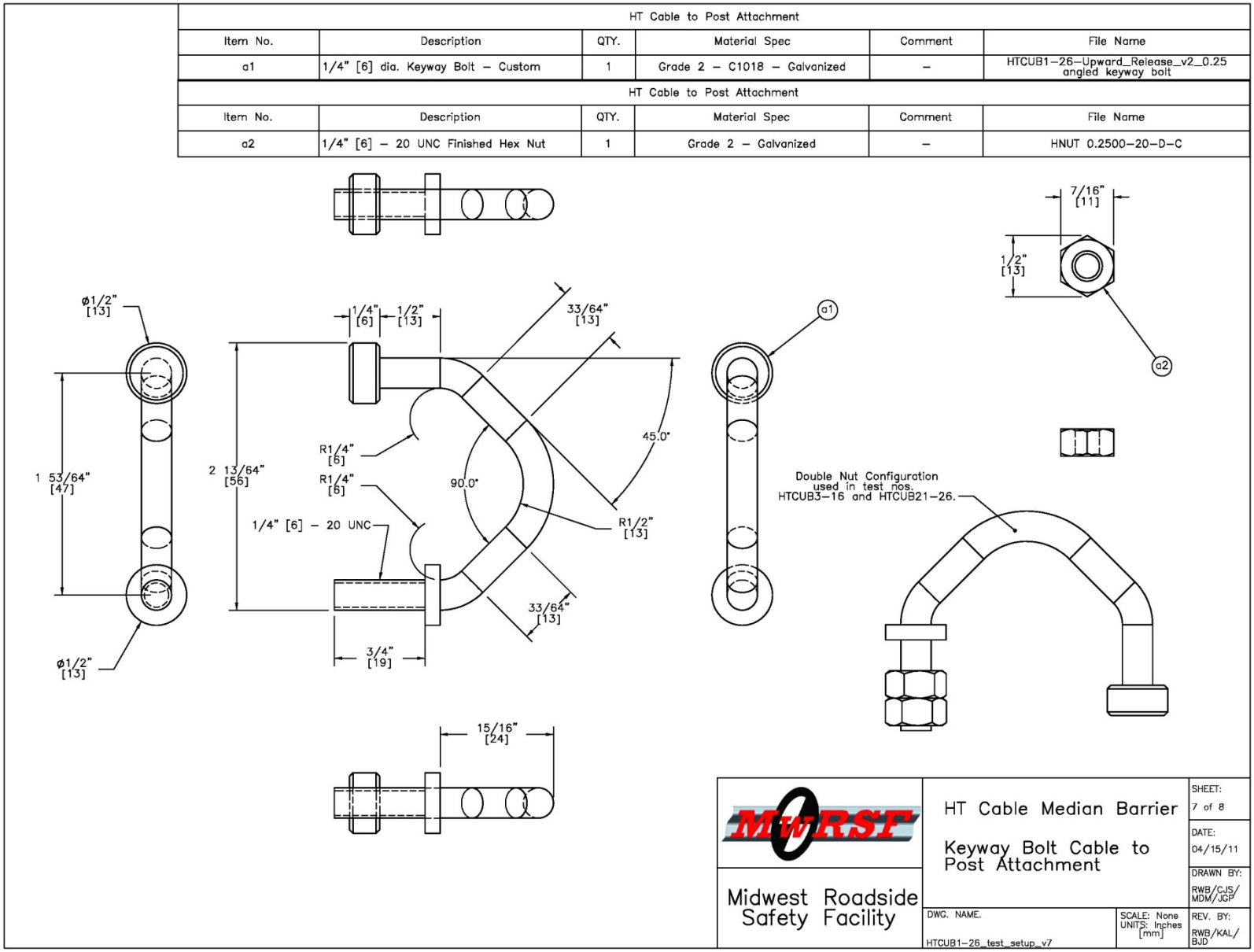


Figure A-6. S3x5.7 Reinforcement Parts and Type 1 Slot and Keyway Design, Test Nos. HTCUB-1 through HTCUB-26



HT Cable to Post Attachment					
Item No.	Description	QTY.	Material Spec	Comment	File Name
a1	1/4" [6] dia. Keyway Bolt – Custom	1	Grade 2 – C1018 – Galvanized	–	HTCUB1–26–Upward_Release_v2_0.25 angled keyway bolt

HT Cable to Post Attachment					
Item No.	Description	QTY.	Material Spec	Comment	File Name
a2	1/4" [6] – 20 UNC Finished Hex Nut	1	Grade 2 – Galvanized	–	HNUT 0.2500–20–D–C

Figure A-7. Keyway Bolt Detail, Test Nos. HTCUB-1 through HTCUB-26

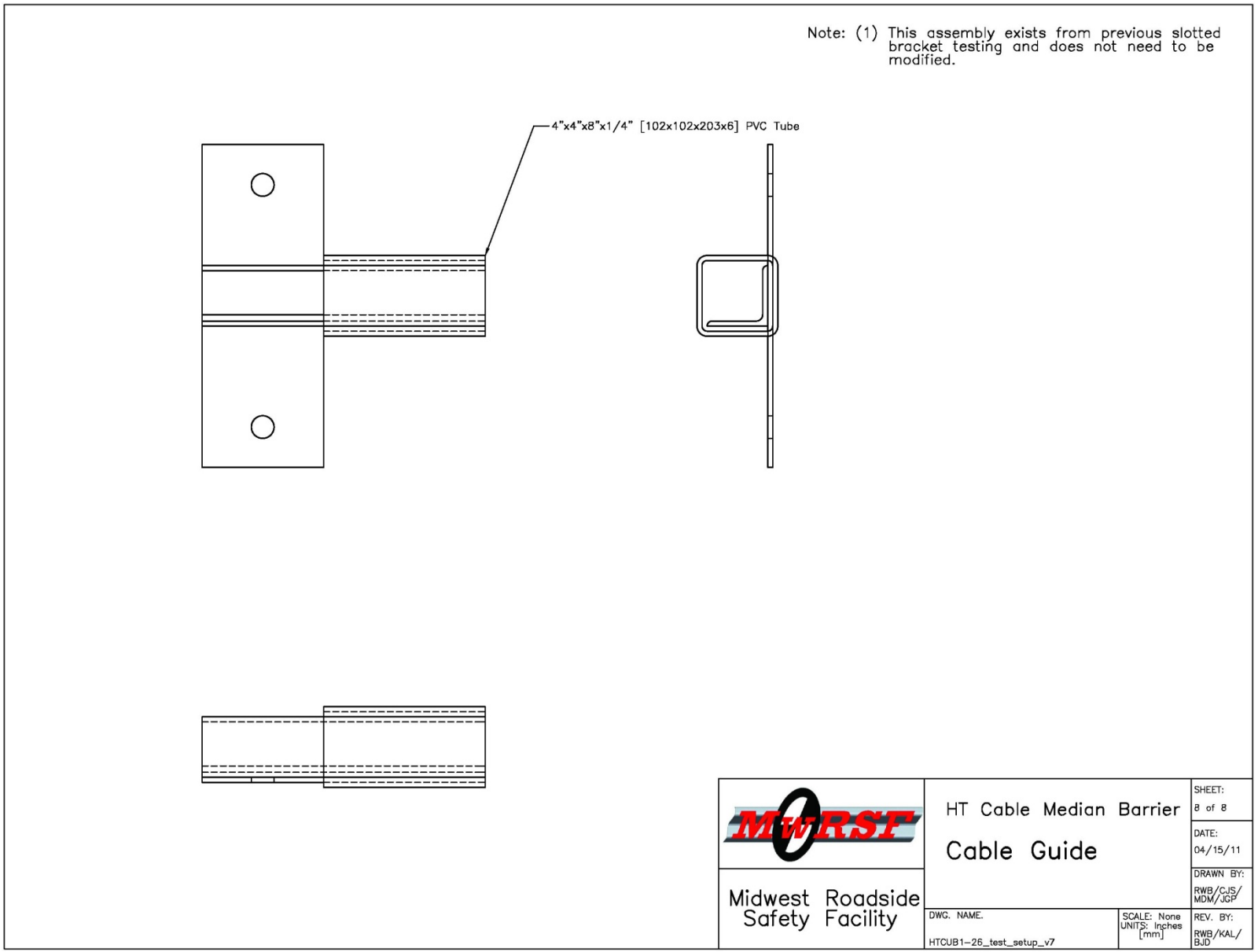


Figure A-8. Cable Guide, Test Nos. HTCUB-1 through HTCUB-26

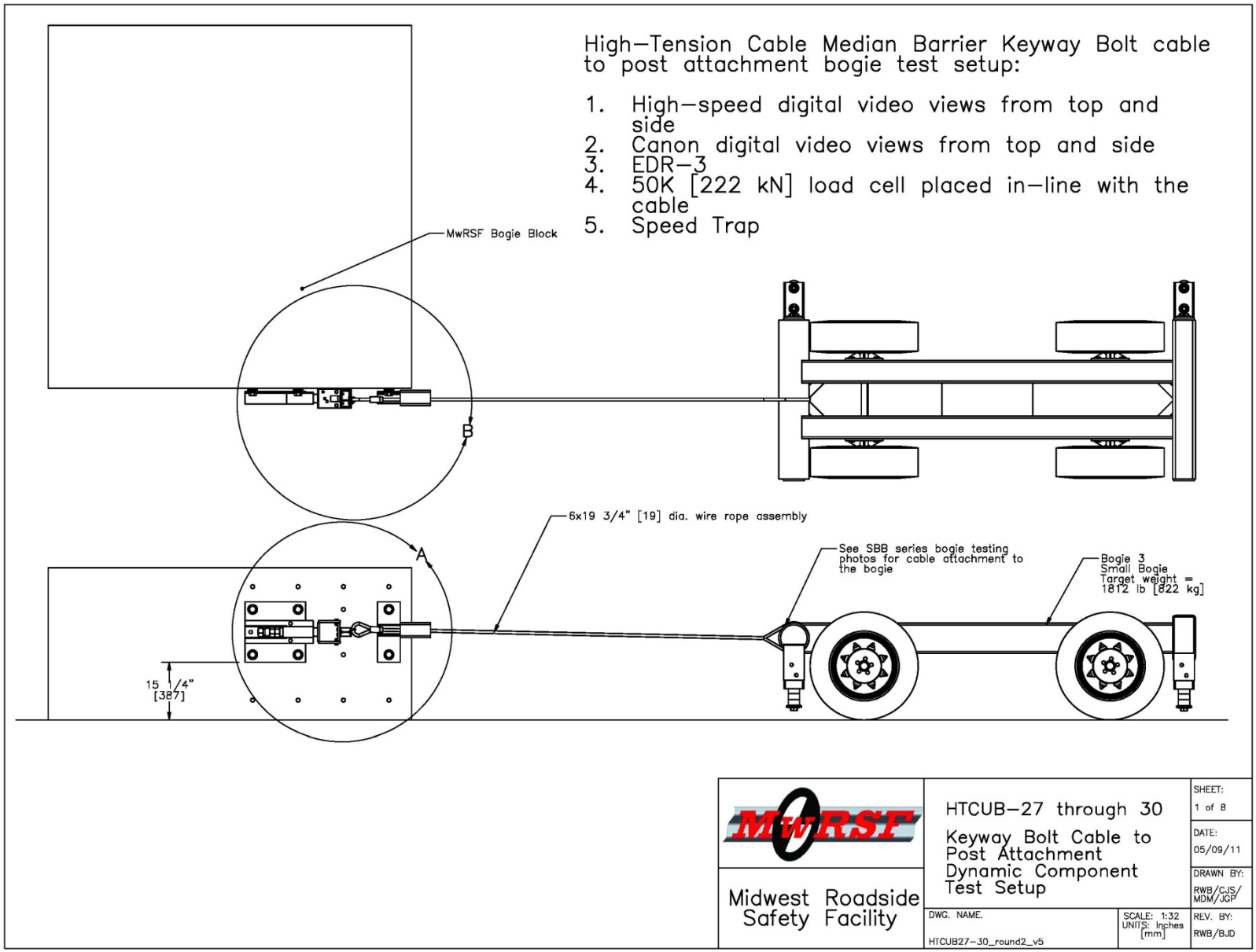


Figure A-9. Test Setup, Test Nos. HTCUB-27 through HTCUB-30

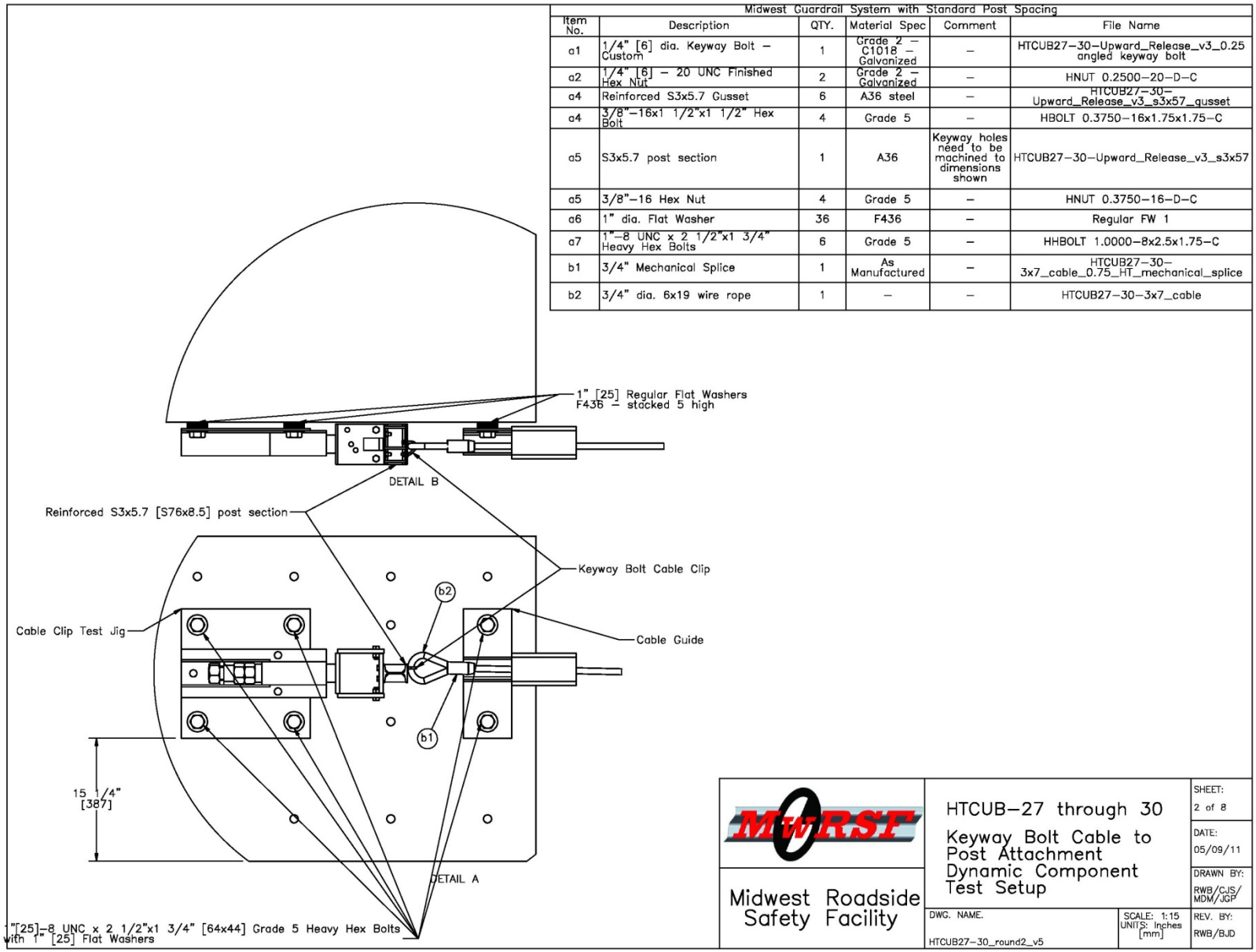


Figure A-10. Test Jig, Test Nos. HTCUB-27 through HTUCB-30

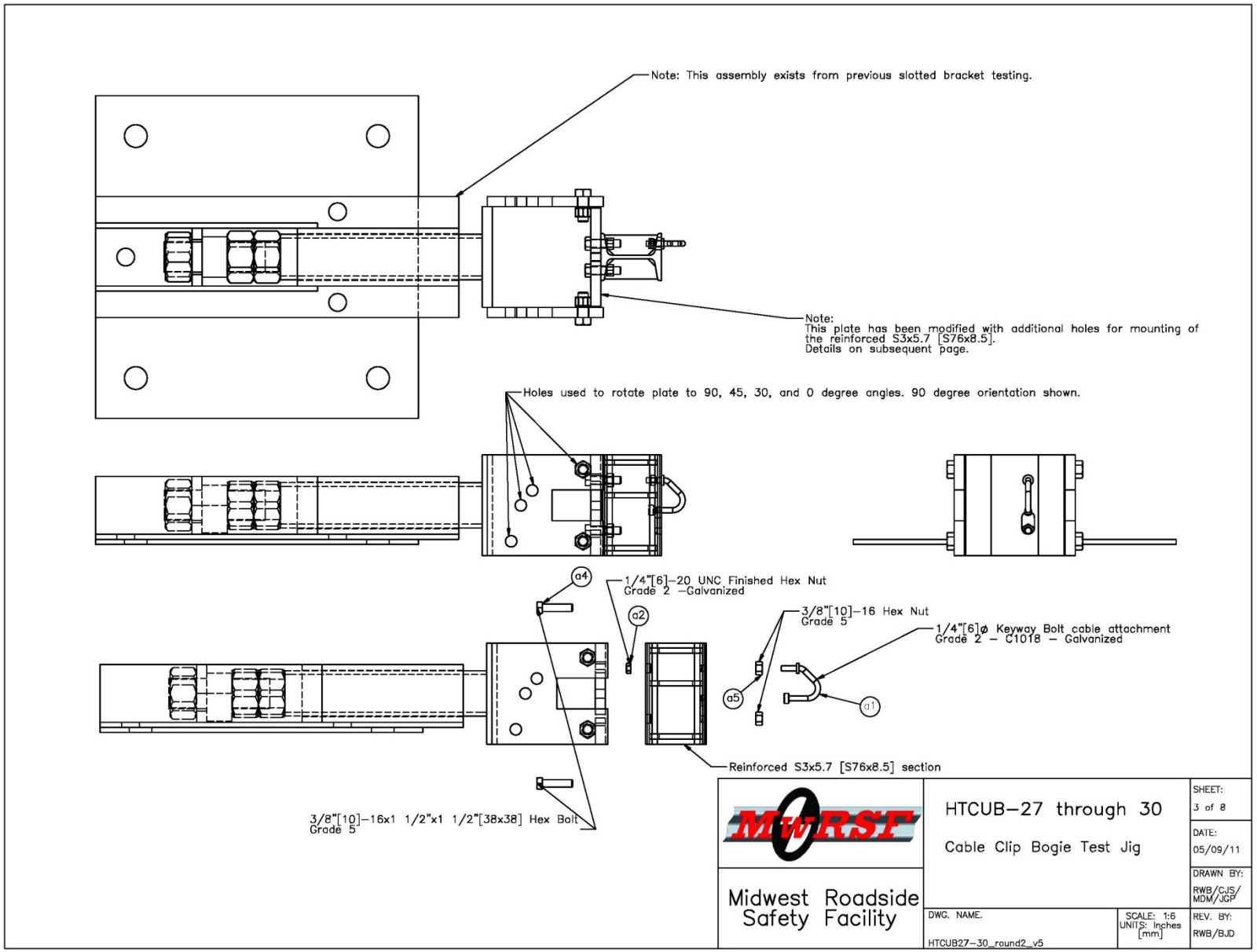


Figure A-11. Test Jig Setup, Test Nos. HTCUB-27 though HTCUB-30

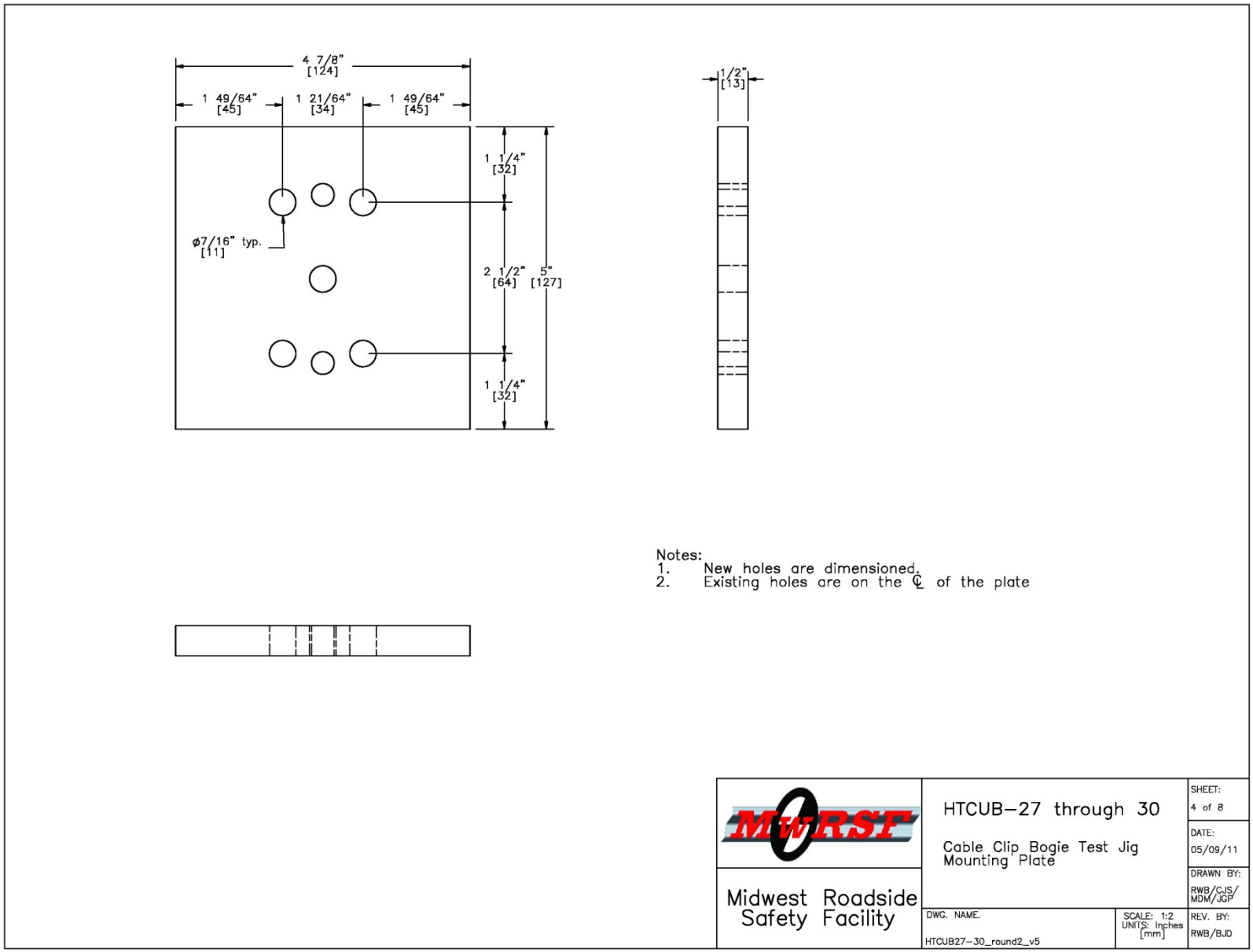


Figure A-12. Test Jig Mounting Plate, Test Nos. HTCUB-27 through HTCUB-30

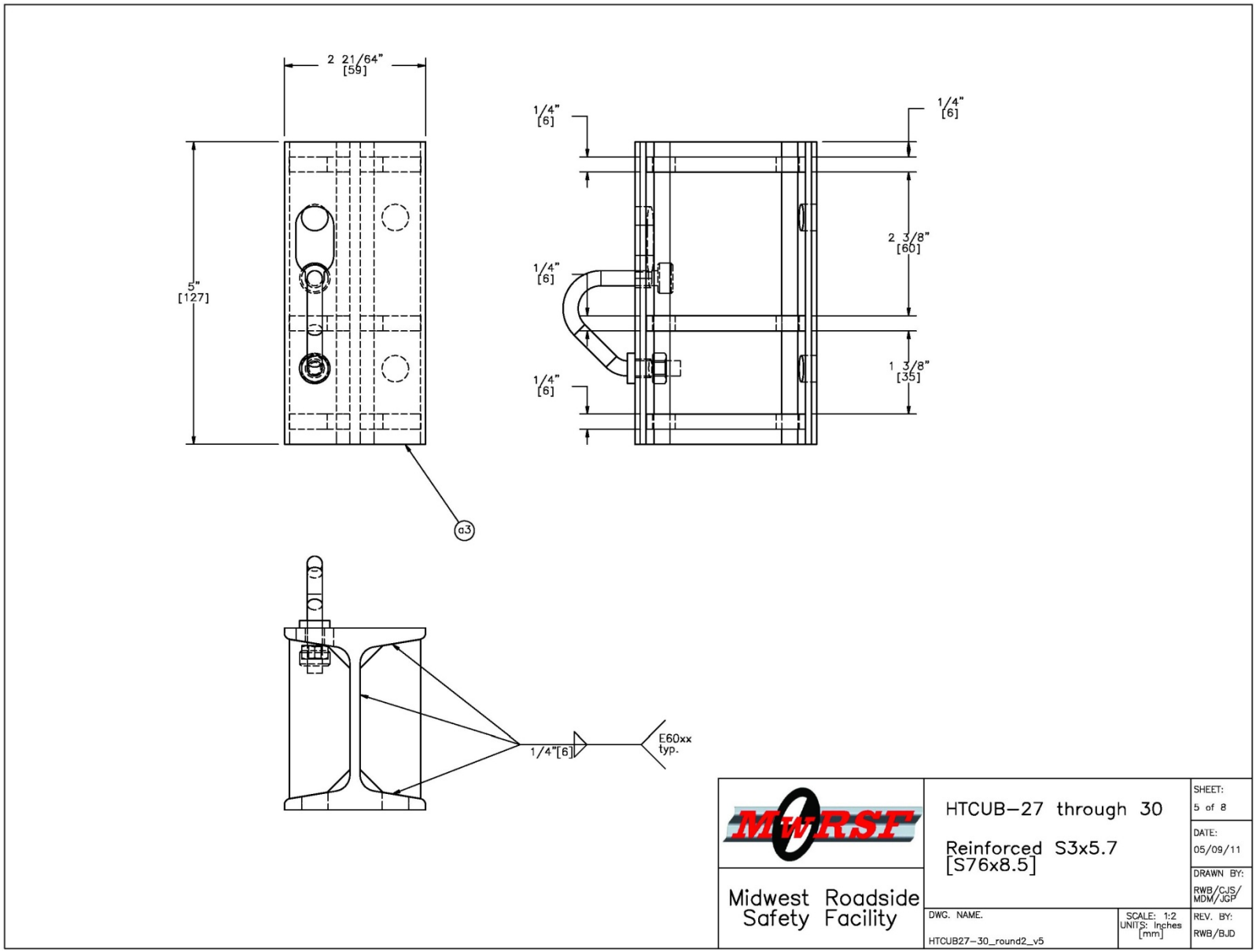


Figure A-13. S3x5.7 Reinforcement, Test Nos. HTCUB-27 through HTCUB-30

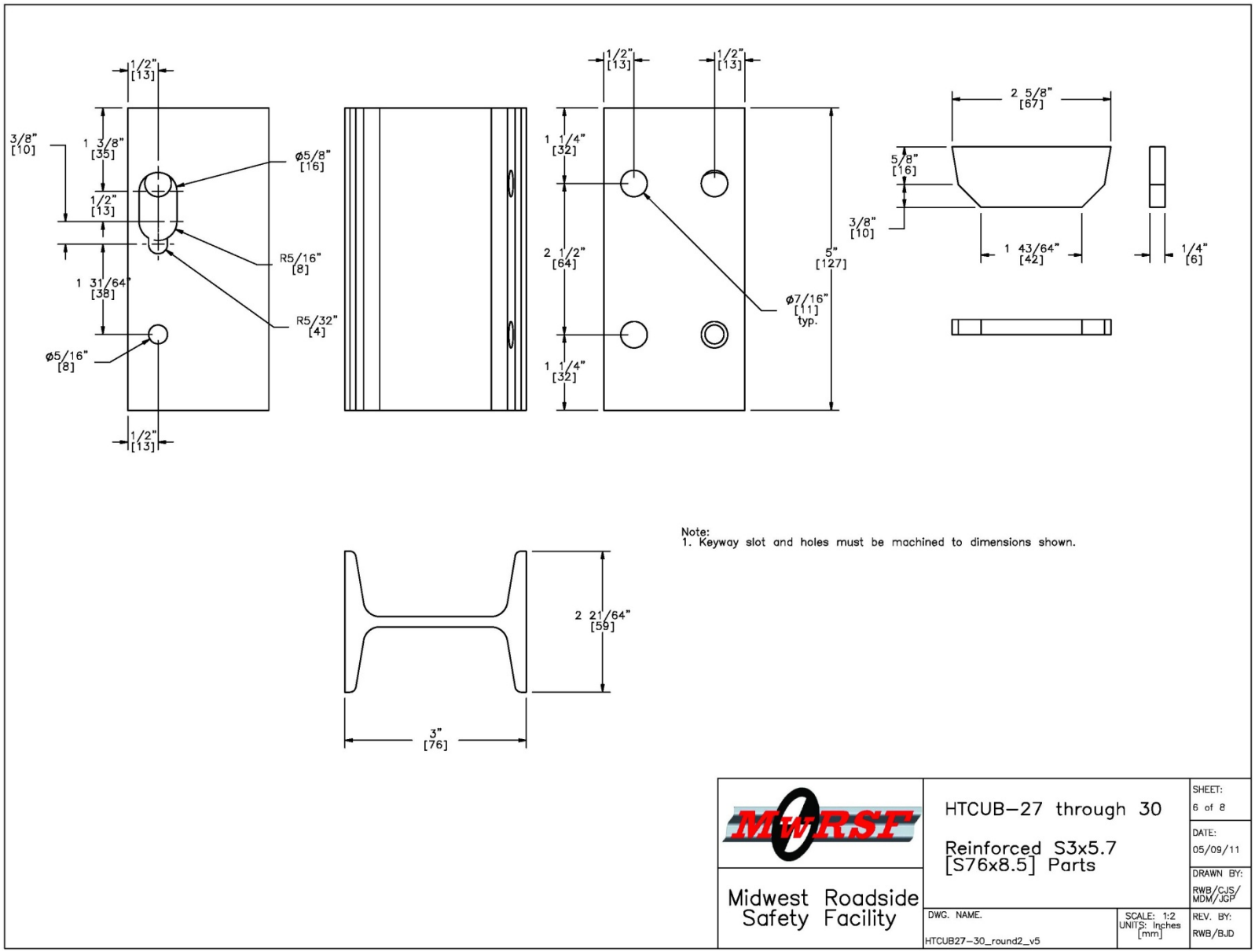


Figure A-14. S3x5.7 Reinforcement Parts and Type 2 Slot and Keyway Design, Test Nos. HTCUB-27 through HTCUB-30

