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STEEL-POST VERSION OF TRAILING-END ANCHORAGE SYSTEM – PHASE I

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16. Abstract

In 2013, a non-proprietary, trailing-end anchorage system with a modified Breakaway Cable Terminal (BCT) was developed by the Midwest Roadside Safety Facility (MwRSF) for the Midwest Guardrail System (MGS). Although this trailing-end, guardrail anchorage system adequately met the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (MASH) TL-3 safety requirements, the use of two breakaway wood posts was deemed to have several drawbacks. For state DOTs that primarily utilize steel posts, it was desired to develop a steel-post alternative for the BCT posts utilized in the trailing-end anchorage system. Thus, a critical need existed to develop a non-wood option to anchor the downstream end of the MGS.

The objective of this research project was to develop a non-proprietary, steel-post version of the trailing-end anchorage system. The Universal Breakaway Steel Post (UBSP), utilized within the thrie-beam bullnose system, was found to be a viable option to replicate the breakaway performance of the BCT wood posts. Design concepts were developed from modification to the UBSP while utilizing the same basic cable anchor and ground line strut as used in the wood-post, trailing-end anchorage system to provide similar breakaway performance and anchorage capacity. Dynamic jerk tests were conducted to evaluate the breakaway performance of the end anchor posts and the capacity of the design concepts. Based on the dynamic jerk test results and input from Midwest Pooled Fund Program member states, a preferred steel-post, downstream anchorage design was selected and further developed. Final anchorage design included: (1) two breakaway steel posts; (2) a steel compression ground line strut between the two steel breakaway steel posts; (3) one steel anchor cable connecting the W-beam rail to the base of the end anchor post; and (4) a T-shaped, breaker bar attached to the end anchor post to facilitate the release and rotation of the end post. Recommendations for full-scale crash testing were provided for the preferred steel-post, trailing-end anchorage system.

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This material is based upon work supported by the Federal Highway Administration, U.S. Department of Transportation and the Midwest Pooled Fund Program under TPF-5(193) Supplement #92. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the University of Nebraska-Lincoln, state highway departments participating in the Midwest Pooled Fund Program nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names, which may appear in this report, are cited only because they are considered essential to the objectives of the report. The United States (U.S.) government and the State of Nebraska do not endorse products or manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration. Test nos. SPDA-1 through SPDA-5 were non-certified component tests conducted for research and development purposes only and are outside the scope of the MwRSF's A2LA Accreditation.

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1 INTRODUCTION

1.1 Problem Statement

In 2010, the Midwest Roadside Safety Facility (MwRSF) developed the Universal Breakaway Steel Post (UBSP) as a replacement for Controlled Release Terminal (CRT) wood posts utilized within the thrie-beam bullnose system [1-2]. The UBSP consisted of an ASTM A36, steel W6x8.5 top section and a 6-in. x 8-in. x 3⁄16-in. ASTM A500 Grade B steel tube bottom section, as shown in Figure 1. The two post sections were welded to the base plates and connected by four 7⁄16-in. diameter, ASTM A325 hex-head bolts. The UBSP breaks away following the fracture of the four vertical bolts in tension due to the moment applied at the base plate connection when the upper post stub is laterally loaded. Different strong- and weak-axis capacities were generated by altering the spacing of the bolts connecting the two base plates to one another. During the development of the UBSP, three successful full-scale crash tests were performed on the thrie-beam bullnose with UBSPs according to the TL-3 criteria provided in NCHRP Report No. 350 [2-3]. Based on the satisfactory crash performance of UBSPs, it was concluded that the UBSP was a suitable alternative for wood CRT posts used in the original thrie-beam bullnose system. During the development of the UBSP, considerations were given to developing a post that could function as a replacement for both the CRT and Breakaway Cable Terminal (BCT) posts. MwRSF researchers concluded that the BCT design would also have to function as part of the anchorage system, and that such a design might be significantly different from the design used for the CRT post replacement. Due to the project time and cost constraints and the fact that CRT posts comprised the timber posts in the bullnose system, a CRT replacement was only developed for the bullnose system.

Figure 1. UBSP Utilized in Thrie Beam Bullnose System [2]

Following the initial UBSP research effort, the Midwest Pooled Fund Program funded a project to further investigate the application of the breakaway steel post technology to other systems. The project consisted of bogie tests of the UBSP and CRT posts in both the strong and weak axes to determine the feasibility of the UBSP as a replacement for CRT posts in other systems. The results indicated that the UBSP compared favorably to existing CRT posts. Strong-axis behavior of the UBSP was nearly identical to the CRT post, while the weak-axis capacity of the UBSP was slightly lower than the CRT post. Thus, it was decided to expand the use of the UBSP to other systems incorporating CRT posts.

In 2013, a non-proprietary, trailing-end anchorage system with BCT wood posts was developed by the Midwest Roadside Safety Facility (MwRSF) for use with the Midwest Guardrail System (MGS) [4-5]. This trailing-end guardrail anchorage system has been successfully crash tested and adequately met the TL-3 safety requirements of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (MASH 2009) [6]. The trailing-end anchorage system consisted of two BCT wood posts set into a 6-in. wide x 8-in. deep x 72-in. long (152-mm x 203-mm x 1,829-mm), ASTM A500 Grade B, steel foundation tube. The two 6-ft (1,829-mm) long steel foundation tubes were connected at the ground line with a strut and yoke assembly. The BCT end anchorage posts were placed in the foundation tubes such that their top was 32 in. (813 mm) above the ground line. One end of a ¾-in. (19-mm) diameter by 6x19 wire rope was attached on the back side of the W-beam, and the other end passed through the hole at the bottom of the end post and was secured through a 8-in. x 8-in. x ⅝-in (203-mm x 203-mm x 16-mm) steel bearing plate, as shown in Figure 2.

Figure 2. MGS Trailing-End, Guardrail Anchorage System [4]

Two successful crash tests were conducted on the wood-post, trailing-end anchorage system under the TL-3 requirements of MASH 2009. The first test, test no. WIDA-1, was a modified MASH test designation no. 3-37 with an 1100C vehicle, which evaluated vehicle snag and instability at the downstream anchorage system [4]. The second test, test no. WIDA-2, was a modified MASH test designation no. 3-37 with a 2270P vehicle impacting the sixth post from the end anchor post to evaluate the downstream MGS length-of-need (LON) [4]. For the downstream end of longitudinal guardrail systems, the end of the LON has been previously defined as a downstream CIP at which the end anchorage system would no longer redirect an errant vehicle but instead gate and permit the vehicle to encroach behind the system. During both tests, the BCT posts within the trailing-end anchorage system fractured near the ground line and allowed the vehicle to pass by without excessive snagging [4].

For the trailing-end guardrail anchorage system, the two BCT wood posts were designed to break away in a controlled manner to allow an impacting vehicle to pass through the barrier without imposing a sudden deceleration or rapidly changing its trajectory. This release behavior minimized the risk of vehicle rollover and/or snag on the cable anchorage system in near end impact events.

Wood has historically been selected for use in breakaway posts due to being readily available, relatively low cost, providing brittle fracture behavior, and the ability to control load duration and fracture energy with holes drilled through the post at the ground level. However, the use of wood posts has also been noted to have drawbacks. First, the structural properties and performance of graded wood posts can still vary due to the presence of small knots, checks, and splits, thus often requiring enhanced grading and inspection. Second, the breakaway holes drilled near the ground line of BCT posts exposes the interior of the wood post to the environment, which may accelerate deterioration. Further, the chemical preservatives used to treat the breakaway wood posts have been deemed harmful to the environment by some government agencies. Thus, the use of treated wood posts may require special consideration during their disposal.

Due to these concerns, a critical need existed to develop a non-wood option to anchor the trailing-end of W-beam guardrail system, which led the researchers to develop a steel-post, trailing-end anchorage system for use with the MGS. Additionally, for state departments of transportation (DOTs) that primarily utilize steel posts, it was desirable to use a steel post alternative for the BCT posts in the non-proprietary, trailing-end anchorage. Although BCT and CRT posts differ in function and design, they have similar cross sections and weakening holes at the ground line. Thus, modifications to the UBSP may result in performance similar to that of a BCT post. Therefore, an adaptation of the UBSP was desired for use in a new steel-post version of the non-proprietary, trailing-end anchorage system.

1.2 Research Objective

The objective of the research project was to develop a steel-post version of the non-proprietary, trailing-end anchorage system based on the success of the UBSP design used in the thrie-beam bullnose system. This new system was to be evaluated according to the MASH 2016 TL-3 safety performance criteria [7].

1.3 Scope

The research objectives were achieved through a series of tasks. The research project began with a review of current systems and patents on guardrail anchorages and end terminal posts to prevent infringement upon existing patents. MwRSF researchers then brainstormed a number of design concepts for the steel-post version of the trailing-end anchorage system. Concepts which satisfied the performance requirements of the trailing-end, anchorage system were further designed and analyzed. The UBSP was modified to replicate the performance of BCT posts in terms of breakaway performance and anchorage load through engineering analysis and design. Dynamic jerk tests were conducted on the selected design concepts to evaluate the performance and overall design capacity. The results of the dynamic jerk tests and the Midwest Pooled Fund Program member states' input were used to select the preferred design to be further evaluated through full-scale crash testing.

2 LITERATURE REVIEW

2.1 Introduction

A literature review was performed on previous trailing-end, anchorage systems. A review of patents was also conducted on guardrail anchorages and end terminal posts to prevent infringement upon the existing patents. The details of previous trailing-end, anchorage systems and patent review are presented in the following sections.

2.2 Previous Trailing-End, Anchorage System Performance

2.2.1 NCHRP Report No. 129 BCT Projects

In the 1970s, researchers at Southwest Research Institute (SwRI) initiated research efforts to design, evaluate, and recommend warrants for guardrail end treatments [8-13]. The first BCT design concept, presented in NCHRP Report No. 129 [10], is shown in Figure 3.

2.2.1.1 First BCT Design

In this BCT design concept, one end of the anchor cable was attached to the rail while the other end was threaded through a U-bar and attached to an 8-in. x 8-in. (203-mm x 203-mm) timber anchor post. The U-bar and anchor post were set in a concrete footing. The test program on the BCT anchor included two head-on (0-degree) crash tests (test nos. 130 and 132) and one 15-degree impact angle crash test (test no. 131) on the second span from the end. Test no. 130 was a head-on crash test on flared end treatment, while test no. 132 was a head-on crash test on tangent end treatment. Both the flared and tangent configurations demonstrated satisfactory performance regarding crash severity. However, the flared terminal showed better performance when considering vehicle dynamic instability. Test no. 131, where the terminal was impacted at an angle of 15 degrees at the second span from the end, demonstrated the effectiveness of the terminal as an anchor. The vehicle was redirected satisfactorily with no damage to the anchor assembly. This BCT concept appeared to be an effective terminal for longitudinal barrier systems and was recommended for use in the field even though improved BCT designs were recommended.

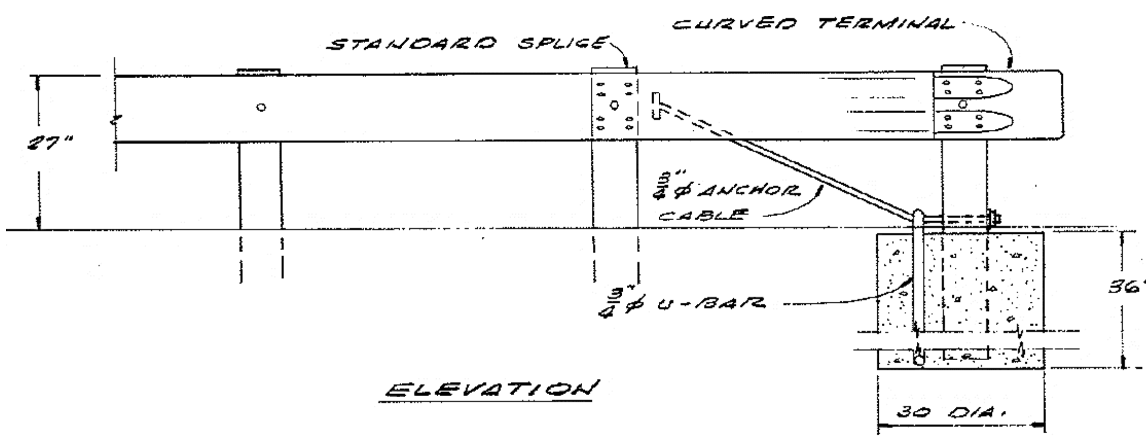


Figure 3. First BCT Design Concept [10]

2.2.1.2 Modified BCT Design

Research continued on guardrail end treatments at the SwRI to evaluate the new prototype BCT designs [11]. The significant modifications made to the first BCT design are shown in Figure 4. Test nos. 133 through 137 were conducted on flared end treatment with timber-post W-beam guardrail or G4W. In test no. 133, a 2,400-lb (1,089-kg) vehicle impacted the system at a speed of 42.5 mph (68.4 km/h) and at an angle of 0 degrees. High vehicle deceleration indicated that the BCT design neither eliminated nor increased the danger of small car end-terminal collisions. Test no. 134 was then conducted on the same end terminal design as test no. 133 but with a 4,200-lb (1,905-kg) vehicle impacting at a speed of 62.8 mph (101 km/h) and at an angle of 0 degrees. In test no. 134, the second post deflected, which was undesirable. Consequently, the BCT design concept was modified to include a concrete footing and drilled hole at the second post, as shown in Figure 4. Test no. 135 was conducted using a 3,800-lb (1,724-kg) vehicle impacting at a speed of 60.7 mph (97.7 km/h) and at an angle of 0 degrees. It performed satisfactorily. Test no. 136 was conducted with a 3,800-lb (1,724-kg) vehicle impacting at a speed of 59.7 mph (96.1 km/h) and an angle of 27 degrees within the second span. Test no. 137 was conducted using a 3,900-lb (1,769-kg) vehicle impacting at a speed of 62.0 mph (100.0 km/h) and at an angle of 27 degrees.

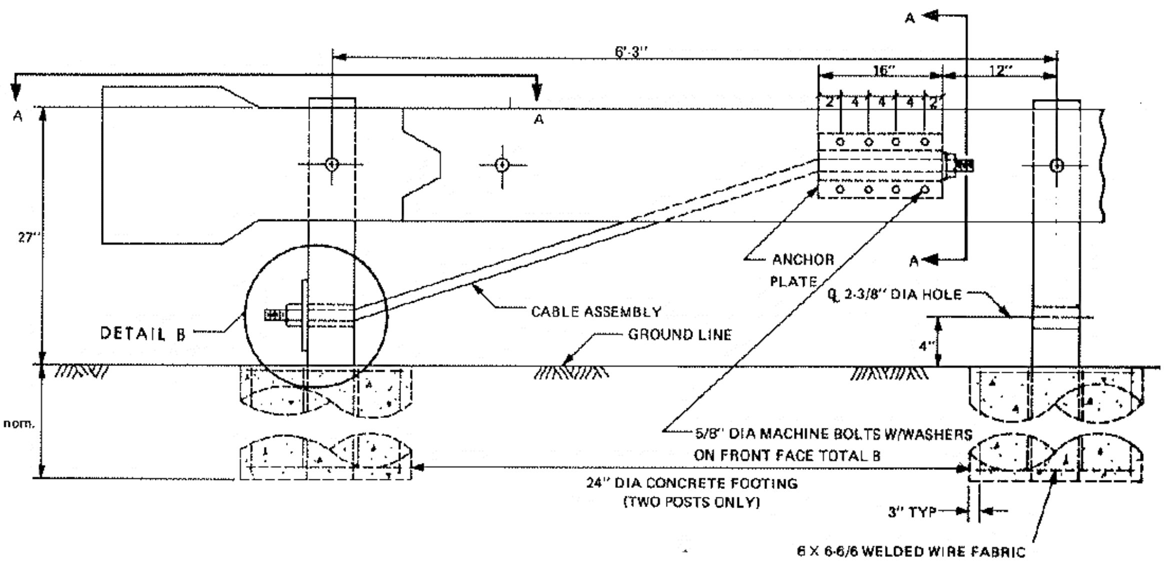


Figure 4. Recommend Guardrail BCT Design [11]

Test nos. 138 through 142 were conducted on non-flared end treatments with steel-post, W-beam guardrail G4S. Test no. 138 utilized a 1,900-lb (862-kg) vehicle impacting the end treatment at a speed of 41.3 mph (66.5 km/h) and at an angle of 0 degrees. High vehicle decelerations indicated that the recommended BCT design neither eliminated nor increased the danger in small car end terminal collisions. Test no. 139 was conducted using a 3,900-lb (1,769-kg) vehicle with a speed of 59.0 mph (95.0 km/h) and at an angle of 25 degrees. The vehicle penetrated the rail due to beam tearing at fourth post, but BCT remained undamaged. Test no. 140 was conducted using a 4,000-lb (1,814-kg) at a speed of 60.0 mph (96.6 km/h) and at an angle of 0 degrees. The right-side of the vehicle's occupant compartment was deformed, but no penetration occurred. Test no. 141 was conducted using a 3,900-lb (1,769-kg) vehicle with a speed of 62.0 mph (100.0 km/h) and at an angle of 27.4 degrees. The vehicle redirected and the BCT posts developed adequate anchorage strength without damage. Test no. 141 was conducted using a 3,850-lb (1,746-kg) vehicle with a speed of 52.5 mph (84.5 km/h) and at an angle of 0 degrees. The vehicle gated through the system and ended behind the rail. No evidence of vehicle occupant compartment damage was found.

In order to improve the earlier BCT designs, SwRI conducted additional component testing, analytical simulation, and full-scale crash testing [12]. The focus of this research included: (1) performance improvement of the guardrail BCT for head-on impacts with a small car; (2) development of steel BCT posts to replace the wood BCT posts; and (3) refinement of the BCT design to reduce cost. During this research, the wood BCT posts were replaced by W6x8.5 slip-base steel posts and a bearing plate to transfer the cable anchor load directly to the foundation tube, as shown in Figure 5. The slip-base post utilized three ASTM A325 bolts in three patterns with Hi-Lok nuts.

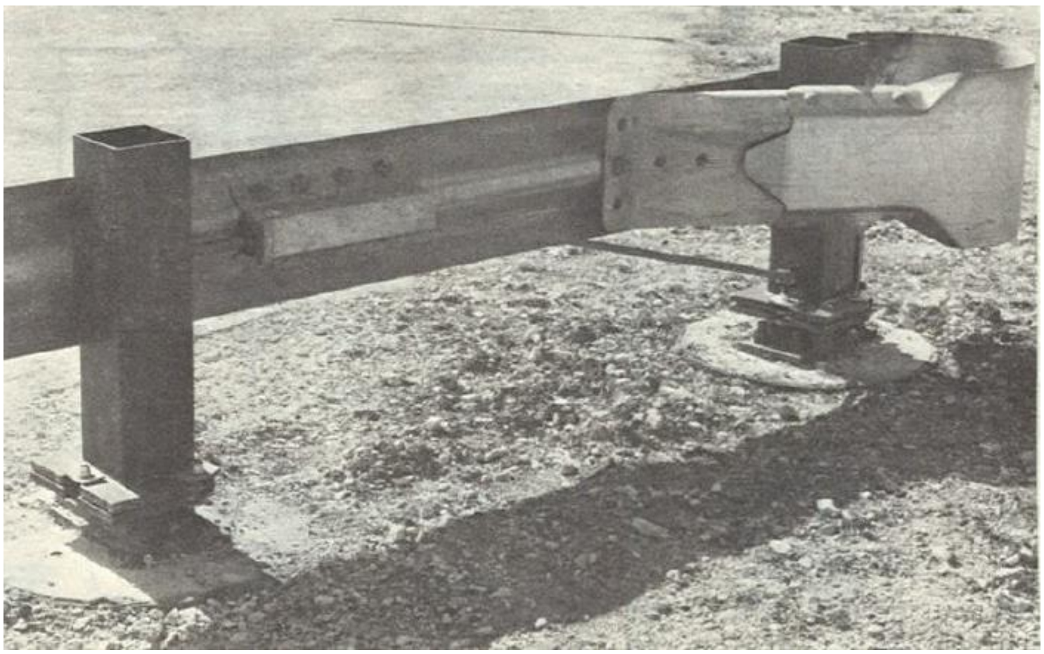


Figure 5. Guardrail BCT with Steel Slip Base Terminal Post [12]

Seven full-scale crash tests were conducted on this modified BCT design. Test nos. 159 through 165 were conducted on a system with a flared end treatment, while test nos. 166 and 167 were conducted on a system with a non-flared end treatment. Test no. 159 was a 0-degree impact test with a 2,402-lb (1,090-kg) vehicle impacting at a speed of 38.0 mph (61.2 km/h). In this test, the vehicle gated through and ended behind the rail. Test no. 160 consisted of a 4,000-lb (1,814-kg) vehicle impacting at a speed of 58.0 mph (93.3 km/h) and at an angle of 25.5 degrees in the second span from the end. In this test, the vehicle pocketed and yawed significantly into a spin. Due to the unexpected results from test no. 160, modifications were made to the BCT design which included post spacing reduction in the third, fourth, and fifth span from 6 ft – 3 in. (1.91 m) to 4 ft – 2 in. (1.2 m).

Test no. 162 was conducted on the modified design using a 4,202-lb (1,906-kg) vehicle impacting the second span from the end at a speed of 58.0 mph (93.3 km/h) and an angle of 24.0

degrees. The vehicle was redirected with significant vehicle wheel-post interaction. In test no. 164, a 4,423-lb (2,006-kg) vehicle impacted the system at a speed of 62.0 mph (100.0 km/h) and at an angle of 0 degrees. The vehicle traveled behind the installation without passenger compartment intrusion. In test no. 165, a 2,130-lb (966-kg) vehicle impacted the system at a speed of 31.5 mph (51.0 km/h) and at an angle of 0 degrees. The vehicle decelerated after contacting the barrier.

Test nos. 166 and 167 were conducted on the steel-post, W-beam median barrier MB4S (blocked-out W-beam) with no rail rub, while test no. 167 included a base flush with the ground. Test no. 166 was conducted on the system with the base of the slip-base terminal post 4 in. above the ground using a 4,500-lb (2,041-kg) vehicle impacting at a speed of 59.7 mph (96 km/h) and at an angle of 1.7 degrees. The vehicle smoothly decelerated until it snagged on the base of the barrier. The vehicle ramped up the barrier but remained in contact with the barrier. Test no. 167 was then conducted on the system with the base of the slip-base terminal flush with the ground using a 4,500-lb (2,041-kg) vehicle impacting the second span from the end at a speed of 62.0 mph (100.0 km/h) and at an angle of 26 degrees. The vehicle vaulted over the W-beam due to the excessive deflection of the terminal rails.

Following the results found in NCHRP Research Results Digest 84, the Federal Highway Administration (FHWA) sponsored a research on a steel-post, BCT anchorage system [13]. The tests were conducted at Texas Transportation Institute (TTI) and indicated improved performance with a reduced stub height. Test no. 3 was conducted using a 2,330-lb (1,057-kg) vehicle with a speed of 65.9 mph (106 km/h) and at an angle of 0 degrees. In this test, the vehicle undercarriage snagged on the slip-base foundation. The maximum barrier penetration was 9.6 ft (2.9 m). Although the 4-in. (102-mm) stub height did not pose problems in previous tests, this result led to the lowering of the slip-base foundation plate. Thus, TTI designed a foundation post with a minimum stub height to eliminate the snagging problem observed in test no. 3, as shown in Figure 6 [13]. Subsequent 0-degree tests (i.e., test nos. 4 through 6) demonstrated an improved safety performance with this modification. Test no. 4 was conducted using a 2,370-lb (1,075-kg) vehicle impacting at a speed of 59.1 mph (95 km/h) and at an angle of 0 degrees. In this test, the maximum barrier deflection was 11 ft (3.4 m). Test no. 5 was conducted using a 4,490-lb (2,037-kg) vehicle impacting at a speed of 55.5 mph (89 km/h) and at an angle of 0 degrees. In this test, the maximum penetration was 21 ft (6.4 m). Test no. 6 was conducted using a 2,270-lb (1,030-kg) vehicle impacting at a speed of 31 mph (50 km/h) and at an angle of 0 degrees. The vehicle came to rest after barrier deflected 6.2 ft (1.9 m).

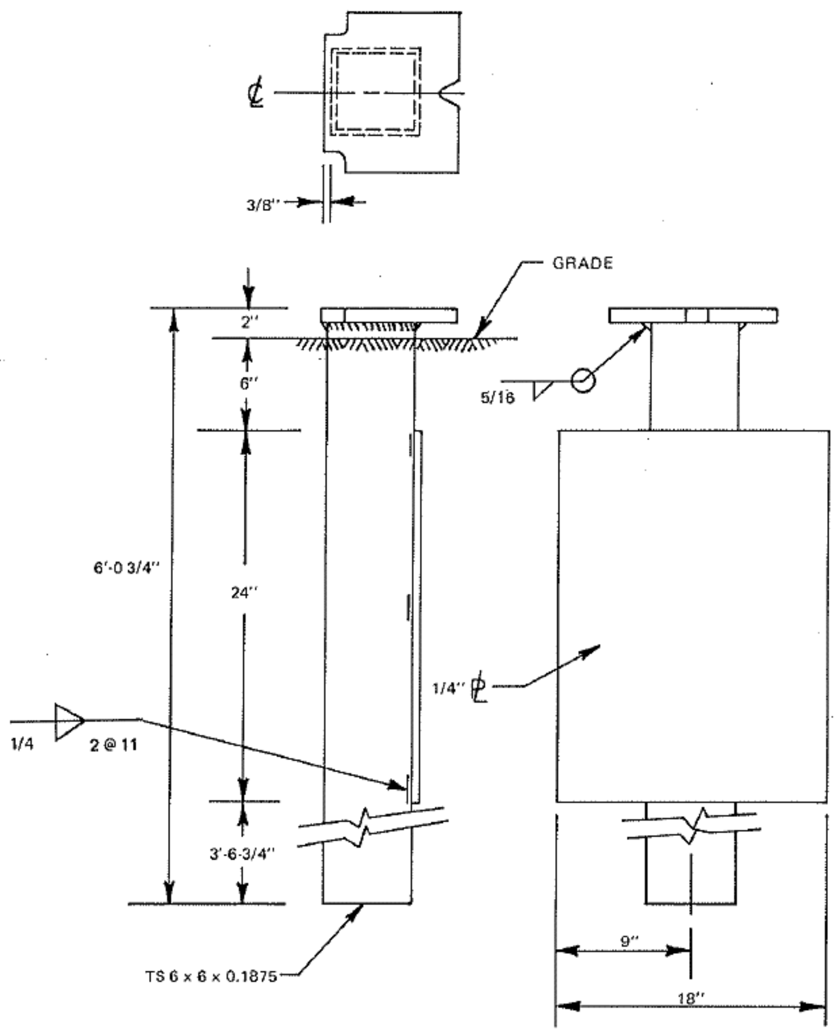


Figure 6. Modified Steel Post BCT Foundation Designs [13]

BCT anchorage systems and their derivatives have often been used as an economical means of providing tensile anchorage for corrugated W-beam guardrail system [4]. End anchorage systems derived from BCT terminals have used the following primary components: (1) two breakaway wood posts; (2) steel foundation tubes with or without soil plates; (3) a steel cable anchor; and (4) a steel groundline compression strut between the two foundation tubes. Variations of the BCT are frequently used by many state DOTs and adopted for use in many crashworthy terminal ends [4].

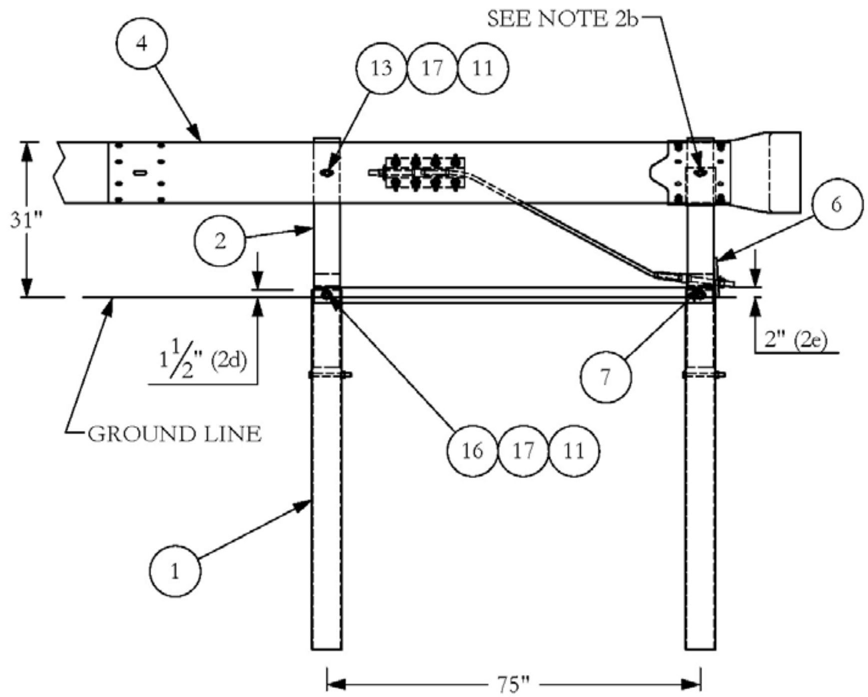
2.2.2 Texas Department of Transportation (TxDOT) Downstream Anchorage

In 2011, TTI developed a downstream anchorage system for TxDOT, as shown in Figures 7 and 8. TTI conducted a reverse-direction, full-scale crash test according to MASH test designation no. 3-20 using an 1100C vehicle to evaluate the performance of the downstream anchorage system [14]. The TxDOT end anchorage system utilized two BCT wood posts embedded into steel foundation tubes along with a cable anchor and two C3x5 channel sections, which connected the two foundation tubes to one another. The W-beam rail was supported at the end anchor post with a steel, shelf-angle bracket. TTI researchers conducted one reverse-direction, full-scale, crash test using an 1100C small car to evaluate the safety performance of the downstream anchorage system. In test no. 420021-1, the TxDOT downstream anchorage system was impacted by a 2420-lb (1098-kg) small car at a speed of 61.9 mph (99.6 km/h) and at an angle of 25.3 degrees. This end anchorage system was successfully crash tested in combination with a 31-in. (787-mm) tall, 8-in. (203-mm) blocked, MGS under MASH 2009 modified test designation no. 3-37 conditions, later defined as test designation no. 3-37b conditions in MASH 2016.

Figure 7. TxDOT Downstream W-beam Terminal [14]

#	PART NAME	QTY.	ARTBA
1	6 x 8 x 72" Foundation Tube	2	
2	Tube Post for Terminal	2	
3	Strut, Channel	2	
4	Rail for Terminal	1	
5	Shelf Angle Bracket	1	FPP02
6	BCT Bearing Plate	1	FPB01
7	BCT Post Sleeve	1	FMM02
8	Guardrail Anchor Bracket	1	FPA01
9	W-beam End Section	1	RWE03a
10	BCT Cable Anchor	1	FCA01
11	Nut, Recessed Guardrail	20	FBB
12	Bolt, Button-head 1-1/4"	4	FBB01
13	Bolt, Button-head 10"	2	FBB03
14	Bolt, 5/8 -11 x 2 hex	8	FBX16a
15	Bolt, 5/8 -11 x 8 hex	4	FBX16a
16	Bolt, 5/8 -11 x 10 hex	2	FBX16a
17	Washer, 5/8 flat	18	FWC16a

DOWNSTREAM TERMINAL
ELEVATION VIEW



2a. All hardware is A307 unless otherwise indicated.
2b. Rail is supported by Shelf Angle Bracket (5) at Post 20 and does not attach to post.
2c. Parts 1, 2, 11, 13, and 15 - 17 callouts at Post 19 or 20 typical at both locations.
2d. Foundation Tube protrudes 1-1/2" above ground line.
2e. Top edge of Strut at 2" above ground line.

The Texas A&M University System

Texas Transportation Institute
College Station, Texas 77843

Revisions:			
No.	Date	By	Chk
1.	2011-04-05	GS	DA
2.			
3.			
4.			
5.			

Date	Drawn By	Scale	Sheet No.
2011-03-30	GES	1:30	2 of 5

Project No.	Sheet Name
420021-1	Downstream Terminal

TxDOT Downstream W-beam Terminal

T:\2010-2011\420021\-1 Downstream Terminal\Drafting\Drawings\420021-1 Drawing

Figure 8. TxDOT Downstream W-beam Terminal Details [14]

2.2.3 MGS Trailing-End Anchorage System

In 2013, MwRSF developed a non-proprietary, trailing-end, anchorage system for the MGS that utilizes two wood BCT posts, steel foundation tubes connected with a steel strut, and an anchor cable connecting the W-beam rail to the base of the end post, as shown in Figure 9. A detailed description of the trailing-end anchorage components and testing of this system are available in Mongiardini et al. [4, 5].

The two steel foundation tubes within the trailing-end anchorage system enhance the post-soil resistance by distributing the tensile load from the rail in a more homogenous manner, while allowing for easier wood post replacement if fractured. The soil resistance can be further increased by attaching vertical steel bearing plates (soil plates) to the foundation tubes, which increases the area of the tube that is exposed to the soil. A compression ground line strut between the two foundation tubes is used to maximize the soil resistance by coupling the two foundation tubes. For common crashworthy guardrail end terminals, steel anchor cables have been used to develop the tensile strength of the rail for impacts occurring beyond the length-of-need (LON) of the barrier. For the downstream end of longitudinal guardrail systems, the end of the LON has been previously defined as a downstream CIP at which the end anchorage system would no longer redirect an errant vehicle but instead gate and permit the vehicle to encroach behind the system [4, 5]. In crashworthy guardrail end terminals, one end of the cable is anchored to the base of the upstream end post and foundation tube near the ground line, while the other end of the cable is connected to the back of the rail near the second post using a steel mounting bracket, which is designed to quickly release away from the rail during end-on impact events.

A series of dynamic component tests and dynamic jerk tests were conducted at MwRSF to investigate the behavior and capabilities of the wood-post BCT anchorages [12]. In test nos. DSAP-1 and DSAP-2, dynamic jerk tests were conducted on a modified MGS trailing-end anchorage system, consisting of two wood BCT posts, a steel W6x8.5 post, two 12- ft 6-in. (3.8-m) long W-beam segments, and an instrumented cable anchor connecting the W-beam rail to the end BCT post, as shown in Figure 10. During test no. DSAP-1, the nylon strap used in the connection joint between the pull cable and upstream end of the guardrail ruptured. Consequently, the anchorage was only partially loaded and no damage occurred to the wood posts nor the post-to-rail connection bolts. In test no. DSAP-2, the tension in the anchor cable increased up to 35 kips (155.7 kN). The increased tension in the anchor cable caused the end anchor post to fracture first. The post was pulled upstream and upward by the anchor cable but it remained attached to the rail following the fracture until it rotated approximately 90 degrees [4]. The second BCT post fractured at nearly the same time, but the post largely rotated about the BCT hole toward the ground level. The post released away from the rail and fractured. The maximum load sustained by the end anchorage system was 35 kips (155.7 kN).

Figure 9. MGS Trailing-End Anchorage System [4]

Figure 10. Test Setup: Test Nos. DSAP-1 and DSAP-2 [4]

Furthermore, two successful crash tests were conducted on the MGS, trailing-end anchorage system per MASH 2009 requirements. In first test, test no. WIDA-1, a 5,172 lb (2,346 kg), 2270P pickup impacted the sixth post from the downstream end of the anchor at 63.0 mph (101.4 km/h) and 26.4 degrees, which caused the end anchorage to gate, and the vehicle proceeded behind the system. The second test, test no. WIDA-2, consisting of a 2,619 lb (1,188 kg) 1100C small car impacting the system 4 in. (102 mm) upstream of the third post from the downstream end of the anchor at 62.0 mph (99.8 km/h) and 25.5 degrees, resulted in acceptable redirection.

2.3 Universal Breakaway Steel Post Performance

In 2010, MwRSF developed a, non-proprietary, UBSP to replicate the strength and behavior of the wood CRT post. The UBSP consisted of a W6x8.5 for the upper portion, which is a standard steel section used for line posts in strong-post guardrail, and a 6-in. x 8-in. x 3⁄16-in. (152-mm x 203-mm x 5-mm) tube for the lower portion, as shown in Figure 11. The lower portion was the same cross-section size as the CRT post to ensure similar soil-post resistance. The two post sections were welded to base plates and connected by four 7⁄16-in. (11-mm) diameter ASTM A325 bolts. The UBSP releases by fracturing the four vertical bolts in tension due to the moment at the base plate connection when the post is loaded. Different strong- and weak-axis capacities were generated by the spacing of the bolts connecting the base plates [1].

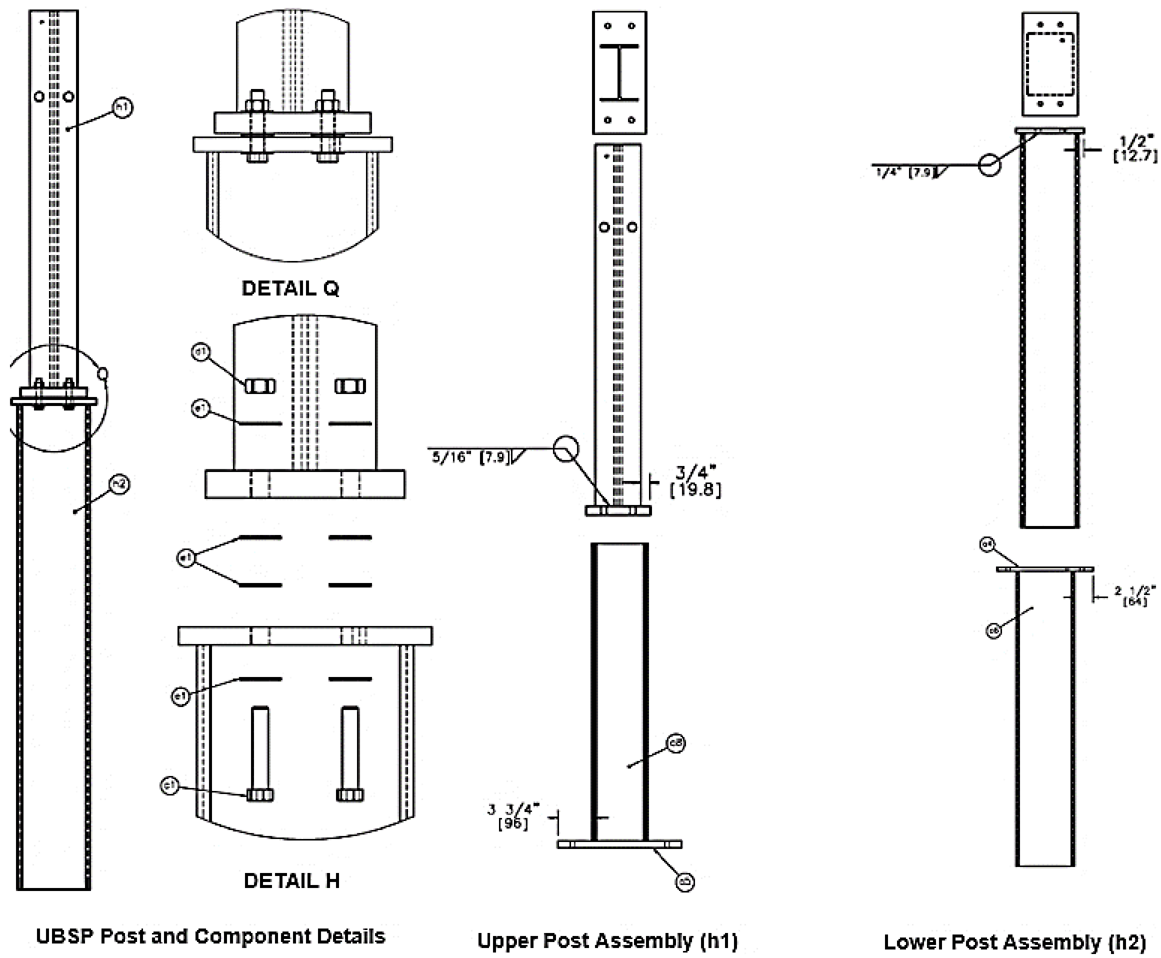


Figure 11. UBSP in Thrie-Beam Bullnose System [1]

During the development of the UBSP, three successful full-scale crash tests were performed on the thrie-beam bullnose with UBSPs according to the TL-3 safety performance criteria provided in NCHRP Report No. 350 [1-2]. Based on the satisfactory crash performance of UBSPs, the researchers determined that the UBSP was a suitable alternative for wood CRT posts used in the original thrie-beam bullnose system.

Following the initial UBSP research efforts, the Midwest Pooled Fund Program funded a project to further investigate the application of this technology to other systems, including guardrail systems [15]. The research study included a series of nine component tests of UBSPs and CRT posts installed in soil and impacted in both the strong and weak axes. The UBSP demonstrated similar strong-axis behavior in terms of disengagement and force and energy levels as compared to the CRT post. The average strong-axis peak force for the UBSP was 14.6 kips (64.9 kN), while the average strong-axis peak force for the CRT post was 14.5 kips (64.5 kN). The weak-axis behavior of the UBSP was found to provide similar post disengagement, but the post released at lower force and energy levels than the CRT post. The average weak-axis peak force for the UBSP was 7.9 kips (35.1 kN), while the average weak-axis peak force for the CRT post was 10.9 kips (48.5 kN). The lower force and energy levels generated by the UBSP were not believed to negatively affect performance, as CRT and other breakaway posts are used to limit the force and energy during weak-axis impacts. As such, the reduced forces and energies in the UBSP were not found to be an issue and may even improve the performance in certain applications. Thus, the UBSP was determined to be a potential replacement for CRT posts used in applications other than the thrie-beam bullnose, such as in guardrail end terminals, long-span guardrail systems, guardrail systems installed in subsurface rock foundations or rigid pavement mow strips, and new, reduced-maintenance barrier systems.

2.4 Patent Review

A patent review was performed to identify the relevant guardrail end terminals, guardrail anchorages, and breakaway post concepts to prevent infringement upon the existing patents. The parent review includes both enforced and expired patents, patent applications, and international patents.

A total of 752 patents, filed under a U.S. classification, related to road safety features were collected. Of the total of 752, 148 patents directly related to guardrails, posts, anchor assemblies for guardrails, and end terminals for highway safety appurtenances. These patents cover a broad range of guardrail end terminals, guardrails, guardrail anchorages, breakaway sign posts, breakaway guardrail posts, and breakaway terminal posts. The filing dates range from 1982 to 2016. The patents earlier than patent no. 4,999,999 are guaranteed to be expired based on the date of issuance.

Design criteria considered to identify the relevance of each patent to the development of a steel-post, trailing-end anchorage system was different for each device category. For guardrail end terminals, guardrails, and breakaway steel posts, the criteria included: (1) proper breakaway mechanism and (2) ease and simplicity in design, fabrication, assembly, and maintenance. For the anchorage assemblies, the criteria included: (1) proper connection between the post and back of the rail; (2) ability to develop sufficient longitudinal tensile force in the rail when impacted by an errant vehicle; and (3) proper release of tension in the cable.

Using the design criteria and parameters, researchers identified the relevant patents, which included thirteen patents related to guardrail end terminals, eight patents related to anchorage assemblies, nine patents related to breakaway sign posts, twelve patents related to breakaway guardrail posts, and eleven patents related to breakaway terminal posts.

2.4.1 Guardrail End Terminal Patents

Eleven patents and two patent applications were found for guardrail end terminals relevant to the trailing-end anchorage system, as listed in Table 1. In the following section, the patents are described in detail.

Table 1. Patents for Guardrail End Terminals

Patent No.	Date of Issue	Title	Notes	Authors	Reference No.
6,729,607	5/4/2004	Cable Release Anchor	Cable release anchor that has bearing plates with U-shaped cutouts	Dean C. Alberson; Lance Bullard, Jr.; Roger P. Bligh; C. Eugene Buth	16
7,694,941	4/13/2010	Guardrail Safety for Dissipating Energy to Decelerate the Impacting Vehicle	Energy dissipating guardrail system	Akram Y. Abu-Odeh; Dean C. Alberson; Roger P. Bligh; Lance D. Bullard Jr.; Eugene C. Buth	17
7,883,075	2/8/2011	Tension Guardrail Terminal	Coupling between post, rail, and tensile cable	Akram Y. Abu-Odeh; Dean C. Alberson; Roger P. Bligh; Lance D. Bullard Jr.; Eugene C. Buth	18
8,882,082	11/11/2014	Tension Guardrail Terminal	Coupling between post, rail, and tensile cable	Akram Y. Abu-Odeh; Dean C. Alberson; Roger P. Bligh; Lance D. Bullard Jr.; Eugene C. Buth	19
20120056143	3/8/2012	Posts	Terminal post for a barrier with slots for receiving cables and to form a predefined failure	Dallas Rex James	20
20160047094	2/18/2016	Posts	Method for releasing an anchor cable from a terminal post	Dallas Rex James	21
6,398,192B1	6/4/2002	Breakaway Support Post for Highway Guardrail End Treatments	Breakaway post with a coupler	James R. Albritton	22
6,619,630B2	9/16/2003	Breakaway Support Post for Highway Guardrail End Treatments	Breakaway base for a guardrail end terminal post	James R. Albritton	23
8,177,194	5/15/2012	Frangible Post for Guardrail	Frangible post to be used with terminal with cable passing through it	Dallas Rex James	24
6,065,894	5/23/2000	Breakaway Post Connector	Frangible coupler for connecting guardrail posts to buried bases	Lance David Wasson; Gary James Melrose	25
6,488,268B1	12/3/2002	Breakaway Support Post for Highway Guardrail End Treatments	I beam post for terminals that resists strong direction impacts	James R. Albritton	26
6,793,204B2	9/21/2004	Breakaway Support Post for Highway Guardrail End Treatments	Includes new embodiments of the TRN posts, including a releasable hinge coupler at post bases	James R. Albritton	27
6,886,813	5/3/2005	Breakaway Support Post for Highway Guardrail End Treatments	Related to 6488268 and 6793204 - additional post base and connection embodiments	James R. Albritton	28

2.4.1.1 Patent No. 6,729,607

Patent no. 6,729,607 [16] describes a guardrail end terminal with a cable release anchor that has bearing plates with U-shaped cutouts to hold the cable. Schematics of patent no. 6,729,607 are shown in Figure 12. The patent includes 20 claims that cover a plurality of cable release anchor options, bearing plates, where the first bearing plate is attached to the top member and the second bearing plate is attached to the lower member, and cable release terminals.

Claim 1 of patent no. 6,729,607 discusses a cable release anchor comprising the first anchor post partially buried in the ground with a bearing plate attached to end of the post and a second anchor post connected to the end of first anchor post. The second anchor post consists of a second bearing plate attached to the end of the anchor post. The two bearing plates join when the top and bottom parts of the anchor post are interconnected.

Claim 2 of patent no. 6,729,607 discusses an anchor plate attached to the top part of the anchor post and a second plate connected to the bottom part of the anchor post. These plates join when the top and bottom parts of the anchor post are interconnected.

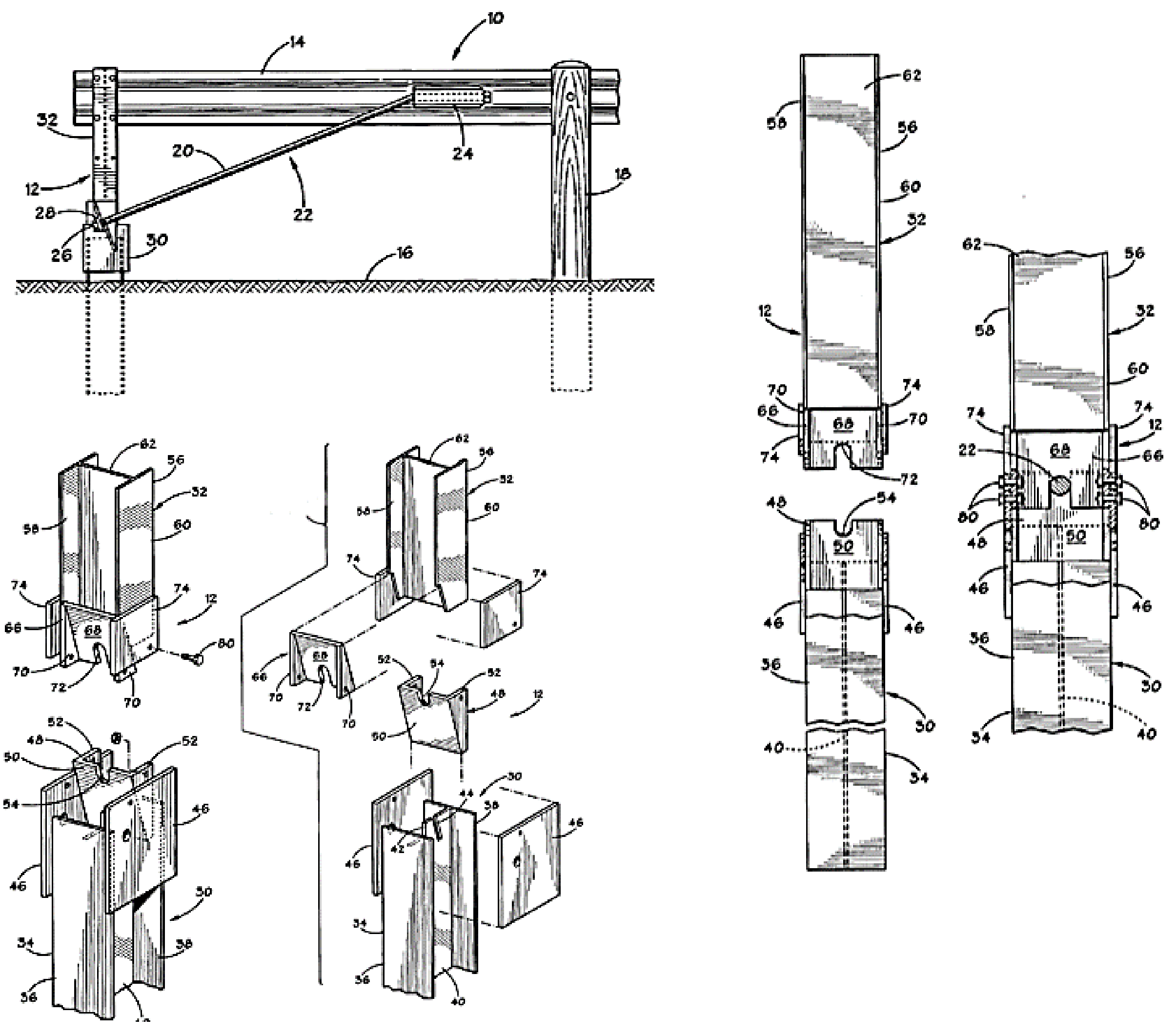


Figure 12. Schematics of Patent No. 6,729,607 [16]

2.4.1.2 Patent No. 7,694,941

Patent no. 7,694,941 [17] describes a guardrail end terminal with an energy-dissipating system. Schematics of patent no. 7,694,941 are shown in Figure 13. The guardrail end terminal slopes from a first vertical height for redirecting an errant vehicle to a second vertical height proximate to the ground surface. An impact plate attaches to the flattening portion. The patent includes 31 claims that cover a plurality of vertically flattened and sloped W-beam with a plate coupled to the flattening portion. The claims also include a plurality of means for flattening the W-beam, a support post for an upstream terminal end, parallel and flared terminal portions of a guardrail system, and a W-beam that has a valley with upper and lower peaks.

Claim 1 of patent no. 7,694,941 discusses an impact plate for disengaging an impacting vehicle at the end of the guardrail system. Claims 2 and 3 of this patent present an end treatment with four vertically stacked plates.

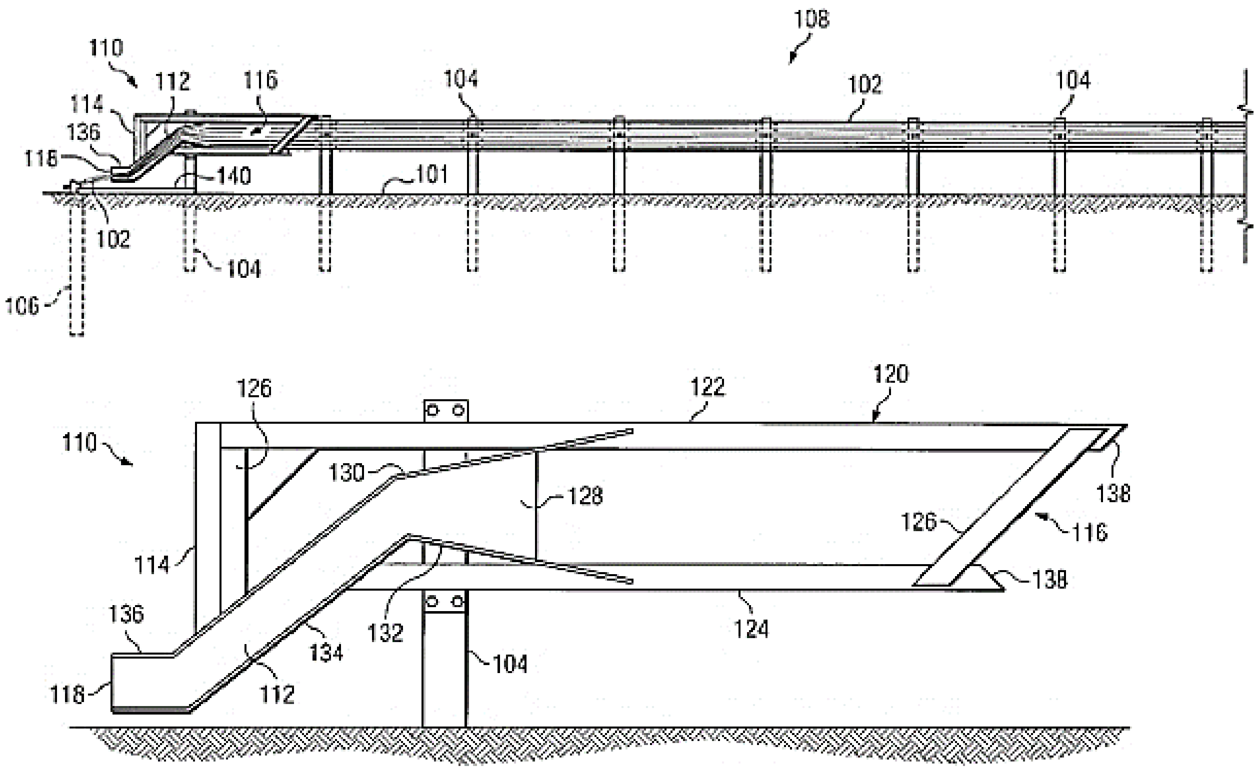


Figure 13. Schematics of Patent No. 7,694,941 [17]

2.4.1.3 Patent No. 7,883,075

Patent no. 7,883,075 [18] describes a guardrail end terminal that is related to patent no. 7,694,914. It contains a sloped anchor plate with a vertical slot and a sloped washer plate. The sloped anchor plate includes rectangular plates with circular-shaped, V-shaped, and U-shaped cutouts; the plates are stacked adjacent to each other. Schematics of patent no. 7,883,075 are shown in Figure 14. The patent includes 33 claims that cover a plurality of sloped anchor plates, a support post for an upstream terminal end, parallel and flared terminal portions of a guardrail system, and a W-beam that has a valley with an upper and lower peak.

Claim 1 of patent no. 7,883,075 discusses a tensile coupling of three plates stacked adjacent to one another. The first plate is a rectangular plate with a V-shaped cut-out in the upper edge, the second plate is a rectangular plate with a circular shaped opening, and the third plate is a rectangular plate with a U-shaped cut-out in an upper edge. These three cutouts align when the first, second, and third plates are stacked adjacent to one another.

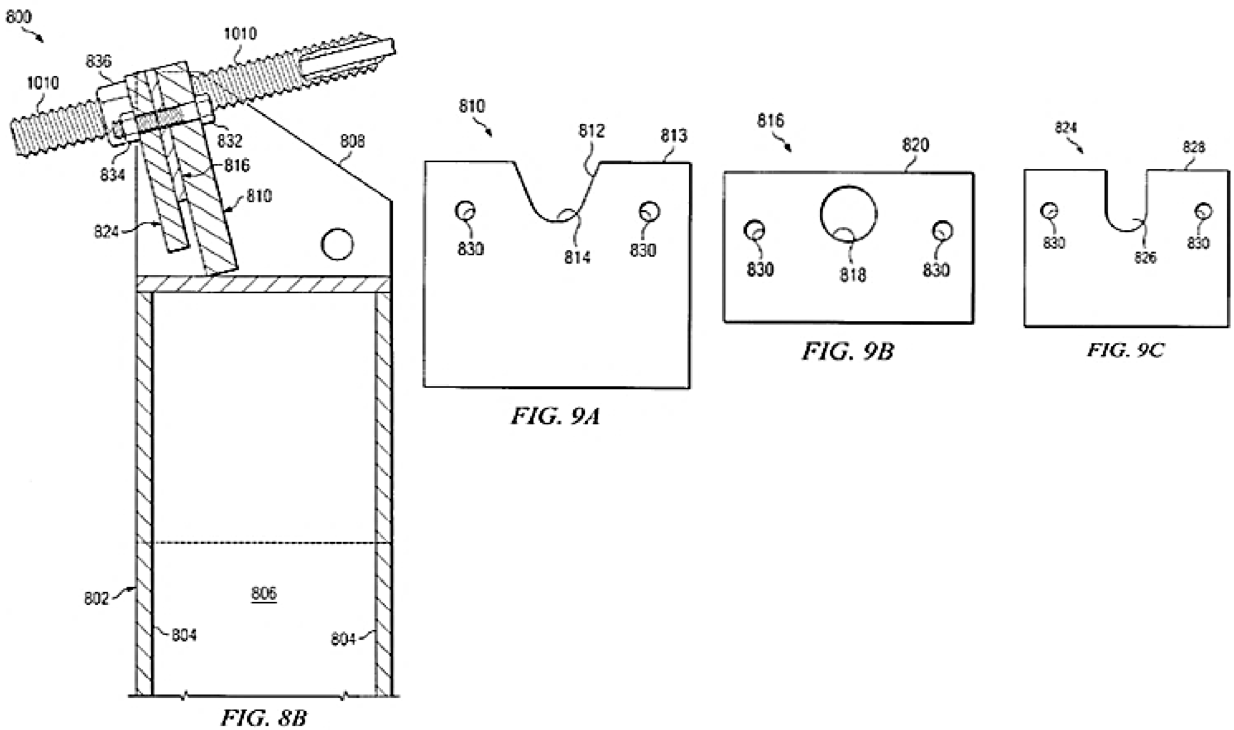


Figure 14. Schematics of Patent No. 7,883,075 [18]

2.4.1.4 Patent No. 8,882,082

Patent no. 8,882,082 [19] describes a guardrail end terminal that slopes down to redirect an errant vehicle to a height adjacent to the surface of the ground at an upstream end of the guardrail terminal. Schematics of patent no. 8,882,082 are shown in Figure 15. This patent is related to patent nos. 7,694,941 [17] and 7,883,075 [18]. The patent includes 35 claims that cover a plurality of support post for the terminal end, parallel and flared terminal portions of a guardrail system; plates comprising V-shaped, U-shaped, and circular-shaped cutouts; and a W-beam that has a valley with upper and lower peaks.

Claim 14 of patent no. 8,882,082 discusses a plurality of plates comprising a first plate with a V-shaped cut-out, a second plate with a circular shaped opening, and the third with a U-shaped cut out. The V-shaped cutout, the circular opening, and U-shaped cut out align when the first, second, and third plates are stacked together.

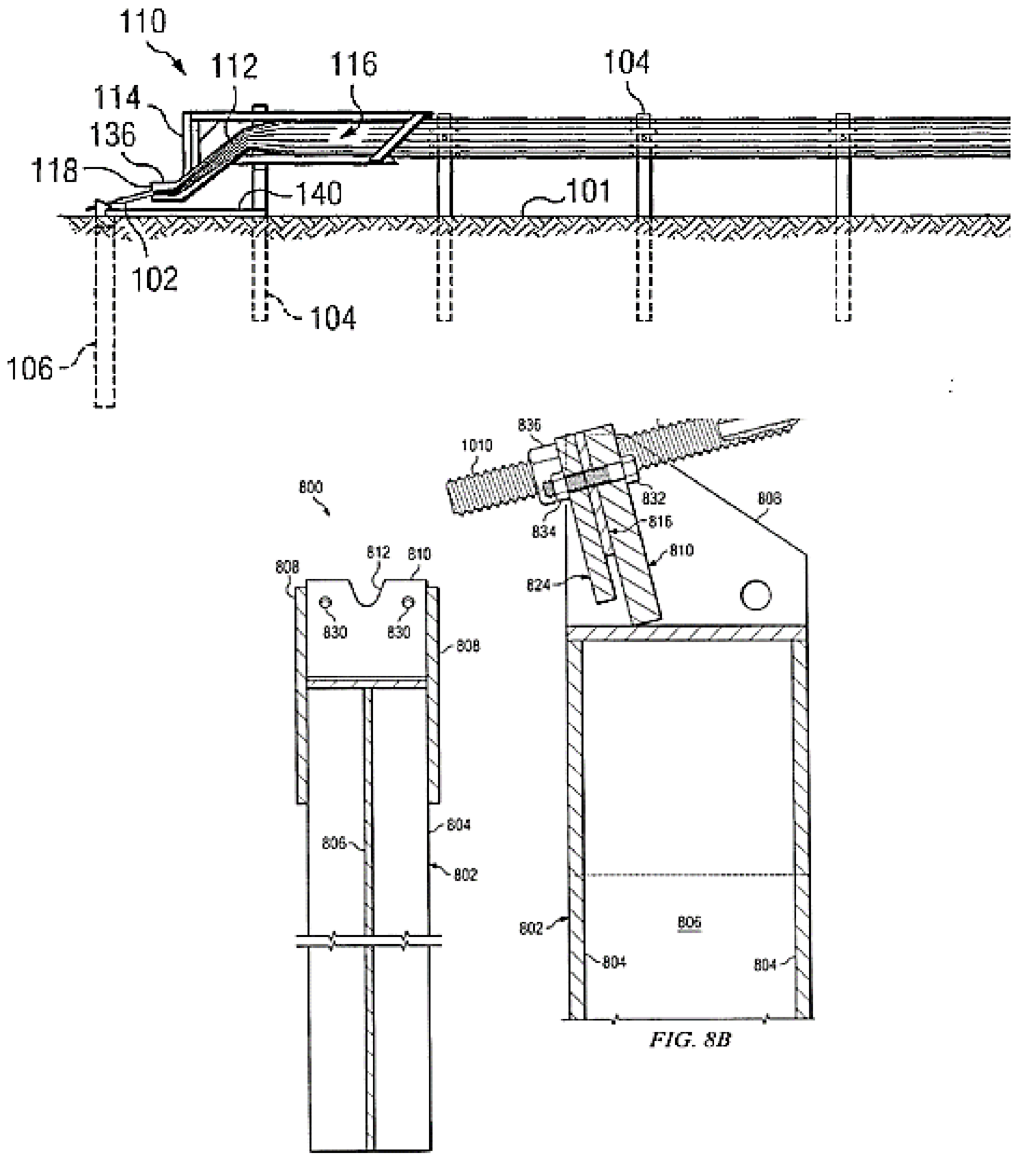


Figure 15. Schematics of Patent No. 8,882,082 [19]

2.4.1.5 Patent Application Nos. 20120056143 and 20160047094

In patent application nos. 20120056143 [20] and 20160047094 [21], the guardrail end terminal includes posts that have a slot for receiving a cable and a pair of notches that form a pre-defined failure line. Schematics of patent application nos. 20120056143 and 20160047094 are shown in Figure 16. Patent application no. 20120056143 includes nine claims that cover a plurality of different terminal posts with a slot for receiving a cable and a guardrail terminal, which includes a post with a disengaging portion. Patent application no. 20160047094 includes six claims that cover possible methods for releasing an anchor cable from a terminal post in a cable barrier, and different methods for deforming the post. These methods include sliding the terminal end of the anchor cable through the slot, levering the terminal end of the anchor cable, and forming a pre-determined failure line.

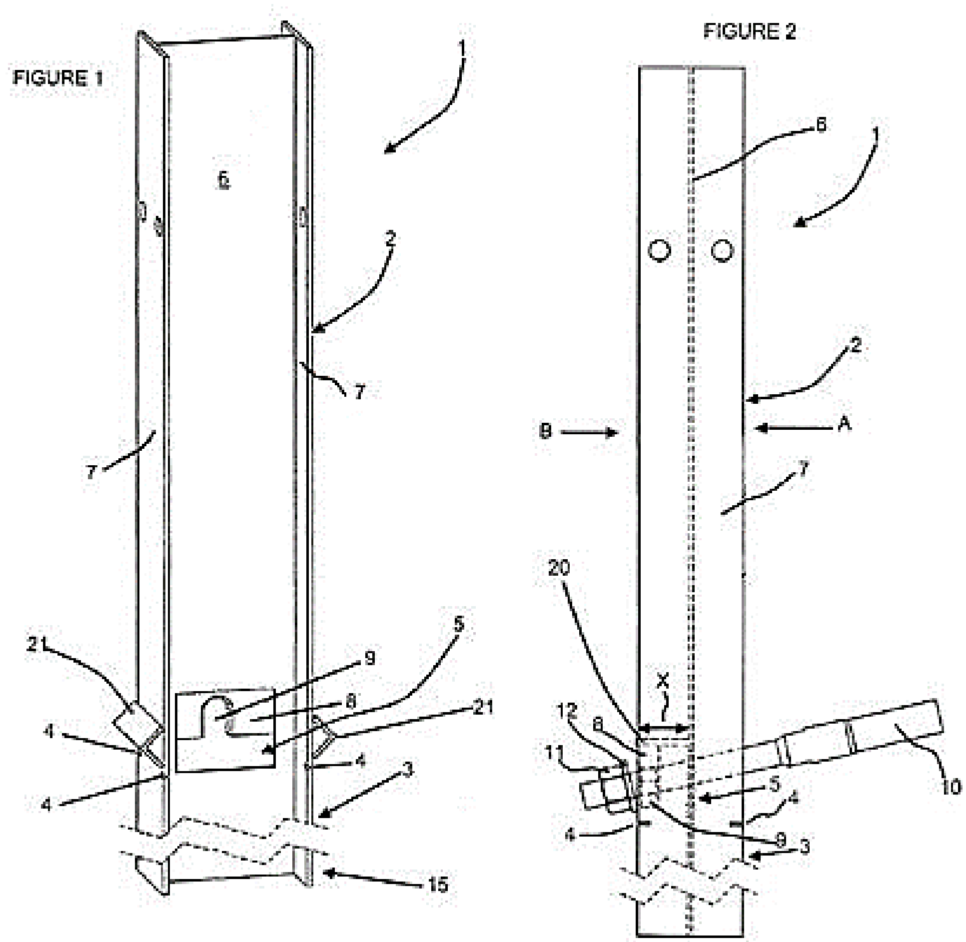


Figure 16. Schematics of Patent Application Nos. 20120056143 [20] and 20160047094 [21]

2.4.1.6 Patent Nos. 6,398,192B1 and 6,619,730B2

Patent nos. 6,398,192B1 [22] and 6,619,630B2 [23] describe a breakaway support post for a guardrail end terminal with a releasable coupling assembly consisting of a shear pin to break away during a weak-axis impact. Schematics of patent nos. 6,398,192B1 and 6,619,630B2 are shown in Figure 17. Both patents include an embodiment for a Hinged Break Away (HBA) post. Patent no. 6,398,192B1 comprises three claims that cover a plurality of guardrail terminal breakaway posts, a method of coupling the post to the guardrail terminal, and a means for rotatable coupling of the upper and the lower portion of the post. Patent no. 6,619,630B2 includes 21 claims that cover a highway guardrail terminal system with a plurality of posts, a method of coupling the upper and lower portion of the post, plates, strut, and different possible means of breaking away the post in the weak direction.

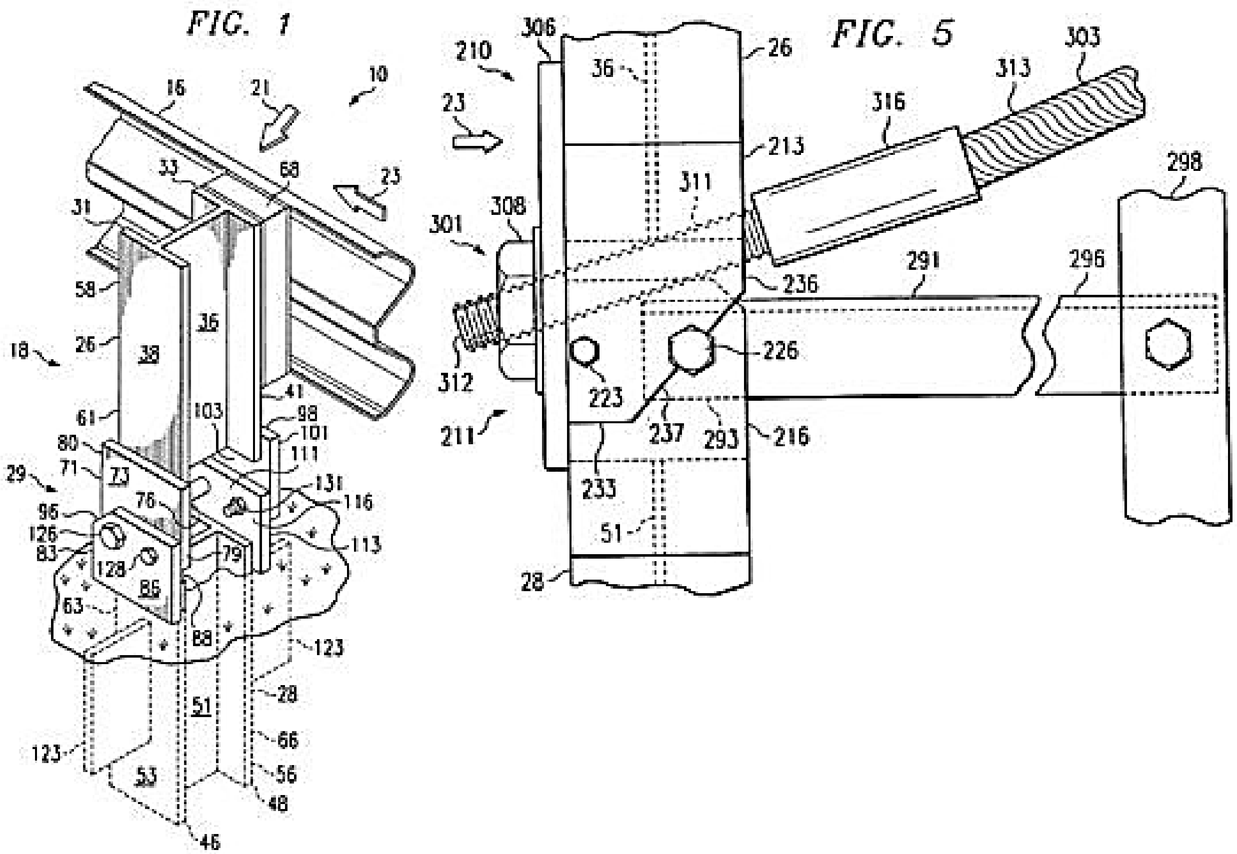


Figure 17. Schematics of Patent Nos. 6,398,192B1 [22] and 6,619,630B2 [23]

2.4.1.7 Patent No. 8,177,194

Patent no. 8,177,194 [24] describes a guardrail end terminal with a frangible post that has a region of weakness defined by notches formed in the vertical edge of the post. Schematics of patent no. 8,177,194 are shown in Figure 18. Patent no. 8,177,194 includes 22 claims that cover a plurality of frangible posts for a guardrail terminal, mainly focusing on possible means of forming a region of weakness in the terminal post and a guardrail terminal system, including a frangible post.

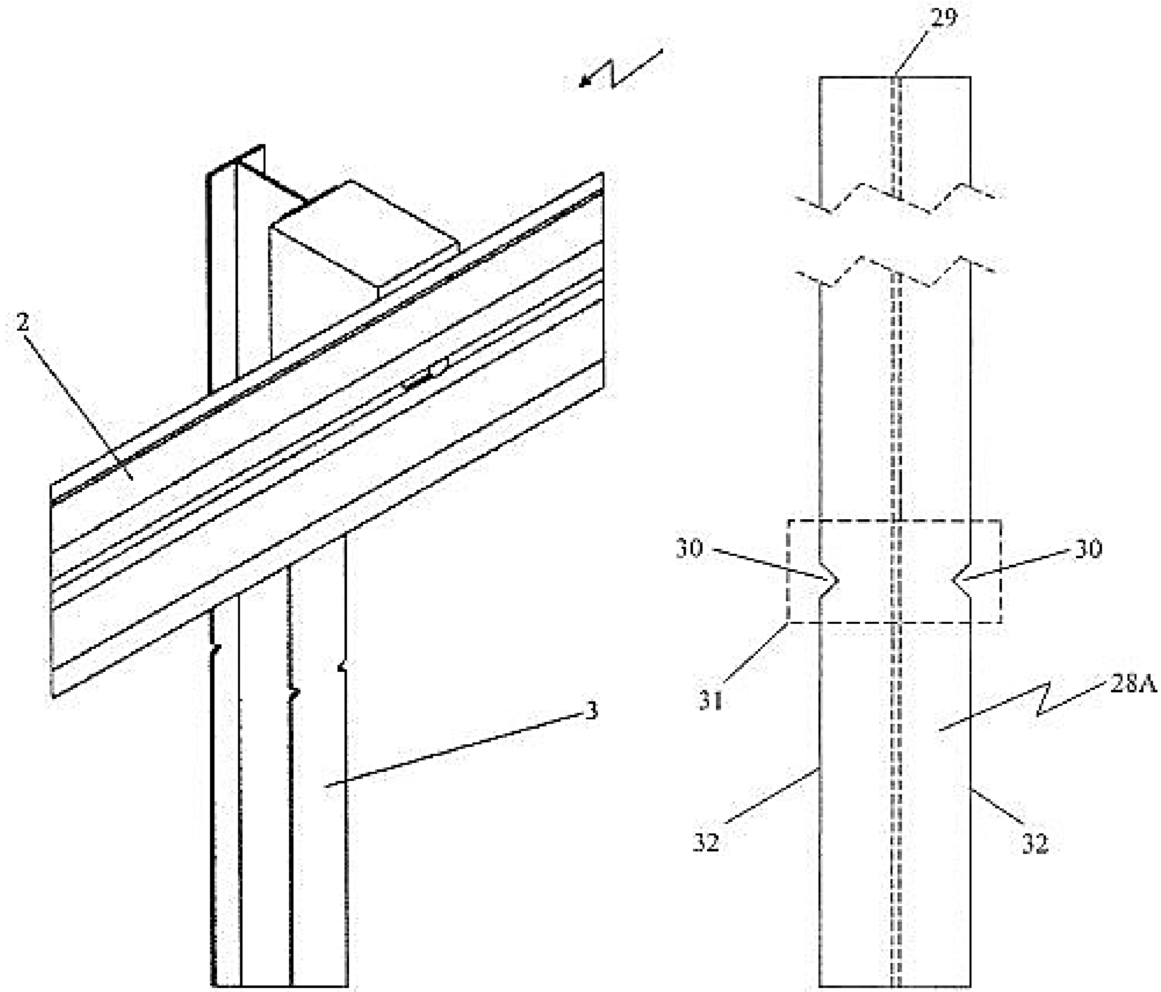


Figure 18. Schematics of Patent No. 8,177,194 [24]

2.4.1.8 Patent No. 6,065,894

Patent no. 6,065,894 [25] describes a molded coupling unit for a breakaway end post in guardrail end terminals that substitutes for the typically-utilized timber posts. The coupling unit has an intermediate fracture zone that allows C-channel, rectangular, or square post segments to separate when subjected to a vehicle impact greater than a predetermined severity. Schematics of patent no. 6,065,894 are shown in Figure 19. Patent no. 6,065,894 also covers a guardrail terminal supported by posts that are coupled by this integrally-molded coupling unit. The patent includes 47 claims that cover a plurality of slotting means for the post, a barrier assembly, a post assembly, fastening means, and different possible materials for constructing the coupling unit.

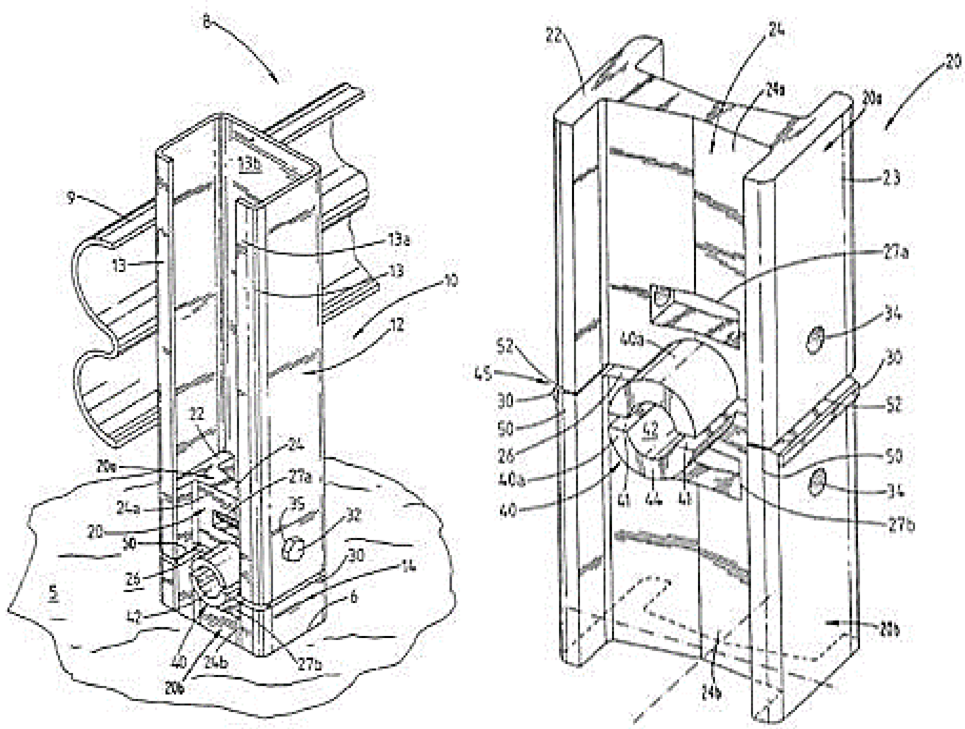


Figure 19. Schematics of Patent No. 6,065,894 [25]

2.4.1.9 Patent Nos. 6,488,268B1, 6,793,204B2, and 6,886,813

Patent nos. 6,488,268B1 [26], 6,793,204B2 [27], and 6,886,813 [28] describe guardrail end terminal systems with breakaway support posts that resist an impact in the strong direction and yield in the weak direction. Schematics of patent nos. 6,488,268B1, 6,793,204B2, and 6,886,813 are shown in Figure 20. Patent nos. 6,488,268B1 and 6,793,204B2 include HBA posts. Patent no. 6,488,268B1 includes five claims that cover a plurality of guardrail terminal systems, a breakaway post with upper and lower portions, a spacer between the upper and lower portions, and a fastening mechanism for the upper and lower posts. Patent no. 6,793,204B2 describes a guardrail end terminal system with two different breakaway support posts that have elongated slots in the flanges of an I-beam to form a yieldable connection in the weak direction. Patent no. 6,793,204B2 includes 18 claims that cover a guardrail terminal system comprising breakaway support posts with slots, openings in the flange and the web of an I-beam, soil plate, support post directly driven into the ground, and a frangible connection. Patent no. 6,886,813 describes a guardrail end terminal system with a breakaway post that has a connection of two rods, or bolts, aligned in the strong direction with spacing between the breaker bars or nuts allowing the post to bend and fail the rods. Patent no. 6,886,813 includes 13 claims that cover a rotatable coupling unit between the upper and lower posts. The rotatable coupling unit has two U-shaped brackets connected by a pivot pin. The claim also includes a guardrail terminal system comprising a rotatable coupling unit between the upper and lower posts, and a means for attaching the post to a guardrail.

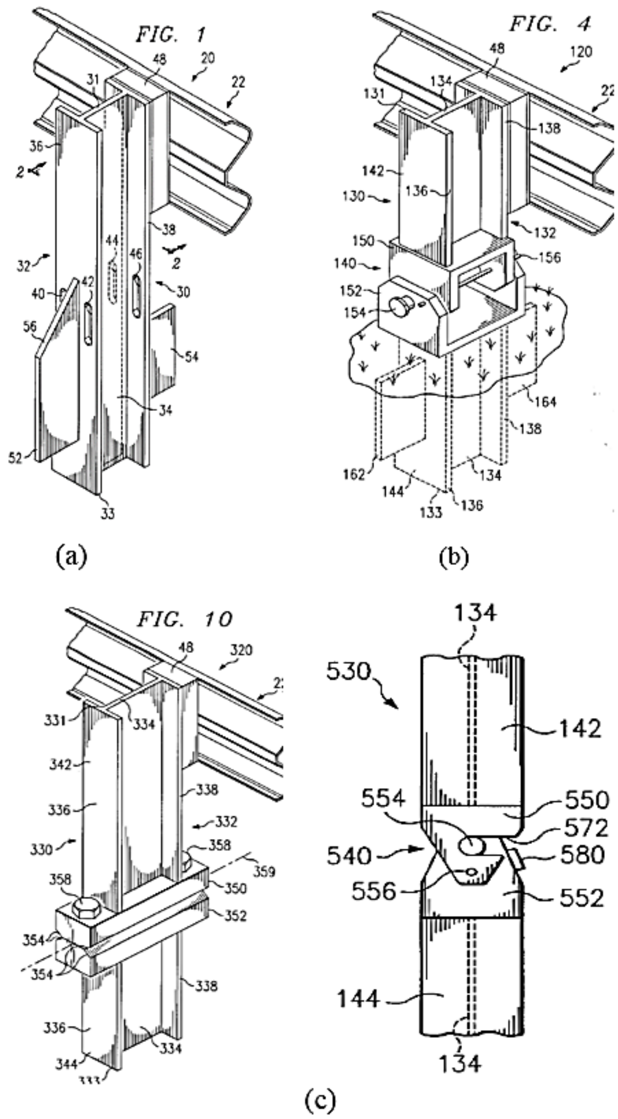


Figure 20. Schematics of: (a) Patent No. 6,488,268B1 [26]; (b) Patent No. 6,793,204B2 [27]; and (c) Patent No. 6,886,813 [28]

2.4.2 Guardrail Anchorage Patents

Eight patents were found for guardrail anchorages that were deemed relevant to the trailing-end anchorage design, as listed in Table 2.

Table 2. Patents for Guardrail Anchorages

Patent No.	Date of Issue	Title	Notes	Authors	Reference No.
6,932,327	8/23/2005	Cable Guardrail Release System	System to release cables in a cable barrier when impacted from the end	Dean C. Alberson; Roger P. Bligh; Lance D. Bullard Jr.; Eugene C. Buth	29
7,556,242	7/7/2009	Cable Guardrail Release System	Continuation of patent no. 6932327 Release for cable rails	Dean C. Alberson; Roger P. Bligh; Lance D. Bullard Jr.; Eugene C. Buth	30
7,367,549	5/6/2008	Safety Barrier Anchorage	Method for anchoring the end of a rope safety barrier into the ground	Michael Thomas Titmus	31
6,065,738	5/23/2000	Anchor for Cables	Anchor system for cable safety barrier systems	Philip Pearce; Timothy John Heldt; Stephen Cawthorne	32
5,503,495	4/2/1996	Thrie-Beam Terminal with Breakaway Post Cable Release	End treatment for a thrie-beam guardrail with breakaway support post cable release mechanism	King K. Mak; Roger P. Bligh; Hayes E. Ross, Dean L. Sicking	33
5,547,309	8/20/1996	Thrie-Beam Terminal with Breakaway Post Cable Release	End treatment for a thrie-beam guardrail with breakaway support post cable release mechanism	King K. Mak; Roger P. Bligh; Hayes E. Ross; Dean L. Sicking	34
6,109,597	8/29/2000	Anchor Cable Release Mechanism for a Guardrail System	Anchor cable release bracket with slots and openings	Dean L. Sicking; John D. Reid; John R. Rohde	35
6,299,141	10/9/2001	Anchor Assembly for Highway Guardrail End Terminal	Anchor assembly with cable anchor bracket	Wilson J. Lindsay; Dennis B. Woodard; Steven D. Easton	36

2.4.2.1 Patent Nos. 6,932,327 and 7,556,242

Patent nos. 6,932,327 [29] and 7,556,242 [30] describe a cable barrier end terminal that was designed and crash tested by TTI in 2002, as shown in Figure 21. Schematics of the end terminal system are shown in Figure 22. The end terminal incorporated proprietary breakaway posts in the end terminal section followed by Rib-Bak or U-Channel posts for the line posts. The breakaway terminal posts were designated as Cable Release Posts (CRP) and were used to anchor one of the three cables used in the system.

Patent no. 6,932,327 includes 16 claims that cover a plurality of possible cable guardrail release systems with a plurality of anchor posts, and a cable guardrail system with a wood post in a foundation tube that has slots in it. Patent no. 7,556,242 includes 20 claims, mainly focusing on the coupling between the cable and the anchor post, a plurality of upper and lower posts, and plates that are coupled to posts.

Claim 1 of patent no. 6,932,327 depicts an anchor post with upper and lower parts. The upper and bottom parts of the anchor post retain a slanted plate at the lower end of the top and a second slanted plate at the upper end of the base. The first slanted plate is adjacent the second slanted plate such that the first cutout of the top portion and the second cutout of the bottom align to form an opening for the cable to pass through.

Claim 1 of patent no. 7,556,242 discusses a cable guardrail release system with the first plate coupled to the upper part of the anchor post and the second plate coupled to the lower part of the anchor post. The first and second plates are coupled to one another to form an opening through which an end of a cable is secured. These plates are uncoupled from one another and the cable releases during an impact of the anchor post while the plate is retained with the anchor post. Claim 14 of the patent depicts the first and second plates being uncoupled from one another and releasing the end of the during an impact of the anchor post. At least one plate is retained with the anchor post when the cable is released.

Figure 21. TTI End Terminal [39]

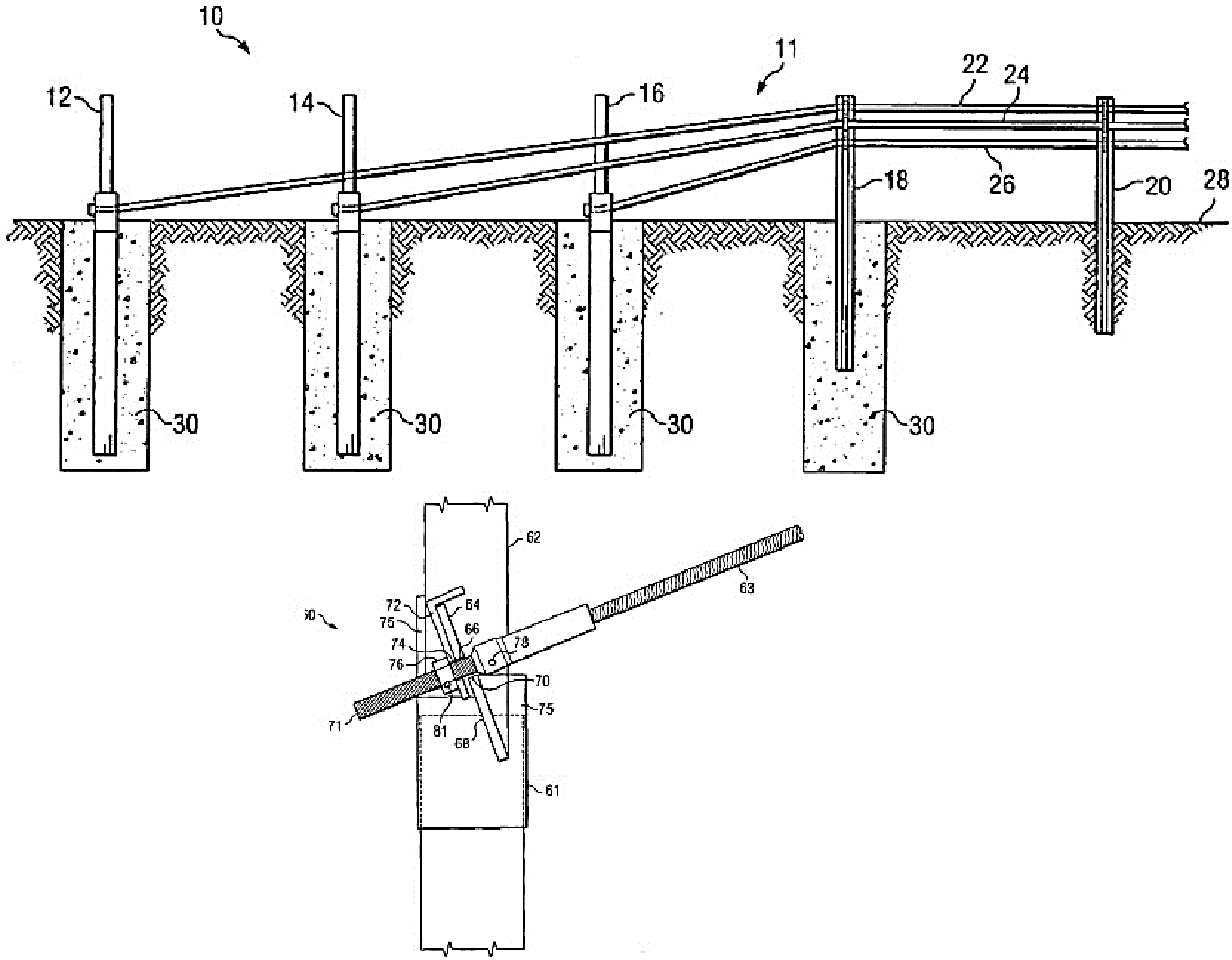


Figure 22. Schematics of Patent Nos. 6,932,327 [29] and 7,556,242 [30]

2.4.2.1 Patent No. 7,367,549

In 2003, Brifen USA, Inc. successfully crash tested a cable end terminal design [40], found in patent no. 7,367,549 [31]. The Brifen design incorporated an angled post no. 2 with proprietary "S" or "Z" posts for the remainder of the system, as shown in Figure 23. The cables were terminated using an anchor bracket that was secured to a buried concrete block. Patent no. 7,367,549 includes ten claims covering a plurality of road safety barriers and a series of posts with a weakened region.

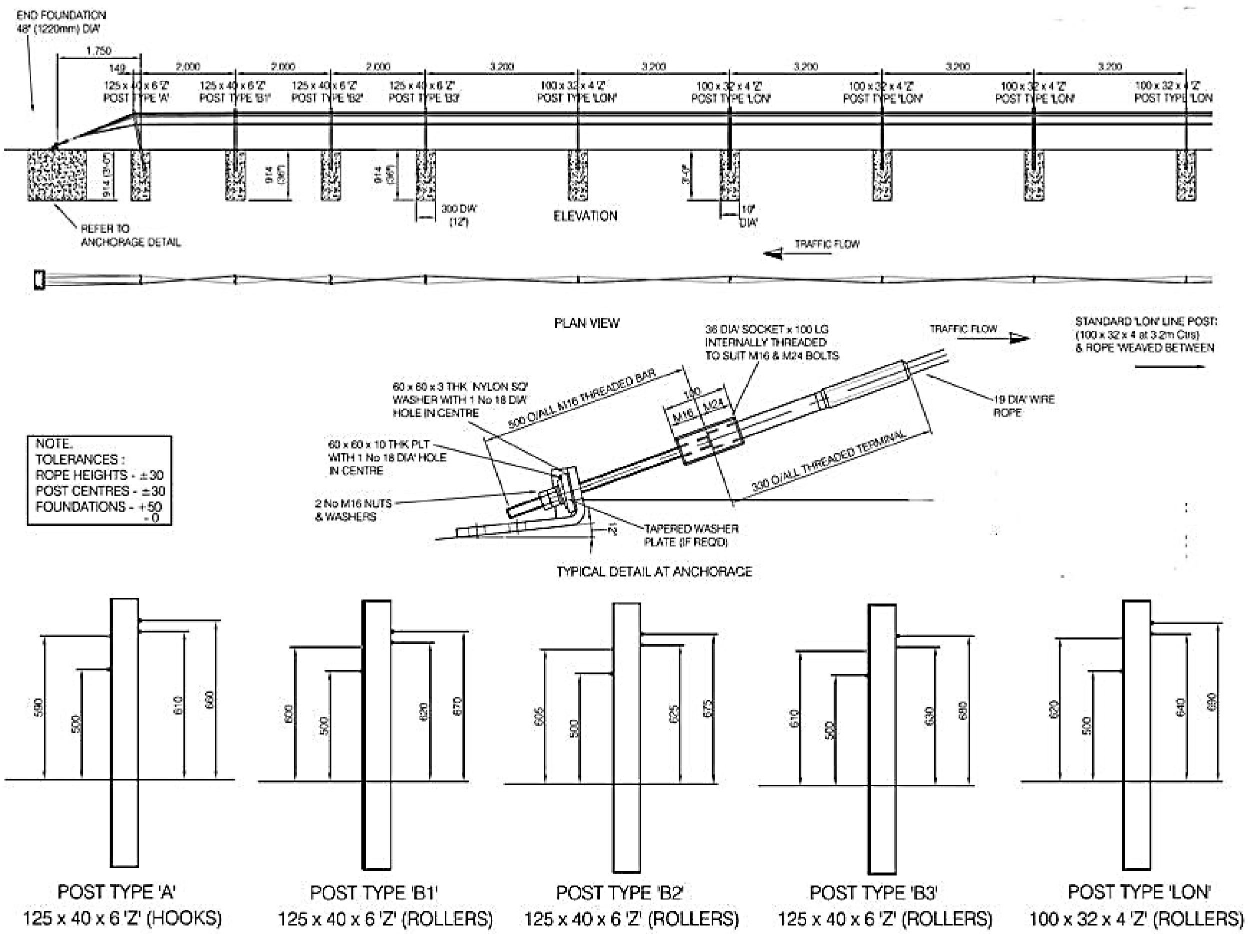


Figure 23. Brifen End Terminal System [40]

2.4.2.2 Patent No. 6,065,738

Brifen Limited GB, Inc. developed an anchor for cables with a series of proprietary posts, found in patent no. 6,065,738 [32]. This patent includes a cable end fitting passing through a slotted angled plate set on a concrete foundation. Different embodiments of the concept are shown in Figure 24. Patent no. 6,065,738 includes 15 claims that cover a plurality of safety barriers, an anchor body, and possible methods for disengaging the cable from the anchor body. The method includes fixing the angle that the end portion of the cable approaches the anchor body relative to the horizontal plane.

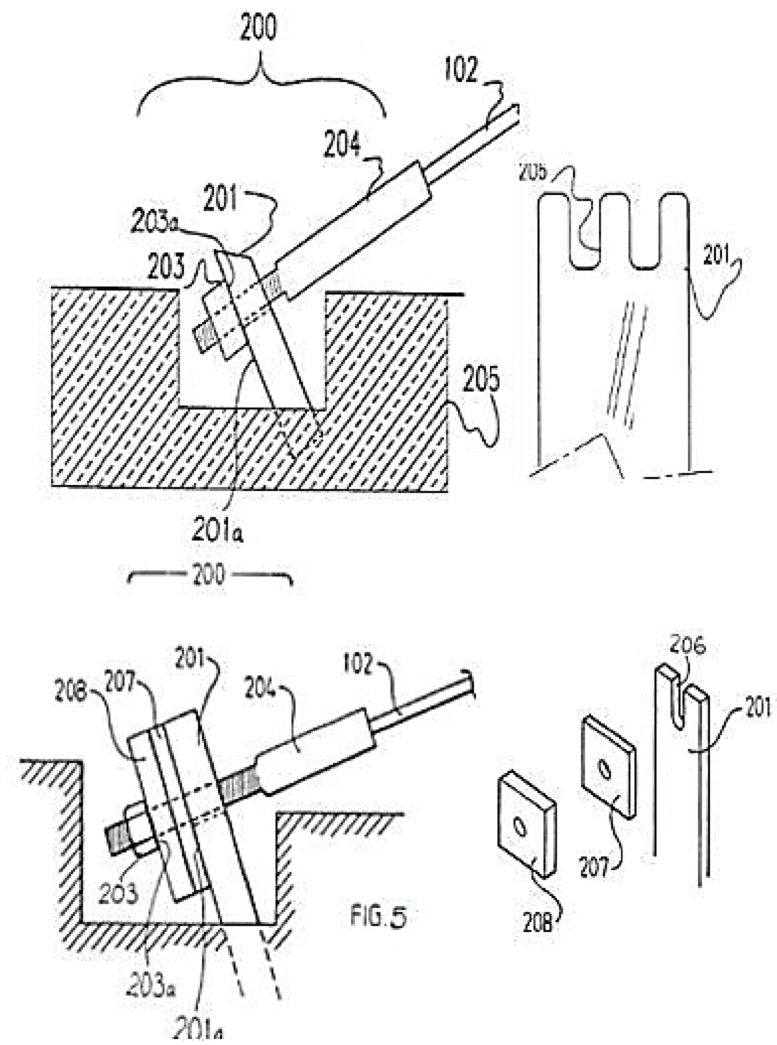


Figure 24. Schematics of Patent No. 6,065,738 [32]

2.4.2.3 Patent Nos. 5,503,495 and 5,547,309

Patent nos. 5,503,495 [33] and 5,547,309 [34] included relevant details for guardrail anchorages. Schematics of patent nos. 5,503,495 and 5,547,309 are shown in Figure 25. These patents describe an end treatment for a thrie-beam guardrail with a slotted section in the thrie-beam terminal to reduce the buckling response to an axial loading in end impacts. Patent no. 5,503,495 includes three claims that cover a cable release mechanism with fragile support post member, a cable anchored at the support post, and a release plate with a V-shaped cutout to anchor the cable. Patent no. 5,547,309 includes six claims that cover a plurality of guardrail terminal with an upstream and downstream end with a cable release mechanism, a release plate that has a cable resting in a V-shaped slot cutout.

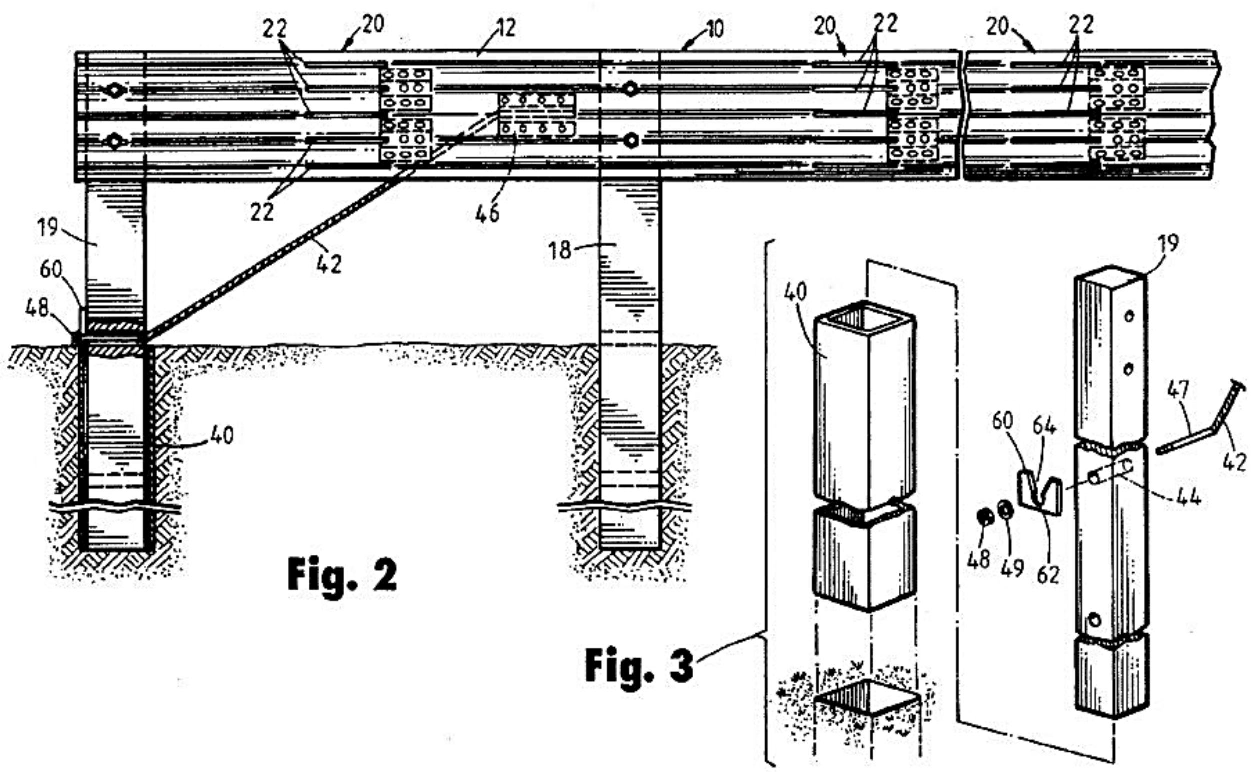


Figure 25. Schematics of Patent Nos. 5,503,495 [33] and 5,547,309 [34]

2.4.2.4 Patent No. 6,109,597

Patent no. 6,109,597 [35] describes an anchor cable release bracket that is connected to a rail by sleeved mounting bolts with openings and slots to release an anchor cable from the guardrail. Schematics of patent no. 6,109,597 are shown in Figure 26. Patent no. 6,109,597 includes two claims that cover an anchor cable release mechanism in a guardrail system, including cable release brackets, bracket bolts, a mounting bolt encompassing a shank, fixed spacer, and a sleeve.

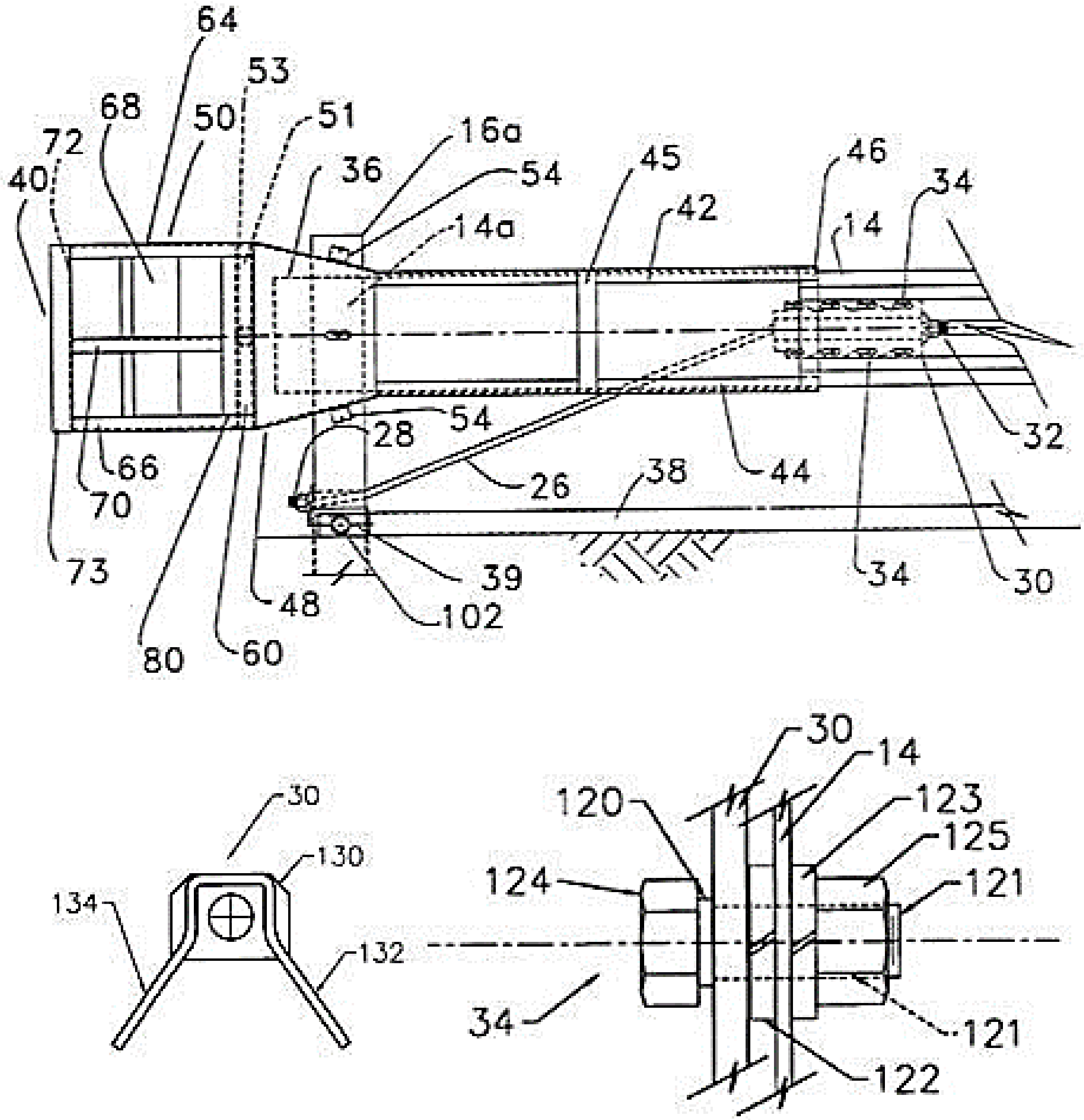


Figure 26. Schematics of Patent No. 6,109,597 [35]

2.4.2.5 Patent No. 6,299,141

Patent no. 6,299,141 [36] describes an anchor assembly for end terminal which includes a cable anchor bracket releasing during a head-on impact at the end of the guardrail. Schematics of patent no. 6,299,141 are shown in Figure 27. Patent no. 6,299,141 includes six claims that cover an anchor cable assembly with a plurality of posts, a cable anchor bracket that has a U-shaped cross section, a plate, possible connection between the end post and the guardrail, and multiplicity of possible construction methods for the end terminal assembly.

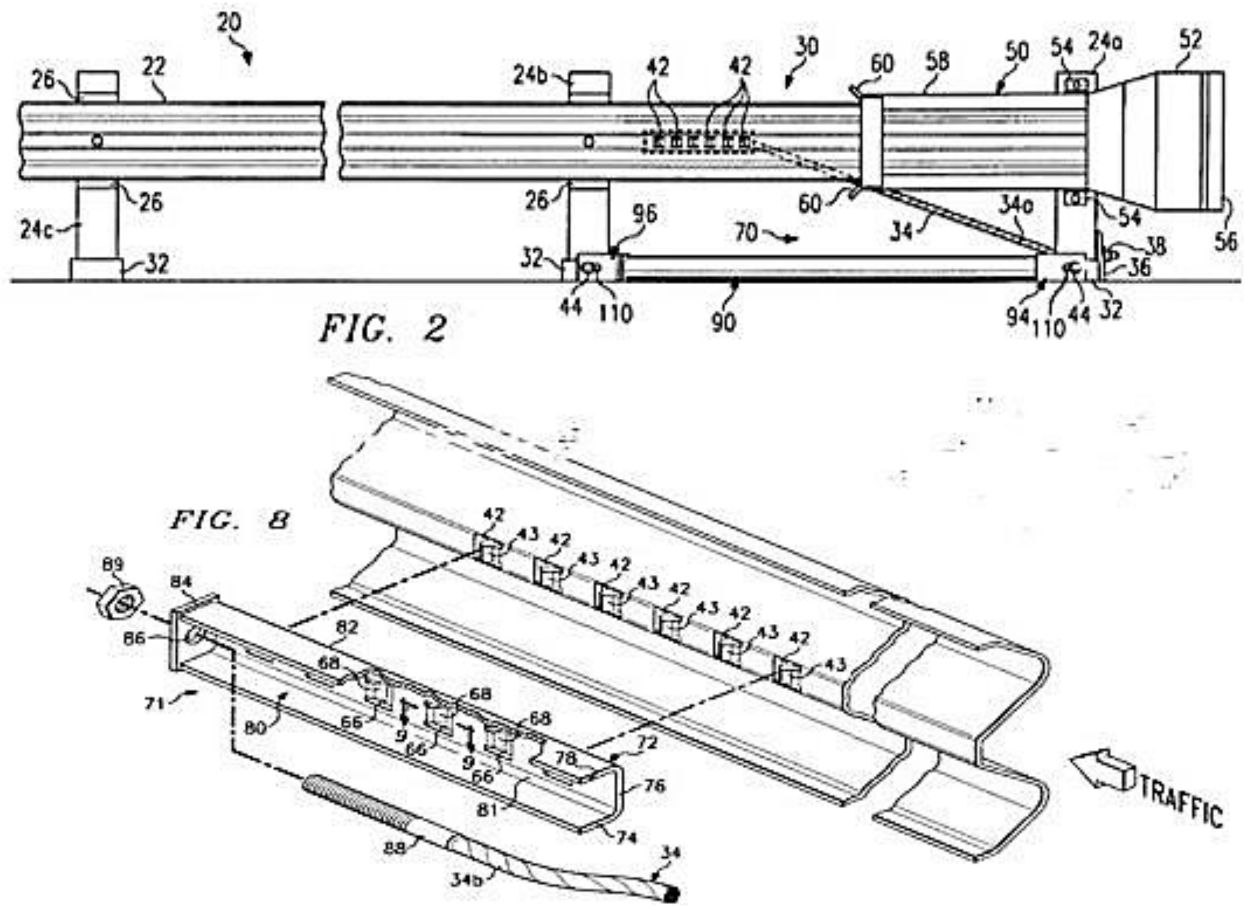


Figure 27. Schematics of Patent No. 6,299,141 [36]

2.4.3 Breakaway Sign Post Patents

Nine patents were found for breakaway sign posts that were deemed relevant to the trailing-end design, as listed in Table 3.

Table 3. Patents for Breakaway Sign Posts

Patent No.	Date of Issue	Title	Description	Authors	Reference Nos.
5,855,443	1/5/1999	Breakaway Connection System for Roadside Use	Breakaway connector with shear plates and bolts	Ronald K. Faller; John D. Reid; Eugene W. Paulsen; Kenneth L. Krenk	37
6,264,162	7/24/2001	Breakaway Sign Post	Breakaway signpost assembly with support post, anchoring post, &breaking collar	Theodore D. Barnes	38
6,390,436	5/21/2002	Breakaway Sign Post	Breakaway sign post assembly with support post, anchoring post, &breaking collar	Theodore D. Barnes; Darren Potter	41
6,409,156	6/25/2002	Breakaway Bracket	Frangible bracket for connecting a post to a base	Clifford Dent	42
6,422,783	7/23/2002	Breakaway Post Slipbase	Triangular omni-directional slip base for posts	Horace M. Jordan	43
6,540,196	4/1/2003	Break Away Support Structure Coupling	Triangular omnidirectional slip base for sign posts	Steven James Ellsworth	44
6,868,641	3/22/2005	Breakaway Post Base	Omnidirectional triangular slip post base	Michael D. Conner, Stanley E. Partee	45
7,195,222	3/27/2007	Flanged Base and Breakaway System Connector for Road Accessory Posts	Triangular post slip base for breakaway posts	Clifford M. Dent	46
7,537,412	5/26/2009	Breakaway Signpost	Sectional I beam sign post with two frangible areas	Donald G. Lewis	47

2.4.3.1 Patent No. 5,855,443

Patent no. 5,855,443 [37] describes a one-directional breakaway connection, as shown in Figure 28. This system includes plate washers that form a plane to shear the fasteners connecting a support surface to a sign support. Patent no. 5,855,443 includes 21 claims covering a plurality of breakaway structure with elongated mounting members, shearing plates, attachment plates, and fasteners.

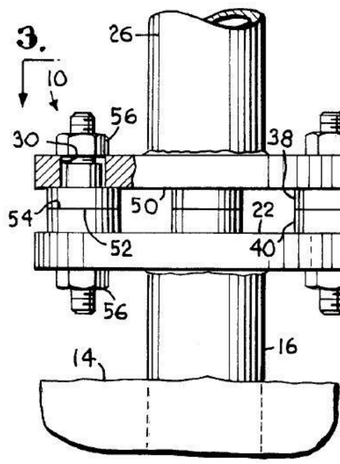


Figure 28. Schematic of Patent No. 5,855,443 [37]

2.4.3.2 Patent Nos. 6,264,162 and 6,390,436

Patent nos. 6,264,162 [38] and 6,390,436 [41] describe a breakaway collar surrounding a sign support post. The sidewall of the collar includes one vertical line of weakness to facilitate a portion of the sidewall breaking away. Schematics of patent nos. 6,264,162 and 6,390,436 are shown in Figure 29. Patent no. 6,264,162 includes 25 claims covering a plurality of breakaway collars with different configurations and collar materials, and a breakaway sign post focusing on methods of forming slots and weakened regions. Patent no. 6,390,436 includes 18 claims covering a plurality of breakaway collars with different means of creating a line of weakness and possible configurations of the breakaway collar to support the sign post.

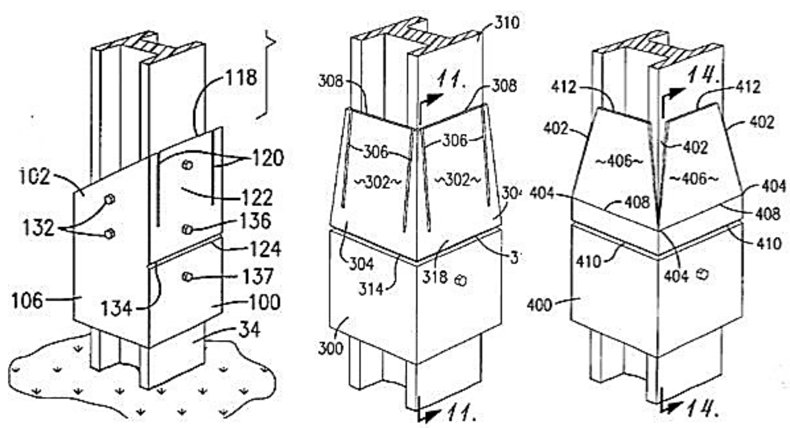


Figure 29. Schematics of Patent Nos. 6,264,162 [38] and 6,390,436 [41]

2.4.3.3 Patent No. 6,409,156

Patent no. 6,409,156 [42] describes a breakaway bracket assembly connecting two structural members with a central section that contains a V-shaped, pre-formed, break point. A schematic from patent no. 6,409,156 is shown in Figure 30. Patent no. 6,409,156 includes four claims focused on the post assembly, base assembly, and breakaway bracket.

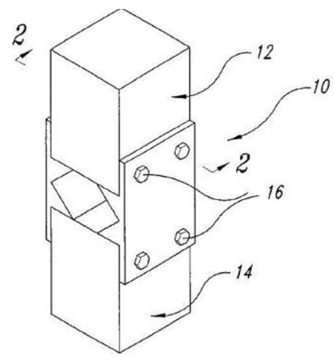


Figure 30. Schematic of Patent No. 6,409,156 [42]

2.4.3.4 Patent No. 6,422,783

Patent no. 6,422,783 [43] describes a breakaway post with a triangular, multi-directional, slip base plate. Low-friction, galvanized sheets of metal are utilized between the ground plate and the base plate to facilitate the breakaway mechanism. Schematics of patent no. 6,422,783 are shown in Figure 31. Patent no. 6,422,783 includes 25 claims covering a plurality of breakaway posts, slip-base systems with a longitudinal cavity, retaining grommets, and different methods for connecting the slip-base flange and base stub flange, including bolts and nuts.

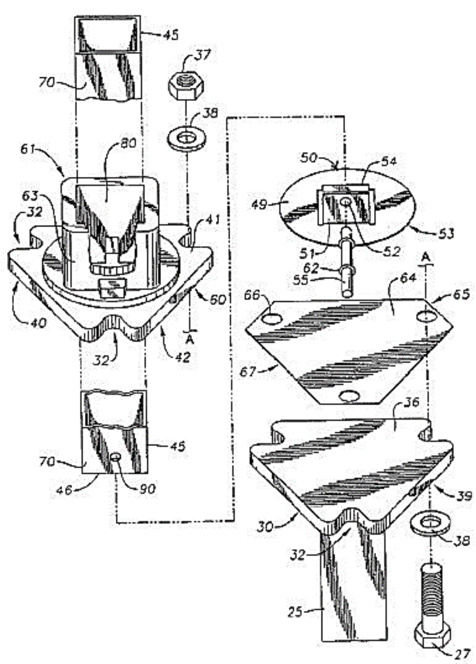


Figure 31. Schematics of Patent No. 6,422,783 [43]

2.4.3.5 Patent No. 6,540,196

Patent no. 6,540,196 [44] describes a breakaway coupling for connecting two posts, as shown in Figure 32. One plate is attached to the top post, and another plate is connected to the bottom post. A bearing housing is fastened between the two plates and a ball bearing contacts the two plates. Patent no. 6,540,196 includes 16 claims that cover a plurality of breakaway couplings for support posts, in particular the means to connect posts with different sections (e.g. tubes and W-sections) and methods for connecting the plates to the support posts, as well as a plurality of bearing housings with various openings.

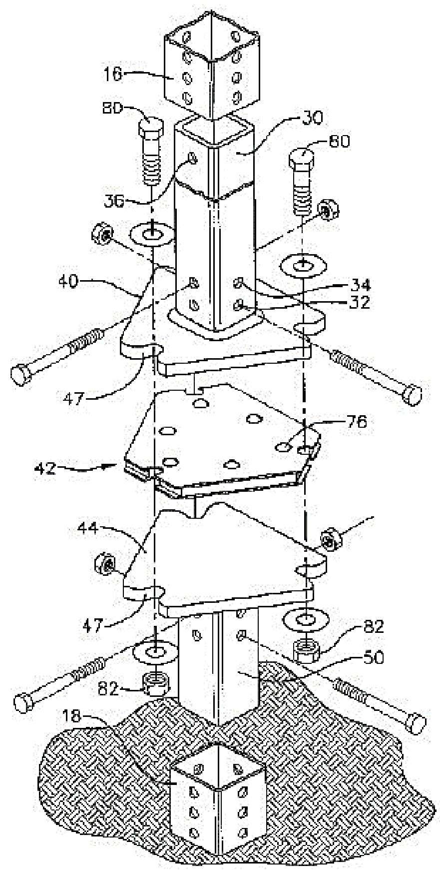


Figure 32. Schematic of Patent No. 6,540,196 [44]

2.4.3.6 Patent No. 6,868,641

Patent no. 6,868,641 [45] describes a breakaway post with notched triangular slip plates that are bolted through the notches. A schematic from patent no. 6,868,641 is shown in Figure 33. Patent no. 6,868,641 includes five claims covering a plurality of breakaway bases and methods of constructing a breakaway post base, and a possible bolt assembly.

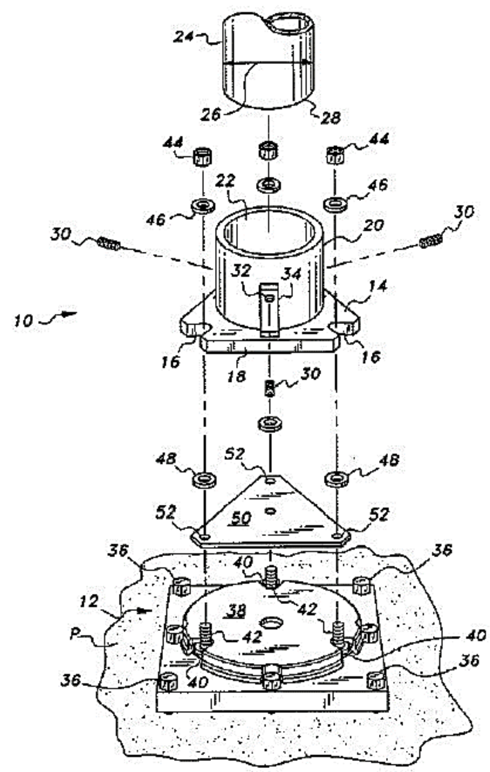


Figure 33. Schematic of Patent No. 6,868,641 [45]

2.4.3.7 Patent No. 7,195,222

Patent no. 7,195,222 [46] describes a breakaway post connector. A schematic from patent no. 7,195,222 is shown in Figure 34. This patent includes 14 claims covering a plurality of breakaway post connectors with different shapes (e.g. polygon and circular shapes) and devices for fasteners.

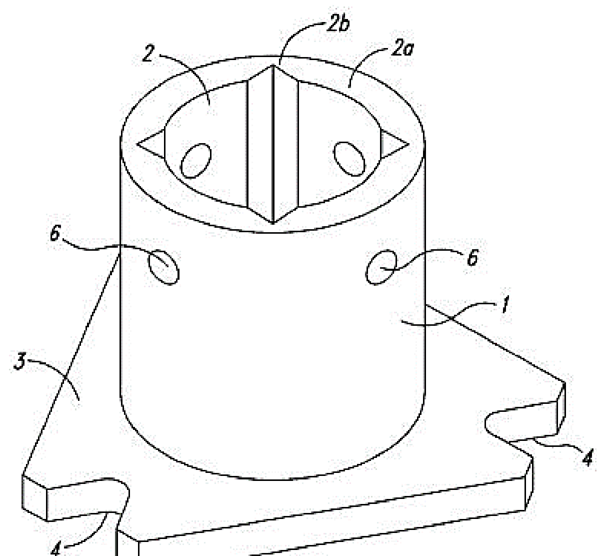


Figure 34. Schematic of Patent No. 7,195,222 [46]

2.4.3.8 Patent No. 7,537,412

Patent no. 7,537,412 [47] describes a breakaway sign post with an I-beam cross-section and slip breakaway mechanism in two regions, as shown in Figure 35. Patent no. 7,537,412 includes four claims covering a plurality of posts with different means of coupling the two regions.

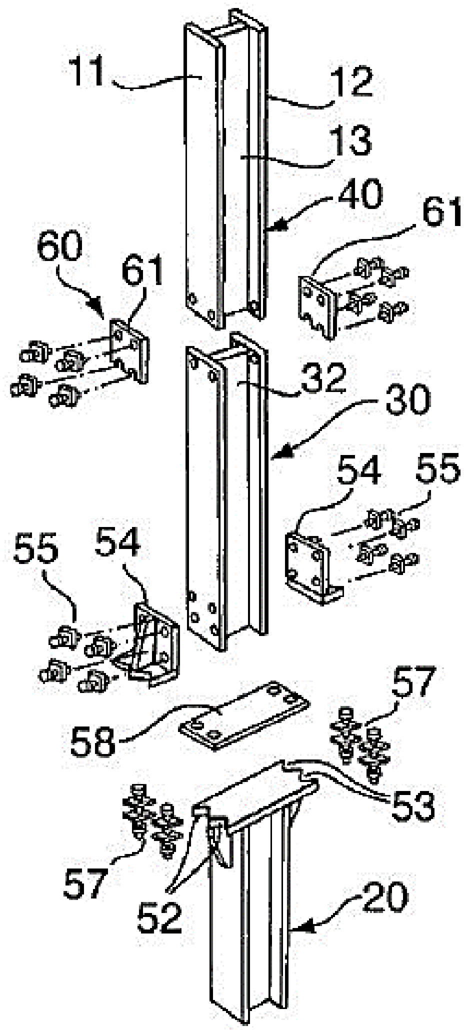


Figure 35. Schematic of Patent No. 7,537,412 [47]

2.4.4 Breakaway Guardrail Post Concepts

Seven patents and seven patent applications were found for guardrail posts that were deemed relevant to the trailing-end design, as listed in Table 4.

Table 4. Patents for Breakaway Guardrail Posts

Patent No.	Date of Issue	Title	Description	Authors	Reference Nos.
4,330,106	5/18/1982	Guardrail Construction	Breakaway guardrail posts with steel channel member	Douglas B. Chisholm	48
5,664,905	9/9/1997	Fence	Post with notches in rear face	Peter John Thompson; Iain James McGregor	49
5,988,598	11/23/1999	Breakaway Steel Guardrail Post	Guardrail I beam post with a plate splice	Dean L. Sicking; John D. Reid; John R. Rohde	50
6,254,063	7/3/2001	Energy Absorbing Breakaway Steel Guardrail Post	Steel I beam breakaway posts for guardrail terminals	John R. Rohde; John D. Reid; Dean L. Sicking	51
6,902,150	6/7/2005	Steel Yielding Guardrail Support Post	I beam post weakened to impact parallel to traffic to induce failure or yield from end-on impact	Dean C. Alberson; Lance D. Bullard Jr., Eugene C. Buth, Roger P. Bligh	52
20070063177	3/22/2007	Yielding Post Guardrail Safety System	Guardrail post with various cutouts including circular cutouts and saw cuts	Dean C. Alberson; Lance D. Bullard Jr.; Eugene C. Buth; Roger P. Bligh	53
20070063178	3/22/2007	Guardrail Flange Protector	Guardrail post with various cutouts including circular cutouts and saw cuts	Dean C. Alberson; Lance D. Bullard Jr.; Eugene C. Buth; Roger P. Bligh	54
20070063179	3/22/2007	A weakened Guardrail Mounting Connection	Guardrail post with various cutouts including circular cutouts and saw cuts	Dean C. Alberson; Lance D. Bullard Jr.; Eugene C. Buth; Roger P. Bligh	55
20060027797	2/9/2006	Energy Absorbing Post for Roadside Safety Devices	Energy absorbing post where impact energy is absorbed by out of -plane deformation.	Dean L. Sicking; John R. Rohde, John D. Reid; King K. Mak	56
20060038164	2/23/2006	Energy Absorbing Post for Roadside Safety Devices	Energy absorbing post where impact energy is absorbed by out of -plane deformation.	Dean L. Sicking; John R. Rohde; John D. Reid; King K. Mak	57
20140110651	10/10/2013	Guardrail	Guardrail post with anchor brackets for cable release.	Aaron James Cox, Brent S. Sindorf	58
20140145132	5/29/2014	Guardrail System with a Releasable Post	Guardrail post with hole and slot	Patrick A. Leonhardt, Brian E. Smith	59
6,644,888	11/11/2003	Roadway Guardrail Structure	Guardrail post with a pair of flanges	Carlos M. Ochoa	60
8,215,619	7/10/2012	Guardrail Assembly, Breakaway Support Post for a Guardrail and Methods for the Assembly and use Thereof	Guardrail breakaway post with coupler	Patrick A. Leonhardt; Barry D. Stephens; Michael J. Buehler; Brent S. Sindorf	61

2.4.4.1 Patent No. 4,330,106

Patent no. 4,330,106 [48] describes a steel channel member with fastening bolts that connects upper and lower I-beam members. The steel channel connection breaks away when impacted in the weak axis. Schematics of patent no. 4,330,106 are shown in Figure 36. Patent no. 4,330,106 includes 29 claims covering a plurality of guardrail systems, means for connecting the upper and lower I-beam members, and a breakaway post focusing on the means of connection between the post and the rail.

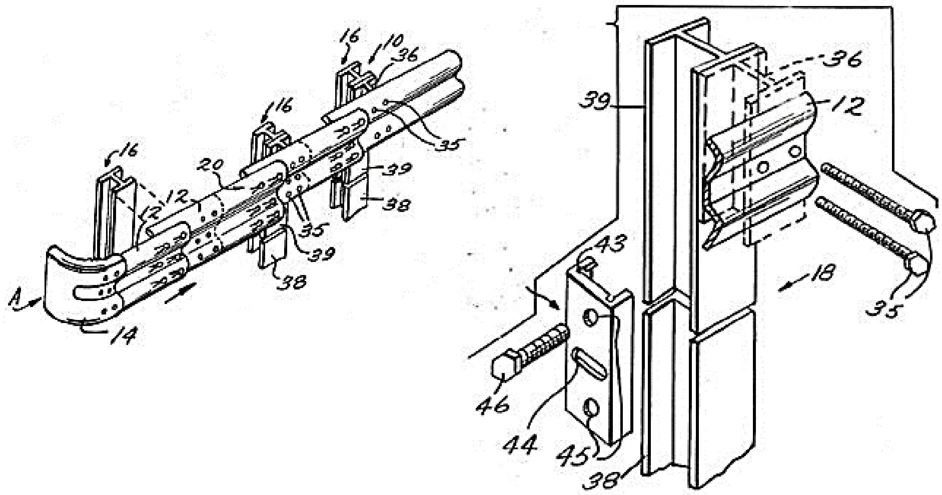


Figure 36. Schematics of Patent No. 4,330,106 [48]

2.4.4.2 Patent No. 5,664,905

Patent no. 5,664,905 [49] describes a post with V-shaped or U-shaped cutouts. Schematics of patent no. 5,664,905 are shown in Figure 37. Patent no. 5,664,905 includes 28 claims covering a plurality of crash barriers, mainly focusing on the type and number of notches and different means of connection between the rail and the post.

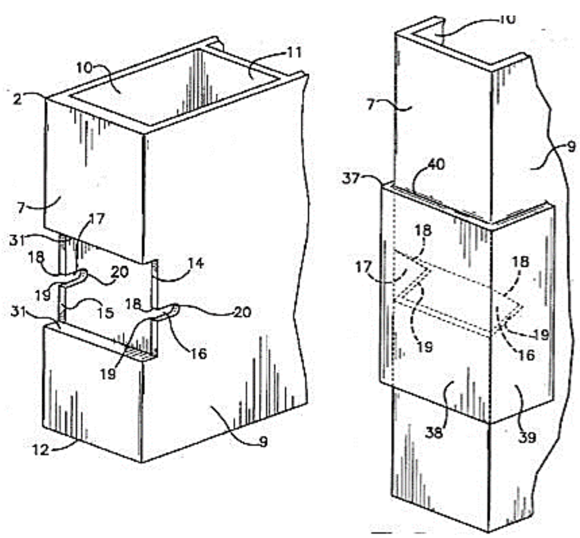


Figure 37. Schematics of Patent No. 5,664,905 [49]

2.4.4.3 Patent Nos. 5,988,598 and 6,254,063

Patent nos. 5,988,598 [50] and 6,254,063 [51] describe a breakaway steel guardrail post that includes upper and lower post sections connected by different breakaway joints, as shown in Figure 38. One type of joint consisted of bolts designed to either break or tear out. Another embodiment comprises of two U- or channel-shaped steel plates with the flanges of the channel designed to yield when impacted in the weak axis. The pin with a larger diameter provides strength in the strong axis. The other breakaway mechanism of the embodiment relies on weld failure in the breakaway joint to control the post strength. Patent no. 5,988,598 includes six claims covering a plurality of posts with different breakaway mechanisms, including bolt tear-out, bolt break, and weld failure. Patent no. 6,254,063 includes 12 claims covering a plurality of guardrail posts focusing on the means of connecting the upper and lower post members, a cable restraining member configuration, and straps with slotted openings.

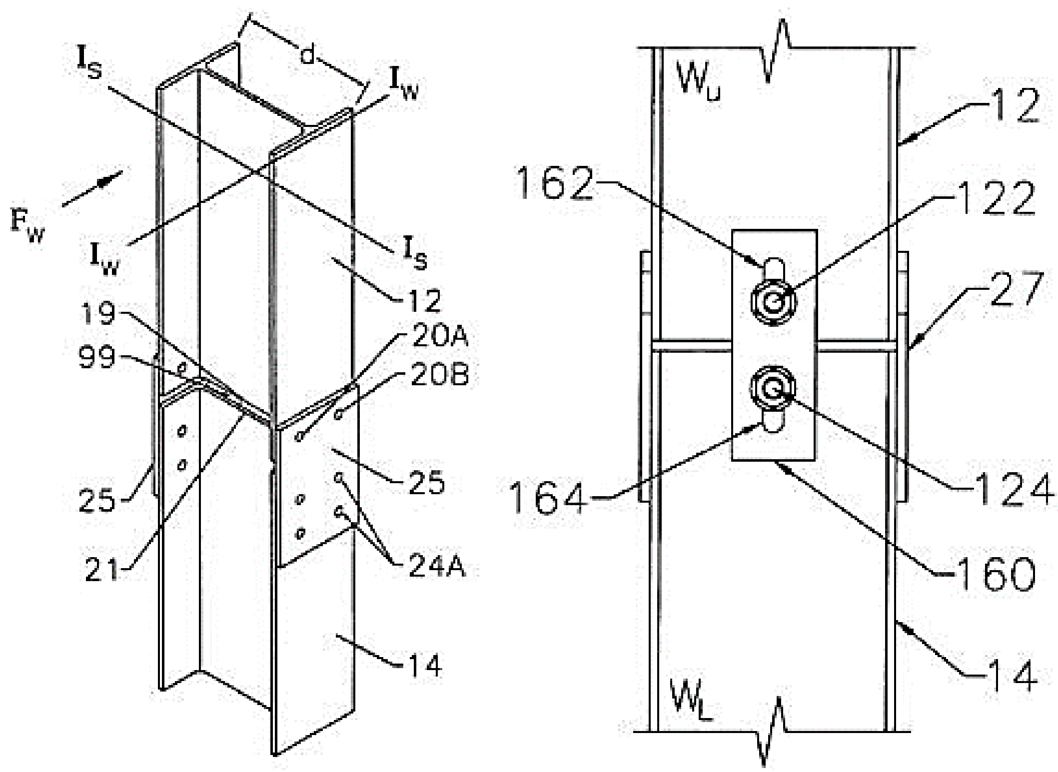


Figure 38. Schematics of Patent Nos. 5,988,598 [50] and 6,254,063 [51]

2.4.4.4 Patent No. 6,902,150 and Application Nos. 20070063177, 20070063178, and 20070063179

Patent no. 6,902,150 [52] and application nos. 20070063177 [53], 20070063178 [54], and 20070063179 [55] describe steel breakaway posts with cutouts in the flanges of I-beams. Various cutouts, including circular cutouts and saw cuts, are detailed to weaken the post and create a failure point in the post. Schematics of patent no. 6,902,150 and application nos. 20070063177, 20070063178, and 20070063179 are shown in Figure 39. Patent no. 6,902,150 includes 25 claims covering a plurality of guardrail posts, particularly focusing on different means of cutouts and bolt holes. Patent application nos. 20070063177, 20070063178, and 20070063179 include 20 claims covering a plurality of guardrail systems consisting of posts with cutouts, a plurality of different cross section breakaway steel posts, and a guardrail beam protector.

