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# MASH TEST NO. 3-10 OF A NON-PROPRIETARY, HIGH-TENSION, CABLE MEDIAN BARRIER FOR USE IN 6H:1V V-DITCH (TEST NO. MWP-9)

Submitted by

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16. Abstract

The Midwest Pooled Fund Program has been developing a prototype design for a non-proprietary, high-tension, cable median barrier for use in a 6H:1V median V-ditch. This system incorporates four evenly spaced cables, Midwest Weak Posts (MWPs) spaced at 8 to 16 ft (2.4 to 4.9 m) intervals, and a bolted, tabbed bracket to attach the cables to each post. Full-scale crash testing was needed to evaluate the barrier's safety performance. According to the *Manual for Assessing Safety Hardware* 2016 (MASH) testing matrix for cable barriers installed within a 6H:1V median V-ditch, a series of eight full-scale crash tests are required to evaluate the safety performance of a system.

Several previous tests have failed due to the posts penetrating into the occupant compartment. In order to mitigate the floor pan tearing, a modified MWP was designed. Test no. MWP-9 was conducted on the modified barrier system, consisting of MWPs with ¾-in. (19-mm) diameter weakening holes at the ground line. Additionally, a two-part cap with a single retainer bolt was added to the top of the posts. The cap shielded the free edges of the MWPs during the post-to-vehicle contact. This test was conducted according to MASH 2016 test designation no. 3-10 and utilized an 1100C small car impacting the barrier on level terrain. The vehicle was contained by the system. The two-piece cap mitigated the floor pan tearing. However, one cable (cable no. 3) snagged on the cap retainer bolt and caused two cables (cable nos. 3 and 4) to become interlocked with the left-side A-pillar on the impact side of the vehicle, which resulted in excessive A-pillar crush. Therefore, test no. MWP-9 was deemed unacceptable. However, the two-part cap demonstrated that a closed-section post should be capable of mitigating floor pan tearing.

| | | | |
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## DISCLAIMER STATEMENT

This report was completed with funding from the Federal Highway Administration, U.S. Department of Transportation and the Midwest Pooled Fund Program. 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 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, regulation, product endorsement, or an endorsement of 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.

## INDEPENDENT APPROVING AUTHORITY

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

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# 1 INTRODUCTION

## 1.1 Background

In recent years, the Midwest Pooled Fund Program has been developing a non-proprietary, high-tension, cable median barrier in conjunction with the Midwest Roadside Safety Facility (MwRSF) [1]. This cable barrier system was intended for use anywhere within a 6H:1V median V-ditch and consisted of four cables supported by Midwest Weak Posts (MWPs) spaced at 8 ft intervals (2.4 m). A bolted, tabbed bracket was utilized to attach the lower three cables to alternating sides of the MWPs, while a brass keeper rod was utilized to contain the top cable within a V-notch cut into the top of the posts.

Previously, this cable barrier system was subjected to eight full-scale crash tests in accordance with the *Manual for Assessing Safety Hardware* (MASH) 2009 and 2016 [2-3]. Note that there is no difference between MASH 2009 and MASH 2016 test designation nos. 3-10 and 3-11 for longitudinal barriers, including the cable barriers studied in this research.

Test no. MWP-1, in accordance with MASH 2009 test designation no. 3-17, was conducted with a 1500A mid-size sedan impacting the system on the slope break point of a 6H:1V median V-ditch. During the test, the sedan was successfully captured and redirected by cable no. 2, having overridden cable no. 1 and underridden cable nos. 3 and 4 [1].

For test no. MWP-2, the barrier was placed on level terrain, and the system cables were mirrored so that cable no. 2 was on the impact side of the posts and cable nos. 1 and 3 were on the non-impact side. A 16-ft (4.9-m) post spacing was utilized to evaluate the system's maximum deflection and working width. During the test, the front tires of the 2270P pickup overrode cable nos. 1 and 3. However, cable nos. 2 and 4 successfully captured and contained the vehicle [1].

For test no. MWP-3, the post spacing was changed to 8 ft (2.4 m) to evaluate the system deflections and working width with tighter post spacing. During the test, the 2270P pickup was initially captured by cable nos. 2 and 3 after overriding cable no. 1 and underriding cable no. 4. However, the capture cables were eventually pushed downward and overridden by the left-front tire of the pickup. After containment of the vehicle was lost, the cables wrapped around the left-rear tire and yawed the pickup rapidly toward the barrier. The pickup ultimately rolled over as the right-side tires dug into the ground [1].

Modifications were made to improve the system performance, which required further full-scale crash testing to evaluate the crashworthiness of the system according to the MASH 2009 Test Level 3 (TL-3) criteria [2]. Test no. MWP-4 was conducted in accordance with MASH 2009 test no. 3-11. The barrier was placed on level terrain and utilized a 10-ft (3.0-m) post spacing to establish the working width associated with a reduced post spacing. During the test, the 2270P pickup truck was initially captured and redirected by cable nos. 2 and 4. However, the vehicle eventually overrode cable no. 2 after the vehicle was parallel with the system [4].

Test no. MWP-6, conducted in accordance with MASH 2009 test no. 3-10, involved an 1100C small car impacting the four-cable median barrier system with an 8-ft (2.4-m) post spacing placed on level terrain. During the test, the small car was captured and redirected by cable no. 2. The A-pillar received only 0.12 in. (3 mm) of deformation, as the vehicle underrode cable nos. 3

and 4. The occupant compartment was penetrated when the top of the posts were overridden, causing tears in the floor pan in two locations. Thus, test no. MWP-6 was determined to have failed the safety performance criteria corresponding to MASH 2009 test designation no. 3-10 [4].

To reduce the likelihood of occupant compartment penetration, the top corners of the MWP were rounded. The outer corners were radiused ⅝ in. (16 mm), and the inner bent corners were filleted ¼ in. (6 mm). Test no. MWP-7 was a repeat of test no. MWP-6, but with the modified MWP. During the test, the 1100C small car was captured and redirected by cable no. 2. However, the floor pan was again torn due to contact with the tops of the MWPs as the vehicle overrode them. Four separate tears occurred. Thus, test no. MWP-7 was determined to have failed the safety performance criteria corresponding to MASH 2009 test designation no. 3-10 [4]. These performance issues highlighted the need to develop new barrier components to improve the safety performance of the cable median barrier.

After a series of 21 bogie tests, a modified post was designed to mitigate the floor pan tearing [5]. Test no. MWP-8 was conducted on the modified barrier system, consisting of MWPs with rounded top edges and ¾-in. (19-mm) diameter weakening holes at the ground line. This test was conducted according to MASH 2016 test designation no. 3-10 and utilized an 1100C small car impacting the barrier on a level terrain [6]. The vehicle was contained by the system. No floor pan tearing was observed throughout the initial two vehicle crossover events across the barrier and posts. During the third impact series with the posts, one post penetrated the occupant compartment due to floor pan tearing in two locations. Therefore, test no. MWP-8 was deemed unacceptable.

Investigation into protecting the free edges at the top of the post included adding a cap to the top of the posts to reduce the propensity for post penetration into the occupant compartment and floor pan. A total of five bogie tests were conducted to evaluate several cap designs and post modifications [7]. From the bogie test results, a two-part cap with a single retainer bolt added to the top of the posts was expected to shield the free edges of the top of the MWP during post-to-vehicle contact and mitigate the floor pan tearing.

### 1.2 Objective

The objective of this report was the evaluation of the safety performance of the modified high-tension cable median barrier in a V-ditch. The system was evaluated according to the TL-3 criteria of the MASH 2016 [2].

### 1.3 Scope

The research objective was achieved through completion of several tasks. One full-scale crash test was conducted on the modified cable median barrier according to MASH 2016 test designation no. 3-10. Next, the full-scale vehicle crash test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made pertaining to the safety performance of the modified cable median barrier.

# 2 TEST REQUIREMENTS AND EVALUATION CRITERIA

## 2.1 Test Requirements

Longitudinal barriers, such as cable median barriers, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [2]. According to TL-3 of MASH 2016, a cable barrier system for use anywhere in a 6H:1V V-ditch must be subjected to eight full-scale vehicle crash tests, as summarized in Table 1.

However, systems with variable post spacing must be conducted with both the narrowest and widest post spacing to bracket the working widths of the barrier system, thereby increasing the required number of crash tests from eight to nine. Note, only one of the prescribed full-scale crash tests, test designation no. 3-10, was conducted and reported herein. Although the impact speed and angle are consistent for all nine tests, the critical location of the barrier system within the median ditch is dependent upon the specific crash test and the slope of the ditch. The MASH 2016 TL-3 testing matrix for a cable median barrier system designed for placement anywhere within a 6H:1V or flatter V-ditch is shown in Table 1.

Many cable barriers have variable post spacing, which allows roadside designers to select the optimal configuration for a specific installation. When evaluating these variable post spacing systems, the critical post spacing should be utilized during crash testing. MASH 2016 has identified the critical post spacing, either the narrowest or the widest spacing, for each individual test within the testing matrix. MASH 2016 test designation no. 3-10 must be conducted with the narrowest post spacing.

In accordance with MASH 2016 requirements, the critical impact point for the 1100C vehicle was determined to be located at the midspan between posts. This impact location was determined to maximize the potential for vehicle penetration by allowing the vehicle to penetrate between cables.

When non-symmetrical cable barriers are tested, it is important to test the orientation that produces the greatest risk of failure. To accomplish this critical evaluation, the orientation of the cables was selected such that primary capture cable would be located on the non-impact side of the post. The primary capture cable for the 1100C vehicle was determined to be the second cable above the ground. Selecting this orientation allowed for the greatest risk of failure delaying vehicle interlock with the barrier and increasing the potential for the vehicle to penetrate through the system.

Table 1. MASH 2016 TL-3 Test Matrix for Barrier Placement Anywhere Within a 6H:1V V–Ditch

| Test No. | Test Vehicle | Vehicle Weight, lb (kg) | Impact Conditions | | System Configuration | | Evaluation Criteria[2] |
|---|---|---|---|---|---|---|---|
| | | | Speed, mph (km/h) | Angle, deg | System Location[1] | Post Spacing | |
| 3-10 | 1100C | 2,425 (1,100) | 62 (100) | 25 | Level Terrain | Narrow | A,D,F,H,I |
| 3-11 | 2270P | 5,000 (2,270) | 62 (100) | 25 | Level Terrain | Both | A,D,F,H,I |
| 3-13 | 2270P | 5,000 (2,270) | 62 (100) | 25 | 9 ft Down Front Slope | Narrow | A,D,F,H,I |
| 3-14 | 1100C | 2,425 (1,100) | 62 (100) | 25 | 9 ft Down Front Slope | Narrow | A,D,F,H,I |
| 3-15 | 1100C | 2,425 (1,100) | 62 (100) | 25 | 4 ft Up Back Slope | Wide | A,D,F,H,I |
| 3-16 | 1100C | 2,425 (1,100) | 62 (100) | 25 | 1 ft Down Back Slope | Narrow | A,D,F,H,I |
| 3-17 | 1500A | 3,300 (1,500) | 62 (100) | 25 | See Note[3] | Wide | A,D,F,H,I |
| 3-18 | 2270P | 5,000 (2,270) | 62 (100) | 25 | At Back Slope Break Point | Wide | A,D,F,H,I |

[1] Test nos. 3-13 through 3-18 shall be conducted within a 30-ft (9.1-m) wide, 6H:1V V-ditch.
[2] Evaluation criteria explained in Table 2.
[3] Testing laboratory to determine critical barrier position on front slope of ditch to maximize propensity for front end of 1500A vehicle to penetrate between vertically adjacent cables.

## 2.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the cable median barrier to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH 2016. The full-scale vehicle crash test documented herein was conducted and reported in accordance with the procedures provided in MASH 2016.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported on the test summary sheet. Additional discussion on PHD, THIV and ASI is provided in MASH 2016.

Table 2. MASH Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s<br>(9.1 m/s)</td><td>40 ft/s<br>(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g's</td><td>20.49 g's</td></tr>
</table>

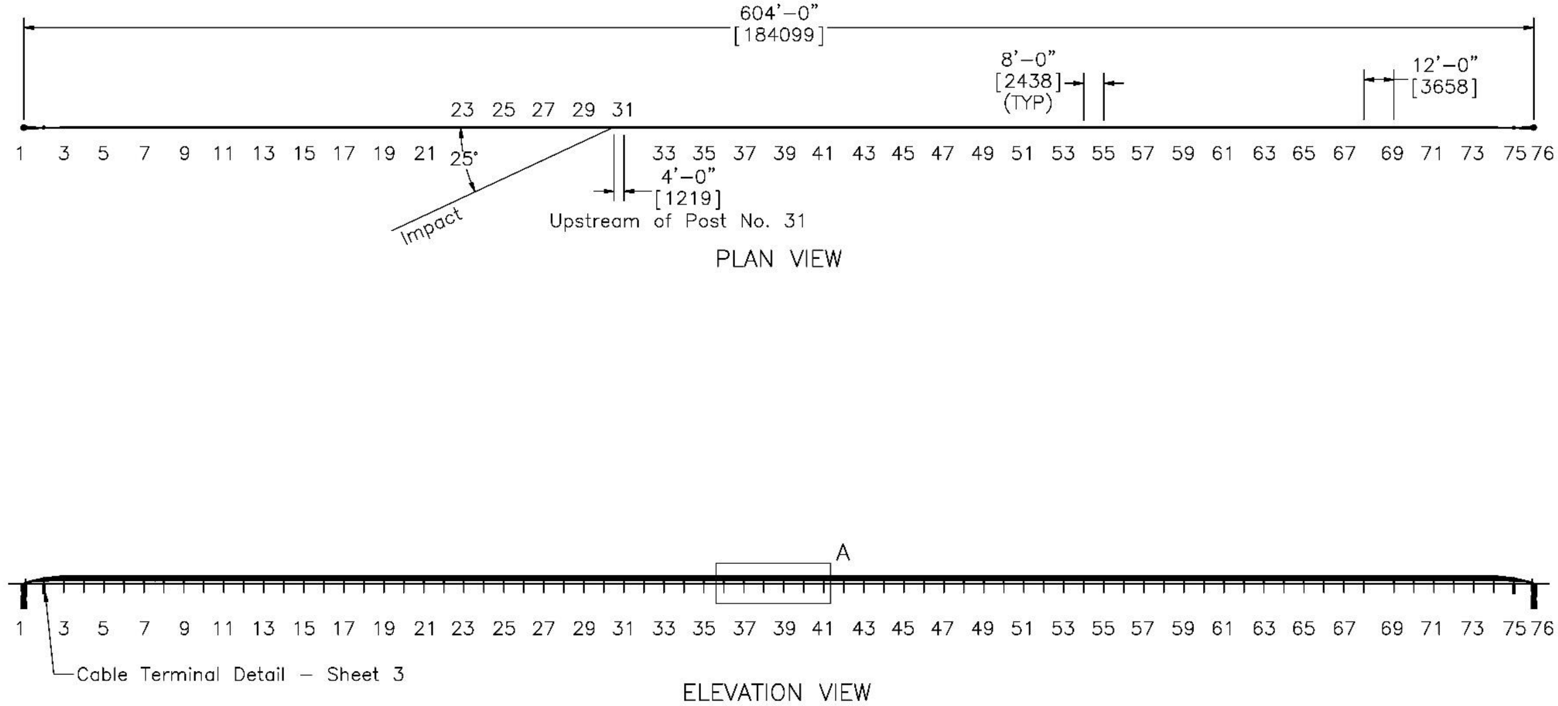
## 2.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, W6x16 (W152x23.8) posts were installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, dynamic impact testing was conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm) measured at a height of 25 in. (635 mm) above the groundline. If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted instead and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90 percent of the static baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Further details can be found in Appendix B of MASH 2016.

# 3 DESIGN DETAILS

The test installation consisted of a 604-ft (184-m) long, four-cable median barrier system, as shown in Figures 1 through 26. Photographs of the test installation are shown in Figures 27 through 33. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The cable barrier system consisted of several distinct components: (1) high-tension cables or wire ropes; (2) cable splices; (3) steel support posts; (4) cable-to-post attachment brackets; (5) breakaway end terminals; and (6) reinforced concrete foundations. Four ¾-in. (19-mm) diameter, Class A galvanized 3x7 (pre-stretched) wire ropes were utilized for the longitudinal cables. The cables were placed at heights of 15½ in. (394 mm), 23 in. (584 mm), 30½ in. (775 mm), and 38 in. (965 mm) above the groundline. The cables were numbered 1 through 4, starting with the bottom cable and proceeding upward to the top cable. The cables were tensioned up to a nominal force of 2,500 lb (11.1 kN). These cables were supported by 81¼-in. (2,108-mm) long MWPs modified to include a ¾-in. (19-mm) diameter weakening hole at the groundline and a two-part cap to protect the free edges of the post. Each MWP was fabricated from 7-gauge (4.6-mm) sheet steel bent to a 3-in. x 1¾-in. (76-mm x 44-mm) cross section. The posts were placed on level terrain, spaced 96 in. (2,438 mm) on center with a soil embedment depth of 42 in. (1,067 mm). The posts were installed in a compacted, coarse, crushed, limestone material with a strength that satisfied MASH 2016 criteria.




Notes:
(1) Test shall be performed according to test designation no. 3–10 of MASH criteria.
(2) At a minimum, critical post nos. 26–48 are placed in 18" [457] diameter hole backfilled and tamped in well compacted soil.
(3) Test cable tensions of 2500 ± 200 lb [11.1 ± 0.890 kN].
(4) Bottom cable on impact side.
(5) Span between posts 68 and 69 is 144" [3658].
(6) Post nos. 3–74 are modified weak posts as shown on sheets 15–18.

| | | |
|---|---|---|
| Midwest Roadside Safety Facility | Midwest 4–Cable Barrier System | SHEET: 1 of 26 |
| | | DATE: 1/26/2018 |
| | System Layout | DRAWN BY: JEK |
| | DWG. NAME. MWP–9_R6 | SCALE: 1:750 UNITS: in.[mm] | REV. BY: KAL/TJD/MP |