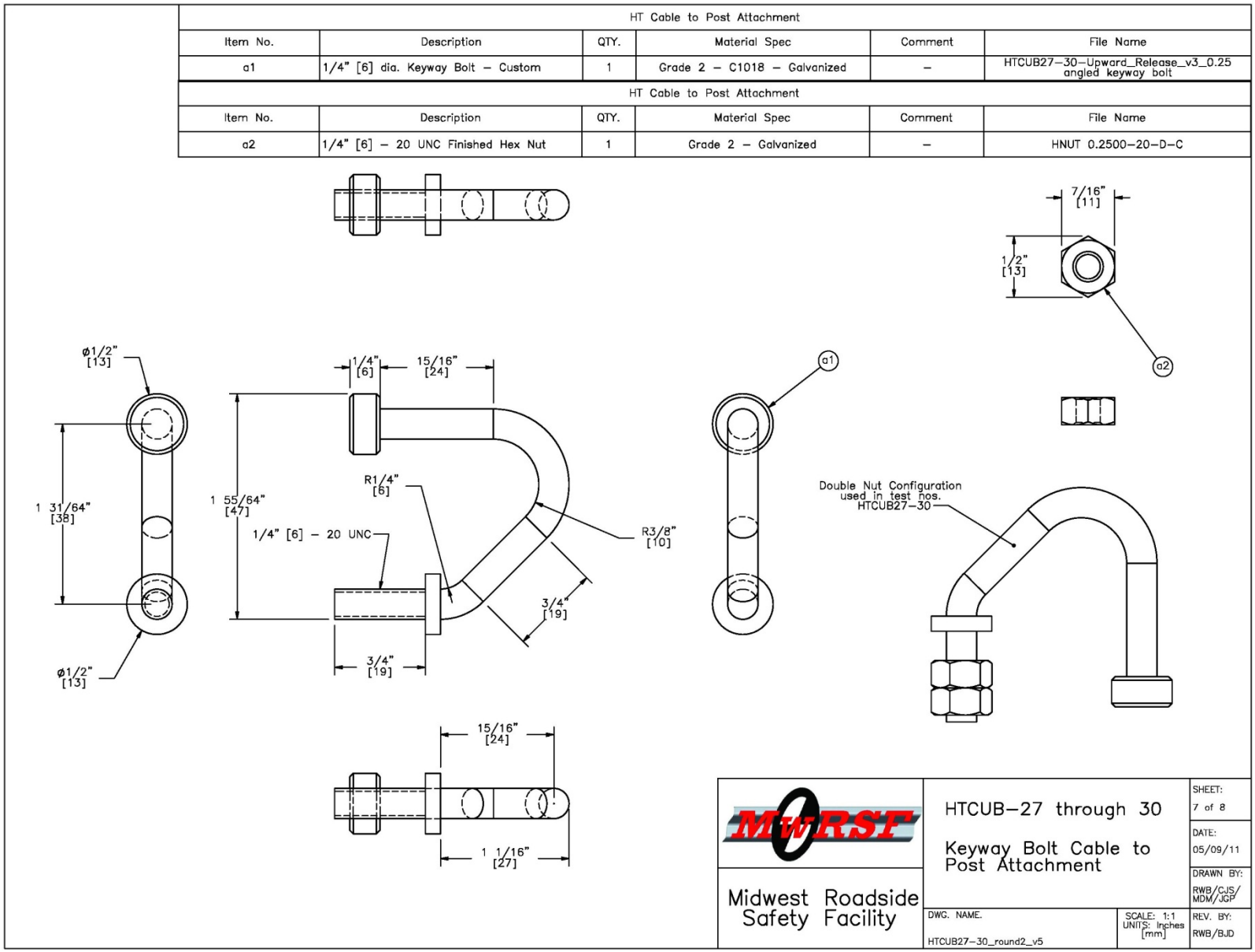


Figure A-15. Keyway Bolt Detail, Test Nos. HTCUB-27 through HTCUB-30

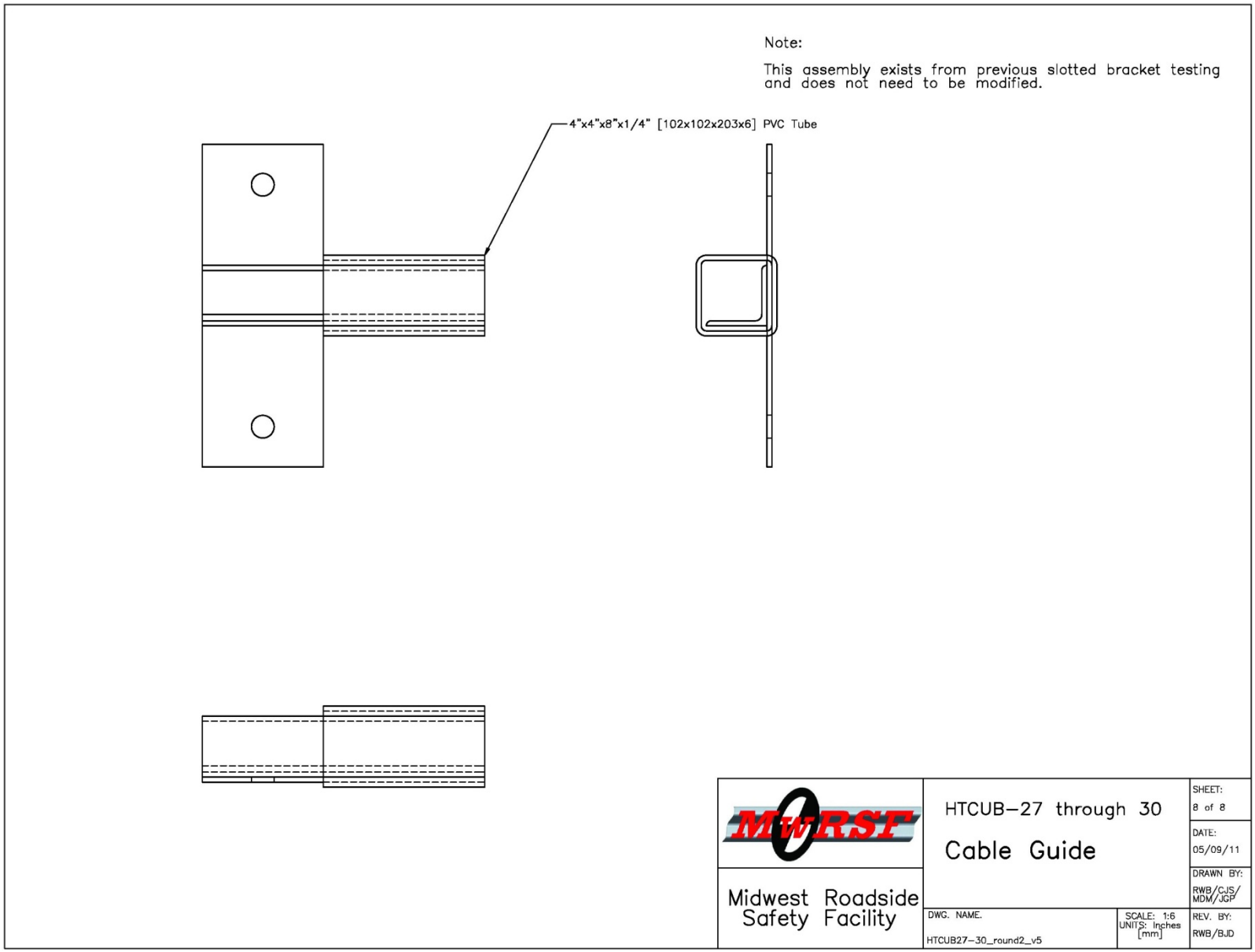


Figure A-16. Cable Guide, Test Nos. HTCUB-27 through HTCUB-30

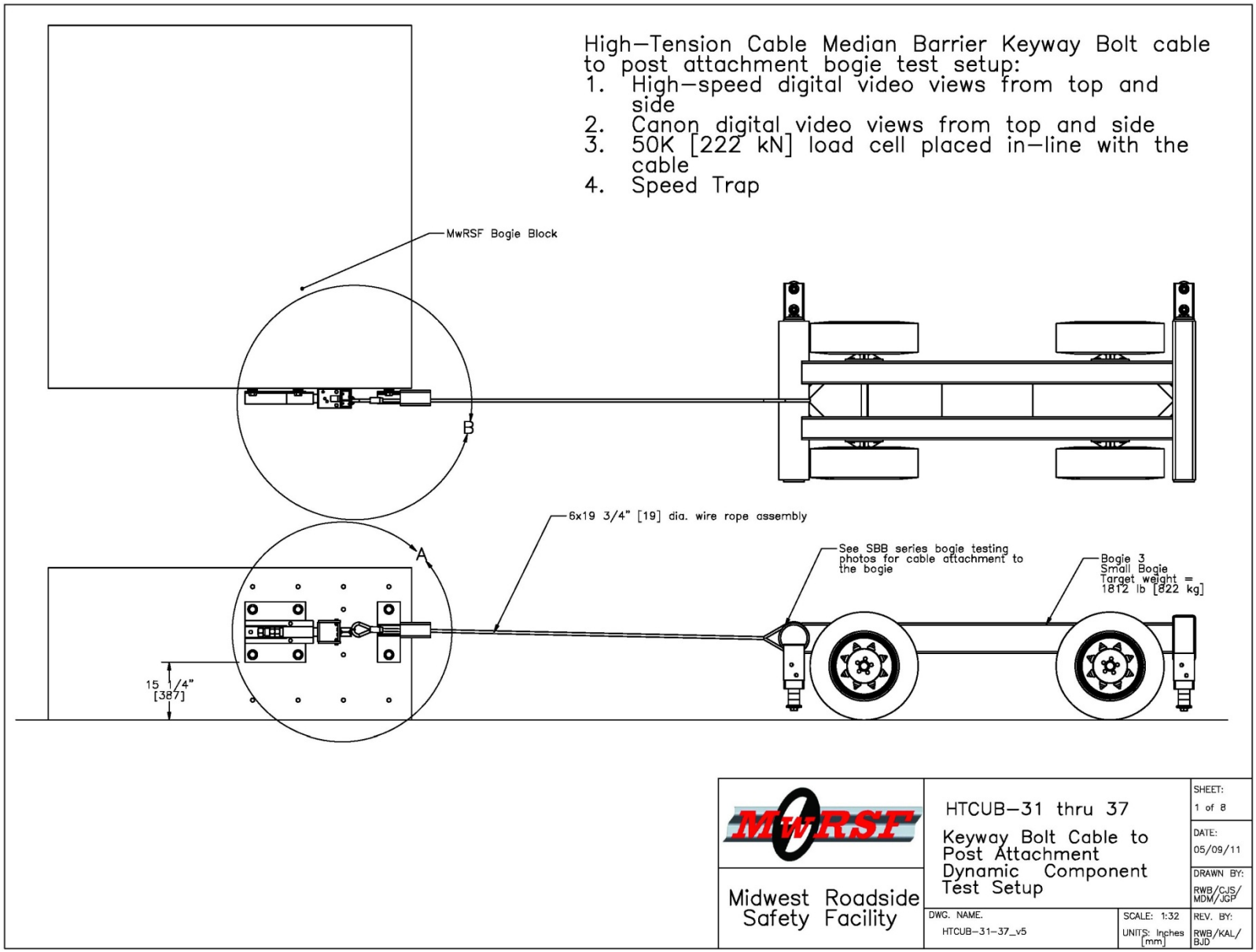
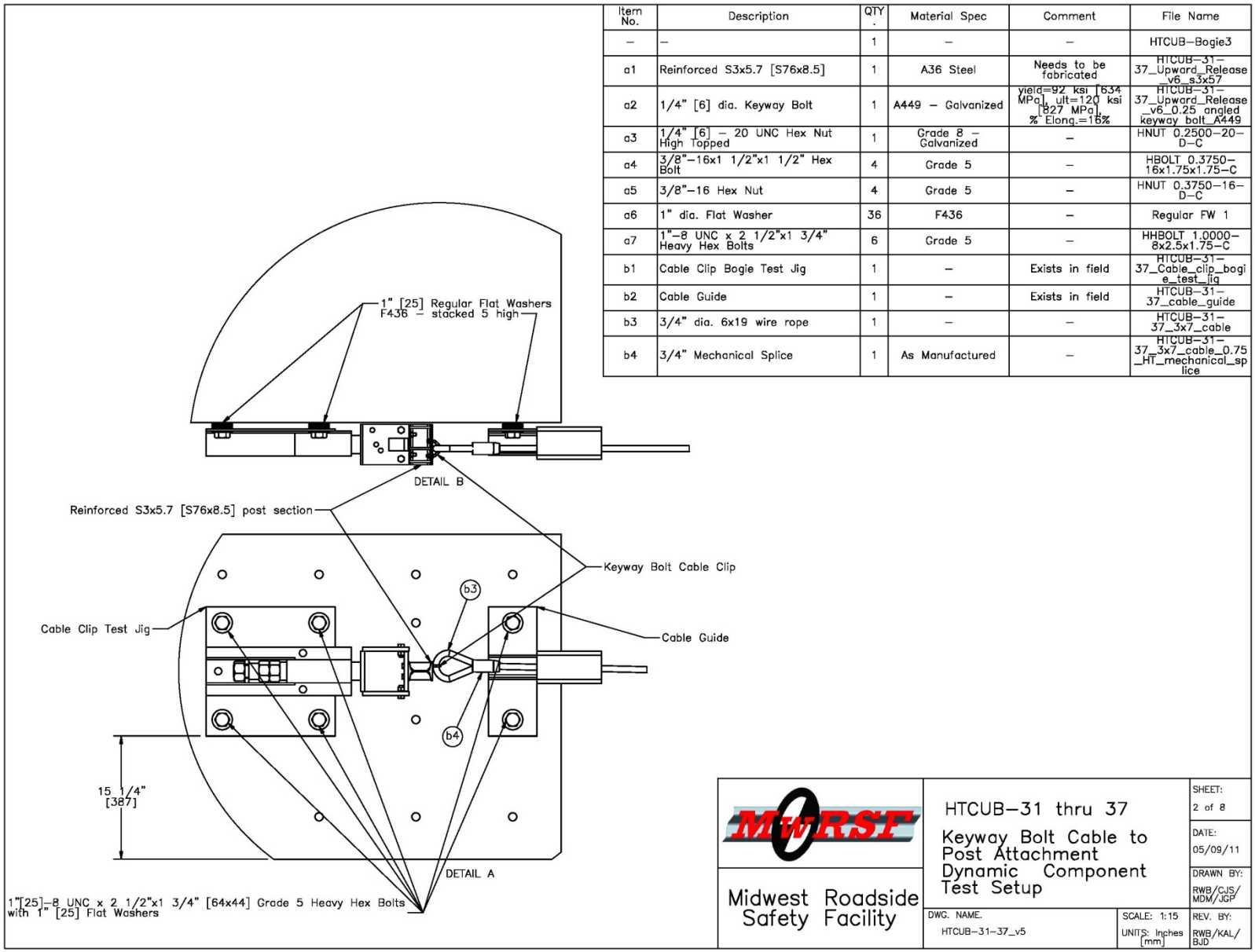


Figure A-17. Test Setup, Test Nos. HTCUB-31 through HTCUB-37



Item No.	Description	QTY.	Material Spec	Comment	File Name
–	–	1	–	–	HTCUB–Bogie3
a1	Reinforced S3x5.7 [S76x8.5]	1	A36 Steel	Needs to be fabricated	HTCUB–31–37_Upward_Release_v6_s3x57
a2	1/4" [6] dia. Keyway Bolt	1	A449 – Galvanized	yield=92 ksi [634 MPa], ult=120 ksi [827 MPa], % Elong.=16%	HTCUB–31–37_Upward_Release_v6_0.25 angled keyway bolt_A449
a3	1/4" [6] – 20 UNC Hex Nut High Topped	1	Grade 8 – Galvanized	–	HNUT 0.2500–20–D–C
a4	3/8"–16x1 1/2"x1 1/2" Hex Bolt	4	Grade 5	–	HBOLT 0.3750–16x1.75x1.75–C
a5	3/8"–16 Hex Nut	4	Grade 5	–	HNUT 0.3750–16–D–C
a6	1" dia. Flat Washer	36	F436	–	Regular FW 1
a7	1"–8 UNC x 2 1/2"x1 3/4" Heavy Hex Bolts	6	Grade 5	–	HHBOLT 1.0000–8x2.5x1.75–C
b1	Cable Clip Bogie Test Jig	1	–	Exists in field	HTCUB–31–37_Cable_clip_bogie_test_jig
b2	Cable Guide	1	–	Exists in field	HTCUB–31–37_cable_guide
b3	3/4" dia. 6x19 wire rope	1	–	–	HTCUB–31–37_3x7_cable
b4	3/4" Mechanical Splice	1	As Manufactured	–	HTCUB–31–37_3x7_cable_0.75_HT_mechanical_splice

Midwest Roadside Safety Facility

HTCUB–31 thru 37
Keyway Bolt Cable to Post Attachment Dynamic Component Test Setup

DWG. NAME. HTCUB–31–37_v5
SCALE: 1:15
UNITS: Inches [mm]

SHEET: 2 of 8
DATE: 05/09/11
DRAWN BY: RWB/CJS/MDM/JGP
REV. BY: RWB/KAL/BJD

Figure A-18. Test Jig, Test Nos. HTCUB-31 through HTUCB-37

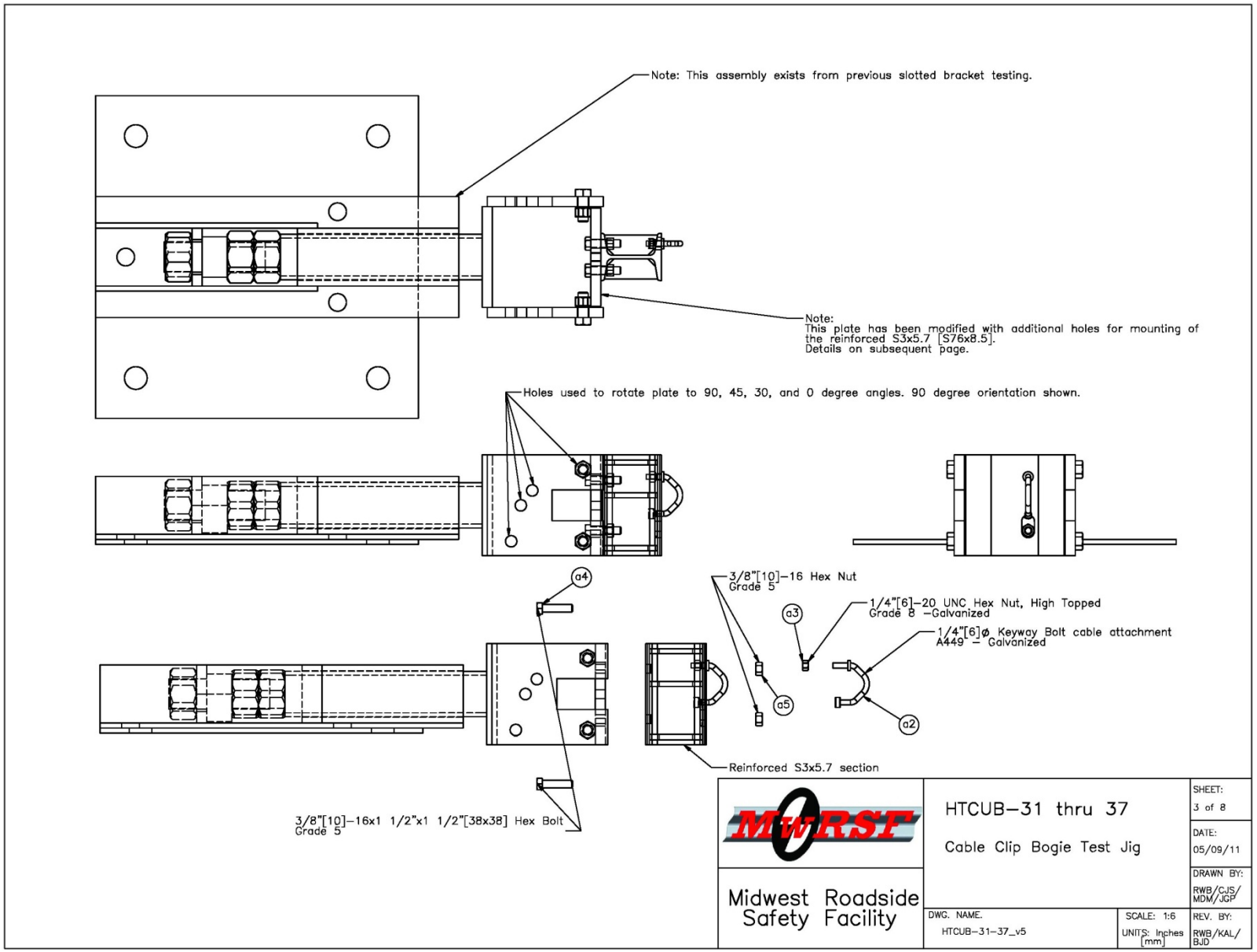


Figure A-19. Test Jig Setup, Test Nos. HTCUB-31 though HTCUB-37

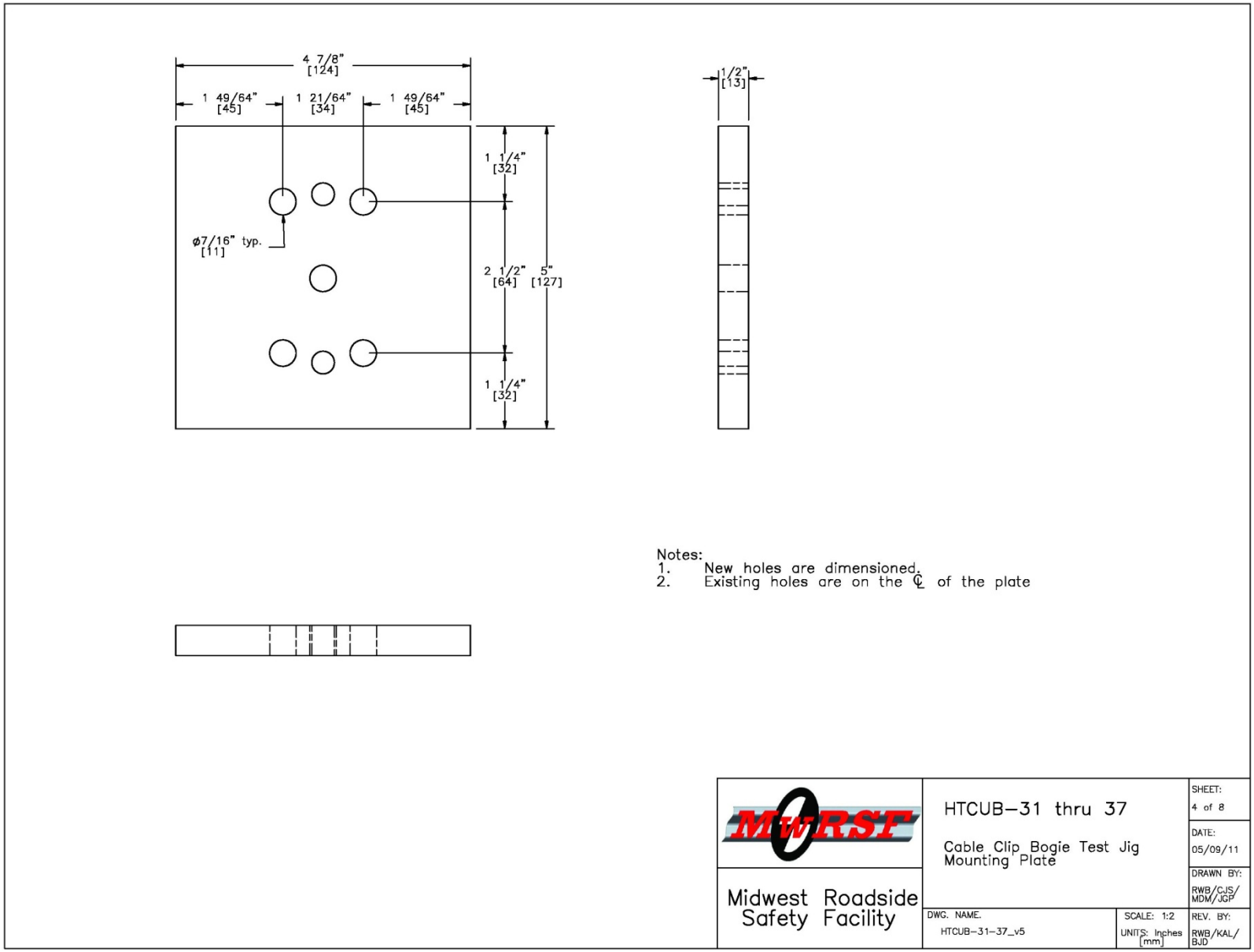


Figure A-20. Test Jig Mounting Plate, Test Nos. HTCUB-31 through HTCUB-37

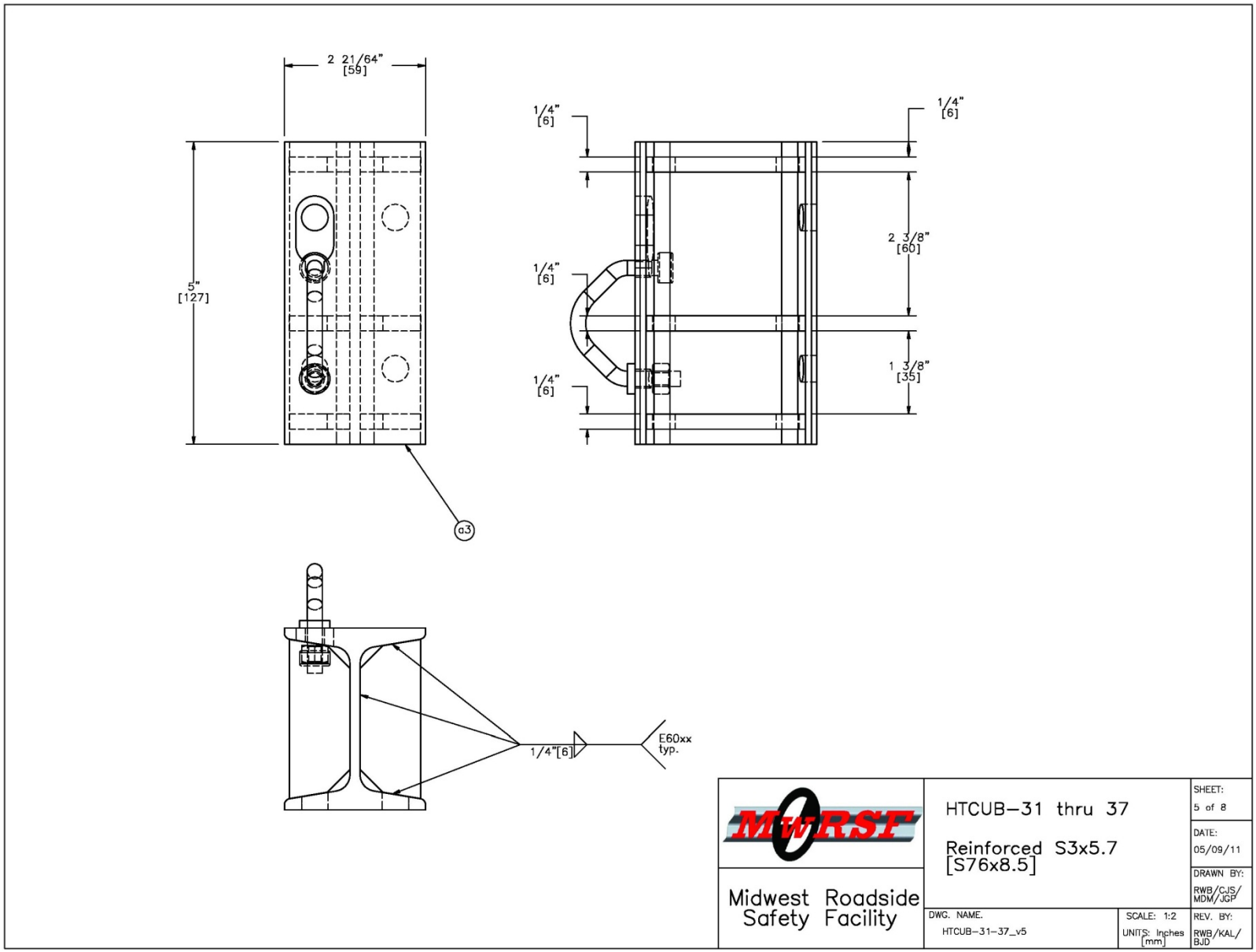


Figure A-21. S3x5.7 Reinforcement, Test Nos. HTCUB-31 through HTCUB-37

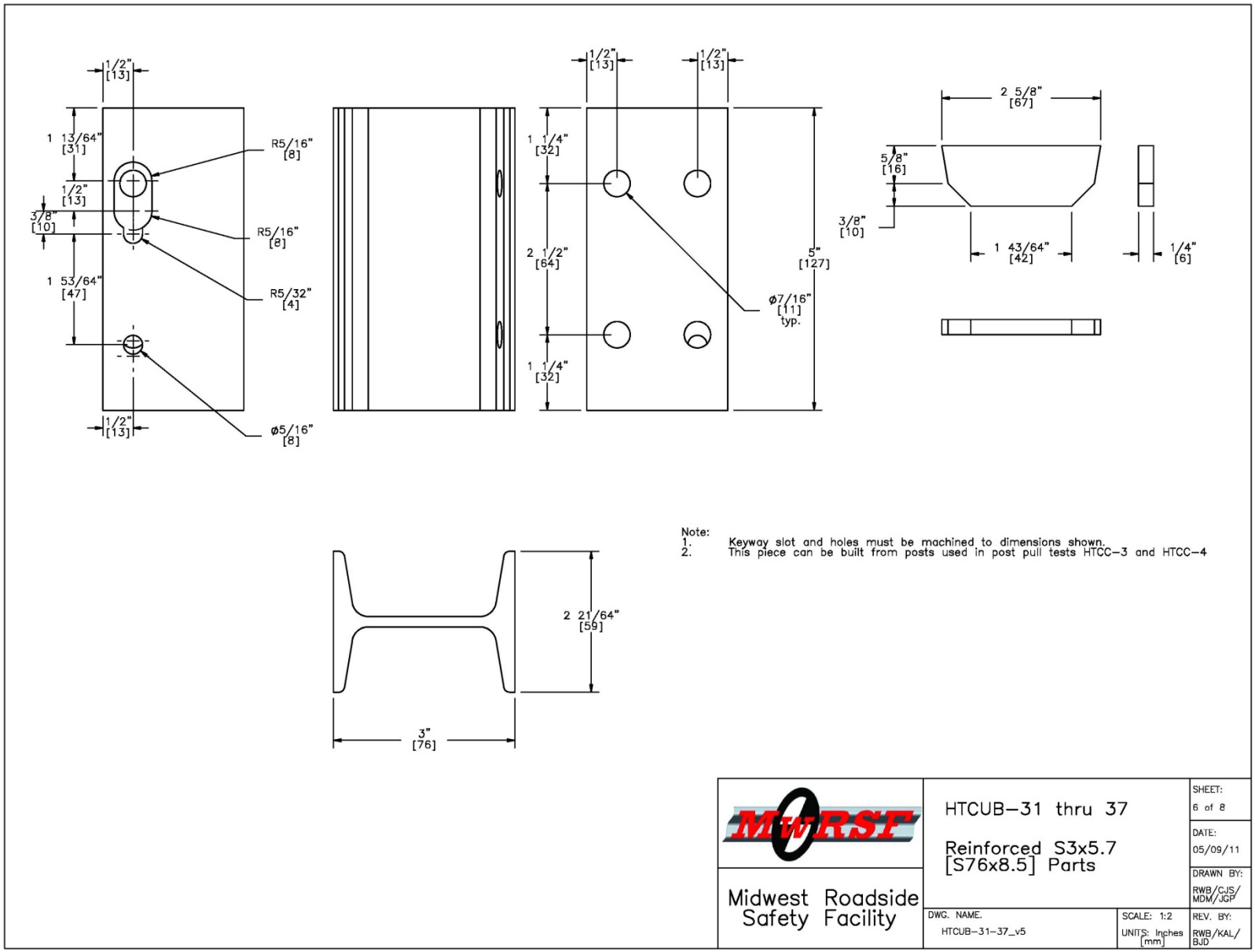


Figure A-22. S3x5.7 Reinforcement Parts and Type 2 Slot and Keyway Design, Test Nos. HTCUB-31 through HTCUB-37