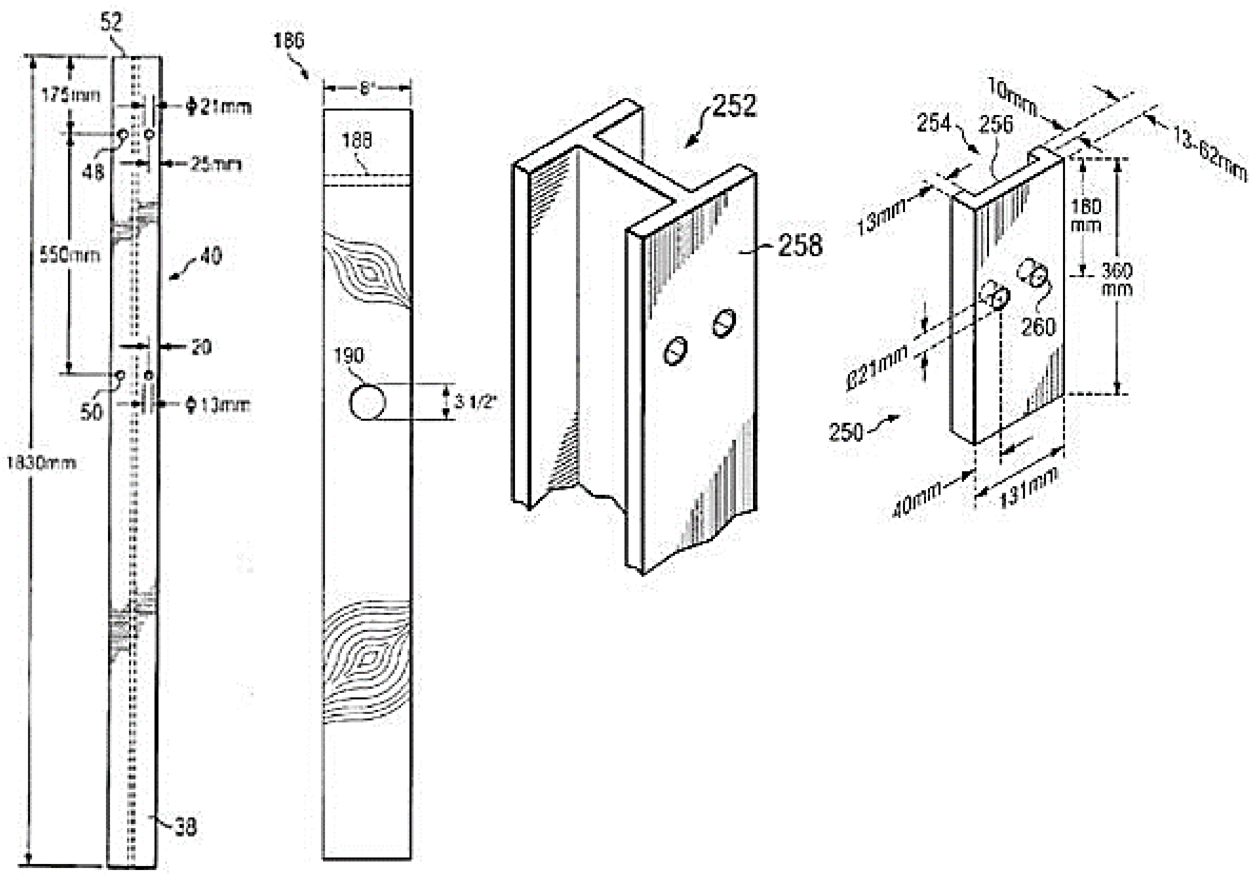


Figure 39. Schematics of Patent No. 6,902,150 [52] and Patent Application Nos. 20070063177 [53], 20070063178 [54], and 20070063179 [55]

2.4.4.5 Patent Application Nos. 20060027797 and 20060038164

Patent application nos. 20060027797 [56] and 20060038164 [57] describe an energy-absorbing post where out-of-plane deformation absorbs the impact energy. The energy is either absorbed through bolt tear-out or by out-of-plane (mode 3) tearing in a splice plate. Schematics of patent application nos. 20060027797 and 20060038164 are shown in Figure 40. Patent application nos. 20060027797 and 20060038164 include 35 claims covering a plurality of energy absorbing posts focusing on the means of coupling the upper and lower post members, a splice plate and fastener, and different slots that would enhance out-of-plane tearing.

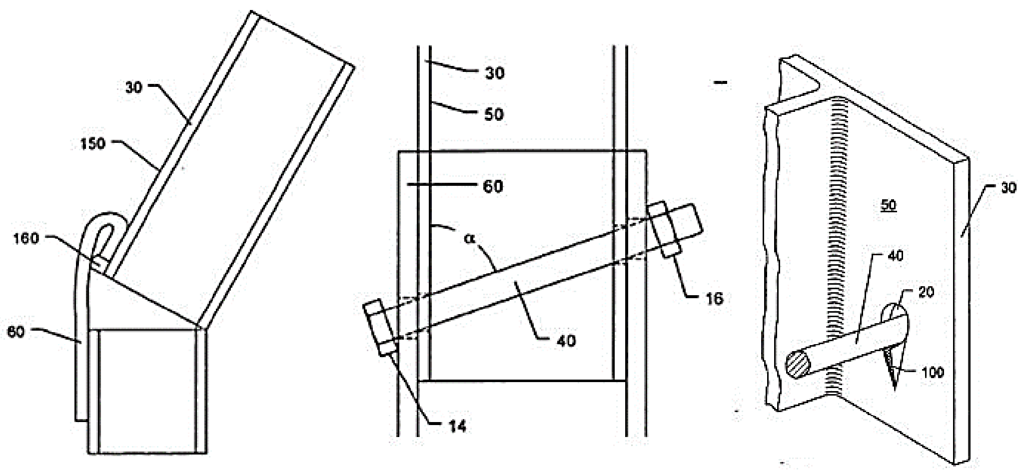


Figure 40. Schematics of Patent Application Nos. 20060027797 [56] and 20060038164 [57]

2.4.4.6 Patent Application No. 20140110651

Patent application no. 20140110651 [58] describes a guardrail system with posts, a cable attached to the rail section and posts, and an anchor bracket. The patent application covers different methods of rehabilitating a guardrail system. Schematics of patent application no. 20140110651 are shown in Figure 41. Patent application no. 20140110651 includes 20 claims that cover a guardrail system with a plurality of posts, anchor brackets focusing on releasing the cable, and a means for connecting the post to the W-beam.

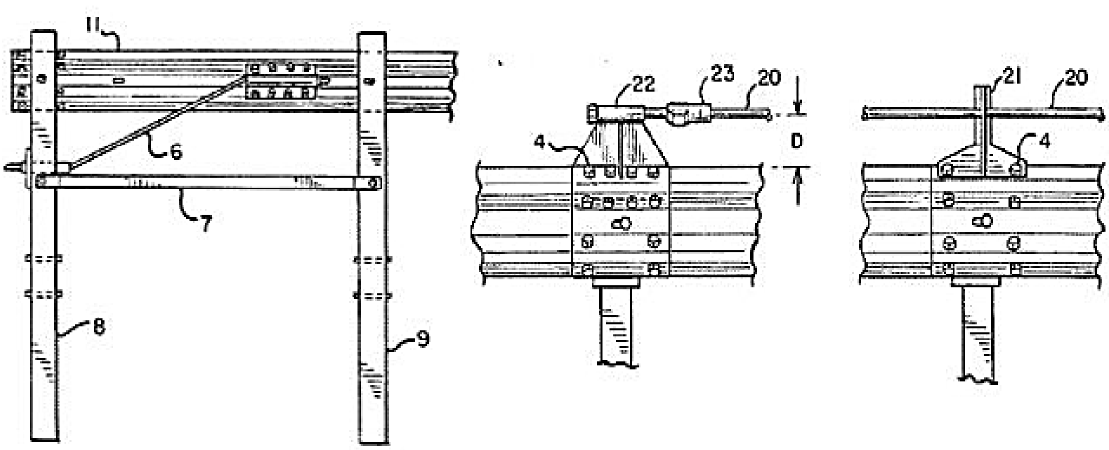


Figure 41. Schematics of Patent Application No. 20140110651 [58]

2.4.4.7 Patent Application No. 20140145132

Patent application no. 20140145132 [59] describes a guardrail system consisting of a post and a fastener for connecting the post to a W-beam rail. The post has a hole and a slot. The slot moves the fastener during an impact. Schematics of patent application no. 20140145132 are shown in Figure 42. Patent application no. 20140145132 includes 25 claims that cover a plurality of guardrail systems focusing on different slots and fastening mechanism, methods for forming slots, and different possible methods for retaining the fastener.

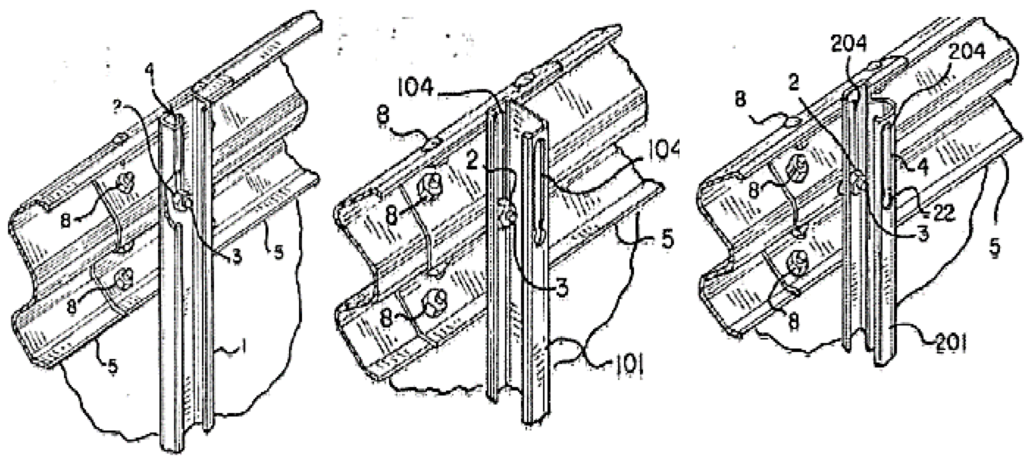


Figure 42. Schematics of Patent Application No. 20140110651 [59]

2.4.4.8 Patent No. 6,644,888

Patent no. 6,644,888 [60] describes a breakaway post with a pair of flanges. The free edges of the post form a tabular sphere for providing reinforcement. Schematics of patent no. 6,644,888 are shown in Figure 43. Patent no. 6,644,888 includes 38 claims covering a plurality of posts with different cross sections and methods of forming various tabular and elliptical shapes. This patent also includes the means of creating openings and a weakened zone in the post, and a plurality of guardrail systems comprising the post.

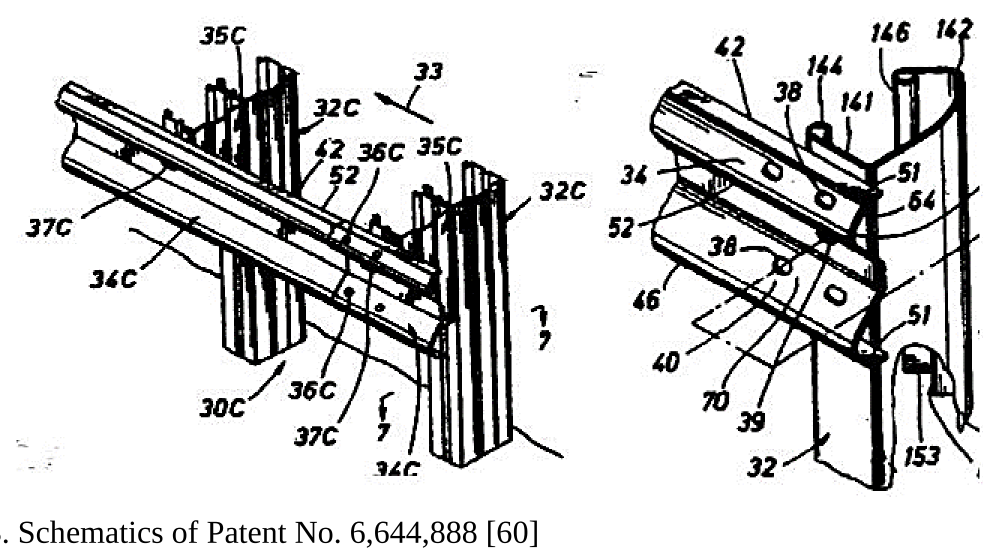


Figure 43. Schematics of Patent No. 6,644,888 [60]

2.4.4.9 Patent No. 8,215,619

Patent no. 8,215,619 [61] describes a guardrail breakaway post comprising a coupler between the upper and lower members. Rotation between the two members is prevented by coupling them with a tension bolt or a shear connection. Schematics of patent no. 8,215,619 are shown in Figure 44. Patent no. 8,215,619 includes 20 claims that cover a plurality of guardrail assemblies with breakaway posts mainly focusing on the means of coupling the post members and different possible configuration with various post cross-sections.

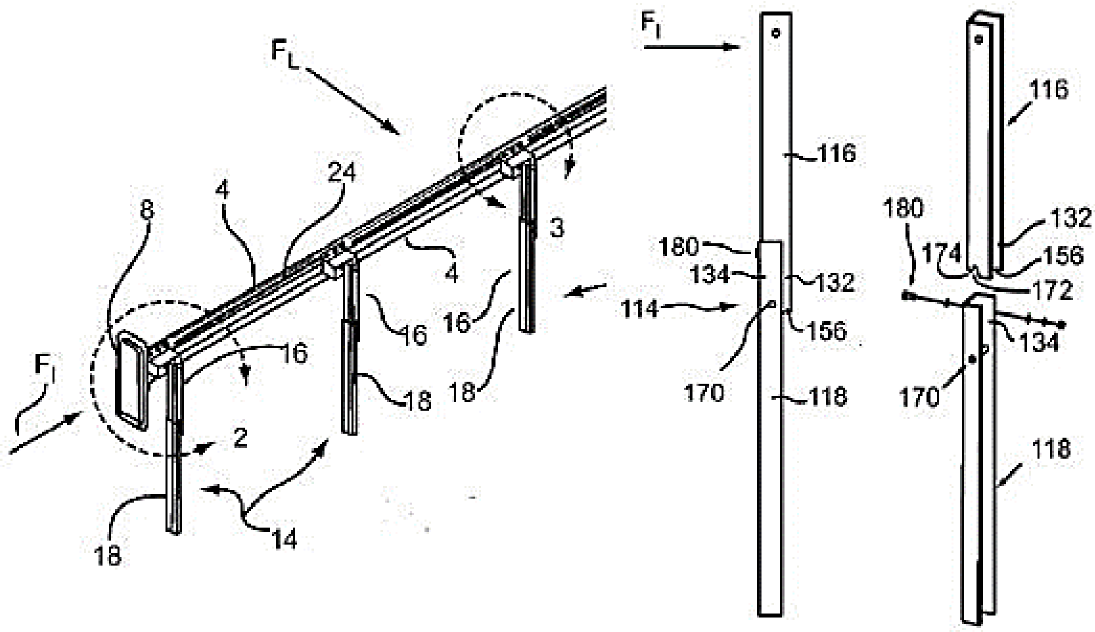


Figure 44. Schematics of Patent No. 8,215,619 [61]

2.4.5 Breakaway Terminal Post Patents

Ten patents and one patent application were found for breakaway terminal posts that were deemed relevant to the trailing-end design, as listed in Table 5.

Table 5. Patents for Breakaway Terminal Posts

Patent no.	Date of Issue	Title	Description	Authors	Reference Nos.
6,729,607	5/4/2004	Cable Release Anchor	Cable release anchor that has bearing plates with U-shaped cutouts	Dean C. Alberson; Lance Bullard, Jr., Roger P. Bligh; Eugene C. Buth	16
6,398,192	6/4/2002	Breakaway Support Post for Highway Guardrail End Treatments	Breakaway post with a coupler	James R. Albritton	22
6,619,630	9/16/2003	Breakaway Support Post for Highway Guardrail End Treatments	Breakaway base for a guardrail end terminal post	James R. Albritton	23
8,177,194	5/15/2012	Frangible Post for Guardrail	Frangible post made of single post construction	Dallas Rex James	24
6,488,268B1	12/3/2002	Breakaway Support Post for Highway Guardrail End Treatments	I beam post for terminals	James R. Albritton	26
6,793,204B2	9/21/2004	Breakaway Support Post for Highway Guardrail End Treatments	Related to 6,488,268B1 - includes new embodiments of the TRN posts, including a releasable hinge coupler at post bases	James R. Albritton	27
6,886,813	5/3/2005	Breakaway Support Post for Highway Guardrail End Treatments	Related to 6488268 and 6793204 - additional post base and connection embodiments to allow the post to resist on the strong axis impacts	James R. Albritton	28
20140110652	4/21/2014	Frangible Post for Highway Barrier End Terminals	Breakaway end terminal posts	Patrick A. Leonhardt	62
6,065,894	5/23/2000	Breakaway Post Connector	Frangible coupler for connecting guardrail terminal posts	Lance David Wasson; Gary James Melrose	63
8,038,126	10/18/2011	Breakaway Support Post for Highway Guardrail End Treatments	Terminal post which fracture at the base	James R. Albritton	64
9,243,375	1/26/2016	Posts	Continuation of 8757597 - post with window in the web to receive tensioning cable includes weakened portion	Dallas Rex James	65

2.4.5.1 Patent No. 6,729,607

Patent no. 6,729,607 [16] describes a terminal breakaway post with a cable release anchor that has bearing plates with U-shaped cutouts to hold a tension cable, as shown in Figure 45. Patent no. 6,729,607 includes 20 claims that cover a plurality of cable release anchor options, bearing plates, and cable release terminals.

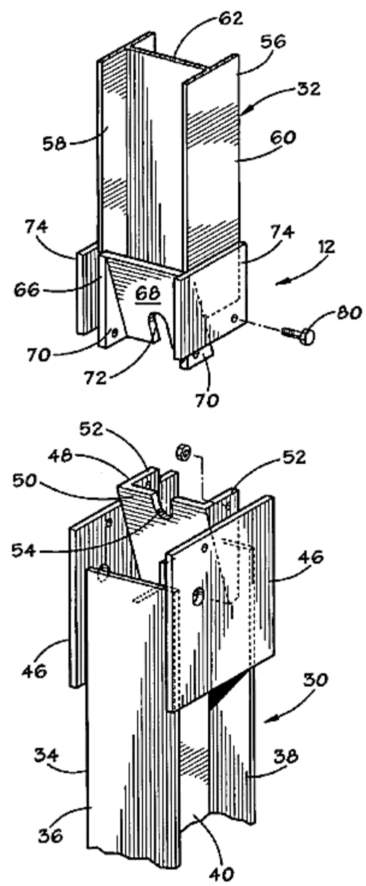


Figure 45. Schematics of Patent No. 6,729,607 [16]

2.4.5.2 Patent Nos. 6,398,192 and 6,619,630

Patent nos. 6,398,192 [22] and 6,619,630 [23] describe a breakaway terminal post with a releasable coupling assembly consisting of a shear pin designed to break away in a weak-axis impact. Schematics of patent nos. 6,398,192 and 6,619,630 are shown in Figure 46. Patent no. 6,398,192 includes three claims that cover a breakaway post and method of coupling the post to the guardrail, as well as a plurality of means for coupling the upper and lower posts. Patent no. 6,619,630 includes 21 claims that cover a highway guardrail terminal system with a plurality of posts, a method of coupling the upper and lower posts, a multiplicity of plates, a strut, and different possible means of breaking the post away in the weak direction.

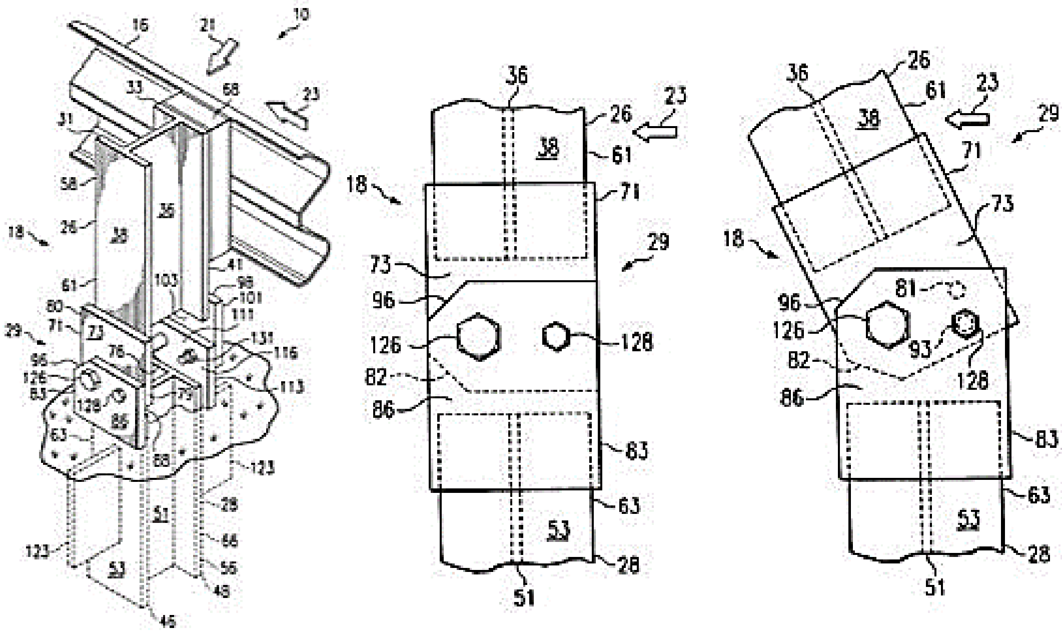


Figure 46. Schematics of Patent Nos. 6,398,192 [22] and 6,619,630 [23]

2.4.5.3 Patent No. 8,177,194

Patent no. 8,177,194 [24] describes a single-piece, frangible, terminal post with a wedge-shaped notch to form a region of weakness, as shown in Figure 47. Patent no. 8,177,194 includes 22 claims that cover a plurality of frangible posts with a variety of different groove shapes and connections between the post and the rail.

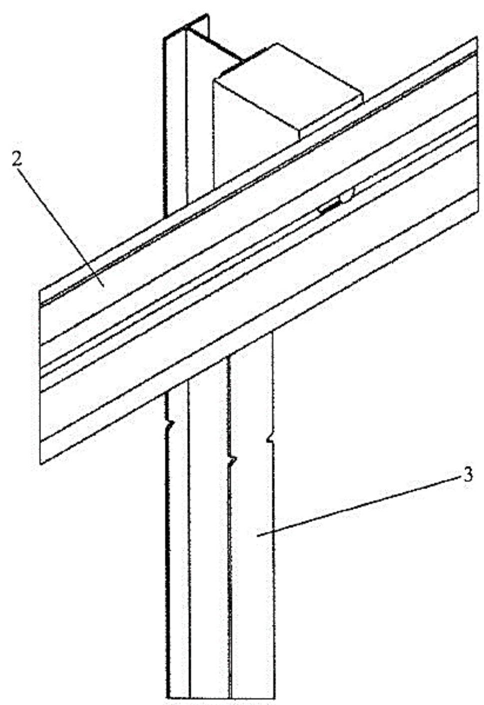


Figure 47. Schematic of Patent No. 8,177,194 [24]

2.4.5.4 Patent Nos. 6,488,268B1, 6,793,204B2, and 6,886,813

Patent nos. 6,488,268B1 [26], 6,793,204B2 [27], and 6,886,813 [28] describe terminal posts that resist impact in the strong direction and yield to impact in the weak direction. Schematics of patent nos. 6,488,268B1, 6,793,204B2, and 6,886,813 are shown in Figure 48. The details of these three patents include (1) elongated slots in the flanges of an I-beam to form a yieldable connection in the weak direction (2) a shear and pivot pin, where the shear pin breaks away in the weak direction, and the post rotates to the ground around the pivot pin, and (3) a connection of two rods or bolts aligned in the strong direction with a spacing between breaker bars or nuts allowing the post to bend and fail the rods.

Patent no. 6,488,268B1 includes five claims that cover a plurality of breakaway posts with upper and lower portions, a spacer between the upper and lower posts, and a fastening mechanism. Patent no. 6,793,204B2 includes 18 claims that cover breakaway support posts, openings in the flange and web of I-beam, soil plate, a guardrail terminal system with slots, a support post that is directly driven into the ground, and a frangible connection. Patent no. 6,886,813 includes 13 claims that cover a rotatable coupling unit between upper and lower posts. The rotatable coupling unit has two U-shaped brackets connected by a pivot pin. The claims also include a guardrail terminal system comprising a rotatable coupling unit between upper and lower posts and a means for attaching the post to a guardrail.

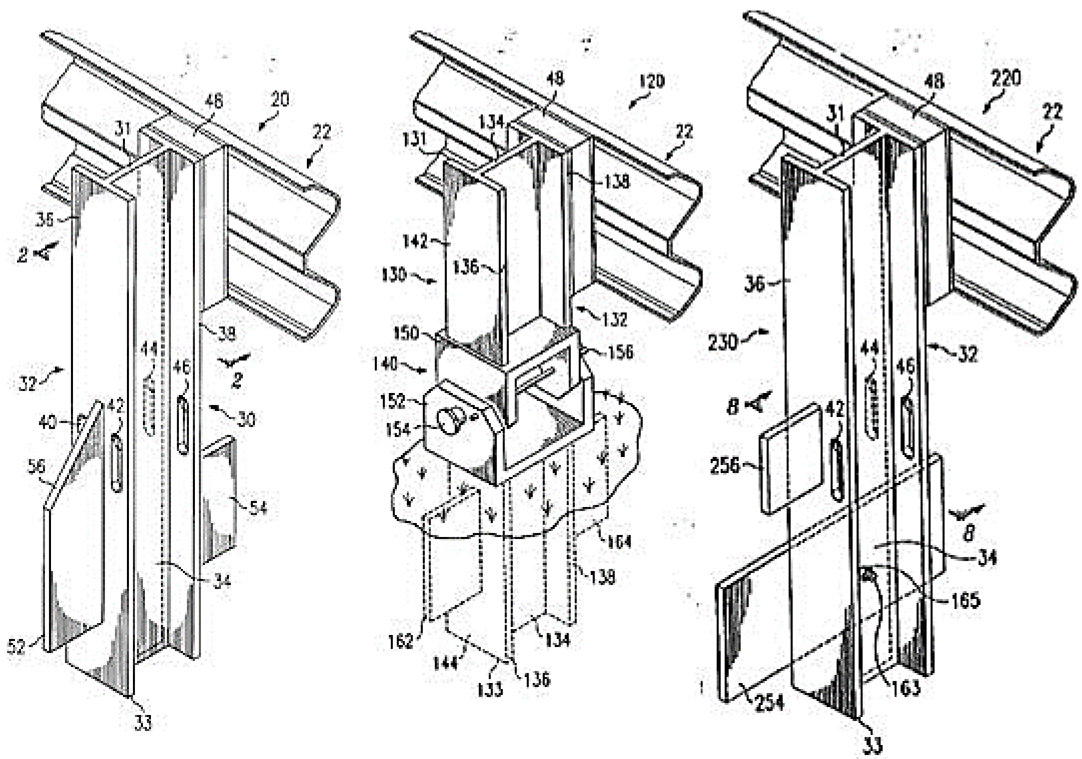


Figure 48. Schematics of Patent Nos. 6,488,268B1 [26], 6,793,204B2 [27], and 6,886,813 [28]

2.4.5.5 Patent Application No. 20140110652

Patent application no. 20140110652 [62] describes a breakaway guardrail terminal post with a notch. Schematics of patent application no. 20140110652 are shown in Figure 49. The breakaway post releases an anchor cable when impacted by an errant vehicle. Patent application no. 20140110652 includes 29 claims that cover a multiplicity of a breakaway guardrail terminal posts with different means of forming a weakness zone and a plurality of guardrail anchors mainly focusing on the disengagement of the bearing plate.

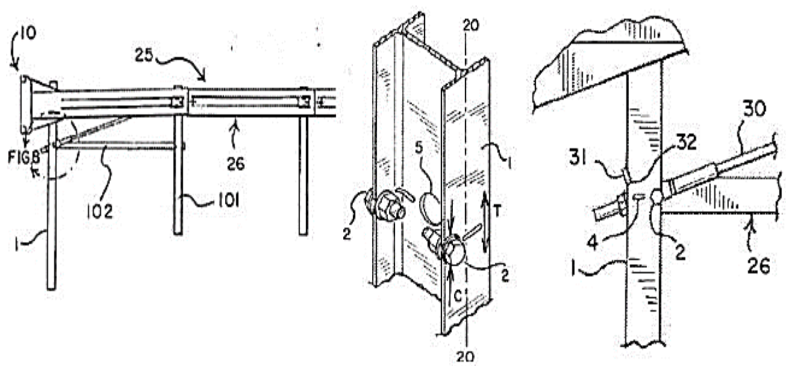


Figure 49. Schematics of Patent Application No. 20140110652 [62]

2.4.5.6 Patent No. 6,065,894

Patent no. 6,065,894 [63] describes a molded coupling unit with an intermediate fracture zone that allows the C-channel post segments to separate when subjected to a vehicle impact greater than a predetermined severity. Schematics of patent no. 6,065,894 is shown in Figure 50. A thermoplastic or formed-up thermosetting compound is molded into the coupling unit. Patent no. 6,065,894 includes 47 claims that cover a plurality of slotting means, barrier assembly, post assembly, fastening means, and the materials for constructing the coupling unit.

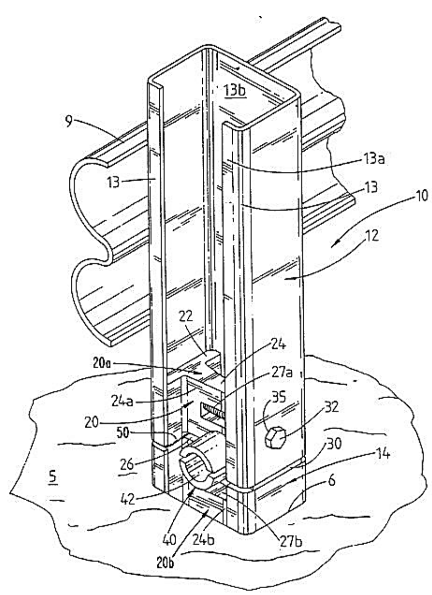


Figure 50. Schematic of Patent No. 6,065,894 [63]

2.4.5.7 Patent No. 8,038,126

In patent no. 8,038,126 [64], a terminal post with an upper and lower member breaks at the base in a weak-axis impact as shown in Figure 51. This patent includes an embodiment for a post. Patent no. 8,038,126 comprises two claims covering a plurality of guardrail terminal post with a means of connecting the upper and lower post members.

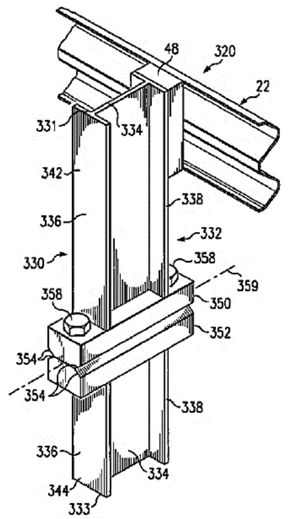


Figure 51. Schematic of Patent No. 8,038,126 [64]

2.4.5.8 Patent No. 9,243,375

Patent no. 9,243,375 [65] describes a guardrail terminal post with an opening in the web to receive a cable, as shown in Figure 52. The post includes a weakened zone to control failure along the rail direction. Patent no. 9,243,375 includes six claims covering a plurality of terminal posts with slots, notches, and an opening on the web.

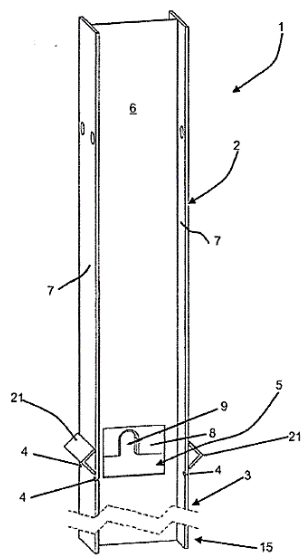


Figure 52. Schematic of Patent No. 9,243,375 [65]

3 STEEL-POST, TRAILING-END ANCHORAGE CONCEPT DEVELOPMENT

3.1 Introduction

Following the review of patents and past studies on trailing-end anchorage systems, possible design concepts were brainstormed. The steel-post version of the non-proprietary, trailing-end anchorage system was required to have a proper breakaway mechanism, sufficient tensile rail strength, and satisfactory soil-post interaction. Thus, the design criteria included: (1) proper breakaway mechanism; (2) ability of the anchor cable to develop longitudinal tensile force, but release in impacts at the end; and (3) ease and simplicity in design, fabrication, installation, and maintenance.

3.2 Design Concepts

3.2.1 Trailing-End Anchorage System with Steel Posts and Breakaway Coupler

The first design concept included: (1) steel top and bottom posts; (2) a breakaway coupler (collar) for connecting the top and bottom posts; (3) a compression groundline strut; and (4) a cable anchorage, as shown in Figure 53. The breakaway coupler was connected to the posts by four ½-in. (13-mm) diameter ASTM A325 bolts. A cable anchor was attached to the end post and the back of the W-beam rail. This system would develop proper longitudinal tensile force in the W-beam rail for impacts within the LON of the guardrail but break away during impacts at the end without developing excessive forces.

This concept was not considered for further analysis as the breakaway coupler connecting the upper and lower posts was deemed insufficient. The bolts may not fracture, and the posts may not break away freely. Also, the breakaway coupler may present design complexities associated with fracturing the bolts. The coupler would be costly since a custom mold would be necessary.

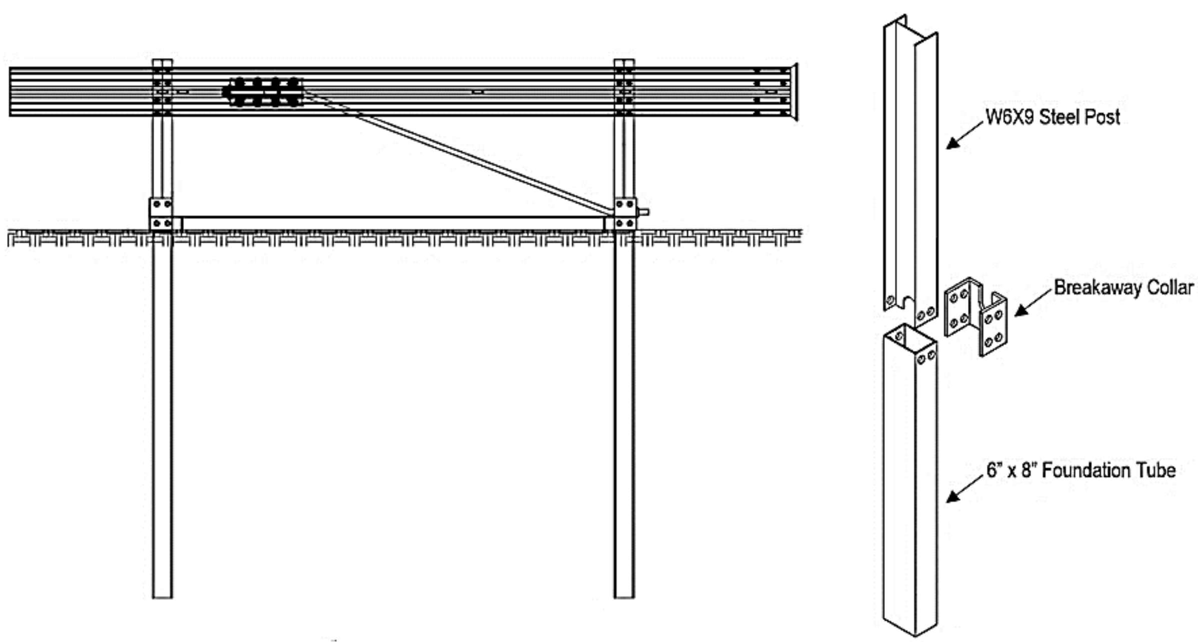


Figure 53. Trailing-End Anchorage with Steel Posts and Breakaway Coupler

3.2.2 Trailing-End Anchorage with Steel Tube Posts

This design concept utilized (1) a steel tube for the top and bottom posts, (2) a compression ground line strut, and (3) a cable anchorage system, as shown in Figure 54. The breakaway mechanism of this trailing-end anchorage system relied on fracture of the brittle steel tube used for the top post. An anchor cable was attached to the foundation tube and the back of the W-beam rail. The anchorage system would provide tensile strength in the W-beam rail for impacts within the LON of the guardrail but break away for impacts at the end without developing excessive force. A concern existed that the top post may not break away similar to the wood BCT post. The steel tube may bend over to the ground and may not fracture due to the ductile behavior of steel. This design concept required complex and uneconomical details. Thus, this concept was not considered for further analysis.

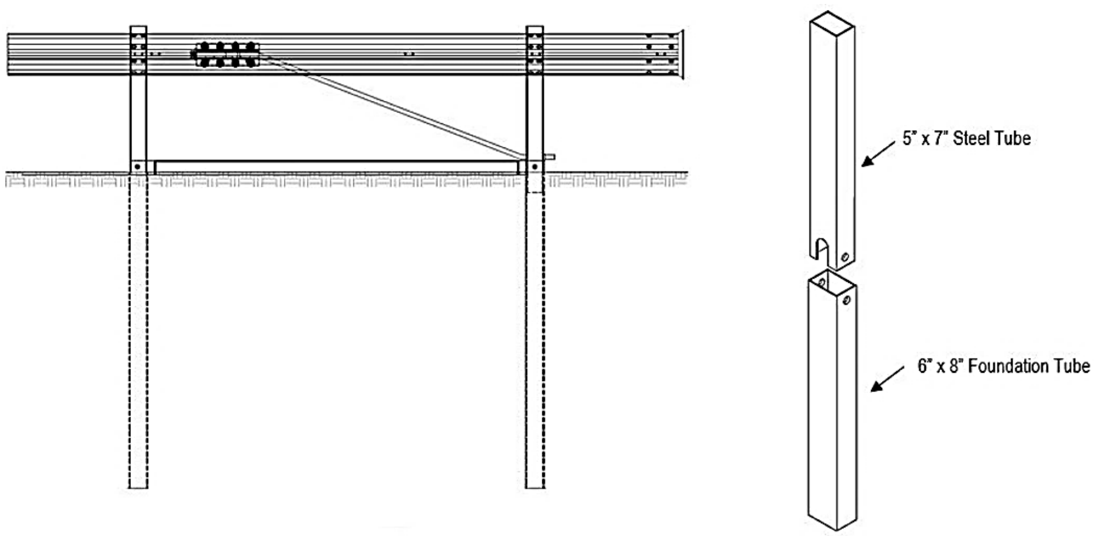


Figure 54. Trailing-End Anchorage with Steel Tube Posts

3.2.3 Trailing-End Anchorage with Slip Base

Another design concept included: (1) a W6x9 steel section for top post and a steel tube for bottom post; (2) a base plate attached to the upper and lower steel posts to provide breakaway performance; (3) a T-shaped, breaker bar attached to the end post; and (4) a compression strut. The breakaway mechanism relied on the failure of the connections between the upper and lower base plates. The slip-base steel post included two base flanges, which are upper and lower posts clamped together with bolts, as shown in Figure 55. Bolts resided in slots that would allow the bolts to disengage the posts.

Considering the breakaway performance of the design concept, a concern was that the system may not breakaway similar to the wood BCT posts due to the dependency of the breakaway performance on friction between the base plates. Thus, this concept was disregarded.

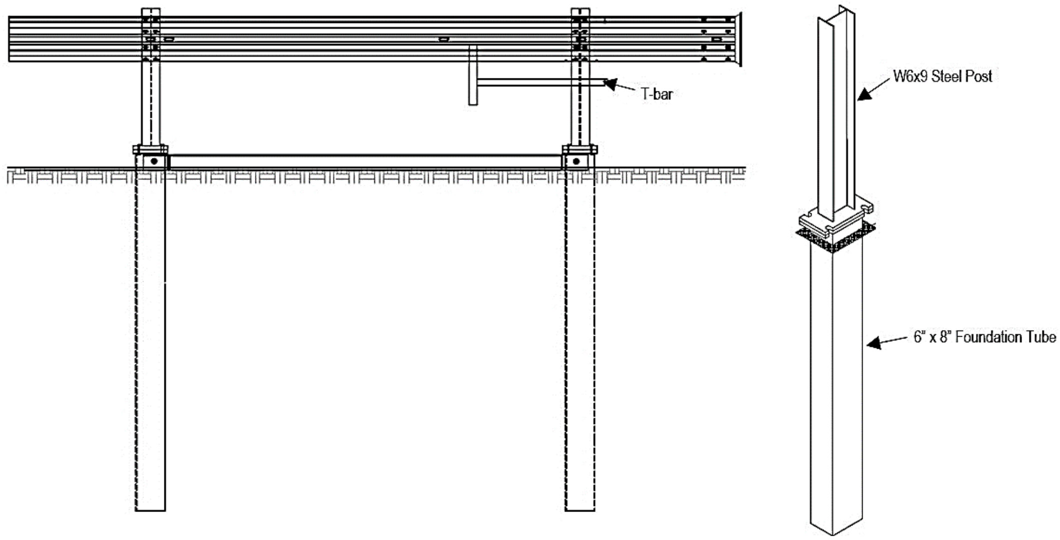


Figure 55. Trailing-End Anchorage with Slip Base and T-Shaped Breaker Bar

3.2.4 Trailing-End Anchorage without Top Post

A fourth design concept consisted of the following main components: (1) a W6x9 steel foundation tube for the bottom post with an attached soil plate; (2) a cable anchorage; (3) a slip-base plate; and (4) a compression ground line strut, as shown in Figure 56. This concept was based on the three-cable guardrail design, described in Nelson et al. [66].

The breakaway performance of this concept relied on the slip-base failure. The system utilized an anchor cable attached to a steel foundation tube to develop tensile strength in the W-beam rail for impacts within the guardrail LON. However, a concern existed that the slip-base and the steel foundation tube may not fracture similar to the wood BCT posts. Additionally, the cable attached to the end steel post may show satisfactory performance for cable barrier systems, but this cable anchorage needs further research to be used in guardrail anchorage systems.

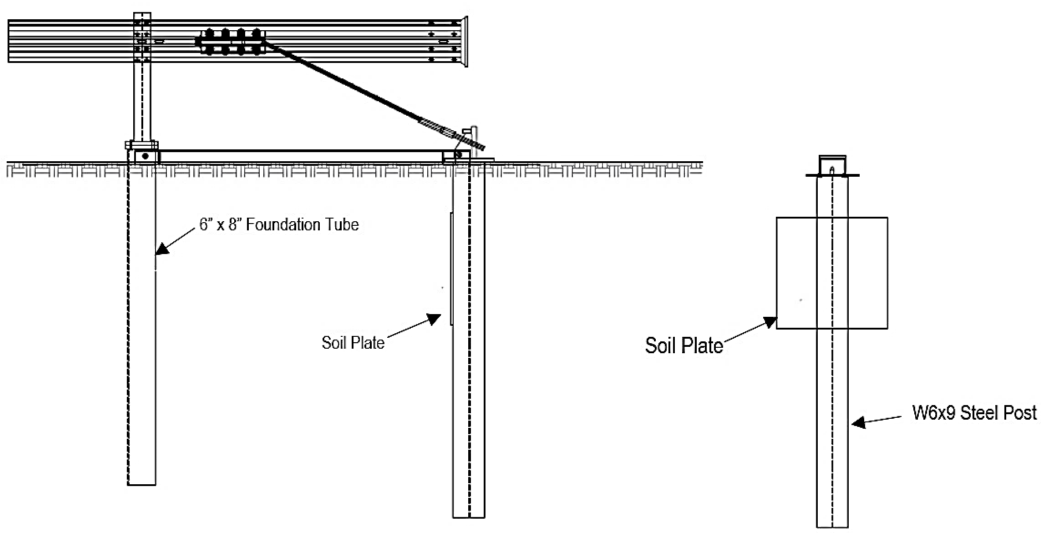


Figure 56. Trailing-End Anchorage without Top Post

3.2.5 Trailing-End Anchorage with Modified UBSP

This design concept, adopted from the original UBSP, included: (1) top and bottom steel posts; (2) a compression ground line strut between the foundation tubes; (3) a T-shaped, breaker bar attached to the end post; and (4) an anchor cable to provide the tensile strength of the guardrail during impacts within the guardrail LON, as shown in Figure 57. The end anchor post and second post utilize a two-part steel post. The top post is a 27½ in. (699 mm) long, W6x9 ASTM A992 steel post welded to a 5½-in. x 5½-in. x ¾-in. (140-mm- x 140-mm x 19-mm), ASTM 36 steel base plate. The bottom post is a HSS 6-in. x 8-in. x 3⁄16-in. (152-mm x 203-mm x 5-mm) ASTM A500 Grade B steel foundation tube welded to a 13-in. x 7-in. x ⅝-in. (330-mm- x 178-mm x 16-mm), ASTM 36 steel base plate. The top and bottom base plates are connected using four 7⁄16-in. (11-mm) diameter, ASTM A325 bolts.

The breakaway performance of the design concept relied on fracturing and shearing of bolts. During an impact, bolts are expected to fracture in tension on the impact side and in shear on the back side. The size and location of the bolts control the post fracture load. In this design concept, posts may break away similar to the BCT wood posts. Thus, this design concept was considered for further design.

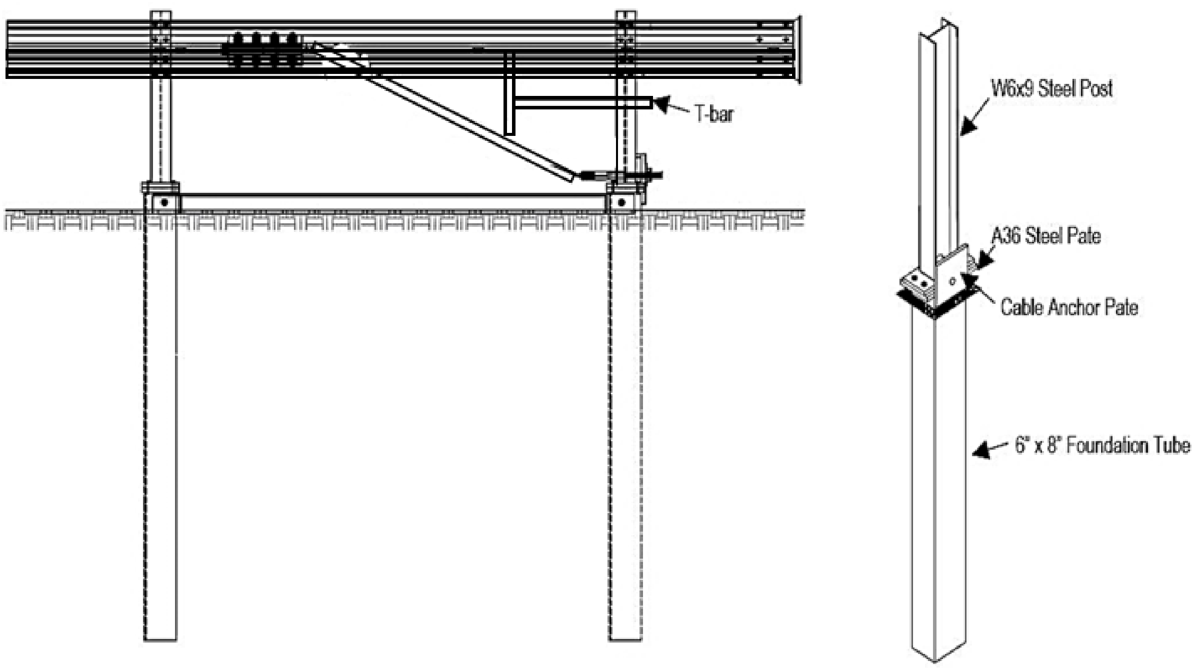


Figure 57. Trailing-End Anchorage with Modified UBSP and T-Shaped Breaker Bar

3.3 Candidate Design Concepts with Modified UBSP

Following the brainstorming of a number of design concepts for the new, steel-post, non-proprietary trailing-end anchorage system, three modified UBSP trailing-end anchorage system design concepts were developed for dynamic component testing.

3.3.1 Design Concept No. 1

The first modified UBSP non-proprietary, trailing-end anchorage design concept contained the following main components:

1. A two-part steel post, where the top post was a W6x8.5 section and the bottom post was a 6-in. x 8-in. x 3⁄16-in. (152-mm x 203-mm x 5-mm) tube section. The top post was welded to a 5½-in. x 5½-in. x ¾-in. (140-mm x 140-mm x 19-mm), ASTM 36 steel base plate. The bottom post was welded to a 13-in. x 7-in. x ⅝-in. (330-mm x 178-mm x 16-mm), ASTM 36 steel base plate. The top and bottom base plates were connected using four 7⁄16-in. (11-mm) diameter, ASTM A325 bolts.

2. An anchor cable assembly to provide anchorage for the guardrail.

3. A compression ground strut connected to the foundation tubes to provide proper load distribution between the posts, as shown in Figure 58.

4. A bearing plate to transfer the load from the cable to the top and bottom sections of the end post.

The details of concept no. 1 are shown in Figure 58. The post breakaway mechanism relied on the fracture of bolts. A slot was included at the bottom of the W6x8.5 post to pass the cable through the top section of the end post. An opening in the base plate allows the cable to release when the top section of the end post disengaged. Calculations were performed to determine the adequacy of the spacing and size of the breakaway bolts for the UBSP within the non-proprietary, trailing-end anchorage system and are detailed in Appendix A. Based on the calculations, the 7⁄16-in. (11-mm) diameter breakaway bolts were found to be adequate with respect to strong-axis bending. The bolts were spaced 2½ in. (64 mm) apart in the weak axis and 10 in. (254 mm) apart in the strong axis.

The anchor cable's ability to release from the W-beam during head-on impacts was considered. Calculations were also performed to determine the tensile capacity of the cable anchor and are detailed in Appendix A. Based on these calculations, the anchor cable could develop a tensile load of 40.2 kips (179 kN) before bolt fracture. The anchor cable would also develop sufficient W-beam rail tensile strength for the impacts within the guardrail LON.

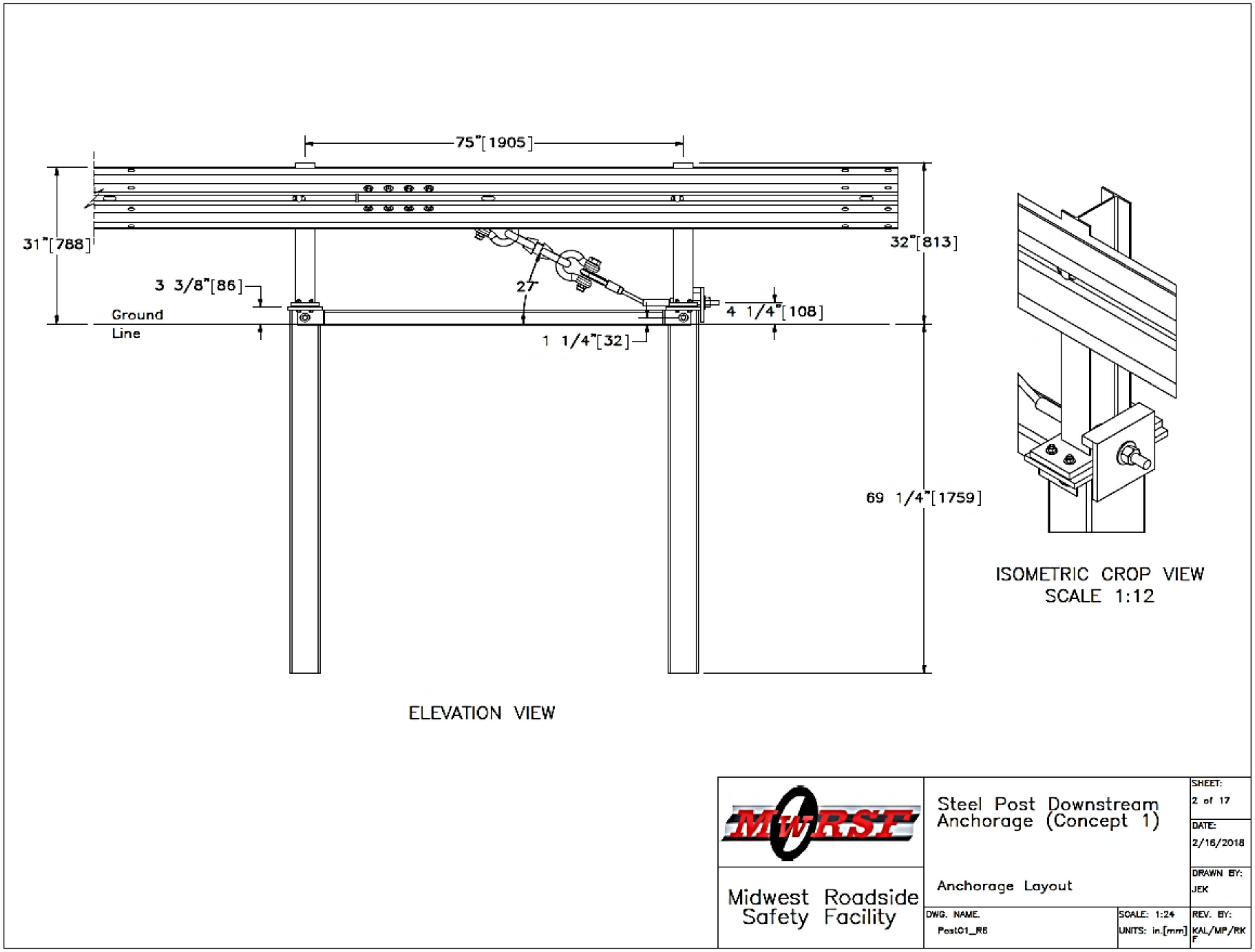


Figure 58. Steel-Post, Trailing-End Anchorage System, Concept No. 1 – Anchorage Layout

3.3.2 Design Concept No. 2

Design concept no. 2 contained the following main components:

1. Two steel posts with post sections similar to design concept no. 1. However, the opening to receive the cable anchor was at the top of the foundation tube.

2. A cable anchor attached to the W-beam rail at one end and anchored to the foundation tube through a slot in the bottom base plate and foundation tube.

3. A slotted bearing plate to anchor the anchor cable to the foundation tube and transfer the longitudinal anchor load to the foundation tube.

4. A compression ground line strut connected to the steel foundation tubes.

The details of concept no. 2 are shown in Figure 59. The bolt spacing and top and bottom base plate thicknesses were similar to design concept no. 1. Design concept no. 2 included a slot in the foundation tube that forms the lower section of the end post and an opening in the bottom base plate to facilitate cable release, as shown in Figure 59. This design concept intended to transfer the longitudinal anchor load primarily to the lower section of the post and the surrounding soil. However, vertical cable loads would still be imparted to the top section of the end post. Calculations were performed to determine the shear and flexural capacity of the fillet welds for the expected loading conditions and are detailed in Appendix B.

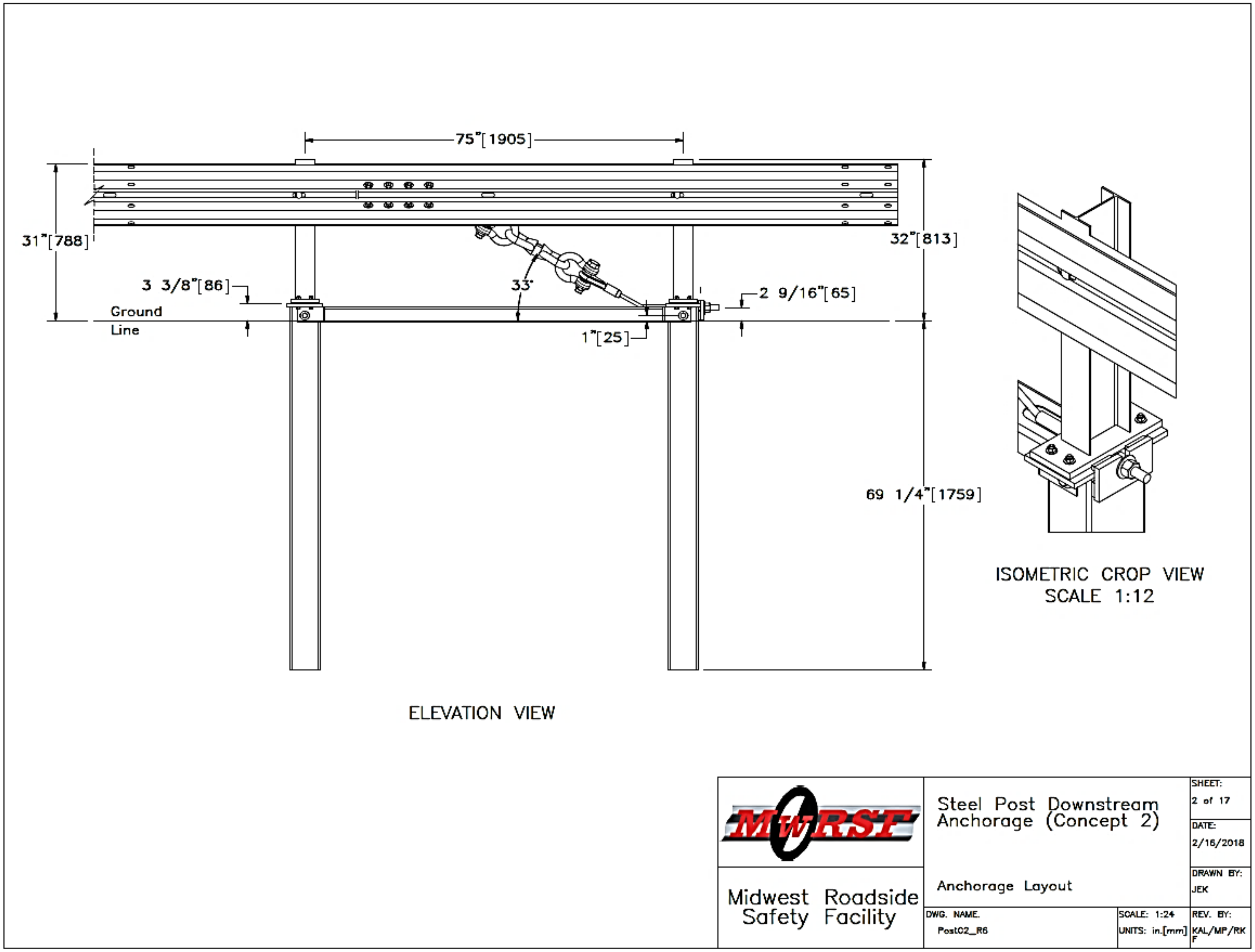


Figure 59. Steel-Post, Trailing-End Anchorage System, Concept No. 2 – Anchorage Layout

3.3.3 Design Concept No. 3

Design concept no. 3 contained the following main components:

1. Two-part steel posts with post sections similar to design concept nos. 1 and 2.

2. An anchor cable assembly similar to design concept nos. 1 and 2. However, the anchor cable was anchored to an inclined slotted bearing plate, which was welded to the bottom base plate and the foundation tube.

3. An inclined slotted bearing plate attached to the foundation tube and the bottom base plate by a ¼-in. (6-mm) fillet weld. The inclined, slotted, bearing plate transfers the load from the anchor cable to the foundation tube.

4. A compression ground line strut, which was similar to design concept nos. 1 and 2.

The anchorage system was similar to design concept nos. 1 and 2. However, design concept no. 3 utilized an inclined, slotted, anchor cable bearing plate that was welded to the bottom base plate and foundation tube with a ¼-in. (6-mm) fillet weld, as shown in Figure 60. This configuration ensured transfer of the entire cable load to the lower foundation tube and the surrounding soil. An opening was made in the bottom of the top post, both base plates, and the top of the foundation tube, as shown in Figure 60. Calculations were performed to check the shear and flexural capacity of the fillet welds for the expected loading conditions and are detailed in Appendix C.

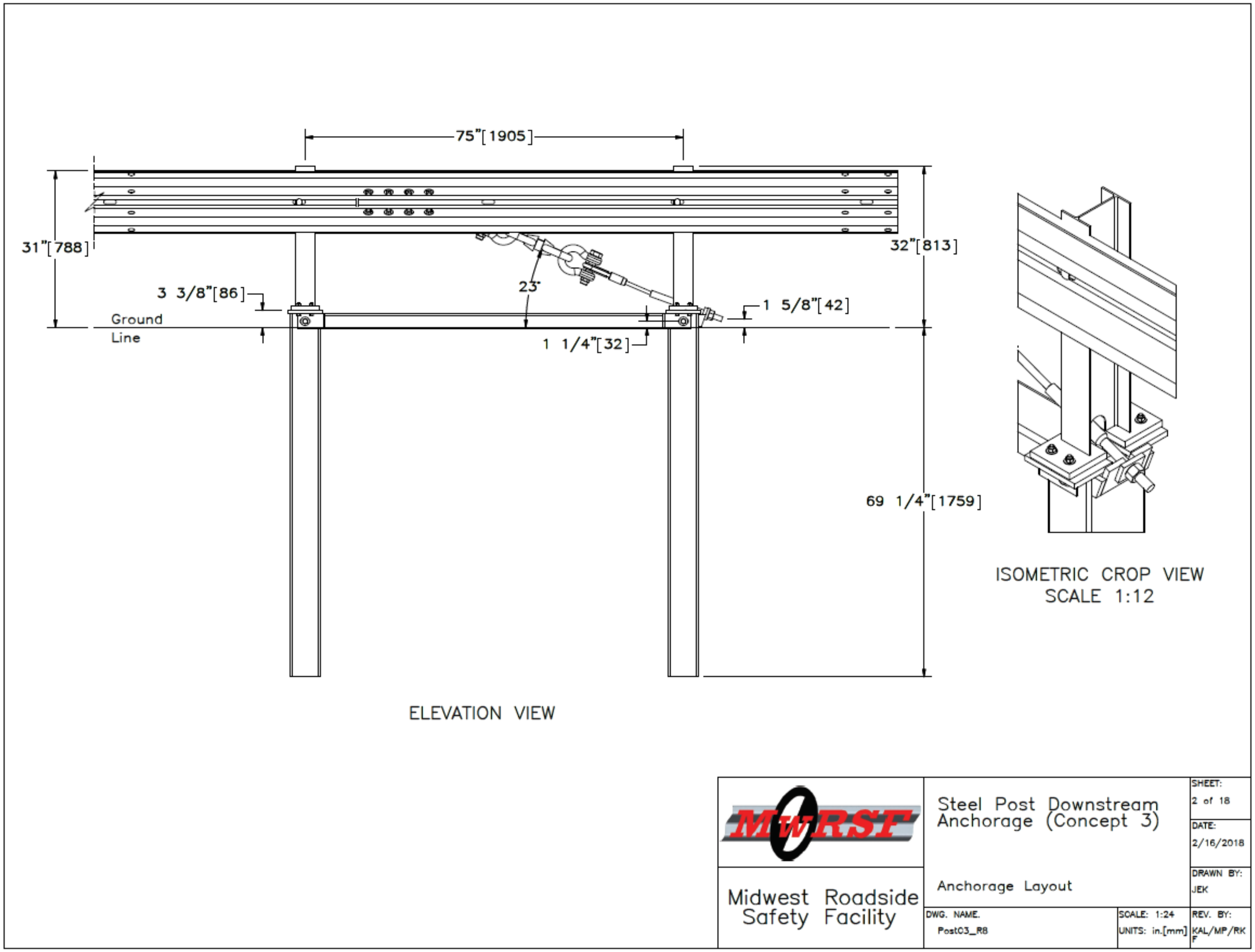


Figure 60. Steel Post, Trailing-End Anchorage System, Concept No. 3 – Anchorage Layout

4 DYNAMIC COMPONENT TEST CONDITIONS AND INSTRUMENTATION

Dynamic component tests were performed to evaluate the behavior and capacity of the steel-post versions of the non-proprietary, trailing-end anchorage design concepts. Dynamic jerk tests were utilized to assess the overall dynamic capacity of the anchorage systems.

4.1 Test Facility

All dynamic jerk tests were conducted at the MwRSF outdoor test site located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport. The facility is approximately 5 miles (8 km) northwest of the University of Nebraska's city campus in Lincoln, Nebraska.

4.2 Test Equipment and Instrumentation

Equipment and instrumentation utilized to collect and record data during the dynamic bogie testing program included a bogie, accelerometers, tensile load cells, string potentiometers, high-speed and standard-speed digital video cameras, and still cameras.

4.2.1 Bogie Vehicle

A rigid-frame bogie vehicle was used to conduct the jerk test on each end-trailing anchorage system. The mass of the bogie vehicle on the test day was 6,652 lb (3,017 kg), and the same bogie vehicle was used for test nos. SPDA-1 through SPDA-5. Four 3x7 wire rope cables were connected in a parallel configuration and used to pull on various components. The wire ropes were terminated with thimble (or cable saver) terminations and attached to the back of the bogie vehicle using a high-strength nylon strap and a pin-and-shackle connection. The bogie vehicle and the pull cable used for all tests are shown in Figure 61.

Figure 61. Rigid-Frame Bogie Vehicle, Test Nos. SPDA-1 through SPDA-5

A pickup truck with a reverse-cable, tow system was used to propel the bogie vehicle to a target impact speed of 20 mph (32 km/h) for all five tests. A steel corrugated beam guardrail guided the tire of the bogie vehicle. When the bogie vehicle approached the end of the guidance system, it was released from the tow cable, allowing it to be free rolling when it started to tension the pull cable. A remote-controlled braking system was installed on the bogie vehicle allowing it to be brought safely to rest after the test.

4.2.2 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the acceleration in the longitudinal, lateral, and vertical directions. All of the accelerometer systems were mounted near the center of gravity (c.g.) of the bogie vehicle.

The two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-1 unit was designated as the primary system. The acceleration sensors were mounted inside the bodies of custom-built, SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.2.3 Tensile Load Cells

One tensile load cell was installed in line with the cable anchor and one load cell was installed in the pull cable for all tests. The load cells were Transducer Techniques model no. TLL−50K with a load range up to 50 kips (222 kN). During testing, output voltage signals were sent from the load cells to a National Instruments data acquisition board, acquired with LabView software, and stored permanently on a personal computer. The data collection rate for the load cells was 10,000 samples per second (10,000 Hz). The location and setup of the load cells are shown in Figures 62 through 66.

4.2.4 String Potentiometers

In test nos. SPDA-1, SPDA-2, and SPDA-3, a linear displacement transducer, or string potentiometer, was attached to the end of the anchor cable. In test nos. SPDA-4 and SPDA-5, the string potentiometer was attached to the bottom base plate welded to the foundation tube. The positioning and setup of the string potentiometer are shown in Figure 67. The string potentiometer used was a UniMeasure PA-50 with a range of 50 in. (1,270 mm). A Measurements Group Vishay Model 2310 signal conditioning amplifier was used to condition and amplify the low-level signals to high-level outputs for multichannel, simultaneous dynamic recording in the "LabView" software. The sample rate of the string potentiometer was 1,000 Hz.

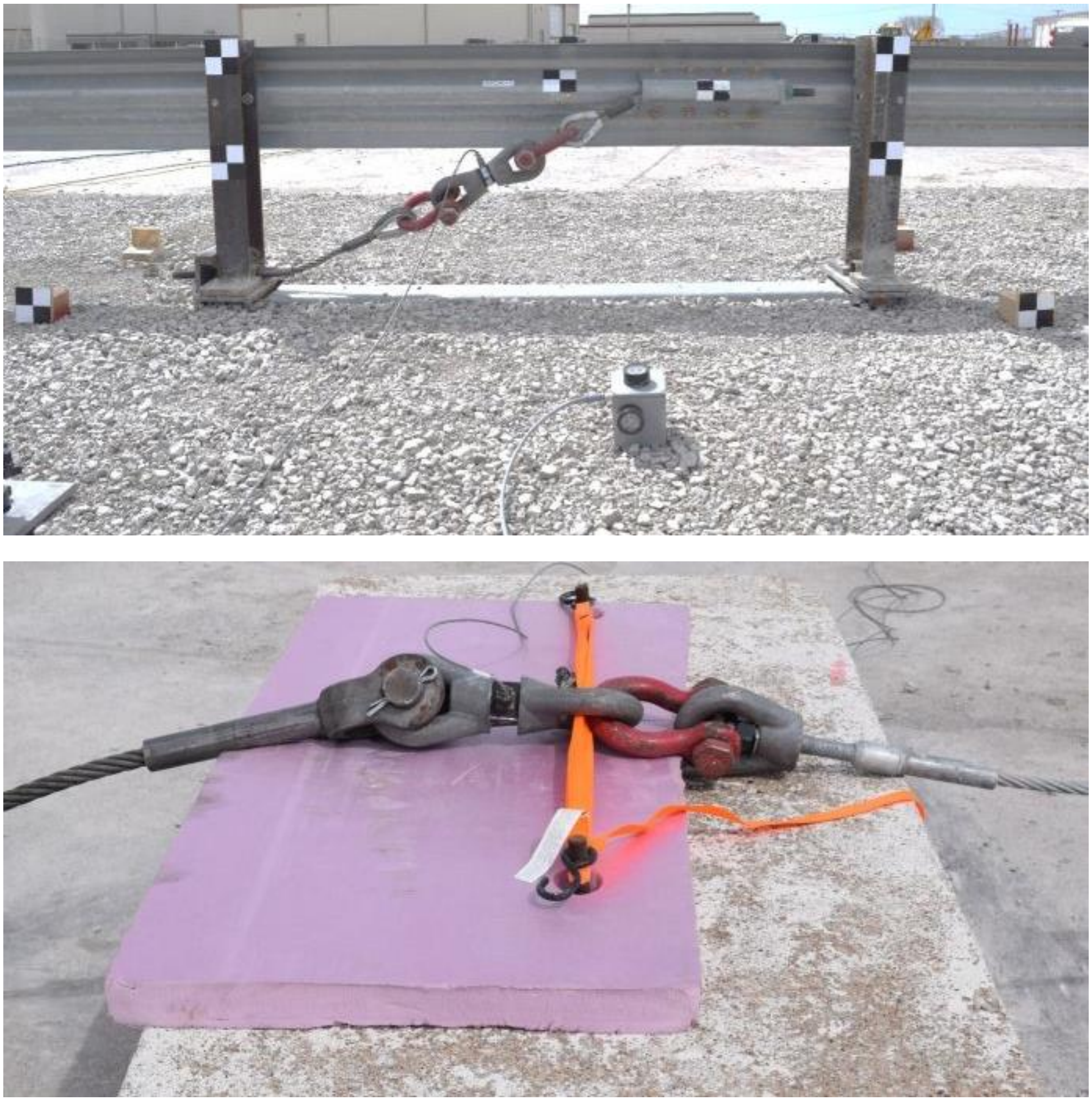


Figure 62. Tensile Load Cell Setup, Test No. SPDA-1

Figure 63. Tensile Load Cell Setup, Test No. SPDA-2

Figure 64. Tensile Load Cell Setup, Test No. SPDA-3

Figure 65. Tensile Load Cell Setup, Test No. SPDA-4

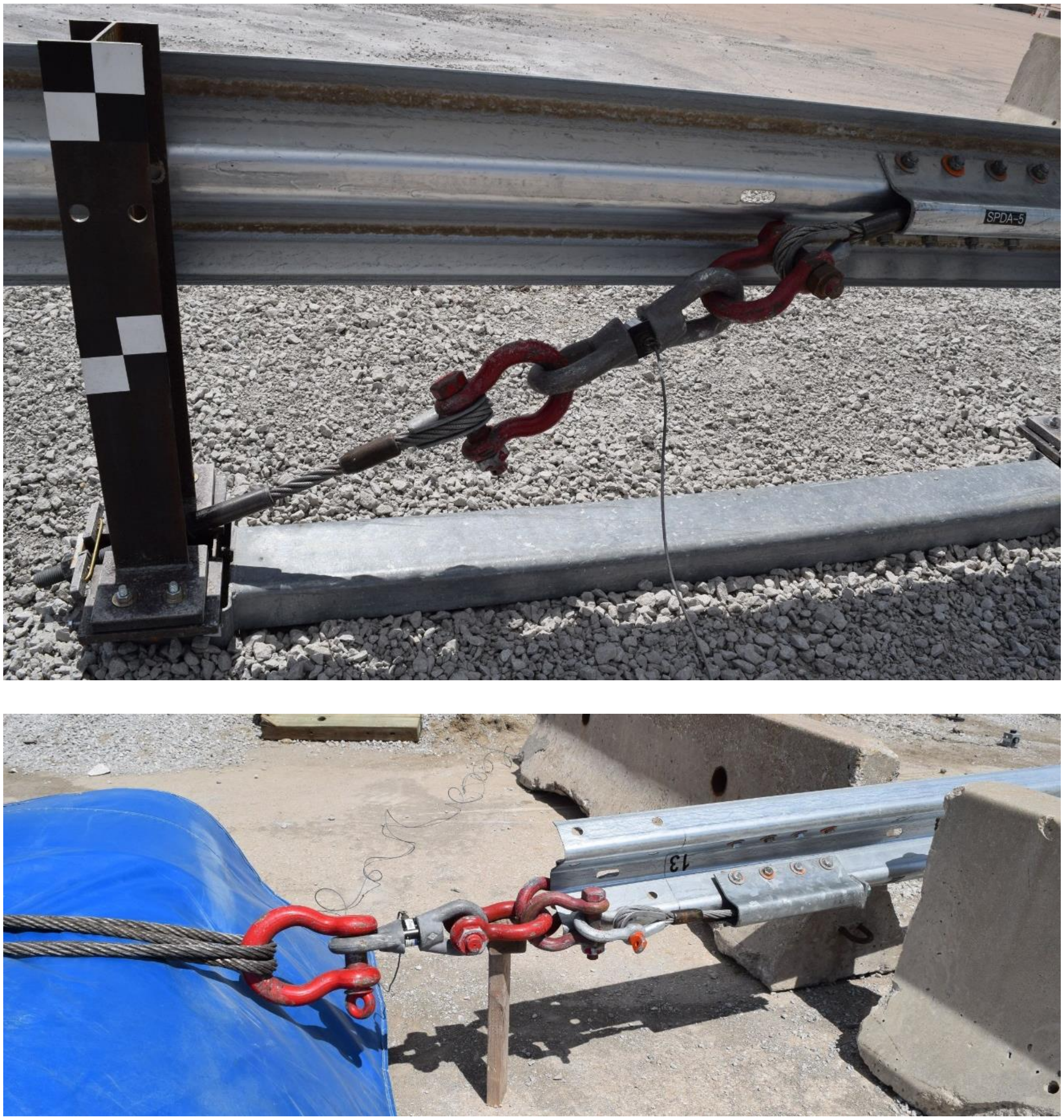
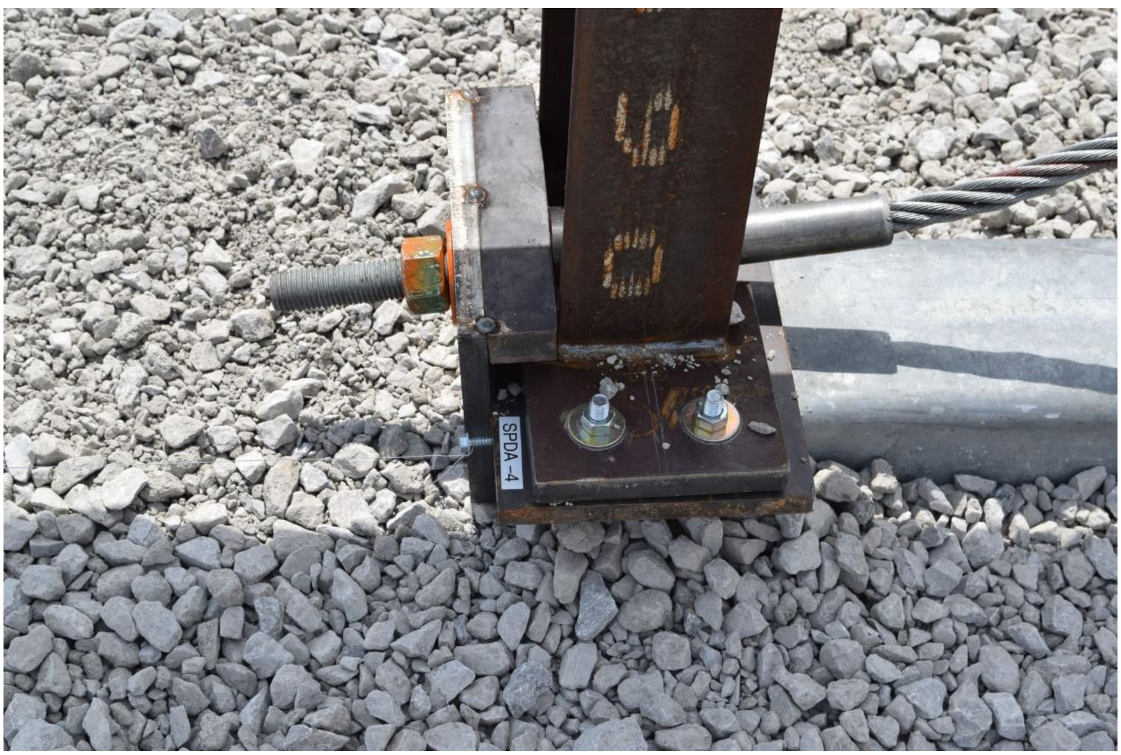


Figure 66. Tensile Load Cell Setup, Test No. SPDA-5

(a)



(b)

Figure 67. String Potentiometer Locations, (a) Test Nos. SPDA-1 through SPDA-3, and (b) Test Nos. SPDA-4 and SPDA-5

4.2.5 Digital Photography

Two AOS high-speed digital video cameras were used to document test no. SPDA-1. One AOS high-speed digital video camera was used to document each of test nos. SPDA-2 through SPDA-5. GoPro digital video cameras were also used to document each test. Six GoPro digital video cameras were used to document test nos. SPDA-1 and SPDA-2, and test nos. SPDA-3, SPDA-4, and SPDA-5 used five, four, and five Go Pro digital video cameras, respectively. The AOS high-speed camera had a frame rate of 500 frames per second and the GoPro video cameras had frame rates of 120 frames per second. The cameras were placed on (1) the front side of the system, (2) perpendicular to the system viewing the back side of the rail focused on the end anchor and connection between the end of the W-beam rail and pull cable, (3) perpendicular to the system viewing the front and back sides of W-beam rail, and (4) parallel to the system viewing anchor post. A Nikon digital still camera was also used to document pre- and post-test conditions for all tests.

4.3 Data Processing

4.3.1 Accelerometers

The electronic accelerometer data obtained in the dynamic testing was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [67]. The pertinent acceleration was extracted from the bulk of the data signals. The processed acceleration data was then multiplied by the mass of the bogie to get the impact force using Newton's Second Law. Next, the acceleration trace was integrated to find the change in velocity versus time. The calculated velocity trace was then integrated to find the bogie's displacement. Combining the previous results, a force versus deflection curve was plotted for each test. Finally, integration of the force versus deflection curve provided the energy versus deflection curve for each test.

4.3.2 Load Cells

For test nos. SPDA-1 through SPDA-5, force data was measured with the load cell transducers and filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [67]. The pertinent voltage signal was extracted from the bulk of the data signal similar to the acceleration data. The filtered voltage data was converted to load using the following equation:

$$\text{Load} = \left[\frac{1}{\text{Gain}}\right]\left[\frac{\text{Filtered Load Cell Data}}{\left(\frac{(\text{Calibration Factor})(\text{Excitation Voltage})}{\text{Full} - \text{Scale Load}}\right)\left(\frac{1\text{ V}}{1000\text{ mV}}\right)}\right]$$

Details behind the theory and equations used for processing and filtering the load cell data are located in SAE J211/1. The gain and excitation voltage were recorded for each test. The full-scale load for the TLL 50K load cells was 50 kips (222 kN). The calibration factor varied depending on the specific load cell being used. The load cell data was recorded in a data file and processed in a specifically designed Microsoft Excel spreadsheet. Force versus time plots were created to describe the load imparted to the system.

4.3.3 String Potentiometers

For test nos. SPDA-1 through SPDA-5, the pertinent data from the string potentiometers was extracted from the bulk signal similar to the accelerometer and load cell data. The extracted data signal was converted to a displacement using the transducer's calibration factor. Displacement versus time plots were created to describe the motion of the system at the ground line. The exact moment of impact could not be determined from the string potentiometer data as impact may have occurred a few milliseconds before post movement. Thus, the extracted time shown in the displacement versus time plots should not be taken as a precise time after impact, but rather a general time in relation to the impact event.

Note that string potentiometer data from test nos. SPDA-1 through SPDA-3 were not accurate for estimating the displacement of the foundation tube as the string potentiometer was attached to the end of the anchor cable. However, considerable effort was made to reasonably compare string potentiometer data obtained from the five tests, as described in the following chapters.

5 DYNAMIC COMPONENT TEST – DESIGN CONCEPT NO. 1

5.1 System Details – Concept No. 1

Test no. SPDA-1 was a dynamic jerk test of design concept no. 1, which was the anchorage system consisting of two modified UBSPs with a slot at the bottom of a W6x8.5 anchor post, allowing the anchor cable to pass through the top post, a steel W6x8.5 post, two 12-ft – 6-in. (3,810-mm) long W-beam segments, and an instrumented cable anchor connecting the W-beam rail to the end post. The test matrix and test setup are shown in Figures 68 through 84. Photographs of the test setup are shown in Figures 85 and 86. Material specifications, mill certifications, and certificates of conformity for the system materials used in test no. SPDA-1 are shown in Appendix G.

Test Name	Bogie No.	Estimated Bogie Weight (lb)	Bogie Speed (mph)
SPDA–1	2	6,667	20

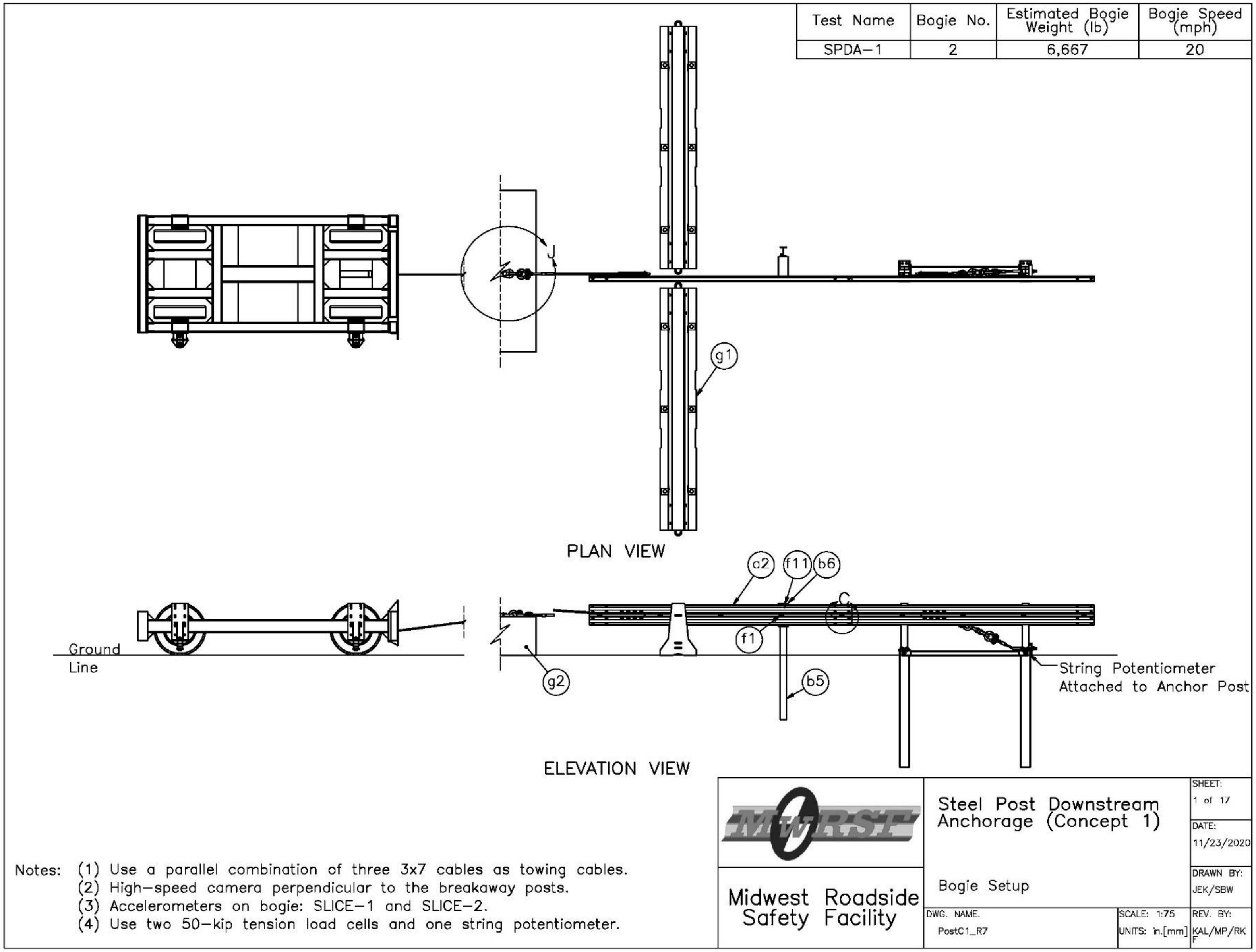


Figure 68. Bogie Testing Matrix and Setup, Test No. SPDA-1

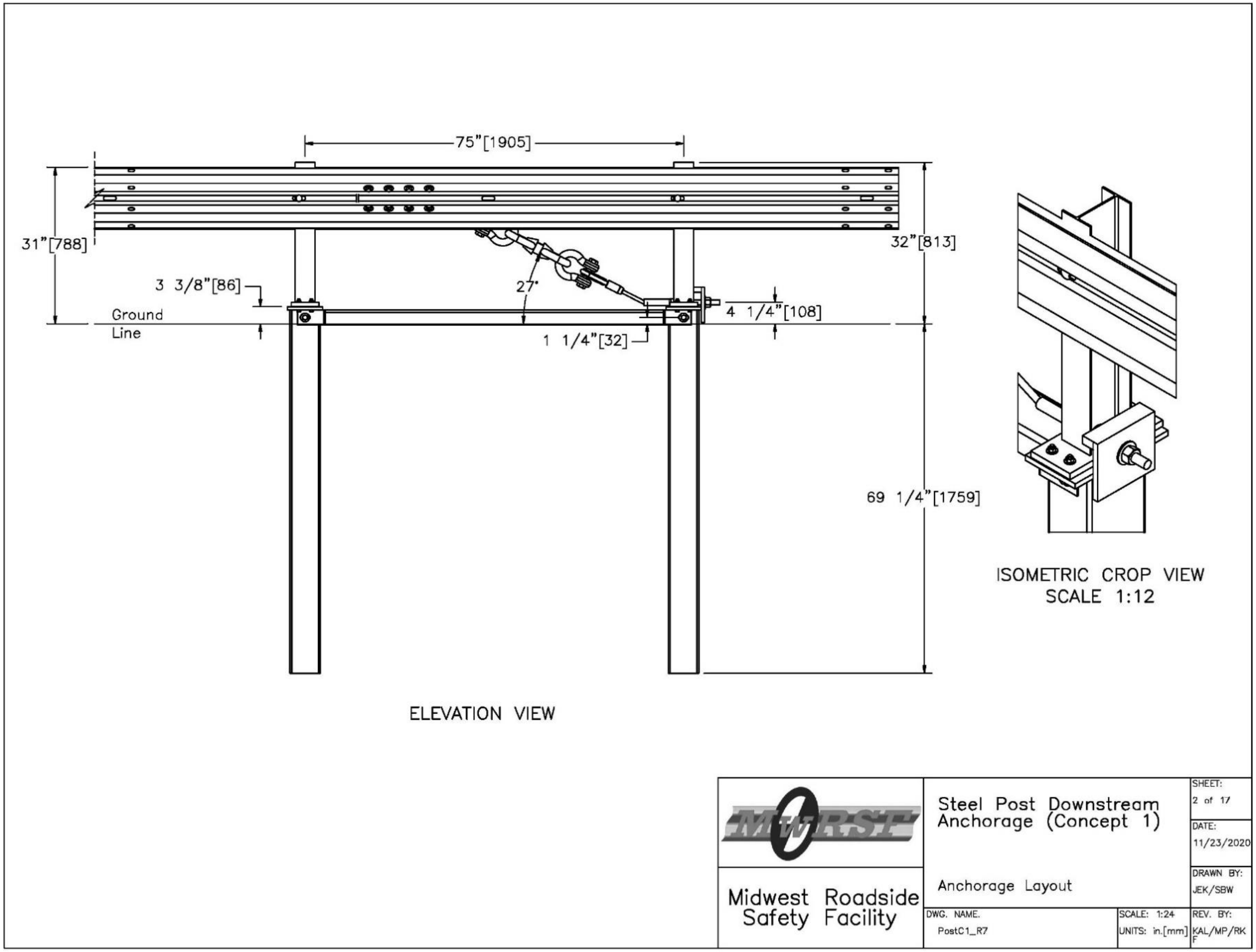


Figure 69. Anchorage Layout, Test No. SPDA-1

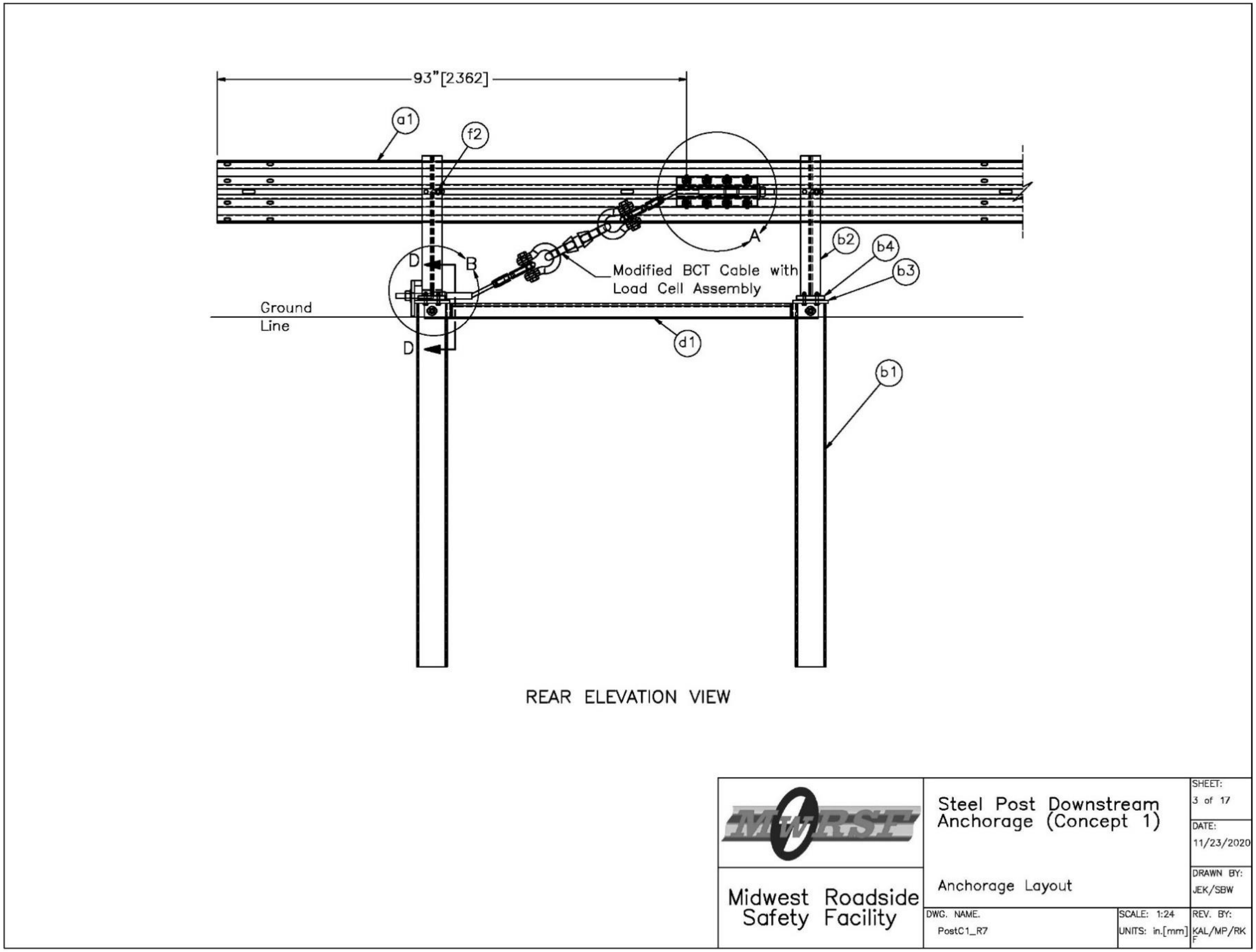


Figure 70. Anchorage Layout, Test No. SPDA-1

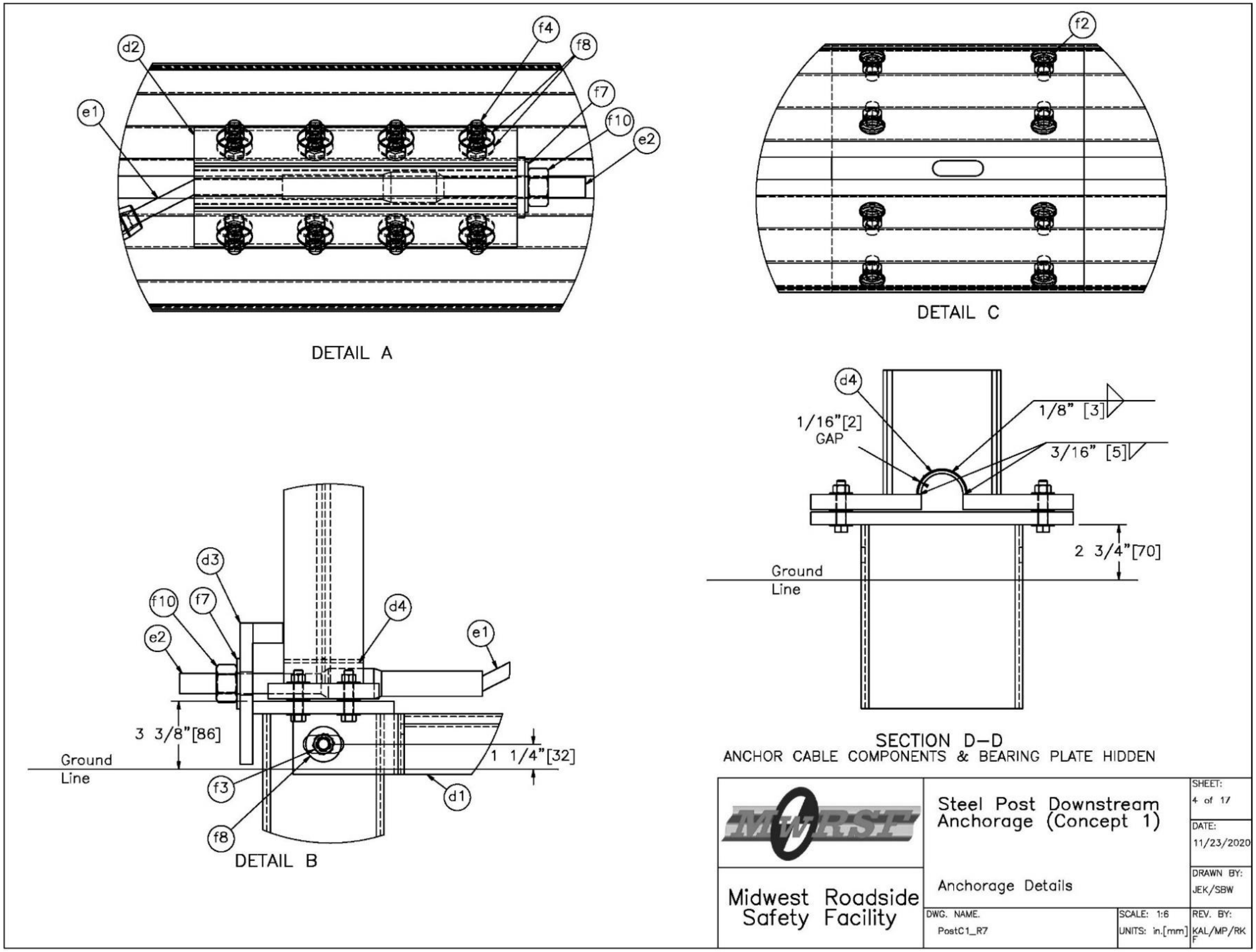


Figure 71. Anchorage Details, Test No. SPDA-1

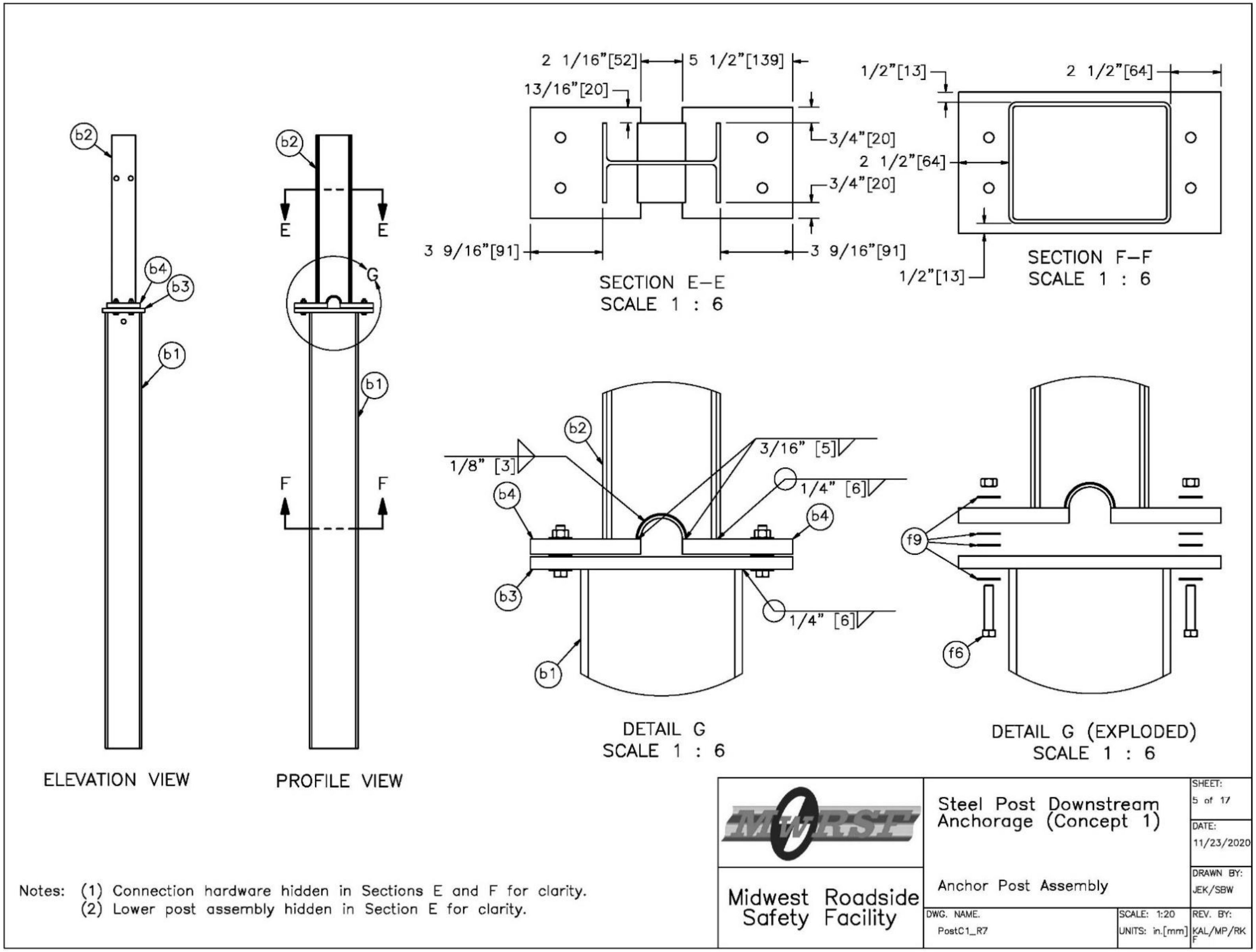


Figure 72. Anchor Post Assembly, Test No. SPDA-1

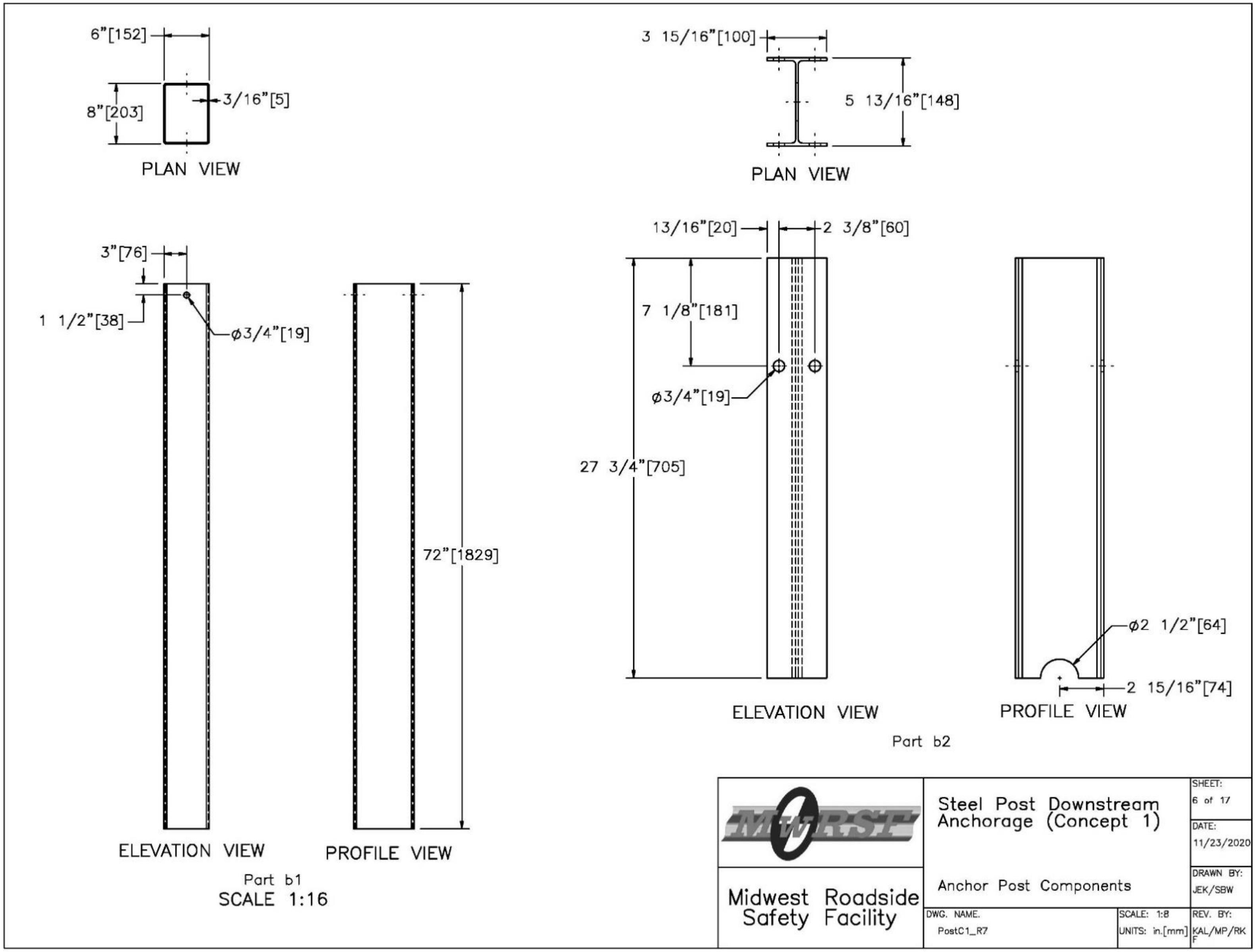


Figure 73. Anchor Post Components, Test No. SPDA-1

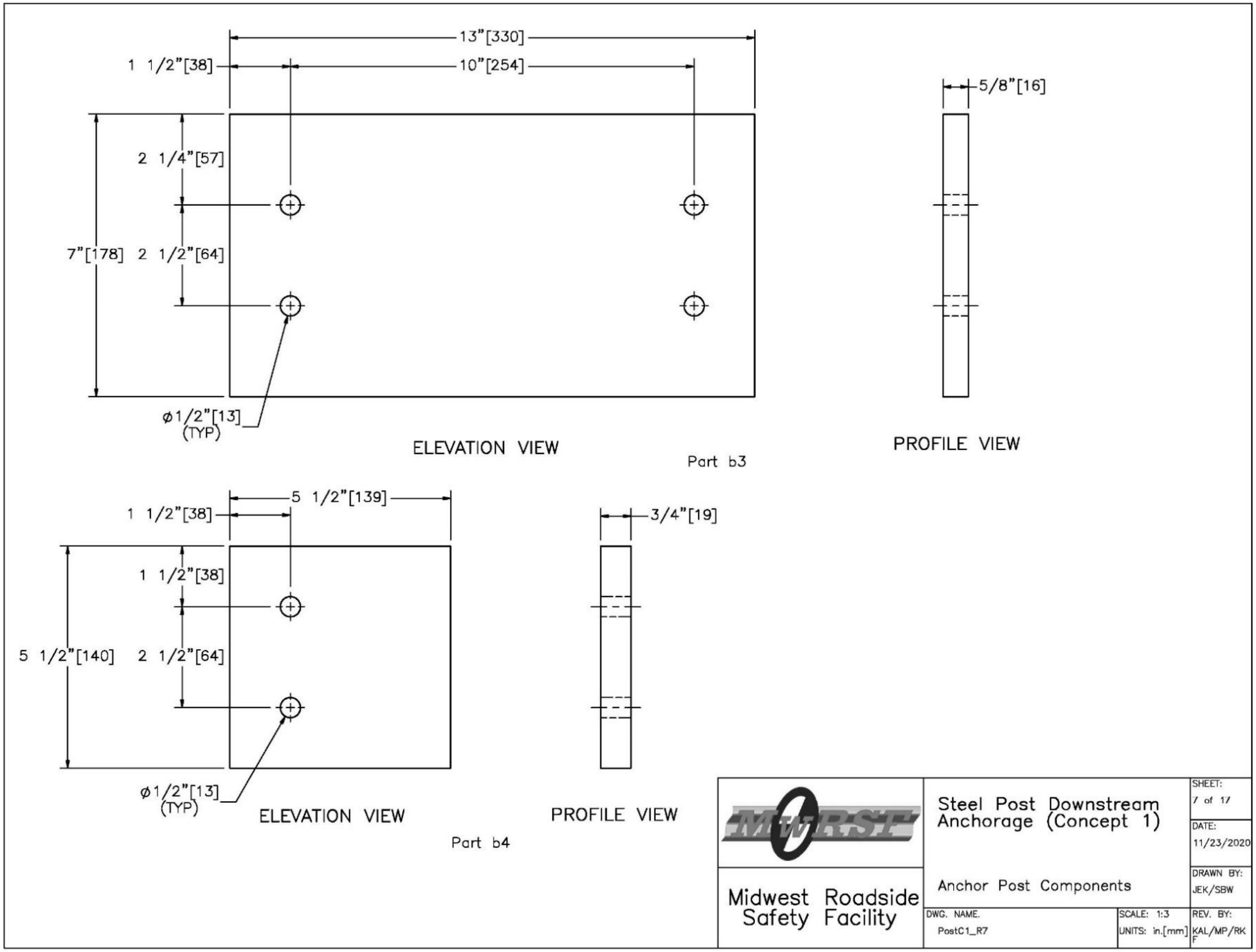


Figure 74. Anchor Post Components, Test No. SPDA-1

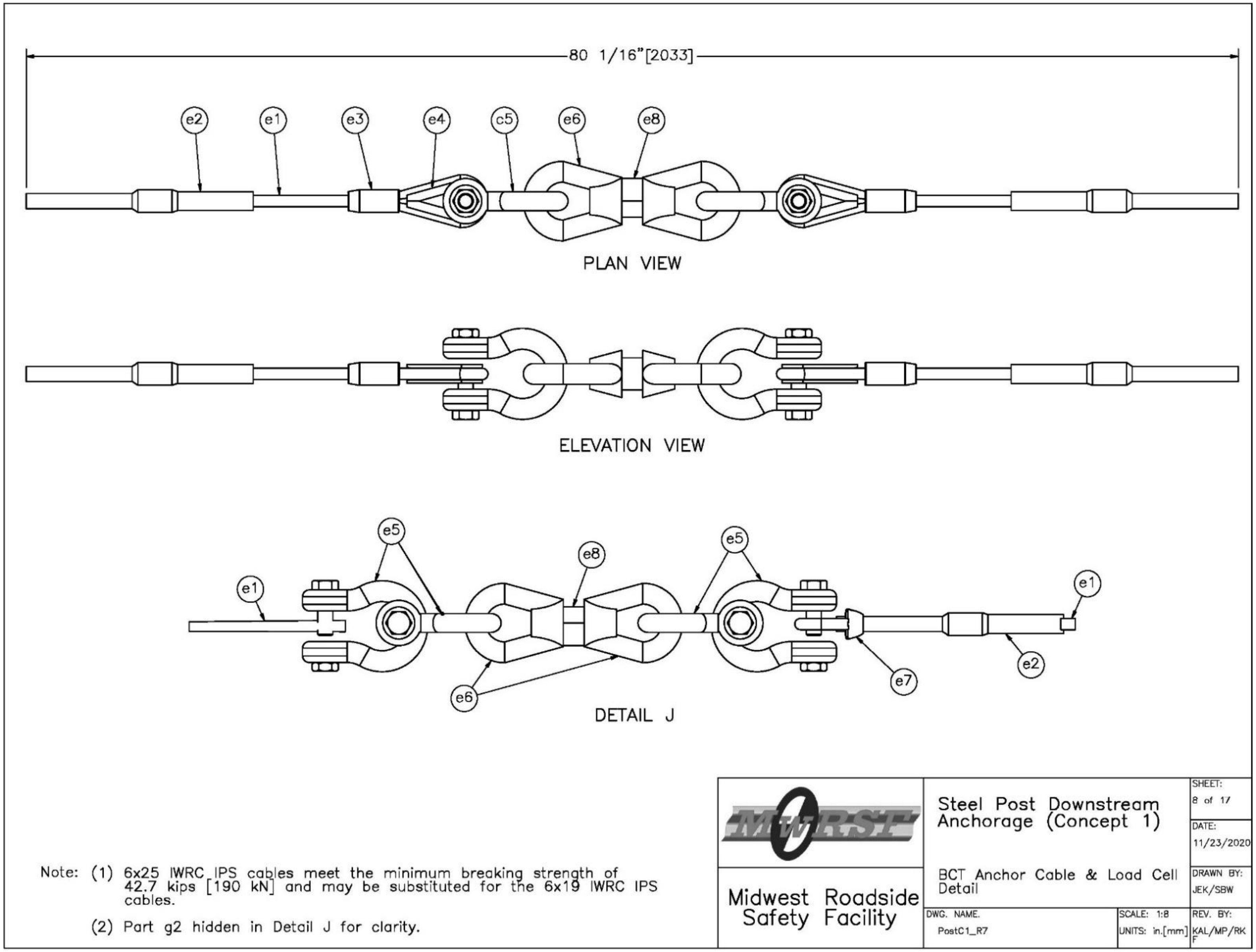


Figure 75. BCT Anchor Cable and Load Cell Detail, Test No. SPDA-1

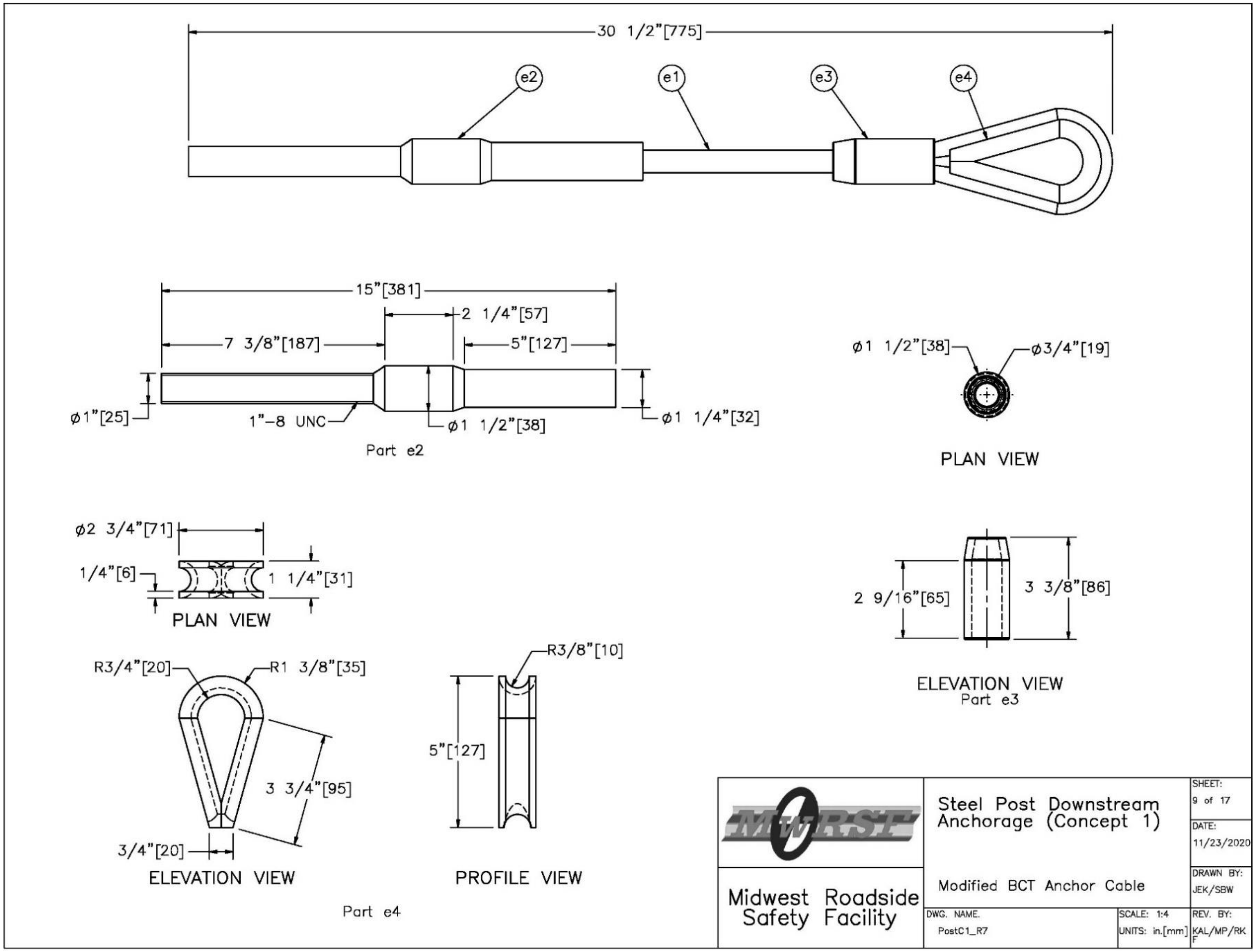


Figure 76. Modified BCT Anchor Cable, Test No. SPDA-1

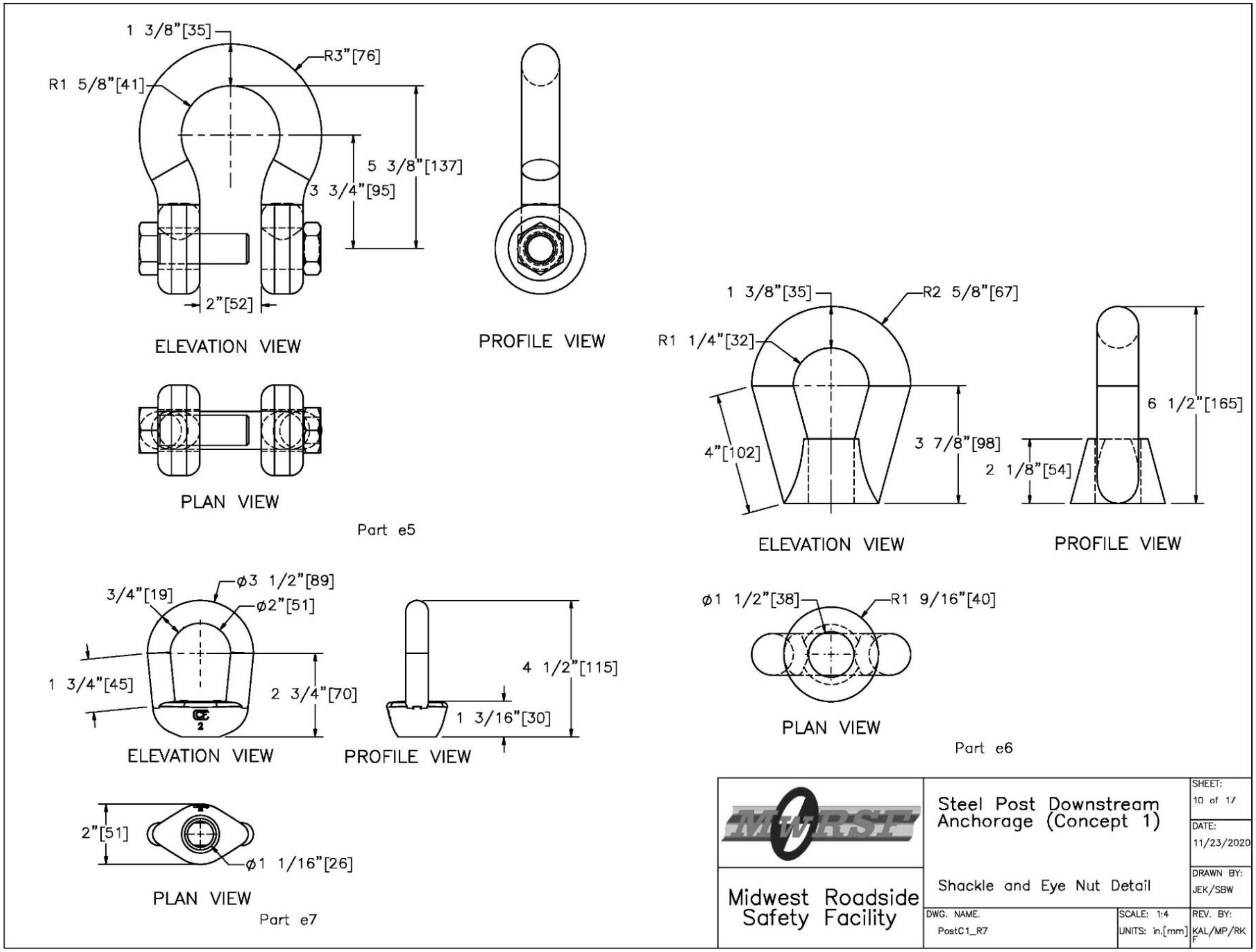


Figure 77. Shackle and Eye Nut, Test No. SPDA-1

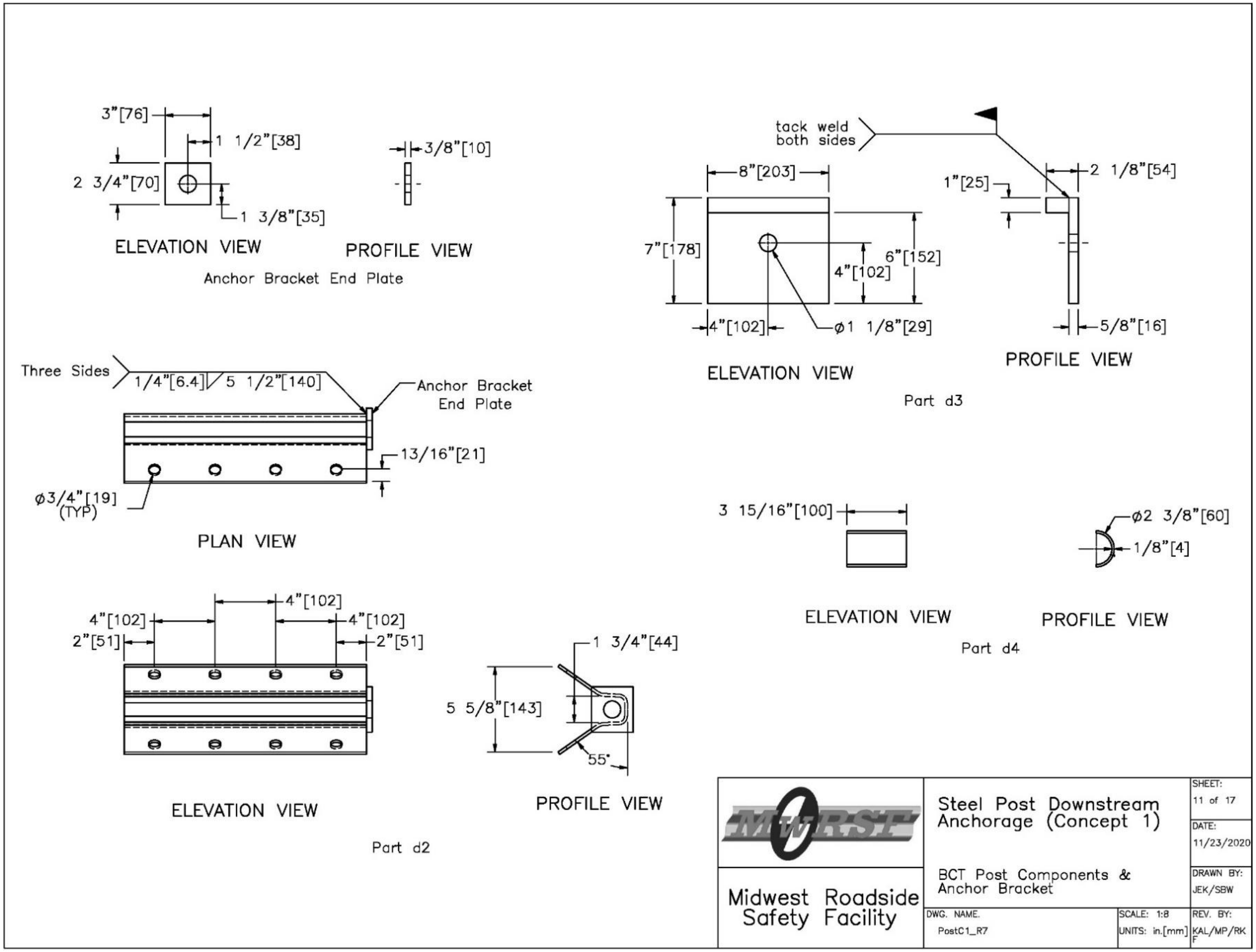


Figure 78. BCT Post Components and Anchor Bracket Details, Test No. SPDA-1

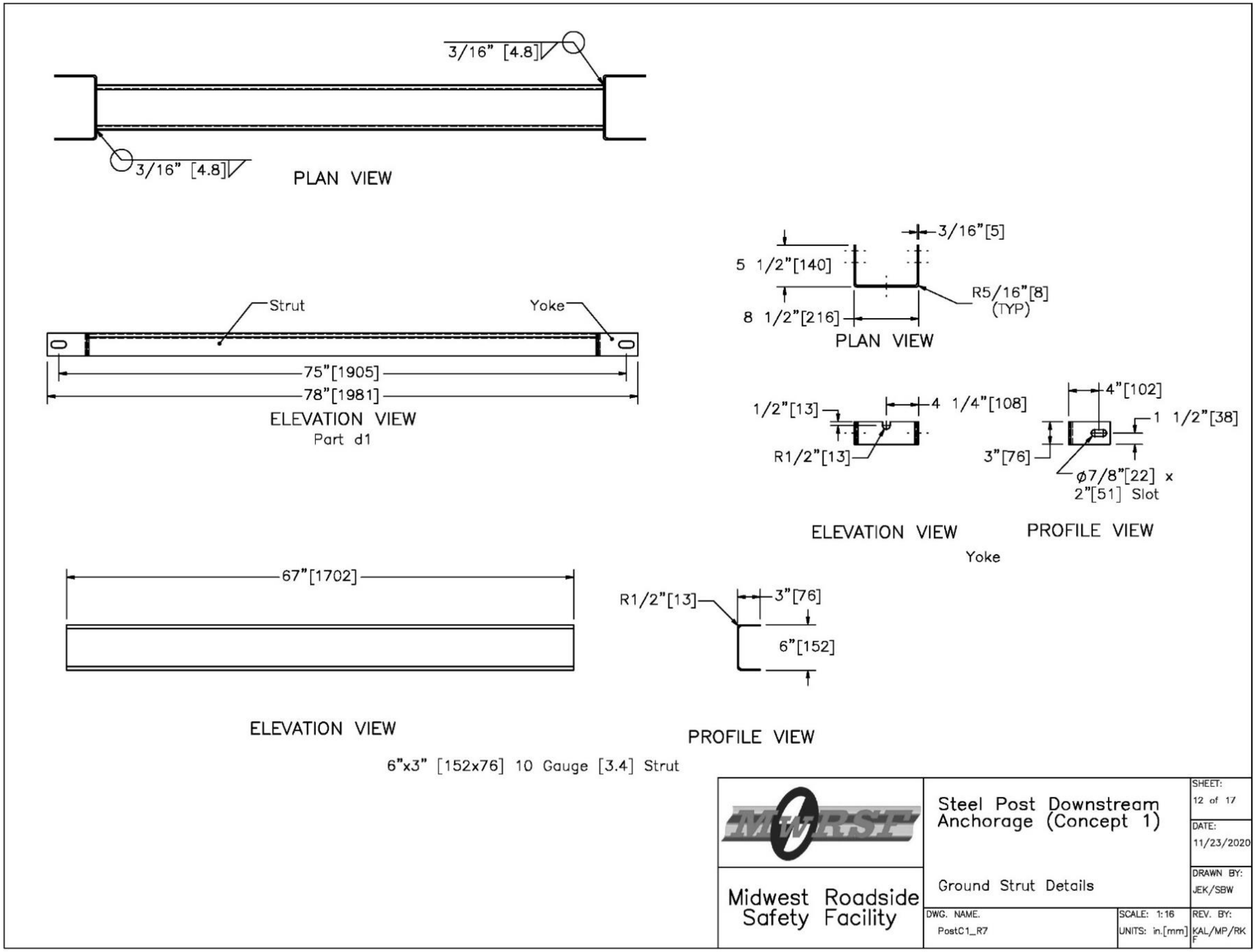


Figure 79. Ground Strut Details, Test No. SPDA-1

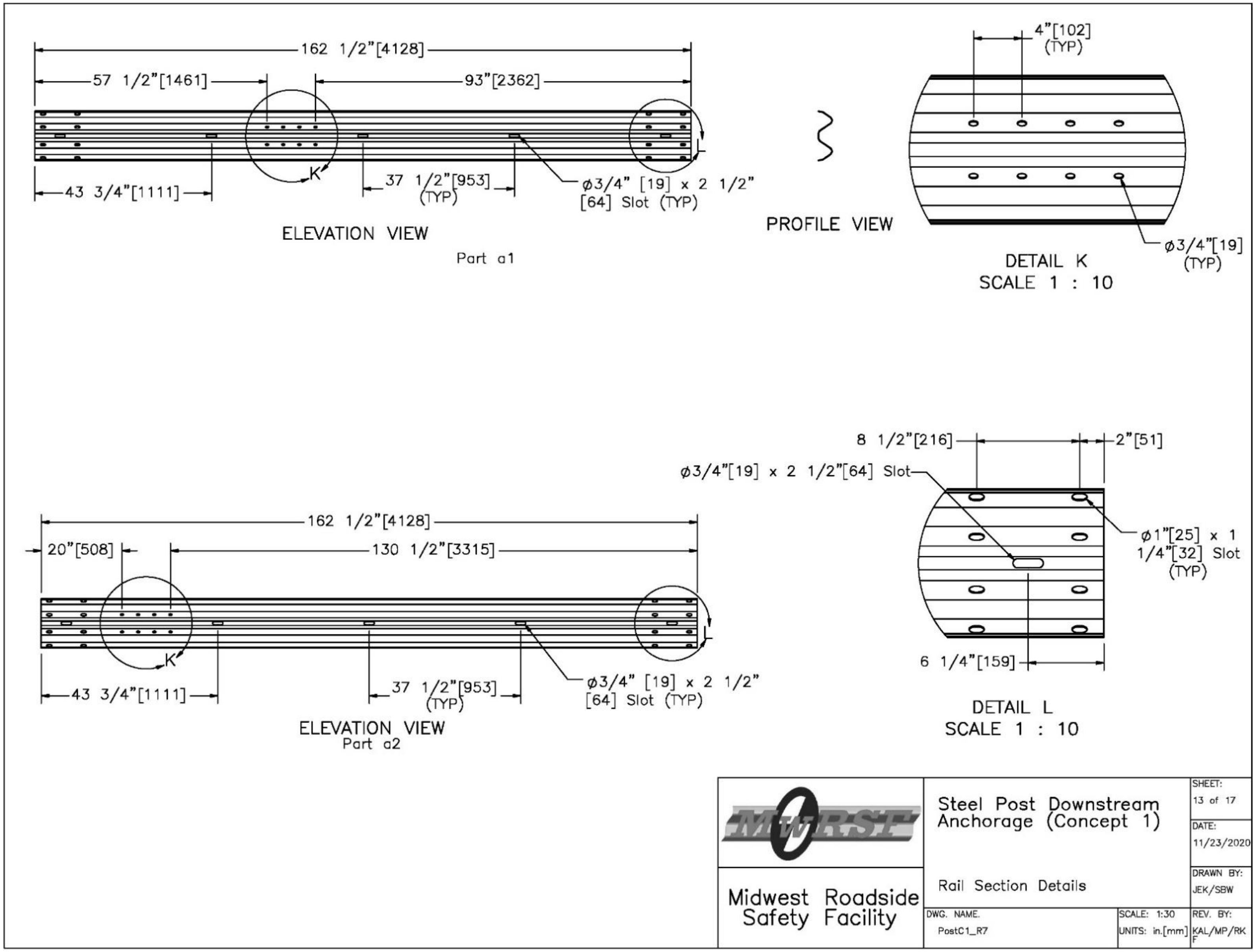


Figure 80. Rail Section Details, Test No. SPDA-1

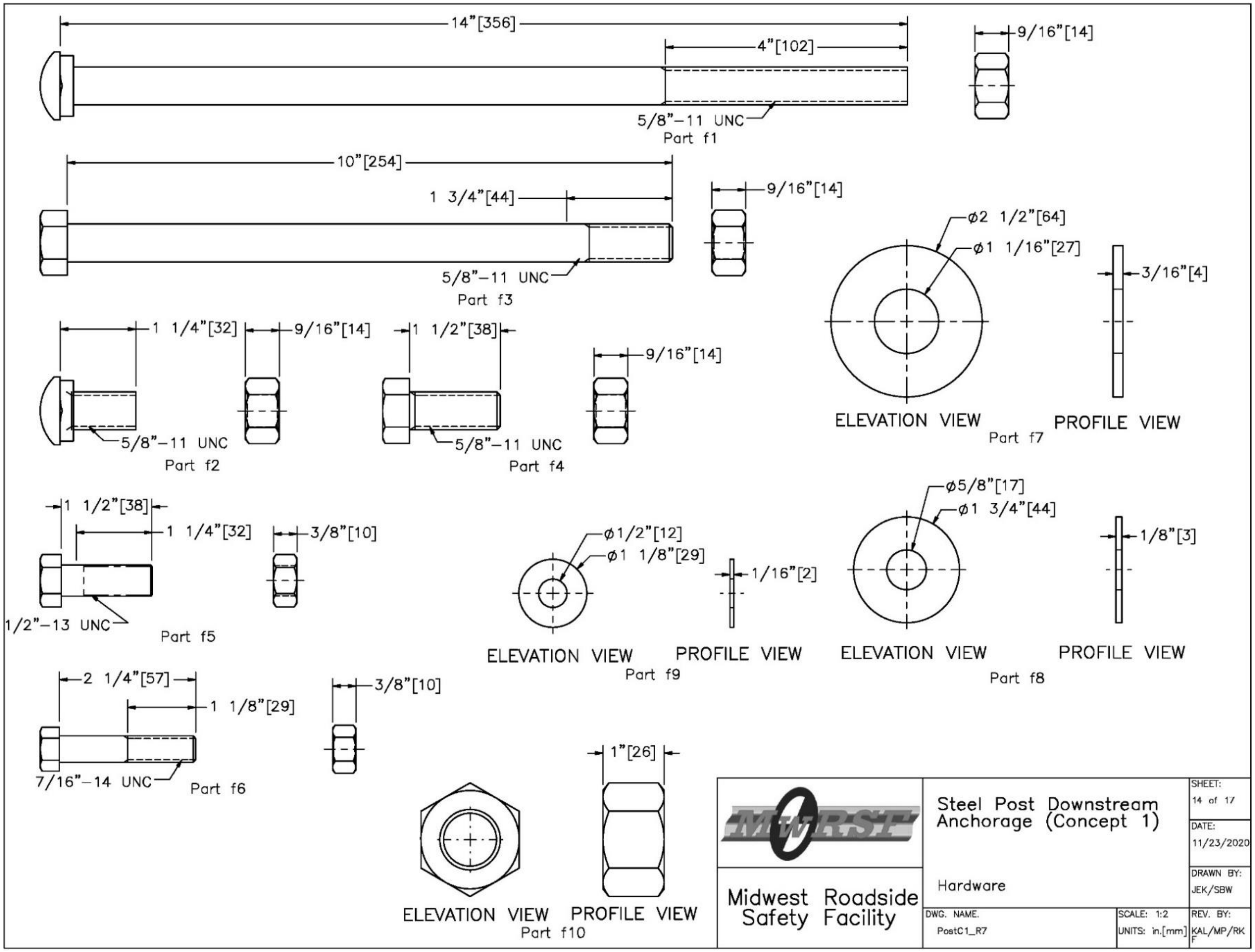


Figure 81. Bolt and Washer Details, Test No. SPDA-1

Item No.	QTY.	Description	Material Spec	Galvanization Spec	Hardware Guide
a1	1	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A123 or A653	–
a2	1	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	–
b1	2	TS6"x8"x3/16" [152x203x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	AASHTO M111 (ASTM A123)	–
b2	2	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 27 3/4" [705] Long Steel Post	ASTM A992	AASHTO M111 (ASTM A123)	–
b3	2	13"x7"x5/8" [330x178x16] Steel Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
b4	4	5 1/2"x5 1/2"x3/4" [140x140x19] Steel Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
b5	1	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa]	ASTM A123	PWE06
b6	1	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
d1	1	Ground Strut Assembly	ASTM A36	ASTM A123	PFP01
d2	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
d3	1	8"x7"x2 1/8" [203x178x54] Bearing Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
d4	1	2 3/8" [60] O.D. x 3 15/16" [100] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	AASHTO M111 (ASTM A123)	–
e1	4	3/4" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS	ASTM A741 Type II Class A	–
e2	4	BCT Anchor Cable End Swaged Fitting	Fitting – ASTM A576 Gr. 1035 Stud – ASTM F568 Class C	Fitting – ASTM A153 Stud – ASTM A153 or B695	–
e3	2	115–HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–	–
e4	2	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773	As Supplied	–
e5	6	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3 or Similar	Stock Nos. 1019597 and 1019604 – As Supplied	–	–
e6	4	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNC 6 [M36x4]	Stock No. 107 – As Supplied	–	–
e7	1	1" [25] Dia. Eye Nut	As Supplied	As Supplied	–
e8	2	TLL–50K–PTB Load Cell	–	–	–

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 1)

Bill of Materials

SHEET: 15 of 17

DATE: 11/23/2020

DRAWN BY: JEK/SBW

DWG. NAME. PostC1_R7

SCALE: None

UNITS: in.[mm]

REV. BY: KAL/MP/RKF

Figure 82. Bill of Materials, Test No. SPDA-1

Item No.	QTY.	Description	Material Spec	Galvanization Spec	Hardware Guide
f1	1	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB06
f2	10	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB01
f3	2	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
f4	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
f6	8	7/16" [11] Dia. UNC, 2 1/4" [57] Long Heavy Hex Bolt and Nut	Bolt – ASTM F3125 Gr. 120 (A325) or A354 Gr. BC Nut – ASTM A563DH or A194 Gr. 2H	Bolt – ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 or F2833 Gr. 1 Nut – ASTM A153 or B633 or B695 Class 55 or F1941 or F2329	–
f7	3	1" [25] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC24a
f8	36	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
f9	32	7/16" [11] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
f10	3	1" [25] Dia. Hex Nut	ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FNX24a
f11	1	16D Double Head Nail	–	–	–
g1	2	Portable Concrete Barrier	Min f'c=5,000 psi [34.5 MPa]	–	SWC09
g2	1	Concrete Block – MN Noise Wall	–	–	–

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 1)

Bill of Materials

SHEET:	DATE:	DRAWN BY:	DWG. NAME.	SCALE:	UNITS:	REV. BY:
16 of 17	11/23/2020	JEK/SBW	PostC1_R7	None	in.[mm]	KAL/MP/RKF

Figure 83. Bill of Materials, Test No. SPDA-1

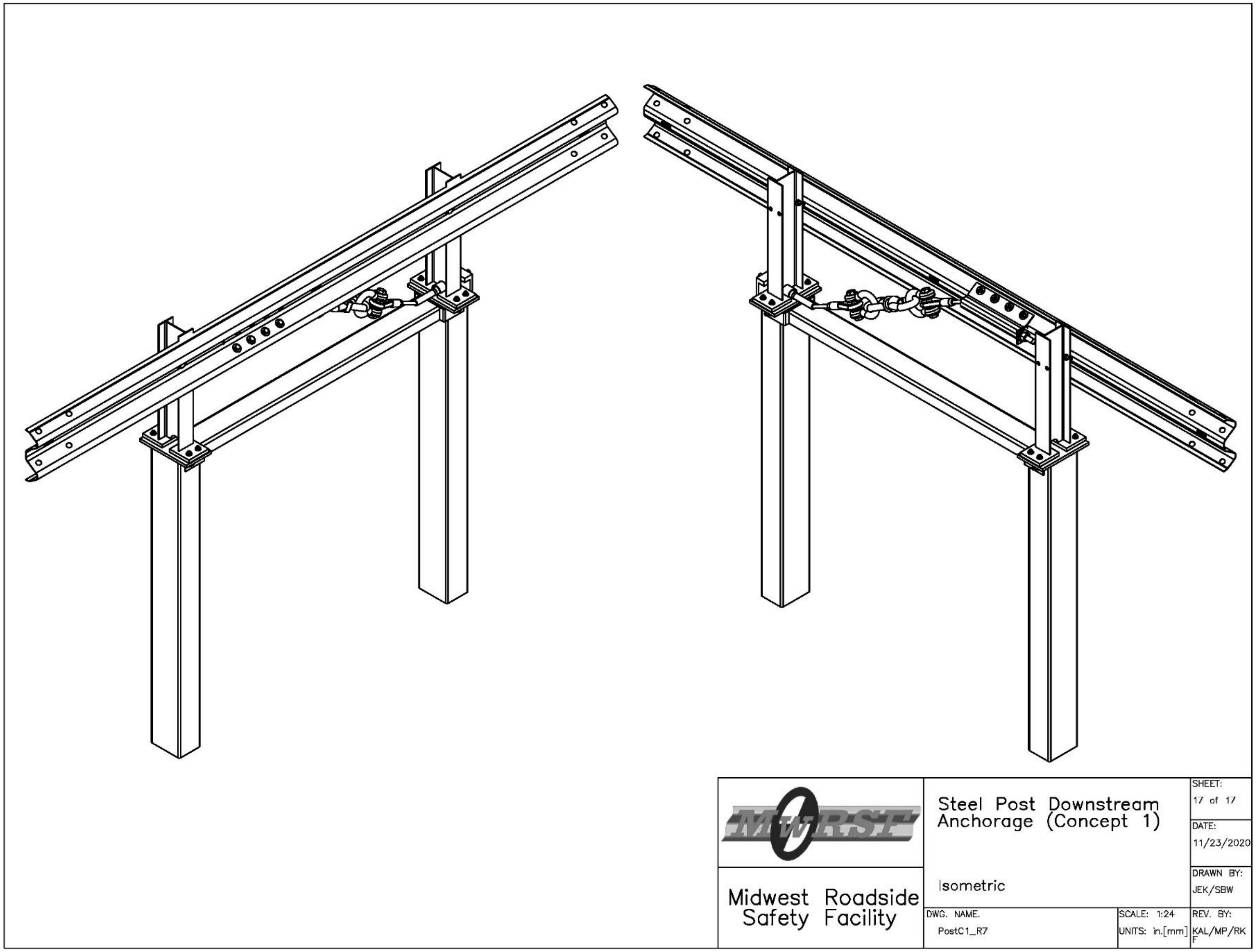


Figure 84. Isometric View, Test No. SPDA-1

Figure 85. Test Setup, Test No. SPDA-1

Figure 86. Test Setup, Test No. SPDA-1

5.2 Test No. SPDA-1 Results

During test no. SPDA-1, the top portion of both anchor posts began to deflect downstream when the tow cable started to pull the rail. The pull force was immediately transferred to the two foundation tubes, which rotated in the soil. When the cable anchor was tensioned, a downward vertical force component was applied to the rail at the second anchor post bolt connection. This force deformed the rail and caused vertical rail tearing at the second anchor post bolt connection. Following the rail tearing, the two downstream bolts in the slip base of the second post fractured in tension, and the top portion of the second post returned to its original position. The two downstream bolts in the slip base of the end anchor post fractured. The remaining bolts in both slip base plates remained undamaged. The tow cable yielded. Thus, the system was not loaded to its full capacity.