Figure 1. System Layout, Test No. MWP-9

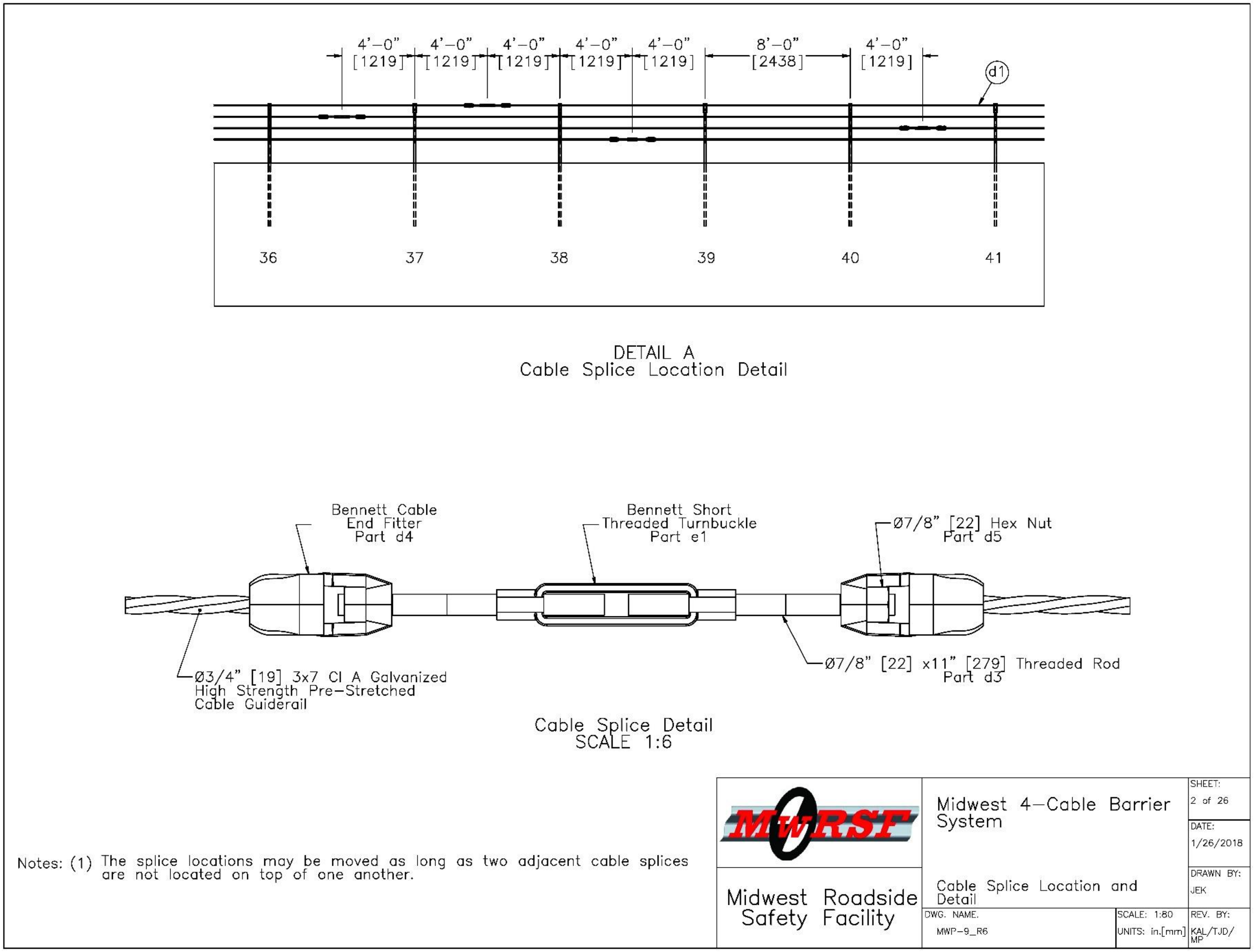



Figure 2. Cable Splice Location and Detail, Test No. MWP-9

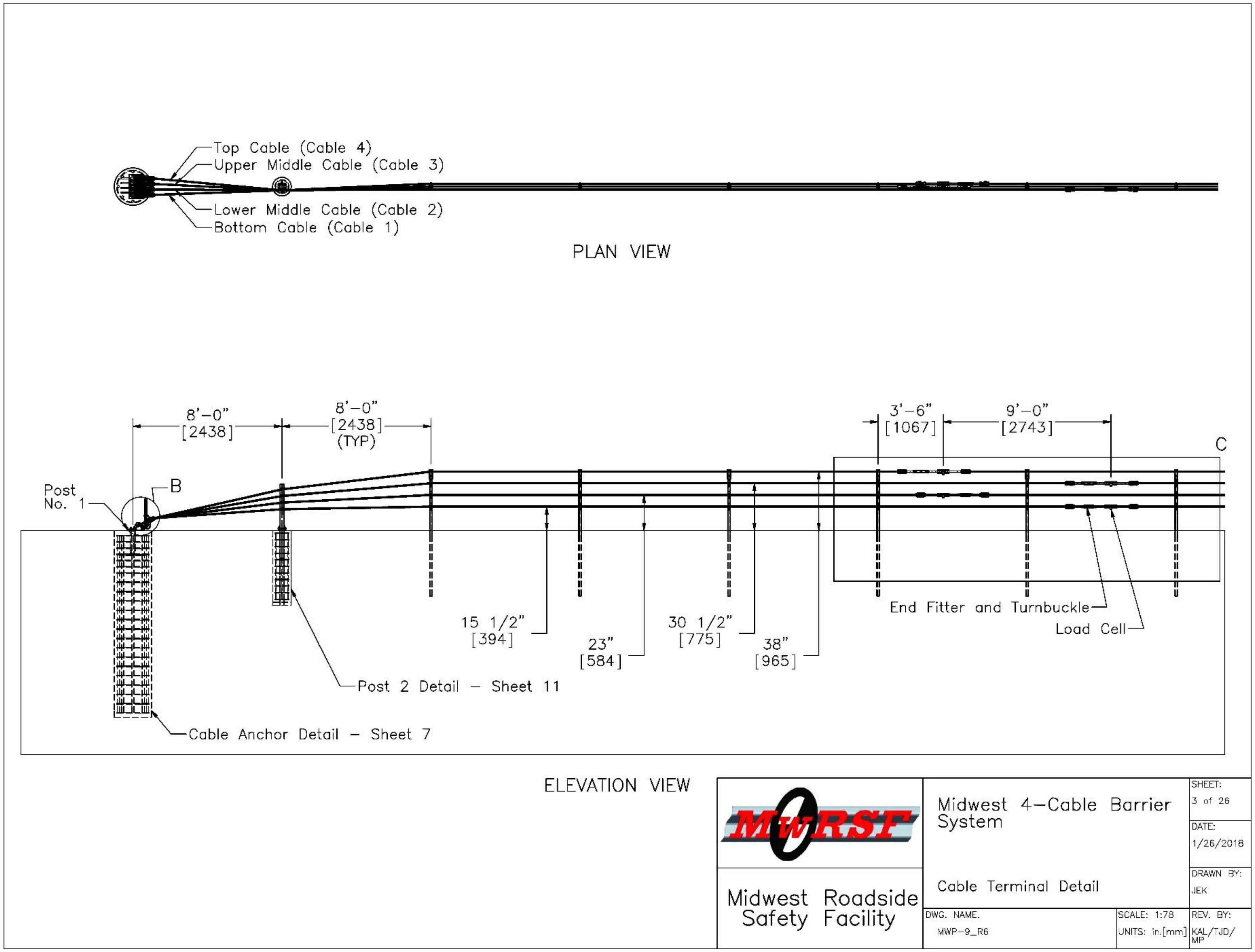



Figure 3. Cable End Terminal Detail, Test No. MWP-9

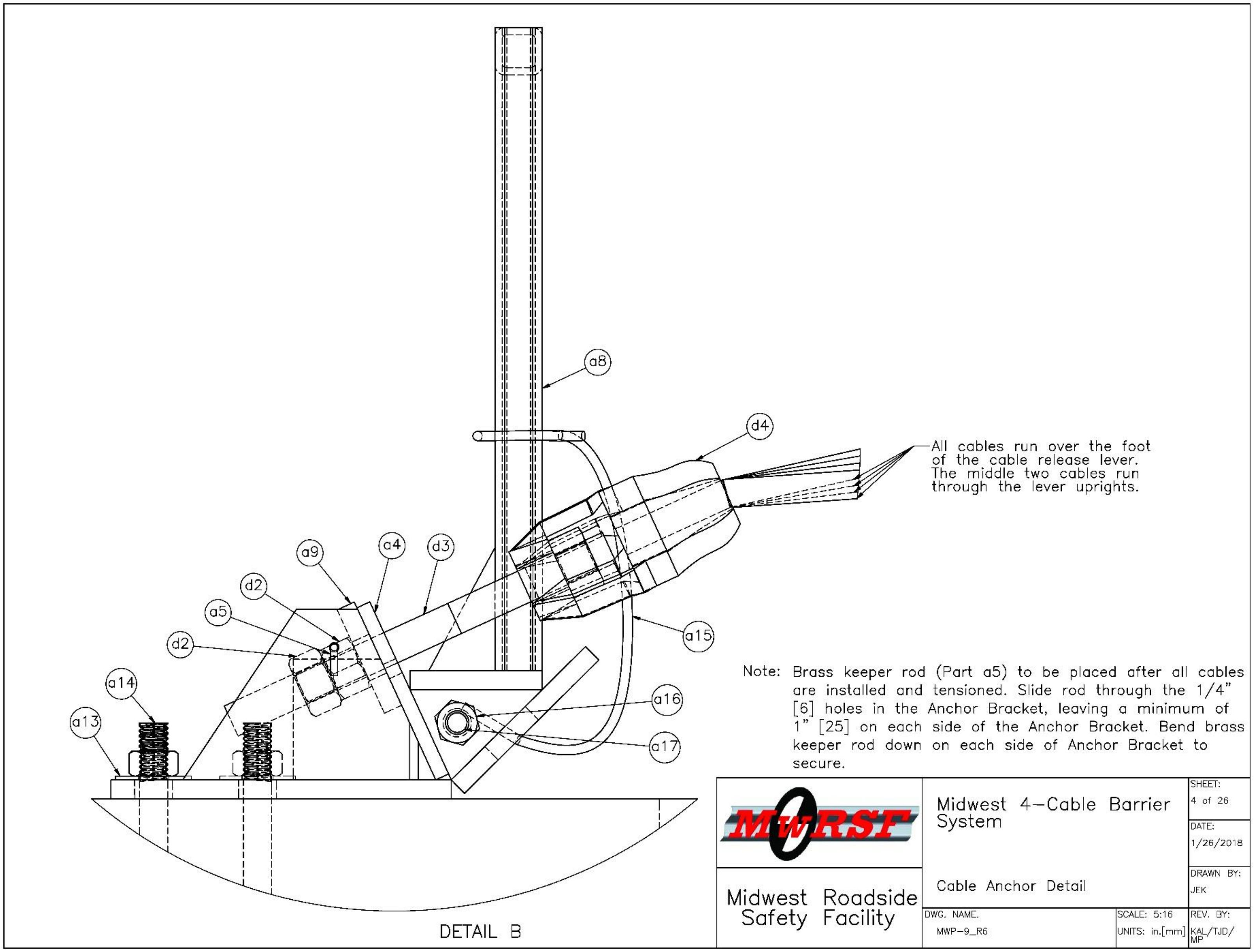



Figure 4. Cable Anchor Detail, Test No. MWP-9

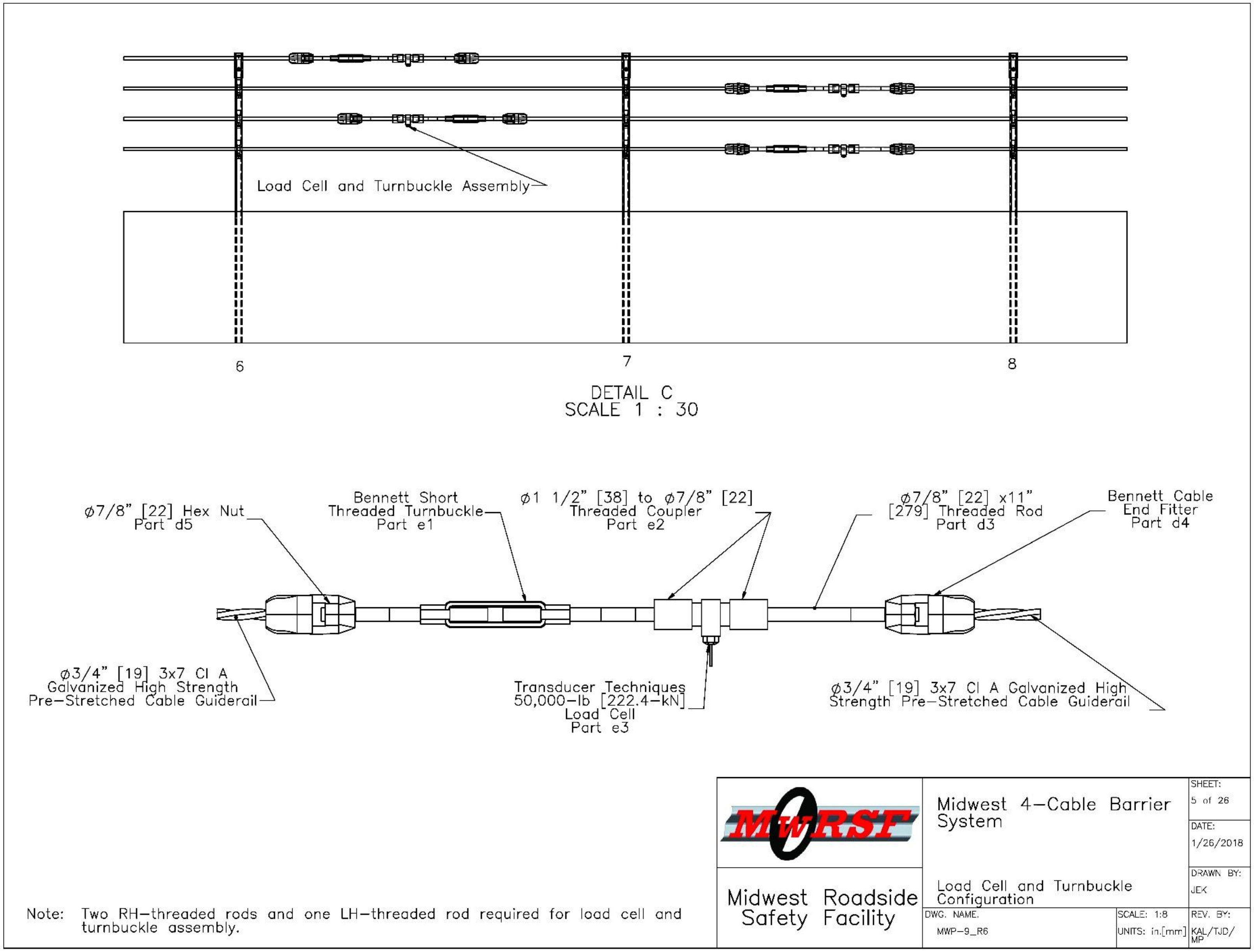



Figure 5. Load Cell and Turnbuckle Configuration, Test No. MWP-9

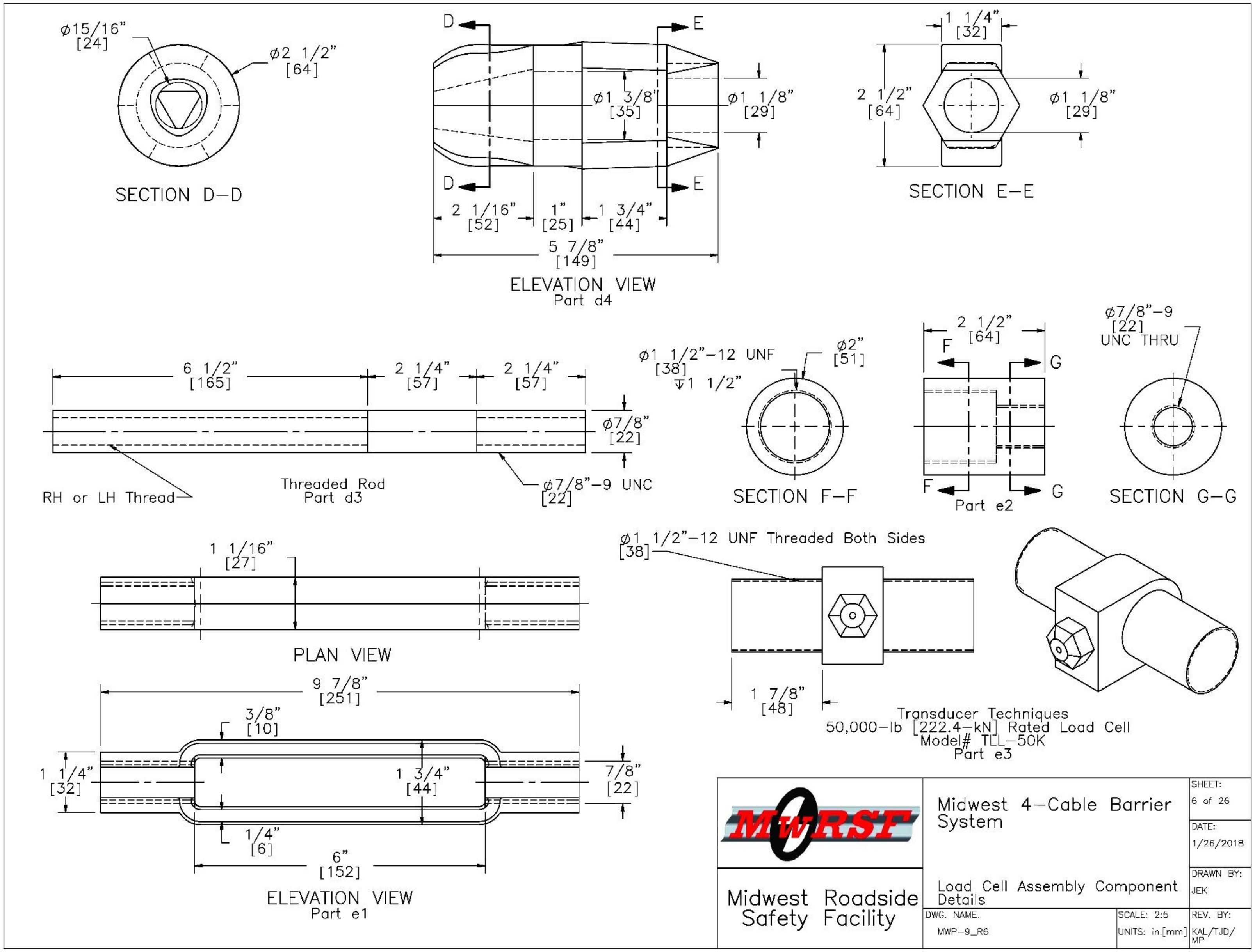



Figure 6. Load Cell Assembly Component Details, Test No. MWP-9

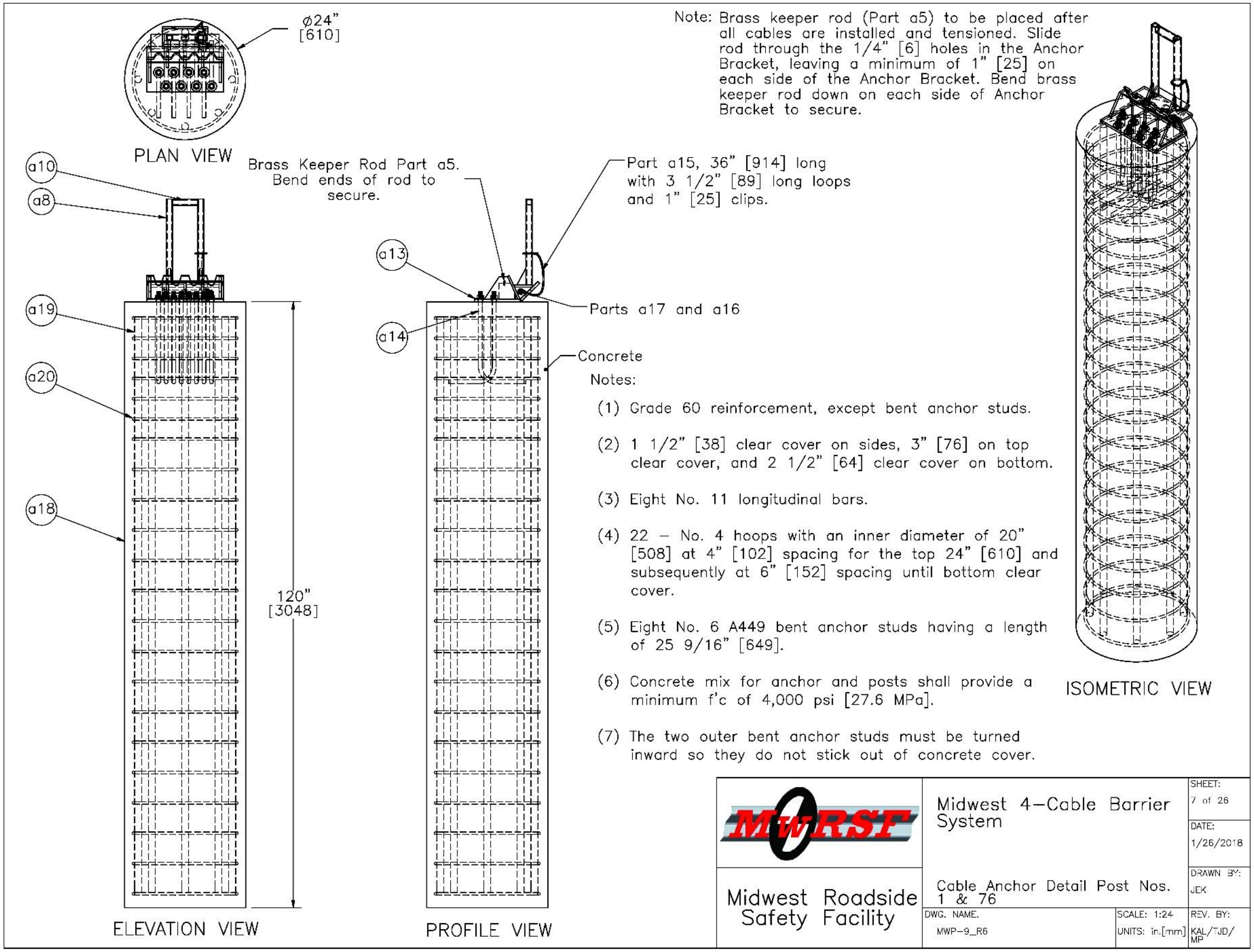



Figure 7. Cable Anchor Detail, Post Nos. 1 and 76, Test No. MWP-9

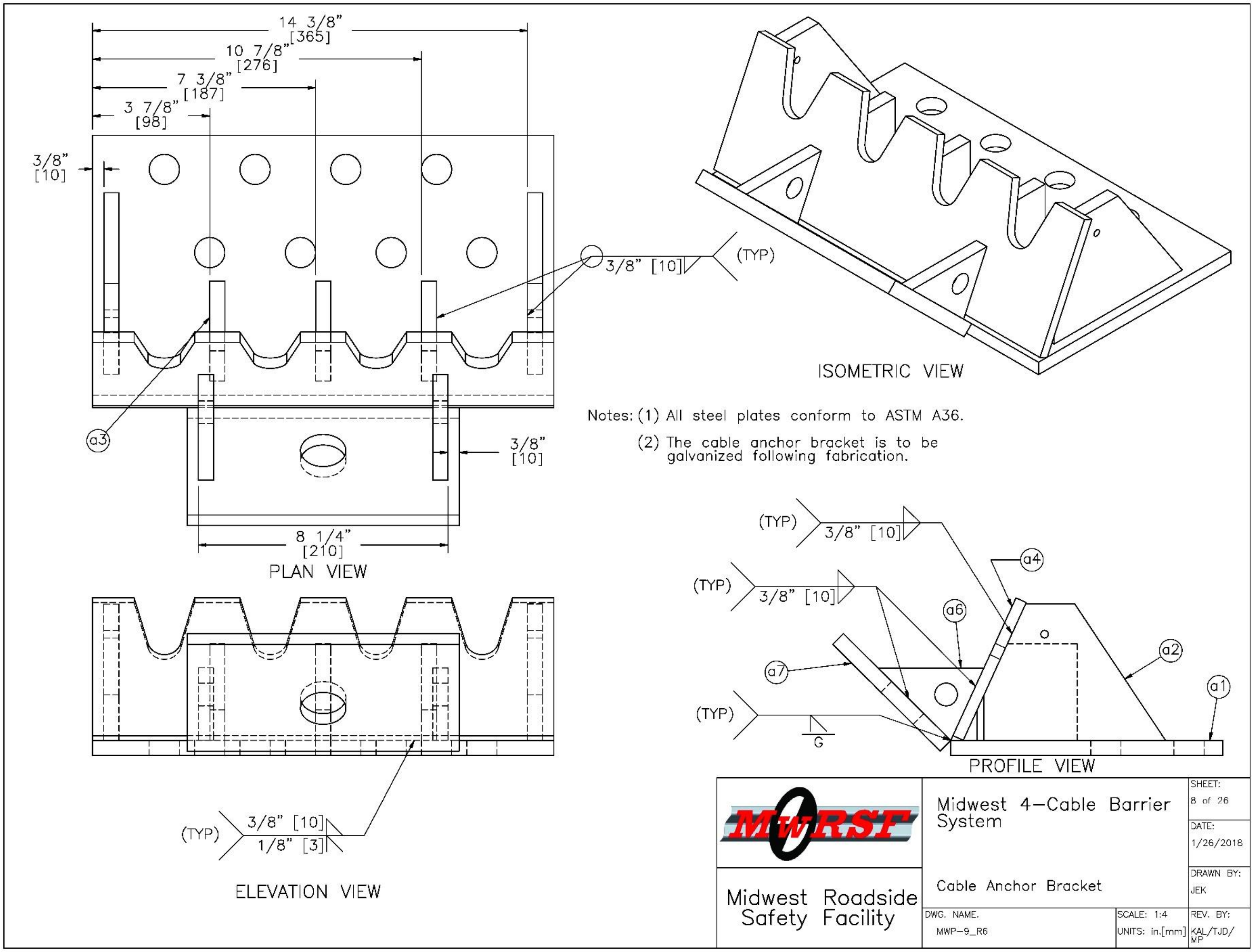



Figure 8. Cable Anchor Bracket, Test No. MWP-9

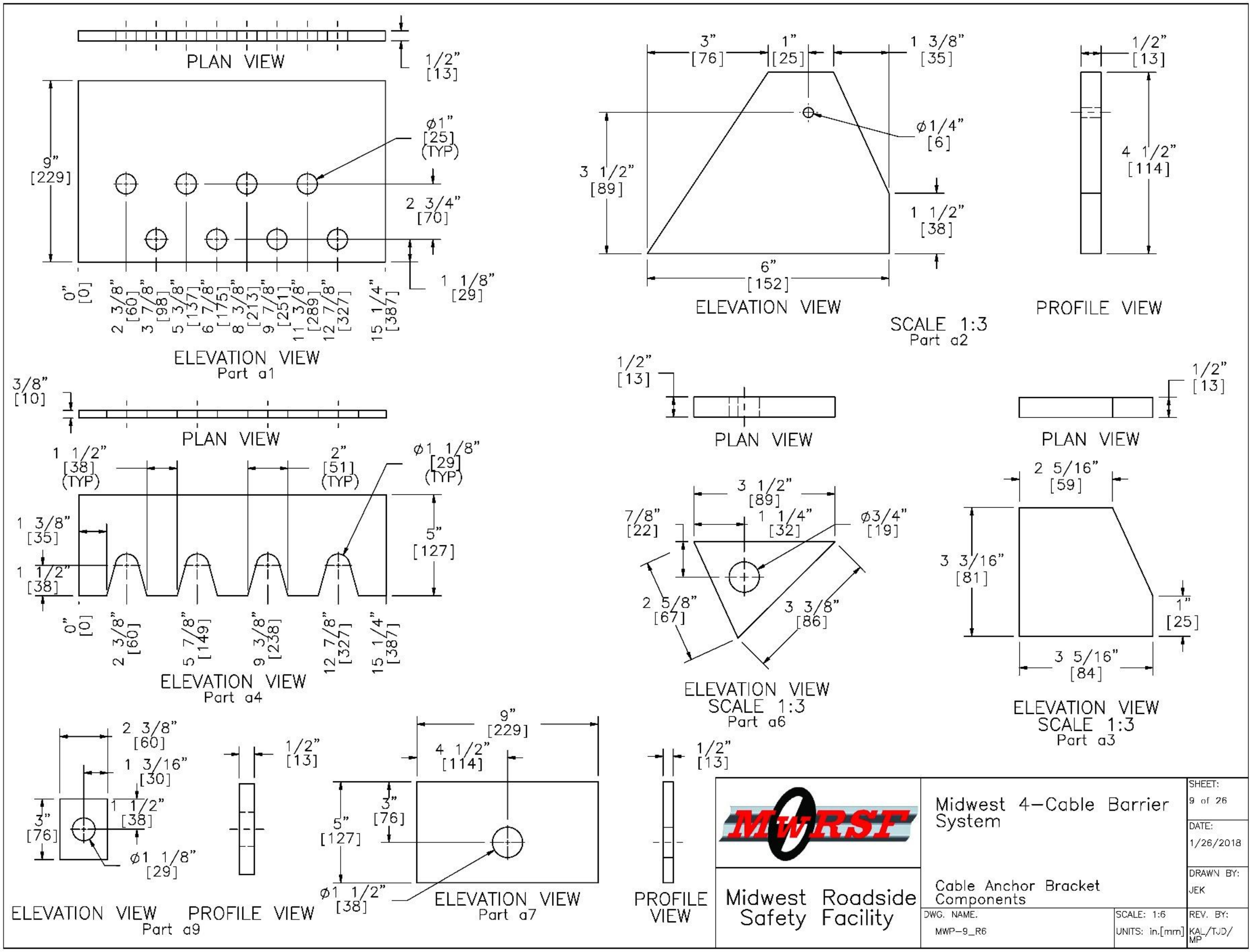



Figure 9. Cable Anchor Bracket Components, Test No. MWP-9

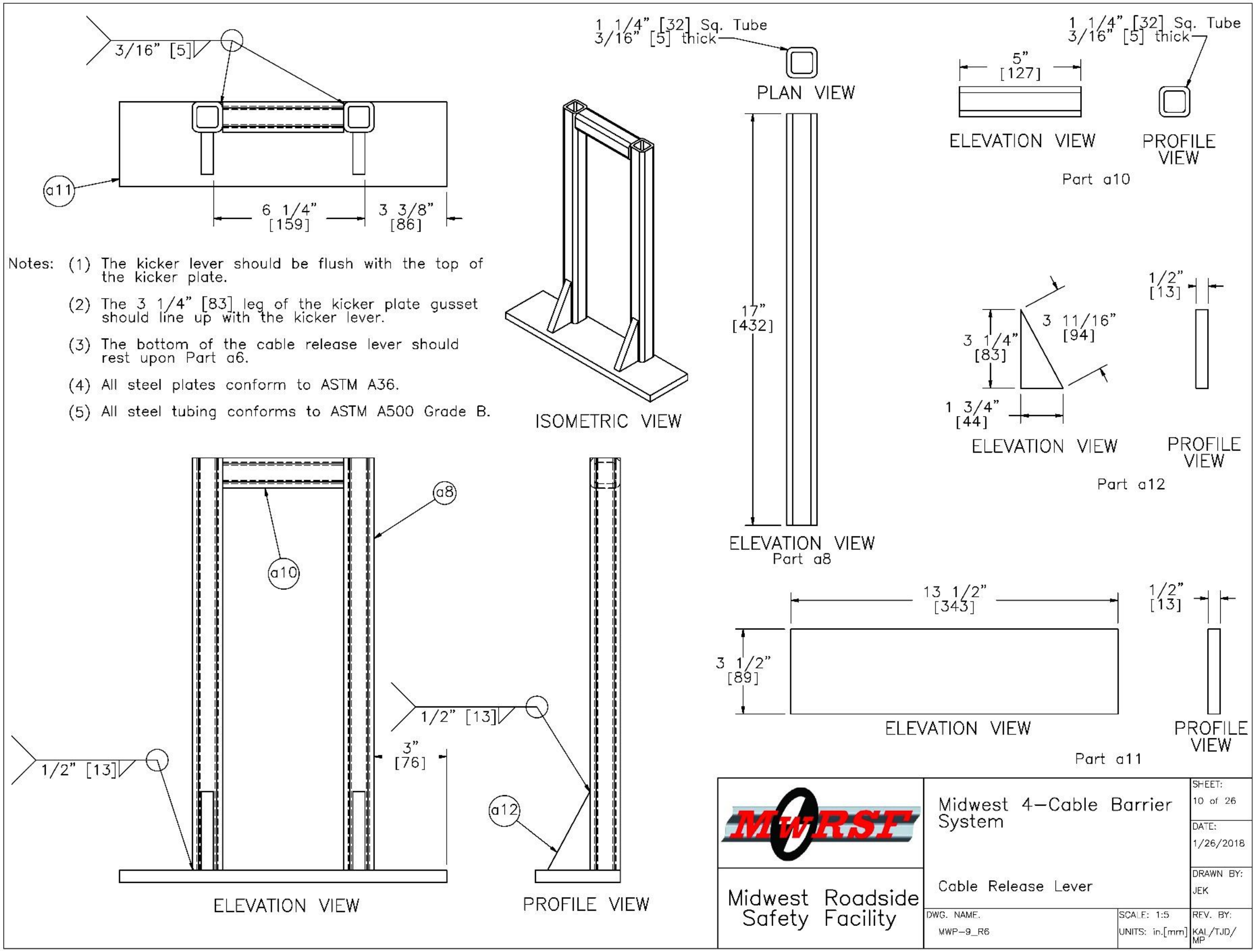


Figure 10. Cable Release Lever, Test No. MWP-9

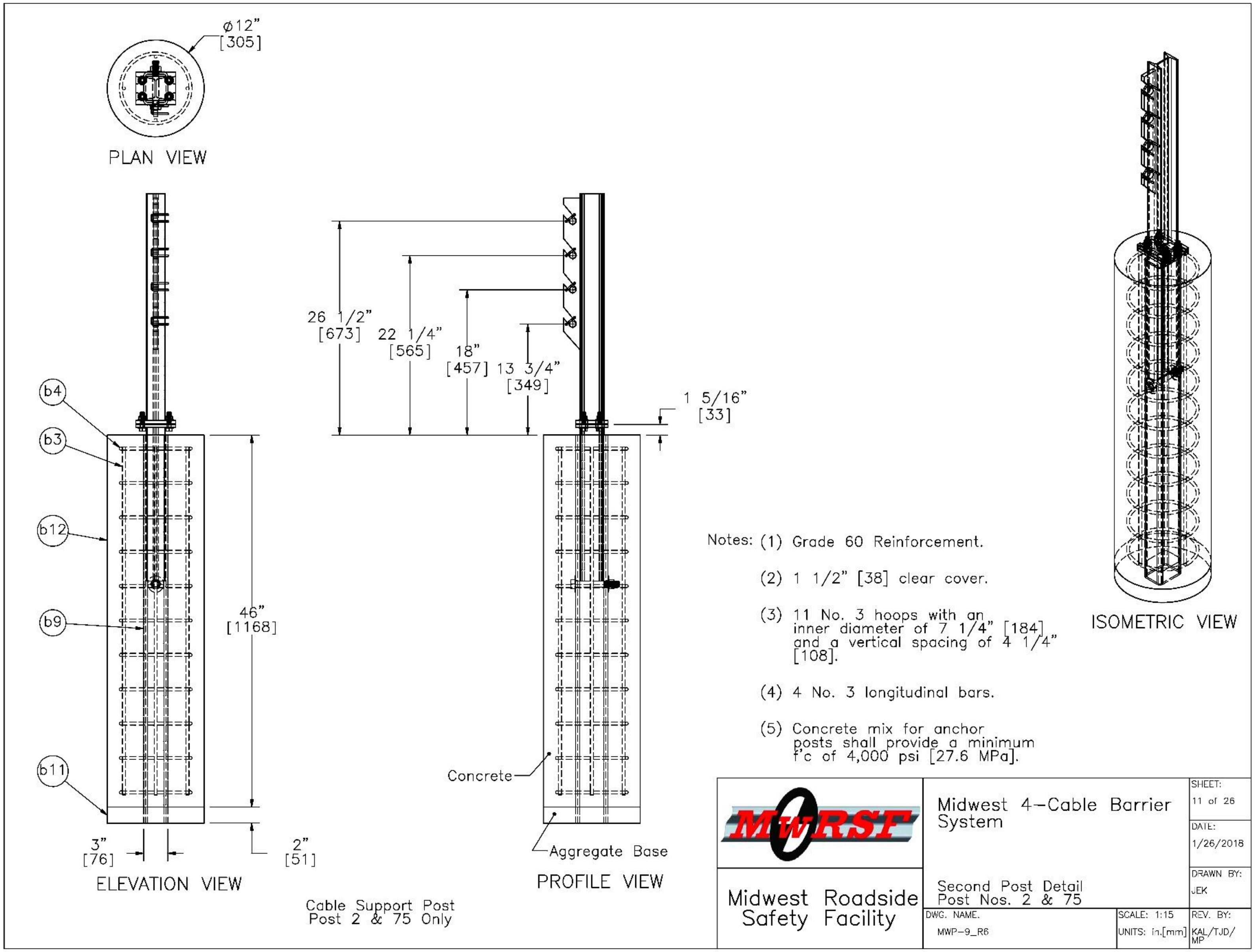



Figure 11. Second Post Detail, Post Nos. 2 and 75, Test No. MWP-9

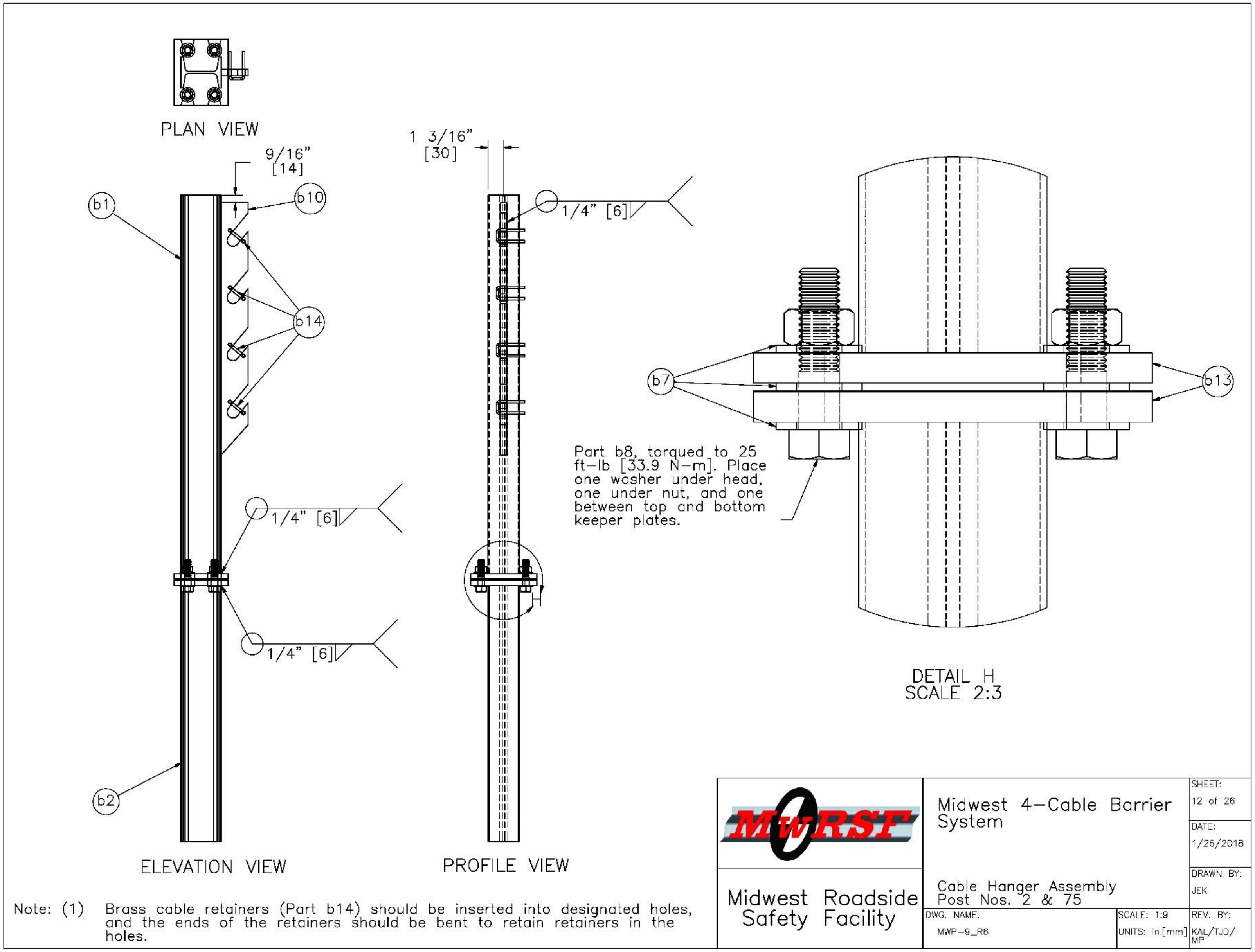



Figure 12. Cable Hanger Assembly, Post Nos. 2 and 75, Test No. MWP-9

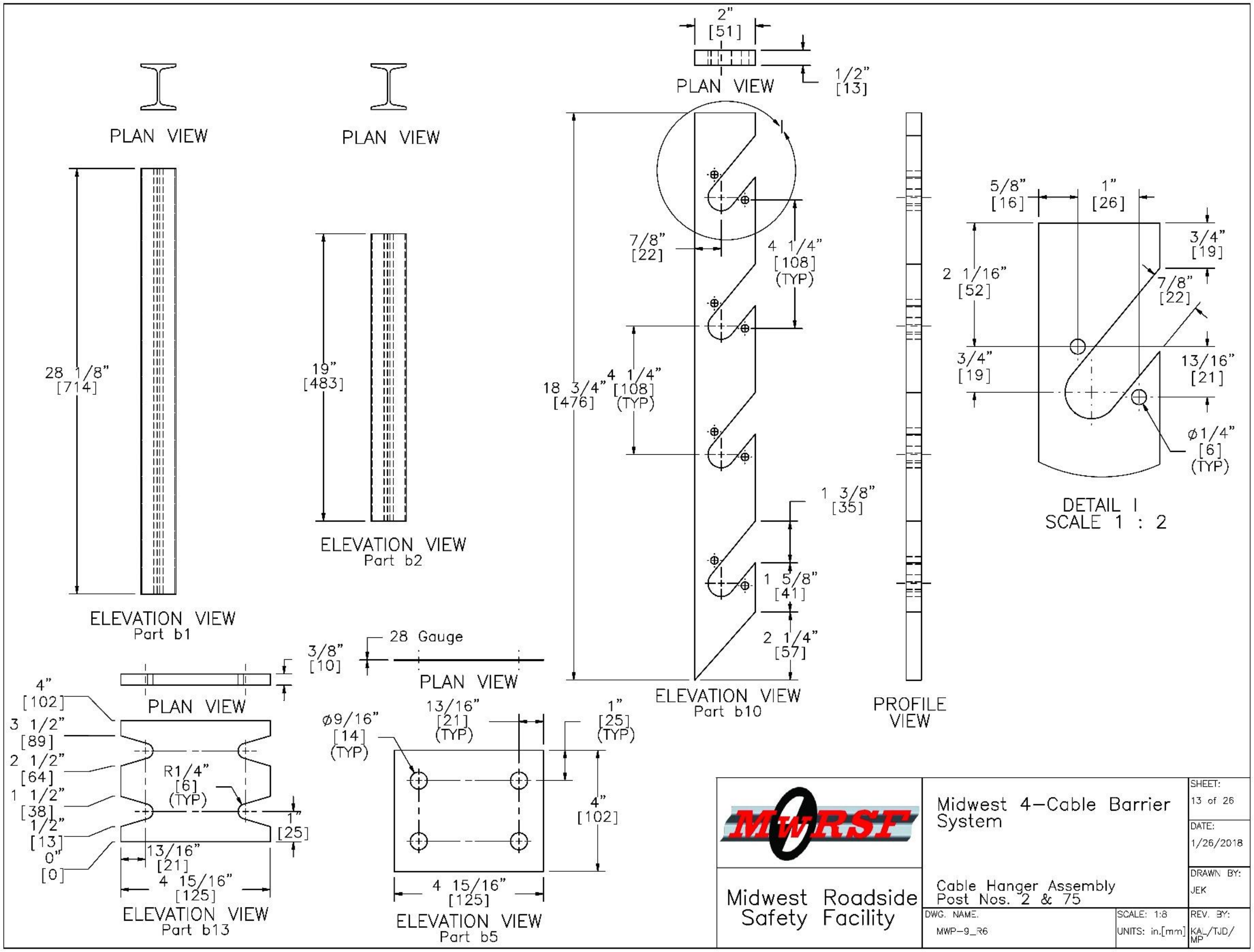



Figure 13. Cable Hanger Assembly, Post Nos. 2 and 75, Test No. MWP-9

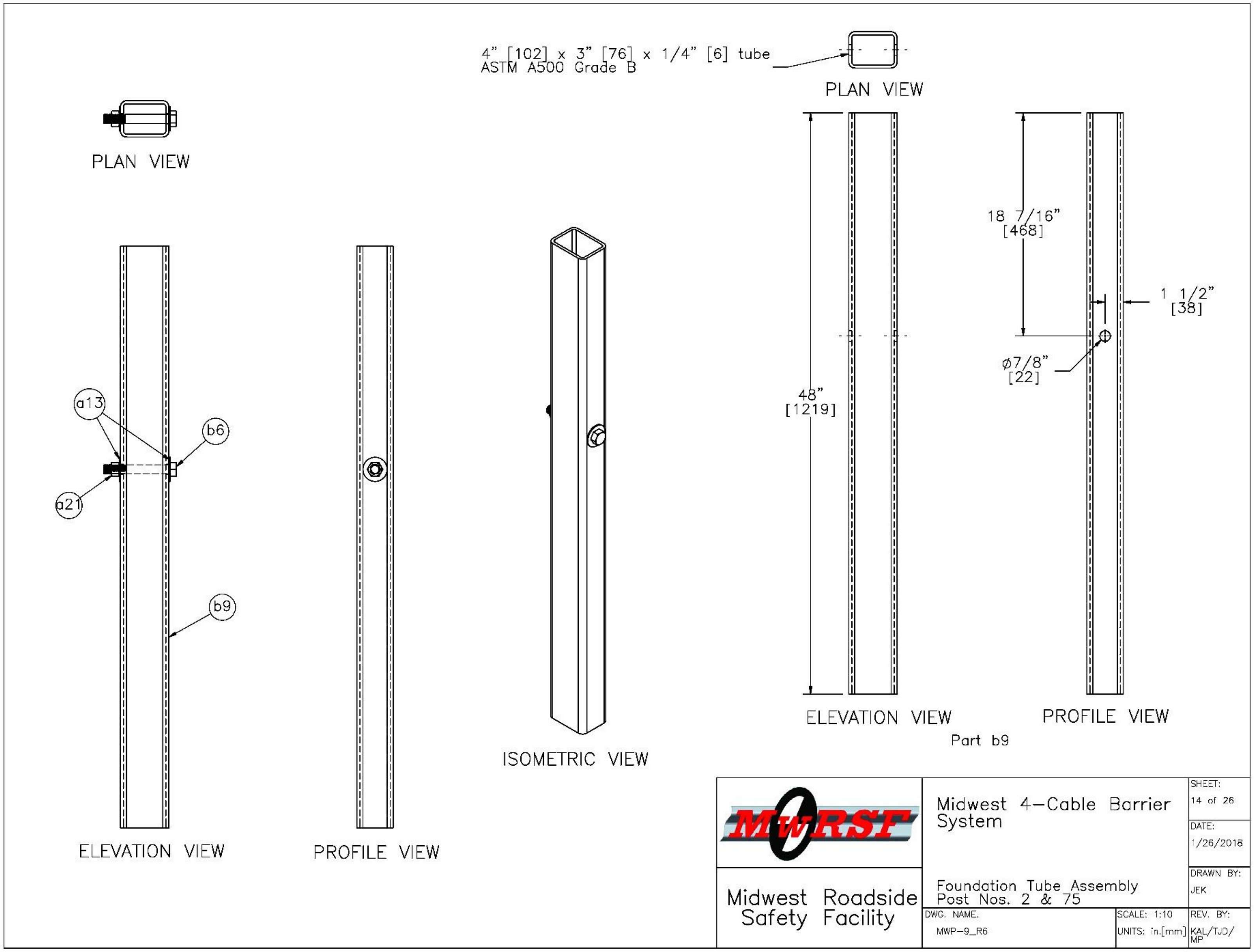



Figure 14. Foundation Tube Assembly, Post Nos. 2 and 75, Test No. MWP-9

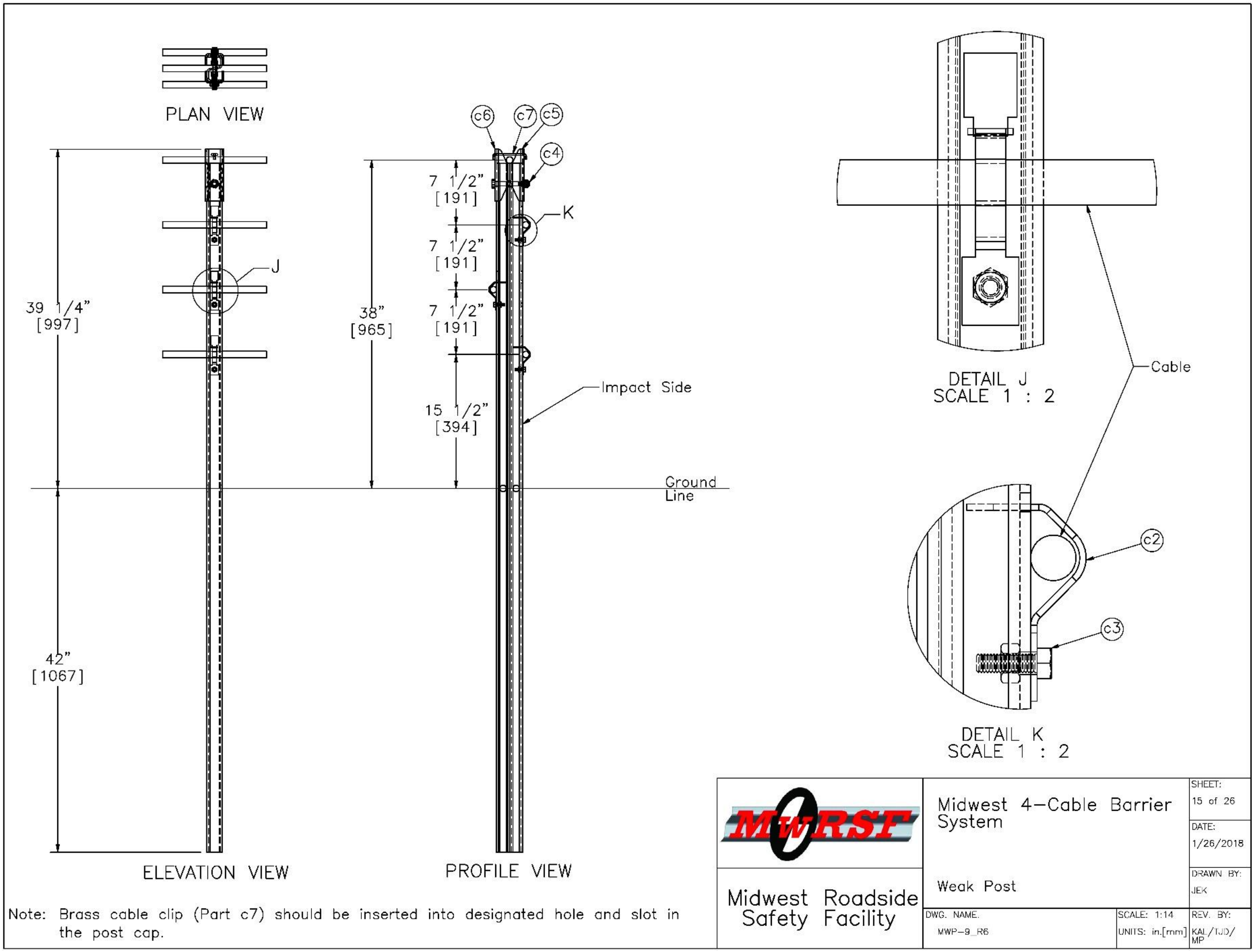



Figure 15. Midwest Weak Post (MWP) Details, Test No. MWP-9

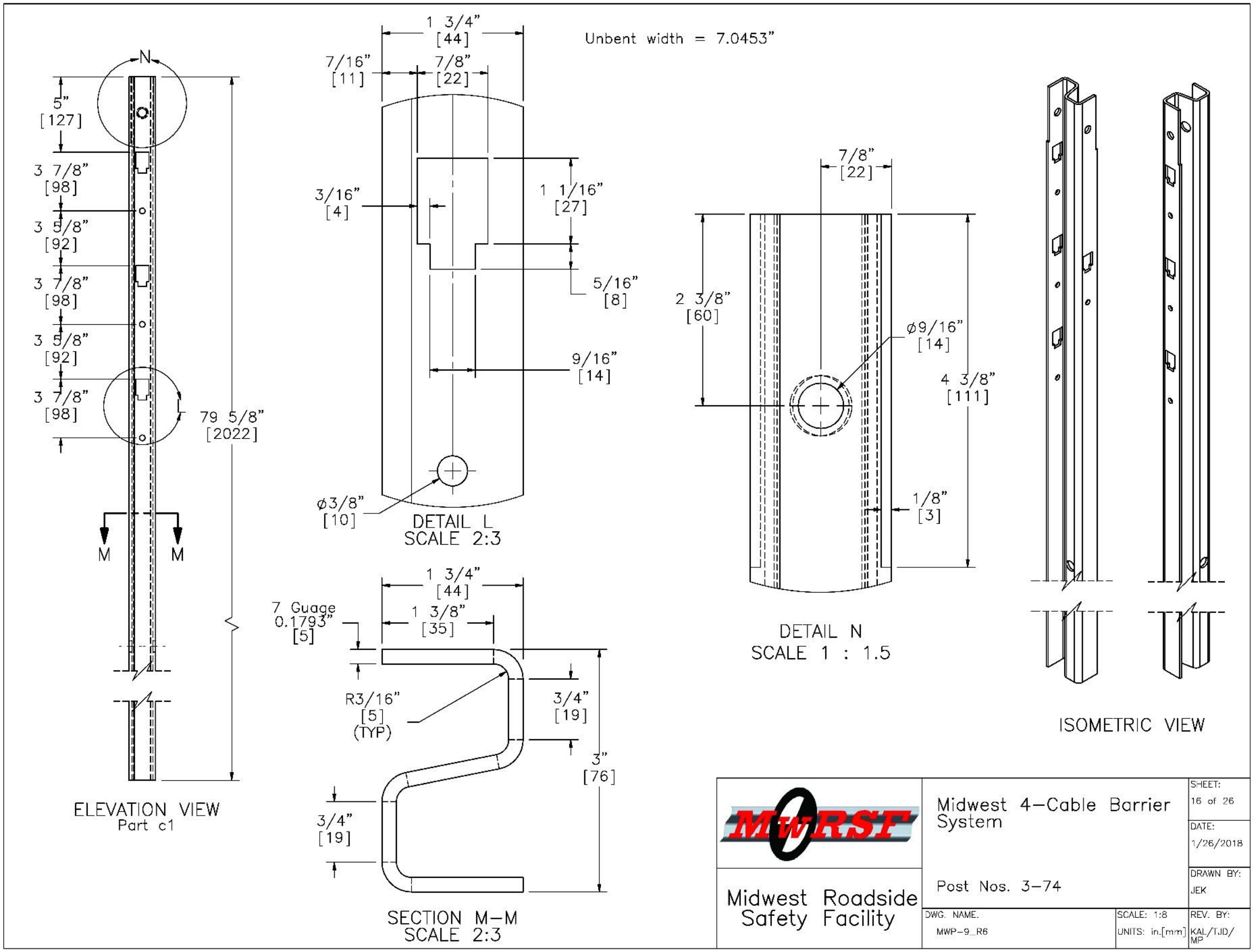



Figure 16. Midwest Weak Post (MWP) Details, Post Nos. 3 through 74, Test No. MWP-9

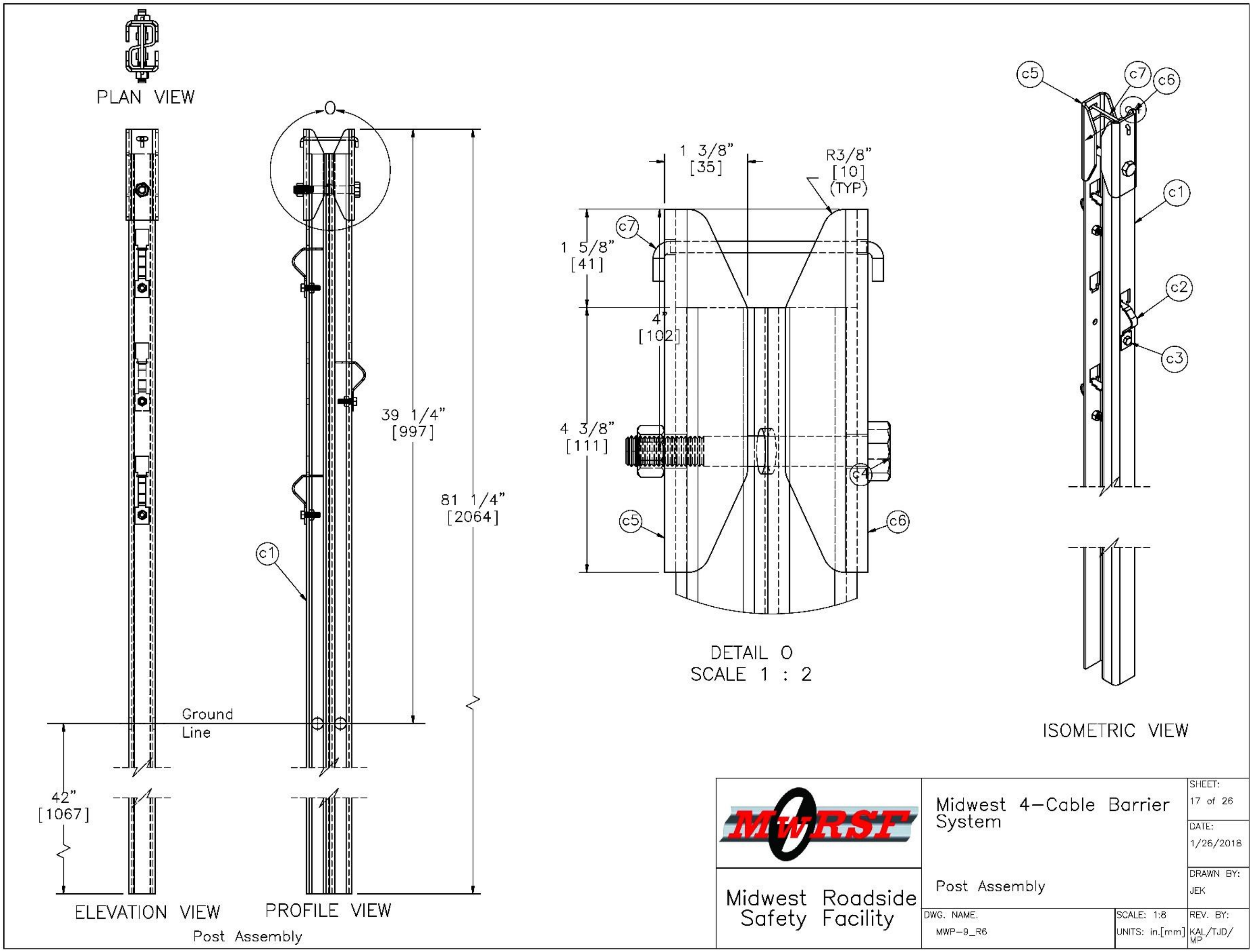



Figure 17. Midwest Weak Post (MWP), Post and Bracket Assembly, Test No. MWP-9

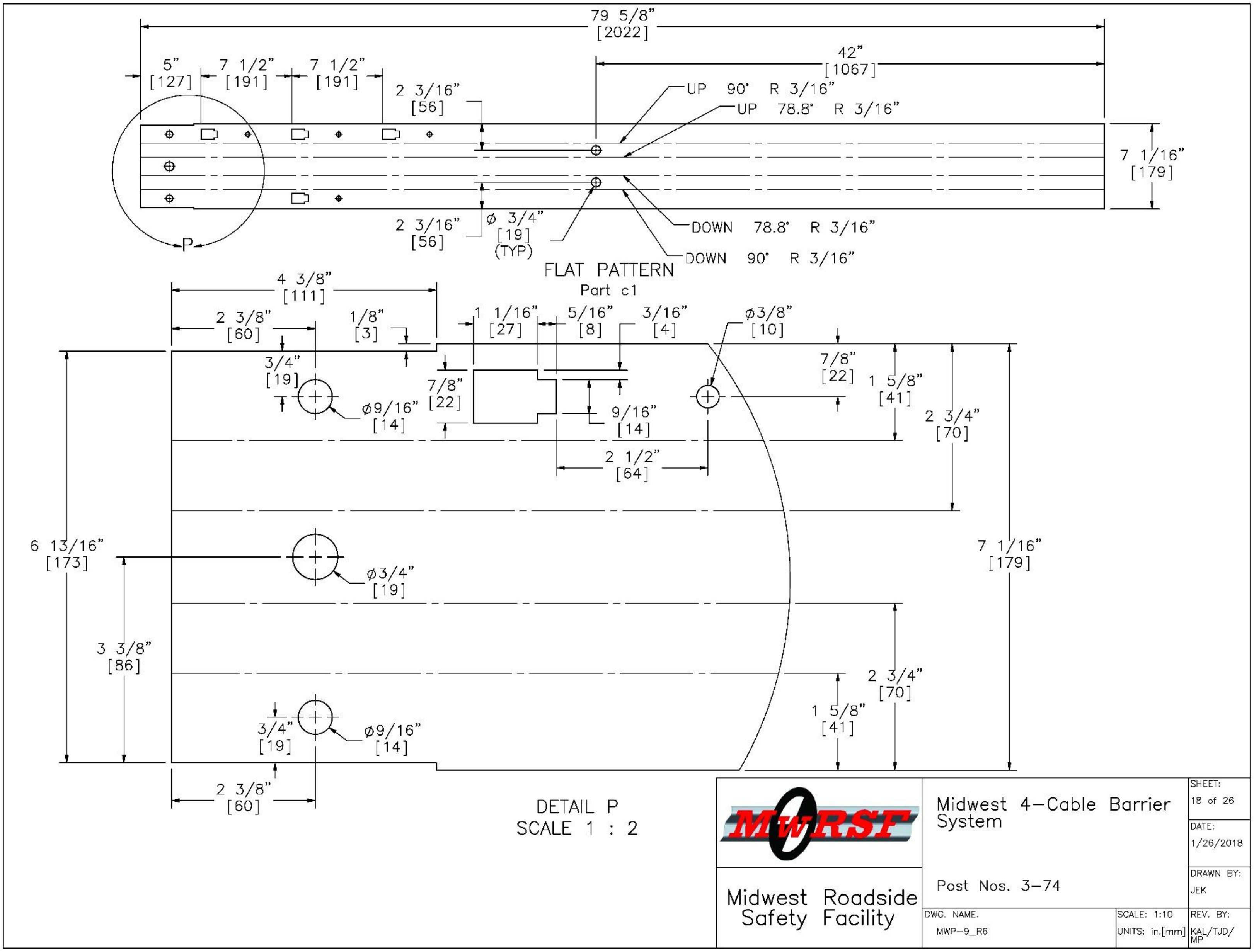



Figure 18. Post Nos. 3 through 74, Flat Pattern, Test No. MWP-9

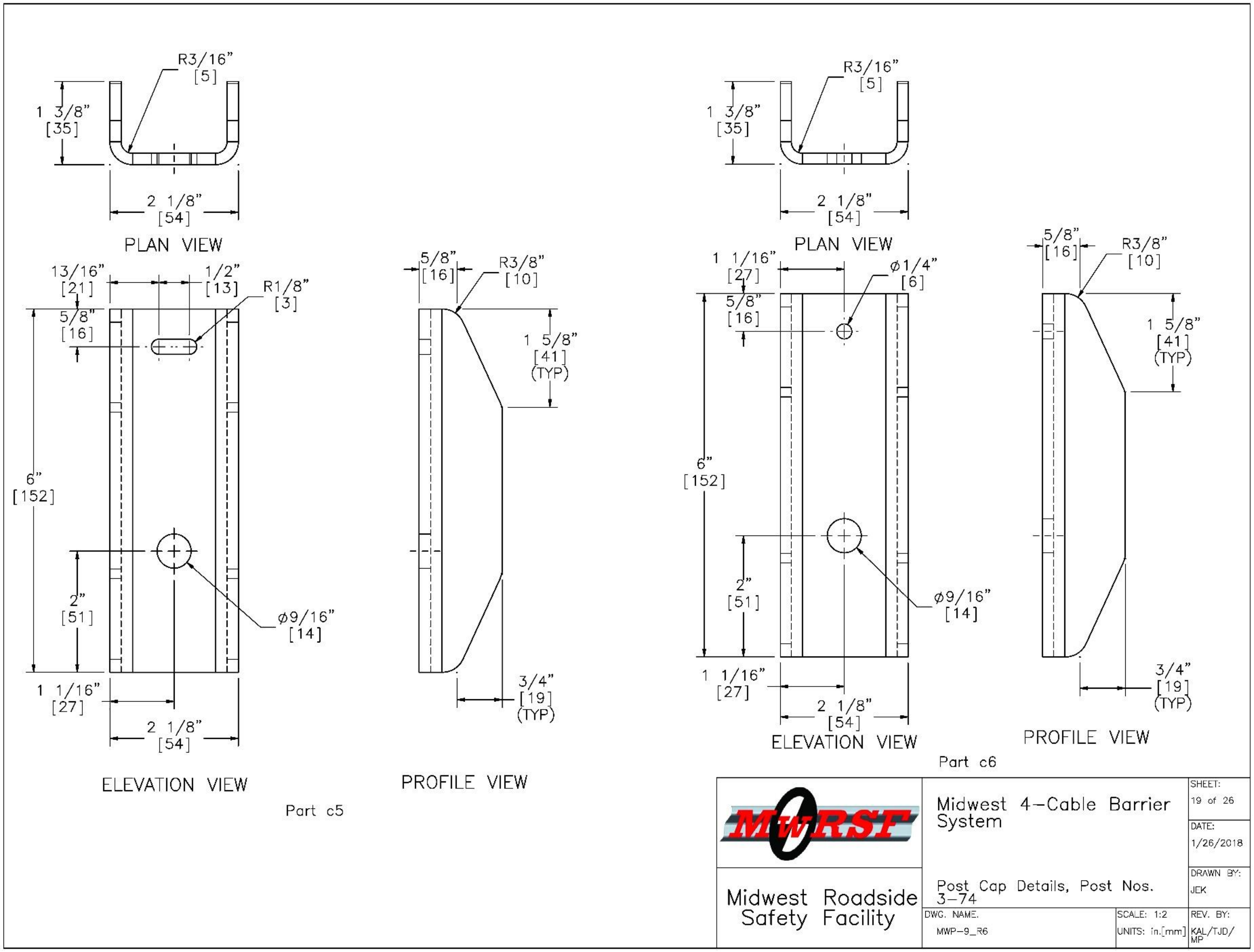



Figure 19. Post Cap Details, Post Nos. 3 through 74, Test No. MWP-9

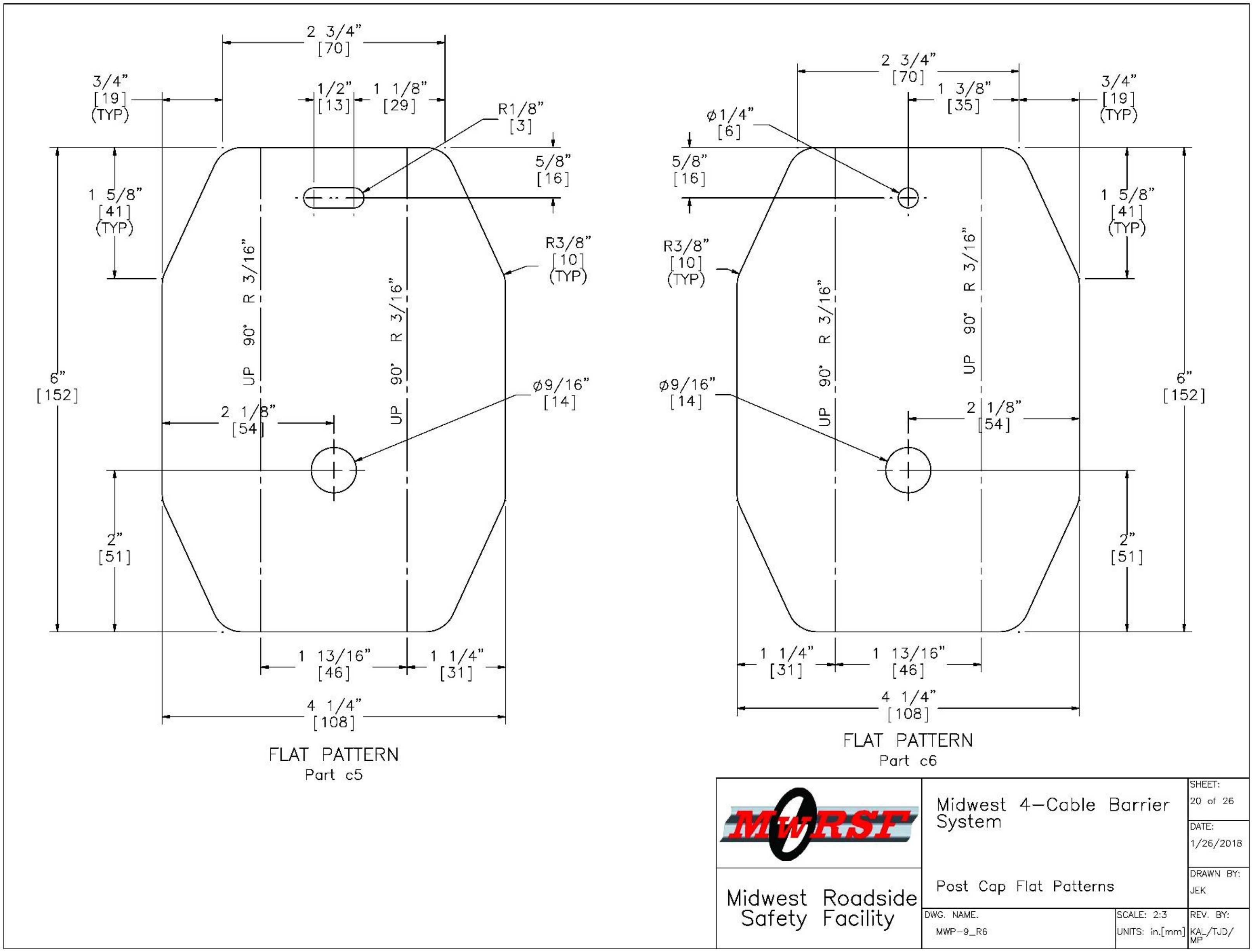



Figure 20. Post Cap Flat Patterns, Test No. MWP-9

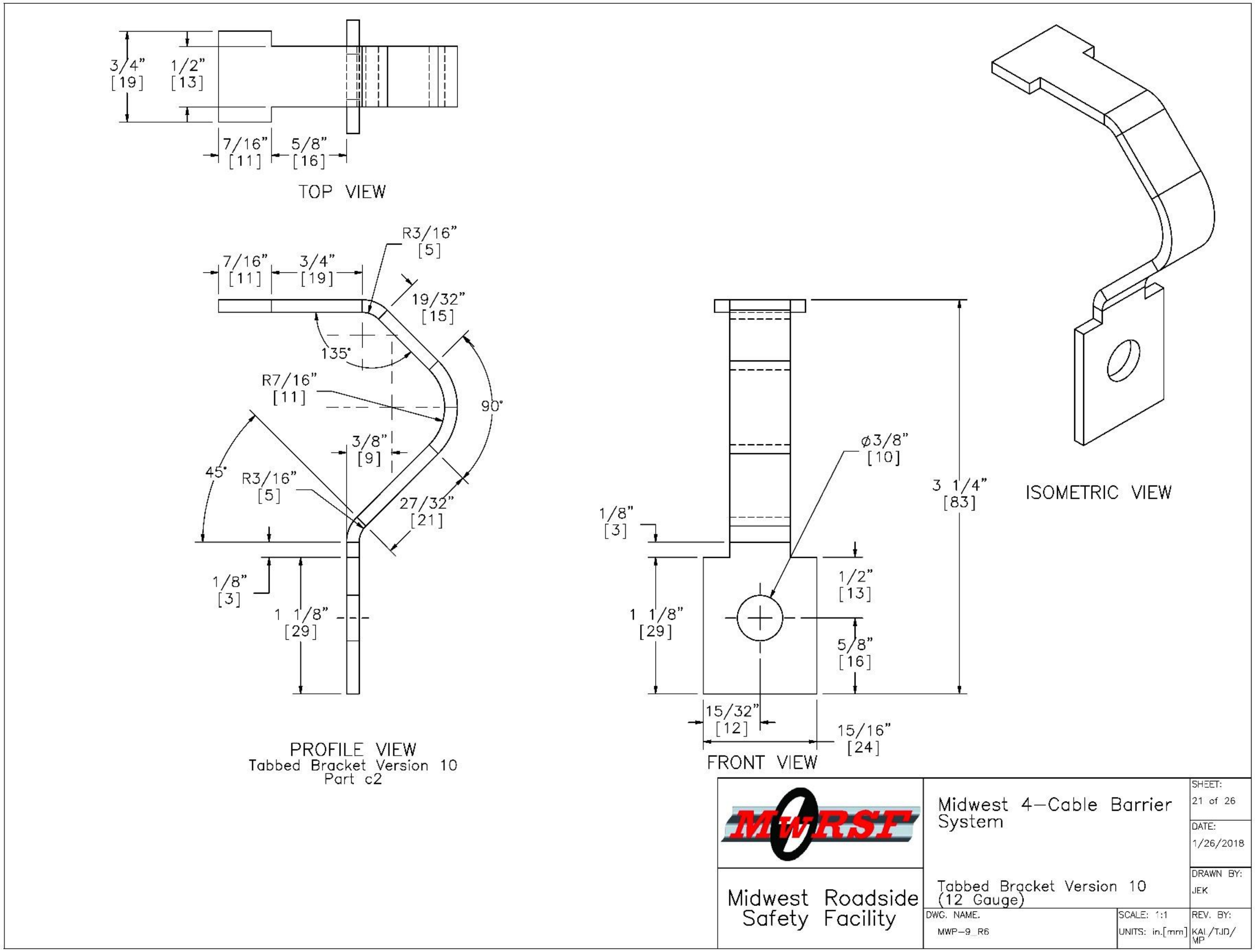



Figure 21.Tabbed Bracket Version 10, Test No. MWP-9

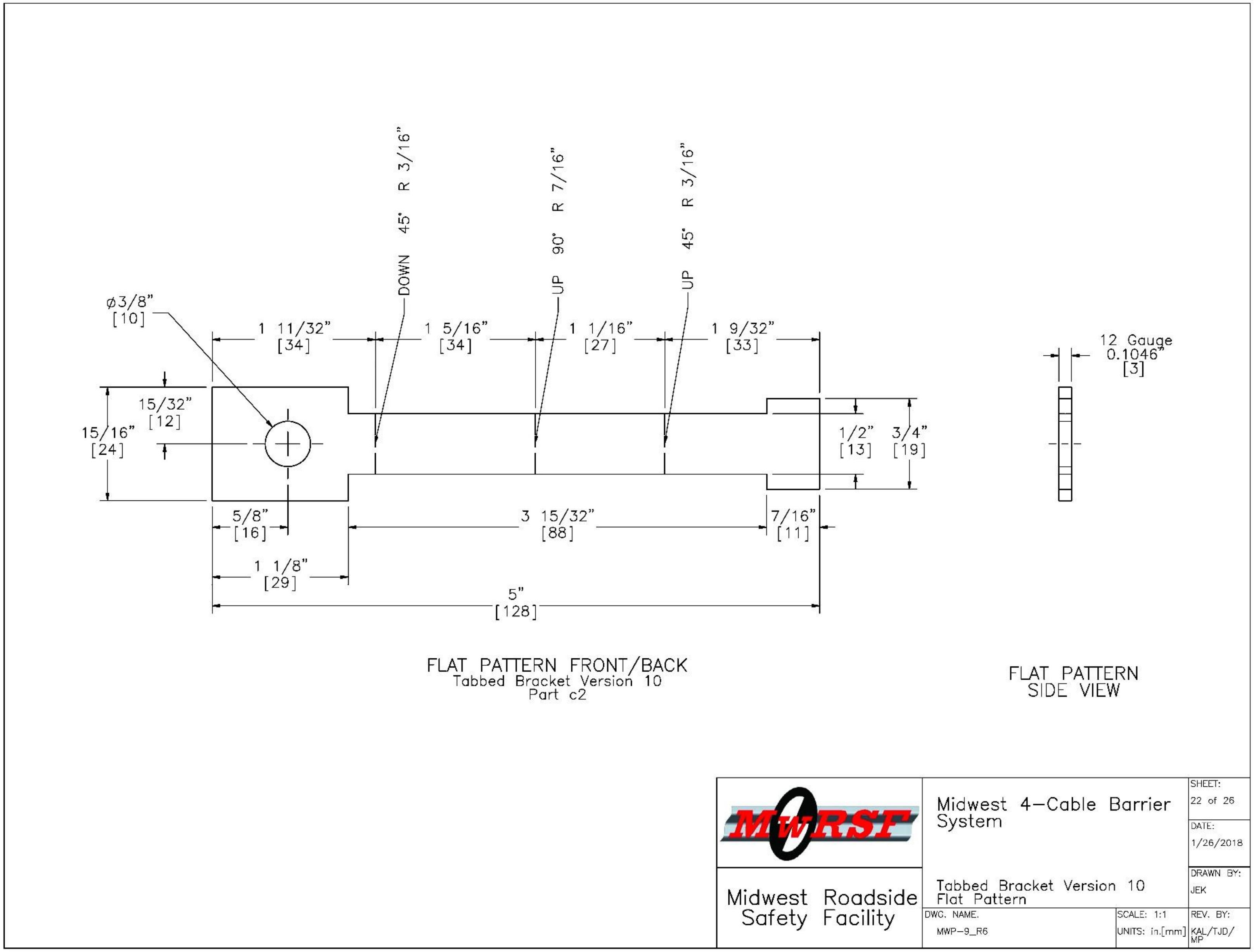



Figure 22. Tabbed Bracket Version 10 Flat Pattern, Test No. MWP-9

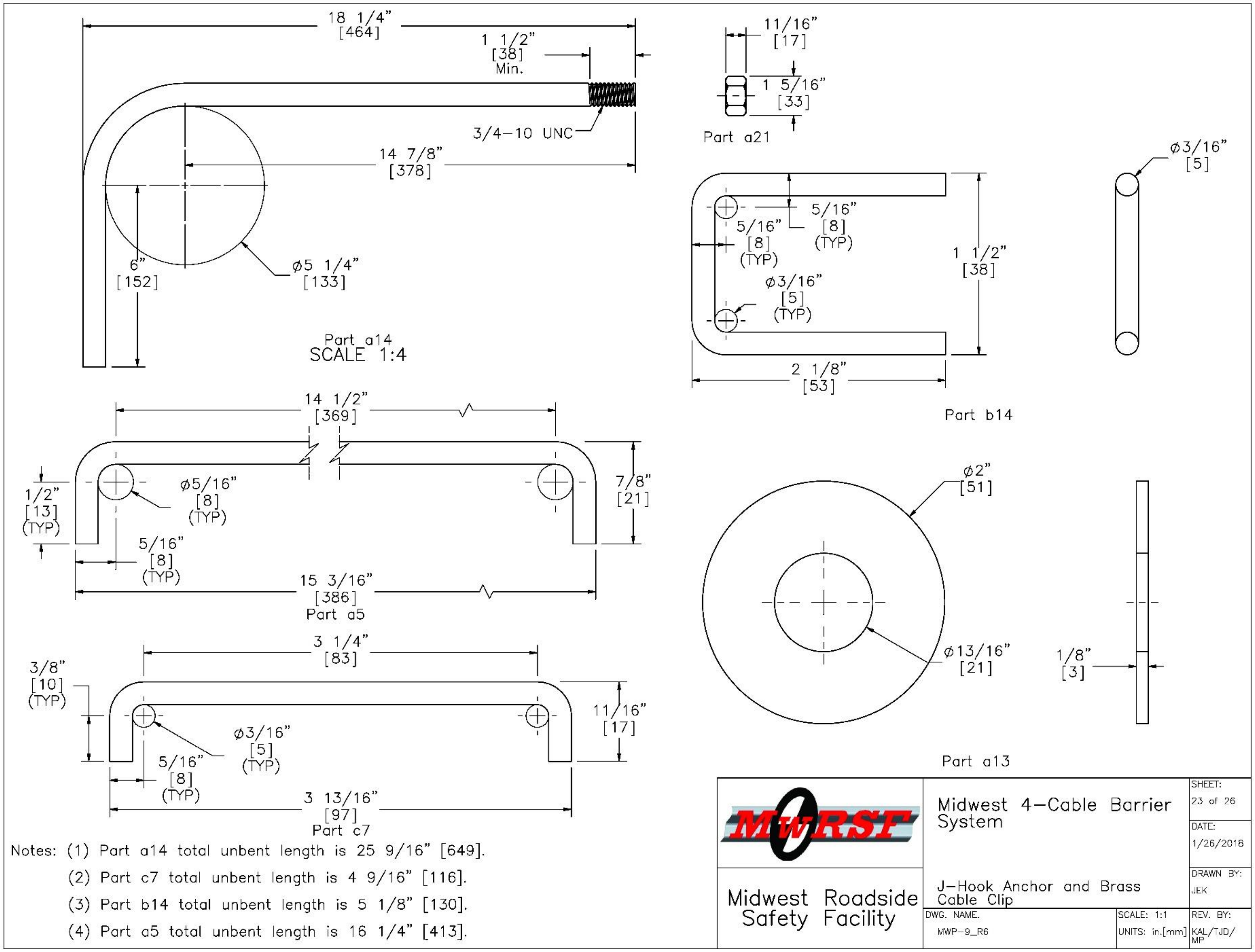



Figure 23. J-Hook Anchor and Brass Cable Clips, Test No. MWP-9

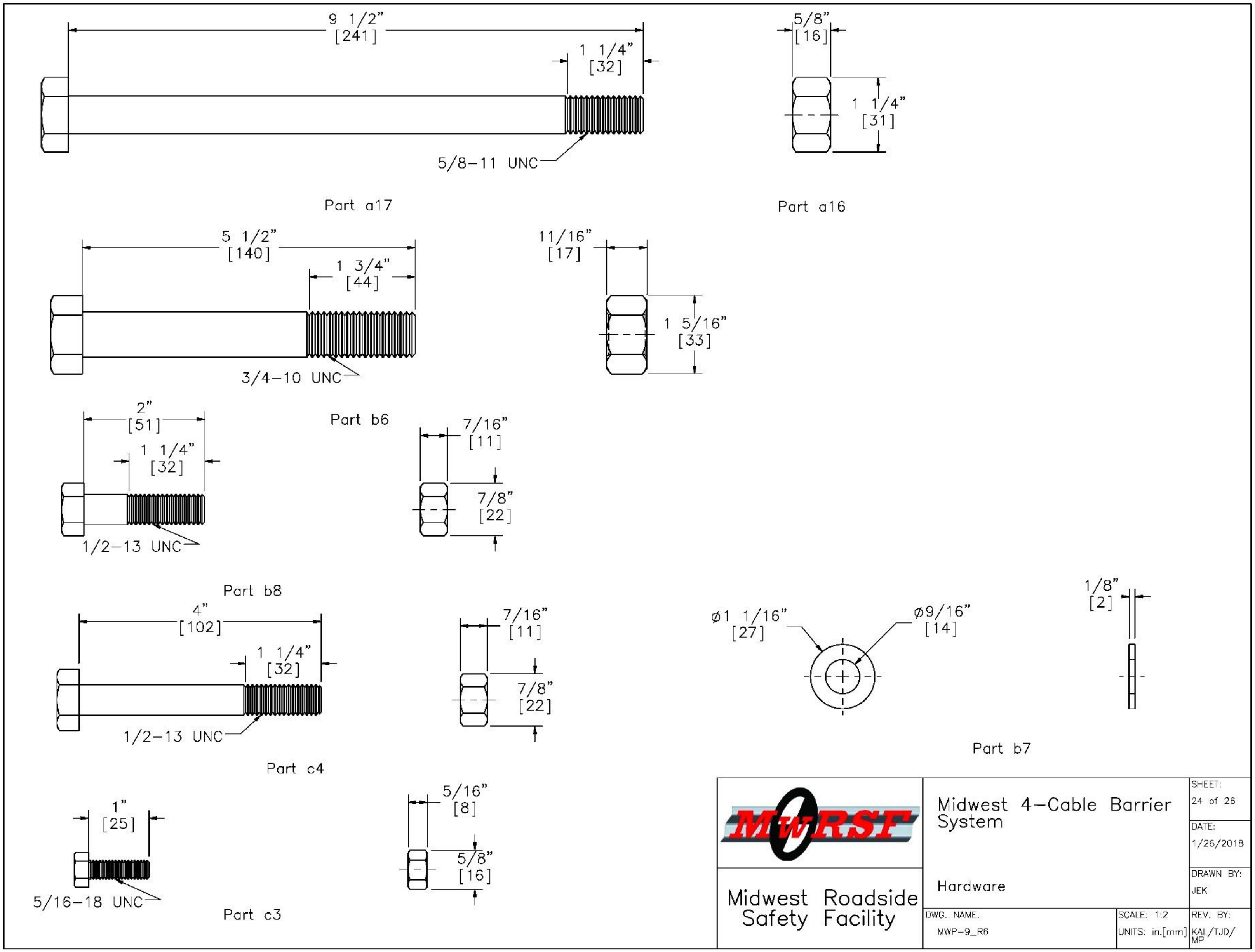



Figure 24. Hardware, Test No. MWP-9

| Item No. | QTY. | Description | Material Specification | Galv. Specification |
|---|---|---|---|---|
| a1 | 2 | Cable Anchor Base Plate | ASTM A36 | AASHTO M111 (ASTM A123) |
| a2 | 4 | Exterior Cable Plate Gusset | ASTM A36 | AASHTO M111 (ASTM A123) |
| a3 | 6 | Interior Cable Plate Gusset | ASTM A36 | AASHTO M111 (ASTM A123) |
| a4 | 2 | Anchor Bracket Plate | ASTM A36 | AASHTO M111 (ASTM A123) |
| a5 | 2 | 3/16" [5] Dia. Brass Keeper Rod, 16 1/4" [413] Long Unbent | ASTM B16-00 | – |
| a6 | 4 | Release Gusset | A36 Steel | AASHTO M111 (ASTM A123) |
| a7 | 2 | Release Lever Plate | A36 Steel | AASHTO M111 (ASTM A123) |
| a8 | 4 | 1 1/4x1 1/4x3/16" [32x32x5] TS CT Kicker Lever Tube | ASTM A500 Gr. B | AASHTO M111 (ASTM A123) |
| a9 | 8 | CMB High Tension Anchor Plate Washer | ASTM A36 | AASHTO M111 (ASTM A123) |
| a10 | 2 | 1 1/4x1 1/4x3/16" [32x32x5] TS CT Kicker Lever Connecting Tube | ASTM A500 Gr. B | AASHTO M111 (ASTM A123) |
| a11 | 2 | 3 1/2"x13 1/2"x1/2" [89x343x13] Kicker Plate | ASTM A36 | AASHTO M111 (ASTM A123) |
| a12 | 4 | CT Kicker – Gusset | ASTM A36 | AASHTO M111 (ASTM A123) |
| a13 | 20 | 3/4" [19] Dia. Flat Washer | ASTM F844 | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| a14 | 16 | 3/4" [19] Dia. UNC J-Hook Anchor | ASTM A449 Type 1 | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| a15 | 2 | 1/4" [6] Dia. 7x19 Aircraft Retaining Cable, 36" [914] Long | ASTM A1023 | ASTM A1007 |
| a16 | 2 | 5/8" [16] Dia. Heavy Hex Nut | ASTM A563C | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| a17 | 2 | 5/8" [16] Dia. UNC, 9 1/2" [241] Long Hex Bolt | ASTM A449 Type 1 or SAE J429 Gr. 5 | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| a18 | 2 | 24" [610] Dia. Concrete Anchor, 120" [3048] Long | Min. f'c = 4,000 psi [27.6 MPa] | – |
| a19 | 16 | #11 Straight Rebar, 114" [2896] Long | ASTM A615 Gr. 60 or ASTM A706 Gr. 60 | – |
| a20 | 44 | #4 Anchor Hoop Rebar with 21" [533] Dia., 84" [2134] Long Unbent | ASTM A615 Gr. 60 or ASTM A706 Gr. 60 | – |
| a21 | 18 | 3/4" [19] Dia. UNC Heavy Hex Nut | ASTM A563DH | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| b1 | 2 | S3x5.7 [S76x8.5] Post, 28 1/8" [714] Long | ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A | AASHTO M111 (ASTM A123) |
| b2 | 2 | S3x5.7 [S76x8.5] Post, 19" [483] Long | ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A | AASHTO M111 (ASTM A123) |
| b3 | 8 | #3 Straight Rebar, 43" [1092] Long | ASTM A615 Gr. 60 or ASTM A706 Gr. 60 | – |
| b4 | 22 | 7 1/4" [184] Dia. No. 3 Hoop Reinforcement, 37" [940] Long Unbent | ASTM A615 Gr. 60 or ASTM A706 Gr. 60 | – |
| b5 | 2 | 2nd Post Keeper Plate, 28 Gauge | ASTM A36 | AASHTO M111 (ASTM A123) |

Midwest Roadside Safety Facility

Midwest 4-Cable Barrier System

Bill of Materials

SHEET: 25 of 26
DATE: 1/26/2018
DRAWN BY: JEK
DWG. NAME. MWP-9_R6
SCALE: NONE
UNITS: in.[mm]
REV. BY: KAL/TJD/MP

Figure 25. Bill of Materials, Test No. MWP-9

| Item No. | QTY. | Description | Material Specification | Galv. Specification |
|---|---|---|---|---|
| b6 | 2 | 3/4" [19] Dia. UNC, 5 1/2" [140] Long Hex Bolt and Nut | Bolt ASTM A307 Gr. A/Nut ASTM A563A | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| b7 | 24 | 1/2" [13] Dia. Washer with 1 1/16" [27] OD | ASTM F844 | AASHTO M232 (ASTM A153) for Class D or AASHTO M298 (ASTM B695) for Class 50 |
| b8 | 8 | 1/2" [13] Dia. UNC, 2" [51] Long Hex Bolt and Nut | Bolt ASTM A307 Gr. A/Nut ASTM A563A | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| b9 | 2 | 4x3x1/4" [102x76x6] Foundation Tube, 48" [1219] Long | ASTM A500 Grade B | AASHTO M111 (ASTM A123) |
| b10 | 2 | 2nd Post Cable Hanger | ASTM A36 | AASHTO M111 (ASTM A123) |
| b11 | 2 | 12" [305] Dia. 2nd Post Anchor Aggregate, 2" [51] Deep | Standard Strong Soil | – |
| b12 | 2 | 12" [305] Dia. 2nd Post Concrete Anchor, 46" [1168] Long | Min f'c = 4,000 psi [27.6 MPa] | – |
| b13 | 4 | 2nd Post Base Plate | ASTM A36 | AASHTO M111 (ASTM A123) |
| b14 | 8 | 3/16" [5] Dia., 5 1/8" [130] Long Unbent Brass Rod | ASTM B16–00 | – |
| c1 | 72 | 3"x1–3/4"x7 Gauge [76x44x4.6] x 79 5/8" [2022] Long Bent Z–Section Post with 3/4" [19] Dia. Weakening Holes | Hot–Rolled ASTM A1011 HSLA Gr. 50 | AASHTO M111 (ASTM A123) |
| c2 | 216 | 12 Gauge Tabbed Bracket – Version 10 | Hot–Rolled ASTM A1011 HSLA Gr. 50 | AASHTO M111 (ASTM A123) |
| c3 | 216 | 5/16" [8] Dia. UNC, 1" [25] Long Hex Cap Screw and Nut | Bolt SAE J429 Gr. 5 or ASTM A449 Type 1/Nut ASTM A563DH | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| c4 | 72 | 1/2" [13] Dia. UNC, 4" [102] Long Hex Bolt and Nut | Bolt SAE J429 Gr. 5 or ASTM A449 or ASTM A325/Nut ASTM A563DH | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| c5 | 72 | 2 1/8"x1 3/8"x7 Gauge [54x35x4.6], 6" [152] Long Bent Steel Plate | Hot–Rolled ASTM A1011 HSLA Gr. 50 | AASHTO M111 (ASTM A123) |
| c6 | 72 | 2 1/8"x1 3/8"x7 Gauge [54x35x4.6], 6" [152] Long Bent Steel Plate | Hot–Rolled ASTM A1011 HSLA Gr. 50 | AASHTO M111 (ASTM A123) |
| c7 | 72 | 3/16" [5] Dia. Brass Cable Clip, 4 9/16" [116] Long Unbent | ASTM B16 Brass C36000 Half Hard (H02), ROUND, TS >= 68.0 ksi, YS >= 52.0 ksi | – |
| d1 | 1 | 3/4" [19] Dia. 3x7 Cable Guiderail | AASHTO M30 Type 1 or ASTM A741 Type 1 with minimum breaking strength = 39 kips (173.5 kN) | Class A |
| d2 | 16 | 7/8" [22] Dia. Heavy Hex Nut | ASTM A563C | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| d3 | 28 | 7/8" [22] Dia. UNC, 11" [279] Long Threaded Rod | ASTM A449 Type 1 or ASTM A193 Gr. B7 | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| d4 | 24 | Bennett Cable End Fitter | ASTM A47 | AASHTO M232 (ASTM A153) for Class A |
| d5 | 24 | 7/8" [22] Dia. Hex Nut | ASTM A563DH | AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50 |
| e1 | 8 | Bennett Short Threaded Turnbuckle | As Supplied | – |
| e2 | 8 | Threaded Load Cell Coupler | Not Applicable (NA) | NA |
| e3 | 4 | 50,000–lb [222.4–kN] Load Cell | Not Applicable (NA) | NA |

MwRSF

Midwest Roadside Safety Facility

Midwest 4–Cable Barrier System

Bill of Materials

SHEET: 26 of 26

DATE: 1/26/2018

DRAWN BY: JEK

DWG. NAME. MWP–9_R6

SCALE: NONE

UNITS: in.[mm]

REV. BY: KAL/TJD/MP

Figure 26. Bill of Materials, Test No. MWP-9

Figure 27. System Installation, Test No. MWP-9


Figure 28. Post and Cap Details, Test No. MWP-9

Figure 29. Bracket Details, Test No. MWP-9

Figure 30. Upstream Cable Splices, Test No. MWP-9

Figure 31. Downstream Cable Splices, Test No. MWP-9

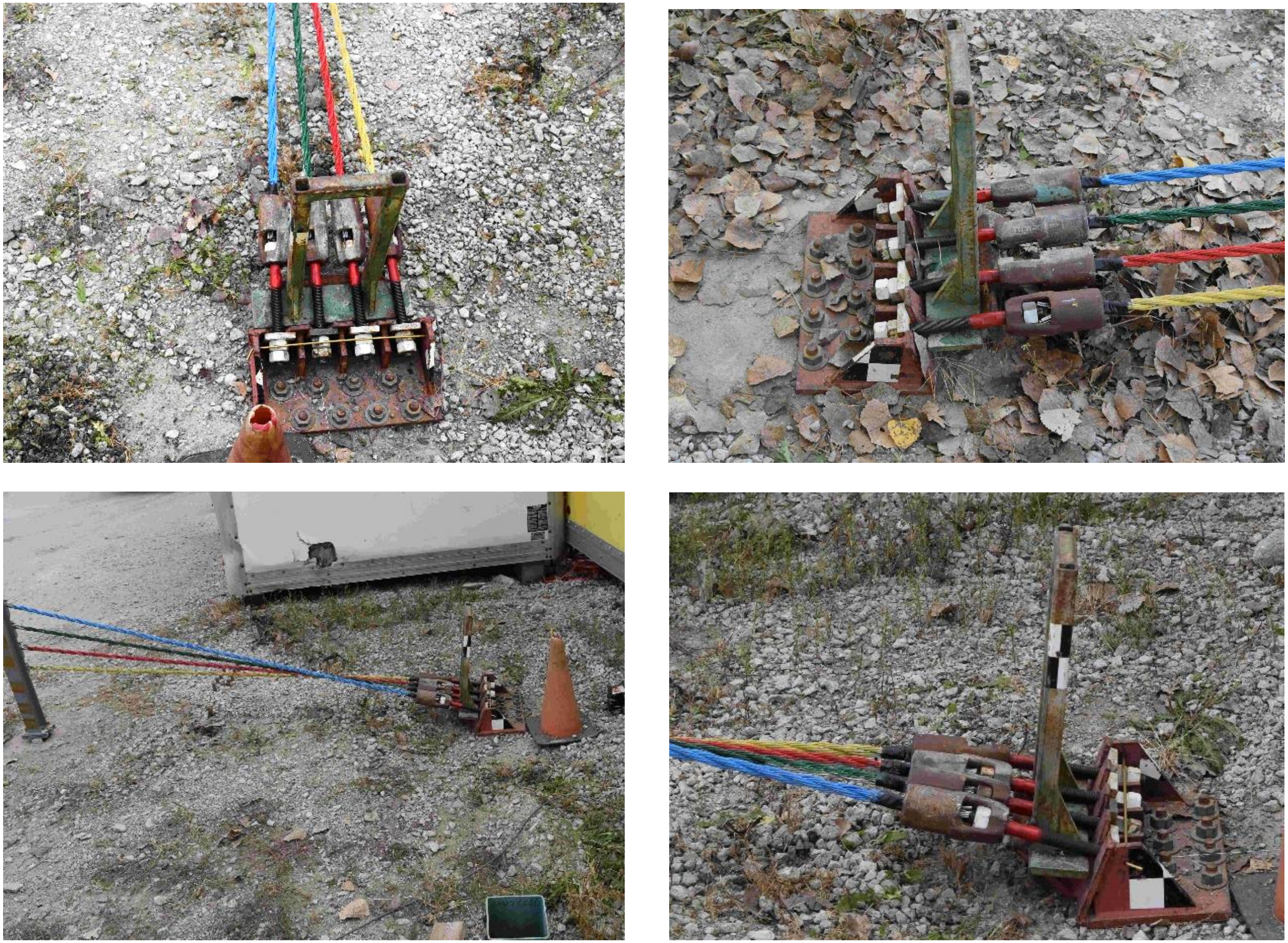


Figure 32. Upstream Anchorage, Test No. MWP-9

Figure 33. Downstream Anchorage, Test No. MWP-9

# 4 TEST CONDITIONS

## 4.1 Test Facility

The outdoor test site is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles (8.0 km) northwest of the University of Nebraska-Lincoln.

## 4.2 Vehicle Tow and Guidance System

A reverse-cable, tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [8] was used to steer the test vehicle. A guide flag, attached to the right-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

## 4.3 Test Vehicle

For test no. MWP-9, a 2008 Kia Rio was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,457 lb (1,114 kg), 2,421 lb (1,098 kg), and 2,594 lb (1,177 kg), respectively. The test vehicle is shown in Figures 34 and 35, and vehicle dimensions are shown in Figure 36. Note that pre-test photographs of the vehicle's undercarriage are not available.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [9]. The location of the final c.g. is shown in Figures 36 and 37. Data used to calculate the location of the c.g. and ballast information is shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 37. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

The front wheels of the test vehicle were aligned to vehicle standards except the toe-in value was adjusted to zero so that the vehicle would track properly along the guide cable. A 5B flash bulb was mounted under the vehicle's left-side windshield wiper and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A remote-controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.