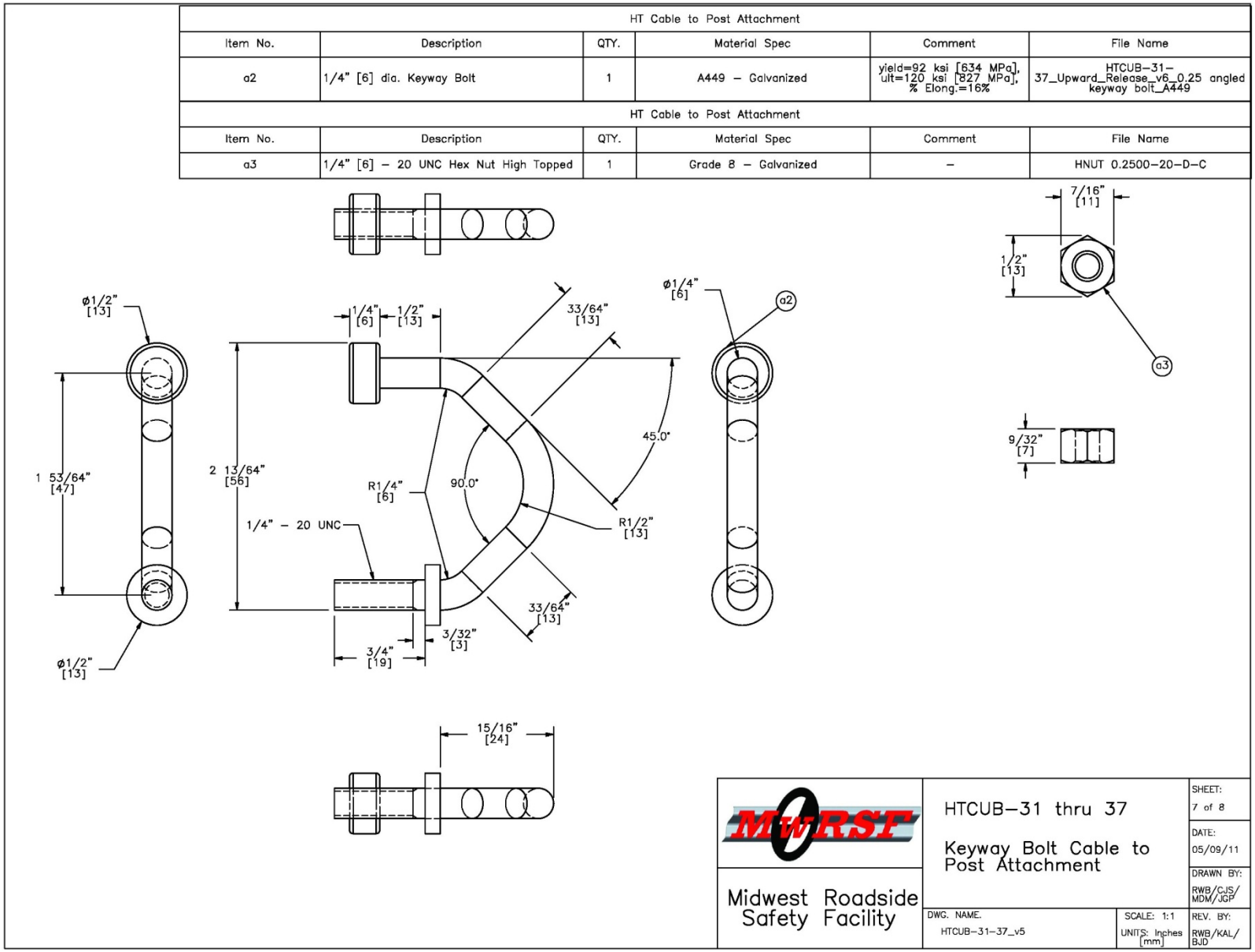


Figure A-23. Keyway Bolt Detail, Test Nos. HTCUB-31 through HTCUB-37

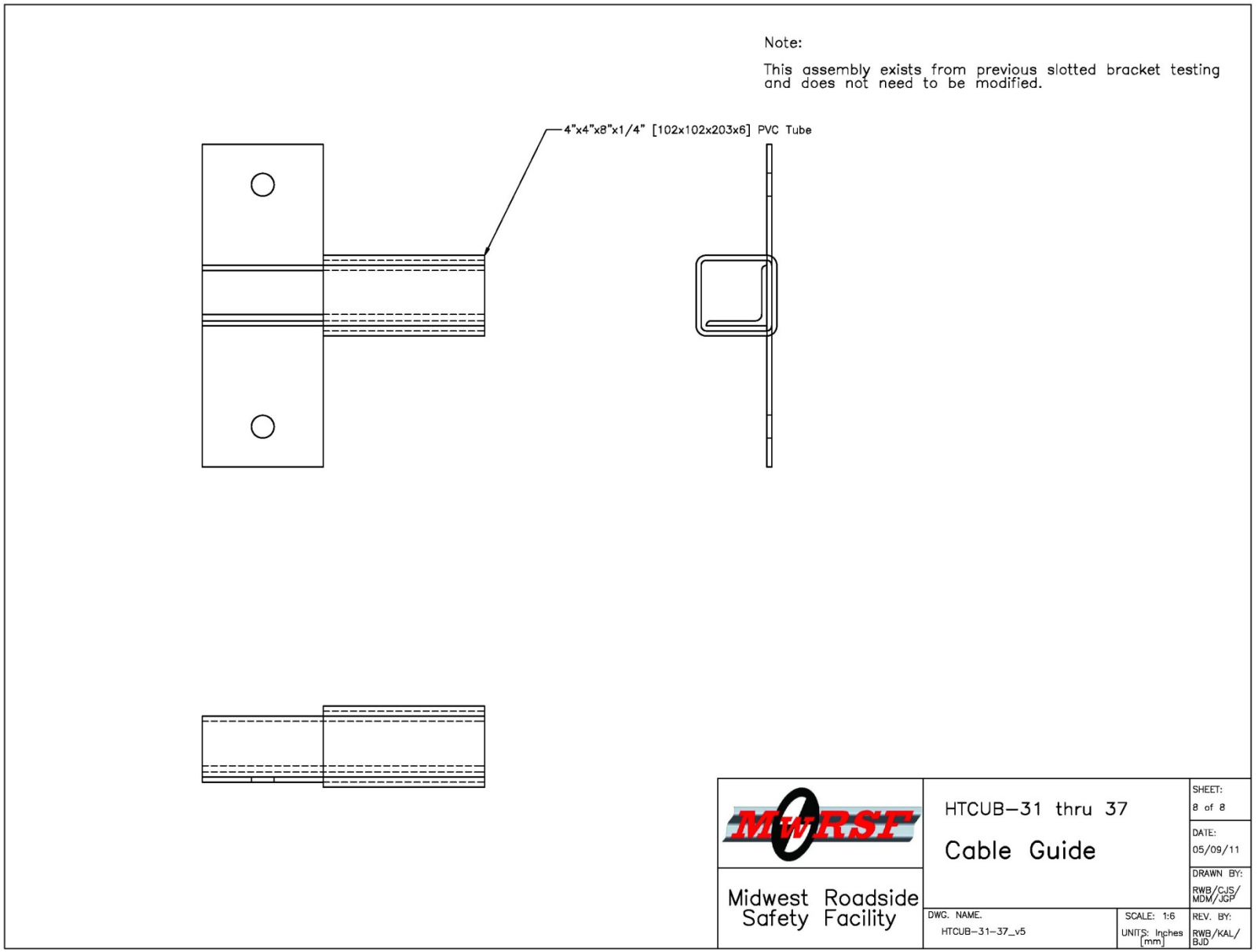
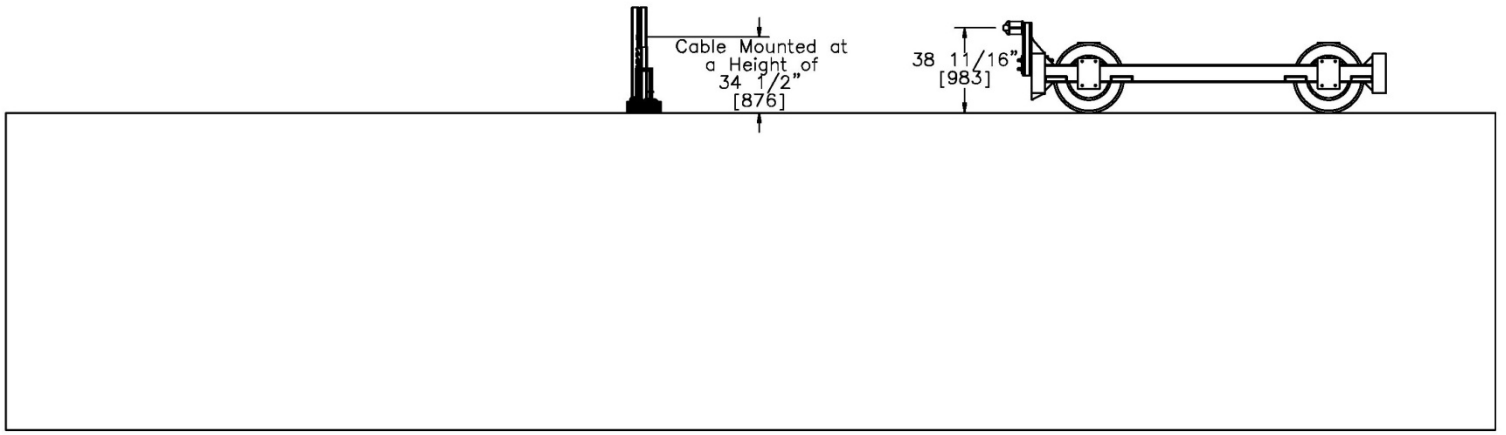


Figure A-24. Cable Guide, Test Nos. HTCUB-31 through HTCUB-37

Test No.	Test Quantity	Bogie Speed	Impact Orientation	Bogie No.
HTCC–1	1	17 mph [27.4 kph]	Normal to the Cable	2



Notes: (1) Posts are to be installed using the auger and backfill method in ø18" [457] with NCHRP 350 soil (same installation as the 4CMB tests).

(2) Place one high speed camera upstream of impact and one downstream of impact perpendicular to the side of the post for test documentation.

(3) Install the EDR–3 for data acquisition on the Bogie.

MwRSF	High Tension Cable Clip	SHEET: 1 of 9
	Impact	DATE: 05/09/2011
		DRAWN BY: RJT/MDM/JGP
Midwest Roadside Safety Facility	DWG. NAME. HTCC_R7 / SCALE: 1:70 / UNITS: Inches [mm]	REV. BY: RWB/KAL/BJD

