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

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16. Abstract (Limit: 200 words)

The research objectives reported herein were based on further development of cable-to-post attachment hardware for use in the non-proprietary high-tension cable barrier system. Specifically, this project aimed to develop and evaluate alternative attachment designs for the bolted, tabbed bracket and evaluate the use of a larger diameter, keeper rod for use in the top cable attachment.

From a group of over 25 alternative attachment concepts, two tabbed bracket designs were selected for evaluation through dynamic component testing: 1) the lateral shear plate attachment and 2) the drop-in shear plate attachment. The drop-in shear plate concept did not perform as intended, as the vertical release load was too high and the lateral release loads were too low. Alternatively, the lateral shear plate design provided vertical and lateral release loads very similar to the original bolted, tabbed bracket V10. However, concerns were raised over the lack of rigidity in the attachment and the ease of installations of the shear plate. Thus, it was recommended that the lateral shear plate design be modified and reevaluated prior to use in the full-scale system.

Dynamic bogie or component testing of the 3/16-in. (4.8-mm) diameter brass keeper rod provided a quick cable release similar to the previous design. The increased strength of the rod also showed promise in distributing impact loads more uniformly to adjacent posts and helping reduce system deflections. Thus, the 3/16-in. (4.8-mm) diameter brass rod was recommended for use in the new high-tension cable barrier system.

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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-41 through HTTB-48 and HTTC-2 were non-certified component tests conducted for research and development purposes only and are outside the scope of MwRSF's A2LA Accreditation.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Dr. Jennifer Schmidt, P.E., 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 non-proprietary 4-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 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

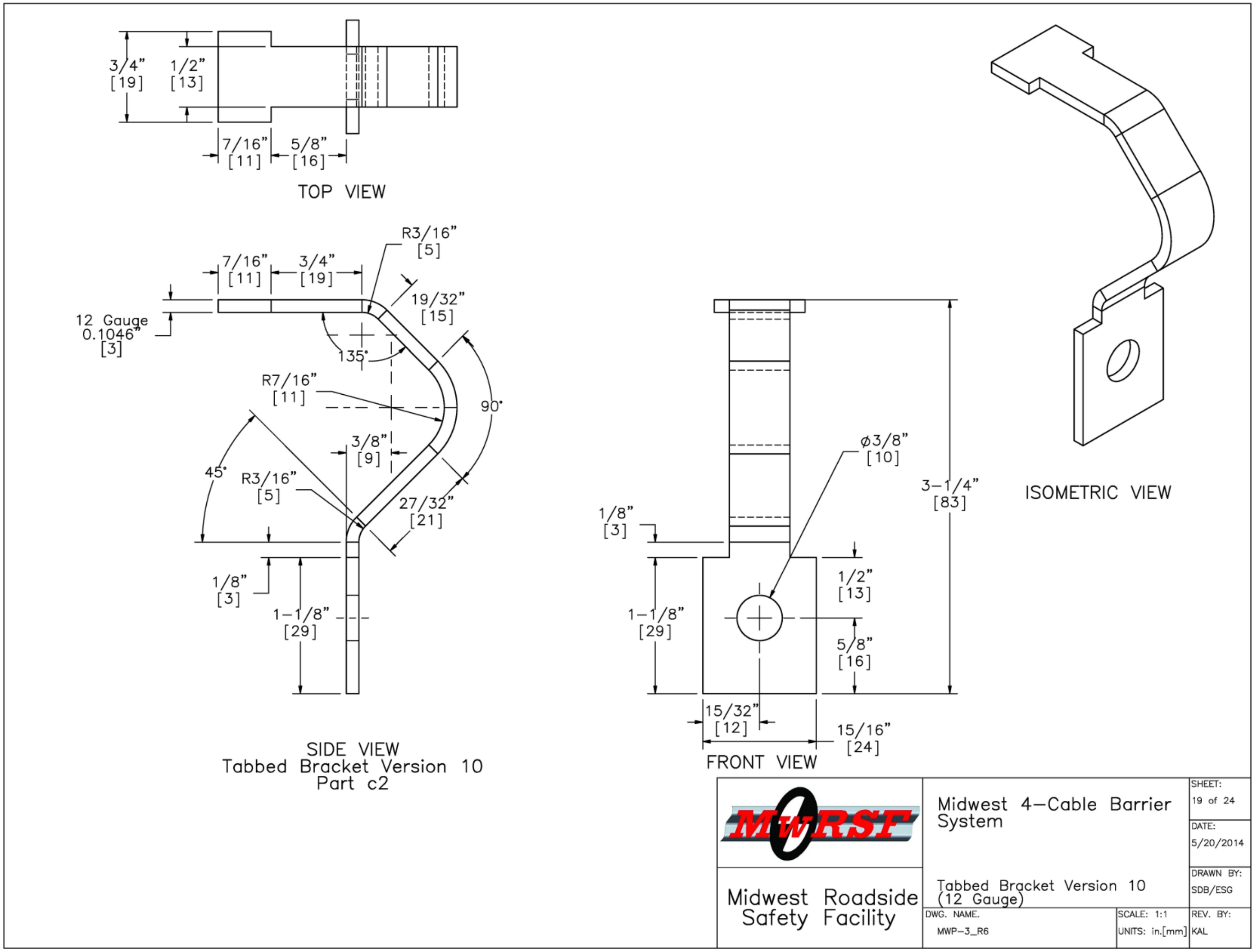


Figure 2. Bolted Tabbed Bracket V-10, Design Details

Although the new design for the 4-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 this alternative attachment study. However, in the interest of time, this study was conducted in parallel with full-scale crash testing on the new 4-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.

Additionally, further evaluation was desired of the brass rod utilized to secure the top cable within the V-notch cut into the top of the post. The original ⅛-in. (3.2-mm) diameter brass rod was designed to release quickly after a vehicle impact to the post, thus preventing the cable from being pulled down and reducing the potential for the vehicle to override the system. Dynamic bogie testing showed the ⅛-in. (3.2-mm) diameter brass rod released the top cable with only a minimal deflection as the post was bending [2]. However, concerns arose that the release loads of the brass rod were too low and would allow large barrier deflections during impacts. Thus, additional testing of stronger top cable attachments was also desired.

1.2 Objective

There were two objectives for this project, both of which dealt with cable-to-post attachments for the non-proprietary high-tension 4-cable median barrier system. The first objective was to develop an alternative cable-to-post attachment bracket for the lower three cables. 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. Additionally, the new bracket design had to perform similarly to the previously developed bolted tabbed bracket V10 in terms of vertical and lateral release loads.

The second objective was to evaluate stronger retainer rods for the top cable attachment. The post and V-notch were to remain identical to the previous design. However, the diameter of the brass rod would be increased to create a stronger release load for the top cable in an attempt to reduce barrier deflections during an impact. The stronger retainer rod was still required to release the top cable quickly when the post was impacted, thus preventing the cable from being pulled down.

1.3 Research Approach

This research began with an extensive brainstorming and design effort which identified over twenty-five possible design alternatives for the lower cable-to-post attachment. Through a combination of analysis and discussions with the project sponsors, the top two design alternatives were selected for further evaluation. Dynamic component testing was conducted to evaluate both the vertical and lateral cable release characteristics of the selected designs. The results of these tests were analyzed and compared against similar tests conducted on the bolted tabbed bracket V10. Conclusions and recommendations were then made pertaining to the use of the two selected designs.

At the same time, a stronger brass rod was designed to retain the top cable within the V-notch cut into the top of the post. A dynamic component test was conducted on a short installation of cable barrier with the increased-diameter rods to evaluate the displacement of the top cable prior to being released from the post. Test results were analyzed and compared against previous testing conducted on the original ⅛-in. (3.2-mm) diameter brass retainer rod. Conclusions and recommendations were then made pertaining to the use of the increased-diameter rod.

2 BRACKET ATTACHMENT DESIGN CONCEPTS

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 keep the top portion of the bracket and the keyway in the post 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 Initial Attachment Design Concepts

During the initial round of brainstorming and concept development, twenty-five new attachment designs were created for the tabbed bracket. A wide variety of attachment hardware options were explored, including pins, plates, rods, and cleats. Additionally, some bracket concepts were designed to slide or snap into place on the post. Concept drawings for each of the attachment designs, beginning with the original bolted tabbed bracket, are shown in Figures 3 through 28. Included on each concept drawing is a brief summary of the advantages and disadvantages associated with the particular design, as well as an indication of the researcher's confidence that the design will be able to perform equivalently to the original bolted tabbed bracket V10.

