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CABLE-TO-POST ATTACHMENTS FOR A NON-PROPRIETARY HIGH-TENSION CABLE BARRIER – PHASE III

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16. Abstract

The objective of this study was to reevaluate and improve the existing cable-to-post attachment hardware that is utilized in the non-proprietary cable barrier being developed at MwRSF. The study focused on redesigning the bolted, tabbed bracket (V10) to eliminate the bolt, reduce the number of components per bracket, eliminate the need for tools during installation, and reduce the number of small parts. Three attachment concepts were selected for evaluation through dynamic testing: (1) the key plate attachment; (2) the wire lock pin attachment; and (3) the pinned back attachment. Each attachment prototype was subjected to two vertical and two lateral dynamic component tests to evaluate the release loads and fracture mechanisms of the brackets. Test results were compared to previous tests on the bolted tabbed bracket (V10).

None of the three bracket attachment designs were found to satisfy all of the design criteria for an alternative bracket. The lack of fixity in the connection between the brackets and the post led to a variable position of the tabs within the keyway which frequently caused unsatisfactory release loads. Therefore, none of the three alternative attachment brackets were recommended for use within the prototype non-proprietary cable barrier.

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UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration. Test nos. HTTB-49 through HTTB-60 were non-certified component tests conducted for research and development purposes only and are outside the scope of the MwRSF's A2LA Accreditation.

INDEPENDENT APPROVING AUTHORITY

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

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1 INTRODUCTION

1.1 Background

In 2012, the Midwest Roadside Safety Facility (MwRSF) conducted an expansive research and development effort that led to a new concept for a non-proprietary, four-cable median barrier system. The new cable barrier system consisted of three unique hardware pieces: 1) a new post fabricated from bent plate, now referred to as the Midwest Weak Post (MWP); 2) a new cable-to-post attachment bracket to be utilized on the lower three cables of the system; and 3) a new V-notch and brass rod cable attachment located on the top of the post [1-2]. The new cable-to-post attachment bracket was fabricated from 12-gauge (2.66-mm) steel, had a tabbed top portion that extended through a keyway in the post, and was attached to the post with a $^{5}/_{16}$-in. (8-mm) diameter bolt. The top of the tabbed bracket was designed to release through the keyway under relatively low vertical loading, approximately 300-400 lb (1.3-1.8 kN). However, when loaded laterally, the tabs would catch the narrow portion of the keyway and provide over 6 kips (26.7 kN) of resistance. The bolted, tabbed bracket (Version 10) is shown in Figures 1 and 2.

Figure 1. Bolted, Tabbed Bracket on MWP

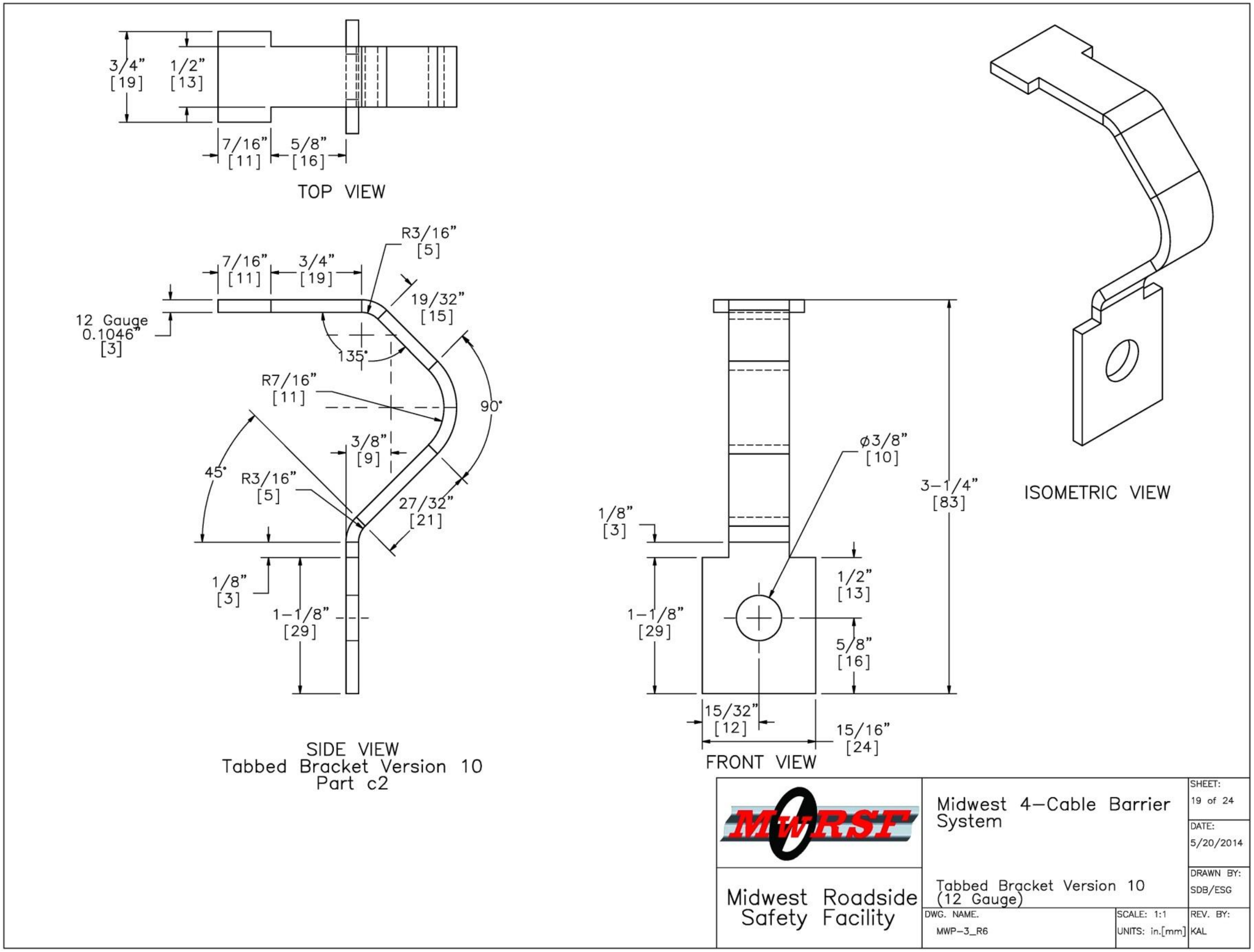

Figure 2. Bolted, Tabbed Bracket V-10, Design Details

Although the new design for the four-cable median barrier seemed promising, a few sponsor states voiced concerns for the bolted, tabbed bracket. Specifically, there were concerns that installation may become cumbersome because each bolted, tabbed bracket required three separate pieces and a tool (wrench/socket) to install. Further, it was thought that the small nut and bolt may be difficult to handle during winter months when workers wear gloves to protect their hands. Thus, there was a need to develop an alternative attachment method for the tabbed brackets that would perform the same as the bolted attachment but simplify the installation process.

In April of 2013, the project sponsors elected to conduct an alternative attachment study [3]. However, in the interest of time, this study was conducted in parallel with full-scale crash testing on the new four-cable barrier system utilizing the bolted, tabbed bracket. If the system performed satisfactorily in the full-scale tests, and the new brackets behaved similar to the bolted, tabbed brackets, it was believed that either bracket design would be acceptable for use within the system.

The alternative attachment study consisted of the concept development of over 25 different bracket and attachment designs. Ultimately, two alternate attachment designs, the lateral shear plate design and the drop-in shear plate design, were selected for evaluation through dynamic component testing. These bracket designs are illustrated in Figures 3 through 6, and the results of these component tests are summarized in Table 1. Unfortunately, neither of the alternative attachment designs performed as well as the original bolted, tabbed bracket. The drop-in shear plate design provided a lateral release load that was 10 percent below the desired release load. Additionally, the bracket was loosely attached to the post, which allowed it to rotate or twist slightly under minimal loads. Minor rotations of the bracket ultimately caused the top tabs to snag on the side of the keyway and during vertical release tests, and the resulting vertical release load was three times higher than desired. The lateral shear plate attachment design satisfied both the lateral and vertical release loads during component testing, but problems arose in the installation and removal process. Specifically, the part would not always snap into place as originally designed, and tools were required to remove the shear plate after installation. A loose attachment in the lateral shear plate design also led to concerns that the bracket may rotate and snag on the keyway (similar to the vertical test result of the drop-in shear plate design) under slightly different load circumstances. Subsequently, the bolted, tabbed bracket was recommended for continued use within the non-proprietary, four-cable barrier system until the alternative brackets were redesigned and successfully tested against these standards [3].

Table 1. Tabbed Bracket Dynamic Testing Results from Previous Tests

Test	Bracket	Load Direction	Load kips (kN)	Failure
HTTB-37	Bolted - V10	Vertical	0.42 (1.86)	Tab release through keyway.
HTTB-38	Bolted - V10	Vertical	0.27 (1.21)	Tab release through keyway
HTTB-41	Lateral Shear Plate	Vertical	0.31 (1.37)	Tab release through keyway
HTTB-42	Lateral Shear Plate	Vertical	0.36 (1.61)	Tab release through keyway
HTTB-43	Drop-In Shear Plate	Vertical	0.31 (1.38)	Tab release through keyway
HTTB-44	Drop-In Shear Plate	Vertical	1.03 (4.56)	Tab release through keyway (snag on inside of keyway)
HTTB-31	Bolted - V10	Lateral	6.03 (26.82)	Fracture around bolt hole
HTTB-32	Bolted - V10	Lateral	6.17 (27.45)	Fracture through bracket spine
HTTB-45	Lateral Shear Plate	Lateral	6.21 (27.61)	Tearing/bending at tabs
HTTB-46	Lateral Shear Plate	Lateral	6.26 (27.84)	Tearing/bending at tabs
HTTB-47	Drop-In Shear Plate	Lateral	5.30 (23.59)	Tearing/bending at tabs and opening of lower legs notch with minor tearing
HTTB-48	Drop-In Shear Plate	Lateral	5.40 (24.03)	Tearing/bending at tabs and opening of lower legs notch with tearing

Bolted, tabbed bracket V10 [2] and shear plate [3] test results from previous studies.

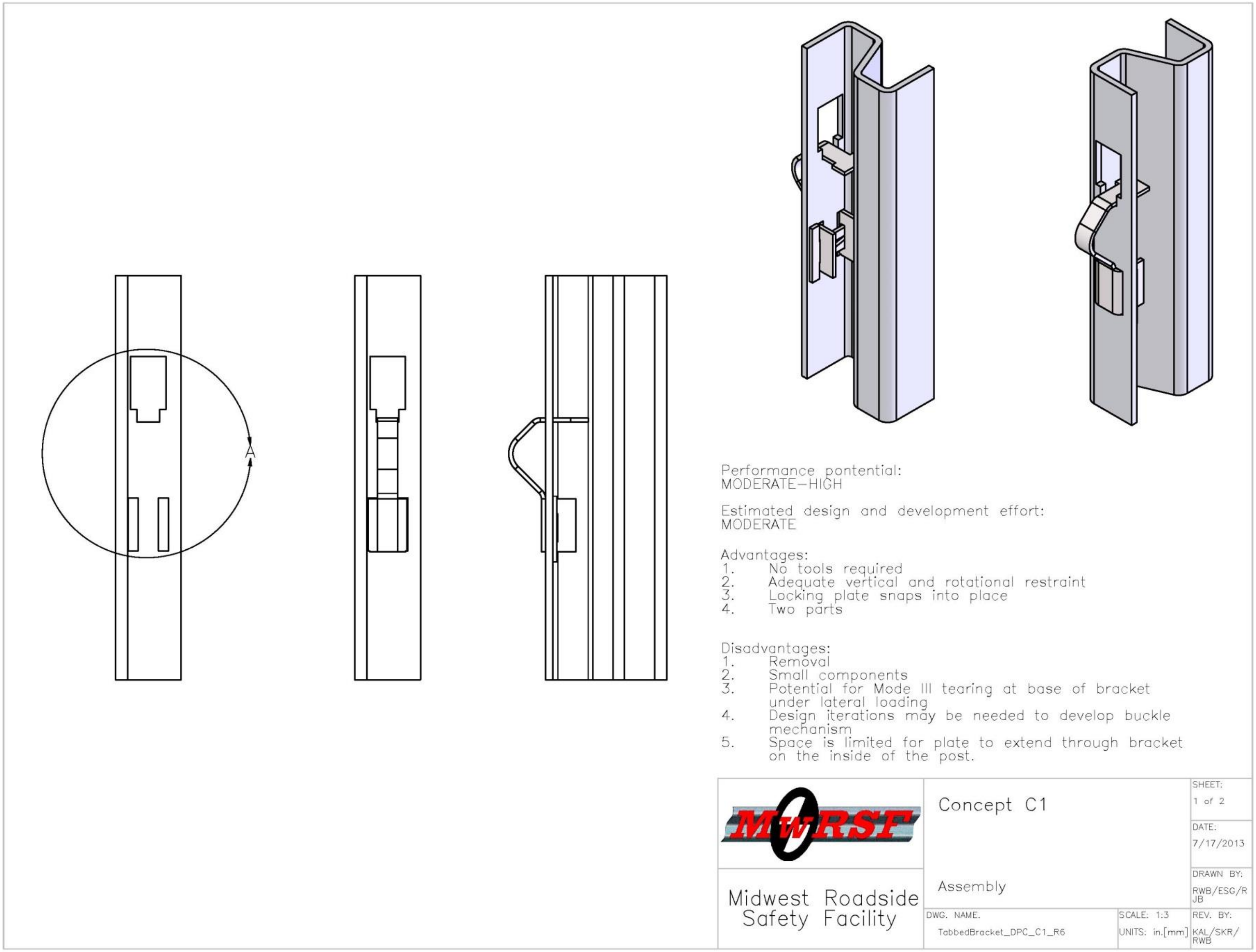

Figure 3. Lateral Shear Plate Attachment Design Concept [3]

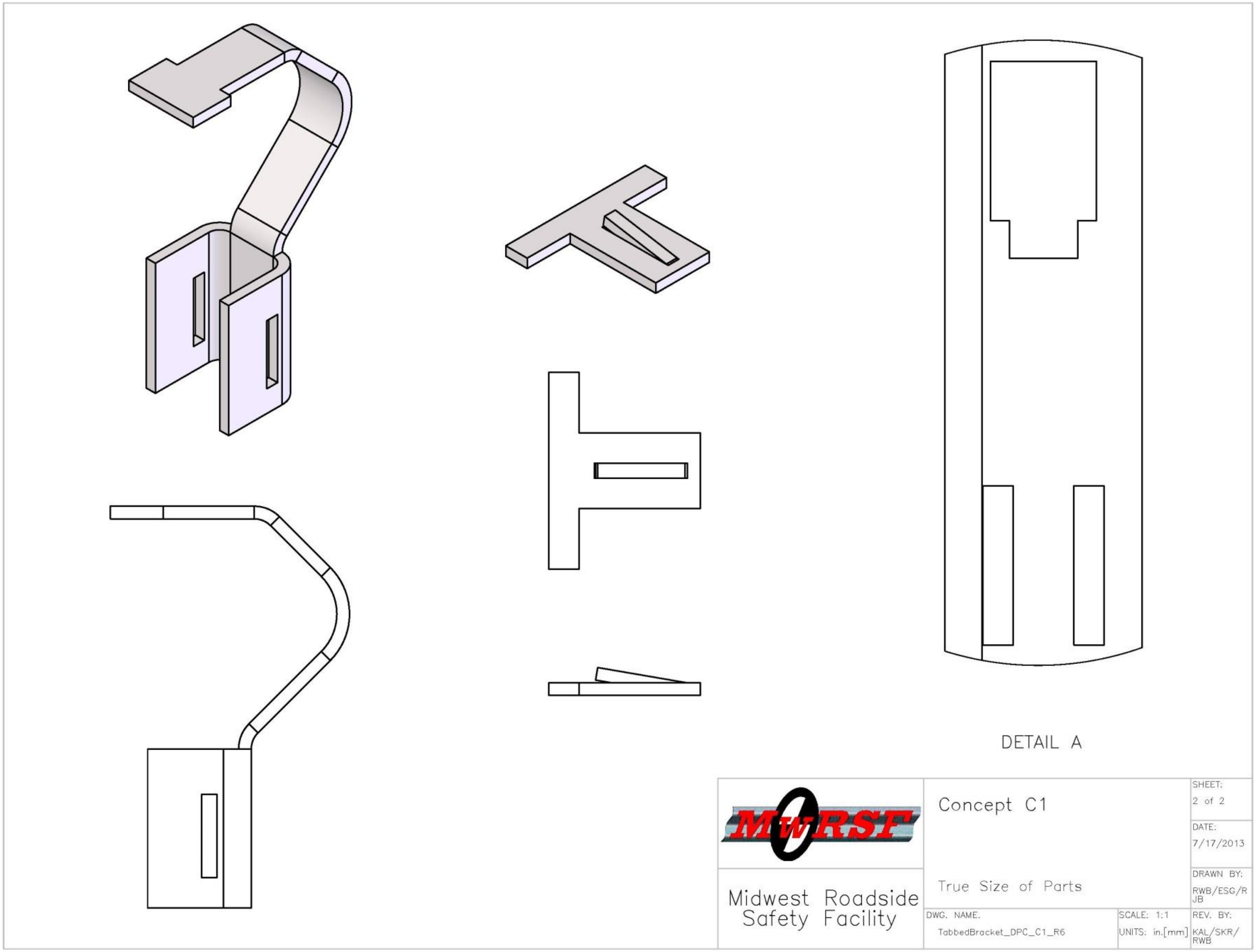

Figure 4. Lateral Shear Plate Attachment Design Concept, Continued [3]

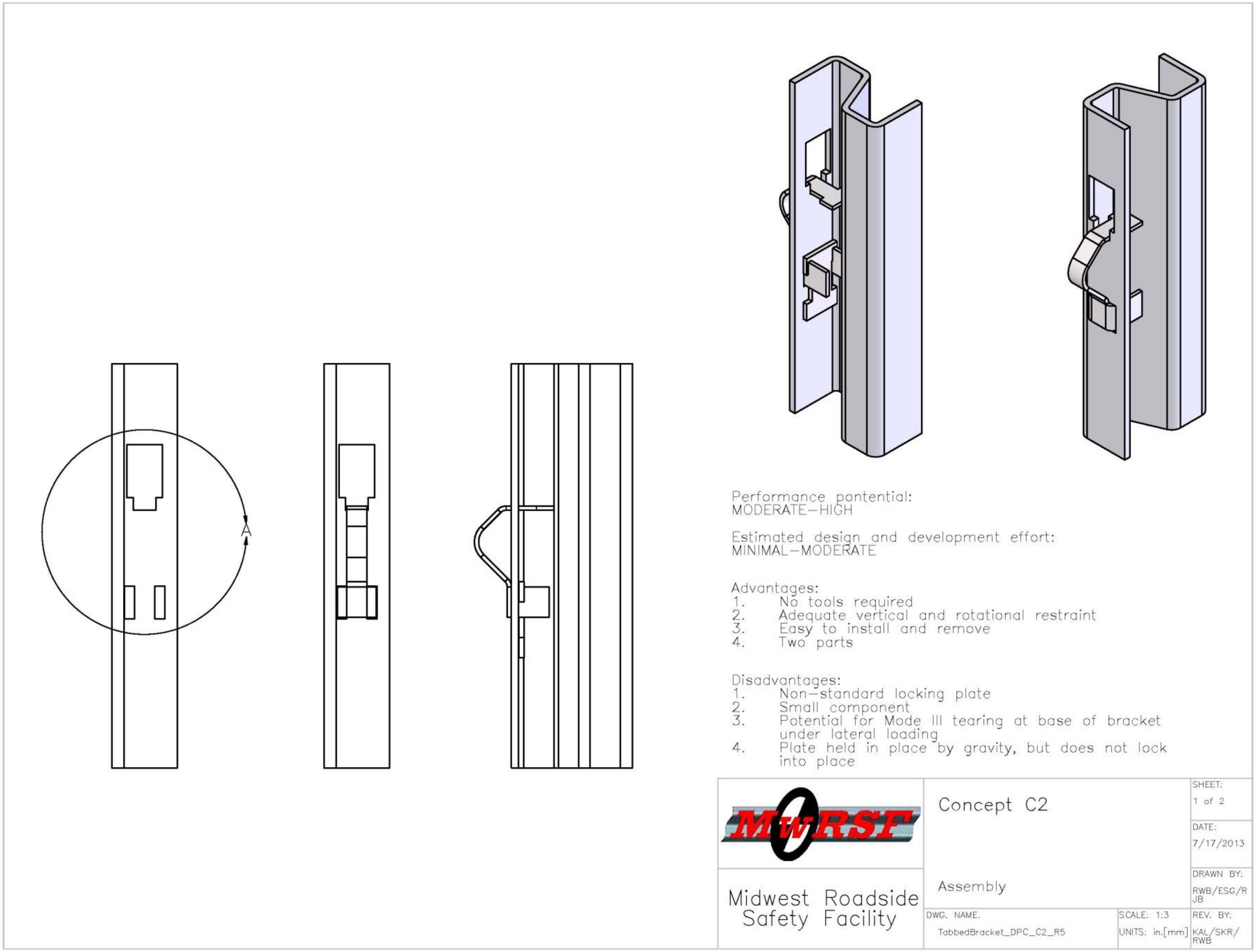

Figure 5. Drop-In Shear Plate Attachment Design Concept [3]

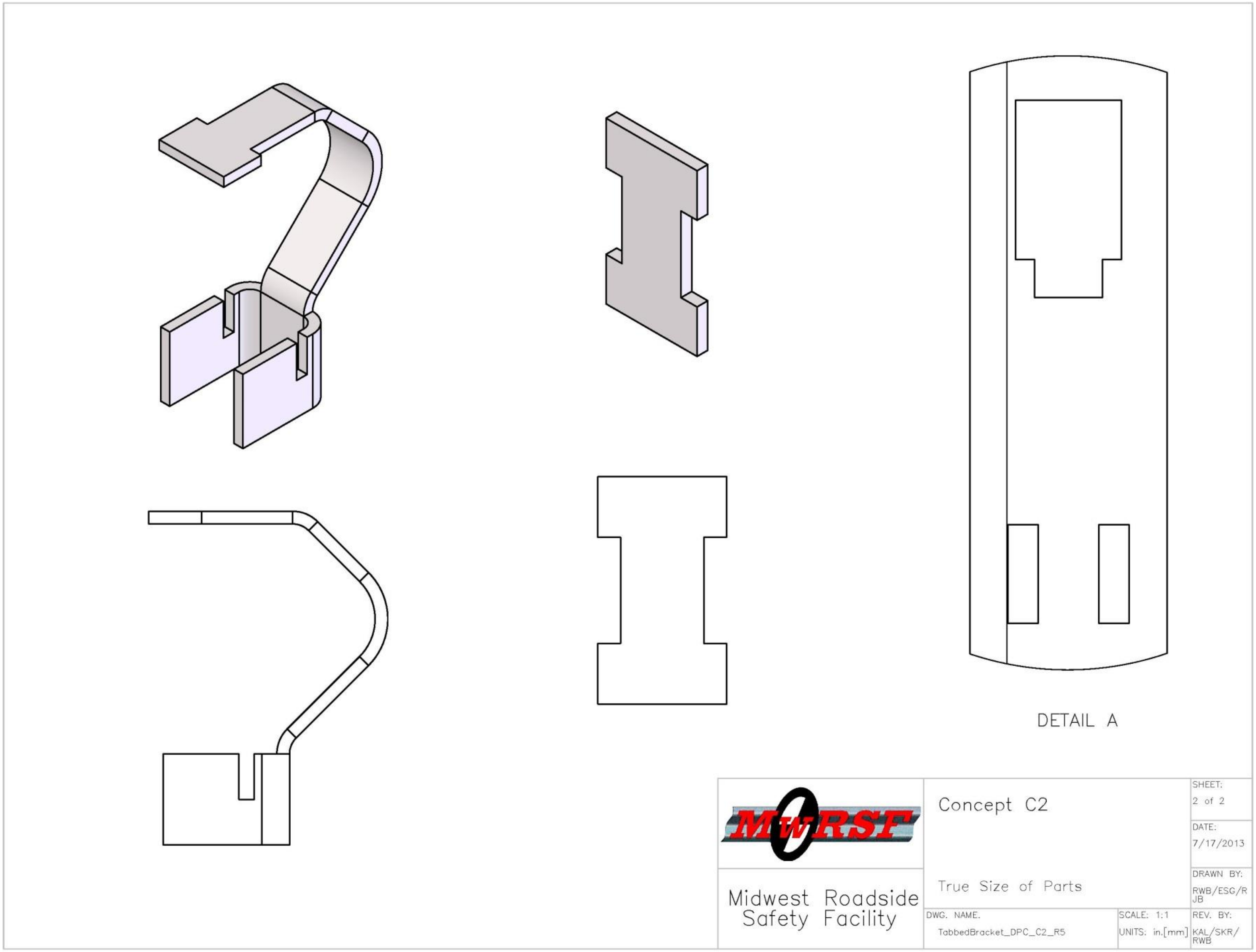

Figure 6. Drop-In Shear Plate Attachment Design Concept, Continued [3]

1.2 Objective

The objective for this project was to develop an alternative cable-to-post attachment bracket for the lower three cables of the non-proprietary, high-tension, four-cable median barrier system. The top of the bracket was to remain the same as the previous bolted, tabbed bracket (V10). However, the bottom of the tabbed bracket was to be redesigned to eliminate the $^{5}/_{16}$-in. (8-mm) diameter bolt and utilize a simpler attachment mechanism. Specifically, it was desired that the alternative bracket 1) provide an attachment that requires no tools during installation, 2) eliminate small components from the design, and 3) reduce the number of parts per attachment. The new bracket design had to perform similarly to the previously developed bolted, tabbed bracket V10 in terms of both vertical and lateral release loads.

1.3 Research Approach

Previous component testing of the lateral shear plate attachment design, conducted during Phase II of the development of cable-to-post attachment hardware, showed potential as a viable alternative to the bolted, tabbed bracket. Thus, the lateral shear plate attachment was redesigned for easier installation and removal, resulting in a new “key plate” attachment design. In addition, two previously proposed concepts from Phase II, the pinned-back attachment and the wire lock pin attachment, were revisited and approved for dynamic component testing. Each design was evaluated for vertical and lateral cable release characteristics and compared against similar tests conducted on the original bolted, tabbed bracket (V10). Conclusions and recommendations were then made pertaining to the use of the three designs.

2 TABBED BRACKET ATTACHMENT DESIGN DETAILS

2.1 Design Criteria

During the development of the bolted, tabbed bracket, the designers desired to create a bracket that would provide enough lateral strength to cause post bending from loading of a single cable. Subsequently, a lateral strength of 6 kips (26.7 kN) was desired prior to cable release. Alternatively, a low vertical cable release load, less than 400 lb (1.8 kN), was desired to prevent vehicle roof and A-pillar crush during redirection. Through dynamic component tests, the bolted, tabbed bracket V10 was shown to satisfy these loading requirements [2]. In order for an alternative bracket design to be deemed equivalent to the bolted, tabbed bracket V10, it would have to perform similarly in terms of its lateral and vertical release loads.

In addition to the strength/release requirements, the new bracket attachment needed to be easier to install. Three criteria were established to optimize the effort required to assemble the barrier:

1. reduce the number of components (currently three: bracket, bolt, and nut);
2. eliminate small components so that attachment pieces were easy to handle, even with gloves on; and
3. eliminate the need for tools during installation.

Due to the successful release characteristics of the bolted, tabbed bracket, it was desired to have the top portion of the bracket and the keyway in the post remain the same. Thus, any alternative brackets would be fabricated from 12-gauge (2.66-mm thick) steel, and only the bottom bracket geometry and the attachment hardware were to be altered.

2.2 Selected Designs

Following the testing of the alternative bracket attachments conducted under Phase II of cable-to-post hardware development, the project sponsors desired to continue the development of the lateral shear plate attachment concept. Subsequently, the bracket, designated the key plate design, was modified to allow easy installation and remove of all connection pieces, tighten the connection between the bracket and the post, and prevent unwanted rotations to the bracket prior to loading (i.e., eliminate the "wiggle" in the previous version of the bracket attachment). In addition to this modified bracket, the project sponsors desired to evaluate two other bracket attachment concepts which had been previously proposed during Phase II of the project. Thus, both the wire lock pin design and the pinned-back design were also selected for evaluation through dynamic component testing.

2.3 Design Details

Three alternative attachment designs for the cable-to-post tabbed brackets were selected for evaluation through dynamic component testing: 1) the key plate design; 2) the wire lock pin design; and 3) the pinned-back design. All three designs were similar to the original bolted, tabbed bracket (Version 10). In fact, the top part of each bracket design (from the top tab to the spine of the bracket) was identical. Only the bottom portion of the brackets and the attachment hardware differed between designs. Design details for the three bracket designs, their respective attachment plates, and the test jig utilized to evaluate the new brackets are shown in Figures 7 through 32. Material specifications, mill certifications, and certificates of conformity for the tabbed brackets and associated components are shown in Appendix A.

The key plate design was developed by modifying the lateral shear plate connection previously evaluated during Phase II of this project [3]. The primary modifications to this shear plate design were made to ease the installation and removal process. Due to difficulties encountered during installation of the previous version of the bracket, the snapping/buckling mechanism utilized to lock the shear plate in place was eliminated. Instead, the key plate was designed to be installed laterally through the slots in the bracket legs and then slid downward to secure the plate. Vertical slots were cut into the bottom of the key plate, as shown in Figure 27, which allowed the plate to fit over the bottom portion of the bracket legs and prevented the key plate from slipping out laterally and releasing the bracket. The outer portion of the key plate was bent at a 90-degree angle to prevent snag and to aid in handling the plate during installation. In order to allow the key plate to slide down into position, both the shear plate and the legs of the bracket were extended ½ in. (13 mm) vertically.

The bracket was also modified to tighten the attachment and prevent bracket rotations which could result in the top tabs being positioned incorrectly within the keyway for proper release. The vertical slots in the bracket legs were narrowed from $^{3}/_{16}$ in. (5 mm) to ⅛ in. (3 mm), and the spine of the bracket, which lies flush with the face of the post, was extended 1 in. (25 mm) beyond the bottom of the bracket legs.

The bracket with wire lock pin was designed to attach to the post using only a single lateral pin. The bracket spine was bent such that a loop near the lower end of the bracket would extend through a slot cut in the face of the post, as shown in Figures 12 and 23. A lateral pin was then inserted through a hole in the web of the post, through the loop in the bracket, and out past the free edge of the post. The pin transfers lateral loads as it bears against the inside face of the post. The wire lock pin was 2½ in. (64 mm) long and had a $^{3}/_{8}$-in. (10-mm) diameter. A $^{3}/_{32}$-in. (2-mm) diameter wire connected the pin head and bottom to secure the pin and prevent it from slipping out and releasing the bracket. The bottom of the bracket widened from ½ in. to 1 in. (13 mm to 25 mm) in order to prevent it from being pulled through the slot in the post when the bracket is loaded laterally. Specific dimensions for this bracket and the wire lock pin are shown in Figures 23 and 28, respectively.

The pinned-back attachment design utilized a vertical pin placed inside the post to secure the bracket. The bottom of the bracket was designed to be installed through a lateral slot in the post and extend horizontally toward the web of the post, as shown in Figure 12. A winged, U-shaped bracket was then inserted over the horizontal extension and the assembly was locked into place using a vertical pin. Both the main bracket and the winged, U-shaped bracket contained $^{7}/_{16}$-in. (11-mm) diameter holes to accept the $^{3}/_{8}$-in. (10-mm) diameter pin. The wings of the U-shaped bracket were designed to bear against the inside face of the post and prevent the tabbed bracket from moving. Specific dimensions for both brackets and the vertical pin utilized in the pinned-back attachment design are shown in Figures 25 and 29, respectively.

Similar to the original bolted, tabbed bracket V10, all of the new tabbed bracket designs were fabricated from 12-gauge (2.66-mm thick) ASTM A1011 HSLA grade 50 steel. Conveniently, the key plate was also fabricated from the same steel. The wire lock pin was fabricated from ANSI C1010 low carbon steel, and the bar stock pin was fabricated from ASTM A307 grade A steel. The short Midwest Weak Post (MWP) sections that were designed to fit within the test jig were fabricated from 7-gauge (4.6-mm thick) ASTM A1011 HSLA grade 50 steel, while the gusset stiffeners were fabricated from ASTM A36 steel. The cable that was utilized to load the brackets was a ¾-in. (19-mm) diameter 6x19 wire rope. Although ¾-in. (19-mm) diameter 3x7 wire rope is typically used in cable barrier systems, the wire rope utilized during testing had the same diameter and would result in similar loading of the brackets.

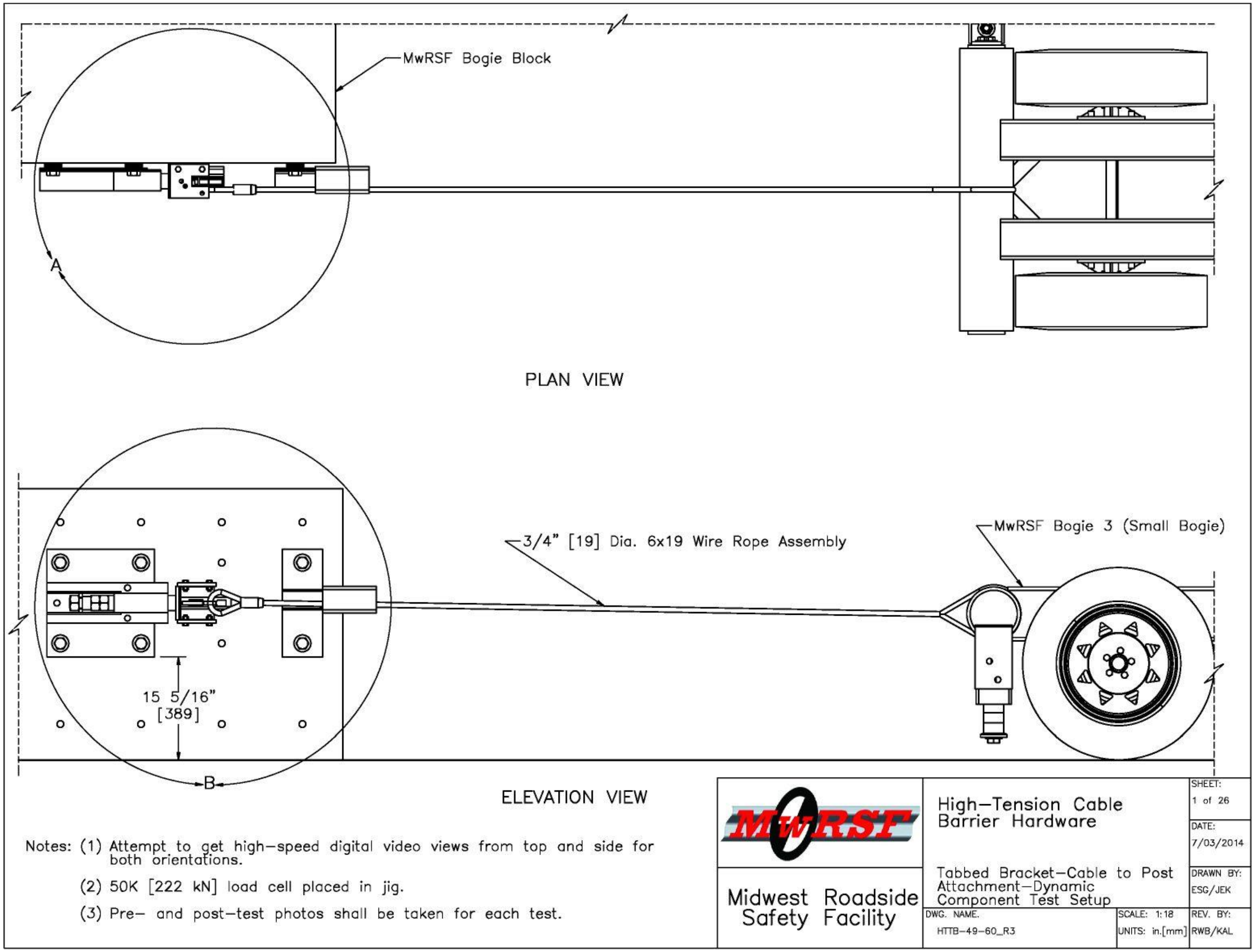

Figure 7. Cable-to-Post Attachment Dynamic Component Test Setup, Test Nos. HTTB-49 through HTTB-60

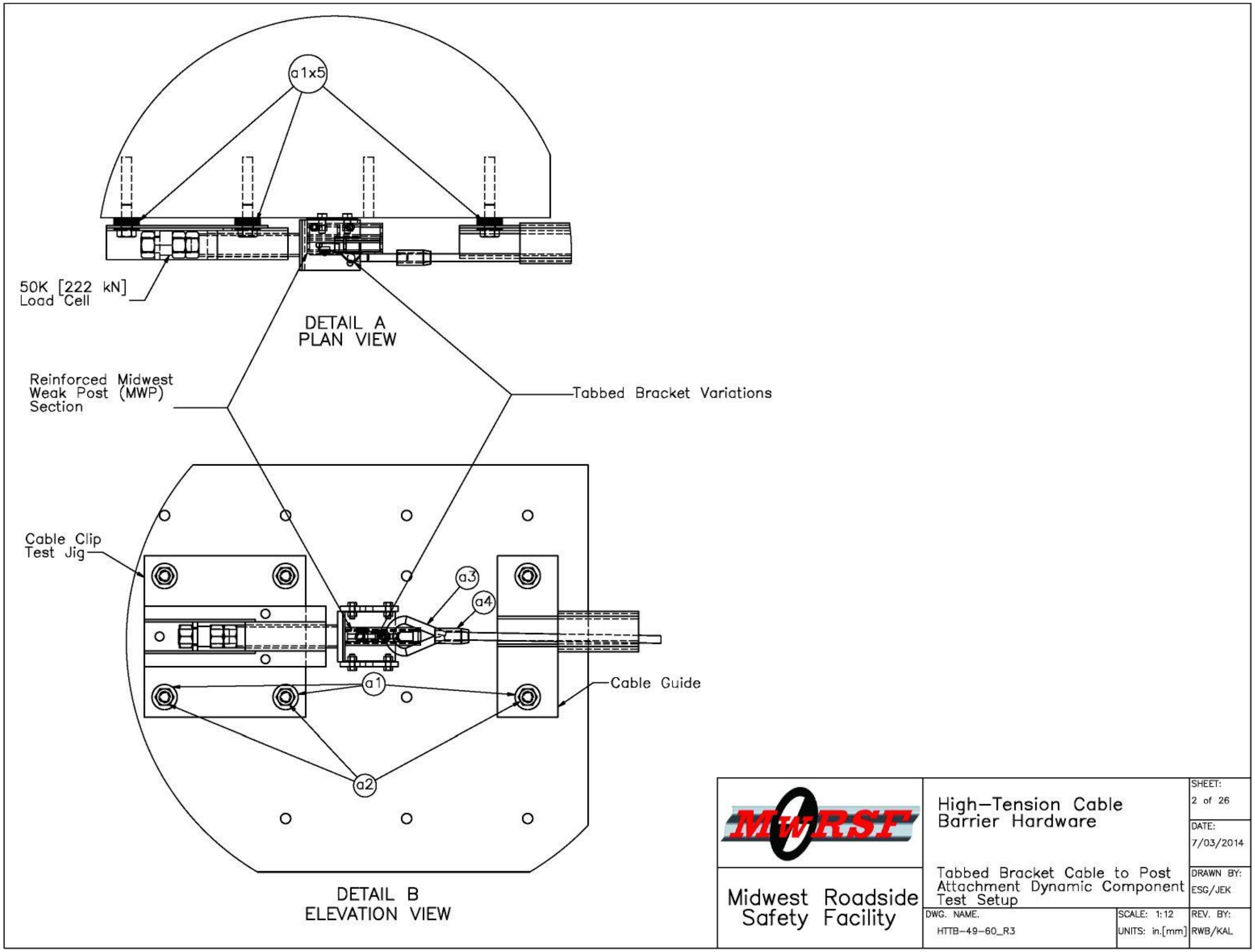

Figure 8. Cable-to-Post Attachment Dynamic Component Test Details, Test Nos. HTTB-49 through HTTB-60