Figure 34. Test Vehicle, Test No. MWP-9


Figure 35. Test Vehicle's Interior Floorboards, Test No. MWP-9

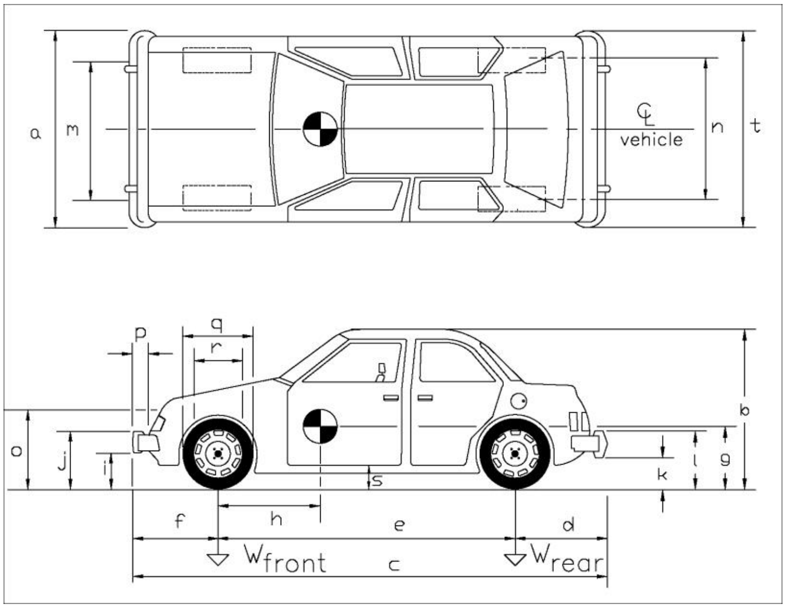
**Date:** 10/31/2016 **Test Number:** MWP-9 **Model:** Rio

**Make:** Kia **Vehicle I.D.#:** KNADE123086347849

**Tire Size:** 185/65R14 86T **Year:** 2008 **Odometer:** 89814

**Tire Inflation Pressure:** 32

***(All Measurements Refer to Impacting Side)**




**Vehicle Geometry -- in. (mm)**

| | | | | | |
|---|---|---|---|---|---|
| a | 64 7/8 | (1648) | b | 58 3/8 | (1483) |
| c | 166 7/8 | (4239) | d | 36 1/4 | (921) |
| e | 98 1/2 | (2502) | f | 33 1/8 | (841) |
| g | 23 1/8 | (587) | h | 36 1/2 | (927) |
| i | 9 1/8 | (232) | j | 21 1/4 | (540) |
| k | 16 1/4 | (413) | l | 25 | (635) |
| m | 57 | (1448) | n | 57 1/8 | (1451) |
| o | 30 3/8 | (772) | p | 4 1/8 | (105) |
| q | 23 1/2 | (597) | r | 15 3/8 | (391) |
| s | 7 7/8 | (200) | t | 65 | (1651) |

| | | |
|---|---|---|
| Wheel Center Height Front | 10 3/4 | (273) |
| Wheel Center Height Rear | 11 1/4 | (286) |
| Wheel Well Clearance (F) | 25 1/4 | (641) |
| Wheel Well Clearance (R) | 25 3/8 | (645) |
| Frame Height (F) | 6 1/4 | (159) |
| Frame Height (R) | 16 3/8 | (416) |
| Engine Type | Gasoline | |
| Engine Size | 1.6 L | |
| Transmission Type: | Automatic | |
| Drive Axle: | Front | |

**Mass Distribution lb (kg)**

| | | | | |
|---|---|---|---|---|
| Gross Static | LF | 826 (375) | RF | 790 (358) |
| | LR | 494 (224) | RR | 484 (220) |

| Weights lb (kg) | Curb | Test Inertial | Gross Static |
|---|---|---|---|
| W-front | 1568 (711) | 1525 (692) | 1616 (733) |
| W-rear | 889 (403) | 896 (406) | 978 (444) |
| W-total | 2457 (1114) | 2421 (1098) | 2594 (1177) |

**GVWR Ratings**

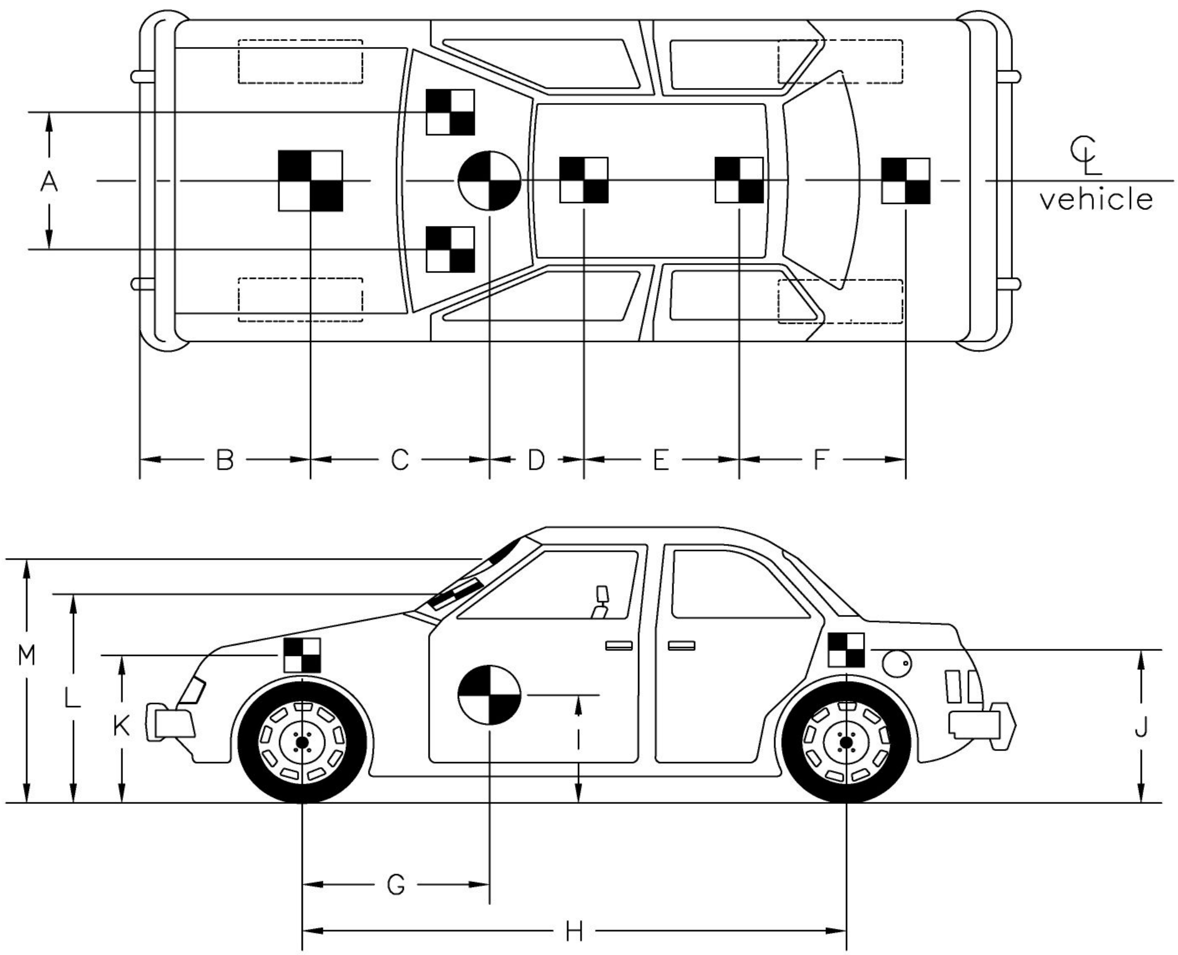
| | |
|---|---|
| Front | 1918 |
| Rear | 1874 |
| Total | 3638 |

**Dummy Data**

**Type:** Hybrid 1I
**Mass:** 173 lb
**Seat Position:** Driver

**Note any damage prior to test:** Extensive Hail Damage

Figure 36. Vehicle Dimensions, Test No. MWP-9




**TEST #: MWP-9 Vehicle: Kia Rio**

**TARGET GEOMETRY-- in. (mm)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A** | **25 5/8** | **(651)** | **E** | **41 3/4** | **(1060)** | **I** | **22 5/8** | **(575)** |
| **B** | **24 7/8** | **(632)** | **F** | **32 1/2** | **(826)** | **J** | **29 3/8** | **(746)** |
| **C** | **43 3/4** | **(1111)** | **G** | **36 3/8** | **(924)** | **K** | **29 1/8** | **(740)** |
| **D** | **11** | **(279)** | **H** | **98 3/4** | **(2508)** | **L** | **50 3/8** | **(1280)** |
| | | | | | | **M** | **52 7/8** | **(1343)** |

Figure 37. Target Geometry, Test No. MWP-9

## 4.4 Simulated Occupant

For test no MWP-9, a Hybrid II $50^{th}$-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the left-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 173 lb (78 kg), was represented by model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH 2016, the dummy was not included in calculating the c.g. location.

## 4.5 Data Acquisition Systems

### 4.5.1 Accelerometers

Two environmental, shock and vibration, sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometer systems were mounted near the c.g. of the test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [10].

The two accelerometer 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.

### 4.5.2 Rate Transducers

Two identical angular rate sensor systems mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders were used to measure the rates of rotation of the test vehicle. Each SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessors. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

### 4.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

### 4.5.4 Load Cells and String Potentiometers

Four load cells were installed upstream of the impact between post nos. 6 and 7 (cable nos. 2 and 4) and between post nos. 7 and 8 (cable nos. 1 and 3). The load cells were Transducer Techniques model no. TLL-50K with a load range up to 50 kips (222 kN). A string potentiometer was also attached to the system on the upstream anchor. The string potentiometer was Unimeasure model no. PA-50-70124 with a displacement range up to 50 in. (127 cm). During testing, output voltage signals were sent from the transducers to a National Instruments PCI-6071E data acquisition board, acquired with LabView software, and stored on a personal computer at a sample rate of 10,000 Hz. The positioning and set up of the transducers are shown in Figure 38.

### 4.5.5 Digital Photography

Six AOS high-speed digital video cameras, eleven GoPro digital video cameras, and three JVC digital video cameras were utilized to film test no. MWP-9. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 39.

The high-speed digital videos were analyzed using ImageExpress MotionPlus, TEMA Motion, and RedLake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A Nikon digital still camera was also used to document pre- and post-test conditions for all tests.

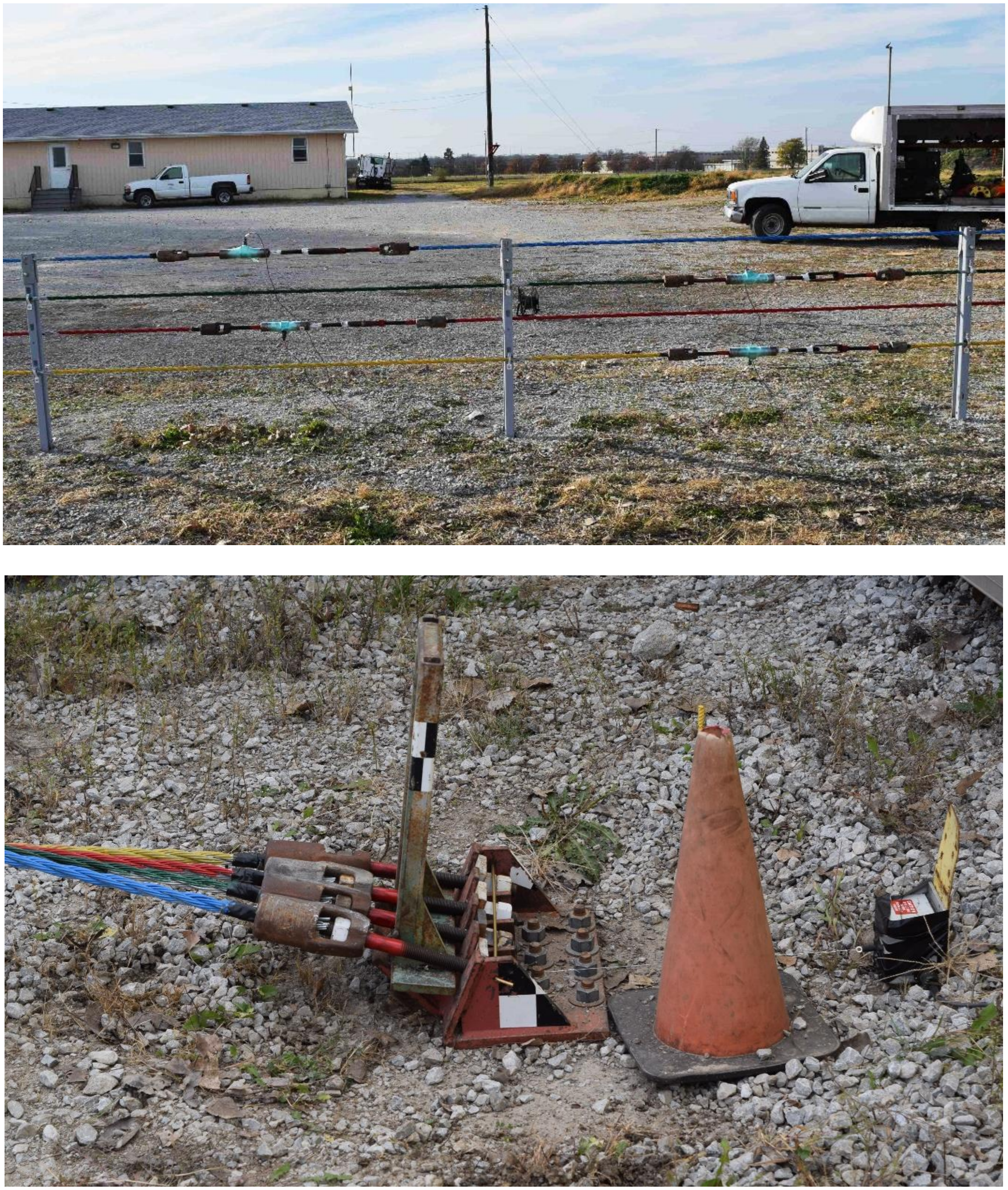
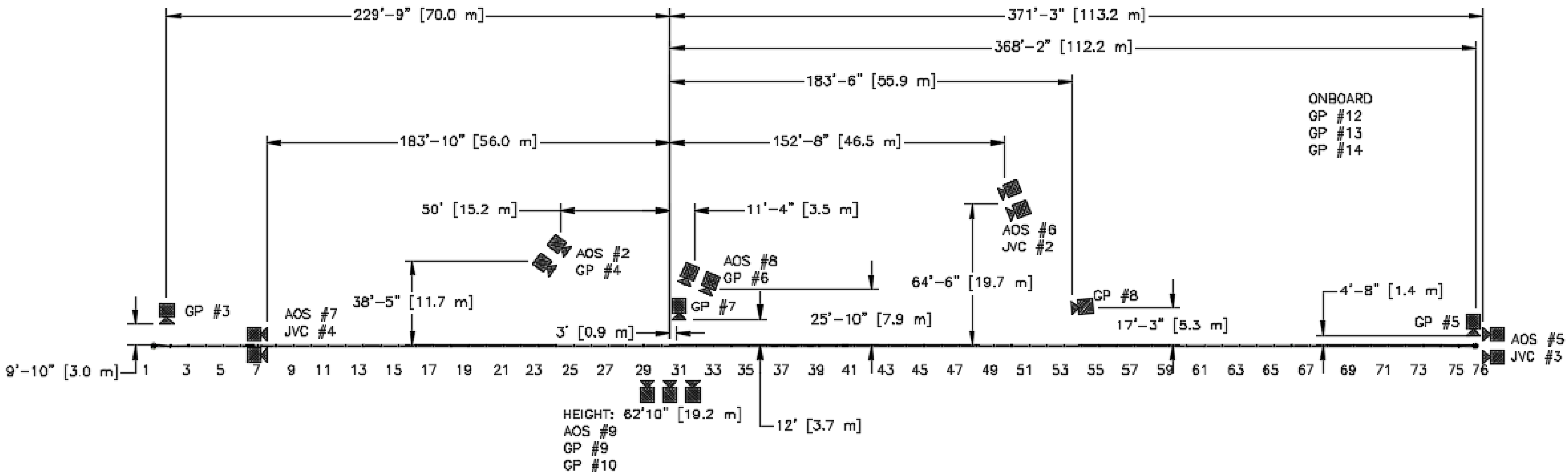


Figure 38. Location of Load Cells and String Potentiometers, Test No. MWP-9




| No. | Type | Operating Speed (frames/sec) | Lens | Lens Setting |
|---|---|---|---|---|
| AOS-2 | AOS Vitcam CTM | 500 | Kowa 25mm Fixed | – |
| AOS-5 | AOS X-PRI Gigabit | 500 | Telesar 135mm Fixed | – |
| AOS-6 | AOS X-PRI Gigabit | 500 | Sigma 28-70 DG | 35 |
| AOS-7 | AOS X-PRI Gigabit | 500 | Sigma 28-70 | 50 |
| AOS-8 | AOS S-VIT 1531 | 500 | Kowa 16mm Fixed | – |
| AOS-9 | AOS TRI-VIT | 1000 | Kowa 12mm Fixed | – |
| GP-3 | GoPro Hero 3+ | 120 | | |
| GP-4 | GoPro Hero 3+ | 120 | | |
| GP-5 | GoPro Hero 3+ | 120 | | |
| GP-6 | GoPro Hero 3+ | 120 | | |
| GP-7 | GoPro Hero 4 | 240 | | |
| GP-8 | GoPro Hero 4 | 240 | | |
| GP-9 | GoPro Hero 4 | 120 | | |
| GP-10 | GoPro Hero 4 | 240 | | |
| GP-12 | GoPro Hero 4 | 120 | | |
| GP-13 | GoPro Hero 4 | 120 | | |
| GP-14 | GoPro Hero 4 | 120 | | |
| JVC-2 | JVC – GZ-MG27u (Everio) | 29.97 | | |
| JVC-3 | JVC – GZ-MG27u (Everio) | 29.97 | | |
| JVC-4 | JVC – GZ-MG27u (Everio) | 29.97 | | |

Figure 39. Camera Locations, Speeds, and Lens Settings, Test No. MWP-9

# 5 FULL-SCALE CRASH TEST NO. MWP-9

## 5.1 Static Soil Test

Before full-scale crash test no. MWP-9 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

## 5.2 Weather Conditions

Test no. MWP-9 was conducted on October 31, 2016 at approximately 3:15 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

Table 3. Weather Conditions, Test No. MWP-9

| | |
|---|---|
| Temperature | 71° F |
| Humidity | 61% |
| Wind Speed | 14 mph |
| Wind Direction | 190° from True North |
| Sky Conditions | Partly Cloudy |
| Visibility | 10 Statute Miles |
| Pavement Surface | Dry |
| Previous 3-Day Precipitation | 0.00 in. |
| Previous 7-Day Precipitation | 0.01 in. |

## 5.3 Test Description

The 2,421-lb (1,098-kg) car impacted the cable barrier system at a speed of 63.1 mph (101.5 km/h) and at an angle of 25.7 degrees. A summary of the test results and sequential photographs are shown in Figure 42. Additional sequential photographs are shown in Figures 43 through 45.

Initial vehicle impact was to occur at a midspan location, or 4 ft (1.22 m) upstream from post no. 31, as shown in Figure 46, which was selected using Table 2-2D of MASH 2016. The actual point of impact was 3 ft – 10 in. (1.17 m) upstream of post no. 31. A sequential description of the impact events is contained in Table 4. The vehicle came to rest approximately 150 ft – 2 in. (45.77 m) downstream from the point of impact, or between post nos. 48 and 49 and in contact with the cables. Cable no. 4 was located on the non-impact side of the vehicle, cable no. 2 was located on the impact side, and cable nos. 1 and 3 were underneath the vehicle. The vehicle trajectory and final position are shown in Figures 47 and 48.

Table 4. Sequential Description of Impact Events, Test No. MWP-9

| TIME (sec) | EVENT |
|---|---|
| 0.000 | Vehicle's left-front bumper contacted cable no. 2. |
| 0.002 | Vehicle's left-front bumper contacted cable no. 1. |
| 0.012 | Vehicle's left fender contacted cable no. 3. |
| 0.024 | Cable no. 3 disengaged from post no. 31. |
| 0.026 | Post no. 31 bent downstream. |
| 0.028 | Cable no. 4 disengaged from post no. 31. |
| 0.032 | Cable no. 1 disengaged from post no. 31. |
| 0.034 | Cable no. 3 disengaged from post no. 30, cable no. 2 disengaged from post no 31. |
| 0.038 | Post no. 31 bent backward. |
| 0.042 | Cable no. 3 disengaged from post no. 32. |
| 0.046 | Post no. 32 bent backward, the vehicle's left-side mirror deformed. |
| 0.050 | Vehicle's left A-pillar contacted cable no. 3, post no. 30 deflected backward. |
| 0.056 | Cable no. 3 disengaged from post no. 29, vehicle's left-front tire overrode cable no. 1. |
| 0.064 | Vehicle's left A-pillar contacted cable no. 4, left-front tire overrode post no. 31, post no. 30 deflected upstream. |
| 0.066 | Cable no. 3 disengaged from post no. 33. |
| 0.069 | Post no. 33 deflected backward. |
| 0.072 | Vehicle's left-fender contacted cable no. 2. |
| 0.084 | Vehicle's left-side mirror disengaged, cable no. 3 disengaged from post no. 34, vehicle's left-front tire regained contact with ground. |
| 0.092 | Vehicle's hood deformed, cable no. 3 contacted windshield. |
| 0.098 | Cable no. 4 contacted vehicle's windshield and disengaged from post no. 32. |
| 0.102 | Post no. 30 bent backward, vehicle's front bumper contacted post no. 32, and vehicle's left-front door contacted cable no. 2. |
| 0.104 | Post no. 33 bent backward, cable no. 2 disengaged from post no. 32. |
| 0.110 | Vehicle yawed away from barrier, post no. 32 bent downstream. |
| 0.120 | Vehicle's left A-pillar deformed, cable no. 2 disengaged from post no. 33. |
| 0.132 | Vehicle rolled away from barrier, cable no. 4 disengaged from post no. 33. |
| 0.138 | Post no. 34 bent backward. |
| 0.150 | Cable no. 4 disengaged from post no. 34, vehicle pitched upward, cable no. 4 disengaged from post no. 30. |
| 0.160 | Vehicle's left-rear tire overrode cable no. 1. |
| 0.166 | Vehicle's windshield shattered from contact with cable nos. 1 and 2, cable no. 4 disengaged from post no. 35. |
| 0.174 | Vehicle's left-front window shattered from contact with cable nos. 1 and 2. |
| 0.176 | Cable no. 4 disengaged from post no. 29. |

| | |
|---|---|
| 0.193 | Post no. 35 deflected backward, cable no. 3 contacted vehicle’s left B-pillar. |
| 0.202 | Cable no. 4 contacted vehicle’s left B-pillar. |
| 0.208 | Vehicle’s right-side headlight deformed, cable no. 4 disengaged from post no. 37, vehicle’s right-front tire overrode cable no. 1. |
| 0.210 | Vehicle’s left-front tire became airborne, right-side headlight contacted post no. 33, post no. 36 deflected backward, cable no. 2 disengaged from post no. 34. |
| 0.224 | Post no. 35 bent backward, cable no. 3 disengaged from post no. 35. |
| 0.234 | Cable no. 1 disengaged from post no. 33. |
| 0.238 | Post no. 36 bent backward. |
| 0.240 | Cable no. 2 disengaged from post no. 35, cable no. 3 disengaged from post no. 36. |
| 0.249 | Post no. 37 deflected backward, cable no. 4 disengaged from post no. 38. |
| 0.262 | Cable no. 3 disengaged from post no. 37, vehicle pitched downward. |
| 0.266 | Cable no. 4 disengaged from post no. 39, post no. 37 bent backward. |
| 0.282 | Post no. 38 deflected backward. |
| 0.286 | Cable no. 2 disengaged from post no. 36. |
| 0.292 | Cable no. 4 disengaged from post no. 40. |
| 0.312 | Cable no. 2 disengaged from post no. 37, post no. 35 deflected downstream, vehicle’s left-front tire regained contact with ground. |
| 0.336 | Cable no. 3 contacted vehicle’s left C-pillar. |
| 0.356 | Cable no. 4 contacted vehicle’s left C-pillar. |
| 0.360 | Cable no. 3 disengaged from post no. 38. |
| 0.365 | Vehicle’s right-side mirror contacted post no. 34 and disengaged. |
| 0.388 | Cable no. 2 disengaged from post no. 38. |
| 0.404 | Post no. 39 deflected backward. |
| 0.430 | Vehicle pitched upward, cable no. 2 disengaged from post no. 30. |
| 0.436 | Cable no. 4 disengaged from post no. 41, post no. 39 rotated backward. |
| 0.454 | Cable no. 1 disengaged from post no. 30, vehicle rolled away from barrier. |
| 0.504 | Cable no. 2 disengaged from post no. 39. |
| 0.542 | Vehicle’s right-rear door contacted post no. 35. |
| 0.565 | Vehicle’s hood and right fender contacted post no. 36. |
| 0.574 | Post no. 36 bent downstream. |
| 0.590 | Cable nos. 3 and 4 contacted vehicle’s roof. |
| 0.596 | Vehicle became parallel to system at a speed of 45.4 mph (73.1 km/h) |
| 0.622 | Vehicle rolled toward barrier. |
| 0.658 | Vehicle underrode cable nos. 3 and 4. |
| 0.678 | Post no. 37 bent downstream, cable no. 3 disengaged from post no. 39. |
| 0.712 | Cable no. 3 disengaged from post no. 40. |
| 0.734 | Cable no. 3 disengaged from post no. 41. |
| 0.802 | Cable no. 1 disengaged from post no. 38. |

| | |
|---|---|
| 0.824 | Post no. 38 bent downstream. |
| 0.832 | Cable no. 1 disengaged from post no. 39, right-front tire overrode cable no. 1. |
| 0.920 | Vehicle rolled away from barrier. |
| 0.928 | Vehicle's front bumper contacted post no. 39. |
| 0.944 | Cable no. 4 contacted vehicle's right fender. |
| 0.966 | Cable no. 4 contacted vehicle right A-pillar. |
| 0.972 | Post no. 39 bent downstream. |
| 1.144 | Vehicle's left tire and fender contacted post no. 40. |
| 1.162 | Post no. 40 bent downstream, cable no. 2 disengaged from post no. 40. |
| 1.214 | Vehicle's right-front tire overrode cable no. 3. |
| 1.297 | Vehicle's left-front fender contacted post no. 41. |
| 1.674 | Vehicle's left-front tire contacted cable no. 3. |
| 1.870 | Vehicle's left-front fender contacted post no. 44. |
| 2.150 | Post no. 45 deflected backward. |
| 2.356 | Vehicle's left-front fender contacted post no. 46, which deflected downstream. |
| 2.958 | Vehicle's left-front fender contacted post no. 47, which deflected downstream. |
| 3.439 | Vehicle's left-front fender contacted post no. 48, which deflected downstream. |
| 4.331 | Vehicle came to rest in system. |

## 5.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 49 through 85. Barrier damage consisted of bent posts, disengaged cables, and deformed brackets. At its final resting position, the vehicle was still in contact with the cables. Cable nos. 1 and 3 were underneath the vehicle while cable no. 4 was on the non-impact side of the vehicle and cable no. 2 was on the impact side of the vehicle. The length of vehicle contact along the barrier was approximately 150 ft – 2 in. (45.77 m), which spanned from 3 ft – 10 in. (1.17 m) upstream of post no. 31 to between post nos. 48 and 49. The release mechanism of each cable from the posts is summarized in Table 5.

Post nos. 27 through 40, 45 through 49, and 51 had varying degrees of plastic deformation in the form of bending and twisting. Typically, the posts were bent laterally backward and longitudinally downstream. Post nos. 30 through 36, 38 through 40, 42 through 45, and 48 through 51 encountered contact marks and grinding marks on the edges due to vehicle override. The vehicle came to a complete stop on top of post nos. 48 and 49.

The working width of the system was found to be 103.2 in. (2,621 mm), as determined from high-speed digital video analysis. The maximum lateral dynamic barrier deflection was 96.4 in. (2,449 mm), as determined from high-speed digital video analysis. The permanent set deflection of the barrier was 33¾ in. (857 mm), as measured in the field. The upstream anchor experienced a dynamic deflection of 0.3 in. (7 mm).

Table 5. Disengaged Cables and Release Mechanisms, Test No. MWP-9

| Post No. | Cable No. | | | |
| --- | --- | --- | --- | --- |
| | 1 | 2 | 3 | 4 |
| 22 | 0 | 0 | 2 | 7 |
| 23 | 0 | 0 | 0 | 2 |
| 24 | 0 | 0 | 0 | 2 |
| 25 | 0 | 0 | 0 | 2 |
| 26 | 0 | 0 | 0 | 2 |
| 27 | 2 | 0 | 2 | 2 |
| 28 | 2 | 0 | 2 | 2 |
| 29 | 2 | 0 | 2 | 2 |
| 30 | 2 | 2 | 2 | 2 |
| 31 | 2 | 2 | 2 | 2 |
| 32 | 2 | 2 | 2 | 2 |
| 33 | 2 | 2 | 2 | 2 |
| 34 | 1 | 2 | 2 | 2 |
| 35 | 1 | 2 | 2 | 2 |
| 36 | 2 | 2 | 2 | 2 |
| 37 | 2 | 2 | 2 | 2 |
| 38 | 4 | 2 | 2 | 2 |
| 39 | 3 | 2 | 2 | 2 |
| 40 | 2 | 2 | 2 | 2 |
| 41 | 0 | 0 | 2 | 2 |
| 42 | 0 | 0 | 2 | 2 |
| 43 | 1 | 0 | 2 | 2 |
| 44 | 1 | 2 | 2 | 2 |
| 45 | 1 | 2 | 2 | 2 |
| 46 | 1 | 2 | 2 | 2 |
| 47 | 1 | 2 | 2 | 2 |
| 48 | 2 | 2 | 2 | 2 |
| 49 | 1 | 2 | 2 | 2 |
| 50 | 0 | 0 | 2 | 2 |
| 51 | 0 | 0 | 2 | 2 |
| 52 | 0 | 0 | 0 | 7 |

0- No Interaction 1- Deformed in Place 2- Released Entirely 3- Fractured at Tab
4- Fractured at Neck 5- Fractured through Bolt Hole 6- Brass Rod Fractured 7- Brass Rod Bent in Place

## 5.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 86 through 88. The maximum occupant compartment deformations are listed in Table 6 along with the deformation limits established in MASH 2016 for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations as well as the corresponding locations are provided in Appendix D.

Table 6. Maximum Occupant Compartment Deformations by Location

| LOCATION | MAXIMUM DEFORMATION in. (mm) | MASH 2016 ALLOWABLE DEFORMATION in. (mm) |
|---|---|---|
| Wheel Well & Toe Pan | ⅜ (10) | ≤ 9 (229) |
| Floor Pan & Transmission Tunnel | ¼ (6) | ≤ 12 (305) |
| A- and B-Pillars | 3.9 (99) | ≤ 5 (127) |
| A- and B-Pillars (Lateral) | 3.4 (86) | ≤ 3 (76) |
| Side Front Panel (in Front of A-Pillar) | ¼ (6) | ≤ 12 (305) |
| Side Door (Above Seat) | ½ (13) | ≤ 9 (229) |
| Side Door (Below Seat) | ¼ (6) | ≤ 12 (305) |
| Roof | $1^7/_8$ (48) | ≤ 4 (102) |
| Windshield | ¼ (6) | ≤ 3 (76) |
| Side Window | Shattered due to contact with cable | No shattering as a result of direct contact with structural member of test article (acceptable if shatters due to contact with cable when A-pillar deformation ≤ 3 (76) |
| Dash | ½ (13) | N/A |

N/A – Not Applicable

The majority of the vehicle damage was concentrated on the left-front corner, where primary impact occurred, and on the right-front corner, where the vehicle redirected back into the system. The cables caused striation marks, scrapes, and gouges along the left-front and right-front fenders and up the entire length of the A-pillar, B-pillar, and C-pillar on the left side of the vehicle. As the vehicle overrode the system, cable no. 3 snagged on the cap retainer bolt and nut and induced an increased downward and lateral force to the A-pillar. Consequently, cable nos. 3 and 4 became interlocked with the A-pillar on the impact side, resulting in an excessive A-pillar crush of 3.4 in. (86 mm), which is greater than the 3-in. (76-mm) MASH 2016 limit. Contact marks were also found on the roof, which were caused by the vehicle underriding cable nos. 3 and 4. The front bumper covers, both headlights, and both side mirrors disengaged from the vehicle. The left-front side window and windshield shattered on the left side of the vehicle near the A-pillar. The left-front rim had contact marks, and the right-front tire was deflated. Several scrapes and dents were observed along both frame rails of the vehicle undercarriage. However, no visible tearing or crush on the vehicle floor pan occurred.

## 5.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 7. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 7. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 42. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 7. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MWP-9

| Evaluation Criteria | | Transducer | | MASH Limits |
|---|---|---|---|---|
| | | SLICE-1 (Primary) | SLICE-2 | |
| OIV ft/s (m/s) | Longitudinal | -15.22 (-4.64) | -16.34 (-4.98) | ± 40 (12.2) |
| | Lateral | 13.07 (3.98) | 12.53 (3.82) | ± 40 (12.2) |
| ORA g's | Longitudinal | -5.53 | -6.15 | ± 20.49 |
| | Lateral | -7.26 | -6.21 | ± 20.49 |
| MAX ANGULAR DISPLACEMENT deg. | Roll | 5.39 | 6.51 | ± 75 |
| | Pitch | 5.98 | 3.27 | ± 75 |
| | Yaw | 34.58 | 34.10 | not required |
| THIV ft/s (m/s) | | 19.23 (5.86) | 20.47 (6.24) | not required |
| PHD g's | | 7.61 | 8.47 | not required |
| ASI | | 0.53 | 0.50 | not required |

## 5.7 Load Cells and String Potentiometer

The pertinent data from the load cells and string potentiometer was extracted from the bulk signal and analyzed using the transducers' calibration factors, as shown in Figures 40 and 41, respectively. The maximum displacement of the upstream anchor was recorded as 0.3 in. (7 mm). A summary of the maximum cable loads can be found Table 8. The recorded data and analyzed results are detailed in Appendix F. The exact moment of impact could not be determined from the transducer data as impact may have occurred a few milliseconds prior to observing a measurable signal in the electronic data. Thus, the extracted data curves should not be taken as a precise time after impact, but rather a general timeline between events within the data curve itself.

Table 8. Maximum Cable Loads, Test No. MWP-9

| Cable Location | Sensor Location | Maximum Cable Load kips (kN) | Time (sec) |
|---|---|---|---|
| Combined Cable Load | Upstream of Impact | 34.7 (154.4) | 0.3364 |
| Cable No. 4 | Upstream of Impact between Post Nos. 6 and 7 | 8.9 (39.6) | 1.2249 |
| Cable No. 3 | Upstream of Impact between Post Nos. 7 and 8 | 11.3 (50.3) | 0.3786 |
| Cable No. 2 | Upstream of Impact between Post Nos. 6 and 7 | 14.6 (64.9) | 0.2821 |
| Cable No. 1 | Upstream of Impact between Post Nos. 7 and 8 | 10.3 (45.8) | 0.7823 |

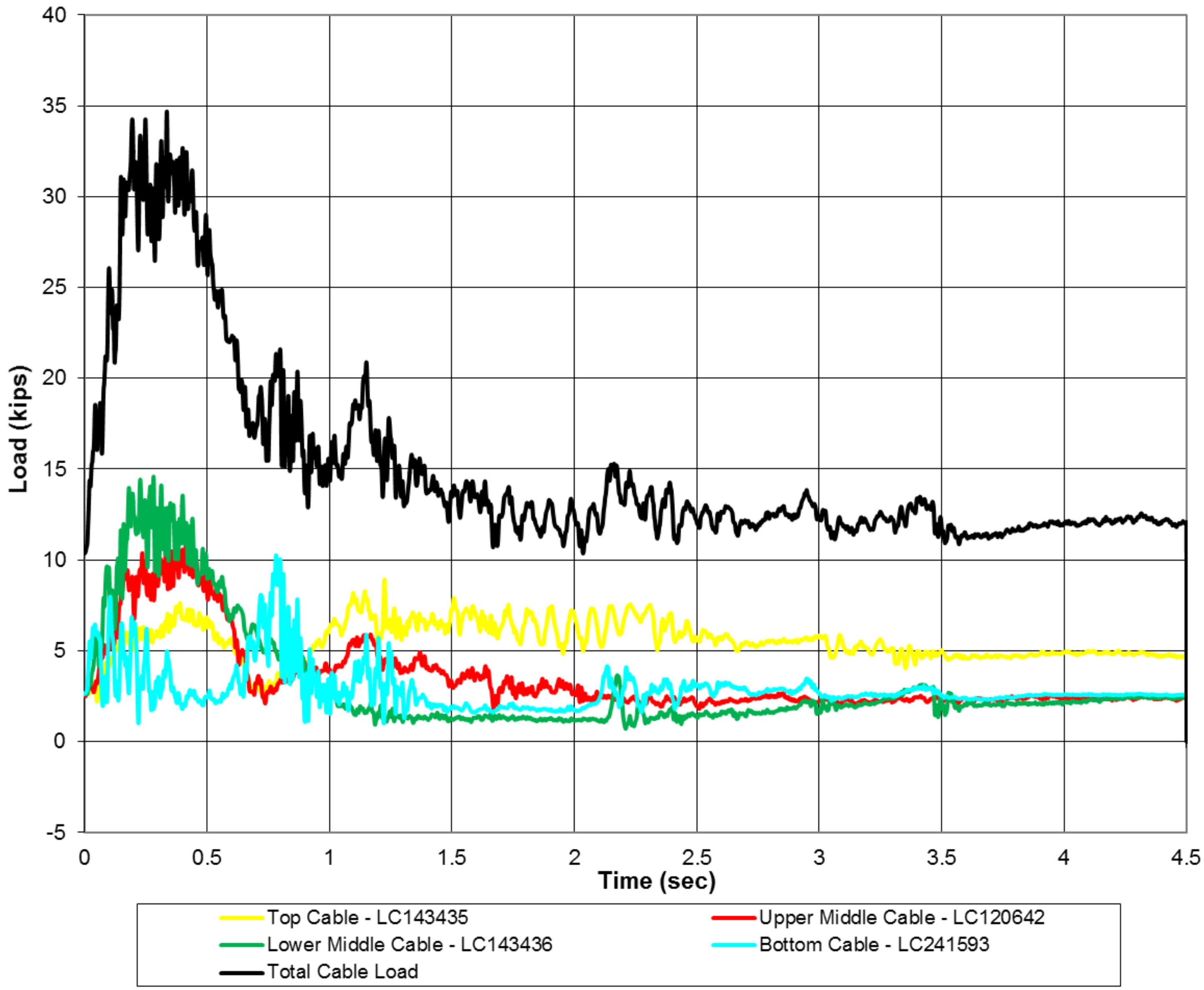



Figure 40. Cable Tension Loads, Test No. MWP-9

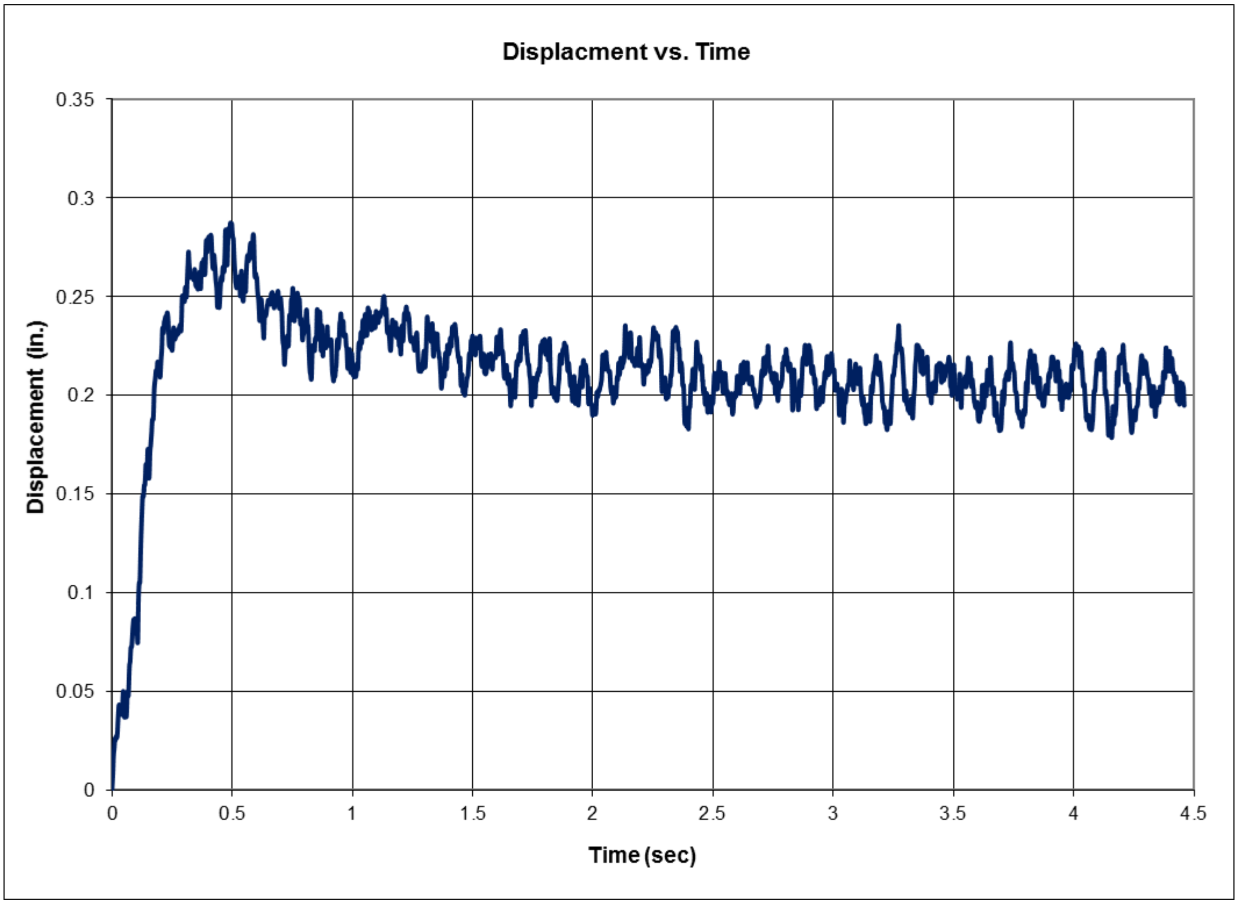
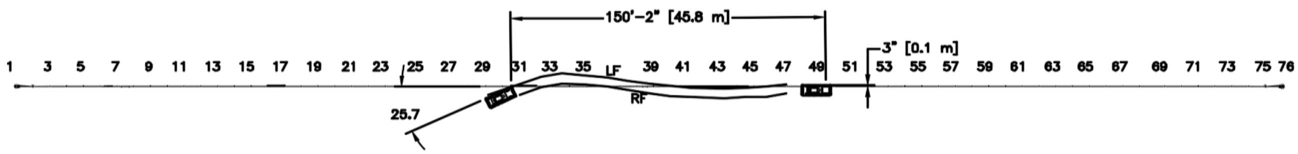


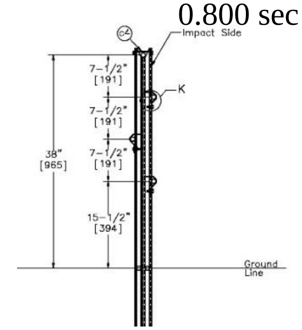
Figure 41. Displacement of Upstream Anchor, Test No. MWP-9

## 5.8 Discussion

The analysis of the test results for test no. MWP-9 showed that the high-tension four-cable median barrier adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. The test vehicle did not penetrate or ride over the barrier, and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle was captured and retained within the system, thus it did not exit the system. As the vehicle passed across various system components, cable no. 3 snagged on the top cap retainer bolt and nut and induced an increased downward and lateral force to the left-side A-pillar. Consequently, cable nos. 3 and 4 became interlocked with the deformed A-pillar on the impact side, resulting in an excessive lateral A-pillar crush of 3.4 in. (86 mm), which is greater than the 3-in. (76-mm) lateral MASH 2016 limit. Additionally, the left-front side window shattered due to contact with cable nos. 1 and 2, which is unacceptable when the A- or B-pillar crush exceeds the MASH 2016 limit of 3 in. (76 mm). Tearing and penetration did not occur to the vehicle’s floor pan. Thus, the two-part cap design that was used in test no. MWP-9 mitigated floor pan tearing and post penetration, but the test results were deemed unacceptable due to excessive A-pillar crush and the shattering of the left-front side window.

0.000 sec | 0.200 sec | 0.400 sec | 0.600 sec | 0.800 sec




- Test Agency ........................................ MwRSF
- Test Number ........................................ MWP-9
- Date ........................................ 10/31/2016
- MASH Test Designation No. ........................................ 3-10
- Test Article ........................................ Four-Cable Median Barrier
- Total Length ........................................ 604 ft (184.1 m)
- Key Component – Cable
  - Size ........................................ 3x7, ¾-in. (19-mm) diameter
  - Cable Heights ........................................ 15½, 23, 30½, 38 in. (394, 584, 775, 965 mm)
- Key Component – MWP
  - Dimensions ........................................ 3 x 1¾ x 81¼ in. (76 x 44 x 2,064 mm)
  - Spacing ........................................ 8 ft (2.44 m)
- Soil Type ........................................ Compacted, coarse, crushed limestone
- Vehicle Make /Model ........................................ 2008 Kia Rio
  - Curb ........................................ 2,457 lb (1,114 kg)
  - Test Inertial ........................................ 2,421 lb (1,098 kg)
  - Gross Static ........................................ 2,594 lb (1,177 kg)
- Impact Conditions
  - Speed ........................................ 63.1 mph (101.4 km/h)
  - Angle ........................................ 25.7 deg
  - Impact Location ........................................ 3 ft – 10 in. (1.17 m) upstream of Post No. 31
- Impact Severity .......... 60.5 kip-ft (82.0 kJ) > 51 kip-ft (69.1 kJ) limit from MASH 2016
- Exit Conditions
  - Speed ........................................ NA
  - Angle ........................................ NA
- Exit Box Criterion ........................................ NA (Did not exit system)
- Vehicle Stability ........................................ Satisfactory
- Vehicle Stopping Distance .......... 150 ft - 2 in. (45.77 m) Downstream within the system
- Vehicle Damage ........................................ Moderate
  - VDS [11] ........................................ 11-LFQ-5
  - CDC [12] ........................................ 11-LYAK-9
  - Maximum Interior Deformation ........................................ 3.4 in. (86 mm)
- Test Article Damage ........................................ Moderate
- Maximum Test Article Deflections
  - Permanent Set ........................................ 33¾ in. (857 mm)
  - Dynamic ........................................ 96.4 in. (2,449 mm)
  - Working Width ........................................ 103.2 in. (2,621 mm)
- Transducer Data

| **Evaluation Criteria** | | **Transducer** | | **MASH 2016 Limit** |
|---|---|---|---|---|
| | | **SLICE-1 (primary)** | **SLICE-2** | |
| OIV ft/s (m/s) | Longitudinal | -15.22 (-4.64) | -16.34 (-4.98) | ± 40 (12.2) |
| | Lateral | 13.07 (3.98) | 12.53 (3.82) | ± 40 (12.2) |
| ORA g's | Longitudinal | -5.53 | -6.15 | ± 20.49 |
| | Lateral | -7.26 | -6.21 | ± 20.49 |
| MAX ANGULAR DISPLACEMENT deg. | Roll | 5.39 | 6.51 | ±75 |
| | Pitch | 5.98 | 3.27 | ±75 |
| | Yaw | 34.58 | 34.10 | not required |
| THIV – ft/s (m/s) | | 19.23 (5.86) | 20.47 (6.24) | not required |
| PHD – g's | | 7.61 | 8.47 | not required |
| ASI | | 0.53 | 0.50 | not required |

Figure 42. Summary of Test Results and Sequential Photographs, Test No. MWP-9


Figure 43. Sequential Photographs, Test No. MWP-9


0.000 sec

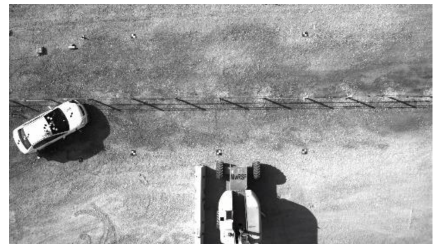

0.078 sec

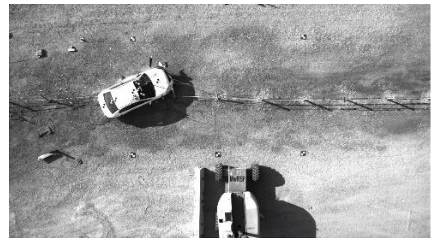

0.210 sec

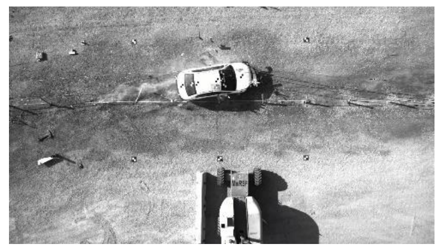

0.596 sec

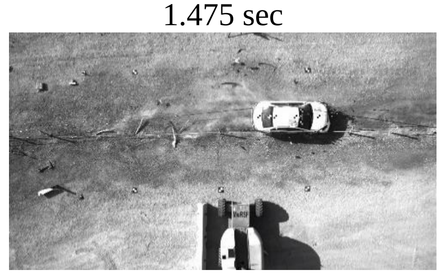

0.946 sec

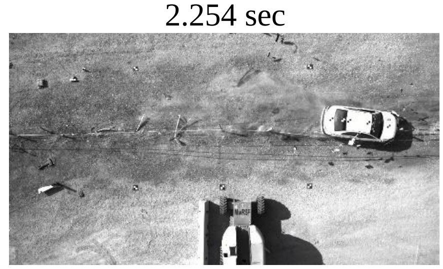

2.204 sec


0.000 sec


0.525 sec


1.475 sec


2.254 sec


2.966 sec

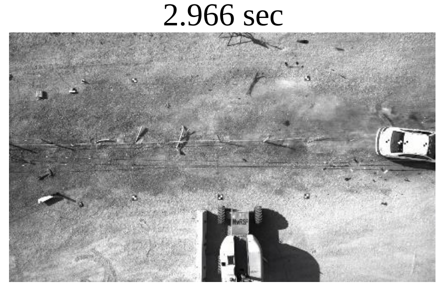

4.050 sec

Figure 44. Sequential Photographs, Test No. MWP-9

0.000 sec

0.143 sec

0.445 sec

0.647 sec

0.950 sec

1.655 sec

0.000 sec

0.525 sec

1.475 sec

2.254 sec

2.966 sec

4.050 sec

Figure 45. Additional Sequential Photographs, Test No. MWP-9

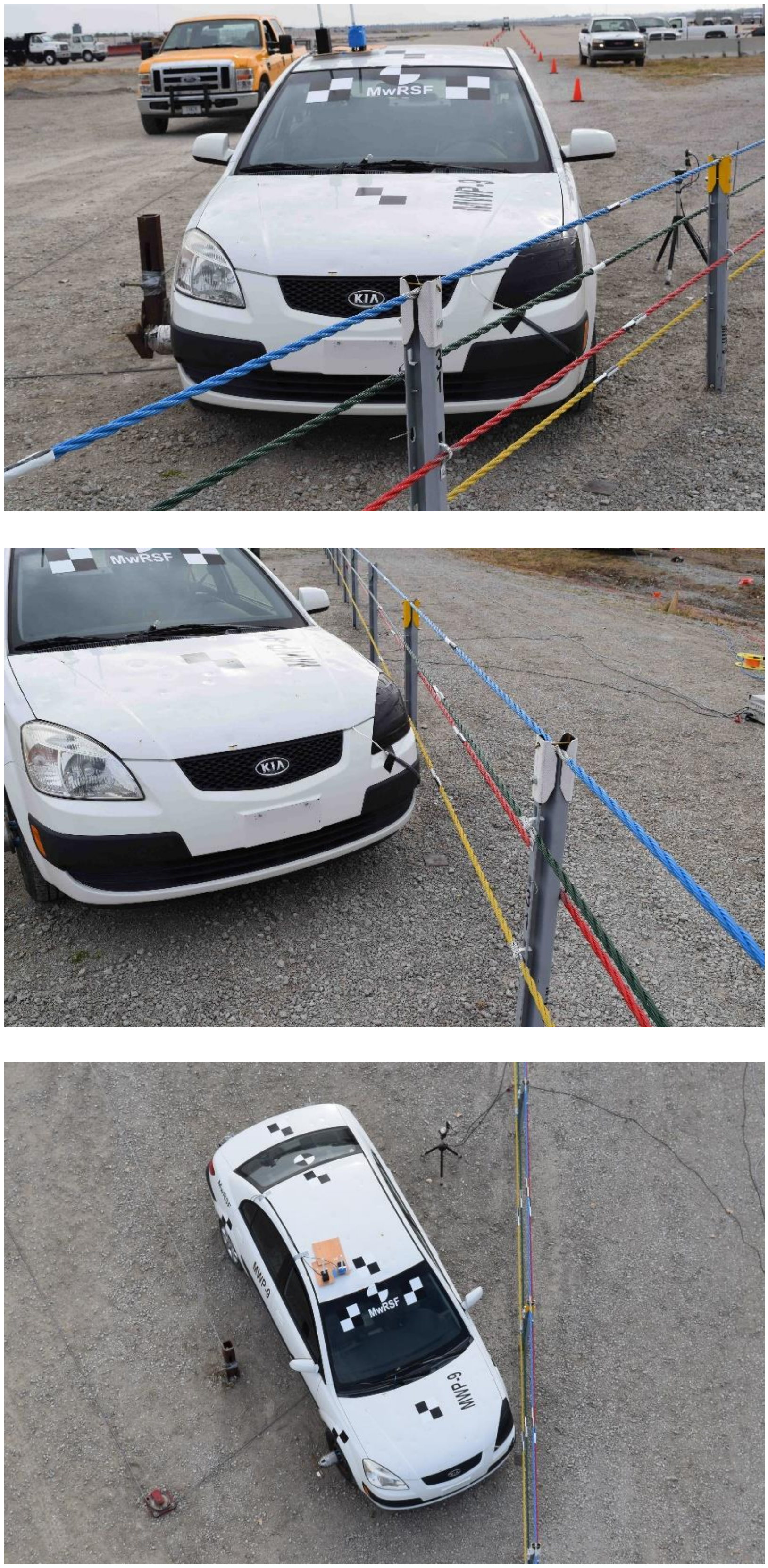



Figure 46. Impact Location, Test No. MWP-9


Figure 47. Vehicle Final Position, Test No. MWP-9

Figure 48. Vehicle Trajectory, Test No. MWP-9

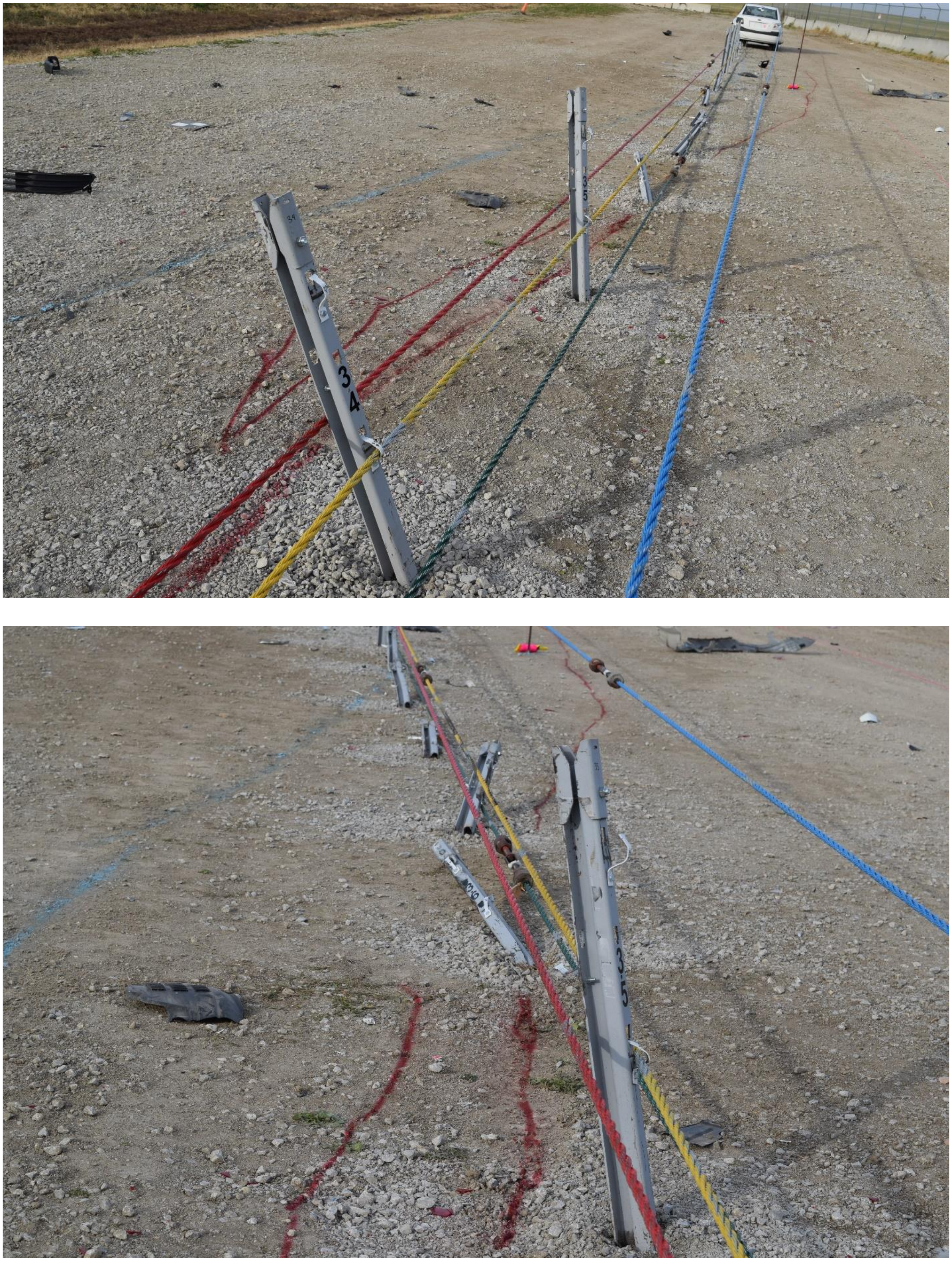



Figure 49. System Damage, Test No. MWP-9

Post Nos. 21 through 23

Post Nos. 24 and 25

Post Nos. 26 and 27

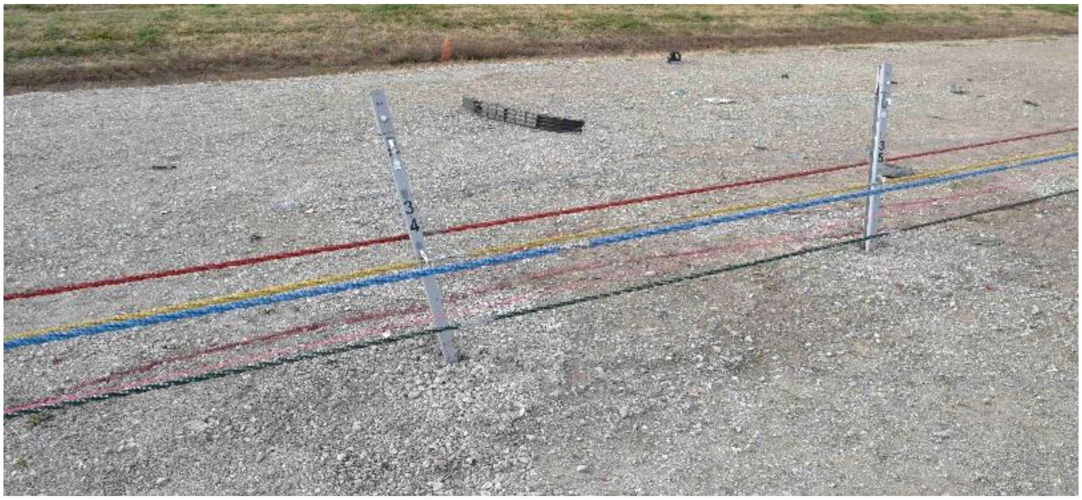
Figure 50. Post Nos. 21 through 27 Damage, Test No. MWP-9