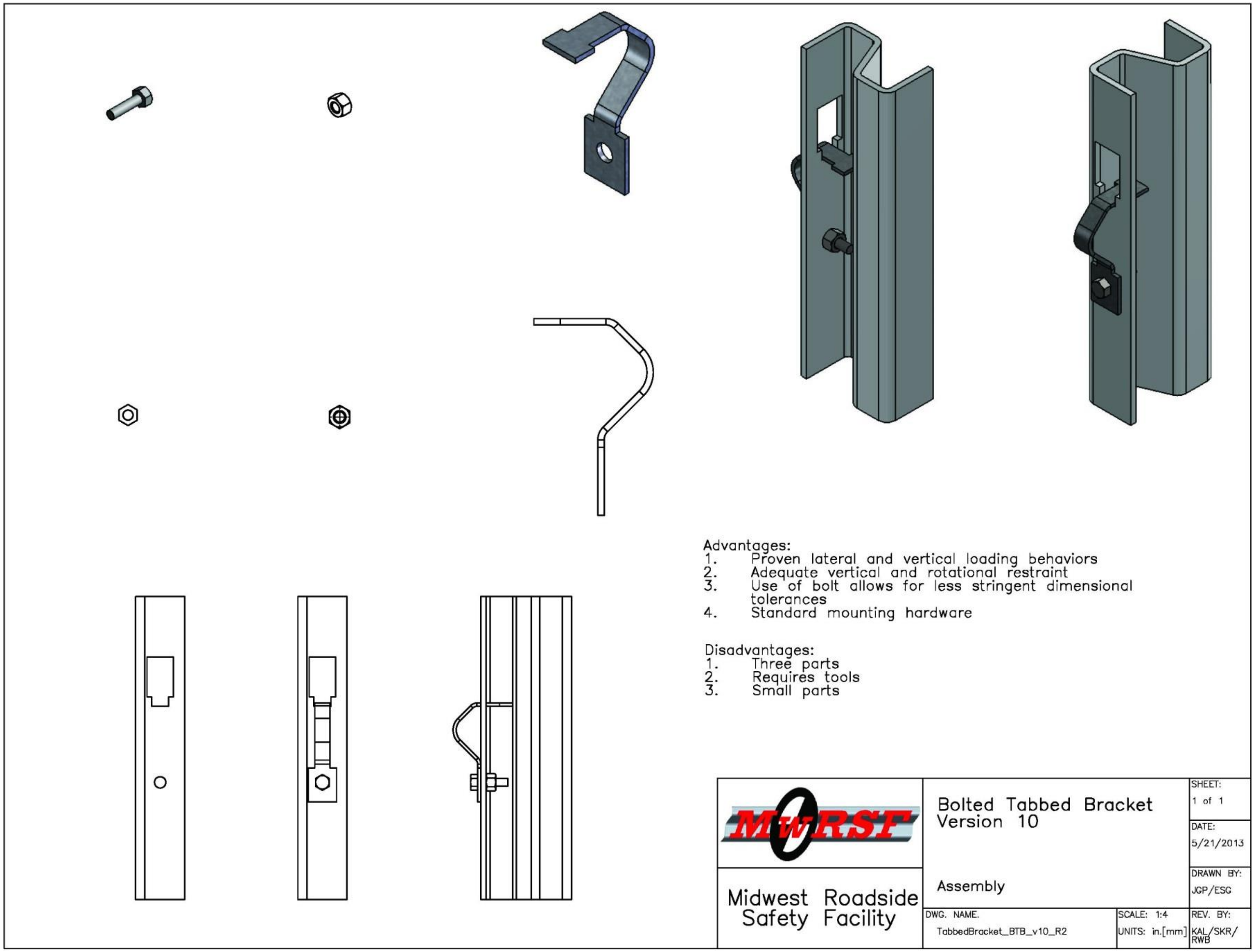


Figure 3. Bolted, Tabbed Bracket V-10

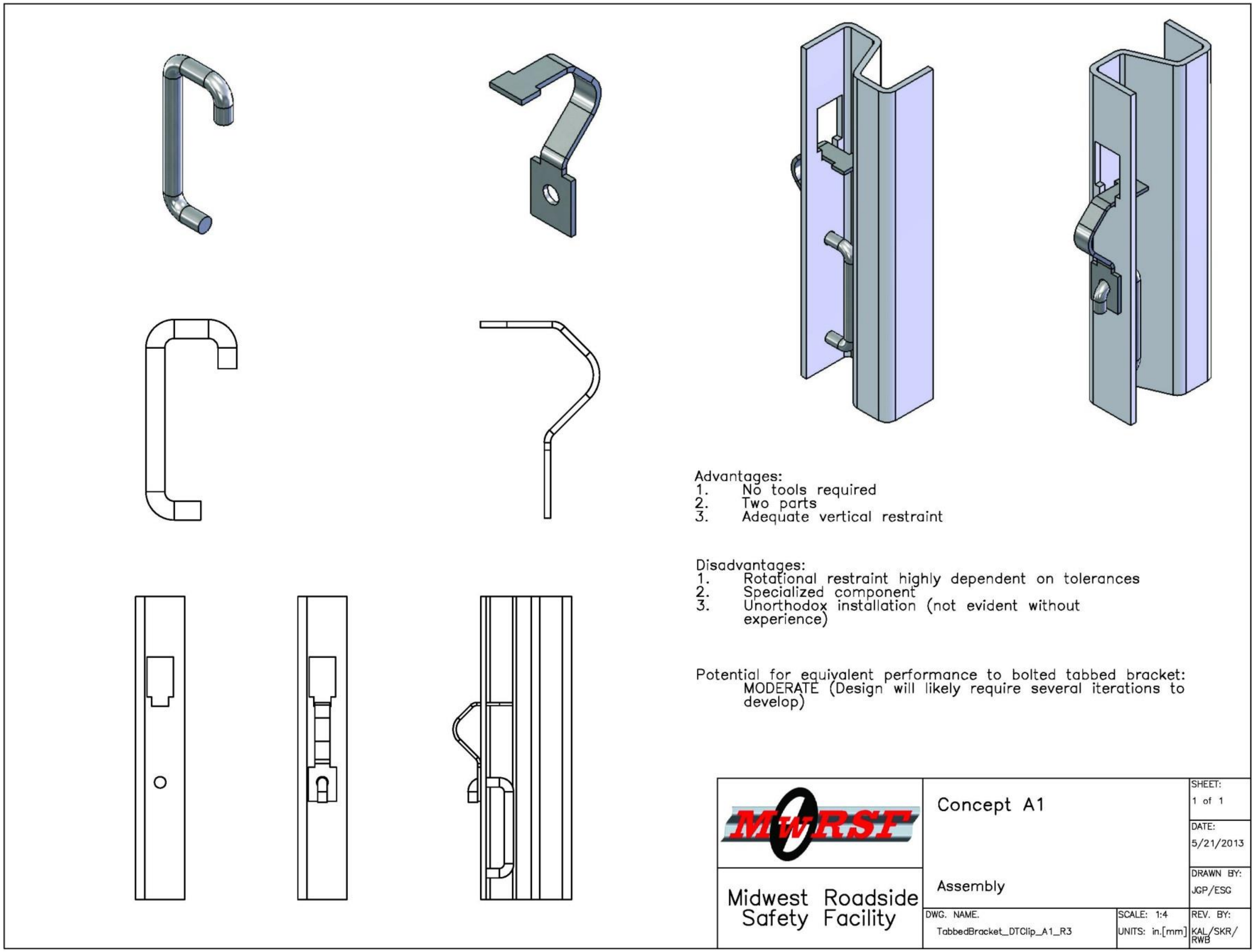


Figure 4. Concept A1

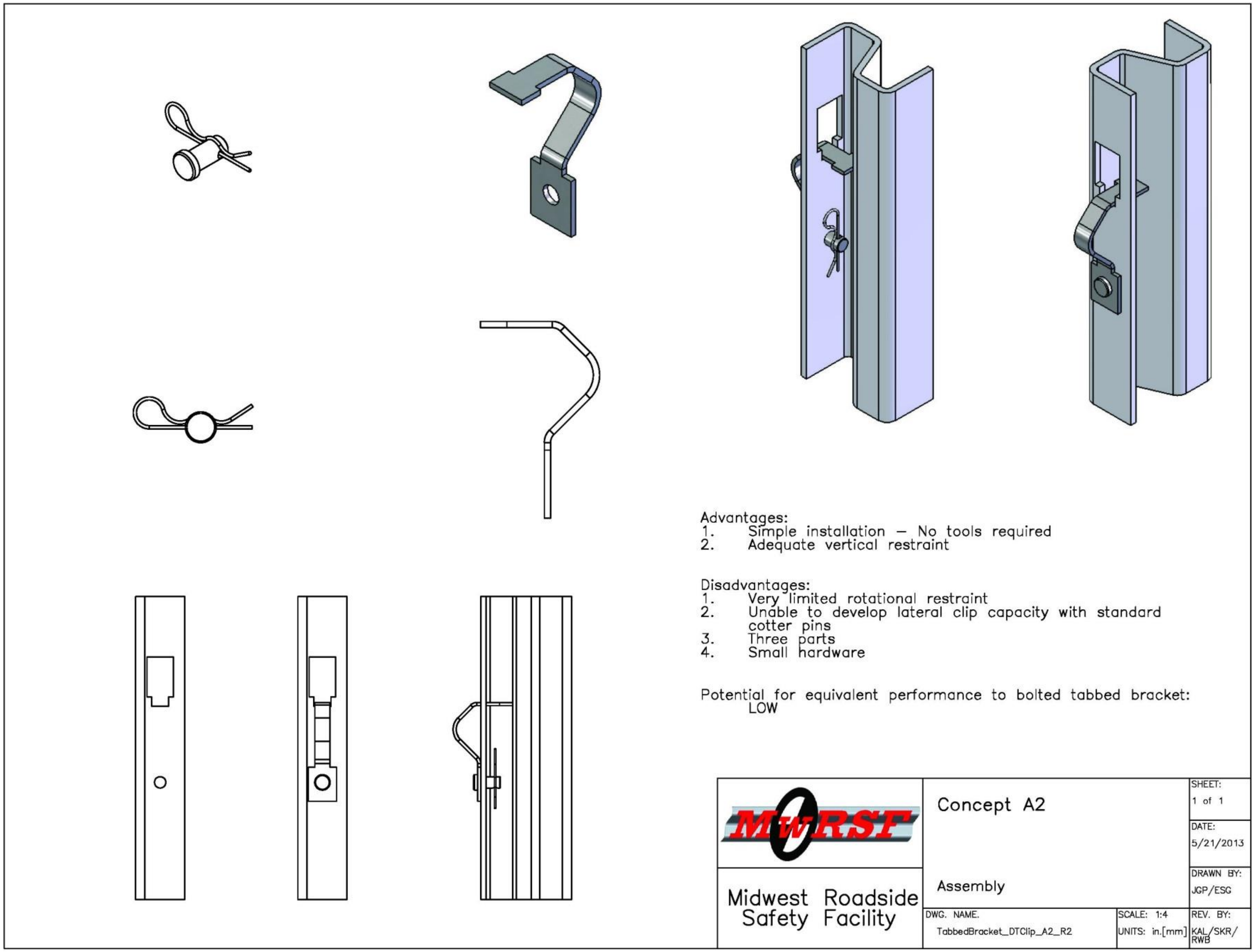


Figure 5. Concept A2

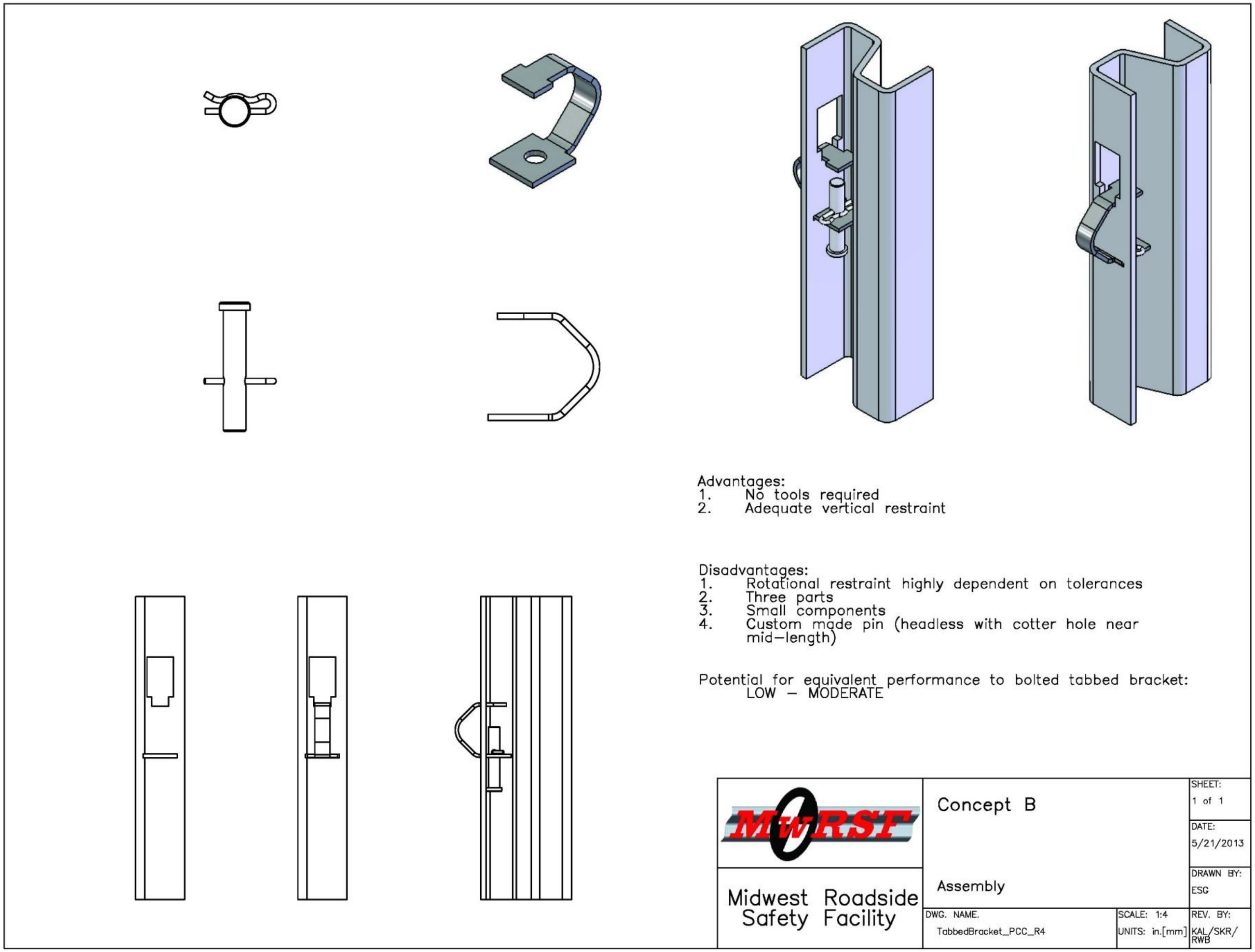


Figure 6. Concept B

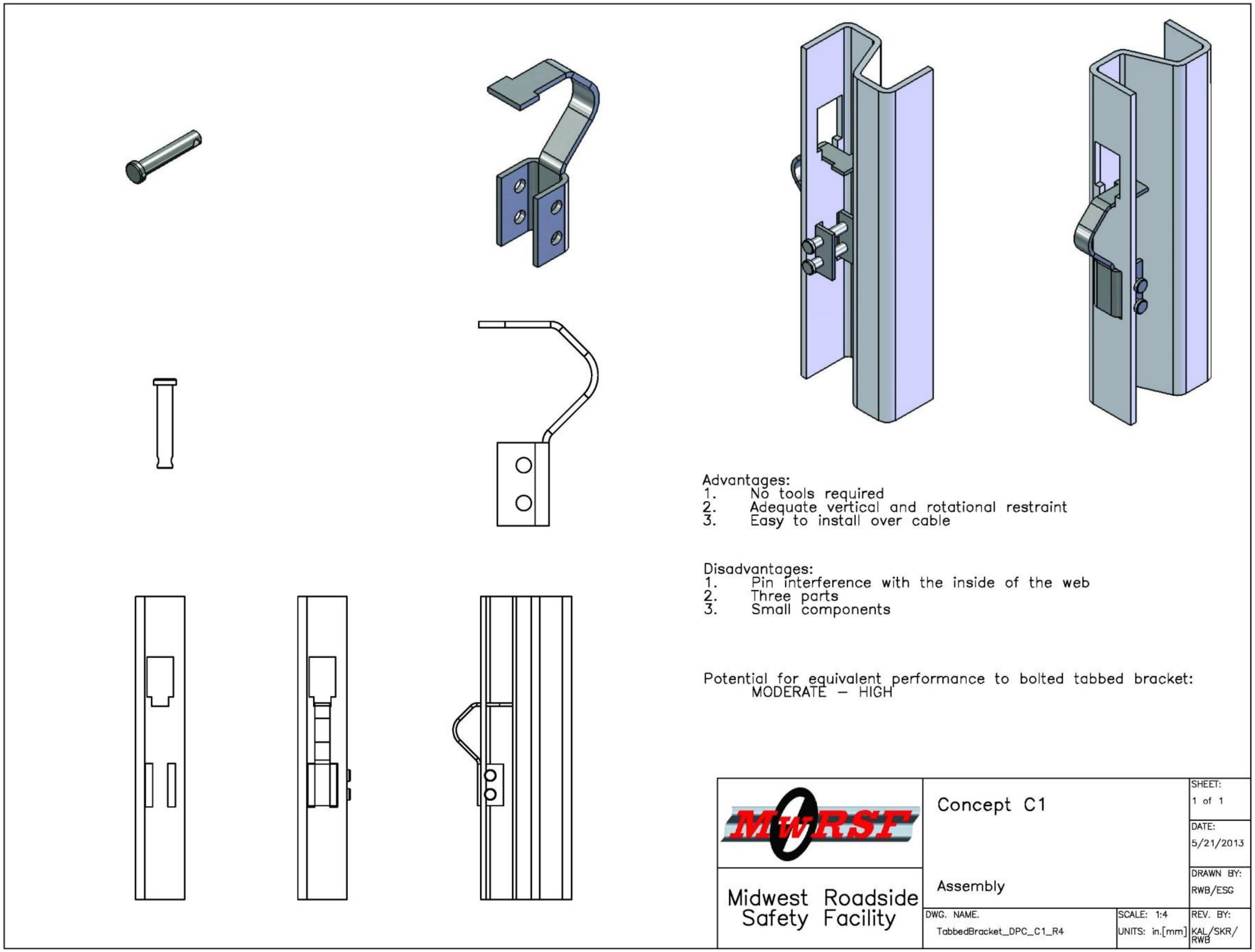


Figure 7. Concept C1

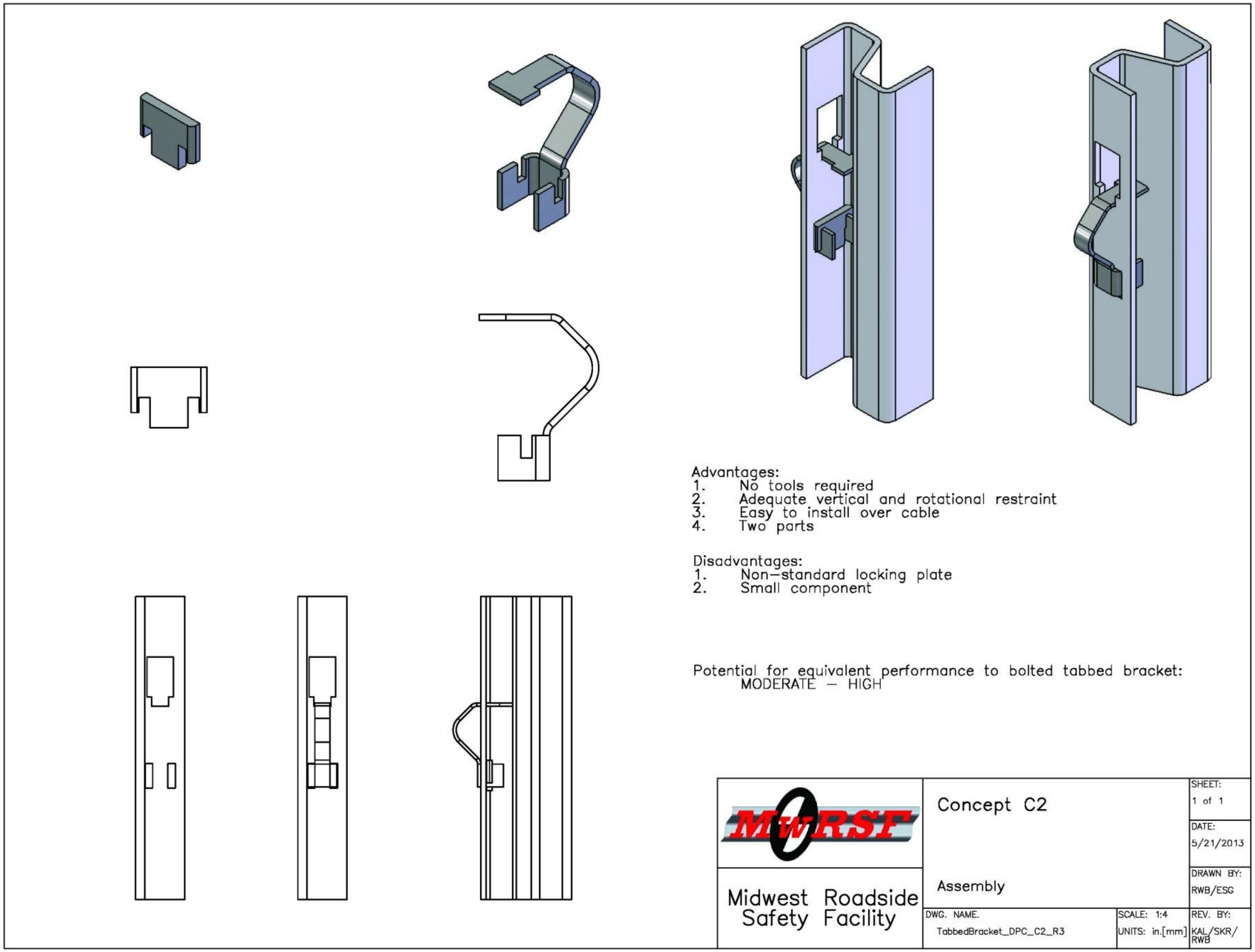


Figure 8. Concept C2

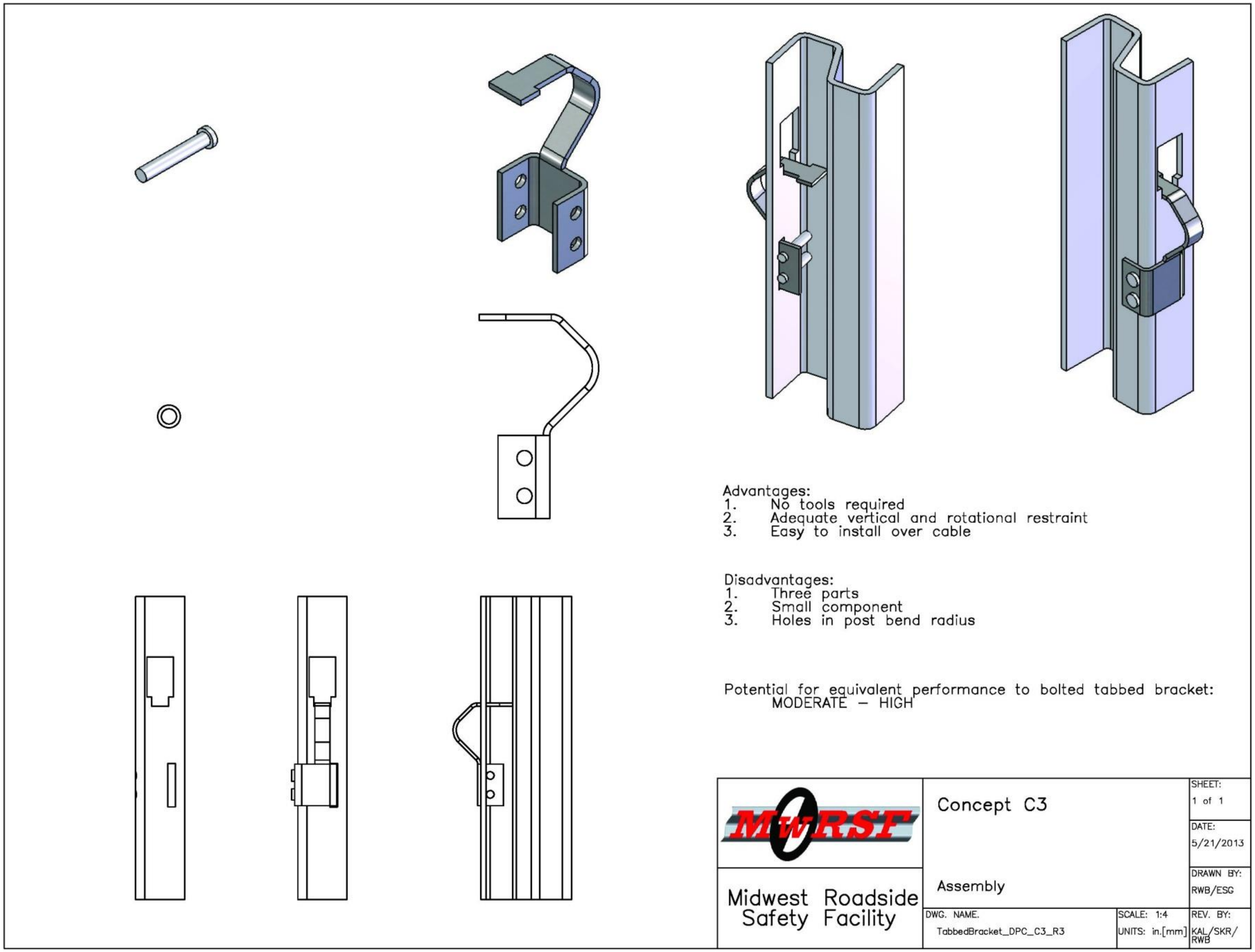


Figure 9. Concept C3

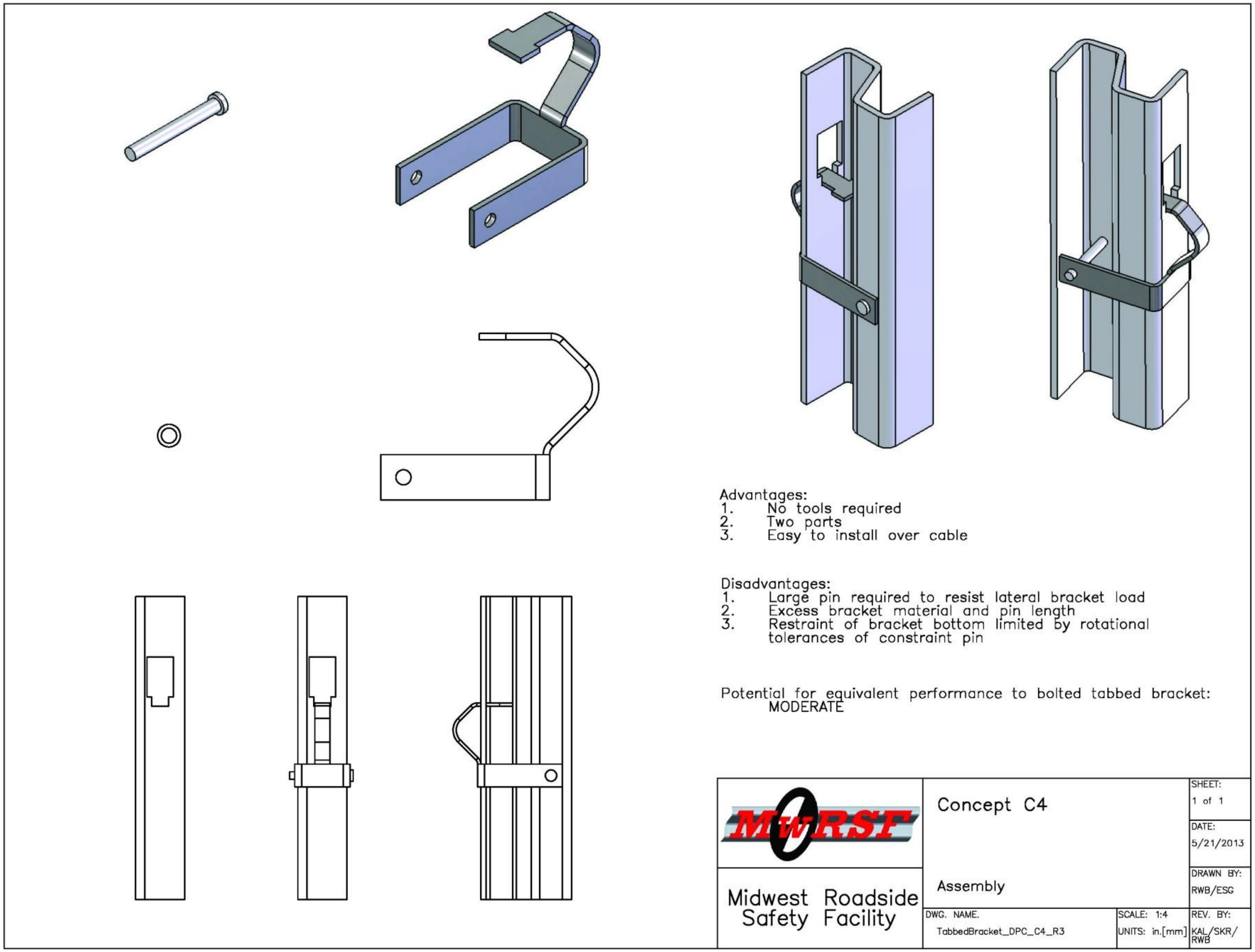


Figure 10. Concept C4

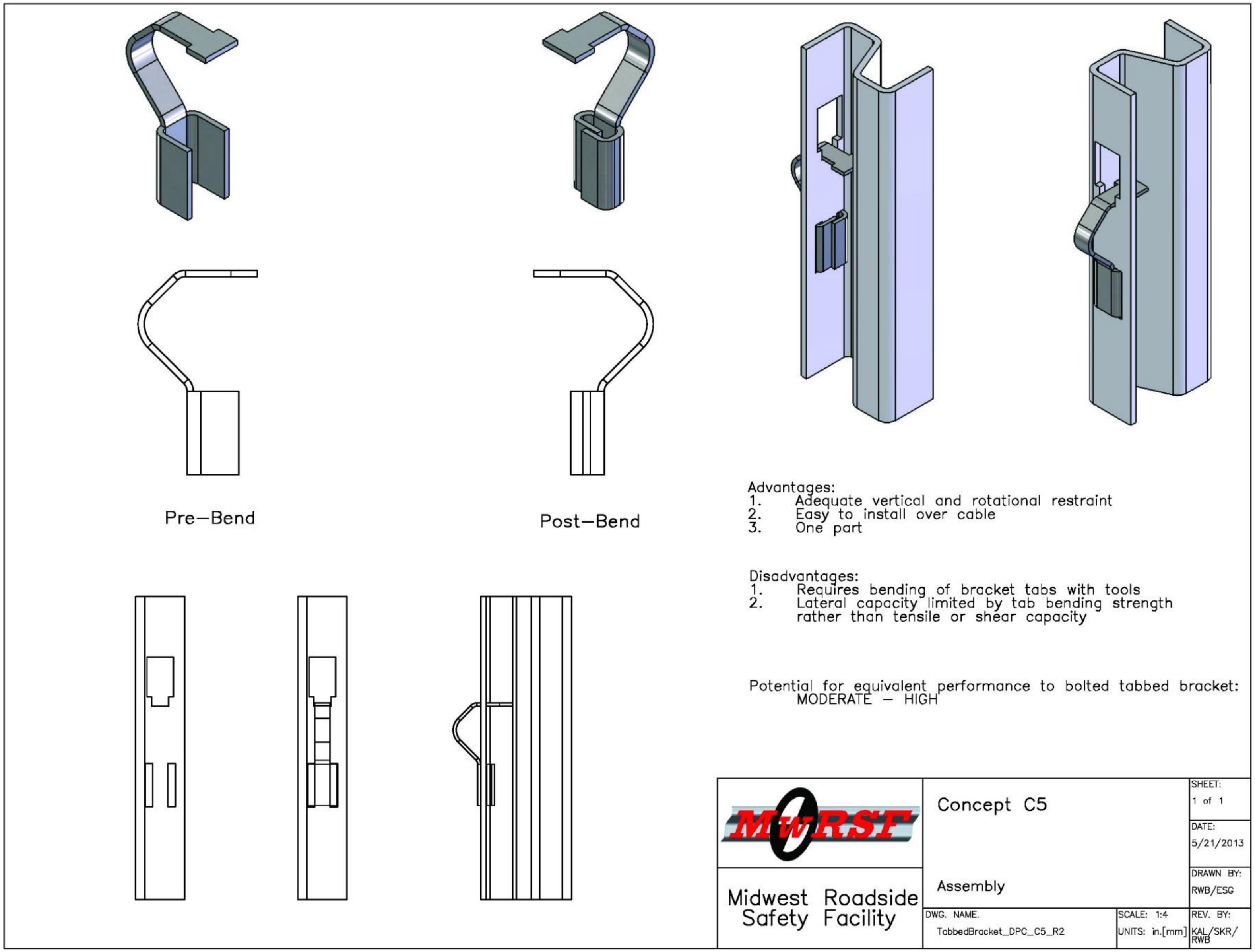


Figure 11. Concept C5

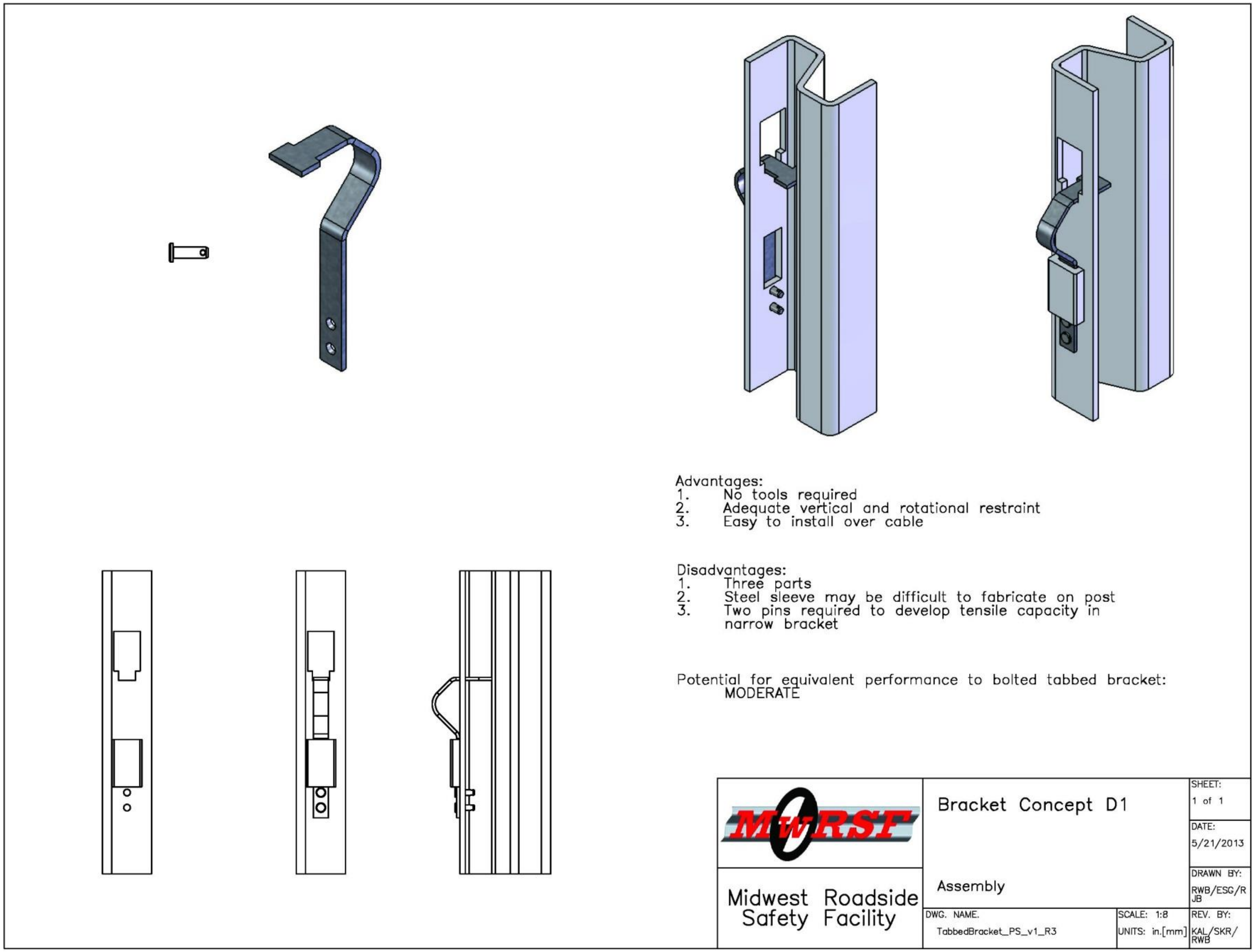


Figure 12. Concept D1

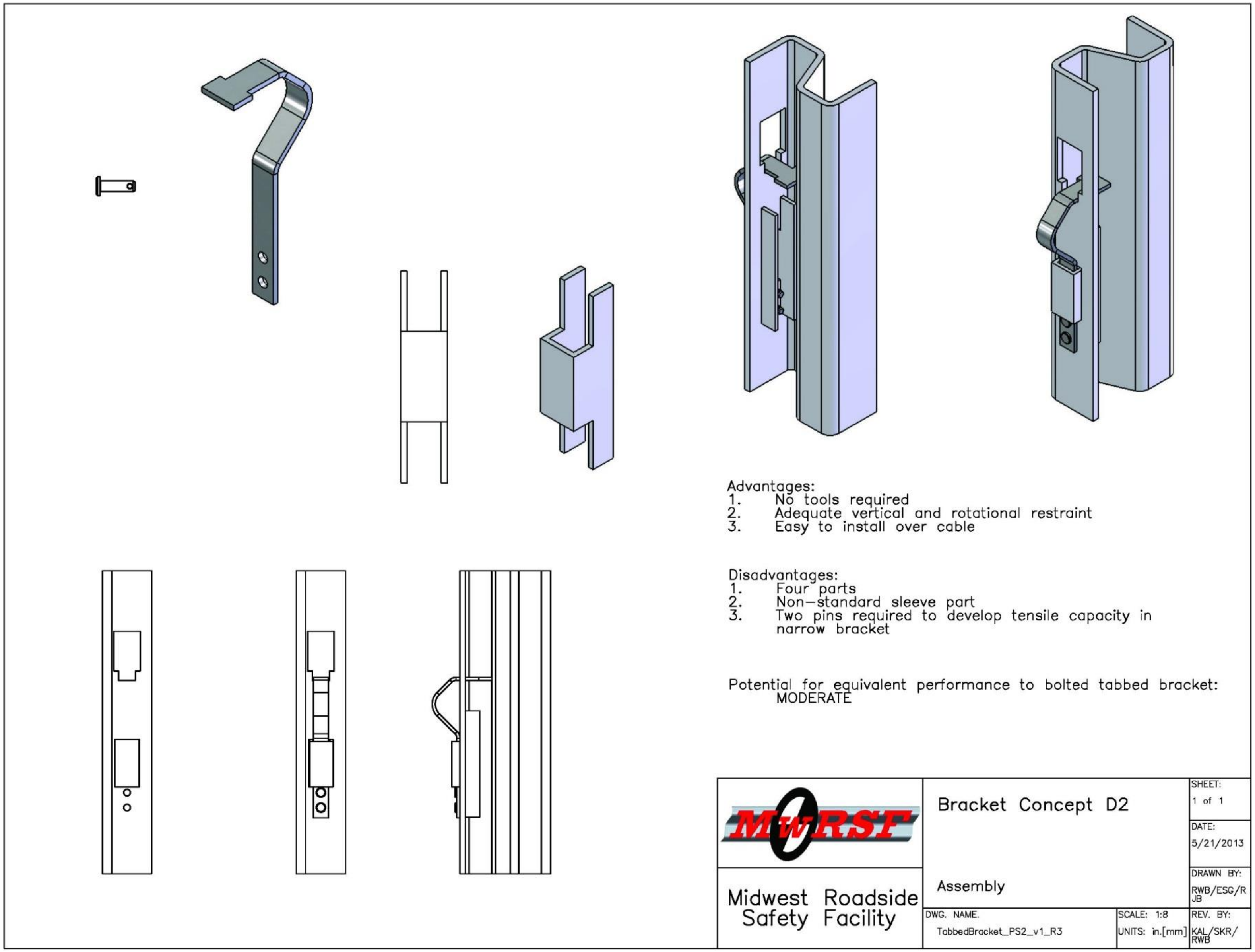


Figure 13. Concept D2

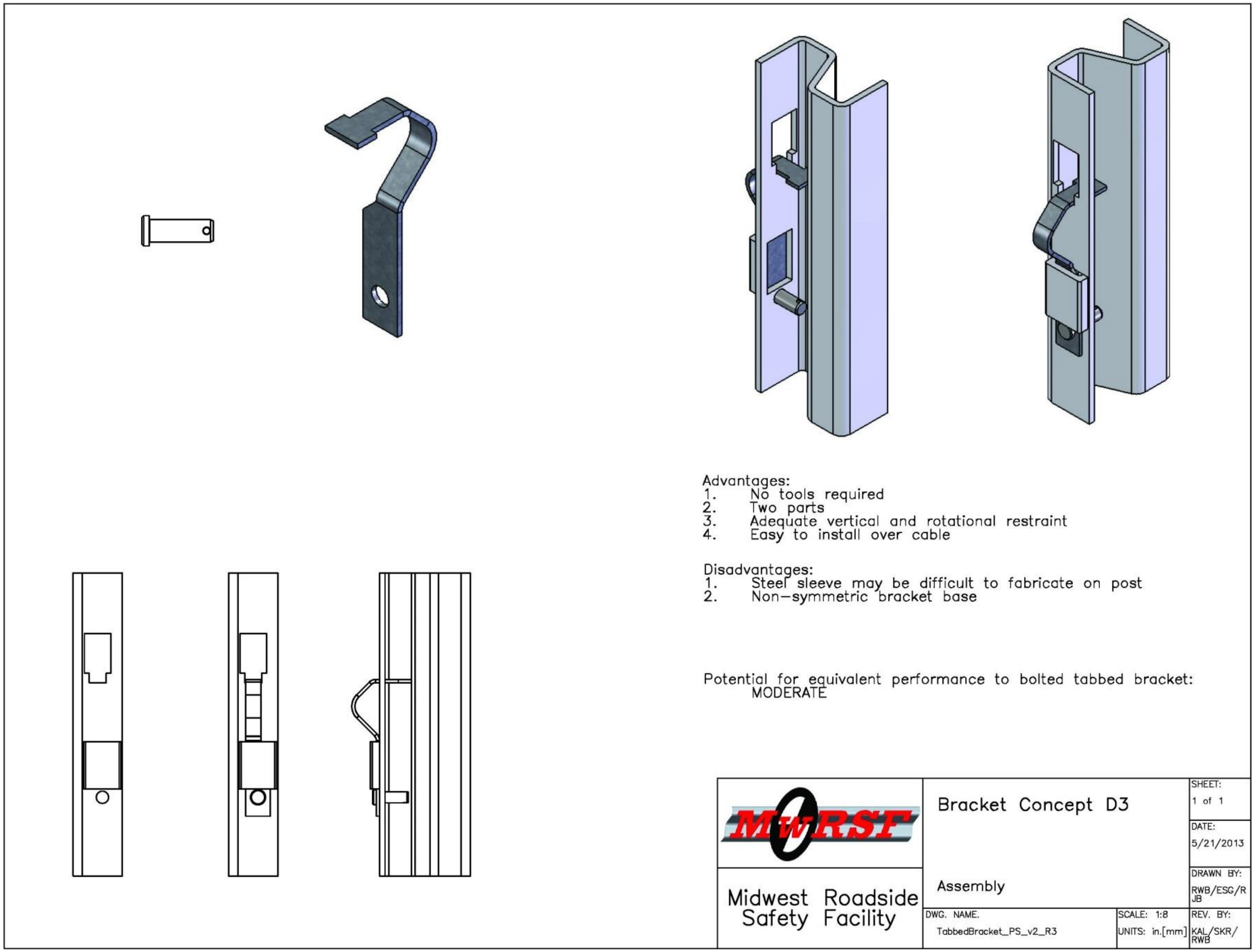


Figure 14. Concept D3

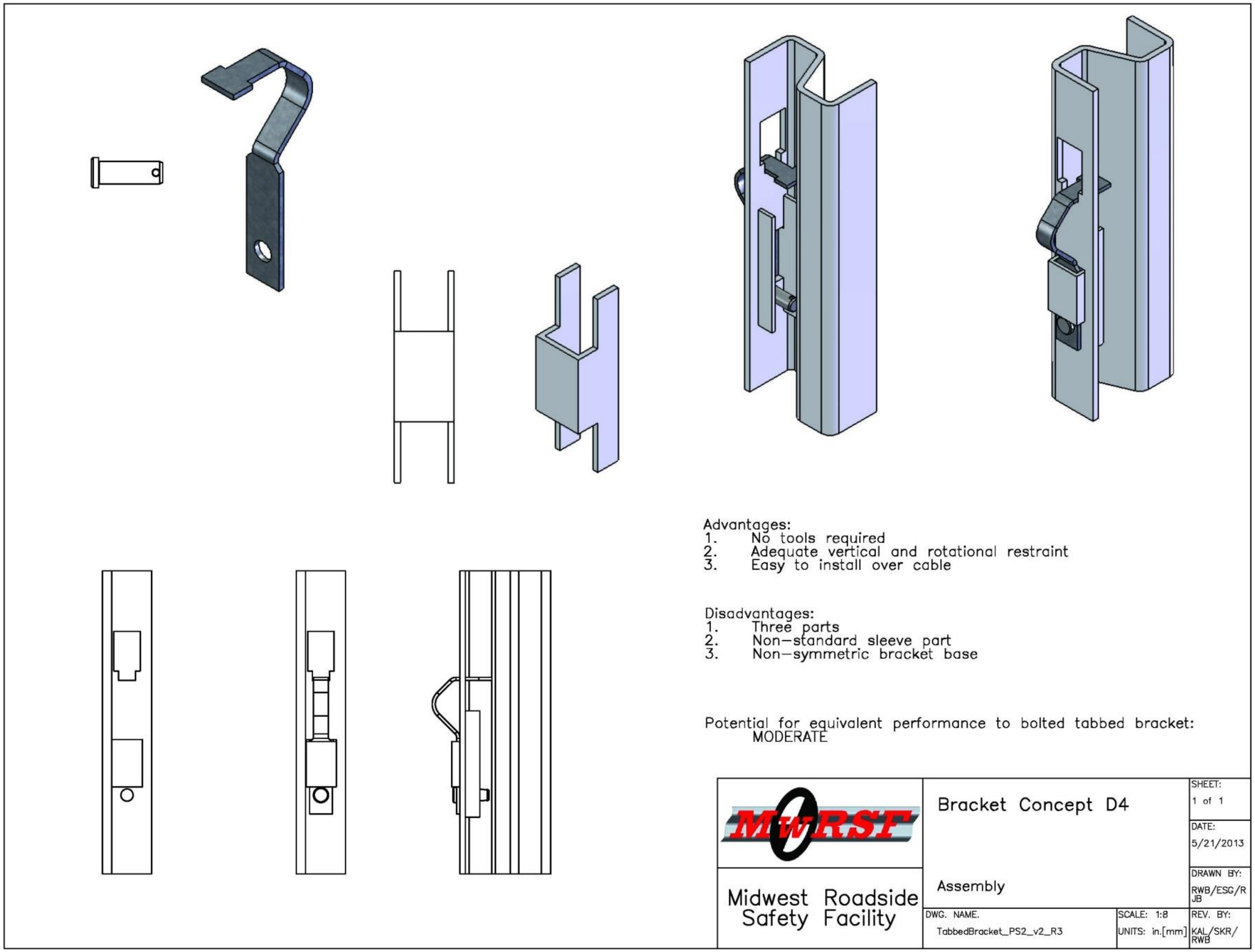


Figure 15. Concept D4

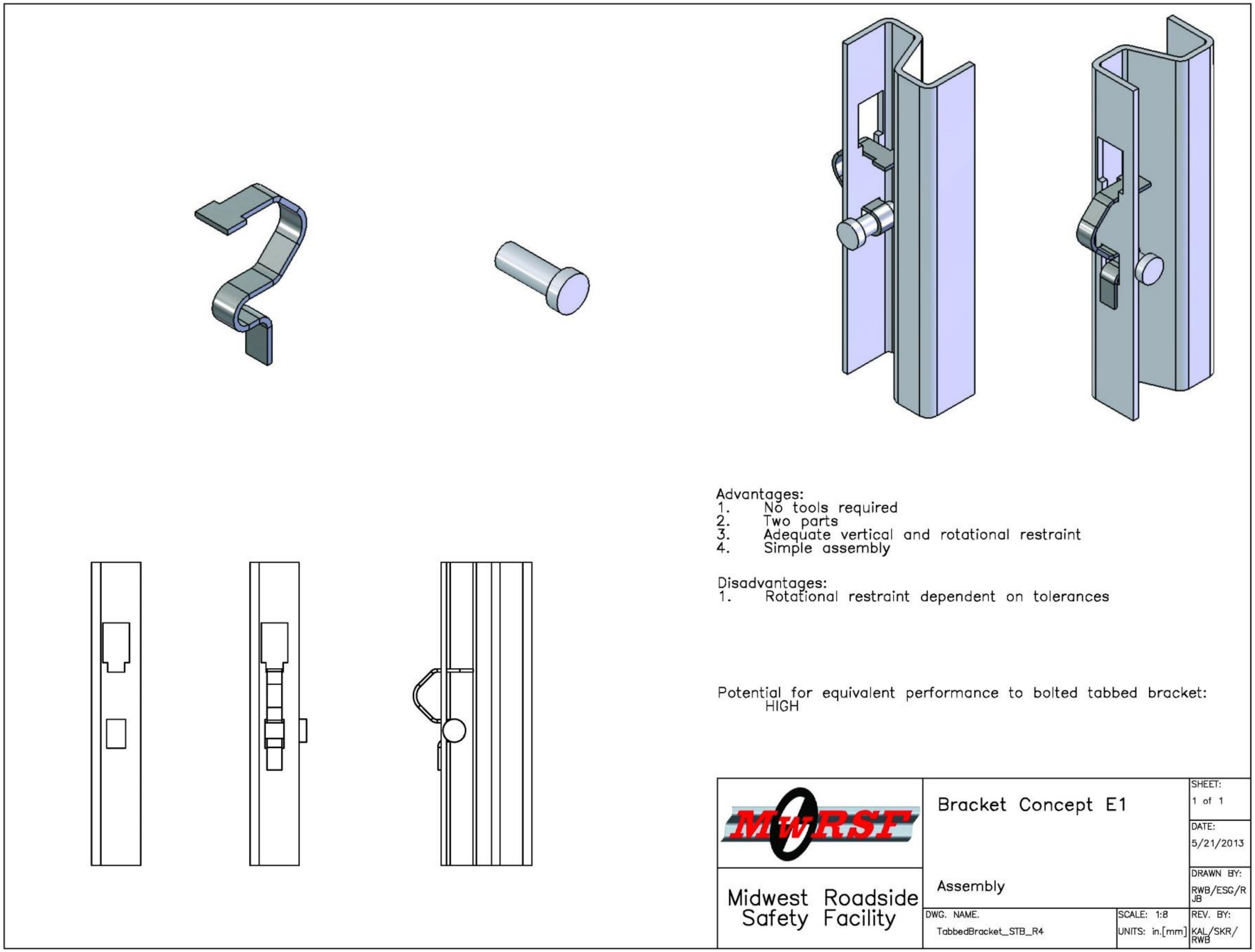


Figure 16. Concept E1

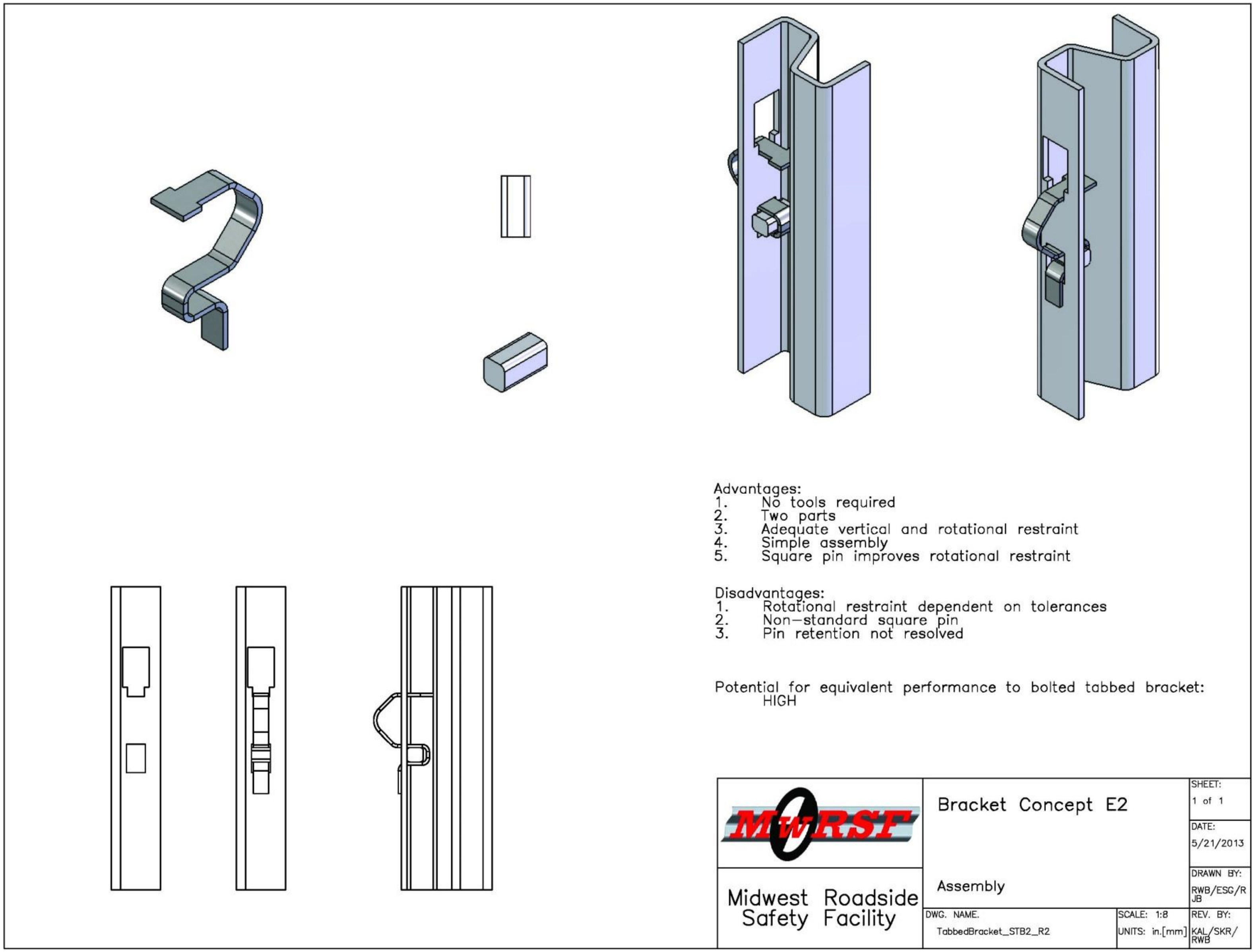


Figure 17. Concept E2

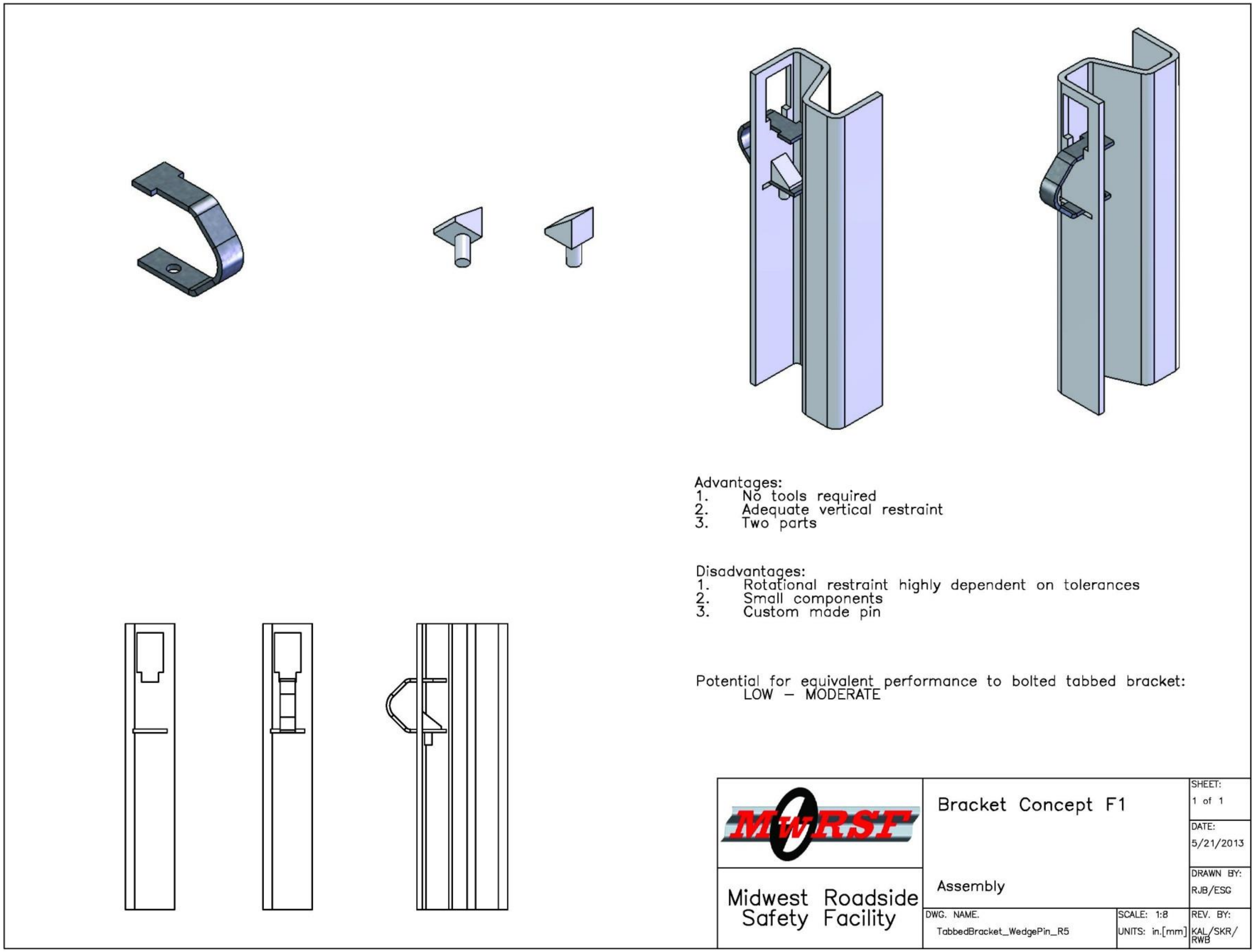


Figure 18. Concept F1

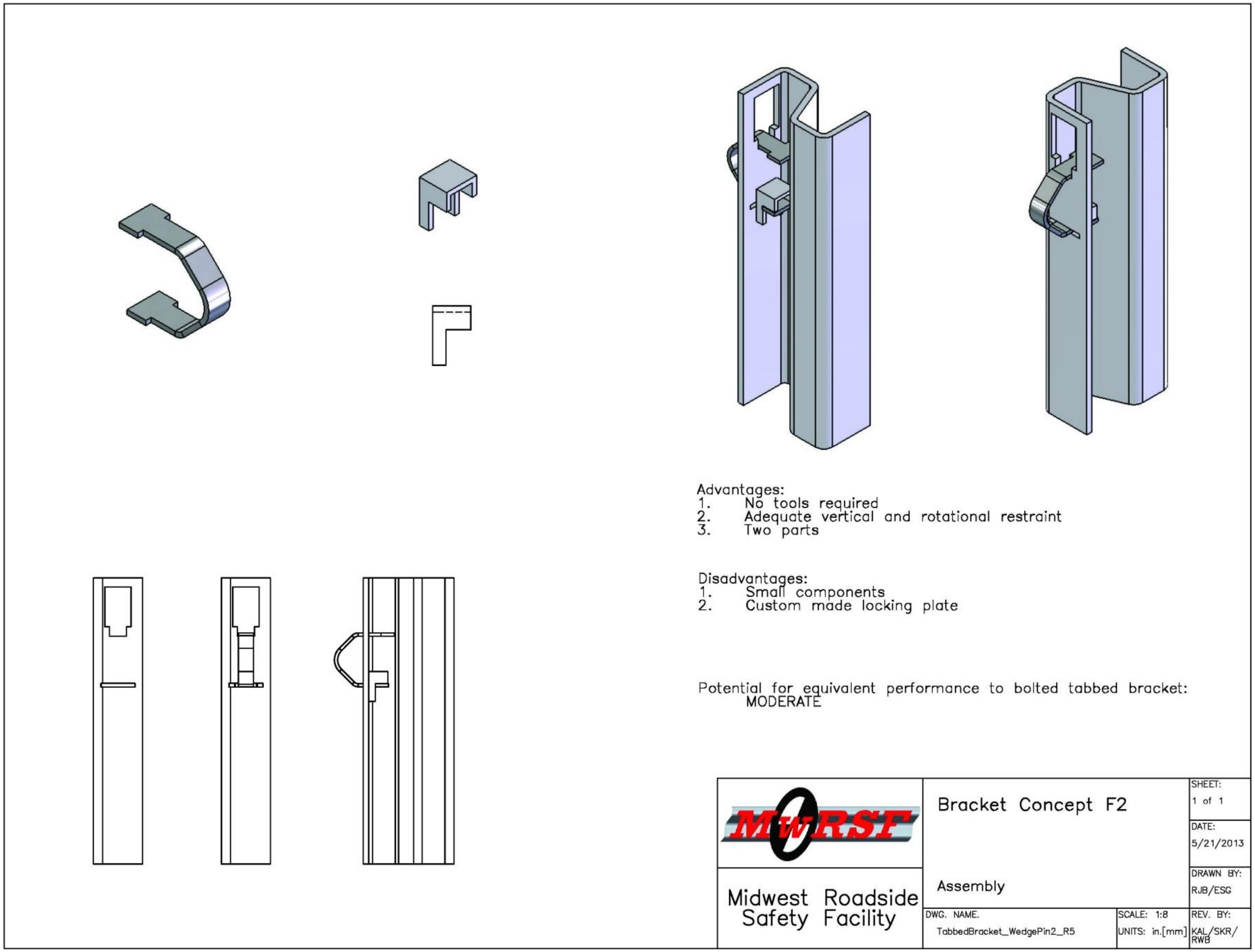
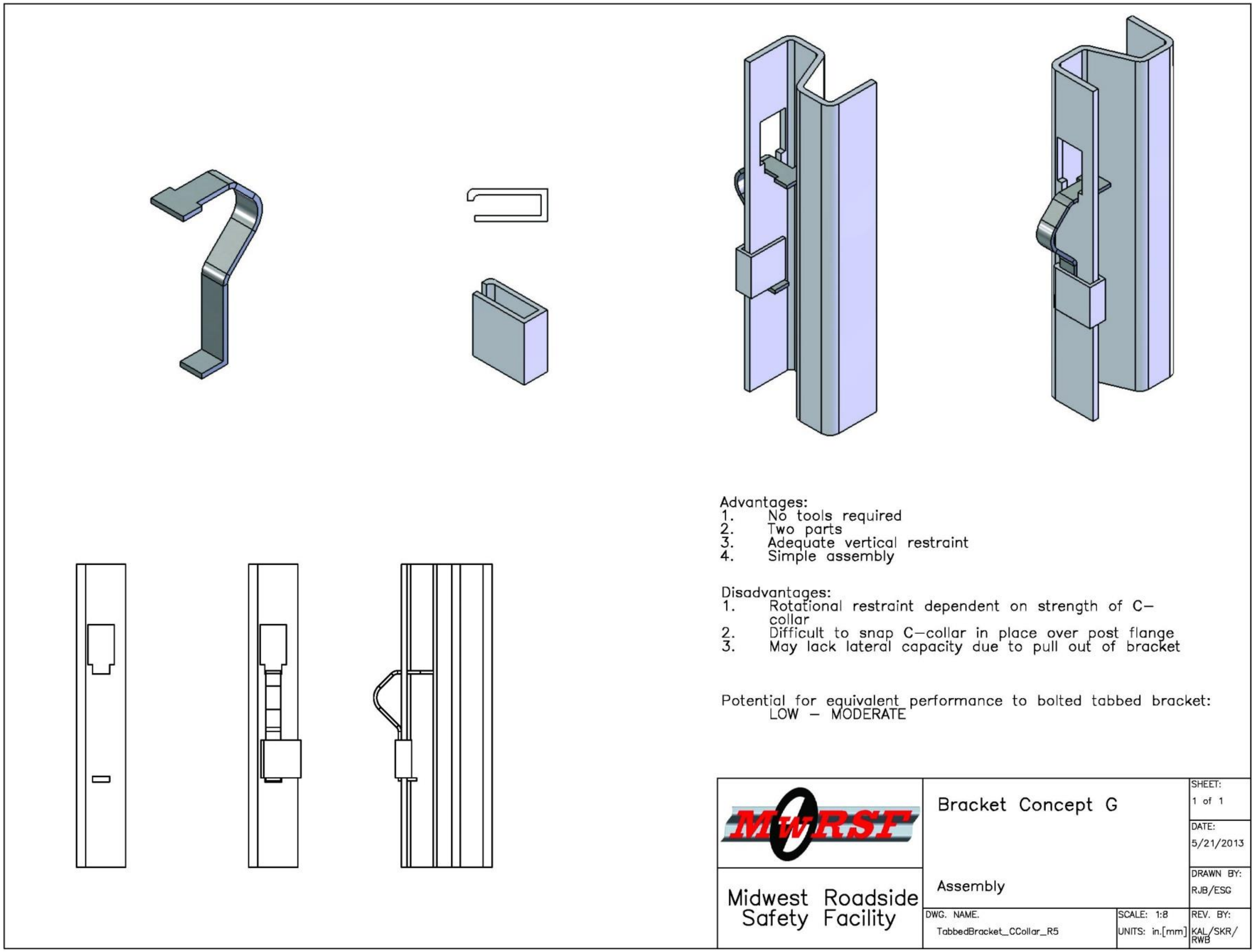


Figure 19. Concept F2



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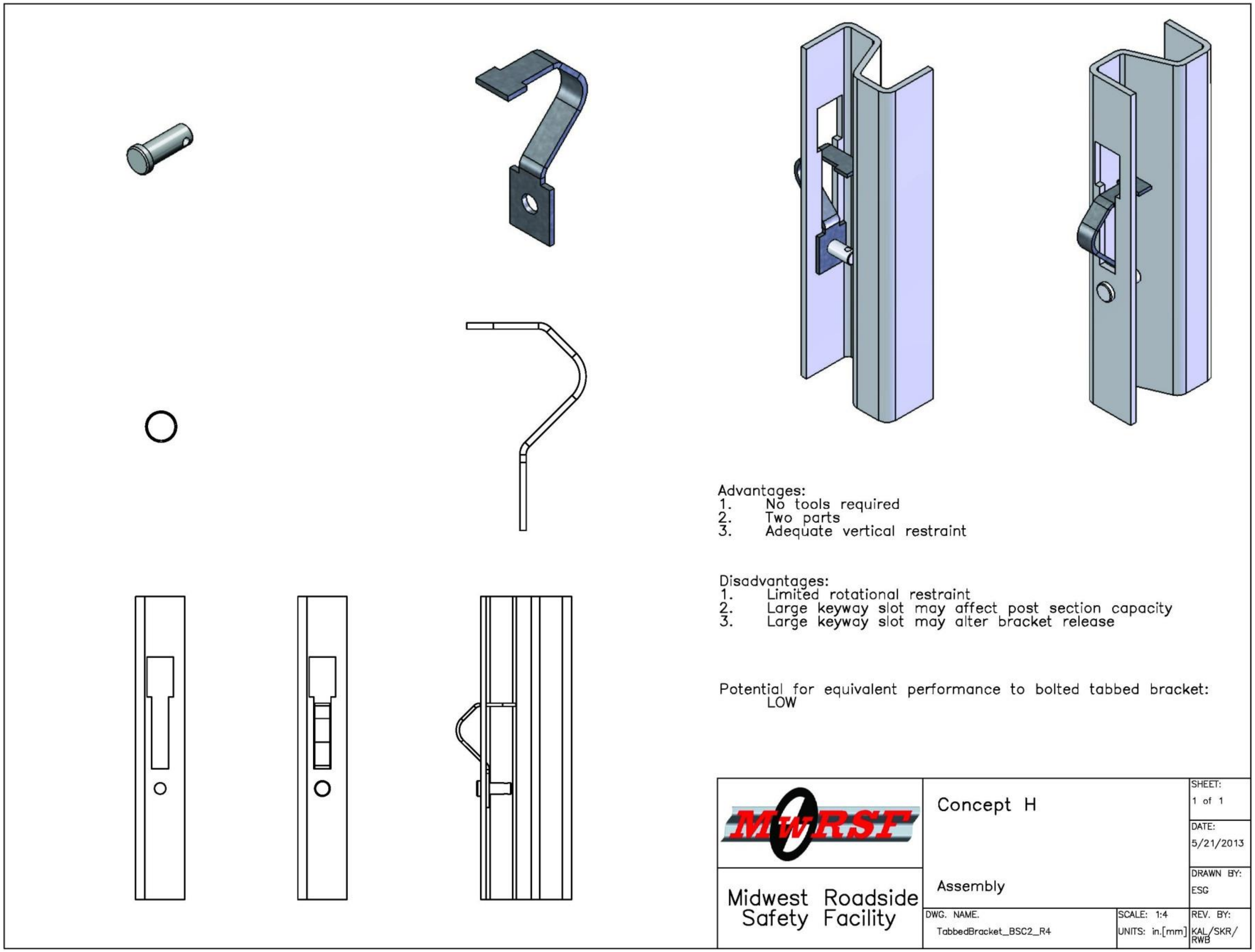

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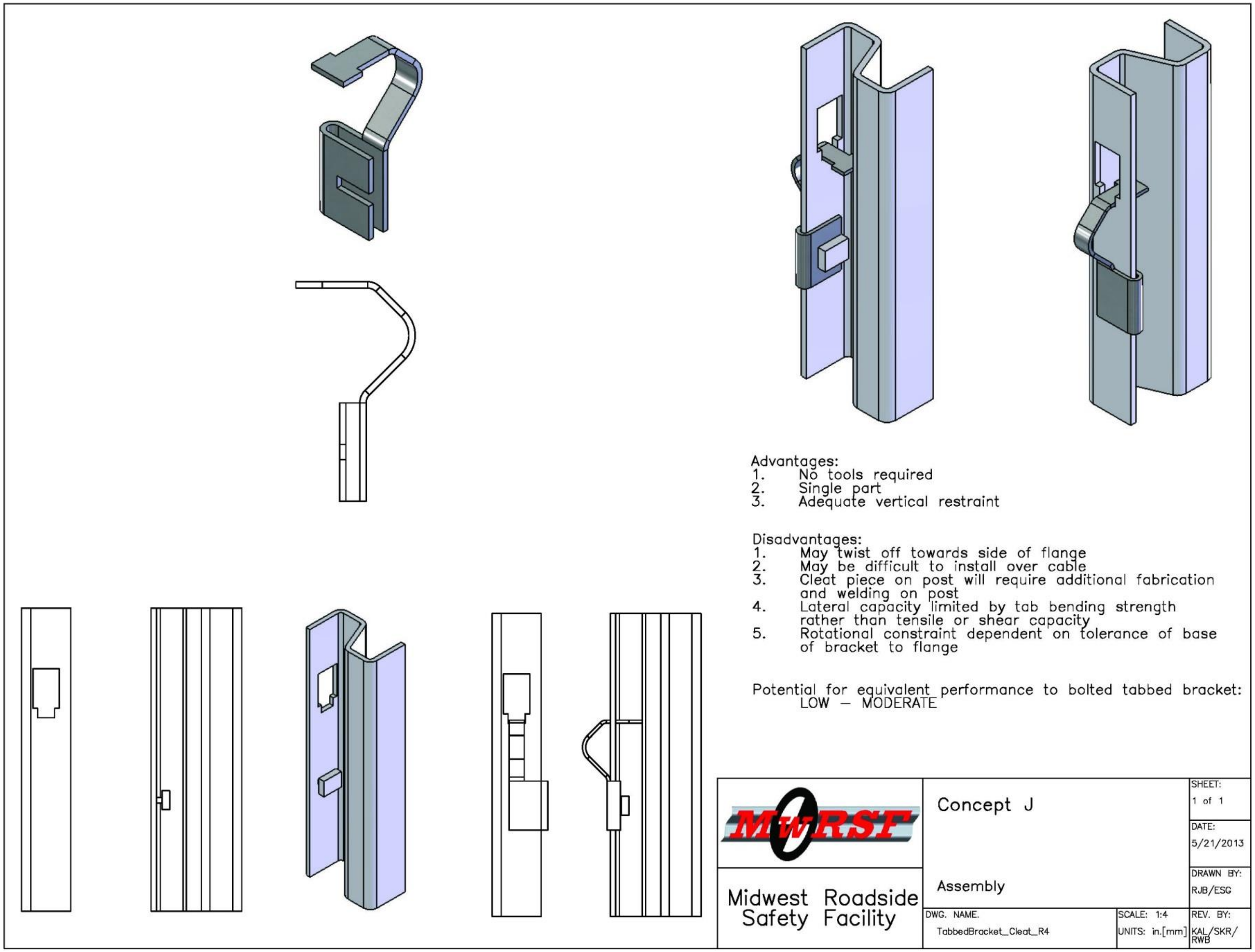

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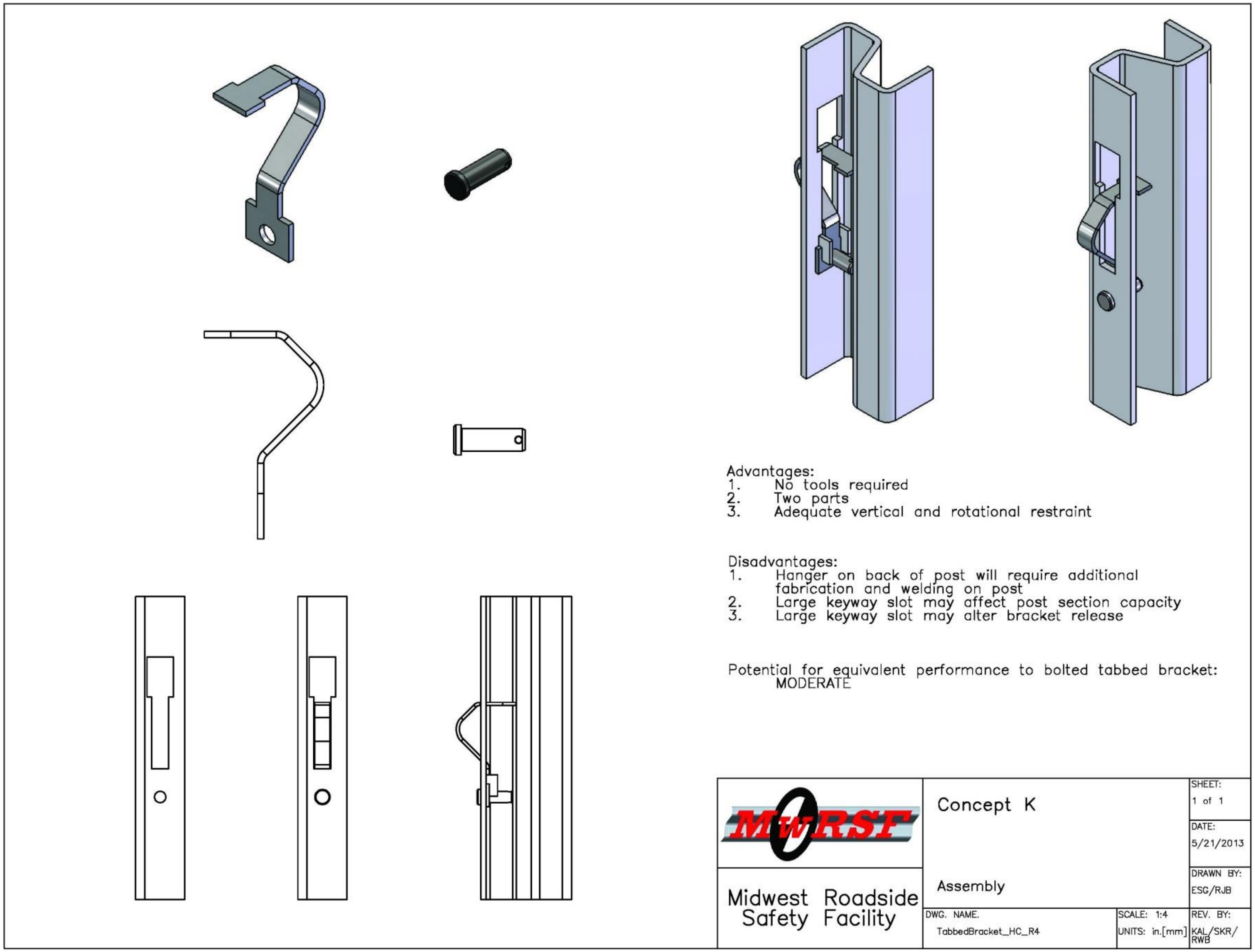


Figure 23. Concept K

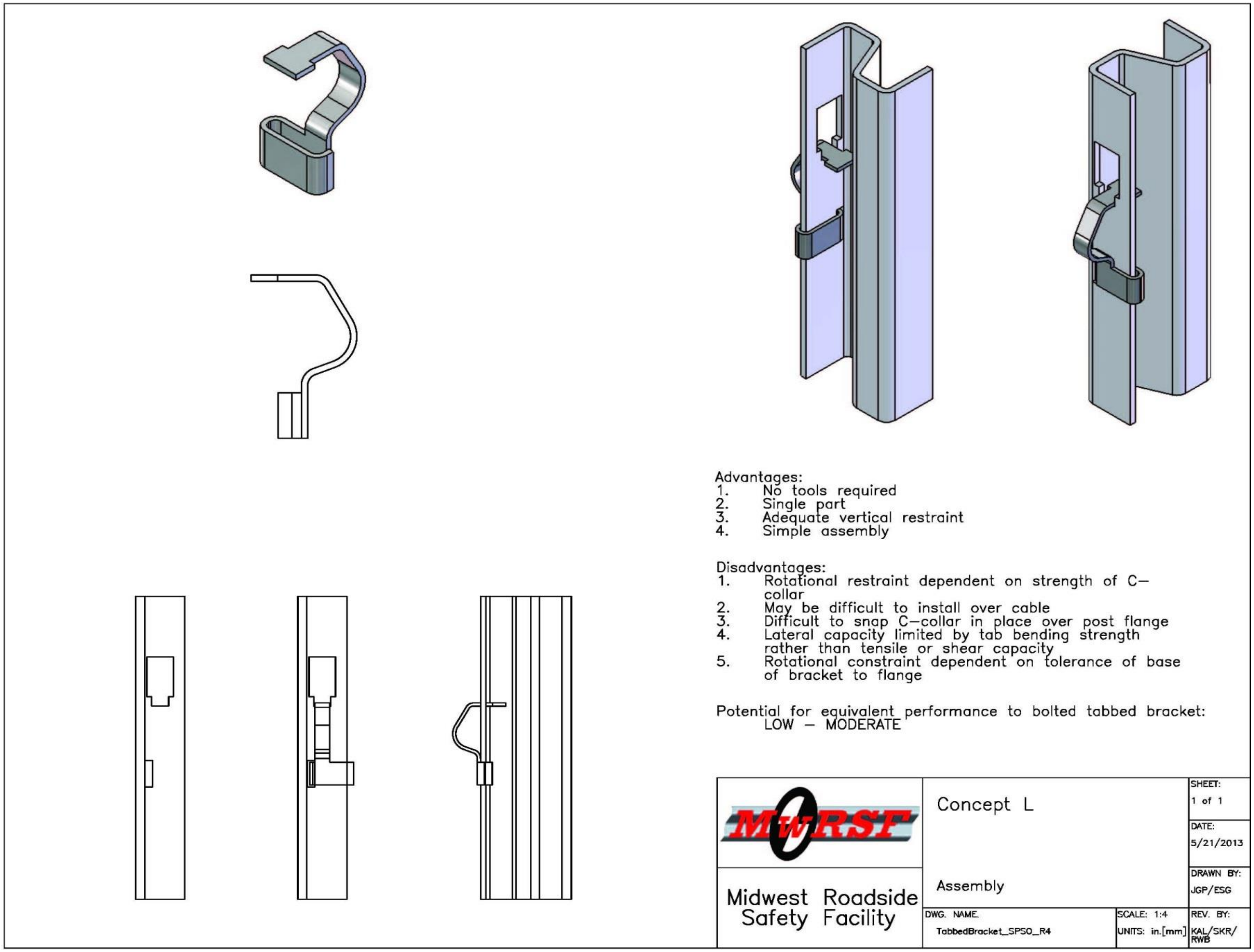


Figure 24. Concept L

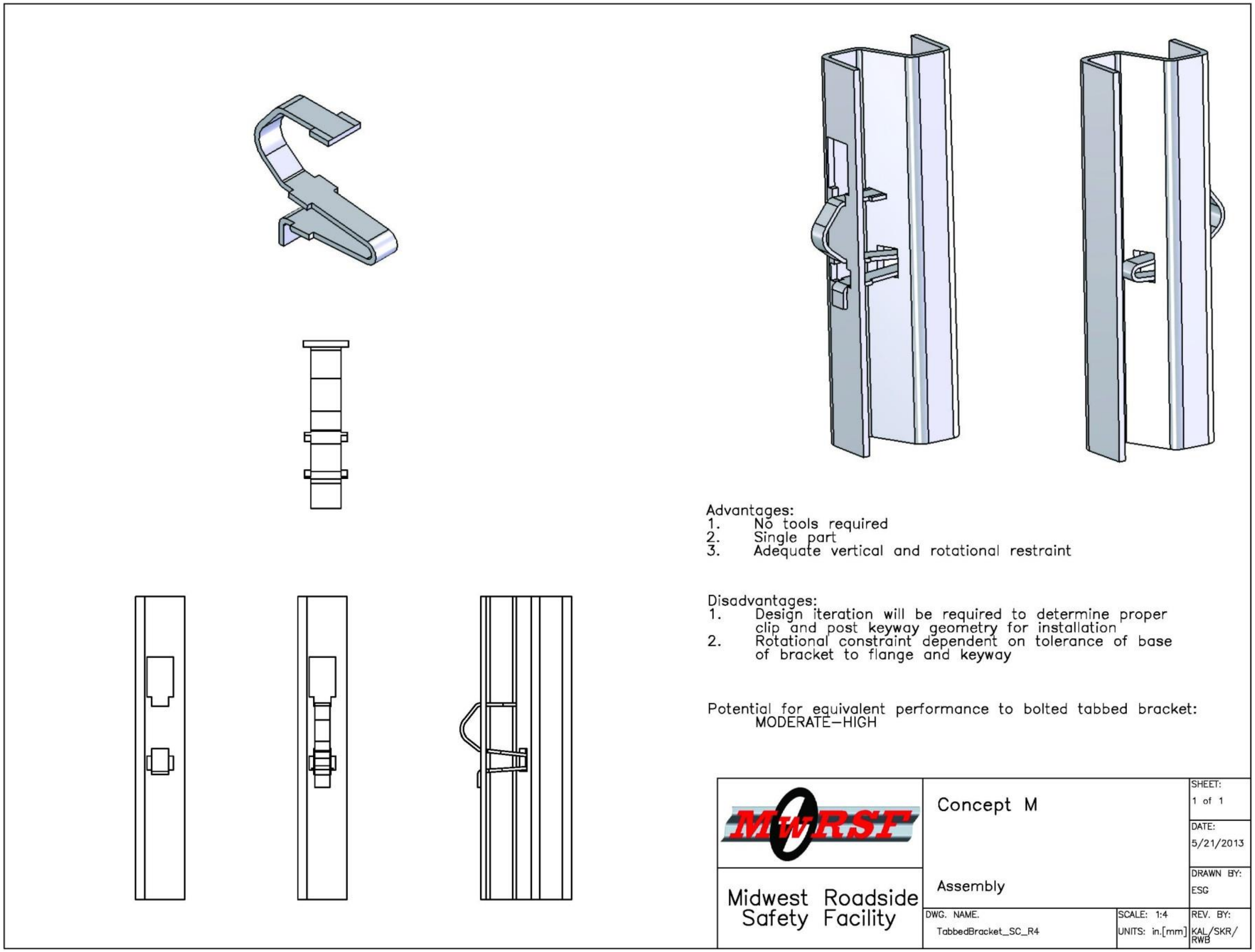


Figure 25. Concept M

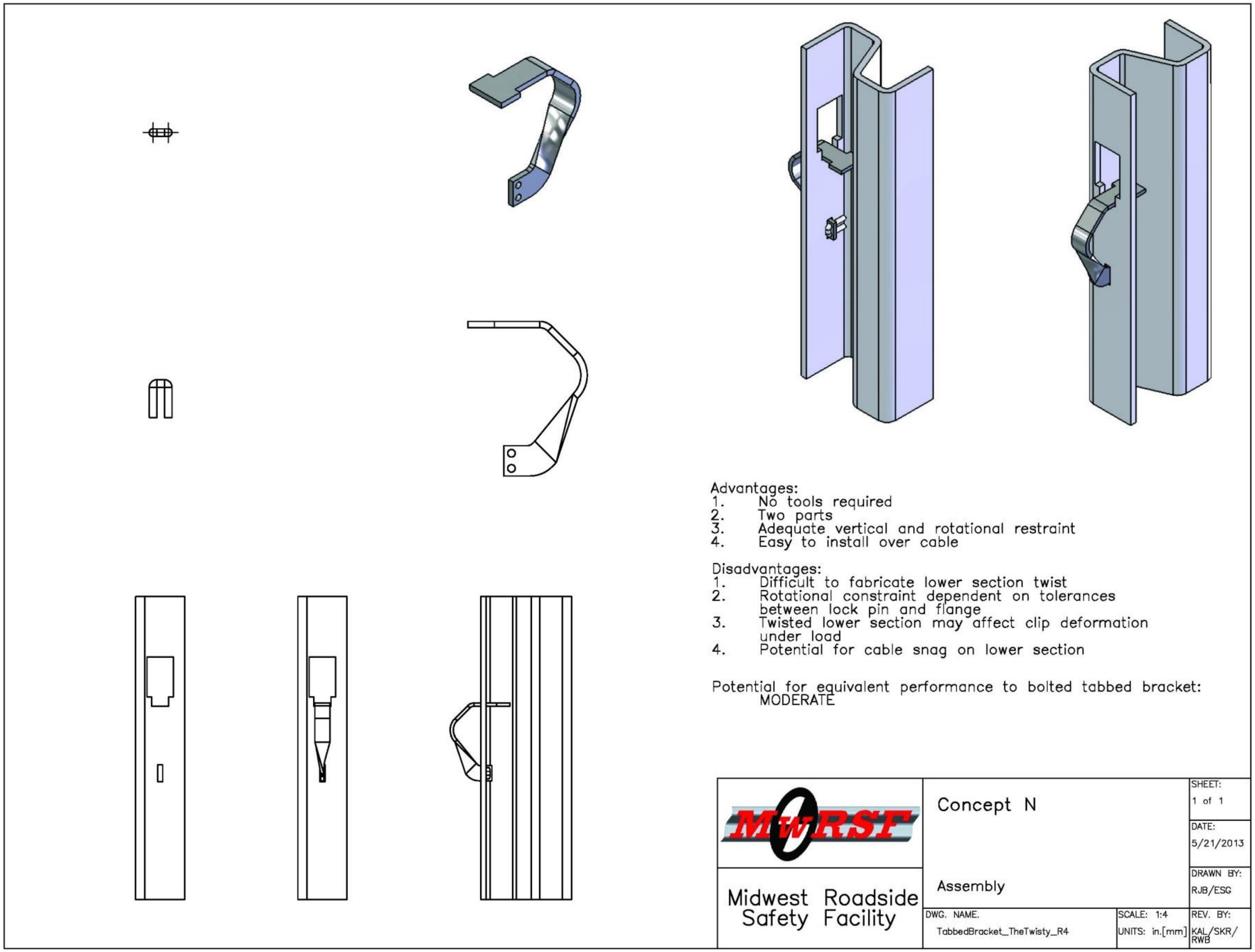


Figure 26. Concept N

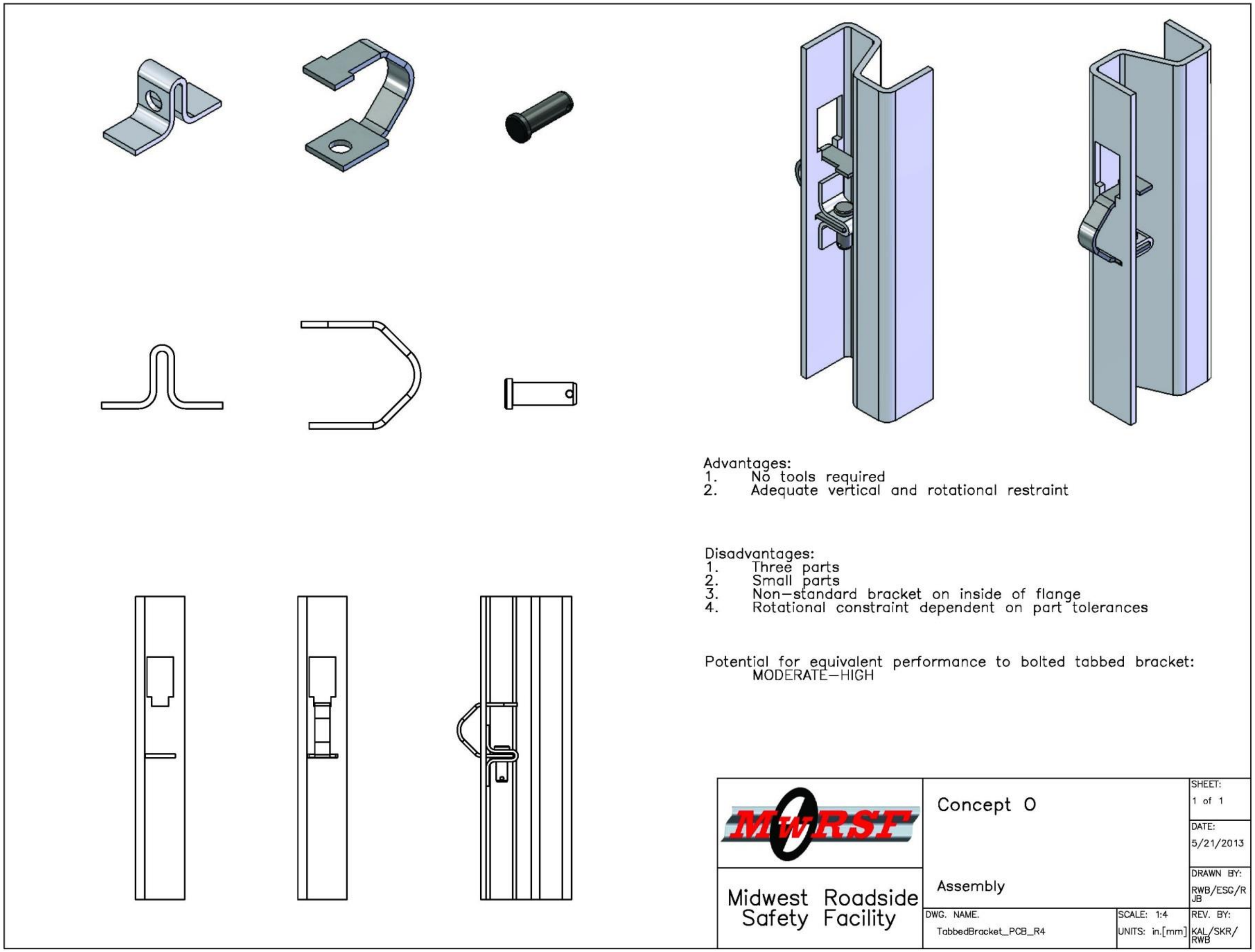


Figure 27. Concept O

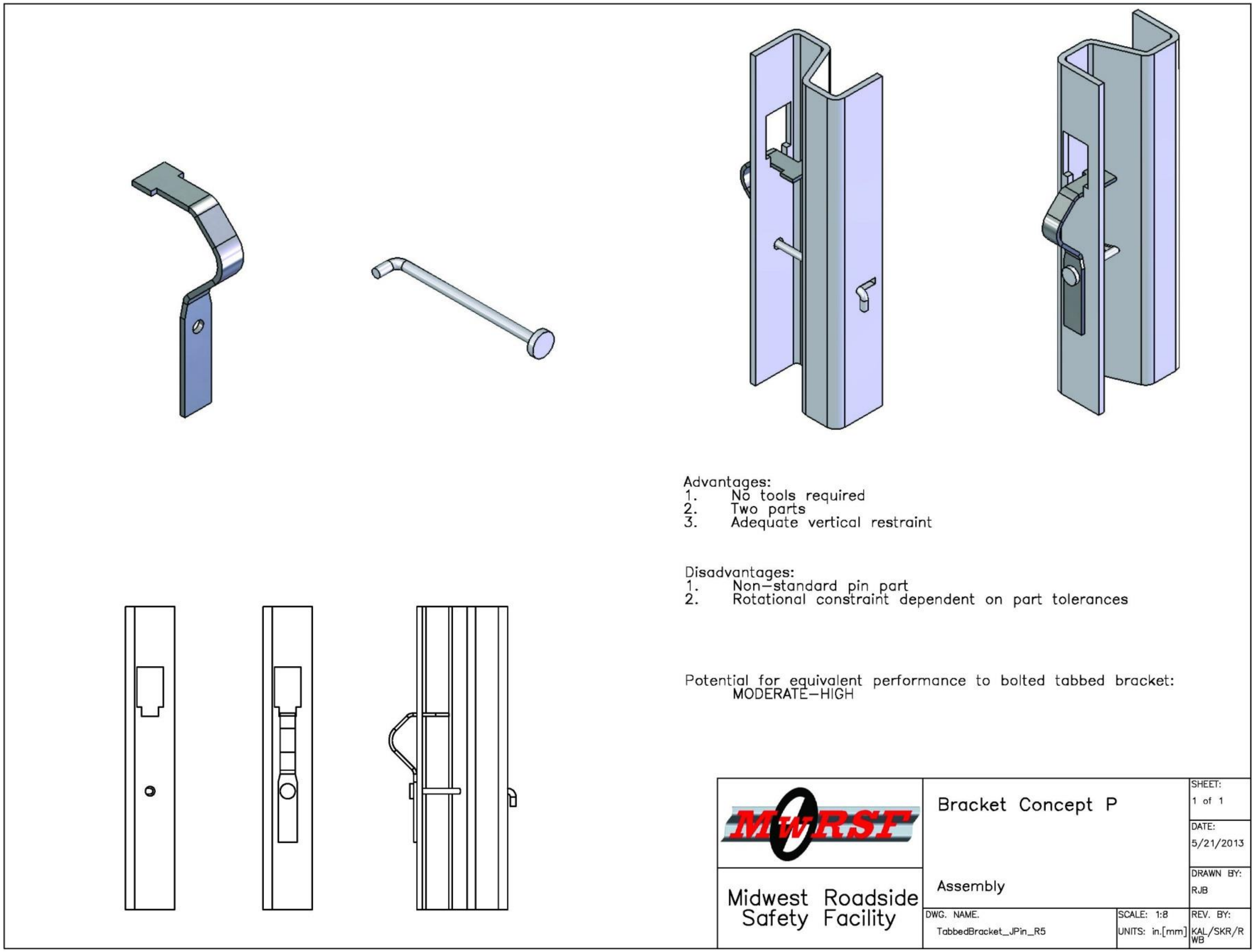


Figure 28. Concept P

2.3 Selection of Attachment Design Concepts

The twenty-five initial attachment concepts were submitted to the members of the Midwest States, Pooled Fund Program for review and comment. Following much discussion, three of these designs were selected for further development and analysis: Concept C1, Concept C2, and Concept E1. Additionally, a new snap-on concept, originally proposed by Missouri DOT, was fleshed out and analyzed. These four concepts were designed to satisfy both the loading and ease of assembly criteria.