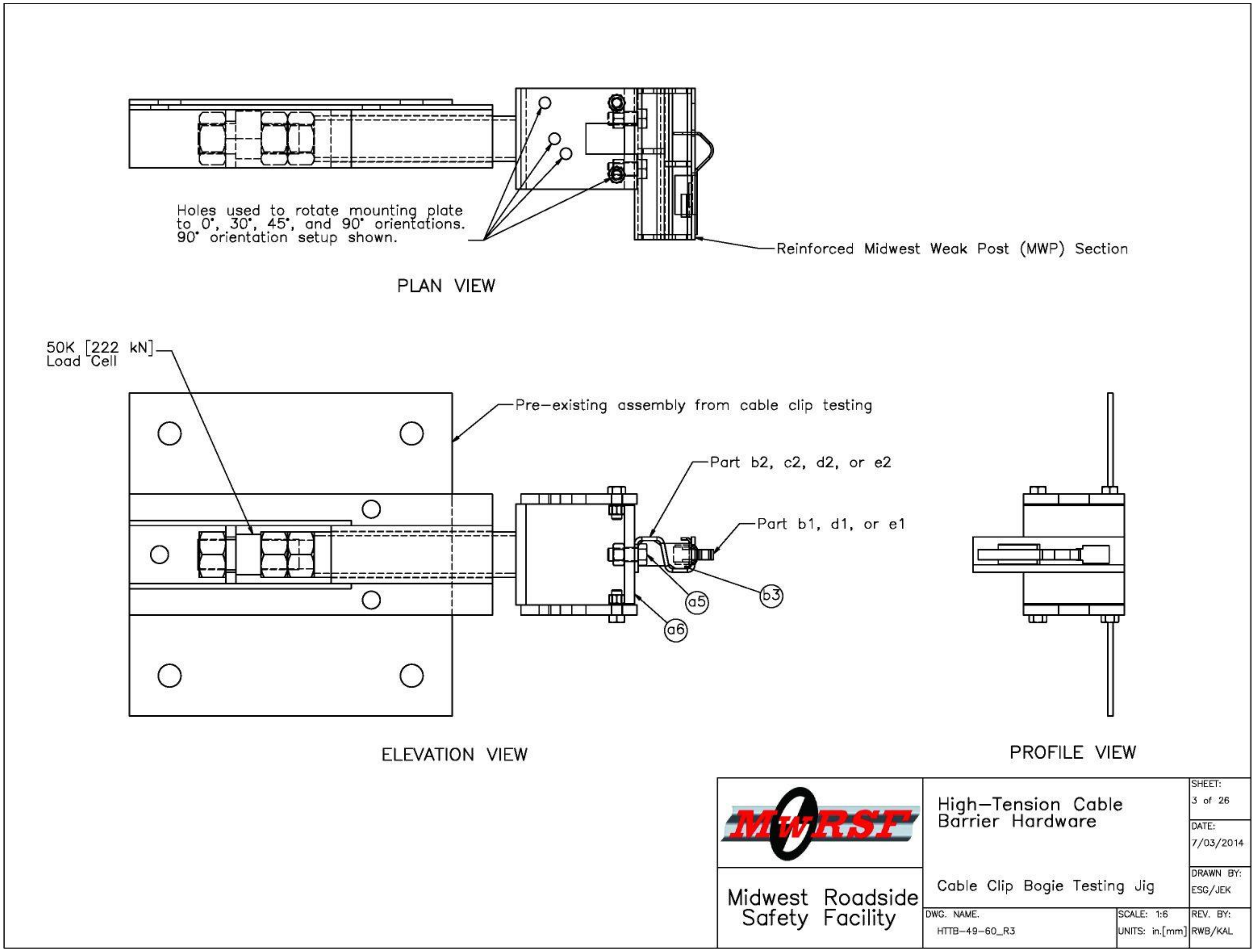

Figure 9. Test Jig Setup, Test Nos. HTTB-49 through HTTB-60

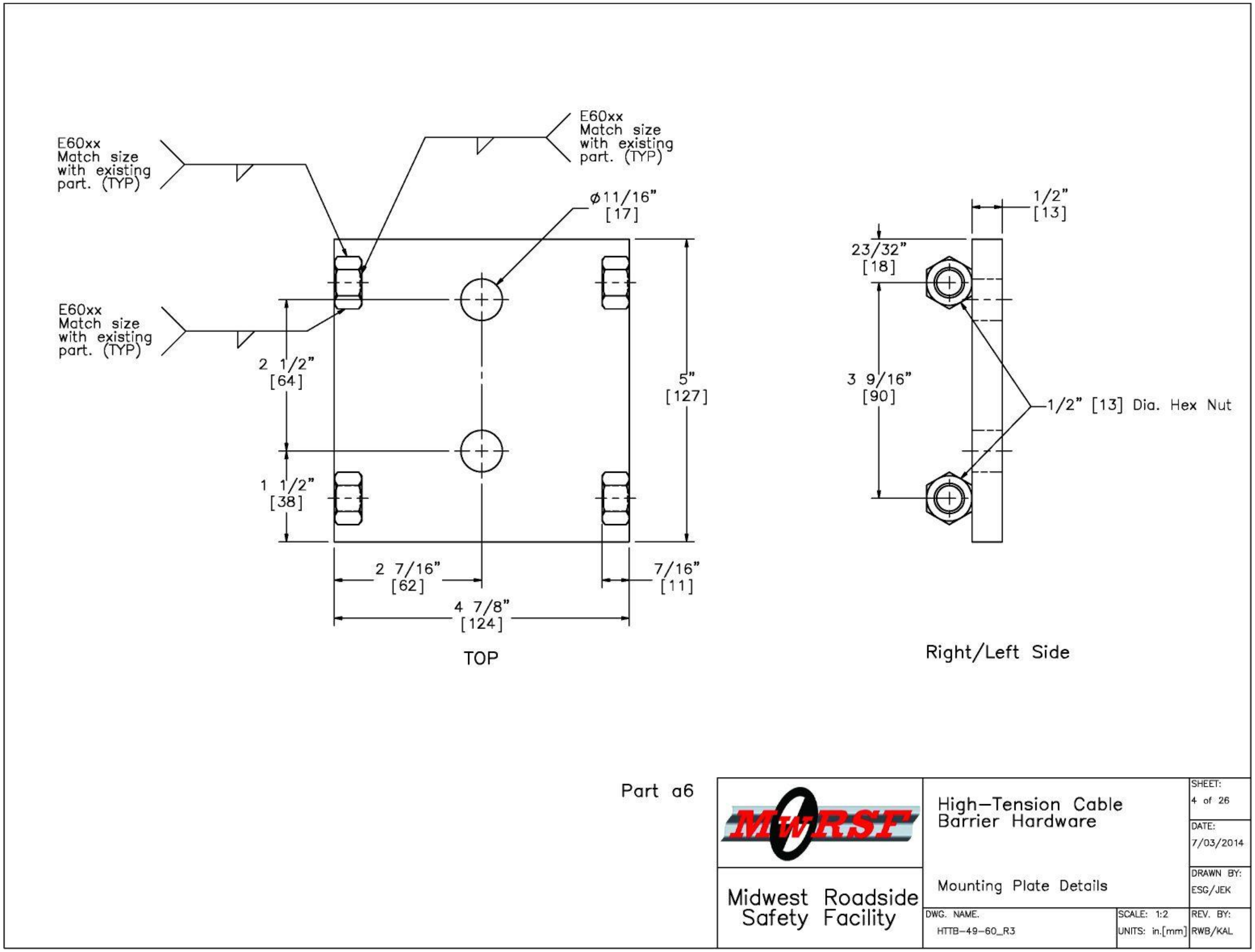

Figure 10. Mounting Plate Details, Test Nos. HTTB-49 through HTTB-60

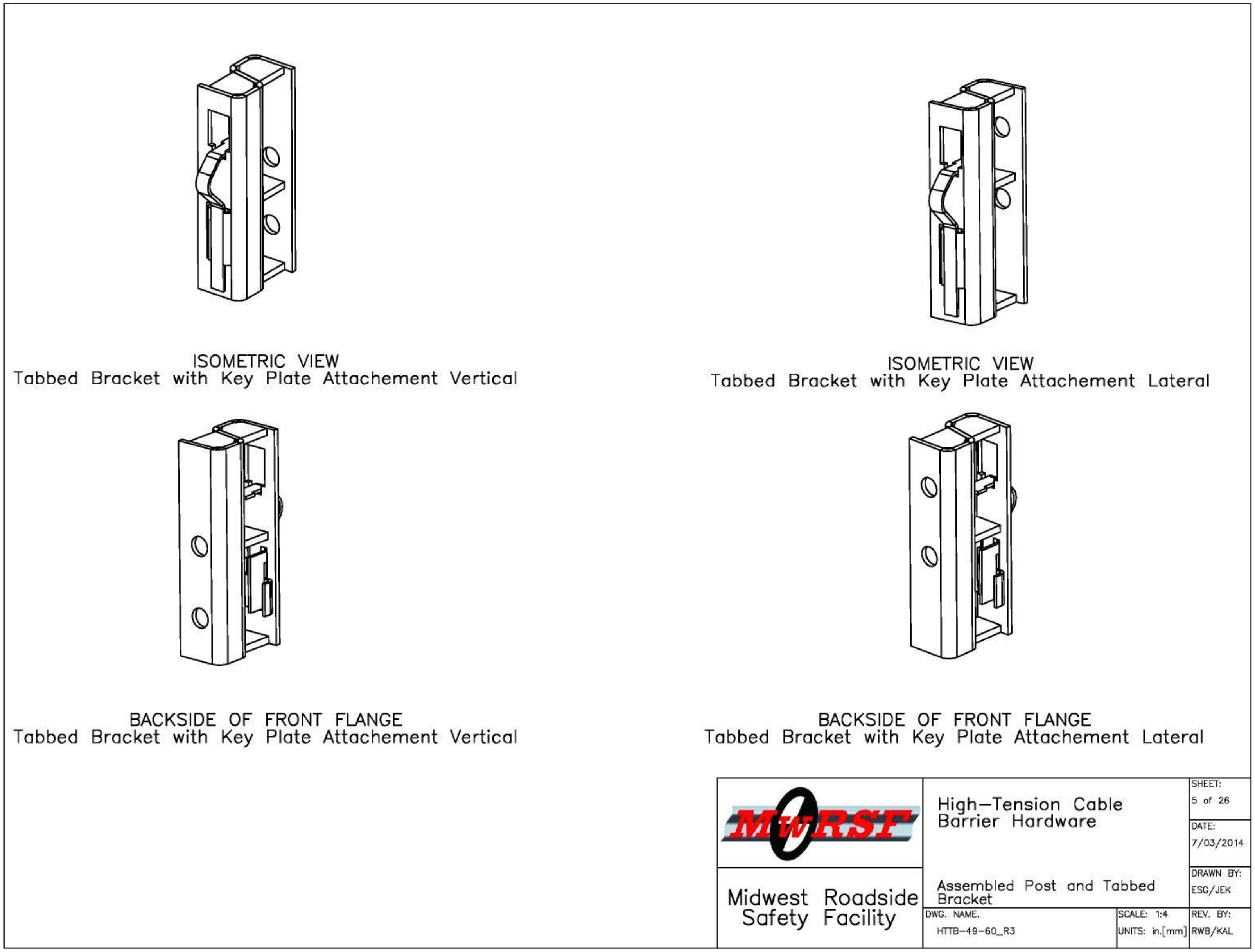

Figure 11. Assembled Post and Tabbed Bracket, Test Nos. HTTB-49, HTTB-50, HTTB-55, and HTTB-56

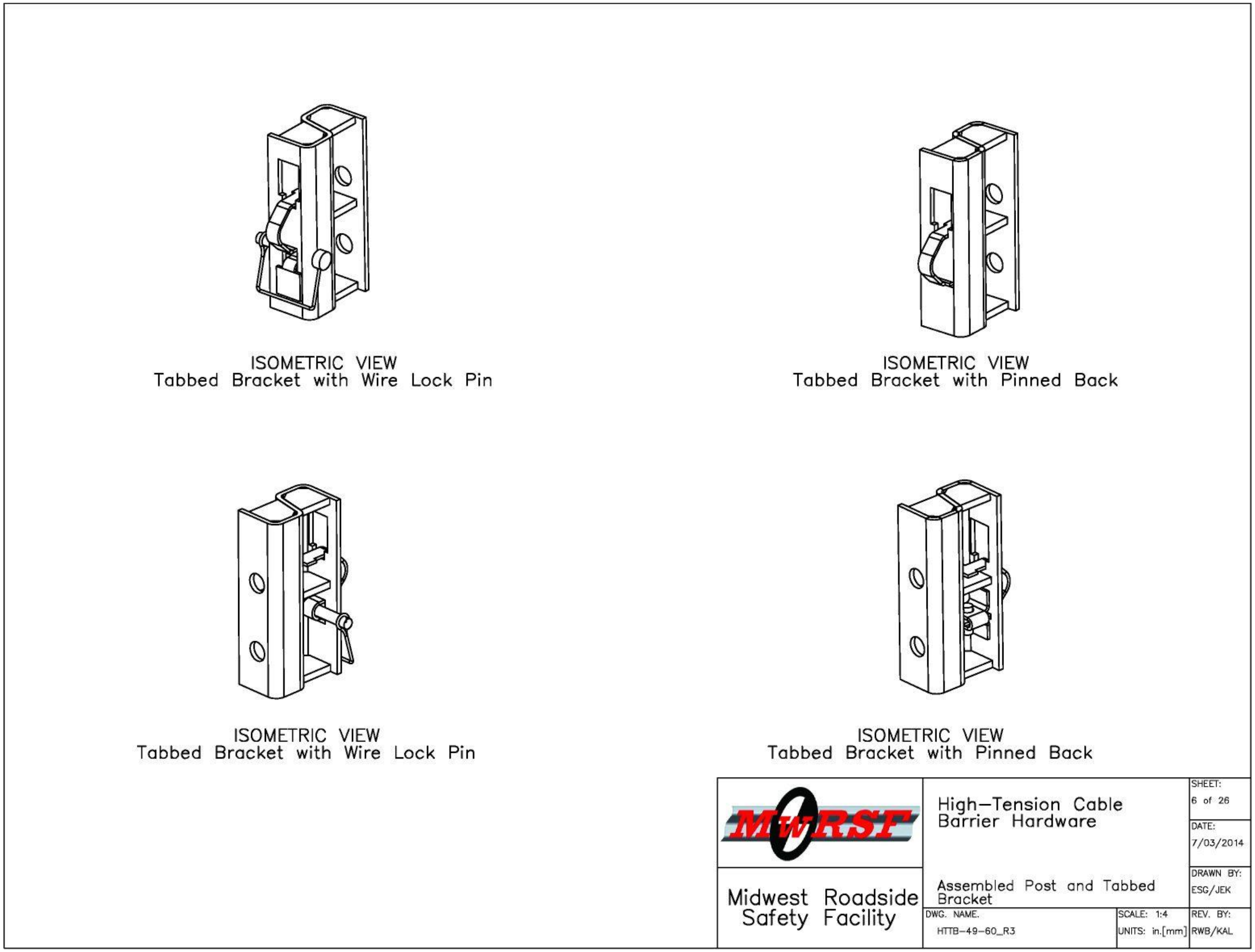

Figure 12. Assembled Post and Tabbed Bracket, Test Nos. HTTB-51 through HTTB-54 and HTTB-57 through HTTB-60

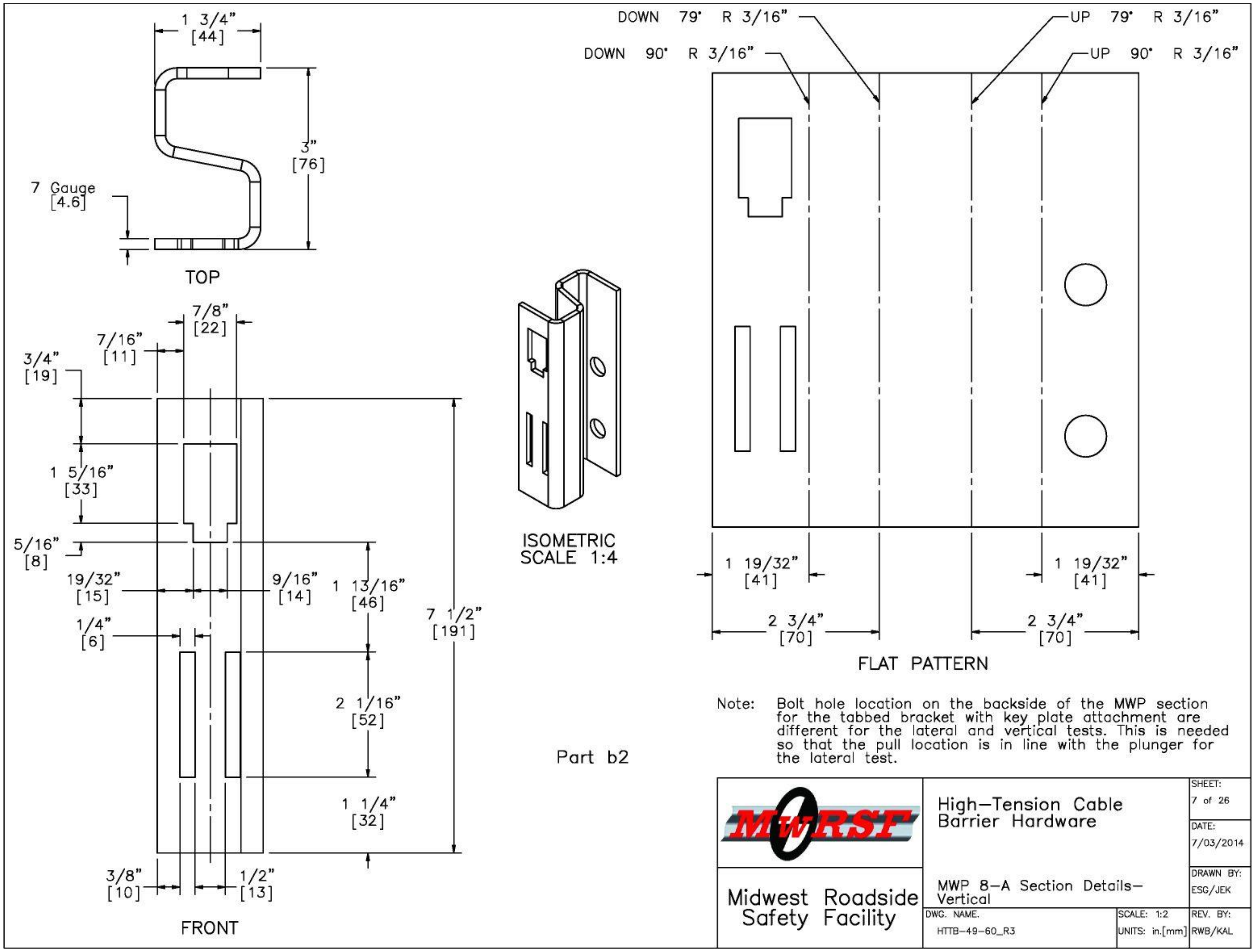

Figure 13. MWP 8-A Section Details, Test Nos. HTTB-49 and HTTB-50

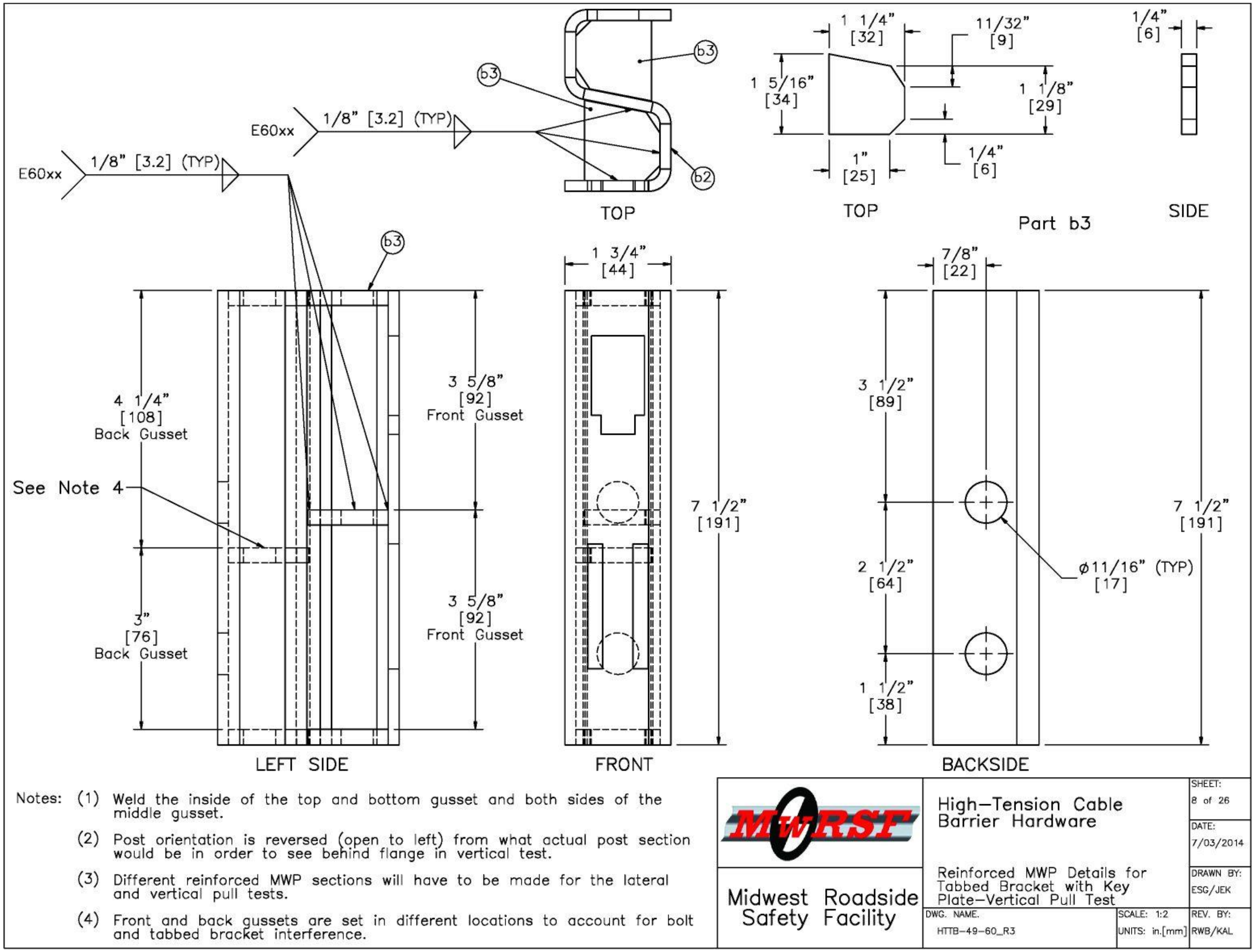

Figure 14. Reinforced MWP Details for Tabbed Bracket with Key Plate, Test Nos. HTTB-49 and HTTB-50

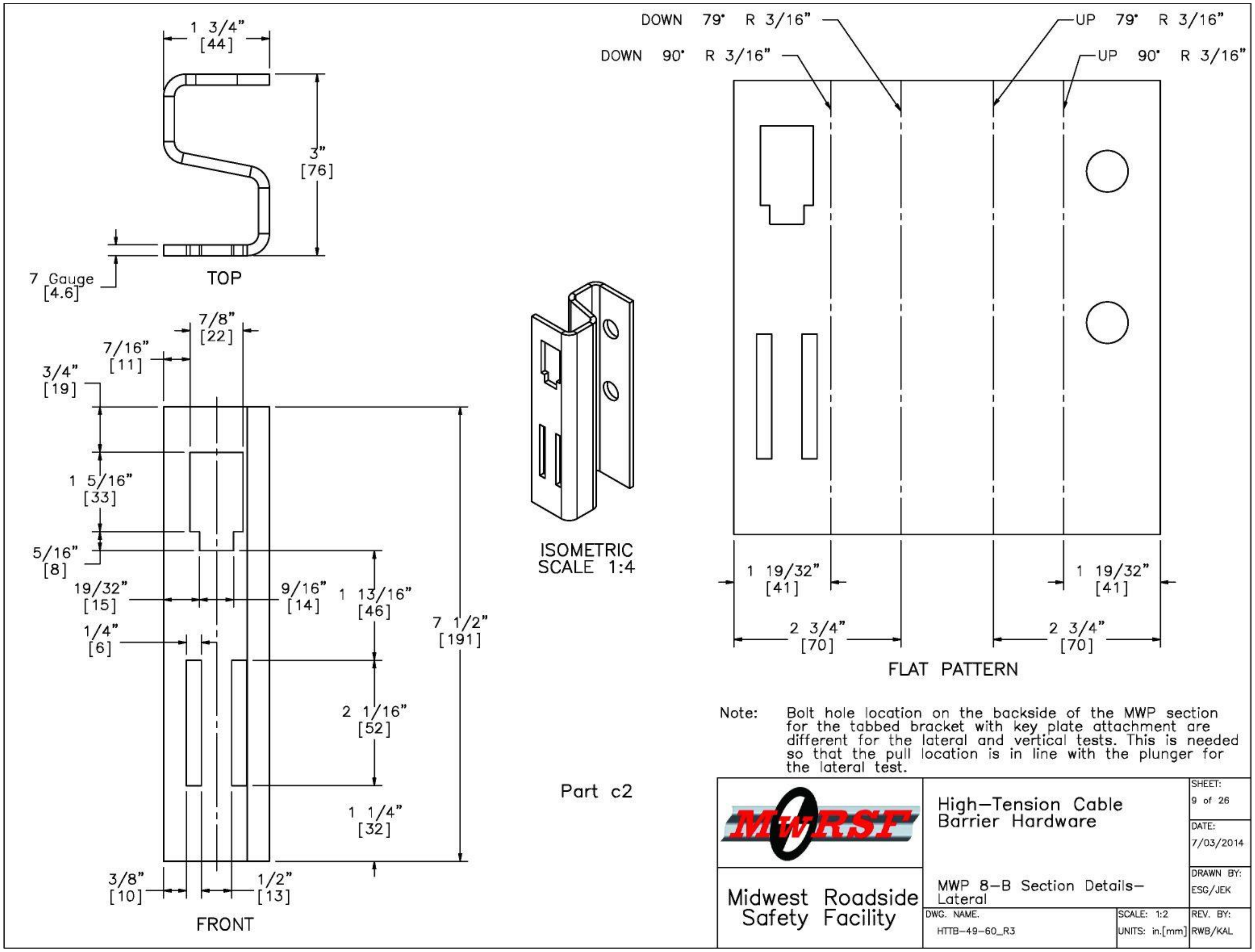

Figure 15. MWP 8-B Section Details, Test Nos. HTTB-55 and HTTB-56

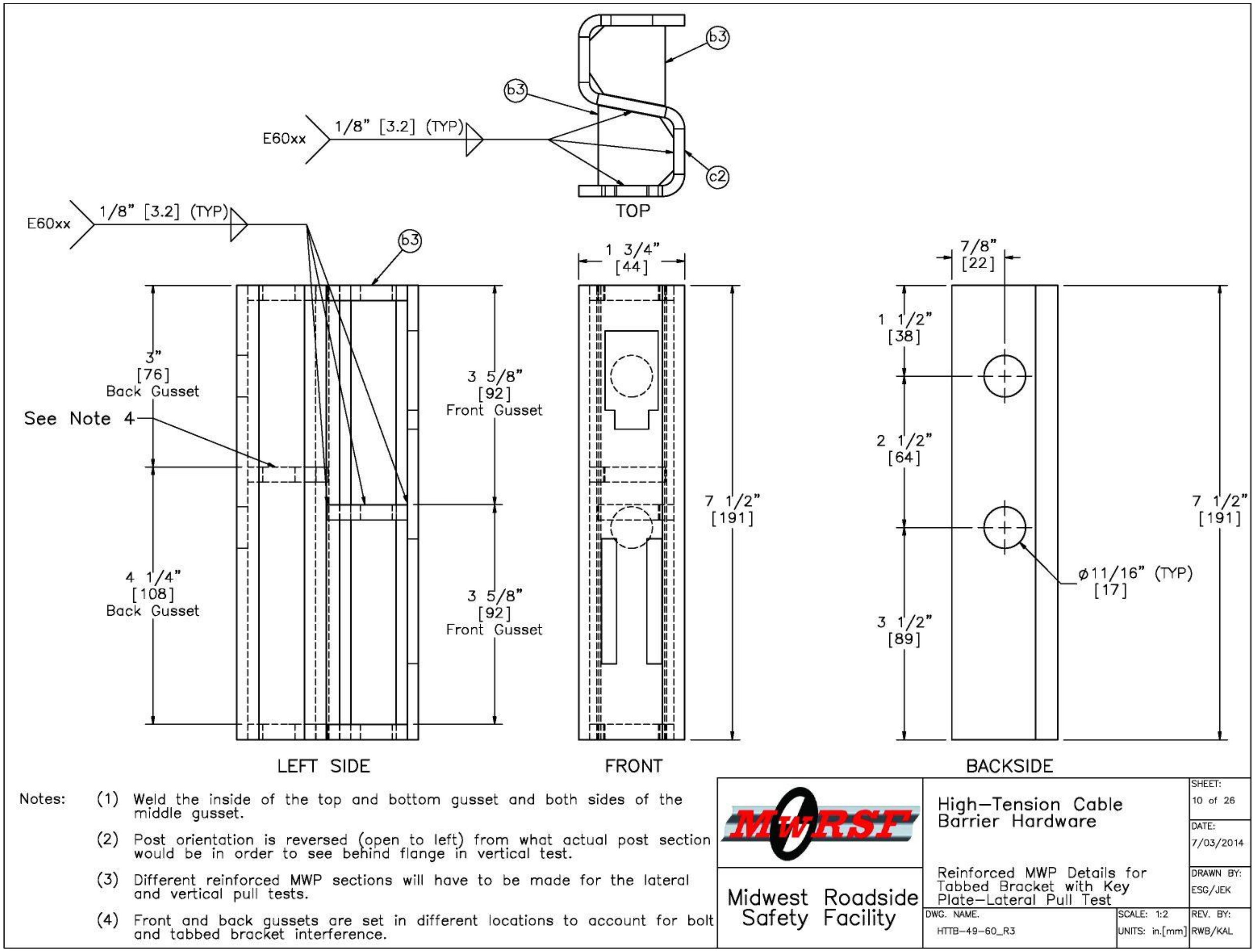

Figure 16. Reinforced MWP Details for Tabbed Bracket with Key Plate, Test Nos. HTTB-55 and HTTB-56

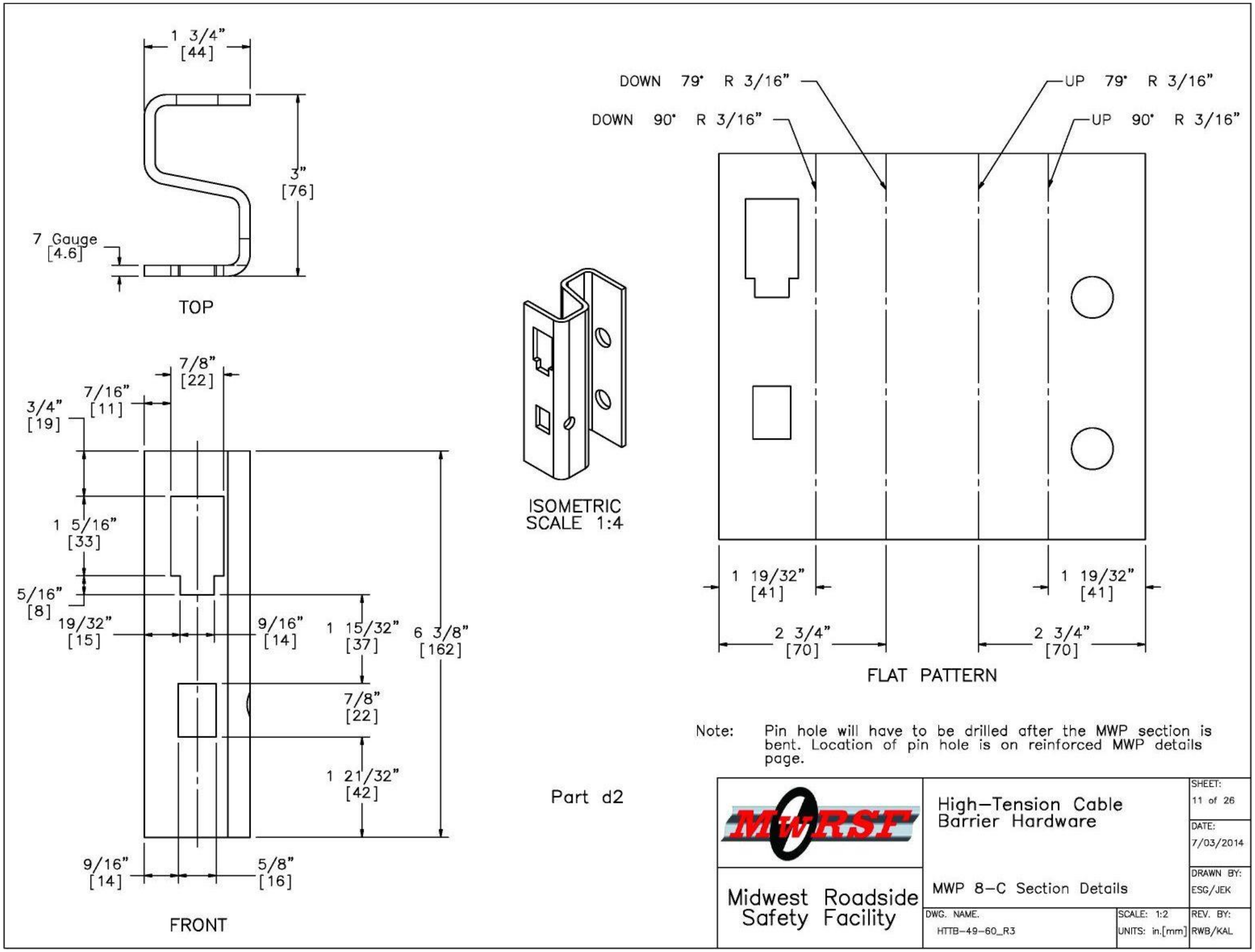

Figure 17. MWP 8-C Section Details, Test Nos. HTTB-51, HTTB-52, HTTB-57, and HTTB-58

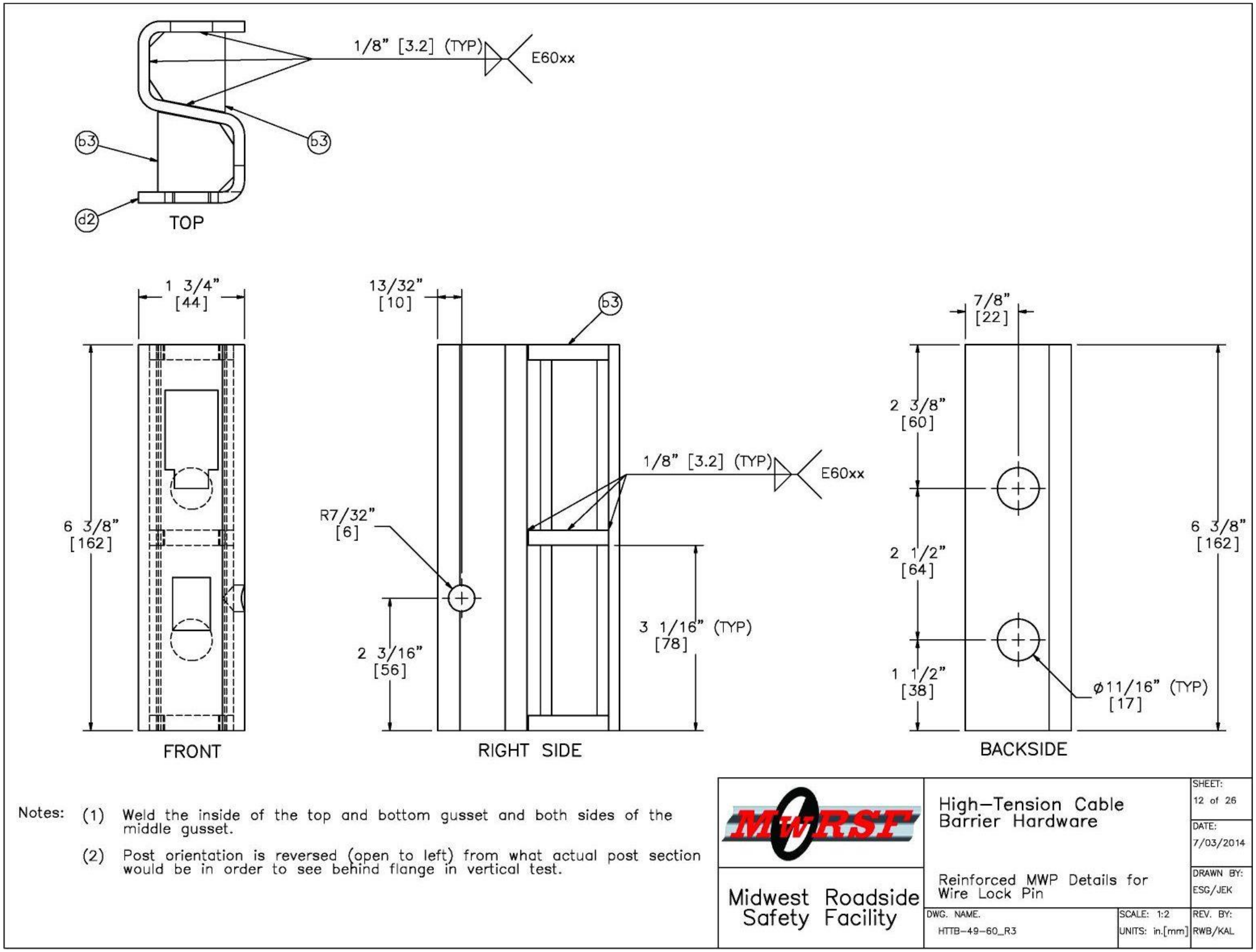

Figure 18. Reinforced MWP Details for Wire Lock Pin, Test Nos. HTTB-51, HTTB-52, HTTB-57, and HTTB-58