Post Nos. 28

Post Nos. 29 and 30


Post Nos. 31 through 33

Figure 51. Post Nos. 28 through 33 Damage, Test No. MWP-9



Post Nos. 34 and 35

Post Nos. 36 through 38

Post Nos. 40 through 43

Figure 52. Post Nos. 34 through 43 Damage, Test No. MWP-9

Post Nos. 44 through 46

Post Nos. 47 and 48

Post Nos. 49 through 51

Figure 53. Post Nos. 44 through 51 Damage, Test No. MWP-9


Figure 54. Post No. 22 Damage, Test No. MWP-9

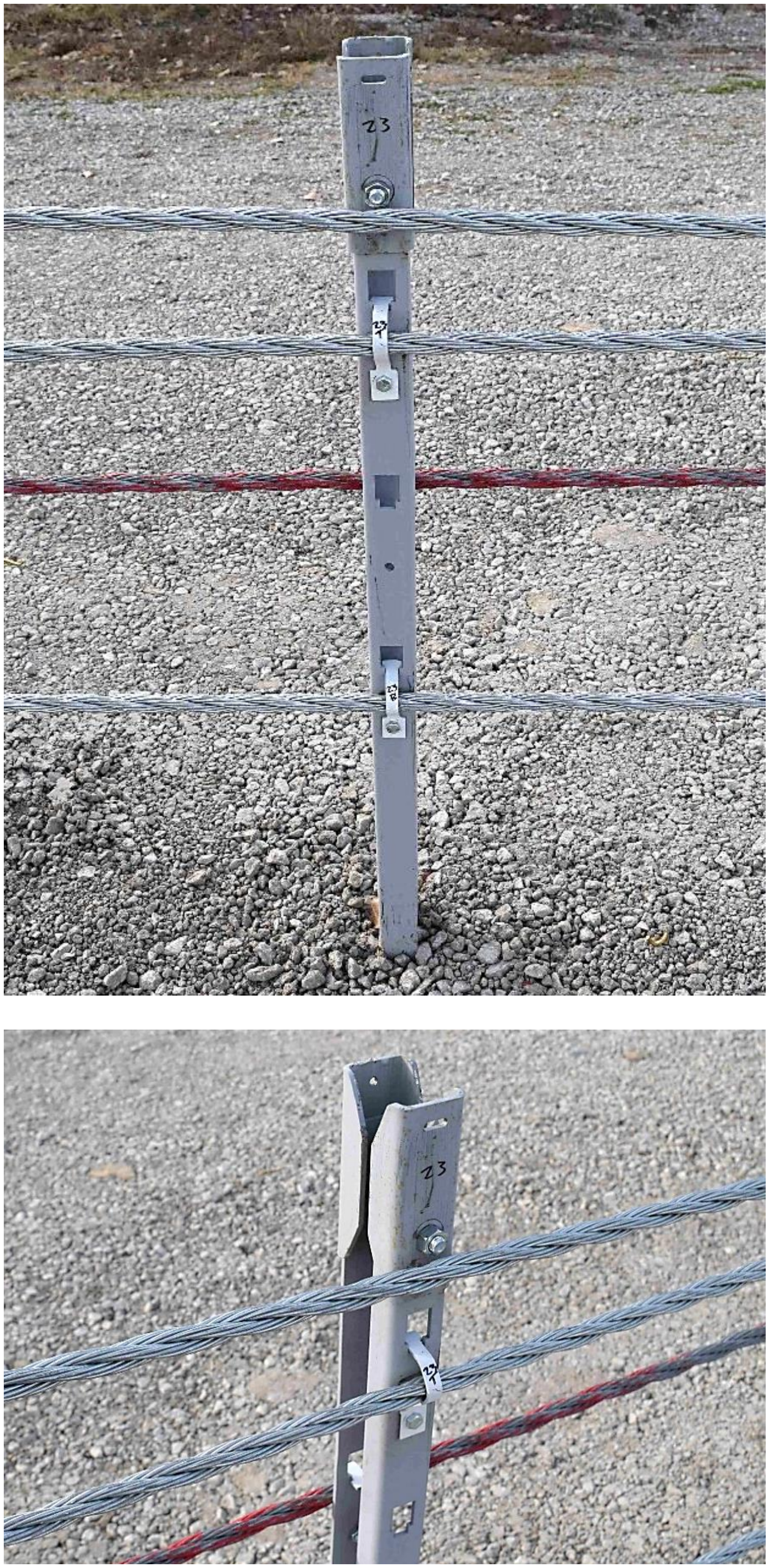



Figure 55. Post No. 23 Damage, Test No. MWP-9


Figure 56. Post No. 24 Damage, Test No. MWP-9


Figure 57. Post No. 25 Damage, Test No. MWP-9

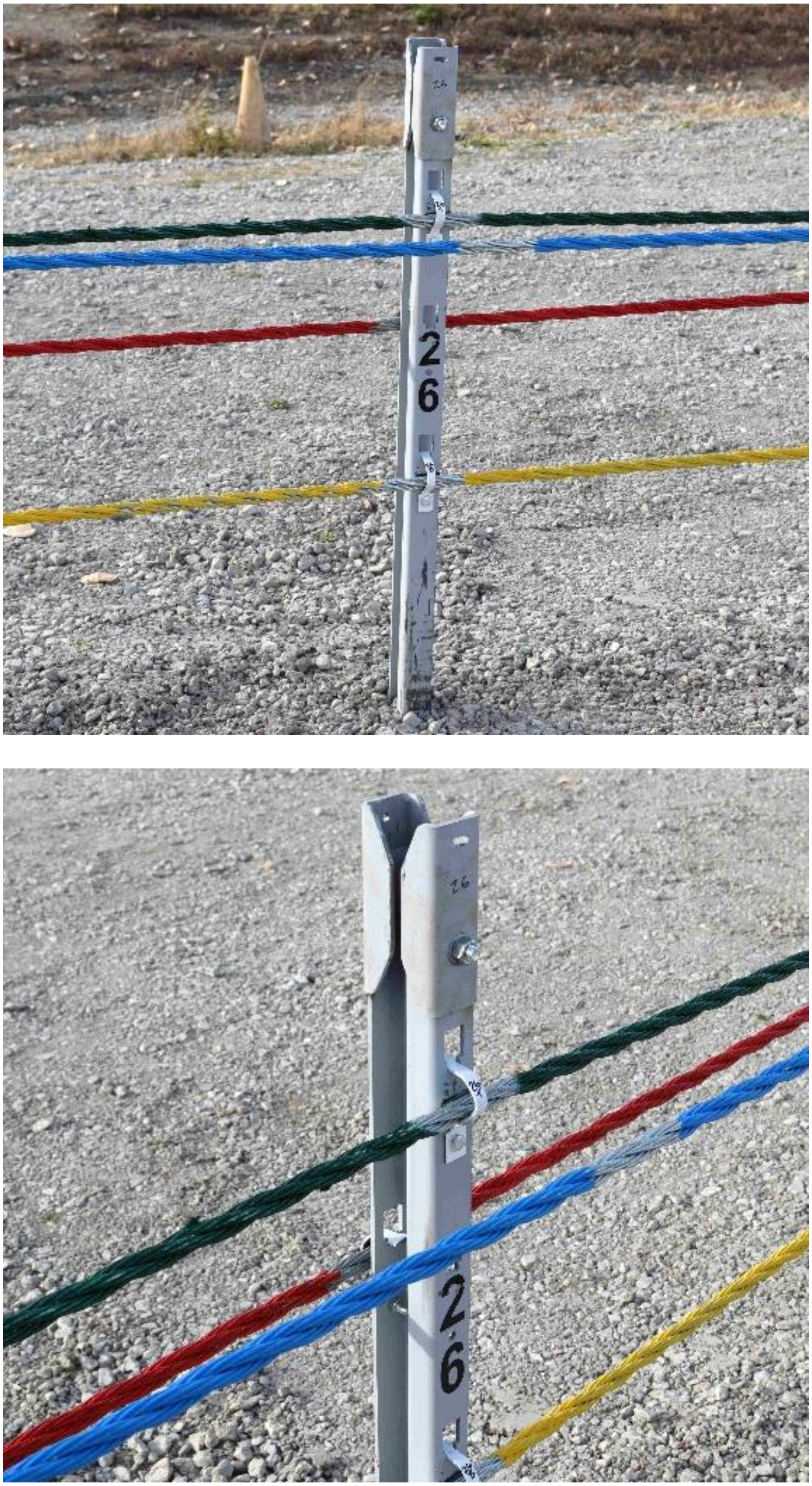



Figure 58. Post No. 26 Damage, Test No. MWP-9

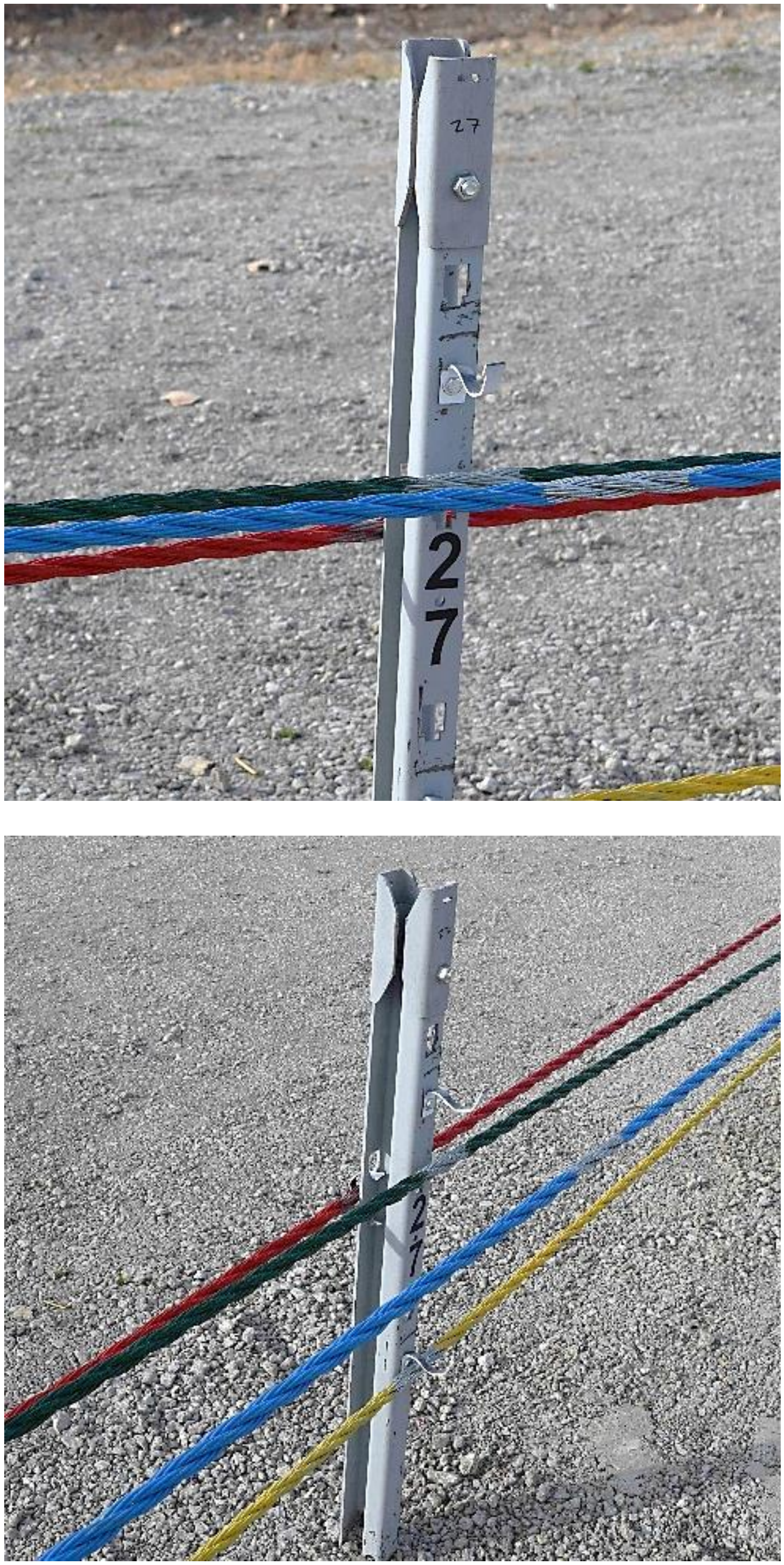



Figure 59. Post No. 27 Damage, Test No. MWP-9

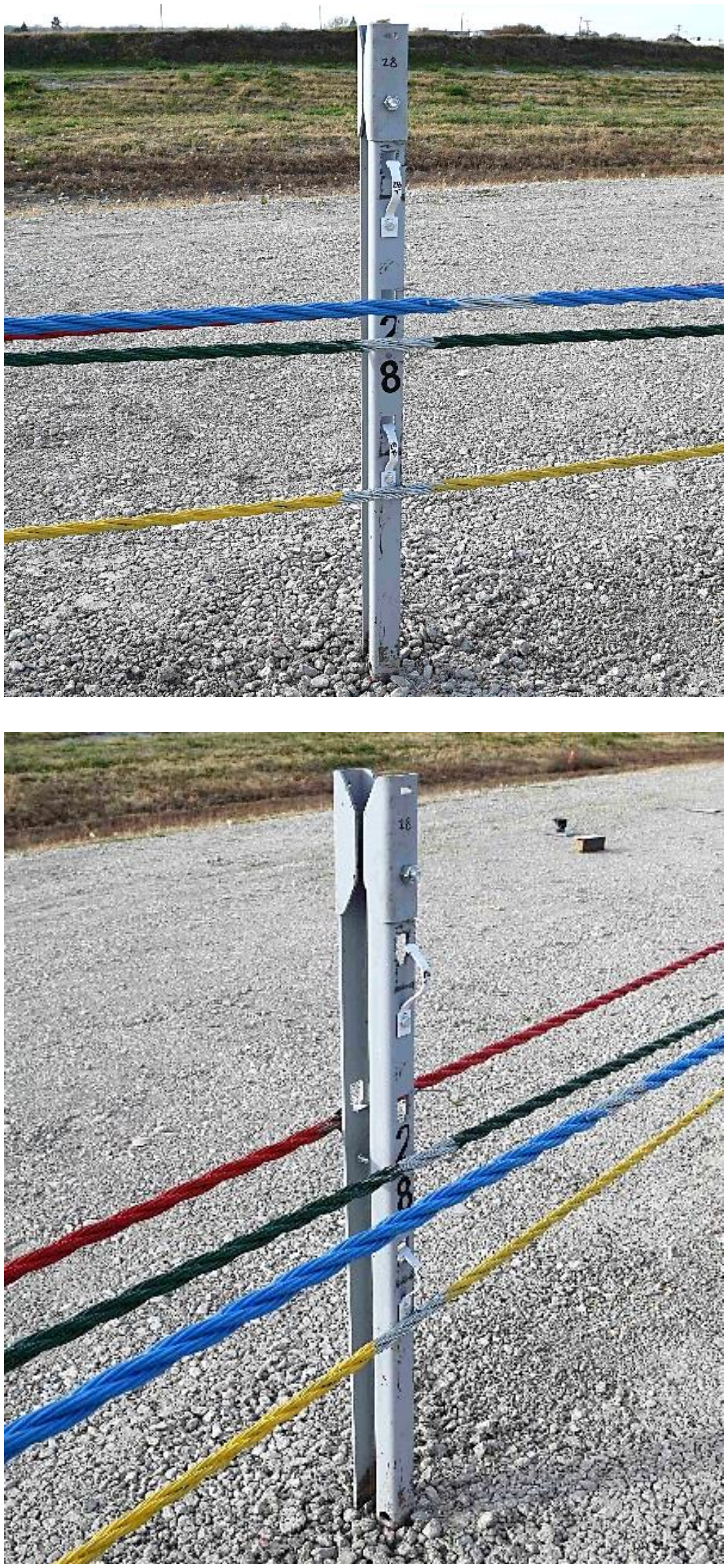


Figure 60. Post No. 28 Damage, Test No. MWP-9

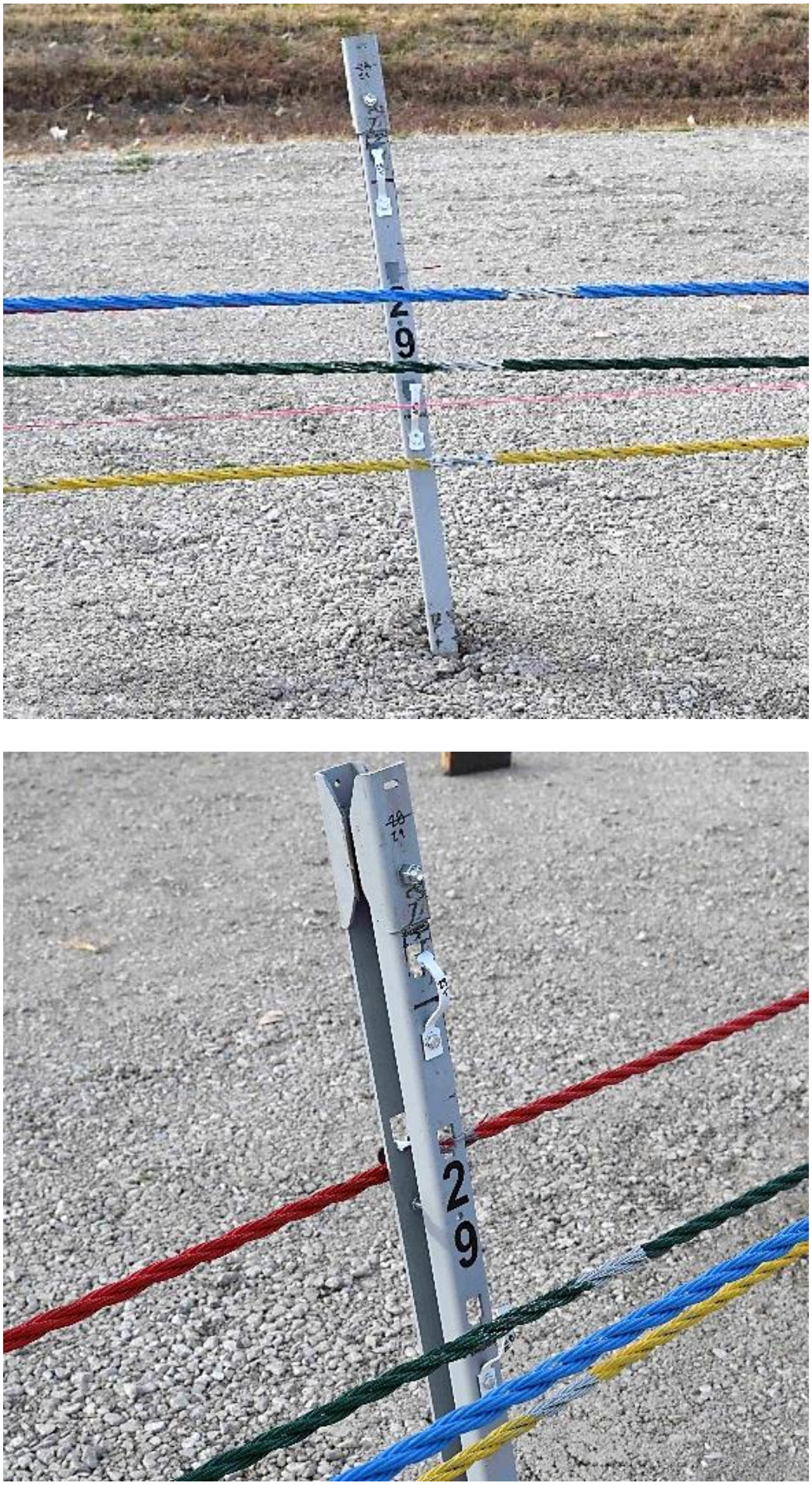



Figure 61. Post No. 29 Damage, Test No. MWP-9

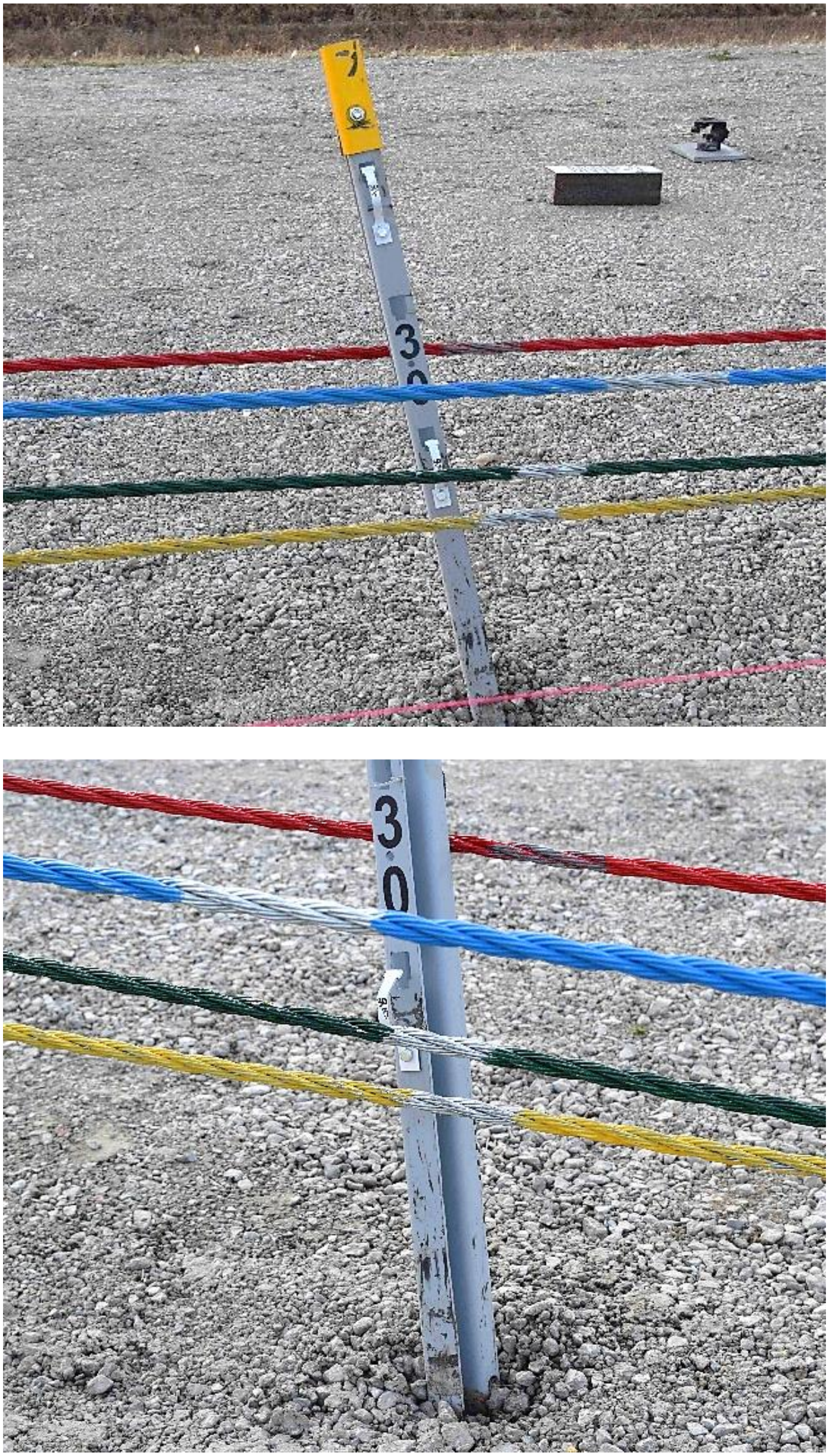


Figure 62. Post No. 30 Damage, Test No. MWP-9


Figure 63. Post No. 31 Damage, Test No. MWP-9

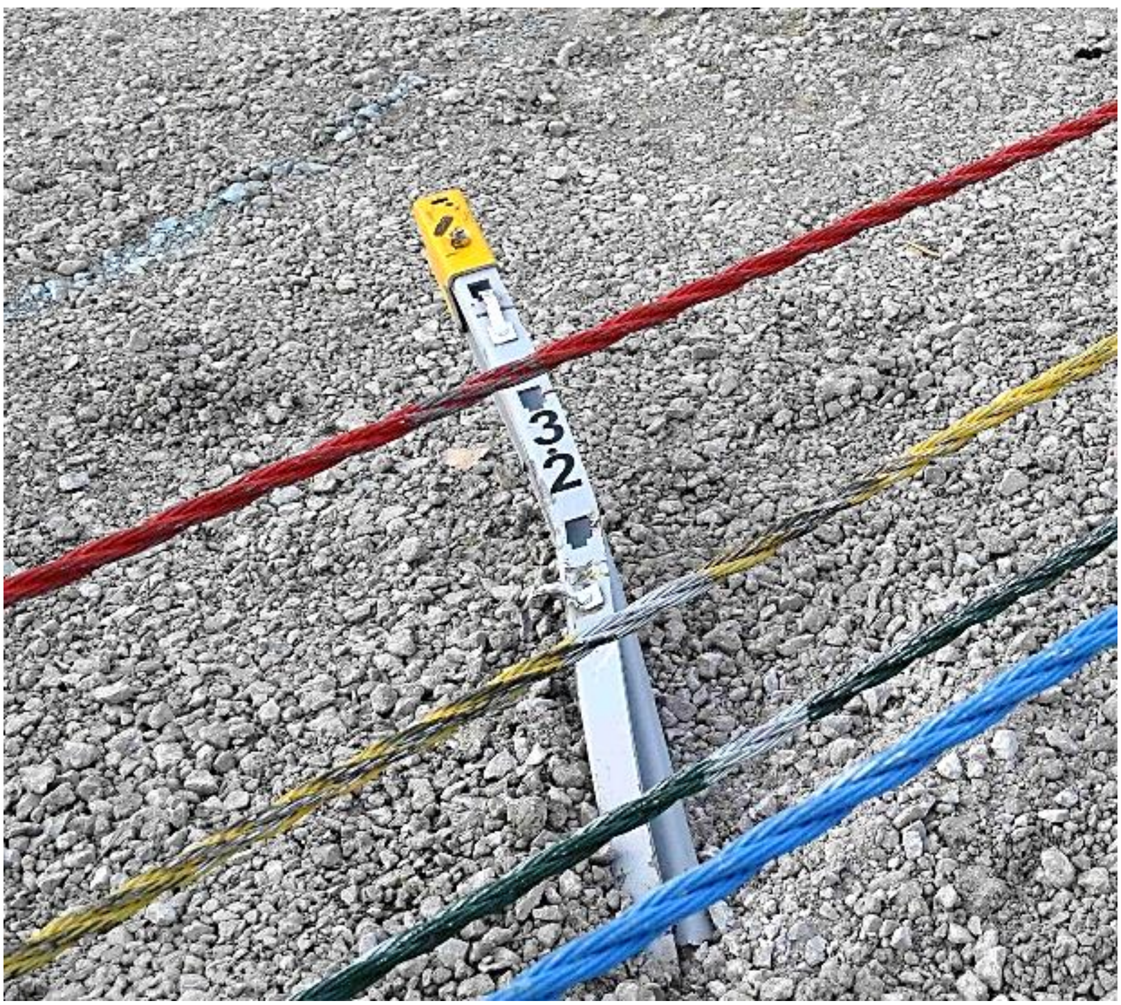




Figure 64. Post No. 32 Damage, Test No. MWP-9

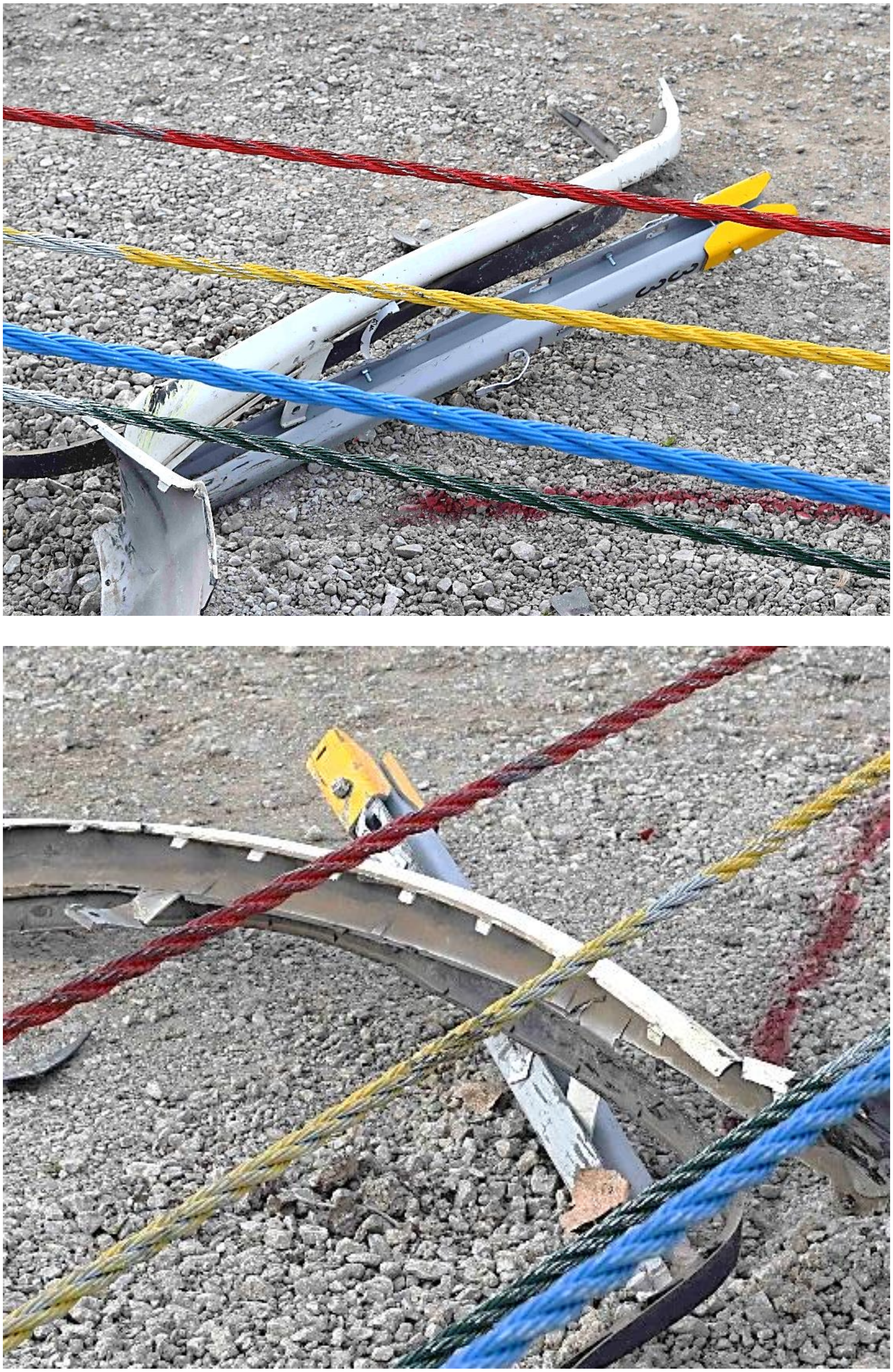


Figure 65. Post No. 33 Damage, Test No. MWP-9

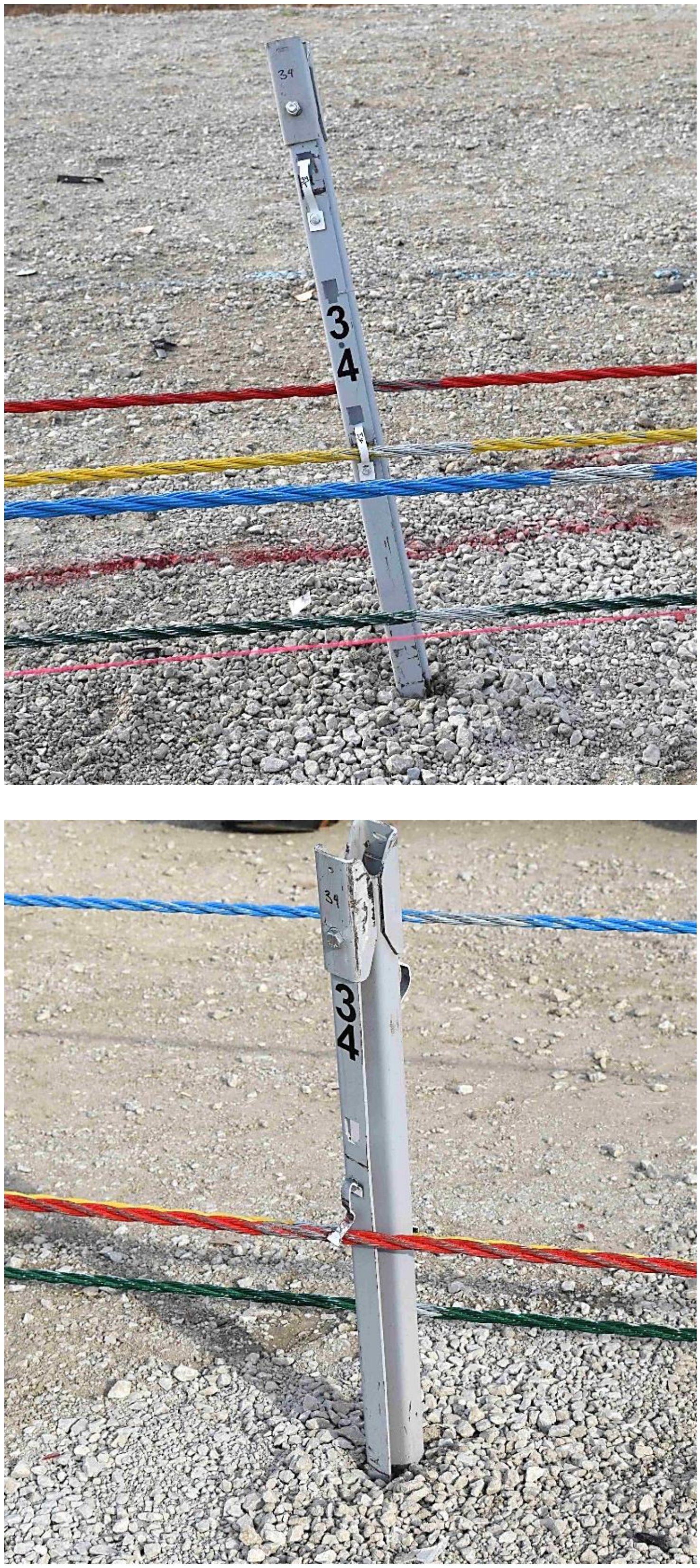



Figure 66. Post No. 34 Damage, Test No. MWP-9

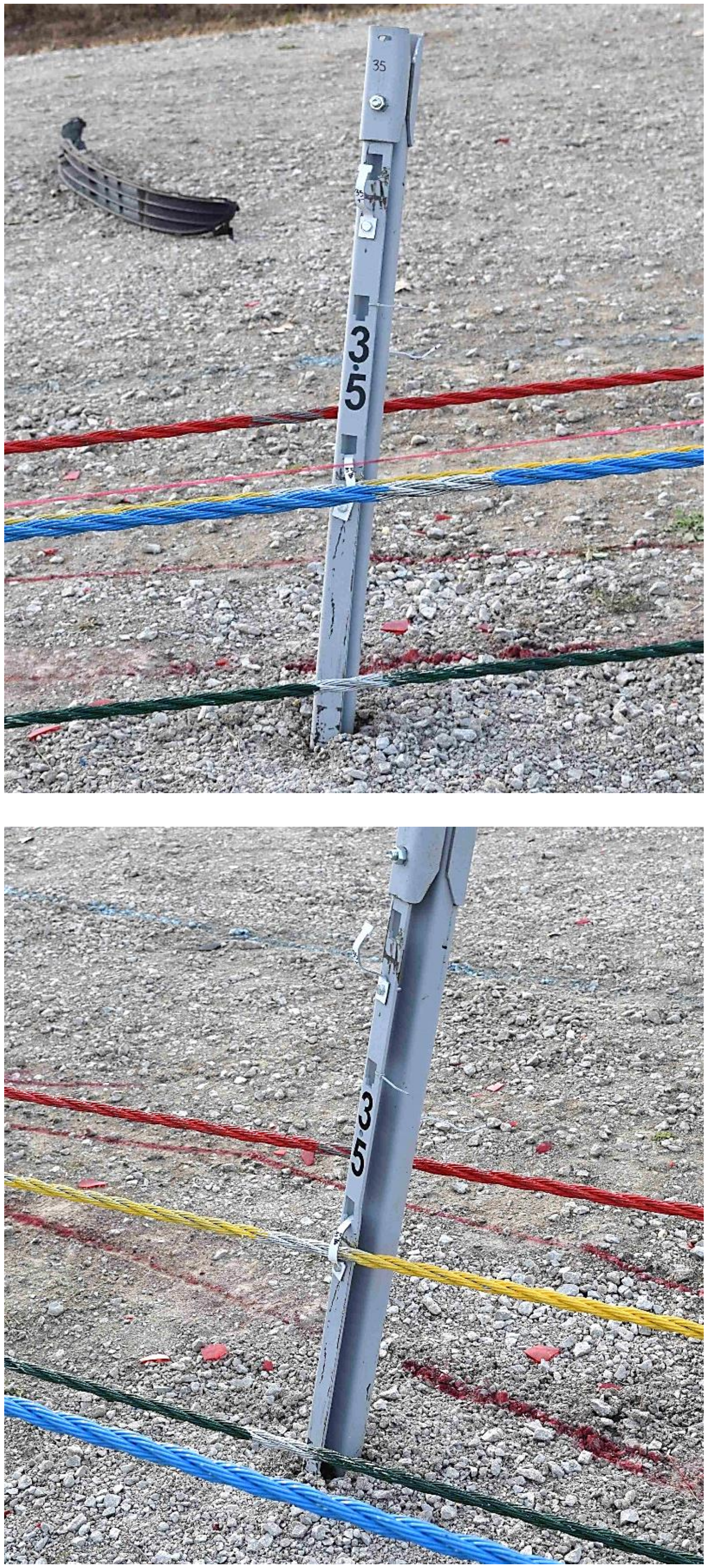



Figure 67. Post No. 35 Damage, Test No. MWP-9

Figure 68. Post No. 36 Damage, Test No. MWP-9

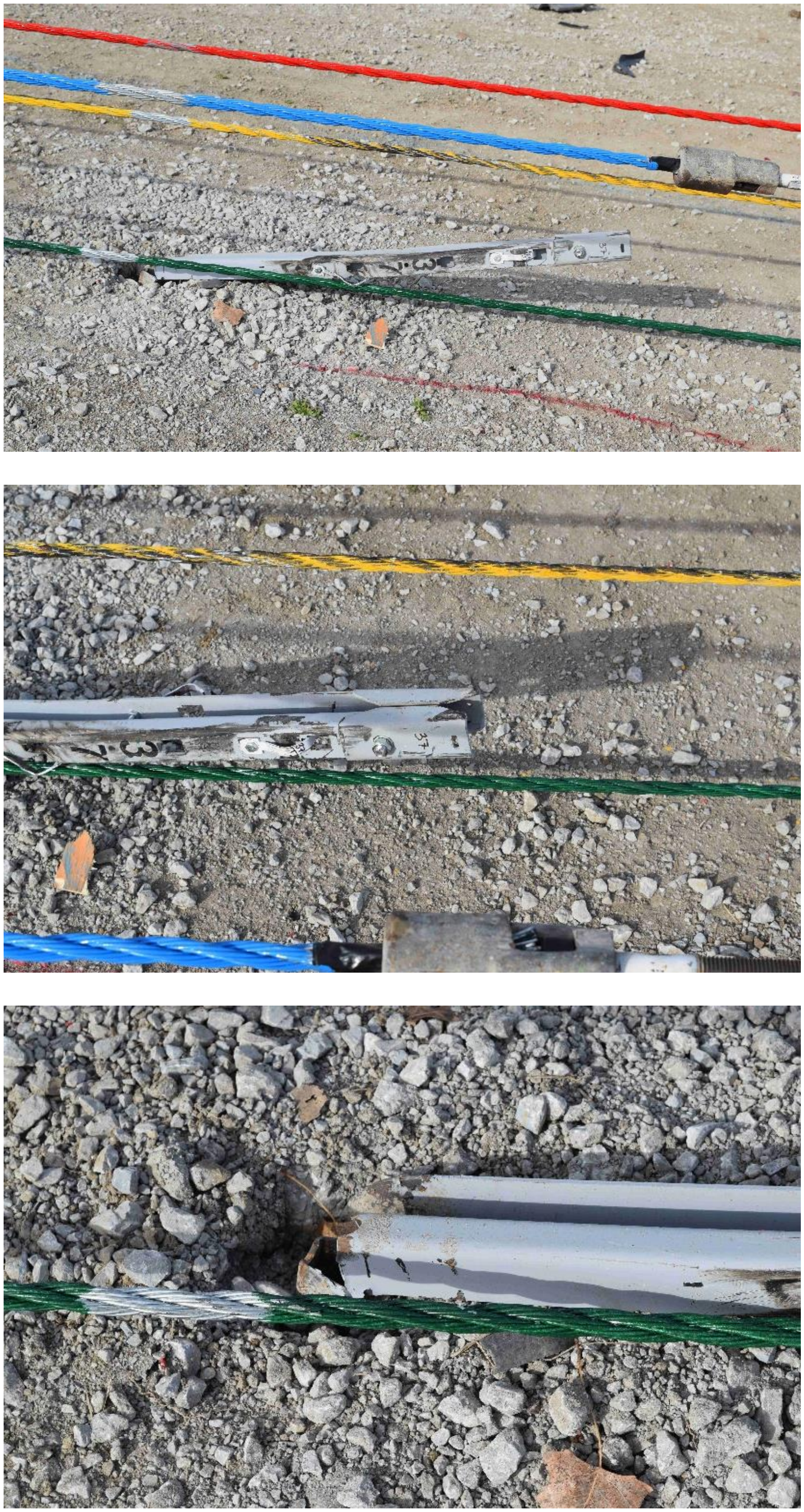


Figure 69. Post No. 37 Damage, Test No. MWP-9

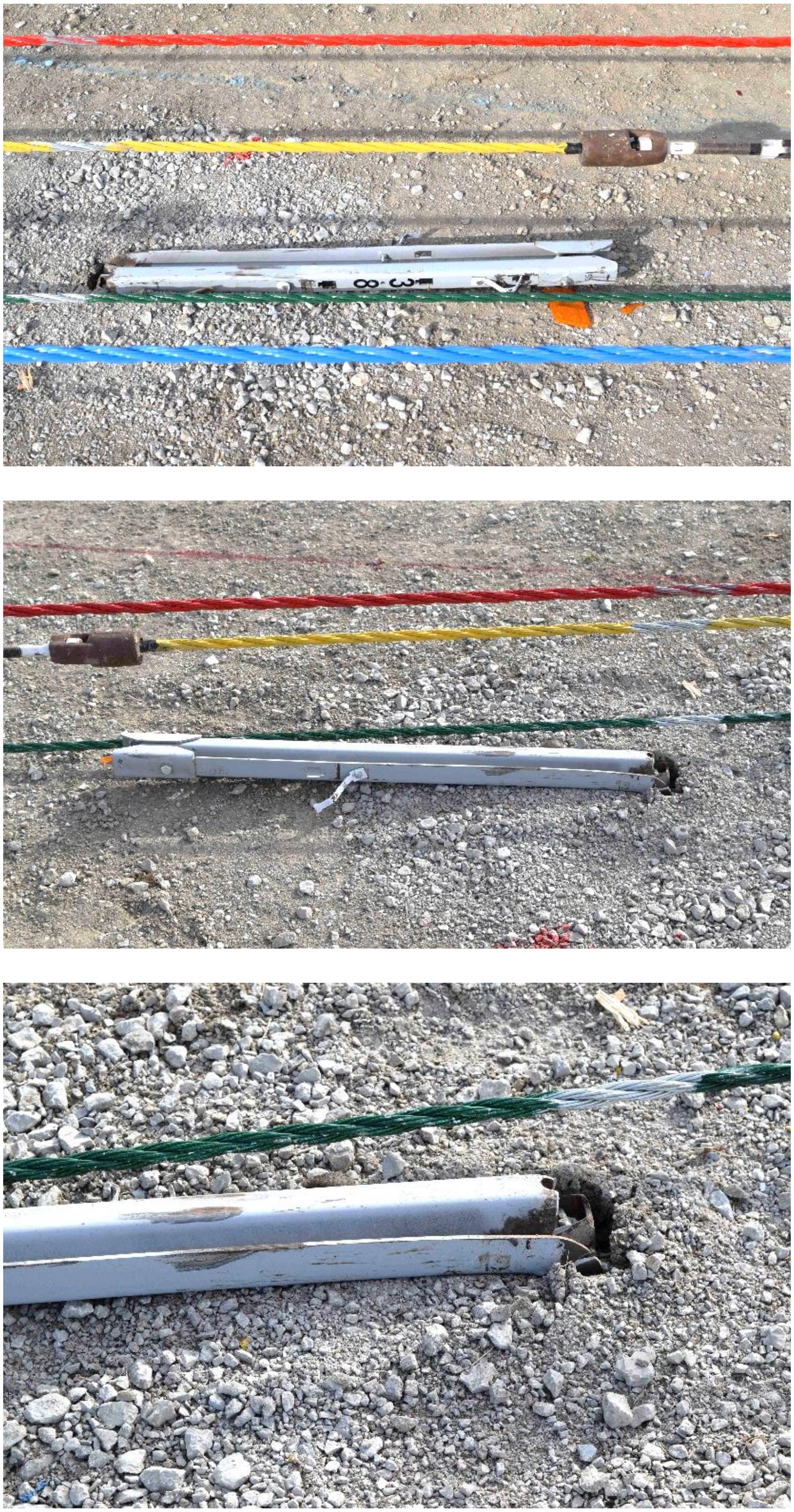



Figure 70. Post No. 38 Damage, Test No. MWP-9

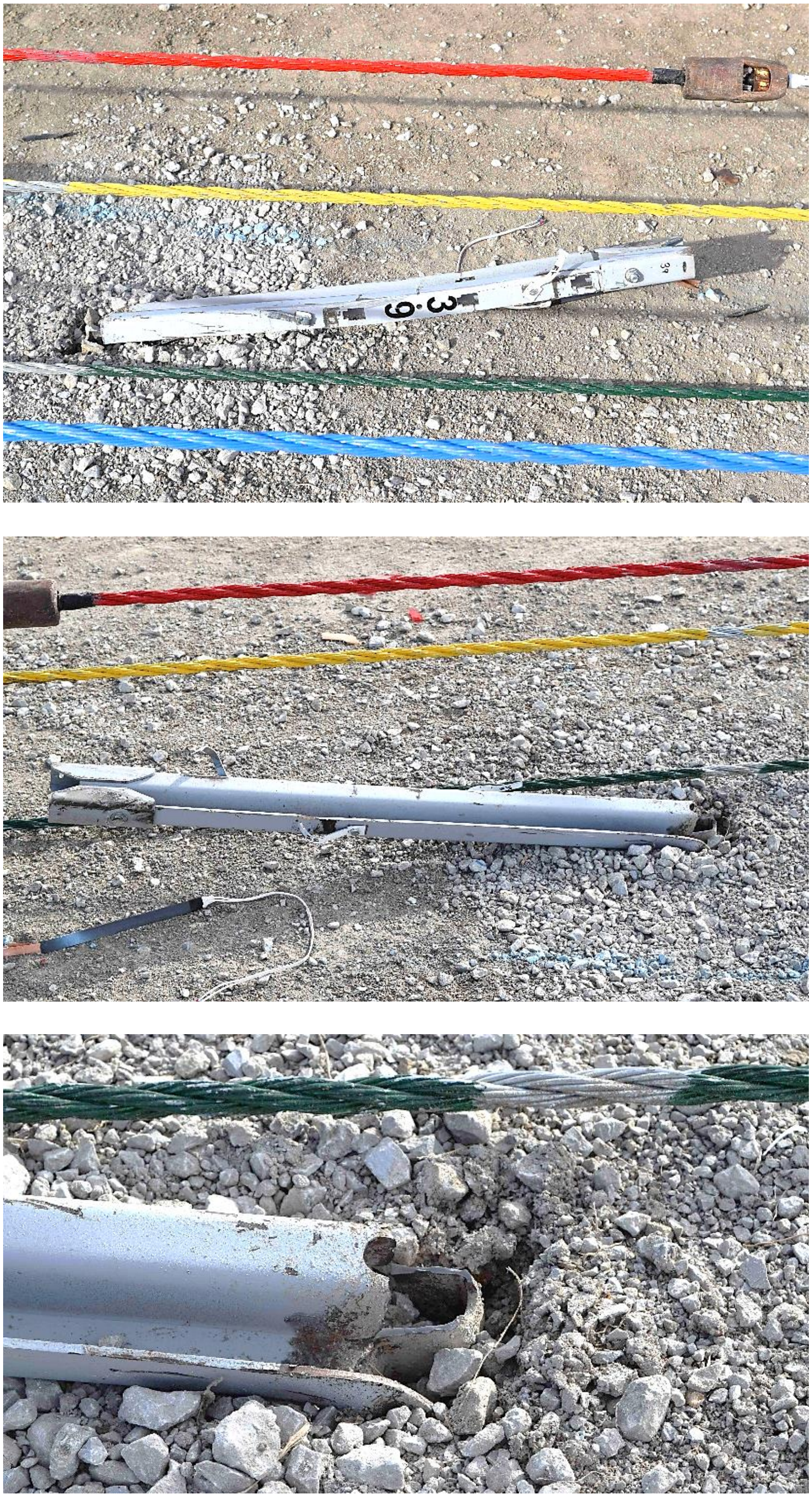


Figure 71. Post No. 39 Damage, Test No. MWP-9

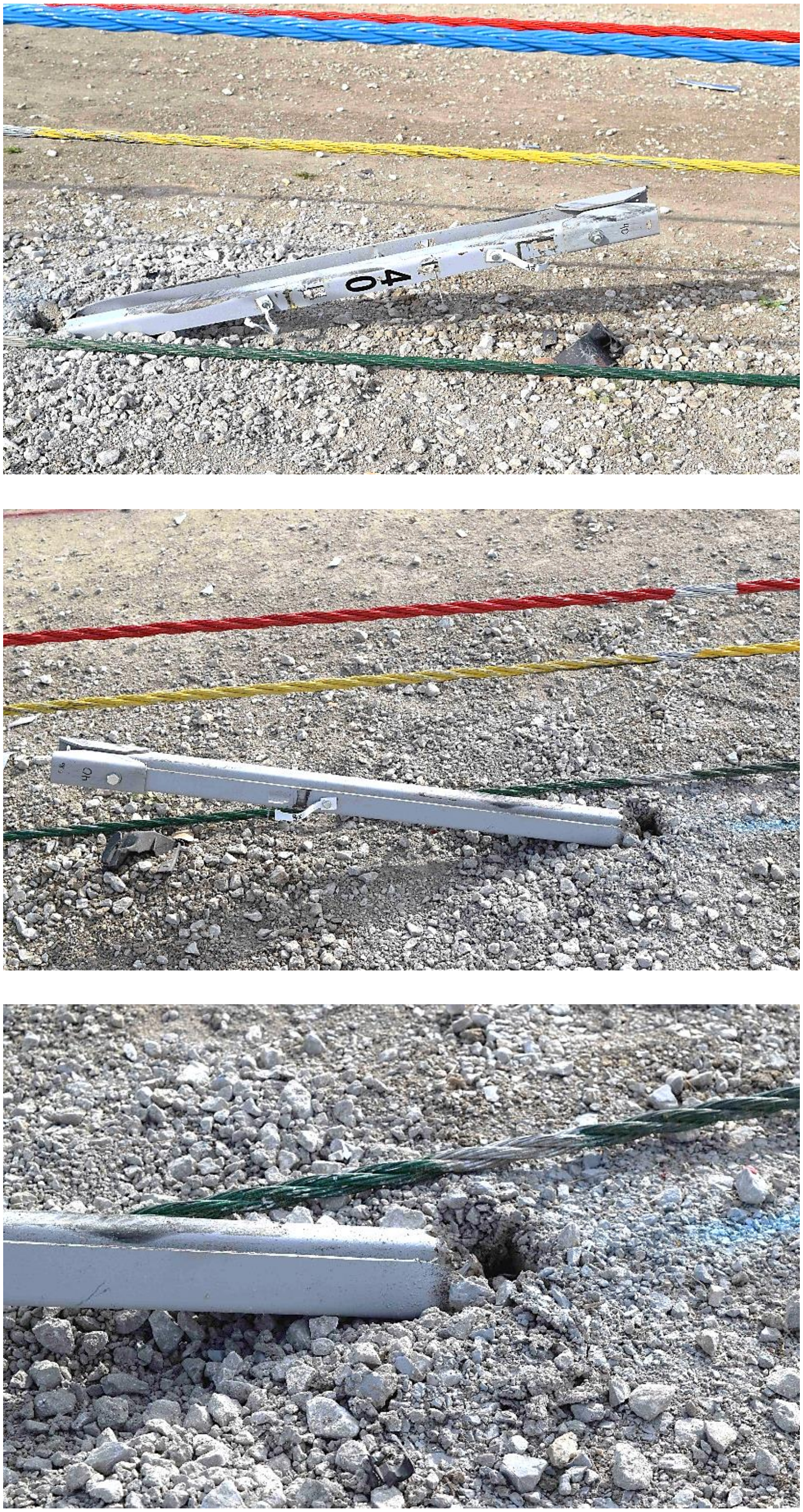



Figure 72. Post No. 40 Damage, Test No. MWP-9

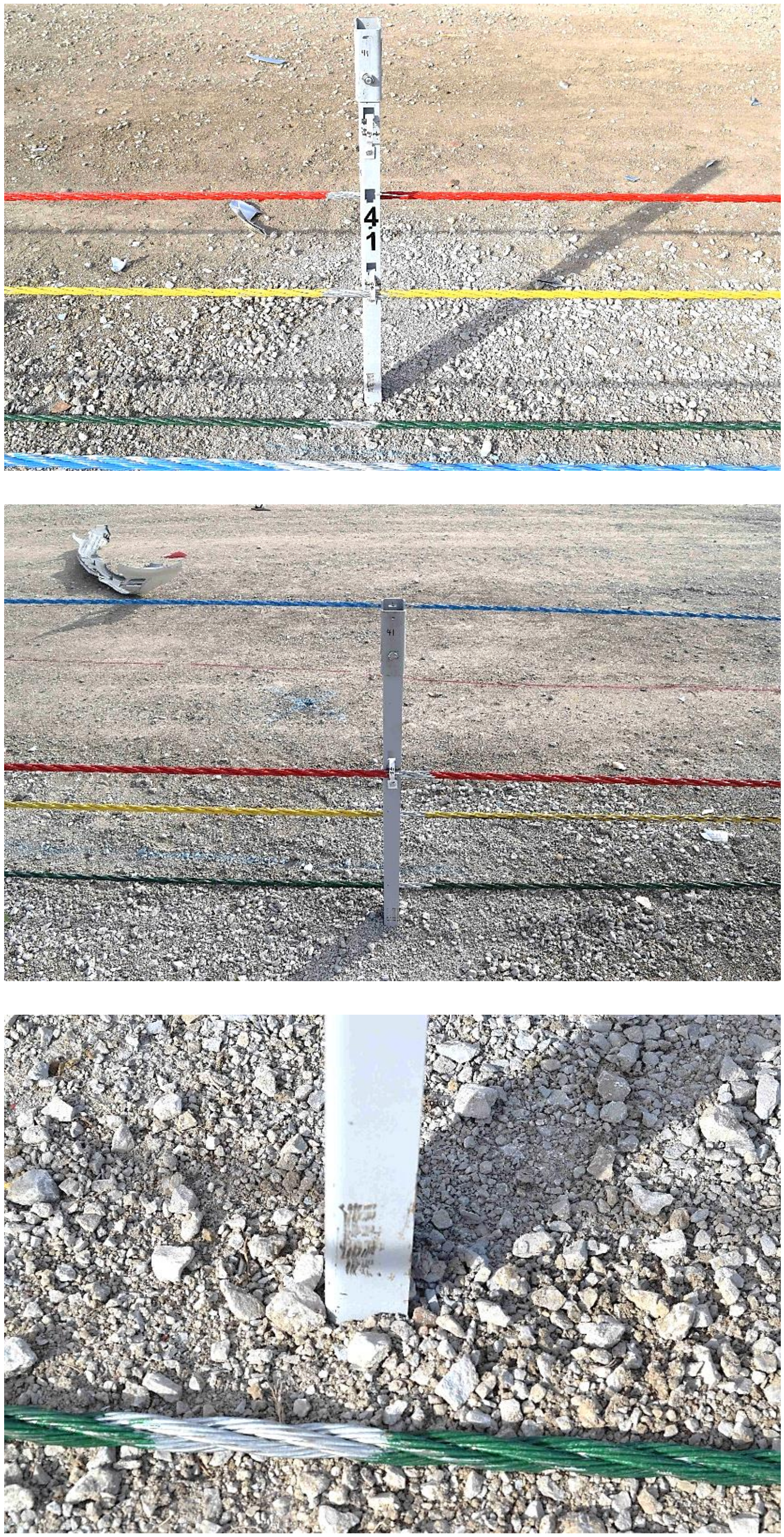



Figure 73. Post No. 41 Damage, Test No. MWP-9

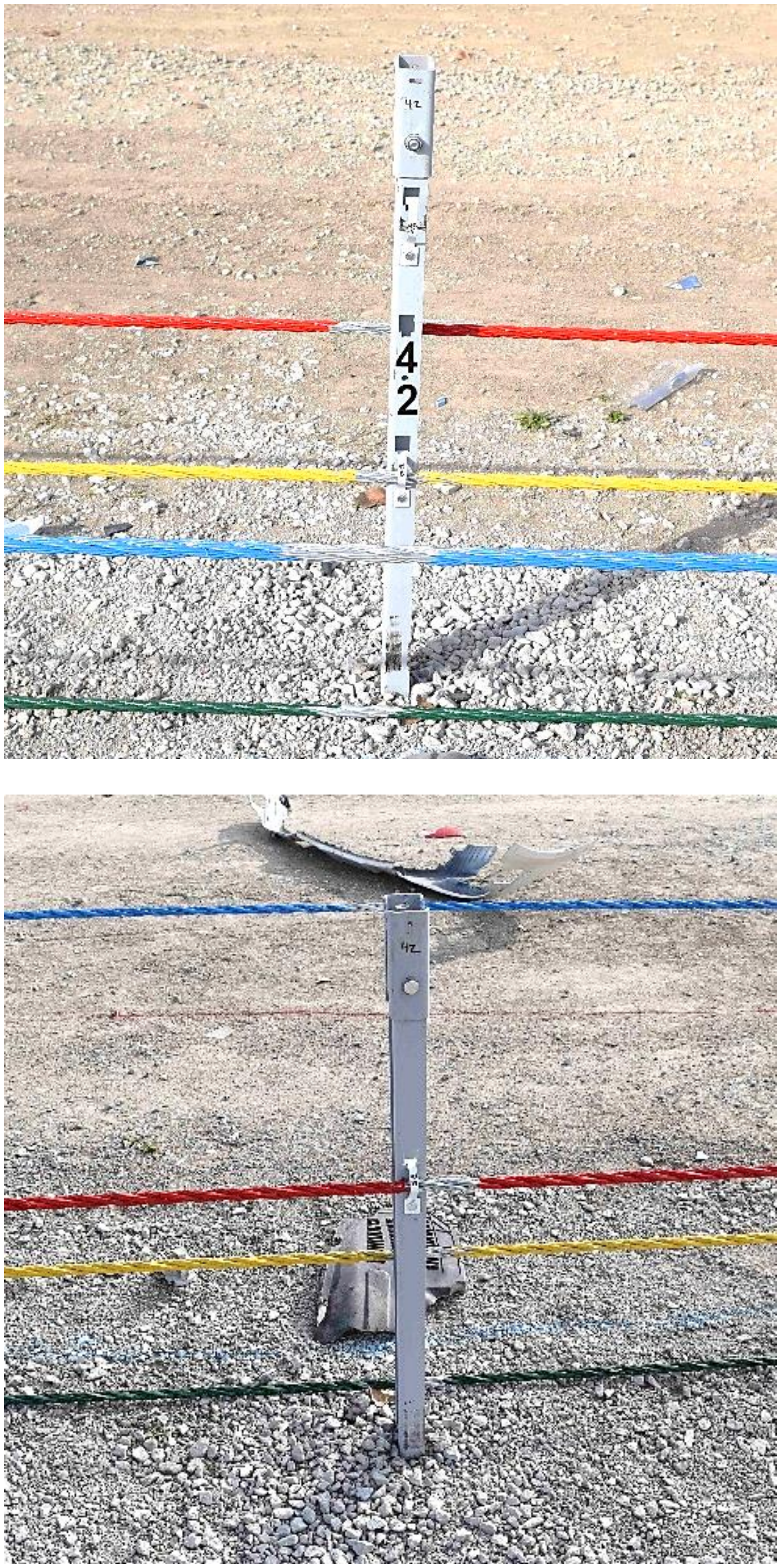



Figure 74. Post No. 42 Damage, Test No. MWP-9

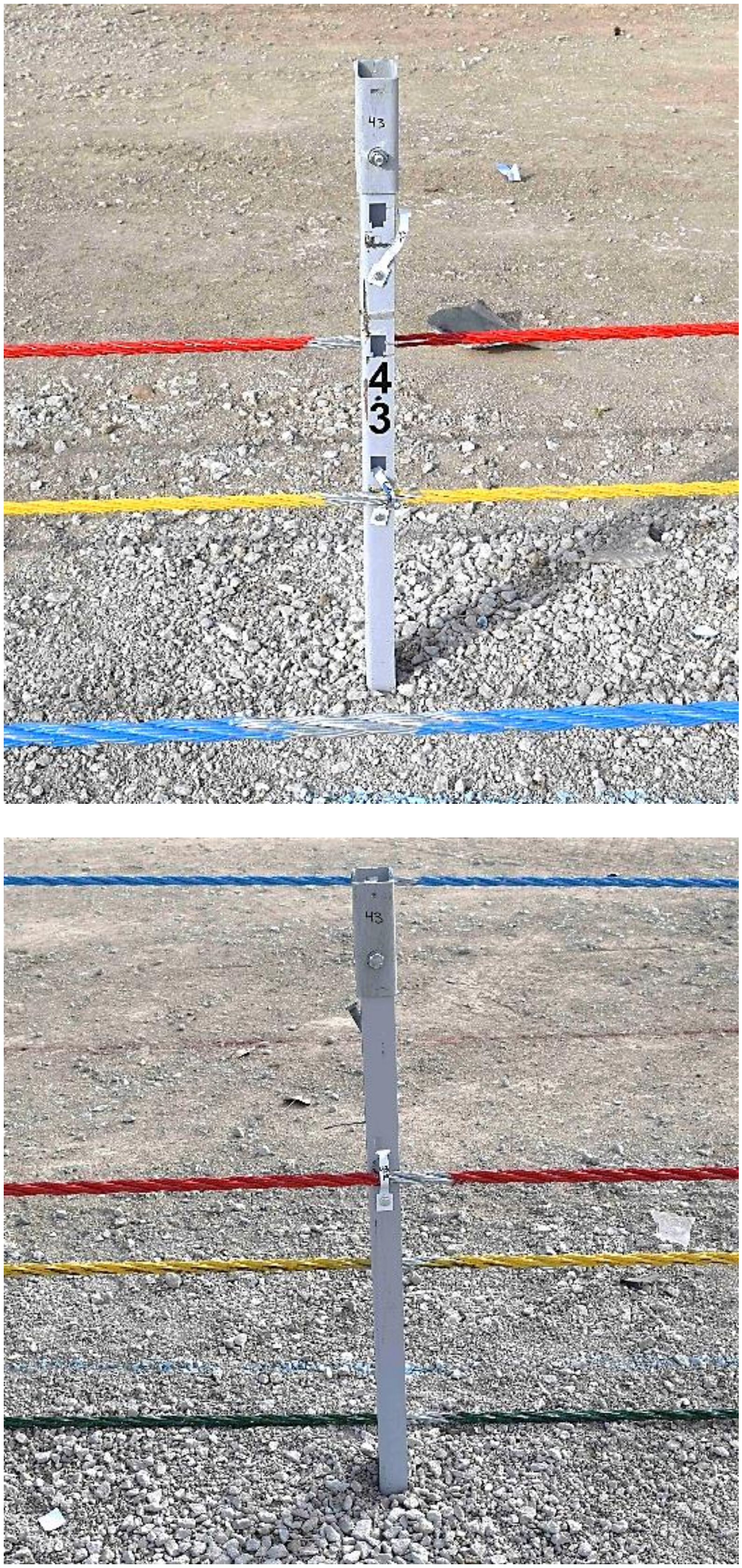


Figure 75. Post No. 43 Damage, Test No. MWP-9


Figure 76. Post No. 44 Damage, Test No. MWP-9

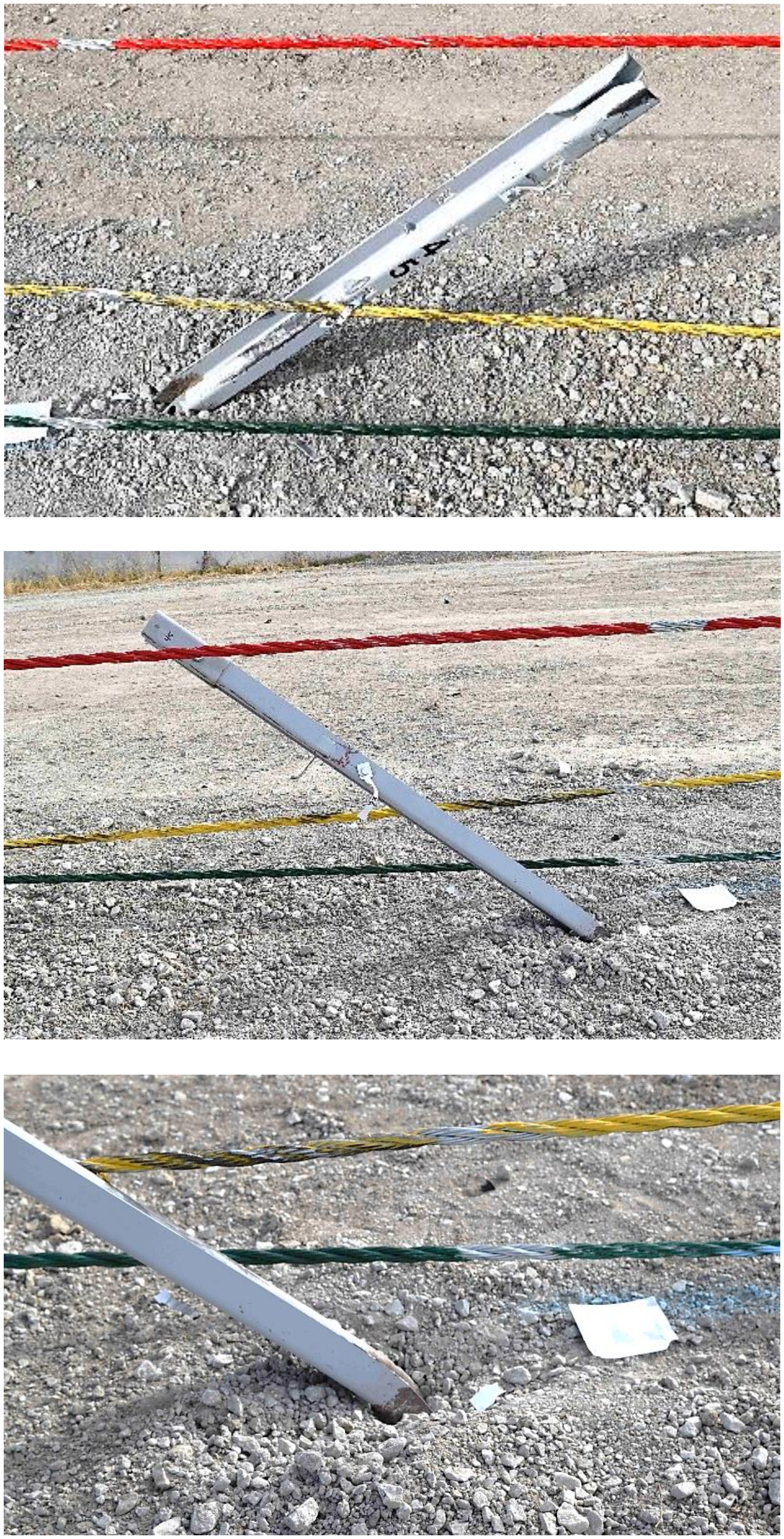


Figure 77. Post No. 45 Damage, Test No. MWP-9

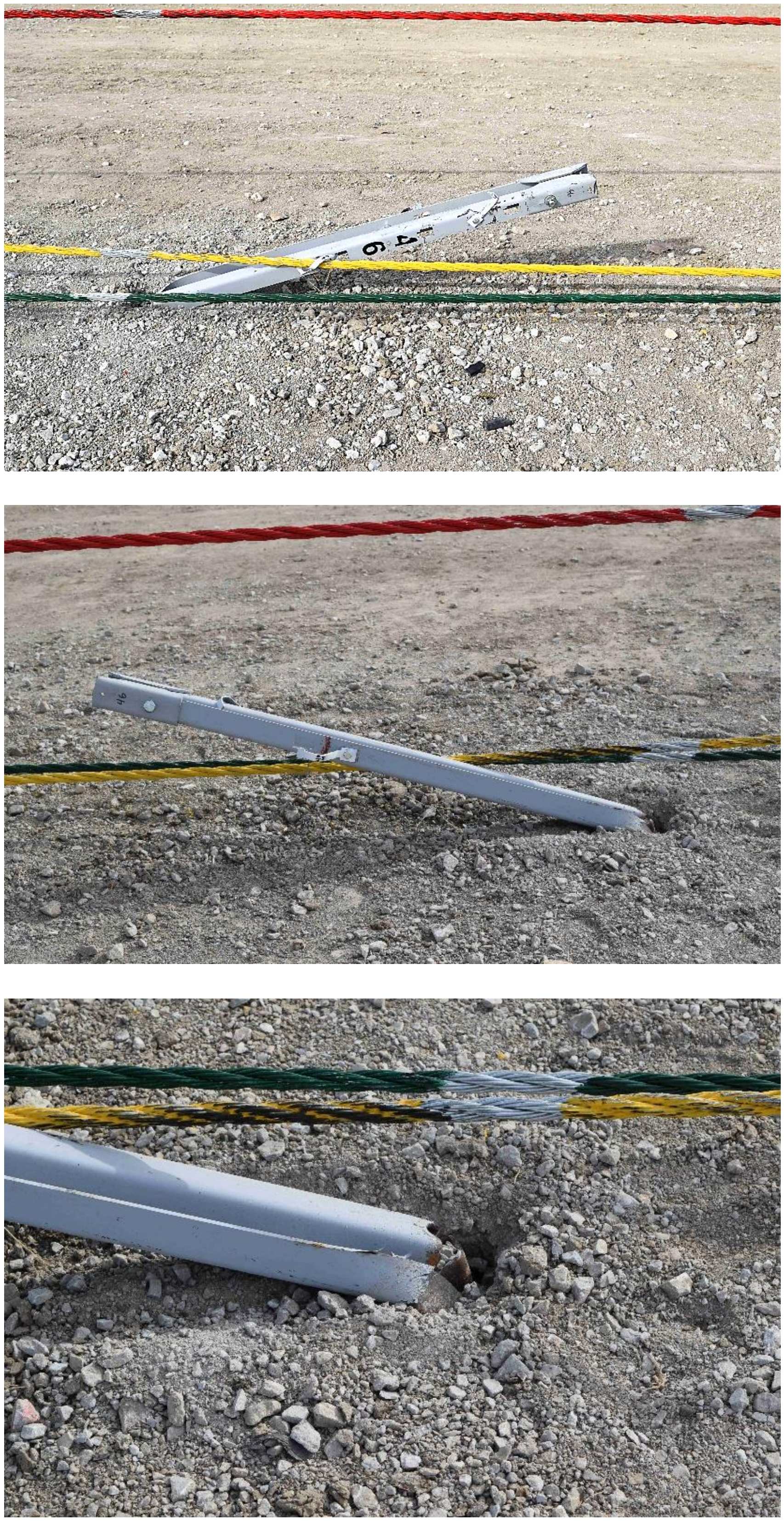


Figure 78. Post No. 46 Damage, Test No. MWP-9

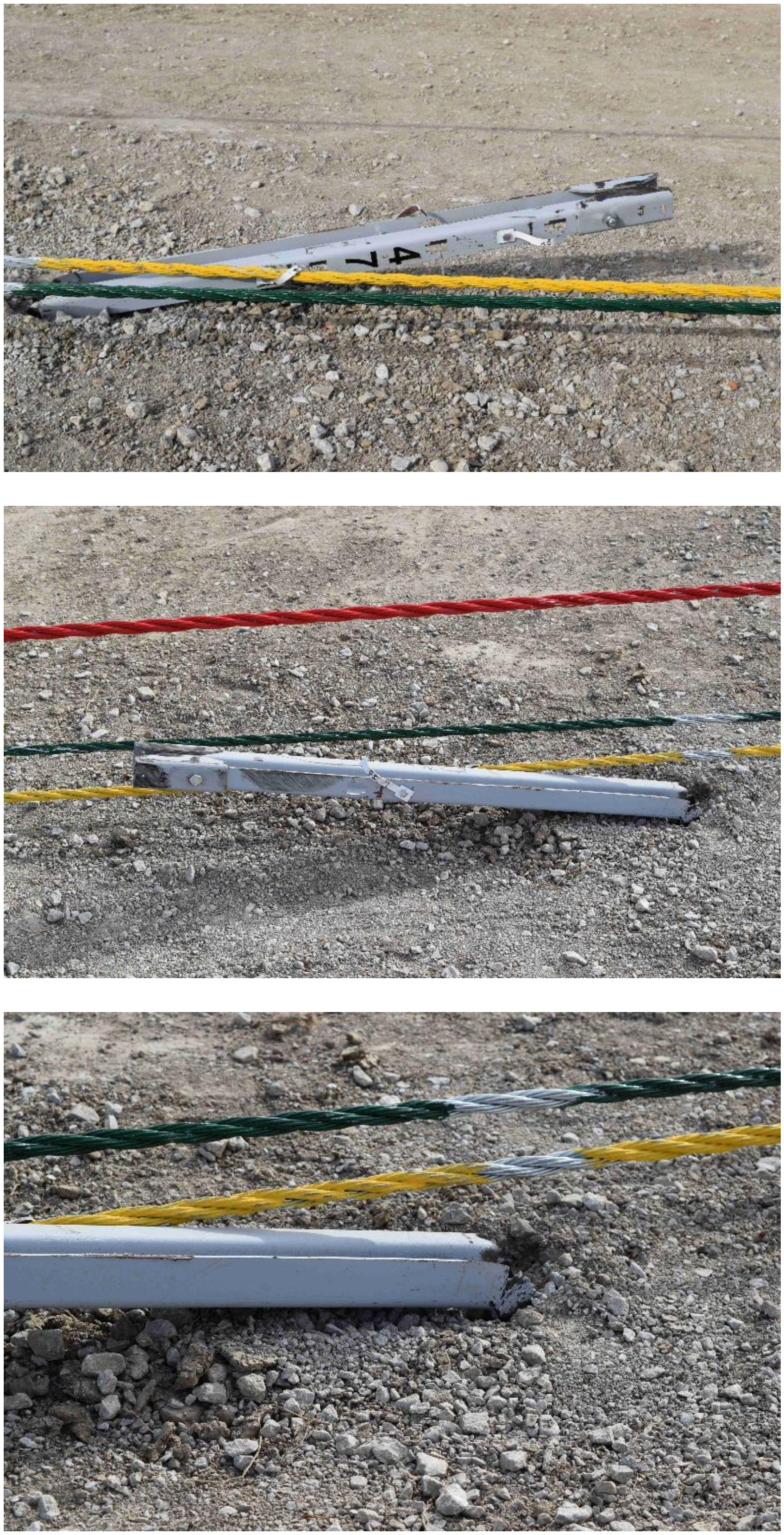


Figure 79. Post No. 47 Damage, Test No. MWP-9

Figure 80. Post No. 48 Damage, Test No. MWP-9

Figure 81. Post No. 49 Damage, Test No. MWP-9

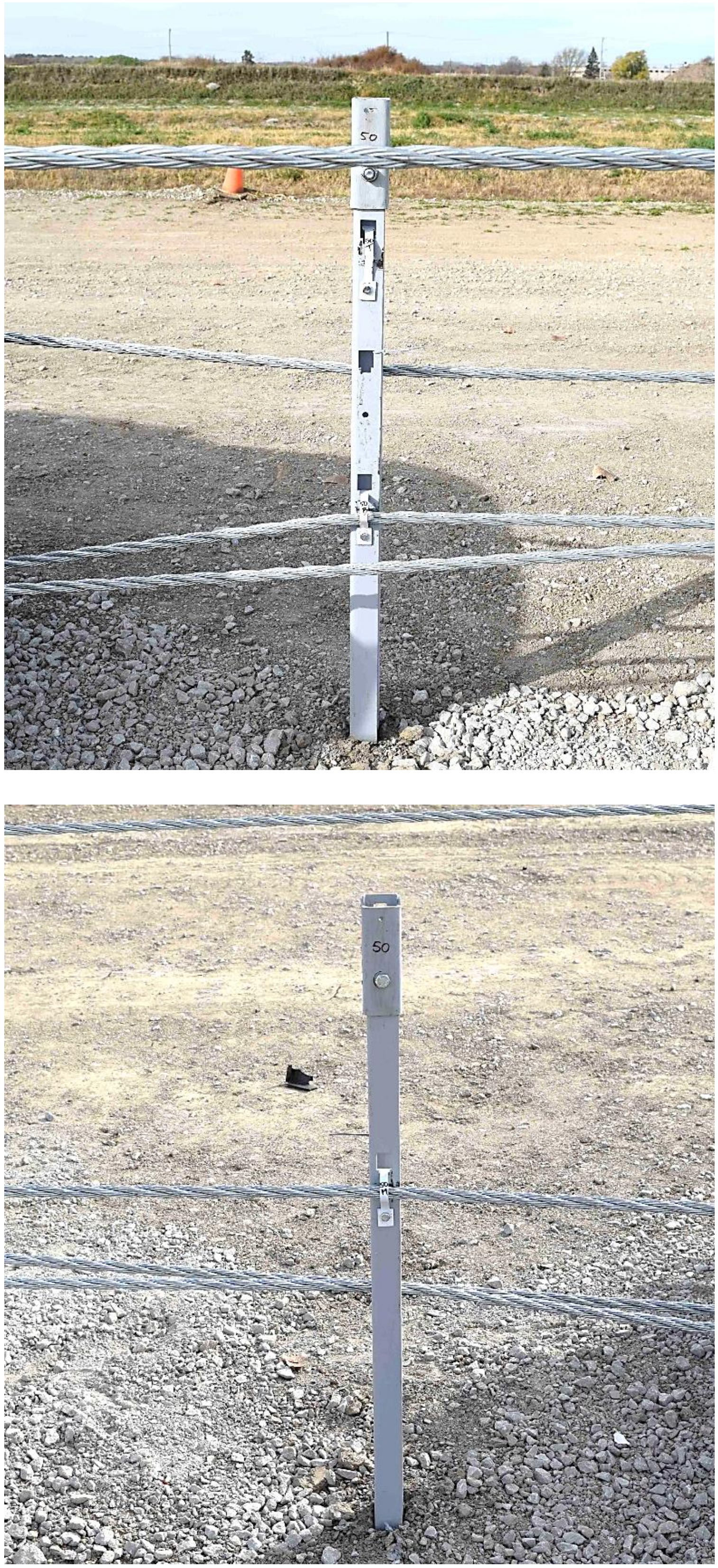



Figure 82. Post No. 50 Damage, Test No. MWP-9

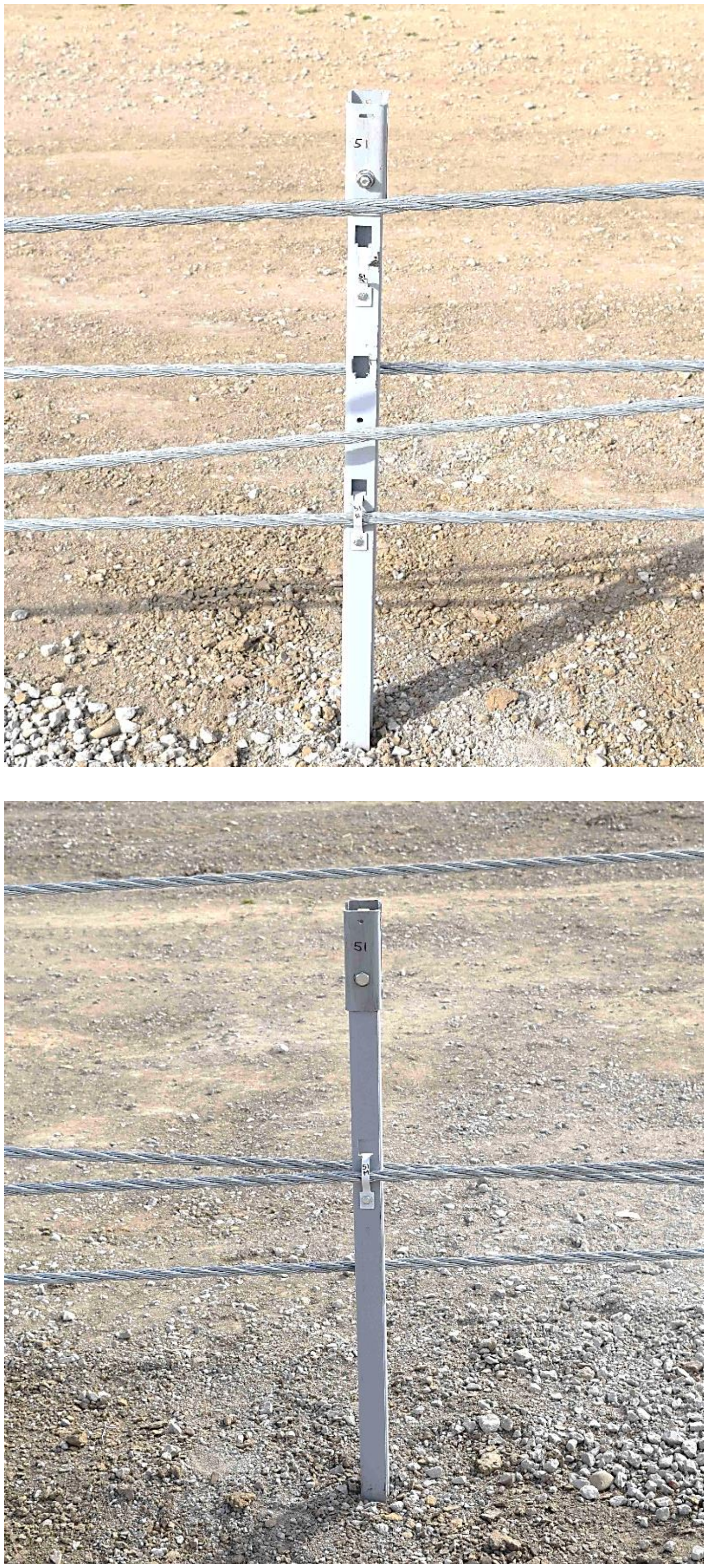



Figure 83. Post No. 51 Damage, Test No. MWP-9

Post No. 52

Post No. 53

Figure 84. Post Nos. 52 and 53 Damage, Test No. MWP-9

Upstream Anchorage Downstream Anchorage

Figure 85. Anchorage Damage, Test No. MWP-9


Figure 86. Vehicle Damage, Test No. MWP-9


Figure 87. Vehicle Damage, Test No. MWP-9

Figure 88. Vehicle Damage, Floor pan, Test No. MWP-9

# 6 SUMMARY AND CONCLUSIONS

The objective of this study was to continue to test and evaluate the prototype, high-tension, four-cable, median barrier system according to the MASH 2016 TL-3 safety criteria using the updated testing matrix for cable barrier systems installed within 6H:1V median V-ditches. One full-scale test was conducted on the system and is reported herein.

Test no. MWP-9, conducted in accordance with MASH 2016 test designation no. 3-10, involved an 1100C small car impacting the four-cable median barrier system with 8-ft (2.4-m) post spacing on level terrain. A summary of the test evaluation is shown in Table 9. Test MWP-9 utilized modified MWP with ¾-in. (19-mm) diameter weakening holes at the ground line. The weakening holes reduced the post's weak-axis bending capacity to lower the contact forces between the post and the floor pan. Additionally, test no. MWP-9 contained a two-part cap at the top of the MWP to shield the free edges during post-to-undercarriage contact. During test no. MWP-9, the 2,421-lb (1,098-kg) car impacted the four-cable median barrier at a speed of 63.1 mph (101.5 km/h) and at an angle of 25.7 degrees, which resulted in an impact severity of 60.5 kip-ft (82.0 kJ).

Analysis of the test results showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. There were no detached elements or fragments that showed potential for penetrating the occupant compartment or presented undue hazard to other traffic. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. However, cable no. 3 snagged on the top cap retainer bolt and nut and induced an increased downward and lateral force to the vehicle's A-pillar. This action caused cable nos. 3 and 4 to become interlocked with the A-pillar on the impact side of the vehicle, resulting in excessive lateral A-pillar crush of 3.4 in. (86 mm), which is greater than the 3-in. (76-mm) lateral MASH 2016 limit. Additionally, the left-front side window shattered due to contact with cable nos. 1 and 2, which is unacceptable when the A- or B-pillar crush exceeds the MASH 2016 limit of 3 in. (76 mm). Tearing and penetration did not occur to the vehicle's floor pan. Thus, the two-part cap designed for this test was able to mitigate the floor pan tearing and post penetration into the occupant compartment, but the test was ultimately deemed unsuccessful due to excessive A-pillar crush and the shattering of the left-front side window.

As a result of the unsuccessful 1100C crash test, the prototype, high-tension, four-cable, median barrier system will need to be further redesigned to prevent the excessive A-pillar crush observed in test no. MWP-9. Possible design changes may include, but are not limited to, the use of closed-section posts, reduction of weak-axis bending strength at groundline, alternative treatment of post edges, and changes to post geometry. After the cable barrier system has been redesigned, it will need to be re-evaluated according to MASH 2016 test designation no. 3-10 criteria before proceeding with the remaining tests listed within the recommended testing matrix for cable barriers installed within median V-ditches. Depending on the nature of the design changes, it may be necessary to evaluate whether prior successful crash tests need to be rerun.

Table 9. Summary of Safety Performance Evaluation, Test No. MWP-9

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. MWP-9</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td></tr>
<tr><td rowspan="9">Occupant Risk</td><td rowspan="2">D.</td><td colspan="3">1. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</td><td>S</td></tr>
<tr><td colspan="3">2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>U</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td></tr>
<tr><td rowspan="3">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:<br>Occupant Impact Velocity Limits</td><td rowspan="3">S</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
<tr><td rowspan="3">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:<br>Occupant Ridedown Acceleration Limits</td><td rowspan="3">S</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
<tr><td colspan="5">MASH 2016 Test Designation No.</td><td>3-10</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Fail</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

# 7 REFERENCES

1. Bielenberg, R.W., Rosenbaugh, S.K., Faller, R.K., Humphrey, B.M., Schmidt, T.L., Lechtenberg, K.A., and Reid, J.D., *MASH Test Nos. 3-17 and 3-11 on a Non-Proprietary Cable Median Barrier*, Report No. TRP-03-303-15, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, November 3, 2015.

2. *Manual for Assessing Safety Hardware (MASH)*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.

3. *Manual for Assessing Safety Hardware, Second Edition (MASH)*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2016.

4. Kohtz, J.E., Bielenberg, R.W., Rosenbaugh, S.K., Faller, R.K., Lechtenberg, K.A., and Reid, J.D., *MASH Test Nos. 3-11 and 3-10 on a Non-Proprietary Cable Median Barrier*, Report No. TRP-03-327-16, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, May 17, 2016.

5. Rosenbaugh, S.K., Hartwell, J.H., Bielenberg, R.W., Faller, R.K., Holloway, J.C., and Lechtenberg, K.A., *Evaluation of Floor pan Tearing and Cable Splices for Cable Barrier Systems*, Report No. TRP-03-324-17, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, May 16, 2017.

6. Meyer, D.T., Lechtenberg, K.A., Faller, R.K., Bielenberg, R.W., Rosenbaugh, S.K., and Reid, J.D., *MASH Test No. 3-10 of a Non-Proprietary, High-Tension, Cable Median Barrier for Use in 6H:1V V-Ditch (Test No. MWP-8)*, Report No. TRP-03-331-17, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, May 10, 2017.

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9. MacInnis, D., Cliff, W., and Ising, K., *A Comparison of the Moment of Inerita Estimation Techniques for Vehicle Dynamics Simulation*, SAE Technical Paper Series – 970951, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1997.

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

11. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

12. *Collision Deformation Classification – Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

# 8 APPENDICES

# Appendix A. Material Specifications

Table A-1. Bill of Materials, Test No. MWP-9

| Item No. | Description | Material Specification | References |
|---|---|---|---|
| a1 | Cable Anchor Base Plate | ASTM A36 | N/A |
| a2 | Exterior Cable Plate Gusset | ASTM A36 | N/A |
| a3 | Interior Cable Plate Gusset | ASTM A36 | N/A |
| a4 | Anchor Bracket Plate | ASTM A36 | N/A |
| a5 | 3/16" [5] Dia. Brass Rod | ASTM B16-00 | H#14-04-05543-2 |
| a6 | Release Gusset | A36 Steel | N/A |
| a7 | Release Lever Plate | A36 Steel | N/A |
| a8 | 1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Tube | ASTM A500 Gr. B | N/A |
| a9 | CMB High Tension Anchor Plate Washer | ASTM A36 | H#64047117 |
| a10 | 1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Connecting Tube | ASTM A 500 Gr. B | N/A |
| a11 | 3x10x0.5" [76x254x13] Kicker Plate | ASTM A36 | N/A |
| a12 | CT kicker - gusset | ASTM A36 | N/A |
| a13 | 3/4" [19] Dia. Flat Washer | ASTM F844 | PFC COC R#14-0082 |
| a14 | 3/4" [19] Dia. UNC J-Hook Anchor and Hex Nut | J-Hook ASTM A449/Nut ASTM A563 DH | BOLT:H#11618020 NUT: H#1F543 |
| a15 | 1/4" [6] Dia. Aircraft Retaining Cable, 36" [914] long | 7x19 Galv. | N/A |
| a16 | 5/8" [16] Dia. Heavy Hex Nut | ASTM A563C | R#14-0343 COC |
| a17 | 5/8" [16] Dia. UNC, 9 1/2" [241] Long Hex Bolt | ASTM A449 or SAE J429 Gr. 5 | L#490-454-94 |
| a18 | 24" [610] Dia. Concrete Anchor, 120" [3048] long | 4,000 psi f'c | T#4156617 |
| a19 | #11 Straight Rebar, 114" [2896] long | Grade 60 | H#58196113 |
| a20 | #4 Anchor Hoop Rebar with 21" [533] Dia. | Grade 60 | H#111485 |
| b1 | S3x5.7 [S76x8.5] Post by 28 1/8" [714] | ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A | H#59058160 |
| b2 | S3x5.7 [S76x8.5] Post by 19" [483] | ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A | H#59058160 |
| b3 | #3 Straight Rebar, 43" [1092] long | Grade 60 | H#JW12105480 |
| b4 | 7 1/4" [184] Dia. No. 3 Hoop Reinforcement | Grade 60 | H#537484 |
| b5 | 2nd Post Keeper Plate, 28 Gauge | ASTM A36 | N/A |
| b7 | 1/2" [13] Dia. Washer with 1 1/16" [27] OD | ASTM F844 | H#A32336, L# 504612 |
| b8 | 1/2" [13] Dia. and 3/4" [19] Dia. UNC, 2" [51] long Hex Bolt and Nut | Bolt ASTM A307 Gr. A/Nut ASTM A563A | Structural Bolt Distributor's Affidavit O#4CMB |
| b9 | 4x3x1/4" [102x76x6] Foundation Tube, 48" [1219] long | ASTM A500 Grade B | H#B200931 |
| b10 | 2nd Post Cable Hanger 1/2" [13] | ASTM A36 | H#A413247 |

| | | | |
|---|---|---|---|
| b11 | 2nd Post Anchor Aggregate 12 in. Depth | - | N/A |
| b12 | 12" [305] Dia. 2nd Post Concrete Anchor, 46" [1168] long | 4,000 psi f'c | T#4156617 |
| b13 | 2nd Post Base Plate 3/8" [10] Thick | ASTM A36 | H# A410722 |
| b14 | 3/16" [5] Dia., 5 1/8" [130] Long Unbent Brass Rod | ASTM B16-00 | H#05543-2 |
| c1 | 3"x1-3/4"x7 Gauge [76x44x4.6], 81 1/4" [2064] Long Midwest Weak Post w/Holes | Hot-Rolled ASTM A1011 HSLA Gr. 50 | H#667827 Coil#1131814950 (Post Nos. 3 through 25 and 62 through 74) AND H#438314 Coil#06025311 (Post Nos. 26 through 61) |
| c2 | 12 Gauge Tabbed Bracket - Version 10 | Hot-Rolled ASTM A1011 HSLA Grade 50 | H#6464T3 |
| c3 | 5/16" [8] Dia. UNC, 1" [25] Long Hex Cap Screw | Bolt SAE J429 Gr. 5 or ASTM A449 | H#4208029BA |
| c3 | 5/16" [8] Nut | Nut ASTM A563 DH | H#2QG45 |
| c4 | Straight Rod - 3/16" [5] Cable Clip | ASTM B16 Brass C36000 Half Hard (HO2), ROUND TS >= 68.0 ksi, YS >= 52.0 ksi | H#198277.1.1 |
| c5 | 2 1/8"x1 3/8"x7 Gauge [54x35x4.6], 6" [152] Long Bent Steel Plate | Hot-Rolled ASTM A1011 HSLA Gr. 50 | H#106387 |
| c6 | 2 1/8"x1 3/8"x7 Gauge [54x35x4.6], 6" [152] Long Bent Steel Plate | Hot-Rolled ASTM A1011 HSLA Gr. 50 | H#106387 |
| c7 | 3/16" [5] Dia. Brass Cable Clip, 4 9/16" [116] Long Unbent | ASTM B16 Brass C36000 Half Hard (HO2), ROUND, TS >= 68.0 ksi, YS >= 52.0 ksi | H#05543-2 |
| d1 | 3/4" [19] Dia. 3x7 Cable Guiderail | AASHTO M30-92(2000)/ASTM A741-98 Type 1 Class A coating except with Type 1 minimum breaking strength = 39 kips [173.5 kN] | H#139920/27, H#139015/21 |
| d2 | 7/8" [22] Dia. Hex Nut | ASTM A563C | H#M643354 |
| d3 | Cable End Threaded Rod | ASTM A449 | H#133079 |
| d4 | Bennet Cable End Fitter | ASTM A47 | H#9Q4, H#OP5 |
| | Cable Wedges | ASTM A47 | H#DA8 |
| d5 | 7/8" [22] Dia. Hex Nut | SAE J429 Gr. 5 | N/A |
| e1 | Bennet Short Threaded Turnbuckle | Not Specified | KEN Forging Inc. COC |
| e2 | Threaded Load Cell Coupler | N/A | N/A |
| e3 | 50,000-lb [222.4-kN] Load Cell | N/A | N/A |

Heat Number
05543-2

Shipper No
323392

Customer PO#
Paid by visa

November 2014 supply
MWP Brass SMT

# CERTIFICATE OF TEST

Customer COPPER AND BRASS SALES INC.
Invoice No 230605K14
P.O. No 5400221060
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 | 46 | 21.0 | 64.8 |

SIGNED FOR DAE CHANG IND.

hyssenKrupp Materials NA
NLINE METALS - TX
345
5 LB
Del.: 2403436857
CstOr 31885
Date 10/08/2014



Figure A-1. ³⁄₁₆-in. (5-mm) Brass Rod, Test No. MWP-9

**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<br>13433 CENTECH RD<br>OMAHA,NE 68138-3492<br>USA | STATE STEEL SUPPLY CO INC<br><br>SIOUX CITY,IA 51102-3224<br>USA | A36 | Flat / 1/2 X 3 | |
| | | LENGTH | WEIGHT | HEAT / BATCH |
| | | 20'00" | 34,272 LB | 64047117/02 |

| SALES ORDER | CUSTOMER MATERIAL N° | SPECIFICATION / DATE or REVISION |
|---|---|---|
| 639595/000050 | | 1-ASTM A6/A6M-11<br>2-A36/A36M-08<br>3-A709-11<br>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 A-2. CMB High Tension Anchor Plate Washer, Test No. MWP-9

Low Deflection Washers R#14-0082
3/4" AND 1" Washers

**Porteous Fastener Company**
**BOLTS NUTS SCREWS WASHERS**

FIRST CLASS SERVICE

CORPORATE OFFICE
1040 Watson Center Road, Carson, CA 90745
(310) 549-9180 Fax (310) 835-0415
www.porteousfastener.com

February 7, 2013

Attn: Chris

The Structural Bolt
Dear: Chris,

You contacted our Denver office and requested that I write to you concerning specifications under which we purchase our USS Flat Washers

Firstly, our products are purchased to specifications where applicable. Our Purchase Orders clearly state that each product supplied to Porteous Fastener Company is to meet the proper specification as referenced in the Industrial Fastener Institute manual for that product when such specifications exist.

( ANSI B18.22.1 and ASTM F844. All HDG plating shall be done per ASTM A153)

Secondly, we require certifications from our suppliers of all products Grade 5 or better: A325 Structural Bolts, Grade 5 Hex Cap Screws, Grade 8 Hex Cap Screws, ASTM A194 2H Hvy, Hex Nuts, F436 Structural Washers, Grade 8 Finished Hex Nuts, ASTM A193 Grade B7 Threaded Rod, SAE Hi Nuts and Grade C Hex Locknuts. These certifications are on file at Porteous corporate office and copies of same are available to our customers.

We trust that you can be confident, as we are, that the product furnished to you meets specifications.

Please let me know if we can be of further service.

Sincerely,
Herbert Recinos
Inventory Control
Cc: Mike Hall -- Denver

Figure A-3. ¾-in (19-mm) Dia. Flat Washer, Test No. MWP-9

AUG/23/2012/THU 02:08 PM TSA MANUFACTURING FAX No. 4028953297 P. 001/001

P.O. # 145117

| | | | |
|---|---|---|---|
| PO# | 30078 | SO# | 89068 |

Item: 3/4-10 X 18 1/4 J HOOK ANCHOR

Material Specification: ASTM A449

| | | | |
|---|---|---|---|
| LOT#: | 11618020 | | |
| Heat Number: | 11618020 | | |
| Tensile Strength PSI: | 131800 PSI | Yield Strength PSI: | 121800 PSI |
| Elongation: | 20 | Reduction of Area: | 58 |
| Hardness: | 27 HRC | Proof Load: | NA |
| Macro Etch: | NA | Tempering Temp.: | 1340 F |

| | | | |
|---|---|---|---|
| Carbon (C): | 0.44 | Chromium (CR): | NA |
| Manganese (MN): | 0.71 | Molybdenum (MO): | NA |
| Phosphorus (P): | 0.013 | Copper (CU): | NA |
| Sulfur (S): | 0.034 | Nitrogen (N): | NA |
| Silicon (SI): | 0.19 | Nickel (NI): | NA |
| Cobalt (CO): | NA | Aluminum (AL): | NA |
| Vanadium (V): | NA | Tin (SN): | NA |
| Tungsten (W): | NA | Titanium (TI): | NA |
| Columbium/Niobium (NB/CB): | NA | Boron (B): | NA |
| Calcium (CA): | NA | | |

We hereby certify that the material was manufactured, sampled, tested and inspected per the most recent revision of the or material specification. The foregoing data was furnished to us by our supplier or resulting from a test performed in a recognized laboratory and is on file in the records of the corporation.
Name: Kayla Patterson Date:08.13.12

Figure A-4. J-Hook Anchor Bolts, Test No. MWP-9

NOV-08-2005 TUE 05:33 PM FAX NO. P. 05

# TEST CERTIFICATE

Purchaser :[illegible]昌[illegible]工廠股份有限公司

| | |
|---|---|
| Order NO : PO# P170277 | Inspection date:9/08/2005 |
| S/C NO : PI# 050594-T37 | Issue date:09/20/2005 |

LOT NO :8VQ

Size: ¾-10 ASTM A563 Grade DH Heavy Hex Nuts - Hot Dip Galvanized O/S: 0.50MM
Marked "DH" + Makers Sign + "01GO"

Quantity :54,000PCS 180CTNS

Vessel Name: APL THAILANO / 089E

**Material : C-CH40ACR**

| Heat NO. | Size Diameter | C 100% | Mn 100% | P 1000% | S 1000% | Si 100% |
|---|---|---|---|---|---|---|
| 1F543 | 28.00mm | 43 | 81 | 20 | 10 | 5 |

**Dimensional Inspections Specification: ANSI B18.2.2-1987**

UNIT:inch

| Characteristic | Specification | Actual Result | Ac. | Re. |
|---|---|---|---|---|
| Visual appearance | ASTM F812-2002 | OK | 32 | 0 |
| Width across flats | 1.250~1.212 | 1.233~1.224 | 32 | 0 |
| Width across corners | 1.443~1.382 | 1.405~1.395 | 32 | 0 |
| Nuts thickness | 0.758~0.710 | 0.736~0.721 | 32 | 0 |
| Hole diameter | 0.683~0.662 | 0.679~0.670 | 32 | 0 |
