TESTING CERT # 2937.01

*Midwest States Pooled Fund Research Program*
*Fiscal Years 2014 (Years 24)*
*Research Project Number TPF-5(193) Supplement #64*
*NDOR Sponsoring Agency Code RPFP-14-CABLE-1*

# MASH TEST NOS. 3-11 AND 3-10 ON A NON-PROPRIETARY CABLE MEDIAN BARRIER

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**MIDWEST STATES POOLED FUND PROGRAM**
Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

MwRSF Research Report No. TRP-03-327-16

May 17, 2016

# TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
TRP-03-327-16

2.

3. Recipient's Accession No.

4. Title and Subtitle
MASH Test Nos. 3-11 and 3-10 on a Non-Proprietary Cable Median Barrier

5. Report Date
May 17, 2016

6.

7. Author(s)
Kohtz, J.E., Bielenberg, R.W., Rosenbaugh, S.K., Faller, R.K., Lechtenberg, K.A., and Reid, J.D.

8. Performing Organization Report No.
TRP-03-327-16

9. Performing Organization Name and Address
Midwest Roadside Safety Facility (MwRSF)
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10. Project/Task/Work Unit No.

11. Contract © or Grant (G) No.
TPF-5(193) Supplement #64

12. Sponsoring Organization Name and Address
Midwest States Pooled Fund Program
Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

13. Type of Report and Period Covered
Final Report: 2014 - 2016

14. Sponsoring Agency Code
RPFP–14-CABLE-1

15. Supplementary Notes
Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The Midwest States Pooled Fund has been developing a new non-proprietary cable median barrier. This system incorporates four evenly spaced cables, Midwest Weak Posts 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* (MASH) updated/proposed testing matrix for cable barriers installed within a 6H:1V or median ditch, a series of eight full-scale tests are required to evaluate the safety performance of a system. A ninth test is required to establish the working width for systems with variable post spacing.

Three full-scale crash tests were performed. Test no. MWP-4 was conducted according to MASH test no. 3-11 and utilized a 2270P pickup truck impacting the barrier on level terrain. The vehicle was contained by the barrier, and the test was deemed acceptable. Test no. MWP-6 was conducted according to MASH test no. 3-10 and utilized a 1100C passenger car impacting the barrier on level terrain. The vehicle was contained and redirected by the system. However, the system posts penetrated the occupant compartment through tearing and rupture of the vehicle floor board, and the test was deemed unacceptable. Test no. MWP-7 was also conducted with a 1100C vehicle according to MASH test no. 3-10. Alterations were made to the system posts. Although the vehicle was contained by the system, occupant compartment penetration by line posts was again observed. Test no. MWP-7 was deemed unacceptable.

17. Document Analysis/Descriptors
Highway Safety, Crash Test, MASH, Compliance Test, Longitudinal Barrier, Cable Barrier, Median Barrier, High-Tension, 6H:1V Median V-Ditch

18. Availability Statement
No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)
Unclassified

20. Security Class (this page)
Unclassified

21. No. of Pages
346

22. Price

## DISCLAIMER STATEMENT

This report was completed with funding from the Federal Highway Administration, U.S. Department of Transportation. 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 States 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. Cody Stolle, E.I.T.

# ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the Midwest States Pooled Fund Program funded by the Illinois Department of Transportation, Indiana Department of Transportation, Iowa Department of Transportation, Kansas Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Nebraska Department of Roads, New Jersey Department of Transportation, Ohio Department of Transportation, South Dakota Department of Transportation, Wisconsin Department of Transportation, and Wyoming Department of Transportation for sponsoring this project and (2) MwRSF personnel for constructing the barriers and conducting the crash tests.

Acknowledgement is also given to the following individuals who made a contribution to the completion of this research project.

**Midwest Roadside Safety Facility**

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# 1 INTRODUCTION

## 1.1 Background

In recent years, the Midwest States Pooled Fund 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 intervals ranging between 8 ft and 16 ft (2.4 m and 4.9 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 three full-scale crash tests in accordance with the *Manual for Assessing Safety Hardware* (MASH) [2]. Test no. MWP-1, in accordance with MASH test designation no. 3-17, was conducted with a 1500A vehicle impacting the system placed 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 underriden 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.

For test no. MWP-3, the post spacing was changed to 8 ft (2.4 m) to evaluate system deflections and working width with the 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.

Following a review of test no. MWP-3, several factors may have contributed to the loss of vehicle capture. First, it was proposed that capture of the vehicle with additional cables were required for vehicle redirection. In order to evaluate the cable median barrier in a worst-case impact scenario, the researchers tested the barrier system in test nos. MWP-2 and MWP-3 with the primary capture cable for the 2270P vehicle, cable no. 3, or the third cable above the ground, on the non-impact side of the system, which limited its effectiveness in assisting in vehicle capture and redirection. This effect was shown in test no. MWP-2 when cable no. 3 was immediately knocked down as the vehicle bumper impacted the first post downstream from impact prior to cable engagement, which prevented the cable from interlocking with the vehicle.

In test no. MWP-3, the vehicle impacted the system slightly downstream from the target impact point, which allowed the vehicle to interlock with cable no. 3 prior to it being pushed down by a post. However, cable no. 3 eventually disengaged away from the vehicle, and vehicle capture was compromised. Thus, it was believed that cable no. 4, the top cable in the system, needs to contribute to interlock with the vehicle. In test no. MWP-2, cable no. 4 interlocked with the vehicle and aided in capture and redirection, but cable no. 4 overrode the vehicle in test no. MWP-3. Thus, it was believed that the height of cable no. 4 needed to be reduced to ensure vehicle interlock for level terrain test no. 3-11. Previous research at MwRSF regarding vehicle trajectories for 4:1 and 6:1 slopes [3] indicated that the top cable could be lowered to 38 in. (965 mm) and still be effective in capturing the 2270P vehicle at its maximum height above the slope in test designation no. 3-11. Thus, the top cable height was reduced from 40 in. (1016 mm) to 38 in. (965 mm) in order to improve vehicle capture.

Similarly, the cable spacing was reduced from 8¾ in. (222 mm) to 7½ in. (191 mm) in order to improve vehicle capture and interlock. More closely-spaced cables tend to improve the potential for multiple cables to interlock with the critical capture area of the vehicle and reduce the potential for penetration between the cables. A reduction of the cable spacing raised the height of the bottom cable to 15½ in. (394 mm). While the bottom cable height increased 2 in. (51 mm) over its original 13½ in. (343 mm) height, a review of simulated vehicle trajectories in 6:1 V-ditches indicated that the height of the bottom cable would still be sufficient for vehicle capture and preventing barrier underride.

Finally, the post spacing for the system was increased from 8 ft (2.4 m) to 10 ft (3.0 m). From a review of results from test no. MWP-3, it was believed that the reduced post spacing may have negatively affected cable motions after being interlocked with the vehicle, thus potentially contributing to the cables being pulled down and the loss of vehicle capture. Thus, it was decided to widen the post spacing slightly to 10 ft (3.0 m) in order to improve vehicle capture while continuing to manage barrier deflections.

After these modifications were made to improve system performance, full-scale crash testing was needed to evaluate the crashworthiness of the system. Therefore, the redesigned non-proprietary, four-cable, median barrier system required further testing according to the MASH Test Level 3 (TL-3) criteria [2].

## 1.2 Research Objectives

The primary objective of this project was to develop a high-tension, four-cable, median barrier that satisfies MASH TL-3 criteria when placed anywhere within a 6H:1V median V-ditch. Specific to this report, the cable system needed to be evaluated according to MASH test designation nos. 3-11 and 3-10.

## 1.3 Research Scope

The non-proprietary, four-cable, median barrier was subjected to three full-scale crash tests that are documented herein. The first test was a MASH test designation no. 3-11 test conducted with a 5,000-lb (2,268-kg) pickup truck impacting at a speed of 62 mph (100 km/h) and an angle of 25 degrees. The test was performed with a 10-ft (3.0-m) post spacing to establish the barrier’s working width in a reduced post spacing configuration, as compared to the 16-ft (4.9-m) post spacing previously evaluated in test no. MWP-2. The second and third tests were MASH test designation no. 3-10 tests conducted with 2,425-lb (1,100-kg) passenger cars impacting at a speed of 62 mph (100 km/h) and an angle of 25 degrees. The tests were performed with 8-ft (2.4-m) post spacing. Minor alterations were made to posts in the impact region between the two small car tests to try to reduce the propensity for occupant compartment penetration. The results from all three tests were analyzed, evaluated, and documented. Conclusions and recommendations were then made pertaining to the safety performance of the cable barrier system.

# 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 [2]. According to the proposed MASH testing matrix for cable barriers placed anywhere within median V-ditches, the barrier system must be subjected to eight full-scale vehicle crash tests. However, for systems with variable post spacings, test designation no. 3-11 must be conducted with both the narrowest and widest post spacings to establish the working width bounds of the barrier system, increasing the required number of crash tests from eight to nine. 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 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. Note, MASH specifies that barrier systems designed for 6H:1V V-ditches are to be tested within a 30-ft (9.1-m) wide, 6H:1V V-ditch.

Many cable barrier systems have variable post spacings, which allow 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. The proposed MASH update has identified the critical post spacing, either the narrowest or the widest spacing, for each individual test within the testing matrix. Proposed MASH test designation no. 3-11 must be conducted with both the narrowest and the widest post spacings to establish the working width bounds of the barrier system.

In accordance with MASH requirements, the critical impact point for the 2270P vehicle was 12 in. (305 mm) upstream of a post to maximize the risk that cables remain engaged with the post are pushed downward below the vehicle.. 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 2270P vehicle was determined to be the third cable above the ground. Selecting this orientation allowed for the greatest risk of failure due to the post pushing the backside cables down and preventing vehicle capture. This behavior would then potentially allow the vehicle to override the barrier. 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 TL-3 Test Matrix for Barrier Placement Anywhere Within a 6V:1H 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. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in MASH.

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.

Table 2. MASH Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td>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="4">Occupant Risk</td><td>D.</td><td>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 5.3 and Appendix E of MASH.</td></tr>
<tr><td>F.</td><td>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>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table>
<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>
</table></td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table>
<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></td></tr>
</table>

## 2.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, additional W6x16 in. (W152x23.8 mm) posts are to be installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, a dynamic impact test must be 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). If dynamic testing near the system is not desired, MASH 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% 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.

# 3 TEST CONDITIONS

## 3.1 Test Facility

The testing facility 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 city campus of the University of Nebraska-Lincoln.

## 3.2 Vehicle Tow and Guide 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 away 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 [4] was used to steer the test vehicle. A guide flag, attached to the left-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.

## 3.3 Test Vehicles

For test no. MWP-4, a 2008 Dodge Ram was used as the test vehicle. This vehicle meets the requirements for a MASH 2270P pickup truck. The curb, test inertial and gross static vehicle weights were 5,140 lb (2,331 kg), 4,967 lb (2,253 kg), and 5,131 lb (2,327 kg), respectively. The test vehicle is shown in Figure 1, and vehicle dimensions are shown in Figure 2.

For test no. MWP-6, a 2009 Kia Rio was used as the test vehicle. This vehicle meets the requirements for a MASH 1100C passenger car. The curb, test inertial and gross static vehicle weights were 2,295 lb (1,041 kg), 2,405 lb (1,091), and 2,572 lb (1,167 kg), respectively. The test vehicle is shown in Figure 3, and the vehicle dimensions are shown in Figure 4.

For test no. MWP-7, a 2009 Kia Rio was used as the test vehicle. This vehicle meets the requirements for a MASH 1100C passenger car. The curb, test inertial and gross static vehicle weights were 2,384 lb (1,081 kg), 2,392 lb (1,085), and 2,557 lb (1,160 kg), respectively. The test vehicle is shown in Figure 5, and the vehicle dimensions are shown in Figure 6.

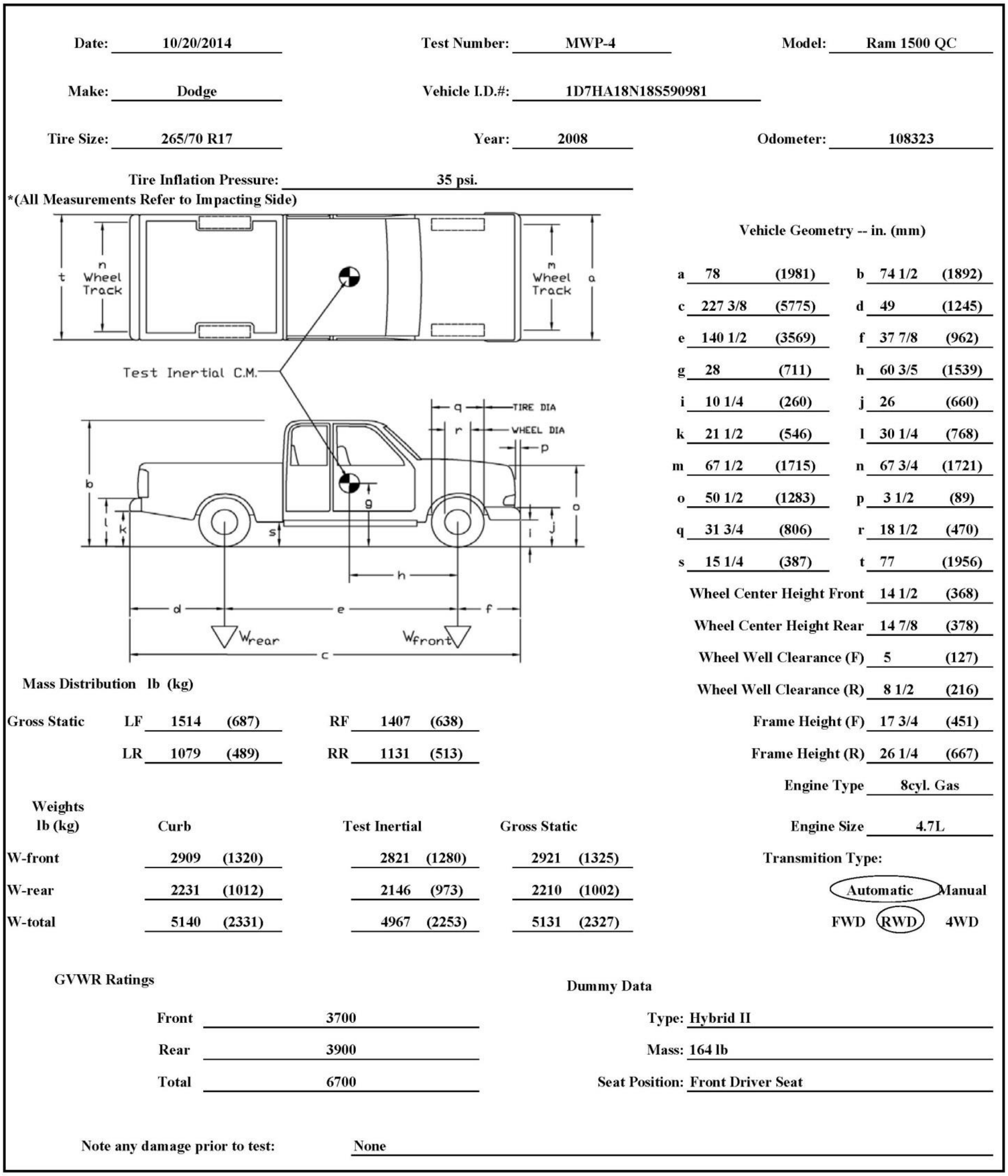
The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The vertical component of the c.g. for the 1100C vehicles was determined utilizing a procedure published by SAE [5]. The Suspension Method [6] was used to determine the vertical component of the c.g. for the 2270P vehicle. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The locations of the c.g. for test nos. MWP-4, MWP-6, and MWP-7 are shown in Figures 2, 4, and 6, respectively. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black-and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in video analysis, as shown in Figures 7 through 9. Round, checkered targets were placed on the center of gravity on the left-side door, the right-side door, and the roof of the vehicles.

The front wheels of the test vehicles were aligned to vehicle standards except the toe-in values were adjusted to zero so that the vehicles would track properly along the guide cable. A

5B flash bulb was mounted on the left side of the vehicles' dash 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 videos. A remote-controlled brake system was installed in the test vehicles so that the vehicles could be brought safely to a stop after the vehicle exited the system.

Figure 1. Test Vehicle, Test No. MWP-4



**Date:** 10/20/2014
**Test Number:** MWP-4
**Model:** Ram 1500 QC

**Make:** Dodge
**Vehicle I.D.#:** 1D7HA18N18S590981

**Tire Size:** 265/70 R17
**Year:** 2008
**Odometer:** 108323

**Tire Inflation Pressure:** 35 psi.

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

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

| | | | | | |
|---|---|---|---|---|---|
| a | 78 | (1981) | b | 74 1/2 | (1892) |
| c | 227 3/8 | (5775) | d | 49 | (1245) |
| e | 140 1/2 | (3569) | f | 37 7/8 | (962) |
| g | 28 | (711) | h | 60 3/5 | (1539) |
| i | 10 1/4 | (260) | j | 26 | (660) |
| k | 21 1/2 | (546) | l | 30 1/4 | (768) |
| m | 67 1/2 | (1715) | n | 67 3/4 | (1721) |
| o | 50 1/2 | (1283) | p | 3 1/2 | (89) |
| q | 31 3/4 | (806) | r | 18 1/2 | (470) |
| s | 15 1/4 | (387) | t | 77 | (1956) |

| | | |
|---|---|---|
| Wheel Center Height Front | 14 1/2 | (368) |
| Wheel Center Height Rear | 14 7/8 | (378) |
| Wheel Well Clearance (F) | 5 | (127) |
| Wheel Well Clearance (R) | 8 1/2 | (216) |
| Frame Height (F) | 17 3/4 | (451) |
| Frame Height (R) | 26 1/4 | (667) |
| Engine Type | 8cyl. Gas | |
| Engine Size | 4.7L | |

**Transmition Type:**
[✓ Automatic] Manual
FWD [✓ RWD] 4WD

**Mass Distribution lb (kg)**

| | | | | | | |
|---|---|---|---|---|---|---|
| Gross Static | LF | 1514 | (687) | RF | 1407 | (638) |
| | LR | 1079 | (489) | RR | 1131 | (513) |

| Weights lb (kg) | Curb | | Test Inertial | | Gross Static | |
|---|---|---|---|---|---|---|
| W-front | 2909 | (1320) | 2821 | (1280) | 2921 | (1325) |
| W-rear | 2231 | (1012) | 2146 | (973) | 2210 | (1002) |
| W-total | 5140 | (2331) | 4967 | (2253) | 5131 | (2327) |

**GVWR Ratings**

| | |
|---|---|
| Front | 3700 |
| Rear | 3900 |
| Total | 6700 |

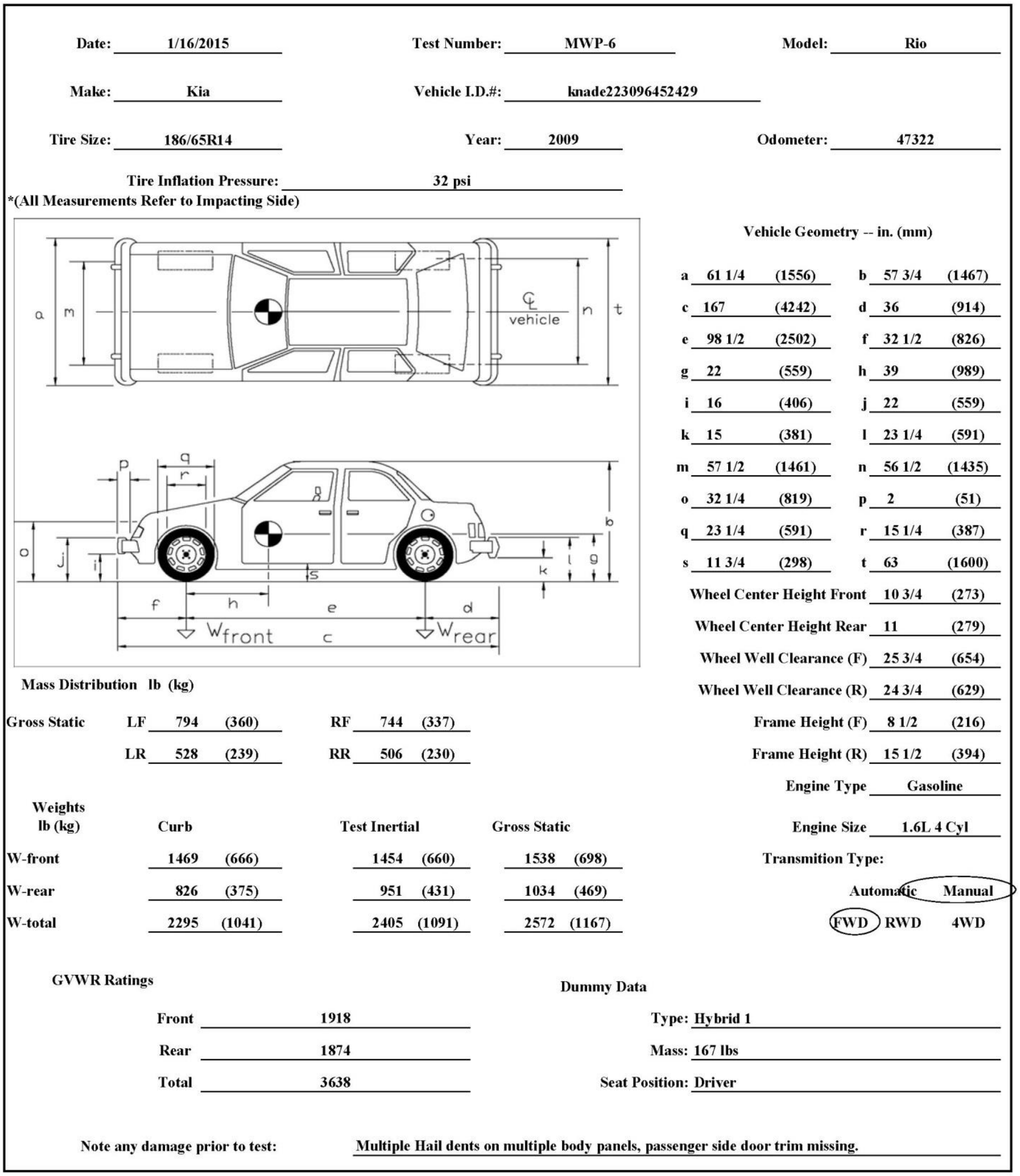
**Dummy Data**

**Type:** Hybrid II
**Mass:** 164 lb
**Seat Position:** Front Driver Seat

**Note any damage prior to test:** None

Figure 2. Vehicle Dimensions, Test No. MWP-4

Figure 3. Test Vehicle, Test No. MWP-6



Date: 1/16/2015
Test Number: MWP-6
Model: Rio

Make: Kia
Vehicle I.D.#: knade223096452429

Tire Size: 186/65R14
Year: 2009
Odometer: 47322

Tire Inflation Pressure: 32 psi

*(All Measurements Refer to Impacting Side)

Vehicle Geometry -- in. (mm)

| | | | | | |
|---|---|---|---|---|---|
| a | 61 1/4 | (1556) | b | 57 3/4 | (1467) |
| c | 167 | (4242) | d | 36 | (914) |
| e | 98 1/2 | (2502) | f | 32 1/2 | (826) |
| g | 22 | (559) | h | 39 | (989) |
| i | 16 | (406) | j | 22 | (559) |
| k | 15 | (381) | l | 23 1/4 | (591) |
| m | 57 1/2 | (1461) | n | 56 1/2 | (1435) |
| o | 32 1/4 | (819) | p | 2 | (51) |
| q | 23 1/4 | (591) | r | 15 1/4 | (387) |
| s | 11 3/4 | (298) | t | 63 | (1600) |

Wheel Center Height Front 10 3/4 (273)
Wheel Center Height Rear 11 (279)
Wheel Well Clearance (F) 25 3/4 (654)
Wheel Well Clearance (R) 24 3/4 (629)
Frame Height (F) 8 1/2 (216)
Frame Height (R) 15 1/2 (394)
Engine Type Gasoline
Engine Size 1.6L 4 Cyl
Transmition Type:
Automatic [✓ Manual]
[✓ FWD] RWD 4WD

Mass Distribution lb (kg)

| | | | | |
|---|---|---|---|---|
| Gross Static | LF | 794 (360) | RF | 744 (337) |
| | LR | 528 (239) | RR | 506 (230) |

| Weights lb (kg) | Curb | Test Inertial | Gross Static |
|---|---|---|---|
| W-front | 1469 (666) | 1454 (660) | 1538 (698) |
| W-rear | 826 (375) | 951 (431) | 1034 (469) |
| W-total | 2295 (1041) | 2405 (1091) | 2572 (1167) |

GVWR Ratings

Front 1918
Rear 1874
Total 3638

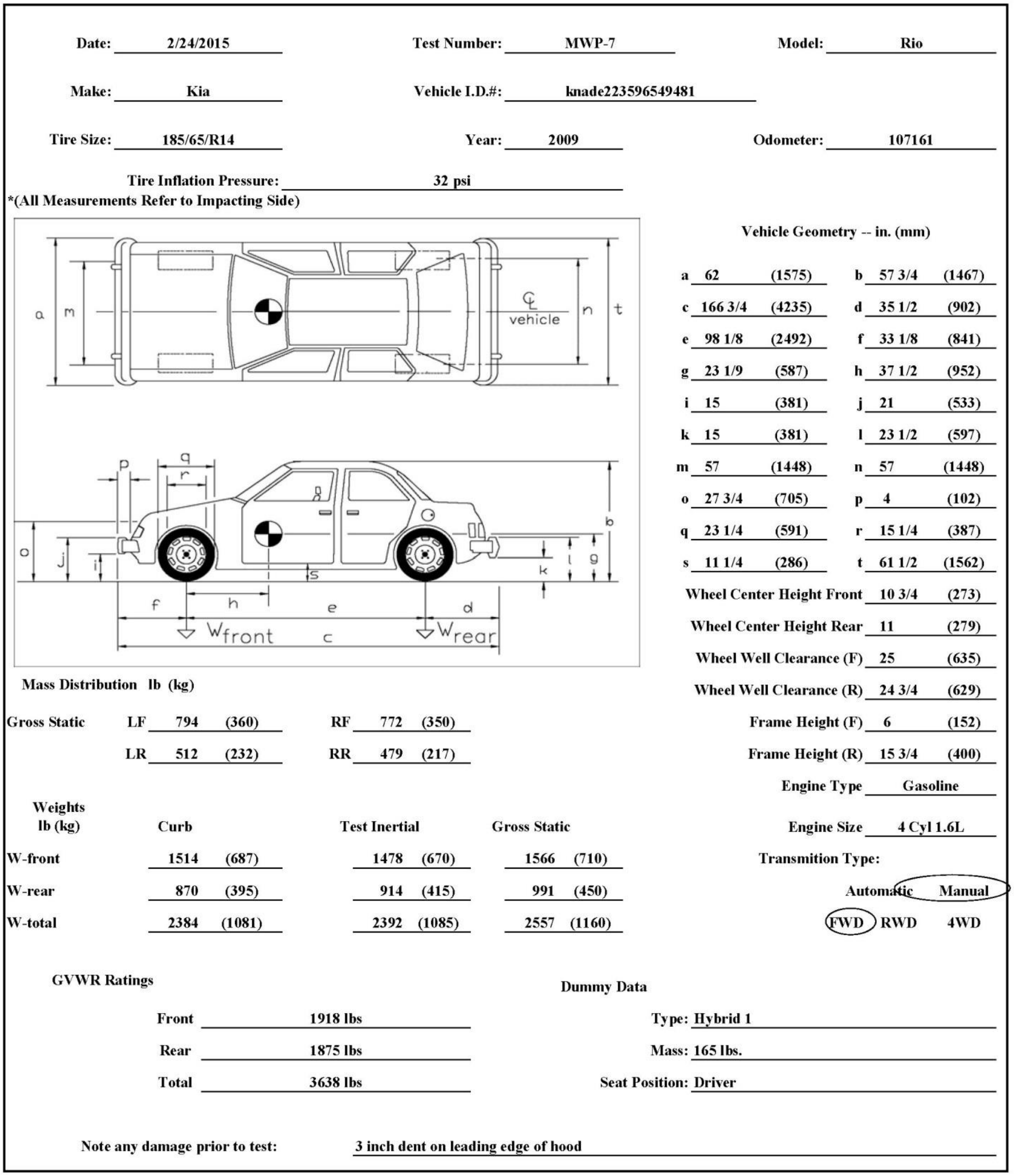
Dummy Data

Type: Hybrid 1
Mass: 167 lbs
Seat Position: Driver

Note any damage prior to test: Multiple Hail dents on multiple body panels, passenger side door trim missing.

Figure 4. Vehicle Dimensions, Test No. MWP-6

Figure 5. Test Vehicle, Test No. MWP-7



**Date:** 2/24/2015 **Test Number:** MWP-7 **Model:** Rio

**Make:** Kia **Vehicle I.D.#:** knade223596549481

**Tire Size:** 185/65/R14 **Year:** 2009 **Odometer:** 107161

**Tire Inflation Pressure:** 32 psi

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

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

| | | | | | |
|---|---|---|---|---|---|
| a | 62 | (1575) | b | 57 3/4 | (1467) |
| c | 166 3/4 | (4235) | d | 35 1/2 | (902) |
| e | 98 1/8 | (2492) | f | 33 1/8 | (841) |
| g | 23 1/9 | (587) | h | 37 1/2 | (952) |
| i | 15 | (381) | j | 21 | (533) |
| k | 15 | (381) | l | 23 1/2 | (597) |
| m | 57 | (1448) | n | 57 | (1448) |
| o | 27 3/4 | (705) | p | 4 | (102) |
| q | 23 1/4 | (591) | r | 15 1/4 | (387) |
| s | 11 1/4 | (286) | t | 61 1/2 | (1562) |

**Wheel Center Height Front** 10 3/4 (273)
**Wheel Center Height Rear** 11 (279)
**Wheel Well Clearance (F)** 25 (635)
**Wheel Well Clearance (R)** 24 3/4 (629)
**Frame Height (F)** 6 (152)
**Frame Height (R)** 15 3/4 (400)
**Engine Type** Gasoline
**Engine Size** 4 Cyl 1.6L
**Transmition Type:**
Automatic [✓ Manual]
[✓ FWD] RWD 4WD

**Mass Distribution lb (kg)**

| | | | | | |
|---|---|---|---|---|---|
| **Gross Static** | LF | 794 (360) | RF | 772 (350) |
| | LR | 512 (232) | RR | 479 (217) |

| **Weights lb (kg)** | **Curb** | **Test Inertial** | **Gross Static** |
|---|---|---|---|
| **W-front** | 1514 (687) | 1478 (670) | 1566 (710) |
| **W-rear** | 870 (395) | 914 (415) | 991 (450) |
| **W-total** | 2384 (1081) | 2392 (1085) | 2557 (1160) |

**GVWR Ratings**

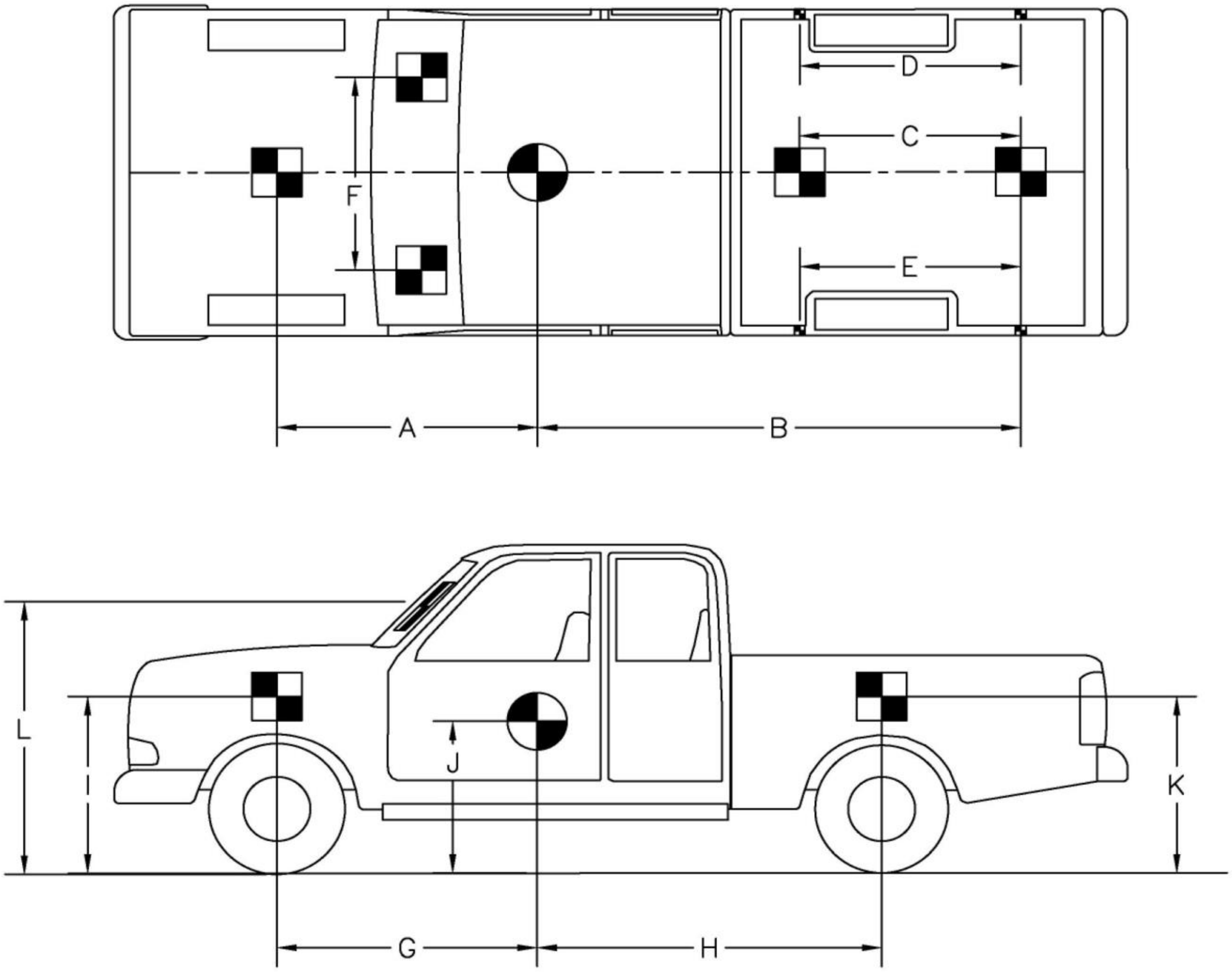
**Front** 1918 lbs
**Rear** 1875 lbs
**Total** 3638 lbs

**Dummy Data**

**Type:** Hybrid 1
**Mass:** 165 lbs.
**Seat Position:** Driver

**Note any damage prior to test:** 3 inch dent on leading edge of hood

Figure 6. Vehicle Dimensions, Test No. MWP-7

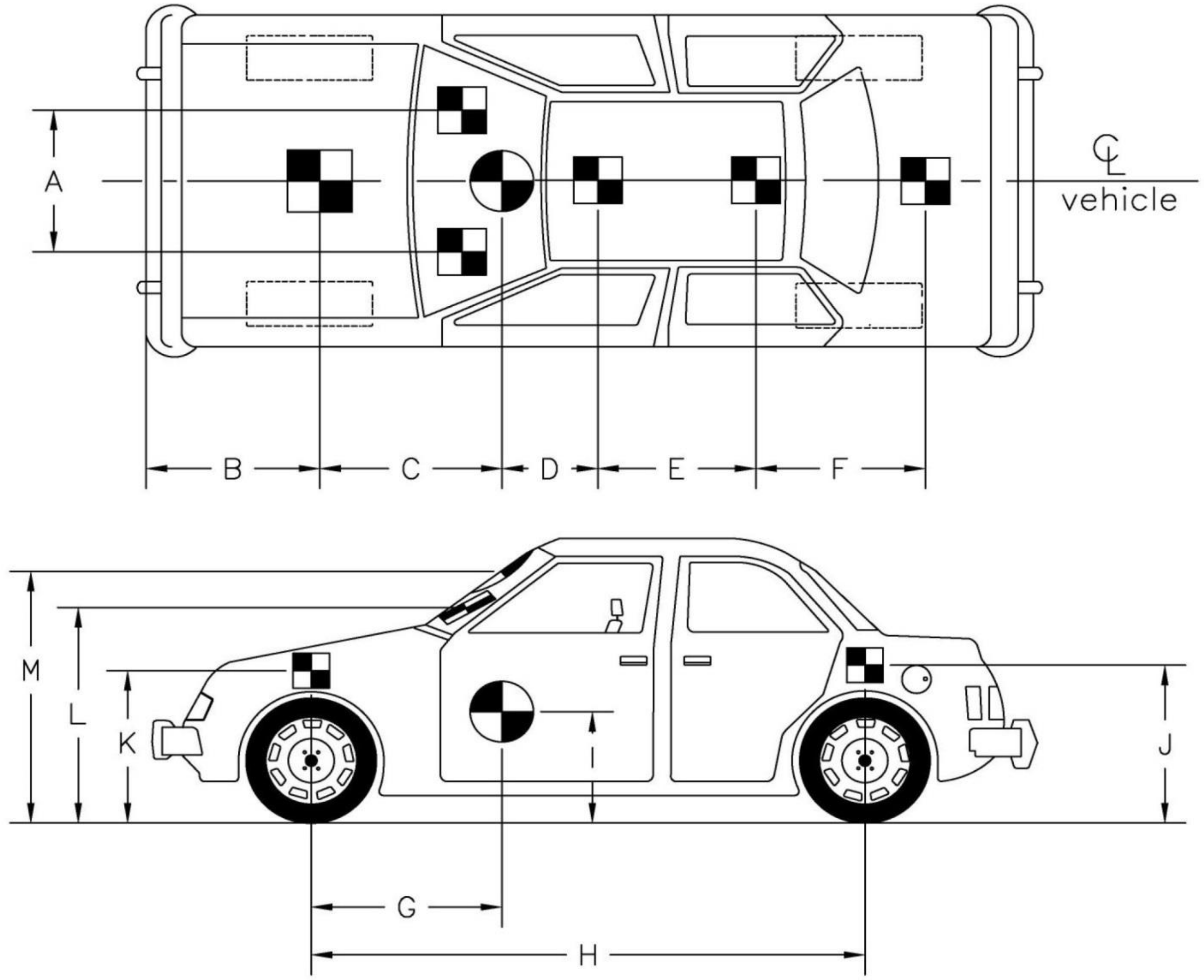


**TEST #: MWP-4**

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

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A** | 70 1/4 | (1784) | **E** | 70 1/4 | (1784) | **I** | 38 5/8 | (981) |
| **B** | 101 1/2 | (2578) | **F** | 30 3/4 | (781) | **J** | 28 | (711) |
| **C** | 44 | (1118) | **G** | 60 1/2 | (1537) | **K** | 42 1/2 | (1080) |
| **D** | 70 1/4 | (1784) | **H** | 84 1/2 | (2146) | **L** | 62 5/8 | (1591) |

Figure 7. Target Geometry, Test No. MWP-4

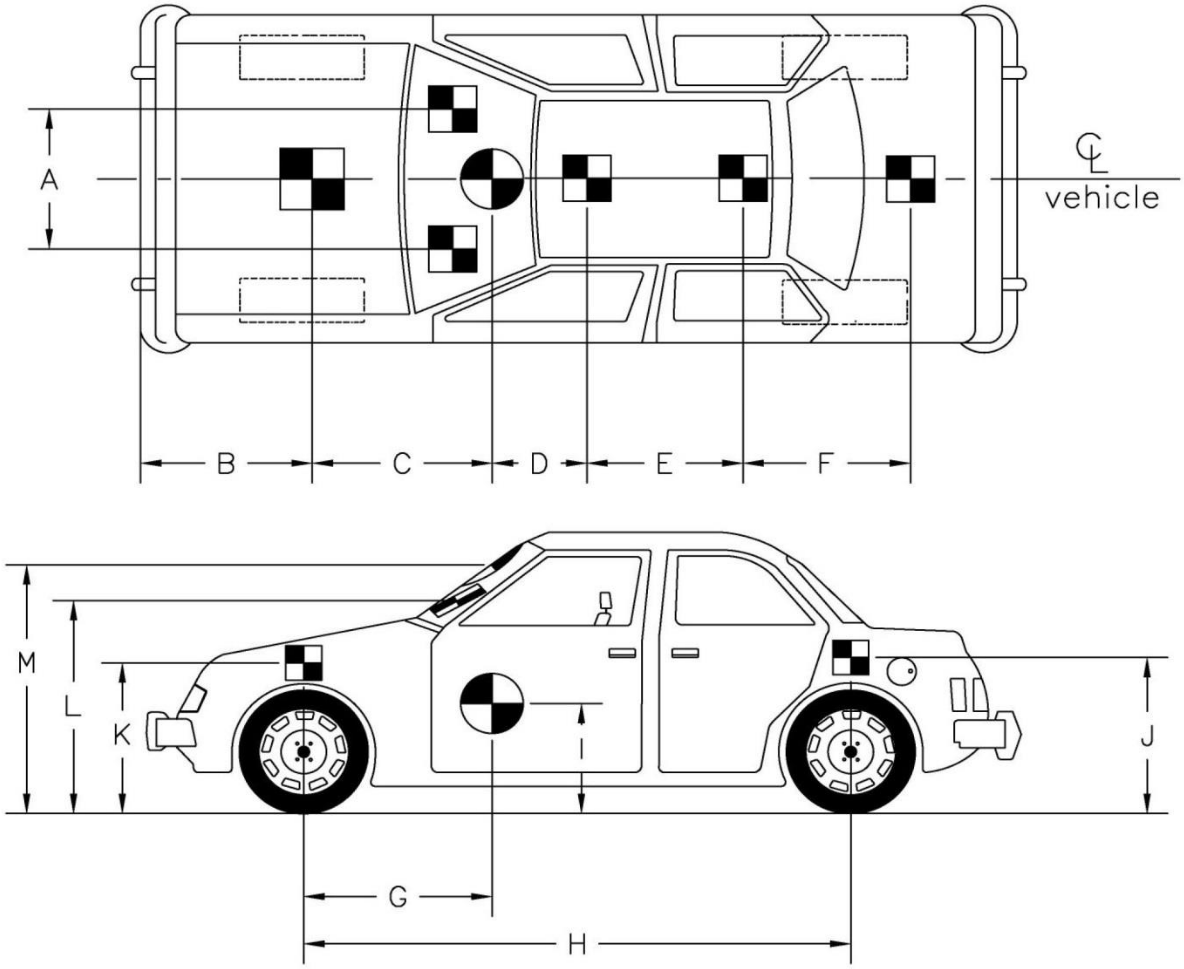


**TEST #: MWP-6**

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

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A** | **33 1/4** | **(845)** | **E** | **39** | **(991)** | **I** | **22** | **(559)** |
| **B** | **20** | **(508)** | **F** | **38 1/4** | **(972)** | **J** | **28 3/4** | **(730)** |
| **C** | **51 1/4** | **(1302)** | **G** | **39** | **(991)** | **K** | **29 1/2** | **(749)** |
| **D** | **7 3/4** | **(197)** | **H** | **98 1/2** | **(2502)** | **L** | **47 1/2** | **(1207)** |
| | | | | | | **M** | **54 1/4** | **(1378)** |

Figure 8. Target Geometry, Test No. MWP-6



## TEST #: MWP-7

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

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A** | **23 7/8** | **(606)** | **E** | **39 7/8** | **(1013)** | **I** | **23 1/8** | **(587)** |
| **B** | **19 3/4** | **(502)** | **F** | **37 1/8** | **(943)** | **J** | **28 7/8** | **(733)** |
| **C** | **50** | **(1270)** | **G** | **37 1/2** | **(953)** | **K** | **28 7/8** | **(733)** |
| **D** | **7 3/4** | **(197)** | **H** | **98 1/8** | **(2492)** | **L** | **48 7/8** | **(1241)** |
| | | | | | | **M** | **53 1/2** | **(1359)** |

Figure 9. Target Geometry, Test No. MWP-7

## 3.4 Simulated Occupant

A Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the left-front seat of all three test vehicles with the seat belt was fastened. The dummy, which had a final weight of 170 lb (77 kg), was model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH, the dummy was not included in calculating the c.g location.

## 3.5 Data Acquisition Systems

### 3.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometers were mounted near the center of gravity of each test vehicle. The electronic accelerometer data obtained during dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filters conforming to the SAE J211/1 specifications [7].

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 acceleration sensors were mounted inside the bodies of the 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 programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

### 3.5.2 Rate Transducers

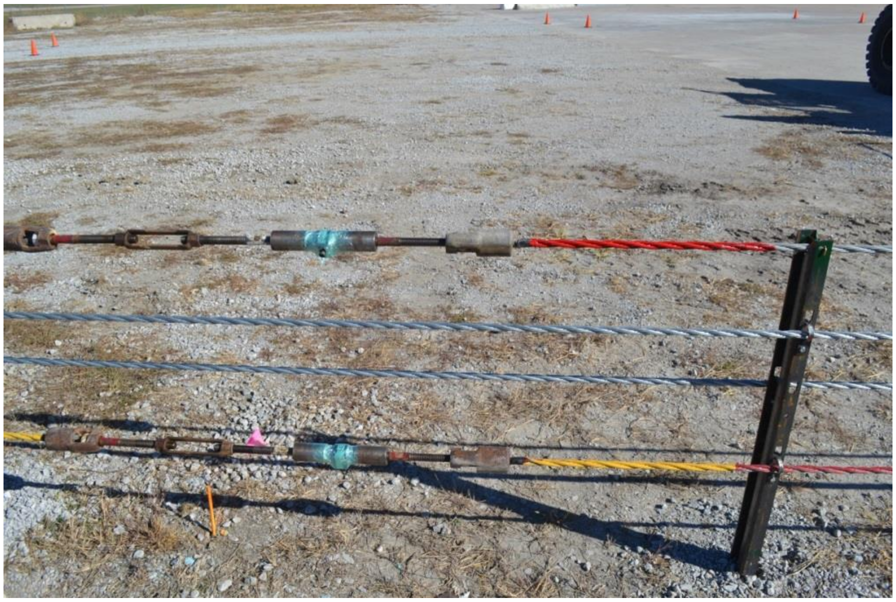
Two angle rate sensor systems were utilized to measure the rates of rotation of the vehicles during testing. Both were SLICE MICRO Triax ARS units, with a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw). The angular rate sensors were mounted inside the bodies of the two custom built SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. 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.

### 3.5.3 Retroreflective Optic Speed Trap

The retroreflective optical speed trap was used to determine the speed of the vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the sides of the vehicles. 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, which recorded at 10,000 Hz, as well as activated the External LED box. The speed was then calculated using the spacing between the retroreflective targets and the time interval 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.

### 3.5.4 Load Cells and String Potentiometers

Load cells were spliced into each cable upstream from impact. The cables in each test were numbered 1 through 4 starting at the bottom cable. For test no. MWP-4 the load cells on cable nos. 2 and 4 were located between post nos. 5 and 6, and the load cells on cable nos. 1 and 3 were located between post nos. 6 and 7. For test nos. MWP-6 and MWP-7, the load cells on cable nos. 2 and 4 were located between post nos. 6 and 7, and the load cells on cable nos. 1 and 3 were located between post nos. 7 and 8. All four 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 upstream anchor foundation, labeled as post no. 1, for all three tests. The string potentiometer was a 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 five 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 10.



Load Cells, Test No. MWP-4

String Potentiometer Test Nos. MWP-4 through MWP-6

Figure 10. Location of Load Cells and String Potentiometer

### 3.5.5 Digital Photography

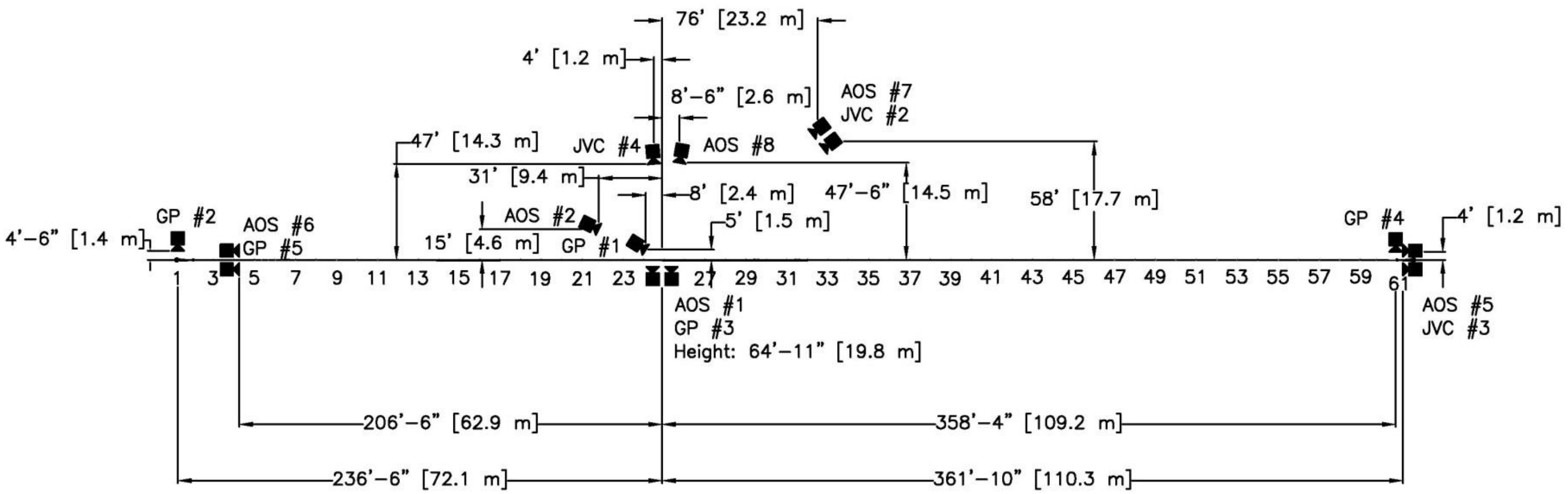
Two AOS VITcam high-speed digital video cameras, three AOS X-PRI high-speed digital video cameras, one AOS S- VIT 1531 high-speed digital video camera, three JVC digital video cameras, four GoPro Hero 3+ digital video cameras and two GoPro Hero 3 digital video cameras were utilized to film test no. MWP-4. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 11.

One AOS VITcam high-speed digital video camera, one AOS S-VIT 1531 high-speed digital video camera, one AOS TRI-VIT 2236 high speed digital camera, two AOS X-PRI high-speed digital video cameras, three JVC digital video cameras, four GoPro Hero 3+ digital video cameras, and two GoPro Hero 3 digital video cameras were utilized to film test no. MWP-6. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 12.

Two AOS Vitcam high-speed digital video cameras, one AOS S-VIT 1531 high-speed digital video camera, two AOS X-PRI high-speed digital video cameras, one AOS TRI-VIT 2236 high speed digital video camera, three JVC digital video cameras, four GoPro Hero 3+ digital video cameras, one GoPro Hero 4 digital video camera, and two GoPro Hero 3 digital video cameras were utilized to film test no. MWP-7. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 13.

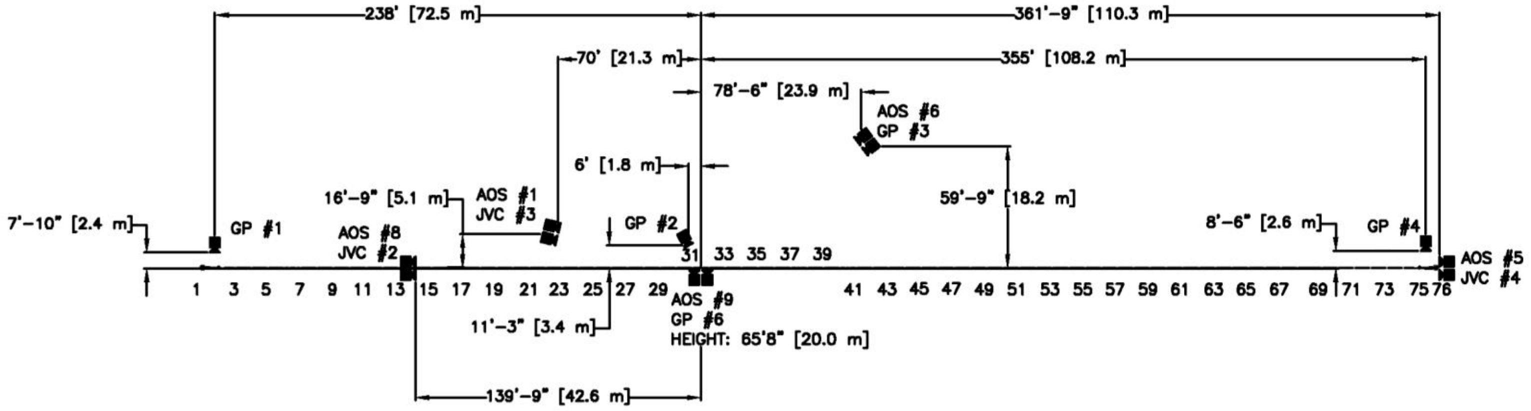
In each of the three tests, one of the GoPro cameras was mounted inside the test vehicle, and therefore does not appear on the camera placement schematic.

The high-speed videos were analyzed using ImageExpress MotionPlus and RedLake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A Nikon D50 digital still camera was also used, to document pre- and post-test conditions for all tests.



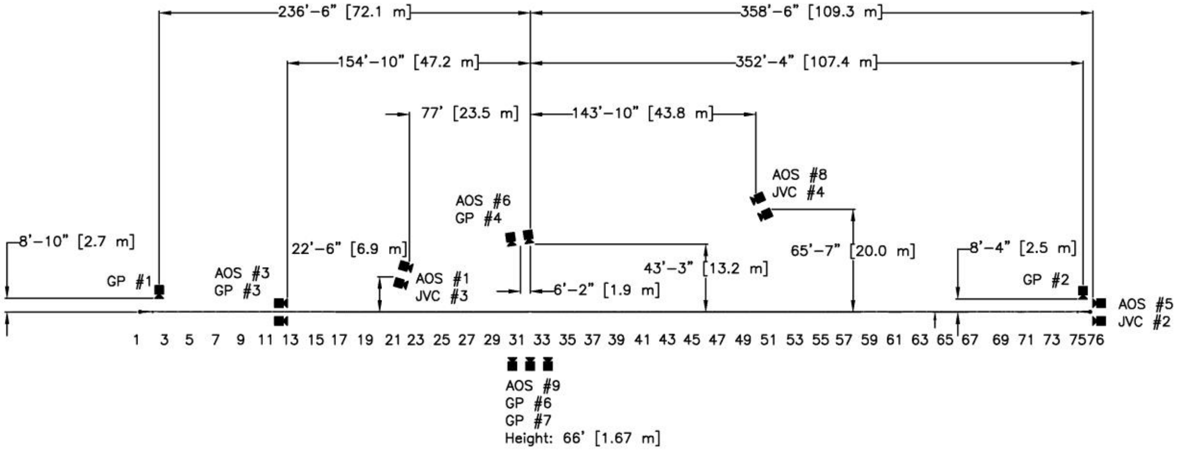
| Camera No. | Type | Operating Speed (frames/sec) | Lens | Lens Setting |
|---|---|---|---|---|
| AOS-1 | AOS Vitcam | 500 | Cosmicar 12.5mm fixed | 12.5mm |
| AOS-2 | AOS Vitcam | 500 | Sigma 28-70 | 28mm |
| AOS-5 | AOS X-PRI | 500 | TV Zoom 17-102 | 102mm |
| AOS-6 | AOS X-PRI | 500 | Fujinon 50mm fixed | 50mm |
| AOS-7 | AOS X-PRI | 500 | Nikon 28mm fixed | 28mm |
| AOS-8 | AOS S-VIT 1531 | 500 | Nikon 28mm fixed | 28mm |
| GP-1 | GoPro Hero 3 | 120 | | |
| GP-2 | GoPro Hero 3 | 120 | | |
| GP-3 | GoPro Hero 3+ | 120 | | |
| GP-4 | GoPro Hero 3+ | 120 | | |
| GP-5 | GoPro Hero 3+ | 120 | | |
| GP-6 | GoPro Hero 3+ | 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 11. Camera Locations, Speeds, and Lens Settings, Test No. MWP-4



| Camera No. | Type | Operating Speed (frames/sec) | Lens | Lens Setting |
|---|---|---|---|---|
| AOS-1 | AOS Vitcam | 500 | Sigma 24-70 | 35mm |
| AOS-5 | AOS X-PRI | 500 | TV Zoom 17-102 | 102mm |
| AOS-6 | AOS X-PRI | 500 | Nikon 28mm fixed | 28mm |
| AOS-8 | AOS S-VIT 1531 | 500 | Sigma 24-135 | 85mm |
| AOS-9 | AOS TRI-VIT 2236 | 500 | Cosmicar 12.5mm fixed | 12.5mm |
| GP-1 | GoPro Hero 3 | 120 | | |
| GP-2 | GoPro Hero 3 | 120 | | |
| GP-3 | GoPro Hero 3+ | 120 | | |
| GP-4 | GoPro Hero 3+ | 120 | | |
| GP-5 | GoPro Hero 3+ | 120 | | |
| GP-6 | GoPro Hero 3+ | 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 12. Camera Locations, Speeds, and Lens Settings, Test No. MWP-6



| Camera No. | Type | Operating Speed (frames/sec) | Lens | Lens Setting |
|---|---|---|---|---|
| AOS-1 | AOS Vitcam | 500 | Sigma 28-70 | 50mm |
| AOS-3 | AOS Vitcam | 500 | Fujinon 50mm fixed | 50mm |
| AOS-5 | AOS X-PRI | 500 | Vivitar 135mm fixed | 135mm |
| AOS-6 | AOS X-PRI | 500 | Nikon Nikkor 20 mm fixed | 20mm |
| AOS-8 | AOS S-VIT 1531 | 500 | Sigma 28-70 | 28mm |
| AOS-9 | AOS TRI-VIT 2236 | 500 | Kowa 12.5mm | 12.5mm |
| GP-1 | GoPro Hero 3 | 120 | | |
| GP-2 | GoPro Hero 3 | 120 | | |
| 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 | | |
| 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 13. Camera Locations, Speeds, and Lens Settings, Test No. MWP-7

# 4 DESIGN DETAILS TEST NO. MWP-4

The non-proprietary, 4-cable median barrier system evaluated in test no. MWP-4 is shown in Figures 14 through 37. The test installation was constructed with a total length of 604 ft (184.1 m) on level terrain. The cable barrier system was comprised 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. Photographs of the test installation are shown in Figures 38 through 41. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

Four ¾-in. (19-mm) diameter, Class A galvanized 3x7 (pre-stretched) wire ropes were utilized for the longitudinal cables. The barrier utilized a consistent 7½-in. (190.5-mm) cable spacing as the cables were placed at heights of 15½ in. (393.7 mm), 23 in. (584.2 mm), 30½ in. (774.7 mm), and 38 in. (965.2 mm) above the ground surface. The cables were numbered 1 through 4, starting with the bottom cable and proceeding upward to the top cable.

Cable nos. 1 and 3 were attached to the non-impact side of each post, while cable no. 2 was attached to the impact side of each post, as shown in Figure 28. Cable no. 4 resided within the V-notch cut into the top of each post. MASH requires that cable barrier systems be tested with cable tensions set to the recommended tension at 100 degrees Fahrenheit. A cable tensioning chart was developed as a function of ambient air temperature for use when installing the barrier system, as shown in Table 3. Thus, the cables were tensioned to a pre-load of 2,500 lb (11.1 kN).

Each of the four wire ropes contained a splice in the impact region, between post nos. 29 and 33, as shown in Figure 15. Additionally, a load cell was spliced into each wire rope upstream from impact, between post nos. 5 and 7, as shown in Figure 18. Details for the load cells, threaded rods, turnbuckles, end fittings, and rod couplers are provided in Figure 19.

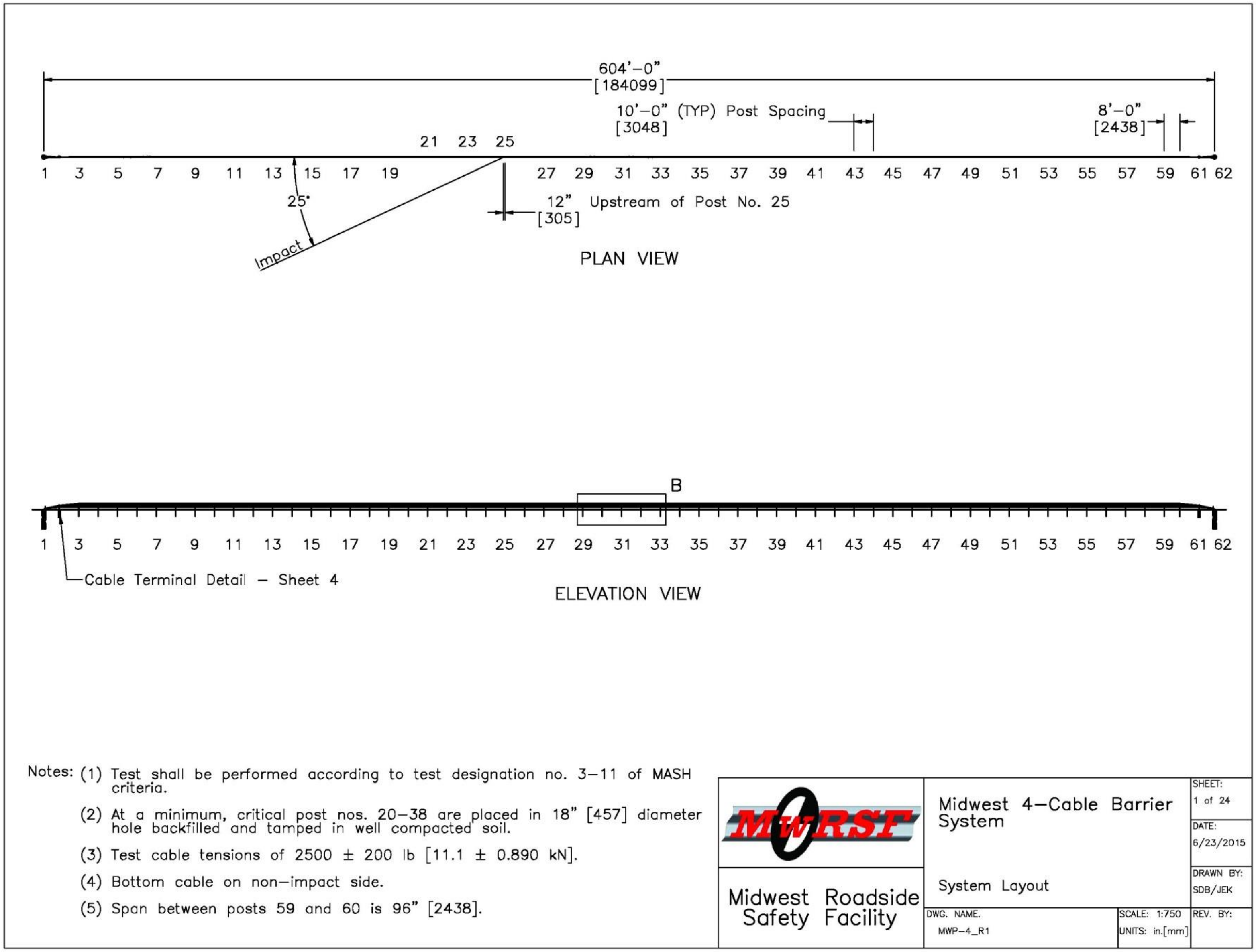
Table 3. Pre-Stretched Cable Tension Chart

| Ambient Air Temperature (Degrees Fahrenheit) | Cable Tension (lb) |
|---|---|
| 110 | 2,240 |
| 100 | 2,500 |
| 90 | 2,760 |
| 80 | 3,021 |
| 70 | 3,281 |
| 60 | 3,541 |
| 50 | 3,801 |
| 40 | 4,062 |
| 30 | 4,322 |
| 20 | 4,582 |
| 10 | 4,842 |
| 0 | 5,102 |
| -10 | 5,363 |
| -20 | 5,623 |
| -30 | 5,883 |
| -40 | 6,143 |

The cables were supported by 58 line posts and anchored at the upstream and downstream ends with selected hardware from a prototype breakaway cable end terminal system. Post nos. 3 through 60 were Midwest Weak Posts (MWPs) measuring 83 in. (2,108 mm) in length. The MWPs were fabricated from bent 7-gauge (4.6-mm) sheet steel to a 3-in. x 1¾-in. (76-mm x 44-mm) cross section, as shown in Figures 28 through 31. The post spacing between adjacent MWPs was 10 ft (3.05 m).

A prototype breakaway cable end terminal system was utilized at each end of the cable barrier system, as shown in Figures 16, 17 and 20 through 23. Post nos. 1 and 62 consisted of 4-cable anchor bracket assemblies that were anchored to reinforced concrete foundations at both ends of the system. Post nos. 2 and 61 were slip-base support posts with attached hanger hardware, as shown in Figures 24 through 27. The spacing between the cable anchor brackets and the adjacent slip-base support posts was 8 ft (2.4 m).

Cable nos. 1 through 3 were attached to the MWPs using bolted, tabbed brackets. These brackets were fabricated from 12 gauge (2.7 mm) steel and bolted to the post utilizing a $^{5}/_{16}$-in. (8-mm) diameter, 1-in. (25-mm) long bolt. Cable no. 4 was secured within the V-notch on top of each post with a $^{3}/_{16}$-in. (5-mm) diameter brass keeper rod. Details for the cable-to-post attachment brackets and brass keeper rods can be found in Figures 28 through 34.



Notes: (1) Test shall be performed according to test designation no. 3–11 of MASH criteria.

(2) At a minimum, critical post nos. 20–38 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 non–impact side.

(5) Span between posts 59 and 60 is 96" [2438].

Figure 14. Test Installation Layout, Test No. MWP-4

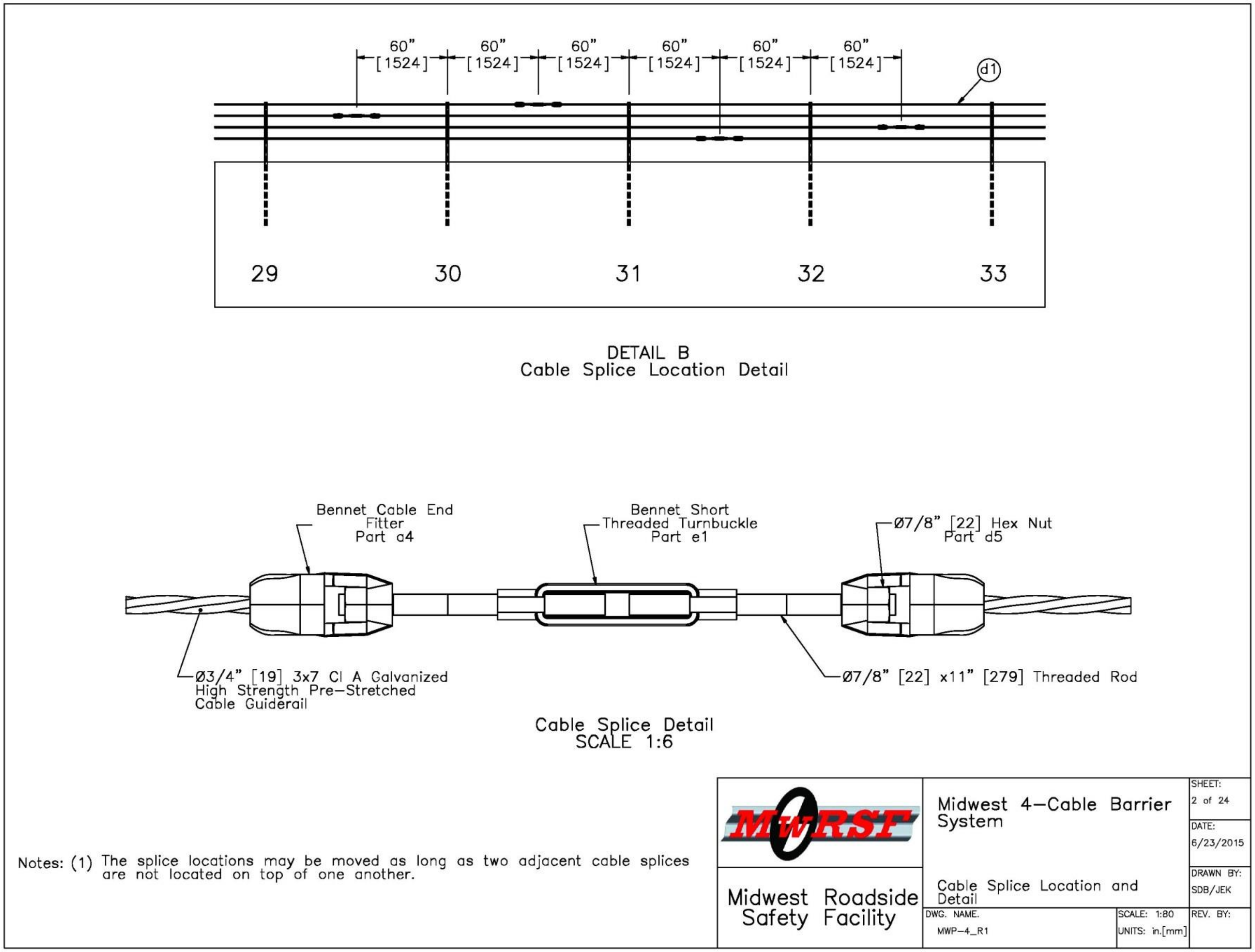


Figure 15. Cable Splice Location and Detail, Test No. MWP-4

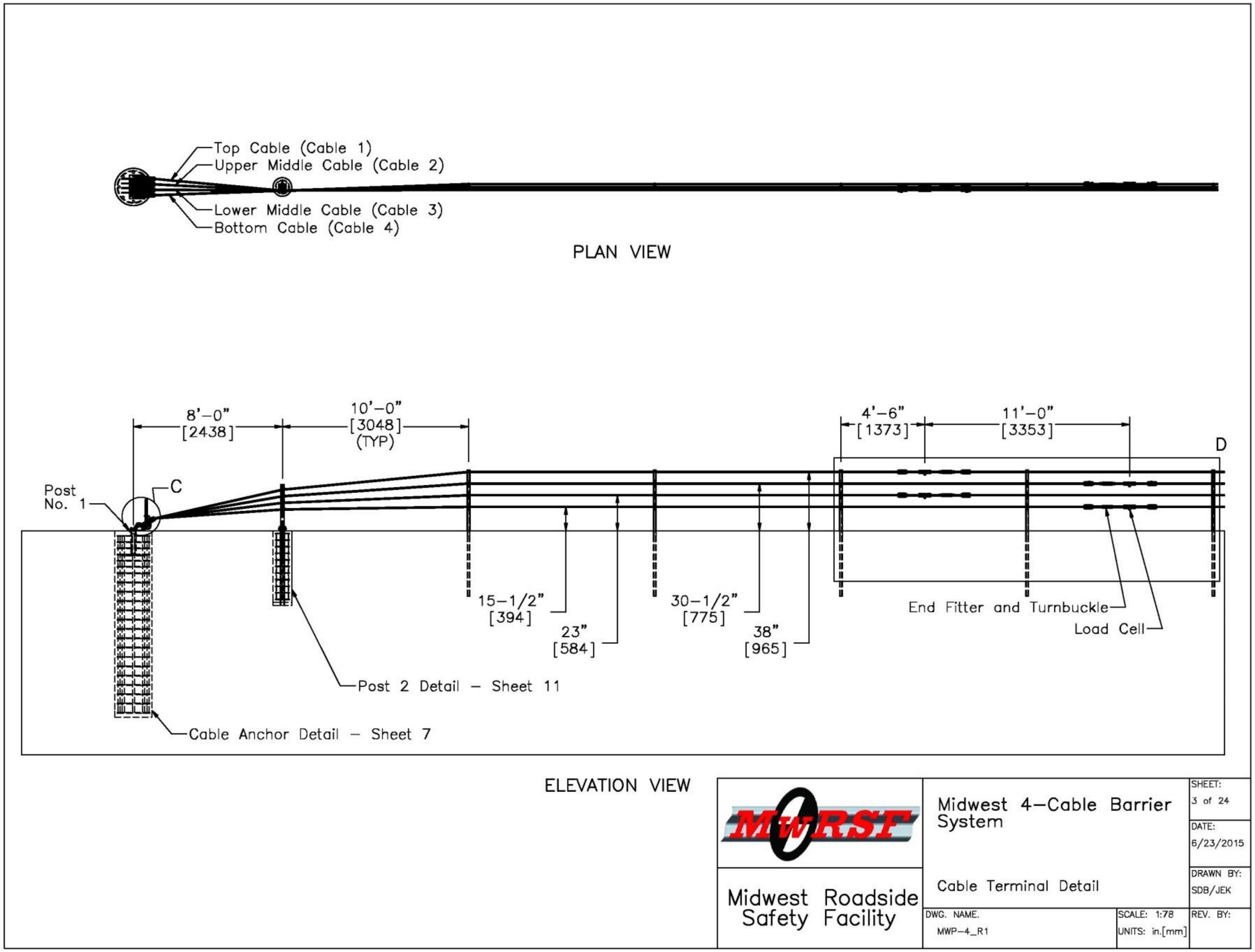


Figure 16. Cable Terminal Detail, Test No. MWP-4

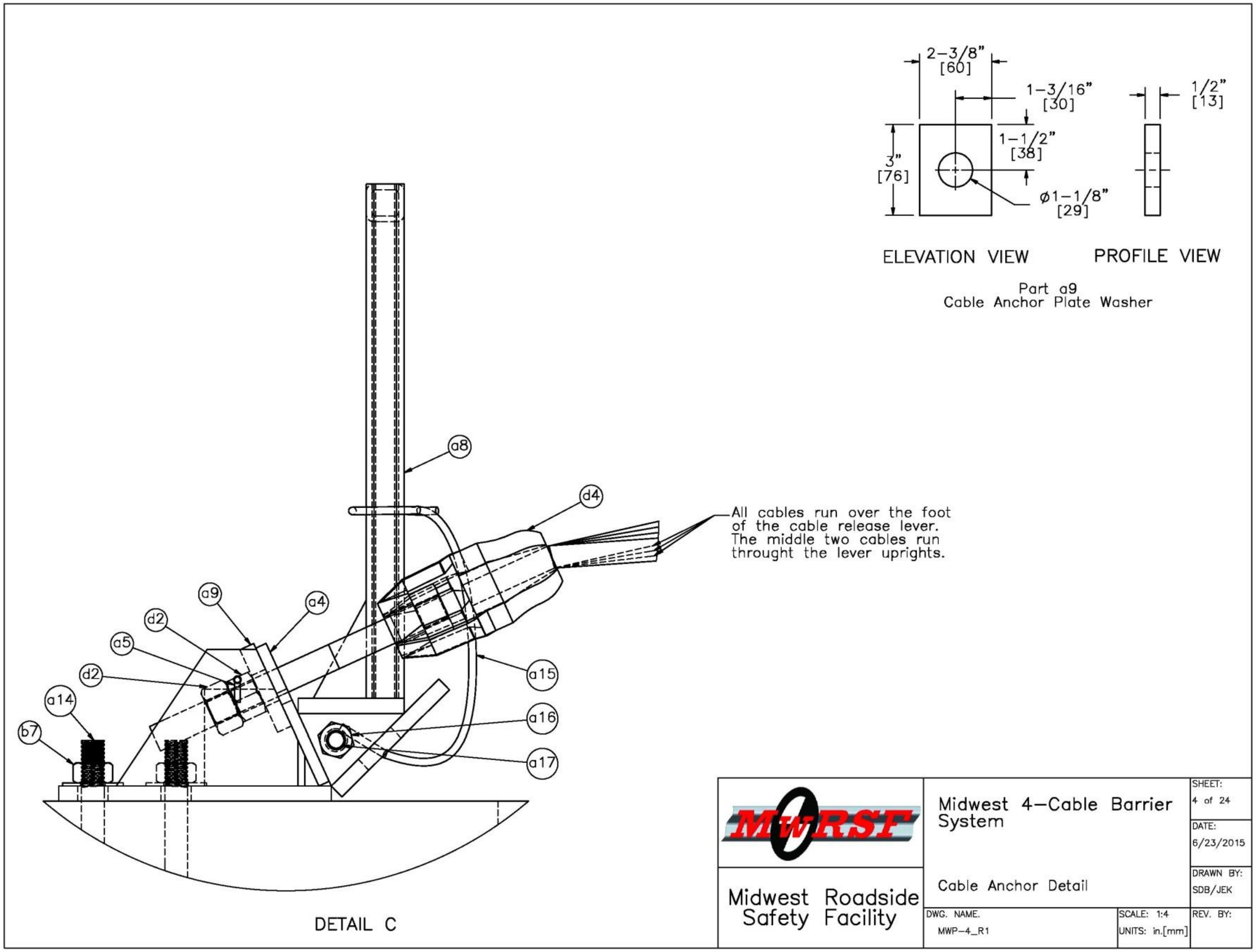


Figure 17. Cable Anchor Detail, Test No. MWP-4

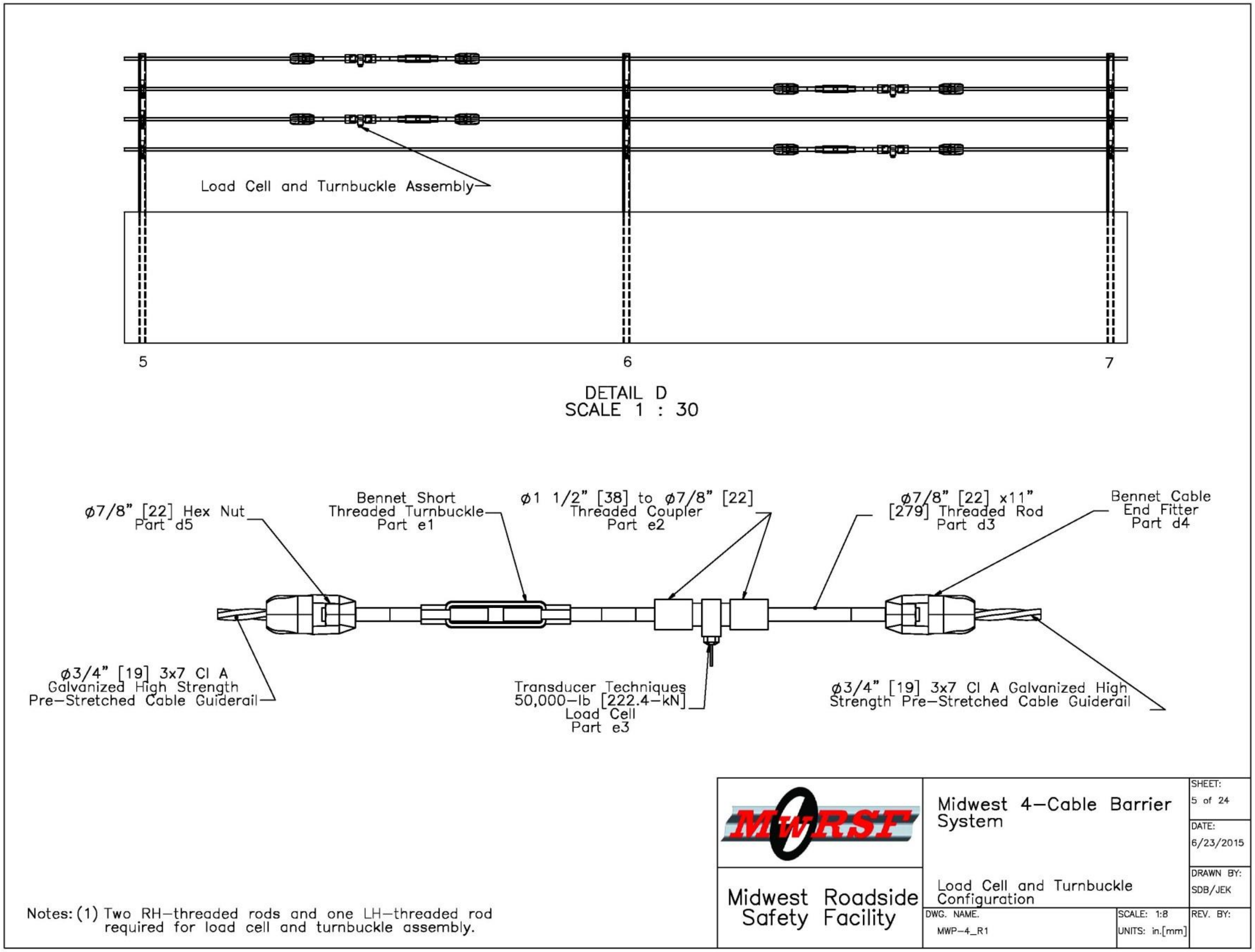


Figure 18. Load Cell and Turnbuckle Configuration, Test No. MWP-4

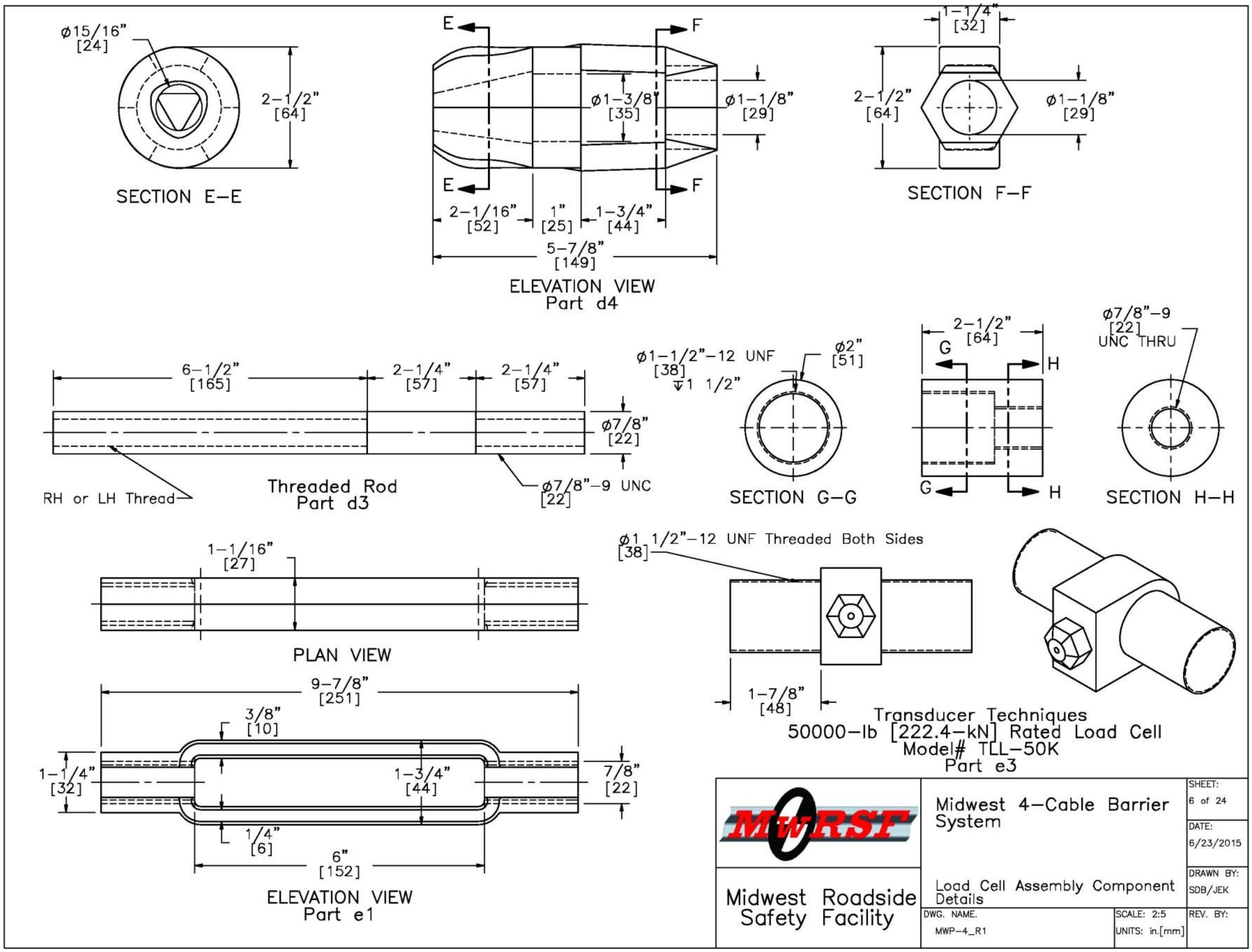
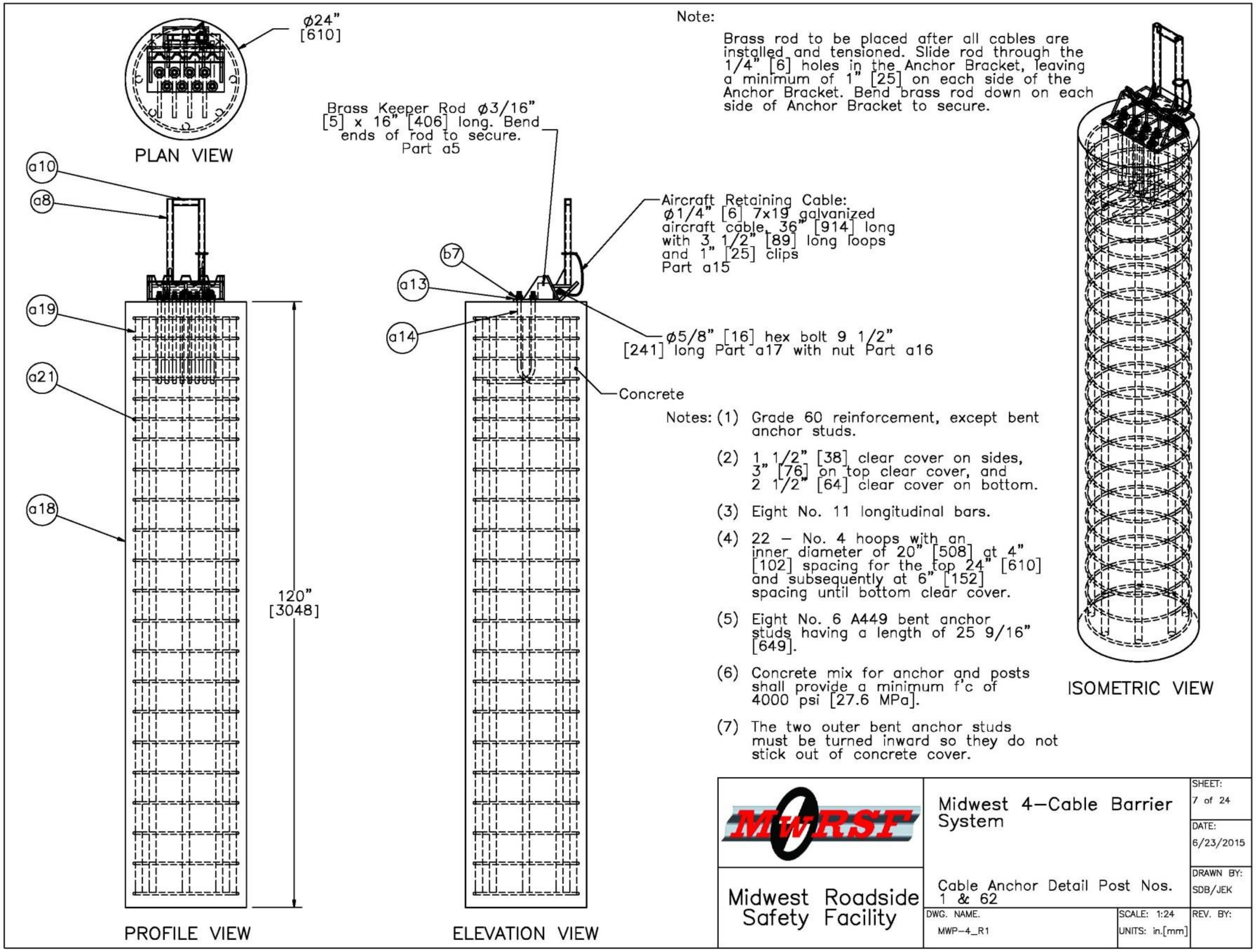


Figure 19. Load Cell Assembly Details, Test No. MWP-4



Note:

Brass rod to be placed after all cables are installed and tensioned. Slide rod through the 1/4" [6] holes in the Anchor Bracket, leaving a minimum of 1" [25] on each side of the Anchor Bracket. Bend brass rod down on each side of Anchor Bracket to secure.

Notes: (1) Grade 60 reinforcement, except bent anchor studs.

(2) 1 1/2" [38] clear cover on sides, 3" [76] on top clear cover, and 2 1/2" [64] clear cover on bottom.

(3) Eight No. 11 longitudinal bars.

(4) 22 – No. 4 hoops with an inner diameter of 20" [508] at 4" [102] spacing for the top 24" [610] and subsequently at 6" [152] spacing until bottom clear cover.

(5) Eight No. 6 A449 bent anchor studs having a length of 25 9/16" [649].

(6) Concrete mix for anchor and posts shall provide a minimum f'c of 4000 psi [27.6 MPa].

(7) The two outer bent anchor studs must be turned inward so they do not stick out of concrete cover.

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Cable Anchor Detail Post Nos. 1 & 62

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DWG. NAME. MWP–4_R1
SCALE: 1:24
UNITS: in.[mm]