The force versus time and the displacement versus time curves for test no. SPDA-1 were processed from transducer data using the SLICE-1 and SLICE-2 units and are shown in Appendix H. The anchor cable loads, pull cable loads, and anchor cable displacements are shown in Figure 87. The peak force from the anchor cable load cell was 36.5 kips (162.4 kN), and the peak force from the pull cable was 43.0 kips (191.3 kN). Both peak loads occurred around 0.160 sec after the start of the dynamic jerk event. The maximum displacement of 2.3 in. (58 mm) occurred at 0.180 sec, measured by the string potentiometer attached to the end of the anchor cable. Time-sequential photographs are shown in Figures 88 and 89. Post-impact photographs are shown in Figures 90 and 91.

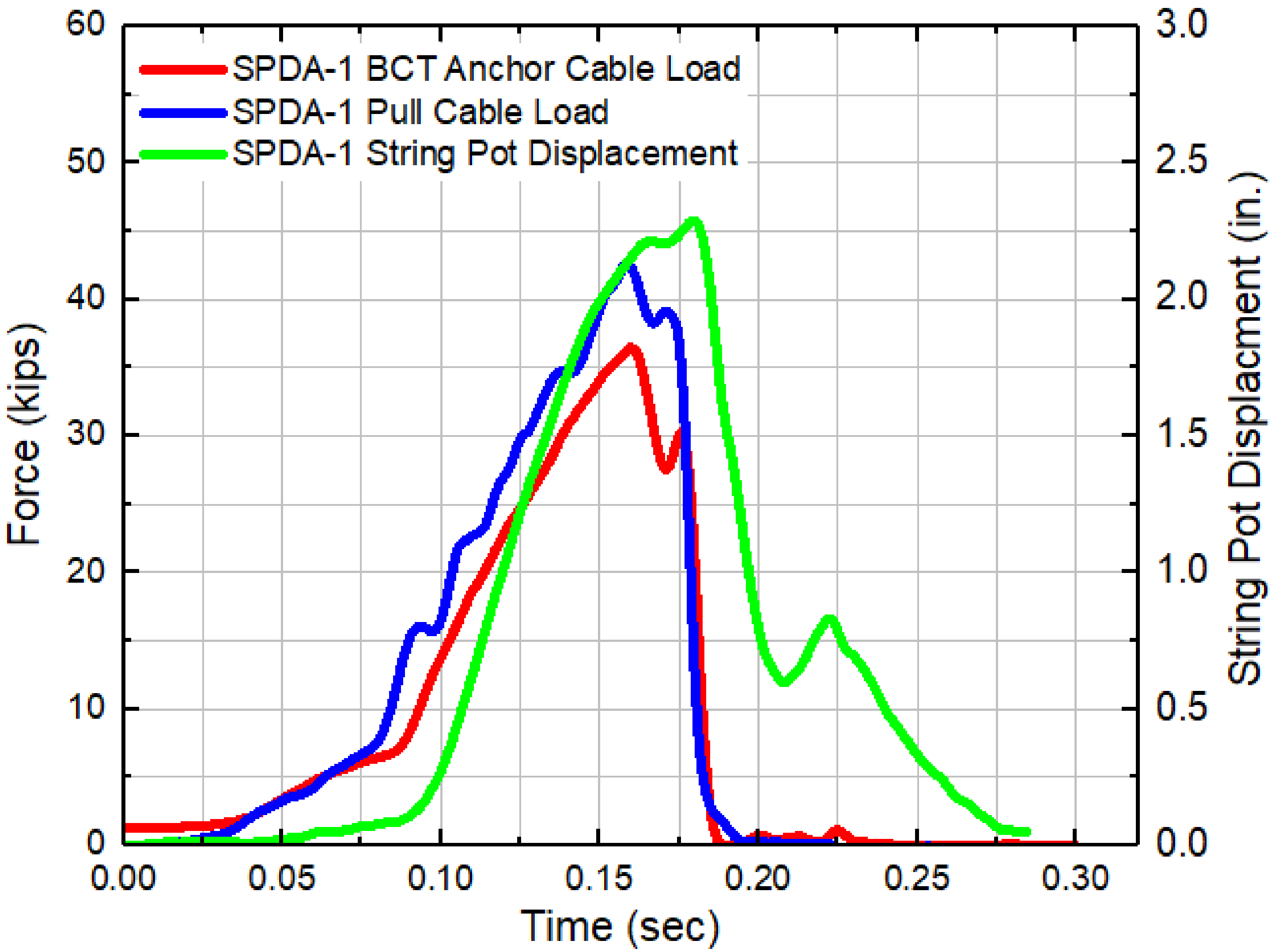
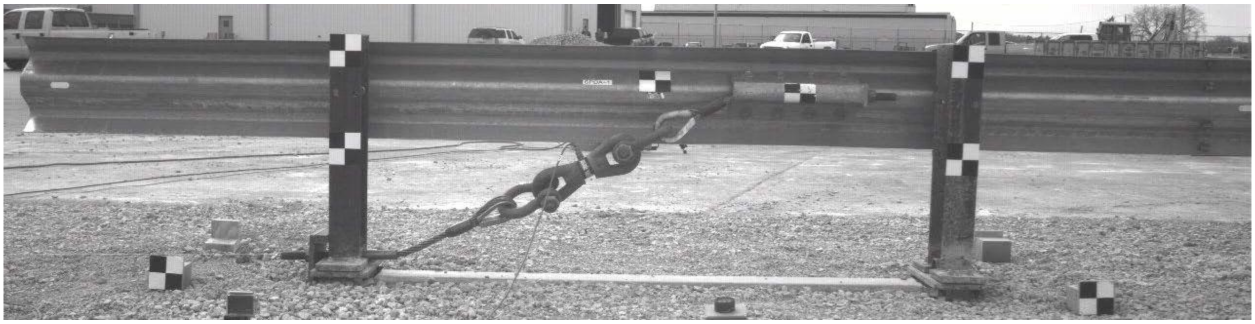
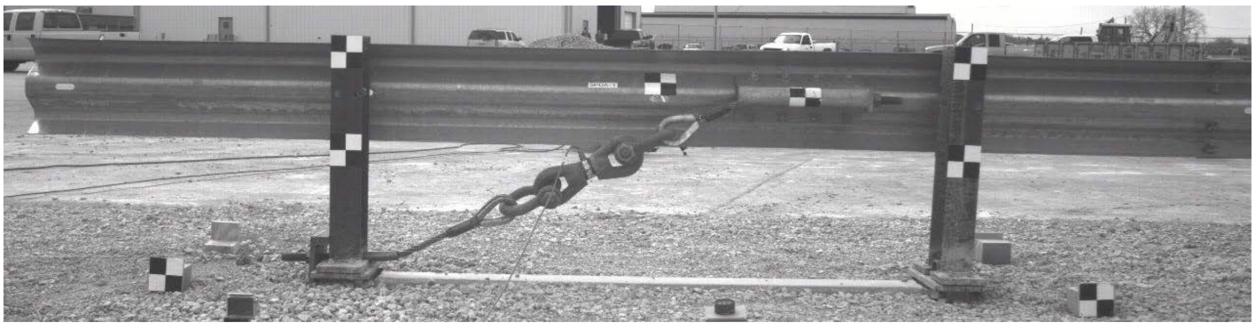


Figure 87. Force vs. Time and Displacement vs. Time, Test No. SPDA-1



0.000 sec



0.050 sec

0.100 sec

0.150 sec

Figure 88. Time-Sequential Photographs, Test No. SPDA-1

0.200 sec

0.250 sec

0.300 sec

0.350 sec

Figure 89. Time-Sequential Photographs, Test No. SPDA-1 (Continued)

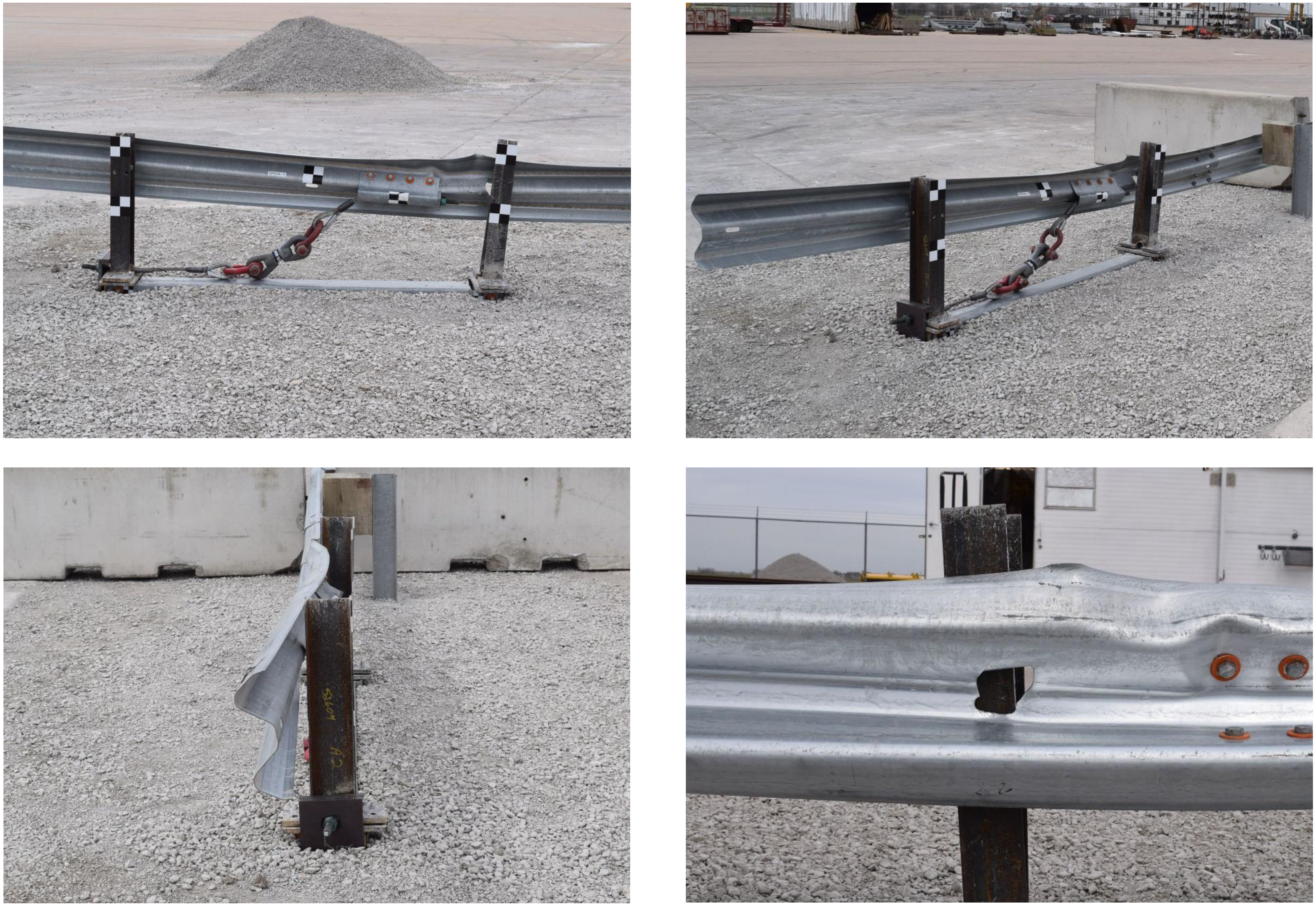


Figure 90. Post-Impact Photographs, Test No. SPDA-1

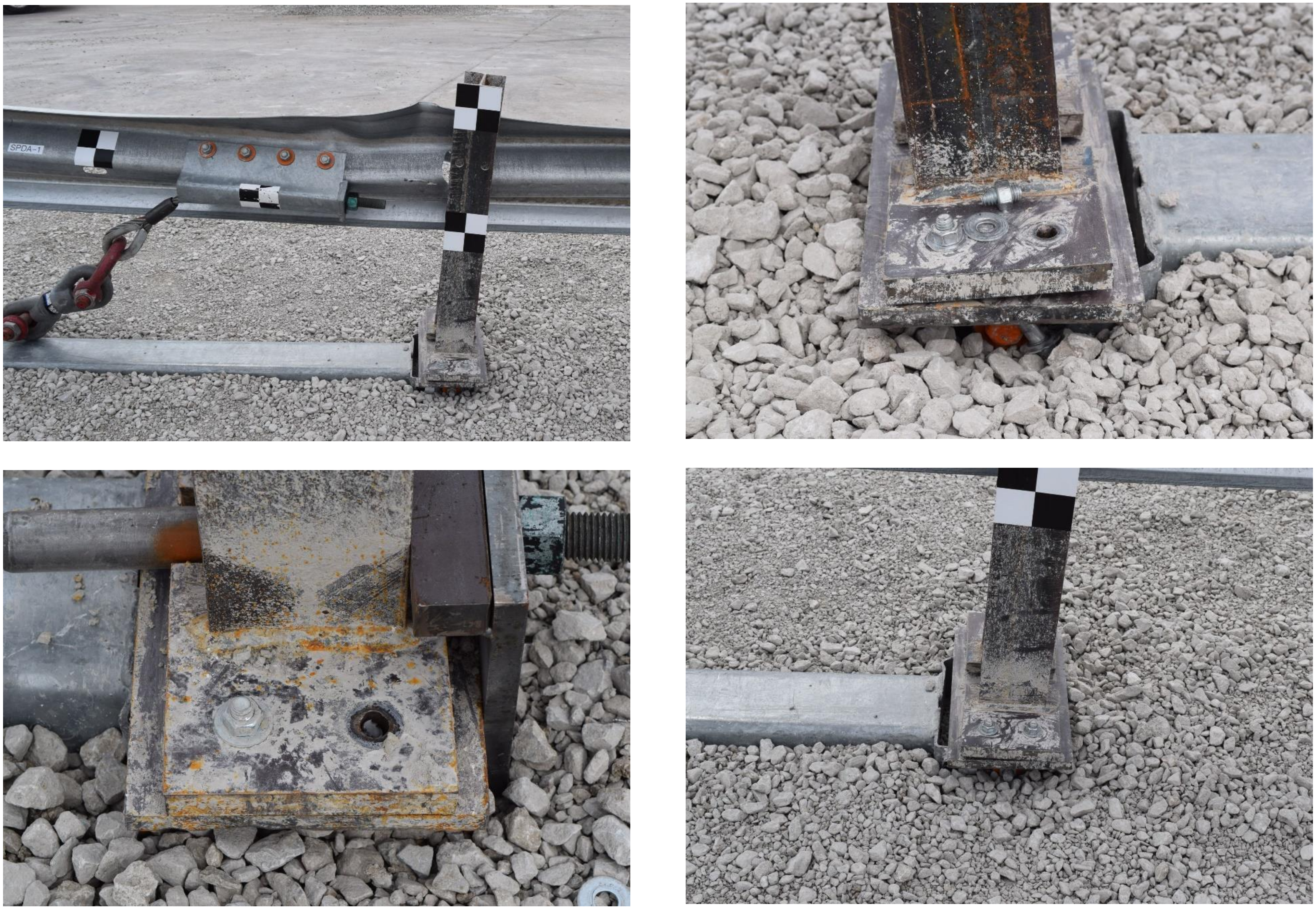


Figure 91. Post-Impact Photographs, Test No. SPDA-1

5.3 Discussion

In test no. SPDA-1, several observations were made. The increased tension in the anchor cable caused the top part of the second anchor post to disengage from the rail. This force tore the rail vertically at the second anchor post bolt connection. The two downstream bolts, which were used to connect the top and bottom parts of the second anchor post, fractured in tension after the post disengaged from the rail. Following this, the two downstream bolts fractured from the first anchor post. The anchor cable remained attached to the first anchor post, and neither posts broke away. The pull cable yielded after the pull load exceeded the strength of the cable. The anchorage system deflected ⅜ in. (10 mm) downstream following the vertical tearing of the rail.

The two downstream bolts in each anchor post fractured in tension. Due to the tensile yielding of the pull cable, the bolts were not loaded to their full capacity. The upper and lower plates in each post did not experience noticeable deformation.

The force versus time data from the BCT cable load cell and the pull cable load cell was different since the pull load was directly applied to the pull cable and then transferred to the anchor cable. The maximum peak tensile load of 36.5 kips (162.4 kN) was measured by the BCT cable load cell. The first peak load occurred when the downstream bolts in the slip base of the second post fractured in tension at approximately 0.160 sec. The second peak load occurred while the downstream bolts in the slip base of the first anchor post fractured in tension at approximately 0.180 sec.

The maximum load sustained by the end anchorage was 36.5 kips (162.4 kN). The anchor cable load versus anchor cable displacement is shown in Figure 92. The maximum load of 36.5 kips (162.4 kN) occurred at nearly the same time as the first peak deflection of 2.2 in. (56 mm). During the test, the anchor cable was not released due to the tensile yield of the pull cable before the full capacity of the system was reached. Results from test no. SPDA-1 are summarized in Table 6.

Table 6. Summary of Test Results, Test No. SPDA-1

Test No.	Impact Velocity mph (km/h)	Peak Force kips (kN)	Displacement at Peak Load in. (mm)	Energy at Peak Load kips-in. (kJ)	Failure Mechanism	Component Damage	Attachment Damage
SPDA-1	18.3 (29.5)	36.5 (162.4)	2.2 (55)	45.3 (5.1)	Pull cable yielded	Rail deformed at second anchor post bolt connection	Downstream bolts in both anchor posts fractured in tension

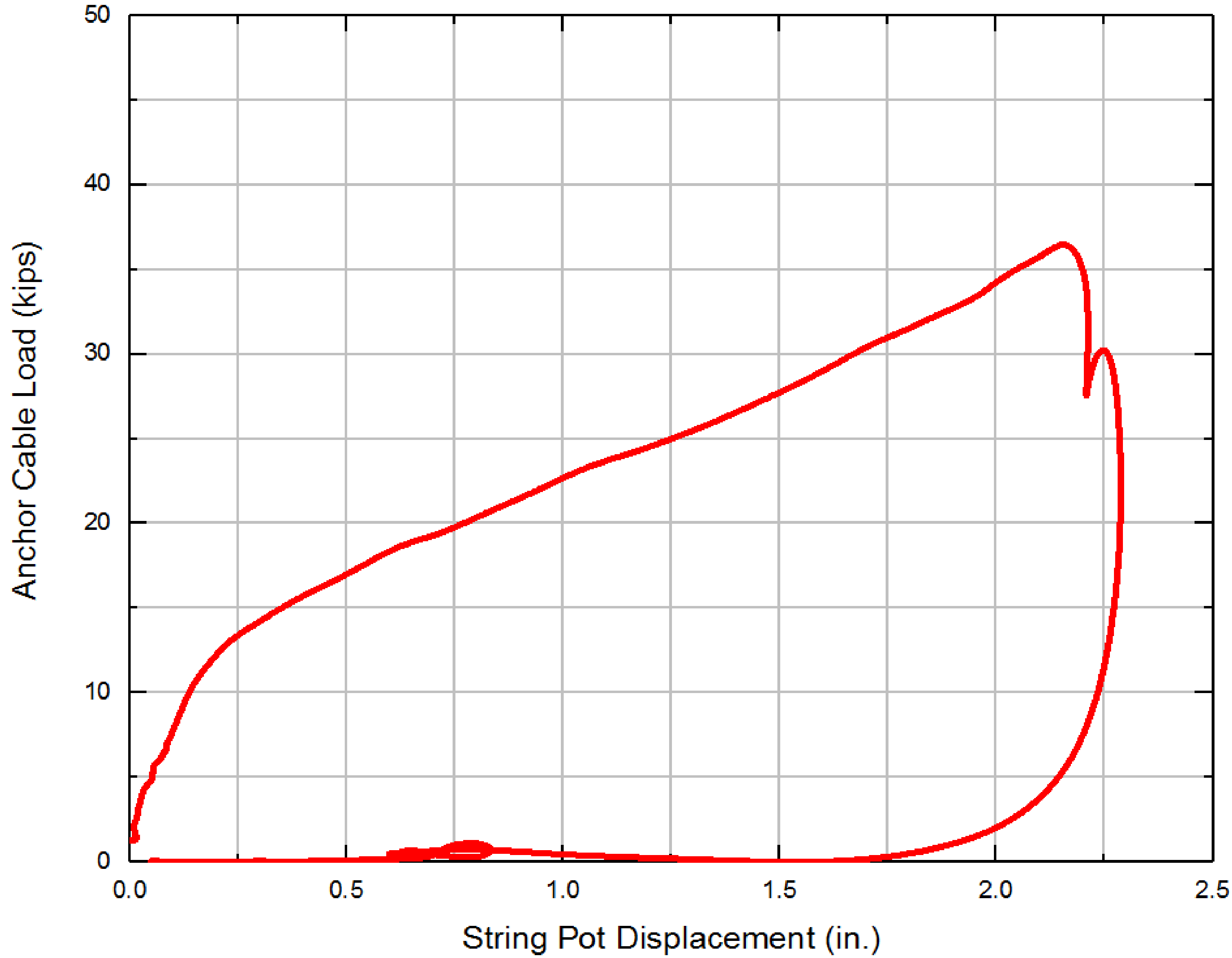


Figure 92. Anchor Cable Load vs. String Pot Displacement, Test No. SPDA-1

6 DYNAMIC COMPONENT TEST – DESIGN CONCEPT NO. 2

6.1 System Details – Concept No. 2

Test no. SPDA-2 was a dynamic jerk test of design concept no. 2 which was the anchorage system with the cable passing through the bottom post. This system design included two modified UBSPs with a slot in the end foundation tube that formed the lower portion of the end anchor post and an opening in the bottom base plate to allow cable release. The test matrix and test setup are shown in Figures 93 through 109. Photographs of the test setup are presented in Figures 110 and 111. Material specifications, mill certifications, and certificates of conformity for the system materials used in test no. SPDA-2 are shown in Appendix G.

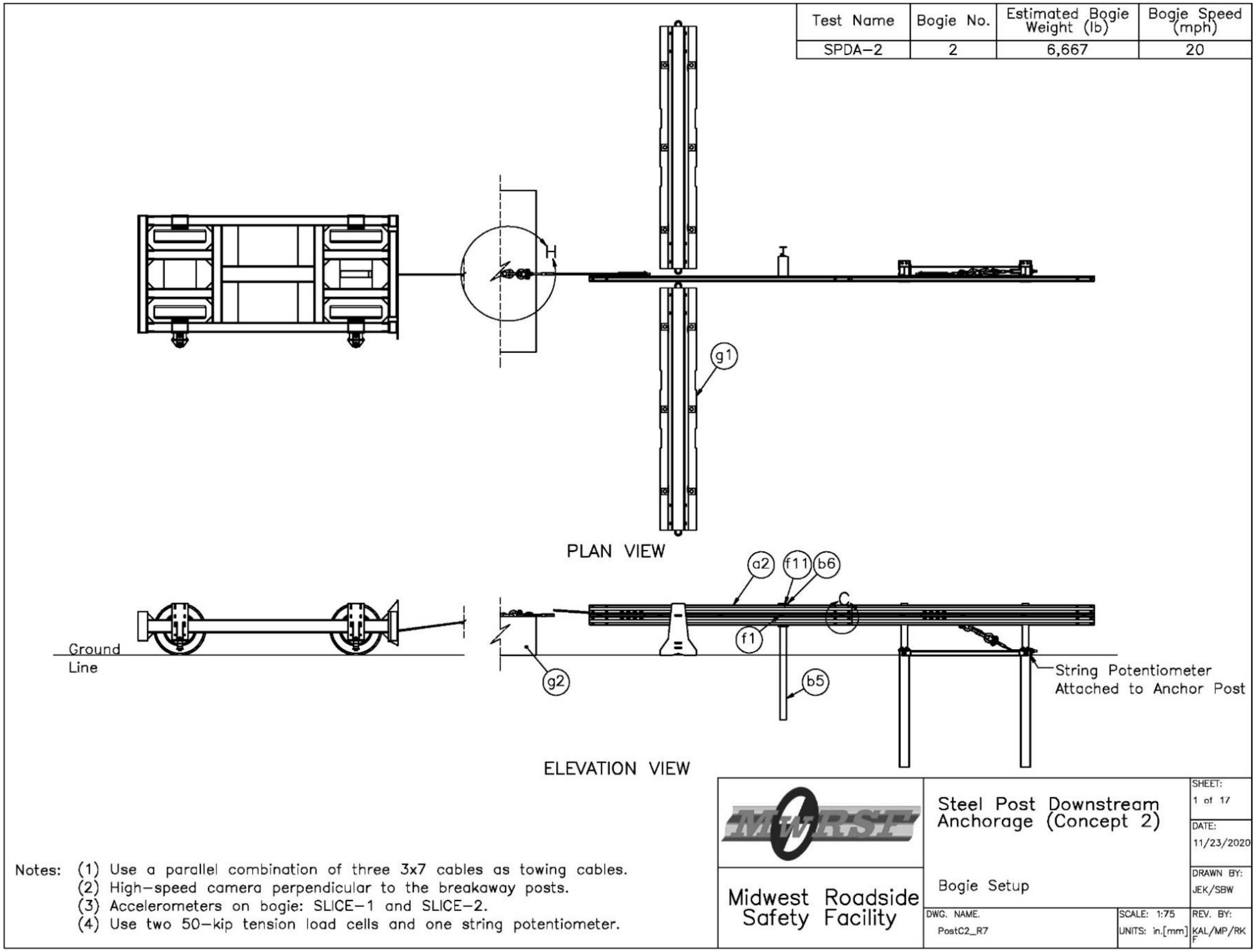


Figure 93. Bogie Testing Matrix and Setup, Test No. SPDA-2

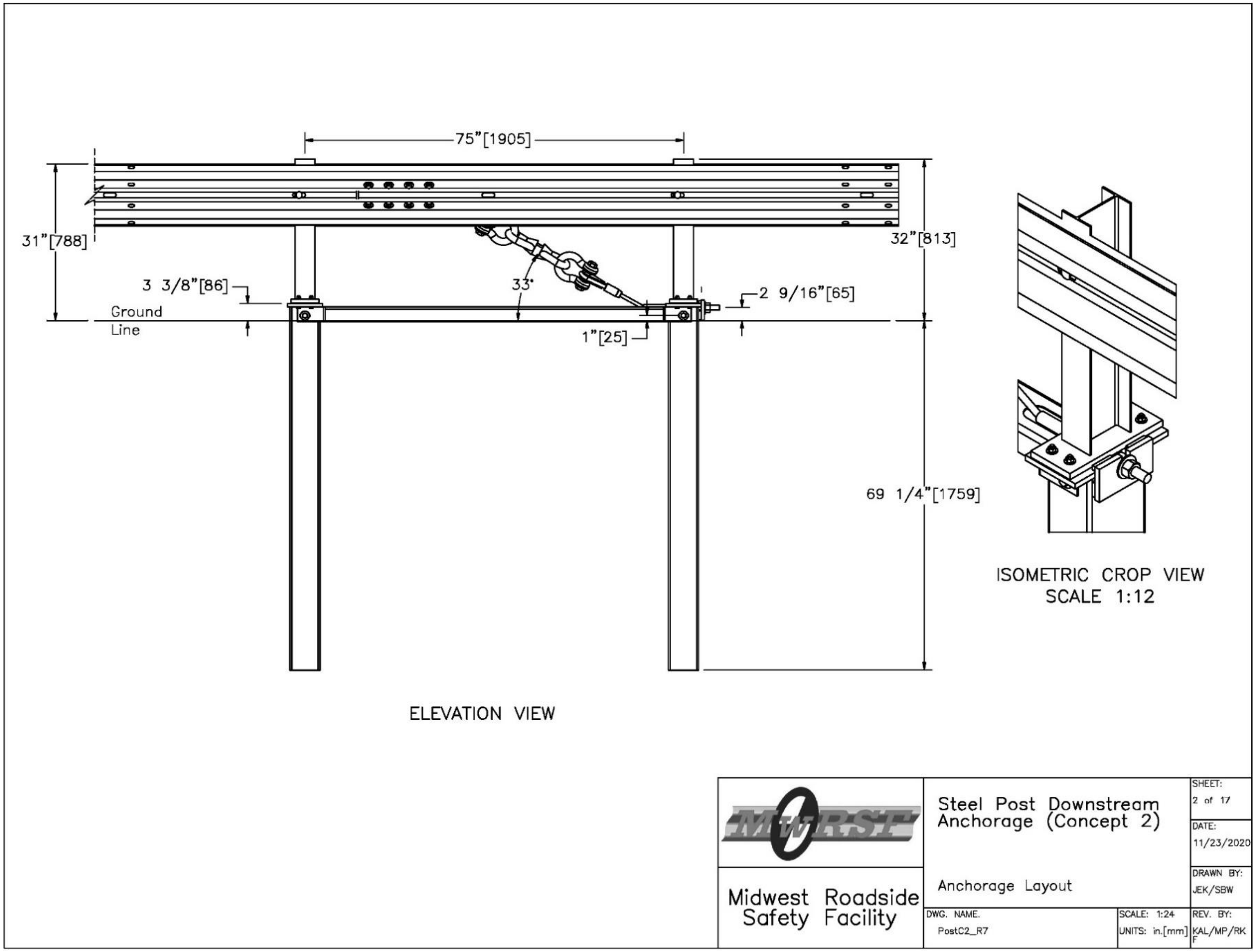


Figure 94. Anchorage Layout, Test No. SPDA-2

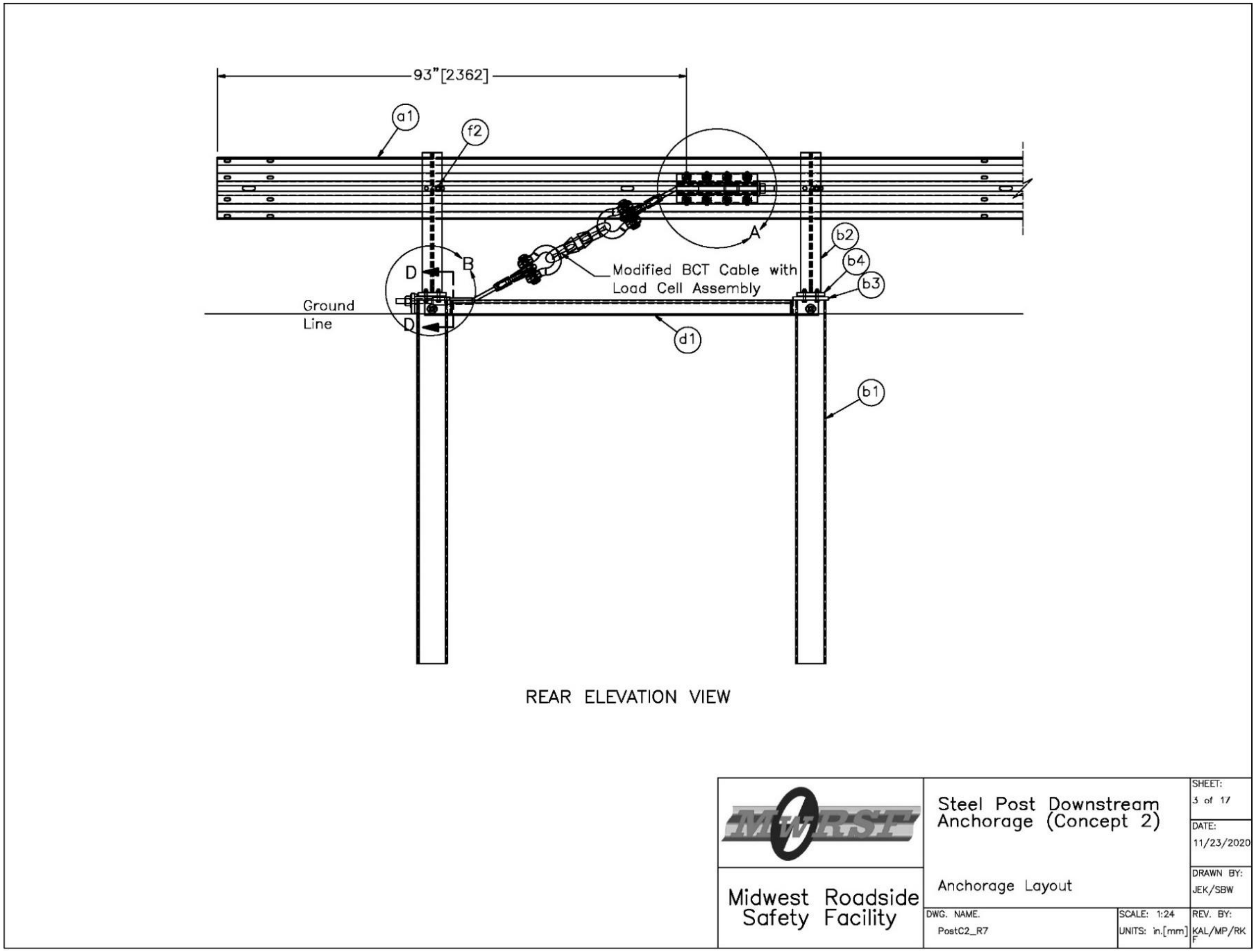


Figure 95. Anchorage Layout, Test No. SPDA-2

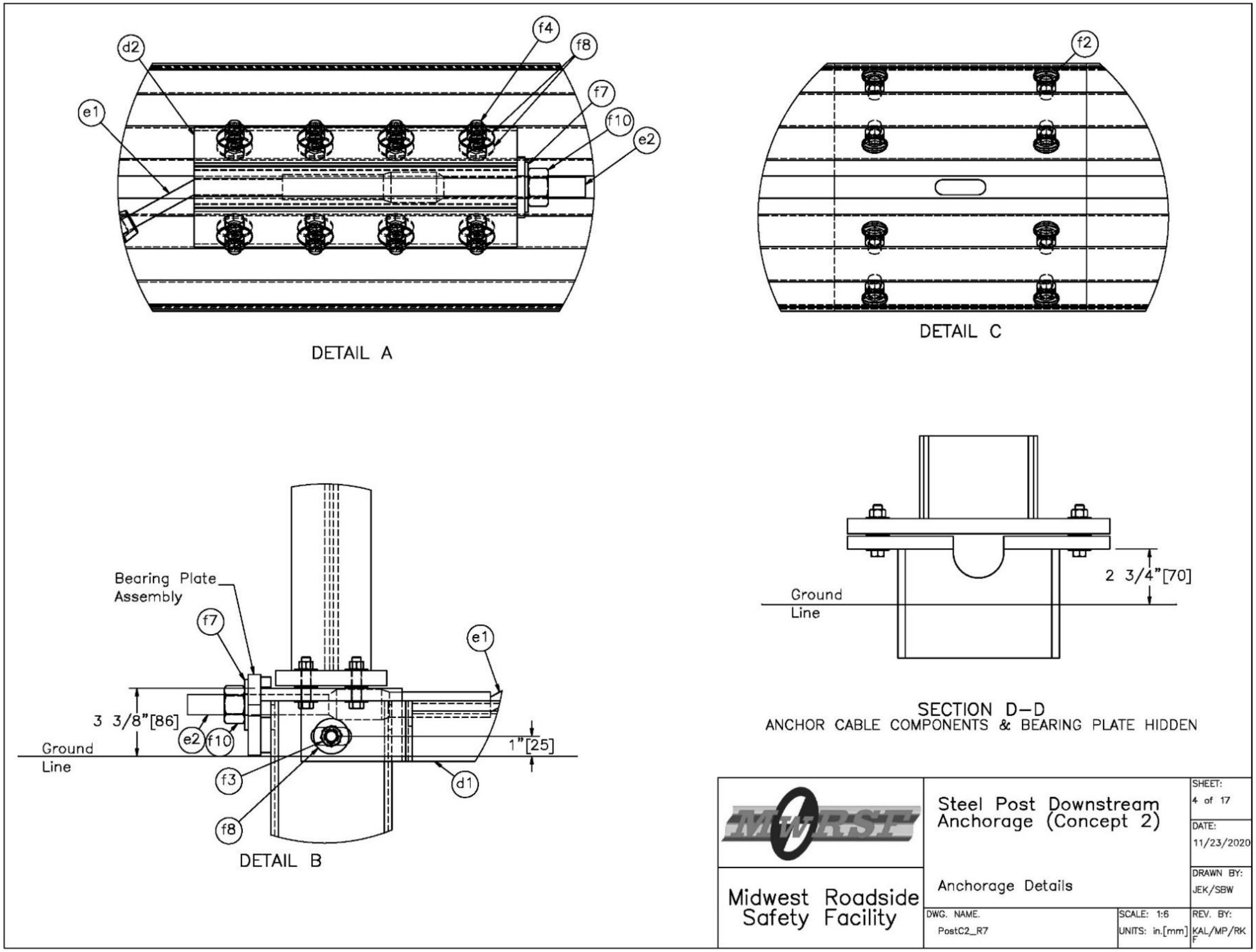


Figure 96. Anchorage Details, Test No. SPDA-2

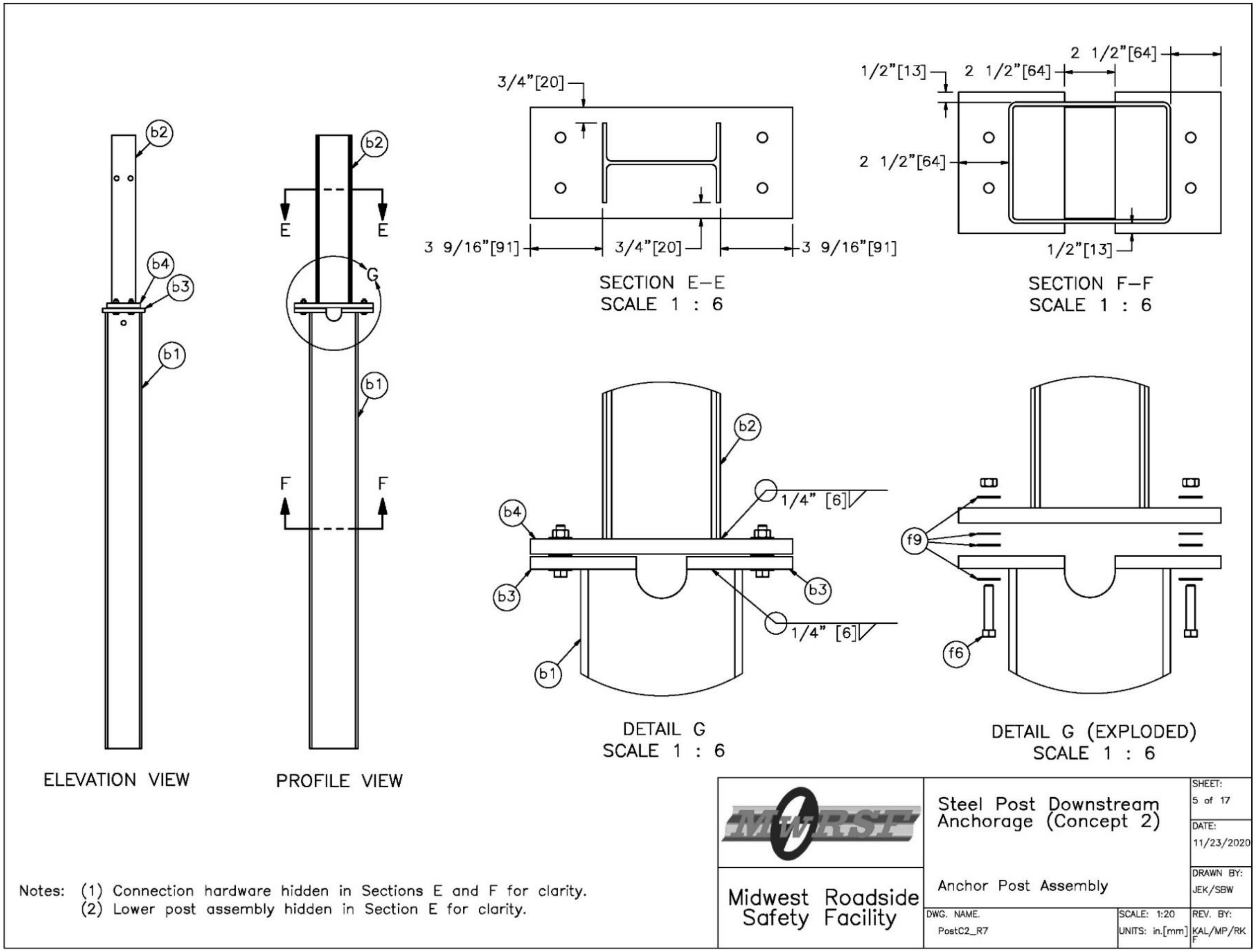


Figure 97. Anchor Post Assembly, Test No. SPDA-2

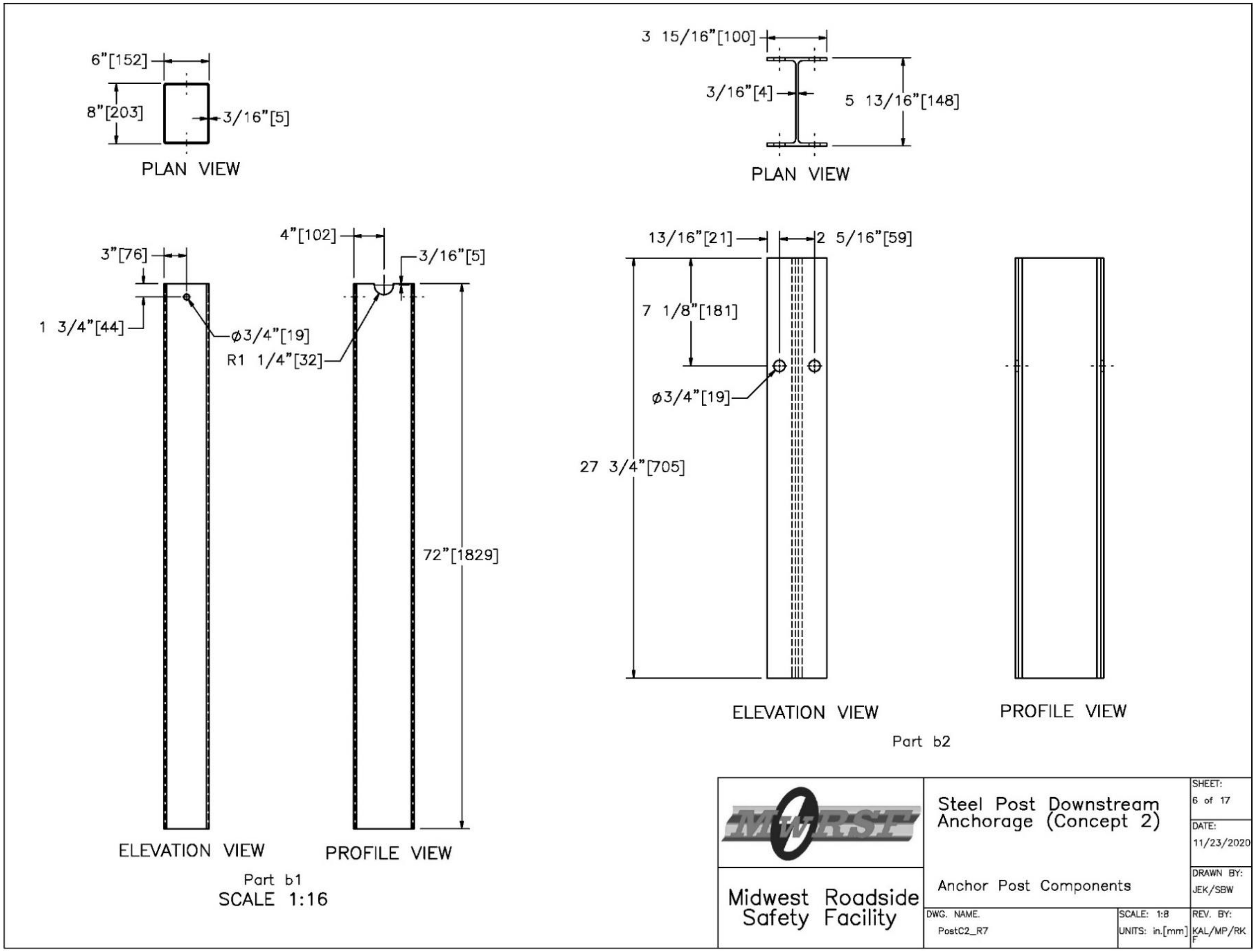


Figure 98. Anchor Post Components, Test No. SPDA-2

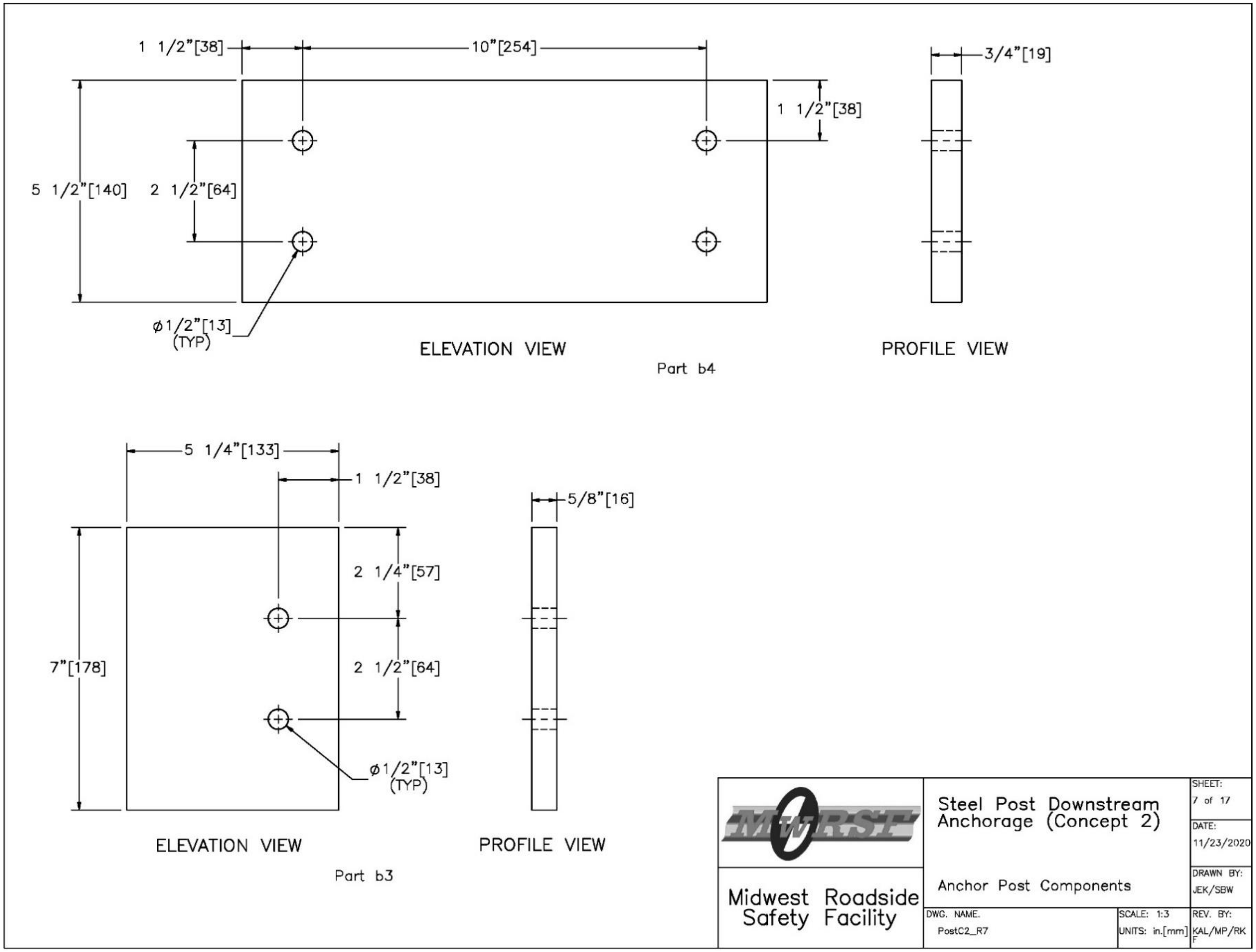


Figure 99. Anchor Post Components, Test No. SPDA-2

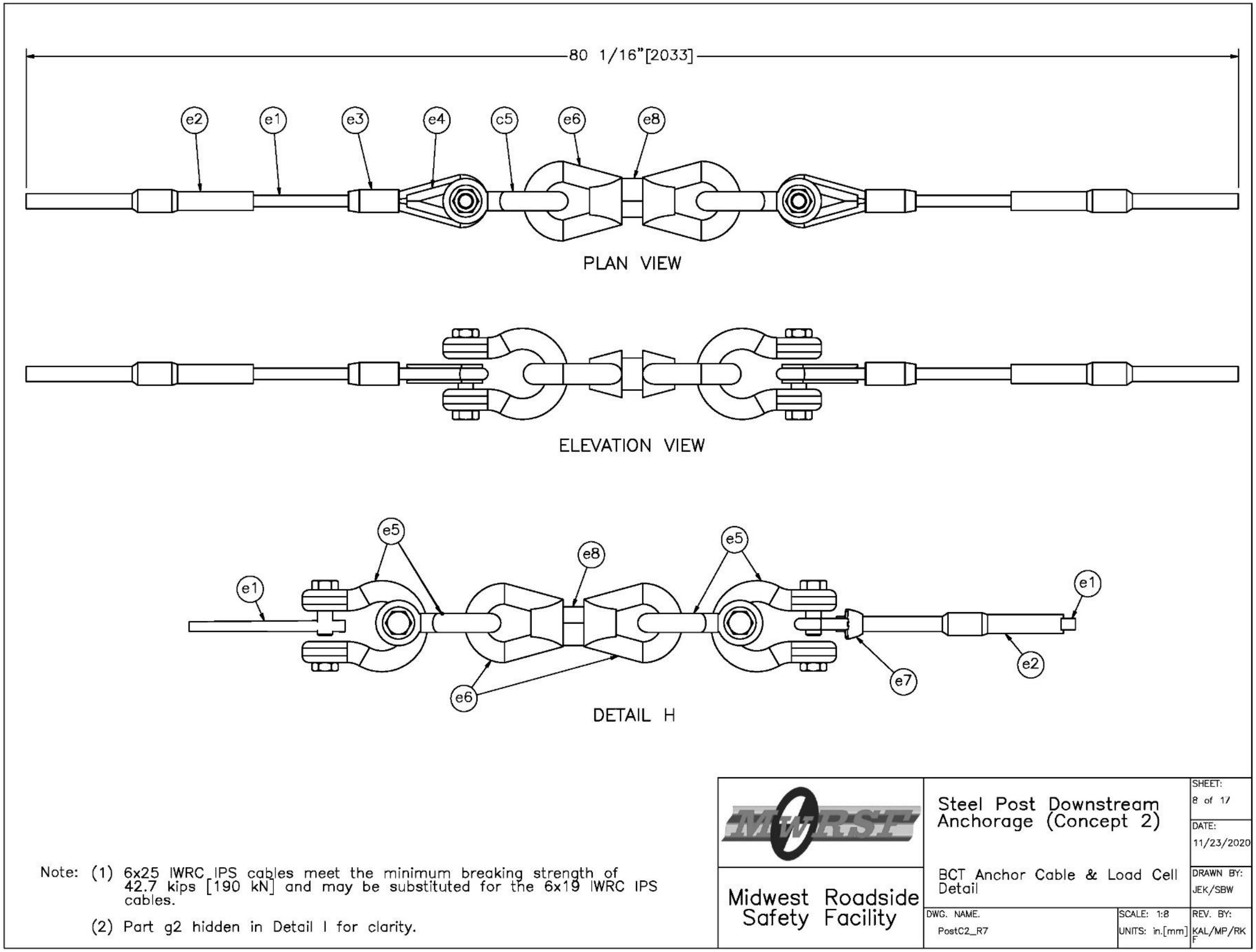


Figure 100. BCT Anchor Cable and Load Cell Detail, Test No. SPDA-2

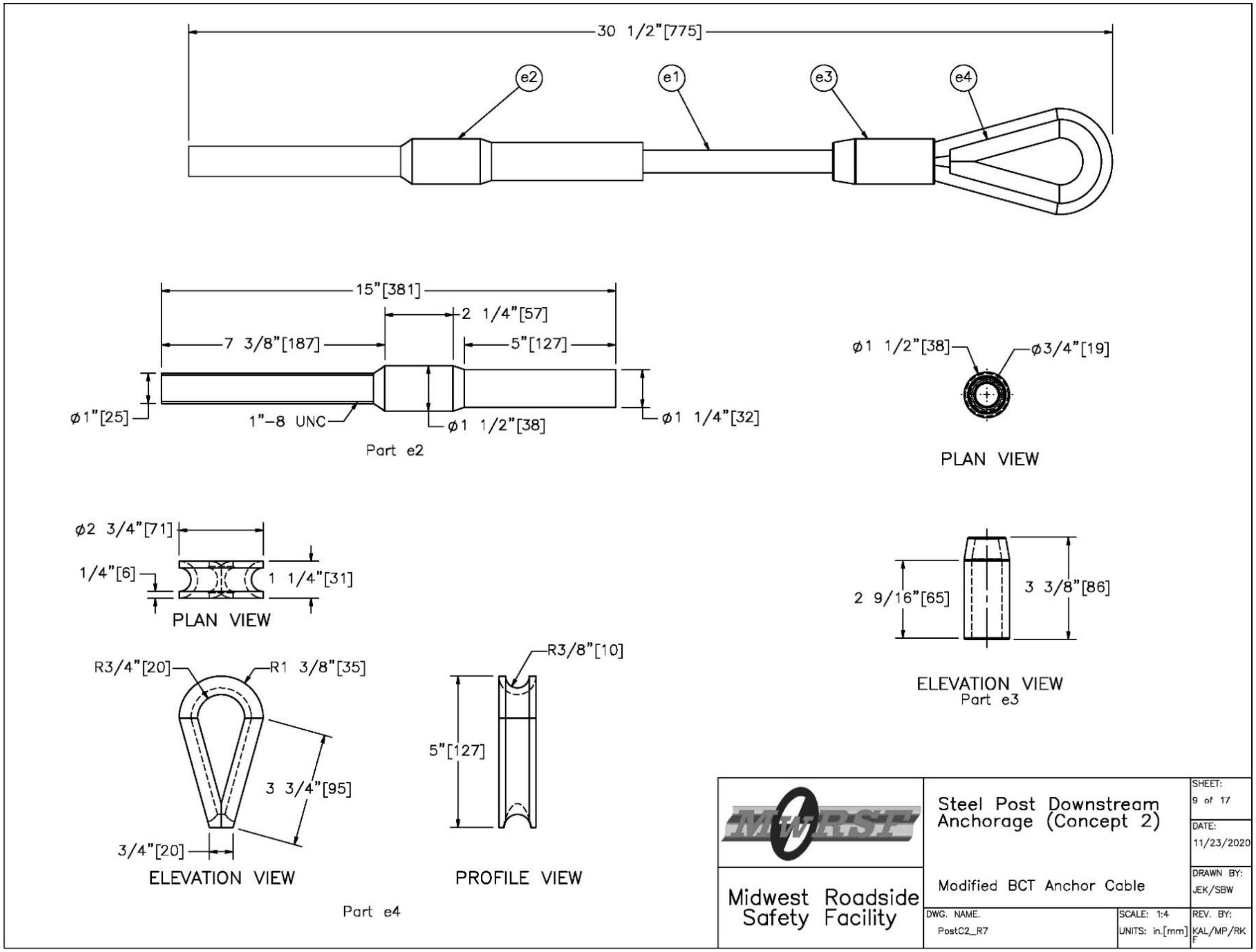


Figure 101. Modified BCT Cable, Test No. SPDA-2

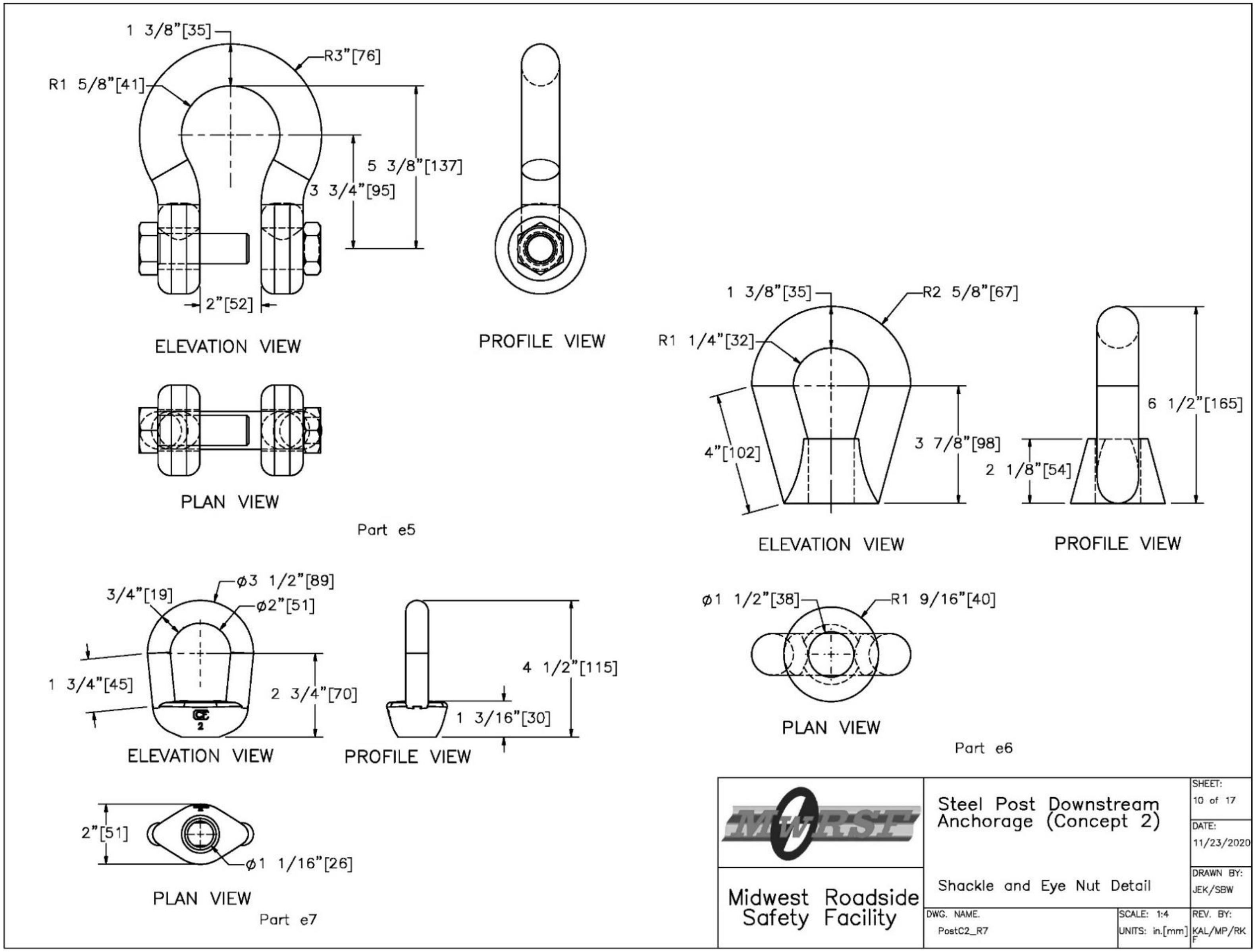


Figure 102. Shackle and Eye Nut, Test No. SPDA-2

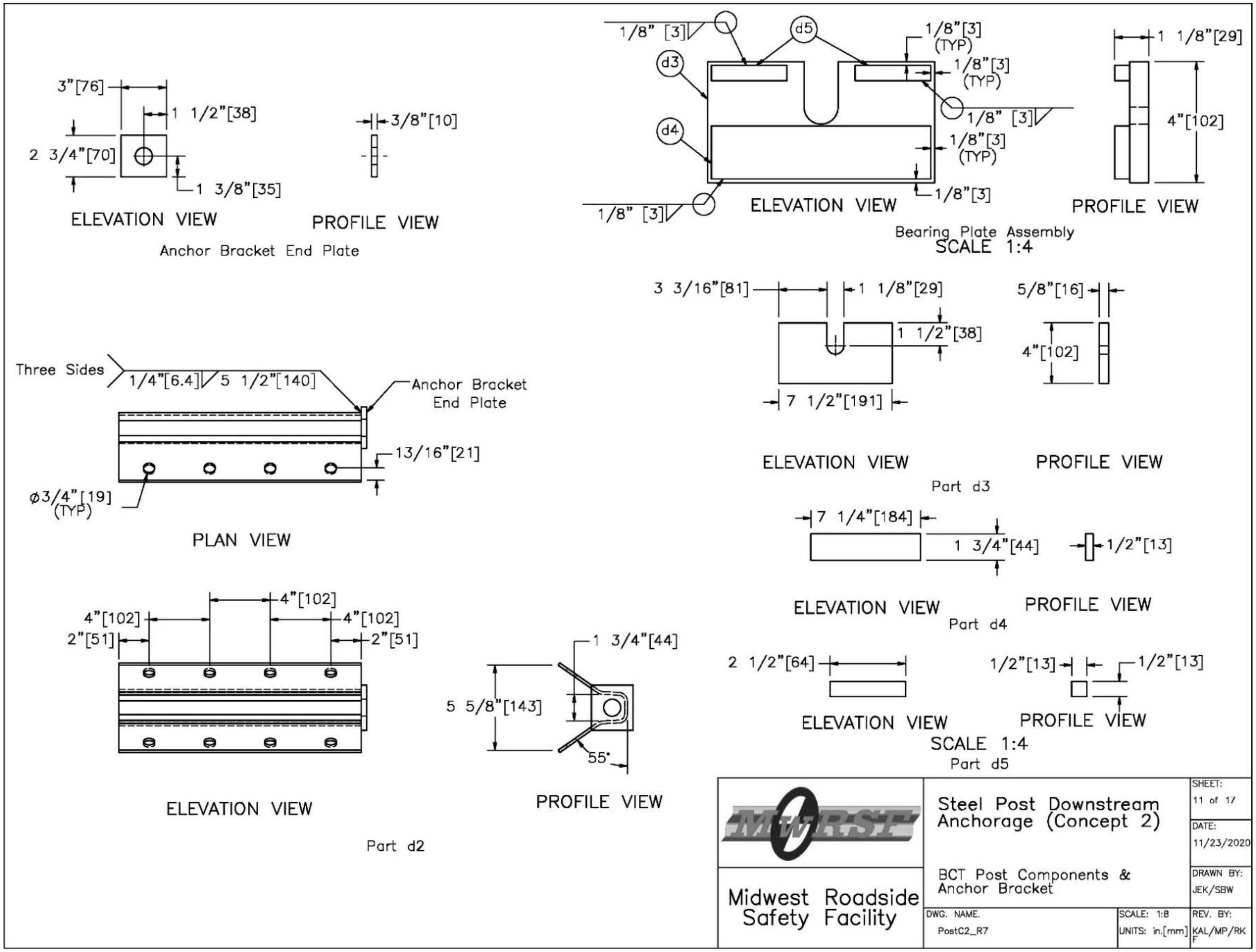


Figure 103. BCT Post Components and Anchor Bracket Details, Test No. SPDA-2

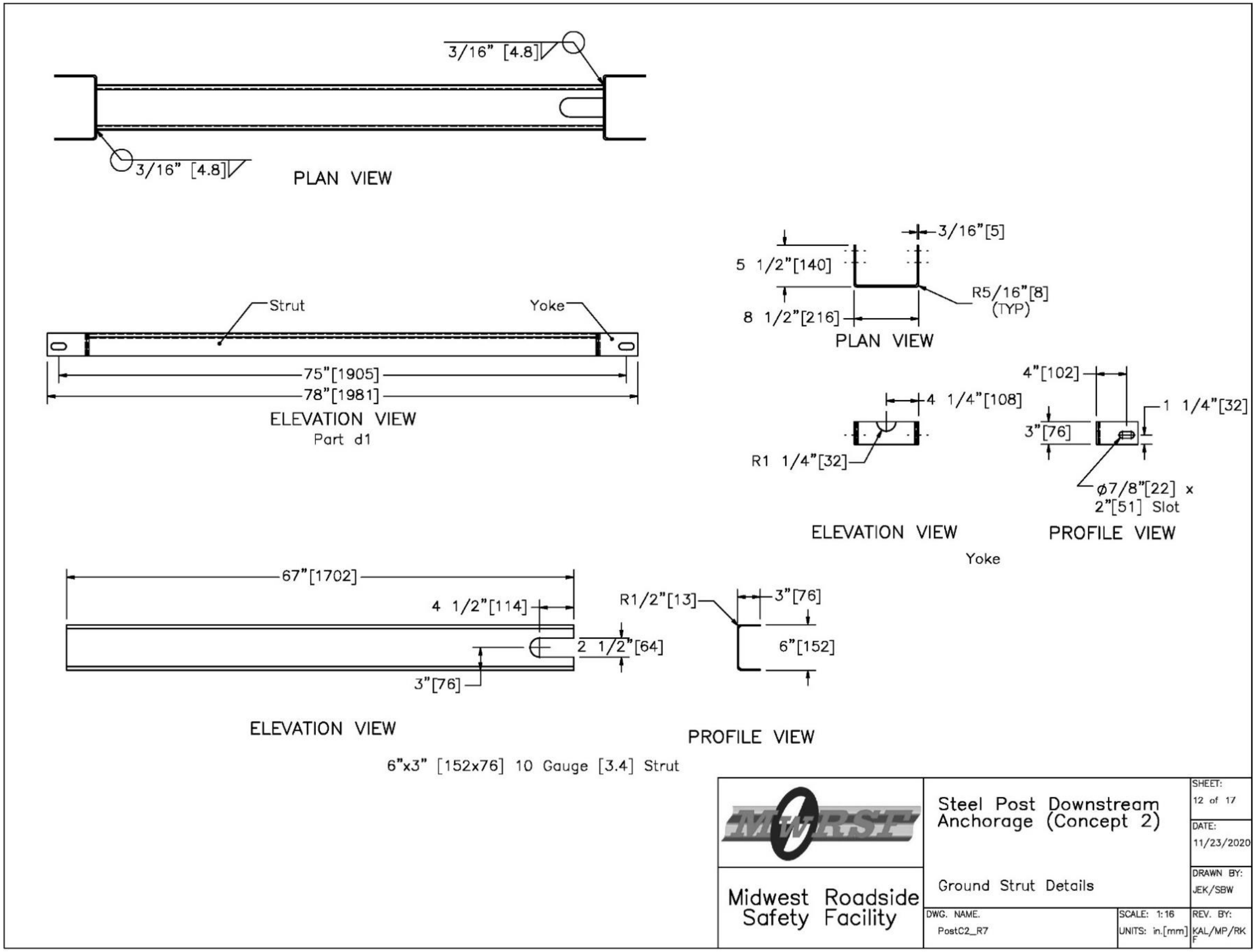


Figure 104. Ground Strut Details, Test No. SPDA-2

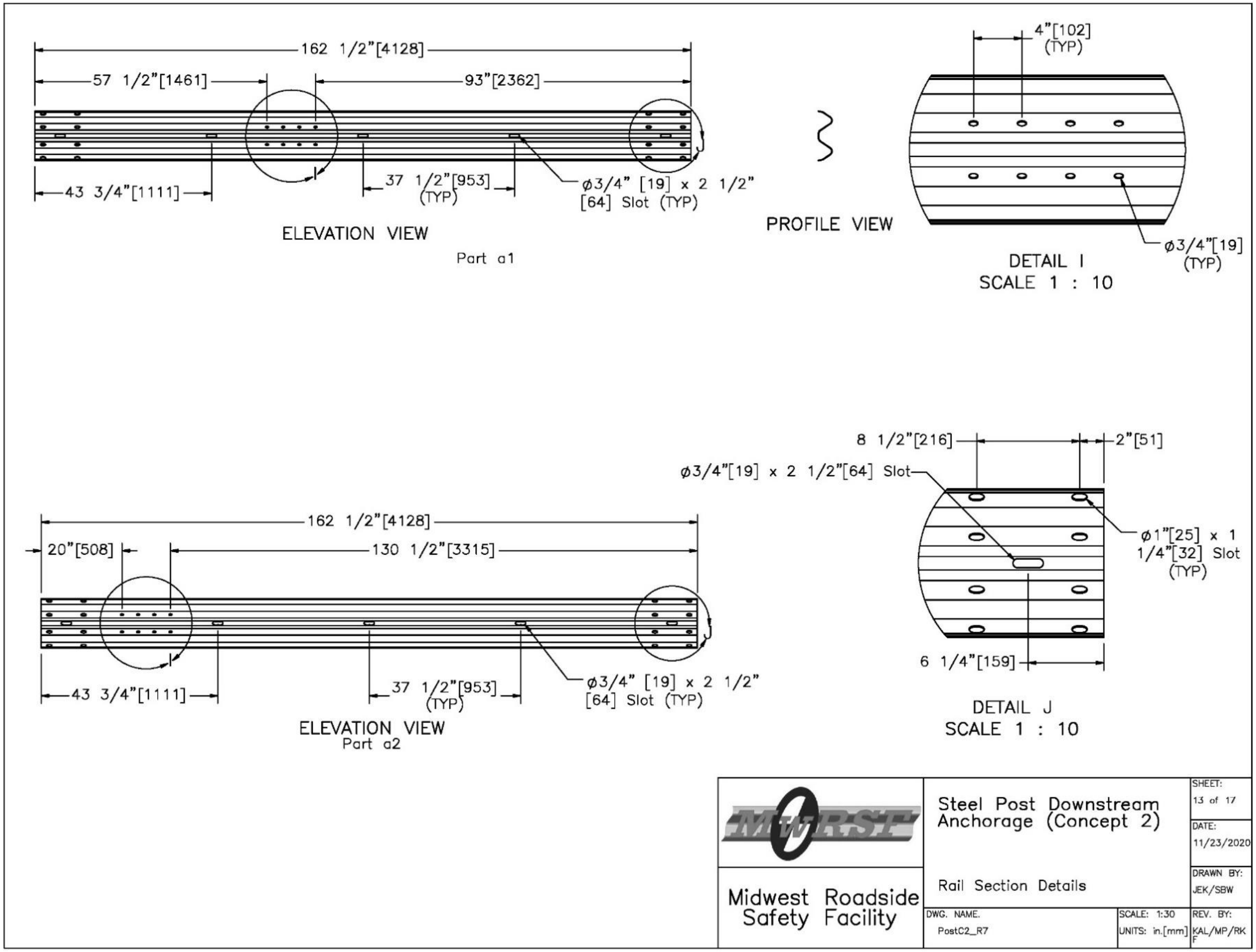


Figure 105. Rail Section Details, Test No. SPDA-2

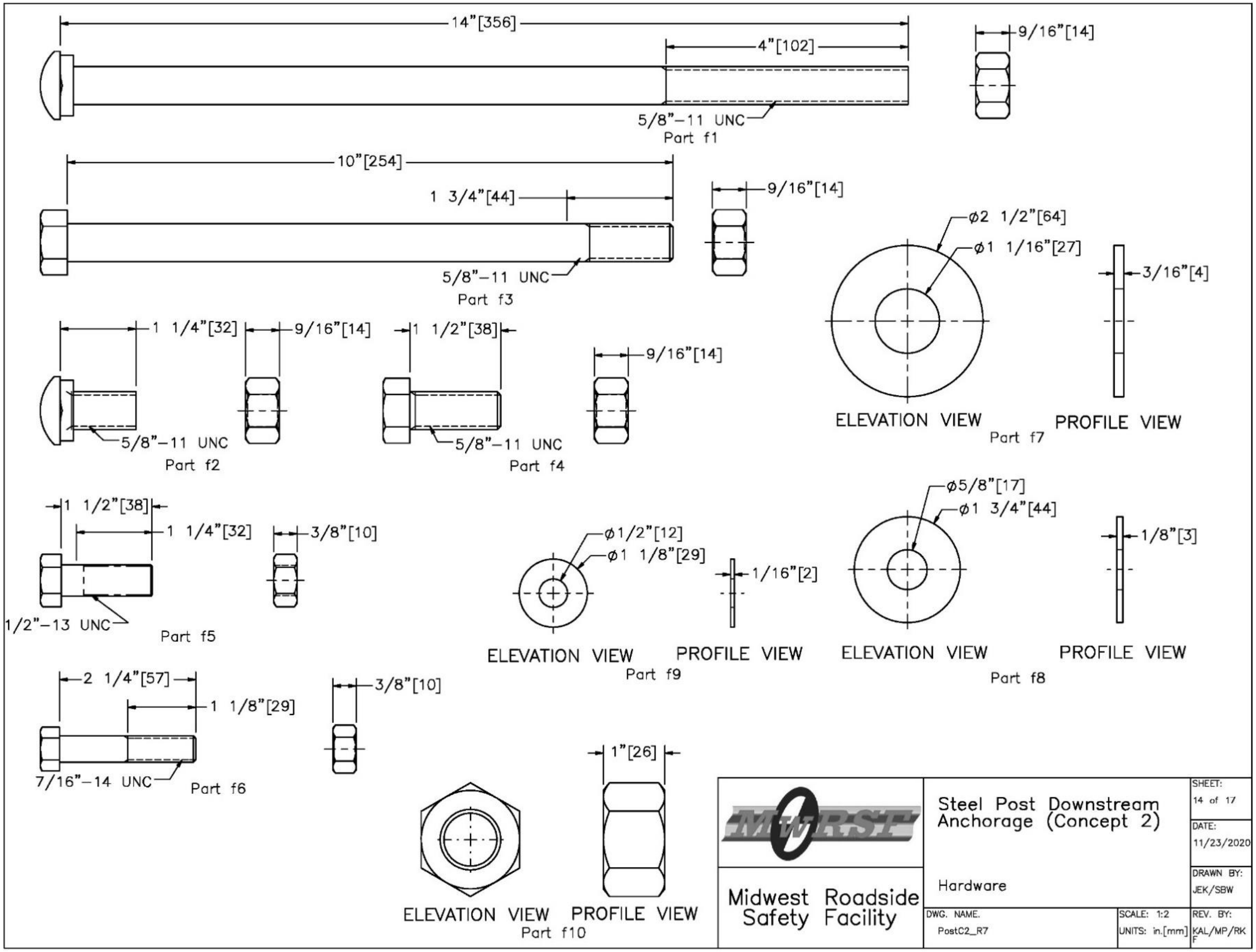


Figure 106. Bolt and Washer Details Test No. SPDA-2

Item No.	QTY.	Description	Material Spec	M-GalvSpec	Hardware Guide
a1	1	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS End Section	AASHTO M180	ASTM A123 or A653	–
a2	1	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS Section	AASHTO M180	ASTM A123 or A653	–
b1	2	TS6"x8"x3/16" [152x203x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	AASHTO M111 (ASTM A123)	–
b2	2	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 27 3/4" [705] Long Steel Post	ASTM A992	AASHTO M111 (ASTM A123)	–
b3	4	7"x5 1/4"x5/8" [178x133x16] Steel Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
b4	2	13"x5 1/2""x3/4" [330x140x19] Steel Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
b5	1	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 or ASTM A36 Min. 50 ksi [345 MPa]	AASHTO M111 (ASTM A123)	PWE06
b6	1	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
d1	1	Modified Ground Strut Assembly	ASTM A36	AASHTO M111 (ASTM A123)	–
d2	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
d3	1	7 1/2"x4"x1 1/8" [191x102x29] Bearing Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
d4	1	7 1/4"x1 3/4"x1/2" [184x44x13] Steel Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
d5	2	2 1/2"x1/2"x1/2" [64x13x13] Square Bar	ASTM A36	AASHTO M111 (ASTM A123)	–
e1	4	3/4" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS	AASHTO M30 (ASTM A741) Type II Class A	–
e2	4	BCT Anchor Cable End Swaged Fitting	Fitting – ASTM A576 Gr. 1035 Stud – ASTM F568 Class C	Fitting – ASTM A153 Stud – ASTM A153 or B695	–
e3	2	115-HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–	–
e4	2	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773	As Supplied	–
e5	6	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3 or Similar	Stock Nos. 1019597 and 1019604 – As Supplied	–	–
e6	4	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNC 6 [M36x4]	Stock No. 107 – As Supplied	–	–
e7	1	1" [25] Dia. Eye Nut	As Supplied	As Supplied	–
e8	2	TLL-50K-PTB Load Cell	–	–	–

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 2)

Bill of Materials

SHEET: 15 of 17
DATE: 11/23/2020
DRAWN BY: JEK/SBW
DWG. NAME. PostC2_R7
SCALE: None
UNITS: in.[mm]
REV. BY: KAL/MP/RKF

Figure 107. Bill of Materials, Test No. SPDA-2

Item No.	QTY.	Description	Material Spec	M–GalvSpec	Hardware Guide
f1	1	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB06
f2	10	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB01
f3	2	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
f4	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
f6	8	7/16" [11] Dia. UNC, 2 1/4" [57] Long Heavy Hex Bolt and Nut	Bolt – ASTM F3125 Gr. 120 (A325) or A354 Gr. BC Nut – ASTM A563DH or A194 Gr. 2H	Bolt – ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 or F2833 Gr. 1 Nut – ASTM A153 or B633 or B695 Class 55 or F1941 or F2329	–
f7	3	1" [25] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC24a
f8	36	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
f9	32	7/16" [11] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
f10	3	1" [25] Dia. Hex Nut	ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FNX24a
f11	1	16D Double Head Nail	–	–	–
g1	2	Portable Concrete Barrier	Min f'c=5,000 psi [34.5 MPa]	–	SWC09
g2	1	Concrete Block – MN Noise Wall	–	–	–
d5	2	2 1/2"x1/2"x1/2" [64x13x13] Square Bar	ASTM A36	AASHTO M111 (ASTM A123)	–

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 2)

Bill of Materials

SHEET: 16 of 17

DATE: 11/23/2020

DRAWN BY: JEK/SBW

DWG. NAME. PostC2_R7

SCALE: None
UNITS: in.[mm]

REV. BY: KAL/MP/RKF

Figure 108. Bill of Materials, Test No. SPDA-2 (Continued)

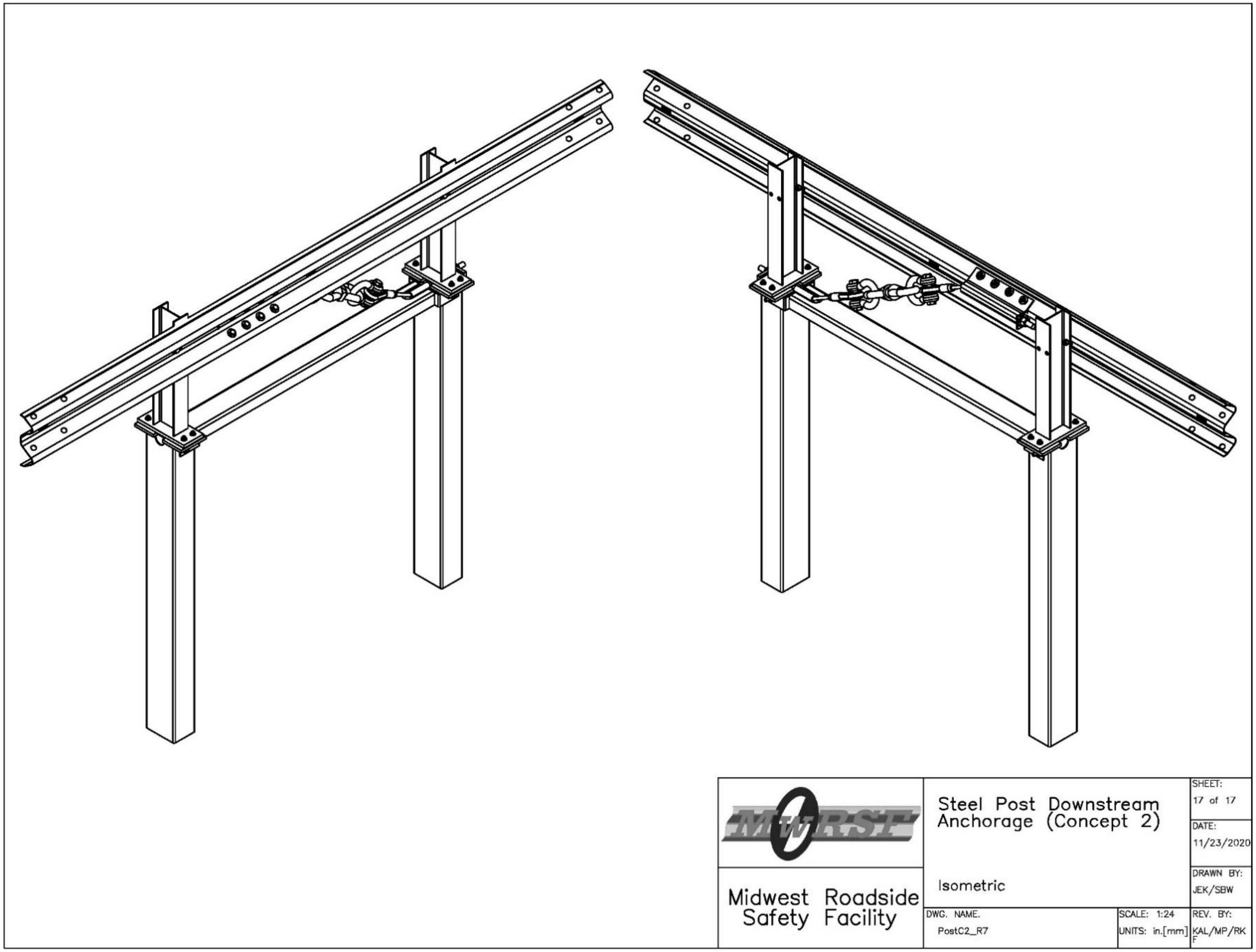


Figure 109. Isometric View, Test No. SPDA-2

Figure 110. Test Setup, Test No. SPDA-2

Figure 111. Test Setup, Test No. SPDA-2

6.2 Test No. SPDA-2 Results

During test no. SPDA-2, the top portion of both anchor posts deflected downstream when the tow cable pulled the rail. The pull force was immediately transferred to the two foundation tubes, which rotated in the soil. When the cable anchor was tensioned, a downward vertical force component was applied to the rail. First, the second anchor post twisted and caused the rail to deform and tear vertically at the rail-to-post bolt connection. Following the rail tearing at the second anchor post, the rail moved vertically downward. All bolts in the first anchor post fractured in tension and the anchor cable and bearing plate were released. All bolts in the second anchor post also fractured.

The force versus time and the displacement versus time curves for test no. SPDA-2 were processed from transducer data using the SLICE-1 and SLICE-2 units and are shown in Appendix H. The anchor cable loads, pull cable loads, and anchor cable displacements are shown in Figure 112. The peak force from the anchor cable and the pull cable were 44.0 kips (195.7 kN) and 17.0 kips (75.6 kN), respectively. These peak loads occurred at 0.190 sec and 0.100 sec, respectively. The peak displacement of 2.4 in. (61 mm) was measured by the string potentiometer attached to the end of the anchor cable which occurred at 0.214 sec. Time-sequential photographs are shown in Figures 113 through 114. Post-impact photographs are shown in Figures 115 and 116.

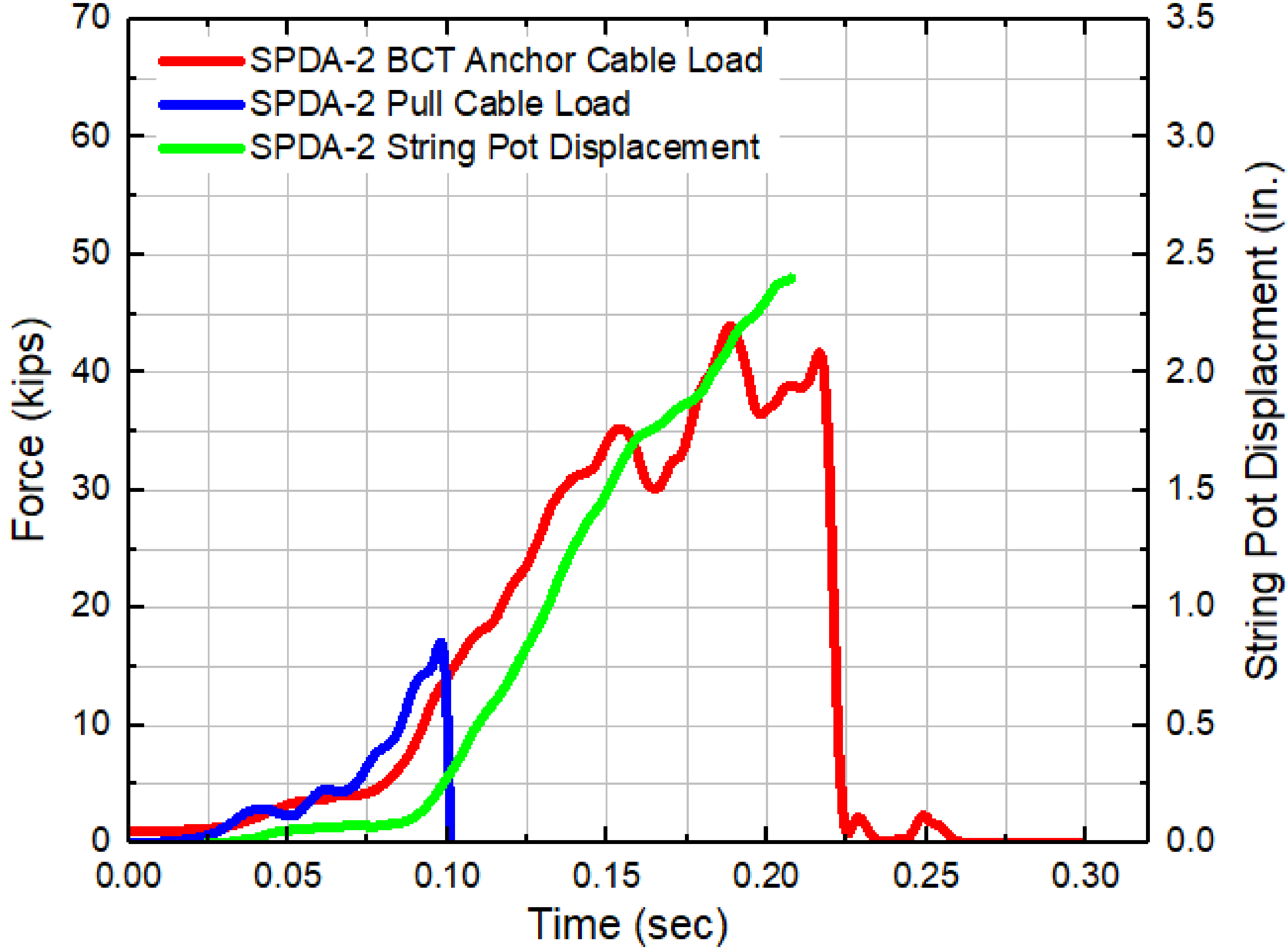
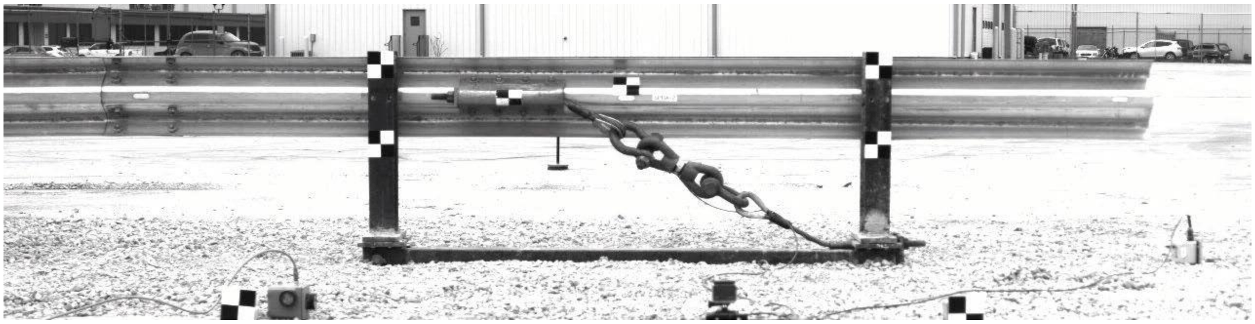
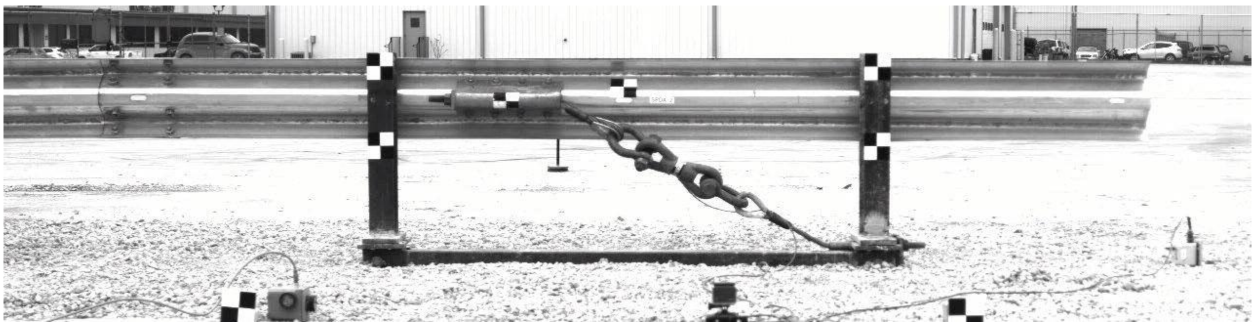


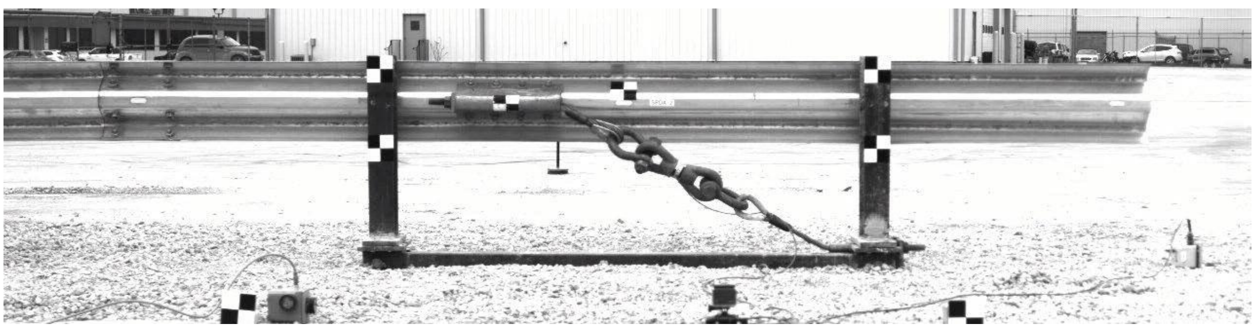
Figure 112. Force vs. Time and Displacement vs. Time, Test No. SPDA-2



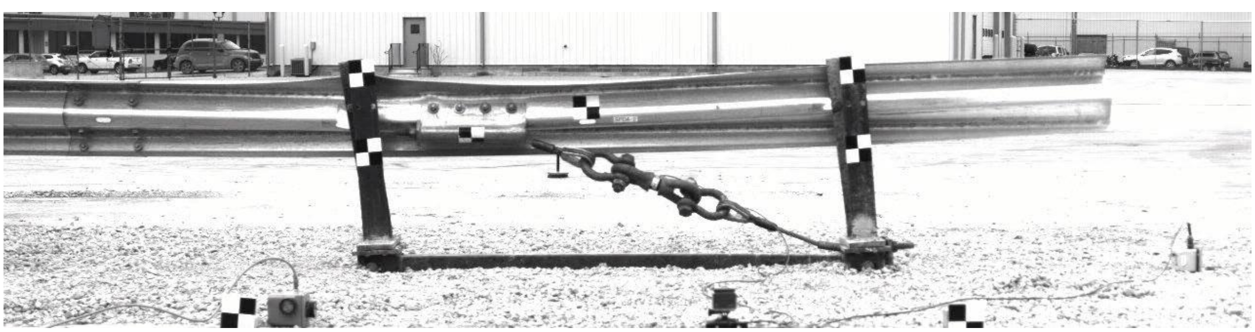
0.000 sec



0.050 sec

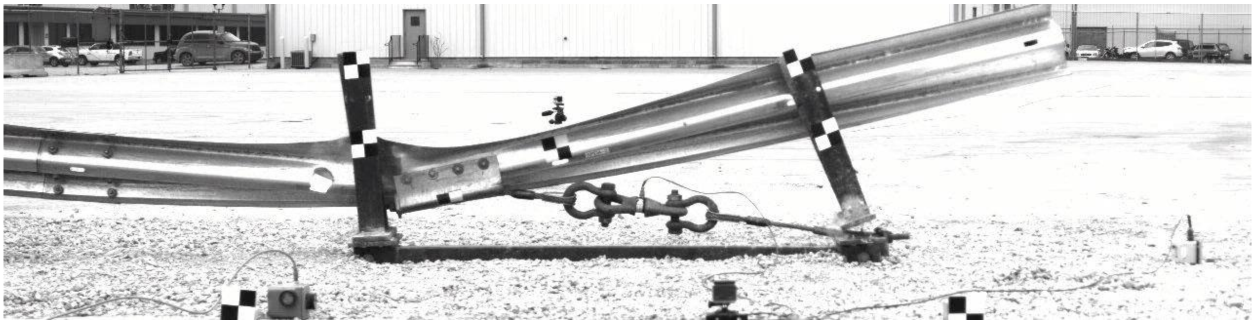


0.100 sec

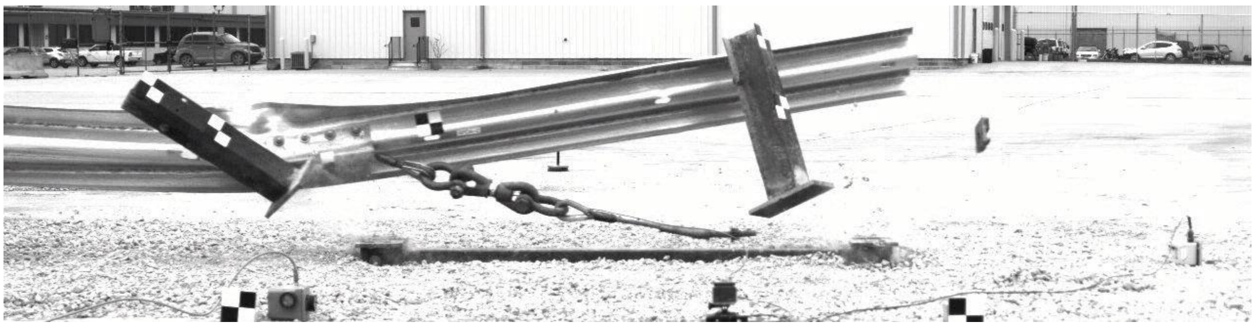


0.150 sec

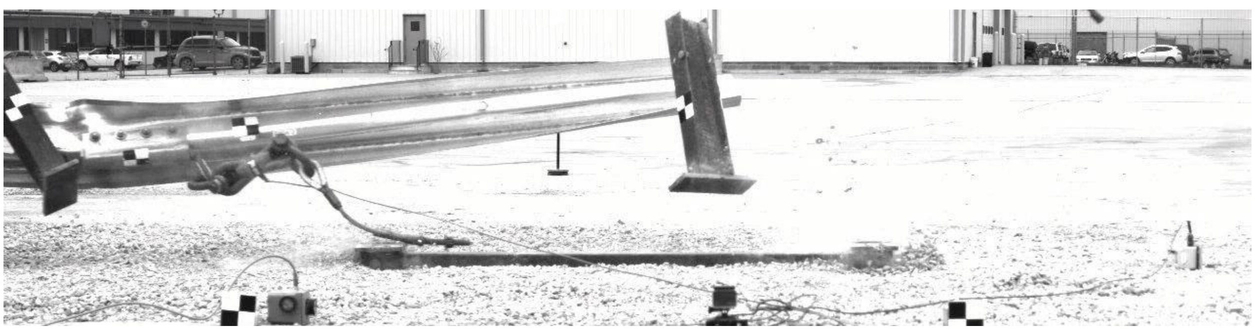
Figure 113. Time-Sequential Photographs, Test No. SPDA-2



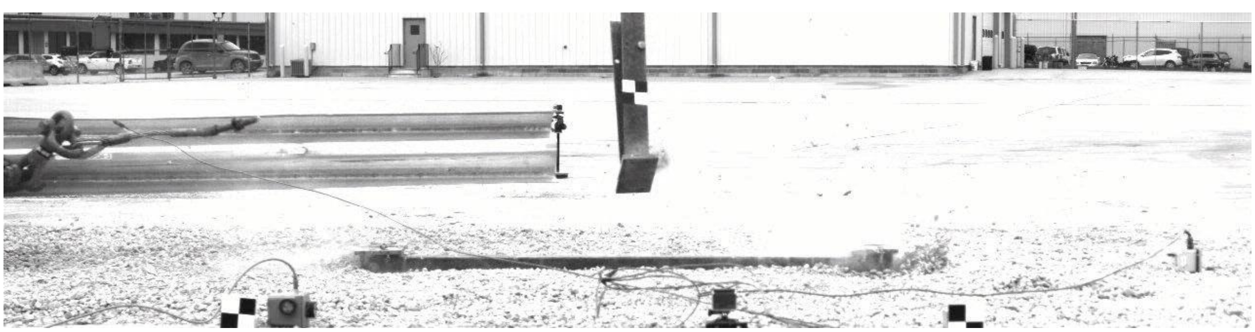
0.200 sec



0.250 sec



0.300 sec



0.350 sec

Figure 114. Time-Sequential Photographs, Test No. SPDA-2 (Continued)

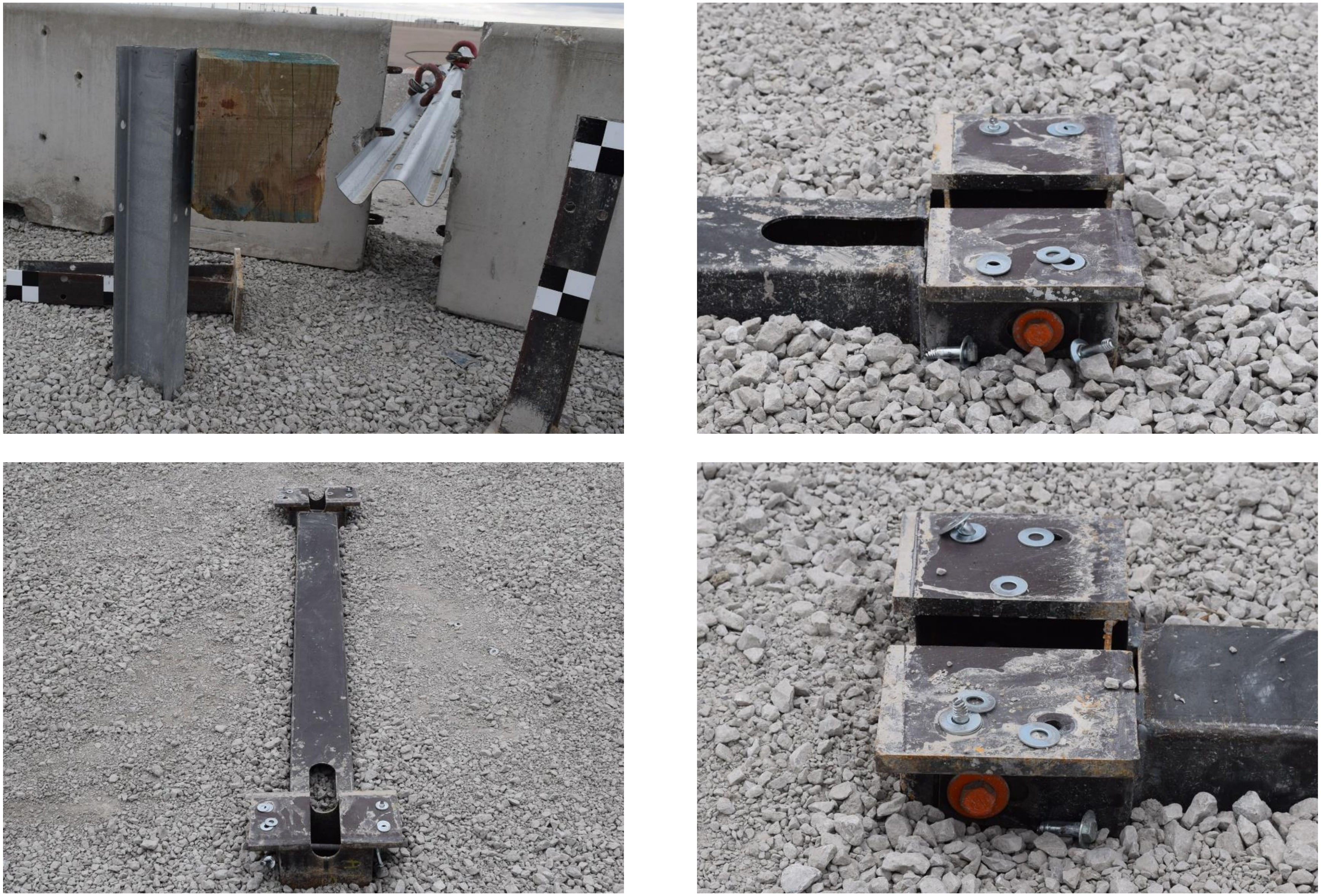


Figure 115. Post-Impact Photographs, Test No. SPDA-2

Figure 116. Post-Impact Photographs, Test No. SPDA-2

6.3 Discussion

In test no. SPDA-2, several observations were made. The increased tension in the anchor cable caused the top part of the second anchor post to disengage from the rail. This force caused the rail to tear vertically at the rail-to-post bolt connection. All four bolts in the slip base of the first anchor post fractured in tension. These bolts fractured after the rail released from the second anchor post. Following this, the anchor cable and bearing plate released from the first anchor post. Finally, all bolts in the slip base of the second anchor post fractured in tension.

The maximum load of 17.0 kips (75.6 kN), measured in the pull cable occurred at 0.100 sec after the start of the dynamic event. After 0.100 sec, the pull cable load dropped to zero, which meant technical difficulty occurred with the load cell. At 0.150 sec, the rail began to deform and tore at the second anchor post with the peak force and displacement during this time at 35.0 kips (155.7 kN) and 1.75 in. (44 mm), respectively. Around 0.170 sec, the peak load dropped to 30.0 kips (133.4 kN) as twisting and rail tearing occurred at the second anchor post. The displacement at 0.170 sec was 1.8 in. (46 mm). At 0.190 sec, a maximum peak force of 44.0 kips (195.7 kN) was measured in the anchor cable, which displaced 2.1 in. (53 mm). At 0.220 sec, a peak force of 42.0 kips (186.8 kN) was measured in the BCT anchor cable. During this time, a maximum displacement of 2.4 in. (61 mm) was measured by the string potentiometer attached to the end of the anchor cable.

Three peak tensile loads of 35.0 kips (155.7 kN), 44.0 kips (195.7 kN), and 42.0 kips (186.8 kN) were recorded by the BCT anchor cable load cell. The first large load occurred when the rail began to tear vertically at the second anchor post bolt connection. The second large load occurred while the rail tearing progressed at the second anchor post bolt attachment. The third large load occurred when all bolts fractured from the first anchor post.

The maximum load sustained by the end anchorage was 44.0 kips (195.7 kN). The anchor cable load versus anchor cable displacement is shown in Figure 117. All bolts in both anchor posts fractured in tension. The anchor cable and bearing plate were released completely after the bolts fractured. Results from test no. SPDA-2 are summarized in Table 7.

Table 7. Summary of Test Results, Test No. SPDA-2

Test No.	**Impact Velocity mph (km/h)**	**Peak Force kips (kN)**	**Displacement at Peak Load in. (mm)**	**Energy at Peak Load kips-in. (kJ)**	**Failure Mechanism**	**Component Damage**	**Attachment Damage**
SPDA-2	18.3 (29.5)	44.0 (195.7)	2.1 (53)	49.6 (5.6)	Anchor post broke away releasing BCT anchor cable	Rail tore on post bolt connection, posts broke away, rail released and pulled downstream	All bolts fractured in tension releasing both anchor posts

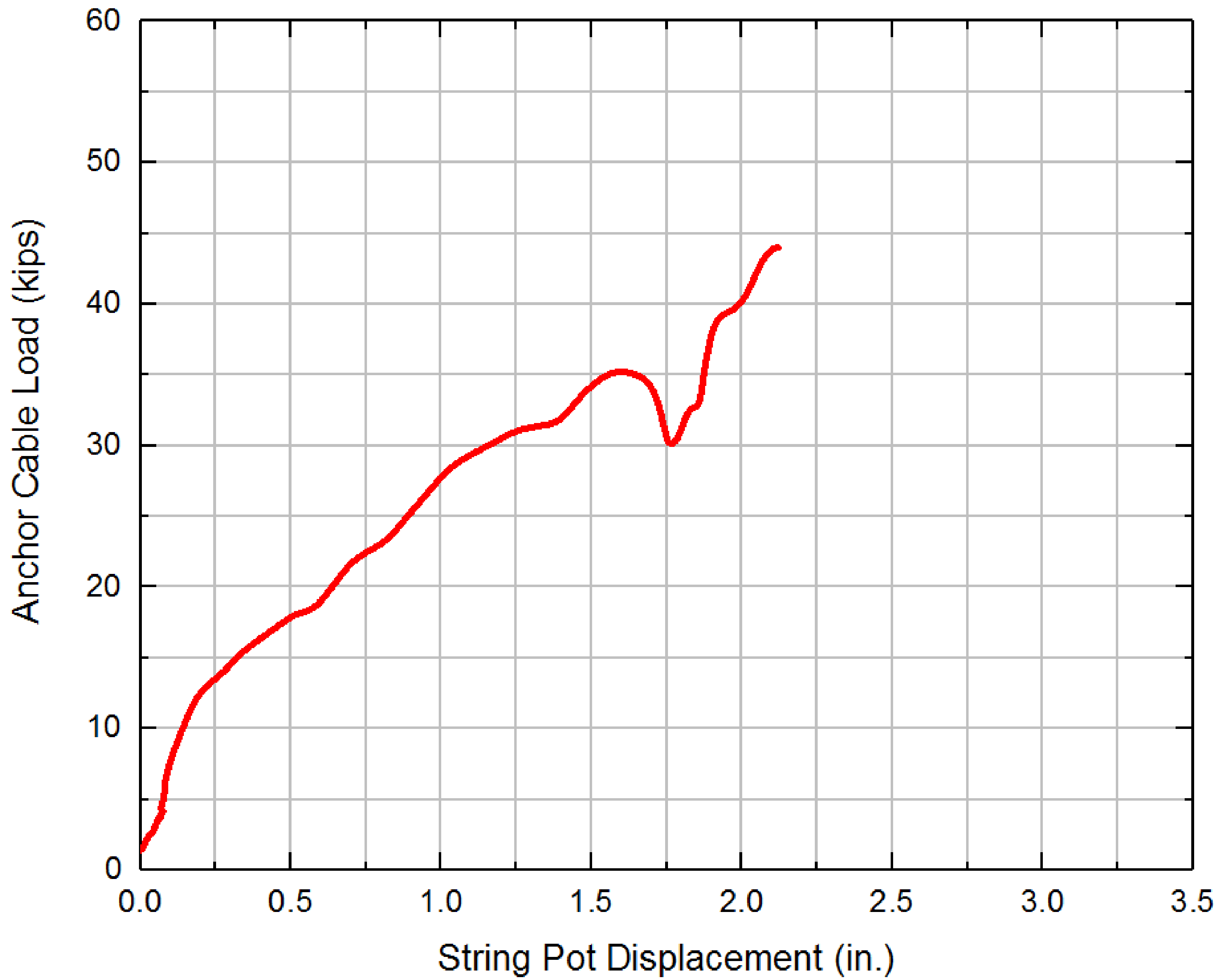


Figure 117. Anchor Cable Load vs. String Pot Displacement, Test No. SPDA-2

7 DYNAMIC COMPONENT TEST – DESIGN CONCEPT NO. 3

7.1 System Details – Concept No. 3

Test no. SPDA-3 was a dynamic jerk test of design concept no. 3 which was the anchorage system with an angled bearing plate. This system design included two modified UBSPs with a slot in the end foundation tube that formed the lower portion of the end anchor post, an opening in the bottom base plate to allow cable release, and an angled bearing plate welded to the bottom post to restrain the anchor cable. The test matrix and test setup are shown in Figures 118 through 135. Photographs of the test setup are presented in Figures 136 and 137. Material specifications, mill certifications, and certificates of conformity for the system materials used in test no. SPDA-3 are shown in Appendix G.