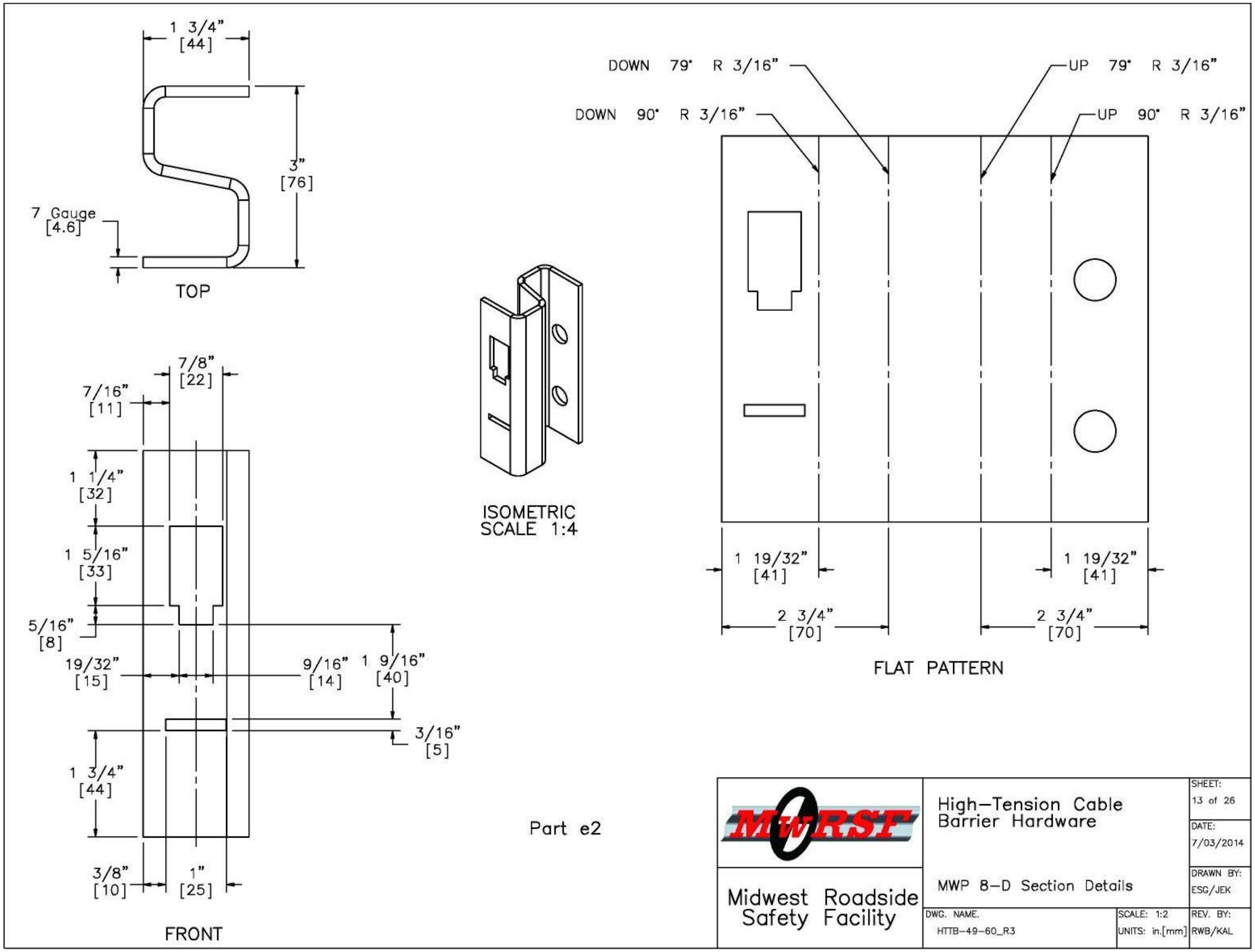

Figure 19. MWP 8-D Section Details, Test Nos. HTTB-53, HTTB-54, HTTB-59, and HTTB-60

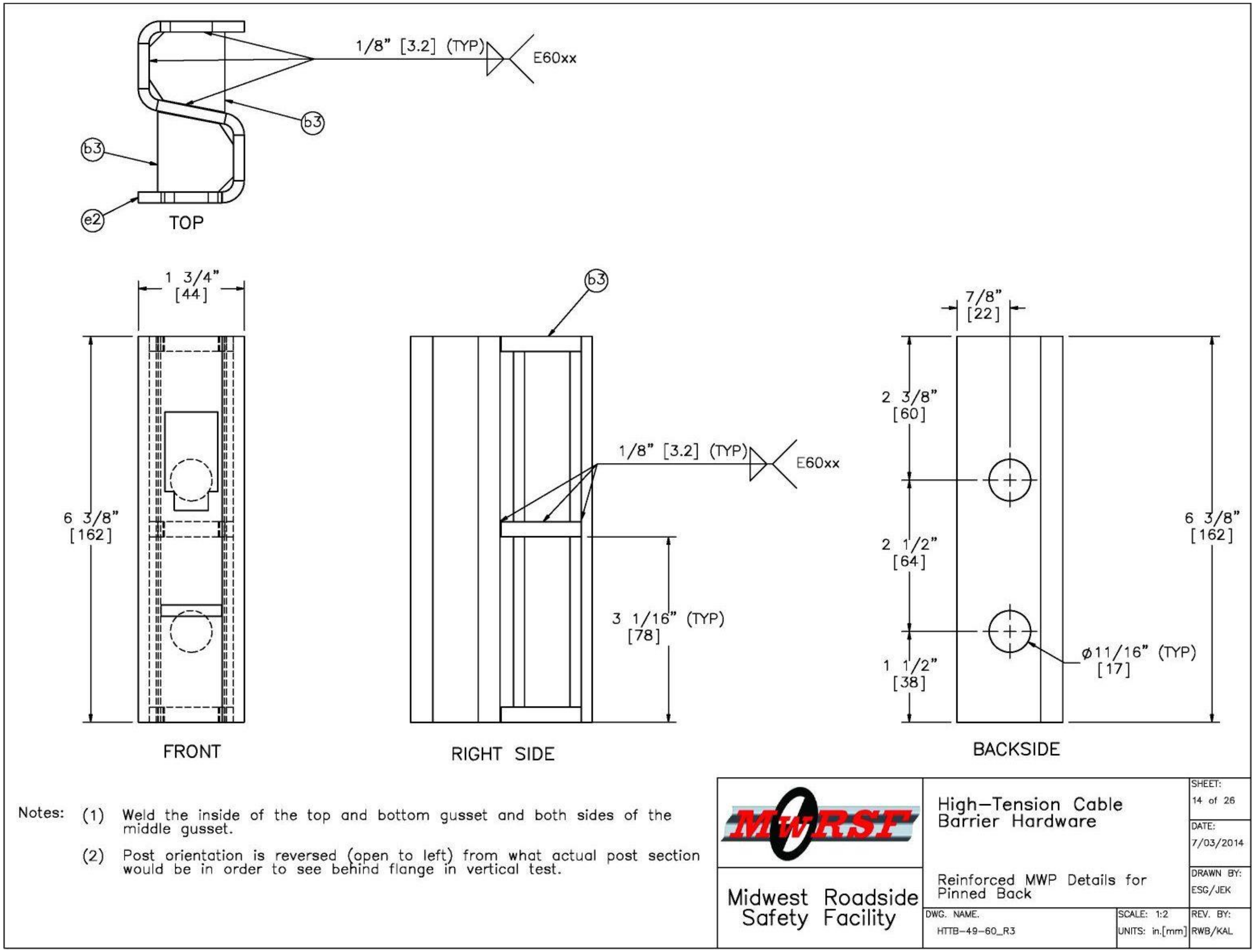

Figure 20. Reinforced MWP Details for Pinned-Back, Test Nos. HTTB-53, HTTB-54, HTTB-59, and HTTB-60

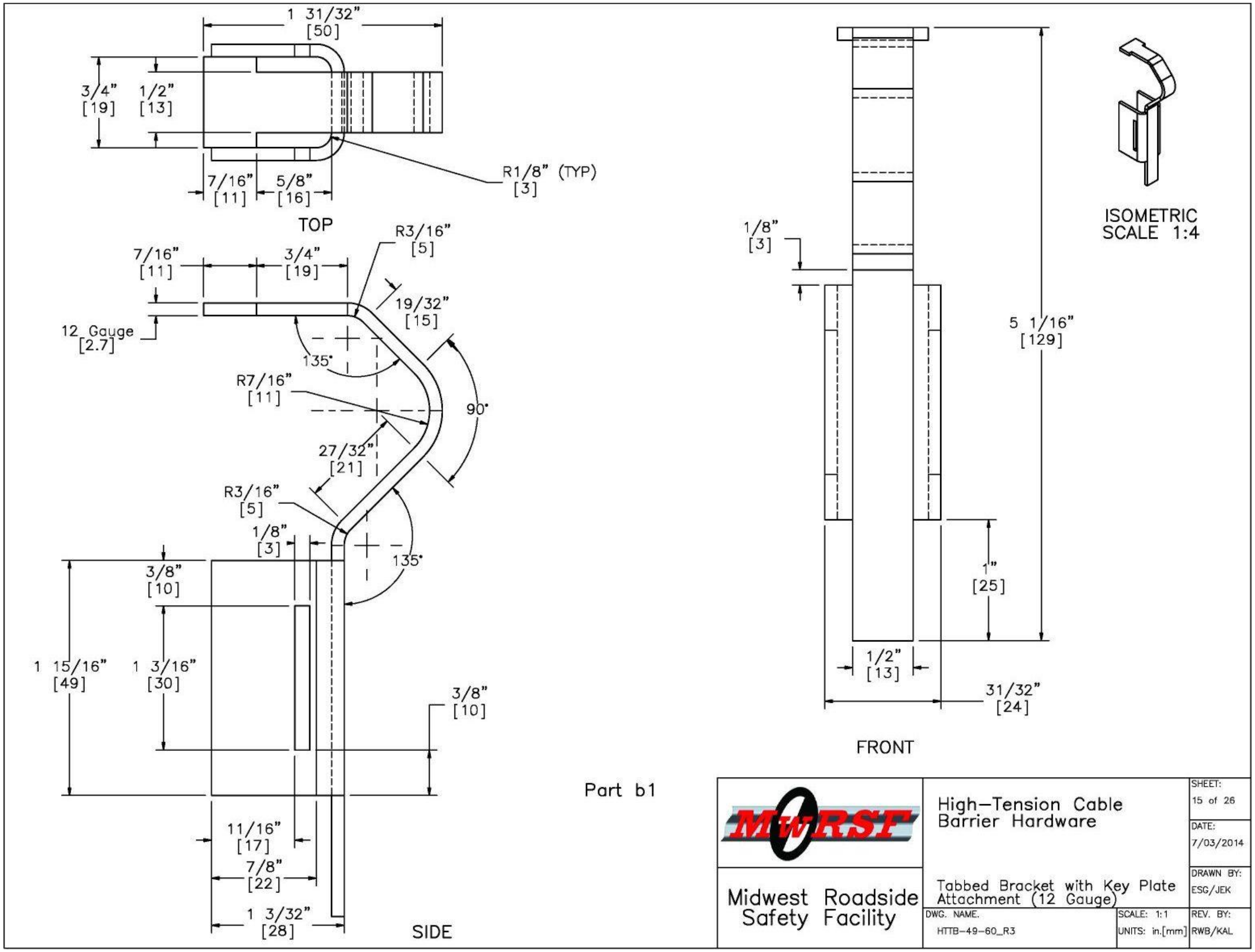

Figure 21. Tabbed Bracket with Key Plate Attachment, Test Nos. HTTB-49, HTTB-50, HTTB-55, and HTTB-56

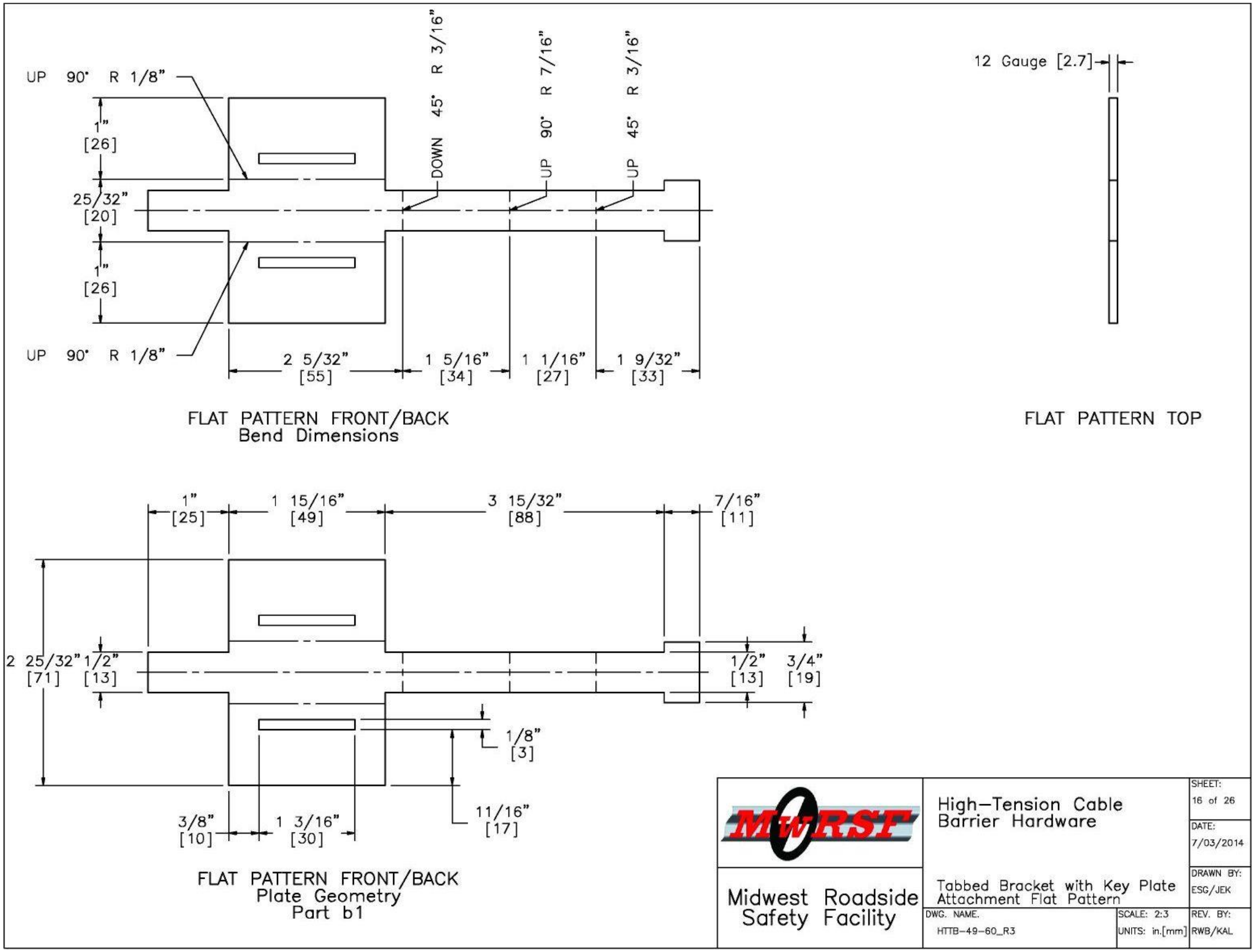

Figure 22. Tabbed Bracket with Key Plate Attachment Flat Pattern, Test Nos. HTTB-49, HTTB-50, HTTB-55, and HTTB-56

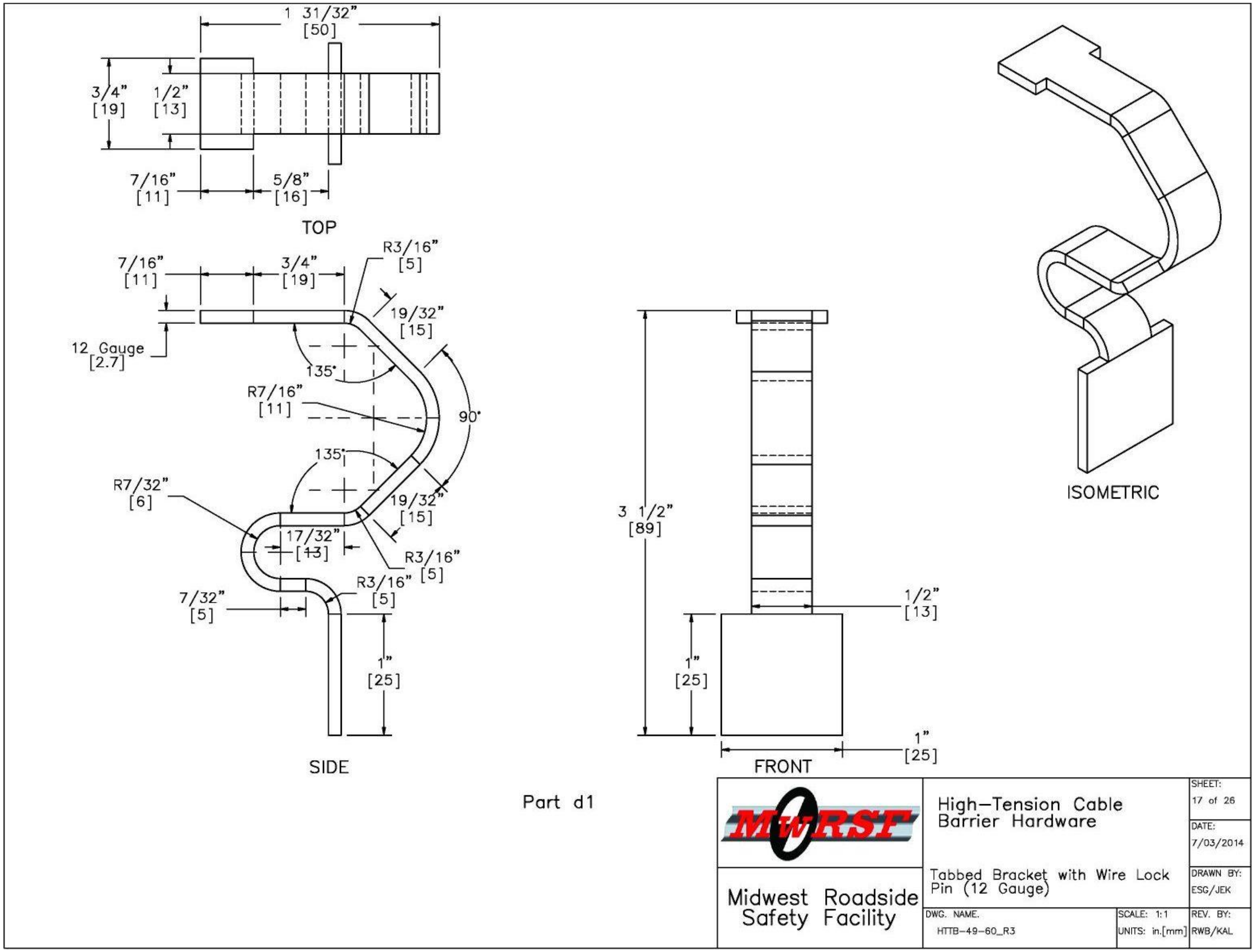

Figure 23. Tabbed Bracket with Wire Lock Pin, Test Nos. HTTB-51, HTTB-52, HTTB-57, and HTTB-58

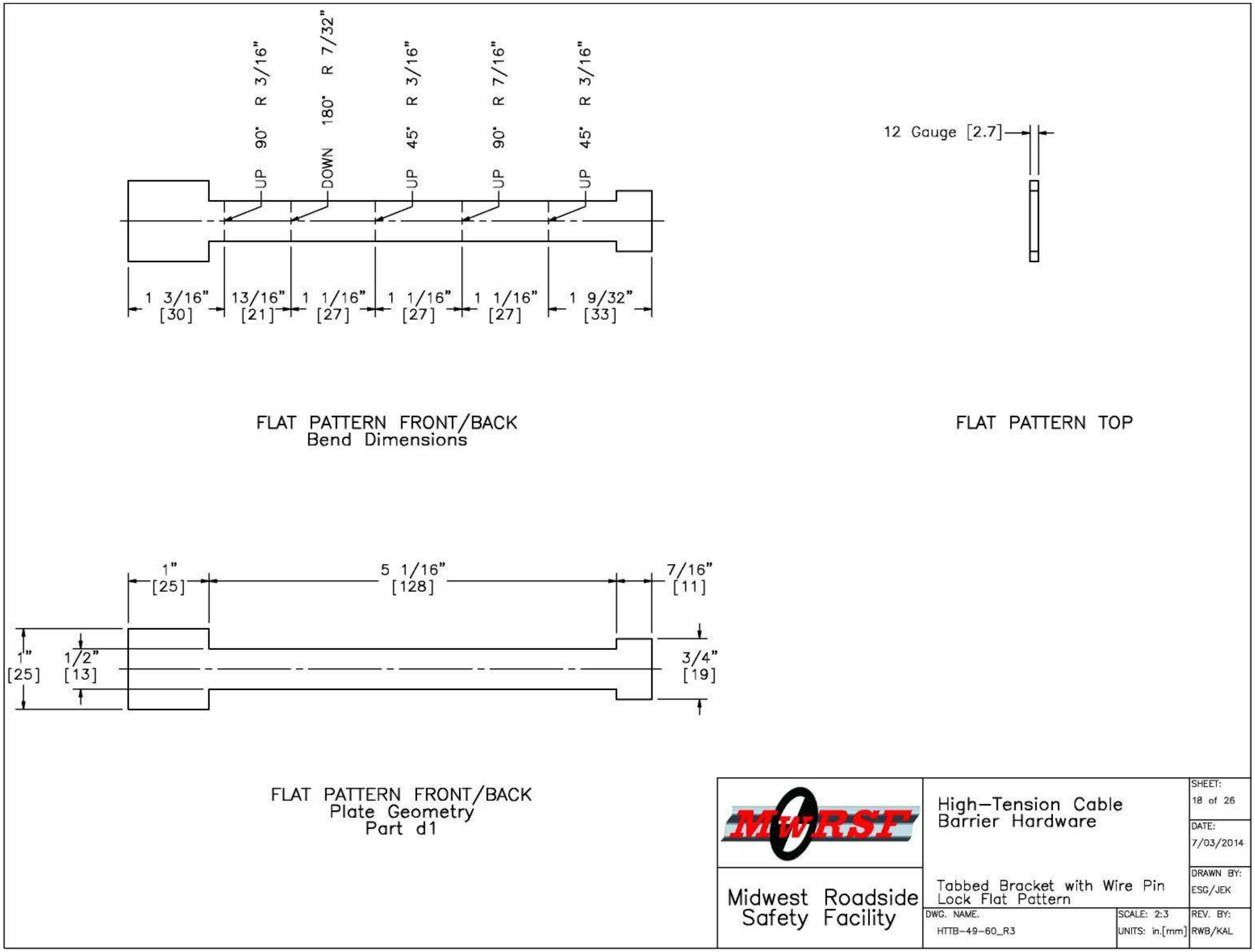

Figure 24. Tabbed Bracket with Wire Pin Lock Flat Pattern, Test Nos. HTTB-51, HTTB-52, HTTB-57, and HTTB-58

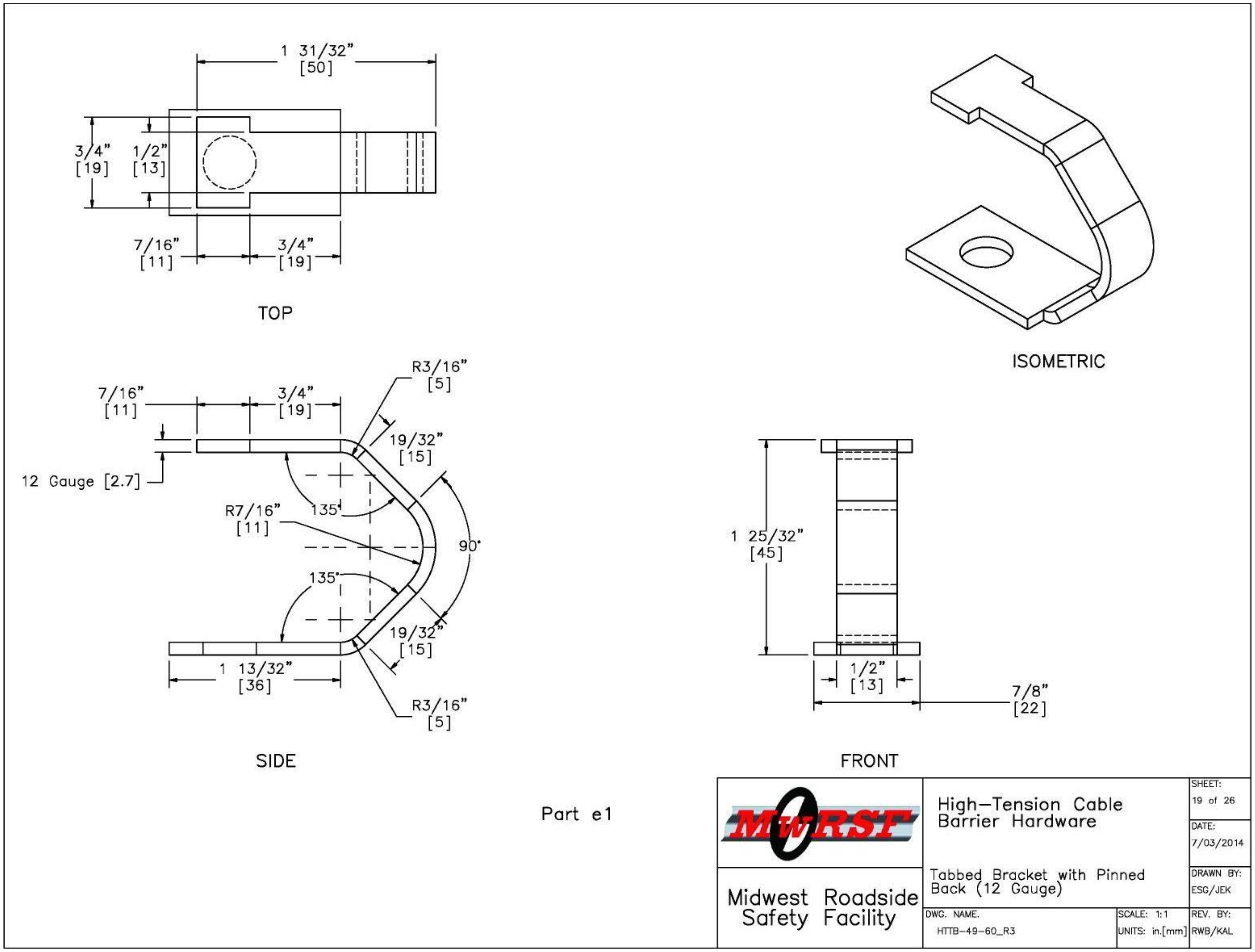

Figure 25. Tabbed Bracket with Pinned Back, Test Nos. HTTB-53, HTTB-54, HTTB-59, and HTTB-60

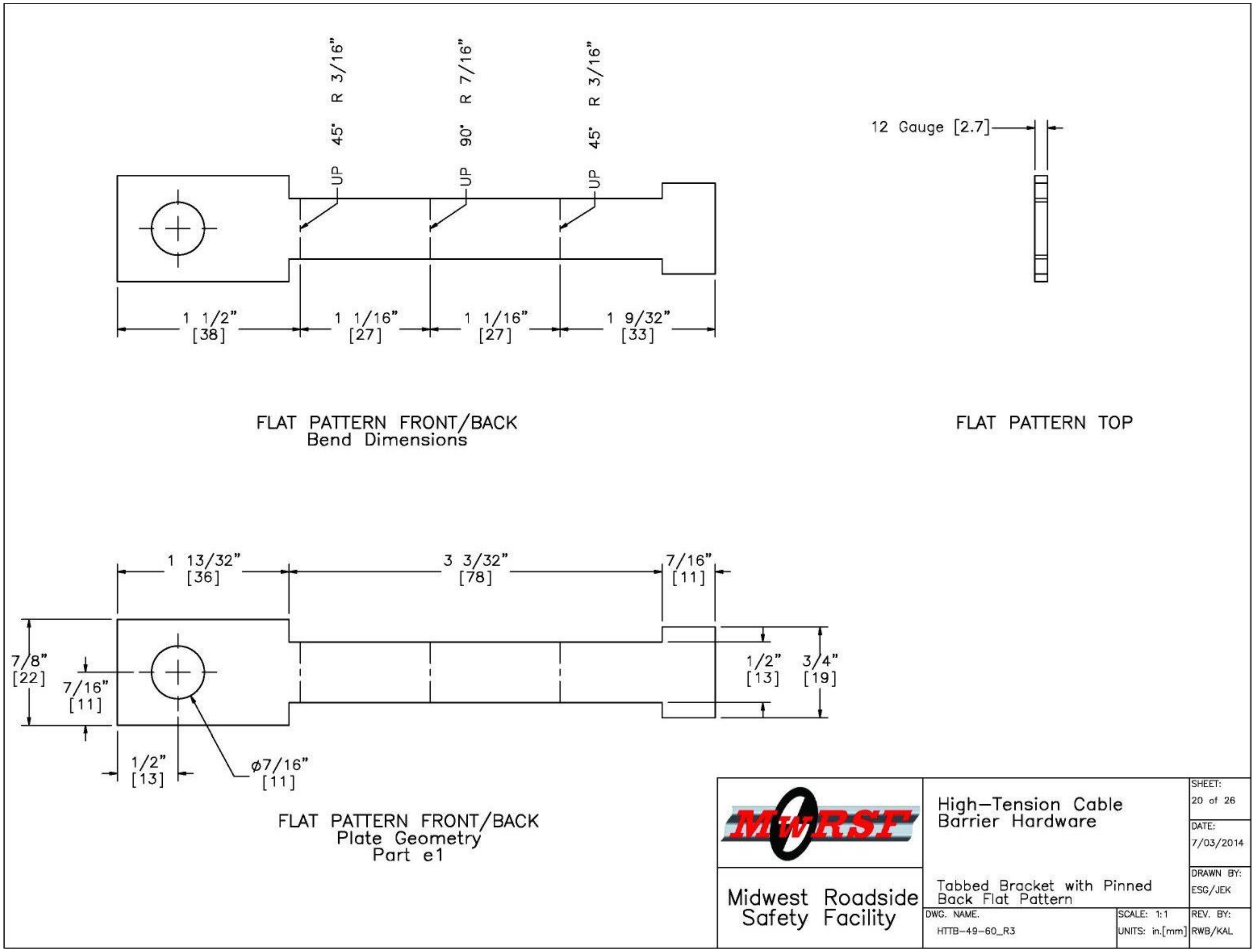

Figure 26. Tabbed Bracket with Pinned Back Flat Pattern, Test Nos. HTTB-53, HTTB-54, HTTB-59, and HTTB-60

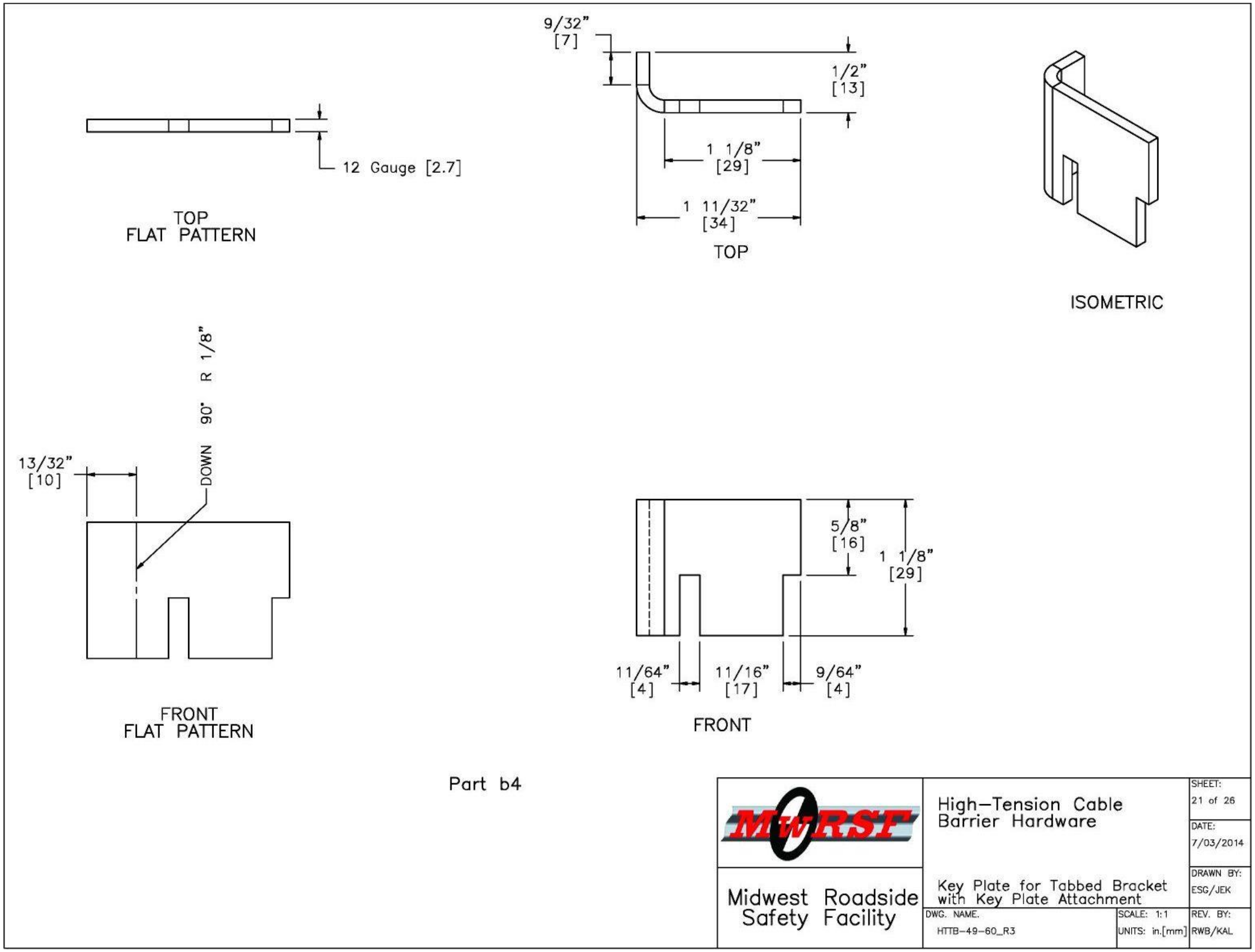

Figure 27. Key Plate for Tabbed Bracket with Key Plate Attachment, Test Nos. HTTB-49, HTTB-50, HTTB-55, and HTTB-56

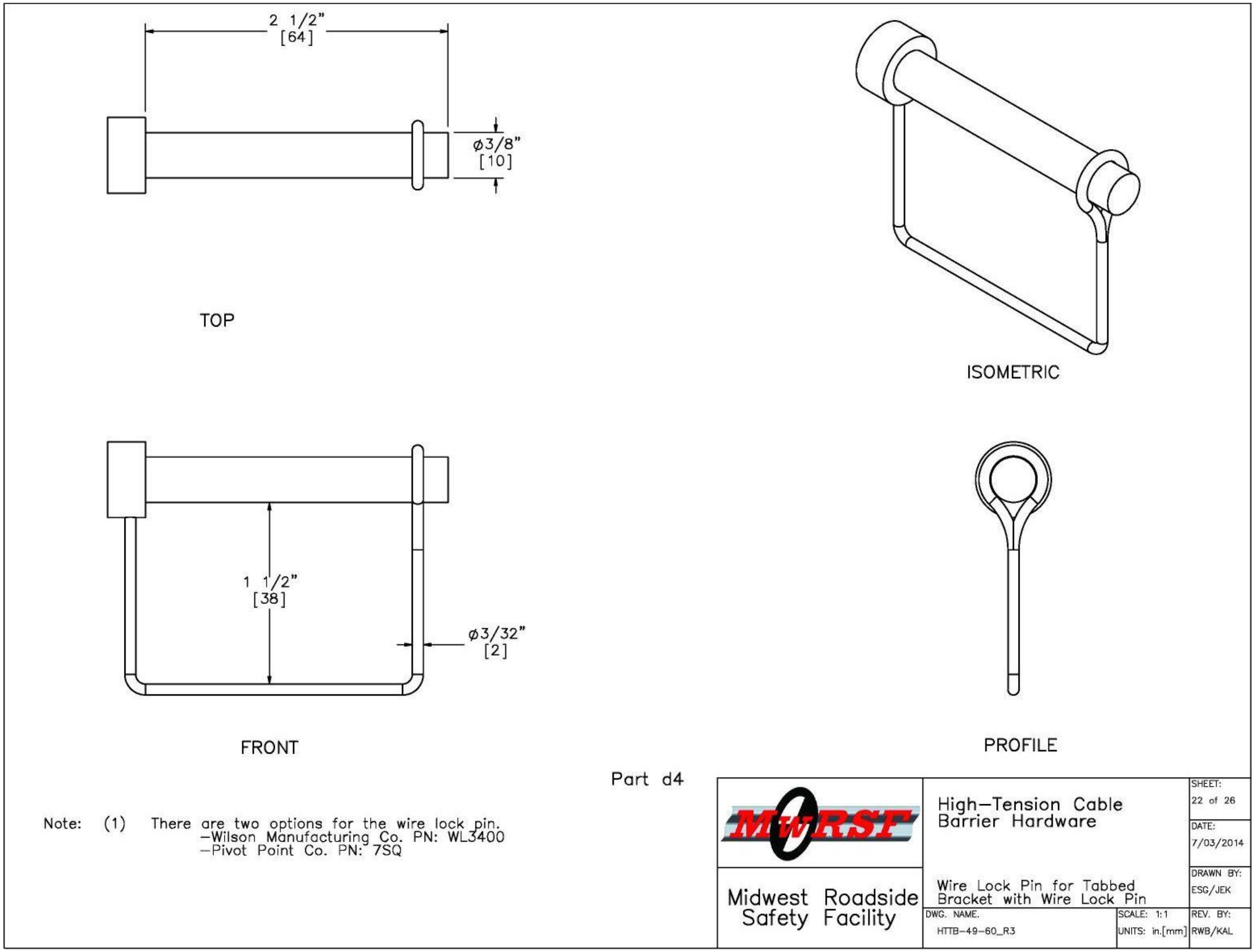

Figure 28. Wire Lock Pin for Tabbed Bracket with Wire Lock Pin, Test Nos. HTTB-51, HTTB-52, HTTB-57, and HTTB-58