Figure 20. Cable Anchor Detail, Post Nos. 1 and 62, Test No. MWP-4

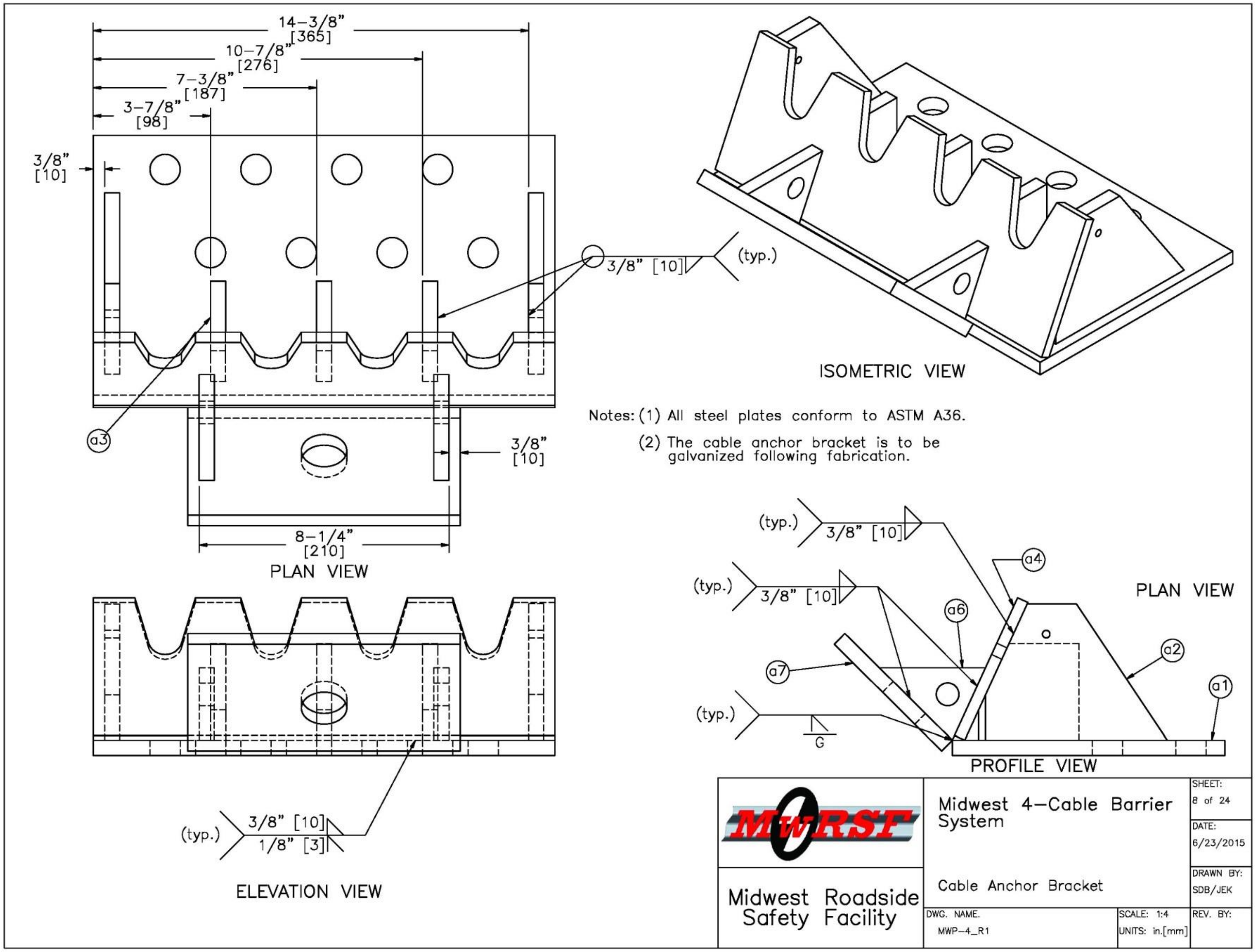

Figure 21. Cable Anchor Bracket, Test No. MWP-4

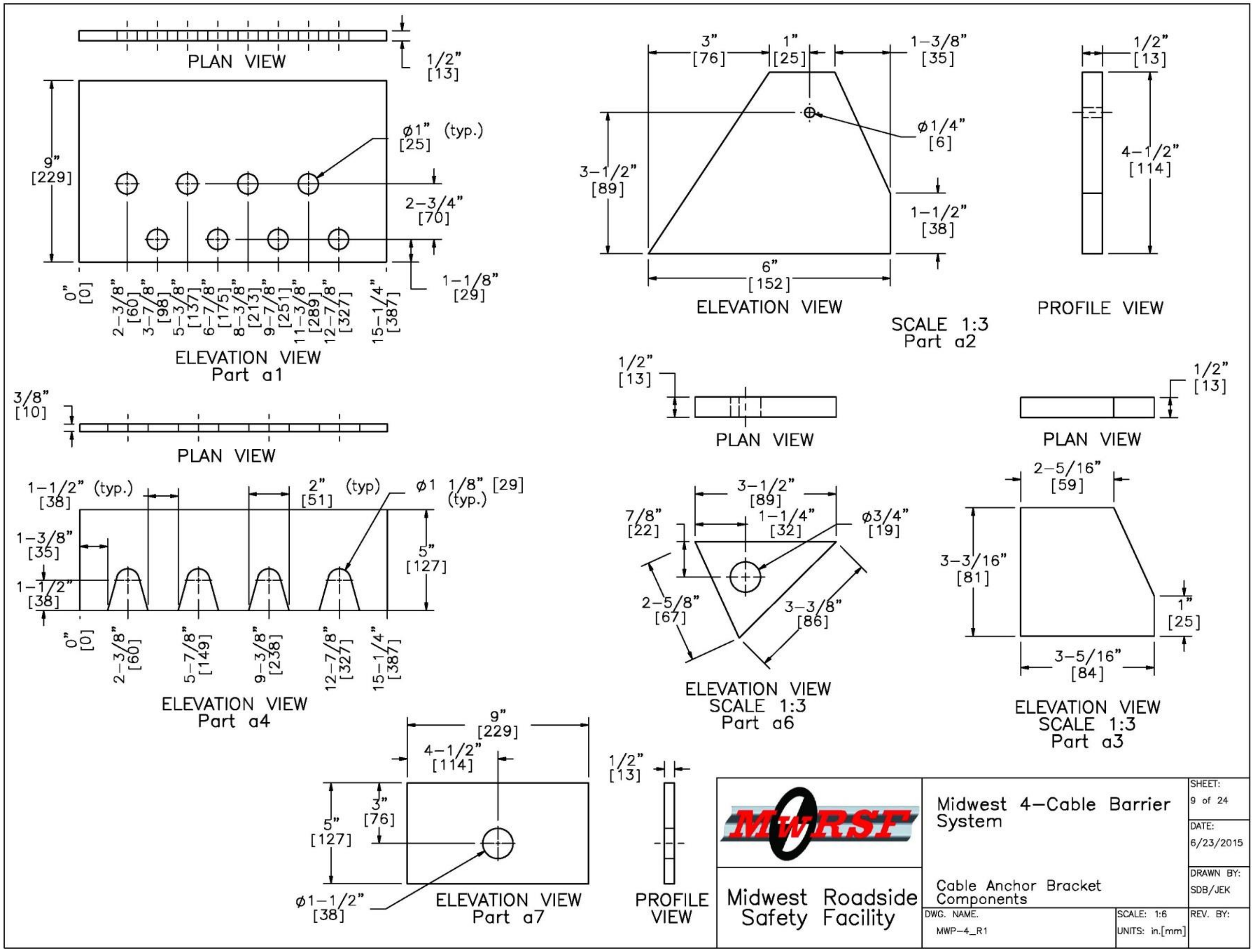

Figure 22. Cable Anchor Bracket Components, Test No. MWP-4

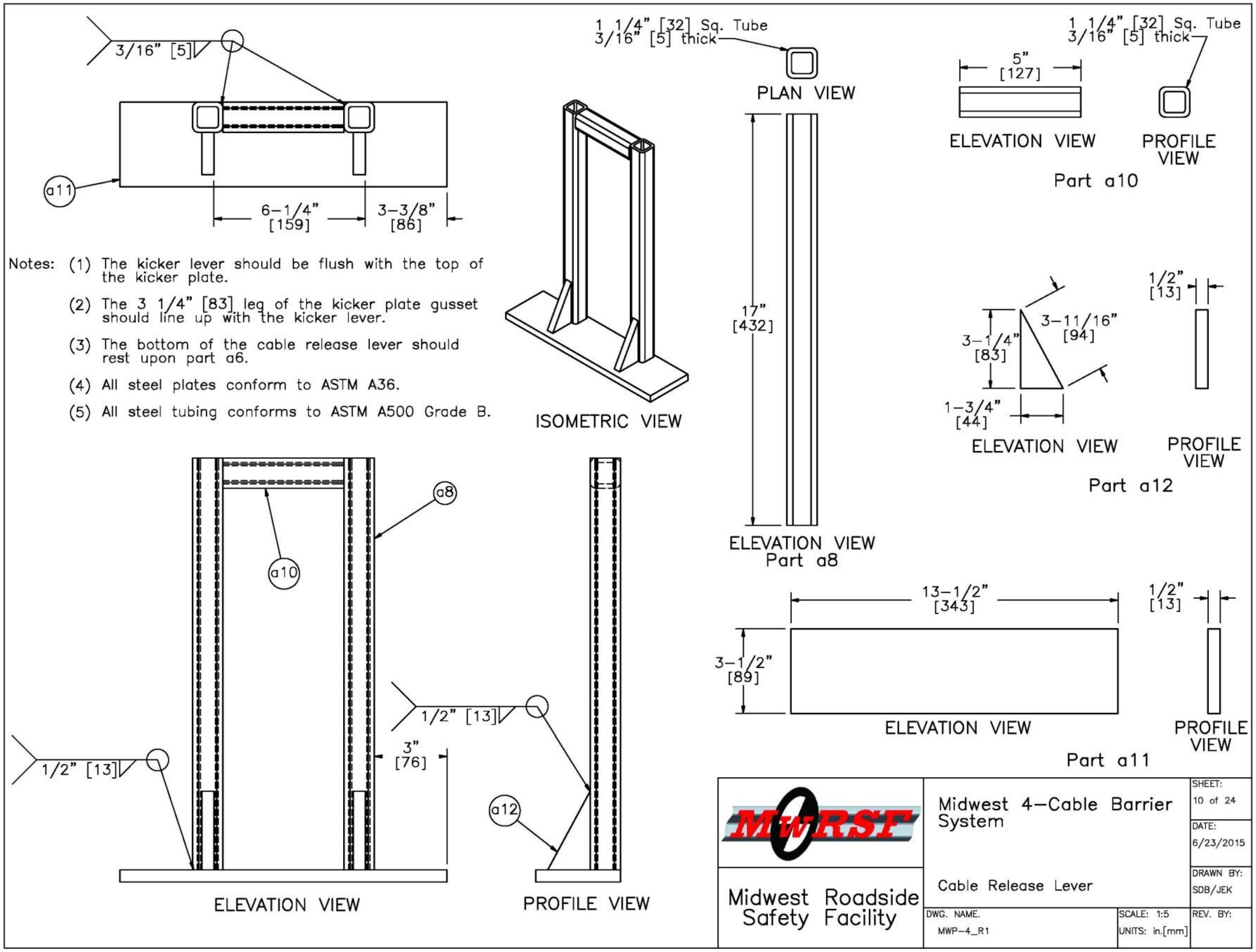

Figure 23. Cable Release Lever, Test No. MWP-4

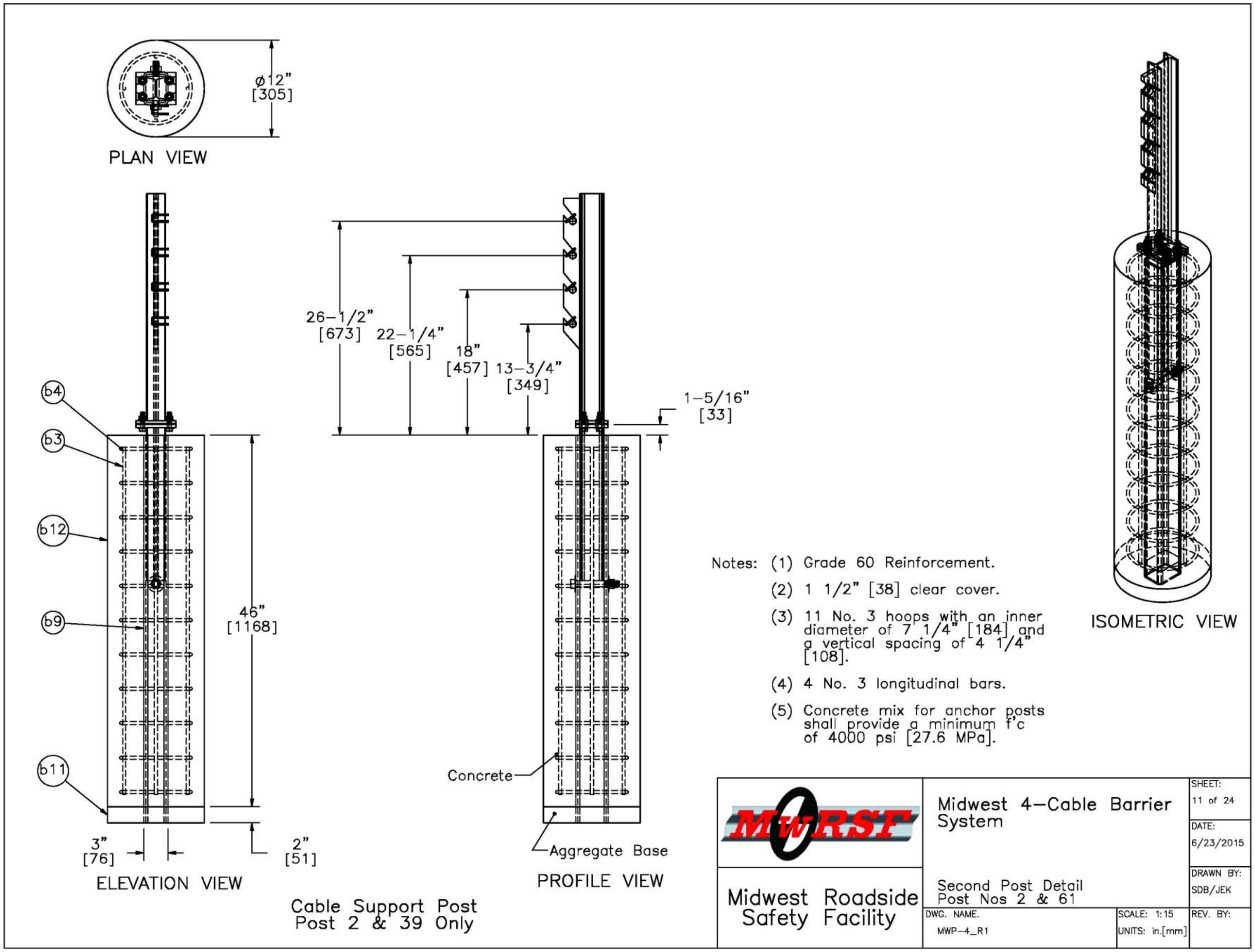

Figure 24. Second Post Details, Post Nos. 2 and 61, Test No. MWP-4

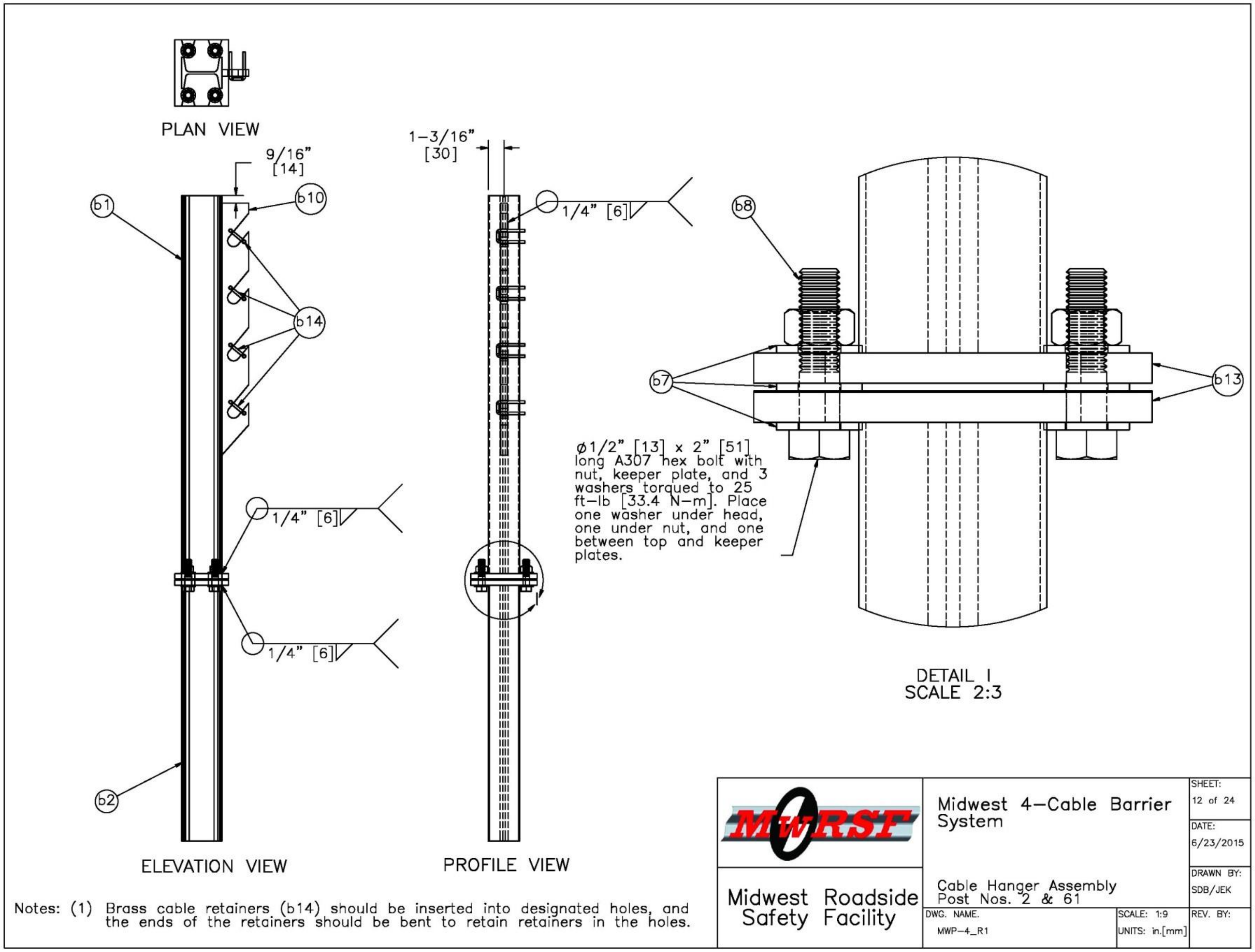

Figure 25. Cable Hanger Assembly, Post Nos. 2 and 61, Test No. MWP-4

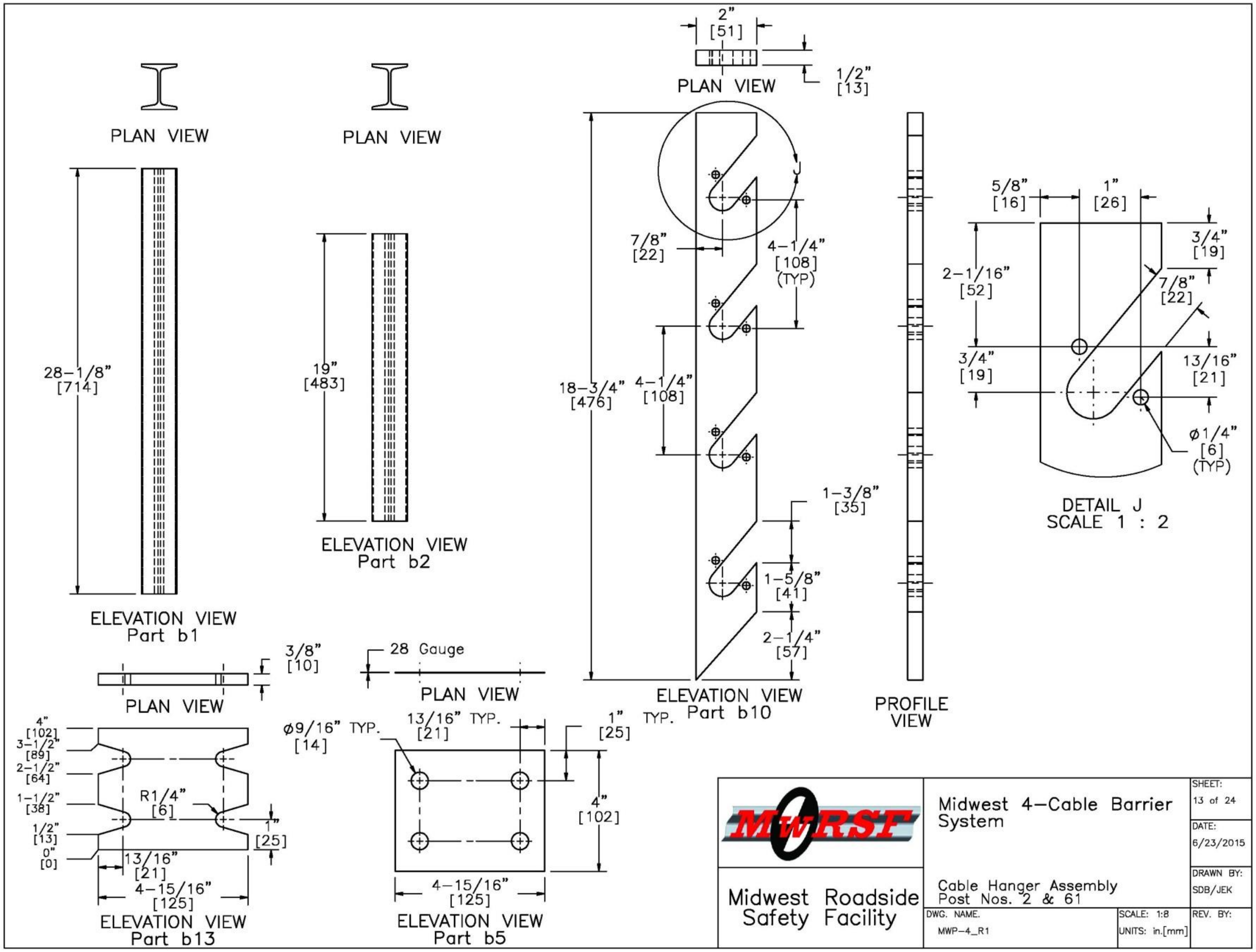

Figure 26. Cable Hanger Assembly, Post Nos. 2 and 61, Test No. MWP-4

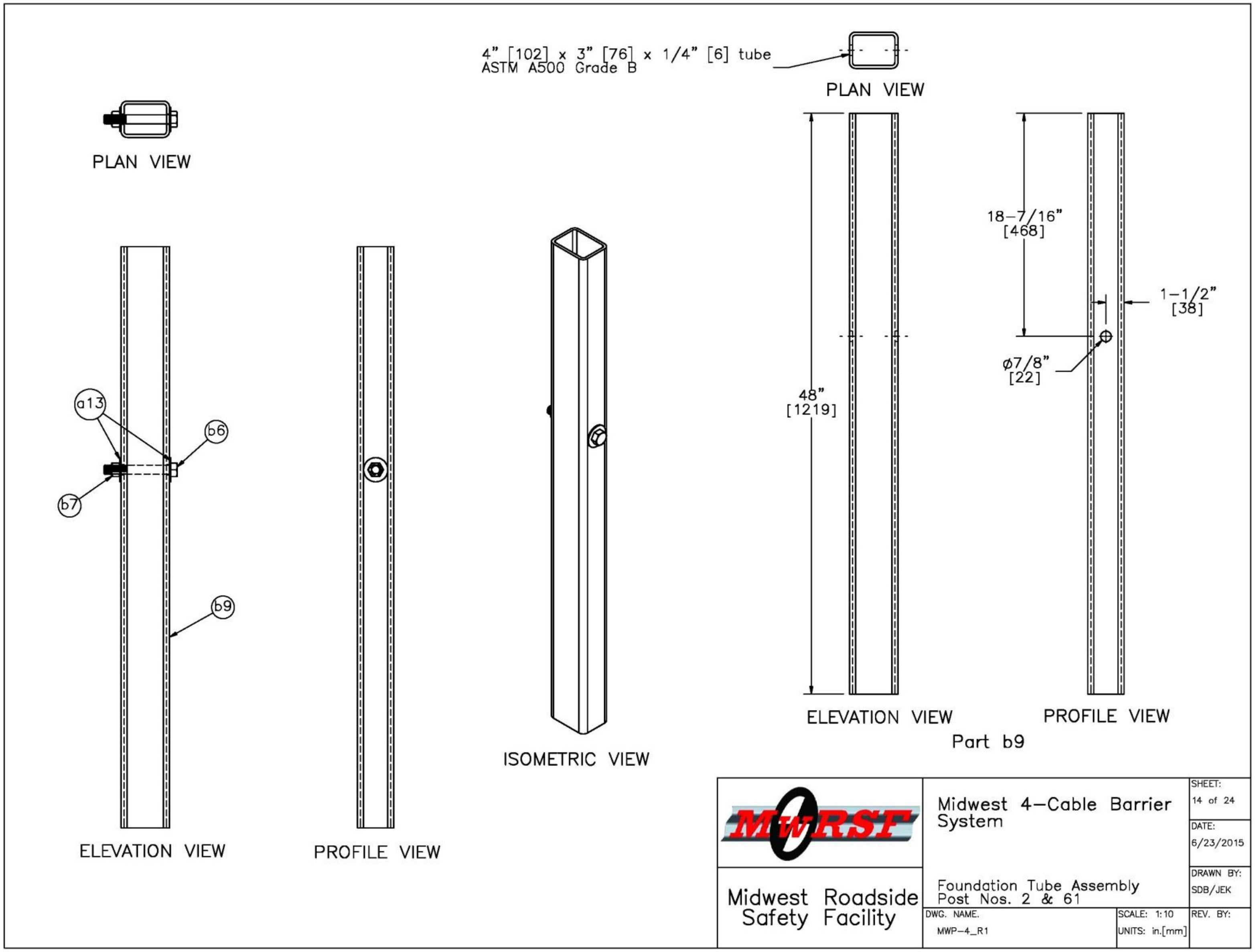

Figure 27. Foundation Tube Assembly, Post Nos. 2 and 61, Test No. MWP-4

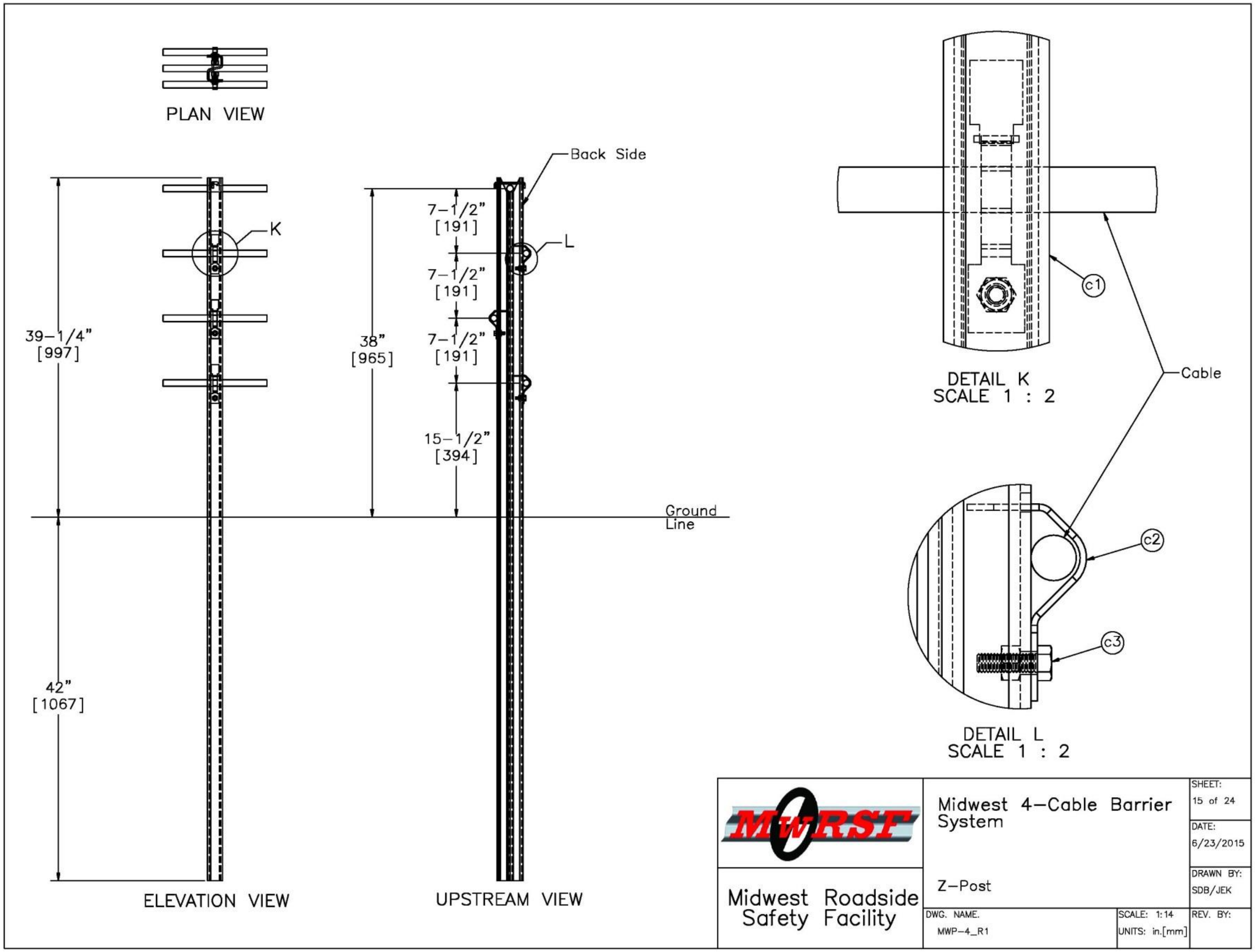

Figure 28. MWP Z-Post Details, Test No. MWP-4

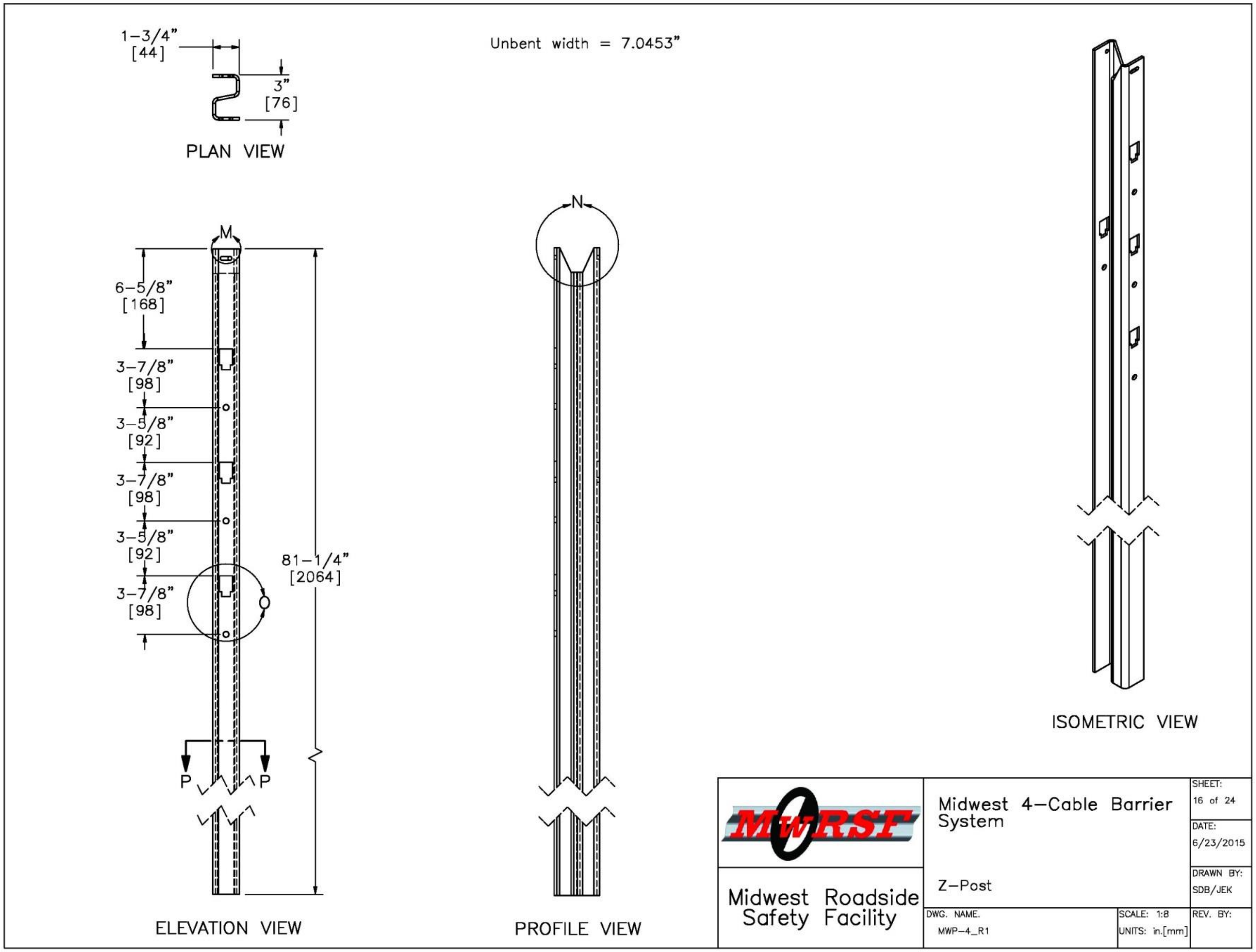

Figure 29. MWP Z-Post Details, Test No. MWP-4

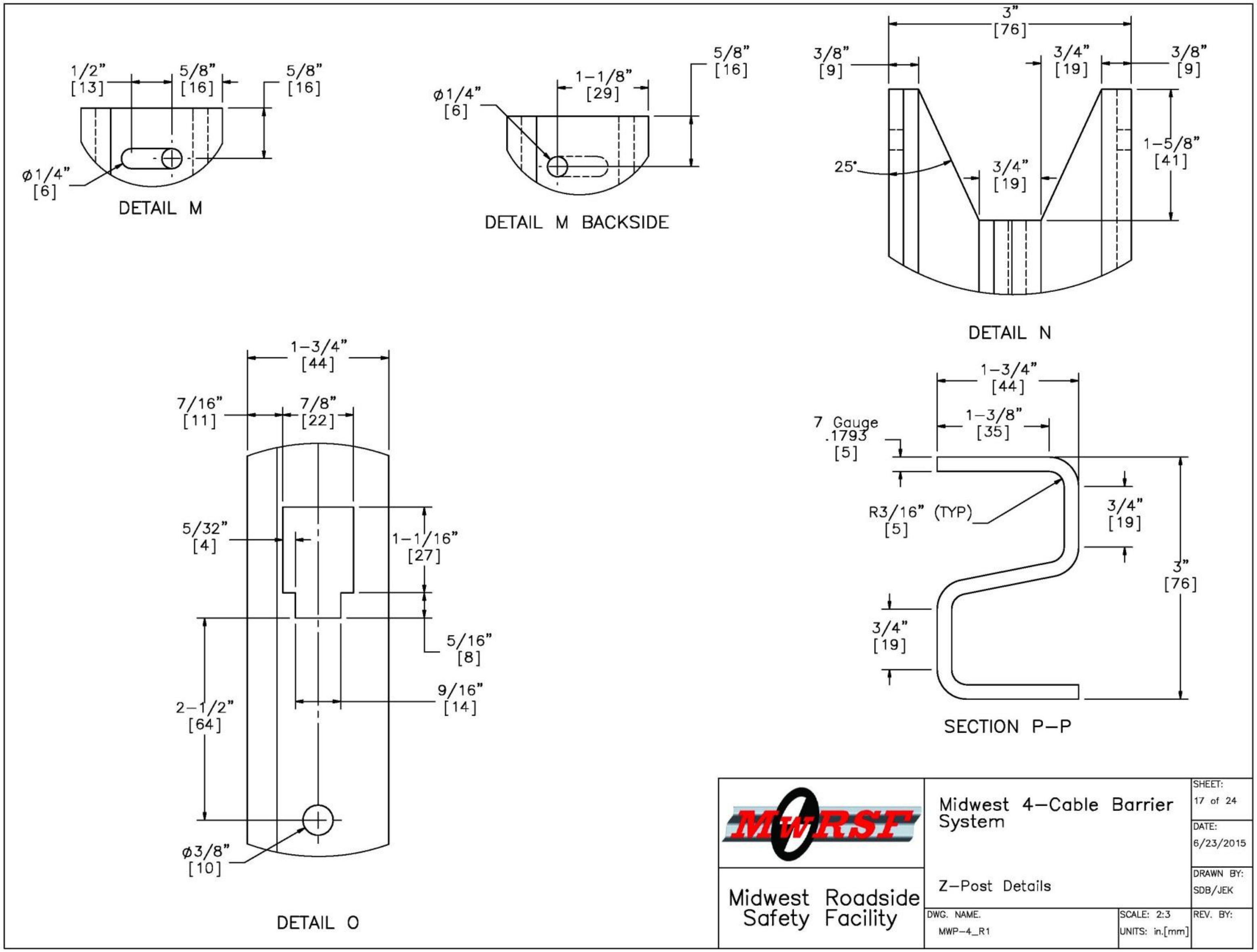

Figure 30. MWP Z-Post Details, Test No. MWP-4

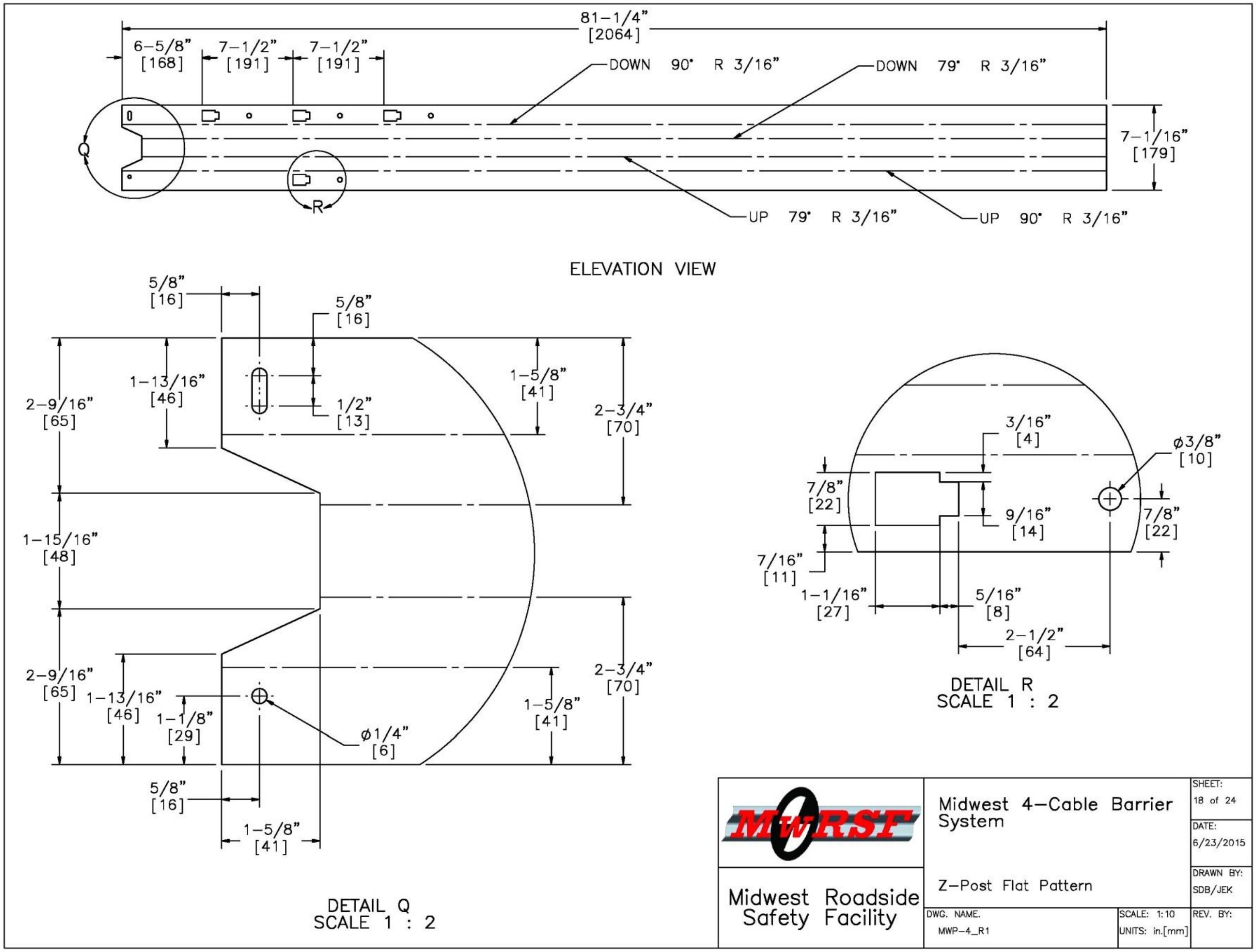

Figure 31. MWP Z-Post Details, Flat Pattern, Test No. MWP-4

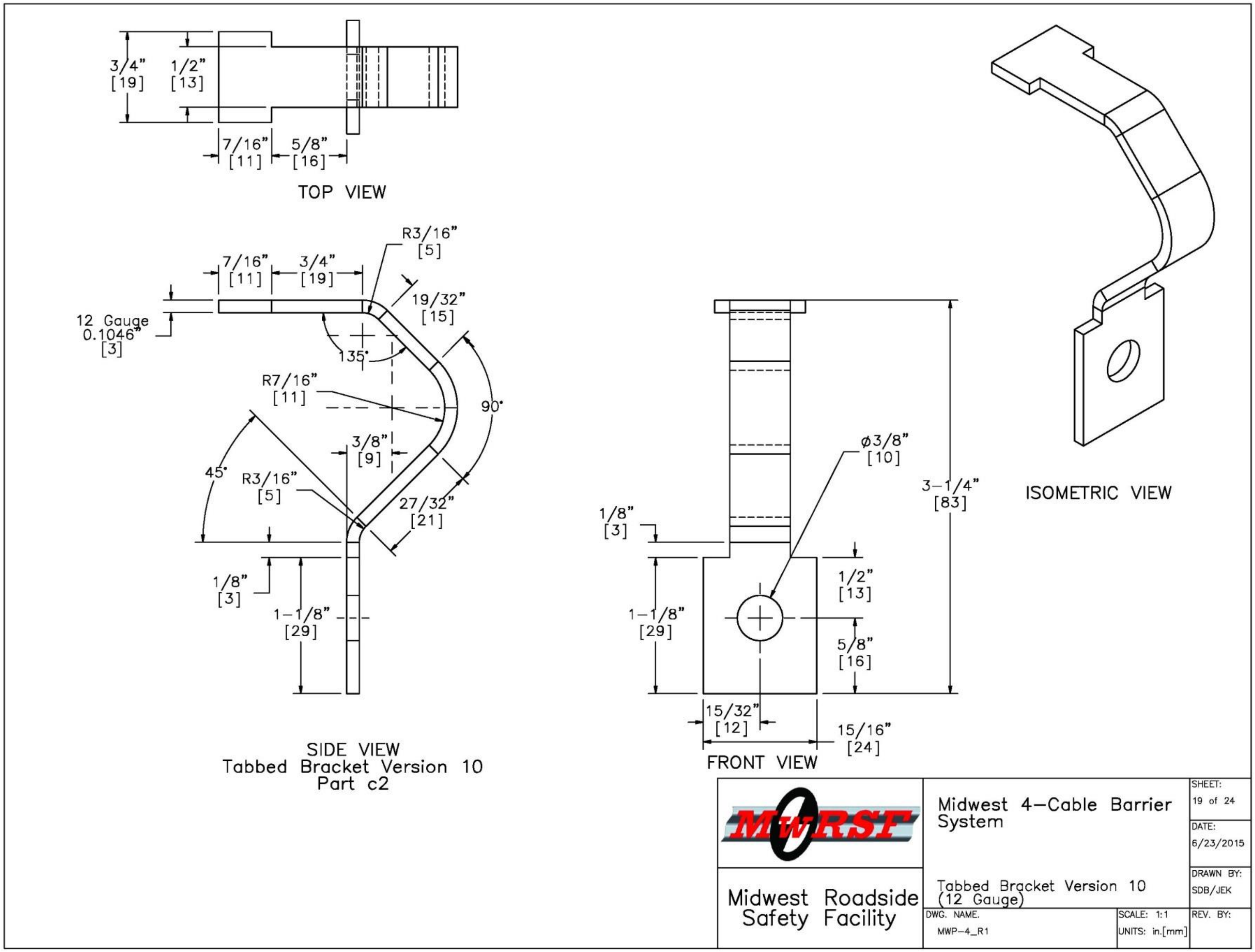

Figure 32. Tabbed Bracket Details, 12-Gauge, Test No. MWP-4

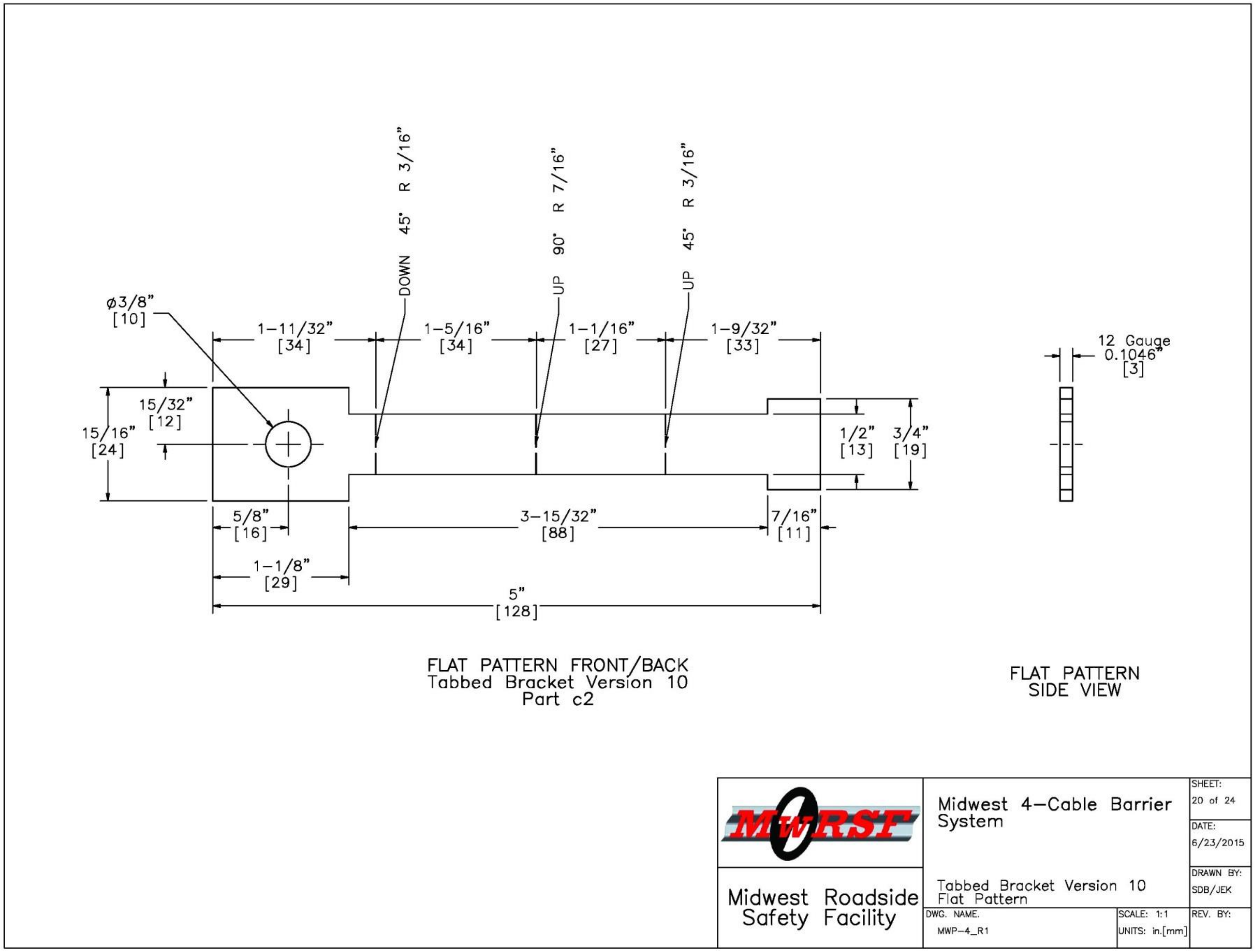

Figure 33. Tabbed Bracket Details, Flat Pattern, Test No. MWP-4

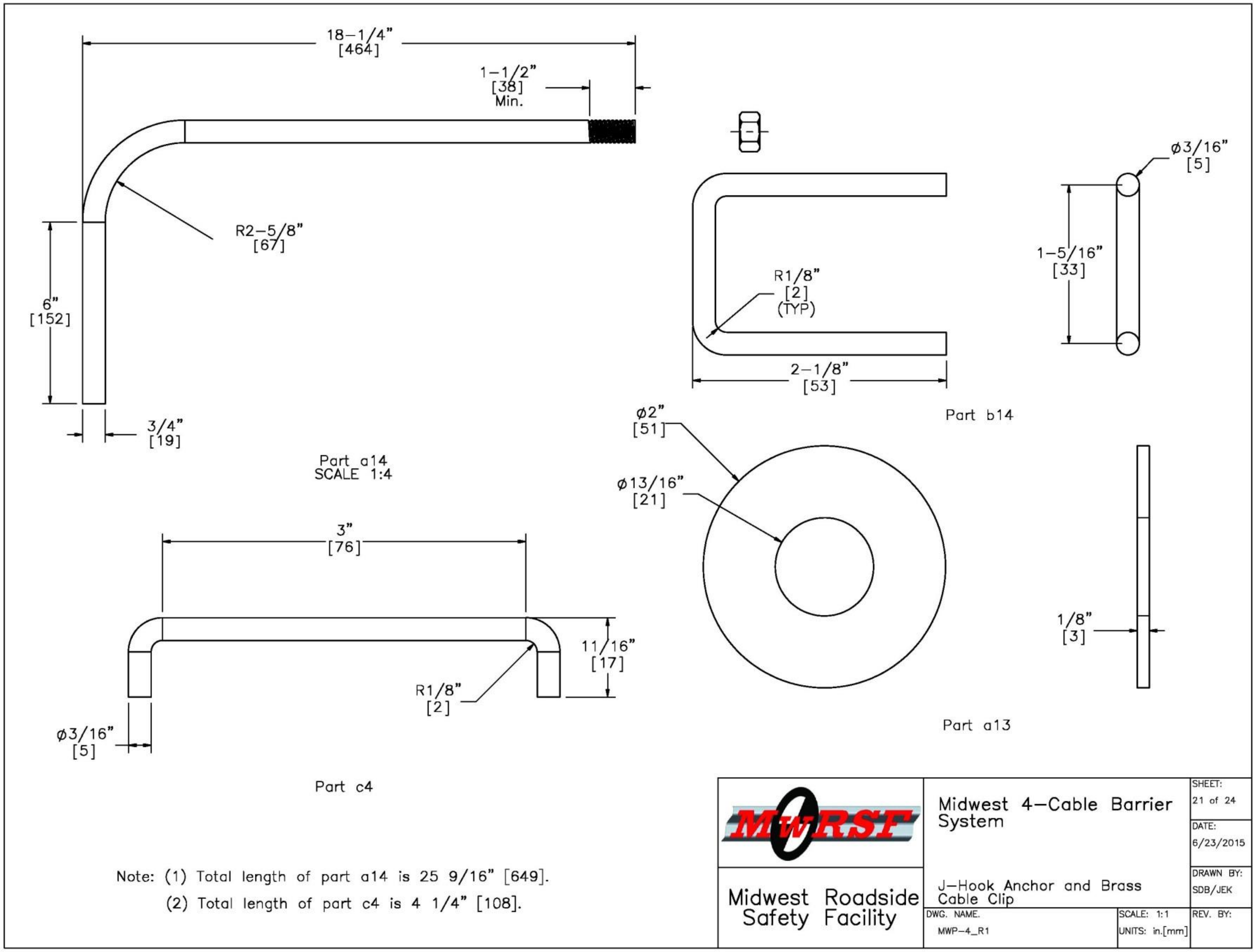

Figure 34. Brass Clips, Test No. MWP-4

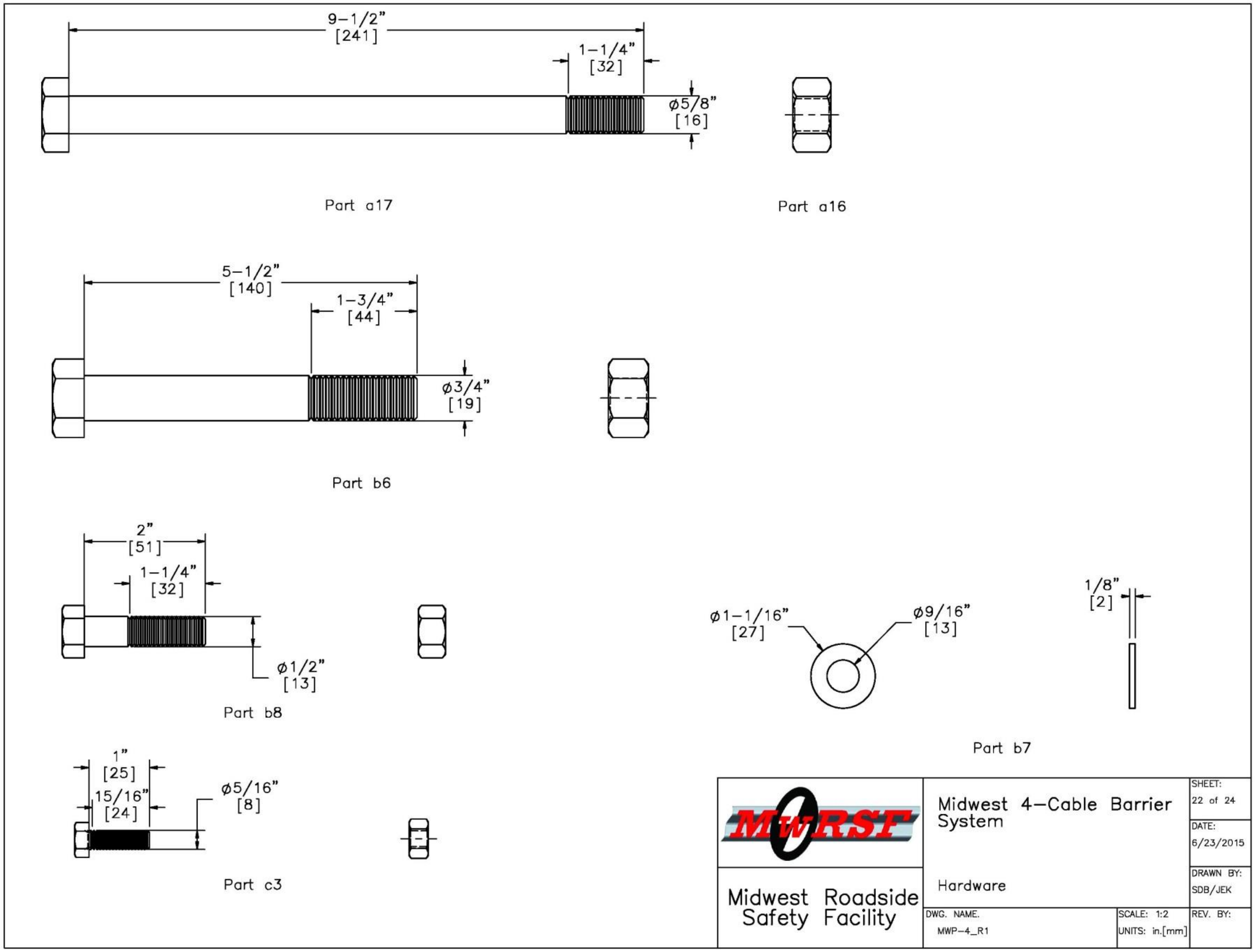

Figure 35. Hardware Details, Test No. MWP-4

| Item No. | QTY. | Description | Material Specification |
|---|---|---|---|
| a1 | 2 | Cable Anchor Base Plate | ASTM A36 |
| a2 | 4 | Exterior Cable Plate Gusset | ASTM A36 |
| a3 | 6 | Interior Cable Plate Gusset | ASTM A36 |
| a4 | 2 | Anchor Bracket Plate | ASTM A36 |
| a5 | 2 | 3/16” [5] Dia. Brass Keeper Rod, 14” [356] long | Brass |
| a6 | 4 | Release Gusset | A36 Steel |
| a7 | 2 | Release Lever Plate | A36 Steel |
| a8 | 4 | 1.25x1.25x0.1875” [32x32x5] TS CT Kicker Lever Tube | ASTM A500 Gr. B |
| a9 | 8 | CMB High Tension Anchor Plate Washer | ASTM A36 |
| a10 | 2 | 1.25x1.25x0.1875” [32x32x5] TS CT Kicker Lever Connecting Tube | ASTM A 500 Gr. B |
| a11 | 2 | 3x10x0.5” [76x254x13] Kicker Plate | ASTM A36 |
| a12 | 4 | CT kicker – gusset | ASTM A36 |
| a13 | 20 | 3/4” [19] Dia. Flat Washer | ASTM F844 |
| a14 | 16 | 3/4” [19] Dia. UNC J–Hook Anchor and Hex Nut | J–Hook ASTM A449/Nut ASTM A563 DH |
| a15 | 2 | 1/4” [6] Dia. Aircraft Retaining Cable, 36” [914] long | 7x19 Galv. |
| a16 | 2 | 5/8” [16] Dia. Heavy Hex Nut | ASTM A563C |
| a17 | 2 | 5/8” [16] Dia. UNC, 9 1/2” [241] Long Hex Bolt | ASTM A449 or SAE J429 Gr. 5 |
| a18 | 2 | 24” [610] Dia. Concrete Anchor, 120” [3048] long | 4,000 psi f'c |
| a19 | 16 | #11 Straight Rebar, 114” [2896] long | Grade 60 |
| a20 | 44 | #4 Anchor Hoop Rebar with 21” [533] Dia. | Grade 60 |
| b1 | 2 | S3x5.7 [S76x8.5] Post by 28 1/8” [714] | ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A |
| b2 | 2 | S3x5.7 [S76x8.5] Post by 19” [483] | ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A |
| b3 | 8 | #3 Straight Rebar, 43” [1092] long | Grade 60 |
| b4 | 22 | 7 1/4” [184] Dia. No. 3 Hoop Reinforcement | Grade 60 |
| b5 | 2 | 2nd Post Keeper Plate, 28 Gauge | ASTM A36 |
| b6 | 2 | 3/4” [19] Dia. UNC, 5 1/2” [140] Long Hex Bolt and Nut | Bolt ASTM A307 Gr. A/Nut ASTM A563A |
| b7 | 24 | 1/2” [13] Dia. Washer with 1 1/16” [27] OD | ASTM F844 |
| b8 | 8 | 1/2” [13] Dia. UNC, 2” [51] long Hex Bolt and Nut | Bolt ASTM A307 Gr. A/Nut ASTM A563A |
| b9 | 2 | 4x3x1/4” [102x76x6] Foundation Tube, 48” [1168] long | ASTM A500 Grade B |
| b10 | 2 | 2nd Post Cable Hanger | ASTM A36 |
| b11 | 2 | 2nd Post Anchor Aggregate 12 in, Depth | – |
| b12 | 2 | 12” Dia. 2nd Post Concrete Anchor, 46” long | 4,000 psi f'c |
| b13 | 4 | 2nd Post Base Plate | ASTM A36 |
| b14 | 8 | 3/16” [5] Dia. 5 1/4” [133] Long Brass Rod | ASTM B16–00 |

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Midwest 4–Cable Barrier System

Bill of Materials

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REV. BY:
DWG. NAME. MWP–4_R1
SCALE: NONE
UNITS: in.[mm]

Figure 36. Bill of Materials, Test No. MWP-4

| Item No. | QTY. | Description | Material Spec |
|---|---|---|---|
| c1 | 58 | 3"x1-3/4"x7 Gauge [76x44x4.6], 81 1/4" [2064] Long Bent MWP Z-Section Post | Hot-Rolled ASTM A1011 HSLA Gr. 50 |
| c2 | 174 | 12 Gauge Tabbed Bracket – Version 10 | Hot-Rolled ASTM A1011 HSLA Grade 50 |
| c3 | 174 | 5/16" [8] Dia. UNC, 1" [25] Long Hex Cap Screw and Nut | Bolt SAE J429 Gr. 5 or ASTM A449/Nut ASTM A563 DH |
| c4 | 58 | Straight Rod – ø3/16" [5] Cable Clip | ASTM B16 Brass C36000 Half Hard (HO2), ROUND. TS >= 68.0 ksi, YS >= 52.0 ksi |
| d1 | 1 | 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] |
| d2 | 16 | 7/8" [22] Dia. Hex Nut | ASTM A563C |
| d3 | 28 | Cable End Threaded Rod | ASTM A449 |
| d4 | 24 | Bennet Cable End Fitter | ASTM A47 |
| d5 | 24 | 7/8" [22] Dia. Hex Nut | SAE J429 Gr. 5 |
| e1 | 8 | Bennet Short Threaded Turnbuckle | Not Specified |
| e2 | 8 | Threaded Load Cell Coupler | N/A |
| e3 | 4 | 50,000-lb [222.4-kN] Load Cell | N/A |

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Bill of Materials

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SCALE: NONE
UNITS: in.[mm]
REV. BY:

Figure 37. Bill of Materials, Test No. MWP-4

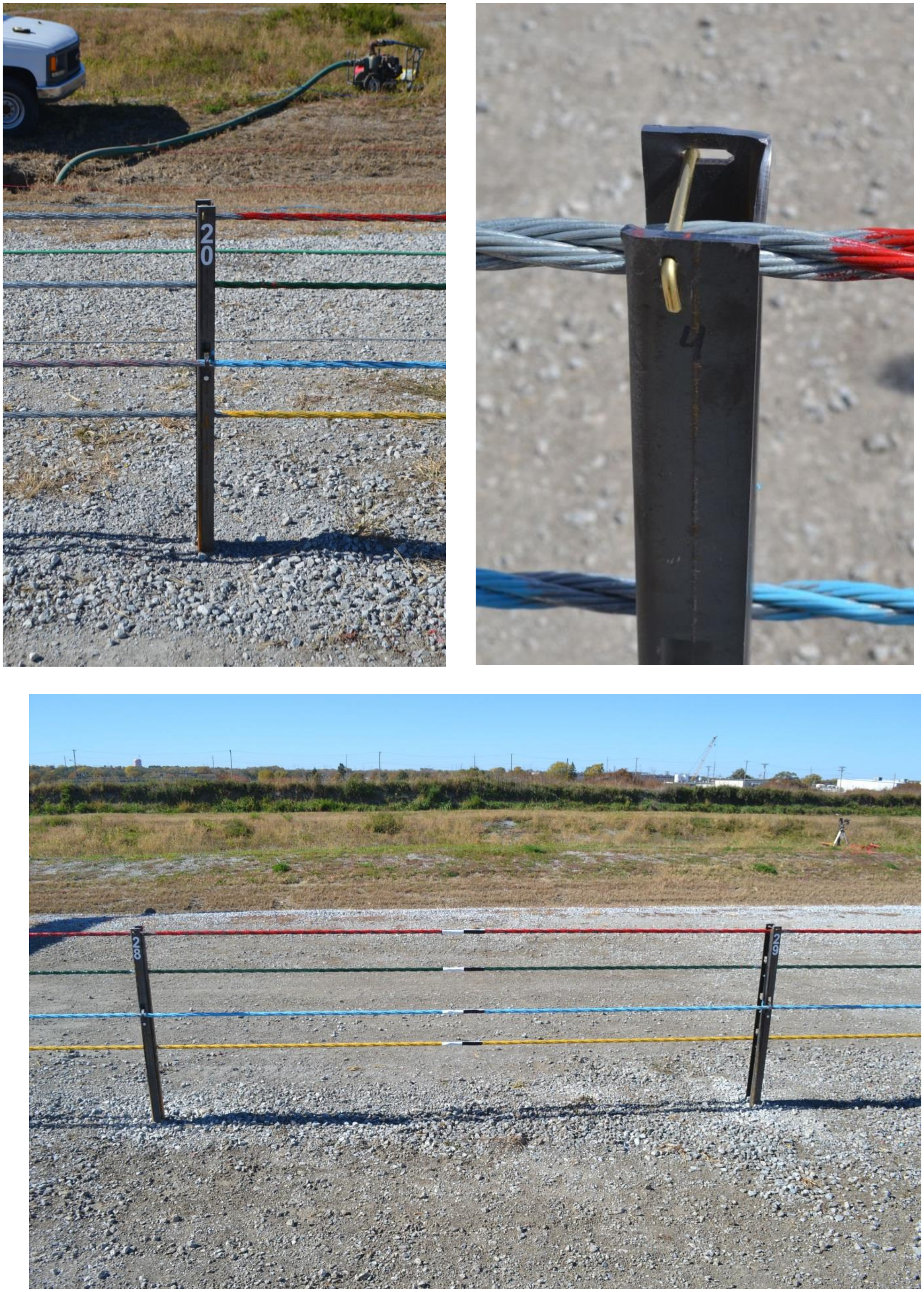


Figure 38. Test Installation Photographs, Test No. MWP-4

Figure 39. Test Installation Photographs, Test No. MWP-4

Figure 40. Test Installation Photographs, Test No. MWP-4

Figure 41. Test Installation Photographs, Test No. MWP-4

# 5 FULL SCALE CRASH TEST NO. MWP-4

## 5.1 Static Soil Test

Before full-scale crash test no. MWP-4 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. 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-4 was conducted on October 20, 2014 at approximately 2:30 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), were reported and are shown in Table 4.

Table 4. Weather Conditions, Test No. MWP-4

| | |
|---|---|
| Temperature | 74°F |
| Humidity | 26% |
| Wind Speed | 6 mph |
| Wind Direction | 10° West of True North |
| Sky Conditions | Sunny |
| Visibility | 6 Statute Miles |
| Pavement Surface | Dry |
| Previous 3-Day Precipitation | 0 in. |
| Previous 7-Day Precipitation | 0 in. |

## 5.3 Test No. MWP-4

The 5,131-lb (2,327-kg) pickup truck impacted the high-tension, four-cable median barrier at a speed of 60.8 mph (97.8 km/h) and an angle of 26.1 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. Documentary photographs of the crash test are shown in Figure 46.

## 5.4 Test Description

Initial vehicle impact was to occur 1 ft (0.3 m) upstream from post no. 25, as shown in Figure 47, which was selected according to proposed MASH updates. The actual point of impact was approximately 1.9 in. (48 mm) upstream from the target impact point. A sequential description of the impact events is contained in Table 5. The vehicle came to rest 144 ft - 10 in. (44.1 m) downstream from the point of impact, between post nos. 38 and 39. The vehicle trajectory and final position are shown in Figures 42 and 48.

Table 5. Sequential Description of Impact Events, Test No. MWP-4

| TIME (sec) | EVENT |
|---|---|
| 0.000 | Vehicle left-front bumper contacted cable no. 2 upstream of post no. 25, and post no. 25 began to deflect backward. |
| 0.004 | Vehicle left-front bumper contacted post no. 25, and post no. 25 began to deflect downstream and bend backward. |
| 0.010 | Vehicle left headlight contacted cable no. 4 upstream of post no. 25, and vehicle left fender began to deform. |
| 0.014 | Vehicle left headlight contacted post no. 25. |
| 0.022 | Vehicle left-front tire contacted post no. 25. |
| 0.024 | Post no. 24 began to deflect backward. |
| 0.026 | Vehicle left fender contacted post no. 25 and cable no. 4, vehicle left headlight was shattered, and vehicle left-front tire began to override post no. 25. |
| 0.028 | Post no. 23 began to deflect backward. |
| 0.030 | Post no. 26 began to deflect backward. |
| 0.036 | Cable no. 4 detached from post no. 25. |
| 0.038 | Cable no. 3 detached from post no. 25. |
| 0.040 | Cable no. 2 detached from post no. 25. |
| 0.046 | Vehicle began to roll away from barrier, and post no. 24 began to twist downstream. |
| 0.052 | Post no. 27 began to deflect backward. |
| 0.056 | Vehicle grill began to deform. |
| 0.068 | Vehicle left-front tire overrode cable no. 1. |
| 0.074 | Post no. 22 began to deflect backward. |
| 0.076 | Vehicle left-front tire overrode post no. 25. |
| 0.080 | Cable no. 4 detached from post no. 26. |
| 0.086 | Cable no. 2 detached from post no. 26. |
| 0.096 | Vehicle left-front tire overrode cable no. 3, and post no. 28 began to deflect backward. |
| 0.108 | Cable no. 4 detached from post no. 27. |

| | |
|---|---|
| 0.110 | Cable no. 2 detached from post no. 27. |
| 0.114 | Vehicle began to yaw away from barrier, and the left-front tire ruptured. |
| 0.124 | Cable no. 2 detached from post no. 24. |
| 0.128 | Cable no. 4 detached from post no. 24. |
| 0.136 | Post no. 29 began to deflect backward. |
| 0.140 | Vehicle left-front bumper contacted post no. 26, and post no. 26 began to bend downstream. |
| 0.156 | Cable no. 2 detached from post no. 28. |
| 0.164 | Post no. 29 began to rotate backward, and cable no. 4 detached from post no. 28. |
| 0.168 | Cable no. 4 detached from post no. 23. |
| 0.170 | Cable no. 2 detached from post no. 29. |
| 0.174 | Post no. 30 began to deflect backward. |
| 0.186 | Vehicle left-rear tire overrode post no. 25 and became airborne. |
| 0.192 | Post no. 30 began to bend backward, and cable no. 4 detached from post no. 29. |
| 0.210 | Post no. 31 began to deflect backward, and cable no. 1 detached from post no. 27. |
| 0.218 | Vehicle left-rear tire overrode cable nos. 1 and 3. |
| 0.222 | Vehicle right-front tire overrode cable no. 1. |
| 0.226 | Cable no. 4 detached from post no. 31. |
| 0.230 | Vehicle right-front bumper contacted post no. 27, and post no. 27 began to bend downstream. |
| 0.242 | Vehicle began to roll toward the barrier. |
| 0.252 | Post no. 32 began to deflect backward. |
| 0.258 | Cable no. 4 detached from post no. 31. |
| 0.268 | Vehicle right-front tire overrode cable no. 3. |
| 0.276 | Cable no. 4 detached from post no. 32. |
| 0.284 | Post no. 33 began to deflect backward. |
| 0.300 | Cable no. 4 detached from post no. 33. |
| 0.318 | Post no. 34 began to bend backward. |
| 0.328 | Cable no. 4 detached from post no. 22. |
| 0.330 | Cable no. 4 detached from post no. 34. |
| 0.342 | Vehicle left-rear tire regained contact with ground. |
| 0.374 | Vehicle right-rear tire overrode cable no. 1, and cable no. 4 detached from post no. 21. |
| 0.388 | Post no. 35 began to bend backward. |
| 0.394 | Vehicle right-rear tire contacted post no. 27. |
| 0.404 | Post no. 36 began to bend backward. |
| 0.414 | Cable no. 4 detached from post no. 35. |
| 0.422 | Vehicle right-rear tire became airborne. |
| 0.470 | Vehicle was parallel to system. |
| 0.516 | Vehicle right-front tire became airborne. |
| 0.560 | Vehicle left-front tire overrode cable no. 2. |
| 0.580 | Cable no. 4 detached from post no. 20. |
| 0.594 | Vehicle began to yaw toward barrier. |
| 0.662 | Cable no. 4 detached from post no. 19. |
| 0.704 | Vehicle left-rear tire overrode cable no. 2. |

| | |
|---|---|
| 0.912 | Cable no. 4 detached from post no. 18. |
| 0.914 | Cable no. 1 detached from post no. 24. |
| 1.038 | Vehicle right-front tire regained contact with ground. |
| 1.102 | Vehicle right-rear tire regained contact with ground. |
| 1.130 | Vehicle right quarter panel contacted post no. 32 and began to deform, and cable no. 4 detached from post no. 36. |
| 1.160 | Vehicle right-front tire ruptured. |
| 1.210 | Vehicle was yawing away from barrier. |
| 1.900 | Vehicle right-front bumper impacted post no. 36, causing it to bend downstream. |
| 2.092 | Vehicle right-front bumper impacted post no. 37, causing it to bend downstream. |
| 2.403 | Vehicle right-front bumper impacted post no. 38, causing it to bend downstream. |
| 2.815 | Vehicle right-front bumper impacted post no. 39, causing it to bend downstream. |
| 3.310 | Vehicle came to rest 144-ft 10-in. (44.1 m) downstream from impact with right-front tire on top of a bent over post no. 39. |

## 5.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 49 through 59. 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 2 were beneath the vehicle, cable no. 4 was on the impact side of the vehicle, and cable no. 3 was on the non-impact side of the vehicle.

Cable no. 4 disengaged from post nos. 18 through 40 due to fracture of the brass keeper rods. Cable no. 3 disengaged from post nos. 25, 27, 32 and 33, as well as post nos. 36 through 39. Cable no. 2 disengaged from post nos. 15 through 40. Cable no. 1 disengaged from post nos. 24, 26, 29, and post nos. 36 through 39. Nearly all of the releases of cable nos. 1 through 3 were due to the tabs rotating through the key to release the cables vertically. However, the release of cable no. 2 at post no. 37 was due to bracket fracture at the tab. Displacement of the cable splices were documented, but they were deemed small. The maximum displacement within a splice measured ½ in. (13 mm) at the load cell splice found in cable no. 4.

Post nos. 17 through 40 deformed in bending and twisting. The posts typically twisted upstream and bent backward. Post nos. 25 through 27 and 36 through 39 exhibited the greatest deformations, with post nos. 36 through 39 partially or fully bent to the ground line due to vehicle override. Post no. 2 was bent slightly downstream from forces on the anchor.

The maximum dynamic barrier deflection of the system was 200 in. (5,080 mm) near post no. 28, and the working width of the system was 201.3 in. (5,113 mm), as determined from high-speed video analysis. The upstream anchor was displaced ¼ in. (6 mm) downstream. The downstream anchor did not show signs of displacement.

### 5.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 60 and 61. The maximum occupant compartment deformations are listed in Table 6 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH-established deformation limits were violated. 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, Test No. MWP-4

| LOCATION | MAXIMUM DEFORMATION in. (mm) | MASH ALLOWABLE DEFORMATION in. (mm) |
|---|---|---|
| Wheel Well & Toe Pan | ¼ (6) | ≤9 (229) |
| Floor Pan & Transmission Tunnel | ¼ (6) | ≤12 (305) |
| Side Front Panel (in Front of A-Pillar) | ¼ (6) | ≤12 (305) |
| Side Door (Above Seat) | ¼ (6) | ≤12 (305) |
| Side Door (Below Seat) | 1 (25) | ≤9 (229) |
| Roof | 0 (0) | ≤12 (305) |

The majority of the vehicle damage was concentrated on the left-front corner and left side of the vehicle where impact occurred. The left-front bumper was partially disengaged. The left fender and left-front bumper separated by 2½ in. (64 mm). The left fender was crushed 3½ in. (89 mm) inward between the left headlight and wheel well. There was a 7-in. (178-mm) buckle at the top of the left wheel well. There was a 1-in. (25-mm) separation between the left fender and the hood. The left-front door separated in the front by 2½ in. (64 mm), along the top by ¾ in. (19 mm), and along the bottom of the door by 1 in. (25 mm). The left-front door also overlapped the left-rear door. Both the left headlight and fog-light disengaged. There was a 5½-in. (140-mm) buckle at the bottom rear of the left-rear wheel well. The left-rear bumper separated 1½ in. (38 mm) from the left quarter panel, and the left taillight separated ¾ in. (19 mm) from the quarter panel. There was a gap of ½ in. (13 mm) between the left-front door and fender. The right headlight was shattered but remained attached. There was a 5-in. (127-mm) deep crush at the front of the right-front wheel well, in the fender. The right-front tire was deflated.

There were contact marks from cables along both the left and right sides of the vehicle. There were sheet metal tears of varying lengths on the back of the right-rear wheel well, the right-rear tire rim, the right-front bumper, the left-rear bumper, the left fender along the back of the left-front wheel well, and the left-front door. There were several cuts in the right quarter panel. Dents occurred at the wheel wells, tire rims, front bumper, and left-front door and quarter panel. Gouging occurred on both rear wheel wells and tire rims, as well as the left-front tire rim. Kinking occurred along the bottom of the left-front door, the right-rear wheel well, and the rear bumper.

### 5.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 7. Note that the OIVs and ORAs were within the suggested limits provided in MASH. 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 also 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-4

| **Evaluation Criteria** | | **Transducer** | | **MASH Limits** |
|---|---|---|---|---|
| | | **DTS (primary)** | **SLICE 2** | |
| **OIV ft/s (m/s)** | Longitudinal | -9.38 (-2.86) | -9.12 (-2.78) | ≤ 40 (12.2) |
| | Lateral | 8.37 (2.55) | 8.66 (2.64) | ≤ 40 (12.2) |
| **ORA g's** | Longitudinal | -8.78 | -8.96 | ≤ 20.49 |
| | Lateral | -5.33 | 4.99 | ≤ 20.49 |
| **MAX. ANGULAR DISPLACEMENT deg.** | Roll | -14.69 | -14.94 | ≤ 75 |
| | Pitch | -4.04 | -4.13 | ≤ 75 |
| | Yaw | 41.57 | 41.34 | not required |
| **THIV ft/s (m/s)** | | 11.81 (3.60) | 12.24 (3.73) | not required |
| **PHD g's** | | 9.29 | 9.52 | not required |
| **ASI** | | 0.43 | 0.40 | not required |

## 5.8 Load Cells and String Potentiometers

The pertinent data from the load cells and string potentiometer were extracted from the bulk signal and analyzed using the transducers' calibration factors. The maximum displacement of the upstream anchor was recorded as 0.73 in. (19 mm), while a summary of the maximum cable loads can be found in 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 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.

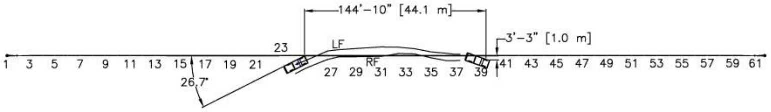
Table 8. Maximum Cable Loads, Test No. MWP-4

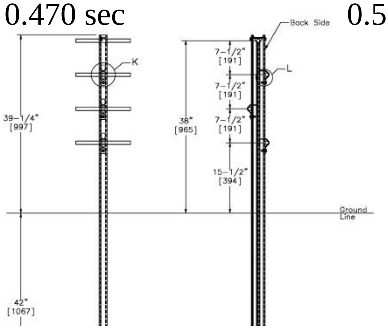
| Cable Location | Sensor Location | Maximum Cable Load | | Time (sec) |
|---|---|---|---|---|
| | | kips | kN | |
| Combined Cable Load | Upstream of Impact | 39.35 | 175.04 | 0.5187 |
| Cable No. 4 | Upstream of Impact | 18.19 | 80.91 | 0.7970 |
| Cable No. 3 | Upstream of Impact | 7.99 | 35.54 | 0.0604 |
| Cable No. 2 | Upstream of Impact | 18.42 | 81.94 | 0.5290 |
| Cable No. 1 | Upstream of Impact | 5.13 | 22.82 | 0.0518 |

### 5.9 Discussion

The analysis of the test results for test no. MWP-4 showed that the high-tension four-cable median barrier adequately contained and redirected the 2270P, with controlled lateral displacements of the barrier. There were no detached elements or fragments which showed potential for penetrating the occupant compartment or which presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. 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 or cause rollover. After impact, the vehicle was captured and retained within the system, so there was no exit information. Therefore, test no. MWP-4, conducted on the four-cable high-tension median barrier system, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-11.


0.000 sec 0.046 sec 0.230 sec 0.470 sec 0.594 sec





- Test Agency ........ MwRSF
- Test Number ........ MWP-4
- Date ........ 10/20/14
- MASH Test Designation ........ 3-11
- 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 mm, 584 mm, 775 mm, 965 mm)
- Key Component - MWP
    - Dimensions ........ 3 x 1¾ x 83 in. (76 x 44 x 2,108 mm)
    - Spacing ........ 10 ft (3.05 m)
- Soil Type ........ Compacted, coarse, crushed limestone
- Vehicle Make /Model ........ 2008 Dodge Ram
    - Curb ........ 5,140 lb (2,331 kg)
    - Test Inertial ........ 4,967 lb (2,253 kg)
    - Gross Static ........ 5,131 lb (2,327 kg)
- Impact Conditions
    - Speed ........ 60.8 mph (97.8 km/h)
    - Angle ........ 26.1 deg
    - Impact Location ........ 13.9 in. (0.35 m) upstream of Post no. 25
- Impact Severity (IS) ........ 118.6 kip-ft (160.8 kJ) > 106 kip-ft (143.7 kJ)
- Exit Conditions
    - Speed ........ NA
    - Angle ........ NA
- Exit Box Criterion ........ NA (Did not exit system)
- Vehicle Stability ........ Satisfactory
- Vehicle Stopping Distance ........ 144 ft - 10 in. (44.1 m)
- Vehicle Damage ........ Moderate
    - VDS [8] ........ 11-LFQ-4
    - CDC [9] ........ 11-LYEN-3
    - Maximum Interior Deformation ........ 1 in. (25 mm)
- Test Article Damage ........ Moderate
- Maximum Test Article Deflections
    - Permanent Set ........ 57 in. (1,448 mm)
    - Dynamic ........ 200 in. (5,080 mm)
    - Working Width ........ 201.3 in. (5,113 mm)
- Transducer Data

| Evaluation Criteria | | Transducer | | MASH Limit |
|---|---|---|---|---|
| | | DTS (primary) | SLICE-2 | |
| OIV ft/s (m/s) | Longitudinal | -9.38 (-2.86) | -9.12 (-2.78) | ≤ 40 (12.2) |
| | Lateral | 8.37 (2.55) | 8.66 (2.64) | ≤ 40 (12.2) |
| ORA g's | Longitudinal | -8.78 | -8.96 | ≤ 20.49 |
| | Lateral | -5.33 | 4.99 | ≤ 20.49 |
| MAX. ANGULAR DISPLACEMENT deg. | Roll | -14.69 | -14.94 | ≤ 75 |
| | Pitch | -4.04 | -4.13 | ≤ 75 |
| | Yaw | 41.57 | 41.34 | not required |
| THIV – ft/s (m/s) | | 11.81 (3.60) | 12.24 (3.73) | not required |
| PHD – g's | | 9.29 | 9.52 | not required |
| ASI | | 0.43 | 0.40 | not required |

Figure 42. Summary of Test Results and Sequential Photographs, Test No. MWP-4

0.000 sec

0.020 sec

0.040 sec

0.092 sec

0.124 sec

0.192 sec

0.000 sec

0.114 sec

0.242 sec

0.388 sec

0.600 sec

1.038 sec

Figure 43. Additional Sequential Photographs, Test No. MWP-4


0.000 sec


0.078 sec


0.156 sec


0.242 sec


0.422 sec


0.576 sec


0.000 sec


0.036 sec

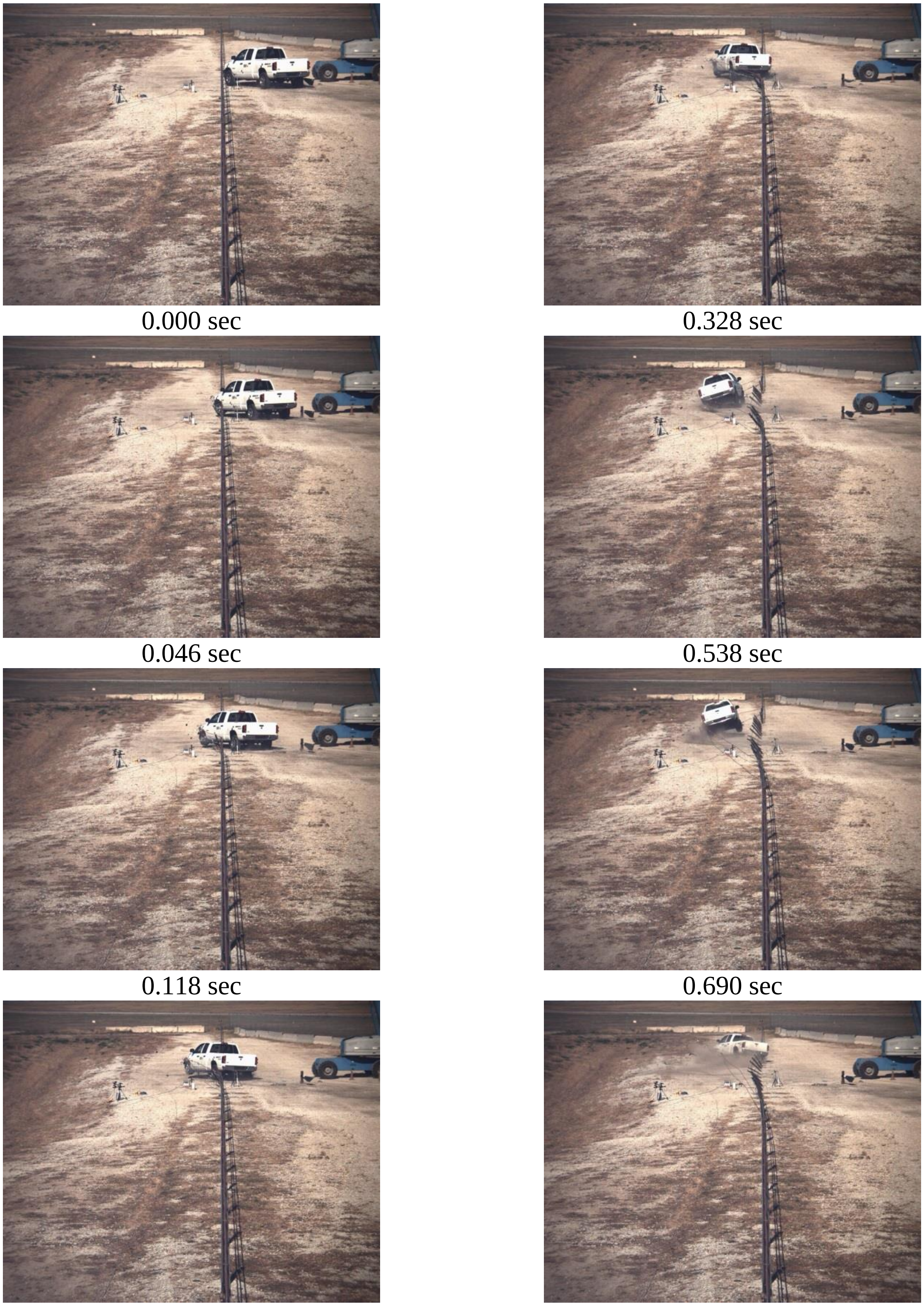

0.080 sec


0.114 sec


0.198 sec


0.242 sec

Figure 44. Additional Sequential Photographs, Test No. MWP-4



0.000 sec

0.046 sec

0.118 sec

0.206 sec

0.328 sec

0.538 sec

0.690 sec

1.210 sec

Figure 45. Additional Sequential Photographs, Test No. MWP-4

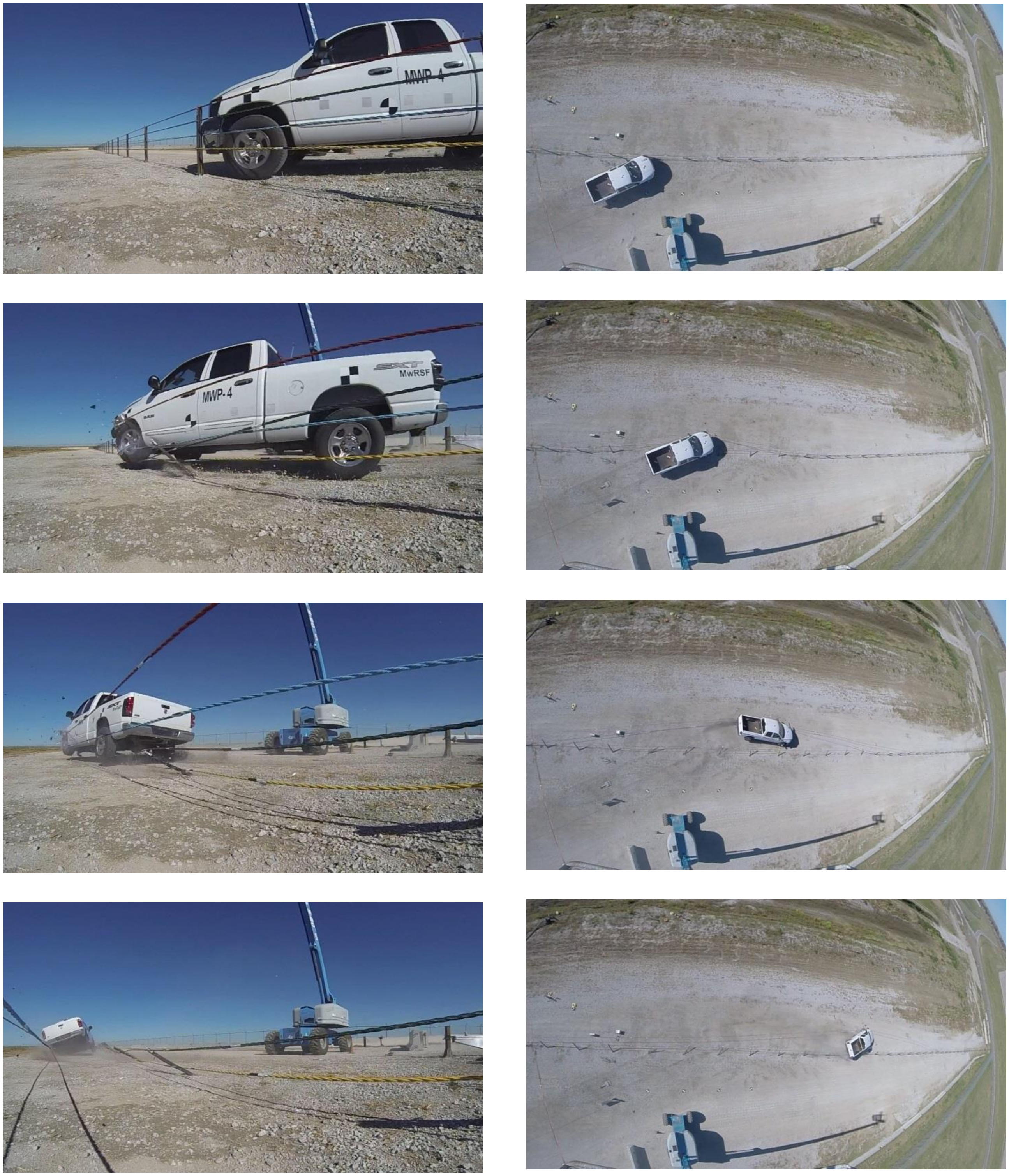


Figure 46. Documentary Photographs, Test No. MWP-4

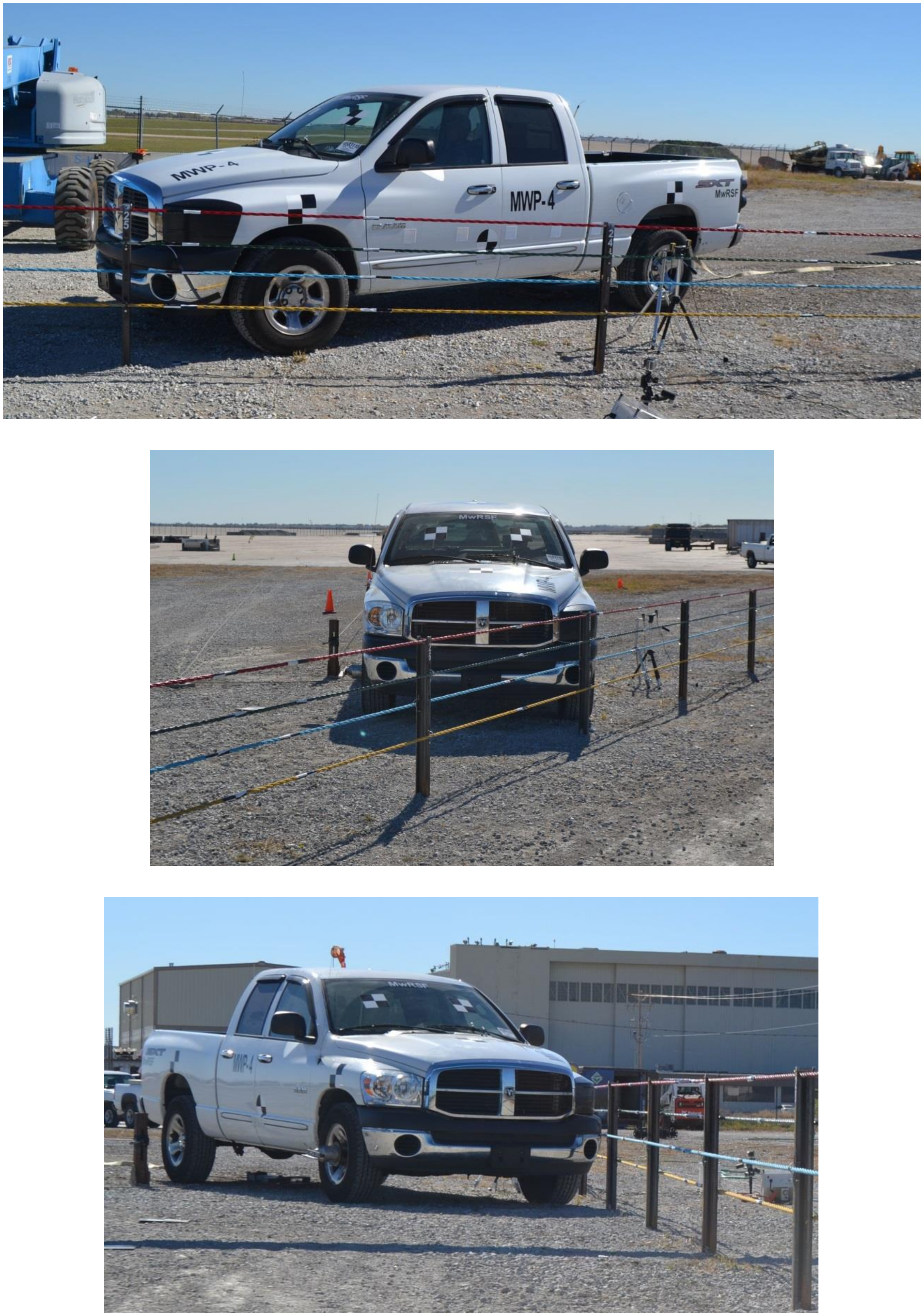


Figure 47. Impact Location, Test No. MWP-4

Figure 48. Vehicle Final Position and Trajectory, Test No. MWP-4

Figure 49. System Damage, Test No. MWP-4

Figure 50. System Damage, End Anchorages, Test No. MWP-4

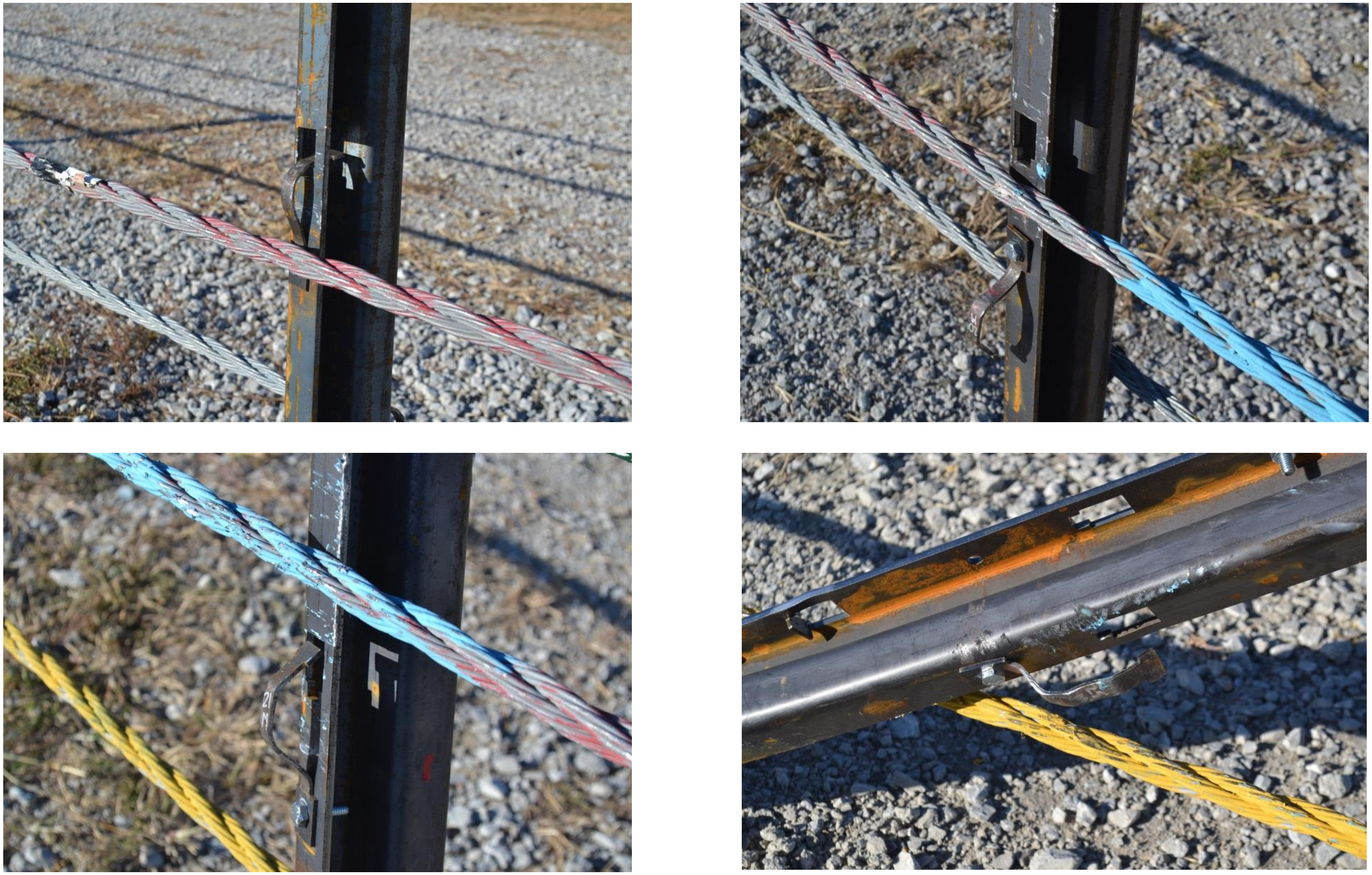
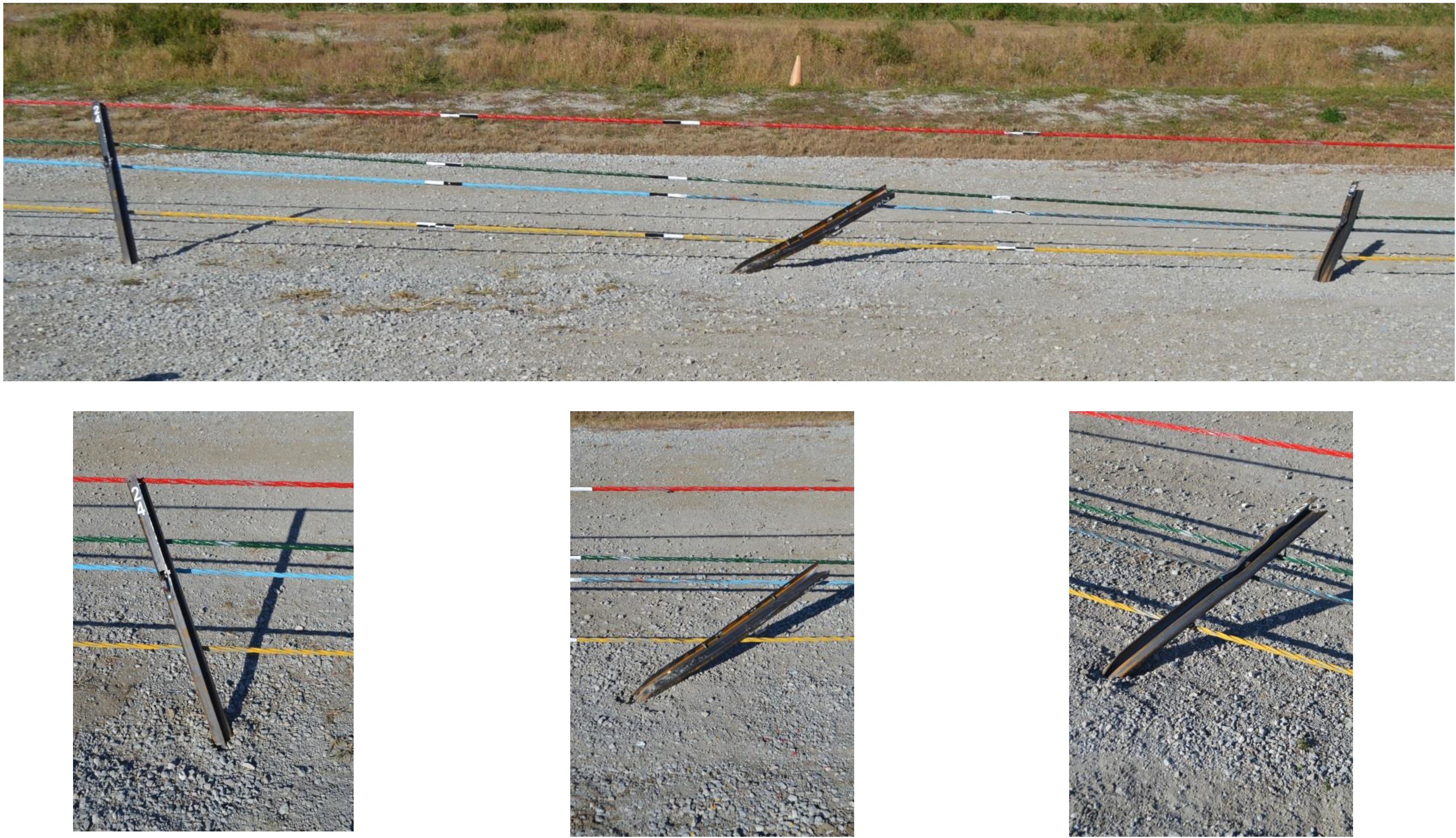


Figure 51. System Damage, Cable Brackets, Test No. MWP-4

Figure 52. System Damage, Cable Brackets, Test No. MWP-4

Figure 53. System Damage, Brass Rods, Test No. MWP-4



Post No. 24

Post No. 25

Post No. 26

Figure 54. System Damage, Post Nos. 24 through 26, Test No. MWP-4

Post No. 27

Post No. 28

Post No. 29

Figure 55. System Damage, Post Nos. 27 through 29, Test No. MWP-4

Post No. 30 Post No. 31 Post No. 32

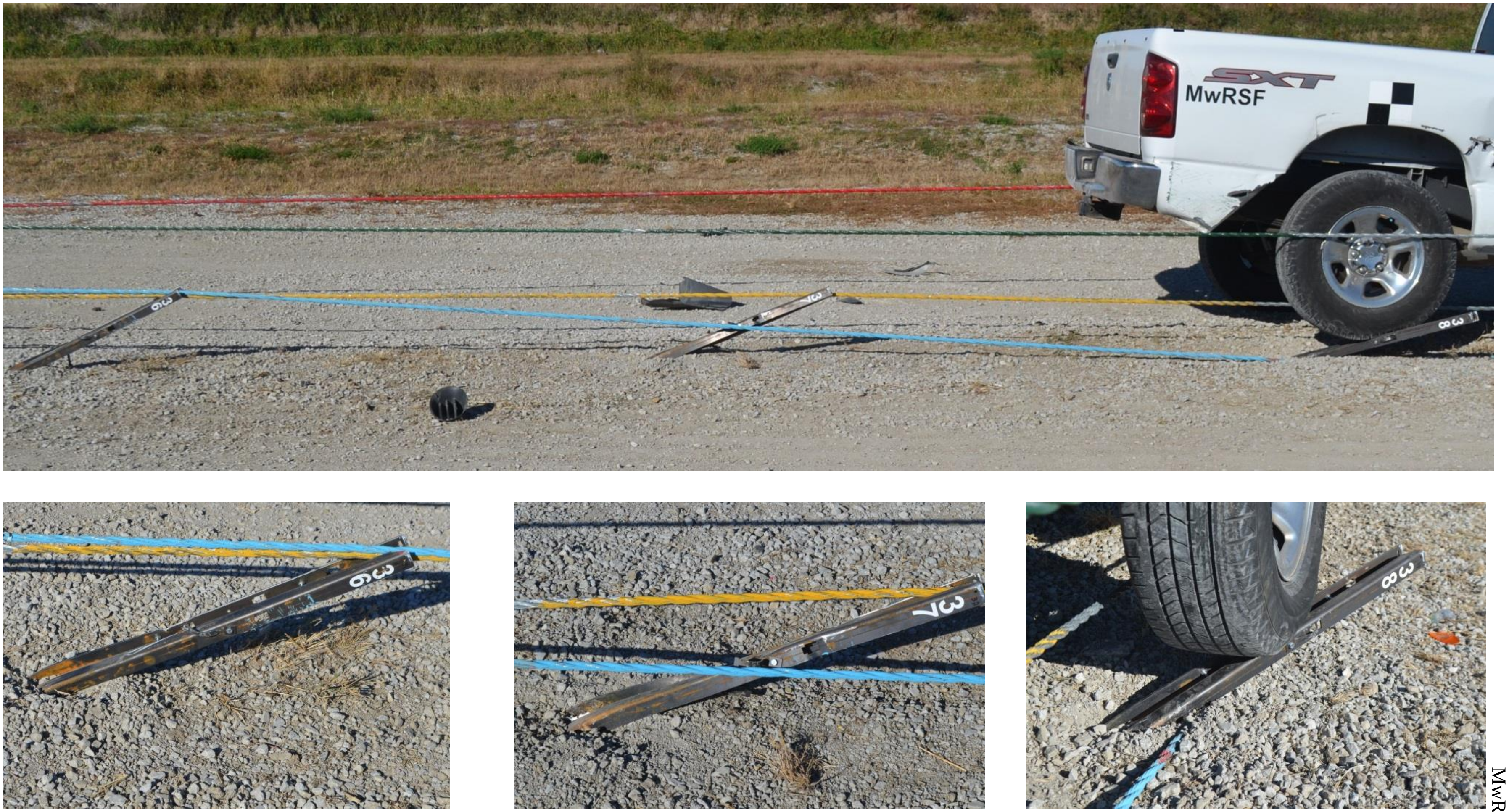
Figure 56. System Damage, Post Nos. 30 through 32, Test No. MWP-4

Post No. 33

Post No. 34

Post No. 35

Figure 57. System Damage, Post Nos. 33 through 35, Test No. MWP-4



Post No. 36

Post No. 37

Post No. 38

Figure 58. System Damage, Post Nos. 36 through 38, Test No. MWP-4

Post No. 39

Post No. 40

Post No. 41

Figure 59. System Damage, Post Nos. 39 through 41, Test No. MWP-4

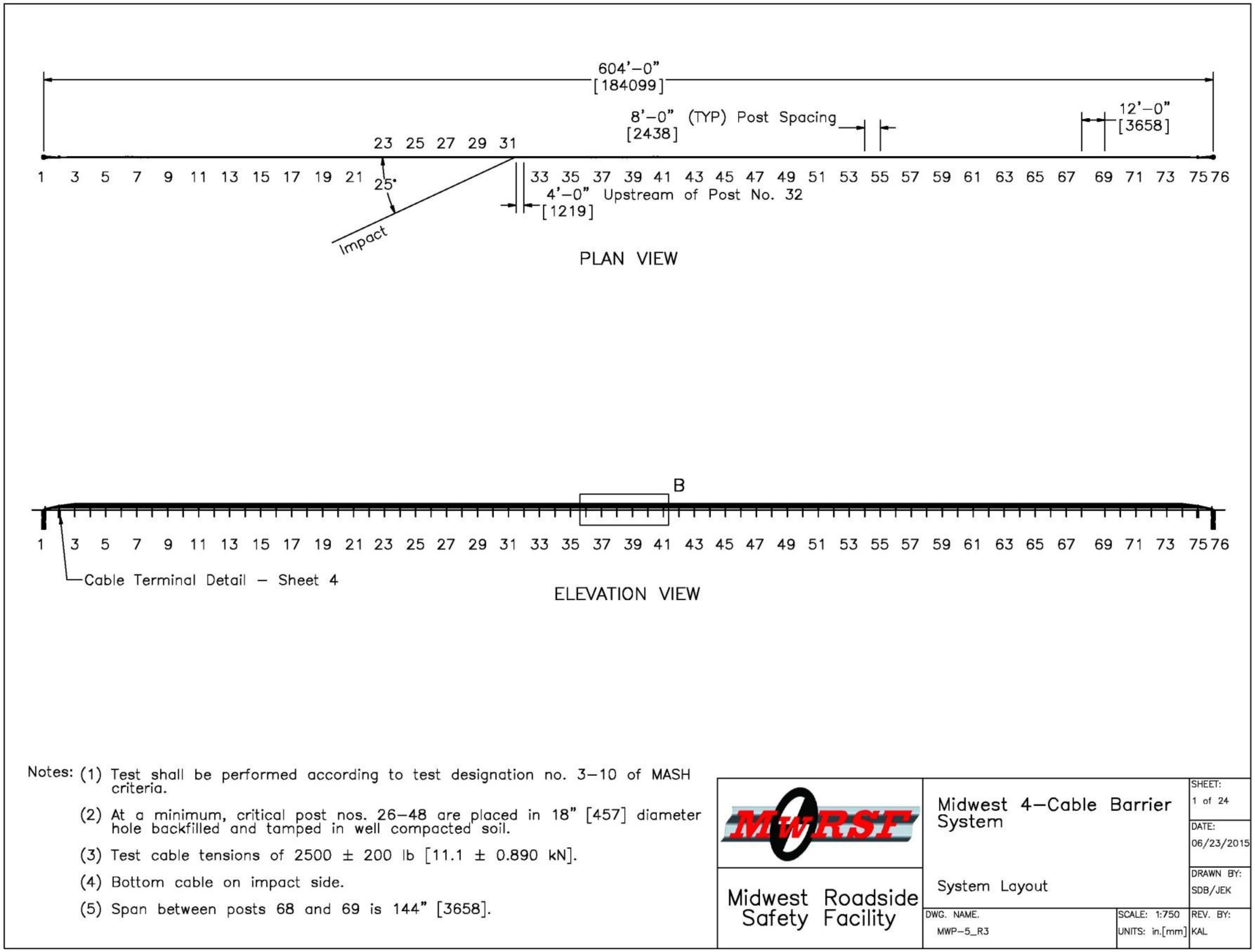
Figure 60. Vehicle Damage, Test No. MWP-4

Figure 61. Vehicle Damage, Test No. MWP-4

# 6 DESIGN DETAILS TEST NO. MWP-6

The four-cable median barrier system used for test no. MWP-6 was nearly identical to that used in test no. MWP-4, as shown in Figures 62 through 85. The targeted impact location for test no. MWP-6 was 4 ft (1.2 m) upstream from post no. 32, as shown in Figure 62. The system was mirrored so that cable nos. 1 and 3 were on impact side and cable no. 2, the critical capture cable, was on the non-impact side of the barrier, as shown in Figure 76. MASH requires that cable barrier systems be tested with cable tensions set to the recommended tension at 100 degrees Fahrenheit. A cable tensioning chart was developed as a function of ambient air temperature for use when installing the barrier system, as shown in Table 3. Thus, the cables were tensioned to a pre-load of 2,500 lb (11.1 kN).

The typical post spacing was reduced to 8 ft (2.4 m), while the system length remained the same. This change resulted in an increased number of line posts, tallying to 72. The spacing between posts no. 68 and 69 was 12 ft (3.7 m), while the anchors remained in the same locations. The longitudinal location of the special 12-ft (3.7-m) post spacing was selected to occur outside of the vehicle contact region and away from the system anchorage. Cable splices were shifted downstream into the new impact region, between post nos. 36 and 41, as shown in Figure 63. The load cell locations were relocated to between post nos. 6 and 8. Details for the load cells, threaded rods, turnbuckles, end fittings, and rod couplers are provided in Figure 67. Photographs of the test installation are shown in Figures 86 to 89. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.



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].

Figure 62. Test Installation Layout, Test No. MWP-6

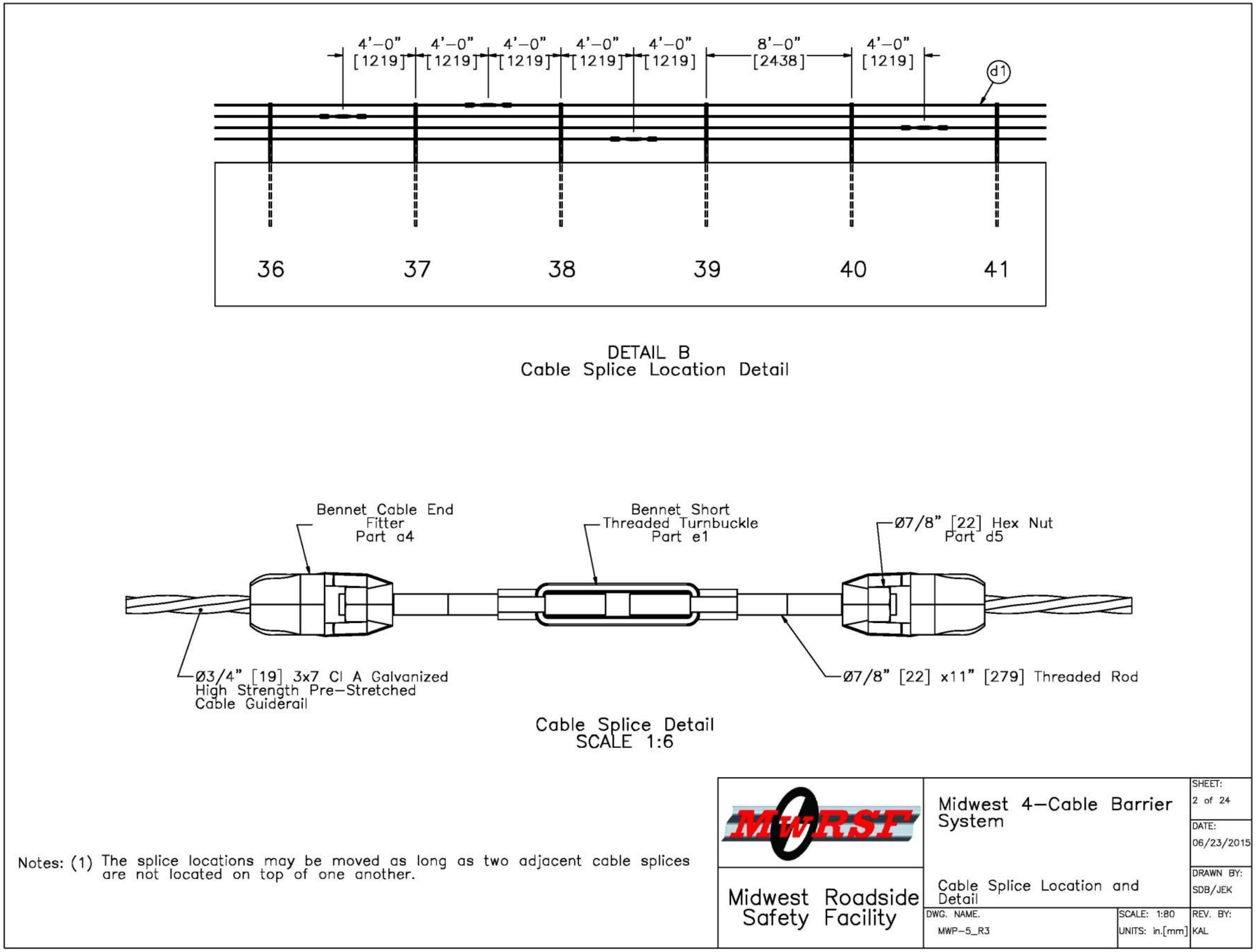


Figure 63. Cable Splice Location and Detail, Test No. MWP-6

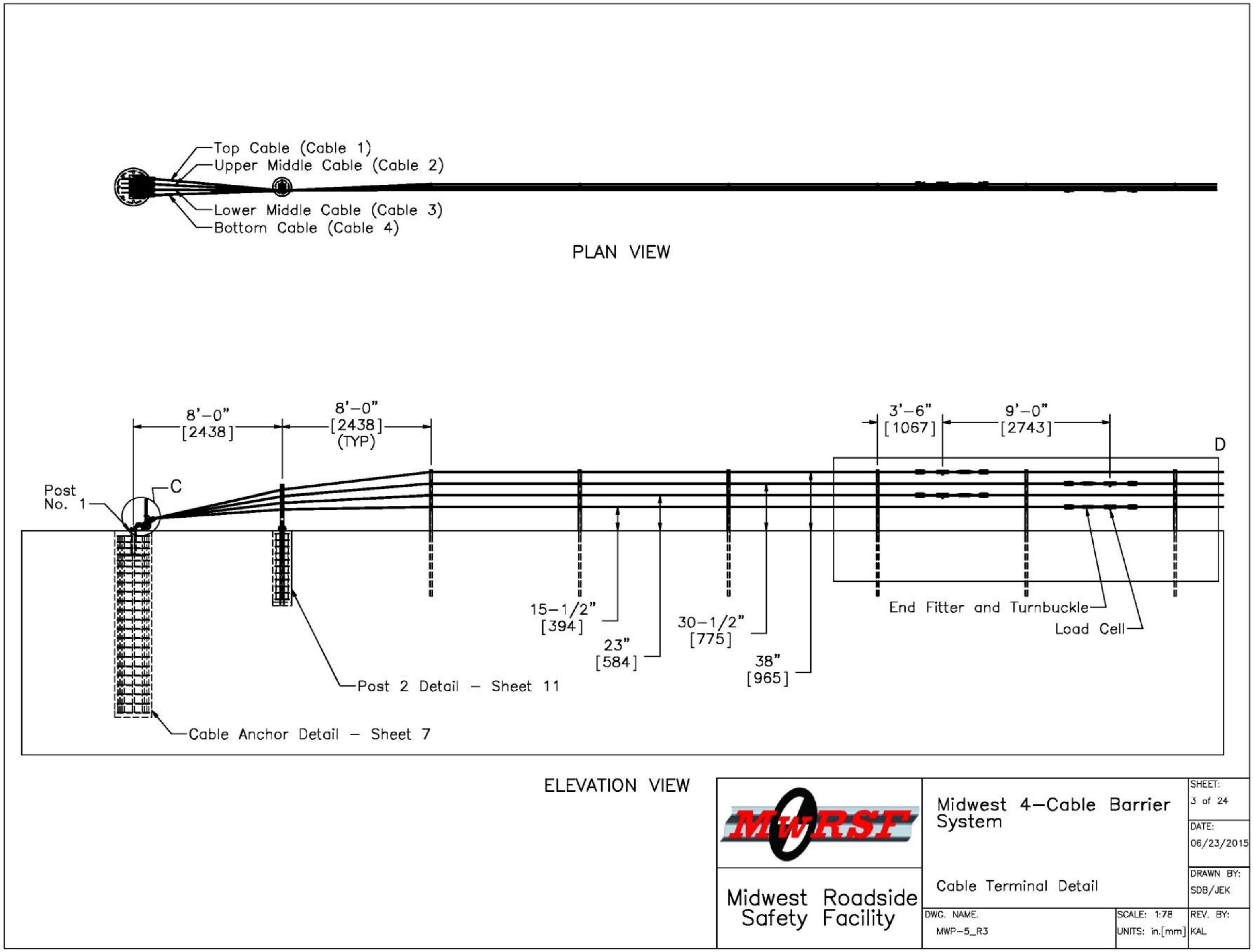


Figure 64. Cable Terminal Detail, Test No. MWP-6

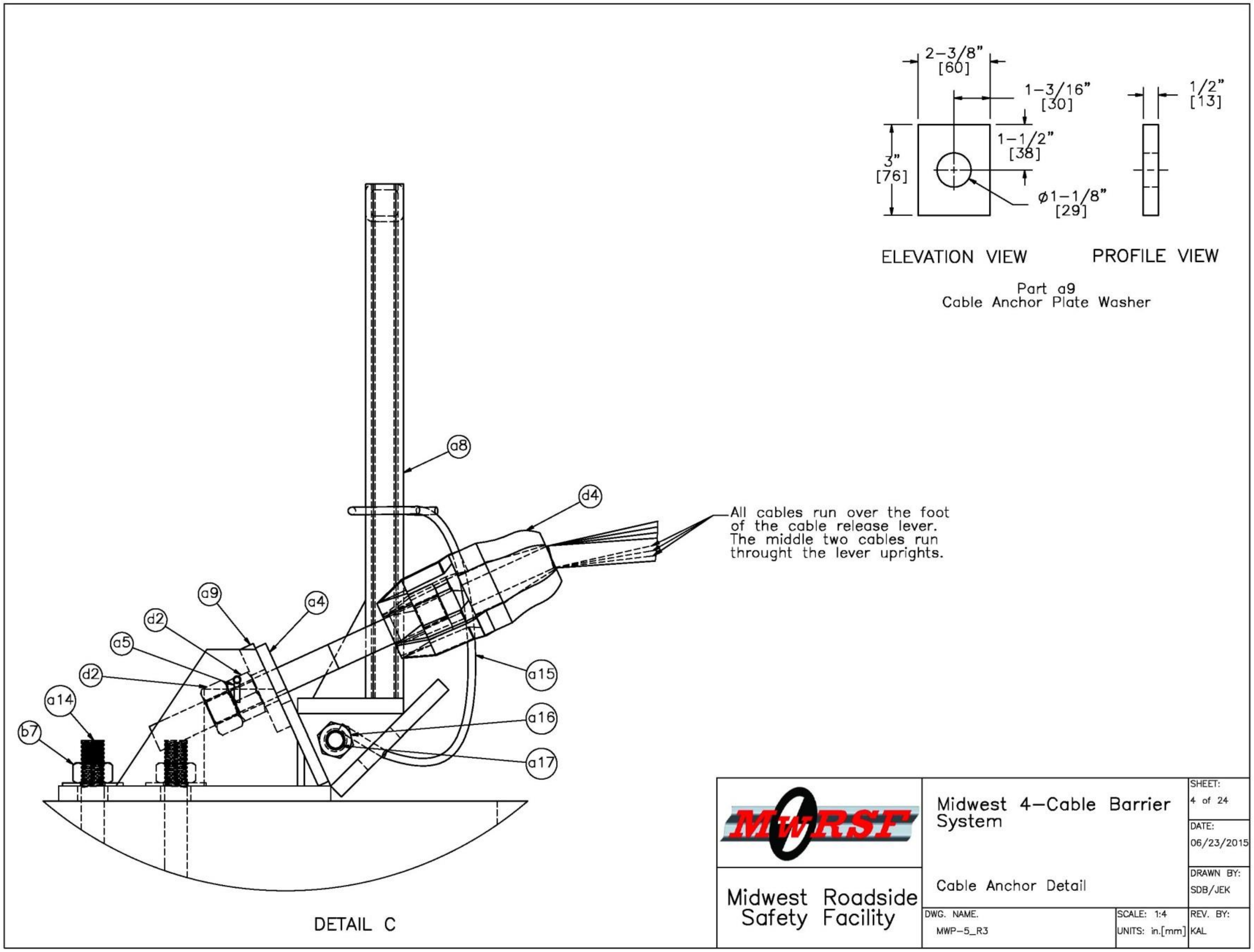


Figure 65. Cable Anchor Detail, Test No. MWP-6

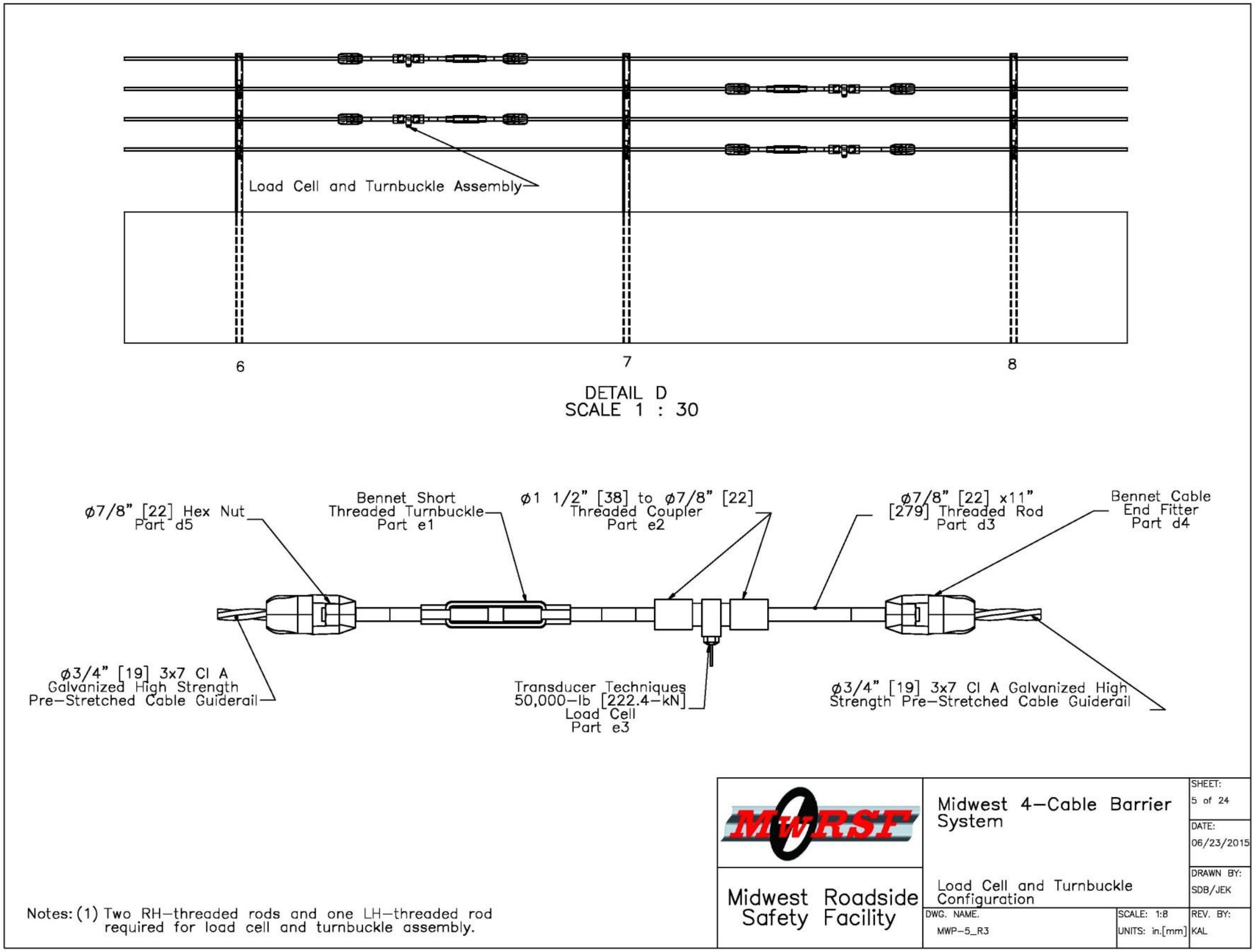


Figure 66. Load Cell and Turnbuckle Configuration, Test No. MWP-6

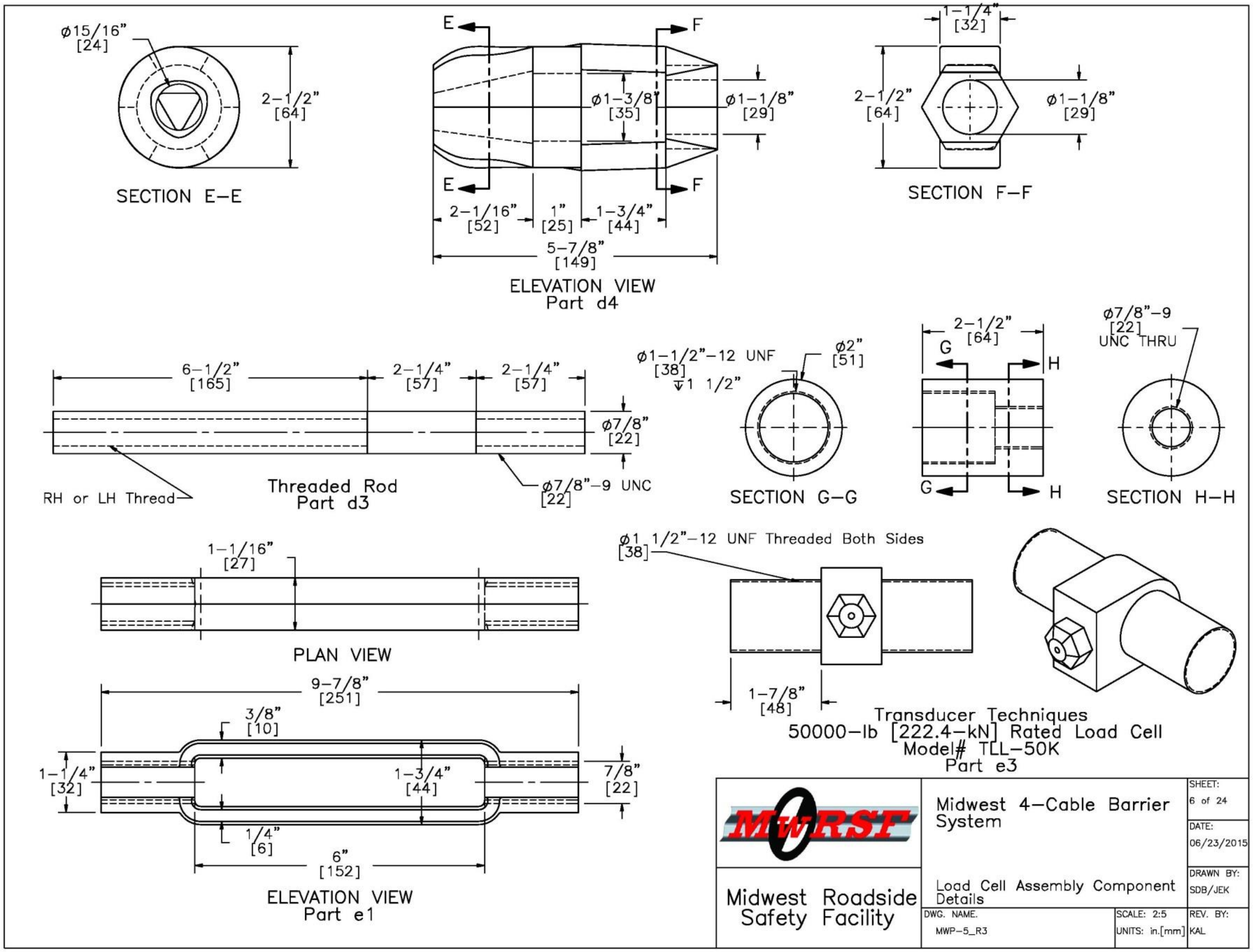
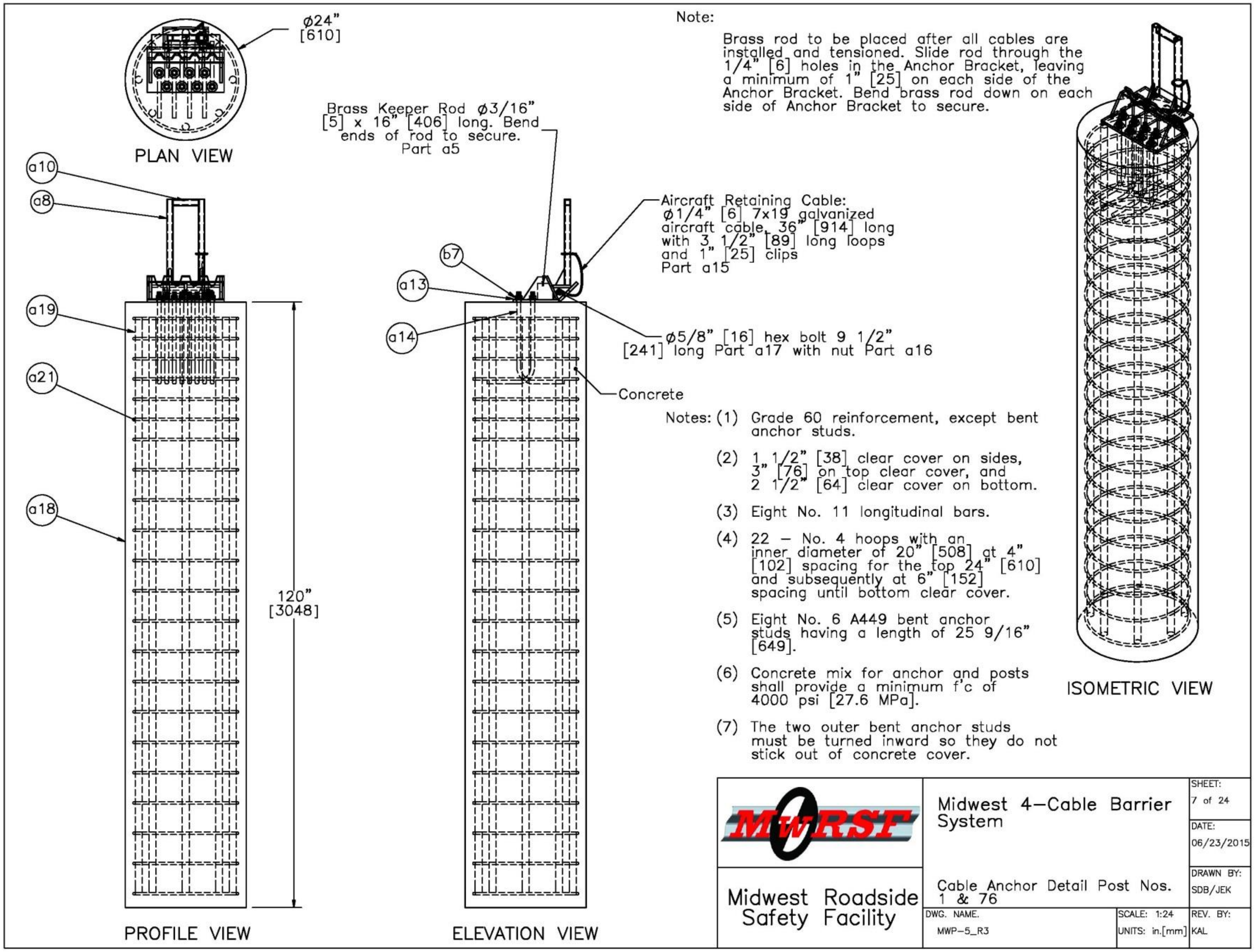


Figure 67. Load Cell Assembly Component Details, Test No. MWP-6



Note:

Brass rod to be placed after all cables are installed and tensioned. Slide rod through the 1/4" [6] holes in the Anchor Bracket, leaving a minimum of 1" [25] on each side of the Anchor Bracket. Bend brass rod down on each side of Anchor Bracket to secure.

Notes:
(1) Grade 60 reinforcement, except bent anchor studs.
(2) 1 1/2" [38] clear cover on sides, 3" [76] on top clear cover, and 2 1/2" [64] clear cover on bottom.
(3) Eight No. 11 longitudinal bars.
(4) 22 – No. 4 hoops with an inner diameter of 20" [508] at 4" [102] spacing for the top 24" [610] and subsequently at 6" [152] spacing until bottom clear cover.
(5) Eight No. 6 A449 bent anchor studs having a length of 25 9/16" [649].
(6) Concrete mix for anchor and posts shall provide a minimum f'c of 4000 psi [27.6 MPa].
(7) The two outer bent anchor studs must be turned inward so they do not stick out of concrete cover.