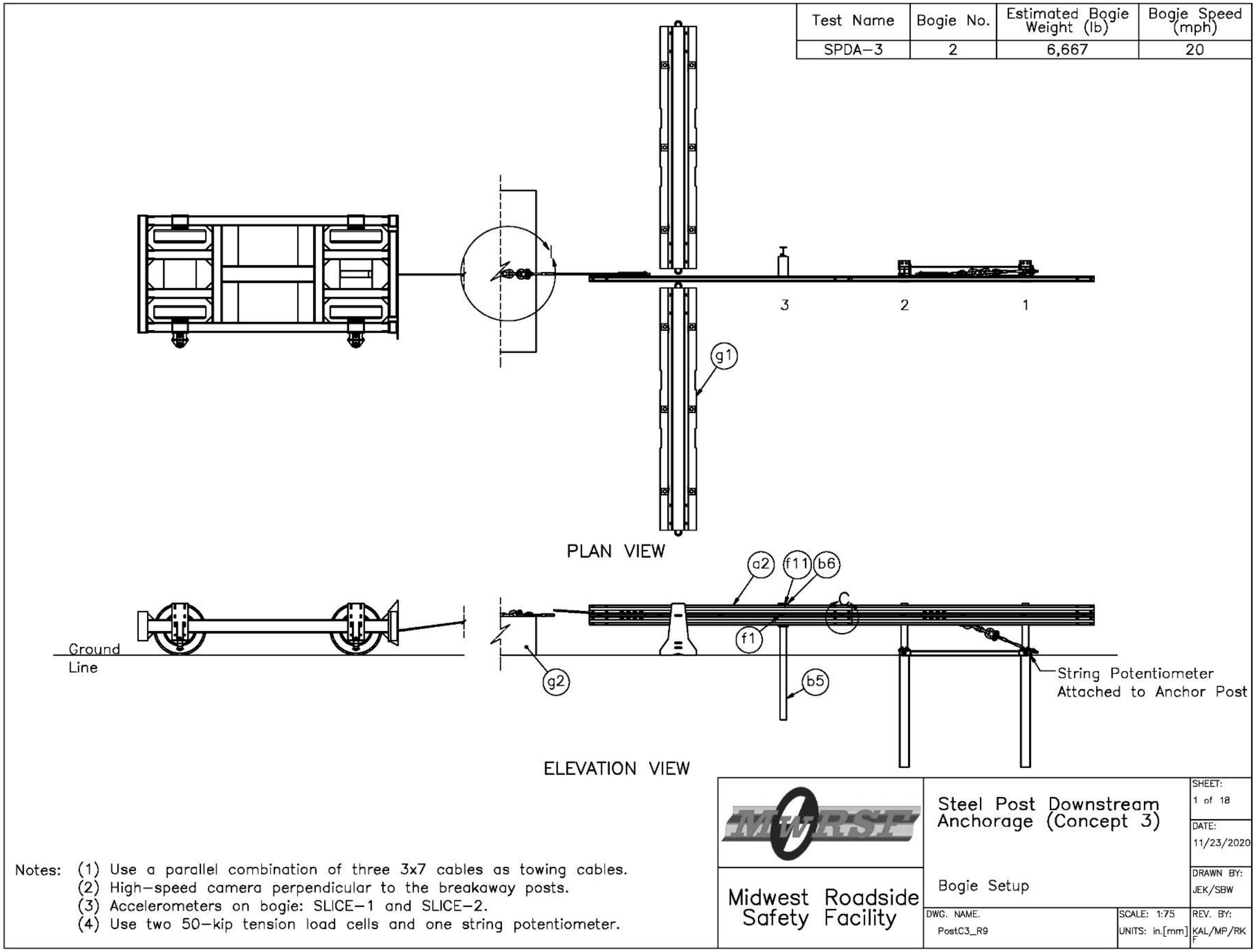


Figure 118. Bogie Testing Matrix and Setup, Test No. SPDA-3

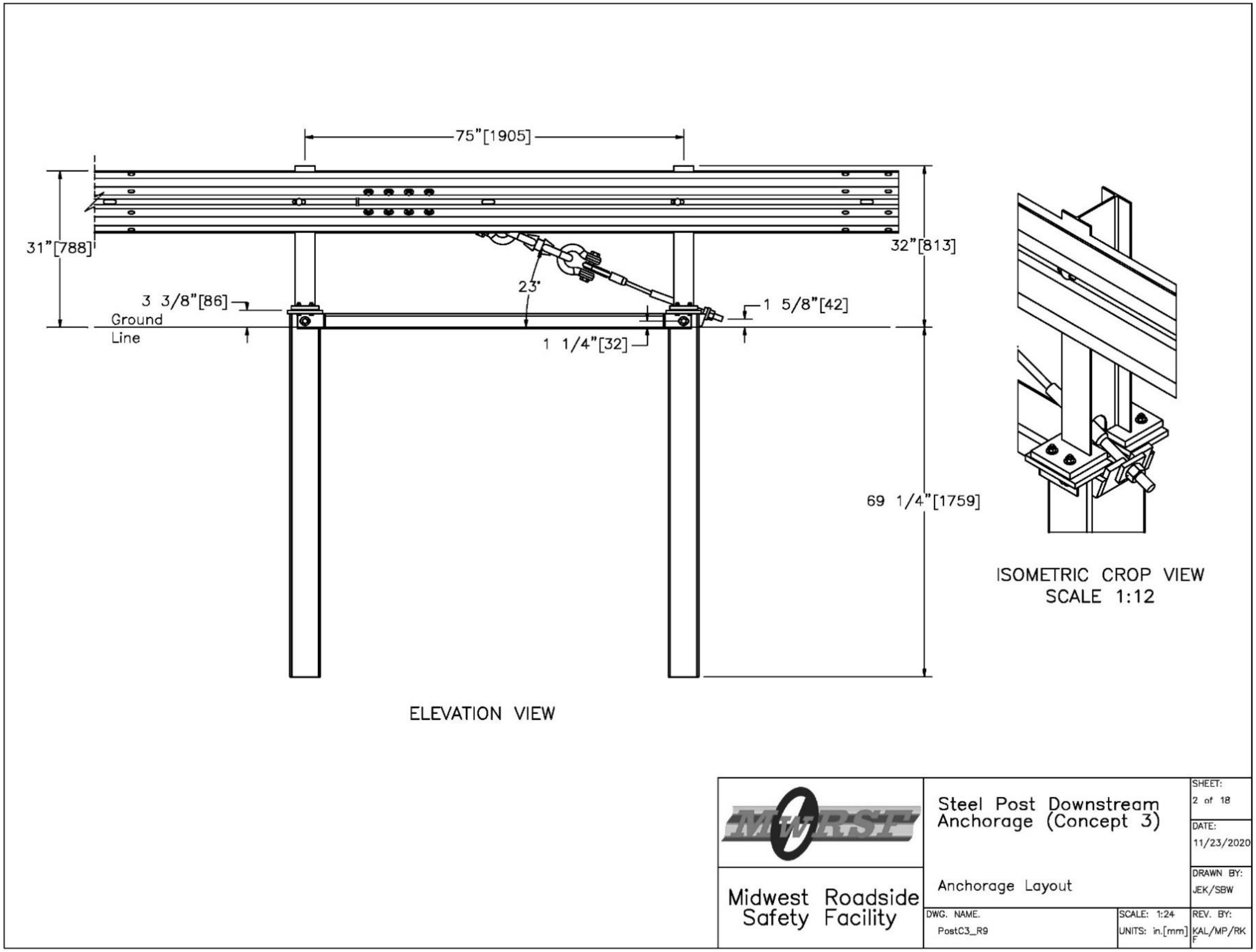


Figure 119. Anchorage Layout, Test No. SPDA-3

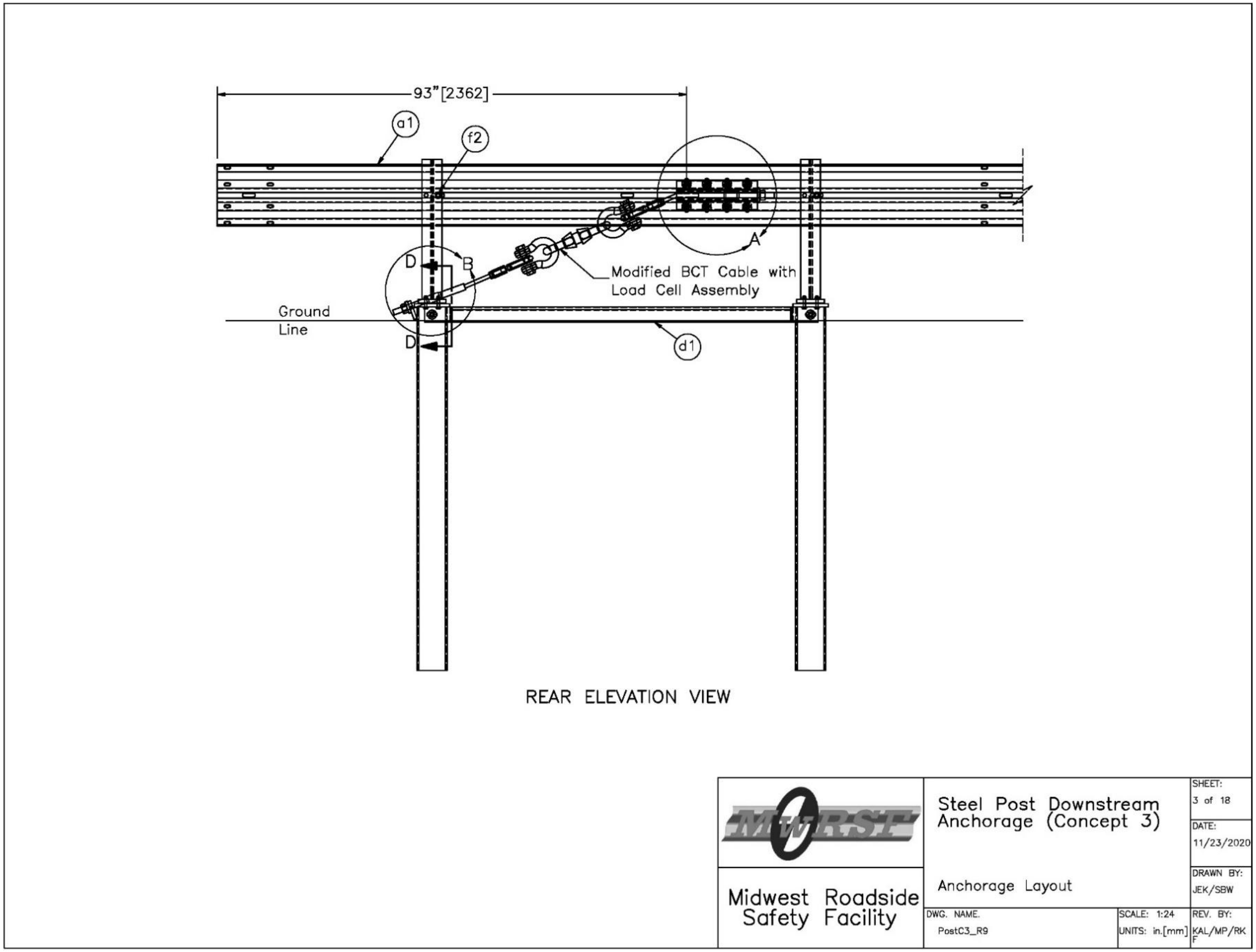


Figure 120. Anchorage Layout, Test No. SPDA-3

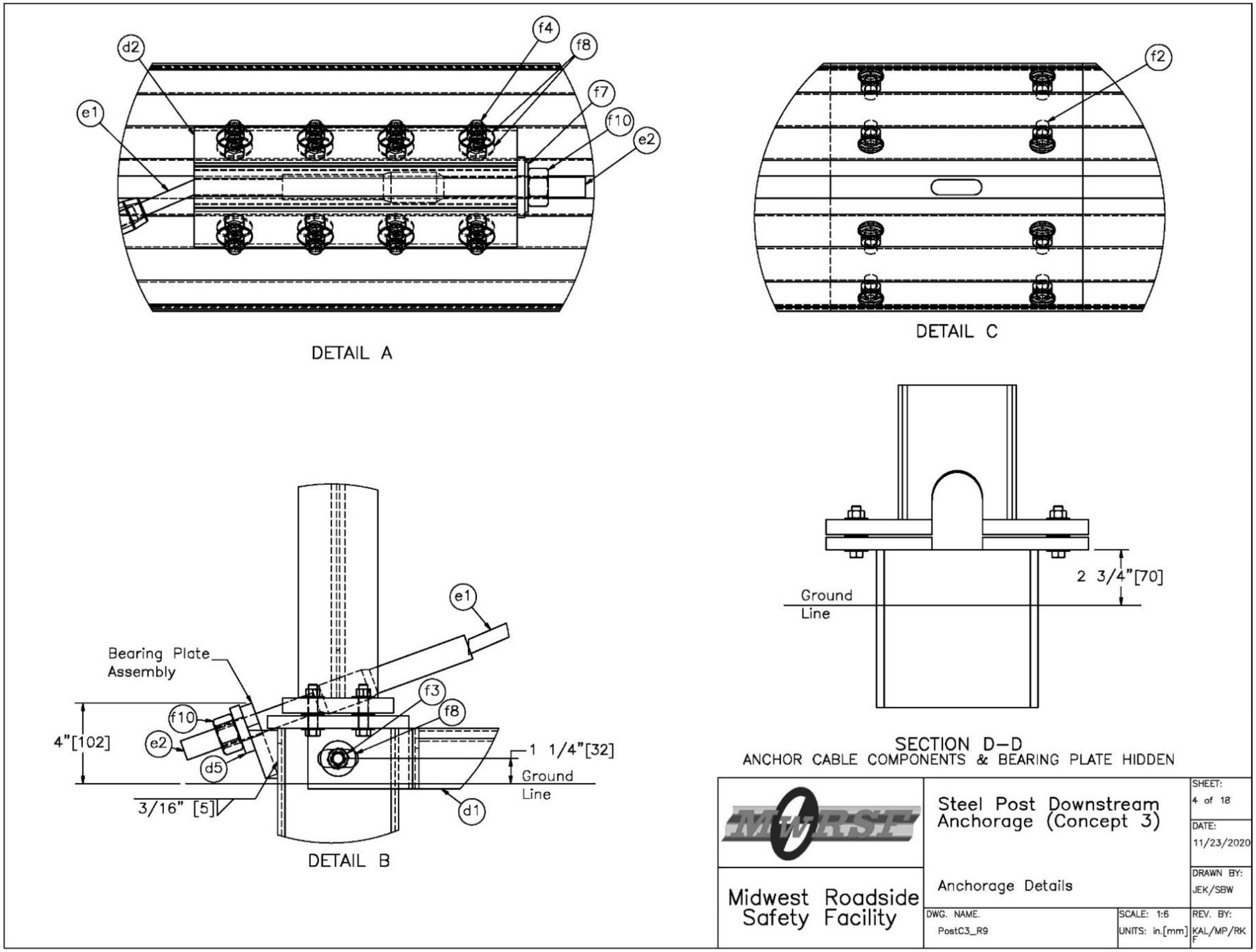


Figure 121. Anchorage Details, Test No. SPDA-3

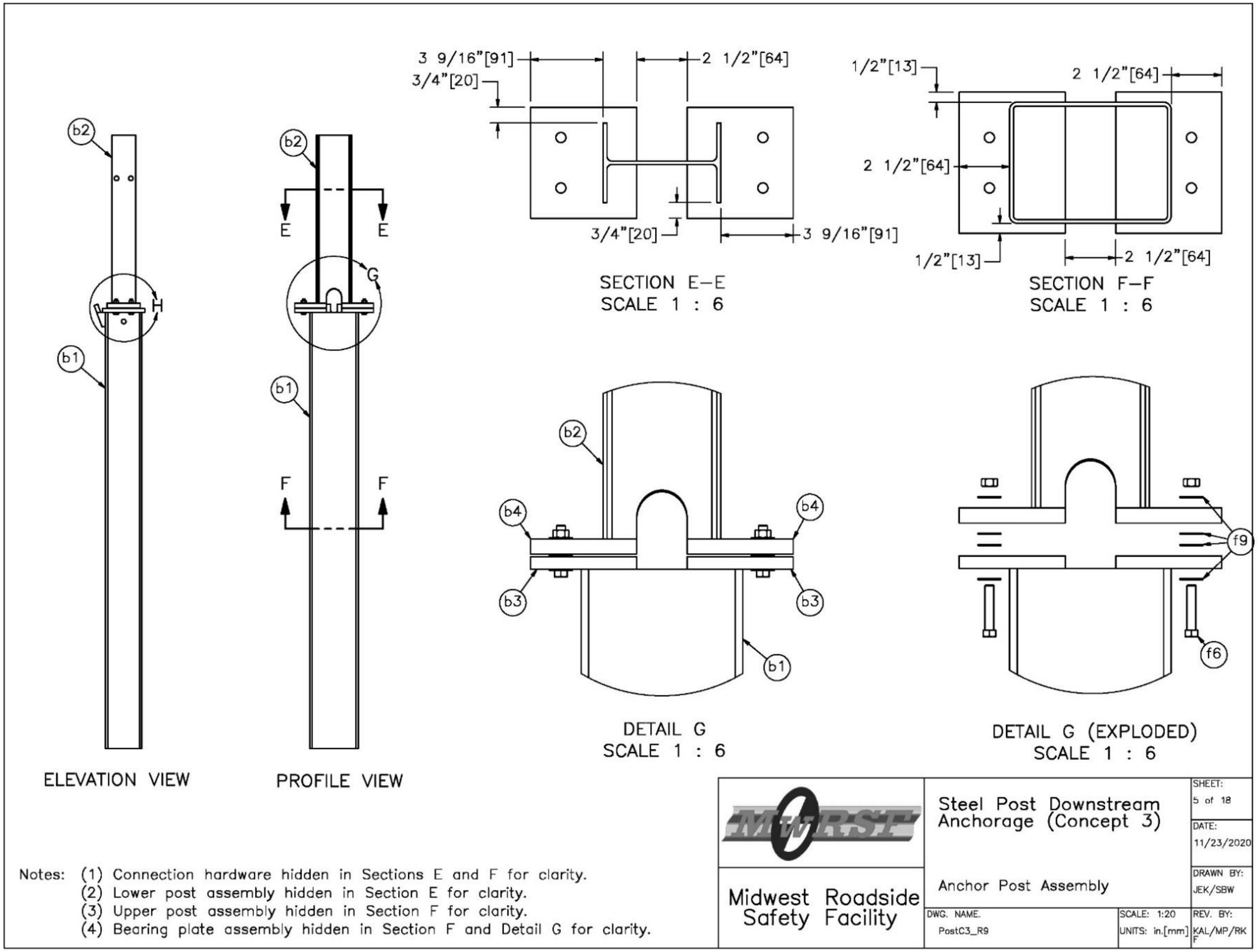


Figure 122. Anchor Post Assembly, Test No. SPDA-3

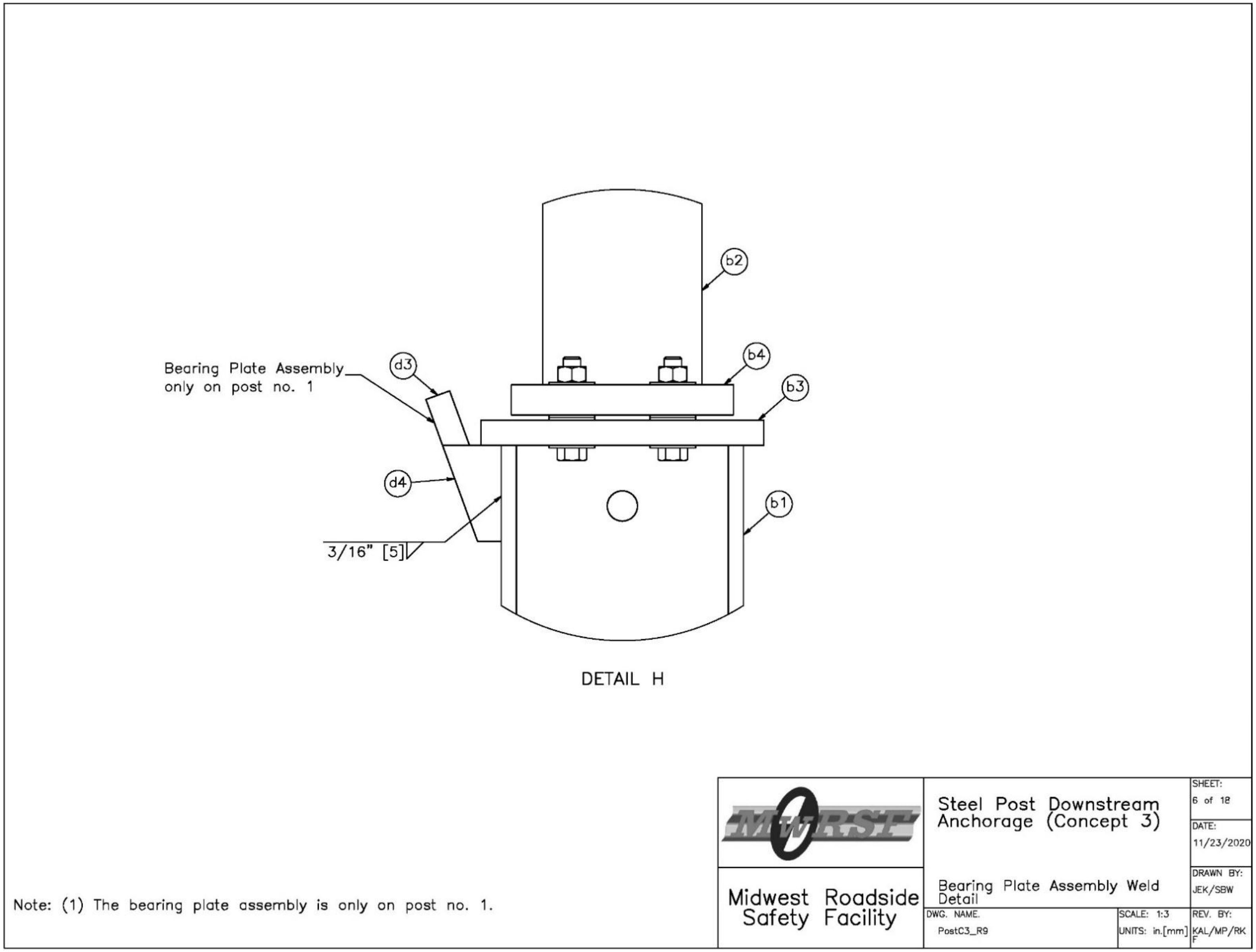


Figure 123. Bearing Plate Assembly Weld, Test No. SPDA-3

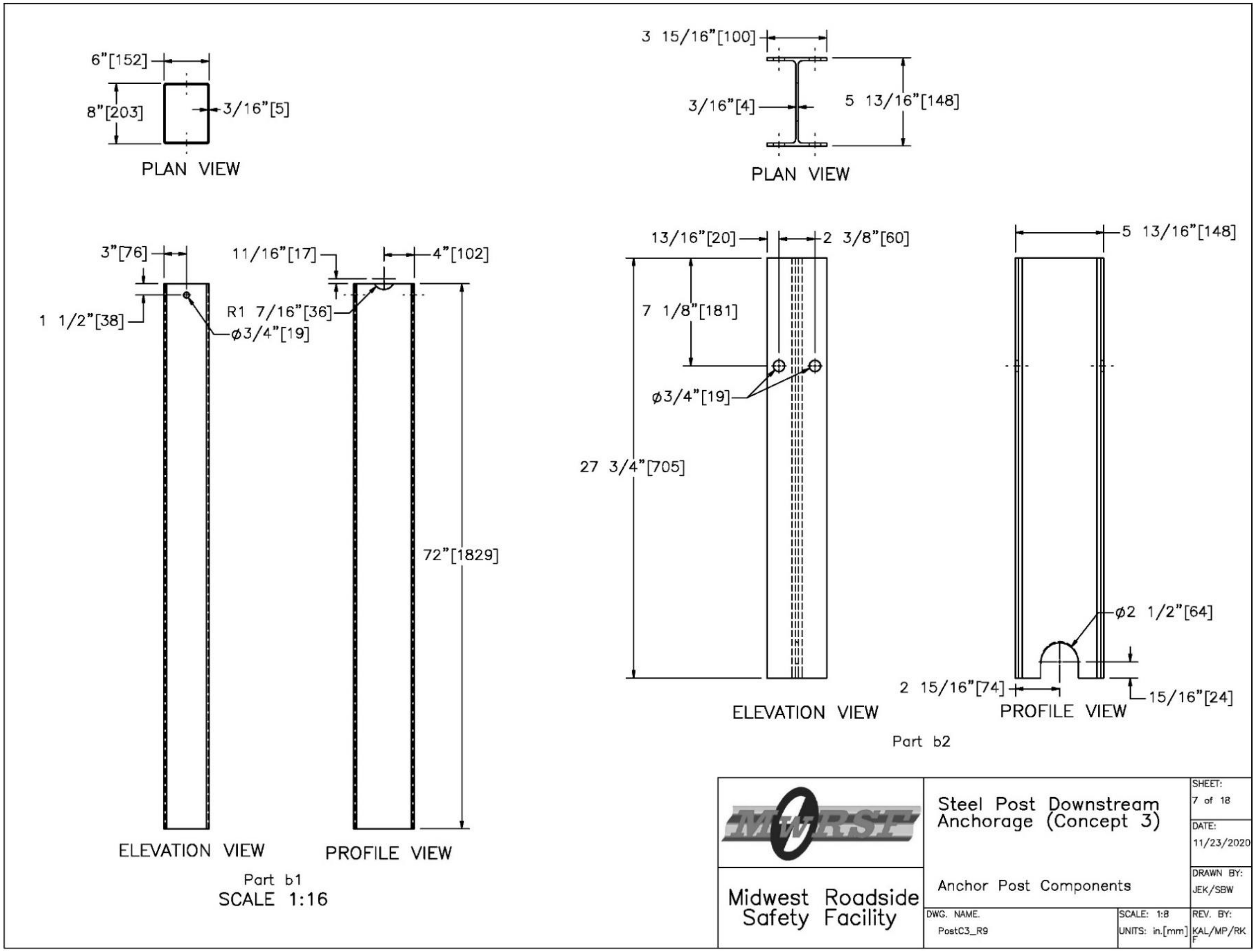


Figure 124. Anchor Post Components, Test No. SPDA-3

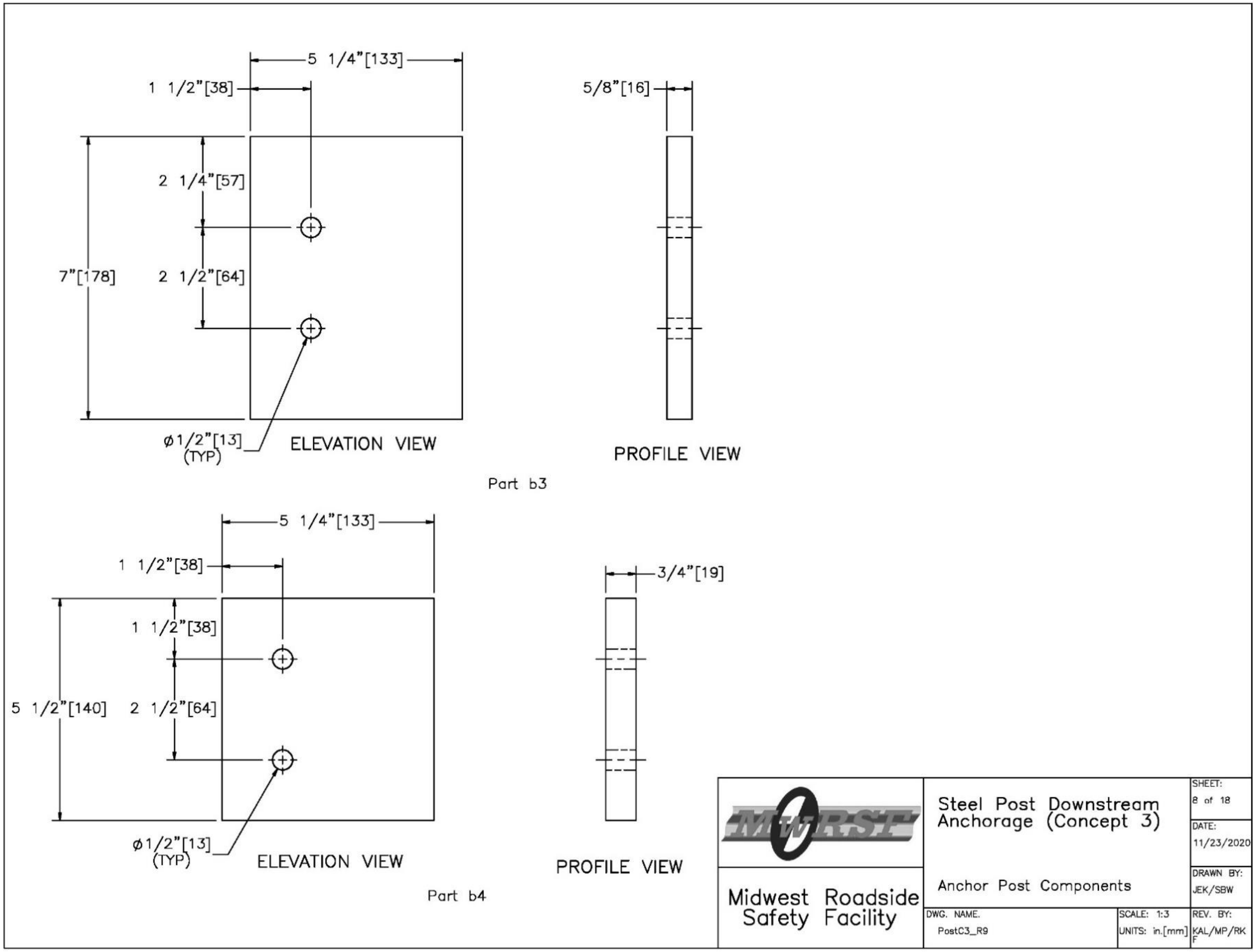


Figure 125. Anchor Post Components, Test No. SPDA-3

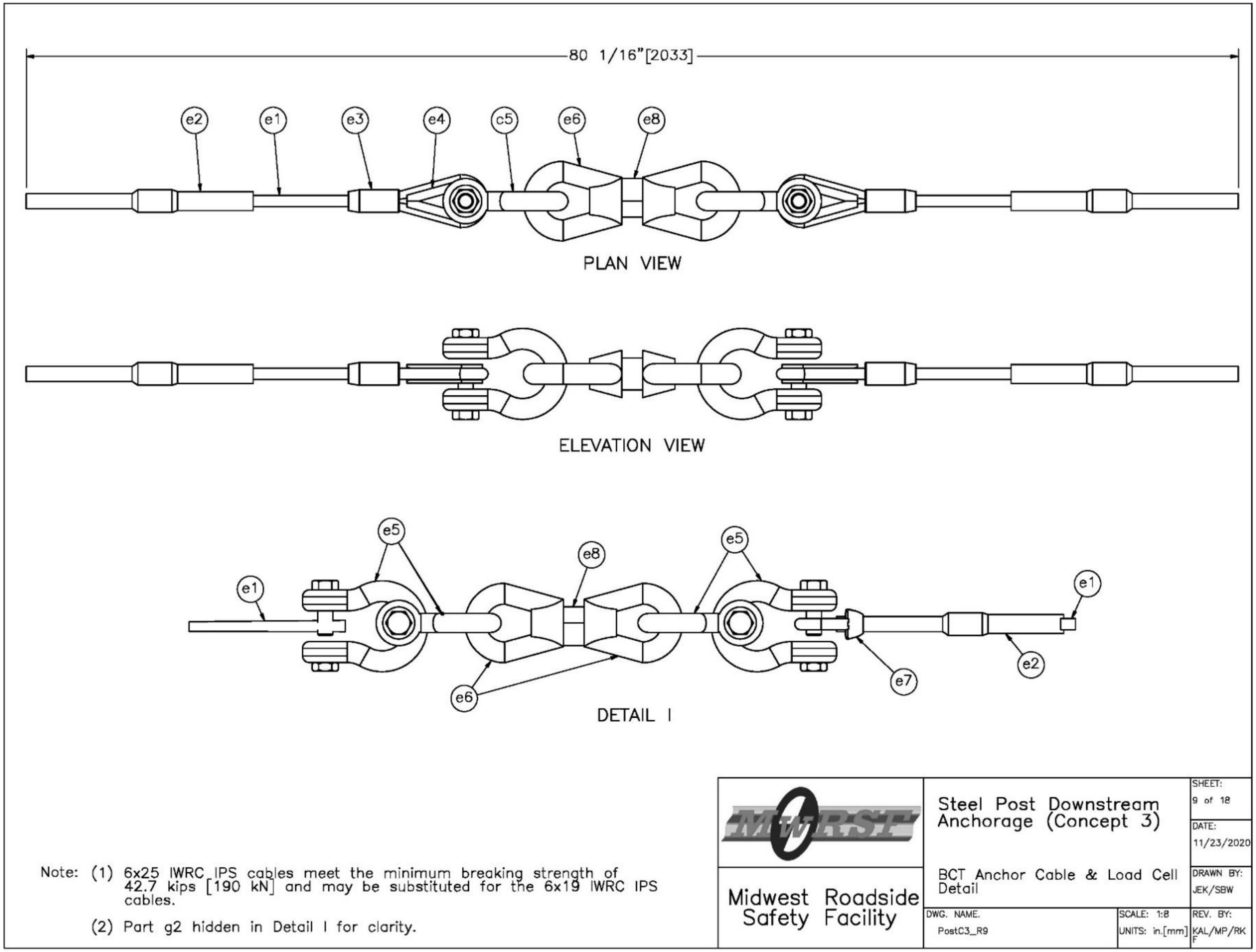


Figure 126. BCT Anchor Cable and Load Cell Detail, Test No. SPDA-3

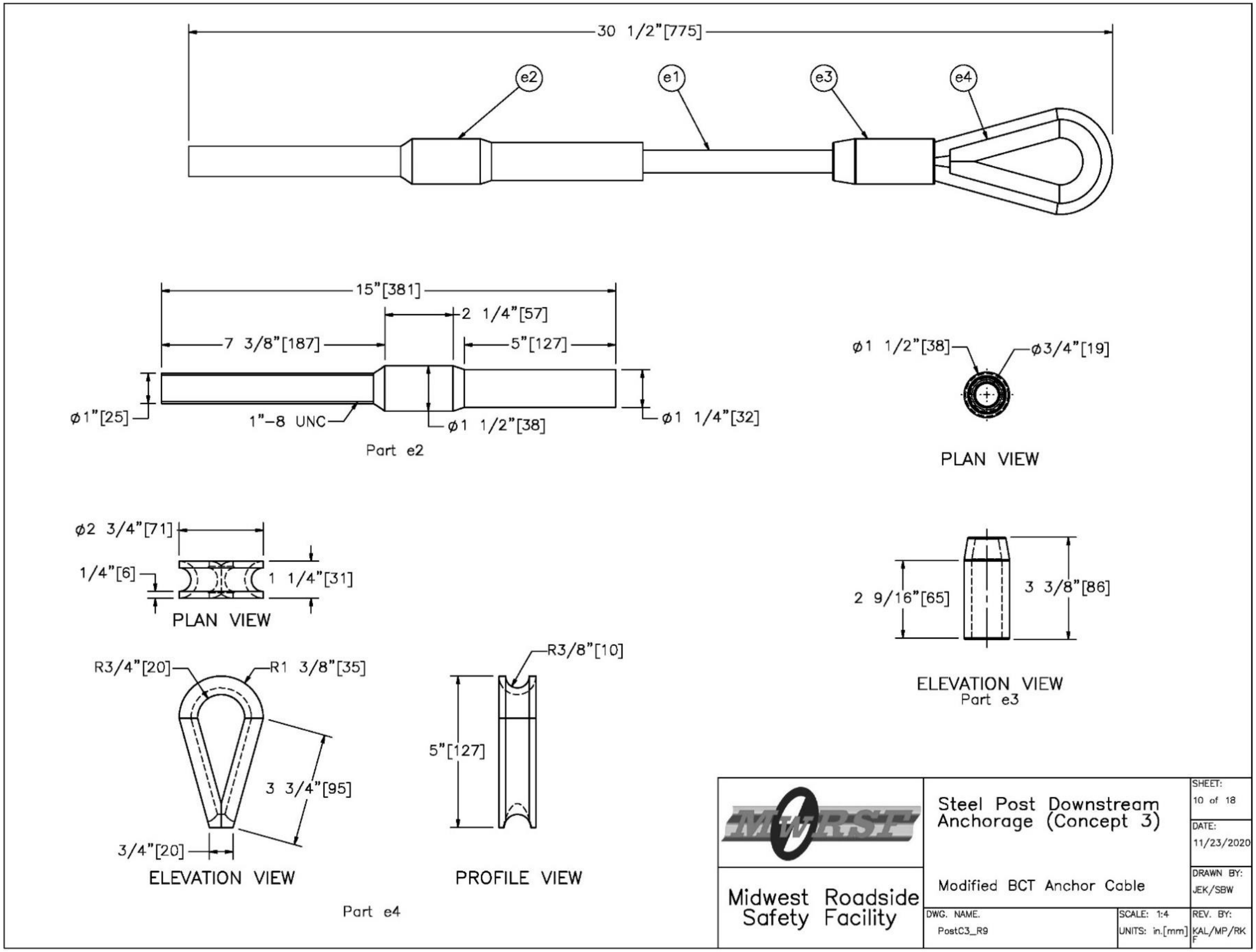


Figure 127. Modified BCT Anchor Cable, Test No. SPDA-3

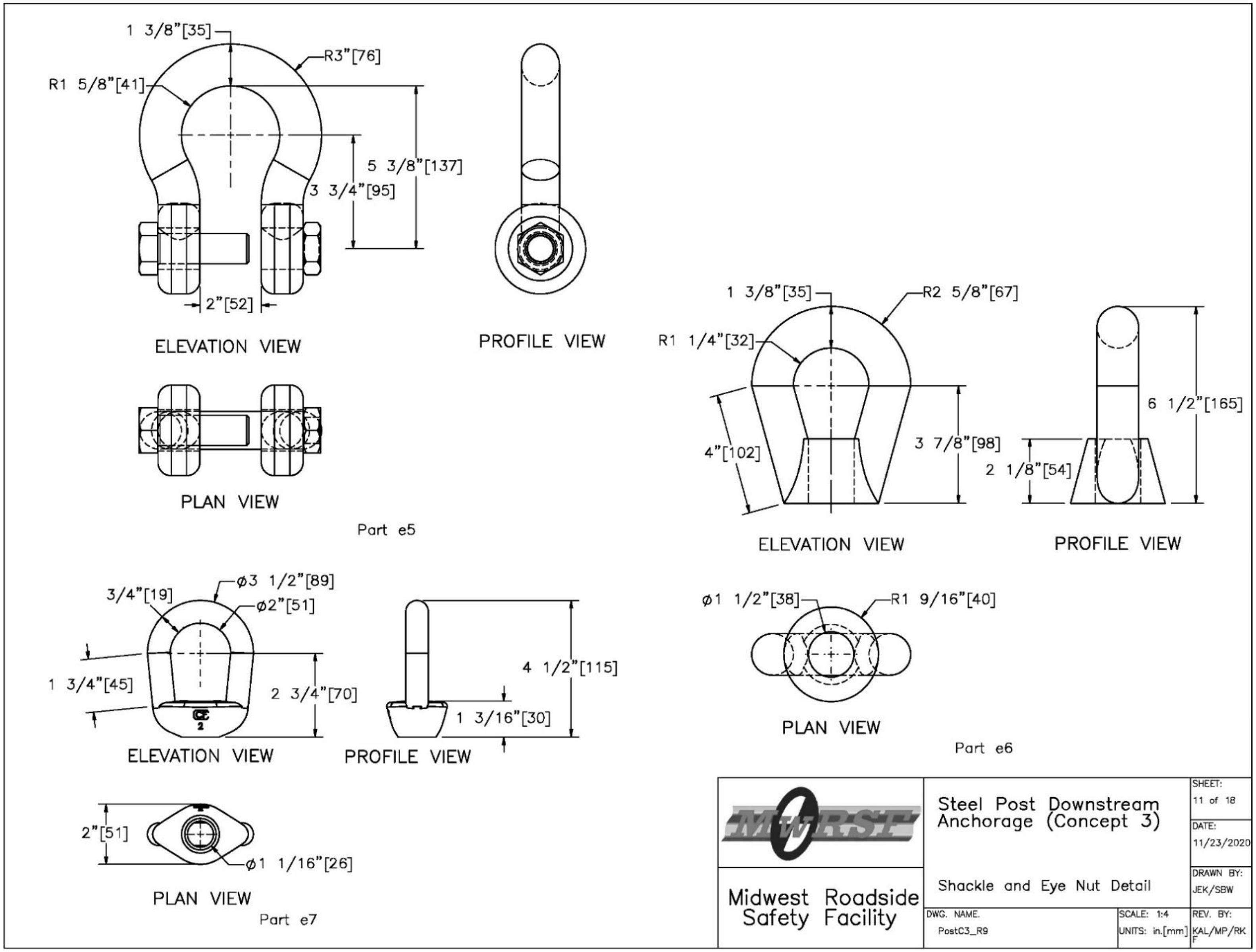


Figure 128. Shackle and Eye Nut Detail, Test No. SPDA-3

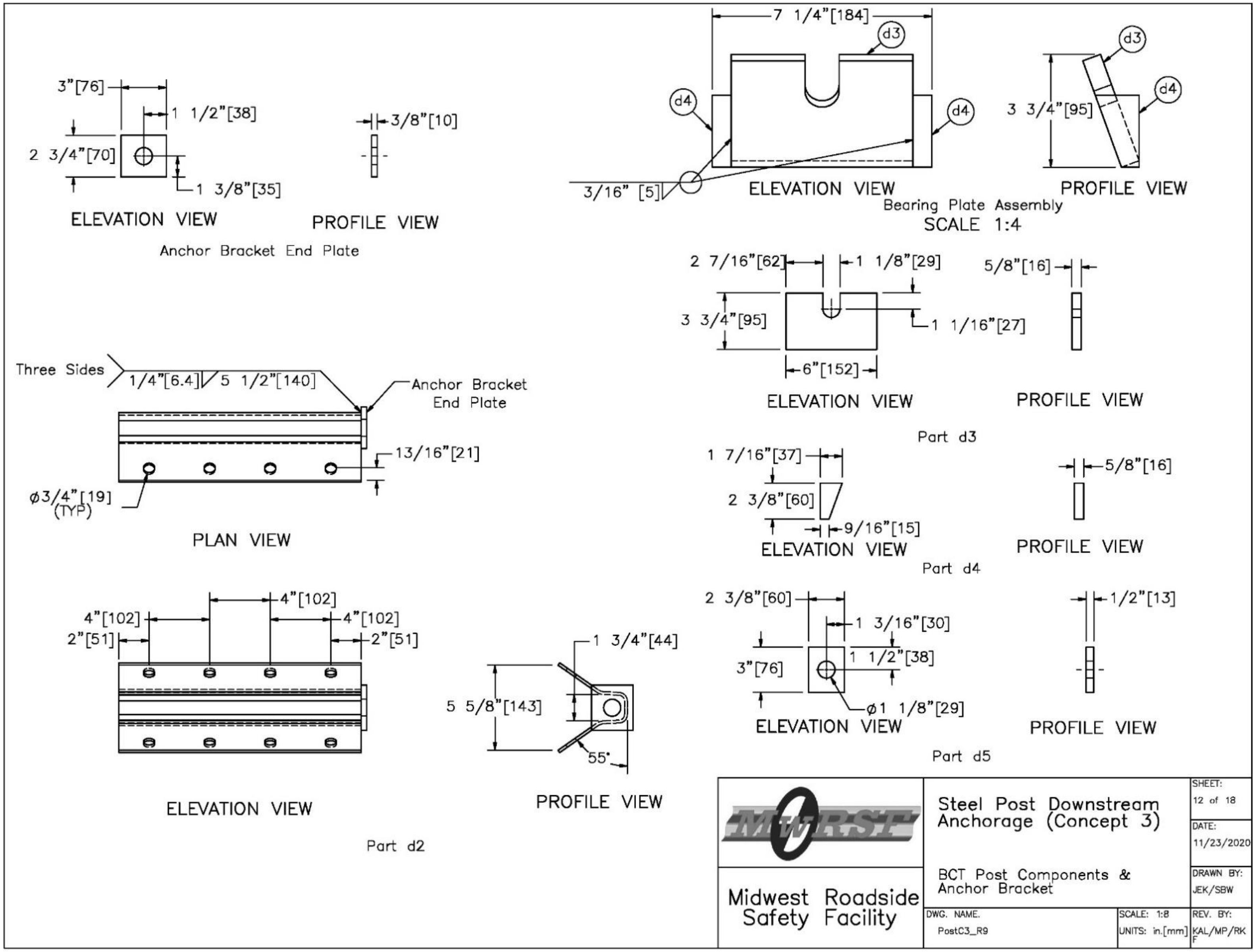


Figure 129. BCT Post Component and Anchor Bracket, Test No. SPDA-3

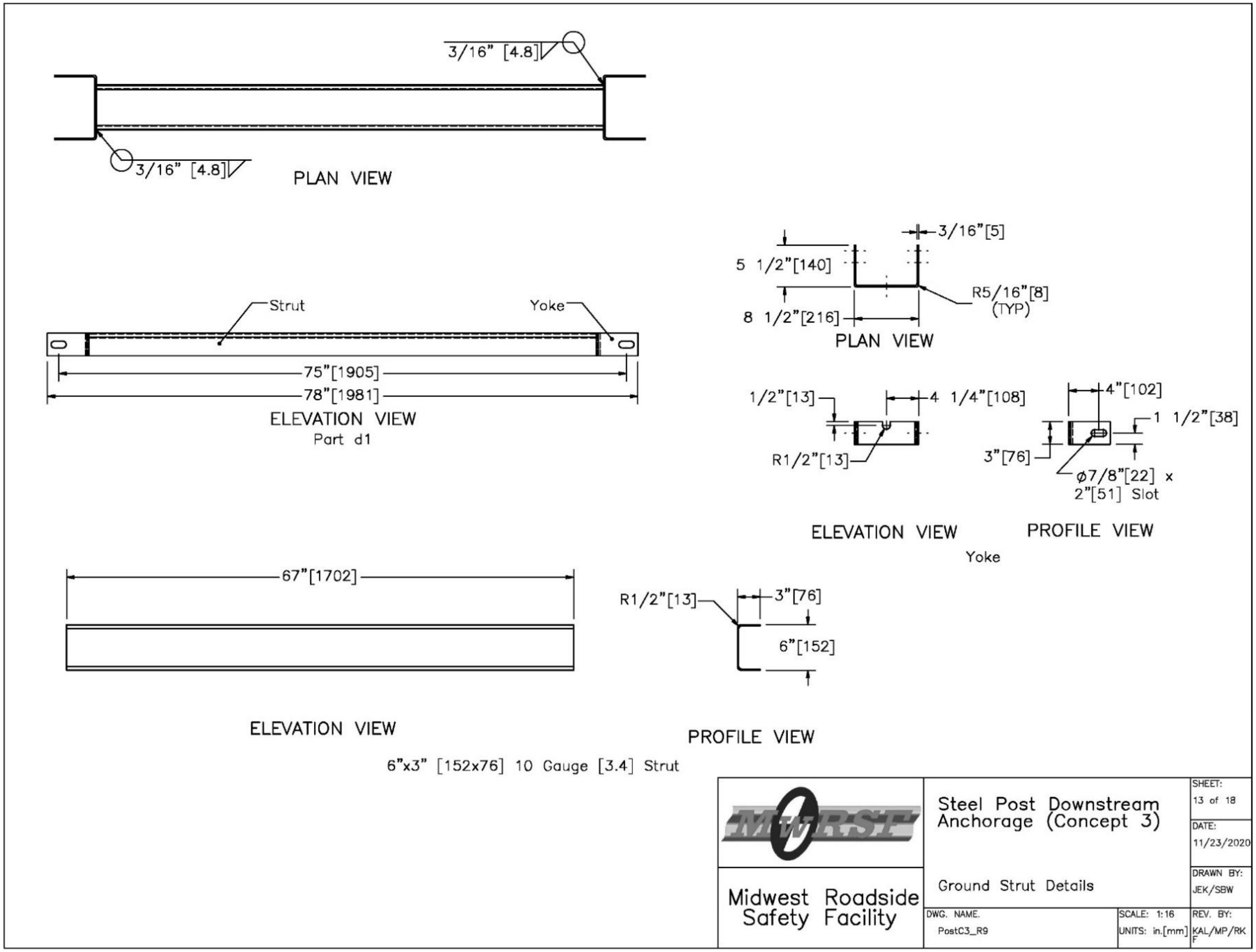


Figure 130. Ground Strut Details, Test No. SPDA-3

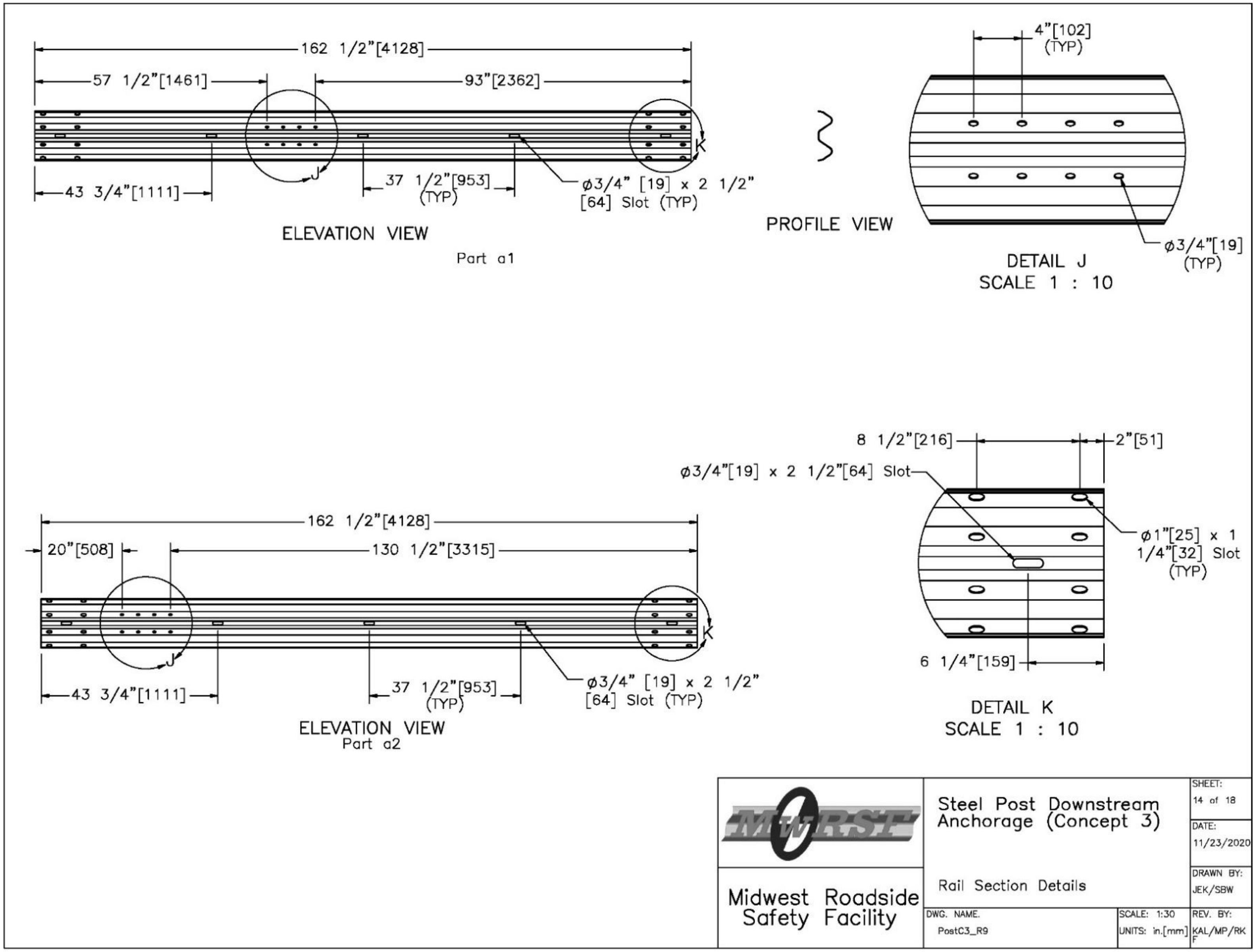


Figure 131. Rail Section Details, Test No. SPDA-3

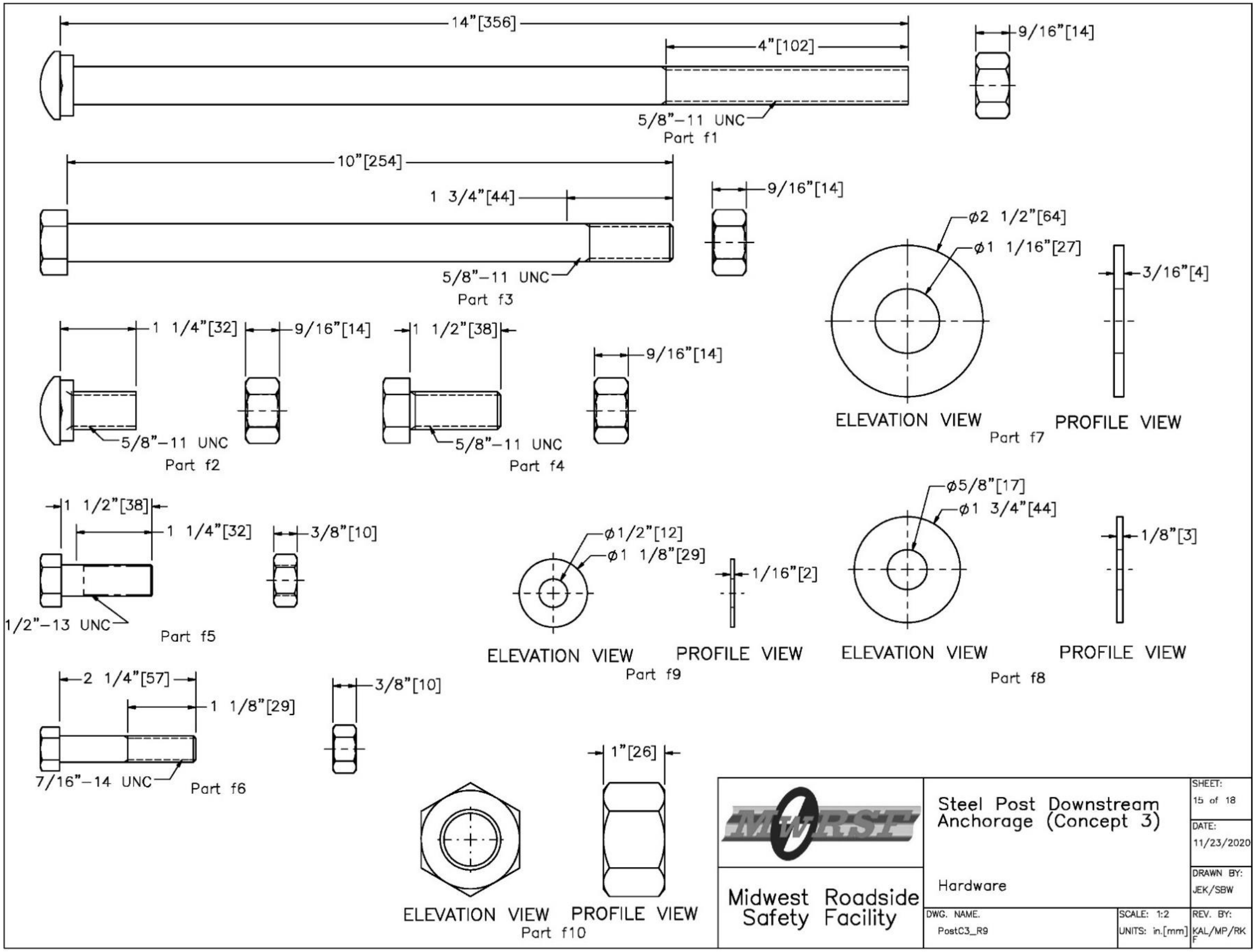


Figure 132. Hardware, Test No. SPDA-3

Item No.	QTY.	Description	Material Spec	Galvanization Spec	Hardware Guide
a1	1	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A123 or A653	–
a2	1	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	–
b1	2	TS6"x8"x3/16" [152x203x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	AASHTO M111 (ASTM A123)	–
b2	2	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 27 3/4" [705] Long Steel Post	ASTM A992	AASHTO M111 (ASTM A123)	–
b3	4	7"x5 1/4"x5/8" [178x133x16] Steel Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
b4	4	5 1/2"x5 1/4"x3/4" [140x133x19] Steel Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
b5	1	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 or ASTM A36 Min. 50 ksi [345 MPa]	AASHTO M111 (ASTM A123)	PWE06
b6	1	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
d1	1	Ground Strut Assembly	ASTM A36	ASTM A123	PFP01
d2	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
d3	1	7 1/2"x3 3/4"x5/8" [191x95x16] Bearing Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
d4	2	2 3/8"x1 7/16"x5/8" [60x37x16] Gusset Plate	ASTM A36	AASHTO M111 (ASTM A123)	–
d5	1	3"x2 3/8"x1/2" [76x60x13] Plate Washer	ASTM A36	AASHTO M111 (ASTM A123)	–
e1	4	3/4" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS	AASHTO M30 (ASTM A741) Type II Class A	–
e2	4	BCT Anchor Cable End Swaged Fitting	Fitting – ASTM A576 Gr. 1035 Stud – ASTM F568 Class C	Fitting – ASTM A153 Stud – ASTM A153 or B695	–
e3	2	115–HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–	–
e4	2	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773	As Supplied	–
e5	6	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3 or Similar	Stock Nos. 1019597 and 1019604 – As Supplied	–	–
e6	4	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNC 6 [M36x4]	Stock No. 107 – As Supplied	–	–
e7	1	1" [25] Dia. Eye Nut	As Supplied	As Supplied	–
e8	2	TLL–50K–PTB Load Cell	–	–	–

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 3)

Bill of Materials

SHEET: 16 of 18
DATE: 11/23/2020
DRAWN BY: JEK/SBW
DWG. NAME. PostC3_R9
SCALE: None
UNITS: in.[mm]
REV. BY: KAL/MP/RK F

Figure 133. Bill of Materials, Test No. SPDA-3

Item No.	QTY.	Description	Material Spec	Galvanization Spec	Hardware Guide
f1	1	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB06
f2	10	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB01
f3	2	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
f4	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
f6	8	7/16" [11] Dia. UNC, 2 1/4" [57] Long Heavy Hex Bolt and Nut	Bolt – ASTM F3125 Gr. 120 (A325) or A354 Gr. BC Nut – ASTM A563DH or A194 Gr. 2H	Bolt – ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 or F2833 Gr. 1 Nut – ASTM A153 or B633 or B695 Class 55 or F1941 or F2329	–
f7	2	1" [25] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC24a
f8	36	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
f9	32	7/16" [11] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
f10	3	1" [25] Dia. Hex Nut	ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FNX24a
f11	1	16D Double Head Nail	–	–	–
g1	2	Portable Concrete Barrier	Min f'c=5,000 psi [34.5 MPa]	–	SWC09
g2	1	Concrete Block – MN Noise Wall	–	–	–

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 3)

Bill of Materials

SHEET: 17 of 18
DATE: 11/23/2020
DRAWN BY: JEK/SBW
DWG. NAME. PostC3_R9
SCALE: None
UNITS: in.[mm]
REV. BY: KAL/MP/RKF

Figure 134 Bill of Materials, Test No. SPDA-3 (Continued)

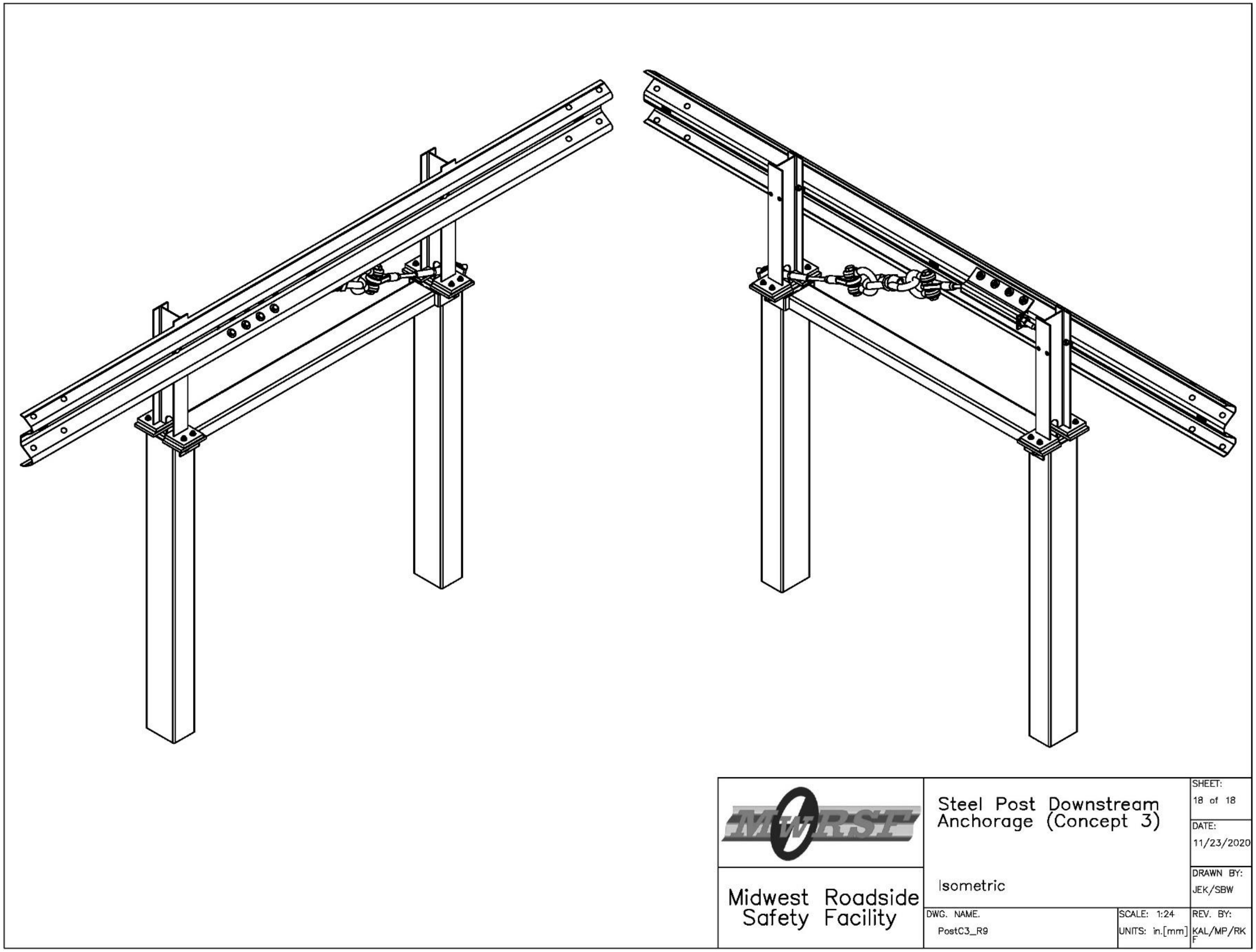


Figure 135 Isometric View, Test No. SPDA-3

Figure 136. Test Setup, Test No. SPDA-3

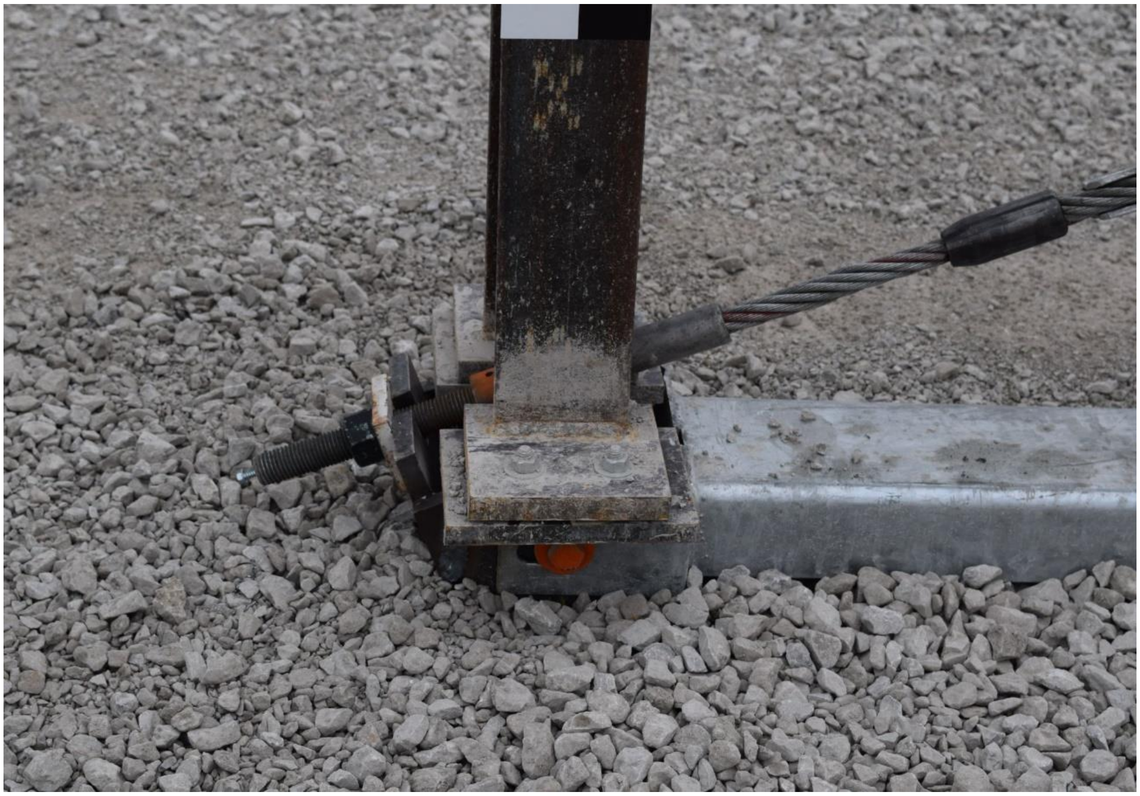


Figure 137. Test Setup, Test No. SPDA-3

7.2 Test No. SPDA-3 Results

During test no. SPDA-3, as the tow cable started to pull the rail, the top portion of both anchor posts began to deflect downstream. The anchor cable released from the bearing plate, and the four bolts connecting the two base plates attached to the top and bottom portions of the first anchor post fractured. Unlike test nos. SPDA-1 and SPDA-2, the rail did not disengage from the posts in test no. SPDA-3 due to the lower peak force developed in the system as compared to test nos. SPDA-1 and SPDA-2.

The force versus time and the displacement versus time curves for test no. SPDA-3 were processed from transducer data using the SLICE-1 and SLICE-2 units and are shown in Appendix H. The anchor cable loads, pull cable loads, and anchor cable displacements are shown in Figure 138. The peak force from the anchor cable and the pull cable were 23.3 kips (103.6 kN) and 29.3 kips (130.3 kN), respectively. The peak loads occurred at 0.120 sec and 0.140 sec, respectively. A maximum displacement of 1.0 in. (25 mm) occurred at 0.130 sec. Time-sequential photographs are shown in Figures 139 and 140. Post-impact photographs are shown in Figure 141.

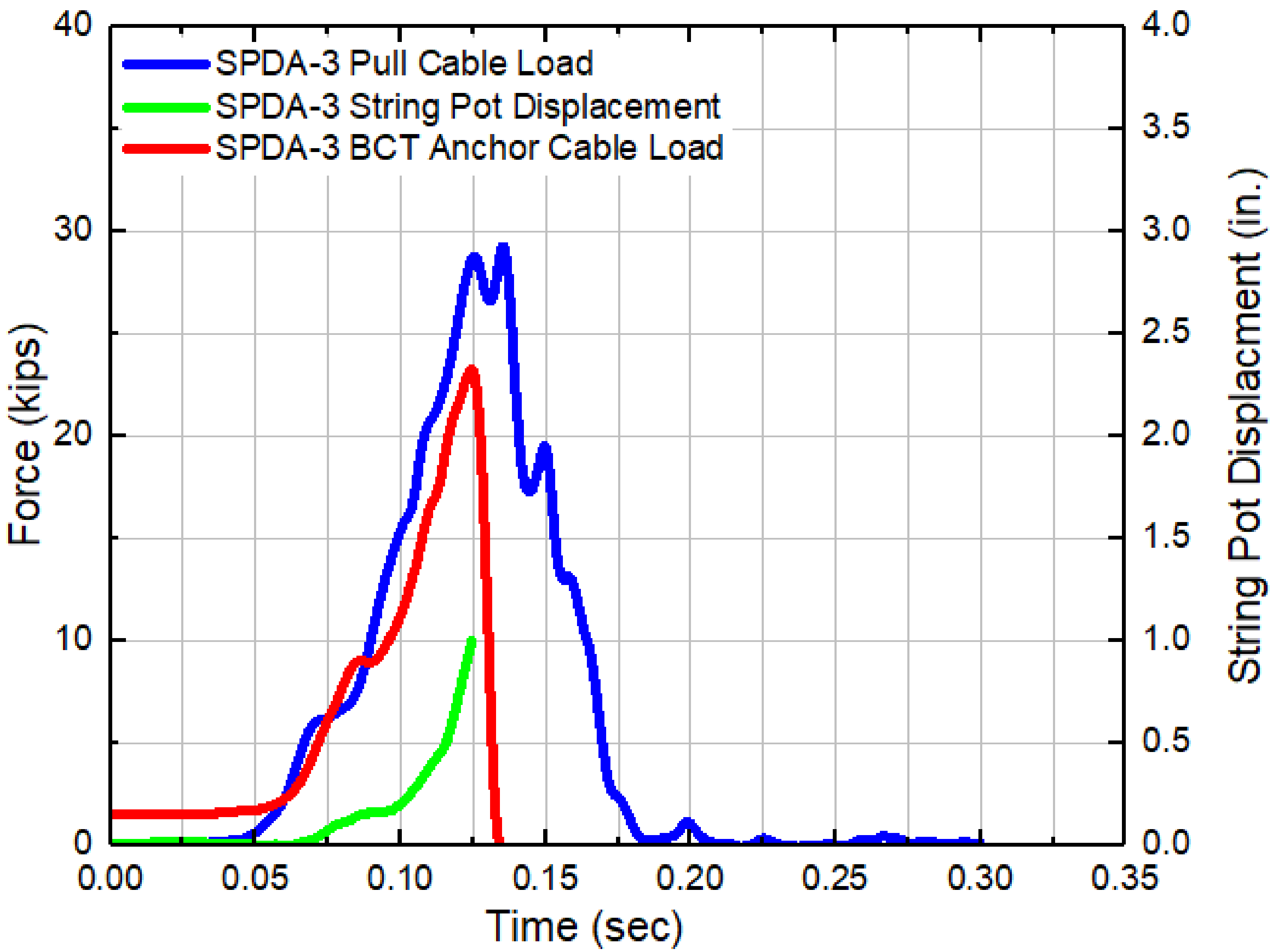
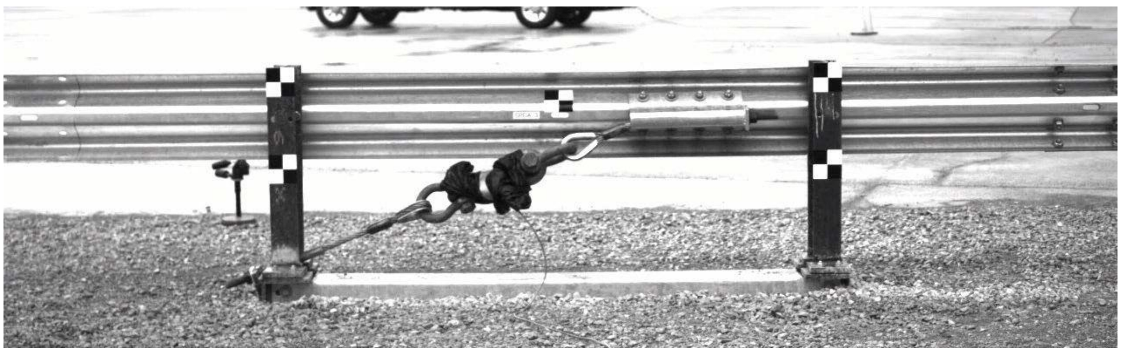
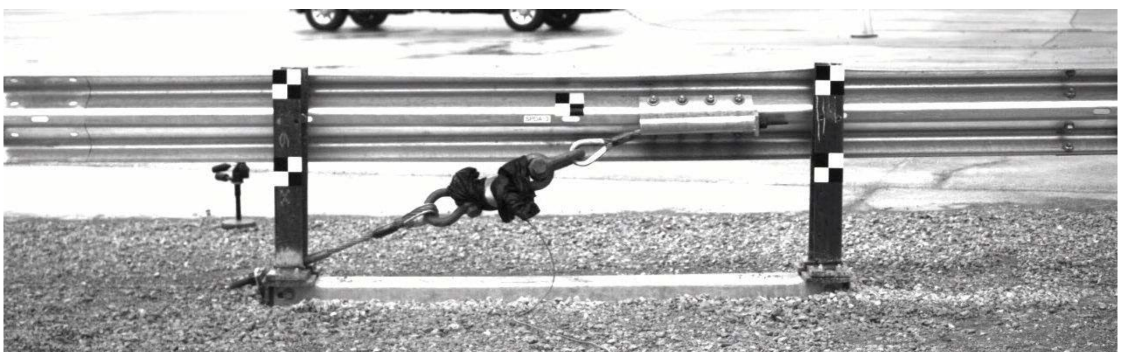


Figure 138. Force vs. Time and Displacement vs. Time, Test No. SPDA-3

0.000 sec



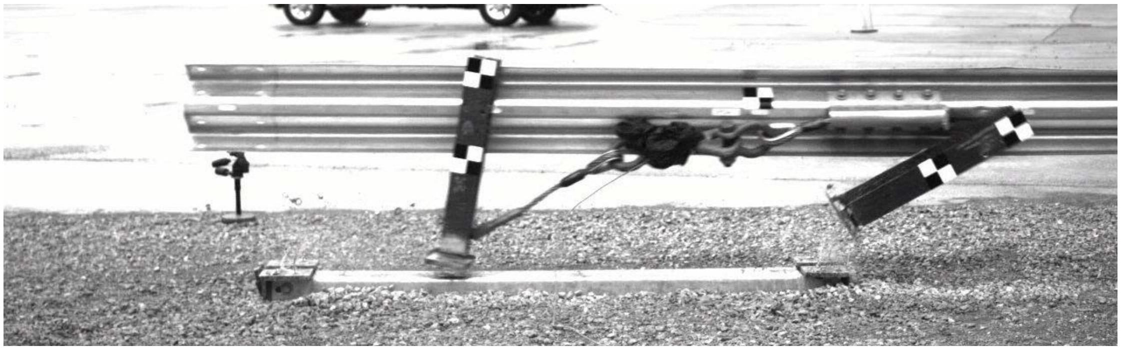
0.030 sec



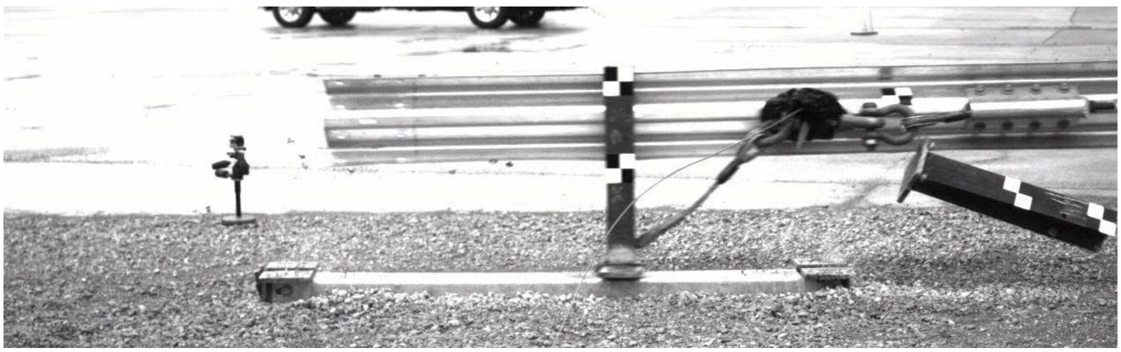
0.060 sec

0.090 sec

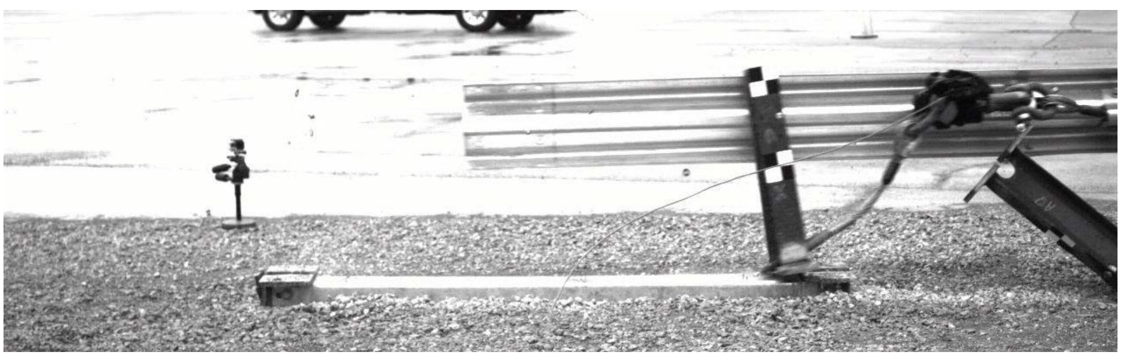
Figure 139. Time-Sequential Photographs, Test No. SPDA-3



0.120 sec



0.150 sec



0.180 sec

0.210 sec

Figure 140. Time-Sequential Photographs, Test No. SPDA-3 (Continued)

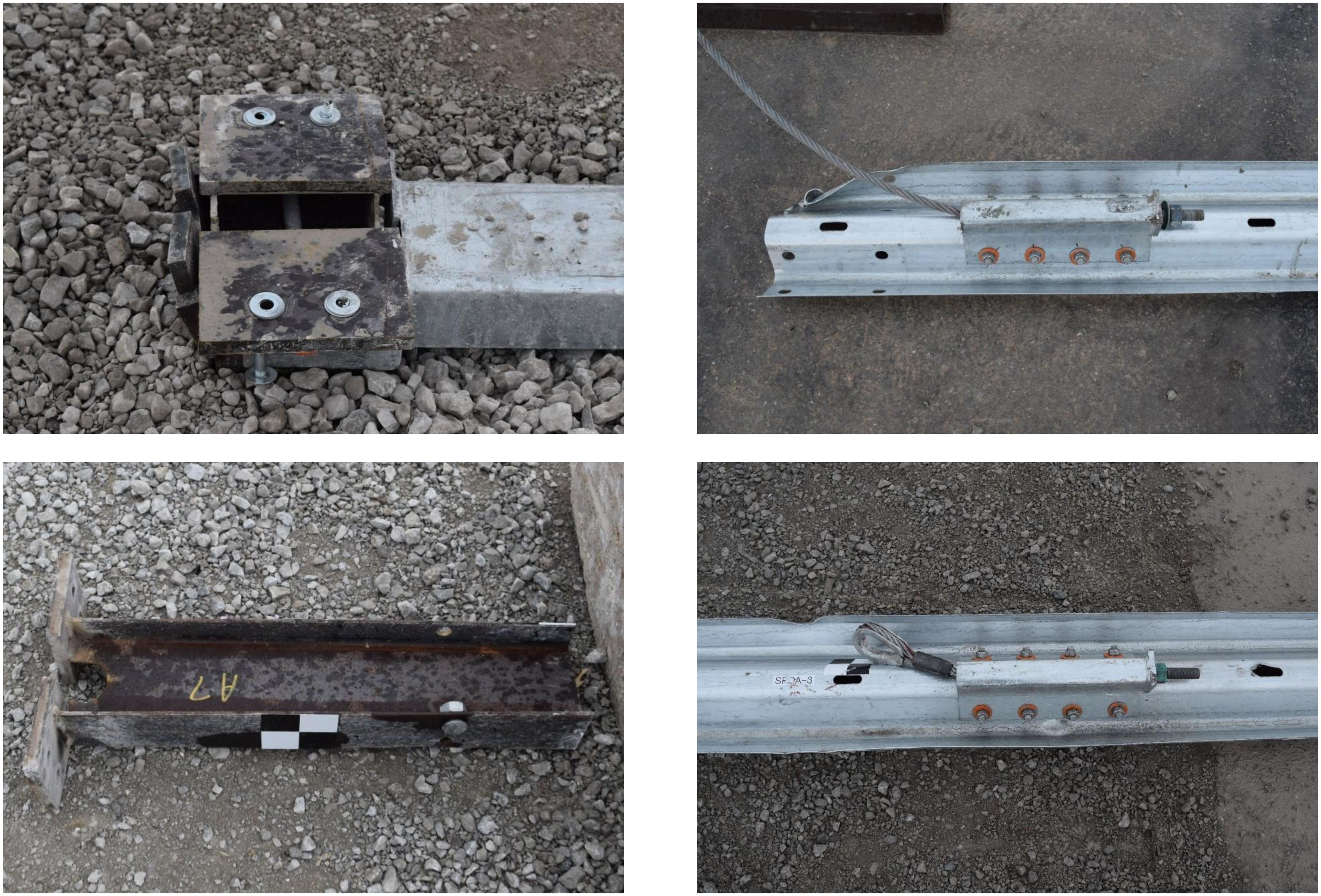


Figure 141. Post-Impact Photographs, Test No. SPDA-3

7.3 Discussion

In test no. SPDA-3, several observations were made. Following the release of the anchor cable from the first anchor post, the top portion of both posts twisted and deflected downstream. The rail deformed at the rail-to-post bolt connection in both anchor posts. The bolts in the slip base of the first anchor post fractured, and the anchor cable released and shifted to the downstream direction together with the first anchor post while the second anchor post twisted. All bolts in the slip base of the second anchor post fractured in tension.

Around 0.110 sec, the anchor cable released from the angled bearing plate. The maximum load sustained by the BCT anchor cable was 23.3 kips (103.6 kN), which occurred at 0.120 sec after the beginning of the test. At 0.130 sec, the four bolts in the first anchor post fractured in tension. The maximum displacement measured by the string potentiometer attached to the end of the BCT anchor cable was 1.0 in. (25 mm), which occurred around 0.130 sec. At this time, the string potentiometer was lifted into the air and shifted to the other side.

The maximum load sustained by the end anchorage was 23.3 kips (103.6 kN). The anchor cable load versus anchor cable displacement is shown in Figure 142. The loading curve of the anchor cable was approximately linear up to 0.5 in. (13 mm). All bolts in each anchor post fractured in tension. The anchor cable was fractured into two pieces. The top portion of the anchor posts were twisted and deformed at the slot in the post. Results from test no. SPDA-3 are summarized in Table 8.

Table 8. Summary of Test Results, Test No. SPDA-3

Test No.	Impact Velocity mph (km/h)	Peak Force kips (kN)	Displacement at Peak Load in. (mm)	Energy at Peak Load kips-in. (kJ)	Failure Mechanism	Component Damage	Attachment Damage
SPDA-3	19.2 (30.9)	23.3 (103.6)	1.0 (25.0)	15.8 (1.8)	Anchor post fractured in tension	Anchor cable slipped from the bearing plate	All bolts fractured after anchor cable slipped off

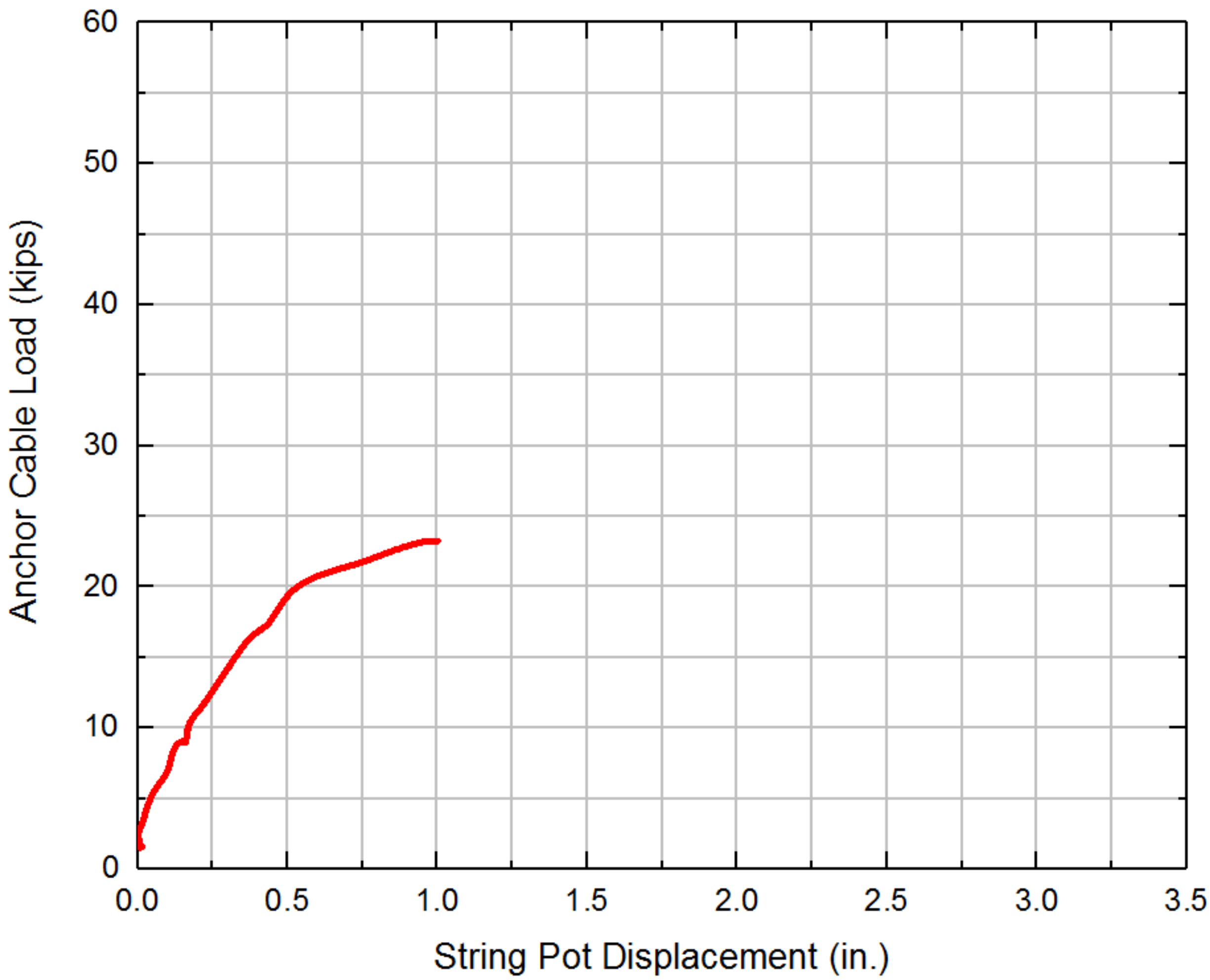


Figure 142. Anchor Cable Load vs. String Pot Displacement, Test No. SPDA-3

8 DYNAMIC COMPONENT TESTING − DESIGN CONCEPT NO. 4

8.1 System Details – Concept No. 4

During test no. SPDA-1, the anchorage system with the cable passing through the top portion of the anchor post performed sufficiently, but the pull cable yielded after the pull load exceeded its capacity. Thus, the four bolts connecting the top and bottom posts were not loaded to their full capacity. As such, the maximum anchorage capacity of this concept was not known. Thus, an additional test was conducted to determine the maximum anchorage capacity of the system.

Test no. SPDA-4 was a dynamic jerk test of design concept no. 4, which was the anchorage system with the cable passing through the top portion of the anchor post (similar to design concept no. 1). The system was modified slightly prior to rerunning the jerk test. The height of the bearing plate was decreased from 7 in. (178 mm) to 6¼ in. (159 mm). It was believed that it would transfer the load distribution in the top and bottom portions of the anchor post more evenly to where more load could be transferred to the foundation tube. This could potentially increase the overall anchorage capacity. Calculations were performed to determine the modified width of the bearing plate and are shown in Appendix D.

The design included two modified UBSPs with a slot at the bottom of the top W6x8.5 anchor post in order to pass the cable of the post and an opening in the top base plate to allow the cable to release when the top portion of the post disengaged. The test matrix and test set up are shown in Figures 143 through 159. Photographs of the test setup are shown in Figures 160 and 161. Material specifications, mill certifications, and certificates of conformity for the system materials used in test no. SPDA-4 are shown in Appendix G.

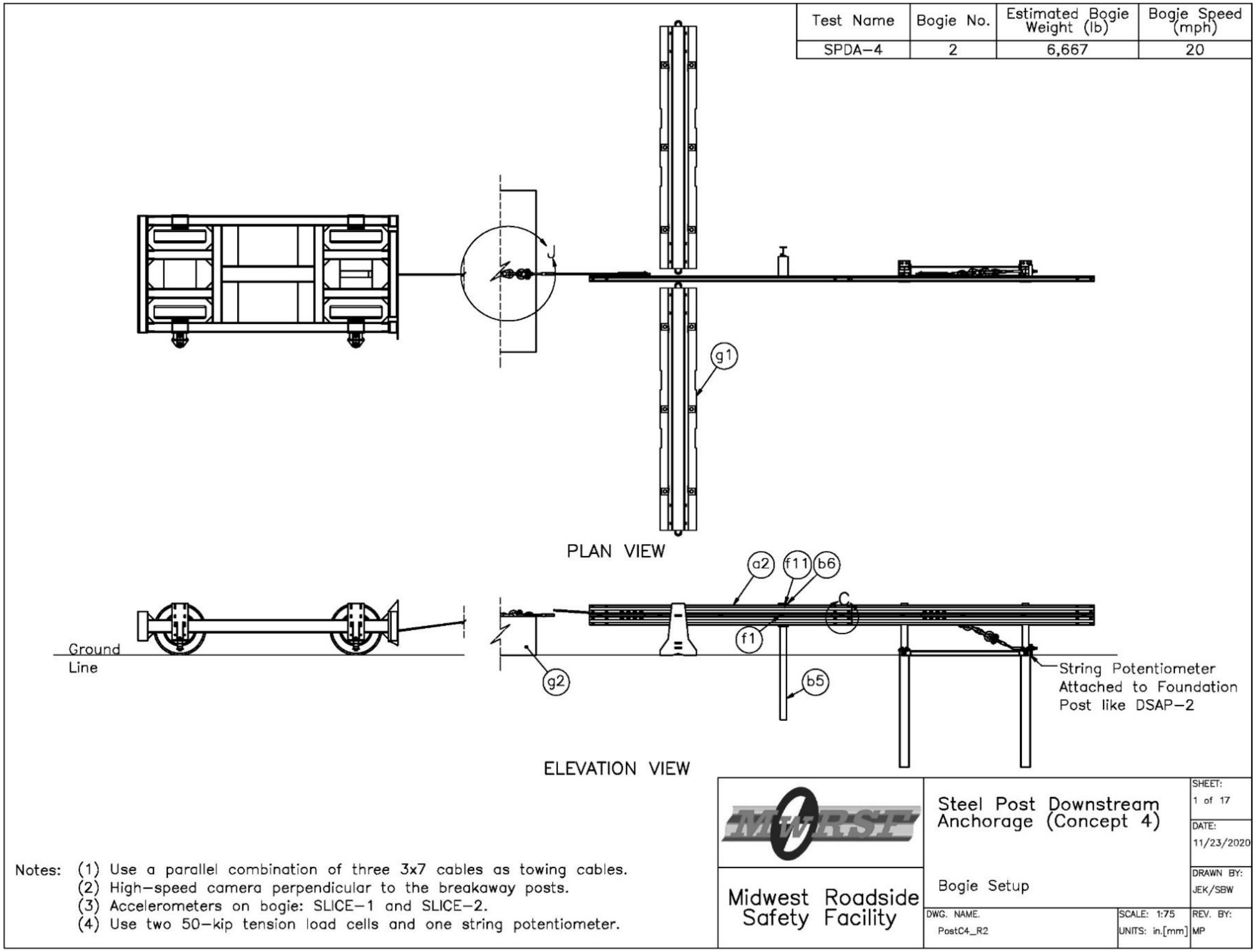


Figure 143. Bogie Setup, Test No. SPDA-4

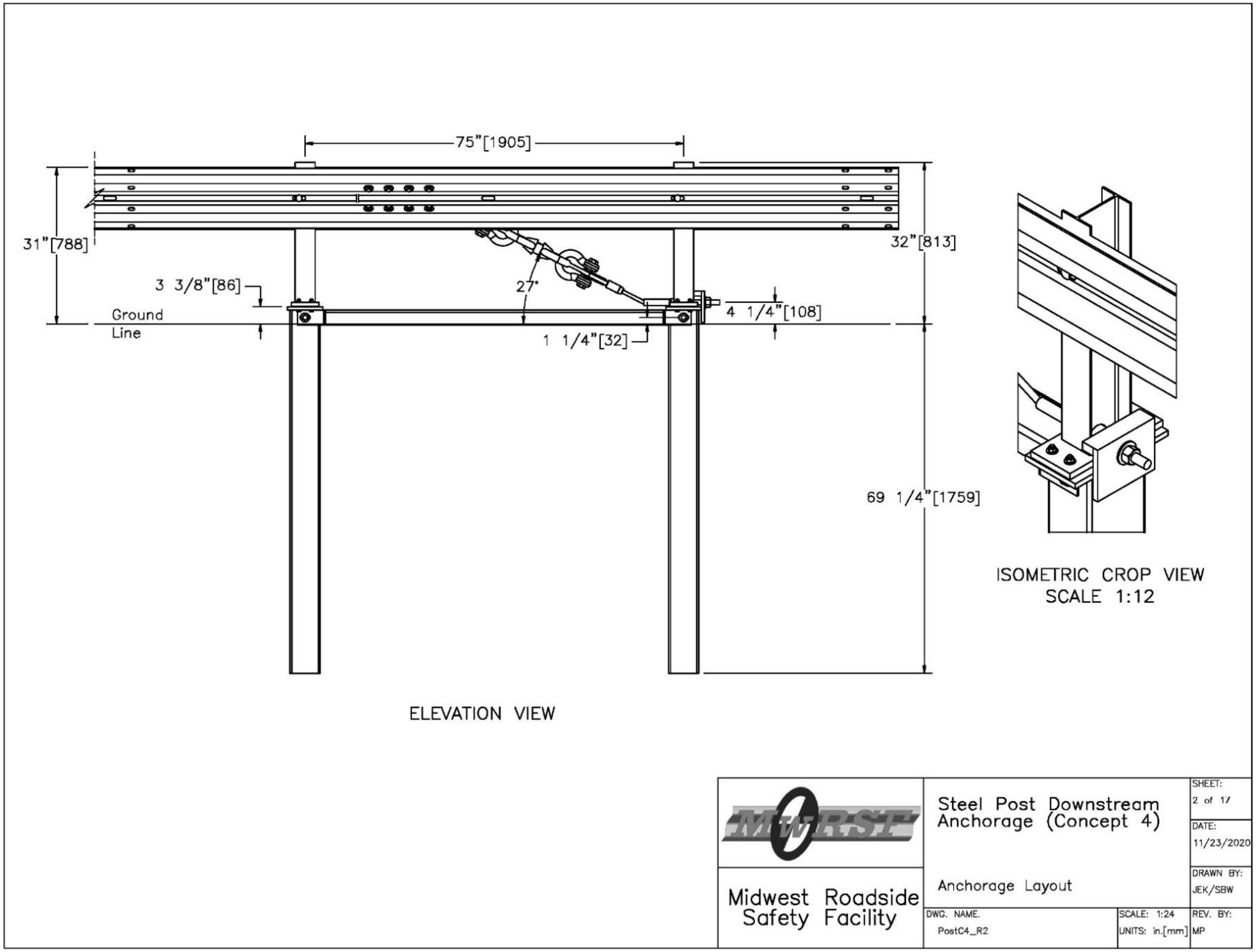


Figure 144. Anchorage Layout, Test No. SPDA-4

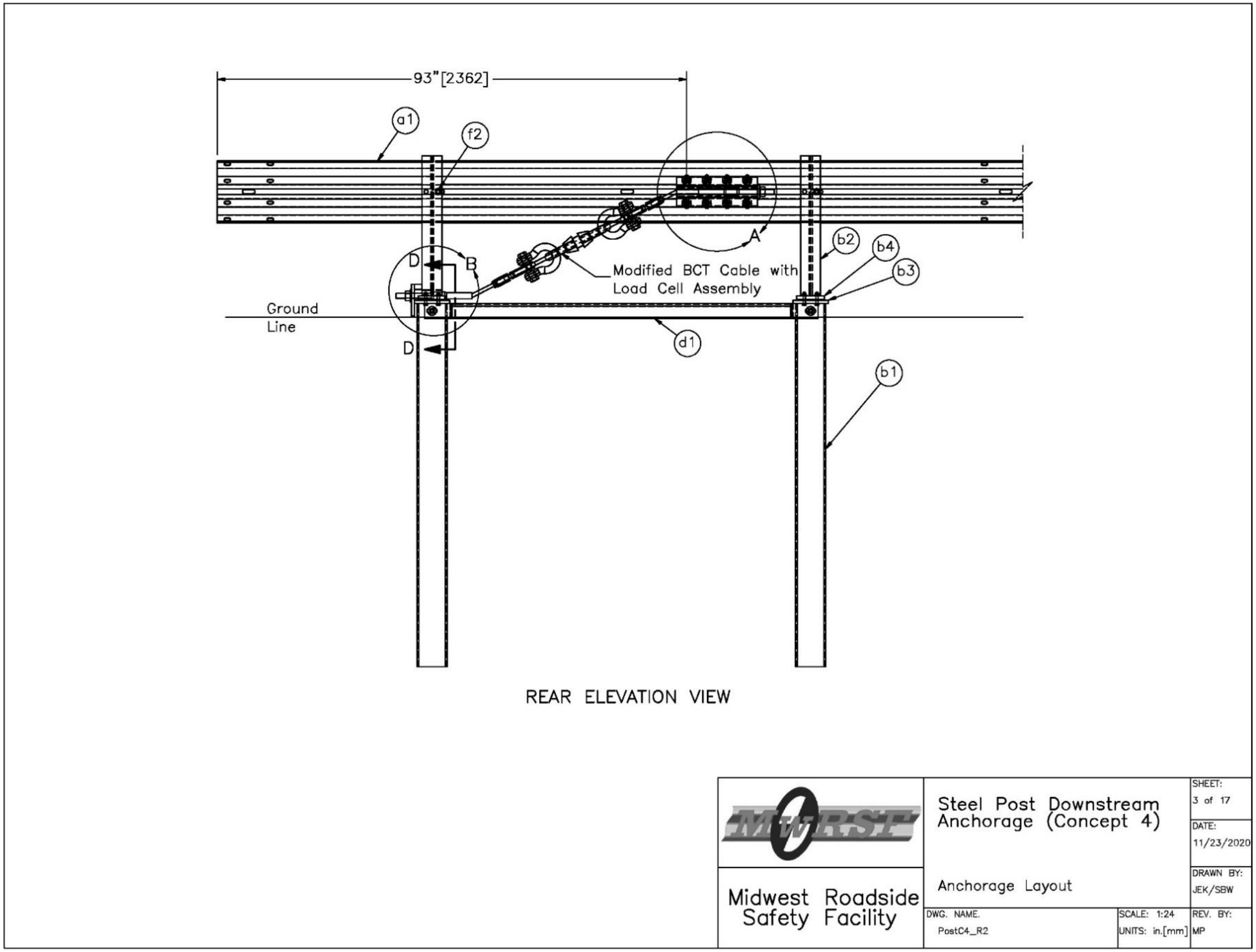


Figure 145. Anchorage Layout, Test No. SPDA-4

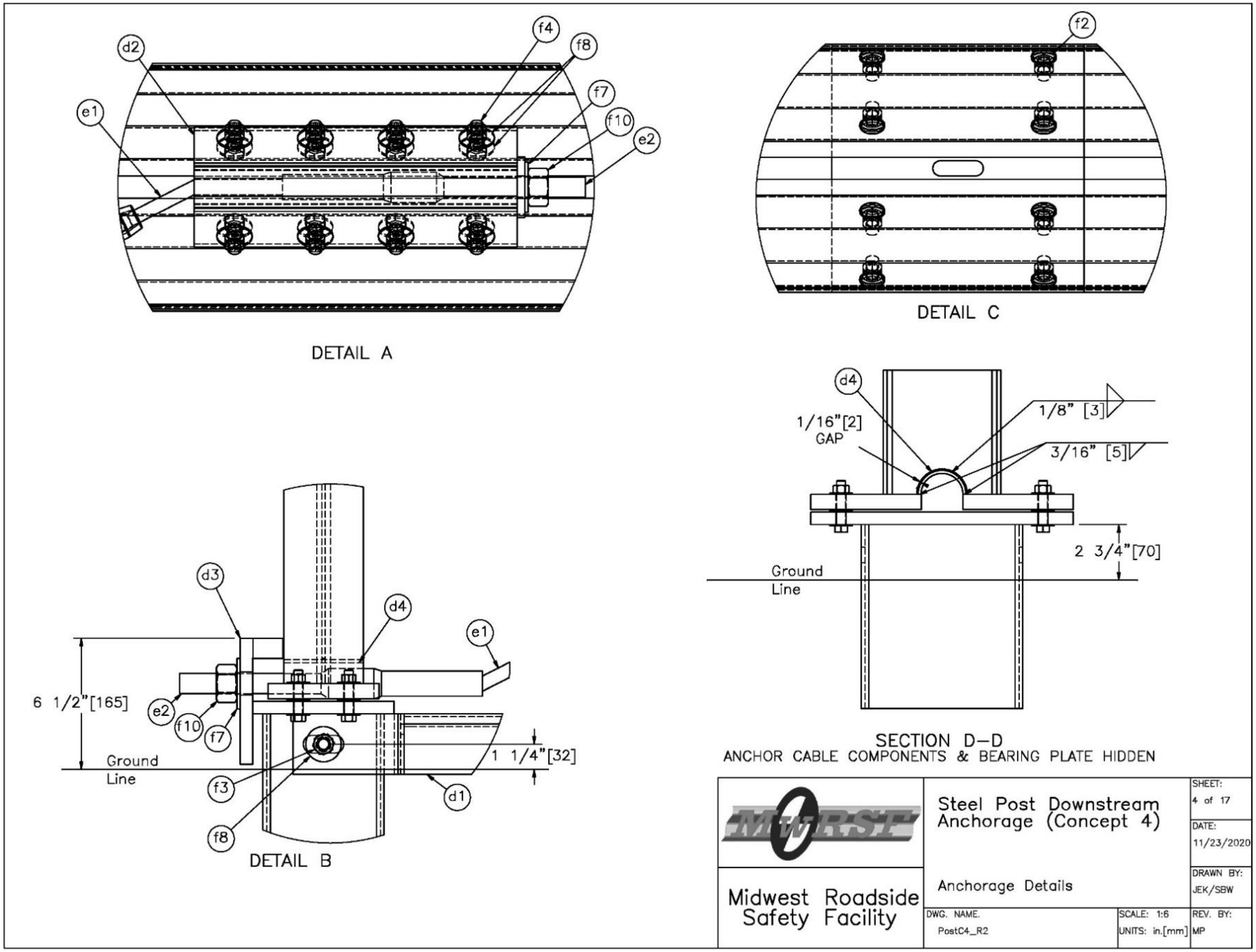


Figure 146. Anchorage Details, Test No. SPDA-4

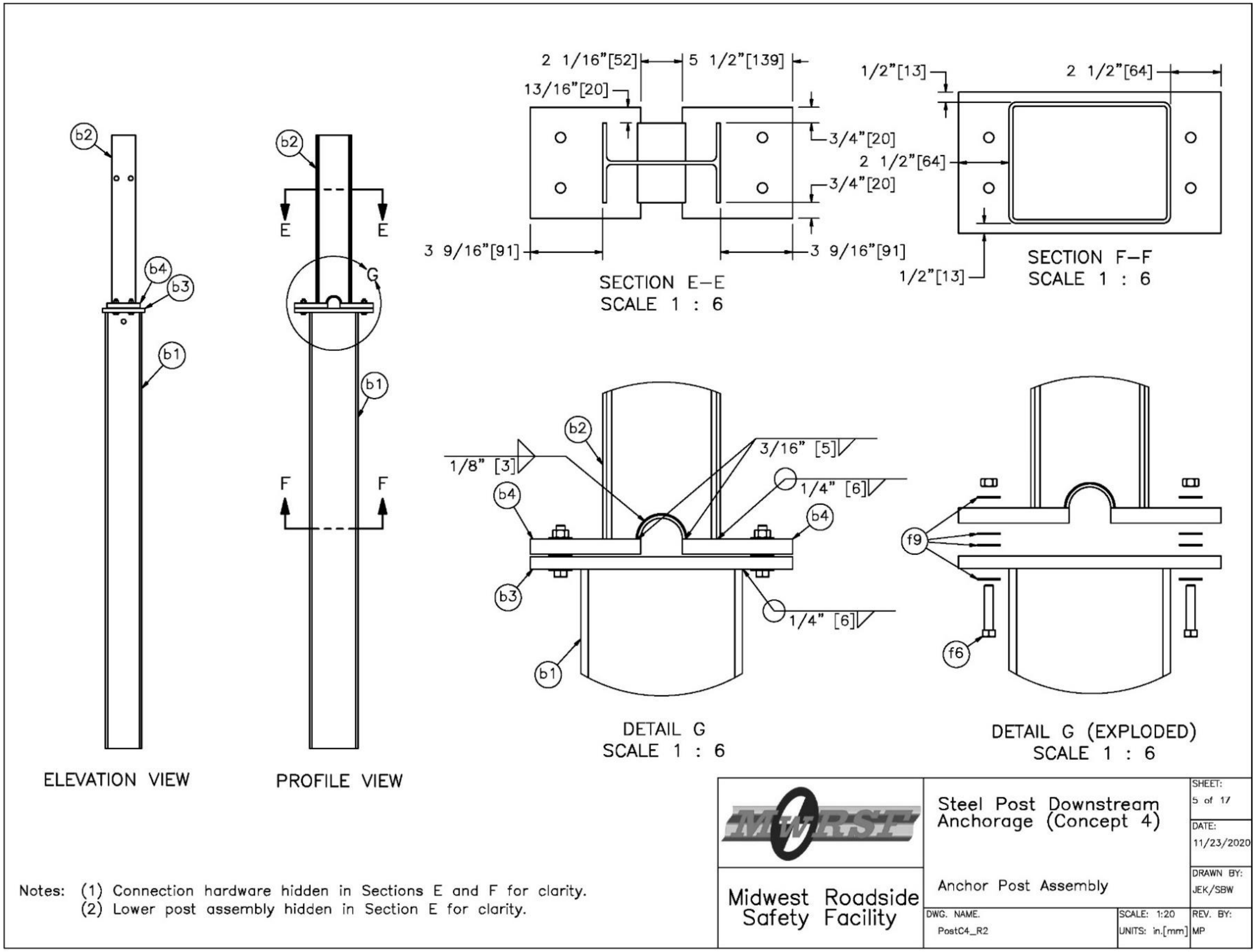


Figure 147. Anchor Post Assembly, Test No. SPDA-4

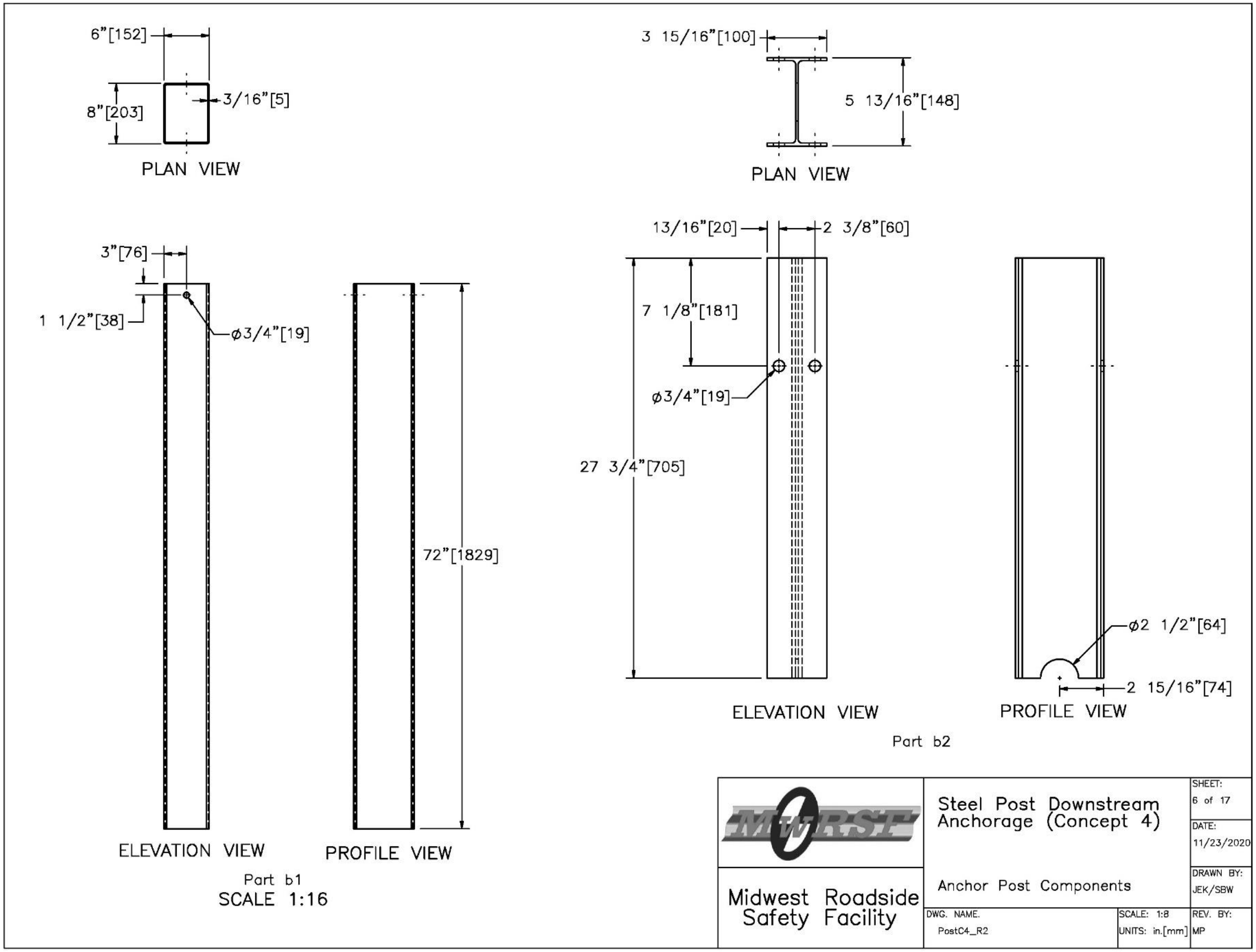


Figure 148. Anchor Post Components, Test No. SPDA-4

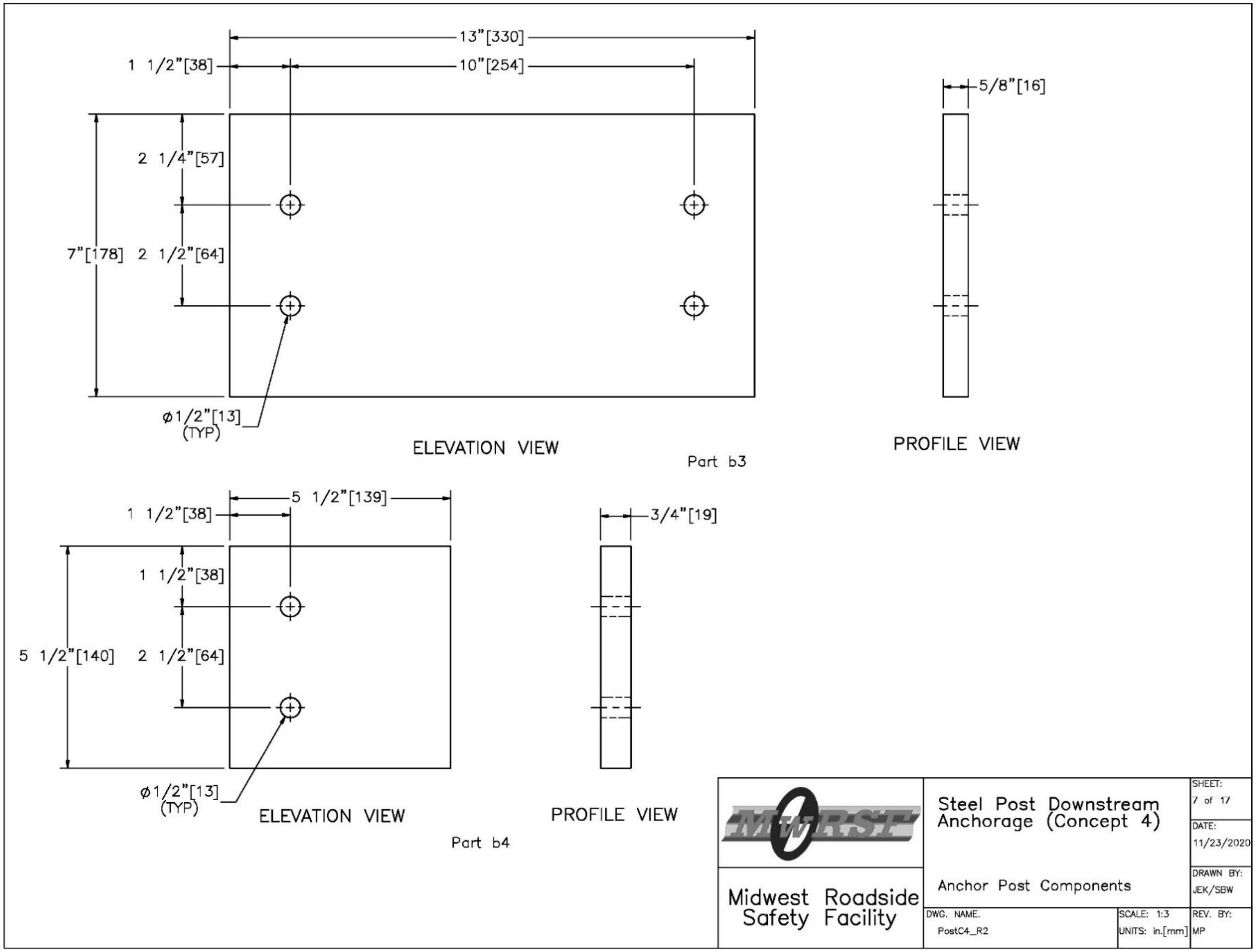


Figure 149. Anchor Post Components, Test No. SPDA-4

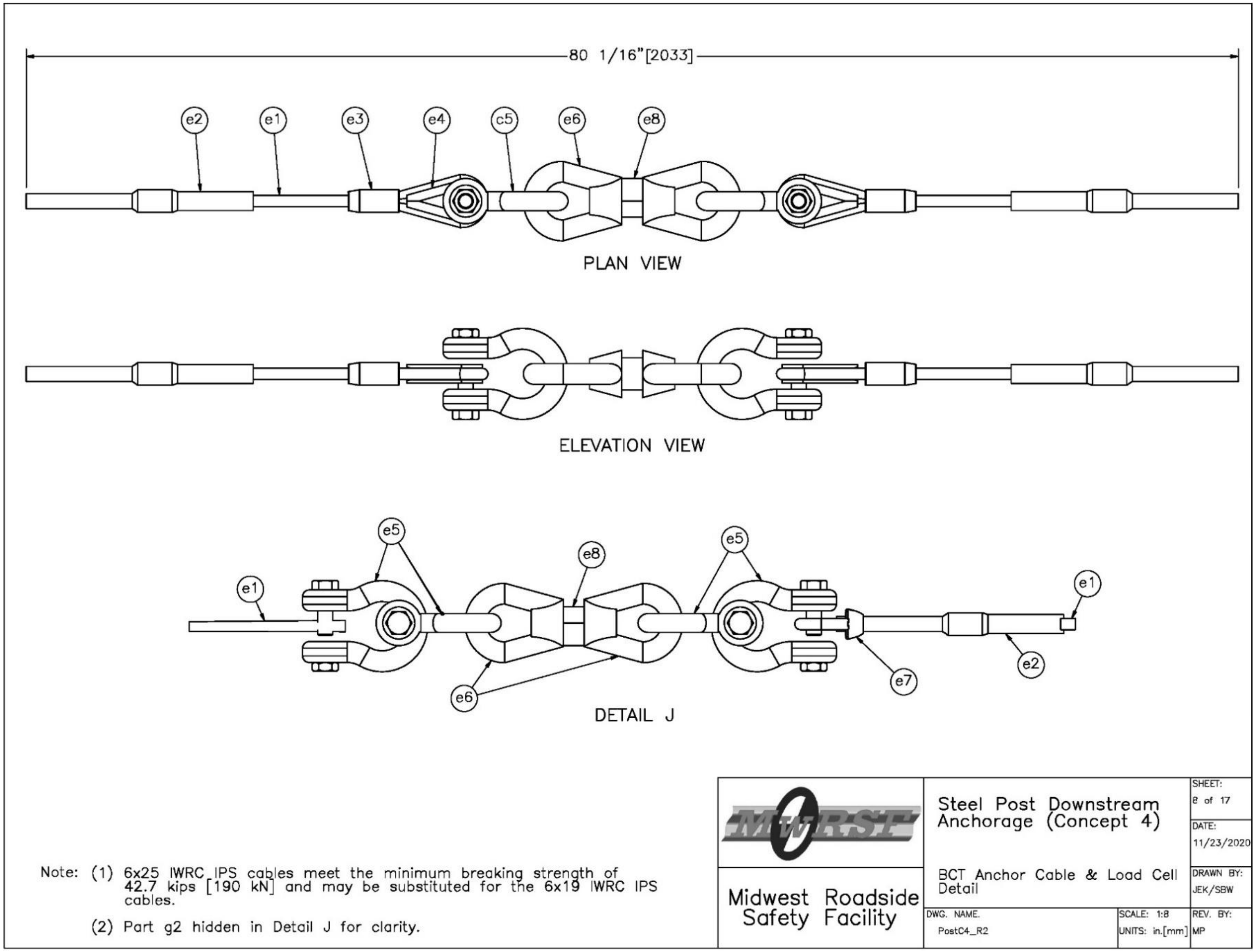


Figure 150. BCT Anchor Cable and Load Cell Detail, Test No. SPDA-4

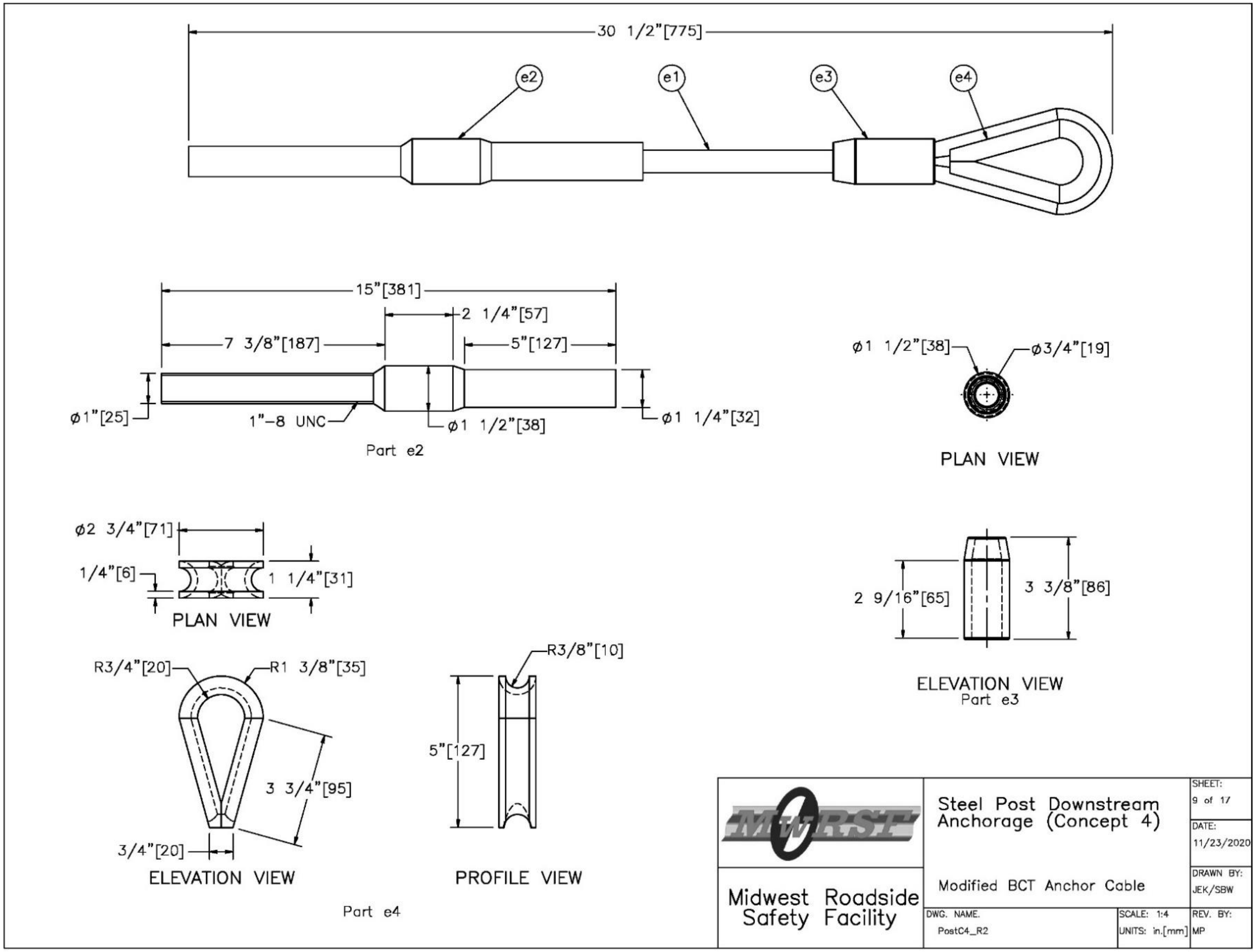


Figure 151. Modified BCT Anchor Cable, Test No. SPDA-4

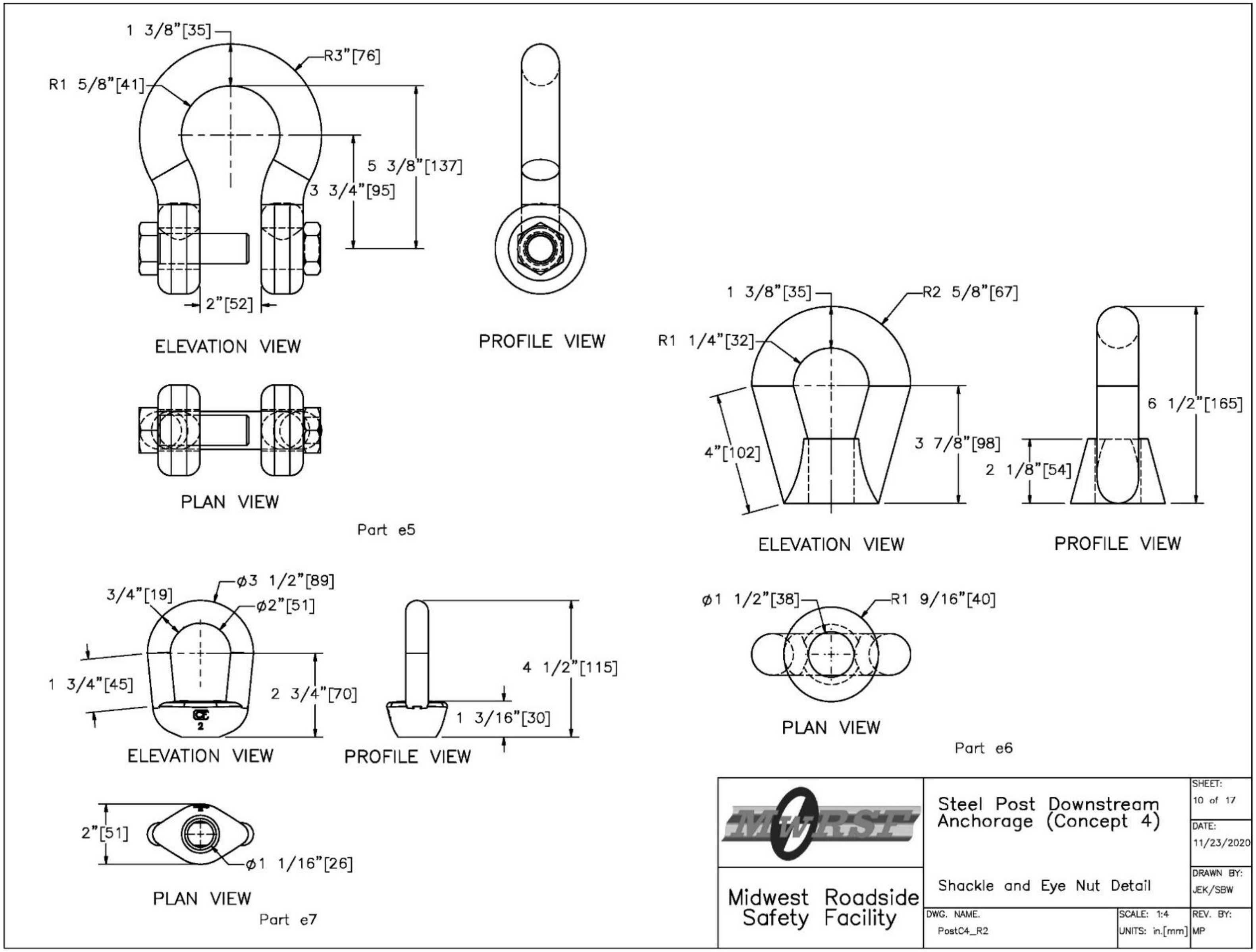


Figure 152. Shackle and Eye Nut, Test No. SPDA-4

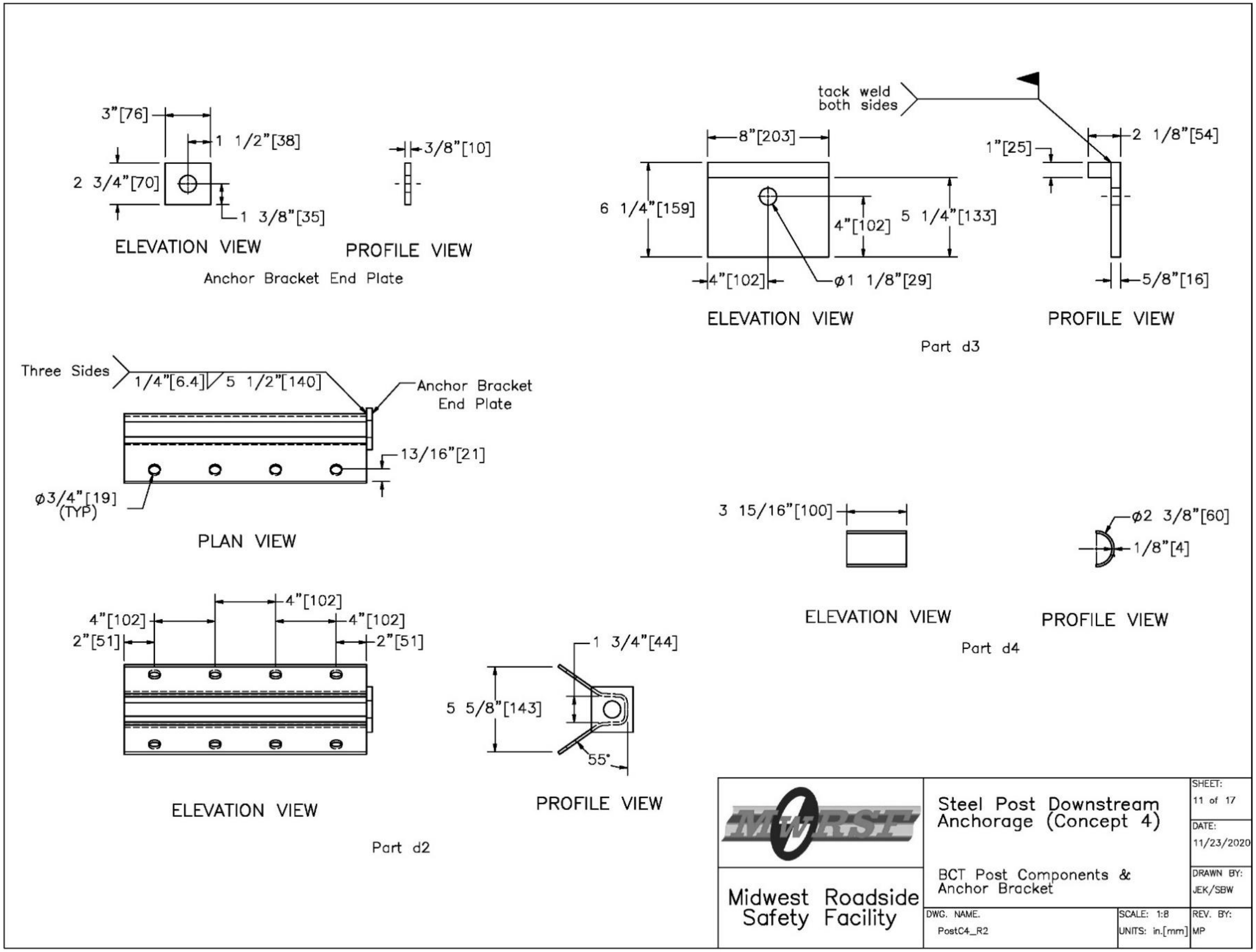


Figure 153. BCT Post Components and Anchor Bracket Details, Test No. SPDA-4

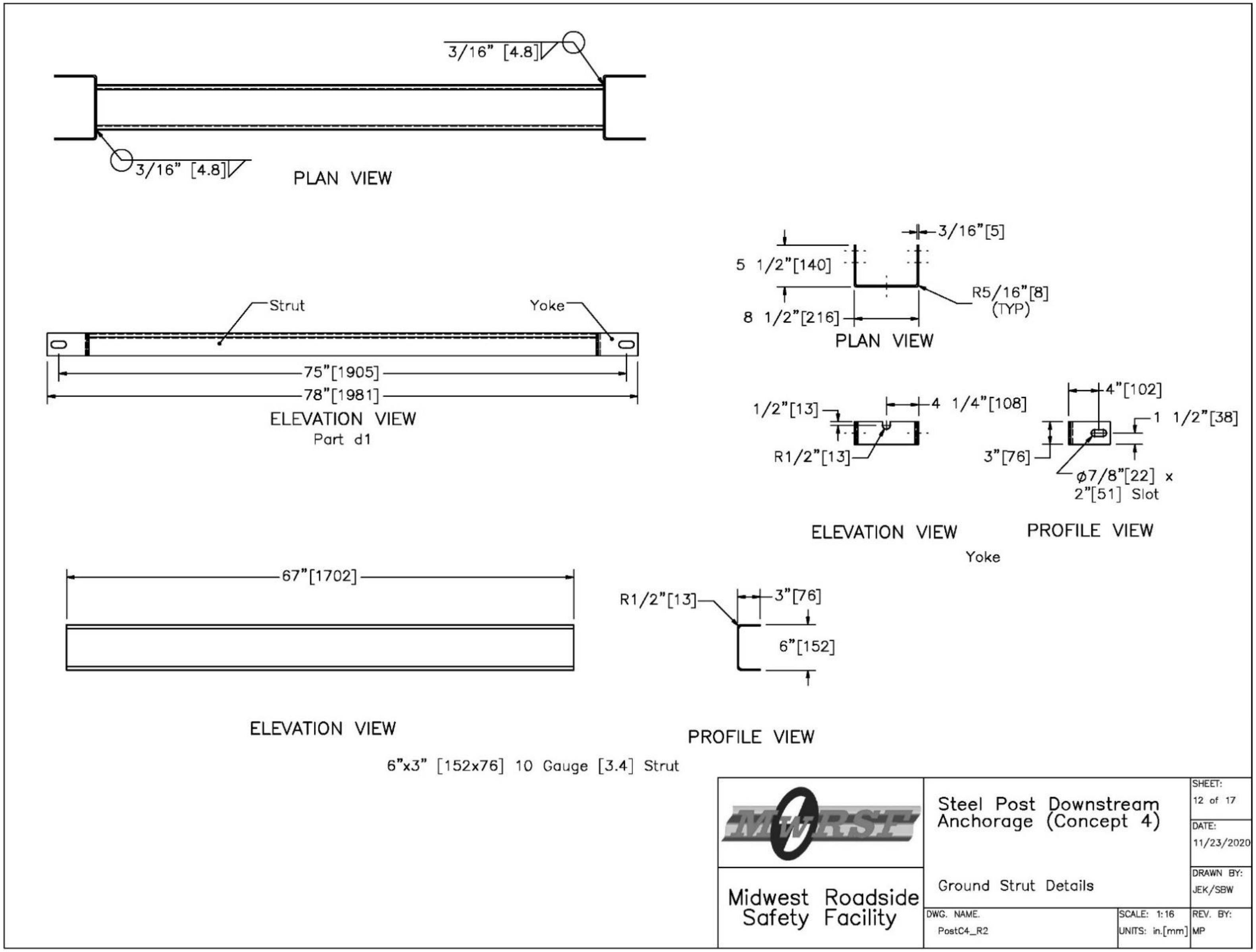


Figure 154. Ground Strut Details, Test No. SPDA-4

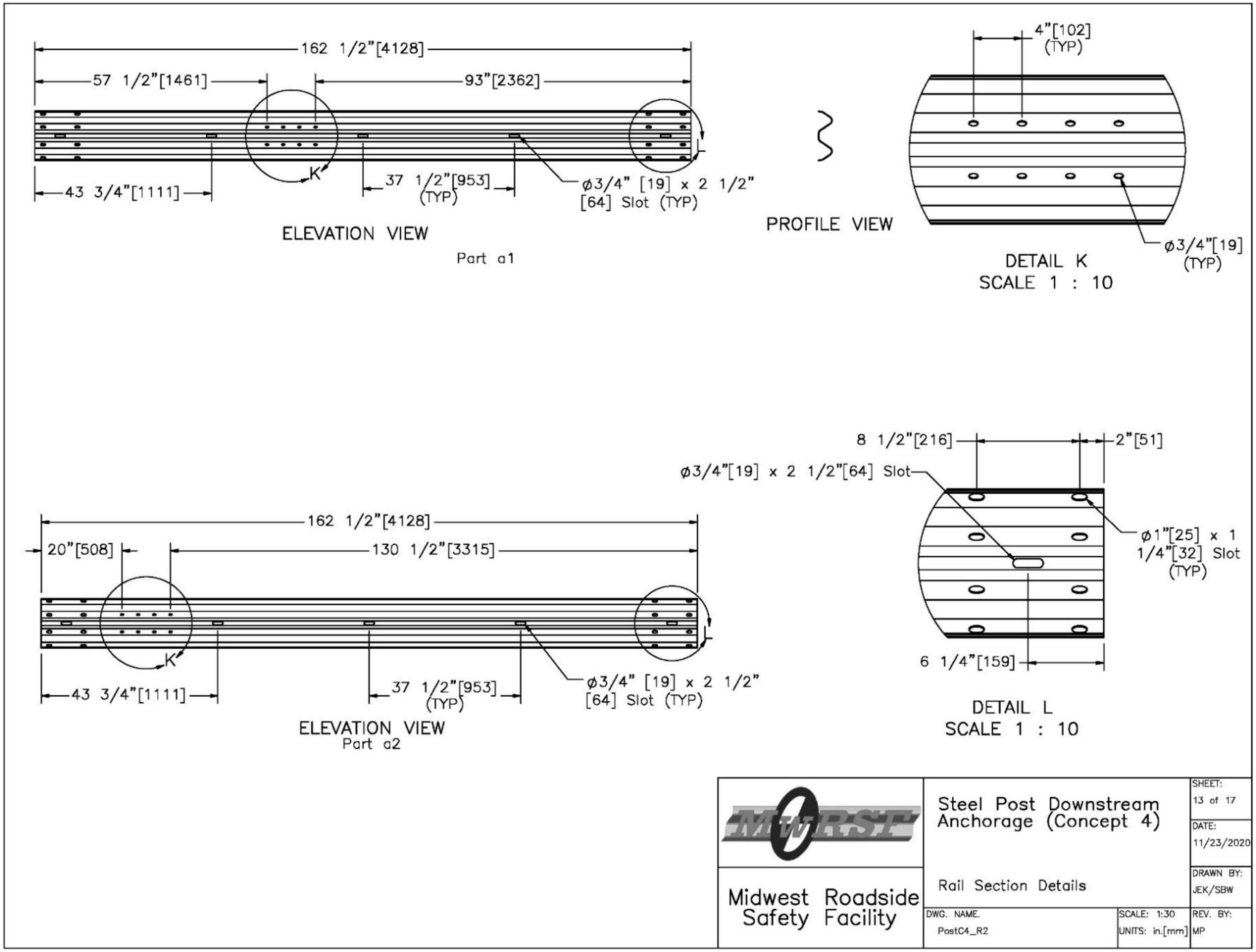


Figure 155. Rail Section Details, Test No. SPDA-4

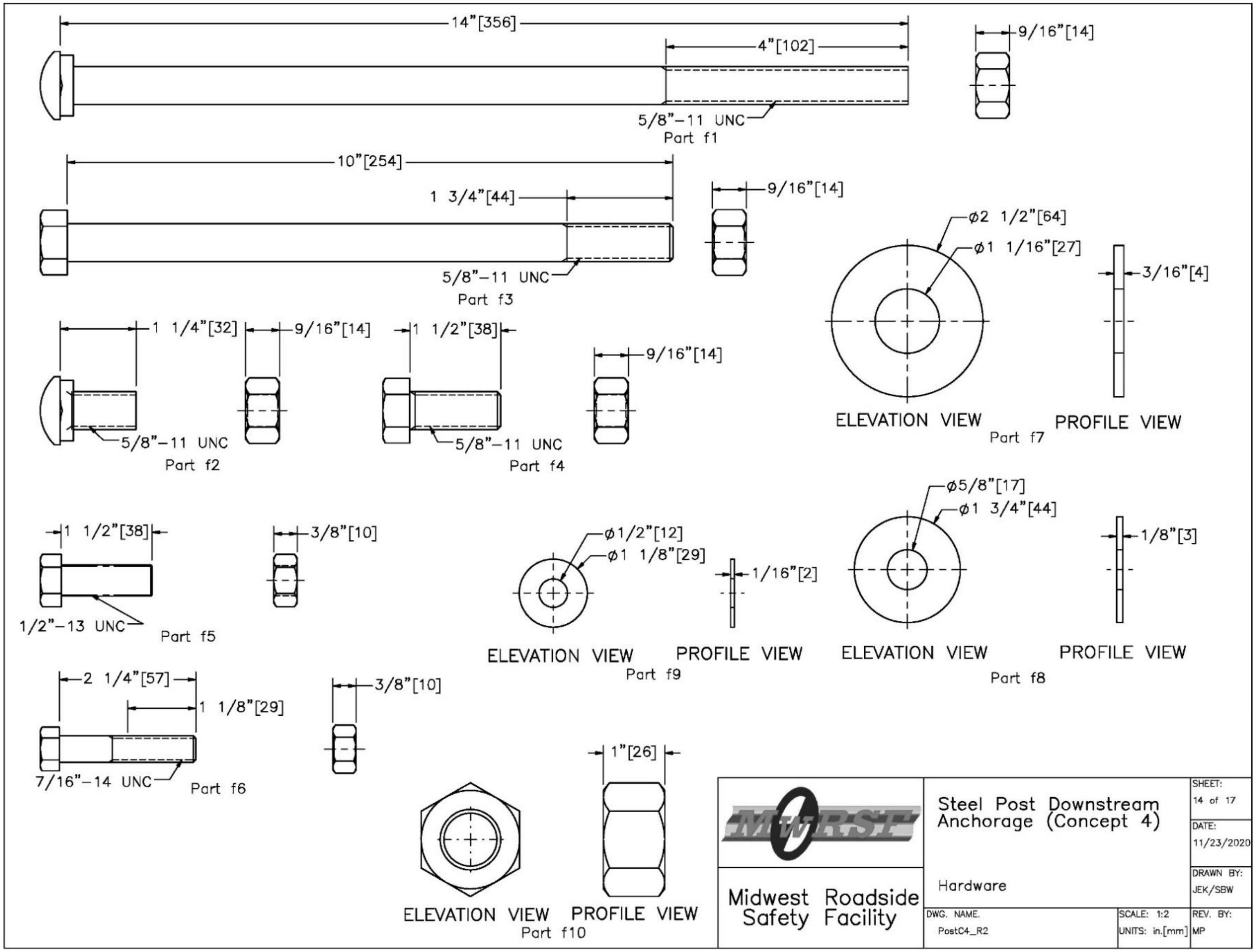


Figure 156. Bolt and Washer Details, Test No. SPDA-4

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	–	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A123 or A653	–
a2	–	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	–
b1	–	TS6"x8"x3/16" [152x203x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	–
b2	–	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 27 3/4" [705] Long Steel Post	ASTM A992	ASTM A123	–
b3	–	13"x7"x5/8" [330x178x16] Steel Plate	ASTM A36	ASTM A123	–
b4	–	5 1/2"x5 1/2"x3/4" [140x140x19] Steel Plate	ASTM A36	ASTM A123	–
b5	–	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa]	ASTM A123	PWE06
b6	–	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
c1x	–	7/16" Dia. [11] Hex Nut	ASTM A563DH	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	–
d1	–	Ground Strut Assembly	ASTM A36	ASTM A123	PFP01
d2	–	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
d3	–	8"x6 1/4"x2 1/8" [203x159x54] Bearing Plate	ASTM A36	ASTM A123	–
d4	–	2 3/8" [60] O.D. x 3 15/16" [100] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	–
e1	4	3/4" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS	ASTM A741 Type II Class A	–
e2	–	BCT Anchor Cable End Swaged Fitting	Fitting – ASTM A576 Gr. 1035 Stud – ASTM F568 Class C	Fitting – ASTM A153 Stud – ASTM A153 or B695	–
e3	–	115–HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–	–
e4	–	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773	As Supplied	–
e5	–	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3 or Similar	Stock Nos. 1019597 and 1019604 – As Supplied	–	–
e6	–	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNC 6 [M36x4]	Stock No. 107 – As Supplied	–	–
e7	–	1" [25] Dia. Eye Nut	As Supplied	As Supplied	–
e8	–	TLL–50K–PTB Load Cell	–	–	–

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 4)

Bill of Materials

SHEET: 15 of 17
DATE: 11/23/2020
DRAWN BY: JEK/SBW
REV. BY: MP
DWG. NAME. PostC4_R2
SCALE: None
UNITS: in.[mm]

Figure 157. Bill of Materials, Test No. SPDA-4

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
f1	–	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB06
f2	–	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB01
f3	–	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
f4	–	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
f6	–	7/16" [11] Dia. UNC, 2 1/4" [57] Long Heavy Hex Bolt and Nut	Bolt – ASTM F3125 Gr. 120 (A325) or A354 Gr. BC Nut – ASTM A563DH or A194 Gr. 2H	Bolt – ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 or F2833 Gr. 1 Nut – ASTM A153 or B633 or B695 Class 55 or F1941 or F2329	–
f7	–	1" [25] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC24a
f8	–	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
f9	–	7/16" [11] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
f10	–	1" [25] Dia. Hex Nut	ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FNX24a
f11	–	16D Double Head Nail	–	–	–
g1	–	Portable Concrete Barrier	Min f'c=5,000 psi [34.5 MPa]	–	SWC09
g2	–	Concrete Block – MN Noise Wall	–	–	–

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 4)

Bill of Materials

SHEET: 16 of 17

DATE: 11/23/2020

DRAWN BY: JEK/SBW

DWG. NAME. PostC4_R2

SCALE: None UNITS: in.[mm]

REV. BY: MP

Figure 158. Bill of Materials, Test No. SPDA-4 (Continued)

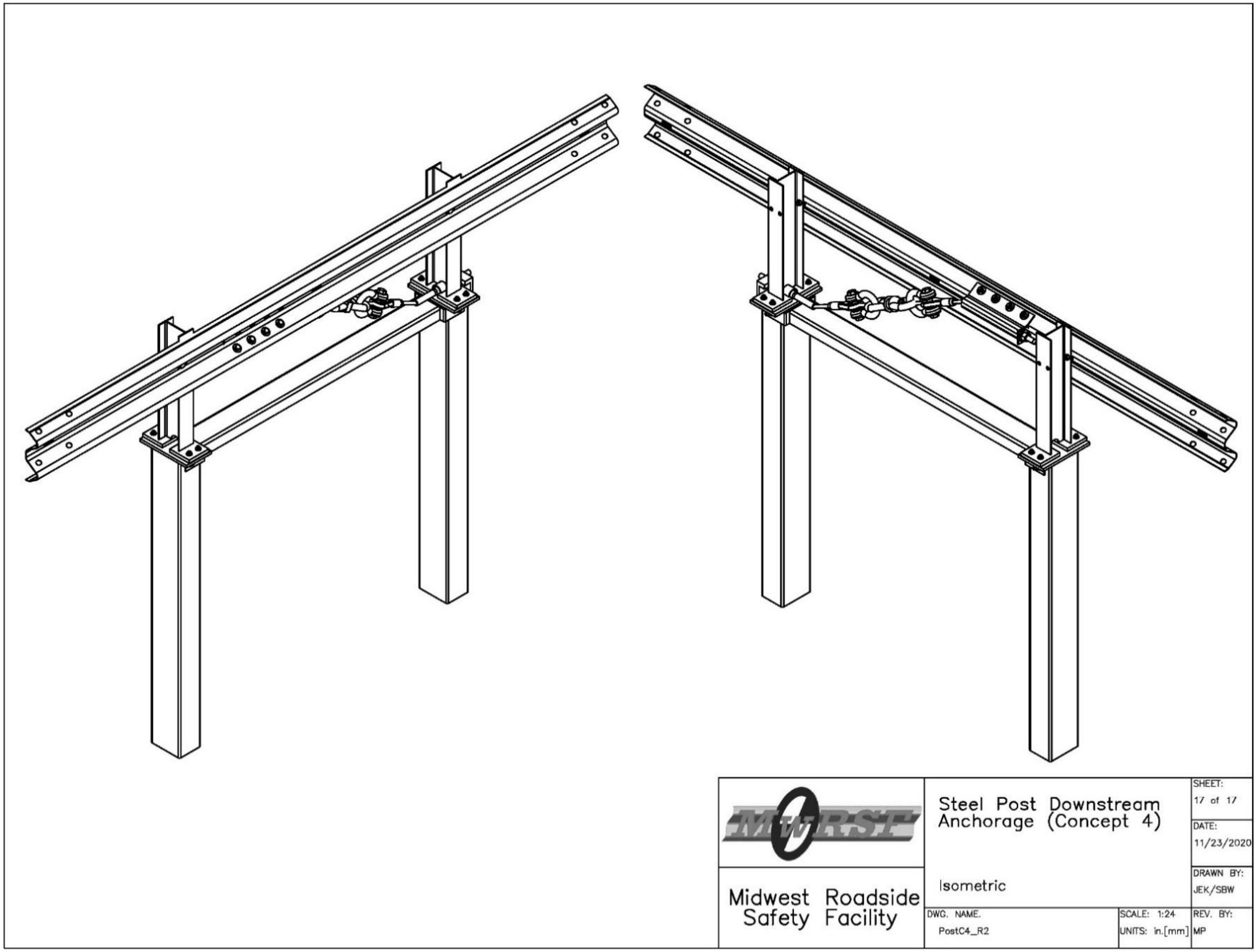


Figure 159. Isometric View, Test No. SPDA-4

Figure 160. Test Setup, Test No. SPDA-4

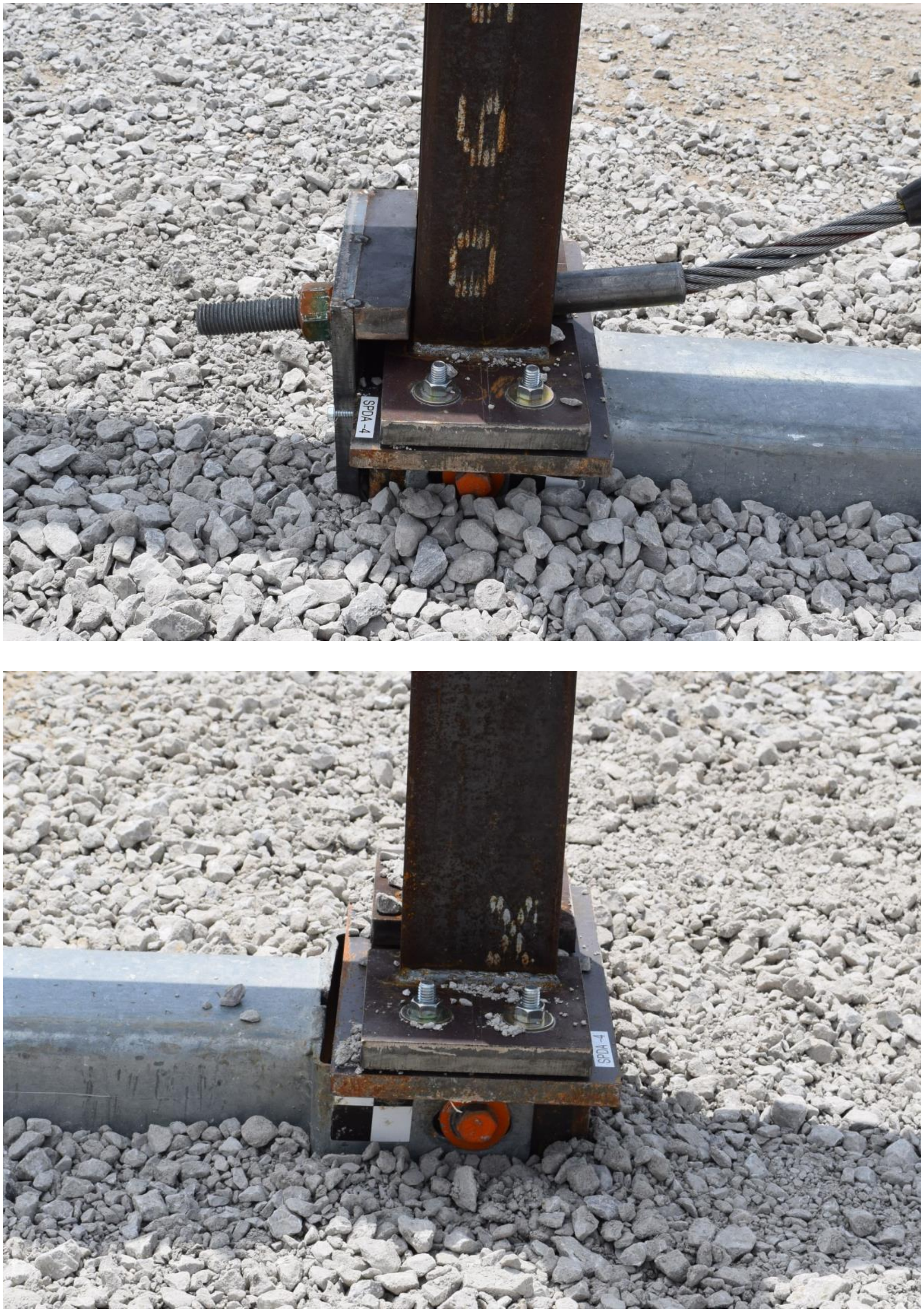


Figure 161. Test Setup, Test No. SPDA-4

8.2 Test No. SPDA-4 Results

During test no. SPDA-4, the rail and the top portion of the anchor posts began to deflect downstream when the tow cable started to pull the rail. The pull force was immediately transferred to the two foundation tubes, which rotated in the soil. When the cable anchor was tensioned, a downward vertical force component was applied to the rail. This force twisted the second anchor post and deformed the rail at the second anchor post bolt connection, causing the rail to tear vertically and move downward. Next, all four bolts in the slip base of the first anchor post fractured in tension. The anchor cable and the bearing plate then released from the first anchor post and moved downstream with the anchor post. The bearing plate and the anchor cable remained attached to the top base plate during the test.

The force versus time and the displacement versus time curves for test no. SPDA-4 were processed from transducer data using the SLICE-1 and SLICE-2 units and are shown in Appendix H. The anchor cable loads, pull cable loads, and anchor cable displacement are shown in Figure 162. The peak loads from the anchor cable and the pull cable load cell were 49.5 kips (220.2 kN) and 58.8 kips (261.6 kN), respectively. The peak loads occurred at 0.086 sec and 0.096 sec, respectively. Two displacements of 1.7 in. (43 mm), and 1.9 in. (48 mm) were measured by the string potentiometer attached to the foundation tube of the first anchor post, which occurred at 0.086 sec and 0.096 sec, respectively. Time-sequential photographs are shown in Figures 163 and 164. Post-impact photographs are shown in Figure 165.