Figure A-25. Cable and Bogie Head Heights, Test No. HTCC-1

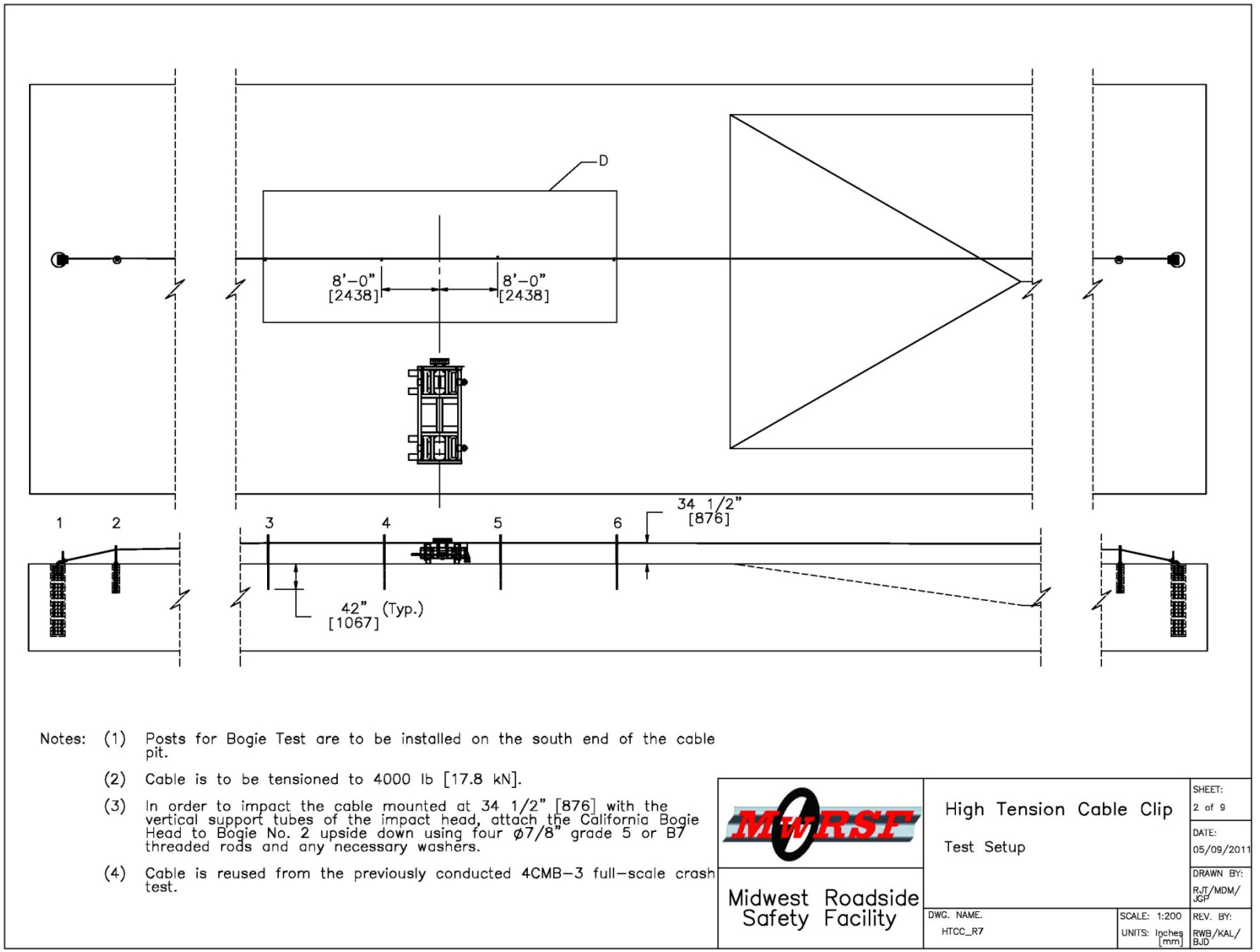


Figure A-26. Test Setup, Test No. HTCC-1

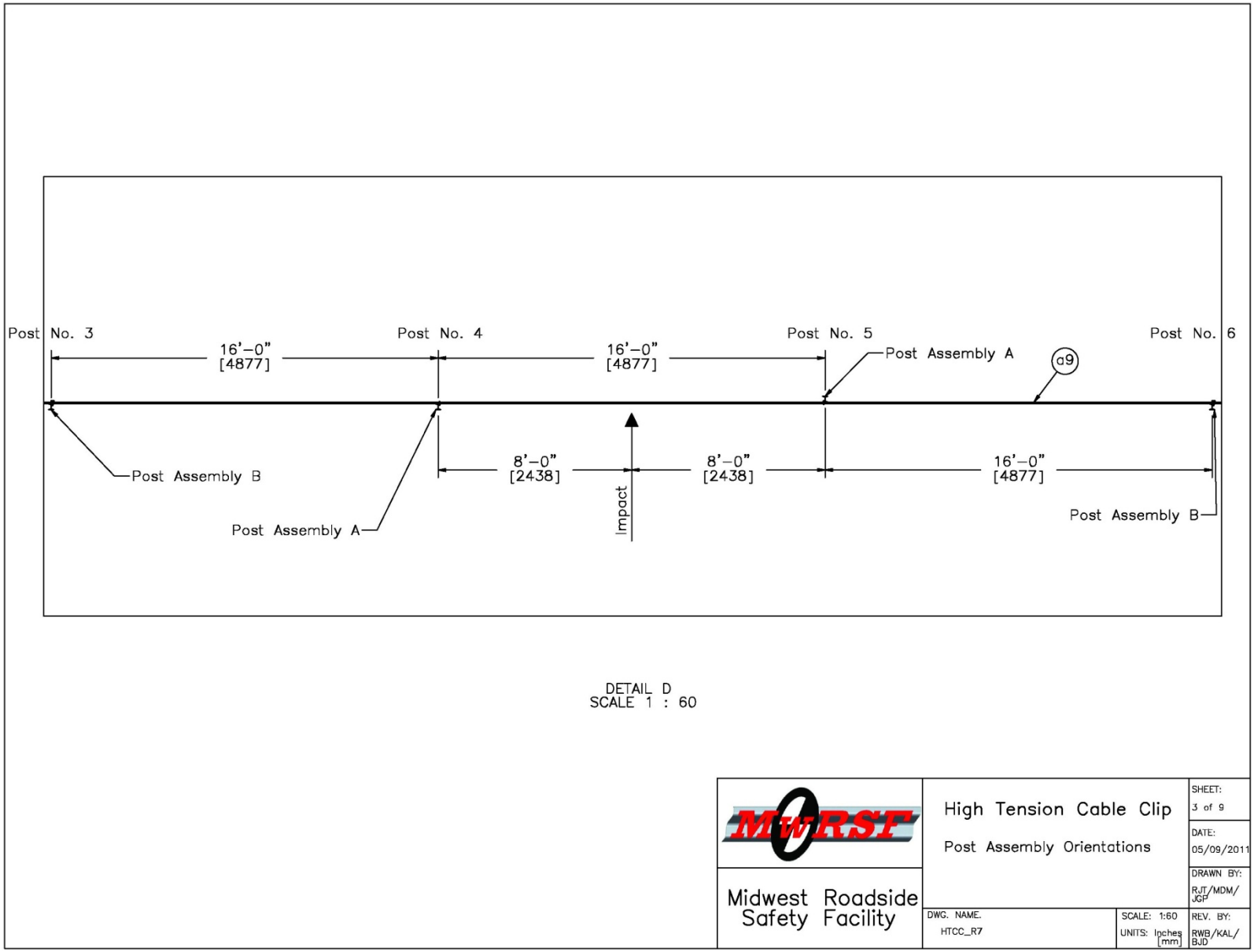


Figure A-27. Detail D, Test No. HTCC-1

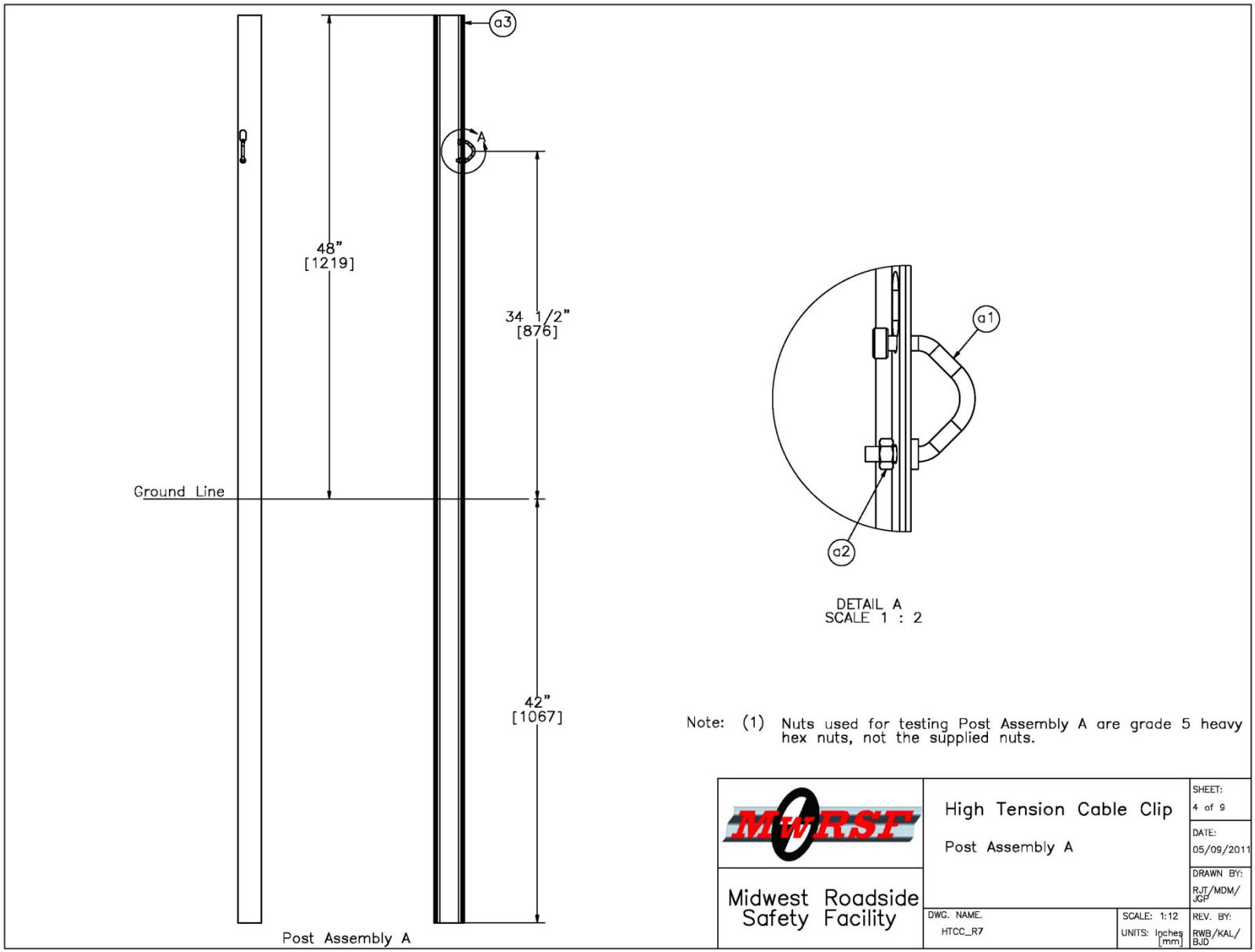


Figure A-28. Post Assembly A, Test No. HTCC-1

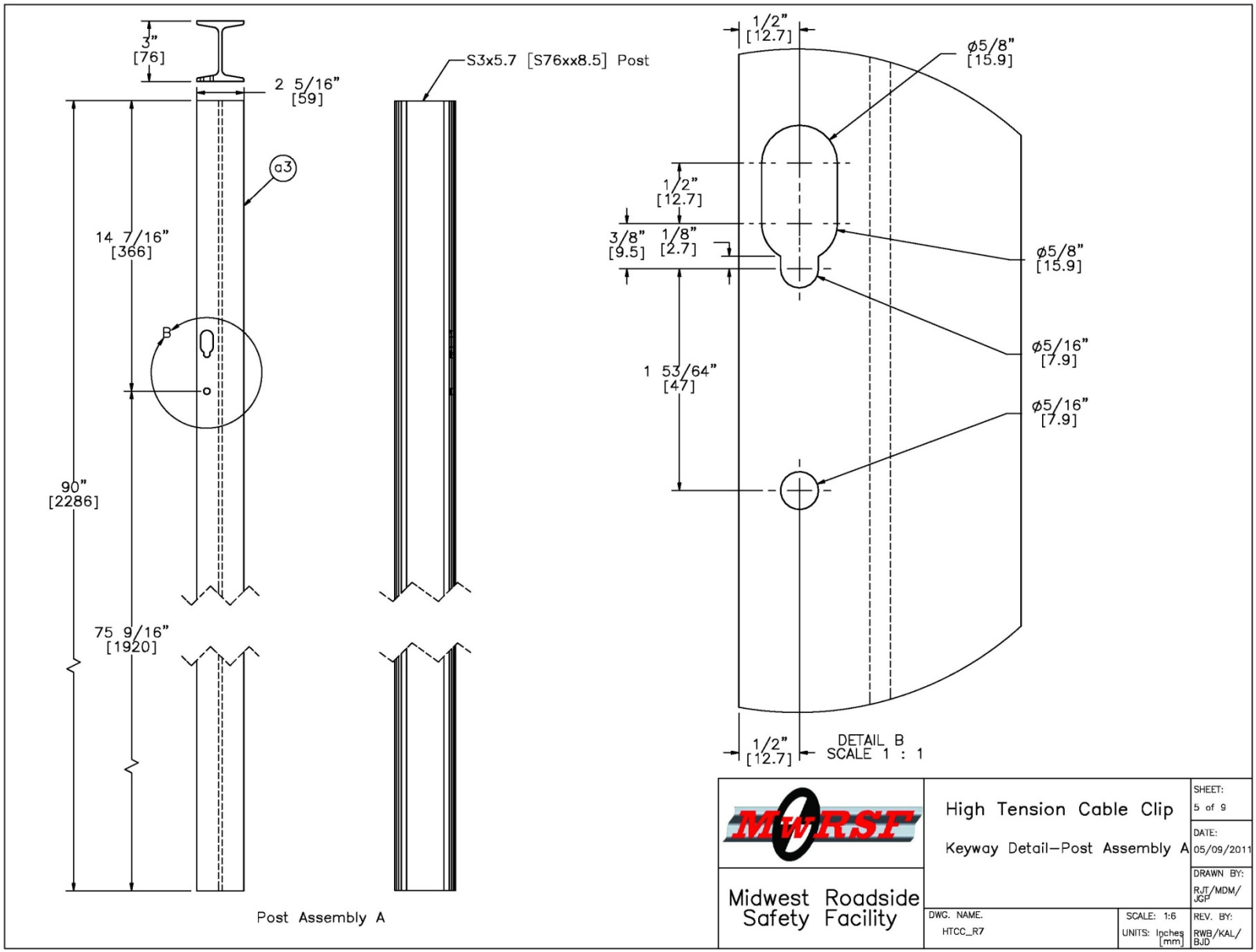


Figure A-29. Keyway Detail, Post Assembly A, Test No. HTCC-1

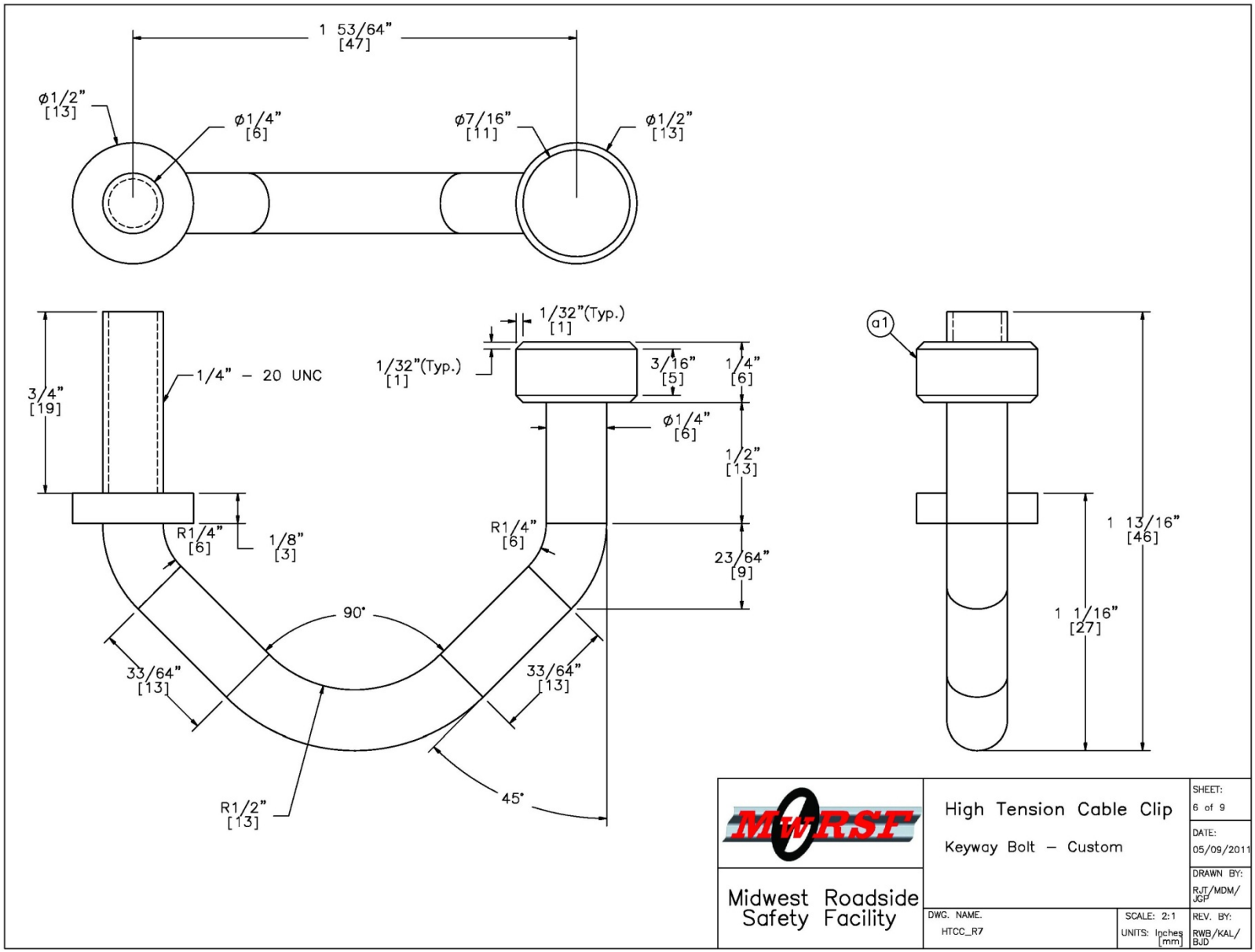


Figure A-30. Keyway Bolt Detail, Post Assembly A, Test No. HTCC-1

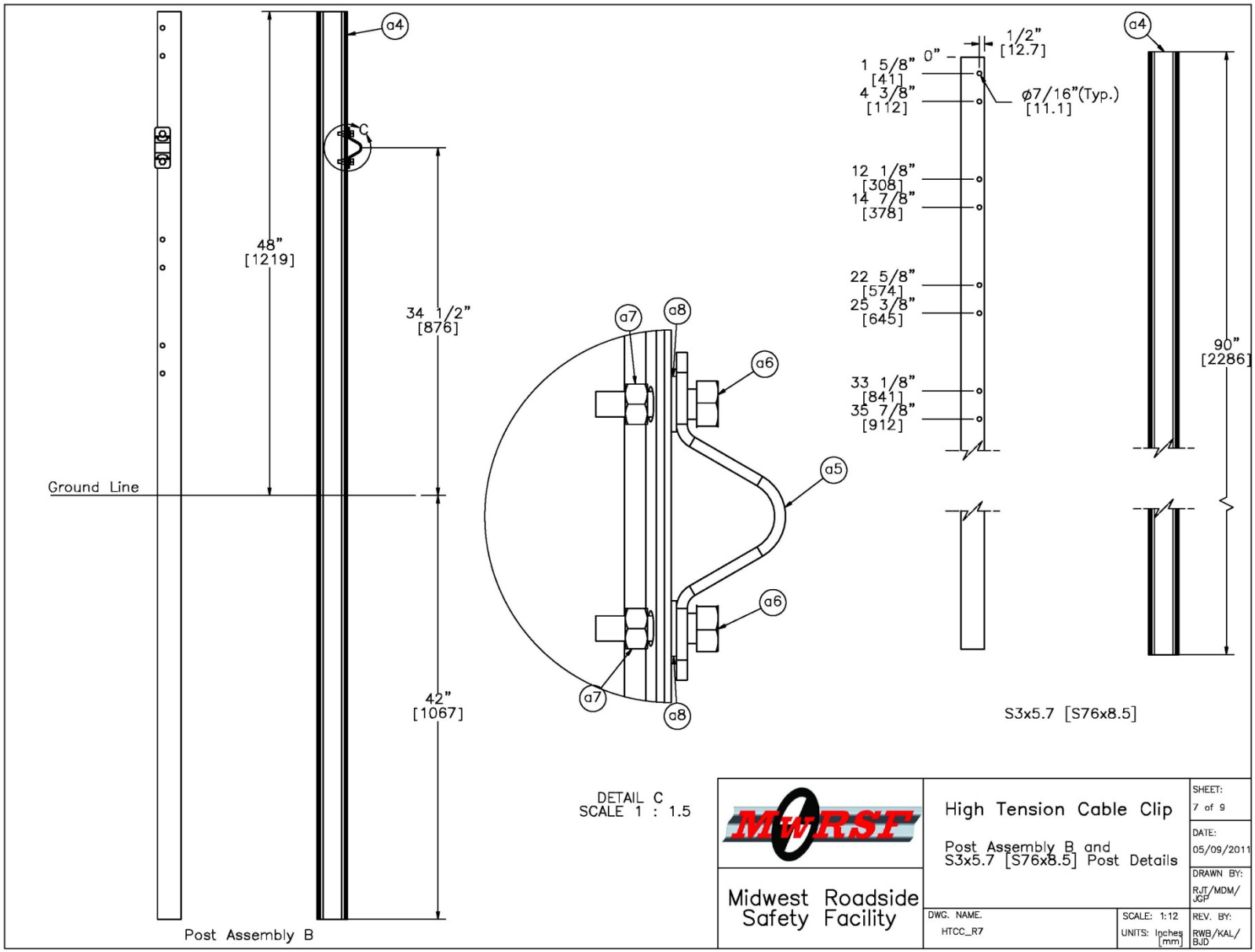


Figure A-31. Post Assembly B, Test No. HTCC-1

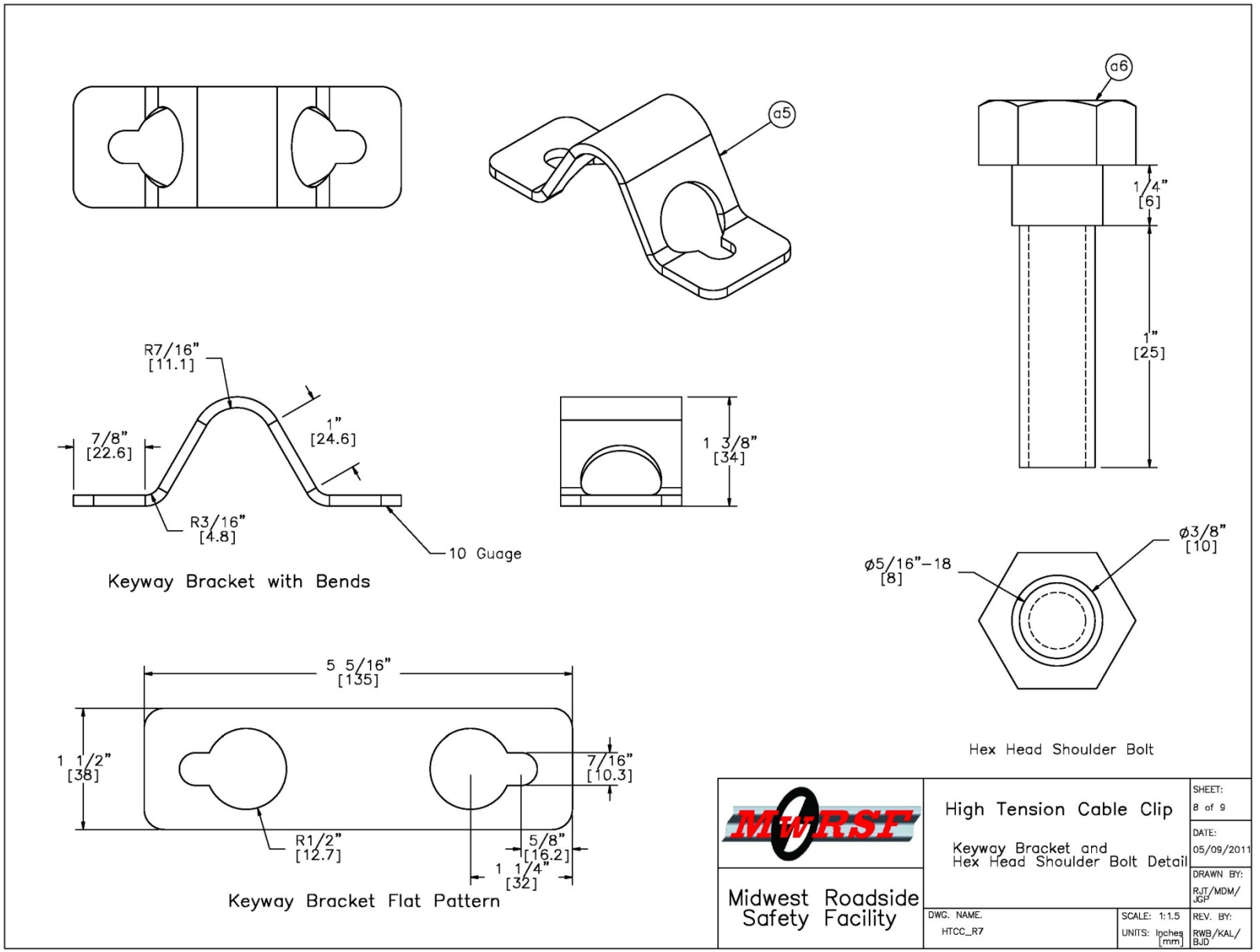


Figure A-32. Keyway Bracket and Bolt Detail, Post Assembly B, Test No. HTCC-1

Item No.	QTY.	Description	Material Specifications	Comments
a1	2	1/4"[6.4]dia. Keyway Bolt – Custom	Grade 2 – C1018 – Galvanized	–
a2	2	1/4"[6.4] – 20 UNC Finished Heavy Hex Nut	Grade 5/ASTM A325	–
a3	2	S3x5.7 [S76x8.5] by 90"[2286]	ASTM A36	Keyway holes need to be machined to dimensions shown
a4	2	S3x5.7 [S76x8.5] by 90"[2286]	ASTM A36	–
a5	2	Keyway Bracket	ASTM A36 – 10 Gauge, Galvanized	–
a6	4	5/16"[7.9]Dia. Hex Head Shoulder Bolt	Grade 5 – Galvanized	Custom
a7	4	5/16"[7.9]Dia. Heavy Hex Nut	Grade 5 – Galvanized	–
a8	4	5/16"[7.9]Dia. Washer	SAE FW 5/16" – Galvanized	–
a9	1	ø3/4"[19.1] 3x7 Cable	Cl A Galvanized Cable Guiderail	Reused from 4CMB–3

Midwest Roadside Safety Facility

High Tension Cable Clip

Bill of Materials

SHEET: 9 of 9

DATE: 05/09/2011

DRAWN BY: RJT/MDM/JGP

REV. BY: RWB/KAL/BJD

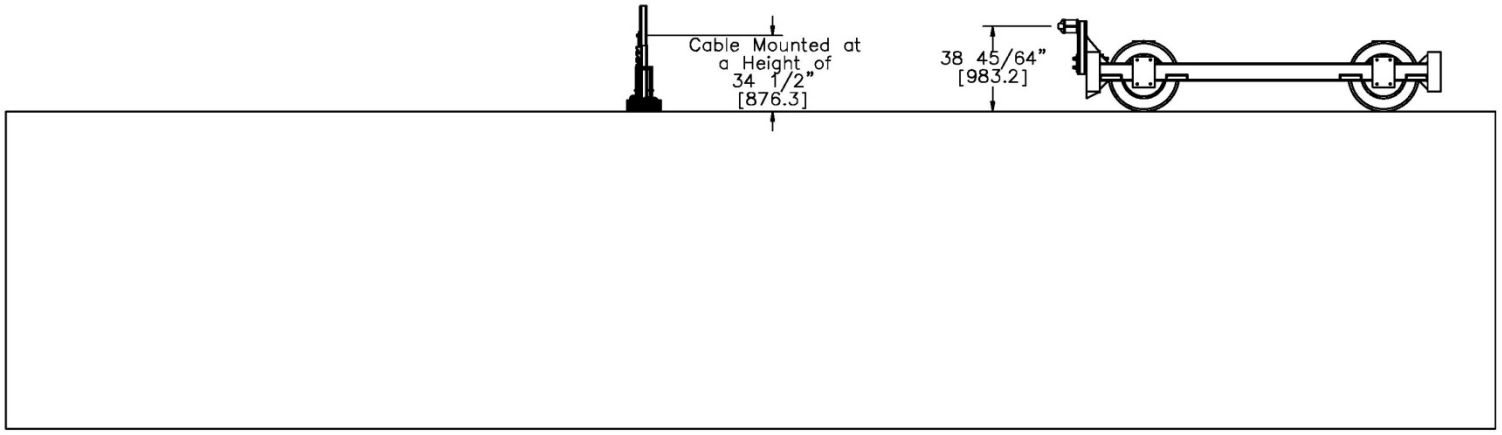
DWG. NAME. HTCC_R7

SCALE: None

UNITS: Inches [mm]

Figure A-33. Bill of Materials, Test No. HTCC-1

Test No.	Test Quantity	Bogie Speed	Impact Orientation	Bogie No.
HTCC–2	1	17 mph [27.4 kph]	Normal to the Cable	2



Notes: (1) Posts are to be installed using the auger and backfill method in ø18" [457] with NCHRP 350 soil (same installation as the 4CMB tests).

(2) Place one high speed camera upstream of impact and one downstream of impact perpendicular to the side of the post for test documentation.

(3) Install the EDR–3 for data acquisition on the Bogie.

Midwest Roadside Safety Facility

High Tension Cable Clip

Impact

SHEET: 1 of 10

DATE: 4/11/2010

DRAWN BY: RJT/CJS/MDM/JGP

REV. BY: RWB

DWG. NAME. HTCC–2_R3

SCALE: 1:70

UNITS: Inches [mm]