Although Concept C1 was a favored design, the two lateral pins were small and added an extra component. Thus, a shear plate was designed to replace the pins, as shown in Figures 29 and 30. To install the shear plate, it would be inserted laterally through the legs of the bracket and bear against the inside face of the post flange. A small strip of steel from the center of the plate was bent out of plane to act as a buckle mechanism and snap/lock the shear plate into position.

Concept C2 also utilized a shear plate, as shown in Figures 31 and 32. However, this shear plate would be placed over the legs of the bracket and dropped into position. The shear plate was given an “I” shape so that minor vibrations would not cause the shear plate to wiggle out of position within the slots in the bracket legs. Additionally, the legs of the bracket were extended inward to prevent premature tearing of the bracket during loading.

For Concept E1, the pin was flipped around so that it would be installed through the web of the post, as shown in Figures 33 and 34. This change gave the pin head a surface (post web) to bear against during installation, while the end of the pin now had more surface (post flange) to bear against when loaded. The bottom of the bracket, which rests against the outside face of the post, was made wider than the keyway to prevent it from being pulled through the keyway and around the pin like a ribbon during loading.

The Missouri Snap-On Concept was an attempt to develop a bracket that would attach to the post without the use of additional hardware, as shown in Figures 35 and 36. To install the bracket, the legs of the bracket would extend through slots in the post flange and web. The bracket would then be pushed downward and the legs would snap outward, locking the bracket in place. The legs were extended through the web of the post in order to provide enough length to the legs to allow them to elastically spring back (or snap into position) after being squeezed together. The material strength and thickness of the bracket made this elastic spring-back impossible for shorter legs that would only interact with the flange of the post.

These four design concepts were submitted to the members of the Midwest States, Pooled Fund Program along with performance predictions and development time estimates, as shown in Figures 29 through 36. After further discussions and member voting, two designs were selected for component testing evaluations: Concept C1, referred to as the tabbed bracket with lateral shear plate, and Concept C2, referred to as the tabbed bracket with drop-in shear plate. Details on the subsequent component tests are found in the following chapters.

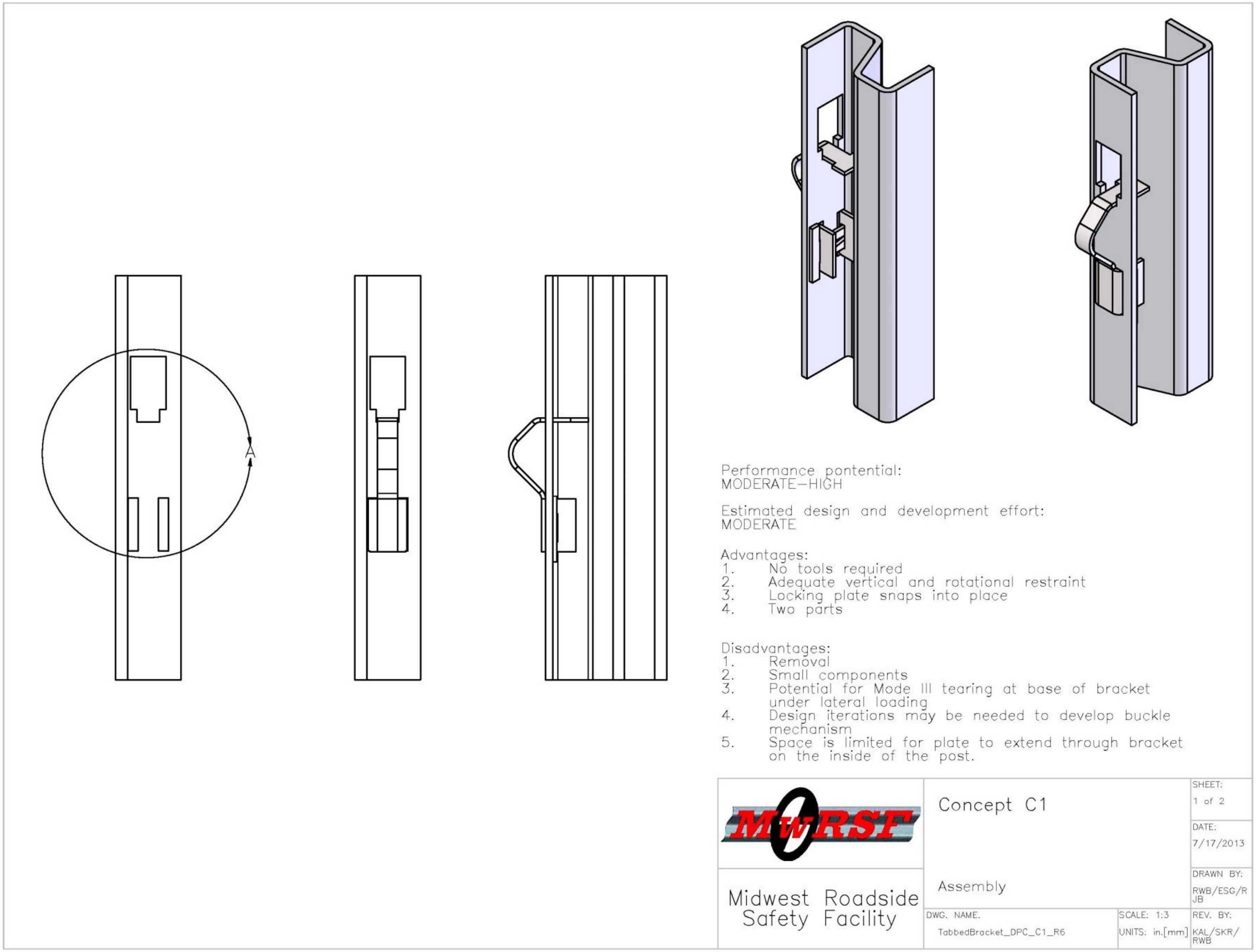


Figure 29. Concept C1, Lateral Shear Plate

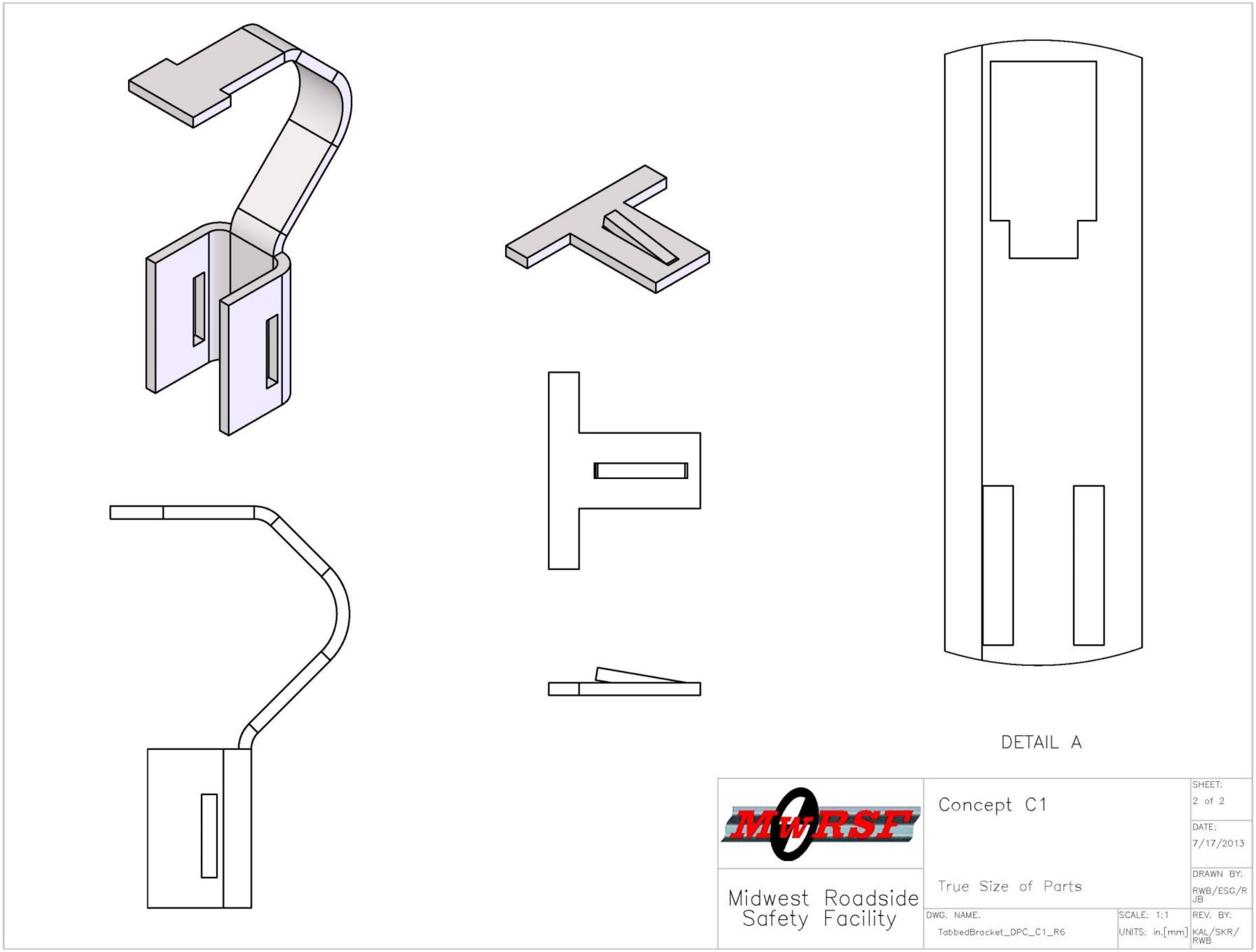


Figure 30. Concept C1, Lateral Shear Plate, Continued

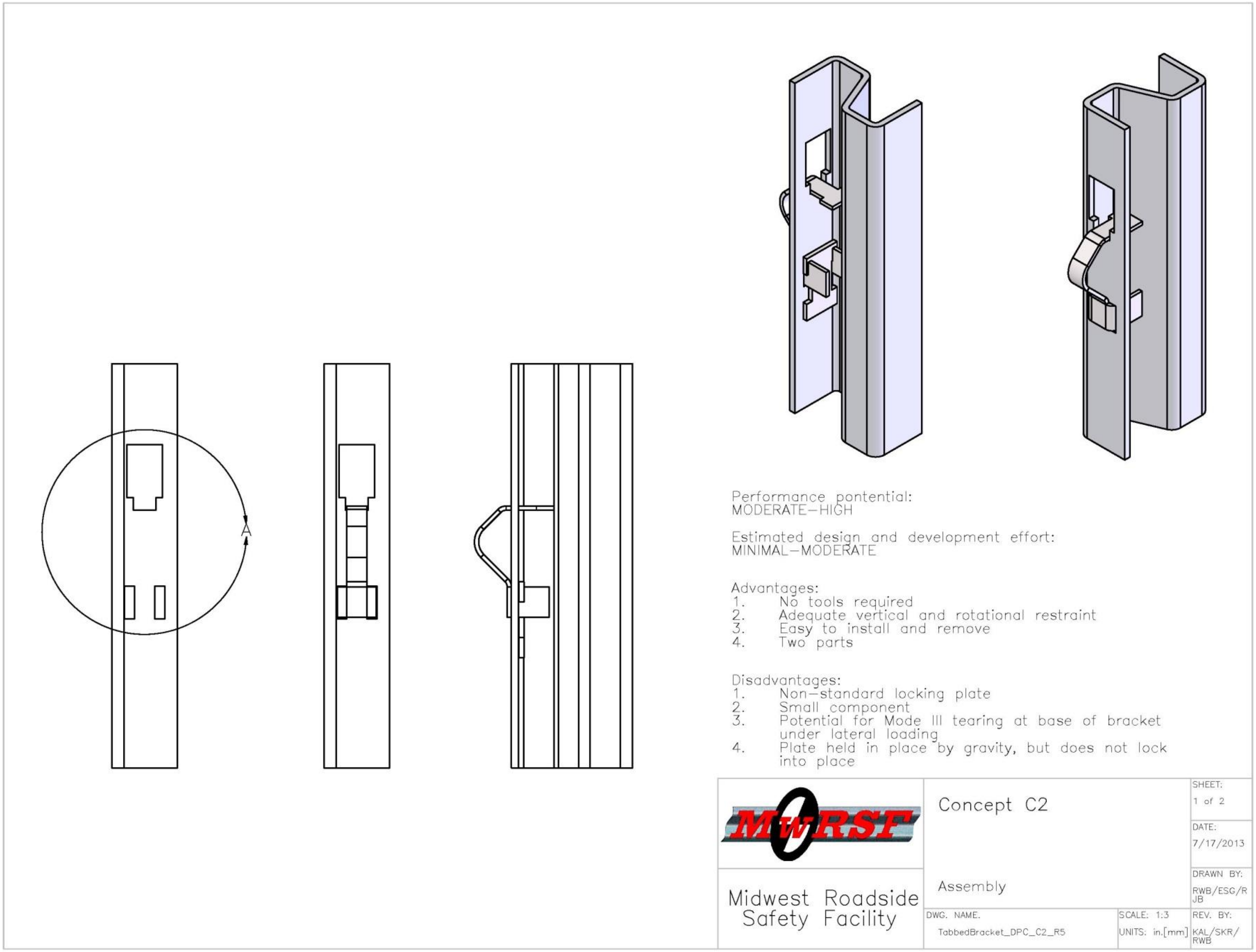


Figure 31. Concept C2, Drop-In Shear Plate

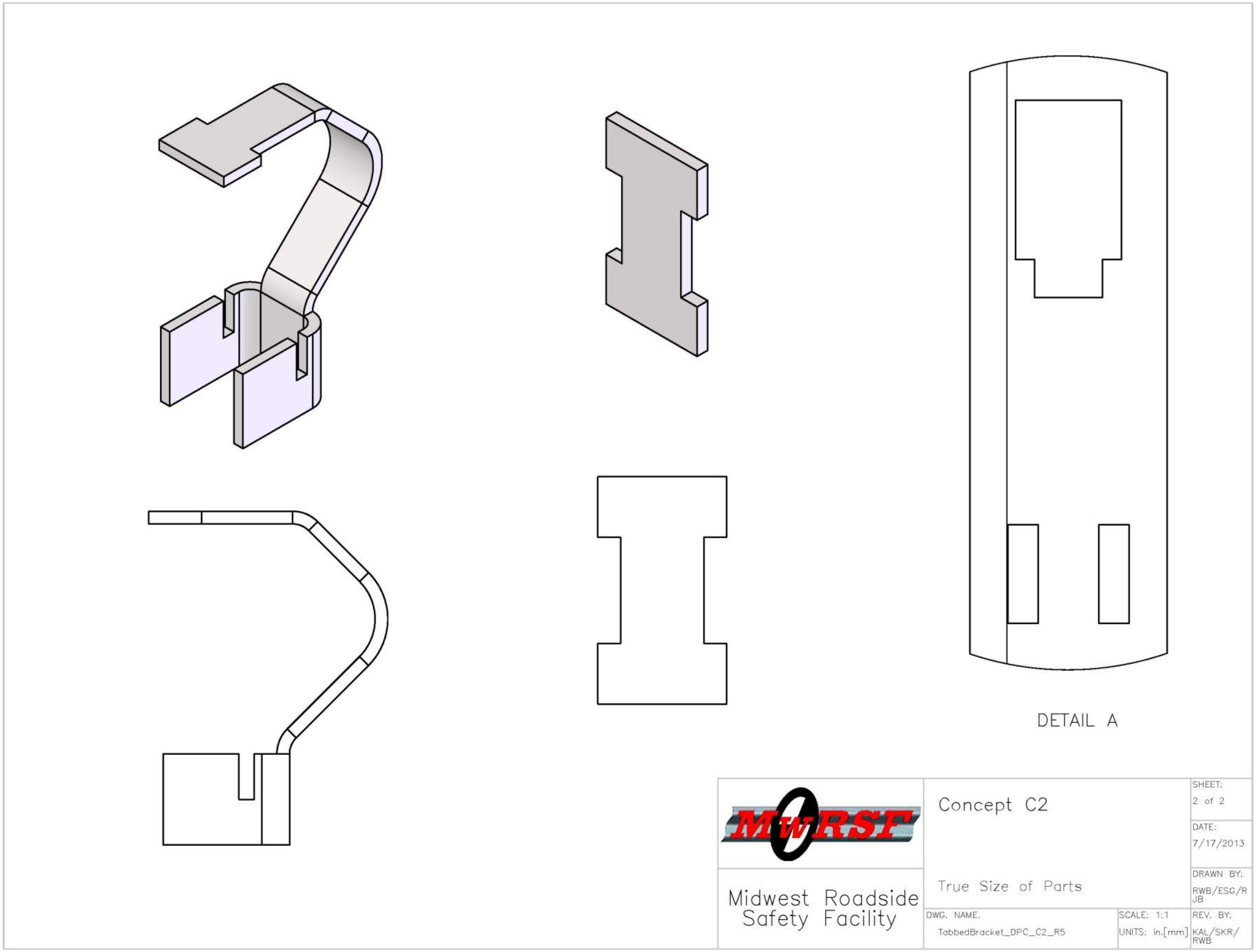


Figure 32. Concept C2, Drop-In Shear Plate, Continued

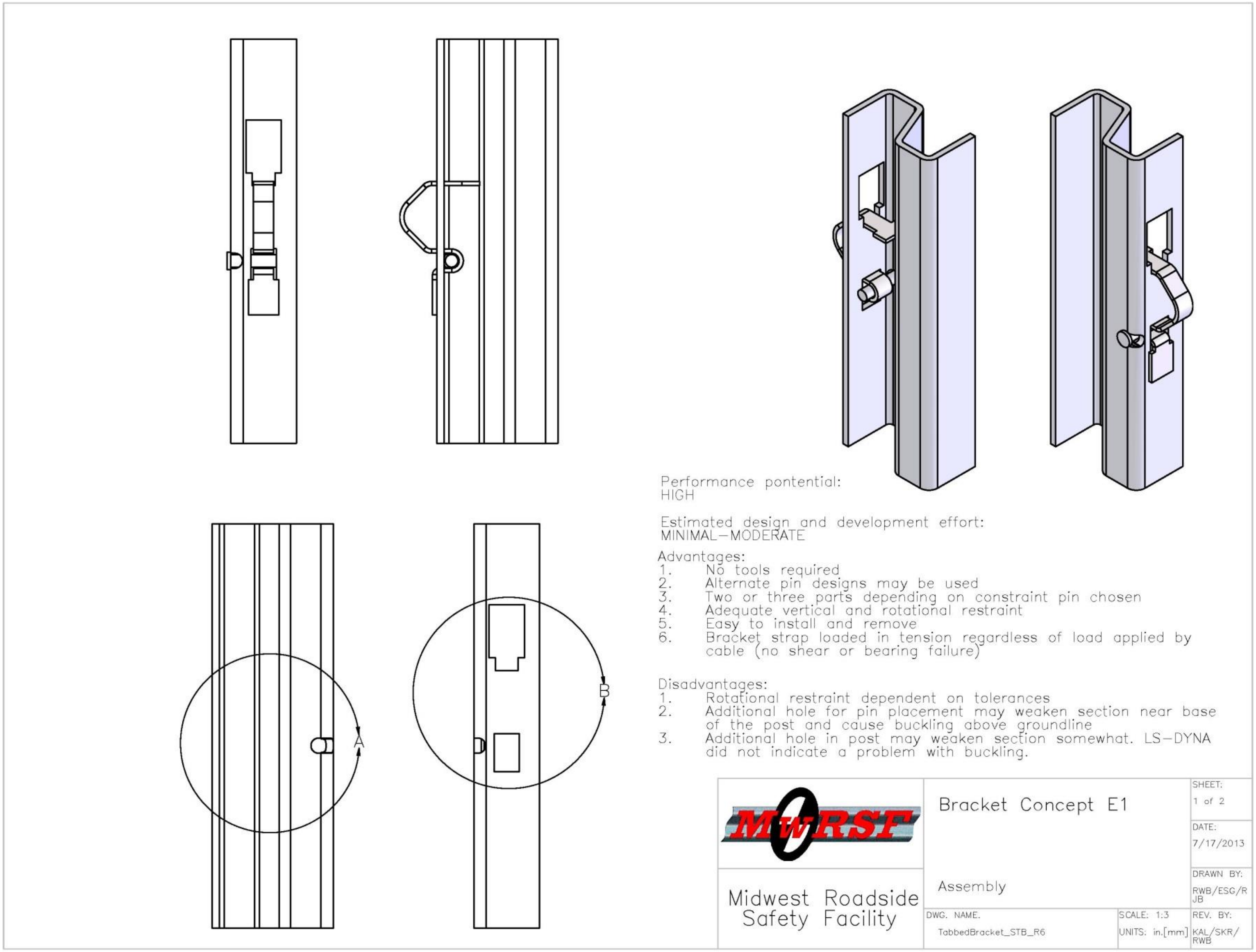


Figure 33. Concept E1, Lateral Pin

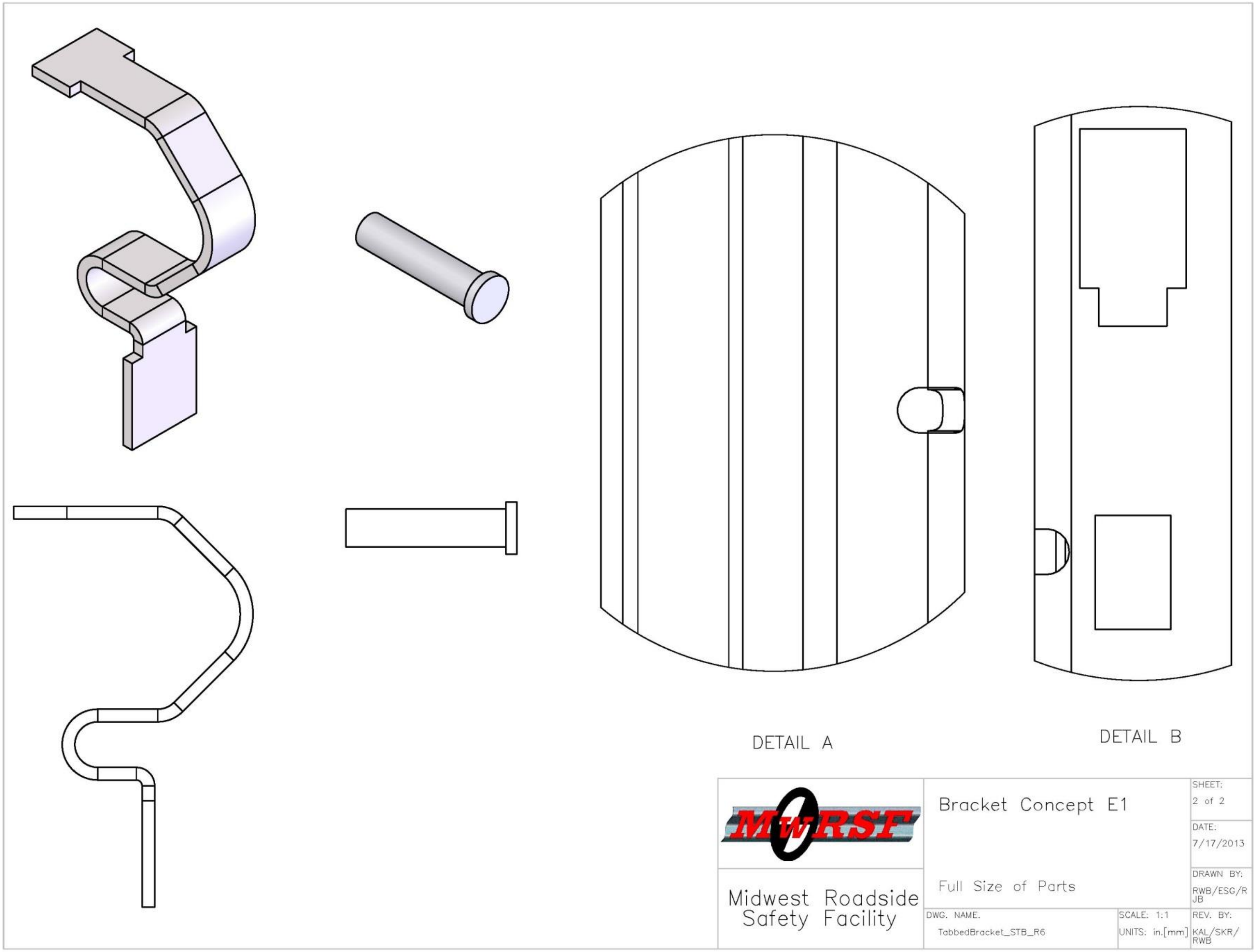


Figure 34. Concept E1, Lateral Pin, Continued

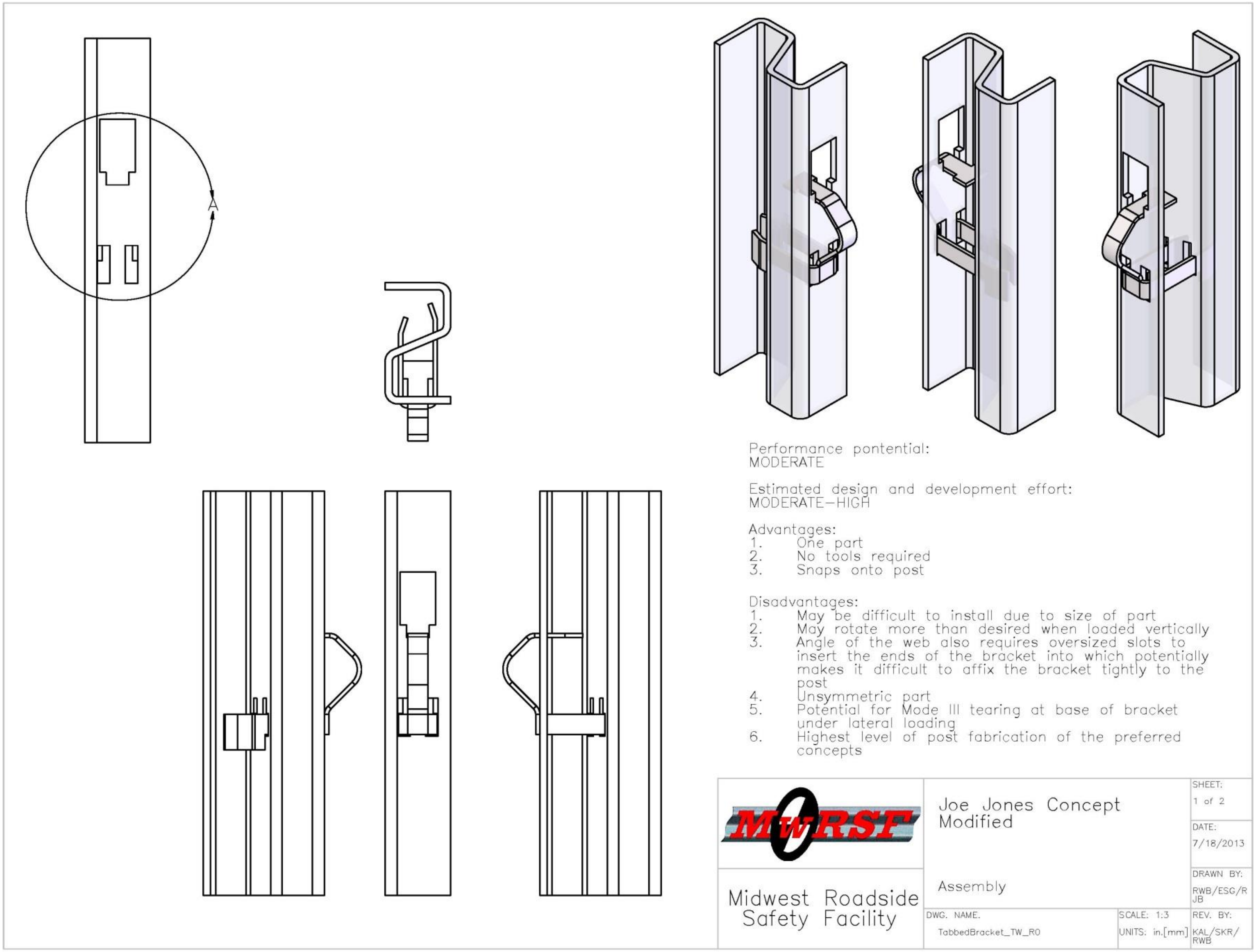


Figure 35. Missouri Snap-On Concept

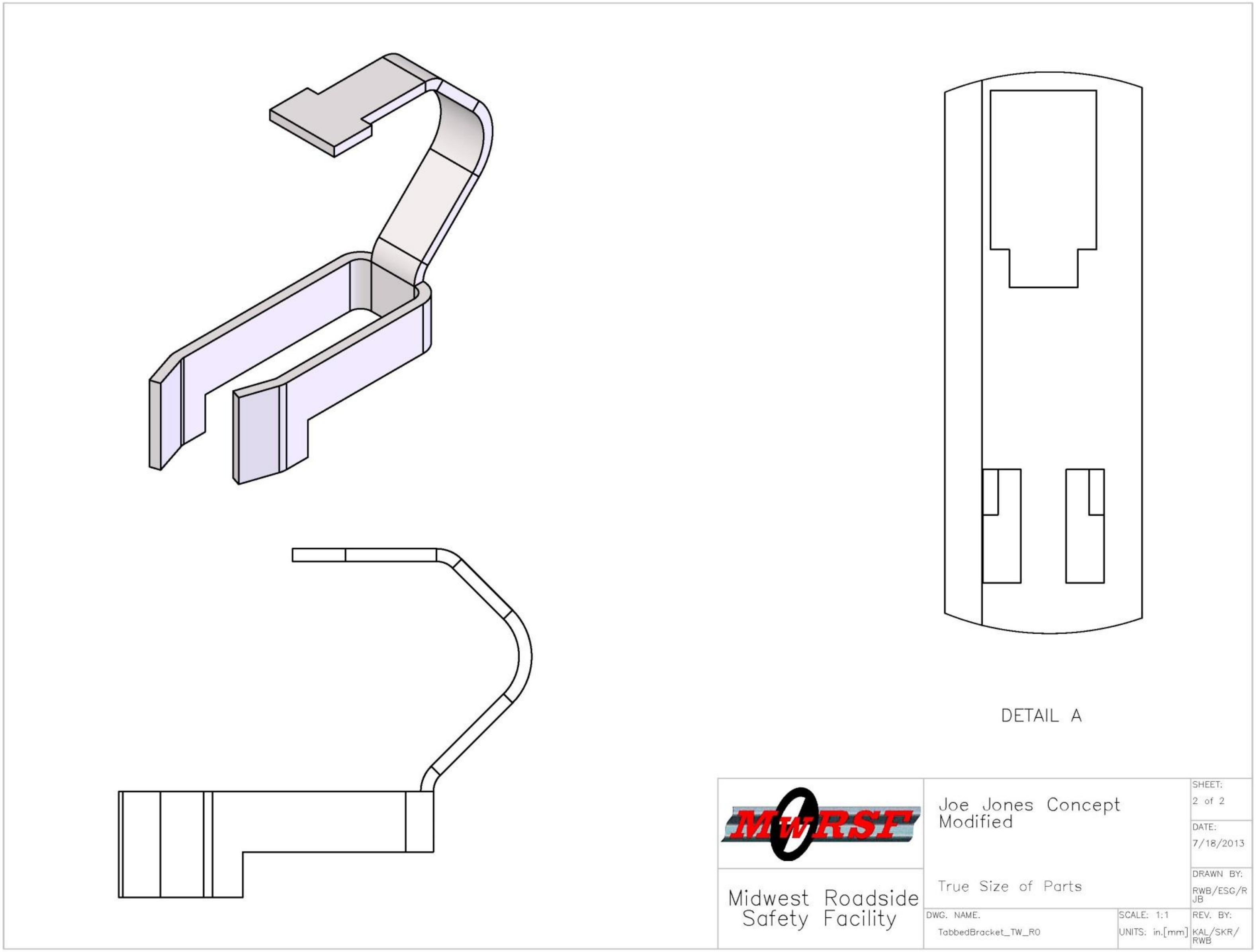


Figure 36. Missouri Snap-On Concept, Continued

3 TABBED BRACKET ATTACHMENT DESIGN DETAILS

Two alternative attachment designs for the cable-to-post tabbed brackets were selected for evaluation through dynamic component testing: Concept C1, the lateral shear plate design and Concept C2, the drop-in shear plate design. Design details for bracket designs, their respective attachment plates, and the test jig utilized to evaluate the new brackets are shown in Figures 37 through 52. Material specifications, mill certifications, and certificates of conformity for the tabbed brackets and associated components are shown in Appendix A.

Both designs were very similar to the original bolted tabbed bracket (Version 10). In fact, the top part of each bracket design (from the top tab to the base of the bracket spine) was identical. Only the bottom portion of the brackets and the attachment hardware differed between designs. The bottom of the bolted tabbed bracket rested flat against the post flange and had a hole in its middle for the attachment bolt. However, the bottom of both of the new bracket designs was widened and bent inward at 90 degrees on both sides of the bracket spine. These bends created two vertical "legs" that would extend through vertical slots in the post flange, while the flat portion of the bracket would rest flush against the outside of the flange. Shear plates would then be used to lock the legs into position against the inside face of the post flange.

For the lateral shear plate design, a ⅛-in. (3.2-mm) thick strip of steel was cut from the center of the plate and bent out of plane to act as a buckling mechanism, as shown in Figure 49. The strip was bent flat as the lateral shear plate was inserted through the slots in the bracket legs, but it sprung out once it passed through the slot. Thus, the lateral shear plate snapped/buckled into position and prevented the bracket from detaching from the post.

The drop-in shear plate was given an "I" shape to prevent the bracket from detaching, as shown in Figure 50. The height and width of the narrow middle portion of the drop-in shear plate matched the height of the bracket legs and the distance between them, respectively. During installation, the shear plate slid laterally over the legs and then dropped into place with the wider top of the shear plate fitting into the slots cut into the bracket legs. The wide bottom of the shear plate would prevent the drop-in shear plate from sliding out vertically.

Similar to the original bolted tabbed bracket V10, both of the new tabbed bracket designs were fabricated from 12-gauge (2.66-mm thick) ASTM A1011 HSLA grade 50 steel. Conveniently, both of the shear plate designs were also fabricated from the same 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.

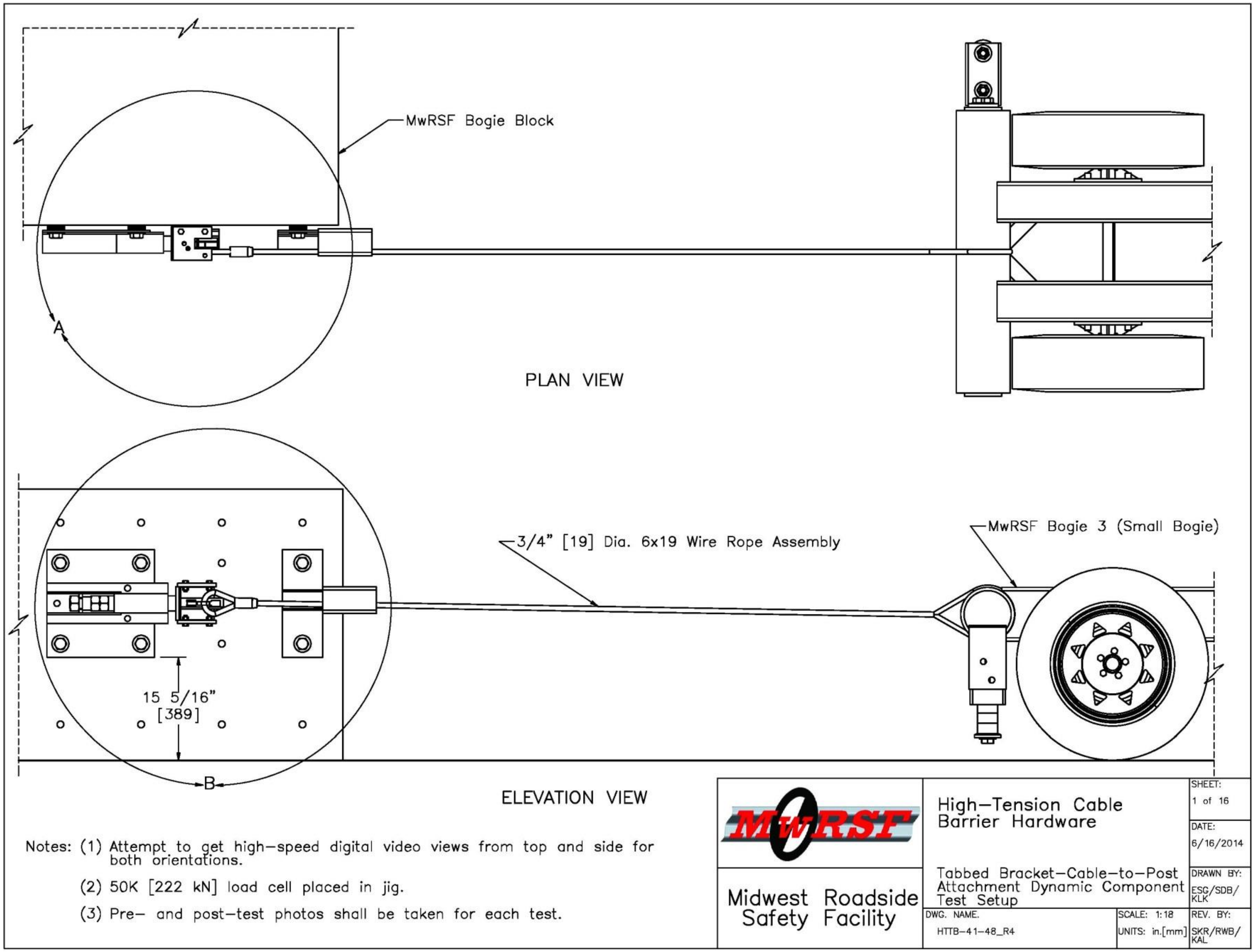


Figure 37. Cable-to-Post Attachment Dynamic Component Test Setup, Test Nos. HTTB-41 through HTTB-48

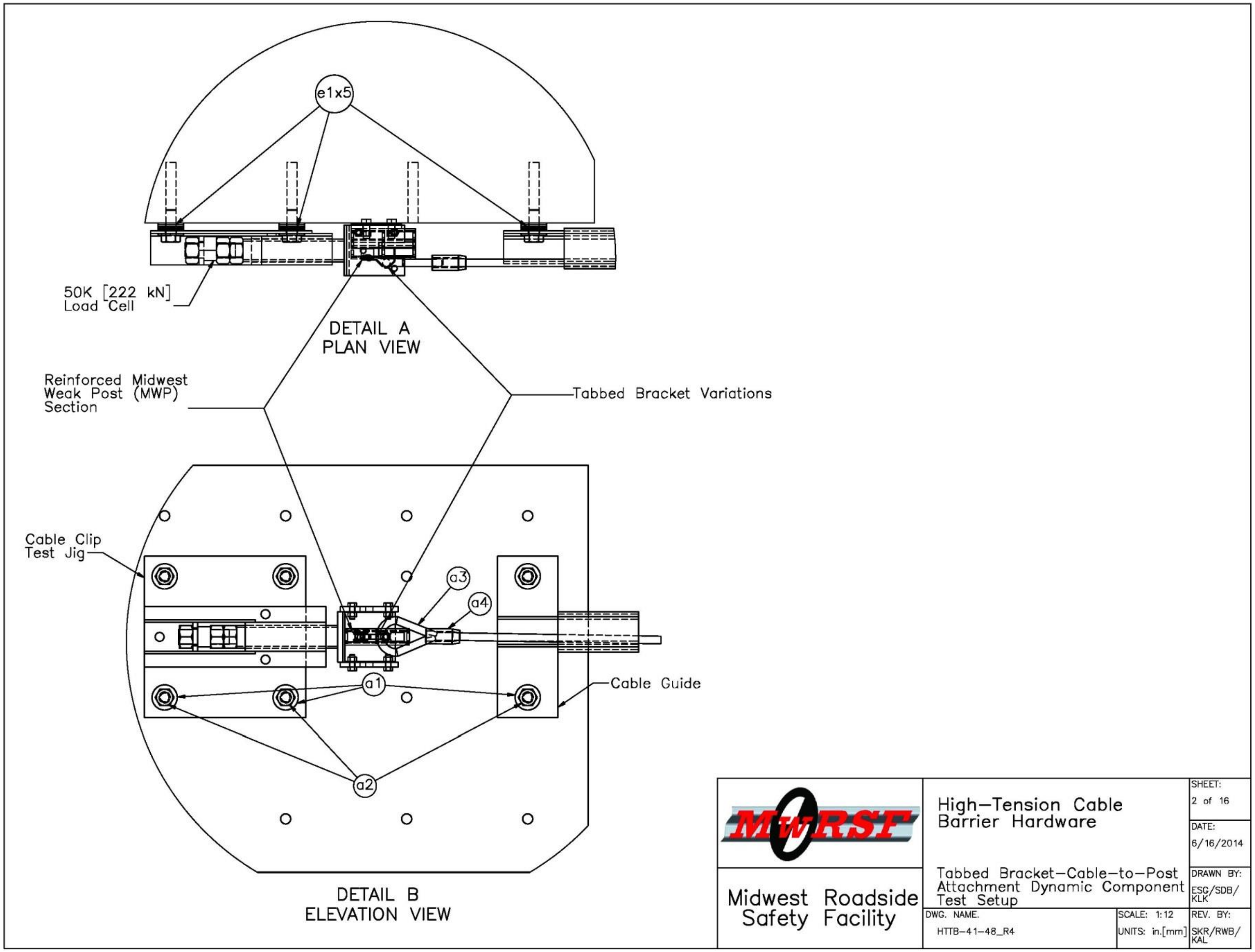


Figure 38. Cable-to-Post Attachment Dynamic Component Test Details, Test Nos. HTTB-41 through HTTB-48