Midwest 4–Cable Barrier System

Cable Anchor Detail Post Nos. 1 & 76

Figure 68. Cable Anchor Detail, Post Nos. 1 and 76, Test No. MWP-6

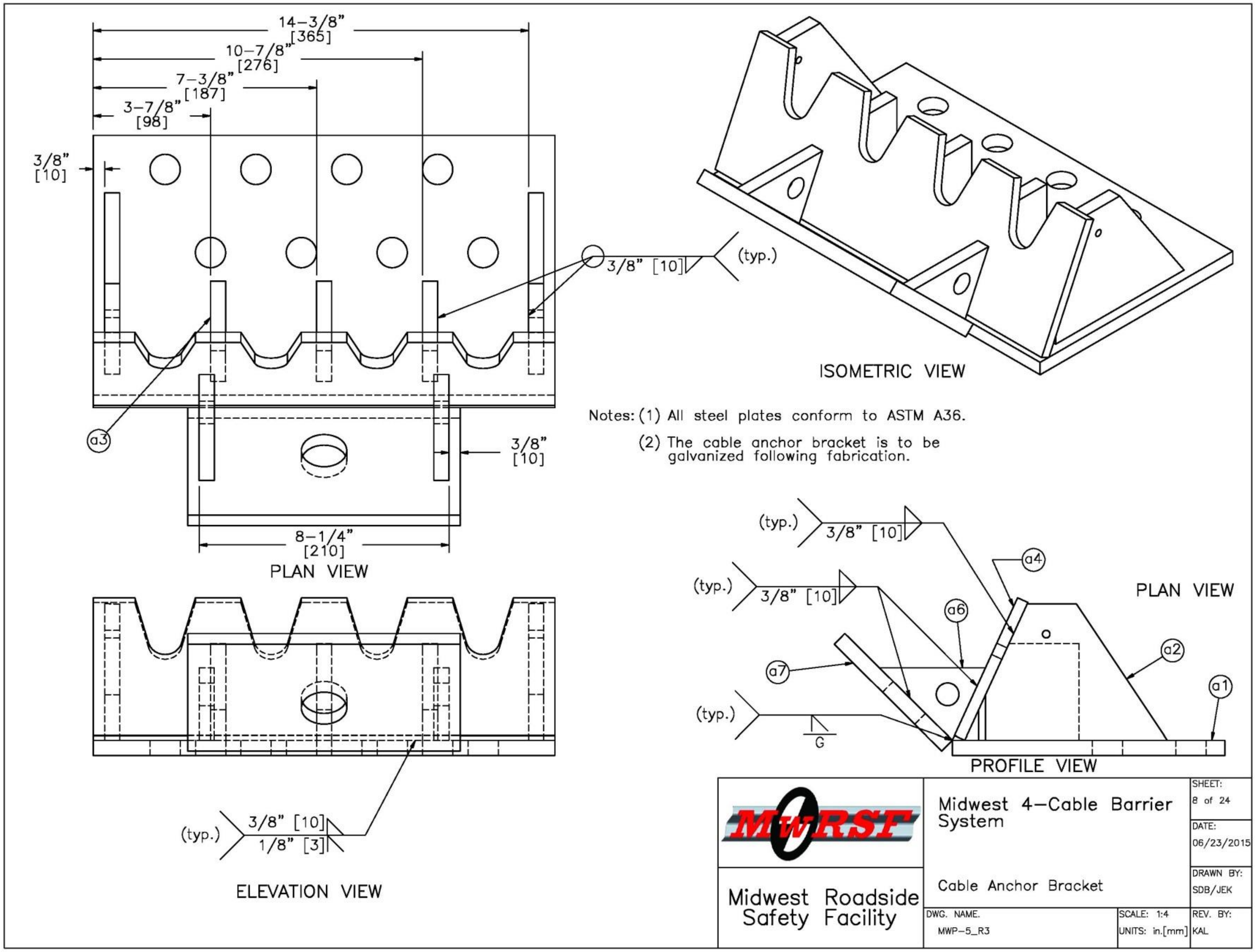


Figure 69. Cable Anchor Bracket, Test No. MWP-6

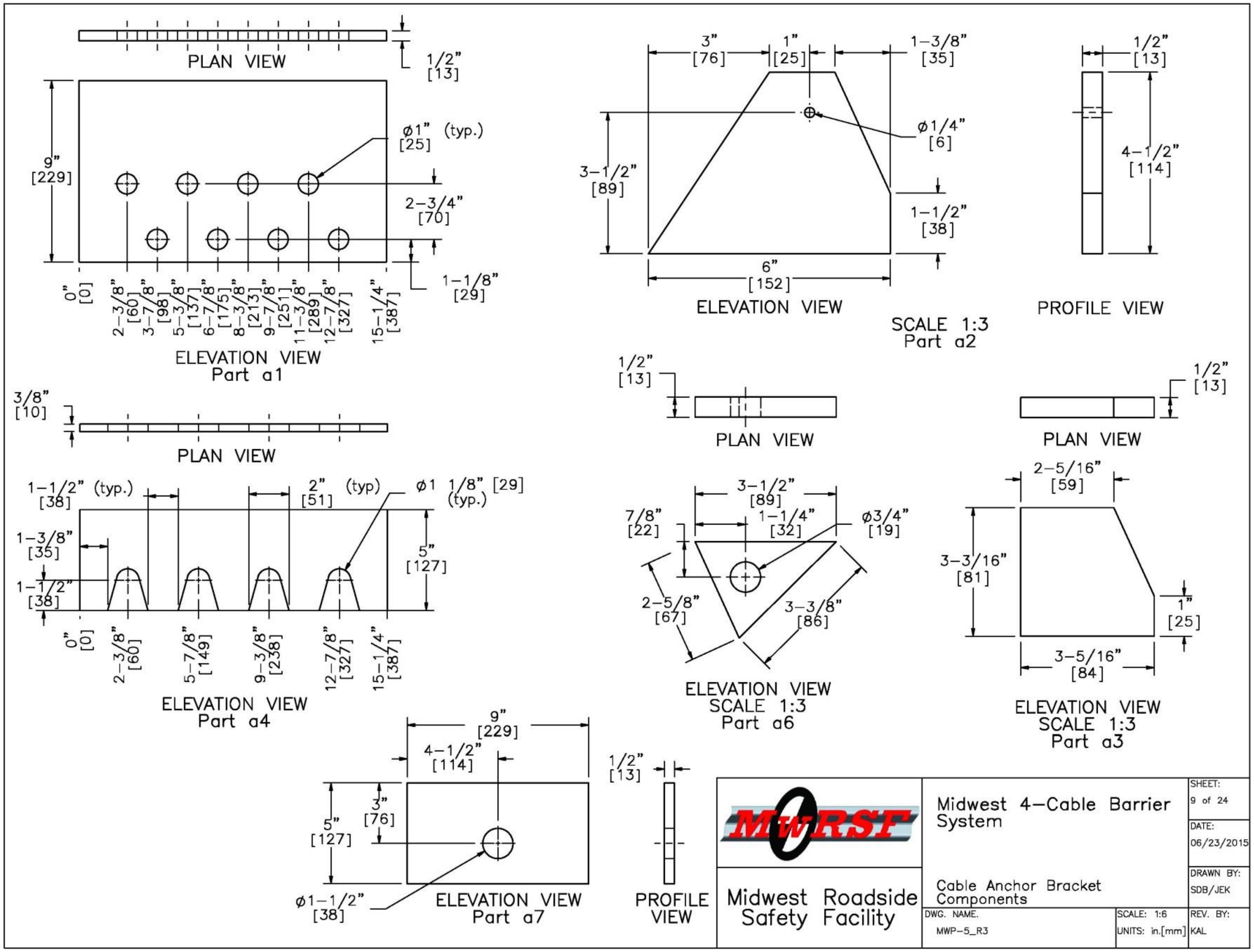
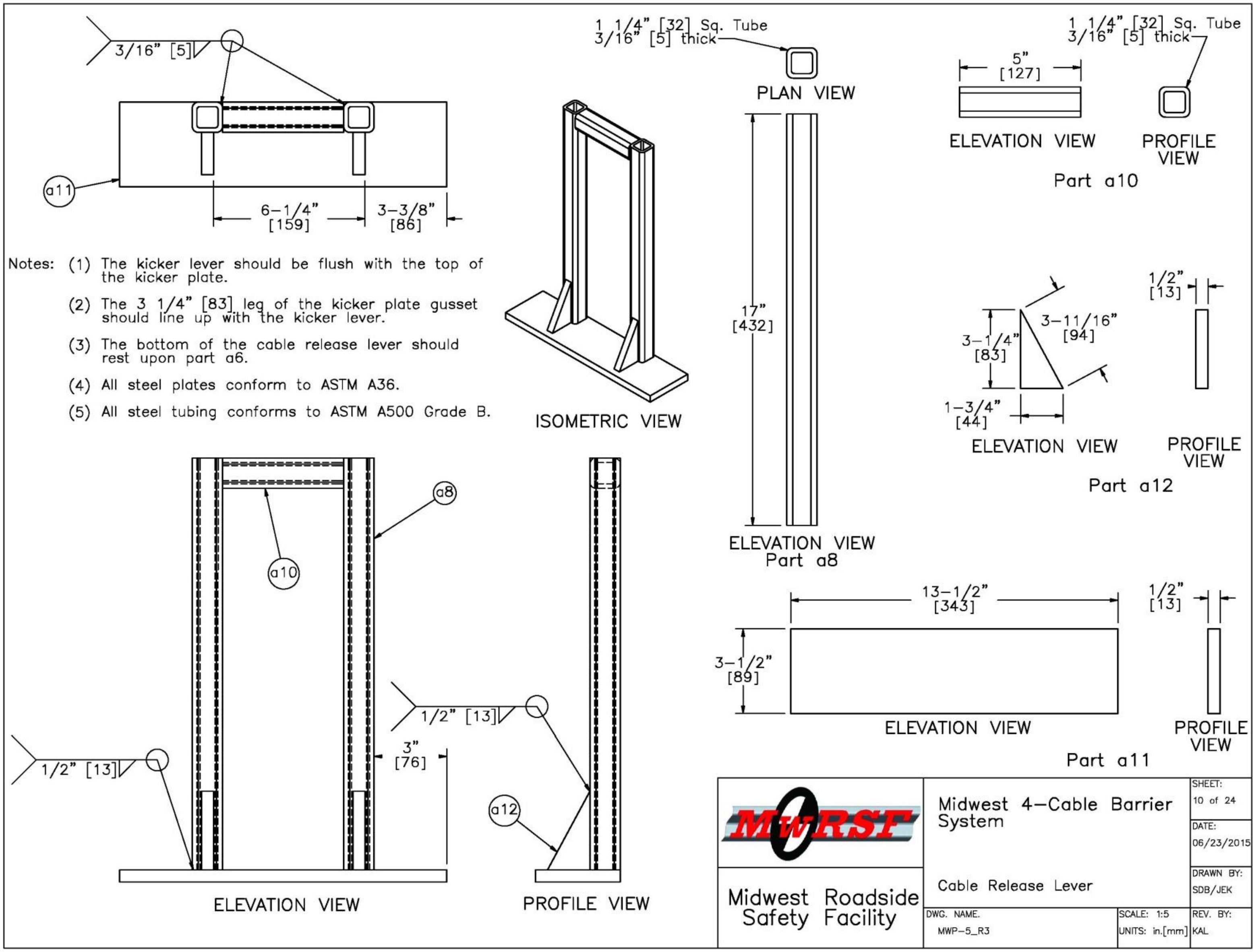


Figure 70. Cable Anchor Bracket Components, Test No. MWP-6



Notes:
1. The kicker lever should be flush with the top of the kicker plate.
2. The 3 1/4" [83] leg of the kicker plate gusset should line up with the kicker lever.
3. The bottom of the cable release lever should rest upon part a6.
4. All steel plates conform to ASTM A36.
5. All steel tubing conforms to ASTM A500 Grade B.

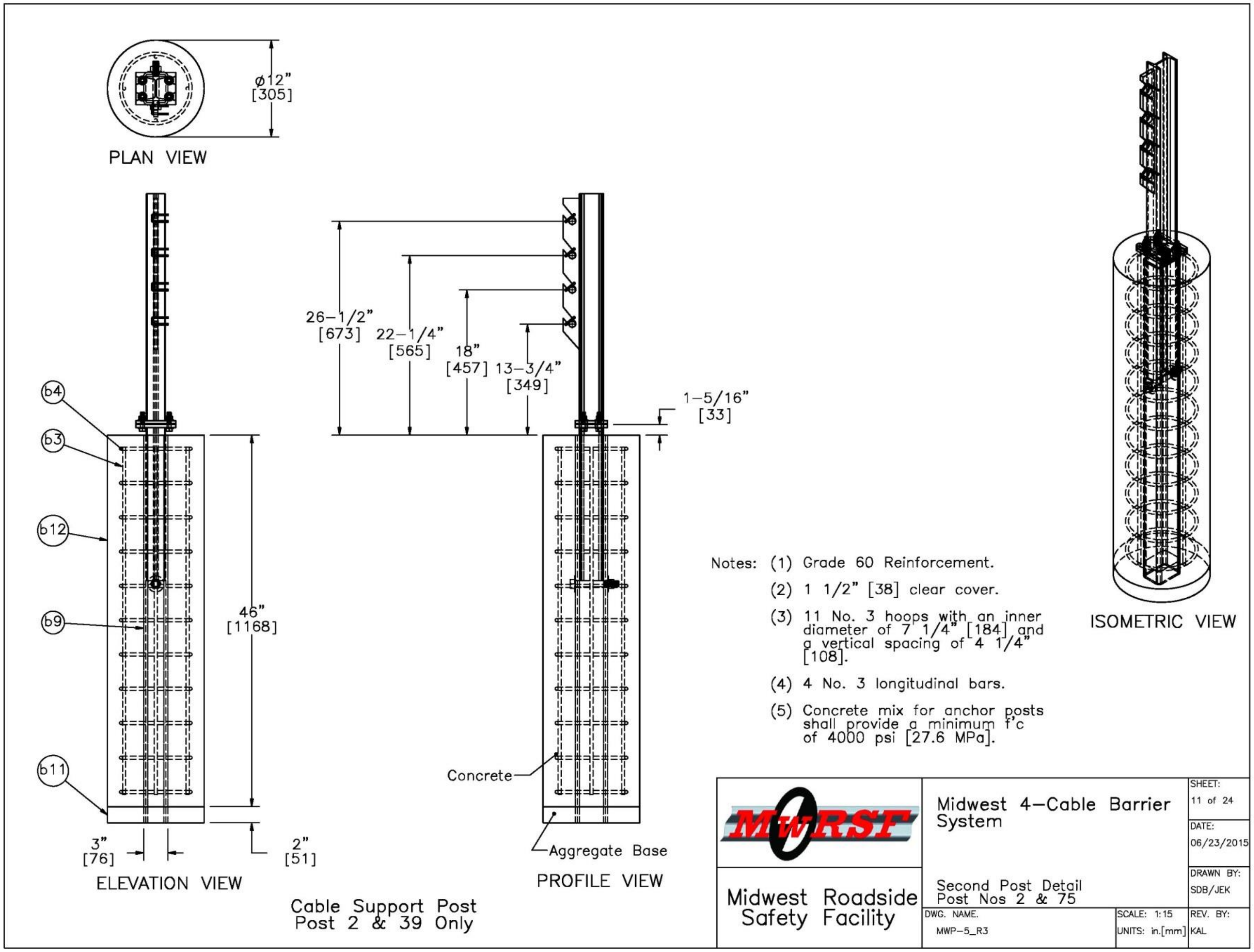
Midwest Roadside Safety Facility

Midwest 4-Cable Barrier System

Cable Release Lever

SHEET: 10 of 24
DATE: 06/23/2015
DRAWN BY: SDB/JEK
DWG. NAME. MWP-5_R3
SCALE: 1:5
UNITS: in.[mm]
REV. BY: KAL

Figure 71. Cable Release Lever, Test No. MWP-6



Notes: (1) Grade 60 Reinforcement.

(2) 1 1/2" [38] clear cover.

(3) 11 No. 3 hoops with an inner diameter of 7 1/4" [184] and a vertical spacing of 4 1/4" [108].

(4) 4 No. 3 longitudinal bars.

(5) Concrete mix for anchor posts shall provide a minimum f'c of 4000 psi [27.6 MPa].

Figure 72. Second Post Details, Post Nos. 2 and 75, Test No. MWP-6

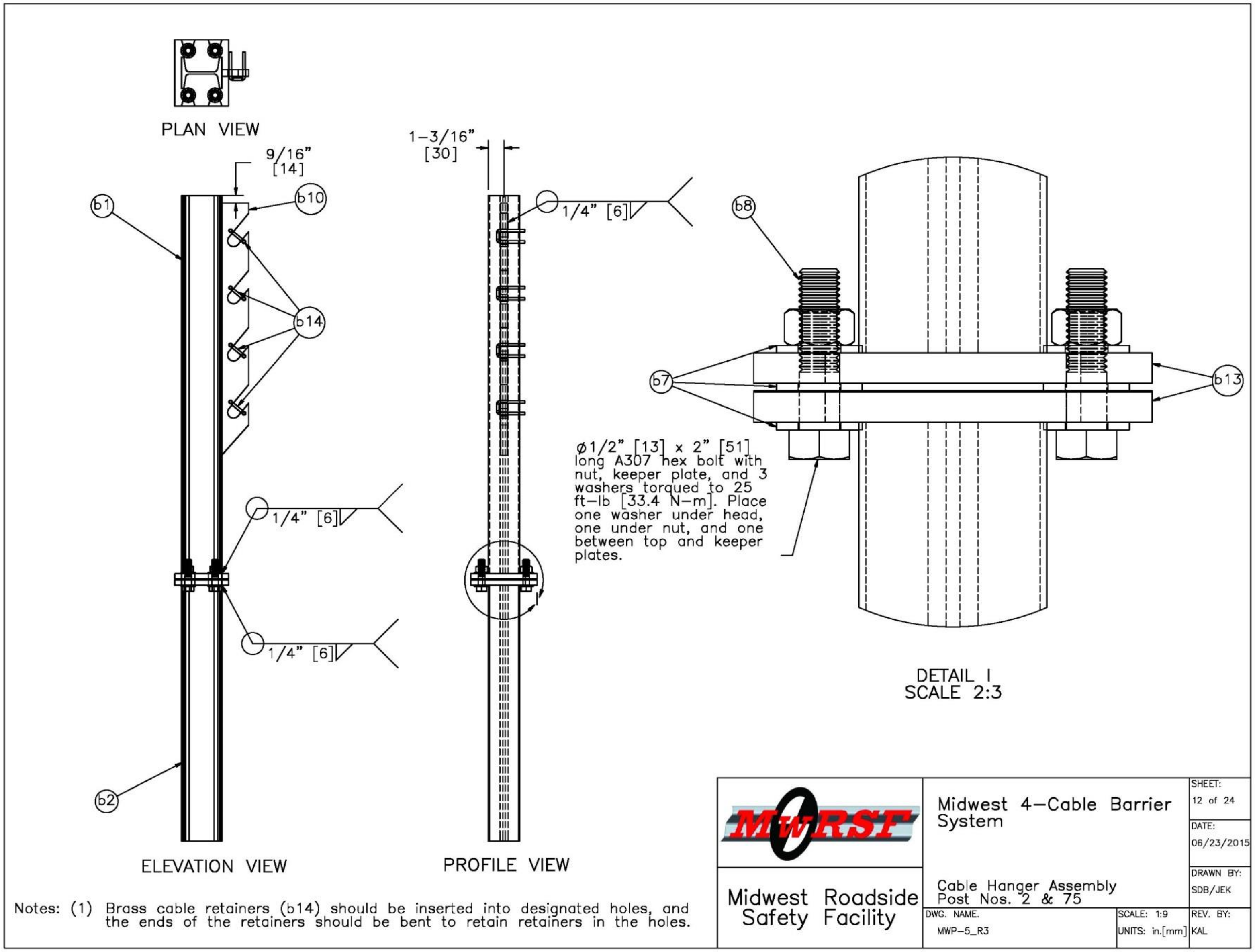


Figure 73. Cable Hanger Assembly, Post Nos. 2 and 75, Test No. MWP-6

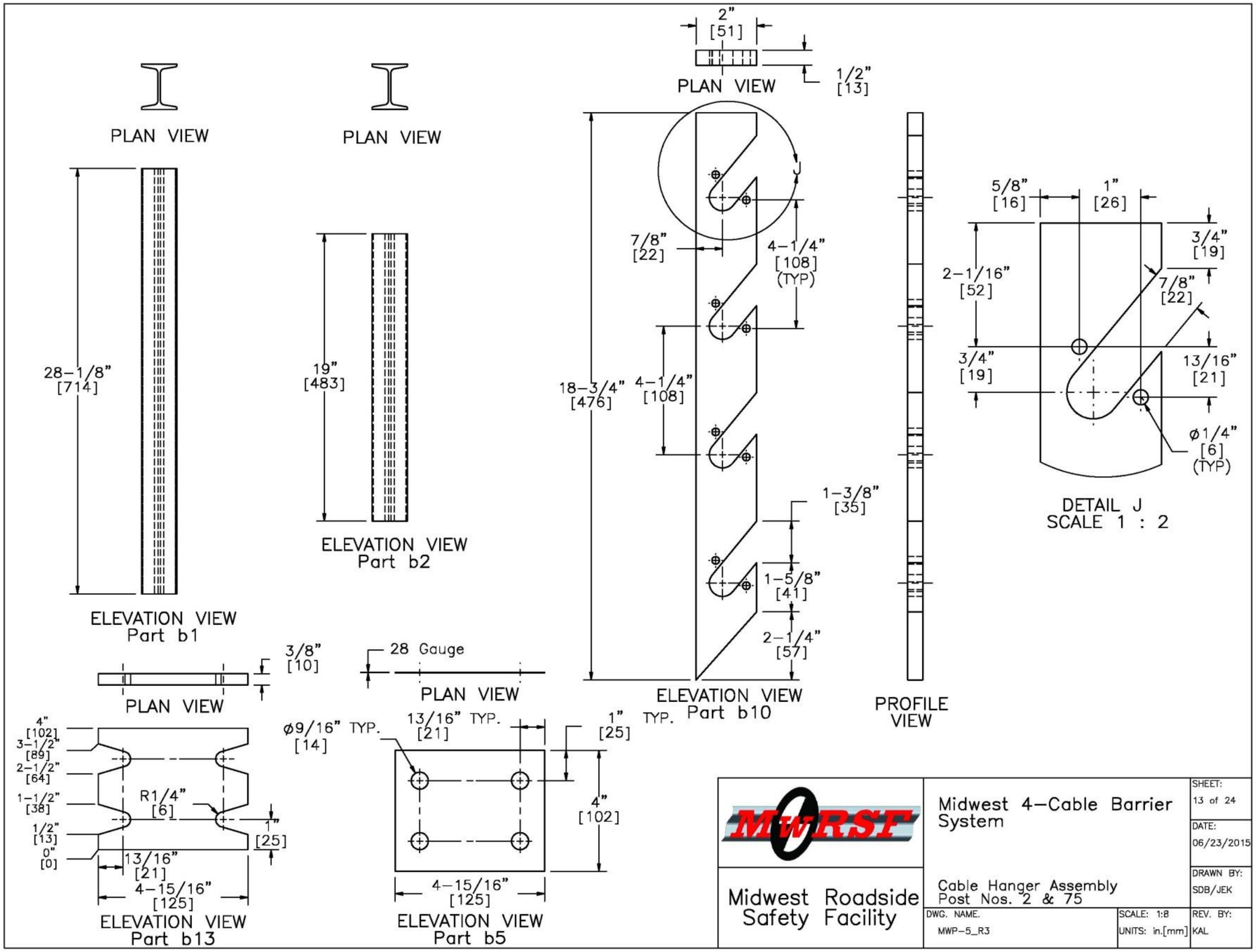


Figure 74. Cable Hanger Assembly, Post Nos. 2 and 75, Test No. MWP-6

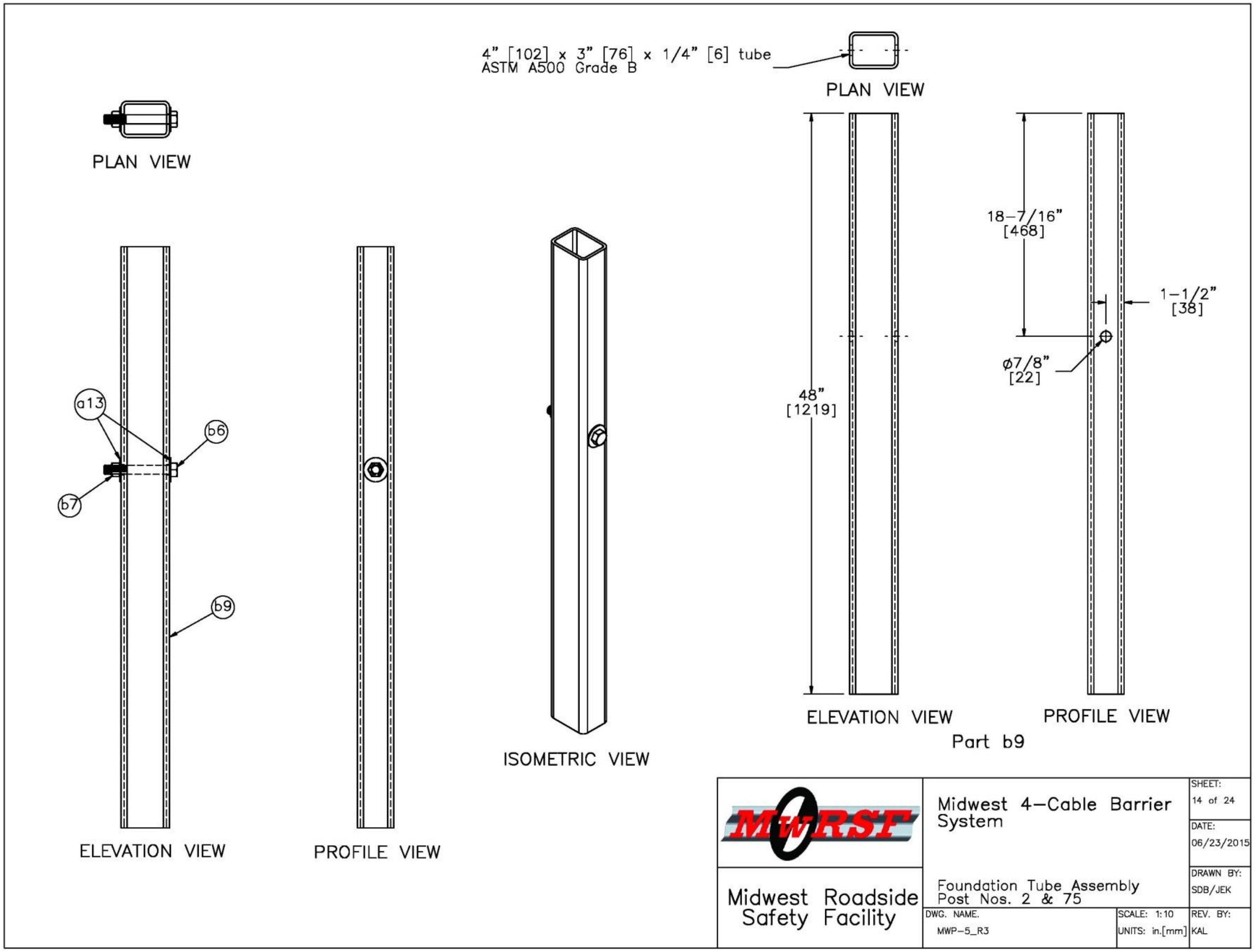


Figure 75. Foundation Tube Assembly, Post Nos. 2 and 75, Test No. MWP-6

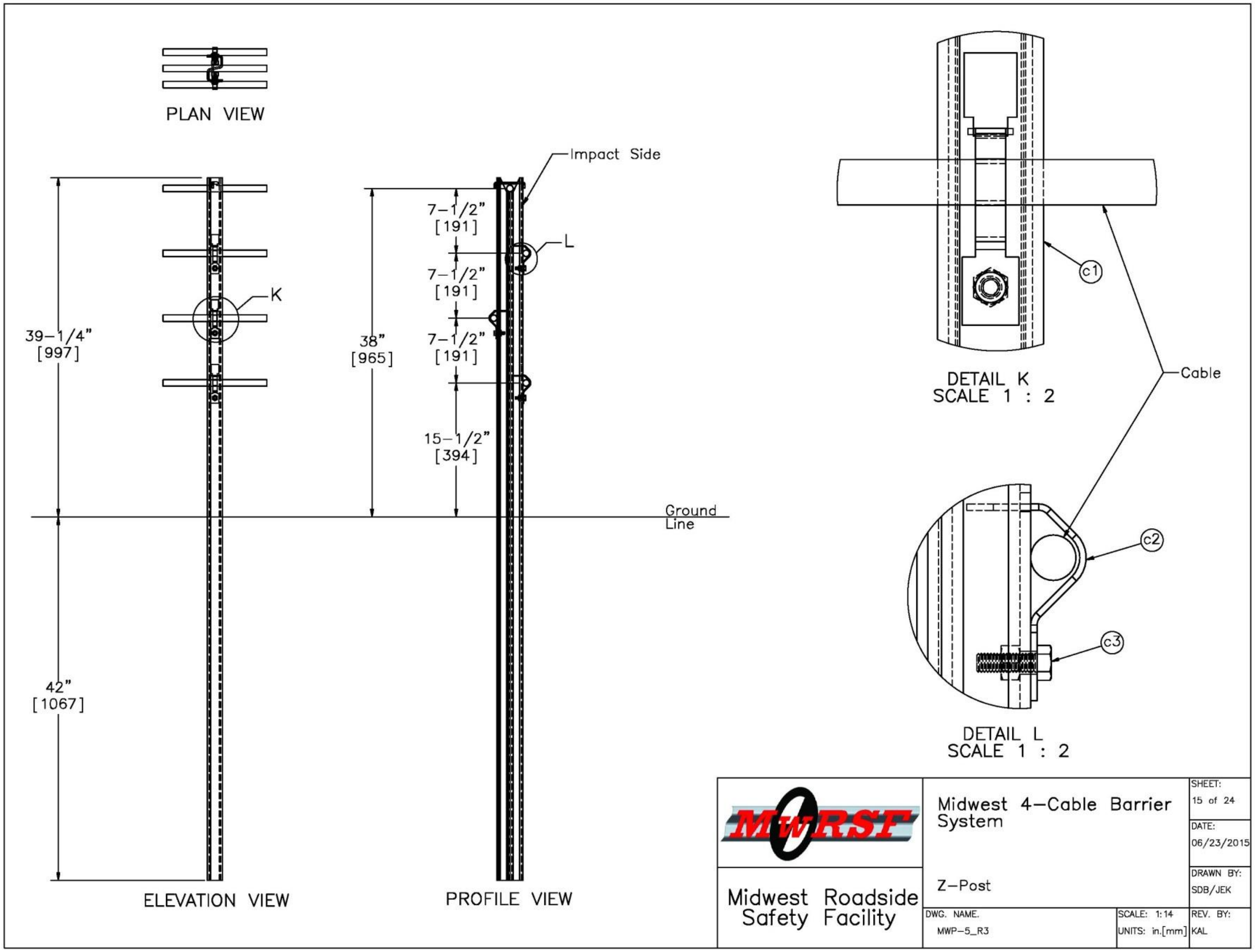


Figure 76. MWP Z-Post Details, Test No. MWP-6

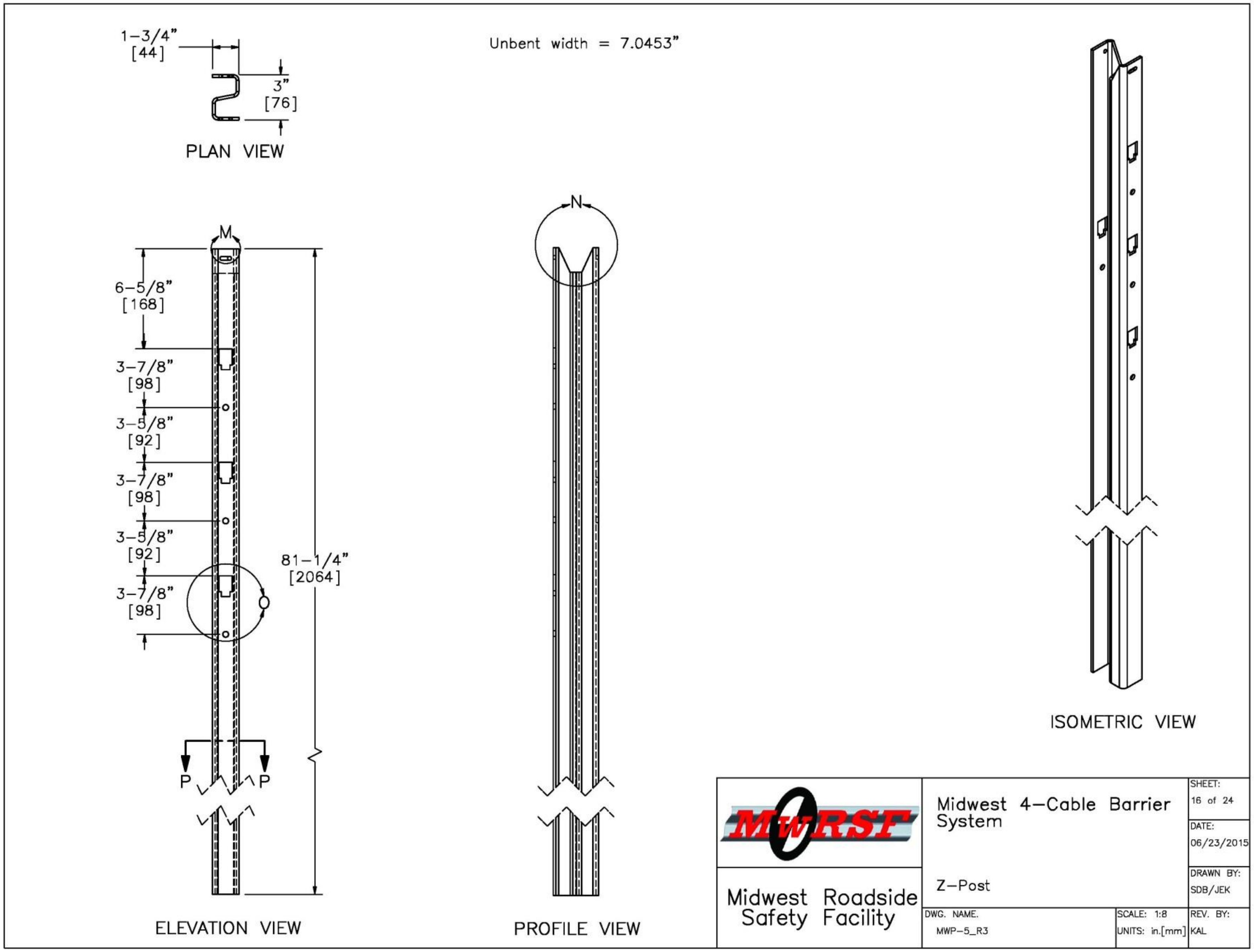


Figure 77. MWP Z-Post Details, Test No. MWP-6

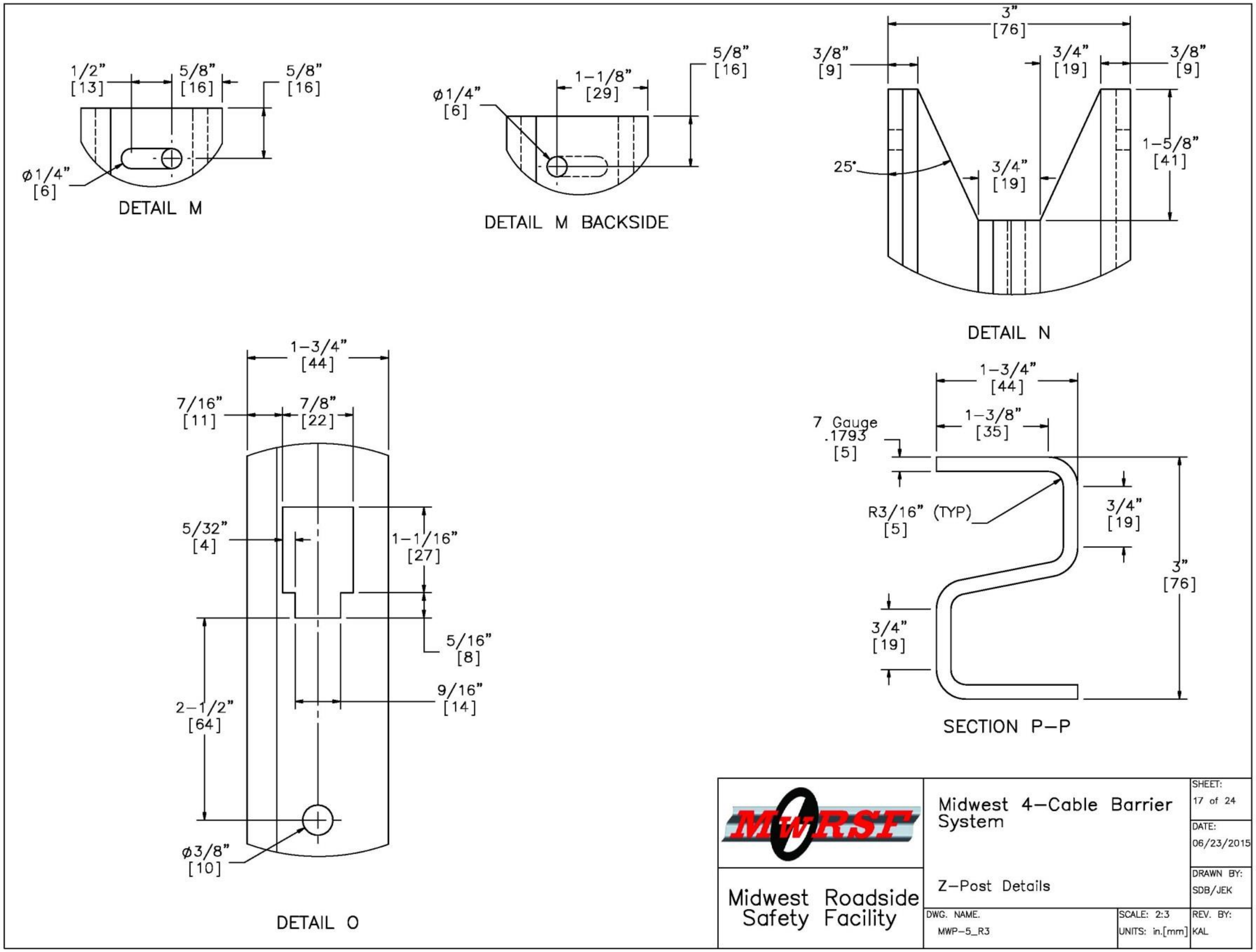


Figure 78. MWP Z-Post Details, Test No. MWP-6

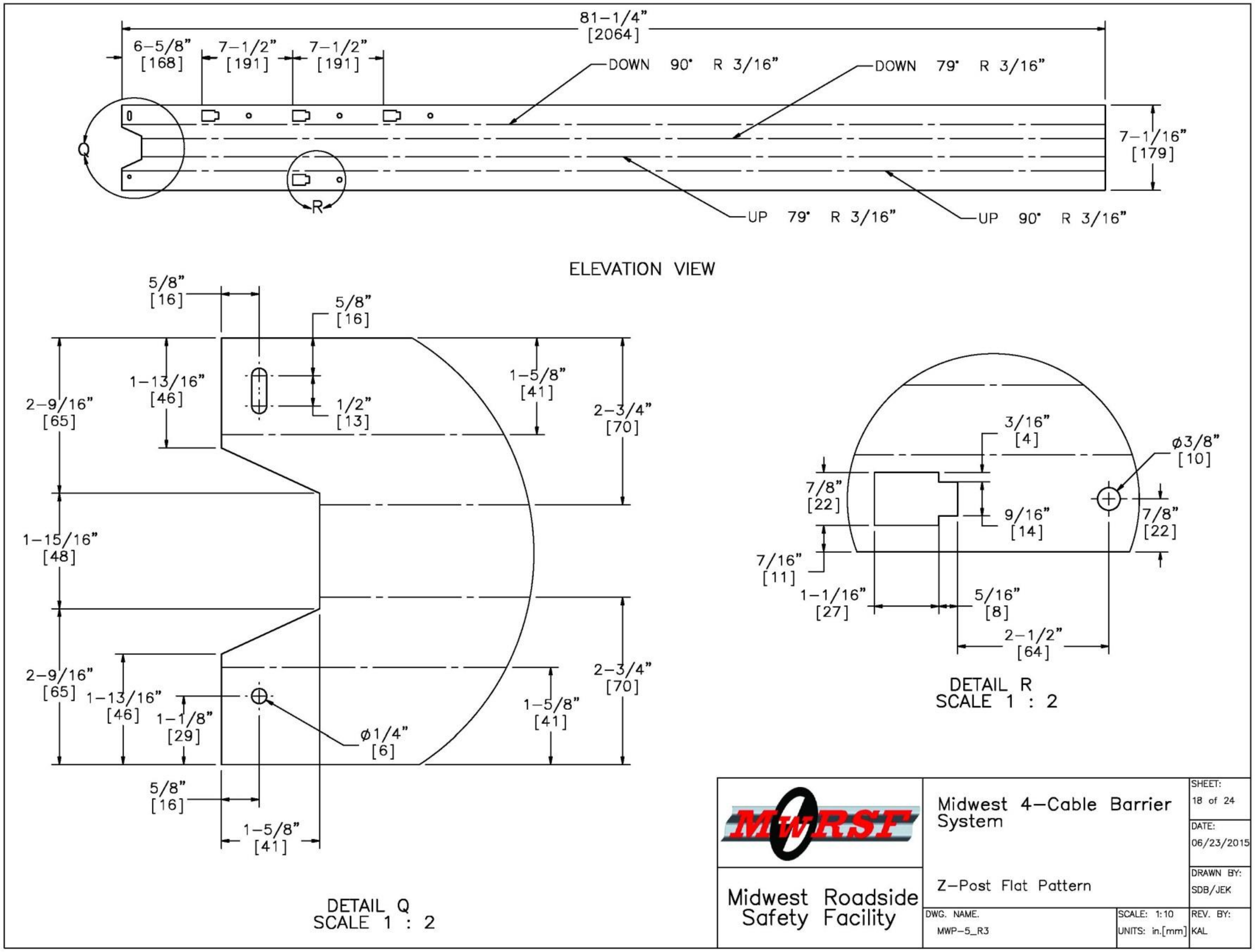


Figure 79. MWP Z-Post Details, Flat Pattern, Test No. MWP-6

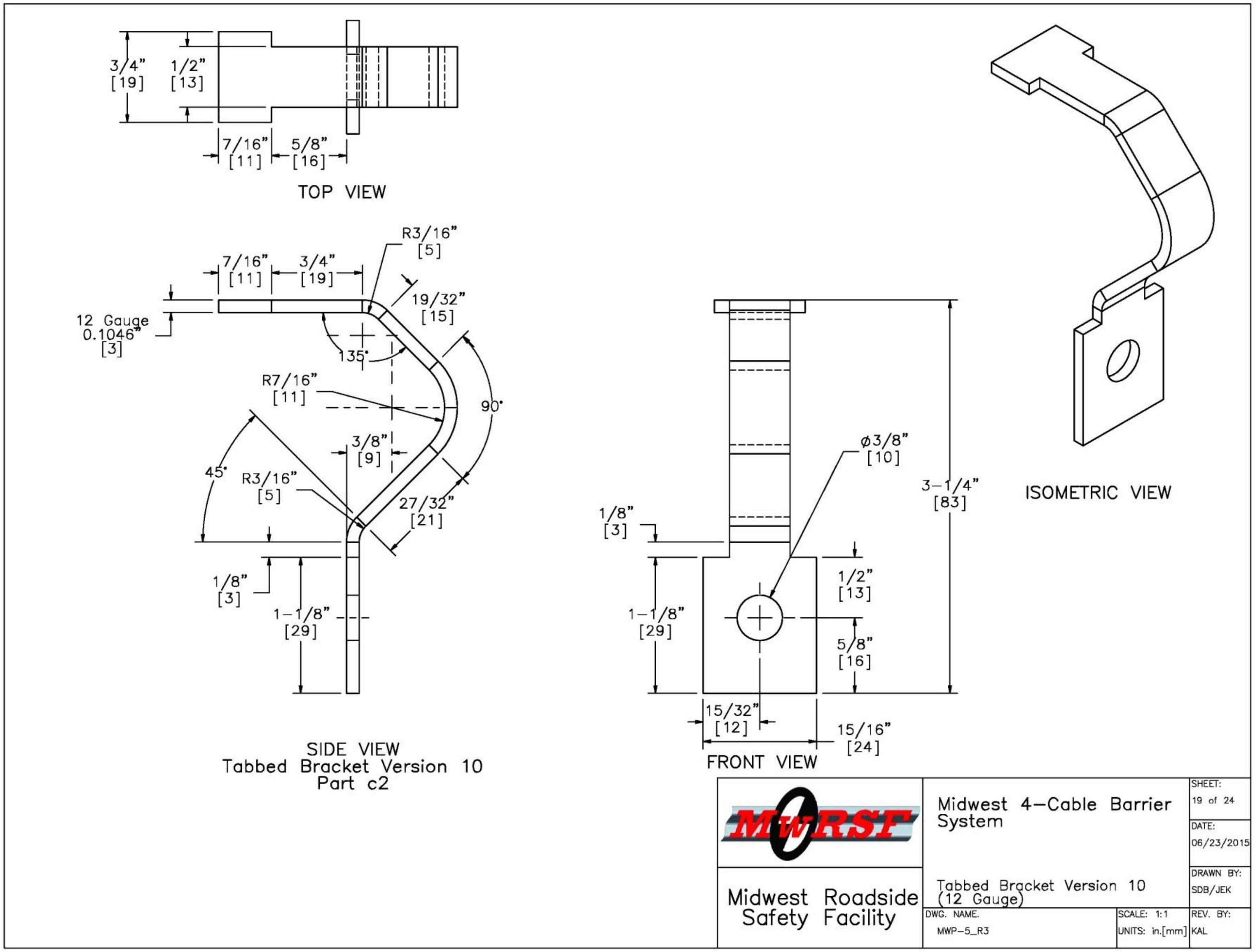


Figure 80. Tabbed Bracket Details, 12-Gauge, Test No. MWP-6

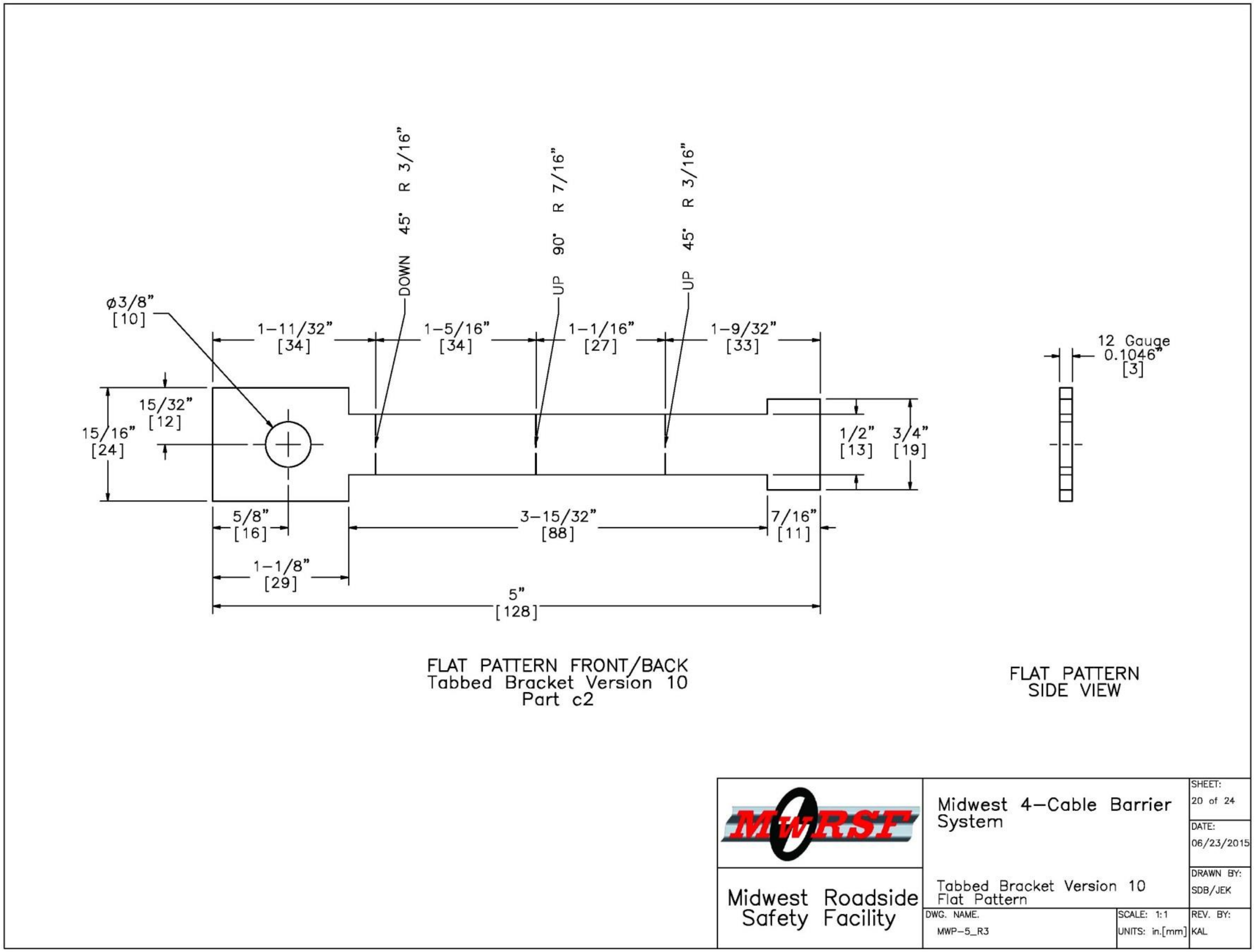


Figure 81. Tabbed Bracket Details, Flat Pattern, Test No. MWP-6

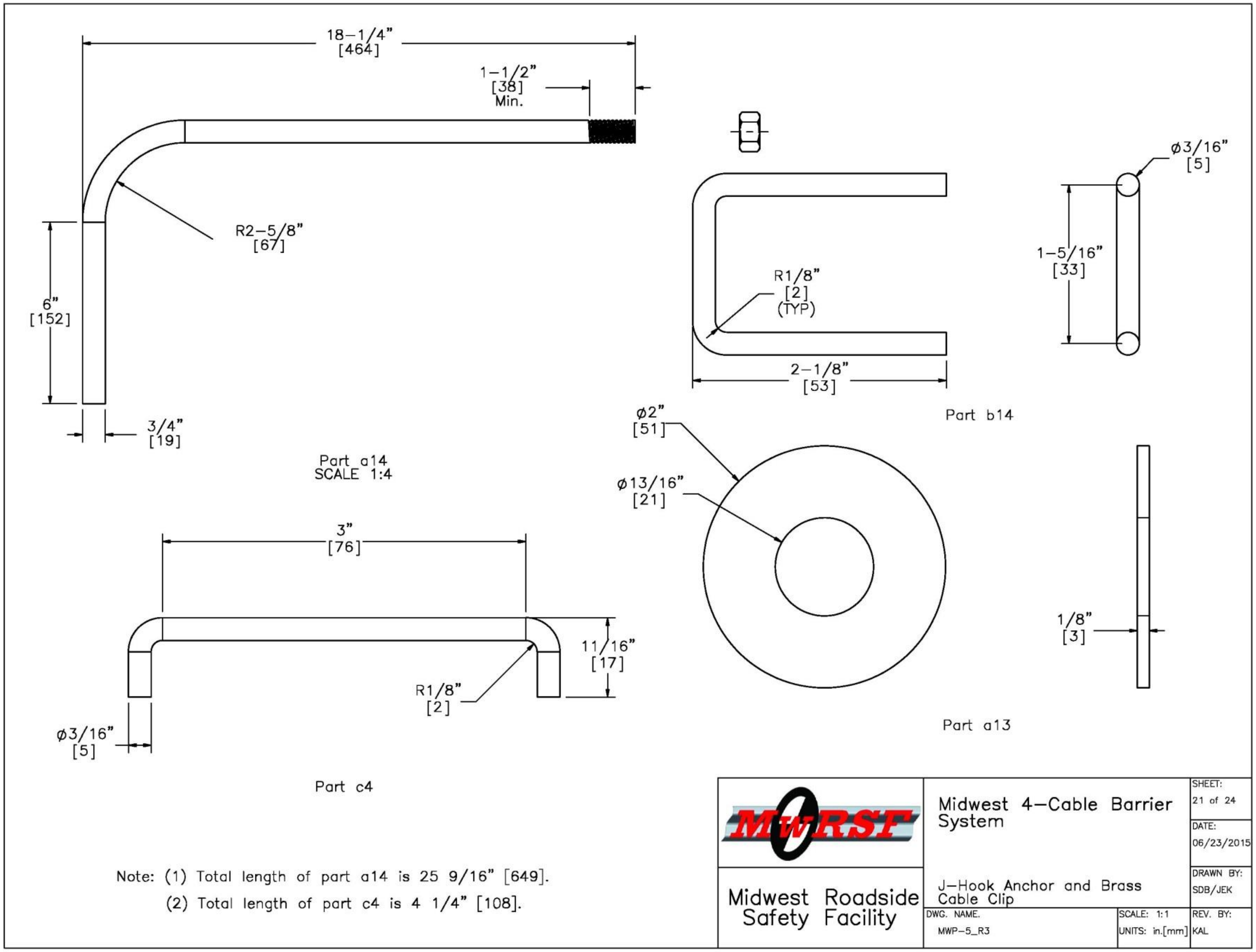


Figure 82. J-Hook Anchor and Brass Clips, Test No. MWP-6

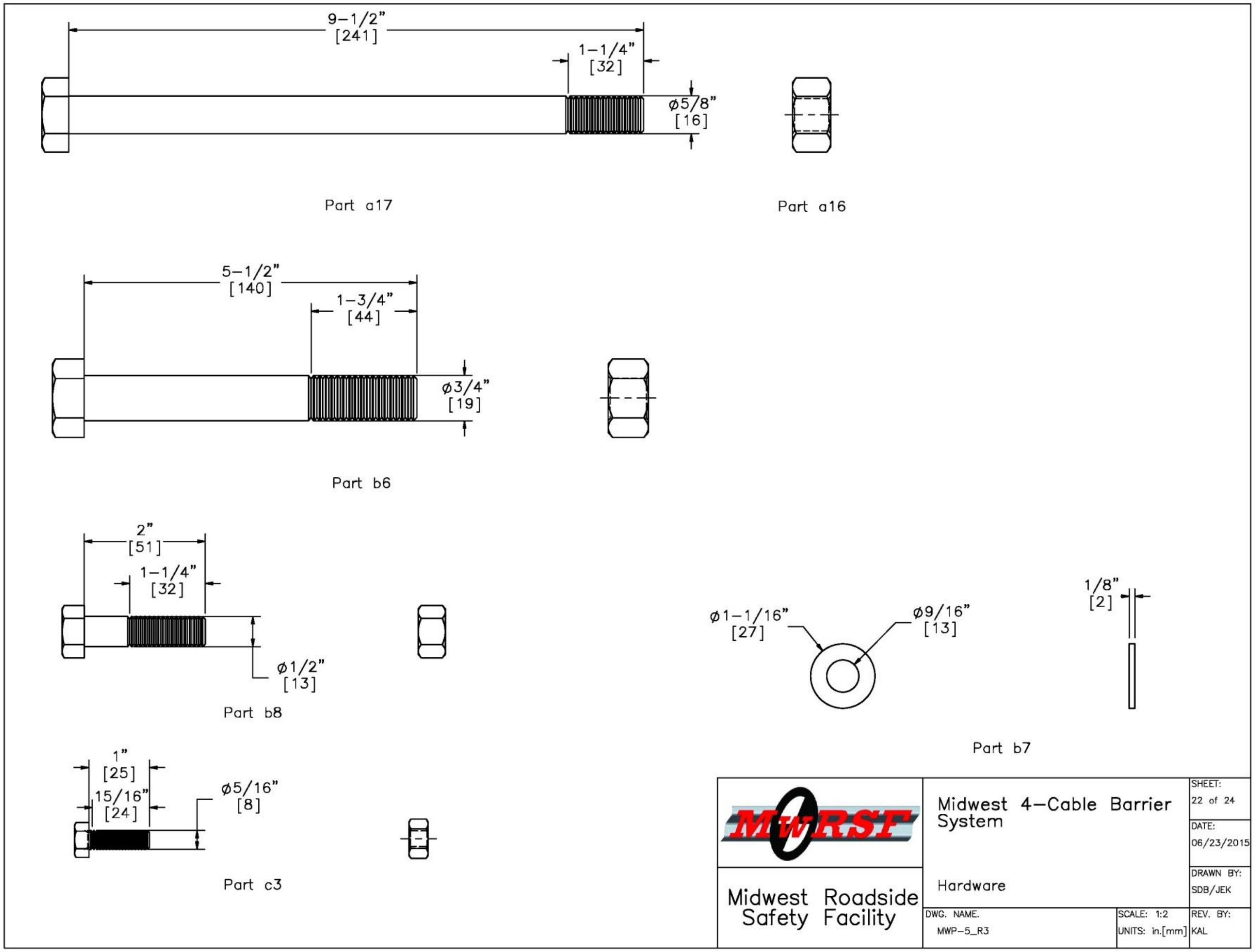


Figure 83. Hardware Details, Test No. MWP-6

| Item No. | QTY. | Description | Material Specification |
|---|---|---|---|
| a1 | 2 | Cable Anchor Base Plate | ASTM A36 |
| a2 | 4 | Exterior Cable Plate Gusset | ASTM A36 |
| a3 | 6 | Interior Cable Plate Gusset | ASTM A36 |
| a4 | 2 | Anchor Bracket Plate | ASTM A36 |
| a5 | 2 | 3/16" [5] Dia. Brass Keeper Rod, 14" [356] long | Brass |
| a6 | 4 | Release Gusset | A36 Steel |
| a7 | 2 | Release Lever Plate | A36 Steel |
| a8 | 4 | 1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Tube | ASTM A500 Gr. B |
| a9 | 8 | CMB High Tension Anchor Plate Washer | ASTM A36 |
| a10 | 2 | 1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Connecting Tube | ASTM A 500 Gr. B |
| a11 | 2 | 3x10x0.5" [76x254x13] Kicker Plate | ASTM A36 |
| a12 | 4 | CT kicker – gusset | ASTM A36 |
| a13 | 20 | 3/4" [19] Dia. Flat Washer | ASTM F844 |
| a14 | 16 | 3/4" [19] Dia. UNC J-Hook Anchor and Hex Nut | J-Hook ASTM A449/Nut ASTM A563 DH |
| a15 | 2 | 1/4" [6] Dia. Aircraft Retaining Cable, 36" [914] long | 7x19 Galv. |
| a16 | 2 | 5/8" [16] Dia. Heavy Hex Nut | ASTM A563C |
| a17 | 2 | 5/8" [16] Dia. UNC, 9 1/2" [241] Long Hex Bolt | ASTM A449 or SAE J429 Gr. 5 |
| a18 | 2 | 24" [610] Dia. Concrete Anchor, 120" [3048] long | 4,000 psi f'c |
| a19 | 16 | #11 Straight Rebar, 114" [2896] long | Grade 60 |
| a20 | 44 | #4 Anchor Hoop Rebar with 21" [533] Dia. | Grade 60 |
| b1 | 2 | S3x5.7 [S76x8.5] Post by 28 1/8" [714] | ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A |
| b2 | 2 | S3x5.7 [S76x8.5] Post by 19" [483] | ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A |
| b3 | 8 | #3 Straight Rebar, 43" [1092] long | Grade 60 |
| b4 | 22 | 7 1/4" [184] Dia. No. 3 Hoop Reinforcement | Grade 60 |
| b5 | 2 | 2nd Post Keeper Plate, 28 Gauge | ASTM A36 |
| b6 | 2 | 3/4" [19] Dia. UNC, 5 1/2" [140] Long Hex Bolt and Nut | Bolt ASTM A307 Gr. A/Nut ASTM A563A |
| b7 | 24 | 1/2" [13] Dia. Washer with 1 1/16" [27] OD | ASTM F844 |
| b8 | 8 | 1/2" [13] Dia. UNC, 2" [51] long Hex Bolt and Nut | Bolt ASTM A307 Gr. A/Nut ASTM A563A |
| b9 | 2 | 4x3x1/4" [102x76x6] Foundation Tube, 48" [1168] long | ASTM A500 Grade B |
| b10 | 2 | 2nd Post Cable Hanger | ASTM A36 |
| b11 | 2 | 2nd Post Anchor Aggregate 12 in, Depth | – |
| b12 | 2 | 12" Dia. 2nd Post Concrete Anchor, 46" long | 4,000 psi f'c |
| b13 | 4 | 2nd Post Base Plate | ASTM A36 |
| b14 | 8 | 3/16" [5] Dia. 5 1/4" [133] Long Brass Rod | ASTM B16-00 |

MwRSF
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Safety Facility

Midwest 4-Cable Barrier
System

Bill of Materials

SHEET:
23 of 24

DATE:
06/23/2015

DRAWN BY:
SDB/JEK

DWG. NAME.
MWP-5_R3

SCALE: NONE
UNITS: in.[mm]

REV. BY:
KAL

Figure 84. Bill of Materials, Test No. MWP-6

| Item No. | QTY. | Description | Material Spec |
|---|---|---|---|
| c1 | 72 | 3"x1−3/4"x7 Gauge [76x44x4.6], 81 1/4" [2064] Long Bent MWP Z−Section Post | Hot−Rolled ASTM A1011 HSLA Gr. 50 |
| c2 | 216 | 12 Gauge Tabbed Bracket − Version 10 | Hot−Rolled ASTM A1011 HSLA Grade 50 |
| c3 | 216 | 5/16" [8] Dia. UNC, 1" [25] Long Hex Cap Screw and Nut | Bolt SAE J429 Gr. 5 or ASTM A449/Nut ASTM A563 DH |
| c4 | 72 | Straight Rod − ϕ3/16" [5] Cable Clip | ASTM B16 Brass C36000 Half Hard (HO2), ROUND. TS >= 68.0 ksi, YS >= 52.0 ksi |
| d1 | 1 | 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] |
| d2 | 16 | 7/8" [22] Dia. Hex Nut | ASTM A563C |
| d3 | 28 | Cable End Threaded Rod | ASTM A449 |
| d4 | 24 | Bennet Cable End Fitter | ASTM A47 |
| d5 | 24 | 7/8" [22] Dia. Hex Nut | SAE J429 Gr. 5 |
| e1 | 8 | Bennet Short Threaded Turnbuckle | Not Specified |
| e2 | 8 | Threaded Load Cell Coupler | N/A |
| e3 | 4 | 50,000−lb [222.4−kN] Load Cell | N/A |

MwRSF

Midwest Roadside
Safety Facility

Midwest 4−Cable Barrier System

Bill of Materials

SHEET:
24 of 24

DATE:
06/23/2015

DRAWN BY:
SDB/JEK

DWG. NAME.
MWP−5_R3

SCALE: NONE
UNITS: in.[mm]

REV. BY:
KAL

Figure 85. Bill of Materials, Test No. MWP-6

Figure 86. Test Installation Photographs, Test No. MWP-6

Figure 87. Test Installation Photographs, Test No. MWP-6

May 17, 2016
MwRSF Report No. TRP-03-327-16

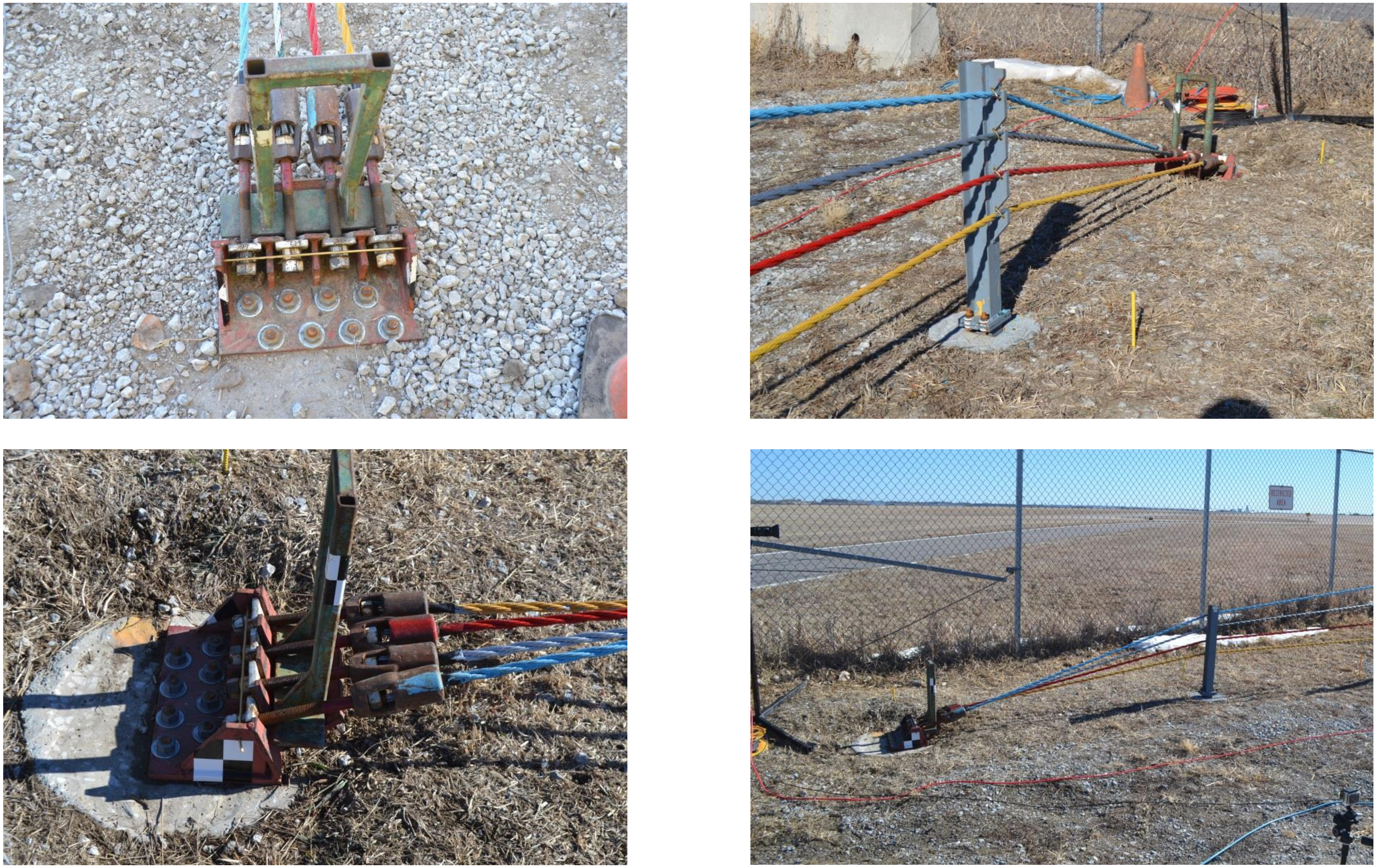


Figure 88. Test Installation Photographs, Test No. MWP-6

Figure 89. Test Installation Photographs, Test No. MWP-6

# 7 FULL SCALE CRASH TEST NO. MWP-6

## 7.1 Static Soil Test

Before full-scale crash test no. MWP-6 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The soil for this test was partially frozen, making it difficult to get a full range of soil strength up to 15 in. of deflection. The winch utilized to load the post actually reached its capacity, prior to reaching 15 in. (381 mm) of displacement. The winch capacity is over 2.5 times the required strength. Note that weak posts used in cable barrier systems do not rotate in strong soil. Instead, weak posts yield at the ground line in both frozen and unfrozen strong soils configured with compacted crushed limestone. Thus, the frozen soil condition was considered acceptable for this cable barrier test. 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.

## 7.2 Weather Conditions

Test no. MWP-6 was conducted on January 16, 2015 at approximately 2:30 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), were reported and are shown in Table 9.

Table 9. Weather Conditions, Test No. MWP-6

| | |
|---|---|
| Temperature | 59°F |
| Humidity | 31% |
| Wind Speed | 15 mph |
| Wind Direction | 40° West of True South |
| Sky Conditions | Sunny |
| Visibility | 10 Statute Miles |
| Pavement Surface | Dry |
| Previous 3-Day Precipitation | 0 in. |
| Previous 7-Day Precipitation | 0 in. |

### 7.3 Test No. MWP-6

The 2,572-lb (1,167-kg) small car impacted the high-tension, four-cable median barrier at a speed of 63.5 mph (102.2 km/h) and at an angle of 24.9 degrees. A summary of the test results and sequential photographs are shown in Figure 90. Additional sequential photographs are shown in Figures 91 and 92. Documentary photographs of the crash test are shown in Figure 93.

### 7.4 Test Description

Initial vehicle impact was to occur at a midspan location, or 4 ft (1.2 m) upstream from post no. 32, as shown in Figure 94, which was selected according to MASH guidelines. The actual point of impact was approximately 4.5 in. (114 mm) upstream from the target impact point. A sequential description of the impact events is contained in Table 10. The vehicle came to rest 234 ft - 6 in. (71.5 m) downstream from the point of impact. The vehicle trajectory and final position are shown in Figures 90 and 95.

Table 10. Sequential Description of Impact Events, Test No. MWP-6

| TIME (sec) | EVENT |
|---|---|
| 0.000 | Vehicle left-front bumper contacted cable no. 2 between post nos. 31 and 32, and front bumper began to deform. |
| 0.006 | Vehicle left-front bumper contacted cable no. 1 between post nos. 31 and 32. |
| 0.008 | Vehicle hood and left headlight contacted cable no. 3 between post nos. 31 and 32. |
| 0.018 | Post no. 32 began to deflect backward and downstream, and post no. 31 began to deflect backward. |
| 0.020 | Cable no. 3 detached from post no. 32. |
| 0.022 | Vehicle hood began to deform and post no. 33 began to deflect upstream. |
| 0.024 | Post no. 33 began to deflect backward. |
| 0.028 | Vehicle left side mirror contacted cable no. 4. |
| 0.030 | Cable no. 3 detached from post no. 31. |
| 0.034 | Vehicle left A-pillar contacted cable no. 3. |
| 0.038 | Vehicle front bumper contacted post no. 32. |
| 0.042 | Vehicle left A-pillar contacted cable no. 4. |
| 0.044 | Cable no. 4 detached from post no. 32. |
| 0.046 | Vehicle hood contacted cable no. 4, and post no. 30 began to deflect backward. |
| 0.056 | Cable no. 3 detached from post no. 33. |

| | |
|---|---|
| 0.062 | Vehicle left A-pillar began to deform, post no. 31 began to bend backward, and post no. 34 began to deflect backward. |
| 0.066 | Post no. 29 began to deflect downstream. |
| 0.080 | Vehicle left-front tire overrode cable no. 1, cable no. 2 detached from post no. 33, and cable no. 3 detached from post no. 34. |
| 0.082 | Vehicle left side mirror detached. |
| 0.086 | Cable no. 3 detached from post no. 29. |
| 0.092 | Vehicle left-front tire overrode cable no. 1, and post no. 29 began to deflect backward. |
| 0.098 | Cable no. 2 detached from post no. 34, and cable no. 3 detached from post no. 35. |
| 0.102 | Post no. 35 began to deflect backward. |
| 0.108 | Vehicle left-front door began to deform. |
| 0.112 | Post no. 36 began to deflect backward, and cable no. 4 detached from post no. 31. |
| 0.114 | Vehicle began to yaw away from barrier. |
| 0.116 | Vehicle right-front bumper contacted post no. 33, and cable no. 3 detached from post no. 36. |
| 0.120 | Cable no. 4 detached from post no. 31. |
| 0.122 | Cable no. 4 detached from post no. 33. |
| 0.130 | Cable no. 2 detached from post no. 36. |
| 0.136 | Vehicle began to pitch upward. |
| 0.138 | Cable no. 3 detached from post no. 28. |
| 0.146 | Post no. 37 began to deflect backward. |
| 0.160 | Post no. 28 began to deflect backward, and cable no. 3 detached from post no. 37. |
| 0.162 | Vehicle left-rear tire overrode cable no. 1. |
| 0.164 | Cable no. 4 detached from post no. 34. |
| 0.166 | Cable no. 4 detached from post no. 30. |
| 0.174 | Vehicle underrode cable nos. 3 and 4 while cables were in contact with roof. Vehicle roof began to deform. |
| 0.176 | Cable no. 4 detached from post no. 35. |
| 0.180 | Vehicle right-front tire overrode cable no. 1. |
| 0.182 | Cable no. 3 detached from post no. 27. |
| 0.194 | Cable no. 4 detached from post no. 29. |
| 0.196 | Cable no. 4 detached from post no. 36. |
| 0.216 | Cable no. 4 detached from post no. 37. |
| 0.244 | Post no. 34 began to bend backward. |
| 0.270 | Vehicle right-rear tire overrode cable no. 1. |
| 0.352 | Cable no. 2 detached from post no. 37 |
| 0.456 | Vehicle was parallel to system. |
| 0.490 | Vehicle left headlight became detached. |
| 0.678 | Vehicle right-rear door contacted post no. 38. |
| 0.742 | Vehicle was yawing away from barrier. |
| 0.752 | Vehicle right-side mirror contacted cable no. 4. |
| 0.764 | Vehicle rear bumper detached. |
| 0.794 | Vehicle began to roll toward barrier. |
| 0.800 | Vehicle bumper impacted post no. 39, and post no. 39 bent downstream. |
| 0.830 | Vehicle right-front tire became airborne. |

| | |
|---|---|
| 0.920 | Vehicle bumper impacted post no. 40, and post no. 40 bent downstream. |
| 0.930 | Vehicle right-front tire overrode cable no. 3 as it came back across system. |
| 1.508 | Vehicle underrode cable no. 4. |
| 1.602 | Vehicle was parallel to system. |
| 1.642 | Vehicle exited system. |
| 6.800 | Vehicle came to a stop 234.5 ft (71.5 m) downstream from impact. |

### 7.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 96 through 104. Barrier damage consisted of bent posts, disengaged cables, and bent and fractured brackets. At its final resting position, the vehicle was no longer in contact with the system.

Cable no. 4 disengaged from post nos. 29 through 52 due to fracturing of the brass keeper rods. Cable no. 3 disengaged from post nos. 24 through 49. Cable no. 2 disengaged from post nos. 32 through 40. Cable no. 1 disengaged from post nos. 32, 33, as well as from post nos. 35 through 39. Two of the brackets that released cable no. 2 fractured at the neck of the bracket. All of the other brackets released cable nos. 1 through 3 through rotation of the bracket tab through the key, allowing cables to release vertically. Displacement of the cable within the splices was documented. The maximum cable displacement within a splice was ½ in. (13 mm), found on the load cell splice located upstream from impact on cable no. 2.

Post nos. 30 through 41 had varying degrees of plastic deformations in the form of bending and twisting. The majority of the posts twisted to face downstream and/or bent back and downstream. In addition, post nos. 32, 33, as well as post nos. 38 through 40 had contact marks due to the vehicle overriding the posts.

The maximum dynamic barrier deflection was 89 in. (2,261 mm), and the working width of the system was 90.5 in. (2,299 mm), as determined from high-speed video analysis. Neither the upstream or downstream anchors showed signs of displacement.

### 7.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 105 through 110. The maximum occupant compartment deformations are listed in Table 11 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH-established deformation limits were violated. Complete occupant compartment and vehicle deformations as well as the corresponding locations are provided in Appendix D.

Table 11. Maximum Occupant Compartment Deformations by Location, Test No. MWP-6

| LOCATION | MAXIMUM DEFORMATION in. (mm) | MASH ALLOWABLE DEFORMATION in. (mm) |
|---|---|---|
| Wheel Well & Toe Pan | 0.5 (13) | ≤9 (229) |
| Floor Pan & Transmission Tunnel | 1.3 (33) | ≤12 (305) |
| Side Front Panel (in Front of A-Pillar) | 0.1 (3) | ≤12 (305) |
| Side Door (Above Seat) | 0.2 (5) | ≤12 (305) |
| Side Door (Below Seat) | 0.0 (0) | ≤9 (229) |
| Roof | 1 (25) | ≤4 (102) |

The majority of the vehicle damage was concentrated on the left-front corner and left side of the vehicle where impact occurred, although other notable damage was found on the right-front corner. The vehicle’s left and right headlights were both disengaged. The lower front bumper, the plastic portion of the rear bumper, both side mirrors, and the right-rear door handle were also disengaged. There was a 2½-in. (64 -mm) gap between the hood and the bumper, and a 4-in. (102-mm) gap between the fender and hood on the left side. The left fender was bent backward 9 in. (229 mm), folding into the vehicle on the bottom, resulting in a 14-in. (356-mm) buckle beginning above the left-front tire. There was also a 9x6-in. (229x152-mm) dent on the right-front door and fender. Three quarters of the left-front wheel well was removed from the vehicle. There was a 1½-in. (38-mm) long tear in the deflated left-front tire. The lower 16 in.

(406 mm) of the left fender as well as the lower 11 in. (279 mm) of the front half of the left-front vehicle door had been torn off. The left-front door was separated from the roof by ⅜ in. (10 mm). There was a ¾ in. (19 mm) gap between the right fender and right-front door and a 1 in. (25 mm) gap between the right fender and hood.

Contact marks from cables covered a majority of the vehicle – specifically on the front bumper, left side of the hood and left fender, left-front wheel rim, bottom of the left-rear door, on the right-rear door, along both A-pillars and on the entire roof. The majority of these contact marks were accompanied by gouges. The worst gouging occurred along the A-pillars, where the gouging on the left A-pillar caused the windshield to crack. Spider-web cracking occurred adjacent to the left-front A-pillar and propagated outward, extending as far as the center of the windshield.

Tears occurred on the plastic portion of the front bumper. There was also a 19-in. (483-mm) by 5-in. (127-mm) tear in the left front door, 11 in. (279 mm) above the bottom of the door. Dents were noted on the lower front bumper, on the front of the hood, at the left-front corner of the roof, along the bottom right side of the vehicle, on the right fender, and on the right-front door.

The floorpan was torn in several locations. A 7.5-in. (191-mm) long floorpan tear was located on the left side of the transmission hump, and a 4-in. (102-mm) long tear was on the right side of the transmission hump extending backward from a hole in the floorpan. These tears can be seen on the interior of the vehicle in Figure 107 and from the undercarriage in Figure 108. Although the occupant compartment deformations were within the bounds set by MASH, the occupant compartment penetrations via floorpan tears were unacceptable. The spare tire area of the trunk also had a 4-in. (102-mm) long tear, as shown in Figure 109. While not part of the occupant compartment, this trunk damage still raises concern. Additional scrapes and gouges were found on the floorpan and vehicle undercarriage, as shown in Figure 110.

### 7.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 12. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 12. The results of the occupant risk analysis, as determined from the accelerometer data, are also summarized in Figure 90. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix G.

Table 12. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MWP-6

| **Evaluation Criteria** | | **Transducer** | | **MASH Limits** |
|---|---|---|---|---|
| | | **SLICE 1 (primary)** | **SLICE 2** | |
| **OIV ft/s (m/s)** | Longitudinal | -11.98 (-3.65) | -11.98 (-3.65) | ≤ 40 (12.2) |
| | Lateral | 11.25 (3.43) | 10.14 (3.09) | ≤ 40 (12.2) |
| **ORA g's** | Longitudinal | -6.77 | -6.26 | ≤ 20.49 |
| | Lateral | 5.77 | 6.78 | ≤ 20.49 |
| **MAX. ANGULAR DISPLACEMENT deg.** | Roll | -19.60 | -16.97 | ≤ 75 |
| | Pitch | 4.52 | -3.02 | ≤ 75 |
| | Yaw | 46.04 | 45.35 | not required |
| **THIV ft/s (m/s)** | | 16.27 (4.96) | 14.86 (4.53) | not required |
| **PHD g's** | | 6.86 | 7.12 | not required |
| **ASI** | | 0.42 | 0.43 | not required |

## 7.8 Load Cells and String Potentiometers

The pertinent data from the load cells and string potentiometer were extracted from the bulk signal and analyzed using each transducer's calibration factor. The upstream anchor showed no displacement. A summary of the maximum cable loads can be found in Table 13. The recorded data and analyzed results are detailed in Appendix H. The exact moment of impact could not be determined from the transducer data, as impact may have occurred 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 13. Maximum Cable Loads, Test No. MWP-6

| Cable Location | Sensor Location | Maximum Cable Load | | Time (sec) |
|---|---|---|---|---|
| | | kips | kN | |
| Combined Cable Load | Upstream of Impact | 32.99 | 146.75 | 0.1249 |
| Cable No. 4 | Upstream of Impact | 7.14 | 31.76 | 1.0997 |
| Cable No. 3 | Upstream of Impact | 7.76 | 34.52 | 0.1521 |
| Cable No. 2 | Upstream of Impact | 18.94 | 84.25 | 0.3838 |
| Cable No. 1 | Upstream of Impact | 11.66 | 51.87 | 0.0442 |

## 7.9 Discussion

The analysis of the test results for test no. MWP-6 showed that the high-tension, four-cable median barrier 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 G, were deemed acceptable, because they did not adversely influence occupant risk safety criteria or cause rollover. After impact, the vehicle trajectory was limited by the barrier system and brought to a rest 234 ft - 6 in. (71.5 m) downstream from the point of impact. As the vehicle overrode the system posts, the posts tore the floorpan in two separate locations. The tears indicated that the top of these posts could have penetrated into the occupant compartment. Therefore, test no. MWP-6, conducted on the four-cable median barrier, was determined to be unacceptable according to the MASH safety performance criteria for test designation no. 3-10.

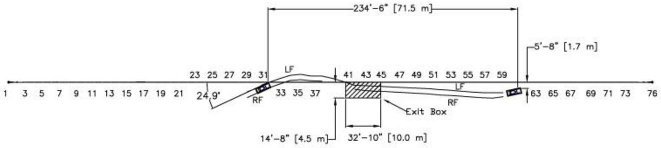

0.000 sec

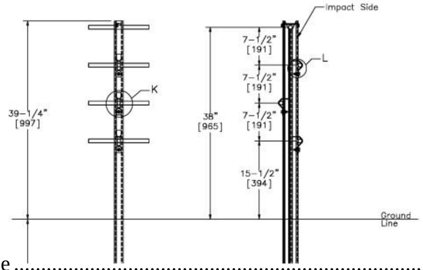

0.092 sec


0.214 sec


0.314 sec


0.414 sec





- Test Agency ........ MwRSF
- Test Number ........ MWP-6
- Date ........ 01/16/2015
- MASH Test Designation ........ 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 mm, 584 mm, 775 mm, 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 ........ 2009 Kia Rio
  - Curb ........ 2,295 lb (1,041 kg)
  - Test Inertial ........ 2,405 lb (1,091 kg)
  - Gross Static ........ 2,572 lb (1,167 kg)
- Impact Conditions
  - Speed ........ 63.5 mph (102.2 km/h)
  - Angle ........ 24.9 deg
  - Impact Location ........ 4 ft - 4.5 in. (1.33 m) upstream of Post No. 32
- Impact Severity (IS) ........ 57.3 kip-ft (77.7 kJ) > 51 kip-ft (69.1 kJ)
- Exit Conditions
  - Speed ........ 24.3 mph (39.1 km/h)
  - Angle ........ 1 deg
- Exit Box Criterion ........ Pass
- Vehicle Stability ........ Satisfactory
- Vehicle Stopping Distance ........ 234 ft - 6 in. (71.5 m)
- Vehicle Damage ........ Extensive
  - VDS [8] ........ 11-FL-6
  - CDC [9] ........ 11-FDAK-8
  - Maximum Interior Deformation ........ 1.52 in. (39 mm)
- Test Article Damage ........ Moderate
- Maximum Test Article Deflections
  - Permanent Set ........ 46¼ in. (1,175 mm)
  - Dynamic ........ 89 in. (2,261 mm)
  - Working Width ........ 90.5 in. (2,299 mm)
- Transducer Data

| Evaluation Criteria | | Transducer | | MASH Limit |
|---|---|---|---|---|
| | | SLICE-1 (primary) | SLICE-2 | |
| OIV ft/s (m/s) | Longitudinal | -11.98 (-3.65) | -11.98 (-3.65) | ≤ 40 (12.2) |
| | Lateral | 11.25 (3.43) | 10.14 (3.09) | ≤ 40 (12.2) |
| ORA g's | Longitudinal | -6.77 | -6.26 | ≤ 20.49 |
| | Lateral | 5.77 | 6.78 | ≤ 20.49 |
| MAX. ANGULAR DISPLACEMENT deg. | Roll | -19.60 | -16.97 | ≤ 75 |
| | Pitch | 4.52 | -3.02 | ≤ 75 |
| | Yaw | 46.04 | 45.35 | not required |
| THIV – ft/s (m/s) | | 16.27 (4.96) | 14.86 (4.53) | not required |
| PHD – g's | | 6.86 | 7.12 | not required |
| ASI | | 0.42 | 0.43 | not required |

Figure 90. Summary of Test Results and Sequential Photographs, Test No. MWP-6


0.000 sec


0.092 sec


0.158 sec


0.204 sec


0.274 sec


0.374 sec


0.000 sec


0.112 sec


0.252 sec


0.450 sec


0.978 sec


1.492 sec

Figure 91. Additional Sequential Photographs, Test No. MWP-6


0.000 sec


0.124 sec


0.216 sec


0.290 sec


0.492 sec


0.630 sec


0.000 sec


0.128 sec


0.360 sec


0.630 sec


0.930 sec


1.508 sec

Figure 92. Additional Sequential Photographs, Test No. MWP-6

Figure 93. Documentary Photographs, Test No. MWP-6

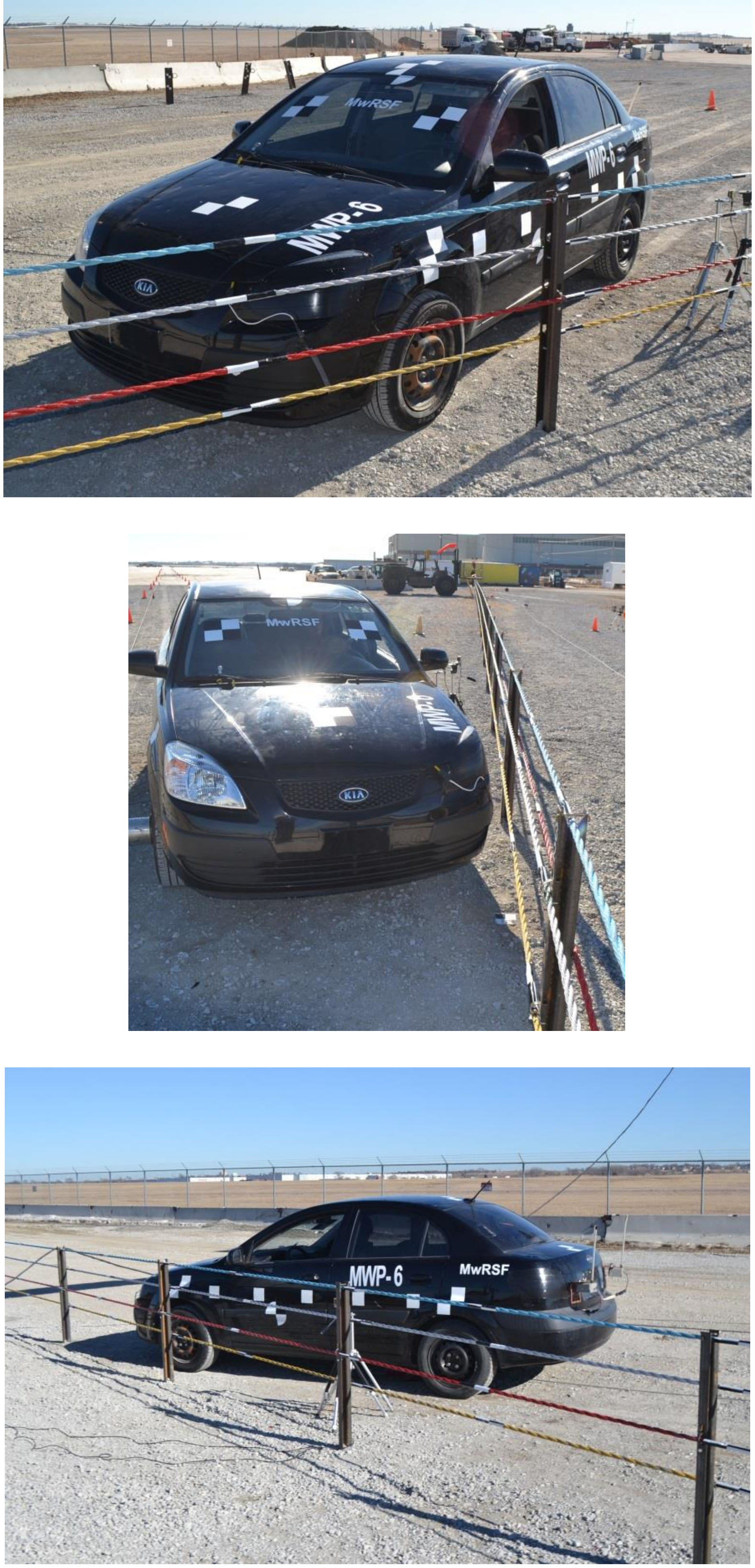


Figure 94. Impact Location, Test No. MWP-6

Figure 95. Vehicle Final Position and Trajectory Marks, Test No. MWP-6

Figure 96. System Damage, Test No. MWP-6

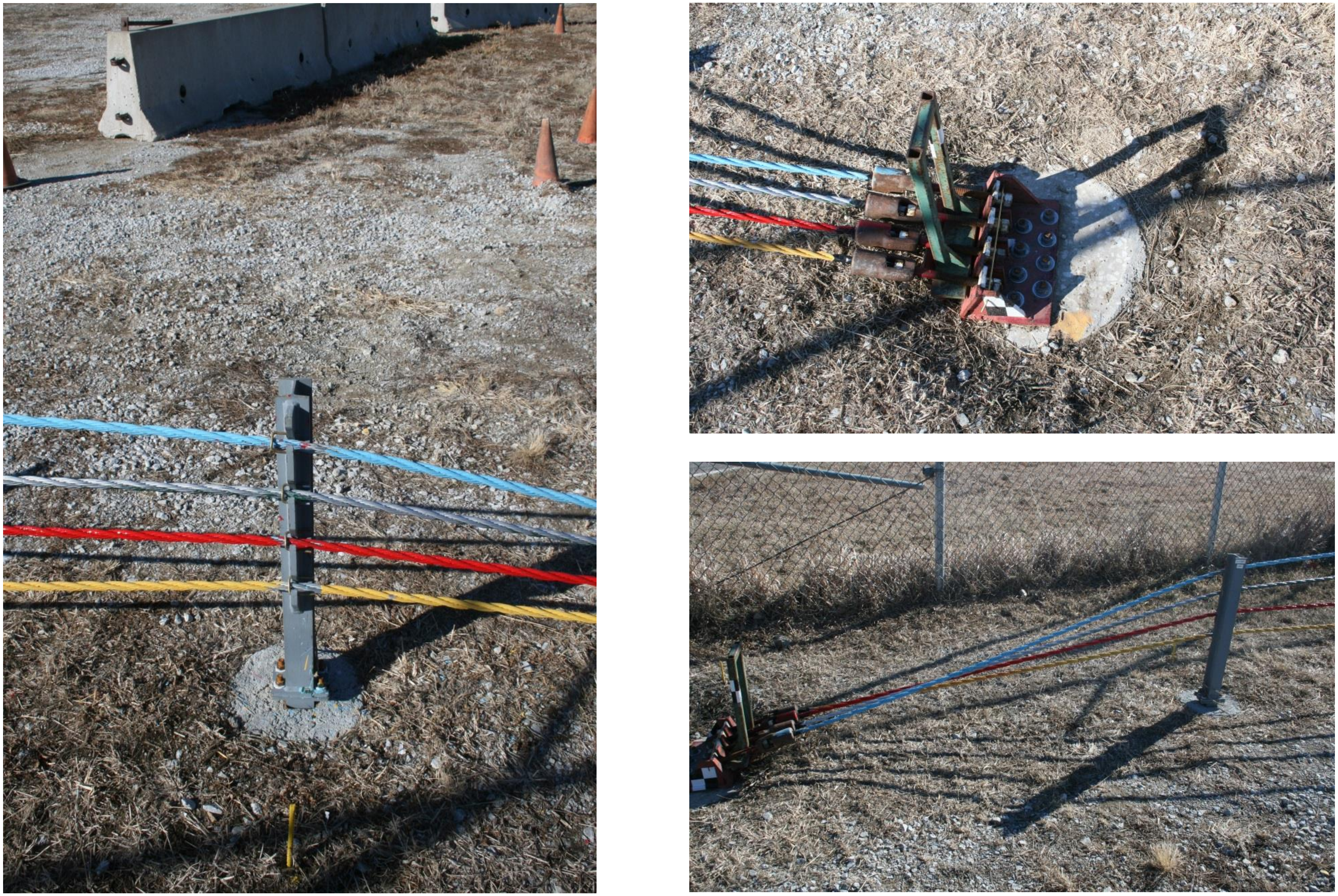


Figure 97. System Damage, End Anchorages, Test No. MWP-6

Figure 98. System Damage, Cable Brackets, Test No. MWP-6

Figure 99. Example System Damage, Brass Rods, Test No. MWP-6

Post No. 31

Post No. 32

Post No. 33

Figure 100. System Damage, Post Nos. 31 through 33, Test No. MWP-6

Post No. 34 Post No. 35 Post No. 36

Figure 101. System Damage, Post Nos. 34 through 36, Test No. MWP-6

Post No. 37

Post No. 38

Post No. 39

Figure 102. System Damage, Post Nos. 37 through 39, Test No. MWP-6

Post No. 40 Post No. 41 Post No. 42

Figure 103. System Damage, Post Nos. 40 through 42, Test No. MWP-6

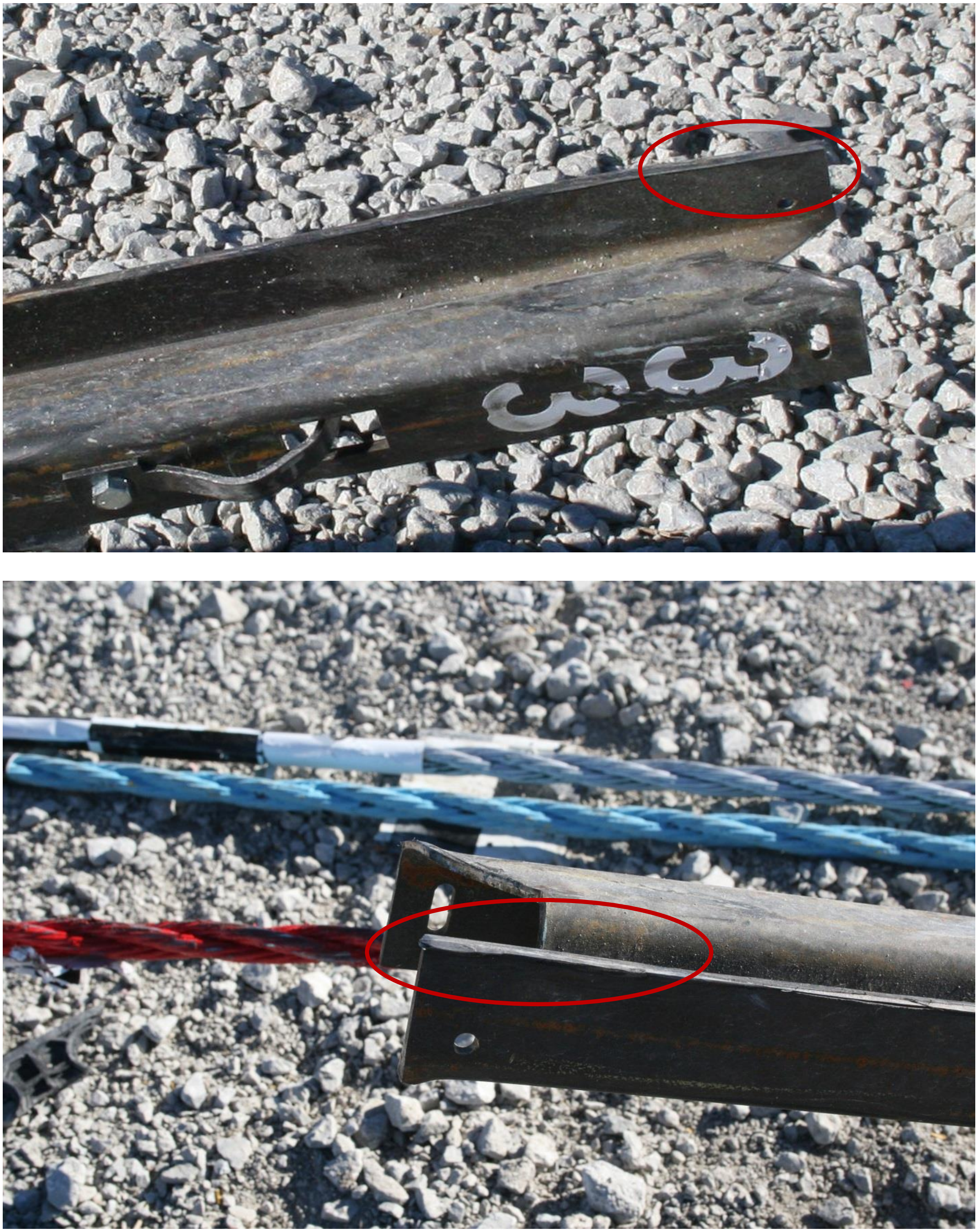


Figure 104. Post Contact Marks, Test No. MWP-6

Figure 105. Vehicle Damage, Test No. MWP-6

Figure 106. Vehicle Damage, Test No. MWP-6

Figure 107. Occupant Compartment Damage, Test No. MWP-6

Figure 108. Occupant Compartment Penetration, Test No. MWP-6

Figure 109. Spare Tire Compartment Penetration, Test No. MWP-6

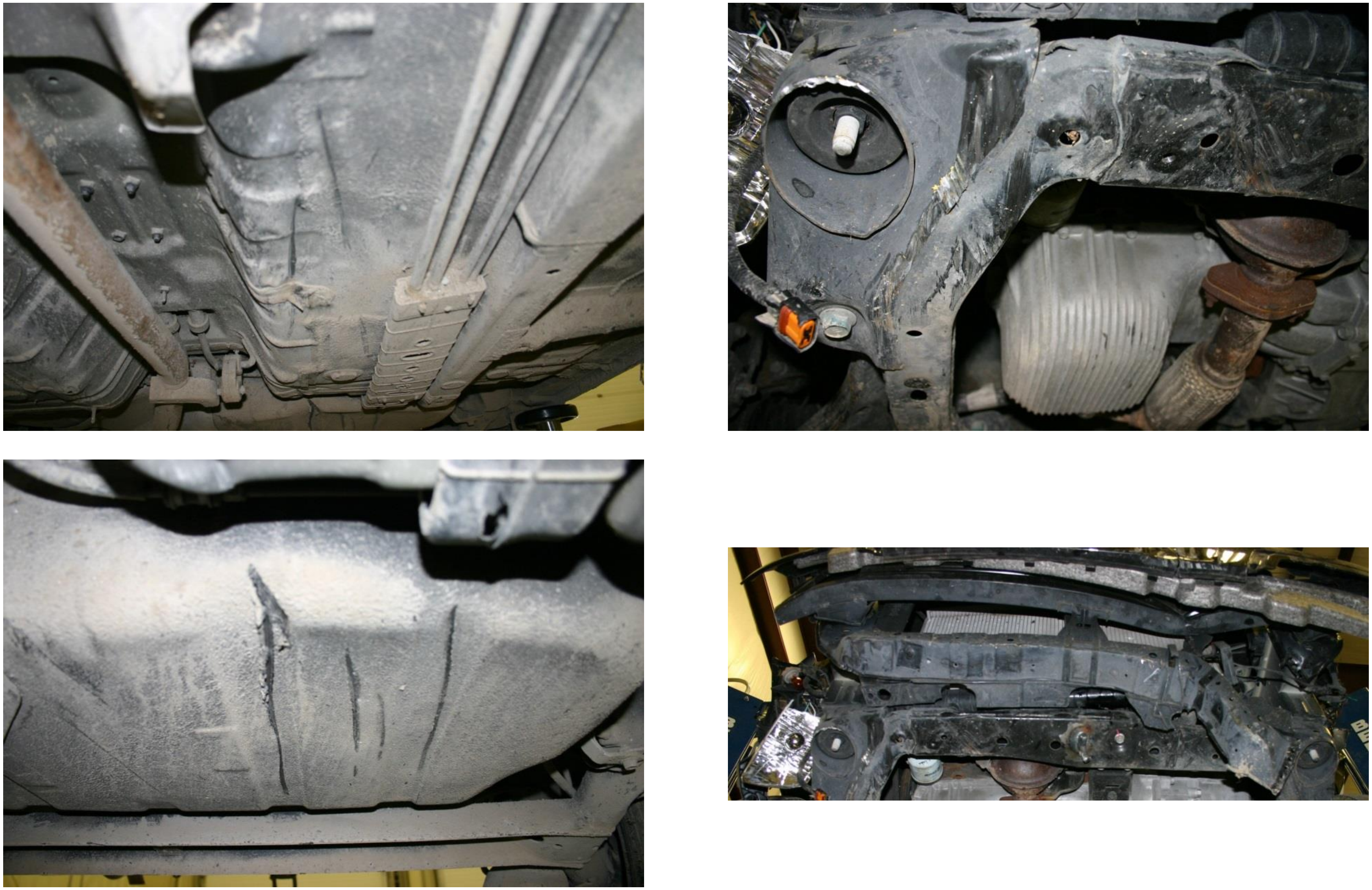


Figure 110. Additional Undercarriage Damage, Test No. MWP-6

# 8 DESIGN DETAILS TEST NO. MWP-7

## 8.1 Proposed System Modifications

Following the unsuccessful system performance in test no. MWP-6, the researchers brainstormed several potential design changes to mitigate floorpan penetrations. Analysis of the vehicle undercarriage and contact marks on both the system posts and the vehicle suggested that the floorpan tears were created as the post was overridden by the vehicle and the edges of the post scraped along the bottom of the vehicle. Contact marks from both the left and right flanges when bending about the weak axis of the post were visible in the deformed floorpan. A review of these contact marks indicated that the tearing was primarily caused by the free edges of the post, as shown in Figures 104 and 108.

In order to mitigate the floorpan tearing, several design modifications were proposed to the line posts. These options included:

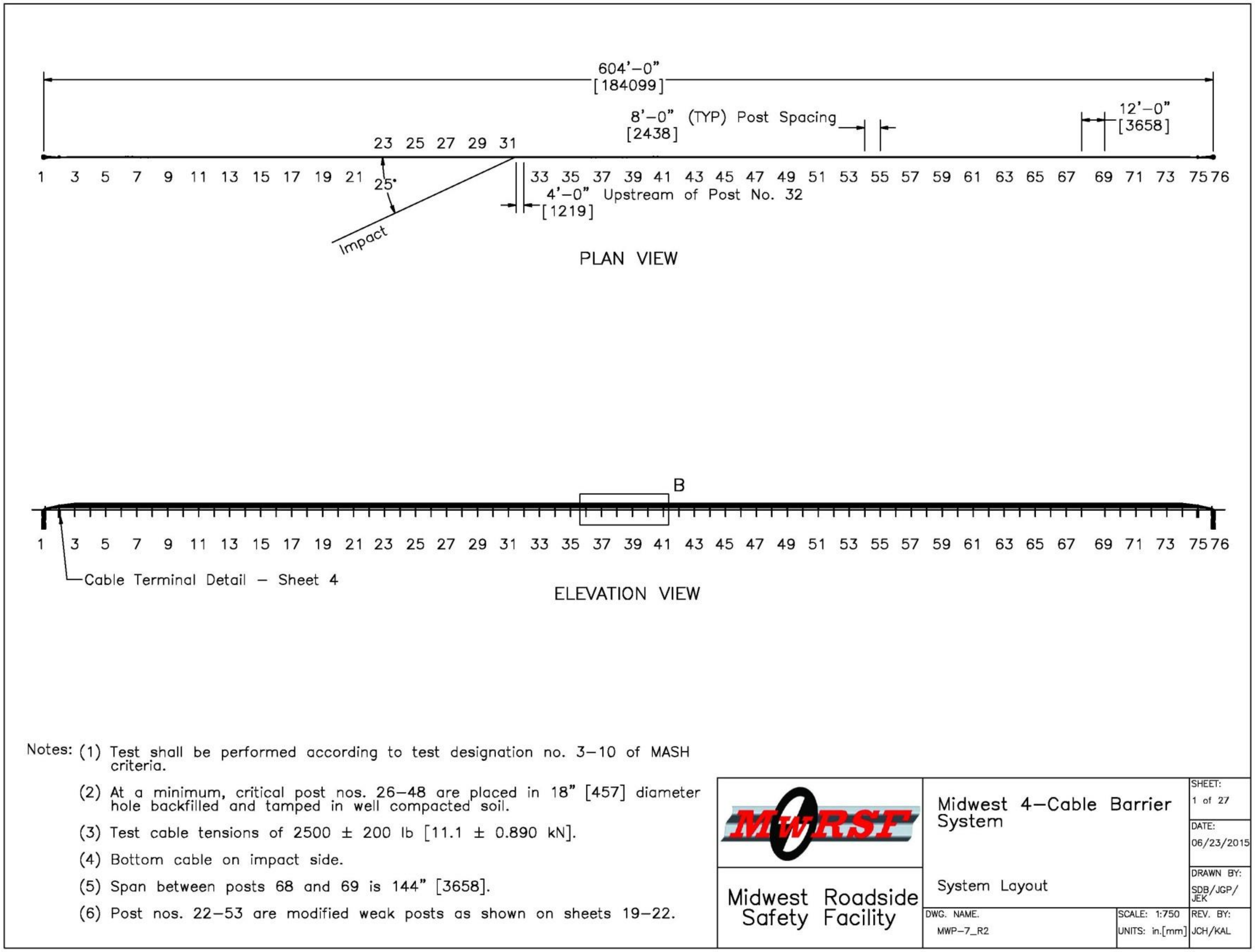
1. a reduction of the weak-axis capacity of the post to lower the upward force exerted by the post on the floorpan, which could be achieved through the addition of weakening holes, reducing the thickness of the post, or altering the post cross-sectional geometry.
2. adding a fillet radius to the post corners to remove sharp corners at the top of the post.
3. treating of the post edges through edge rounding or hemming.
4. adding edge or corner protectors to the upper portion of the post.
5. developing a new post section without free edges.

An alteration of the post cross-section and a reduction in the weak-axis bending capacity of the post were both deemed good options, but they were anticipated to require a significant amount of research and development prior to proceeding with a modified design. Treatment of the sheet metal edges through rounding or hemming was also considered, but it was thought to be costly with respect to edge rounding. Hemming was eliminated due to complications with hemming sheet steel as thick as 7 gauge (5 mm). The addition of edge or corner protectors to the upper portion of the post was believed to be an effective option. However, the additional component and potential cost made it initially less attractive. Thus, the addition of a fillet radius to the corners of the post was chosen to mitigate the floorpan tears. It was believed that removal of sharp corners near the top of the post would mitigate the stress concentrations imparted to the floorpan, while providing for minimal modification of the MWP post. As such, a ⅝-in. (16-mm) radius was added to the top corners of the free edges of the MWP post, and a ¼-in. (6-mm) radius was added to the top corners of the V-notch in the center of the post.

## 8.2 System Design Details

The four-cable median barrier system used for test no. MWP-7 was nearly identical to that used in test no. MWP-6, as shown in Figures 111 through 137. The targeted impact location, post spacing, and cable orientation for test no. MWP-7 remained the same as used in test no. MWP-6. The cables were tensioned to MASH specifications, as in the other tests, using the cable tensioning chart shown in Table 3. Thus, the cables were tensioned to a pre-load of 2,500 lb (11.1 kN).

The system layout for test no. MWP-7 is shown in Figure 111. For test no. MWP-7, post nos. 24 through 47 were substituted with a modified MWP that had rounded edges at its top in an attempt to reduce the likelihood of tearing the floorboard and penetrating into the occupant compartment. These modifications are detailed in Figures 129 through 131. Photographs of the test installation are shown in Figures 138 to 141. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.



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. 22–53 are modified weak posts as shown on sheets 19–22.