| Thread | ASME B1.1-2002 | OK | 32 | 0 |

**Mechanical Properties Specification: ASTM A563-04a**

| Characteristic | Requirement | Result | Ac. | Re. |
|---|---|---|---|---|
| Hardness | HRC 24~38 | HRC30.9~33.0 | 8 | 0 |
| Proof Load | Min 50100Lbf | 58960Lbf | 8 | 0 |

Signatory: M. Wang
Y.M. WANG/Q.C.MANAGER

Figure A-5. ¾-in. (19-mm) Dia. Heavy Hex Nut, Test No. MWP-9

PFC
FIRST CLASS SERVICE

**Porteous Fastener Company**
**BOLTS NUTS SCREWS WASHERS**

CORPORATE OFFICE
1040 Watson Center Road, Carson, CA 90745
(310) 549-9180 Fax (310) 835-0415
www.porteousfastener.com

May 30, 2013

Attn: Chris Burris

Structural Bolt
2140 Cornhusker Hwy
Lincoln NE 68521
Fax: 402-435-3135

Dear: Chris,

You contacted our Denver office concerning specifications under which we purchase our N.C. Gr. 5 Hex Cap Screws.

Firstly, our products are purchased to specification where applicable. Our Purchase Orders clearly state that each product supplied to Porteous Fastener Company is to meet the proper specification as referenced in the Industrial Fastener Institute manual for that product when such specifications exist.

( ASME / ANSI B18.2.1 and SAE J429, GRADE 5. )

Secondly, we require certifications from our suppliers of all products Grade 5 or better: A325 Structural Bolts, Grade 5 Hex Cap Screws, Grade 8 Hex Cap Screws, ASTM A194 2H Hvy, Hex Nuts, F436 Structural Washers, Grade 8 Finished Hex Nuts, ASTM A193 Grade B7 Threaded Rod, SAE Hi Nuts and Grade C Hex Locknuts. These certifications are on file at Porteous corporate office and copies of same are available to our customers.

We trust that you can be confident, as we are, that the product furnished to you meets specifications.

Please let me know if we can be of further service.

Sincerely,

Herbert Recinos
Inventory Control

Cc: Carrie- Denver

Figure A-6. $^5/_8$-in. (16-mm) Dia. Heavy Hex Nut, Test No. MWP-9

Certificate of Conformance | Page 1 of 1

Shipment Date: 04/18/2012

**KANEBRIDGE CORPORATION**

**CERTIFICATE OF CONFORMANCE**

**Company:**
HODELL-NATCO IND.
11688 FAIRGROVE IND. BLVD.
MARYLAND HEIGHTS, MO 63043
*Attn:* ONL/DANIEL

**P.O. #:** 4137087

**Sales Order #:** 4678123

**Shipment #:** 3243260

| Item Number | Description | Lot No | Cert Ref |
|---|---|---|---|
| 62152CH5O | 5/8-11X9 1/2 COAR HEX CAP SCR GR5 ZINC | 490-454-94 | 1 |
| | **Origin**: CANADA | **Mfr:** 1110615263157G | |

**CertRef Certification Description**

1 WE CERTIFY THAT THIS ITEM WAS MANUFACTURED TO SAE J429 SPECIFICATIONS. THE MANUFACTURER'S CHEMICAL AND PHYSICAL TEST REPORTS CERTIFYING THIS PART TO SAE J429 ARE ON FILE AND AVAILABLE AT ANY TIME UPON REQUEST. ADDITIONALLY, THEY HAVE NOT COME INTO CONTACT WITH MERCURY WHILE IN OUR POSSESSION.

*Signed:* RICK SAUL
*Title:* Certification Department

Claims against Kanebridge Corporation shall be limited to a refund or credit for the price billed or paid for improper merchandise. Seller shall not be responsible for buyer's manufacturing costs, labor, alternate purchases, extra freight, replating, plating, lost profit, good will, recall costs, or other incidental or consequential damages.

http://www.kanebridge.com/kanecofc.asp?InvoiceNo=3243260&PassAllLotInd=Y 2/21/2014

Figure A-7. 5/8-in. (16-mm) Dia. UNC, 9½-in. (241-mm) Long Hex Bolt, Test No. MWP-9

**CAUTION**
**FRESH CONCRETE**

Body and or eye contact with fresh (moist) concrete should be avoided because it contains alkali and is caustic.

**Ready Mixed Concrete Company**
6200 Cornhusker Highway, P.O. Box 29288
Lincoln, Nebraska 68529
Telephone 402-434-1844

| PLANT | MIX CODE | YARDS | TRUCK | DRIVER | DESTINATION | CLASS | TIME | DATE | TICKET |
|---|---|---|---|---|---|---|---|---|---|
| 04 | 25513000 | 3.00 | 0135 | 056 | | | 10:23AM | 03/12/14 | 4156617 |

| CUSTOMER | JOB | CUSTOMER NAME | TAX CODE | PARTIAL | NIGHT R. | LOADS |
|---|---|---|---|---|---|---|
| 00003 | | CIA---MIDWEST ROADSIDE SAFTEY | | | | 1 |

| DELIVERY ADDRESS | SPECIAL INSTRUCTIONS | P.O. NUMBER |
|---|---|---|
| 4800 NW. 35TH | N OF N GOODYEAR HANGER | 402-450-6250 |

| LOAD QUANTITY | CUMULATIVE QUANTITY | ORDERED QUANTITY | PRODUCT CODE | PRODUCT DESCRIPTION | | UNIT PRICE | AMOUNT |
|---|---|---|---|---|---|---|---|
| 3.00 | 3.00 | 3.00 | 25513000 | L5500 (HE) .40 | 4.00 | 104.91 | 314.73 |
| | | | | MINIMUM HAUL | | | 40.00 |
| | | | | WINTER SERVICE | | | 12.00 |
| | | | | | | | 366.73 |
| | | | | | | SUBTOTAL | 366.73 |
| | | | | | | TAX | |
| | | | | | | TOTAL | 366.73 |

WATER ADDED ON JOB AT CUSTOMER'S REQUEST ___ GAL. RECEIVED BY MWRSF [signature]

| TRUCK | USER LOGIN | DISP TICKET NUM | TICKET NUM | TICKET ID | TIME | DATE |
|---|---|---|---|---|---|---|
| 0135 | USER | 4156617 | 176448 | 191052 | 10:23 | 03/12/2014 |

| LOAD SIZE | MIX CODE | SEQ | LOAD ID |
|---|---|---|---|
| 3.00 yd | 25513000 | W | 193041 |

| MATERIAL | SOURCE | DESIGN QTY | REQUIRED | BATCHED | VAR | % VAR | %MOISTURE | ACTUAL WAT |
|---|---|---|---|---|---|---|---|---|
| G47B | 47B GRAVEL | 1915.0 lb | 5825.4 lb | 5800.0 | -25.4 | -.44% | 1.40 M | 9.60 gl |
| L47B | 47B ROCK | 833.0 lb | 2509.0 lb | 2500.0 | -9.0 | -.36% | 0.40 M | 1.19 gl |
| CEM1 | CEMENT TYP | 752.0 lb | 2256.0 lb | 2245.0 | -11.0 | -.49% | | |
| LRWR | POZZ 322N | 23.0 oz | 69.0 oz | 69.0 | 0.0 | 0.00% | | |
| AIR | MB-AE 90 A | 3.0 oz | 9.0 oz | 9.0 | 0.0 | 0.00% | | |
| WATER | WATER | 34.0 gl | 94.2 gl | 94.9 | 0.7 | 0.74% | | 94.91 gl |
| WATER2 | RECYCLE WA | 0.0 gl # | 0.0 gl | 0.0 | 0.0 | 0.00% | | |

NON-SIMULATED NUM BATCHES: 1
LOAD TOTAL: 11342 lb DESIGN W/C: 0.377 WATER/CEMENT: 0.393A DESIGN WATER: 102.0 gl ACTUAL WATER: 105.7 gl
SLUMP: 4.00 "# WATER IN TRUCK: 0.0 gl

MWP-1 Concrete Anchorage (6:1 Slope)
R# 14-0353 SMT

Figure A-8. Concrete Anchor, Test No. MWP-9

**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 |
|---|---|---|---|
| NEBCO INC<br>STEEL DIVISION<br>HAVELOCK,NE 68529<br>USA | CONCRETE INDUSTRIES INC<br>LINCOLN,NE 68529-0529<br>USA | 60/420 | REBAR ROUND / #11 (36MM) |

| LENGTH | WEIGHT | HEAT / BATCH |
|---|---|---|
| 60'00" | 33,790 LB | 5819611302 |

| SALES ORDER | SPECIFICATION / DATE or REVISION |
|---|---|
| 126287/000020 | ASTM A615/A615M-09B |

| CUSTOMER PURCHASE ORDER NUMBER | BILL OF LADING | DATE |
|---|---|---|
| 95510 | 1327-0000015536 | 08/01/2012 |

CHEMICAL COMPOSITION

| C % | Mn % | P % | S % | Si % | Cu % | Ni % | Cr % | Mo % | Sn % | V % | Nb % | Al % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.44 | 0.87 | 0.012 | 0.022 | 0.23 | 0.24 | 0.07 | 0.09 | 0.027 | 0.007 | 0.025 | 0.021 | 0.002 |

CHEMICAL COMPOSITION

| CEA706 % |
|---|
| 0.60 |

MECHANICAL PROPERTIES

| YS KSI | YS MPa | UTS MPa | G/L Inch | G/L mm | Elong. % |
|---|---|---|---|---|---|
| 73.4 | 506 | 730 | 8.000 | 200.0 | 12.90 |

MECHANICAL PROPERTIES

| Bend tes |
|---|
| OK |

COMMENTS / NOTES

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. We certify that these data are correct and in compliance with specified requirements. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

TOM HARRINGTON
QUALITY ASSURANCE MGR.

Figure A-9. #11 Rebar for Anchorage, Test No. MWP-9

EVRAZ ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

P.O. Box 316
Pueblo, CO 81002 USA

**MATERIAL TEST REPORT**
Date Printed: 21–MAR–12

| | | | |
|---|---|---|---|
| Date Shipped: 21–MAR–12 | Product: DEF 13mm | | Specification: ASTM–A–615M09b GR 420/ASTM–A–706M09b |
| | FWIP: 52815348 | Customer: CONCRETE INDUSTRIES INC | Cust. PO: 93051 |

CHEMICAL ANALYSIS (Heat chemistry entered 03/05/12)

| Heat Number | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | Al | V | B | Cb | Sn | N | Ti |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 111485 | 0.27 | 1.23 | 0.012 | 0.024 | 0.24 | 0.31 | 0.13 | 0.10 | 0.044 | | 0.046 | 0.0003 | | 0.014 | 0.0108 | 0.001 |

Carbon Equivalent = 0.494

MECHANICAL PROPERTIES

| Heat Number | Sample No. | | Yield (Psi) | Ultimate (Psi) | Elongation (%) | Reduction (%) | Bend | Wt/ft |
|---|---|---|---|---|---|---|---|---|
| 111485 | 01 | | 74160 | 103330 | 14.4 | | ok | 0.664 |
| | | (MPa) | 511.3 | 712.4 | | | | |
| 111485 | 02 | | 74037 | 102730 | 15.6 | | ok | 0.663 |
| | | (MPa) | 510.5 | 708.3 | | | | |

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.
ERMS also certifies this material to be free from Mercury contamination.

This material has been produced and tested in accordance with the requirements of the applicable specifications. We hereby certify that the above test results represent those contained in the records of the Company.

Mark Espanee

*Quality Assurance Department*

Figure A-10. #4 Rebar for Anchorage, Test No. MWP-9

GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

**CERTIFIED MATERIAL TEST REPORT** Page 1/1

| CUSTOMER SHIP TO | CUSTOMER BILL TO | GRADE | SHAPE / SIZE |
|---|---|---|---|
| STEEL & PIPE SUPPLY CO INC<br>1003 FORT GIBSON RD<br>CATOOSA,OK 74015-3033<br>USA | STEEL & PIPE SUPPLY CO INC<br>MANHATTAN,KS 66505-1688<br>USA | A36/A57250 | Standard I-Beam / 3 X 5.7# / 75 X 8.5 |

| LENGTH | WEIGHT | HEAT / BATCH |
|---|---|---|
| 40'00" | 8,208 LB | 59058160/03 |

| SALES ORDER | CUSTOMER MATERIAL Nº | SPECIFICATION / DATE or REVISION |
|---|---|---|
| 812105/000020 | 000000000035357040 | A36/A36M-08<br>A572/A572M-07<br>ASTM A6/A6M-11 |

| CUSTOMER PURCHASE ORDER NUMBER | BILL OF LADING | DATE |
|---|---|---|
| 4500221191 | 1327-0000099969 | 04/02/2014 |

CHEMICAL COMPOSITION

| C % | Mn % | P % | S % | Si % | Cu % | Ni % | Cr % | Mo % | Sn % | V % | Nb % | Al % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.09 | 0.79 | 0.014 | 0.026 | 0.20 | 0.36 | 0.11 | 0.06 | 0.027 | 0.009 | 0.001 | 0.011 | 0.003 |

CHEMICAL COMPOSITION

| CEqvA6 % |
|---|
| 0.3 |

MECHANICAL PROPERTIES

| YS KSI | UTS KSI | YS MPa | UTS MPa | G/L Inch | G/L mm |
|---|---|---|---|---|---|
| 53.4 | 69.5 | 382 | 468 | 8.000 | 200.0 |
| 55.3 | 67.9 | 368 | 479 | 8.000 | 200.0 |

MECHANICAL PROPERTIES

| Elong. % | Y/T rati % |
|---|---|
| 23.20 | 0.786 |
| 23.60 | 0.796 |

COMMENTS / NOTES

4 Cable MWP 6-2part Posts
R#15-0500
April 2015 SMT

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

TOM HARRINGTON
QUALITY ASSURANCE MGR.

Figure A-11. S3x5.7 (S76x8.5) Posts – $28^{1}/_{8}$ in. (714 mm) and 19 in. (483 mm) Long, Test No. MWP-9

SOLD TO: ADELPHIA METALS I LLC
411 MAIN ST E
NEW PRAGUE, MN 56071-

NUCOR
NUCOR CORPORATION
NUCOR STEEL TEXAS

CERTIFIED MILL TEST REPORT

Page: 1

SHIP TO: ADELPHIA METALS-CUST PU
N/A
JEWETT, TX 75846-

Ship from:
Nucor Steel - Texas
8812 Hwy 79 W
JEWETT, TX 75846
800-527-6445

Date: 25-Jul-2012
B.L. Number: 611543
Load Number: 217850

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

| LOT # / HEAT # | DESCRIPTION | PHYSICAL TESTS | | | | | CHEMICAL TESTS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | YIELD P.S.I. | TENSILE P.S.I. | ELONG % IN 8" | BEND | WT% / DEF | C / Ni | Mn / Cr | P / Mo | S / V | Si / Cb | Cu / Sn | C.E. |
| PO# => | 804132 | | | | | | | | | | | | |
| JW1210548001 | Nucor Steel - Texas | 77,800 | 111,200 | 12.0% | | | .38 | .86 | .012 | .026 | .14 | .38 | .56 |
| JW12105480 | 10/#3 Rebar | 536MPa | 767MPa | | | | .17 | .18 | .045 | .015 | .002 | | |
| | 40' A615M GR 420 (Gr60) | | | | | | | | | | | | |
| | ASTM A615/A615M-12 GR 60[420] | | | | | | | | | | | | |
| | AASHTO M31-07 | | | | | | | | | | | | |

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.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Nathan Stewart

Figure A-12. #3 Rebar for Anchorage, Test No. MWP-9

EVRAZ ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

P.O. Box 316
Pueblo, CO 81002 USA

**MATERIAL TEST REPORT**
Date Printed: 16–DEC–10

| | | | |
|---|---|---|---|
| Date Shipped: 16–DEC–10 | Product: DEF 10mm | | Specification: ASTM–A–615M09b GR 420/ ASTM–A–706M09I |
| | FWIP: 52815347 | Customer: CONCRETE INDUSTRIES INC | Cust. PO: 86205 |

**CHEMICAL ANALYSIS** (Heat cast 09/27/10)

| Heat Number | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | Al | V | B | Cb | Sn | N | Ti |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 537484 | 0.26 | 1.24 | 0.015 | 0.007 | 0.24 | 0.25 | 0.08 | 0.14 | 0.013 | 0.004 | 0.037 | 0.0006 | 0.000 | 0.013 | 0.0081 | 0.002 |

Carbon Equivalent = 0.487

**MECHANICAL PROPERTIES**

| Heat Number | Sample No. | | Yield (Psi) | Ultimate (Psi) | Elongation (%) | Reduction (%) | Bend | Wt/ft |
|---|---|---|---|---|---|---|---|---|
| 537484 | 01 | | 68260 | 98900 | 17.3 | | OK | 0.372 |
| | | (MPa) | 470.6 | 681.9 | | | | |
| 537484 | 02 | | 66012 | 96040 | 16.5 | | OK | 0.372 |
| | | (MPa) | 455.1 | 662.2 | | | | |

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.
ERMS also certifies this material to be free from Mercury contamination.

This material has been produced and tested in accordance with the requirements of the applicable specifications. We hereby certify that the above test results represent those contained in the records of the Company.

Mark F Espamer
*Quality Assurance Department*

Figure A-13. 7¼-in. (184-mm) Dia. #3 Hoop Rebar, Test No. MWP-9

| SUPERIOR WASHER AND GASKET CORP. | SUPERIOR WASHER AND GASKET CORP. |
|---|---|
| 170 Adams Avenue<br>Hauppauge, New York 11788<br>Phone: (631) 273-8282<br>Fax: (631) 273-8088<br>E-Mail: swg@superiorwasher.com<br>Web: superiorwasher.com<br>**(In the East)** | 662 Bryant Blvd.<br>Rock Hill, South Carolina 29732<br>Phone: (803) 366-3250<br>Fax: (803) 366-3511<br>E-Mail: swg@superiorwasher.com<br>Web: superiorwasher.com<br>**(In the South)** |

ACCURATE MANUFACTURE GROUP
P.O. BOX 7232 - DEPT. 168

INDIANAPOLIS , IN 46206

| Customer Purchase Order Number | | Superior Order Number | Superior Lot Number | Tracer No. |
|---|---|---|---|---|
| 9454 | | 504612-1 | 504612 - 1 | SC31483 -3 /21153114 |
| Date | Production Card | Part Number | | Quantity |
| 04-02-13 | 175383 | WASB12NZ | | 15,000 |
| Drawing | | Dual Cert No. | | |
| P/N S-1/2TYBNZ A | | | | |

We hereby certify that all materials and processes conform
to the required drawing specifications and that the parts
have been manufactured in the U.S.A.
All parts are manufactured in a Mercury-free environment

**Material**

1008 LOW CARBON STEEL No. 5

ZINC TRIVALENT CHROMIUM

**Chemical Analysis**

| | | |
|---|---|---|
| C | CARBON | .0700 |
| Mn | MANGANESE | .3300 |
| P | PHOSPHORUS | .0080 |
| S | SULPHUR | .0070 |
| Si | SILICON | .0100 |
| Cr | CHROMIUM | .0200 |
| Ni | NICKEL | .0100 |
| Mo | MOLYBDENUM | .0100 |
| Cu | COPPER | .0200 |
| Fe | IRON | |
| Ti | TITANIUM | |
| Co | COBALT | |
| N | NITROGEN | |
| Cb | COLUMBIUM | |
| Al | ALUMINUM | .0430 |
| Sn | TIN | |
| Mg | MAGNESIUM | |
| Zn | ZINC | |
| Pb | LEAD | |
| Va | VANADIUM | |

**Mechanical Properties**

| | |
|---|---|
| Yield | |
| Tensile | |
| Elongation | |
| Hardness | B 49.0 |
| Heat | 4179170 |
| Magnetic Permeability | |
| Bend Test | |

SUPERIOR WASHER & GASKET CORP.

By Richard Anderson Jr.

Richard Anderson, Jr.
Quality Control Manager

Figure A-14. ½-in. (13-mm) Washers, Test No. MWP-9

THE STRUCTURAL BOLT COMPANY

# DISTRIBUTOR'S AFFIDAVIT

DISTRIBUTOR:
THE STRUCTURAL BOLT CO
2140 CORNHUSKER HWY
LINCOLN, NE 68521

REFERENCE PO# 4CMB

The Strcutrual Bolt Co, hereby certifies that the items below meets or exceeds requirements per your purchase order

| Quantity | Size | Descriplion | Spec | Finish |
|---|---|---|---|---|
| 20 | 3/4 x 5-1/2 | HEX BOLT | A307 | PL |
| 20 | 3/4-10 NUT | HEX NUT | A307 | PL |
| 100 | 1/2 WASHER | FLAT WASHER | A307 | PL |
| 50 | 1/2-13 X 2 | HEX BOLT | A307 | PL |
| 50 | 1/2-13 NUT | HEX NUT | A307 | PL |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Order# 4CMB
TSBC Inv# 108423

Distributor's Signature Chris Burris Date: 2/18/2014
Title: General Manager

Figure A-15. Hex Bolts and Nuts – ½-in. (13-mm) Dia. UNC, 2-in. (51-mm) Long and ¾-in. (19-mm) Dia. UNC, 5½-in. (140-mm) Long, Test No. MWP-9

26Apr12 9:26 TEST CERTIFICATE No: MAR 877775

INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 4500179833
Rel
S/O No MAR 212696-001
B/L No MAR 123862-004 Shp 23Apr12
Inv No Inv

Sold To: ( 5017)
STEEL & PIPE SUPPLY
401 NEW CENTURY PARKWAY
KANSAS CITY WHSE.
NEW CENTURY, KS 66031

Ship To: ( 1)
STEEL & PIPE SUPPLY
401 NEW CENTURY PKWY
NEW CENTURY, KS 66031

Tel: 913-768-4333 Fax: 913 768-6683

CERTIFICATE of ANALYSIS and TESTS Cert. No: MAR 877775
19Apr12

Part No
TUBING A500 GRADE B(C) Pcs 20 Wgt 8,408
4" X 3" X 1/4" X 40'

Heat Number B200931 Tag No 621072 Pcs 20 Wgt 8,408
YLD=69070/TEN=81790/ELG=23.9

Heat Number B200931 *** Chemical Analysis ***
C=0.2000 Mn=0.4500 P=0.0120 S=0.0020 Si=0.0300 Al=0.0330
Cu=0.1200 Cr=0.0400 Mo=0.0100 V=0.0010 Ni=0.0400

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
**************************************************
CURRENT STANDARDS:
................................A500/A500M-10a
................................A513-07
................................A252-98 (2002)

Figure A-16. Foundation Tube, Test No. MWP-9

**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 02/05/2015
TIME 16:05:32
USER MEHEULAL

SOLD TO

SHIP TO
13713
Warehouse 0020
1050 Fort Gibson Rd
CATOOSA OK 74015

| Order | Material No. | Description | Quantity | Weight | Customer Part | Customer PO | Ship Date |
|---|---|---|---|---|---|---|---|
| 40237114-0040 | 701672120TM | 1/2 72 X 120 A36 TEMPERPASS STPMLPL | 8 | 9,801.600 | | | 02/05/2015 |

**Chemical Analysis**

Heat No. A413247 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA
Batch 0003769220 8 EA 9,801.600 LB Produced from Coil

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.2000 | 0.8000 | 0.0110 | 0.0020 | 0.0300 | 0.0400 | 0.0700 | 0.0100 | 0.0001 | 0.0900 | 0.0300 | 0.0010 | 0.0030 | 0.0010 | 0.0068 | 0.0070 |

**Mechanical/ Physical Properties**

Mill Coil No. A413247-01

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 74800.000 | 49800.000 | 32.10 | | | 0 | NA | | | |
| 73300.000 | 47900.000 | 32.70 | | | 0 | NA | | | |

**Chemical Analysis**

Heat No. A413247 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA
Batch 0003769231 7 EA 8,576.400 LB Produced from Coil

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.2000 | 0.8000 | 0.0110 | 0.0020 | 0.0300 | 0.0400 | 0.0700 | 0.0100 | 0.0001 | 0.0900 | 0.0300 | 0.0010 | 0.0030 | 0.0010 | 0.0068 | 0.0070 |

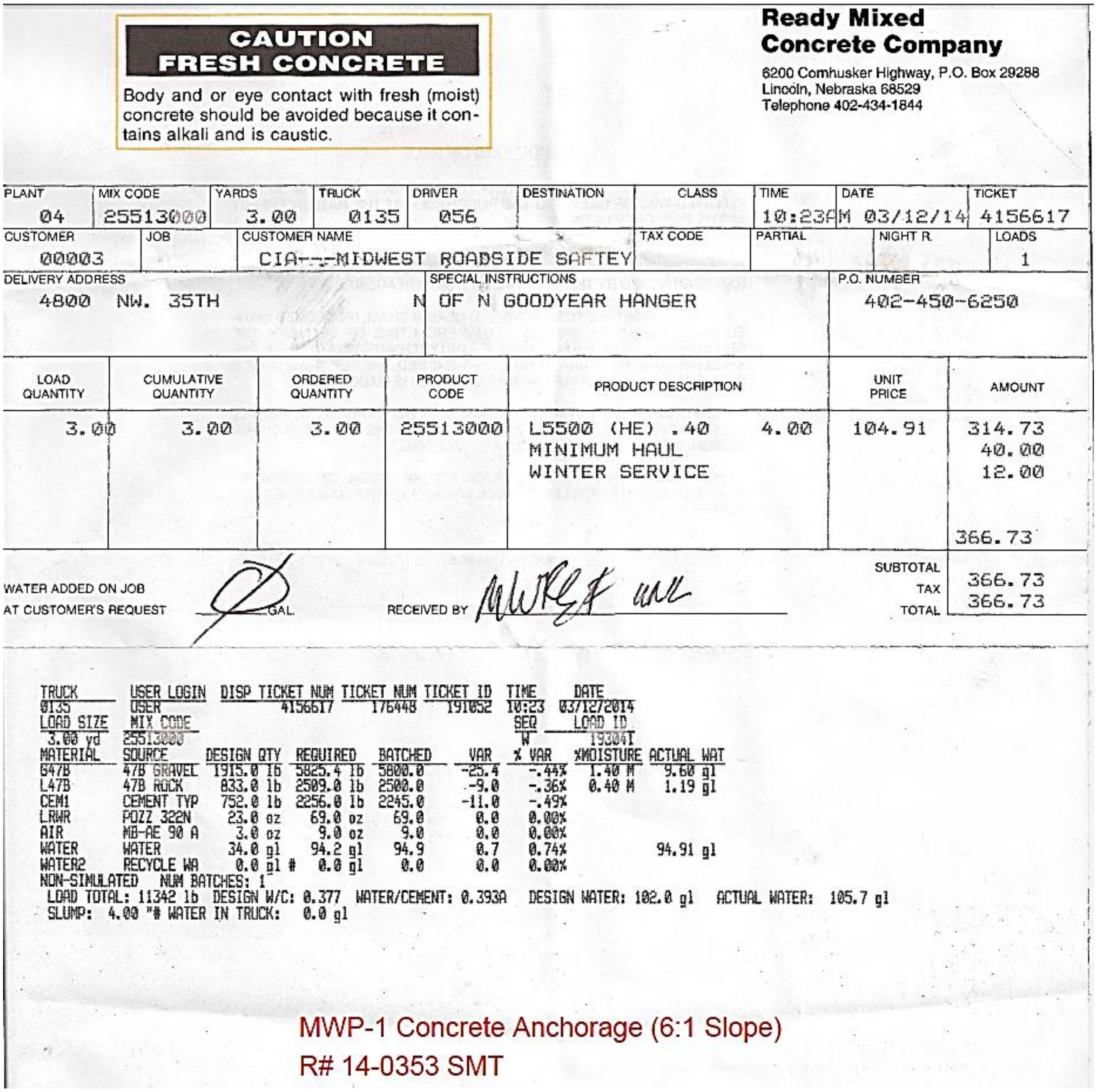
**Mechanical/ Physical Properties**

Mill Coil No. A413247-01

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 74800.000 | 49800.000 | 32.10 | | | 0 | NA | | | |
| 73300.000 | 47900.000 | 32.70 | | | 0 | NA | | | |

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE

Figure A-17. 2nd Post Cable Hanger, ½ in. (13 mm) Thick, Test No. MWP-9



**CAUTION FRESH CONCRETE**

Body and or eye contact with fresh (moist) concrete should be avoided because it contains alkali and is caustic.