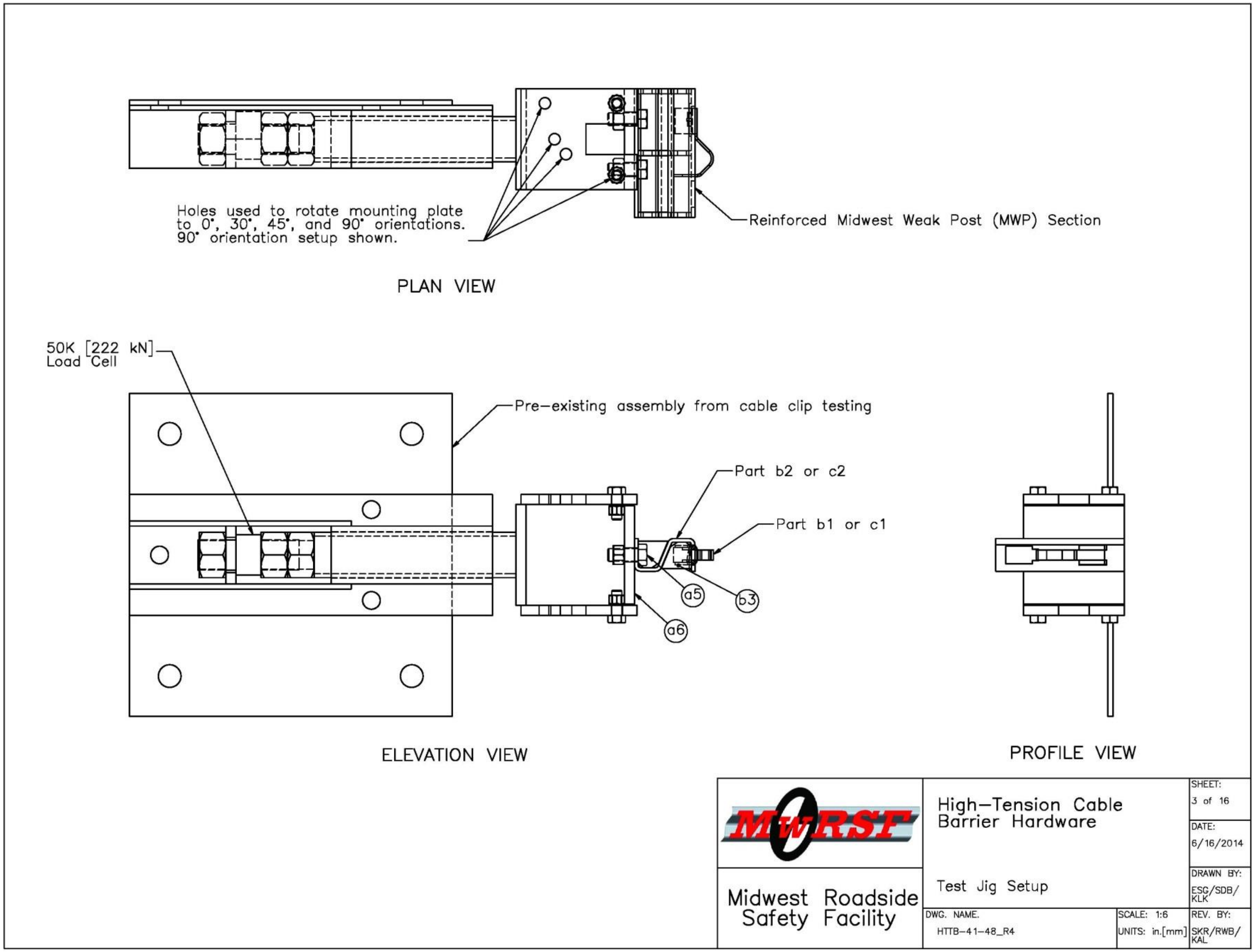


Figure 39. Test Jig Setup, Test Nos. HTTB-41 through HTTB-48

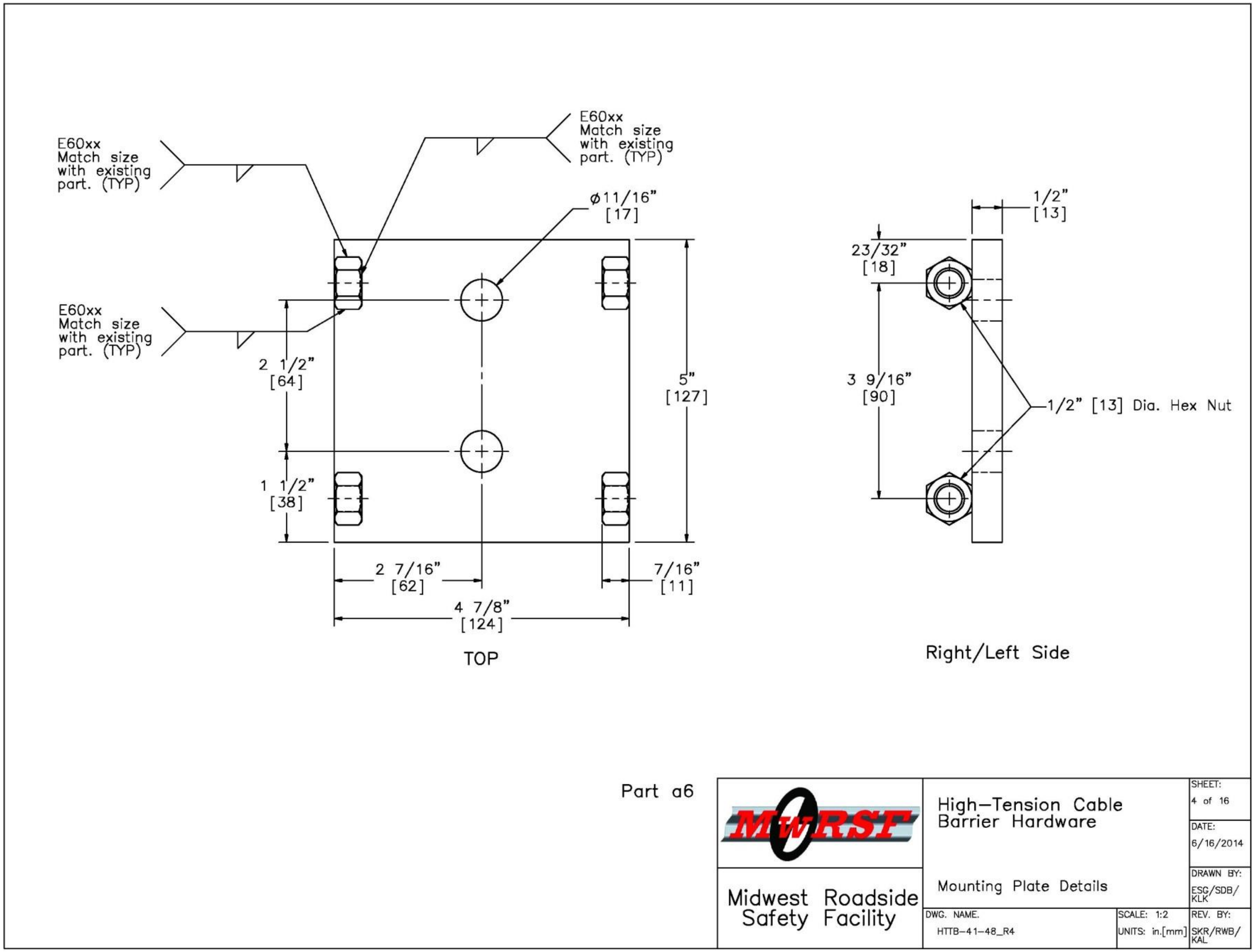


Figure 40. Mounting Plate Details, Test Nos. HTTB-41 through HTTB-48

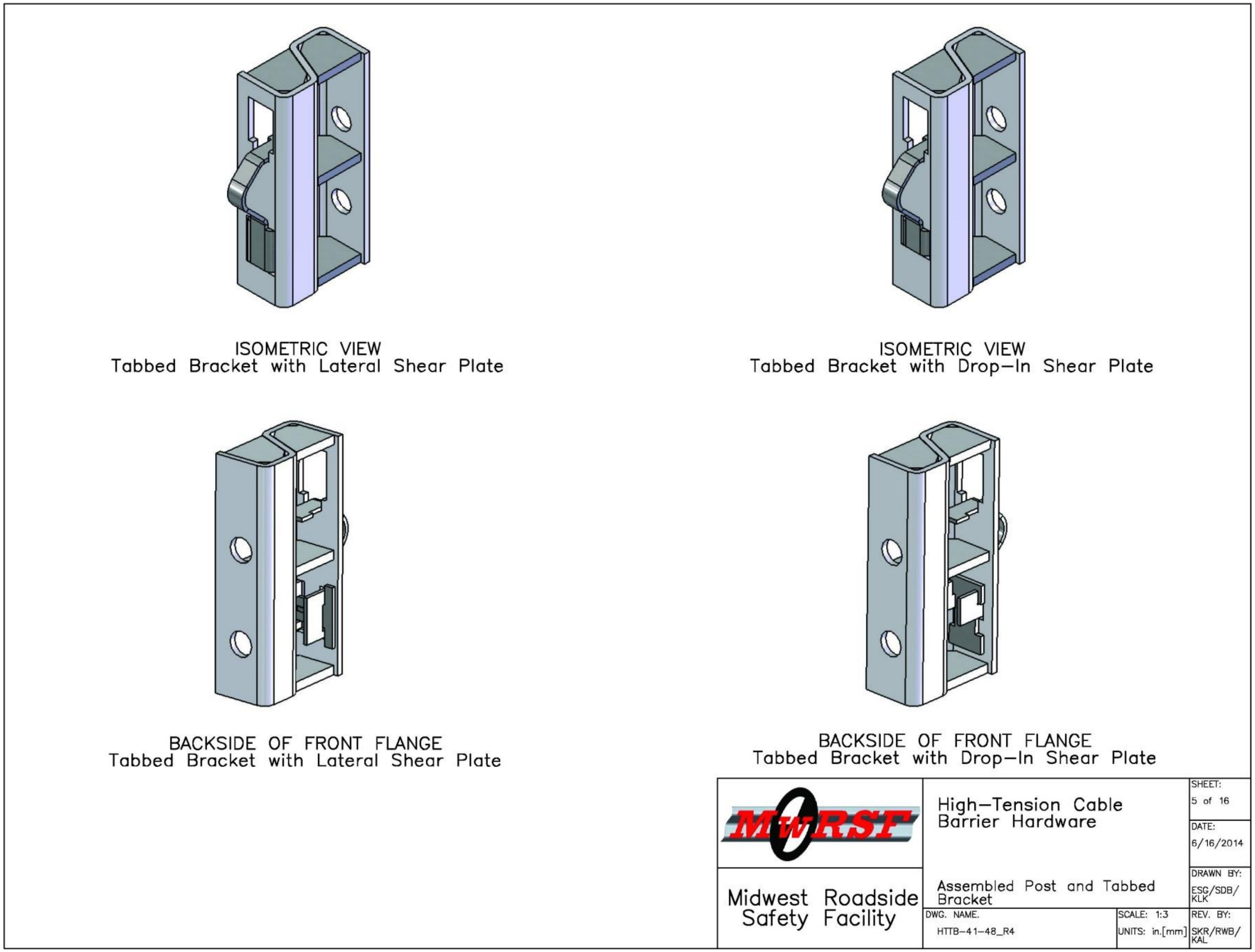


Figure 41. Assembled Post and Tabbed Bracket, Test Nos. HTTB-41 through HTTB-48

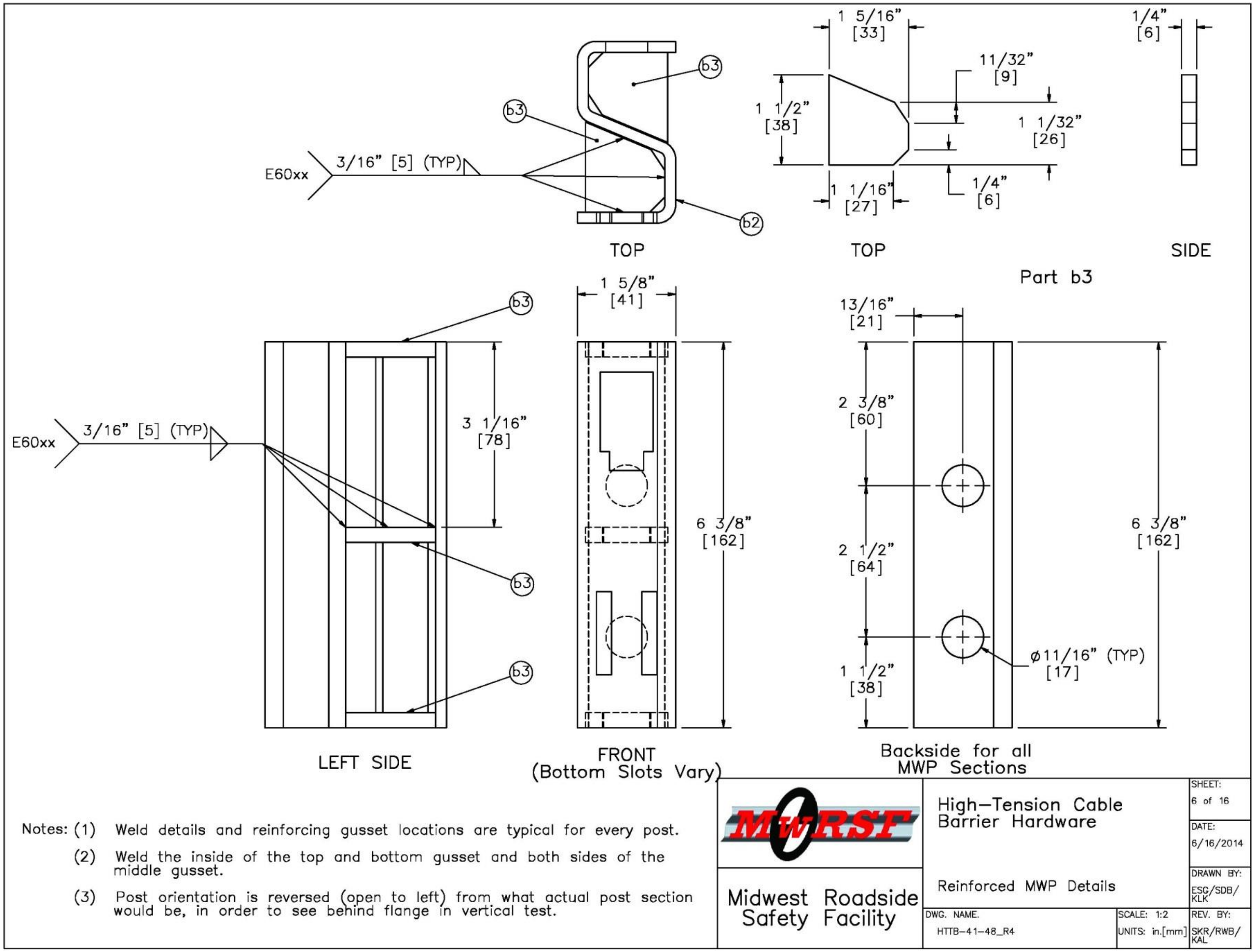


Figure 42. Reinforced MWP Details, Test Nos. HTTB-41 through HTTB-48

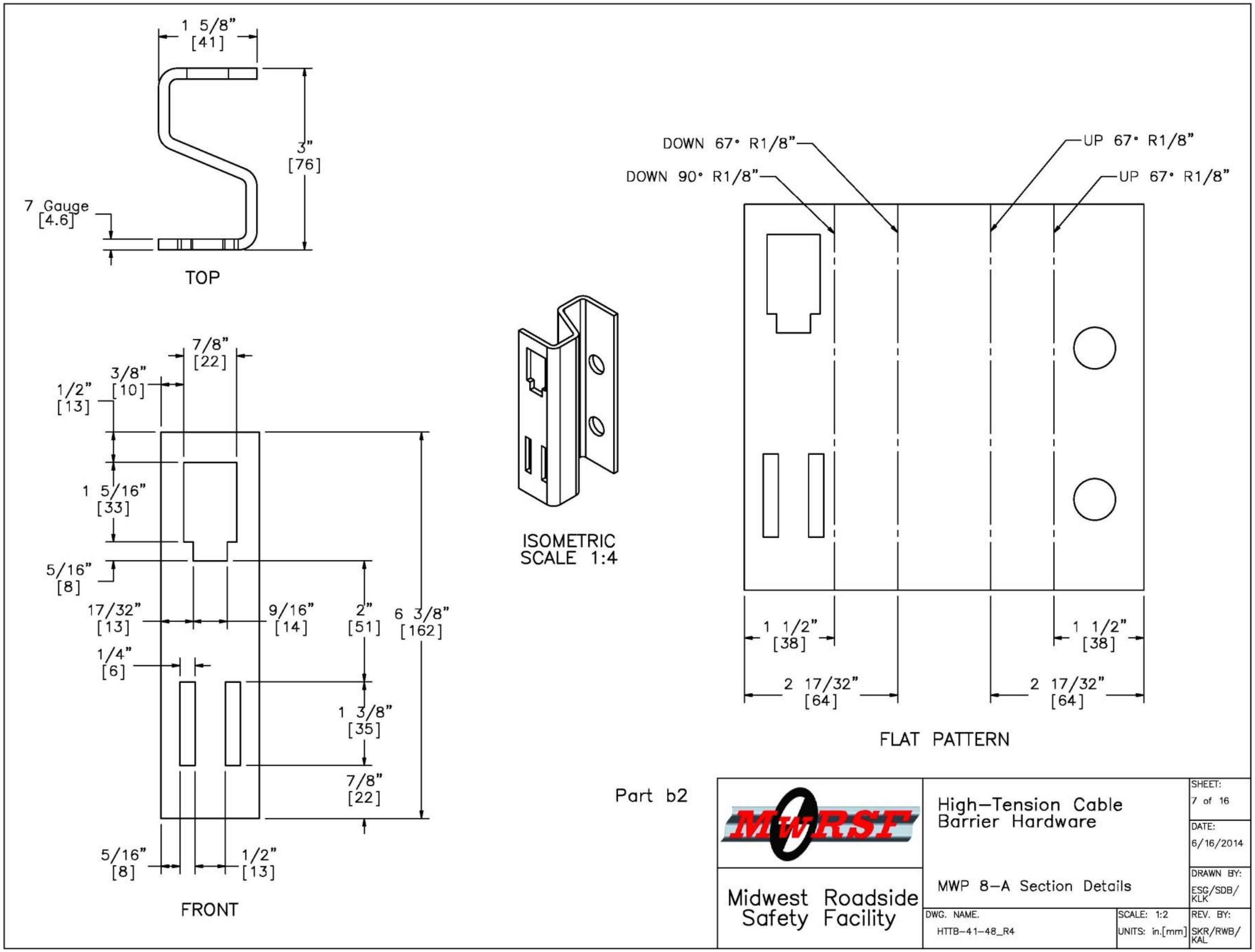


Figure 43. MWP 8-A Section, Test Nos. HTTB-41, HTTB-42, HTTB-45, and HTTB-46

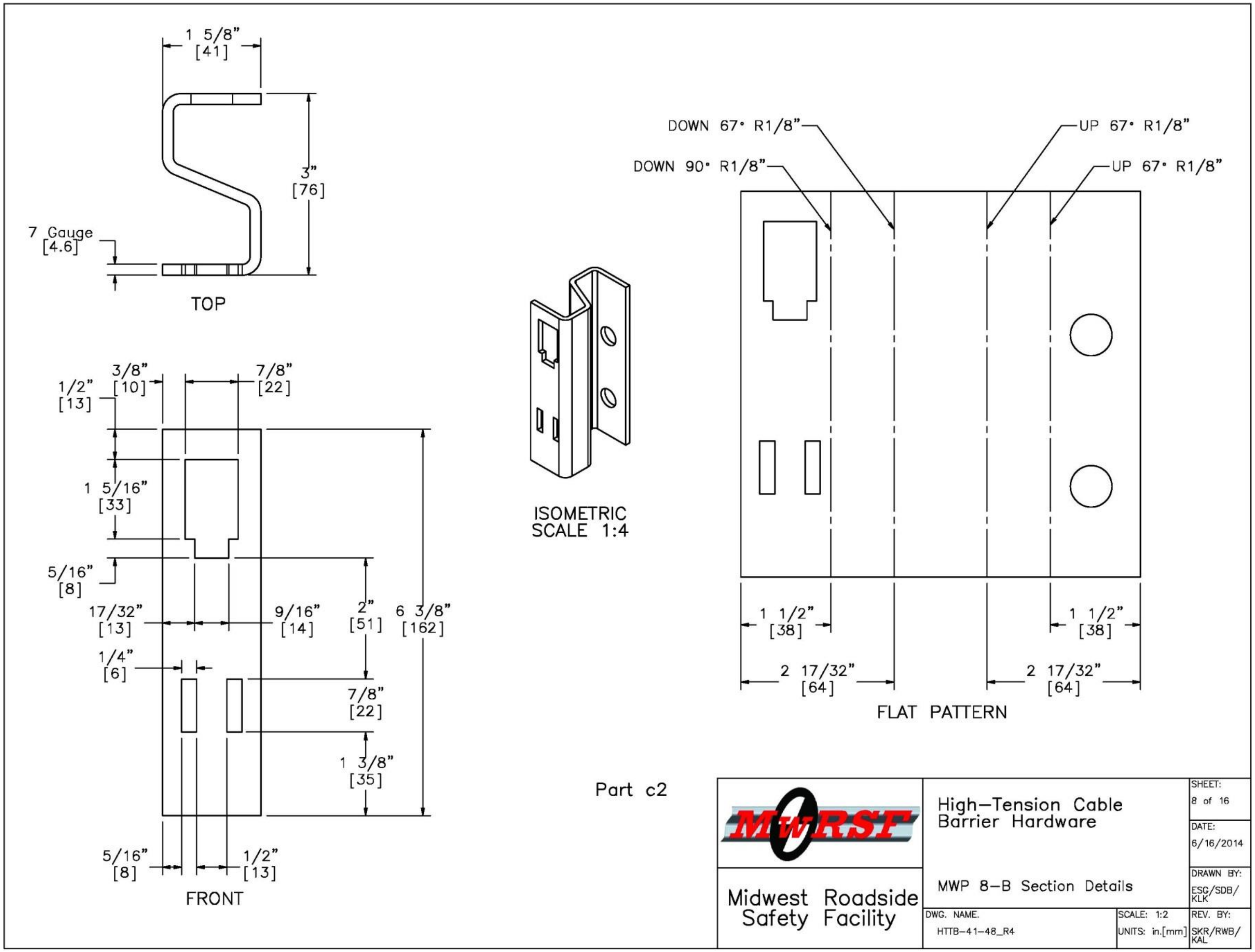


Figure 44. MWP 8-B Section Details, Test Nos. HTTB-43, HTTB-44, HTTB-47, and HTTB-48

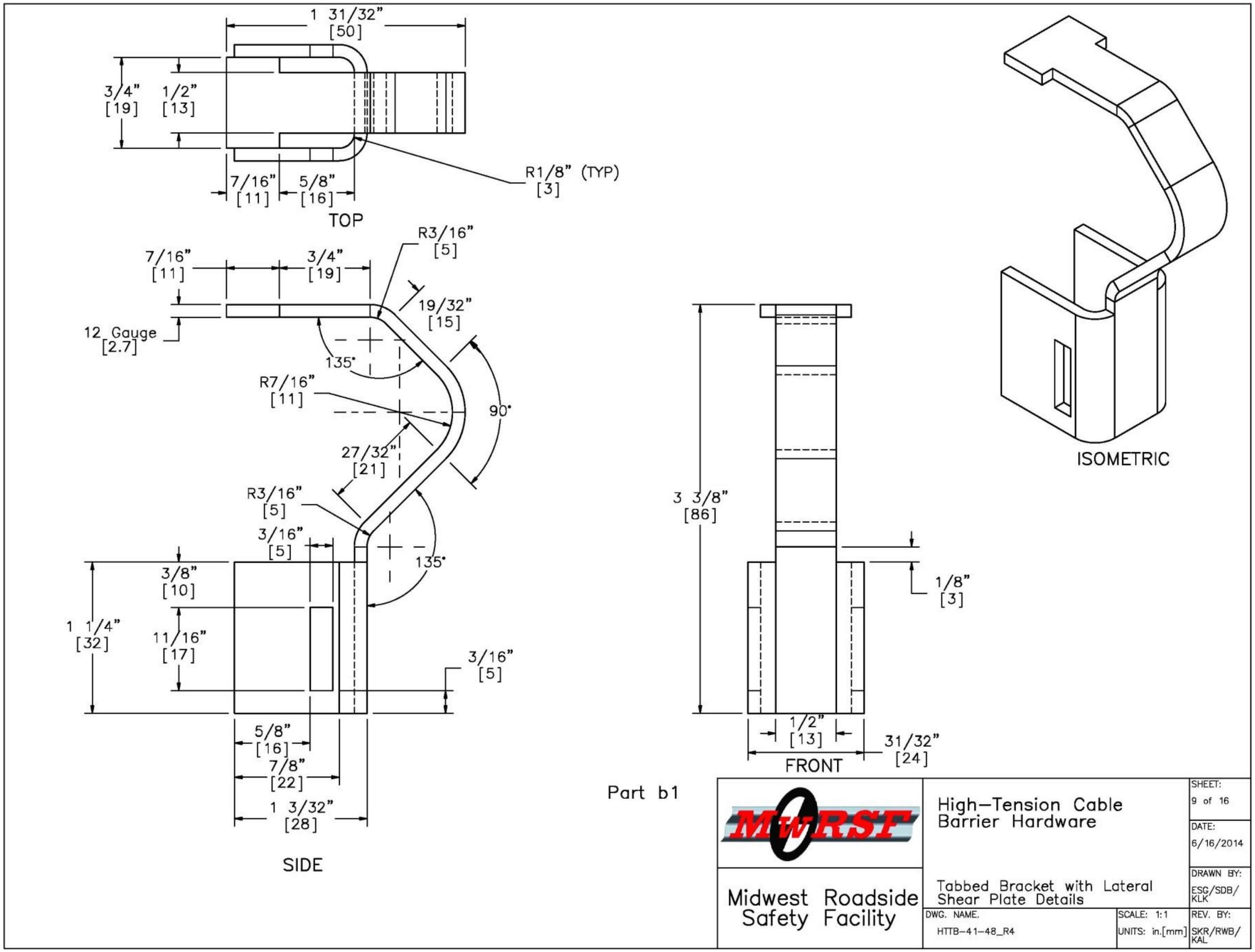


Figure 45. Tabbed Bracket with Lateral Shear Plate Details, Test Nos. HTTB-41, HTTB-42, HTTB-45, and HTTB-46

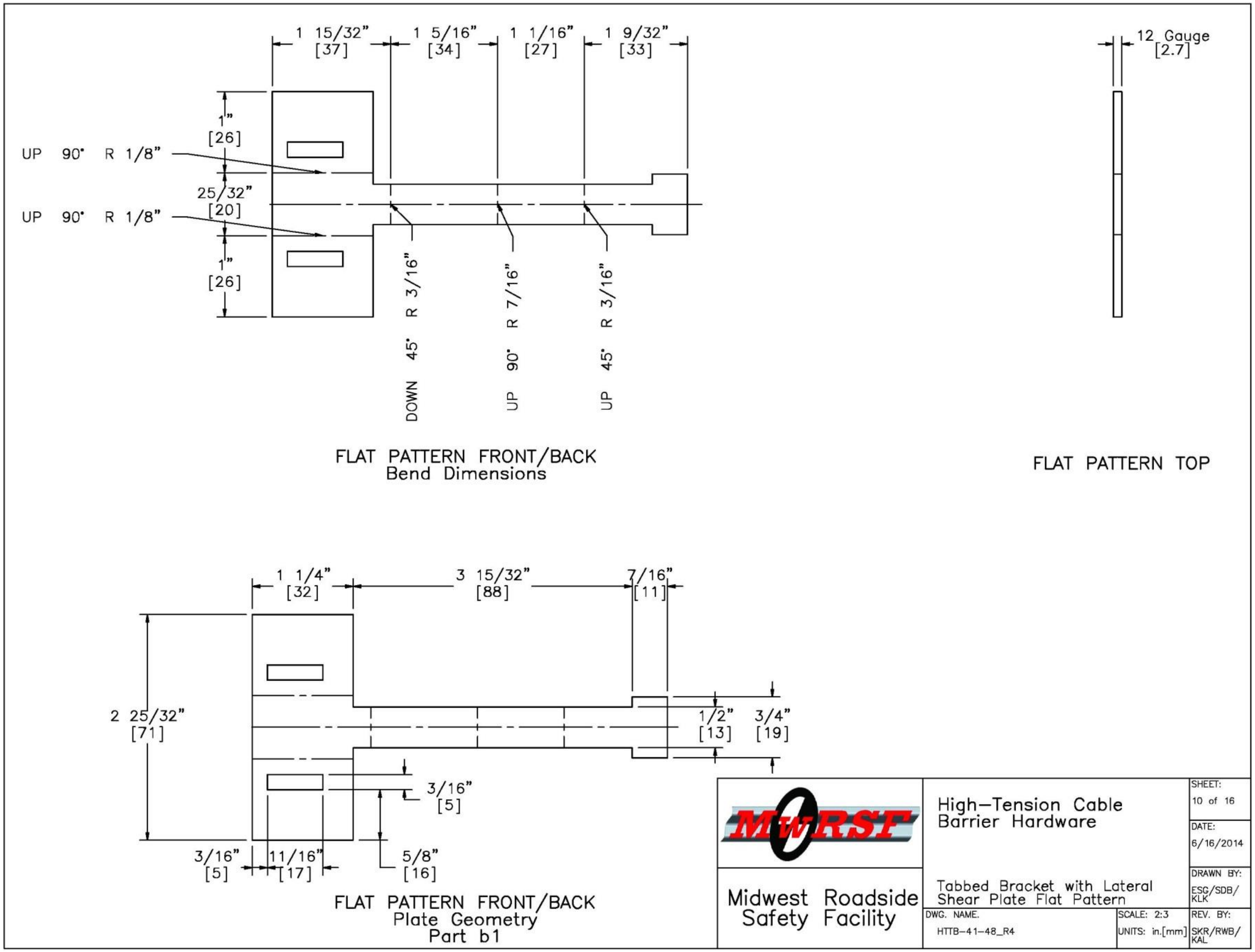


Figure 46. Tabbed Bracket with Lateral Shear Plate Flat Pattern, Test Nos. HTTB-41, HTTB-42, HTTB-45, and HTTB-46

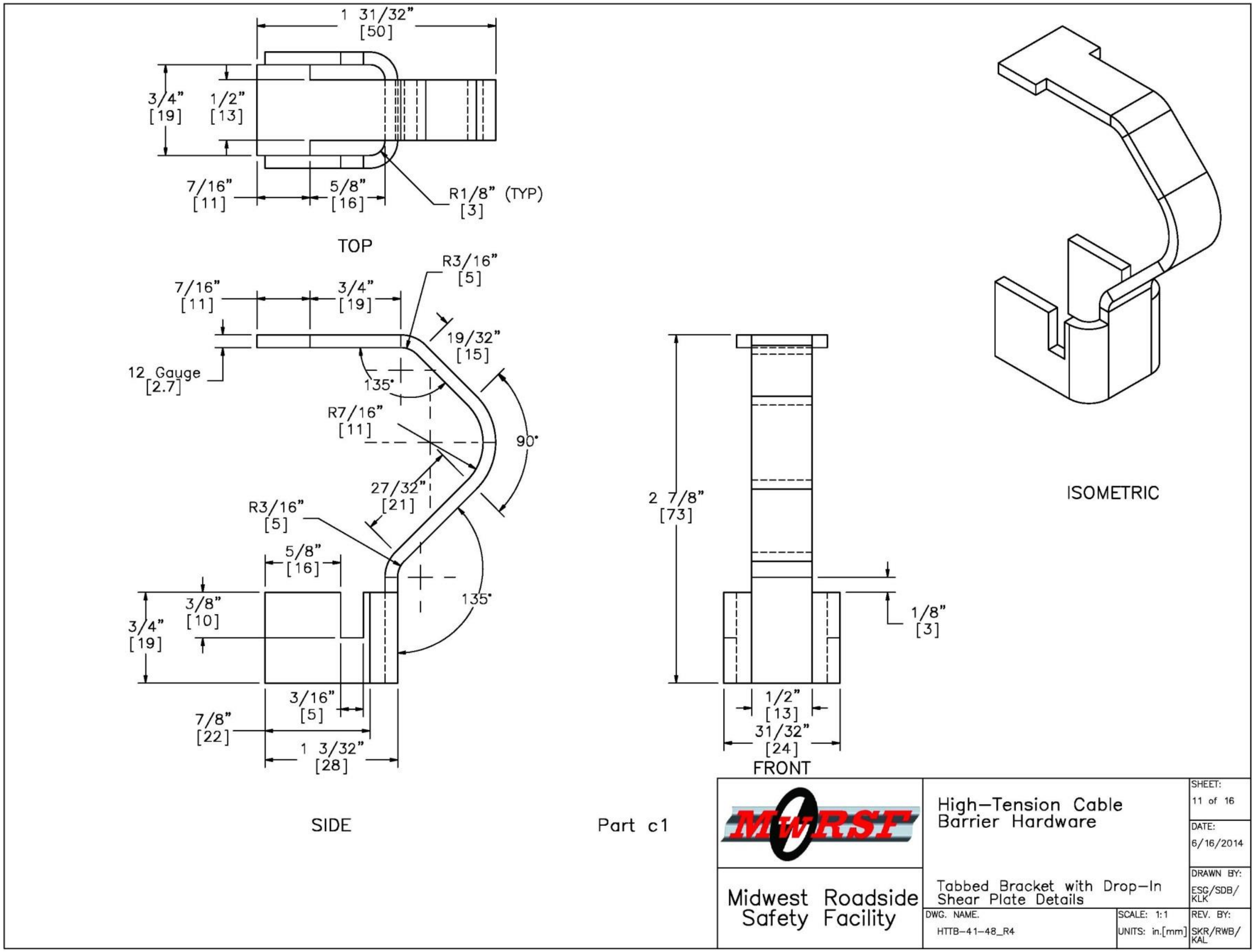


Figure 47. Tabbed Bracket with Drop-In Shear Plate Details, Test Nos. HTTB-43, HTTB-44, HTTB-47, and HTTB-48

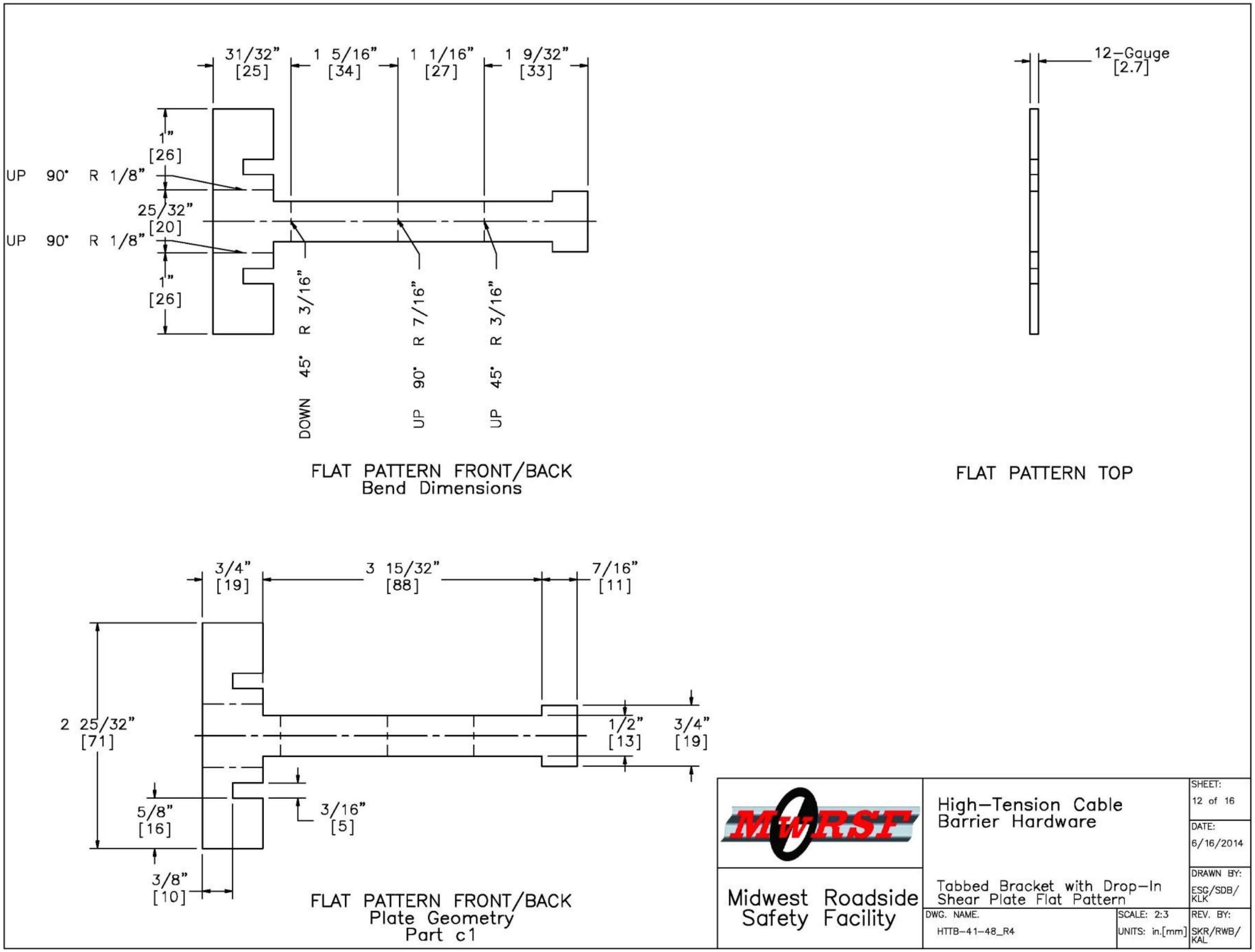
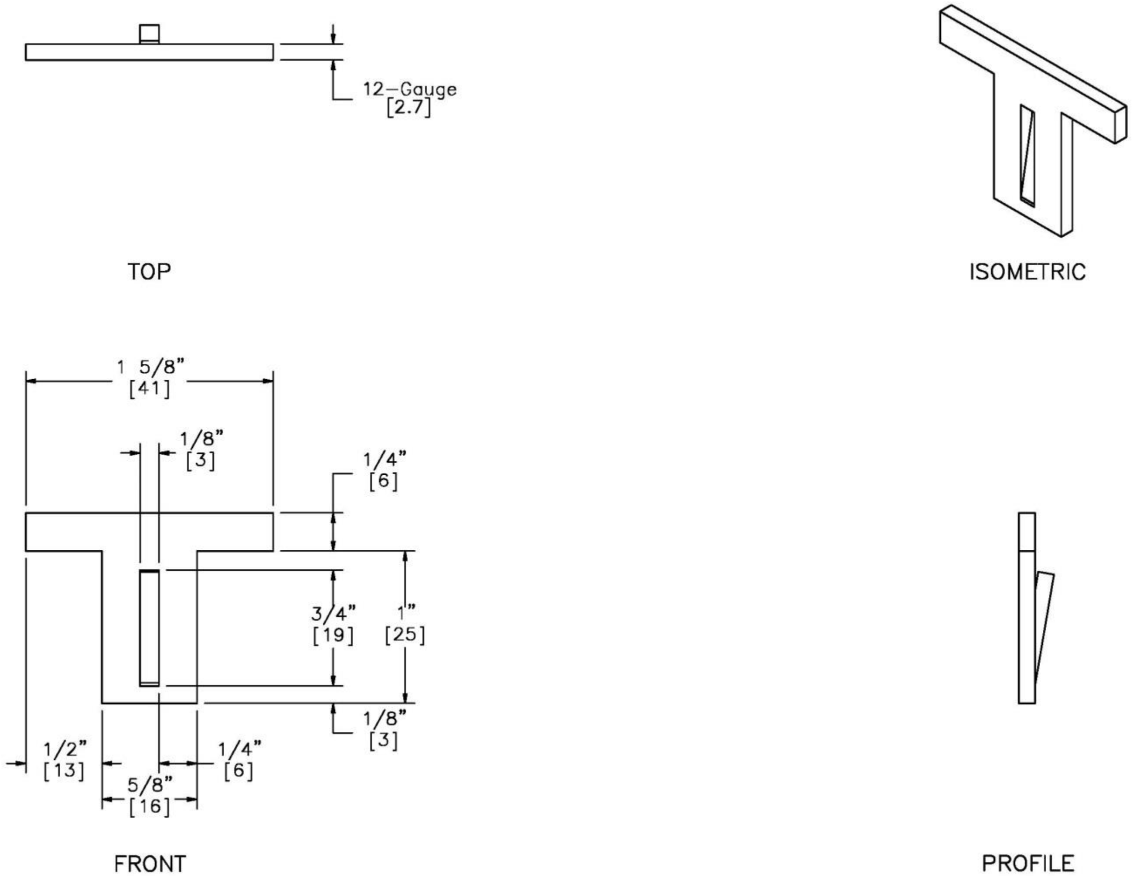


Figure 48. Tabbed Bracket with Drop-In Shear Plate Flat Pattern, Test Nos. HTTB-43, HTTB-44, HTTB-47, and HTTB-48



Part b4

Note: (1) Bend 1/8" [3] wide strip out of plane approximately 1/8" [3].

Midwest Roadside Safety Facility	High-Tension Cable Barrier Hardware	SHEET: 13 of 16
		DATE: 6/16/2014
	Lateral Shear Plate Details	DRAWN BY: ESG/SDB/KLK
	DWG. NAME. HTTB-41-48_R4 / SCALE: 1:1 / UNITS: in.[mm]	REV. BY: SKR/RWB/KAL

Figure 49. Lateral Shear Plate Details, Test Nos. HTTB-41, HTTB-42, HTTB-45, and HTTB-46

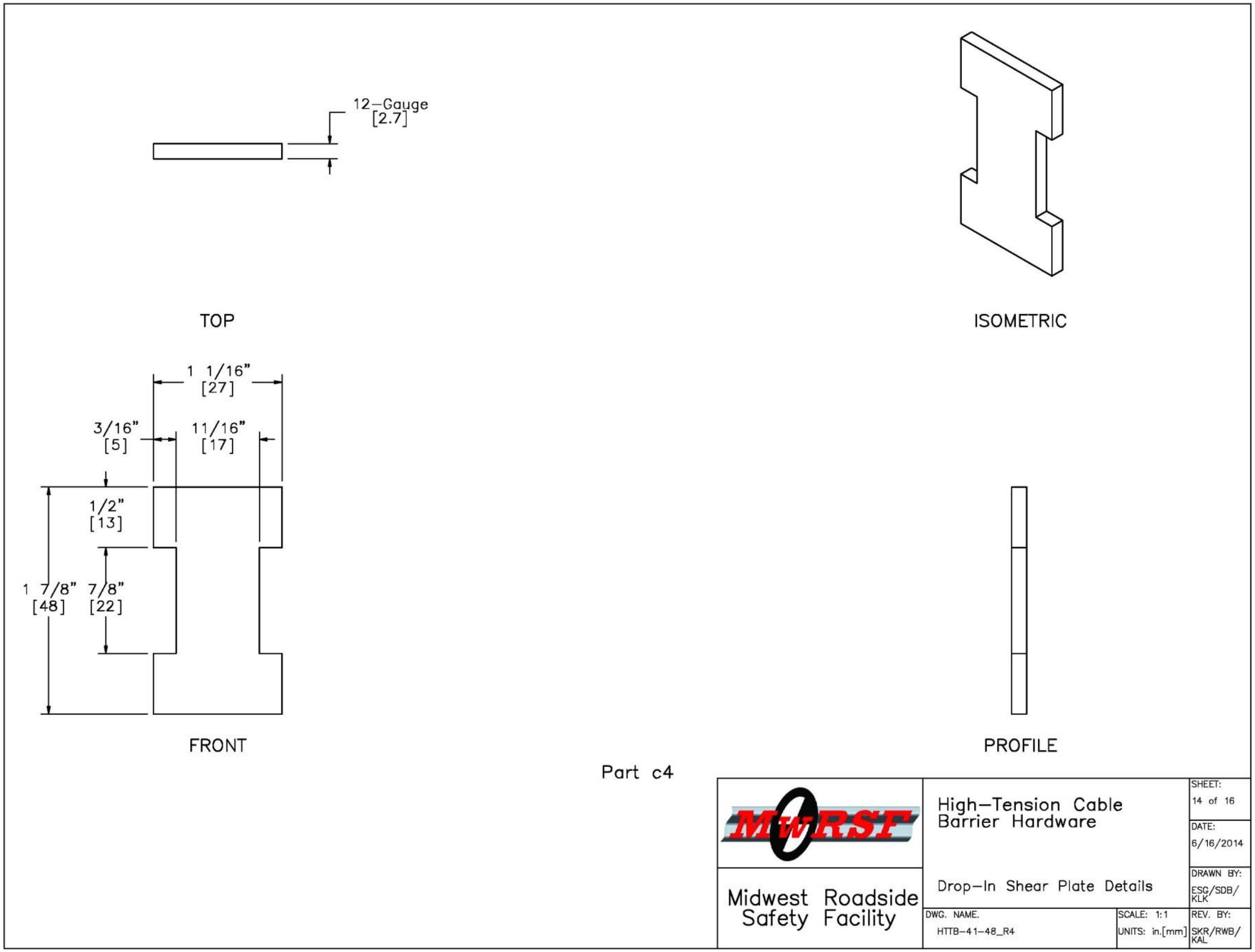


Figure 50. Drop-In Shear Plate Details, Test Nos. HTTB-43, HTTB-44, HTTB-47, and HTTB-48

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–A	90	Lateral	3	5
c1	c4	2	8–B	0	Vertical	3	5
c1	c4	2	8–B	90	Lateral	3	5

Midwest Roadside Safety Facility

High–Tension Cable Barrier Hardware

Bogie Testing Matrix

SHEET: 15 of 16

DATE: 6/16/2014

DRAWN BY: ESG/SDB/KLK

DWG. NAME. HTTB–41–48_R4

SCALE: 1:96

UNITS: in.[mm]

REV. BY: SKR/RWB/KAL

Figure 51. Bogie Testing Matrix

Cable–Clip Test Jig Setup			
Item No.	QTY.	Description	Material Specification
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	Test Jig (Pre–Existing in Field)	–
–	1	Cable Guide (Pre–Existing in Field)	–

Tabbed Bracket with Buckle Shear Plate			
Item No.	QTY.	Description	Material Specification
b1	4	Tabbed Bracket with Buckle Shear Plate	12–Gauge [2.7] Hot–Rolled ASTM A1011 HSLA Grade 50
b2	1	3"x1–5/8" [76x41], 6–1/4" [1835] Long Bent MWP	7–Gauge [4.6] Hot–Rolled ASTM A1011 HSLA Gr. 50
b3	6	1 17/32"x1 7/16"x1/4" [39x37x6] Gusset	ASTM A36
b4	4	Tabbed Bracket–Buckle Shear Plate	12–Gauge [2.7] Hot–Rolled ASTM A1011 HSLA Grade 50

Tabbed Bracket with Drop–In Shear Plate			
Item No.	QTY.	Description	Material Spec
c1	4	Tabbed Bracket with Drop–In Shear Plate	12–Gauge [2.7] Hot–Rolled ASTM A1011 HSLA Grade 50
c2	1	3"x1–5/8" [76x41], 6–1/4" [159] Long Bent MWP	7–Gauge [4.6] Hot–Rolled ASTM A1011 HSLA Gr. 50
b3	6	1 17/32"x1 7/16"x1/4" [39x37x6] Gusset	ASTM A36
c4	4	Tabbed Bracket–Drop–In Shear Plate	12–Gauge [2.7] Hot–Rolled ASTM A1011 HSLA Grade 50

Midwest Roadside Safety Facility

High–Tension Cable Barrier Hardware

Bill of Materials, Continued

SHEET: 16 of 16
DATE: 6/16/2014
DRAWN BY: ESG/SDB/KLK
REV. BY: SKR/RWB/KAL
DWG. NAME. HTTB–41–48_R4
SCALE: NONE
UNITS: in.[mm]

Figure 52. Bill of Materials

4 TABBED BRACKET COMPONENT TESTING CONDITIONS

4.1 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 within the non-proprietary high-tension cable barrier system.

4.2 Scope

Eight 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 designs. Loading continued to increase until the cable was released from the bracket. An adjustable plate was used within the jig, which allowed the post segment to be rotated between 0 and 90 degrees. Thus, the brackets were loaded in both the vertical and lateral directions, respectively. Both the lateral shear plate and drop-in shear plate attachment designs were subjected to two tests in each direction for a total of eight component tests. The test matrix is shown in Table 1. The load cell data was then analyzed and the results were compared with the bolted tabbed bracket V10 dynamic test results [2].

Table 1. Tabbed Bracket Testing Matrix

Test No.	Bracket Attachment Design	Orientation (deg.)	Load Direction	Target Speed mph (km/h)
HTTB-41	Lateral Shear Plate	0	Vertical	5 (8)
HTTB-42	Lateral Shear Plate	0	Vertical	5 (8)
HTTB-43	Drop-In Shear Plate	0	Vertical	5 (8)
HTTB-44	Drop-In Shear Plate	0	Vertical	5 (8)
HTTB-45	Lateral Shear Plate	90	Lateral	5 (8)
HTTB-46	Lateral Shear Plate	90	Lateral	5 (8)
HTTB-47	Drop-In Shear Plate	90	Lateral	5 (8)
HTTB-48	Drop-In Shear Plate	90	Lateral	5 (8)

4.3 Test Facility

Physical testing of the alternative attachment designs for the tabbed brackets 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.

4.4 Equipment and Instrumentation

Equipment and instrumentation 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.

4.4.1 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 1,916 lb (869 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 53.

Figure 53. Rigid-Frame Bogie on Guidance Track

4.4.2 Test Jig

A test jig was utilized to support and anchor the test article. The short post section 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 54.

Figure 54. Test Jig

4.4.3 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.

4.4.4 Digital Photography

One AOS high-speed digital video camera and two GoPro Hero 3 digital cameras were used to document each test. The AOS high-speed camera had a frame rate of 500 frames per second and the GoPro digital video cameras 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.

4.5 Data Processing and Analysis

Force data was measured with the load cell transducer and filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [3]. 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.

5 TABBED BRACKET COMPONENT TESTING

5.1 Results

A total of eight component tests (test nos. HTTB-41 through HTTB-48) were conducted on the two tabbed bracket alternative attachment designs. Each design concept was tested 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 the high-speed video. Test results for all load cells are provided in Appendix B.

5.1.1 Test No. HTTB-41

Test no. HTTB-41 evaluated the tabbed bracket with the lateral shear 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 lateral shear 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 0.076 seconds after the initial loading, a peak load of 0.31 kips (1.37 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 0.096 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 as it released from the bracket. These two trailing peaks had loads of 0.24 kips and 0.23 kips (1.08 kN and 1.03 kN), respectively. The force vs. time curve is shown in Figure 55. Pre- and post-test photographs and sequential photographs are shown in Figures 56 and 57, respectively.