Figure A-34. Cable and Bogie Head Heights, Test No. HTCC-2

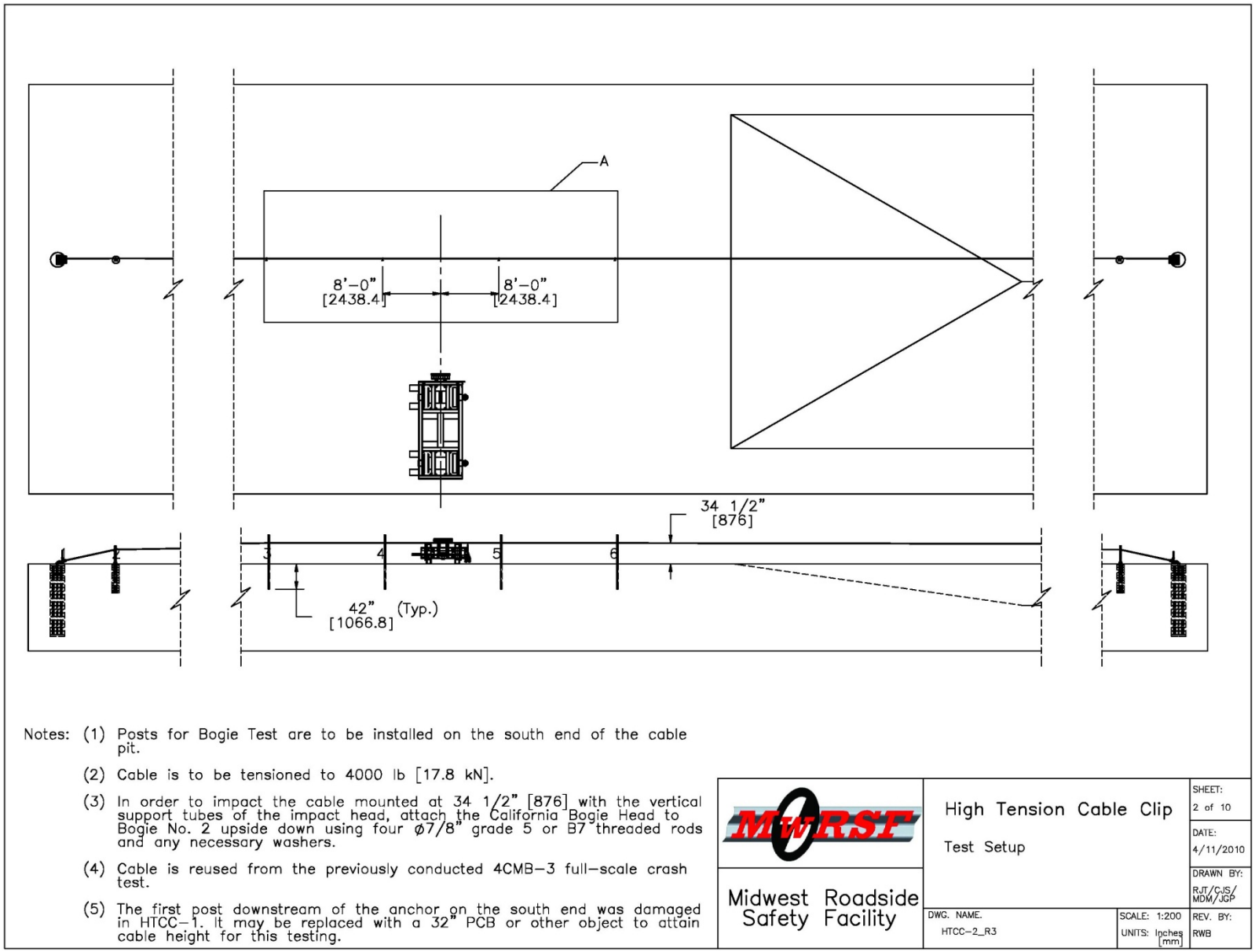


Figure A-35. Test Setup, Test No. HTCC-2

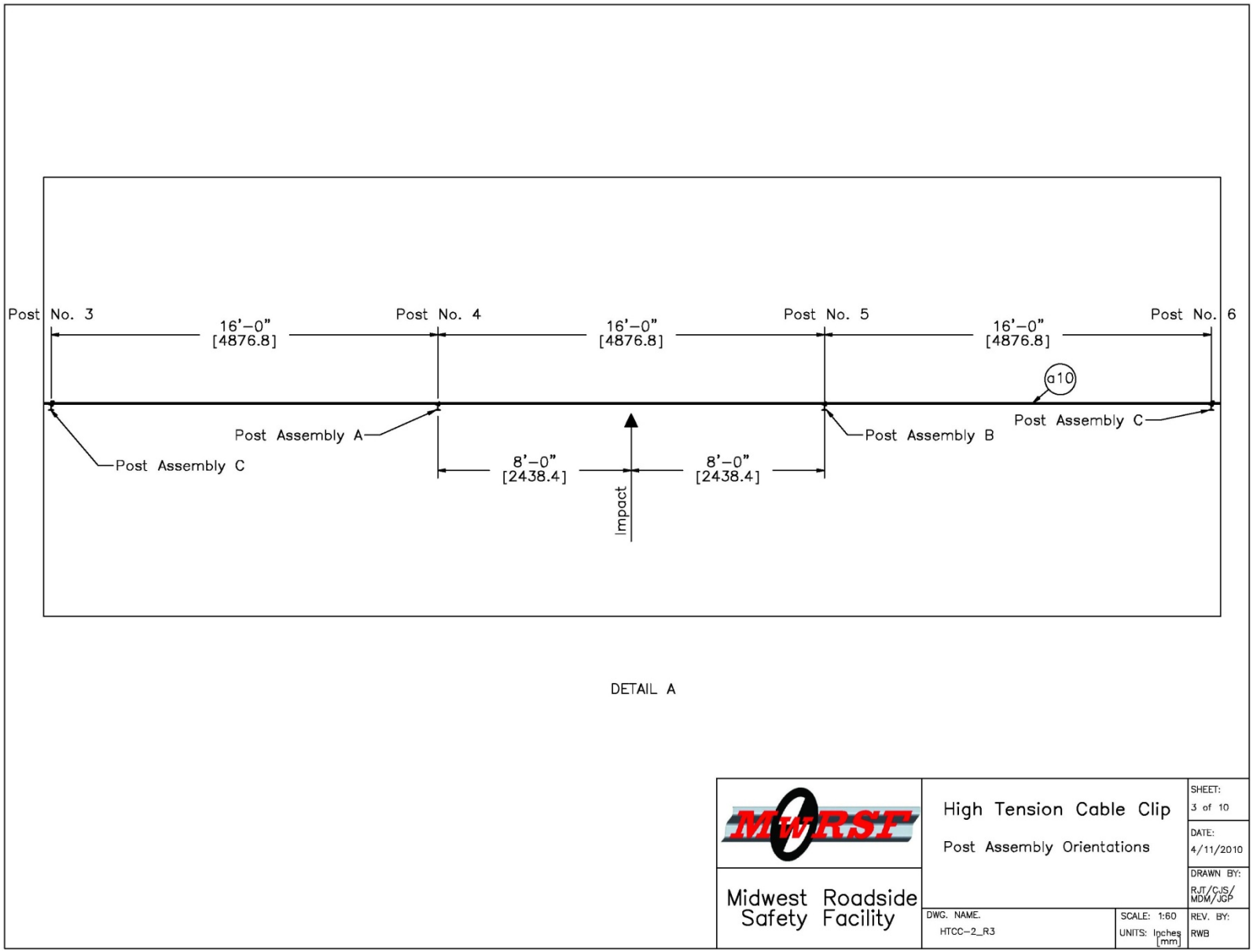


Figure A-36. Detail A, Test No. HTCC-2

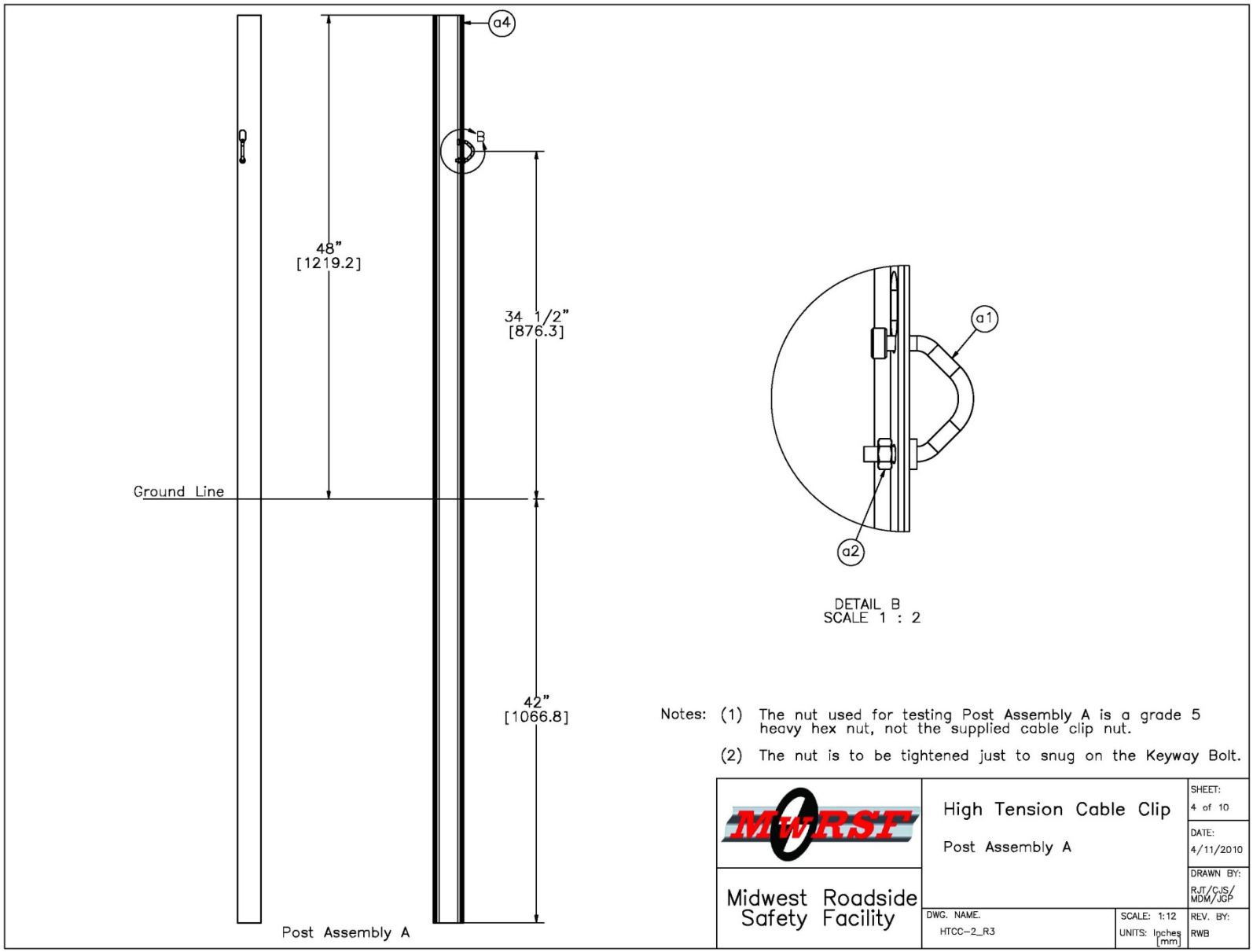


Figure A-37. Post Assembly A, Test No. HTCC-2

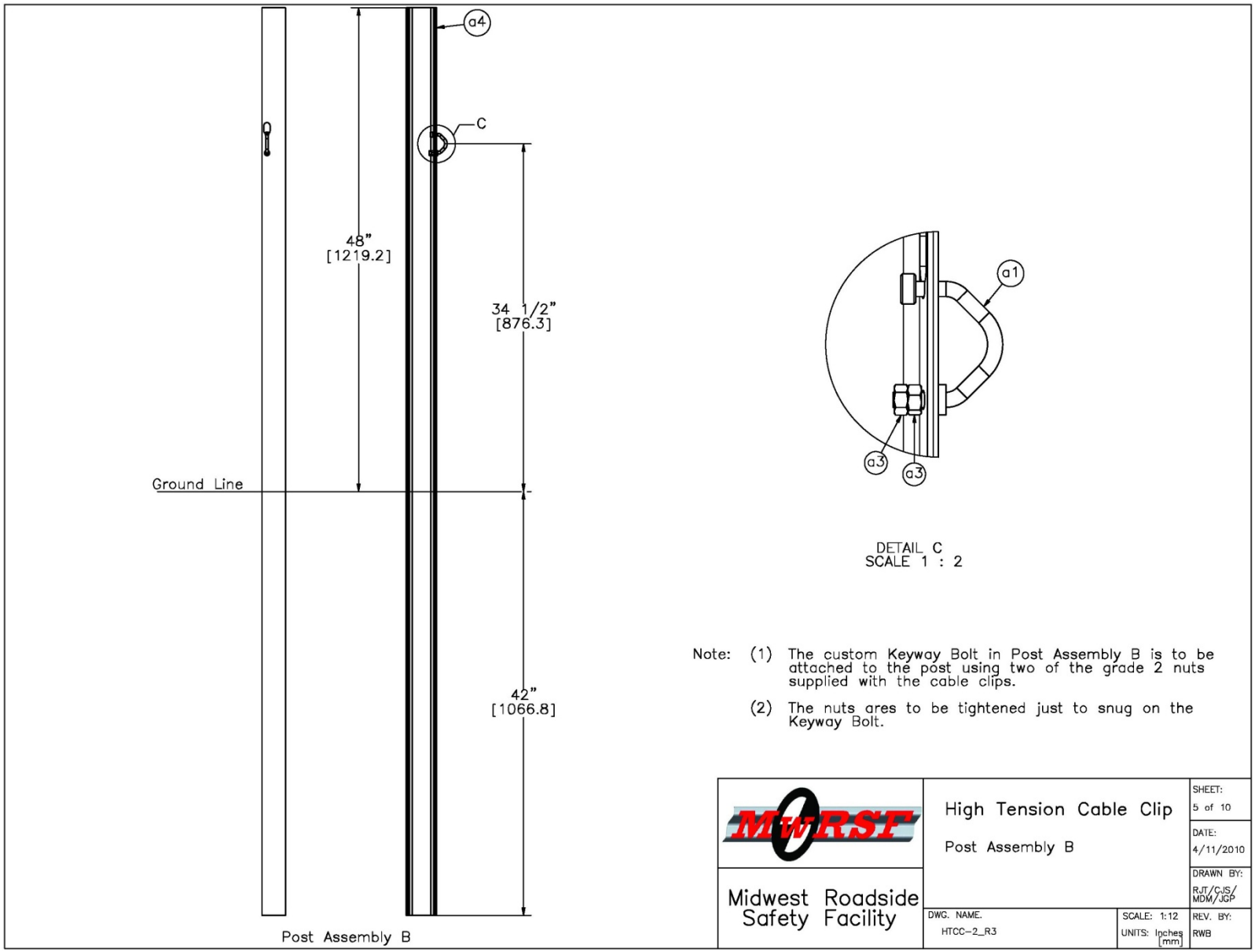


Figure A-38. Post Assembly B, Test No. HTCC-2

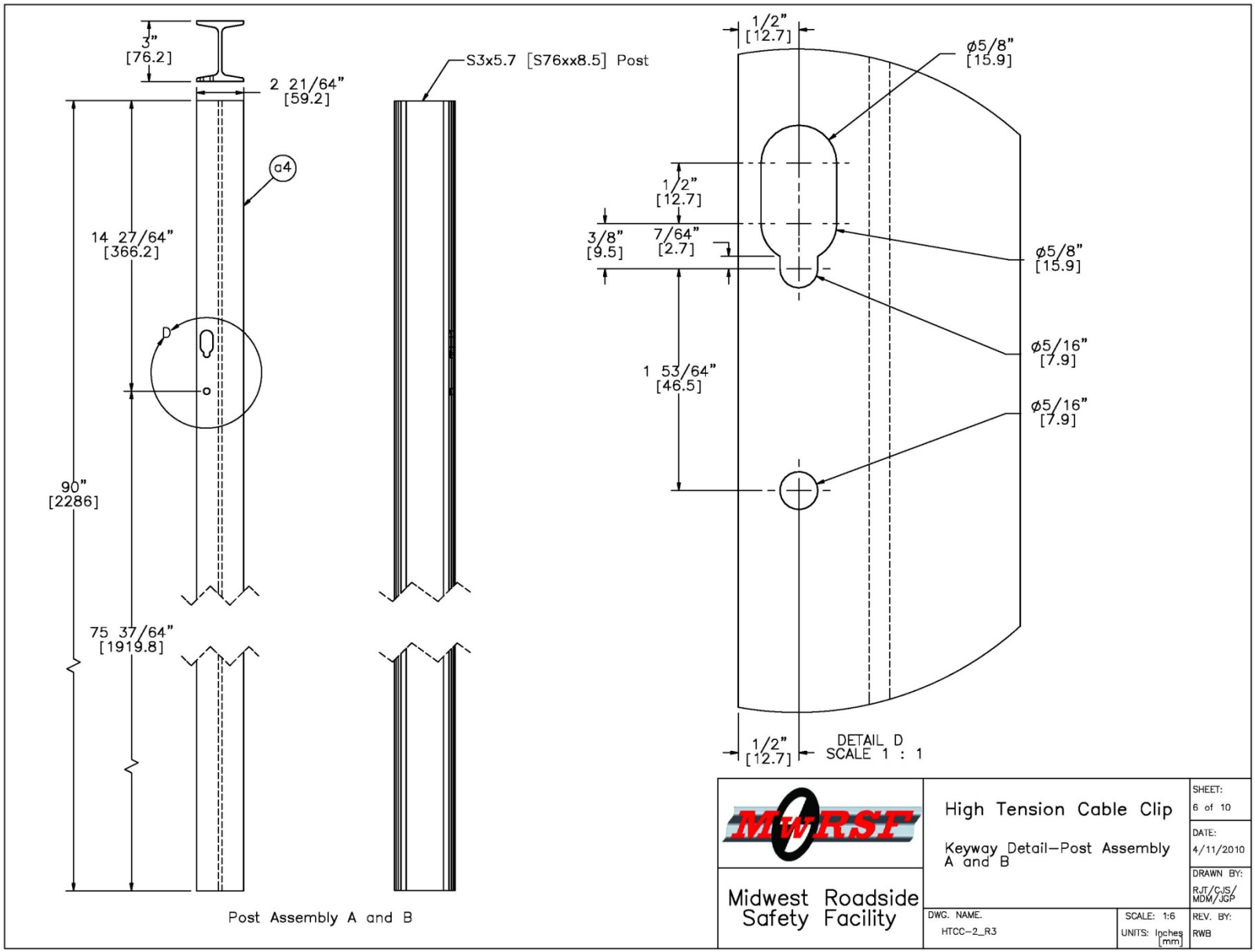


Figure A-39. Keyway Detail, Post Assembly A and B, Test No. HTCC-2

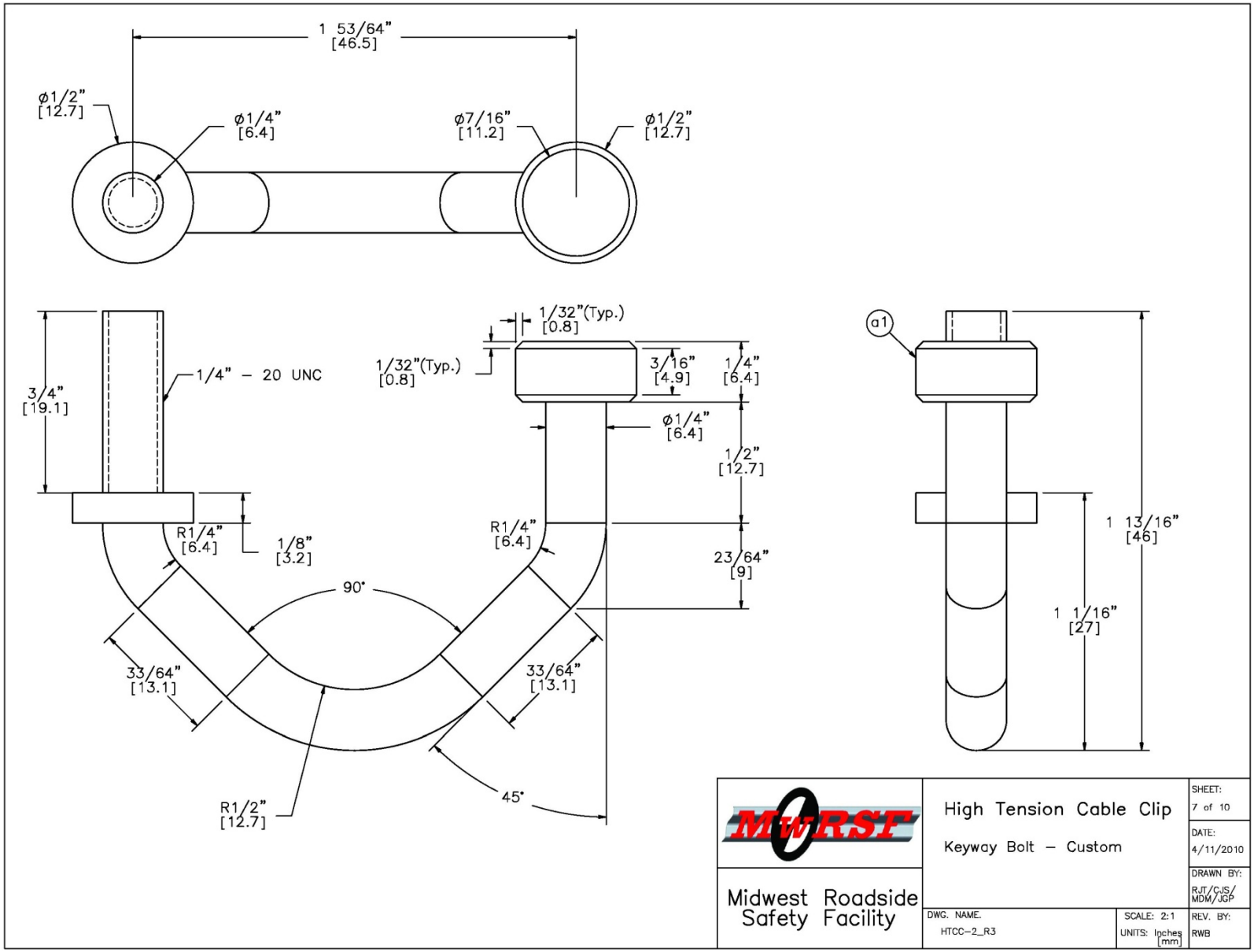


Figure A-40. Keyway Bolt Detail, Post Assembly A and B, Test No. HTCC-2

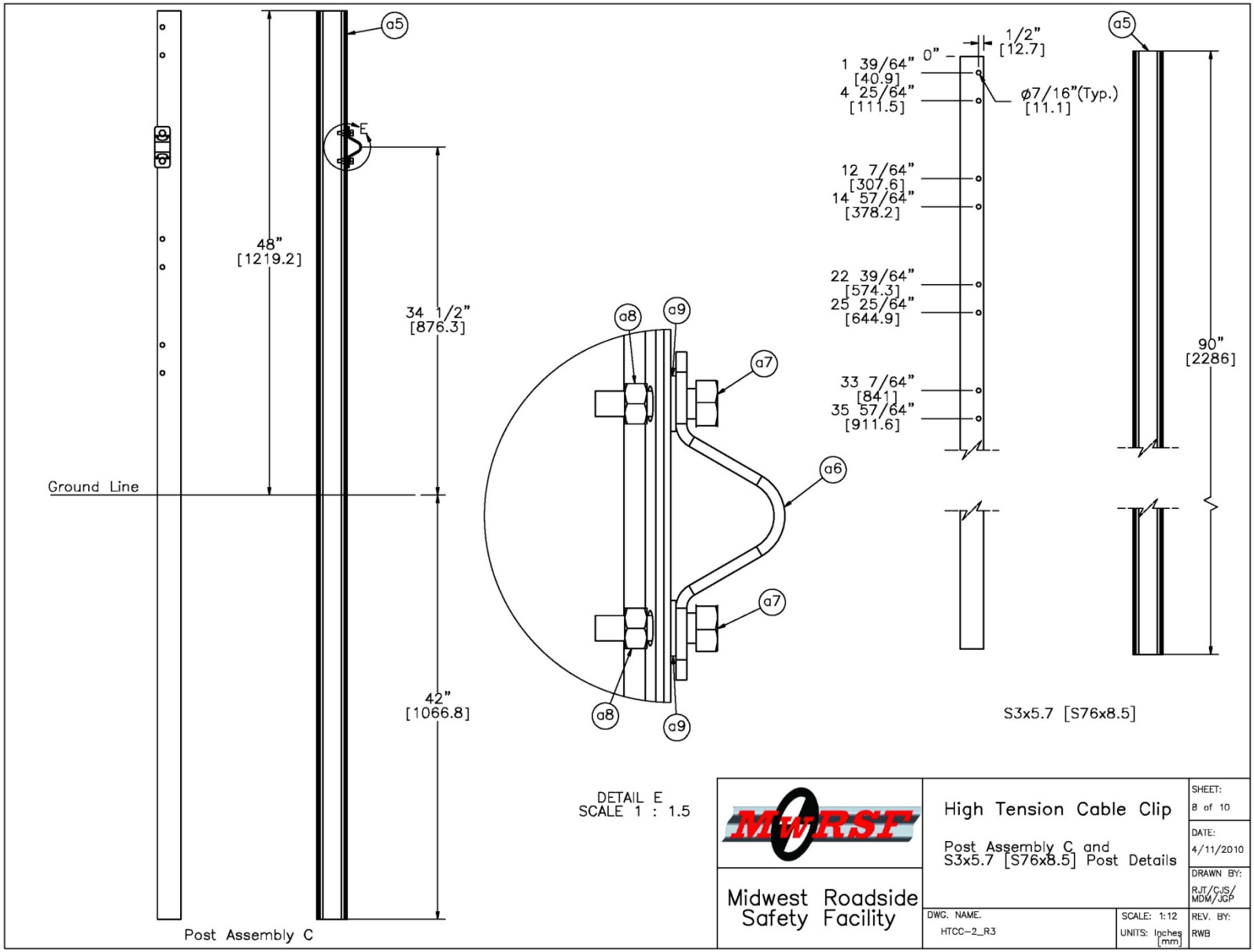


Figure A-41. Post Assembly C, Test No. HTCC-2

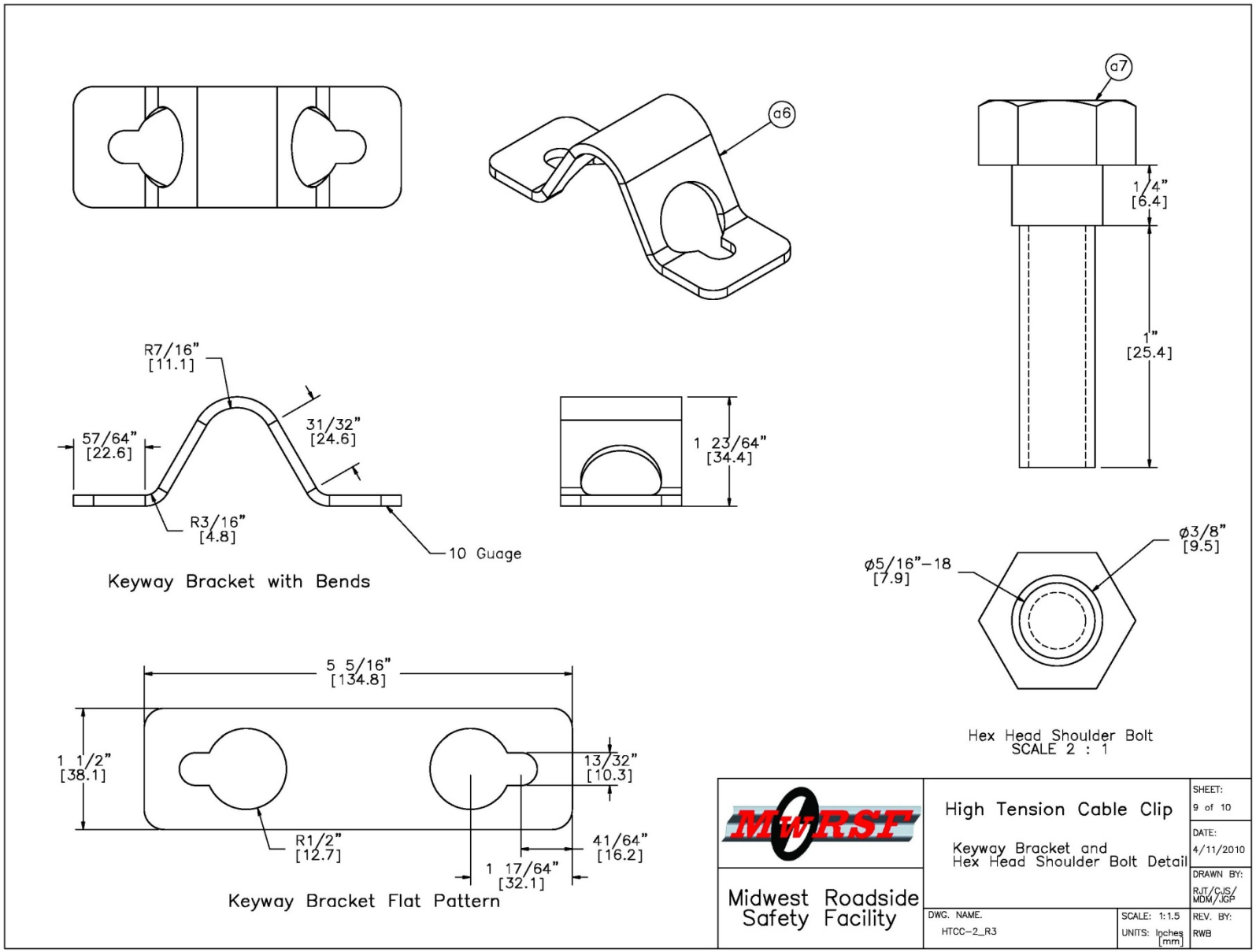


Figure A-42. Keyway Bracket and Bolt Detail, Test No. HTCC-2

Item No.	QTY.	Description	Material Specifications	Comments
a1	2	1/4"[6.4] dia. Keyway Bolt – Custom	Grade 2 – C1018 – Galvanized	–
a2	1	1/4"[6.4]–20 dia. UNC Finished Heavy Hex Nut	Grade 5/ASTM A325	–
a3	2	1/4"[6.4]–20 dia. Hex Nut	Grade 2	Nuts supplied with clips
a4	2	S3x5.7 [S76x8.5] by 90"[2286]	ASTM A36	Keyway holes need to be machined to dimensions shown
a5	2	S3x5.7 [S76x8.5] by 90"[2286]	ASTM A36	–
a6	2	Keyway Bracket	ASTM A36 – 10 Gauge, Galvanized	–
a7	4	5/16"[7.9] dia. Hex Head Shoulder Bolt	Grade 5 – Galvanized	Custom
a8	4	5/16"[7.9] dia. Heavy Hex Nut	Grade 5 – Galvanized	–
a9	4	5/16"[7.9] dia. Washer	SAE FW 5/16" – Galvanized	–
a10	1	3/4"[19.1] dia. 3x7 Cable	Cl A Galvanized Cable Guiderail	Reused from 4CMB–3

Midwest Roadside Safety Facility

High Tension Cable Clip

Bill of Materials

SHEET: 10 of 10

DATE: 4/11/2010

DRAWN BY: RJT/CJS/MDM/JGP

REV. BY: RWB

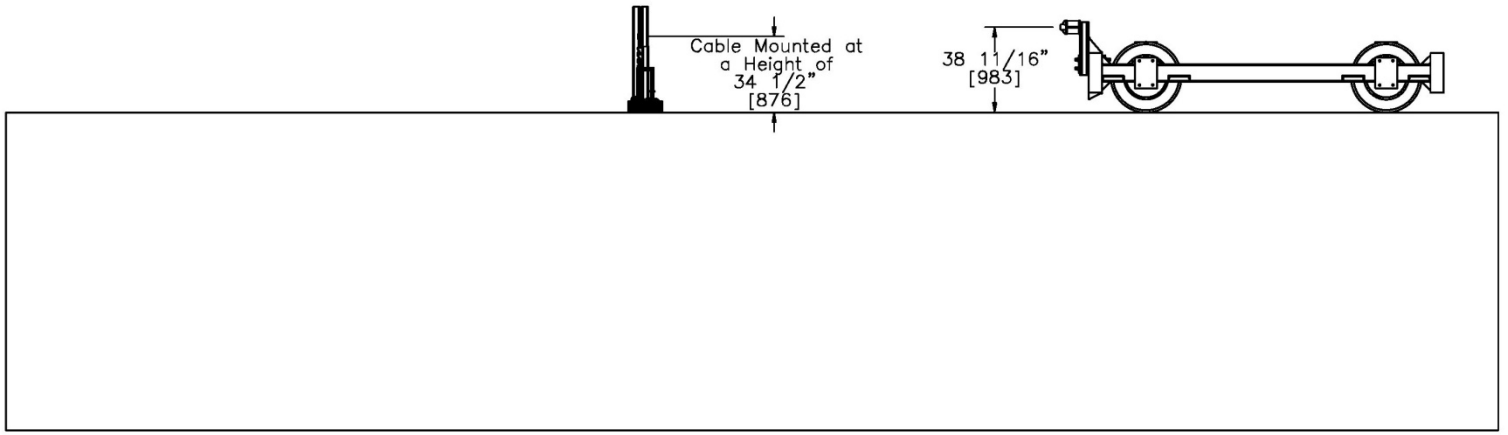
DWG. NAME. HTCC–2_R3

SCALE: None

UNITS: Inches [mm]

Figure A-43. Bill of Materials, Test No. HTCC-2

Test No.	Bogie Speed	Impact Orientation	Bogie No.	Bolt
HTCC–3	17 mph [27.4 kph]	Normal to the Cable	2	C1018
HTCC–4	17 mph [27.4 kph]	Normal to the Cable	2	A449
HTCC–5	17 mph [27.4 kph]	Normal to the Cable	2	A449



Notes: (1) Posts are to be installed using the auger and backfill method in ø18" [457] with NCHRP 350 soil (same installation as the 4CMB tests).

(2) Place one high–speed camera upstream of impact and one downstream of impact perpendicular to the side of the post for test documentation. Place one high–speed camera upstream and offset on the non–impact side of the impact location for the test documentation.

(3) Install the EDR–3 for data acquisition on the Bogie.

MwRSF Midwest Roadside Safety Facility	High Tension Cable Clip Impact	SHEET: 1 of 11 DATE: 5/11/2011 DRAWN BY: RJT/MDM/JGP REV. BY: RWB/KAL
	DWG. NAME. HTCC–3–5_R5 SCALE: 1:70 UNITS: Inches [mm]	