**Ready Mixed Concrete Company**
6200 Cornhusker Highway, P.O. Box 29288
Lincoln, Nebraska 68529
Telephone 402-434-1844

| PLANT | MIX CODE | YARDS | TRUCK | DRIVER | DESTINATION | CLASS | TIME | DATE | TICKET |
|---|---|---|---|---|---|---|---|---|---|
| 04 | 25513000 | 3.00 | 0135 | 056 | | | 10:23AM | 03/12/14 | 4156617 |

| CUSTOMER | JOB | CUSTOMER NAME | TAX CODE | PARTIAL | NIGHT R. | LOADS |
|---|---|---|---|---|---|---|
| 00003 | | CIA-.-MIDWEST ROADSIDE SAFTEY | | | | 1 |

| DELIVERY ADDRESS | SPECIAL INSTRUCTIONS | P.O. NUMBER |
|---|---|---|
| 4800 NW. 35TH | N OF N GOODYEAR HANGER | 402-450-6250 |

| LOAD QUANTITY | CUMULATIVE QUANTITY | ORDERED QUANTITY | PRODUCT CODE | PRODUCT DESCRIPTION | | UNIT PRICE | AMOUNT |
|---|---|---|---|---|---|---|---|
| 3.00 | 3.00 | 3.00 | 25513000 | L5500 (HE) .40 | 4.00 | 104.91 | 314.73 |
| | | | | MINIMUM HAUL | | | 40.00 |
| | | | | WINTER SERVICE | | | 12.00 |
| | | | | | | | 366.73 |

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 0 GAL.  RECEIVED BY [signature]

SUBTOTAL 366.73
TAX
TOTAL 366.73

| TRUCK | USER LOGIN | DISP TICKET NUM | TICKET NUM | TICKET ID | TIME | DATE |
|---|---|---|---|---|---|---|
| 0135 | USER | 4156617 | 176448 | 191052 | 10:23 | 03/12/2014 |

| LOAD SIZE | MIX CODE | SEQ | LOAD ID |
|---|---|---|---|
| 3.00 yd | 25513000 | W | 193041 |

| MATERIAL | SOURCE | DESIGN QTY | REQUIRED | BATCHED | VAR | % VAR | %MOISTURE | ACTUAL WAT |
|---|---|---|---|---|---|---|---|---|
| G47B | 47B GRAVEL | 1915.0 lb | 5825.4 lb | 5800.0 | -25.4 | -.44% | 1.40 M | 9.60 gl |
| L47B | 47B ROCK | 833.0 lb | 2509.0 lb | 2500.0 | -9.0 | -.36% | 0.40 M | 1.19 gl |
| CEM1 | CEMENT TYP | 752.0 lb | 2256.0 lb | 2245.0 | -11.0 | -.49% | | |
| LRWR | POZZ 322N | 23.0 oz | 69.0 oz | 69.0 | 0.0 | 0.00% | | |
| AIR | MB-AE 90 A | 3.0 oz | 9.0 oz | 9.0 | 0.0 | 0.00% | | |
| WATER | WATER | 34.0 gl | 94.2 gl | 94.9 | 0.7 | 0.74% | | 94.91 gl |
| WATER2 | RECYCLE WA | 0.0 gl # | 0.0 gl | 0.0 | 0.0 | 0.00% | | |

NON-SIMULATED NUM BATCHES: 1
LOAD TOTAL: 11342 lb DESIGN W/C: 0.377 WATER/CEMENT: 0.393A DESIGN WATER: 102.0 gl ACTUAL WATER: 105.7 gl
SLUMP: 4.00 "# WATER IN TRUCK: 0.0 gl

MWP-1 Concrete Anchorage (6:1 Slope)
R# 14-0353 SMT

Figure A-18. 12-in. (305-mm) Dia. 2nd Post Concrete Anchor, Test No. MWP-9

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 01/23/2015
TIME 11:13:42
USER WILLIAMR

SOLD TO

SHIP TO
13713
Warehouse 0020
1050 Fort Gibson Rd
CATOOSA OK 74015

| Order | Material No. | Description | Quantity | Weight | Customer Part | Customer PO | Ship Date |
|---|---|---|---|---|---|---|---|
| 40235941-0020 | 701272120TM | 3/8 72 X 120 A36 TEMPERPASS STPMLPL | 5 | 4,596 | | | 01/23/2015 |

**Chemical Analysis**

Heat No. A410722 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill SEVERSTAL COLUMBUS Melted and Manufactured in the USA
Batch 0003748836 5 EA 4,596 LB Produced from Coil

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.2000 | 0.8800 | 0.0160 | 0.0010 | 0.0200 | 0.0500 | 0.0700 | 0.0100 | 0.0001 | 0.0900 | 0.0280 | 0.0020 | 0.0030 | 0.0020 | 0.0073 | 0.0040 |

**Mechanical/ Physical Properties**

Mill Coil No. A410722-04

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 73700.000 | 50200.000 | 32.00 | | | 0 | NA | | | |
| 70900.000 | 47900.000 | 32.80 | | | 0 | NA | | | |
| 72100.000 | 48800.000 | 33.30 | | | 0 | NA | | | |
| 70200.000 | 47100.000 | 31.20 | | | 0 | NA | | | |

**Chemical Analysis**

Heat No. A410722 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill SEVERSTAL COLUMBUS Melted and Manufactured in the USA
Batch 0003748828 10 EA 9,192 LB Produced from Coil

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.2000 | 0.8800 | 0.0160 | 0.0010 | 0.0200 | 0.0500 | 0.0700 | 0.0100 | 0.0001 | 0.0900 | 0.0280 | 0.0020 | 0.0030 | 0.0020 | 0.0073 | 0.0040 |

**Mechanical/ Physical Properties**

Mill Coil No. A410722-04

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 73700.000 | 50200.000 | 32.00 | | | 0 | NA | | | |
| 70900.000 | 47900.000 | 32.80 | | | 0 | NA | | | |
| 72100.000 | 48800.000 | 33.30 | | | 0 | NA | | | |
| 70200.000 | 47100.000 | 31.20 | | | 0 | NA | | | |

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION

Figure A-19. 2nd Post Base Plate, $^{3}/_{8}$ in. (10 mm) Thick, Test No. MWP-9

ThyssenKrupp Steel USA
1 ThyssenKrupp Drive
Calvert, Al. 36513

ThyssenKrupp

Mill Certificate

CUSTOMER ORIGINAL

| Order - Item | Certificate Number | Delivery No | Ship Date | Page |
|---|---|---|---|---|
| 42820-70 | 1131814950 | 80554939-10 | 02/27/2014 | 1 of 1 |

Customer No: 10779 Cust PO: 01013159

Customer Part No: 26576

| Customer Sold to: | Customer Ship to: | Contact - Customer Service |
|---|---|---|
| Norfolk Iron & Metal Company<br>3001 North Victory Rd.<br>NORFOLK NE 68702<br>USA | Norfolk Iron & Metal Company<br>3001 North Victory Rd.<br>NORFOLK NE 68702<br>USA | Company<br>ThyssenKrupp Steel USA<br>P.O. Box 456<br>CALVERT AL 36513<br>USA<br>Email: CS.Calvert@Thyssenkrupp.com<br>Ph : 1-251-289-3000 |

Steel Grade / Customer Specification
Hot Roll Black Coil HSLAS-F GRADE 50 [340] / 0.1750 " X 60.0000 " ACCORDING TO A1011 {Light < 0.230"(6.0 mm)}

Type of Product/Surface
Hot Roll Black Coil Semi exposed

TEST METHOD
ASTM

MATERIAL DESCRIPTION

| | ORDERED | Heat No. | Coil No. | Weight Net LB | Weight Gross LB |
|---|---|---|---|---|---|
| (mm) | 4.445 | 667827 | 1131814950 | 47,818 | 47,818 |
| (in) | 0.1750 | | | | |

CHEMICAL COMPOSITION OF THE LADLE *

| Heat No. | C | Si | Mn | P | S | Al | Cr | Cu | Mo | N |
|---|---|---|---|---|---|---|---|---|---|---|
| 667827 | 0.0550 | 0.02 | 0.42 | 0.013 | 0.004 | 0.049 | 0.01 | 0.01 | 0.00 | 0.0058 |

| Ni | Nb | Ti | B | V | Ca |
|---|---|---|---|---|---|
| 0.011 | 0.018 | 0.000 | 0.0001 | 0.001 | 0.0032 |

TENSILE TEST

| Test Direction | Yield Strength | Tensile Strength | % Total Elong. |
|---|---|---|---|
| L | 60.7 ksi | 67.1 ksi | 33.0 |

ThyssenKrupp Steel USA, LLC certify that the material herein described has been manufactured, sampled, tested and inspected in accordance with the contract requirements and is fully in compliance.

Bertram Ehrhardt
Director, Quality Assurance and Development

Rev.

Figure A-20. 3x1¾x7-gauge (76x44x4.6 mm), 81¼-in. (2,064 mm) Long Midwest Weak Post with Holes, Post Nos. 3 through 25 and 62 through 74, Test No. MWP-9

*** TEST REPORT ***

SHIPPER NO/MILL ORDER F122521 3628996

REPORT DATE: 10/20,2014 PAGE: 1 OF 1
INVOICE DATE: 10/20,2014 INV NO: F306083
CUST P.O. NO: 01015461
CUSTOMER CD: 62380-1040

COIL/LIFT IDS
OSP: 06025311
ARCELORMITTAL:

VEH. ID. UP /249146

ArcelorMittal

ArcelorMittal USA Inc.
Quality Department 2-104
3210 Watling Street
East Chicago, Indiana 46312

I certify that the test results shown are correct as contained in the records of ArcelorMittal Indiana Harbor and in compliance with the requirements of the order.

Peter J. Hollingsworth
Division Manager, Quality Assurance

SOLD TO: NORFOLK IRON & METAL CO
PO BOX 1129
NORFOLK NE 68702-1129

SHIP TO: NORFOLK IRON & METAL CO
THEIR SIDING
3003 N VICTORY RD - WEST PIT
NORFOLK NE 68702

SPECIFICATION:

ARCELORMITTAL / HOT ROLL BLACK STEEL / COILS / HSLAS-F 50 / INCLUSION SHAPE CONTROL / ASTM A1011-14 GR 50 / NON TEMPER ROLLED / MILL EDGE

ORDER DESCRIPTION: QTY (LBS) HEAT NO.
.1750 IN X 60.0000 IN COIL 1 65660 438314
COMMODITY: AGNCY:
PART # 27509 DESC: LASER CUT / PAINTED

| TEST PARAMETER | AGENCY | BY | POS | DIR | | UOM |
|---|---|---|---|---|---|---|
| YIELD STRENGTH | ASTM E8,A370 | HT | | L | 60,400 | psi |
| TENSILE STRENGTH | ASTM E8,A370 | HT | | L | 71,100 | psi |
| TOTAL ELONGATION | ASTM E8,A370 | HT | | L | 29 | %@2in |
| YIELD STRENGTH | ASTM E8,A370 | HT | | L | 57,700 | psi |
| TENSILE STRENGTH | ASTM E8,A370 | HT | | L | 69,100 | psi |
| TOTAL ELONGATION | ASTM E8,A370 | HT | | L | 30 | %@2in |

R#16-0104 MWP Posts

Orange Paint

September 2015

| HEAT (wt.%) | C | MN | P | S | SI | CU | NI | MO | CR | CB | V | AL | SN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 438314 | .06 | .93 | .013 | .003 | .01 | .02 | .01 | .01 | .04 | .025 | .002 | .03 | .01 |
| | TI | N | B | | | | | | | | | | |
| | .014 | .0050 | .0001 | | | | | | | | | | |

MELTED AND MANUFACTURED IN USA

ilac-MRA A2LA ACCREDITED
Testing Certs 0111.01, 0111.02 and 2333.01

ArcelorMittal Indiana Harbor has an A2LA accredited testing laboratory in the fields of chemical testing (certificate 0111-01) and mechanical testing (certificate 0111-02)
Charpy Impact testing may be performed by ArcelorMittal Burns Harbor's A2LA accredited testing laboratory (certificate 2333.01) per ASTM E23
All tests were performed by ArcelorMittal Indiana Harbor laboratories, unless otherwise specified in accordance with the following: chemical analysis per ASTM E415 and E1019. All tests performed to the current version of the standard, unless otherwise noted. These results relate only to the items from the heat or coil tested.
Test certificates are prepared in accordance with procedures outlined in DIN EN 10204:2005 Type 3.1.
Test results marked with: - an asterisk (*) were reported by an external accredited laboratory - an (@) were reported by a non-accredited laboratory
Uncertainties of measurements were estimated and are available when requested.
The management systems for manufacture of this product were certified to ISO 9001 (Certificate 40715), ISO/TS 16949 (Certificates 38325 and 41440) and ISO 14001 (Certificates 36274 and 42270).

This report shall not be reproduced except in full.

FORM INP1 REC. 10/2011

Figure A-21. 3x1¾x7-gauge (76x44x4.6 mm), 81¼-in. (2,064 mm) Long Midwest Weak Post with Holes, Post Nos. 26 through 61, Test No. MWP-9

12Ga. Tabbed Bracket Clips

MWP Clips R#16-0188 H#6464T3

White Paint

ESSAR STEEL

ESSAR STEEL ALGOMA INC.,105 West Street, Sault Ste. Marie,Ontario, Canada P6A 7B4

| | | |
|---|---|---|
| SO No.,Item & Date: 8020680 000010 2014/04/14 | Shipment No.& Date.: 1000098384 2014/04/14 | TC No., Date & Time: ESA-149266 2014/04/15 - 02:10:17 |
| Sold to Customer Name and Address: STATE STEEL SUPPLY CO. COURT STREET 214 SIOUX CITY,Iowa,USA 51102 | Ship to Customer Name and Address: STATE STEEL SUPPLY CO. COURT STREET 214 SIOUX CITY,Iowa,USA 51102 | Customer PO NO./Item: P40213FJ901 / 1<br>BOL NO.: 1000098384<br>Cust.Part No.:<br>Carrier: CN (USD FUNDS) - GTW 188034 |

Customer Specification: HR STEEL SHEET HSLA DQ / DS ASTM A1011 HSLAS-F GR 50 (2013) MOD CU .10 MAX Top Semi Critical Surface Improved Shape Restr Thickness 1/2 Tol

Supplementary Instructions: Test Cert 1:fjx@statesteel.com

Insp T/R: Test Report As Per Spec — Cust Use: VETTED RESALE

ESSAR STEEL ALGOMA INC. HEREBY CERTIFIES THAT THE MATERIAL HEREIN DESCRIBED WAS MADE AND TESTED IN ACCORDANCE WITH THE RULES OF THE SPECIFICATION SHOWN. ALL RESULTS ARE RETAINED IN ACCORDANCE WITH THE COMPANY'S STANDARD RECORD KEEPING PRACTICES.
THIS MILL TEST REPORT MAY NOT BE REPRODUCED EXCEPT IN FULL WITHOUT WRITTEN APPROVAL OF ESSAR STEEL ALGOMA INC. IF YOU RECEIVE THIS DOCUMENT AND ARE NOT THE INTENDED RECEIVER, PLEASE CALL (705)945-4005 FOR INSTRUCTIONS ON METHOD OF DISPOSAL OF DOCUMENT.

MEETS EN 10204 3.1
ISO QUALITY AND ENVIRONMENTAL CERTIFICATES AVAILABLE AT WWW.ESSARSTEELALGOMA.COM

ALL HEATS FULLY KILLED.
HEATS INDICATED WITH (*) FINE GRAINED.
HEATS INDICATED WITH (+) MADE IN CANADA WITH DOMESTIC AND NORTH AMERICAN MATERIALS.

| Dimensions (T x W x L) | Batch No. | Heat No-MS | Quantity | No. of Pcs | Dimensions (T x W x L) | Batch No. | Heat No-MS | Quantity | No. of Pcs |
|---|---|---|---|---|---|---|---|---|---|
| 0.0970 " x 60.000 " | TAP1178 | 6464T3-04 | 46,570 LB | 1 | 0.0970 " x 60.000 " | SAP1179 | 6464T3-05 | 44,370 LB | 1 |

CHEMICAL PROPERTIES

| Heat No. (wt%) | C | Mn | P | S | Si | Cr | Ni | Cu | Mo | Al | Nb | V | Ti | N | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6464T3*+ | 0.05 | 0.46 | 0.009 | 0.002 | 0.020 | 0.02 | 0.01 | 0.02 | 0.00 | 0.025 | 0.005 | 0.038 | 0.001 | 0.0109 | 0.00330 |

MECHANICAL PROPERTIES

Tensile Tests

| Heat No. | Batch No. | SRCE | LAB | GAUGE | COND | METH | DIR | LOC | YIELD(KSI) | TENSILE(KSI) | EL SCALE | ELONG(%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6464T3 | | DSPC | ALG | 0.0970 | AR | 2 | L | F | 58.0 | 68.0 | 2" | 30 |

*P50507JL00101*

*6464T3*

Figure A-22. 12-gauge Tabbed Bracket, Version 10, Test No. MWP-9

MWP Hardware
R#16-0105
P#13055
Sept2015 SMT

# 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 : | 2015-01-09 |
| Product: | HEX CAP SCREWS | Contract No: | 14JDF643T |
| Class: | 5 | Invoice No: | 00331052-1 |
| Size: | 5/16-18X1 | Lot No: | 3324910004 |
| Marking: | JDF three radius | Order No. | 100045659 |
| Quantity: | 53.200 mpcs | Part No. | 13055 |
| | | Production Date | 2014-11-05 |
| Dimensions Of SPEC: | | Certificate No.: | 20141024022 |

| Inspection Items | | Standard | Result | Sample | Pass |
|---|---|---|---|---|---|
| Visual Appearance | | -------------- | OK | 29 | 29 |
| Body Diameter | | / | / | 5 | 5 |
| Thread | Go | 3A | OK | 15 | 15 |
| | No Go | 2A | OK | 15 | 15 |
| Width Across Flats | | 0.500-0.489 | 0.490-0.494 | 5 | 5 |
| Width Across Corners | | 0.577-0.557 | 0.571-0.567 | 5 | 5 |
| Major Diameter | | 0.311-0.303 | 0.309-0.310 | 15 | 15 |
| Head Height | | 0.211-0.195 | 0.201-0.207 | 5 | 5 |
| Total Length | | 0.970-1.000 | 0.984-0.976 | 15 | 15 |
| Thread Length | | min 0.861 | 0.886-0.925 | 15 | 15 |
| Key Engagement | | / | / | | |
| Head Diameter | | / | / | | |
| Mechanical Properties | | | | | |
| CharacTeristics | | Standard | Result | | |
| Surface Hardness | [30N] | MAX 54 | 43-46 | 15 | 15 |
| Core Hardness | [HRC] | 25-34 | 27-29 | 15 | 15 |
| Wedge Strength | [psi] | min 119880 | 140779-143536 | 5 | 5 |
| Yield Strength | [psi] | min 91869 | 108995-110446 | 5 | 5 |
| Elongation | [%] | min 14 | 17.4-17.7 | 5 | 5 |
| Reduction Of area | [%] | min 35 | 48.9-50.5 | 5 | 5 |
| Proof Load | [Ib] | 4450 | 4450 | 5 | 5 |
| Impact test -20℃ | [Akv/J] | / | / | | |
| Decarburization | | N≥1/2H1 HV0.3 | 299.54 299.54 308.46 | 5 | 5 |
| HV2>=HV1-30, HV3<=HV1+30 | | G 0.0006max | | | |
| CHEMICAL COMPOSITION(%) | | | | | |

| Heat No | | C | Si | Mn | P | S | Cr | Ni | Cu | Mo | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 35# | 4208029BA | 0.36 | 0.18 | 0.67 | 0.018 | 0.009 | | | | | |
| Thickness | [UM] | | min 5 | | | | 10.2-7.73 | | | 29 | 29 |

| | |
|---|---|
| Surface Coating: | ZPCr3+(coating test method: X ray according to ASTM B568M 2007 standard test |
| Thread Specification: ASME B1.1 2008, UNIFIED INCH SCREW THREADS(UN AND UNR THREAD FORM) | |
| Sampling Dimension Specification: ASME B18.18.2 2011 inspection and quality assurance for high-volume machine assembly | |
| 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 | |
| Mechanical Properties: SAE J429 2013, MECHANICAL AND MATERIAL REQUIREMENTS FOR EXTERNALLY THREADED FASTENERS | |
| Surface Defect: ASTM F788/F788M, SURFACE DISCONTINUITIES OF BOLTS, SCREWS, AND STUDS | |
| Plating Specification: ASTM 1941 2010, Electrodeposited Coatings On Threaded Fasteners | |
| Quality Control Supervisor | Quality Control Manager |

NINGBO JINDING FASTENING PIECE CO., LTD INSPECTION DEP
宁波金鼎紧固件有限公司质检科

Figure A-23. 5/16-in. (8-mm) Dia. UNC, 1-in. (25-mm) Long Hex Cap Screw, Test No. MWP-9

# SUPER CHENG INDUSTRIAL CO.,LTD.

NO. 18 BEN-GONG 2nd ROAD., BEN CHOU INDUSTRIAL PARK, KAOHSIUNG COUNTY 820, TAIWAN R.O.C.
TEL：886-7-6225326-30(5 LINES)  FAX：886-7-6215377/6212335/6235829

## CERTIFICATE OF INSPECTION

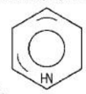
**CERT. #：** S77-1411-02T  **ISSUED DATE：** 2014/12/13  **PAGE 1 OF 1**

**CLIENT：SUPER CHENG INDUSTRIAL CO., LTD.**
**ADDRESS：** NO. 18 BEN-GONG 2nd ROAD., BEN CHOU INDUSTRIAL PARK, KAOHSIUNG COUNTY 820, TAIWAN R.O.C.

**PURCHASER：** FASTENAL COMPANY PURCHASING  **PO #：** 210085084
PART #36304  **QTY SHIPPED：** 162,000 PCS

**COMMODITY：** GRADE 5 FIN HEX NUT  **FINISH：** TRIVALENT ZINC
**SIZE：** 5/16-18  **LOT#：** S77-1411-02  **SAMPLING PLAN：** ANSI/ASME B18.18.2M-93
**QTY：** 820000 PCS  **MATERIAL：** SAE1010  **HEAT NO.：** 2QG45
**MANUFACTURER：** SUPER CHENG IND. CO., LTD.  **MANU. DATE：** 2014/11/15

**DIMENSIONAL INSPECTION**  **SPEC.：** ANSI/ASME B18.2.2-10  **SAMPLED BY：** FENG TE SU




| ITEM | SAMPLE SIZE | SPECIFIED | ACTUAL RESULT | JUDGMENT |
|---|---|---|---|---|
| APPEARANCE | 100 | ASTM F812-12 | GOOD | OK |
| W.A.F. | 32 | 0.500 ~ 0.489 in. | 0.494 ~ 0.494 in. | OK |
| W.A.C. | 8 | 0.577 ~ 0.557 in. | 0.562 ~ 0.559 in. | OK |
| THICKNESS | 8 | 0.273 ~ 0.258 in. | 0.268 ~ 0.264 in. | OK |
| THREAD | 32 | ANSI/ASME B1.1 | PASS | OK |

**MECHANICAL PROPERTIES**  **SPEC.：** SAE J995-12  **SAMPLED BY：** FENG TE SU

| ITEM | SAMPLE SIZE | TEST METHOD | SPECIFIED | ACTUAL RESULT | JUDGMENT |
|---|---|---|---|---|---|
| HARDNESS | 8 | ASTM F606-13 | MAX HRC32 | 12.0 ~ 9.0 HRC | PASS |
| PROOF LOAD | 4 | ASTM F606-13 | MIN 6300LB | 6493 ~ 6486 LB | PASS |
| PLATING THICKNESS | 4 | ASTM B568-98 | MIN 0.0001 in | 0.00023 ~ 0.00016 in | PASS |

MWP Hardware
R#16-0105
Sept2015 SMT

**REMARK：** 1、THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL WITHOUT WRITTEN APPROVAL OF THE LAB.
2、THIS INSPECTION CERTIFICATE IS FOR RESPONSIBILITY UNDER SAMPLE ONLY
3、ABOVE SAMPLES TESTED CONFORM TO THE FASTENER SPECIFICATION OR STANDARDS

世鎧工廠產業股份有限公司 測試實驗室專用章 SUPER CHENG INDUSTRIAL CO. LTD.

**LAB. DIRECTOR(SIGNATORY)：**

表單編號：LQC 10E Rev.0

Figure A-24. 5/16-in. (8-mm) Nut, Test No. MWP-9

7 Gauge Sheet Steel
4CMwP Z-Posts
Red Paint

ThyssenKrupp Steel USA
1 ThyssenKrupp Drive
Calvert, AL 36513

ThyssenKrupp

Mill Certificate

CUSTOMER ORIGINAL

| Order - Item | Certificate Number | Delivery No | Ship Date | Page |
|---|---|---|---|---|
| 27519-221 | 1118689850 | 80351618-10 | 03/06/2013 | 1 of 1 |

CustomerNo: 10780 | Cust PO: 01010892

CustomerPart No: 27509

| Customer Sold to: | Customer Ship to: | Contact - Customer Service |
|---|---|---|
| Norfolk Iron & Metal Company<br>3001 North Victory Rd.<br>NORFOLK NE 68702<br>USA | Norfolk Iron & Metal Company<br>3003 North Victory Rd.<br>West Plt<br>NORFOLK NE 68702<br>USA | Company<br>ThyssenKrupp Steel USA<br>PO Box 456<br>CALVERT AL 36513<br>USA |

Steel Grade / Customer Specification
HR HSLAS-F GRADE 50 [340] / 0.1750 " X 60.0000 " ACCORDING TO A1011 (Light < 0.230"(6.0 mm))

Type of Product/Surface
HR Unexposed

TEST METHOD
ASTM

MATERIAL DESCRIPTION

| | ORDERED | Heat No. | Coil No. | Weight Net LB | Weight Gross LB |
|---|---|---|---|---|---|
| (mm) | 4.445 | 106387 | 1118689850 | 59,149.030 | 59,149.030 |
| (in) | 0.1750 | | | | |

CHEMICAL COMPOSITION OF THE LADLE

| Heat No. | C | Si | Mn | P | S | Al | Cr | Cu | Mo | N |
|---|---|---|---|---|---|---|---|---|---|---|
| 106387 | 0.0487 | 0.01 | 0.45 | 0.009 | 0.003 | 0.042 | 0.01 | 0.00 | 0.00 | 0.0048 |

| Ni | Nb | Ti | B | V | Ca |
|---|---|---|---|---|---|
| 0.009 | 0.022 | 0.001 | 0.0001 | 0.001 | 0.003 |

TENSILE TEST

| Heat No. | Coil No. | Test Direction | Yield Strength | Tensile Strength | % Total Elong. |
|---|---|---|---|---|---|
| 106387 | 1118689850 | L | 55.2 ksi | 64.8 ksi | 34.6 |

n
0.176

ThyssenKrupp Steel USA, LLC certify that the material herein described has been manufactured, sampled, tested and inspected in accordance with the contract requirements and is fully in compliance.

Bertram Ehrhardt
Director, Quality Assurance and Development

Figure A-25. 2$^{1}/_{8}$"x1$^{3}/_{8}$"x7 Gauge [54x35x4.6], 6" [152] Long Bent Steel Plate, Test No. MWP-9

| Customer Name | Customer PO# | Shipper No | Heat Number |
|---|---|---|---|
| UNL-MwRSF | Paid by visa | 763182 | 198277.1.1 |

# CERTIFIED TEST REPORT

Trip No. 223858 Bill of Lading: 161516 Packing Slip: 1625610 Ship Date: 06/10/2016

Customer No. 01293

Bill To
COPPER & BRASS SALES
PO BOX 5116
SOUTHFIELD , MI 48086-5116

Ship to
COPPER & BRASS SALES
5230 ASHLAND WAY
FRANKLIN , WI 53132

02

IN-PROCESS OR FINISHED PRODUCT SAMPLES, AS INDICATED BELOW, HAVE BEEN ANALYZED AND TESTED AND FOUND TO CONFORM TO THE CHEMICAL AND PHYSICAL REQUIREMENTS OF THE SPECIFICATION INDICATED WITH THE FOLLOWING RESULTS

| | Copper | Lead | Iron | TOE | Zinc |
|---|---|---|---|---|---|
| ASTM B16/B16M-10 (2015) | 60.0-63.0% | 2.5-3.0% | 0.35%max | 0.50%max | Balance |

**CHEMICAL ANALYSIS STATEMENT OF CONFORMITY**
Chase Brass maintains chemical control according to the following statistical measures which are recalculated monthly:

| | Copper | Lead | Iron | TOE | Zinc |
|---|---|---|---|---|---|
| Cpk: | 3.94 | 1.61 | | | |
| Mean: | 61.38 | 2.67 | 0.15 | | |
| Max: | 62.28 | 2.98 | 0.26 | 0.31 | Balance |
| Min: | 60.46 | 2.50 | | | |

| Order Traceability No | Product | Specification No | Customer PO | Quantity | Item No Custom Item No. |
|---|---|---|---|---|---|
| 198277.10.1 | C36000 ALLOY T.R. QUALITY H02 HALF HARD | | 5400307675/0100 | 2010 | 0406RD12 CURD00137 |
| 198277.11.1 | C36000 ALLOY T.R. QUALITY H02 HALF HARD | | 5400307675/0110 | 1008 | 1437RD12 CURD00094 |
| 198277.12.1 | C36000 ALLOY T.R. QUALITY H02 HALF HARD | | 5400307675/0120 | 2108 | 0547RD12 CURD00115 |
| 198277.13.1 | C36000 ALLOY T.R. QUALITY H02 HALF HARD | | 5400307675/0130 | 1945 | 1812RD12 CURD01211 |
| 198277.15.1 | C36000 ALLOY T.R. QUALITY H02 HALF HARD | | 5400307675/0150 | 1057 | 2000SQ12 CUSQ00089 |
| 198277.3.1 | C36000 ALLOY T.R. QUALITY H02 HALF HARD | | 5400307675/0030 | 1033 | 0750HX12 CUHEX00033 |
| 198277.4.1 | C36000 ALLOY T.R. QUALITY H02 HALF HARD | | 5400307675/0040 | 1067 | 1750RD12 CURD00967 |
| 198277.5.1 | C36000 ALLOY T.R. QUALITY H02 HALF HARD | | 5400307675/0050 | 1018 | 1312RD12 CURD00067 |
| 198277.6.1 | C36000 ALLOY T.R. QUALITY H02 HALF HARD | | 5400307675/0060 | 1986 | 0390RD12 CURD00198 |
| 198277.7.1 | C36000 ALLOY T.R. QUALITY H02 HALF HARD | | 5400307675/0070 | 1500 | 0687HX12 CUHEX00245 |

Certified Mercury Free Material
ISO9001 Certified Quality System
Certificate Number: US006875-1 (Bureau Veritas Certification)
Material is Directive 2000/53/EC Compliant
Material is Directive 2002/95/EC (RoHS) Compliant
Material is Directive 2011/65/EU (RoHS2) Compliant
This test report meets the guidelines of EN 10204 2.1

Melted and manufactured in the USA
Chase produced rod: NAFTA - Yes

*We hereby certify that the foregoing data is a true copy of the data furnished us by the producing mill or the data resulting from tests performed in the* CHASE BRASS AND COPPER COMPANY, LLC LABORATORY.

**Chase Brass and Copper Company, LLC**
14212 Selwyn Drive
Montpelier, Ohio 43543-0152

Chase

By Jack A. Homer
Jack A. Homer
Quality Manager

From: ThyssenKrupp Materials NA
Cust. ONLINE METALS - TX Del.: 2404792793
CstAr 4345 CstOr 64199
Wgt.: 9.793 LB Date 09/28/2016

Tomas Sanchez

Figure A-26. Brass Straight Rod – $^{3}/_{16}$-in. (5-mm) Cable Clip, Test No. MWP-9

Certificate of Quality

Date: 09/16/2016

BEKAERT CORPORATION Van Buren , Arkansas
1881 BEKAERT DRIVE
VAN BUREN, AR 72956
TEL(479)474-5211 FAX(479)474-9075
TELEFAX 537439

| | | | |
|---|---|---|---|
| Customer | : Colorguard Rail Products | Our Order No | : 4210322864 / 000010 |
| Final Customer | : Midwest Machinery & Supply Company | Product No | : AST3043SE10S02000 3/4 GUIDERAIL 3X7 200 |
| Customer Order No | : 16-0831 | QTY | : 3427.998 LBS |
| Customer Part No. | : | MFG SMP No | : AST3043SE10S02000 |
| Customer Specification | : ASTM A 741 | | |

| Heat# | %C | %Mn | %P | %S | %Si |
|---|---|---|---|---|---|
| 139920 | 0.64 | 0.62 | 0.008 | 0.021 | 0.18 |
| 139927 | 0.61 | 0.59 | 0.009 | 0.013 | 0.19 |
| 586105 | 0.64 | 0.70 | 0.007 | 0.015 | 0.20 |

| Tag# | Heat# | Lay Length | Breaking Strength | Adherence Appearance of wires | Steel Ductility |
|---|---|---|---|---|---|
| | | " | lbf | | |
| | | 3.00<br>7.50 | 25000 | | |
| 43750025 | 139920<br>139927 | 6.74 | 42069 | Pass | Pass |
| 43788809 | 139920<br>586105 | 6.65 | 43514 | Pass | Pass |

R#17-171 3/4" Guardrail Cable
Tag#43750025
October 2016 SMT

Made & Melted in USA.

The undersigned certifies that the results are actual results and conform to the standards as contained in the records of this Corporation.

David Berta
Quality Engineer

Notary Public

1 of 1

Figure A-27. ¾-in. (19-mm) Diameter 3x7 Cable Guiderail, Test No. MWP-9

**Certificate of Quality**
**BEKAERT CORPORATION Van Buren , Arkansas Date:03/28/2016**

| | | | |
|---|---|---|---|
| Customer | : Colorguard Rail Products | Our Order No | : 4209973815 / 000010 |
| Final Customer | : Midwest Machinery & Supply Company | Product No | : AST3043SE10S02000 3/4 GUIDERAIL 3X7 200 |

| Tag# | Heat# | Lay Length " 3.00 7.50 | Breaking Strength lbf 25000 | Adherence Appearance of wires | Steel Ductility |
|---|---|---|---|---|---|
| 43383706 | 139012<br>139024 | 6.12 | 43896 | Pass | Pass |
| 43383832 | 139012<br>139024 | 6.12 | 43896 | Pass | Pass |
| 43383972 | 139012<br>139024 | 6.31 | 43896 | Pass | Pass |
| 43383983 | 139012<br>139024 | 6.31 | 43896 | Pass | Pass |
| 43384097 | 139012<br>139024 | 6.31 | 43896 | Pass | Pass |
| 43384719 | 139015<br>139021 | 6.11 | 44100 | Pass | Pass |
| 43384721 | 139015<br>139021 | 6.11 | 44100 | Pass | Pass |
| 43384723 | 139015<br>139021 | 6.11 | 44100 | Pass | Pass |
| 43384728 | 139015<br>139021 | 6.20 | 44100 | Pass | Pass |
| 43384729 | 139015<br>139021 | 6.20 | 44100 | Pass | Pass |
| 43384730 | 139015<br>139021 | 6.20 | 44100 | Pass | Pass |
| 43384858 | 139016 | 6.14 | 44100 | Pass | Pass |
| 43384869 | 139016 | 6.14 | 44100 | Pass | Pass |
| 43385035 | 139016 | 6.14 | 44100 | Pass | Pass |
| 43385106 | 139012<br>139015 | 6.21 | 44100 | Pass | Pass |
| 43385126 | 139012<br>139015 | 6.21 | 44100 | Pass | Pass |
| 43385846 | 139012<br>139015 | 6.21 | 44100 | Pass | Pass |

Made & Melted in USA.

The undersigned certifies that the results are actual results and conform to the standards as contained in the records of this Corporation.

David Berta
Quality Engineer

Notary Public

2 of 2

Figure A-28. ¾-in. (19-mm) Diameter 3x7 Cable Guiderail, Test No. MWP-9

4CMwP 7/8" Nuts
R# 14-0325 White Paint
Feb 2014 SMT

# INSPECTION CERTIFICATE

UNYTITE,INC.
One Unytite Drive
Peru, Illinois 61354
815-224-2221 — FAX# 815-224-3434

| Customer | Specification | Size | Lot No. | Date |
|---|---|---|---|---|
| BENNETT BOLT WORKS<br>12 ELBRIDGE STREET<br>JORDAN, N.Y. 13080 | ASTM A-563<br>GRADE DH<br>HEAVY HEX NUT | 7/8- 9 UNC | MW471 | Aug. 19,'08 |

Mechanical properties tested in accordance to ASTM F606/F606M, ASTM A370, ASTM E18

Chemical Composition (%)

| Mill Maker | Material Size | Heat No. / Spec. | C | Si | Mn | P | S | Cu | Ni | Cr | Mo | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GERDAU AMER | CARBON | | 0.20<br>0.55 | - | MIN.<br>0.60 | MAX.<br>0.040 | MAX.<br>0.050 | - | - | - | - | - |
| ISTEEL(NO | STEEL | M643354 | 0.45 | 0.20 | 0.70 | 0.009 | 0.029 | 0.24 | 0.12 | 0.07 | 0.03 | - |

| Shape & Dimension Inspection | ANSI B18.2.2<br>GOOD |
|---|---|
| Thread Precision Inspection | ANSI B1.1<br>CLASS 2B<br>GOOD |
| Appearance Inspection | GOOD |

Mechanical Property Inspection

| Item | Proof Load | Cone Stripping | Hardness | Hardness | Absorbed Energy | Heat Treatment |
|---|---|---|---|---|---|---|
| Spec. | 80,850<br>lbf | -<br>kN • kgf • lbf | 24-38<br>HRC | HRB • HB | J • kgfm • ftlbf | T:MIN.800 F |
| Results | n<br>5<br>Results<br>GOOD | n<br>-<br>Results<br>- | 27.1<br>27.2<br>27.1<br>27.5<br>27.6<br>27.3 | Hardness Treatment<br>After 24 Hr.X °F (°C) | at °F (°C) | Q:FORGING Q (W.Q.)<br>T:1149 F/45M. (W.C.<br>Q : Quenching<br>T : Tempering<br>ST : Solution Treatment |

OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/18/09
08-26-08

Remarks:

"DH U"

Production Quantity
71,940 pcs.

Material used for the nut was melted and manufactured in the USA. The nut was manufactured in the USA to the above specification.

We hereby certify that the material described has been manufactured and inspected satisfactorily with the requirement of the above specification.

Chief of Quality Assurance Section

Figure A-29. $^{7}/_{8}$-in. (22-mm) Dia. Hex Nut, Test No. MWP-9

**TC Industries Test Center**
3703 South Route 31
Crystal Lake, IL 60012-1412
Telephone (815) 459-2400 Fax (815) 459-3419

# TEST REPORT

REPORT NO: 168646
DATE: JULY 30, 2013
PAGE 1 OF 1

BILL TO: AMERICAN EAGLE STEEL
317 EAST 11TH STREET
CHICAGO HEIGHTS, IL 60411

SHIP TO: AMERICAN EAGLE STEEL
317 EAST 11TH STREET
CHICAGO HEIGHTS, IL 60411

DESC: 362 PCS .875"RD X 24' | PO: 1563-TC | HEAT: 133079 | MO: 60190 | GRADE: 1045 | CO: 1563 | WT: 17740 | LOT: 88006

SPEC: QUENCH,TEMPER,STRAIGHTEN PINK ENDS | ASTM A449-10

PROCESS: FURN TEMP: 1600 | TEMPER TEMP: 1125 | STRESS TEMP: | FURN TIME hh.mm: 1.00 | TEMPER TIME hh.mm: 1.00 | STRESS TIME hh.mm: | QUENCH: WATER

| PARAMETER | UNITS | LIMITS | | TEST RESULTS (See sampling plan on back) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| TENSILE | KSI | 120.0 | N/A | 143.0 | | | | | |
| YIELD .2% | KSI | 92.0 | N/A | 130.0 | | | | | |
| ELONG 2" | % | 14.0 | N/A | 17.0 | | | | | |
| RED AREA | % | 35.0 | N/A | 48.0 | | | | | |
| SURF HB | HBW | 255 | 321 | 282 | 285 | 285 | 293 | 285 | 285 |
| | | | | 285 | 285 | | | | |

4CMwP
Cable End Threaded Rod A449/1045
White Paint for Left
Red Paint for Right
Bennett Bolt Lot# 83219(left)83218(right)
Feb 2014 R#14-0325 SMT

ACCREDITED
Testing Cert #1281-01

TC INDUSTRIES and SUBCONTRACTED LABS (A2LA ACCREDITED)

| | | |
|---|---|---|
| Tensile, Standard TC | Rockwell | Micro Analysis |
| Tensile, Full Size | Brinell TC | Decarb Measure |
| Charpy V Notch | Ultra Sonic* | Chemistry* |
| Microhardness,Knoop* | Bend Test* | |

| | | | |
|---|---|---|---|
| TC: TC Test Center | BE: Berg Eng. | EX: Exova | MSI: Metallurgical Ser. |
| Cert #1281.01 | Cert #L1157-1 | Cert #104.02 | Cert #0510.01 |
| 2/28/15 | 2/4/14 | 6/30/14 | 12/31/14 |

Time 17:39 DATE IN: 7/20/13 *not included in our scope of accreditation FC 4.12.16F 7/15/10
NOTES:

Ken Rueff
Ken Rueff
Test Center Supervisor

*There are no deviations from test methods unless noted. It should not be assumed that mechanical properties of raw material heat treated to a fastener standard will have the same properties of a finished fastener whose original material characteristics may have been significantly altered.*
*No mercury was used/added and no welding/weld repair was performed on this material while in the possession of TC Industries, Inc.*
*This test report relates only to the items tested and shall not be reproduced, except in full, without the written permission of TC Industries Test Center.*

Figure A-30. Cable End Threaded Rod, Test No. MWP-9

09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 04
SEP-26-2007 10:13AM FROM-Buck Co. HR 717-284-4321 T-131 P.004/004 F-840

# BUCK COMPANY, INC.

897 Lancaster Pike, Quarryville, PA 17566-9738
Phone (717) 284-4114 Fax (717) 284-4321
www.buckcompany.com greatcastings@buckcompany.com

## MATERIAL CERTIFICATION

Date 8-30-07 Form# CERT-7A Rev C 4-21-06

CUSTOMER Bennett Bolt, Inc

ORDER NUMBER 75590

PATTERN NUMBER CGBBWTH REV. —

This is to certify that the castings listed conform to the following specifications and comply in all respects with the drawing or ordered requirements. All Quality Assurance provisions and / or Quality Assurance requirements and / or supplementary Quality Assurance provisions have been completed and accepted. SPC data is on file and available upon request.

Type Material: Malleable Iron

Specifications: ASTM-A47

Grade or Class: 32510

Heat Number: 9Q4

| MECHANICAL PROPERTIES | | CHEMICAL ANALYSIS | |
|---|---|---|---|
| Tensile Str. PSI | 24,562 | Total Carbon | 3.70 |
| Yield Str. PSI | 45,032 | Silicon | 2.86 |
| Elongation | 22 | Manganese | .34 |
| | | Sulfur | .016 |
| | | Phosphorus | .020 |
| | | Chrome | .045 |
| | | Magnesium | .019 |
| | | Copper | .052 |

PHYSICAL PROPERTIES

Brinell Hardness 163

PCS SHIPPED 20

1 of 1

DATE SHIPPED 8-30-07

Quality Assurance Representative

Quality Castings
ISO 9001: 2000 CERTIFIED
Ferritic and Pearlitic Malleable Iron, Gray and Ductile Iron, Brass, Aluminum

Figure A-31. Bennett Cable End Fitter, H# 9Q4, Test No. MWP-9

09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 05
SEP-26-2007 10:13AM FROM-Buck Co. HR 717-284-4321 T-131 P.003/004 F-840

# BUCK COMPANY, INC.

897 Lancaster Pike, Quarryville, PA 17566-9738
Phone (717) 284-4114 Fax (717) 284-4321
www.buckcompany.com greatcastings@buckcompany.com

## MATERIAL CERTIFICATION

Date 11/14/06 Form Number CERT-7C REV. A

CUSTOMER: Bennett Bolt Works

ORDER NUMBER 75410

PATTERN NUMBER CGBBHT REV. —

This is to certify that the castings listed conform to the following specifications and comply in all respects with the drawing or ordered requirements. All Quality Assurance provisions and / or Quality Assurance requirements and / or supplementary Quality Assurance provisions have been completed and accepted. SPC data is on file and available upon request. Melted & Manufactured in the USA.

Type Material: Malleable Iron

Specifications: ASTM-A47

Grade or Class: 32510

Heat Number: OP5

| MECHANICAL PROPERTIES | | CHEMICAL ANALYSIS | |
|---|---|---|---|
| Tensile Str. PSI | 57,112 | Total Carbon | 2.53 |
| Yield Str. PSI | 35,584 | Silicon | 1.57 |
| Elongation | 15 | Manganese | .33 |
| | | Sulfur | .130 |
| | | Phosphorus | .015 |
| | | Chrome | .0310 |
| | | Magnesium | .001 |
| | | Copper | .115 |

PHYSICAL PROPERTIES

Brinell Hardness 121

PCS SHIPPED 105

DATE SHIPPED 11/14/06

1 of 1

Quality Assurance Representative

Quality Castings
ISO 9002 CERTIFIED

Ferritic and Pearlitic Malleable Iron, Gray and Ductile Iron - Brass - Aluminum

Figure A-32. Bennett Cable End Fitter, H# OP5, Test No. MWP-9

Cable Wedges H#DA8 R#15-0635
June 2015 SMT

**BUCK COMPANY, INC.**

897 Lancaster Pike, Quarryville, PA 17566-9738
Phone (717) 284-4114 Fax (717) 284-4321
www.buckcompany.com greatcastings@buckcompany.com

## MATERIAL CERTIFICATION

**Date** 4/28/14 **Form# CERT-7C Rev A 4/21/06**

**CUSTOMER:** Bennett Bolt

**ORDER NUMBER** 6011934

**PATTERN NUMBER** W1 Wedge

**This is to certify that the castings listed conform to the following specifications and comply in all respects with the drawing or ordered requirements. All Quality Assurance provisions and / or Quality Assurance requirements and / or supplementary Quality Assurance provisions have been completed and accepted. SPC data is on file and available upon request. Melted & Manufactured in the USA.**

**Type Material:** Malleable Iron

**Specifications:** ASTM - A47

**Grade or Class:** 32510

**Heat Number:** DA8

**MECHANICAL PROPERTIES**

**Tensile Str. PSI** 53,665

**Yield Str. PSI** 35,031

**Elongation** 14

**PHYSICAL PROPERTIES**

**Brinell Hardness** 126

**CHEMICAL ANALYSIS**

| | |
|---|---|
| **Total Carbon** | 2.61 |
| **Silicon** | 1.56 |
| **Manganese** | .38 |
| **Sulfur** | .113 |
| **Phosphorus** | .014 |
| **Chrome** | .039 |
| **Magnesium** | .001 |
| **Copper** | .373 |

**PCS SHIPPED** 9,698 **DATE SHIPPED** 4/25/14

1 **OF** 1

*Quality Assurance Representative*

Quality Castings
ISO 9001: 2008 CERTIFIED
Ferritic and Pearlitic Malleable Iron, Gray and Ductile Iron, Brass, Aluminum

Figure A-33. Cable Wedges, Test No. MWP-9

10/05/99 15:05 ☎14409920360 KEN FORGING 002/002

**KEN FORGING**
KEN FORGING, INC.

OCTOBER 5, 1999

BENNETT BOLT WORKS, INC.
12 ELBRIDGE STREET
JORDAN, NY 13080

4CMwP Turnbuckles
R# 14-0325 White Paint
Bennett Bolt Lot# 21331/18305
COC Feb 2014 SMT

CERIFICATION OF CONFORMANCE

THIS LETTER IS TO ADVISE THE TURNBUCKLES NOTED BELOW ARE MANUFACTURED IN THE UNITED STATES OF AMERICA BY KEN FORGING, INC,

THESE TURNBUCKLES ARE MANUFACTURED IN COMPLIANCE WITH FEDERAL SPECIFICATION FF-T-791 1b TYPE 1

PURCHASED ORDER NO. 7158

PART NUMBER : TB109-G TB110-G

QUANTITY SHIPPED: 8PCS. 100PCS

DATE SHIPPED: 9/8/99

KEN FORGING, INC.

[signature]

1049 Griggs Road • Post Office Box 277 • Jefferson, OH 44047
(440) 993-8091 • Fax: (440) 992-0360

Figure A-34. Bennet Short Threaded Turnbuckle, Test No. MWP-9

# Appendix B. Vehicle Center of Gravity Determination

Test: MWP-9 Vehicle: Kia Rio

**Vehicle CG Determination**

| VEHICLE | Equipment | Weight (lb.) |
|---|---|---|
| + | Non-ballasted Car (curb) | 2457 |
| + | Brake receivers/wires | 5 |
| + | Brake Actuator and Frame | 7 |
| + | Nitrogen Cylinder | 22 |
| + | Strobe/Brake Battery | 5 |
| + | Hub | 19 |
| + | Data Acquisition Tray | 13 |
| + | DTS Rack | 0 |
| - | Battery | -36 |
| - | Oil | -6 |
| - | Interior | -53 |
| - | Fuel | -11 |
| - | Coolant | -9 |
| - | Washer fluid | -5 |
| | Water Ballast | 0 |
| | Onboard Battery | 14 |
| | Misc. | 0 |

Estimated Total Weight (lb.) 2422

Roof Height (in.) 58 3/8
Wheel base (in.) 98 1/2

| **Center of Gravity** | **1100C MASH Targets** | **Test Inertial** | **Difference** |
|---|---|---|---|
| Test Inertial Weight (lb.) | 2420 (+/-)55 | 2421 | 1.0 |
| Longitudinal CG (in.) | 39 (+/-)4 | 36.45 | -2.54564 |
| Lateral CG (in.) | NA | 2/9 | NA |
| Vertical CG (in.) | NA | 23.10 | NA |

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side
Note: Cells Highlighted in Red do not meet target requirements

**CURB WEIGHT (lb.)**

| | Left | Right |
|---|---|---|
| Front | 801 | 767 |
| Rear | 444 | 445 |

FRONT 1568 lb.
REAR 889 lb.
TOTAL 2457 lb.

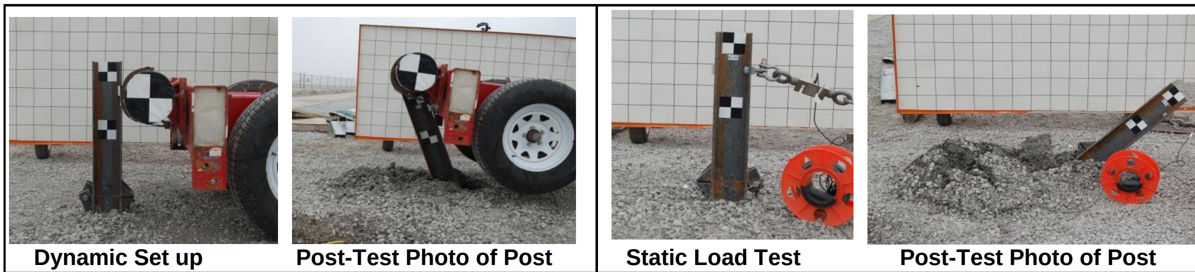
**TEST INERTIAL WEIGHT (lb.)**
(from scales)

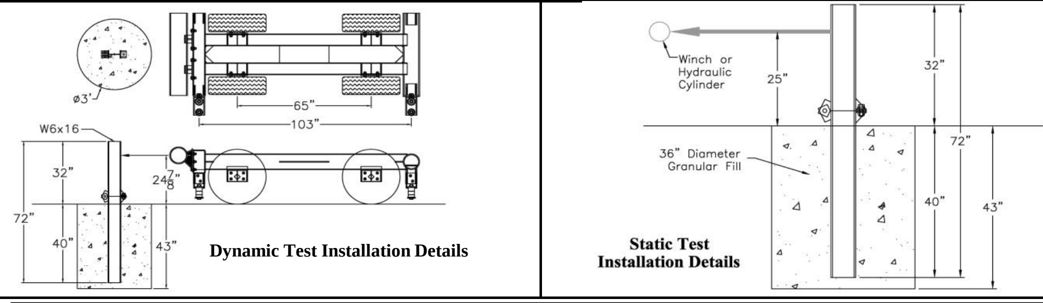
| | Left | Right |
|---|---|---|
| Front | 759 | 766 |
| Rear | 442 | 454 |

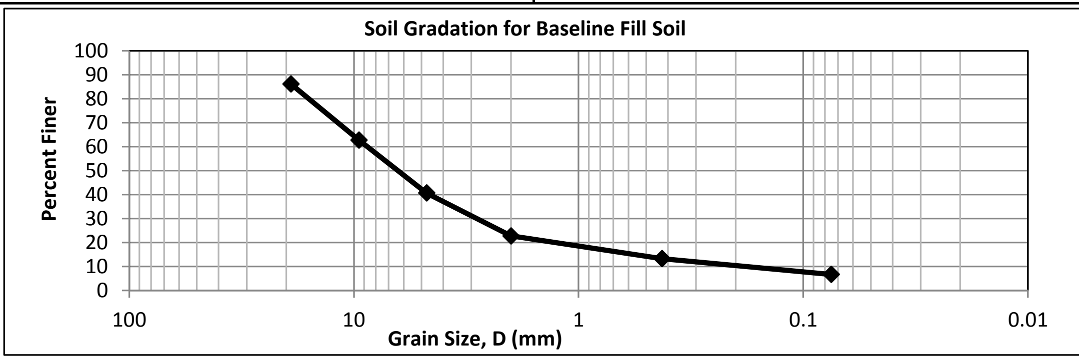
FRONT 1525 lb.
REAR 896 lb.
TOTAL 2421 lb.