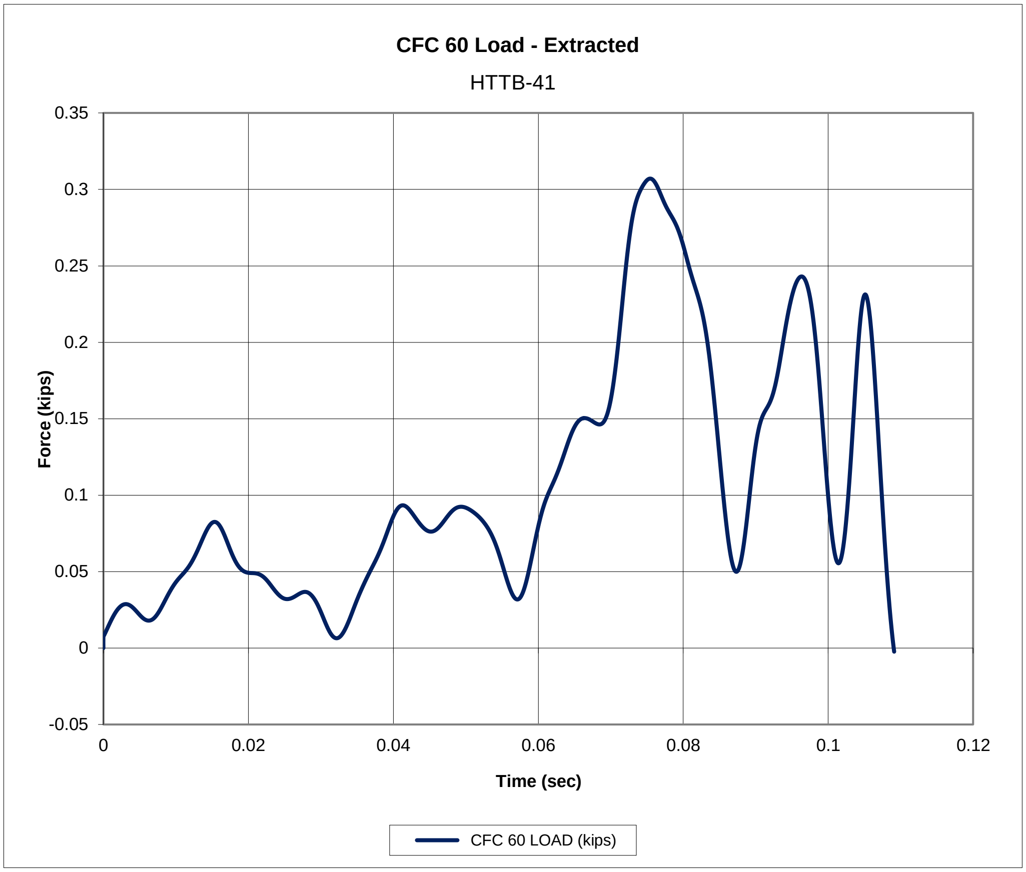


Figure 55. Force vs. Time Data, Test No. HTTB-41

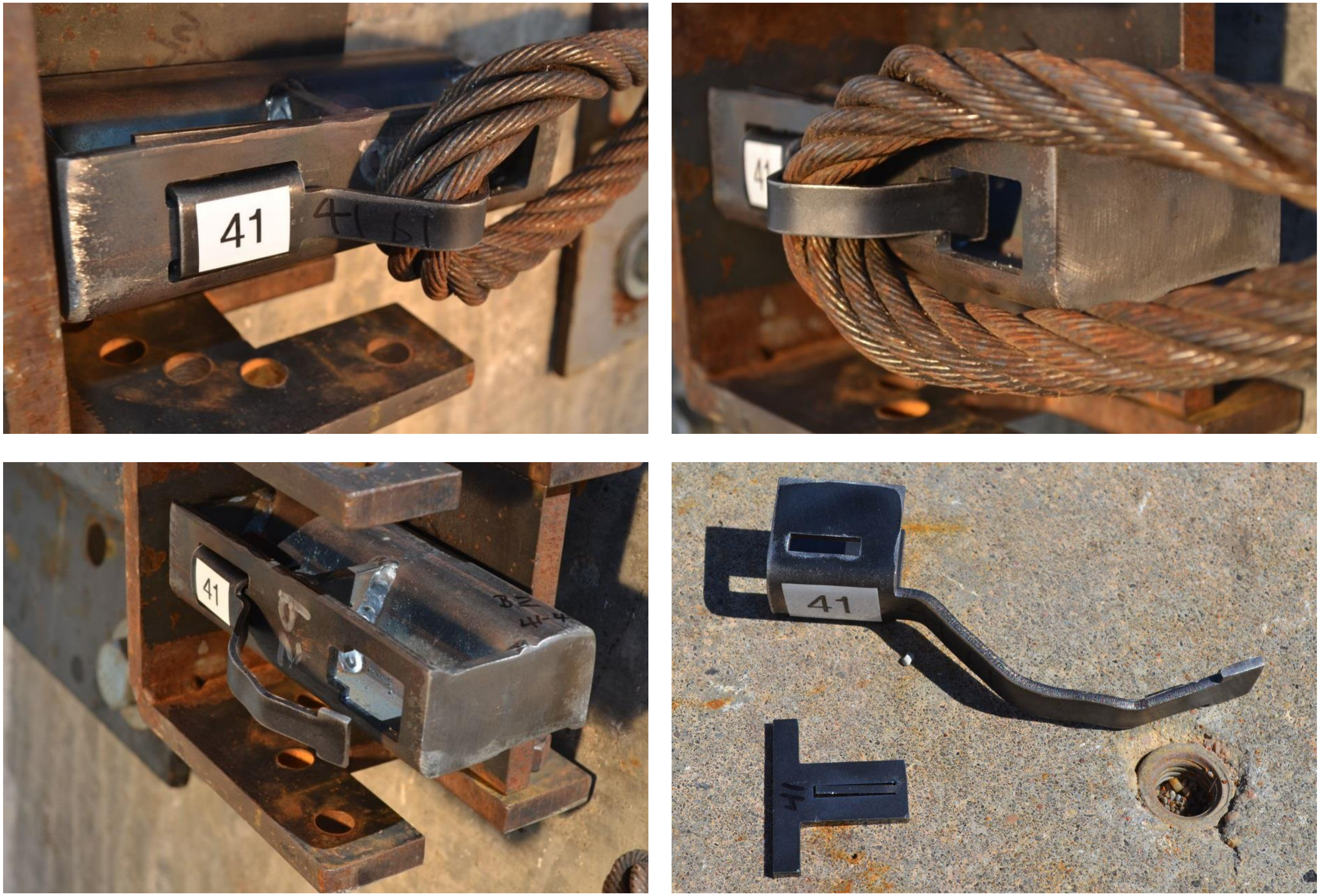
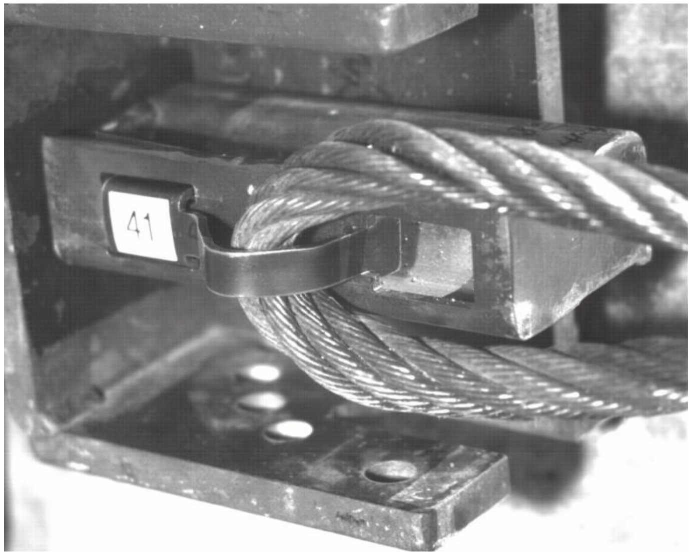
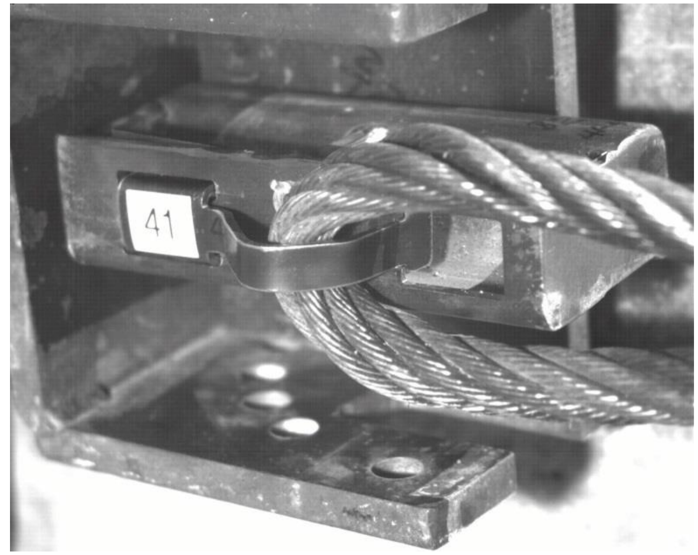


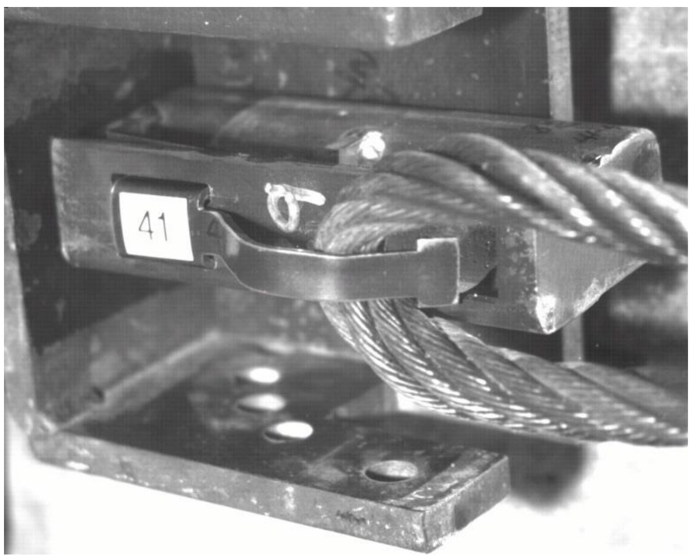
Figure 56. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-41



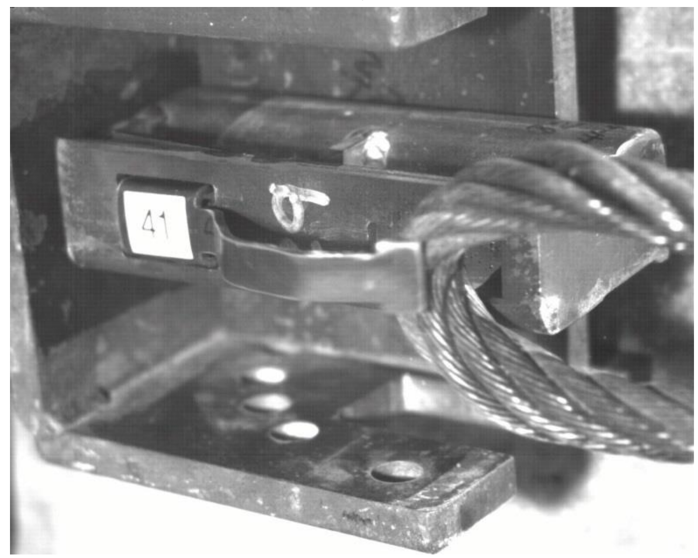
Time = 0 sec



Time = 0.076 sec



Time = 0.096 sec



Time = 0.108 sec

Figure 57. Sequential Photographs, Test No. HTTB-41

5.1.2 Test No. HTTB-42

Test no. HTTB-42 evaluated the tabbed bracket with the lateral shear 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 lateral shear 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 open. At 0.212 seconds after the initial loading, a peak load of 0.36 kips (1.61 kN) was reached. The cable then slid upward a short distance and the bracket rotated about the shear plate connection. A second force peak of 0.30 kips (1.32 kN) was obtained at 0.226 seconds. After this peak, the force fell quickly as the bracket continued to open and the tabs were lifted out of the keyway. By 0.236 seconds, the tabs had completely exited the keyway. The force vs. time curve is shown in Figure 58. Pre- and post-test photographs and sequential photographs are shown in Figures 59 and 60, respectively.

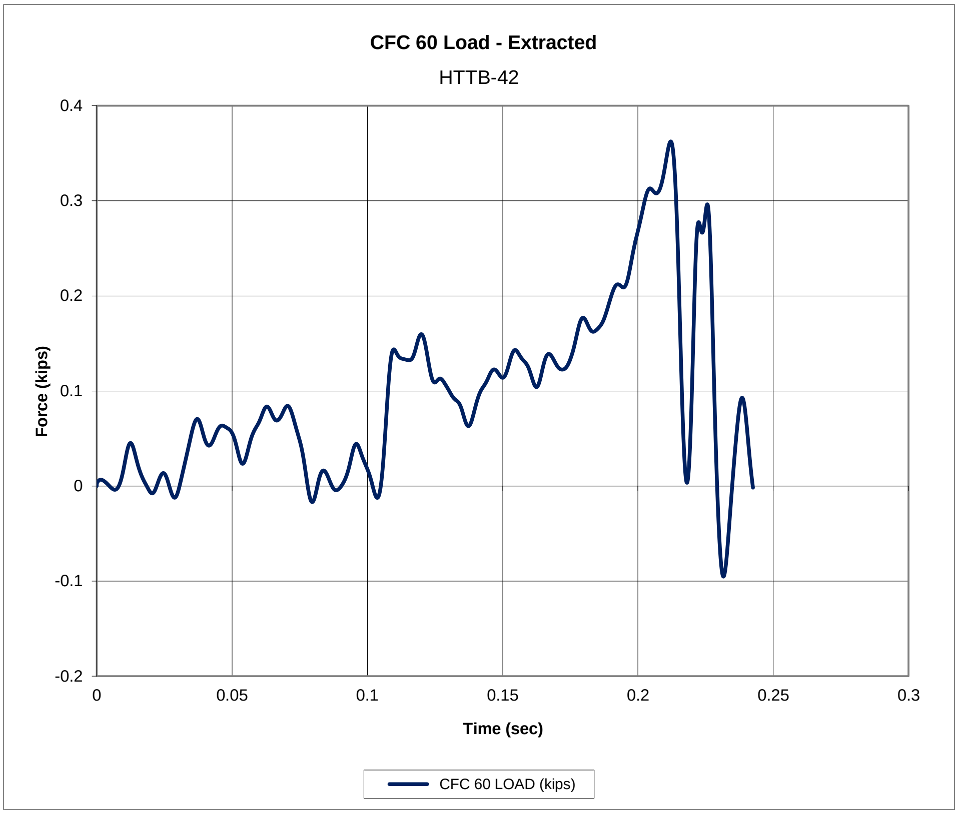


Figure 58. Force vs. Time Data, Test No. HTTB-42

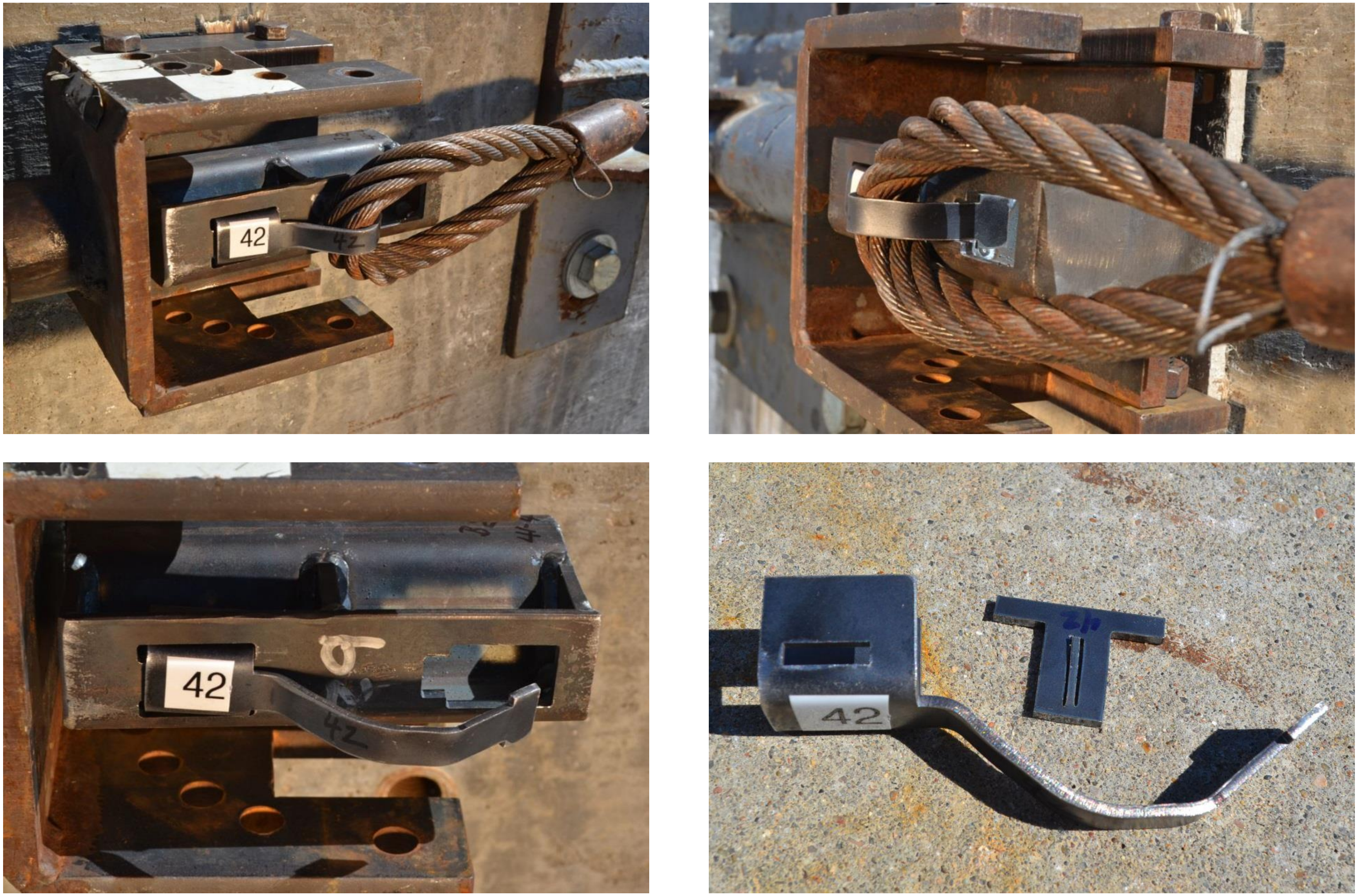
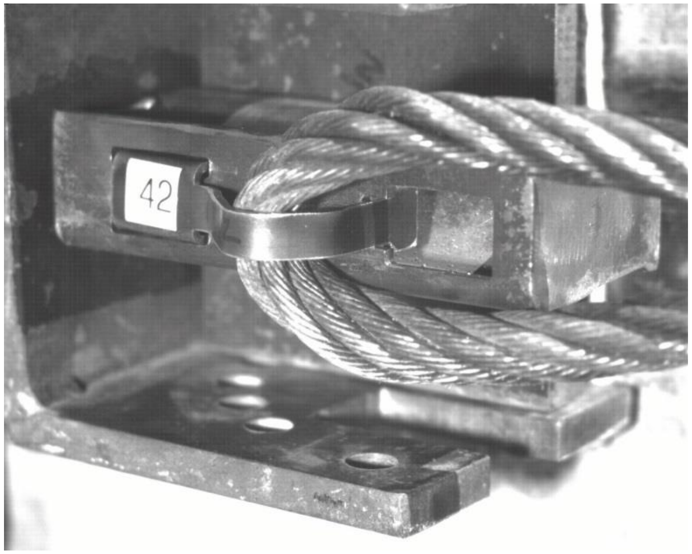
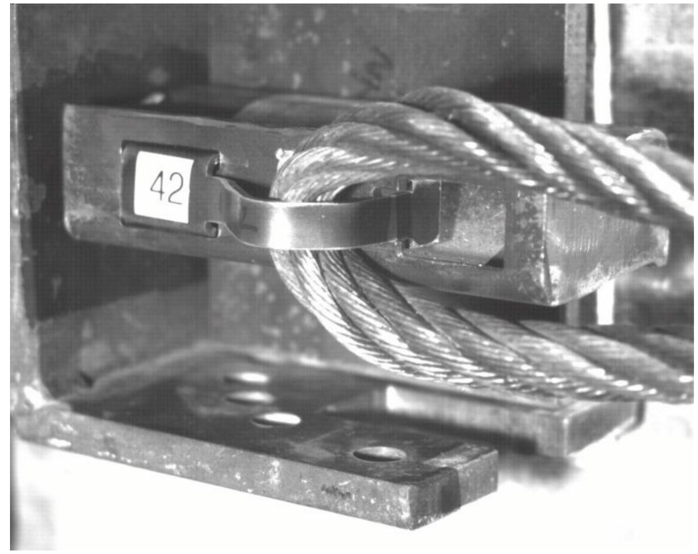


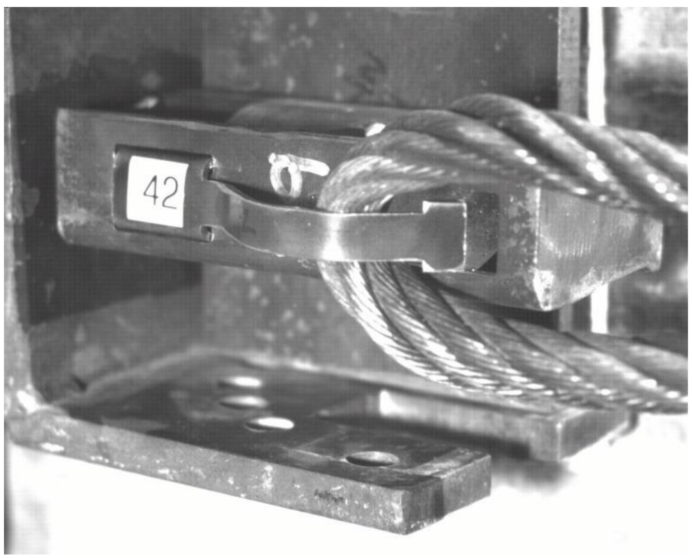
Figure 59. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-42



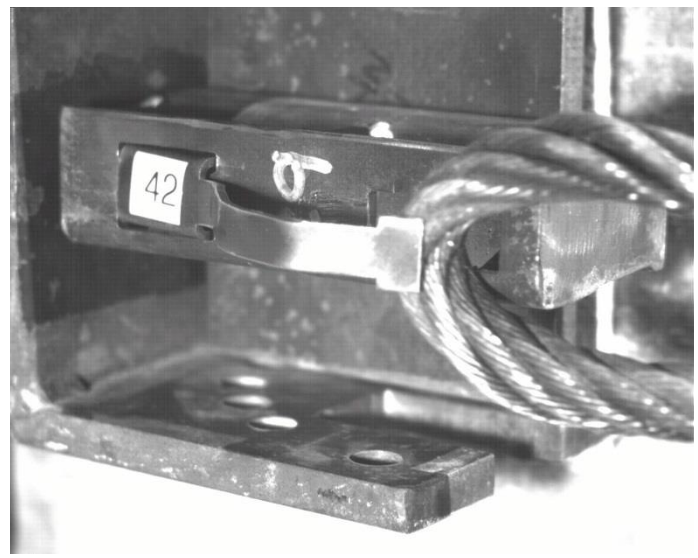
Time = 0 sec



Time = 0.212 sec



Time = 0.236 sec



Time = 0.246 sec

Figure 60. Sequential Photographs, Test No. HTTB-42

5.1.3 Test No. HTTB-43

Test no. HTTB-43 evaluated the tabbed bracket with the drop-in shear 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 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 0.205 seconds after the initial loading, a peak load of 0.31 kips (1.38 kN) was reached. The cable then slid upward a short distance and the bracket rotated outward about its legs. A second force peak of 0.30 kips (1.32 kN) was obtained at 0.218 seconds. After this peak, the force fell quickly as the bracket continued to open as the tabs were lifted out of the keyway. By 0.226 seconds, the tabs had completely exited the keyway. The force vs. time curve is shown in Figure 61. Pre- and post-test photographs and sequential photographs are shown in Figures 62 and 63, respectively.

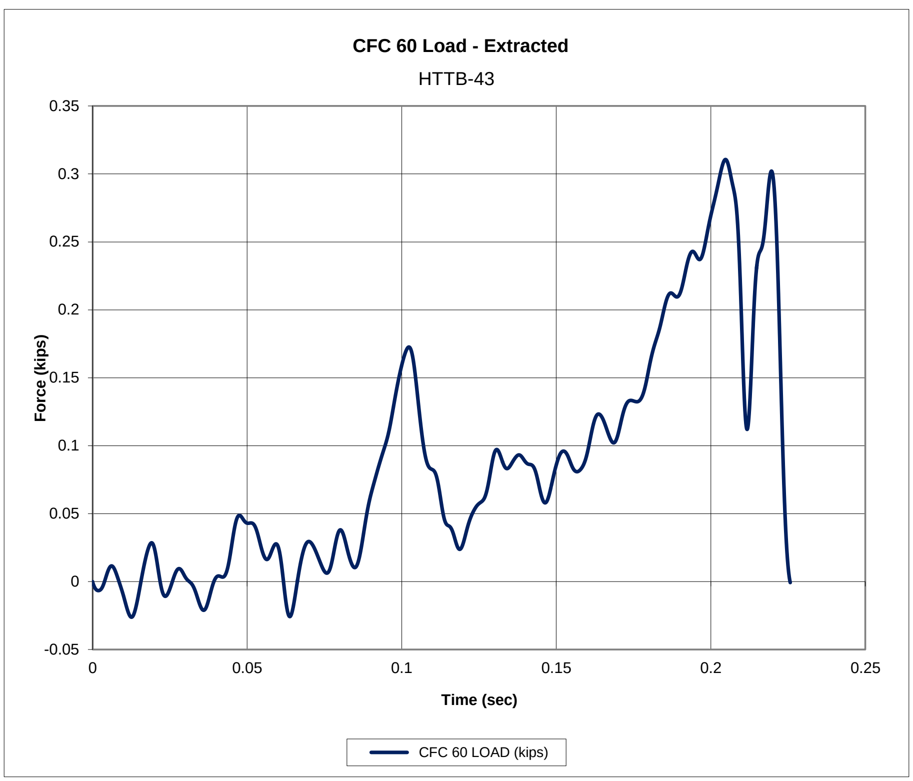


Figure 61. Force vs. Time Data, Test No. HTTB-43

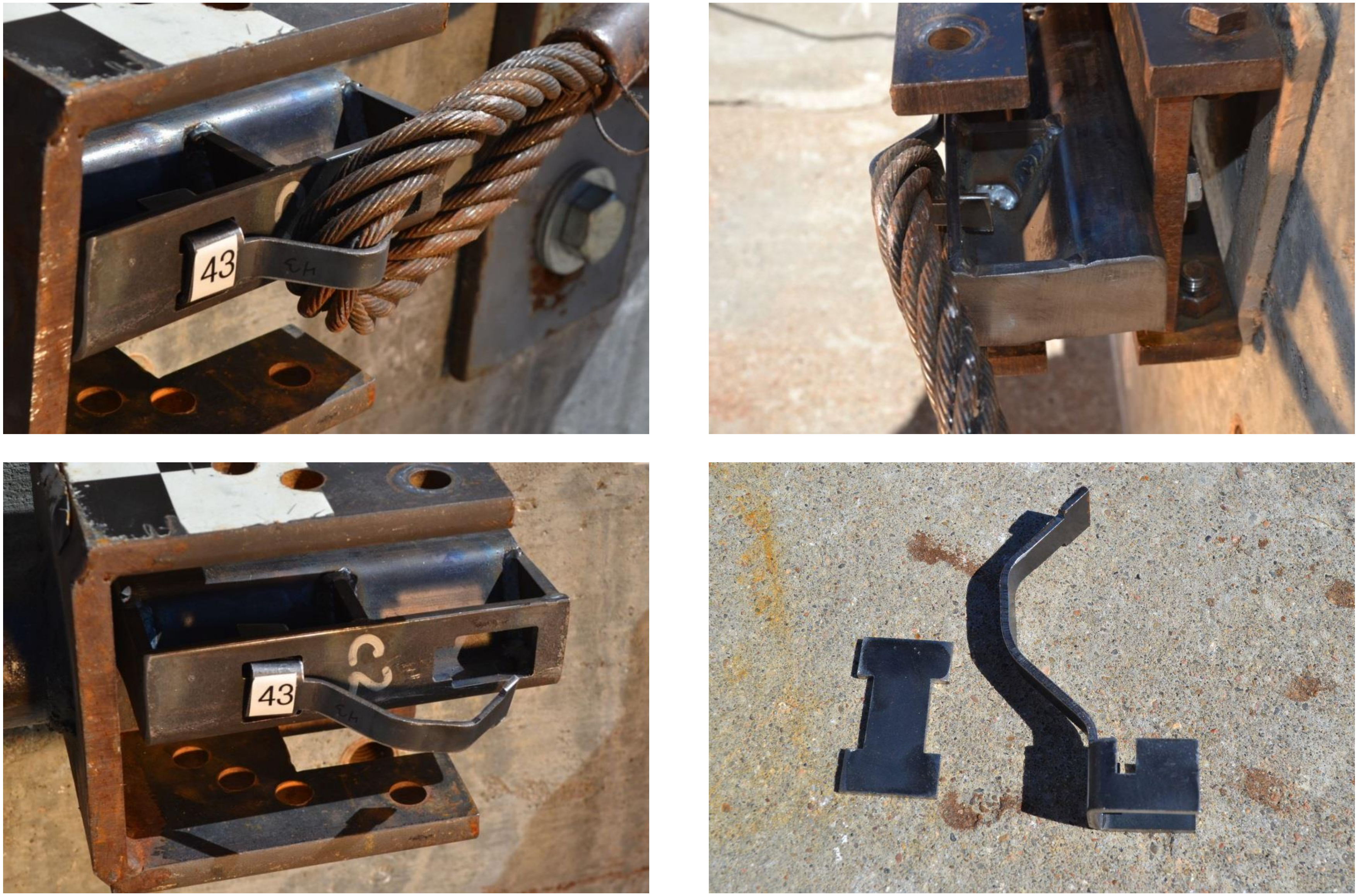
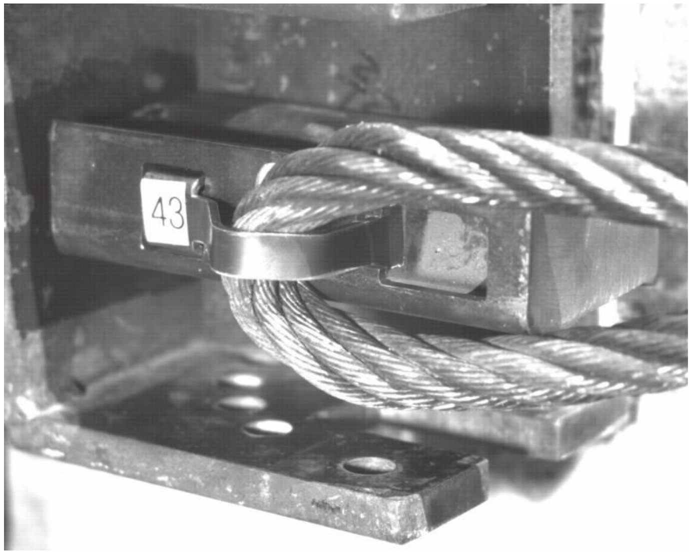
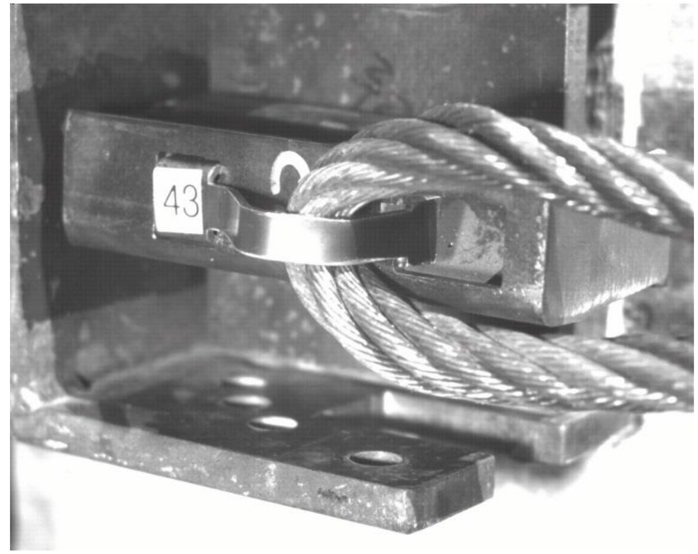


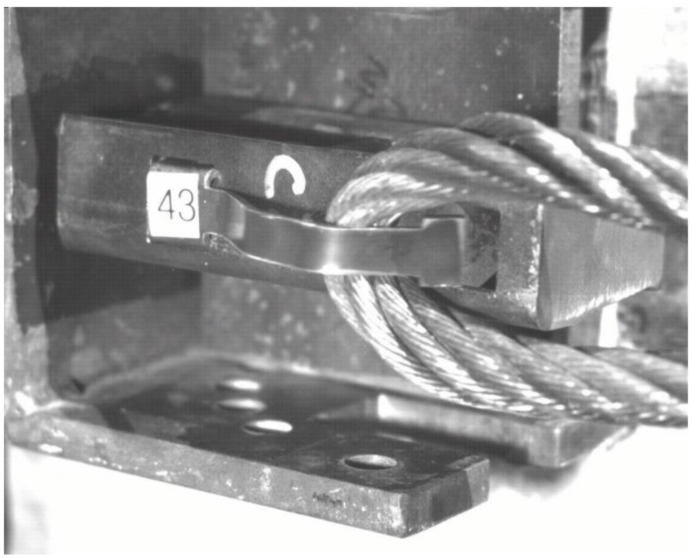
Figure 62. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-43



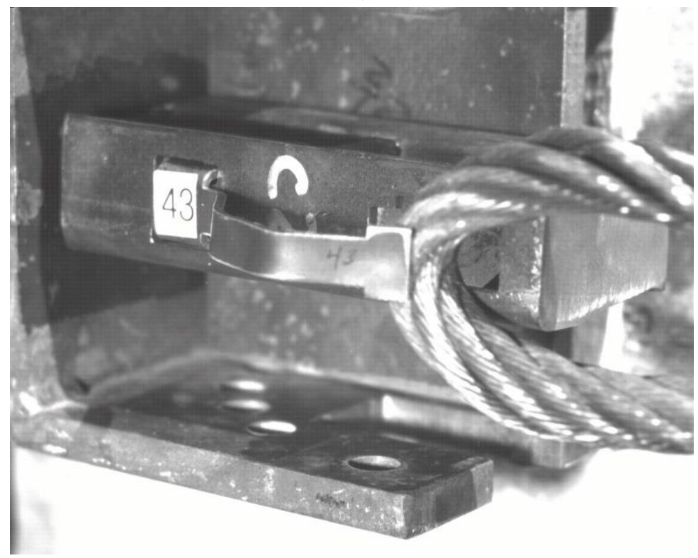
Time = 0 sec



Time = 0.204 sec



Time = 0.218 sec



Time = 0.226 sec

Figure 63. Sequential Photographs, Test No. HTTB-43

5.1.4 Test No. HTTB-44

Test no. HTTB-44 evaluated the tabbed bracket with the drop-in shear 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 connection allowed the bracket to shift and rotate outward until the tabs pressed against the inside of the post flange. As the load imparted to the tabbed bracket increased, the spine of the bracket began to bend. However, the tabs were snagged against the inside of the flange, which prevented the bracket from opening. At 0.218 seconds after the initial loading, a peak load of 1.03 kips (4.56 kN) was reached. After this peak, the tabs finally slid up and through the keyway, and the force fell quickly. By 0.232 seconds, the tabs had completely exited the keyway. The force vs. time curve is shown in Figure 64. Pre- and post-test photographs and sequential photographs are shown in Figures 65 and 66, respectively.

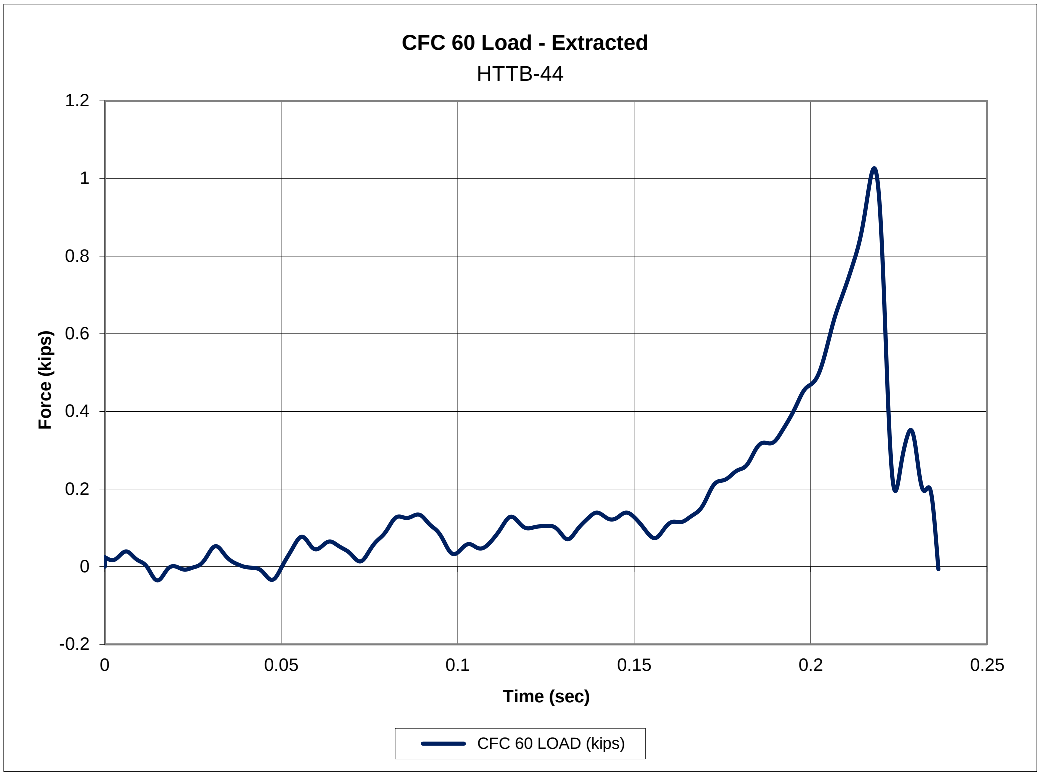


Figure 64. Force vs. Time Data, Test No. HTTB-44

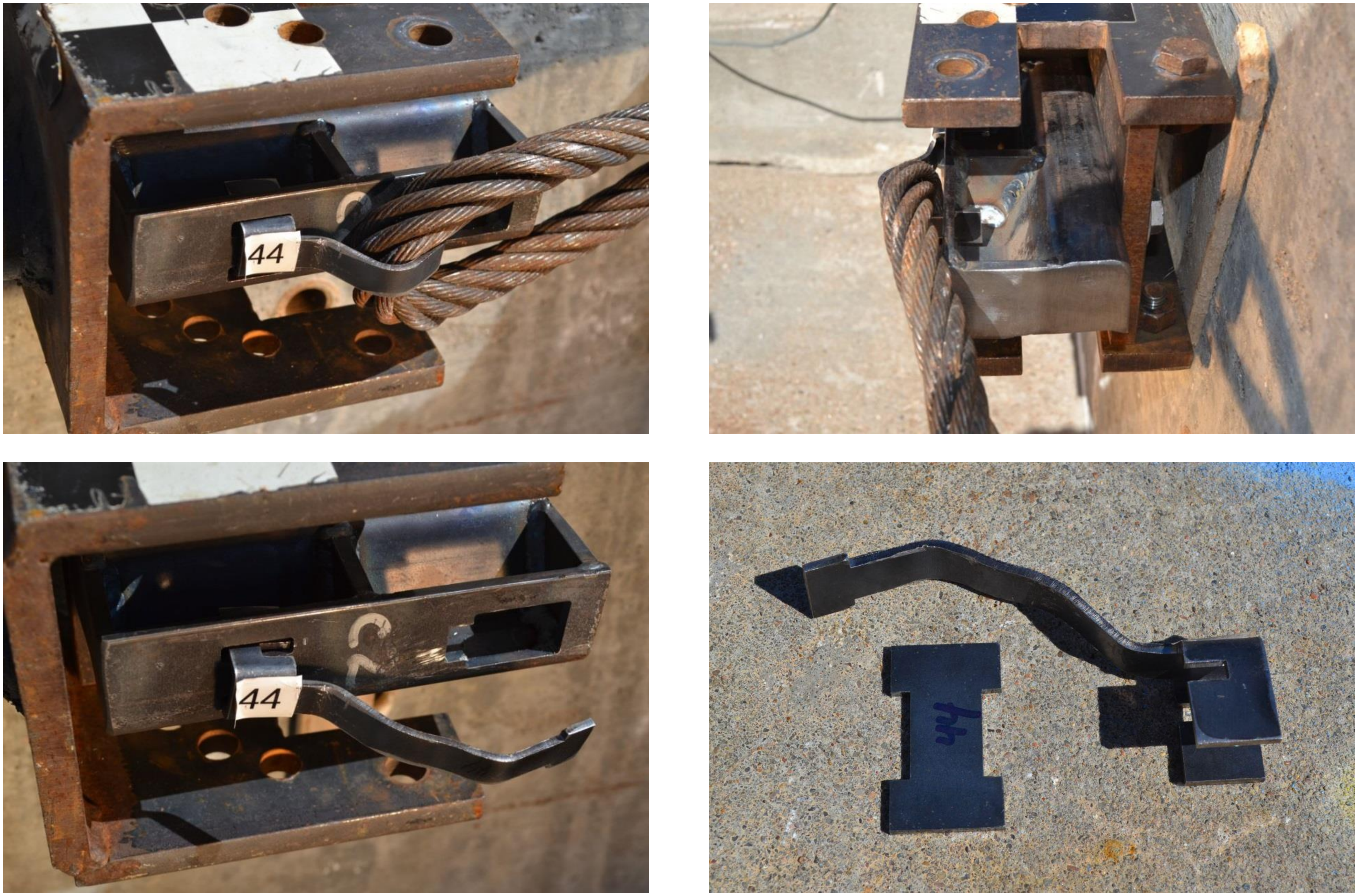
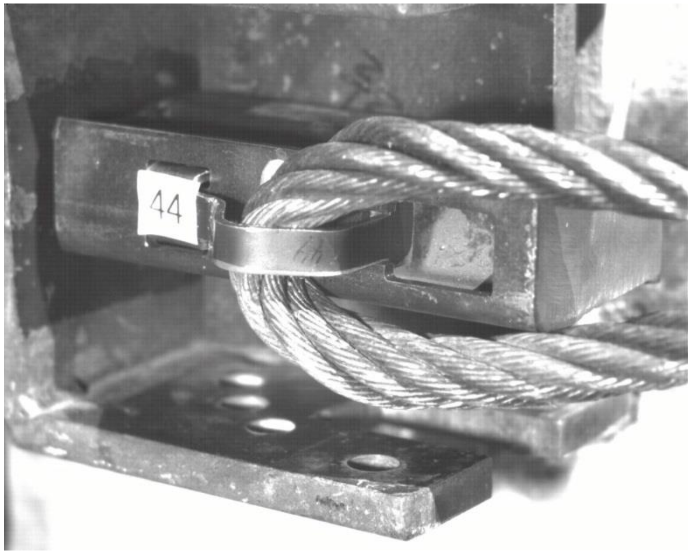
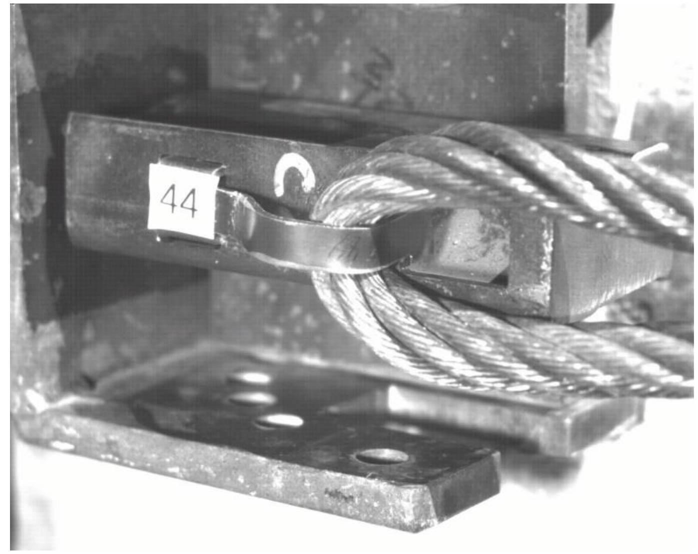


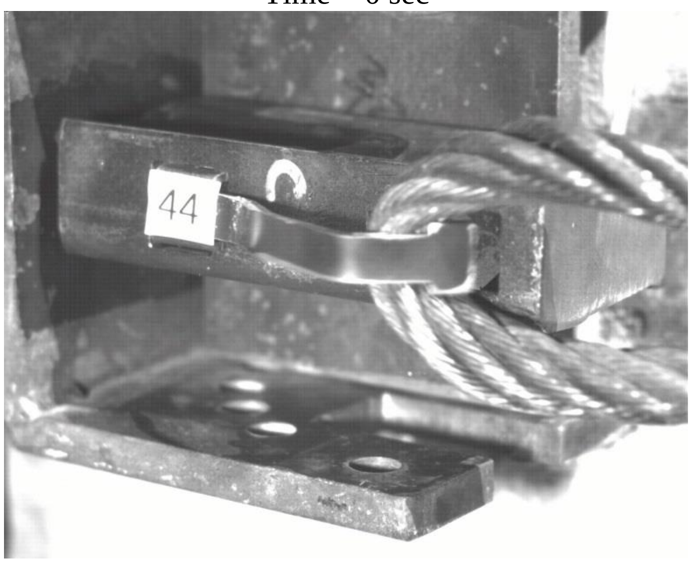
Figure 65. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-44



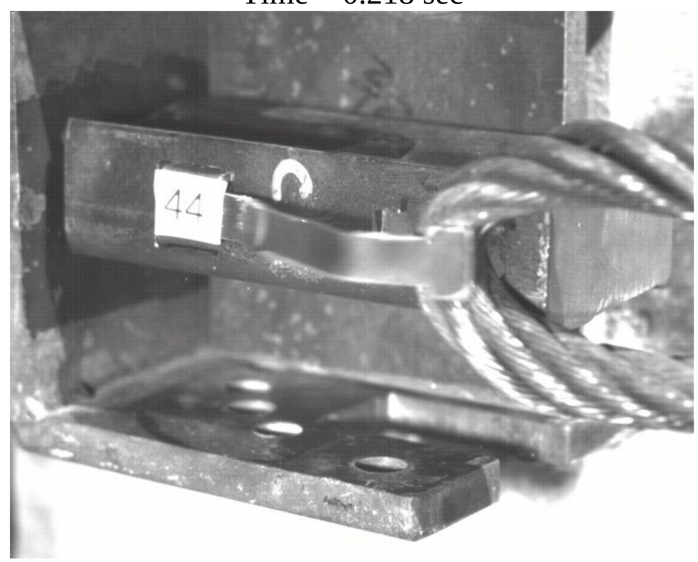
Time = 0 sec



Time = 0.218 sec



Time = 0.228 sec



Time = 0.232 sec

Figure 66. Sequential Photographs, Test No. HTTB-44

5.1.5 Test No. HTTB-45

Test no. HTTB-45 evaluated the tabbed bracket with the lateral shear 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 0.168 seconds after loading began, small tears began to form in the tabs in the area where the spine meets the tabs. Additional tears formed in the base of the bracket where the spine met the lower legs. At 0.178 seconds, a peak load of 6.21 kips (27.61 kN) was reached, and further tearing and bending of the tabs resulted in the tabs being pulled through the lower portion of the keyway. Subsequently, the spine of the bracket bent open, and the cable was released at 0.182 seconds. The force vs. time curve is shown in Figure 67. Pre- and post-test and photographs and sequential photographs are shown in Figures 68 and 69, respectively.

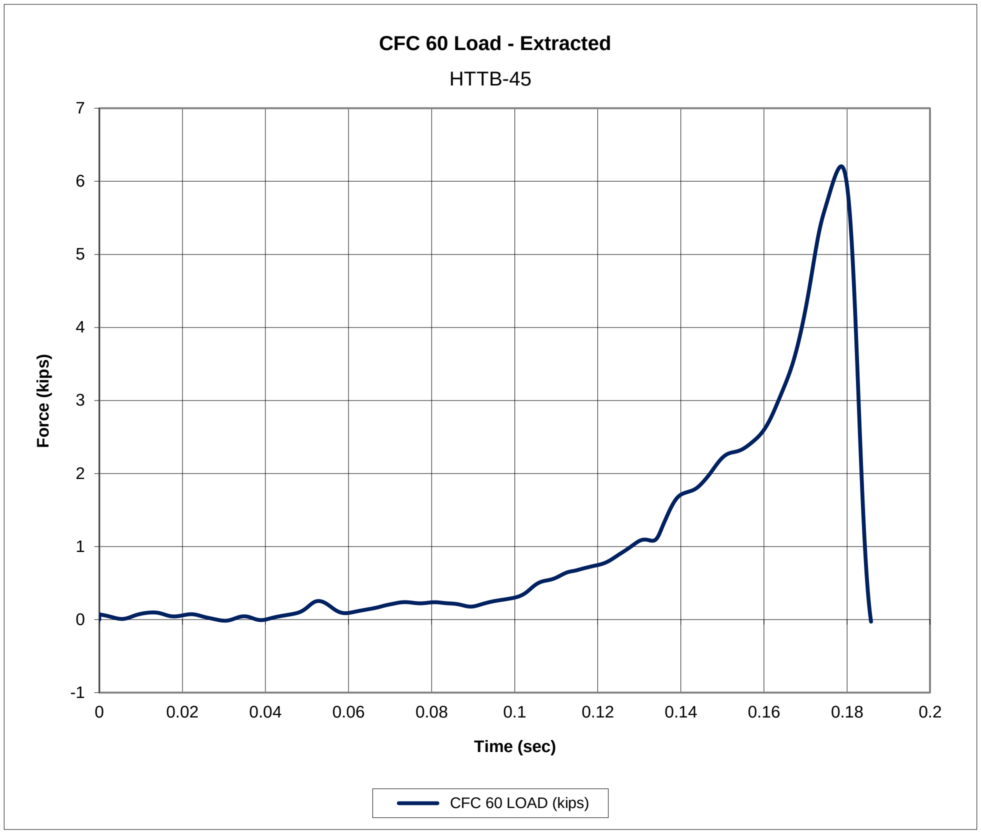
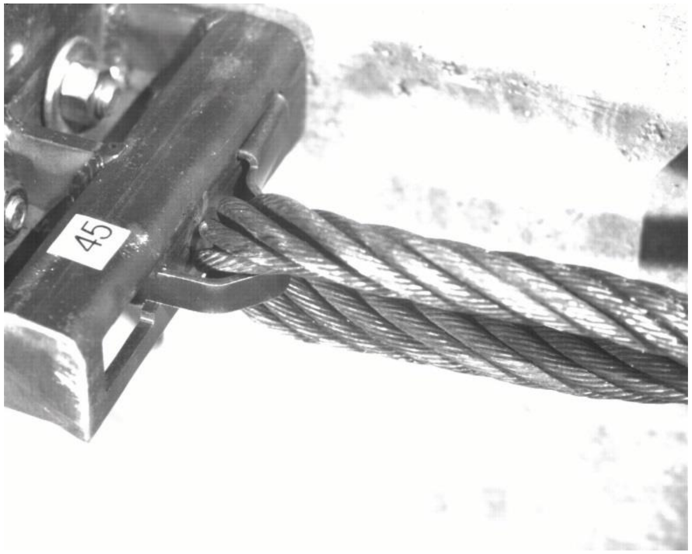


Figure 67. Force vs. Time Data, Test No. HTTB-45

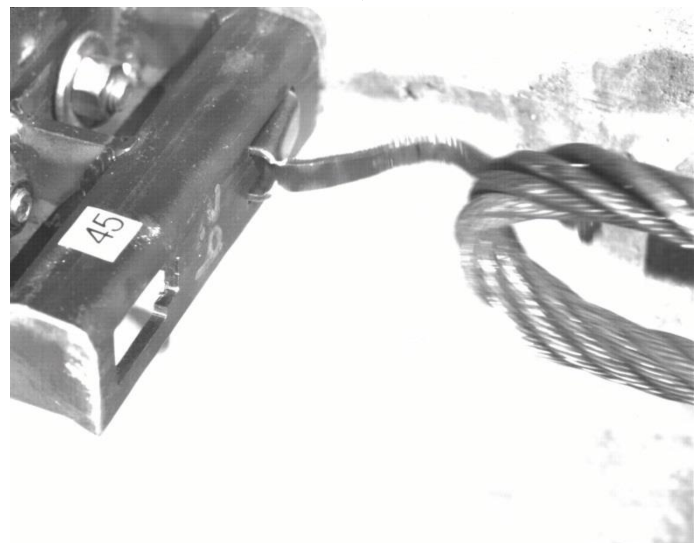
Figure 68. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-45



Time = 0 sec

Time = 0.168 sec

Time = 0.178 sec



Time = 0.182 sec

Figure 69. Sequential Photographs, Test No. HTTB-45

5.1.6 Test No. HTTB-46

Test no. HTTB-46 evaluated the tabbed bracket with the lateral shear 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 0.206 seconds after loading began, small tears began to form in the base of the bracket where the spine met the lower legs. Additional tears formed in the tabs by 0.224 seconds. At 0.230 seconds, a peak load of 6.26 kips (27.84 kN) was reached, and further tearing and bending of the tabs resulted in the tabs being pulled through the lower portion of the keyway. Subsequently, the spine of the bracket bent open, and the cable was released at 0.234 seconds. The force vs. time curve is shown in Figure 70. Pre- and post-test photographs and sequential photographs are shown in Figures 71 and 72, respectively.