Midwest Roadside Safety Facility

Midwest 4–Cable Barrier System

System Layout

SHEET: 1 of 27

DATE: 06/23/2015

DRAWN BY: SDB/JGP/JEK

DWG. NAME. MWP–7_R2

SCALE: 1:750

UNITS: in.[mm]

REV. BY: JCH/KAL

Figure 111. Test Installation Layout, Test No. MWP-7

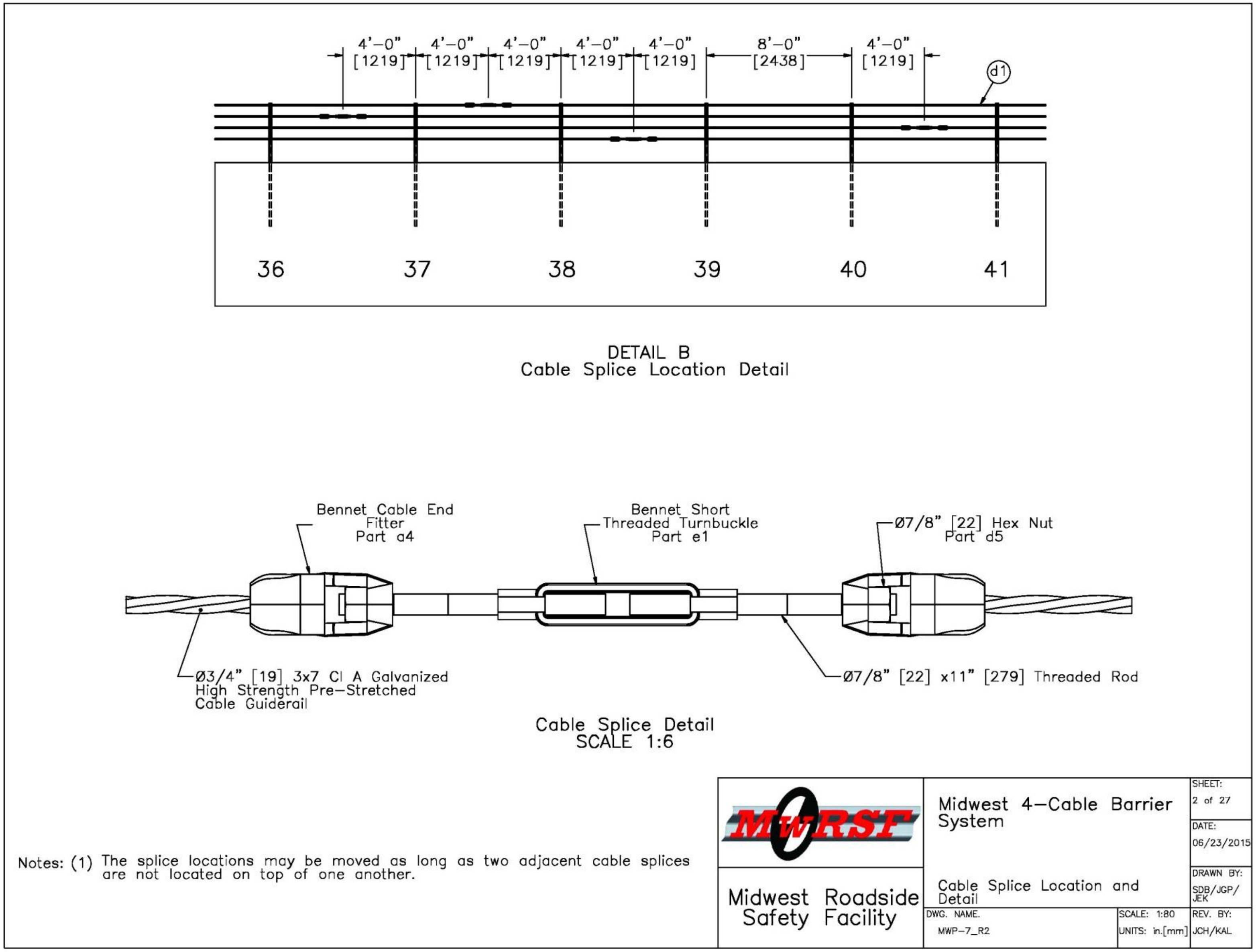


Figure 112. Cable Splice Location and Detail, Test No. MWP-7

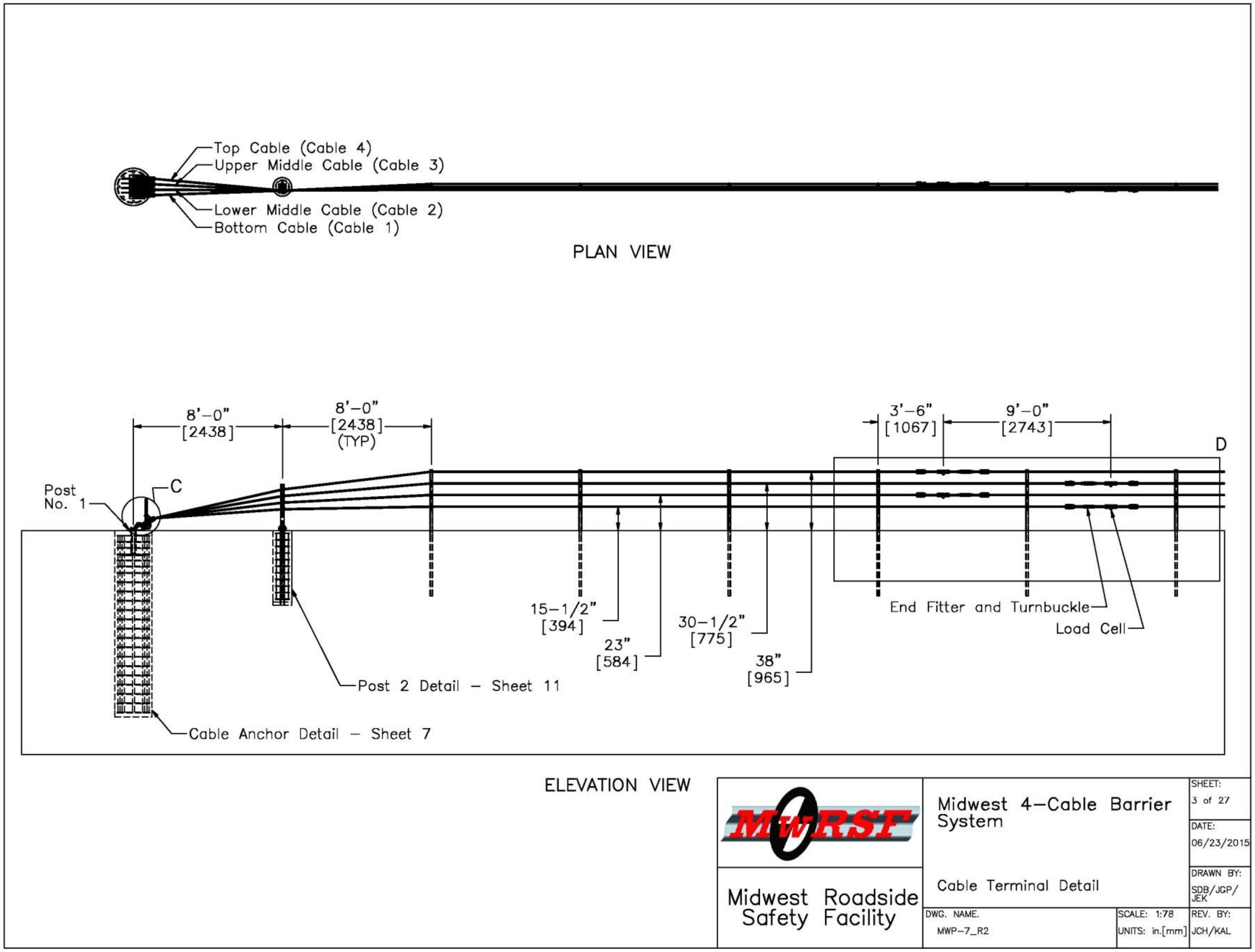


Figure 113. Cable Terminal Detail, Test No. MWP-7

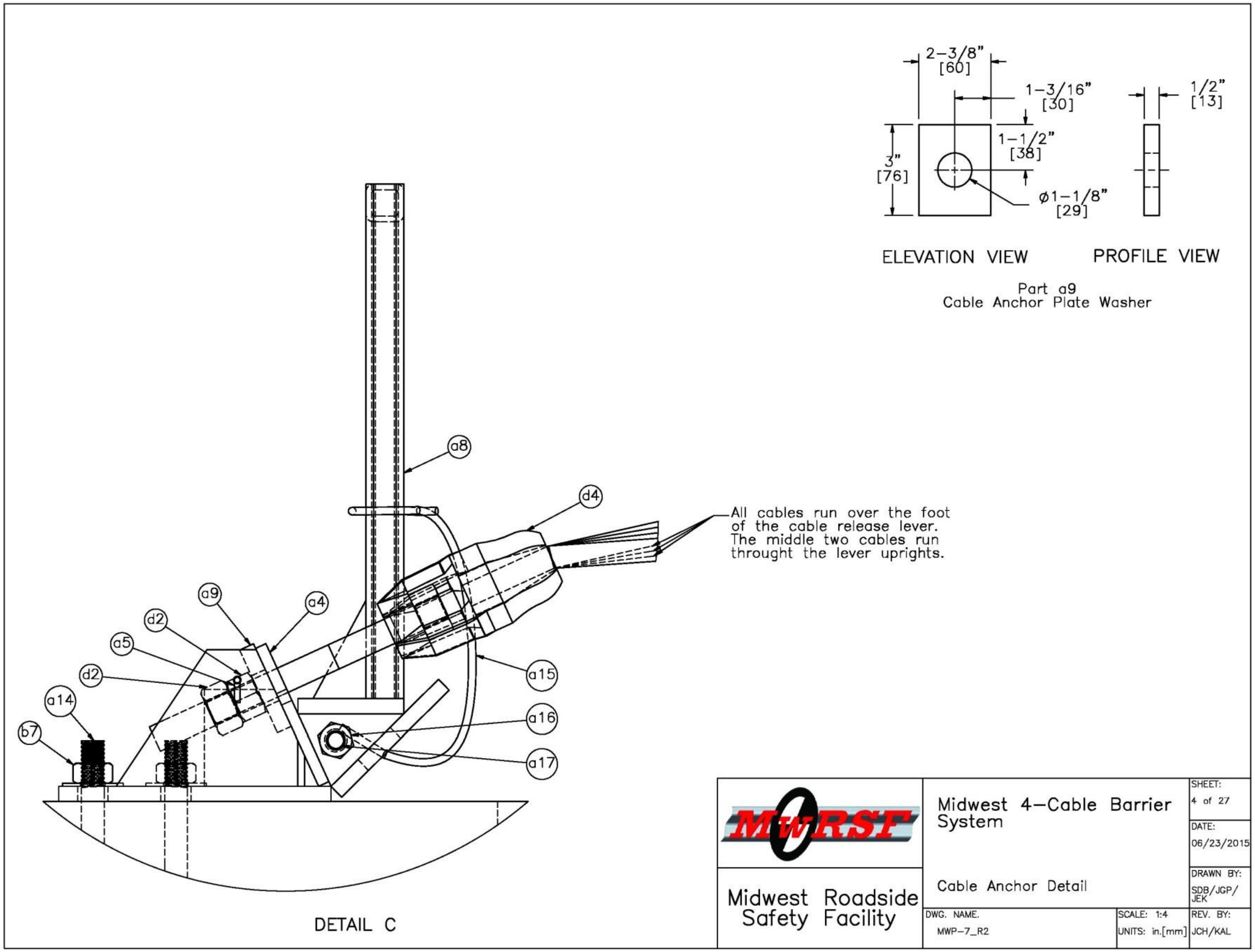


Figure 114. Cable Anchor Detail, Test No. MWP-7

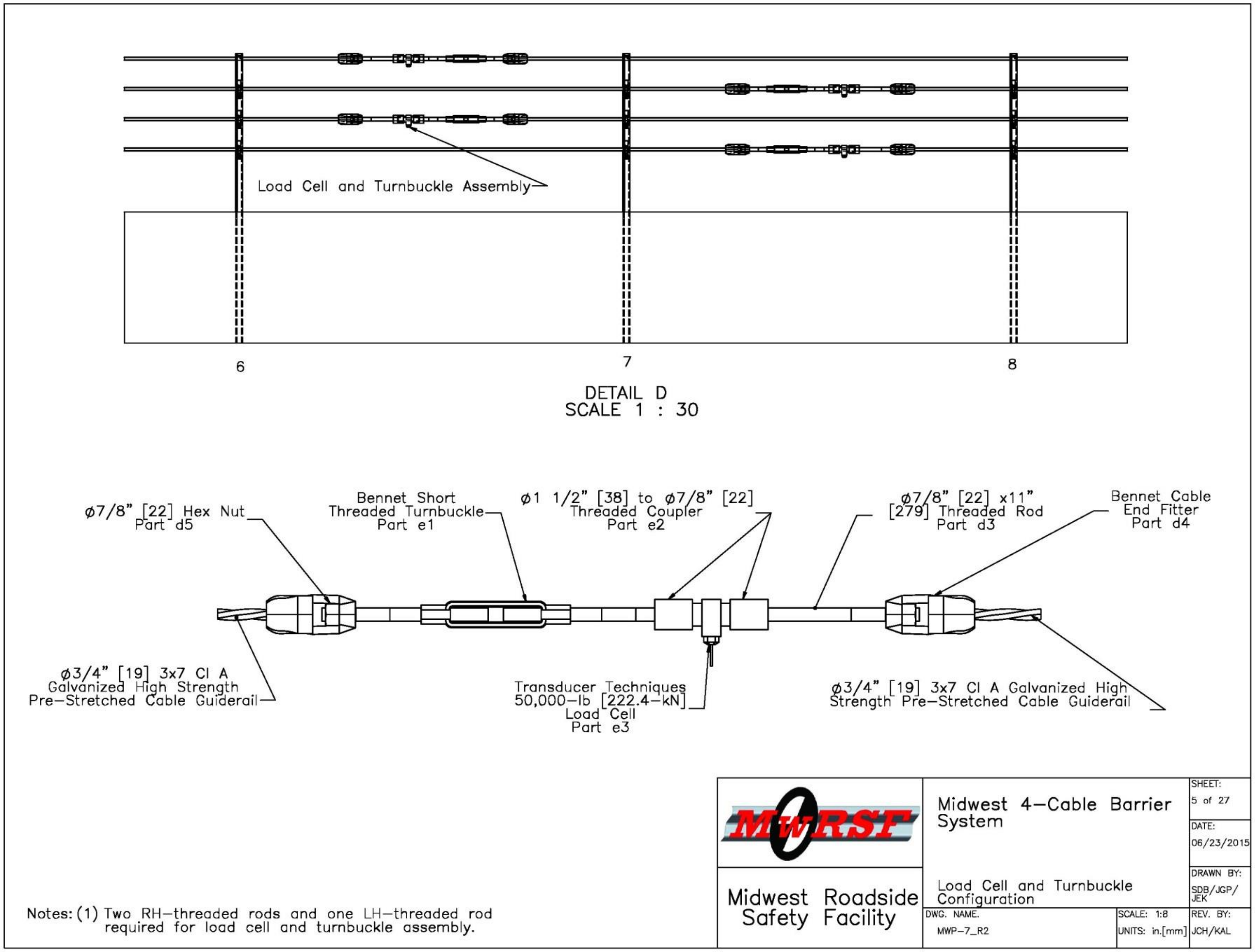


Figure 115. Load Cell and Turnbuckle Configuration, Test No. MWP-7

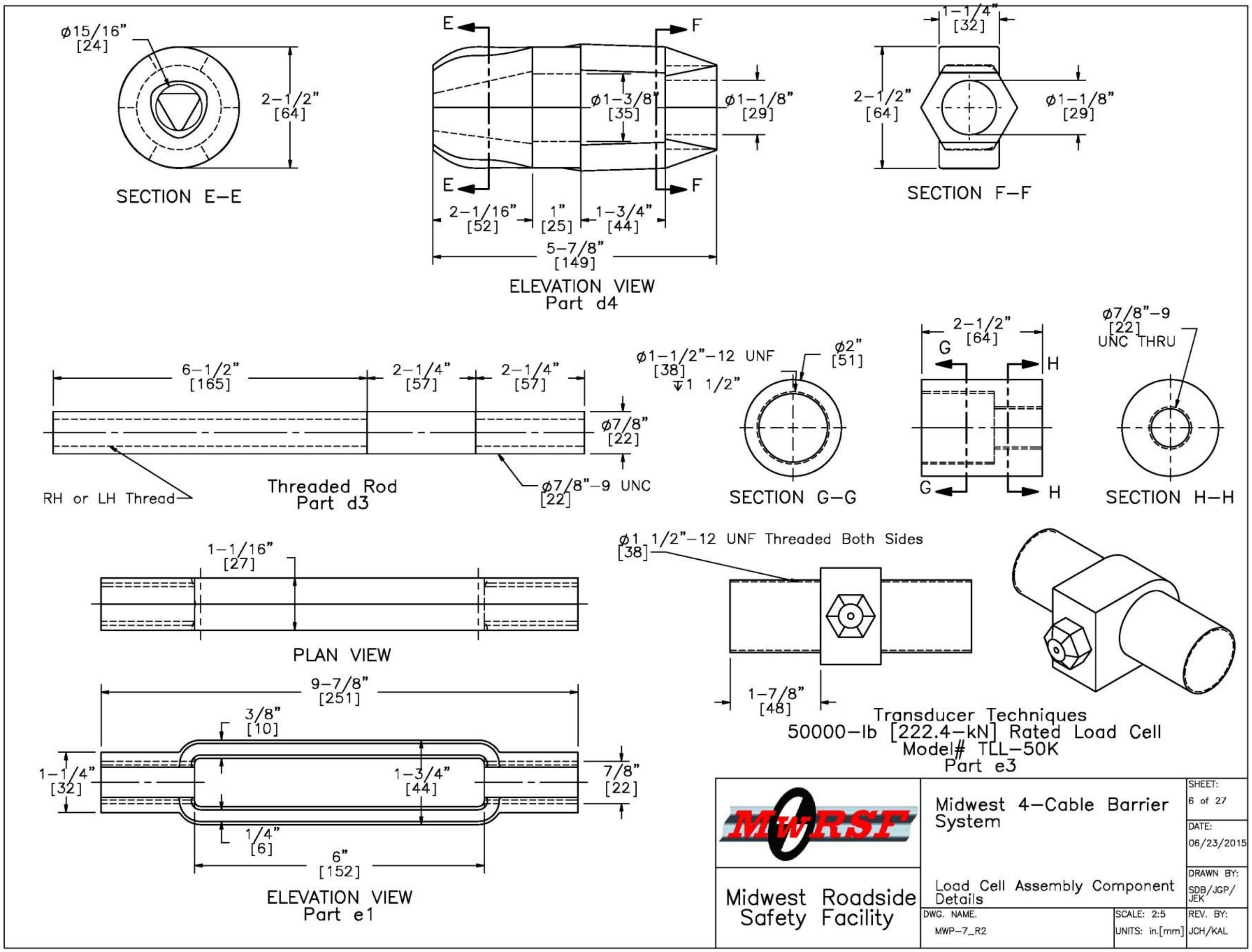
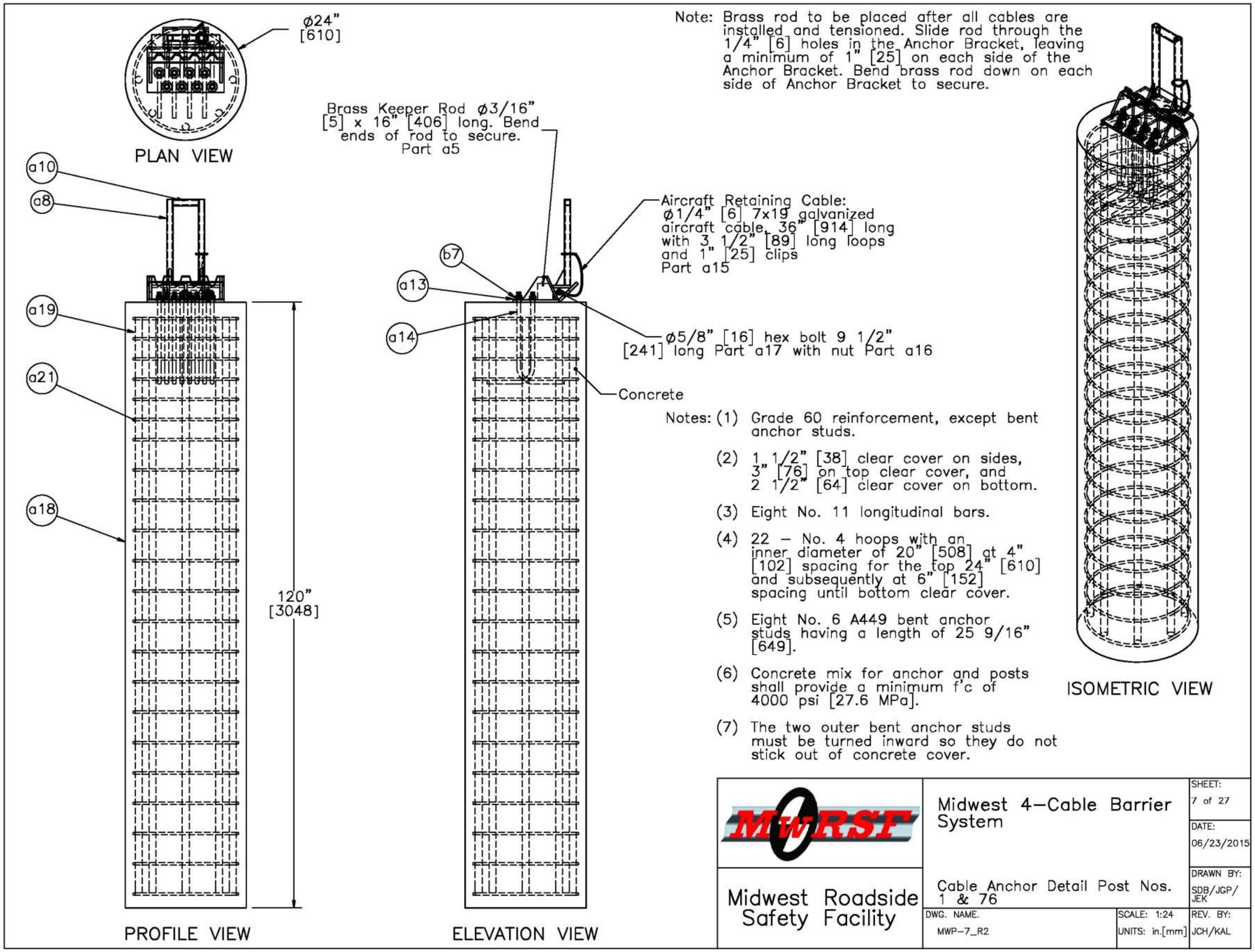


Figure 116. Load Cell Assembly Details, Test No. MWP-7



Note: Brass rod to be placed after all cables are installed and tensioned. Slide rod through the 1/4" [6] holes in the Anchor Bracket, leaving a minimum of 1" [25] on each side of the Anchor Bracket. Bend brass rod down on each side of Anchor Bracket to secure.

Notes:
(1) Grade 60 reinforcement, except bent anchor studs.
(2) 1 1/2" [38] clear cover on sides, 3" [76] on top clear cover, and 2 1/2" [64] clear cover on bottom.
(3) Eight No. 11 longitudinal bars.
(4) 22 – No. 4 hoops with an inner diameter of 20" [508] at 4" [102] spacing for the top 24" [610] and subsequently at 6" [152] spacing until bottom clear cover.
(5) Eight No. 6 A449 bent anchor studs having a length of 25 9/16" [649].
(6) Concrete mix for anchor and posts shall provide a minimum f'c of 4000 psi [27.6 MPa].
(7) The two outer bent anchor studs must be turned inward so they do not stick out of concrete cover.

Figure 117. Cable Anchor Foundation, Post Nos. 1 and 76, Test No. MWP-7

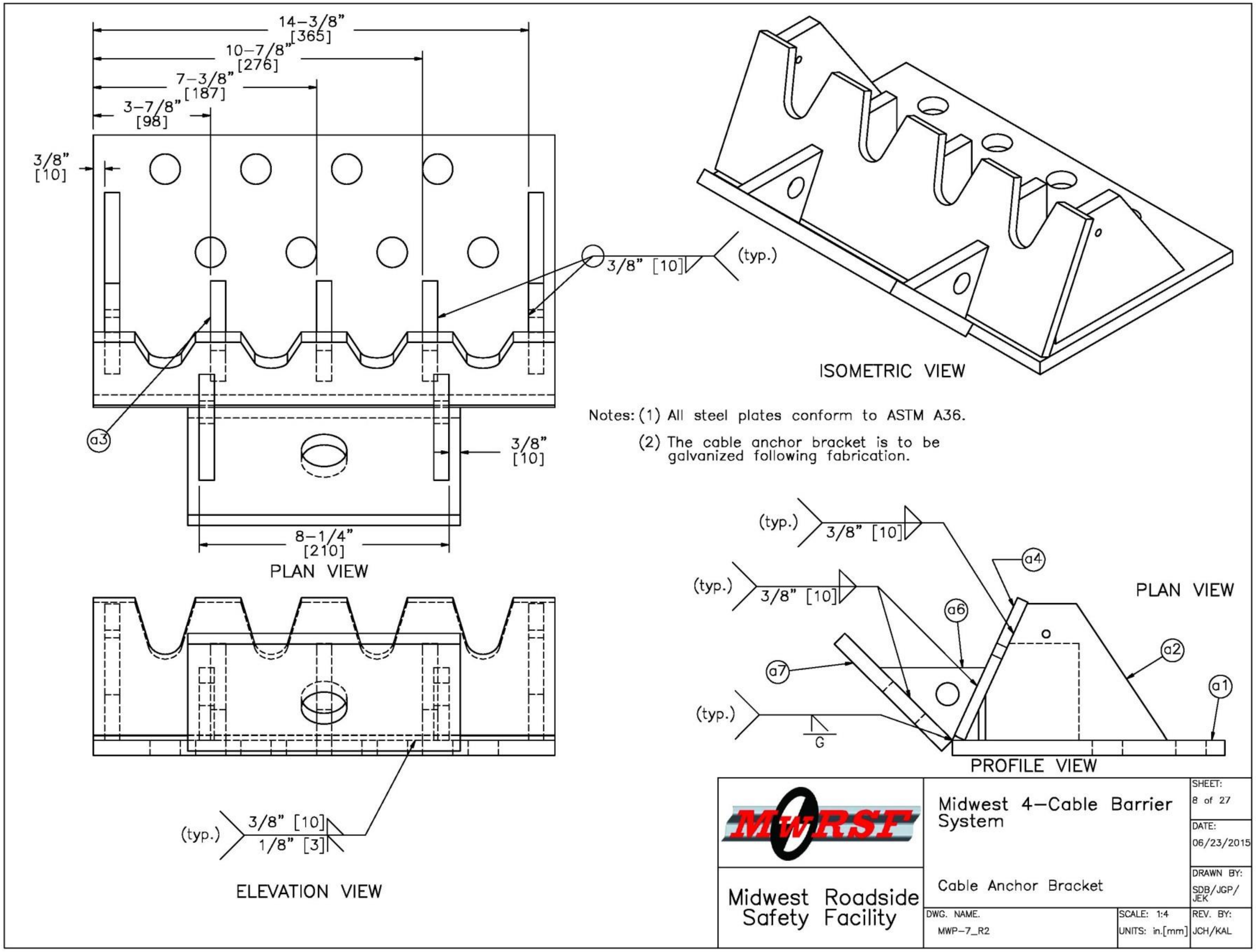


Figure 118. Cable Anchor Bracket, Test No. MWP-7

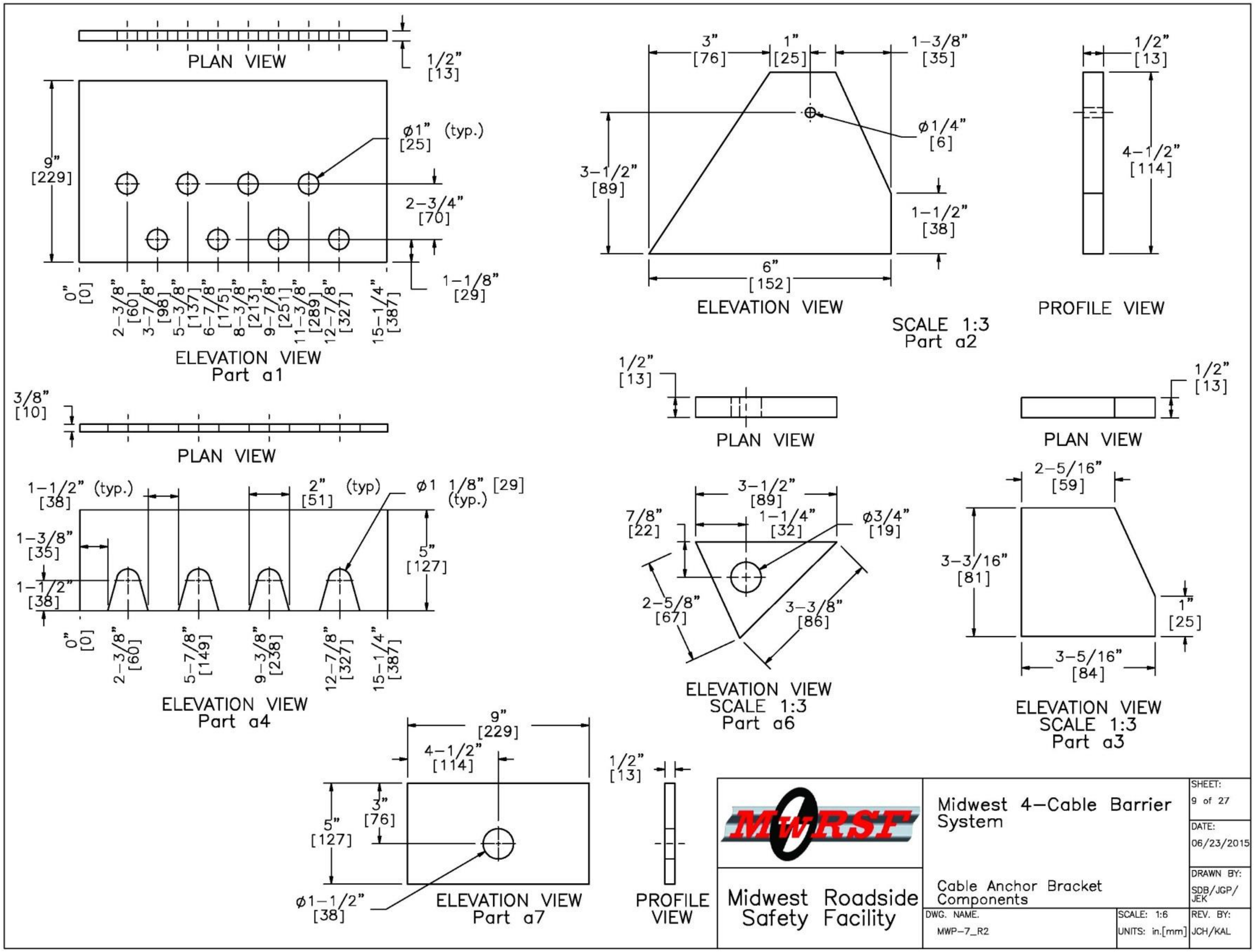
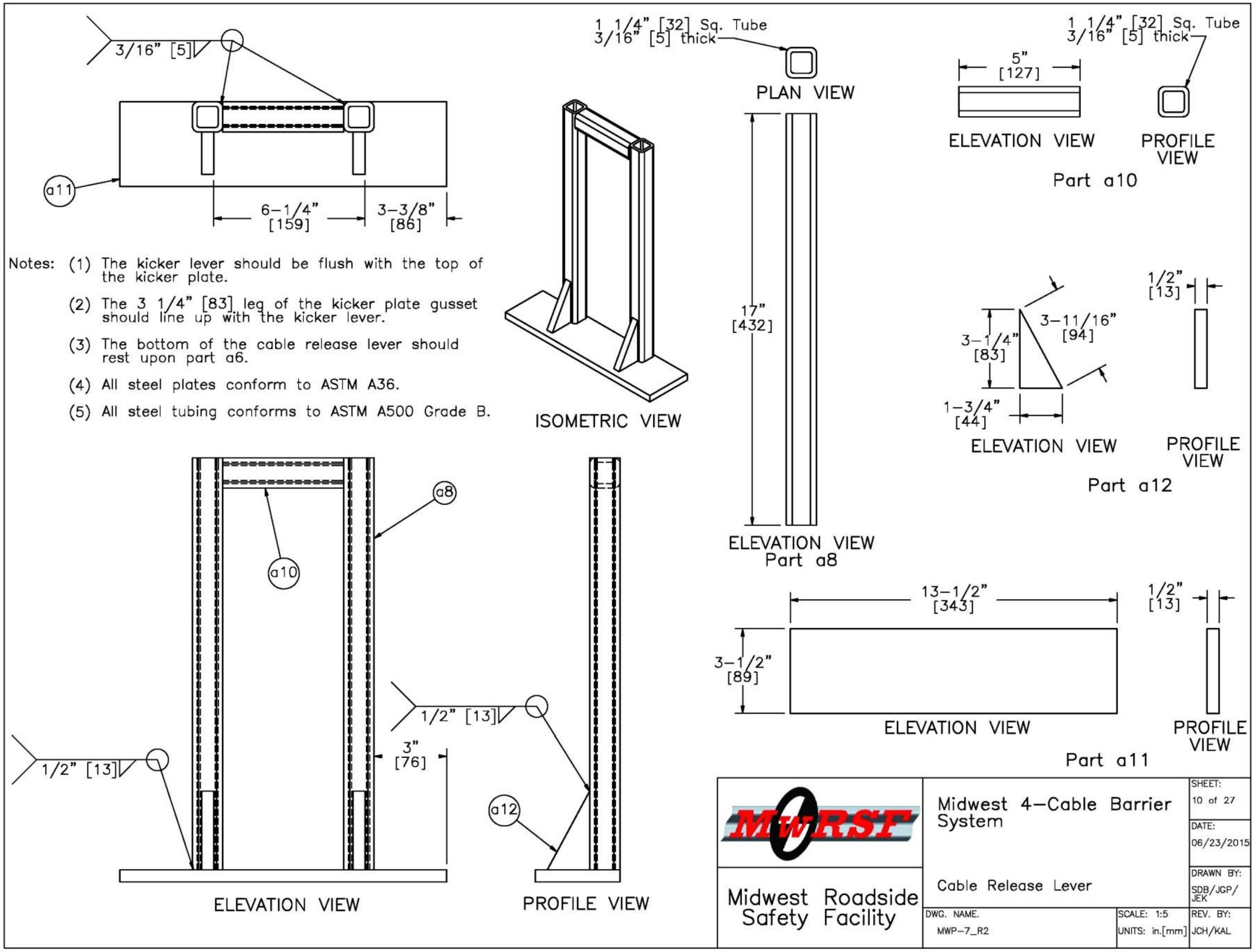
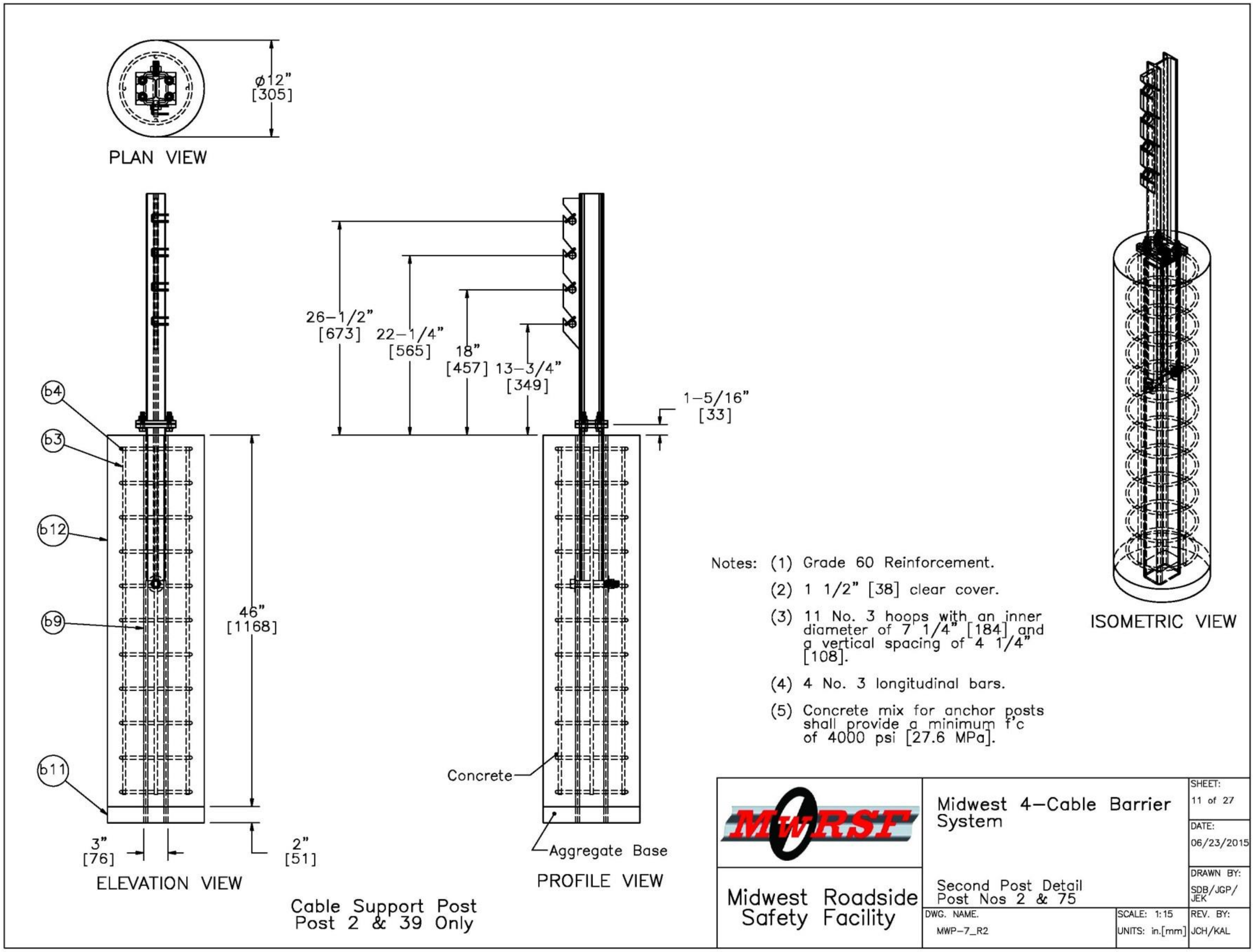


Figure 119. Cable Anchor Bracket Components, Test No. MWP-7



Notes: (1) The kicker lever should be flush with the top of the kicker plate.
(2) The 3 1/4" [83] leg of the kicker plate gusset should line up with the kicker lever.
(3) The bottom of the cable release lever should rest upon part a6.
(4) All steel plates conform to ASTM A36.
(5) All steel tubing conforms to ASTM A500 Grade B.

Figure 120. Cable Release Lever, Test No. MWP-7



Notes:
(1) Grade 60 Reinforcement.
(2) 1 1/2" [38] clear cover.
(3) 11 No. 3 hoops with an inner diameter of 7 1/4" [184] and a vertical spacing of 4 1/4" [108].
(4) 4 No. 3 longitudinal bars.
(5) Concrete mix for anchor posts shall provide a minimum f'c of 4000 psi [27.6 MPa].

Figure 121. Second Post Details, Post Nos. 2 and 75, Test No. MWP-7

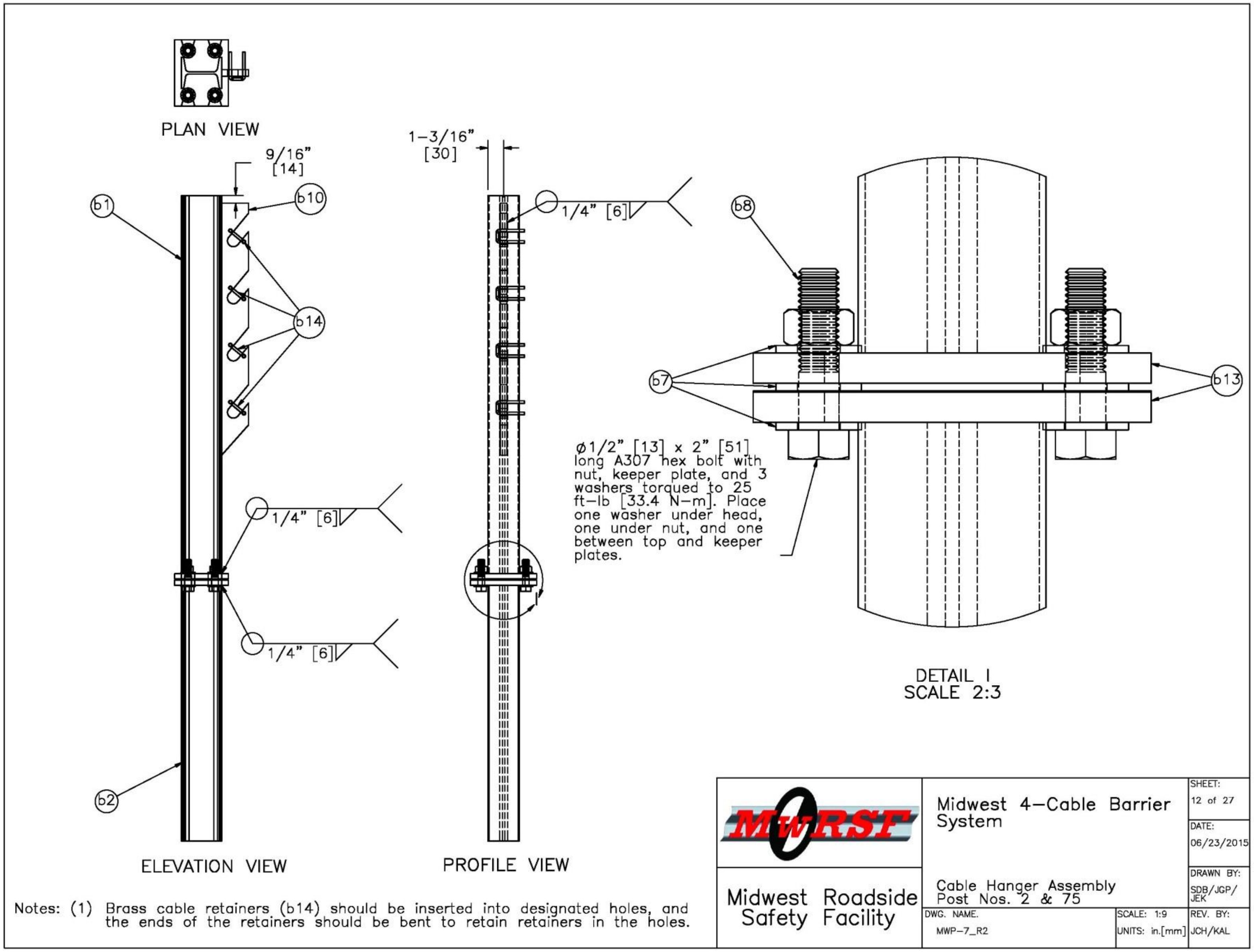


Figure 122. Cable Hanger Assembly, Post Nos. 2 and 75, Test No. MWP-7

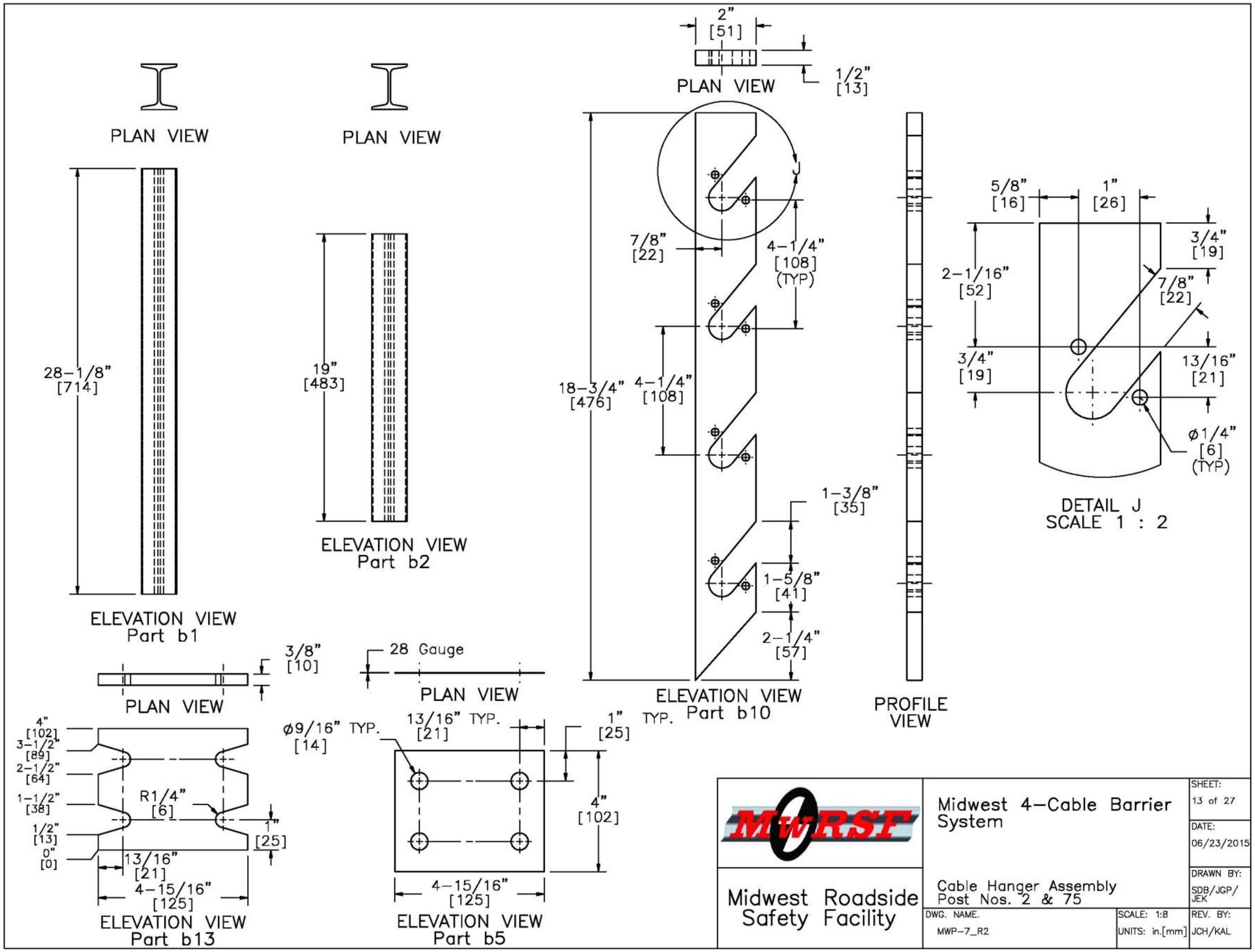


Figure 123. Cable Hanger Assembly, Post Nos. 2 and 75, Test No. MWP-7

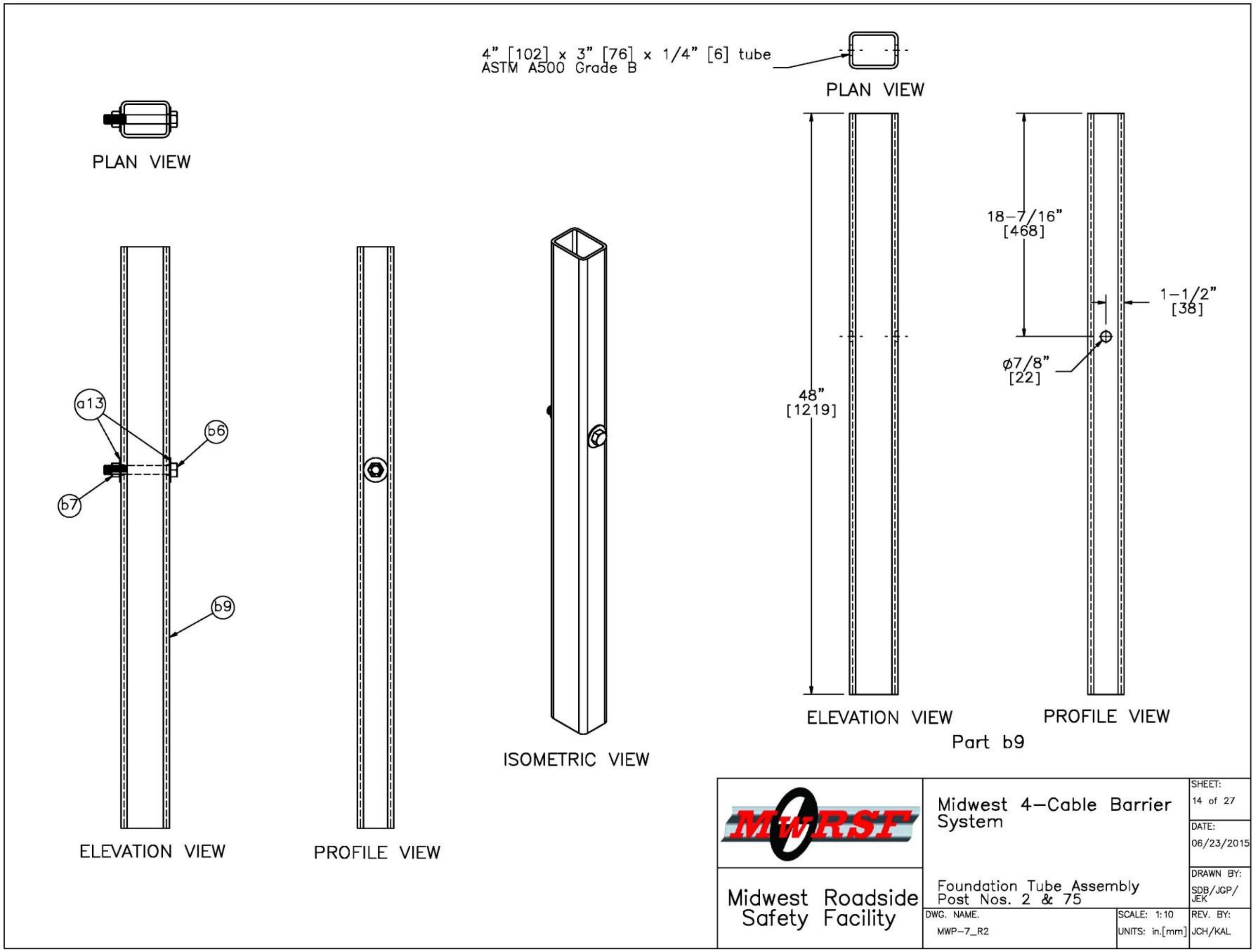


Figure 124. Foundation Tube Assembly, Post Nos. 2 and 75, Test No. MWP-7

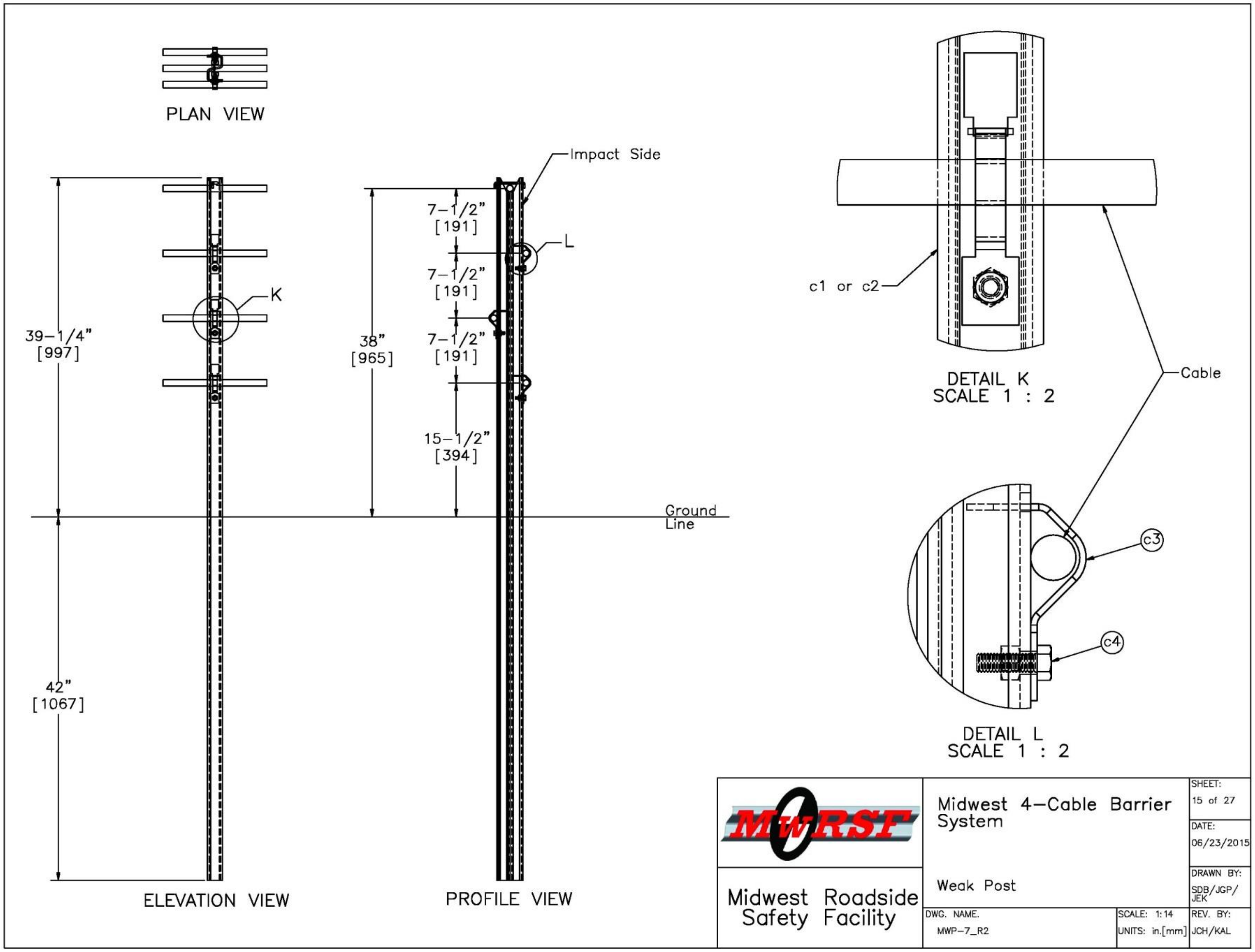


Figure 125. MWP Z-Post Details, Test No. MWP-7

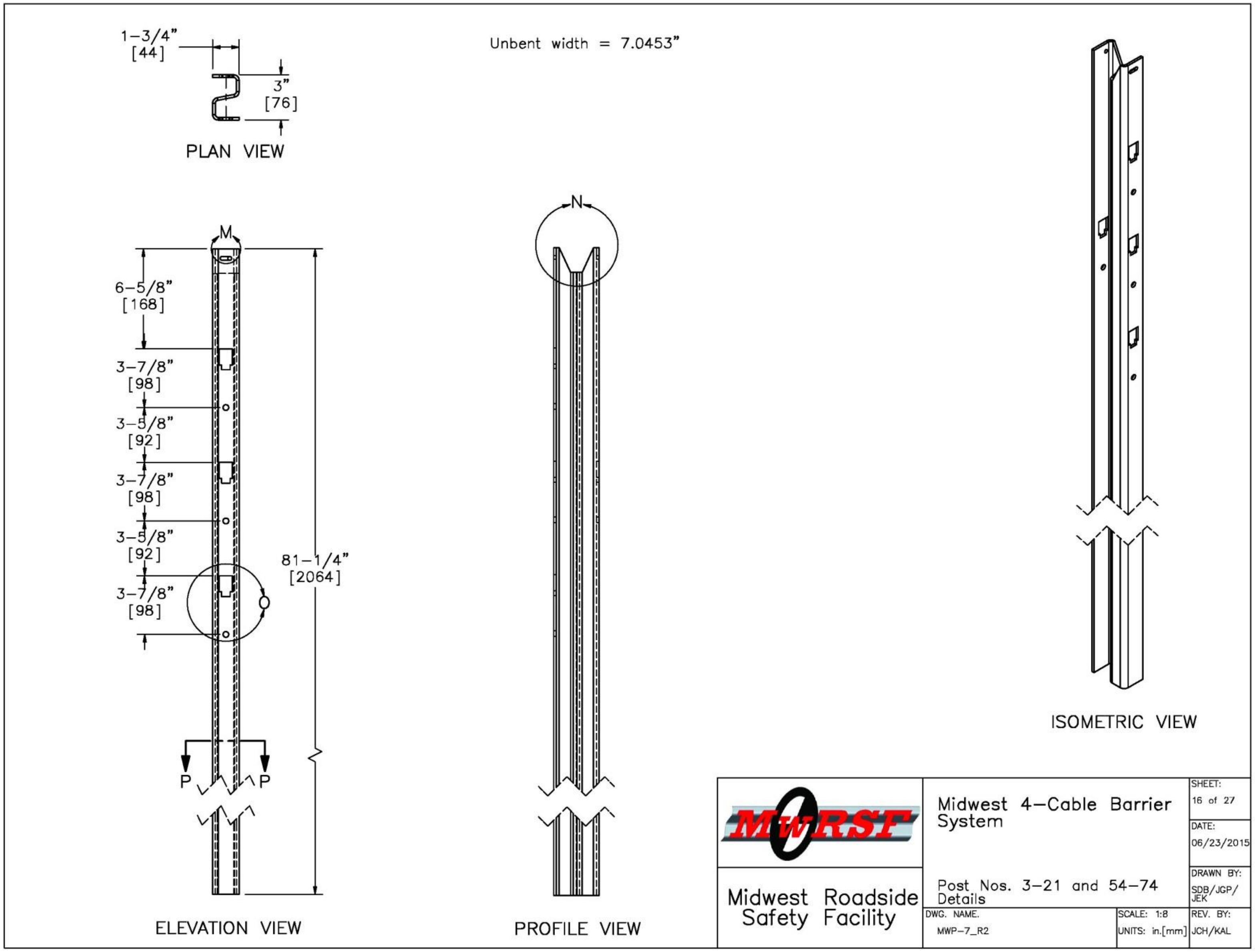


Figure 126. MWP Z-Post Details, Post Nos. 3 through 26 and 48 through 74, Test No. MWP-7

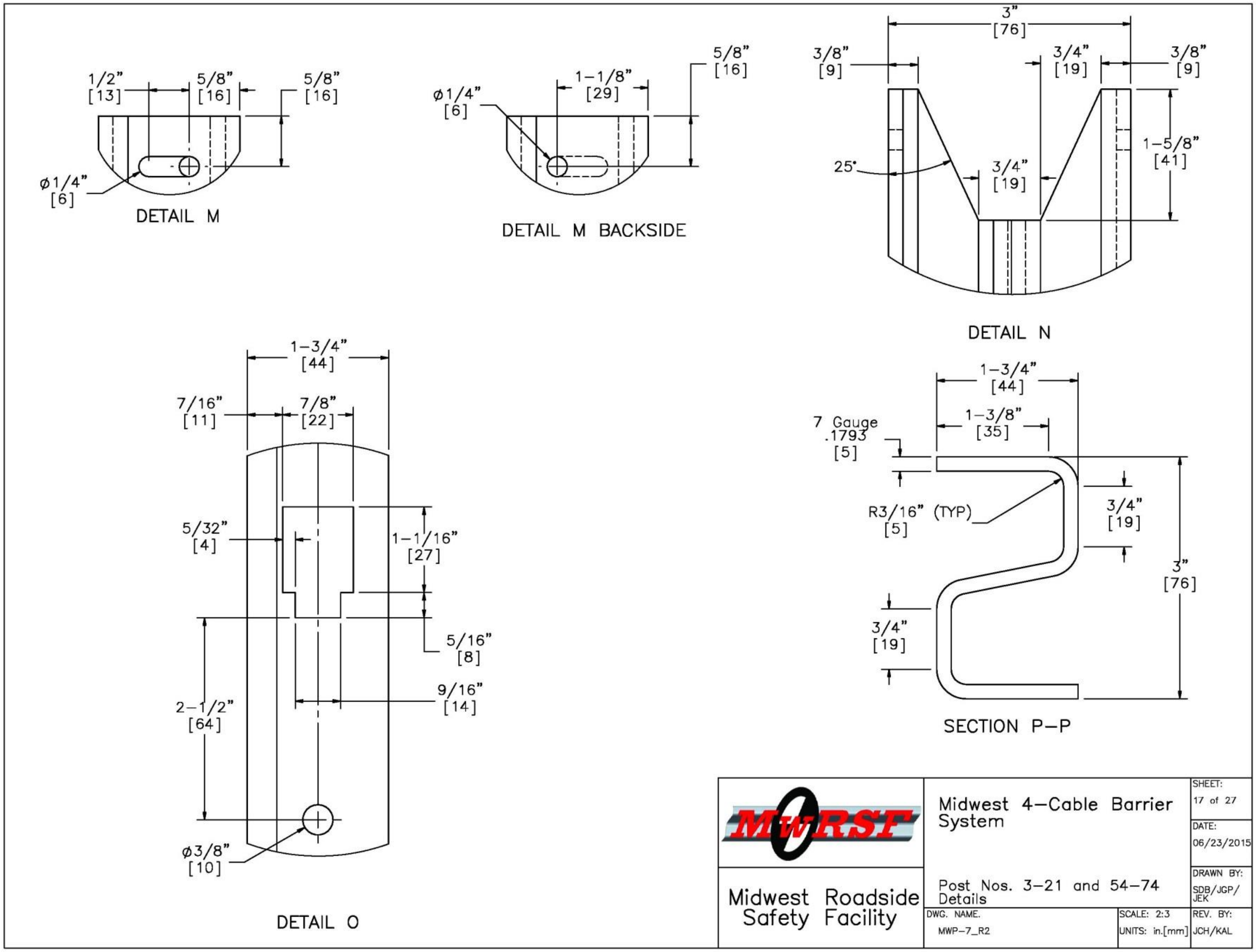


Figure 127. MWP Z-Post Details, Post Nos. 3 through 26 and 48 through 74, Test No. MWP-7

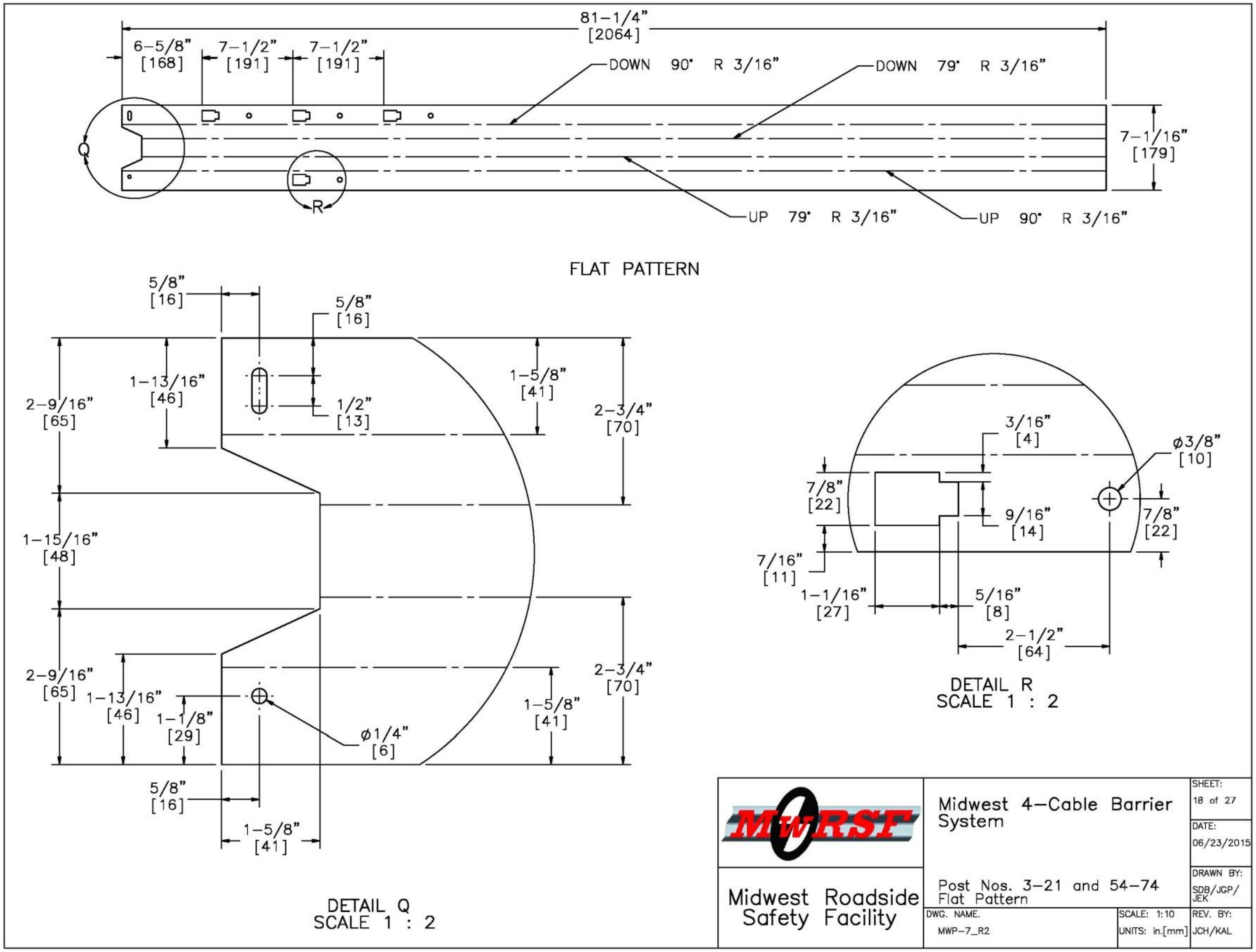


Figure 128. MWP Z-Post Details, Flat Pattern, Post Nos. 3 through 26 and 48 through 74, Test No. MWP-7

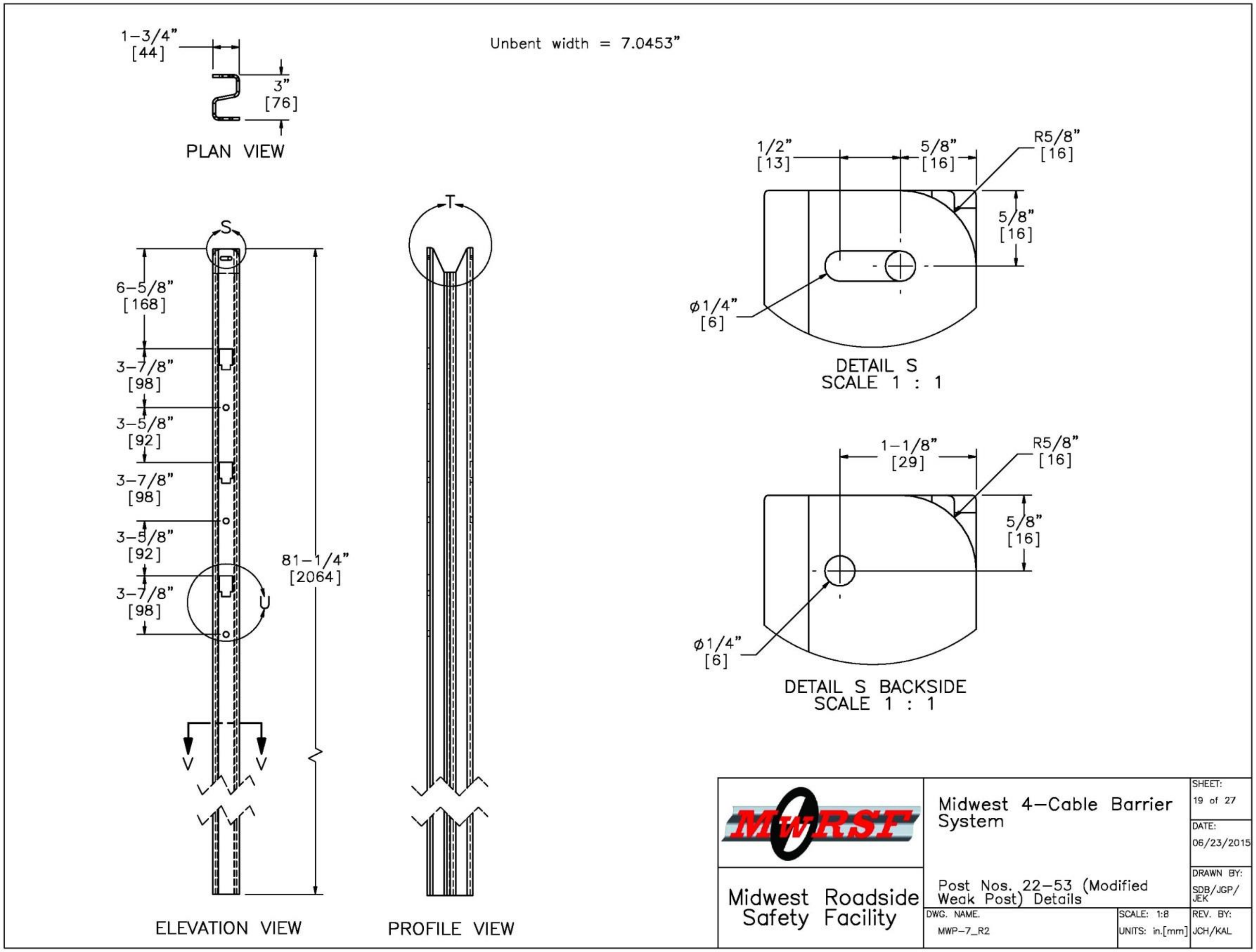


Figure 129. MWP Z-Post Details, Post Nos. 27 through 47, Test No. MWP-7

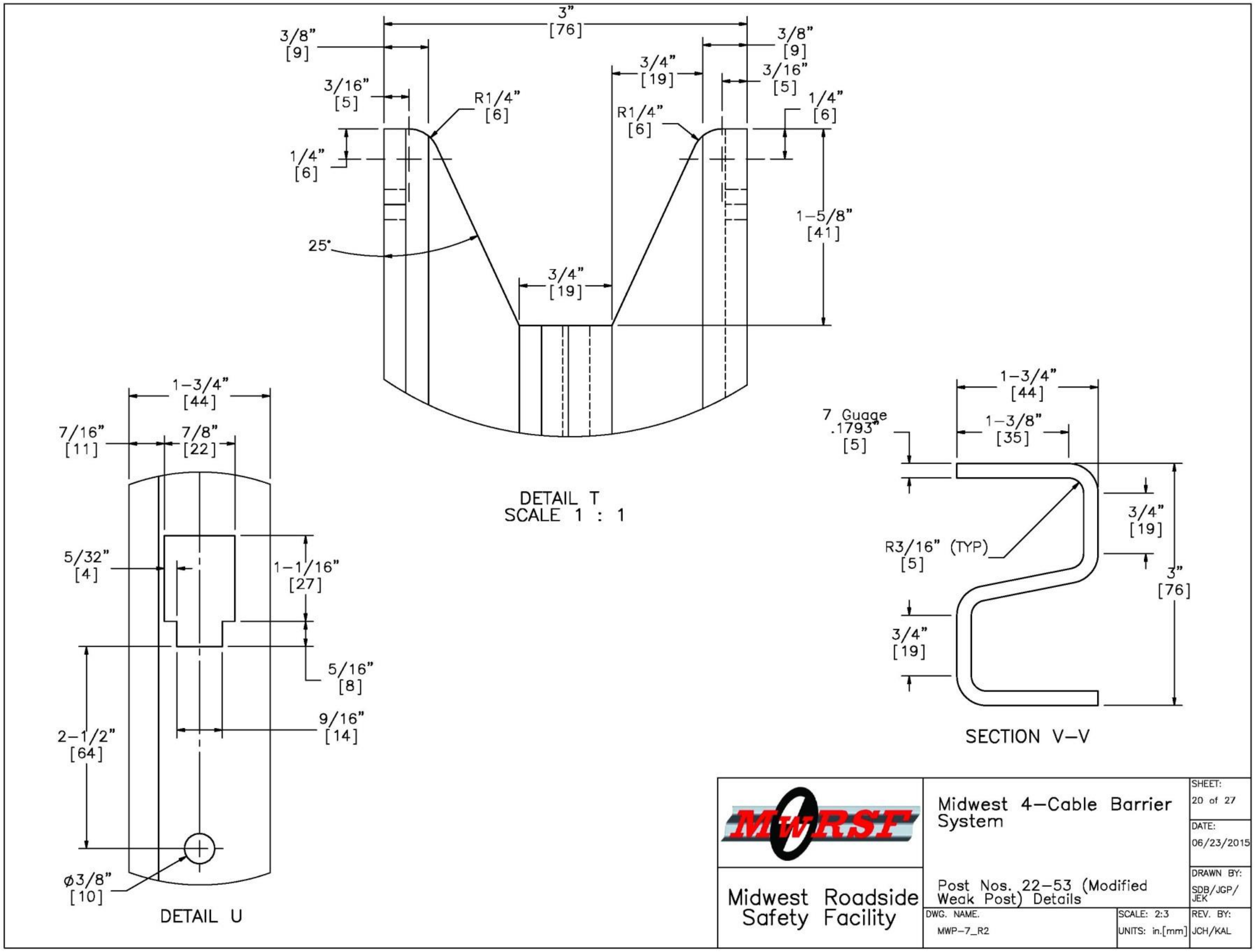


Figure 130. MWP Z-Post Details, Post Nos. 27 through 47, Test No. MWP-7

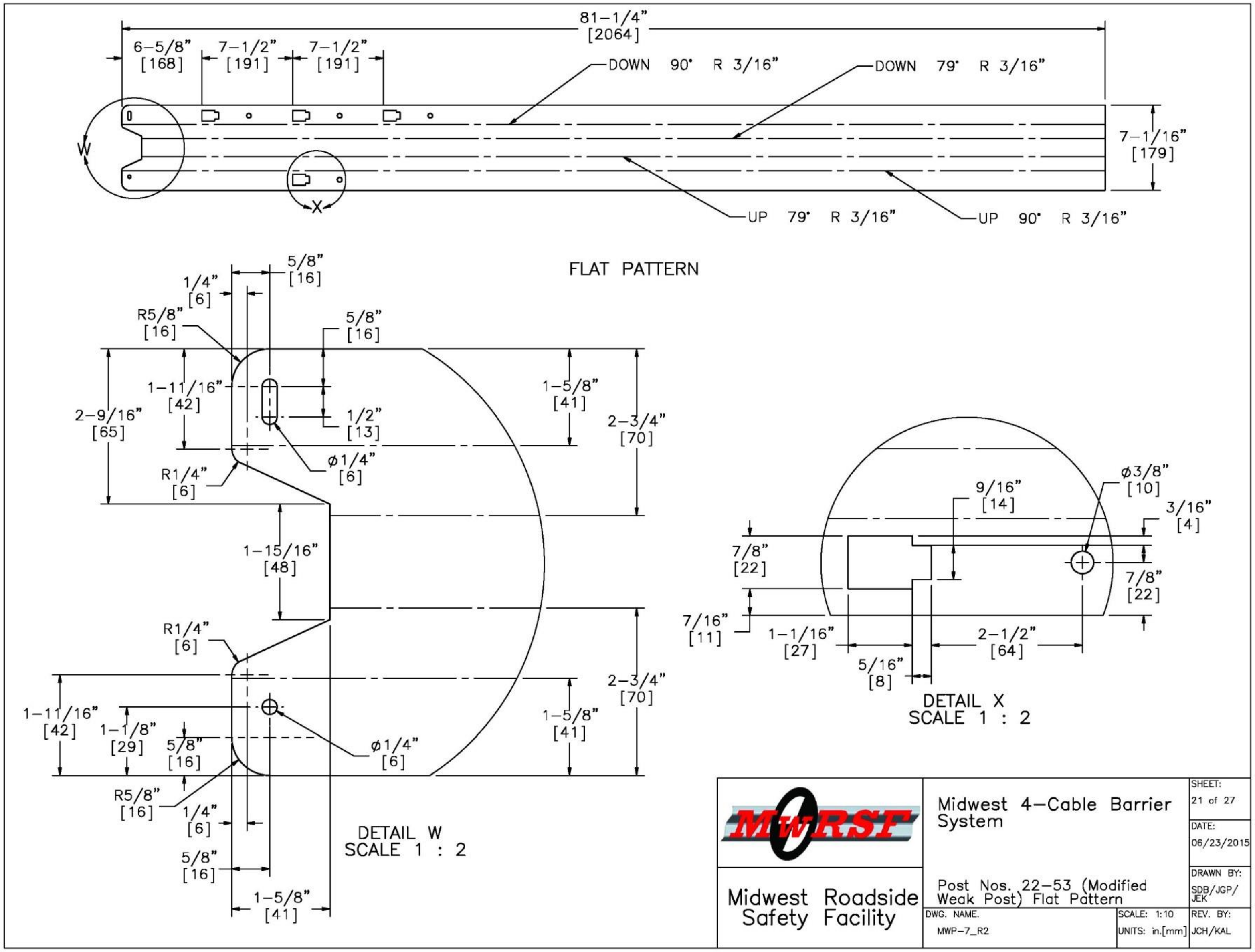


Figure 131. MWP Z-Post Details, Flat Pattern, Post Nos. 27 through 47, Test No. MWP-7

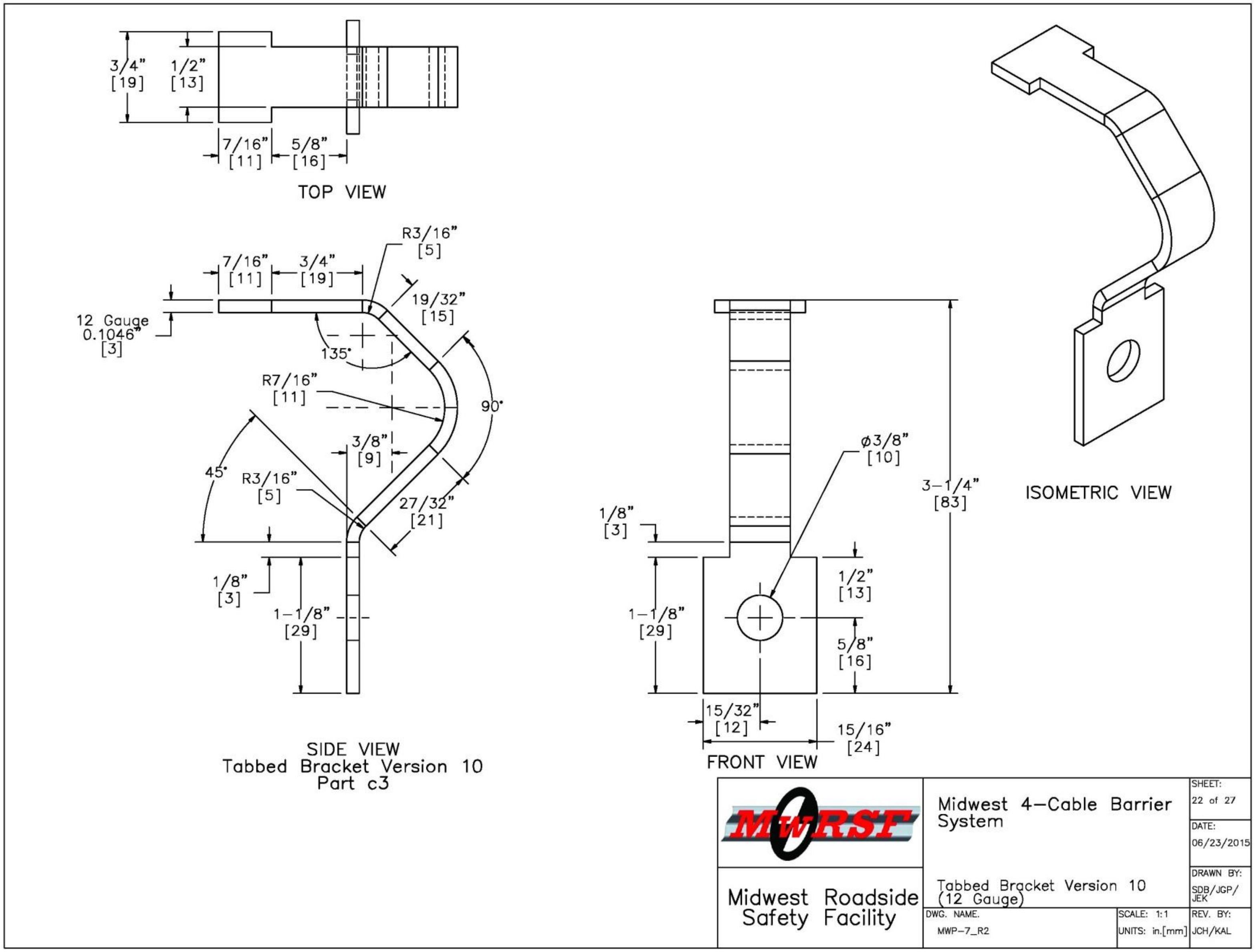


Figure 132. Tabbed Bracket Details, 12-Gauge, Test No. MWP-7

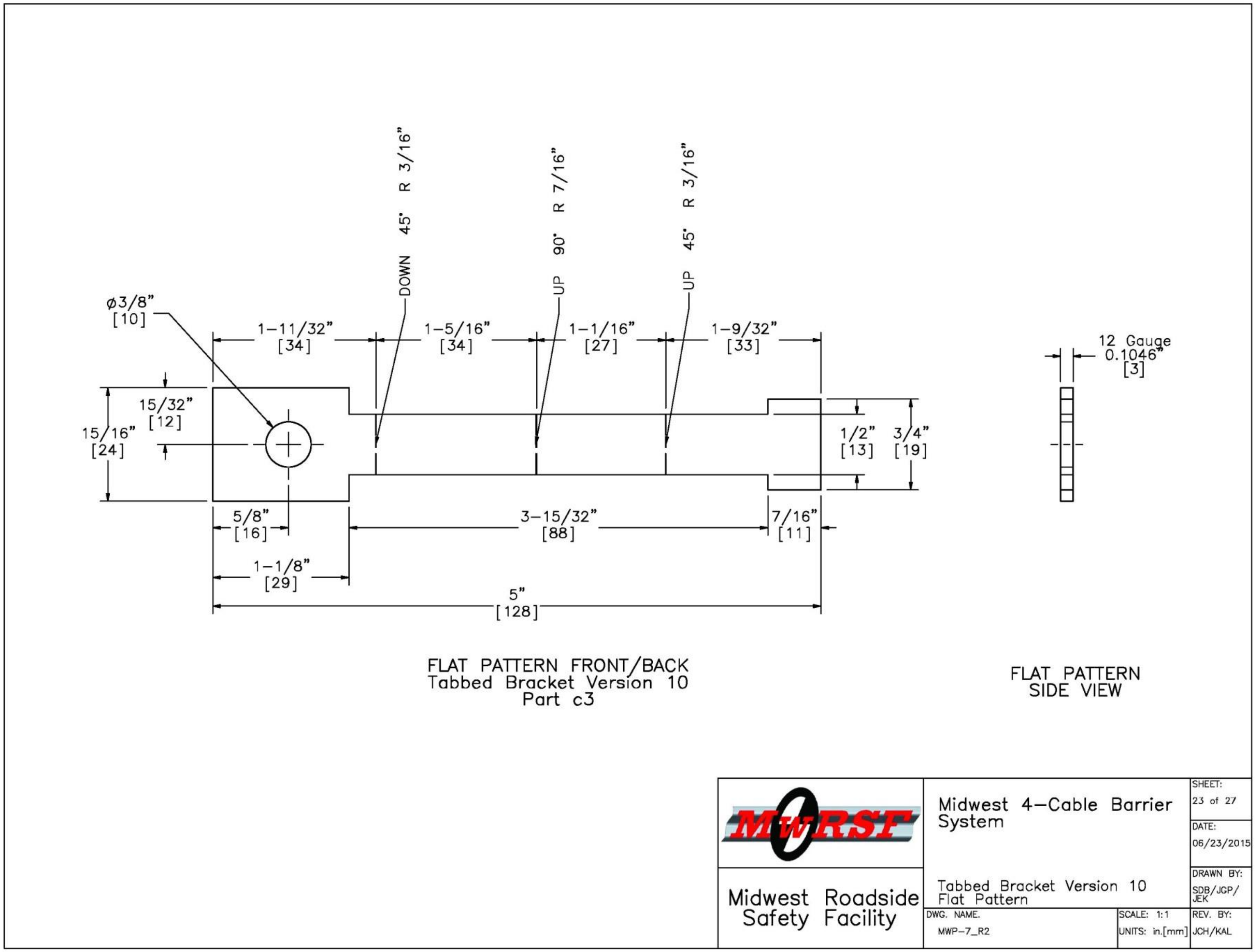


Figure 133. Tabbed Bracket Details, Flat Pattern, Test No. MWP-7

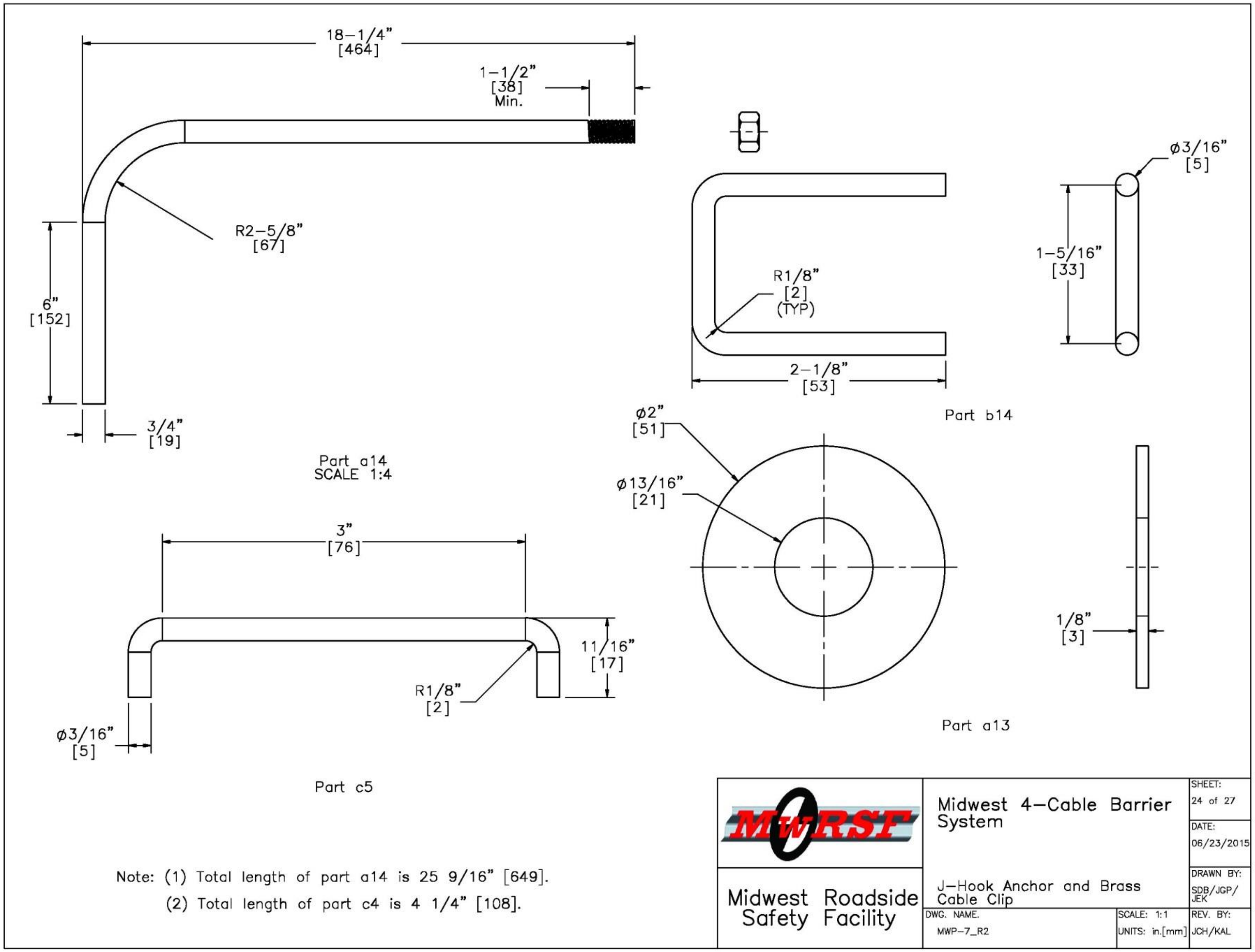


Figure 134. J-Hook Anchor and Brass Clips, Test No. MWP-7

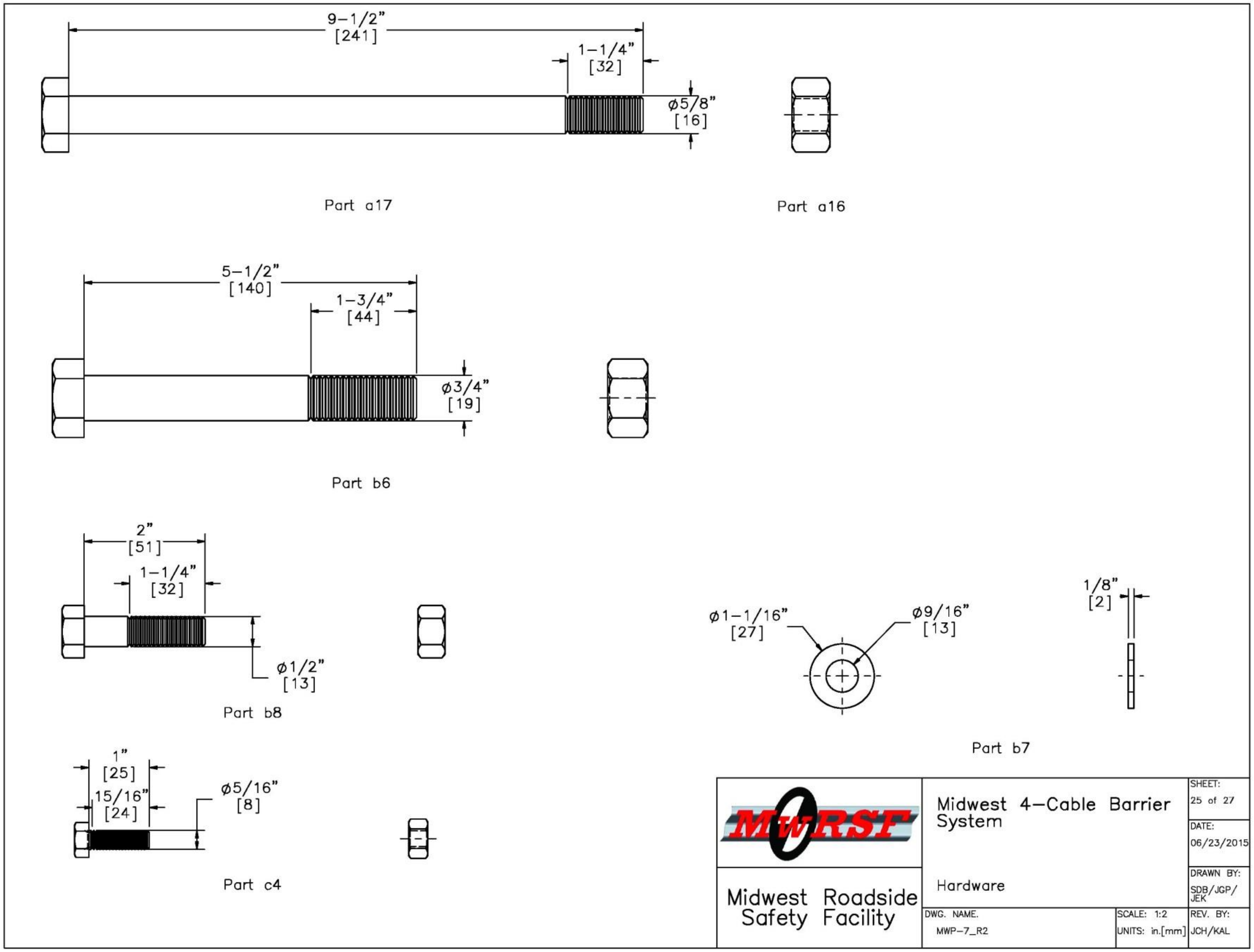


Figure 135. Hardware Details, Test No. MWP-7

| Item No. | QTY. | Description | Material Specification |
|---|---|---|---|
| a1 | 2 | Cable Anchor Base Plate | ASTM A36 |
| a2 | 4 | Exterior Cable Plate Gusset | ASTM A36 |
| a3 | 6 | Interior Cable Plate Gusset | ASTM A36 |
| a4 | 2 | Anchor Bracket Plate | ASTM A36 |
| a5 | 2 | 3/16" [5] Dia. Brass Keeper Rod, 14" [356] long | Brass |
| a6 | 4 | Release Gusset | A36 Steel |
| a7 | 2 | Release Lever Plate | A36 Steel |
| a8 | 4 | 1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Tube | ASTM A500 Gr. B |
| a9 | 8 | CMB High Tension Anchor Plate Washer | ASTM A36 |
| a10 | 2 | 1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Connecting Tube | ASTM A 500 Gr. B |
| a11 | 2 | 3x10x0.5" [76x254x13] Kicker Plate | ASTM A36 |
| a12 | 4 | CT kicker – gusset | ASTM A36 |
| a13 | 20 | 3/4" [19] Dia. Flat Washer | ASTM F844 |
| a14 | 16 | 3/4" [19] Dia. UNC J–Hook Anchor and Hex Nut | J–Hook ASTM A449/Nut ASTM A563 DH |
| a15 | 2 | 1/4" [6] Dia. Aircraft Retaining Cable, 36" [914] long | 7x19 Galv. |
| a16 | 2 | 5/8" [16] Dia. Heavy Hex Nut | ASTM A563C |
| a17 | 2 | 5/8" [16] Dia. UNC, 9 1/2" [241] Long Hex Bolt | ASTM A449 or SAE J429 Gr. 5 |
| a18 | 2 | 24" [610] Dia. Concrete Anchor, 120" [3048] long | 4,000 psi f'c |
| a19 | 16 | #11 Straight Rebar, 114" [2896] long | Grade 60 |
| a20 | 44 | #4 Anchor Hoop Rebar with 21" [533] Dia. | Grade 60 |
| b1 | 2 | S3x5.7 [S76x8.5] Post by 28 1/8" [714] | ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A |
| b2 | 2 | S3x5.7 [S76x8.5] Post by 19" [483] | ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A |
| b3 | 8 | #3 Straight Rebar, 43" [1092] long | Grade 60 |
| b4 | 22 | 7 1/4" [184] Dia. No. 3 Hoop Reinforcement | Grade 60 |
| b5 | 2 | 2nd Post Keeper Plate, 28 Gauge | ASTM A36 |
| b6 | 2 | 3/4" [19] Dia. UNC, 5 1/2" [140] Long Hex Bolt and Nut | Bolt ASTM A307 Gr. A/Nut ASTM A563A |
| b7 | 24 | 1/2" [13] Dia. Washer with 1 1/16" [27] OD | ASTM F844 |
| b8 | 8 | 1/2" [13] Dia. UNC, 2" [51] long Hex Bolt and Nut | Bolt ASTM A307 Gr. A/Nut ASTM A563A |
| b9 | 2 | 4x3x1/4" [102x76x6] Foundation Tube, 48" [1168] long | ASTM A500 Grade B |
| b10 | 2 | 2nd Post Cable Hanger | ASTM A36 |
| b11 | 2 | 2nd Post Anchor Aggregate 12 in, Depth | – |
| b12 | 2 | 12" Dia. 2nd Post Concrete Anchor, 46" long | 4,000 psi f'c |
| b13 | 4 | 2nd Post Base Plate | ASTM A36 |
| b14 | 8 | 3/16" [5] Dia. 5 1/4" [133] Long Brass Rod | ASTM B16–00 |

Midwest Roadside
Safety Facility

Midwest 4–Cable Barrier
System

Bill of Materials

SHEET:
26 of 27

DATE:
06/23/2015

DRAWN BY:
SDB/JGP/
JEK

DWG. NAME.
MWP–7_R2

SCALE: NONE
UNITS: in.[mm]

REV. BY:
JCH/KAL

Figure 136. Bill of Materials, Test No. MWP-7

| Item No. | QTY. | Description | Material Spec |
|---|---|---|---|
| c1 | 40 | 3"x1-3/4"x7 Gauge [76x44x4.6], 81 1/4" [2064] Long Bent MWP Z-Section Post | Hot-Rolled ASTM A1011 HSLA Gr. 50 |
| c2 | 32 | 3"x1-3/4"x7 Gauge [76x44x4.6], 81 1/4" [2064] Long Bent MWP Z-Section Post (Modified) | Hot-Rolled ASTM A1011 HSLA Gr. 50 |
| c3 | 216 | 12 Gauge Tabbed Bracket – Version 10 | Hot-Rolled ASTM A1011 HSLA Grade 50 |
| c4 | 216 | 5/16" [8] Dia. UNC, 1" [25] Long Hex Cap Screw and Nut | Bolt SAE J429 Gr. 5 or ASTM A449/Nut ASTM A563 DH |
| c5 | 72 | Straight Rod – ø3/16" [5] Cable Clip | ASTM B16 Brass C36000 Half Hard (HO2), ROUND. TS >= 68.0 ksi, YS >= 52.0 ksi |
| d1 | 1 | 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] |
| d2 | 16 | 7/8" [22] Dia. Hex Nut | ASTM A563C |
| d3 | 28 | Cable End Threaded Rod | ASTM A449 |
| d4 | 24 | Bennet Cable End Fitter | ASTM A47 |
| d5 | 24 | 7/8" [22] Dia. Hex Nut | SAE J429 Gr. 5 |
| e1 | 8 | Bennet Short Threaded Turnbuckle | Not Specified |
| e2 | 8 | Threaded Load Cell Coupler | N/A |
| e3 | 4 | 50,000-lb [222.4-kN] Load Cell | N/A |

Midwest Roadside
Safety Facility

Midwest 4-Cable Barrier System

Bill of Materials

SHEET: 27 of 27
DATE: 06/23/2015
DRAWN BY: SDB/JGP/JEK
DWG. NAME. MWP-7_R2
SCALE: NONE
UNITS: in.[mm]
REV. BY: JCH/KAL

Figure 137. Bill of Materials, Test No. MWP-7

Figure 138. Test Installation Photographs, Test No. MWP-7

Figure 139. Test Installation Photographs, Test No. MWP-7

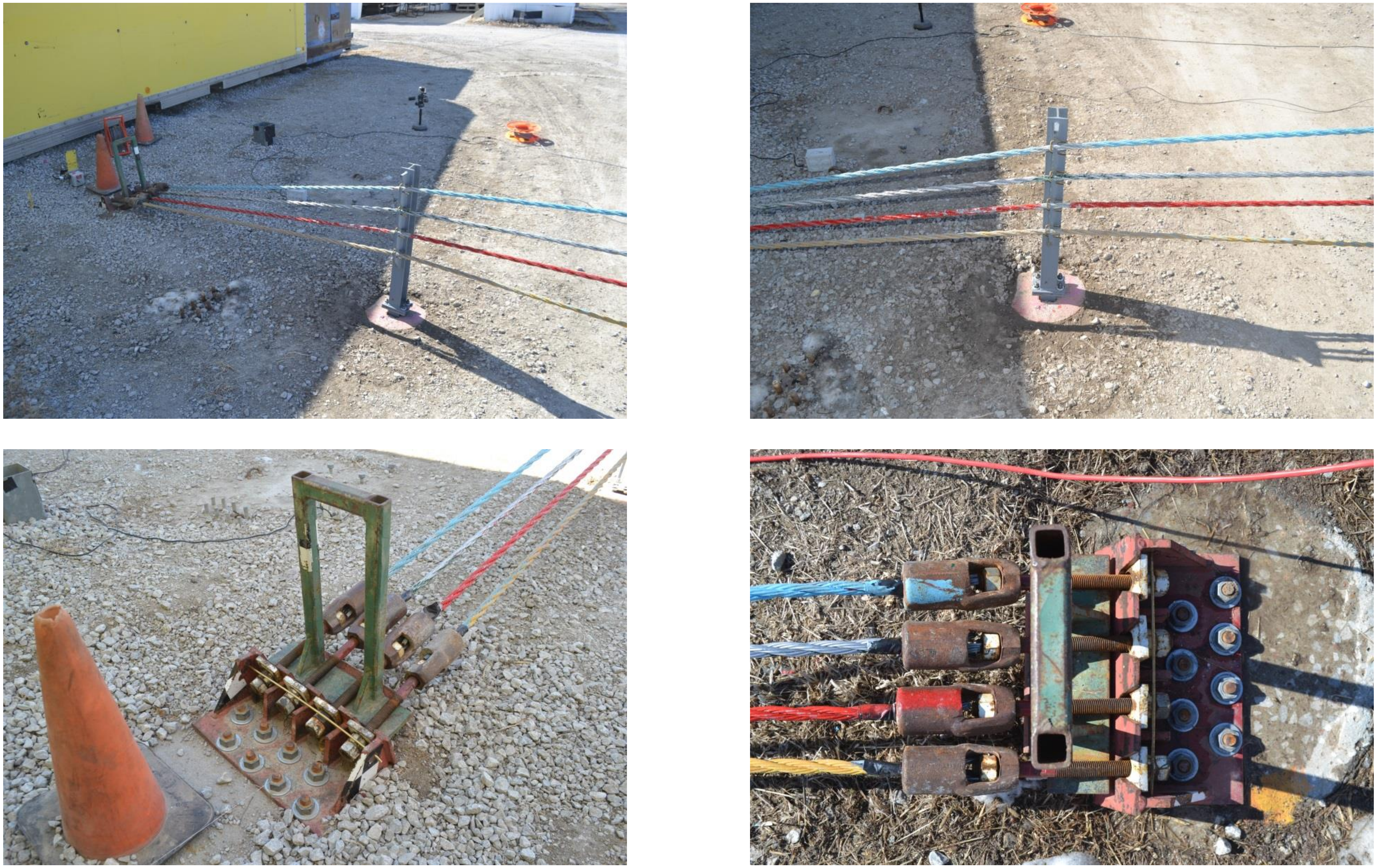


Figure 140. Test Installation Photographs, Test No. MWP-7

Figure 141. Test Installation Photographs, Test No. MWP-7

# 9 FULL SCALE CRASH TEST MWP-7

## 9.1 Static Soil Test

Before full-scale crash test no. MWP-7 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The soil for this test was partially frozen, making it difficult to get a full range of soil strength up to 15 in. of deflection. The winch utilized to load the post reached its capacity, prior to reaching 15 in. (381 mm) of displacement. The winch capacity is over 2.5 times the required strength. Note that weak posts used in cable barrier systems do not rotate in strong soil. Instead, weak posts yield at the ground line in both frozen and unfrozen strong soils configured with compacted crushed limestone. Thus, the frozen soil condition was considered acceptable for this cable barrier test. 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 was conducted.

## 9.2 Weather Conditions

Test no. MWP-7 was conducted on February 24, 2015 at approximately 2:30 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), were reported and are shown in Table 14.

Table 14. Weather Conditions, Test No. MWP-7

| | |
|---|---|
| Temperature | 49°F |
| Humidity | 36% |
| Wind Speed | 16 mph |
| Wind Direction | 30° West of True North |
| Sky Conditions | Sunny |
| Visibility | 10 Statute Miles |
| Pavement Surface | Dry |
| Previous 3-Day Precipitation | 0 in. |
| Previous 7-Day Precipitation | 0.01 in. |

## 9.3 Test No. MWP-7

The 2,557-lb (1,160-kg) small car impacted the high-tension, four-cable median barrier at a speed of 63.9 mph (102.9 km/h) and at an angle of 25.7 degrees. A summary of the test results and sequential photographs are shown in Figure 142. Additional sequential photographs are shown in Figures 143 and 144. Documentary photographs of the crash test are shown in Figure 145.

## 9.4 Test Description

Initial vehicle impact was to occur at a midspan location, or 4 ft (1.2 m) upstream from post no. 32, as shown in Figure 146, which was selected according to MASH guidelines. The actual point of impact was approximately 9.2 in. (234 mm) upstream from the target impact point. A sequential description of the impact events is contained in Table 15. The vehicle came to rest 89 ft (27.1 m) downstream from the point of impact, or between post nos. 42 and 43. The vehicle trajectory and final position are shown in Figures 142 and 147.

Table 15. Sequential Description of Impact Events, Test No. MWP-7

| TIME (sec) | EVENT |
|---|---|
| 0.000 | Vehicle left-front bumper contacted cable no. 1 between post nos. 31 and 32. |
| 0.008 | Vehicle left fender contacted cable no. 3 between post nos. 31 and 32. |
| 0.010 | Vehicle left-front bumper contacted cable no. 2 between post nos. 31 and 32. |
| 0.014 | Cable no. 3 detached from post no. 31. |
| 0.016 | Vehicle left fender began to deform. |
| 0.020 | Vehicle left headlight began to deform, and post no. 32 began to deflect downstream. |
| 0.022 | Cable no. 3 detached from post no. 32. |
| 0.024 | Post nos. 31 and 32 began to deflect backward. |
| 0.032 | Vehicle left side mirror contacted cable no. 4 and began to deform. |
| 0.036 | Vehicle front bumper contacted post no. 32, and post no. 33 began to deflect backward. |
| 0.042 | Post no. 30 began to deflect backward. |
| 0.044 | Vehicle left A-pillar contacted cable no. 3. |
| 0.048 | Vehicle left A-pillar began to deform, and cable no. 4 detached from post no. 32. |
| 0.052 | Cable no. 2 detached from post no. 32. |

| | |
|---|---|
| 0.060 | Cable no. 3 detached from post no. 33. |
| 0.062 | Post no. 34 began to deflect backward. |
| 0.068 | Post no. 29 began to deflect backward. |
| 0.076 | Vehicle overrode post no. 32. |
| 0.078 | Vehicle left A-pillar contacted cable no. 4. |
| 0.080 | Cable no. 2 detached from post no. 33. |
| 0.084 | Vehicle left-front tire overrode cable no. 1, and cable no. 3 detached from post no. 34. |
| 0.086 | Vehicle left side mirror detached, and post no. 35 began to deflect backward. |
| 0.088 | Vehicle left-front tire overrode cable no. 1. |
| 0.098 | Cable no. 4 detached from post no. 31. |
| 0.102 | Cable no. 3 detached from post no. 35. |
| 0.108 | Post no. 36 began to deflect backward. |
| 0.112 | Cable no. 3 detached from post no. 30 |
| 0.118 | Vehicle front bumper contacted post no. 33, and cable no. 4 detached from post no. 33. |
| 0.128 | Vehicle left-front door contacted cable no. 2. |
| 0.132 | Vehicle left-front door began to deform, and cable no. 3 detached from post no. 29. |
| 0.142 | Cable no. 4 detached from post no. 34. |
| 0.164 | Vehicle left-rear tire overrode cable no. 1, and cable no. 2 detached from post no. 34. |
| 0.166 | Vehicle right fender began to deform, and cable no. 4 detached from post no. 35. |
| 0.180 | Cable no. 2 detached from post no. 35. |
| 0.186 | Post no. 37 began to deflect backward, and vehicle under-rode cable nos. 3 and 4. |
| 0.188 | Post no. 38 began to deflect backward. |
| 0.204 | Vehicle left-front tire became airborne. |
| 0.232 | Vehicle left headlight detached. |
| 0.242 | Cable no. 2 detached from post no. 31. |
| 0.252 | Vehicle left-front tire regained contact with ground. |
| 0.274 | Vehicle right-rear tire overrode cable no. 1. |
| 0.350 | Cable no. 3 detached from post no. 43. |
| 0.424 | Vehicle was parallel to system. |
| 0.516 | Vehicle was yawing toward barrier. |
| 0.522 | Cable no. 3 detached from post no. 44. |
| 0.528 | Cable no. 3 detached from post no. 45. |
| 0.588 | Vehicle right fender contacted post no. 37. |
| 0.626 | Vehicle right-front door contacted post no. 37. |
| 0.660 | Vehicle right headlight contacted post no. 38. |
| 0.730 | Vehicle right A-pillar contacted cable no. 4. |
| 0.734 | Vehicle right-front window, and right C-pillar contacted cable no. 4. |
| 0.815 | Vehicle bumper contacted post no. 39. |
| 0.880 | Vehicle began to yaw away from barrier. |
| 0.926 | Vehicle left-front tire became airborne. |
| 0.960 | Vehicle was wedged between cable no. 2 (impact side) and cable nos. 1 and 4 (non-impact side). |
| 1.002 | Vehicle bumper contacted post no. 40. |

| | |
|---|---|
| 1.006 | Vehicle left-front tire regained contact with ground. |
| 1.152 | Vehicle right-front tire deflated. |
| 1.178 | Vehicle began to yaw toward barrier. |
| 1.202 | Vehicle bumper contacted post no. 41. |
| 1.220 | Vehicle began to transverse back toward barrier. |
| 1.340 | Vehicle right B-pillar contacted cable no. 4 coupler, grinding through one layer of steel. |
| 1.458 | Vehicle bumper contacted post no. 42. |
| 2.096 | Vehicle front bumper contacted post no. 43. |
| 2.258 | Vehicle came to a rest with its bumper pressed against post no. 43. |

### 9.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 148 through 158. Barrier damage consisted of bent posts, disengaged cables, and bent and fractured brackets. At its final resting position, the vehicle was still in contact with the cables. Cable no. 3 was beneath the vehicle, cable no. 2 was on the impact side of the vehicle, and cable nos. 1 and 4 were on the non-impacting side of the vehicle.

Cable no. 4 disengaged from post nos. 31 through 46 due to fracturing of the brass keeper rods. Cable no. 3 disengaged from post nos. 23 through 45. Cable no. 2 disengaged from post nos. 31 through 43. Cable no. 1 disengaged from post nos. 32, 33, as well as from post nos. 36 through 44. Seven of these cable brackets fractured at the neck, and two fractured at the tabs. The remainder of the brackets released the cables due to rotation of the bracket tab through the keyway. Negligible cable slip occurred at splice locations.

Post nos. 31 through 45 had varying degrees of plastic deformations in the form of bending and twisting, while other posts were only slightly displaced through the soil. Typically, posts were twisted to face downstream, and were bent laterally backward and/or longitudinally downstream, or a combination of both. In addition, post nos. 32, 33, as well as post nos. 37 through 42 had contact marks from the vehicle undercarriage overriding them. These same posts showed the greatest deflection.

The maximum dynamic barrier deflection was 97 in. (2,464 mm), and the working width of the system was 103.6 in. (2,631 mm), as determined from high-speed video analysis. Neither anchor was permanently displaced as a result of the impact loads imparted to it.

## 9.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 159 through 162. The maximum occupant compartment deformations are listed in Table 16 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH-established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 16. Maximum Occupant Compartment Deformations by Location, Test No. MWP-7

| LOCATION | MAXIMUM DEFORMATION in. (mm) | MASH ALLOWABLE DEFORMATION in. (mm) |
|---|---|---|
| Wheel Well & Toe Pan | 0.3 (8) | ≤9 (229) |
| Floor Pan & Transmission Tunnel | 1.2 (30) | ≤12 (305) |
| Side Front Panel (in Front of A-Pillar) | 0.2 (5) | ≤12 (305) |
| Side Door (Above Seat) | 0.1 (3) | ≤12 (305) |
| Side Door (Below Seat) | 0.1 (3) | ≤9 (229) |
| Roof | 0.5 (13) | ≤4 (102) |

The majority of the vehicle damage was concentrated on the left-front corner, where the initial impact occurred, and on the right-front corner of the vehicle, where it impacted the system again as it crossed from behind the system to the front side of the system. The front bumper, left headlight, left side mirror, a 19 in. (483 mm) long portion of the left fender, right-front door handle and rear antennae were disengaged. The right headlight was partially disengaged and fractured. Both front tires and the right-rear tire had deflated. The suspension on the right-front wheel was also damaged.

The left fender had been crushed into the wheel well. The right fender had crushed, which caused some tearing. The right-front door was crushed and dented inward. The left fender and engine hood were separated by a gap of 4 in. (102 mm), and the right fender separated away from the hood by 6¼ in. (159 mm).

The cable to vehicle contacts left striation marks on the left-front fender, up the length of the left A-pillar, and across the roof. This contact caused minor gouging on the A-pillar and denting on the roof. The damage to the left A-pillar caused spider-web cracking adjacent to the left-front A-pillar, which extended across the entire windshield. The cables also left gouges and scrapes along the entire left side of the vehicle and on the left-front rim. There was a 23 x 4½-in. (584 x 114-mm) long tear in the left-front door at the height of cable no. 2. On the right side of the vehicle, there were gouges on both right side tire rims, along both right side doors, and on the right A-pillar. Scraping was found on the right B- and C-pillars, as well as on the right-front and rear bumpers. There was a 5-in. (127-mm) kink in the front bumper, 10 in. (254 mm) left of center. Dents were observed on the right-front corner of the hood, the right-front tire rim, the right-rear wheel well, as well as on the roof.

There were four tears in the floor pan of the vehicle. There was a 2¾-in. (70-mm) long tear in the right-front floor pan, an 8-in. (203-mm) long tear behind the left-front seat, a 3½-in. (89-mm) long tear behind the right-front seat, and a 1-in. (25-mm) long tear in the left-rear of the floor pan. This damage can be seen in Figures 161 and 162.

## 9.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 17. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 17. The results of the occupant risk analysis, as determined from the accelerometer data, are also summarized in Figure 142. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix I.

Table 17. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MWP-7

| **Evaluation Criteria** | | **Transducer** | | **MASH Limits** |
|---|---|---|---|---|
| | | **SLICE 1 (primary)** | **SLICE 2** | |
| **OIV ft/s (m/s)** | Longitudinal | -15.45 (-4.71) | -15.65 (-4.77) | ≤ 40 (12.2) |
| | Lateral | 12.03 (3.67) | 12.41 (3.78) | ≤ 40 (12.2) |
| **ORA g's** | Longitudinal | -10.29 | -9.72 | ≤ 20.49 |
| | Lateral | 6.78 | 7.13 | ≤ 20.49 |
| **MAX. ANGULAR DISPLACEMENT deg.** | Roll | 5.31 | 4.05 | ≤ 75 |
| | Pitch | 4.14 | 2.89 | ≤ 75 |
| | Yaw | 33.72 | 33.12 | not required |
| **THIV ft/s (m/s)** | | 18.90 (5.76) | 18.93 (5.77) | not required |
| **PHD g's** | | 11.38 | 11.42 | not required |
| **ASI** | | 0.49 | 0.49 | not required |

## 9.8 Load Cells and String Potentiometers

The pertinent data from the load cells and string potentiometer were extracted from the bulk signal and analyzed using each transducer's calibration factor. The maximum displacement of the upstream anchor was recorded as 0.06 in. (2 mm). A summary of the maximum cable loads can be found in Table 18. The recorded data and analyzed results are detailed in Appendix J. The exact moment of impact could not be determined from the transducer data, as impact may have occurred 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.

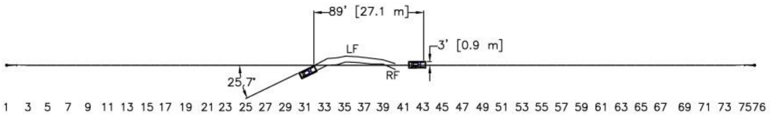
Table 18. Maximum Cable Loads, Test No. MWP-7

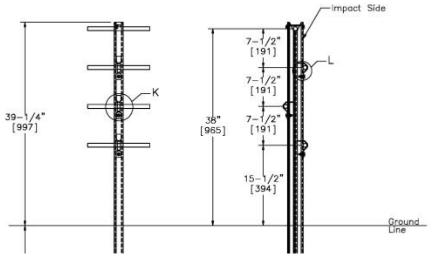
| Cable Location | Sensor Location | Maximum Cable Load | | Time (sec) |
|---|---|---|---|---|
| | | kips | kN | |
| Combined Cable Load | Upstream of Impact | 31.57 | 140.43 | 0.1234 |
| Cable No. 4 | Upstream of Impact | 7.66 | 34.07 | 1.2421 |
| Cable No. 3 | Upstream of Impact | 7.18 | 31.94 | 0.1429 |
| Cable No. 2 | Upstream of Impact | 19.21 | 85.45 | 0.3614 |
| Cable No. 1 | Upstream of Impact | 15.10 | 67.17 | 0.9403 |

## 9.9 Discussion

The analysis of the test results for test no. MWP-7 showed that the high-tension four-cable median barrier 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 I, were deemed acceptable, because they did not adversely influence occupant risk safety criteria or cause rollover. After impact, the vehicle was captured and retained within the system, so there was no exit information. As the vehicle overrode the system posts, the posts tore the floorpan in multiple locations. The tears indicated that the top of these posts penetrated into the occupant compartment. Therefore, test no. MWP-7, conducted on the four-cable median barrier, was determined to be unacceptable according to the MASH safety performance criteria for test designation no. 3-10.