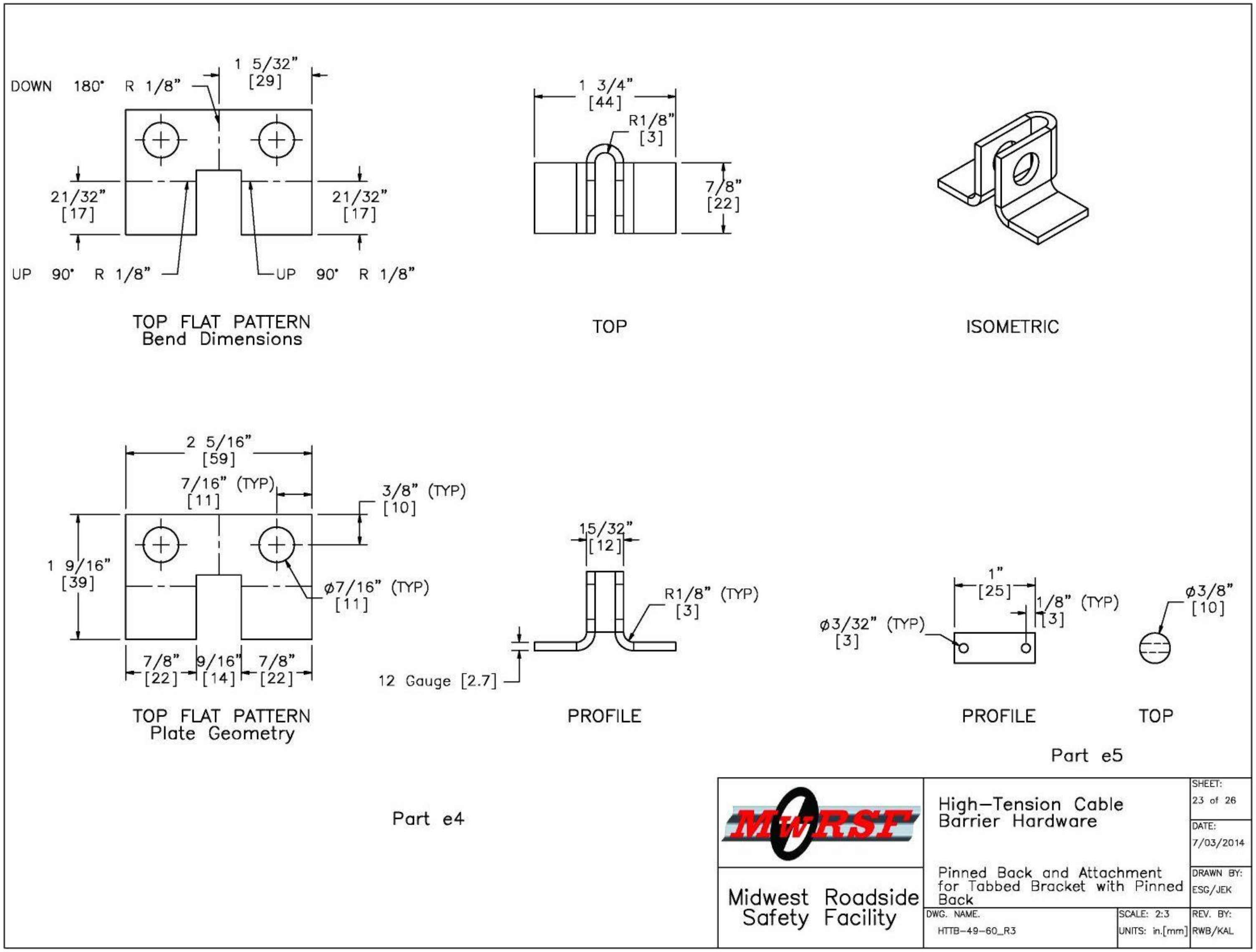

Figure 29. Pinned Back and Attachment for Tabbed Bracket with Pinned Back, Test Nos. HTTB-53, HTTB-54, HTTB-59, and HTTB-60

Bogie Testing Matrix							
Tabbed Bracket	Shear Plate	Test Qty.	Post Type	Orientation (deg)	Load Direction	Bogie No.	Target Speed (mph)
b1	b4	2	8–A	0	Vertical	3	5
b1	b4	2	8–B	90	Lateral	3	5
d1	d4	2	8–C	0	Verticle	3	5
d1	d4	2	8–C	90	Lateral	3	5
e1	e4	2	8–D	0	Verticle	3	5
e1	e4	2	8–D	90	Lateral	3	5

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			DATE: 7/03/2014
Midwest Roadside Safety Facility	Bogie Testing Matrix		DRAWN BY: ESG/JEK
	DWG. NAME. HTTB–49–60_R3	SCALE: 1:96 UNITS: in.[mm]	REV. BY: RWB/KAL

Figure 30. Bogie Testing Matrix

Cable Clip Test Jig Setup			
Item No.	QTY.	Description	Material Spec
a1	36	1" [25] Dia. Hardened Round Washer	ASTM F436
a2	6	1" [25] Dia. UNC, 2 1/2" [64] Long Heavy Hex Bolt	ASTM A307
a3	1	3/4" [19] Dia. 6x19 Wire Rope	–
a4	1	3/4" [19] Mechanical Splice	–
a5	2	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Bolt and Nut	Bolt ASTM A307, Nut ASTM A563
a6	1	4 7/8"x5"x1/4" [124x127x6] Mounting Plate with 4 welded Hex Nuts	ASTM A36
–	1	Cable Clip Bogie Test Jig (Pre–Existing in Field)	–
–	1	Cable Guide (Pre–Existing in Field)	–

Tabbed Bracket with Key Plate Attachment – Vertical			
Item No.	QTY.	Description	Material Spec
b1	2	Tabbed Bracket with Key Plate Attachment	12 Gauge [2.7] Hot–Rolled ASTM A1011 HSLA Grade 50
b2	1	3"x1 3/4" [76x44], 7 1/2 [191] Long Bent MWP	7 Gauge [4.6] Hot–Rolled ASTM A1011 HSLA Gr. 50
b3	6	1 5/16"x1 1/4"x1/4" [33x32x6] Gusset	ASTM A36
b4	2	Tabbed Bracket – Key Plate Attachment	12 Gauge Hot–Rolled ASTM A1011 HSLA Grade 50

Tabbed Bracket with Key Plate Attachment – Lateral			
Item No.	QTY.	Description	Material Spec
b1	2	Tabbed Bracket with Key Plate Attachment	12 Gauge [2.7] Hot–Rolled ASTM A1011 HSLA Grade 50
c2	1	3"x1 3/4" [76x44], 7 1/2" [191] Long Bent MWP	7 Gauge [4.6] Hot–Rolled ASTM A1011 HSLA Gr. 50
b3	6	1 5/16"x1 1/4"x1/4" [33x32x6] Gusset	ASTM A36
b4	2	Tabbed Bracket – Key Plate Attachment	12 Gauge Hot–Rolled ASTM A1011 HSLA Grade 50

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High–Tension Cable Barrier Hardware

Bill of Materials

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DRAWN BY: ESG/JEK
DWG. NAME. HTTB–49–60_R3
SCALE: NONE
UNITS: in.[mm]
REV. BY: RWB/KAL

Figure 31. Bill of Materials

Tabbed Bracket with Wire Lock Pin			
Item No.	QTY.	Description	Material Spec
d1	4	Tabbed Bracket with Wire Lock Pin	12 Gauge [2.7] Hot–Rolled ASTM A1011 HSLA Grade 50
d2	1	3"x1 3/4" [76x44], 6 3/8" [162] Long Bent MWP	7 Gauge [4.6] Hot–Rolled ASTM A1011 HSLA Gr. 50
b3	6	1 5/16"x1 1/4"x1/4" [33x32x6] Gusset	ASTM A36
d4	4	ϕ3/8"x2 1/2" [9.5x64] Wire Lock Pin	ANSI C1010 Low Carbon Steel

Tabbed Bracket with Pinned Back			
Item No.	QTY.	Description	Material Spec
e1	4	Tabbed Bracket with Pinned Back	12 Gauge [2.7] Hot–Rolled ASTM A1011 HSLA Grade 50
e2	1	3"x1 3/4" [76x44], 6 3/8" [162] Long Bent MWP	7 Gauge [4.6] Hot–Rolled ASTM A1011 HSLA Gr. 50
b3	6	1 5/16"x1 1/4"x1/4" [33x32x6] Gusset	ASTM A36
e4	4	Tabbed Bracket – Pinned Back	12 Gauge [2.7] Hot–Rolled ASTM A1011 HSLA Grade 50
e5	4	3/8" [9.5] Dia., 1" [25] Long Bar Stock Pin	ASTM A307 Gr. A

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Bill of Materials

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DWG. NAME. HTTB–49–60_R3
SCALE: NONE
UNITS: in.[mm]
REV. BY: RWB/KAL

Figure 32. Bill of Materials, Continued

3 TABBED BRACKET COMPONENT TESTING CONDITIONS

3.1 Purpose

Dynamic component testing of the new tabbed bracket attachment designs was conducted to evaluate their performance. Specifically, testing was conducted to obtain the cable release loads in both the vertical and lateral directions. The results were compared to the release loads of the previously tested bolted, tabbed bracket (V10) to evaluate the performance of the new bracket designs for potential use within the non-proprietary high-tension cable barrier system.

3.2 Scope

Twelve dynamic component tests were conducted on the new tabbed bracket designs. These tests consisted of attaching one end of a cable to a bogie and looping the other end through the inside of the test article (tabbed bracket). The bracket and cable assembly were mounted to a rigid MWP section, which was contained within the test jig. The test jig linked the MWP section to a load cell and was anchored to a rigid concrete block. A target bogie speed of 5 mph (8 km/h) away from the test article was used to load the cable in tension and dynamically load the new bracket configurations. Loading continued to increase until the cable was released from the bracket. An adjustable plate was used within the jig, which allowed the MWP segment to be rotated between 0 and 90 degrees. Thus, the brackets were loaded in both the vertical and lateral directions, respectively. The key plate, wire lock pin, and pinned-back attachment designs were subjected to two tests in each direction for a total of twelve component tests. The test matrix is shown in Table 2. The load cell data was then analyzed and the results were compared with the bolted tabbed bracket (V10) dynamic test results [2].

Table 2. Tabbed Bracket Testing Matrix

Test No.	Bracket Attachment Design	Orientation (deg.)	Load Direction	Target Speed mph (km/h)
HTTB-49	Key Plate	0	Vertical	5 (8)
HTTB-50	Key Plate	0	Vertical	5 (8)
HTTB-51	Wire Lock Pin	0	Vertical	5 (8)
HTTB-52	Wire Lock Pin	0	Vertical	5 (8)
HTTB-53	Pinned Back	0	Vertical	5 (8)
HTTB-54	Pinned Back	0	Vertical	5 (8)
HTTB-55	Key Plate	90	Lateral	5 (8)
HTTB-56	Key Plate	90	Lateral	5 (8)
HTTB-57	Wire Lock Pin	90	Lateral	5 (8)
HTTB-58	Wire Lock Pin	90	Lateral	5 (8)
HTTB-59	Pinned Back	90	Lateral	5 (8)
HTTB-60	Pinned Back	90	Lateral	5 (8)

3.3 Test Facility

Physical testing of the tabbed bracket alternative attachment designs was conducted at the MwRSF outdoor proving grounds, which is located at the Lincoln Air Park on the northwest side of Lincoln Municipal Airport. The facility is approximately 5 miles (8 km) northwest of the University of Nebraska-Lincoln city campus.

3.4 Equipment and Instrumentation

The equipment and instrumentation that was utilized to collect and record data during the cable-to-post dynamic bogie tests included a bogie vehicle, a 50-kip (222-kN) load cell, a test jig, high-speed and standard-speed digital video cameras, and still cameras.

3.4.1 Bogie Vehicle

A rigid-frame bogie was used to pull the cable that was attached to the various tabbed bracket designs. The weight of the bogie was 1,682 lb (763 kg). A pickup truck was used to propel the bogie along a guidance track to a target speed of 5 mph (8 km/h). The pickup truck braked, allowing the bogie to be free-rolling as it approached the end of the guidance system and applied the load to the cable-to-post attachment. A remote braking system was installed on the bogie, allowing it to be brought safely to rest after the test. The bogie with the test setup is shown in Figure 33.

Figure 33. Rigid-Frame Bogie on Guidance Track

3.4.2 Test Jig

A test jig was utilized to support and anchor the test article. The short MWP post selection was bolted to a mounting plate, which could be adjusted to change the angle at which the cable pulled on the post-bracket assembly. A steel rod was used to connect and transfer loads from the mounting plate to the load cell. The steel rod was encased by a cylindrical steel tube to restrict motion to only the direction of loading. A looped cable was placed through the tabbed bracket and through a feeder tube in line with the load cell and mounting plate. The other end of the cable was attached to the bogie. The test jig was mounted to the side of a rigid concrete block, as shown in Figure 34.

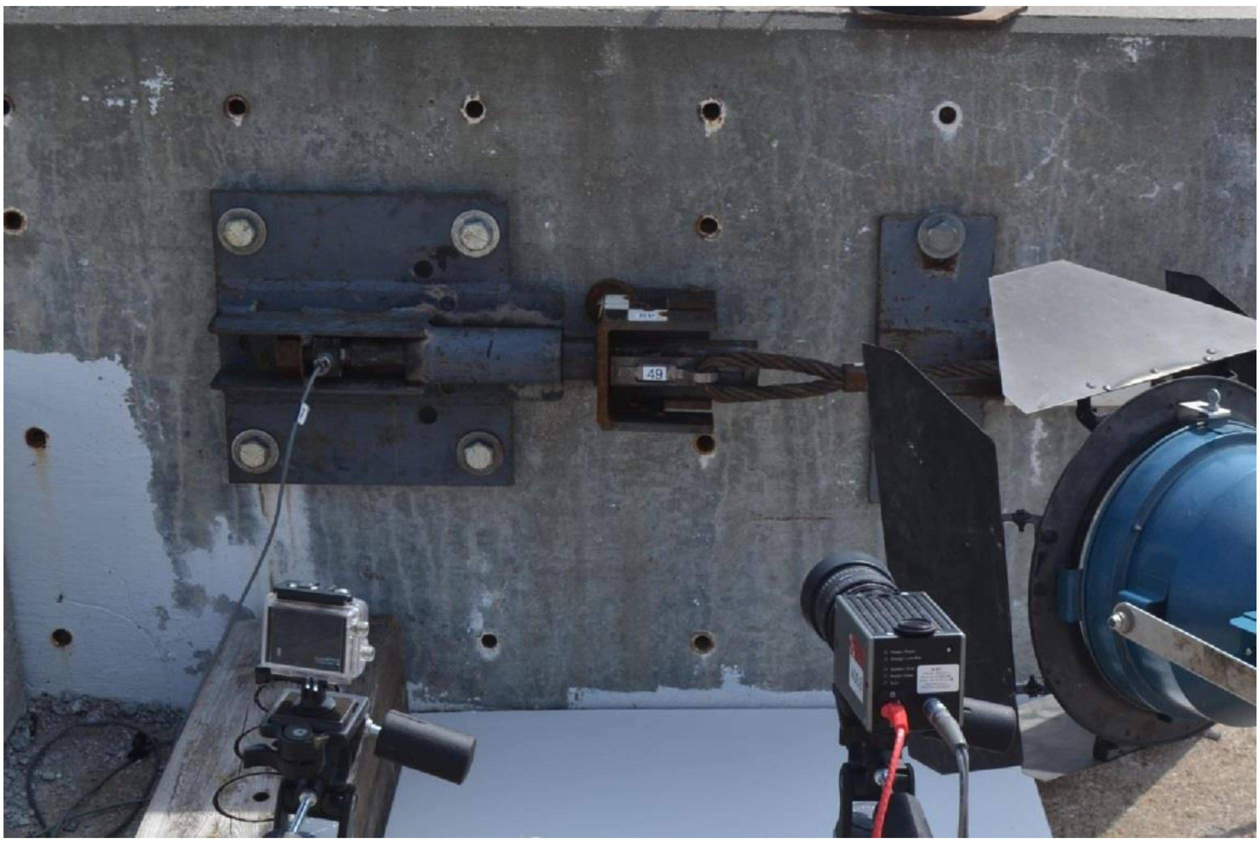


Figure 34. Test Jig

3.4.3 Load Cell

A 50-kip (222-kN) capacity load cell was used to measure the force exerted on the test article by the cable until the cable was released. This load cell was placed between the mounting plate and a rigid anchor plate and recorded the tensile loads imparted to the tabbed bracket and post assembly.

3.4.4 Digital Photography

Two AOS high speed digital video cameras and one GoPro Hero 3 digital camera were used to document each test. The AOS high-speed cameras had a frame rate of 500 frames per second and the GoPro digital video camera recorded at 120 frames per second. A Nikon D50 digital still camera was also used, to document pre- and post-test conditions for all tests.

3.5 Data Processing and Analysis

Force data was measured with the load cell transducer and filtered using the SAE Class 60 Butterworth filter conforming to SAE J211/1 specifications [4]. Once the data was processed, the period of the loading event was determined. Since the tensile load in the cable was gradually increased until the cable was pulled taut, it was often difficult to determine the beginning of loading from the load cell data alone. However, the moment of cable release was easily detectable as the point when the load dropped to zero very rapidly. Thus, high-speed video was utilized to determine the time duration between initial loading and cable release. The load cell data was then cropped to reflect the same time duration.

4 TABBED BRACKET COMPONENT TESTING

4.1 Results

A total of twelve component tests, test nos. HTTB-49 through HTTB-60, were conducted on the three tabbed bracket alternative attachment designs. Each design concept was loaded twice in its vertical orientation and twice in its lateral orientation. The peak forces were obtained from the load cell data, and the behavior of the cable and the bracket was observed from high-speed video. Test results for all load cells are provided in Appendix B.

4.1.1 Test No. HTTB-49

Test no. HTTB-49 evaluated the tabbed bracket with the key plate attachment by loading the bracket vertically, or at an angle of 0 degrees relative to the face of the post. Once the cable was pulled into tension, the construction tolerances within the key plate connection allowed the bracket to rotate slightly outward. As the load imparted to the tabbed bracket increased, the spine of the bracket began to bend, and the bracket opened. At 0.209 seconds after the initial loading, a peak load of 0.27 kips (1.20 kN) was reached. After this peak, the force fell quickly as the bracket continued to open. The peak occurring after this time was caused by the cable briefly catching on the tabs after it released from the bracket, a phenomenon possible only because of the cable loop. In an actual installation where the cable is straight, the tabs would not be expected to snag the cable. As such, the forces associated with the snag were not considered part of the release load. The tabs completely exited the keyway by 0.220 seconds. The force vs. time curve is shown in Figure 35. Pre- and post-test photographs and sequential photographs are shown in Figures 36 and 37, respectively.

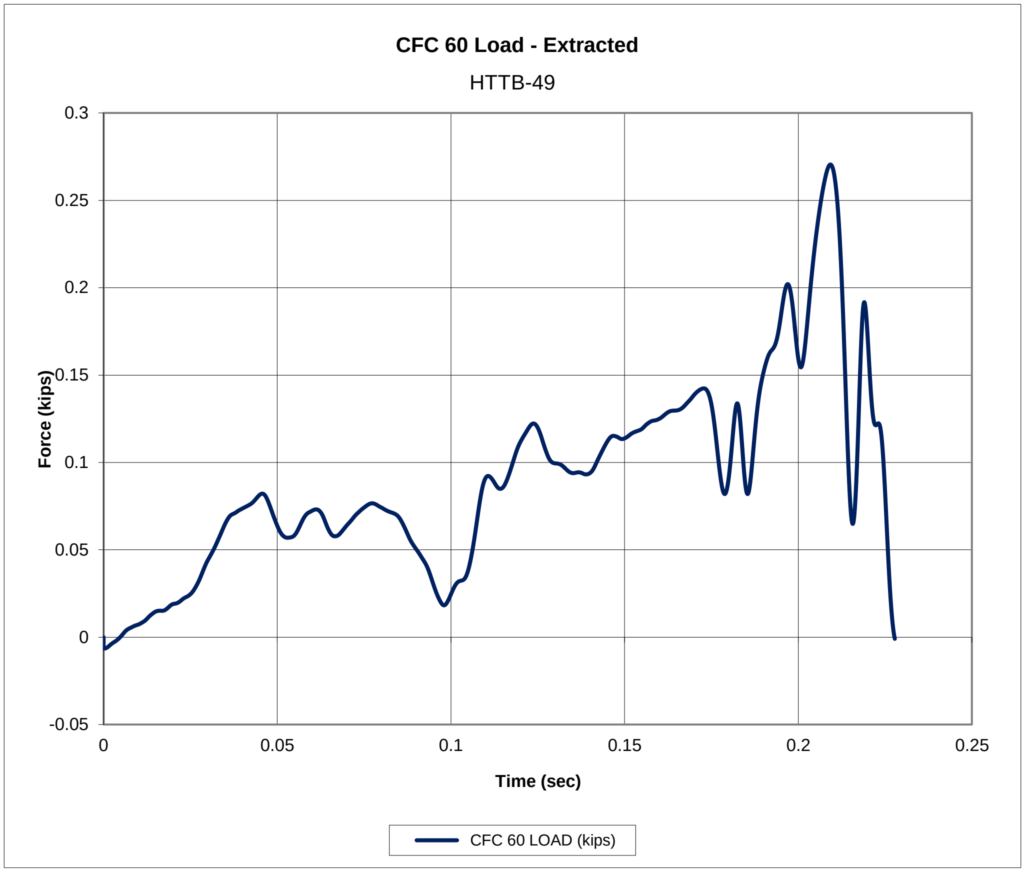


Figure 35. Force vs. Time Data, Test No. HTTB-49

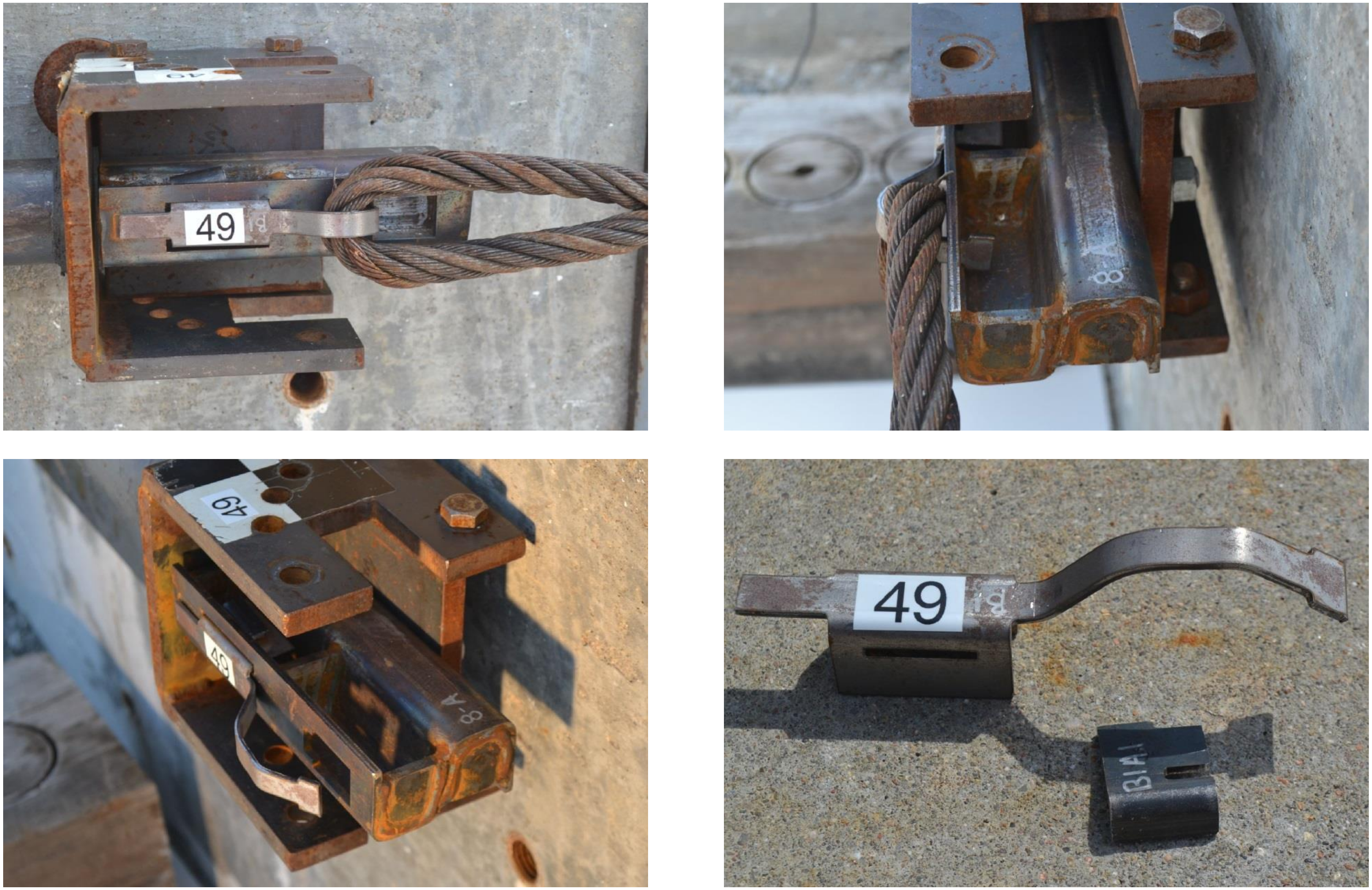
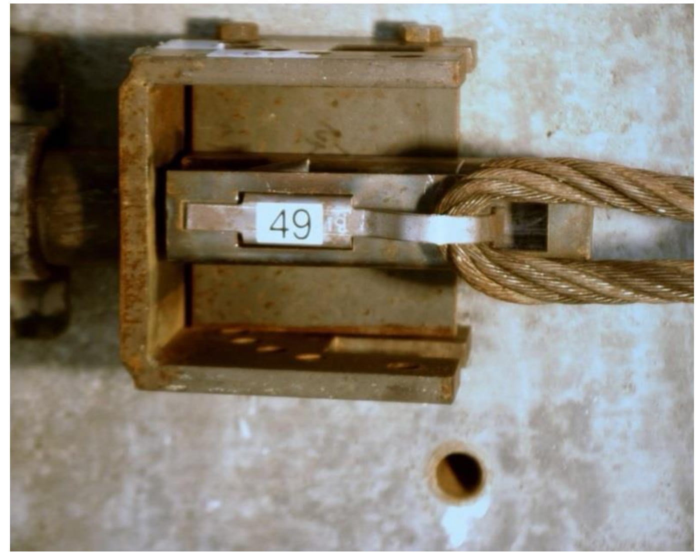
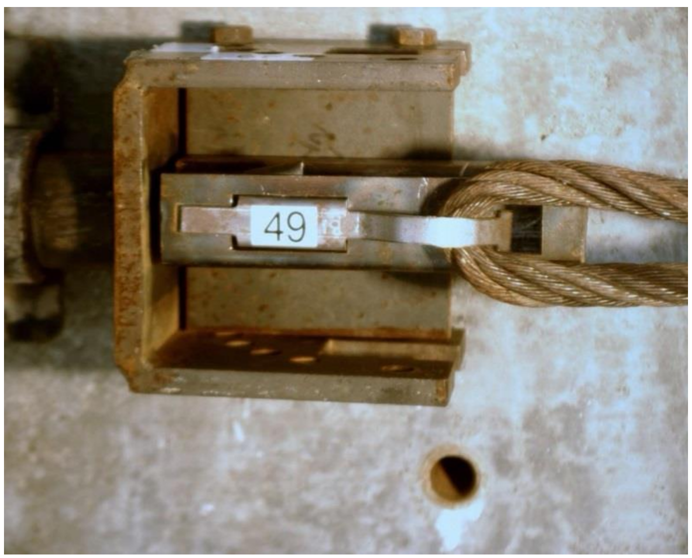


Figure 36. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-49

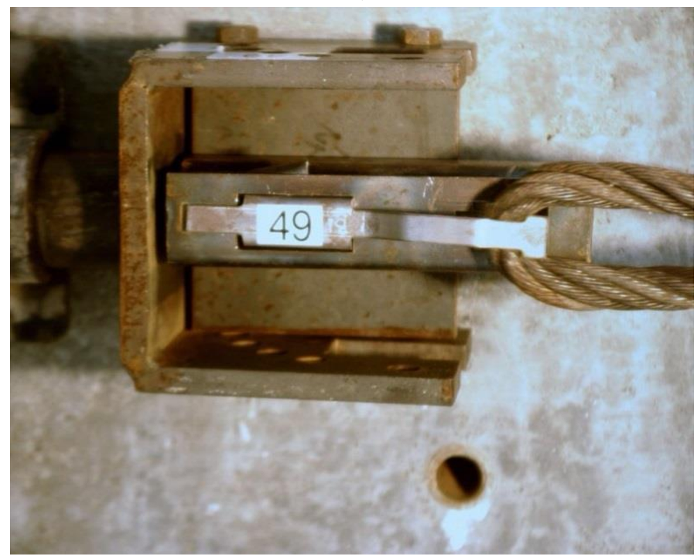
Time = 0 sec



Time = 0.204 sec



Time = 0.209 sec



Time = 0.228 sec

Figure 37. Sequential Photographs, Test No. HTTB-49

4.1.2 Test No. HTTB-50

Test no. HTTB-50 evaluated the tabbed bracket with the key plate attachment by loading the bracket vertically, or at an angle of 0 degrees relative to the face of the post. Once the cable was pulled into tension, the construction tolerances within the key plate connection allowed the bracket to rotate slightly outward. As the load imparted to the tabbed bracket increased, the spine of the bracket began to bend, and the bracket opened. At 0.211 seconds after the initial loading, a peak load of 0.29 kips (1.29 kN) was reached. After this peak, the force fell quickly as the bracket continued to open and the tabs were lifted out of the keyway. The tabs completely exited the keyway at 0.218 seconds. The force vs. time curve is shown in Figure 38. Pre- and post-test photographs and sequential photographs are shown in Figures 39 and 40, respectively.

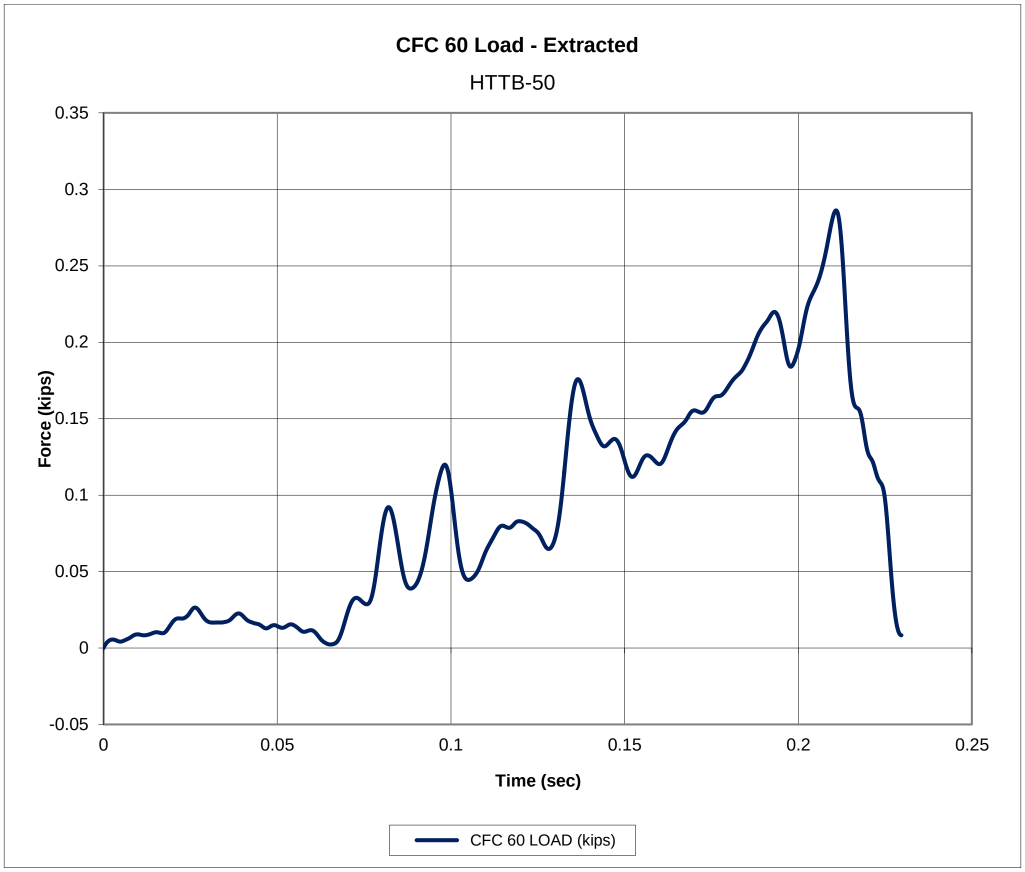
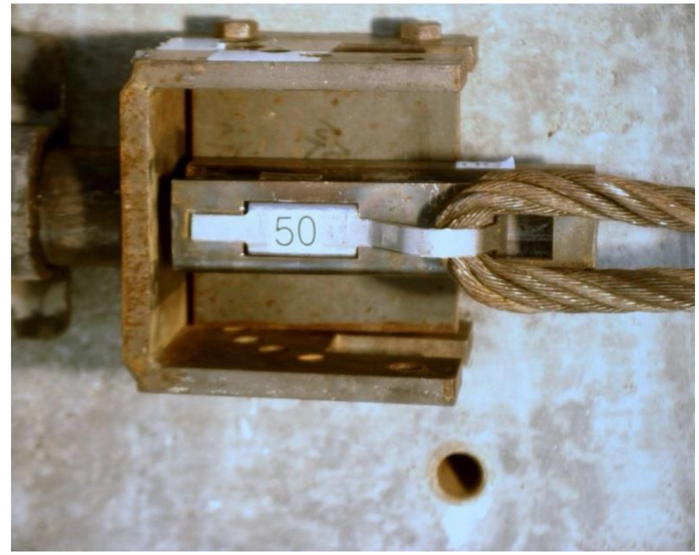


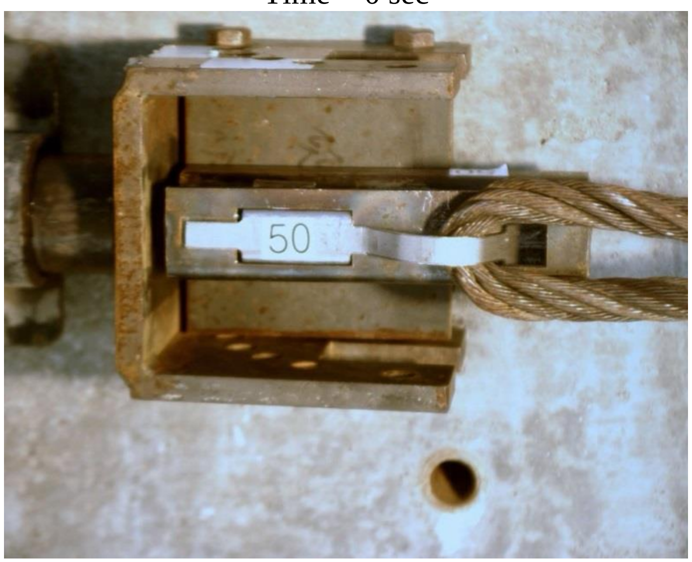
Figure 38. Force vs. Time Data, Test No. HTTB-50

Figure 39. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-50

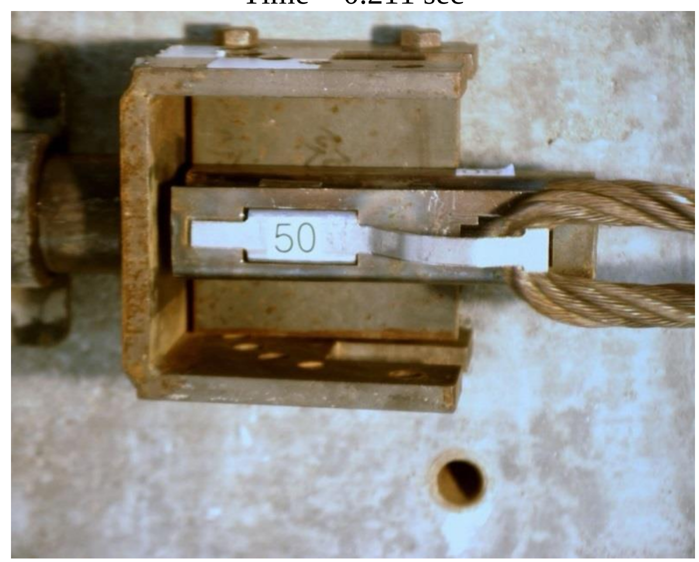
Time = 0 sec



Time = 0.211 sec



Time = 0.218 sec



Time = 0.230 sec

Figure 40. Sequential Photographs, Test No. HTTB-50

4.1.3 Test No. HTTB-51

Test no. HTTB-51 evaluated the tabbed bracket with the wire lock pin attachment by loading the bracket vertically, or at an angle of 0 degrees relative to the face of the post. Once the cable was pulled into tension, the construction tolerances within the wire lock pin connection allowed the bracket to rotate slightly outward. As the load imparted to the tabbed bracket increased, the spine of the bracket began to bend, and the bracket opened. At 0.213 seconds after the initial loading, a peak load of 0.26 kips (1.16 kN) was reached. After this peak, the force fell quickly as the bracket continued to open and the tabs were lifted out of the keyway. By 0.226 seconds, the tabs had completely exited the keyway. The two peaks occurring after this time were caused by the cable briefly catching on the tabs after it released from the bracket and were not considered part of the release load. The force vs. time curve is shown in Figure 41. Pre- and post-test photographs and sequential photographs are shown in Figures 42 and 43, respectively.