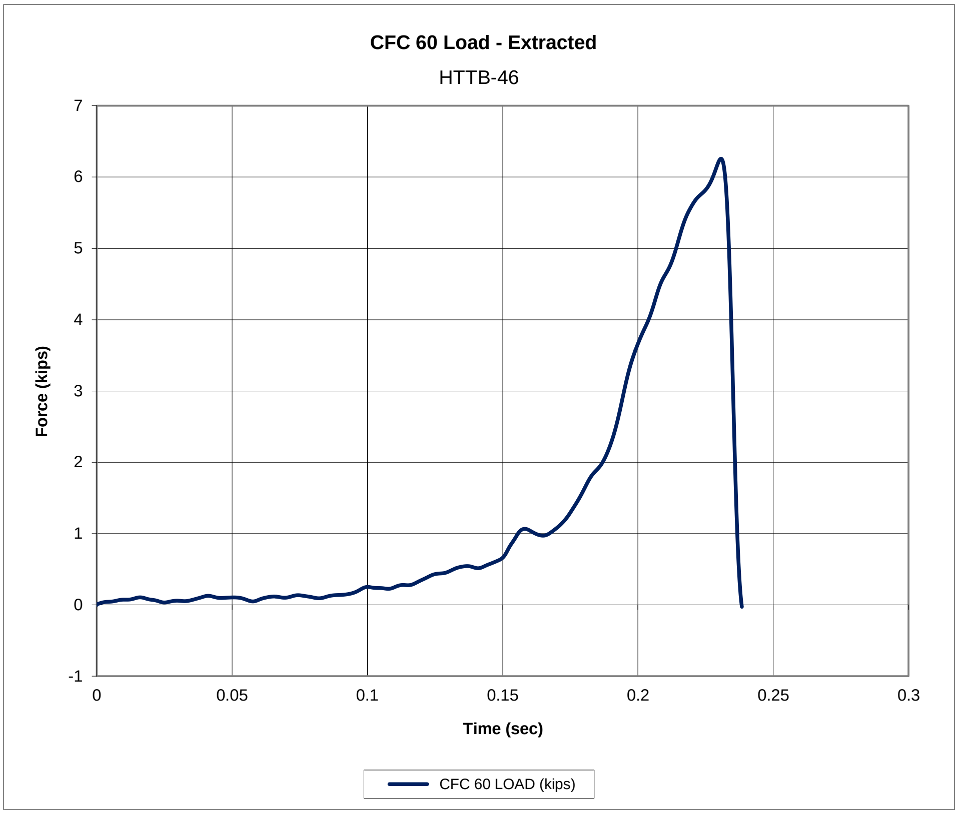
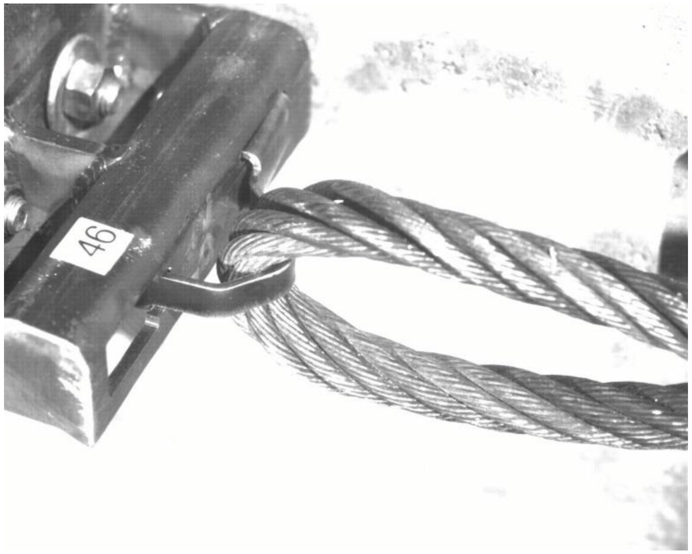


Figure 70. Force vs. Time Data, Test No. HTTB-46

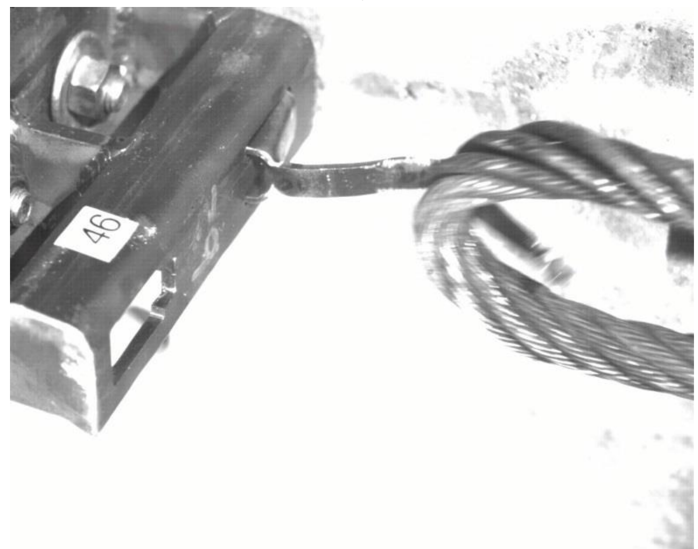
Figure 71. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-46



Time = 0 sec

Time = 0.206 sec

Time = 0.230 sec



Time = 0.234 sec

Figure 72. Sequential Photographs, Test No. HTTB-46

5.1.7 Test No. HTTB-47

Test no. HTTB-47 evaluated the tabbed bracket with the drop-in shear 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 0.238 seconds after initial loading, the bracket legs began to bend such that the notches in the legs were opening. By 0.240 seconds, small tears formed in the tabs. At 0.244 seconds, the notches in the legs opened and the base of the bracket slid upward over the post flange. At 0.249 seconds, a peak load of 5.30 kips (23.59 kN) was reached, and the tabs sheared off. Subsequently, the top of the bracket pulled through the lower portion of the keyway, the spine was bent open, and the cable was released by 0.254 seconds. The force vs. time curve is shown in Figure 73. Pre- and post-test photographs and sequential photographs are shown in Figures 74 and 75, respectively.

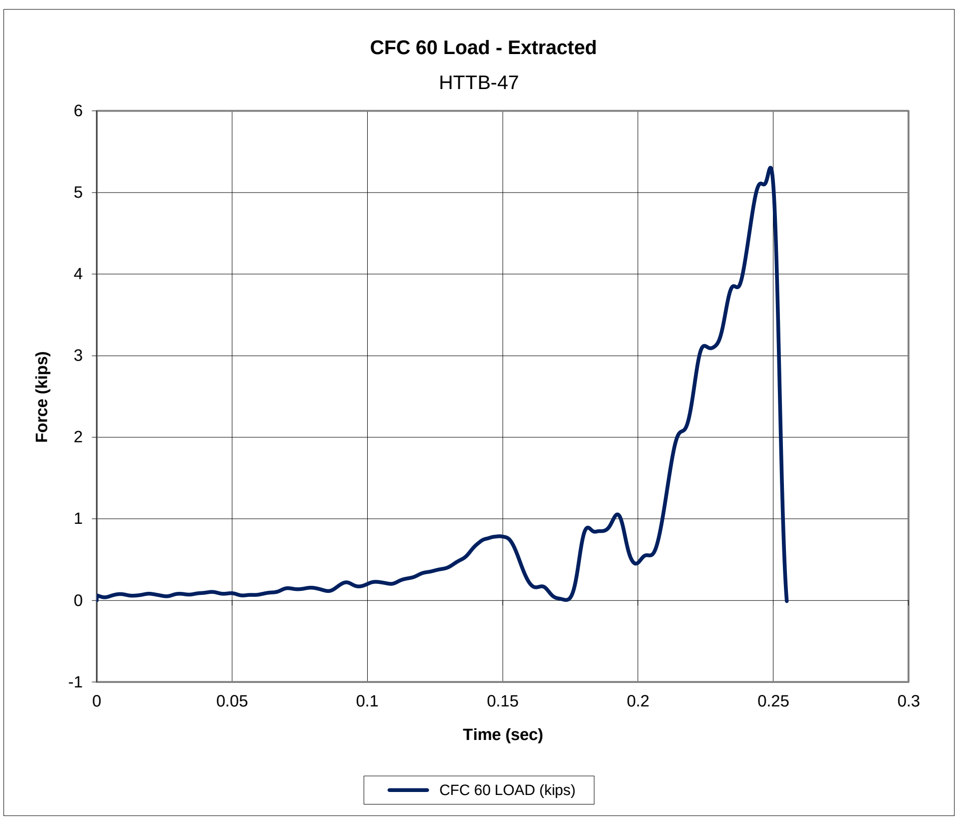
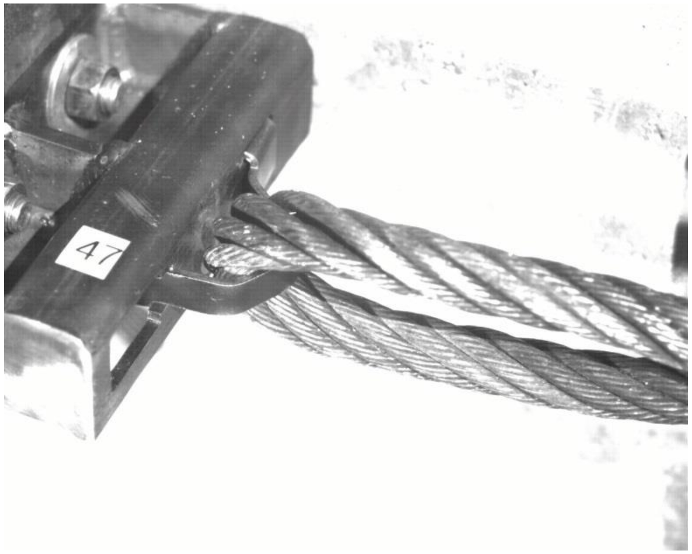


Figure 73. Force vs. Time Data, Test No. HTTB-47

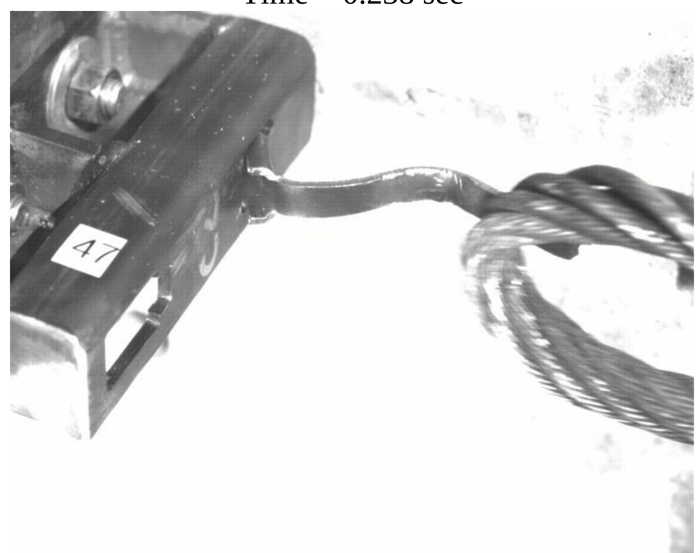
Figure 74. Pre-Test (Upper) and Post-Test (Lower) Photographs, Test No. HTTB-47



Time = 0 sec

Time = 0.238 sec

Time = 0.248 sec



Time = 0.254 sec

Figure 75. Sequential Photographs, Test No. HTTB-47

5.1.8 Test No. HTTB-48

Test no. HTTB-48 evaluated the tabbed bracket with the drop-in shear 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. Around 0.210 seconds after initial loading, the bracket legs began to bend such that the notches in the legs were opening. Additionally, small tears formed in the tabs. At 0.220 seconds, the notches in the legs opened and the base of the bracket slid upward over the post flange. At 0.225 seconds, a peak load of 5.40 kips (24.03 kN) was reached before further tearing and bending of the tabs resulted in the top of the bracket being pulled through the keyway. Immediately following the release of the tabs, tearing began at the bottom of the notches in the bracket legs. As the notches opened to nearly 90 degrees, the legs were pulled through the slots in the post, and the cable pulled the entire bracket away at 0.235 seconds. The force vs. time curve is shown in Figure 76. Pre- and post-test photographs and sequential photographs are shown in Figures 77 and 78, 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.

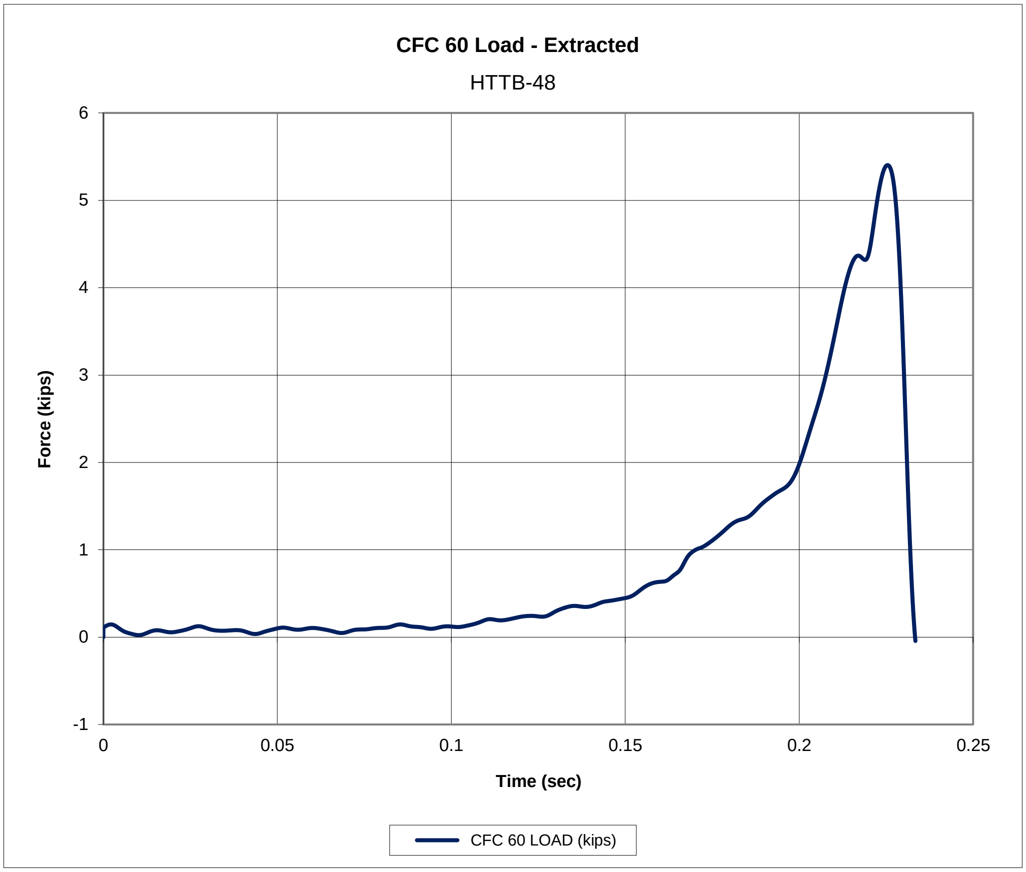


Figure 76. Force vs. Time Data, Test No. HTTB-48

Figure 77. Pre-Test (Top Two) and Post-Test (Bottom Four) Photographs, Test No. HTTB-48

Time = 0 sec

Time = 0.215 sec

Time = 0.225 sec

Time = 0.240 sec

Figure 78. Sequential Photographs, Test No. HTTB-48

5.2 Discussion

Eight dynamic component tests were performed to evaluate the two 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 2. Previous test results of the bolted tabbed bracket V10 [2] were added to the table to allow for direct comparisons. These previous tests are highlighted to avoid confusion with the eight component tests conducted herein.

Table 2. 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-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 test results from previous study [2]

Results from the vertical tests showed promise, as the tabbed portion of the brackets rotated up through the keyway and released the cable in all four tests. Three out of the four tests had release loads within the 300-400-lb (1.3-1.8-kN) targeted range. Test no. HTTB-44 resulted in a release load of over 1 kip (4.4 kN) due to the tabs rubbing and snagging on the inside of the flange prior to release. This type of snagging was also observed in previous component tests of unsuccessful versions of the bolted tabbed bracket [2]. When the tabs are not located properly with respect to the keyway, the tabs will rub and snag on the inside of the flange, causing increased vertical release loads. Even though only one of the four vertical tests resulted in the tabs rubbing and snagging on the flange, all four tests began with the brackets rotating outward, which brought the tabs closer to the flange.

The reason for this bracket rotation was the bracket-to-post attachment mechanisms. Although the tops of the new brackets were identical to the original bolted tabbed bracket V10, the bottom attachments of the new designs did not provide the rigidity that the bolted design did. The bolted attachment prevented rotations and displacements; thus, the bottom of the bracket was fixed. Both of the shear plate attachments lacked this fixity and allowed some rotation of the brackets to occur prior to loading that moved the tabs closer to the post flange which ultimately caused the snagging and higher loads. Even though the shear plate attachments were only given a $^{1}/_{16}$-in. (1.6-mm) construction/installation tolerance, high-speed video showed the new brackets rotating and shifting under low initial loads.

All lateral tests resulted in the tabs being caught by the narrow end of the keyway. As the load in the cable was increased, the brackets eventually released as the tabs were torn/bent, which allowed the top of the bracket to pull through the keyway. Additional bending and tearing deformations were found in the brackets around the bottom legs. The lateral shear plate design provided loads very similar to the original bolted bracket, at just over 6 kips (26.7 kN). However, the release loads for the drop-in shear plate design were lower than expected at 5.4 kips (24.0

kN). The slots cut into the legs of the bracket for the drop-in shear plate design provided a weak spot, and the bracket legs bent open and even tore (test no. HTTB-48) during the tests.

The location of the bracket fracture/failure during the lateral tests varied between the original bolted bracket and the new shear plate brackets, as shown in Figure 79. This finding may be explained in part by the small bracket rotations allowed by the shear plate attachments. These rotations may have led to tabs contacting the post flange at an angle and causing tab bending and out-of-plane tearing that would not have occurred if the tabs were normal to the flange. Or put more simply, the difference in the constraints at the base of the bracket may have changed the loading and failure of the drop-in shear plate design. However, this variation in fracture/failure locations was not a major concern. The bolted tabbed bracket was designed with the same failure/fracture strength for failures around the bolt hole, through the spine of the bracket, and at the tabbed portion of the bracket. Consequently, the release load between the bolted bracket and the lateral shear plate bracket remained nearly identical. The bending/tearing of the bracket legs in the drop-in shear plate design was not intended and potentially lowered the release loads.

Tearing was also initiated in the lateral shear plate brackets at the junction between the bracket spine and the bottom legs, as shown in Figure 79. This out-of-plane tearing (mode III fracture) was considered a possibility before the tests were conducted. However, the tearing was minor, and this additional failure mechanism did not affect the release loads in the brackets. Thus, it is no longer a concern.

As mentioned previously, the shear plate attachment mechanisms were designed with $^{1}/_{16}$ in. (1.6 mm) of construction tolerance between the bracket legs and the shear plates. This small amount of tolerance was considered necessary to ensure the components would fit together properly during installation, and is half of the ⅛-in. (3.2-mm) tolerance typically given to bolts and bolt holes in steel connections, including the bolted tabbed bracket. However, this small tolerance allowed the brackets to rotate about their bases, resulting in the location of the top tabs being much closer to the post flange than intended. Again, if the tabs are located too close to the flange or located incorrectly in the keyway and rub against the inside of the flange during loading, the vertical release loads may increase dramatically. The vertical release loads are important to prevent occupant compartment crush by the cables when the vehicle is being redirected by lower cables and passing under the upper cables. Thus, it is important that the top of the bracket be positioned correctly.

The initial locations of the tabbed brackets after installation but prior to component testing are shown in Figures 80 through 82. The bolted tabbed brackets have the intended offset between the tabs and the inside of the post-flange as shown in Figure 80. This seating of the tabbed bracket can be attributed to the rigidity of the bolted attachment which prevented any "wiggle" in the bracket. The initial position of the tabbed bracket with the lateral shear plate attachment is much closer to the inside of the post flange than in the bolted brackets due to the allowed rotation and displacement of the shear plate attachment as shown in Figure 81. In the lateral test setup photograph shown in Figure 81, the base of the bracket rotated around the shear plate enough to bring the tabbed top adjacent to the inside of the flange, even prior to loading. These same issues with the drop-in shear plate design as the tabs appear to be directly adjacent to the flanges prior to loading are shown in Figure 82. To summarize, two factors in the tabbed bracket design give potential for issues. First, multiple slots and interlocking parts cause excess slip in the attachment, potentially allowing rotation of the bracket. Second, the lack of a bolted constraint prevents preloading the base of the bracket to hold the bracket in position regardless of tolerance.

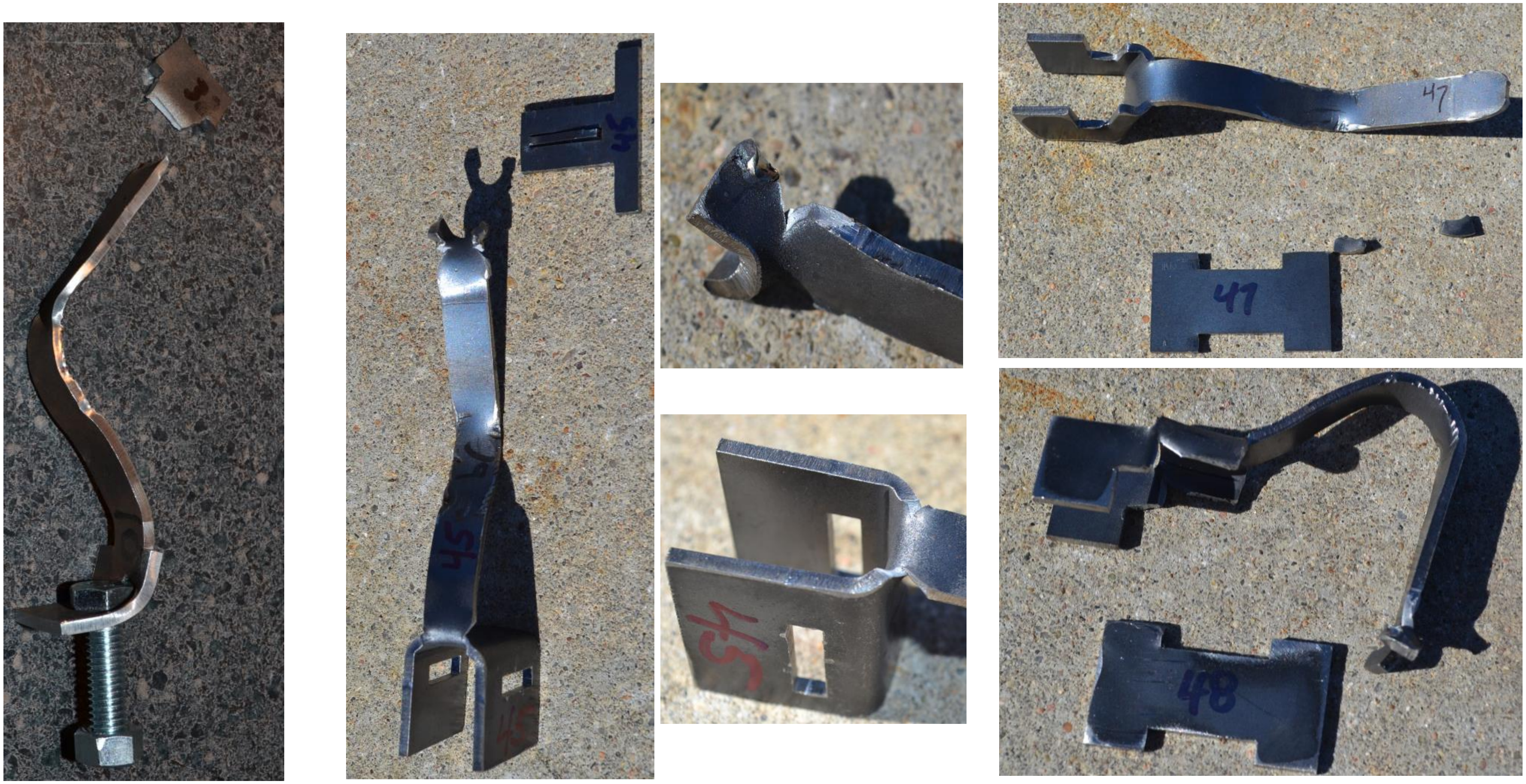
It was recognized that galvanizing the post and bracket hardware will eliminate a portion of the tolerance and help prevent the bracket from rotating as much. However, the rotations will likely still occur unless the bracket is redesigned to prevent such rotations. One solution could be to extend the bracket a short distance past the vertical slots in the post (legs of the bracket). This extension would lie flush against the outside face of the post and should minimize the amount of rotation allowed to the bracket.

Although the new bracket attachments were designed to reduce the effort required to install the brackets, test site personnel had difficulty installing and removing the lateral shear plate. First, a few of the snapping levers on the shear plates were not bent far enough out of plane to snap/lock into position. Thus, they had to be adjusted prior to installation, which required substantial effort, as it still takes about 50 lb (220 N) to bend the tiny lever arm. Consequently, installers may need tools to aid in this effort during installations. Additionally, removal of the lateral shear plates proved to be challenging. The buckling mechanism was on the inside of the bracket legs and was difficult to get at within the small confines of the MWP segment. Thus, tools may also be required during removal of an attachment bracket. Even if the buckle was moved to the outside of the bracket legs, removal would still require 50 lb (220 N) of force, which is a large force to squeeze between a finger and thumb. Therefore, a tool would still be necessary to squeeze the part together for removal.

It should also be recognized that the shear plates are not much larger than the bolt of the original bolted tabbed bracket design, as shown in Figure 83. The MWP utilized in the current cable barrier system is only 1⅝ in. (41 mm) wide and 3 in. (76 mm) deep through its cross section. This leaves very little room for attachment hardware, and the designed shear plates cannot get much bigger.

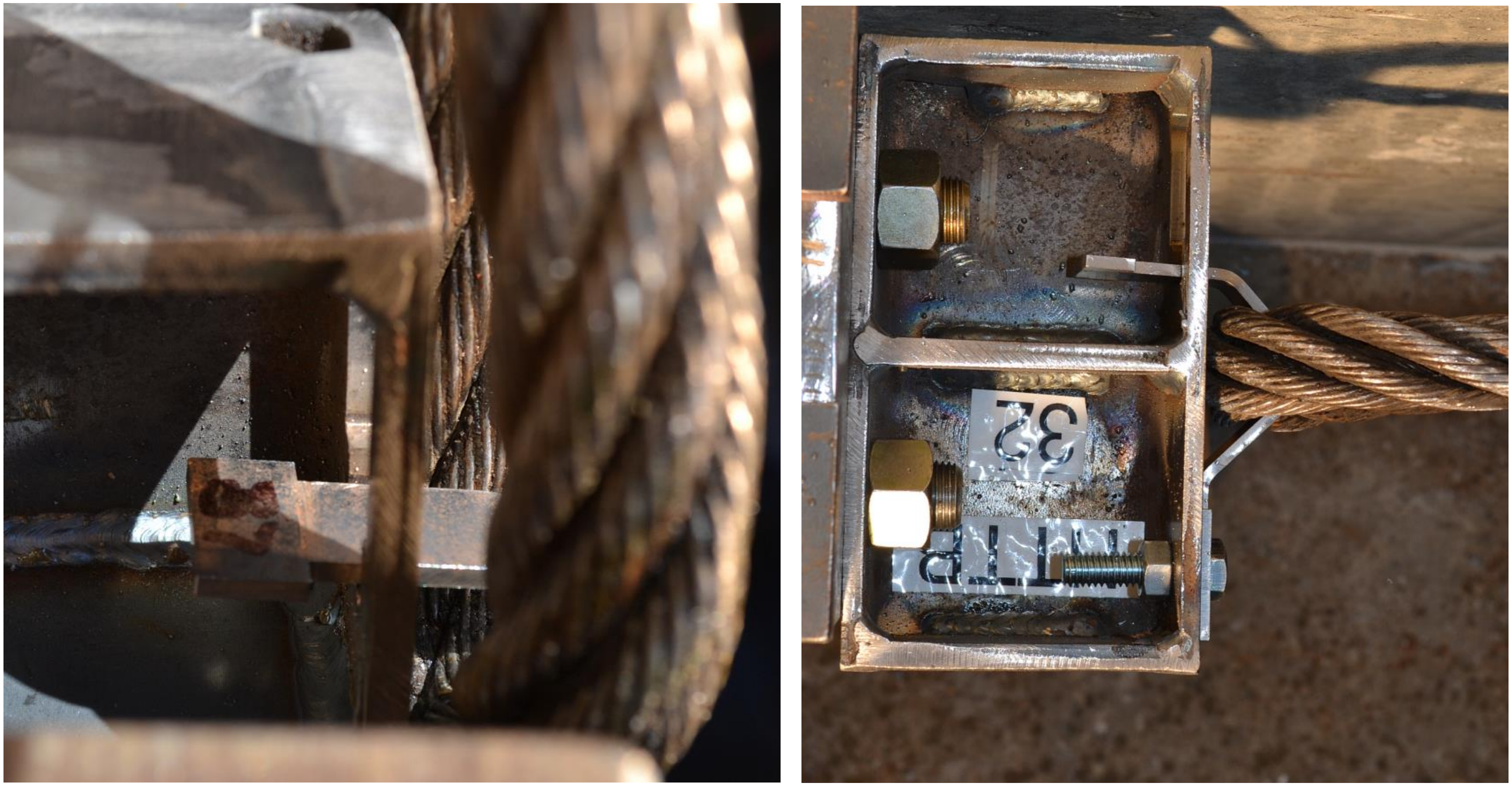
5.3 Conclusion

Based on the testing and analysis performed, conclusions can be made pertaining to the performance of the tested tabbed brackets. First, the lateral shear plate performed adequately in lateral and vertical testing, but bracket rotation caused concern for consistent function of the bracket. Furthermore, the installation and removal was difficult as designed. Second, the drop-in shear plate did not perform well in lateral and vertical testing. The installation and removal of the drop-in shear plate was difficult. It should be noted that neither design simplified installation significantly. As a result, the bolted tabbed bracket is currently the best option unless further redesign of these concepts or other concepts is undertaken to address these concerns.



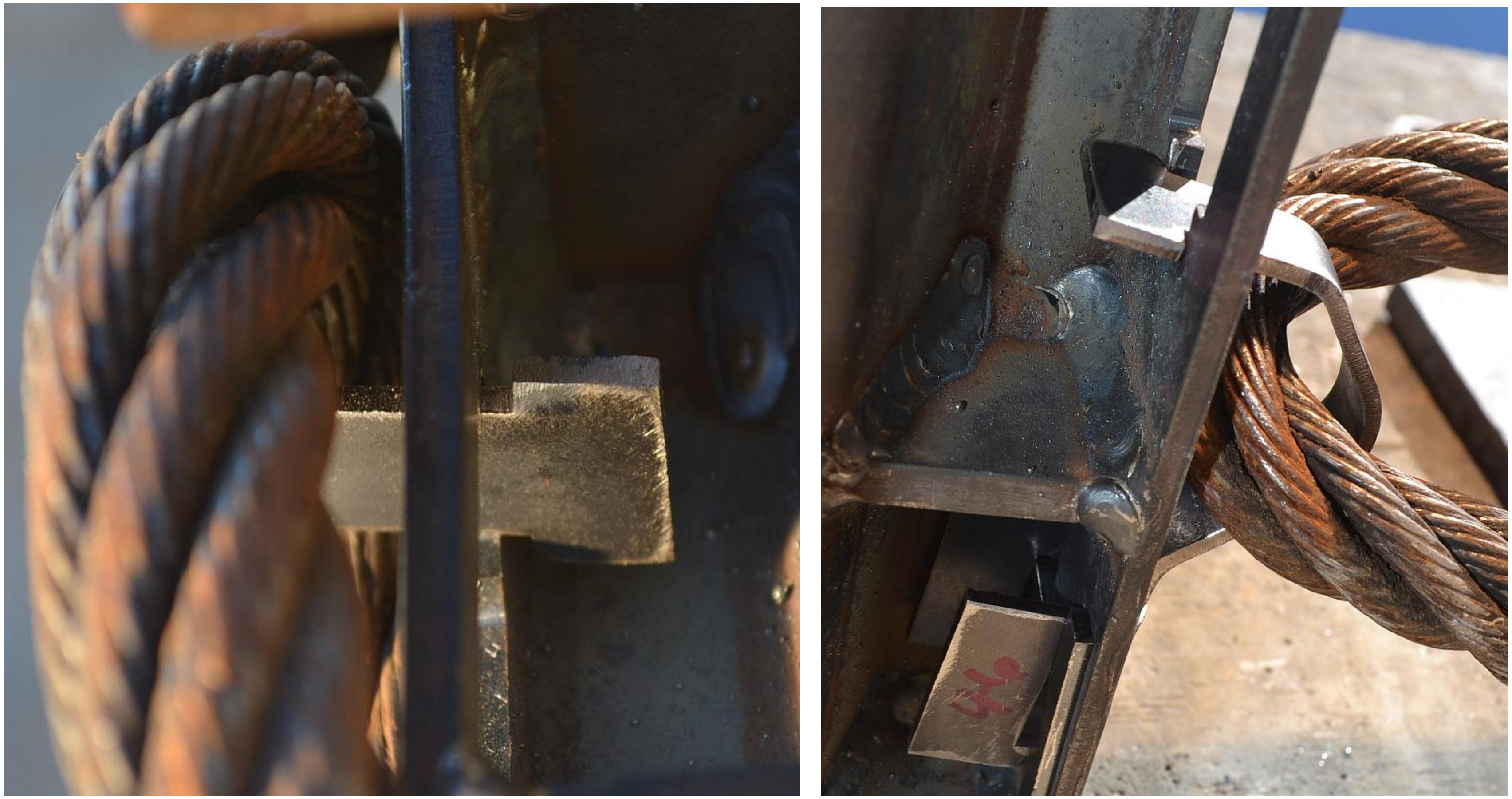
Bolted Bracket | Lateral Shear Plate Bracket | Drop-In Shear Plate Bracket

Figure 79. Lateral Test Fracture/Failure Mechanisms for Various Bracket Designs



Vertical Test Lateral Test

Figure 80. Bolted, Tabbed Bracket, Pre-Test Tab Locations Relative to Post Flange



Vertical Test Lateral Test

Figure 81. Lateral Shear Plate Bracket, Pre-Test Tab Locations Relative to Post Flange

Vertical Test Lateral Test

Figure 82. Drop-In Shear Plate Bracket, Pre-Test Tab Locations Relative to Post Flange

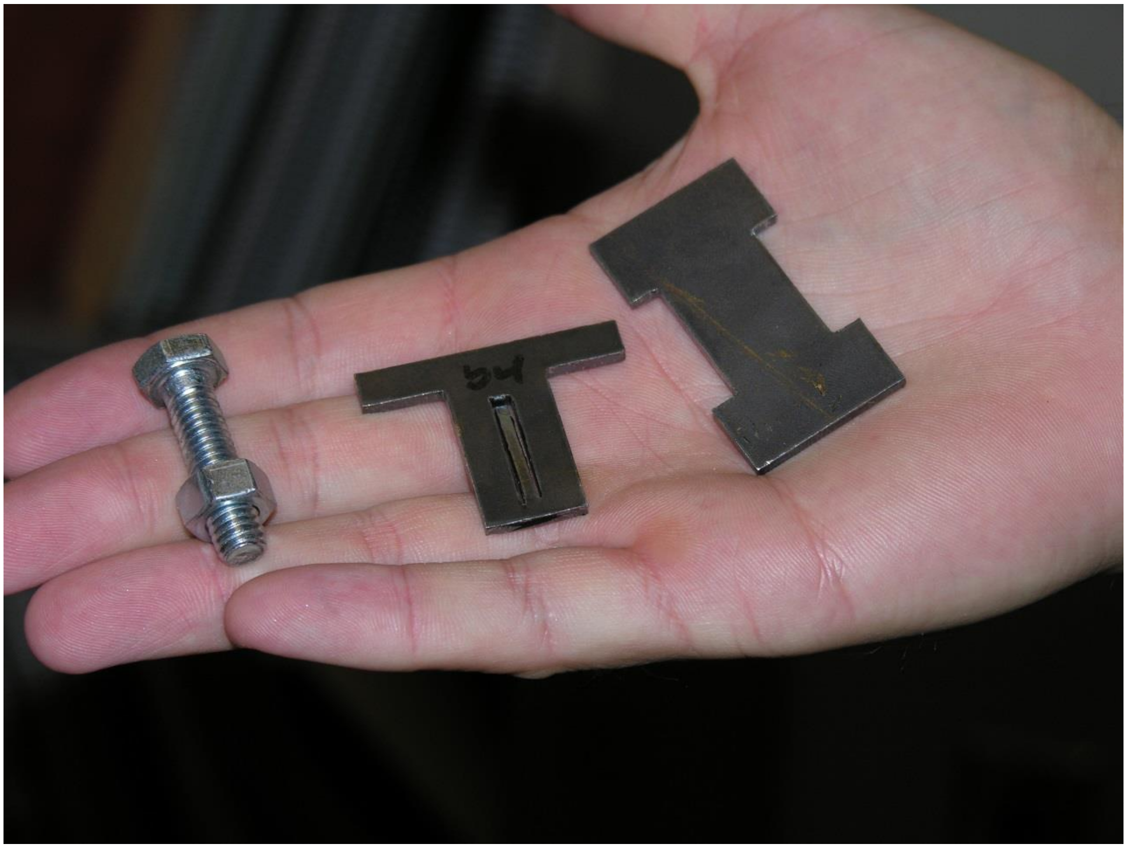


Figure 83. Component Size Comparison for the Various Tabbed Bracket Attachments

6 TOP CABLE ATTACHMENT DESIGN AND TESTING CONDITIONS

6.1 Scope

Between 2011 and 2012, MwRSF developed a top cable attachment, in which the cable was positioned inside a notch cut into the top of the post and held in place by a brass keeper rod [2]. The original ⅛-in. (3.2-mm) diameter brass rod was designed to release quickly after a vehicle impacts a post, thus preventing the cable from being pulled down and the vehicle overriding the system. Dynamic bogie testing showed the ⅛-in. (3.2-mm) diameter brass rod released the top cable with only a minimal deflection as the post was bending [2]. However, further testing was desired to evaluate the dynamic release of larger and stronger keeper rods. Utilizing results from the original static testing conducted on various keeper rod sizes and materials, a $^{3}/_{16}$-in. (4.8-mm) diameter C360 brass rod was selected for evaluation. Brass rods with diameters larger than $^{3}/_{16}$ in. (4.8 mm) were not chosen for further testing, due to the static test release loads exceeding 1,000 lb (4.4 kN) [2].

One dynamic bogie test, test no. HTTC-2, was performed to evaluate the performance of $^{3}/_{16}$-in. (4.8-mm) diameter brass rods for use in the top cable-to-post attachments within the new cable barrier system. The test setup and impact conditions were established to repeat the test on the original ⅛-in. (3.2-mm) diameter rod, as shown in Figures 84 through 97. The small-scale cable barrier system consisted of five MWPs and two end terminals. The MWPs were embedded 18 in. (457 mm) in compacted soil and had v-notches cut into the top of the line posts. Only the top cable was installed on the posts for this component test, and it was tensioned to 2,480 lb (11.0 kN). The targeted impact conditions were a speed and angle of 45 mph (72.4 km/h) and 25 degrees, respectively. The middle post was impacted $24^{7}/_{8}$ in. (632 mm) above the groundline. Pre-test photographs can be found in Figure 98. Material specifications, mill certifications, and certificates of conformity for the prototype system are shown in Appendix A.