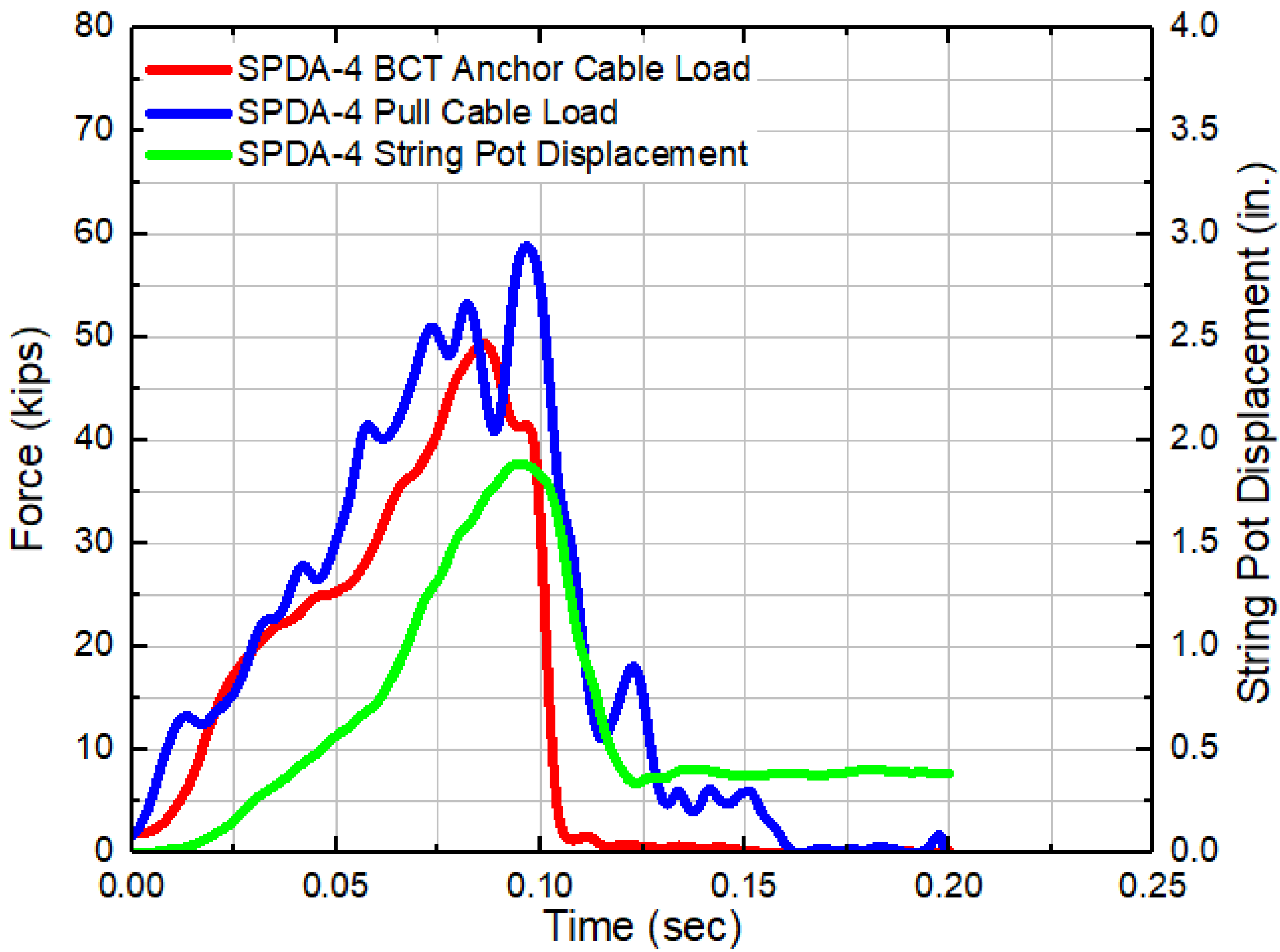
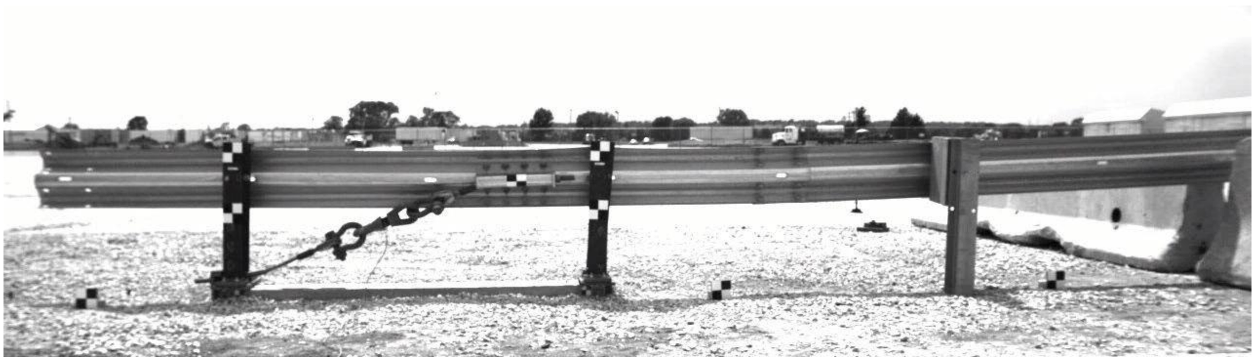
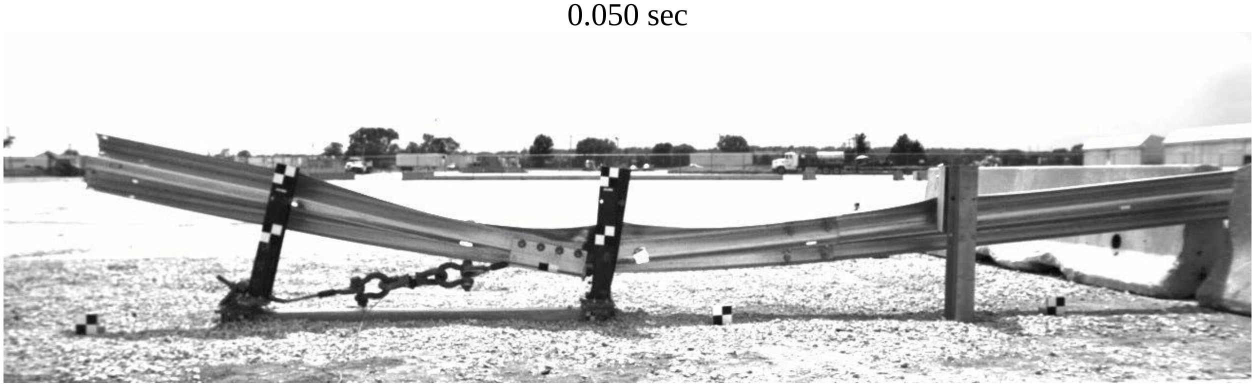


Figure 162. Force vs. Time and Displacement vs. Time, Test No. SPDA-4

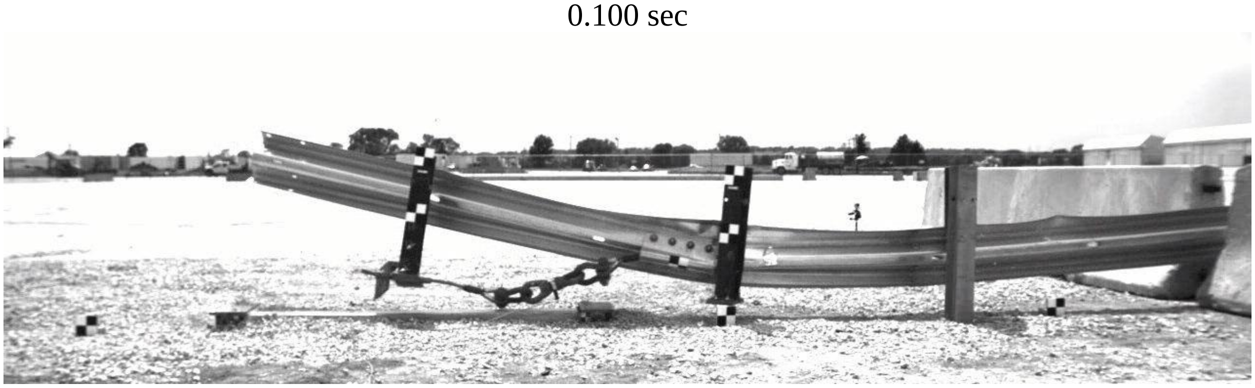
0.000 sec



0.050 sec

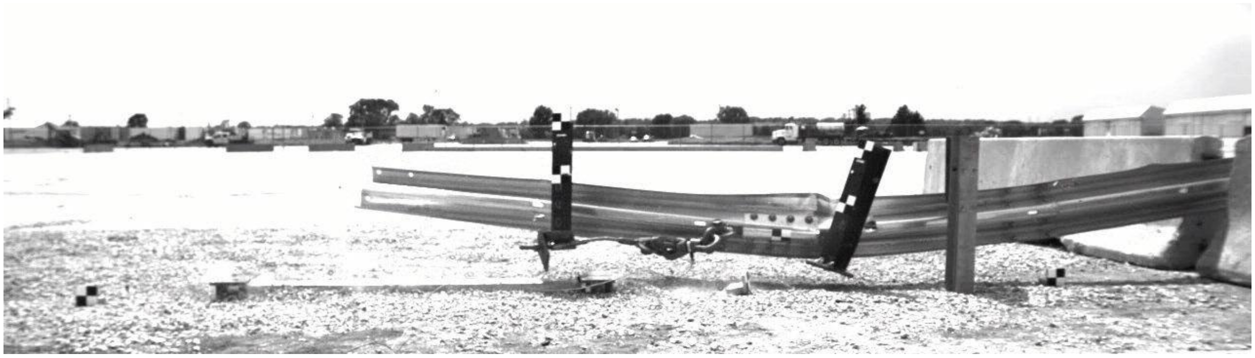


0.100 sec



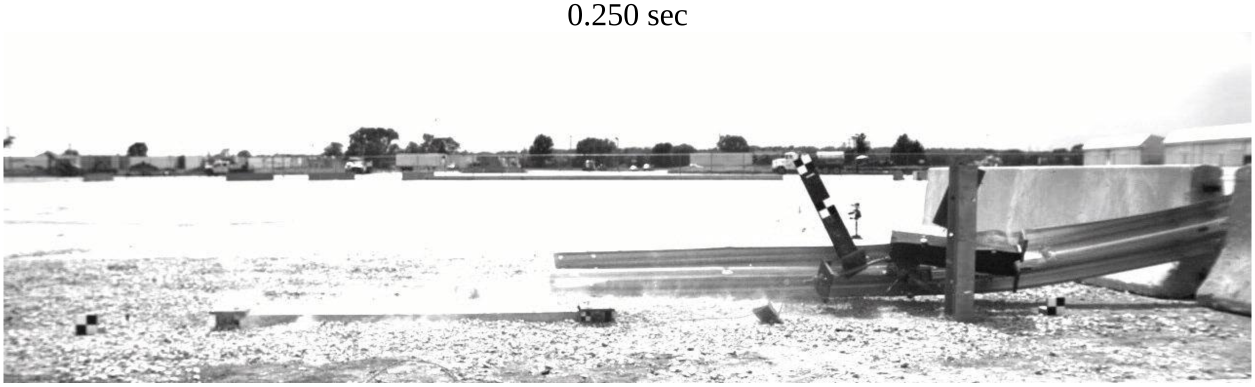
0.150 sec

Figure 163. Time-Sequential Photographs, Test No. SPDA-4

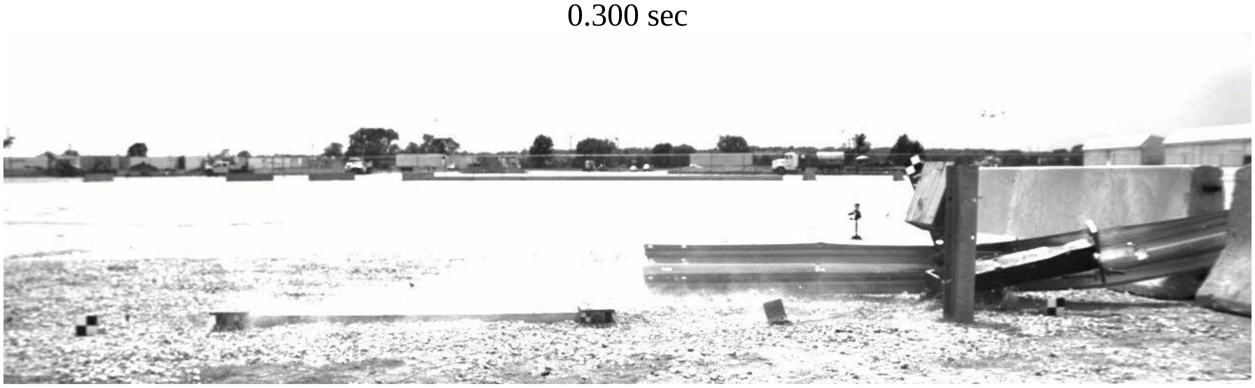


0.200 sec

0.250 sec



0.300 sec



0.350 sec

Figure 164. Time-Sequential Photographs, Test No. SPDA-4 (Continued)

Figure 165. Post-Impact Photographs, Test No. SPDA-4

8.3 Discussion

In test no. SPDA-4, the increased tension in the anchor cable caused the rail to tear vertically at the second anchor post bolt connection. All four bolts connecting the top and bottom parts of the first anchor post fractured in tension after the rail moved approximately half the post length downward. Following the bolt fracture, the bearing plate and the anchor cable were released away from the first anchor post and remained together with the top post base plate. Finally, all bolts from the second anchor post fractured in tension.

A first peak load of 41.6 kips (185.9 kN) occurred when the rail tore vertically at the second anchor post bolt connection at 0.086 sec. A second peak load of 49.5 kips (220.2 kN) occurred when all bolts fractured in the base plate of the first anchor post at 0.096 sec.

The maximum load sustained by the end anchorage was 49.5 kips (220.2 kN). The anchor cable load versus foundation tube displacement is shown in Figure 166. All bolts in each anchor post fractured in tension. The anchor cable and bearing plate remained together and moved downstream after the anchor post bolts fractured. Results from test no. SPDA-4 are summarized in Table 9.

Table 9. Summary of Test Results, Test No. SPDA-4

Test No.	Impact Velocity mph (km/h)	Peak Force kips (kN)	Displacement at Peak Load in. (mm)	Energy at Peak Load kips-in. (kJ)	Failure Mechanism	Component Damage	Attachment Damage
SPDA-4	21.1 (34.0)	49.5 (220.2)	1.7 (43)	50.6 (5.7)	Anchor posts fractured in tension	Rail tore at post bolt connection, posts broke away, and bearing plate released	All bolts fractured in tension releasing both anchor posts

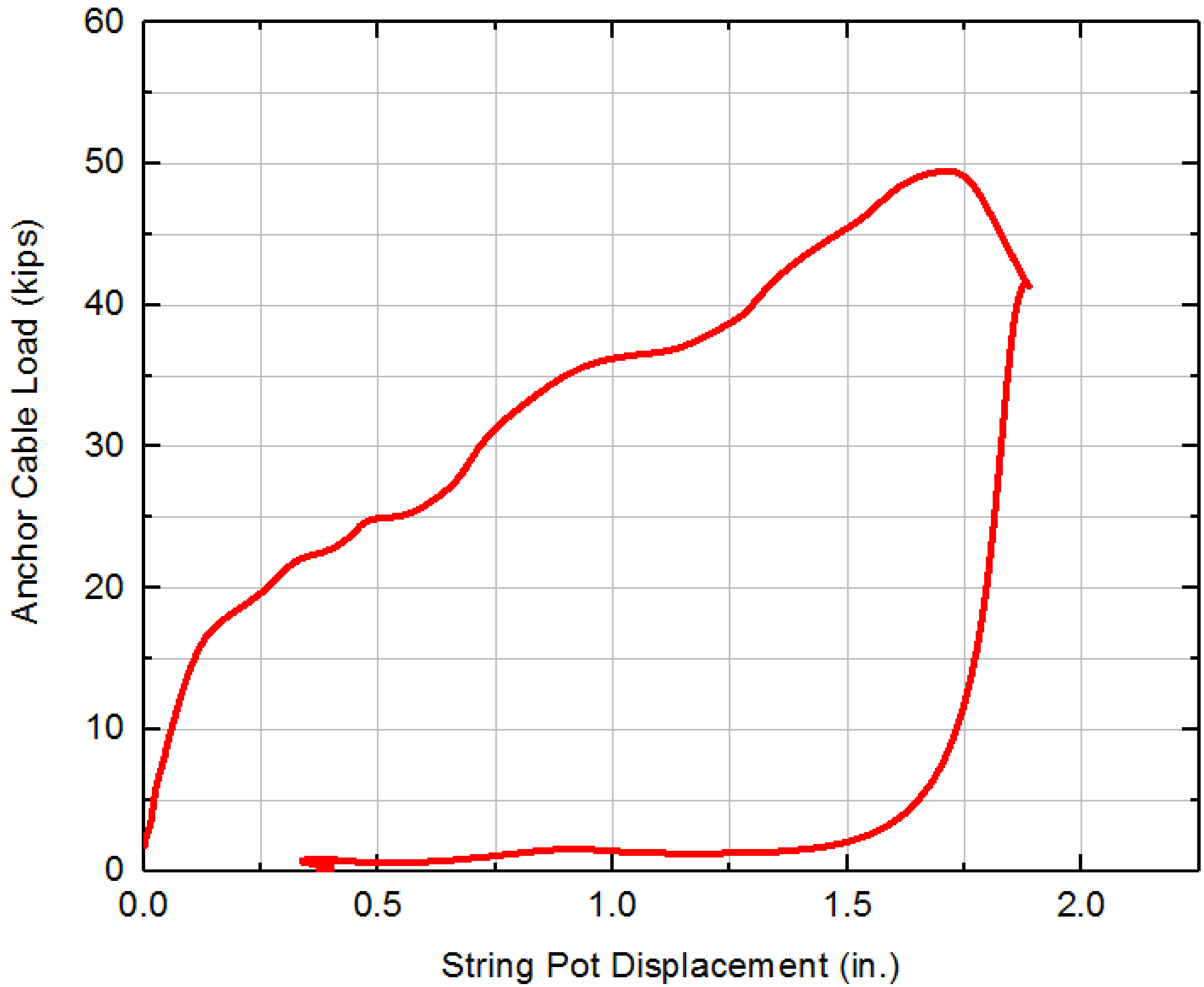


Figure 166. Anchor Cable Load vs. String Pot Displacement, Test No. SPDA-4

9 DYNAMIC COMPONENT TESTING − DESIGN CONCEPT NO. 5

9.1 System Details – Concept No. 5

During test no. SPDA-3, the anchor cable released from the angled bearing plate early in the event. The peak force measured by the BCT anchor cable load cell was 23.3 kips (103.6 kN), which was a lower peak load as compared to design concept nos. 1 and 2. This resulted in modifications to design concept no. 3 to better anchor the cable in the bearing plate. The modifications included changing the angle of the bearing plate, welding the bearing plate to the foundation tube, and adding a brass keeper rod across the cable end. A patent review was conducted to avoid infringing upon any available patent, and it was determined that no patents were using this design concept.

Calculations were performed to determine the fillet weld capacity, as detailed in Appendix E. Based on these calculations, the fillet weld size of 3⁄16 in. (5 mm) was sufficient to resist the anchor cable load, which was estimated to be 40.0 kips (177.9 kN).

Test no. SPDA-5 was a dynamic jerk test of design concept no. 5, which was the anchorage system with the cable passing through the top portion of the anchor post and connecting to a welded, angled bearing plate (similar to design concept no. 3). The test matrix and test setup are shown in Figures 167 through 184. Photographs of the test setup are presented in Figures 185 and 186. Material specifications, mill certifications, and certificates of conformity for the system materials used in test no. SPDA-5 are provided in Appendix G.

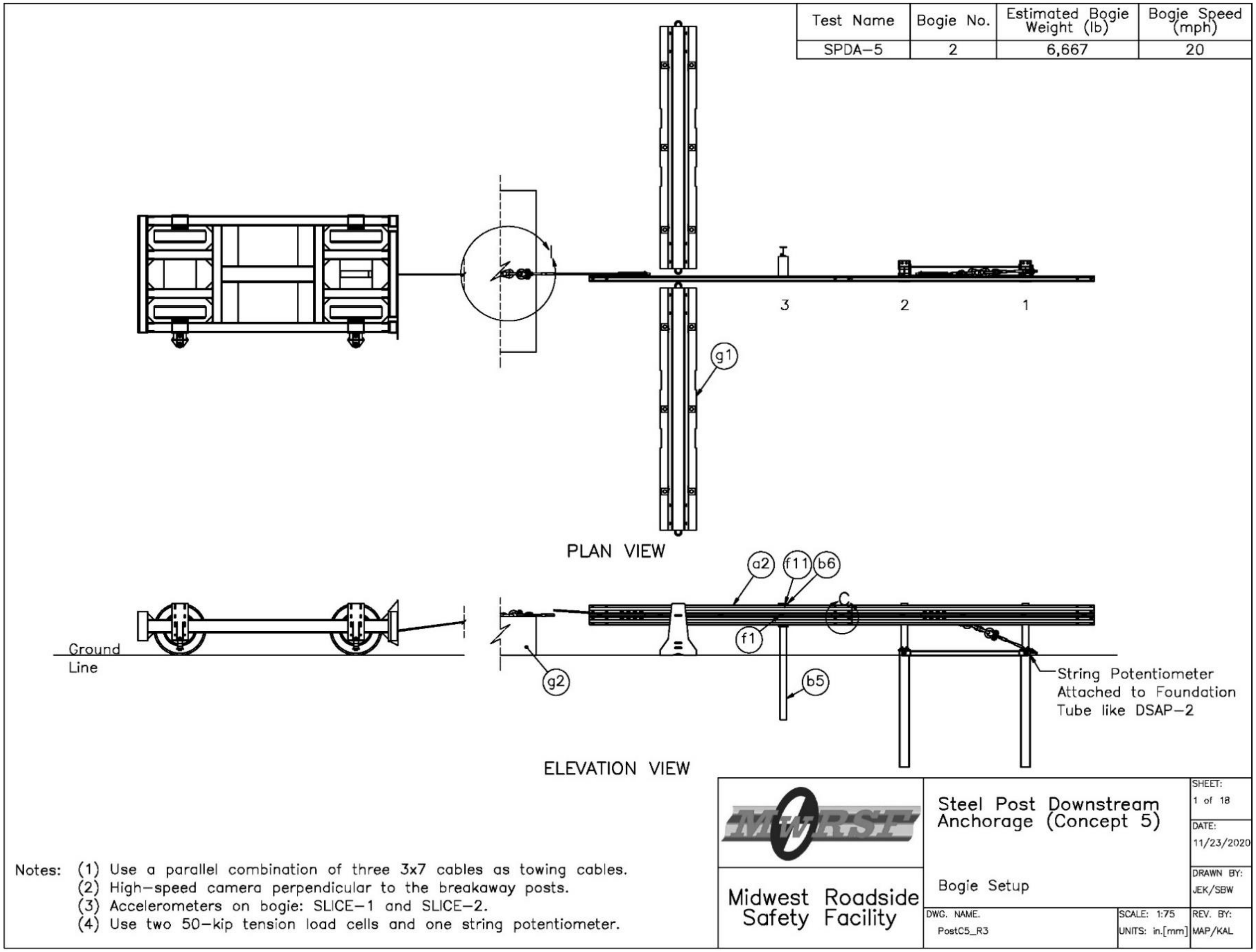


Figure 167. Bogie Setup, Test No. SPDA-5

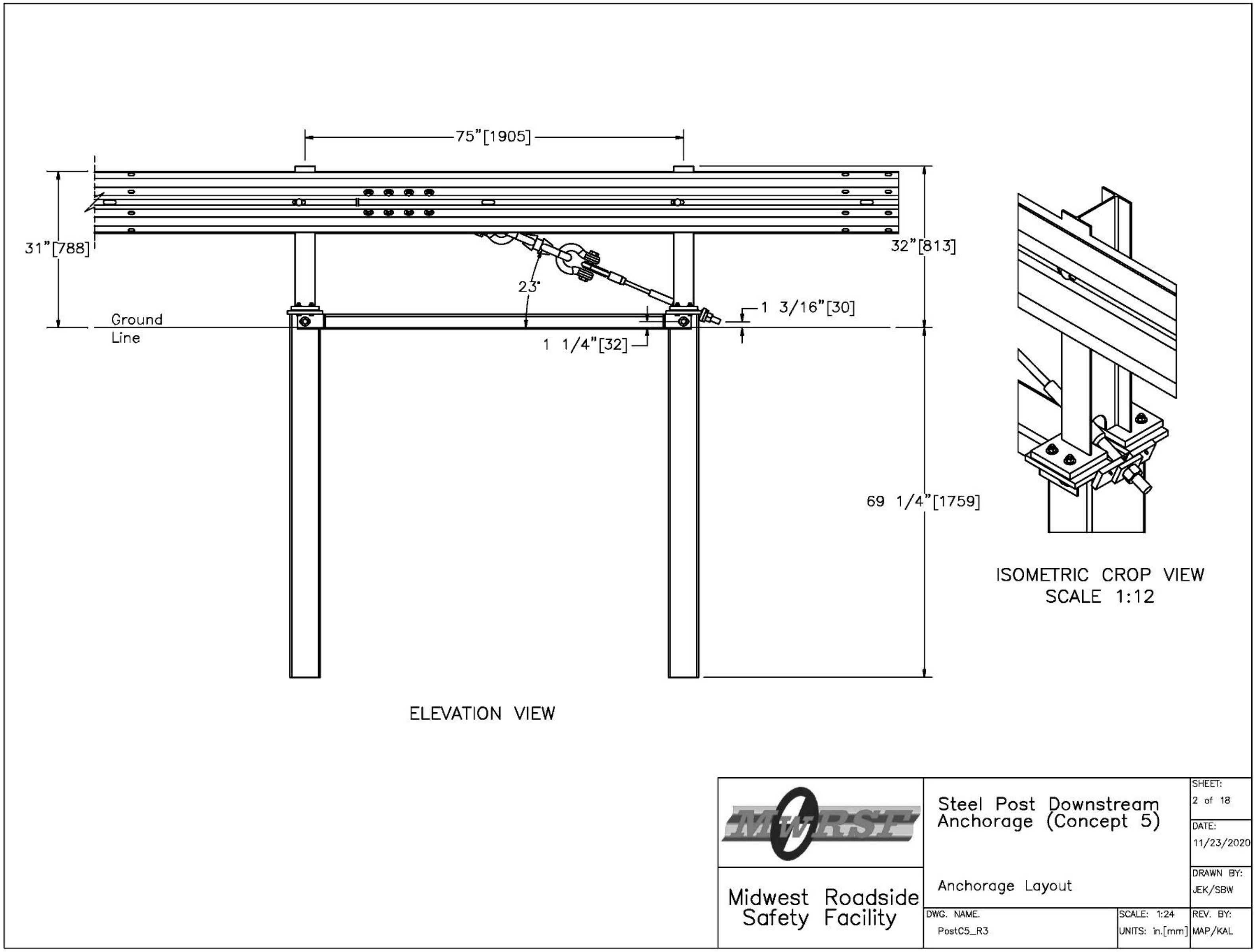


Figure 168. Anchorage Layout, Test No. SPDA-5

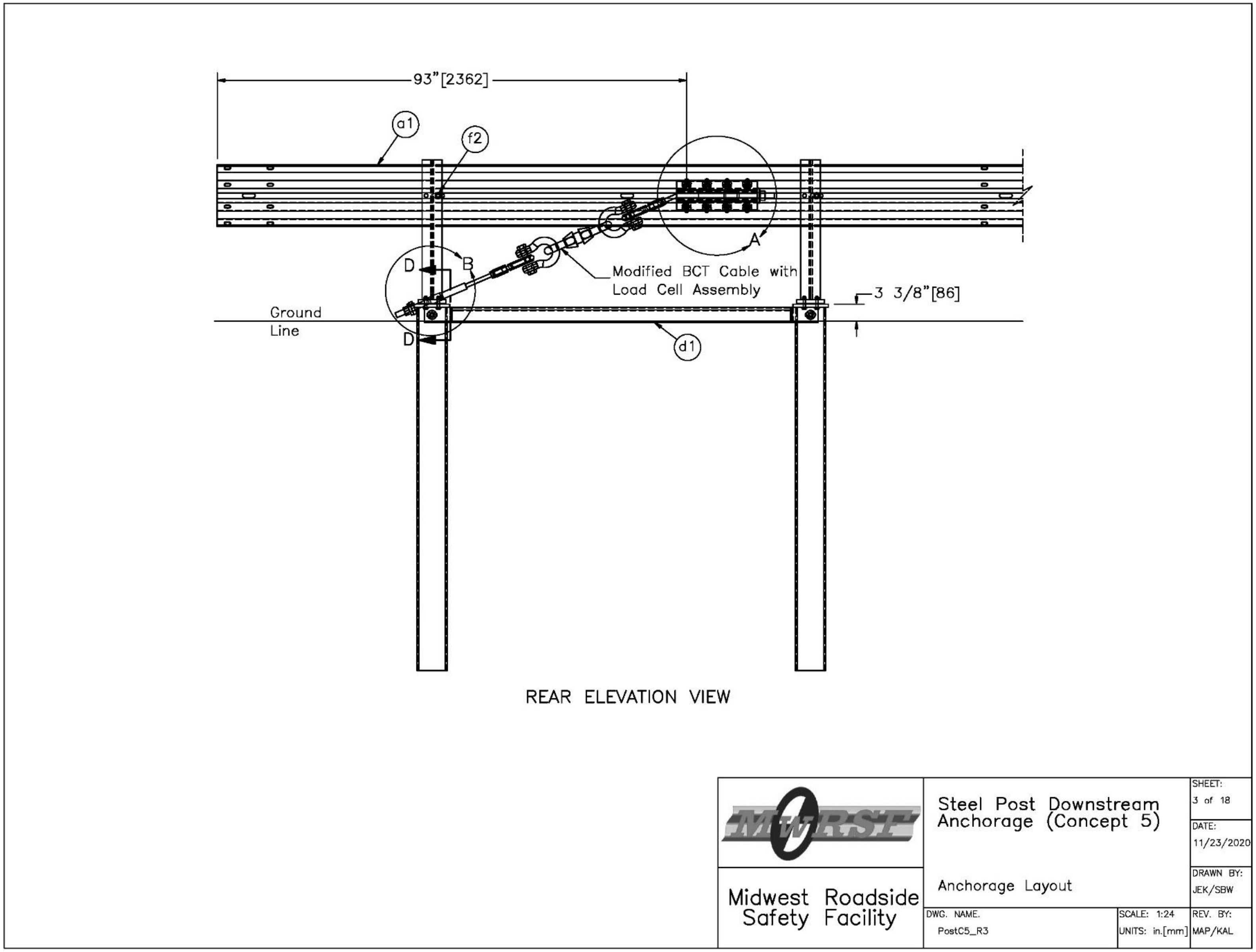


Figure 169. Anchorage Layout, Test No. SPDA-5

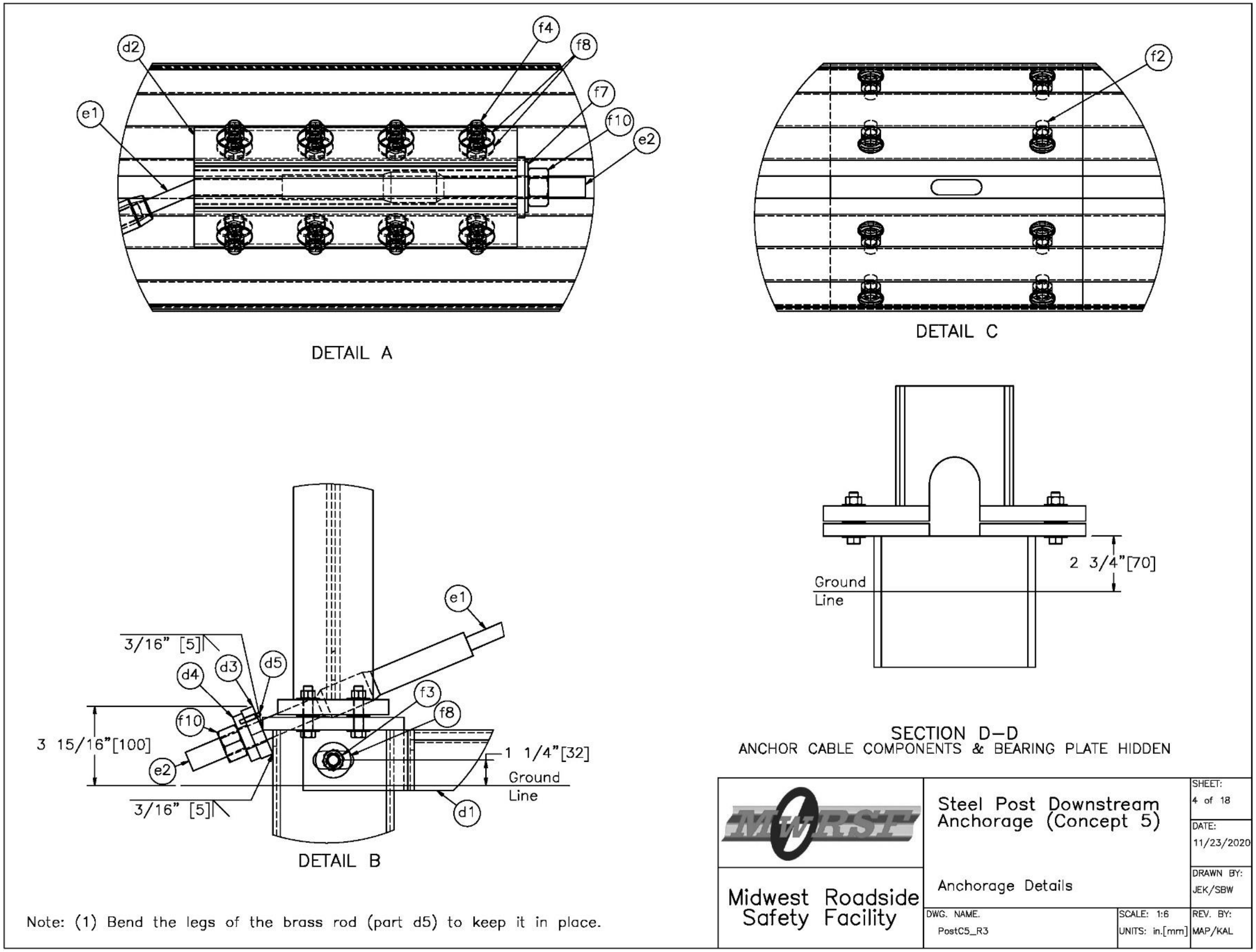


Figure 170. Anchorage Details, Test No. SPDA-5

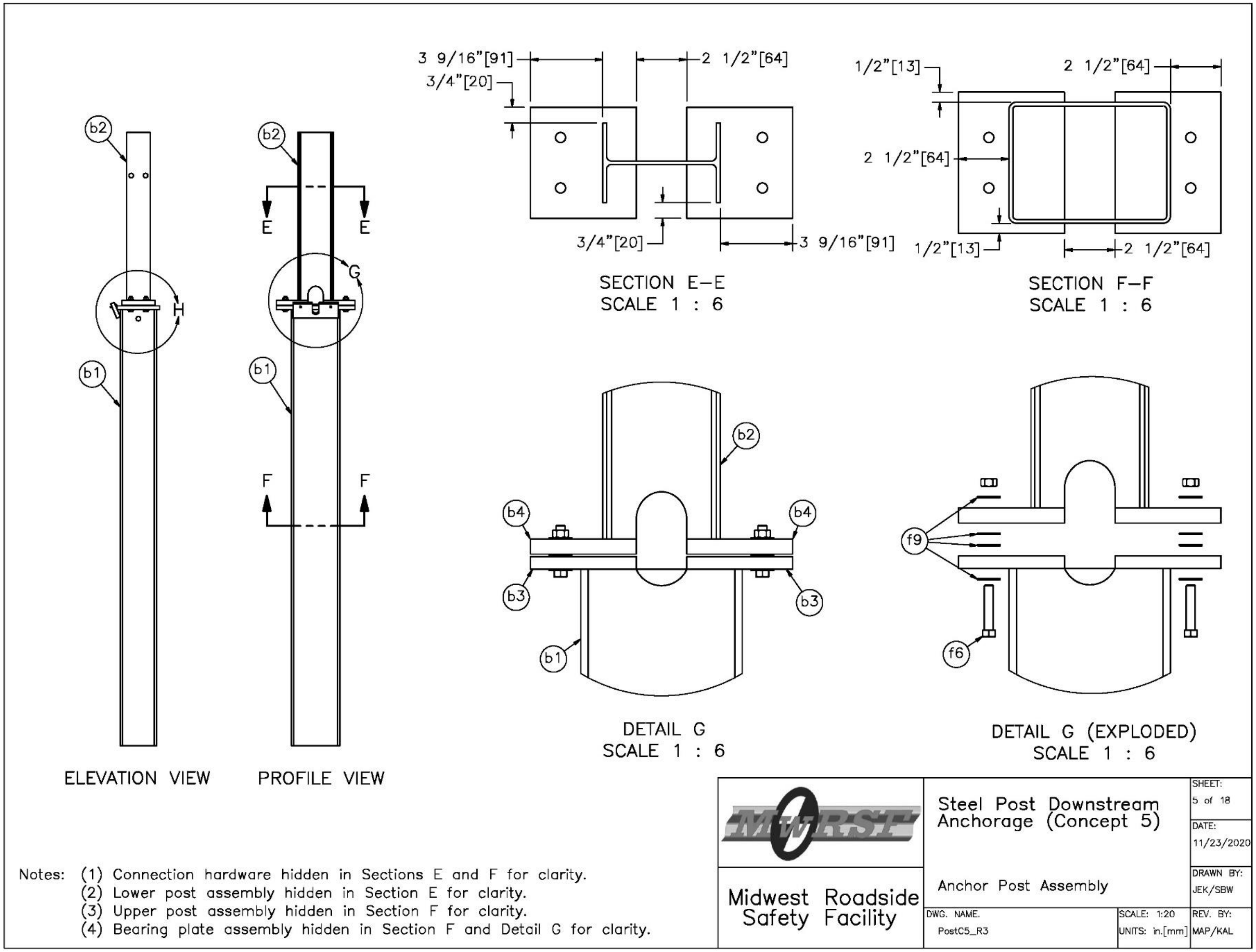
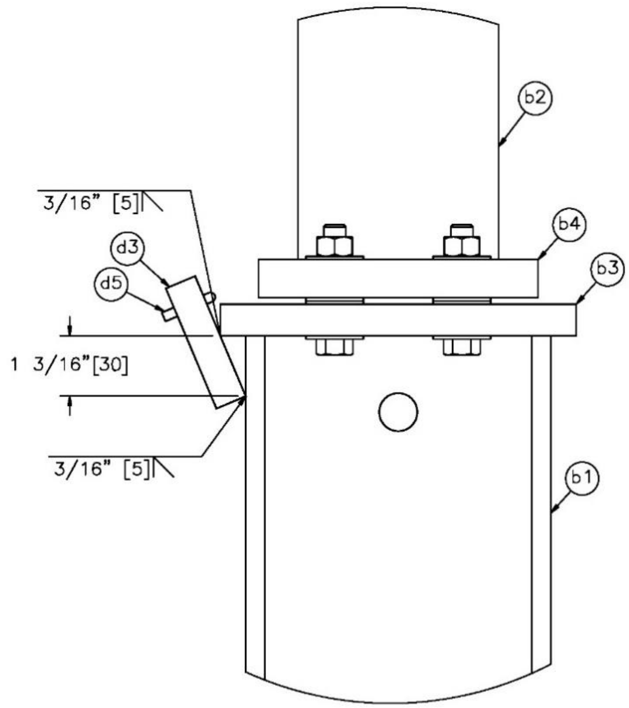


Figure 171. Anchor Post Assembly, Test No. SPDA-5



DETAIL H

Note: (1) The bearing plate is only on post no. 1.
(2) Bend the legs of the brass rod (part d5) to keep it in place.

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 5)

Bearing Plate Weld Detail

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DATE: 11/23/2020

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DWG. NAME. PostC5_R3

SCALE: 1:3
UNITS: in.[mm]

REV. BY: MAP/KAL

Figure 172. Bearing Plate Weld Detail, Test No. SPDA-5

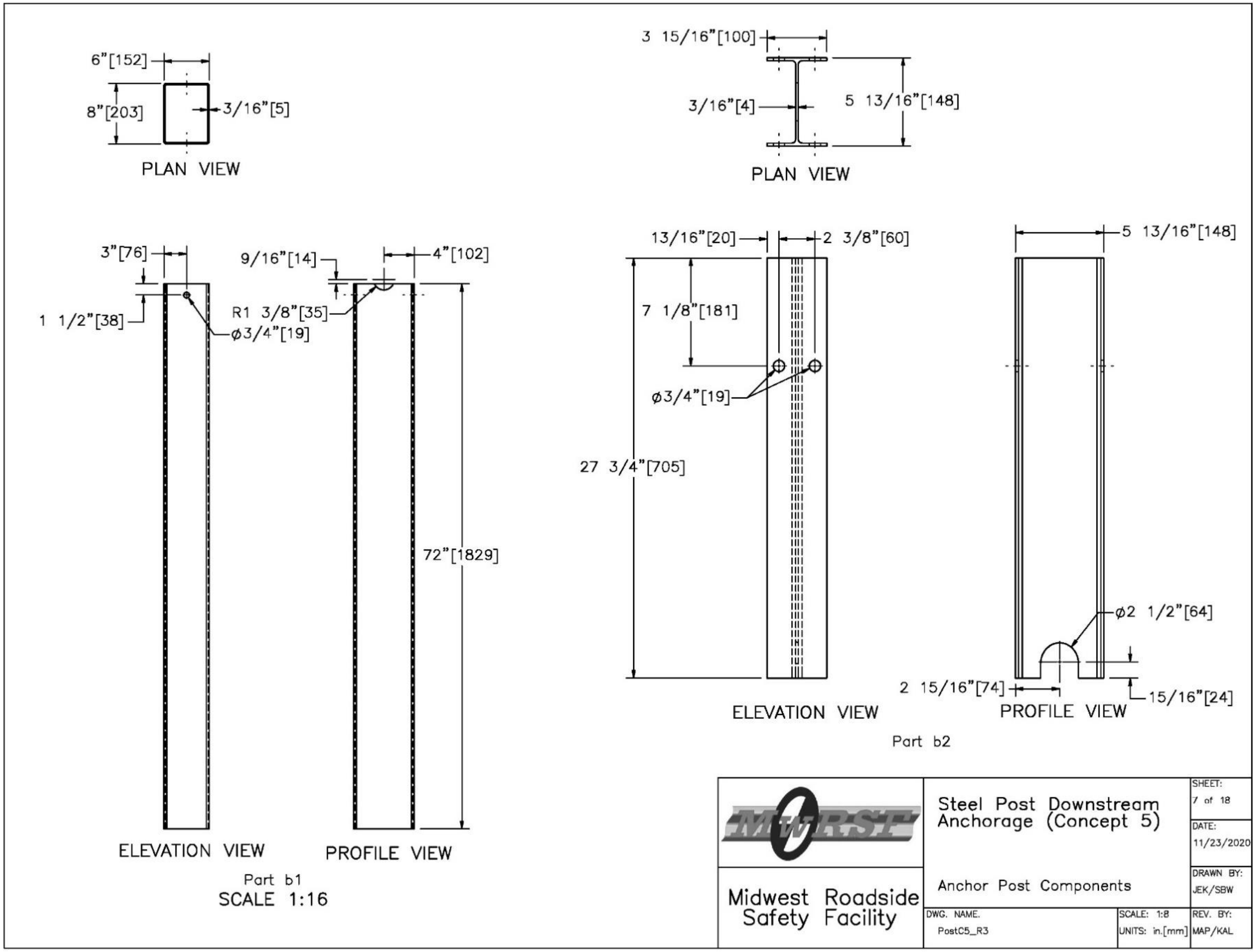


Figure 173. Anchor Post Components, Test No. SPDA-5

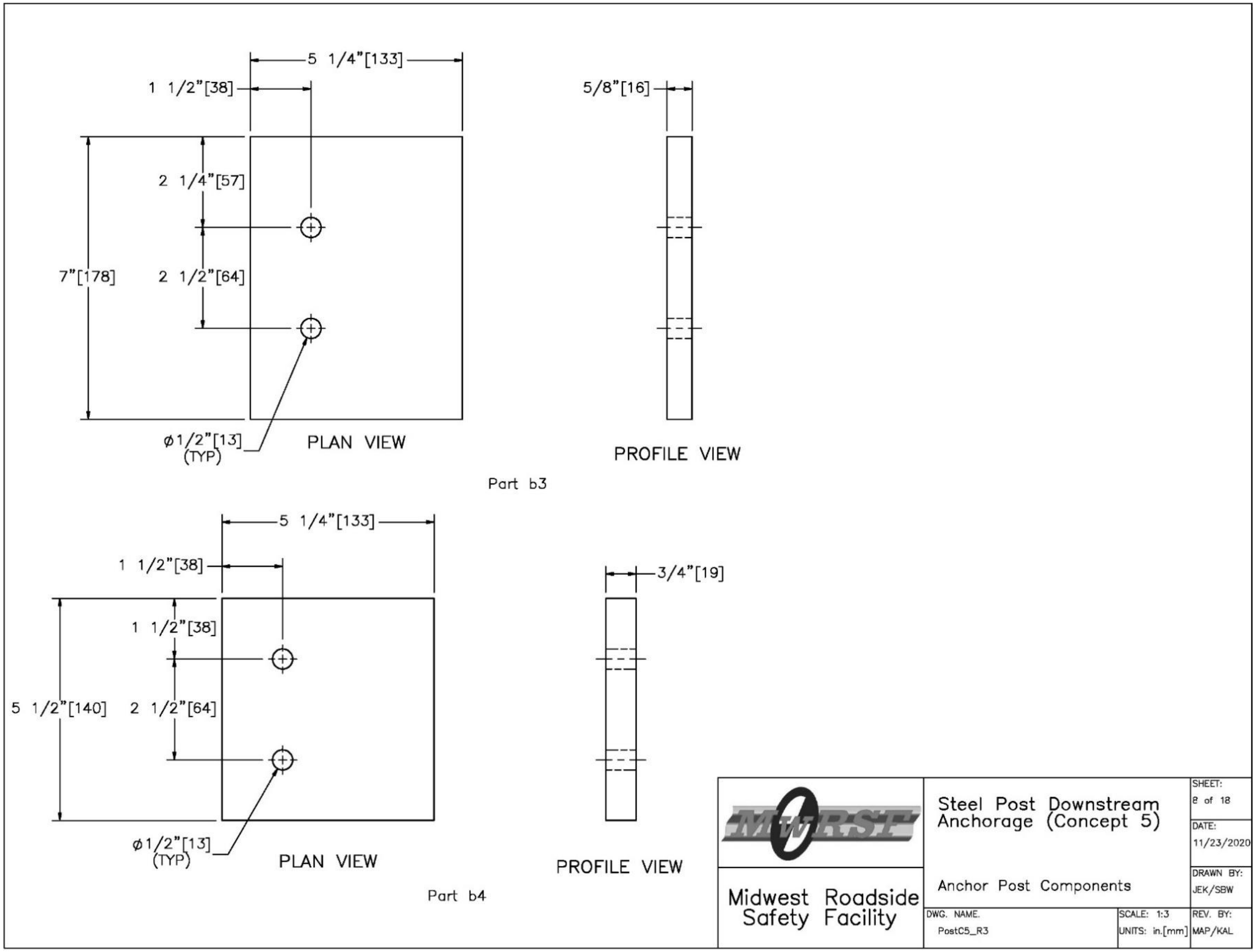


Figure 174. Anchor Post Components, Test No. SPDA-5

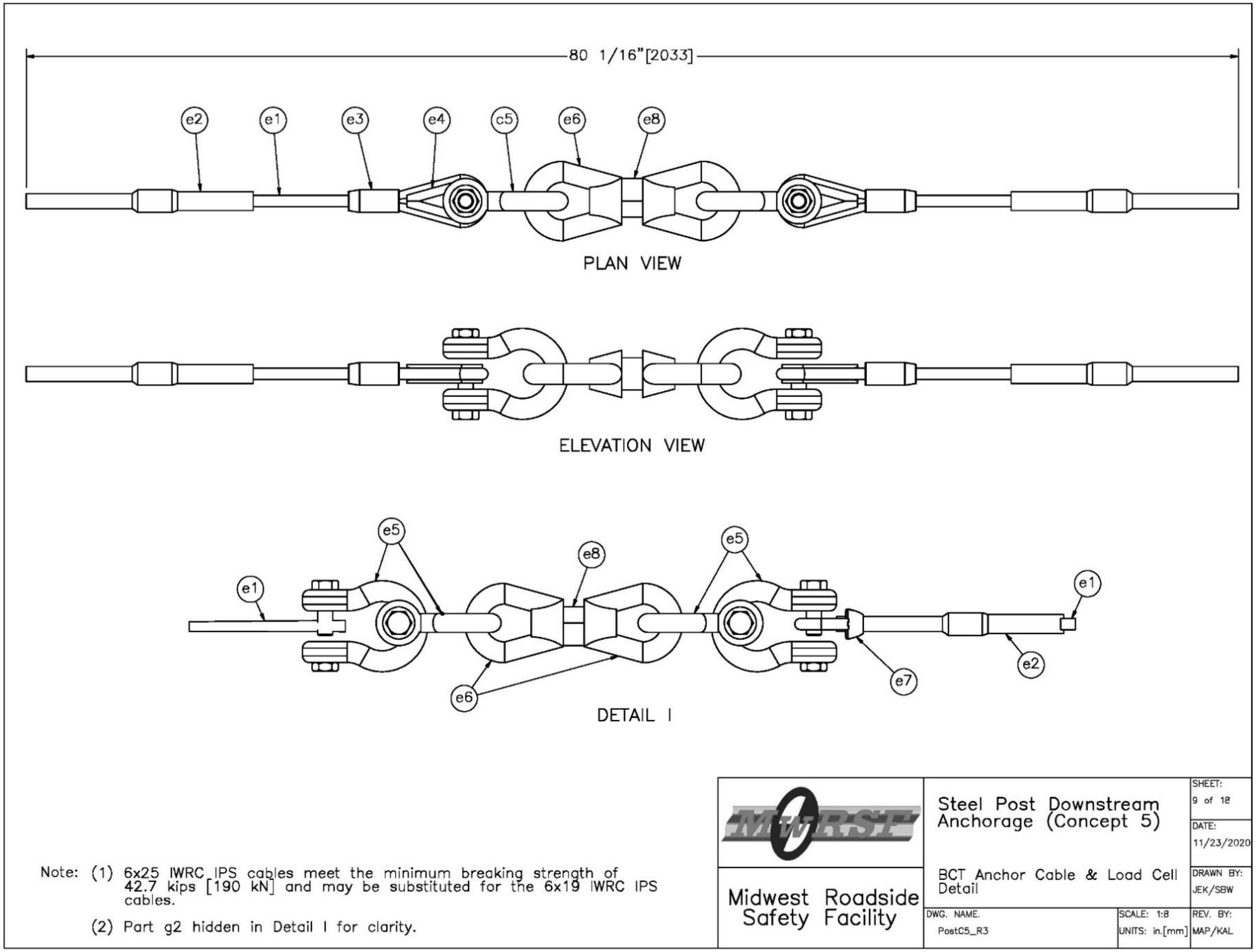


Figure 175. BCT Anchor Cable and Load Cell Detail, Test No. SPDA-5

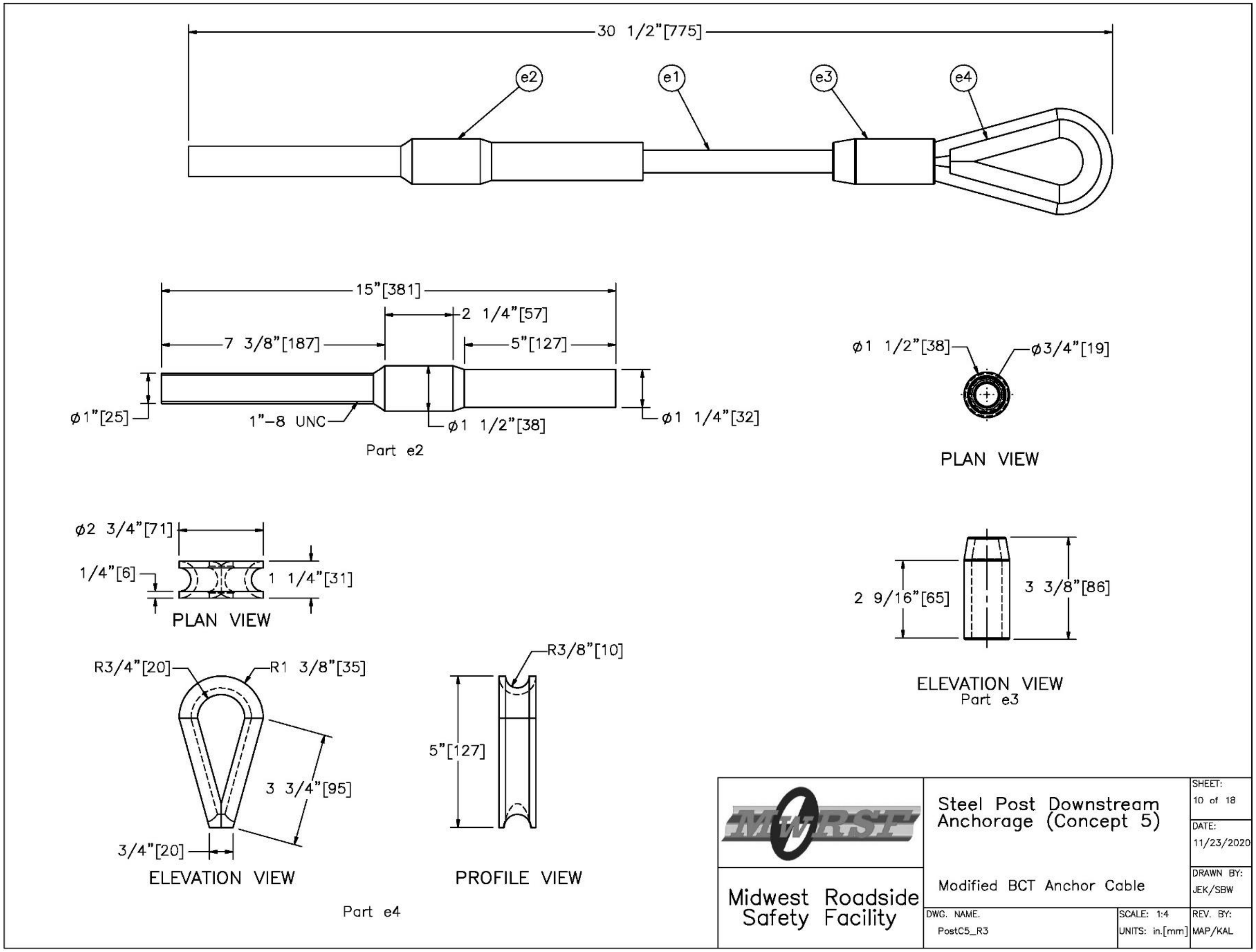


Figure 176. Modified BCT Anchor Cable, Test No. SPDA-5

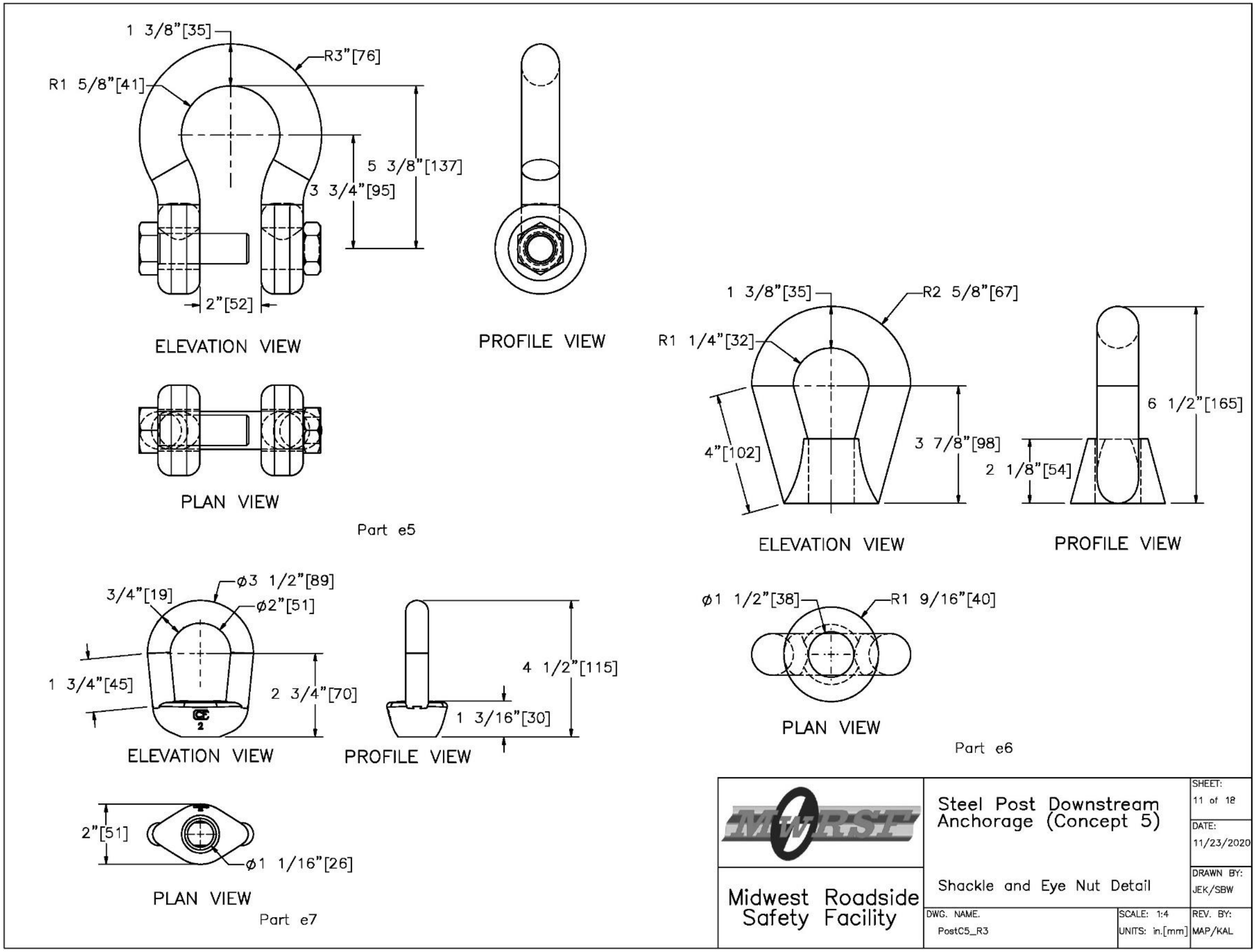


Figure 177. Shackle and Eye Nut Detail, Test No. SPDA-5

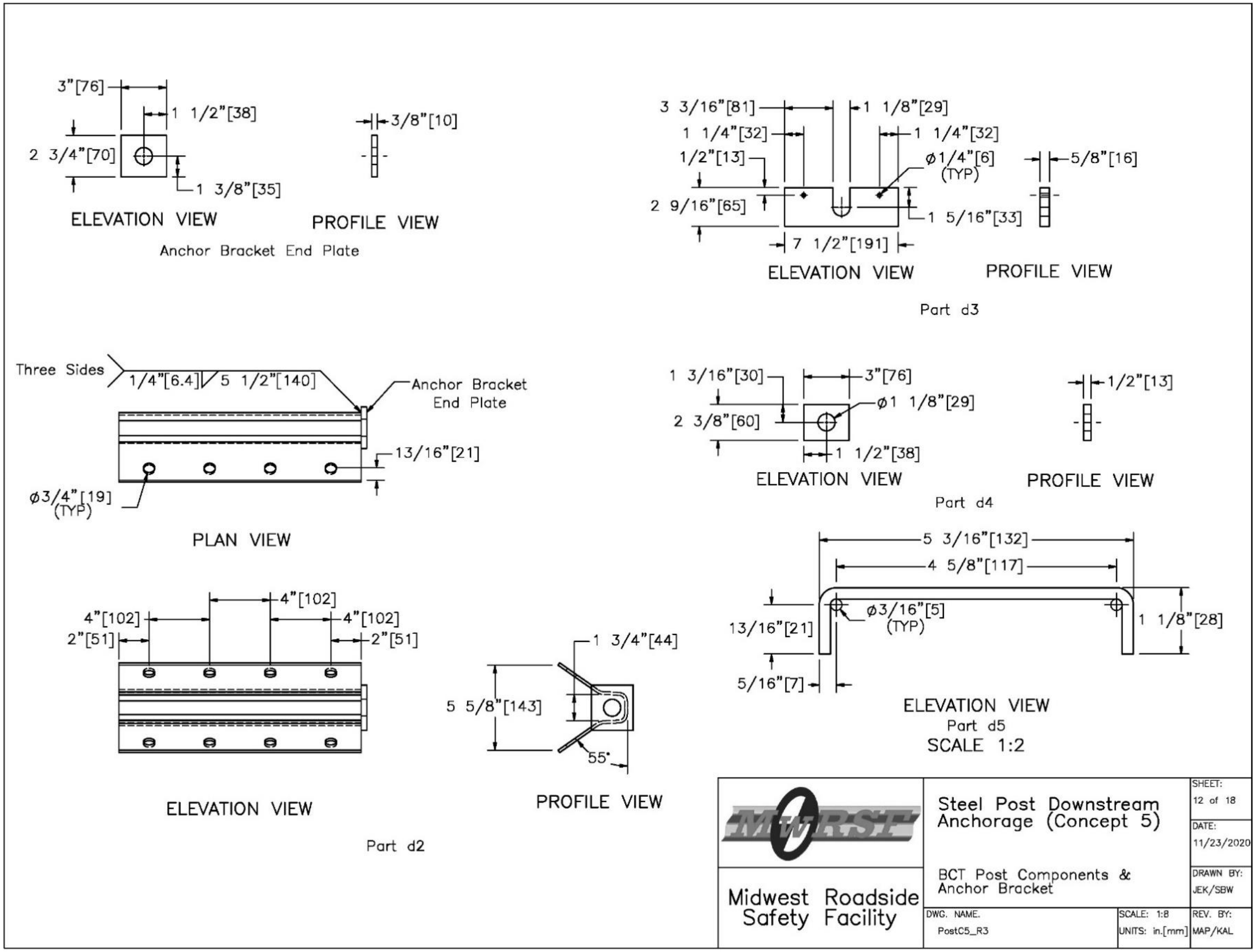


Figure 178. BCT Post Components and Anchor Bracket, Test No. SPDA-5

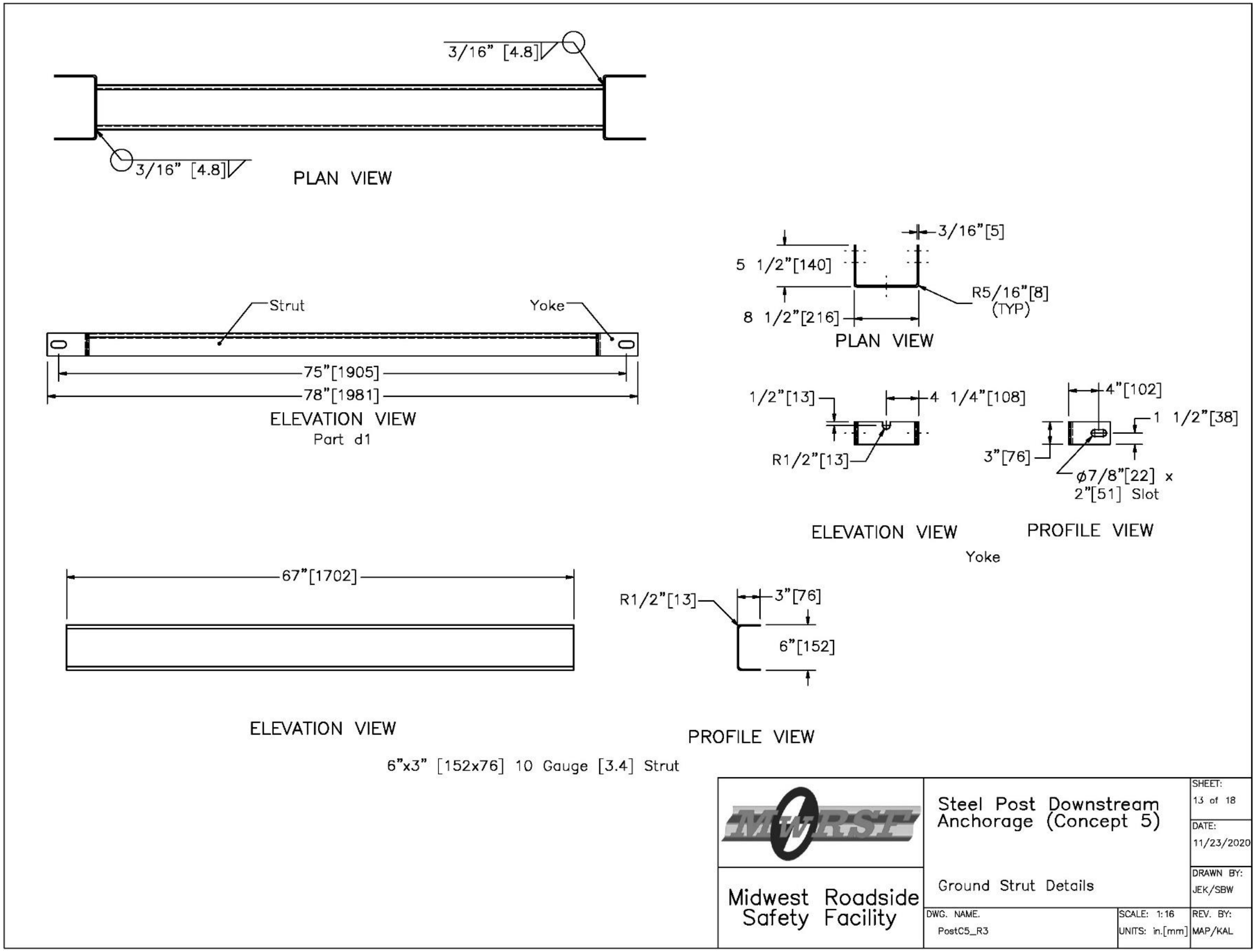


Figure 179. Ground Strut Details, Test No. SPDA-5

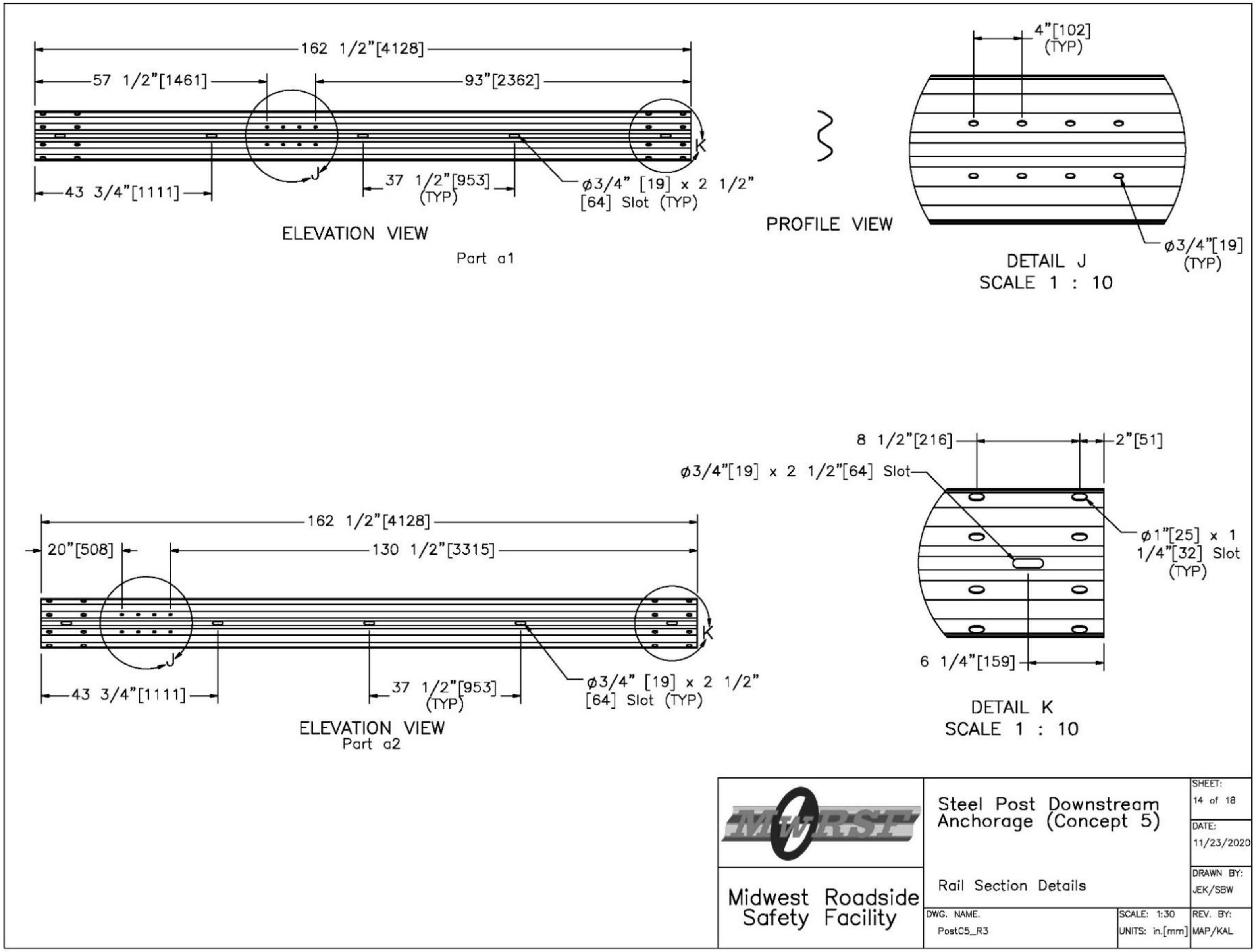


Figure 180. Rail Section Details, Test No. SPDA-5

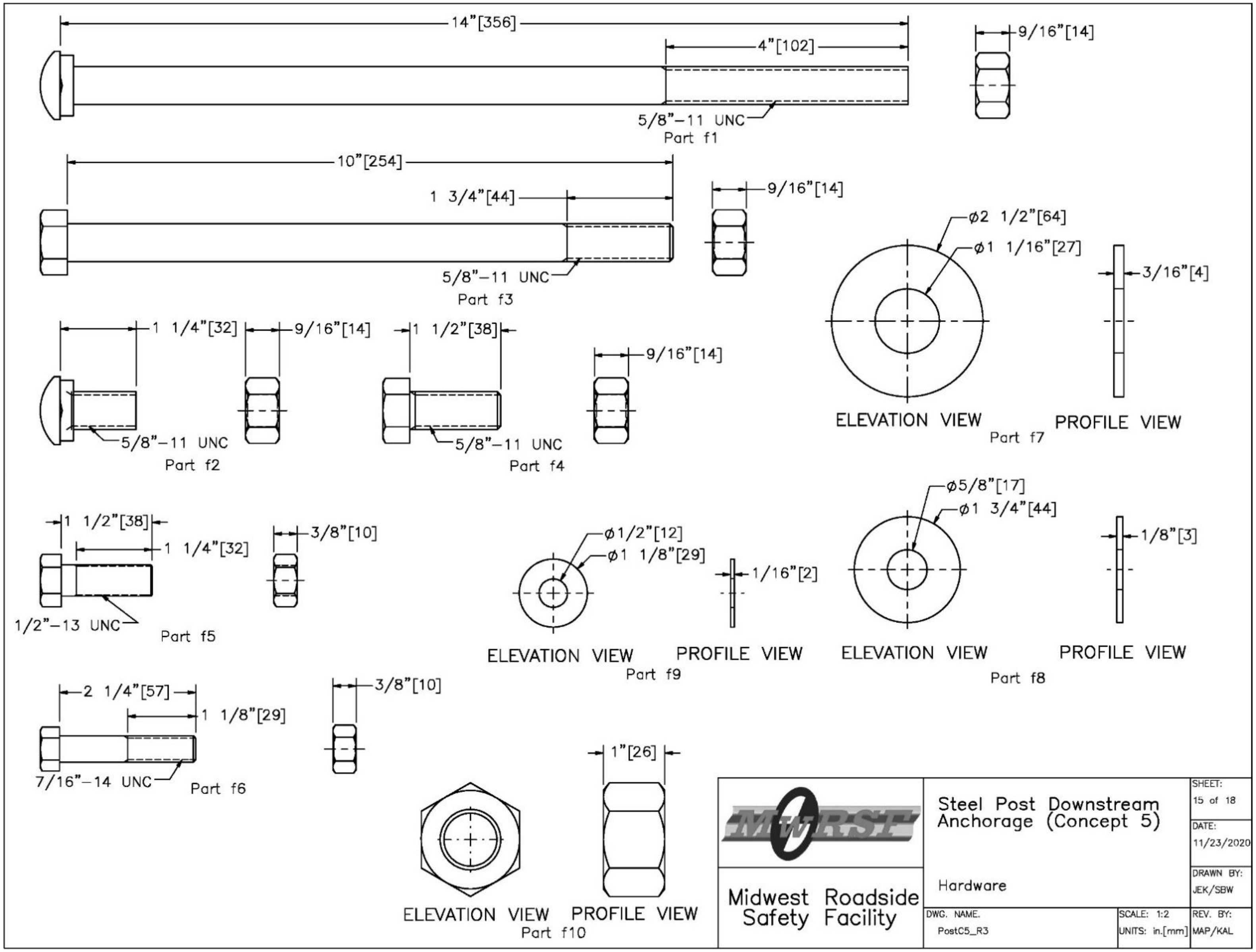


Figure 181. Bolt and Washer Details, Test No. SPDA-5

Item No.	QTY.	Description	Material Spec	Galvanization Spec	Hardware Guide
a1	1	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A123 or A653	–
a2	1	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	–
b1	2	TS6"x8"x3/16" [152x203x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	–
b2	2	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 27 3/4" [705] Long Steel Post	ASTM A992	ASTM A123	–
b3	4	7"x5 1/4"x5/8" [178x133x16] Steel Plate	ASTM A36	ASTM A123	–
b4	4	5 1/2"x5 1/4"x3/4" [140x133x19] Steel Plate	ASTM A36	ASTM A123	–
b5	1	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa]	ASTM A123	PWE06
b6	1	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
d1	1	Ground Strut Assembly	ASTM A36	ASTM A123	PFP01
d2	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
d3	1	7 1/2"x2 9/16"x5/8" [191x65x16] Bearing Plate	ASTM A36	ASTM A123	–
d4	1	3"x2 3/8"x1/2" [76x60x13] Plate Washer	ASTM A36	ASTM A123	–
d5	1	3/16" [5] Dia. Brass Rod, 6 7/8" [175] Long Unbent	ASTM B16–00	–	–
e1	4	3/4" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS	ASTM A741 Type II Class A	–
e2	4	BCT Anchor Cable End Swaged Fitting	Fitting – ASTM A576 Gr. 1035 Stud – ASTM F568 Class C	Fitting – ASTM A153 Stud – ASTM A153 or B695	–
e3	2	115–HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–	–
e4	2	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773	As Supplied	–
e5	6	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3 or Similar	Stock Nos. 1019597 and 1019604 – As Supplied	–	–
e6	4	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNC 6 [M36x4]	Stock No. 107 – As Supplied	–	–
e7	1	1" [25] Dia. Eye Nut	As Supplied	As Supplied	–
e8	2	TLL–50K–PTB Load Cell	–	–	–

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 5)

Bill of Materials

SHEET: 16 of 18
DATE: 11/23/2020
DRAWN BY: JEK/SBW
DWG. NAME. PostC5_R3
SCALE: None
UNITS: in.[mm]
REV. BY: MAP/KAL

Figure 182. Bill of Materials, Test No. SPDA-5

Item No.	QTY.	Description	Material Spec	Galvanization Spec	Hardware Guide
f1	1	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB06
f2	10	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB01
f3	2	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
f4	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
f6	8	7/16" [11] Dia. UNC, 2 1/4" [57] Long Heavy Hex Bolt and Nut	Bolt – ASTM F3125 Gr. 120 (A325) or A354 Gr. BC Nut – ASTM A563DH or A194 Gr. 2H	Bolt – ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 or F2833 Gr. 1 Nut – ASTM A153 or B633 or B695 Class 55 or F1941 or F2329	–
f7	2	1" [25] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC24a
f8	36	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
f9	32	7/16" [11] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
f10	3	1" [25] Dia. Hex Nut	ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FNX24a
f11	1	16D Double Head Nail	–	–	–
g1	2	Portable Concrete Barrier	Min f'c=5,000 psi [34.5 MPa]	–	SWC09
g2	1	Concrete Block – MN Noise Wall	–	–	–

Midwest Roadside Safety Facility

Steel Post Downstream Anchorage (Concept 5)

Bill of Materials

SHEET: 17 of 18

DATE: 11/23/2020

DRAWN BY: JEK/SBW

DWG. NAME. PostC5_R3

SCALE: None UNITS: in.[mm]

REV. BY: MAP/KAL

Figure 183. Bill of Materials, Test No. SPDA-5 (Continued)

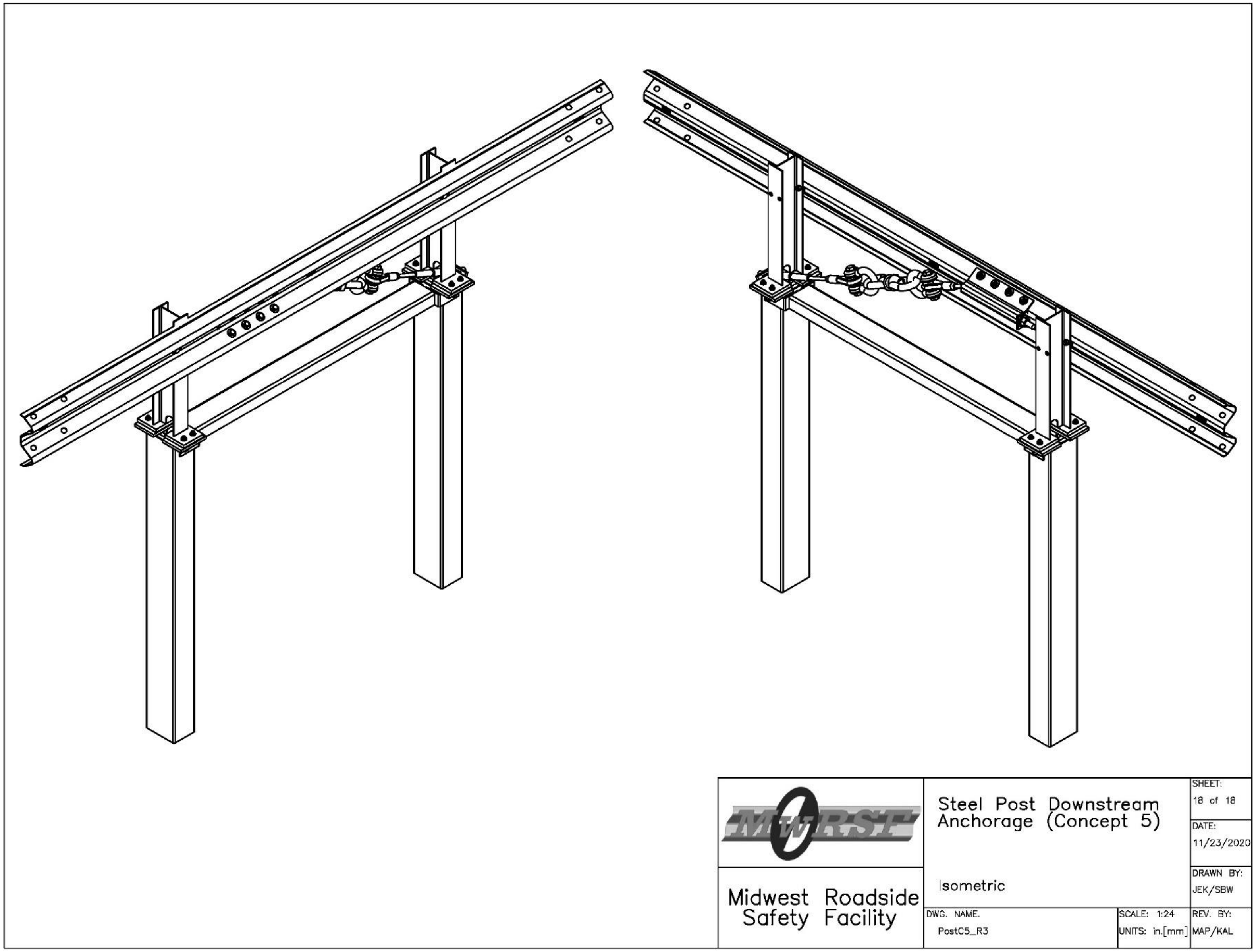


Figure 184. Isometric View, Test No. SPDA-5

Figure 185. Test Setup, Test No. SPDA-5

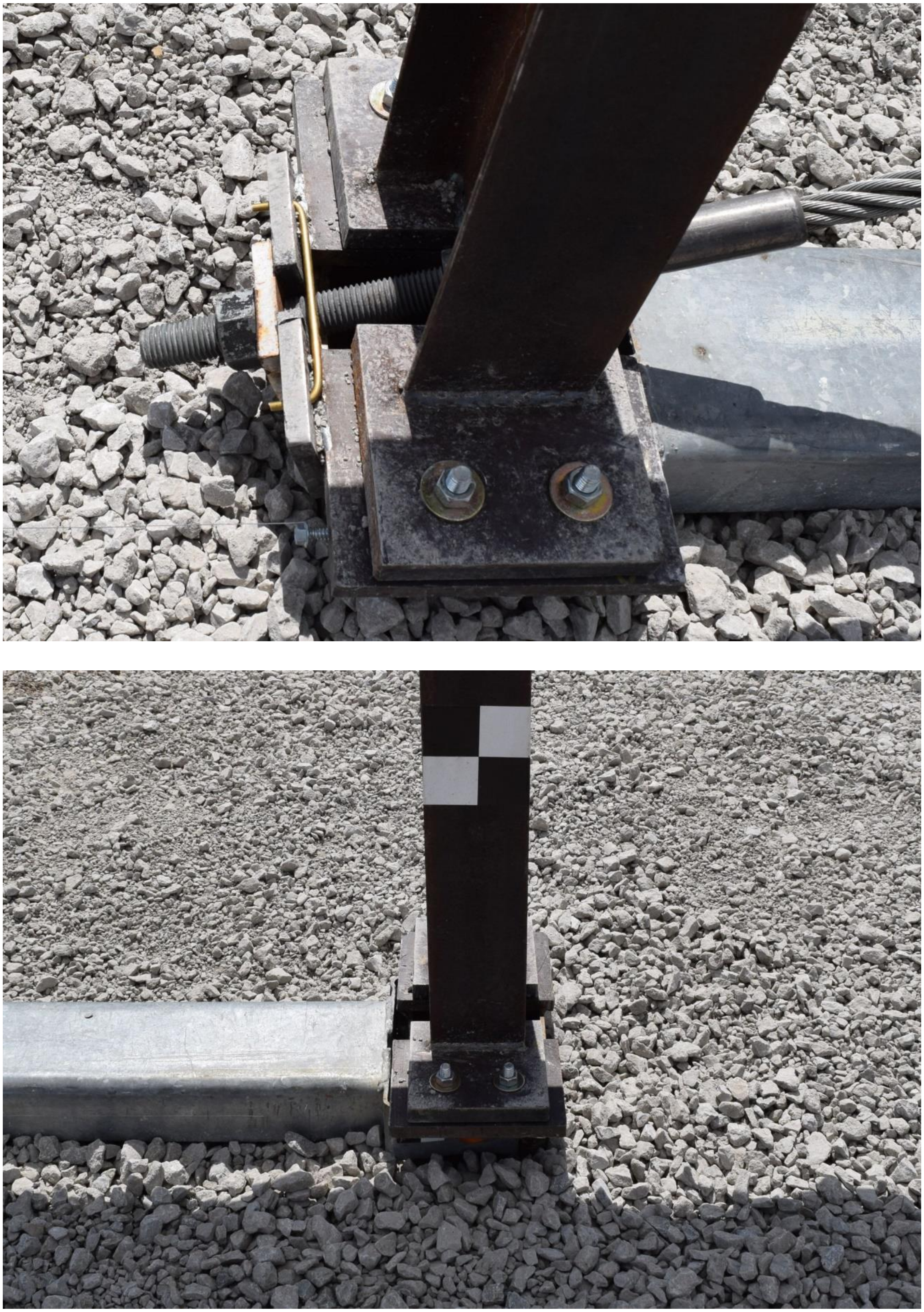


Figure 186. Test Setup, Test No. SPDA-5

9.2 Test No. SPDA-5 Results

During test no. SPDA-5, the top portion of both anchor posts deflected downstream. The pull force was immediately transferred to the two foundation tubes, which rotated in the soil. When the cable anchor was tensioned, a downward vertical force component was applied to the rail. This force twisted the second anchor post and deformed the rail slot at the second anchor post bolt connection, causing the rail to tear and disengage from the first anchor post bolt connection. After the rail disengagement, the anchor cable fractured. The peak load in the anchor cable exceeded the cable breaking strength. The breaking strength of a ¾-in. (19-mm) diameter 6x19 IWRC IPS wire rope was 52.0 kips (231.3 kN).

The force versus time and the displacement versus time curves for test no. SPDA-5 were processed from transducer data using the SLICE-1 and SLICE-2 units and are shown in Appendix H. The anchor cable loads, pull cable loads, and anchor cable displacements are shown in Figure 187. The peak force from the anchor cable and pull cable load cell were 49.4 kips (219.7 kN) and 54.0 kips (240.2 kN), respectively. Both peak loads occurred at around 0.08 sec. A maximum displacement of 3.2 in. (81.3 mm) was measured by the string potentiometer attached to the anchor post foundation tube. Time-sequential photographs are presented in Figures 188 and 189. Post-impact photographs are displayed in Figures 190 and 191.

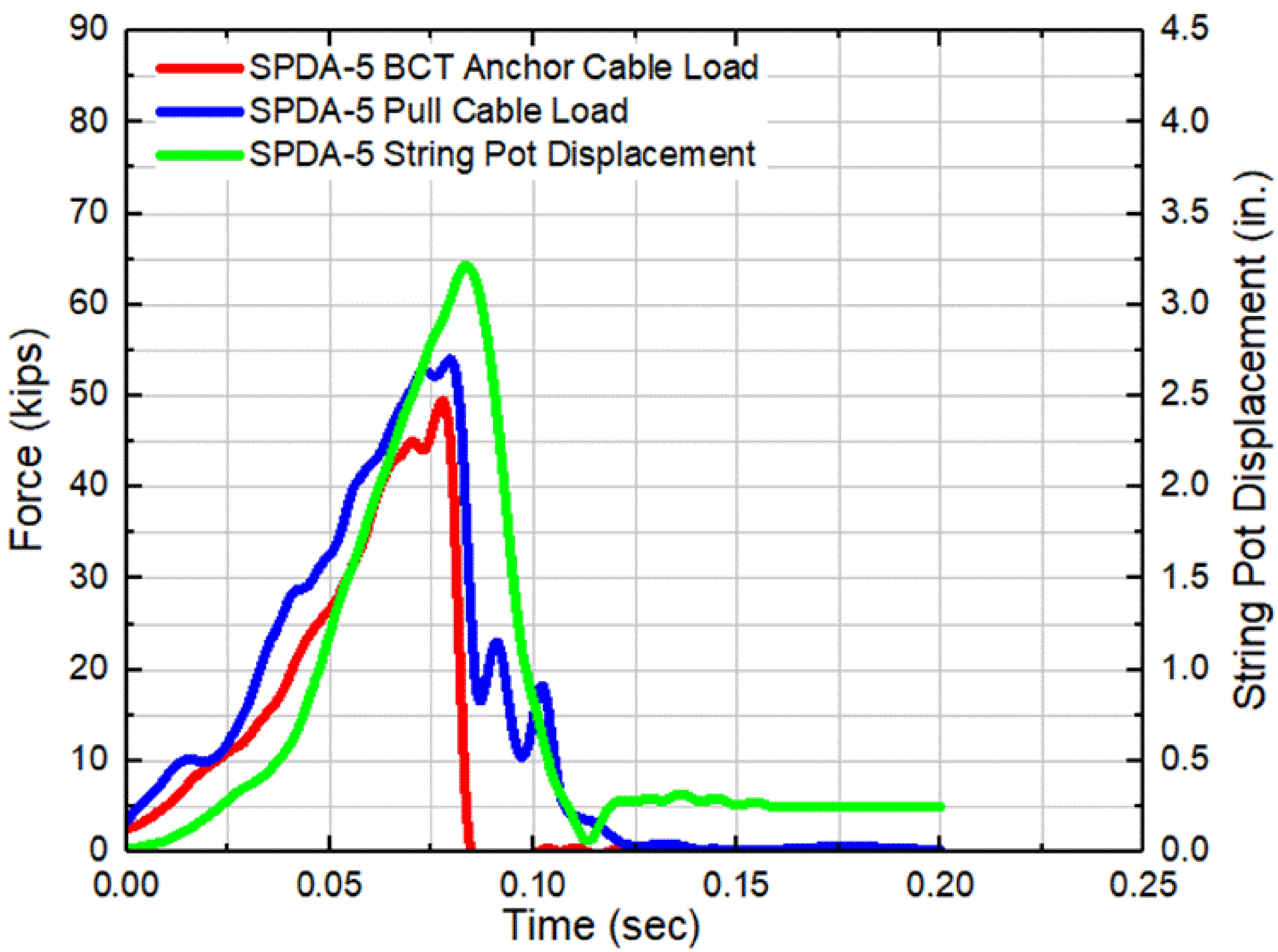
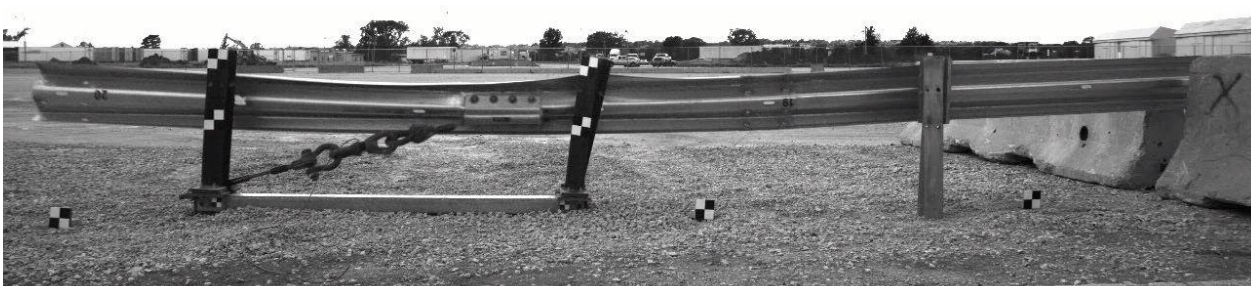


Figure 187. Force vs. Time and Displacement vs. Time, Test No. SPDA-5

0.000 sec

0.050 sec



0.100 sec

0.150 sec

Figure 188. Time-Sequential Photographs, Test No. SPDA-5

0.200 sec

0.250 sec

0.300 sec

0.350 sec

Figure 189. Time-Sequential Photographs, Test No. SPDA-5 (Continued)

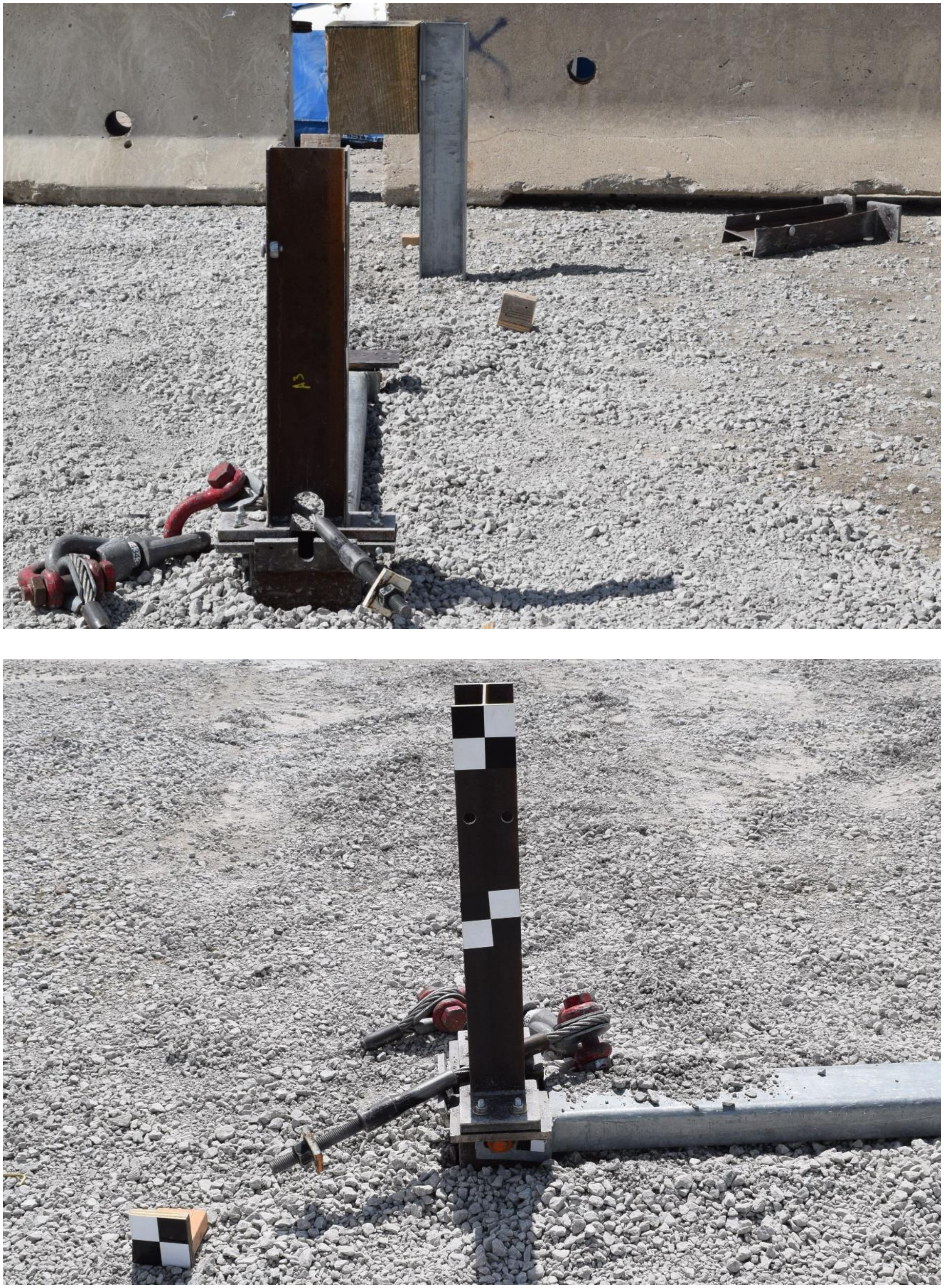


Figure 190. Post-Impact Photographs, Test No. SPDA-5

Figure 191. Post-Impact Photographs, Test No. SPDA-5

9.3 Discussion

In test no. SPDA-5, the increased tension in the anchor cable caused the top portion of the first anchor post to disengage from the rail. Following the rail tearing, the anchor cable fractured at 95% of its breaking strength (i.e., 49.5 kips). All bolts in the slip base of the second anchor post fractured in tension.

Two peak tensile loads of 44.8 kips (199.3 kN) and 49.4 kips (219.7 kN) were measured by the BCT cable load cell. A peak load of 44.8 kips (199.3 kN) occurred during rail tearing at the first anchor post at 0.070 sec. A second peak load of 49.4 kips (219.7 kN) occurred when the anchor cable fractured at 0.080 sec. The maximum load sustained by the end anchorage was 49.4 kips (219.7 kN). The anchor cable load versus foundation tube displacement is shown in Figure 192.

The four bolts in the first anchor post did not fracture, while all bolts in the second anchor post fractured in tension. The upper and lower base plates for each anchor post remained undamaged. Test results from test no. SPDA-5 are summarized in Table 10.

Table 10. Summary of Test Results, Test No. SPDA-5.

Test No.	Impact Velocity mph (km/h)	Peak Force kips (kN)	Displacement at Peak Load in. (mm)	Energy at Peak Load kips-in. (kJ)	Failure Mechanism	Component Damage	Attachment Damage
SPDA-5	20.6 (33.1)	49.4 (219.7)	2.9 (74)	81.2 (9.2)	Rail tearing at both anchor posts	Anchor cable broke, second post broke away	Bolts fractured in tension in second post

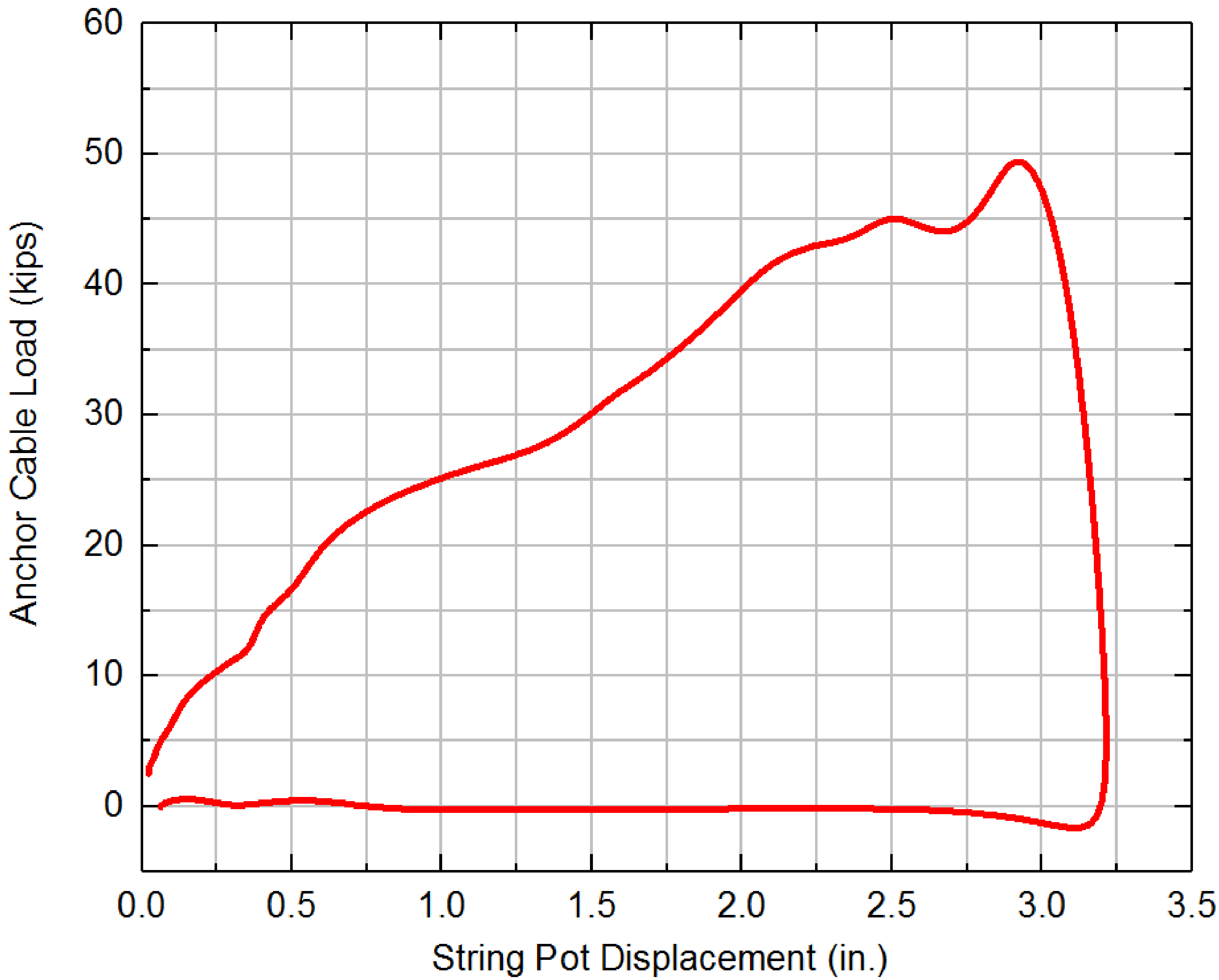


Figure 192. Anchor Cable Load vs. String Pot Displacement, Test No. SPDA-5

10 SUMMARY OF RESULTS AND DISCUSSION

10.1 Summary of Results

The results from the dynamic jerk tests were analyzed to evaluate the performance of the trailing-end anchorage design concepts and are summarized in Table 11. Test no. SPDA-1 was conducted on design concept no. 1, which consisted of two modified UBSPs with a slot at the bottom of a W6x8.5 anchor post for passing the anchor cable through the top post. Test no. SPDA-2 was conducted on design concept no. 2, which consisted of two modified UBSPs with a slot in the foundation tube and bottom base plate to facilitate cable release. The third test, test no. SPDA-3, was conducted on design concept no. 3, which consisted of two modified UBSPs with a slot in the foundation tube and bottom base plate and an angled bearing plate welded to the foundation tube. Test no. SPDA-4 was conducted on design concept no. 4, which was similar to design concept no. 1, except it included a decreased width for the bearing plate from 7 in. (178 mm) to 6¼ in. (159 mm). Test no. SPDA-5 was conducted on design concept no. 5, which was similar to design concept 3, and it included a change to the angle of the bearing plate, welding the angled bearing plate to the foundation tube, and adding a brass keeper rod. Comparisons of the design concepts in terms of force, energy, deflection, and impulse are shown in Figures 193 through 198.

10.1.1 Force Versus Time Response

The force versus time plot for test nos. SPDA-1 through SPDA-5 is shown in Figure 193. The peak forces from the anchor cable load cell were 36.5 kips (162.4 kN), 44.0 kips (195.7 kN), 23.3 kips (103.6 kN), 49.5 kips (220.2 kN), and 49.4 kips (219.7 kN) for test nos. SPDA-1 through SPDA-5, respectively. The increase in peak loads in test nos. SPDA-4 and SPDA-5 as compared to test nos. SPDA-1 and SPDA-3 were due to the design modification made to design concept nos. 1 and 3, respectively. Based on the peak force value, the design concepts were ranked from highest to lowest: (1) test no. SPDA-4, (2) test no. SPDA-5, (3) test no. SPDA-2, (4) test no. SPDA-1, and (5) test no. SPDA-3.

10.1.2 Displacement Versus Time Response

In test nos. SPDA-1 through SPDA-3, the string potentiometer was attached to the end of the anchor cable, while in test nos. SPDA-4 and SPDA-5, the string potentiometer was attached to the foundation tube base plate. The displacement versus time plot is shown in Figure 194. In test nos. SPDA-1 through SPDA-5, the displacements at the peak load were 2.2 in. (55 mm), 2.1 in. (53 mm), 1.0 in. (25 mm), 1.7 in. (43 mm), and 2.9 in. (74 mm), respectively. String potentiometer data from test nos. SPDA-1 through SPDA-3 were not accurate for estimating the displacement of the foundation tube as the string potentiometer was attached to the end of the anchor cable.

10.1.3 Energy Versus Displacement Response

As discussed previously, a linear displacement transducer (string potentiometer) was attached to the end of the anchor cable in test nos. SPDA-1, SPDA-2, SPDA-3, while in test nos. SPDA-4 and SPDA-5, the string potentiometer was attached to the bottom base plate that was welded to the foundation tube. Also, string potentiometers were used in the steel-post MGS downstream anchorage systems to measure the horizontal displacement. In order to properly use the data from these string potentiometers and the in-line cable anchor tensile load cells, the horizontal component of the BCT anchor cable force was compared. Thus, the estimated horizontal anchor cable force was calculated using the in-line BCT anchor cable force and the angle formed by the anchor cable and the ground line.

The energy versus displacement plot was created by integrating the area under the estimated horizontal anchor cable force versus displacement curve, as shown in Figure 196. Design concept nos. 2, 4, and 5 were the concepts with higher energy levels (i.e., energy at peak load) of 49.6 kips-in. (5.6 kJ), 50.6 kips-in. (5.7 kJ), and 81.2 kips-in. (9.2 kJ), respectively.

10.1.4 Impulse Versus Time Response

The impulse versus time plot was generated by integrating the area under the force versus time curve, as shown in Figure 198. A design concept with maximum impulse should sustain the peak load for a longer period, which was desired for a guardrail anchorage system. Ranking of maximum impulse response from highest to lowest is as follows: design concept nos. 2, 4, 1, 5, and 3.

Table 11. Results of Dynamic Jerk Tests – Test Nos. SPDA-1 through SPDA-5

Test No.	Impact Velocity mph (km/h)	Peak Load kips (kN)	Displacement at Peak Load in. (mm)	Energy at Peak Load kips-in. (kJ)	Energy at Peak Displacement kips-in. (kJ)	Failure Mechanism	Component Damage	Attachment Damage
SPDA-1	18.3 (29.5)	36.5 (162.4)	2.2 (55)	45.3 (5.1)	49.8 (5.5)	Pull cable yielded	Rail deformed at second anchor post bolt connection	downstream bolts in both anchor posts fractured in tension
SPDA-2	18.3 (29.5)	44.0 (195.7)	2.1 (53)	49.6 (5.6)	61.2 (6.9)	Anchor post broke away releasing BCT anchor cable	Rail tore at post bolt connection, anchor posts broke away, rail released and pulled downstream	All bolts fractured in tension releasing both anchor posts
SPDA-3	19.2 (30.9)	23.3 (103.6)	1.0 (25)	15.8 (1.8)	15.9 (1.8)	Anchor post fractured in tension	Anchor cable slipped from the bearing plate	All bolts fractured after anchor cable slipped off
SPDA-4	21.1 (34.0)	49.5 (220.2)	1.7 (43)	50.6 (5.7)	57.9 (6.5)	Anchor posts fractured in tension	Rail tore on post bolt connection, posts broke away, and bearing plate released	All bolts fractured in tension releasing both posts
SPDA-5	20.6 (33.1)	49.4 (219.7)	2.9 (74)	81.2 (9.2)	90.8 (10.3)	Rail tearing at both anchor posts	Anchor cable broke, and the second post broke away	Bolts fractured in tension in the second post

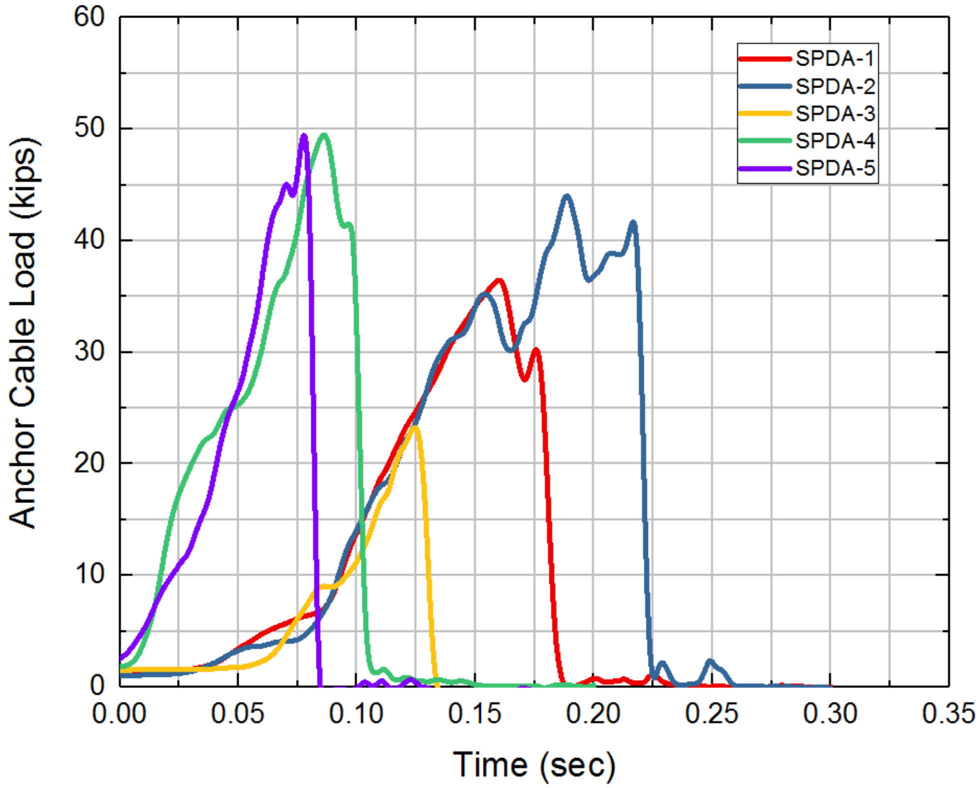


Figure 193. Force versus Time Plot, Test Nos. SPDA-1 through SPDA-5

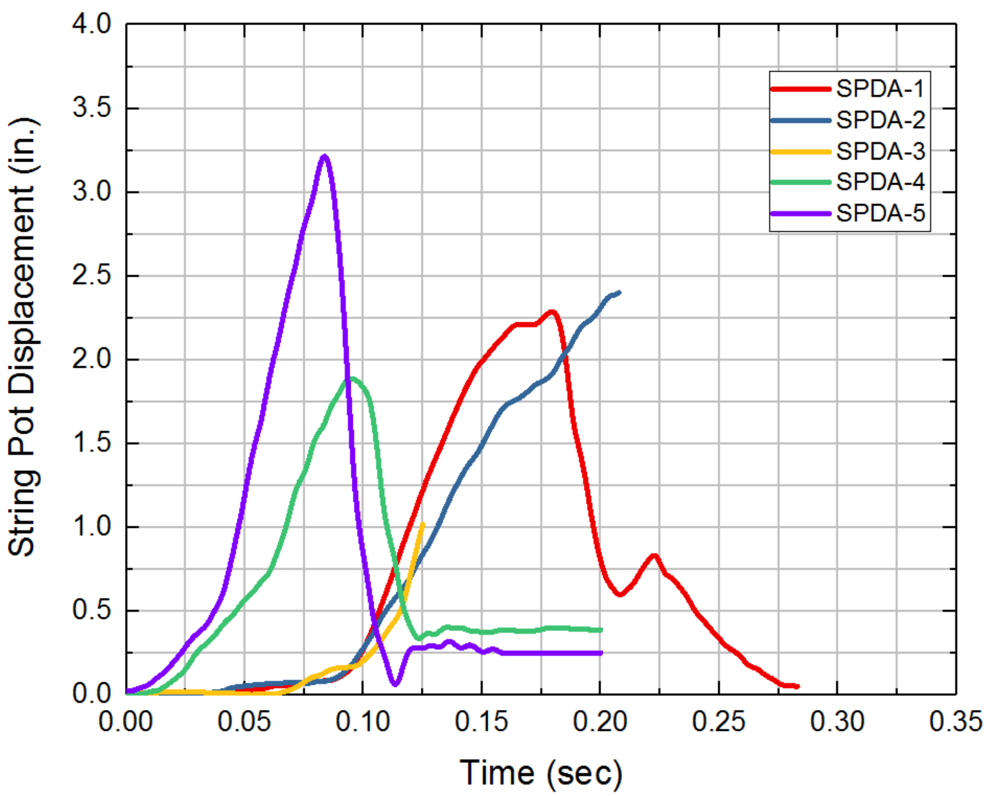


Figure 194. Displacement versus Time Plot, Test Nos. SPDA-1 through SPDA-5

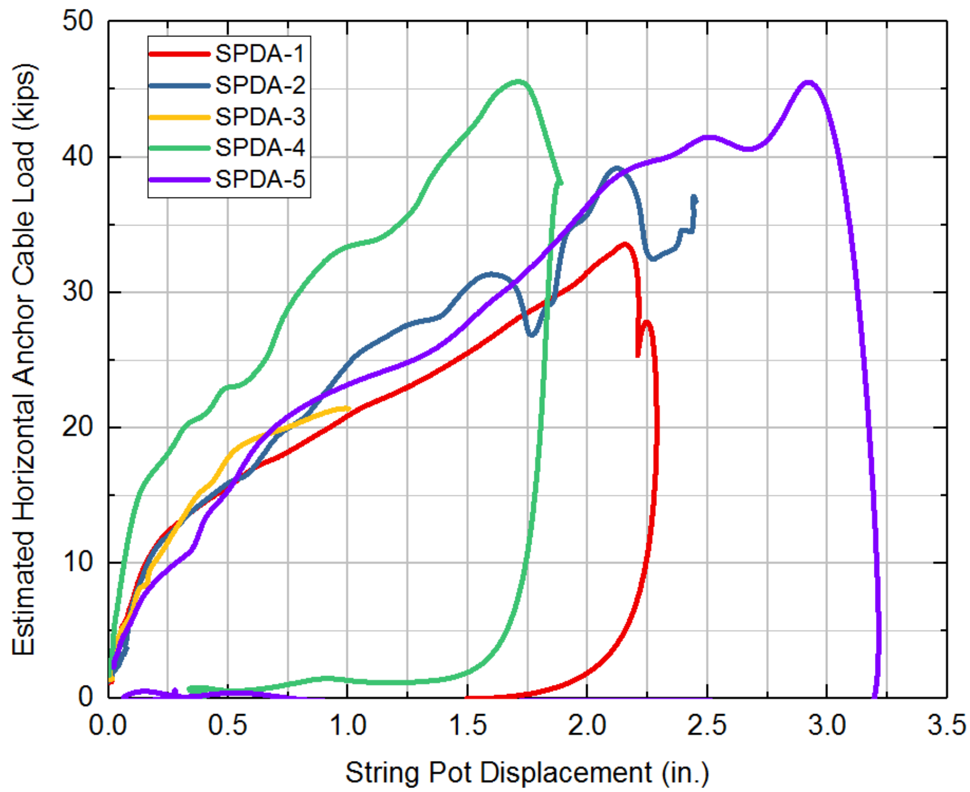


Figure 195. Force versus Displacement Plot, Test Nos. SPDA-1 through SPDA-5

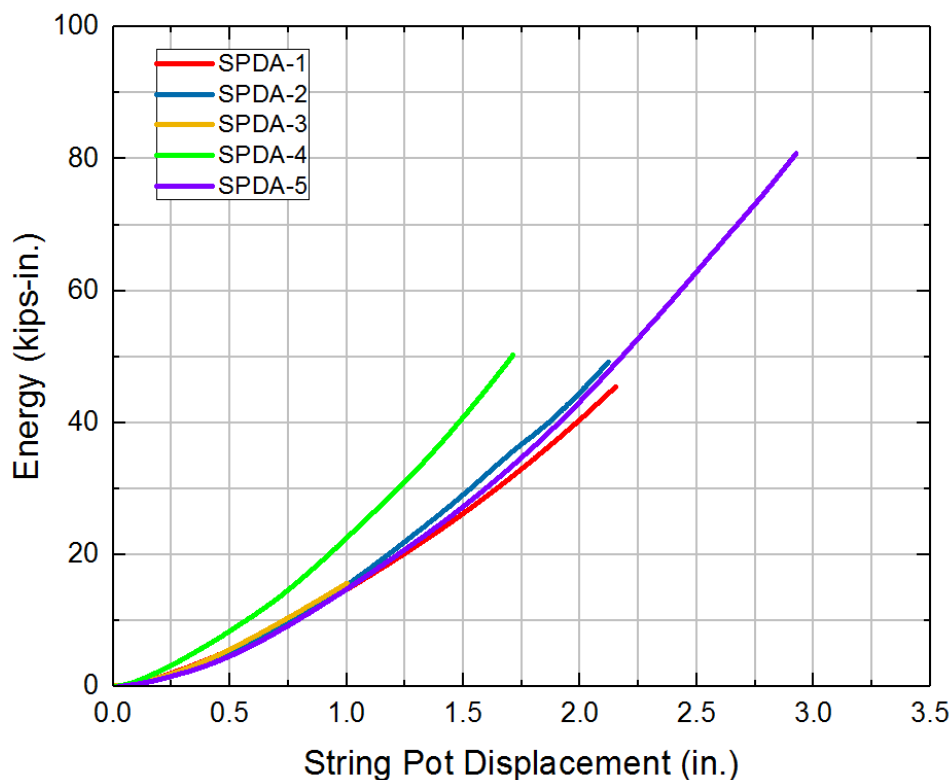


Figure 196. Energy versus Displacement Plot, Test Nos. SPDA-1 through SPDA-5 (Note: Energy calculated using peak load)

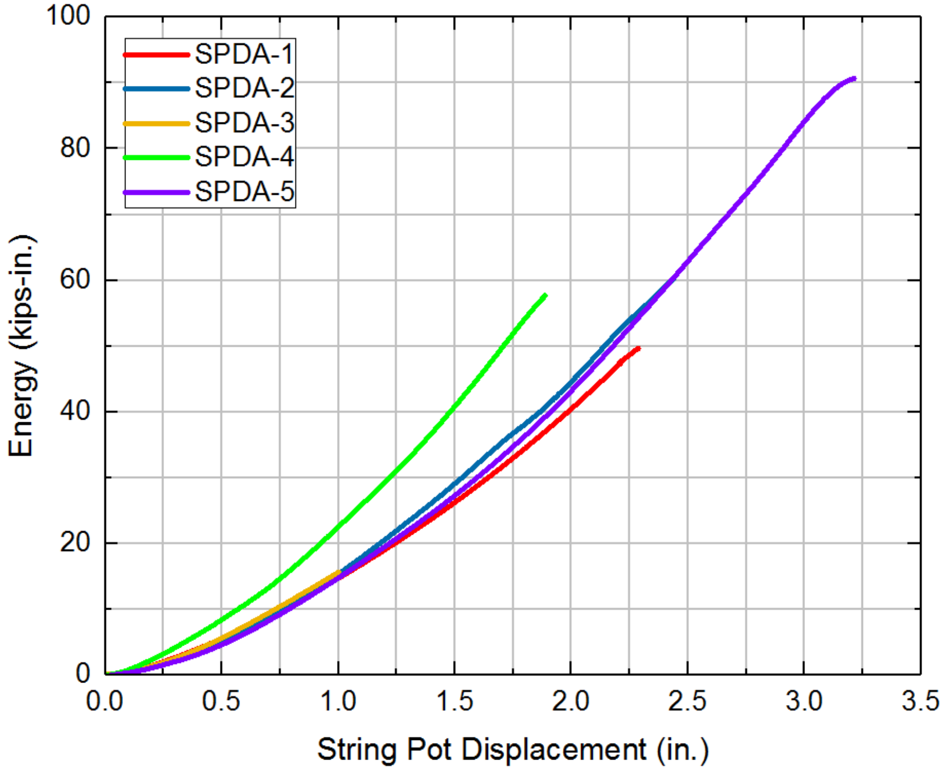


Figure 197. Energy versus Displacement Plot, Test Nos. SPDA-1 through SPDA-5 (Note: Energy calculated using maximum displacement)

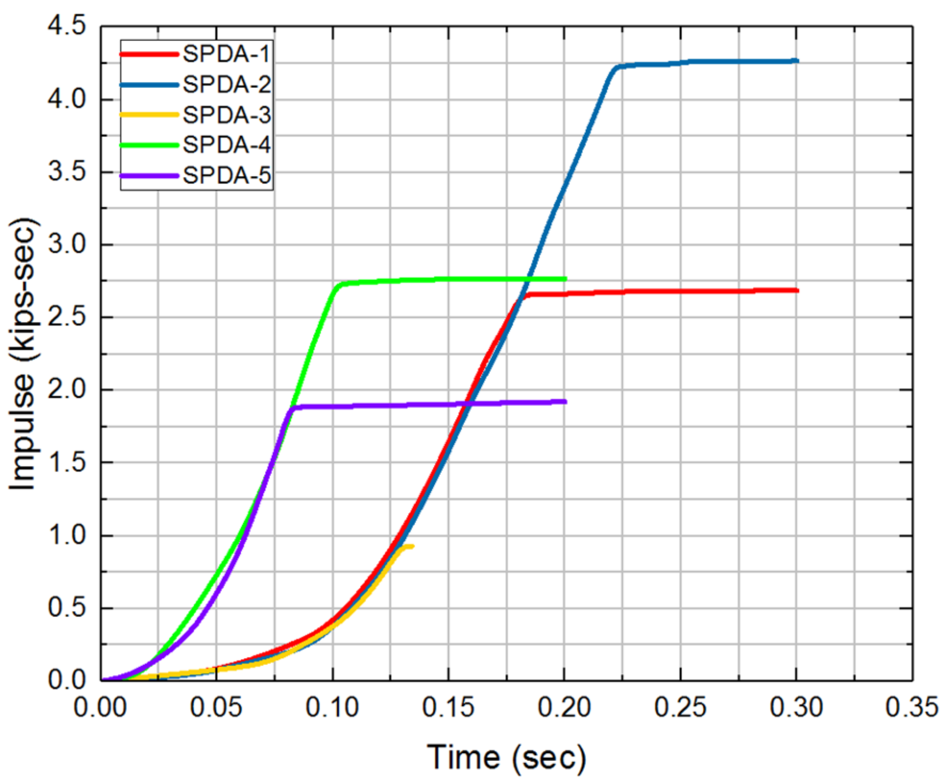


Figure 198. Impulse versus Time Plot, Test Nos. SPDA-1 through SPDA-5

10.2 Discussion on Rail Tearing

During the dynamic jerk test nos. SPDA-1, SPDA-2, SPDA-4, and SPDA-5, the rail tore at the second anchor post rail-to-post bolt attachment. The pre-test rail-to-post attachments are shown in Figure 199. A review was performed to investigate concerns about rail tearing and mitigation considerations. Results from this investigation are summarized in Table 12.

In test nos. SPDA-1 and SPDA-2, rail tearing occurred between force levels of 34.0 kips (151.2 kN) and 44.0 kips (195.7 kN). In test no. SPDA-3, the anchor cable released from the anchor bearing plate and resulted in no rail tearing. In test nos. SPDA-4 and SPDA-5, rail tearing occurred between force levels of 33.0 kips (146.8 kN) and 49.0 kips (218 kN) kips. The load curve for all five tests is shown in Figure 200. The rail tearing for test nos. SPDA-1, SPDA-2, SPDA-4, and SPDA-5 are shown in Figure 201.

In the previous dynamic component tests conducted on the downstream anchorage system with BCT wood posts, the maximum anchor cable load was 35.0 kips (155.7 kN) [4]. This wood-post, downstream anchorage system in combination with the MGS was successfully crash tested and adequately met the TL-3 safety requirements outlined in MASH. In test nos. SPDA-2, SPDA-4, and SPDA-5, peak loads of 44.0 kips (195.7 kN), 49.5 kips (220.2 kN), and 49.4 kips (219.7 kN), respectively, were sustained by the anchor cable. The peak force levels in test nos. SPDA-2, SPDA-4, and SPDA-5 were 20% to 30% higher than the peak force measured in the BCT wood-post anchorage system. Given these higher peak force levels and the successful full-scale crash tests conducted on MGS with the BCT wood-post downstream anchorage system, it was believed that rail tearing mitigation would not be necessary.

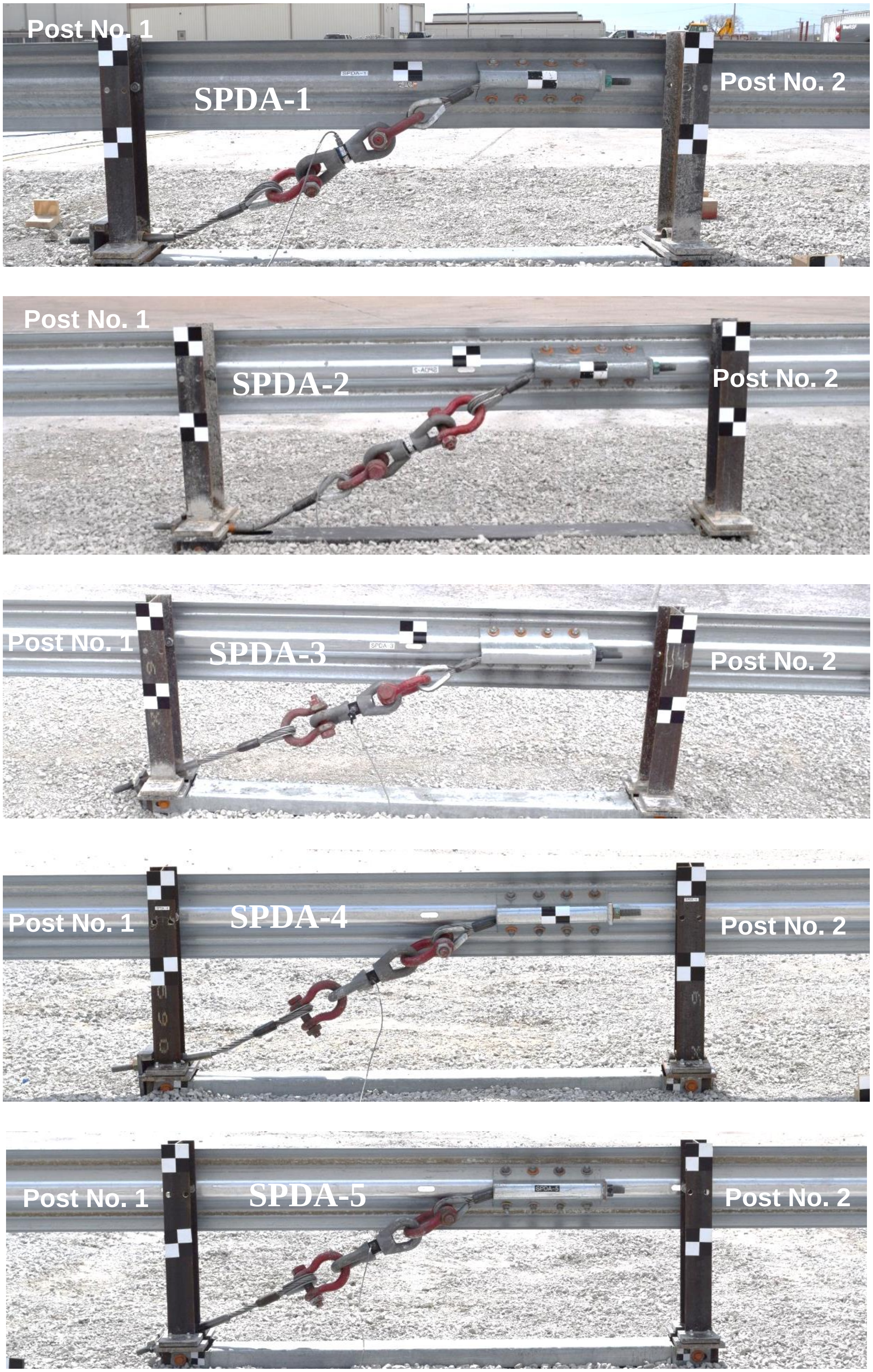


Figure 199. Pre-Test Rail-To-Post Attachment, Test Nos. SPDA-1 through SPDA-5

Table 12 Summary of Rail Tearing, Test Nos. SPDA-1 through SPDA-5

Test No.	Rail Tearing	Range of Load at Which Rail Tearing Occurred kips (kN)	Peak Load kips (kN)	Failure Mechanism
SPDA-1	Rail tore at second anchor post bolt connection	34.0 to 36.5 (151.2 to 162.4)	36.5 (162.4)	Pull cable yielded
SPDA-2	Rail tore at second anchor post bolt attachment	35.0 to 44.0 (155.7 to 195.7)	44.0 (195.7)	Anchor post broke away releasing BCT anchor cable
SPDA-3	N/A	N/A	23.3 (103.6)	Anchor post fractured in tension
SPDA-4	Rail tore at second anchor post bolt attachment	33.0 to 49.5 (146.8 to 220.2)	49.5 (220.2)	Anchor posts fractured in tension
SPDA-5	Rail tore at both anchor post bolt connection	35.0 to 49.0 (155.7 to 218)	49.4 (219.7)	Rail tearing at both anchor post

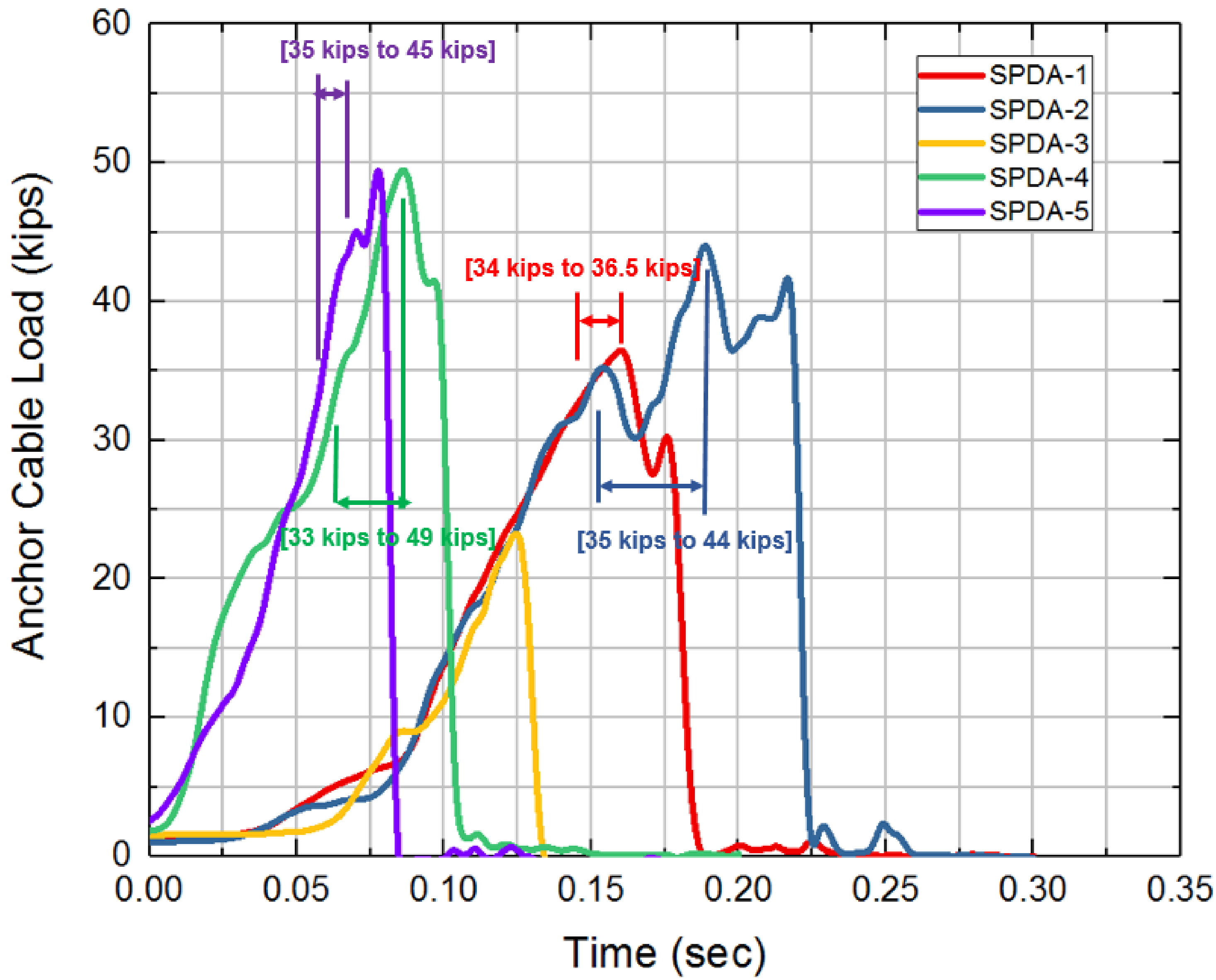


Figure 200. Rail Tearing Forces, Test Nos. SPDA-1 through SPDA-5

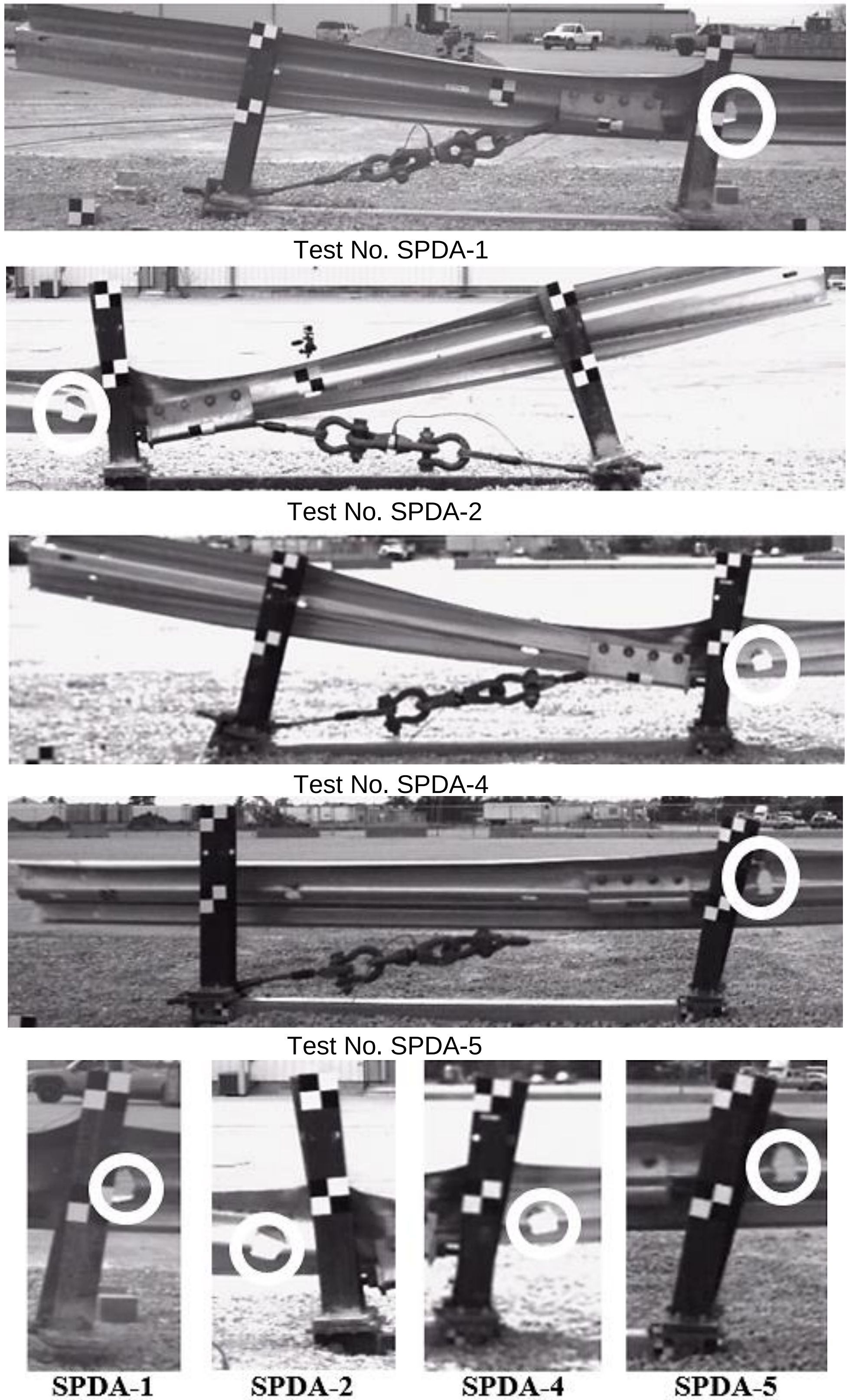


Figure 201. Rail Tearing, Test Nos. SPDA-1, SPDA-2, SPDA-4, and SPDA-5

10.3 Comparison of Test Nos. SPDA-2, SPDA-4, SPDA-5, and DSAP-2

Three design concepts for the steel-post, trailing-end anchorage system were determined to have the highest potential for passing MASH TL-3 impacts. The results from the dynamic jerk tests on steel-post, trailing-end anchorage design concept nos. 2, 4, and 5 were compared to the results obtained from test no. DSAP-2 on the wood-post, trailing-end anchorage system, as shown in Table 13. Test no. DSAP-2 was a dynamic jerk test conducted on a wood-post, trailing-end anchorage system consisting of two BCT wood posts in steel foundation tubes with a compression ground line strut and a cable anchor. Criteria were established to evaluate the safety performance of the systems, economics, and aesthetics. A trailing-end, anchorage system should:

1) Develop tensile strength necessary to ensure satisfactory redirection performance in impacts within the LON, withstanding the peak forces and the energy levels absorbed at the peak force of the anchorage system.

2) Minimize vehicle deceleration for end impacts while containing, or redirecting vehicle, or controlling penetration. Thus, the impacting vehicle does not launch, roll, or pocket.

3) Minimize potential for occupant compartment penetration.

4) Be economically feasible for fabrication and installation.

5) Provide functional appearance.

Table 13. Comparison Parameters and Associated Values

End-trailing, Anchorage Performance Parameters	Steel-Post Trailing-End Anchorage			Wood-Post, Trailing-End Anchorage (DSAP-2)
	Design Concept No. 2 (SPDA-2)	Design Concept No. 4 (SPDA-4)	Design Concept No. 5 (SPDA-5)	
Peak Force, kips (kN)	44.0 (195.7)	49.5 (220.2)	49.4 (219.7)	35.0 (155.7)
Energy at Peak Force, kip-in. (kJ)	49.6 (5.6)	50.6 (5.7)	81.2 (9.2)	16.8 (1.9)
Breakaway Behavior	Excellent	Excellent	N/A*	Excellent
Anchor Cable Releasability	Excellent	Excellent	N/A*	Excellent

*Anchor cable broke exceeding yield strength

The wood-post, trailing-end anchorage system developed a peak force of 35.0 kips (155.7 kN) in test no. DSAP-2 [4]. The steel-post, trailing-end anchorage concepts developed peak forces of 44.0 kips (195.7 kN), 49.5 kips (220.2 kN), and 49.4 kips (219.7 kN) during the dynamic jerk tests of design concept nos. 2, 4, and 5, respectively. Design concept no. 2 generated 25% more peak force than the wood-post, trailing-end anchorage system, while design concept nos. 4 and 5 generated 40% more peak force than the wood-post, trailing-end anchorage system. Considering the peak force response of design concept nos. 2, 4, and 5, these steel-post, trailing-end anchorage designs developed the adequate tensile strength necessary to ensure desirable redirection performance.

A comparison was made between the energy level at the peak force during test no. DSAP-2 and test nos. SPDA-2, SPDA-4, and SPDA-5. The energies at peak force in test nos. DSAP-2, SPDA-2, SPDA-4, and SPDA-5 were 16.8 kips-in. (1.9 kJ), 49.6 kips-in. (5.6 kJ), 50.6 kips-in. (5.7 kJ), and 81.2 kips-in. (9.2 kJ), respectively. The energies at peak force in test nos. SPDA-2 and SPDA-4 were approximately three times greater than the energy level in test no. DSAP-2, while the energy at peak force in test no. SPDA-5 was approximately five times greater than the energy level in test no. DSAP-2. Considering the energy at the peak force, all design concepts for the steel-post, trailing-end anchorage system performed well as compared to the wood-post, trailing-end anchorage system. Based on the results of the dynamic jerk tests, the three best options for the steel-post, trailing-end anchorage system absorbed adequate energy to ensure the desired redirection performance.

In test nos. SPDA-2 and SPDA-4, both modified UBSPs broke away cleanly and released the anchor cable. In test no. SPDA-5, the anchor cable broke and remained attached to the bearing plate. This behavior was due to overloading the anchor cable. If this behavior of anchor cable yielding did not occur, this design concept may have developed an adequate tensile strength. In this test, the second post broke away. In test no. DSAP-2, the BCT wood posts cleanly broke away and released the anchor cable. Thus, considering the breakaway behavior and anchor cable release, the new steel-post, trailing-end anchorage design concepts performed satisfactorily as compared to the wood-post, trailing-end anchorage system.

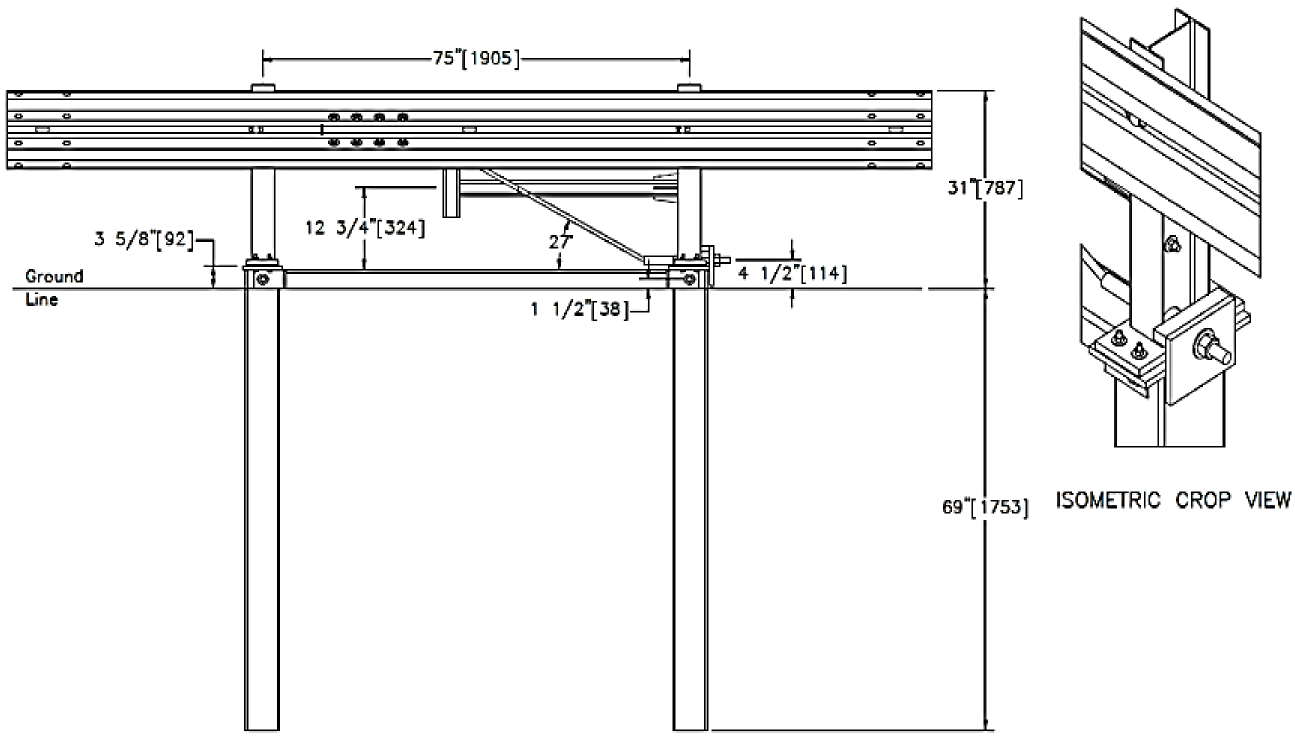
Full-scale crash testing should be conducted to verify performance for the steel-post versus wood-post trailing-end anchorage system. Breakaway load values, anchorage capacity, and W-beam performance are essential to assure the effectiveness and integrity of the trailing-end anchorage performance. Thus, the researchers recommended the evaluation of the performance for the steel-post, trailing-end anchorage system through full-scale crash testing.