Figure A-44. Cable and Bogie Head Heights, Test Nos. HTCC-3, HTCC-4, and HTCC-5

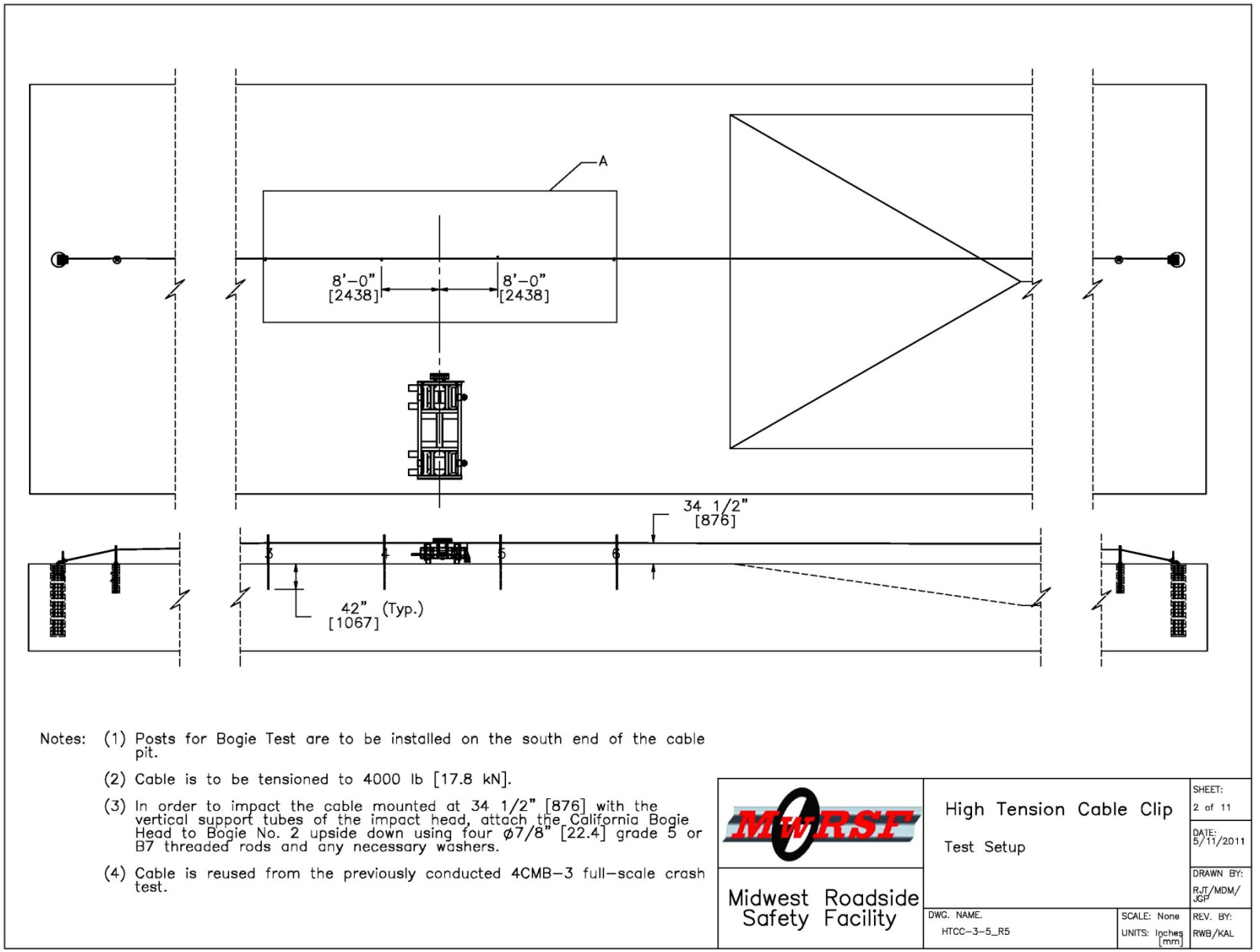


Figure A-45. Test Setup, Test Nos. HTCC-3, HTCC-4, and HTCC-5

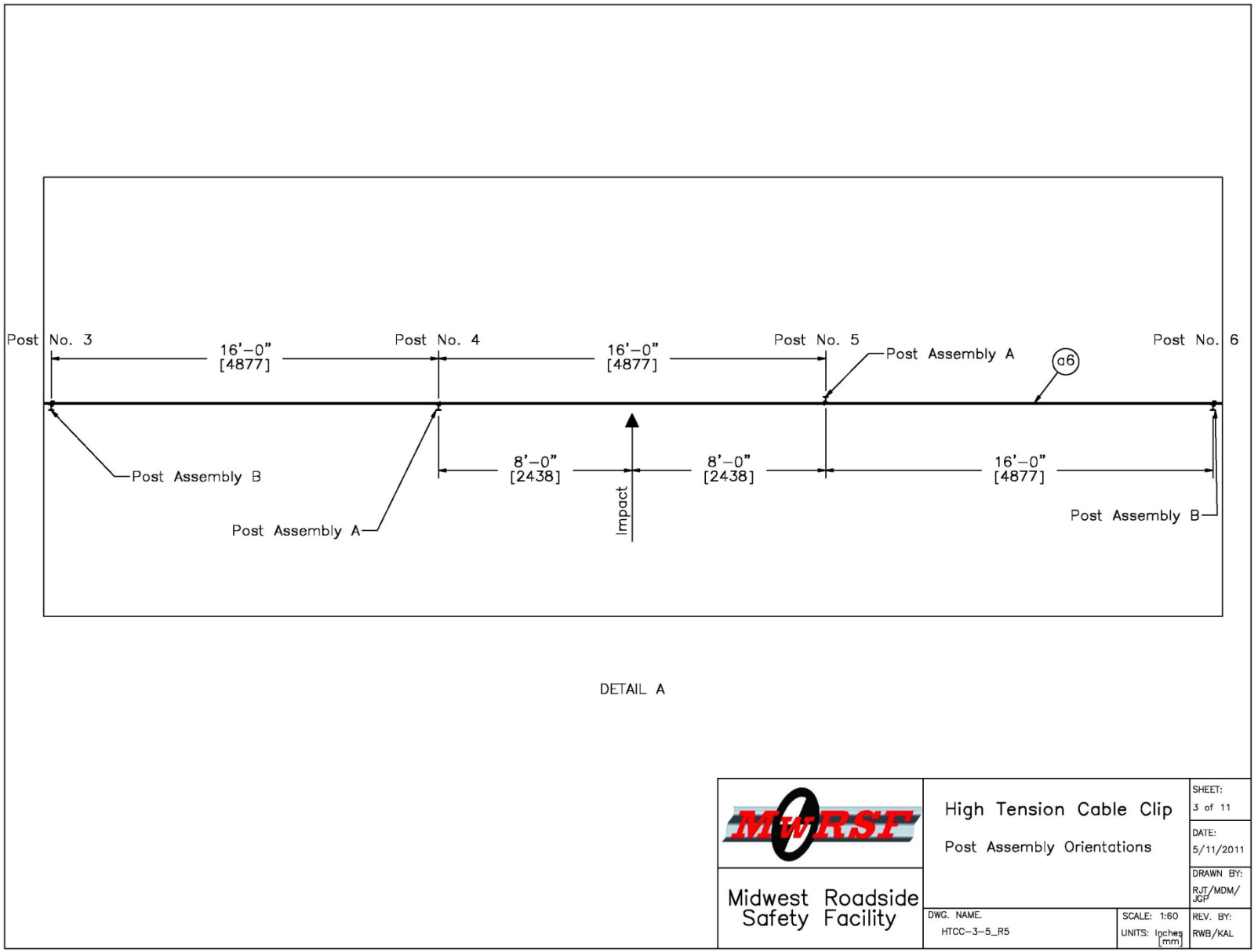


Figure A-46. Detail A, Test Nos. HTCC-3, HTCC-4, and HTCC-5

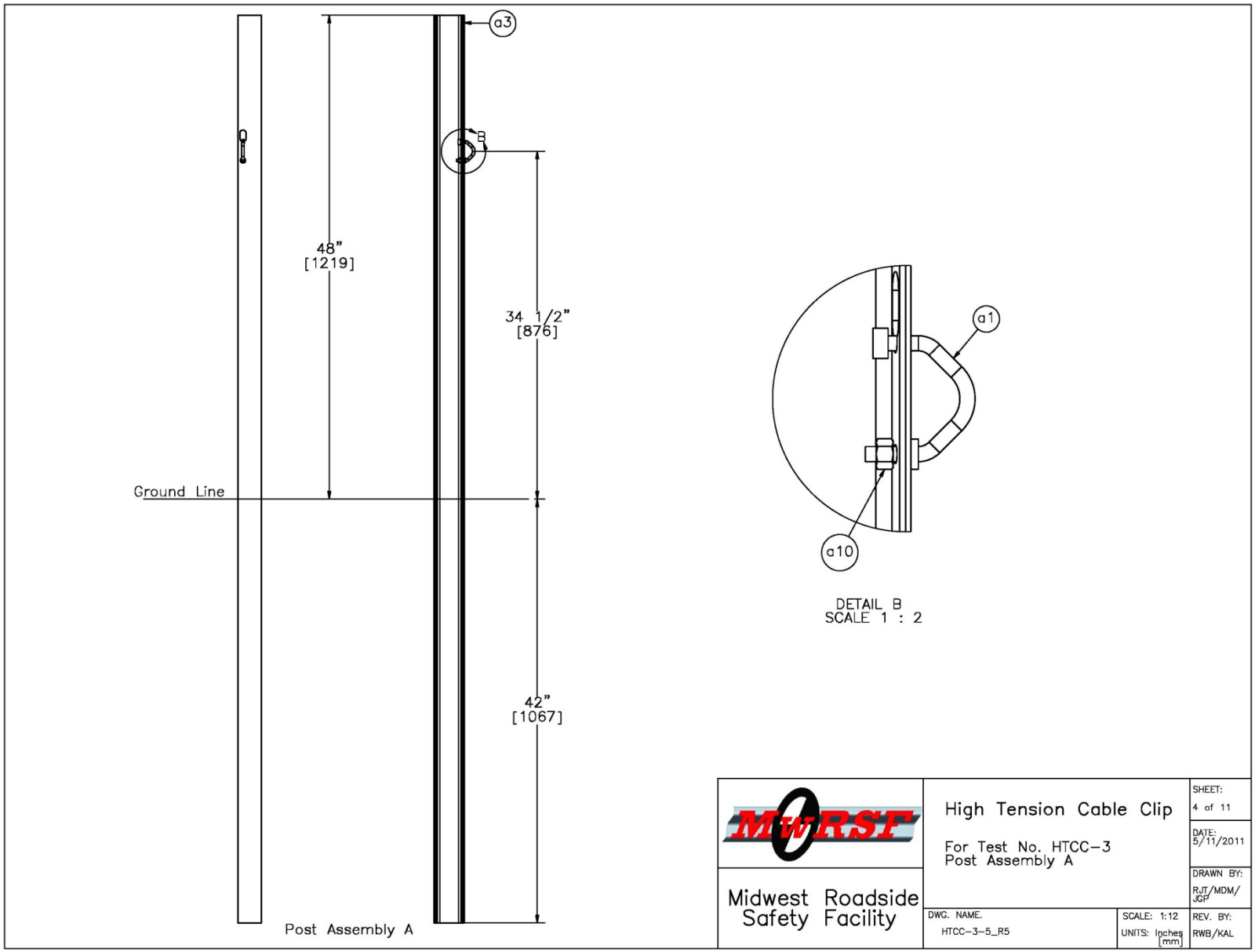


Figure A-47. Post Assembly A, Test No. HTCC-3

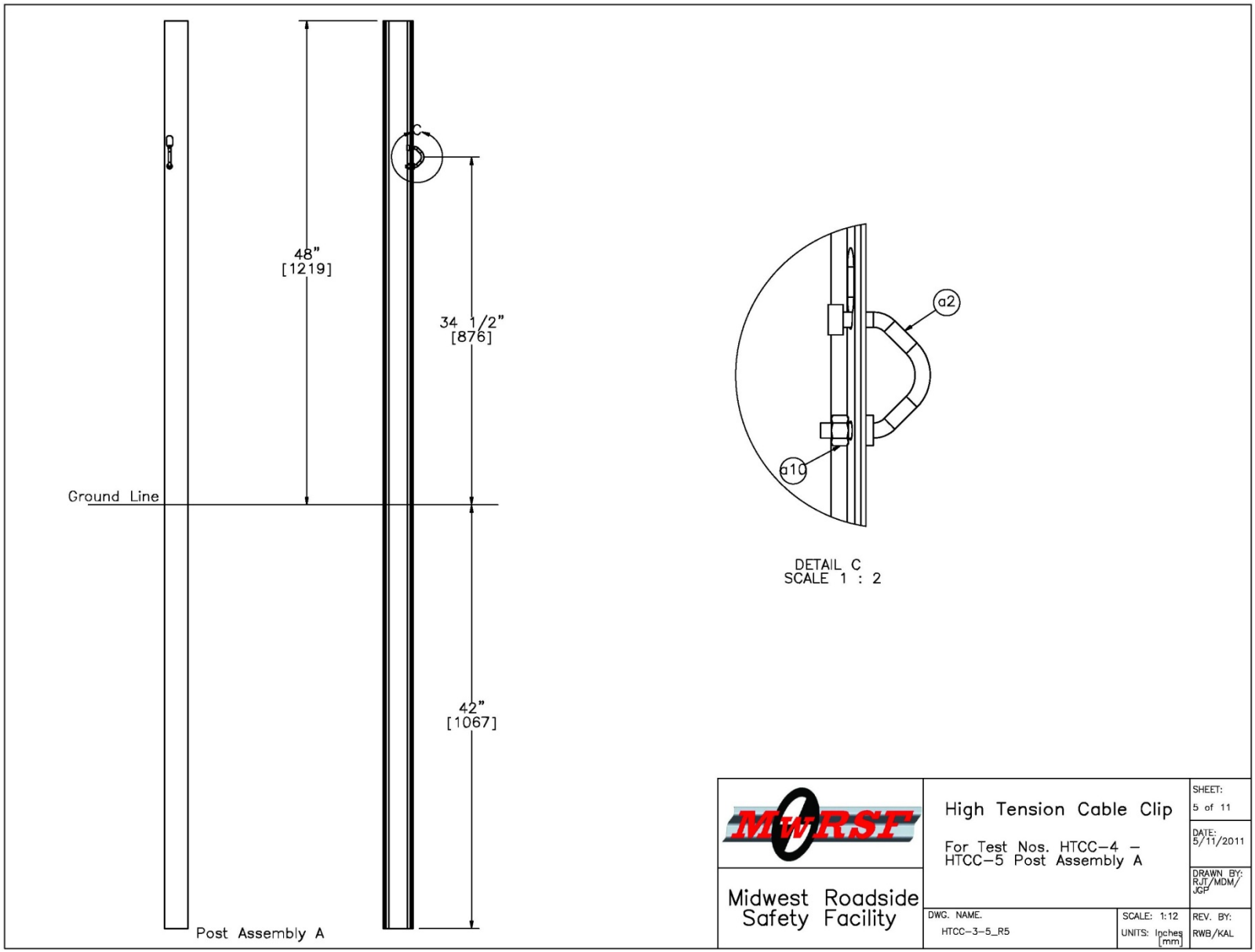


Figure A-48. Post Assembly A, Test Nos. HTCC-4 and HTCC-5

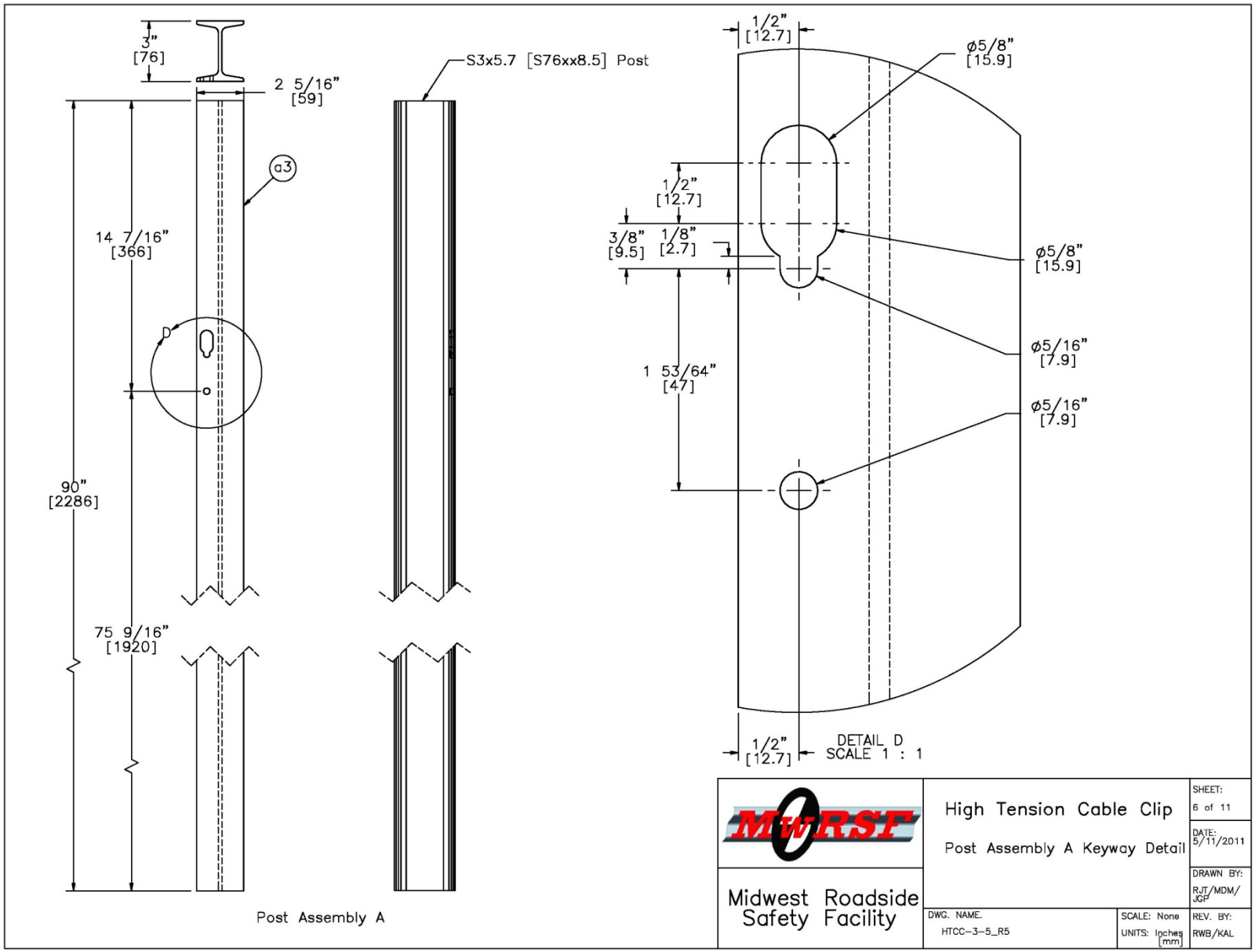


Figure A-49. Keyway Detail, Post Assembly A, Test Nos. HTCC-3, HTCC-4, and HTCC-5

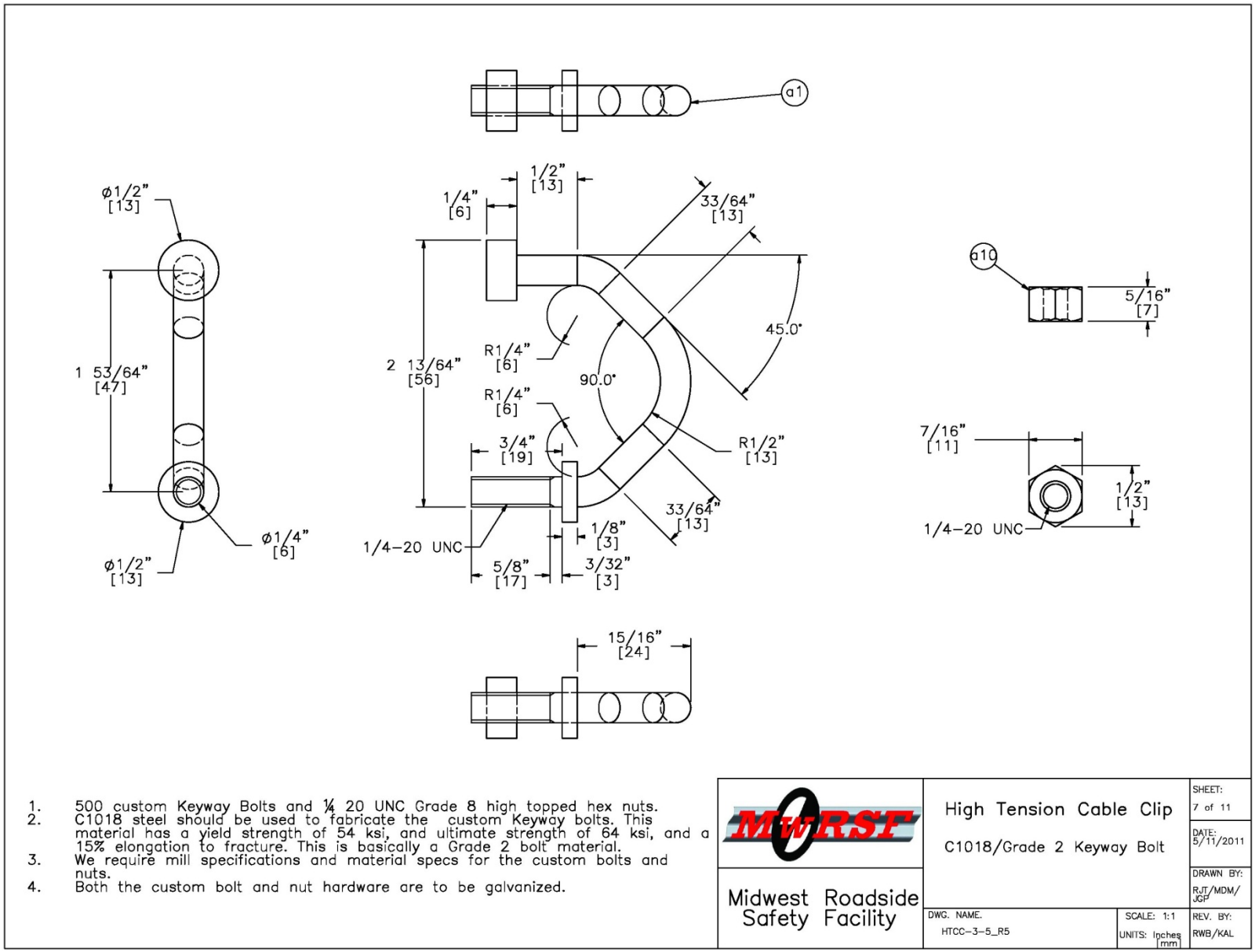


Figure A-50. Keyway Bolt Detail, Post Assembly A, Test No. HTCC-3

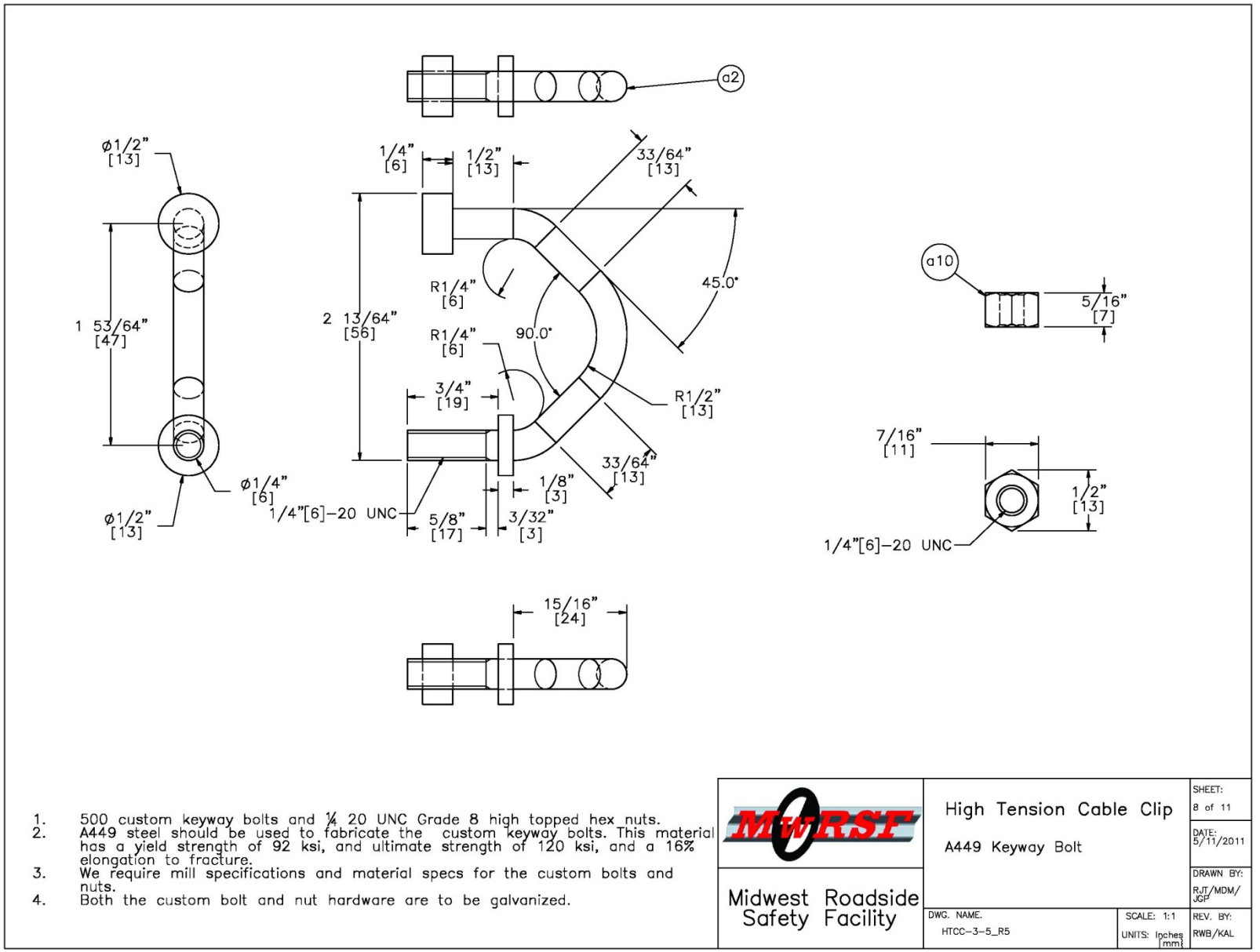


Figure A-51. Keyway Bolt Detail, Post Assembly A, Test Nos. HTCC-4 and HTCC-5

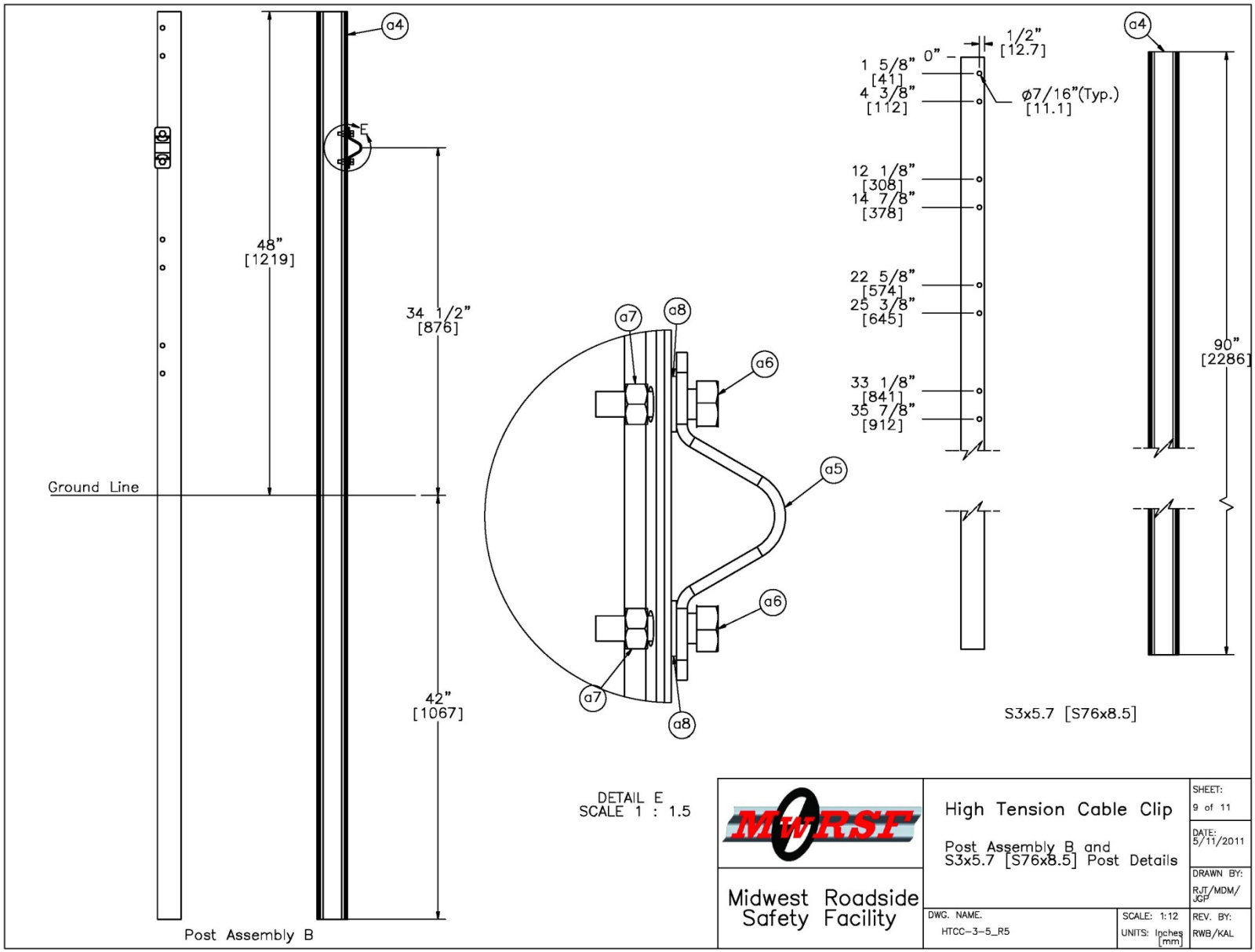


Figure A-52. Post Assembly B, Test Nos. HTCC-3, HTCC-4, and HTCC-5

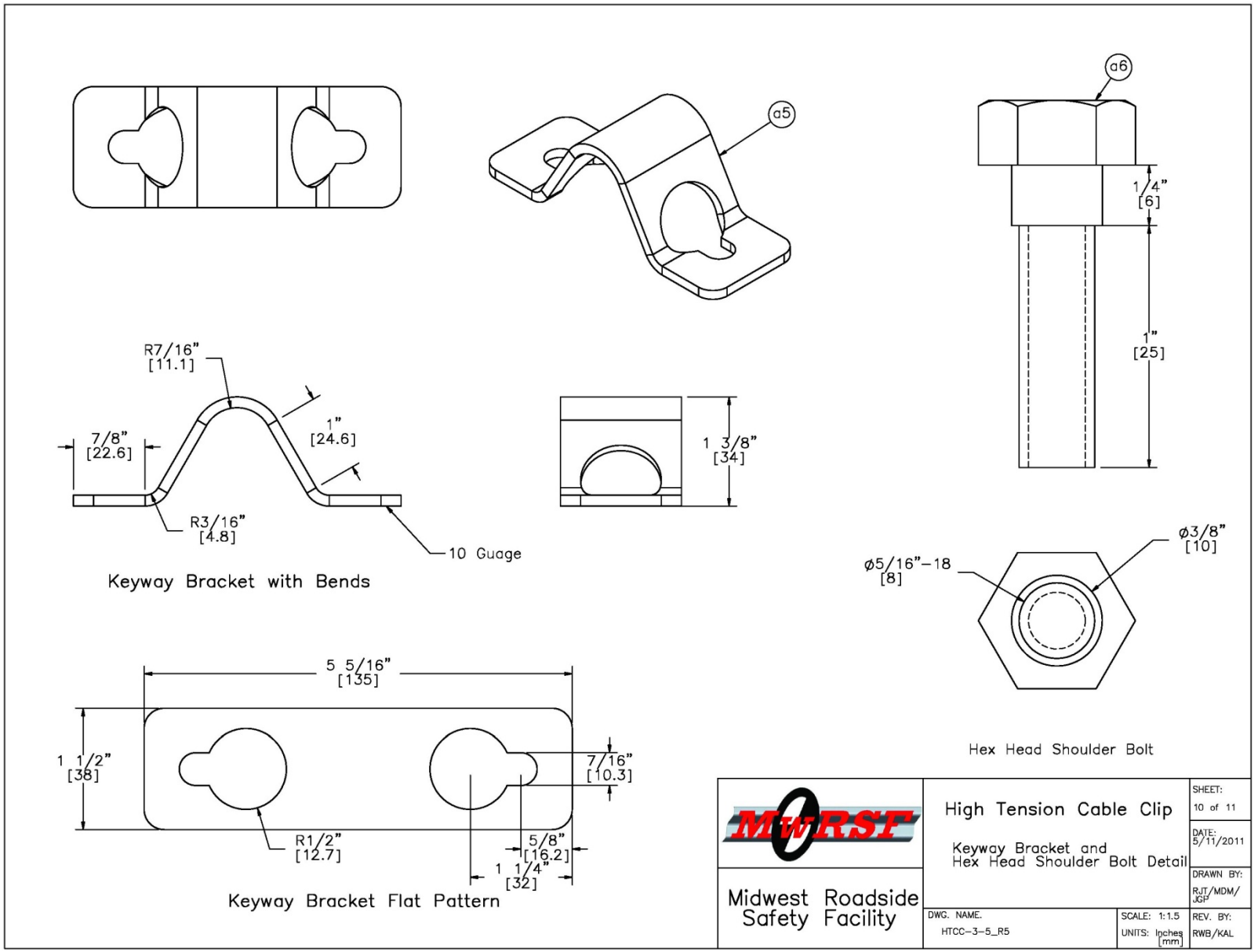


Figure A-53. Keyway Bracket and Bolt Detail, Test Nos. HTCC-3, HTCC-4, and HTCC-5

Item No.	QTY.	Description	Material Specifications	Comments
a1	2	1/4" [6] dia. Keyway bolt	Grade 2 – C1018 – Galvanized	yield=54 ksi, ult=64 ksi, % Elong.=15%
a2	2	1/4" [6] dia. Keyway bolt	A449–Galvanized	yeild=92 ksi, ult=120 ksi, % Elong.=16%
a3	4	S3x5.7 [S76x8.5] by 90"[2286]	ASTM A36	Keyway holes need to be machined to dimensions shown
a4	4	S3x5.7 [S76x8.5] by 90"[2286]	ASTM A36	–
a5	4	Keyway Bracket	ASTM A36 – 10 Gauge, Galvanized	–
a6	8	5/16"[7.9]Dia. Hex Head Shoulder Bolt	Grade 5 – Galvanized	Custom
a7	8	5/16"[7.9]Dia. Heavy Hex Nut	Grade 5 – Galvanized	–
a8	8	5/16"[7.9]Dia. Washer	SAE FW 5/16" – Galvanized	–
a6	2	ø3/4" [19.1] 3x7 Cable	Cl A Galvanized Cable Guiderail	Reused from 4CMB–3
a10	4	0.25" – 20 UNC Hex Nut High Topped	Grade 8 – Galvanized	–

Midwest Roadside Safety Facility

High Tension Cable Clip

Bill of Materials

SHEET: 11 of 11

DATE: 5/11/2011

DRAWN BY: RJT/MDM/JGP

REV. BY: RWB/KAL

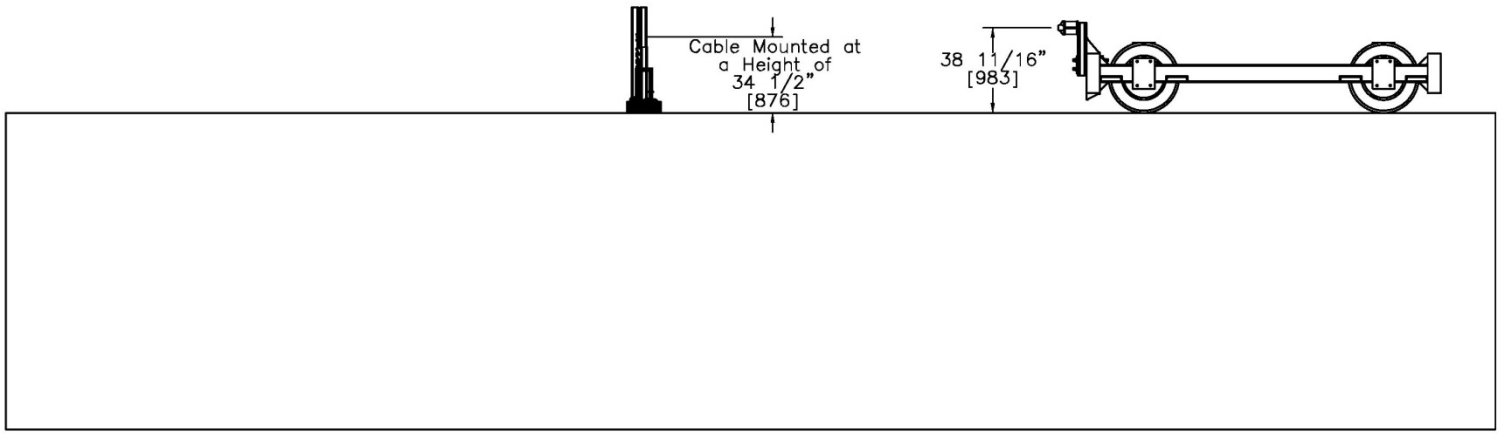
DWG. NAME. HTCC–3–5_R5

SCALE: None

UNITS: Inches [mm]

Figure A-54. Bill of Materials, Test Nos. HTCC-3, HTCC-4, and HTCC-5

Test No.	Bogie Speed	Impact Orientation	Bogie No.	Approximate Bogie Test Weight
HTCC-6	17 mph [27.4 kph]	Normal to the Cable	2	4,800 lb [2,177 kg]



Notes: (1) Posts are to be installed using the auger and backfill method in ø18" [457] holes with NCHRP 350 soil (same installation as the 4CMB tests).