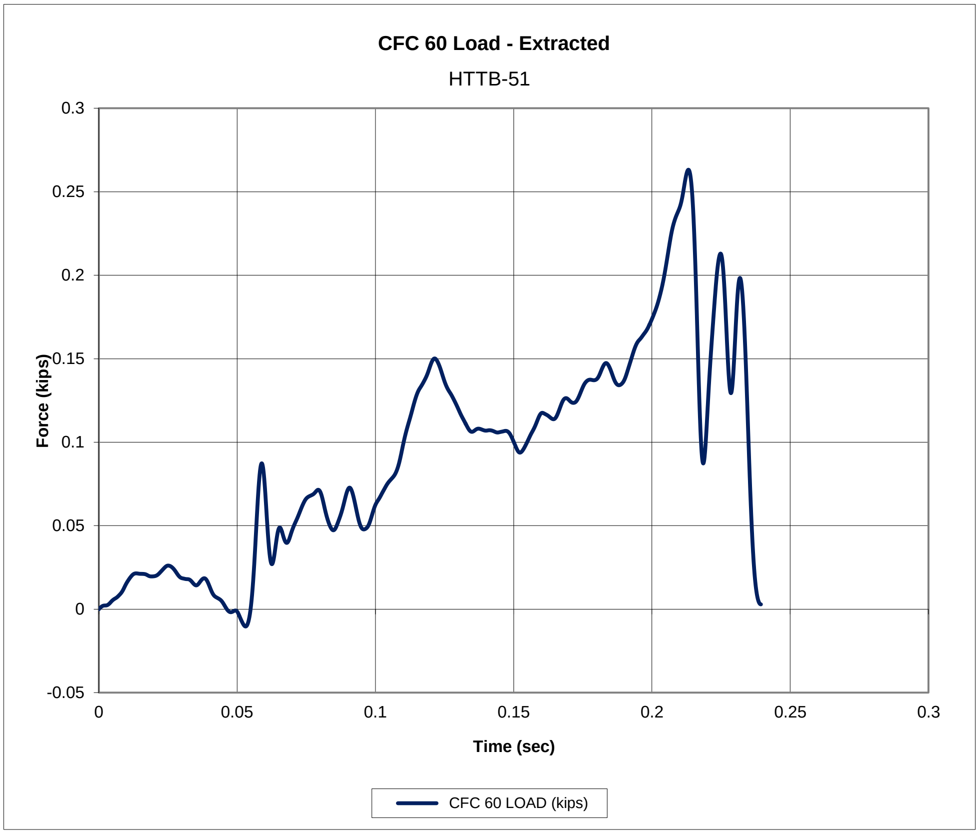
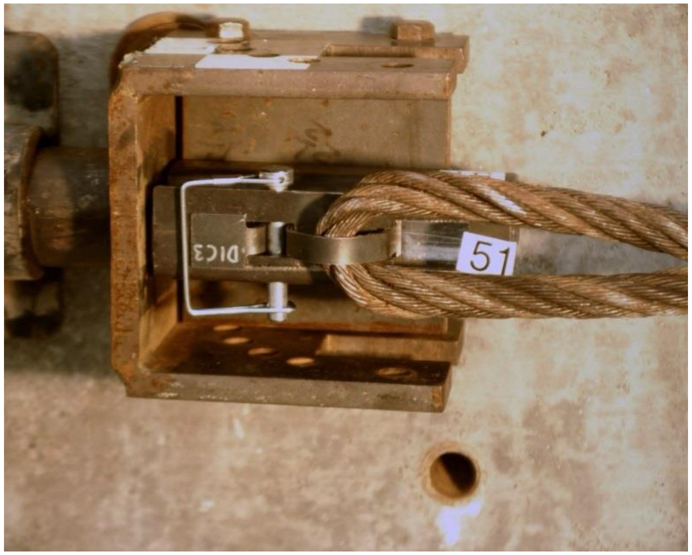
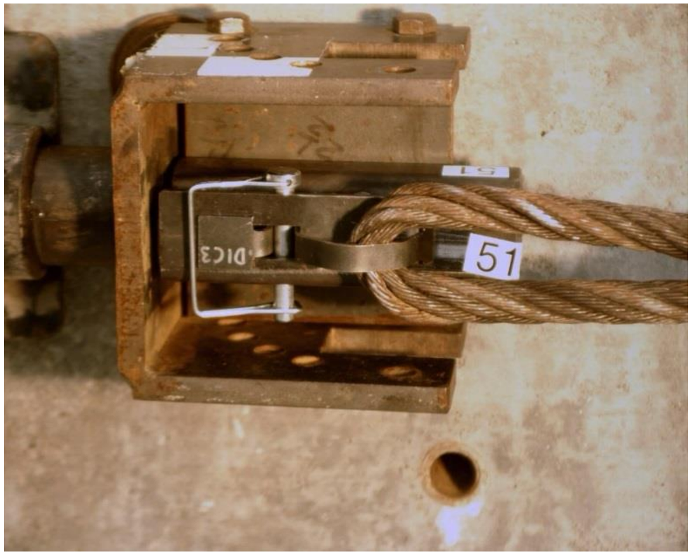


Figure 41. Force vs. Time Data, Test No. HTTB-51

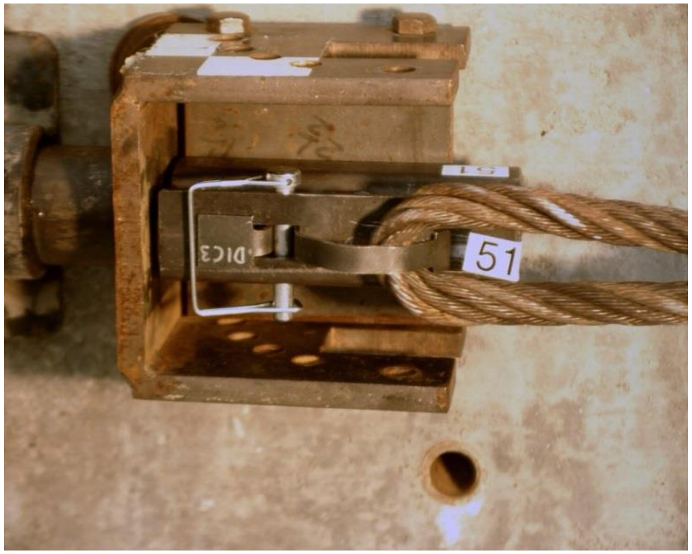
Figure 42. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-51



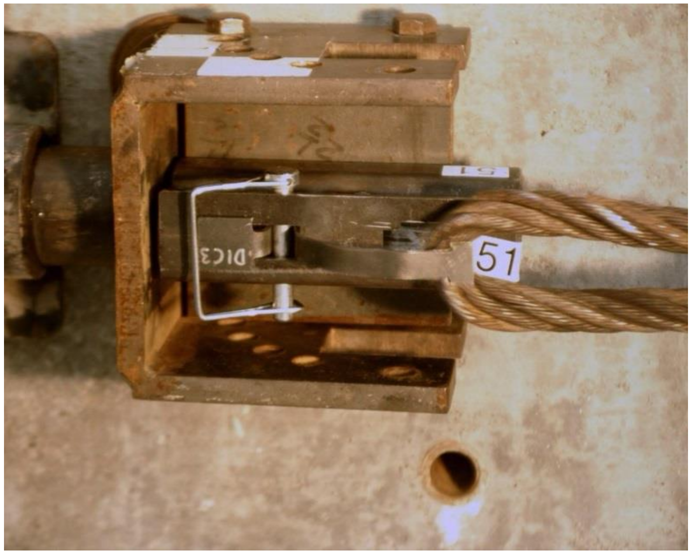
Time = 0 sec



Time = 0.213 sec



Time = 0.226 sec



Time = 0.239 sec

Figure 43. Sequential Photographs, Test No. HTTB-51

4.1.4 Test No. HTTB-52

Test no. HTTB-52 evaluated the tabbed bracket with the wire lock pin attachment when loaded vertically, or at an angle of 0 degrees relative to the face of the post. Once the cable was pulled into tension, the construction tolerances within the wire lock pin connection allowed the bracket to rotate slightly outward. As the load imparted to the tabbed bracket increased, the spine of the bracket began to bend, and the bracket opened. At 0.228 seconds after the initial loading, a peak load of 0.79 kips (3.51 kN) was reached. Installation tolerances allowed the bracket to twist and the tabs to catch on the side of the keyway for a short time before releasing at 0.238 seconds. After this, the force fell quickly as the bracket continued to open and the tabs were lifted out of the keyway. After the tab released from its snagged position on the keyway, bracket flexure and snag on the cable produced loads similar to the previous vertical release loads with a peak load of 0.25 kips (1.11 kN). The force vs. time curve is shown in Figure 44. Pre- and post-test photographs and sequential photographs are shown in Figures 45 and 46, respectively.

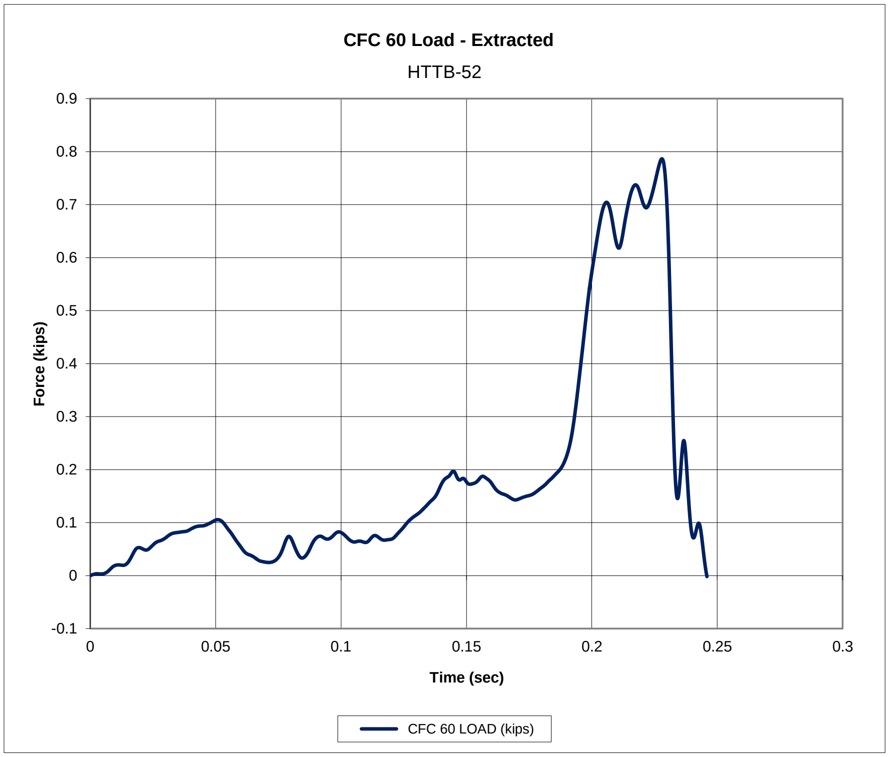
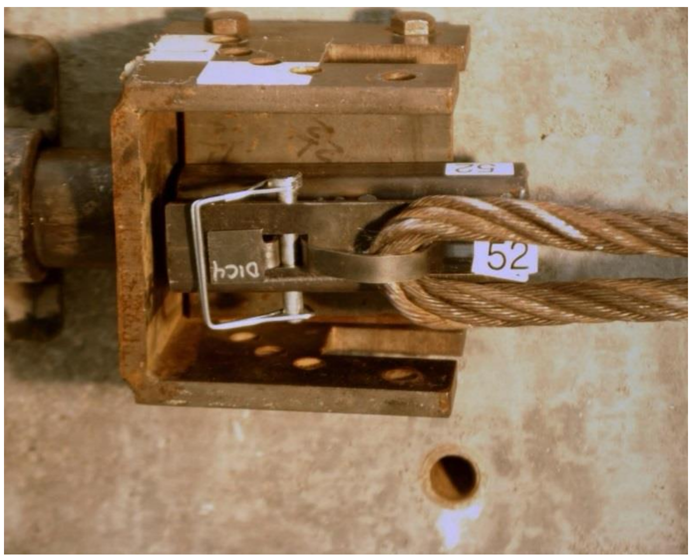


Figure 44. Force vs. Time Data, Test No. HTTB-52

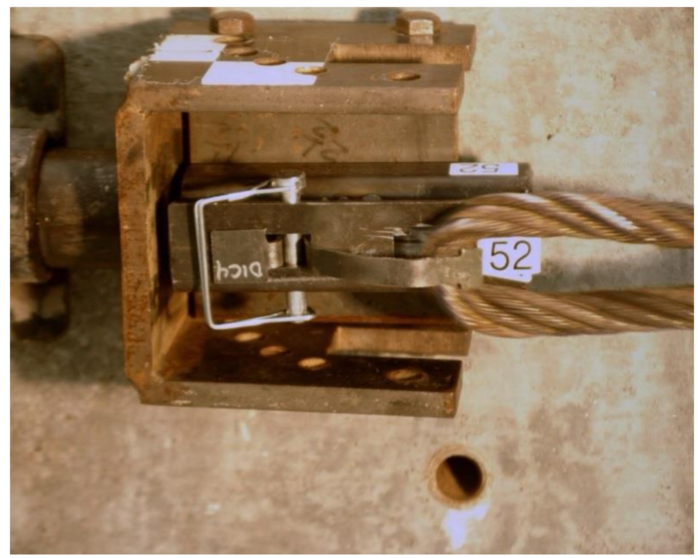
Figure 45. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-52

Time = 0 sec

Time = 0.228 sec



Time = 0.238 sec



Time = 0.246 sec

Figure 46. Sequential Photographs, Test No. HTTB-52

4.1.5 Test No. HTTB-53

Test no. HTTB-53 evaluated the tabbed bracket with the pinned-back attachment by loading the bracket vertically, or at an angle of 0 degrees relative to the face of the post. Once the cable was pulled into tension, the construction tolerances within the pinned-back connection allowed the bracket to rotate slightly outward. As the load imparted to the tabbed bracket increased, the spine of the bracket began to bend, and the bracket opened. At 0.159 seconds after the initial loading, a peak load of 0.28 kips (1.25 kN) was reached. After this peak, the force fell quickly as the bracket continued to open and the tabs were lifted out of the keyway. By 0.160 seconds, the tabs had completely exited the keyway. The two peaks occurring after this time were caused by the cable briefly catching on the tabs after it released from the bracket and were not considered part of the release load. The force vs. time curve is shown in Figure 47. Pre- and post-test photographs and sequential photographs are shown in Figures 48 and 49, respectively.

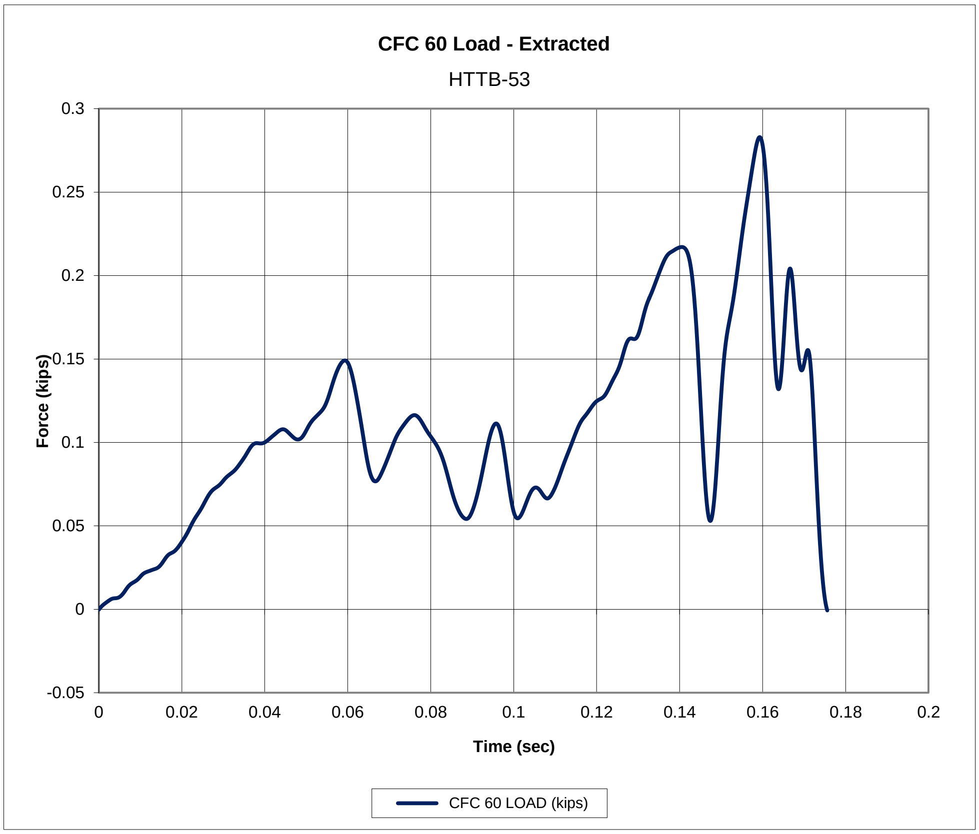


Figure 47. Force vs. Time Data, Test No. HTTB-53

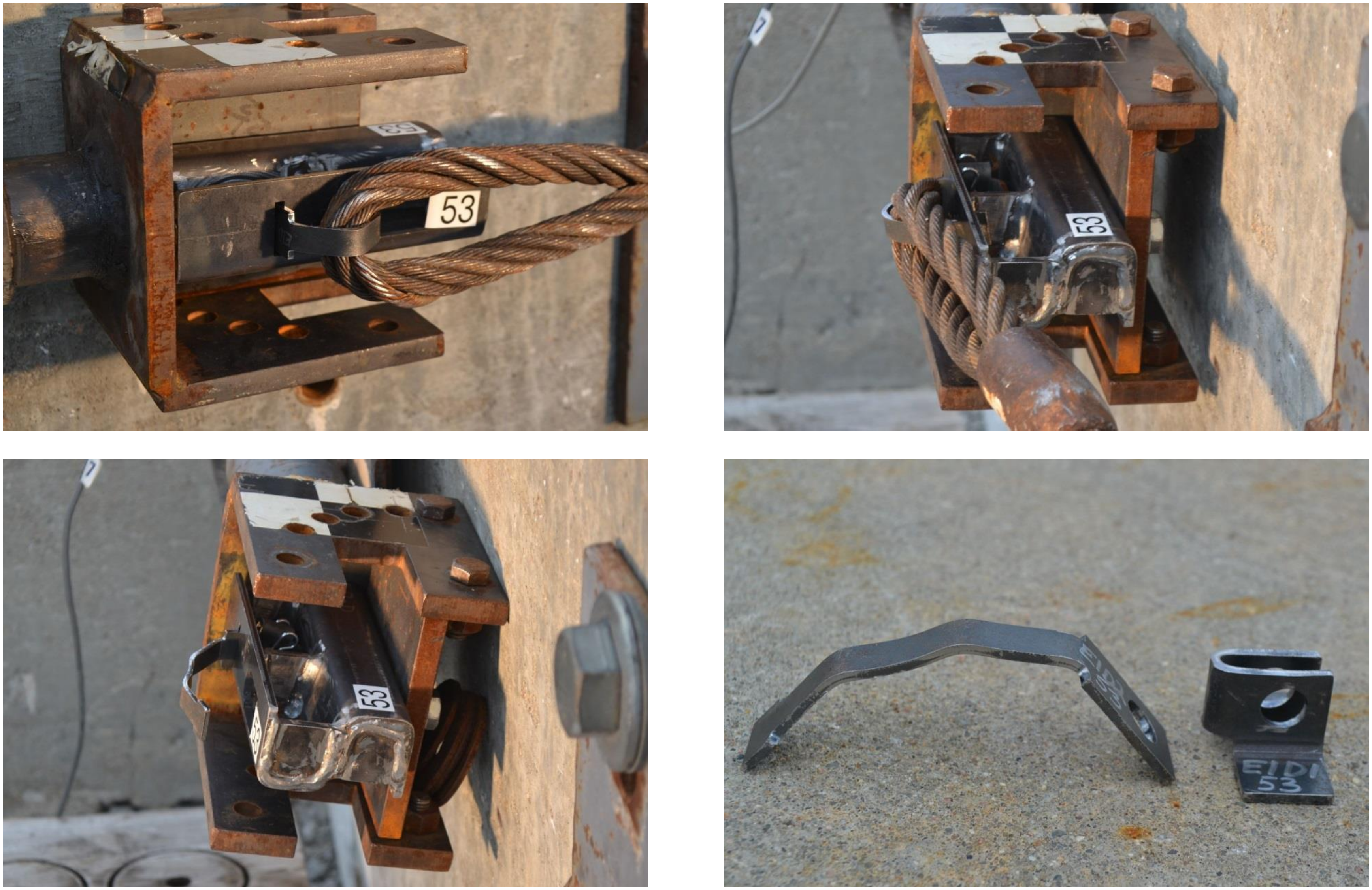
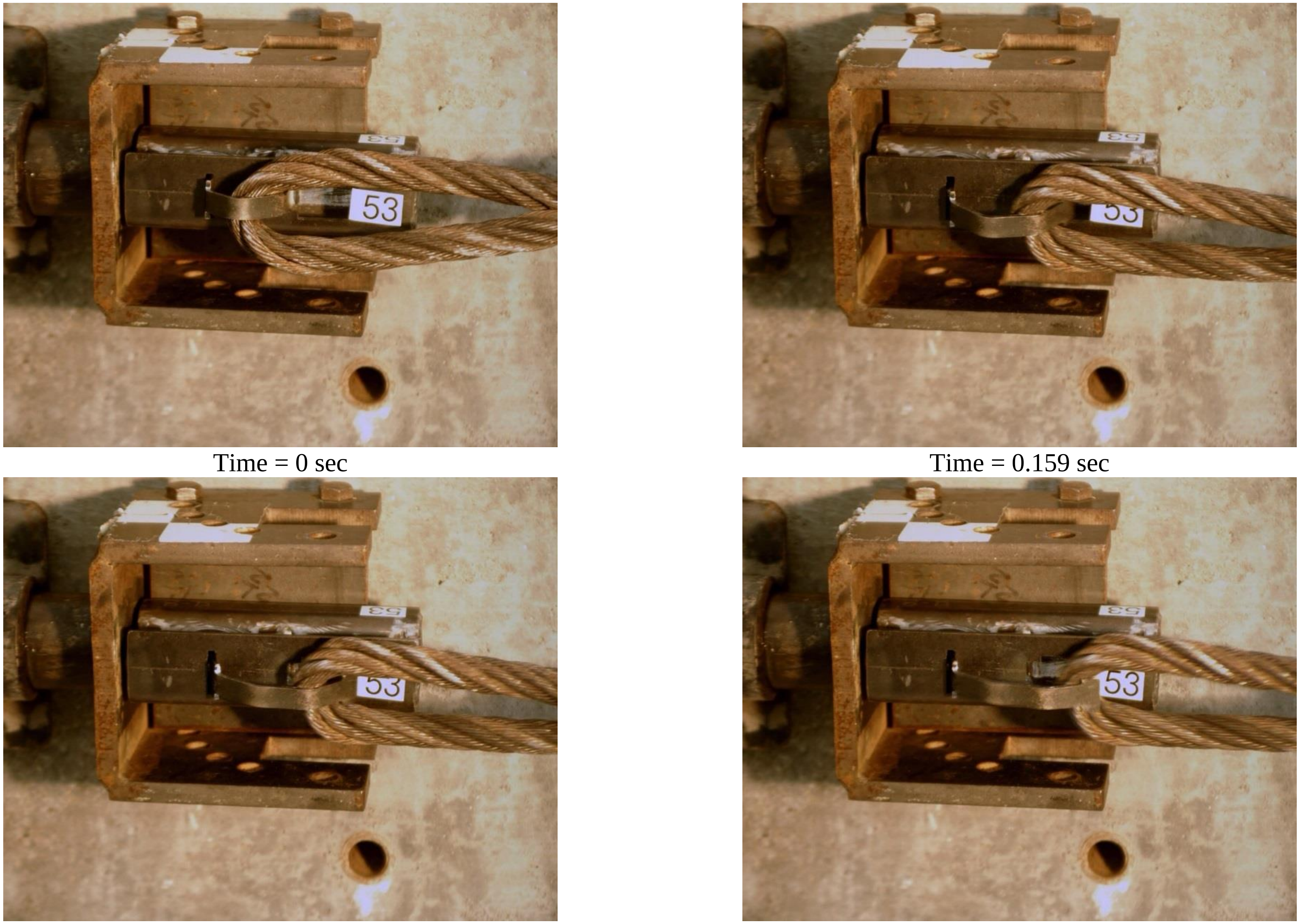


Figure 48. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-53



Time = 0 sec

Time = 0.159 sec

Time = 0.168 sec

Time = 0.176 sec

Figure 49. Sequential Photographs, Test No. HTTB-53

4.1.6 Test No. HTTB-54

Test no. HTTB-54 evaluated the tabbed bracket with the pinned-back attachment by loading the bracket vertically, or at an angle of 0 degrees relative to the face of the post. Once the cable was pulled into tension, the construction tolerances within the pinned-back connection allowed the bracket to rotate slightly outward. As the load imparted to the tabbed bracket increased, the spine of the bracket began to bend, and the bracket opened. At 0.244 seconds after the initial loading, a peak load of 0.29 kips (1.29 kN) was reached. By 0.276 seconds, the bracket had completely released the cable. The force vs. time curve is shown in Figure 50. Pre- and post-test photographs and sequential photographs are shown in Figures 51 and 52, respectively.

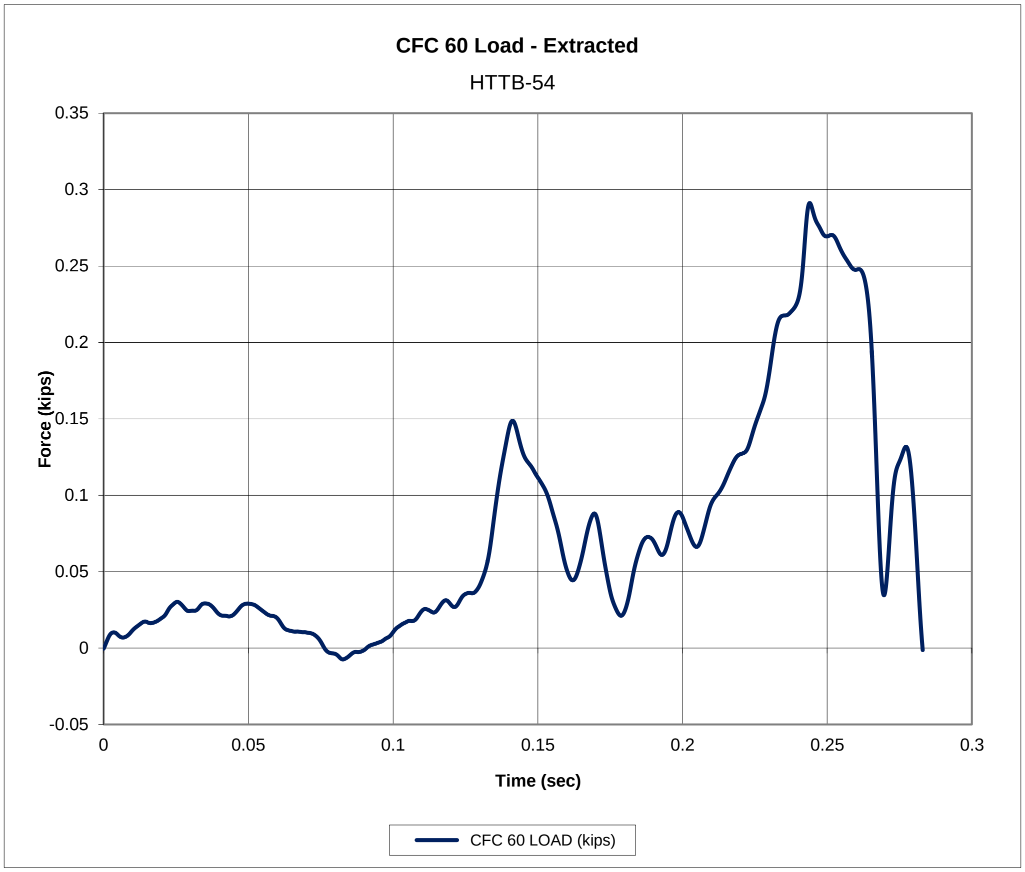
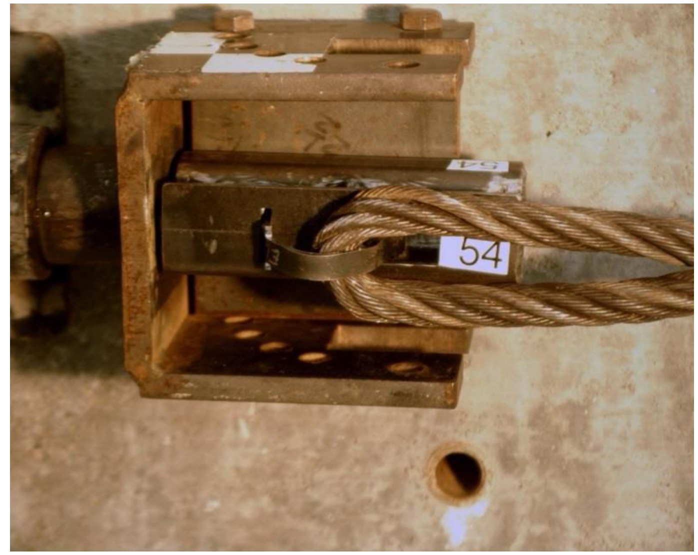


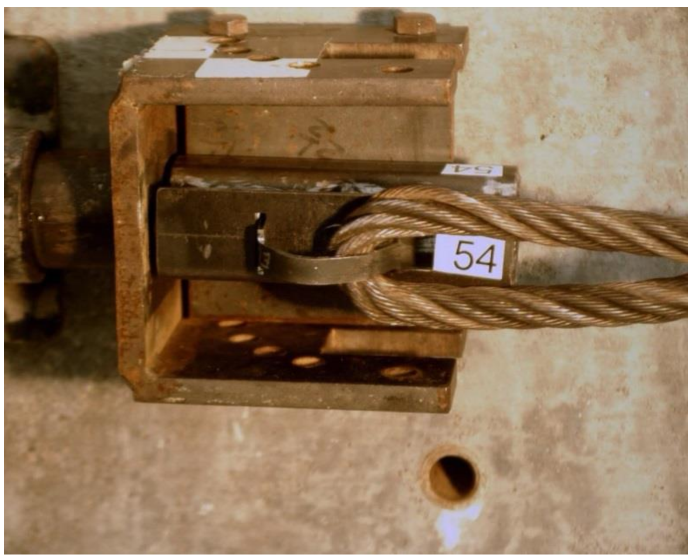
Figure 50. Force vs. Time Data, Test No. HTTB-54

Figure 51. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-54

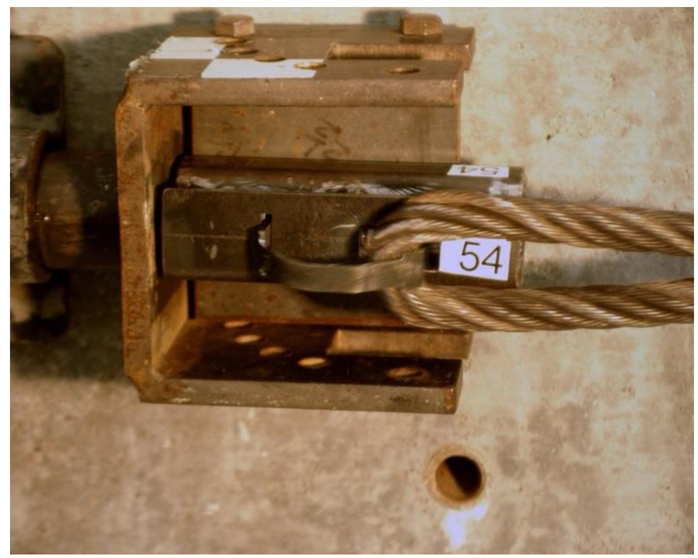
Time = 0 sec



Time = 0.244 sec



Time = 0.276 sec



Time = 0.283 sec

Figure 52. Sequential Photographs, Test No. HTTB-54

4.1.7 Test No. HTTB-55

Test no. HTTB-55 evaluated the tabbed bracket with the key plate attachment by loading the bracket laterally, or normal to the flange of the post. As the cable was pulled into tension, the tabs were pulled against the post flange at the bottom of the keyway. As the load increased, the spine of the bracket began to bend and stretch. At 0.236 seconds, a peak load of 4.77 kips (21.22 kN) was reached and bending of the tabs resulted in the tabs being pulled through the keyway. By 0.240 seconds, the tabs had completely exited the keyway. The spine of the bracket bent open, and the cable was released at 0.246 seconds. The force vs. time curve is shown in Figure 53. Pre- and post-test photographs and sequential photographs are shown in Figures 54 and 55, respectively.

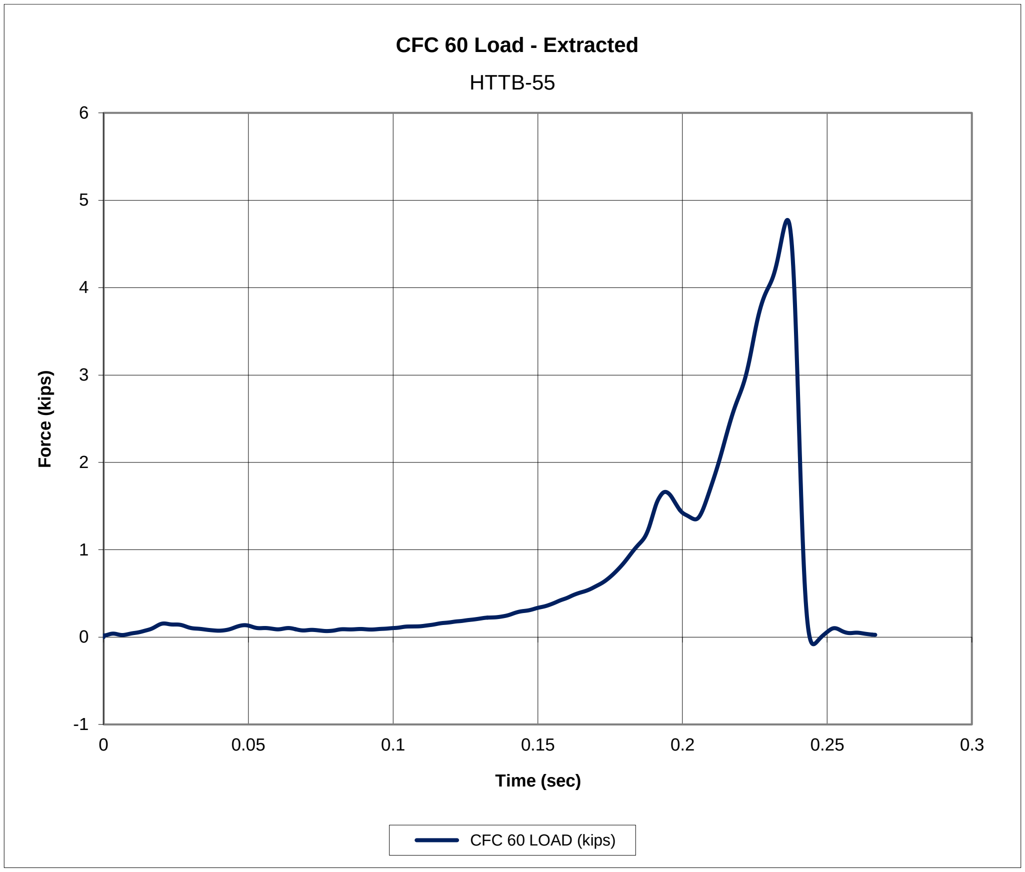


Figure 53. Force vs. Time Data, Test No. HTTB-55

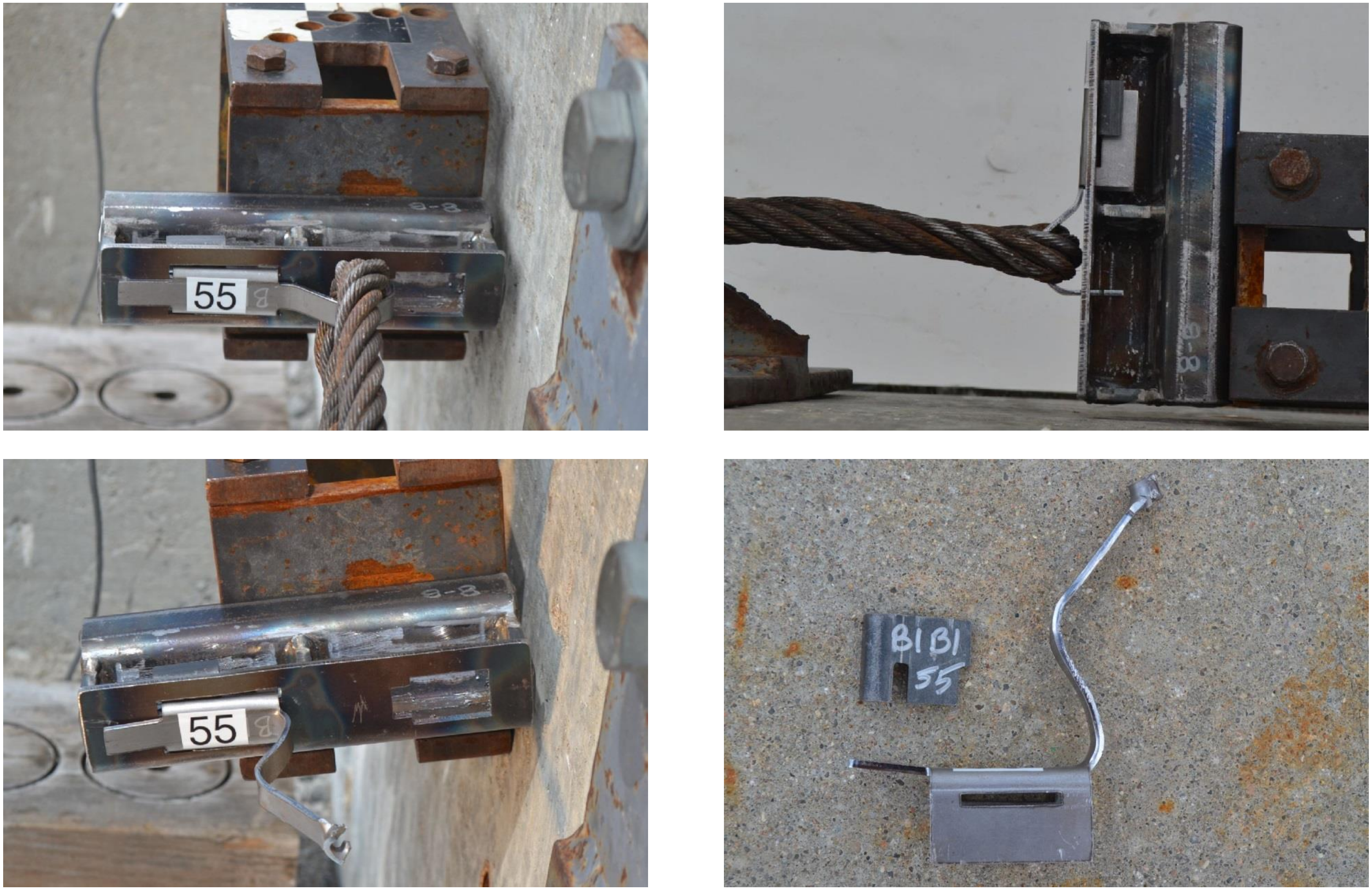
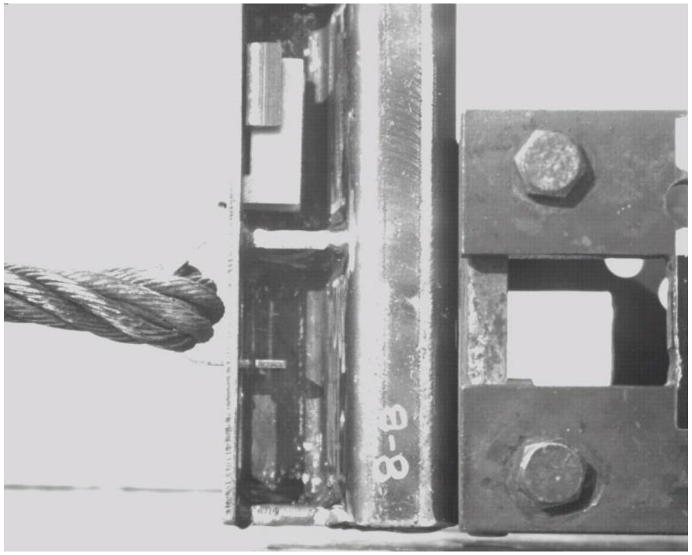
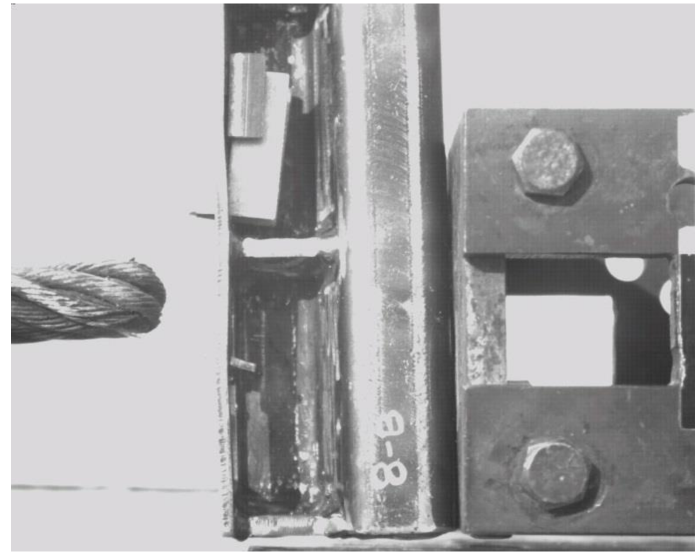


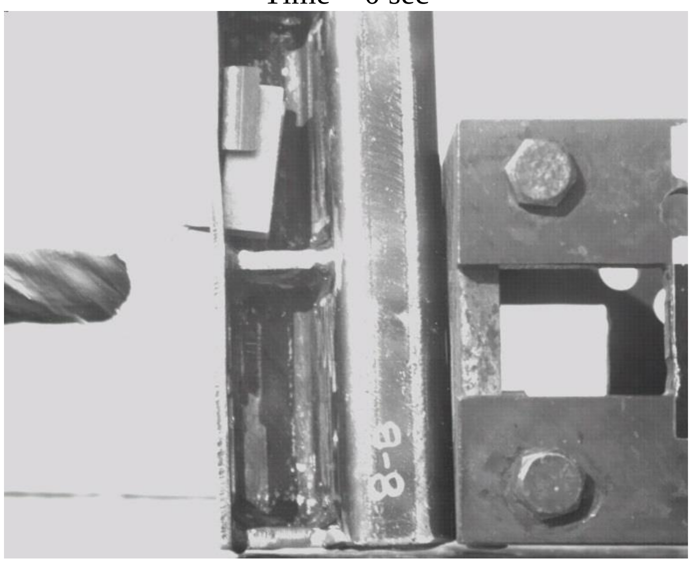
Figure 54. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-55



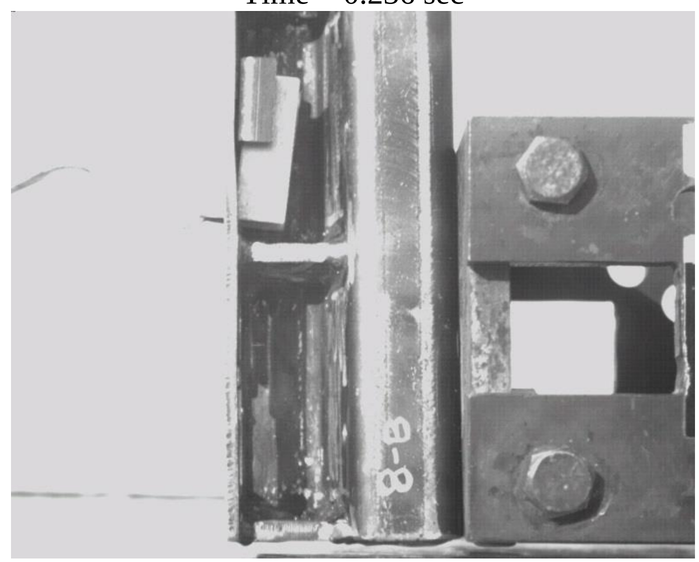
Time = 0 sec



Time = 0.236 sec



Time = 0.240 sec



Time = 0.246 sec

Figure 55. Sequential Photographs, Test No. HTTB-55

4.1.8 Test No. HTTB-56

Test no. HTTB-56 evaluated the tabbed bracket with the key plate attachment by loading the bracket laterally, or normal to the flange of the post. As the cable was pulled into tension, the tabs were pulled against the post flange at the bottom of the keyway. As the load increased, the spine of the bracket began to bend and stretch. At 0.184 seconds, the spine continued to bend, causing the tabs to rotate out of the keyway without ever catching on the keyway. At 0.243 seconds, a peak load of 0.41 kips (1.82 kN) was reached. The remaining force peaks were caused by further bending of the spine before the cable was released. The cable was completely released from the bracket at 0.272 seconds after initial loading. The force vs. time curve is shown in Figure 56. Pre- and post-test photographs and sequential photographs are shown in Figures 57 and 58, respectively.