10.4 Steel-Post, Trailing-End Anchorage Design Concept Selection

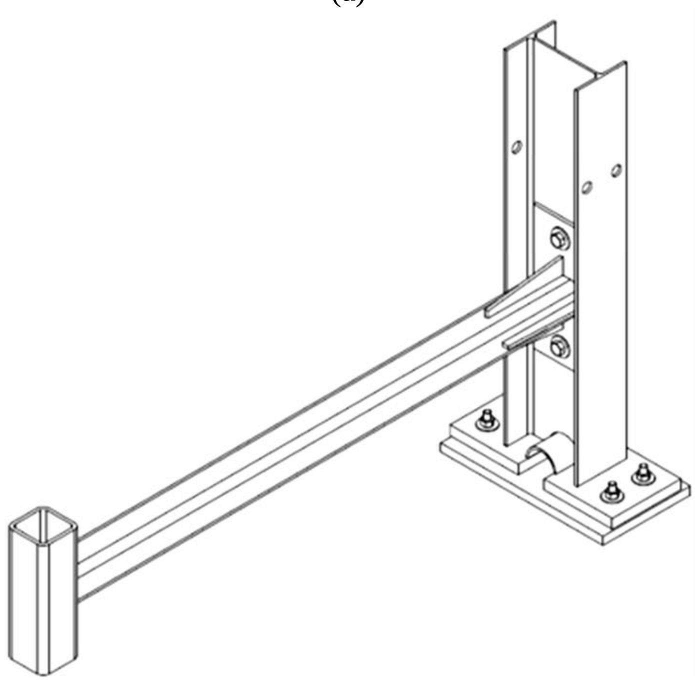
Design concept nos. 2, 4, and 5 were considered as potential alternatives for the steel-post version of the trailing-end anchorage system. The candidate design concepts and their impact performance were presented and discussed with the Midwest Pooled Fund Program member states. The three design concepts differed primarily in how the anchorage cable was secured to the end post. Concept no. 2 passed through the foundation tube, concept no. 4 passed the cable through the top W6x8.5 steel post, and concept no. 3 passed the cable through an angled plate welded to the foundation tube. Member states gave input on a preferred final concept for full-scale crash testing through a survey. More details on the survey results can be found in Appendix I.

Based on this input, a modified version of concept no. 4, as shown in Figure 202a, was selected as the final design and slightly modified for use in full-scale vehicle crash testing. Modifications to the system included the addition of a T-shaped, breaker bar assembly attached to the end anchor post to facilitate the release and rotation of the end post as well as the subsequent release of the cable anchor for impacts occurring upstream from the anchor post, as shown in

Figure 202b. The T-shaped, breaker bar assembly was bolted to the web of the upper end post stub to ensure a controlled release of the anchor as well as to reduce the potential for vehicle instability and/or unacceptable ridedown decelerations.



(a)



(b)

Figure 202. Final Design Concept for Steel-Post, MGS Trailing-End Anchorage System – (a) Design Concept No. 4 and (b) T-Shaped, Breaker Bar Design

11 FURTHER DESIGN RECOMMENDATIONS

11.1 Ground Line Strut Design Concepts

During installation of the wood-post, trailing-end anchorage system using two BCT wood posts, ground line struts are often installed to maximize the resistance of soil surrounding the foundation tubes. For actual field installations of the MGS wood-post, trailing-end anchorage system, the ground line strut can be installed before or after the installation of the two breakaway wood posts. However, for the current prototypes of the steel-post, trailing-end anchorage system, steel baseplates are welded to the top and bottom ends of the adjoining sections, thus making installation of the ground line strut difficult. Therefore, modifications were necessary to facilitate the ground line strut installation procedure.

A total of four ground line strut design concepts were developed based on different alternatives for coupling the 66½-in. x 11¾-in. x 10-gauge (1,689-mm x 298-mm x 3.4-mm) ASTM A36 steel C-channel ground line strut with the two TS 8x6x3⁄16 ASTM A500 Grade B foundation tubes. It should be noted these modifications have not been component tested. These ground line strut design concepts include: (1) bolted yoke placed outside strut; (2) bolted yoke placed inside strut; (3) welded yoke placed outside strut; and (4) welded yoke placed inside strut.

11.1.1 Ground Line Strut Design Concept No. 1 − Bolted Yoke Placed Outside Strut

Design concept no. 1, bolted yoke placed outside of the strut, included: (1) a 66½-in. x 11¾-in. x 10-gauge (1,689-mm x 298-mm x 3.34-mm) steel C-channel strut, (2) two 17-in. x 3-in. x ¼-in. (432-mm x 76-mm x 6-mm) steel bent plates placed outside the steel bent C-channel strut, and (3) two 7-in. x 2¾-in. x ½-in. (178-mm x 70-mm x 13-mm) steel plates bolted to the steel bent plates and the foundation tubes. At the location of the anchor and second posts, a 17-in. x 3-in. x ¼-in. (432-mm x 76- mm x 6-mm) steel bent plate was placed outside of the C-channel strut and was bolted to the strut using one ⅞-in. (22-mm) diameter, 8½-in. (216-mm) long hex-head bolt. The steel bent plate was bolted to the 7-in. x 2¾-in. x ½-in. (178-mm x 70-mm x 13-mm) steel plate and the foundation tube using two ½-in. (13-mm) diameter, 2-in. (51-mm) long hex-head bolts. To secure the connection between the steel plate and foundation tube, the heads of the bolts were designed to be welded inside the foundation tube using a 3⁄16-in. (5-mm) weld. Detailed drawings for design concept no. 1 are shown in Figures 203 through 210.

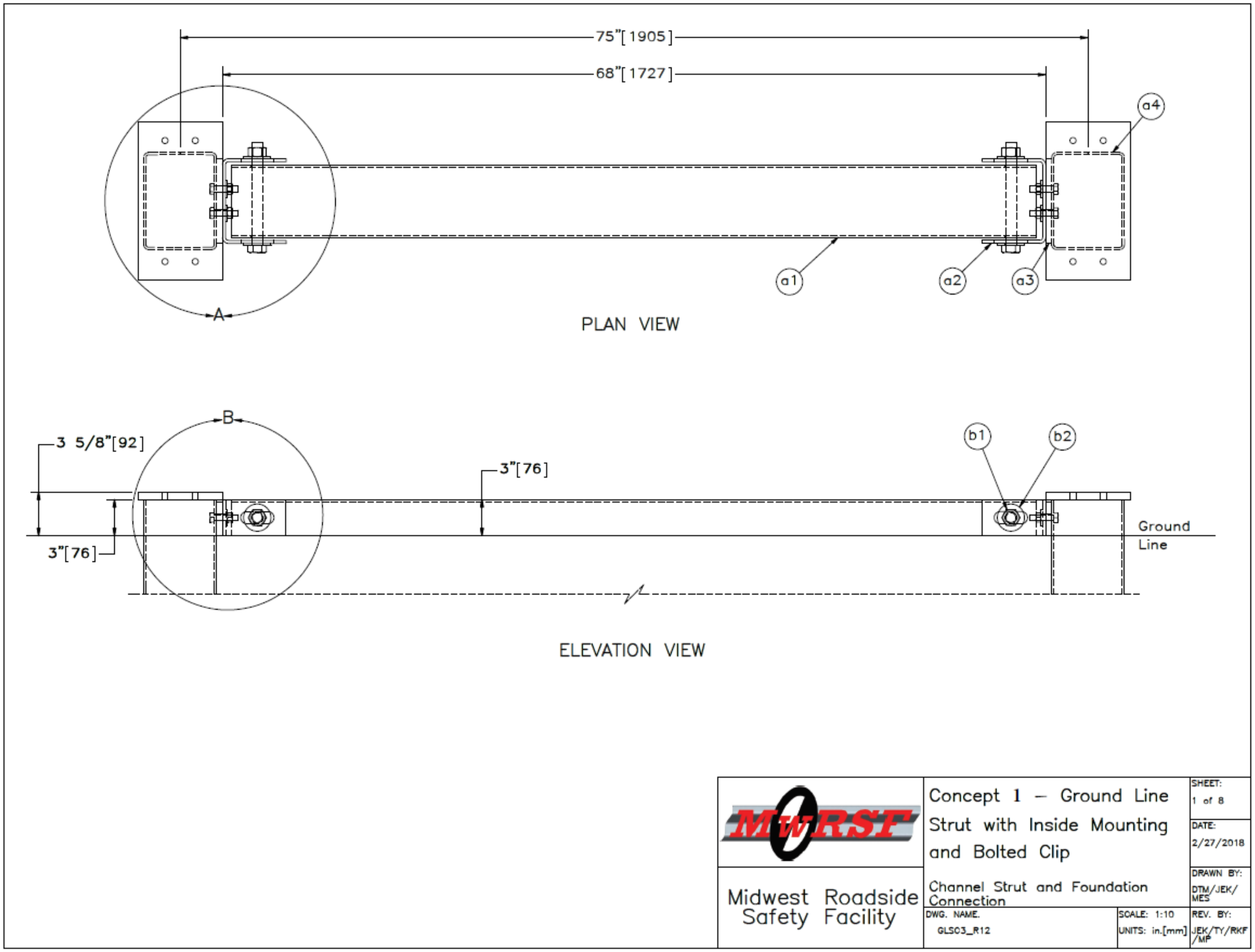


Figure 203. Ground Line Strut Design Concept No. 1 – Channel Strut and Foundation Connection

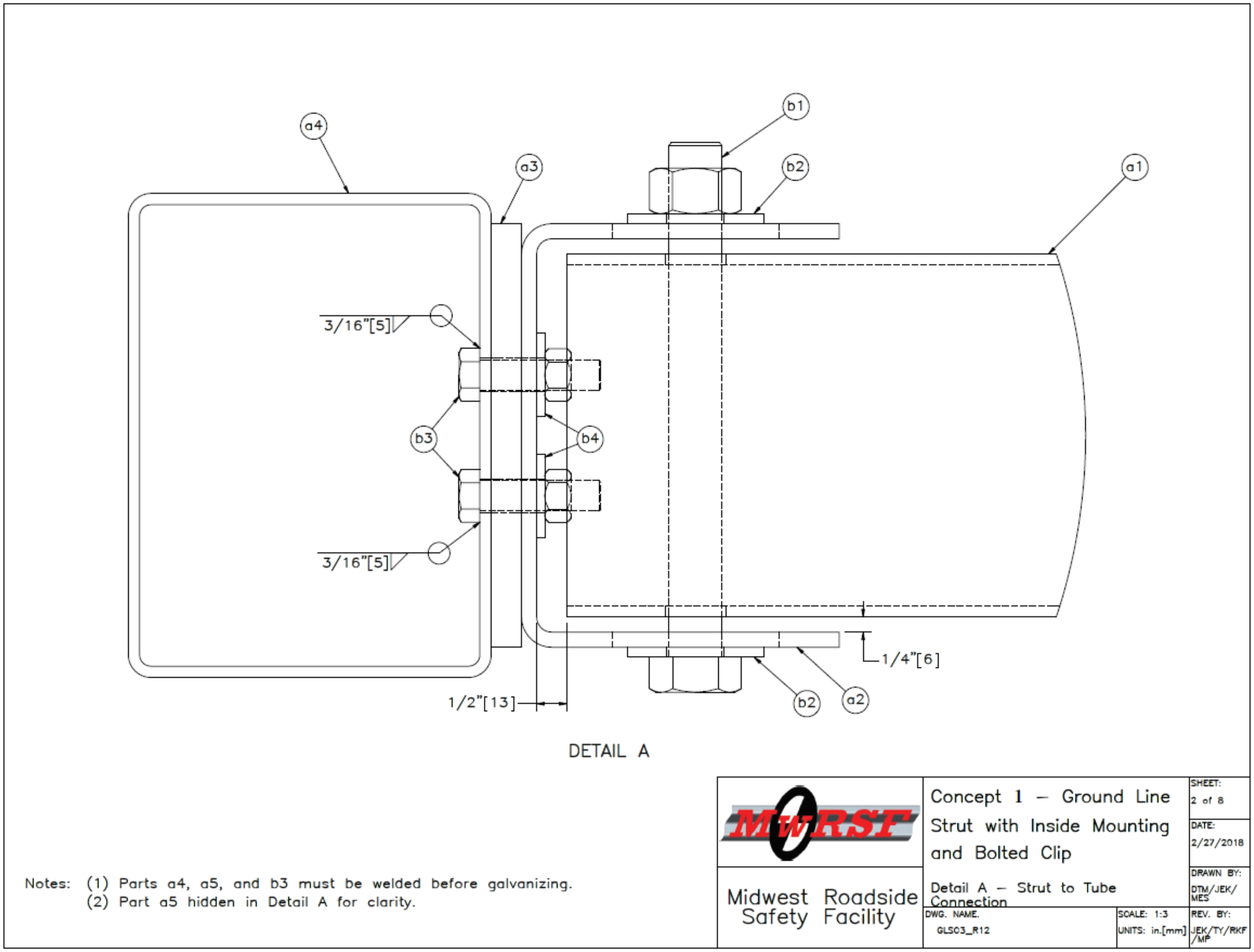


Figure 204. Ground Line Strut Design Concept No. 1 – Strut to Tube Connection

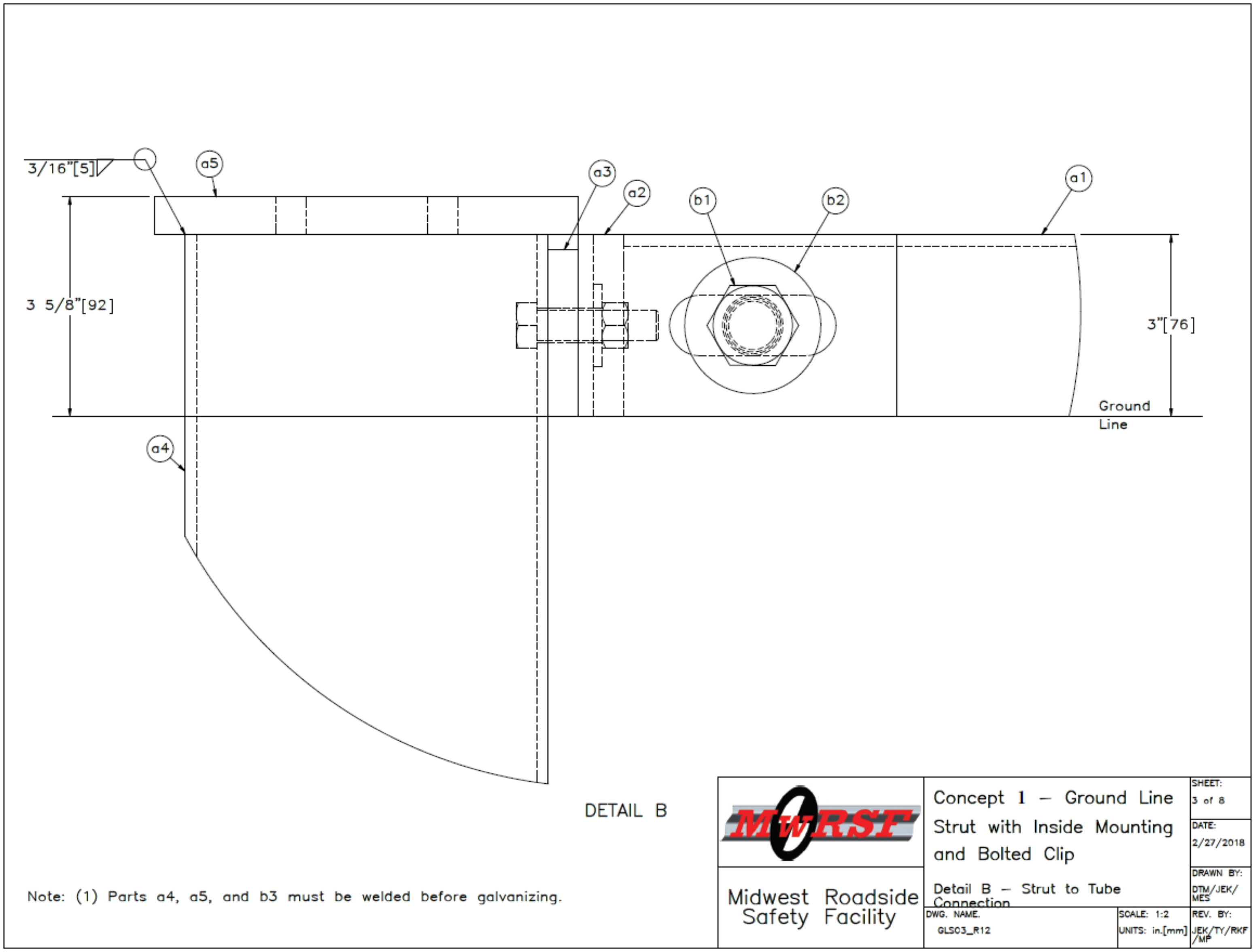


Figure 205. Ground Line Strut Design Concept No. 1 – Strut to Tube Connection

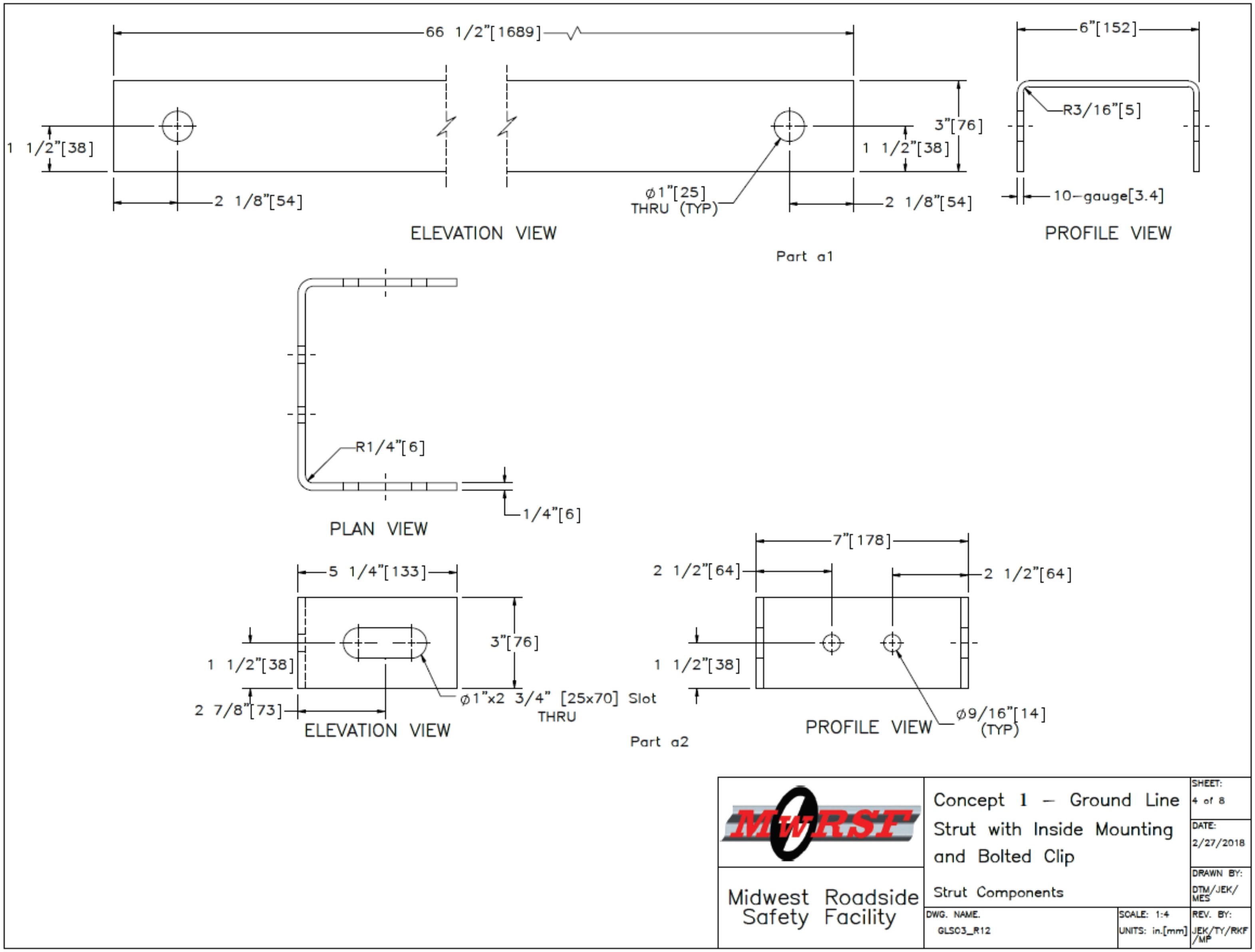


Figure 206. Ground Line Strut Design Concept No. 1 – Strut Components

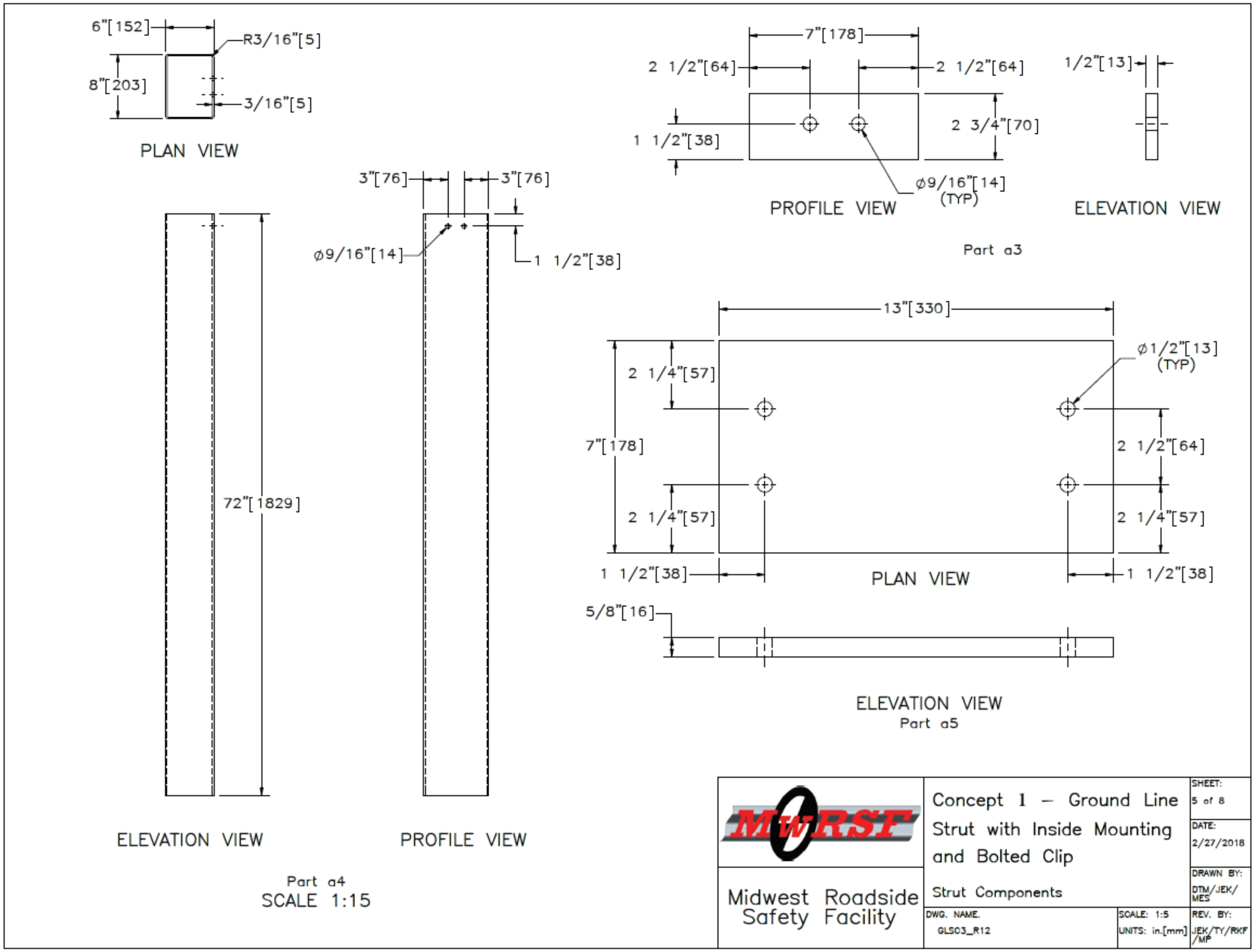


Figure 207. Ground Line Strut Design Concept No. 1 – Strut Components

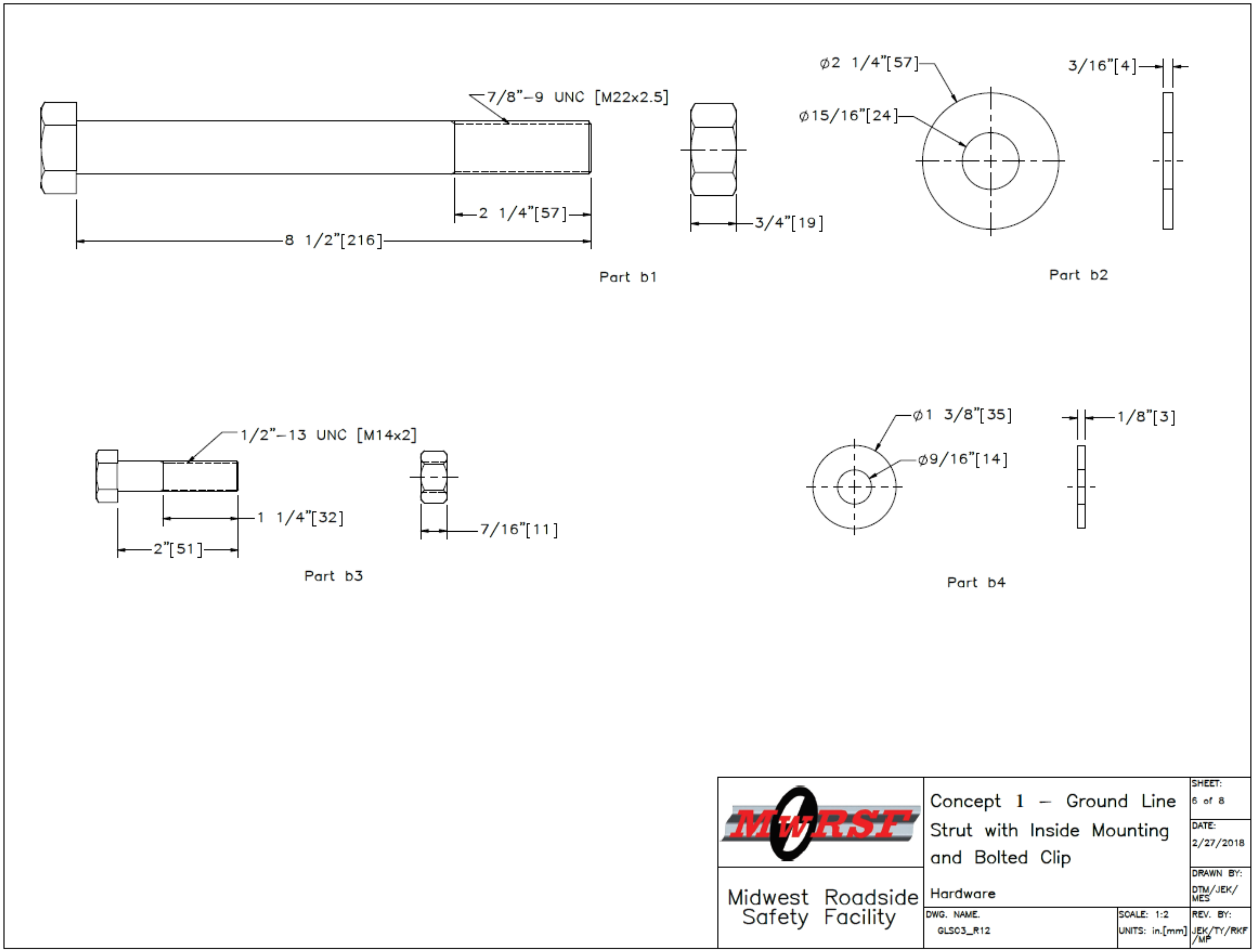


Figure 208. Ground Line Strut Design Concept No. 1 – Hardware

Item No.	Qty.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	1	66 1/2"x11 3/4"x10-gauge [1,689x298x3.4] Bent Steel Channel Strut	ASTM A36	ASTM A123	–
a2	2	17"x3"x1/4" [432x76x6] Bent Steel Plate	ASTM A36	ASTM A123	–
a3	2	7"x2 3/4"x1/2" [178x70x13] Steel Plate	ASTM A36	ASTM A123	–
a4	2	TS 8"x6"x3/16" [203x152x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123*	–
a5	2	13"x7"x5/8" [330x178x16] Steel Plate	ASTM A36	ASTM A123*	–
b1	2	7/8"-9 UNC [M22x2.5], 8 1/2" [216] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	–
b2	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
b3	4	1/2"-13 UNC [M14x2], 2" [51] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329*	FWC14a
b4	4	1/2" [13] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FBX14a

* Weld before galvanizing

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Concept 1 – Ground Line Strut with Inside Mounting and Bolted Clip

Bill of Materials

SHEET: 7 of 8
DATE: 2/27/2018
DRAWN BY: DTM/JEK/MES
DWG. NAME. GLS03_R12
SCALE: None
UNITS: in.[mm]
REV. BY: JEK/TY/RKF/MP

Figure 209. Ground Line Strut Design Concept No. 1 – Bill of Materials

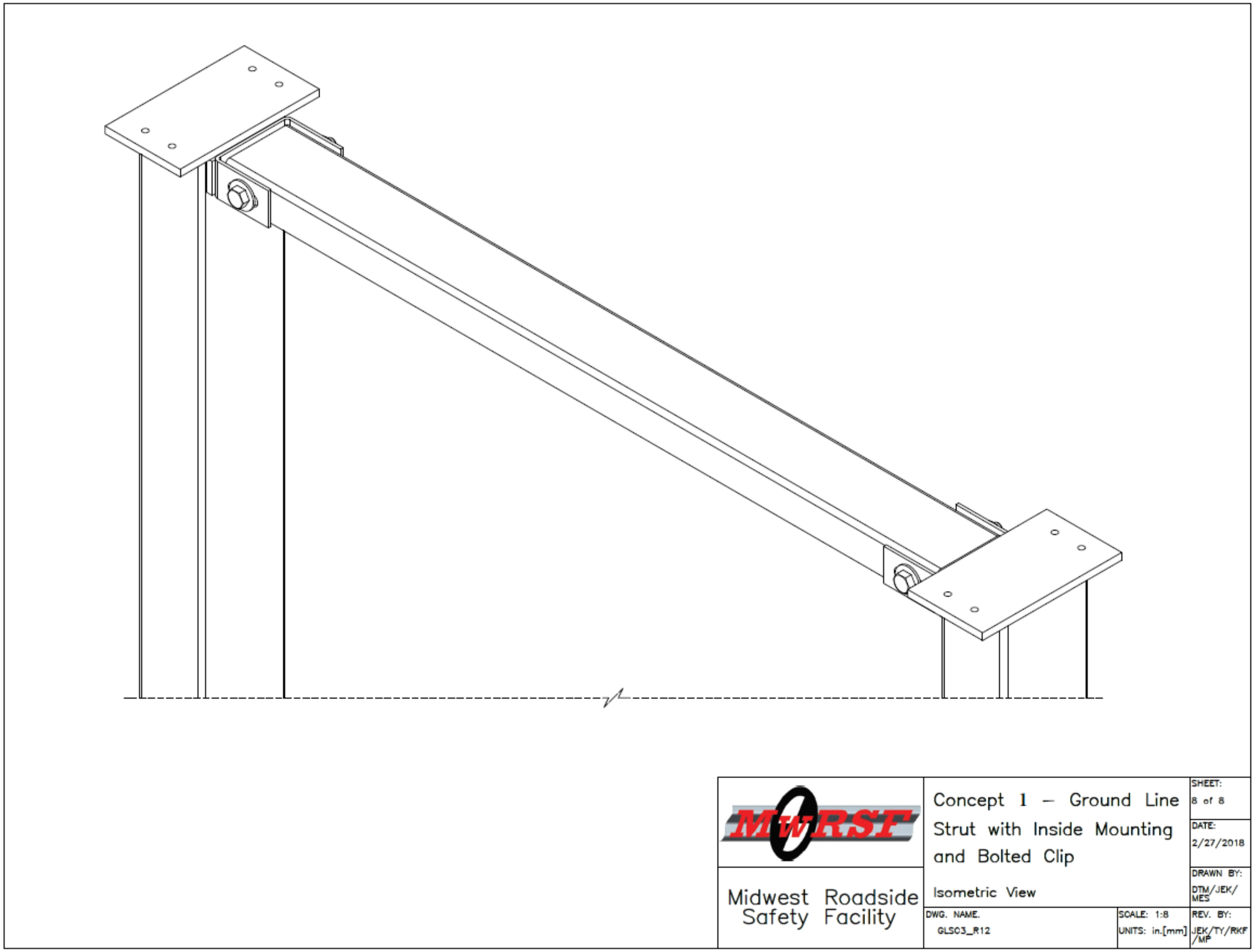

Figure 210. Ground Line Strut Design Concept No. 1 – Isometric View

11.1.2 Ground Line Strut Design Concept No. 2 − Bolted Yoke Placed Inside Strut

Design concept no. 2, bolted yoke placed inside the strut, was similar to the ground line strut design concept no. 1, except the two 15⅜-in. x 3-in. x ¼-in (391-mm x 76-mm x 6-mm) steel bent plates were placed inside the C-channel ground line strut. This design concept included: (1) a 67-in. x 11¾-in. x 10-gauge (1,702-mm x 298-mm x 3.4-mm) steel C-channel strut; (2) two 15⅜-in. x 3-in. x ¼-in. (391-mm x 76-mm x 6-mm) steel bent plates; and (3) two 7-in. x 2¾-in. x ½-in. (178-mm x 70-mm x 13-mm) steel plates bolted to the steel bent plate and the foundation tube. At the location of the anchor and second posts, two 15⅜-in. x 3-in. x ¼-in (391-mm x 76-mm x 6-mm) steel bent plates were placed inside the strut and bolted to the strut using one ⅞-in. (22-mm) diameter, 7½-in. (191-mm) long hex head bolt at each end. The steel bent plate was bolted to the 7-in. x 2¾-in. x ½-in. (178-mm x 70-mm x 13-mm) steel plate and the foundation tube using two ½-in. (13-mm) diameter, 2-in. (51-mm) long hex head bolts. To secure the connection between the steel plate and foundation tube, the heads of the bolts were designed to be welded inside the foundation tube using a 3⁄16-in. (5-mm) weld. Detailed drawings for design concept no. 2 are shown in Figures 211 through 218.

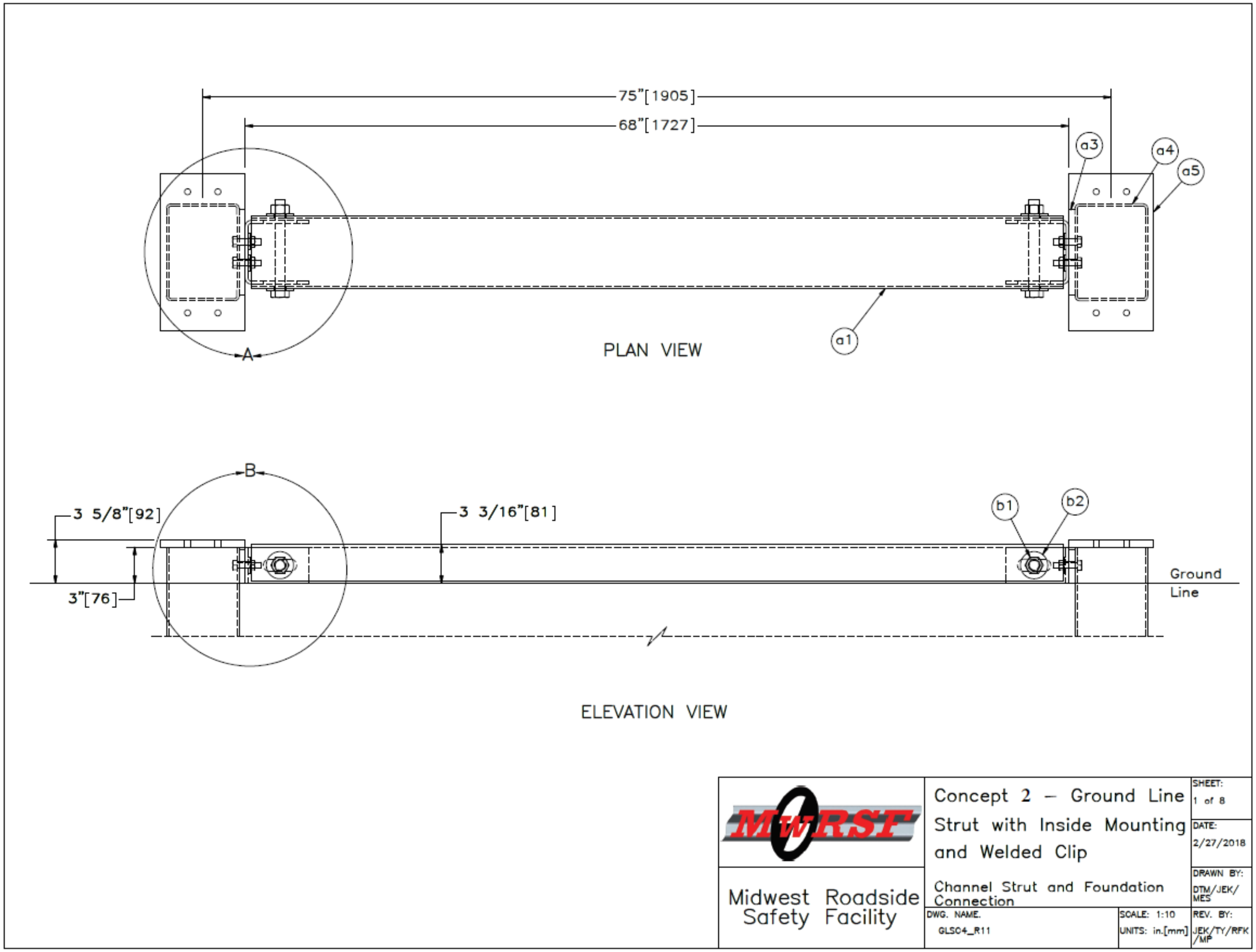

Figure 211. Ground Line Strut Design Concept No. 2 – Channel Strut and Foundation Connection

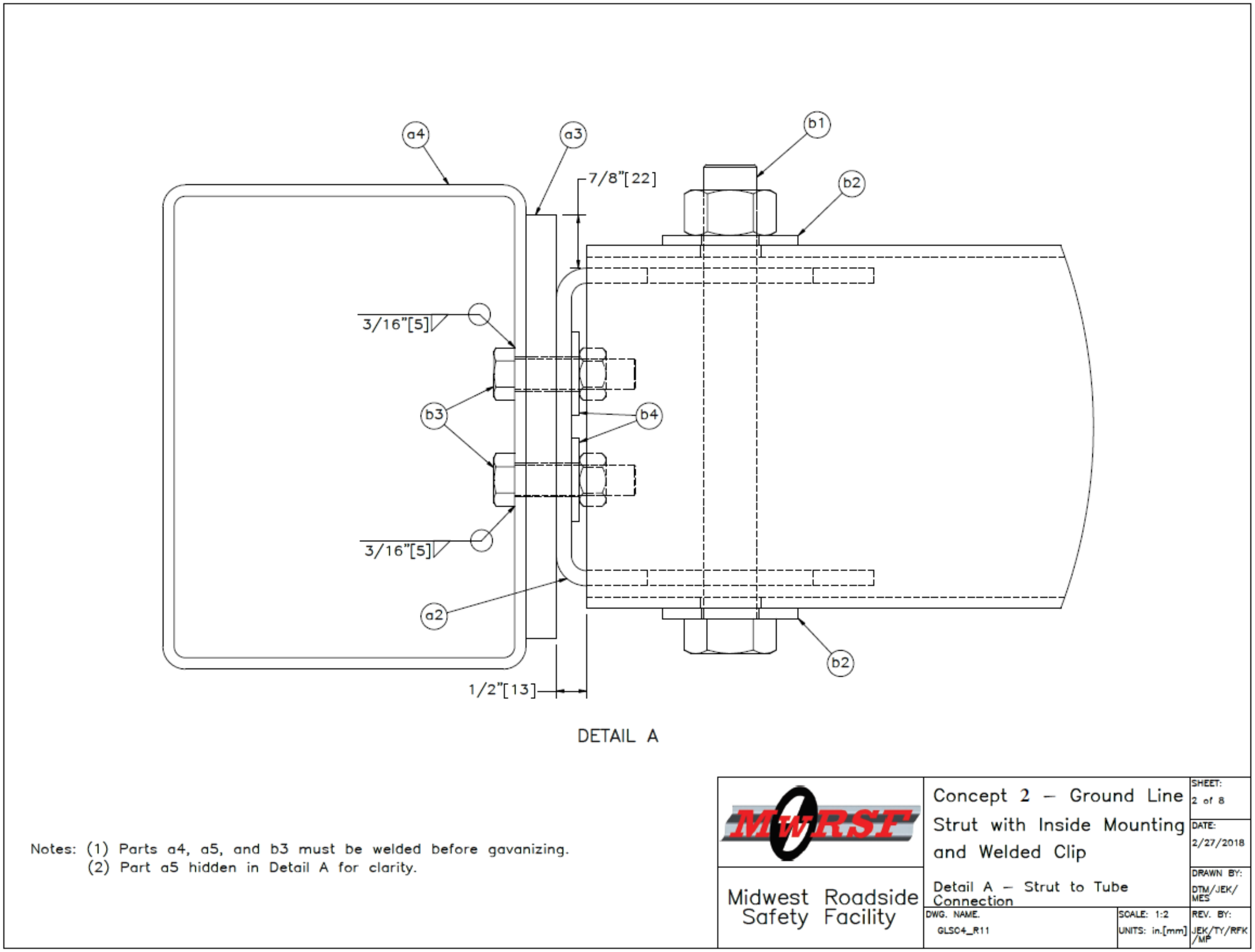

Figure 212. Ground Line Strut Design Concept No. 2 – Strut to Tube Connection

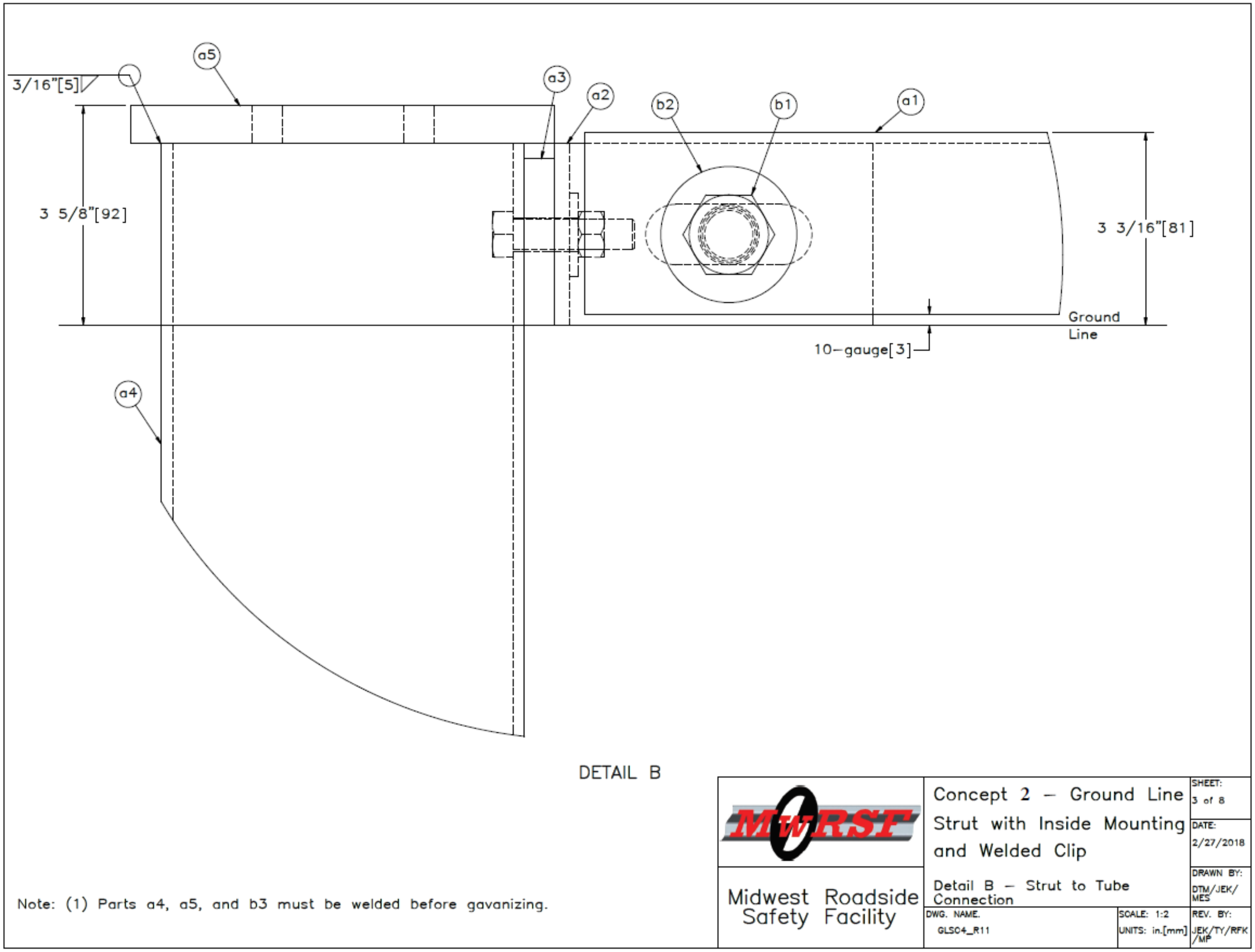

Figure 213. Ground Line Strut Design Concept No. 2 – Strut to Tube Connection

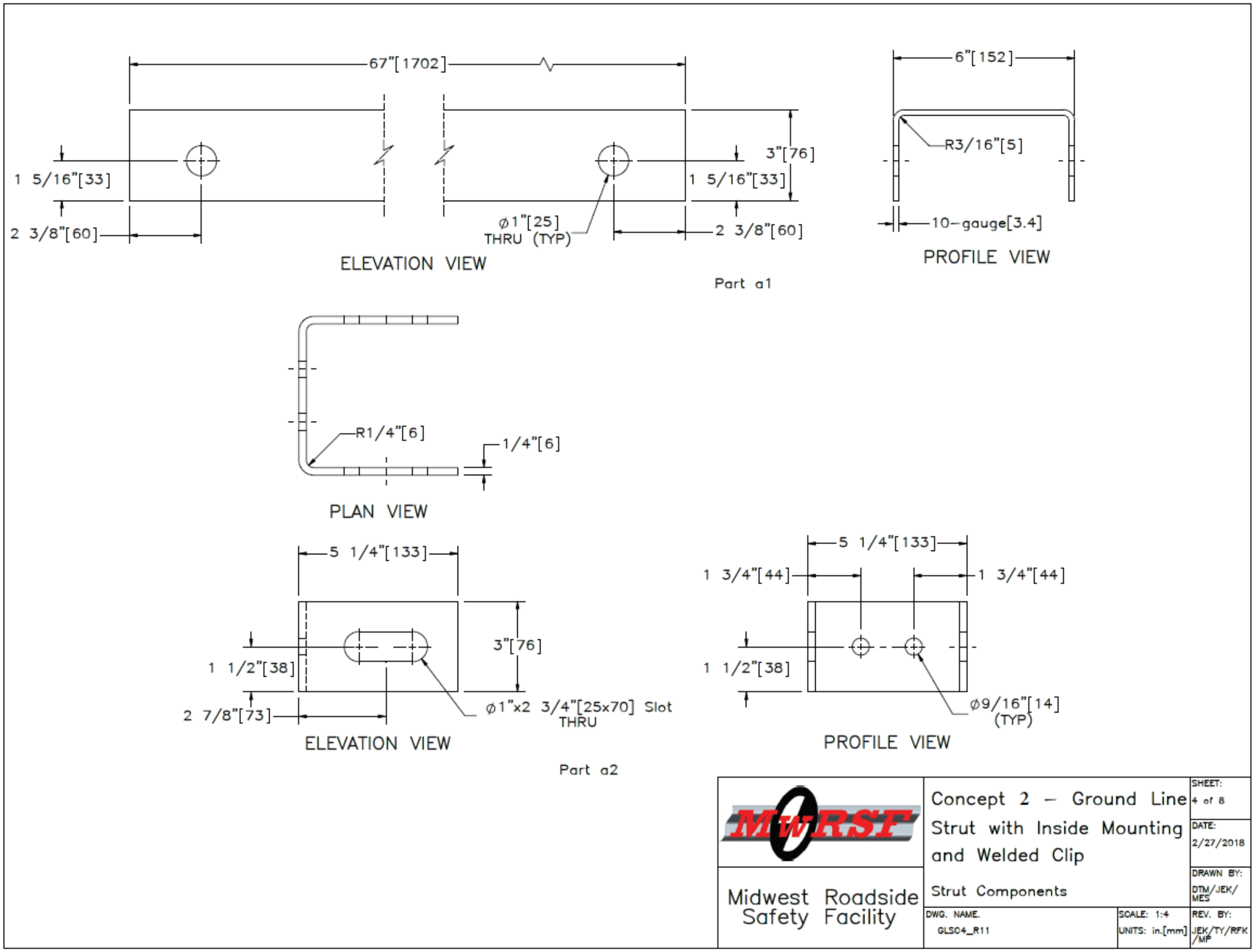

Figure 214. Ground Line Strut Design Concept No. 2 – Strut Components

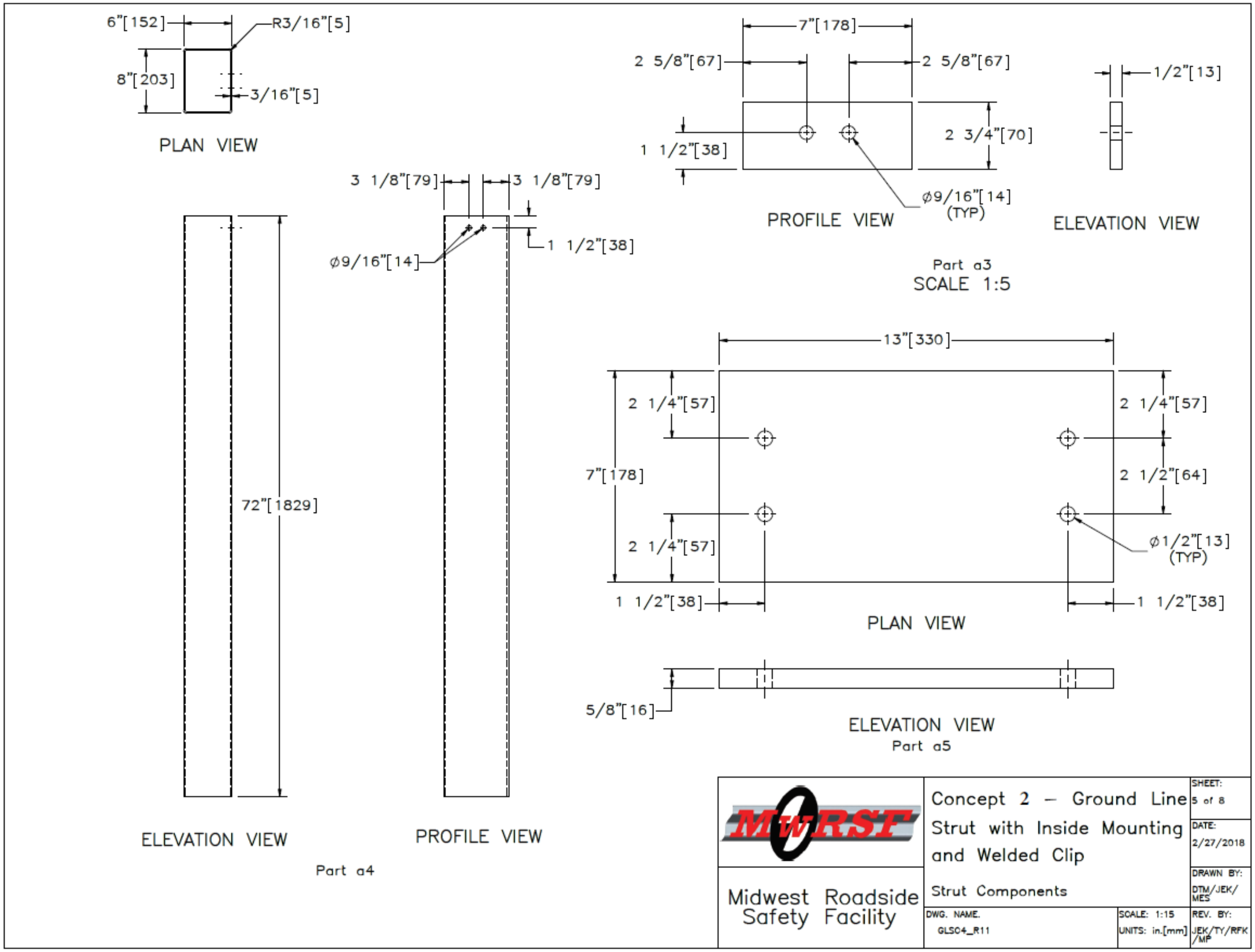

Figure 215. Ground Line Strut Design Concept No. 2 – Strut Components

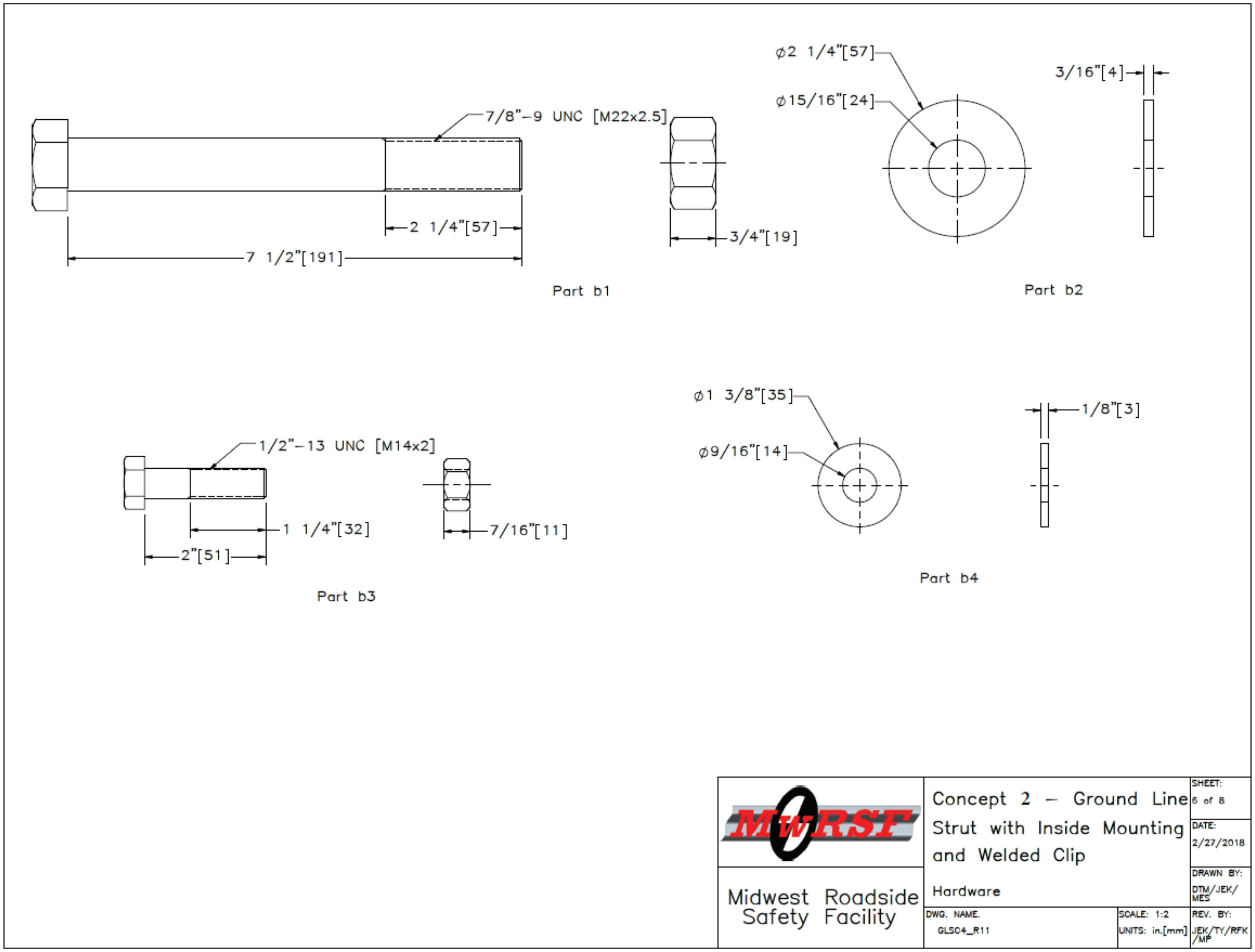

Figure 216. Ground Line Strut Design Concept No. 2 – Hardware

Item No.	Qty.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	1	67"x11 3/4"x10-gauge [1,702x298x3.4] Bent Steel Channel Strut	ASTM A36	ASTM A123	–
a2	2	15 3/8"x3"x1/4" [391x76x6] Bent Steel Plate	ASTM A36	ASTM A123	–
a3	2	7"x2 3/4"x1/2" [178x70x13] Steel Plate	ASTM A36	ASTM A123	–
a4	2	TS 8"x6"x3/16" [203x152x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123*	–
a5	2	13"x7"x5/8" [330x178x16] Steel Plate	ASTM A36	ASTM A123*	–
b1	2	7/8"-9 UNC [M22x2.5], 7 1/2" [191] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	–
b2	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
b3	4	1/2"-13 UNC [M14x2], 2" [51] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329*	FBX14a
b4	4	1/2" [13] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC14a

* Weld before galvanization.

Midwest Roadside Safety Facility

Concept 2 – Ground Line Strut with Inside Mounting and Welded Clip

Bill of Materials

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DATE: 2/27/2018
DRAWN BY: DTM/JEK/MES
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SCALE: None
UNITS: in.[mm]
REV. BY: JEK/TY/RFK/MP

Figure 217. Ground Line Strut Design Concept No. 2 – Bill of Materials

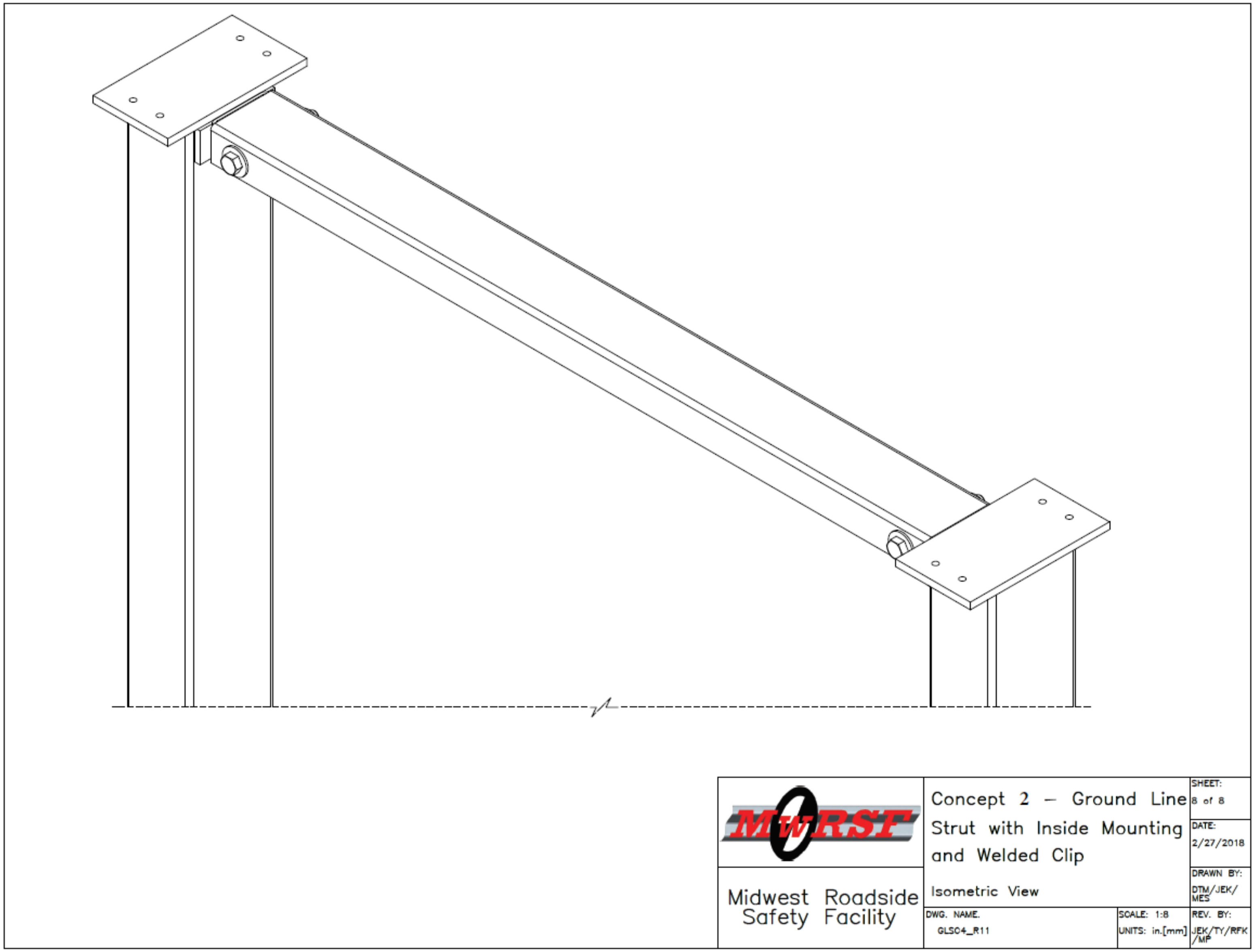

Figure 218. Ground Line Strut Design Concept No. 2 – Isometric View

11.1.3 Ground Line Strut Design Concept No. 3 − Welded Yoke Placed Outside Strut

Design concept no. 3, welded yoke placed outside the strut, included; (1) a 66½-in. x 11¾-in. x 10-gauge (1,689-mm x 298-mm x 3.4-mm) steel bent C-channel strut; (2) two 17-in. x 3-in. x ¼-in. (432-mm x 76-mm x 6-mm) steel bent plates placed outside the C-channel strut and bolted to the strut using one ⅞-in. (22-mm) diameter, 8½-in. (216-mm) long hex head bolt at each end; and (3) two 7-in. x 2¾-in. x ½-in. (178-mm x 70-mm x 13-mm) steel plates welded to the steel bent plate and the foundation tube with a 3⁄16-in. (5-mm) weld at the location of the anchor and second posts. Detailed drawings for design concept no. 3 are shown in Figures 219 through 226.

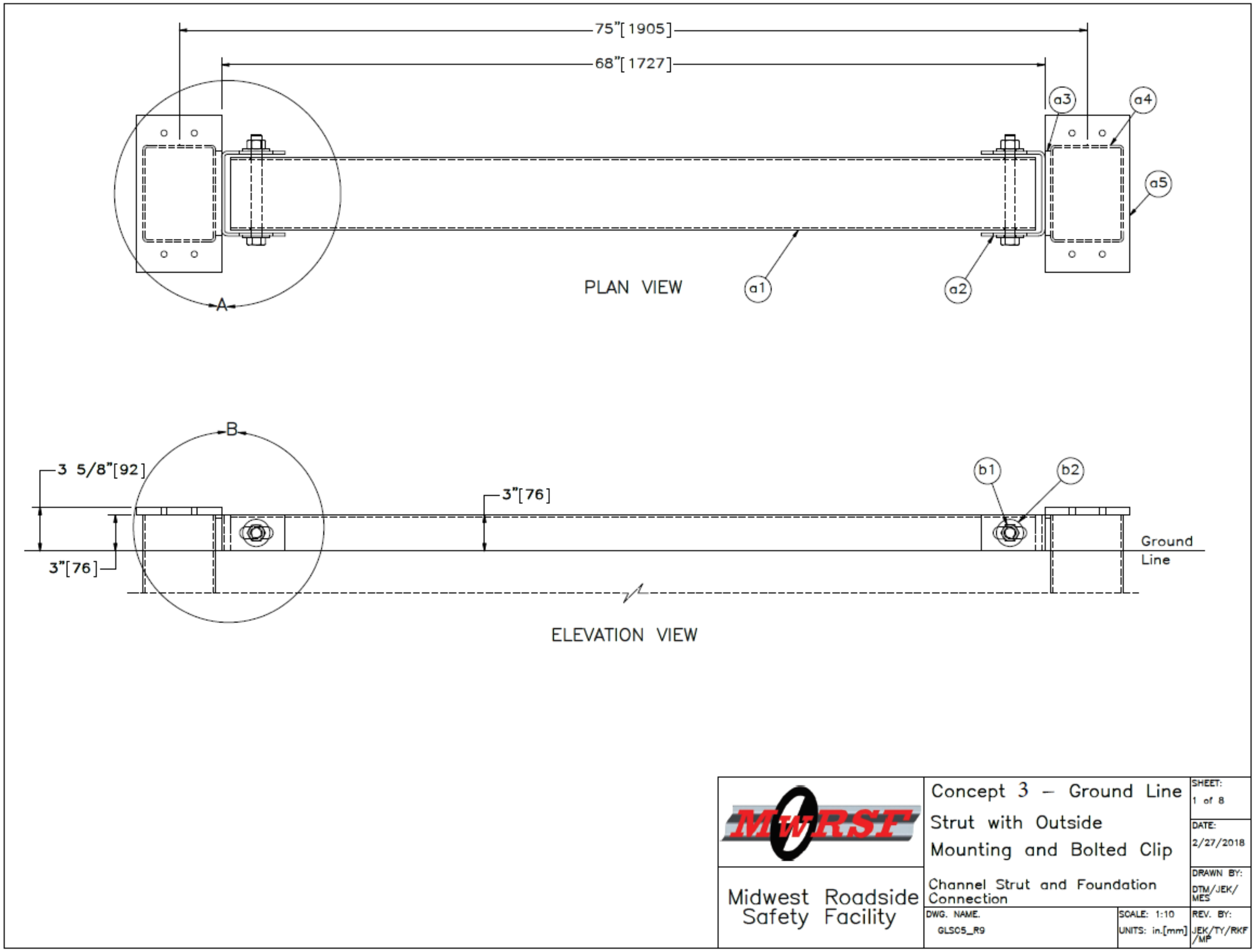

Figure 219. Ground Line Strut Design Concept No. 3 – Channel Strut and Foundation Connection

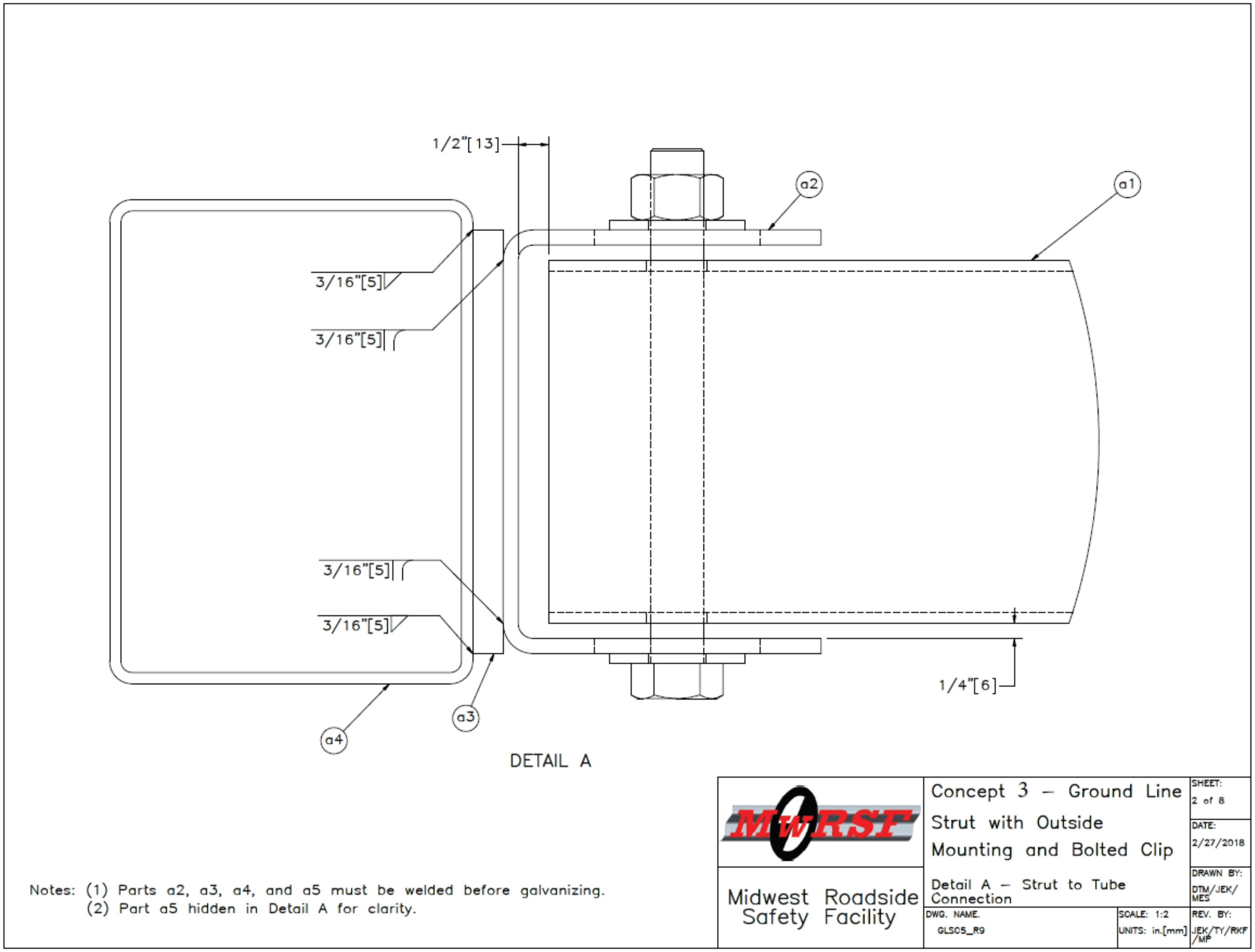

Figure 220. Ground Line Strut Design Concept No. 3 – Strut to Tube Connection

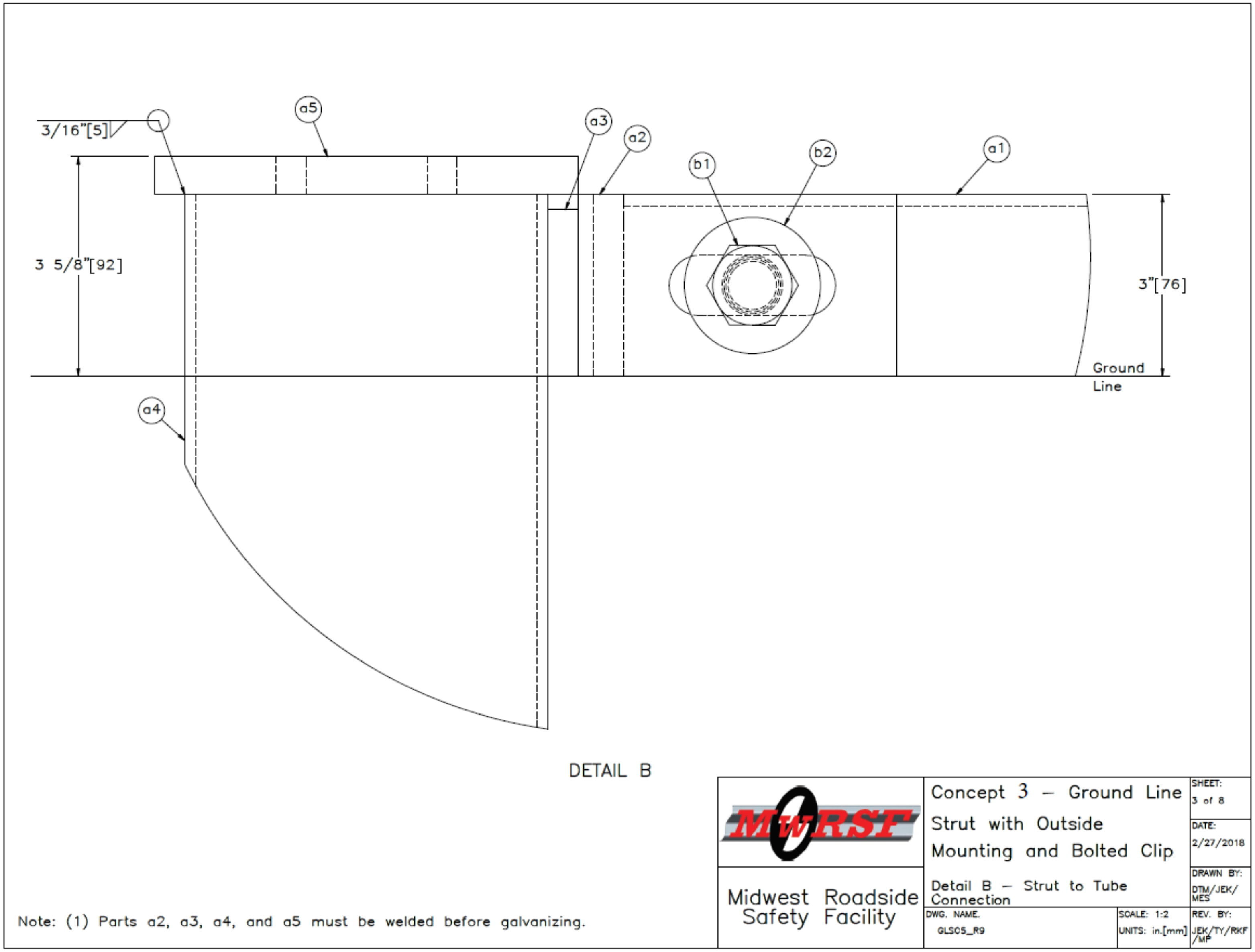

Figure 221. Ground Line Strut Design Concept No. 3 – Strut to Tube Connection

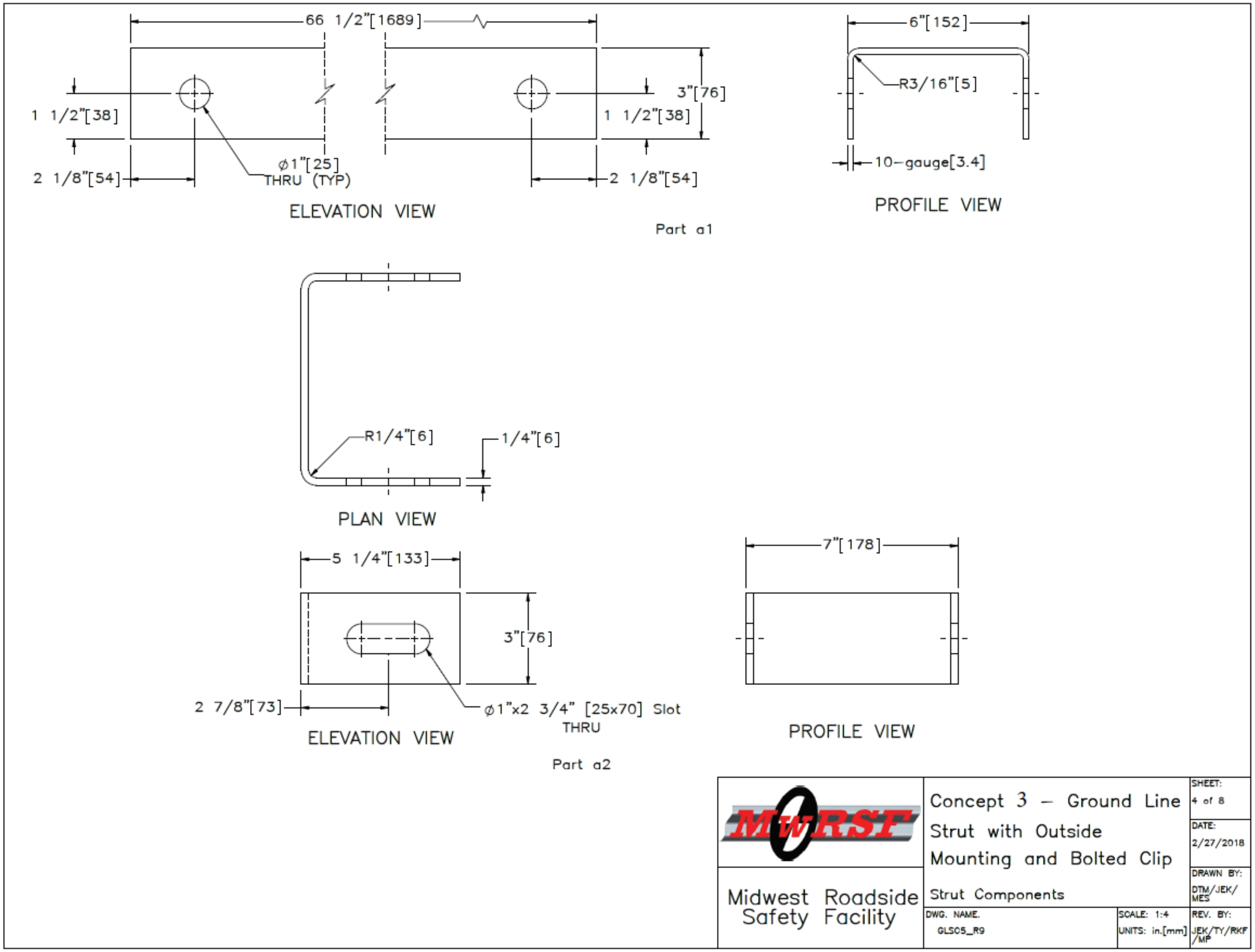

Figure 222. Ground Line Strut Design Concept No. 3 – Strut Components

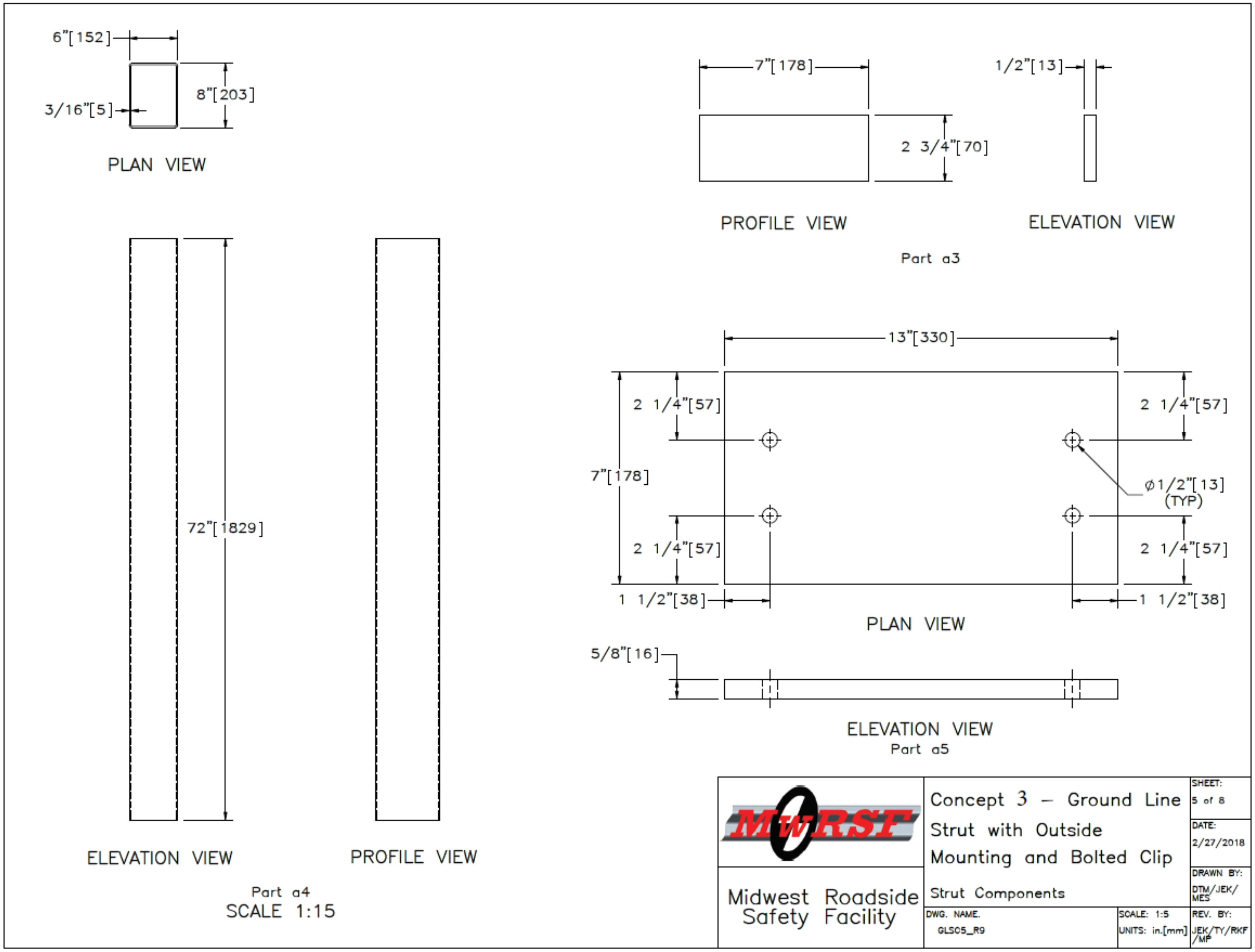

Figure 223. Ground Line Strut Design Concept No. 3 – Strut Components

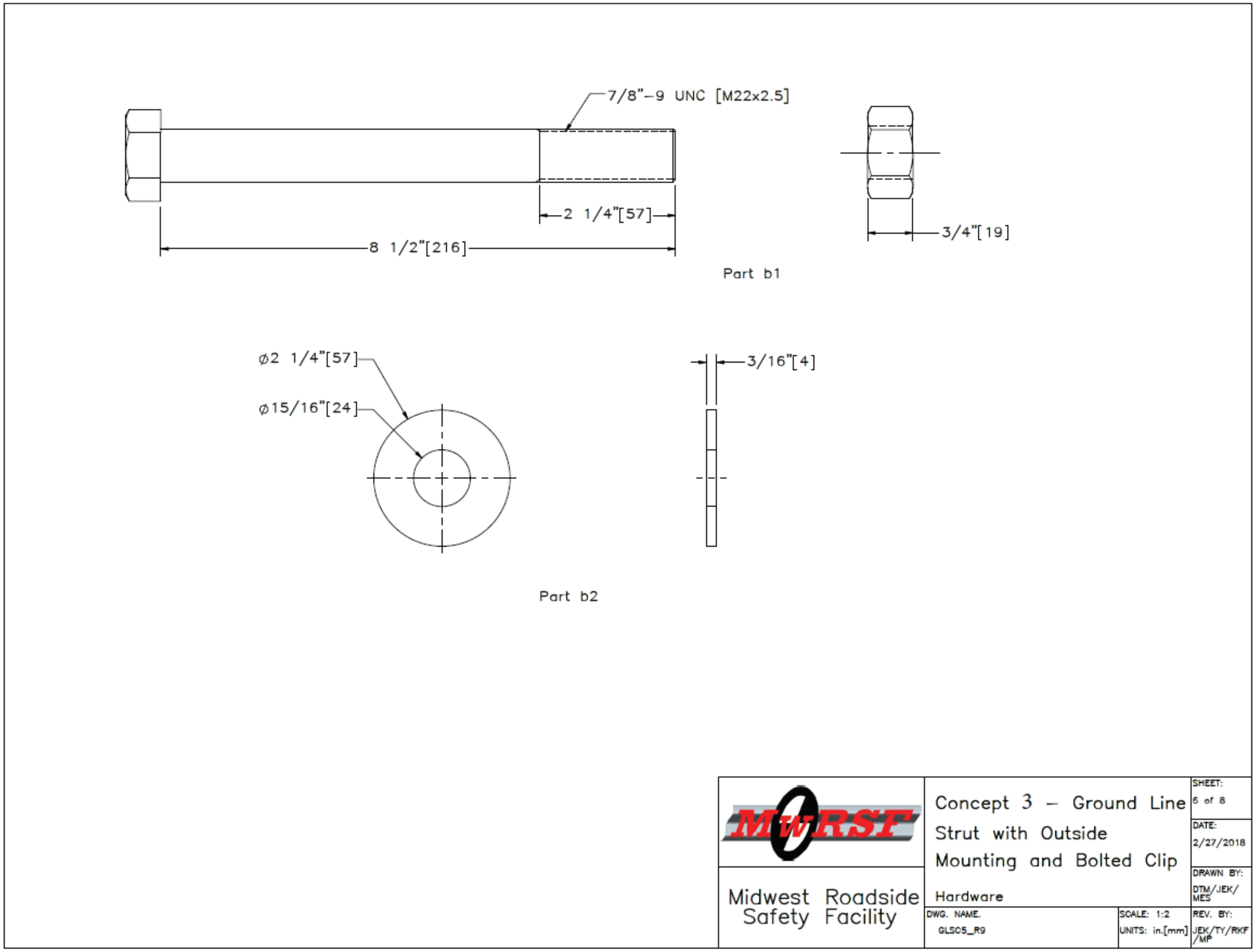

Figure 224. Ground Line Strut Design Concept No. 3 – Hardware

Item No.	Qty.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	1	66 1/2"x11 3/4"x10-gauge [1,689x298x3.4] Bent Steel Channel Strut	ASTM A36	ASTM A123	–
a2	2	17"x3"x1/4" [432x76x6] Bent Steel Plate	ASTM A36	ASTM A123*	–
a3	2	7"x2 3/4"x1/2" [178x70x13] Steel Plate	ASTM A36	ASTM A123*	–
a4	2	TS 8"x6"x3/16" [203x152x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123*	PTE06
a5	2	13"x7"x5/8" [330x178x16] Steel Plate	ASTM A36	ASTM A123*	–
b1	2	7/8"-9 UNC [M22x2.5], 8 1/2" [216] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	–
b2	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–

* Weld before galvanizing

Midwest Roadside Safety Facility

Concept 3 – Ground Line Strut with Outside Mounting and Bolted Clip

Bill of Materials

SHEET:	DATE:	DRAWN BY:	DWG. NAME.	SCALE:	UNITS:	REV. BY:
7 of 8	2/27/2018	DTM/JEK/MES	GLS05_R9	None	in.[mm]	JEK/TY/RKF/MP

Figure 225. Ground Line Strut Design Concept No. 3 – Bill of Materials

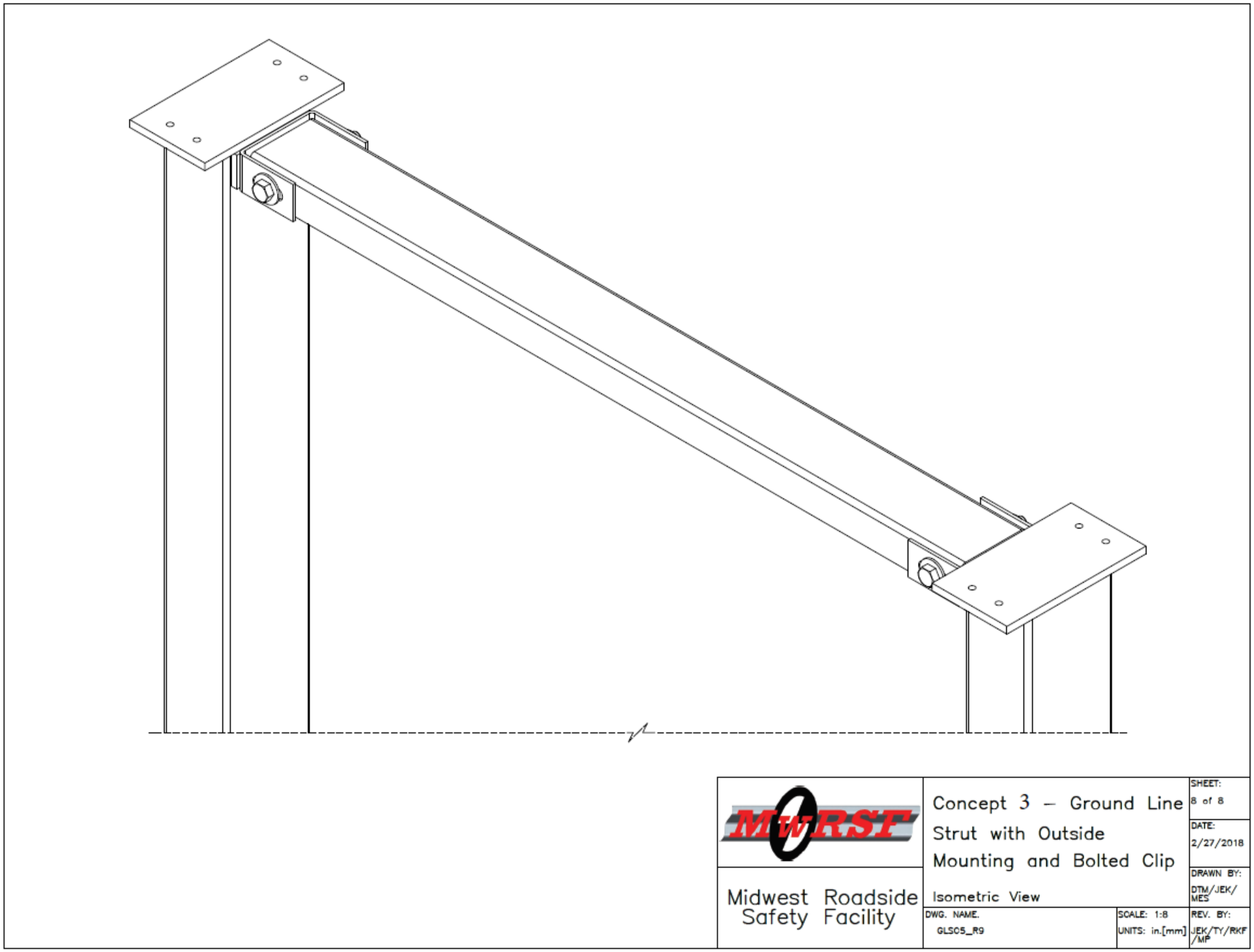

Figure 226. Ground Line Strut Design Concept No. 3 – Isometric View

11.1.4 Ground Line Strut Design Concept No. 4 − Welded Yoke Placed Inside Strut

Design concept no. 4, welded yoke placed inside the strut, was similar to ground line strut design concept no. 3, except the two 15⅜-in. x 3-in. x ¼-in. (391-mm x 76-mm x 6-mm) steel bent plates were placed inside the C-channel strut. This ground line strut design concept included: (1) a 67-in. x 11¾-in. x 10-gauge (1,702-mm x 298-mm x 3.4-mm) steel bent C-channel strut; (2) two 15⅜-in. x 3-in. x ¼-in. (391-mm x 76-mm x 6-mm) steel bent plates placed outside the steel bent channel strut and bolted to the strut using one ⅞-in. (22-mm) diameter, 7½-in. (191-mm) long hex head bolt at each end; and (3) two 7-in. x 2¾-in. x ½-in. (178-mm x 70-mm x 13-mm) steel plates welded to the steel bent plate and the foundation tube with a 3⁄16-in. (5-mm) weld at the location of the anchor and second posts. Detailed drawings for design concept no. 4 are shown in Figures 227 through 234.

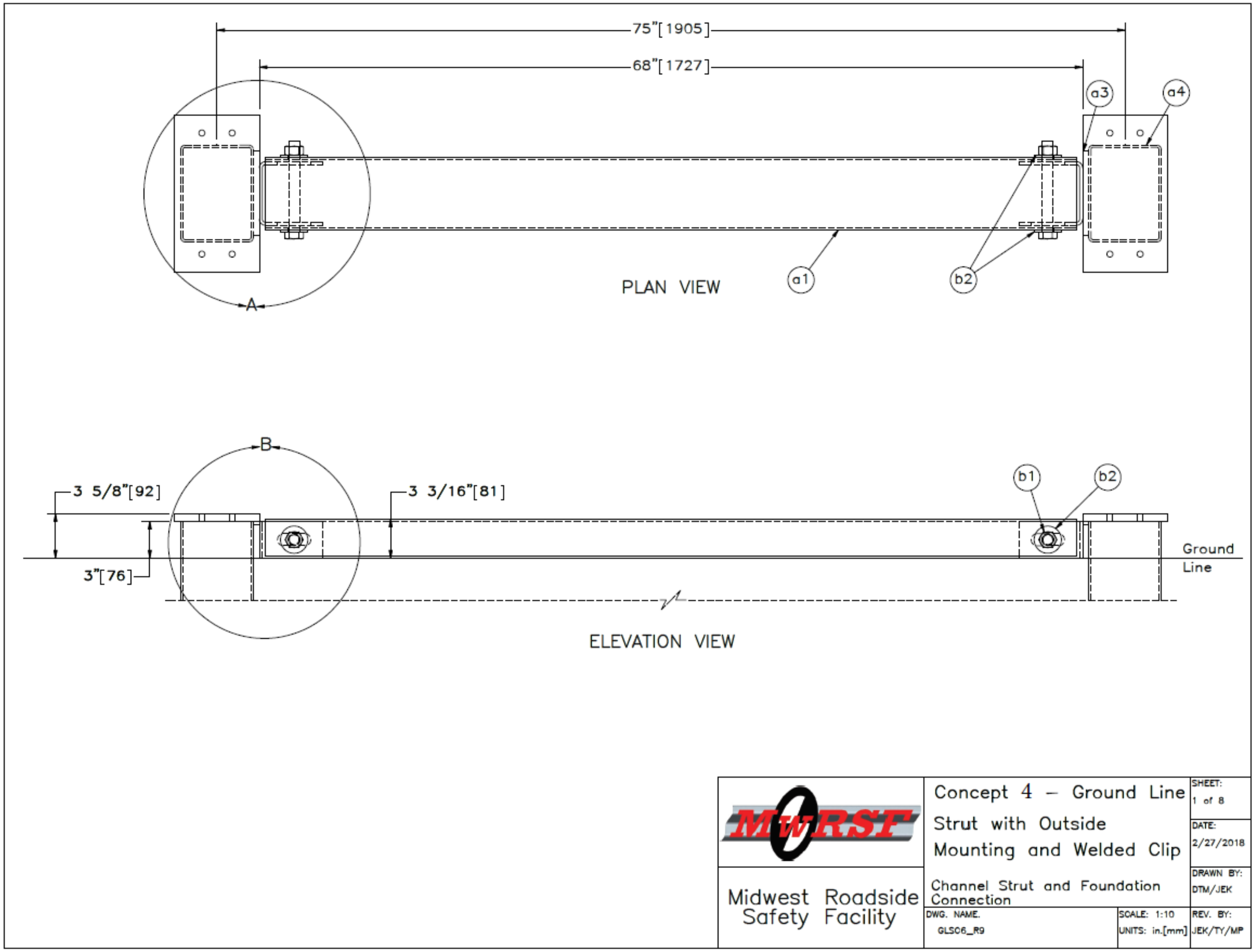

Figure 227. Ground Line Strut Concept No. 4 – Channel Strut and Foundation Connection

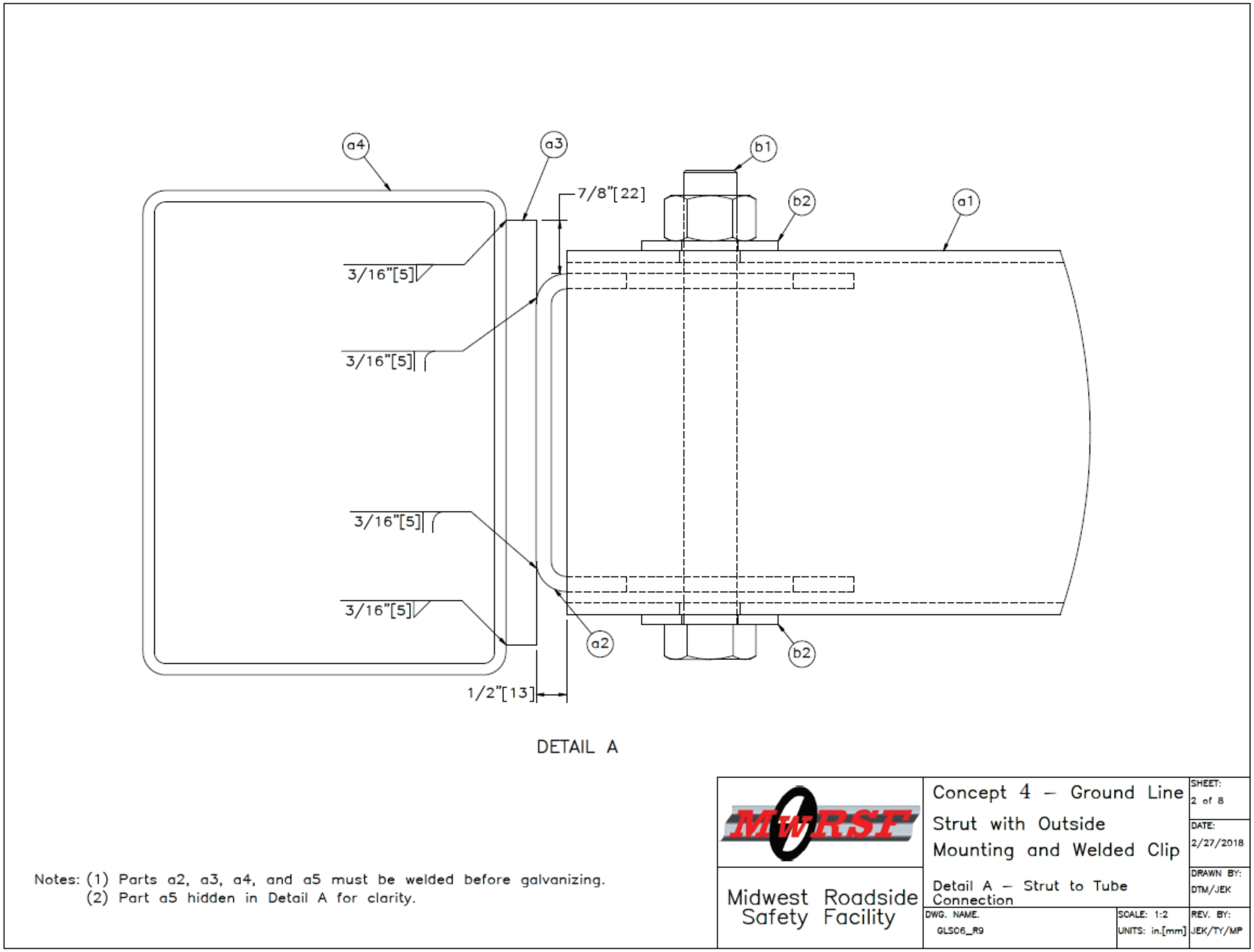

Figure 228. Ground Line Strut Concept No. 4 – Strut to Tube Connection

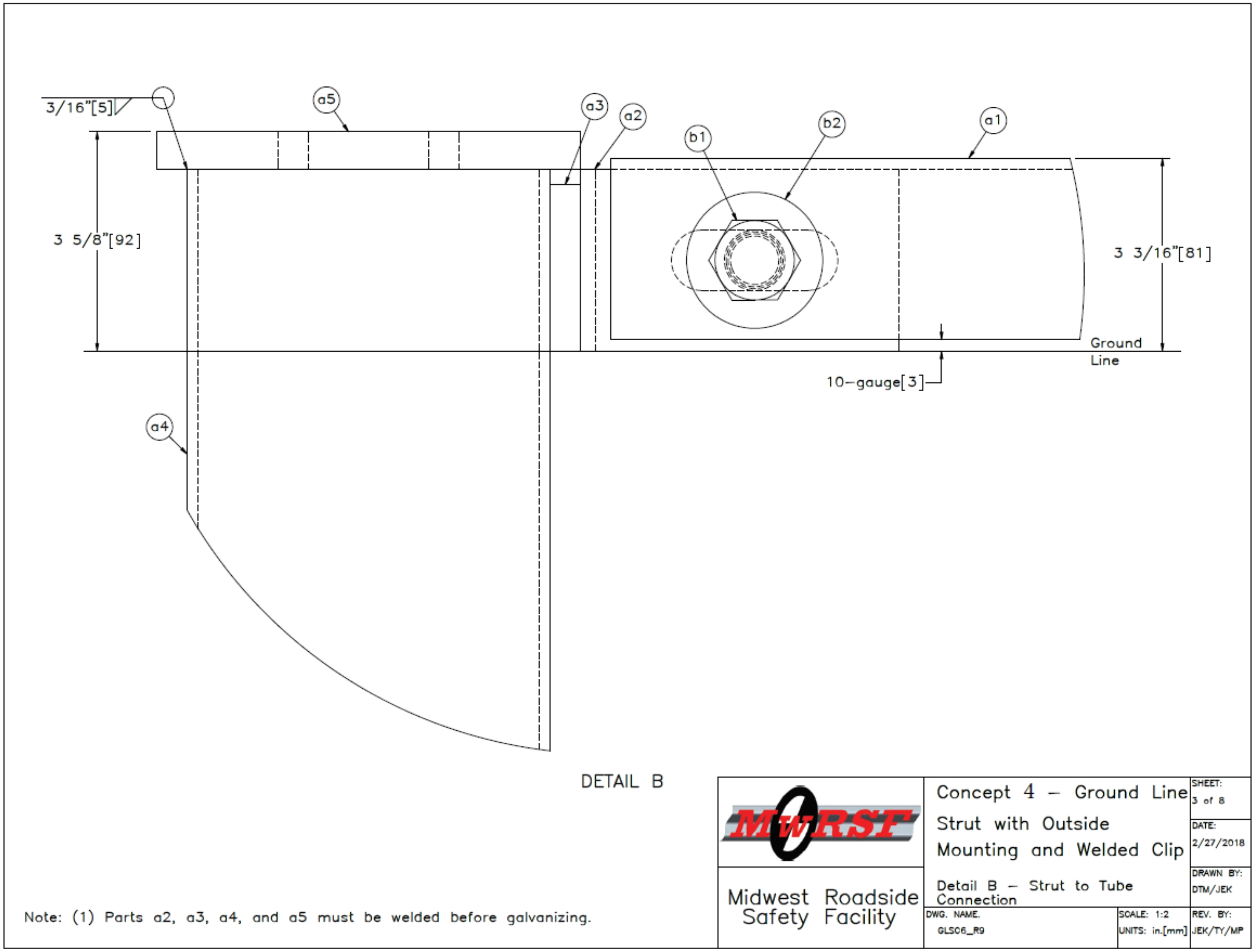

Figure 229. Ground Line Strut Concept No. 4 – Strut to Tube Connection

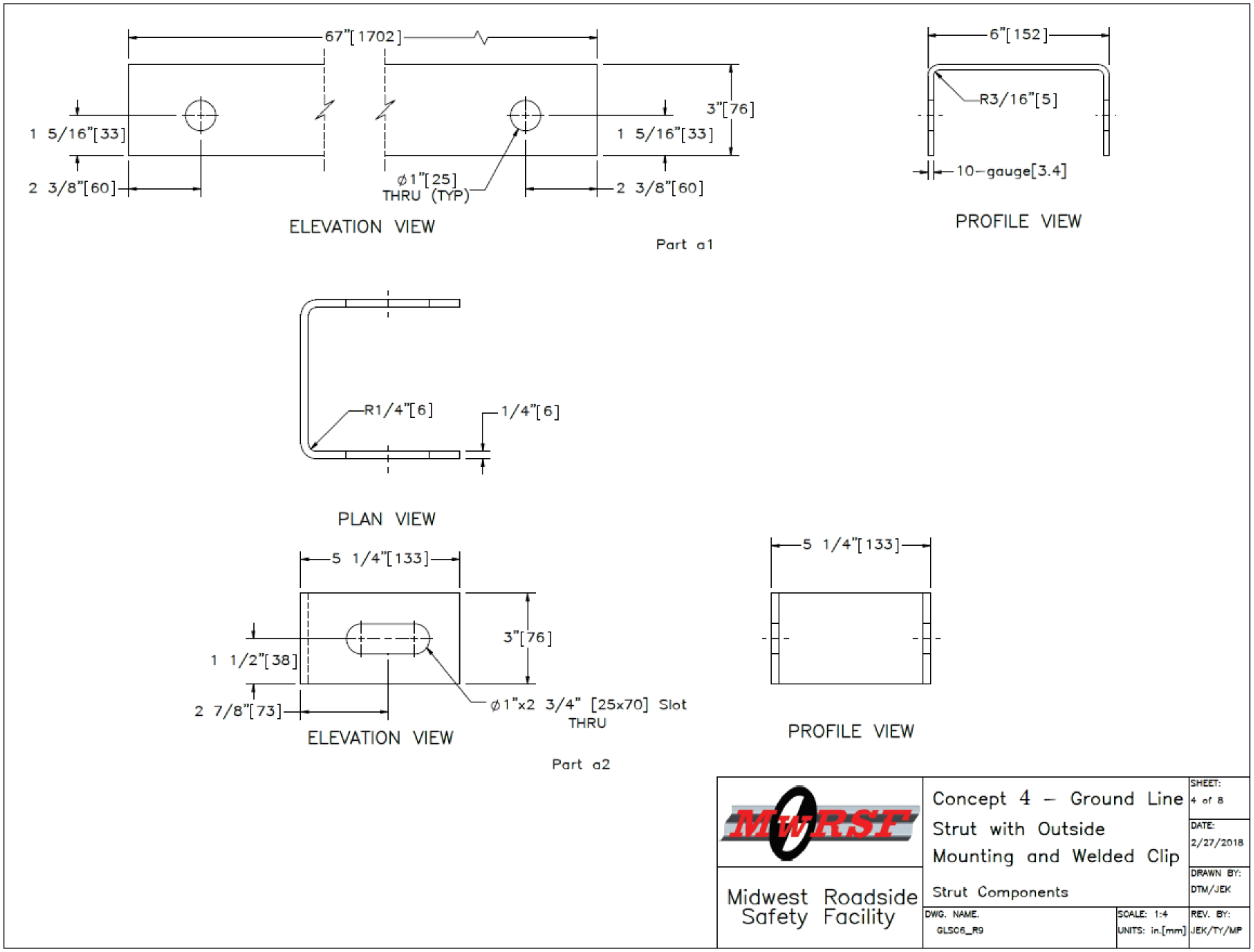

Figure 230. Ground Line Strut Concept No. 4 – Strut Components

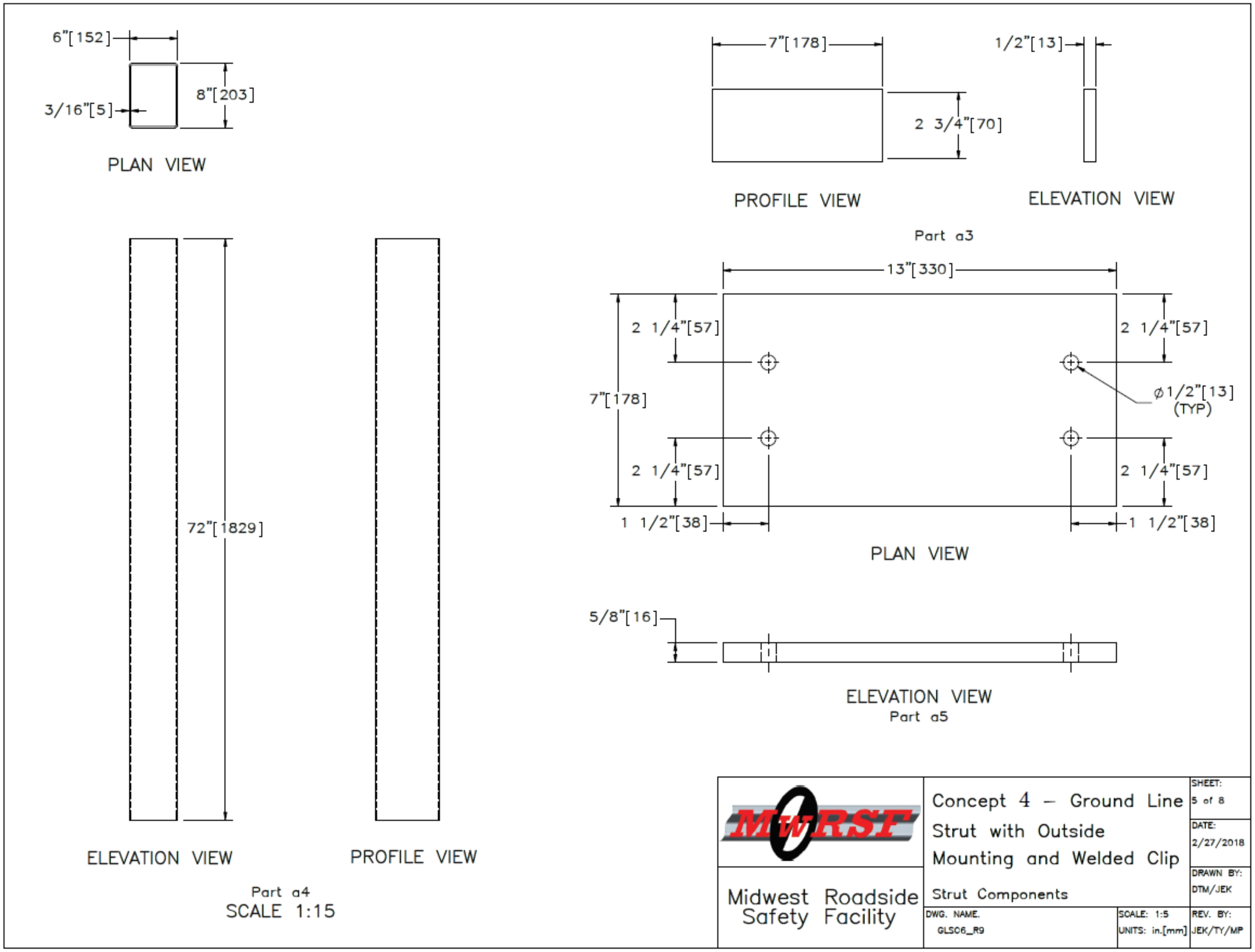

Figure 231. Ground Line Strut Concept No. 4 – Strut Components

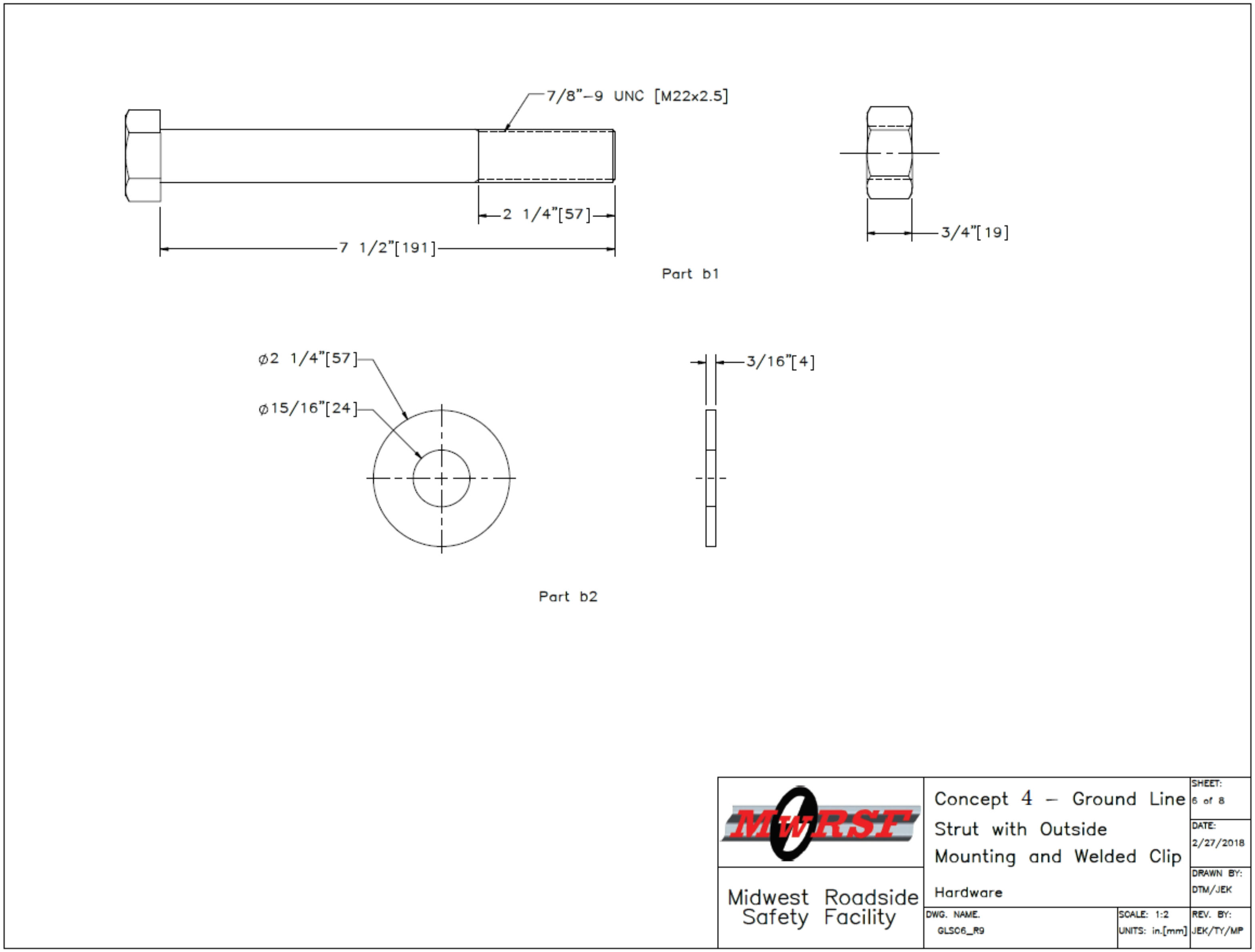

Figure 232. Ground Line Strut Concept No. 4 – Hardware

Item No.	Qty.	Description	Material Specification	Galvanization Specification	Hardware Guide
a1	1	67"x11 3/4"x10-gauge [1,702x298x3.4] Bent Steel Channel Strut	ASTM A36	ASTM A123	–
a2	2	15 3/8"x3"x1/4" [391x76x6] Bent Steel Plate	ASTM A36	ASTM A123*	–
a3	2	7"x2 3/4"x1/2" [178x70x13] Steel Plate	ASTM A36	ASTM A123*	–
a4	2	TS 8"x6"x3/16" [203x152x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123*	PTE06
a5	2	13"x7"x5/8" [330x178x16] Steel Plate	ASTM A36	ASTM A123*	–
b1	2	7/8"-9 UNC [M22x2.5], 7 1/2" [191] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	–
b2	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–

* Weld before galvanizing

Midwest Roadside Safety Facility

Concept 4 – Ground Line Strut with Outside Mounting and Welded Clip

Bill of Materials

SHEET: 7 of 8
DATE: 2/27/2018
DRAWN BY: DTM/JEK
DWG. NAME. GLS06_R9
SCALE: None
UNITS: in.[mm]
REV. BY: JEK/TY/MP

Figure 233. Ground Line Strut Concept No. 4 – Bill of Materials

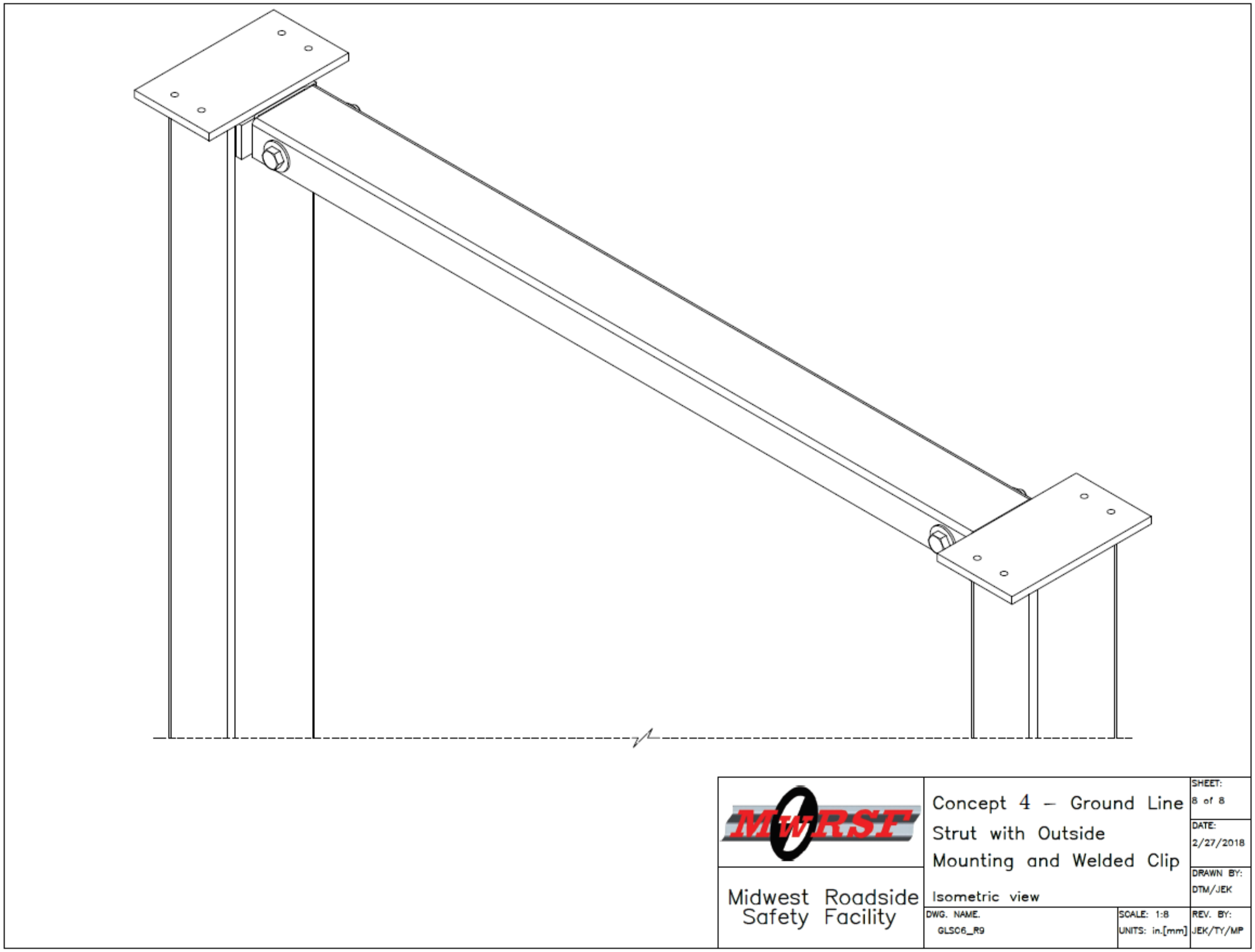

Figure 234. Ground Line Strut Concept No. 4 – Isometric View

11.1.5 Ground Line Strut Design Concept Selection

The four candidate design concepts for the groundline strut were discussed with the Midwest Pooled Fund Program member states. Using a survey, a majority of the member states desired ground-line strut concept no. 1, (i.e., bolted yoke placed outside strut) due to its increased ease of installation over the other concepts. More details on the survey results can be found in Appendix I.

11.2 T-Shaped, Breaker Bar Design Concept

Anchor cables are advantageous to efficiently anchor the trailing end of a guardrail system. However, these cable anchors may affect the safety performance of the system when struck during impacts approaching the downstream end. A vehicle snagging on the anchor cable when directly impacting the trailing-end anchorage system is a potential hazard. Thus, a T-shaped, breaker bar assembly attached to the anchor post was developed to facilitate the release of the anchor post and the cable anchor during impact events, thus reducing the potential for vehicle instabilities or unacceptable ride-down decelerations. Design details of the T-shaped, breaker bar assembly are shown in Figures 235 through 241.

The T-shaped, breaker bar consisted of a horizontal 40-in. (1,016-mm) long, 2½-in. x 2½-in. x ¼-in. (64-mm x 64-mm x 6-mm) ASTM A500 Grade B steel square tube welded to a vertical 9-in. (229-mm) long, 3-in. x 3-in. x ¼-in. (76-mm x 76-mm x 6-mm) steel square tube. This T-shaped, breaker bar was attached to the end anchor post with a mounting height of 15¾ in. using a 10-in. x 4½-in. x ¼-in. (254-mm x 114-mm x 6-mm) ASTM A36 steel plate and four ¼-in. (6-mm) thick, ASTM A36 steel gusset plates to facilitate cable anchor disengagement and mitigate vehicle snag under the anchor cable.

Calculations were performed to determine adequate T-shaped, breaker bar properties, including size, bending or flexural capacity, buckling strength, axial load carrying capacity, size of stiffeners (steel gussets) utilized at the end of the T-shaped, breaker bar, and the connection details for the assembly including bearing plates and welds. These calculations are provided in Appendix F. It should be noted that this T-shaped, breaker bar concept was not component tested but rather planned for full-scale crash testing.