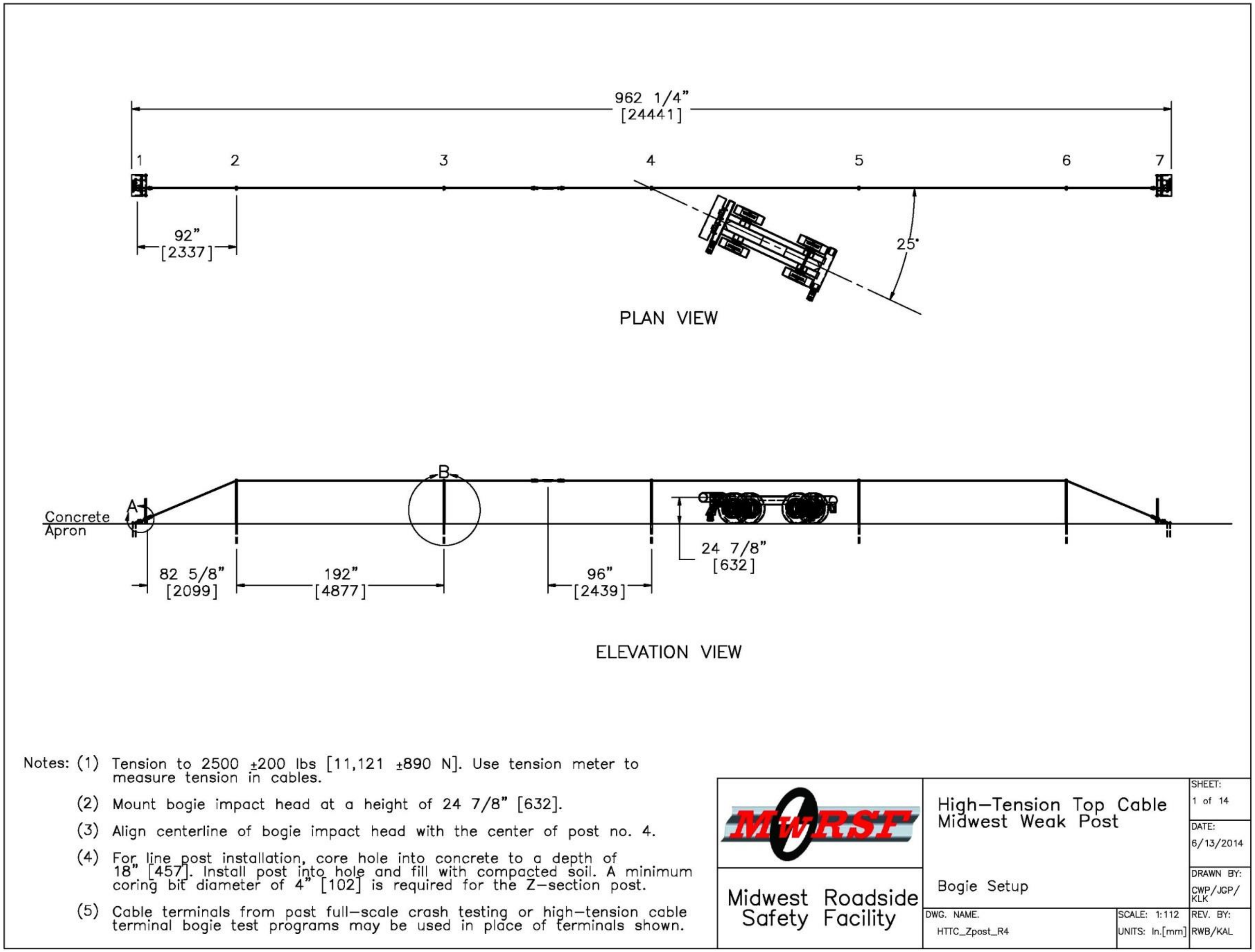


Figure 84. Bogie Setup, Test No. HTTC-2

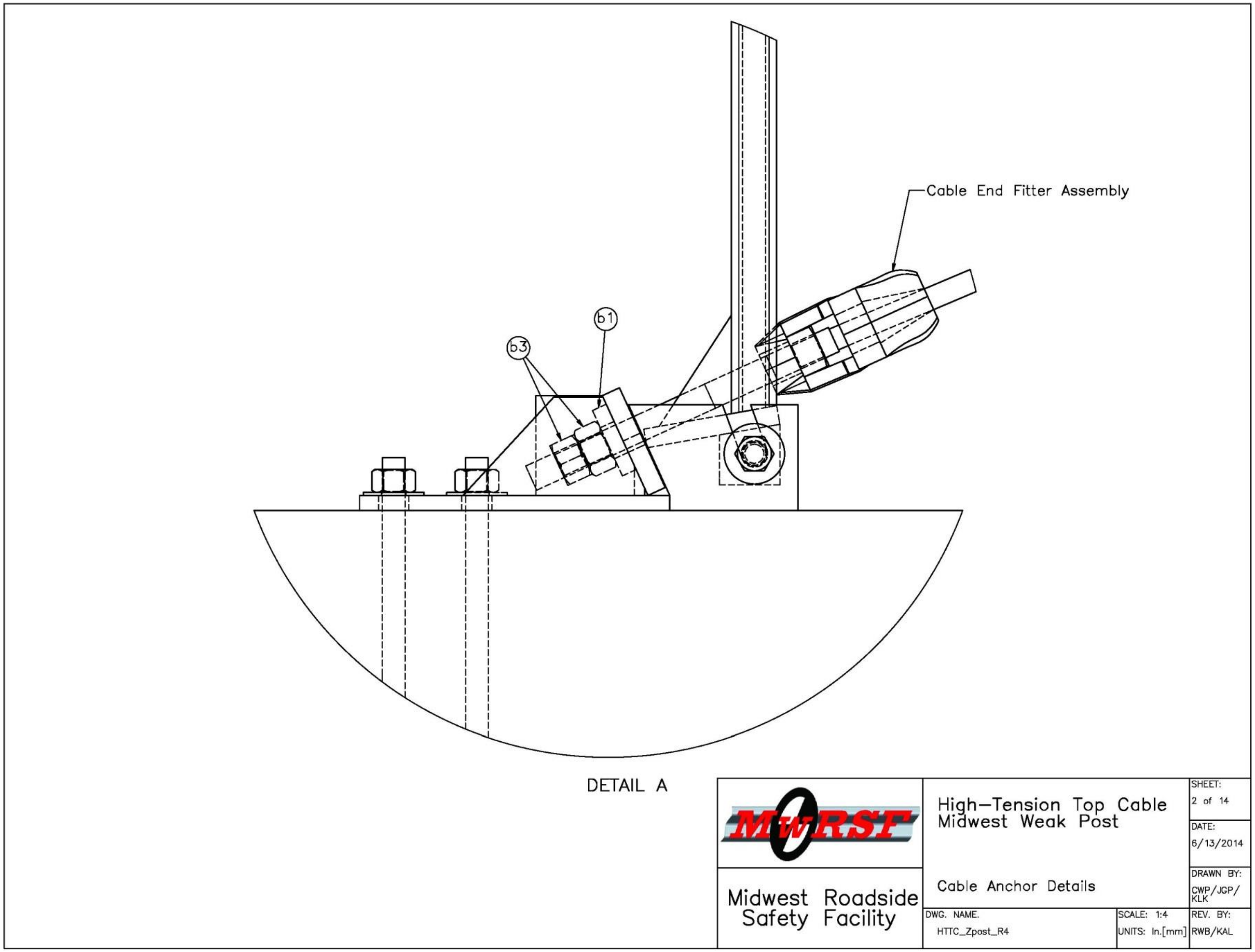


Figure 85. Cable Anchor Details, Test No. HTTC-2

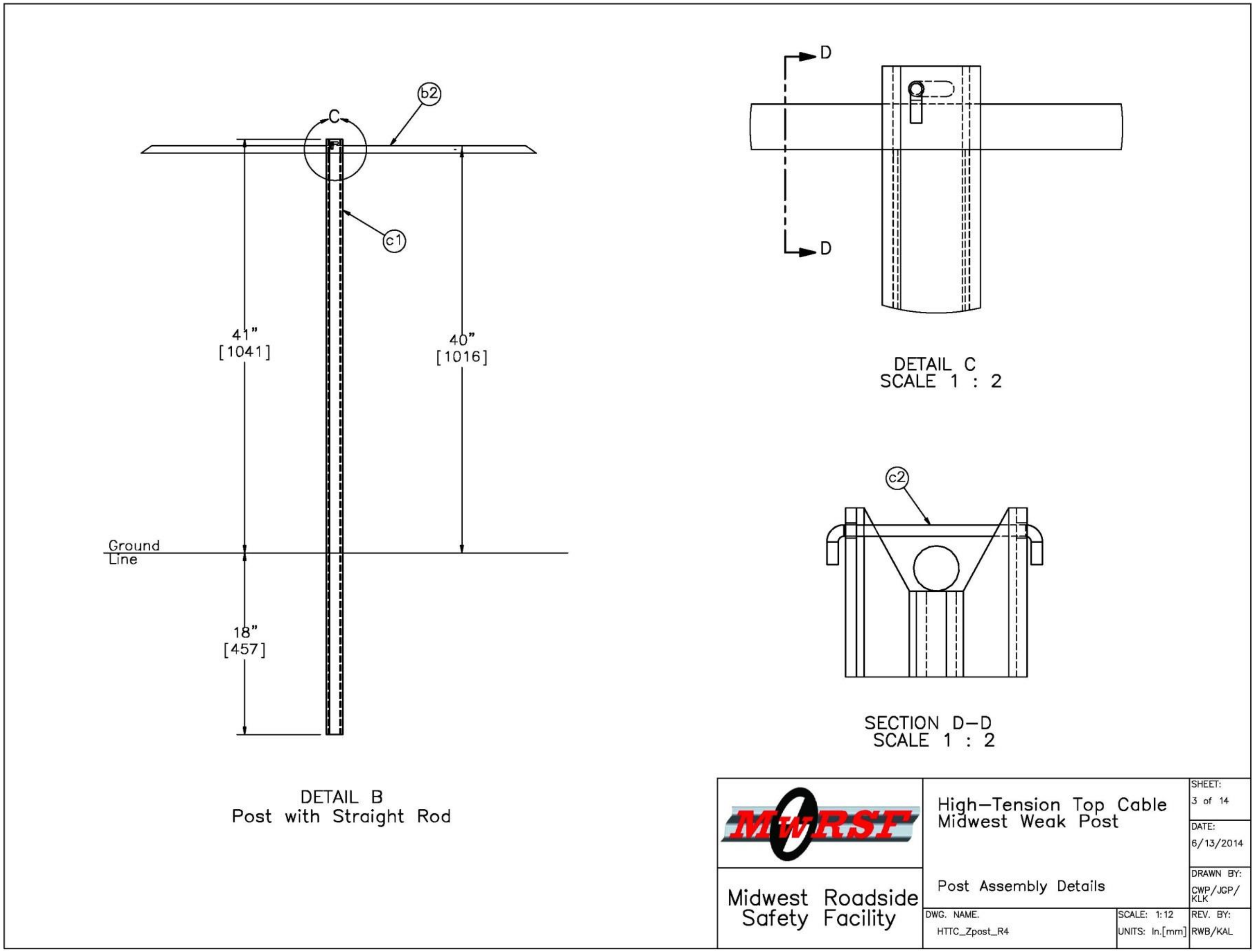


Figure 86. Post Assembly Details, Test No. HTTC-2

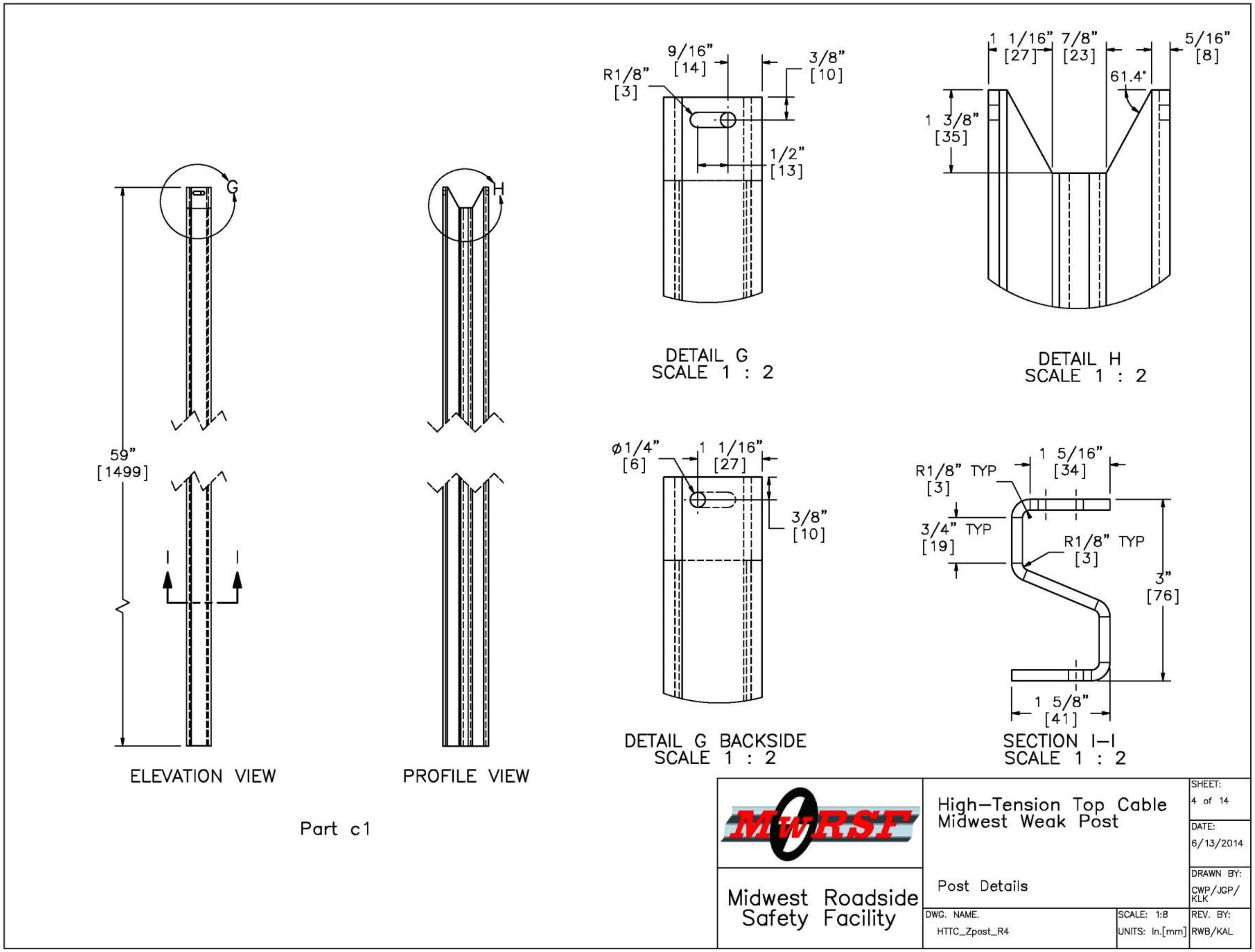


Figure 87. Midwest Weak Post Details, Test No. HTTC-2

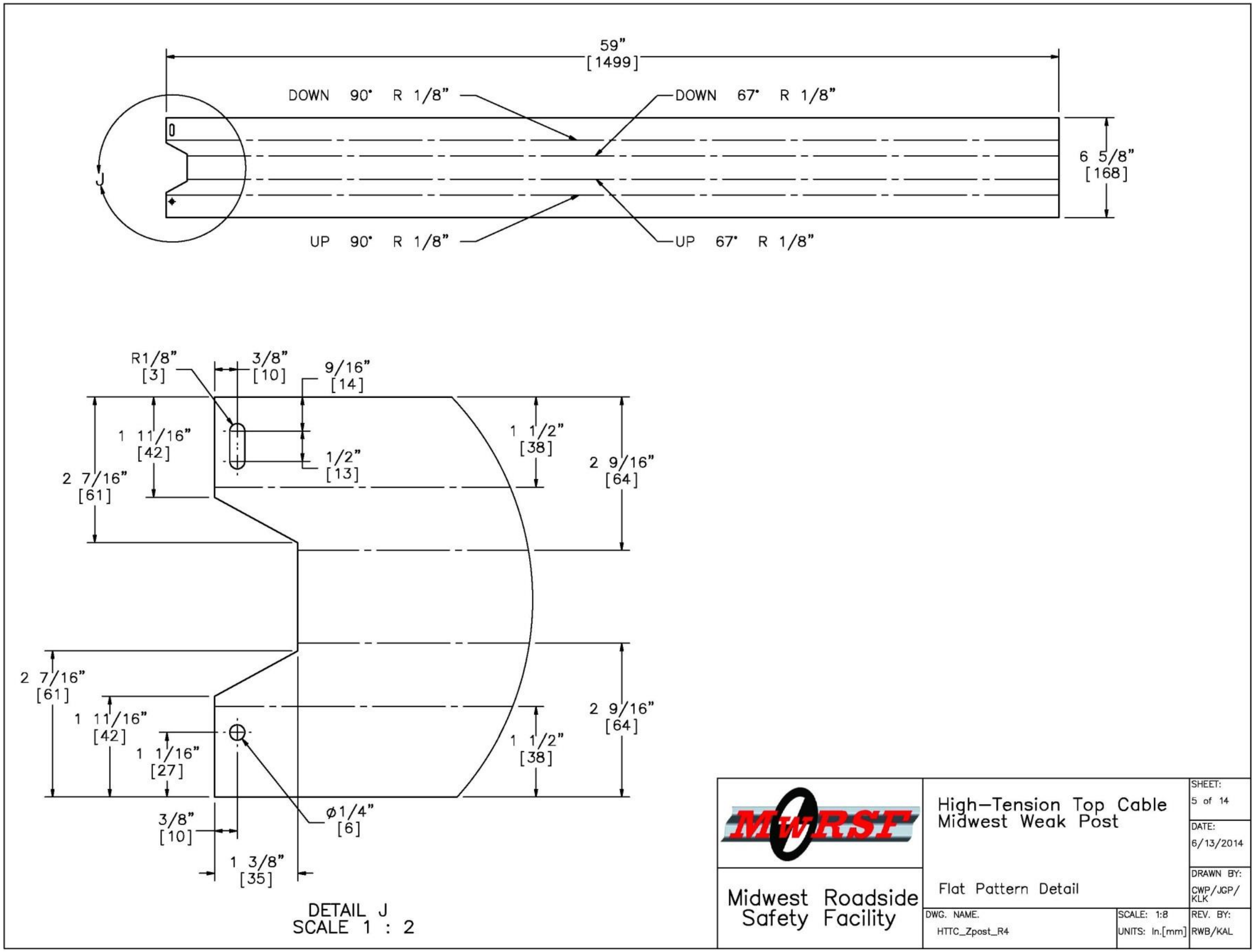


Figure 88. Midwest Weak Post Flat Pattern Detail, Test No. HTTC-2

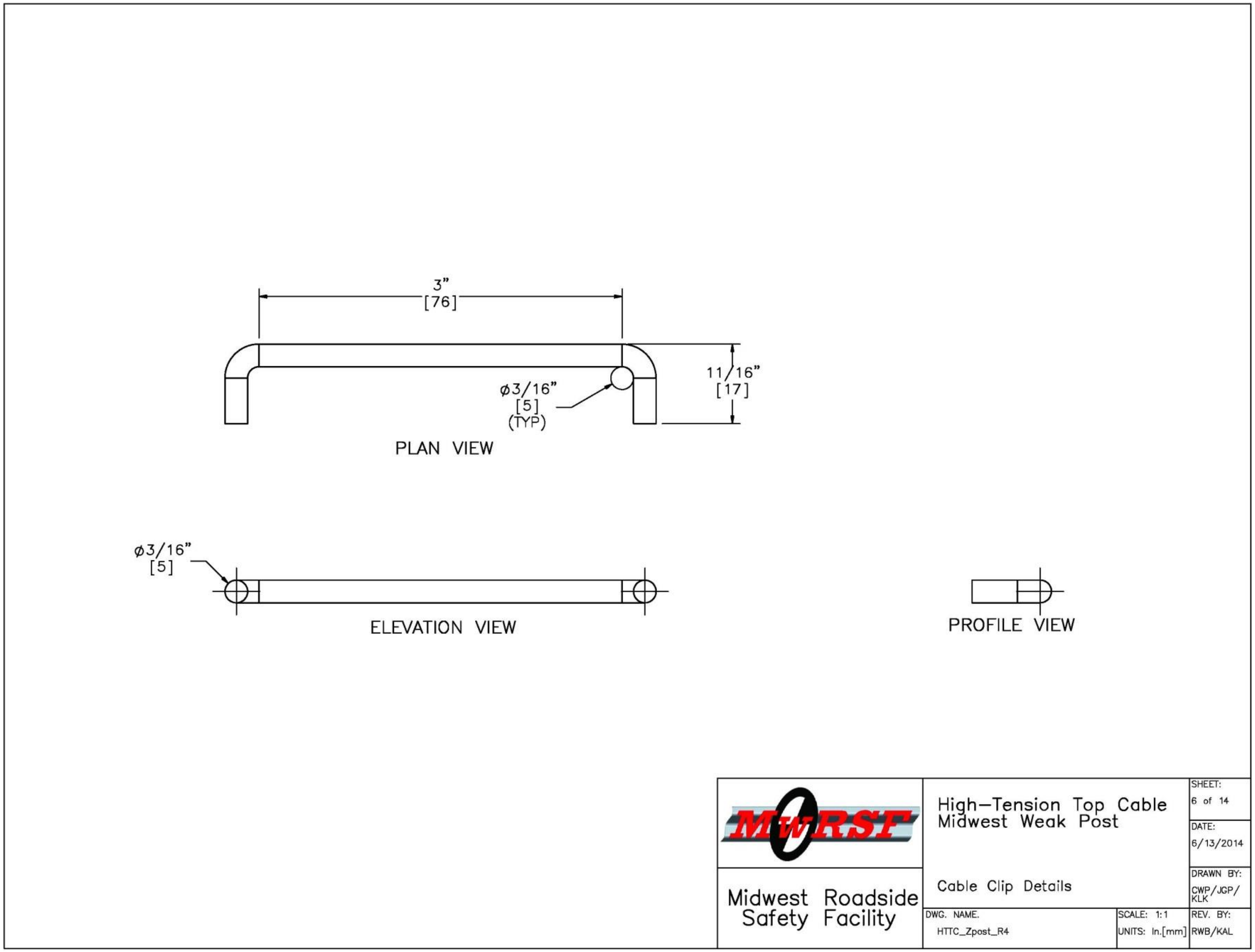


Figure 89. Cable Clip Details, Test No. HTTC-2

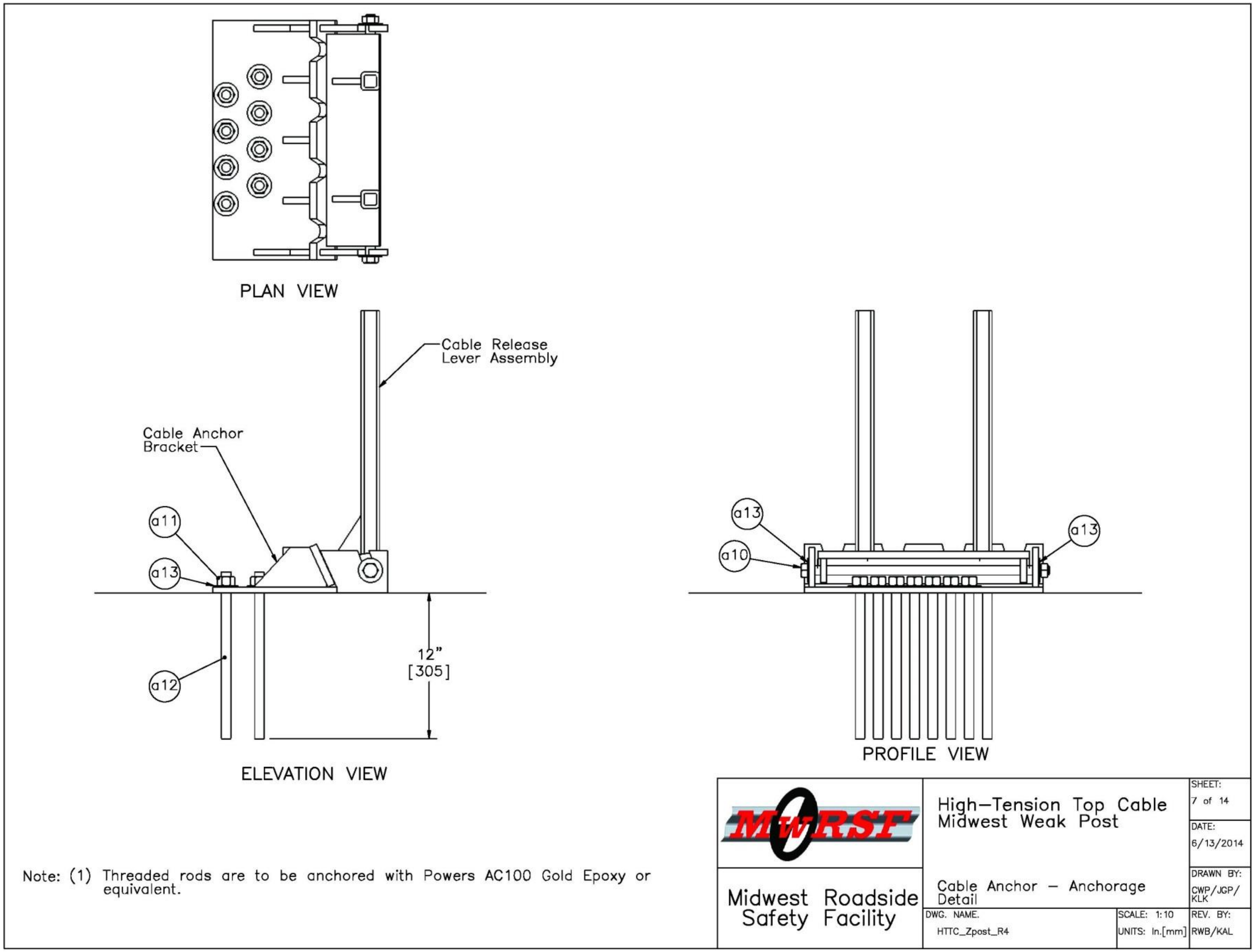


Figure 90. Cable Anchor – Anchorage Detail, Test No. HTTC-2

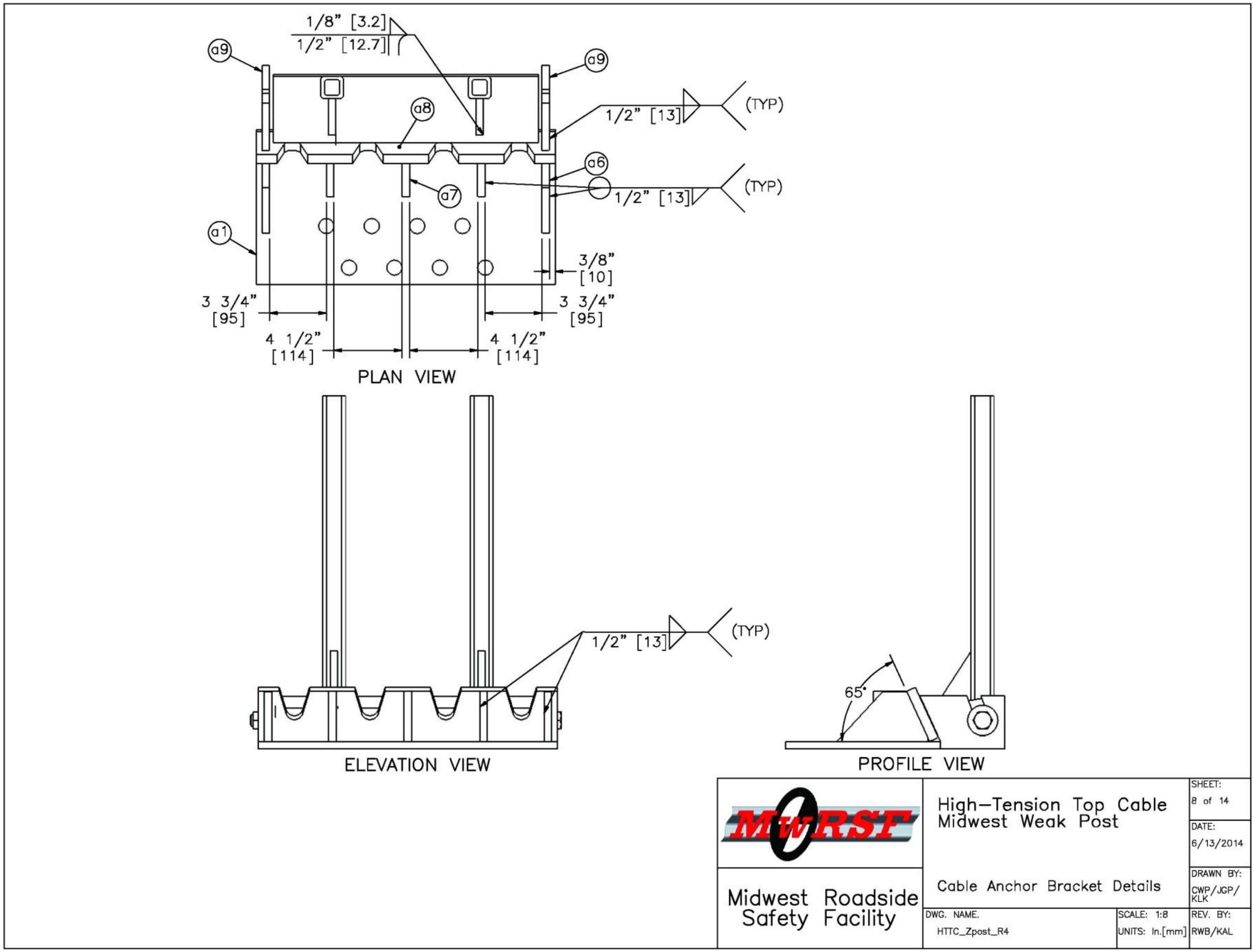


Figure 91. Cable Anchor Bracket Details, Test No. HTTC-2

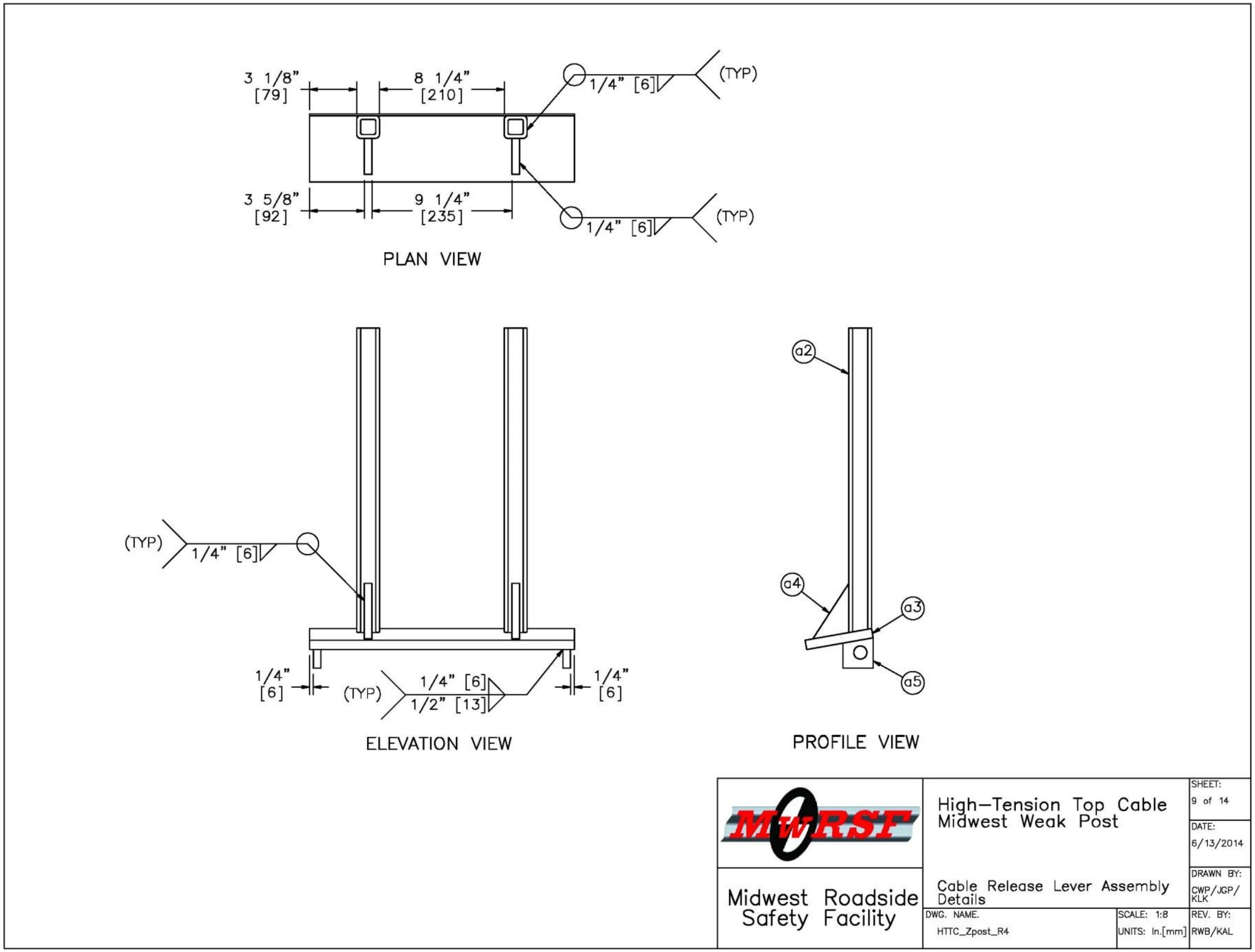


Figure 92. Cable Release Lever Assembly Details, Test No. HTTC-2

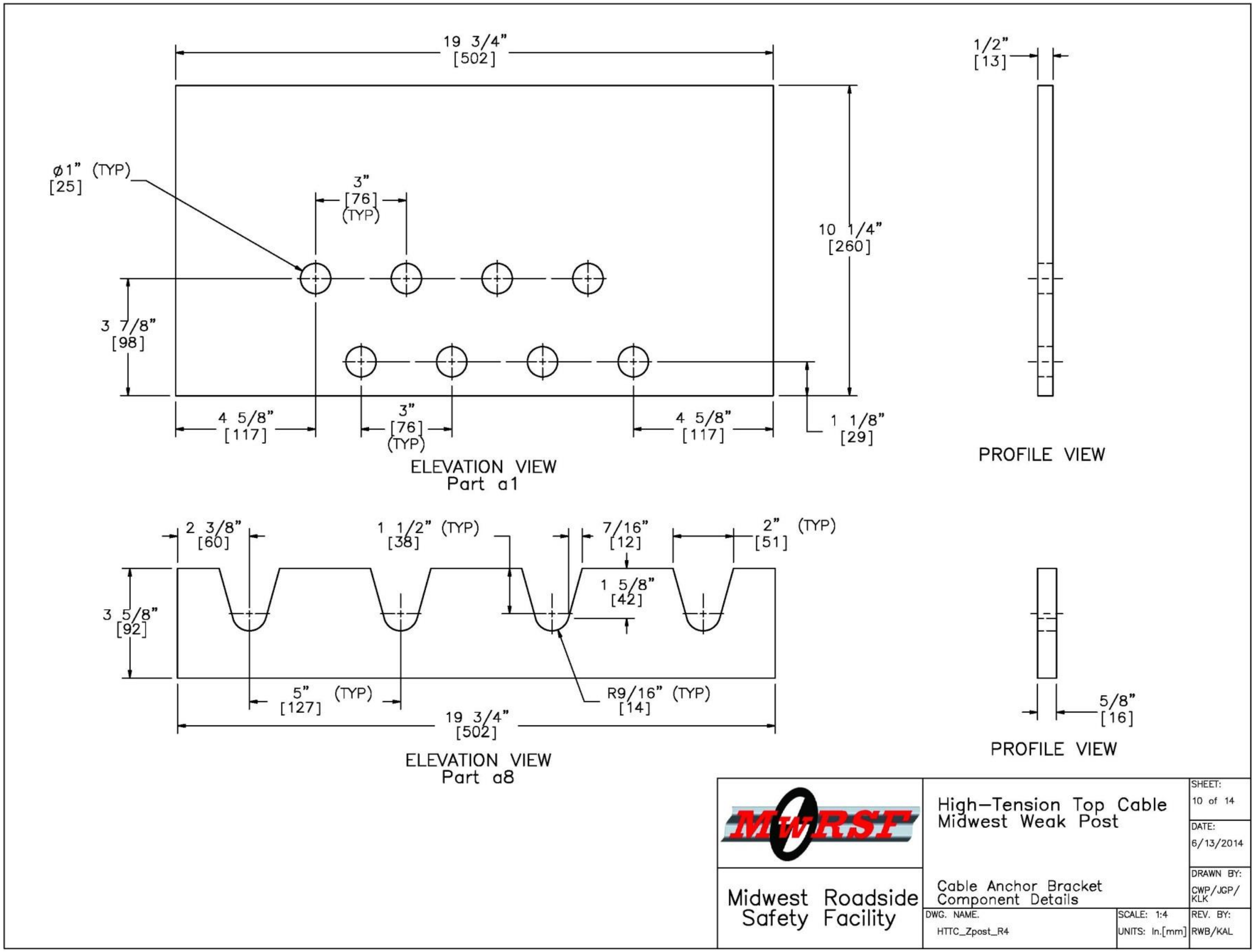


Figure 93. Cable Anchor Bracket Component Details, Test No. HTTC-2

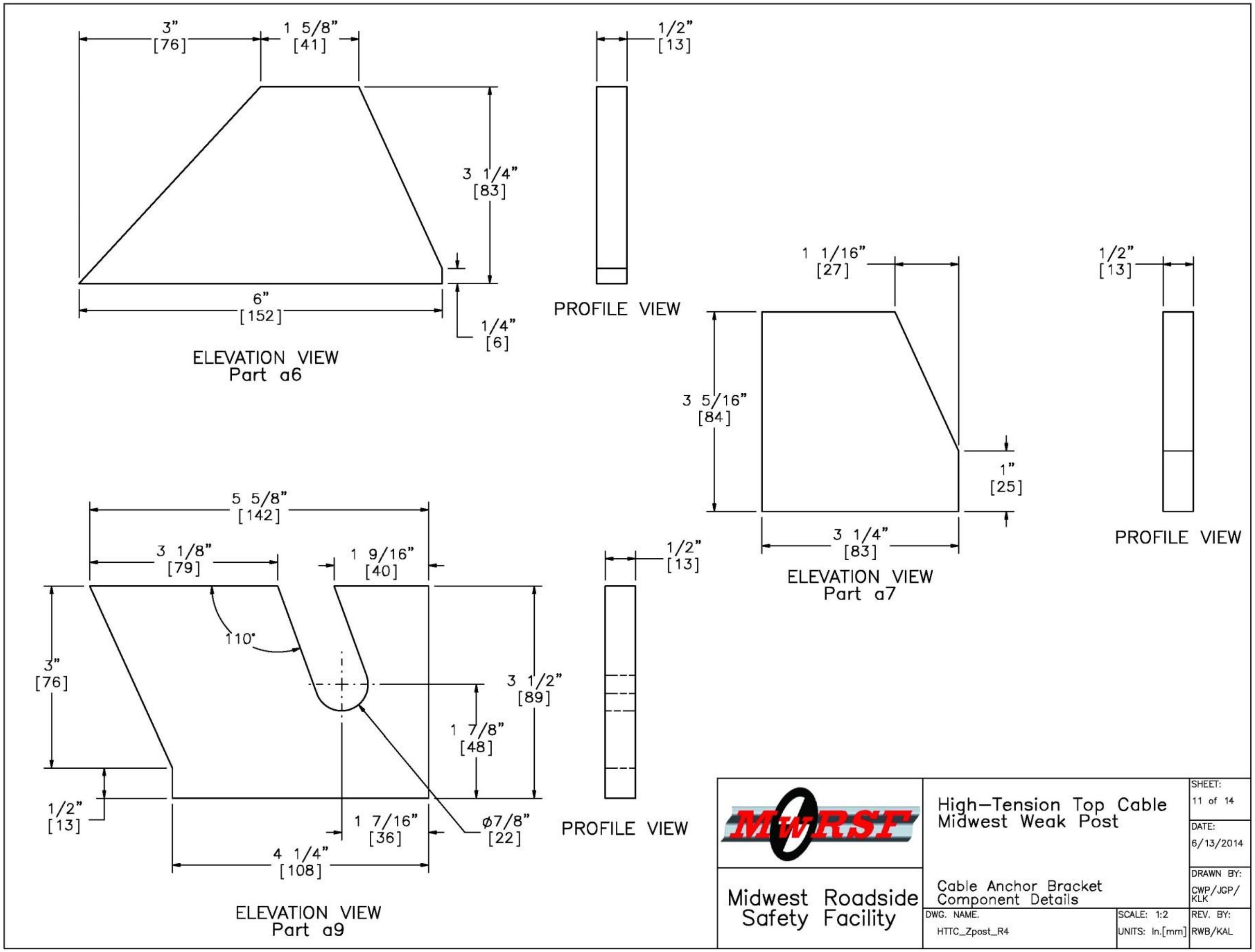


Figure 94. Cable Anchor Bracket Component Details, Test No. HTTC-2

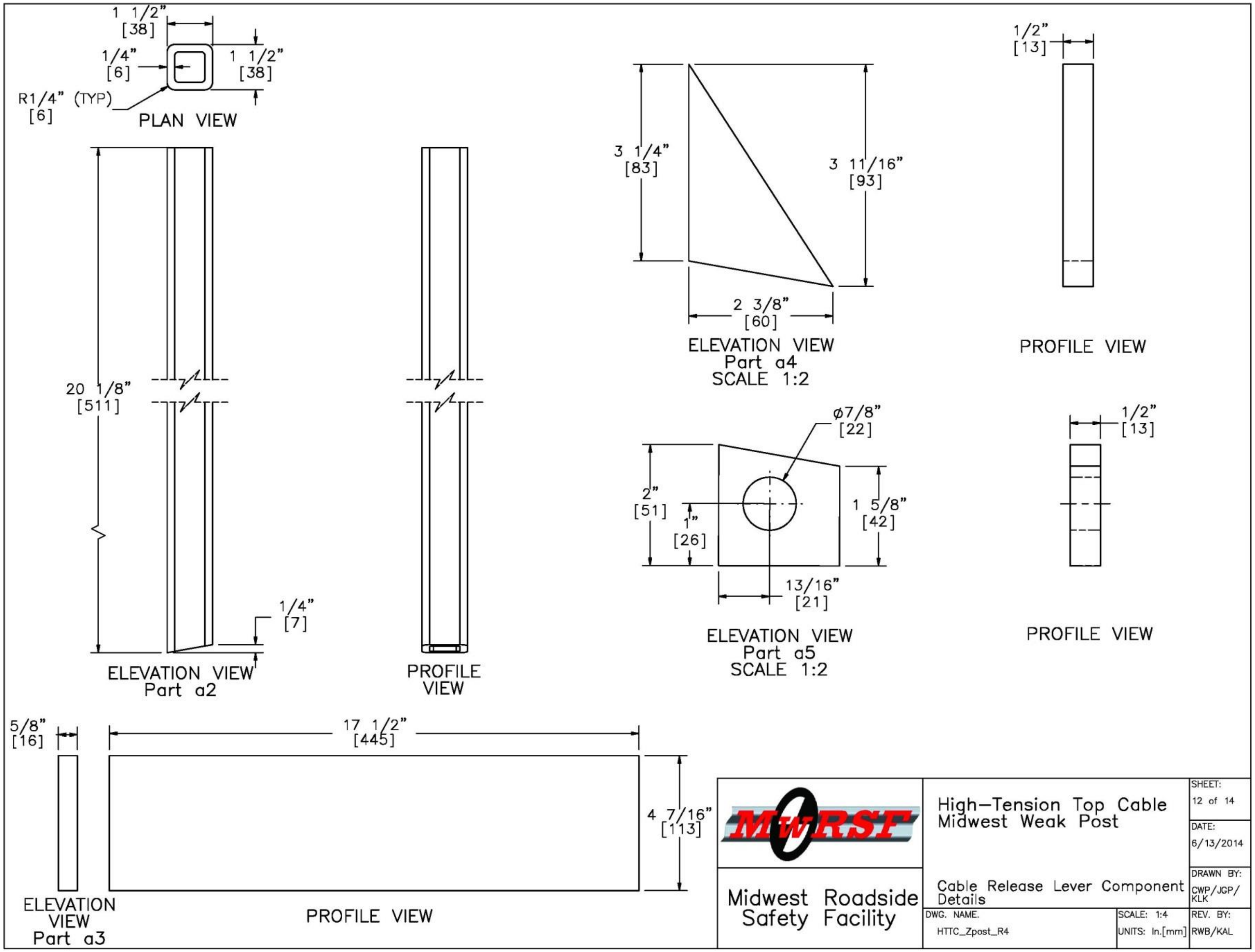


Figure 95. Cable Release Lever Component Details, Test No. HTTC-2

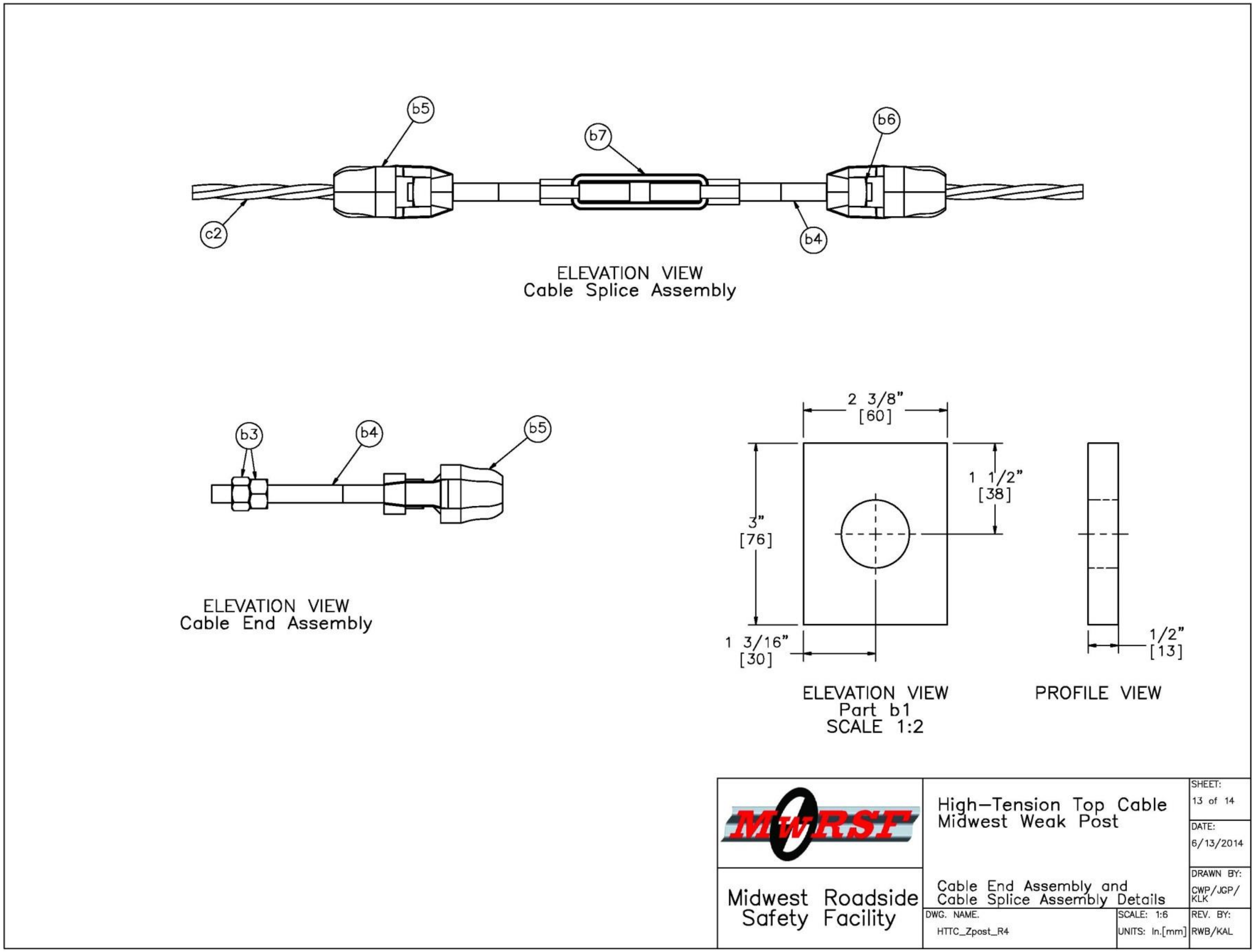


Figure 96. Cable End Assembly and Cable Splice Assembly Details, Test No. HTTC-2

Item No.	QTY.	Description	Material Specifications	Hardware Guide
a1	2	Cable Anchor Bracket Base Plate, 19 3/4" x 10 1/4" x 1/2" [502 x 260 x 13]	ASTM A36 Steel	–
a2	4	Cable Release Lever Impact Tube, 1 1/2" x 1 1/2" x 1/4" [38 x 38 x 6]	ASTM A500 Gr. B	–
a3	2	Cable Release Lever Base Plate, 17 1/2" x 4 7/16" x 5/8" [445 x 113 x 16]	ASTM A36 Steel	–
a4	4	Cable Release Lever Support Gusset, 3 11/16" x 2 3/8" x 1/2" [94 x 60 x 13]	ASTM A36 Steel	–
a5	4	Cable Release Lever Rotation Bracket, 2" x 2" x 1/2" [51 x 51 x 13]	ASTM A36 Steel	–
a6	4	Cable Anchor Bracket Exterior Gusset, 6" x 3 1/4" x 1/2" [152 x 83 x 13]	ASTM A36 Steel	–
a7	6	Cable Anchor Bracket Interior Gusset, 3 5/16" x 3 1/4" x 1/2" [84 x 83 x 13]	ASTM A36 Steel	–
a8	2	Cable Anchor Bracket Cable Plate, 19 3/4" x 3 5/8" x 5/8" [502 x 92 x 16]	ASTM A36 Steel	–
a9	4	Cable Anchor Bracket Rotation Bracket, 5 5/8" x 3 1/2" x 1/2" [143 x 89 x 13]	ASTM A36 Steel	–
a10	2	3/4" [19] Dia. UNC, 20" [508] Long Hex Bolt* and Nut	ASTM A307	
a11	16	3/4" [19] Dia. UNC Heavy Hex Nut	ASTM A563 C	FNX20a
a12	16	3/4" [19] Dia. UNC, 13 3/4" [349] Long Threaded Rod	ASTM A449/ASTM A193 Gr. B7 Galv. or Stainless/SAE Gr. 5	–
a13	20	3/4" [19] Dia. Plain Round Washer	ASTM F844/ SAE Gr. 2	FWC20a
b1	2	CMB High Tension Anchor Plate Washer, 3" x 2 3/8" x 1/2" [76 x 60 x 13]	ASTM A36 Steel	–
b2	1	3/4" [19] Dia. Cable	AASHTO M30 Type 1 Class A	–
b3	4	7/8" [22] Dia. UNC Heavy Hex Nut	ASTM A563 Gr. C	RCE03
b4	4	7/8" [22] Dia. UNC, 11" [279] Long Threaded Rod	ASTM A449/ASTM A193 Gr. B7 Galv. or Stainless/SAE Gr. 5	RCE03
b5	4	Bennet Cable End Fitter	ASTM A47	RCE03
b6	4	7/8" [22] Dia. UNC Square Nut	SAE Gr. 5	FNS20
b7	1	Bennet Short Threaded Turnbuckle	As Supplied	–
c1	5	3" x 1 5/8" x 7-Gauge [76 x 41 x 4.6], 58 7/8" [1495] Long Bent Midwest Weak Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	–
c2	5	Straight Rod – ϕ3/16" [5] Cable Clip	ASTM B16 Brass C36000 Half Hard (HO2), ROUND. TS >= 58.0 ksi, YS >= 45.0 ksi	–

* A 22" [559] long threaded rod may be substituted for the part no. a10 if necessary. Use of threaded rod will require two extra hex nuts and flat washers.

Notes: (1) Previously tested material for part c2 has had TS >= 68.0 ksi and YS >= 52.0 ksi.

Midwest Roadside Safety Facility

High-Tension Top Cable Midwest Weak Post

Bill of Materials

SHEET: 14 of 14

DATE: 6/13/2014

DRAWN BY: CWP/JGP/KLK

DWG. NAME. HTTC_Zpost_R4

SCALE: NONE

UNITS: In.[mm]

REV. BY: RWB/KAL

Figure 97. Bill of Materials, Test No. HTTC-2

Figure 98. Pre-Test Photographs, Test No. HTTC-2

6.2 Testing Facility

The dynamic test was conducted at the MwRSF outdoor proving ground 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.

6.3 Equipment and Instrumentation

Equipment and instrumentation utilized to collect and record data during the dynamic bogie tests included a bogie vehicle, accelerometer, a retroreflective speed trap, pressure tape switches, high-speed and standard-speed digital video cameras, and still cameras.

6.3.1 Bogie Vehicle

A rigid-frame bogie was used to impact the posts. A variable-height detachable impact head was used in the testing. The bogie head was constructed of 8-in. (203-mm) diameter, ½-in. (13-mm) thick standard steel pipe, with ¾-in. (19-mm) neoprene belting wrapped around the pipe to prevent local damage to the post from the impact. The impact head was bolted to the bogie vehicle, creating a rigid frame with an impact height of $24^{7}/_{8}$ in. (632 mm). The bogie, with impact head, is shown in Figure 99. The weight of the bogie with the addition of the mountable impact head and accelerometers was 1,861 lb (844 kg).

A pickup truck with a reverse cable tow system was used to propel the bogie to a target impact speed of 45 mph (72.4 km/h). When the bogie approached the end of the guidance system, it was released from the tow cable, allowing it to be free-rolling when it impacted the post. A remote braking system was installed on the bogie, allowing it to be brought safely to rest after the test.

Figure 99. Rigid-Frame Bogie on Guidance Track

6.3.2 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. However, the acceleration data was not reported herein as the impact forces were not important to the test results.

The system was a modular data acquisition system manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The acceleration sensors were mounted inside the body of a custom-built SLICE 6DX event data recorder and recorded data at 10,000 Hz to the onboard microprocessor. The SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter.

6.3.3 Retroreflective Optic Speed Trap

A retroreflective optic speed trap was used to determine the speed of the bogie vehicle before impact. Three retroreflective targets, spaced at 18-in. (457-mm) intervals, were applied to the side of the bogie vehicle. When the emitter/receiver had emitted a beam of light and received it after reflection off the vehicle targets, a signal was sent to the Optic Control Box, which in turn sent a signal to the data computer and activated the external LED box. The computer recorded the signals at the time at which each occurred. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

6.3.4 Digital Photography

Three AOS VITcam high-speed digital video cameras, two JVC digital video cameras, and two GoPro Hero 3 digital video cameras were used to document each test. The AOS high-speed cameras had a frame rate of 500 frames per second, the JVC digital video cameras had a frame rate of 29.97 frames per second, and the GoPro Hero 3 digital cameras had a frame rate of 200 frames per second. A Nikon D50 digital still camera was also used, to document pre- and post-test conditions for the test.

7 TOP CABLE ATTACHMENT TESTING RESULTS

7.1 Test No. HTTC-2 – $^{3}/_{16}$-in. (5-mm) Diameter Brass Rod

During test no. HTTC-2, the bogie impacted post no. 4 at a speed of 46.5 mph (74.8 km/h) and an angle of 25 degrees. Upon impact, the post began to bend, and a plastic hinge formed in the post near the groundline. By 0.002 seconds after impact, the impact side of the notch impacted the cable and began to move the cable laterally away from impact. At 0.006 seconds, the cable rode up the slope of the notch and bent the center of the brass rod upward. The brass rod fractured at 0.010 seconds, releasing the cable after displacing it 3.0 in. (76 mm) laterally. The lateral pulse wave in the cable traveled along the cable until it reached the adjacent posts 0.046 seconds after impact. The lateral pulse wave in the cable caused post nos. 3 and 5 to displace laterally approximately 0.5 in. (13 mm). The posts adjacent to the impacted post immediately returned to their original positions after the cable wave passed. The bogie vehicle traveled underneath the cable without any direct cable contact and eventually overrode post no. 4 as it traveled along its original trajectory. Sequential photographs of the test are shown in Figures 100 through 102.

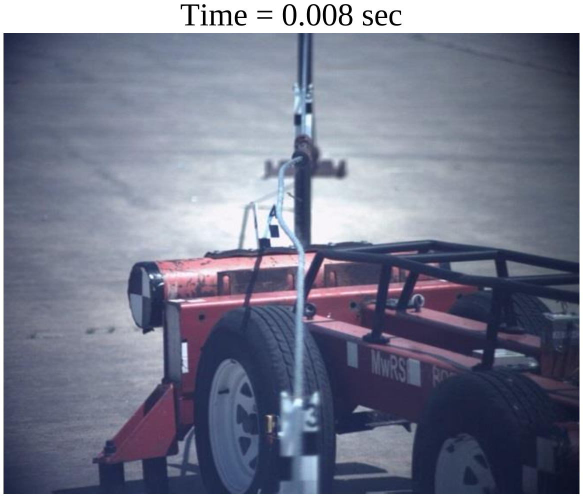
Post-test examination revealed minimal damage to the test article, as shown in Figures 103 and 104. A plastic hinge had developed in post no. 4 near the groundline, and the post was bent over along the 25-degree angle of the bogie vehicle’s path. The brass rod fractured on the non-impact side. Additionally, the brass rod was bent upward on the impact side, as shown in Figure 104. Examination of the adjacent posts revealed no significant damage to the posts or the brass keeper rods.