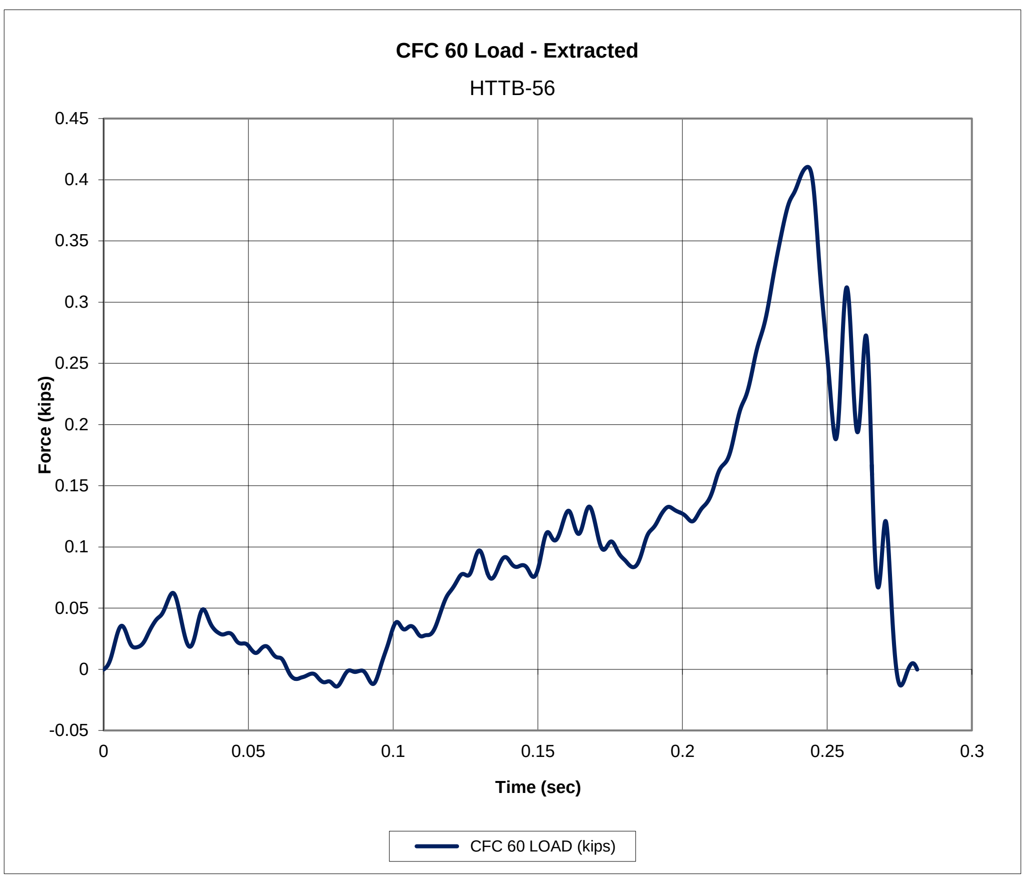
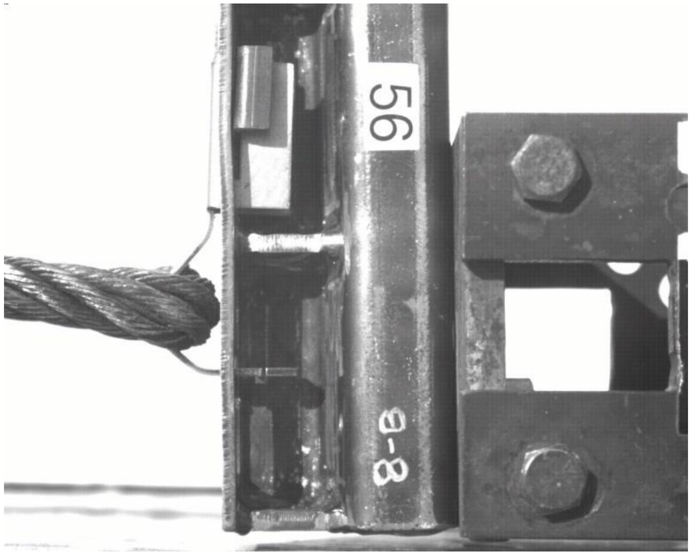
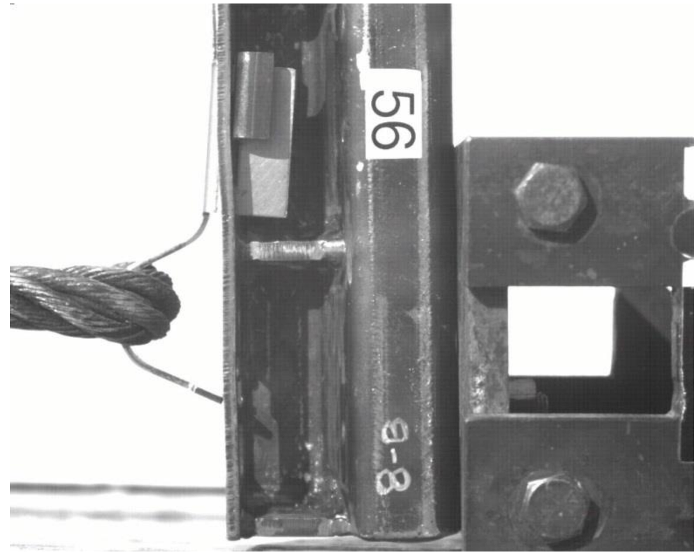


Figure 56. Force vs. Time Data, Test No. HTTB-56

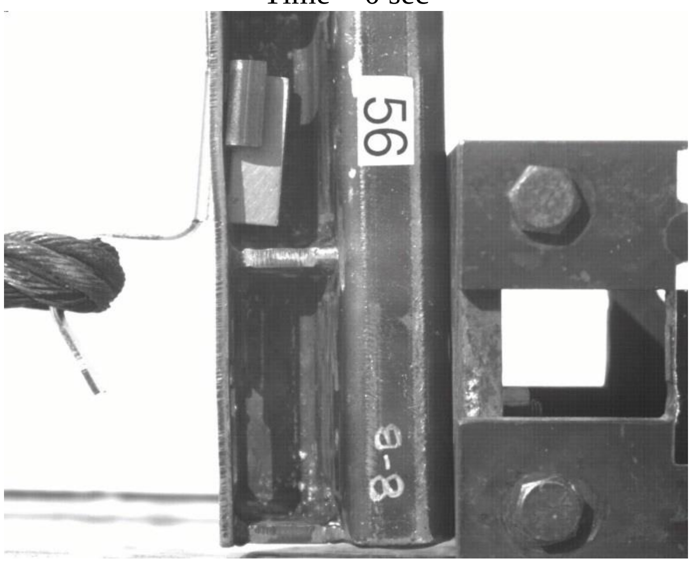
Figure 57. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-56



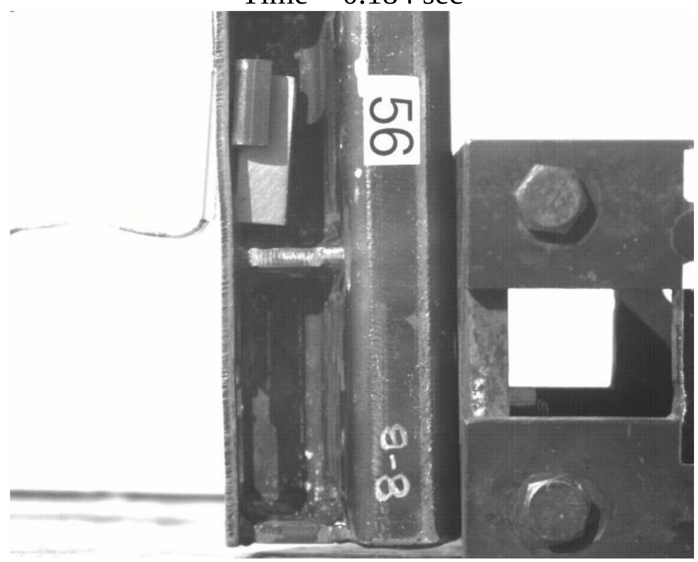
Time = 0 sec



Time = 0.184 sec



Time = 0.243 sec



Time = 0.281 sec

Figure 58. Sequential Photographs, Test No. HTTB-56

4.1.9 Test No. HTTB-57

Test no. HTTB-57 evaluated the tabbed bracket with the wire lock pin attachment by loading the bracket laterally, or normal to the flange of the post. As the cable was pulled into tension, the tabs were pulled against the post flange at the bottom of the keyway. As the load increased, the spine of the bracket began to bend and stretch. At 0.193 seconds, a peak load of 6.59 kips (29.31 kN) was reached. The tabs sheared off while exiting the keyway at 0.198 seconds. The cable was fully released from the bracket at 0.202 seconds. The force vs. time curve is shown in Figure 59. Pre- and post-test photographs and sequential photographs are shown in Figures 60 and 61, respectively.

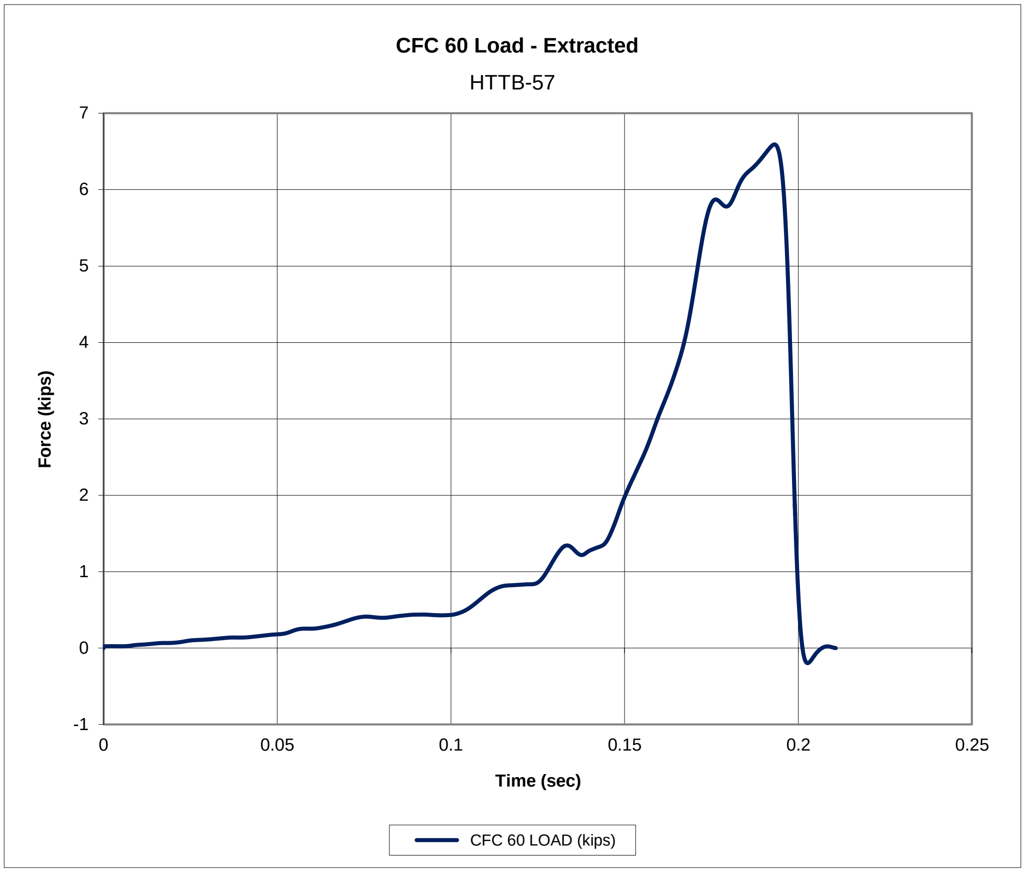
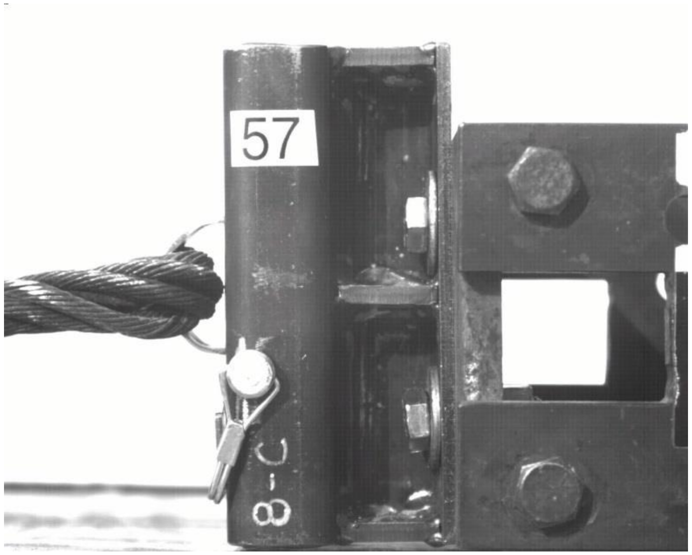
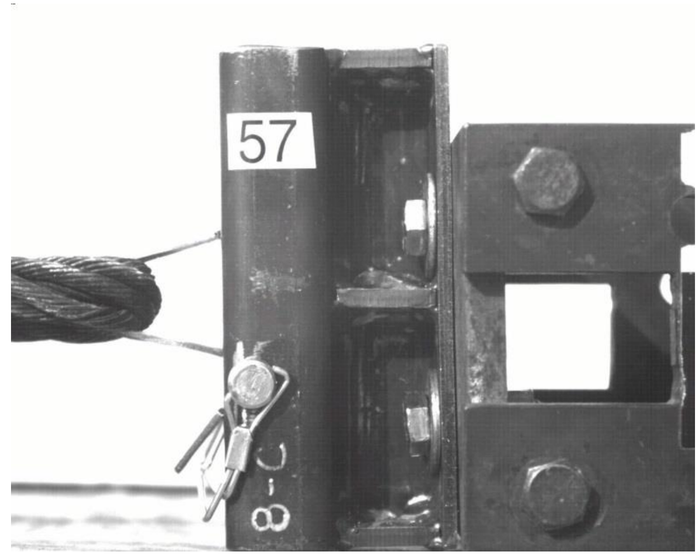


Figure 59. Force vs. Time Data, Test No. HTTB-57

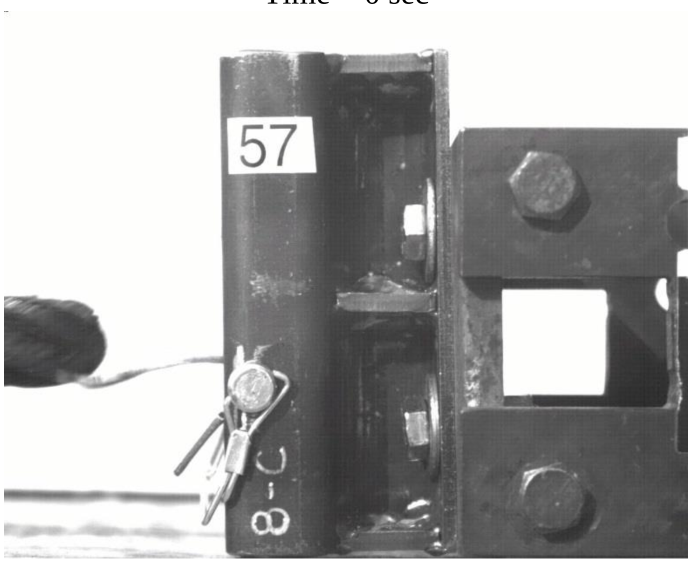
Figure 60. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-57



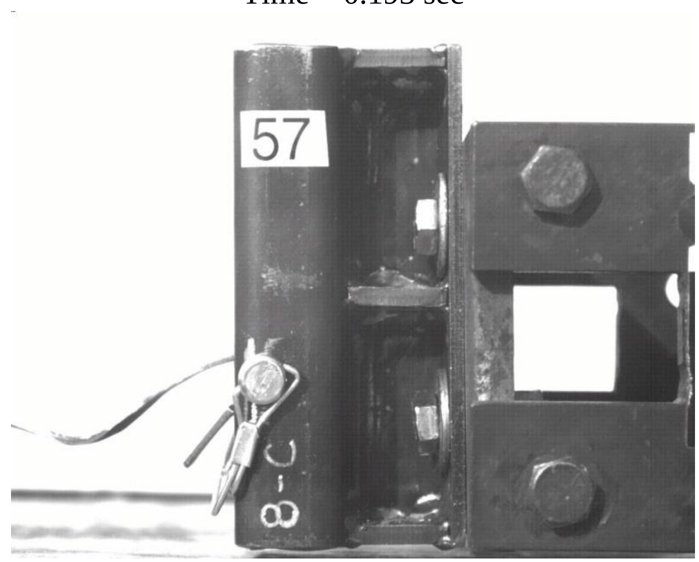
Time = 0 sec



Time = 0.193 sec



Time = 0.198 sec



Time = 0.202 sec

Figure 61. Sequential Photographs, Test No. HTTB-57

4.1.10 Test No. HTTB-58

Test no. HTTB-58 evaluated the tabbed bracket with the wire lock pin attachment by loading the bracket laterally, or normal to the flange of the post. As the cable was pulled into tension, the tabs were pulled against the post flange at the bottom of the keyway. As the load increased, the spine of the bracket began to bend and stretch. The tabs may not have been fully engaged with the keyway as a peak load of 3.50 kips (15.57 kN) was reached at 0.253 seconds. At this time, the tab edges sheared and the bracket exited the keyway at 0.256 seconds. The cable was fully released from the bracket at 0.264 seconds. The force vs. time curve is shown in Figure 62. Pre- and post-test photographs and sequential photographs are shown in Figures 63 and 64, respectively.

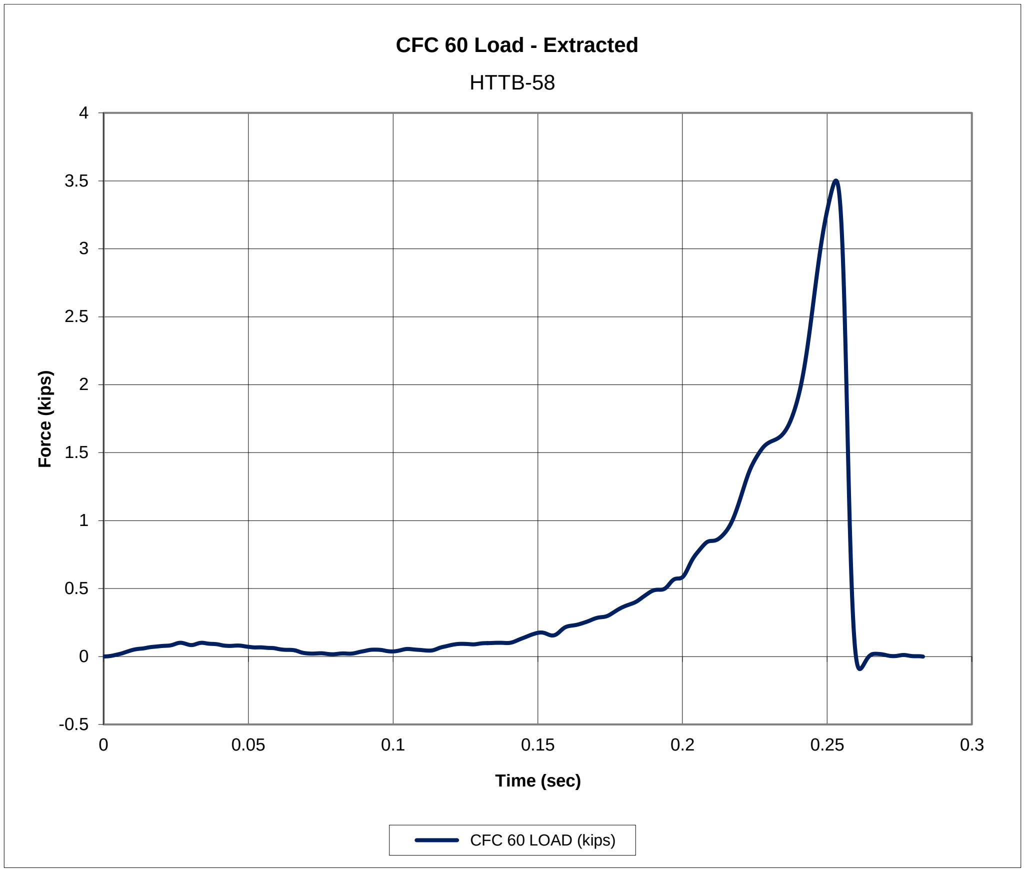
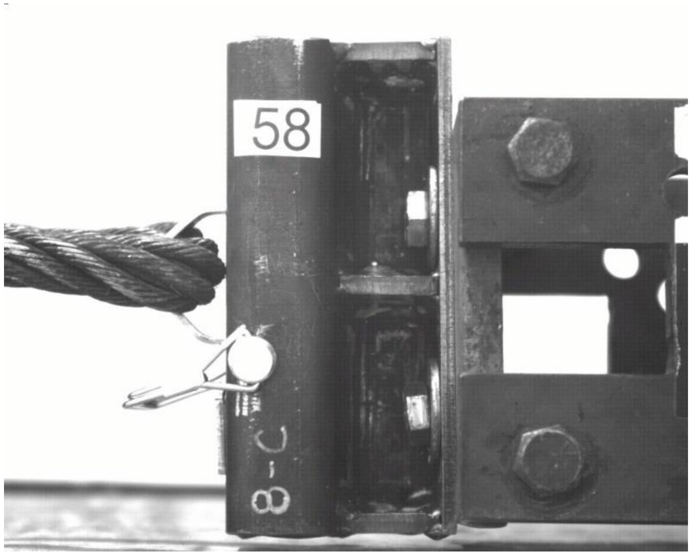
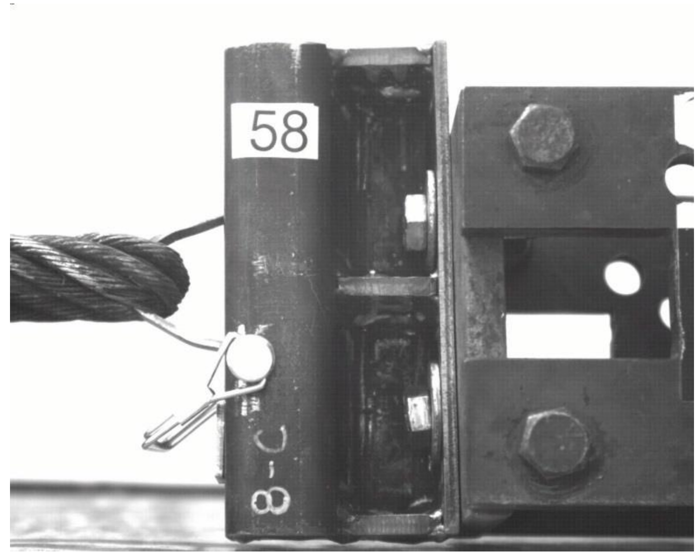


Figure 62. Force vs. Time Data, Test No. HTTB-58

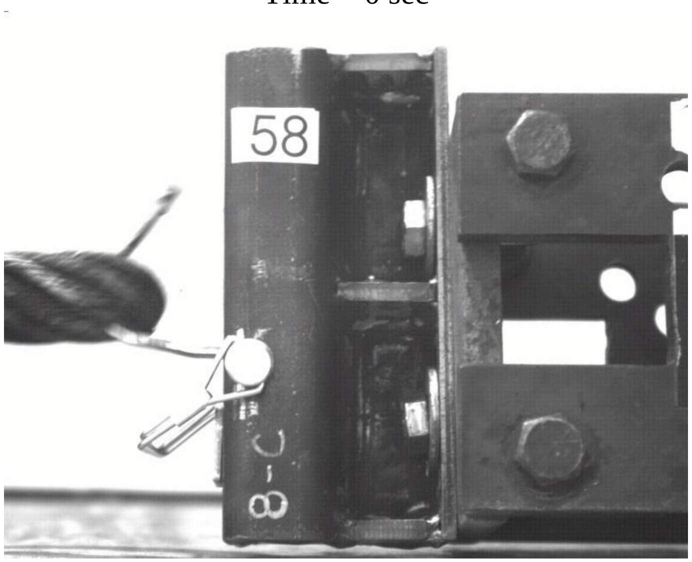
Figure 63. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-58



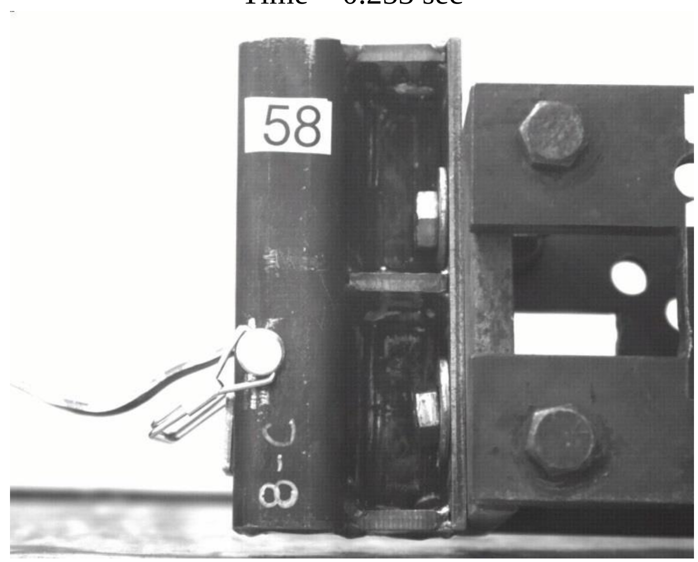
Time = 0 sec



Time = 0.253 sec



Time = 0.256 sec



Time = 0.264 sec

Figure 64. Sequential Photographs, Test No. HTTB-58

4.1.11 Test No. HTTB-59

Test no. HTTB-59 evaluated the tabbed bracket with the pinned-back attachment by loading the bracket laterally, or normal to the flange of the post. As the cable was pulled into tension, the tabs were pulled against the post flange at the bottom of the keyway. As the load increased, the spine of the bracket began to bend and stretch. At 0.244 seconds, a peak load of 6.24 kips (27.76 kN) was reached. The bracket continued to bend and stretch but never fractured or released from the keyway. Instead, the bogie vehicle was brought to a stop, and the load ended at 0.390 seconds. Because the tabs never released, the actual failure load would be greater than the recorded peak. The force vs. time curve is shown in Figure 65. Pre- and post-test photographs and sequential photographs are shown in Figures 66 and 67, respectively.

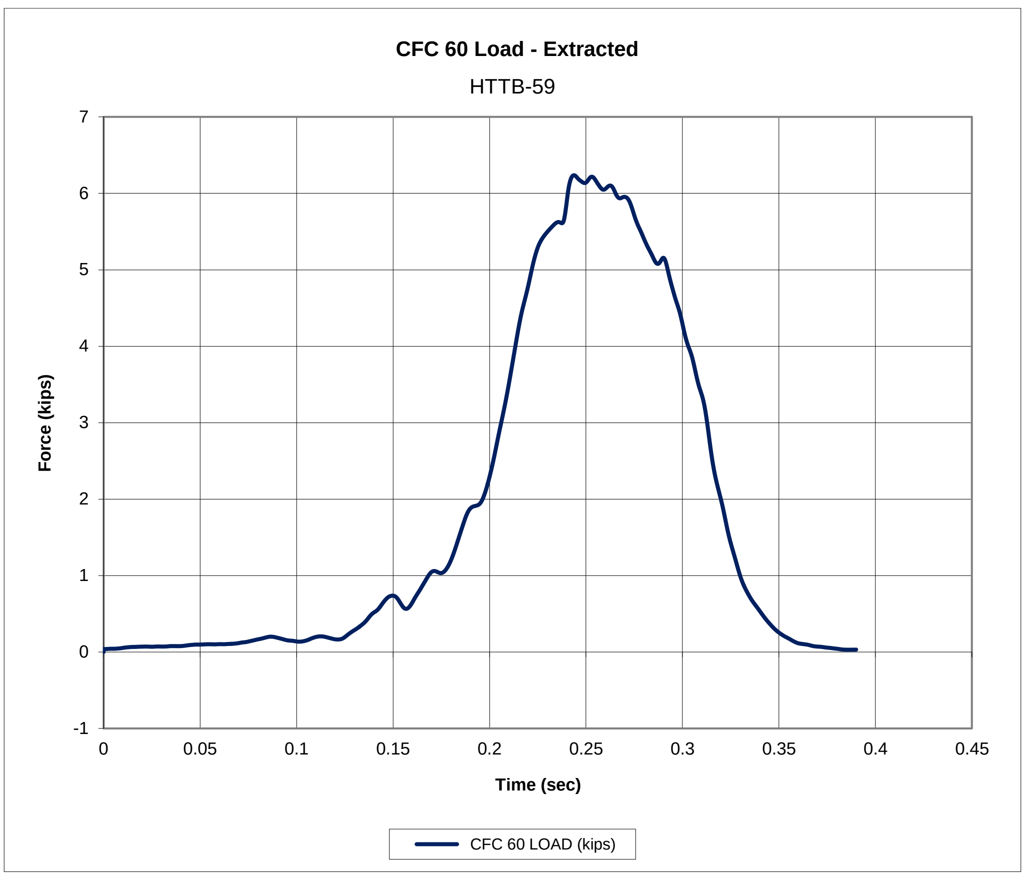
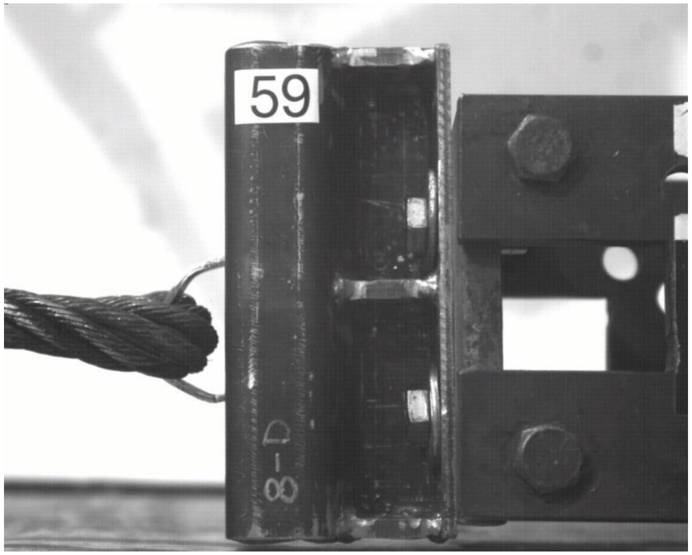
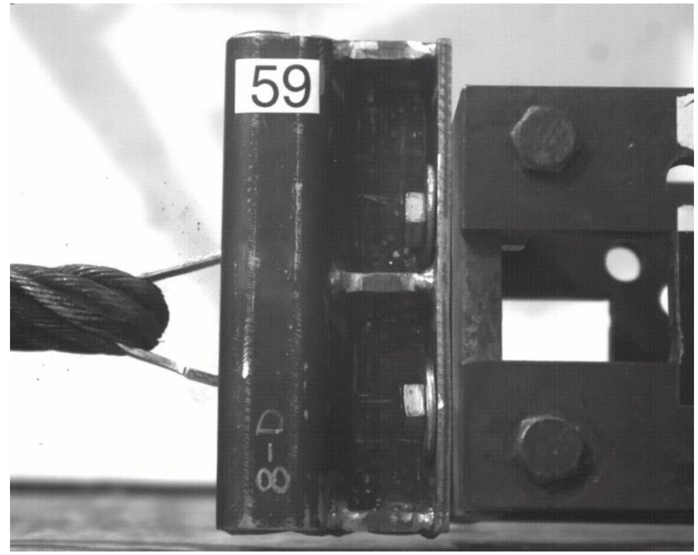


Figure 65. Force vs. Time Data, Test No. HTTB-59

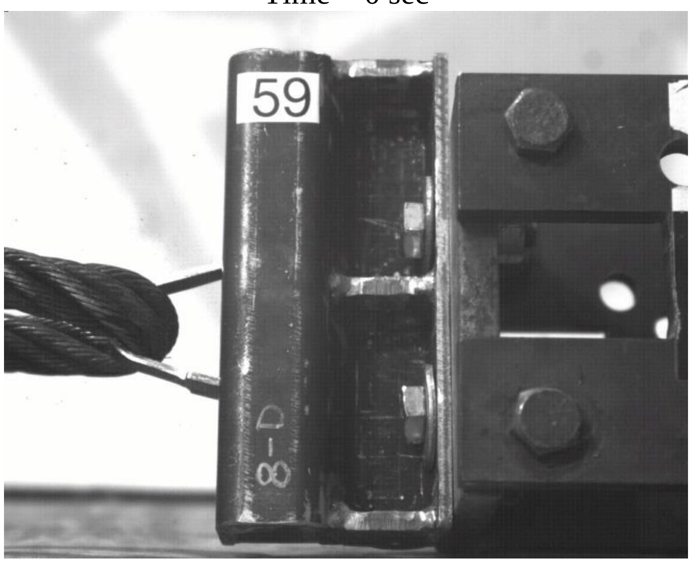
Figure 66. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-59



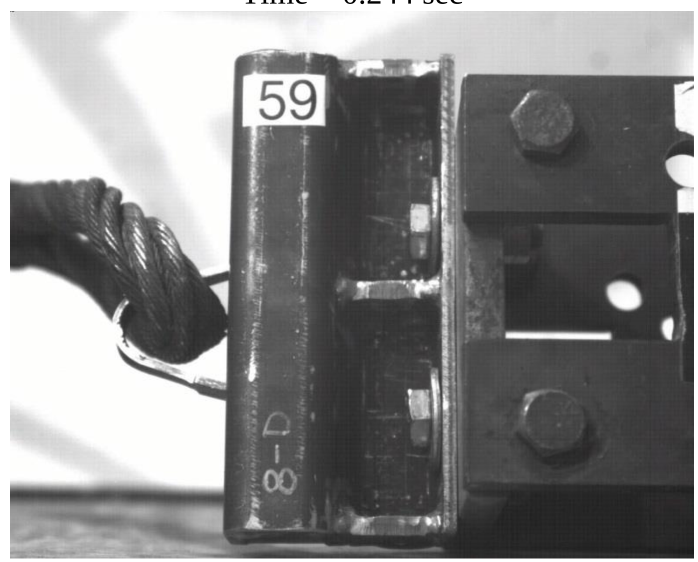
Time = 0 sec



Time = 0.244 sec



Time = 0.390 sec



Time = 1.228 sec

Figure 67. Sequential Photographs, Test No. HTTB-59

4.1.12 Test No. HTTB-60

Test no. HTTB-60 evaluated the tabbed bracket with the pinned-back attachment by loading the bracket laterally, or normal to the flange of the post. As the cable was pulled into tension, the tabs were pulled against the post flange at the bottom of the keyway. As the load increased, the spine of the bracket began to bend and stretch. At 0.194 seconds, a peak load of 6.84 kips (30.43 kN) was reached. The tabs sheared off while exiting the keyway shortly after this peak was reached. The force vs. time curve is shown in Figure 68. Pre- and post-test photographs and sequential photographs are shown in Figures 69 and 70, respectively. Due to a faulty trigger, the AOS high-speed digital video camera failed to record the test. Thus, video from a GoPro Hero 3 digital camera was used for sequential photographs.