(2) Place one high-speed camera on the left side of impact and one on the right side of impact perpendicular to the side of the post for test documentation.

(3) Install the EDR-3 for data acquisition on the bogie.

MwRSF	High Tension Cable Clip		SHEET: 1 of 6
	Impact		DATE: 8/13/2010
			DRAWN BY: MJW/MDM
Midwest Roadside Safety Facility	DWG. NAME. HTCC-6_R3	SCALE: 1:70 UNITS: Inches [mm]	REV. BY: KAL

Figure A-55. Cable and Bogie Head Heights, Test No. HTCC-6

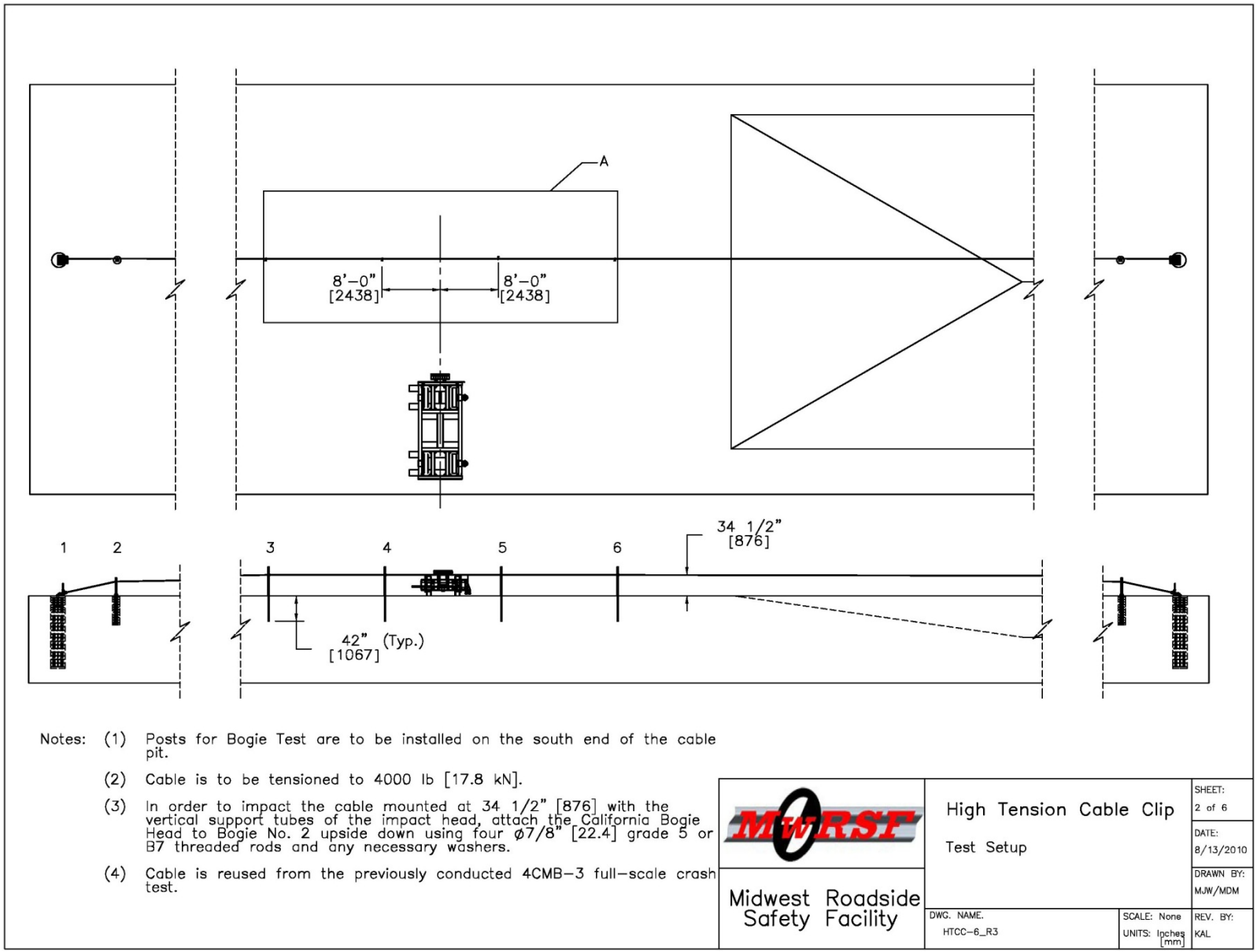


Figure A-56. Test Setup, Test No. HTCC-6

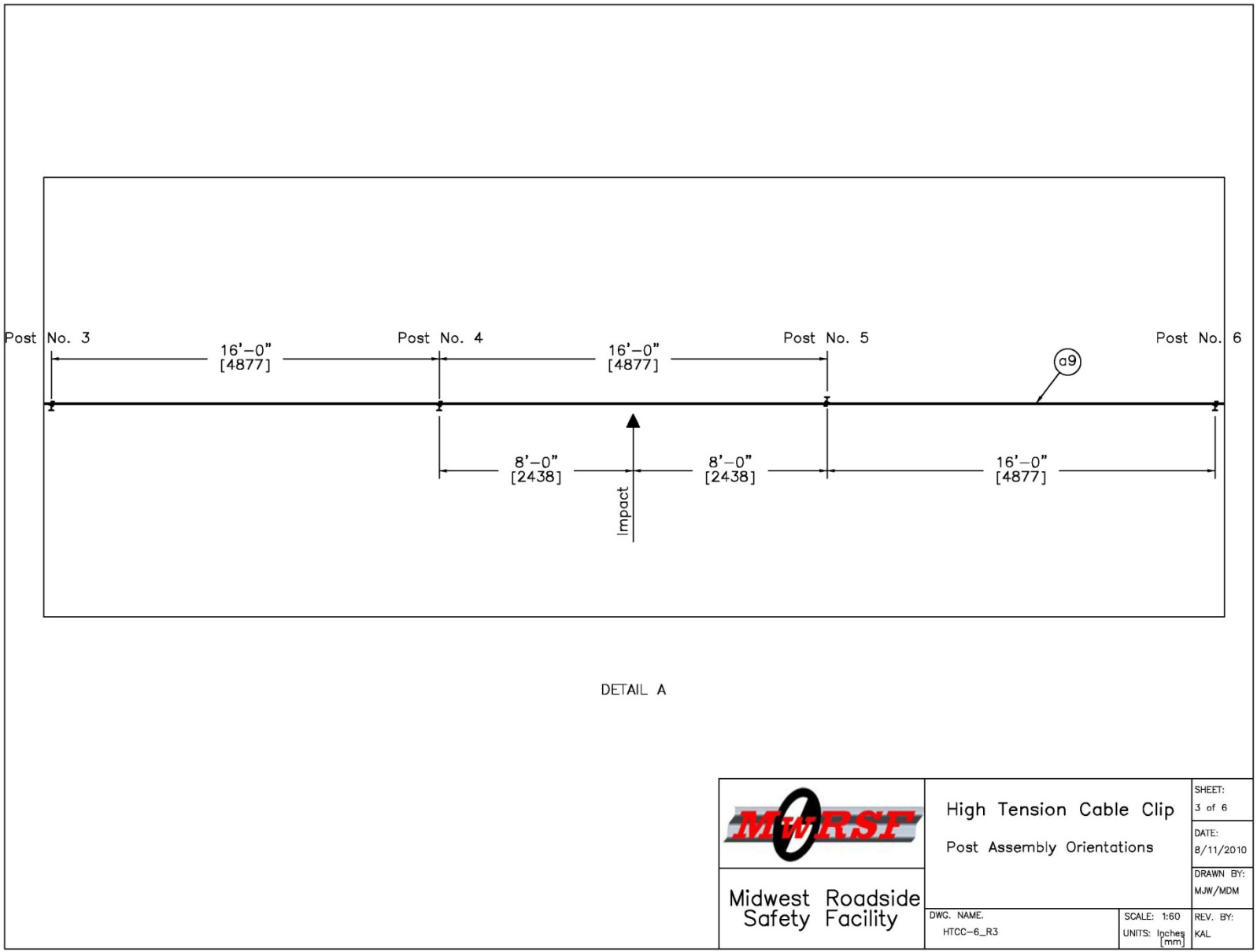


Figure A-57. Detail A, Test No. HTCC-6

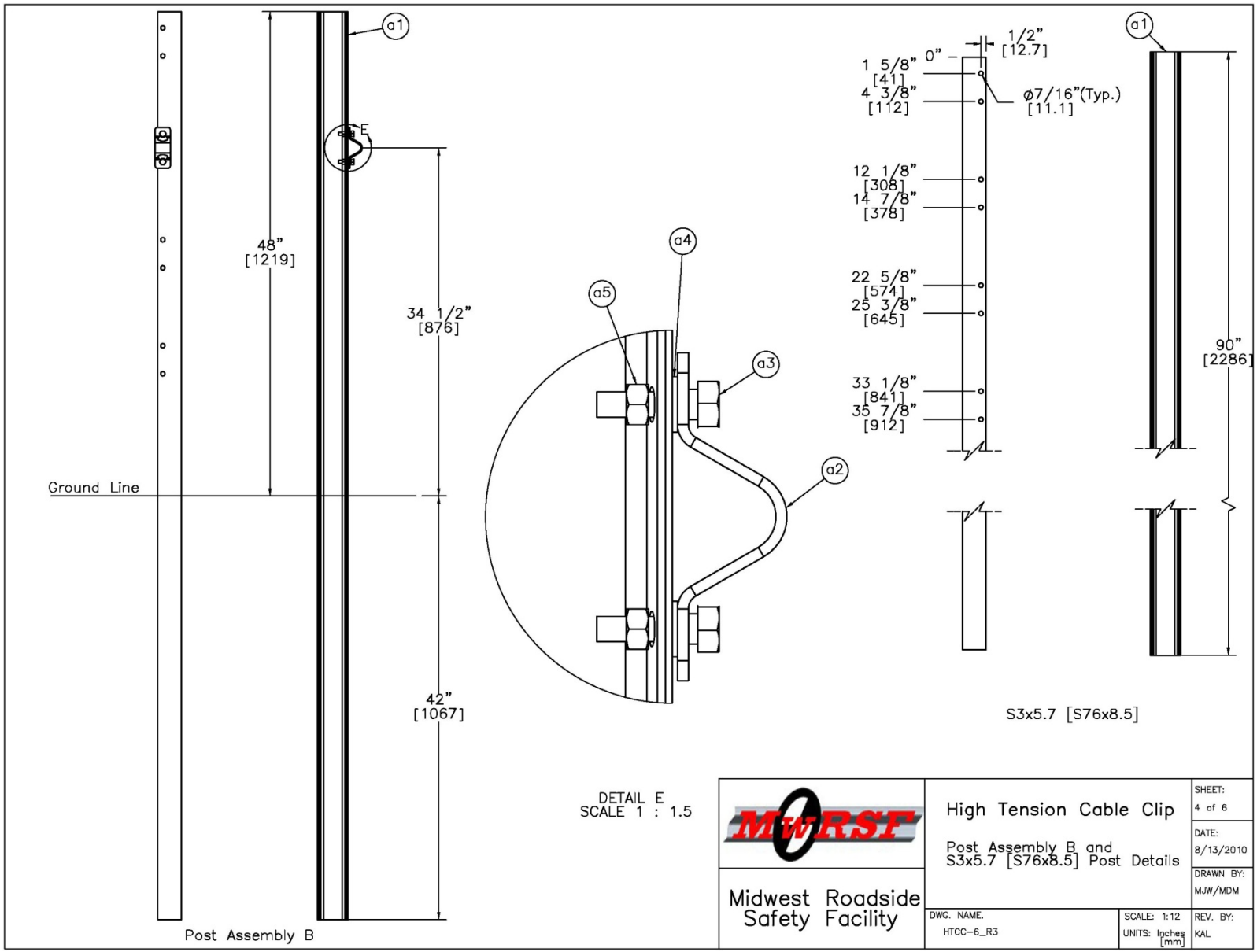


Figure A-58. Post Assembly, Test No. HTCC-6

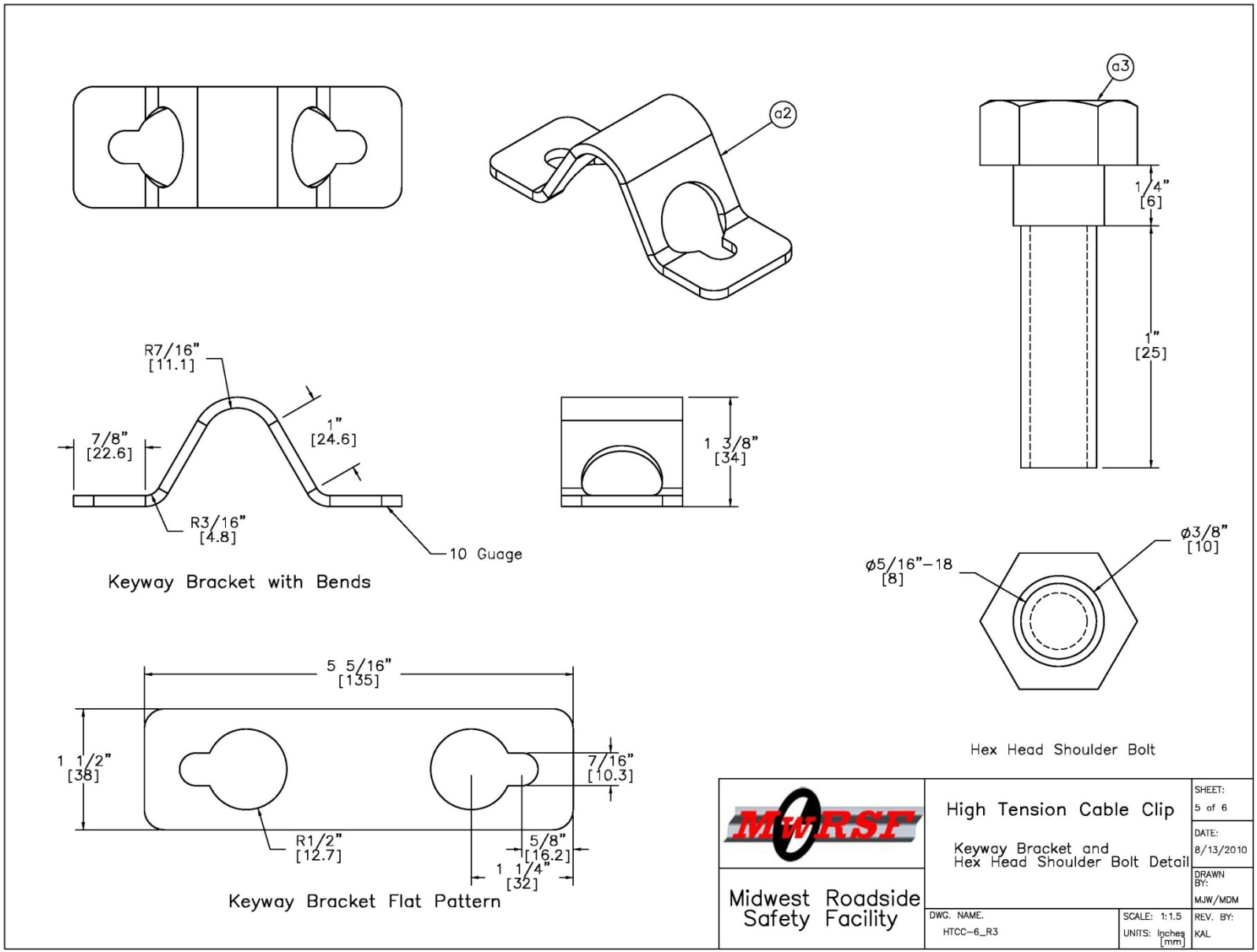


Figure A-59. Keyway Bracket and Bolt Detail, Test No. HTCC-6

HTCC–6 Bill of Materials				
Item No.	QTY.	Description	Material Spec	Comments
a1	4	S3x5.7 [S76x8.5] by 90"[2286]	ASTM A36	–
a2	4	Keyway Bracket	ASTM A36 – 10 Gauge, Galvanized	–
a3	8	5/16" [7.9] Dia. Hex Head Shoulder Bolt	Grade 5 – Galvanized	Custom
a4	8	5/16" [7.9] Dia. Washer	SAE FW 5/16" – Galvanized	–
a5	8	5/16" [7.9] Dia. Heavy Hex Nut	Grade 5 – Galvanized	–
a6	1	ø3/4"[19.1] 3x7 Cable	Cl A Galvanized Cable Guiderail	Reused from 4CMB–3

Midwest Roadside Safety Facility

High Tension Cable Clip

Bill of Materials

SHEET: 6 of 6

DATE: 8/11/2010

DRAWN BY: MJW/MDM

REV. BY: KAL

DWG. NAME. HTCC–6_R3

SCALE: None

UNITS: Inches [mm]

Figure A-60. Bill of Materials, Test No. HTCC-6

Appendix B. Material Specifications

Amanda Bent Bolt Co.

1120 C.I.C. Drive Logan, Ohio 43138
Phone: 740-385-9380 x 322
Fax: 740-385-6872 or 740-385-5445
E-Mail: thorton@abb1.com

CERTIFICATION OF CONFORMANCE

SHIP TO: Bennett Bolt
12 Elbridge Street
Jordan, New York 13080
Attn: Quality

Part Number:	BUA25-UW-M
Part Name:	1/4-20 Angle U-Bolt
Print Revision:	
Print Revision Date:	5/3/2009
PO Number	6005570
Date of Shipment:	7/15/2009
Quantity Shipped:	529
Lot Number:	070801

We hereby certify that the supplies furnished in this shipment have been inspected and have passed all examinations and testing. The material meets print requirements and specifications or other requirements as stated in the purchase order. Results of these inspections and tests are on file and will be furnished upon request.

Tammy Horton	Q.A. Manager	7/15/2009
Authorizing Person's Name	Authorizing Person's Title	Date

Authorizing Person's Signature

Figure B-1. Grade 2 Keyway Bolt Specifications, Test Nos. HTCUB-1 through HTCUB-30, HTCC-1, and HTCC-2

LOAD

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

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

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

Jd. 6-9-2010

Amanda Bent Bolt Co.
P.O. Box 1027
1120 CIC Drive
Logan,OH 43138-
Attn: Tammy Horton, QC

Cust. P.O.	7956-1
Cust Part#	
Charter Sales Order	278967
Heat #	555431
Ship Lot #	598009
Grade#	1018 A AK FG IQ
Process	CC
Finish Size	.265 17/64

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side, and that it satisfies those requirements.

Test Results of Heat Lot# 555431

Lab Code: 7388
OUTS. MELT SOURCE HEAT NUM. = N/R

Chemistry	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
Wt%	0.18	0.82	0.008	0.015	0.080	0.05	0.10	0.02	0.09	0.006	0.001

AL	N	B	TI	NB
0.024	0.0080	0.0001	0.001	0.001

CHEM. DEVIATION EXT.-GREEN = N/R

Test Results of Rolling Lot # 405135

QC DEVIATION EXT.-GREEN = N/R

Test Results of Processing Lot # 598009

QC DEVIATION EXT.-PROCESSED = N/R

Specifications: Manufactured per Charter Steel Quality Manual Rev 8, 12-05-07
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = Revision = Dated =

Additional Comments: PHOSPHATE COATING

SEP 12 2008

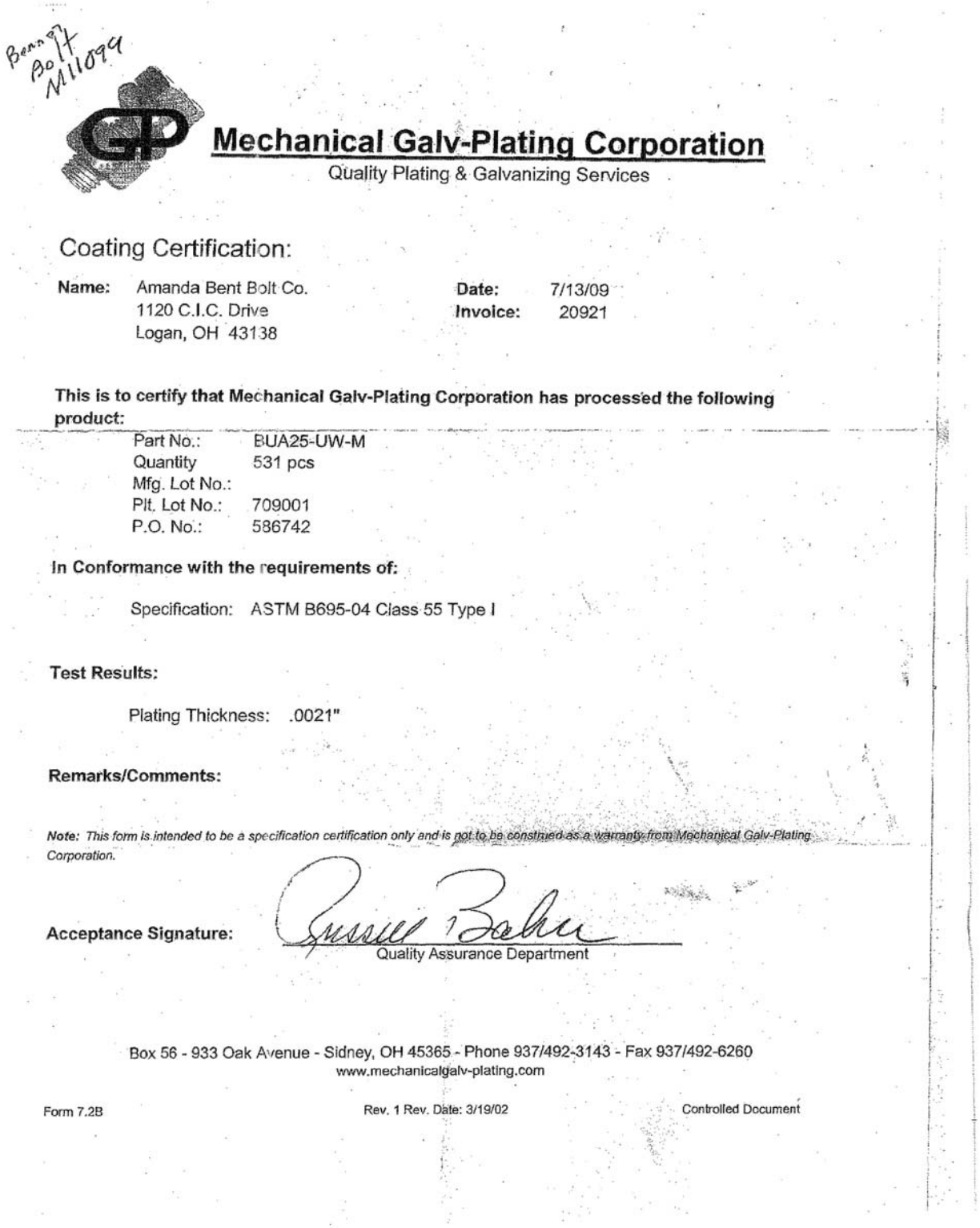
Charter Steel
Saukville, WI, USA

ACCREDITED

Janice Barnard
Manager of Quality Assurance
09/11/2008

Page 1 of 1

Figure B-2. Grade 2 Keyway Bolt Specifications, Test Nos. HTCUB-1 through HTCUB-30, HTCC-1, and HTCC-2



Bent Bolt M11099

Mechanical Galv-Plating Corporation
Quality Plating & Galvanizing Services

Coating Certification:

Name: Amanda Bent Bolt Co.
1120 C.I.C. Drive
Logan, OH 43138

Date: 7/13/09
Invoice: 20921

This is to certify that Mechanical Galv-Plating Corporation has processed the following product:

Part No.:	BUA25-UW-M
Quantity	531 pcs
Mfg. Lot No.:	
Plt. Lot No.:	709001
P.O. No.:	586742

In Conformance with the requirements of:

Specification: ASTM B695-04 Class 55 Type I

Test Results:

Plating Thickness: .0021"

Remarks/Comments:

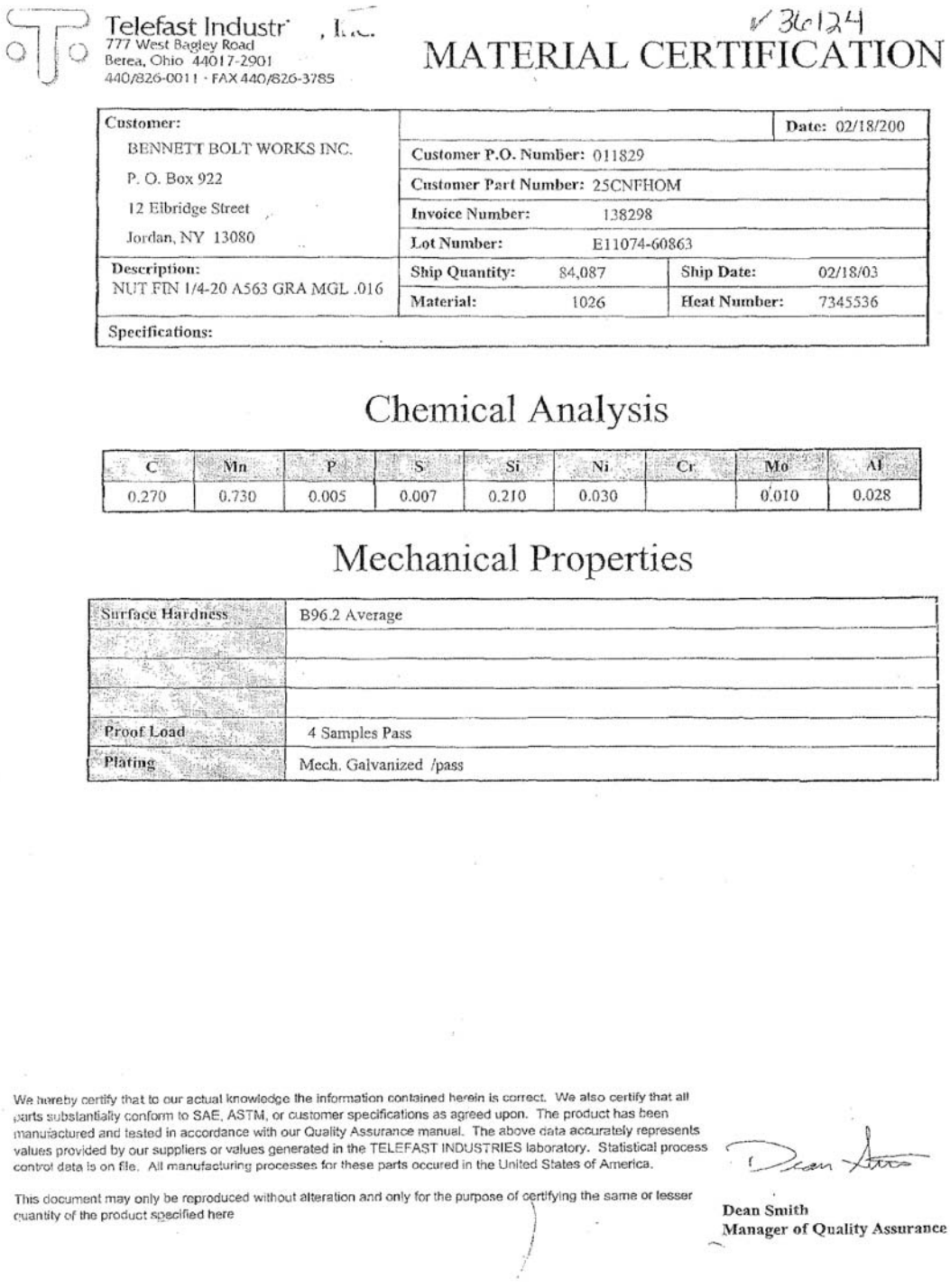
Note: *This form is intended to be a specification certification only and is not to be construed as a warranty from Mechanical Galv-Plating Corporation.*

Acceptance Signature: Russell Bohn
Quality Assurance Department

Box 56 - 933 Oak Avenue - Sidney, OH 45365 - Phone 937/492-3143 - Fax 937/492-6260
www.mechanicalgalv-plating.com

Form 7.2B Rev. 1 Rev. Date: 3/19/02 Controlled Document

Figure B-3. Grade 2 Keyway Bolt Specifications, Test Nos. HTCUB-1 through HTCUB-30, HTCC-1, and HTCC-2



Telefast Industr , Inc.
777 West Bagley Road
Berea, Ohio 44017-2901
440/826-0011 · FAX 440/826-3785

V 36124

MATERIAL CERTIFICATION

Customer: BENNETT BOLT WORKS INC. P. O. Box 922 12 Elbridge Street Jordan, NY 13080			**Date:** 02/18/200
	Customer P.O. Number: 011829		
	Customer Part Number: 25CNFHOM		
	Invoice Number: 138298		
	Lot Number: E11074-60863		
Description: NUT FIN 1/4-20 A563 GRA MGL .016	**Ship Quantity:** 84,087	**Ship Date:**	02/18/03
	Material: 1026	**Heat Number:**	7345536
Specifications:			

Chemical Analysis

C	Mn	P	S	Si	Ni	Cr	Mo	Al
0.270	0.730	0.005	0.007	0.210	0.030		0.010	0.028

Mechanical Properties

Surface Hardness	B96.2 Average
Proof Load	4 Samples Pass
Plating	Mech. Galvanized /pass

We hereby certify that to our actual knowledge the information contained herein is correct. We also certify that all parts substantially conform to SAE, ASTM, or customer specifications as agreed upon. The product has been manufactured and tested in accordance with our Quality Assurance manual. The above data accurately represents values provided by our suppliers or values generated in the TELEFAST INDUSTRIES laboratory. Statistical process control data is on file. All manufacturing processes for these parts occured in the United States of America.