0.000 sec 0.062 sec 0.166 sec 0.232sec 0.516 sec





- Test Agency .......... MwRSF
- Test Number .......... MWP-7
- Date .......... 02/24/2015
- MASH Test Designation .......... 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 mm, 584 mm, 775 mm, 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 .......... 2009 Kia Rio
    - Curb .......... 2,384 lb (1,081 kg)
    - Test Inertial .......... 2,392 lb (1,085 kg)
    - Gross Static .......... 2,557 lb (1,160 kg)
- Impact Conditions
    - Speed .......... 63.9 mph (102.9 km/h)
    - Angle .......... 25.7 deg
    - Impact Location .......... 4 ft - 9.2 in. (1.45 m) upstream of Post No. 32
- Impact Severity (IS) .......... 61.7 kip-ft (83.6 kJ) > 51 kip-ft (69.1 kJ)
- Exit Conditions
    - Speed .......... NA
    - Angle .......... NA
- Exit Box Criterion .......... NA (Did not exit system)
- Vehicle Stability .......... Satisfactory
- Vehicle Stopping Distance .......... 89 ft (27.1 m)
- Vehicle Damage .......... Moderate
    - VDS [8] .......... 11-FL-5
    - CDC [9] .......... 11-FDAK-6
    - Maximum Interior Deformation .......... 3.46 in. (88 mm)
- Test Article Damage .......... Moderate
- Maximum Test Article Deflections
    - Permanent Set .......... 24 in. (610 mm)
    - Dynamic .......... 97 in. (2,464 mm)
    - Working Width .......... 103.6 in. (2,631 mm)
- Transducer Data

| Evaluation Criteria | | Transducer | | MASH Limit |
|---|---|---|---|---|
| | | SLICE-1 (primary) | SLICE-2 | |
| OIV ft/s (m/s) | Longitudinal | -15.45 (-4.71) | -15.65 (-4.77) | ≤ 40 (12.2) |
| | Lateral | 12.03 (3.67) | 12.41 (3.78) | ≤ 40 (12.2) |
| ORA g's | Longitudinal | -10.29 | -9.72 | ≤ 20.49 |
| | Lateral | 6.78 | 7.13 | ≤ 20.49 |
| MAX. ANGULAR DISPLACEMENT deg. | Roll | 5.31 | 4.05 | ≤ 75 |
| | Pitch | 4.14 | 2.89 | ≤ 75 |
| | Yaw | 33.72 | 33.12 | not required |
| THIV – ft/s (m/s) | | 18.90 (5.76) | 18.93 (5.77) | not required |
| PHD – g's | | 11.38 | 11.42 | not required |
| ASI | | 0.49 | 0.49 | not required |

Figure 142. Summary of Test Results and Sequential Photographs, Test No. MWP-7


0.000 sec


0.068 sec


0.204 sec


0.350 sec


0.522 sec


2.864 sec


0.000 sec


0.160 sec

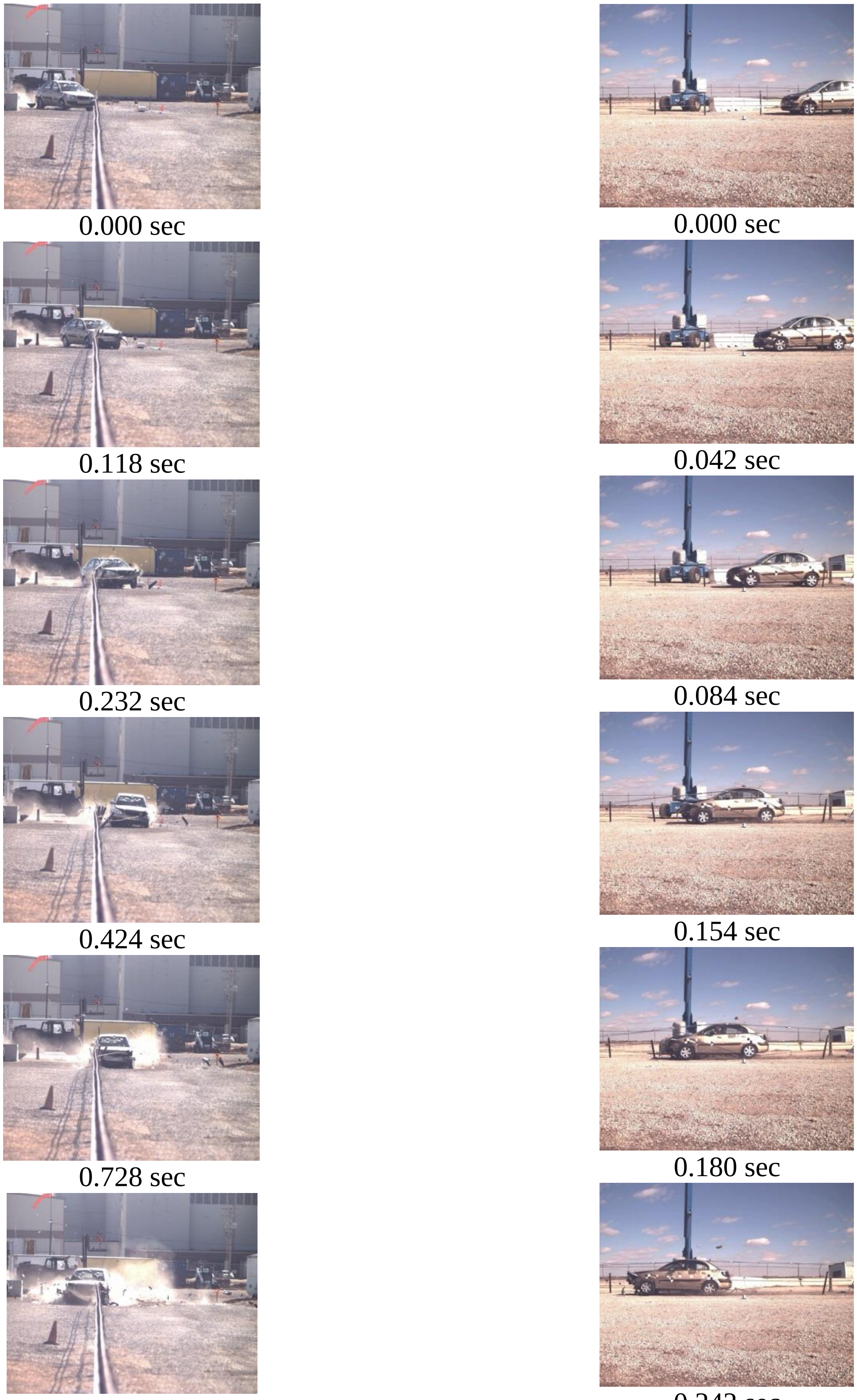

0.326 sec


0.482 sec


0.880 sec


1.734 sec

Figure 143. Additional Sequential Photographs, Test No. MWP-7



0.000 sec

0.118 sec

0.232 sec

0.424 sec

0.728 sec

1.152 sec

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0.042 sec

0.084 sec

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0.180 sec

0.242 sec

Figure 144. Additional Sequential Photographs, Test No. MWP-7

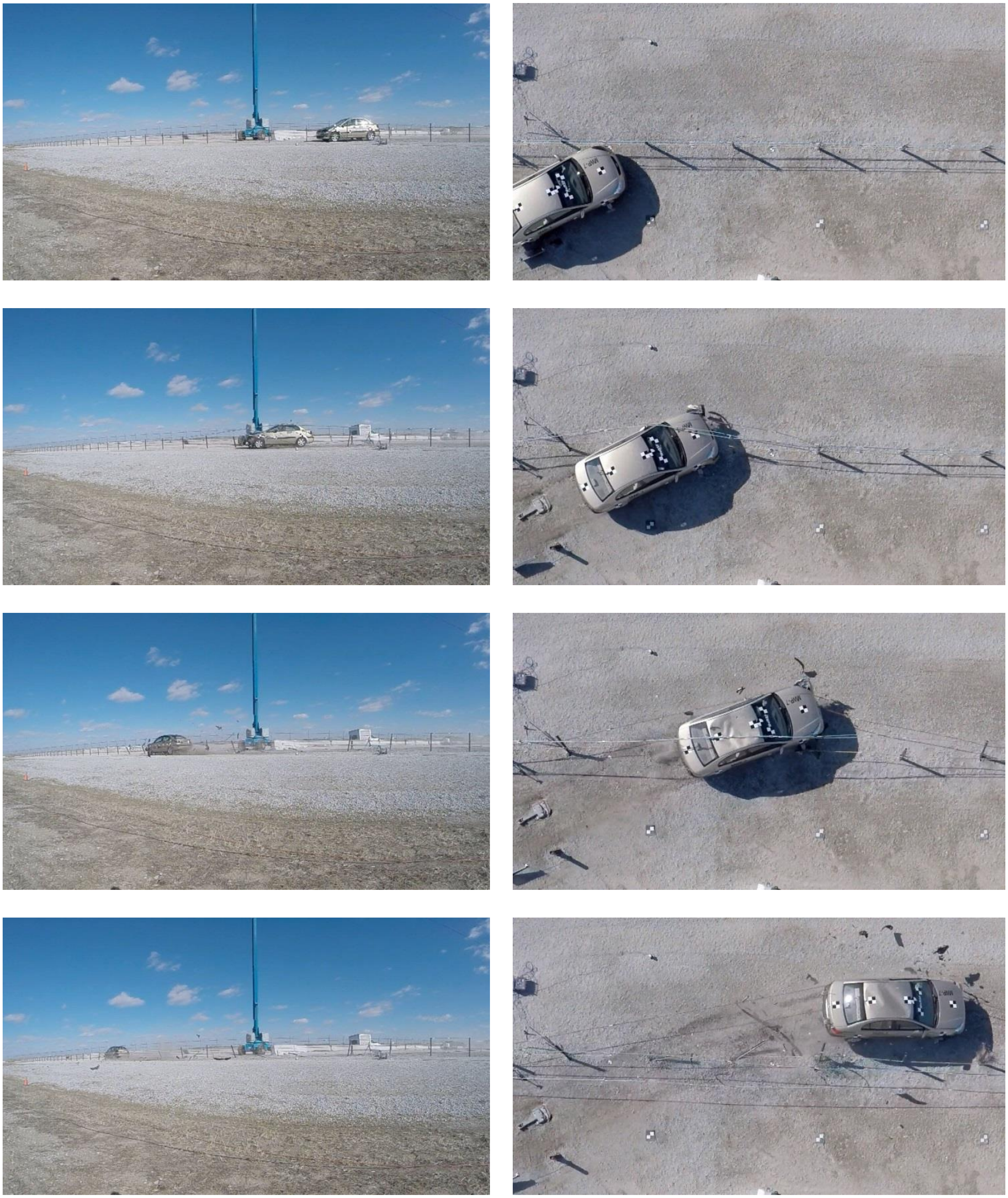


Figure 145. Documentary Photographs, Test No. MWP-7

Figure 146. Impact Location, Test No. MWP-7

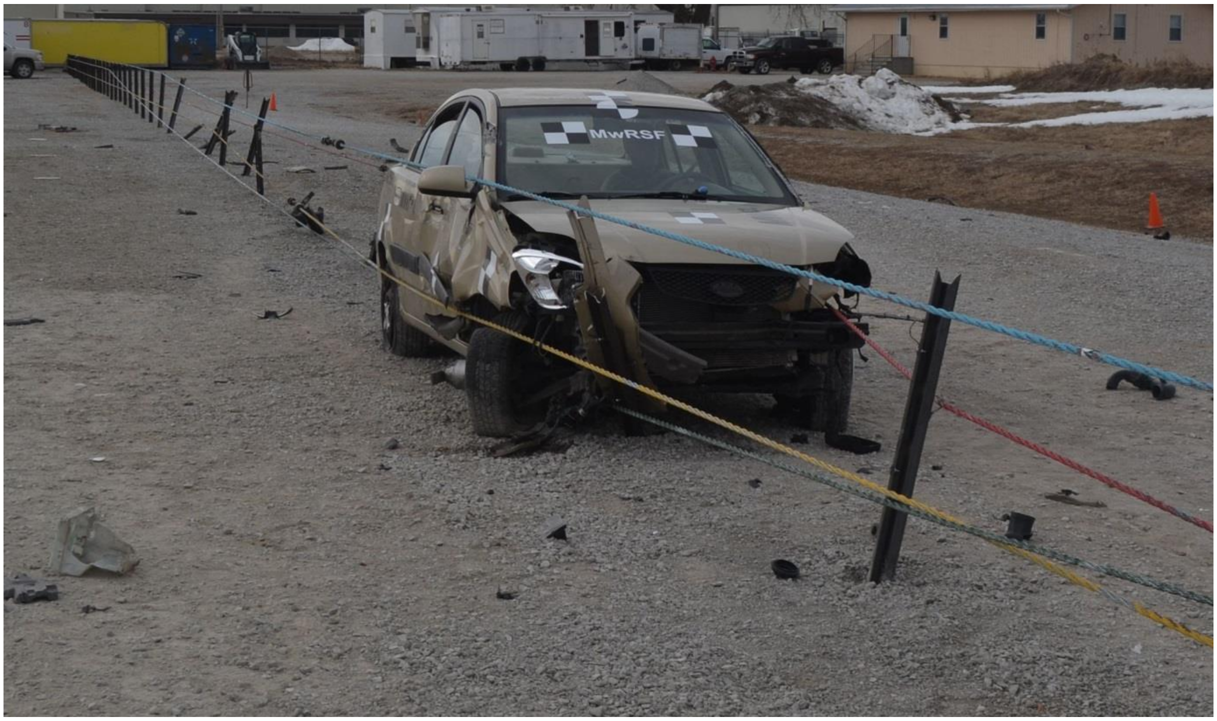


Figure 147. Vehicle Final Position and Trajectory Marks, Test No. MWP-7

Figure 148. System Damage, Test No. MWP-7

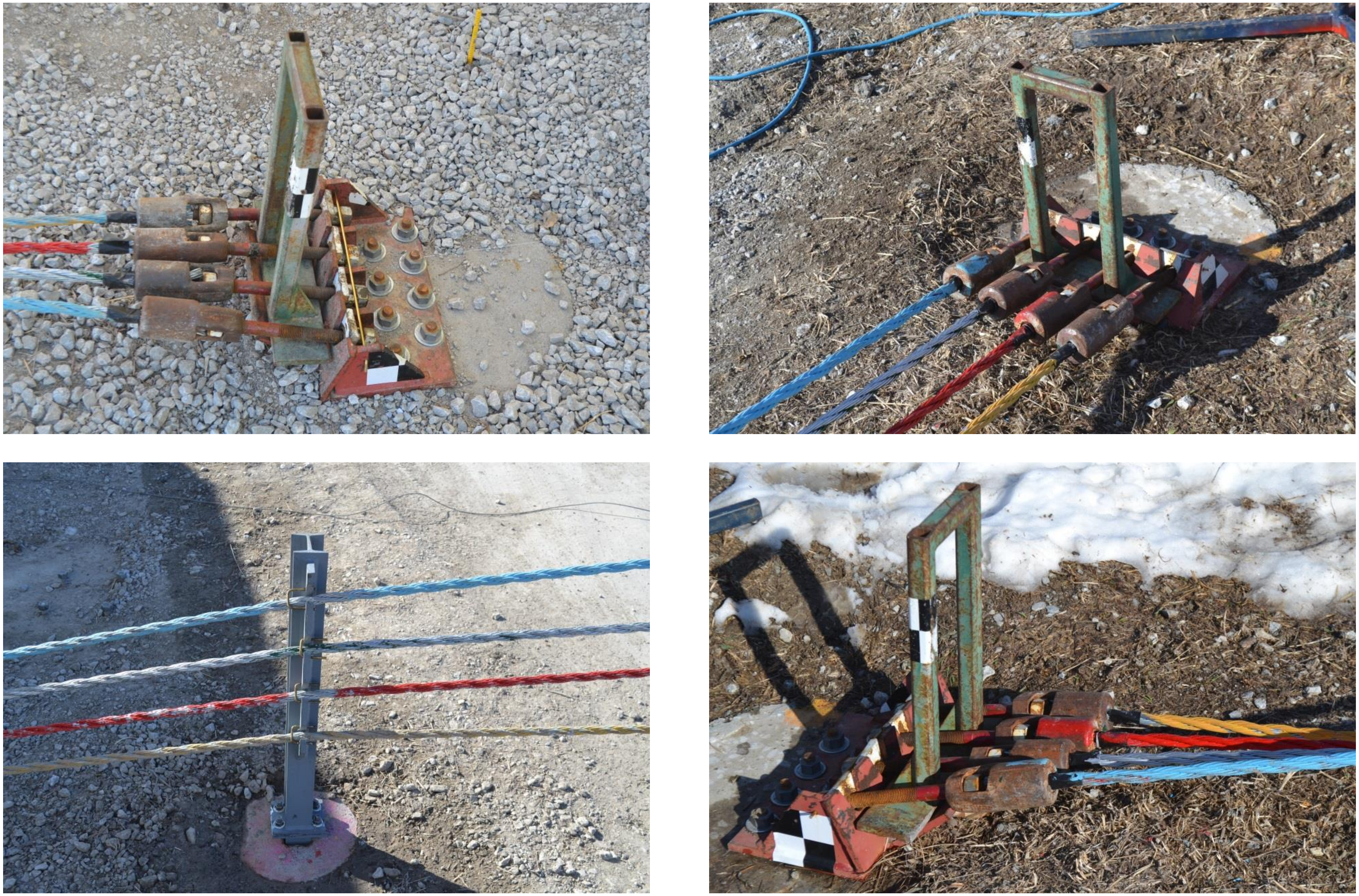
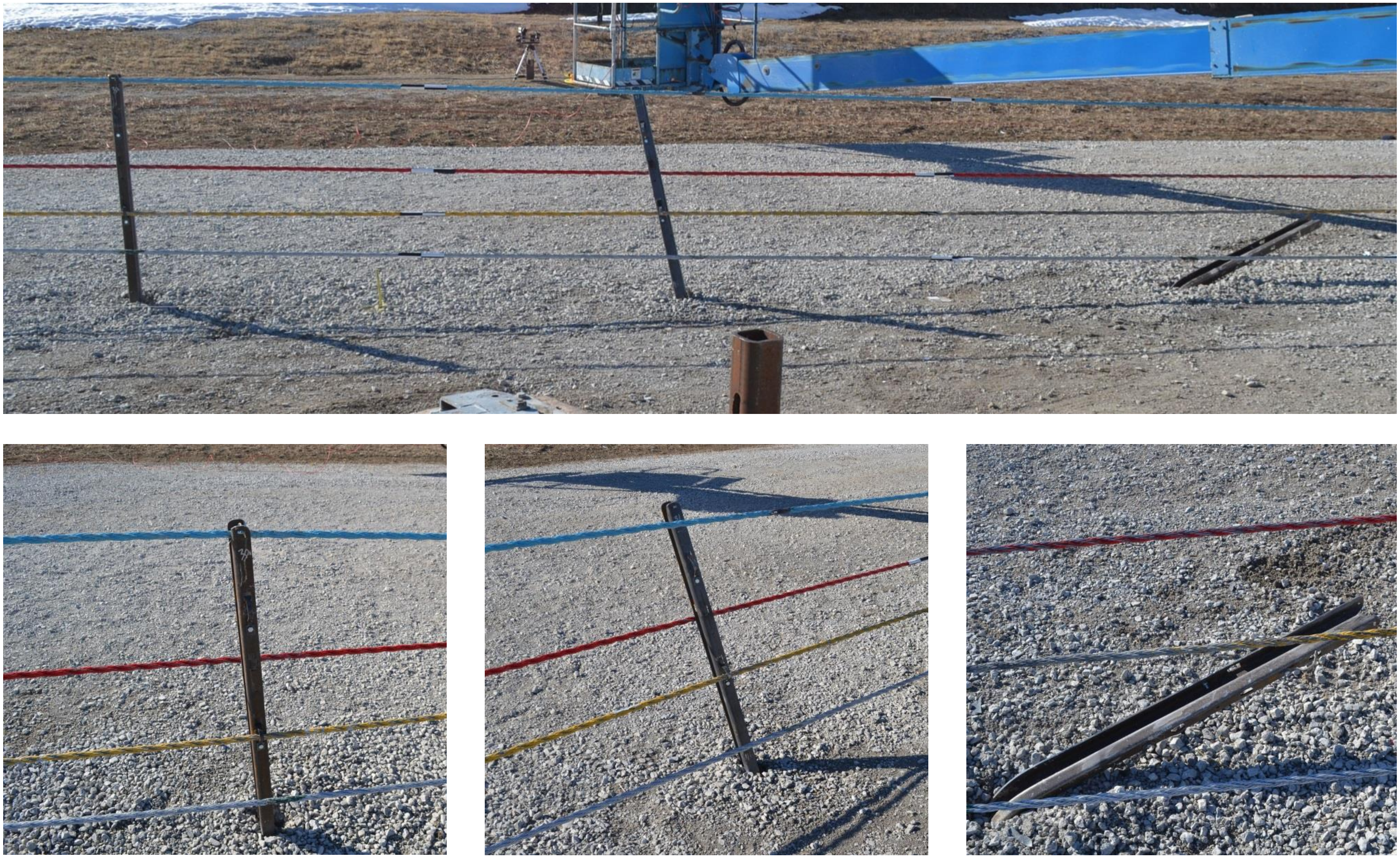


Figure 149. System Damage, End Anchorages, Test No. MWP-7

Figure 150. System Damage, Cable Brackets, Test No. MWP-7

Figure 151. System Damage, Brass Rods, Test No. MWP-7



Post No. 30

Post No. 31

Post No. 32

Figure 152. System Damage, Post Nos. 30 through 32, Test No. MWP-7

Post No. 32

Post No. 33

Post No. 34

Figure 153. System Damage, Post Nos. 32 through 34, Test No. MWP-7

Post No. 34

Post No. 35

Post No. 36

Figure 154. System Damage, Post Nos. 34 through 36, Test No. MWP-7

Post No. 37

Post No. 38

Figure 155. System Damage, Post Nos. 37 through 38, Test No. MWP-7

Post No. 39

Post No. 40

Figure 156. System Damage, Post Nos. 39 through 40, Test No. MWP-7


Post No. 41

Post No. 43


Post No. 42


Post No. 43

Figure 157. System Damage, Post Nos. 41 through 43, Test No. MWP-7

Post No. 32

Post No. 39

Post No. 33

Post No. 42

Figure 158. Contact Marks, Post Nos. 33 through 39, Test No. MWP-7

Figure 159. Vehicle Damage, Test No. MWP-7

Figure 160. Vehicle Damage, Test No. MWP-7

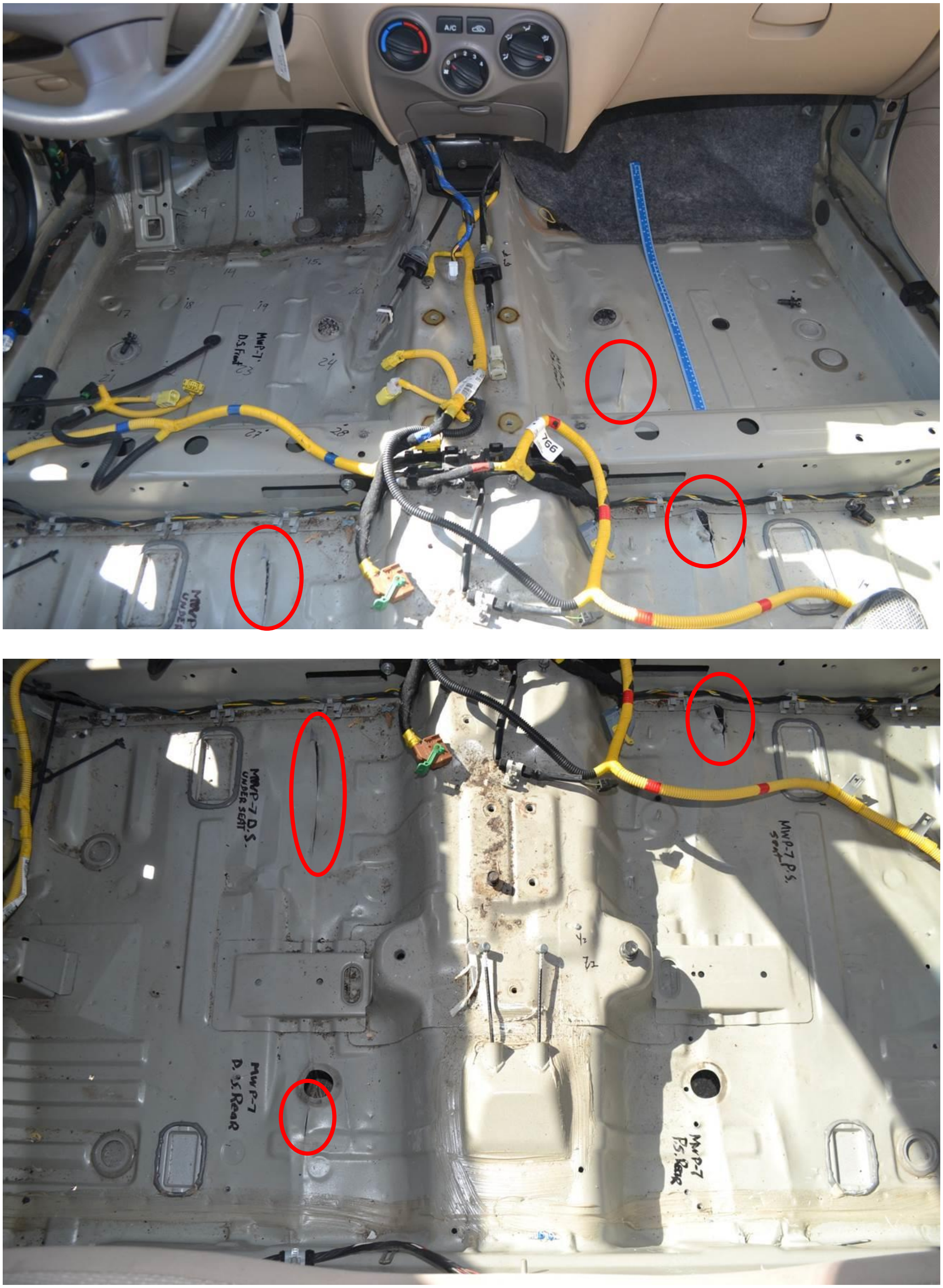


Figure 161. Occupant Compartment Damage, Test No. MWP-7

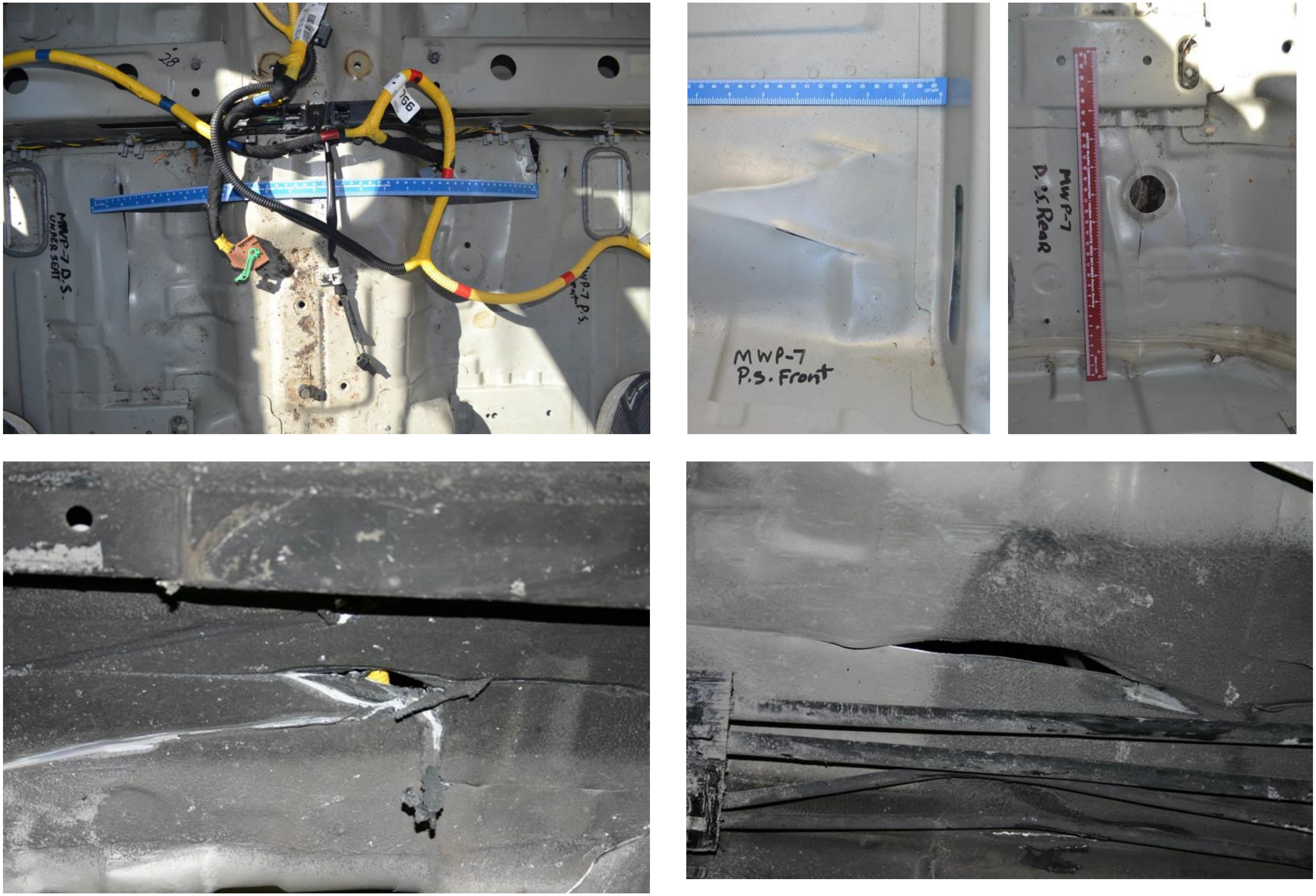


Figure 162. Occupant Compartment Damage, Test No. MWP-7

# 10 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

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 TL-3 safety criteria using the updated testing matrix for cable barrier systems installed within 6:1 median V-ditches. Three full-scale tests were conducted on the system and are reported herein.

Test no. MWP-4 was conducted in accordance with MASH 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. A working width of 16 ft - 9 in. (5.1 m) was observed during the test before the before the pickup came to rest in line with the barrier 144 ft - 10 in. (44.1 m) downstream from the point of impact. All occupant risk values were found to be within limits, and the occupant compartment deformations were also deemed acceptable. Subsequently, test no. MWP-4 was determined to satisfy the safety performance criteria for MASH test designation no. 3-11.

Test no. MWP-6, conducted in accordance with MASH test no. 3-10, involved a 1100C small car impacting the four-cable median barrier system with 8-ft (2.4-m) post spacing 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 vehicle remained stable throughout the test, and the OIV and ORA values were below the MASH recommended limits.  However, the occupant compartment was penetrated. When the top of posts were overridden, the floorpan was torn in two locations. Thus, test no. MWP-6 was determined to have failed the safety performance criteria corresponding to of MASH test designation no. 3-10.

To reduce the likelihood of occupant compartment penetration, the top corners of the MWP post 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 MWP-6, but with the modified MWP post. During the test, the small car was captured and redirected by cable no. 2. The A-pillar received only 0.22 in. (6 mm) of deformation, as the vehicle under-rode cable nos. 3 and 4. The vehicle remained stable throughout the test, and the OIV and ORA values were below the MASH recommended limits. However, the floorpan was again torn due to contact with the tops of the MWP posts 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 test designation no. 3-10. The safety performance evaluation for each full-scale crash test is summarized in Table 19.

As a result of the unsuccessful 1100C crash tests, the prototype high-tension, four-cable, median barrier system will need to be further redesigned to prevent penetration of the occupant compartment observed in test nos. MWP-6 and MWP-7. Possible design changes may include, but are not limited to, alternative post spacings, reduction of weak-axis post strength at the ground line, further treatment of the post edges, and changes to post geometry. After the cable barrier system has been redesigned, it will need to be reevaluated according to MASH test designation no. 3-10 criteria before proceeding with 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. The potential test designation nos. may be nos. 3-17 and 3-11 at a wide post spacings, and test no. 3-11 with a narrow post spacing.

Table 19. Summary of Safety Performance Evaluation – Test Nos. MWP-4, MWP-6, and MWP-7

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. MWP-4</th><th>Test No. MWP-6</th><th>Test No. MWP-7</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>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><td>S</td><td>S</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D.</td><td>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 5.3 and Appendix E of MASH.</td><td>S</td><td>U</td><td>U</td></tr>
<tr><td>F.</td><td>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><td>S</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Impact Velocity Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></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></table></td><td>S</td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr></table></td><td>S</td><td>S</td><td>S</td></tr>
<tr><td colspan="3">Final Evaluation</td><td>PASS</td><td>FAIL</td><td>FAIL</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

# 11 REFERENCES

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# 12 APPENDICES

# Appendix A. Material Specifications

Table A-1. Bill of Materials, Test No. MWP-4

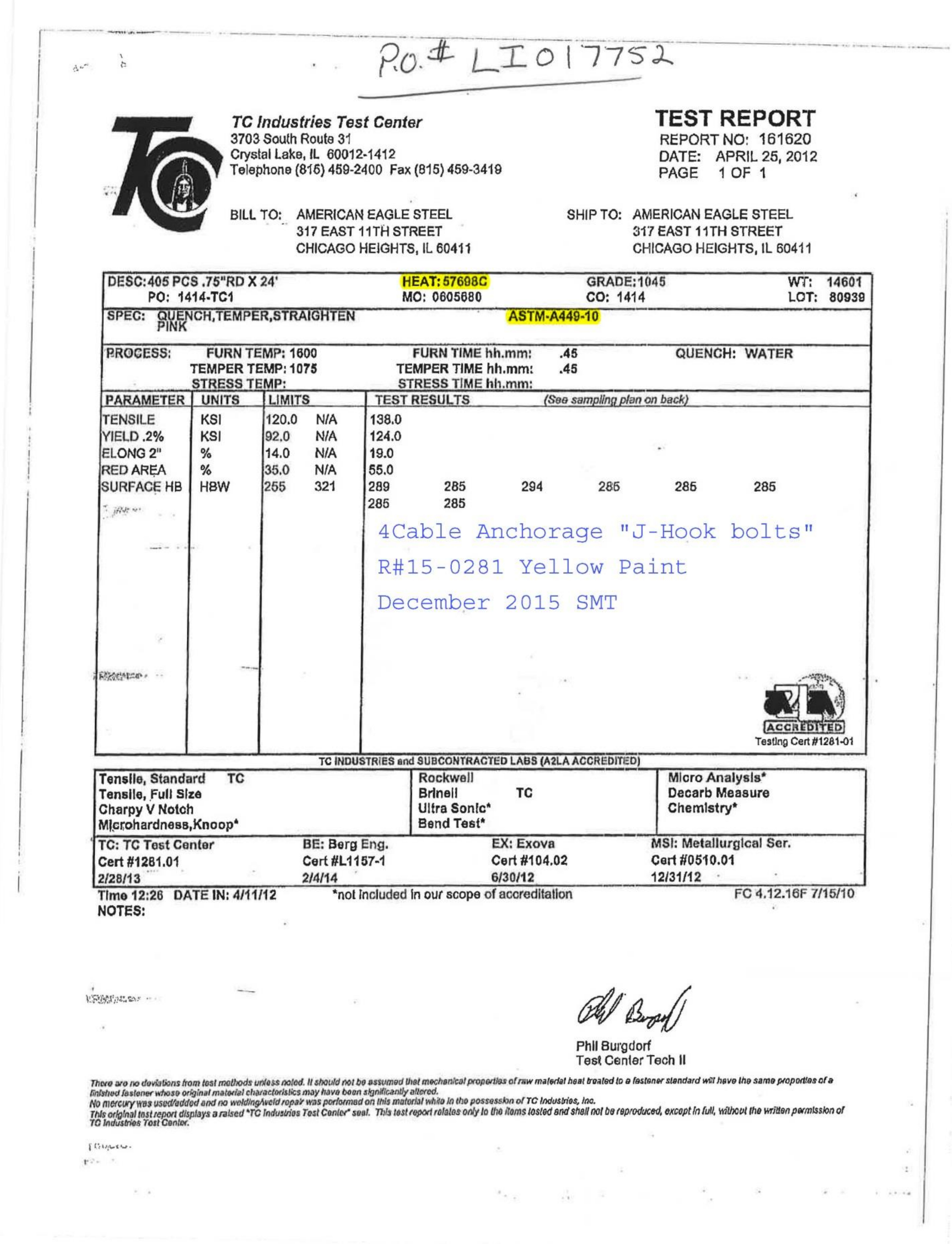
| Item No. | Description | Material Specification | Reference |
|---|---|---|---|
| **a1** | Cable Anchor Base Plate | ASTM A36 | N/A |
| **a2** | Exterior Cable Plate Gusset | ASTM A36 | N/A |
| **a3** | Interior Cable Plate Gusset | ASTM A36 | N/A |
| **a4** | Anchor Bracket Plate | ASTM A36 | N/A |
| **a5** | 3/16 [5] Dia. Brass Keeper Rod 14" [356] long " | Brass | H# 05543-1 |
| **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: Item# DHHNO75CG Lot# 170277 |
| **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 | R# 14-0343 COC |
| **a18** | 24 [610] Dia. Concrete Anchor 120" [3048] long " | 4,000 psi f'c | R# 14-0353 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 | R# 14-0476 H# 11935540 |
| **b2** | S3x5.7 [S76x8.5] Post by 19 [483] " | ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A | R# 14-0476 H# 11935540 |
| **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 |
| **b6** | 3/4 [19] Dia. UNC 5 1/2" [140] Long Hex Bolt and Nut " | Bolt ASTM A307 Gr. A/Nut ASTM A563A | Structural Bolt Distributor's Affidavit R# 14-0343 |
| **b7** | 1/2 [13] Dia. Washer with 1 1/16" [27] OD " | ASTM F844 (F436-SAE 1050 MOD4) | R#14-0106 H# A32336 BL# 195624 |
| **b8** | 1/2 [13] Dia. UNC 2" [51] long Hex Bolt and Nut " | Bolt ASTM A307 Gr. A/Nut ASTM A563A | Structural Bolt Distributor's Affidavit R# 14-0343 |
| **b9** | 4x3x1/4 [102x76x6] Foundation Tube 48" [1168] long " | ASTM A500 Grade B | H#B200931 / R# 13-0175 |
| **b10** | 2nd Post Cable Hanger | ASTM A36 | R# 14-0476 H# A402276 |
| **b11** | 2nd Post Anchor Aggregate 12 in, Depth | - | - |
| **b12** | 12 Dia. 2nd Post Concrete Anchor 46" long " | 4,000 psi f'c | R# 14-0353 T# 4156617 |
| **b13** | 2nd Post Base Plate | ASTM A36 | R# 14-0476 H# B314839 |
| **b14** | 3/16" [5] Dia. 5 1/4" [133] Long Brass Rod | ASTM B16-00 | H# 05543-1 |
| **c1** | 3x1-3/4"x7 Gauge [76x44x4.6] 83" [2108] Long Bent Z-Section Post " | Hot-Rolled ASTM A1011 HSLA Gr. 50 | H# 667827 Coil# 1131814950 R#14-0491 Green Paint |
| **c2** | 12 Gauge Tabbed Bracket - Version 10 | Hot-Rolled ASTM A1011 HSLA Grade 50 | H# 832D32560 |
| **c3** | 5/16 [8] Dia. UNC 1" [25] Long Hex Cap Screw | Bolt SAE J429 Gr. 5 or ASTM A449 | Lot# 3278740008 Order# 210072383 |

| | | | |
|---|---|---|---|
| **c3** | 5/16 Nut" | Nut ASTM A563 DH | Part# 1136304 H# 328711 AND H# 328481 |
| **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# 05543-1 |
| **d1** | 3/4 [19] Dia. High Strength Pre-Stretched Cable Guiderail " | 3x7 Cl A Galv. | C1/C2 and C3, see next tab |
| **d2** | 7/8 [22] Dia. Hex Nut " | ASTM A563C | R# 14-0325 H# M643354 White Paint |
| **d3** | Cable End Threaded Rod | ASTM A449 | R# 14-0325 H# 133079 White Paint (left) Red Paint (right) |
| **d4** | Bennet Cable End Fitter | ASTM A47 | H# 9Q4 AND OP5 |
| **x** | Cable Wedges | ASTM A47 | R# 14-0455 H# BR1 |
| **d5** | 7/8 [22] Dia. Square Nut " | SAE J429 Gr. 5 | N/A |
| **e1** | Bennet Short Threaded Turnbuckle | Not Specified | COC |
| **e2** | Threaded Loadcell Coupler | N/A | N/A |
| **e3** | 50,000-lb [222.4-kN] Load Cell | N/A | N/A |

Table A-2. Bill of Materials, Test Nos. MWP-6 and MWP-7

| Item No. | Description | Material Specification | Reference |
|---|---|---|---|
| **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 Keeper Rod 14" [356] long " | Brass | H# 05543-1 |
| **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: Item# DHHNO75CG Lot# 170277 |
| **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 | R# 14-0343 COC |
| **a18** | 24 [610] Dia. Concrete Anchor 120" [3048] long " | 4,000 psi f'c | R# 14-0353 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 | R# 14-0476 H# 11935540 |
| **b2** | S3x5.7 [S76x8.5] Post by 19 [483] " | ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A | R# 14-0476 H# 11935540 |
| **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 |
| **b6** | 3/4 [19] Dia. UNC 5 1/2" [140] Long Hex Bolt and Nut " | Bolt ASTM A307 Gr. A/Nut ASTM A563A | Structural Bolt Distributor's Affidavit R# 14-0343 |
| **b7** | 1/2 [13] Dia. Washer with 1 1/16" [27] OD " | ASTM F844 (F436-SAE 1050 MOD4) | R#14-0106 H# A32336 BL# 195624 |
| **b8** | 1/2 [13] Dia. UNC 2" [51] long Hex Bolt and Nut " | Bolt ASTM A307 Gr. A/Nut ASTM A563A | Structural Bolt Distributor's Affidavit R# 14-0343 |
| **b9** | 4x3x1/4 [102x76x6] Foundation Tube 48" [1168] long " | ASTM A500 Grade B | H#B200931 / R# 13-0175 |
| **b10** | 2nd Post Cable Hanger | ASTM A36 | R# 14-0476 H# A402276 |
| **b11** | 2nd Post Anchor Aggregate 12 in, Depth | - | - |
| **b12** | 12 Dia. 2nd Post Concrete Anchor 46" long " | 4,000 psi f'c | R# 14-0353 T# 4156617 |
| **b13** | 2nd Post Base Plate | ASTM A36 | R# 14-0476 H# B314839 |
| **b14** | 3/16" [5] Dia. 5 1/4" [133] Long Brass Rod | ASTM B16-00 | H# 05543-1 |
| **c1** | 3x1-3/4"x7 Gauge [76x44x4.6] 83" [2108] Long Bent Z-Section Post " | Hot-Rolled ASTM A1011 HSLA Gr. 50 | H# 667827 Coil# 1131814950 R#14-0491 Green Paint |
| **c2** | 12 Gauge Tabbed Bracket - Version 10 | Hot-Rolled ASTM A1011 HSLA Grade 50 | H# 832D32560 |
| **c3** | 5/16 [8] Dia. UNC 1" [25] Long Hex Cap Screw | Bolt SAE J429 Gr. 5 or ASTM A449 | Lot# 3305380002 Order# 210072383 H# 311406798 |
| **c3** | 5/16 Nut" | Nut ASTM A563 DH | Part# 1136304 H# 328711 AND H# 328481 AND H# KV894 |

| | | | |
|---|---|---|---|
| **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# 05543-1 |
| **d1** | 3/4 [19] Dia. High Strength Pre-Stretched Cable Guiderail " | 3x7 Cl A Galv. | C1/C2 and C3, H# 131499 see next tab |
| **d2** | 7/8 [22] Dia. Hex Nut " | ASTM A563C | R# 14-0325 H# M643354 White Paint |
| **d3** | Cable End Threaded Rod | ASTM A449 | R# 14-0325 H# 133079 White Paint (left) Red Paint (right) |
| **d4** | Bennet Cable End Fitter | ASTM A47 | H# 9Q4 AND OP5 |
| **x** | Cable Wedges | ASTM A47 | R# 14-0455 H# BR1 |
| **d5** | 7/8 [22] Dia. Square Nut " | SAE J429 Gr. 5 | N/A |
| **e1** | Bennet Short Threaded Turnbuckle | Not Specified | COC |
| **e2** | Threaded Loadcell Coupler | N/A | N/A |
| **e3** | 50,000-lb [222.4-kN] Load Cell | N/A | N/A |



P.O.# LI017752

**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: 161620
DATE: APRIL 25, 2012
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: 405 PCS .75"RD X 24'
PO: 1414-TC1
HEAT: 57698C
MO: 0605680
GRADE: 1045
CO: 1414
WT: 14601
LOT: 80939

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

PROCESS: FURN TEMP: 1600
TEMPER TEMP: 1075
STRESS TEMP:
FURN TIME hh.mm: .45
TEMPER TIME hh.mm: .45
STRESS TIME hh.mm:
QUENCH: WATER

| PARAMETER | UNITS | LIMITS | | TEST RESULTS | | (See sampling plan on back) | | | |
|---|---|---|---|---|---|---|---|---|---|
| TENSILE | KSI | 120.0 | N/A | 138.0 | | | | | |
| YIELD .2% | KSI | 92.0 | N/A | 124.0 | | | | | |
| ELONG 2" | % | 14.0 | N/A | 19.0 | | | | | |
| RED AREA | % | 35.0 | N/A | 55.0 | | | | | |
| SURFACE HB | HBW | 255 | 321 | 289 | 285 | 294 | 285 | 285 | 285 |
| | | | | 285 | 285 | | | | |

4Cable Anchorage "J-Hook bolts"
R#15-0281 Yellow Paint
December 2015 SMT

ACCREDITED
Testing Cert #1281-01

TC INDUSTRIES and SUBCONTRACTED LABS (A2LA ACCREDITED)

Tensile, Standard TC
Tensile, Full Size
Charpy V Notch
Microhardness,Knoop*

Rockwell
Brinell TC
Ultra Sonic*
Bend Test*

Micro Analysis*
Decarb Measure
Chemistry*

TC: TC Test Center
Cert #1281.01
2/28/13

BE: Berg Eng.
Cert #L1157-1
2/4/14

EX: Exova
Cert #104.02
6/30/12

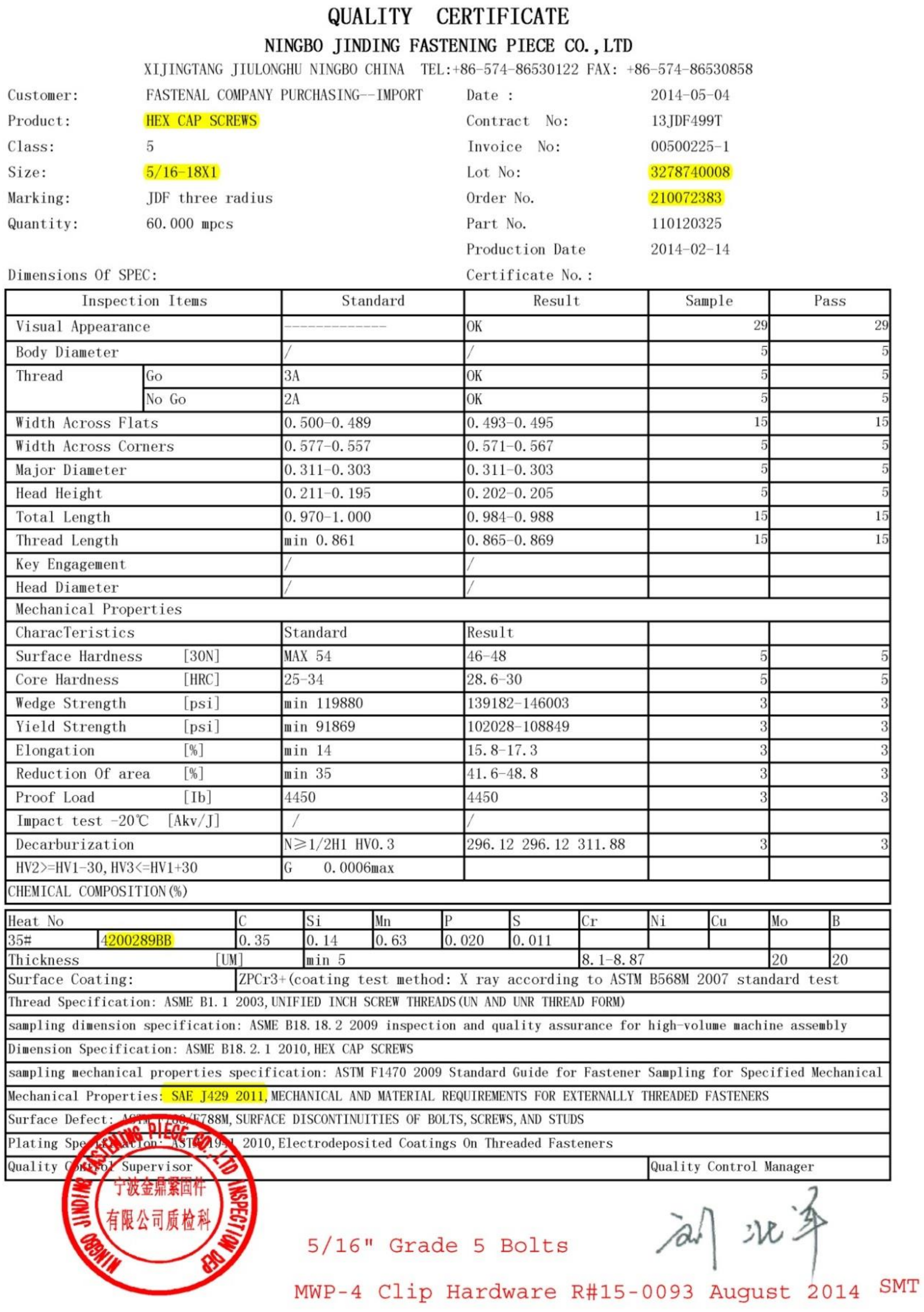
MSI: Metallurgical Ser.
Cert #0510.01
12/31/12

Time 12:26 DATE IN: 4/11/12 *not included in our scope of accreditation FC 4.12.16F 7/15/10
NOTES:

Phil Burgdorf
Test Center Tech II

*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 original test report displays a raised "TC Industries Test Center" seal. 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-1. Cable End Threaded Rod, Test No. MWP-4



## 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 : | 2014-05-04 |
| Product: | HEX CAP SCREWS | Contract No: | 13JDF499T |
| Class: | 5 | Invoice No: | 00500225-1 |
| Size: | 5/16-18X1 | Lot No: | 3278740008 |
| Marking: | JDF three radius | Order No. | 210072383 |
| Quantity: | 60.000 mpcs | Part No. | 110120325 |
| | | Production Date | 2014-02-14 |
| Dimensions Of SPEC: | | Certificate No.: | |

| Inspection Items | | Standard | Result | Sample | Pass |
|---|---|---|---|---|---|
| Visual Appearance | | ------------- | OK | 29 | 29 |
| Body Diameter | | / | / | 5 | 5 |
| Thread | Go | 3A | OK | 5 | 5 |
| | No Go | 2A | OK | 5 | 5 |
| Width Across Flats | | 0.500-0.489 | 0.493-0.495 | 15 | 15 |
| Width Across Corners | | 0.577-0.557 | 0.571-0.567 | 5 | 5 |
| Major Diameter | | 0.311-0.303 | 0.311-0.303 | 5 | 5 |
| Head Height | | 0.211-0.195 | 0.202-0.205 | 5 | 5 |
| Total Length | | 0.970-1.000 | 0.984-0.988 | 15 | 15 |
| Thread Length | | min 0.861 | 0.865-0.869 | 15 | 15 |
| Key Engagement | | / | / | | |
| Head Diameter | | / | / | | |
| Mechanical Properties | | | | | |
| CharacTeristics | | Standard | Result | | |
| Surface Hardness | [30N] | MAX 54 | 46-48 | 5 | 5 |
| Core Hardness | [HRC] | 25-34 | 28.6-30 | 5 | 5 |
| Wedge Strength | [psi] | min 119880 | 139182-146003 | 3 | 3 |
| Yield Strength | [psi] | min 91869 | 102028-108849 | 3 | 3 |
| Elongation | [%] | min 14 | 15.8-17.3 | 3 | 3 |
| Reduction Of area | [%] | min 35 | 41.6-48.8 | 3 | 3 |
| Proof Load | [Ib] | 4450 | 4450 | 3 | 3 |
| Impact test -20℃ | [Akv/J] | / | / | | |
| Decarburization | | N≥1/2H1 HV0.3 | 296.12 296.12 311.88 | 3 | 3 |
| HV2>=HV1-30, HV3<=HV1+30 | | G 0.0006max | | | |

CHEMICAL COMPOSITION(%)

| Heat No | | C | Si | Mn | P | S | Cr | Ni | Cu | Mo | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 35# | 4200289BB | 0.35 | 0.14 | 0.63 | 0.020 | 0.011 | | | | | |
| Thickness | [UM] | | min 5 | | | | 8.1-8.87 | | | 20 | 20 |
| Surface Coating: | ZPCr3+(coating test method: X ray according to ASTM B568M 2007 standard test | | | | | | | | | | |

Thread Specification: ASME B1.1 2003, UNIFIED INCH SCREW THREADS(UN AND UNR THREAD FORM)

sampling dimension specification: ASME B18.18.2 2009 inspection and quality assurance for high-volume machine assembly

Dimension Specification: ASME B18.2.1 2010, HEX CAP SCREWS

sampling mechanical properties specification: ASTM F1470 2009 Standard Guide for Fastener Sampling for Specified Mechanical

Mechanical Properties: SAE J429 2011, MECHANICAL AND MATERIAL REQUIREMENTS FOR EXTERNALLY THREADED FASTENERS

Surface Defect: ASTM F788/F788M, SURFACE DISCONTINUITIES OF BOLTS, SCREWS, AND STUDS

Plating Specification: ASTM F1941 2010, Electrodeposited Coatings On Threaded Fasteners

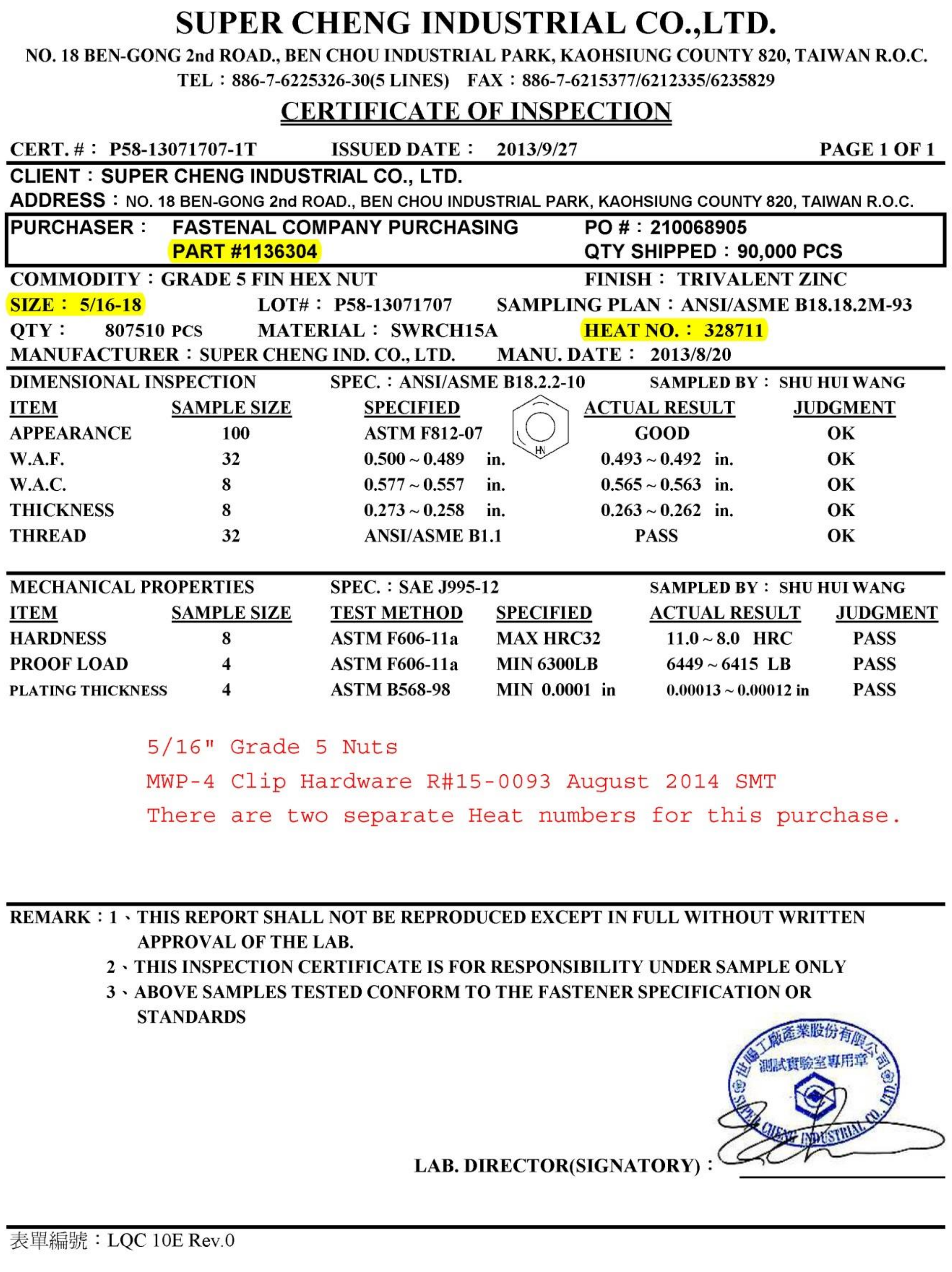
| | |
|---|---|
| Quality Control Supervisor | Quality Control Manager |

宁波金鼎紧固件有限公司质检科

5/16" Grade 5 Bolts

MWP-4 Clip Hardware R#15-0093 August 2014 SMT

Figure A-2. $^5/_{16}$ in. (8 mm) Hex Cap Screws, Test No. MWP-4



## 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. #：** P58-13071707-1T **ISSUED DATE：** 2013/9/27 **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 #：** 210068905
PART #1136304 **QTY SHIPPED：** 90,000 PCS

**COMMODITY：** GRADE 5 FIN HEX NUT **FINISH：** TRIVALENT ZINC
**SIZE：** 5/16-18 **LOT#：** P58-13071707 **SAMPLING PLAN：** ANSI/ASME B18.18.2M-93
**QTY：** 807510 PCS **MATERIAL：** SWRCH15A **HEAT NO.：** 328711
**MANUFACTURER：** SUPER CHENG IND. CO., LTD. **MANU. DATE：** 2013/8/20

**DIMENSIONAL INSPECTION** **SPEC.：** ANSI/ASME B18.2.2-10 **SAMPLED BY：** SHU HUI WANG

| ITEM | SAMPLE SIZE | SPECIFIED | ACTUAL RESULT | JUDGMENT |
|---|---|---|---|---|
| APPEARANCE | 100 | ASTM F812-07 | GOOD | OK |
| W.A.F. | 32 | 0.500 ~ 0.489 in. | 0.493 ~ 0.492 in. | OK |
| W.A.C. | 8 | 0.577 ~ 0.557 in. | 0.565 ~ 0.563 in. | OK |
| THICKNESS | 8 | 0.273 ~ 0.258 in. | 0.263 ~ 0.262 in. | OK |
| THREAD | 32 | ANSI/ASME B1.1 | PASS | OK |

**MECHANICAL PROPERTIES** **SPEC.：** SAE J995-12 **SAMPLED BY：** SHU HUI WANG

| ITEM | SAMPLE SIZE | TEST METHOD | SPECIFIED | ACTUAL RESULT | JUDGMENT |
|---|---|---|---|---|---|
| HARDNESS | 8 | ASTM F606-11a | MAX HRC32 | 11.0 ~ 8.0 HRC | PASS |
| PROOF LOAD | 4 | ASTM F606-11a | MIN 6300LB | 6449 ~ 6415 LB | PASS |
| PLATING THICKNESS | 4 | ASTM B568-98 | MIN 0.0001 in | 0.00013 ~ 0.00012 in | PASS |

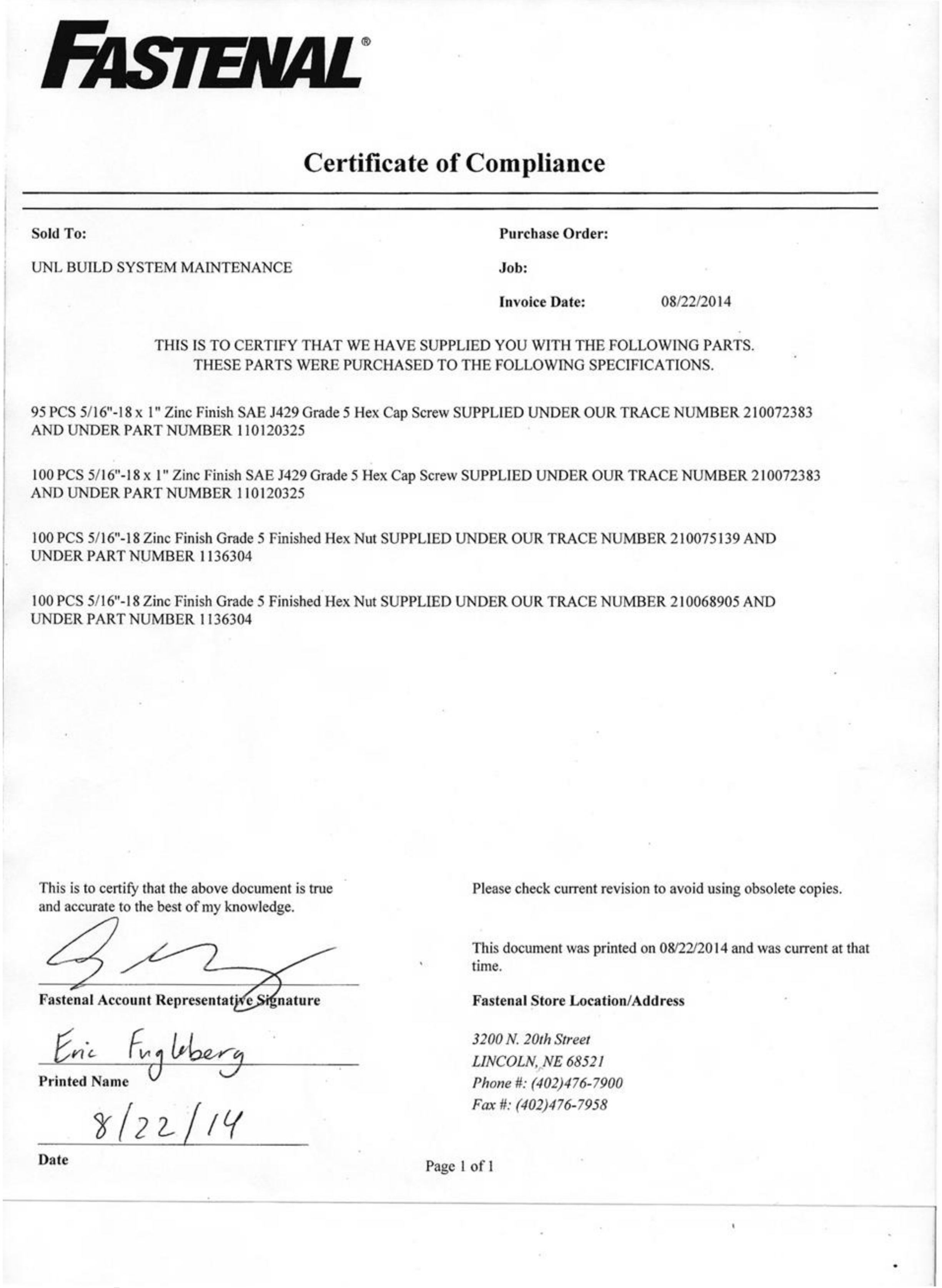
5/16" Grade 5 Nuts
MWP-4 Clip Hardware R#15-0093 August 2014 SMT
There are two separate Heat numbers for this purchase.

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

LAB. DIRECTOR(SIGNATORY)：

表單編號：LQC 10E Rev.0

Figure A-3. $^{5}/_{16}$ in. (8 mm) Hex Cap Nuts, Test No. MWP-4



**FASTENAL**®

## Certificate of Compliance

**Sold To:**

UNL BUILD SYSTEM MAINTENANCE

**Purchase Order:**

**Job:**

**Invoice Date:** 08/22/2014

THIS IS TO CERTIFY THAT WE HAVE SUPPLIED YOU WITH THE FOLLOWING PARTS.
THESE PARTS WERE PURCHASED TO THE FOLLOWING SPECIFICATIONS.

95 PCS 5/16"-18 x 1" Zinc Finish SAE J429 Grade 5 Hex Cap Screw SUPPLIED UNDER OUR TRACE NUMBER 210072383 AND UNDER PART NUMBER 110120325

100 PCS 5/16"-18 x 1" Zinc Finish SAE J429 Grade 5 Hex Cap Screw SUPPLIED UNDER OUR TRACE NUMBER 210072383 AND UNDER PART NUMBER 110120325

100 PCS 5/16"-18 Zinc Finish Grade 5 Finished Hex Nut SUPPLIED UNDER OUR TRACE NUMBER 210075139 AND UNDER PART NUMBER 1136304

100 PCS 5/16"-18 Zinc Finish Grade 5 Finished Hex Nut SUPPLIED UNDER OUR TRACE NUMBER 210068905 AND UNDER PART NUMBER 1136304

This is to certify that the above document is true and accurate to the best of my knowledge.

**Fastenal Account Representative Signature**

Eric Fugleberg

**Printed Name**

8/22/14

**Date**

Please check current revision to avoid using obsolete copies.

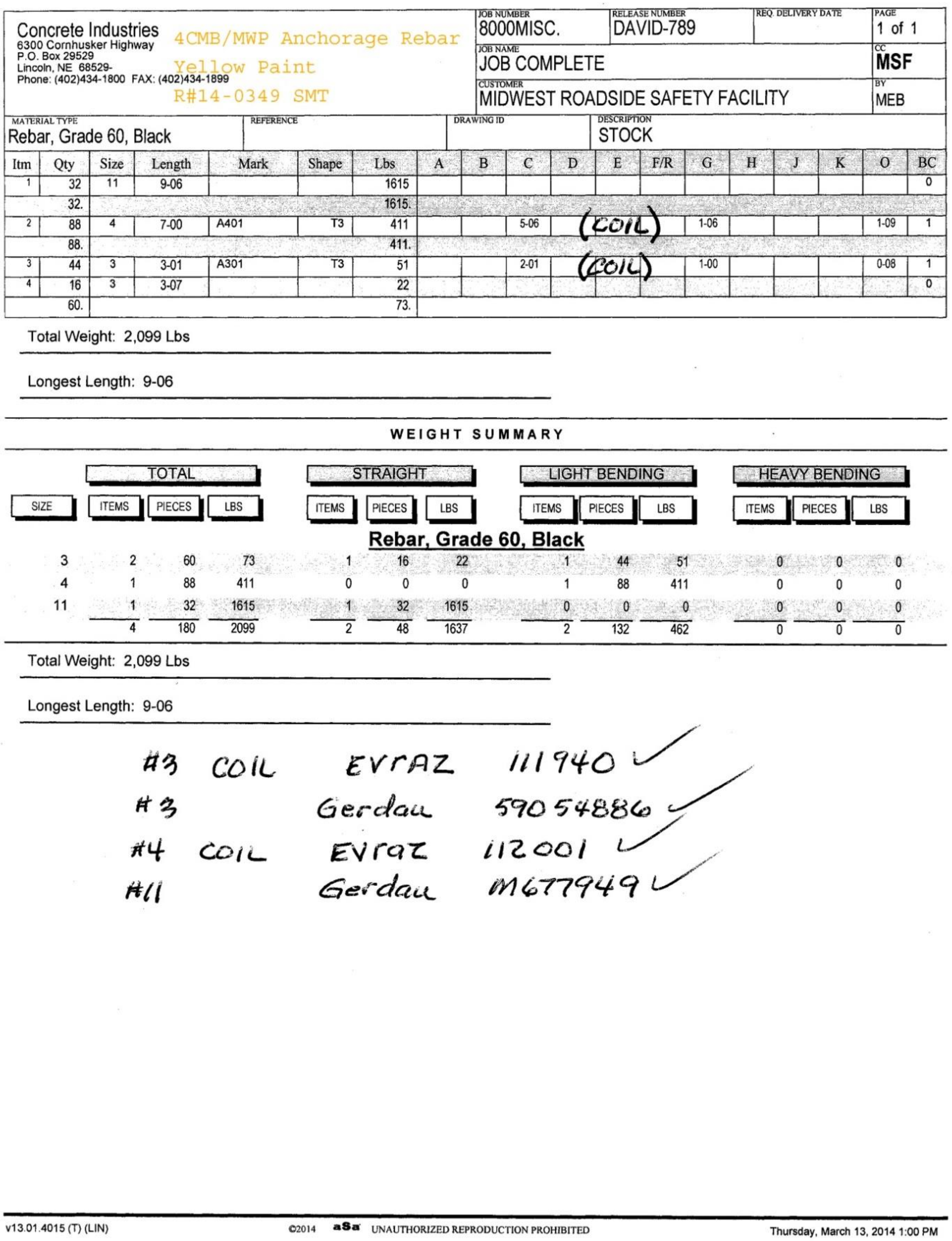
This document was printed on 08/22/2014 and was current at that time.

**Fastenal Store Location/Address**

*3200 N. 20th Street*
*LINCOLN, NE 68521*
*Phone #: (402)476-7900*
*Fax #: (402)476-7958*

Page 1 of 1

Figure A-4. $^{5}/_{16}$ in. (8 mm) Hex Cap Screws and Nuts, Test No. MWP-4



**Concrete Industries**
6300 Cornhusker Highway
P.O. Box 29529
Lincoln, NE 68529-
Phone: (402)434-1800 FAX: (402)434-1899

4CMB/MWP Anchorage Rebar
Yellow Paint
R#14-0349 SMT

JOB NUMBER: 8000MISC.
RELEASE NUMBER: DAVID-789
REQ. DELIVERY DATE:
PAGE: 1 of 1
JOB NAME: JOB COMPLETE
CC: MSF
CUSTOMER: MIDWEST ROADSIDE SAFETY FACILITY
BY: MEB
MATERIAL TYPE: Rebar, Grade 60, Black
REFERENCE:
DRAWING ID:
DESCRIPTION: STOCK

| Itm | Qty | Size | Length | Mark | Shape | Lbs | A | B | C | D | E | F/R | G | H | J | K | O | BC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 32 | 11 | 9-06 | | | 1615 | | | | | | | | | | | | 0 |
| | 32. | | | | | 1615. | | | | | | | | | | | | |
| 2 | 88 | 4 | 7-00 | A401 | T3 | 411 | | | 5-06 | | (COIL) | | 1-06 | | | | 1-09 | 1 |
| | 88. | | | | | 411. | | | | | | | | | | | | |
| 3 | 44 | 3 | 3-01 | A301 | T3 | 51 | | | 2-01 | | (COIL) | | 1-00 | | | | 0-08 | 1 |
| 4 | 16 | 3 | 3-07 | | | 22 | | | | | | | | | | | | 0 |
| | 60. | | | | | 73. | | | | | | | | | | | | |

Total Weight: 2,099 Lbs

Longest Length: 9-06

**WEIGHT SUMMARY**

| | TOTAL | | | STRAIGHT | | | LIGHT BENDING | | | HEAVY BENDING | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SIZE | ITEMS | PIECES | LBS | ITEMS | PIECES | LBS | ITEMS | PIECES | LBS | ITEMS | PIECES | LBS |
| Rebar, Grade 60, Black | | | | | | | | | | | | |
| 3 | 2 | 60 | 73 | 1 | 16 | 22 | 1 | 44 | 51 | 0 | 0 | 0 |
| 4 | 1 | 88 | 411 | 0 | 0 | 0 | 1 | 88 | 411 | 0 | 0 | 0 |
| 11 | 1 | 32 | 1615 | 1 | 32 | 1615 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 180 | 2099 | 2 | 48 | 1637 | 2 | 132 | 462 | 0 | 0 | 0 |

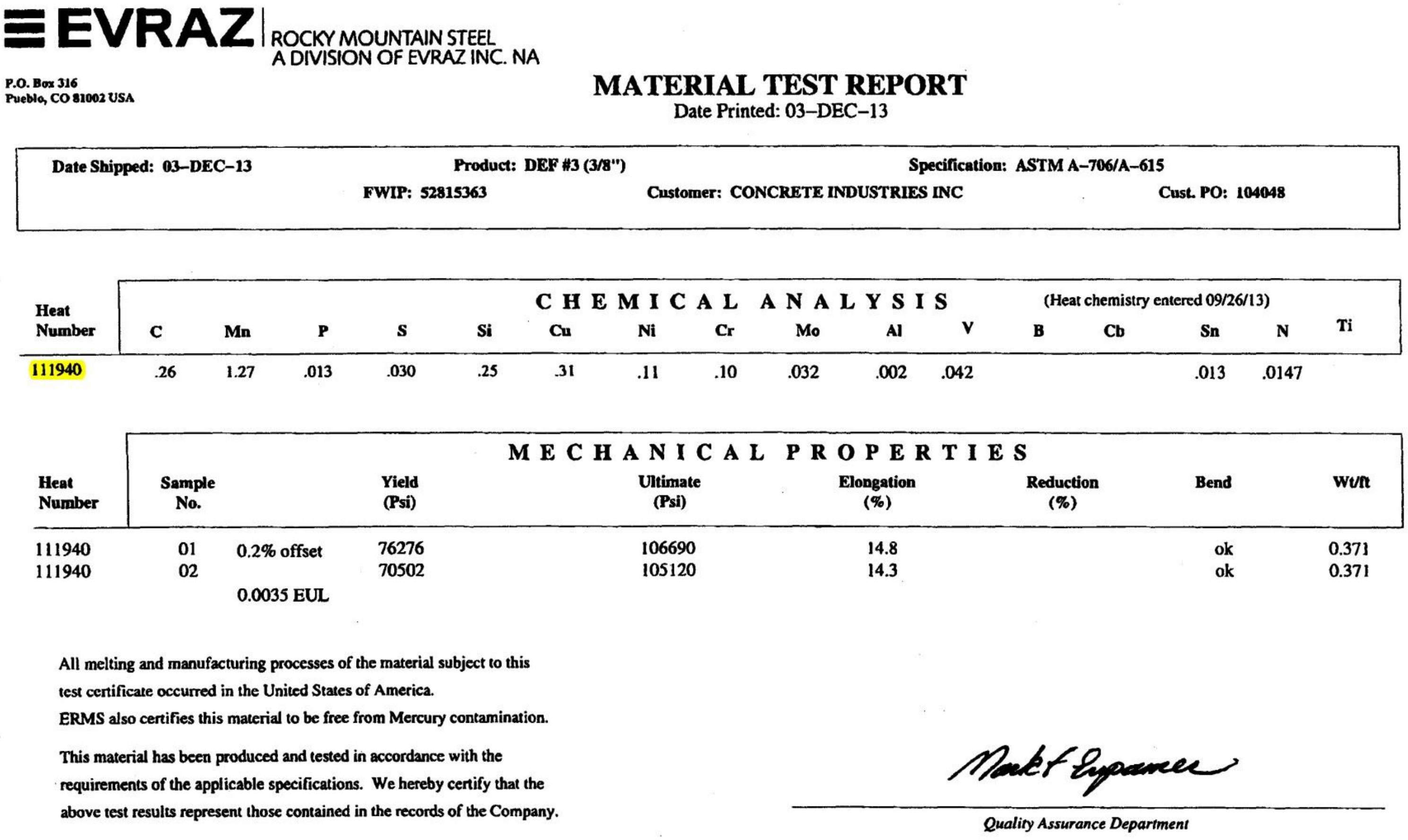
Total Weight: 2,099 Lbs

Longest Length: 9-06

| | | | |
|---|---|---|---|
| #3 | COIL | EVrAZ | 111940 ✓ |
| #3 | | Gerdau | 59054886 ✓ |
| #4 | COIL | EVraz | 112001 ✓ |
| #11 | | Gerdau | M677949 ✓ |

v13.01.4015 (T) (LIN) ©2014 aSa UNAUTHORIZED REPRODUCTION PROHIBITED Thursday, March 13, 2014 1:00 PM

Figure A-5. Rebar in Concrete Anchor, Test Nos. MWP-4, MWP-6 and MWP-7



**EVRAZ** | ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

P.O. Box 316
Pueblo, CO 81002 USA

## MATERIAL TEST REPORT

Date Printed: 03–DEC–13

**Date Shipped:** 03–DEC–13 **Product:** DEF #3 (3/8") **Specification:** ASTM A–706/A–615
**FWIP:** 52815363 **Customer:** CONCRETE INDUSTRIES INC **Cust. PO:** 104048

CHEMICAL ANALYSIS (Heat chemistry entered 09/26/13)

| Heat Number | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | Al | V | B | Cb | Sn | N | Ti |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 111940 | .26 | 1.27 | .013 | .030 | .25 | .31 | .11 | .10 | .032 | .002 | .042 | | | .013 | .0147 | |

MECHANICAL PROPERTIES

| Heat Number | Sample No. | | Yield (Psi) | Ultimate (Psi) | Elongation (%) | Reduction (%) | Bend | Wt/ft |
|---|---|---|---|---|---|---|---|---|
| 111940 | 01 | 0.2% offset | 76276 | 106690 | 14.8 | | ok | 0.371 |
| 111940 | 02 | | 70502 | 105120 | 14.3 | | ok | 0.371 |
| | | 0.0035 EUL | | | | | | |

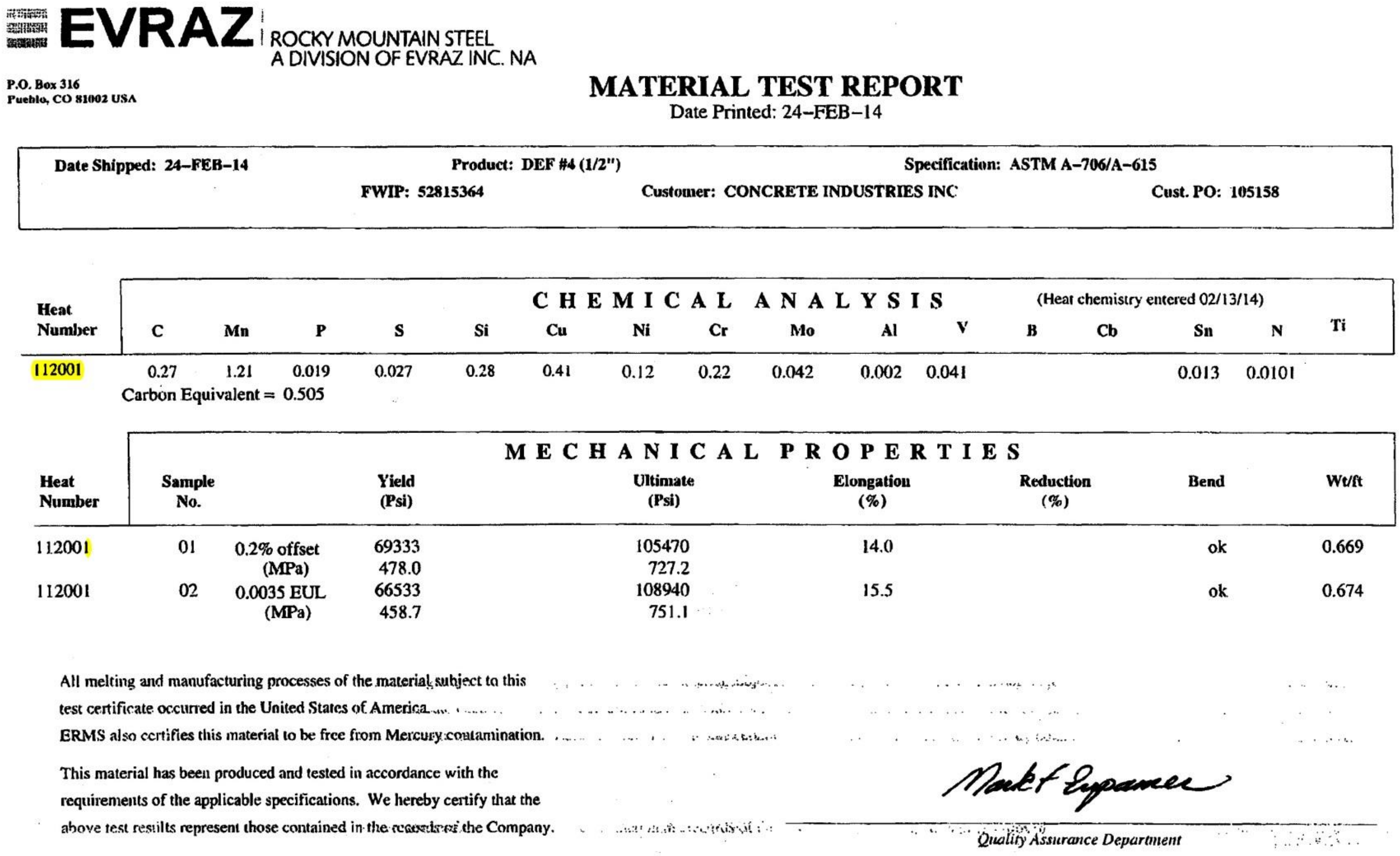
All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.
ERMS also certifies this material to be free from Mercury contamination.

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 Esparza

*Quality Assurance Department*

Figure A-6. Steel Rebar within Concrete Anchors, Test Nos. MWP-4, MWP-6 and MWP-7



**EVRAZ** ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

P.O. Box 316
Pueblo, CO 81002 USA

## MATERIAL TEST REPORT

Date Printed: 24–FEB–14

**Date Shipped:** 24–FEB–14 **Product:** DEF #4 (1/2") **Specification:** ASTM A–706/A–615
**FWIP:** 52815364 **Customer:** CONCRETE INDUSTRIES INC **Cust. PO:** 105158

CHEMICAL ANALYSIS (Heat chemistry entered 02/13/14)

| Heat Number | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | Al | V | B | Cb | Sn | N | Ti |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 112001 | 0.27 | 1.21 | 0.019 | 0.027 | 0.28 | 0.41 | 0.12 | 0.22 | 0.042 | 0.002 | 0.041 | | | 0.013 | 0.0101 | |

Carbon Equivalent = 0.505

MECHANICAL PROPERTIES

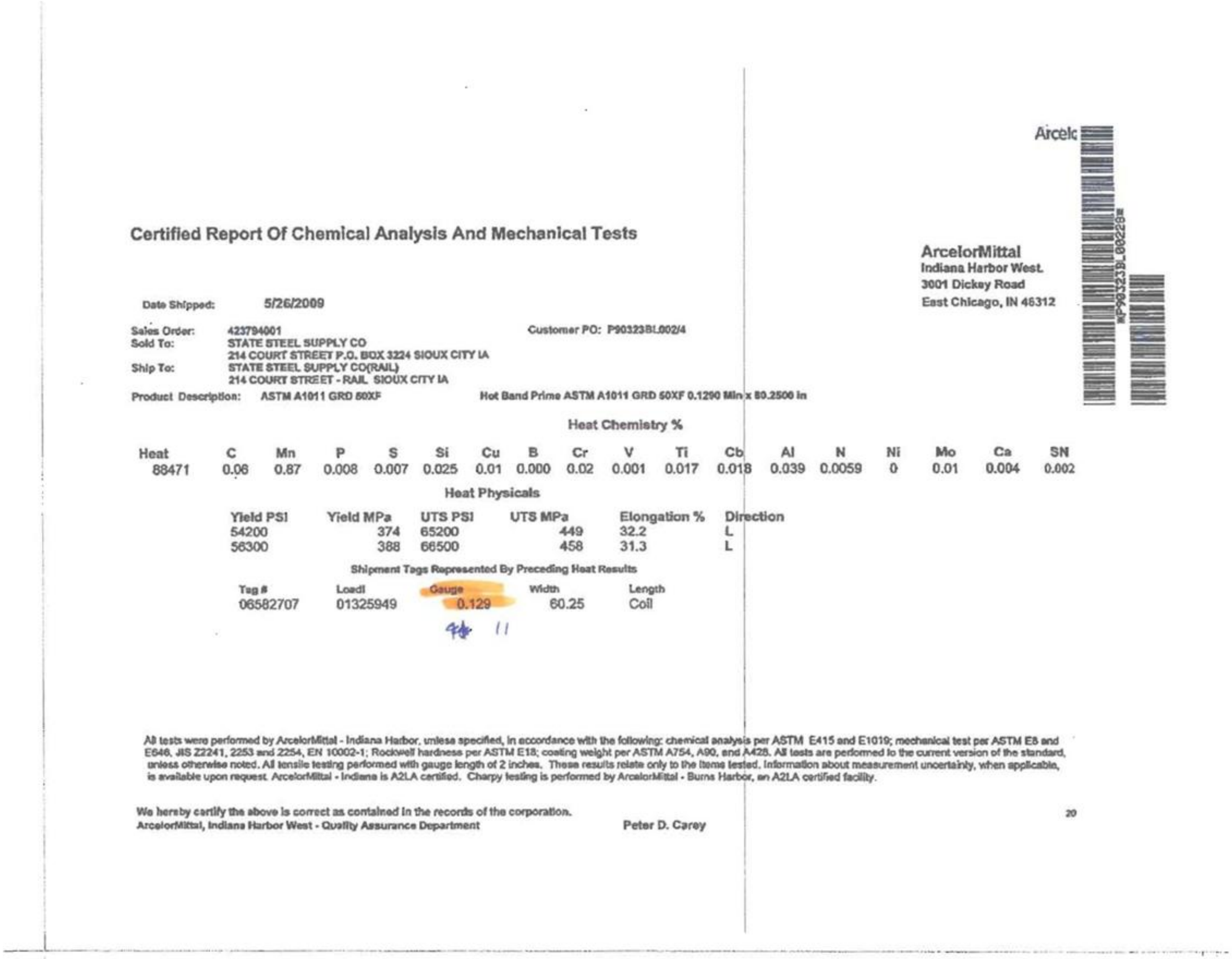
| Heat Number | Sample No. | | Yield (Psi) | Ultimate (Psi) | Elongation (%) | Reduction (%) | Bend | Wt/ft |
|---|---|---|---|---|---|---|---|---|
| 112001 | 01 | 0.2% offset | 69333 | 105470 | 14.0 | | ok | 0.669 |
| | | (MPa) | 478.0 | 727.2 | | | | |
| 112001 | 02 | 0.0035 EUL | 66533 | 108940 | 15.5 | | ok | 0.674 |
| | | (MPa) | 458.7 | 751.1 | | | | |

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.

*Quality Assurance Department*

Figure A-7. Steel Rebar within Concrete Anchors, Test Nos. MWP-4, MWP-6 and MWP-7



## Certified Report Of Chemical Analysis And Mechanical Tests

**ArcelorMittal**
Indiana Harbor West
3001 Dickey Road
East Chicago, IN 46312

**Date Shipped:** 5/26/2009

**Sales Order:** 423794001
**Sold To:** STATE STEEL SUPPLY CO
214 COURT STREET P.O. BOX 3224 SIOUX CITY IA
**Ship To:** STATE STEEL SUPPLY CO(RAIL)
214 COURT STREET - RAIL SIOUX CITY IA

**Customer PO:** P90323BL002/4

**Product Description:** ASTM A1011 GRD 50XF    Hot Band Prime ASTM A1011 GRD 50XF 0.1290 Min x 60.2500 in

**Heat Chemistry %**

| Heat | C | Mn | P | S | Si | Cu | B | Cr | V | Ti | Cb | Al | N | Ni | Mo | Ca | SN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 88471 | 0.06 | 0.87 | 0.008 | 0.007 | 0.025 | 0.01 | 0.000 | 0.02 | 0.001 | 0.017 | 0.018 | 0.039 | 0.0059 | 0 | 0.01 | 0.004 | 0.002 |

**Heat Physicals**

| Yield PSI | Yield MPa | UTS PSI | UTS MPa | Elongation % | Direction |
|---|---|---|---|---|---|
| 54200 | 374 | 65200 | 449 | 32.2 | L |
| 56300 | 388 | 66500 | 458 | 31.3 | L |

**Shipment Tags Represented By Preceding Heat Results**

| Tag # | Load# | Gauge | Width | Length |
|---|---|---|---|---|
| 06582707 | 01325949 | 0.129 | 60.25 | Coil |

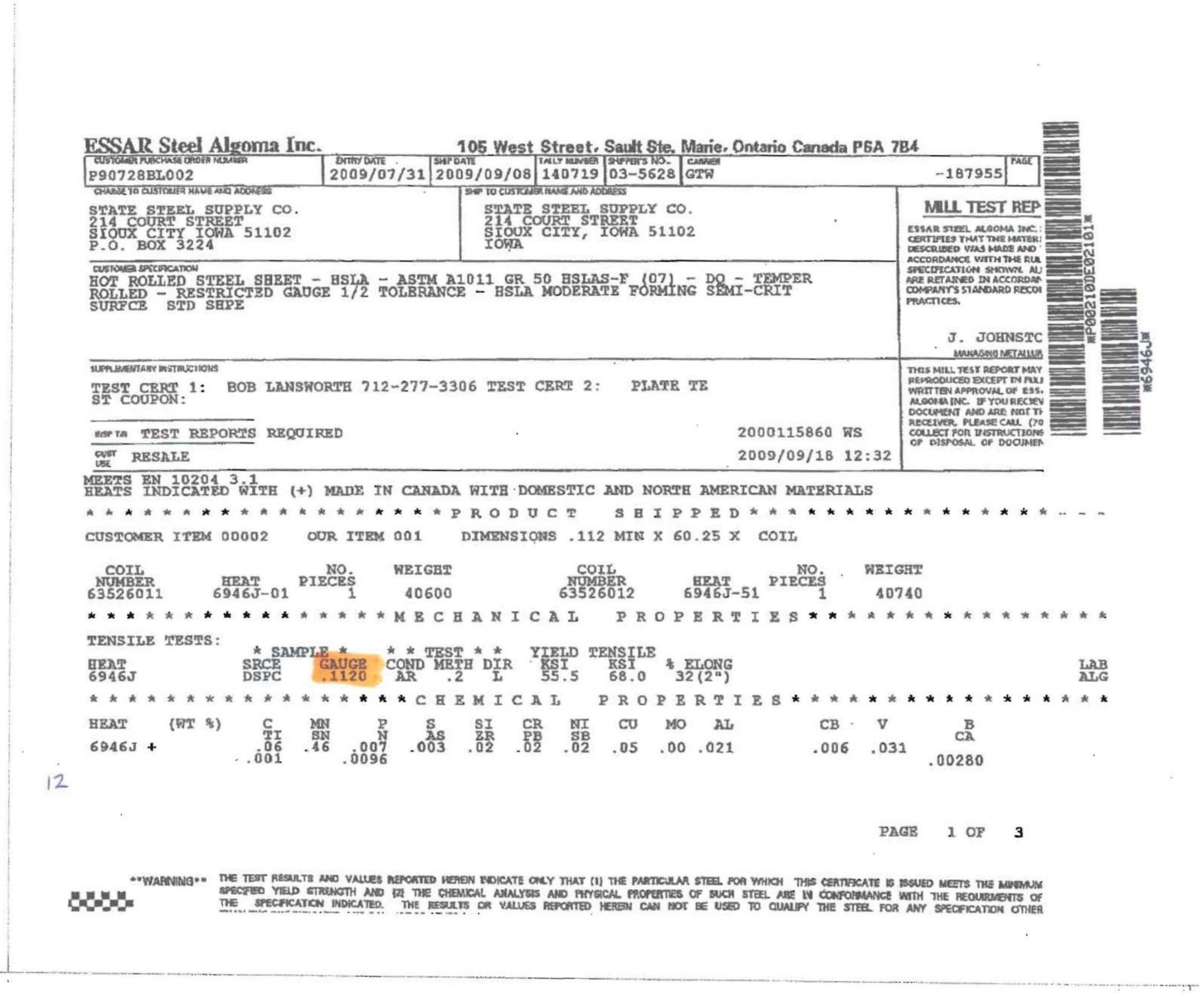
4# 11

All tests were performed by ArcelorMittal - Indiana Harbor, unless specified, in accordance with the following: chemical analysis per ASTM E415 and E1019; mechanical test per ASTM E8 and E646, JIS Z2241, 2253 and 2254, EN 10002-1; Rockwell hardness per ASTM E18; coating weight per ASTM A754, A90, and A428. All tests are performed to the current version of the standard, unless otherwise noted. All tensile testing performed with gauge length of 2 inches. These results relate only to the items tested. Information about measurement uncertainty, when applicable, is available upon request. ArcelorMittal - Indiana is A2LA certified. Charpy testing is performed by ArcelorMittal - Burns Harbor, an A2LA certified facility.

We hereby certify the above is correct as contained in the records of the corporation.
ArcelorMittal, Indiana Harbor West - Quality Assurance Department    Peter D. Carey

20

Figure A-8. Cable Clips Chemical Report, Test Nos. MWP-4, MWP-6 and MWP-7



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

| CUSTOMER PURCHASE ORDER NUMBER | ENTRY DATE | SHIP DATE | TALLY NUMBER | SHIPPER'S NO. | CARRIER | | PAGE |
|---|---|---|---|---|---|---|---|
| P90728BL002 | 2009/07/31 | 2009/09/08 | 140719 | 03-5628 | GTW | -187955 | |

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

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

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

**MILL TEST REP**

ESSAR STEEL ALGOMA INC. CERTIFIES THAT THE MATER DESCRIBED WAS MADE AND ACCORDANCE WITH THE RUL SPECIFICATION SHOWN. AL ARE RETAINED IN ACCORDAN COMPANY'S STANDARD RECO PRACTICES.

J. JOHNSTC
MANAGING METALLUR

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

THIS MILL TEST REPORT MAY REPRODUCED EXCEPT IN FUL WRITTEN APPROVAL OF ESS. ALGOMA INC. IF YOU RECIEV DOCUMENT AND ARE NOT TH RECEIVER, PLEASE CALL (70 COLLECT FOR INSTRUCTIONS OF DISPOSAL OF DOCUMEN

RSP TA TEST REPORTS REQUIRED 2000115860 WS
CUST USE RESALE 2009/09/18 12:32

*P00210DE02101*
*6946J*

MEETS EN 10204 3.1
HEATS INDICATED WITH (+) MADE IN CANADA WITH DOMESTIC AND NORTH AMERICAN MATERIALS

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

CUSTOMER ITEM 00002 OUR ITEM 001 DIMENSIONS .112 MIN X 60.25 X COIL

| COIL NUMBER | HEAT | NO. PIECES | WEIGHT | COIL NUMBER | HEAT | NO. PIECES | WEIGHT |
|---|---|---|---|---|---|---|---|
| 63526011 | 6946J-01 | 1 | 40600 | 63526012 | 6946J-51 | 1 | 40740 |

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

TENSILE TESTS:

| | * SAMPLE * | | * * TEST * * | | | YIELD | TENSILE | | |
|---|---|---|---|---|---|---|---|---|---|
| HEAT | SRCE | GAUGE | COND | METH | DIR | KSI | KSI | % ELONG | LAB |
| 6946J | DSPC | .1120 | AR | .2 | L | 55.5 | 68.0 | 32(2") | ALG |

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

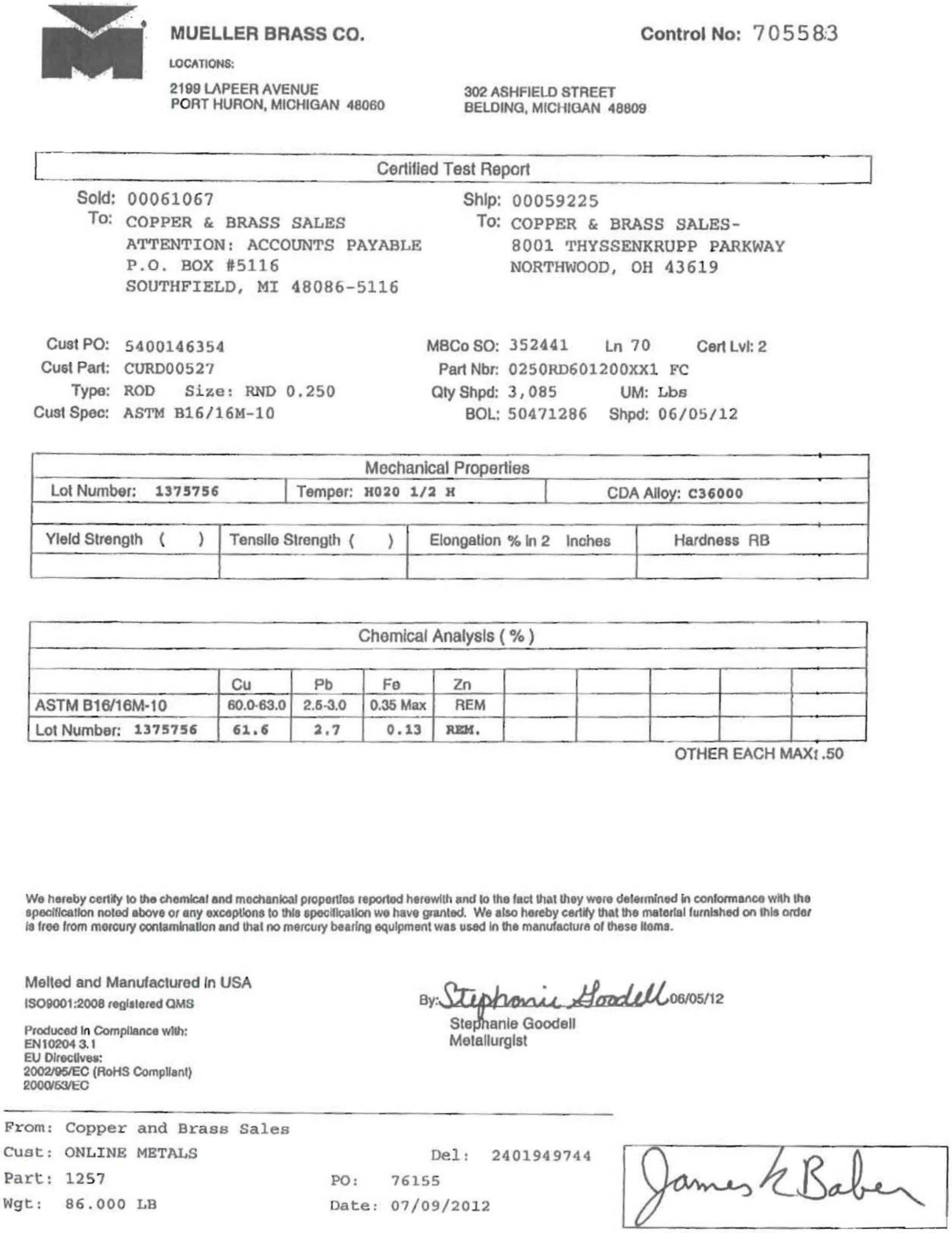
| HEAT | (WT %) | C<br>TI | MN<br>SN | P<br>N | S<br>AS | SI<br>ZR | CR<br>PB | NI<br>SB | CU | MO | AL | CB | V | B<br>CA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6946J + | | .06<br>.001 | .46 | .007<br>.0096 | .003 | .02 | .02 | .02 | .05 | .00 | .021 | .006 | .031 | .00280 |

12

PAGE 1 OF 3

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

Figure A-9. Cable Clips Chemical Report, Test Nos. MWP-4, MWP-6 and MWP-7



**MUELLER BRASS CO.**

**Control No:** 705583

LOCATIONS:

2199 LAPEER AVENUE
PORT HURON, MICHIGAN 48060

302 ASHFIELD STREET
BELDING, MICHIGAN 48809

Certified Test Report

Sold To: 00061067
COPPER & BRASS SALES
ATTENTION: ACCOUNTS PAYABLE
P.O. BOX #5116
SOUTHFIELD, MI 48086-5116

Ship To: 00059225
COPPER & BRASS SALES-
8001 THYSSENKRUPP PARKWAY
NORTHWOOD, OH 43619

Cust PO: 5400146354
Cust Part: CURD00527
Type: ROD Size: RND 0.250
Cust Spec: ASTM B16/16M-10

MBCo SO: 352441 Ln 70 Cert Lvl: 2
Part Nbr: 0250RD601200XX1 FC
Qty Shpd: 3,085 UM: Lbs
BOL: 50471286 Shpd: 06/05/12

Mechanical Properties

| | | | |
|---|---|---|---|
| Lot Number: 1375756 | Temper: H020 1/2 H | CDA Alloy: C36000 | |
| Yield Strength ( ) | Tensile Strength ( ) | Elongation % in 2 Inches | Hardness RB |
| | | | |

Chemical Analysis ( % )

| | Cu | Pb | Fe | Zn | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ASTM B16/16M-10 | 60.0-63.0 | 2.5-3.0 | 0.35 Max | REM | | | | | |
| Lot Number: 1375756 | 61.6 | 2.7 | 0.13 | REM. | | | | | |

OTHER EACH MAX: .50

We hereby certify to the chemical and mechanical properties reported herewith and to the fact that they were determined in conformance with the specification noted above or any exceptions to this specification we have granted. We also hereby certify that the material furnished on this order is free from mercury contamination and that no mercury bearing equipment was used in the manufacture of these items.

Melted and Manufactured in USA
ISO9001:2008 registered QMS

Produced in Compliance with:
EN10204 3.1
EU Directives:
2002/95/EC (RoHS Compliant)
2000/53/EC

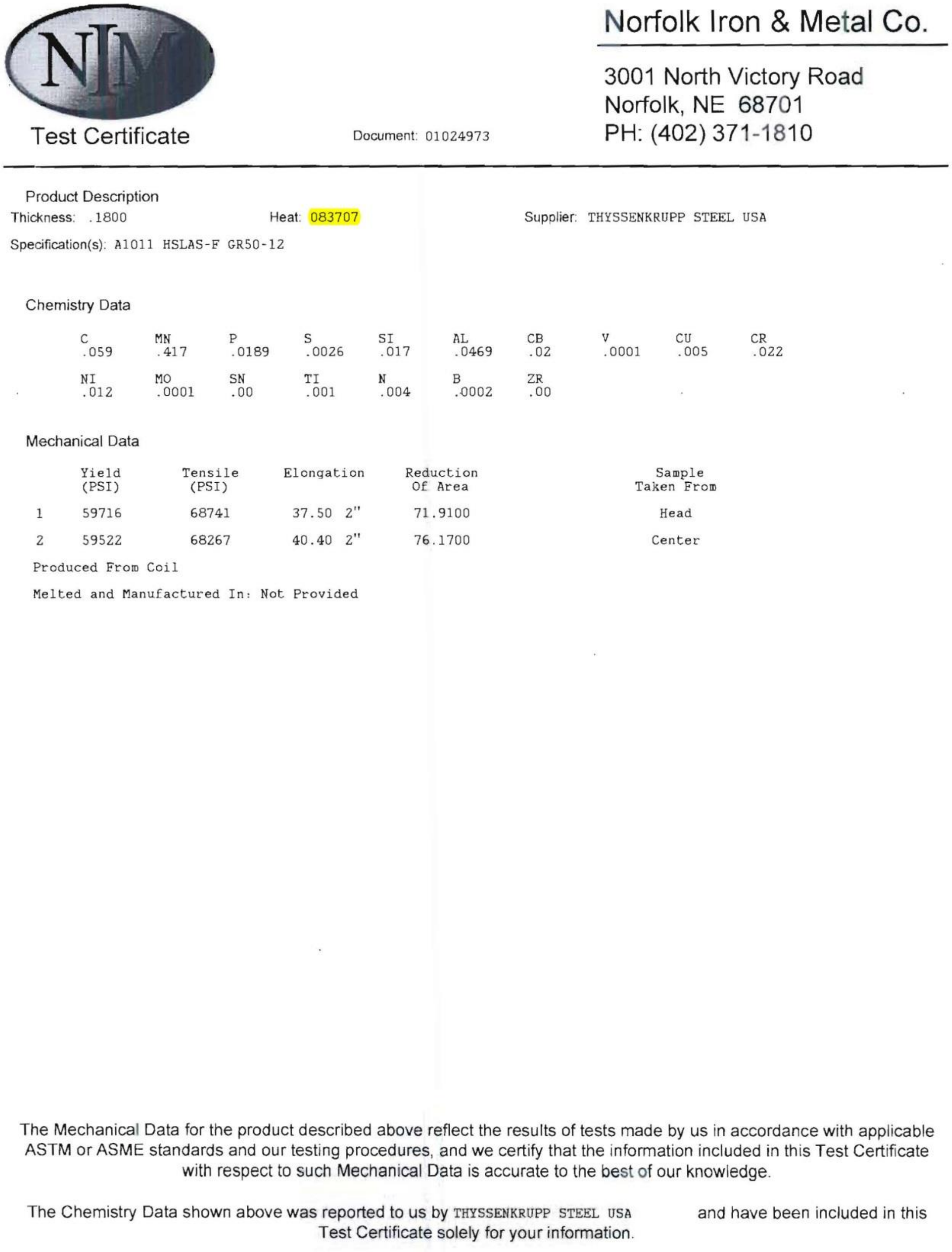
By: Stephanie Goodell 06/05/12
Stephanie Goodell
Metallurgist

From: Copper and Brass Sales
Cust: ONLINE METALS
Part: 1257
Wgt: 86.000 LB

Del: 2401949744
PO: 76155
Date: 07/09/2012

James K Baber

Figure A-10. Straight Brass Rod Cable Clip, Test Nos. MWP-4, MWP-6 and MWP-7



Test Certificate

Document: 01024973

Norfolk Iron & Metal Co.

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

Product Description

Thickness: .1800

Heat: 083707

Supplier: THYSSENKRUPP STEEL USA

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

Chemistry Data

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

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

Mechanical Data

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

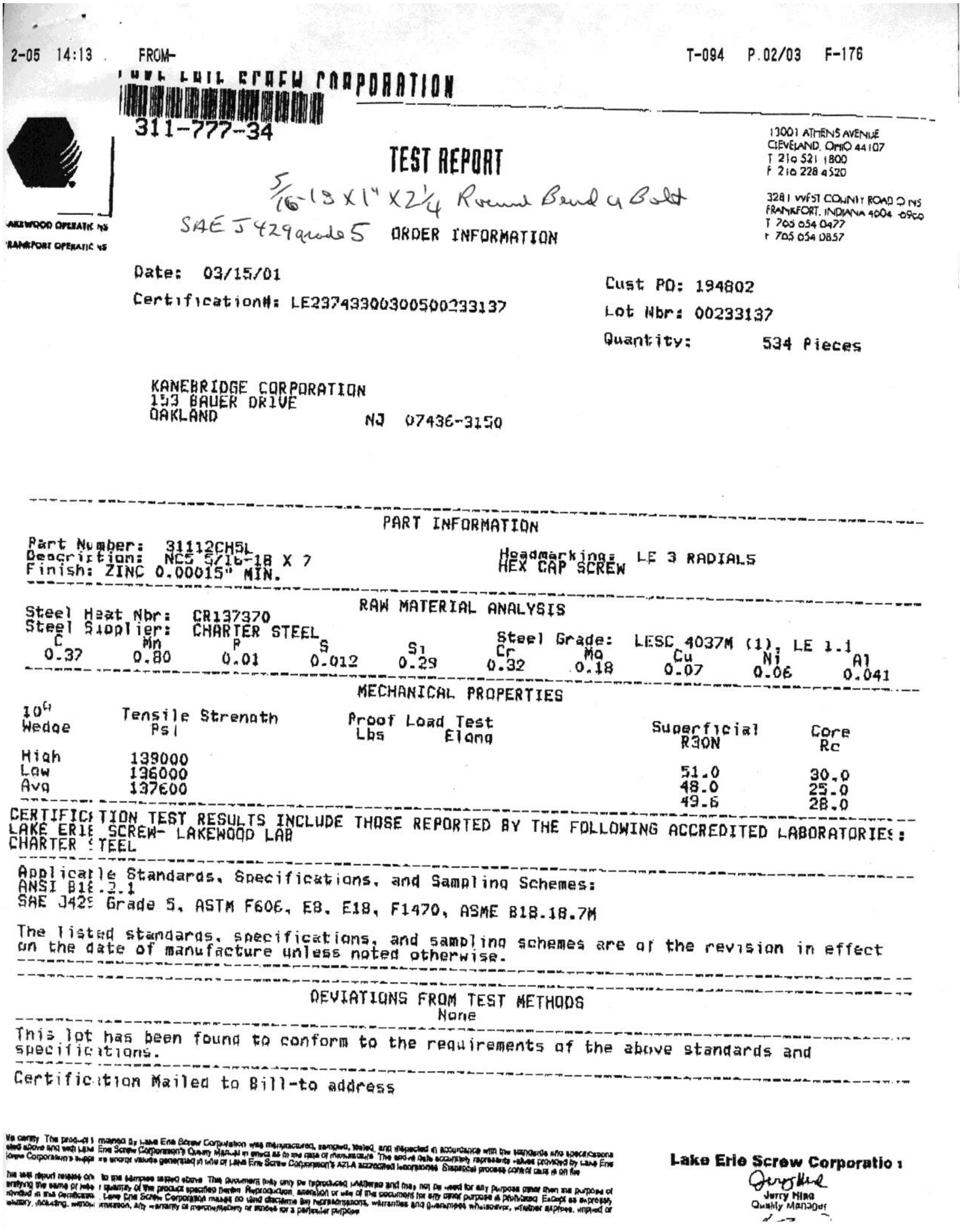
Produced From Coil

Melted and Manufactured In: Not Provided

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

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

Figure A-11. Z-Post Chemical Report, Test Nos. MWP-4, MWP-6 and MWP-7



2-05 14:13 FROM- T-094 P.02/03 F-176

**LAKE ERIE SCREW CORPORATION**

311-777-34

LAKEWOOD OPERATIONS
FRANKFORT OPERATIONS

13001 ATHENS AVENUE
CLEVELAND, OHIO 44107
T 216 521 1800
F 216 228 4520

3281 WEST COUNTY ROAD 0 NS
FRANKFORT, INDIANA 46041-0960
T 765 654 0477
F 765 654 0857

# TEST REPORT

5/16-13 X 1" X 2 1/4 Round Bend U Bolt
SAE J429 grade 5

## ORDER INFORMATION

Date: 03/15/01
Certification#: LE23743300300500233137

Cust PO: 194802
Lot Nbr: 00233137
Quantity: 534 Pieces

KANEBRIDGE CORPORATION
153 BAUER DRIVE
OAKLAND NJ 07436-3150

## PART INFORMATION

Part Number: 31112CH5L
Description: NC5 5/16-18 X 7
Finish: ZINC 0.00015" MIN.
Headmarking: LE 3 RADIALS
HEX CAP SCREW

## RAW MATERIAL ANALYSIS

Steel Heat Nbr: CR137370
Steel Supplier: CHARTER STEEL
Steel Grade: LESC 4037M (1), LE 1.1

| C | Mn | P | S | Si | Cr | Mo | Cu | Ni | Al |
|---|---|---|---|---|---|---|---|---|---|
| 0.37 | 0.80 | 0.01 | 0.012 | 0.29 | 0.32 | 0.18 | 0.07 | 0.06 | 0.041 |

## MECHANICAL PROPERTIES

| 10° Wedge | Tensile Strength Psi | Proof Load Test Lbs | Elong | Superficial R30N | Core Rc |
|---|---|---|---|---|---|
| High | 139000 | | | 51.0 | 30.0 |
| Low | 136000 | | | 48.0 | 25.0 |
| Avg | 137600 | | | 49.6 | 28.0 |

CERTIFICATION TEST RESULTS INCLUDE THOSE REPORTED BY THE FOLLOWING ACCREDITED LABORATORIES:
LAKE ERIE SCREW- LAKEWOOD LAB
CHARTER STEEL

Applicable Standards, Specifications, and Sampling Schemes:
ANSI B18.2.1
SAE J429 Grade 5, ASTM F606, E8, E18, F1470, ASME B18.18.7M

The listed standards, specifications, and sampling schemes are of the revision in effect on the date of manufacture unless noted otherwise.

## DEVIATIONS FROM TEST METHODS

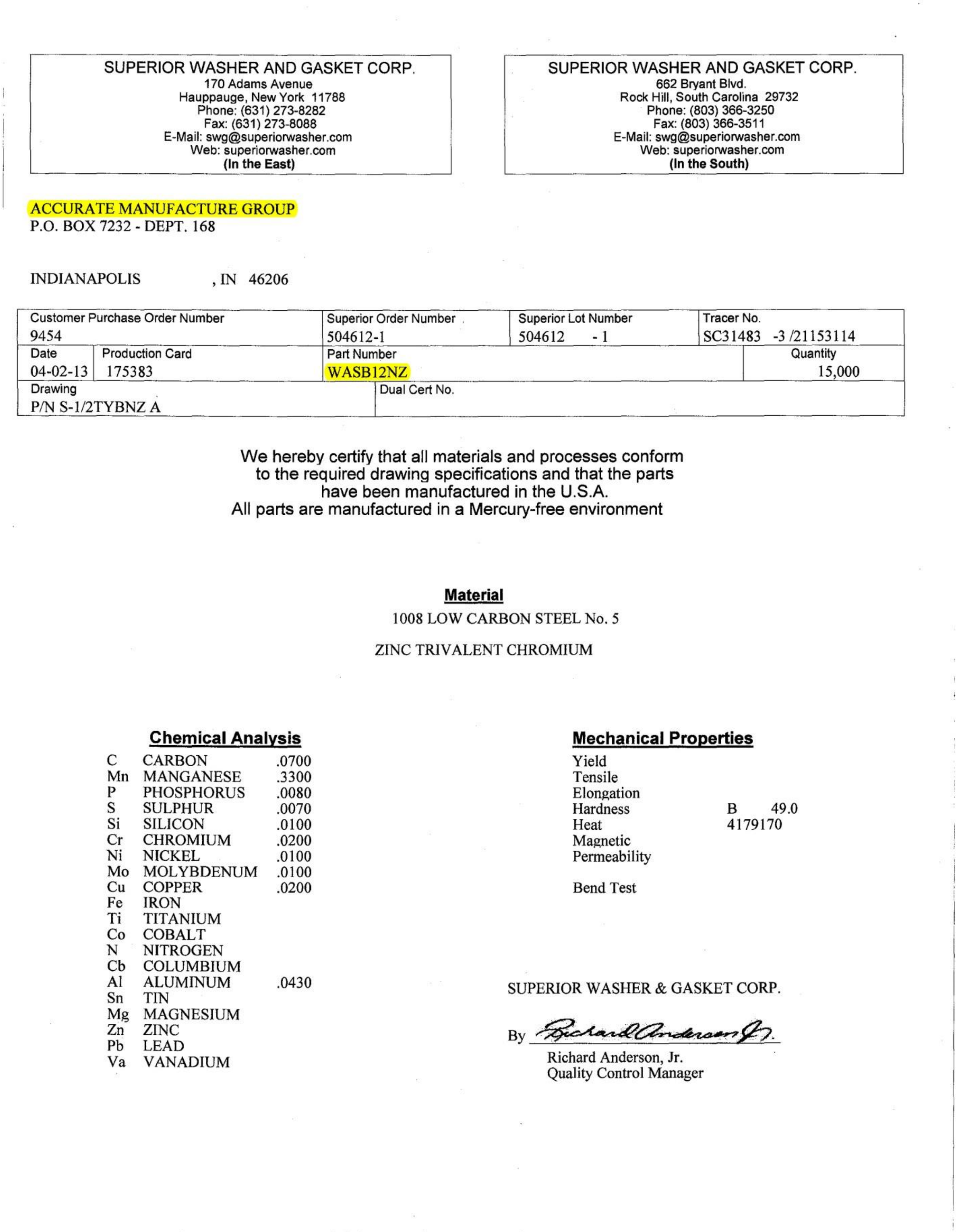
None

This lot has been found to conform to the requirements of the above standards and specifications.