Time = 0 sec, Impact

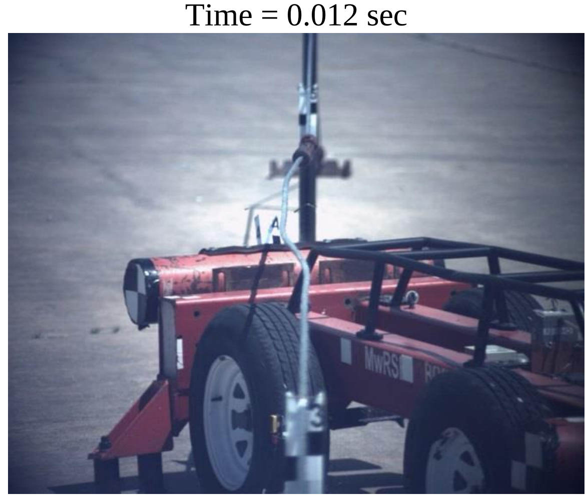
Time = 0.004 sec

Time = 0.008 sec

Time = 0.012 sec



Time = 0.016 sec



Time = 0.020 sec

Figure 100. Sequential Photographs, Test No. HTTC-2


Time = 0 sec, Impact


Time = 0.004 sec

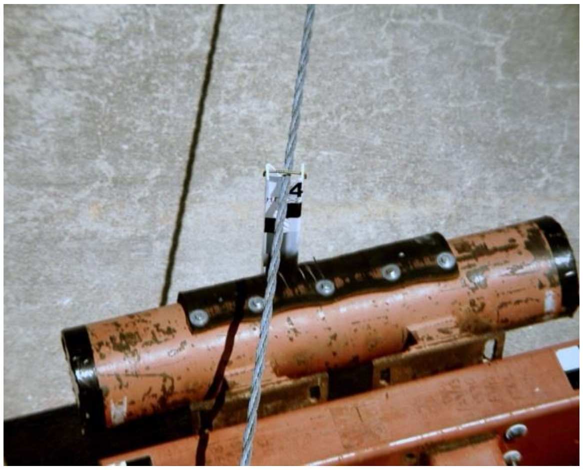

Time = 0.008 sec

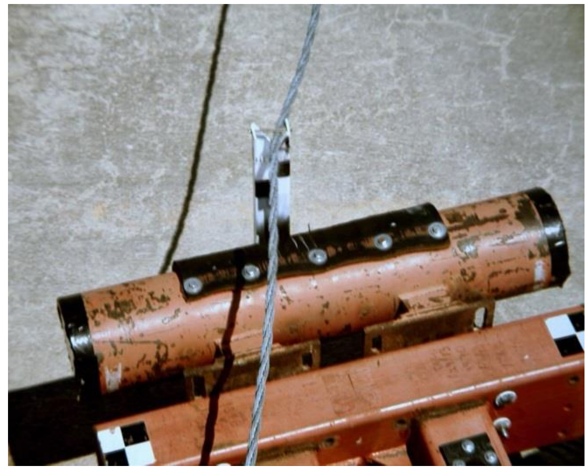

Time = 0.012 sec


Time = 0.016 sec


Time = 0.020 sec

Figure 101. Sequential Photographs, Test No. HTTC-2


Time = 0 sec, Impact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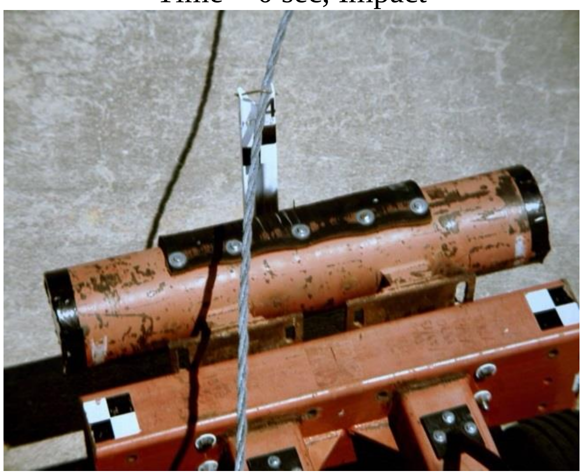
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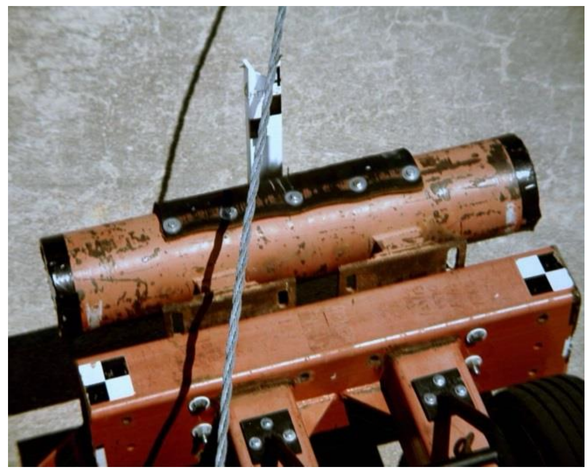
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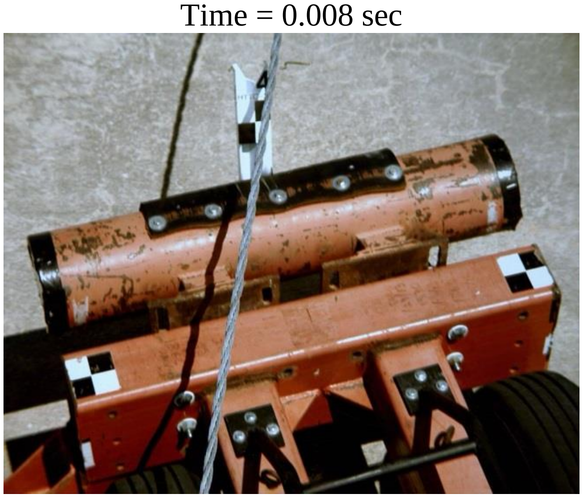
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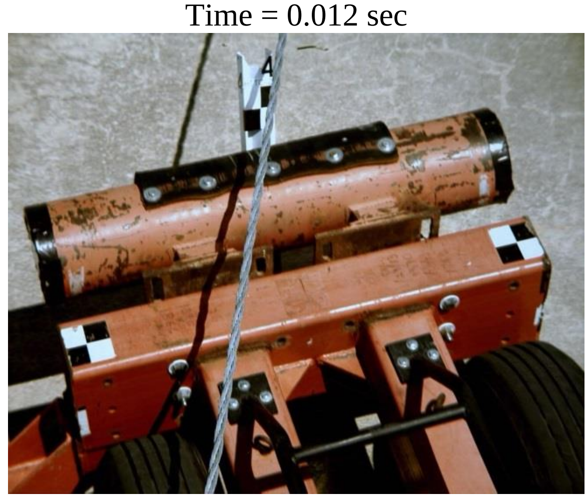

Time = 0.020 sec

Figure 102. Sequential Photographs, Test No. HTTC-2

Figure 103. Post-Test Photograph, Test No. HTTC-2

Figure 104. Post-Test Photographs of Post No. 4, Test No. HTTC-2

7.2 Discussion

Test results illustrated that the $^{3}/_{16}$-in. (4.8-mm) diameter brass rod will release the top cable quickly upon vehicle impact with the supporting post. A direct comparison of the test results between the previous $^{1}/_{8}$-in. (3.2-mm) diameter rod evaluated in test no. HTTC-1 and the larger $^{3}/_{16}$-in. (4.8-mm) diameter rod are shown in Table 3. The larger diameter rod took 0.002 seconds longer to release the cable and resulted in a 0.5-in. (13-mm) increase in lateral displacement at release. However, a release time of 0.010 seconds was still considered very quick. Furthermore, a lateral displacement of only 3.0 in. (76 mm) would equate to a vertical displacement of less than ¼ in. (6 mm) as the post rotates about the groundline. Thus, the $^{3}/_{16}$-in. (4.8-mm) diameter keeper rod would still release prior to the cable being pulled down by the post and compromising vehicle capture.

However, a significant difference in performance was found in the keeper rods located on the posts adjacent to the impacted post. As shown in Table 3, the $^{1}/_{8}$-in. (3.2-mm) diameter rods on post nos. 3 and 5 were bent and damaged from the lateral displacement wave that traveled along the cable after it released from post no. 4. The $^{3}/_{16}$-in. (4.8-mm) diameter rods located in the same positions during test no. HTTC-2 appeared undamaged after the test, even though they were subjected to a larger displacement wave in the cable. This finding indicates that the larger-diameter keeper rods would decrease the propensity for cable whip to cause premature release of the top cable during a vehicle redirection event. Thus, the larger rods would better distribute the lateral impact loads to adjacent posts and aid in limiting deflections. Subsequently, the $^{3}/_{16}$-in. (4.8-mm) diameter brass keeper rod was recommended for use over the original $^{1}/_{8}$-in. (3.2-mm) diameter design. Brass rods with diameters larger than $^{3}/_{16}$-in. (4.8-mm) were not chosen for further testing, due to the static test release loads exceeding 1 kip (4.4 kN) [2].

Table 3. Top Cable-to-Post Attachment Bogie Impact Testing Results

Test No.	**HTTC-1**	**HTTC-2**
Brass Rod Diameter	1/8 in. (3.2 mm)	3/16 in. (4.8 mm)
Cable Tension	4300 lb (19.1 kN)	2480 lb (11.0 kN)
Release Time	0.008 sec	0.010 sec
Release Distance	2.5 in. (64 mm)	3.0 in. (76 mm)
Adjacent US Post		
Adjacent DS Post		

8 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

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. This effort was completed in two phases. The first phase focused on redesigning the bolted tabbed bracket that was used on the lower three cables of the barrier, for easier installation. The second phase involved the evaluation of stronger keeper rods for use in the top cable attachment.

The study began with the development of over twenty-five alternative attachment concepts for the tabbed brackets. All of the new bracket designs had the same top portion as the bolted tabbed bracket V10, but each had a unique method of attaching the base of the bracket to the post flange. Analysis and sponsor feedback led to the selection of two attachment concepts for evaluation through dynamic testing: a lateral shear plate concept and a drop-in shear plate concept. Both of the selected bracket concepts were then subjected to two vertical and two lateral dynamic component tests to evaluate the release loads and fracture mechanisms of the brackets. The results of these tests were then compared to those of the bolted tabbed bracket currently being utilized in the full-scale crash testing of the new cable barrier system.

The drop-in shear plate concept did not provide the desired release loads. During the vertical tests, the bracket would rotate outward at the onset of loading. This behavior caused the top tabs to rub and snag on the inside of the post flange. Consequently, the vertical release load for test no. HTTB-44 was over 1 kip (4.4 kN), well over the 0.3 kips to 0.4 kips (1.3 kN to 1.8 kN) targeted release load. During the lateral tests of the drop-in shear plate concept, the tabs caught in the narrow part of the keyway, but the slots in the lower legs of the bracket bent open and allowed the bracket to shift. As a result, the average lateral release load of 5.4 kips (24.0 kN) fell below the targeted 6-kip (26.7-kN) minimum. Due to the weakness in the bracket legs and the lack of rigidity in the attachment that allowed the bracket to rotate upon loading, the drop-in shear plate concept was no longer considered a viable alternative to the bolted tabbed bracket V10.

The lateral shear plate attachment concept performed quite well in terms of the release loads observed during testing. The average vertical release load was 0.34 kips (1.5 kN), and the average lateral release load was 6.24 kips (27.8 kN). Thus, the new bracket concept satisfied both vertical and lateral release loading criteria established with the development of the bolted tabbed bracket. However, concerns were raised with the rigidity of the attachment, as the lateral shear plate concept did allow the bracket to rotate slightly relative to the post prior to any significant loading, as shown previously in Figure 81. Although the tabs did not snag on the inside of the flange in either of the two vertical component tests conducted herein, there remains a possibility that much higher vertical release loads could be observed, similar to those of test no. HTTB-44.

The current design utilizes only $^{1}/_{16}$ in. (1.6 mm) of tolerance between the shear plate and the slot in the bracket legs, half of the tolerance typically provided for bolted connections. Further reducing this construction tolerance was not advised, as it may lead to installation issues with the shear plate not fitting into the slot. It was recognized that galvanizing both the post and the bracket would result in the joint tightening up a little and help prevent some of this undesired bracket rotation. However, it was not believed that galvanization alone would provide the attachment rigidity missing from the current design. Thus, it was recommended that the lateral shear plate attachment bracket be modified to stiffen the joint prior to its inclusion in the non-proprietary high-tension cable barrier system.

Additionally, installation issues with the lateral shear plate arose due to the out-of-plane lever designed to lock the plate into position. The levers were seldom bent to the correct offset that would result in the plate "snapping" into position between the bracket legs. The levers had to be adjusted by testing personnel prior to installation. This additional effort to install a bracket would quickly add up to significant losses in time when installing a full-scale system. Further, the shear plates were difficult to remove, as the lever was located in a tight area and surrounded on four sides by the post flange, the post web, and the two bracket legs. Therefore, it was recommended to redesign the locking mechanism of the lateral shear plate for ease of installation and removal of the plate and bracket.

Phase two of this study involved the testing and evaluation of a stronger keeper rod for use in the top cable attachment of the non-proprietary cable barrier system. After a review of previous static testing results, a $^{3}/_{16}$-in. (4.8-mm) diameter brass keeper rod was selected for dynamic testing. Similar to the evaluation of the original $^{1}/_{8}$-in. (3.2-mm) diameter rod, the component test involved a short segment of cable barrier installation with only the top cable attached to the posts, and a bogie vehicle was utilized to impact the center post. As the post bent over, the increased-diameter keeper rod fractured and released the cable after only 0.010 seconds and 3.0 in. (76 mm) of deflection. This quick cable release was very comparable to the results first witnessed through the testing of the original $^{1}/_{8}$-in. (3.2-mm) diameter rod. Thus, the $^{3}/_{16}$-in. (4.8-mm) diameter keeper rod was not expected to alter the cable barrier's ability to capture an errant vehicle.

A comparison of the brass rods on the posts adjacent to impact illustrated a significant difference between the two rod sizes. The smaller brass rods were bent upward over 0.5 in. (13 mm), while the larger brass rods showed no signs of deformation. This finding indicated that the larger-diameter keeper rods decrease the propensity for cable whip to cause premature release of the top cable during a vehicle redirection event. Consequently, the larger rods would better distribute impact loads to adjacent posts and reduce system deflections. Therefore, the $^{3}/_{16}$-in.

(4.8-mm) diameter brass keeper rod was recommended for use in the non-proprietary high-tension cable barrier system over the original $^{1}/_{8}$-in. (3.2-mm) diameter design.

9 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* Draft Report to the Midwest States Regional Pooled Fund Program, Report No. TRP-03-286-15, Midwest Roadside Safety Facility, Lincoln, Nebraska, University of Nebraska-Lincoln, February 23, 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, August 29, 2013.
3. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, NY, July, 2007.

10 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. 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. JOHNSTO
MANAGING METALLU

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:

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

DISP TM 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

* P R O D U C T S H I P P E D * * * * * * * * * * * * * * * * * * *

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				

* * * * * * * * * * * * * * * * * M E C H A N I C A L P R O P E R T I E S * * * * * * * * * * * * * * * *

TENSILE TESTS:

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

* * * * * * * * * * * * * * * * * * * C H E M I C A L P R O P E R T I E S * * * * * * * * * * * * * * * * *

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 and Shear Plates

KME Brass Italy S.r.l.

KME

TEST REPORT

Certificate Nr : 336254 Groupe Nr : 1157685
Customer : COPPER AND BRASS
Customer Ref. : KMA 111019 06 PO 5400120
Job Number : 511938/3 Item EM: 0044519
Material Desc. : ROD FREE MACHINING ASTM B16 - Brass C36000 - H02 -
RND 3 16 IN L. 12 FT - Pointed/Chamfered
Part Number : CURD00477
Quantity : LB 6093.6

Chemical Composition:ASTM B16 C36000

%	Cu	Pb	Zn	Fe	Other Imp.
Min	60.0	2.5		0.0	0.0
Max	63.0	3.0		0.35	0.5
	60.2589	2.7831	p.d.	0.2092	0.2954

Physical Characteristics:ASTM B16 H02

Test	Elong. 5.65 %	Tensile Streng. ksi	Yeld St. 0.5 ksi
Min	7.0	57	25
Max			
12076783	15.2	68	63

Dimensional Characteristics:ASTM B249

Test	Size inch
Min	0.1860
Max	0.1890
12076783	0.1874

Serravalle Scrivia 01/02/2012

Company with the quality management system certified by IGQ according to ISO 9001-2008

Document complying to EN 10204 2.2 standard, issued under computerized control.
Signature not required. The Quality Manager Mr. Orazio Ruggieri. - MADE IN ITALY -

From: Copper and Brass Sales
Cust: ONLINE METALS Del: 2401967075
Part: 4345 PO: 76614
Wgt: 90.000 LB Date: 07/19/2012

James K Baber

Figure A-3. $^{3}/_{16}$-in. Top Cable Retainer Rod

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:

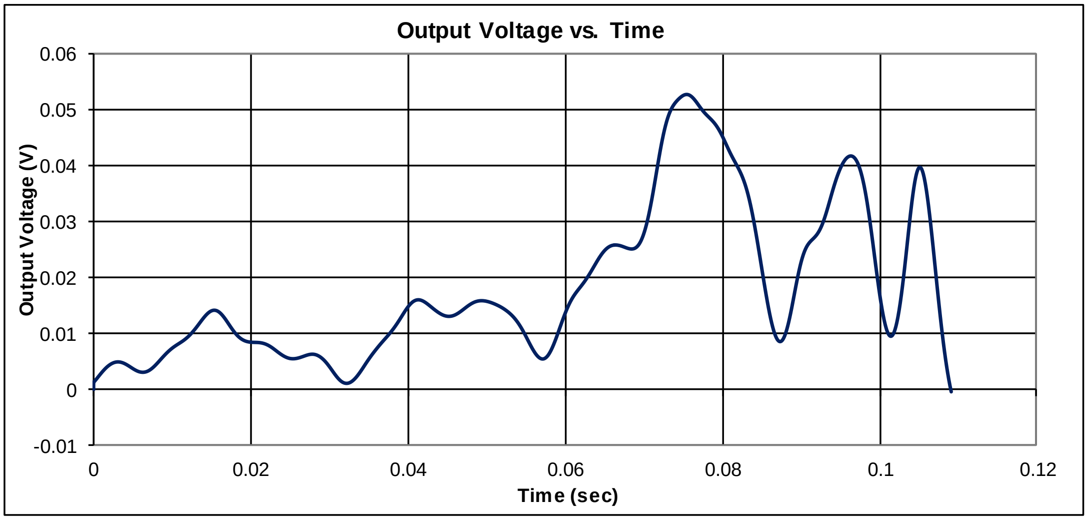
Test No:	HTTB-41
Date:	9/20/2013
System / Test Article:	Tabbed Bracket w/ Buckle Shear Plate
LC Location / Component:	base of test jig (in line with pull)
Additional Notes:	Vertical pull/release from cable attachment bracket

Load Cell Information:

Load Cell No.:	413436
Calibration Factor:	2.14575 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:	0.307 kips
Time of Max. Load:	0.0754 sec
Event Duration:	0.1091 sec
Final Load:	0.00 kips



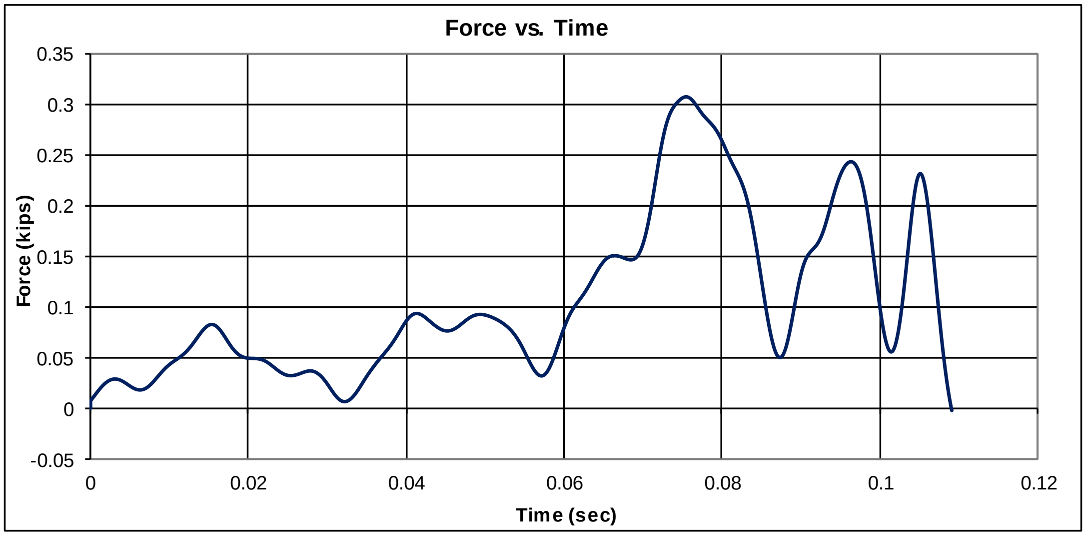


Figure B-1. Load Cell Results, Test No. HTTB-41

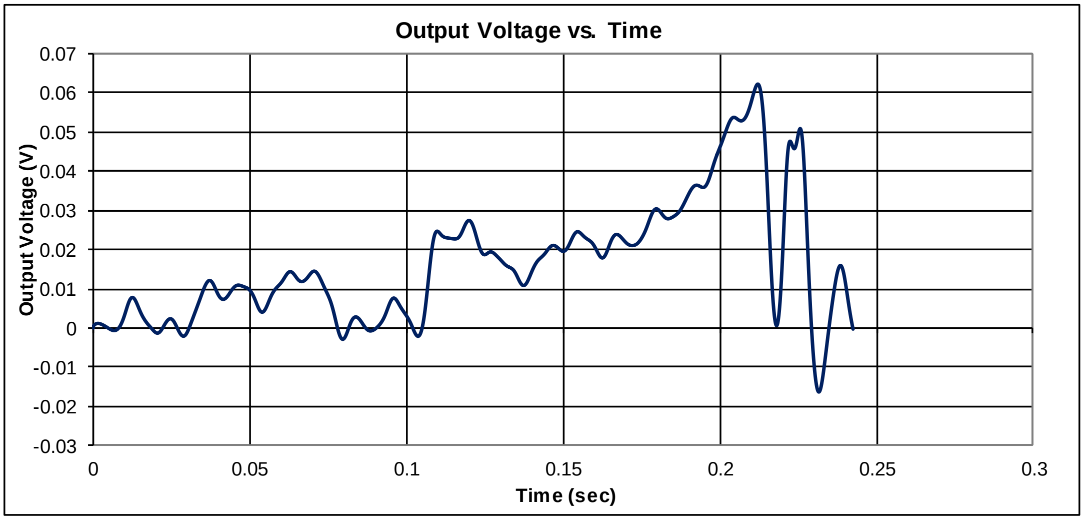
MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

Test No: HTTB-42
Date: 9/20/2013
System / Test Article: Tabbed Bracket w/ Buckle Shear Plate
LC Location / Component: base of test jig (in line with pull)
Additional Notes: Vertical pull/release from cable attachment bracket

Load Cell Information:		**Results:**	
Load Cell No.:	413436	Preload:	0 kips
Calibration Factor:	2.14575 mv/V	Max. Load:	0.362 kips
Input Voltage (excitation):	10 Volts	Time of Max. Load:	0.2121 sec
Gain:	400	Event Duration:	0.2425 sec
Full Scale Load:	50 kips	Final Load:	0.00 kips
Sample Rate:	10000 Hz		
Cutoff Frequency:	100 Hz		



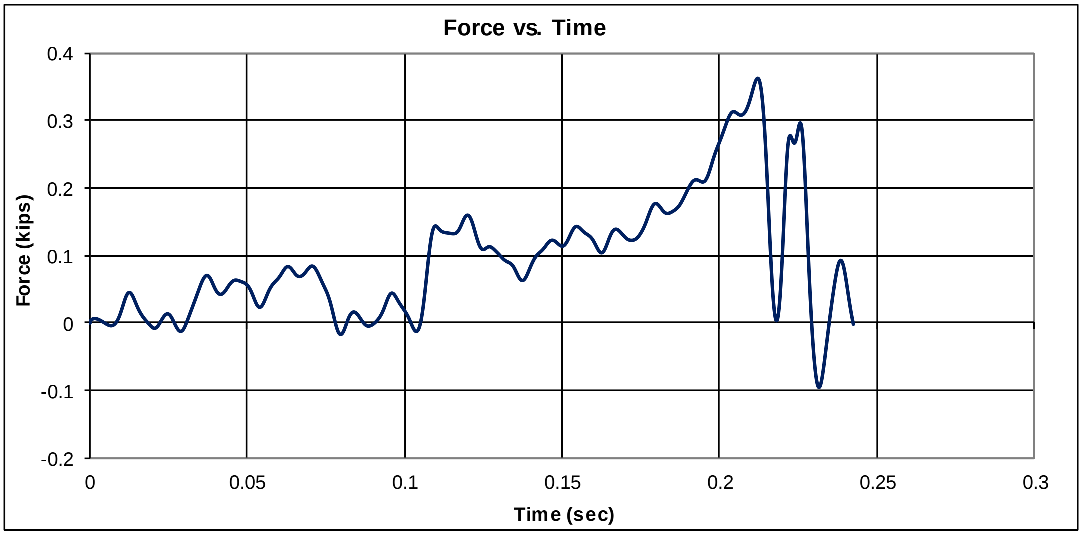


Figure B-2. Load Cell Results, Test No. HTTB-42

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

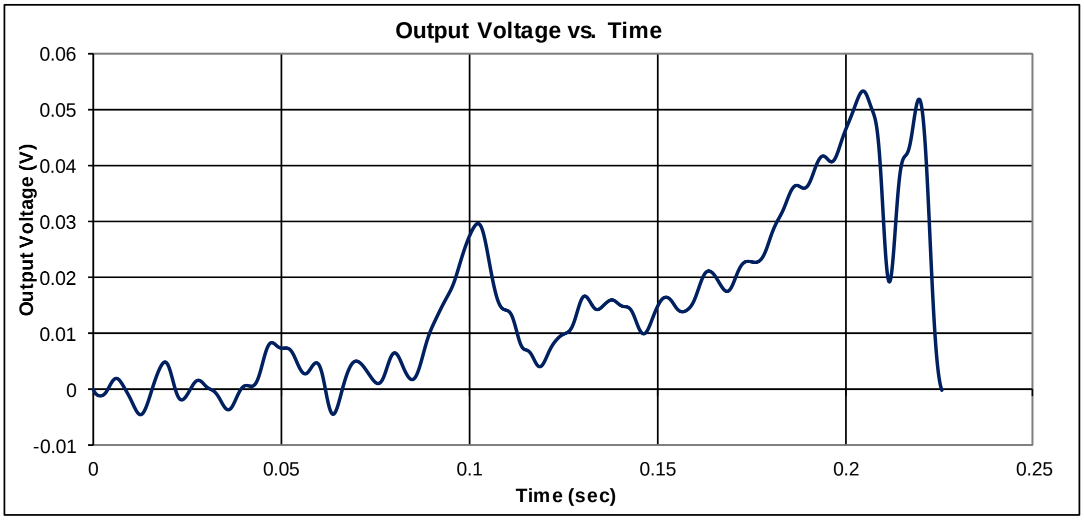
Test No:	HTTB-43
Date:	9/20/2013
System / Test Article:	Tabbed Bracket w/ Drop-in Shear Plate
LC Location / Component:	base of test jig (in line with pull)
Additional Notes:	Vertical pull/release from cable attachment bracket

Load Cell Information:

Load Cell No.:	413436
Calibration Factor:	2.14575 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:	0.311 kips
Time of Max. Load:	0.2048 sec
Event Duration:	0.2257 sec
Final Load:	0.00 kips



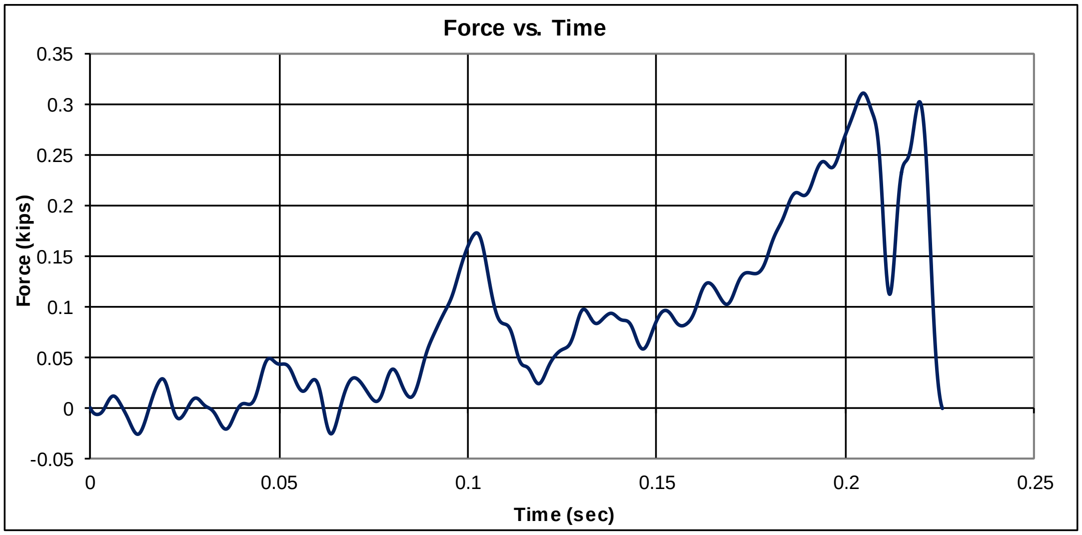


Figure B-3. Load Cell Results, Test No. HTTB-43

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

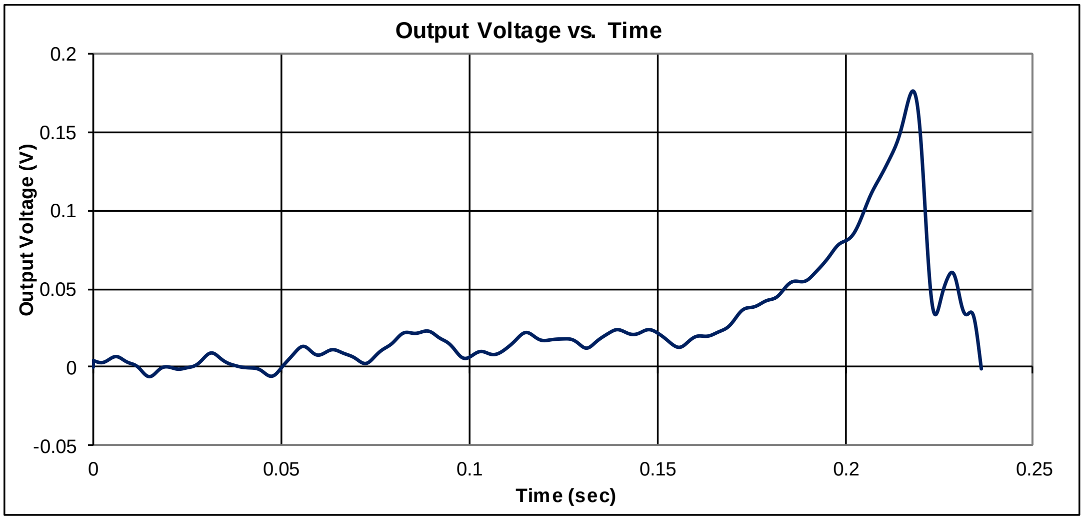
Test No:	HTTB-44
Date:	9/20/2013
System / Test Article:	Tabbed Bracket w/ Drop-in Shear Plate
LC Location / Component:	base of test jig (in line with pull)
Additional Notes:	Vertical pull/release from cable attachment bracket

Load Cell Information:

Load Cell No.:	413436
Calibration Factor:	2.14575 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:	1.026 kips
Time of Max. Load:	0.218 sec
Event Duration:	0.2362 sec
Final Load:	-0.01 kips



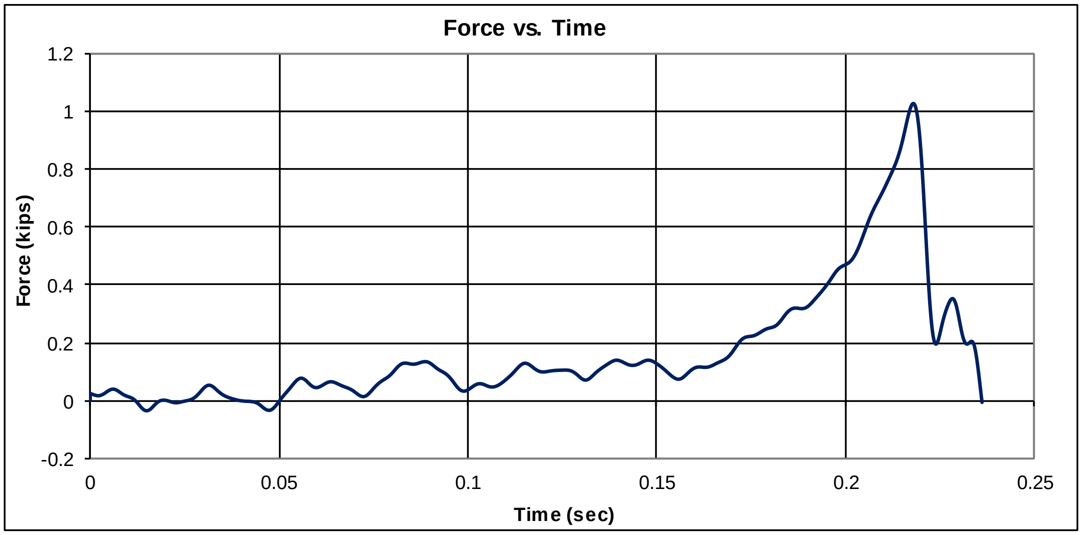


Figure B-4. Load Cell Results, Test No. HTTB-44

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

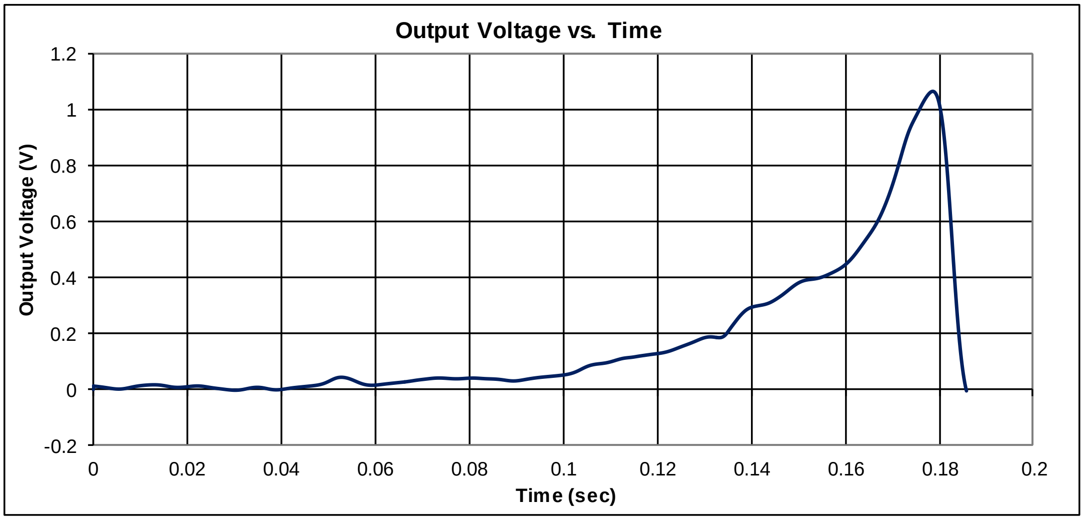
Test No:	HTTB-45
Date:	9/20/2013
System / Test Article:	Tabbed Bracket w/ Buckle Shear Plate
LC Location / Component:	base of test jig (in line with pull)
Additional Notes:	Lateral pull on cable attachment bracket

Load Cell Information:

Load Cell No.:	413436
Calibration Factor:	2.14575 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:	6.206 kips
Time of Max. Load:	0.1786 sec
Event Duration:	0.1858 sec
Final Load:	-0.03 kips



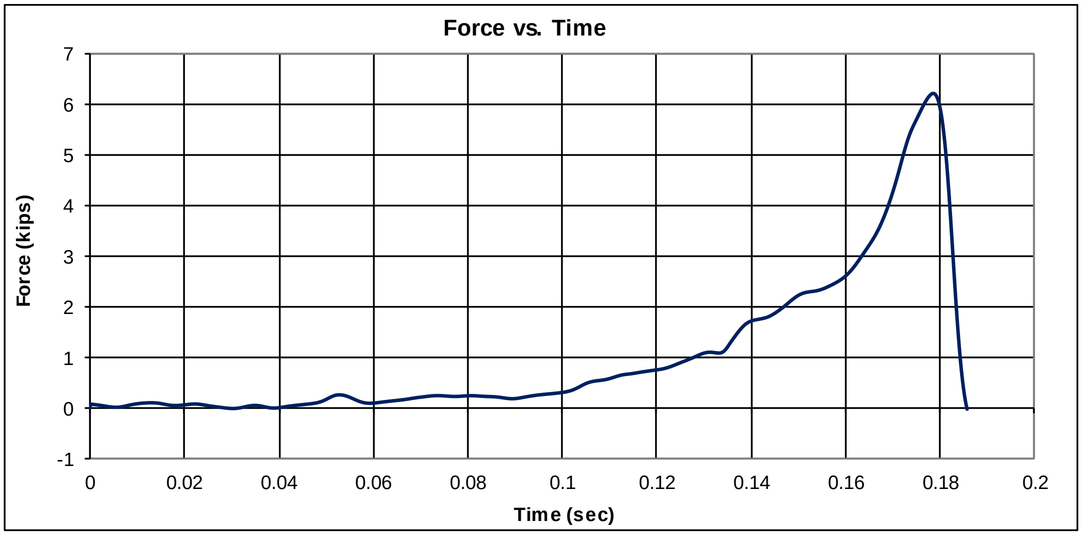


Figure B-5. Load Cell Results, Test No. HTTB-45

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

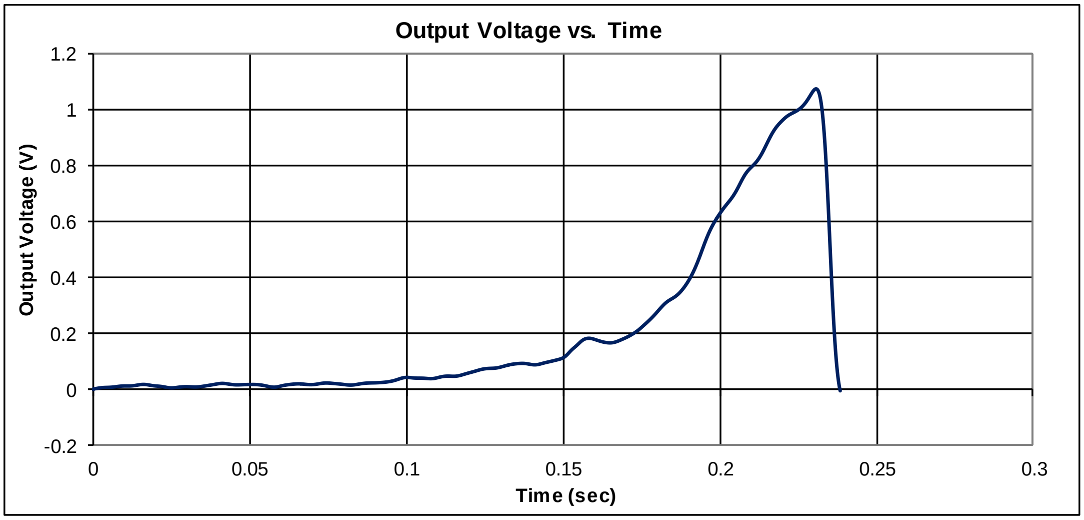
Test No:	HTTB-46
Date:	9/20/2013
System / Test Article:	Tabbed Bracket w/ Buckle Shear Plate
LC Location / Component:	base of test jig (in line with pull)
Additional Notes:	Lateral pull on cable attachment bracket

Load Cell Information:

Load Cell No.:	413436	
Calibration Factor:	2.14575	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:	6.258	kips
Time of Max. Load:	0.2307	sec
Event Duration:	0.2384	sec
Final Load:	-0.03	kips



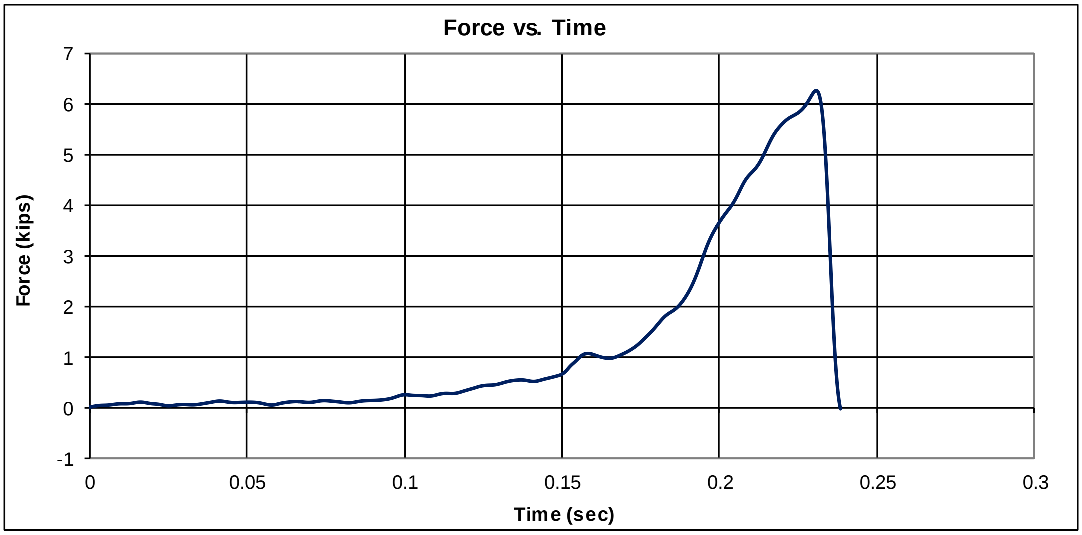


Figure B-6. Load Cell Results, Test No. HTTB-46

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

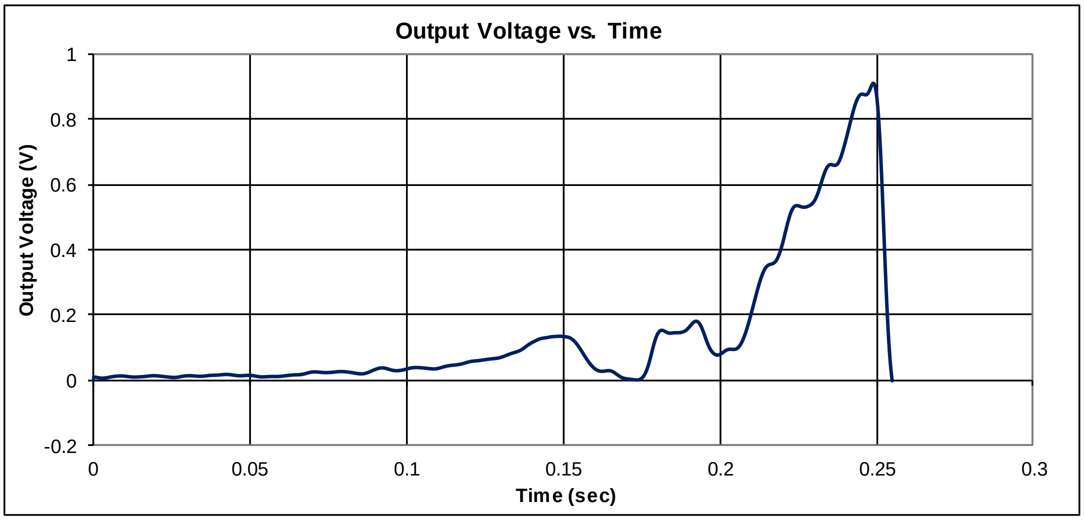
Test No:	HTTB-47
Date:	9/20/2013
System / Test Article:	Tabbed Bracket w/ Drop-in Shear Plate
LC Location / Component:	base of test jig (in line with pull)
Additional Notes:	Lateral pull on cable attachment bracket

Load Cell Information:

Load Cell No.:	413436
Calibration Factor:	2.14575 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:	5.304 kips
Time of Max. Load:	0.249 sec
Event Duration:	0.255 sec
Final Load:	-0.01 kips



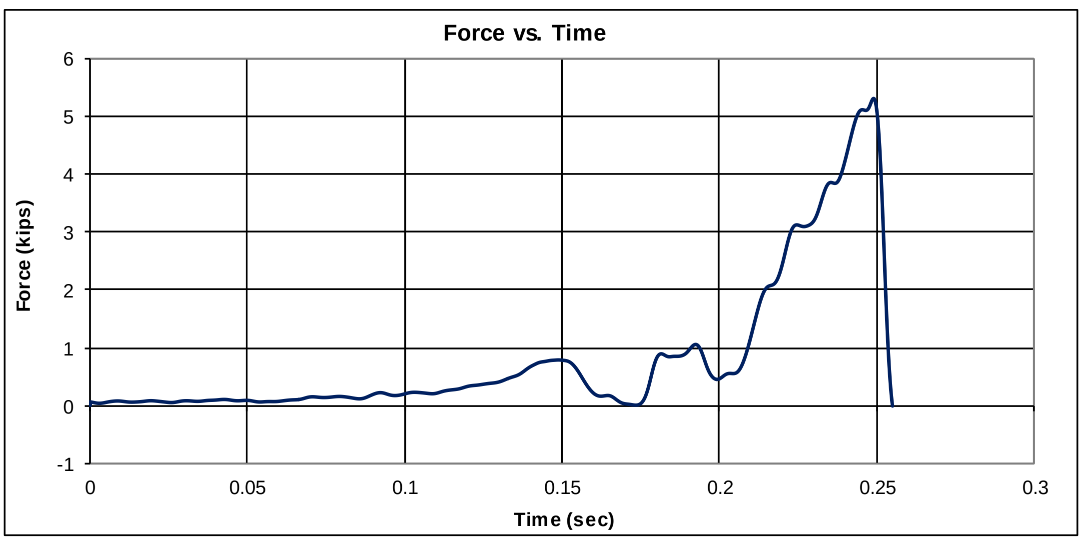


Figure B-7. Load Cell Results, Test No. HTTB-47

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

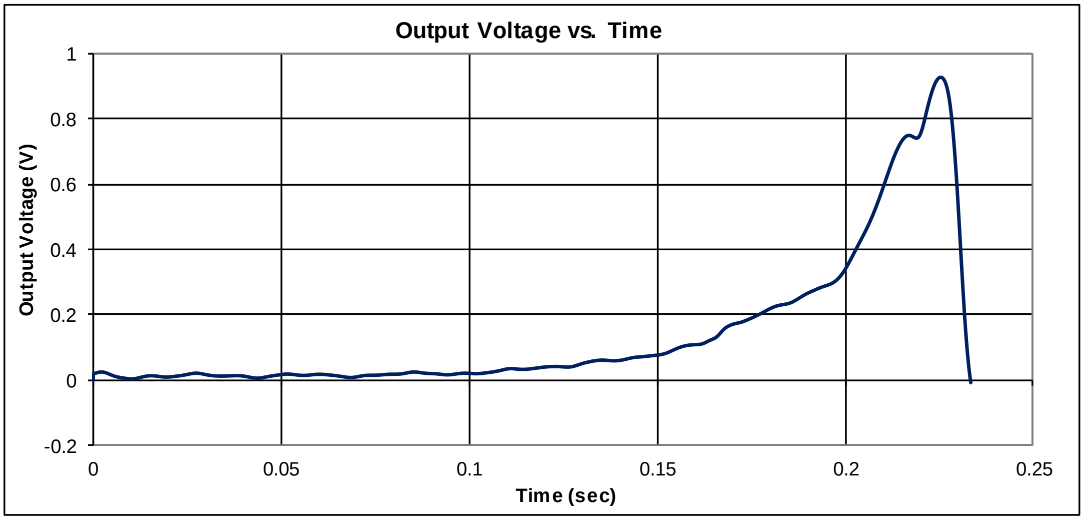
Test No:	HTTB-48
Date:	9/20/2013
System / Test Article:	Tabbed Bracket w/ Drop-in Shear Plate
LC Location / Component:	base of test jig (in line with pull)
Additional Notes:	Lateral pull on cable attachment bracket

Load Cell Information:

Load Cell No.:	413436
Calibration Factor:	2.14575 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:	5.403 kips
Time of Max. Load:	0.2254 sec
Event Duration:	0.2334 sec
Final Load:	-0.04 kips



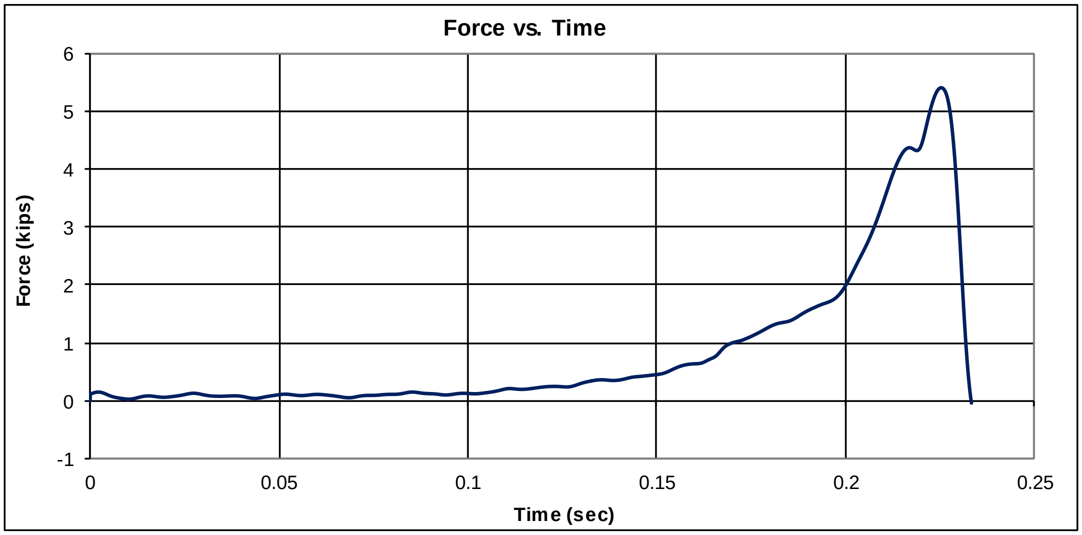


Figure B-8. Load Cell Results, Test No. HTTB-48

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