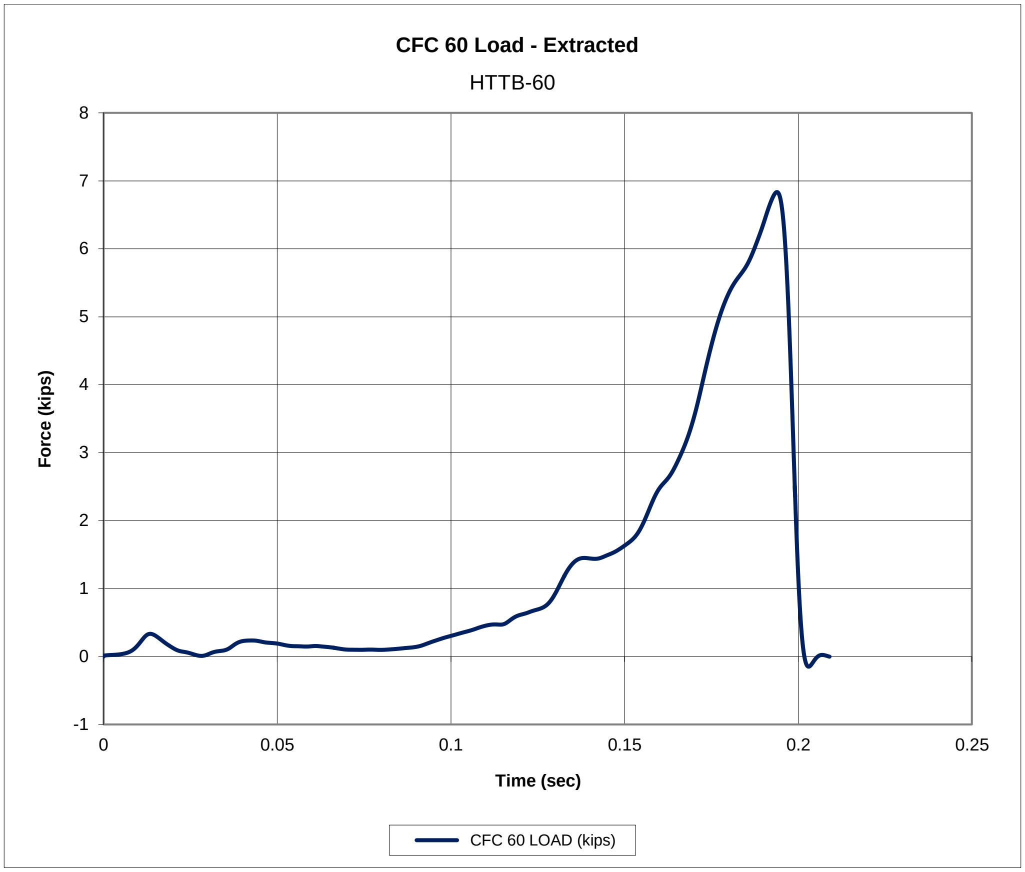
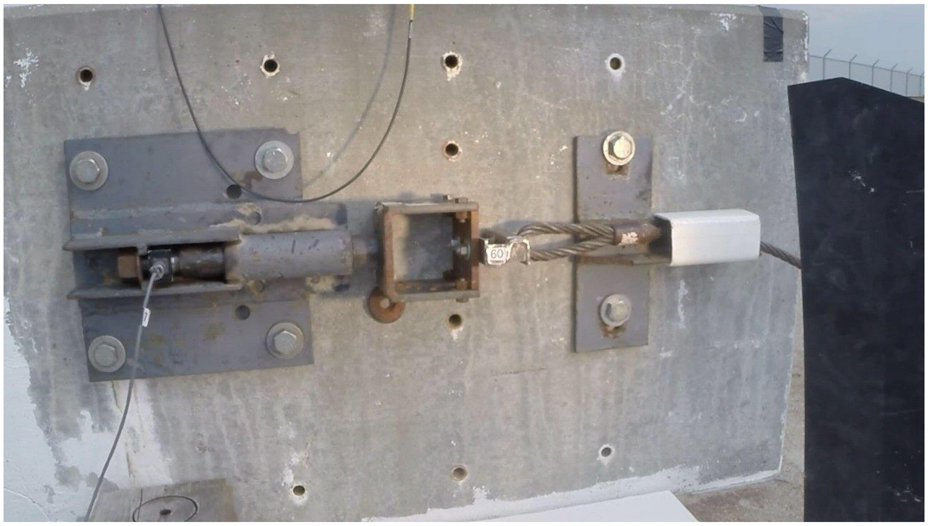
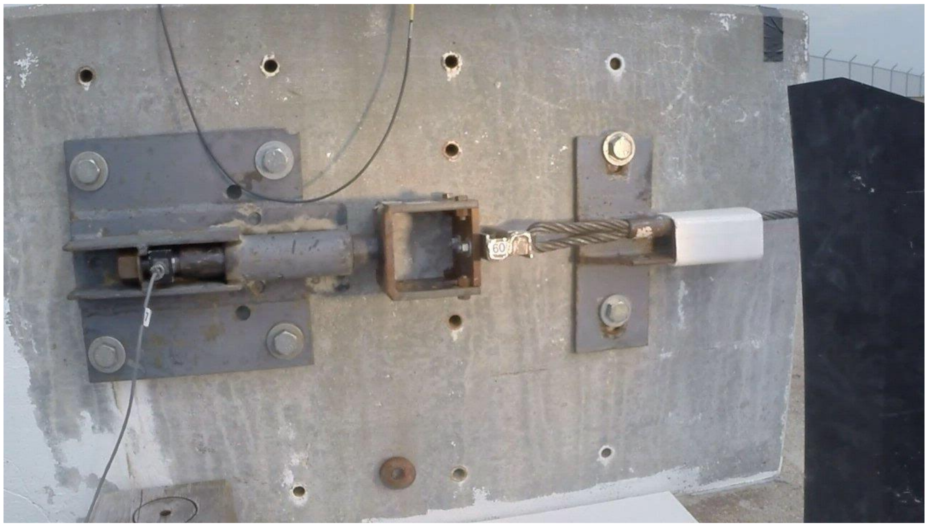


Figure 68. Force vs. Time Data, Test No. HTTB-60

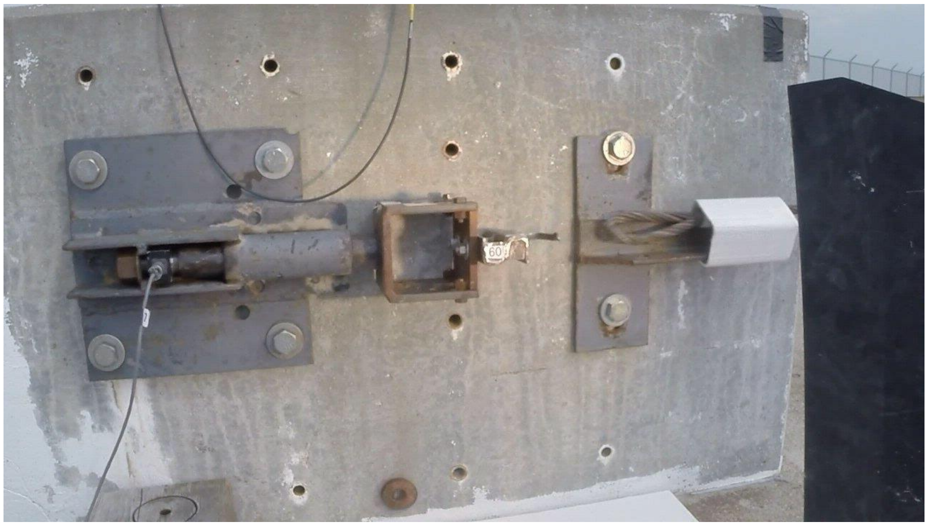
Figure 69. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-60



Time = 0 sec



Time = 0.194 sec



Time = 0.209 sec

Figure 70. Sequential Photographs, Test No. HTTB-60

4.2 Discussion

Twelve dynamic component tests were performed to evaluate three alternative attachment designs that simplified the installation process of the bolted, tabbed bracket (V10). Two vertical and two lateral load tests were conducted on each attachment design. A summary of the tabbed bracket component testing results is shown in Table 3. Previous test results of the bolted, tabbed bracket (V10) were added to the table to allow for direct comparisons [2]. These previous tests are highlighted to avoid confusion with the component tests conducted herein.

All six of the brackets loaded in the vertical direction released the cable after the bracket bent, and the tabs rotated out of the upper portion of the keyway, as expected. However, one of the vertical load tests, test no. HTTB-52 with the wire lock pin attachment, exceeded the desired maximum force of 400 lb (1.8 kN). During test no. HTTB-52, the bracket twisted, and the tabs snagged on the side of the keyway. This behavior was not expected nor desired, and caused the peak force to increase to 790 lb (3.5 kN), more than double the targeted value. This behavior was attributed to a loose connection between the bracket and the post segment resulting from construction tolerances and limited fixity in the connection. The connection ultimately allowed the bracket to twist prior to being loaded. All other vertical tests resulted in the bracket tabs releasing through the keyway, and peak loads ranged between 260 lb and 290 lb (1.2 and 1.3 kN).

The release/failure mechanism observed in the lateral load tests was variable, as shown in Figures 71 and 72. Two lateral tests resulted in the tabs rotating out of the keyway, a release mechanism not desired for lateral loads. Three of the tests resulted in the tabs tearing just prior to cable release, one of three failure mechanisms of the original bolted, tabbed bracket (V10). Due to the variable release mechanisms, the lateral load tests produced rather inconsistent release loads, and only half of the tests produced release loads above the 6-kip (27-kN) design value.

The key plate attachment brackets both released prior to achieving the targeted lateral load. During test no. HTTB-55 the tabs caught in the keyway and sheared off, one of the intended failure modes. However, a maximum load of only 4.77 kips (21.2 kN) was observed, well short of the desired 6 kips (27 kN). This outcome may be a result of the lack of fixity in the bracket-to-post connection that allowed the bracket to rotate slightly prior to loading of the bracket. This rotation could have resulted in the tabs being loaded out of plane and introducing Mode III fracture where there was previously only Mode II. The lack of fixity in the connection was also thought to contribute to unexpected release of the tabs in test no. HTTB-56 when the bracket opened up without the tabs ever catching on the keyway and resulted in a very low release load of 0.41 kips (1.8 kN).

The wire lock pin bracket tests produced lateral release loads of 6.59 kips and 3.50 kips (29.3 kN and 15.6 kN). The low release load, obtained during test no. HTTB-58, did not fully engage the keyway and the tabs slipped out prior to their failure. Similar to the key plate attachment, a lack of fixity in the connection was thought to be responsible for the unexpected release of the tabs through the keyway.

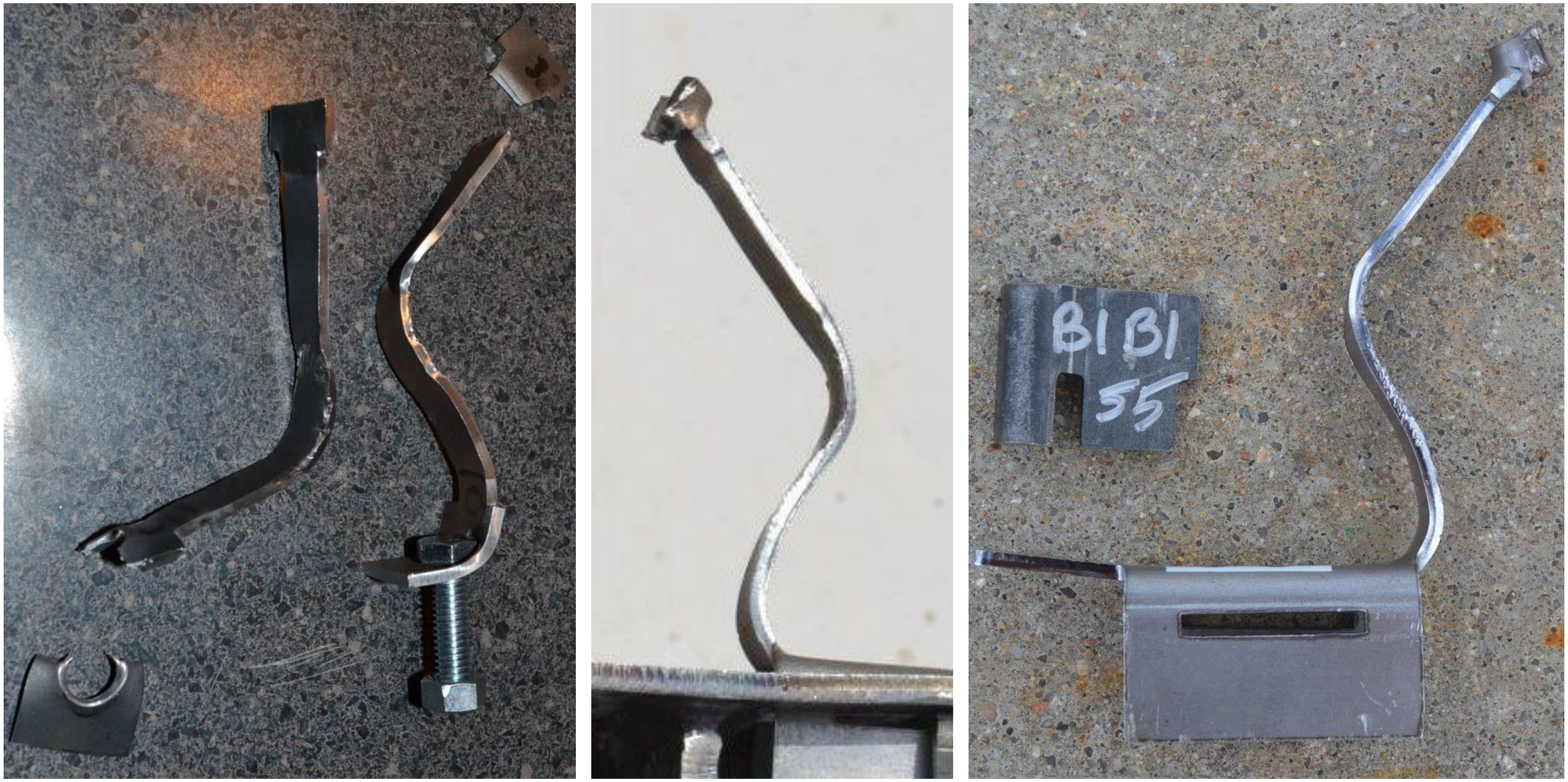
Both of the pinned-back brackets produced lateral release loads above the 6-kip (27-kN) design value. Interestingly, during test no. HTTB-59, the bracket never released the cable, and the bogie was brought to a stop. Thus, the actual failure load for that bracket would be greater than the maximum recorded force of 6.25 kips (27.8 kN). However, the connection design still resulted in a lack of fixity and a lot of allowable movement of the bracket prior to loading. Thus, a concern for potential unexpected failures similar to the other two designs still exists.

In general, all three of the alternative attachment designs for the tabbed brackets resulted in loose connections that allowed each bracket some “wiggle room” after attached. This freedom to rotate and translate slightly while attached to the post resulted in a variable pre-test location of the tabs within the keyway, as shown Figures 73 and 74. Throughout the testing and evaluation of these tabbed brackets, both herein and during previous phases [2-3], the performance of the brackets was sensitive to the initial location of the tabs within the keyway. Thus, the alternative attachment brackets continued to demonstrate more variable results than the bolted, tabbed brackets where the bracket is fixed to the post.

Table 3. Tabbed Bracket Dynamic Testing Results

Test	Bracket	Load Direction	Load kips (kN)	Failure
HTTB-37	Bolted - V10	Vertical	0.42 (1.86)	Tab release through keyway.
HTTB-38	Bolted - V10	Vertical	0.27 (1.21)	Tab release through keyway
HTTB-49	Key Plate	Vertical	0.27 (1.20)	Tab release through keyway
HTTB-50	Key Plate	Vertical	0.29 (1.29)	Tab release through keyway
HTTB-51	Wire Lock Pin	Vertical	0.26 (1.16)	Tab release through keyway
HTTB-52	Wire Lock Pin	Vertical	0.79 (3.51)	Tab release through keyway (snag on upper part of keyway)
HTTB-53	Pinned Back	Vertical	0.28 (1.25)	Tab release through keyway
HTTB-54	Pinned Back	Vertical	0.29 (1.29)	Tab release through keyway
HTTB-31	Bolted - V10	Lateral	6.03 (26.82)	Fracture around bolt hole
HTTB-32	Bolted - V10	Lateral	6.17 (27.45)	Fracture through bracket spine
HTTB-55	Key Plate	Lateral	4.77 (21.22)	Bending and tearing of tabs
HTTB-56	Key Plate	Lateral	0.41 (1.82)	Tabs rotated up and through keyway – tabs never caught
HTTB-57	Wire Lock Pin	Lateral	6.59 (29.31)	Tearing off of tabs
HTTB-58	Wire Lock Pin	Lateral	3.50 (15.57)	Minor tab deformation – tabs released through keyway
HTTB-59	Pinned Back	Lateral	6.24 (27.76)	No failure – stopped bogie
HTTB-60	Pinned Back	Lateral	6.84 (30.43)	Tearing off of tabs

Bolted, tabbed bracket (V10) test results from previous study [2]



Bolted Bracket

Key Plate Bracket

Figure 71. Lateral Test Fracture/Failure Mechanisms for Bolted Bracket and Key Plate Bracket Designs

Wire Lock Pin Bracket

Pinned Back Bracket

Figure 72. Lateral Test Fracture/Failure Mechanisms for Wire Lock Pin Bracket and Pinned-Back Bracket Designs

Vertical

Lateral

Bolted Bracket

Vertical

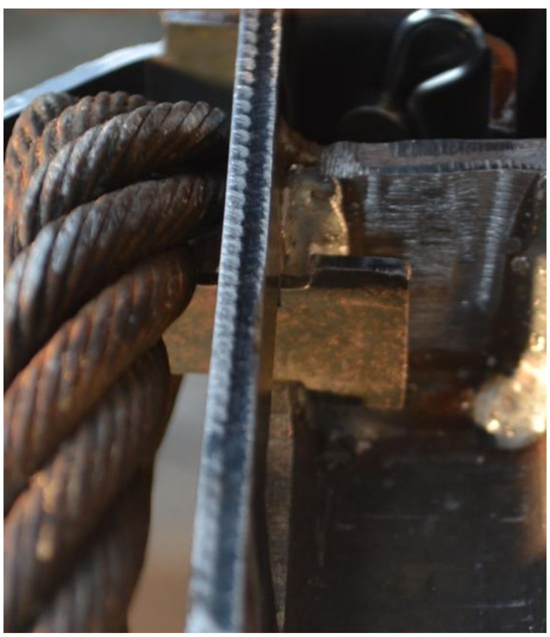
Lateral

Key Plate Bracket

Figure 73. Pre-Test Tab Locations for Bolted Brackets and Key Plate Brackets

Vertical Lateral

Wire Lock Pin Bracket



Vertical Lateral

Pinned-Back Bracket

Figure 74. Pre-Test Tab Locations for Wire Lock Pin Brackets and Pinned-Back Brackets

5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This study was undertaken to redesign and improve the bolted, tabbed bracket (V10) that was utilized as the cable-to-post attachment hardware in the cable barrier under development at MwRSF. The objectives of the study were to eliminate the bolt within the connection, reduce the number of components per bracket, eliminate the need for tools during installation, and reduce the number of small parts. Three attachment concepts were selected for evaluation through dynamic testing: 1) the key plate attachment; 2) the wire lock pin attachment; and 3) the pinned-back attachment. Each attachment design was subjected to two vertical and two lateral dynamic component tests to evaluate the release loads and fracture mechanisms of each bracket design. The results of these tests were then compared to the performance of the bolted, tabbed bracket (V10). Specifically, vertical release loads of less than 400 lb (1.8 kN) and lateral release loads greater than 6 kips (27 kN) were desired, based on testing of the bolted, tabbed bracket (V10).

The key plate attachment bracket performed well when loaded vertically, as both vertical tests resulted in release loads below the maximum desired value. However, neither of the lateral load tests produced release loads above the desired 6 kips (27 kN). Test no. HTTB-56 resulted in the tabs unexpectedly rotating out without ever catching on the keyway. The tabs did catch in the keyway during test no. HTTB-55, but the tabs failed at a peak load of only 4.77 kips (21.2 kN). It was believed that a lack of fixity in the connection allowed the bracket to rotate and translate slightly, which led to the bracket tabs being located at variable locations within the keyway prior to loading. The variable initial position of the tabs allowed the premature tab failures and release of the cable. Consequently, the key plate attachment did not satisfy the desired release loads.

The wire lock pin attachment had variable results when loaded in both the vertical and lateral directions. During one of the vertical load tests, test no. HTTB-52, the bracket tabs snagged on the side of the keyway as they rotated up and out and caused the release load to greatly exceed the desired maximum. Similar to the key plate attachment, the lack of fixity in the wire lock pin attachment allowed the bracket to rotate and twist prior to loading, which led to the tabs snagging on the side of the keyway. Lateral testing of the wire lock pin attachment resulted in one of the two brackets failing to satisfy the minimum desired release load. During test no. HTTB-58, the tabs caught within the keyway, but slipped out prior to significant bending or tearing. Movement of the bracket before loading likely resulted in the tabs being too high in the keyway and only partially catching as the bracket was being loaded. Thus, due to the loose attachment and variable position of the bracket tabs within the keyway, the wire lock pin attachment bracket did not satisfy the desired release loads in either the vertical or lateral directions.

The pinned-back attachment bracket satisfied the release load criteria in both the vertical and lateral directions. However, similar to the other alternative attachment methods, it was noted that a lack of fixity in the attachment resulted in variable initial positions of the bracket tabs within the keyway prior to loading. Thus, the possibility for variable and inadequate release loads exists if more testing were to be conducted or if the loading conditions were altered slightly. Additionally, the pinned-back attachment design was found to be difficult to install. Although the bracket could be installed without the use of tools, there were multiple small components that had to be assembled in the small area between the flange and web of the post. Subsequently, there would be little benefit to utilizing this alternative bracket attachment design over the original bolted, tabbed bracket (V10).

In summary, none of the three bracket attachment designs were found to satisfy all of the design criteria for an alternative bracket design. The lack of fixity in the connection between the bracket and the post led to a variable position of the tabs within the keyway, which in turn caused variable performance of the bracket in terms of vertical and lateral release loads and failure mechanisms. Therefore, until an alternative bracket attachment can be designed which locks the bracket into place and eliminates the “wiggle” within the non-bolted connection, it is recommended that the bolted, tabbed bracket (V10) continue to be utilized as the cable-to-post attachment hardware within the non-proprietary cable barrier.

6 REFERENCES

1. Bielenberg, R.W., Schmidt, T.L., Faller, R.K., Lechtenberg, K.A., Rosenbaugh, S.K., Reid, J.D., and Sicking, D.L., *Design of an Improved Post for Use in a Non-Proprietary, High-Tension, Cable Median Barrier* Final Report to the Midwest States Regional Pooled Fund Program, Report No. TRP-03-286-15, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, May 7, 2015.

2. Bateman, R.J., Faller, R.K., Bielenberg, R.W., Sicking, D.L., Reid, J.D., Stolle, C.S., Lechtenberg, K.A., and Rosenbaugh, S.K., *Designing of Cable-to-Post Attachments for Use in a Non-Proprietary, High-Tension, Cable Median Barrier,* Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-285-13, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, August 29, 2013.

3. Rosenbaugh, S.K., Bielenberg, R.W., Humphrey, B.M., Faller, R.K., Reid, J.R., and Lechtenberg, K.A., *Cable-to-Post Attachments for a Non-Proprietary High-Tension Cable Barrier—Phase II* Final Report to the Midwest States Regional Pooled Fund Program, Report No. TRP-03-313-15, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, June 2, 2015.

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

7 APPENDICES

Appendix A. Material Specifications

Norfolk Iron & Metal Co.

3001 North Victory Road
Norfolk, NE 68701
PH: (402) 371-1810

Test Certificate

Document: 01024973

Product Description

Thickness: .1800 Heat: 083707 Supplier: THYSSENKRUPP STEEL USA

Specification(s): A1011 HSLAS-F GR50-12

Chemistry Data

C	MN	P	S	SI	AL	CB	V	CU	CR
.059	.417	.0189	.0026	.017	.0469	.02	.0001	.005	.022

NI	MO	SN	TI	N	B	ZR
.012	.0001	.00	.001	.004	.0002	.00

Mechanical Data

	Yield (PSI)	Tensile (PSI)	Elongation	Reduction Of Area	Sample Taken From
1	59716	68741	37.50 2"	71.9100	Head
2	59522	68267	40.40 2"	76.1700	Center

Produced From Coil

Melted and Manufactured In: Not Provided

The Mechanical Data for the product described above reflect the results of tests made by us in accordance with applicable ASTM or ASME standards and our testing procedures, and we certify that the information included in this Test Certificate with respect to such Mechanical Data is accurate to the best of our knowledge.

The Chemistry Data shown above was reported to us by THYSSENKRUPP STEEL USA and have been included in this Test Certificate solely for your information.

Figure A-1. Midwest Weak Post

ESSAR Steel Algoma Inc. Fax Server 9/9/2009 4:04:43 PM PAGE 3/003

ESSAR Steel Algoma Inc. 105 West Street, Sault Ste. Marie, Ontario Canada P6A 7B4

CUSTOMER PURCHASE ORDER NUMBER	ENTRY DATE	SHIP DATE	TALLY NUMBER	SHIPPER'S NO.	CARRIER		PAGE
P90728BL002	2009/07/31	2009/09/08	140893	-	IC	-299670	

CHARGE TO CUSTOMER NAME AND ADDRESS
STATE STEEL SUPPLY CO.
214 COURT STREET
SIOUX CITY IOWA 51102
P.O. BOX 3224

SHIP TO CUSTOMER NAME AND ADDRESS
STATE STEEL SUPPLY CO.
214 COURT STREET
SIOUX CITY, IOWA 51102
IOWA

MILL TEST REI
ESSAR STEEL ALGOMA INC. CERTIFIES THAT THE MATEI DESCRIBED WAS MADE AND ACCORDANCE WITH THE RU SPECIFICATION SHOWN. AI ARE RETAINED IN ACCORDA COMPANY'S STANDARD RECO PRACTICES.

J. JOHNST
MANAGING METALLU

THIS MILL TEST REPORT MA REPRODUCED EXCEPT IN FU WRITTEN APPROVAL OF ESS ALGOMA INC. IF YOU RECIE DOCUMENT AND ARE NOT T RECEIVER, PLEASE CALL (7 COLLECT FOR INSTRUCTION OF DISPOSAL OF DOCUME

CUSTOMER SPECIFICATION
HOT ROLLED STEEL SHEET - HSLA - ASTM A1011 GR 50 HSLAS-F (07) - DQ - TEMPER ROLLED - CUT EDGE ACCEPTABLE - RESTRICTED GAUGE 1/2 TOLERANCE - HSLA MODERATE FORMING SEMI-CRIT SURFCE STD SHPE

SUPPLEMENTARY INSTRUCTIONS
TEST CERT 1: BOB LANSWORTH 712-277-3306 TEST CERT 2: PLATE TE
ST COUPON:

DISP TR TEST REPORTS REQUIRED 2000115881 WS
CUST USE RESALE 2009/09/09 15:55

MEETS EN 10204 3.1
HEATS INDICATED WITH (+) MELTED AND ROLLED IN CANADA WITH IMPORTED AND DOMESTIC PARTS

******************* PRODUCT SHIPPED *******************

CUSTOMER ITEM 00001 OUR ITEM 002 DIMENSIONS .097 MIN X 60.25 X COIL

COIL NUMBER	HEAT	NO. PIECES	WEIGHT	COIL NUMBER	HEAT	NO. PIECES	WEIGHT
63526025	6947J-03	1	38990				

******************* MECHANICAL PROPERTIES *******************

TENSILE TESTS:

HEAT	* SAMPLE * SRCE	GAUGE	* * TEST * * COND	METH	DIR	YIELD KSI	TENSILE KSI	% ELONG	LAB
6947J	DSPC	.0970	AR	.2	L	55.5	66.5	36(2")	ALG

******************* CHEMICAL PROPERTIES *******************

HEAT	(WT %)	C / TI	MN / SN	P / N	S / AS	SI / ZR	CR / PB	NI / SB	CU	MO	AL	CB	V	B / CA
6947J +		.05 / .001	.49	.009 / .0094	.004	.02	.03	.02	.07	.00	.017	.006	.031	.00303

PAGE 3 OF 3

WARNING THE TEST RESULTS AND VALUES REPORTED HEREIN INDICATE ONLY THAT (1) THE PARTICULAR STEEL FOR WHICH THIS CERTIFICATE IS ISSUED MEETS THE MINIMUM SPECIFIED YIELD STRENGTH AND (2) THE CHEMICAL ANALYSIS AND PHYSICAL PROPERTIES OF SUCH STEEL ARE IN CONFORMANCE WITH THE REQUIREMENTS OF THE SPECIFICATION INDICATED. THE RESULTS OR VALUES REPORTED HEREIN CAN NOT BE USED TO QUALIFY THE STEEL FOR ANY SPECIFICATION OTHER

Gauge 12 Sheet Steel

Figure A-2. Tabbed Brackets

Appendix B. Cable-to-Post Attachment Dynamic Load Cell Test Results

The results of the recorded data from the load cell for every dynamic bogie test are provided in the summary sheets found in this appendix. Summary sheets include output voltage vs. time and force vs. time plots.

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

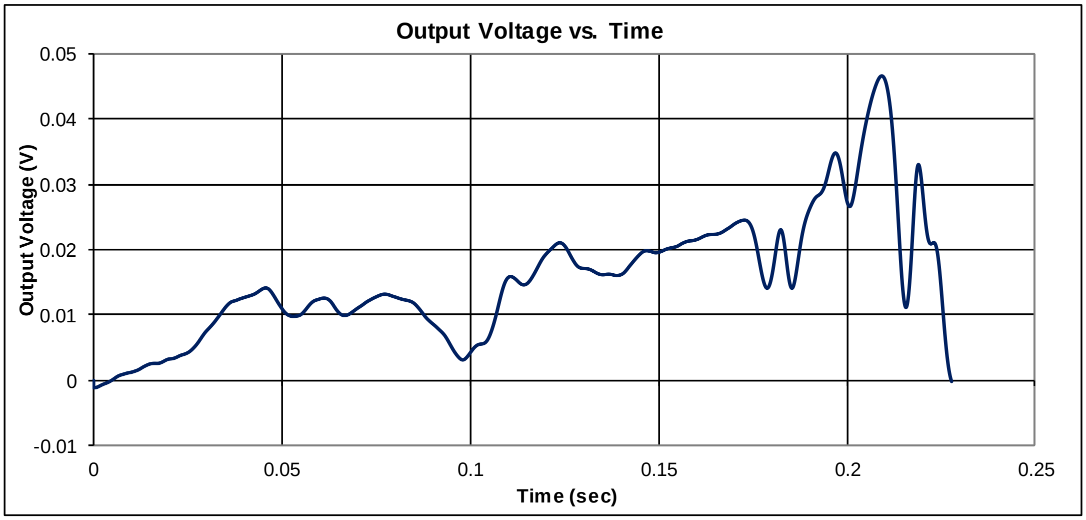
Test No:	HTTB-49
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Key Plate
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Vertical pull on cable attachment bracket
Failure Discription:	Tab release through keyway

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	0.27 kips
Time of Max. Load:	0.2093 sec
Event Duration:	0.2278 sec
Final Load:	0.00 kips



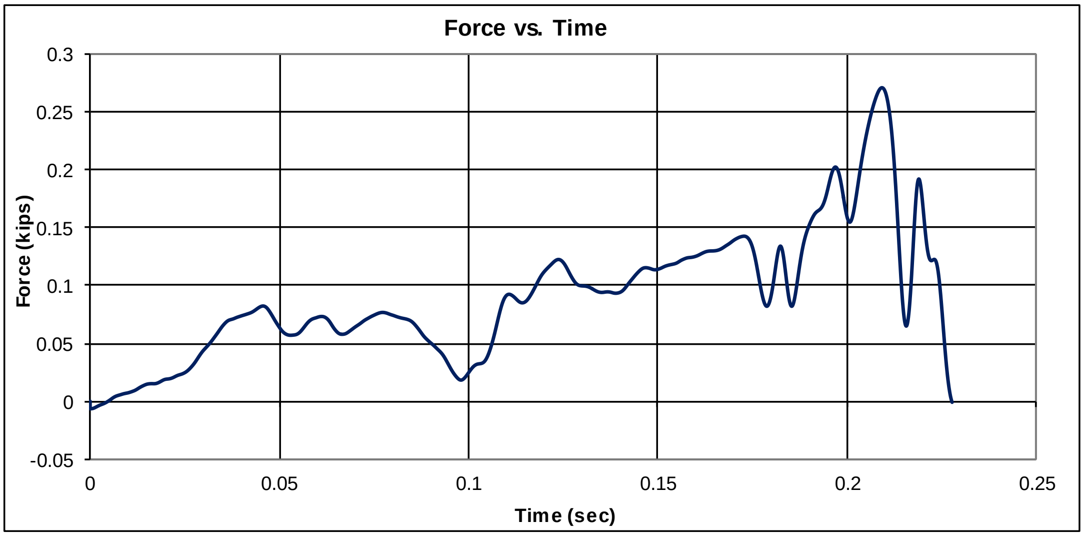


Figure B-1. Load Cell Results, Test No. HTTB-49

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

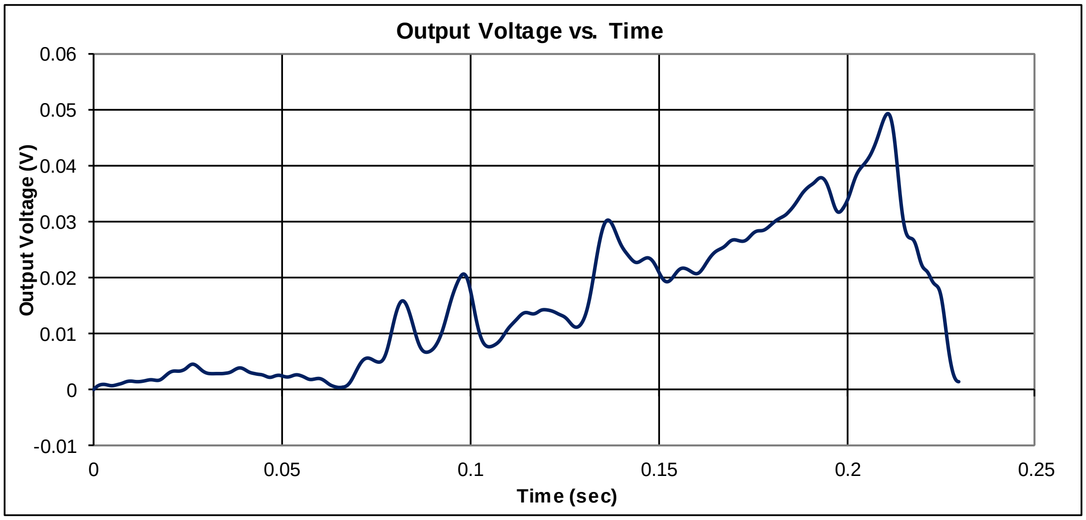
Test No:	HTTB-50
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Key Plate
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Vertical pull on cable attachment bracket
Failure Discription:	Tab release through keyway

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	0.29 kips
Time of Max. Load:	0.2109 sec
Event Duration:	0.2297 sec
Final Load:	0.01 kips



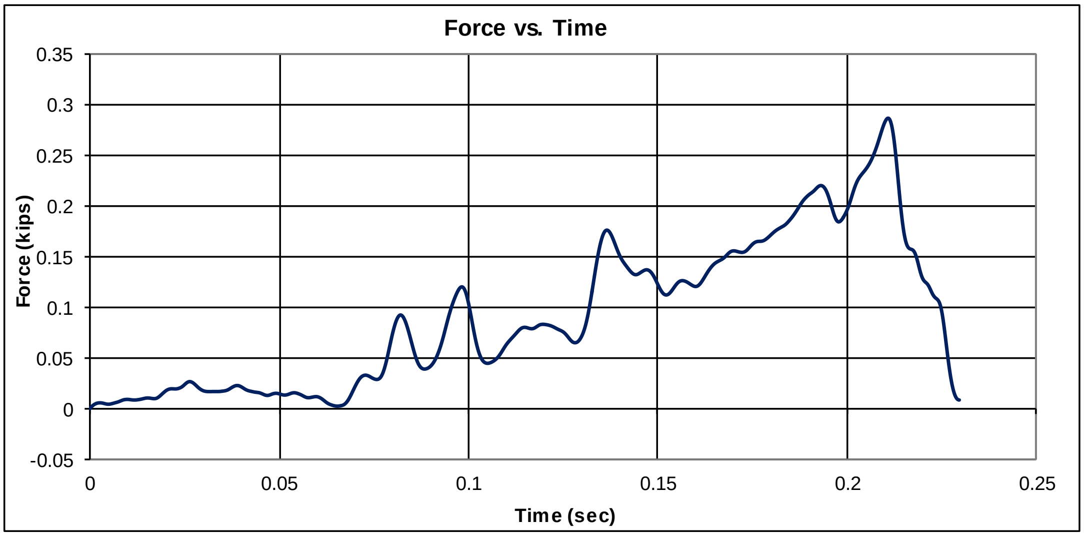


Figure B-2. Load Cell Results, Test No. HTTB-50

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

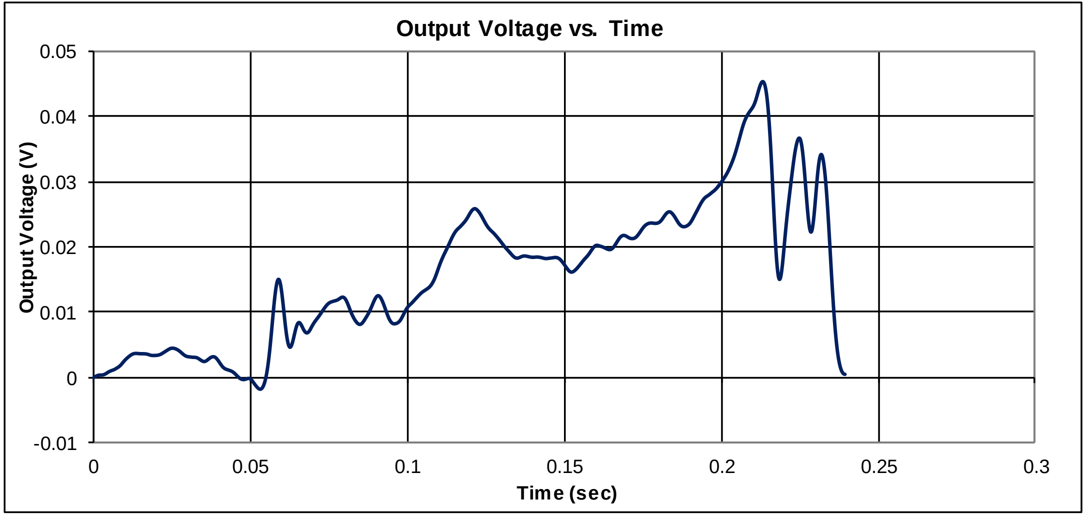
Test No:	HTTB-51
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Lateral Pin
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Vertical pull on cable attachment bracket
Failure Discription:	Tab release through keyway