Certification Mailed to Bill-to address

**Lake Erie Screw Corporation**
Jerry Hine
Jerry Hine
Quality Manager

Figure A-12. $^{5}/_{16}$ in. (8 mm) Round U bolt, Test Nos. MWP-4, MWP-6 and MWP-7



SUPERIOR WASHER AND GASKET CORP.
170 Adams Avenue
Hauppauge, New York 11788
Phone: (631) 273-8282
Fax: (631) 273-8088
E-Mail: swg@superiorwasher.com
Web: superiorwasher.com
**(In the East)**

SUPERIOR WASHER AND GASKET CORP.
662 Bryant Blvd.
Rock Hill, South Carolina 29732
Phone: (803) 366-3250
Fax: (803) 366-3511
E-Mail: swg@superiorwasher.com
Web: superiorwasher.com
**(In the South)**

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

INDIANAPOLIS , IN 46206

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

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 | |

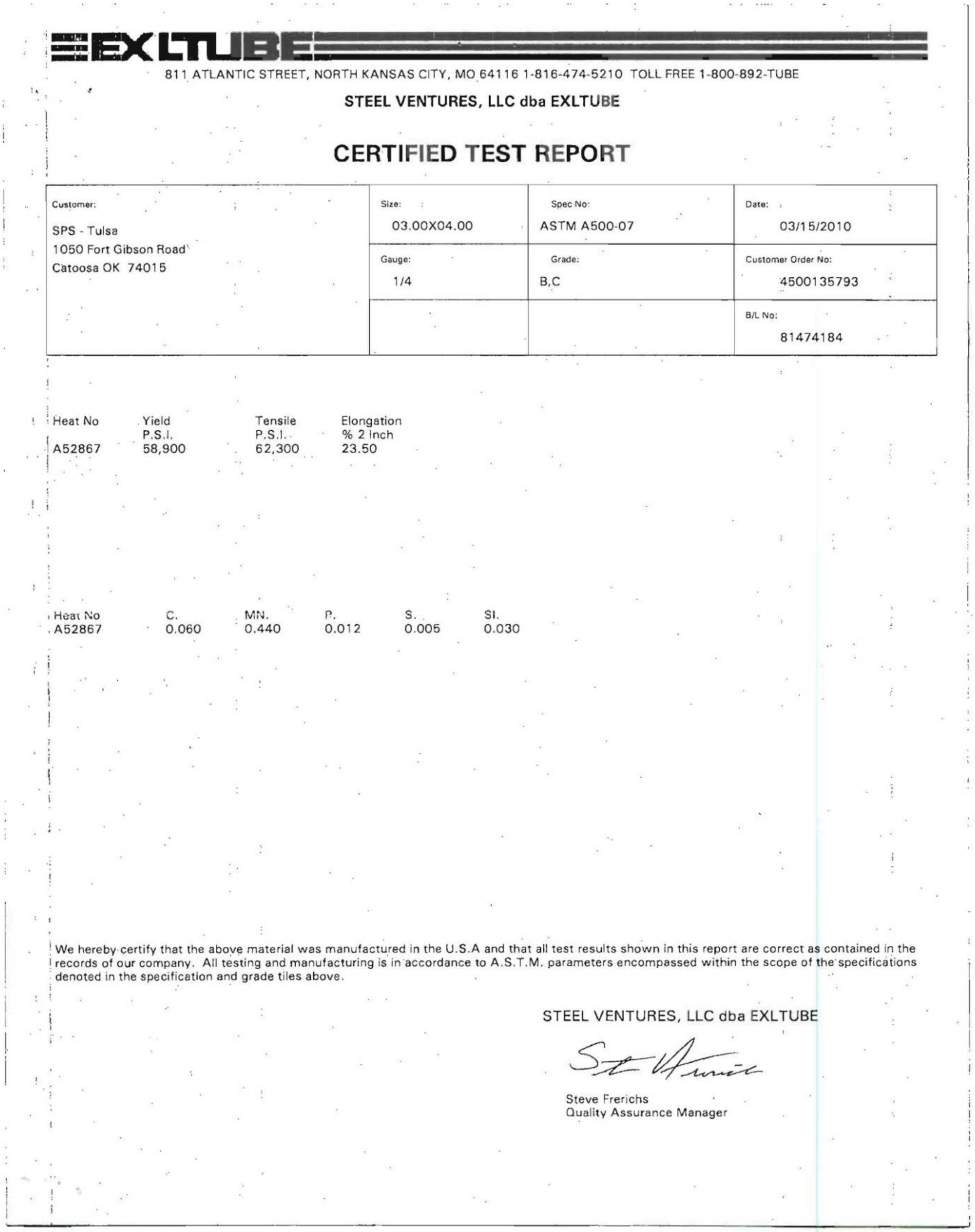
**Mechanical Properties**

| | |
|---|---|
| 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-13. ½ in. (13 mm) Washers, Test Nos. MWP-4, MWP-6 and MWP-7



EXLTUBE

811 ATLANTIC STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

# CERTIFIED TEST REPORT

Customer:
SPS - Tulsa
1050 Fort Gibson Road
Catoosa OK 74015

Size: 03.00X04.00

Spec No: ASTM A500-07

Date: 03/15/2010

Gauge: 1/4

Grade: B,C

Customer Order No: 4500135793

B/L No: 81474184

| Heat No | Yield P.S.I. | Tensile P.S.I. | Elongation % 2 inch |
|---|---|---|---|
| A52867 | 58,900 | 62,300 | 23.50 |

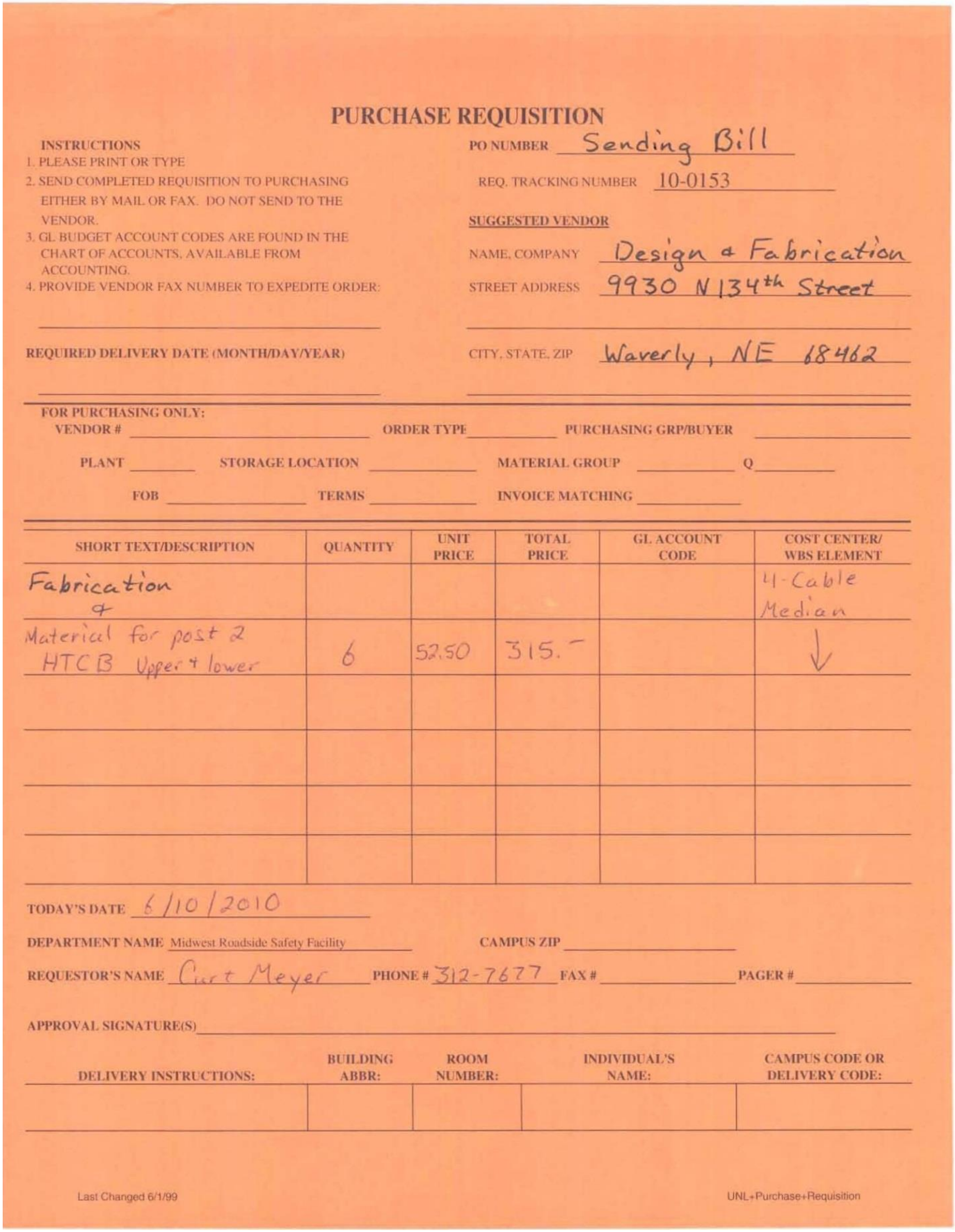
| Heat No | C. | MN. | P. | S. | SI. |
|---|---|---|---|---|---|
| A52867 | 0.060 | 0.440 | 0.012 | 0.005 | 0.030 |

We hereby certify that the above material was manufactured in the U.S.A and that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above.

STEEL VENTURES, LLC dba EXLTUBE

Steve Frerichs
Quality Assurance Manager

Figure A-14. 3x4 Tube Post, Test Nos. MWP-4, MWP-6 and MWP-7



**PURCHASE REQUISITION**

**INSTRUCTIONS**
1. PLEASE PRINT OR TYPE
2. SEND COMPLETED REQUISITION TO PURCHASING EITHER BY MAIL OR FAX. DO NOT SEND TO THE VENDOR.
3. GL BUDGET ACCOUNT CODES ARE FOUND IN THE CHART OF ACCOUNTS, AVAILABLE FROM ACCOUNTING.
4. PROVIDE VENDOR FAX NUMBER TO EXPEDITE ORDER:

PO NUMBER Sending Bill

REQ. TRACKING NUMBER 10-0153

**SUGGESTED VENDOR**

NAME, COMPANY Design & Fabrication

STREET ADDRESS 9930 N 134th Street

**REQUIRED DELIVERY DATE (MONTH/DAY/YEAR)**

CITY, STATE, ZIP Waverly, NE 68462

**FOR PURCHASING ONLY:**

**VENDOR #**

**ORDER TYPE**

**PURCHASING GRP/BUYER**

**PLANT**

**STORAGE LOCATION**

**MATERIAL GROUP**

**Q**

**FOB**

**TERMS**

**INVOICE MATCHING**

| SHORT TEXT/DESCRIPTION | QUANTITY | UNIT PRICE | TOTAL PRICE | GL ACCOUNT CODE | COST CENTER/ WBS ELEMENT |
|---|---|---|---|---|---|
| Fabrication<br>& |  |  |  |  | 4-Cable<br>Median |
| Material for post 2<br>HTCB Upper & lower | 6 | 52.50 | 315.– |  | ↓ |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

**TODAY'S DATE** 6/10/2010

**DEPARTMENT NAME** Midwest Roadside Safety Facility

**CAMPUS ZIP**

**REQUESTOR'S NAME** Curt Meyer **PHONE #** 312-7677 **FAX #** **PAGER #**

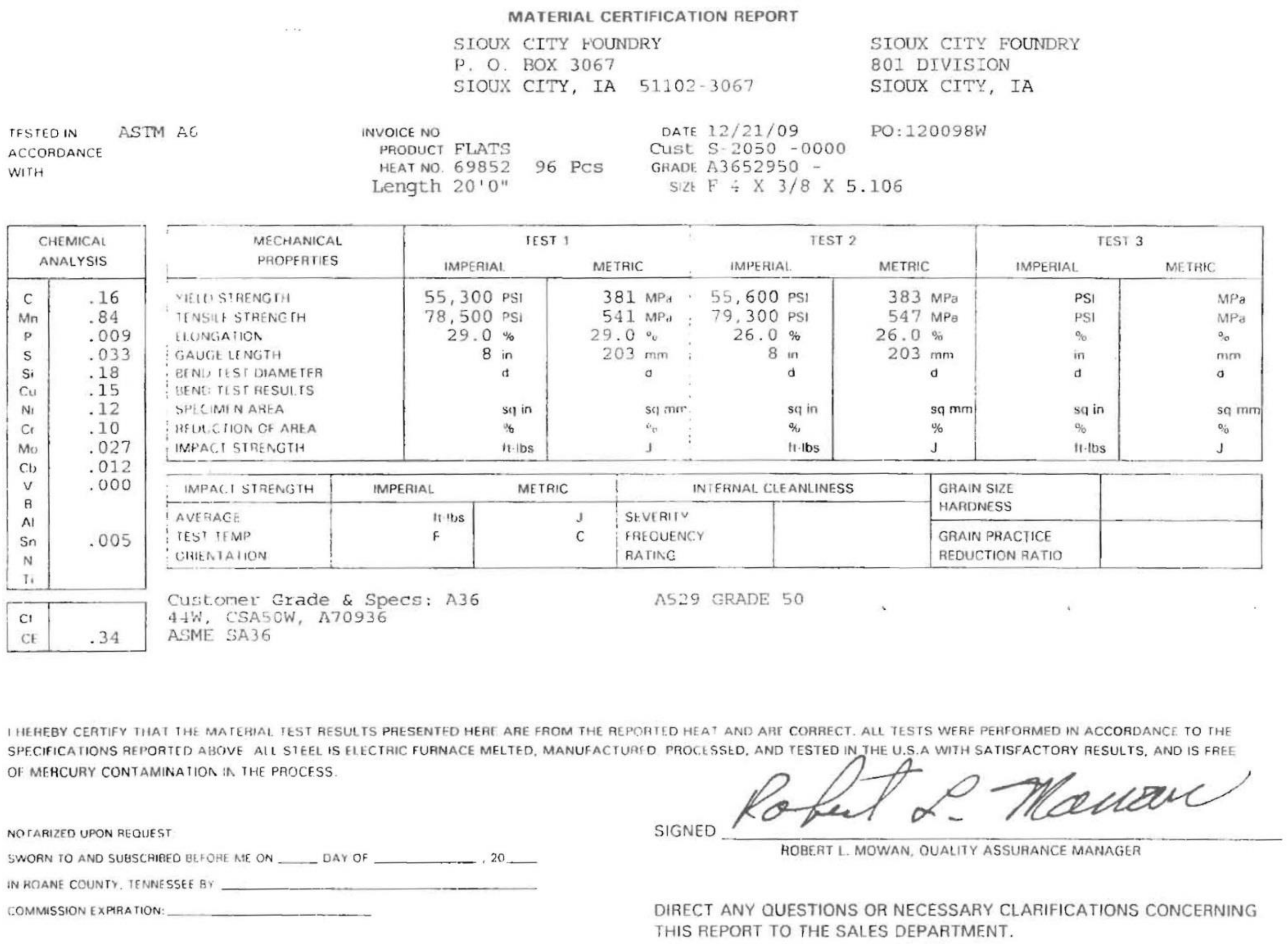
**APPROVAL SIGNATURE(S)**

| DELIVERY INSTRUCTIONS: | BUILDING ABBR: | ROOM NUMBER: | INDIVIDUAL'S NAME: | CAMPUS CODE OR DELIVERY CODE: |
|---|---|---|---|---|
|  |  |  |  |  |

Last Changed 6/1/99

UNL+Purchase+Requisition

Figure A-15. Upper and Lower HTCB Posts, Test Nos. MWP-4, MWP-6 and MWP-7



**MATERIAL CERTIFICATION REPORT**

SIOUX CITY FOUNDRY
P. O. BOX 3067
SIOUX CITY, IA 51102-3067

SIOUX CITY FOUNDRY
801 DIVISION
SIOUX CITY, IA

TESTED IN ACCORDANCE WITH ASTM A6

INVOICE NO
PRODUCT FLATS
HEAT NO. 69852 96 Pcs
Length 20'0"

DATE 12/21/09
Cust S-2050 -0000
GRADE A3652950 -
SIZE F 4 X 3/8 X 5.106

PO:120098W

| CHEMICAL ANALYSIS | |
|---|---|
| C | .16 |
| Mn | .84 |
| P | .009 |
| S | .033 |
| Si | .18 |
| Cu | .15 |
| Ni | .12 |
| Cr | .10 |
| Mo | .027 |
| Cb | .012 |
| V | .000 |
| B | |
| Al | |
| Sn | .005 |
| N | |
| Ti | |
| CI | |
| CE | .34 |

| MECHANICAL PROPERTIES | TEST 1 | | TEST 2 | | TEST 3 | |
|---|---|---|---|---|---|---|
| | IMPERIAL | METRIC | IMPERIAL | METRIC | IMPERIAL | METRIC |
| YIELD STRENGTH | 55,300 PSI | 381 MPa | 55,600 PSI | 383 MPa | PSI | MPa |
| TENSILE STRENGTH | 78,500 PSI | 541 MPa | 79,300 PSI | 547 MPa | PSI | MPa |
| ELONGATION | 29.0 % | 29.0 % | 26.0 % | 26.0 % | % | % |
| GAUGE LENGTH | 8 in | 203 mm | 8 in | 203 mm | in | mm |
| BEND TEST DIAMETER | d | d | d | d | d | d |
| BEND TEST RESULTS | | | | | | |
| SPECIMEN AREA | sq in | sq mm | sq in | sq mm | sq in | sq mm |
| REDUCTION OF AREA | % | % | % | % | % | % |
| IMPACT STRENGTH | ft-lbs | J | ft-lbs | J | ft-lbs | J |

| IMPACT STRENGTH | IMPERIAL | METRIC | INTERNAL CLEANLINESS | | GRAIN SIZE<br>HARDNESS | |
|---|---|---|---|---|---|---|
| AVERAGE | ft-lbs | J | SEVERITY | | GRAIN PRACTICE<br>REDUCTION RATIO | |
| TEST TEMP | F | C | FREQUENCY | | | |
| ORIENTATION | | | RATING | | | |

Customer Grade & Specs: A36 A529 GRADE 50
44W, CSA50W, A70936
ASME SA36

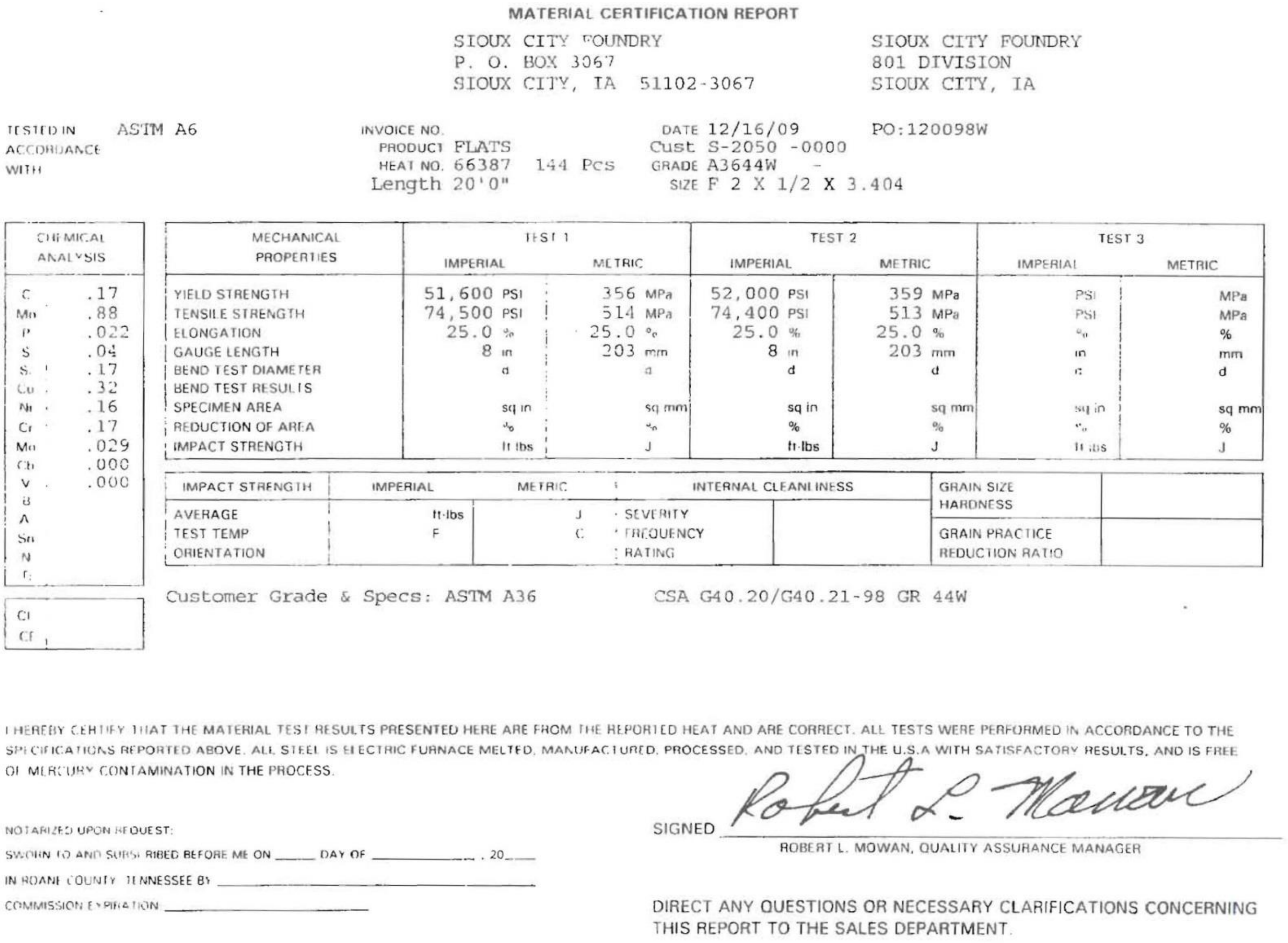
I HEREBY CERTIFY THAT THE MATERIAL TEST RESULTS PRESENTED HERE ARE FROM THE REPORTED HEAT AND ARE CORRECT. ALL TESTS WERE PERFORMED IN ACCORDANCE TO THE SPECIFICATIONS REPORTED ABOVE. ALL STEEL IS ELECTRIC FURNACE MELTED, MANUFACTURED, PROCESSED, AND TESTED IN THE U.S.A WITH SATISFACTORY RESULTS, AND IS FREE OF MERCURY CONTAMINATION IN THE PROCESS.

SIGNED Robert L. Mowan
ROBERT L. MOWAN, QUALITY ASSURANCE MANAGER

NOTARIZED UPON REQUEST
SWORN TO AND SUBSCRIBED BEFORE ME ON ____ DAY OF ________, 20___
IN ROANE COUNTY, TENNESSEE BY ____________
COMMISSION EXPIRATION: ____________

DIRECT ANY QUESTIONS OR NECESSARY CLARIFICATIONS CONCERNING THIS REPORT TO THE SALES DEPARTMENT.

Figure A-16. Post Baseplate, Test Nos. MWP-4, MWP-6 and MWP-7



**MATERIAL CERTIFICATION REPORT**

SIOUX CITY FOUNDRY
P. O. BOX 3067
SIOUX CITY, IA 51102-3067

SIOUX CITY FOUNDRY
801 DIVISION
SIOUX CITY, IA

TESTED IN ACCORDANCE WITH ASTM A6

INVOICE NO.
PRODUCT FLATS
HEAT NO. 66387 144 Pcs
Length 20'0"

DATE 12/16/09
Cust S-2050 -0000
GRADE A3644W -
SIZE F 2 X 1/2 X 3.404

PO:120098W

| CHEMICAL ANALYSIS | |
|---|---|
| C | .17 |
| Mn | .88 |
| P | .022 |
| S | .04 |
| Si | .17 |
| Cu | .32 |
| Ni | .16 |
| Cr | .17 |
| Mo | .029 |
| Cb | .000 |
| V | .000 |
| B | |
| A | |
| Sn | |
| N | |
| Ti | |
| CI | |
| CE | |

| MECHANICAL PROPERTIES | TEST 1 | | TEST 2 | | TEST 3 | |
|---|---|---|---|---|---|---|
| | IMPERIAL | METRIC | IMPERIAL | METRIC | IMPERIAL | METRIC |
| YIELD STRENGTH | 51,600 PSI | 356 MPa | 52,000 PSI | 359 MPa | PSI | MPa |
| TENSILE STRENGTH | 74,500 PSI | 514 MPa | 74,400 PSI | 513 MPa | PSI | MPa |
| ELONGATION | 25.0 % | 25.0 % | 25.0 % | 25.0 % | % | % |
| GAUGE LENGTH | 8 in | 203 mm | 8 in | 203 mm | in | mm |
| BEND TEST DIAMETER | d | d | d | d | d | d |
| BEND TEST RESULTS | | | | | | |
| SPECIMEN AREA | sq in | sq mm | sq in | sq mm | sq in | sq mm |
| REDUCTION OF AREA | % | % | % | % | % | % |
| IMPACT STRENGTH | ft lbs | J | ft-lbs | J | ft lbs | J |

| IMPACT STRENGTH | IMPERIAL | METRIC | INTERNAL CLEANLINESS | | GRAIN SIZE<br>HARDNESS | |
|---|---|---|---|---|---|---|
| AVERAGE | ft-lbs | J | SEVERITY | | GRAIN PRACTICE<br>REDUCTION RATIO | |
| TEST TEMP | F | C | FREQUENCY | | | |
| ORIENTATION | | | RATING | | | |

Customer Grade & Specs: ASTM A36 CSA G40.20/G40.21-98 GR 44W

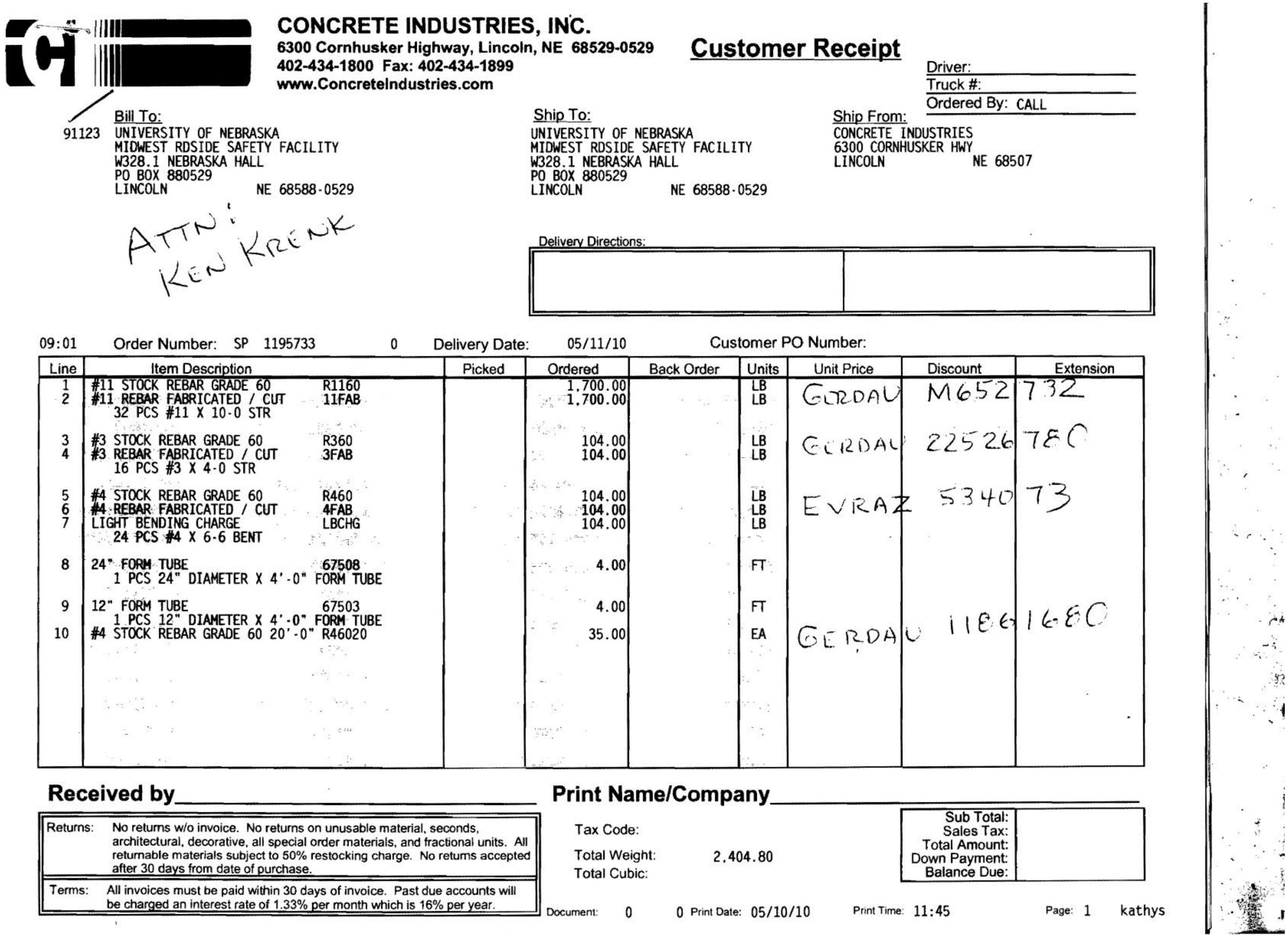
I HEREBY CERTIFY THAT THE MATERIAL TEST RESULTS PRESENTED HERE ARE FROM THE REPORTED HEAT AND ARE CORRECT. ALL TESTS WERE PERFORMED IN ACCORDANCE TO THE SPECIFICATIONS REPORTED ABOVE. ALL STEEL IS ELECTRIC FURNACE MELTED, MANUFACTURED, PROCESSED, AND TESTED IN THE U.S.A WITH SATISFACTORY RESULTS, AND IS FREE OF MERCURY CONTAMINATION IN THE PROCESS.

NOTARIZED UPON REQUEST:
SWORN TO AND SUBSCRIBED BEFORE ME ON _____ DAY OF ____________, 20____
IN ROANE COUNTY TENNESSEE BY ______________________________
COMMISSION EXPIRATION ____________________

SIGNED Robert L. Mowan
ROBERT L. MOWAN, QUALITY ASSURANCE MANAGER

DIRECT ANY QUESTIONS OR NECESSARY CLARIFICATIONS CONCERNING THIS REPORT TO THE SALES DEPARTMENT.

Figure A-17. Cable Retainer Post, Test Nos. MWP-4, MWP-6 and MWP-7



**CONCRETE INDUSTRIES, INC.**
6300 Cornhusker Highway, Lincoln, NE 68529-0529
402-434-1800 Fax: 402-434-1899
www.ConcreteIndustries.com

## Customer Receipt

Driver:
Truck #:
Ordered By: CALL

Bill To:
91123 UNIVERSITY OF NEBRASKA
MIDWEST RDSIDE SAFETY FACILITY
W328.1 NEBRASKA HALL
PO BOX 880529
LINCOLN NE 68588-0529

ATTN: KEN KRENK

Ship To:
UNIVERSITY OF NEBRASKA
MIDWEST RDSIDE SAFETY FACILITY
W328.1 NEBRASKA HALL
PO BOX 880529
LINCOLN NE 68588-0529

Ship From:
CONCRETE INDUSTRIES
6300 CORNHUSKER HWY
LINCOLN NE 68507

Delivery Directions:

09:01 Order Number: SP 1195733 0 Delivery Date: 05/11/10 Customer PO Number:

| Line | Item Description | | Picked | Ordered | Back Order | Units | Unit Price | Discount | Extension |
|---|---|---|---|---|---|---|---|---|---|
| 1<br>2 | #11 STOCK REBAR GRADE 60<br>#11 REBAR FABRICATED / CUT<br>32 PCS #11 X 10-0 STR | R1160<br>11FAB | | 1,700.00<br>1,700.00 | | LB<br>LB | GERDAU | M652 | 732 |
| 3<br>4 | #3 STOCK REBAR GRADE 60<br>#3 REBAR FABRICATED / CUT<br>16 PCS #3 X 4-0 STR | R360<br>3FAB | | 104.00<br>104.00 | | LB<br>LB | GERDAU | 22526 | 780 |
| 5<br>6<br>7 | #4 STOCK REBAR GRADE 60<br>#4 REBAR FABRICATED / CUT<br>LIGHT BENDING CHARGE<br>24 PCS #4 X 6-6 BENT | R460<br>4FAB<br>LBCHG | | 104.00<br>104.00<br>104.00 | | LB<br>LB<br>LB | EVRAZ | 5340 | 73 |
| 8 | 24" FORM TUBE<br>1 PCS 24" DIAMETER X 4'-0" FORM TUBE | 67508 | | 4.00 | | FT | | | |
| 9 | 12" FORM TUBE<br>1 PCS 12" DIAMETER X 4'-0" FORM TUBE | 67503 | | 4.00 | | FT | | | |
| 10 | #4 STOCK REBAR GRADE 60 20'-0" | R46020 | | 35.00 | | EA | GERDAU | 1186 | 1680 |

**Received by**_______________ **Print Name/Company**_______________

Returns: No returns w/o invoice. No returns on unusable material, seconds, architectural, decorative, all special order materials, and fractional units. All returnable materials subject to 50% restocking charge. No returns accepted after 30 days from date of purchase.

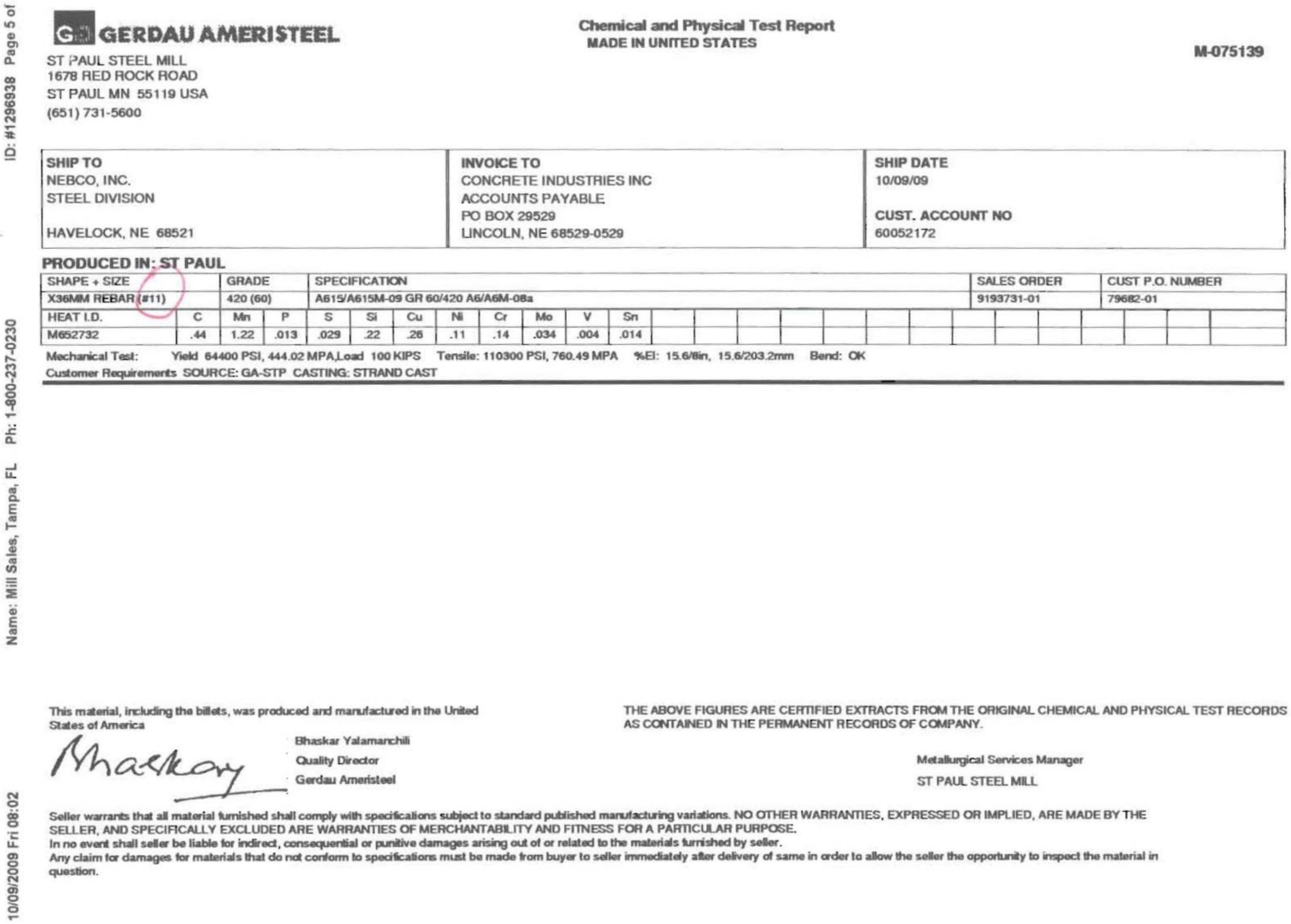
Terms: All invoices must be paid within 30 days of invoice. Past due accounts will be charged an interest rate of 1.33% per month which is 16% per year.

Tax Code:
Total Weight: 2,404.80
Total Cubic:

Sub Total:
Sales Tax:
Total Amount:
Down Payment:
Balance Due:

Document: 0 0 Print Date: 05/10/10 Print Time: 11:45 Page: 1 kathys

Figure A-18. Rebar for Anchorage, Test Nos. MWP-4, MWP-6 and MWP-7



ID: #1296938 Page 5 of

Name: Mill Sales, Tampa, FL Ph: 1-800-237-0230

10/09/2009 Fri 08:02

**GERDAU AMERISTEEL**

ST PAUL STEEL MILL
1678 RED ROCK ROAD
ST PAUL MN 55119 USA
(651) 731-5600

**Chemical and Physical Test Report**
**MADE IN UNITED STATES**

**M-075139**

| SHIP TO | INVOICE TO | SHIP DATE |
|---|---|---|
| NEBCO, INC.<br>STEEL DIVISION<br>HAVELOCK, NE 68521 | CONCRETE INDUSTRIES INC<br>ACCOUNTS PAYABLE<br>PO BOX 29529<br>LINCOLN, NE 68529-0529 | 10/09/09<br>**CUST. ACCOUNT NO**<br>60052172 |

**PRODUCED IN: ST PAUL**

| SHAPE + SIZE | GRADE | SPECIFICATION | SALES ORDER | CUST P.O. NUMBER |
|---|---|---|---|---|
| X36MM REBAR (#11) | 420 (60) | A615/A615M-09 GR 60/420 A6/A6M-08a | 9193731-01 | 79682-01 |

| HEAT I.D. | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | V | Sn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| M652732 | .44 | 1.22 | .013 | .029 | .22 | .26 | .11 | .14 | .034 | .004 | .014 |

Mechanical Test: Yield 64400 PSI, 444.02 MPA,Load 100 KIPS Tensile: 110300 PSI, 760.49 MPA %El: 15.6/8in, 15.6/203.2mm Bend: OK
Customer Requirements SOURCE: GA-STP CASTING: STRAND CAST

This material, including the billets, was produced and manufactured in the United States of America

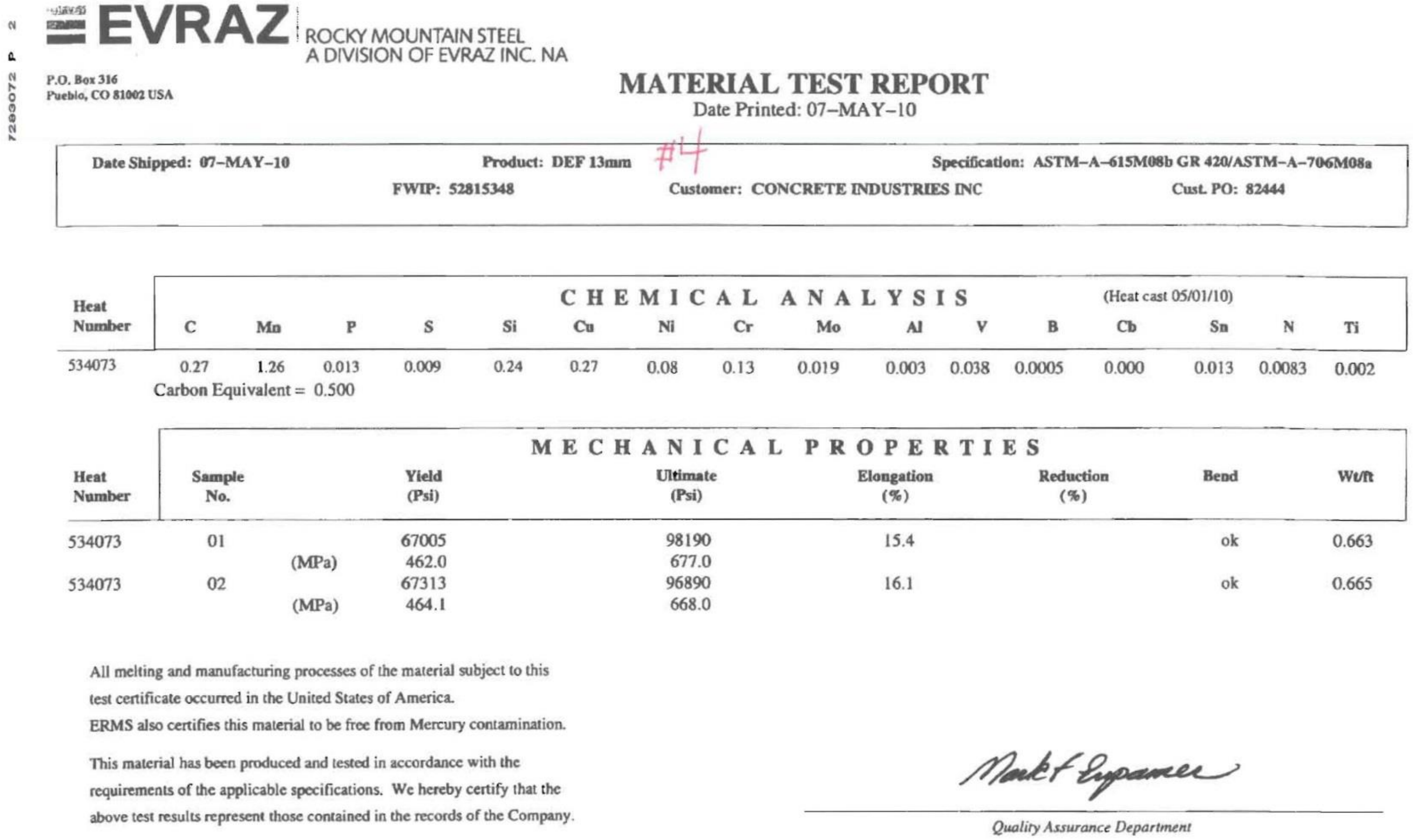
Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

THE ABOVE FIGURES ARE CERTIFIED EXTRACTS FROM THE ORIGINAL CHEMICAL AND PHYSICAL TEST RECORDS AS CONTAINED IN THE PERMANENT RECORDS OF COMPANY.

Metallurgical Services Manager
ST PAUL STEEL MILL

Seller warrants that all material furnished shall comply with specifications subject to standard published manufacturing variations. NO OTHER WARRANTIES, EXPRESSED OR IMPLIED, ARE MADE BY THE SELLER, AND SPECIFICALLY EXCLUDED ARE WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.
In no event shall seller be liable for indirect, consequential or punitive damages arising out of or related to the materials furnished by seller.
Any claim for damages for materials that do not conform to specifications must be made from buyer to seller immediately after delivery of same in order to allow the seller the opportunity to inspect the material in question.

Figure A-19. #11 Rebar for Anchorage, Test Nos. MWP-4, MWP-6 and MWP-7



7289072 P 2

**EVRAZ** ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

P.O. Box 316
Pueblo, CO 81002 USA

# MATERIAL TEST REPORT

Date Printed: 07–MAY–10

**Date Shipped:** 07–MAY–10 **Product:** DEF 13mm #4 **Specification:** ASTM–A–615M08b GR 420/ASTM–A–706M08a

**FWIP:** 52815348 **Customer:** CONCRETE INDUSTRIES INC **Cust. PO:** 82444

CHEMICAL ANALYSIS (Heat cast 05/01/10)

| Heat Number | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | Al | V | B | Cb | Sn | N | Ti |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 534073 | 0.27 | 1.26 | 0.013 | 0.009 | 0.24 | 0.27 | 0.08 | 0.13 | 0.019 | 0.003 | 0.038 | 0.0005 | 0.000 | 0.013 | 0.0083 | 0.002 |

Carbon Equivalent = 0.500

MECHANICAL PROPERTIES

| Heat Number | Sample No. | | Yield (Psi) | Ultimate (Psi) | Elongation (%) | Reduction (%) | Bend | Wt/ft |
|---|---|---|---|---|---|---|---|---|
| 534073 | 01 | | 67005 | 98190 | 15.4 | | ok | 0.663 |
| | | (MPa) | 462.0 | 677.0 | | | | |
| 534073 | 02 | | 67313 | 96890 | 16.1 | | ok | 0.665 |
| | | (MPa) | 464.1 | 668.0 | | | | |

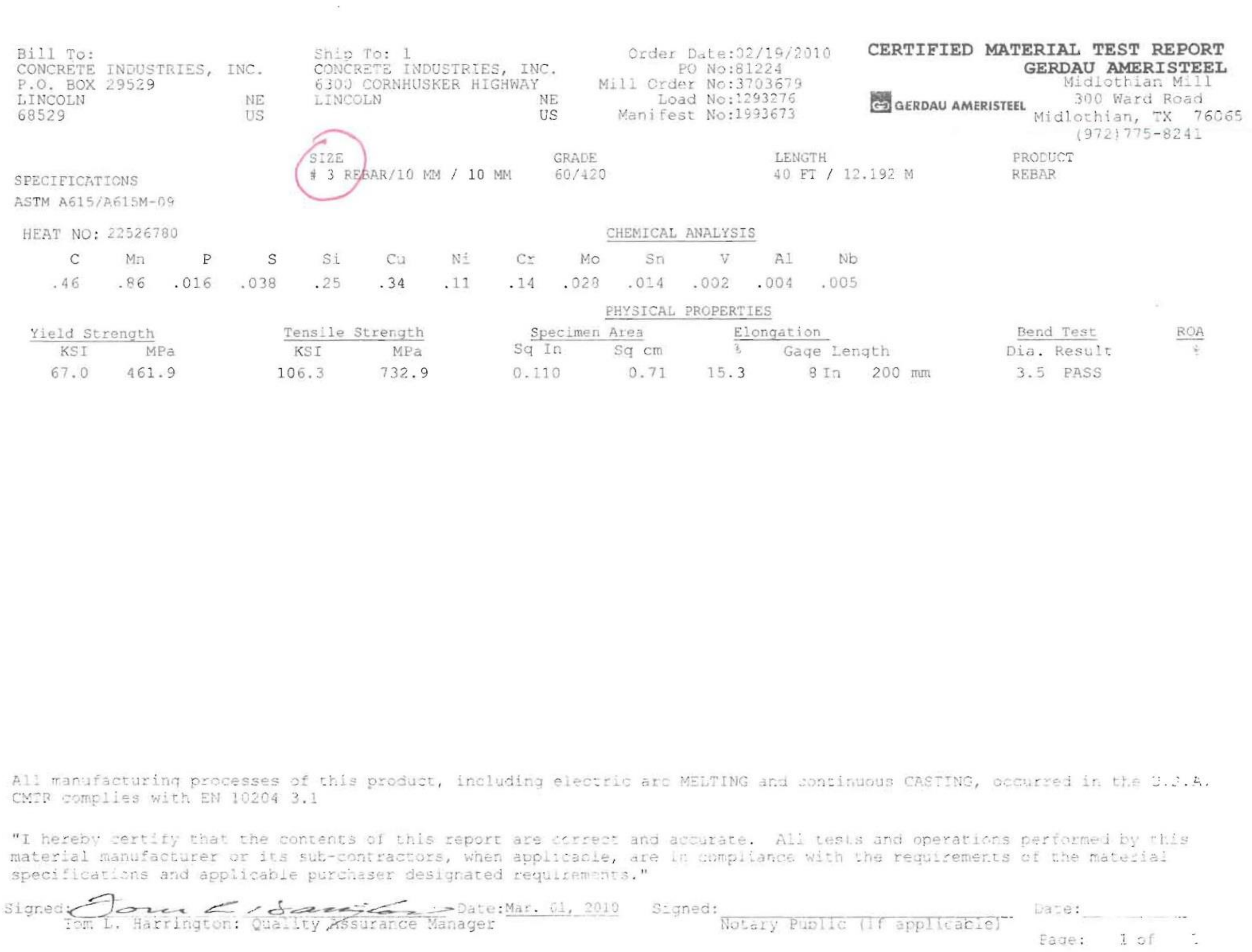
All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.
ERMS also certifies this material to be free from Mercury contamination.

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 Espanoza

*Quality Assurance Department*

Figure A-20. #4 Rebar for Anchorage, Test Nos. MWP-4, MWP-6 and MWP-7



Bill To:
CONCRETE INDUSTRIES, INC.
P.O. BOX 29529
LINCOLN NE
68529 US

Ship To: 1
CONCRETE INDUSTRIES, INC.
6300 CORNHUSKER HIGHWAY
LINCOLN NE
US

Order Date:02/19/2010
PO No:81224
Mill Order No:3703679
Load No:1293276
Manifest No:1993673

**CERTIFIED MATERIAL TEST REPORT**
**GERDAU AMERISTEEL**
Midlothian Mill
300 Ward Road
Midlothian, TX 76065
(972)775-8241

GERDAU AMERISTEEL

| SPECIFICATIONS | SIZE | GRADE | LENGTH | PRODUCT |
|---|---|---|---|---|
| ASTM A615/A615M-09 | # 3 REBAR/10 MM / 10 MM | 60/420 | 40 FT / 12.192 M | REBAR |

HEAT NO: 22526780

CHEMICAL ANALYSIS

| C | Mn | P | S | Si | Cu | Ni | Cr | Mo | Sn | V | Al | Nb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .46 | .86 | .016 | .038 | .25 | .34 | .11 | .14 | .028 | .014 | .002 | .004 | .005 |

PHYSICAL PROPERTIES

| Yield Strength | | Tensile Strength | | Specimen Area | | Elongation | Gage Length | | Bend Test | | ROA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| KSI | MPa | KSI | MPa | Sq In | Sq cm | % | | | Dia. | Result | % |
| 67.0 | 461.9 | 106.3 | 732.9 | 0.110 | 0.71 | 15.3 | 8 In | 200 mm | 3.5 | PASS | |

All manufacturing processes of this product, including electric arc MELTING and continuous CASTING, occurred in the U.S.A.
CMTR complies with EN 10204 3.1

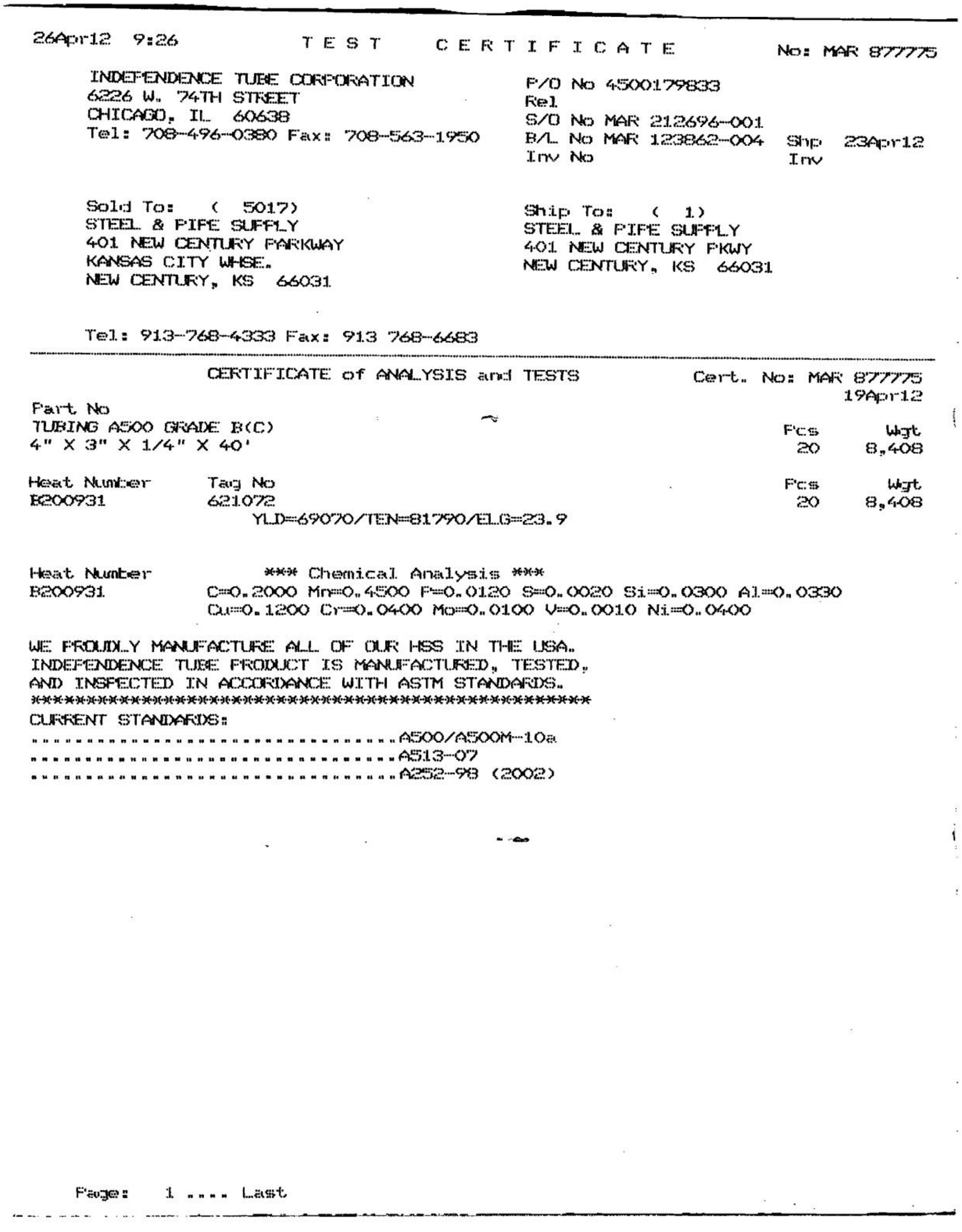
"I hereby certify that the contents of this report are correct and accurate. All tests and operations performed by this material manufacturer or its sub-contractors, when applicable, are in compliance with the requirements of the material specifications and applicable purchaser designated requirements."

Signed: Tom L. Harrington Date: Mar. 01, 2010
Tom L. Harrington: Quality Assurance Manager

Signed: ______________________ Date: __________
Notary Public (If applicable)

Page: 1 of 1

Figure A-21. #3 Rebar for Anchorage, Test Nos. MWP-4, MWP-6 and MWP-7



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 | Pcs | Wgt |
|---|---|---|
| TUBING A500 GRADE B(C)<br>4" X 3" X 1/4" X 40' | 20 | 8,408 |

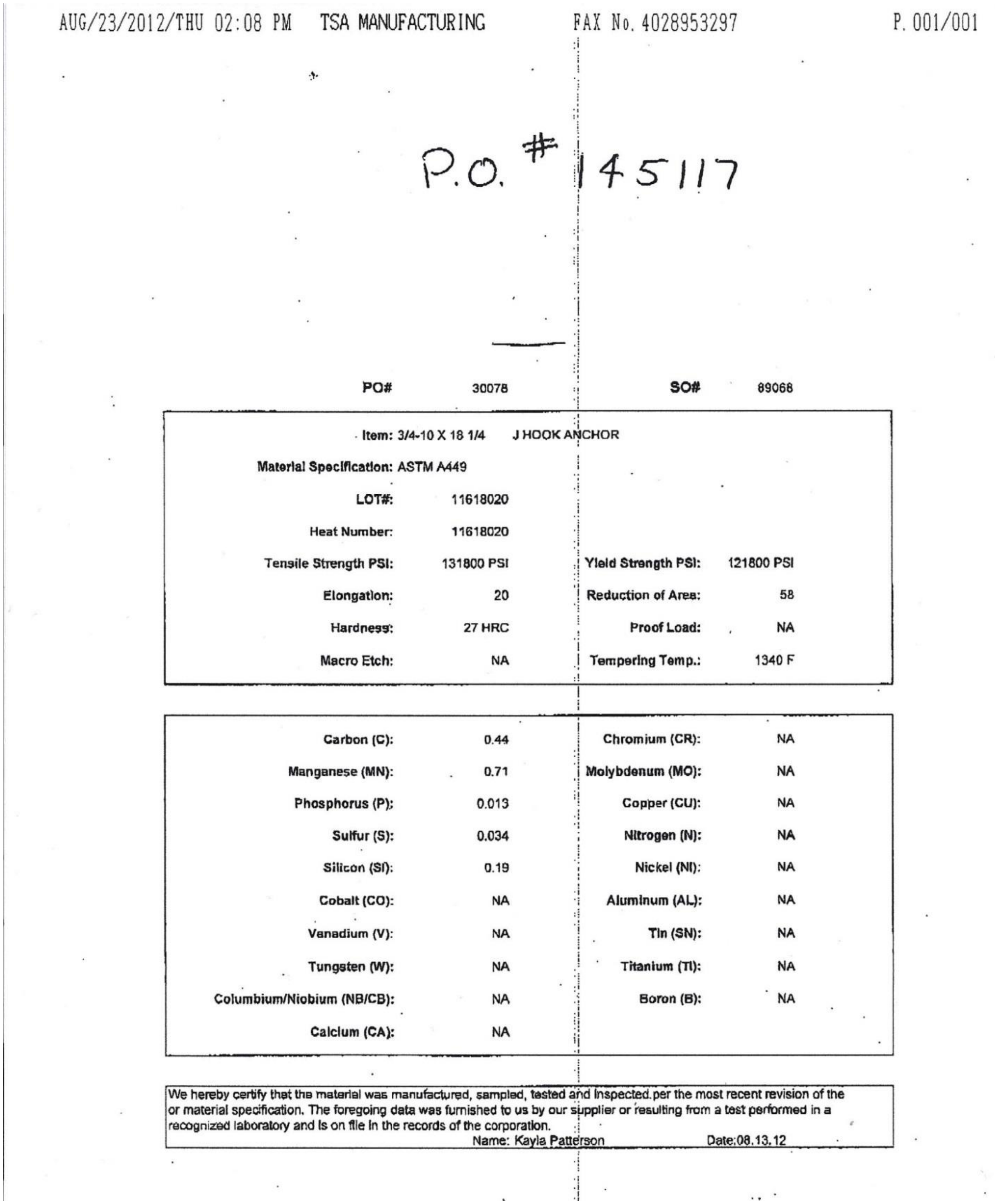
| Heat Number | Tag No | Pcs | Wgt |
|---|---|---|---|
| B200931 | 621072<br>YLD=69070/TEN=81790/ELG=23.9 | 20 | 8,408 |

| Heat Number | *** Chemical Analysis *** |
|---|---|
| B200931 | C=0.2000 Mn=0.4500 P=0.0120 S=0.0020 Si=0.0300 Al=0.0330<br>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)

Page: 1 .... Last

Figure A-22. Foundation Tubes, Test Nos. MWP-4, MWP-6 and MWP-7



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

P.O. # 145117

**PO#** 30078 **SO#** 89066

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

**Material Specification:** ASTM A449

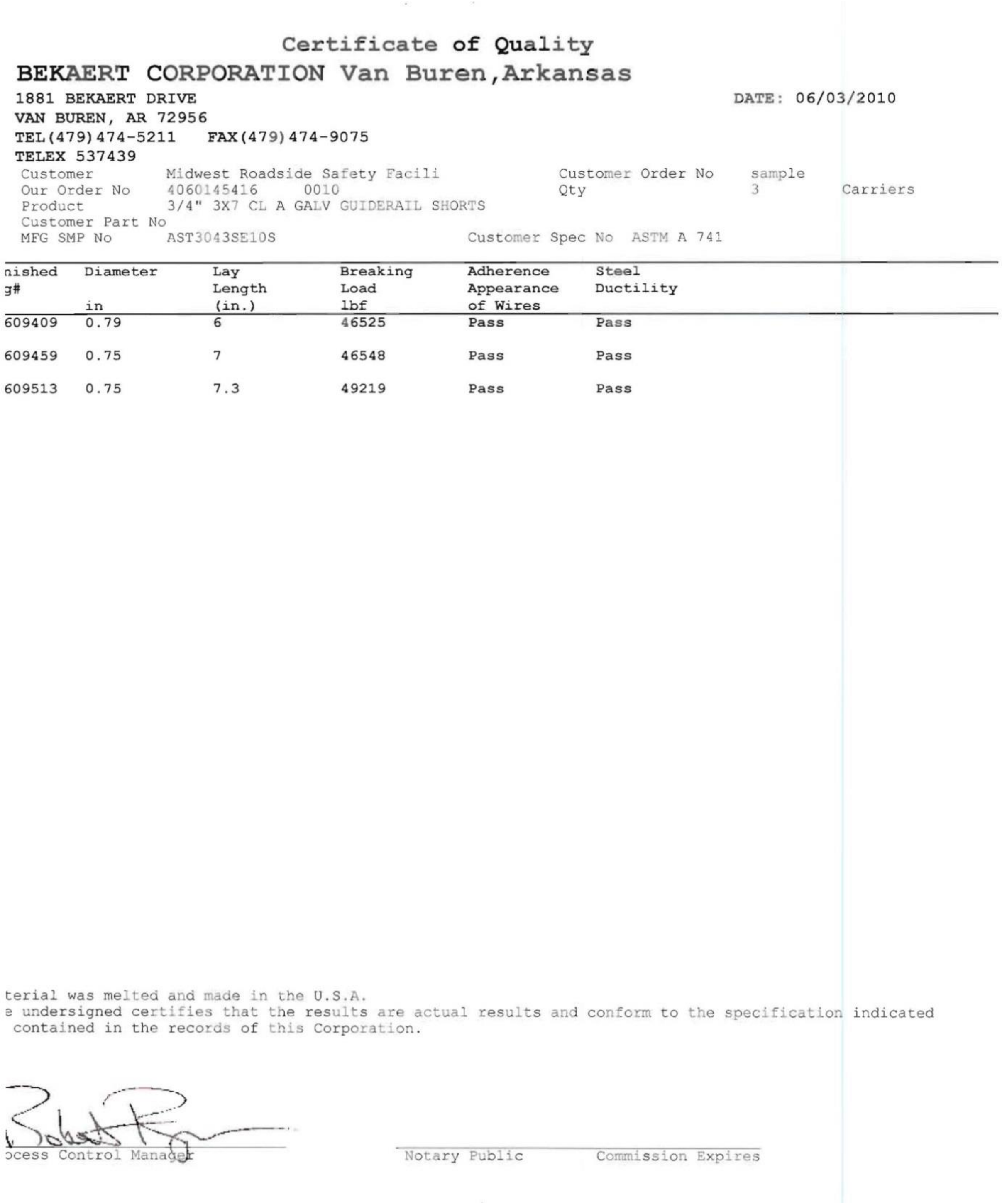
| | | | |
|---|---|---|---|
| **LOT#:** | 11618020 | | |
| **Heat Number:** | 11618020 | | |
| **Tensile Strength PSI:** | 131800 PSI | **Yield Strength PSI:** | 121800 PSI |
| **Elongation:** | 20 | **Reduction of Area:** | 58 |
| **Hardness:** | 27 HRC | **Proof Load:** | NA |
| **Macro Etch:** | NA | **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-23. J-Hook Anchor Bolts, Test Nos. MWP-4, MWP-6 and MWP-7



## Certificate of Quality

**BEKAERT CORPORATION Van Buren,Arkansas**

**1881 BEKAERT DRIVE**
**VAN BUREN, AR 72956**
**TEL(479)474-5211 FAX(479)474-9075**
**TELEX 537439**

**DATE: 06/03/2010**

Customer Midwest Roadside Safety Facili
Customer Order No sample
Our Order No 4060145416 0010
Qty 3 Carriers
Product 3/4" 3X7 CL A GALV GUIDERAIL SHORTS
Customer Part No
MFG SMP No AST3043SE10S
Customer Spec No ASTM A 741

| nished g# | Diameter in | Lay Length (in.) | Breaking Load lbf | Adherence Appearance of Wires | Steel Ductility |
|---|---|---|---|---|---|
| 609409 | 0.79 | 6 | 46525 | Pass | Pass |
| 609459 | 0.75 | 7 | 46548 | Pass | Pass |
| 609513 | 0.75 | 7.3 | 49219 | Pass | Pass |

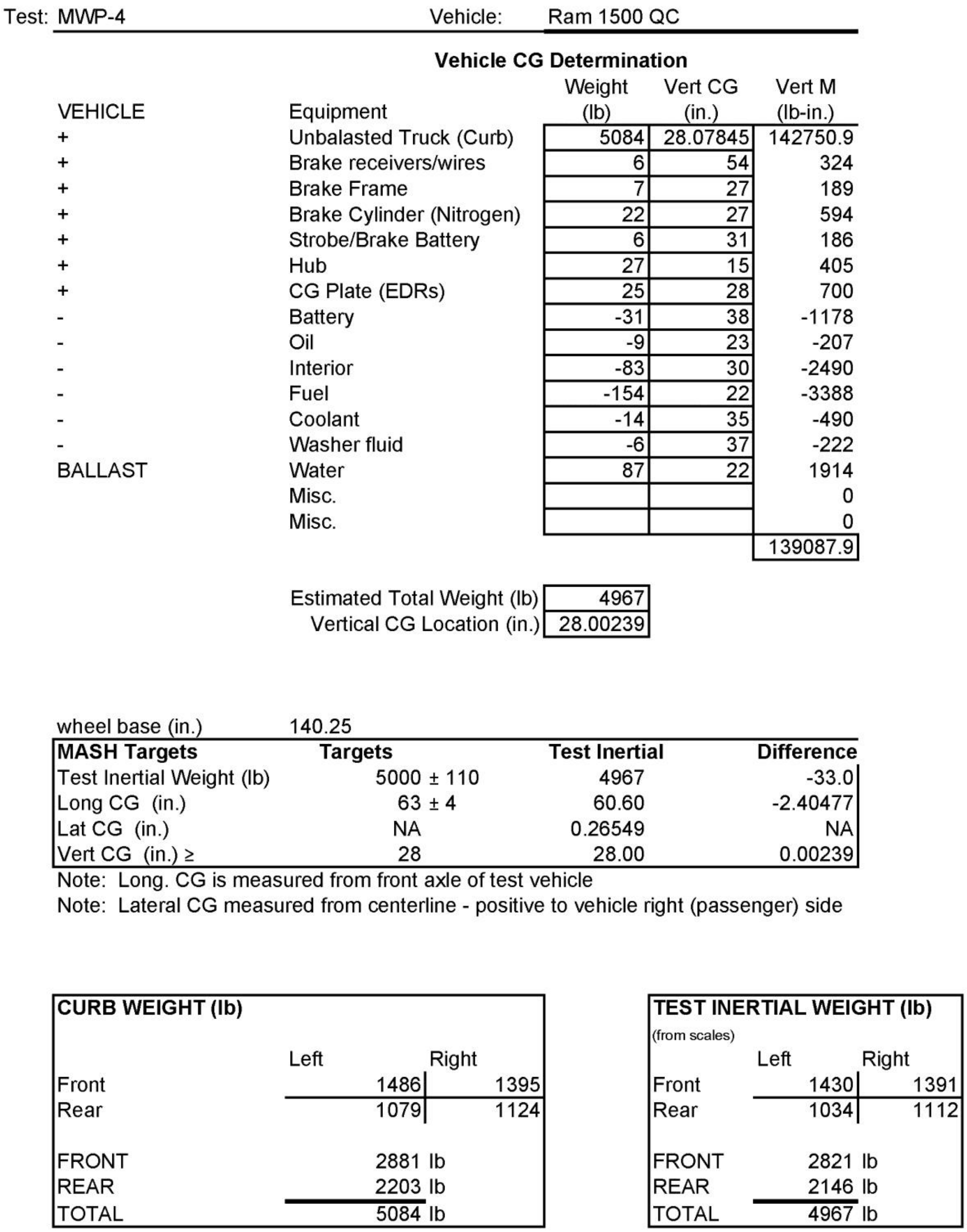
terial was melted and made in the U.S.A.
e undersigned certifies that the results are actual results and conform to the specification indicated
contained in the records of this Corporation.

ocess Control Manager

Notary Public Commission Expires

Figure A-24. Bekaert Wire Rope, Test Nos. MWP-4, MWP-6 and MWP-7

# Appendix B. Vehicle Center of Gravity Determination



Test: MWP-4 Vehicle: Ram 1500 QC

**Vehicle CG Determination**

| VEHICLE | Equipment | Weight (lb) | Vert CG (in.) | Vert M (lb-in.) |
|---|---|---|---|---|
| + | Unbalasted Truck (Curb) | 5084 | 28.07845 | 142750.9 |
| + | Brake receivers/wires | 6 | 54 | 324 |
| + | Brake Frame | 7 | 27 | 189 |
| + | Brake Cylinder (Nitrogen) | 22 | 27 | 594 |
| + | Strobe/Brake Battery | 6 | 31 | 186 |
| + | Hub | 27 | 15 | 405 |
| + | CG Plate (EDRs) | 25 | 28 | 700 |
| - | Battery | -31 | 38 | -1178 |
| - | Oil | -9 | 23 | -207 |
| - | Interior | -83 | 30 | -2490 |
| - | Fuel | -154 | 22 | -3388 |
| - | Coolant | -14 | 35 | -490 |
| - | Washer fluid | -6 | 37 | -222 |
| BALLAST | Water | 87 | 22 | 1914 |
| | Misc. | | | 0 |
| | Misc. | | | 0 |
| | | | | 139087.9 |

| | |
|---|---|
| Estimated Total Weight (lb) | 4967 |
| Vertical CG Location (in.) | 28.00239 |

wheel base (in.) 140.25

| MASH Targets | Targets | Test Inertial | Difference |
|---|---|---|---|
| Test Inertial Weight (lb) | 5000 ± 110 | 4967 | -33.0 |
| Long CG (in.) | 63 ± 4 | 60.60 | -2.40477 |
| Lat CG (in.) | NA | 0.26549 | NA |
| Vert CG (in.) ≥ | 28 | 28.00 | 0.00239 |

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

**CURB WEIGHT (lb)**

| | Left | Right |
|---|---|---|
| Front | 1486 | 1395 |
| Rear | 1079 | 1124 |

| | | |
|---|---|---|
| FRONT | 2881 | lb |
| REAR | 2203 | lb |
| TOTAL | 5084 | lb |

**TEST INERTIAL WEIGHT (lb)**

(from scales)

| | Left | Right |
|---|---|---|
| Front | 1430 | 1391 |
| Rear | 1034 | 1112 |

| | | |
|---|---|---|
| FRONT | 2821 | lb |
| REAR | 2146 | lb |
| TOTAL | 4967 | lb |

Figure B-1. Vehicle Mass Distribution, Test No. MWP-4

Test: MWP-6 Vehicle: Rio

**Vehicle CG Determination**

| VEHICLE | Equipment | Weight (lb) |
|---|---|---|
| + | Unbalasted Car (curb) | 2295 |
| + | Brake receivers/wires | 5 |
| + | Brake Frame | 7 |
| + | Brake Cylinder | 22 |
| + | Strobe Battery | 5 |
| + | Hub | 27 |
| + | CG Plate (EDRs) | 15 |
| + | DTS | 0 |
| - | Battery | -31 |
| - | Oil | -7 |
| - | Interior | -29 |
| - | Fuel | 0 |
| - | Coolant | -7 |
| - | Washer fluid | -5 |
| BALLAST | Water | 108 |
|  | Misc. |  |
|  | Misc. |  |

Estimated Total Weight 2405 lb

wheel base 98.5 in.

| **MASH targets** |  | **Test Inertial** | **Difference** |
|---|---|---|---|
| Test Inertial Wt (lb) | 2420 (+/-)55 | 2405 | -15.0 |
| Long CG (in.) | 39 (+/-)4 | 38.95 | -0.05052 |
| Lateral CG (in.) | N/A | 0.106653 | NA |

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

**CURB WEIGHT (lb)**

|  | Left | Right |
|---|---|---|
| Front | 777 | 692 |
| Rear | 390 | 436 |

FRONT 1469 lb
REAR 826 lb
TOTAL 2295 lb

Dummy = 166lbs.

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

|  | Left | Right |
|---|---|---|
| Front | 724 | 730 |
| Rear | 474 | 477 |

FRONT 1454 lb
REAR 951 lb
TOTAL 2405 lb

Figure B-2. Vehicle Mass Distribution, Test No. MWP-6

Test: MWP-7 Vehicle: Rio

### Vehicle CG Determination

| VEHICLE | Equipment | Weight (lb) |
|---|---|---|
| + | Unbalasted Car (curb) | 2384 |
| + | Brake receivers/wires | 6 |
| + | Brake Frame | 7 |
| + | Brake Cylinder | 22 |
| + | Strobe Battery | 5 |
| + | Hub | 22 |
| + | CG Plate (EDRs) | 13 |
| + | | 0 |
| - | Battery | -31 |
| - | Oil | -6 |
| - | Interior | -33 |
| - | Fuel | 0 |
| - | Coolant | -8 |
| - | Washer fluid | -4 |
| BALLAST | Water | |
| | Misc. Battery | 12 |
| | Misc. | |

Estimated Total Weight 2389 lb

wheel base 98.125 in.

| MASH targets | | | Test Inertial | Difference |
|---|---|---|---|---|
| Test Inertial Wt (lb) | 2420 | (+/-)55 | 2392 | -28.0 |
| Long CG (in.) | 39 | (+/-)4 | 37.49 | -1.50575 |
| Lateral CG (in.) | N/A | | 0.357441 | NA |

Note: Long. CG is measured from front axle of test vehicle

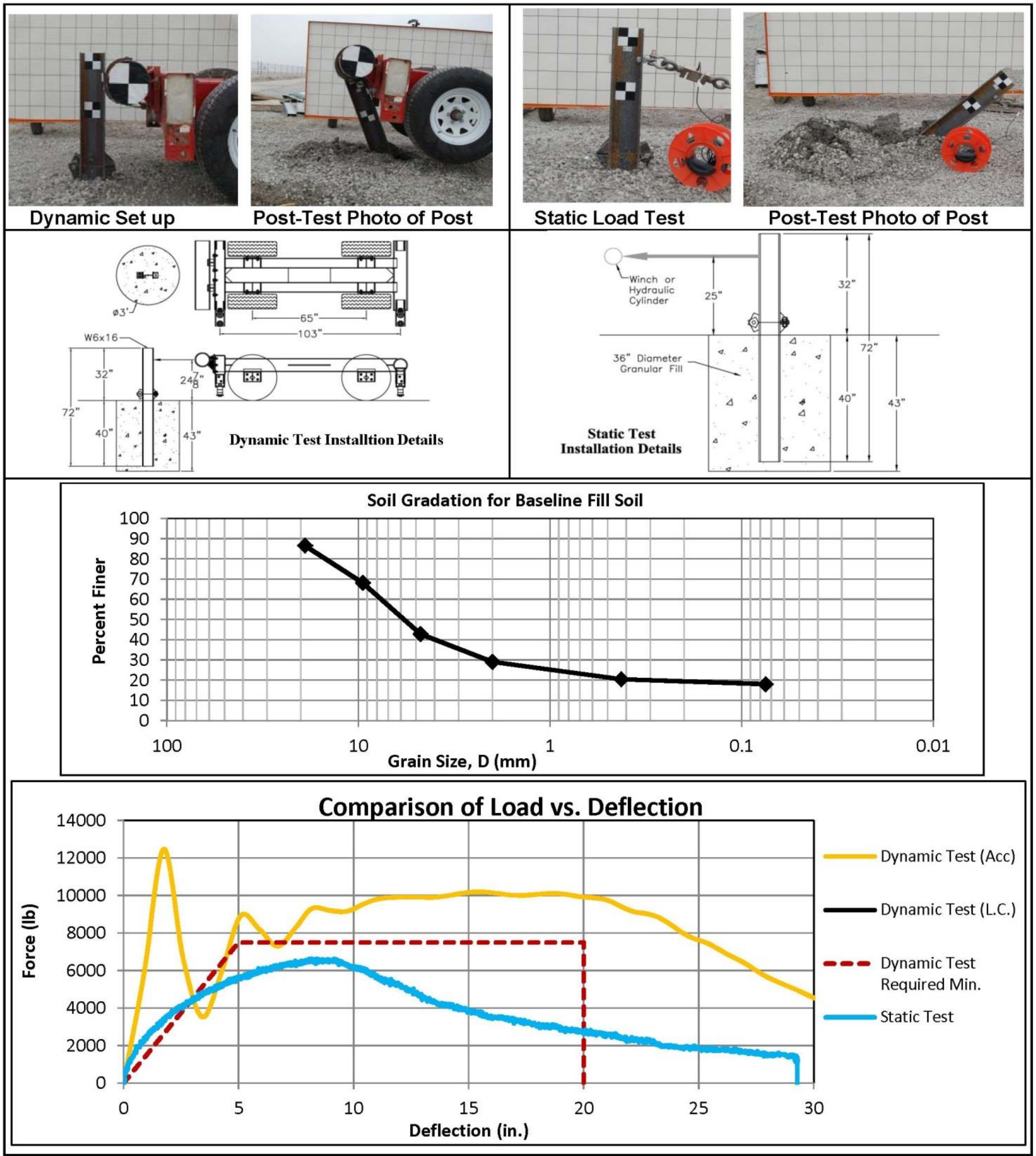
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

| CURB WEIGHT (lb) | | | |
|---|---|---|---|
| | Left | Right | |
| Front | 770 | 744 | |
| Rear | 427 | 443 | |
| FRONT | 1514 | lb | |
| REAR | 870 | lb | |
| TOTAL | 2384 | lb | |

| TEST INERTIAL WEIGHT (lb)<br>(from scales) | | | |
|---|---|---|---|
| | Left | Right | |
| Front | 723 | 755 | |
| Rear | 458 | 456 | |
| FRONT | 1478 | lb | |
| REAR | 914 | lb | |
| TOTAL | 2392 | lb | |

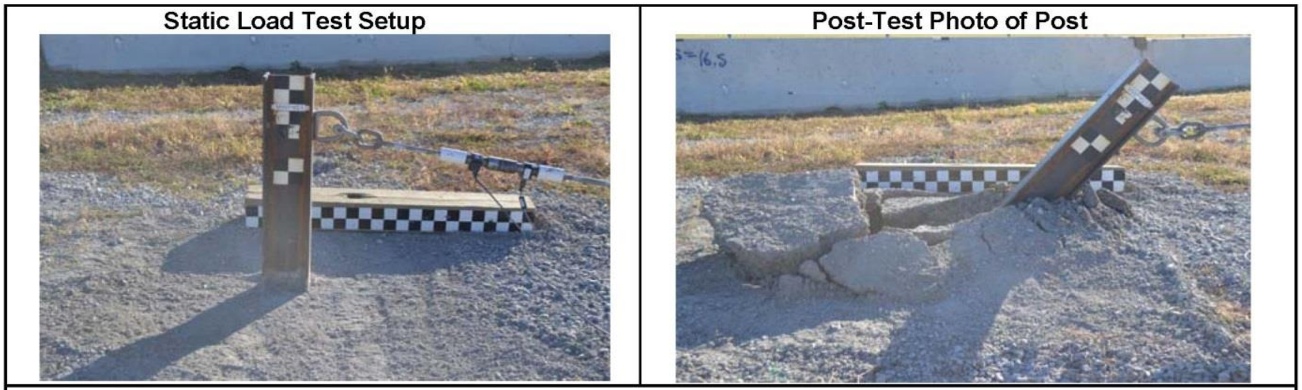
Figure B-3. Vehicle Mass Distribution, Test No. MWP-7

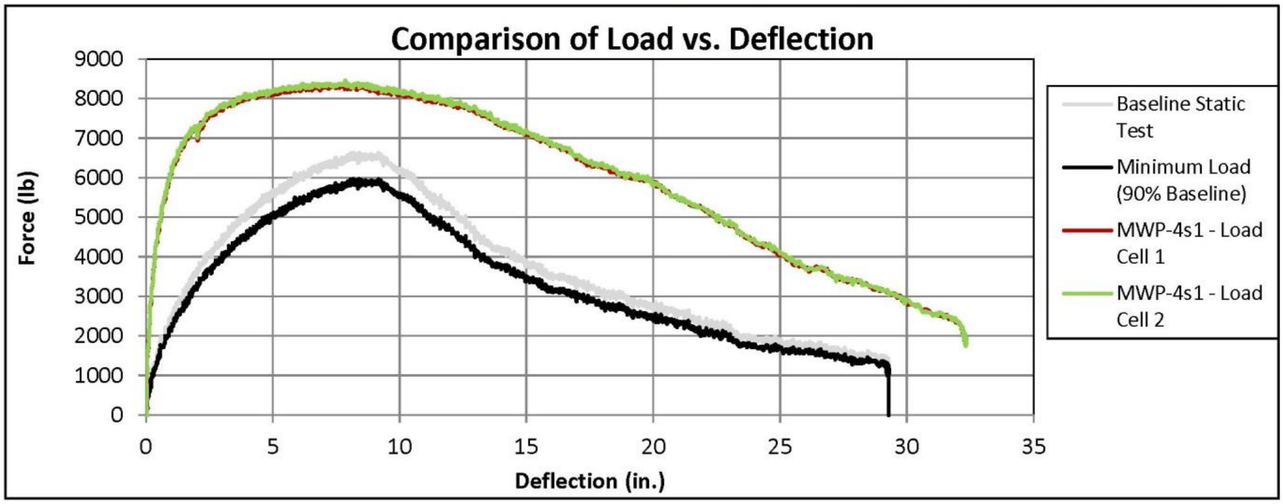
# Appendix C. Static Soil Tests

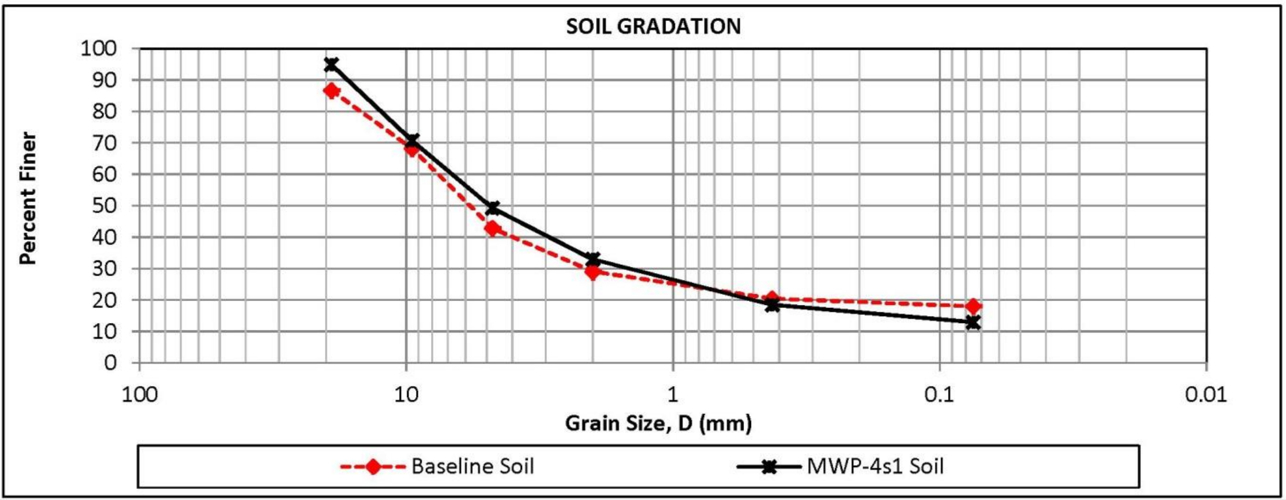


| | |
|---|---|
| **Date**........................................................ | 4/4/2012 |
| **Test Facility & Site Location**....................... | Midwest Roadside Safety Facility |
| **In situ soil description (ASTM D2487)**........... | Well Graded Gravel (GW) |
| **Fill material description (ASTM D2487)**......... | Well Graded Gravel (GW) (see sieve analyses above) |
| **Description of fill placement procedure**........ | 3 Pass, 8" Lift |
| **Bogie Weight**........................................... | 1,844 lb |
| **Impact Velocity**........................................ | 20.07 mph |

Figure C-1. Soil Strength, Initial Calibration Test, Test Nos. MWP-4, MWP-6, and MWP-7

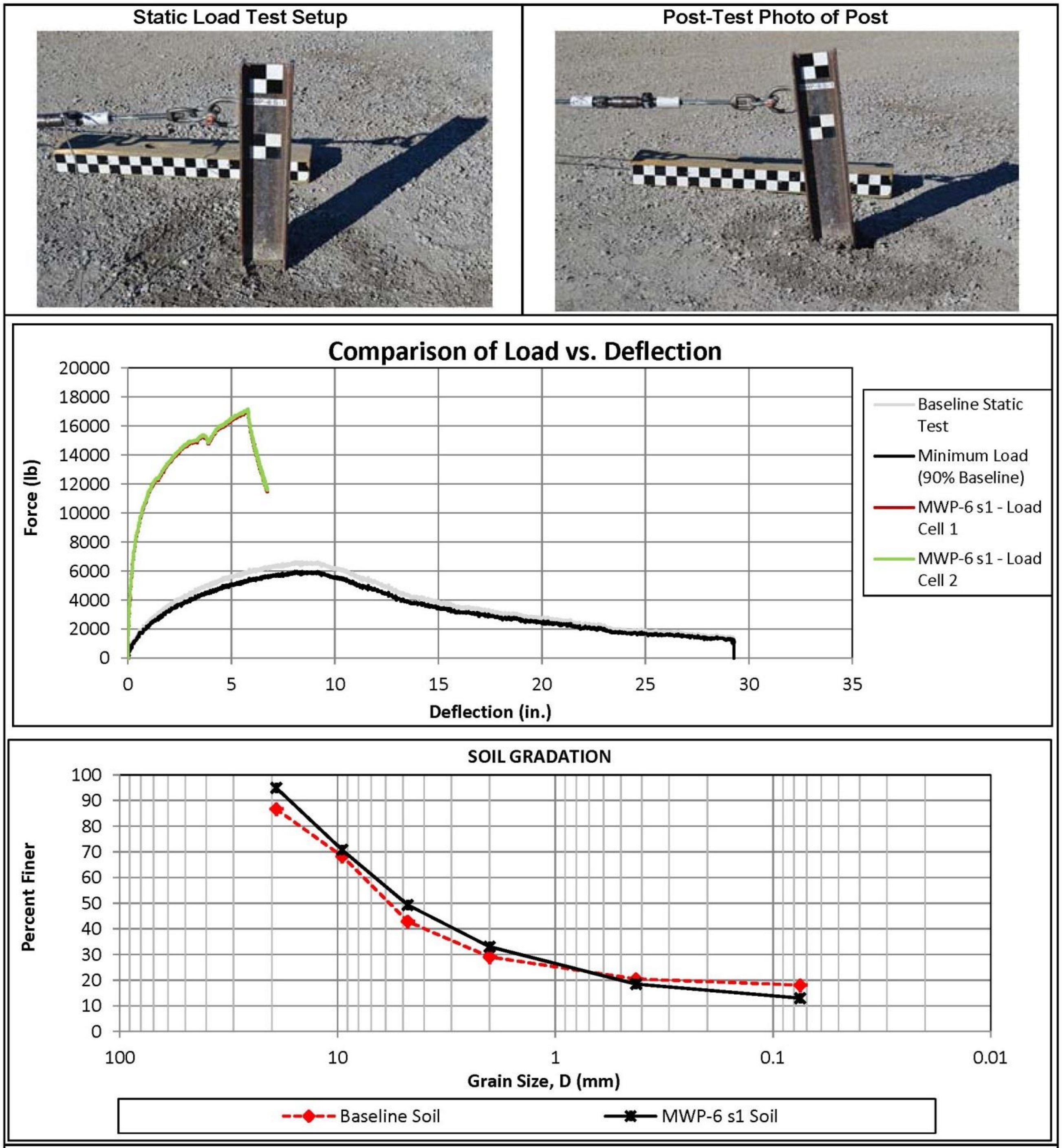






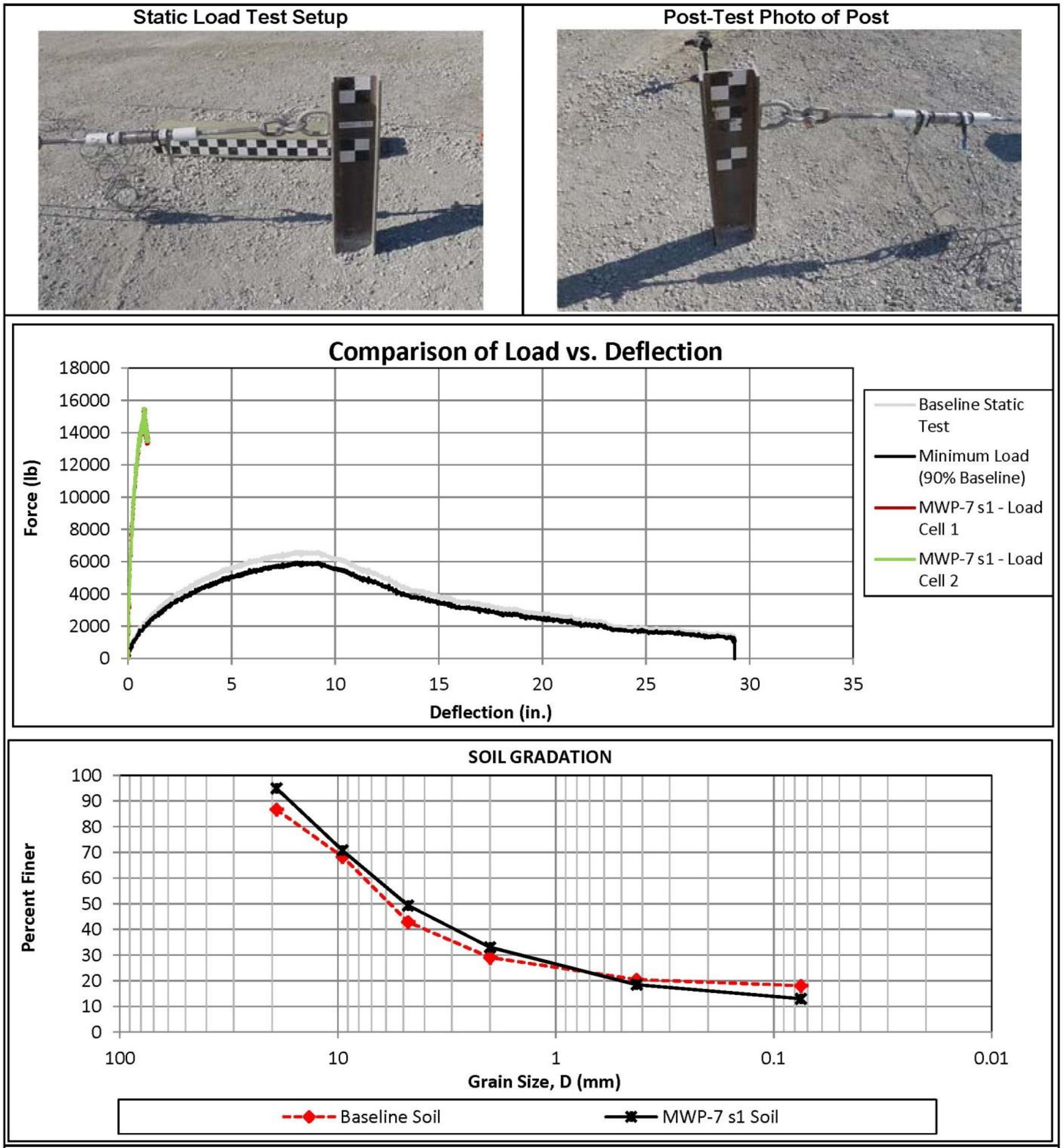
**Date**..........................................................10/20/2014
**Test Facility & Site Location**....................... Midwest Roadside Safety Facility
**In situ soil description (ASTM D2487)**...........Well Graded Gravel (GW)
**Fill material description (ASTM D2487)**.........Well Graded 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-4



**Date**..........................................................1/15/2015
**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-3. Static Soil Test, Test No. MWP-6



Static Load Test Setup

Post-Test Photo of Post

Comparison of Load vs. Deflection

SOIL GRADATION

**Date**..........................................................2/23/2015
**Test Facility & Site Location**........................Midwest Roadside Safety Facility
**In situ soil description (ASTM D2487)**...........Low Plasticity Silt (ML)
**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-4. Static Soil Test, Test No. MWP-7

# Appendix D. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MWP-4
VEHICLE: Ram 1500 QC

Note: If impact is on driver side need to enter negative number for Y

| POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 30 3/4 | -27 1/2 | 2 | 30 3/4 | -27 3/4 | 2 | 0 | - 1/4 | 0 |
| 2 | 32 3/4 | -25 3/4 | 1 3/4 | 32 3/4 | -25 1/4 | 1 3/4 | 0 | 1/2 | 0 |
| 3 | 33 1/2 | -19 | 1 | 33 1/2 | -19 3/4 | 3/4 | 0 | - 3/4 | - 1/4 |
| 4 | 30 1/2 | -13 3/4 | -1 1/2 | 30 1/2 | -14 | -1 1/2 | 0 | - 1/4 | 0 |
| 5 | 27 3/4 | -28 1/4 | -1 3/4 | 27 3/4 | -28 1/4 | -1 3/4 | 0 | 0 | 0 |
| 6 | 29 1/2 | -24 1/4 | -2 1/4 | 29 1/2 | -24 1/2 | -2 1/4 | 0 | - 1/4 | 0 |
| 7 | 28 1/4 | -17 1/4 | -3 1/2 | 28 1/4 | -17 1/4 | -3 1/4 | 0 | 0 | 1/4 |
| 8 | 26 1/2 | -11 1/4 | -3 3/4 | 26 1/2 | -12 | -3 1/2 | 0 | - 3/4 | 1/4 |
| 9 | 23 3/4 | -28 1/2 | -5 1/2 | 23 3/4 | -28 | -5 3/4 | 0 | 1/2 | - 1/4 |
| 10 | 23 3/4 | -21 3/4 | -5 3/4 | 23 3/4 | -22 | -5 3/4 | 0 | - 1/4 | 0 |
| 11 | 23 3/4 | -17 1/2 | -5 1/2 | 23 3/4 | -17 3/4 | -5 1/2 | 0 | - 1/4 | 0 |
| 12 | 23 3/4 | -10 3/4 | -5 3/4 | 23 3/4 | -11 1/2 | -5 1/2 | 0 | - 3/4 | 1/4 |
| 13 | 20 1/2 | -28 | -7 1/2 | 20 1/2 | -27 3/4 | -7 1/2 | 0 | 1/4 | 0 |
| 14 | 20 1/2 | -22 1/2 | -7 1/4 | 20 1/2 | -22 1/4 | -7 1/4 | 0 | 1/4 | 0 |
| 15 | 20 1/2 | -18 | -7 1/4 | 20 1/2 | -17 1/4 | -7 1/4 | 0 | 3/4 | 0 |
| 16 | 20 3/4 | -11 | -7 1/4 | 20 1/2 | -11 1/2 | -7 1/4 | - 1/4 | - 1/2 | 0 |
| 17 | 16 1/2 | -28 1/2 | -7 3/4 | 16 1/2 | -29 | -7 1/2 | 0 | - 1/2 | 1/4 |
| 18 | 17 | -20 | -7 1/2 | 17 | -20 | -7 1/2 | 0 | 0 | 0 |
| 19 | 17 | -12 3/4 | -7 1/2 | 17 1/4 | -13 1/4 | -7 1/2 | 1/4 | - 1/2 | 0 |
| 20 | 14 | -6 1/2 | - 1/2 | 14 | -6 1/2 | - 1/4 | 0 | 0 | 1/4 |
| 21 | 10 1/2 | -28 3/4 | -7 1/2 | 10 3/4 | -28 3/4 | -7 1/2 | 1/4 | 0 | 0 |
| 22 | 10 3/4 | -20 1/2 | -7 1/2 | 10 3/4 | -20 1/4 | -7 1/2 | 0 | 1/4 | 0 |
| 23 | 10 1/2 | -12 3/4 | -7 1/2 | 10 3/4 | -12 1/2 | -7 1/4 | 1/4 | 1/4 | 1/4 |
| 24 | 8 1/2 | -6 1/2 | -1 1/4 | 8 1/2 | -6 1/2 | -1 | 0 | 0 | 1/4 |
| 25 | 3/4 | -27 1/4 | -3 1/2 | 3/4 | -27 1/4 | -3 3/4 | 0 | 0 | - 1/4 |
| 26 | 3/4 | -20 1/2 | -3 1/2 | 3/4 | -20 3/4 | -3 3/4 | 0 | - 1/4 | - 1/4 |
| 27 | 3/4 | -13 | -3 1/2 | 1/2 | -13 | -3 1/2 | - 1/4 | 0 | 0 |
| 28 | 1 | -6 3/4 | -1 | 1 | -6 3/4 | -1 | 0 | 0 | 0 |
| 29 | | | | | | | 0 | 0 | 0 |
| 30 | | | | | | | 0 | 0 | 0 |
| 31 | | | | | | | 0 | 0 | 0 |

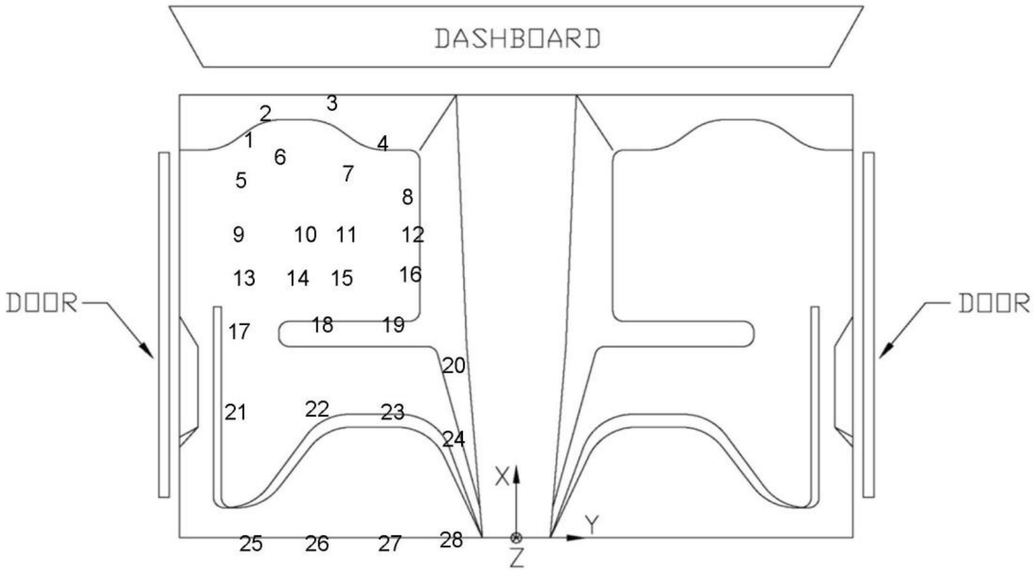


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. MWP-4

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MWP-4
VEHICLE: Ram 1500 QC

Note: If impact is on driver side need to enter negative number for Y

| POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 46 1/2 | -32 1/4 | 1 3/4 | 46 1/2 | -32 1/2 | 1 3/4 | 0 | - 1/4 | 0 |
| 2 | 48 1/2 | -29 3/4 | 1 1/2 | 48 1/2 | -30 | 1 1/2 | 0 | - 1/4 | 0 |
| 3 | 49 1/2 | -25 1/4 | 1/2 | 49 3/4 | -25 | 1/2 | 1/4 | 1/4 | 0 |
| 4 | 46 1/2 | -19 1/4 | -1 3/4 | 46 3/4 | -19 1/2 | -1 3/4 | 1/4 | - 1/4 | 0 |
| 5 | 43 3/4 | -33 1/4 | -2 | 43 3/4 | -33 | -2 | 0 | 1/4 | 0 |
| 6 | 45 3/4 | -29 1/2 | -2 1/4 | 45 3/4 | -29 3/4 | -2 1/2 | 0 | - 1/4 | - 1/4 |
| 7 | 44 1/2 | -22 1/4 | -3 3/4 | 44 1/2 | -22 1/2 | -3 1/2 | 0 | - 1/4 | 1/4 |
| 8 | 42 3/4 | -15 3/4 | -4 | 42 3/4 | -15 1/2 | -4 | 0 | 1/4 | 0 |
| 9 | 40 | -33 | -6 | 40 1/4 | -33 | -6 | 1/4 | 0 | 0 |
| 10 | 40 | -27 | -6 | 40 | -26 3/4 | -6 | 0 | 1/4 | 0 |
| 11 | 40 | -22 1/4 | -6 | 40 1/4 | -22 | -5 3/4 | 1/4 | 1/4 | 1/4 |
| 12 | 40 | -16 | -6 | 40 1/4 | -15 3/4 | -6 | 1/4 | 1/4 | 0 |
| 13 | 37 | -32 1/4 | -7 3/4 | 37 | -32 1/4 | -7 3/4 | 0 | 0 | 0 |
| 14 | 37 | -27 1/4 | -7 1/2 | 37 | -27 1/4 | -7 1/2 | 0 | 0 | 0 |
| 15 | 37 | -21 3/4 | -7 1/2 | 37 | -21 1/2 | -7 1/2 | 0 | 1/4 | 0 |
| 16 | 37 | -15 3/4 | -7 1/2 | 37 | -15 1/2 | -7 1/2 | 0 | 1/4 | 0 |
| 17 | 32 3/4 | -33 1/4 | -8 | 32 3/4 | -33 | -8 | 0 | 1/4 | 0 |
| 18 | 33 1/4 | -23 1/2 | -7 3/4 | 33 1/4 | -24 1/4 | -7 3/4 | 0 | - 3/4 | 0 |
| 19 | 33 1/2 | -17 1/4 | -7 3/4 | 33 1/2 | -17 1/4 | -7 3/4 | 0 | 0 | 0 |
| 20 | 30 1/4 | -10 3/4 | - 1/2 | 30 1/4 | -11 1/4 | - 3/4 | 0 | - 1/2 | - 1/4 |
| 21 | 27 3/4 | -33 1/4 | -7 3/4 | 27 1/2 | -32 3/4 | -7 3/4 | - 1/4 | 1/2 | 0 |
| 22 | 27 3/4 | -25 1/2 | -7 3/4 | 28 | -24 3/4 | -7 3/4 | 1/4 | 3/4 | 0 |
| 23 | 27 3/4 | -17 1/4 | -7 1/2 | 27 3/4 | -17 3/4 | -7 3/4 | 0 | - 1/2 | - 1/4 |
| 24 | 24 3/4 | -10 3/4 | -1 1/2 | 24 3/4 | -11 | -1 1/2 | 0 | - 1/4 | 0 |
| 25 | 17 | -31 3/4 | -4 | 17 | -32 | -4 | 0 | - 1/4 | 0 |
| 26 | 17 | -25 1/4 | -4 | 17 | -25 1/2 | -4 | 0 | - 1/4 | 0 |
| 27 | 17 | -17 1/2 | -3 3/4 | 17 1/4 | -17 3/4 | -3 3/4 | 1/4 | - 1/4 | 0 |
| 28 | 17 1/4 | -11 1/4 | -1 1/4 | 17 1/4 | -11 1/4 | -1 1/4 | 0 | 0 | 0 |
| 29 | | | | | | | 0 | 0 | 0 |
| 30 | | | | | | | 0 | 0 | 0 |
| 31 | | | | | | | 0 | 0 | 0 |

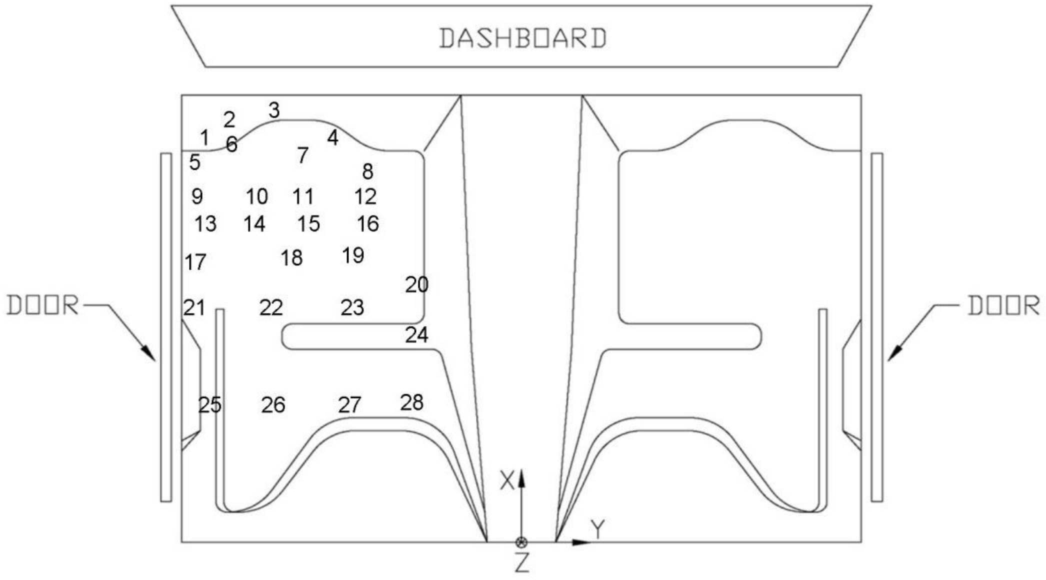


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. MWP-4

## VEHICLE PRE/POST CRUSH
## INTERIOR CRUSH - SET 1

TEST: MWP-4
VEHICLE: Ram 1500 QC

Note: If impact is on driver side need to enter negative number for Y

| | POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|---|
| DASH | A1 | 40 | -55 1/2 | 25 3/4 | 40 1/4 | -55 1/2 | 26 | 1/4 | 0 | 1/4 |
| | A2 | 40 | -39 3/4 | 26 | 40 1/4 | -39 | 26 | 1/4 | 3/4 | 0 |
| | A3 | 40 | -30 1/4 | 26 3/4 | 40 | -30 1/4 | 26 3/4 | 0 | 0 | 0 |
| | A4 | 34 3/4 | -57 1/2 | 19 | 34 3/4 | -57 1/2 | 19 | 0 | 0 | 0 |
| | A5 | 32 | -44 3/4 | 15 1/2 | 32 | -45 | 15 1/2 | 0 | - 1/4 | 0 |
| | A6 | 33 1/4 | -32 1/4 | 18 1/2 | 33 1/4 | -32 1/2 | 18 1/2 | 0 | - 1/4 | 0 |
| SIDE PANEL | B1 | 20 3/4 | -25 1/2 | 3 | 20 3/4 | -25 1/4 | 3 | 0 | 1/4 | 0 |
| | B2 | 20 | -25 1/4 | -1 3/4 | 20 | -25 | -1 3/4 | 0 | 1/4 | 0 |
| | B3 | 23 | -25 3/4 | 1/2 | 23 | -25 3/4 | 1/2 | 0 | 0 | 0 |
| IMPACT SIDE DOOR | C1 | 8 3/4 | -35 1/2 | 19 1/2 | 8 3/4 | -35 3/4 | 19 1/2 | 0 | - 1/4 | 0 |
| | C2 | 15 1/2 | -35 1/2 | 19 1/2 | 15 1/2 | -35 1/2 | 19 1/2 | 0 | 0 | 0 |
| | C3 | 27 | -34 1/4 | 18 1/4 | 26 1/2 | -34 1/4 | 18 1/4 | - 1/2 | 0 | 0 |
| | C4 | 6 1/4 | -28 1/4 | 4 1/4 | 6 | -28 1/4 | 4 1/4 | - 1/4 | 0 | 0 |
| | C5 | 17 3/4 | -29 1/4 | 5 1/2 | 17 3/4 | -29 | 5 1/4 | 0 | 1/4 | - 1/4 |
| | C6 | 23 1/2 | -28 1/2 | 3 | 23 1/4 | -27 1/2 | 2 3/4 | - 1/4 | 1 | - 1/4 |
| ROOF | D1 | | | | | | | 0 | 0 | 0 |
| | D2 | | | | | | | 0 | 0 | 0 |
| | D3 | | | | | | | 0 | 0 | 0 |
| | D4 | | | | | | | 0 | 0 | 0 |
| | D5 | | | | | | | 0 | 0 | 0 |
| | D6 | | | | | | | 0 | 0 | 0 |
| | D7 | | | | | | | 0 | 0 | 0 |
| | D8 | | | | | | | 0 | 0 | 0 |
| | D9 | | | | | | | 0 | 0 | 0 |
| | D10 | | | | | | | 0 | 0 | 0 |
| | D11 | | | | | | | 0 | 0 | 0 |
| | D12 | | | | | | | 0 | 0 | 0 |
| | D13 | | | | | | | 0 | 0 | 0 |
| | D14 | | | | | | | 0 | 0 | 0 |
| | D15 | | | | | | | 0 | 0 | 0 |

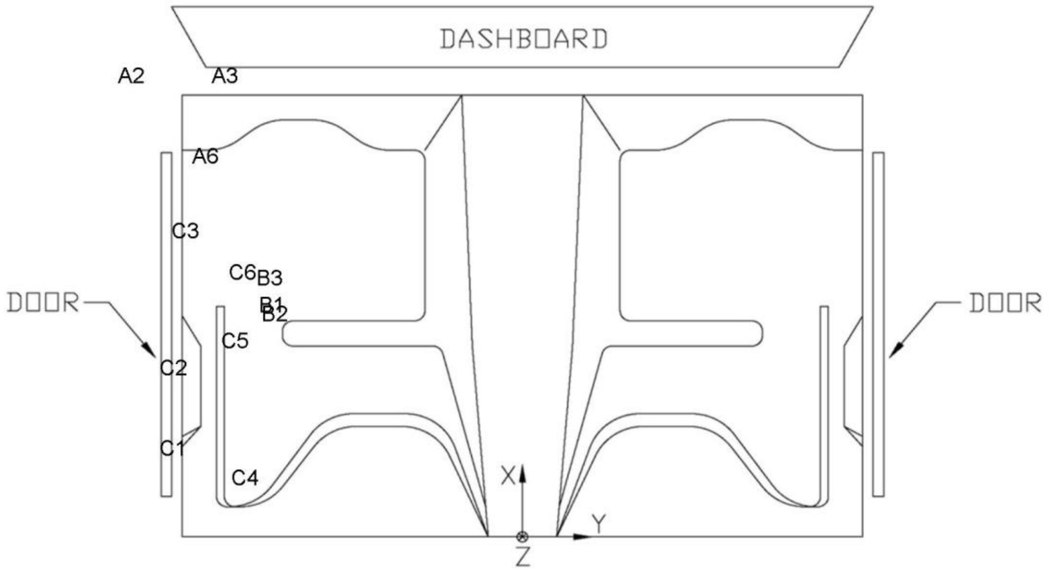


Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. MWP-4

### VEHICLE PRE/POST CRUSH
### INTERIOR CRUSH - SET 2

TEST: MWP-4
VEHICLE: Ram 1500 QC

Note: If impact is on driver side need to enter negative number for Y

| | POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|---|
| DASH | A1 | 55 3/4 | -55 1/2 | 25 1/2 | 56 | -55 | 25 1/2 | 1/4 | 1/2 | 0 |
| | A2 | 53 1/2 | -39 | 25 1/2 | 53 1/4 | -39 | 25 1/2 | - 1/4 | 0 | 0 |
| | A3 | 50 | -30 1/4 | 26 1/2 | 50 | -30 1/4 | 26 1/2 | 0 | 0 | 0 |
| | A4 | 52 | -57 1/4 | 18 3/4 | 51 1/2 | -57 1/4 | 18 3/4 | - 1/2 | 0 | 0 |
| | A5 | 47 | -45 1/4 | 15 1/4 | 47 | -45 1/4 | 15 | 0 | 0 | - 1/4 |
| | A6 | 44 1/2 | -33 | 18 1/4 | 44 1/2 | -33 | 18 1/4 | 0 | 0 | 0 |
| SIDE PANEL | B1 | 37 | -27 3/4 | 2 3/4 | 36 3/4 | -27 3/4 | 2 1/2 | - 1/4 | 0 | - 1/4 |
| | B2 | 37 | -27 1/2 | -2 | 37 | -27 1/2 | -2 | 0 | 0 | 0 |
| | B3 | 40 | -29 | 1/4 | 40 | -29 | 1/4 | 0 | 0 | 0 |
| IMPACT SIDE DOOR | C1 | 11 1/2 | -43 | 19 | 11 1/2 | -43 1/4 | 19 1/4 | 0 | - 1/4 | 1/4 |
| | C2 | 18 1/2 | -43 1/4 | 19 | 18 1/2 | -43 1/2 | 19 | 0 | - 1/4 | 0 |
| | C3 | 30 | -43 | 18 | 29 3/4 | -43 | 18 1/4 | - 1/4 | 0 | 1/4 |
| | C4 | 11 | -38 1/2 | 3 3/4 | 10 1/2 | -38 1/2 | 3 3/4 | - 1/2 | 0 | 0 |
| | C5 | 22 1/2 | -38 3/4 | 5 | 22 1/4 | -39 | 5 | - 1/4 | - 1/4 | 0 |
| | C6 | 28 1/4 | -38 1/2 | 2 1/2 | 28 | -38 3/4 | 2 1/2 | - 1/4 | - 1/4 | 0 |
| ROOF | D1 | | | | | | | 0 | 0 | 0 |
| | D2 | | | | | | | 0 | 0 | 0 |
| | D3 | | | | | | | 0 | 0 | 0 |
| | D4 | | | | | | | 0 | 0 | 0 |
| | D5 | | | | | | | 0 | 0 | 0 |
| | D6 | | | | | | | 0 | 0 | 0 |
| | D7 | | | | | | | 0 | 0 | 0 |
| | D8 | | | | | | | 0 | 0 | 0 |
| | D9 | | | | | | | 0 | 0 | 0 |
| | D10 | | | | | | | 0 | 0 | 0 |
| | D11 | | | | | | | 0 | 0 | 0 |
| | D12 | | | | | | | 0 | 0 | 0 |
| | D13 | | | | | | | 0 | 0 | 0 |
| | D14 | | | | | | | 0 | 0 | 0 |
| | D15 | | | | | | | 0 | 0 | 0 |

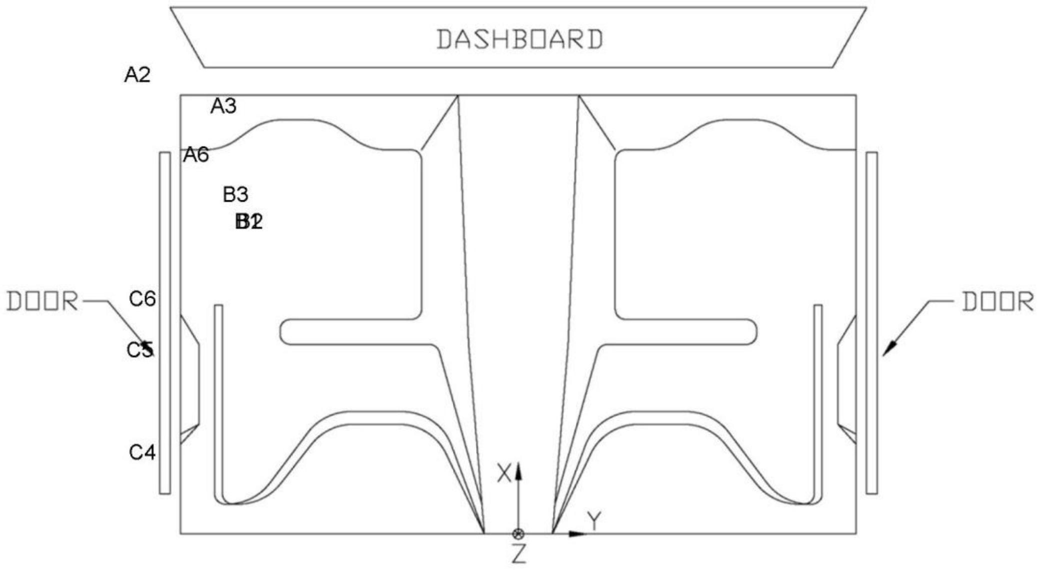
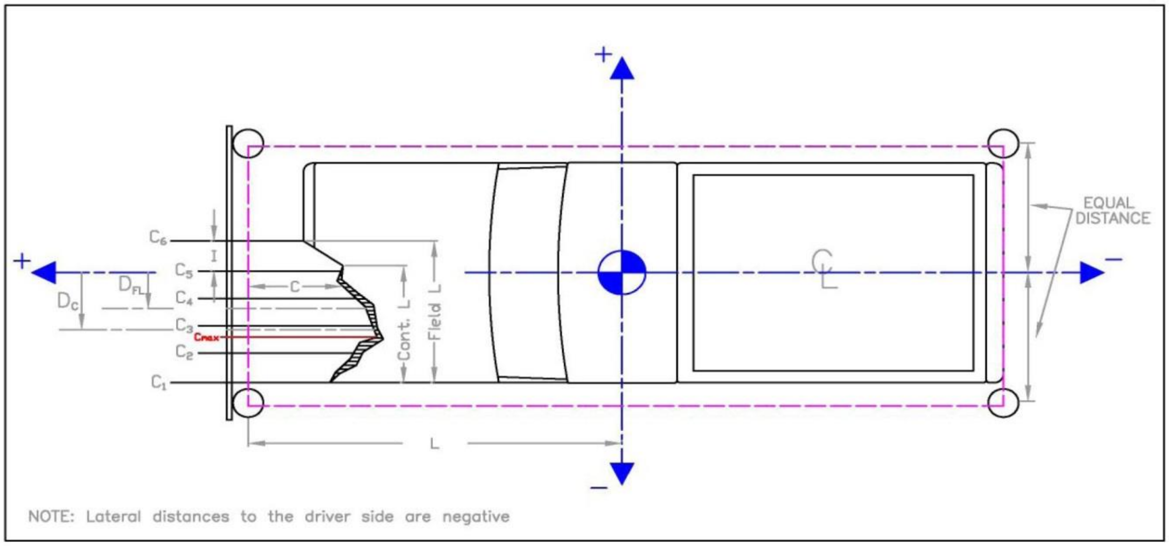


Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. MWP-4

**Date:** 11/4/2014 **Test Number:** MWP-4

**Make:** Dodge **Model:** Ram 1500 QC **Year:** 2008



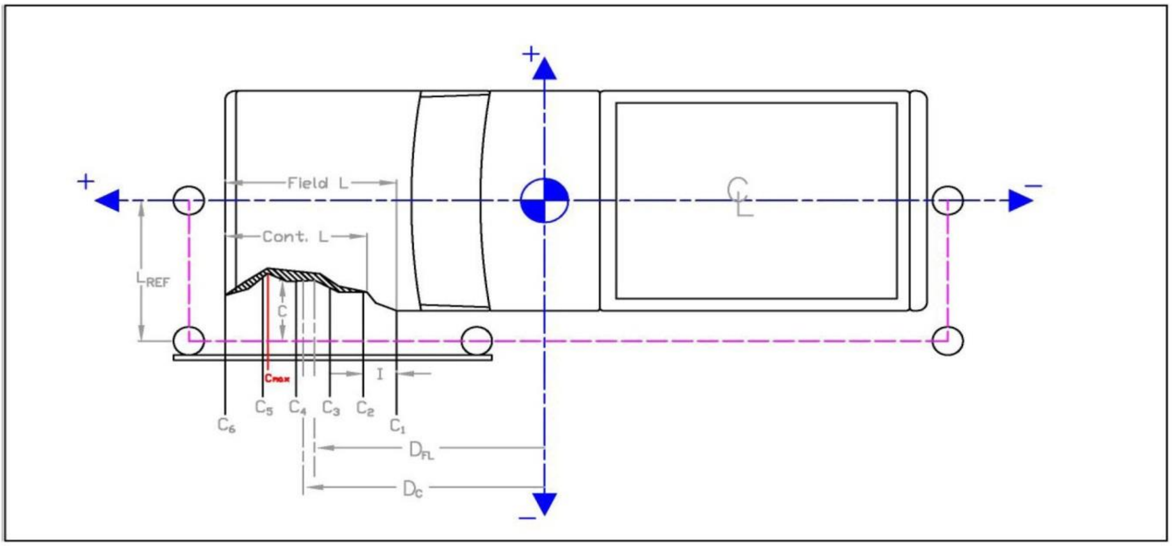
| | in. | (mm) |
|---|---|---|
| Distance from C.G. to reference line - $L_{REF}$: | 104 | (2642) |
| Width of contact and induced crush - Field L: | 19 1/2 | (495) |
| Crush measurement spacing interval (L/5) - I: | 3.9 | (99) |
| Distance from center of vehicle to center of Field L - $D_{FL}$: | -29.25 | -(743) |
| Width of Contact Damage: | 19 1/2 | (495) |
| Distance from center of vehicle to center of contect damage - $D_C$: | 29 1/4 | (743) |

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

| | Crush Measurement | | Lateral Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual | Crush |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | na | NA | -39 | -(991) | 29 | (737) | -6 | -(155) | NA | NA |
| $C_2$ | 22 | (559) | -35 1/9 | -(892) | 21 | (533) | | | 7 1/8 | (181) |
| $C_3$ | 18 1/4 | (464) | -31 1/5 | -(792) | 17 | (431) | | | 7 1/3 | (187) |
| $C_4$ | 11 | (279) | -27 1/3 | -(693) | 15 | (383) | | | 2 | (52) |
| $C_5$ | 7 3/4 | (197) | -23 2/5 | -(594) | 13 1/2 | (342) | | | 3/8 | (10) |
| $C_6$ | 6 | (152) | -19 1/2 | -(495) | 12 4/9 | (316) | | | - 1/3 | -(9) |
| $C_{MAX}$ | 22 | (559) | -35 | -(889) | 20 5/8 | (524) | | | 7 1/2 | (190) |

Figure D-5. Exterior Vehicle Crush (NASS) – Front, Test No. MWP-4

**Date:** 11/4/2014
**Test Number:** MWP-4
**Make:** Dodge
**Model:** Ram 1500 QC
**Year:** 2008



| | in. | (mm) |
|---|---|---|
| **Distance from centerline to reference line - $L_{REF}$:** | 43 | (1092) |
| **Width of contact and induced crush - Field L:** | 227 3/8 | (5775) |
| **Crush measurement spacing interval (L/5) - I:** | 45.475 | (1155) |
| **Distance from vehicle c.g. to center of Field L - $D_{FL}$:** | -15.0625 | -(383) |
| **Width of Contact Damage:** | 227 3/8 | (5775) |
| **Distance from vehicle c.g. to center of contect damage - $D_C$:** | 15 | (383) |

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 remeoved)

| | 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 | -128 3/4 | -(3270) | 15 3/8 | (391) | -7 | -(178) | NA | NA |
| $C_2$ | 4 3/4 | (121) | -83 2/7 | -(2115) | 10 1/2 | (267) | | | 1 1/4 | (32) |
| $C_3$ | 4 3/4 | (121) | -37 4/5 | -(960) | 11 4/7 | (294) | | | 1/5 | (5) |
| $C_4$ | 4 | (102) | 7 2/3 | (195) | 11 1/4 | (286) | | | - 1/4 | -(6) |
| $C_5$ | 5 3/4 | (146) | 53 1/7 | (1350) | 10 1/2 | (267) | | | 2 1/4 | (57) |
| $C_6$ | na | NA | 98 5/8 | (2505) | 37 | (940) | | | NA | NA |
| $C_{MAX}$ | 12 1/2 | (318) | 88 1/2 | (2248) | 14 1/2 | (368) | | | 5 | (127) |

Figure D-6. Exterior Vehicle Crush (NASS) – Side, Test No. MWP-4

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MWP-6
VEHICLE: 2009 Kia Rio

| POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 27.994 | 20.933 | 1.677 | 27.862 | 21.195 | 1.195 | -0.132 | 0.262 | -0.482 |
| 2 | 29.737 | 17.772 | 1.220 | 29.569 | 18.172 | 0.755 | -0.168 | 0.400 | -0.465 |
| 3 | 32.954 | 15.211 | 0.645 | 32.830 | 15.624 | 0.189 | -0.124 | 0.413 | -0.456 |
| 4 | 33.124 | 11.844 | -0.152 | 33.024 | 12.132 | -0.688 | -0.100 | 0.289 | -0.537 |
| 5 | 30.537 | 3.835 | -2.707 | 30.488 | 4.208 | -3.083 | -0.049 | 0.373 | -0.376 |
| 6 | 28.560 | 17.687 | -2.679 | 28.398 | 18.035 | -3.125 | -0.163 | 0.347 | -0.446 |
| 7 | 29.388 | 12.035 | -3.424 | 29.268 | 12.390 | -3.841 | -0.120 | 0.355 | -0.417 |
| 8 | 28.618 | 7.001 | -3.910 | 28.557 | 7.348 | -4.259 | -0.061 | 0.347 | -0.349 |
| 9 | 28.006 | 2.850 | -4.273 | 27.972 | 3.188 | -4.618 | -0.033 | 0.338 | -0.344 |
| 10 | 22.268 | 18.048 | -6.943 | 22.099 | 18.320 | -7.364 | -0.169 | 0.272 | -0.421 |
| 11 | 22.801 | 13.481 | -6.685 | 22.659 | 13.757 | -7.071 | -0.142 | 0.276 | -0.387 |
| 12 | 22.012 | 7.048 | -7.049 | 21.796 | 7.415 | -6.873 | -0.216 | 0.367 | 0.176 |
| 13 | 16.672 | 21.975 | -7.288 | 16.469 | 22.186 | -7.699 | -0.203 | 0.211 | -0.411 |
| 14 | 16.574 | 17.745 | -7.412 | 16.393 | 17.962 | -7.801 | -0.181 | 0.218 | -0.390 |
| 15 | 16.572 | 12.640 | -7.088 | 16.440 | 12.862 | -7.436 | -0.132 | 0.222 | -0.348 |
| 16 | 16.439 | 6.620 | -7.635 | 16.393 | 6.875 | -6.361 | -0.046 | 0.255 | 1.274 |
| 17 | 10.614 | 21.906 | -7.488 | 10.397 | 22.075 | -7.859 | -0.217 | 0.170 | -0.372 |
| 18 | 11.465 | 15.973 | -7.044 | 11.326 | 16.151 | -7.386 | -0.139 | 0.178 | -0.342 |
| 19 | 11.592 | 10.805 | -7.069 | 11.487 | 11.011 | -7.370 | -0.105 | 0.206 | -0.301 |
| 20 | 11.740 | 4.470 | -7.654 | 11.584 | 4.741 | -6.973 | -0.156 | 0.270 | 0.681 |
| 21 | 7.140 | 20.615 | -7.417 | 6.935 | 20.757 | -7.751 | -0.205 | 0.141 | -0.334 |
| 22 | 7.197 | 15.328 | -7.052 | 7.040 | 15.472 | -7.362 | -0.156 | 0.144 | -0.310 |
| 23 | 7.921 | 10.947 | -7.079 | 7.804 | 11.098 | -7.359 | -0.117 | 0.151 | -0.280 |
| 24 | 8.129 | 4.670 | -7.595 | 8.066 | 4.833 | -7.613 | -0.063 | 0.163 | -0.019 |
| 25 | 2.061 | 18.731 | -3.610 | 1.921 | 18.850 | -3.897 | -0.140 | 0.118 | -0.287 |
| 26 | 1.935 | 14.083 | -3.600 | 1.777 | 14.185 | -3.871 | -0.158 | 0.102 | -0.270 |
| 27 | 1.904 | 9.988 | -3.593 | 1.785 | 10.129 | -3.840 | -0.119 | 0.140 | -0.247 |
| 28 | 1.886 | 4.191 | -3.777 | 1.869 | 4.310 | -3.982 | -0.017 | 0.119 | -0.204 |
| | | | | | | | | | |
| | | | | | | | | | |

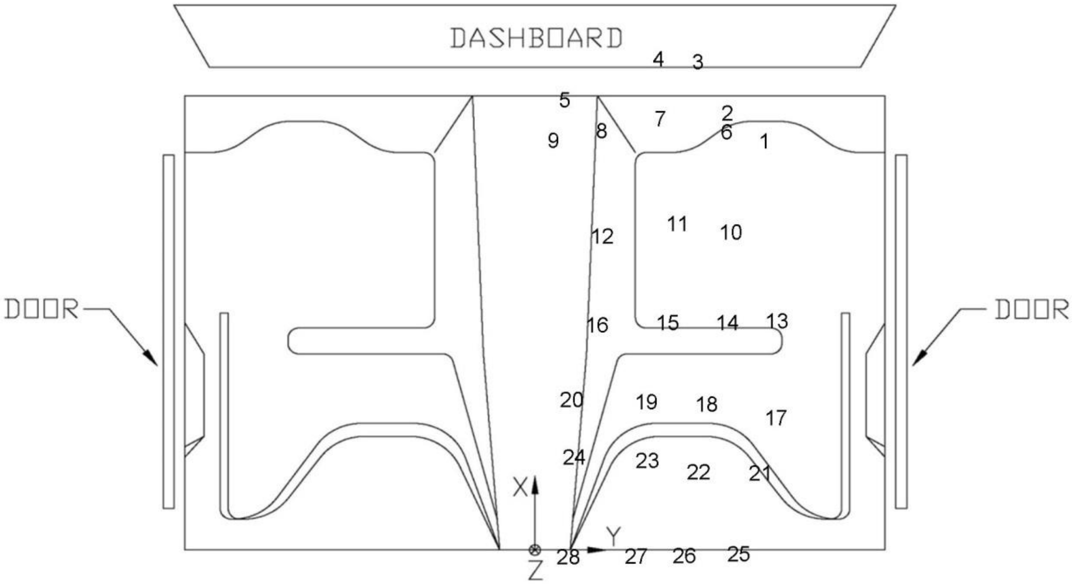


Figure D-7. Floor Pan Deformation Data – Set 1, Test No. MWP-6

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MWP-6
VEHICLE: 2009 Kia Rio

| POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 37.527 | 25.751 | 1.875 | 37.503 | 25.910 | 1.816 | -0.024 | 0.159 | -0.059 |
| 2 | 39.366 | 22.620 | 1.264 | 39.284 | 22.893 | 1.236 | -0.082 | 0.273 | -0.028 |
| 3 | 42.573 | 20.208 | 0.413 | 42.532 | 20.456 | 0.392 | -0.042 | 0.248 | -0.021 |
| 4 | 42.794 | 16.802 | -0.387 | 42.755 | 16.999 | -0.470 | -0.039 | 0.197 | -0.083 |
| 5 | 40.200 | 8.706 | -2.686 | 40.227 | 8.981 | -2.691 | 0.027 | 0.274 | -0.005 |
| 6 | 37.778 | 22.467 | -2.563 | 37.744 | 22.706 | -2.592 | -0.034 | 0.240 | -0.028 |
| 7 | 38.769 | 16.872 | -3.302 | 38.741 | 17.119 | -3.323 | -0.028 | 0.247 | -0.021 |
| 8 | 38.154 | 11.808 | -3.685 | 38.135 | 12.058 | -3.699 | -0.019 | 0.250 | -0.015 |
| 9 | 37.659 | 7.636 | -3.973 | 37.637 | 7.883 | -4.002 | -0.022 | 0.247 | -0.029 |
| 10 | 31.146 | 22.593 | -6.190 | 31.093 | 22.750 | -6.225 | -0.053 | 0.157 | -0.035 |
| 11 | 31.870 | 18.054 | -5.958 | 31.842 | 18.299 | -5.987 | -0.028 | 0.245 | -0.029 |
| 12 | 31.144 | 11.634 | -6.212 | 31.254 | 11.845 | -5.730 | 0.110 | 0.211 | 0.483 |
| 13 | 25.406 | 26.305 | -6.049 | 25.373 | 26.546 | -6.079 | -0.033 | 0.241 | -0.030 |
| 14 | 25.450 | 22.078 | -6.142 | 25.419 | 22.322 | -6.184 | -0.031 | 0.245 | -0.042 |
| 15 | 25.667 | 16.983 | -5.791 | 25.637 | 17.227 | -5.832 | -0.030 | 0.244 | -0.040 |
| 16 | 25.705 | 10.957 | -6.293 | 25.798 | 11.340 | -4.776 | 0.093 | 0.383 | 1.518 |
| 17 | 19.359 | 26.023 | -5.699 | 19.329 | 26.267 | -5.728 | -0.029 | 0.244 | -0.029 |
| 18 | 20.399 | 20.084 | -5.293 | 20.425 | 20.346 | -5.344 | 0.025 | 0.262 | -0.051 |
| 19 | 20.782 | 14.973 | -5.313 | 20.669 | 15.205 | -5.344 | -0.113 | 0.232 | -0.031 |
| 20 | 21.107 | 8.640 | -5.876 | 21.063 | 8.954 | -4.963 | -0.043 | 0.314 | 0.913 |
| 21 | 15.970 | 24.612 | -5.303 | 15.943 | 24.860 | -5.329 | -0.028 | 0.248 | -0.026 |
| 22 | 16.239 | 19.329 | -4.921 | 16.210 | 19.570 | -4.963 | -0.030 | 0.241 | -0.042 |
| 23 | 17.150 | 14.926 | -4.994 | 17.087 | 15.224 | -5.029 | -0.064 | 0.298 | -0.035 |
| 24 | 17.509 | 8.708 | -5.493 | 17.507 | 8.968 | -5.312 | -0.002 | 0.260 | 0.182 |
| 25 | 11.313 | 22.558 | -1.047 | 11.303 | 22.817 | -1.071 | -0.010 | 0.259 | -0.024 |
| 26 | 11.351 | 17.921 | -1.003 | 11.313 | 18.141 | -1.040 | -0.038 | 0.220 | -0.037 |
| 27 | 11.449 | 13.852 | -0.974 | 11.445 | 14.107 | -1.019 | -0.003 | 0.254 | -0.045 |
| 28 | 11.653 | 8.026 | -1.123 | 11.647 | 8.263 | -1.170 | -0.006 | 0.237 | -0.047 |
| | | | | | | | | | |
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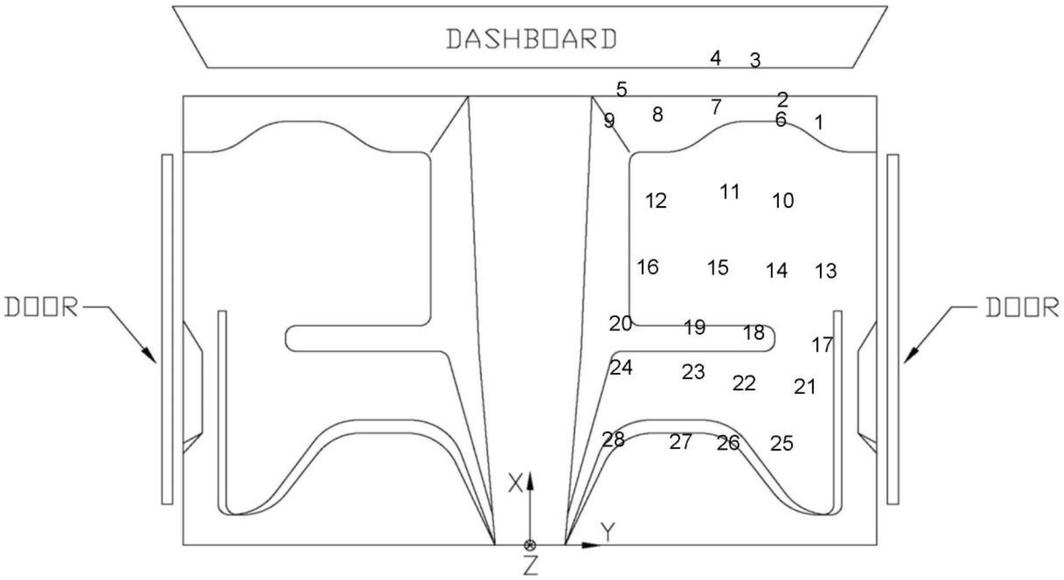
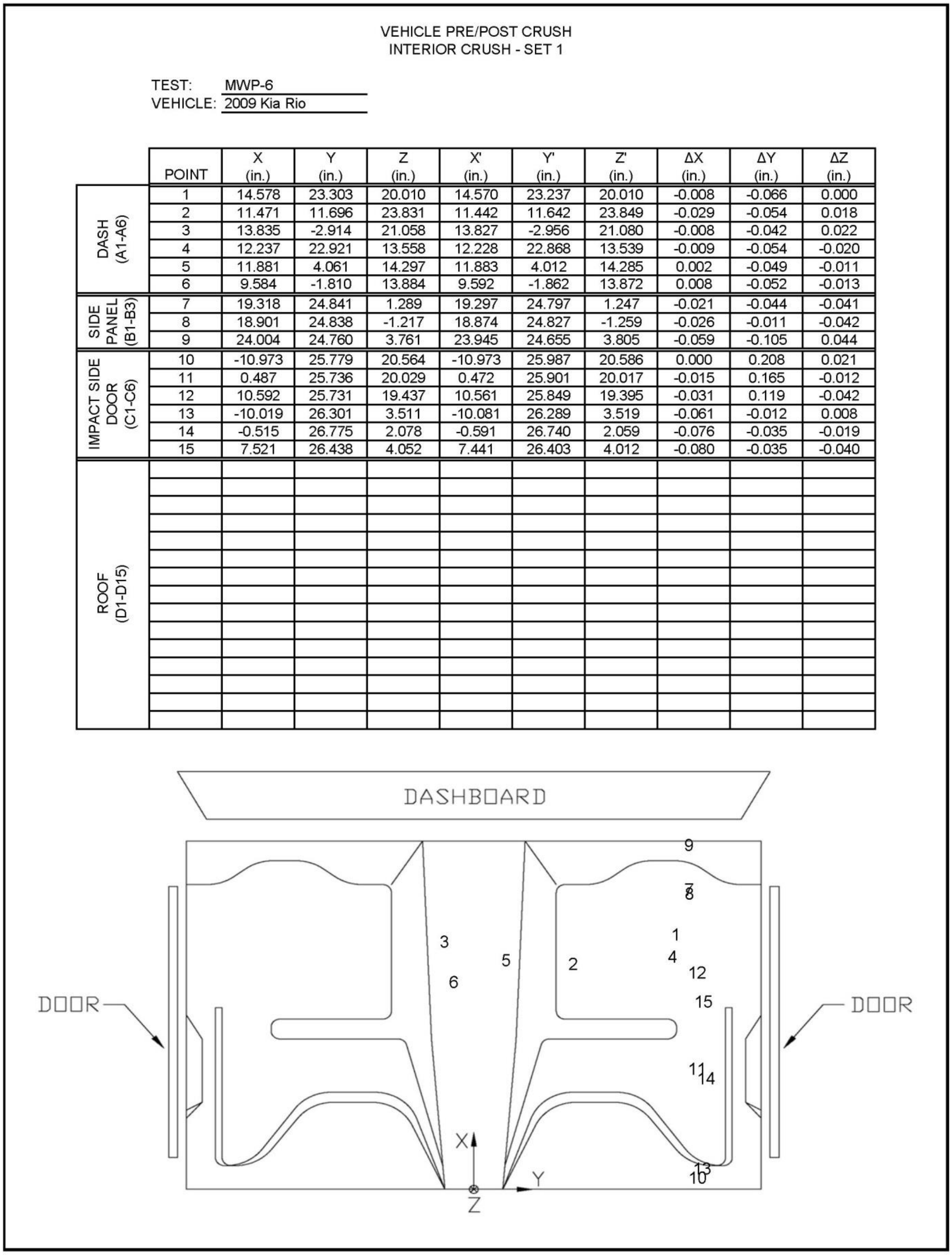


Figure D-8. Floor Pan Deformation Data – Set 2, Test No. MWP-6



VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MWP-6
VEHICLE: 2009 Kia Rio

| | POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|---|
| DASH (A1-A6) | 1 | 14.578 | 23.303 | 20.010 | 14.570 | 23.237 | 20.010 | -0.008 | -0.066 | 0.000 |
| | 2 | 11.471 | 11.696 | 23.831 | 11.442 | 11.642 | 23.849 | -0.029 | -0.054 | 0.018 |
| | 3 | 13.835 | -2.914 | 21.058 | 13.827 | -2.956 | 21.080 | -0.008 | -0.042 | 0.022 |
| | 4 | 12.237 | 22.921 | 13.558 | 12.228 | 22.868 | 13.539 | -0.009 | -0.054 | -0.020 |
| | 5 | 11.881 | 4.061 | 14.297 | 11.883 | 4.012 | 14.285 | 0.002 | -0.049 | -0.011 |
| | 6 | 9.584 | -1.810 | 13.884 | 9.592 | -1.862 | 13.872 | 0.008 | -0.052 | -0.013 |
| SIDE PANEL (B1-B3) | 7 | 19.318 | 24.841 | 1.289 | 19.297 | 24.797 | 1.247 | -0.021 | -0.044 | -0.041 |
| | 8 | 18.901 | 24.838 | -1.217 | 18.874 | 24.827 | -1.259 | -0.026 | -0.011 | -0.042 |
| | 9 | 24.004 | 24.760 | 3.761 | 23.945 | 24.655 | 3.805 | -0.059 | -0.105 | 0.044 |
| IMPACT SIDE DOOR (C1-C6) | 10 | -10.973 | 25.779 | 20.564 | -10.973 | 25.987 | 20.586 | 0.000 | 0.208 | 0.021 |
| | 11 | 0.487 | 25.736 | 20.029 | 0.472 | 25.901 | 20.017 | -0.015 | 0.165 | -0.012 |
| | 12 | 10.592 | 25.731 | 19.437 | 10.561 | 25.849 | 19.395 | -0.031 | 0.119 | -0.042 |
| | 13 | -10.019 | 26.301 | 3.511 | -10.081 | 26.289 | 3.519 | -0.061 | -0.012 | 0.008 |
| | 14 | -0.515 | 26.775 | 2.078 | -0.591 | 26.740 | 2.059 | -0.076 | -0.035 | -0.019 |
| | 15 | 7.521 | 26.438 | 4.052 | 7.441 | 26.403 | 4.012 | -0.080 | -0.035 | -0.040 |
| ROOF (D1-D15) | | | | | | | | | | |
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Figure D-9. Occupant Compartment Deformation Data – Set 1, Test No. MWP-6

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MWP-6
VEHICLE: 2009 Kia Rio

|  | POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|---|
| DASH (A1-A6) | 1 | 26.253 | 27.680 | 21.664 | 26.241 | 27.633 | 21.637 | -0.012 | -0.047 | -0.027 |
|  | 2 | 23.793 | 15.995 | 25.718 | 23.829 | 15.957 | 25.680 | 0.035 | -0.037 | -0.038 |
|  | 3 | 26.334 | 1.468 | 22.735 | 26.363 | 1.410 | 22.729 | 0.029 | -0.058 | -0.007 |
|  | 4 | 23.387 | 27.223 | 15.426 | 23.416 | 27.149 | 15.376 | 0.029 | -0.074 | -0.050 |
|  | 5 | 23.628 | 8.378 | 16.216 | 23.664 | 8.316 | 16.141 | 0.037 | -0.062 | -0.074 |
|  | 6 | 21.455 | 2.432 | 15.978 | 21.513 | 2.364 | 15.938 | 0.058 | -0.068 | -0.040 |
| SIDE PANEL (B1-B3) | 7 | 29.368 | 29.310 | 2.607 | 29.381 | 29.247 | 2.573 | 0.013 | -0.064 | -0.034 |
|  | 8 | 28.745 | 29.290 | 0.145 | 28.748 | 29.260 | 0.111 | 0.003 | -0.030 | -0.034 |
|  | 9 | 34.237 | 29.360 | 4.737 | 34.224 | 29.243 | 4.676 | -0.014 | -0.117 | -0.061 |
| IMPACT SIDE DOOR (C1-C6) | 10 | 0.776 | 29.429 | 24.335 | 0.787 | 29.659 | 24.367 | 0.011 | 0.230 | 0.032 |
|  | 11 | 12.151 | 29.693 | 22.891 | 12.151 | 29.876 | 22.848 | 0.000 | 0.183 | -0.043 |
|  | 12 | 22.195 | 29.982 | 21.421 | 22.152 | 30.101 | 21.385 | -0.043 | 0.119 | -0.036 |
|  | 13 | 0.286 | 29.945 | 7.268 | 0.255 | 29.934 | 7.285 | -0.030 | -0.011 | 0.017 |
|  | 14 | 9.625 | 30.681 | 5.049 | 9.577 | 30.651 | 5.018 | -0.048 | -0.030 | -0.031 |
|  | 15 | 17.792 | 30.579 | 6.341 | 17.749 | 30.533 | 6.309 | -0.043 | -0.046 | -0.031 |
| ROOF (D1-D15) |  |  |  |  |  |  |  |  |  |  |
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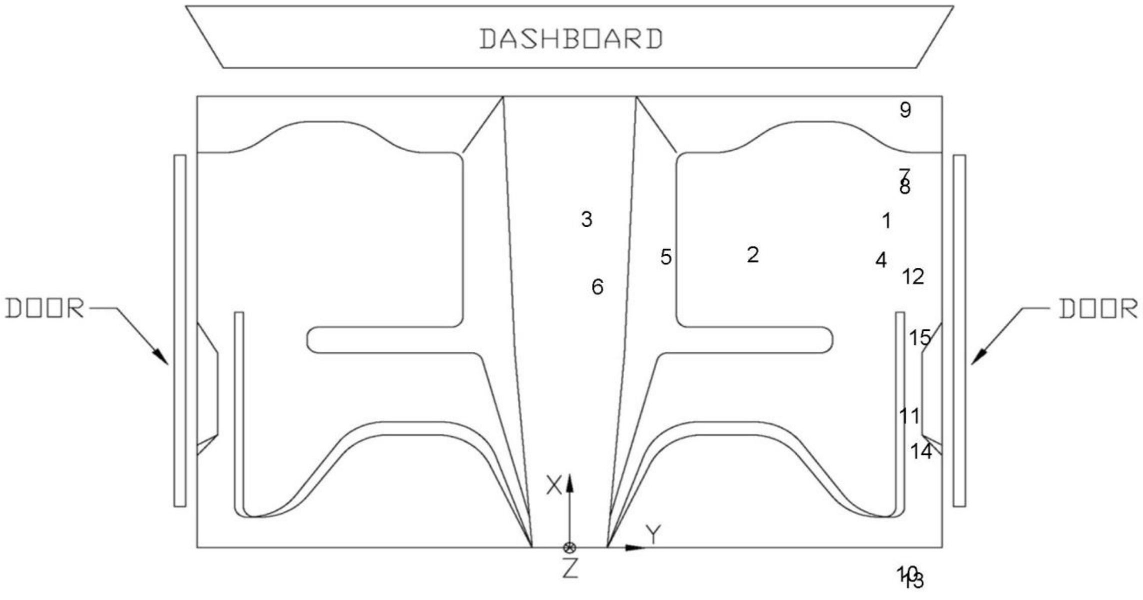


Figure D-10. Occupant Compartment Deformation Data – Set 2, Test No. MWP-6

MWP-6 Roof Crush

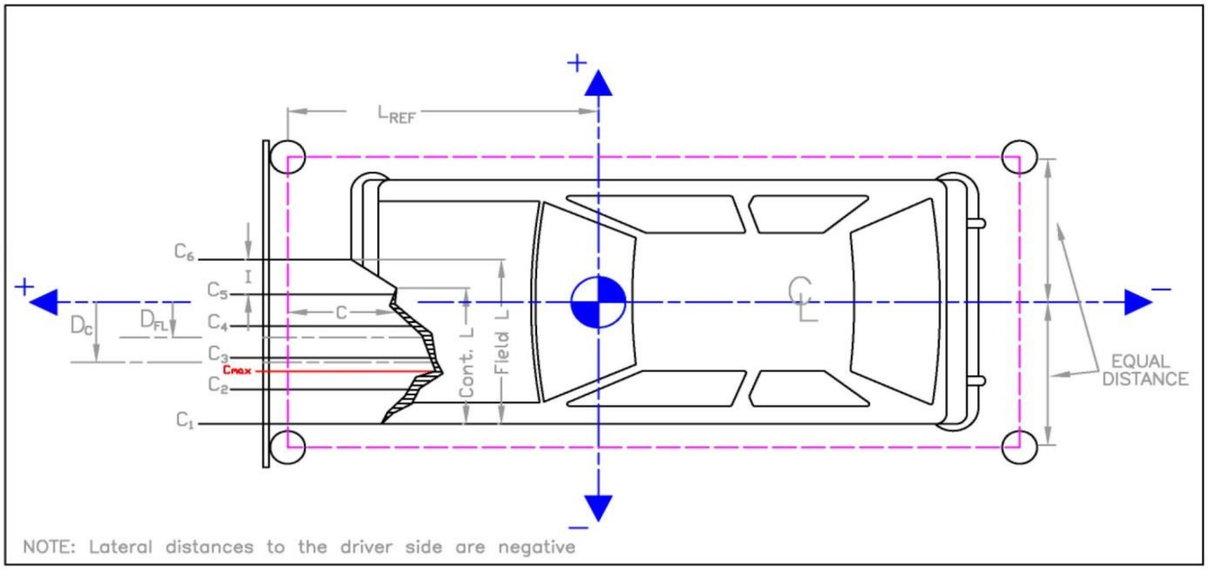
Comparative measurement of SFH-2 roof damage to undamaged vehicle:

| | |
|---|---|
| MWP-6 at max point of crush | 6.25" |
| Undamaged vehicle | 5.25" |
| Total crush | 1" |

Figure D-11. Roof Deformation Documentation, Test No. MWP-6

**Date:** 1/21/2015
**Test Number:** MWP-6

**Make:** Kia
**Model:** Rio
**Year:** 2009



| | in. | (mm) |
|---|---|---|
| Distance from C.G. to reference line - $L_{REF}$: | 71 | (1803) |
| Width of contact and induced crush - Field L: | 61 1/4 | (1556) |
| Crush measurement spacing interval (L/5) - I: | 12 1/4 | (311) |
| Distance from center of vehicle to center of Field L - $D_{FL}$: | 0 | 0 |
| Width of Contact Damage: | 61 1/4 | (1556) |
| Distance from center of vehicle to center of contect damage - $D_C$: | 0 | 0 |

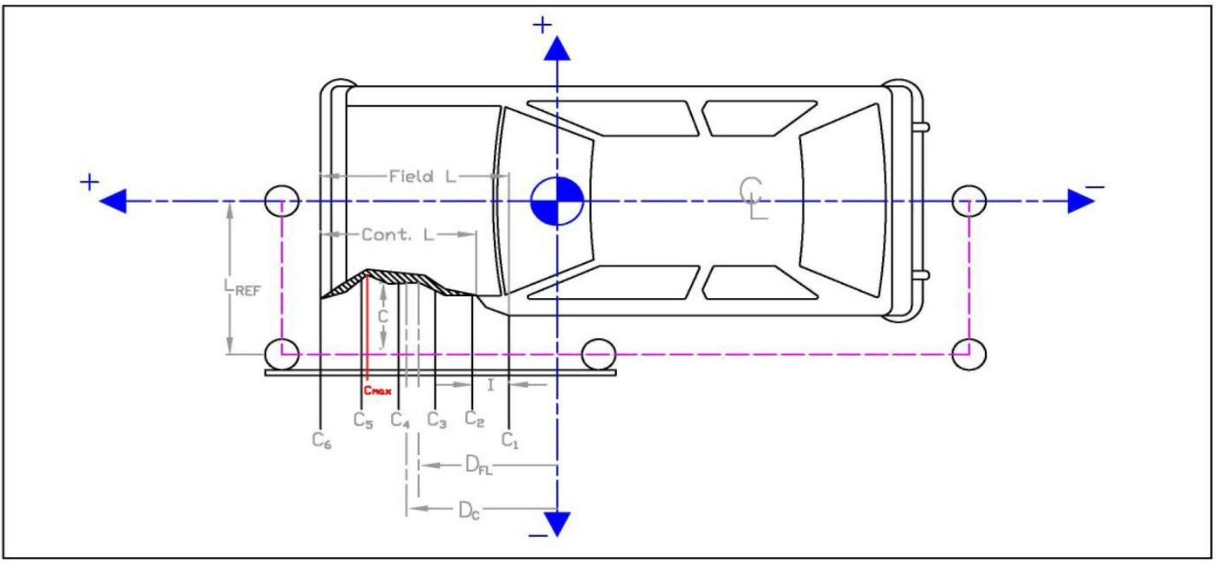
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

| | Crush Measurement | | Lateral Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual Crush | |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | NA | NA | -30 5/8 | -(778) | 18 5/6 | (479) | -7 | -(177) | NA | NA |
| $C_2$ | 3 | (76) | -18 3/8 | -(467) | 8 2/9 | (209) | | | 1 3/4 | (44) |
| $C_3$ | 4 3/4 | (121) | -6 1/8 | -(156) | 6 1/7 | (156) | | | 5 5/9 | (141) |
| $C_4$ | 2 1/2 | (64) | 6 1/8 | (156) | 6 1/8 | (156) | | | 3 1/3 | (84) |
| $C_5$ | 2 3/4 | (70) | 18 3/8 | (467) | 8 1/6 | (208) | | | 1 1/2 | (39) |
| $C_6$ | na | NA | 30 5/8 | (778) | 17 4/5 | (452) | | | NA | NA |
| $C_{MAX}$ | 6 | (152) | 9 | (229) | 6 3/8 | (162) | | | 6 4/7 | (167) |

Figure D-12. Exterior Vehicle Crush (NASS) – Front, Test No. MWP-6

**Date:** 1/21/2015 **Test Number:** MWP-6

**Make:** Kia **Model:** Rio **Year:** 2009



| | in. | (mm) |
|---|---|---|
| Distance from centerline to reference line - $L_{REF}$: | 36 | (914) |
| Width of contact and induced crush - Field L: | 167 | (4242) |
| Crush measurement spacing interval (L/5) - I: | 33.4 | (848) |
| Distance from vehicle c.g. to center of Field L - $D_{FL}$: | -12 | -(305) |
| Width of Contact Damage: | 167 | (4242) |
| Distance from vehicle c.g. to center of contect damage - $D_C$: | 12 | (305) |

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 remeoved)

| | 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 | -95.5 | -(2426) | 26.00 | (660) | 0 | () | NA | NA |
| $C_2$ | 4 | (102) | -62.1 | -(1577) | 4.00 | (102) | | | 0.0 | () |
| $C_3$ | 3.5 | (89) | -28.7 | -(729) | 3.63 | (92) | | | -0.1 | -(3) |
| $C_4$ | 2 | (51) | 4.7 | (119) | 3.75 | (95) | | | -1.8 | -(44) |
| $C_5$ | 4 | (102) | 38.1 | (968) | 3.25 | (83) | | | 0.8 | (19) |
| $C_6$ | na | NA | 71.5 | (1816) | 21.75 | (552) | | | NA | NA |
| $C_{MAX}$ | 15.25 | (387) | 55 | (1397) | 4.56 | (116) | | | 10.7 | (271) |

Figure D-13. Exterior Vehicle Crush (NASS) – Side, Test No. MWP-6

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MWP-7
VEHICLE: 1100C

| POINT | X<br>(in.) | Y<br>(in.) | Z<br>(in.) | X'<br>(in.) | Y'<br>(in.) | Z'<br>(in.) | ΔX<br>(in.) | ΔY<br>(in.) | ΔZ<br>(in.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 28.397 | 20.090 | 0.597 | 28.220 | 19.883 | 3.999 | -0.178 | -0.207 | 3.402 |
| 2 | 30.500 | 16.692 | -0.552 | 30.450 | 16.589 | 2.858 | -0.050 | -0.102 | 3.410 |
| 3 | 32.970 | 13.502 | -1.716 | 33.034 | 13.483 | 1.744 | 0.063 | -0.020 | 3.460 |
| 4 | 30.723 | 4.341 | -3.735 | 30.993 | 4.396 | -0.932 | 0.270 | 0.055 | 2.803 |
| 5 | 27.775 | 17.645 | -3.824 | 28.061 | 17.693 | -0.587 | 0.286 | 0.047 | 3.237 |
| 6 | 29.364 | 13.722 | -4.197 | 29.696 | 13.861 | -1.003 | 0.332 | 0.139 | 3.194 |
| 7 | 28.655 | 9.983 | -4.730 | 28.982 | 10.124 | -1.830 | 0.327 | 0.141 | 2.900 |
| 8 | 28.128 | 3.545 | -4.981 | 28.526 | 3.738 | -2.447 | 0.398 | 0.193 | 2.534 |
| 9 | 24.217 | 17.537 | -6.526 | 24.783 | 17.812 | -3.605 | 0.566 | 0.275 | 2.921 |
| 10 | 24.123 | 13.278 | -6.281 | 24.688 | 13.554 | -3.576 | 0.566 | 0.276 | 2.706 |
| 11 | 24.014 | 9.616 | -6.610 | 24.599 | 9.896 | -4.091 | 0.585 | 0.280 | 2.519 |
| 12 | 23.954 | 3.773 | -6.671 | 24.534 | 4.054 | -4.478 | 0.580 | 0.281 | 2.193 |
| 13 | 19.099 | 18.936 | -6.647 | 19.670 | 19.240 | -4.107 | 0.571 | 0.304 | 2.540 |
| 14 | 19.037 | 14.049 | -6.547 | 19.596 | 14.349 | -4.289 | 0.559 | 0.300 | 2.258 |
| 15 | 18.977 | 8.651 | -6.766 | 19.578 | 8.993 | -4.660 | 0.601 | 0.342 | 2.105 |
| 16 | 19.182 | 4.633 | -6.643 | 19.856 | 4.945 | -4.602 | 0.674 | 0.312 | 2.041 |
| 17 | 15.563 | 21.748 | -6.506 | 16.133 | 22.005 | -4.134 | 0.570 | 0.256 | 2.372 |
| 18 | 15.450 | 16.312 | -6.245 | 15.997 | 16.610 | -4.194 | 0.547 | 0.298 | 2.051 |
| 19 | 14.793 | 11.237 | -6.165 | 15.384 | 11.541 | -4.440 | 0.591 | 0.304 | 1.725 |
| 20 | 15.136 | 4.499 | -6.653 | 15.785 | 4.798 | -4.012 | 0.649 | 0.298 | 2.641 |
| 21 | 9.652 | 19.901 | -6.048 | 10.192 | 20.206 | -4.321 | 0.539 | 0.306 | 1.727 |
| 22 | 9.611 | 16.211 | -5.326 | 10.150 | 16.467 | -3.815 | 0.539 | 0.257 | 1.512 |
| 23 | 9.353 | 10.456 | -5.302 | 9.852 | 10.715 | -4.077 | 0.498 | 0.259 | 1.225 |
| 24 | 9.150 | 5.848 | -5.994 | 9.694 | 6.148 | -3.866 | 0.544 | 0.300 | 2.128 |
| 25 | 2.231 | 20.401 | -0.887 | 2.355 | 20.467 | 0.168 | 0.124 | 0.066 | 1.055 |
| 26 | 1.818 | 15.840 | -0.610 | 1.922 | 15.895 | 0.161 | 0.104 | 0.055 | 0.771 |
| 27 | 1.734 | 7.978 | -0.596 | 1.827 | 8.029 | -0.252 | 0.093 | 0.050 | 0.344 |
| 28 | 2.124 | 4.216 | -0.973 | 2.248 | 4.261 | -0.783 | 0.124 | 0.045 | 0.190 |
| | | | | | | | | | |
| | | | | | | | | | |

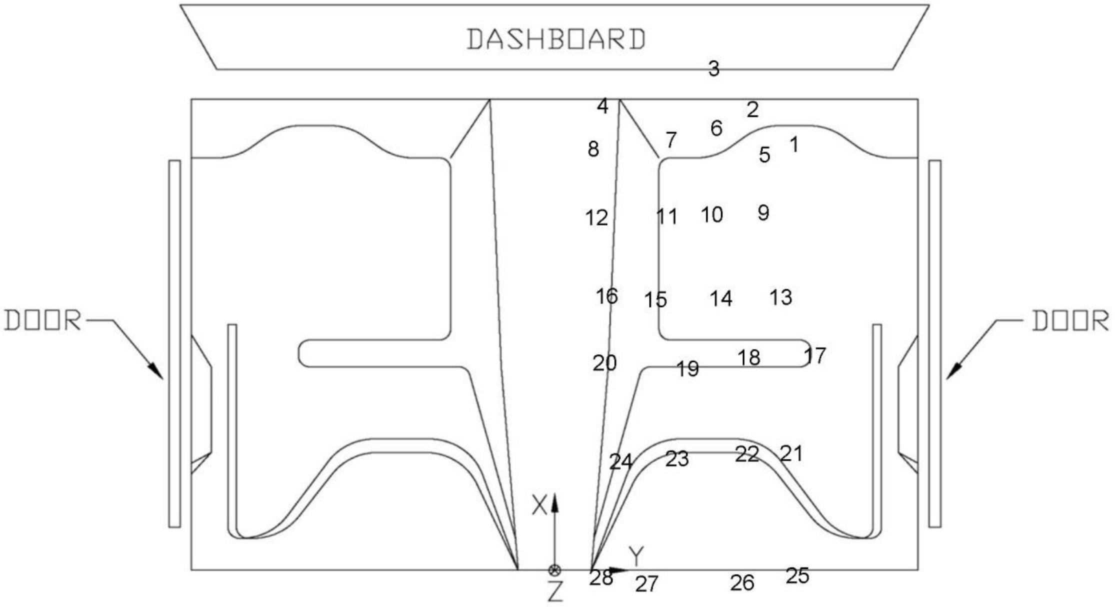


Figure D-14. Floor Pan Deformation Data – Set 1, Test No. MWP-7

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MWP-7
VEHICLE: 1100C

| POINT | X<br>(in.) | Y<br>(in.) | Z<br>(in.) | X'<br>(in.) | Y'<br>(in.) | Z'<br>(in.) | ΔX<br>(in.) | ΔY<br>(in.) | ΔZ<br>(in.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 38.788 | 24.949 | 2.006 | 38.483 | 24.867 | 2.041 | -0.304 | -0.081 | 0.035 |
| 2 | 40.955 | 21.543 | 0.960 | 40.709 | 21.495 | 0.996 | -0.246 | -0.047 | 0.037 |
| 3 | 43.523 | 18.387 | -0.042 | 43.262 | 18.395 | 0.025 | -0.261 | 0.007 | 0.068 |
| 4 | 41.467 | 9.147 | -2.119 | 41.216 | 9.196 | -2.092 | -0.251 | 0.049 | 0.027 |
| 5 | 38.502 | 22.410 | -2.490 | 38.229 | 22.416 | -2.430 | -0.273 | 0.006 | 0.059 |
| 6 | 40.120 | 18.542 | -2.699 | 39.885 | 18.557 | -2.659 | -0.235 | 0.016 | 0.041 |
| 7 | 39.426 | 14.819 | -3.287 | 39.158 | 14.833 | -3.266 | -0.267 | 0.015 | 0.021 |
| 8 | 38.982 | 8.345 | -3.528 | 38.736 | 8.299 | -3.507 | -0.246 | -0.046 | 0.022 |
| 9 | 35.143 | 22.354 | -5.384 | 34.924 | 22.352 | -5.370 | -0.220 | -0.002 | 0.014 |
| 10 | 35.059 | 18.109 | -5.126 | 34.787 | 18.084 | -5.127 | -0.272 | -0.025 | -0.001 |
| 11 | 34.960 | 14.420 | -5.463 | 34.712 | 14.423 | -5.429 | -0.248 | 0.003 | 0.034 |
| 12 | 34.891 | 8.606 | -5.529 | 34.701 | 8.597 | -5.466 | -0.190 | -0.009 | 0.063 |
| 13 | 30.006 | 23.762 | -5.869 | 29.749 | 23.769 | -5.864 | -0.257 | 0.007 | 0.005 |
| 14 | 29.947 | 18.834 | -5.764 | 29.709 | 18.850 | -5.768 | -0.238 | 0.016 | -0.003 |
| 15 | 29.945 | 13.481 | -5.971 | 29.659 | 13.487 | -5.832 | -0.286 | 0.006 | 0.139 |
| 16 | 30.131 | 9.434 | -5.825 | 29.970 | 9.412 | -5.545 | -0.161 | -0.021 | 0.280 |
| 17 | 26.462 | 26.525 | -5.980 | 26.214 | 26.493 | -5.972 | -0.249 | -0.032 | 0.008 |
| 18 | 26.331 | 21.069 | -5.717 | 26.089 | 21.070 | -5.728 | -0.242 | 0.001 | -0.010 |
| 19 | 25.710 | 16.044 | -5.670 | 25.494 | 16.029 | -5.675 | -0.216 | -0.015 | -0.005 |
| 20 | 26.094 | 9.265 | -6.111 | 25.906 | 9.328 | -4.873 | -0.188 | 0.062 | 1.238 |
| 21 | 20.486 | 24.657 | -5.919 | 20.279 | 24.650 | -5.934 | -0.207 | -0.007 | -0.015 |
| 22 | 20.516 | 20.997 | -5.204 | 20.261 | 20.964 | -5.219 | -0.256 | -0.033 | -0.015 |
| 23 | 20.256 | 15.209 | -5.181 | 20.013 | 15.233 | -5.157 | -0.242 | 0.024 | 0.024 |
| 24 | 20.073 | 10.599 | -5.872 | 19.825 | 10.588 | -4.664 | -0.248 | -0.011 | 1.209 |
| 25 | 12.796 | 25.148 | -1.299 | 12.535 | 25.153 | -1.310 | -0.262 | 0.005 | -0.011 |
| 26 | 12.389 | 20.567 | -1.033 | 12.106 | 20.579 | -1.045 | -0.284 | 0.012 | -0.012 |
| 27 | 12.289 | 12.745 | -0.999 | 12.071 | 12.725 | -1.019 | -0.218 | -0.020 | -0.020 |
| 28 | 12.703 | 8.920 | -1.326 | 12.484 | 8.925 | -1.351 | -0.219 | 0.006 | -0.024 |
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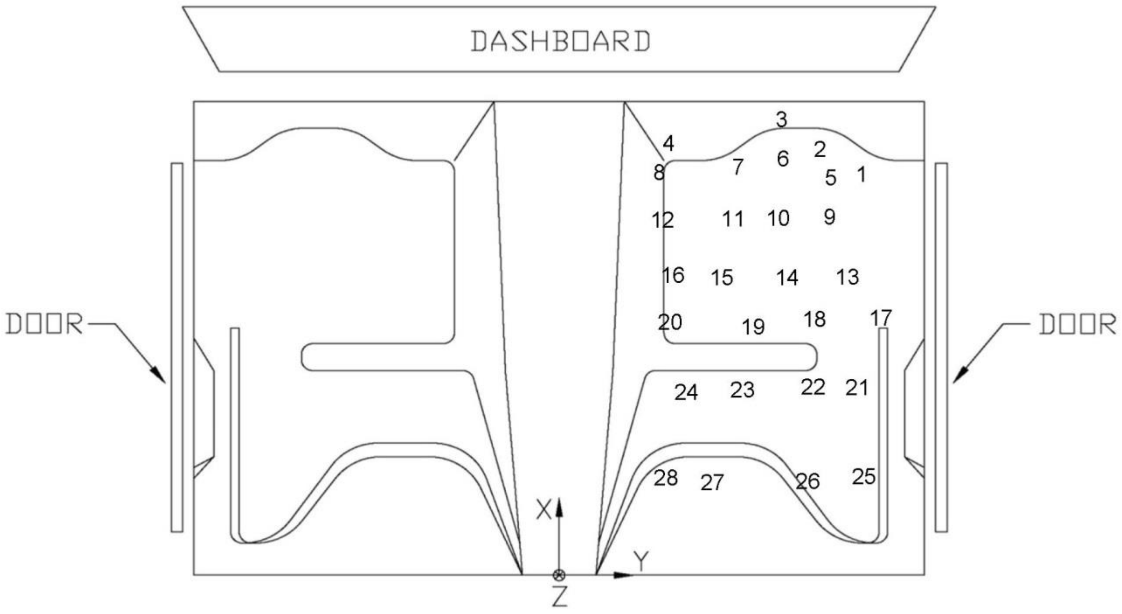

Figure D-15. Floor Pan Deformation Data – Set 2, Test No. MWP-7

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MWP-7
VEHICLE: 1100C

| | POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|---|
| DASH (A1-A6) | 1 | 18.131 | 22.778 | 21.114 | 16.213 | 21.533 | 23.603 | -1.918 | -1.246 | 2.489 |
| | 2 | 15.380 | 11.158 | 25.226 | 13.170 | 9.719 | 26.842 | -2.210 | -1.439 | 1.615 |
| | 3 | 17.355 | -3.126 | 22.207 | 15.355 | -4.377 | 23.219 | -1.999 | -1.251 | 1.012 |
| | 4 | 15.297 | 22.503 | 11.615 | 14.222 | 21.742 | 13.892 | -1.074 | -0.761 | 2.277 |
| | 5 | 14.799 | 4.525 | 15.642 | 13.400 | 3.607 | 16.915 | -1.398 | -0.918 | 1.272 |
| | 6 | 11.938 | -2.677 | 15.659 | 10.556 | -3.567 | 16.293 | -1.382 | -0.890 | 0.634 |
| SIDE PANEL (B1-B3) | 7 | 20.192 | 24.272 | 2.283 | 19.919 | 23.942 | 5.154 | -0.273 | -0.330 | 2.871 |
| | 8 | 18.671 | 24.343 | -0.631 | 18.713 | 24.249 | 2.100 | 0.041 | -0.095 | 2.731 |
| | 9 | 25.113 | 24.208 | 3.618 | 24.778 | 23.705 | 6.843 | -0.335 | -0.503 | 3.225 |
| IMPACT SIDE DOOR (C1-C6) | 10 | -8.369 | 25.471 | 25.957 | -10.605 | 24.244 | 26.168 | -2.236 | -1.228 | 0.211 |
| | 11 | 2.813 | 25.341 | 23.686 | 0.763 | 24.134 | 24.984 | -2.050 | -1.207 | 1.298 |
| | 12 | 15.496 | 25.232 | 20.951 | 13.561 | 24.087 | 23.361 | -1.936 | -1.146 | 2.410 |
| | 13 | -6.027 | 26.187 | 6.131 | -6.538 | 25.888 | 6.760 | -0.511 | -0.300 | 0.630 |
| | 14 | 2.551 | 26.080 | 3.908 | 2.230 | 25.800 | 5.290 | -0.321 | -0.280 | 1.382 |
| | 15 | 9.072 | 26.025 | 5.925 | 8.470 | 25.576 | 7.797 | -0.602 | -0.448 | 1.871 |
| ROOF (D1-D15) | | | | | | | | | | |
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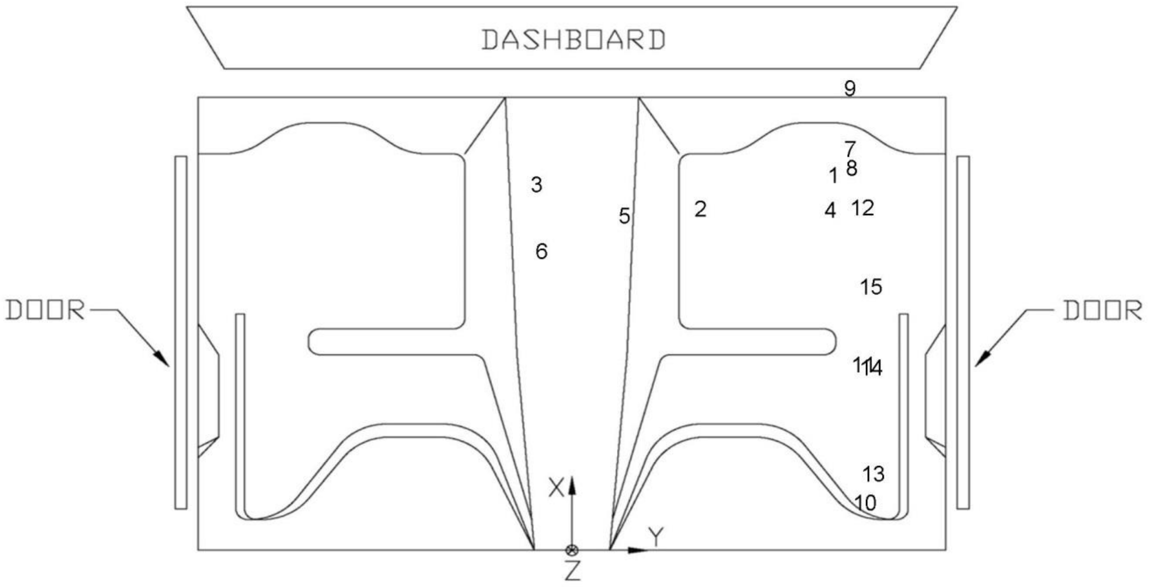

Figure D-16. Occupant Compartment Deformation Data – Set 1, Test No. MWP-7

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MWP-7
VEHICLE: 1100C

| | POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) |
|---|---|---|---|---|---|---|---|---|---|---|
| DASH (A1-A6) | 1 | 27.126 | 27.632 | 21.746 | 26.851 | 27.581 | 21.736 | -0.275 | -0.051 | -0.010 |
| | 2 | 24.193 | 15.988 | 25.717 | 23.958 | 15.931 | 25.720 | -0.235 | -0.058 | 0.003 |
| | 3 | 26.364 | 1.700 | 22.861 | 26.141 | 1.698 | 22.864 | -0.223 | -0.002 | 0.003 |
| | 4 | 24.947 | 27.329 | 12.072 | 24.680 | 27.235 | 12.067 | -0.267 | -0.094 | -0.005 |
| | 5 | 24.240 | 9.361 | 16.119 | 23.983 | 9.283 | 16.124 | -0.257 | -0.079 | 0.005 |
| | 6 | 21.413 | 2.120 | 15.974 | 21.196 | 2.105 | 16.020 | -0.218 | -0.015 | 0.046 |
| SIDE PANEL (B1-B3) | 7 | 30.420 | 29.099 | 3.121 | 30.182 | 28.959 | 3.120 | -0.238 | -0.140 | -0.001 |
| | 8 | 29.128 | 29.156 | 0.092 | 28.897 | 29.092 | 0.042 | -0.231 | -0.064 | -0.050 |
| | 9 | 35.246 | 29.052 | 4.764 | 34.999 | 28.829 | 4.746 | -0.247 | -0.223 | -0.018 |
| IMPACT SIDE DOOR (C1-C6) | 10 | 0.335 | 30.271 | 24.841 | 0.022 | 30.396 | 24.757 | -0.314 | 0.125 | -0.084 |
| | 11 | 11.738 | 30.163 | 23.252 | 11.412 | 30.277 | 23.288 | -0.327 | 0.114 | 0.036 |
| | 12 | 24.515 | 30.074 | 21.333 | 24.190 | 30.144 | 21.440 | -0.325 | 0.070 | 0.107 |
| | 13 | 4.067 | 30.926 | 5.167 | 3.723 | 30.938 | 5.127 | -0.345 | 0.011 | -0.039 |
| | 14 | 12.779 | 30.847 | 3.511 | 12.482 | 30.783 | 3.550 | -0.297 | -0.064 | 0.039 |
| | 15 | 19.136 | 30.819 | 5.938 | 18.787 | 30.724 | 5.965 | -0.350 | -0.094 | 0.027 |
| ROOF (D1-D15) | | | | | | | | | | |
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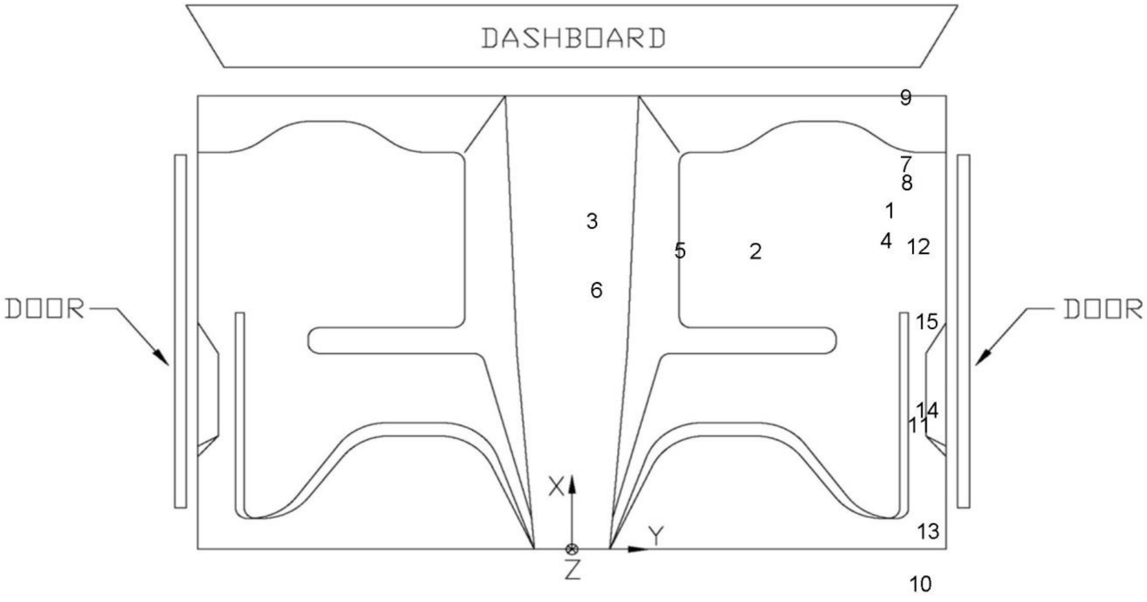


Figure D-17. Occupant Compartment Deformation Data – Set 2, Test No. MWP-7

MWP-7 Roof Crush

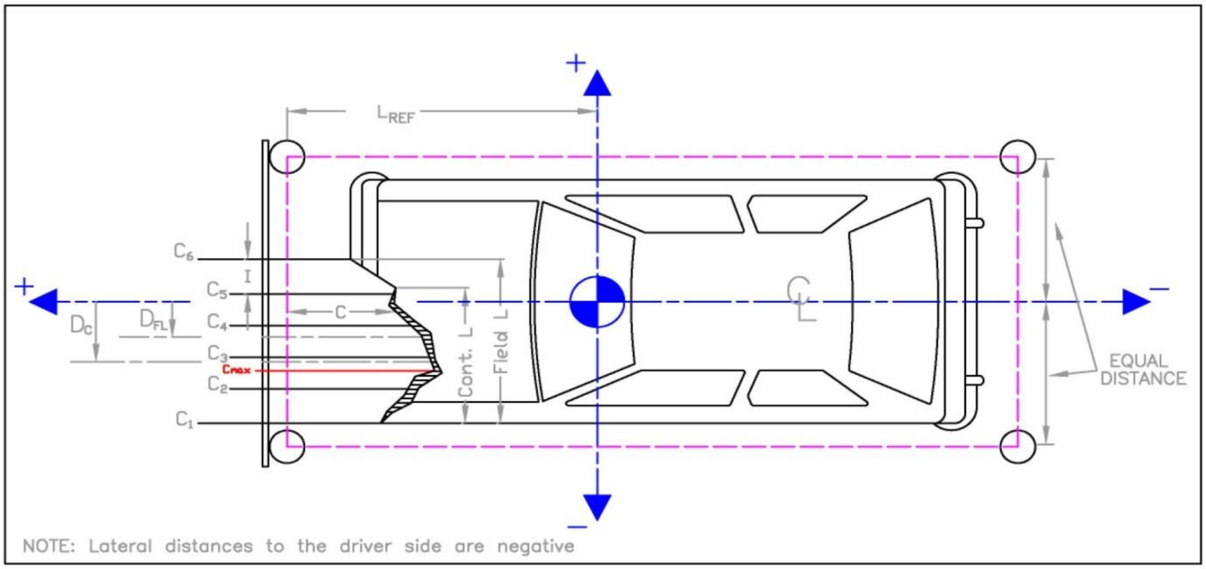
Comparative measurement of SFH-2 roof damage to undamaged vehicle:

| | |
|---|---|
| MWP-7 at max point of crush | 6.00" |
| Undamaged vehicle | 5.5" |
| Total crush | .5" |

Figure D-18. Roof Deformation Documentation, Test No. MWP-7

**Date:** 2/26/2015
**Test Number:** MWP-7

**Make:** Kia
**Model:** Rio
**Year:** 2009

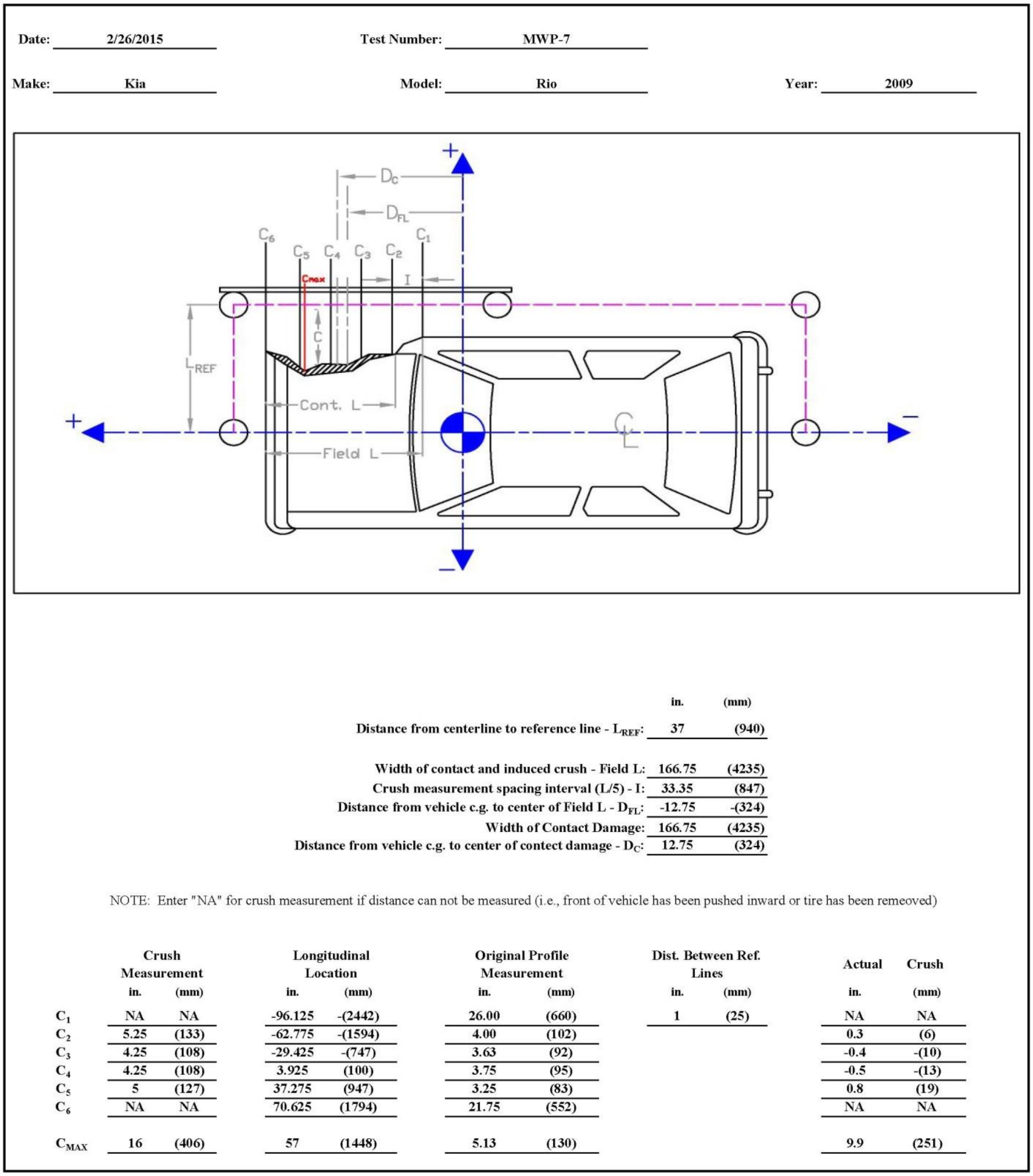


| | in. | (mm) |
|---|---|---|
| Distance from C.G. to reference line - $L_{REF}$: | 73 | (1854) |
| Width of contact and induced crush - Field L: | 62 | (1575) |
| Crush measurement spacing interval (L/5) - I: | 12 2/5 | (315) |
| Distance from center of vehicle to center of Field L - $D_{FL}$: | 0 | 0 |
| Width of Contact Damage: | 62 | (1575) |
| Distance from center of vehicle to center of contect damage - $D_C$: | 0 | 0 |

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

| | Crush Measurement | | Lateral Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual | Crush |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | na | NA | -31 | -(787) | 19 7/8 | (505) | -3 7/8 | -(98) | NA | NA |
| $C_2$ | 5 3/4 | (146) | -18 3/5 | -(472) | 8 1/4 | (210) | | | 1 1/3 | (34) |
| $C_3$ | 7 | (178) | -6 1/5 | -(157) | 6 1/7 | (156) | | | 4 3/4 | (120) |
| $C_4$ | 5 1/8 | (130) | 6 1/5 | (157) | 6 1/8 | (156) | | | 2 7/8 | (73) |
| $C_5$ | 6 1/4 | (159) | 18 3/5 | (472) | 8 2/9 | (209) | | | 2 | (48) |
| $C_6$ | na | NA | 31 | (787) | 19 7/8 | (505) | | | NA | NA |
| $C_{MAX}$ | 10 3/4 | (273) | 22 | (559) | 9 1/2 | (241) | | | 5 1/8 | (130) |

Figure D-19. Exterior Vehicle Crush (NASS) – Front, Test No. MWP-7



**Date:** 2/26/2015 **Test Number:** MWP-7

**Make:** Kia **Model:** Rio **Year:** 2009

| | in. | (mm) |
|---|---|---|
| Distance from centerline to reference line - $L_{REF}$: | 37 | (940) |
| Width of contact and induced crush - Field L: | 166.75 | (4235) |
| Crush measurement spacing interval (L/5) - I: | 33.35 | (847) |
| Distance from vehicle c.g. to center of Field L - $D_{FL}$: | -12.75 | -(324) |
| Width of Contact Damage: | 166.75 | (4235) |
| Distance from vehicle c.g. to center of contect damage - $D_C$: | 12.75 | (324) |

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 remeoved)

| | 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 | -96.125 | -(2442) | 26.00 | (660) | 1 | (25) | NA | NA |
| $C_2$ | 5.25 | (133) | -62.775 | -(1594) | 4.00 | (102) | | | 0.3 | (6) |
| $C_3$ | 4.25 | (108) | -29.425 | -(747) | 3.63 | (92) | | | -0.4 | -(10) |
| $C_4$ | 4.25 | (108) | 3.925 | (100) | 3.75 | (95) | | | -0.5 | -(13) |
| $C_5$ | 5 | (127) | 37.275 | (947) | 3.25 | (83) | | | 0.8 | (19) |
| $C_6$ | NA | NA | 70.625 | (1794) | 21.75 | (552) | | | NA | NA |
| $C_{MAX}$ | 16 | (406) | 57 | (1448) | 5.13 | (130) | | | 9.9 | (251) |