This document may only be reproduced without alteration and only for the purpose of certifying the same or lesser quantity of the product specified here

Dean Smith
Manager of Quality Assurance

Figure B-4. Grade 2 Nut Specifications, Test Nos. HTCUB-1 through HTCUB-16, HTCUB-21 through HTCUB-30, HTCC-1, and HTCC-2

To:TOM TIMCHAK From:LORAIN HOT ROLL 24-Apr-02 10:45 page 1 of 2

Republic
TECHNOLOGIES INTERNATIONAL

1807 EAST 28TH ST. LORAIN, OH 44055
PHONE: 330-438-5658 FAX: 330-438-5656

CERTIFICATE OF TESTS REPUBLIC TECHNOLOGIES INTERNATIONAL APRIL 24, 2002
PAGE: 1 OF 2

PURCHASE ORDER: 18426 PURCHASE ORDER DATE: 01/04/02
PART NUMBER : M1026SF0390 ACCOUNT NUMBER . . : 7378010I
ORDER NUMBER: 05-45059-07 403 SCHEDULE . . . . . : 05419-81
HEAT . . . . : 7345536

==== CHARGE ADDRESS ==== SHIP TO ====

TELEFAST INDUSTRIES INC
777 WEST BAGLEY RD
BEREA OH 440172901

TELEFAST INDUSTRIES INC
TOM TIMCHAK
777 WEST BAGLEY RD
BEREA OH 440172901

---------- MATERIAL DESCRIPTION ----------
COLD FINISHED STEEL COILS CARBON TELEFAST SPEC TMS-1026 REV 5.2 DTD 05/24/93
TELEFAST SPEC CODE M1026SF0390 DTD 03/10/92 EXC HARD ASTM A 576-90B AISI-1026
SI K FINE GRAIN COLD WORK Q COLD DRAWN SPHERO A PICKLE LIME COAT REST CHEM

SIZE: RDS .39 X COILS
COIL WT 2500 LB ID 32 MN OD 47 MX

---------- LADLE CHEMISTRY ----------

C	MN	P	S	SI	CU	NI	CR	MO	AL
0.27	00.73	.005	.007	0.21	0.04	00.03	00.04	0.01	00.028

V	N	CB	SN
0.005	.0049	0.001	.001

---------- SEMI-FINISH RESULTS ----------
AUSTENITIC GRAIN SIZE
AUST GRAIN SZ 7.

---------- FINISH SIZE RESULTS SCHEDULE: 0541981 ----------
HEAT TREAT ROCKWELL ASTM E18 ASTM A370
PCE 01 MIDRADIUS 74.0 SCALE B

REDUCTION RATIO 300.5 TO 1

---------- NOTES ----------
MELT SOURCE: RTI-LORAIN
MELT COUNTRY: U.S.A.
HOT ROLL SRCE: RTI-LORAIN
HOT ROLL COUNTRY: U.S.A.
MELT METHOD: STRAND CAST

CHEMICAL ANALYSIS IS DETERMINED BY METHODS DEFINED IN THE
APPLICABLE SPECIFICATIONS OF ASTM E415, E1019, E1085

REPUBLIC TECHNOLOGIES INTERNATIONAL LORAIN HOT ROLLED BAR PLANT IS
QS-9000 REGISTERED.

REPUBLIC TECHNOLOGIES INTERNATIONAL HEREBY CERTIFY THAT THE MATERIAL
LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE
METHODS PRESCRIBED IN THE GOVERNING SPECIFICATION AND BASED UPON THE
RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR
CONFORMANCE TO THE SPECIFICATION.

CERTIFICATION OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL

THE MATERIAL WAS NOT EXPOSED TO MERCURY OR ANY METAL ALLOY THAT IS
LIQUID AT AMBIENT TEMPERATURE DURING PROCESSING OR WHILE IN OUR
POSSESSION. NO WELDING OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL

ALL TESTING HAS BEEN PERFORMED USING THE CURRENT REVISION OF THE
TESTING SPECIFICATION

MATERIAL IS OF U. S. ORIGIN AND WAS MELTED AND MANUFACTURED IN THE
U.S.A.

----- END OF DATA ---------- CC ---------- END OF DATA -----
FAX BY FAX PC | COPY ATTENTION TOM TIMCHAK 440-826-3785
FILE | COPY

R. A. BULLOCK BY D. STOKES
DIRECTOR QUAL ASSURANCE

R. A. Bullock

Figure B-5. Grade 2 Nut Specifications, Test Nos. HTCUB-1 through HTCUB-16, HTCUB-21 through HTCUB-30, HTCC-1, and HTCC-2

To:TOM TIMCHAK From:LORAIN HOT ROLL 24-Apr-02 10:45 page 2 of 2

Republic
TECHNOLOGIES INTERNATIONAL

1807 EAST 28TH ST. LORAIN, OH 44055
PHONE: 330-438-5658 FAX: 330-438-5656

CERTIFICATE OF TESTS REPUBLIC TECHNOLOGIES INTERNATIONAL APRIL 24, 2002
PAGE: 2 OF 2

PURCHASE ORDER: 18426 PURCHASE ORDER DATE: 01/04/02
PART NUMBER : MI026SF0390 ACCOUNT NUMBER . . : 73780101
ORDER NUMBER: 05-45059-07 403 SCHEDULE . . . . . : 05419-81
HEAT . . . . : 7345536

----- END OF DATA ---------- CC (CONTINUED) ---------- END OF DATA -----
WITH SHIPMENT 1 COPY PRINTED AT SHIPPING AREA

R. A. BULLOCK BY D. STOKES
DIRECTOR QUAL ASSURANCE

R. A. Bullock

Figure B-6. Grade 2 Nut Specifications, Test Nos. HTCUB-1 through HTCUB-16, HTCUB-21 through HTCUB-30, HTCC-1, and HTCC-2

Amanda Bent Bolt Co.

1120 C.I.C. Drive Logan, Ohio 43138
Phone: 740-385-9380 x 322
Fax: 740-385-6872 or 740-385-5445
E-Mail: thorton@abb1.com

CERTIFICATION OF CONFORMANCE

SHIP TO: Bennett Bolt
12 Elbridge Street
Jordan, New York 13080
Attn: Quality

Part Number:	BUA25-UW-M
Part Name:	1/4-20 Angle U-Bolt
Print Revision:	
Print Revision Date:	5/3/2009
PO Number	6006500
Date of Shipment:	3/13/2010
Quantity Shipped:	500
Lot Number:	031101

We hereby certify that the supplies furnished in this shipment have been inspected and have passed all examinations and testing. The material meets print requirements and specifications or other requirements as stated in the purchase order. Results of these inspections and tests are on file and will be furnished upon request.

Tammy Horton	Q.A. Manager	4/1/2010
Authorizing Person's Name	Authorizing Person's Title	Date

Authorizing Person's Signature

Figure B-7. Grade 2 Keyway Bolt Specifications, Test No. HTCC-3

Republic ENGINEERED PRODUCTS
1807 EAST 28TH ST.
PHONE: 330-438-5694
LORAIN, OH 44055
FAX: 330-438-5695

CERTIFICATE OF TESTS — REPUBLIC ENGINEERED PRODUCTS — August 20, 2009
PAGE 1

OF 1

PURCHASE ORD:	8828	PURCHASE ORDER DATE:	7/1/2009
PART NUMBER:	296C1800	ACCOUNT NUMBER:	6475-3381-01
ORDER NUMBER:	1414224 - 01	SCHEDULE:	9074-86
HEAT:	5072404	REVISION:	1

CHARGE ADDRESS

AMANDA BENT BOLT
1120 CIC DRIVE
ATTN PURCHASING 7403859380
LOGAN, OH 43138-4027

SHIP TO

AMANDA BENT BOLT
Tammy Horton
1120 CIC DRIVE
LOGAN, OH 43138-4027

MATERIAL DESCRIPTION

HOT ROLLED STEEL COILS CARBON AISI-1018 AK AL KILLED FINE GRAIN COLD WORKING QUALITY CLEANED PICKLE & LIME RESTRICTED CHEMISTRY
SIZE: RDS .2960 DIAM X COIL
RDS 7.5184MM DIAM X COIL

LADLE CHEMISTRY %

C	MN	P	S	SI	CU	NI	CR
0.16	0.76	0.010	0.006	0.10	0.08	0.08	0.06
V	MO	SN	AL	CB	N		
0.000	0.02	0.004	0.037	0.000	0.0090		

CALCULATED TESTS

REDUCTION RATIO 519.9 TO 1

AUSTENITIC GRAIN SIZE 5 OR FINER BASED ON A TOTAL ALUMINUM CONTENT EQUAL TO OR GREATER THAN .020% PER ASTM A29.

SEMI - FINISHED RESULTS

FINISHED SIZE RESULTS

NOTES

CHEMICAL ANALYSIS CONFORMS TO APPLICABLE SPECS: ASTM E415, LBL10129, LBL10130, ASTM E1019, LBL10158, LBL10114, AND ASTM E1085, LBL10184, LBL10188.

REPUBLIC ENGINEERED PRODUCTS HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

CERTIFICATE OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL.

ALL TESTING HAS BEEN PERFORMED USING THE CURRENT REVISION OF THE TESTING SPECIFICATIONS.

RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELONY UNDER FED STATUES TITLE 18 CHAPTER 47.

THE MATERIAL WAS NOT EXPOSED TO MERCURY OR ANY METAL ALLOY THAT IS LIQUID AT AMBIENT TEMPERATURE DURING PROCESSING OR WHILE IN OUR POSSESSION.

NO WELD OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL.

THE RESULTS REPORTED RELATE ONLY TO THE ITEMS TESTED

SOURCE INFORMATION

MELT SOURCE: CANTON FLEX CASTER MELT COUNTRY: U.S.A HOT ROLL SOURCE: LORAIN 9/10, U.S.A
MELT METHOD: EF BILLET RED. RATIO: 519.9

END OF DATA — CC — END OF DATA

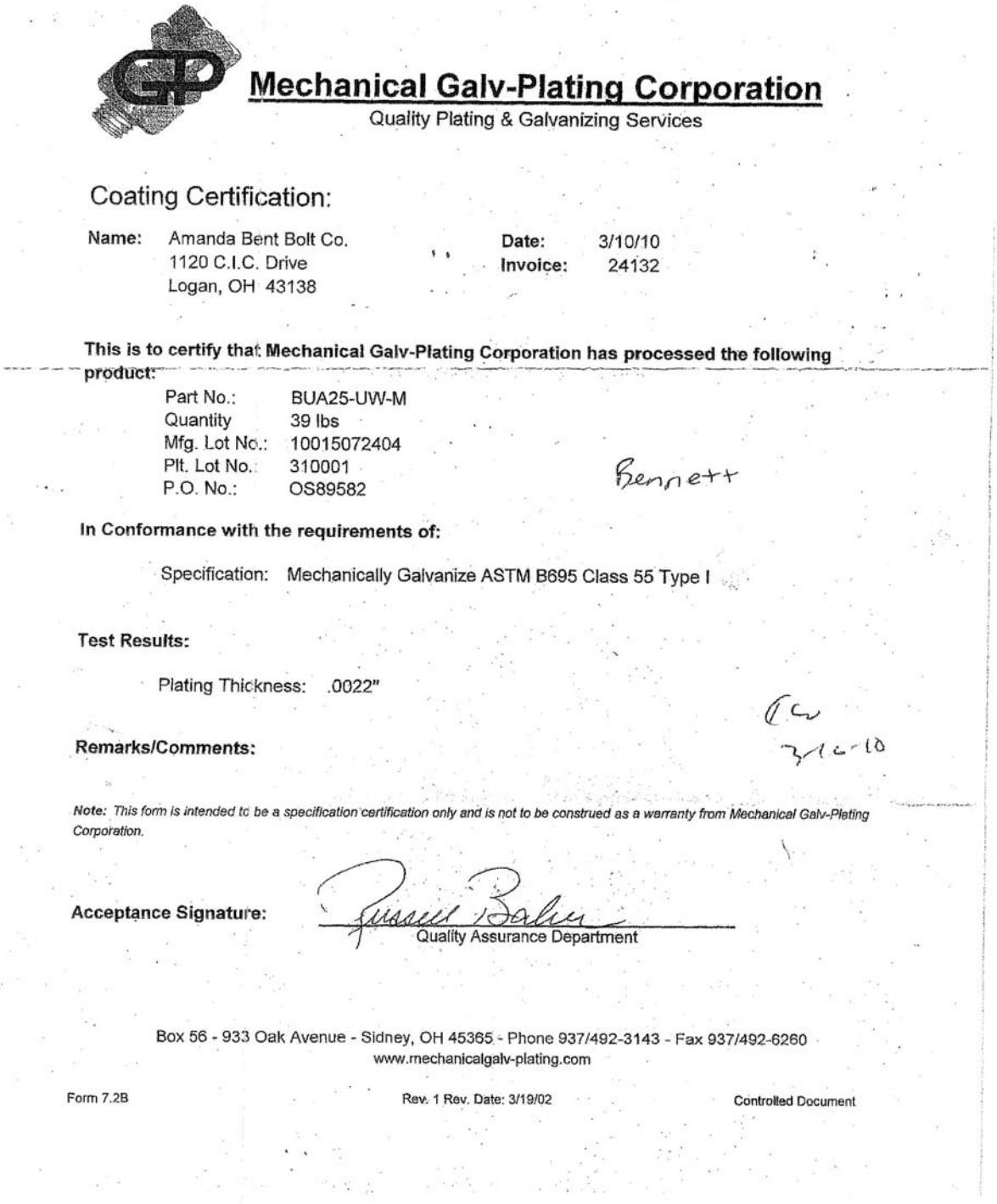
FILE 1 COPY

R. A. SZELIGA
MANAGER TECH. SERVICES
R. A. Szeliga

BY HILDA BEGUE

AUG 21 2009

Figure B-8. Grade 2 Keyway Bolt Specifications, Test No. HTCC-3



Mechanical Galv-Plating Corporation
Quality Plating & Galvanizing Services

Coating Certification:

Name: Amanda Bent Bolt Co.
1120 C.I.C. Drive
Logan, OH 43138

Date: 3/10/10
Invoice: 24132

This is to certify that Mechanical Galv-Plating Corporation has processed the following product:

Part No.:	BUA25-UW-M
Quantity	39 lbs
Mfg. Lot No.:	10015072404
Plt. Lot No.:	310001
P.O. No.:	OS89582

Bennett

In Conformance with the requirements of:

Specification: Mechanically Galvanize ASTM B695 Class 55 Type I

Test Results:

Plating Thickness: .0022"

Remarks/Comments:

3/16-10

Note: This form is intended to be a specification certification only and is not to be construed as a warranty from Mechanical Galv-Plating Corporation.

Acceptance Signature: Quality Assurance Department

Box 56 - 933 Oak Avenue - Sidney, OH 45365 - Phone 937/492-3143 - Fax 937/492-6260
www.mechanicalgalv-plating.com

Form 7.2B Rev. 1 Rev. Date: 3/19/02 Controlled Document

Figure B-9. Grade 2 Keyway Bolt Specifications, Test No. HTCC-3

Amanda Bent Bolt Co.

1120 C.I.C. Drive Logan, Ohio 43138
Phone: 740-385-9380 x 322
Fax: 740-385-6872 or 740-385-5445
E-Mail: thorton@abb1.com

CERTIFICATION OF CONFORMANCE

SHIP TO: Bennett Bolt
12 Elbridge Street
Jordan, New York 13080
Attn: Quality

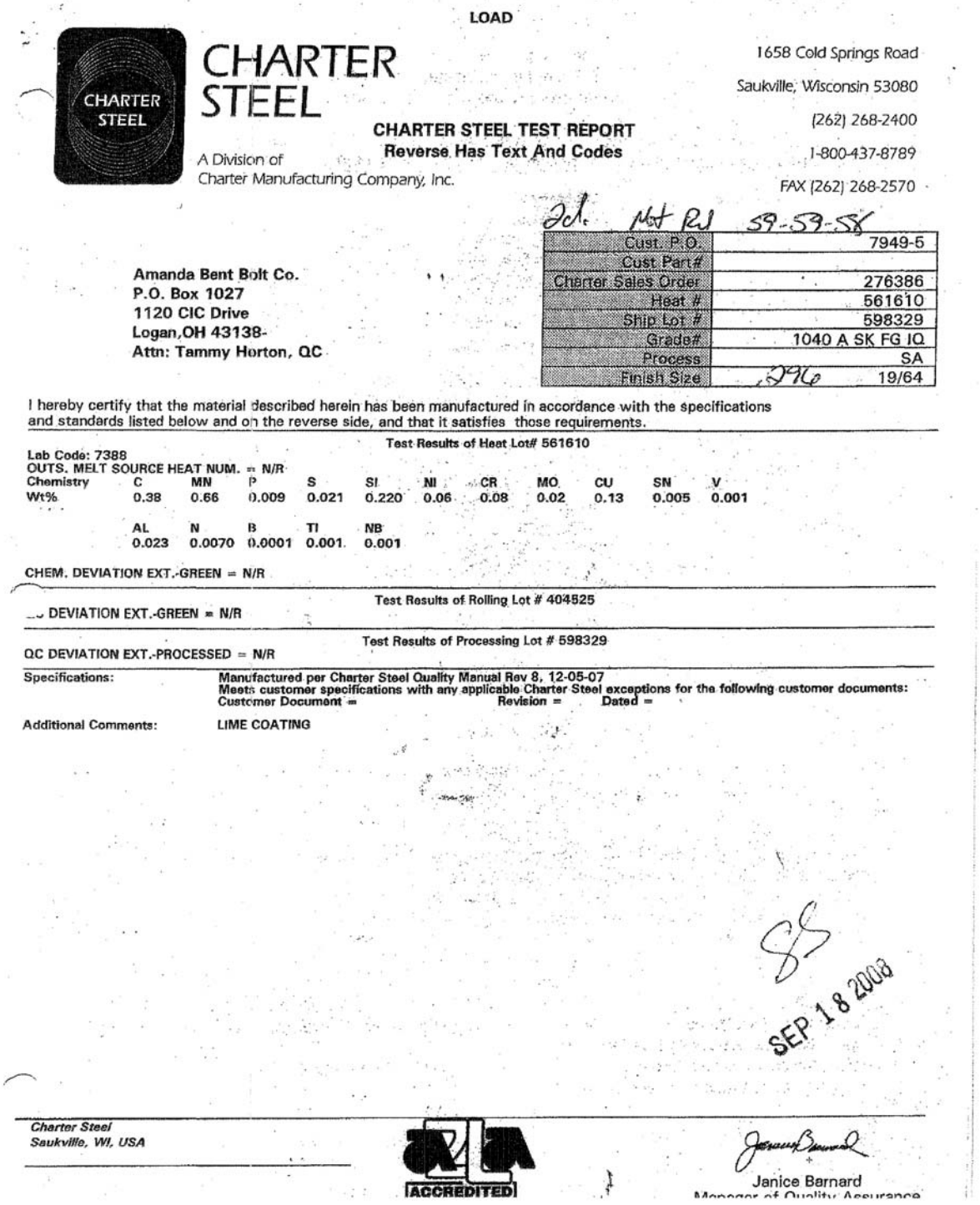
Part Number:	BUA25-UW-M-A449
Part Name:	Custom Bolt and Nut
Print Revision:	
Print Revision Date:	
PO Number	6006500
Date of Shipment:	3/25/2010
Quantity Shipped:	556
Lot Number:	032501

We hereby certify that the supplies furnished in this shipment have been inspected and have passed all examinations and testing. The material meets print requirements and specifications or other requirements as stated in the purchase order. Results of these inspections and tests are on file and will be furnished upon request.

Tammy Horton	Q.A. Manager	4/1/2010
Authorizing Person's Name	Authorizing Person's Title	Date

Tammy L. Horton
Authorizing Person's Signature

Figure B-10. A449 Keyway Bolt and Grade 8 Nut Specifications, Test Nos. HTCUB-31 through HTCUB-37, and HTCC-3 through HTCC-5



LOAD

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

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

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

2cl. Mat RJ 59-59-58

Cust. P.O.	7949-5
Cust Part#	
Charter Sales Order	276386
Heat #	561610
Ship Lot #	598329
Grade#	1040 A SK FG IQ
Process	SA
Finish Size	.596 19/64

Amanda Bent Bolt Co.
P.O. Box 1027
1120 CIC Drive
Logan,OH 43138-
Attn: Tammy Horton, QC

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side, and that it satisfies those requirements.

Test Results of Heat Lot# 561610

Lab Code: 7388
OUTS. MELT SOURCE HEAT NUM. = N/R

Chemistry	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
Wt%	0.38	0.66	0.009	0.021	0.220	0.06	0.08	0.02	0.13	0.005	0.001

AL	N	B	TI	NB
0.023	0.0070	0.0001	0.001	0.001

CHEM. DEVIATION EXT.-GREEN = N/R

Test Results of Rolling Lot # 404525

DEVIATION EXT.-GREEN = N/R

Test Results of Processing Lot # 598329

QC DEVIATION EXT.-PROCESSED = N/R

Specifications: Manufactured per Charter Steel Quality Manual Rev 8, 12-05-07
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = Revision = Dated =

Additional Comments: LIME COATING

SEP 18 2008

Charter Steel
Saukville, WI, USA

ACCREDITED

Janice Barnard
Manager of Quality Assurance

Figure B-11. A449 Keyway Bolt and Grade 8 Nut Specifications, Test Nos. HTCUB-31 through HTCUB-37, and HTCC-3 through HTCC-5

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled and processed in the United States.
2. Mercury was not used during the manufacture of this product; nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	**CSMD**	Charter Steel Melting Division	1658 Cold Springs Road, Saukville, WI 53080
0358-02	8171	**CSRD/ CSPD**	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	**P4**	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	**CSC**	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
0358.05	128003	**CSDT**	Charter Steel Detroit	23860 Sherwood Ave. Center Line, MI 48015
*	*	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Possible Laboratory	Specification
Chemistry Analysis	CSMD, CSC	ASTM E415; ASTM E1019
X-ray Fluorescence Stainless and Alloy Steel	CSC	ASTM E572
Macroetch	CSMD, CSC	ASTM E381
Hardenability (Jominy)	CSMD, CSC	ASTM A255; SAE J406; JIS G0561
Grain Size	CSMD	ASTM E112
Tensile Test	CSRD/CSPD, P4, CSC, CSDT	ASTM E8; ASTM A370
Rockwell Hardness	CSMD, CSRD/CSPD, P4, CSC, CSDT	ASTM E18; ASTM A370
Microstructure (spheroidization)	CSRD/CSPD, P4	ASTM A892
Inclusion Content (Methods A, E)	CSRD/CSPD, CSC	ASTM E45

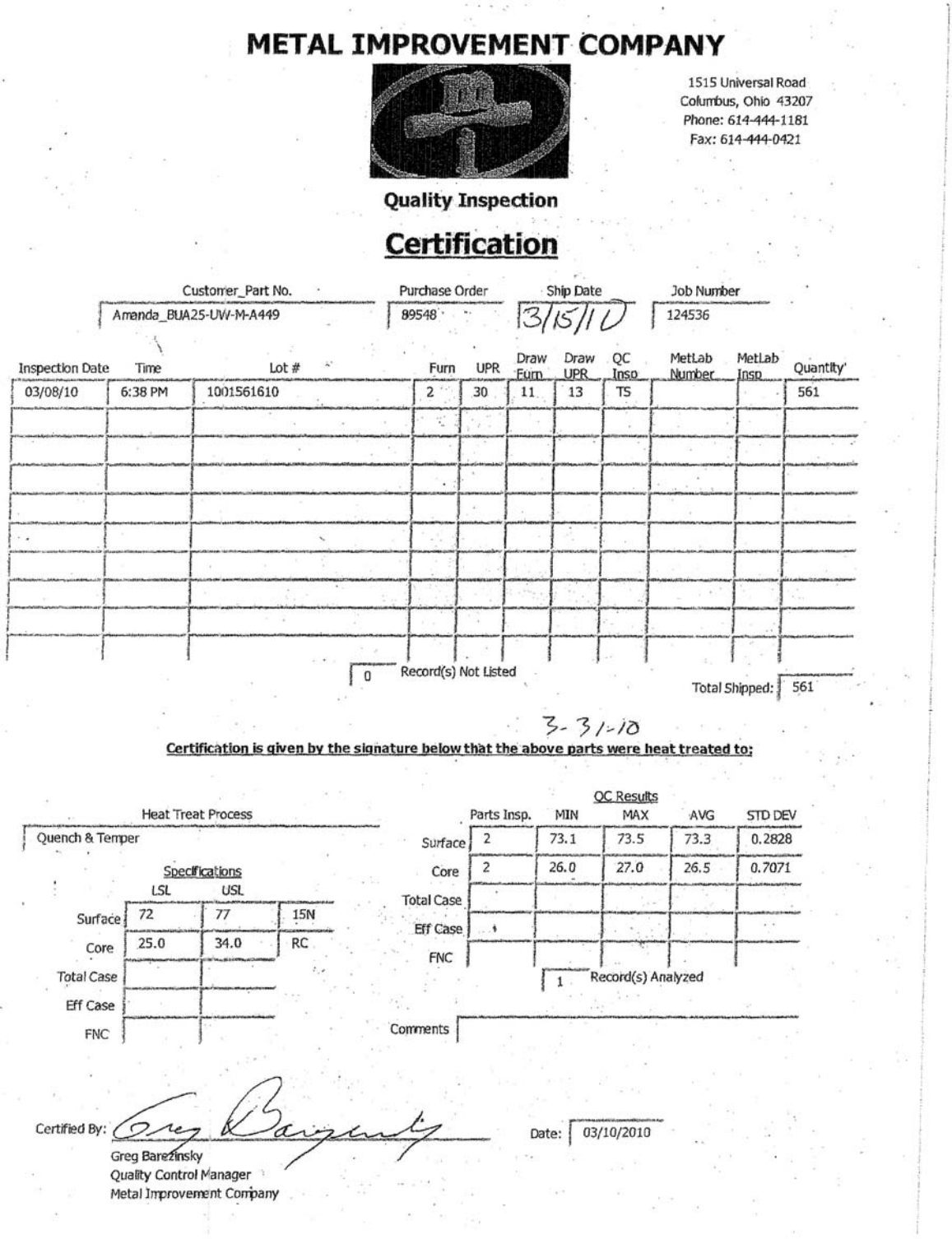
Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/09

All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report, subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgment (designated by our Sales Order number) to the customer's purchase order. Both Order numbers appear on the front page of this Report.
9. Where the customer has provided a specification, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

A2LA ACCREDITED
Testing Laboratory

Figure B-12. A449 Keyway Bolt and Grade 8 Nut Specifications, Test Nos. HTCUB-31 through HTCUB-37, and HTCC-3 through HTCC-5



METAL IMPROVEMENT COMPANY

1515 Universal Road
Columbus, Ohio 43207
Phone: 614-444-1181
Fax: 614-444-0421

Quality Inspection

Certification

Customer_Part No.	Purchase Order	Ship Date	Job Number
Amanda_BUA25-UW-M-A449	89548	3/15/10	124536

Inspection Date	Time	Lot #	Furn	UPR	Draw Furn	Draw UPR	QC Insp	MetLab Number	MetLab Insp	Quantity
03/08/10	6:38 PM	1001561610	2	30	11	13	TS			561

0 Record(s) Not Listed

Total Shipped: 561

3-31-10

Certification is given by the signature below that the above parts were heat treated to:

Heat Treat Process: Quench & Temper

Specifications	LSL	USL	
Surface	72	77	15N
Core	25.0	34.0	RC
Total Case			
Eff Case			
FNC			

QC Results

	Parts Insp.	MIN	MAX	AVG	STD DEV
Surface	2	73.1	73.5	73.3	0.2828
Core	2	26.0	27.0	26.5	0.7071
Total Case					
Eff Case					
FNC					

1 Record(s) Analyzed

Comments

Certified By: Greg Barezinsky

Date: 03/10/2010

Greg Barezinsky
Quality Control Manager
Metal Improvement Company

Figure B-13. A449 Keyway Bolt and Grade 8 Nut Specifications, Test Nos. HTCUB-31 through HTCUB-37, and HTCC-3 through HTCC-5

Mechanical Galv-Plating Corporation
Quality Plating & Galvanizing Services

Coating Certification:

Name: Amanda Bent Bolt Co.
1120 C.I.C. Drive
Logan, OH 43138

Date: 3/25/10
Invoice: 24341

This is to certify that Mechanical Galv-Plating Corporation has processed the following product:

Part No.: BUA25-UW-M
Quantity 556 pcs
Mfg. Lot No.: 1001561610
Plt. Lot No.: 310002
P.O. No.: OS89795

In Conformance with the requirements of:

Specification: Mechanically Galvanize ASTM B695 Class 55 Type I

Test Results:

Plating Thickness: .0022"

Remarks/Comments:

Note: This form is intended to be a specification certification only and is not to be construed as a warranty from Mechanical Galv-Plating Corporation.

Acceptance Signature: Russell Baker
Quality Assurance Department

Box 56 - 933 Oak Avenue - Sidney, OH 45365 - Phone 937/492-3143 - Fax 937/492-6260
www.mechanicalgalv-plating.com

Form 7.2B Rev. 1 Rev. Date: 3/19/02 Controlled Document

Figure B-14. A449 Keyway Bolt and Grade 8 Nut Specifications, Test Nos. HTCUB-31 through HTCUB-37, and HTCC-3 through HTCC-5

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