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	0.26 kips
Time of Max. Load:	0.2132 sec
Event Duration:	0.2394 sec
Final Load:	0.00 kips



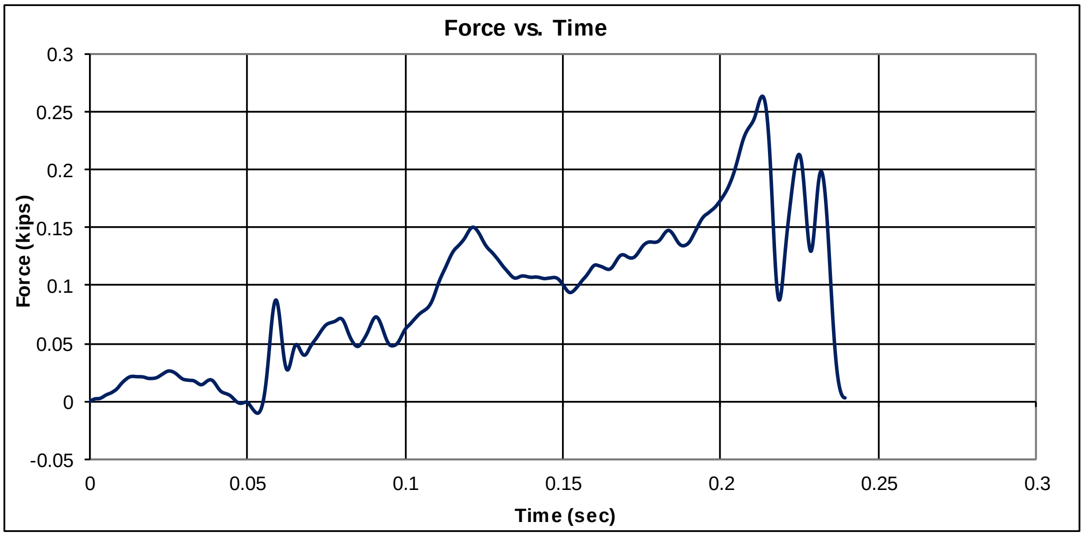


Figure B-3. Load Cell Results, Test No. HTTB-51

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

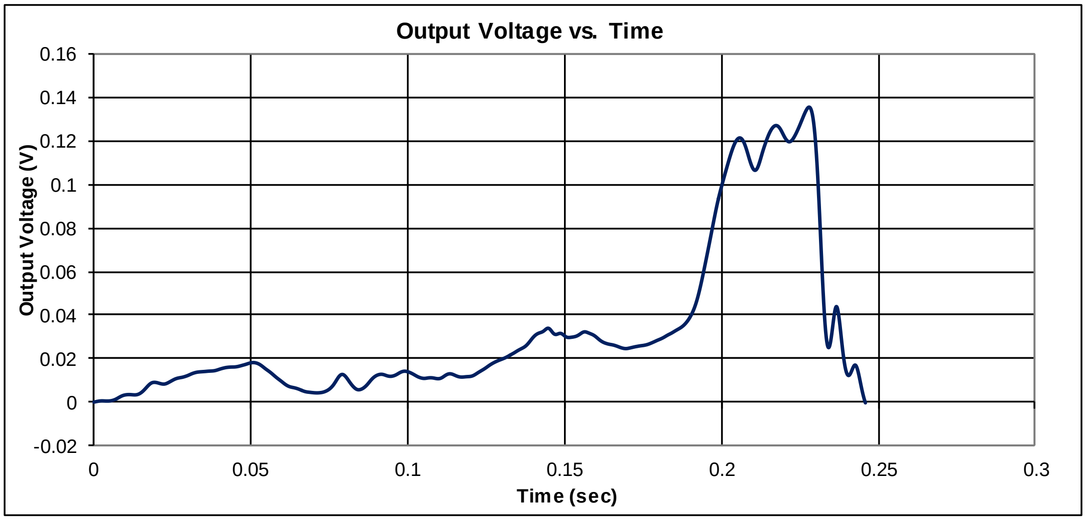
Test No:	HTTB-52
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Lateral Pin
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Vertical pull on cable attachment bracket
Failure Discription:	Tab release through keyway - bracket rotation led to snag on upper keyway

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	0.79 kips
Time of Max. Load:	0.2279 sec
Event Duration:	0.2459 sec
Final Load:	0.00 kips



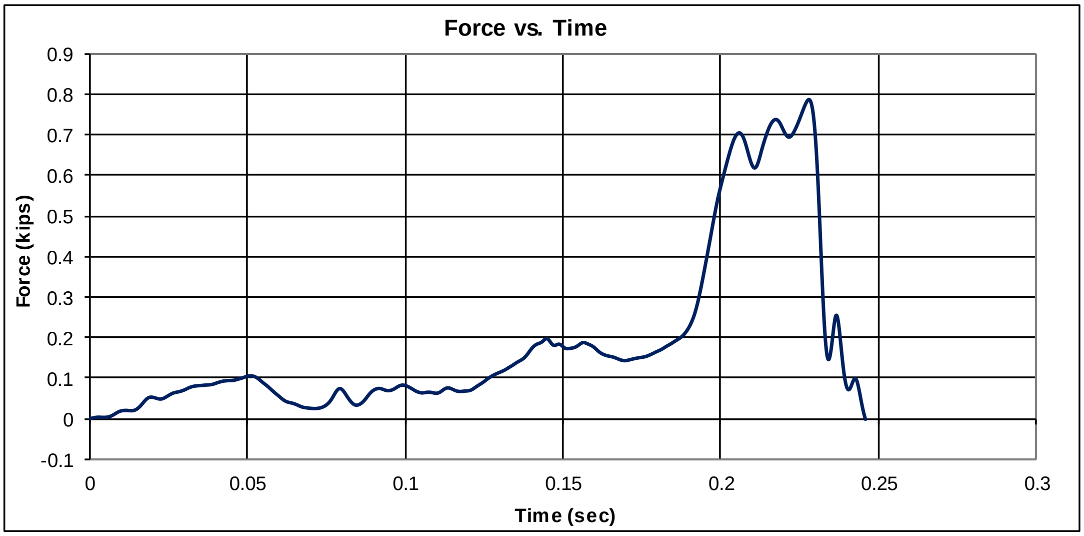


Figure B-4. Load Cell Results, Test No. HTTB-52

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

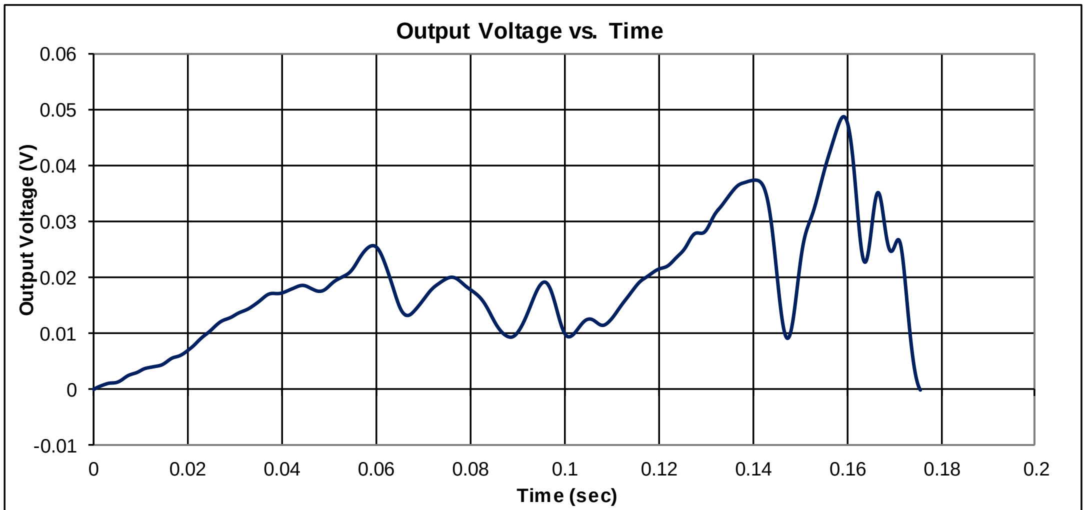
Test No:	HTTB-53
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Pinned Back
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Vertical pull on cable attachment bracket
Failure Discription:	Tab release through keyway

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	0.28 kips
Time of Max. Load:	0.1593 sec
Event Duration:	0.1756 sec
Final Load:	0.00 kips



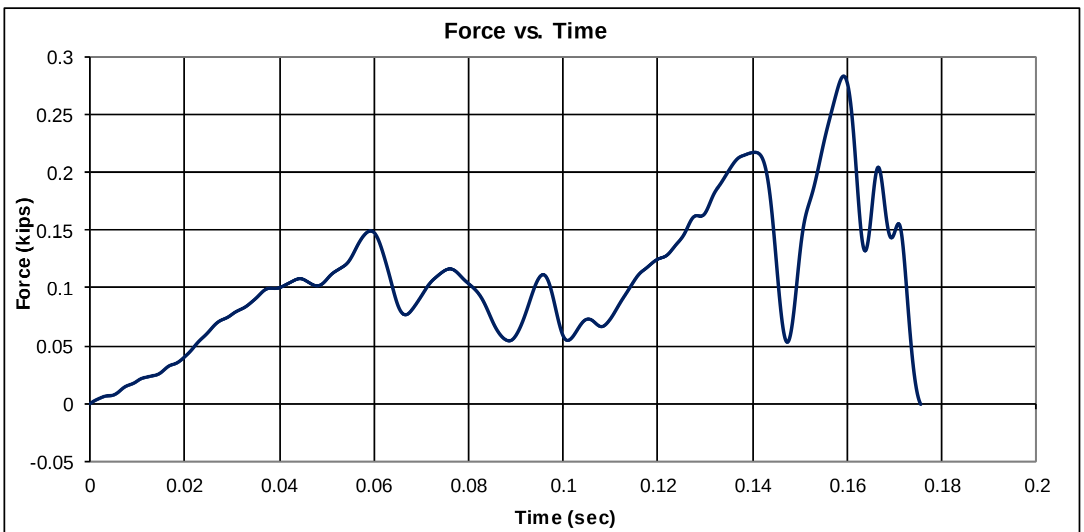


Figure B-5. Load Cell Results, Test No. HTTB-53

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

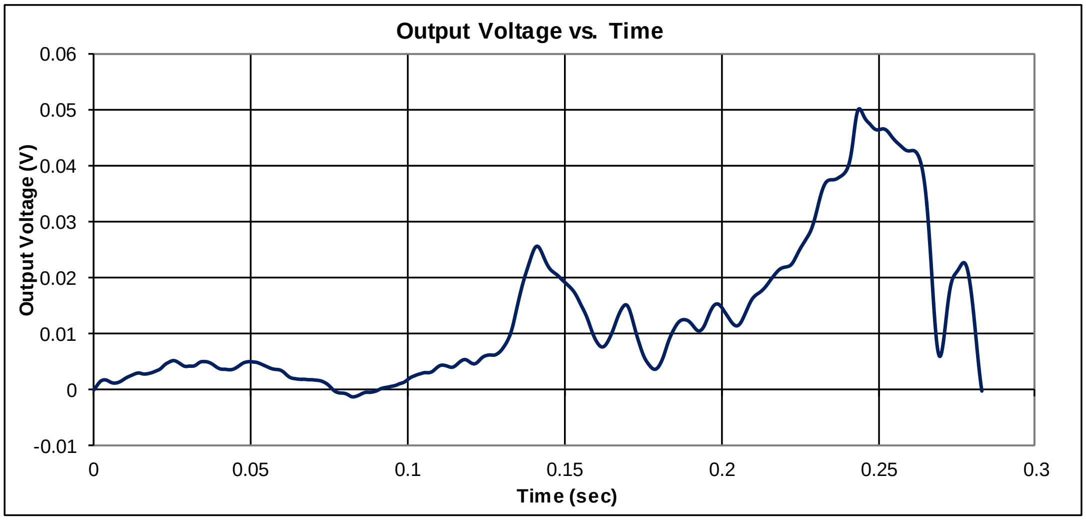
Test No:	HTTB-54
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Pinned Back
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Vertical pull on cable attachment bracket
Failure Discription:	Tab release through keyway

Load Cell Information:

Load Cell No.:	143435	
Calibration Factor:	2.15385	mv/V
Input Voltage (excitation):	10	Volts
Gain:	400	
Full Scale Load:	50	kips
Sample Rate:	10000	Hz
Cutoff Frequency:	100	Hz

Results:

Preload:	0	kips
Max. Load:	0.29	kips
Time of Max. Load:	0.244	sec
Event Duration:	0.283	sec
Final Load:	0.00	kips



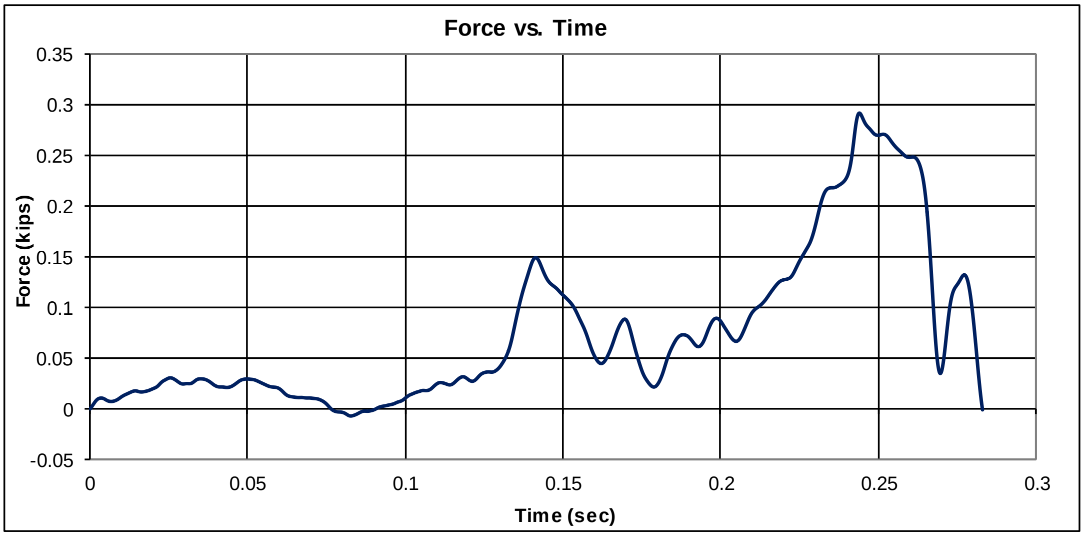


Figure B-6. Load Cell Results, Test No. HTTB-54

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

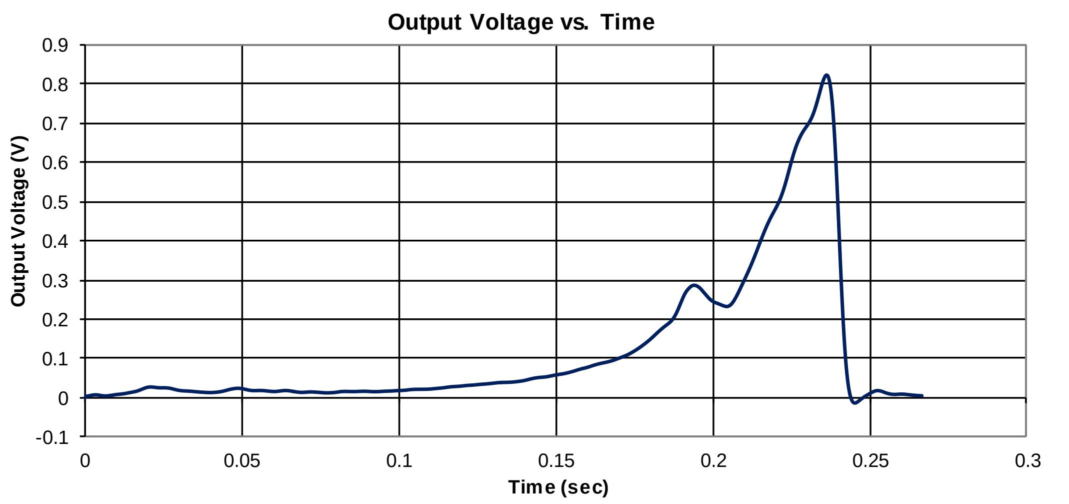
Test No:	HTTB-55
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Key Plate
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Lateral pull on cable attachment bracket
Failure Discription:	Bending and tearing of tabs

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	4.77 kips
Time of Max. Load:	0.2363 sec
Event Duration:	0.2666 sec
Final Load:	0.03 kips



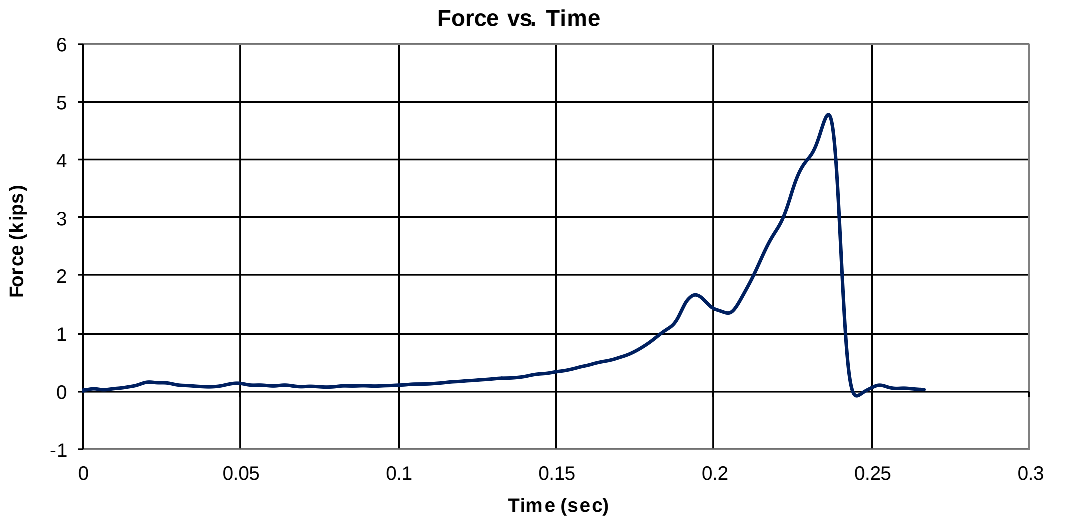


Figure B-7. Load Cell Results, Test No. HTTB-55

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

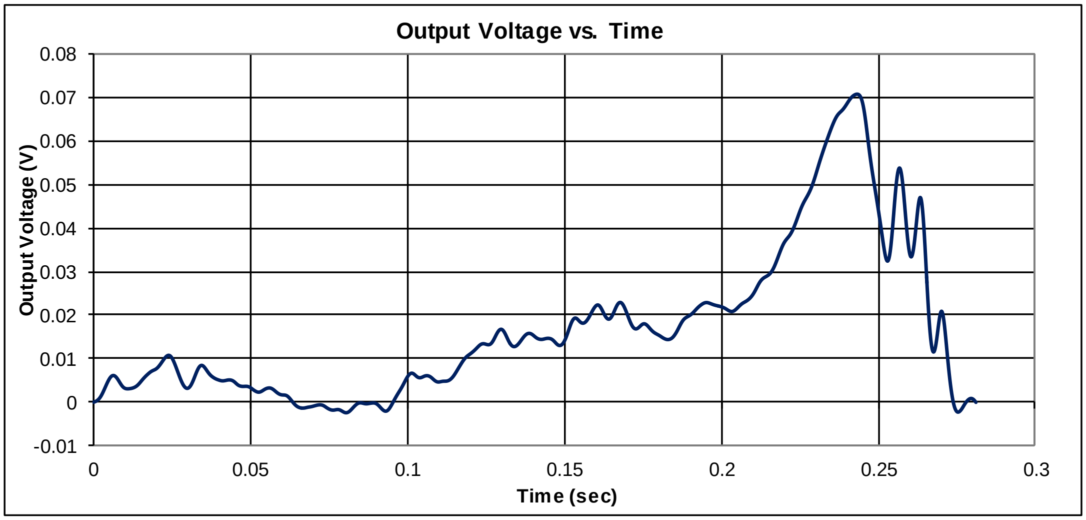
Test No:	HTTB-56
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Key Plate
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Lateral pull on cable attachment bracket
Failure Discription:	Tabs rotated up and through keyway - Tabs never caught

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	0.41 kips
Time of Max. Load:	0.2433 sec
Event Duration:	0.2811 sec
Final Load:	0.00 kips



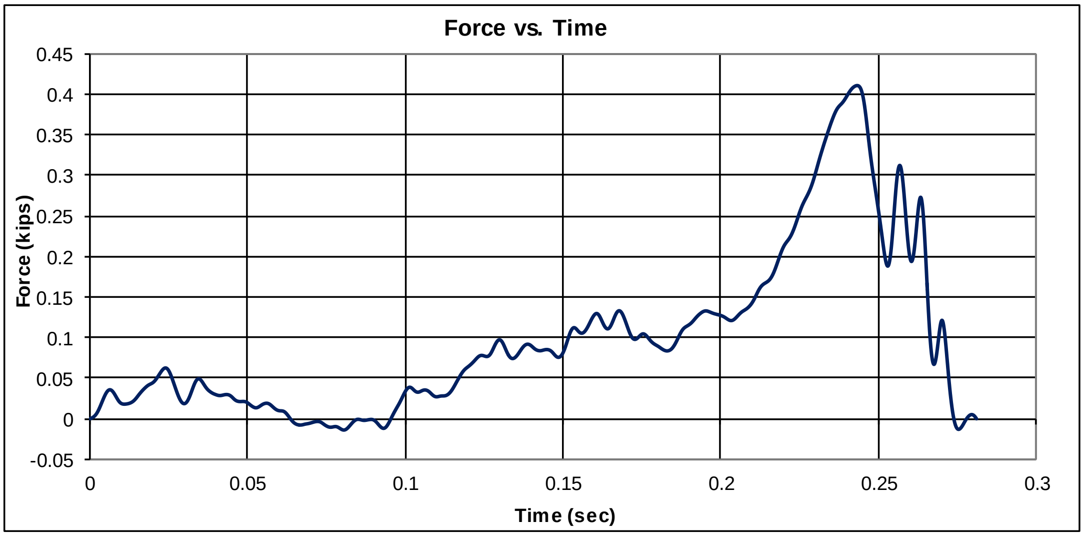


Figure B-8. Load Cell Results, Test No. HTTB-56

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

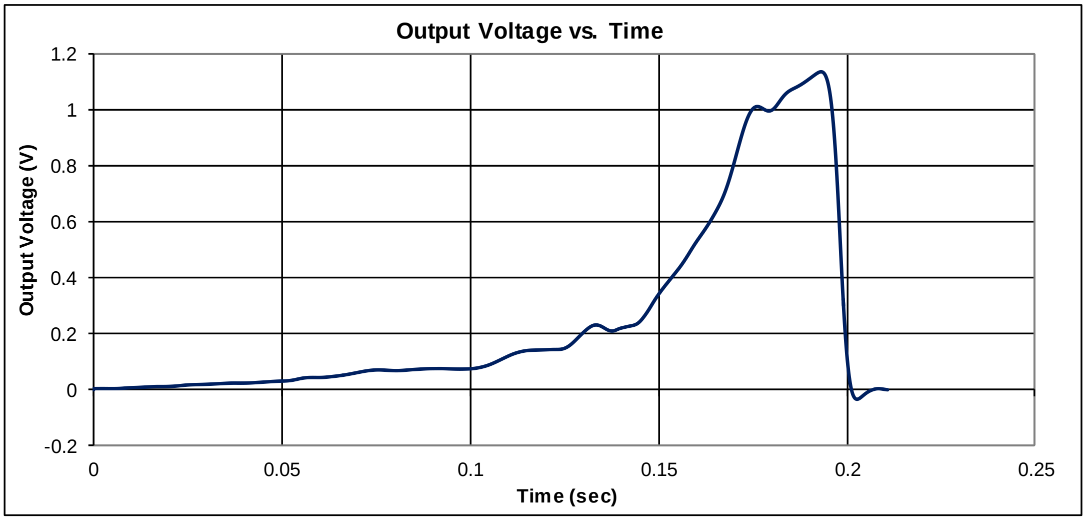
Test No:	HTTB-57
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Lateral Pin
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Lateral pull on cable attachment bracket
Failure Discription:	Tearing off of tabs

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	6.59 kips
Time of Max. Load:	0.1932 sec
Event Duration:	0.2108 sec
Final Load:	0.00 kips



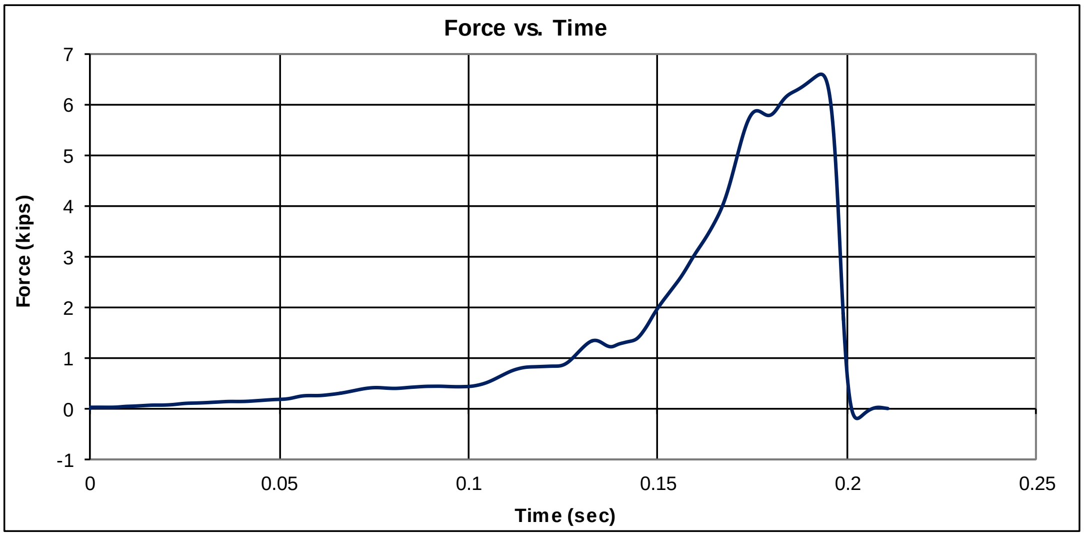


Figure B-9. Load Cell Results, Test No. HTTB-57

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

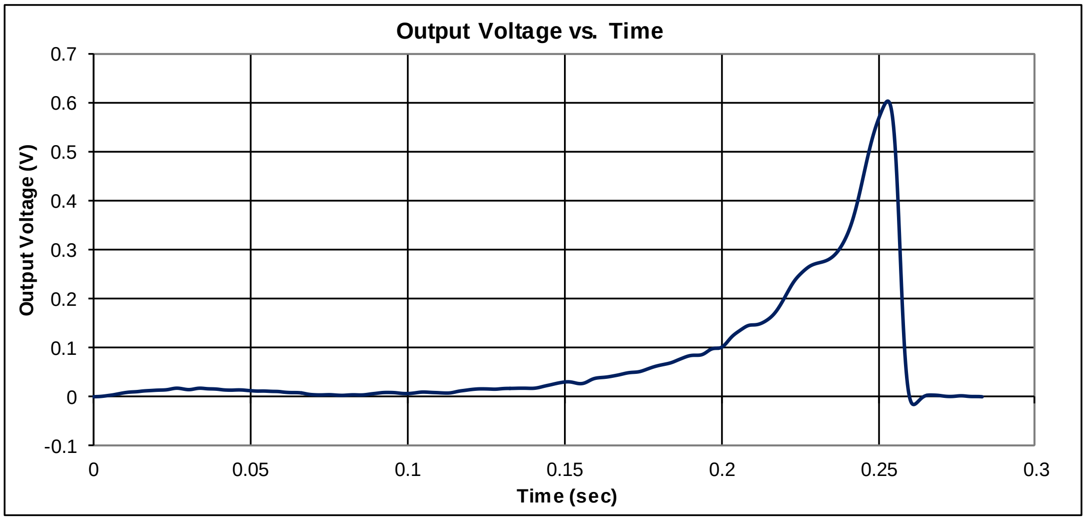
Test No:	HTTB-58
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Lateral Pin
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Lateral pull on cable attachment bracket
Failure Discription:	Tabs deformed and released through keyway

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	3.50 kips
Time of Max. Load:	0.253 sec
Event Duration:	0.2831 sec
Final Load:	0.00 kips



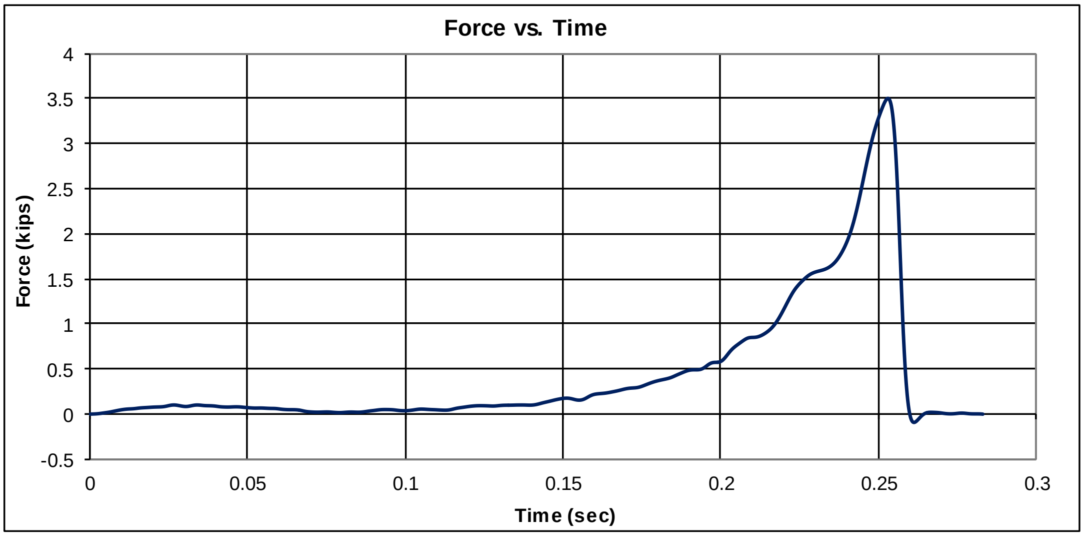


Figure B-10. Load Cell Results, Test No. HTTB-58

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

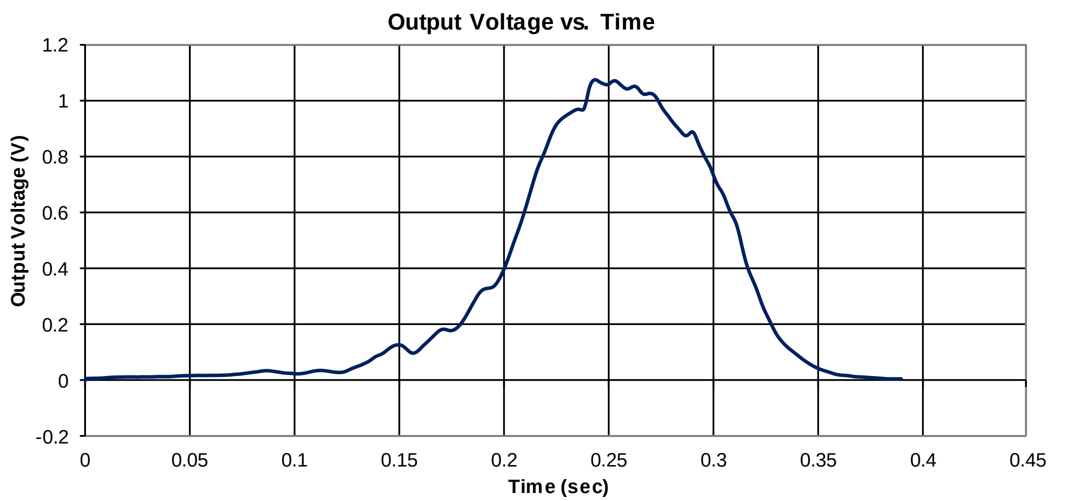
Test No:	HTTB-59
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Pinned Back
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Lateral pull on cable attachment bracket
Failure Discription:	No Failure - stopped bogie

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	6.24 kips
Time of Max. Load:	0.2438 sec
Event Duration:	0.39 sec
Final Load:	0.03 kips



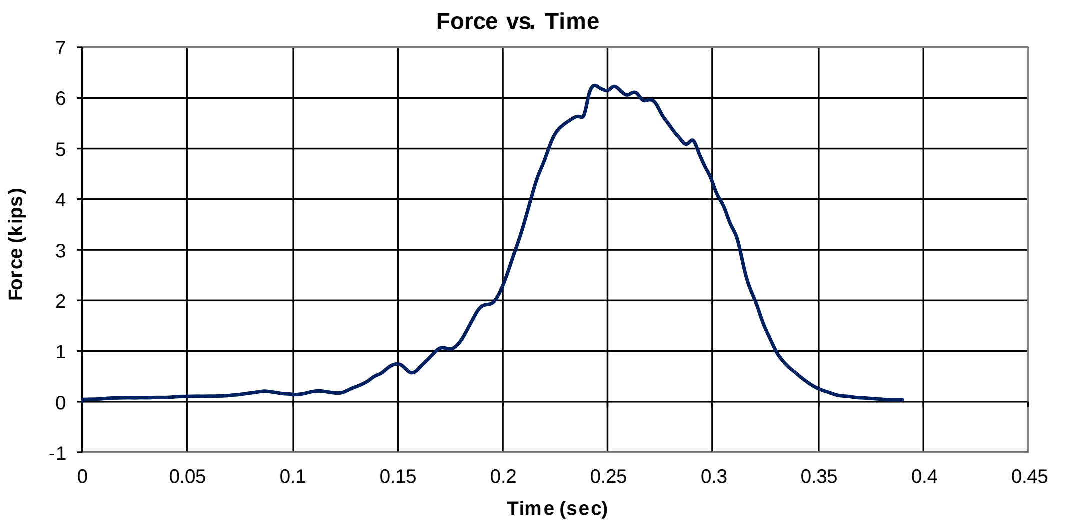


Figure B-11. Load Cell Results, Test No. HTTB-59

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

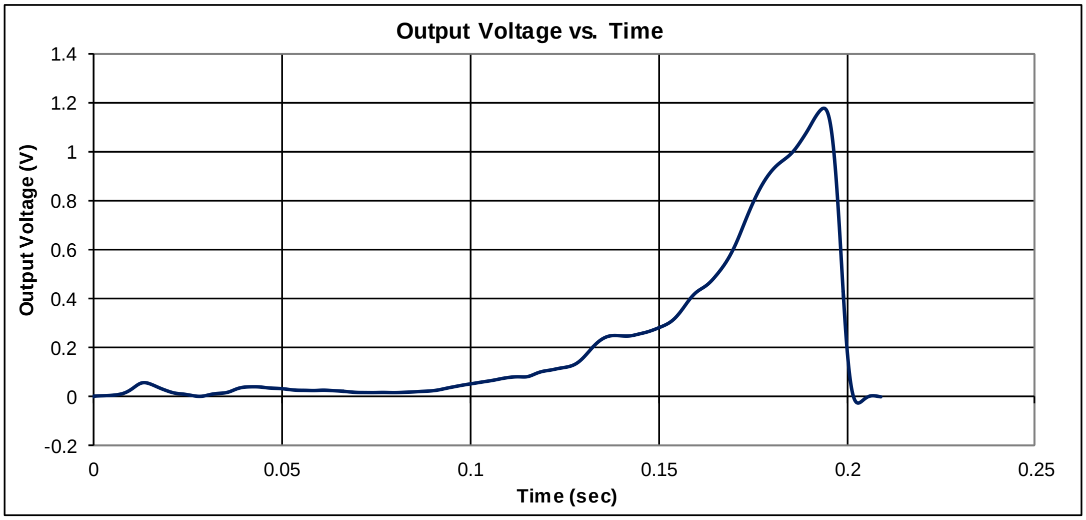
Test No:	HTTB-60
Date:	8/22/2014
System / Test Article:	Tabbed Bracket with Pinned Back
LC Location / Component:	Base of test jig (in line with pull)
Additional Notes:	Lateral pull on cable attachment bracket
Failure Discription:	Tearing of Tabs

Load Cell Information:

Load Cell No.:	143435
Calibration Factor:	2.15385 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	6.84 kips
Time of Max. Load:	0.1939 sec
Event Duration:	0.209 sec
Final Load:	0.00 kips



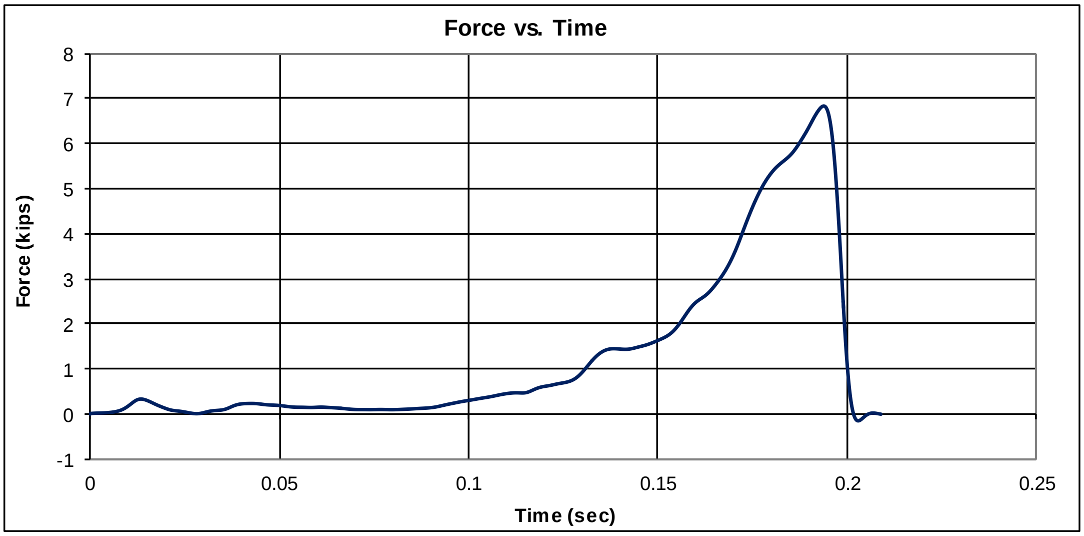


Figure B-12. Load Cell Results, Test No. HTTB-60

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