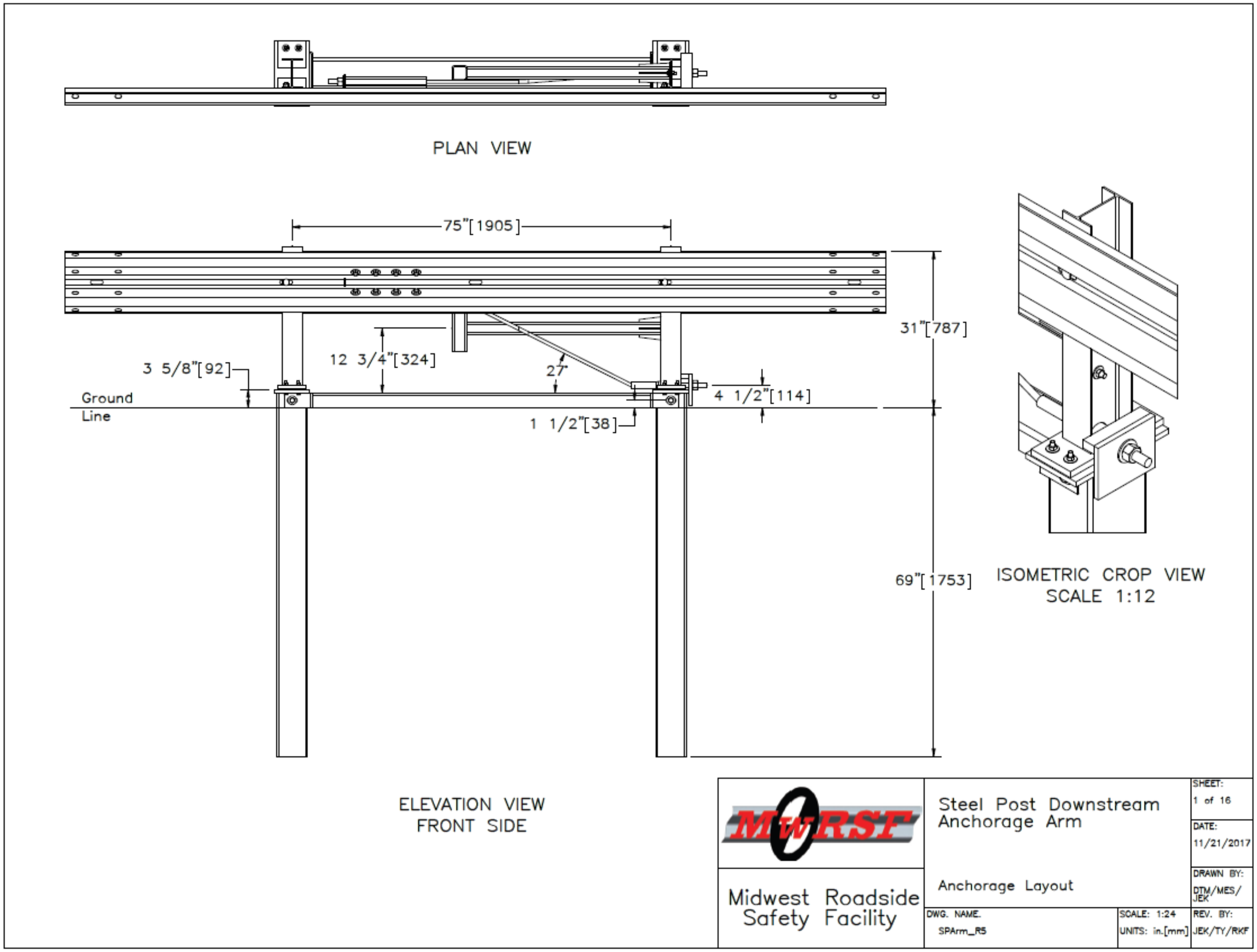

Figure 235. T-Shaped, Breaker Bar Design – Anchorage Layout

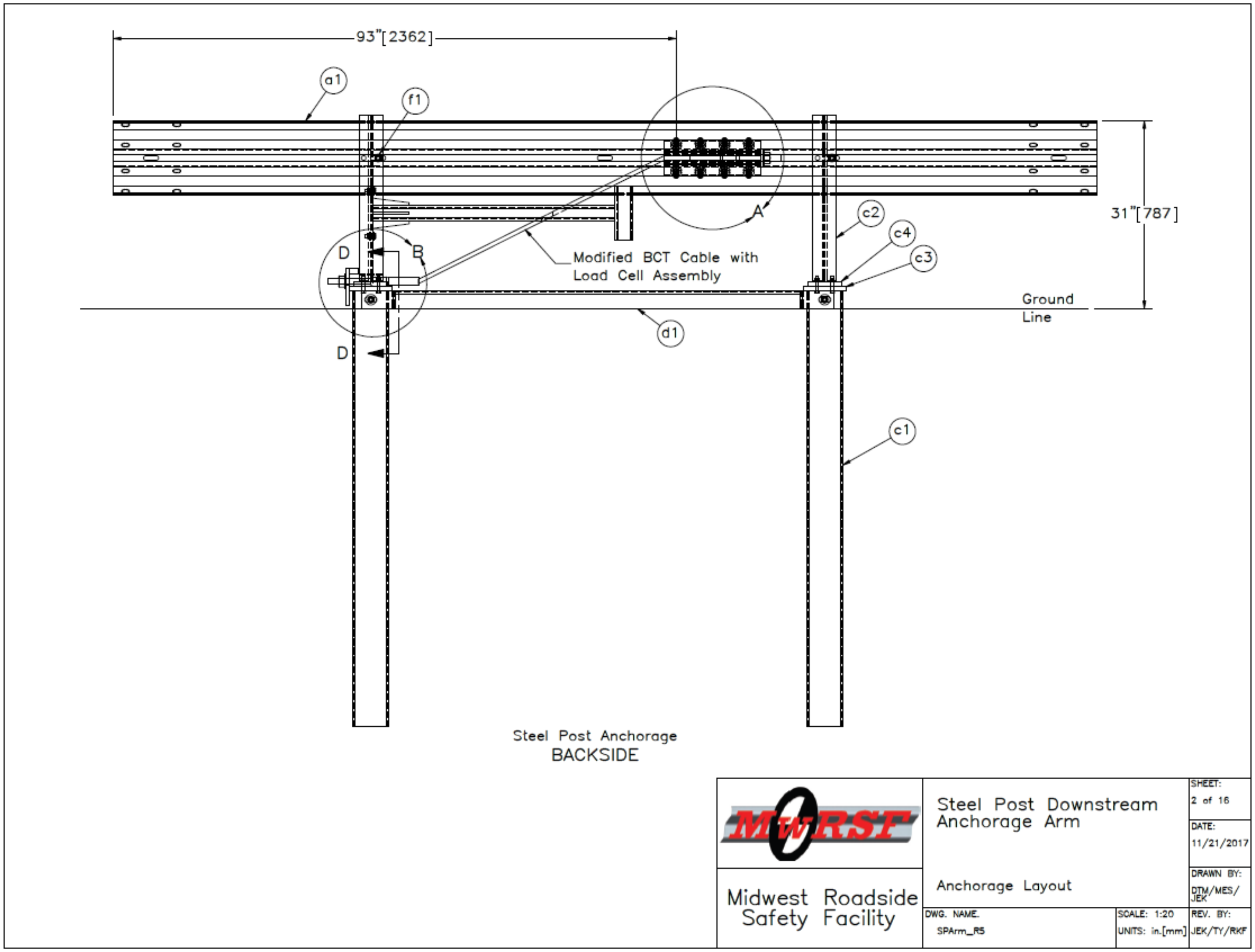

Figure 236. T-Shaped, Breaker Bar Design – Anchorage Layout

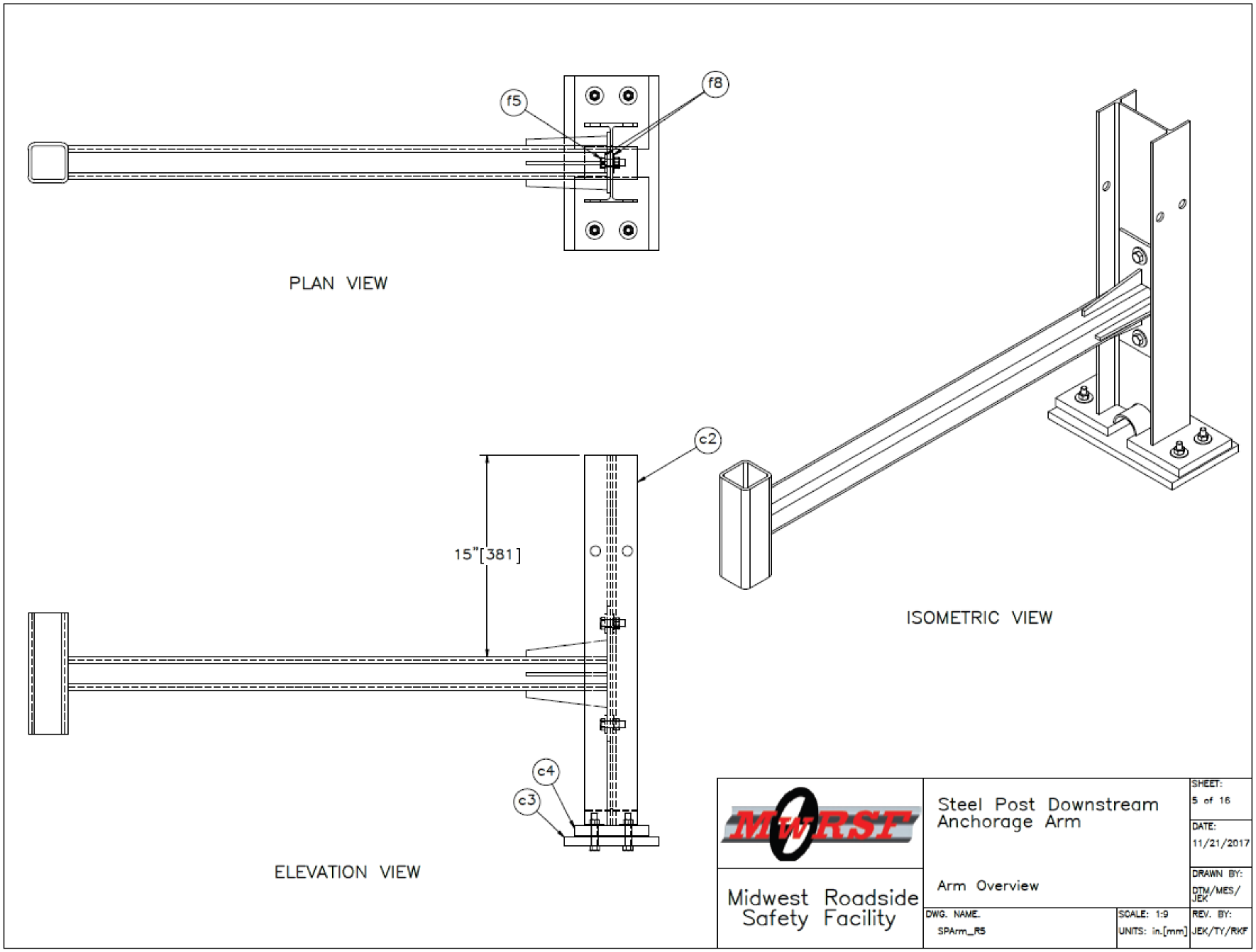

Figure 237. T-Shaped, Breaker Bar Design – Arm Overview

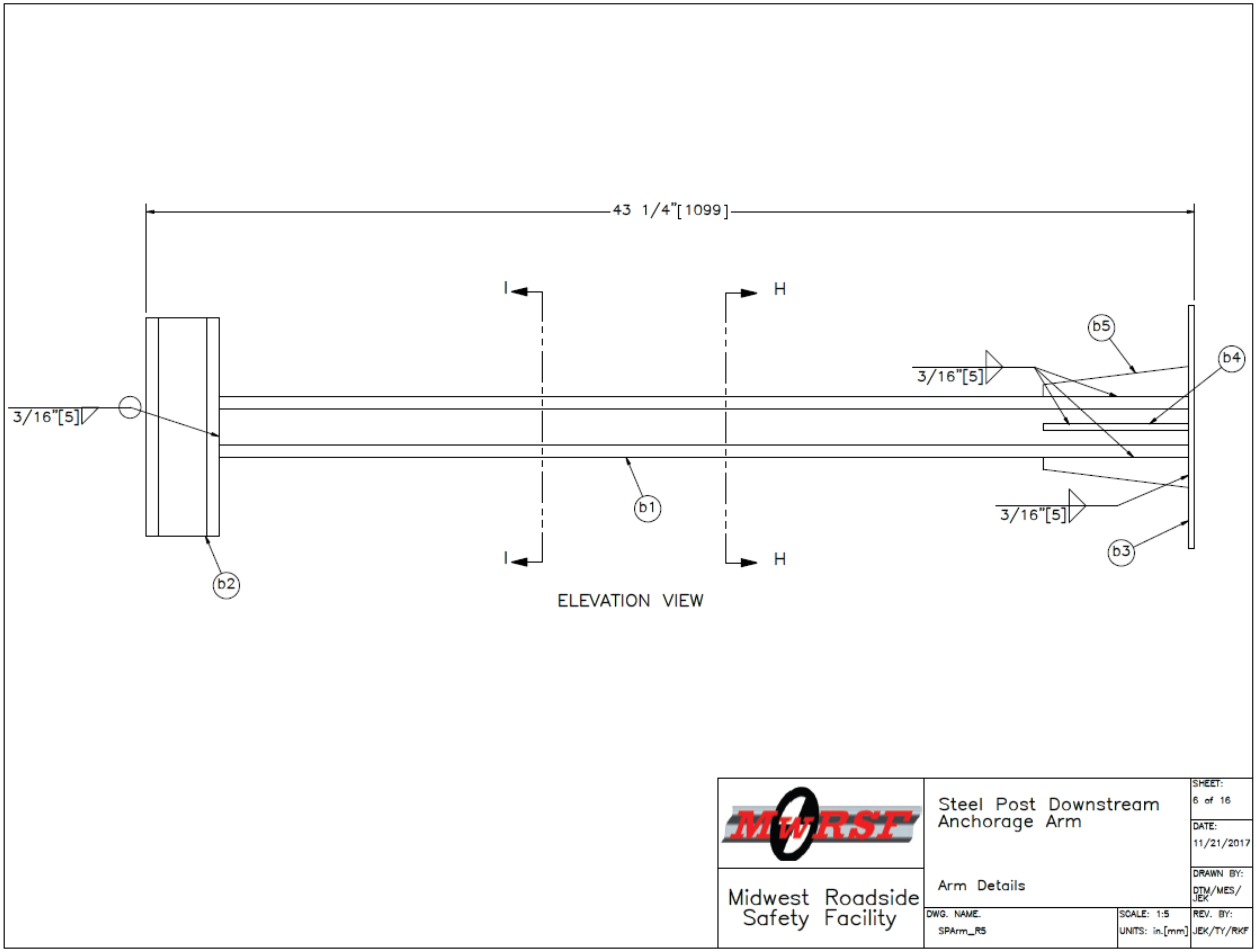

Figure 238. T-Shaped, Breaker Bar Design − Arm Details

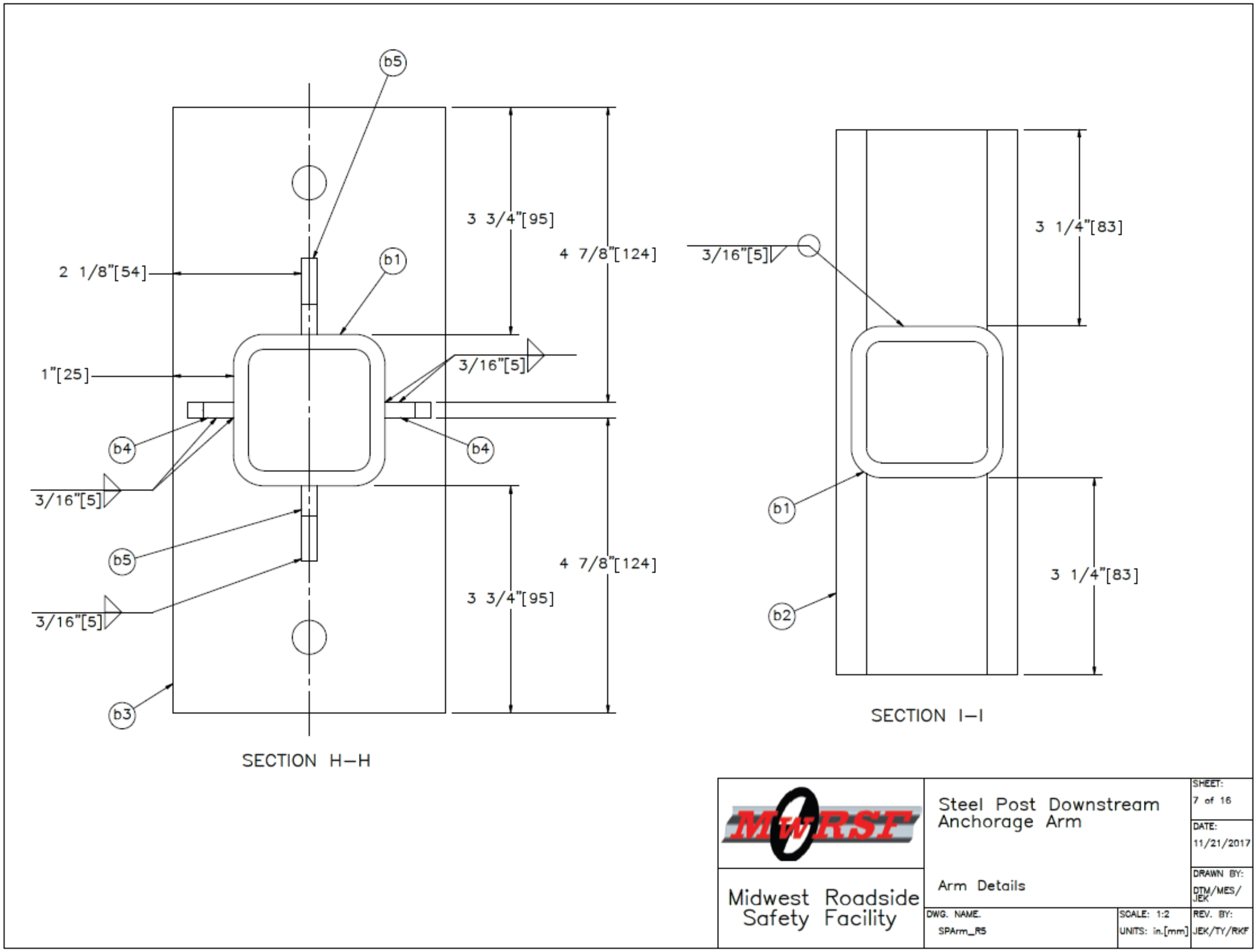

Figure 239. T-Shaped, Breaker Bar Design – Arm Details

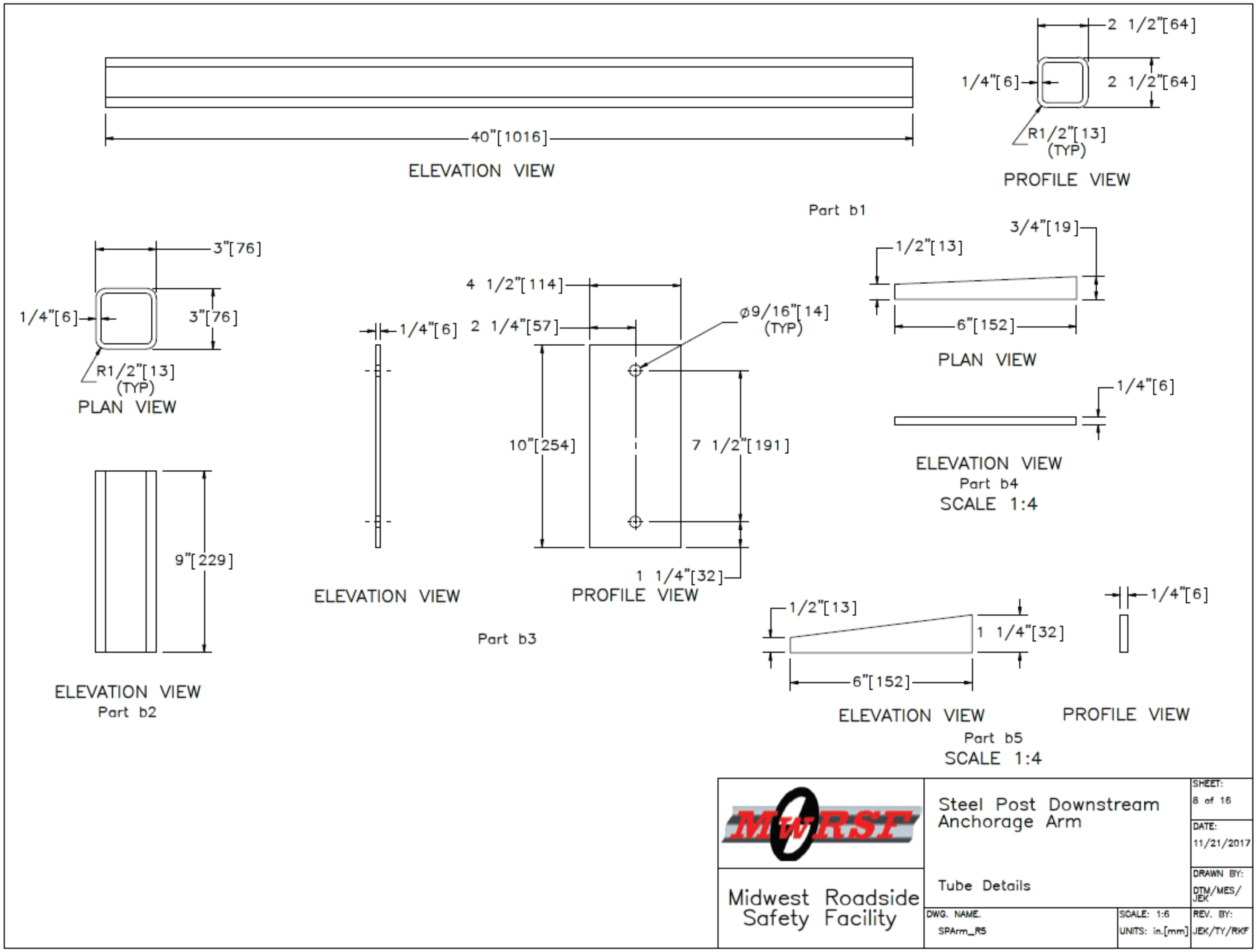

Figure 240. T-Shaped, Breaker Bar Design – Tube Details

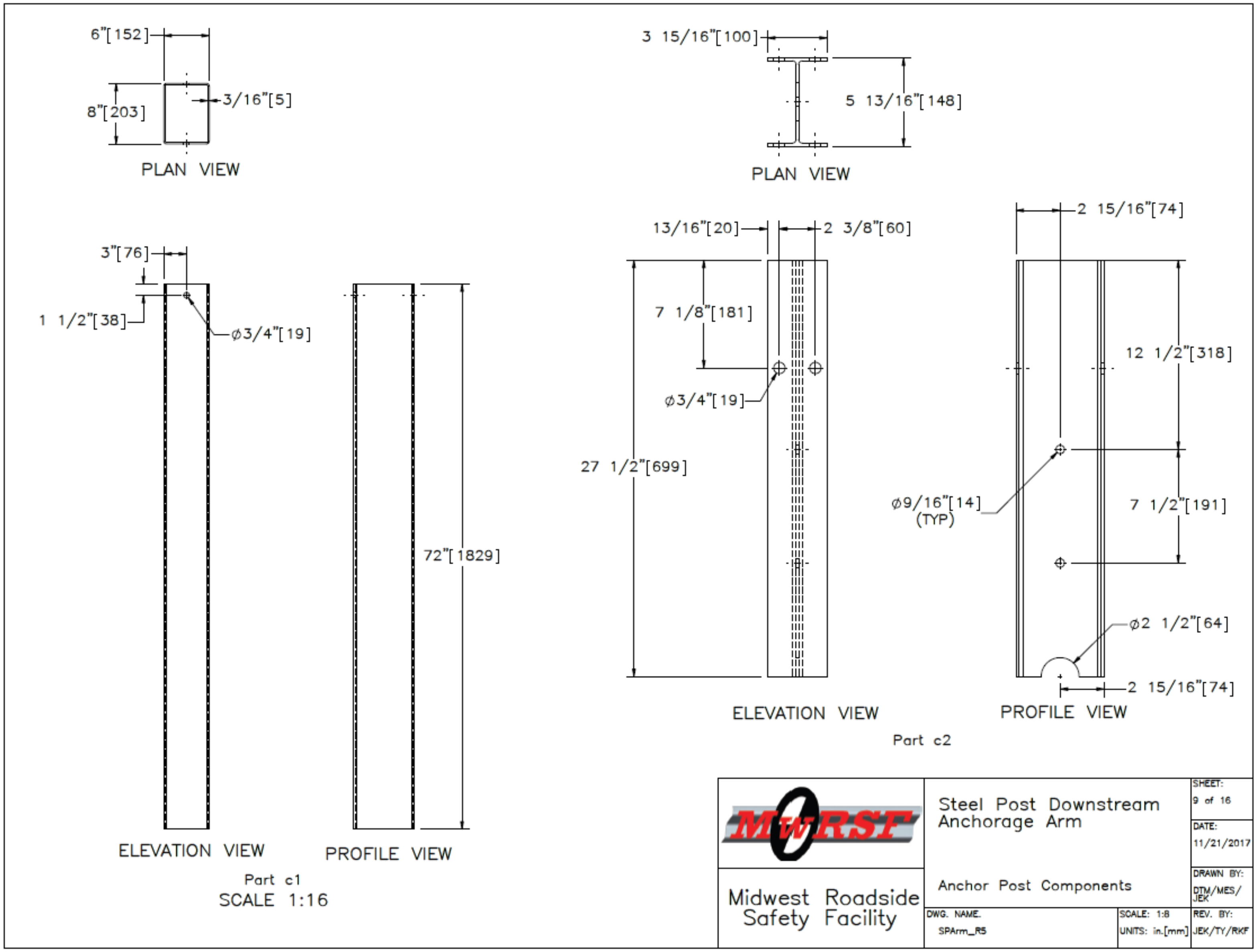

Figure 241. T-Shaped, Breaker Bar Design – Anchor Post Components

12 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of the project was to develop a non-proprietary, steel-post version of the wood-post, trailing-end anchorage system. The new system was adapted from the UBSP that was utilized within the thrie-beam bullnose system. Following brainstorming of initial concepts, five design concepts were developed for the steel-post, trailing-end anchorage. These concepts included modifications of the UBSP while using the same basic cable anchorage and ground line strut as used in the existing trailing-end anchorage to provide similar breakaway performance and anchorage capacity. The design concepts utilized a two-part steel post based on the original UBSP. The top post was 27½-in. (699-mm) long, W6x8.5 ASTM A992 steel post welded to a 5½-in. x 5½-in. x ¾-in. (140-mm- x 140-mm x 19-mm) ASTM 36 steel base plate. The bottom post was HSS 6-in. x 8-in. x 3/16-in. (152-mm x 203-mm x 5-mm) ASTM A500 Grade B steel foundation tube welded to a 13-in. x 7-in. x ⅝-in. (330-mm- x 178-mm x 16-mm) ASTM 36 steel base plate. The top and bottom base plates were connected using four 7/16-in. (11-mm) diameter ASTM A325 bolts. Five design concepts were explored through dynamic component tests: (1) design concept no. 1 included a slot at the bottom of the W6x8.5 post for passing the cable through the top post and an opening in the top base plate to allow the cable to release when the top post disengaged; (2) design concept no. 2 included a slot in the foundation tube that formed the lower post and an opening in the bottom plate to facilitate cable release; (3) design concept no. 3 used an angled bearing plate welded to the lower section of the post to restrain the cable; (4) design concept no. 4 was a modification of design concept no. 1 and included a decreased width of the bearing plate from 7 in. (178 mm) to 6¼ in. (159 mm); and (5) design concept no. 5 was a modification of design concept no. 3 that changed the angle of the bearing plate, welded the angled bearing plate to the foundation tube, and added a brass keeper rod to better anchor the bearing plate.

Dynamic jerk tests revealed that the new steel-post version of the trailing-end anchorage system may be an alternative for the existing wood-post, trailing-end anchorage system. Compared to the BCT wood-post, trailing-end anchorage system, three design concepts, concept nos. 2, 4, and 5, demonstrated adequate tensile strength. The steel-post, trailing-end anchorage concepts developed peak forces of 44.0 kips (195.7 kN), 49.5 kips (220.2 kN), and 49.4 kips (219.7 kN) during the dynamic jerk tests of design concept nos. 2, 4, and 5, respectively. Design concept no. 2 generated 25% more peak force than the wood-post, trailing-end anchorage system, while design concept nos. 4 and 5 generated 40% more peak force than the wood-post, trailing-end anchorage system.

With input from the Midwest Pooled Fund Program member states, a modified version of concept no. 4, as shown in Figure 242, was selected as the final design and was slightly modified for use in a full-scale vehicle crash testing program. Modifications to the system included the addition of a T-shaped, breaker bar assembly attached to the end anchor post to facilitate the release and rotation of the end post as well as the subsequent release of the cable anchor for impacts occurring upstream from the anchor post. The T-shaped, breaker bar assembly was bolted to the web of the upper end post stub to ensure a controlled release of the anchor as to well as reduce the potential for vehicle instabilities and/or unacceptable ridedown decelerations.

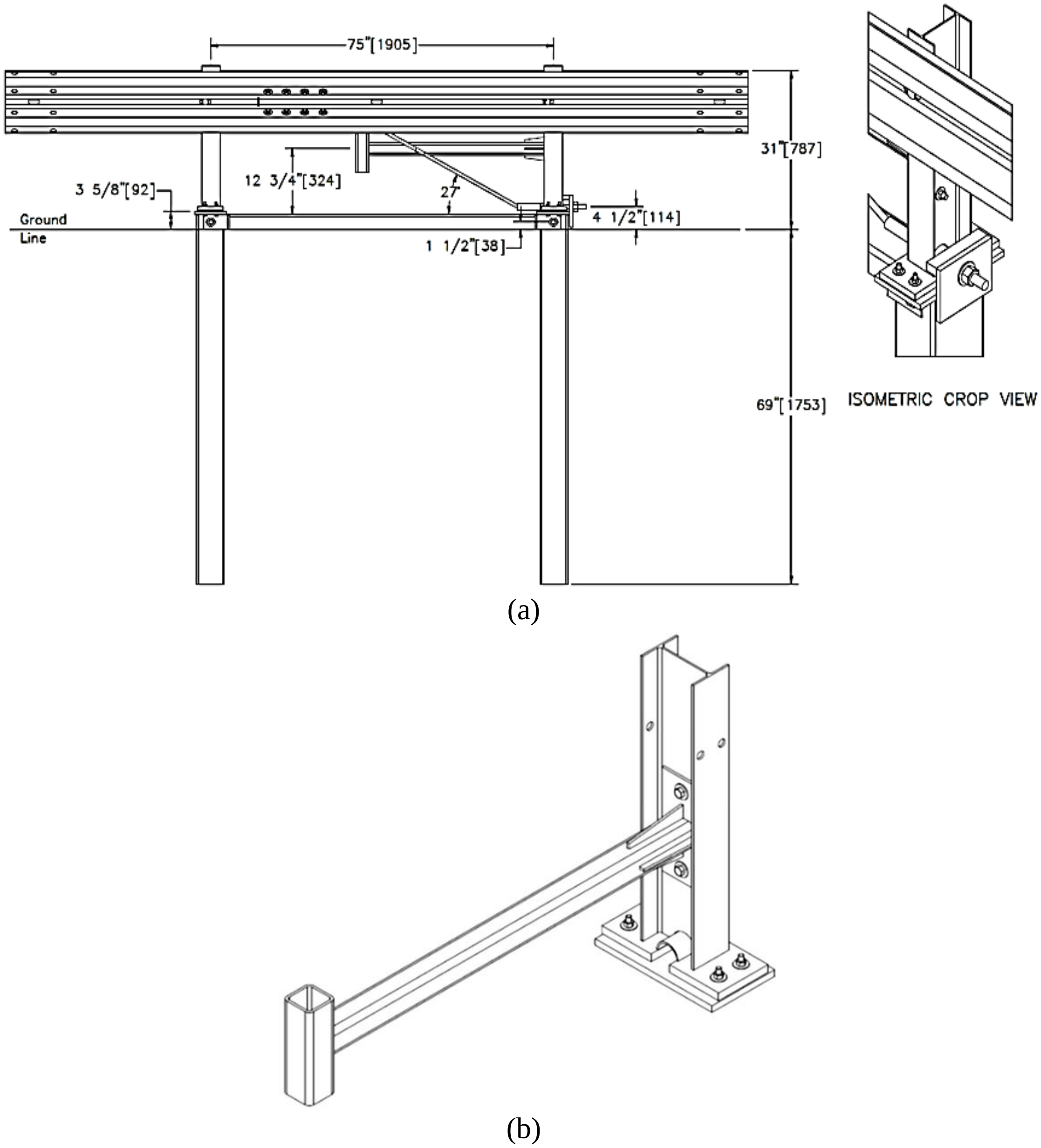

Figure 242. Final Design Concept for Steel-Post, MGS Trailing-End Anchorage System – (a) Design Concept No. 4, and (b) T-Shaped, Breaker Bar Design

Furthermore, a total of four ground line strut design concepts were developed, including (1) bolted yoke placed outside strut, (2) bolted yoke placed inside strut, (3) welded yoke placed outside strut, and (4) welded yoke placed inside strut. Again, with sponsor input, the ground line strut concept no. 1, (i.e., bolted yoke placed outside strut) was selected because it provided increased ease of installation.

Although the performance of the steel-post version of the trailing-end anchorage system was explored through dynamic jerk tests, full-scale crash tests are necessary to evaluate the safety performance of the steel-post, trailing-end anchorage system according to MASH 2016. The full-scale testing program and results will be contained in a subsequent report.

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14 APPENDICES

Appendix A. Steel-Post, Trailing-End Anchorage Design Concept No. 1 Calculations

Calculation: Design Concept No. 1

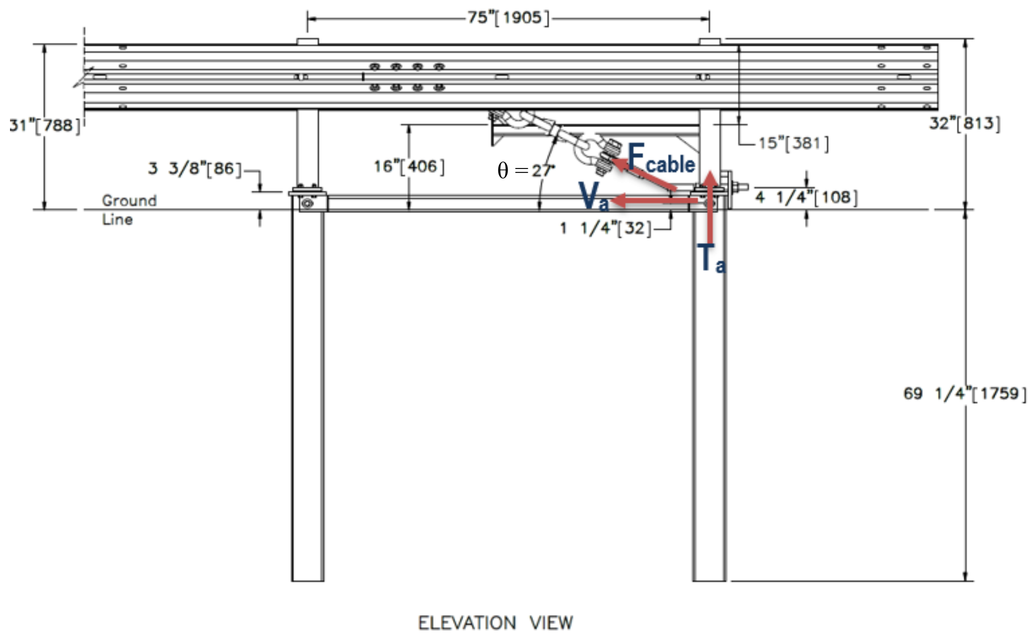


Figure A-1. Steel-Post, Trailing-End Anchorage Design Concept No. 1

1. Force Calculation

The maximum load sustained by the BCT wood post downstream anchorage system was 35 kips (155.7 kN). This load was used as a baseline for the following calculations. More details regarding BCT wood post anchorange capacity are provided in Mongiardini et al. [4].

$$\cos\theta \ = \frac{Va}{F_{cable}}$$

$$T_a \ = F_{cable} * \ \sin\theta = 35kips * \ \sin 27^0 = 15.89 \ kips \ (70.27 \ kN)$$

$$V_a \ = 35kips * \ \cos 27^0 \ = 31.2kips \ (138.84 \ kN)$$

Where:

F_{cable}= Force in anchor cable

T_a = Tension force

V_a = Shear force

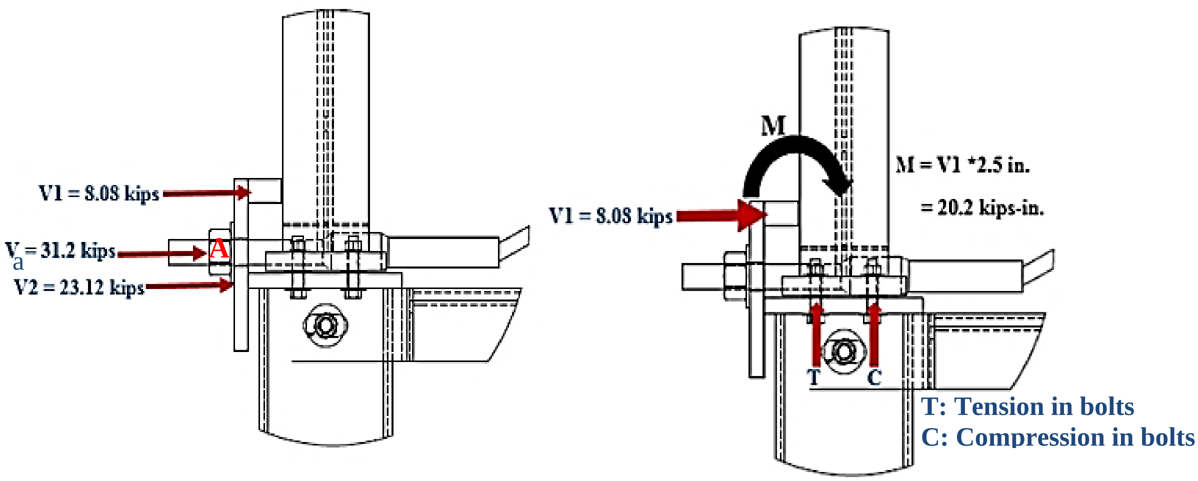


Figure A-2. Forces Acting on Design Concept No. 1

Moment about A:

V1 x (2.5 in.) = V2 x (0.875 in.)

Where:

0.875 in. (22 mm) = distance between V and V2

2.5 in. (64 mm) = distance between V and V1

Equilibrium of Forces:

$V1+V2 = V_a = 35$ kips*cos(27°)

V1 = 8.08 kips (35.96 kN)

V2= 23.12 kips (102.88 kN)

Tension in a single bolt:

T= (M /2.5 in.) /2 = 4.04 kips (17.98 kN) (2.5 in. = distance b/n bolts)

2. Capacity of Bolts: Tension [Load and Resistance Factor Design (LRFD)]

a) Pure Tension:

As per the American Institute of Steel Construction (AISC) specification Table J3.2, Group B (e.g. A325) bolt has the following strength properties found in [68]:

F_{nt} = Nominal tensile stress = 90ksi (0.62 GPa) (ϕF_{nt} = 0.75 * 90 ksi = 67.5 ksi (0.465 GPa))

F_{nv} = Nominal shear stress = 54 ksi (0.372 GPa) (ϕF_{nv} = 0.75 * 54 ksi = 40.5 ksi (0.279 GPa))

F_u = Ultimate stress F_u = 120 ksi (0.826 GPa)

Area of a 7/16-in. diameter bolt is:

$A_b = \pi/4*(7/16)^2 = 0.1503$ in.^{2} (97 mm^2)

<u>Acting tensile stress in a single bolt:</u>

$f_t = (T)/A_b + (T_a/4)/A_b$ (T= 4.04 kips (17.98 kN), T_a= 15.89 kips (70.27 kN))

f_t = (4.04 kips) /0.1503 in.^{2} + (15.89 kips/4) /0.1503 in.^{2}

= 26.87 ksi + 26.43 ksi = 53.33 ksi (0.367 GPa) (acting tensile stress)

ϕF_{nt} (Tensile strength) > (Acting tensile stress) f_t (OK)

b) <u>Combined Shear and Tension:</u>

When a bolt is subjected to combined tension and shear force, the available tensile strength is determined according to the limit states of tensile and shear rupture, as follows [68]:

$$F'_{nt} = 1.3F_{nt} - \frac{F_{nt}}{\emptyset F_{nv}} f_{rv} \leq F_{nt} \quad \text{(AISC Spec. Eq J3.3a [68])}$$

Where:

F'_{nt} = Available tensile strength in combined shear and tensile

$$f_{rv} = \frac{V_a *}{A_b}$$

Where:

f_{rv} = Required shear stress

V_a^* = Acting shear force in a single bolt

A_b = Area of a single bolt

V_a^* = (8.08 kips)/4 = 2.02 kips (8.98 kN) f_{rv} = (2.02 kips)/(0.1503 in.^{2}) =13.44 ksi (0.092 GPa)

F'_{nt} = 1.3*(90 ksi) - (90 ksi*13.44 ksi)/(0.75*54 ksi) = 87.13 ksi (0.6 GPa)

F'_{nt} = 87.13 ksi (0.6 GPa) → Available tensile strength > Acting (OK)

3. Capacity of Bolts: Shear Strength (Pure Shear)

The shear stress (f_{rv}=13.44 ksi (0.092 GPa)) < the shear strength (φF_{nv}=40.5 ksi (0.279 GPa)) (OK)

4. Capacity of Bolts: Combined Tensile and Shear Strength

Tests have shown that the strength of bearing fasteners subjected to combined shear and tension resulting from externally applied forces can be defined by an ellipse [68].

$$\left(\frac{f_t}{\phi_{F_{nt}}}\right)^2 + \left(\frac{f_v}{\phi_{F_{nv}}}\right)^2 \leq \quad 1 \quad \text{(B3.3, AISC [68])}$$

Where:

ϕ = LRFD strength reduction factor, ϕ = 0.75

f_v = Required shear stress, ksi (MPa)

f_t = Required tensile stress, ksi (MPa)

F_{nv} = Nominal shear stress, ksi (MPa)

F_{nt} = Nominal tensile stress, ksi (MPa)

$(f_t/\phi F_{nt})^2 + (f_v/\phi F_{nv})^2 \leq 1$

$(53.30 \text{ ksi} / (0.75 * 90 \text{ ksi}))^2 + (13.44 \text{ ksi} /(0.75 * 54 \text{ ksi}))^2 \leq 1$

$0.62 + 0.11 \leq 1$

$0.73 \leq 1$

Therefore, the strength of the fasteners is enough to resist the applied shear and tensile load.

5. Capacity of Bolts: Bearing Strength at Bolt Hole

a) Top Base Plate

i. Minimum edge distance:

From Table J3.4 of the AISC manual [68], the minimum edge distance = 0.75 in. (19 mm) for a $^7/_{16}$-in. diameter bolt.

Available edge distance (1.5 in. (38 mm)) > 0.75 in. (19 mm). Therefore, minimum edge distance requirements are satisfied.

AISC specifications in section J3.3 state that the minimum distance (s) between the centers of bolt holes shall not be less than 2.67 d_b. However, a distance of 3d_b is preferred [68]. (Where: d_b = nominal diameter of fastener)

Minimum spacing = 2.67 d_b = 2.67 x 0.4375 = 1.17 in. (30 mm)

Preferred spacing = 3.0 d_b = 3.0 x 0.4375 = 1.31 in. (33 mm)

Available spacing 2.5 in. (64 mm) > 1.31 in. (33 mm), therefore, spacing requirements are satisfied.

ii. Bearing strength at bolt holes:

AISC specifications in section J3.10 state that the available bearing strength at bolt holes is ϕR_n (ϕ = 0.75, LRFD) when deformation at the bolt holes is a design consideration [68]:

$R_n = 1.2\ L_c\ t\ F_u \leq 2.4\ d_b\ t\ F_u$ (J3-6a, [68])

Where:

F_u = Specified minimum tensile strength of the connected material (for ASTM A36, F_u = 58 ksi)

L_c = Clear distance, in the direction of the force, between the edge of the hole and the edge of the adjacent hole or edge of the material (in.)

t = Thickness of connected material (in.)

L_c = 1.5 – hole diameter/2 = 1.5 – (7/16 + 1/16)/2 = 1.25 in. (32 mm)

ϕR_n = 0.75 x (1.2 L_c t F_u) = 0.75 x (1.2 x 1.25 x 0.75 x 58) = 48.78 kips (217.07 kN)

But, $\phi R_n \leq$ 0.75 (2.4 d_b t F_u) = 0.75 x (2.4 x 0.4375 x 0.75 x 58) = 34.26 kips (152.46 kN)

Therefore, ϕR_n =34.26 kips (152.46 kN) at edge holes

At other holes, S = 2.5 in, L_c = 2.5 – (7/16 +1/16) = 2.0 in. (51 mm)

ϕR_n = 0.75 x (1.2 L_c t F_u) = 0.75 x (1.2 x 2.0 x 0.75 x 58) = 78.3 kips (348.44 kN)

But, $\phi R_n \leq$ 0.75 (2.4 d_b t F_u) = 34.26 kips. Therefore, ϕR_n = 34.26 kips (152.46 kN)

Therefore, bearing strength at bolt holes = 2x 34.26 = 68.52 kips (304.92 kN). Bearing strength at bolt holes (upper base plate) = 68.52 kips (304.92 kN).

b) Bottom Base Plate

i. Minimum edge distance

As per Table J3.4 of the AISC manual [68], minimum edge distance = 0.75 in. (19 mm) for 7/16 diameter bolt.

Available edge distance 1.5 in. (38 mm) > 0.75 in. (19 mm), therefore, minimum edge distance requirements are satisfied.

AISC specification in section J3.3 state that the minimum distance (s) between the centers of bolt holes shall not be less than 2.67 d_b. However, a distance of 3d_b is preferred [68]. (Where: d_b = Nominal diameter of fastener)

Minimum spacing = 2.67 d_b = 2.67 x 0.4375 = 1.17 in. (30 mm)

Preferred spacing = 3.0 d_b = 3.0 x 0.4375 = 1.31 in. (33 mm)

Available spacing 1.50 in. (38 mm) > 1.31 in. (33 mm), therefore, spacing requirements are satisfied.

ii. Bearing strength at bolt holes:

AISC specification J3.10 indicates the available bearing strength at bolt holes is Rn (= 0.75, LRFD), when deformation at the bolt holes is a design consideration [68]:

$$Rn = 1.2\ Lc\ t\ Fu \leq 2.4\ db\ t\ Fu \qquad \text{(J3-6a)}$$

Where:

Fu = Specified minimum tensile strength of the connected material (for ASTM A36, Fu = 58 ksi (0.399 GPa))

Lc = Clear distance, in the direction of the force, between the edge of the hole and the edge of the adjacent hole or edge of the material (in.).

t = Thickness of connected material (in.).

L_c = 1.5 – hole diameter/2 = 1.5 – (7/16 + 1/16)/2 = 1.25 in. (32 mm)

ϕR_n = 0.75 x (1.2 L_c t F_u) = 0.75 x (1.2 x 1.25 x 0.75 x 58) = 40.78 kips (217.07 kN)

But, $\phi R_n \leq$ 0.75 (2.4 d_b t F_u) = 0.75 x (2.4 x 0.4375 x 0.625 x 58) = 28.54 kips (127.00 kN)

Therefore, ϕR_n =28.54 kips at edge holes

At other holes, s = 2.5 in, L_c = 2.5 – (7/16 +1/16) = 2.0 in. (51 mm)

ϕR_n = 0.75 x (1.2 L_c t F_u) = 0.75 x (1.2 x 2.0 x 0.75 x 58) = 65.25 kips (290.36 kN)

But, $\phi R_n \leq$ 0.75 (2.4 d_b t F_u) = 28.54 kips. Therefore, ϕR_n = 28.54 kips (127.00 kN)

Therefore, bearing strength at bolt holes = 2 x 28.54 = 57.09 kips (254.05 kN) .

Bearing strength (ϕRn) > applied load (15.79 kips (70.26 kN)) (OK)

6. Weld Design Capacity

a) Top Post (W6X8.5)

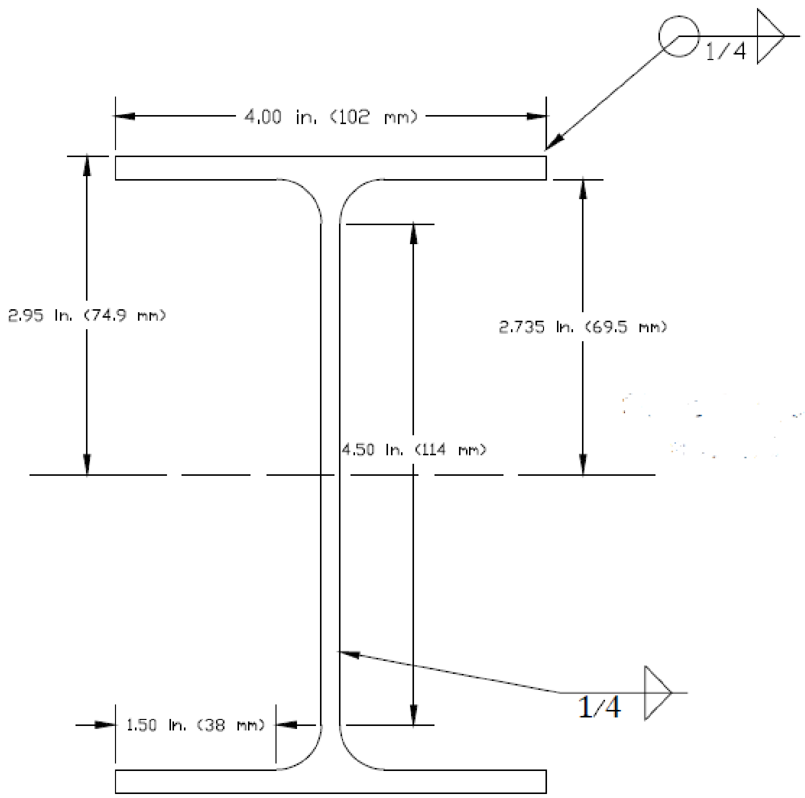


Figure A-3. Top Post (W6X8.5) Weld Size

Web thickness (t_w) = 0.17 in. (4 mm)

Flange width (b_f) = 4.0 in. (102 mm)

Flange thickness (t_f) = 0.215 in. (5 mm)

Area (A) = 2.68 in.^{2} (1729 mm^2)

<u>Moment capacity of the weld</u>

$I_{\text{outside flange}} = (2)*(\frac{1}{12})*(4)*(0.707*0.25)^3 + (2)*(0.707)*(0.25)*(4)*(2.95)^2 = 12.31$ in.^{4} (5123809 mm^4)

$I_{\text{inside flange}} = (2)*(\frac{1}{12})*(3)*(0.707*0.25)^3 + (2)*(0.707)*(0.25)*(3)*(2.95)^2 = 7.94$ in.^{4} (3304878 mm^4)

$I_{web} = (2)*(\frac{1}{12})*(0.707)*(0.25)*(2)^3 = 0.24$ in.^{4} (99896 mm^4)

$I_{total} =$ 20.5 in.^{4} (8532744 mm^4)

S = 20.5/2.95 = 6.94 in.^{3} (113726 mm^3)

$M_{capacity}$ = (6.94 in.^{3})*(70 ksi) = 486.1 kips-in. > M_{acting} =20.2 kips-in. (OK) (F_u = 70 ksi)

Peak Force capacity = $\frac{486.1\ kips}{(2.5 in.)}$ = 194.44 kips (865.26 kN) > 15.79 kips (70.26 kN) (OK)

b) Lower Post (Foundation Tube)

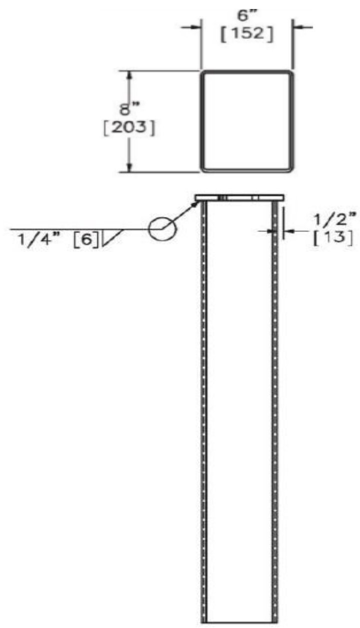


Figure A-4. Lower Post (Foundation Tube) Weld Size

Weld size (a_{min}) = ¼ in. (6 mm)

Length of the weld (L_w) = 2*6 in. + 2*8 in. = 28 in. (711 mm)

Shear strength of weld metal = ϕR_n

$R_n = F_{nw} A_{we}$ [68]

Where:

$F_{nw} = 0.60\ F_{EXX}$ (F_{EXX} = Filler metal classification strength = 70 ksi (E70XX electrode for the fillet welds))

Shear strength of weld metal = $\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times a \times L_w$

Where: 0.707 a = Throat (The shear failure of the fillet weld occurs along a plane through the throat of the weld)

$\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times a \times L_w$

$= 0.75 \times 0.60 \times 70 \text{ ksi} \times 0.707 \times 0.25 \text{ in} \times 28 \text{ in.}$

$= 155.89$ kips (693.71 kN)

Shear strength of the weld metal (ϕRn =155.89 kips (693.71 kN)) > acting shear (OK)

7. Design of Top Post: Shear Strength

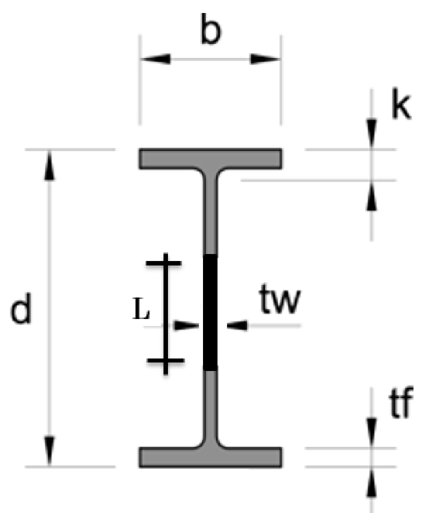


Figure A-5. Top Post Cross section

Material Specifications (ASTM designation): A992 (AISC Table 2-4, [68]).

F_y (yield stress) = 50 ksi (0.344 GPa)

F_u (tensile stress) = 65 ksi (0.447 GPa)

Section dimensions and properties (AISC, Table 1-1 (1-28), [68]):

Area (A) = 2.68 in.^{2} (1729 mm^2)

Depth (d) = 6.0 in. (152 mm)

Web thickness (t_w) = 0.17 in. (4 mm)

As per AISC manual section 16.1-67 (chapter G) [68], the nominal shear strength, V_n, according to the limit states of shear yielding is:

$V_n = 0.6F_yA_WC_v$, $C_v = 1.0$ for I-shaped members

Where:

$A_w = dt_w$ (area of web, in.^{2})

d = Overall depth,

t_w = Thickness of web

F_y = Specified minimum yield stress, ksi

V_n = 0.6*50 ksi * ((6-2.5)*0.17) in.^{2} = 18 kips (80.1 kN) > Acting (8.08 kips (35.96 kN)) (OK)

8. Maximum Capacity of Design Concept No. 1

Combined Tensile and shear strength (LRFD) is given by:

$$\left(\frac{f_t}{\phi_{F_{nt}}}\right)^2 + \left(\frac{f_v}{\phi_{F_{nv}}}\right)^2 \leq 1 \quad \text{(B3.3, AISC [68])}$$

Where:

ϕ = LRFD strength reduction factor, ϕ = 0.75

$f_{v\,=}$ Required shear stress, ksi (MPa)

$f_{t\,=}$ Required tensile stress, ksi (MPa)

$F_{nv\,=}$ Nominal shear stress, ksi (MPa)

F_{nt} = Nominal tensile stress, ksi (MPa)

f_t = (T) /A_b + (T_a/4) /A_b

T= (M /2.5 in.) /2 = (V1 * 2.5)/5 (2.5 in. = distance b/n bolts and V1 = 0.26 V_a = 0.26 $Fc_{apacity}$ *cos(27))

T = (0.26 $F_{capacity}$ * cos (27) *2.5)/5 = 0.12 $Fc_{apacity}$

T_a = $Fc_{apacity}$ * sin (27) = 0.45 $Fc_{apacity}$

f_t = (0.12 $F_{capacity)}$ / (0.1503) + ((0.45 $Fc_{apacity/}$4)/0.1503)

= 0.798 $F_{capacity}$ + 0.749 $F_{capacity}$

= 1.547 $Fc_{apacity}$

f_v = (V1/4)/A_b = (0.26 V/4)/ A_b = ((0.26 *$Fc_{apacity}$ *cos(27))/4)/ 0.1503

f_v = 0.4 $Fc_{apacity}$

$\left(\frac{f_t}{\phi_{F_{nt}}}\right)^2 + \left(\frac{f_v}{\phi_{F_{nv}}}\right)^2 = 1$ (To find the maximum capacity of the anchorage system, the equation was set to be equal to unity)

$$\left(\frac{1.547\ \text{Fcapacity}}{67.5}\right)^2 + \left(\frac{0.4\ \text{Fcapacity}}{40.5}\right)^2 = 1$$

$0.00052\ (F_{capacity})^2 + 0.0001\ (F_{capacity})^2 = 1$

$F_{capacity}$ = 40 kips (177. 92 kN)

Appendix B. Steel-Post, Trailing-End Anchorage Design Concept No. 2 Calculations

Calculation: Design Concept No. 2

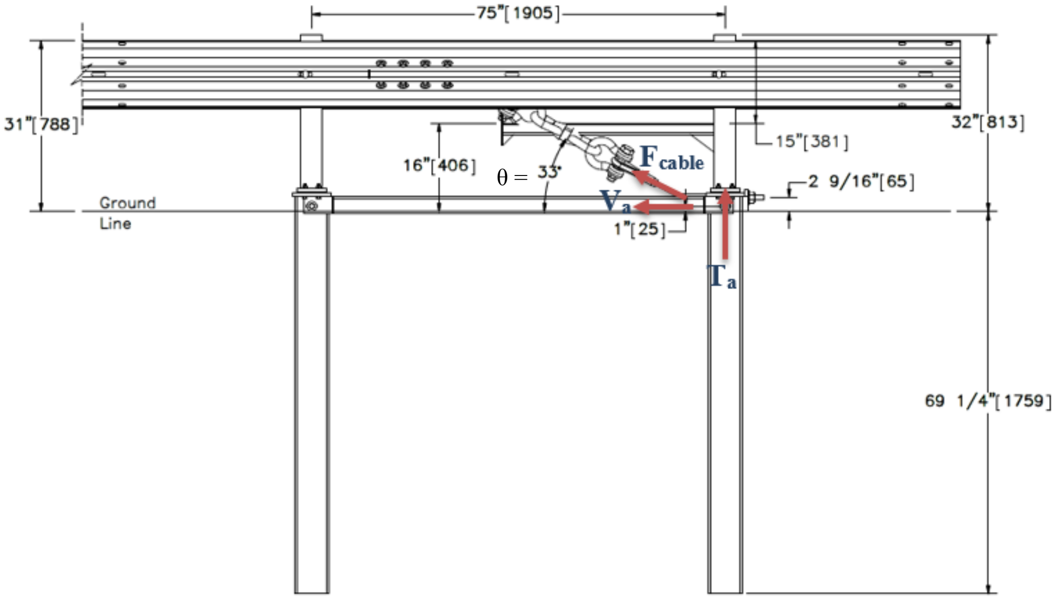


Figure B-1. Steel-Post, Trailing-End Anchorage Design Concept No. 2

1. Force Calculation

The maximum load sustained by the BCT wood post downstream anchorage system was 35 kips (155.7 kN). This load was used as a baseline for the following calculations. More details regarding BCT wood post anchorange capacity are provided in Mongiardini et al. [4].

$$\cos\theta = \frac{Va}{F_{cable}}$$

$$T_a = F_{cable} * \sin\theta = 35kips * \sin 33^0 = 19.06\ kips\ (84.82\ kN)$$

$$V_a = 35kips * \cos 33^0 = 29.35kips\ (130.61\ kN)$$

Where:

F_{cable}= Force in anchor cable

T_a = Tension force

V_a = Shear force

2. Design Force Calculation

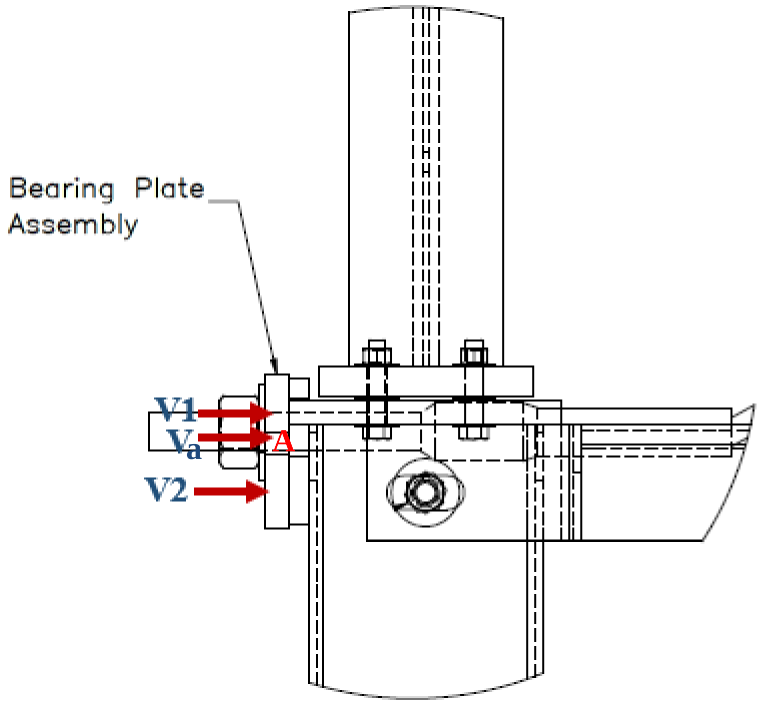


Figure B-2. Forces Acting on Design Concept No. 2

Moment about A:

V1 x (0.5625) = V2 x (1.4375)

Where: 0.5625 in. (14 mm) = distance b/n V and V1

1.4375 in. (37 mm) = distance b/n V and V2

Equilibrium of Forces:

V1 + V2 = V_a = 35 kips *cos (33.0) = 29.35 kips (130.61 kN)

V1 = 21.05 kips (93.67 kN)

V2 = 8.3 kips (36.94 kN)

3. Weld Capacity (Bottom Base Plate)

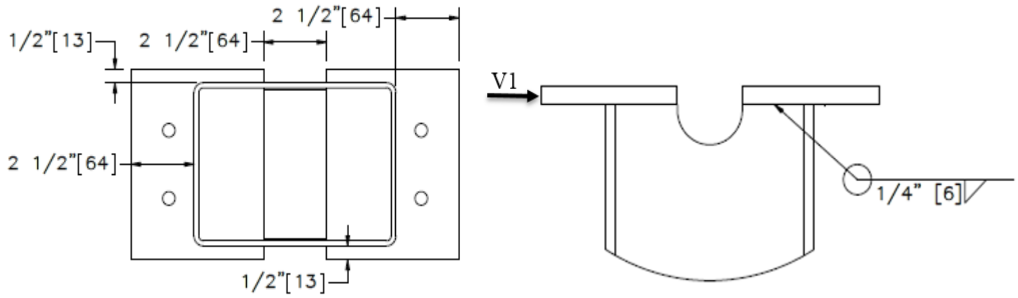


Figure B-3. Weld Size of the Bottom Base Plate

Weld capacity as per AISC manual, section J2.5 [68]:

Weld size (a_{min}) = ¼ in. (6.35 mm)

Length of the weld (L_w) = 2*8 in. + 2*6 in. - 2*2.5 in. = 23 in. (584 mm)

Shear strength of weld metal = ϕR_n

$R_n = F_{nw} A_{we}$

Where:

$F_{nw} = 0.60\ F_{EXX}$ (F_{EXX} = Filler metal classification strength = 70 ksi (E70XX electrode for the fillet welds)

Shear strength of weld metal = $\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times a \times L_w$

Where:

0.707 a = Throat (The shear failure of the fillet weld occurs along a plane through the throat of the weld)

ϕ = LRFD strength reduction factor = 0.75

$\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times 0.25 \times L_w > V1 = 21.05$ kips (93.67 kN)

Lw > 3.85 in. (98 mm)

L_w (provided) = 23.in. (584 mm) > L_w = 3.85 in. (98 mm) (O.K)

4. Shear Strength of Foundation Tube

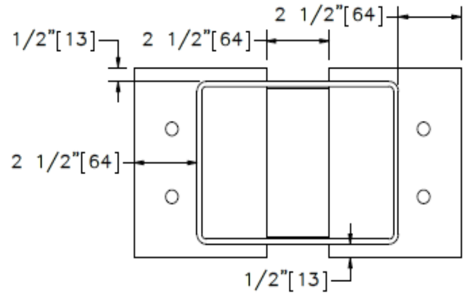


Figure B-4. Foundation Tube Cross-Section

<u>Material Specifications (ASTM Designation):</u>

The material A992 is the preferred material for W-sections [68].

F_y (yield stress) = 50 ksi (0.344 GPa)

F_u (tensile stress) = 65 ksi (0.447 GPa)

<u>Section dimensions</u>

Depth (d) = 8.0 in. (203 mm)

Web thickness (t_w) = 0.1875 in. (5 mm)

Area (A_w) = (8-2.5) in. * 0.1875 in. = 1.03 in.^{2} (645 mm^2)

As per AISC section 16.1-67 (chapter G) [68], the nominal shear strength, V_n, according to the limit states of shear yielding is:

$V_n = 0.6F_yA_W$

Where: $A_w = dt_w$ (area of web, in^2)

d = Overall depth, t_w = thickness of web

F_y = Specified minimum yield stress, ksi

V_n = 0.6*50 ksi * 1.03 in.^{2} = 31 kips (137.95 kN) > Acting (V2 = 8.3 kips (36.94 kN)) (OK)

Appendix C. Steel-Post, Trailing-End Anchorage Design Concept No. 3 Calculations

Calculation: Design Concept No. 3

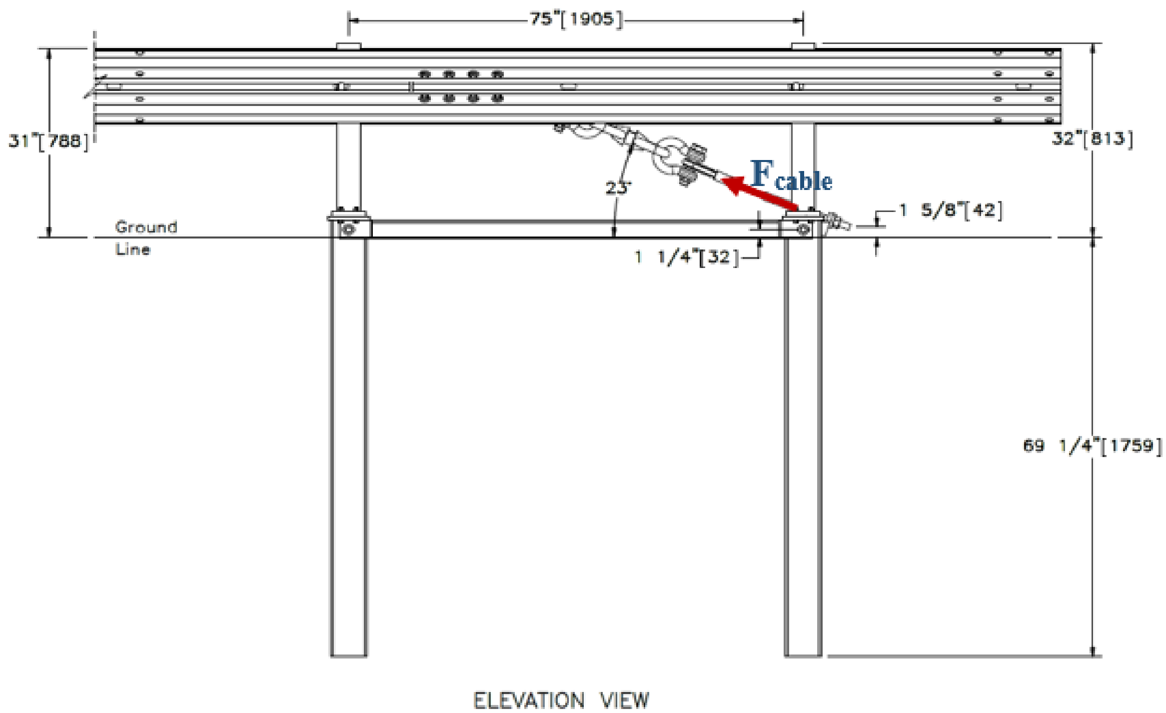


Figure C-1. UBSP Downstream Anchorage Design Concept No. 3

1. Force Calculation

The maximum load sustained by the BCT wood post downstream anchorage system was 35 kips (155.7 kN). This load was used as a baseline for the following calculations. More details regarding BCT wood post anchorange capacity are provided in Mongiardini et al. [4].

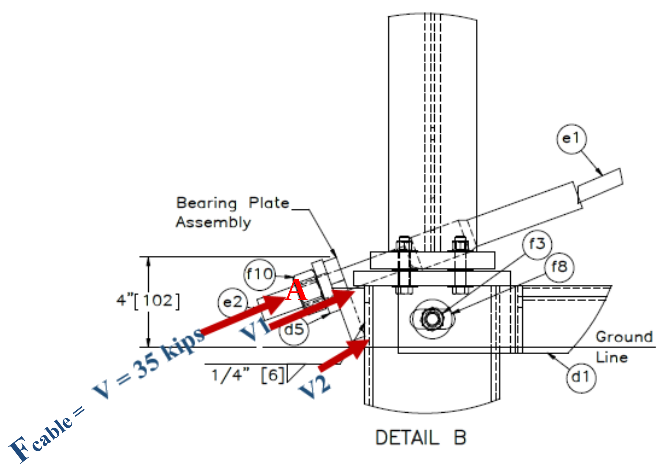


Figure C-2. Forces Acting on Design Concept No. 3

<u>Moment about V:</u>

V1 x (0.5625) = V2 x (2.6875)

Where: 0.5625 in. (14 mm) = distance b/n V and V1

2.6875 in. (68 mm) = distance b/n V and V2

<u>Equilibrium of Forces</u>:

V1 + V2 = V = 35 kips (155.75 kN) = F_{cable}

V1 = 29.5 kips (131.275 kN)

V2 = 5.5 kips (24.475 kN)

2. Weld capacity (Bottom base plate)

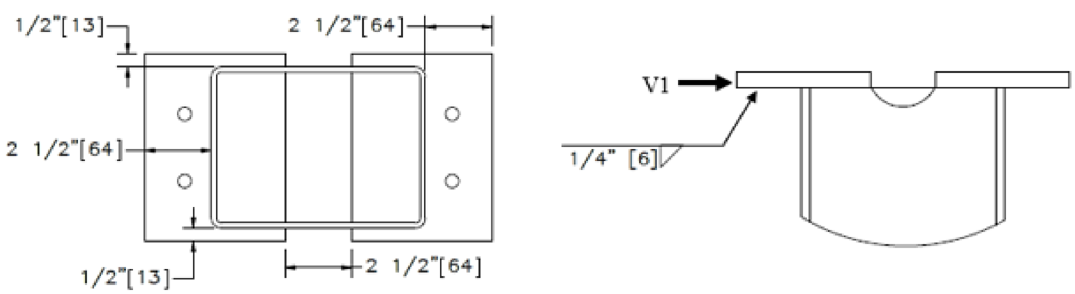


Figure C-3. Weld Details and Force Acting on Bottom Base Plate

<u>Weld capacity as per AISC, J2.5 [68]</u>

Weld size (a_{min}) = ¼ in. (6.35 mm)

Length of the weld (L_w) = 2*8 in. + 2*6 in. - 2*2.5 in. = 23 in. (584 mm)

Shear strength of weld metal = ϕR_n

$R_n = F_{nw} A_{we}$

Where:

$F_{nw} = 0.60\ F_{EXX}$ (F_{EXX} = Filler metal classification strength = 70 ksi (E70XX electrode for the fillet welds))

Shear strength of weld metal = $\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times a \times L_w$

Where:

0.707 a = Throat (The shear failure of the fillet weld occurs along a plane through the throat of the weld)

ϕ = LRFD strength reduction factor = 0.75

$\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times 0.25 \times L_w > V1$ = 29.50 kips (131.275 kN)

$L_w > 5.3$ in. (135 mm)

L_w (provided) = 23 in. (584 mm) > L_w = 5.3 in. (135 mm) OK

3. Shear Strength of Foundation Tube

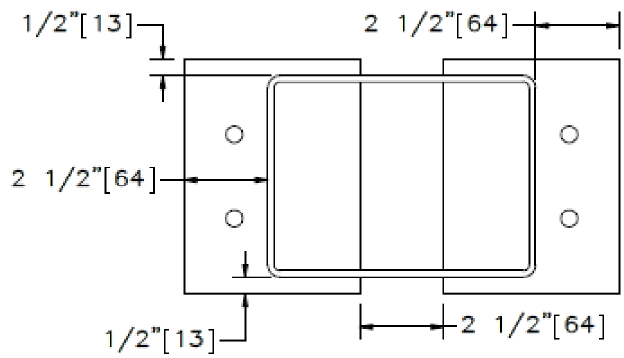


Figure C-4. Design Details of Foundation Tube

Material Specifications (ASTM designation):

The material A992 has the following yield and tensile strength capacity [68]:

F_y (yield stress) = 50 ksi (0.344 GPa)

F_u (tensile stress) = 65 ksi (0.447 GPa)

Section dimensions and properties:

Depth (d) = 8.0 in. (203 mm)

Web thickness (t_w) = 0.1875 in. (93.67 kN)

Area (A_w) = (8-2.5) in. * 0.1875 in. = 1.03 in.^{2} (645 mm^2)

As per AISC section 16.1-67 (chapter G) [68], the nominal shear strength, V_n, according to the limit states of shear yielding is:

$V_n = 0.6F_yA_W$

Where: $A_w = dt_w$ (area of web, in.^{2})

d = Overall depth, t_w = thickness of web

F_y = Specified minimum yield stress, ksi

$V_n = 0.6*50$ ksi * 1.03 in.^{2} = 30.93 kips (137.64 kN) > Acting (V2 = 5.50 kips (37.895 kN)) (OK)

Appendix D. Steel-Post, Trailing-End Anchorage Design Concept No. 4 Calculations

Calculation: Design Concept No. 4

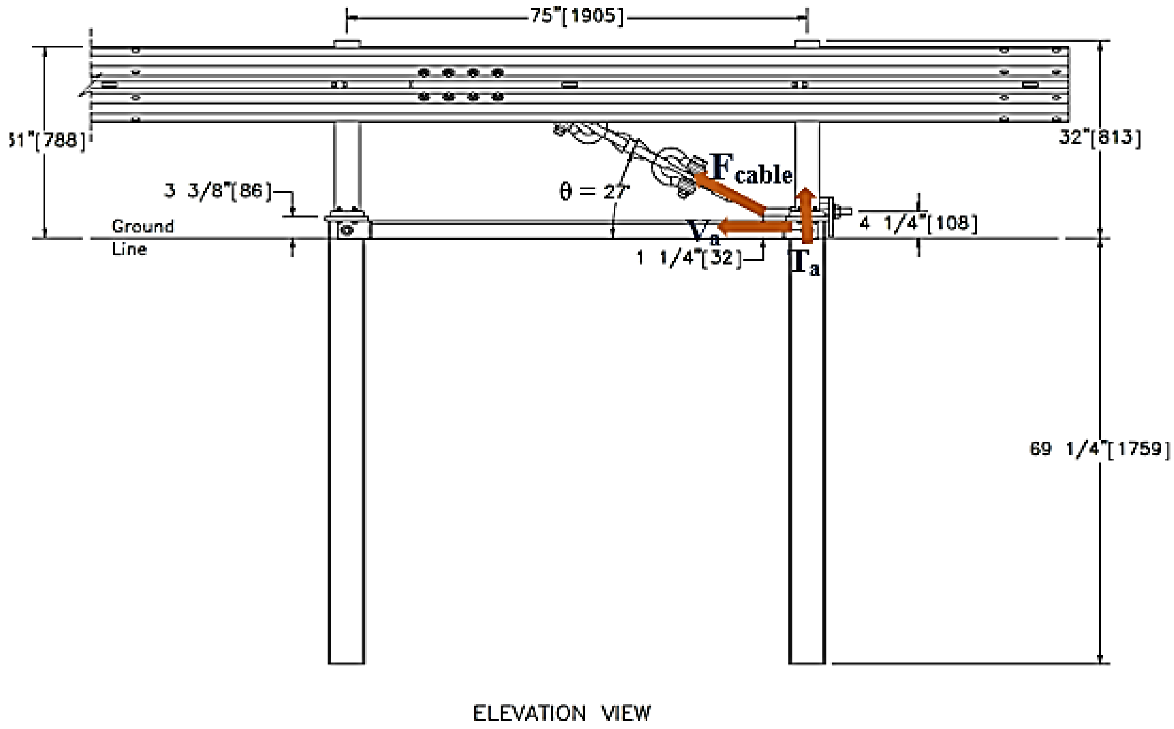


Figure D-1. Modified UBSP Downstream Anchorage Design Concept No. 4

1. Force Calculation

The maximum load sustained by the BCT steel post downstream anchorage system (design concept no. 1) is F_{cable} = 40 kips (178 kN).

$$\cos\theta = \frac{Va}{F_{cable}}$$

$T_a = F_{cable} * \sin\theta = 40 kips * \sin 27^0 = 18.16\ kips\ (80.78\ kN)$

$V_a = 40 kips * \cos 27^0 = 35.64 kips\ (158.53\ kN)$

Where:

F_{cable}= Force in anchor cable

T_a = Tension force

V_a = Shear force

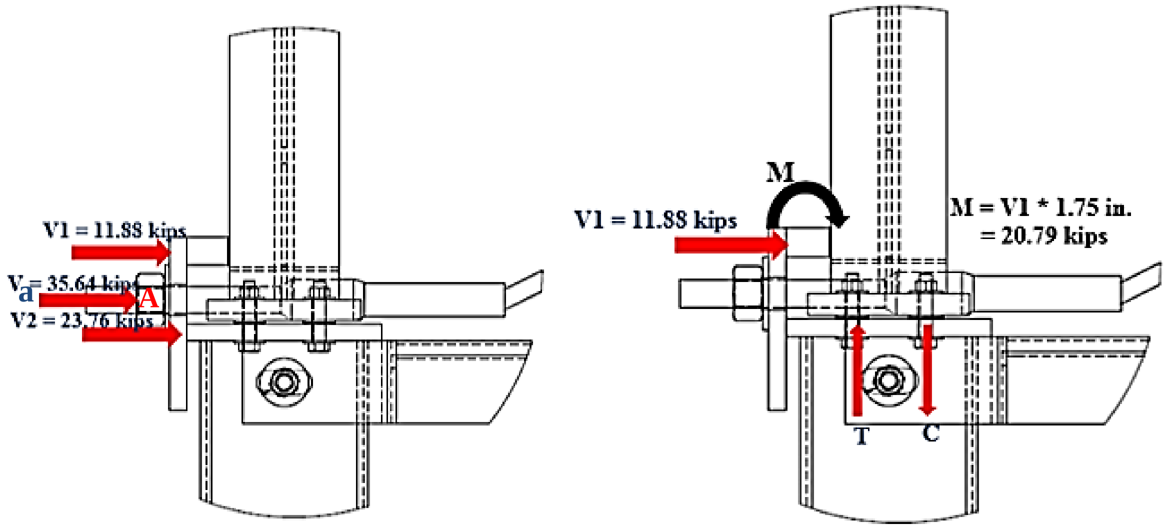


Figure D-2. Forces Acting on Design Concept No. 4

Moment about A:

V1 x (1.75 in.) = V2 x (0.875 in.)

Where:

0.875 in. (22 mm) = distance between V and V2

1.75 in. (64 mm) = distance between V and V1

Equilibrium of Forces:

V1+V2 = V_a = 40 kips*cos(27°)

V1 = 11.88 kips (52.984 kN)

V2= 23.76 kips (105.7 kN)

Tension in a single bolt:

T= (M /2.5 in.) /2 = 4.2 kips (18.68 kN) (2.5 in. = distance b/n bolts)

2. Capacity of Bolts: Tension [Load and Resistance Factor Design (LRFD)]

a) Pure Tension:

As per the American Institute of Steel Construction (AISC) specification, Table J3.2, Group B (e.g. A325) bolt has the following strength properties found in [68]:

F_{nt} = Nominal tensile stress = 90 ksi (0.62 GPa) (ϕF_{nt} = 0.75 * 90 ksi = 67.5 ksi (0.465 GPa))

F_{nv} = Nominal shear stress = 54 ksi (0.372 GPa) (ϕF_{nv} = 0.75 * 54 ksi = 40.5 ksi (0.279 GPa))

F_u = Ultimate stress F_u = 120ksi (0.826 GPa)

Area of a 7/16-in. diameter bolt is:

$A_b = \pi/4*(7/16)^2$ = 0.1503 in.^{2} (97 mm^2)

Acting tensile stress in a single bolt:

$f_t = (T)/A_b + (T_a/4)/A_b$ (T= 4.04 kips (17.98 kN), T_a= 18.46 kips (82.11 kN))

f_t = (4.2 kips) /0.1503 in.^{2} + (18.46 kips/4) /0.1503 in.^{2}

= 27.94 ksi + 30.71 ksi = 58.65 ksi (0.404 GPa) (acting tensile stress)

ϕF_{nt} (Tensile strength) > (Acting tensile stress) f_t (OK)

b) Combined shear and tension:

When a bolt is subjected to combined tension and shear force, the available tensile strength is determined according to the limit states of tensile and shear rupture, as follows [68]:

$$F'_{nt} = 1.3F_{nt} - \frac{F_{nt}}{\emptyset F_{nv}} f_{rv} \leq F_{nt} \quad \text{(AISC Spec. Eq J3.3a [68])}$$

Where:

F'_{nt} = Available tensile strength in combined shear and tensile

$$f_{rv} = \frac{V_a *}{A_b}$$

Where:

f_{rv} = Required shear stress

V_a^* = Acting shear force in a single bolt

A_b = Area of a single bolt

V_a^* = (11.88 kips)/4 = 2.97 kips (13.21 kN) frv = (2.97 kips)/ (0.1503 in.^{2}) =19.76 ksi (0.136 GPa)

F'_{nt} = 1.3*(90 ksi) - (90 ksi*19.76 ksi)/ (0.75*54 ksi) = 73.1 ksi (0.504 GPa)

F'_{nt} = 73.1 ksi (0.504 GPa) → Available tensile strength > Acting (OK)

3. Capacity of Bolts: Shear Strength (Pure Shear)

The shear stress (f_{rv}=19.76 ksi (0.136 GPa)) < the shear strength (φF_{nv} = 40.5 ksi (0.279 GPa)) (OK)

4. Capacity of Bolts: Combined Tensile and Shear Strength

Tests have shown that the strength of bearing fasteners subjected to combined shear and tension resulting from externally applied forces can be defined by an ellipse [68].

$$\left(\frac{f_t}{\phi_{F_{nt}}}\right)^2 + \left(\frac{f_v}{\phi_{F_{nv}}}\right)^2 \leq \quad 1 \quad \text{(B3.3, AISC [68])}$$

Where:

ϕ = LRFD strength reduction factor, ϕ = 0.75

f_{v} = Required shear stress, ksi (MPa)

f_{t} = Required tensile stress, ksi (MPa)

F_{nv} = Nominal shear stress, ksi (MPa)

F_{nt} = Nominal tensile stress, ksi (MPa)

$(f_t/\phi F_{nt})^2 + (f_v/\phi F_{nv})^2 \leq 1$

$(58.65 \text{ ksi} /(0.75 * 90 \text{ ksi}))^2 + (19.76 \text{ ksi} /(0.75 * 54 \text{ ksi}))^2 \leq 1$

$0.75 + 0.23 \leq 1$

$0.98 \leq 1$

Therefore, strength of fasteners is enough to resist the applied shear and tensile load.

5. Capacity of Bolts: Bearing Strength at Bolt Hole

a) Top Base Plate

i. Minimum edge distance:

From Table J3.4 of the AISC manual [68], minimum edge distance = 0.75 in. (19 mm) for $^{7}/_{16}$-in. diameter bolt.

Available edge distance (1.5 in. (38 mm)) > 0.75 in. (19 mm). Therefore, minimum edge distance requirements are satisfied.

AISC specifications in section J3.3 state that the minimum distance (s) between the centers of bolt holes shall not be less than 2.67 d_b. However, a distance of 3d_b is preferred [68]. (Where: d_b = nominal diameter of fastener)

Minimum spacing = 2.67 d_b = 2.67 x 0.4375 = 1.17 in. (30 mm)

Preferred spacing = 3.0 d_b = 3.0 x 0.4375 = 1.31 in. (33 mm)

Available spacing 2.5 in. (64 mm) > 1.31 in. (33 mm), therefore, spacing requirements are satisfied.

AISC specifications in section J3.10 state that the available bearing strength at bolt holes is ϕR_n (ϕ=0.75, LRFD) when deformation at the bolt holes is a design consideration [68]:

$R_n = 1.2\ L_c\ t\ F_u \leq 2.4\ d_b\ t\ F_u$ (J3-6a, [68])

Where:

F_u = Specified minimum tensile strength of the connected material (for ASTM A36, F_u = 58 ksi)

L_c = Clear distance, in the direction of the force, between the edge of the hole and the edge of the adjacent hole or edge of the material (in.)

t = Thickness of connected material (in.)

ii. Bearing strength at bolt holes:

L_c = 1.5 – hole diameter/2 = 1.5 – (7/16 + 1/16)/2 = 1.25 in. (32 mm)

ϕR_n = 0.75 x (1.2 L_c t F_u) = 0.75 x (1.2 x 1.25 x 0.75 x 58) = 48.78 kips (217.07 kN)

But, $\phi R_n \leq$ 0.75 (2.4 d_b t F_u) = 0.75 x (2.4 x 0.4375 x 0.75 x 58) = 34.26 kips (152.46 kN)

Therefore, ϕR_n =34.26 kips (152.46 kN) at edge holes

At other holes, S = 2.5 in, L_c = 2.5 – (7/16 +1/16) = 2.0 in. (51 mm)

$\phi R_n = 0.75 \times (1.2\ L_c\ t\ F_u) = 0.75 \times (1.2 \times 2.0 \times 0.75 \times 58) = 78.3$ kips (348.44 kN)

But, $\phi R_n \leq 0.75\ (2.4\ d_b\ t\ F_u) = 34.26$ kips. Therefore, $\phi R_n = 34.26$ kips (152.46 kN)

Therefore, bearing strength at bolt holes = 2x 34.26 = 68.52 kips (304.92 kN). Bearing strength at bolt holes (upper base plate) = 68.52 kips (304.92 kN).

b) Bottom Base Plate

i. Minimum edge distance

As per Table J3.4 of the AISC manual [68], minimum edge distance = 0.75 in. (19 mm).

Available edge distance 1.5 in. (38 mm) > 0.75 in. (19 mm), therefore, minimum edge distance requirements are satisfied.

AISC specifications in section J3.3 state that the minimum distance (s) between the centers of bolt holes shall not be less than 2.67 d_b. However, a distance of 3d_b is preferred [68]. (Where: d_b = Nominal diameter of fastener)

Minimum spacing = 2.67 d_b = 2.67 x 0.4375 = 1.17 in. (30 mm)

Preferred spacing = 3.0 d_b = 3.0 x 0.4375 = 1.31 in. (33 mm)

Available spacing 1.31 in. (33 mm) > 1.50 in. (38 mm), therefore, spacing requirements are satisfied.

AISC specification J3.10 indicates the available bearing strength at bolt holes is ϕR_n (ϕ=0.75, LRFD) when deformation at the bolt holes is a design consideration [68]:

$R_n = 1.2\ L_c\ t\ F_u \leq 2.4\ d_b\ t\ F_u$ (J3-6a)

Where:

F_u = Specified minimum tensile strength of the connected material (for ASTM A36, F_u = 58 ksi (0.399 GPa))

L_c = Clear distance, in the direction of the force, between the edge of the hole and the edge of the adjacent hole or edge of the material (in.).

t = Thickness of connected material (in.).

ii. Bearing strength at bolt holes:

L_c = 1.5 – hole diameter/2 = 1.5 – (7/16 + 1/16)/2 = 1.25 in. (32 mm)

$\phi R_n = 0.75 \times (1.2\ L_c\ t\ F_u) = 0.75 \times (1.2 \times 1.25 \times 0.75 \times 58) = 40.78$ kips (217.07 kN)

But, $\phi R_n \leq 0.75\ (2.4\ d_b\ t\ F_u) = 0.75 \times (2.4 \times 0.4375 \times 0.625 \times 58) = 28.54$ kips (127.00 kN)

Therefore, ϕR_n =28.54 kips at edge holes

At other holes, s = 2.5 in, L_c = 2.5 – (7/16 +1/16) = 2.0 in. (51 mm)

ϕR_n = 0.75 x (1.2 L_c t F_u) = 0.75 x (1.2 x 2.0 x 0.75 x 58) = 65.25 kips (290.36 kN)

But, $\phi R_n \leq$ 0.75 (2.4 d_b t F_u) = 28.54 kips. Therefore, ϕR_n = 28.54 kips (127.00 kN)

Therefore, bearing strength at bolt holes = 2 x 28.54 = 57.09 kips (254.05 kN) .

Bearing strength (ϕRn) > applied load (18.16 kips (80.78 kN)) (OK)

6. Weld Design Capacity

a) Top Post (W6X8.5)

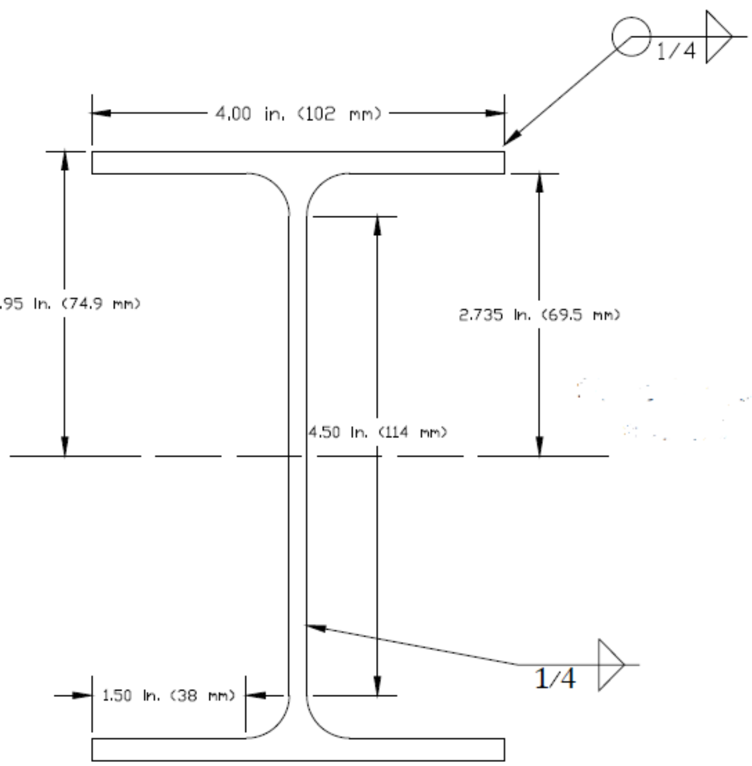


Figure D-3. Top Post (W6X8.5) Weld Size

Web thickness (t_w) = 0.17 in. (4 mm)

Flange width (b_f) = 4.0 in. (102 mm)

Flange thickness (t_f) = 0.215 in. (5 mm)

Area (A) = 2.68 in.^{2} (1729 mm^2)

Moment capacity of the weld

$I_{\text{outside flange}} = (2)*(\frac{1}{12})*(4)*(0.707*0.25)^3 + (2)*(0.707)*(0.25)*(4)*(2.95)^2 = 12.31$ in.^{4} (5123809 mm^4)

$I_{\text{inside flange}} = (2)*(\frac{1}{12})*(3)*(0.707*0.25)^3 + (2)*(0.707)*(0.25)*(3)*(2.95)^2 = 7.94$ in.^{4} (3304878 mm^4)

$I_{\text{web}} = (2)*(\frac{1}{12})*(0.707)*(0.25)*(2)^3 = 0.24$ in.^{4} (99896 mm^4)

$I_{\text{total}} = 20.5$ in.^{4} (8532744 mm^4)

S = 20.5/2.95 = 6.94 in.^{3} (113726 mm^3)

$M_{capacity}$ = (6.94 in.^{3})*(70 ksi) = 486.1 kips-in. > M_{acting} =20.2 kips-in. (OK) (F_u = 70 ksi)

Peak Force capacity = $\frac{486.1\ kips}{(2.5 in.)}$ = 194.44 kips (865.26 kN) > 18.16 kips (80.78 kN) (OK)

b) Lower Post (Foundation Tube)

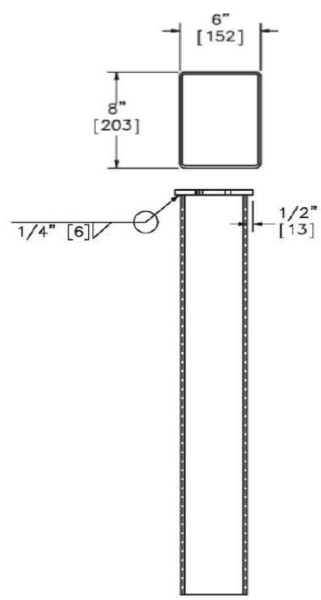


Figure D-4. Lower Post (Foundation Tube) Weld Size

Weld size (a_{min}) = ¼ in. (6 mm)

Length of the weld (L_w) = 2*6 in. + 2*8 in. = 28 in. (711 mm)

Shear strength of weld metal = ϕR_n

$R_n = F_{nw}\ A_{we}$ [68]

Where:

$F_{nw} = 0.60\ F_{EXX}$ (F_{EXX} = Filler metal classification strength = 70 ksi (E70XX electrode for the fillet welds))

Shear strength of weld metal = $\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times a \times L_w$

Where: 0.707 a = Throat (The shear failure of the fillet weld occurs along a plane through the throat of the weld)

$\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times a \times L_w$

= 0.75 x 0.60 x 70 ksi x 0.707 x 0.25 in x 28 in.

= 155.89 kips (693.71 kN)

Shear strength of the weld metal (ϕRn =155.89 kips (693.71 kN)) > acting shear (OK)

7. Design of Top Post: Shear Strength

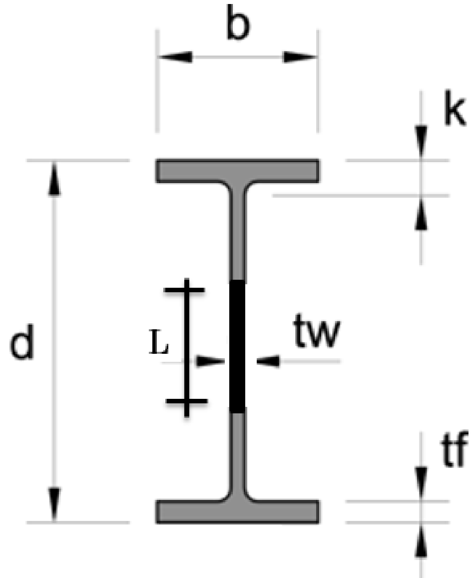


Figure D-5. Top Post Cross section

Material Specifications (ASTM designation): A992 (AISC Table 2-4, [68]).

F_y (yield stress) = 50 ksi (0.344 GPa)

F_u (tensile stress) = 65 ksi (0.447 GPa)

Section dimensions and properties (AISC, Table 1-1 (1-28), [68]):

Area (A) = 2.68 in.^{2} (1729 mm^2)

Depth (d) = 6.0 in. (152 mm)

Web thickness (t_w) = 0.17 in. (4 mm)

As per AISC manual section 16.1-67 (chapter G) [68], the nominal shear strength, V_n, according to the limit states of shear yielding is:

$V_n = 0.6F_yA_WC_v$, C_v = 1.0 for I-shaped members

Where:

$A_w = dt_w$ (area of web, in.^{2})

d = Overall depth,

t_w = Thickness of web

F_y = Specified minimum yield stress, ksi

V_n = 0.6*50 ksi * ((6-2.5)*0.17) in.^{2} = 18 kips (80.1 kN) > Acting (7.03 kips (31.28 kN)) (OK)

8. Maximum Capacity of Design Concept No. 4

Combined Tensile and shear strength (LRFD) is given by:

$$\left(\frac{f_t}{\phi_{F_{nt}}}\right)^2 + \left(\frac{f_v}{\phi_{F_{nv}}}\right)^2 \leq 1 \quad \text{(B3.3, AISC [68])}$$

Where:

ϕ = LRFD strength reduction factor, ϕ = 0.75

f_{v} = Required shear stress, ksi (MPa)

f_{t} = Required tensile stress, ksi (MPa)

F_{nv} = Nominal shear stress, ksi (MPa)

F_{nt} = Nominal tensile stress, ksi (MPa)

$f_t = (T) /A_b + (T_a/4) /A_b$

T= (M /2.5 in.) /2 = (V1 * 1.75)/5 (2.5 in. = distance b/n bolts and V1 = 0.333 V_a = 0.333 $Fc_{apacity}$ *cos(27))

$T = (0.333\ F_{capacity} * \cos(27) * 1.75)/5 = 0.12\ F_{capacity}$

$T_a = F_{capacity} * \sin(27) = 0.45\ F_{capacity}$

$f_t = (0.104\ F_{capacity}) / (0.1503) + ((0.45\ F_{capacity} /4)/0.1503)$

$= 0.692\ F_{capacity} + 0.749\ F_{capacity}$

$= 1.441\ F_{capacity}$

$f_v = (V1/4)/A_b = (0.333\ V/4)/\ A_b = ((0.333 * F_{capacity} * \cos(27))/4)/\ 0.1503$

$f_v = 0.494\ F_{capacity}$

$\left(\frac{f_t}{\phi_{F_{nt}}}\right)^2 + \left(\frac{f_v}{\phi_{F_{nv}}}\right)^2 = 1$ (To find the maximum capacity of the anchorage system, the equation was set to be equal to unity)

$$\left(\frac{1.441\ \text{Fcapacity}}{67.5}\right)^2 + \left(\frac{0.494\ \text{Fcapacity}}{40.5}\right)^2 = 1$$

$0.00046\ (F_{capacity})^2 + 0.000148\ (F_{capacity})^2 = 1$

$F_{capacity} = 41$ kips (182.38 kN)

Appendix E. Steel-Post, Trailing-End Anchorage Design Concept No. 5 Calculations

Calculation: Design Concept No. 5

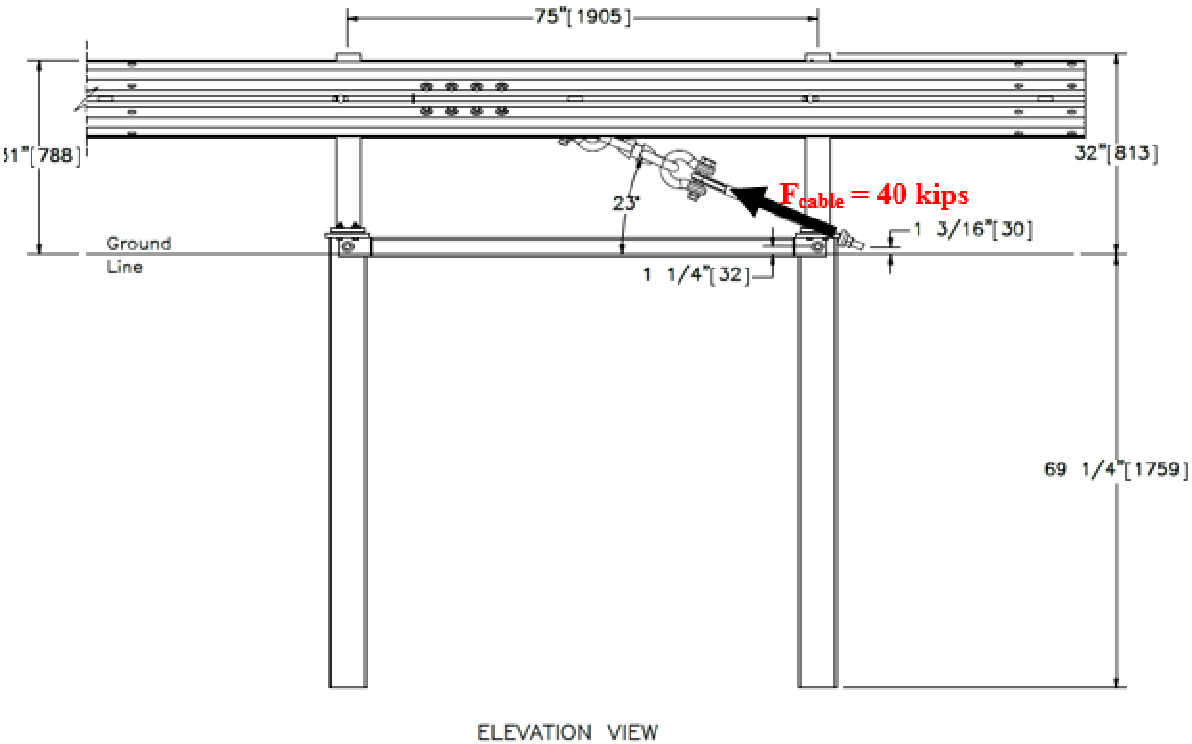


Figure E-1. Downstream Anchorage Modified Design Concept No. 3

1. Force Calculation

The maximum load sustained by the BCT steel post downstream anchorage system is F_{cable} = 40 kips (178 kN).

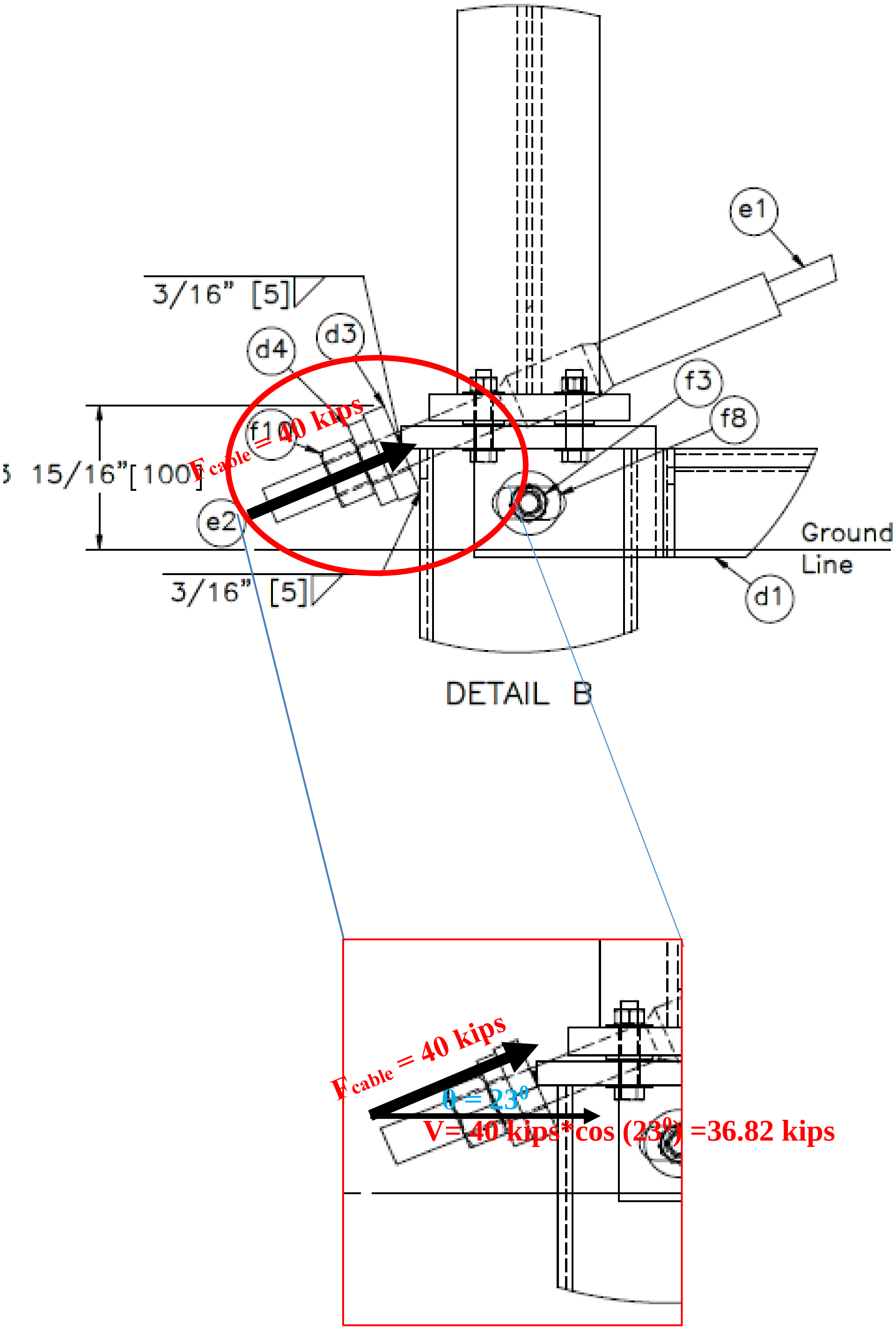
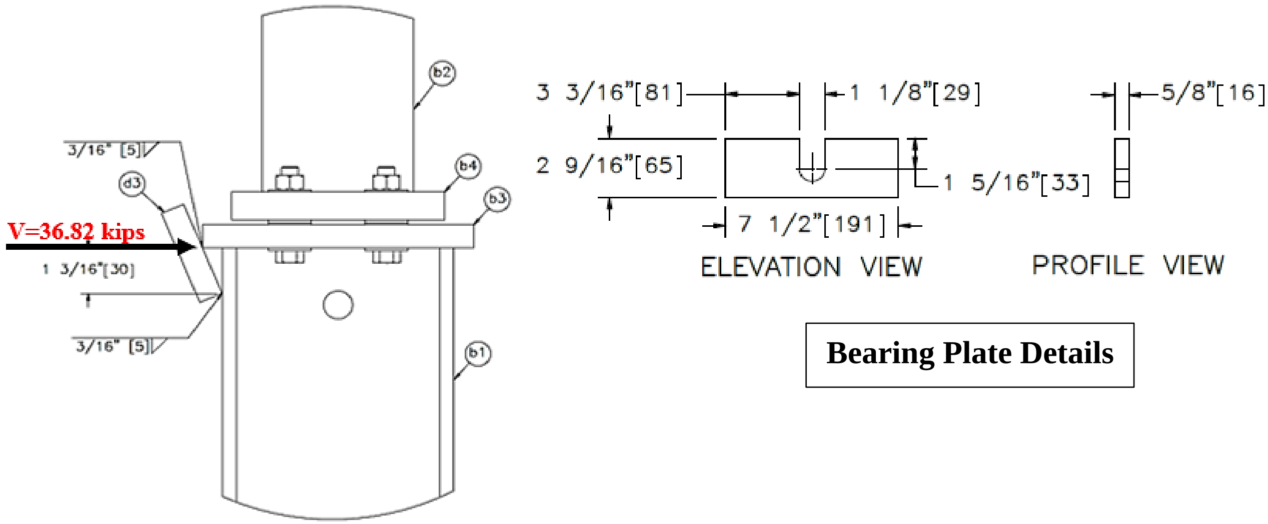


Figure E-2. Forces Acting on Modified Design Concept No. 3

2. Weld Capacity (Weld Around the Bearing Plate)



Weld capacity as per AISC section J2.5

Weld size (a) = 3/16 in. (5 mm)

Length of the weld (L_w) = 7.5 in. + 7.5 in. - 2.5 in. - 1.125 in. = 11.375 in. (299 mm)

Where:

7.5 in. is bottom length of the weld

7.5 in. - 2.5 in. - 1.125 in. is top length of the weld (where: 2.5 in. is length opening in the foundation tube base plate and 1.125 in. is the length of opening in the anchor bearing plate)

Shear strength of weld metal = ϕR_n

$R_n = F_{nw} A_{we}$

Where:

$F_{nw} = 0.60 F_{EXX}$ (F_{EXX} = Filler metal classification strength = 70 ksi (E70XX electrode for the fillet welds))

Shear strength of weld metal = $\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times a \times L_w$

Where:

0.707 a = Throat (the shear failure of the fillet weld occurs along a plane through the throat of the weld)

ϕ = LRFD strength reduction factor = 0.75

ϕR_n = 0.75 x 0.60 x 70 x 0.707 x 0.1875 x 11.375

ϕR_n = 47.5 kips (211.29 kN) > V = 36.82 kips (163.78 kN) OK

3. Weld Capacity (Bottom Base Plate)

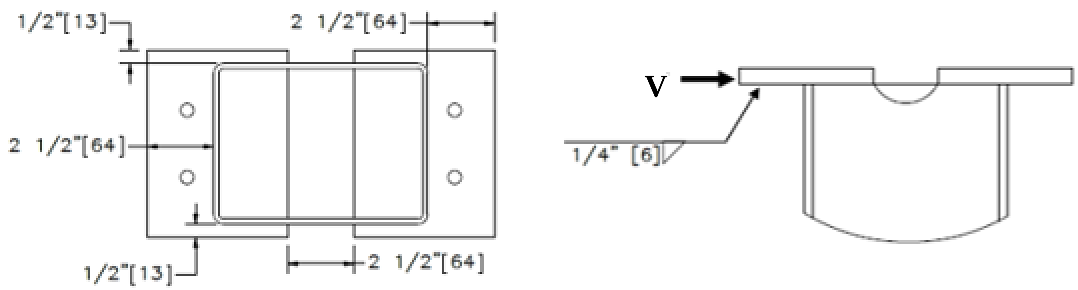


Figure E-3. Weld Details and Force Acting on Bottom Base Plate

<u>Weld capacity as per AISC Section J2.5</u>

Weld size (a) = ¼ in. (6 mm)

Length of the weld (L_w) = 2*8 in. + 2*6 in. - 2*2.5 in. = 23 in. (584 mm)

Shear strength of weld metal = ϕR_n

$R_n = F_{nw} A_{we}$

Where:

$F_{nw} = 0.60 F_{EXX}$ (F_{EXX} = Filler metal classification strength = 70 ksi (E70XX electrode for the fillet welds))

Shear strength of weld metal = $\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times a \times L_w$

Where:

0.707 a = Throat (the shear failure of the fillet weld occurs along a plane through the throat of the weld)

ϕ = LRFD strength reduction factor = 0.75

$\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times 0.25 \times L_w > V = 36.82$ kips (163.78 kN)

$L_w > 6.61$ in. (168 mm)

L_w (provided) = 23 in. (584 mm) > L_w = 6.61in. (168 mm) OK

Appendix F. T-Shaped, Breaker Bar Assembly Design Calculations

T-Shaped, Breaker Bar Design Calculation

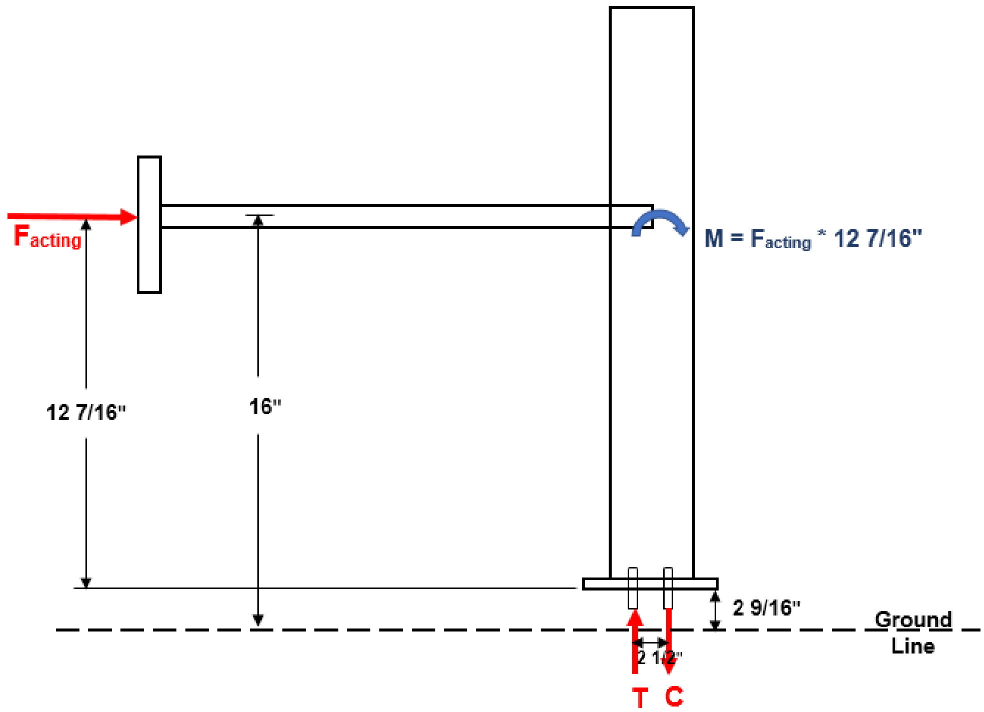


Figure F-1. T-Shaped, Breaker Bar Assembly

Where:
- T = Tension in bolts
- C = Compression in bolts
- 2½" = spacing between bolts

Note:
- Drawing is not to scale
- Drawing is based on design concept no. 2

1. Determine F_{acting}

a) Capacity of a single bolt in tension (ASTM A325 Bolt)

F_{nt} = 67.5 ksi (AISC Specification, Table J3.2)

b) Tensile force capacity of a single bolt ($^{7}/_{16}$ in. diameter bolt)

$F_{capacity} = F_{nt} * A_b$ $\quad A_b = \Pi/4*(^{7}/_{16} \text{ in.})^2 = 0.1503 \text{ in.}^2$

$= 67.5 \text{ ksi} * 0.1503 \text{ in.}^2$

$= 10.15 \text{ kips}$

c) Acting tensile force in a single bolt

$T = (M/ 2.5 \text{ in.})/2 \quad = (F_{acting} * 12.4375)/2 = 2.5\ F_{acting}$

Where:

M = acting moment = F_{acting} * 12.4375

2.5 in. = spacing between bolts

2 = number of bolts in tension

Thus, at failure (when bolts fracture):

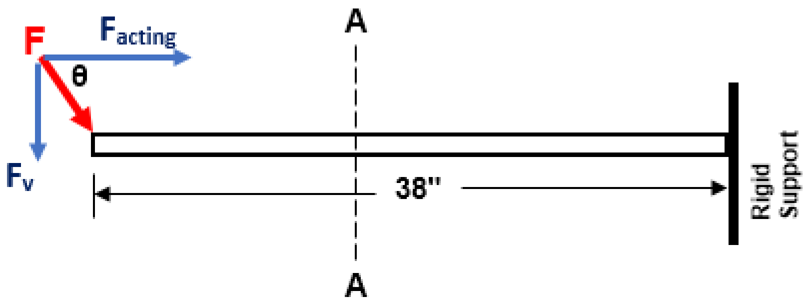
$T_{single\ bolt} = F_{capacity}$ (single bolt)

2.5 * F_{acting} = 10.15 kips

F_{acting} = 4.06 kips

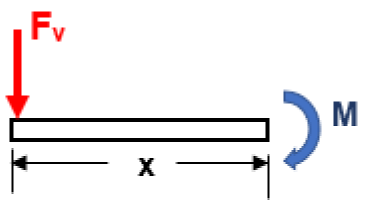
Beyond this load, the post will break away. This much load is needed to break away the anchor post; the post breaker should resist this force without bending, yielding, and buckling.

2. Bending (Flexural) capacity of T-shaped, breaker bar



- Assume a 25-degrees impact
- $F_{acting} = F_H$, (F_H is the force which fractures the bolt, F_H = 4.06 kips)
- Thus, for a 25-degrees impact, $F_v = 0.461\ F_H$

Sec A-A for $0 < x < l$, l = 38 in

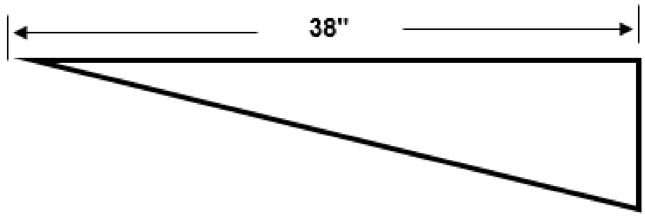


$M = F_v * x$, @ $x = 0$, $M = 0$ and @ $x = l$, $M = F_v*l$

$M = 0.461\ F_H * 38$ in.

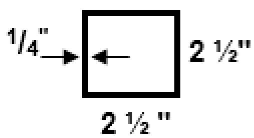
$= (0.461 * 4.06 * 38)$ kips-in.

$= 71.12$ kips-in.



Bending Moment Diagram

3. Design of Stiffeners (Steel Gussets)



Relevant Section Properties:

$I = 1.63$ in.^{4} $F_y = 50$ ksi

$r = 0.908$ in. $S = 1.30$ in.^{3}

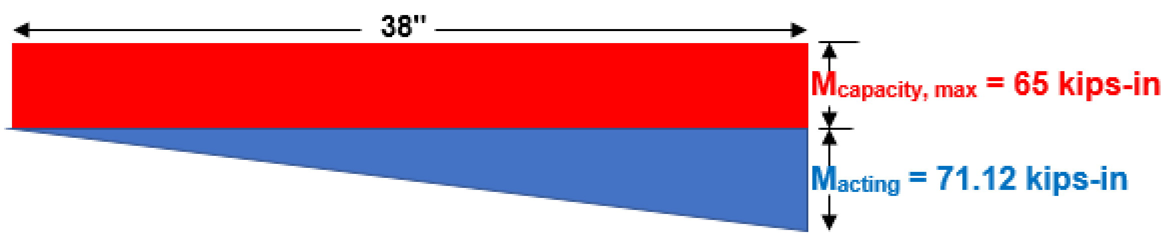
$A = 1.97$ in.^{2}

Maximum moment capacity, M_{max}

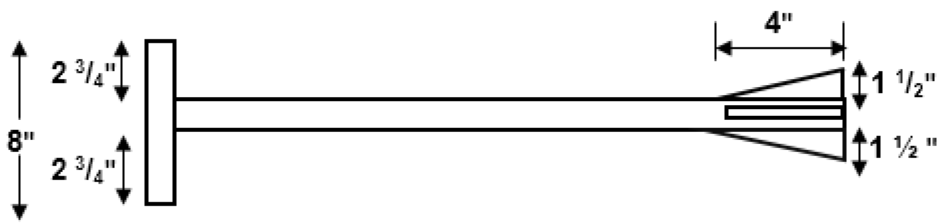
$M_{max} = F_y * S$

$= 50$ ksi $* 1.30$ in.^{3}

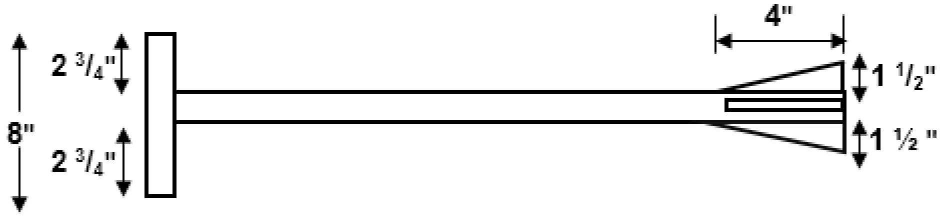
$= 65$ kips-in.



Thus, need to provide small stiffeners (steel gussets) to strengthen the post breaker.



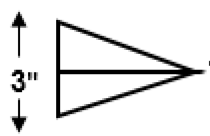
4. Check the section capacity of the recommended design



i. Steel tube:

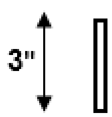
TS2 or HSS 2 $^{1}/_{2}$" x 2 $^{1}/_{2}$" x $^{1}/_{4}$" has a moment capacity of 65 kips-in.

ii. Gusset Plates:



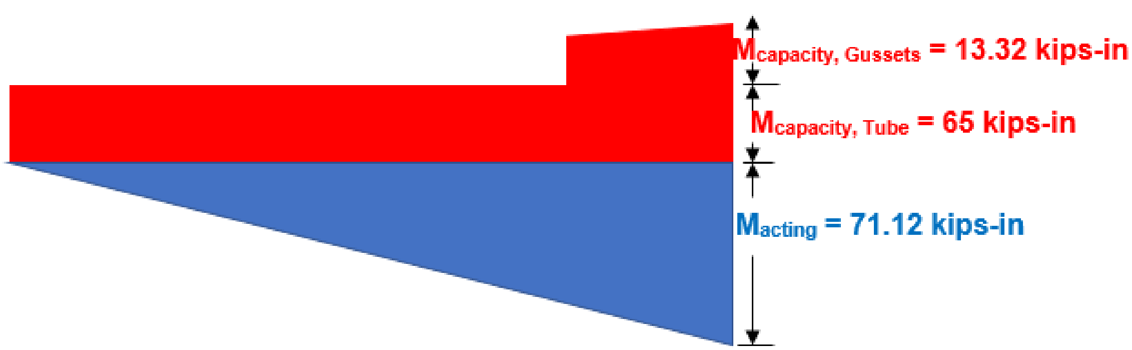
Thickness of steel gusset = ¼ in.

The moment of inertia of the section varies, thus, the inertias at intermediate locations were calculated



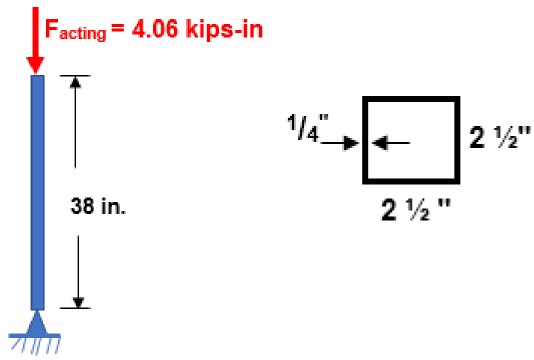
I = (¼ * 3^3)/12
I = 0.56 in.^{4}
S= 0.37 in.^{3}
M = Fy * S
= 13.32 kips-in.

iii. Overall Moment Capacity:



The overall moment capacity > Moment acting (**O.K)**

5. Buckling of T-shaped, breaker bar



Relevant Section Properties:

Nominal Weight = 7.11 lb/ft

$A = 1.97 \text{ in.}^2$

$I = 1.63 \text{ in.}^4$

$r = 0.908$ in.

$E = 29000$ ksi

ASTM A500 Grade B = $F_y = 50$ ksi

K = 2, Effective Length = 2*38 in = 76 in.

i. Buckling Strength

Critical load for buckling: $P_{cr} = \Pi^2 EI/(KL)^2$

$= (\Pi^2 * 29000 \text{ ksi} * 1.63 \text{ in.}^4)/(2*38 \text{ in.})^2$

$= 80.77$ kips

Buckling Strength of the member = 80 kips

ii. AISC Specification for compression member strength

The design strength of columns for flexural buckling limit state is $\Phi_c P_n$ [AISC Spec E2]

Where:

$\Phi_c = 0.85$

$P_n = A_g F_{cr}$

For $\lambda_c < 1.5$ $F_{cr} = (0.658^{\lambda_c ^2}) F_y$ (Inelastic Buckling Occurs)

For $\lambda_c > 1.5$ $F_{cr} = (0.877/ \lambda_c^2) F_y$ (Elastic Buckling Occurs)

$\lambda_c = (KL/r\pi) (F_y/E)^{1/2}$

Where:

A_g = Gross member area

L = Unbraced length of the member

K = Effective length factor

r = radius of gyration

$\lambda_c = ((2*38 \text{ in.})/(0.908*\Pi)) (50 \text{ ksi}/29000 \text{ ksi})^{1/2}$

$\lambda_c = 1.11 < 1.5$, thus

$Fcr = (0.658^{\lambda_c ^2}) F_y$

$= (0.658^{1.11^2}) * 50$ ksi

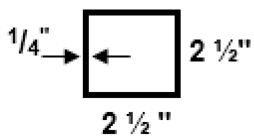
$= 29.85$ kips

Design strength of the member = $\Phi_c P_n = 0.85*(A_g F_{cr})$

$= 0.85 * 1.97 * 29.85$ kips

$= 50$ kips (Design strength) >> $F_{acting} = 4.06$ kips

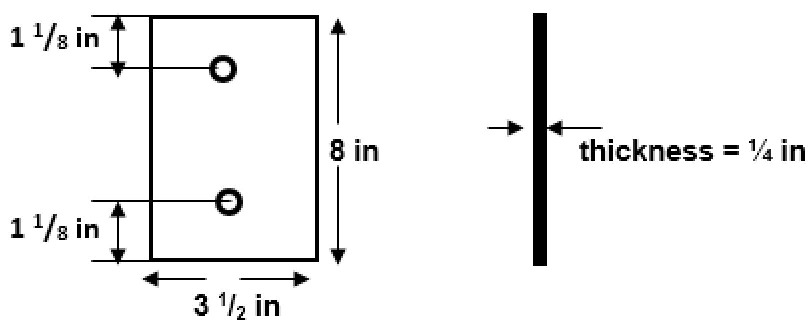
6. Axial Load Capacity



Relevant Section Properties:
Nominal Weight = 7.11 lb/ft
A = 1.97 in.^{2}
I =1.63 in.^{4}
r = 0.908 in.
E = 29000 ksi
ASTM A500 Grade B = F_y = 50 ksi
K = 2, Effective Length = 2*38 in. = 76 in.

$\sigma = F_{acting} / A$
$= 4.06 \text{ kips} / 1.97 \text{ in}^2$
$= 2.06$ ksi << Fy = 50 ksi

7. Design of Bearing Plate, Part C3



i. Minimum edge distance:

From Table J3.4 of the AISC manual, minimum edge distance = 0.75 in. for ½ in. diameter bolt.

AISC specification, section J3.3 states that the minimum distance (s) between the centers of bolt holes shall not be less than 2.67 db. However, a distance of 3db is preferred. (Where: d_b = nominal diameter of fastener)

Minimum spacing = 2.67 d_b = 2.67 x 0.4375 = 1.17 in.

Preferred spacing = 3.0 d_b = 3.0 x 0.4375 = 1.31 in.

Available spacing 5.75 in. > 1.31 in., therefore, spacing requirements are satisfied.

ii. Bearing strength at bolt holes:

AISC specification, section J3.10 states that the available bearing strength at bolt holes is φRn (φ= 0.75, LRFD), when deformation at the bolt holes is a design consideration:

$Rn = 1.2\ Lc\ t\ F_u \leq 2.4\ d_b\ t\ F_u$ (J3-6a)

Where:

F_u = Specified minimum tensile strength of the connected material (for ASTM A36, F_u = 58 ksi)

Lc = Clear distance, in the direction of the force, between the edge of the hole and the edge of the adjacent hole or edge of the material (in.)

t = Thickness of connected material (in)

L_c = 1.125 – hole diameter/2 = 1.125 – (1/2 + 1/16)/2 = 0.84 in.

$\varphi R_n = 0.75 \times (1.2\ L_c\ t\ F_u) = 0.75 \times (1.2 \times 0.84 \times 0.25 \times 58) = 10.96$ kips

Therefore, bearing strength at bolt holes = 2 x 10.96 = 21.92 kips > F_{acting} **(O.K)**

Appendix G. Material Specifications and Mill Certifications

Table G-1. Material Certifications, Test No. SPDA-1

Item No.	Description	Material Specification	Reference
a1	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS End Section	AASHTO M180	HT#8534 H#9411949
a2	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS Section	AASHTO M180	HT#8534 H#9411949
b1	TS6"x8"x3⁄16" [152x203x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	H#167622
b2	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 27¾" [705] Long Steel Post	ASTM A992	H#59064972
b3	13"x7"x⅝" [330x178x16] Steel Plate	ASTM A36	H#E6I159
b4	5½"x5½"x¾" [140x140x19] Steel Plate	ASTM A36	H#B6L752
b5	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 or ASTM A36 Min. 50 ksi [345 MPa]	H#55044251 Black Paint
b6	6"x12"x14¼" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	Invoice#43270 Charge#335
d1	Ground Strut Assembly	ASTM A36	R#090453-8
d2	Anchor Bracket Assembly	ASTM A36	Black H#V911470 AND H#4153095
d3	8"x7"x2⅛" [203x178x54] Bearing Plate	ASTM A36	⅝-in. plate: H#E6I159 1-in. plate: H#A7A884
d4	2⅜" [60] O.D. x 3 15⁄16" [100] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	H#C80017
e1	¾" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS	R#17-516 Orange
e2	BCT Anchor Cable End Swaged Fitting	Fitting - ASTM A576 Gr. 1035 Stud - ASTM F568 Class C	R#17-516 Orange
e3	115-HT Mechanical Splice - ¾" [19] Dia.	As Supplied	n/a
e4	Crosby Heavy Duty HT - ¾" [19] Dia. Cable Thimble	Stock No. 1037773	n/a
e5	Crosby G2130 or S2130 Bolt Type Shackle - 1¼" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3 or Similar	Stock Nos. 1019597 and 1019604 - As Supplied	n/a

Table G-2. Material Certifications, Test No. SPDA-1 (Cont.)

Item No.	Description	Material Specification	Reference
e6	Chicago Hardware Drop Forged Heavy Duty Eye Nut - Drilled and Tapped 1½" [38] Dia. - UNC 6 [M36x4]	Stock No. 107 - As Supplied	n/a
e7	1" [25] Dia. Eye Nut	As Supplied	n/a
e8	TLL-50K-PTB Load Cell	-	n/a
f1	⅝" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#16100453 L#28667-B Nut:H#20479830
f2	⅝" [16] Dia. UNC, 1¼" [32] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#20460760 Nut: H#20479830
f3	⅝" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: R#16-692 H#DL15107048 L#208977 Orange Paint Nut: P#36713 C#210101526
f4	⅝" [16] Dia. UNC, 1½" [38] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: R#16-0009 L#25203 H#10207560 Nut: R#16-0217 P#36713 C#210101526
f6	7⁄16" [11] Dia. UNC, 2¼ " [57] Long Heavy Hex Bolt and Nut	Bolt - ASTM F3125 Gr. A325 or ASTM A449 or SAI J429 Gr. 5 Nut - ASTM A563DH or ASTM A194 Gr. 2H	Bolt: L#3412980006 H#5210760BA Nut: C#210110353 L#1N1640850
f7	1" [25] Dia. Plain Round Washer	ASTM F844	n/a
f8	⅝" [16] Dia. Plain Round Washer	ASTM F844	n/a
f9	7⁄16" [11] Dia. Plain Round Washer	ASTM F844	Grainger COC L#2015043021
f10	1" [25] Dia. Hex Nut	ASTM A563A	H#DL15103032 L#366055B
f11	16D Double Head Nail	-	n/a
g1	Portable Concrete Barrier	Min f'c=5,000 psi [34.5 MPa]	n/a
g2	Concrete Block - MN Noise Wall	-	n/a

Table G-3. Material Certifications, Test No. SPDA-2

Item No.	Description	Material Specification	Reference
a1	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS End Section	AASHTO M180	HT#8534 H#9411949
a2	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS Section	AASHTO M180	HT#8534 H#9411949
b1	TS6"x8"x3⁄16" [152x203x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	H#167622
b2	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 27¾" [705] Long Steel Post	ASTM A992	H#59064972
b3	7"x5¼"x⅝" [178x133x16] Steel Plate	ASTM A36	H#E6I159
b4	5½"x5½"x¾" [140x140x19] Steel Plate	ASTM A36	H#B6L752
b5	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 or ASTM A36 Min. 50 ksi [345 MPa]	H#55044251 Black Paint
b6	6"x12"x14¼" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	R#17-282 Light Blue
d1	Modified Ground Strut Assembly	ASTM A36	R#17-515
d2	Anchor Bracket Assembly	ASTM A36	H#4153095 AND Black H#V911470
d3	7½"x4"x1⅛" [191x102x29] Bearing Plate	ASTM A36	⅝-in. plate: H#E6I159
d4	7¼"x1¾"x½" [184x44x13] Steel Plate	ASTM A36	H#B702405
d5	2½"x½"x½" [64x13x13] Square Bar	ASTM A36	H#54153457/02
e1	¾" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS	R#17-516 Orange
e2	BCT Anchor Cable End Swaged Fitting	Fitting - ASTM A576 Gr. 1035 Stud - ASTM F568 Class C	R#17-516 Orange
e3	115-HT Mechanical Splice - ¾" [19] Dia.	As Supplied	n/a
e4	Crosby Heavy Duty HT - ¾" [19] Dia. Cable Thimble	Stock No. 1037773	n/a
e5	Crosby G2130 or S2130 Bolt Type Shackle - 1¼" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3 or Similar	Stock Nos. 1019597 and 1019604 - As Supplied	n/a

Table G-4. Material Certifications, Test No. SPDA-2 (Cont.)

Item No.	Description	Material Specification	Reference
e6	Chicago Hardware Drop Forged Heavy Duty Eye Nut - Drilled and Tapped 1½" [38] Dia. - UNC 6 [M36x4]	Stock No. 107 - As Supplied	n/a
e7	1" [25] Dia. Eye Nut	As Supplied	n/a
e8	TLL-50K-PTB Load Cell	-	n/a
f1	⅝" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#16100453 L#28667-B Nut:
f2	⅝" [16] Dia. UNC, 1¼" [32] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#20460760 Nut: H#20479830
f3	⅝" [16] Dia. UNC, 10" [254] Long Hex Head Bolt	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#DL15107048 L#208977 Orange Paint Nut: P#36713 C#210101526
f4	⅝" [16] Dia. UNC, 1½" [38] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: L#25203 H#10207560 Nut: P#36713 C#210101526
f6	7⁄16" [11] Dia. UNC, 2¼" [57] Long Heavy Hex Bolt and Nut	Bolt - ASTM F3125 Gr. A325 or ASTM A449 or SAI J429 Gr. 5 Nut - ASTM A563DH or ASTM A194 Gr. 2H	Bolt: L#3412980006 H#5210760BA Nut: C#210110353 L#1N1640850
f7	1" [25] Dia. Plain Round Washer	ASTM F844	n/a
f8	⅞" [16] Dia. Plain Round Washer	ASTM F844	n/a
f9	7⁄16" [11] Dia. Plain Round Washer	ASTM F844	Grainger COC L#2015043021
f10	1" [25] Dia. Hex Nut	ASTM A563A	H#DL15103032 L#366055B
f11	16D Double Head Nail	-	n/a
g1	Portable Concrete Barrier	Min f'c=5,000 psi [34.5 MPa]	n/a
g2	Concrete Block - MN Noise Wall	-	n/a

Table G-5. Material Certifications, Test No. SPDA-3

Item No.	Description	Material Specification	Reference
a1	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS End Section	AASHTO M180	HT#8534 H#9411949
a2	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS Section	AASHTO M180	HT#8534 H#9411949
b1	TS6"x8"x3⁄16" [152x203x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	H#167622
b2	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 27¾" [705] Long Steel Post	ASTM A992	H#59064972
b3	7"x5¼"x⅝" [178x133x16] Steel Plate	ASTM A36	H#E6I159
b4	5½"x5½"x¾" [140x140x19] Steel Plate	ASTM A36	H#B6L752
b5	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 or ASTM A36 Min. 50 ksi [345 MPa]	H#55044251 Black Paint
b6	6"x12"x14¼" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	Invoice#43270 Charge#335
d1	Ground Strut Assembly	ASTM A36	Green Paint R#15-0157 H#163375
d2	Anchor Bracket Assembly	ASTM A36	Black H#V911470
d3	7½"x3¾"x⅝" [191x95x16] Bearing Plate	ASTM A36	H#E6I159
d4	2⅜"x17⁄16"x⅝" [60x37x16] Gusset Plate	ASTM A36	H#E6I159
d5	3"x2⅜"x½" [76x60x13] Plate Washer	ASTM A36	H#64047117
e1	¾" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS	R#17-516 Orange
e2	BCT Anchor Cable End Swaged Fitting	Fitting - ASTM A576 Gr.1035 Stud - ASTM F568 Class C	R#17-516 Orange
e3	115-HT Mechanical Splice - ¾" [19] Dia.	As Supplied	n/a
e4	Crosby Heavy Duty HT - ¾" [19] Dia. Cable Thimble	Stock No. 1037773	n/a
e5	Crosby G2130 or S2130 Bolt Type Shackle – 1¼" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3 or Similar	Stock Nos. 1019597 and 1019604 - As Supplied	n/a

Table G-6. Material Certifications, Test No. SPDA-3 (Cont.)

Item No.	Description	Material Specification	Reference
e6	Chicago Hardware Drop Forged Heavy Duty Eye Nut - Drilled and Tapped 1½" [38] Dia. - UNC 6 [M36x4]	Stock No. 107 - As Supplied	n/a
e7	1" [25] Dia. Eye Nut	As Supplied	n/a
e8	TLL-50K-PTB Load Cell	-	n/a
f1	⅝" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#16100453 L#28667-B Nut:
f2	⅝" [16] Dia. UNC, 1¼" [32] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: R#17-000 H#20460760 Nut: H#20479830
f3	⅝" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#DL15107048 L#208977 Orange Paint Nut: P#36713 C#210101526
\f4	⅝" [16] Dia. UNC, 1½" [38] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: R#16-0009 L#25203 H#10207560 Nut: R#16-0217 P#36713 C#210101526
f6	7⁄16" [11] Dia. UNC, 2¼" [57] Long Heavy Hex Bolt and Nut	Bolt - ASTM F3125 Gr. A325 or ASTM A449 or SAI J429 Gr. 5 Nut - ASTM A563DH or ASTM A194 Gr. 2H	Bolt: L#3412980006 H#5210760BA Nut: C#210110353 L#1N1640850
f7	1" [25] Dia. Plain Round Washer	ASTM F844	n/a
f8	⅝" [16] Dia. Plain Round Washer	ASTM F844	n/a
f9	7⁄16" [11] Dia. Plain Round Washer	ASTM F844	Grainger COC L#2015043021
f10	1" [25] Dia. Hex Nut	ASTM A563A	H#DL15103032 L#366055B
f11	16D Double Head Nail	-	n/a
g1	Portable Concrete Barrier	Min f'c=5,000 psi [34.5 MPa]	n/a
g2	Concrete Block - MN Noise Wall	-	n/a

Table G-7. Material Certifications, Test No. SPDA-4

Item No.	Description	Material Specification	Reference
a1	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS End Section	AASHTO M180	HT#8534 H#9411949
a2	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS Section	AASHTO M180	HT#8534 H#9411949
b1	TS6"x8"x3⁄16" [152x203x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	H#C72251
b2	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 27¾" [705] Long Steel Post	ASTM A992	H#59064972
b3	13"x7"x⅝" [330x178x16] Steel Plate	ASTM A36	H#E6I159
b4	5½"x5½"x¾" [140x140x19] Steel Plate	ASTM A36	H#B7E531
b5	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa]	H#2413988
b6	6"x12"x14¼" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	R#16-692 Black Paint C#21327
d1	Ground Strut Assembly	ASTM A36	R#090453-8
d2	Anchor Bracket Assembly	ASTM A36	R#17-282 H#JK16101488
d3	8"x6¼"x2⅛" [203x159x54] Bearing Plate	ASTM A36	1-in. plate: H#A7A884/A7B2038 ⅝-in. plate: H#E6I159
d4	2⅜" [60] O.D. x 315⁄16" [100] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	H#C80017
e1	¾" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS	R#17-700 Yellow Paint
e2	BCT Anchor Cable End Swaged Fitting	Fitting - ASTM A576 Gr. 1035 Stud - ASTM F568 Class C	R#17-700 Yellow Paint
e3	115-HT Mechanical Splice - ¾" [19] Dia.	As Supplied	n/a
e4	Crosby Heavy Duty HT - ¾" [19] Dia. Cable Thimble	Stock No. 1037773	n/a
e5	Crosby G2130 or S2130 Bolt Type Shackle - 1¼" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3 or Similar	Stock Nos. 1019597 and 1019604 - As Supplied	n/a

Table G-8. Material Certifications, Test No. SPDA-4 (Cont.)

Item No.	Description	Material Specification	Reference
e6	Chicago Hardware Drop Forged Heavy Duty Eye Nut - Drilled and Tapped 1½" [38] Dia. - UNC 6 [M36x4]	Stock No. 107 - As Supplied	n/a
e7	1" [25] Dia. Eye Nut	As Supplied	n/a
e8	TLL-50K-PTB Load Cell	-	n/a
f1	⅝" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#16100453 L#28667-B Nut:
f2	⅝" [16] Dia. UNC, 1¼" [32] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#20460760 Nut: H#20479830
f3	⅝" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#DL15107048 L#208977 Nut: R#16-0217 P#36713 C#210101526
f4	⅝" [16] Dia. UNC, 1½" [38] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#816070039 Nut: P#36713 C#210101526
f6	7⁄16" [11] Dia. UNC, 2¼" [57] Long Heavy Hex Bolt and Nut	Bolt - ASTM F3125 Gr. 120 (A325) or A354 Gr. BC Nut - ASTM A563DH or A194 Gr. 2H	Bolt: H#J631004272 Nut: H#168D0400
f7	1" [25] Dia. Plain Round Washer	ASTM F844	P#33188 L#16H-168236-30
f8	⅝" [16] Dia. Plain Round Washer	ASTM F844	n/a
f9	7⁄16" [11] Dia. Plain Round Washer	ASTM F844	H#LU683
f10	1" [25] Dia. Hex Nut	ASTM A563A	BCT Cable Nuts H#DL15105591
f11	16D Double Head Nail	-	COC PO#E000357170
g1	Portable Concrete Barrier	Min f'c=5,000 psi [34.5 MPa]	n/a
g2	Concrete Block - MN Noise Wall	-	n/a

Table G-9. Material Certifications, Test No. SPDA-5

Item No.	Description	Material Spec	Reference
a1	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS End Section	AASHTO M180	HT#8534 H#9411949
a2	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS Section	AASHTO M180	HT#8534 H#9411949
b1	TS6"x8"x3⁄16" [152x203x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	H#C72251
b2	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 27¾" [705] Long Steel Post	ASTM A992	H#59064972
b3	7"x5¼"x⅝" [178x133x16] Steel Plate	ASTM A36	H#E6I159
b4	5½"x5¼"x¾" [140x133x19] Steel Plate	ASTM A36	H#B7E531
b5	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa]	H#2413988
b6	6"x12"x14¼" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	Black Paint R#16-692 C#21327
d1	Ground Strut Assembly	ASTM A36	R#090453-08
d2	Anchor Bracket Assembly	ASTM A36	R#17-282 H#JK16101488
d3	7½"x29⁄16"x⅝" [191x65x16] Bearing Plate	ASTM A36	H#E6I159
d4	3"x2⅜"x ½" [76x60x13] Plate Washer	ASTM A36	H#64047117
d5	3⁄16" [5] Dia. Brass Rod, 6⅞" [175] Long, Unbent	ASTM B16-00	H#05543-2
e1	¾" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS	PO: 2441 O:1145215
e2	BCT Anchor Cable End Swaged Fitting	Fitting - ASTM A576 Gr. 1035 Stud - ASTM F568 Class C	PO: 2441 O:1145215
e3	115-HT Mechanical Splice - ¾" [19] Dia.	As Supplied	n/a
e4	Crosby Heavy Duty HT - ¾" [19] Dia. Cable Thimble	Stock No. 1037773	n/a
e5	Crosby G2130 or S2130 Bolt Type Shackle - 1¼" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3 or Similar	Stock Nos. 1019597 and 1019604 - As Supplied	n/a

Table G-10. Material Certifications, Test No. SPDA-5 (Cont.)

Item No.	Description	Material Spec	Reference
e6	Chicago Hardware Drop Forged Heavy Duty Eye Nut - Drilled and Tapped 1½" [38] Dia. - UNC 6 [M36x4]	Stock No. 107 - As Supplied	n/a
e7	1" [25] Dia. Eye Nut	As Supplied	n/a
e8	TLL-50K-PTB Load Cell	-	n/a
f1	⅝" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#16100453 L#28667-B Nut:
f2	⅝" [16] Dia. UNC, 1¼" [32] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#20460760 Nut: H#20479830
f3	⅝" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#DL15107048 L#208977 Orange Paint Nut: P#36713 C#210101526
f4	⅝" [16] Dia. UNC, 1½" [38] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#816070039 Nut: P#36713 C#210101526
f6	7⁄16" [11] Dia. UNC, 2¼" [57] Long Heavy Hex Bolt and Nut	Bolt - ASTM F3125 Gr. 120 (A325) or A354 Gr. BC Nut - ASTM A563DH or A194 Gr. 2H	Bolt: H#J631004272 Nut: H#168D0400
f7	1" [25] Dia. Plain Round Washer	ASTM F844	n/a
f8	⅝" [16] Dia. Plain Round Washer	ASTM F844	n/a
f9	7⁄16" [11] Dia. Plain Round Washer	ASTM F844	H#LU683
f10	1" [25] Dia. Hex Nut	ASTM A563A	H#DL15103032 L#366055B
f11	16D Double Head Nail	-	COC PO#E000357170
g1	Portable Concrete Barrier	Min f'c=5,000 psi [34.5 MPa]	n/a
g2	Concrete Block - MN Noise Wall	-	n/a

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer: UNIVERSITY OF NEBRASKA-LINCOLN
401 CANFIELD ADMIN BLDG
P O BOX 880439
LINCOLN,NE,68588-0439

Test Report
Ship Date: 7/9/2015
Customer P.O.: 4500274709/ 07/07/2015
Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
Project: TESTING COIL
GHP Order No.: 183306

HT # code	Heat #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	10	A	2	12GA 25FT WB T2 MGS ANCHOR PANEL
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	100	A	2	12GA 12FT6IN/3FT1 1/2IN WB T2
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	20	A	2	12GA 25FT0IN 3FT1 1/2IN WB T2

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: ______________________
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 17 day of July, 2015
Notary Public, State of Ohio

NOTARIAL SEAL
STATE OF OHIO

DAWN R. BATTON
NOTARY PUBLIC
STATE OF OHIO
Comm. Expires
March 03, 2018
Recorded in
Portage County

Figure G-1. 12-ft 6-in. (3,810-mm) 12-gauge (2.7-mm) W-Beam MGS End Section, Test Nos. SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item Nos. a1 and a2)

Atlas Tube Corp (Chicago)
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

Atlas Tube
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80745585
Date: 12.27.2016
Customer: 179

MATERIAL TEST REPORT

Sold to
Steel & Pipe Supply Company
PO Box 1688
MANHATTAN KS 66505
USA

Steel Post Downstream Anchorage
R#17-518 H#167622
8x6 Steel Tube
March 2017 SMT

Shipped to
Steel & Pipe Supply Company
310 Smith Road
JONESBURG MO 63351
USA

Material: 5.0x5.0x250x24'0"0(4x4). Material No: 500502502400 Made in: USA Melted in: Canada
Sales order: 1144226 Purchase Order: 4500278309 Cust Material #: 6550025024

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
3539C4	0.200	0.770	0.010	0.004	0.030	0.035	0.020	0.000	0.000	0.010	0.030	0.000	0.001	0.000	0.000

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M800672698	16	059250 Psi	073827 Psi	29 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 8.0x6.0x188x40'0"0(2x3). Material No: 800601884000 Made in: USA Melted in: USA
Sales order: 1144578 Purchase Order: 4500278335 Cust Material #: 6680060018840

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
167623	0.190	0.840	0.010	0.001	0.024	0.033	0.078	0.000	0.013	0.040	0.075	0.001	0.003	0.000	0.009

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.36
M800670389	6	060259 Psi	076210 Psi	29 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 8.0x6.0x188x40'0"0(2x3). Material No: 800601884000 Made in: USA Melted in: USA
Sales order: 1144578 Purchase Order: 4500278335 Cust Material #: 6680060018840

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
167622	0.190	0.840	0.011	0.002	0.020	0.025	0.078	0.000	0.015	0.037	0.071	0.001	0.002	0.000	0.007

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.36
M800670386	6	059855 Psi	075450 Psi	29 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Authorized by Quality Assurance: Jason Richard
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
Calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

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Metals Service Center Institute

Figure G-2. TS 6-in. x 8-in. x $^{3}/_{16}$-in. (152-mm x 203-mm x 5-mm), 72-in. (1,829-mm) Long Foundation Tube, Test Nos. SPDA-1, SPDA-2, and SPDA-3 (Item No. b1)

Atlas ABC Corp (Atlas Tube Chicago)
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

Atlas Tube JMC STEEL GROUP

Ref.B/L: 80661791
Date: 04.22.2015
Customer: 179

MATERIAL TEST REPORT

Sold to

Steel & Pipe Supply Compan
PO Box 1688
MANHATTAN KS 66505
USA

Shipped to

Steel & Pipe Supply Compan
1020 West Fort Gibson
CATOOSA OK 74015
USA

Material: 8.0x2.0x188x40'0"0(2x7). Material No: 800201884000 Made in: USA Melted in: USA

Sales order: 996432 Purchase Order: C450004977 Cust Material #: 6680020018840

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
A73508	0.210	0.470	0.009	0.003	0.030	0.037	0.130	0.000	0.010	0.050	0.050	0.001	0.002	0.000	0.008

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.32
M800547918	14	059070 Psi	073606 Psi	28 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 8.0x6.0x188x40'0"0(2x3). Material No: 800601884000 Made in: USA Melted in: USA

Sales order: 996433 Purchase Order: C450004977 Cust Material #: 6680060018840

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
C72251	0.200	0.460	0.010	0.006	0.020	0.035	0.180	0.000	0.020	0.060	0.050	0.001	0.001	0.000	0.009

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.31
M800550505	6	060426 Psi	073432 Psi	30 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

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

Steel Tube Institute OF NORTH AMERICA

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Metals Service Center Institute

Figure G-3. TS 6-in. x 8-in. x $^{3}/_{16}$-in. (152-mm x 203-mm x 5-mm), 72-in. (1,829-mm) Long Foundation Tube, Test Nos. SPDA-4 and SPDA-5 (Item No. b1)

CERTIFIED MATERIAL TEST REPORT Page 1/1

GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
STEEL & PIPE SUPPLY CO INC 1003 FORT GIBSON RD CATOOSA,OK 74015-3033 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	A992/A572-50	Wide Flange Beam / 6 X 9# / 150 X 13.5

LENGTH	WEIGHT	HEAT / BATCH
40'00"	8,640 LB	59064972/02

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
1965914/000020	000000000037690040	ASTM A6-13A ASTM A709-13A ASTM A992-11, A572-13A CSA G40.21-13 345WM

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
G450016489	1327-0000147652	03/12/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.09	0.88	0.015	0.019	0.23	0.26	0.09	0.14	0.023	0.006	0.002	0.013	0.003

CHEMICAL COMPOSITION

CEqyA6 %
0.29

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	Y/T rati %	G/L Inch
59392	75073	410	518	0.791	8.000
59088	74547	407	514	0.793	8.000

MECHANICAL PROPERTIES

G/L mm	Elong. %
200.0	24.40
200.0	24.00

COMMENTS / NOTES

Steel Post Downstream Anchorage
R#17-518 H#59064972
w6x9 Steel Posts
March 2017 SMT

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

TOM HARRINGTON
QUALITY ASSURANCE MGR.