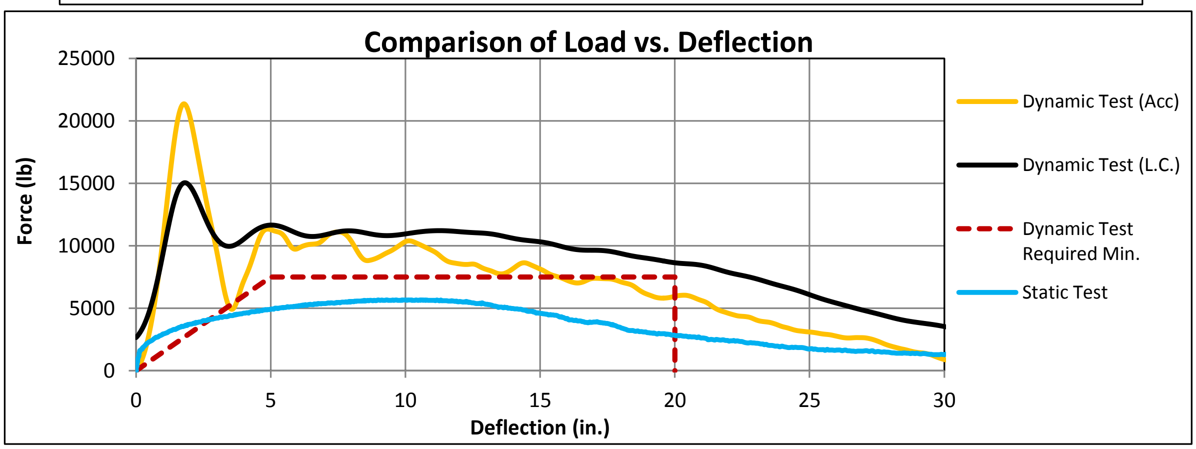
Figure B-1. Vehicle Mass Distribution, Test No. MWP-9

# Appendix C. Static Soil Tests



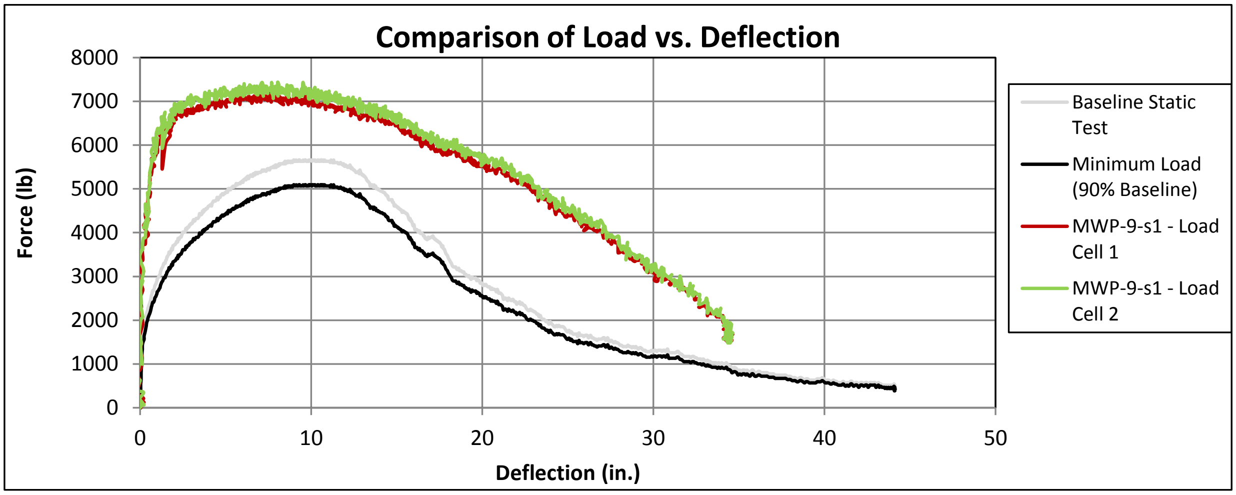



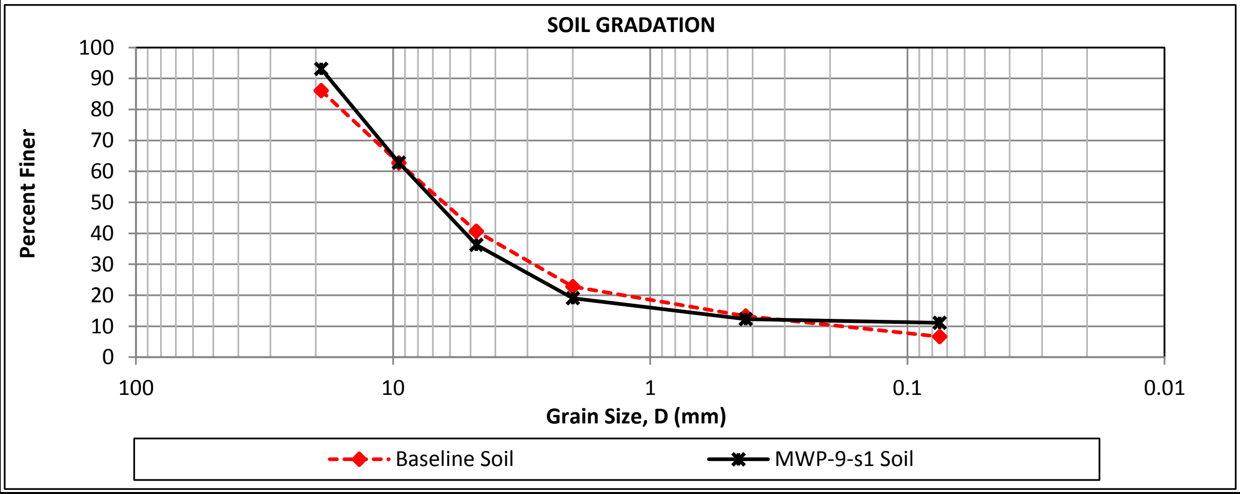




| | | |
|---|---|---|
| **Date**........................................................ | 5/17/2013 | |
| **Test Facility & Site Location**........................ | Midwest Roadside Safety Facility | |
| **In situ soil description (ASTM D2487)**........... | Well-Graded Gravel (GW) | |
| **Fill material description (ASTM D2487)**......... | Well-Graded Gravel (GW) (see sieve analyses above) | |
| **Description of fill placement procedure**........ | H.E.-8 | |
| **Bogie Weight**............................................ | 1857 lb | 842 kg |
| **Impact Velocity**......................................... | 20.6 mph | 33.2 km/h |

Figure C-1. Soil Strength, Initial Calibration Tests, Test No. MWP-9

| Static Load Test Setup | Post-Test Photo of Post |
|---|---|
|  |  |




| | |
|---|---|
| **Date**…………………………………………… | 10/28/2016 |
| **Test Facility & Site Location**…………………… | Midwest Roadside Safety Facility |
| **In situ soil description (ASTM D2487)**……….. | Well-Graded Gravel (GW) |
| **Fill material description (ASTM D2487)**……… | Well-Graded Gravel (GW) (see sieve analyses above) |
| **Description of fill placement procedure**…….. | 8-inch lifts tamped with a pneumatic compactor |

Figure C-2. Static Soil Test, Test No. MWP-9

# Appendix D. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MWP-9
VEHICLE: Kia Rio

| POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 27.427 | -21.827 | 2.170 | 27.115 | -21.982 | 2.282 | -0.311 | -0.154 | 0.112 |
| 2 | 29.795 | -15.642 | -1.253 | 29.559 | -15.849 | -1.093 | -0.236 | -0.208 | 0.160 |
| 3 | 29.322 | -11.554 | -1.773 | 29.077 | -11.791 | -1.629 | -0.245 | -0.237 | 0.144 |
| 4 | 28.814 | -5.764 | -1.983 | 28.566 | -6.016 | -1.890 | -0.248 | -0.253 | 0.092 |
| 5 | 25.889 | -22.018 | -1.637 | 25.658 | -22.241 | -1.424 | -0.230 | -0.223 | 0.213 |
| 6 | 26.287 | -15.713 | -2.978 | 26.106 | -15.963 | -2.809 | -0.181 | -0.249 | 0.169 |
| 7 | 26.042 | -11.446 | -3.387 | 25.893 | -11.703 | -3.211 | -0.149 | -0.257 | 0.176 |
| 8 | 25.780 | -6.028 | -3.528 | 25.596 | -6.304 | -3.419 | -0.183 | -0.275 | 0.109 |
| 9 | 20.076 | -21.637 | -4.868 | 19.906 | -21.899 | -4.748 | -0.169 | -0.263 | 0.120 |
| 10 | 19.706 | -15.577 | -4.742 | 19.555 | -15.795 | -4.662 | -0.152 | -0.217 | 0.079 |
| 11 | 19.831 | -11.280 | -5.036 | 19.565 | -11.414 | -4.958 | -0.267 | -0.134 | 0.078 |
| 12 | 18.999 | -5.988 | -4.860 | 18.765 | -6.156 | -4.801 | -0.234 | -0.168 | 0.058 |
| 13 | 16.142 | -21.997 | -5.123 | 15.939 | -22.212 | -5.036 | -0.203 | -0.215 | 0.087 |
| 14 | 15.940 | -15.776 | -4.732 | 15.798 | -16.105 | -4.678 | -0.142 | -0.329 | 0.053 |
| 15 | 15.444 | -10.914 | -4.759 | 15.246 | -11.140 | -4.573 | -0.198 | -0.226 | 0.186 |
| 16 | 15.241 | -6.008 | -5.124 | 15.095 | -6.257 | -5.018 | -0.146 | -0.249 | 0.106 |
| 17 | 12.524 | -21.990 | -5.142 | 12.344 | -22.222 | -5.115 | -0.181 | -0.232 | 0.028 |
| 18 | 12.068 | -15.903 | -4.473 | 11.874 | -16.192 | -4.427 | -0.194 | -0.289 | 0.046 |
| 19 | 11.460 | -10.907 | -4.481 | 11.211 | -11.249 | -4.278 | -0.250 | -0.342 | 0.203 |
| 20 | 11.127 | -6.478 | -5.090 | 10.988 | -6.783 | -4.871 | -0.138 | -0.305 | 0.218 |
| 21 | 8.503 | -21.855 | -4.758 | 8.193 | -22.131 | -4.729 | -0.310 | -0.276 | 0.029 |
| 22 | 8.367 | -15.929 | -4.181 | 8.186 | -16.191 | -4.163 | -0.181 | -0.262 | 0.018 |
| 23 | 8.337 | -11.133 | -4.205 | 8.125 | -11.407 | -4.110 | -0.211 | -0.275 | 0.095 |
| 24 | 8.222 | -6.275 | -4.735 | 8.070 | -6.541 | -4.729 | -0.152 | -0.266 | 0.006 |
| 25 | 0.326 | -21.830 | 0.175 | 0.036 | -22.098 | 0.166 | -0.290 | -0.268 | -0.009 |
| 26 | 0.267 | -15.890 | -0.022 | -0.014 | -15.993 | -0.031 | -0.281 | -0.103 | -0.009 |
| 27 | 0.127 | -10.692 | -0.047 | -0.060 | -10.913 | -0.067 | -0.187 | -0.221 | -0.020 |
| 28 | 0.000 | -5.278 | 0.026 | -0.093 | -5.446 | -0.028 | -0.093 | -0.169 | -0.054 |
| | | | | | | | | | |
| | | | | | | | | | |

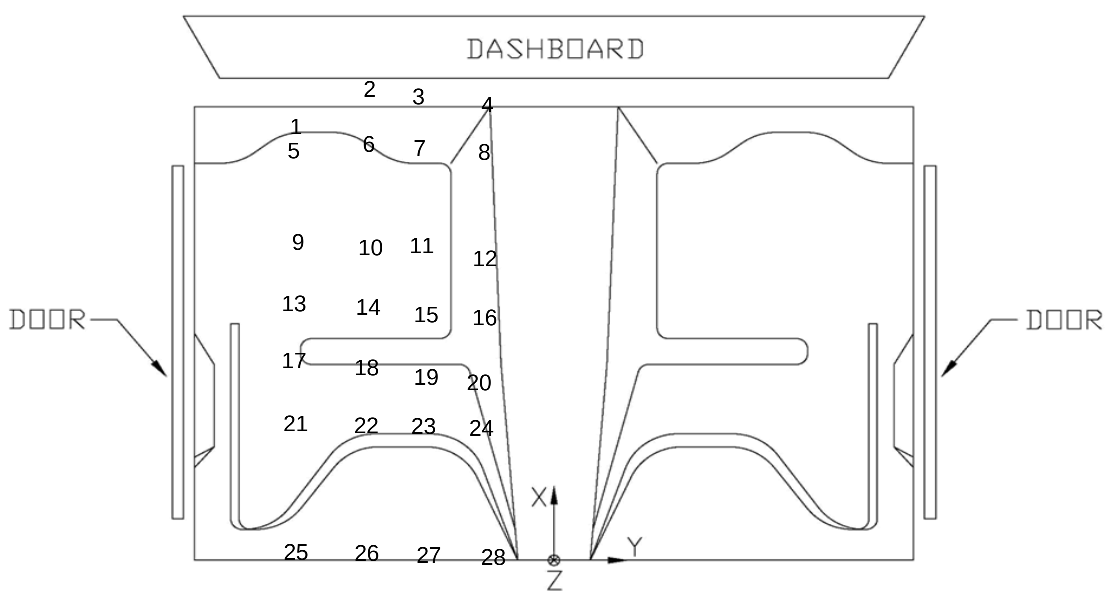



Figure D-1. Floor pan Deformation Data – Set 1, Test No. MWP-9

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MWP-9
VEHICLE: Kia Rio

| POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 41.889 | -24.564 | 3.894 | 41.798 | -24.529 | 3.884 | -0.091 | 0.035 | -0.010 |
| 2 | 44.665 | -18.437 | 0.796 | 44.598 | -18.393 | 0.706 | -0.067 | 0.043 | -0.090 |
| 3 | 44.365 | -14.346 | 0.310 | 44.265 | -14.320 | 0.238 | -0.100 | 0.026 | -0.072 |
| 4 | 44.103 | -8.547 | 0.189 | 44.015 | -8.458 | 0.131 | -0.088 | 0.089 | -0.058 |
| 5 | 40.625 | -24.650 | 0.088 | 40.547 | -24.561 | -0.032 | -0.078 | 0.088 | -0.120 |
| 6 | 41.311 | -18.331 | -1.143 | 41.233 | -18.384 | -1.226 | -0.078 | -0.053 | -0.084 |
| 7 | 41.267 | -14.097 | -1.464 | 41.154 | -14.087 | -1.547 | -0.114 | 0.010 | -0.083 |
| 8 | 41.229 | -8.674 | -1.519 | 41.026 | -8.582 | -1.642 | -0.203 | 0.092 | -0.123 |
| 9 | 35.083 | -24.010 | -3.526 | 35.054 | -23.983 | -3.646 | -0.030 | 0.027 | -0.121 |
| 10 | 34.991 | -17.882 | -3.319 | 34.844 | -17.944 | -3.439 | -0.147 | -0.063 | -0.120 |
| 11 | 35.083 | -13.622 | -3.526 | 35.025 | -13.573 | -3.628 | -0.058 | 0.049 | -0.102 |
| 12 | 34.413 | -8.294 | -3.298 | 34.353 | -8.319 | -3.389 | -0.060 | -0.025 | -0.091 |
| 13 | 31.179 | -24.177 | -4.039 | 31.047 | -24.115 | -4.183 | -0.132 | 0.062 | -0.145 |
| 14 | 31.210 | -18.094 | -3.551 | 31.000 | -18.120 | -3.684 | -0.210 | -0.026 | -0.133 |
| 15 | 30.835 | -13.092 | -3.517 | 30.751 | -13.172 | -3.490 | -0.084 | -0.080 | 0.027 |
| 16 | 30.873 | -8.262 | -3.821 | 30.628 | -8.268 | -3.826 | -0.245 | -0.006 | -0.005 |
| 17 | 27.536 | -24.072 | -4.289 | 27.531 | -24.157 | -4.463 | -0.005 | -0.085 | -0.174 |
| 18 | 27.228 | -18.000 | -3.546 | 27.141 | -18.016 | -3.664 | -0.086 | -0.016 | -0.118 |
| 19 | 26.712 | -13.011 | -3.481 | 26.614 | -13.117 | -3.436 | -0.098 | -0.107 | 0.045 |
| 20 | 26.617 | -8.550 | -4.050 | 26.466 | -8.637 | -3.933 | -0.152 | -0.088 | 0.118 |
| 21 | 23.404 | -23.797 | -4.179 | 23.393 | -23.920 | -4.334 | -0.011 | -0.123 | -0.156 |
| 22 | 23.582 | -17.914 | -3.510 | 23.392 | -17.997 | -3.621 | -0.190 | -0.083 | -0.112 |
| 23 | 23.736 | -13.160 | -3.437 | 23.542 | -13.199 | -3.456 | -0.193 | -0.039 | -0.019 |
| 24 | 23.838 | -8.229 | -3.888 | 23.634 | -8.274 | -3.950 | -0.205 | -0.046 | -0.063 |
| 25 | 15.128 | -23.576 | 0.191 | 14.908 | -23.702 | 0.077 | -0.220 | -0.125 | -0.114 |
| 26 | 15.181 | -17.471 | 0.131 | 15.103 | -17.666 | 0.025 | -0.078 | -0.195 | -0.106 |
| 27 | 15.278 | -12.417 | 0.193 | 15.067 | -12.558 | 0.114 | -0.212 | -0.140 | -0.079 |
| 28 | 15.464 | -6.936 | 0.332 | 15.194 | -7.069 | 0.299 | -0.271 | -0.133 | -0.032 |
| | | | | | | | | | |
| | | | | | | | | | |

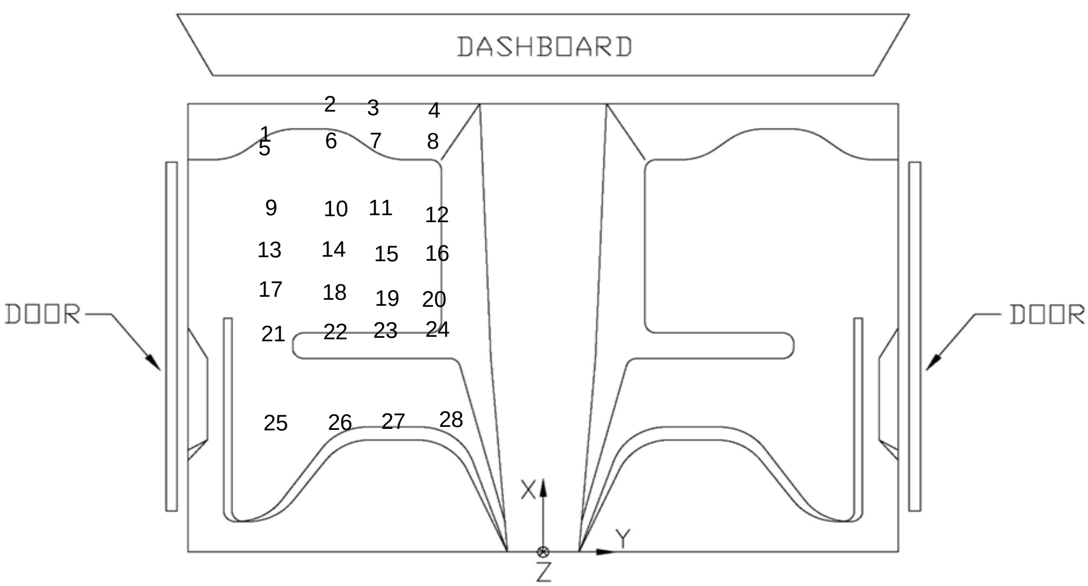



Figure D-2. Floor pan Deformation Data – Set 2, Test No. MWP-9

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MWP-9
VEHICLE: Kia Rio

| | POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|---|
| DASH | 1 | 15.881 | -23.669 | 22.723 | 15.423 | -23.571 | 22.754 | -0.459 | 0.098 | 0.031 |
| | 2 | 12.559 | -12.554 | 26.483 | 12.147 | -12.420 | 26.529 | -0.412 | 0.134 | 0.045 |
| | 3 | 14.760 | 1.844 | 23.674 | 14.376 | 1.959 | 23.658 | -0.383 | 0.115 | -0.016 |
| | 4 | 14.390 | -22.054 | 12.669 | 13.987 | -22.032 | 12.663 | -0.403 | 0.022 | -0.006 |
| | 5 | 13.954 | -12.326 | 11.953 | 13.665 | -12.282 | 11.945 | -0.289 | 0.044 | -0.008 |
| | 6 | 11.083 | 0.414 | 11.384 | 10.722 | 0.476 | 11.418 | -0.361 | 0.062 | 0.034 |
| SIDE PANEL | 7 | 23.761 | -25.929 | 6.576 | 23.455 | -26.027 | 6.692 | -0.306 | -0.098 | 0.116 |
| | 8 | 19.360 | -26.081 | 3.405 | 19.101 | -26.212 | 3.456 | -0.259 | -0.131 | 0.051 |
| | 9 | 22.640 | -25.912 | 0.745 | 22.524 | -26.156 | 0.856 | -0.115 | -0.244 | 0.111 |
| IMPACT SIDE DOOR | 10 | -10.768 | -27.467 | 25.539 | -11.266 | -27.738 | 25.459 | -0.499 | -0.271 | -0.080 |
| | 11 | 1.766 | -27.195 | 23.720 | 1.331 | -27.611 | 23.774 | -0.436 | -0.416 | 0.054 |
| | 12 | 14.152 | -27.049 | 21.719 | 13.672 | -27.251 | 21.872 | -0.479 | -0.202 | 0.153 |
| | 13 | -9.600 | -28.102 | 8.056 | -9.943 | -28.279 | 7.936 | -0.343 | -0.177 | -0.120 |
| | 14 | 4.984 | -28.046 | 7.226 | 4.641 | -28.244 | 7.123 | -0.343 | -0.198 | -0.103 |
| | 15 | 17.467 | -27.163 | 5.708 | 17.113 | -27.215 | 5.802 | -0.354 | -0.052 | 0.094 |
| ROOF | 1 | 3.449 | -18.203 | 39.683 | 3.378 | -17.470 | 39.889 | -0.071 | 0.733 | 0.206 |
| | 2 | 4.158 | -12.241 | 39.869 | 4.065 | -12.166 | 40.748 | -0.093 | 0.075 | 0.878 |
| | 3 | 4.401 | -7.846 | 39.956 | 4.287 | -7.768 | 40.622 | -0.114 | 0.078 | 0.666 |
| | 4 | 4.448 | -3.171 | 40.038 | 4.374 | -3.107 | 40.512 | -0.074 | 0.064 | 0.474 |
| | 5 | 4.455 | 0.506 | 40.022 | 4.225 | 0.621 | 40.424 | -0.230 | 0.115 | 0.403 |
| | 6 | -3.017 | -17.534 | 42.733 | -3.267 | -17.256 | 42.889 | -0.250 | 0.277 | 0.157 |
| | 7 | -2.301 | -12.445 | 42.911 | -2.708 | -12.396 | 42.424 | -0.407 | 0.049 | -0.488 |
| | 8 | -2.446 | -7.890 | 43.200 | -2.896 | -7.741 | 42.499 | -0.450 | 0.149 | -0.701 |
| | 9 | -2.512 | -3.384 | 43.334 | -2.914 | -3.215 | 42.777 | -0.403 | 0.169 | -0.557 |
| | 10 | -2.752 | 0.723 | 43.389 | -3.180 | 0.847 | 42.805 | -0.427 | 0.124 | -0.584 |
| | 11 | -9.380 | -16.389 | 44.300 | -9.755 | -16.238 | 43.744 | -0.374 | 0.151 | -0.556 |
| | 12 | -9.063 | -11.938 | 44.546 | -9.649 | -11.878 | 42.998 | -0.586 | 0.059 | -1.548 |
| | 13 | -9.430 | -7.651 | 44.801 | -10.072 | -7.511 | 42.945 | -0.642 | 0.140 | -1.856 |
| | 14 | -9.558 | -3.849 | 44.897 | -10.141 | -3.636 | 43.204 | -0.583 | 0.213 | -1.693 |
| | 15 | -9.752 | -0.342 | 44.947 | -10.419 | -0.251 | 43.328 | -0.667 | 0.092 | -1.619 |

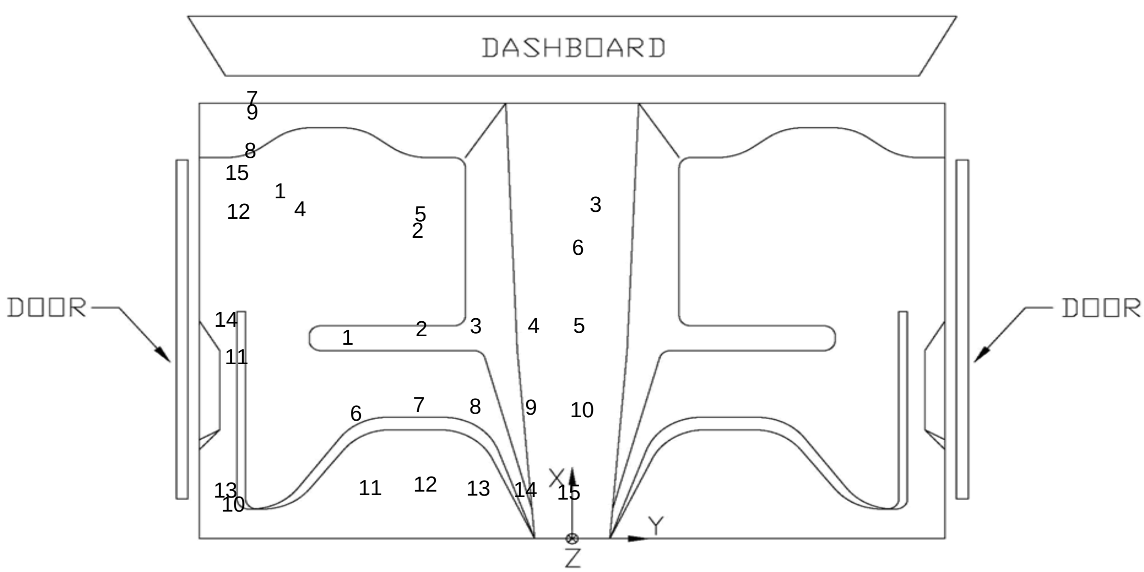



Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. MWP-9

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MWP-9
VEHICLE: Kia Rio

| | POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|---|
| DASH | 1 | 28.997 | -26.331 | 23.676 | 28.846 | -26.138 | 23.446 | -0.151 | 0.193 | -0.230 |
| | 2 | 25.859 | -15.129 | 27.385 | 25.710 | -15.039 | 27.346 | -0.148 | 0.091 | -0.039 |
| | 3 | 28.707 | -0.884 | 24.992 | 28.490 | -0.687 | 24.899 | -0.217 | 0.197 | -0.093 |
| | 4 | 28.188 | -24.468 | 13.618 | 28.073 | -24.319 | 13.369 | -0.116 | 0.149 | -0.249 |
| | 5 | 28.199 | -14.734 | 13.019 | 28.076 | -14.600 | 12.877 | -0.123 | 0.134 | -0.142 |
| | 6 | 25.807 | -1.830 | 12.513 | 25.543 | -1.767 | 12.491 | -0.264 | 0.063 | -0.021 |
| SIDE PANEL | 7 | 37.830 | -28.614 | 8.048 | 37.670 | -28.509 | 7.902 | -0.160 | 0.105 | -0.145 |
| | 8 | 33.649 | -28.545 | 4.666 | 33.631 | -28.487 | 4.364 | -0.018 | 0.058 | -0.302 |
| | 9 | 37.294 | -28.539 | 1.987 | 37.166 | -28.510 | 1.919 | -0.128 | 0.029 | -0.068 |
| IMPACT SIDE DOOR | 10 | 2.108 | -29.129 | 24.782 | 1.856 | -29.558 | 24.627 | -0.252 | -0.428 | -0.155 |
| | 11 | 14.657 | -29.309 | 23.699 | 14.513 | -29.784 | 23.628 | -0.144 | -0.475 | -0.071 |
| | 12 | 27.186 | -29.598 | 22.516 | 26.985 | -29.771 | 22.454 | -0.200 | -0.174 | -0.062 |
| | 13 | 4.386 | -29.524 | 7.226 | 4.266 | -29.752 | 7.095 | -0.120 | -0.227 | -0.130 |
| | 14 | 18.963 | -30.005 | 7.366 | 18.790 | -30.190 | 7.240 | -0.173 | -0.185 | -0.126 |
| | 15 | 31.526 | -29.594 | 6.730 | 31.424 | -29.482 | 6.606 | -0.102 | 0.113 | -0.124 |
| ROOF | 1 | 15.639 | -20.636 | 39.909 | 15.977 | -20.071 | 40.045 | 0.338 | 0.565 | 0.137 |
| | 2 | 16.545 | -14.734 | 40.258 | 16.790 | -14.838 | 41.060 | 0.245 | -0.104 | 0.802 |
| | 3 | 16.982 | -10.377 | 40.430 | 17.128 | -10.446 | 41.069 | 0.146 | -0.069 | 0.639 |
| | 4 | 17.321 | -5.745 | 40.551 | 17.287 | -5.810 | 41.098 | -0.034 | -0.065 | 0.547 |
| | 5 | 17.369 | -2.024 | 40.653 | 17.249 | -2.157 | 41.098 | -0.120 | -0.133 | 0.445 |
| | 6 | 8.998 | -19.772 | 42.560 | 9.162 | -19.702 | 42.651 | 0.165 | 0.070 | 0.091 |
| | 7 | 9.950 | -14.843 | 42.858 | 9.973 | -14.908 | 42.323 | 0.024 | -0.065 | -0.535 |
| | 8 | 9.914 | -10.169 | 43.235 | 9.861 | -10.252 | 42.498 | -0.054 | -0.083 | -0.737 |
| | 9 | 10.099 | -5.666 | 43.429 | 9.934 | -5.789 | 42.880 | -0.165 | -0.123 | -0.549 |
| | 10 | 9.975 | -1.533 | 43.550 | 9.785 | -1.629 | 42.995 | -0.190 | -0.096 | -0.555 |
| | 11 | 2.681 | -18.443 | 43.709 | 2.788 | -18.579 | 43.136 | 0.107 | -0.136 | -0.573 |
| | 12 | 3.112 | -14.005 | 44.061 | 3.029 | -14.108 | 42.493 | -0.083 | -0.103 | -1.568 |
| | 13 | 2.866 | -9.667 | 44.378 | 2.788 | -9.786 | 42.522 | -0.078 | -0.119 | -1.856 |
| | 14 | 2.984 | -5.842 | 44.523 | 2.749 | -5.918 | 42.866 | -0.235 | -0.077 | -1.657 |
| | 15 | 2.763 | -2.360 | 44.652 | 2.636 | -2.482 | 43.059 | -0.127 | -0.122 | -1.594 |

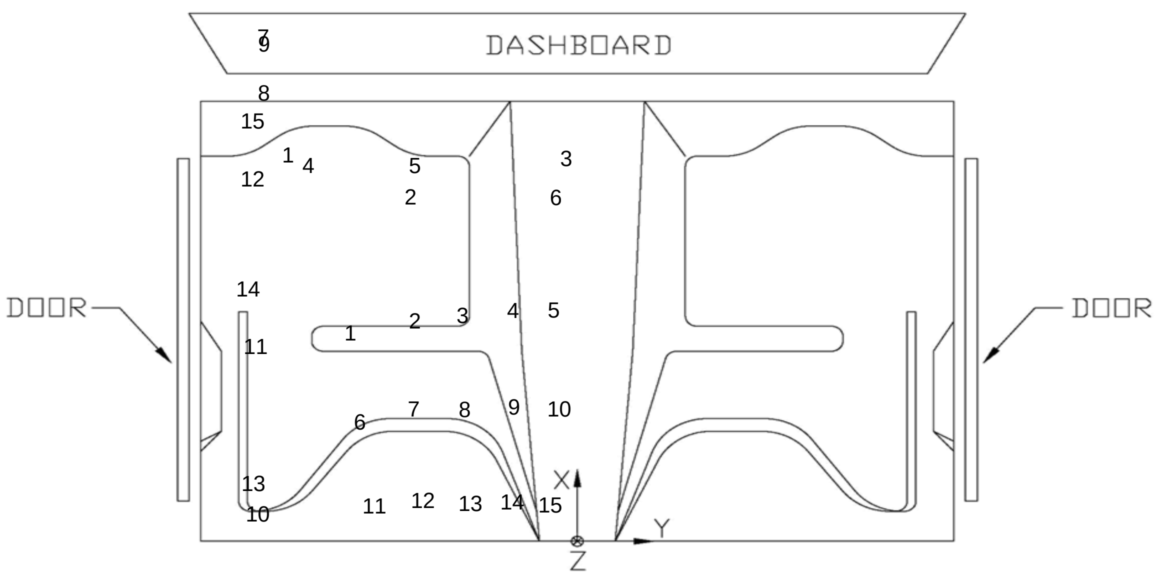
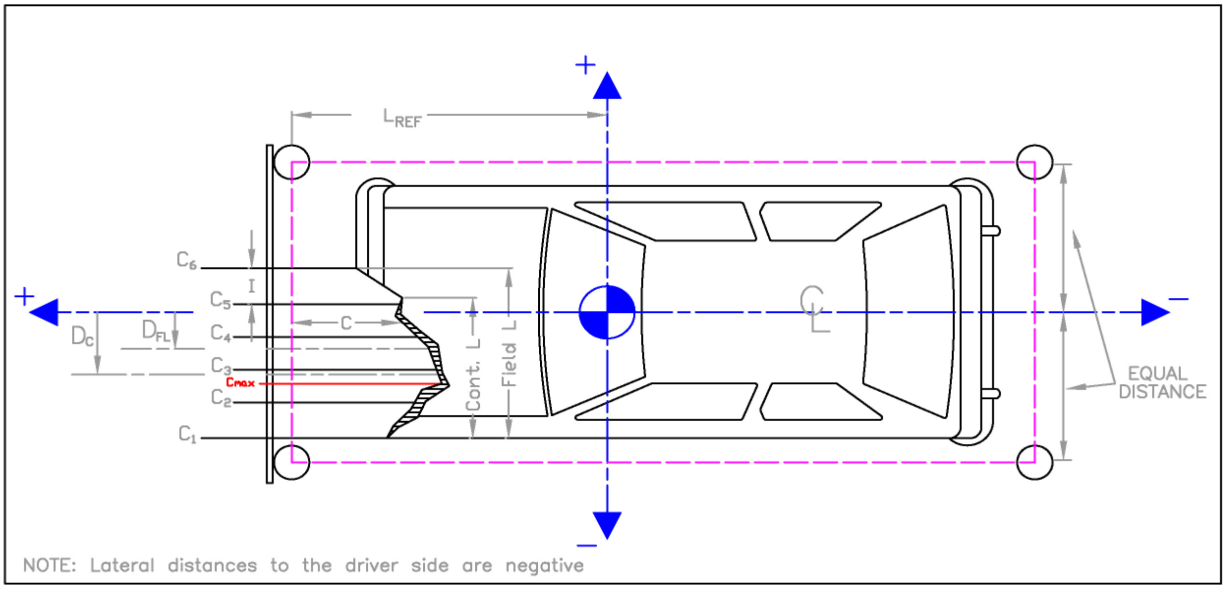



Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. MWP-9

Date: 10/31/2016 Test Number: MWP-9

Make: Kia Model: Rio Year: 2008




Blue Cells to be filled out Before Test
Orange Cells to Be filled out After Test

| | in. | (mm) |
|---|---|---|
| Distance from C.G. to reference line - $L_{REF}$: | 67 | (1702) |
| Total Width of Vehicle: | 64 7/8 | (1648) |
| Width of contact and induced crush - Field L: | 64 7/8 | (1648) |
| Crush measurement spacing interval (L/5) - I: | 13 | (330) |
| Distance from center of vehicle to center of Field L - $D_{FL}$: | 0 | () |
| Width of Contact Damage: | 64 7/8 | (1648) |
| Distance from center of vehicle to center of contact damage - $D_C$: | 0 | () |

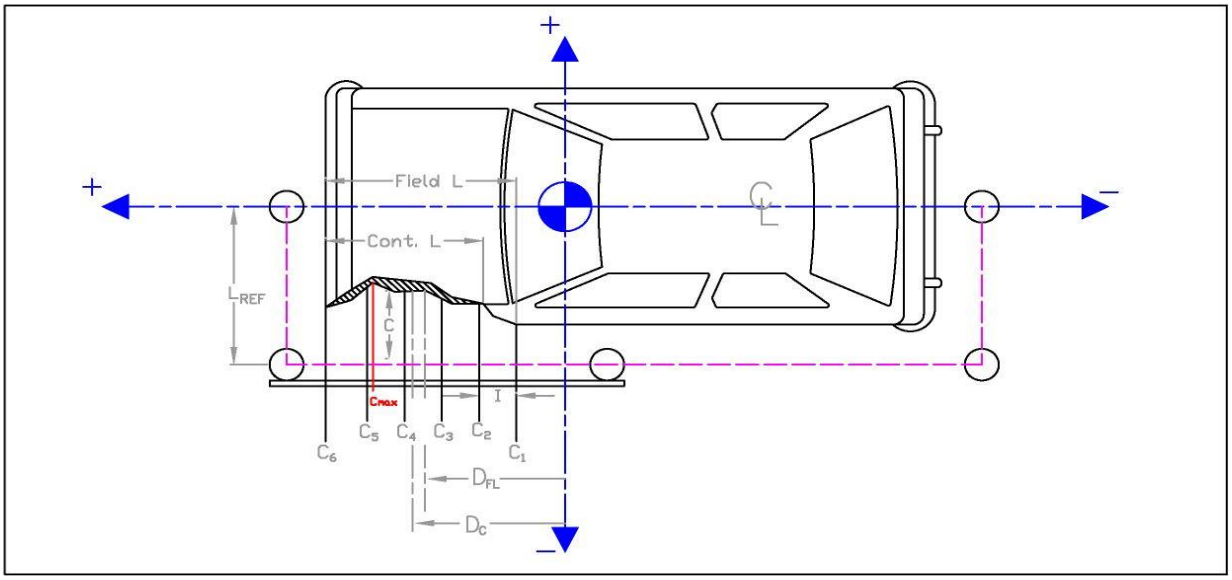
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

| | Crush Measurement | | Lateral Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual | Crush |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | 22 1/2 | (572) | -32 4/9 | -(824) | 24 | (610) | -8 4/9 | -(215) | 7 | (177) |
| $C_2$ | 2 1/2 | (64) | -19 1/2 | -(494) | 8 2/5 | (214) | | | 2 5/9 | (65) |
| $C_3$ | 2 | (51) | -6 1/2 | -(165) | 6 1/6 | (156) | | | 4 2/7 | (109) |
| $C_4$ | 1 3/4 | (44) | 6 1/2 | (165) | 6 1/7 | (156) | | | 4 | (103) |
| $C_5$ | 2 3/4 | (70) | 19 1/2 | (494) | 8 1/3 | (212) | | | 2 5/6 | (72) |
| $C_6$ | 24 1/4 | (616) | 32 4/9 | (824) | 24 | (610) | | | 8 5/7 | (221) |
| $C_{MAX}$ | 14 1/2 | (368) | 25 | (635) | 10 7/8 | (276) | | | 12 | (307) |

Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. MWP-9

**Date:** 42674 **Test Number:** MWP-9

**Make:** Kia **Model:** Rio **Year:** 2008




Blue Cells to be filled out Before Test
Orange Cells to Be filled out After Test

| | in. | (mm) |
|---|---|---|
| Distance from centerline to reference line - $L_{REF}$: | 38 1/4 | (972) |
| Total Vehicle Length: | 166.875 | (4239) |
| Width of contact and induced crush - Field L: | 166 7/8 | (4239) |
| Crush measurement spacing interval (L/5) - I: | 33.375 | (848) |
| Distance from vehicle c.g. to center of Field L - $D_{FL}$: | 13 6/7 | (352) |
| Width of Contact Damage: | 166 7/8 | (4239) |
| Distance from vehicle c.g. to center of contact damage - $D_C$: | 13 6/7 | (352) |

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

| | Crush Measurement | | Longitudinal Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual Crush | |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | NA | NA | -69.579 | -(1767) | 4.00 | (102) | 2.25 | (57) | NA | NA |
| $C_2$ | 5 1/4 | (133) | -36.204 | -(920) | 3.63 | (92) | | | -0.6 | -(16) |
| $C_3$ | 6 1/4 | (159) | -2.8294 | -(72) | 3.75 | (95) | | | 0.3 | (6) |
| $C_4$ | 6 | (152) | 30.5456 | (776) | 3.25 | (83) | | | 0.5 | (13) |
| $C_5$ | 5 3/4 | (146) | 63.9206 | (1624) | 8.75 | (222) | | | -5.3 | -(133) |
| $C_6$ | 23 | (584) | 97.2956 | (2471) | 21.75 | (552) | | | -1.0 | -(25) |
| $C_{MAX}$ | 17 | (432) | -55 | -(1397) | 4.00 | (102) | | | 10.8 | (273) |

Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. MWP-9

Date: 11/7/2016 Test Name: MWP-9 VIN:
Year: 2008 Make: Kia Model: Rio

VEHICLE PRE/POST CRUSH
A-Pillar Measurements

| POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) | Total Δ (in.) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.981 | 16.091 | 37.228 | 1.860 | 16.554 | 37.270 | -0.121 | 0.462 | 0.043 | 0.480 |
| 2 | 15.992 | 18.752 | 28.671 | 15.840 | 19.131 | 28.624 | -0.152 | 0.379 | -0.047 | 0.411 |
| 3 | 0.985 | -26.911 | 37.279 | 0.467 | -24.344 | 35.988 | -0.518 | 2.566 | -1.292 | 2.919 |
| 4 | 14.821 | -30.216 | 28.676 | 14.403 | -28.448 | 27.683 | -0.419 | 1.769 | -0.993 | 2.071 |
| 5 | 7.777 | -28.648 | 33.931 | 7.258 | -25.270 | 31.958 | -0.519 | 3.378 | -1.973 | 3.946 |
| 6 | 0.570 | 17.008 | 0.111 | 0.313 | 17.263 | 0.105 | -0.257 | 0.255 | -0.006 | 0.362 |
| 7 | 0.115 | -0.118 | 0.110 | -0.117 | 0.118 | 0.114 | -0.232 | 0.236 | 0.004 | 0.331 |
| 8 | -17.308 | -0.119 | 0.120 | -17.565 | 0.117 | 0.121 | -0.257 | 0.236 | 0.001 | 0.349 |