Figure G-4. W6x8.5 (W152x12.6) or W6x9 (W152x13.4), 27¾-in. (705-mm) Long Steel Posts, Test Nos. SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item No. b2)

SSAB

12400 Highway 43 North, Axis, Alabama 36505, US

Test Certificate

Form TC1: Revision 2: Date 23 Apr 2014

Customer: STEEL & PIPE SUPPLY P.O. BOX 1688 MANHATTAN KS 66502	Customer P.O. No.: 4500272903	Mill Order No.: 41-478949-02	Shipping Manifest: AT232187
	Product Description: ASTM A36(14)/A709(16A)36/ASME SA36(15) AASHTO M270(15)36	Ship Date: 23 Sep 16 Cert Date: 23 Sep 16	Cert No: 081577993 (Page 1 of 1)
	Size: 0.625 X 72.00 X 240.0 (IN)		

Heat Id	Piece Id	Tested Thickness	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in	Elong % 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1	2	3	Avg	% Shear 1	2	3	Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp	%Shr
E6I159	D51	0.439 (DISCRT)	L	51	71			24	T														
E6I159	D54	0.756 (DISCRT)	L	45	67			26	T														

Chemical Analysis

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	B	N	ORGN
E6I159	.19	.53	.011	.001	.17	.024	.27	.16	.20	.05	.002	.004	.013	.0001	.0076	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA.
PRODUCTS SHIPPED:
- E6I159 D53 PCES: 8, LBS: 24504

Steel Post Downstream Anchorage
R#17-518 H#E6I159
5/8" Steel Plate
March 2017 SMT

(U) Cust Part # : 722072240

WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION

Justin Ward
SENIOR METALLURGIST - PRODUCT

Figure G-5. ⅝-in. (16-mm) Steel Plate, Test Nos. SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item Nos. b3 and d3); Test No. SPDA-3 (Item No. d4)

SSAB

1770 Bill Sharp Boulevard, Muscatine, IA 52761-9412, US

Test Certificate

Form TC1: Revision 2: Date 23 Apr 2014

Customer: STEEL & PIPE SUPPLY P.O. BOX 1688 MANHATTAN KS 66502	Customer P.O. No.: 4500276929	Mill Order No.: 41-486269-04	Shipping Manifest: MT304685
	Product Description: ASTM A36(14)/A709(16A)36/ASME SA36(15) AASHTO M270(15)36	Ship Date: 05 Jan 17 Cert Date: 05 Jan 17	Cert No: 061619358 (Page 1 of 1)
	Size: 0.750 X 72.00 X 240.0 (IN)		

Tested Pieces				Tensiles							Charpy Impact Tests											
Heat Id	Piece Id	Tested Thickness	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in	Elong % 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1	2	3	Avg	% Shear 1	2	3	Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp %Shr
B6L752	B30	0.747 (DISCRT)	L	47	71		32		T													

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	B	N	ORGN
B6L752	.15	.84	.012	.004	.17	.031	.29	.14	.13	.04	.002	.005	.001	.0001	.0090	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA.
PRODUCTS SHIPPED:
B6L752 B30 PCES: 6, LBS: 22050

Steel Post Downstream Anchorage
R#17-518 3/4" Plate
March 2017 SMT

(U) Cust Part # : 722472240

WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION

Brian Wales
SENIOR METALLURGIST - PRODUCT

Figure G-6. 5½-in. x 5½-in. x ¾-in. (140-mm x 140-mm x 19-mm) Steel Plate, Test Nos. SPDA-1, SPDA-2, and SPDA-3 (Item No. b4)

JUNE, 17

SSAB

Preliminary Test Certificate

Form TC1: Revision 2: Date 23 Apr 2014

1770 Bill Sharp Boulevard, Muscatine, IA 52761-9412, US **Official copy to follow**

Customer:	Customer P.O. No.: 4500284612	Mill Order No.: 41-502910-01	Shipping Manifest: MT315225
STEEL & PIPE SUPPLY P.O. BOX 1688 MANHATTAN KS 66502	Product Description: ASTM A36(14)/A709(16A)36/ASME SA36(15) AASHTO M270(15)36 Size: 0.750 X 72.00 X 240.0 (IN)	Ship Date: 09 May 17 Cert Date: 09 May 17	Cert No: 061642676 (Page 1 of 1)

Tested Pieces			Tensiles								Charpy Impact Tests													
Heat Id	Piece Id	Tested Thickness	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in	Elong % 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1	2	3	Avg	% Shear 1	2	3	Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp	%Shr
A7E055	A42	0.371 (DISCRT)	L	53	74		39		T														
A7E055	A46	1.179 (DISCRT)	L	48	70			21	T														
B7E531	A40	0.748 (DISCRT)	L	47	69		35		T														

Chemical Analysis

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	B	N	ORGN
A7E055	.18	1.15	.011	.002	.08	.035	.29	.15	.10	.03	.001	.006	.021	.0003	.0093	USA
B7E531	.18	.53	.013	.004	.06	.032	.41	.21	.21	.05	.001	.006	.006	.0002	.0098	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA.
PRODUCTS SHIPPED:
B7E531 A40 PCES: 3, LBS: 11025 A7E055 A47 PCES: 8, LBS: 29400

Cust Part # : 722472240

WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION

SENIOR METALLURGIST - PRODUCT

Figure G-7. ¾-in. (19-mm) Steel Plate, Test Nos. SPDA-4 and SPDA-5 (Item No. b4)

GERDAU

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
HIGHWAY SAFETY CORP 473 W FAIRGROUND ST MARION,OH 43302-1701 USA	HIGHWAY SAFETY CORP GLASTONBURY,CT 06033-0358 USA	A992/A709-36	Wide Flange Beam / 6 X 8.5# / 150 X 13.0	0000006197
		LENGTH: 42'00"	WEIGHT: 44,982 LB	HEAT / BATCH: 55044251/02

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
3390484/000010	IB-B0600800	ASTM A6-14 ASTM A709-13A ASTM A992-11 CSA G40.21-13 345WM

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
000167 PO#1677008	1323-0000066391	03/16/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %
0.14	0.90	0.014	0.019	0.19	0.28	0.08	0.09	0.023	0.012	0.017	0.000

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	G/L Inch	Elong. %
56700	77700	391	536	8.000	21.30
54800	75700	378	522	8.000	22.60

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure G-8. W6x8.5 (W152x12.6) or W6x9 (W152x13.4), 72-in. Long (1,829-mm) Steel Posts, Test Nos. SPDA-1, SPDA-2, and SPDA-3 (Item No. b5)

NUCOR STEEL BERKELEY
P.O. Box 2259
Mt. Pleasant, S.C. 29464
Phone: (843) 336-6000

CERTIFIED MILL TEST REPORT

12/22/14 18:46:36
100% MELTED AND MANUFACTURED IN THE USA
All beams produced by Nucor-Berkeley are cast and rolled to a fully killed and fine grain practice.
Mercury has not been used in the direct manufacturing of this material.

Sold To: HIGHWAY SAFETY CORP
PO BOX 358
GLASTONBURY, CT 06033

Ship To: HIGHWAY SAFETY CORP
473 WEST FAIRGROUND STREET
MARION, OH 43301

Customer #.: 352 - 3
Customer PO: 1627044
B.O.L. #...: 1110076
MOS: I

SPECIFICATIONS: Tested in accordance with ASTM specification A6/A6M-14 and A370. Quality Manual Rev #27.
ASTM : A572 5013a;A529-14-50 IB-B0600800

Description	Heat# Grade(s) Test/Heat JW	Yield/ Tensile Ratio	Yield (PSI) (MPa)	Tensile (PSI) (MPa)	Elong %	C Cr ******	Mn Mo Ti	P Sn ******	S B ******	Si V N	Cu Nb ******	Ni ****** CI	CE1 CE2 Pcm
W6X8.5 042' 00.00" W150X12.6 012.8016m	2413985 A572 5013a A992-11 ANS	.83 .82	57200 394 56400 389	69300 478 69100 476	25.54 26.69 90 Pc(s)	.07 .06 32,130 lbs	.84 .01 .001	.013 .0091	.039 .0005	.21 .005 .0051	.20 .015	.05 4.59 Inv#:	.25 .2835 .1404 0
W6X8.5 042' 00.00" W150X12.6 012.8016m	2413988 A572 5013a A992-11 ANS	.83 .82	58300 402 57200 394	70600 487 69600 481	26.70 28.55 36 Pc(s)	.07 .06 12,852 lbs	.86 .01 .001	.014 .0091	.034 .0005	.17 .004 .0051	.23 .015	.06 4.87 Inv#:	.25 .2773 .1356 0

2 Heat(s) for this MTR.

R#15-0515 H#2413988

W6x8.5x6'

April 2015 SMT

Elongation based on 8' (20.32cm) gauge length. 'No Weld Repair' was peformed.
CI = 26.01Cu+3.88Ni+1.20Cr+1.49Si+17.28P (7.29Cu*Ni) (9.10Ni*P) 33.39(Cu*Cu)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B
CE1 = C+(Mn/6)+((Cr+Mo+V)/5)+((Ni+Cu)/15)
CE2 = C+((Mn+Si)/6)+((Cr+Mo+V+Cb)/5)+((Ni+Cu)/15)

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with material specifications, and when designated by the Purchaser, meet applicable specifications.

Bruce A. Work
Metallurgist

Figure G-9. W6x8.5 (W152x12.6) or W6x9 (W152x13.4), 72-in. Long (1,829-mm) Steel Post, Test Nos. SPDA-4 and SPDA-5 (Item No. b5)

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

CWNP Invoice 43270

Shipped To Midwest Matting

Customer PO 2589-2

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Date: 5/8/12

Specifications: Highway Construction Use

Preservative: CCA – C 0.60 pcf

Charge #	Date Treated	Grade	Material Size, Length & Dressing	# Pieces	White Moisture Readings	Penetration # of Borings & % Conforming	Actual Retentions % Conforming
335	5/3/12	MGA #1	6x12 - 14" Rgh	732	18%	2/20 90%	.657 pcf
334	4/20/12	MGA #1	6x12 - 19" Adjst. Rgh	36	17%	1/20 95%	.623 pcf
332	4/19/12	MGA #1	6x12 - 19" Rgh	176	19%	3/20 85%	.620 pcf

Number of pieces rejected and reason for rejection:
None

Statement: The above reference material was treated and inspected in accordance with the above referenced specifications.

Kurt Andres, General Manager

5/8/12
Date

Figure G-10. 6-in. x 12-in. x 14¼-in. (152-mm x 305-mm x 368-mm) Timber Blockout for Steel Posts, Test Nos. SPDA-1 and SPDA-3 (Item No. b6)

CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

R#17-282 BCT Posts 70 Acct AND Wood Blocks for Bullnose
Nov2016 SMT Wood Blockouts are painted Light Blue

Date: 11/11/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10055387

Customer PO# 3339 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6806.5PST	6x8-6.5" PST	35	22973	.679
GR6806.5CRT	6x8-6.5" CRT	35	22973	.679
GS6846PST	5.5-7.5-46" BCT	42	22927	.638
GR61214BLK	6x12-14" OCD	168	22927	.638

I certify the above referenced material has been produced, treated and tested in accordance with AWPA standards and conforms to AASHTO M133 & M168.

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

11/11/16
Date

Figure G-11. 6-in. x 12-in. x 14¼-in. (152-mm x 305-mm x 368-mm) Timber Blockout, Test No. SPDA-2 (Item No. b6)

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

R#16-692 6x12x14 Timber Blockouts
COC June2016 SMT Black Paint Tags

Date: 10/29/15

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery. BOL# 18052937

Customer PO# 3161 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
	6x12- 14" OD Blok	84	21327	.658 pcf

I certify the above referenced material has been produced, treated and tested in accordance with AWPA standards and conforms to AASHTO M133 & M168.

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards. Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

[signature] GM
Nick Sowl, General Counsel

10/29/15
Date

Figure G-12. 6-in. x 12-in. x 14¼-in. (152-mm x 305-mm x 368-mm) Timber Blockout for Steel Posts, Test Nos. SPDA-4 and SPDA-5 (Item No. b6)

425 E. O'Connor
Lima, OH

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

Pieces	Description
64	5/8"X10" GR BOLT A307
192	5/8"X18" GR BOLT A307
32	1" ROUND WASHER F844
64	1" HEX NUT A563
192	WD 6'0 POST 6X8 CRT
192	WD BLK 6X8X14 DR
64	NAIL 16d SRT
64	WD 3'9 POST 5.5X7.5 BAND
32	STRUT & YOKE ASSY
128	SLOT GUARD '98
32	3/8 X 3 X 4 PL WASHER

MGSBR

Ground Strut

090453-8

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

2

402-761-3288 16:36 06/04/2009

Figure G-13. Ground Strut Assembly, Test Nos. SPDA-1, SPDA-4, and SPDA-5 (Item No. d1)

STEEL AND PIPE SUPPLY
SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

METALLURGICAL TEST REPORT

PAGE 1 of 2
DATE 04/18/2016
TIME 12:48:19
USER WILLIAMR

SOLD TO:
strut and yoke assembly
for Downstream Anchor Testing
Concept#2
R#17-515 March 2017 SMT

SHIP TO:
17238
Longview Warehouse
4750 West Marshall Ave
LONGVIEW TX 75604

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40261064-0010	801060120TM	10GA 60 X 120 A1011-CS-TYB TEMP HS	24	6,750			04/18/2016

Chemical Analysis

Heat No. A604934 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA
Batch 0004289843 24 EA 6,750 LB

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0600	0.3700	0.0100	0.0010	0.0400	0.0400	0.0800	0.0200	0.0001	0.1000	0.0350	0.0010	0.0040	0.0010	0.0068	0.0050

Mechanical/ Physical Properties

Mill Coil No. 16B612662

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen

Chemical Analysis

Heat No. A604934 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA
Batch 0004289834 30 EA 8,437.500 LB

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0600	0.3700	0.0100	0.0010	0.0400	0.0400	0.0800	0.0200	0.0001	0.1000	0.0350	0.0010	0.0040	0.0010	0.0068	0.0050

Mechanical/ Physical Properties

Mill Coil No. 16B612662

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

Figure G-14. Modified Ground Strut Assembly, Test No. SPDA-2 (Item No. d1)

STEEL AND PIPE SUPPLY
SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

METALLURGICAL TEST REPORT

PAGE 2 of 2
DATE 04/18/2016
TIME 12:48:19
USER WILLIAMR

SOLD TO

SHIP TO
17238
Longview Warehouse
4750 West Marshall Ave
LONGVIEW TX 75604

Chemical Analysis

Heat No. A604934 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA
Batch 0004289814 35 EA 9,843.750 LB

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0600	0.3700	0.0100	0.0010	0.0400	0.0400	0.0800	0.0200	0.0001	0.1000	0.0350	0.0010	0.0040	0.0010	0.0068	0.0050

Mechanical/ Physical Properties

Mill Coil No. 16B612662

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

Figure G-15. Modified Ground Strut Assembly, Test No. SPDA-2 (Continued) (Item No. d1)

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

Order Number: 1214903
Customer PO: 2878
BOL Number: 80278
Document #: 1
Shipped To: NE
Use State: KS

Prod Ln Grp: 9-End Terminals (Dom)
Ship Date:

As of: 3/7/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
36	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
20	3000G	CBL 3/4X6'6/DBL	HW			98790													
22	9852A	STRUT & YOKE ASSY	A-1011-SS			163375	48,380	64,020	32.9	0.190	0.520	0.011	0.003	0.030	0.110	0.000	0.050	0.000	4
	9852A		A-36			11237730	45,500	70,000	30.0	0.170	0.500	0.010	0.008	0.020	0.080	0.000	0.070	0.001	4

Ground Strut Green Paint
R#15-0157 September 2014 SMT

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)
FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

Figure G-16. Ground Strut Assembly, Test No. SPDA-3 (Item No. d1)

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097
Project: RESALE

Order Number: 1095199
Customer PO: 2041
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/6'3/S	M-180	A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	6'0 TUBE SL/.188X8X6	A-500			A8F1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.180	0.830	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 20th day of June, 2008

Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products , LLC
Certified By:

Stefanie Onal.s

Figure G-17. Anchor Bracket Assembly, Test Nos. SPDA-1 and SPDA-2 (Item No. d2)

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1145215
Customer PO: 2441
BOL Number: 61905
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/15/11

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	206G	T12/6'3/S	M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	[illegible]	[illegible]	[illegible]
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	[illegible]	
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	[illegible]	
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	[illegible]	[illegible]
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	[illegible]	[illegible]
55	260G	T12/25/6'3/S	M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.00	0.050	0.002	[illegible]
			M-180	A	2	139206	61,730	78,580	26.0	0.180	0.710	0.012	0.004	0.020	0.140	0.000	0.050	[illegible]	[illegible]
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	[illegible]	[illegible]
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	[illegible]	
			M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.000	0.060	[illegible]	[illegible]
	260G		M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	[illegible]	[illegible]
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	[illegible]	[illegible]
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	[illegible]	[illegible]
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	[illegible]	
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	[illegible]	[illegible]
26	701A	.25X11.75X16 CAB ANC	A-36			V911470	51,460	71,280	27.5	0.120	0.800	0.015	0.030	0.190	0.300	0.00	0.090	[illegible]	4
	701A		A-36			N3540A	46,200	65,000	31.0	0.120	0.380	0.010	0.019	0.010	0.180	0.00	0.070	[illegible]	4
24	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	[illegible]	[illegible]	[illegible]
24	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	[illegible]	[illegible]
22	782G	5/8"X8"X8" BEAR PL/OF	A-36			18486	49,000	78,000	25.1	0.210	0.860	0.021	0.036	0.250	0.260	0.00	0.170	[illegible]	[illegible]
25	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	140735	61,390	80,240	27.1	0.200	0.740	0.014	0.005	0.010	0.120	0.00	[illegible]	[illegible]	[illegible]

Figure G-18. Anchor Bracket Assembly, Test Nos. SPDA-1, SPDA-2, and SPDA-3 (Item No. d2)

NUCOR
NUCOR STEEL JACKSON, INC.

Mill Certification
7/27/2016

MTR #: M1-150903
NUCOR STEEL JACKSON, INC.
3630 Fourth Street
Flowood, MS 39232
(601) 939-1623
Fax: (601) 936-6202

Sold To: O'NEAL STEEL INC
ATTN ACCOUNTS PAYABLE
PO BOX 98
BIRMINGHAM, AL 35202-0098
(205) 599-8000
Fax: (205) 599-8052

Ship To: O'NEAL STEEL INC
4530 MESSER-AIRPORT HWY
BIRMINGHAM, AL 35222
(205) 599-8000
Fax: (205) 599-8052

Customer P.O.	00771356	Sales Order	343125.5
Product Group	Merchant Bar Quality	Part Number	5350030024010W0
Grade	NUCOR MULTIGRADE	Lot #	JK1610148801
Size	1/2x3" Flat	Heat #	JK16101488
Product	1/2x3" Flat 20' NUCOR MULTIGRADE	B.L. Number	M1-429898
Description	NUCOR MULTIGRADE	Load Number	M1-150903
Customer Spec		Customer Part #	00777557

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Roll Date: 4/5/2016 **Melt Date: 3/30/2016** **Qty Shipped LBS: 4,900** **Qty Shipped Pcs: 48**

Melt Date: 3/30/2016

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.16%	0.78%	0.017%	0.028%	0.20%	0.28%	0.09%	0.14%	0.020%	0.0280%	0.001%	0.010%
CE4020	CEA529										
0.35%	0.39%										

CE4020: C. E. CSA G4020, AASHTO M270
CEA529: A529 CARBON EQUIVALENT

Roll Date: 4/5/2016

Yield 1: 56,172psi	Tensile 1: 75,460psi	Elongation: 25% in 8"(% in 203.3mm)
Yield 2: 56,126psi	Tensile 2: 76,500psi	Elongation 25% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/36M, ASTM A529/529M GR50 ASTM A572/572M GR50 ASTM709/709M GR36/GR50 CSA G40.21 GR44W(300W)/GR50W(350W) AASHTO M270/M270M GR36/GR50 ASME SA36/SA36M MEETS EN10204 SEC 3.1 REPORTING REQUIREMENTS

ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT, INCLUDING MELTING, HAVE OCCURRED WITHIN THE UNITED STATES. ALL PRODUCTS PRODUCED ARE WELD FREE. MERCURY, IN ANY FORM, HAS NOT BEEN USED IN THE PRODUCTION OR TESTING OF THIS MATERIAL.

QA Approved
SI# 777557

Christopher Smith
Christopher Smith
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 1

Figure G-19. Anchor Bracket Assembly, Test Nos. SPDA-4 and SPDA-5 (Item No. d2)

SSAB

1770 Bill Sharp Boulevard, Muscatine, IA 52761-9412, US **Official copy to follow**

Preliminary Test Certificate

Form TC1: Revision 2: Date 23 Apr 2014

Customer: STEEL & PIPE SUPPLY P.O. BOX 1688 MANHATTAN KS 66502	Customer P.O. No.: 4500279931	Mill Order No.: 41-491570-01	Shipping Manifest : MT308648
	Product Description: ASTM A36(14)/A709(16A)36/ASME SA36(15) AASHTO M270(15)36	Ship Date: 19 Feb 17 Cert Date: 19 Feb 17	Cert No: 061627837 (Page 1 of 1)
	Size: 1.000 X 72.00 X 240.0 (IN)		

Heat Id	Piece Id	Tested Thickness	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in	Elong % 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1	2	3	Avg	% Shear 1	2	3	Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp	%Shr
A7A884	A08	0.999 (DISCRT)	L	48	71			24	T														
A7B038	A01	0.998 (DISCRT)	L	51	77			23	T														

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	B	N	ORGN
A7A884	.18	.96	.012	.005	.12	.032	.28	.21	.13	.05	.001	.019	.004	.0002	.0087	USA
A7B038	.19	1.03	.011	.003	.23	.027	.29	.15	.15	.05	.002	.006	.008	.0003	.0088	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA.
PRODUCTS SHIPPED:
A7B038 A01 PCES: 2, LBS: 9802 A7A884 A08 PCES: 2, LBS: 9802

Steel Post Downstream Anchorage
R#17-518 H#A7A884
1" Steel Plate
March 2017 SMT

(H) Cust Part # : 7210072240

WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION

SENIOR METALLURGIST - PRODUCT

Figure G-20. 1-in. (25-mm) Steel Plate, Test Nos. SPDA-1 and SPDA-4 (Item No. d3)

EXLTUBE

1000 BURLINGTON STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

Customer:	Size:	Customer Order No:	Date:
SPS - New Century 401 New Century Parkway NEW CENTURY KS 66031-1127	02.375	4500276584	12/19/2016
	Gauge: .154	Delivery No: 82874363 Load No: 3826270	
	Specification: ASTM A500-13 Gr.B/C, ASTM A53-12 Gr.B BNT*, ASME SA53 Gr.B BNT*		

Heat No	Yield KSI	Tensile KSI	Elongation % 2 Inch
C80017	63.6	67.6	31.00

R#17-518 Steel Post Downstream Anchorage
2" Pipe March 2017 SMT

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
C80017	0.0600	0.8400	0.0080	0.0010	0.0200	0.1000	0.0300	0.0400	0.0200	0.0010

This material was melted & manufactured in the U.S.A.
Coil Producing Mill: NUCOR STEEL GALLATIN, GHENT, KY

We hereby certify that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above. This product was manufactured in accordance with your purchase order requirements.
BNT=Grade B not pressure tested - meets tensile & chemical properties ONLY.

This material has not come into direct contact with mercury, any of its compounds, or any mercury bearing devices during our manufacturing process, testing, or inspections.

This material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

This material has passed NDE (eddy current, A309) testing. This material has passed flattening tests.

Tensile test completed using test specimen with 3/4" reduced area.

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe
Quality Assurance Manager

Figure G-21. 2⅜-in. (60-mm.) O.D. x $3^{15}/_{16}$-in. (100-mm) Long BCT Post Sleeve, Test Nos. SPDA-1 and SPDA-4 (Item No. d4)

STEEL AND PIPE SUPPLY
SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 03/08/2017
TIME 21:07:48
USER J.DUBOIS

SOLD TO:
Steel Post Downstream Anchorage
R#17-518 1/2" Plate
March 2017 SMT

SHIP TO:
13713
Warehouse 0020
1050 Fort Gibson Rd
CATOOSA OK 74015-3033

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40278646-0030	701672240TM	1/2 72 X 240 A36 TEMPERPASS STPMLPL	4	9,801.600			03/08/2017

Chemical Analysis

Heat No. B702405 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA
Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0600	0.8400	0.0200	0.0030	0.0200	0.0300	0.0900	0.0100	0.0001	0.1100	0.0260	0.0030	0.0040	0.0030	0.0073	0.0070

Mechanical / Physical Properties

Mill Coil No. 17B727156

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
61500.000	43800.000	37.80			0	NA			
61300.000	43500.000	38.10			0	NA			

Batch 0004675841 4 EA 9,801.600 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

Figure G-22. ½-in. (13-mm) Plate, Test No. SPDA-2 (Item No. d4)

GERDAU

US-ML-WILTON
1500-2500 WEST 3RD STREET
WILTON, IA 52778
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	
STATE STEEL SUPPLY CO INC 13433 CENTECH RD OMAHA,NE 68138-3492 USA	STATE STEEL SUPPLY CO INC SIOUX CITY,IA 51102-3224 USA	A36	Flat / 1/2 X 3	
		LENGTH 20'00"	WEIGHT 34,272 LB	HEAT / BATCH 64047117/02

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
639595/000050		1-ASTM A6/A6M-11 2-A36/A36M-08 3-A709-11 4-AASHTO M270-11

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
P31101SW251	1334-0000007548	11/05/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Al %	Pb %
0.18	0.56	0.007	0.036	0.18	0.27	0.08	0.11	0.023	0.000	0.001	0.000	0.0003

CHEMICAL COMPOSITION

Sn %
0.010

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
26.30	8.000	66800	461	43700	301
30.00	8.000	67600	466	44100	304

GEOMETRIC CHARACTERISTICS

R:R
20.52

COMMENTS / NOTES

4CMB Cable Anchor Plate Washer

P31101SW25105

64047117

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

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

BRETT KRAUSE
QUALITY ASSURANCE MGR.

Figure G-23. 3-in. x 2⅜-in. x ½-in. (76-mm x 60-mm x 13-mm) Plate Washer, Test Nos. SPDA-3 (Item No. d5) and SPDA-5 (Item No. d4)

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

US-ML-CHARLOTTE
6601 LAKEVIEW ROAD
CHARLOTTE, NC 28269
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
STEEL & PIPE SUPPLY CO INC 401 NEW CENTURY PKWY NEW CENTURY,KS 66031-1127 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	A36/44W	Square Bar / 1/2"	0000016933

LENGTH	WEIGHT	HEAT / BATCH
20'00"	10,166 LB	54153457/02

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
4606064/000010	000000000000851620	ASME SA36 ASTM A6-14, A36-14 ASTM A709-15, AASHTO M270-12 CSA G40.20-13/G40.21-13

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500278904	1321-0000044503	01/23/2017

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Sn %
0.16	0.68	0.009	0.030	0.20	0.32	0.09	0.10	0.020	0.002	0.002	0.008

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
25.60	8.000	78053	538	56694	391

GEOMETRIC CHARACTERISTICS

R:R
99.00

COMMENTS / NOTES

Also meets ASME SA36-13

Steel Post Downstream Anchorage
R#17-518 1/2" Square Bar
March 2017 SMT

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 769-1014 Email: Bhaskar.Yalamanchili@gerdau.com

JORDAN FOSTER
QUALITY ASSURANCE MGR.
Phone: (704) 596-0361 EX3708 Email: Jordan.Foster@gerdau.com

Figure G-24. ½-in. (13-mm) Square Bar, Test No. SPDA-2 (Item No. d5)

Customer Name	Customer PO#	Shipper No	Heat Number
UNL MwRSF	Paid by visa	323392	05543-2

November 2014 supply
MWP Brass SMT

CERTIFICATE OF TEST

Customer COPPER AND BRASS SALES INC.
Invoice No 230605K14
P.O. No 6400221060
Mill & Country Melting DAECHANG, KOREA

No 2014-05-26-083
Date 05/26/14
Commodity FREE CUTTING BRASS C36000 HALF HARD IN 12 FT L
Spec PER ASTM B 16/B16M, RV. 2010, B249, ROHS COMPLIANT

Job No.	14-04-	DESCRIPTION	Quantity		Temper	Remarks	B/D No.	Mat No.	Inspection Result	
Line No.	Lot No.	SIZE	Pieces	Wt, Lbs	-	-		-	Dimension	Surface
0010	14686-1 ✓	7/16"(+/-0.0015) DIA, ROUND		5,033	H02			CURD00133	GOOD	GOOD
0020	08516-1	1/4"(+/-0.0015) DIA, ROUND, W/PACKING		944	H02		10	CURD00527	GOOD	GOOD
0020	14689-1 ✓	1/4"(+/-0.0015) DIA, ROUND, W/PACKING		3,790	H02		6 – 9	CURD00527	GOOD	GOOD
0030	14690-1 ✓	3/8"(+/-0.0015) DIA, ROUND		4,923	H02			CURD00231	GOOD	GOOD
0040	14691-1 ✓	7/16"(+/-0.003) DPS, HEXAGON, S.C.		4,687	H02			CUHEX00097	GOOD	GOOD
0050	14692-1 ✓	5/16"(+/-0.0015) DIA, ROUND, W/PACKING		5,015	H02			CURD00289	GOOD	GOOD
0060	05543-2 ✓	3/16"(+/-0.0015) DIA, ROUND, W/PACKING		4,774	H02			CURD00477	GOOD	GOOD
0070	14695-1 ✓	3/8"(+/-0.003) DPS, HEXAGON, S.C.		3,703	H02			CUHEX00246	GOOD	GOOD
0080	14696-1 ✓	1/4"(+/-0.0035) DPS, SQUARE, W/PACKING		1,814	H02			CUSQ00086	GOOD	GOOD
0090	14697-1 ✓	9/32"(+/-0.0015) DIA, ROUND, W/PACKING		2,006	H02			CURD00480	GOOD	GOOD
0100	14687-1 ✓	3/8"(+/-0.0035) DPS, SQUARE		1,825	H02			CUSQ00048	GOOD	GOOD

Chemical/Physical	Element	Cu	Pb	Fe	-	-	Zn	S/C	T.S., Ksi	Y.S., Ksi	E/L (%)	HRB
Composition, %	Spec	60.0-63.0	2.50-3.00	0.35 max	-	-	Rem.	Ammonia	-	-	-	-
0010	14686-1	60.8492	2.7492	0.1675	-	-	Rem.	GOOD	64	58	19.8	72.1
0020	08516-1	60.5254	2.7669	0.1766	-	-	Rem.	GOOD	68	56	12.4	78.8
0020	14689-1	60.2003	2.8459	0.1571	-	-	Rem.	GOOD	76	57	10.4	80.6
0030	14690-1	60.2872	2.6908	0.1604	-	-	Rem.	GOOD	67	50	10.7	73.2
0040	14691-1	60.5934	2.6127	0.1305	-	-	Rem.	GOOD	67	54	15.8	79.5
0050	14692-1	60.6773	2.6018	0.1416	-	-	Rem.	GOOD	69	59	10.9	82.2
0060	05543-2	60.5388	2.7248	0.1118	-	-	Rem.	GOOD	75	63	8.5	89.5
0070	14695-1	60.4889	2.7365	0.1339	-	-	Rem.	GOOD	65	54	17.6	79.4
0080	14696-1	60.5934	2.6127	0.1305	-	-	Rem.	GOOD	59	55	15.2	69.3
0090	14697-1	60.6180	2.7040	0.1471	-	-	Rem.	GOOD	72	59	10.7	81.0
0100	14687-1	60.4889	2.7365	0.1339	-	-	Rem.	GOOD	59	45	21.0	64.8

SIGNED FOR DAE CHANG IND.

From: ThyssenKrupp Materials NA
Cust. ONLINE METALS - TX
CstAr 4345
Wgt.: 15 LB
Del.: 2403436857
CstOr 31895
Date 10/08/2014

Lloyds Pacific International, Inc.

Figure G-25. MWP Brass Rod, Test No. SPDA-5 (Item No. d5)

COMMERCIAL GROUP LIFTING PRODUCTS

SEPT 26TH 2016

SOLD TO:
GREGORY INDUSTRIES, INC.
4100 13TH ST. SW
CANTON, OH. 44710

SHIP TO:
HIGHWAY – FINISHED GOODS
GREGORY INDUSTRIES, INC.
ATTN: STEVE PENNINGTON
CANTON, OH 44710

CERTIFICATON

CGLP ORDER# 231442
GREGORY PO# 33960

R#17-516 6'6" BCT Cables
Each are modified into 2part Cables and painted Orange

THIS LETTER AND THE ENCLOSED ATTACHMENTS ARE TO CERTIFY THAT THE FOLLOWING ITEMS WERE 100% MANUFACTURED IN THE UNITED STATES OF AMERICA.

1,500 PCS, PART# 3012G, 3/4IN X 6FT 6IN DOUBLE SWAGE GUARD RAIL ASSEMBLYS.

THEY SHOW THE DOMESTICITY OF ALL MATERIAL USED, 100% MELTED & MANUFACTURED IN THE USA. THESE ITEMS ARE HOT DIPPED GALVANIZED TO ASTM-153 SPECIFICATIONS AND STANDARDS, GALV PROCESS ALSO TOOK PLACE IN THE U.S.A.

ATTACHMENTS:
(WIRE ROPE) WIRECO WORLD GROUP REEL# 428-6311548-3; HEAT# 15R58140 15R582068; 14R575264; 15R577383; 15R583009; 15R582607; 14R571205; 15R582608; 14R574048; 15R581838; 15R581452; 14R571682; . (ROCKY MOUNTAIN STEEL / EVRAZ)

(END FITTINGS) REMLINGER MFG: HEAT#S 75060985; M59285; 75061614; (GERDAU NORTH AMERICA)

VERY TRULY YOURS

BILL KOTARSKI
GEN MGR CLEV OFFICE

HEADQUARTERS	FLINT BRANCH	CLEVELAND BRANCH
12801 UNIVERSAL DRIVE TAYLOR, MI 48180 *NEW PH# (734) 947-4000* *NEW FAX# (734) 947-4004*	G2427 E. JUDD ROAD BURTON, MI 48529 PH# (810) 744-4540 FAX# (810) 744-1588	5213 GRANT AVE CLEVELAND, OH 44105 PH# (216) 641-4100 FAX# (216) 641-1814

Figure G-26. $^{3}/_{4}$-in. (190-mm) Dia. 6x19 IWRC IPS Wire Rope, Test Nos. SPDA-1, SPDA-2, and SPDA-3 (Item Nos. e1 and e2)

CG COMMERCIAL GROUP LIFTING PRODUCTS

Feb 15th 2017

SOLD TO:
GREGORY INDUSTRIES, INC.
4100 13TH ST. SW
CANTON, OH. 44710

SHIP TO:
HIGHWAY – FINISHED GOODS
GREGORY INDUSTRIES, INC.
ATTN: STEVE PENNINGTON
CANTON, OH 44710

R#17-700

CERTIFICATON BCT Cables Yellow Paint

CGLP ORDER# 256284
GREGORY PO# 36454

THIS LETTER AND THE ENCLOSED ATTACHMENTS ARE TO CERTIFY THAT THE FOLLOWING ITEMS WERE 100% MANUFACTURED IN THE UNITED STATES OF AMERICA.

1,330 PCS, PART# 3012G, 3/4IN X 6FT 6IN DOUBLE SWAGE GUARD RAIL ASSEMBLYS.

THEY SHOW THE DOMESTICITY OF ALL MATERIAL USED, 100% MELTED & MANUFACTURED IN THE USA. THESE ITEMS ARE HOT DIPPED GALVANIZED TO ASTM-153 SPECIFICATIONS AND STANDARDS, GALV PROCESS ALSO TOOK PLACE IN THE U.S.A.

ATTACHMENTS:

(WIRE ROPE) WIRECO WORLD GROUP REEL# 428-671806-1; HEAT# .15R582807; 16R584001; 72987C; 16R586548; 73253F; 16R588160; 16R584967; 16R585464; 16R586547; 14R574048; 14R571682; 16R586549; 16R586401; (ROCKY MOUNTAIN STEEL / EVRAZ)

(END FITTINGS) REMLINGER MFG: HEAT#S 75063022; 75062074; 765063075 (GERDAU NORTH AMERICA)

VERY TRULY YOURS

BILL KOTARSKI
GEN MGR CLEV OFFICE

HEADQUARTERS	FLINT BRANCH	CLEVELAND BRANCH
12801 UNIVERSAL DRIVE	G2427 E. JUDD ROAD	5213 GRANT AVE
TAYLOR, MI 48180	BURTON, MI 48529	CLEVELAND, OH 44105
NEW PH# (734) 947-4000	PH# (810) 744-4540	PH# (216) 641-4100
NEW FAX# (734) 947-4004	FAX# (810) 744-1588	FAX# (216) 641-1814

Figure G-27. BCT Anchor Cable End Swaged Fitting, Test No. SPDA-4 (Item No. e1 and e2)

Certified Analysis

Trinity Highway Products, LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1145215
Customer PO: 2441
BOL Number: 61905
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/15/11

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	980G	T10/END SHOE/SLANT	A-1011-SS			A57723	49,000	64,500	34.8	0.080	0.350	0.018	0.005	0.020	0.090	0.00	0.060	0.001	4

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. LG-002.
ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Ohio, County of Allen. Sworn and subscribed before me this 15th day of April, 2011
Notary Public:
Commission Expires 1/23/2016

STATE OF OHIO ANGELA COUNTS NOTARY PUBLIC I.D.# 2011NT0014 Commission Expires January 23, 2016 AUGLAIZE COUNTY

Trinity Highway Products, LLC
Certified By:
Quality Assurance

2 of 2

Figure G-28. ¾-in. (19-mm) Dia. Wire Rope and BCT Anchor Cable End Swaged Fitting, Test No. SPDA-5 (Item Nos. e1 and e2)

R#16-692 5/8"x14"GR Bolt
Orange Paint H#16100453 L#28667-B
June2016 SMT

CERTIFICATE OF COMPLIANCE

3540G

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 176703

SHIPPER #: 057716
DATE SHIPPED: 05/17/2016

LOT#: 28667-B

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 78,080 76,544

HARDNESS: 100 max 82.10 83.50

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
ROGERS GALVANIZE: 28667-B

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si
NUCOR	1010	NF16100453	.12	.56	.006	.030	.19

QUANTITY AND DESCRIPTION:

5,950 PCS 5/8" X 14" GUARD RAIL BOLT
P/N 3540G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENT PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
17th DAY OF May 2016
Merry F Shane

Linda Melomas
APPROVED SIGNATORY

5/17/16
DATE

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Figure G-29. ⅝-in. (16-mm) Dia. UNC, 14-in. (356-mm) Long Guardrail Bolt and Nut, Test Nos. SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item No. f1)

TFI Telefast Industries
A Division of EFG

CERTIFICATION

DATE: 4/3/2017

CUSTOMER
Bennett Bolt Works, Inc.
12 Elbridge Street
Jordan, NY 13080

DESCRIPTION
Nut Guardrail 5/8-11 + .031
A563 GrA HDG

EFG PART NUMBER: T3400

CUSTOMER P.O.
6015438 BLANKET

LOT NUMBER
0068078-124590

MATERIAL
1018

CUSTOMER PART NUMBER
62CNDR0H

INVOICE
58432

SHIP DATE
4/3/2017

HEAT NUMBER
20479830

QUANTITY
36000

HARDNESS: B 85.4
PROOF LOAD: 5 samples passed at 75,000 psi min.
PLATING: Hot Dip Galvanized - Pass

All parts processed Mercury free and without Welds.

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

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

The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal Statutes.

Joe Kilpatrick

Joe Kilpatrick
Quality Assurance Technician

ENGINEERED FASTENING SOLUTIONS

Figure G-30. ⅝-in. (16-mm) Dia. UNC Guardrail Nut, Test Nos. SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item No. f1)

CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: GREGORY INDUSTRIES

CUSTOMER PO: 37464

SHIPPER#: 060204
DATE SHIPPED: 04/10/2017

LOT#: 29256-G

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 66,593
67,960

HARDNESS: 100 max 70.40
70.30

*Pounds Per Square Inch.
COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
ROGERS GALVANIZE: 29256-G

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si
CHARTER	1010	20460760	.09	.33	.006	.003	.06

QUANTITY AND DESCRIPTION:

105,000 PCS 5/8" X 1.25" GUARD RAIL BOLT
P/N 1001G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENT PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS

10th DAY OF April, 20 17 — APPROVED SIGNATORY — 4/10/17 DATE

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Figure G-31. ⅝-in. (16-mm) Dia. UNC, 1¼-in. (32-mm) Long Guardrail Bolt, Test Nos. (SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item No. f2)

TFI
Telefast Industries
A Division of
EFG

CERTIFICATION

DATE: 4/3/2017

CUSTOMER
Bennett Bolt Works, Inc.
12 Elbridge Street
Jordan, NY 13080

DESCRIPTION
Nut Guardrail 5/8-11 + .031
A563 GrA HDG

EFG PART NUMBER: T3400

CUSTOMER P.O.
6015438 BLANKET

LOT NUMBER
0068078-124590

MATERIAL
1018

CUSTOMER PART NUMBER
62CNDR0H

INVOICE
58432

SHIP DATE
4/3/2017

HEAT NUMBER
20479830

QUANTITY
36000

HARDNESS: B 85.4
PROOF LOAD: 5 samples passed at 75,000 psi min.
PLATING: Hot Dip Galvanized - Pass

All parts processed Mercury free and without Welds.

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

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

The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal Statutes.

Joe Kilpatrick

Joe Kilpatrick

Quality Assurance Technician

ENGINEERED FASTENING SOLUTIONS

Figure G-32. ⅝-in. (16-mm) Dia. UNC Guardrail Nut, Test Nos. SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item No. f2)

Johnstown Wire Technologies

124 Laurel Ave,
Johnstown, PA 15906

Phone: 814 532-5756
Fax: 814 532-5684

TEST REPORT

WORK ORDER
611768

LOT NUMBER
C-20479830

SALES ORDER / RLS
374173 / 003

CERT ID / REV
00053717 / 01

SOLD TO

Elgin Fastener Group / Berea Plant
777 West Bagley Road
Berea, OH 44017
USA

CUSTOMER P.O.	CUSTOMER PART	QUANTITY	COILS	LADING NO	SHIPMENT DATE
118127	T10011	4,616 LBS	2	00143198	01/27/2017

SPECIFICATION Berea-22687P
Elgin ASTM A 29/A 29M-05 1018 C .15/.20 Mn .60/.90 P.040 Max
S.050 Max Aluminum Killed Fine Grain Cold Heading Quality Direct Drawn PHOS & POLYMER COATED
Size: .687 +.003 -.003

CERTIFICATION REQUIREMENTS

Chemical

C	Mn	P	S	Si	Al	Ni	Cr	Mo	Cu	V
.16	.64	.008	.004	.060	.051	.03	.05	.01	.04	.001

N	Sn
.0050	.003

Physical

Rod Source	Melt Source	Country of Origin	Nafta
Charter	Charter	USA	Yes

Mechanical

TEST	UNITS	HIGH	LOW	AVERAGE
Tensile Str	Lbs/SqIn	73000	73000	73000

Rod / Melt Source

End of Certification

I certify that the results are a true and correct copy of the records prepared and maintained by JOHNSTOWN WIRE TECHNOLOGIES in compliance with the requirements of the cited specification. Chemistry is as reported by the rod / bar supplier and is not in JWT A2LA accreditation. This test report cannot be reproduced or distributed except in full without the written permission of JOHNSTOWN WIRE TECHNOLOGIES. The test results certified herein relate only to the items tested.

Daniel J. Mallet, Director of Quality Assurance

(C) AXIS Computer Systems - qtc302 (v6.0) Page 1 of 1 Date Printed: 01/27/2017

Figure G-33. ⅝-in. (16-mm) Dia. UNC Guardrail Nut, Test Nos. SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item No. f2) (Continued)

Birmingham Fastener Manufacturing

P.O. Box 10323
Birmingham, Alabama 35202
(205) 595-3512

Pg 1 of 1

Certificate of Compliance

Customer : Midwest Machinery & Supply
P.O. # : 3275

BFM # : 1338859
Date Shipped : 6/16/2016

	Quantity	Description	Lot#	Heat #	Specification	Finish
1	104	5/8"-11 x 8" HEX BOLT	208976	DL15107048	ASTM A307 Gr A	HDG
2	157	5/8"-11 x 10" HEX BOLT	208977	DL15107048	ASTM A307 Gr A	HDG
3	402	7/8"-9 x 16" Hex Bolt	208978	JK15100276	ASTM A307 Gr A	HDG
4	67	7/8"-9 X 26" Hex Bolt	208979	JK15100276	ASTM A307 Gr A	HDG

Birmingham Fastener Manufacturing. hereby certifies that the material furnished in reference to the above purchase order number will meet or exceed the above assigned specifications.

Signed: Brian Hughes **Date:** 06/15/2016

R#16-692 5/8"x10" BCT Hex Bolts
Orange Paint H#DL15107048
June2016 SMT

Figure G-34. ⅝-in. (16-mm) Dia. UNC, 10-in. (254-mm) Long Hex Head Bolt, Test Nos. SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item No. f3)

Certificate of Compliance

Birmingham Fastener Manufacturing
PO Box 10323
Birmingham, AL 35202
(205) 595-3512

Customer Midwest Machinery **Date Shipped** 06/16/2016

Customer Order Number 3275 **BFM Order Number** 1338859

Item Description

Description 5/8"-11 x 10" Hex Bolt **Qty** 157

Lot # 208977 **Specification** ASTM A307-14 Gr A **Finish** ASTM F2329

Raw Material Analysis

Heat# DL15107048

Chemical Composition (wt% Heat Analysis) By Material Supplier

C	Mn	P	S	Si	Cu	Ni	Cr	Mo
0.22	0.82	0.007	0.010	0.27	0.20	0.06	0.10	0.015

Mechanical Properties

Sample #	Hardness	Tensile Strength (lbs)	Tensile Strength (psi)
1	91 HRBW	21,700	97,660
2			
3			
4			
5			

This information represents the most recent analysis of the product supplied on the stated customer order. The samples tested conform to the ASTM standard listed above.
All steel melted and manufactured in the U.S.A.

Authorized Signature: **Date:** 6/16/2016

Brian Hughes
Quality Assurance

Figure G-35. ⅝-in. (16-mm) Dia. UNC, 10-in. (254-mm) Long Hex Head Bolt, Test Nos. SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item No. f3) (Continued)

R#16-0217
BCT Hex Nuts
December 2015 SMT
Fastenal part#36713
Control# 210101523

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 129980
- Part No: AFH2G0625C
- Cust Part No: 36713
- Quantity (PCS): 1200
- Description: 5/8-11 Fin Hx Nut Gr2 HDG/TOS 0.020
- Specification: SAE J995(99) - GRADE 2 / ANSI B18.2.2
- Stelfast I.D. NO: 595689-O201087
- Customer PO: 210101523
- Warehouse: DAL

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

This document may only be reproduced unaltered and only for certifying the same or lesser quantity of the product specified herein. Reproduction or alteration of this document for any other purpose is prohibited.

Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

December 07, 2015

Page 1 of 1

Figure G-36. ⅝-in. (16-mm) Dia. UNC Hex Head Nut, Test Nos. SPDA-1, SPDA-2, SPDA-3, SPDA-4, and SPDA-5 (Item nos. f3 and f4)

Mid West Fabricating

3115 W. Fair Ave.
Lancaster, Oh 43130

CERTIFICATE OF COMPLIANCE

WE CERTIFY THAT ALL BOLTS ARE MADE AND MANUFACTURED IN THE USA.

TO: Trinity Industries, Inc.
Plant #55
550 East Robb Ave.
Lima, Ohio 45801

5/8"x1-1/2" Hex Bolt
Lot#25203 H#10207560 R#16-0009
July 2015 SMT

SHIP DATE: 12/12/12
MANUFACTURER: MID WEST FABRICATING CO.
ASTM: A307A
PROCESSOR
GALVANIZERS: AZZ-Pilot TO A-153 CLASS C

QTY	PART NO.	HEAT NO.	LOT NO.	P.O. NO.
38,000	5/8 X 1 1/2"	10207560	25203	150897

PASSED & CERTIFIED
DEC 19 2012
Trinity Highway Products, LLC
Dallas, Texas Plant 99

SIGNATURE: Amy Bailes

TITLE: QUALITY CONTROL

Date: 12/12/12

Figure G-37. ⅝-in. (16-mm) Dia. UNC, 1½-in. (38-mm) Long Hex Head Bolts, Test Nos. SPDA-1, SPDA-2, and SPDA-3 (Item No. f4)

LOAD   Po # 71267

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

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

Beta Steel
44225 Utica Rd.
Laurie Dailey
Utica,MI-48318

Cust P.O.	284371-01
Customer Part#	062501015000SF(SW1015-C)
Charter Sales Order	30048422
Heat #	10207560
Ship Lot #	1074155
Grade	1015 A SK FG IQ 5/8
Process	HR
Finish Size	5/8

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

Test Results of Heat Lot# 10207560

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.14	.41	.007	.011	.13	.05	.07	.02	.10	.009	.001

AL	N	B	TI	CA	NB
.022	.0050	.0002	.000	.0001	.004

JOMINY(HRC) J0M01
41

JOMINY SAMPLE TYPE ENGLISH = C
CHEM. DEVIATION EXT.-GREEN =

43445

Test Results of Rolling Lot# 1074155

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE	3	59.7	60.1	59.9	TENSILE LAB = 0358-02
REDUCTION OF AREA	3	49	56	53	RA LAB = 0358-02

NUM DECARB = 1   AVE DECARB = .003
REDUCTION RATIO = 99:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = PS-1   Revision =   Dated = 11-MAR-08

Additional Comments:

8-8-12

Charter Steel
Saukville, WI, USA

ACCREDITED

This MTR supersedes all previously dated MTRs for this order
Janice Barnard
Manager of Quality Assurance

Figure G-38. ⅝-in. (16-mm) Dia. UNC, 1½-in. (38-mm) Long Hex Head Bolts, Test Nos. SPDA-1, SPDA-2, and SPDA-3 (Item No. f4) (Continued)

CERTIFIED MATERIAL TEST REPORT
FOR ASTM A307, GRADE A - MACHINE BOLTS

FACTORY: NINGBO ECONOMIC & TECHNICAL DEVELOPMENT ZONE YONGGANG FASTENERS CO., LTD.
REPORT DATE:2016/12/29
R#17-507 H#816070039
ADDRESS: FuShan South Road No.17,BeiLun NingBo China
BCT Cable Bracket Bolts
MANUFACTURE DATE:2016/12/2
TEL#(852)25423366
CUSTOMER: FASTENAL
MFG LOT NUMBER:M-2016HT927-9
SAMPE SIZE: ACC.TO Dimension:ASME B18.18-11;Mechanical Properties:ASTM F1470-12
MANU QTY: 4800PCS
SHIPPED QTY: 4800PCS
SIZE: 5/8-11X1 1/2 HDG
HEADMARKS: 307A PLUS NY
PO NUMBER:220023115
PART NO:1191919

STEEL PROPERTIES:
MATERIAL TYPE:Q195
HEAT NUMBER:816070039

CHEMISTRY SPEC:	C %*100	Mn%*100	P %*1000	S %*1000
Grade A ASTM A307-12	0.29max	1.20 max	0.04max	0.15max
TEST:	0.07	0.28	0.016	0.003

DIMENSIONAL INSPECTIONS Unit:inch SPECIFICATION: ASME B18.2.1 - 2012

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
VISUAL	ASTM F788-2013	PASSED	22	0
THREAD	ASME B1.1-2003,3A GO,2A NOGO	PASSED	15	0
WIDTH FLATS	0.906-0.938	0.915-0.928	4	0
WIDTH A/C	1.033-1.083	1.048-1.057	4	0
HEAD HEIGHT	0.378-0.444	0.394-0.424	4	0
THREAD LENGTH	1.420-1.560	1.435-1.541	15	0
LENGTH	1.420-1.560	1.435-1.541	15	0

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307-2012 GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS :	ASTM F606-2014	69-100 HRB	76-79 HRB	4	0
WEDGE TENSILE:	ASTM F606-2014	Min 60 KSI	65-69 KSI	4	0

COATINGS OF ZINC: SPECIFIATION:ASTM F2329-2013

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
HOT DIP GALVANIZED	ASTM B568-98(2104)	Min 0.0017"	0.0017" -0.0018"	4	0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

Maker's ISO# 00109Q16722R3M/3302

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

Figure G-39. ⅝-in. (16-mm) Dia. UNC, 1½-in. (38-mm) Long Hex Head Bolt and Nut, Test Nos. SPDA-4 and SPDA-5 (Item No. f4)

QUALITY CERTIFICATE

NINGBO JINDING FASTENING PIECE CO.,LTD

XIJINGTANG JIULONGHU NINGBO CHINA TEL:+86-574-86530122 FAX: +86-574-86530858

Customer:	FASTENAL COMPANY PURCHASING—IMPORT	Date :	2016-08-01
Product:	HEX CAP SCREWS	Contract No:	16JDF223T
Class:	5	Invoice No:	16-01336006
Size:	7/16-14X2-1/4	Lot No:	3412980005
Marking:	JDF three radius	Order No.	220021716
Quantity:	7.750 mpcs	Part No.	110120366
		Production Date	2016-05-13
Dimensions Of SPEC:		Certificate No.:	

R#17-398 BULLNOSE
7/16"
BOLTS,NUTS,WASHERS
7/8" BOLTS,NUTS
JAN2017 SMT

Inspection Items		Standard	Result	Sample	Pass
Visual Appearance		————————	OK	20	20
Body Diameter		0.430-0.437	0.431-0.432	20	20
Thread	Go	3A	OK	20	20
	No Go	2A	OK	20	20
Width Across Flats		0.625-0.612	0.613-0.614	20	20
Width Across Corners		0.722-0.698	0.702-0.705	20	20
Major Diameter		0.426-0.436	0.433-0.435	20	20
Head Height		0.291-0.272	0.281-0.282	20	20
Total Length		2.250-2.191	2.226-2.226	20	20
Thread Length		min 1.128	1.223-1.226	20	20
Mechanical Properties					
CharacTeristics		Standard	Result		
Surface Hardness	[30N]	MAX 54	43-44	10	10
Core Hardness	[HRC]	25-34	27-28	10	10
Wedge Strength	[psi]	min 119880	134538-138021	8	8
Yield Strength	[psi]	min 91869	105511-112188	8	8
Elongation	[%]	min 14	16.6-18.1	8	8
Reduction Of area	[%]	min 35	45.2-52.4	8	8
Proof Load	[Ib]	9050	9050	4	4
Decarburization		N≥1/2H1 HV0.3	317.43 317.43 290.57	6	6
HV2>=HV1-30, HV3<=HV1+30		G 0.0006max		6	6

CHEMICAL COMPOSITION(%)

Heat No		C	Si	Mn	P	S	Cr	Ni	Cu	Mo	B
Spec.:	min	0.2500									
	max	0.5500			0.0250	0.0250					0.0030
35#	5210760BA	0.36	0.16	0.64	0.016	0.010					

Thickness [UM]	min 5	10.0-13.5	20	20
Surface Coating:	ZPCr3+(coating test method: X ray according to ASTM B568M 2007 standard test method for measurement of coating thickness by X-Ray spectrometry)			

Parts are manufactured and tested according to above specification and compliance with order

we certify that this is a true representation of information provided by manufacturer and laboratory.

Thread Specification: ASME B1.1 2008, UNIFIED INCH SCREW THREADS(UN AND UNR THREAD FORM)

Sampling Dimension Specification: ASME B18.18-2011 inspection and quality assurance for high-volume machine assembly fasteners

Dimension Specification: ASME B18.2.1 2012,HEX CAP SCREWS

Sampling mechanical properties specification: ASTM F1470 2012 Standard Guide for Fastener Sampling for Specified Mechanical Properties and Performance Inspection

Mechanical Properties: SAE J429 2014,MECHANICAL AND MATERIAL REQUIREMENTS FOR EXTERNALLY THREADED FASTENERS

Surface Defect:ASTM F788/F788M-2013,SURFACE DISCONTINUITIES OF BOLTS,SCREWS,AND STUDS

Plating Specification: ASTM 1941 2015,Electrodeposited Coatings On Threaded Fasteners

Quality Control Supervisor | Quality Control Manager

Figure G-40. $^{7}/_{16}$-in. (11-mm) Dia. UNC, 2¼-in. (57-mm) Long Heavy Hex Bolt, Test Nos. SPDA-1, SPDA-2, and SPDA-3 (Item No. f6)

ISO/TS 16949 BUREAU VERITAS Certification

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

MANUFACTURER :GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2016/06/15

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 210110353
COMMODITY : FINISHED HEX NUT GR-5
SIZE : 7/16-14 NC
LOT NO : 1N1640850
SHIP QUANTITY : 22, 500 PCS
LOT QUANTITY 181, 067 PCS
HEADMARKS : GENIUS SYMBOL & 2 ARC LINES(120 DEGREE)
MANUFACTURE DATE : 2016/05/17
COUNTRY OF ORIGIN : CHINA

PACKING NO : GEM160602037
INVOICE NO : GEM/FNL-160618ED
PART NO : 1136308
SAMPLING PLAN : ASME B18. 18-2011(Category. 2)/ASTM F1470-2012
HEAT NO : 169D0620
MATERIAL : 1022A
FINISH : Fe/Zn 3AN ASTM F1941/F1941M-2015

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO SAE J995-2012

Chemistry	AL%	C%	MN%	P%	S%	SI%
Spec. : MIN.			0. 3000			
MAX.		0. 5500		0. 0500	0. 1500	
Test Value	0. 0280	0. 2000	0. 8000	0. 0130	0. 0060	0. 1000

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18. 2. 2-2010

SAMPLED BY : FCHUN

INSPECTIONS ITEM	SAMPLE	SPECIFIED		ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	6PCS		0. 7680-0. 7940 inch	0. 7730-0. 7920 inch	6	0
FIM	15PCS	ASME B18. 2. 2-2010	Max. 0. 0180 inch	0. 0060-0. 0170 inch	15	0
THICKNESS	6PCS		0. 3650-0. 3850 inch	0. 3670-0. 3770 inch	6	0
WIDTH ACROSS FLATS	6PCS		0. 6750-0. 6880 inch	0. 6760-0. 6800 inch	6	0
SURFACE DISCONTINUITIES	29PCS		ASTM F812-2012	PASSED	29	0
THREAD	15PCS		GAGING SYSTEM 21	PASSED	15	0

MECHANICAL PROPERTIES : ACCORDING TO SAE J 995-2012

SAMPLED BY : GDAN LIAN

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	15 PCS	ASTM F606-2014		Max. 32 HRC	12-16 HRC	15	0
PROOF LOAD	6 PCS	ASTM F606-2014		Min. 120, 000 PSI	OK	6	0
PLATING THICKNESS(μ m)	29 PCS	ASTM B568-1998		>=3	3. 48-4. 98	29	0
SALT SPRAY TEST	15 PCS	ASTM B117-11		6 HOURS NO WHITE RUST, 12 HOURS NO RED RUST	OK	15	0

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER

Quality Supervisor: [signature]

Figure G-41. $^{7}/_{16}$-in. (11-mm) Dia. UNC Heavy Hex Nut, Test Nos. SPDA-1, SPDA-2, and SPDA-3 (Item No. f6)

CERTIFIED MATERIAL TEST REPORT

FOR SAE J429 GRADE 5 HEX TAP BOLTS

SUPPLIER'S NAME:ZHEJIANG GOLDEN AUTOMOTIVE FASTENER CO.LTD — REPORT DATE: 2017-2-24
ADDRESS: XITANGQIAO HAIYAN ZHEJIANG CHINA — MANUFACTURE COMPLETE DATE: 2017-1-22
CONTACT INFORMATION: JACK /(86)-0573-86862565
CUSTOMER: FASTENAL COMPANY PURCHASING--IMPORT TRAFFIC
MFG LOT NUMBER: 1701201123E
SAMPLING PLAN PER ASME B18.18-2011 Categories 2;ASTM F1470-12 — PO NUMBER: 220023220
DESCRIPTION: HEX TAP BOLTS GRADE 5 ZINC PLATED
SIZE: 7/16-14X2-1/2" QTY: 6650 PCS PART NO: 0144506
HEADMARKS: NDF+THREE RADIAL LINE

STEEL PROPERTIES:
STEEL GRADE:1035 — HEAT NUMBER: J631004272

CHEMISTRY SPEC:	C %	Mn%	P %	S %
	0.25~0.55	min	0.025max	0.025max
TEST:	0.36	0.74	0.012	0.003

DIMENSIONAL INSPECTIONS — SPECIFICATION: ASME B18.2.1-2012

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
**********************	************************************	*******************	********	********
APPEARANCE	ASTM F788/F788M-13	PASSED	100	0
THREAD	ASME B1.1-08 2A	PASSED	32	0
WIDTH FLATS	0.625 " - 0.603 "	0.605 " - 0.622 "	8	0
WIDTH A/C	0.722 " - 0.687 "	0.694 " - 0.702 "	8	0
HEAD HEIGHT	0.316 " - 0.272 "	0.275 " - 0.301 "	8	0
MAJOR DIA	0.436 " - 0.426 "	0.429 " - 0.433 "	8	0
LENGTH	2.54 " - 2.44 "	2.45 " - 2.46 "	8	0

MECHANICAL PROPERTIES: 1/4"thru1" — SPECIFICATION: SAE J429-2014 GR-5

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
**********************	******************	******************	******************	********	********
CORE HARDNESS:	ASTM F606-14	25-34 HRC	27 - 30 HRC	8	0
SURFACE HARDNESS :	ASTM F606-14	30N54 MAX	46 - 48	8	0
WEDGE TENSILE:	ASTM F606-14	MIN 120000 PSI	130145 - 133750 PSI	4	0
PROOF LOAD	ASTM F606-14	MIN 85000 PSI	PASS	1	0
DECARBURIZATION	ASTM F2328-14		PASSED	1	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*****************	******************	******************	******************	********	********
ZINC PLATED	ASTM F1941-15	Clear Zinc FE/Zn 3AN			
Thickness	ASTM B568-98	Min3 μ m	4.5-5 μ m	8	0
Salt Spray Corrosion	ASTM B117-11	6 hours NO White Corrosion 12 hours NO Red Rust	PASS	8	0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE SAE SPECIFICATION. WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

All parts meet the requirements of FQA and records of compliance are on file.
Maker's ISO#CN11/20818

(SIGNATURE OF Q.A. MGR.)
(ZHEJIANG GOLDEN AUTOMOTIVE FASTENER CO.LTD)

Figure G-42. $^{7}/_{16}$-in. (11-mm) Dia. UNC, 2¼-in. (57-mm) Long Heavy Hex Bolt, Test Nos. SPDA-4 and SPDA-5 (Item No. f6)

ISO/TS 16949 BUREAU VERITAS Certification

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

MANUFACTURER :GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA
Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2017/03/07

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 210124595
COMMODITY : FINISHED HEX NUT GR-5
SIZE : 7/16-14 NC
LOT NO : 1N16C0434
SHIP QUANTITY : 45, 000 PCS
LOT QUANTITY 126, 608 PCS
HEADMARKS : GENIUS SYMBOL & 2 ARC LINES(120 DEGREE)
MANUFACTURE DATE : 2017/01/15
COUNTRY OF ORIGIN : CHINA

PACKING NO : GEM170220019
INVOICE NO : GEM/FNL-170308ED-1
PART NO : 1136308
SAMPLING PLAN : ASME B18.18-2011(Category.2)/ASTM F1470-2012
HEAT NO : 16BD0400
MATERIAL : 1022A
FINISH : Fe/Zn 3AN ASTM F1941/F1941M-2015

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO SAE J995-2012

Chemistry	C%	MN%	P%	S%	SI%
Spec. : MIN.		0.3000			
MAX.	0.5500		0.0500	0.1500	
Test Value	0.2000	0.7500	0.0160	0.0070	0.0500

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.2-2010

SAMPLED BY : LXQING

INSPECTIONS ITEM	SAMPLE	SPECIFIED		ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	5PCS	ASME B18.2.2-2010	0.7680-0.7940 inch	0.7710-0.7720 inch	5	0
FIM	15PCS		Max. 0.0180 inch	0.0140-0.0150 inch	15	0
THICKNESS	5PCS		0.3650-0.3850 inch	0.3680-0.3770 inch	5	0
WIDTH ACROSS FLATS	5PCS		0.6750-0.6880 inch	0.6770-0.6780 inch	5	0
SURFACE DISCONTINUITIES	29PCS		ASTM F812-2012	PASSED	29	0
THREAD	15PCS		GAGING SYSTEM 21	PASSED	15	0

MECHANICAL PROPERTIES : ACCORDING TO SAE J 995-2012

SAMPLED BY : SHENXIA JIN

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	15 PCS	ASTM F606-2014		Max. 32 HRC	25-27 HRC	15	0
PROOF LOAD	5 PCS	ASTM F606-2014		Min. 120,000 PSI	OK	5	0
PLATING THICKNESS(μ m)	29 PCS	ASTM B568-1998		>=5	5.3-7.87	29	0
SALT SPRAY TEST	15 PCS	ASTM B117-11		6 HOURS NO WHITE RUST, 12 HOURS NO RED RUST	OK	15	0

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER

Quality Supervisor: [signature]

Figure G-43. $^{7}/_{16}$-in. (11-mm) Dia. UNC Heavy Hex Nut, Test Nos. SPDA-4 and SPDA-5 (Item No. f6)

Certified Material Test Report to BS EN ISO 10204-2004 3.1

FOR USS FLAT WASHER HDG

COUNTRY OF ORIGIN: CHINA
CUSTOMER: FASTENAL
FACTORY NAME: IFI & MORGAN LTD.
FACTORY ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China

DESCRIPTION: 1
INVOICE NBR: TD16680155
PART NBR.: 33188
LOT NO.: 16H-168236-30

DATE: 2016-10-08
ORDER NBR. 210114135
QUANTITY:3240PCS

DIMENSIONS (UNIT:INCH)

	STANDARD	RESULT				
		1	2	3	4	5
INSIDE DIA	1.055-1.092	1.068	1.068	1.067	1.069	1.068
OUTSIDE DIA	2.493-2.530	2.514	2.513	2.514	2.514	2.511
THICKNESS	0.136-0.192	0.146	0.149	0.152	0.152	0.147

WE HEREBY CERTIFY THAT THIS WAS PRODUCED AS PER CUSTOMER'S REQUIREMENT.

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
HOT DIP GALVANIZED ASTM F2329				
	Min 43 um	48-64um	8	0

NOTE

1. QUANTITY OF SAMPLES: 5 PCS

2. JUDGEMENT: GOOD

3. CHIEF INSPECTOR:

IFI & MORGAN LTD.
检验专用章
QUANLITY CONTROL

Figure G-44. 1-in. (25-mm) Dia. Plain Round Washer, Test No. SPDA-4 (Item No. f7)

GRAINGER

100 Grainger Parkway
Lake Forest, IL 60045

CERTIFICATE OF COMPLIANCE

Date: April 4, 2017

Grainger Item #: 22UH07

Manufacturer #: U38400.043.0003

LOT#: 2015043021

Country or Origin: United States

Product Description: Flat Washer, Steel, Inch, Washer Material Grade Low Carbon, Fastener Finish Zinc Plated, Fits Bolt Sizes 7/16 In., Washer Inside Dia. 15/32 In., Washer Outside Dia. 1-1/8 In., Thickness 0.063 In., Washer Standards ASME B18.22.1, Package Quantity 50

C	MN	P	S	SI	CO	NI	CR	MO	SN	AL	N	V
.09	0.37	.012	.009	.011	.02	.01	. 04	.008	.003	.035	.005	.001

Grainger product(s) are manufactured in accordance to product description and standards as described in the Grainger General Catalog or on Grainger.com®.

Dossie Ware
Product Engineering Specialist
4/4/2017

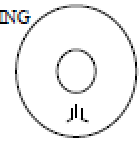
Dossie Ware

Figure G-45. $^{7}/_{16}$-in. (11-mm) Dia. Plain Round Washer, Test Nos. SPDA-1, SPDA-2, and SPDA-3 (Item No. f9)

HEXICO ENTERPRISE CO., LTD.

NO.355-3,SEC. 3,CHUNG SHAN ROAD,KAU-JEN,TAINAN,TAIWAN,R.O.C.
TEL : 886 - 6 - 2390616 FAX : 886 - 6 - 2308947

MARKING



INSPECTION CERTIFICATE

CUSTOMER	FASTENAL COMPANY		
PART NAME	FLAT WASHER		
SIZE	7/16 "	DATE	January 20, 2017
PART NO.	WYA3C3500S2LQ5	REPORT NO.	1060120-25
CUST. PART NO.	1133860	ORDER NO.	110214337
MATERIAL	S50C / 1.8 mm	DOCUMENT NO.	E1050608
HEAT(COIL) NO.	LU683	LOT NO.	58253FNQD
LOT QTY	67,500 PCS	MAF. QTY	67,500 PCS

THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH REQUIREMENT OF THE ORDER.

SAMPLING PLAN STANDARD	ASME B18.18-2011
DIMENSION STANDARD	ASME B18.21.1-2009
COATING STANDARD	ASTM F1941-2011
HARDNESS TEST METHOD	ASTM F606-2014
COATING TEST METHOD	ASTM E376-2011
SALT PRAY TEST METHOD	ASTM B117-2011

DIMENSIONS IN inch

	INSPECTION ITEM	SPECIFICATION	TEST QTY	INSPECTION RESULTS MIN.	INSPECTION RESULTS MAX.	INSPECTION EQUIPMENT
1	OUTSIDE DIAMETER	1.2430 - 1.2800	8	1.2520	1.2547	Caliper
2	INSIDE DIAMETER	0.4950 - 0.5150	8	0.5043	0.5059	Caliper
3	THICKNESS	0.0640 - 0.1040	8	0.0709	0.0732	Caliper
4	HARDNESS	HRC 38 - 45	5	39.7	40.9	Rockwell
5	COATING (BAKED)	ZINC YEL.CR6+ 0.0002 in.	5	0.0003	0.0004	Eddy current
6	SALT SPRAY TEST	72 hrs. No White Rust 96 hrs. No Red Rust	4	OK		S.S.T tester
7	APPEARANCE	VISUAL	100	OK		

INSPECTOR *Yu Tain Lin* QC CHIEF *Jing Yeh Tsao*

Figure G-46. $^{7}/_{16}$-in. (11-mm) Dia. Plain Round Washer, Test Nos. SPDA-4 and SPDA-5 (Item No. f9)

NUCOR

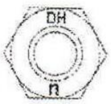
FASTENER DIVISION

LOT NO.
366055B

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
8061 STRUCTURAL BOLT CO LLC — NUCOR ORDER # 957233
TEST REPORT SERIAL# FB482520 — CUST PART #
TEST REPORT ISSUE DATE 1/08/16
DATE SHIPPED 1/21/16 — CUSTOMER P.O. # 18131
NAME OF LAB SAMPLER: JOSEPH BYERLY, LAB TECHNICIAN

****************CERTIFIED MATERIAL TEST REPORT****************



NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175647	3600	366055B	1-8 GR DH HV H.D.G. HEX NUT H.D.G./GREEN LUBE

MANUFACTURE DATE 10/01/15

--CHEMISTRY — MATERIAL GRADE -1045L

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI	
RM030068	DL15103032	.45	.67	.003	.019	.20	NUCOR STEEL - SOUTH CAROL

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-07a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	30.8	PASS	N/A	N/A
N/A	28.6	PASS	N/A	N/A
N/A	26.6	PASS	N/A	N/A
N/A	26.2	PASS	N/A	N/A
N/A	24.5	PASS	N/A	N/A
AVERAGE VALUES FROM TESTS	27.3			

PRODUCTION LOT SIZE 42800 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a — 80 PCS. SAMPLED — LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-13 - GALVANIZING PERFORMED IN THE U.S.A.
1. 0.00278 2. 0.00892 3. 0.00428 4. 0.00237 5. 0.00321 6. 0.00228 7. 0.00603
8. 0.00676 9. 0.00315 10. 0.00321 11. 0.00371 12. 0.00264 13. 0.00252 14. 0.00348
15. 0.00287
AVERAGE THICKNESS FROM 15 TESTS .00388
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2012

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.823	1.833
Thickness	32	0.978	0.996

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 01/31/16

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Figure G-47. 1-in. (25-mm) Dia. Hex Nut, Test Nos. SPDA-1, SPDA-2, SPDA-3, and SPDA-5 (Item No. f10)

NUCOR
FASTENER DIVISION

LOT NO.
371123B

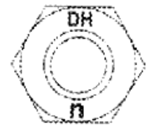
Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
8001 FASTENAL COMPANY-KS — NUCOR ORDER # 978943
TEST REPORT SERIAL# FB488556 — CUST PART # 38210
TEST REPORT ISSUE DATE 3/04/16
DATE SHIPPED 8/17/16 — CUSTOMER P.O. # 210117217
NAME OF LAB SAMPLER: SANDRA NEUMANN-PLUMMER, LAB TECHNICIAN

*****************CERTIFIED MATERIAL TEST REPORT*****************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175647	3600	371123B	1-8 GR DH HV H.D.G.

MANUFACTURE DATE 1/07/16 — HEX NUT H.D.G./GREEN LUBE



--CHEMISTRY — MATERIAL GRADE -1045L

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER — NUCOR STEEL - SOUTH CAROL

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM030412	DL15105591	.44	.64	.005	.020	.20

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-07a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	26.6	PASS	N/A	N/A
N/A	27.0	PASS	N/A	N/A
N/A	27.6	PASS	N/A	N/A
N/A	28.9	PASS	N/A	N/A
N/A	26.7	PASS	N/A	N/A

AVERAGE VALUES FROM TESTS
27.4
PRODUCTION LOT SIZE 90800 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a — 80 PCS. SAMPLED — LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-13 - GALVANIZING PERFORMED IN THE U.S.A.

1. 0.00294 2. 0.00311 3. 0.00346 4. 0.00235 5. 0.00218 6. 0.00270 7. 0.00353
8. 0.00322 9. 0.00406 10. 0.00269 11. 0.00275 12. 0.00315 13. 0.00487 14. 0.00253
15. 0.00416

AVERAGE THICKNESS FROM 15 TESTS .00318
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.824	1.844
Thickness	32	0.980	1.001

Figure G-48. 1-in. (25-mm) Dia. UNC Hex Nut, Test Nos. SPDA-4 (Item No. f10)

McMASTER-CARR Certificate of Compliance

600 N County Line Rd
Elmhurst IL 60126-2081
630-600-3600
chi.sales@mcmaster.com

University of Nebraska
Midwest Roadside Safety Facility
M W R S F
4630 Nw 36TH St
Lincoln NE 68524-1802
Attention: Shaun M Tighe
Midwest Roadside Safety Facility

Purchase Order
E000357170

Order Placed By
Shaun M Tighe

McMaster-Carr Number
2098331-01

Page 1 of 1

Line		Product	Ordered	Shipped
1	**97812A109**	Steel Double-Headed Nail Size 16D, 3" Length, .16" Shank Diameter, 200 Pieces/Pack, Packs of 5	**5 Packs**	**5**

Certificate of compliance

This is to certify that the above items were supplied in accordance with the description and as illustrated in the catalog. Your order is subject only to our terms and conditions, available at www.mcmaster.com or from our Sales Department.

Sarah Weinberg
Compliance Manager

Figure G-49. 16D Double Head Nail, Test Nos. SPDA-4 and SPDA-5 (Item No. f11)

Appendix H. Dynamic Jerk Test Results

The results of the recorded data from each accelerometer for dynamic jerk tests are provided herein. The summary sheets include acceleration, velocity, deflection versus time, force versus deflection, and energy versus deflection plots.

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Dynamic jerk test, design concept no. 1
Test Number:	SPDA-1
Test Date:	4/7/2017
Failure Type:	Pull cable fractured, exceeded the breaking strength

Post Properties

Post Type:	W6x9 with four 3/4" diameter holes
Post Size:	W6x9 Steel Post
Post Length:	27.75 in.
Embedment Depth:	69.25 in.
Orientation:	Weak-axis bending

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	18.31 mph	(26.86 ft/s)
Impact Height:	NA	
Bogie Mass:	6667 lb	

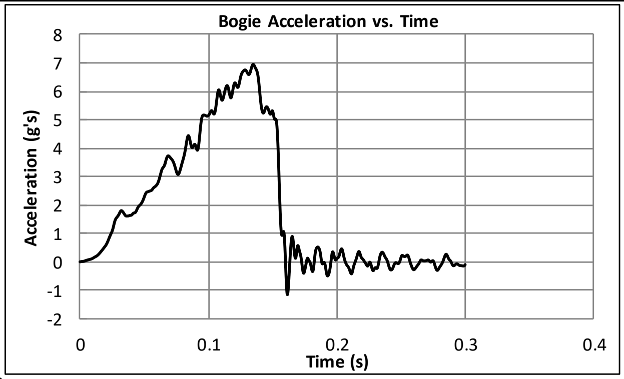
Data Acquired

Accelerometer:	SLICE-1
Camera Data:	aos01, aos09

Test Results Summary

Event Duration:	0.3000	sec
Max. Deflection:	54.0	in.
Peak Force:	46.3	k
Initial Linear Stiffness:	1.3	k/in.
Total Energy:	802.2	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	0.72	3.55	6.23	8.93
Energy (k-in.)	3.6	35.5	93.4	178.6



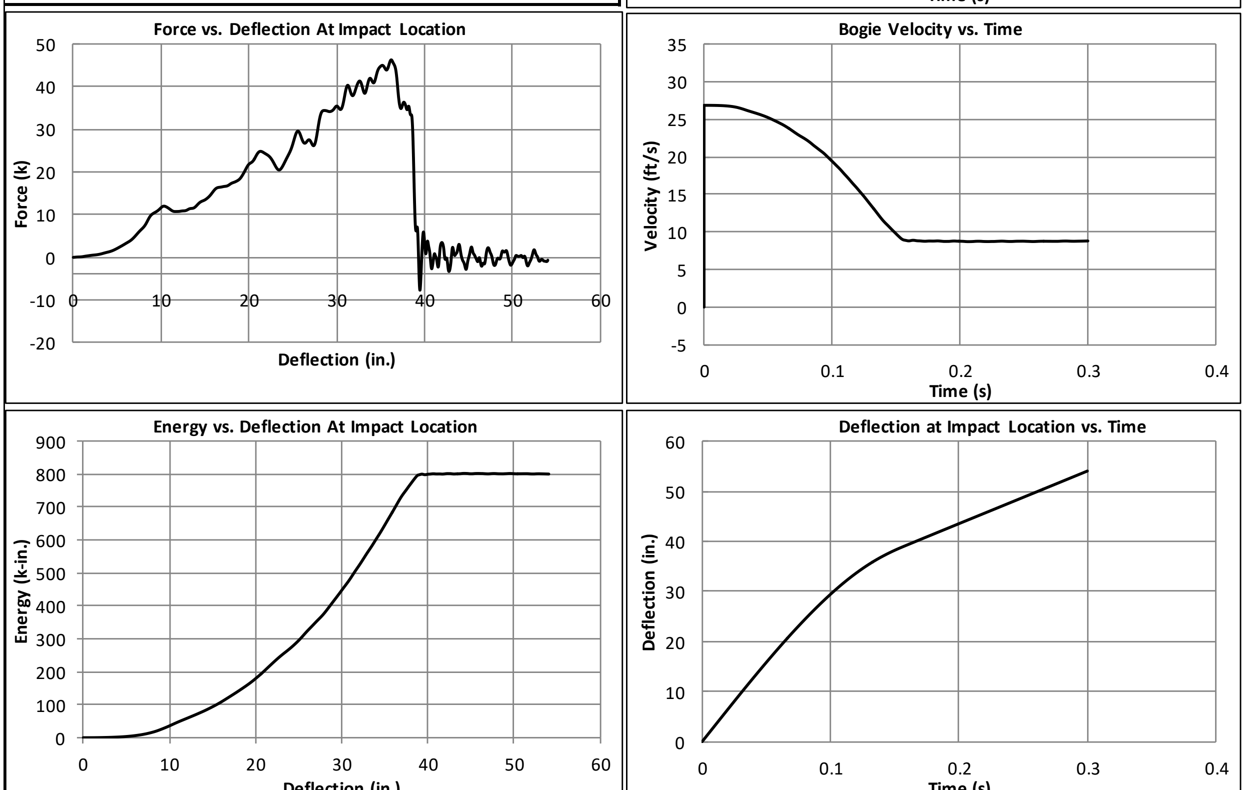


Figure H-1. Test No. SPDA-1 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Dynamic jerk testm design concept no. 1
Test Number:	SPDA-1
Test Date:	4/7/2017
Failure Type:	Pull cable fractured, exceeded the breaking strength

Post Properties

Post Type:	W6x9 with four 3/4" diameter holes
Post Size:	W6x9 Steel Post
Post Length:	27.75 in.
Embedment Depth:	69.25 in.
Orientation:	Weak-axis bending

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	18.31 mph	(26.86 ft/s)
Impact Height:	NA	
Bogie Mass:	6667 lb	

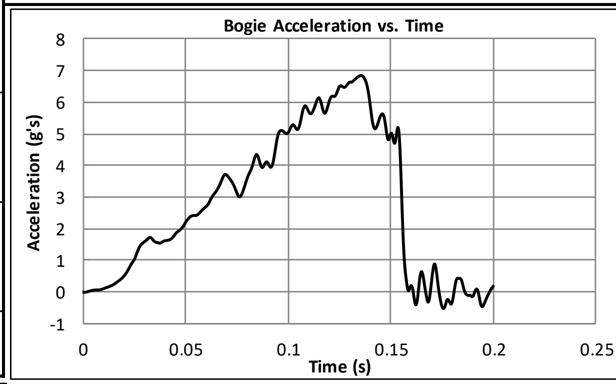
Data Acquired

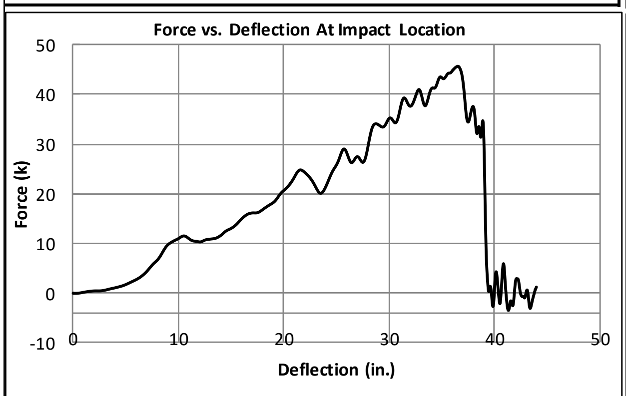
Accelerometer:	SLICE-2
Camera Data:	aos09

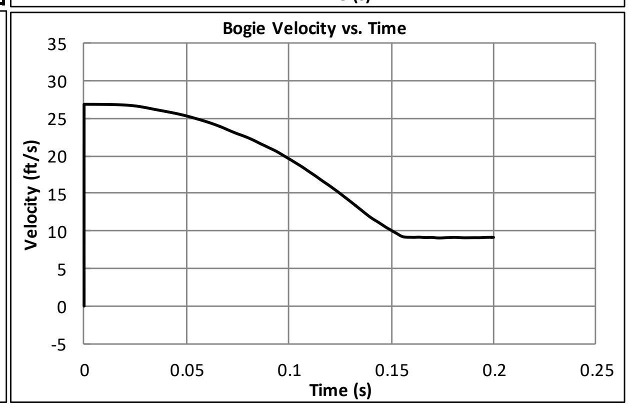
Test Results Summary

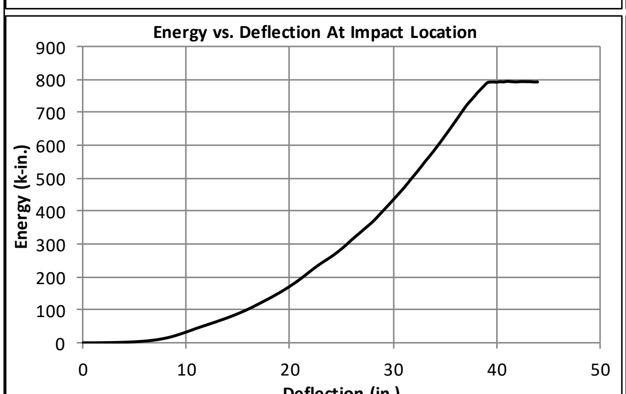
Event Duration:	0.2000	sec
Max. Deflection:	44.0	in.
Peak Force:	45.6	k
Initial Linear Stiffness:	1.2	k/in.
Total Energy:	794.3	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	0.59	3.26	5.91	8.55
Energy (k-in.)	2.9	32.6	88.6	171.0









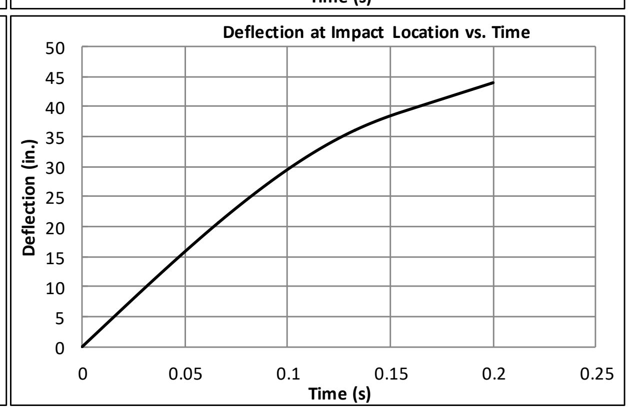


Figure H-2. Test No. SPDA-1 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Dynamic jerk test, design concept no. 2
Test Number:	spda-2
Test Date:	4/10/2017
Failure Type:	Anchor post broke away releasing BCT anchor cable

Post Properties

Post Type:	W6x9 with four 3/4" diameter holes
Post Size:	W6x9 Steel Post
Post Length:	27.75 in.
Embedment Depth:	69.25 in.
Orientation:	Weak-axis bending

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	18.33 mph	(26.88 ft/s)
Impact Height:	NA	
Bogie Mass:	6667 lb	

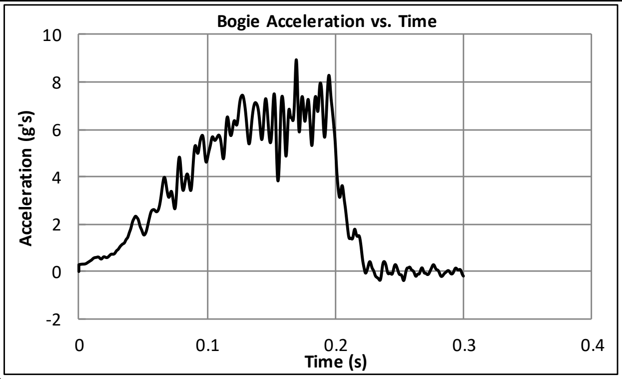
Data Acquired

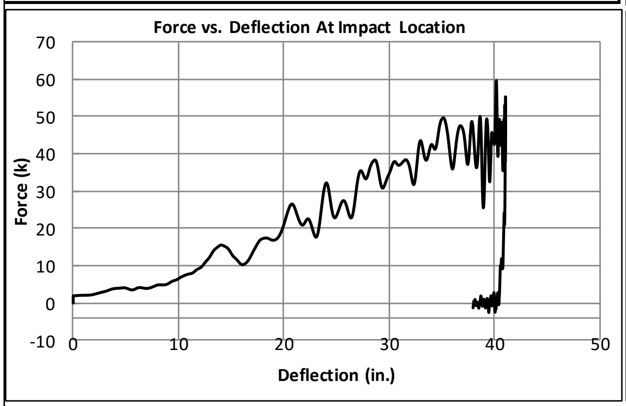
Accelerometer:	SLICE-1
Camera Data:	aos09

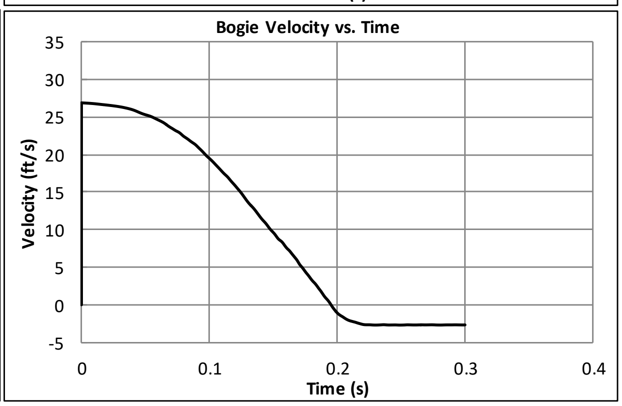
Test Results Summary

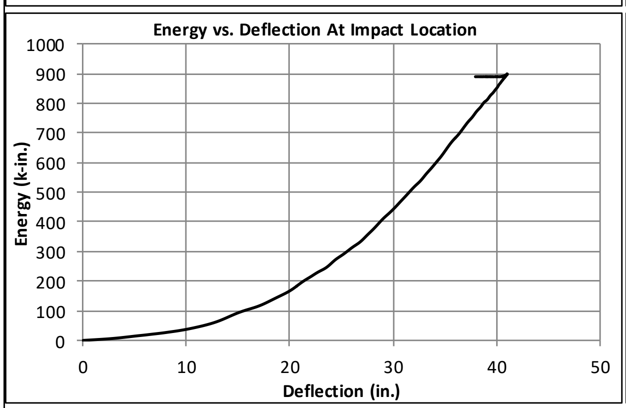
Event Duration:	0.3000	sec
Max. Deflection:	41.1	in.
Peak Force:	59.6	k
Initial Linear Stiffness:	1.5	k/in.
Total Energy:	898.2	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	2.88	3.72	6.19	8.33
Energy (k-in.)	14.4	37.2	92.9	166.7









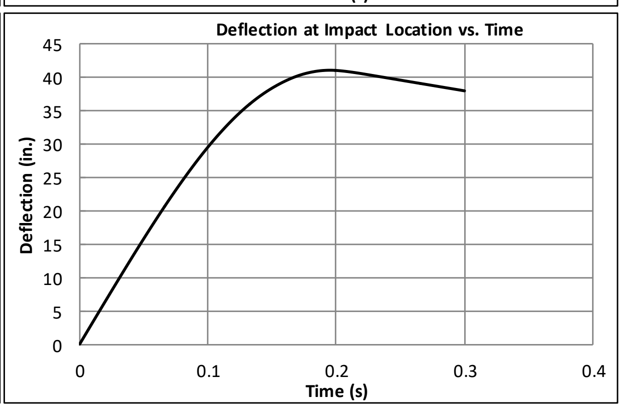


Figure H-3. Test No. SPDA-2 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Dynamic jerk test, design concept no. 2
Test Number:	spda-2
Test Date:	4/10/2017
Failure Type:	Anchor post broke away releasing BCT anchor cable

Post Properties

Post Type:	W6x9 with four 3/4" diameter holes
Post Size:	W6x9 Steel Post
Post Length:	27.75 in.
Embedment Depth:	69.25 in.
Orientation:	Weak-axis bending

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	18.33 mph	(26.88 ft/s)
Impact Height:	NA	
Bogie Mass:	6667 lb	

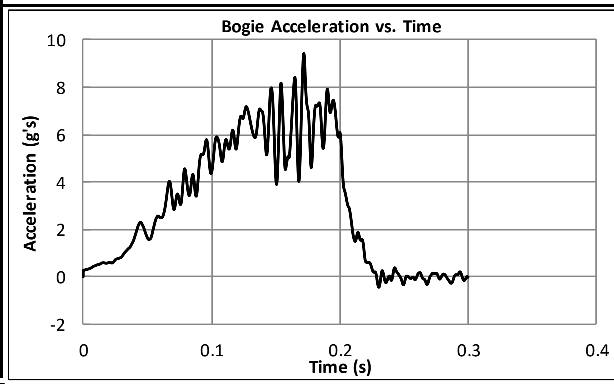
Data Acquired

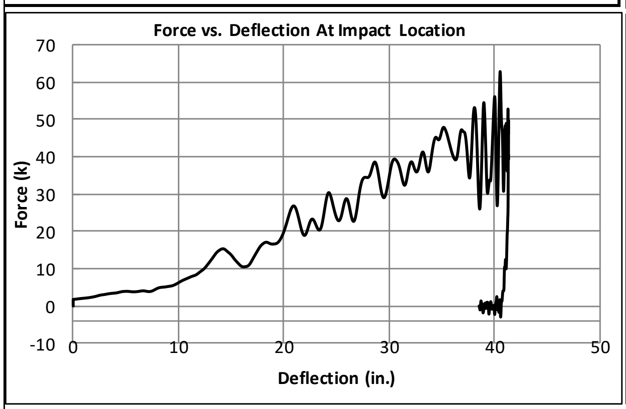
Accelerometer:	SLICE-2
Camera Data:	aos09

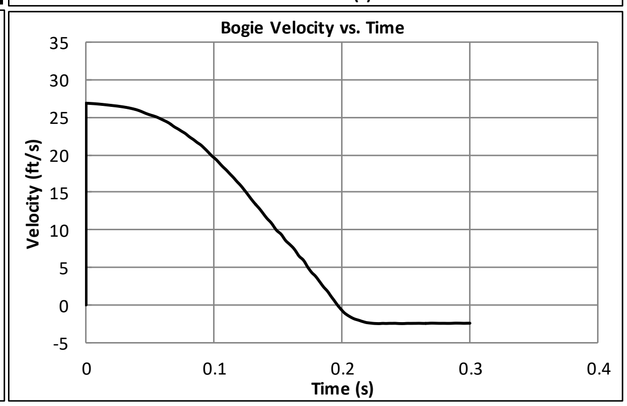
Test Results Summary

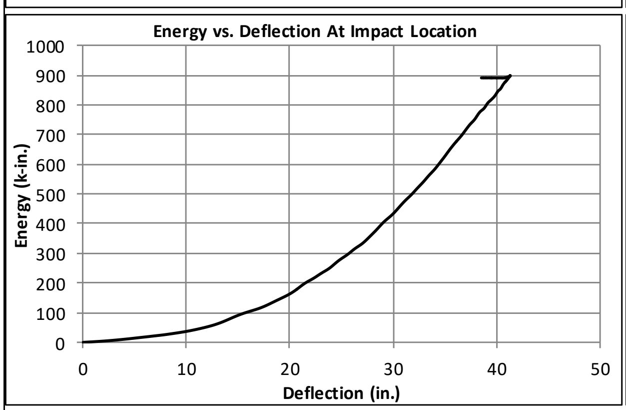
Event Duration:	0.3000	sec
Max. Deflection:	41.3	in.
Peak Force:	62.8	k
Initial Linear Stiffness:	1.5	k/in.
Total Energy:	898.2	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	2.81	3.66	6.06	8.15
Energy (k-in.)	14.1	36.6	90.9	163.0









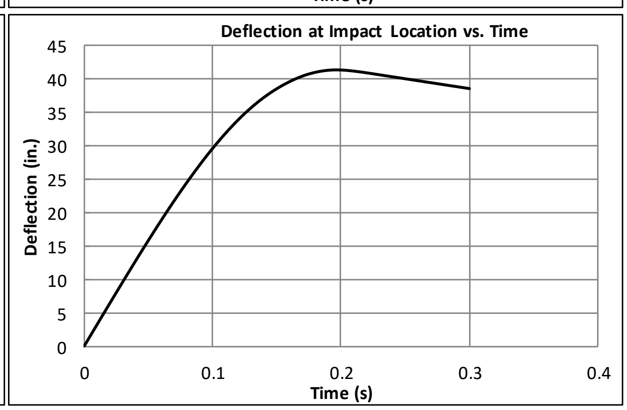


Figure H-4. Test No. SPDA-2 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Dynamic jerk test, design concept no. 3
Test Number:	spda-3
Test Date:	4/12/2017
Failure Type:	Anchor post fractured in tension

Post Properties

Post Type:	W6x9 with four 3/4" diameter holes
Post Size:	W6x9 Steel Post
Post Length:	27.75 in.
Embedment Depth:	69.25 in.
Orientation:	Weak-axis bending

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	19.17 mph	(28.12 ft/s)
Impact Height:	NA	
Bogie Mass:	6667 lb	

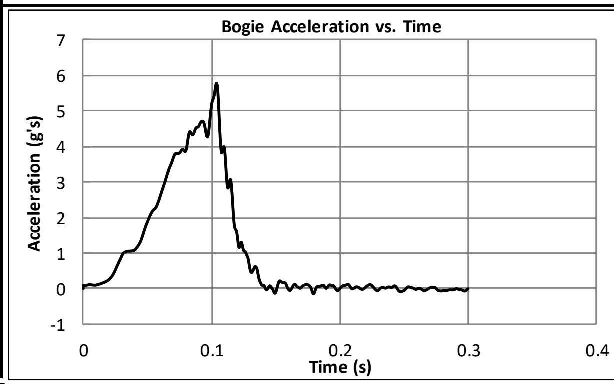
Data Acquired

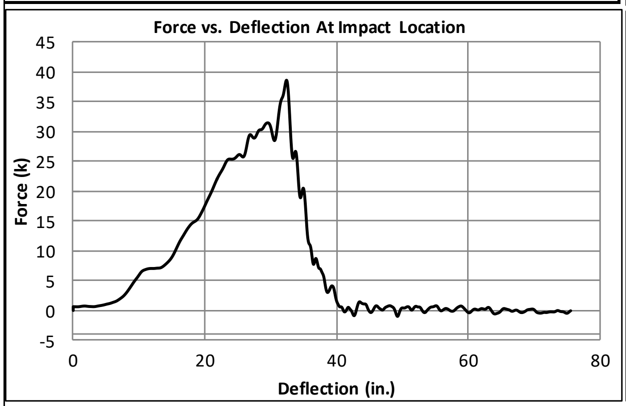
Accelerometer:	SLICE-1
Camera Data:	aos09

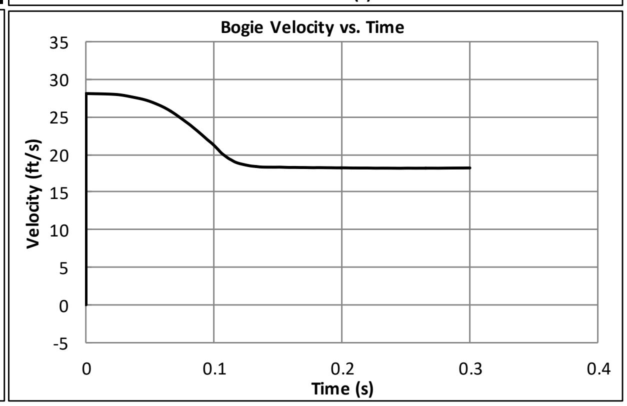
Test Results Summary

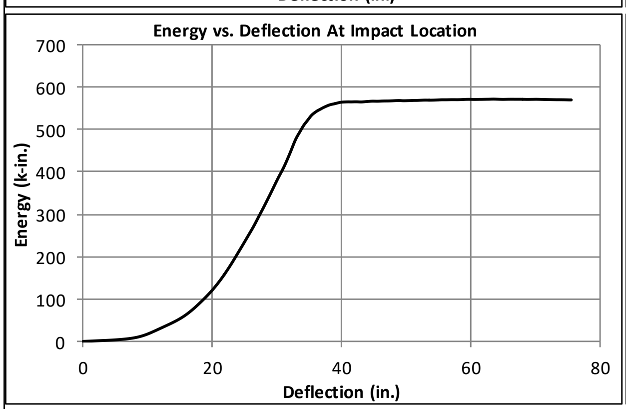
Event Duration:	0.3000	sec
Max. Deflection:	75.6	in.
Peak Force:	38.6	k
Initial Linear Stiffness:	1.2	k/in.
Total Energy:	571.9	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	0.73	1.75	3.58	6.05
Energy (k-in.)	3.6	17.5	53.6	121.0









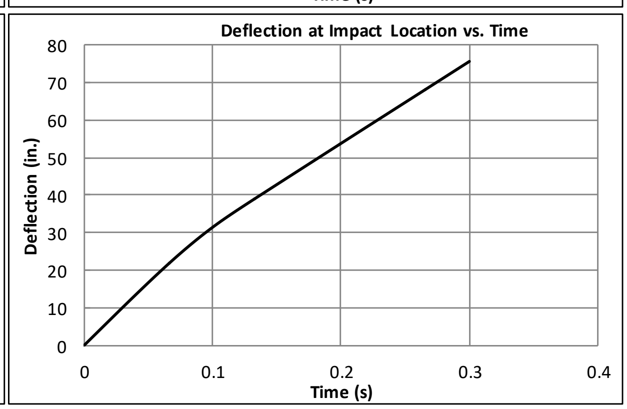


Figure H-5. Test No. SPDA-3 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Dynamic jerk test, design concept no. 3
Test Number:	spda-3
Test Date:	4/12/2017
Failure Type:	Anchor post fractured in tension

Post Properties

Post Type:	W6x9 with four 3/4" diameter holes
Post Size:	W6x9 Steel Post
Post Length:	27.75 in.
Embedment Depth:	69.25 in.
Orientation:	Weak-axis bending

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	19.17 mph	(28.12 ft/s)
Impact Height:	NA	
Bogie Mass:	6667 lb	

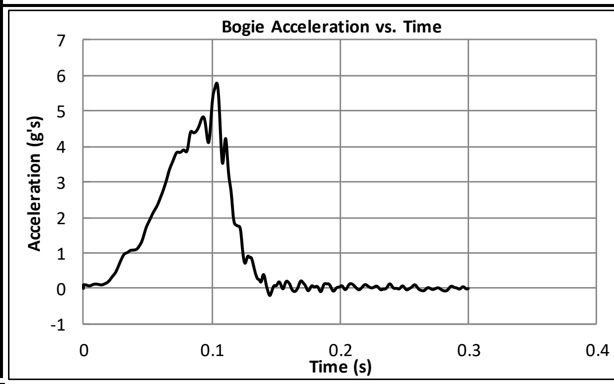
Data Acquired

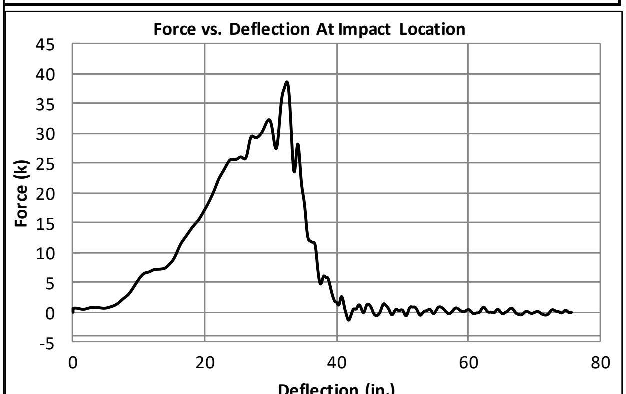
Accelerometer:	SLICE-2
Camera Data:	aos09

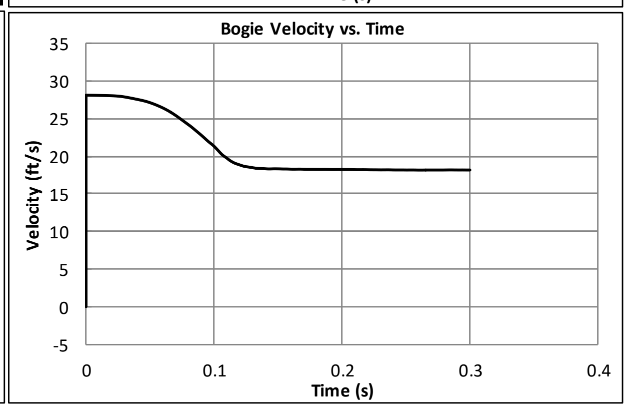
Test Results Summary

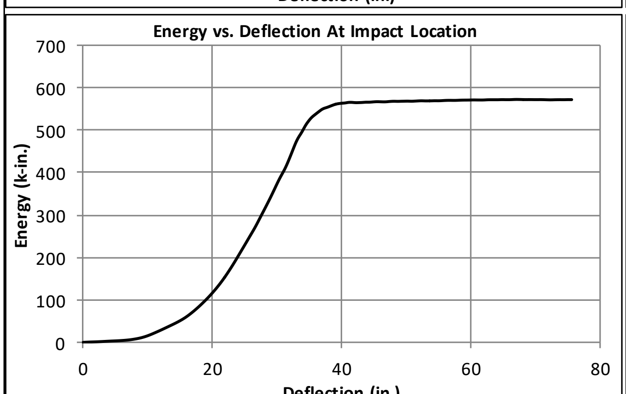
Event Duration:	0.3000	sec
Max. Deflection:	75.7	in.
Peak Force:	38.6	k
Initial Linear Stiffness:	1.2	k/in.
Total Energy:	572.7	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	0.68	1.56	3.38	5.80
Energy (k-in.)	3.4	15.6	50.7	116.0









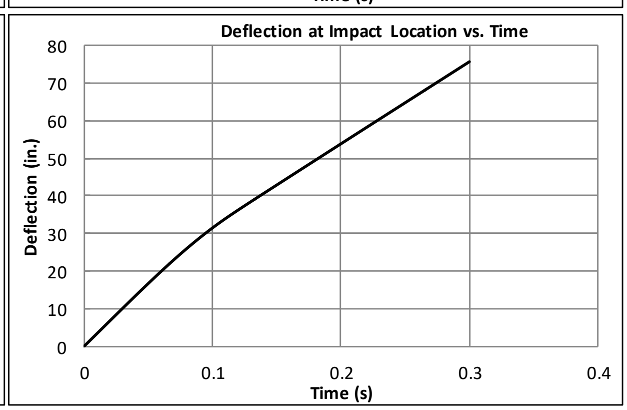


Figure H-6. Test No. SPDA-3 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Dynamic jerk test, design concept no. 4
Test Number:	SPDA-4
Test Date:	6/22/2017
Failure Type:	Anchor post fractured in tension

Post Properties

Post Type:	W6x9 with four 3/4" diameter holes
Post Size:	W6x9 Steel Post
Post Length:	27.75 in.
Embedment Depth:	69.25 in.
Orientation:	Weak-axis bending

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	21.14 mph	(31.01 ft/s)
Impact Height:	NA	
Bogie Mass:	6667 lb	

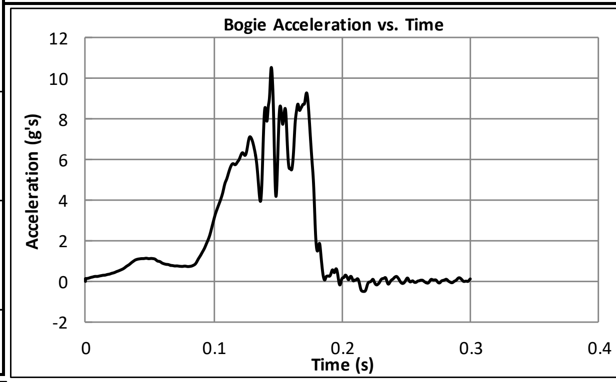
Data Acquired

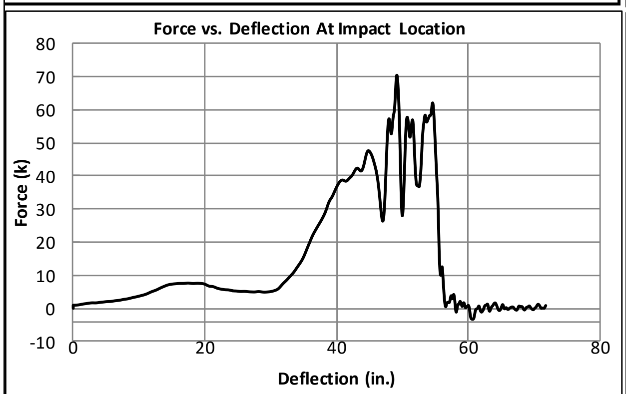
Accelerometer:	SLICE-1
Camera Data:	aos09

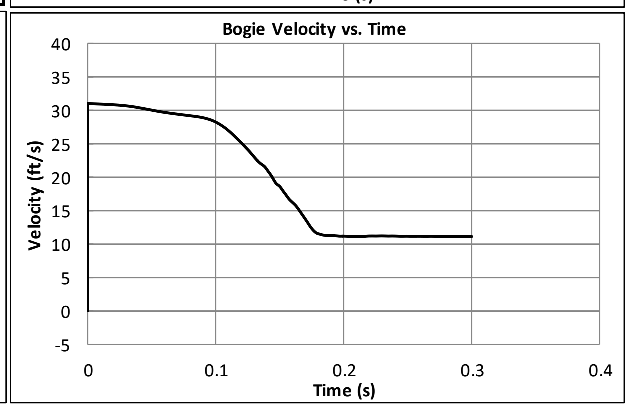
Test Results Summary

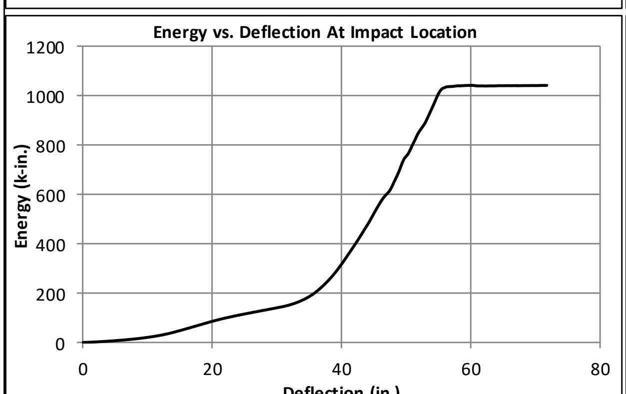
Event Duration:	0.3000	sec
Max. Deflection:	71.8	in.
Peak Force:	70.4	k
Initial Linear Stiffness:	1.4	k/in.
Total Energy:	1041.8	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	1.46	2.06	3.19	4.28
Energy (k-in.)	7.3	20.6	47.9	85.5









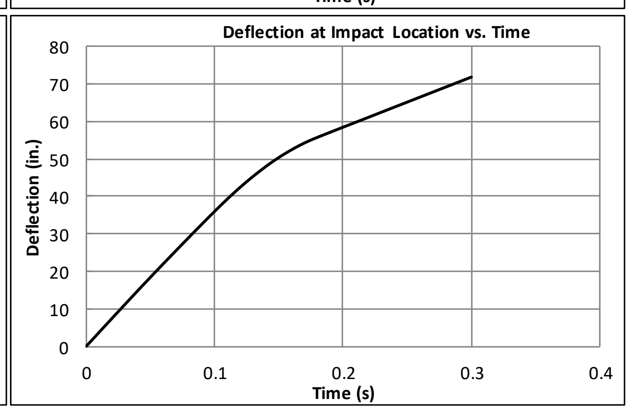


Figure H-7. Test No. SPDA-4 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Dynamic jerk test, design concept no. 4
Test Number:	SPDA-4
Test Date:	6/22/217
Failure Type:	Anchor post fractured in tension

Post Properties

Post Type:	W6x9 with four 3/4" diameter holes
Post Size:	W6x9 Steel Post
Post Length:	27.75 in.
Embedment Depth:	69.25 in.
Orientation:	Weak-axis bending

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	21.14 mph	(31.01 ft/s)
Impact Height:	NA	
Bogie Mass:	6667 lb	

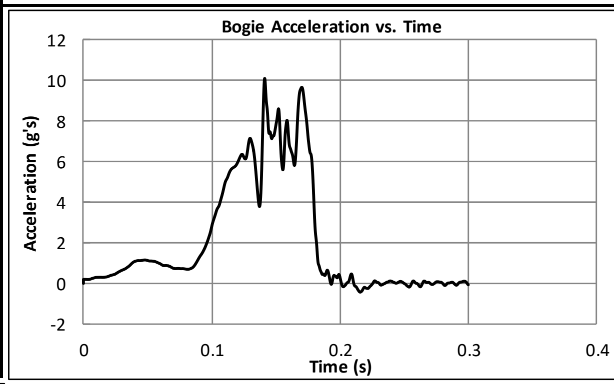
Data Acquired

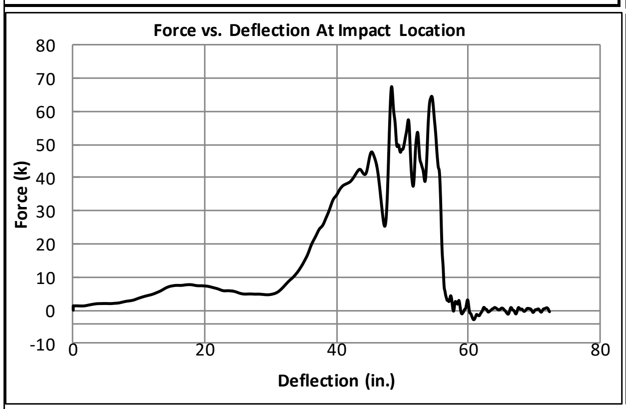
Accelerometer:	SLICE-2
Camera Data:	aos09

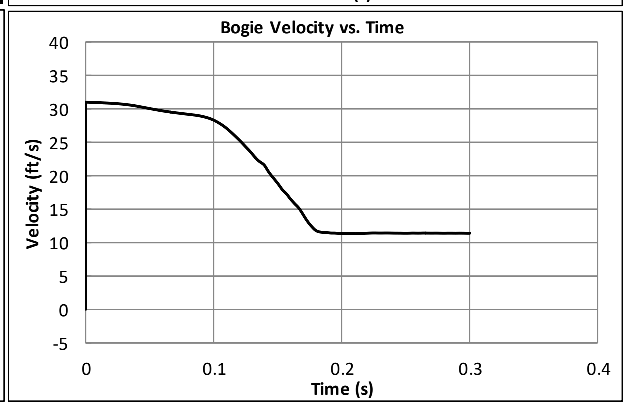
Test Results Summary

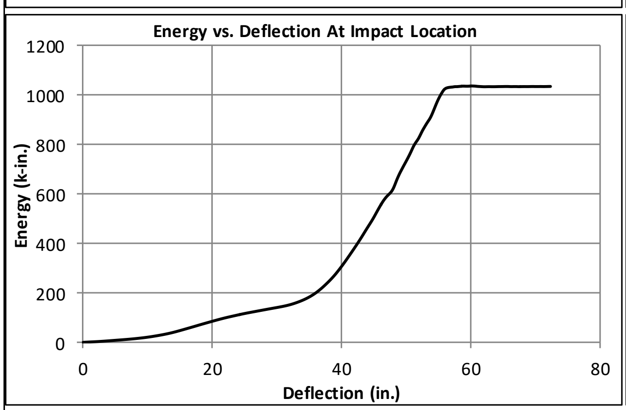
Event Duration:	0.3000	sec
Max. Deflection:	72.4	in.
Peak Force:	67.4	k
Initial Linear Stiffness:	1.4	k/in.
Total Energy:	1036.2	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	1.62	2.07	3.15	4.24
Energy (k-in.)	8.1	20.7	47.2	84.9









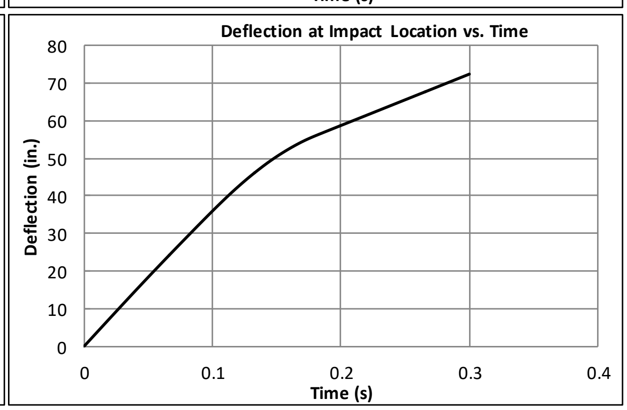


Figure H-8. Test No. SPDA-4 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Dynamic jerk test, design concept no. 5
Test Number:	SPDA-5
Test Date:	6/23/2017
Failure Type:	Rail tearing at second anchor post

Post Properties

Post Type:	W6x9 with four 3/4" diameter holes
Post Size:	W6x9 Steel Post
Post Length:	27.75 in.
Embedment Depth:	69.25 in.
Orientation:	Weak-axis bending

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	20.59 mph	(30.2 ft/s)
Impact Height:	NA	
Bogie Mass:	6667 lb	

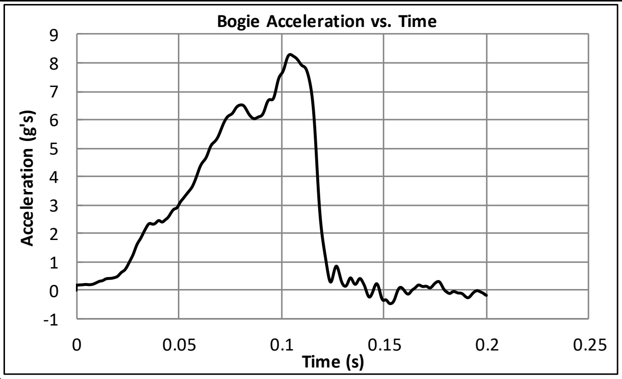
Data Acquired

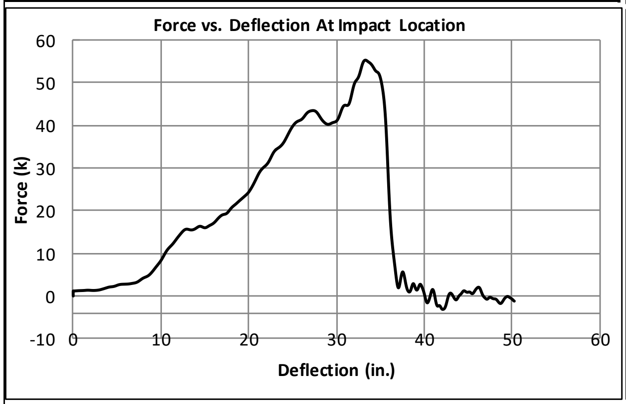
Accelerometer:	SLICE-1
Camera Data:	aos09

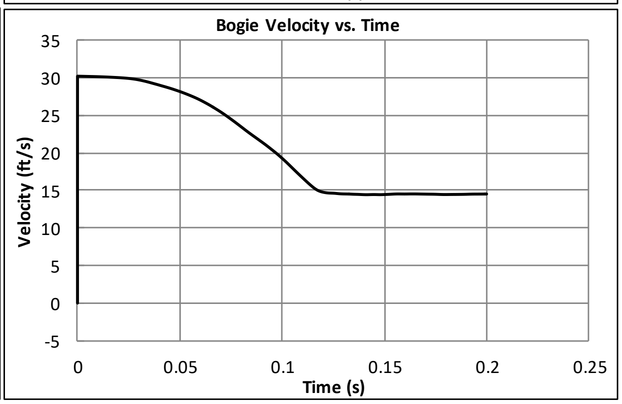
Test Results Summary

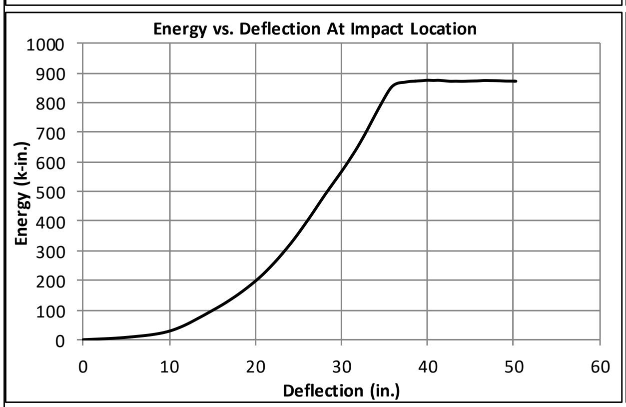
Event Duration:	0.2000	sec
Max. Deflection:	50.3	in.
Peak Force:	55.3	k
Initial Linear Stiffness:	1.7	k/in.
Total Energy:	874.9	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	1.57	2.88	6.52	9.84
Energy (k-in.)	7.8	28.8	97.8	196.8









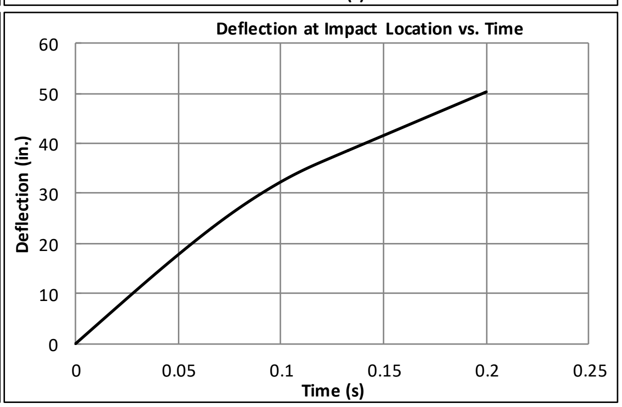


Figure H-9. Test No. SPDA-5 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Dynamic jerk test, design concept no. 5
Test Number:	SPDA-5
Test Date:	6/23/2017
Failure Type:	Rail tearing at second anchor post

Post Properties

Post Type:	W6x9 with four 3/4" diameter holes
Post Size:	W6x9 Steel Post
Post Length:	27.75 in.
Embedment Depth:	69.25 in.
Orientation:	Weak-axis bending

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	20.59 mph	(30.2 ft/s)
Impact Height:	NA	
Bogie Mass:	6667 lb	

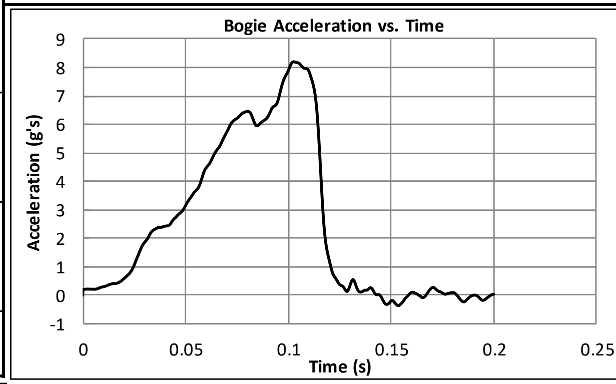
Data Acquired

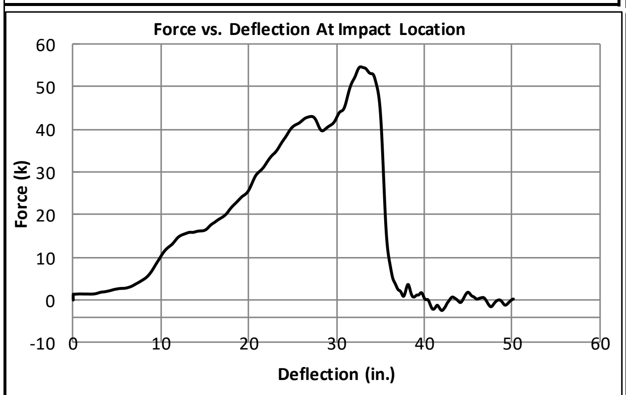
Accelerometer:	SLICE-2
Camera Data:	aos09

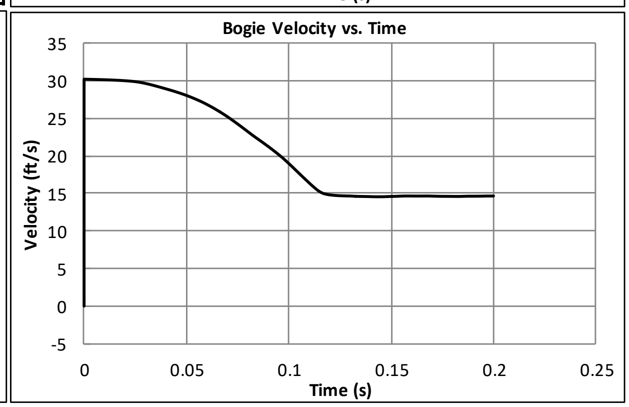
Test Results Summary

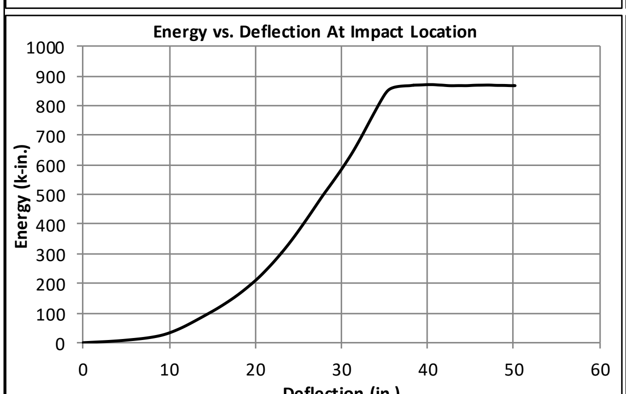
Event Duration:	0.2000	sec
Max. Deflection:	50.2	in.
Peak Force:	54.7	k
Initial Linear Stiffness:	1.7	k/in.
Total Energy:	870.4	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	1.71	3.28	7.02	10.43
Energy (k-in.)	8.6	32.8	105.3	208.6









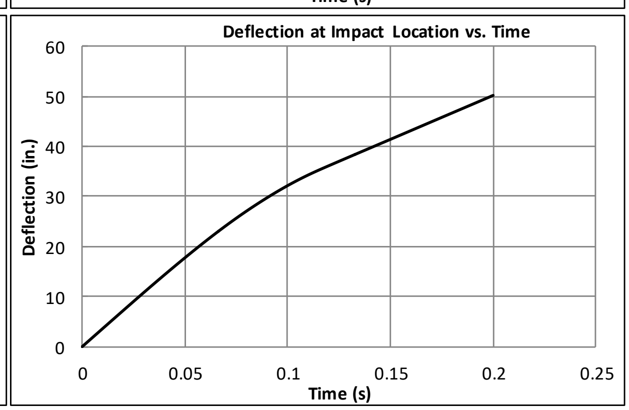


Figure H-10. Test No. SPDA-5 Results (SLICE-2)

Appendix I. Survey Data

A summary of design details for the three candidate design concepts for steel-post, trailing-end anchorage system along with the ground line strut concepts were presented to the Midwest Pooled Fund Program member states. A survey was sent out to the member states to rank the design options for (1) trailing-end anchorage system, and (2) ground line strut based on their best engineering preference, as shown in Tables I-1 and I-2. It should be noted that 1 was the preferred, 3 (in the case of the steel-post, trailing-end anchorage system option – Table I-1), and 4 (in the case of the ground line strut – Table I-2) was the least desired option. The Midwest Pooled Fund Program member states' responses are presented in Tables I-3 and I-4. Per the state DOTs input, the final prototype was design concept no. 2 (i.e., cable passing through top post). Additionally, for ground line strut, design concept no. 1 (i.e., bolted yoke placed outside strut) was selected.

Table I-1. Survey Question 1 - Steel Downstream Anchorage Design Concepts

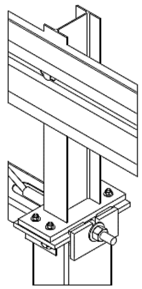
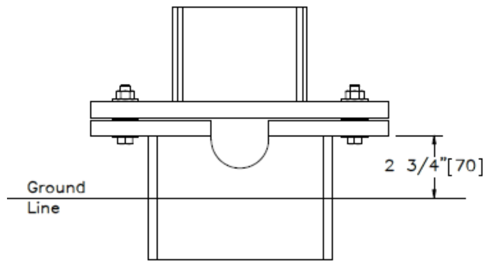
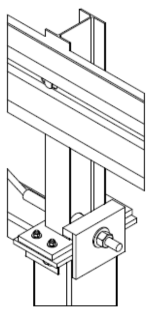
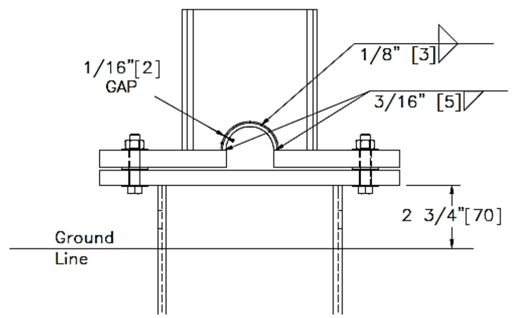
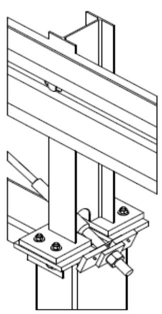
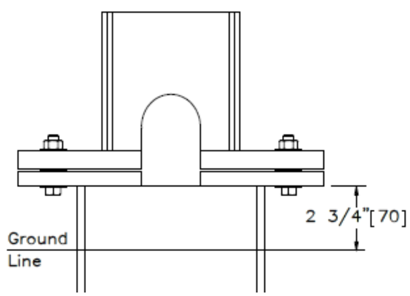
Design Concepts	Steel Downstream Anchorage Design Concepts – Details	State Ranking
Concept No. 2 **Cable Passing through Bottom Post**	  	
Concept No. 4 **Cable Passing through Top Post**	  	
Concept No. 5 **Angled Plate**	  	

Table I-2. Survey Question 2 - Ground Line Strut Design Concepts

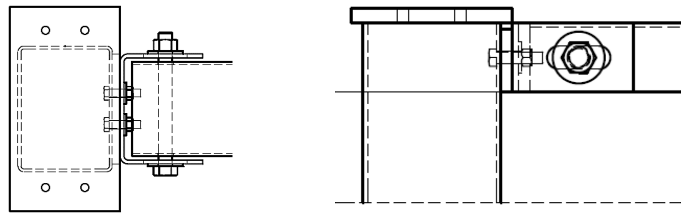
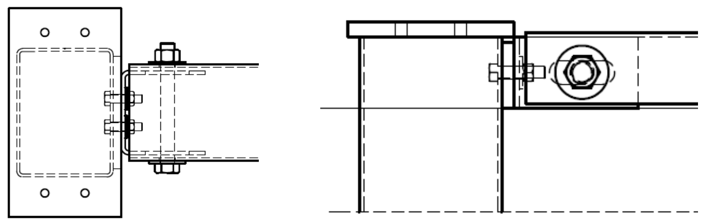
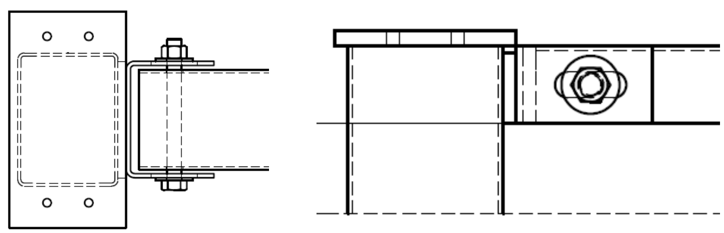
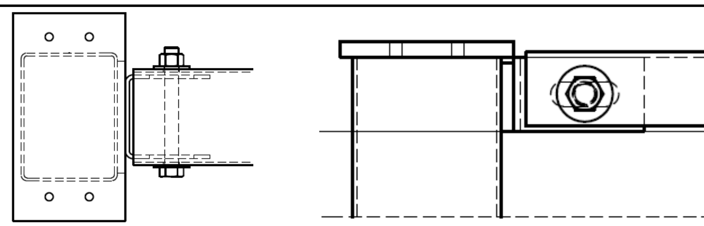
Design Concepts	Ground Line Strut Design Concepts – Details	State Ranking
Concept No. 1 **Bolted Yoke Placed Outside Strut**		
Concept No. 2 **Bolted Yoke Placed Inside Strut**		
Concept No. 3 **Welded Yoke Placed Outside Strut**		
Concept No. 4 **Welded Yoke Placed Inside Strut**		

Table I-3. Survey Results – Steel Downstream Anchorage Design Concepts Ranking

Design Concepts	California	Florida	Illinois	Indiana	Iowa	Kansas	Kentucky	Minnesota	Missouri	Nebraska	New Jersey	North Carolina	Ohio	South Carolina	South Dakota	Utah	Virginia	Wisconsin	Wyoming	Total
Concept No. 2 Cable Passing through Bottom Post	1	3	2	1	3	2	2	2	1	2	2	3	1	1	2	1	1	1	2	33
Concept No. 4 Cable Passing through Top Post	2	1	1	2	1	1	1	1	2	1	1	1	2	1	1	2	2	2	1	26
Concept No. 5 Angled Plate	3	2	3	3	2	3	3	3	3	2	3	2	3	1	3	3	3	2	3	50

Table I-4. Survey Results – Ground Line Strut Design Concepts Ranking

Design Concepts	California	Florida	Illinois	Indiana	Iowa	Kansas	Kentucky	Minnesota	Missouri	Nebraska	New Jersey	North Carolina	Ohio	South Carolina	South Dakota	Utah	Virginia	Wisconsin	Wyoming	Total
Concept No. 1 Bolted Yoke Placed Outside Strut	1	3	1	2	1	3	1	2	1	1	2	3	1	1	3	2	1	2	1	32
Concept No. 2 Bolted Yoke Placed Inside Strut	3	4	2	4	2	4	2	4	3	1	4	4	2	1	1	4	3	2	2	52
Concept No. 3 Welded Yoke Placed Outside Strut	2	1	3	1	3	1	2	1	2	1	1	1	3	1	4	1	2	1	4	35
Concept No. 4 Welded Yoke Placed Inside Strut	4	2	4	3	4	2	2	3	4	1	3	2	4	1	2	4	4	2	3	54

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