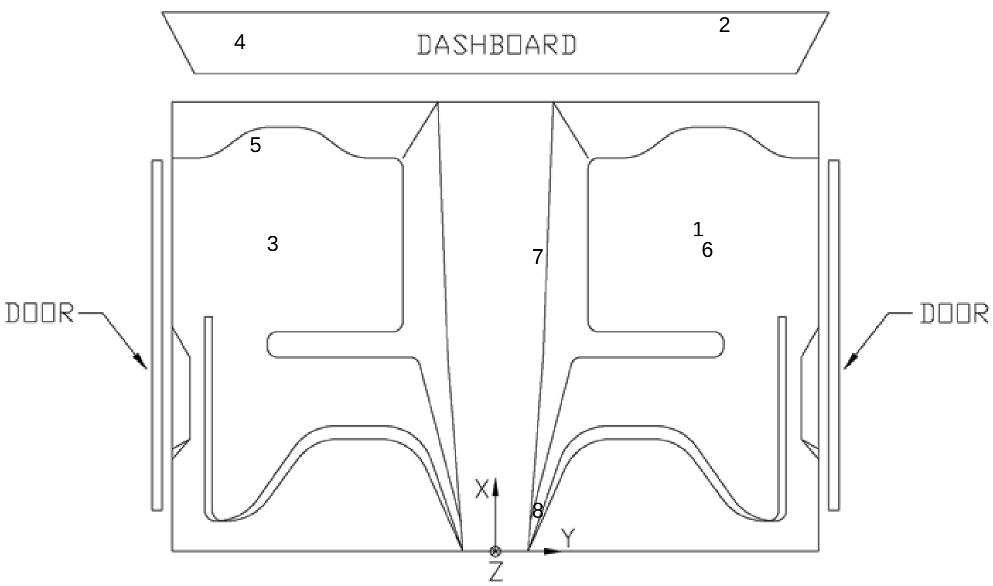



Figure D-7. A-Pillar Measurements, Test No. MWP-9

# Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. MWP-9

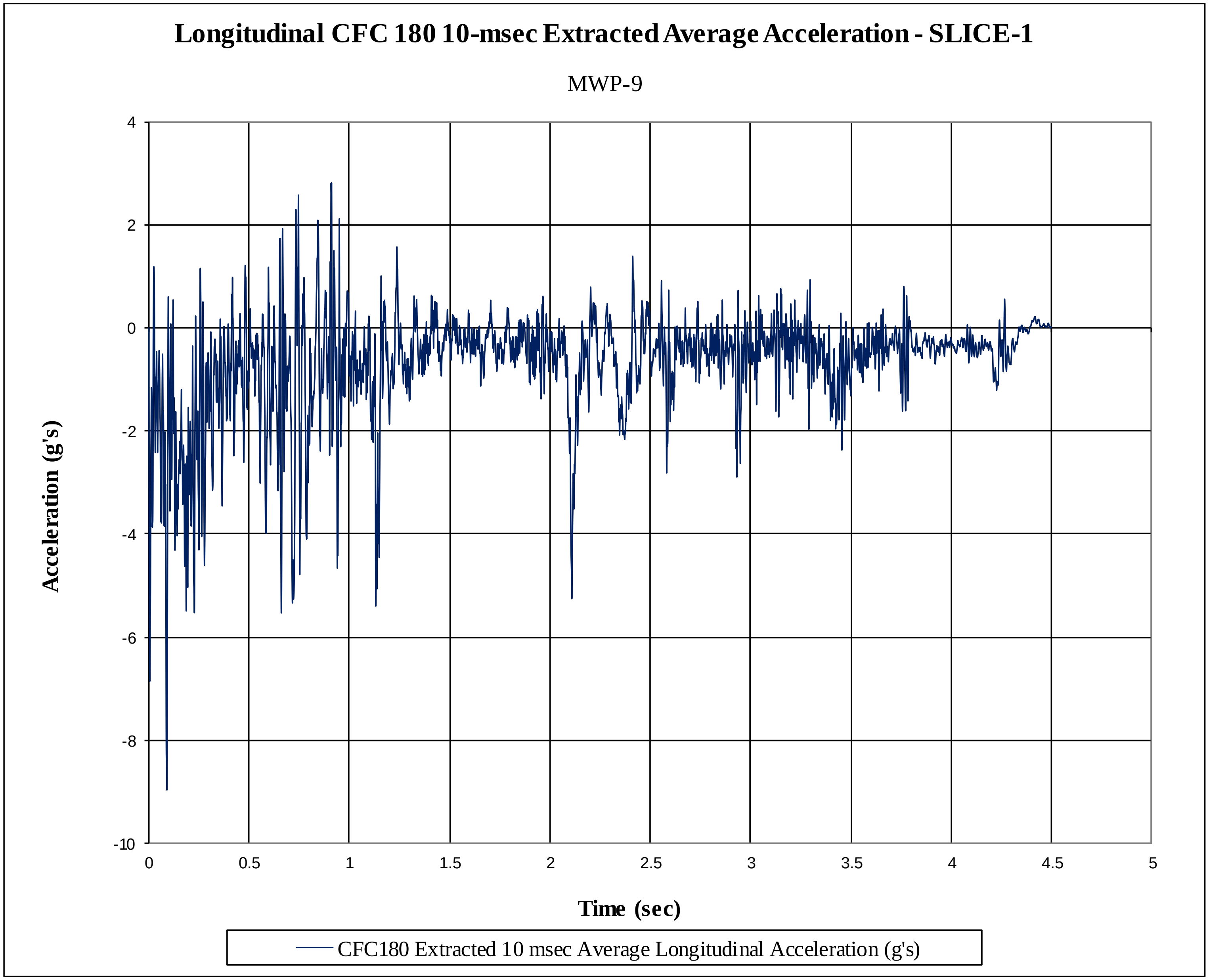


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MWP-9

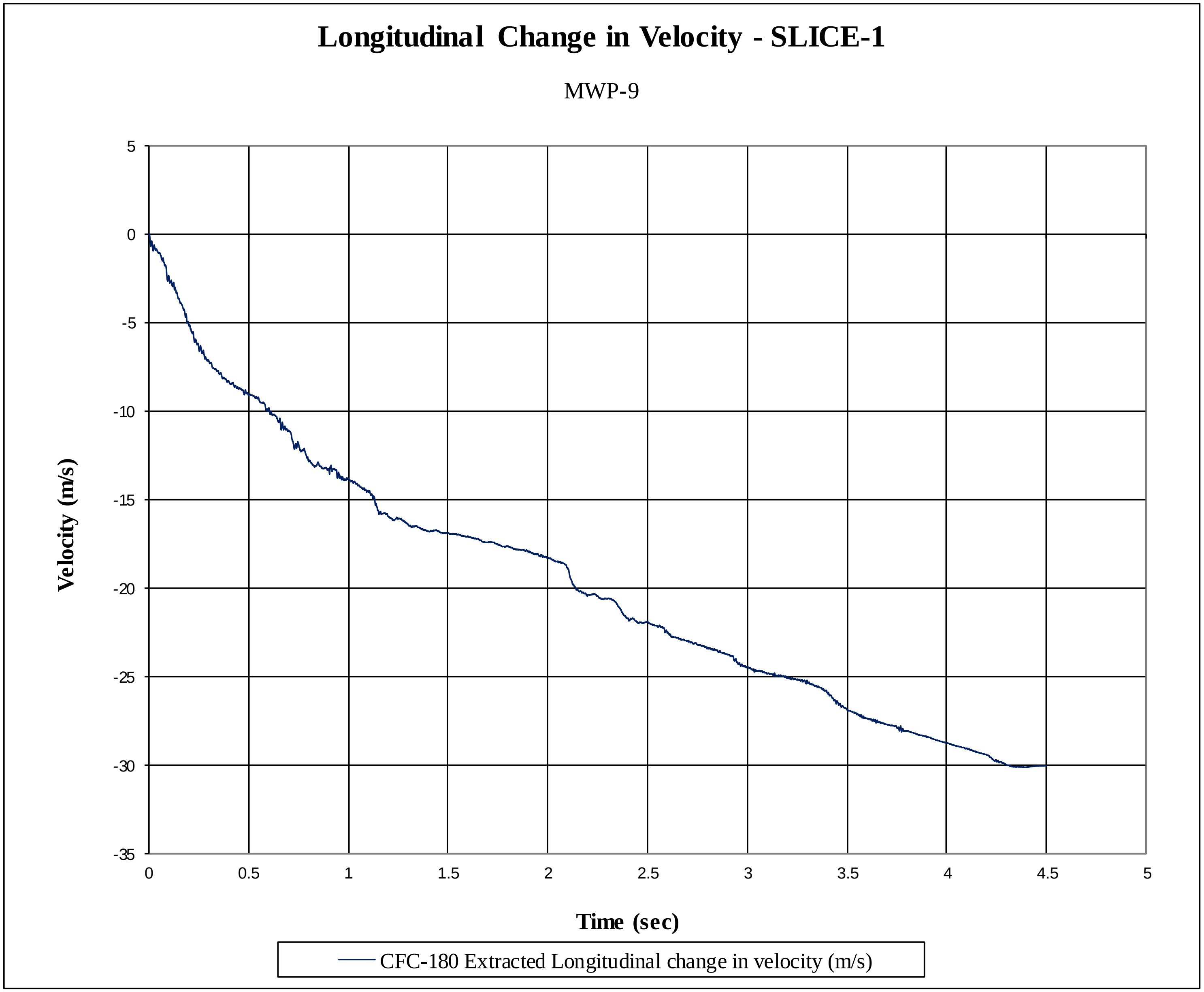



Figure E-2. Longitudinal Occupant Velocity (SLICE-1), Test No. MWP-9

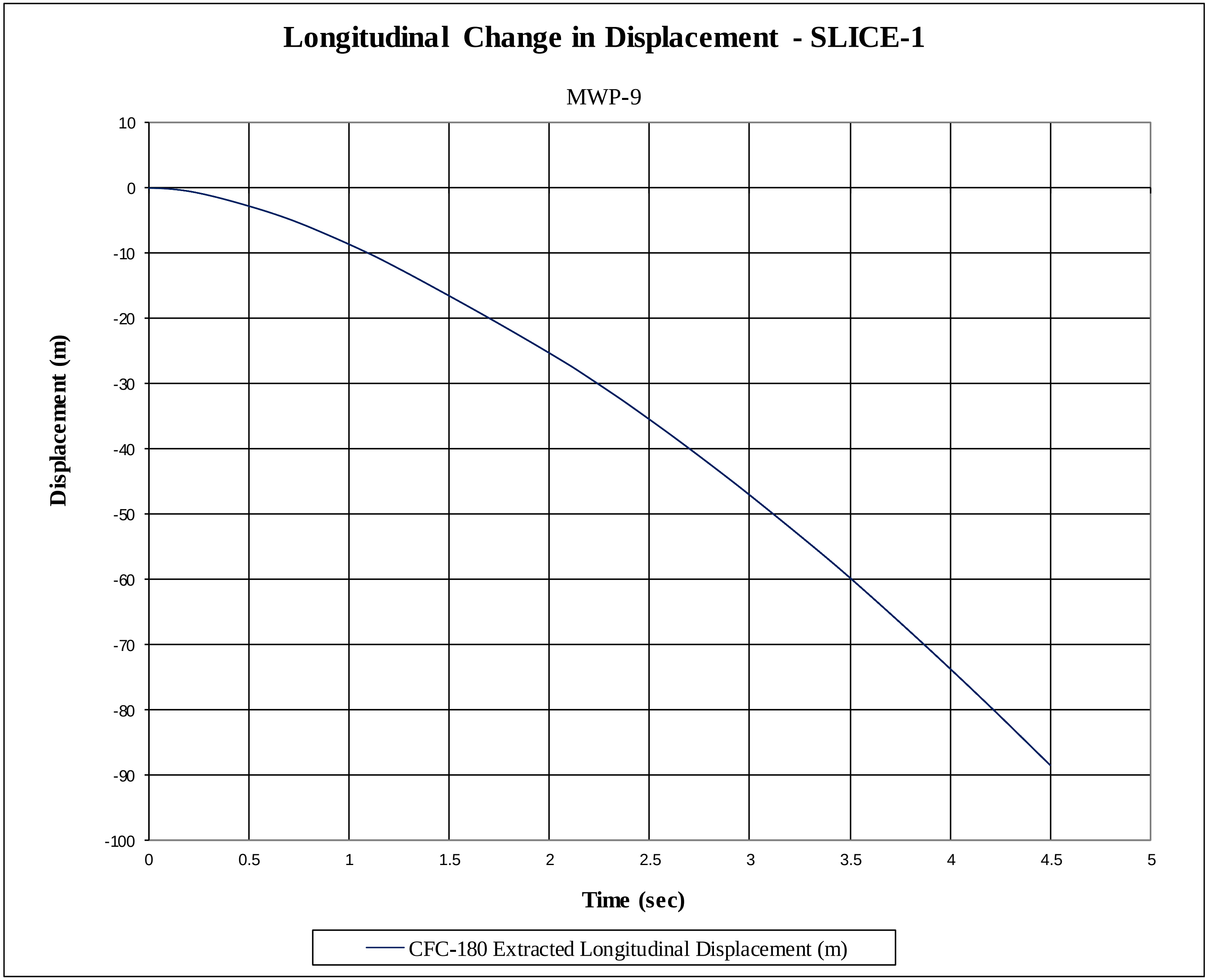



Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MWP-9

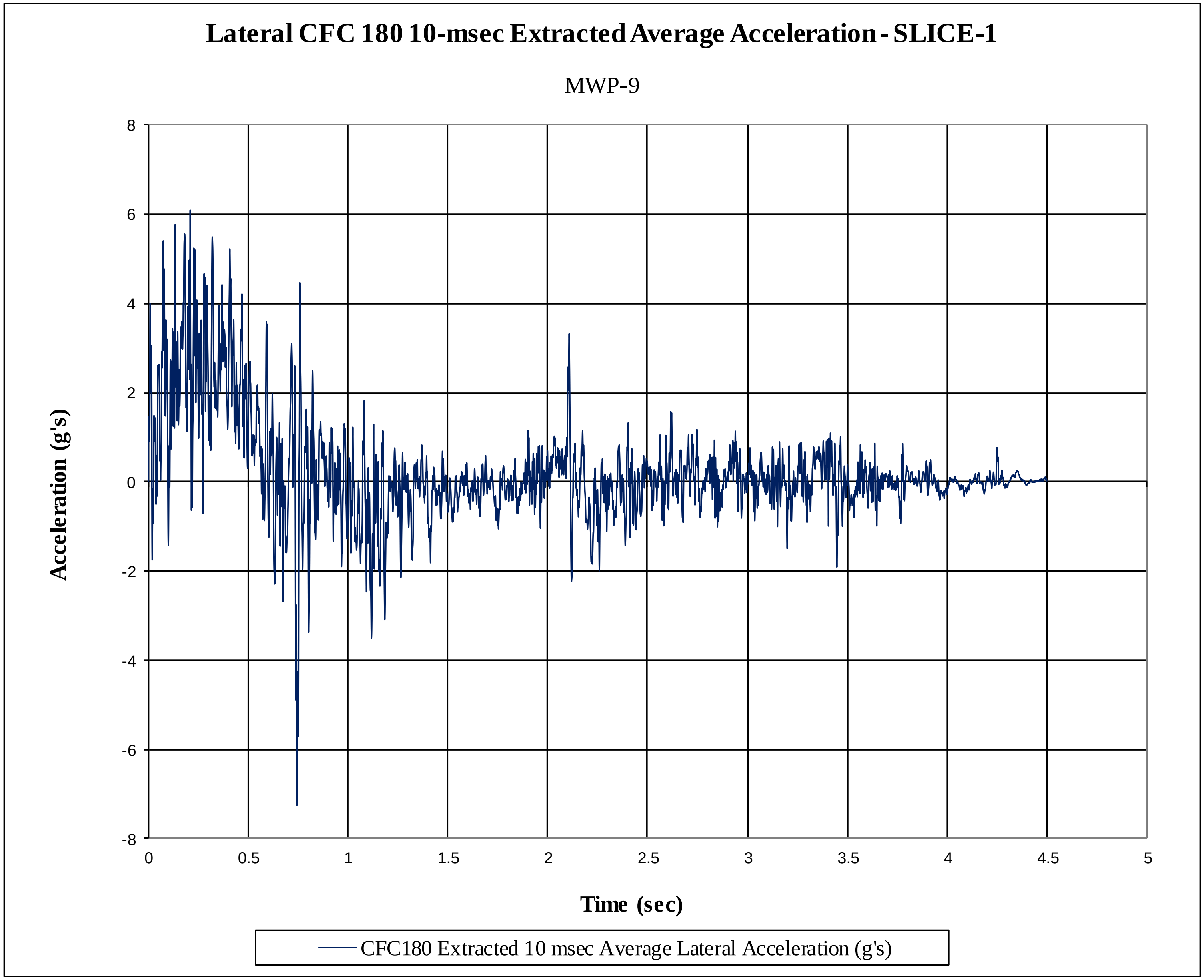



Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MWP-9

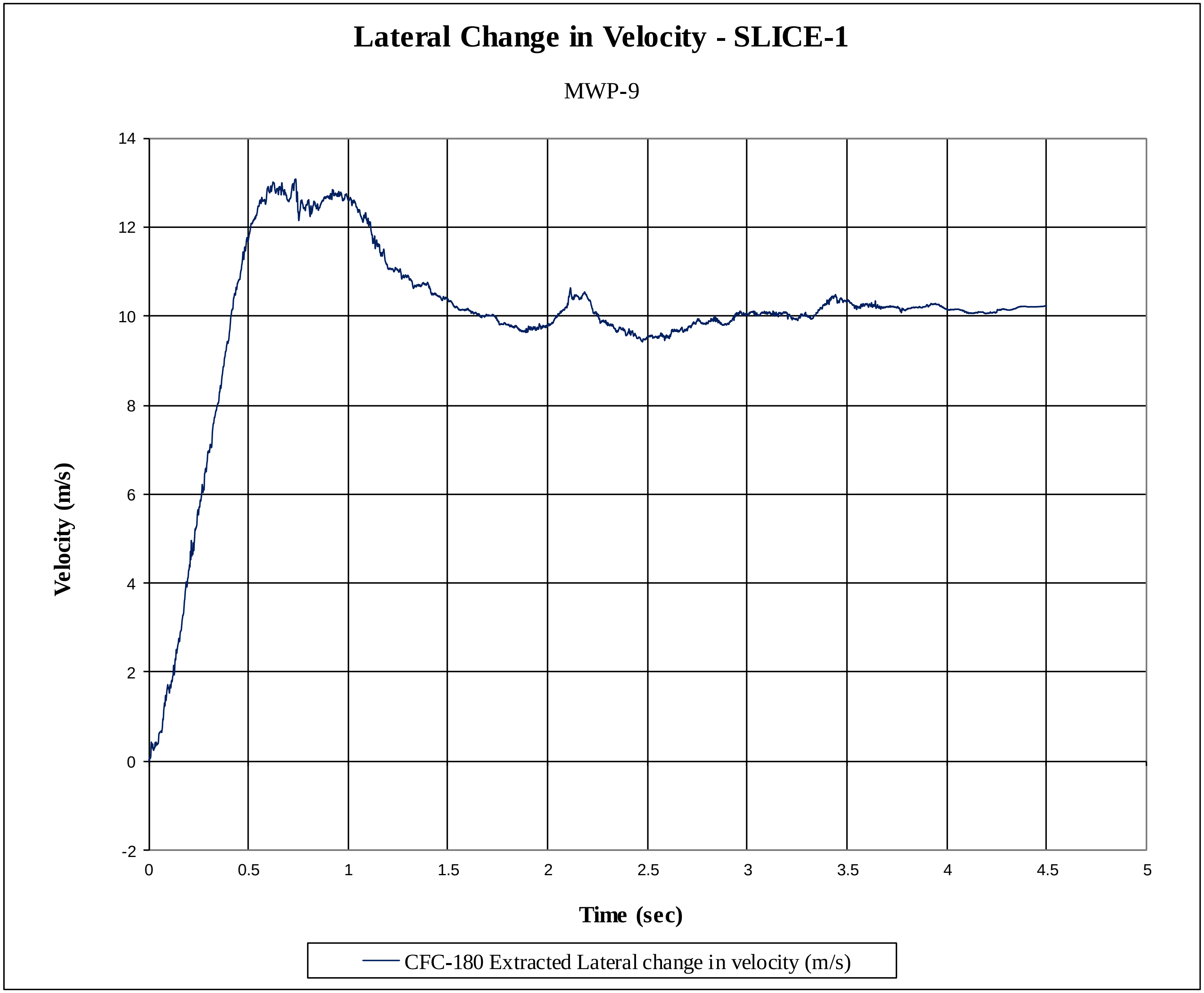



Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MWP-9

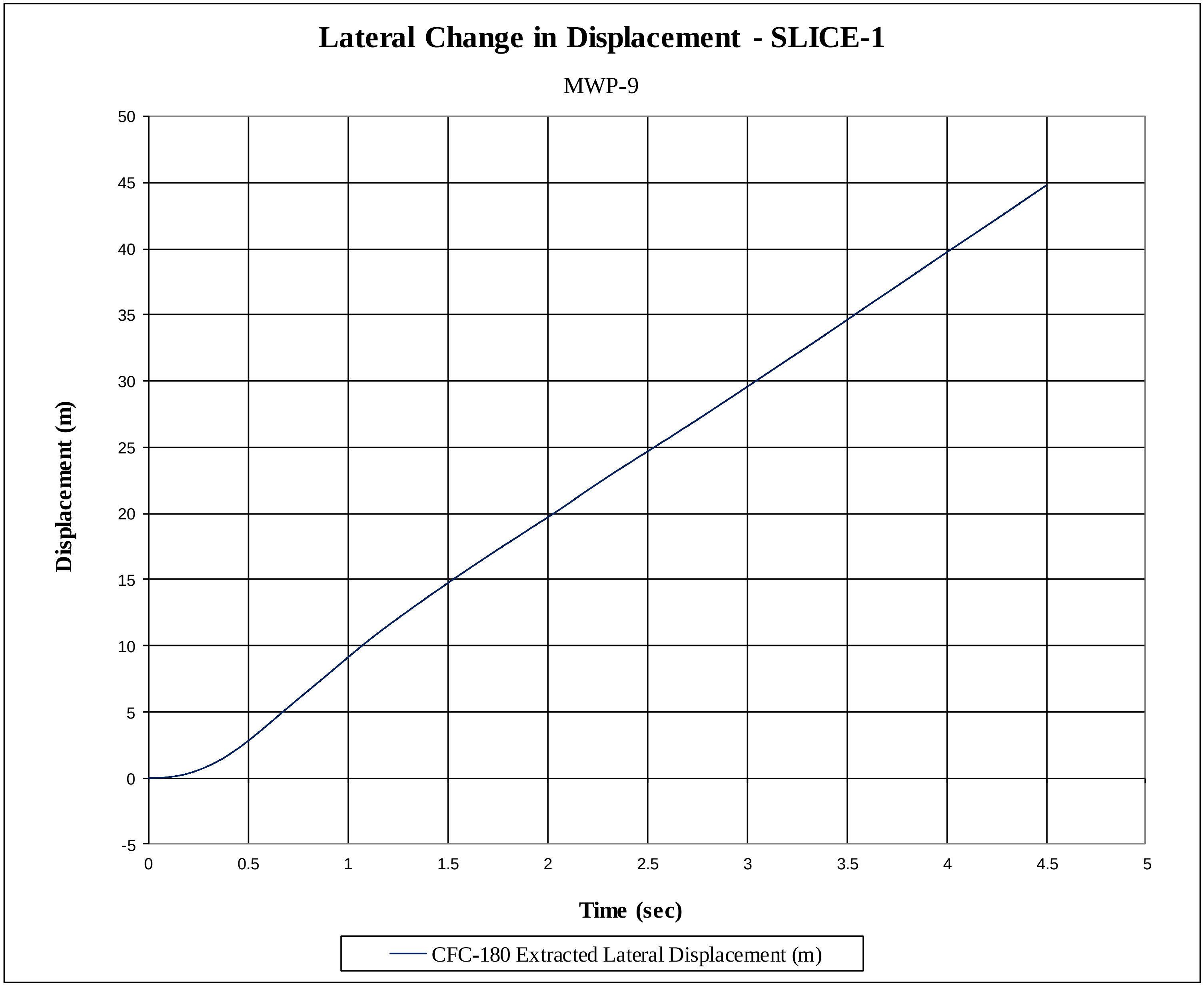



Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. MWP-9

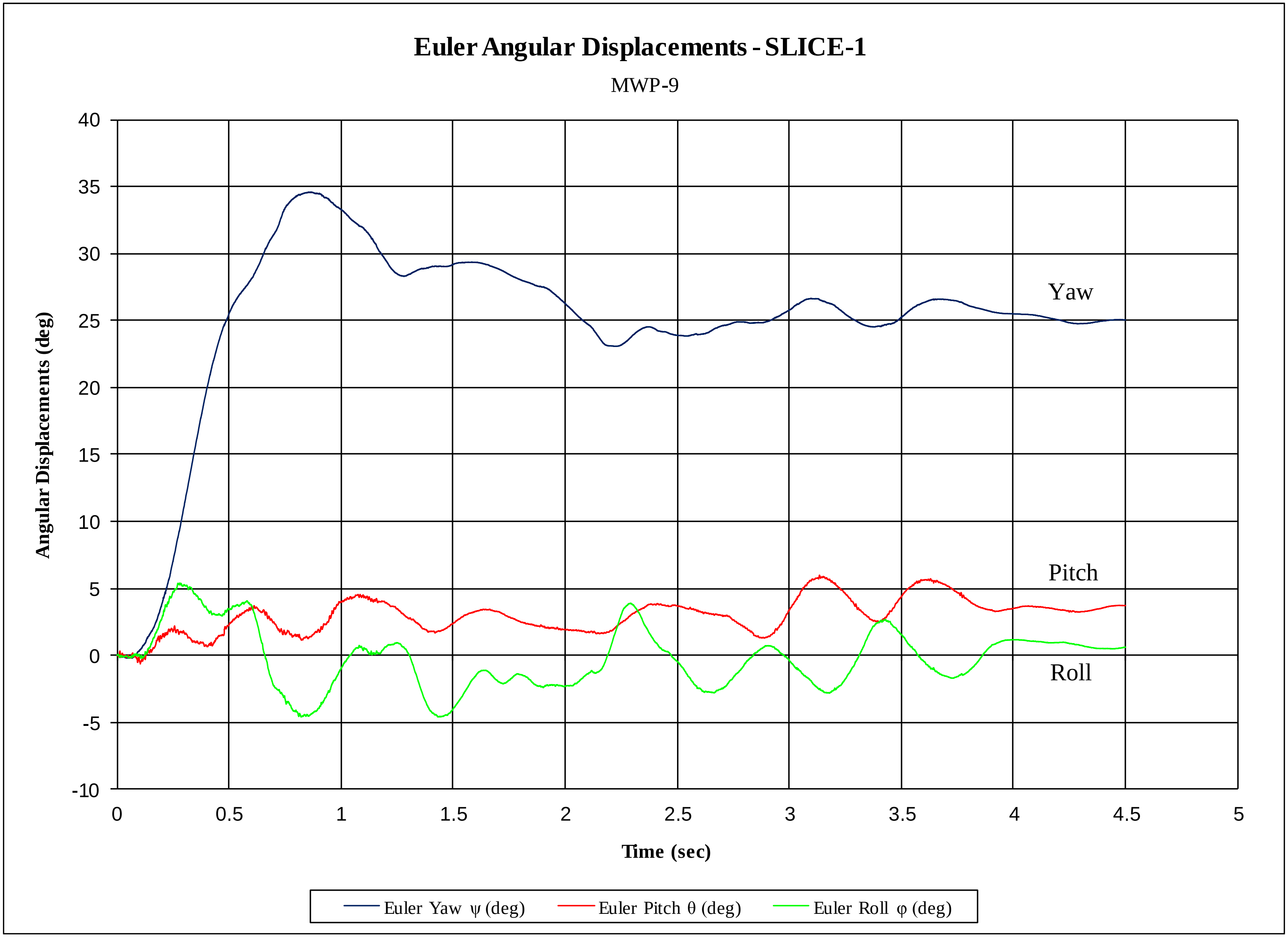



Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. MWP-9

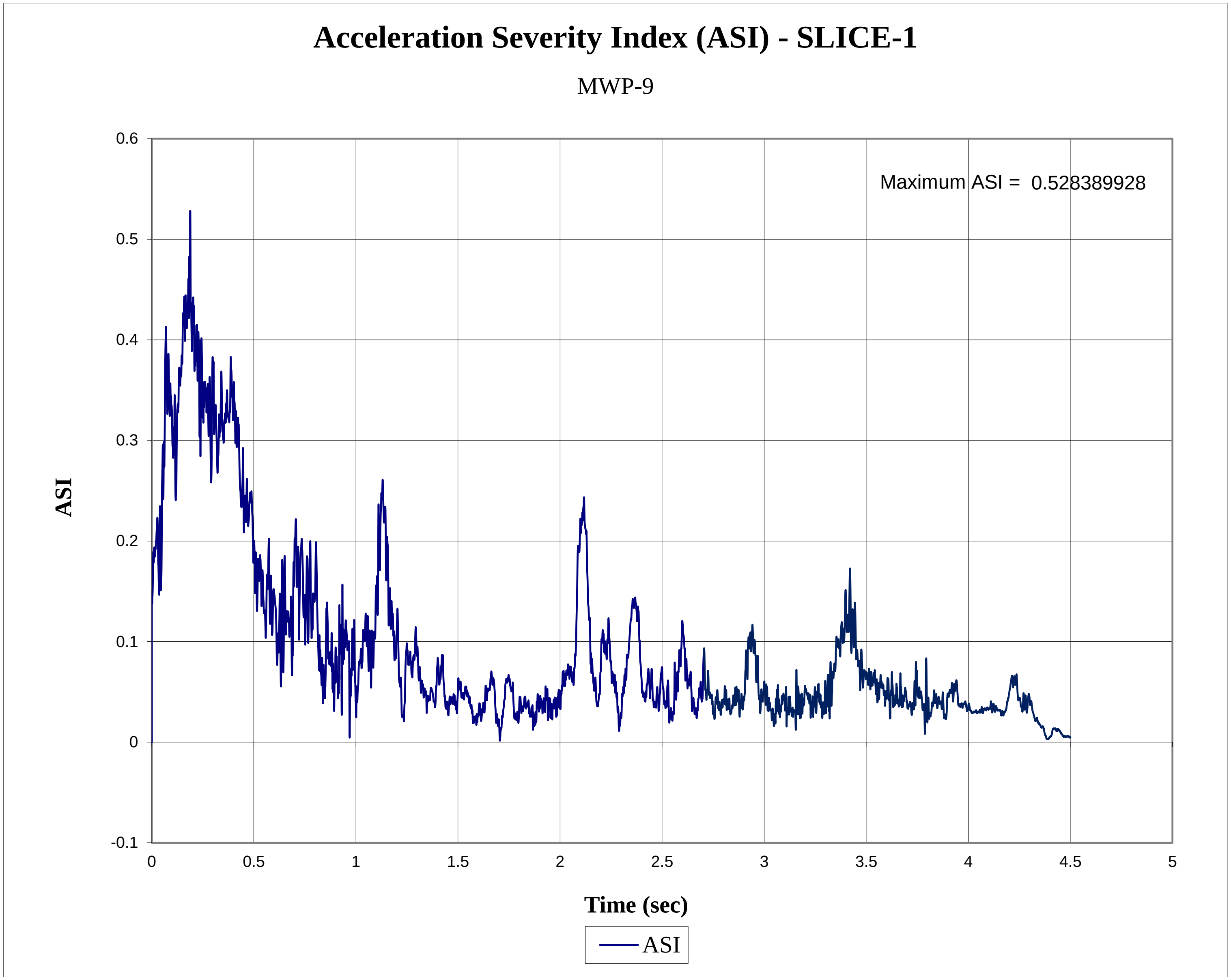



Figure E-8. Acceleration Severity Index (SLICE-1), Test No. MWP-9

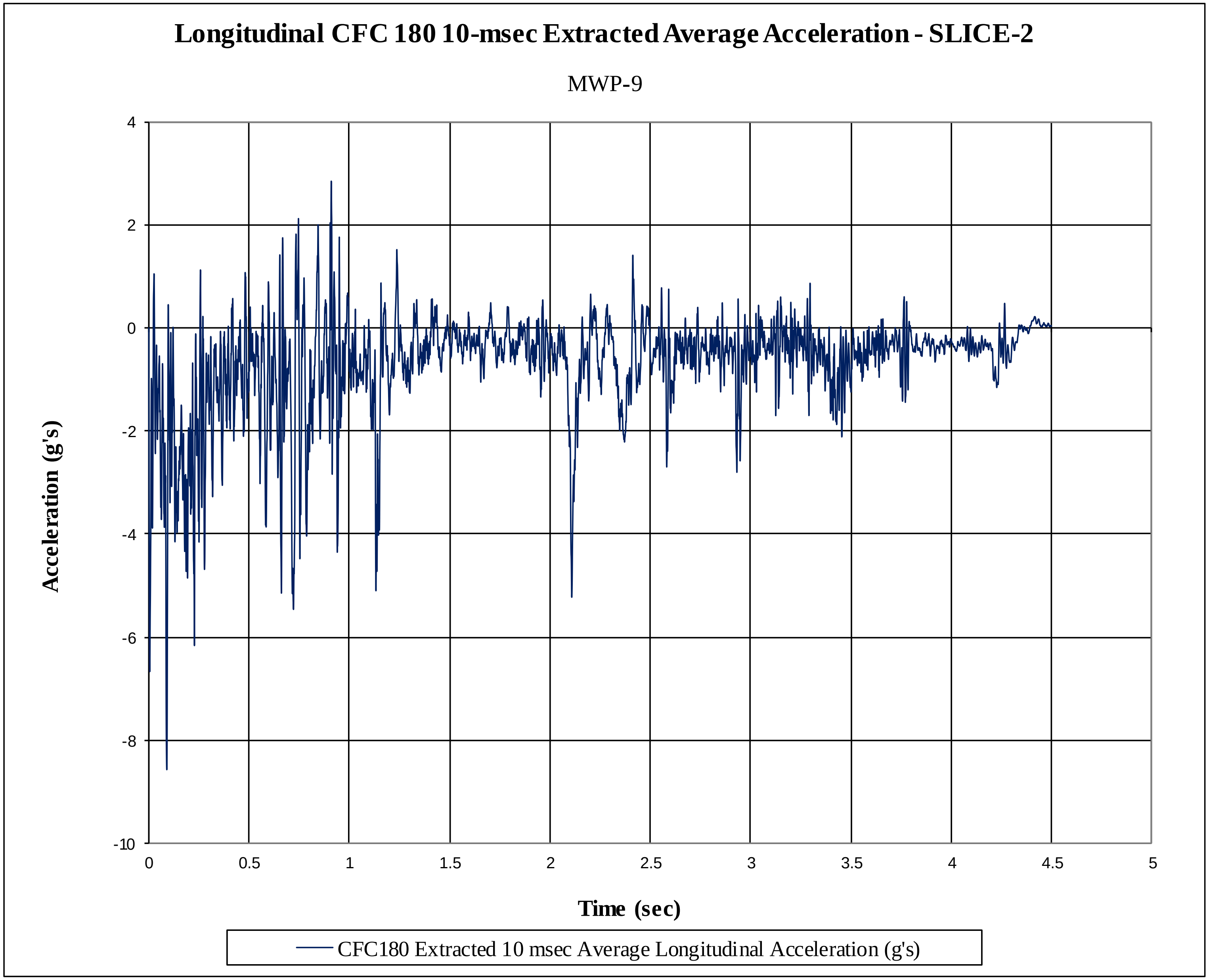



Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MWP-9

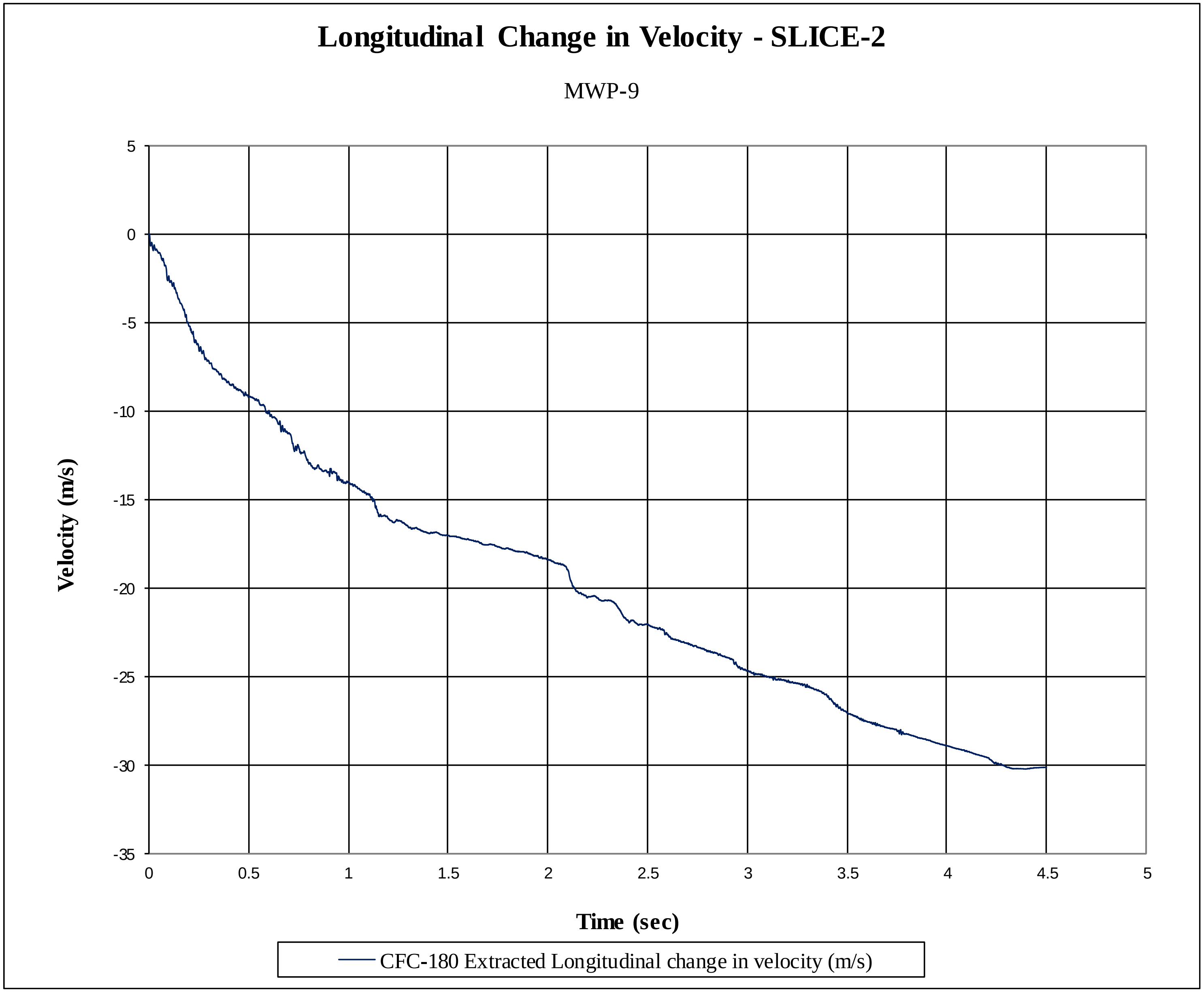



Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MWP-9

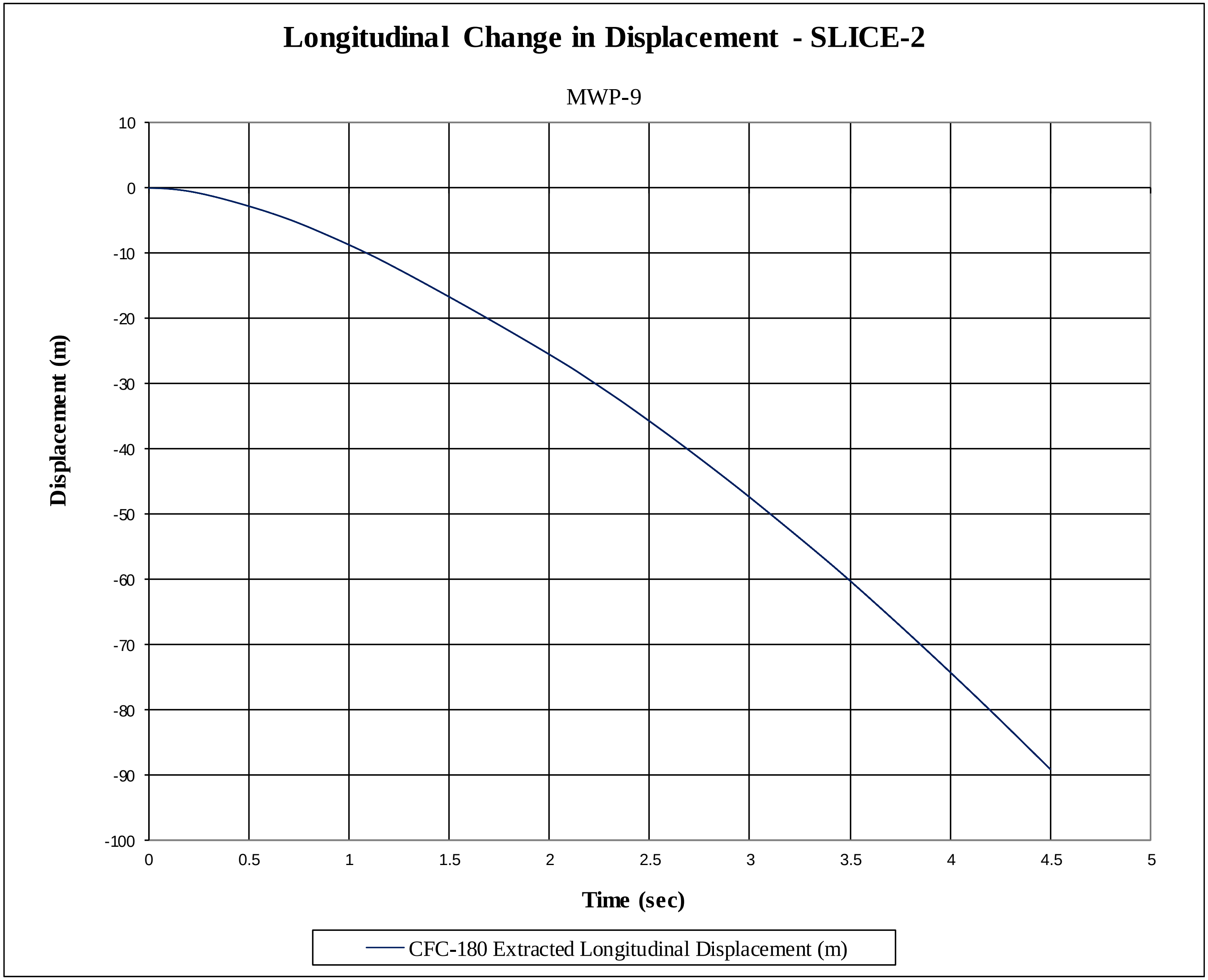



Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MWP-9

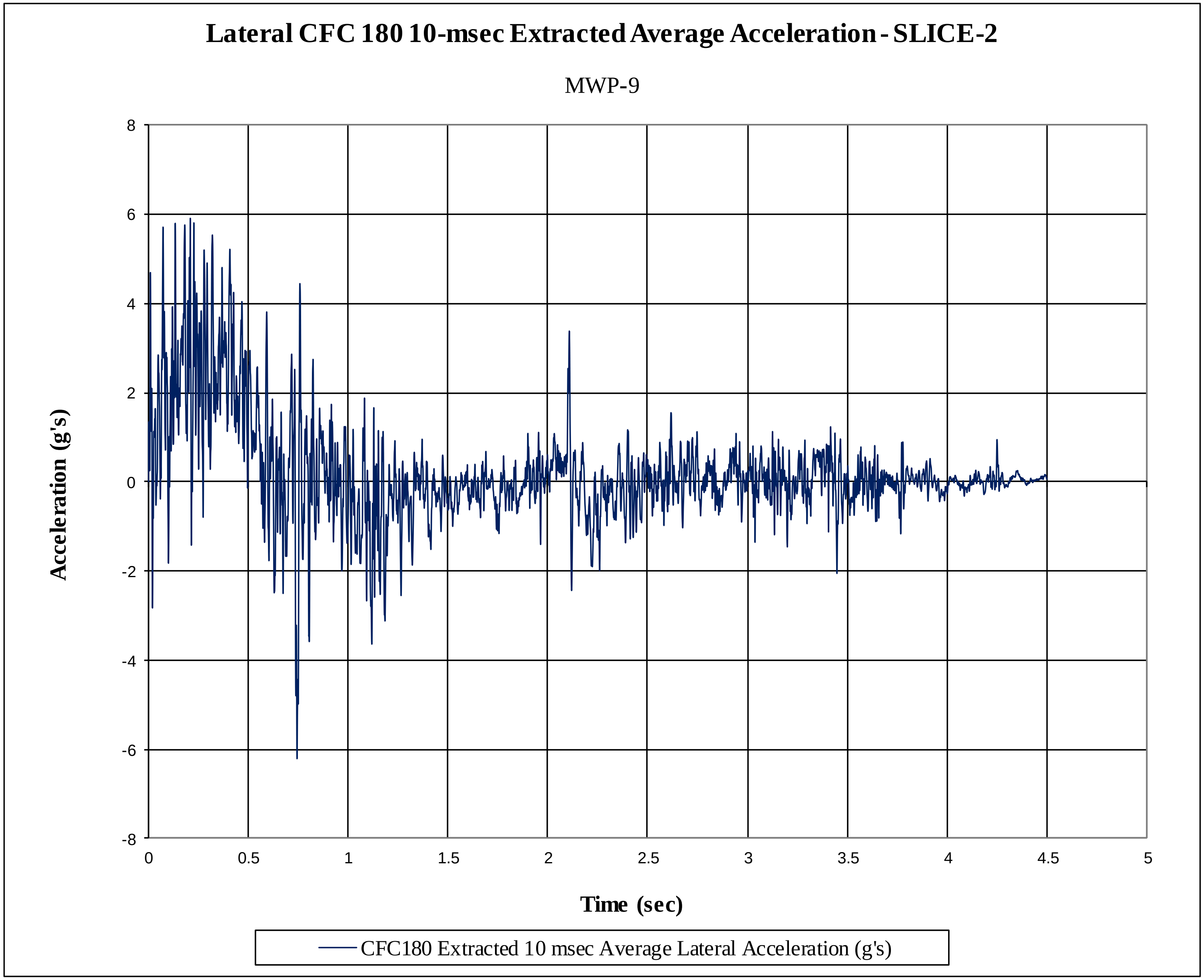



Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MWP-9

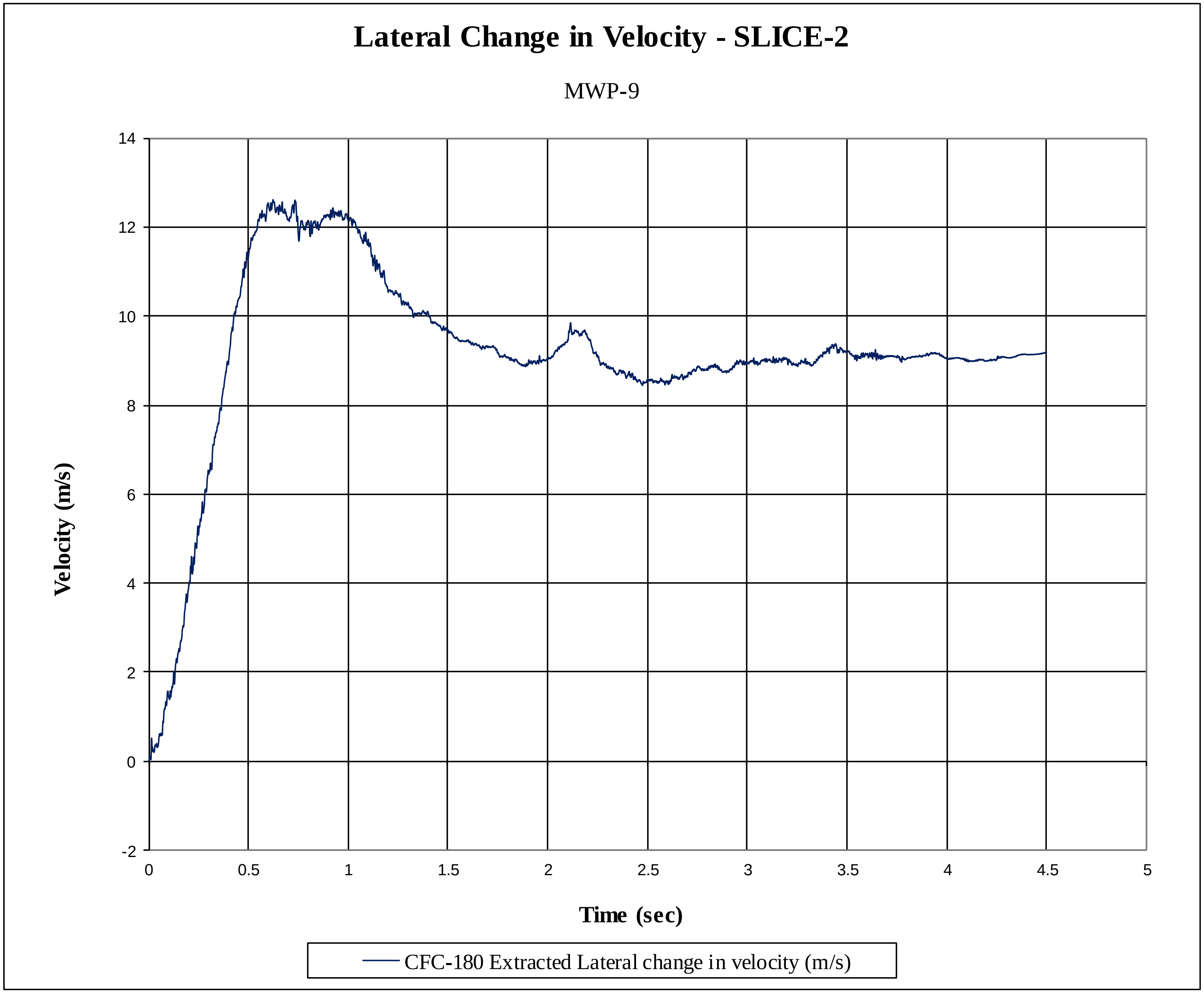



Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MWP-9

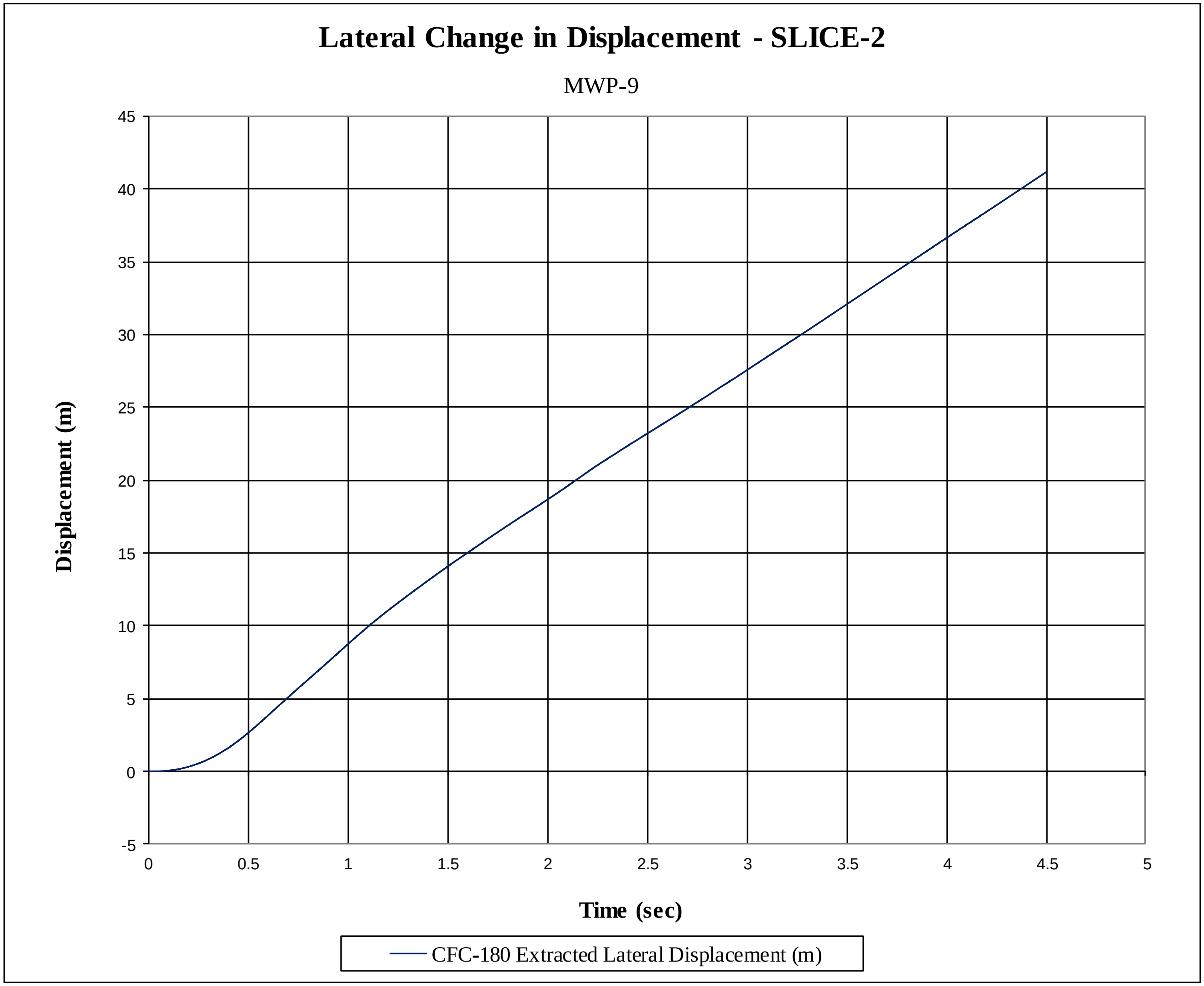



Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. MWP-9

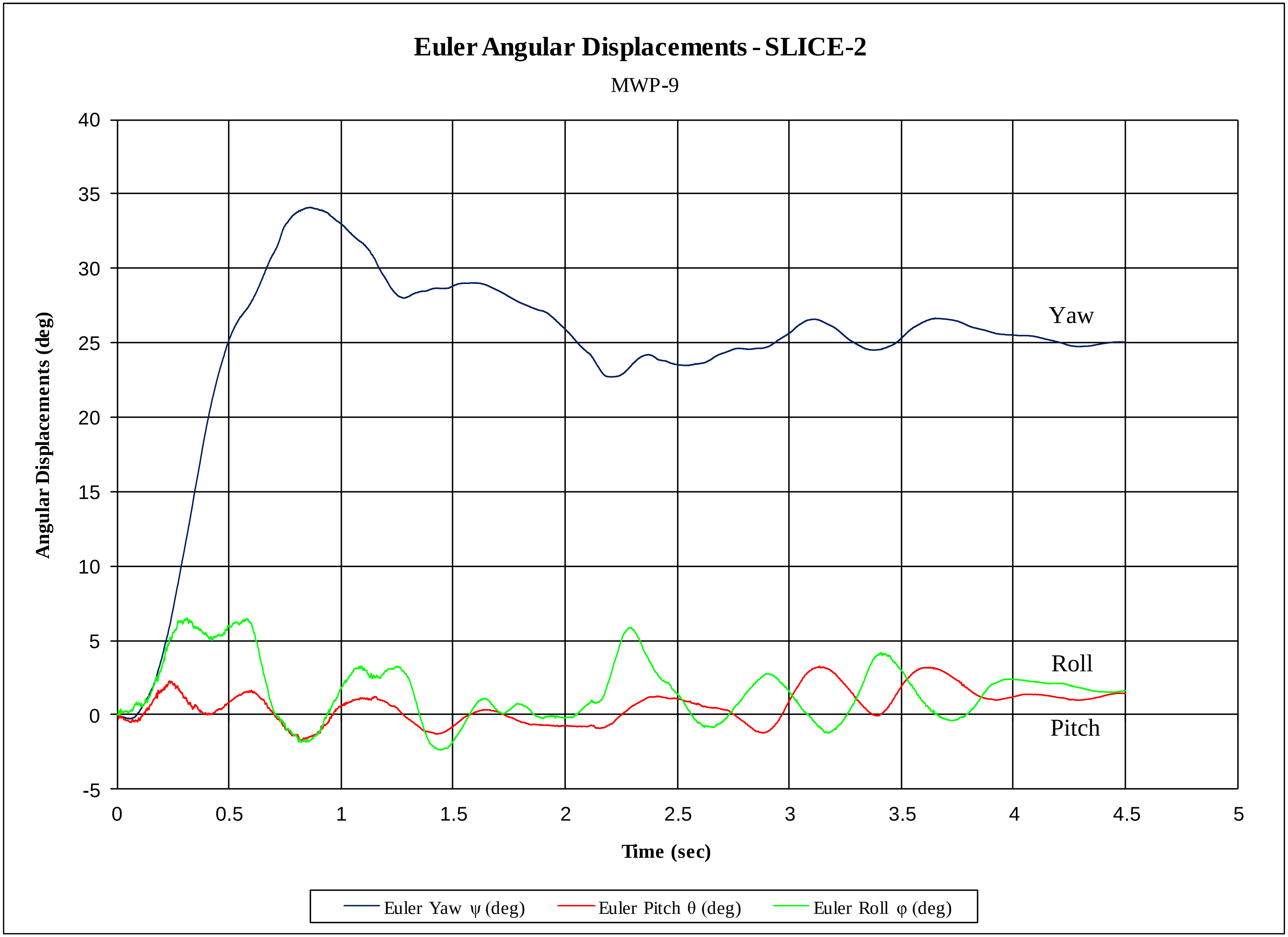



Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. MWP-9

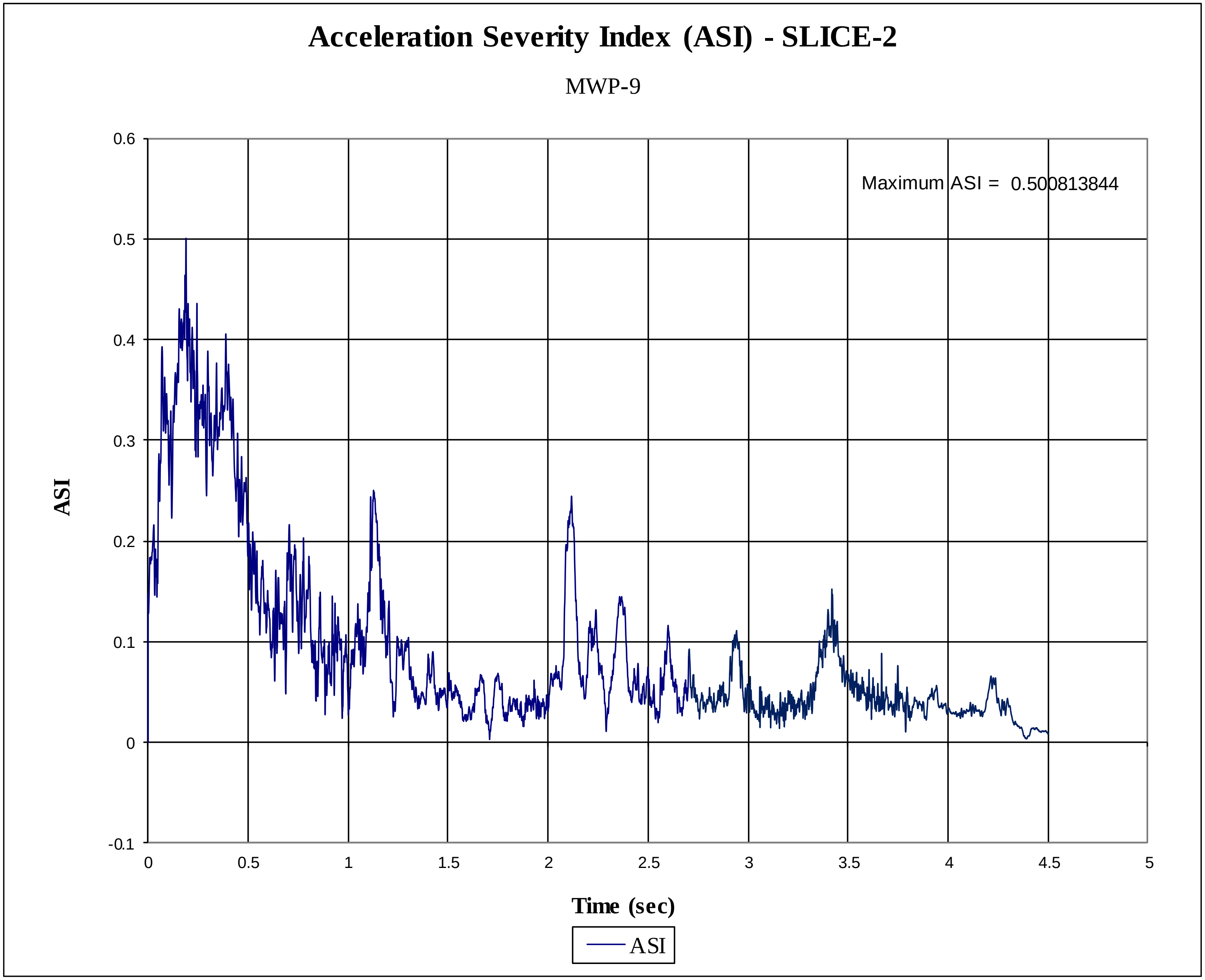



Figure E-16. Acceleration Severity Index (SLICE-2), Test No. MWP-9

# Appendix F. Load Cell and String Potentiometer Data

# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

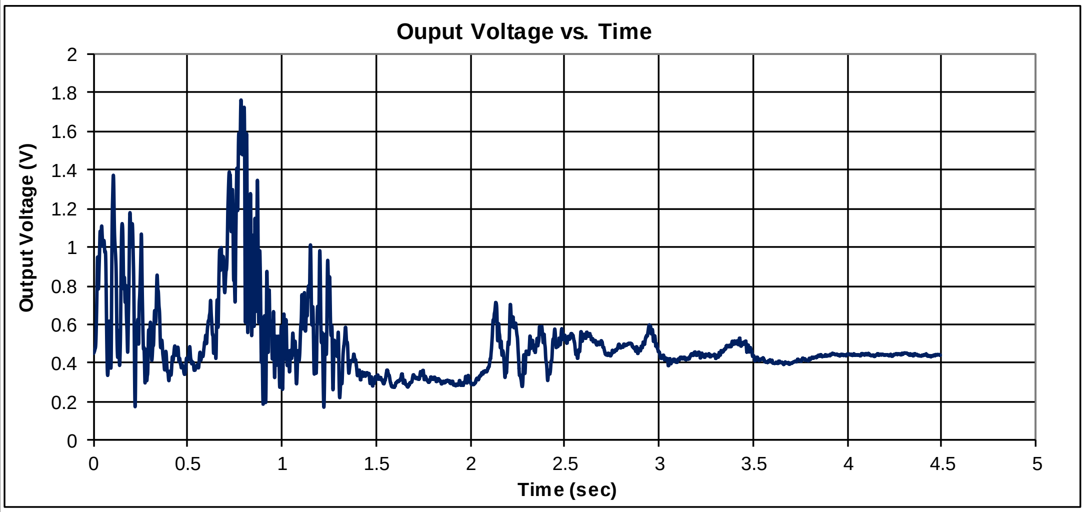
| | |
|---|---|
| Test No: | MWP-9 |
| Date: | 10/31/2016 |
| System / Test Article: | 4-Cable Median Barrier |
| LC Location / Component: | Bottom Cable-US of Impact |
| Additional Notes: | |

**Load Cell Information:**

| | |
|---|---|
| Load Cell No.: | 241593 |
| Calibration Factor: | 2.14857 mv/V |
| Input Voltage (excitation): | 10 Volts |
| Gain: | 400 |
| Full Scale Load: | 50 kips |
| Sample Rate: | 10000 Hz |
| Cutoff Frequency: | 100 Hz |

**Results:**

| | |
|---|---|
| Preload: | 2.62 kips |
| Max. Load: | 12.87 kips |
| Time of Max. Load: | 0.7823 sec |
| Event Duration: | 4.5 sec |
| Final Load: | 5.17 kips |



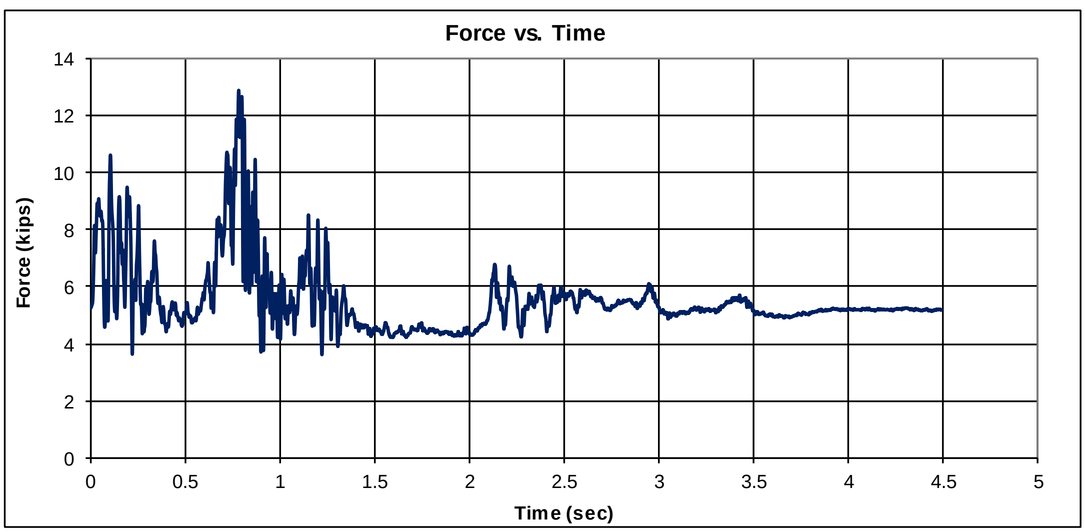




Figure F-1. Load Cell Data, Cable No. 1, Test No. MWP-9

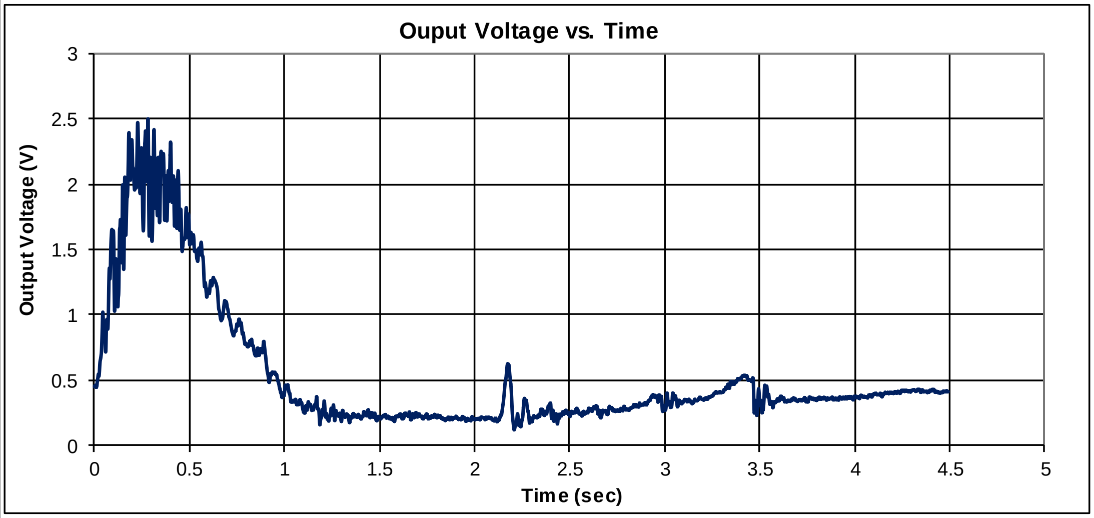
# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

Test No: MWP-9
Date: 10/31/2016
System / Test Article: 4-Cable Median Barrier
LC Location / Component: Bottom Middle Cable-US of Impact
Additional Notes:

| Load Cell Information: | | Results: | |
|---|---|---|---|
| Load Cell No.: | 143436 | Preload: | 2.62 kips |
| Calibration Factor: | 2.14575 mv/V | Max. Load: | 17.21 kips |
| Input Voltage (excitation): | 9.99 Volts | Time of Max. Load: | 0.2821 sec |
| Gain: | 400 | Event Duration: | 4.5 sec |
| Full Scale Load: | 50 kips | Final Load: | 5.03 kips |
| Sample Rate: | 10000 Hz | | |
| Cutoff Frequency: | 100 Hz | | |



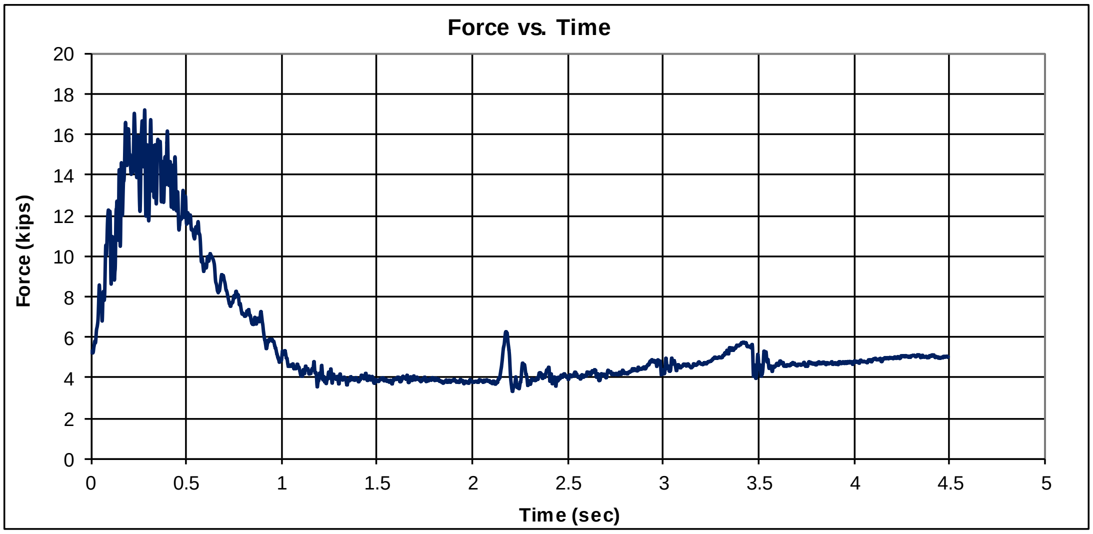




Figure F-2. Load Cell Data, Cable No. 2, Test No. MWP-9

# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

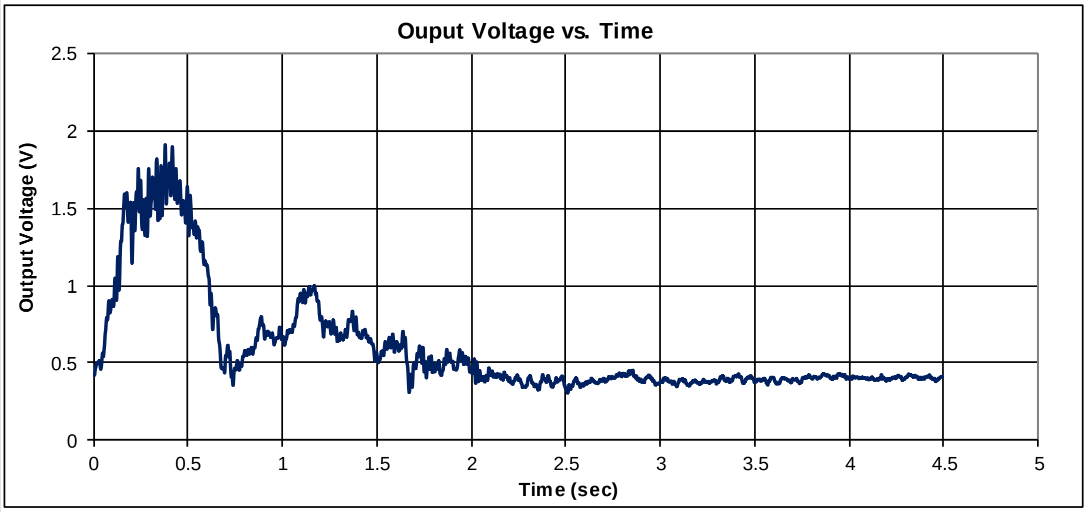
| | |
|---|---|
| Test No: | MWP-9 |
| Date: | 10/31/2015 |
| System / Test Article: | 4-Cable Median Barrier |
| LC Location / Component: | Top Middle Cable -US of Impact |
| Additional Notes: | |

**Load Cell Information:**

| | |
|---|---|
| Load Cell No.: | 120642 |
| Calibration Factor: | 2.11878 mv/V |
| Input Voltage (excitation): | 9.99 Volts |
| Gain: | 400 |
| Full Scale Load: | 50 kips |
| Sample Rate: | 10000 Hz |
| Cutoff Frequency: | 100 Hz |

**Results:**

| | |
|---|---|
| Preload: | 2.52 kips |
| Max. Load: | 13.80 kips |
| Time of Max. Load: | 0.3786 sec |
| Event Duration: | 4.5 sec |
| Final Load: | 4.97 kips |



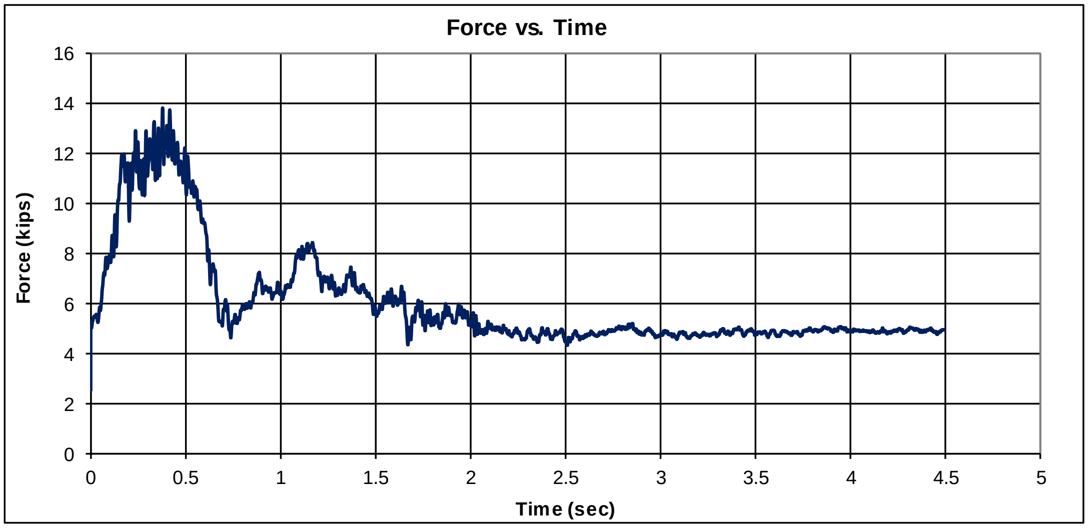




Figure F-3. Load Cell Data, Cable No. 3, Test No. MWP-9

# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

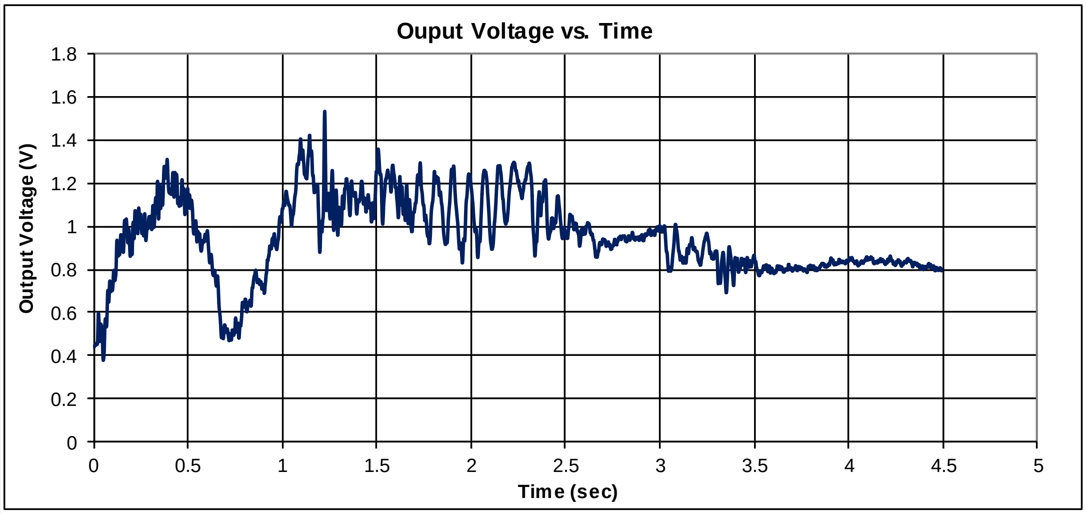
| | |
|---|---|
| Test No: | MWP-9 |
| Date: | 10/31/2016 |
| System / Test Article: | 4-Cable Median Barrier |
| LC Location / Component: | Top Cable - US of Impact |
| Additional Notes: | |

**Load Cell Information:**

| | |
|---|---|
| Load Cell No.: | 143435 |
| Calibration Factor: | 2.1539 mv/V |
| Input Voltage (excitation): | 9.96 Volts |
| Gain: | 400 |
| Full Scale Load: | 50 kips |
| Sample Rate: | 10000 Hz |
| Cutoff Frequency: | 100 Hz |

**Results:**

| | |
|---|---|
| Preload: | 2.59 kips |
| Max. Load: | 11.52 kips |
| Time of Max. Load: | 1.2249 sec |
| Event Duration: | 4.5 sec |
| Final Load: | 7.26 kips |



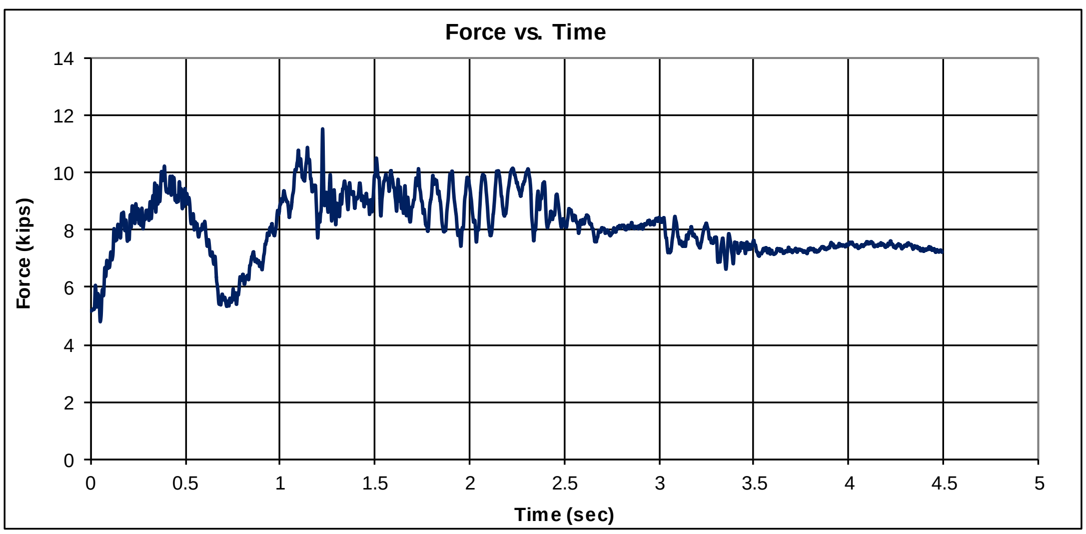




Figure F-4. Load Cell Data, Cable No. 4, Test No. MWP-9

# MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

**Test Information:**

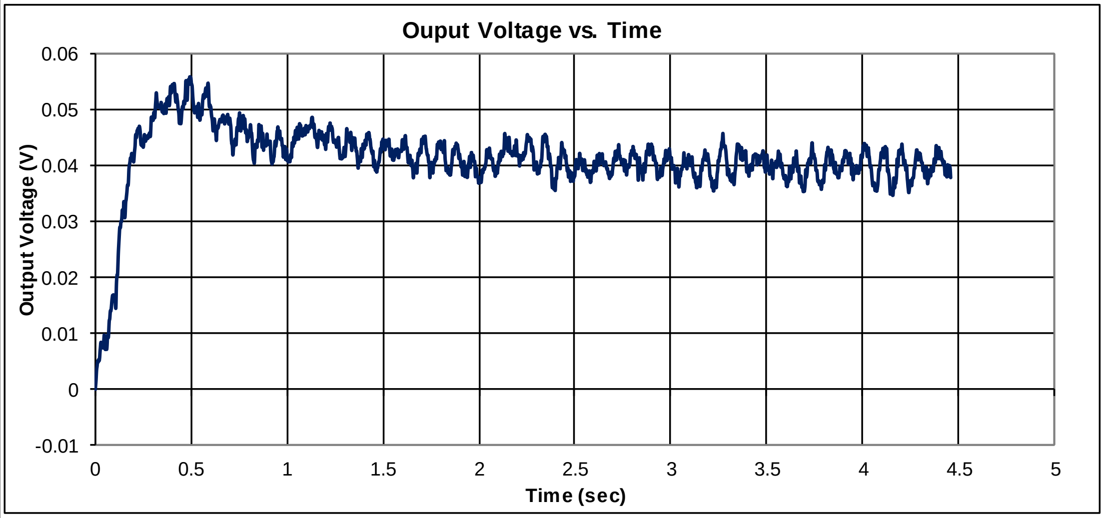
| | |
|---|---|
| Test No: | MWP-9 |
| Date: | 10/31/2016 |
| System / Test Article: | 4-Cable Median Barrier |
| SP Location / Component: | Upstream Anchor |
| Additional Notes: | |

**String Potentiometer Information:**

| | |
|---|---|
| String Pot No.: | 27039202 |
| Calibration Factor: | 19.4483 mV/V/in. |
| Input Voltage (excitation): | 9.99 Volts |
| Gain: | 1 |
| Full Scale Load: | 1 |
| Sample Rate: | 10000 Hz |
| Cutoff Frequency: | 100 Hz |

**Results:**

| | |
|---|---|
| Max. Displacement: | 0.29 in. |
| Time of Max. Displacement: | 0.4928 sec |
| Event Duration: | 4.4665 sec |
| Final Displacement: | 0.21 in. |



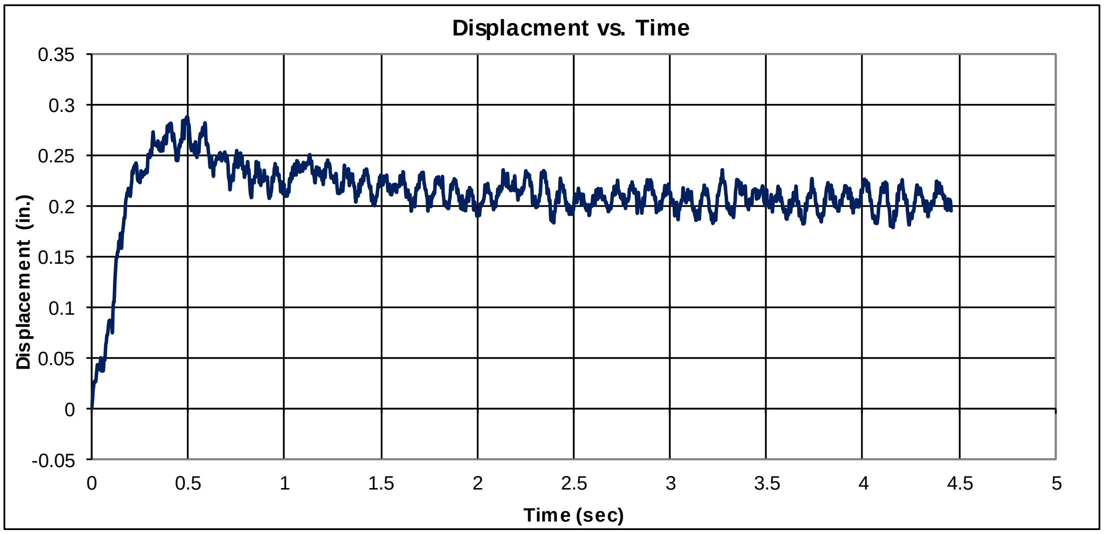




Figure F-5. String Potentiometer Data, Upstream Anchor, Test No. MWP-9

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