Figure D-20. Exterior Vehicle Crush (NASS) – Side, Test No. MWP-7

# Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. MWP-4

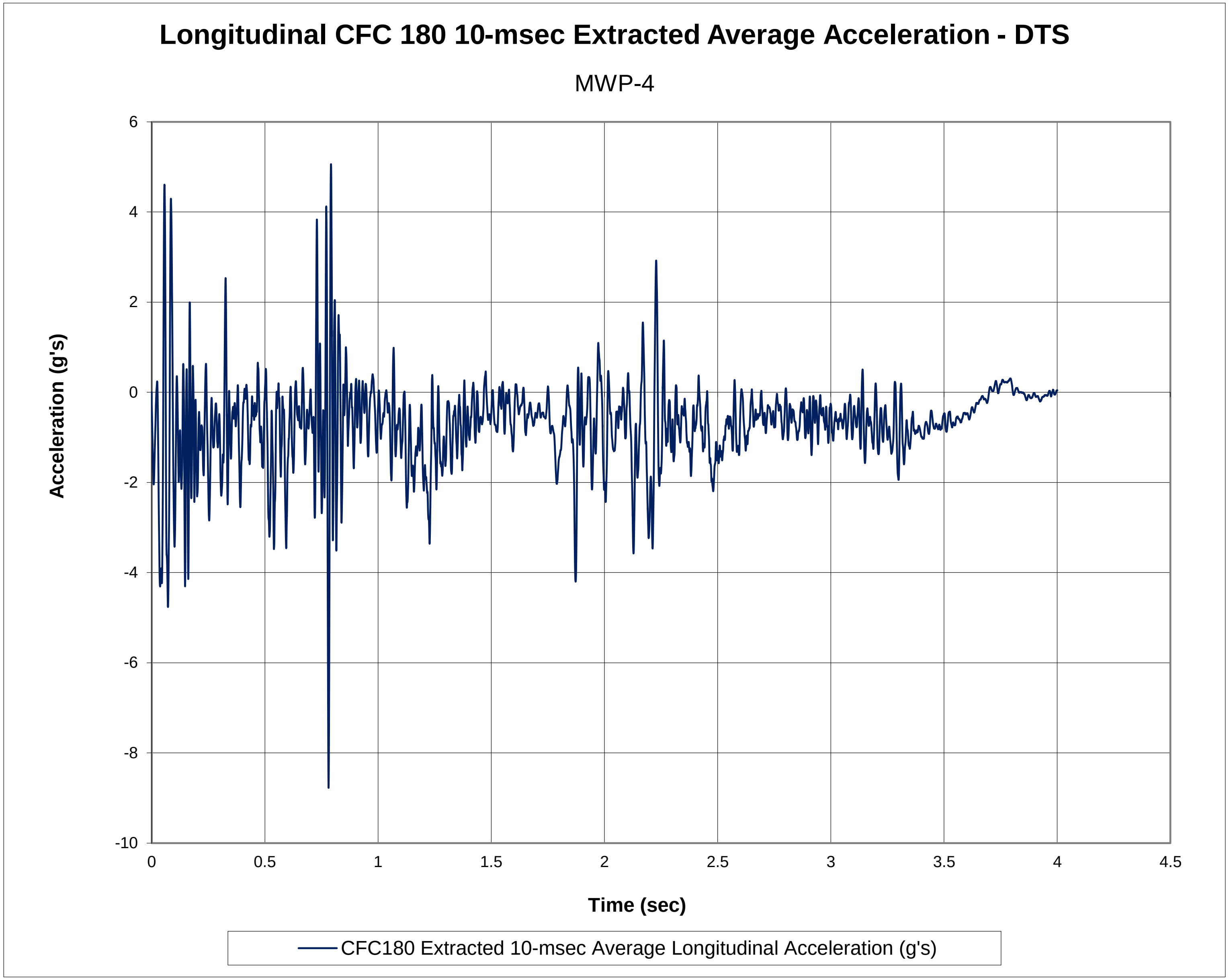


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE 1), Test No. MWP-4

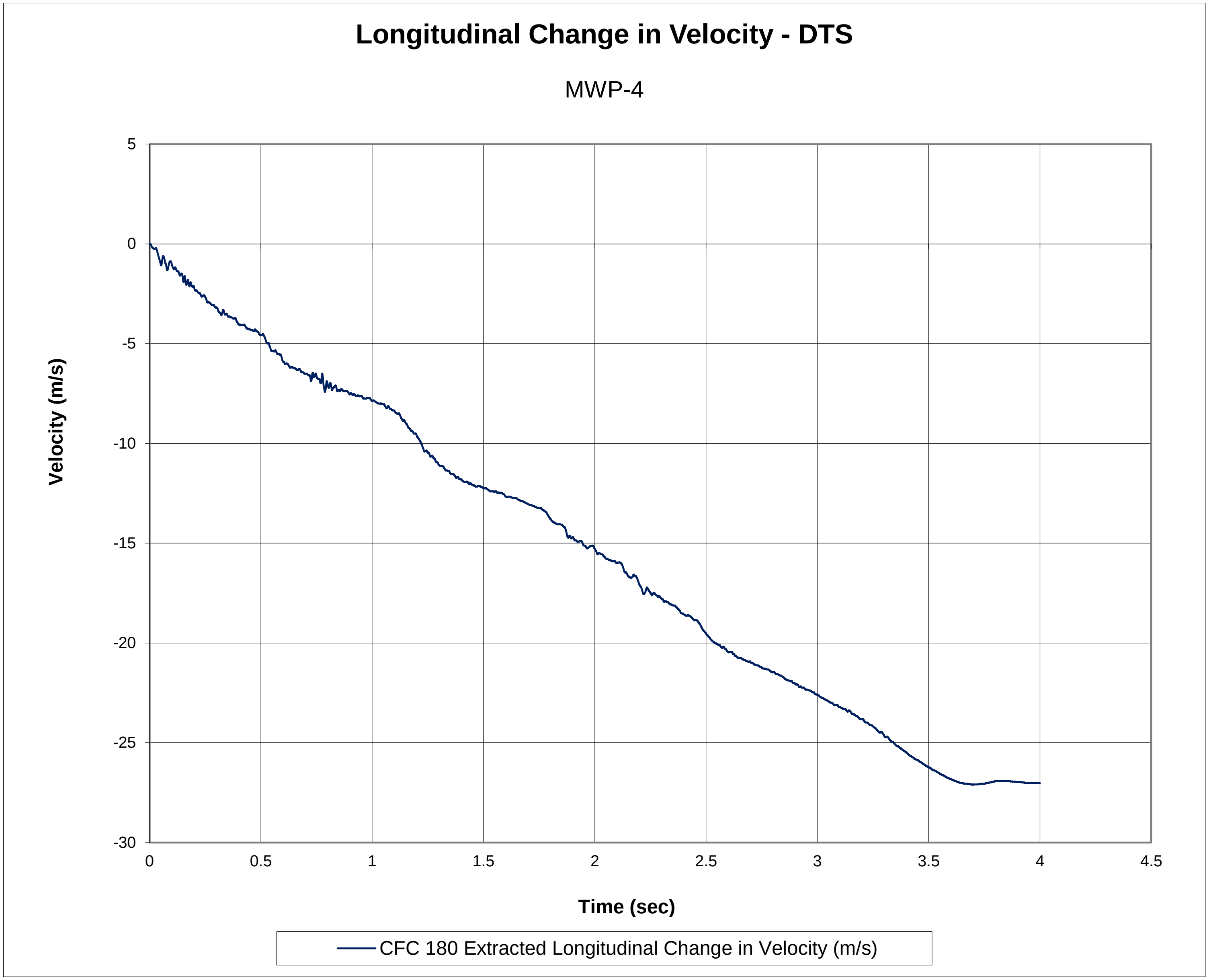


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE 1), Test No. MWP-4

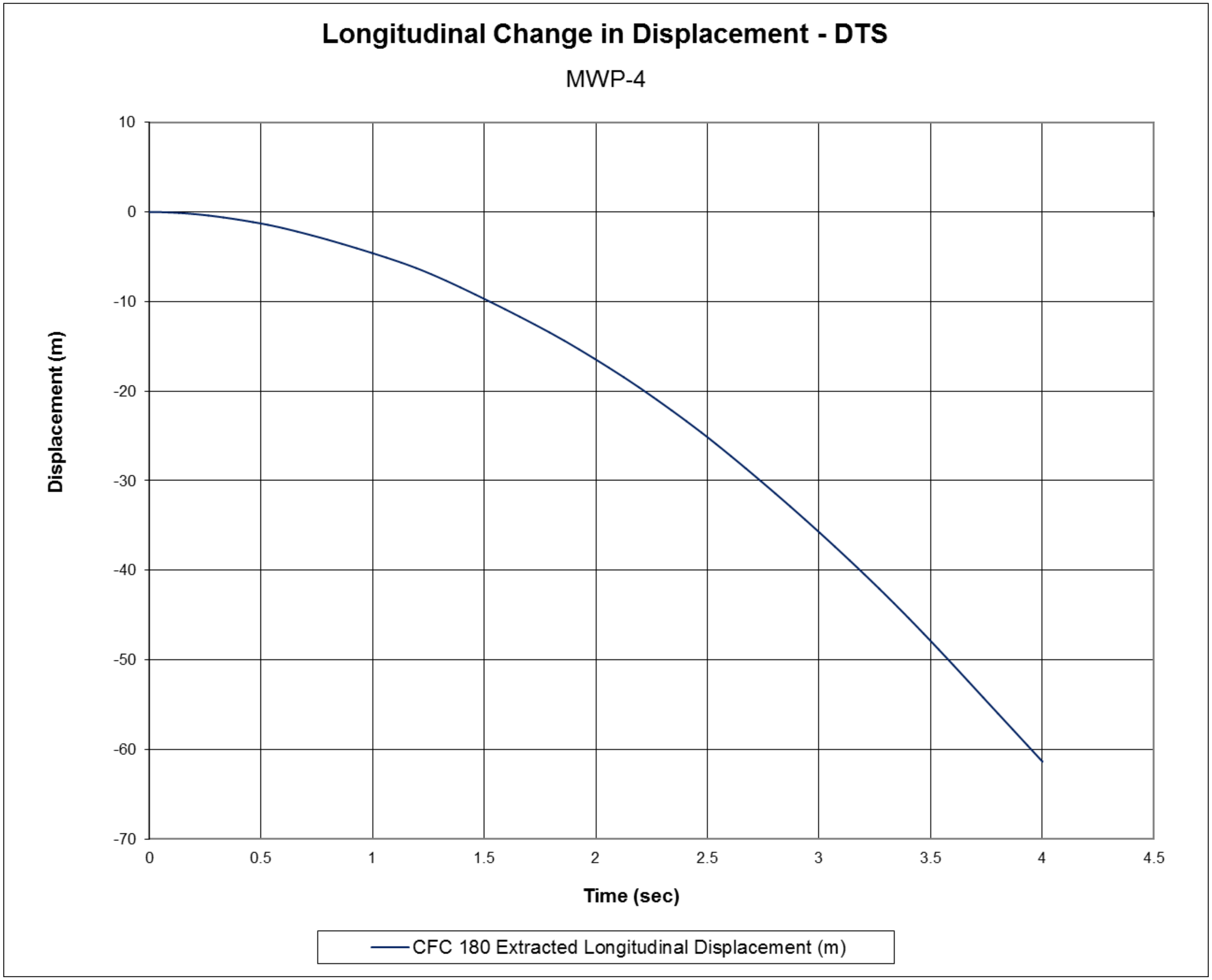


Figure E-3. Longitudinal Occupant Displacement (SLICE 1), Test No. MWP-4

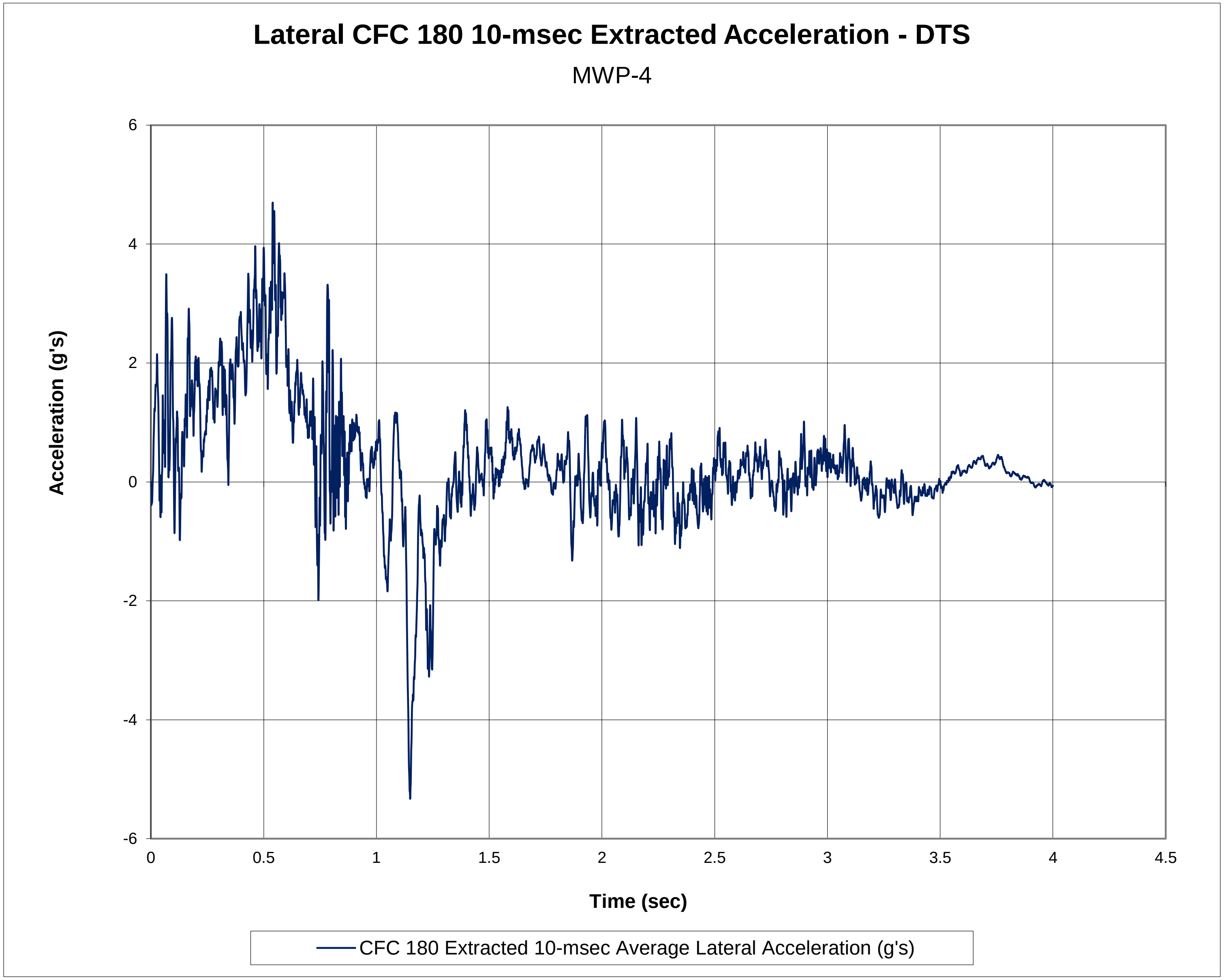


Figure E-4. 10-ms Average Lateral Deceleration (SLICE 1), Test No. MWP-4

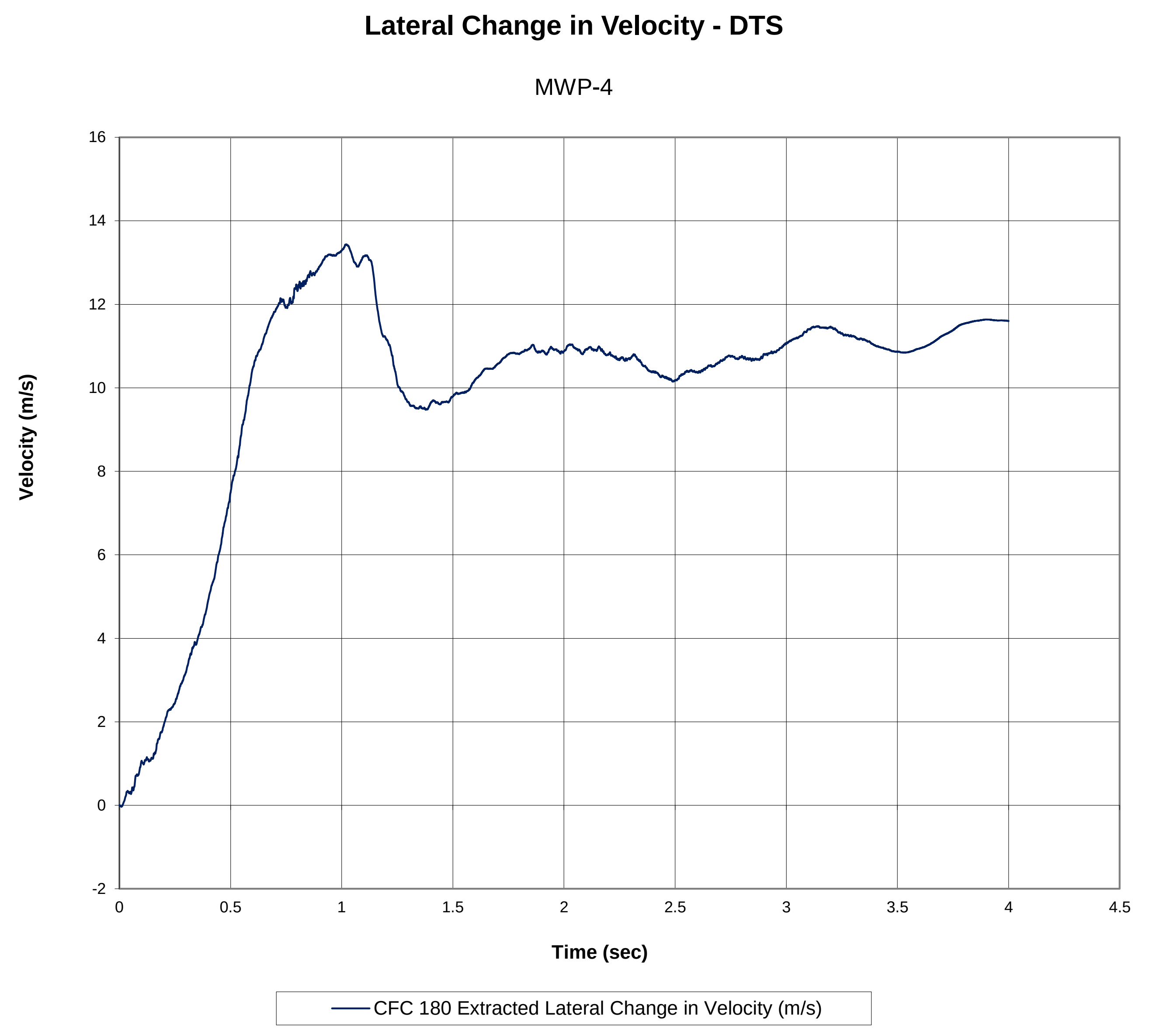


Figure E-5. Lateral Occupant Impact Velocity (SLICE 1), Test No. MWP-4

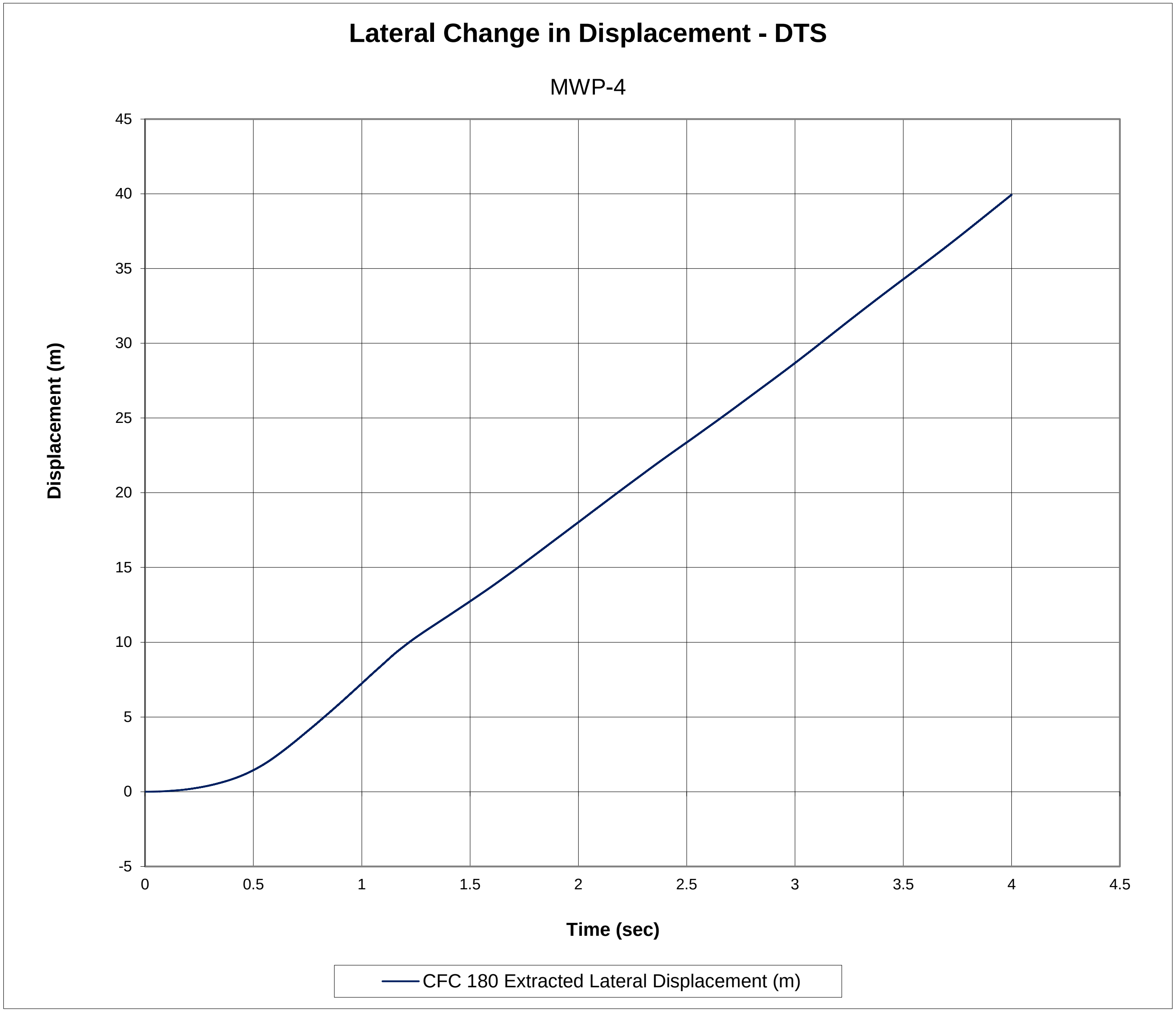


Figure E-6. Lateral Occupant Displacement (SLICE 1), Test No. MWP-4

Figure E-7. Vehicle Angular Displacements (SLICE 1), Test No. MWP-4

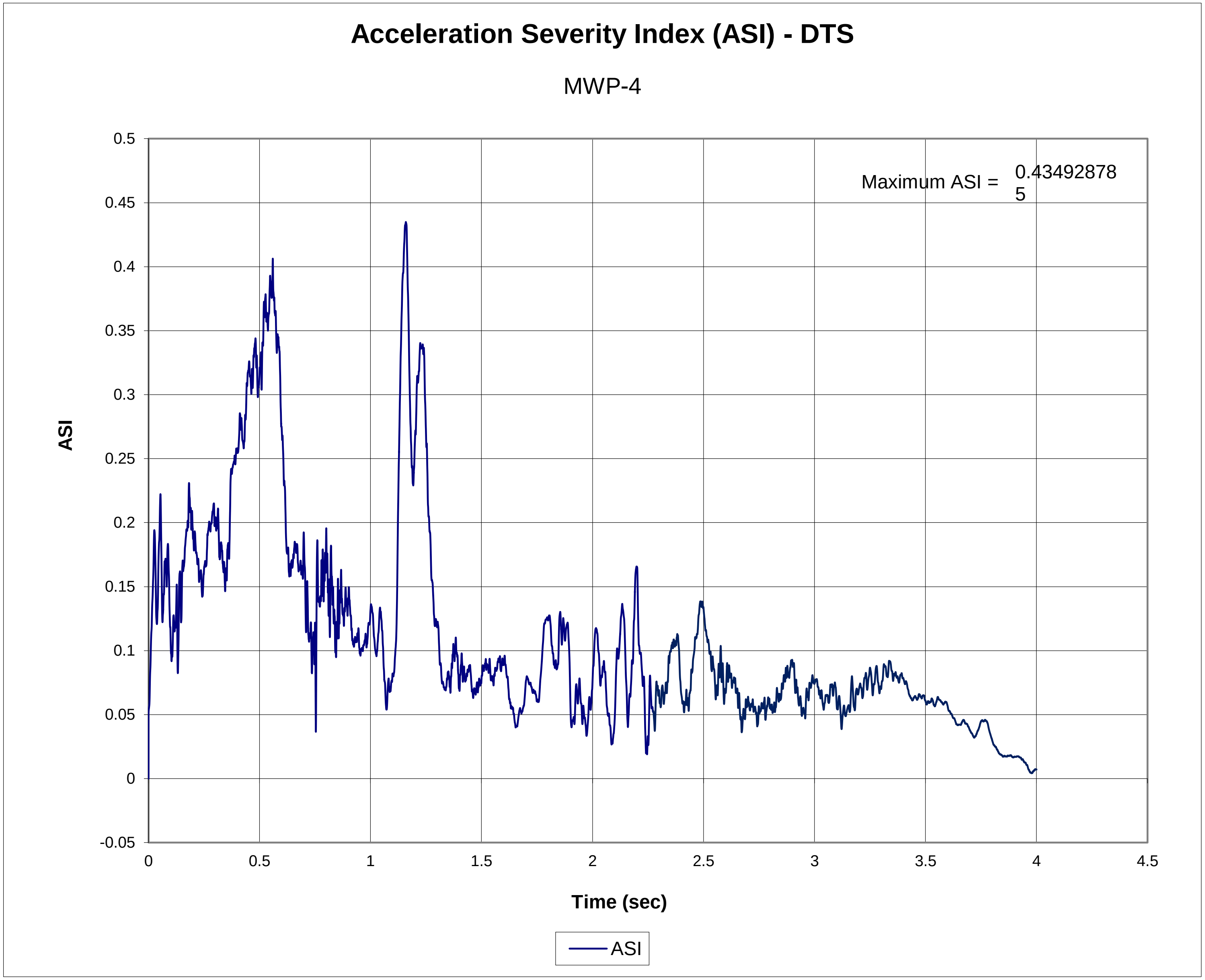


Figure E-8. Acceleration Severity Index (SLICE 1), Test No. MWP-4

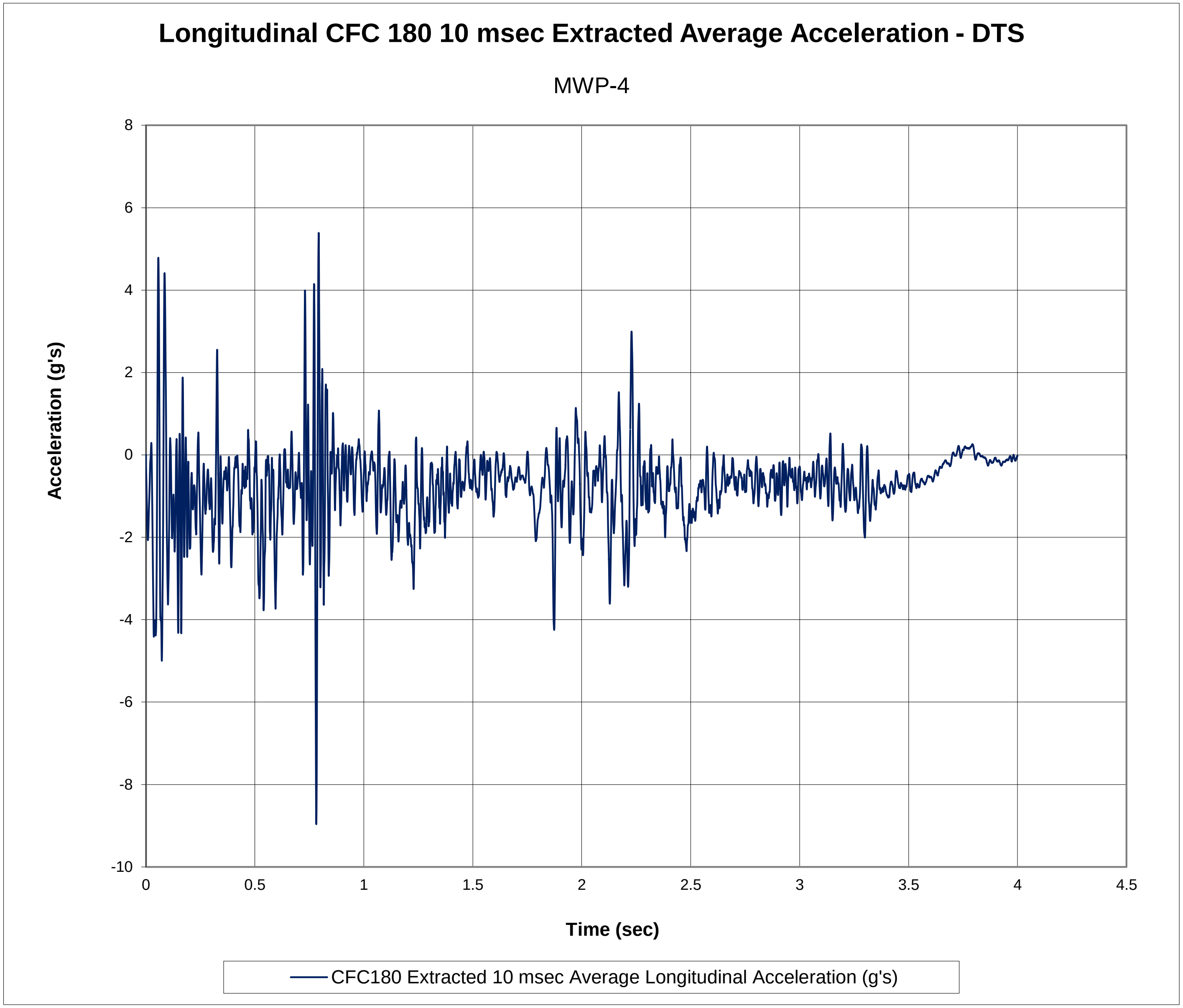


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE 2), Test No. MWP-4

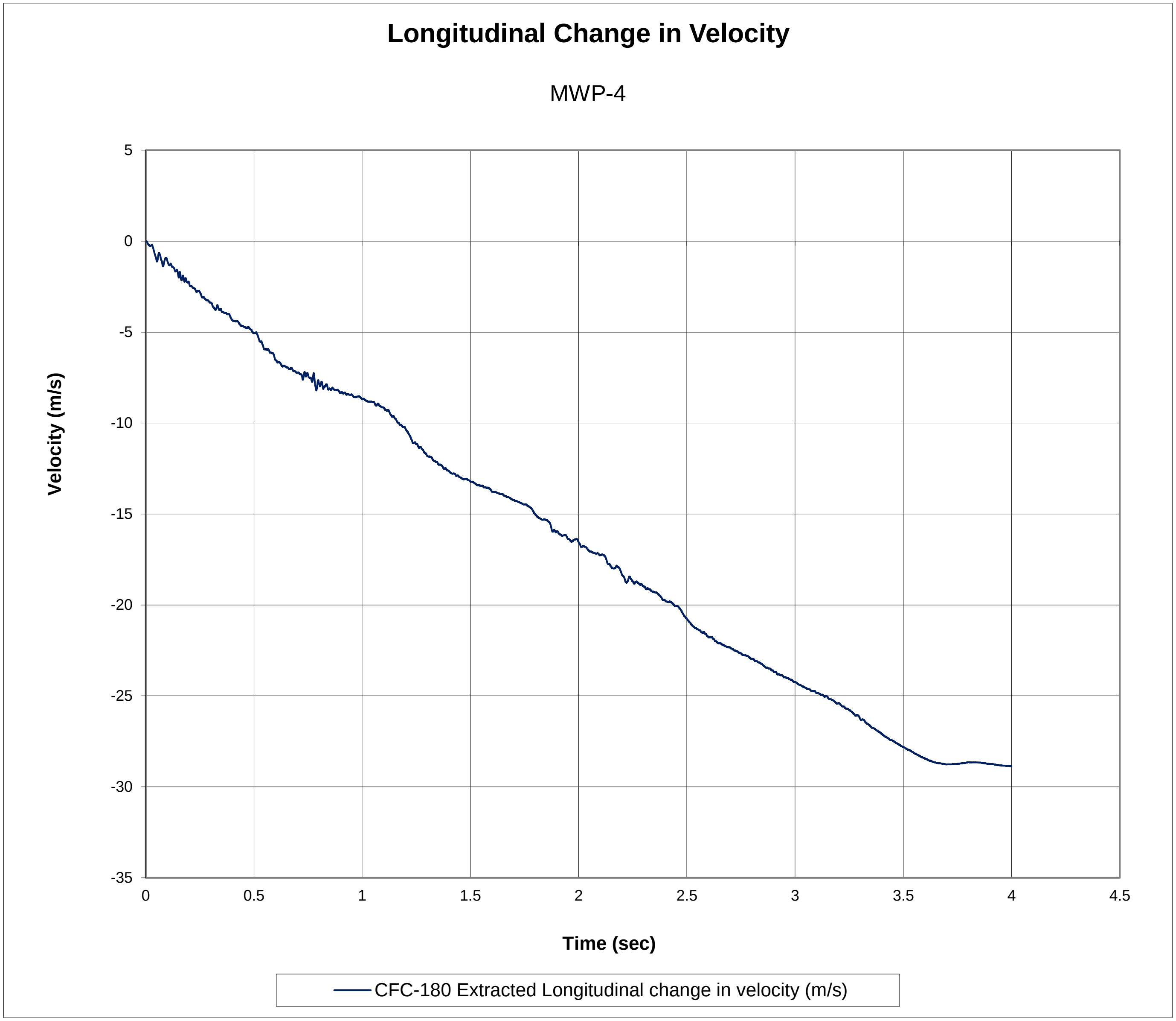


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE 2), Test No. MWP-4

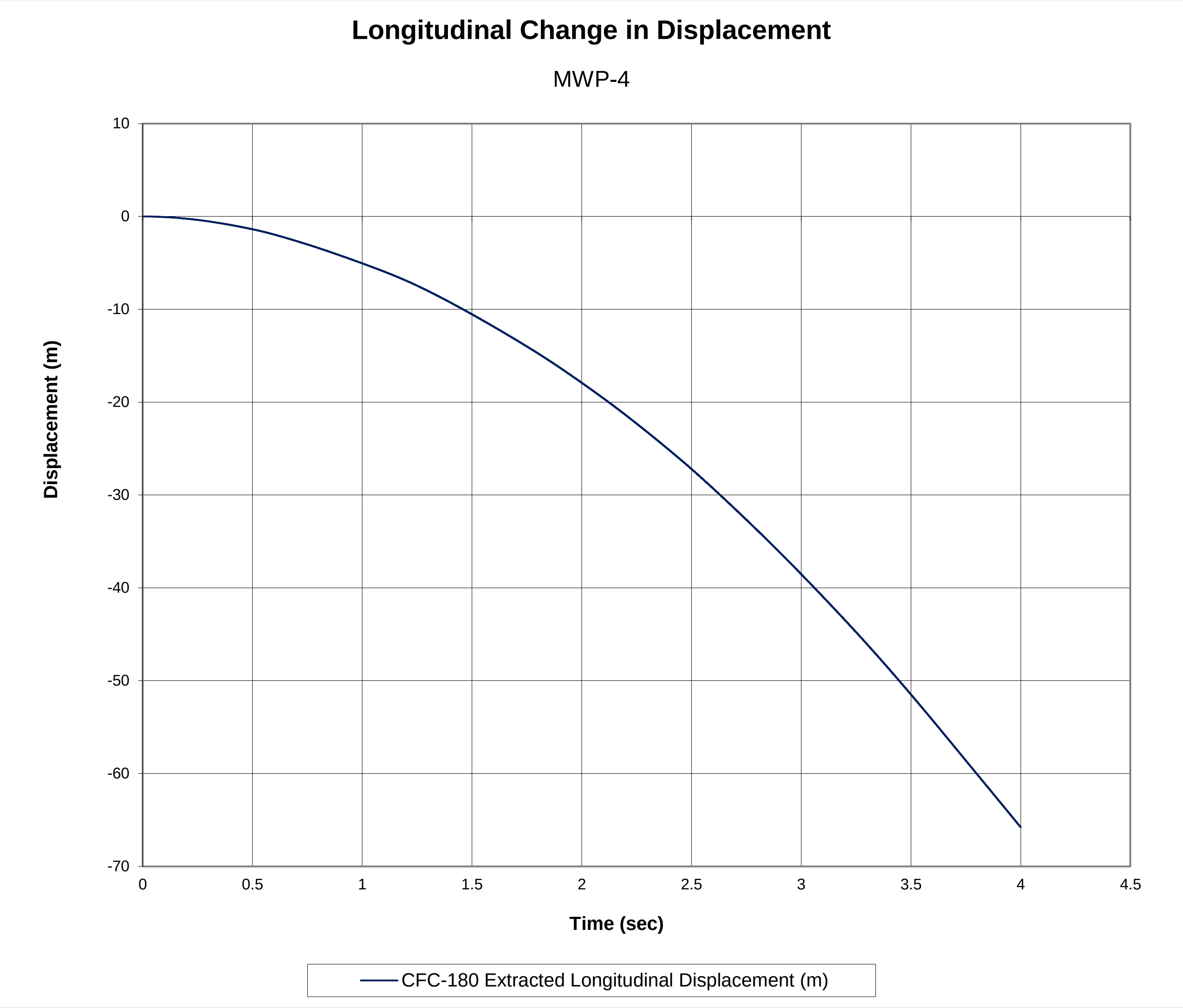


Figure E-11. Longitudinal Occupant Displacement (SLICE 2), Test No. MWP-4

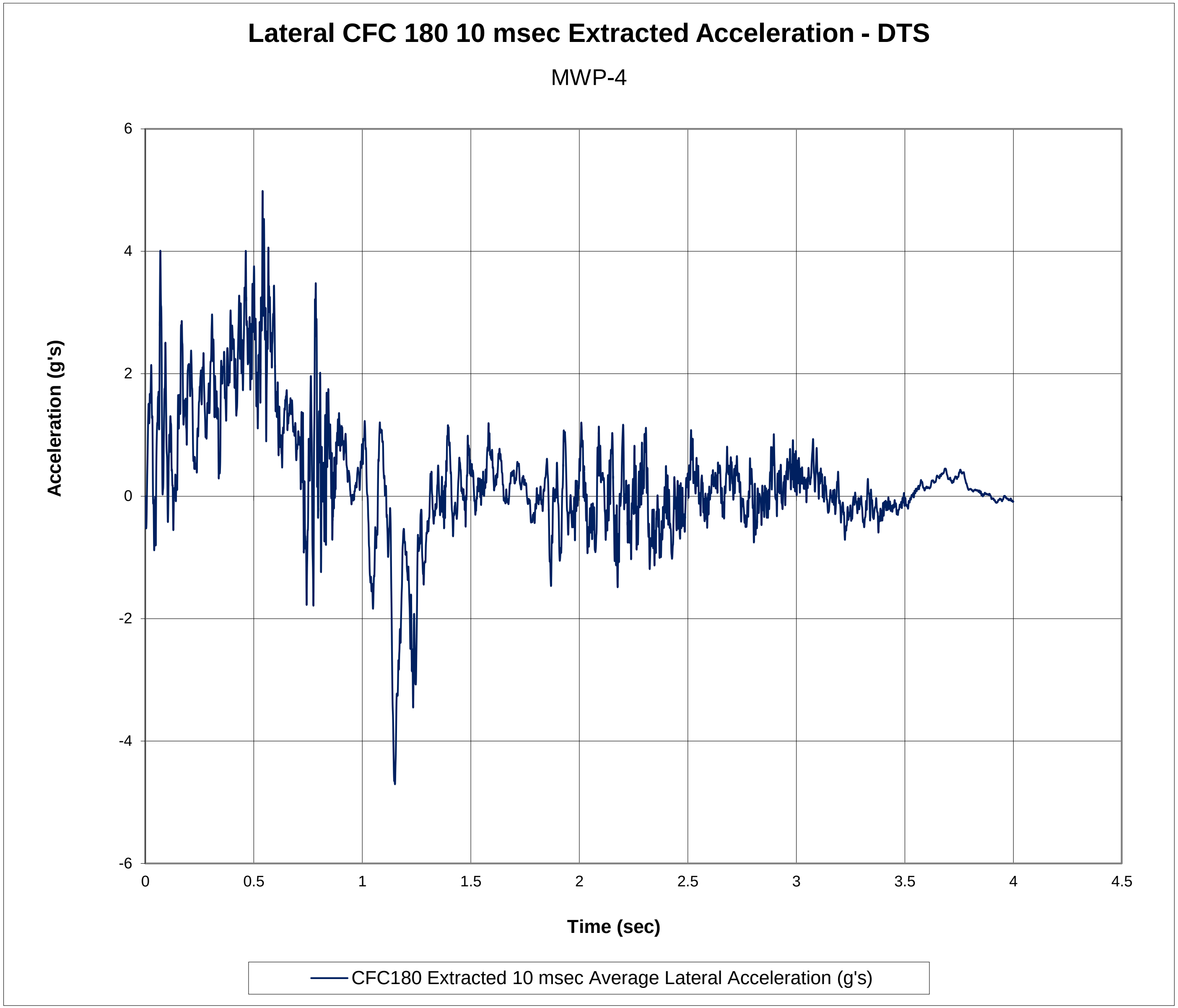


Figure E-12. 10-ms Average Lateral Deceleration (SLICE 2), Test No. MWP-4

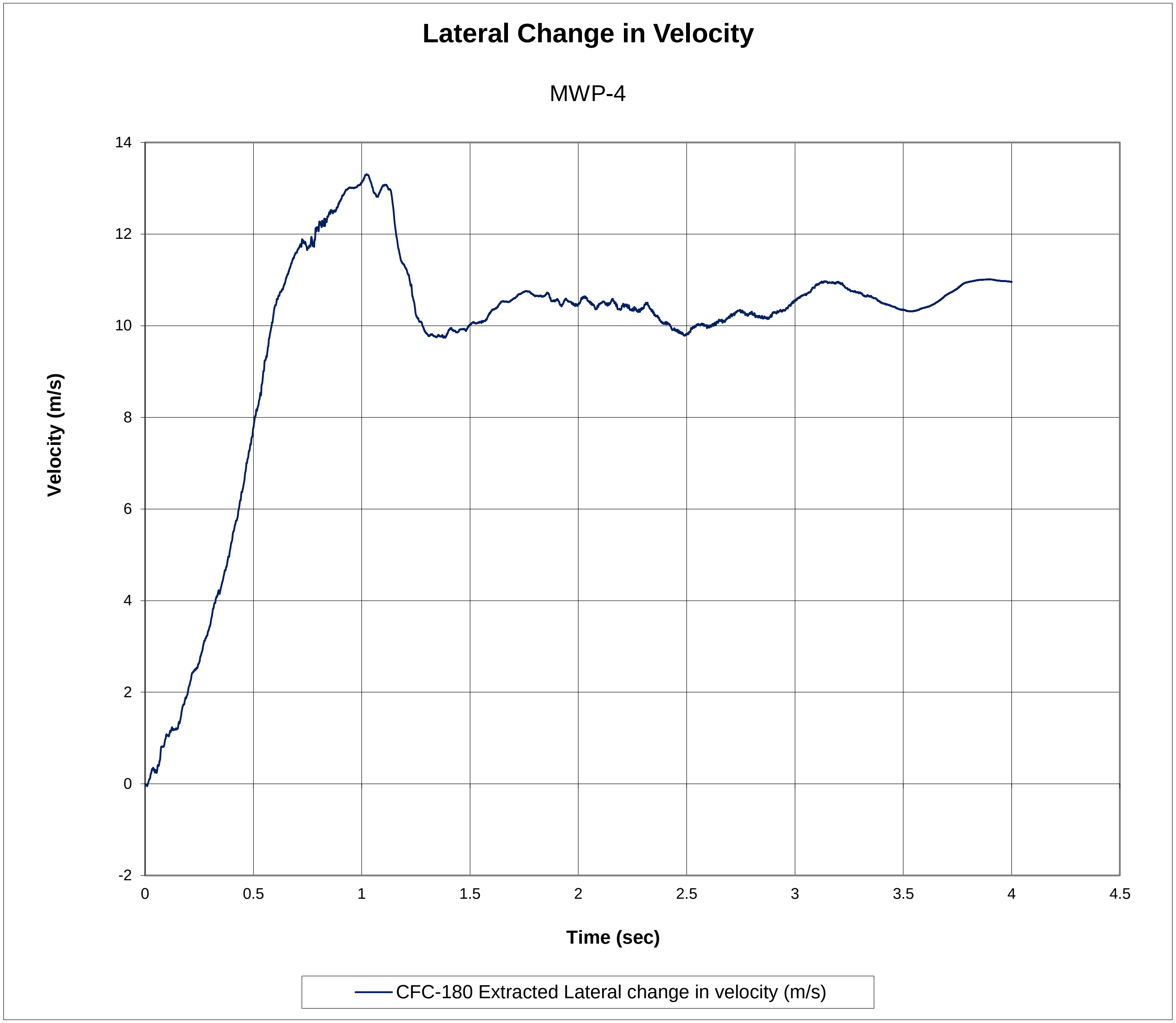


Figure E-13. Lateral Occupant Impact Velocity (SLICE 2), Test No. MWP-4

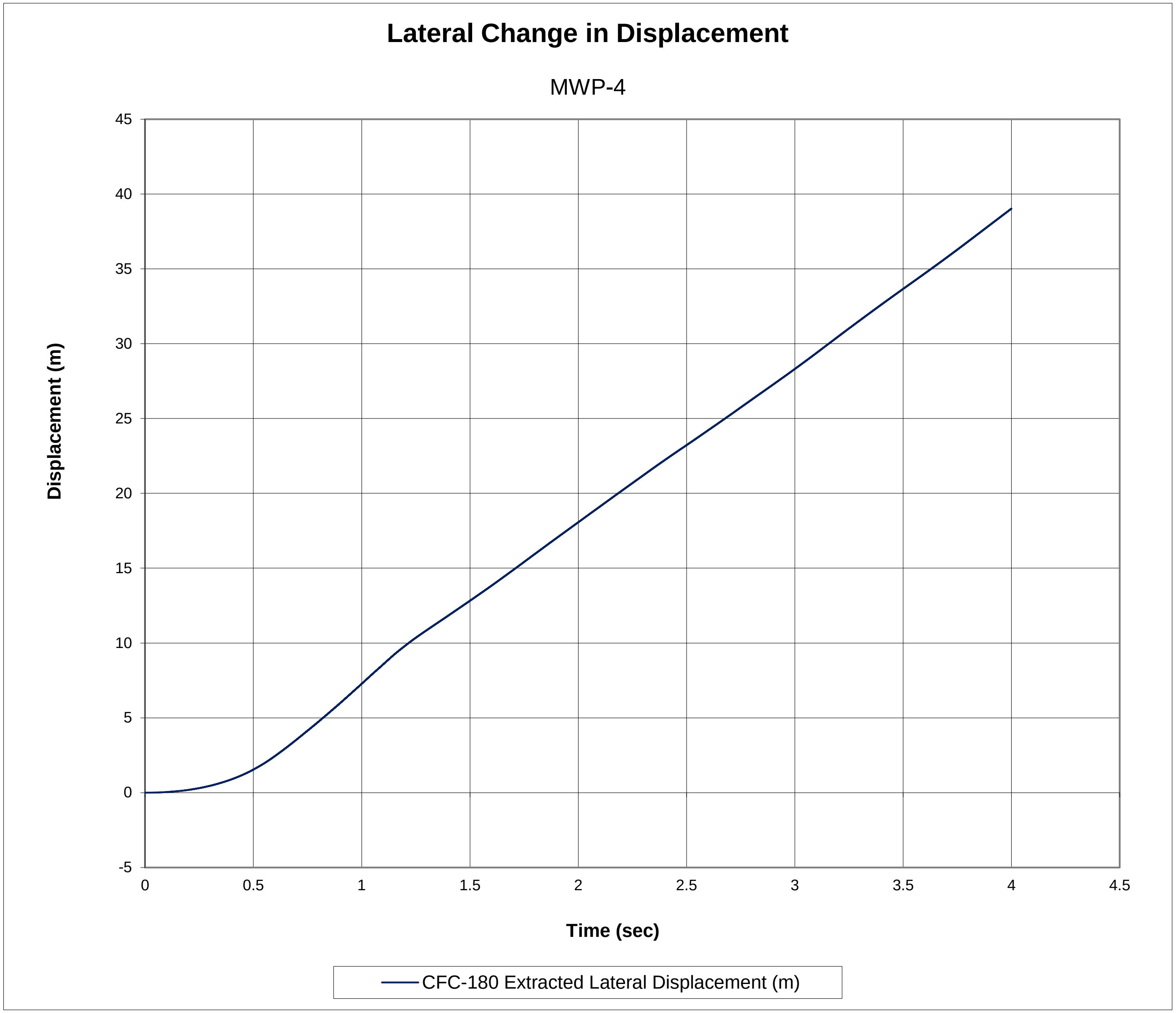


Figure E-14. Lateral Occupant Displacement (SLICE 2), Test No. MWP-4

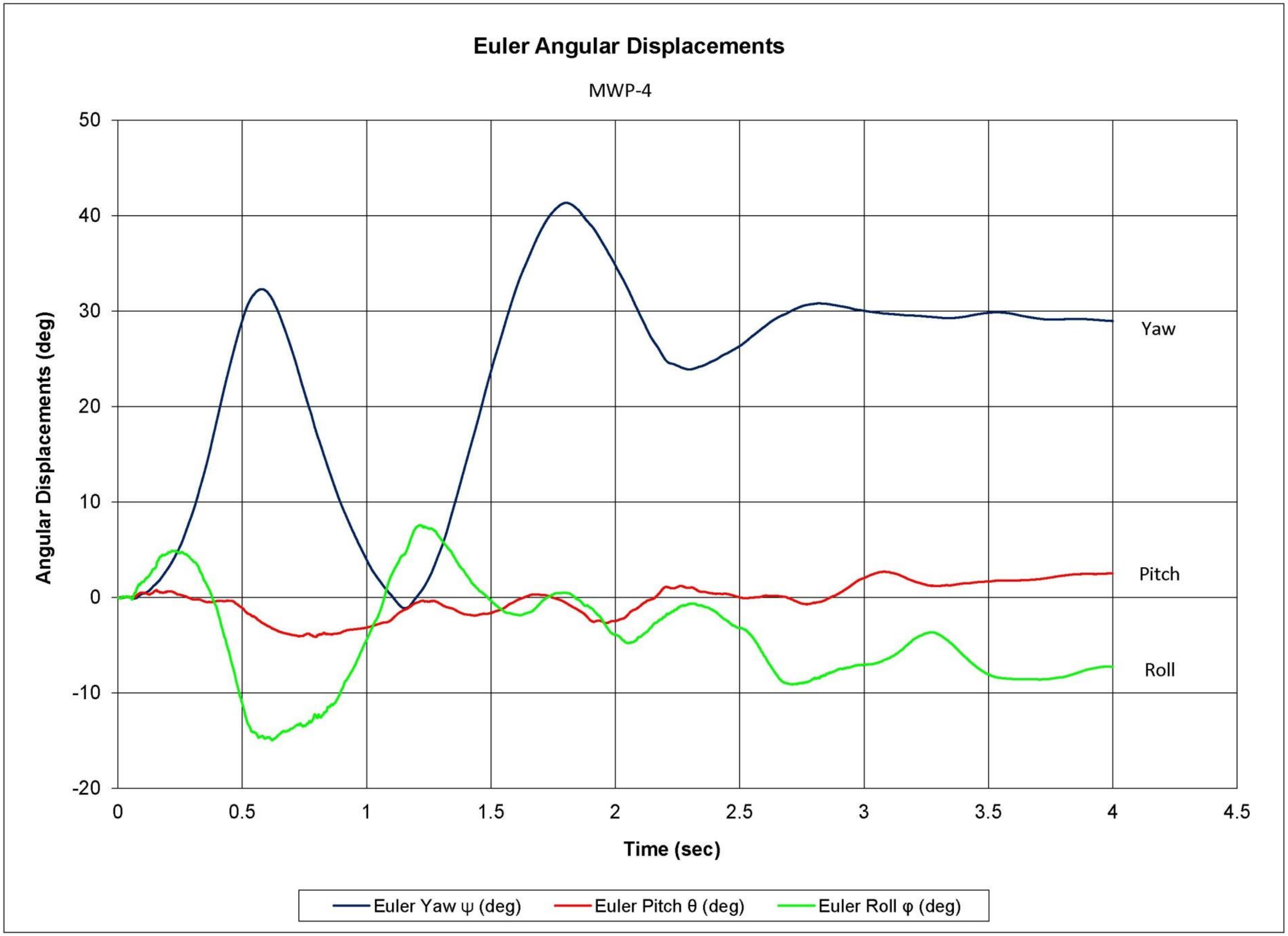


Figure E-15. Vehicle Angular Displacements (SLICE 2), Test No. MWP-4

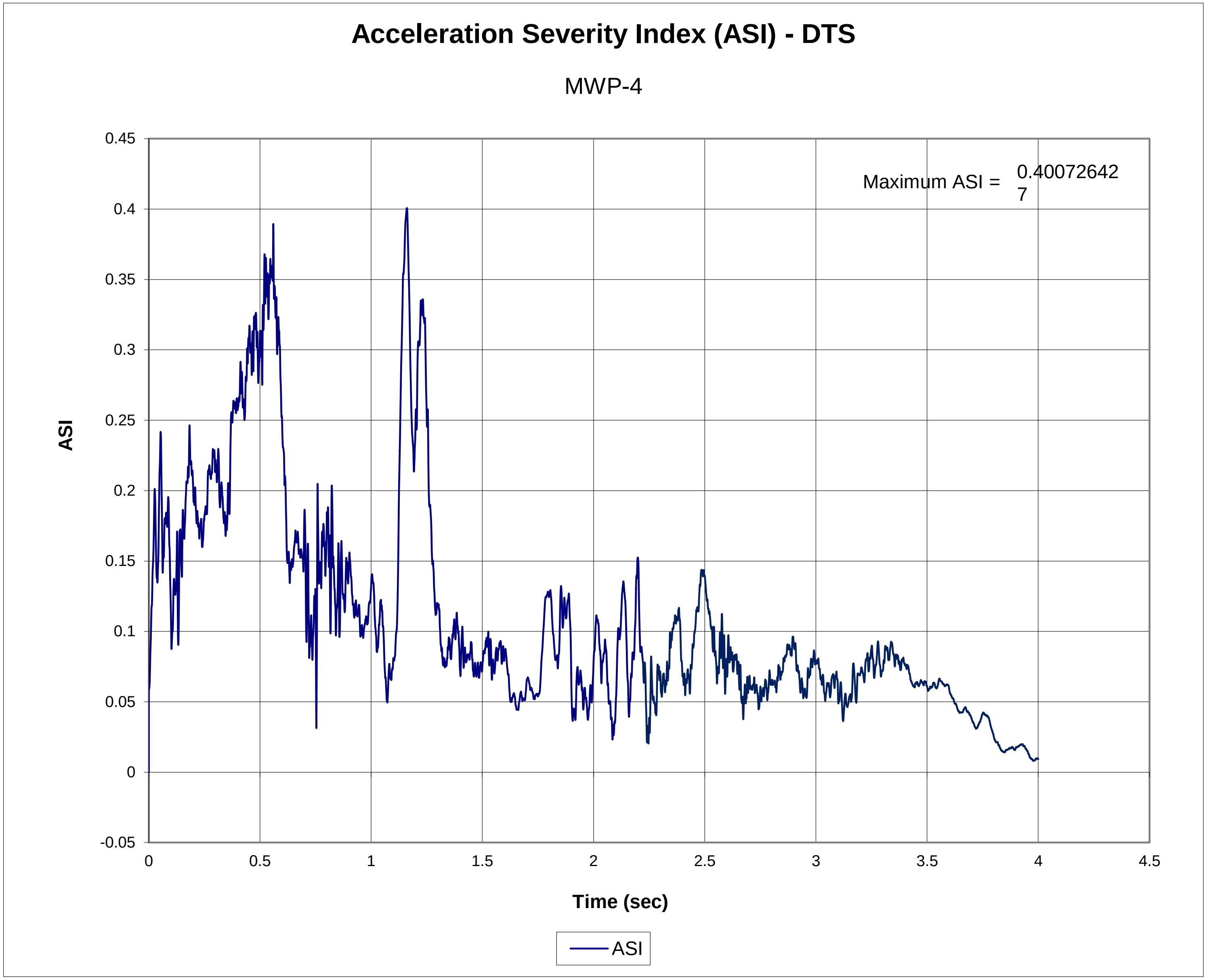


Figure E-16. Acceleration Severity Index (SLICE 2), Test No. MWP-4

# Appendix F. Load Cell and String Potentiometer Data, Test No. MWP-4

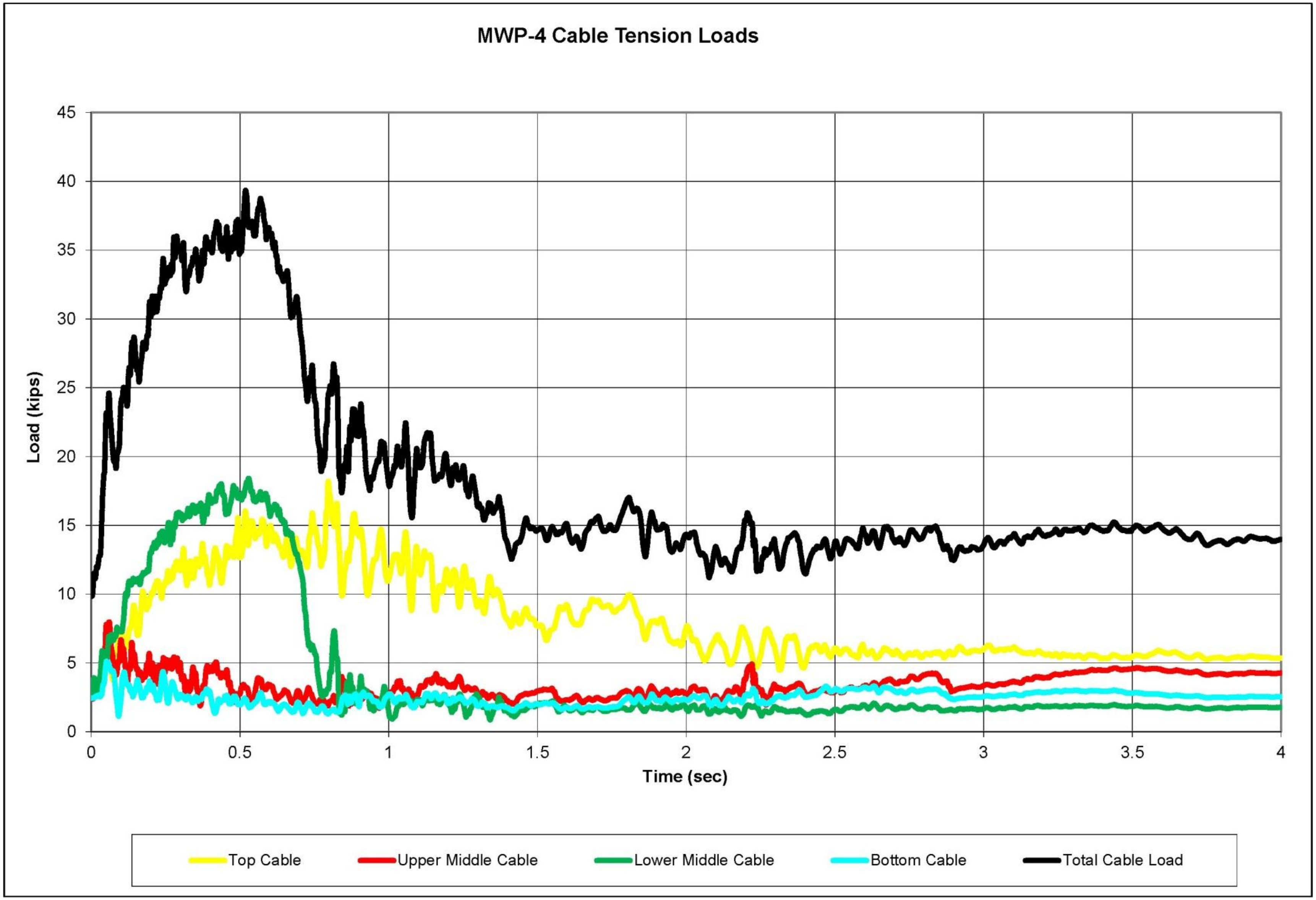


Figure F-1. Combined Load Cell Data, Test No. MWP-4

# MIDWEST ROADSIDE SAFETY FACILITY

## Load Cell Summary

**Test Information:**

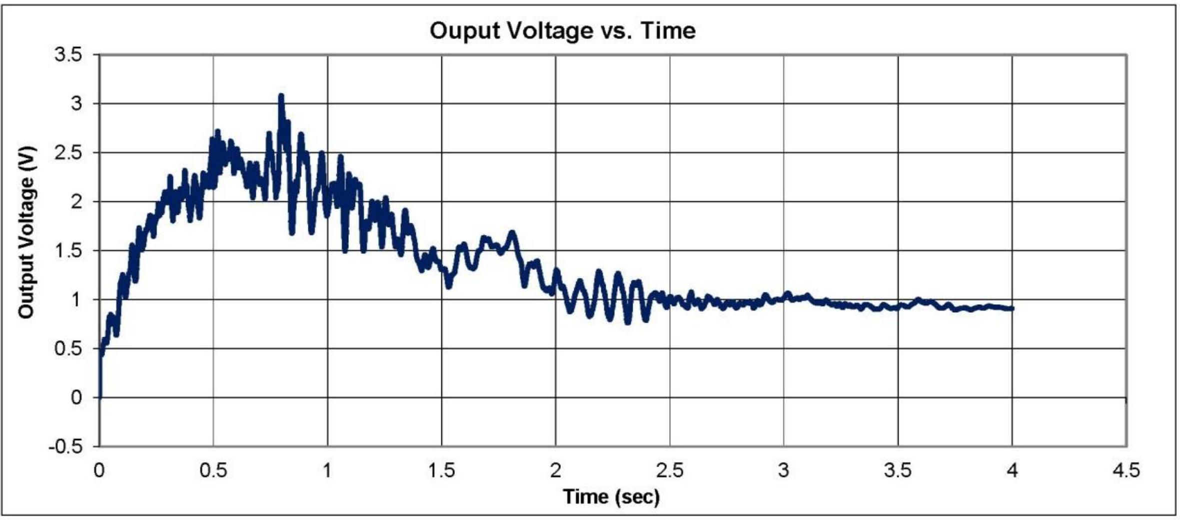
Test No: MWP-4
Date: 10/20/2014
System / Test Article: 4-cable median barrier
LC Location / Component: Top Cable - US of Impact
Additional Notes:

**Load Cell Information:**

Load Cell No.: 120642
Calibration Factor: 2.12022 mv/V
Input Voltage (excitation): 10 Volts
Gain: 400
Full Scale Load: 50 kips
Sample Rate: 10000 Hz
Cutoff Frequency: 100 Hz

**Results:**

Preload: 0 kips
Max. Load: 18.19 kips
Time of Max. Load: 0.797 sec
Event Duration: 4 sec
Final Load: 5.36 kips



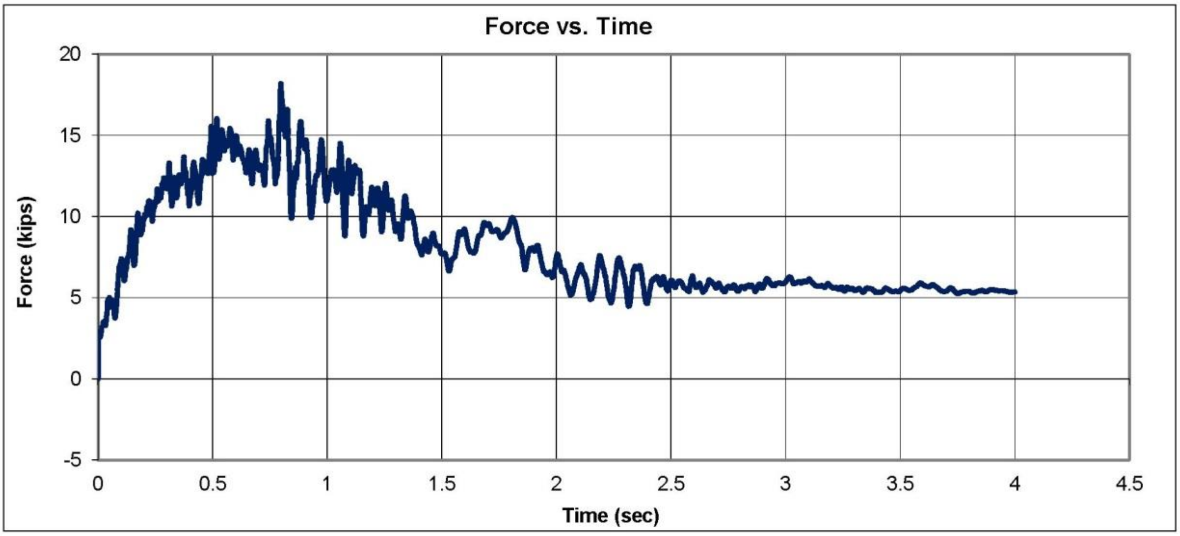


Figure F-2. Load Cell Data, Cable No. 4, Test No. MWP-4

# MIDWEST ROADSIDE SAFETY FACILITY

## Load Cell Summary

**Test Information:**

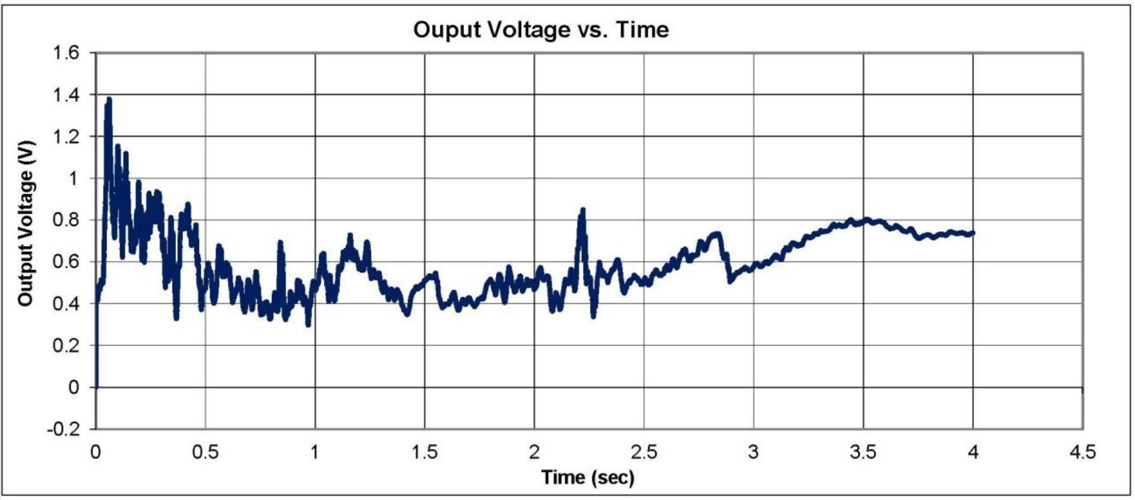
Test No: MWP-4
Date: 10/20/2014
System / Test Article: 4-cable median barrier
LC Location / Component: Top Middle Cable - US of Impact
Additional Notes:

**Load Cell Information:**

Load Cell No.: 143432
Calibration Factor: 2.15992 mv/V
Input Voltage (excitation): 10 Volts
Gain: 400
Full Scale Load: 50 kips
Sample Rate: 10000 Hz
Cutoff Frequency: 100 Hz

**Results:**

Preload: 0 kips
Max. Load: 7.99 kips
Time of Max. Load: 0.0604 sec
Event Duration: 4 sec
Final Load: 4.28 kips



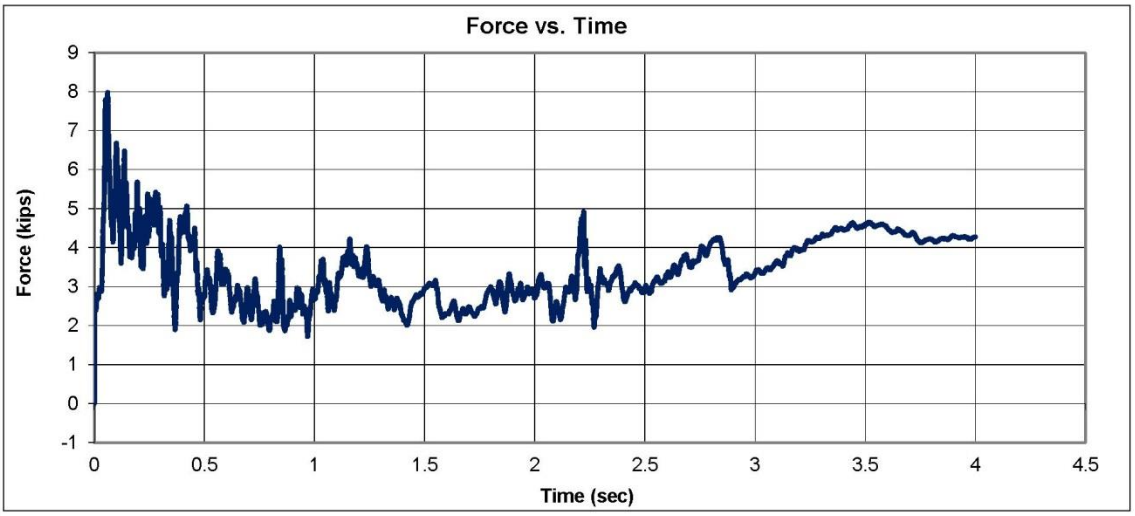


Figure F-3. Load Cell Data, Cable No. 3, Test No. MWP-4

# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

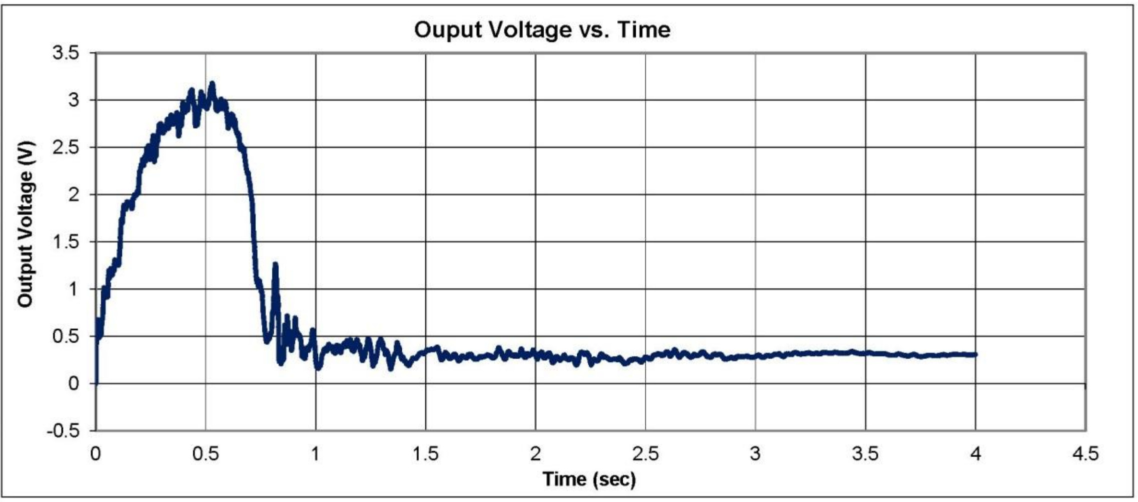
Test No: MWP-4
Date: 10/20/2014
System / Test Article: 4-cable median barrier
LC Location / Component: Bottom Middle Cable - US of Impact
Additional Notes:

**Load Cell Information:**

Load Cell No.: 143435
Calibration Factor: 2.15835 mv/V
Input Voltage (excitation): 10 Volts
Gain: 400
Full Scale Load: 50 kips
Sample Rate: 10000 Hz
Cutoff Frequency: 100 Hz

**Results:**

Preload: 0 kips
Max. Load: 18.42 kips
Time of Max. Load: 0.529 sec
Event Duration: 4 sec
Final Load: 1.79 kips



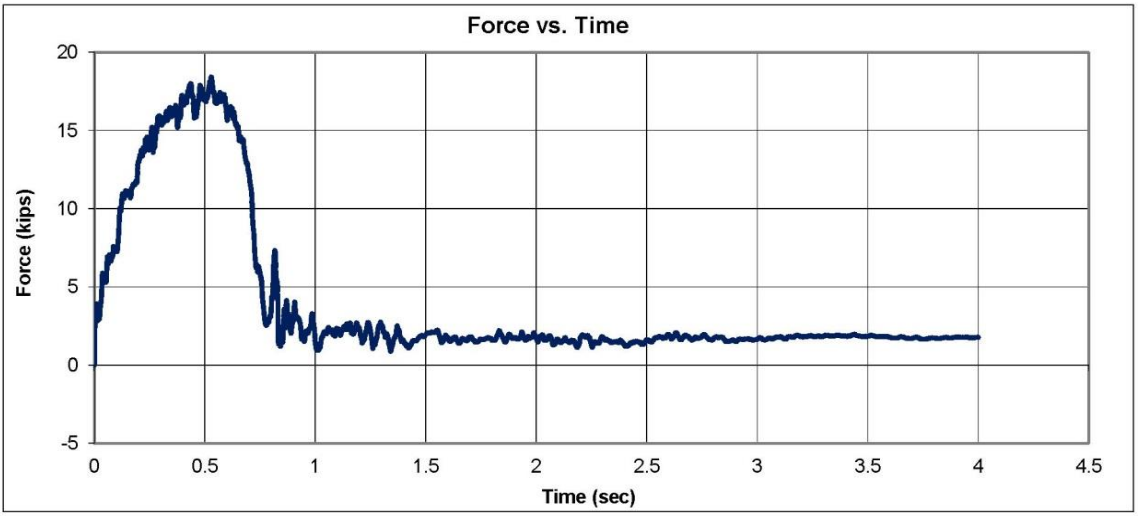


Figure F-4. Load Cell Data, Cable No. 2, Test No. MWP-4

# MIDWEST ROADSIDE SAFETY FACILITY

## Load Cell Summary

**Test Information:**

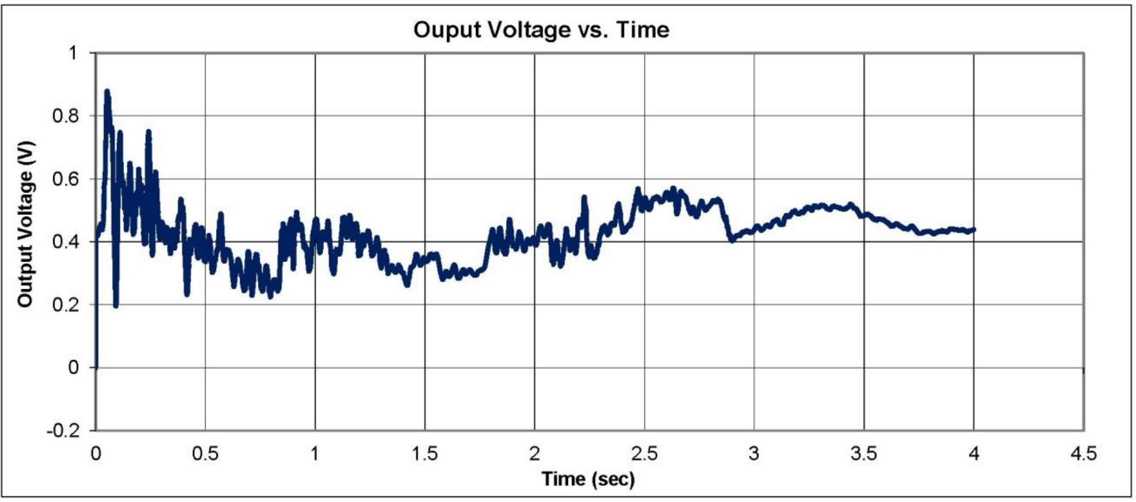
Test No: MWP-4
Date: 10/20/2014
System / Test Article: 4-cable median barrier
LC Location / Component: Bottom Cable - US of Impact
Additional Notes:

**Load Cell Information:**

Load Cell No.: 143436
Calibration Factor: 2.14575 mv/V
Input Voltage (excitation): 10 Volts
Gain: 400
Full Scale Load: 50 kips
Sample Rate: 10000 Hz
Cutoff Frequency: 100 Hz

**Results:**

Preload: 0 kips
Max. Load: 5.13 kips
Time of Max. Load: 0.0518 sec
Event Duration: 4 sec
Final Load: 2.56 kips



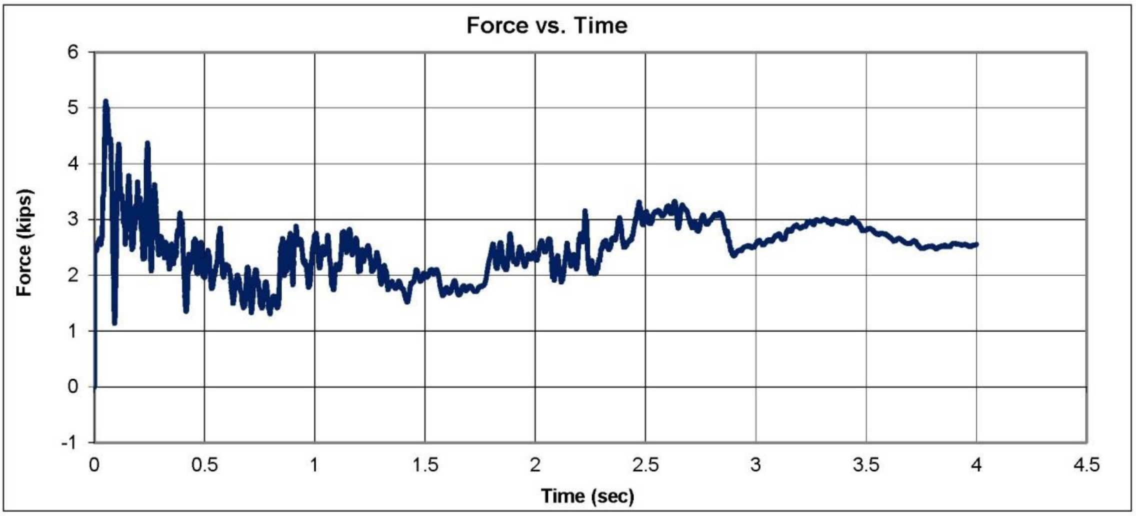


Figure F-5. Load Cell Data, Cable No. 1, Test No. MWP-4

# MIDWEST ROADSIDE SAFETY FACILITY

## String Potentiometer Summary

**Test Information:**

Test No: MWP-4
Date: 10/20/2014
System / Test Article: 4-Cable Median Barrier
SP Location / Component: US Anchor
Additional Notes:

**String Potentiometer Information:**

String Pot No.: 27039202
Calibration Factor: 19.4483 mV/V/in.
Input Voltage (excitation): 10 Volts
Gain: 1
Full Scale Load: 1
Sample Rate: 10000 Hz
Cutoff Frequency: 100 Hz

**Results:**

Max. Displacement: 0.73 in.
Time of Max. Displacement: 0.6151 sec
Event Duration: 4 sec
Final Displacement: 0.65 in.

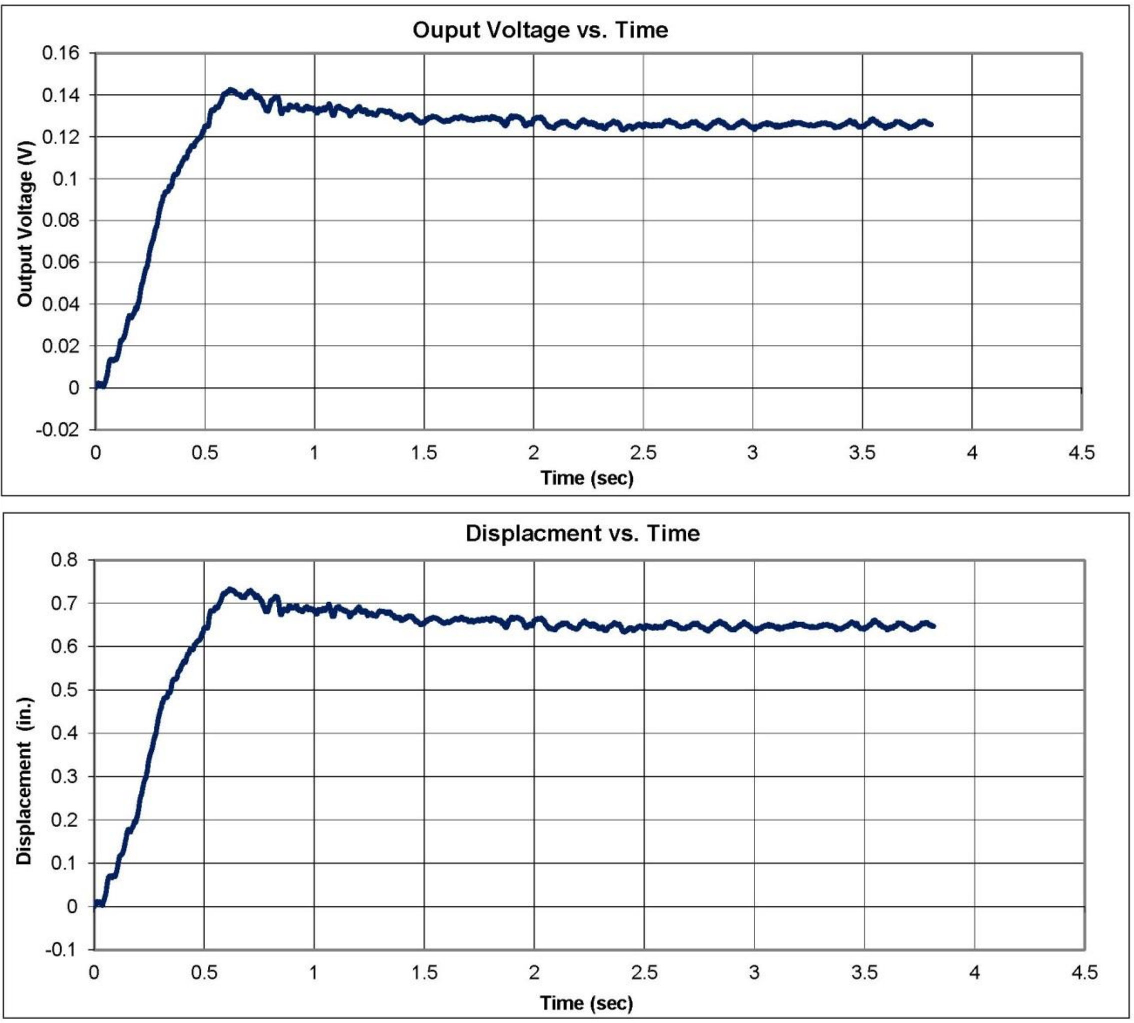


Figure F-6. String Potentiometer Data, Test No. MWP-4

# Appendix G. Accelerometer and Rate Transducer Data Plots, Test No. MWP-6

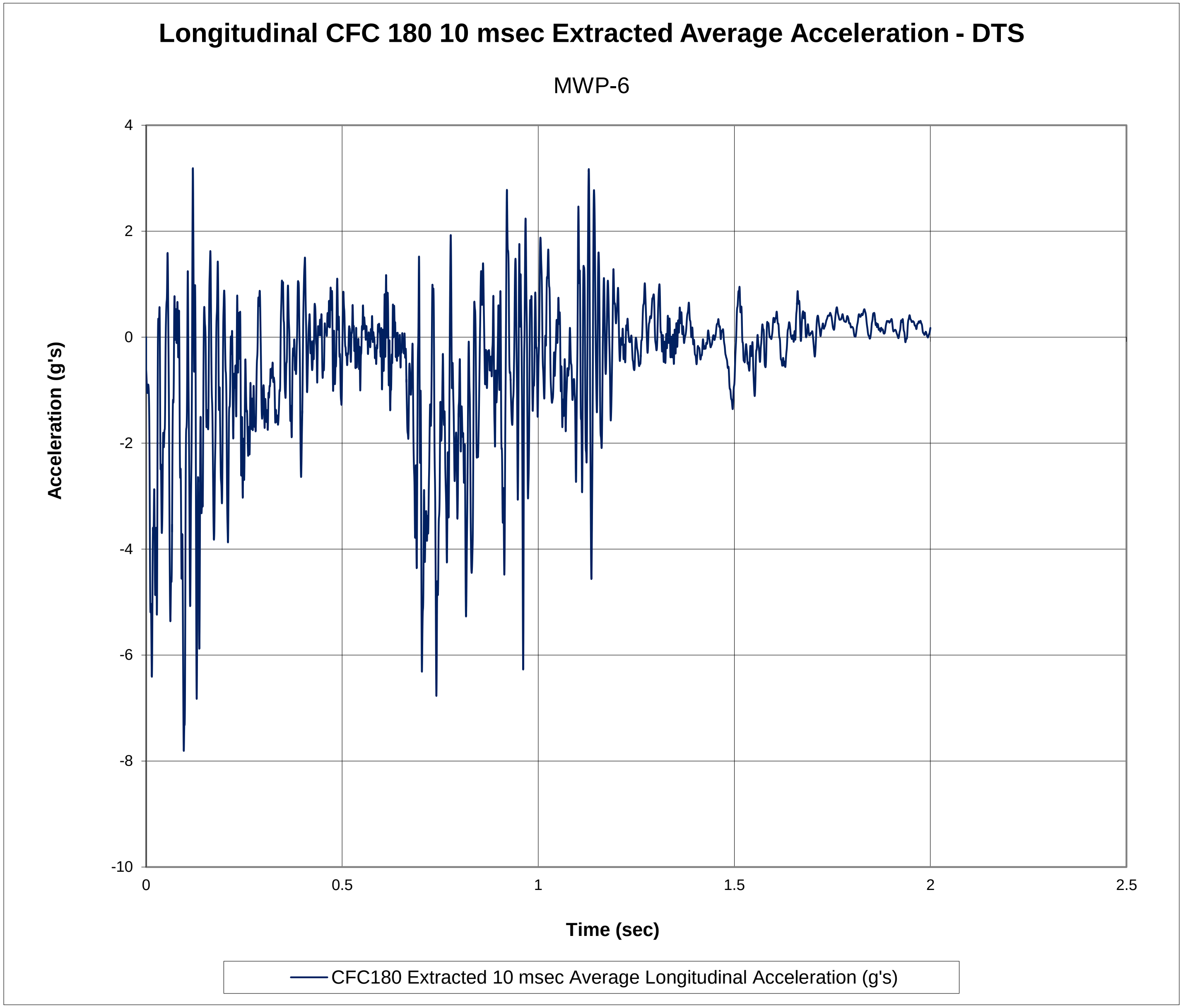


Figure G-1. 10-ms Average Longitudinal Deceleration (SLICE 1), Test No. MWP-6

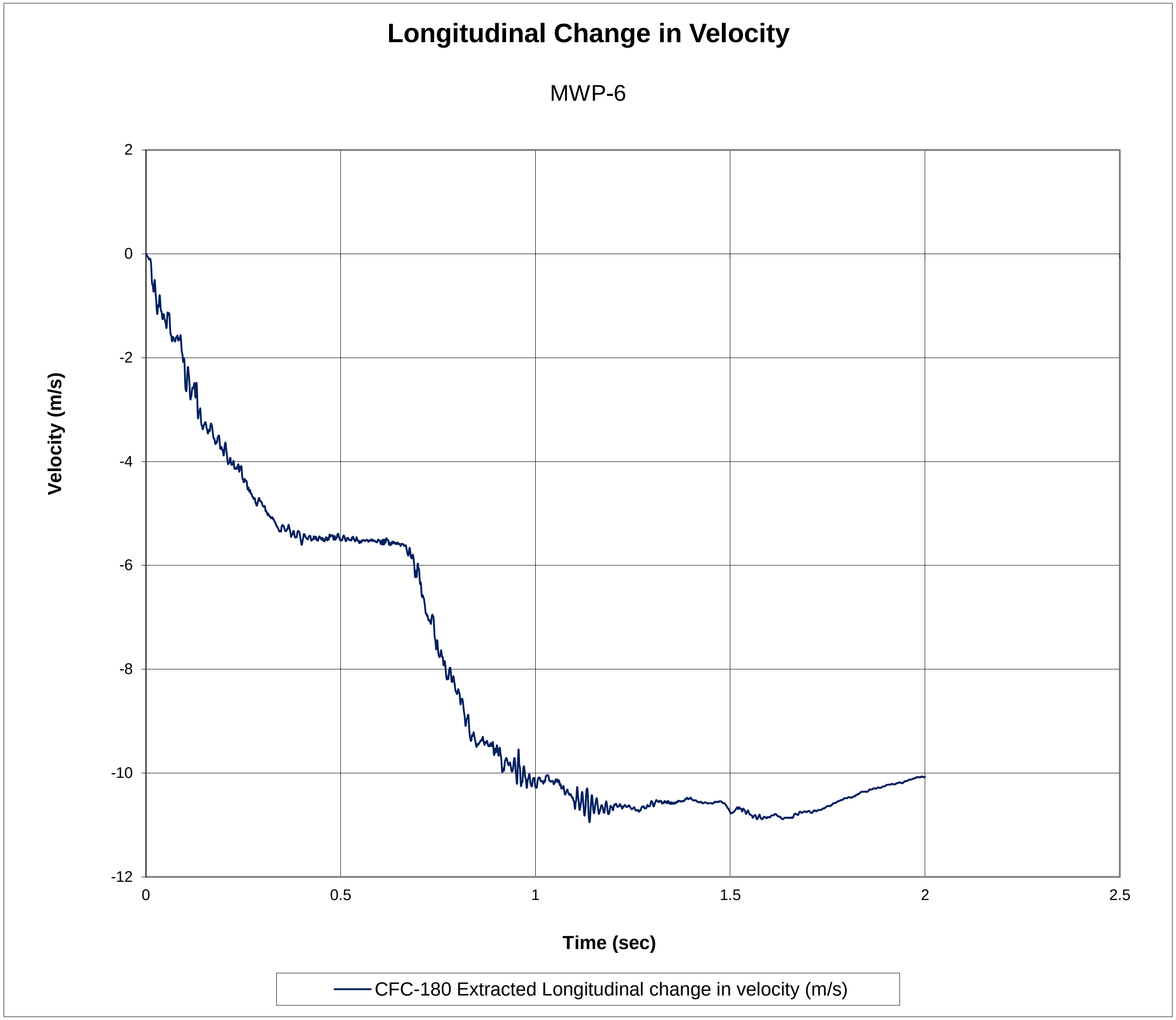


Figure G-2. Longitudinal Occupant Impact Velocity (SLICE 1), Test No. MWP-6

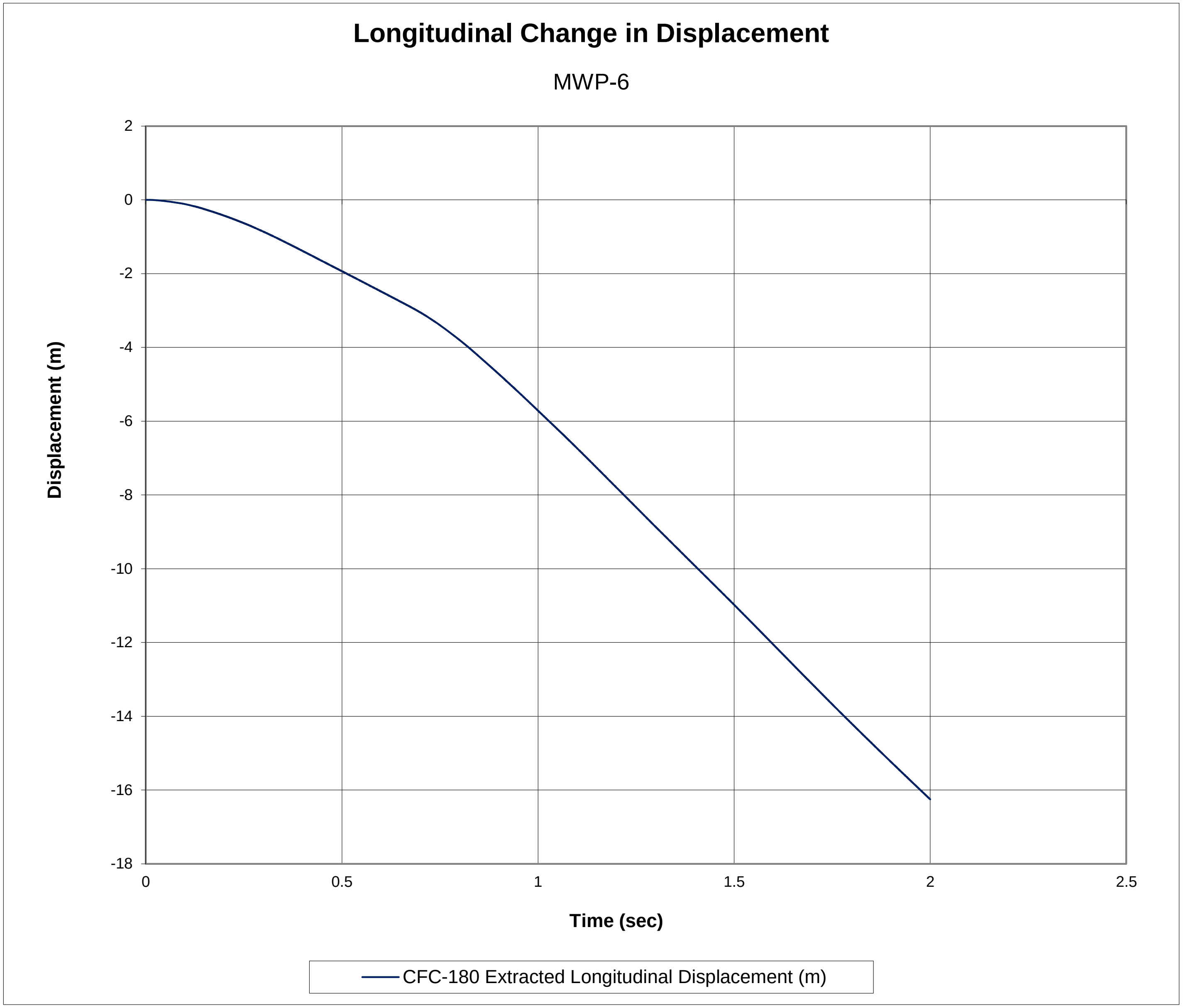


Figure G-3. Longitudinal Occupant Displacement (SLICE 1), Test No. MWP-6

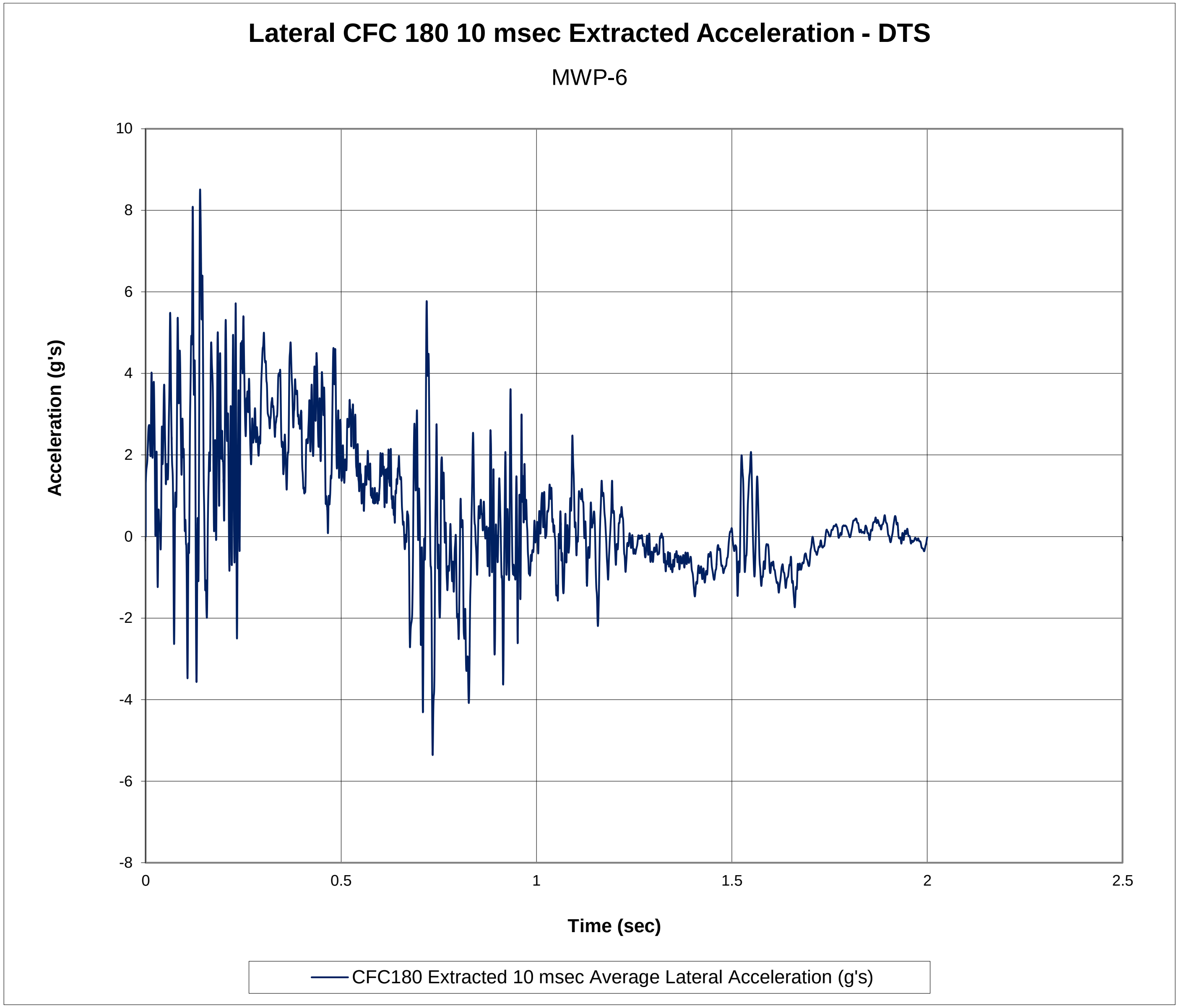


Figure G-4. 10-ms Average Lateral Deceleration (SLICE 1), Test No. MWP-6

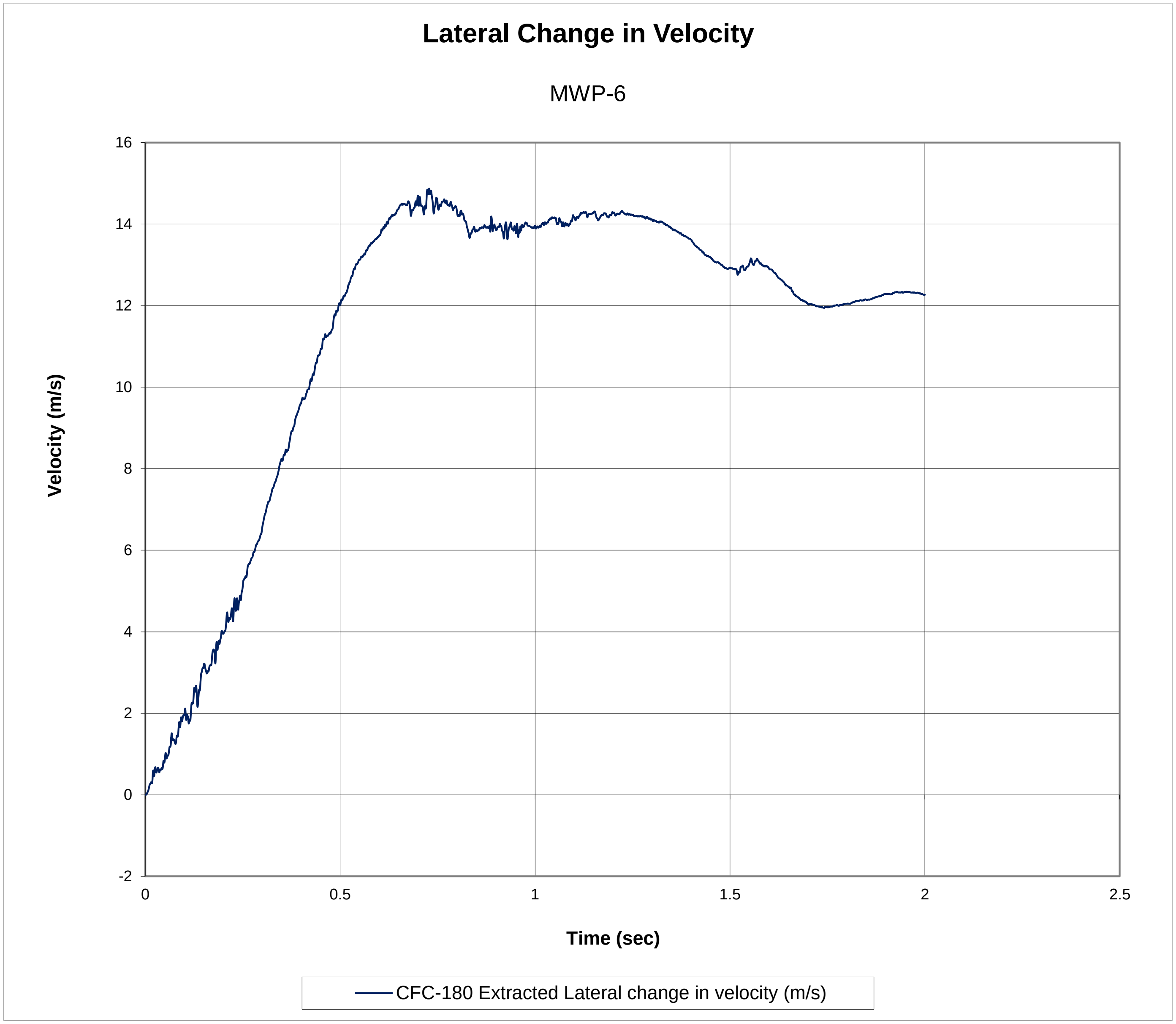


Figure G-5. Lateral Occupation Impact Velocity (SLICE 1), Test No. MWP-6

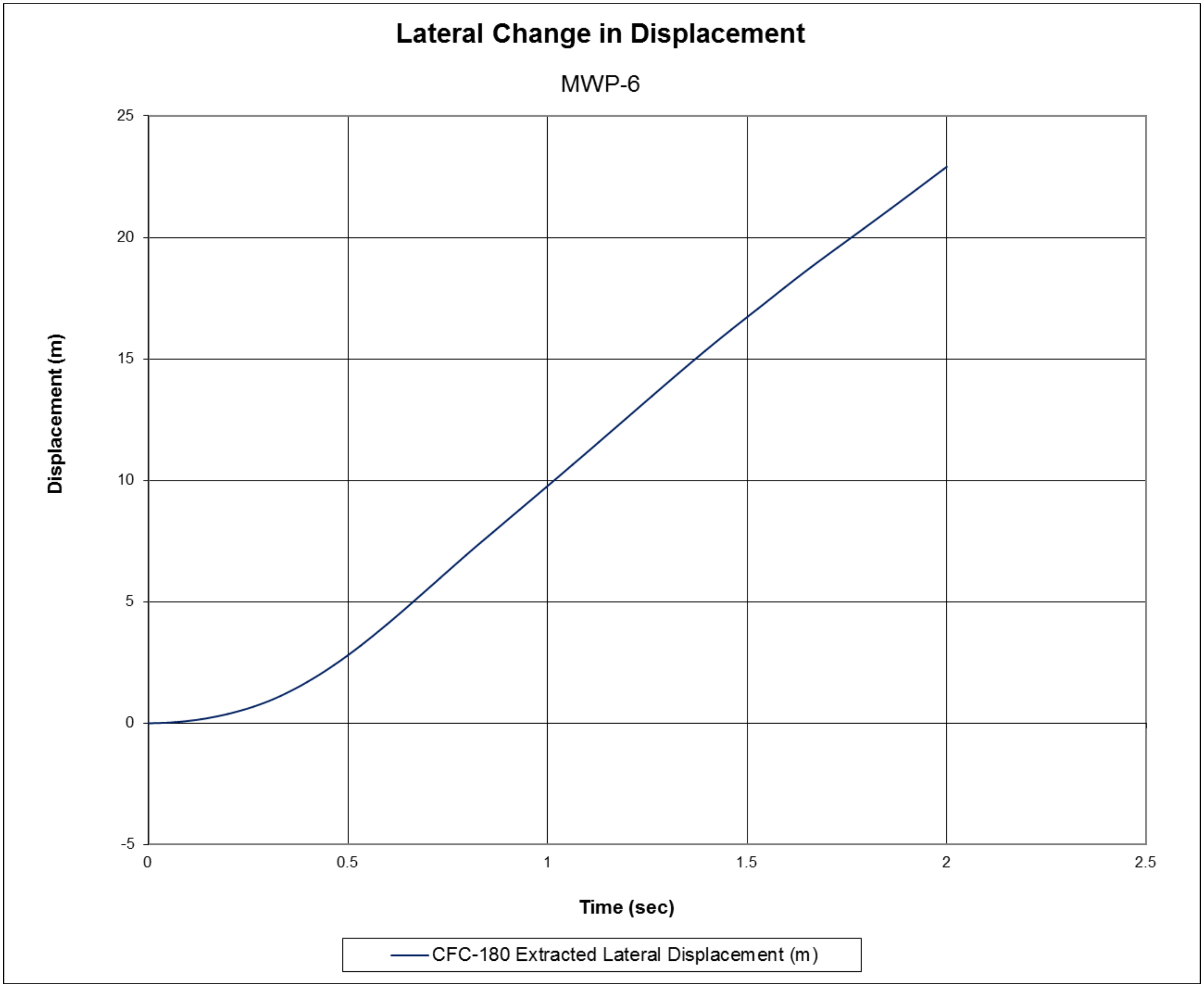


Figure G-6. Lateral Occupant Displacement (SLICE 1), Test No. MWP-6

Figure G-7. Vehicle Angular Displacements (SLICE 1), Test No. MWP-6

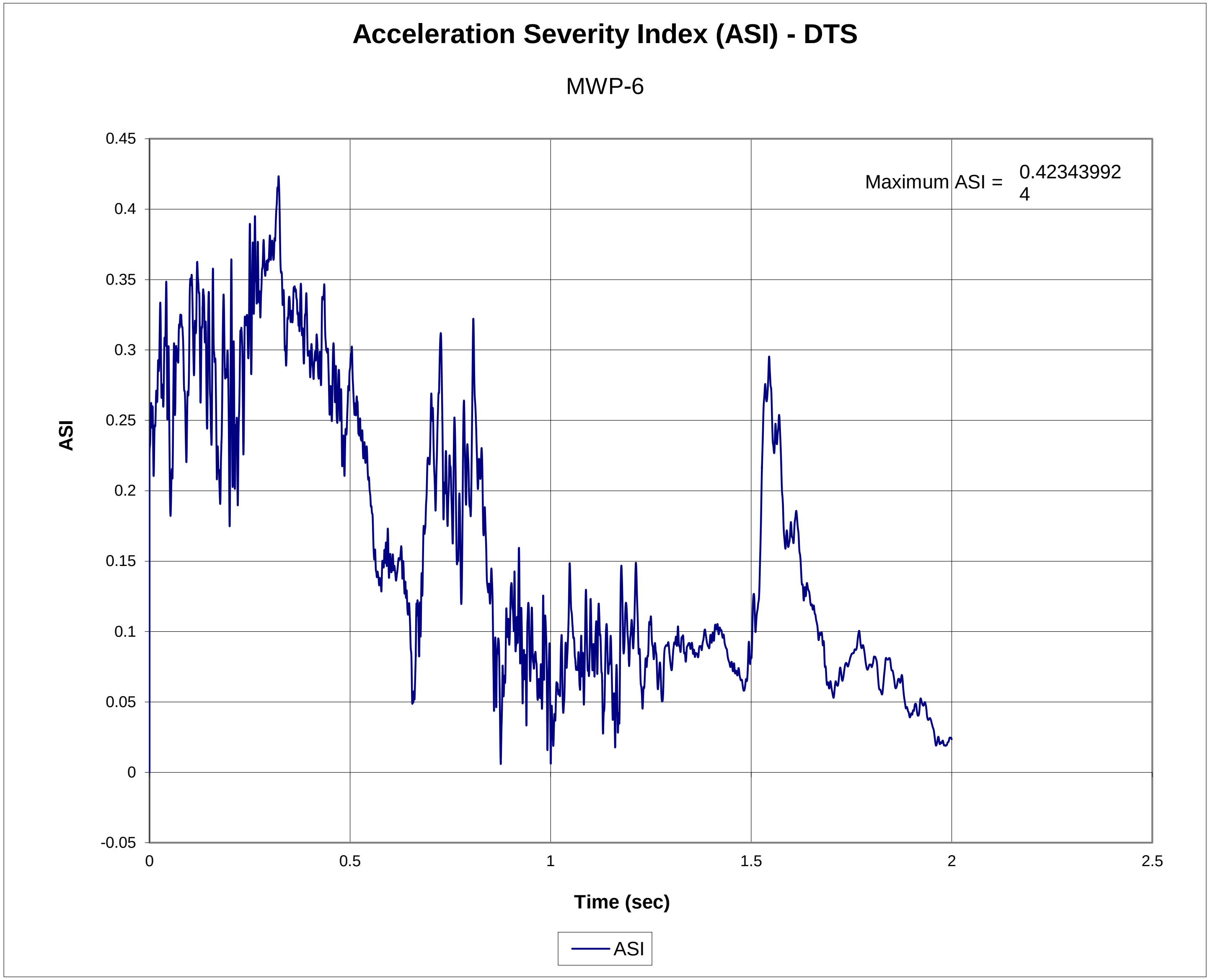


Figure G-8. Acceleration Service Index (SLICE 1), Test No. MWP-6

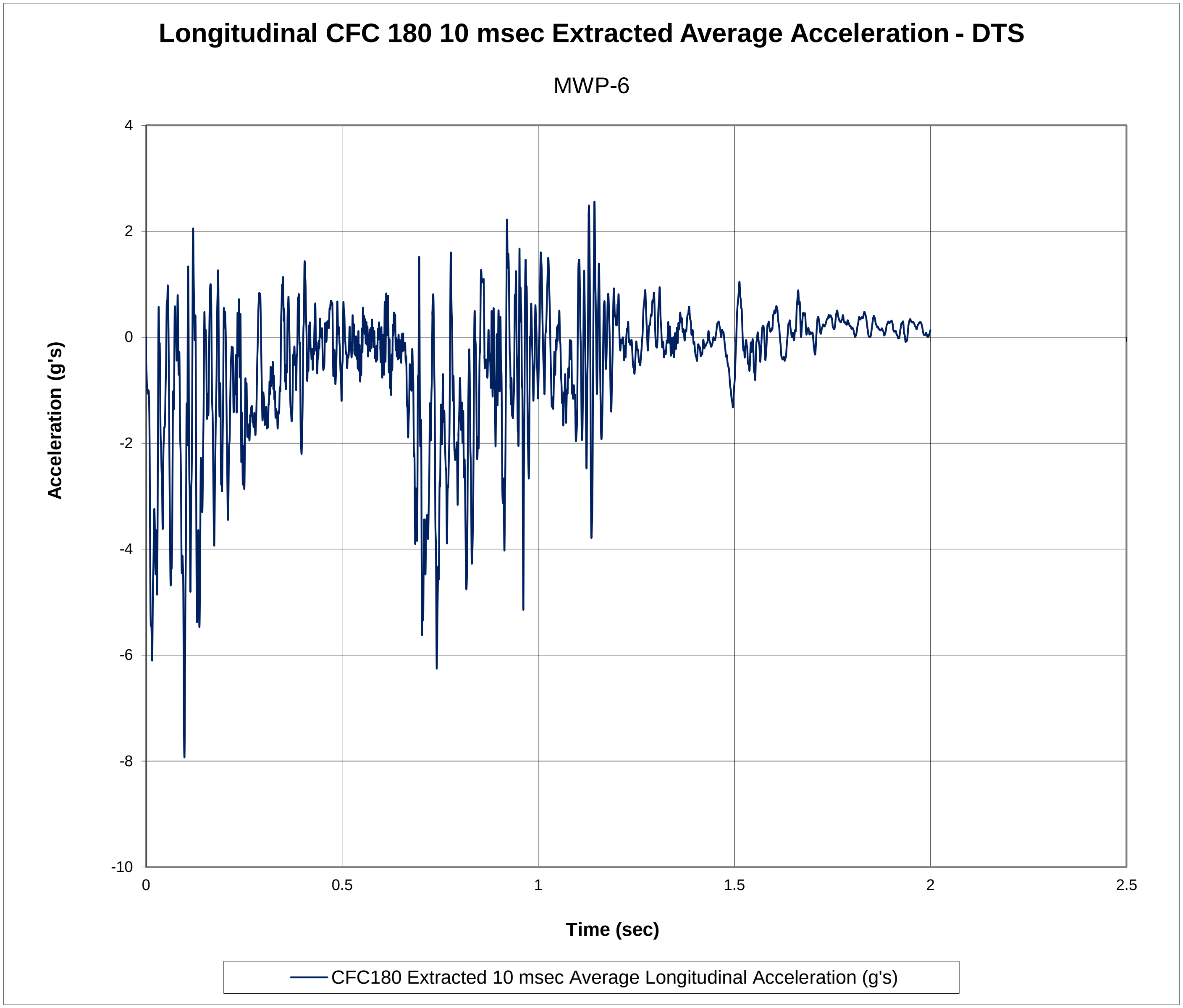


Figure G-9. 10-ms Average Longitudinal Deceleration (SLICE 2), Test No.MWP-6

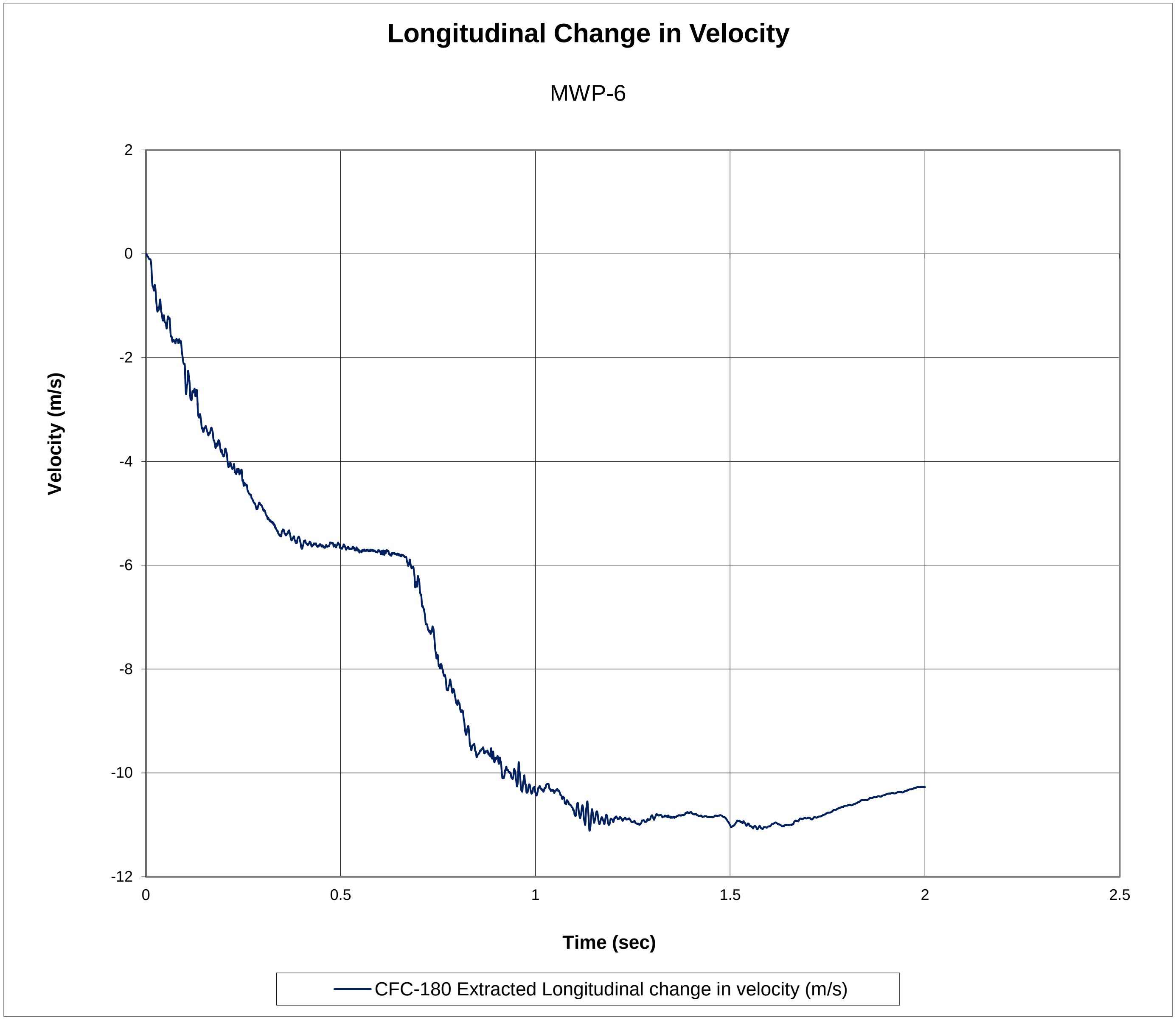


Figure G-10. Longitudinal Occupant Impact Velocity (SLICE 2), Test No. MWP-6

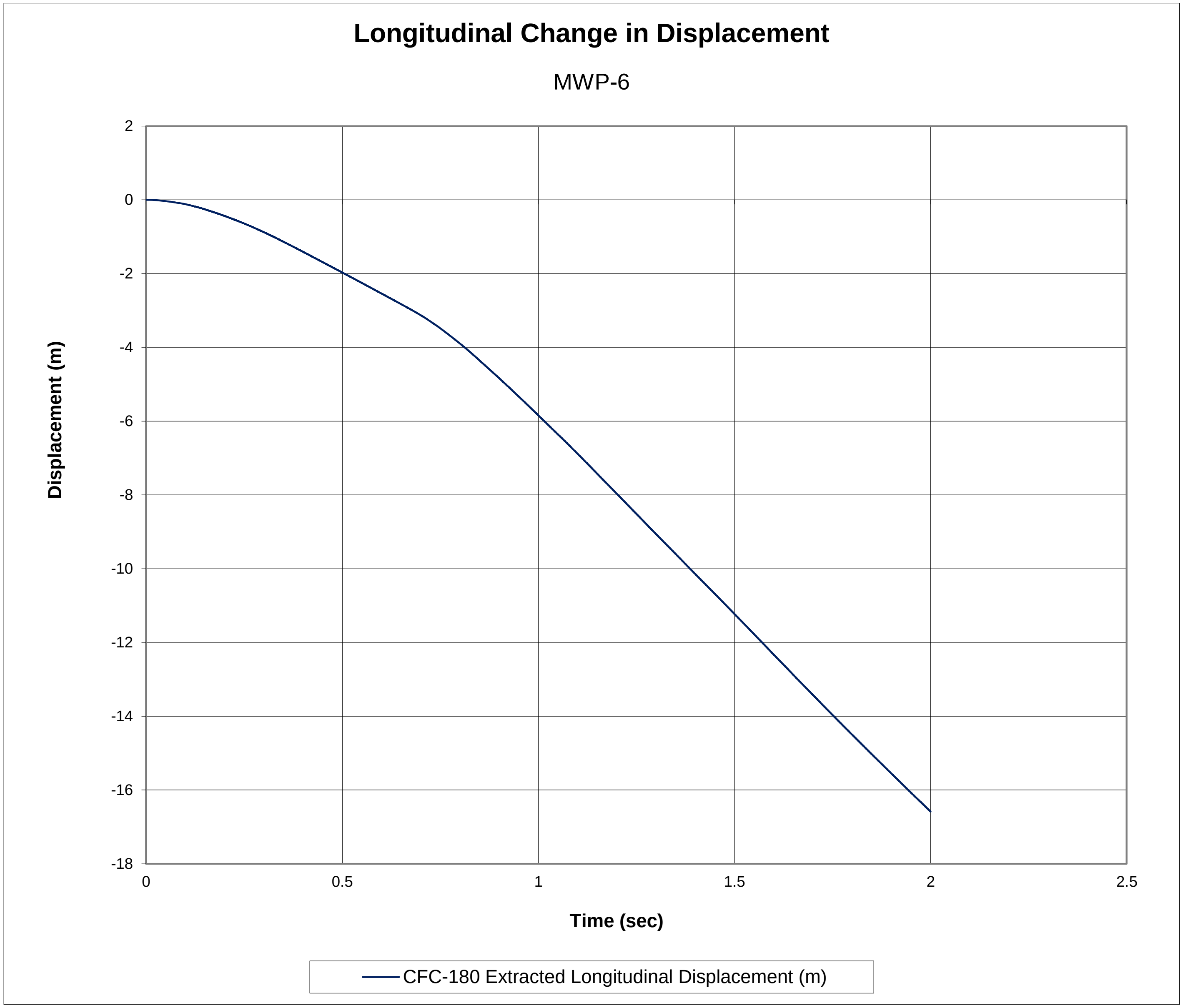


Figure G-11. Longitudinal Occupant Displacement (SLICE 2), Test No. MWP-6

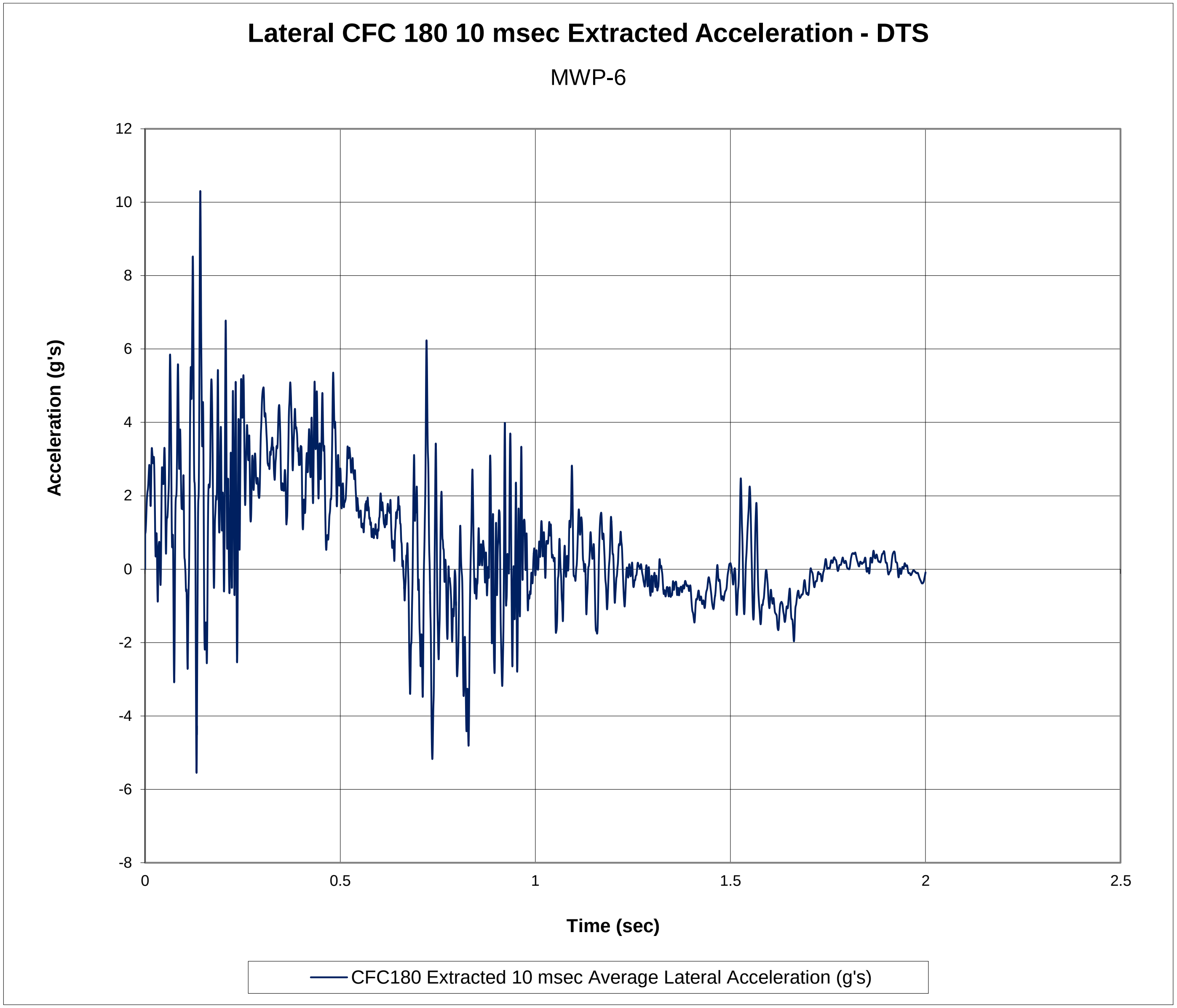


Figure G-12. 10-ms Average Lateral Deceleration (SLICE 2), Test No.MWP-6

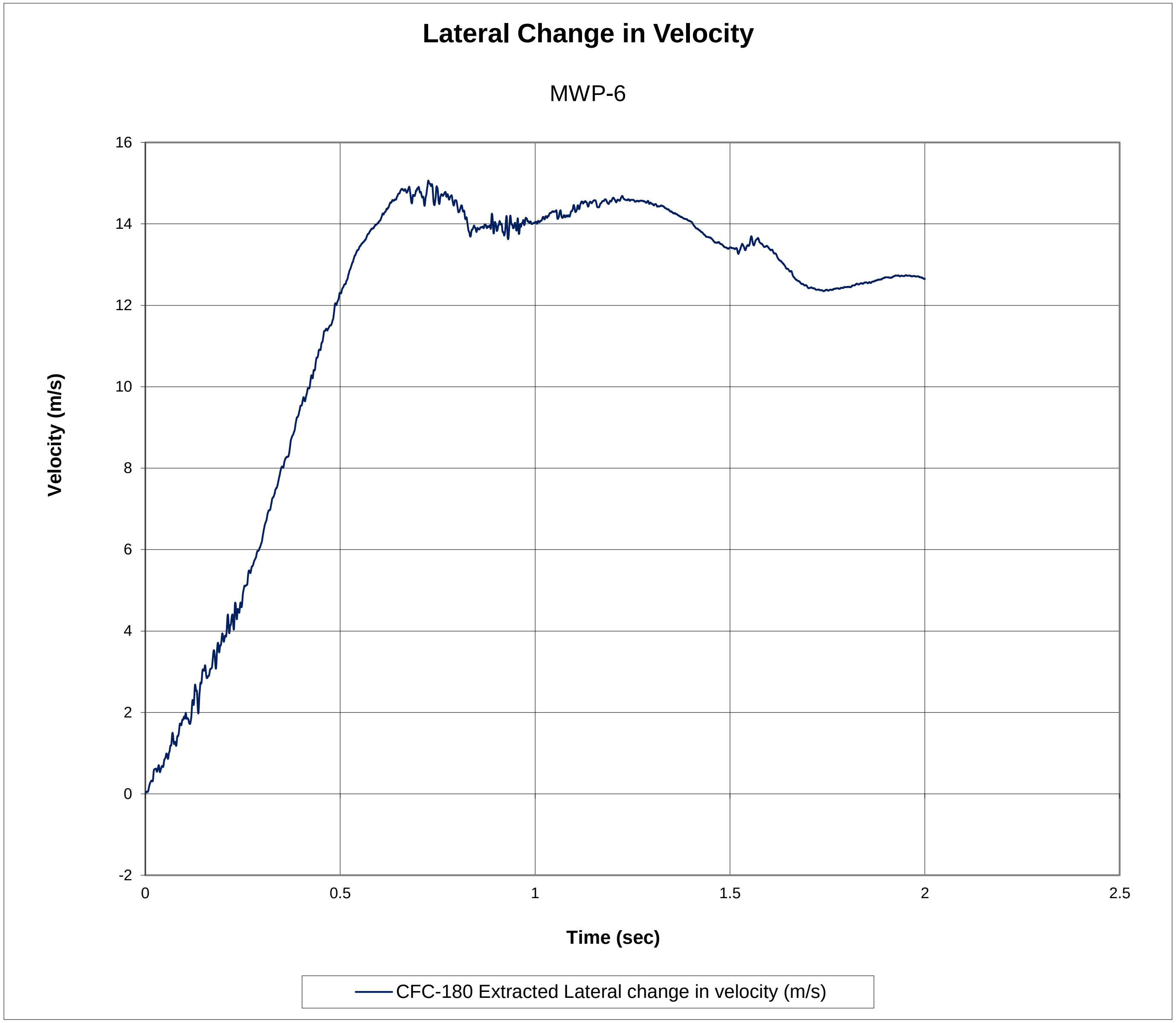


Figure G-13. Lateral Occupant Impact Velocity (SLICE 2), Test No. MWP-6

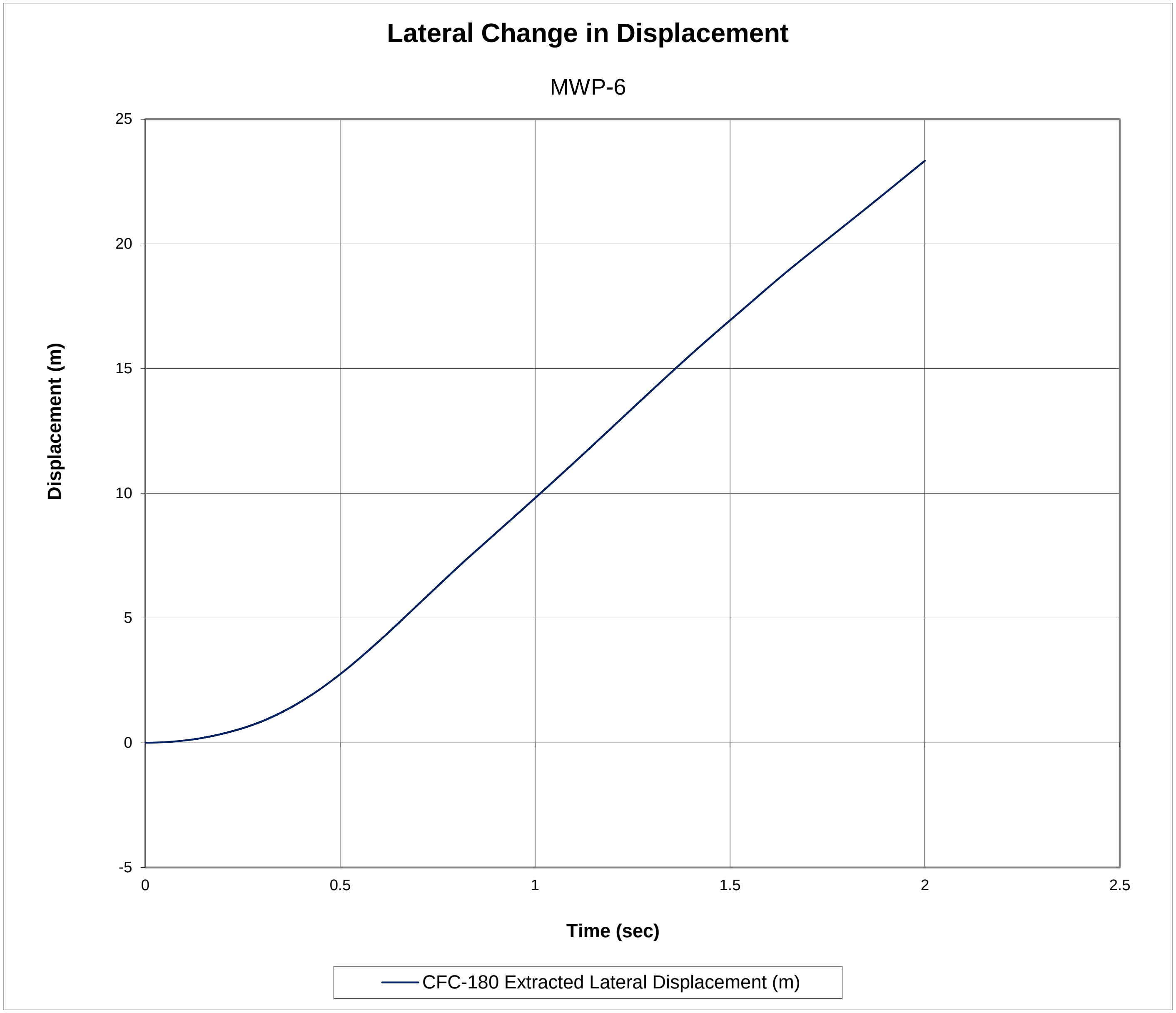


Figure G-14. Lateral Occupant Displacement (SLICE 2), Test No. MWP-6

Figure G-15. Vehicle Angular Displacements (SLICE 2), Test No. MWP-6

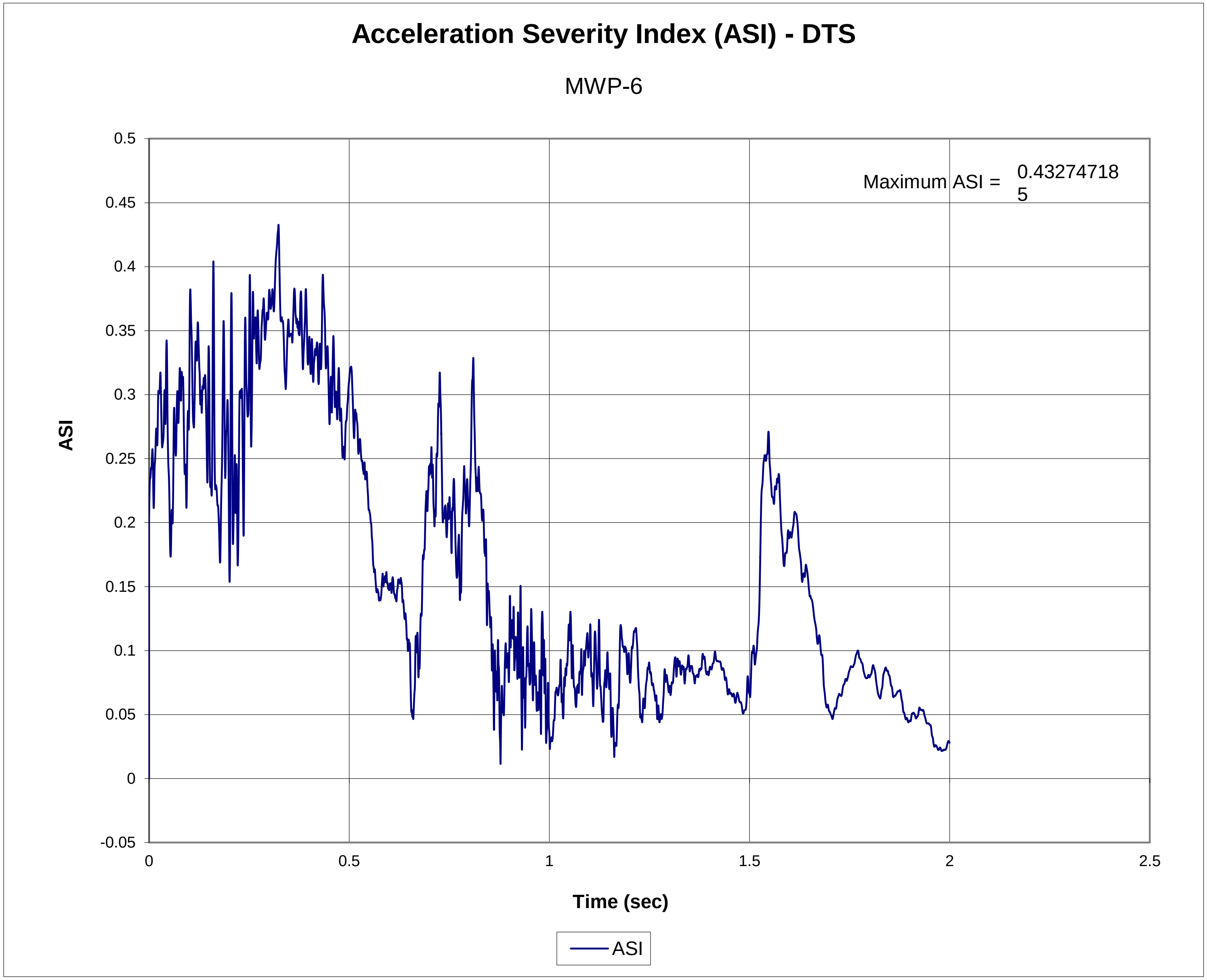


Figure G-16. Acceleration Severity Index (SLICE 2), Test No. MWP-6

# Appendix H. Load Cell and String Potentiometer Data, Test No. MWP-6

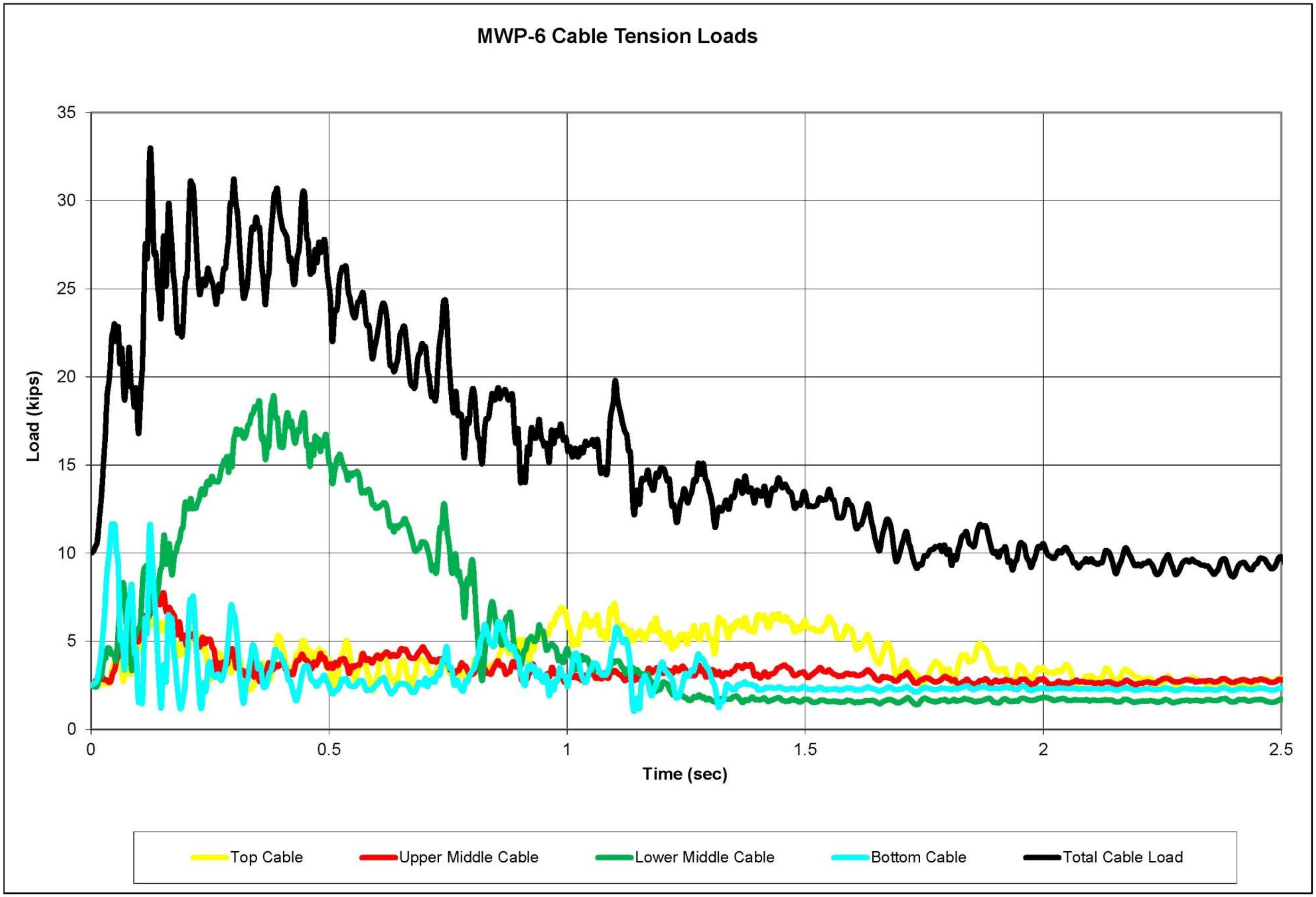


Figure H-1. Combined Load Cell Data, Test No. MWP-6

# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

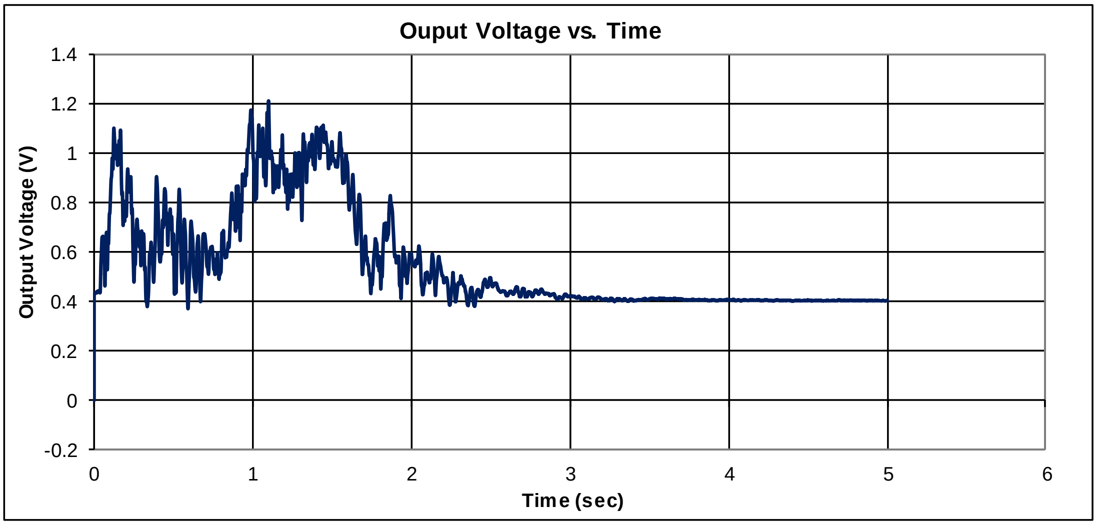
| | |
|---|---|
| Test No: | MWP-6 |
| Date: | 1/16/2015 |
| System / Test Article: | 4-cable median barrier |
| LC Location / Component: | Top Cable - US of Impact |
| Additional Notes: | |

**Load Cell Information:**

| | |
|---|---|
| Load Cell No.: | 120642 |
| Calibration Factor: | 2.12022 mv/V |
| Input Voltage (excitation): | 10 Volts |
| Gain: | 400 |
| Full Scale Load: | 50 kips |
| Sample Rate: | 10000 Hz |
| Cutoff Frequency: | 100 Hz |

**Results:**

| | |
|---|---|
| Preload: | 0 kips |
| Max. Load: | 7.14 kips |
| Time of Max. Load: | 1.0997 sec |
| Event Duration: | 5 sec |
| Final Load: | 2.38 kips |



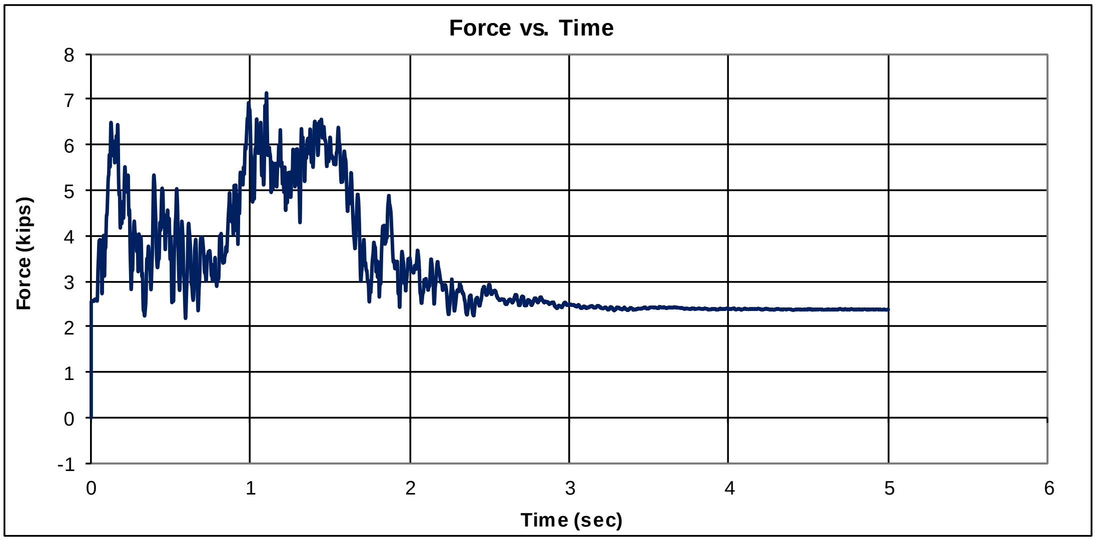


Figure H-2. Load Cell Data, Cable No. 4, Test No. MWP-6

# MIDWEST ROADSIDE SAFETY FACILITY

## Load Cell Summary

**Test Information:**

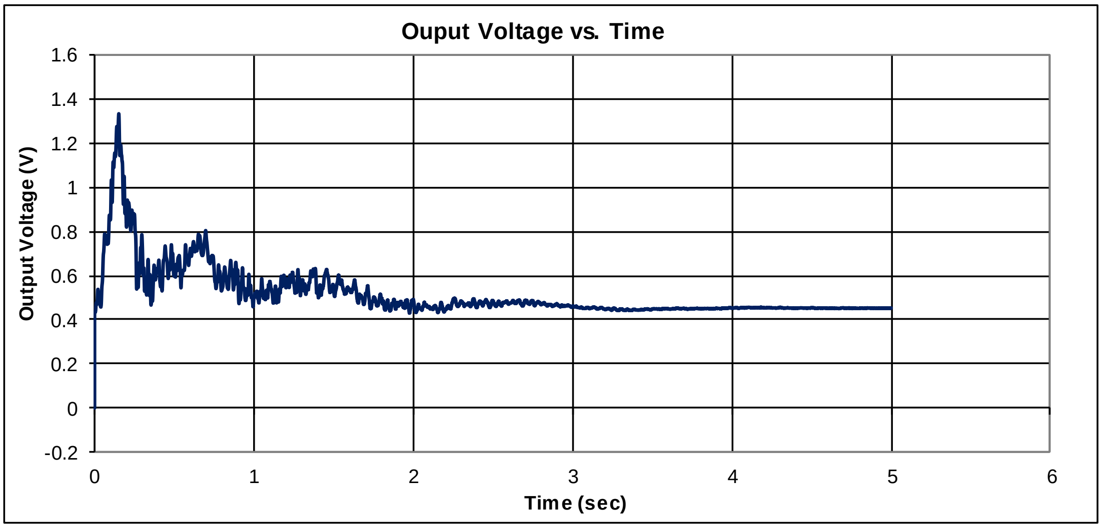
Test No: MWP-6
Date: 1/16/2015
System / Test Article: 4-cable median barrier
LC Location / Component: Top Middle Cable - US of Impact
Additional Notes:

**Load Cell Information:**

| | |
|---|---|
| Load Cell No.: | 143436 |
| Calibration Factor: | 2.14575 mv/V |
| Input Voltage (excitation): | 10 Volts |
| Gain: | 400 |
| Full Scale Load: | 50 kips |
| Sample Rate: | 10000 Hz |
| Cutoff Frequency: | 100 Hz |

**Results:**

| | |
|---|---|
| Preload: | 0 kips |
| Max. Load: | 7.76 kips |
| Time of Max. Load: | 0.1521 sec |
| Event Duration: | 5 sec |
| Final Load: | 2.64 kips |



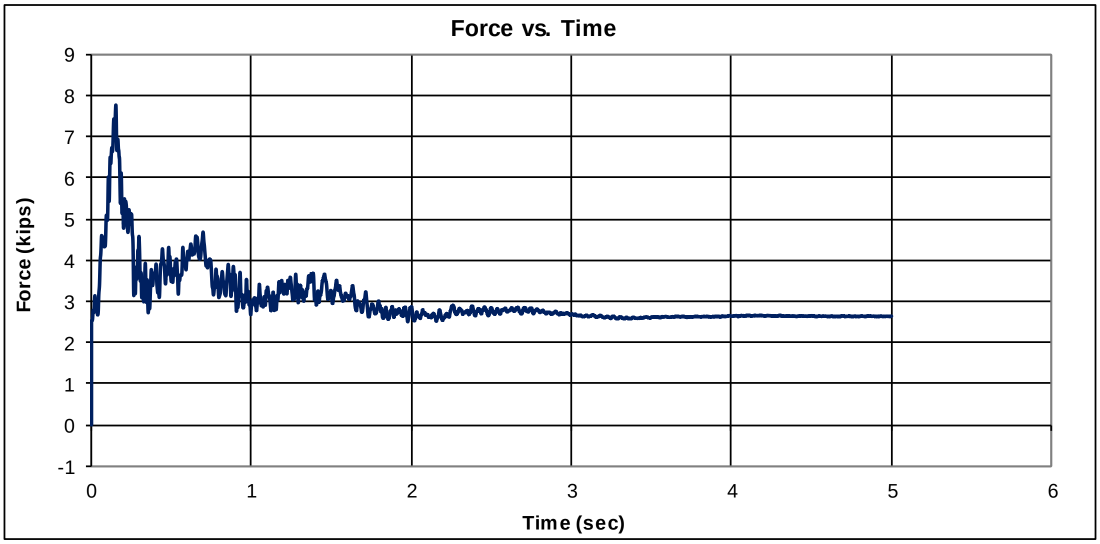


Figure H-3. Load Cell Data, Cable No. 3, Test No. MWP-6

# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

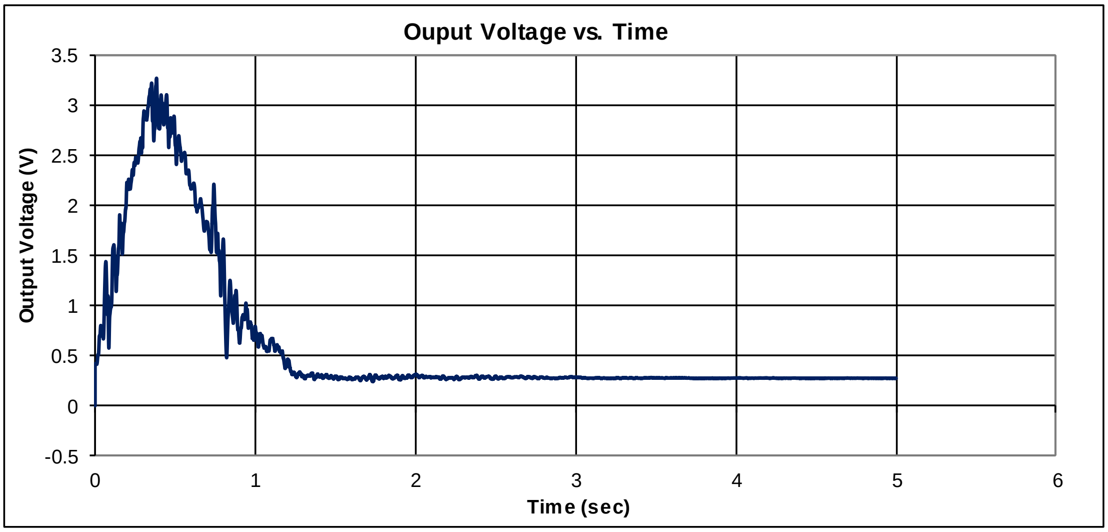
Test No: MWP-6
Date: 1/16/2015
System / Test Article: 4-cable median barrier
LC Location / Component: Bottom Middle Cable - US of Impact
Additional Notes:

**Load Cell Information:**

| | |
|---|---|
| Load Cell No.: | 143435 |
| Calibration Factor: | 2.15835 mv/V |
| Input Voltage (excitation): | 10 Volts |
| Gain: | 400 |
| Full Scale Load: | 50 kips |
| Sample Rate: | 10000 Hz |
| Cutoff Frequency: | 100 Hz |

**Results:**

| | |
|---|---|
| Preload: | 0 kips |
| Max. Load: | 18.94 kips |
| Time of Max. Load: | 0.3838 sec |
| Event Duration: | 5 sec |
| Final Load: | 1.59 kips |



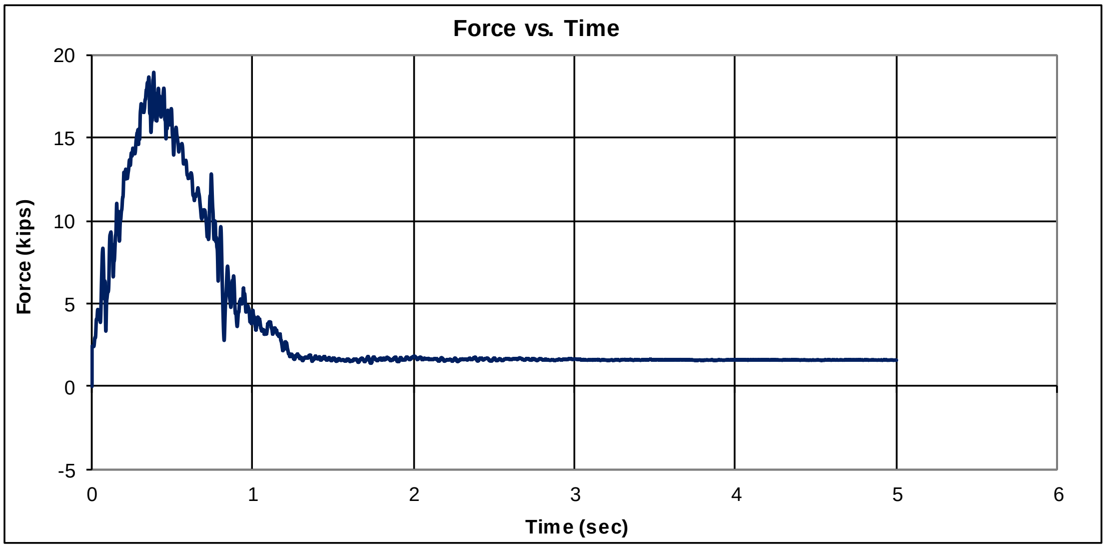


Figure H-4. Load Cell Data, Cable No. 2, Test No. MWP-6

# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

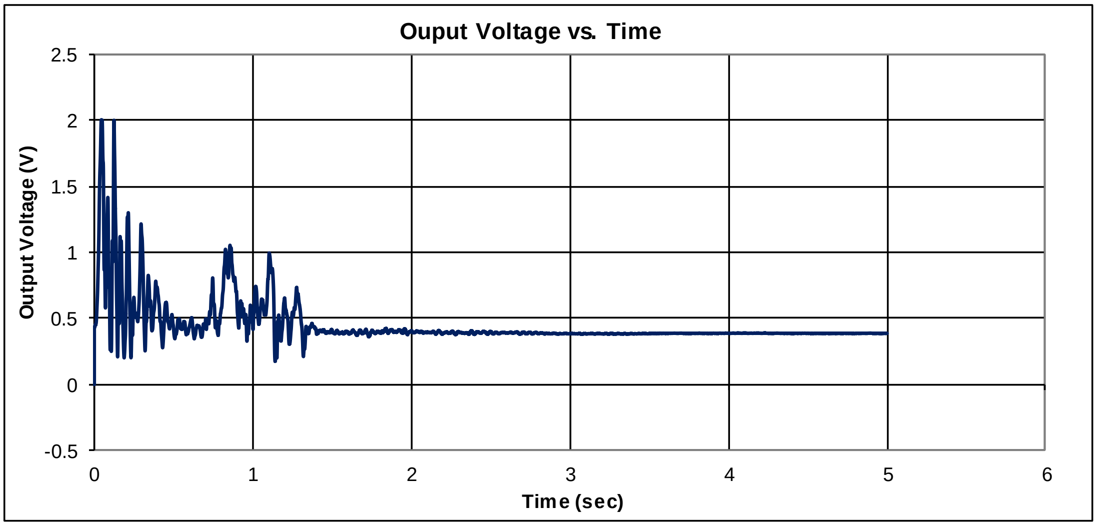
Test No: MWP-6
Date: 1/16/2015
System / Test Article: 4-cable median barrier
LC Location / Component: Bottom Cable - US of Impact
Additional Notes:

**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: 0 kips
Max. Load: 11.66 kips
Time of Max. Load: 0.0442 sec
Event Duration: 5 sec
Final Load: 2.26 kips



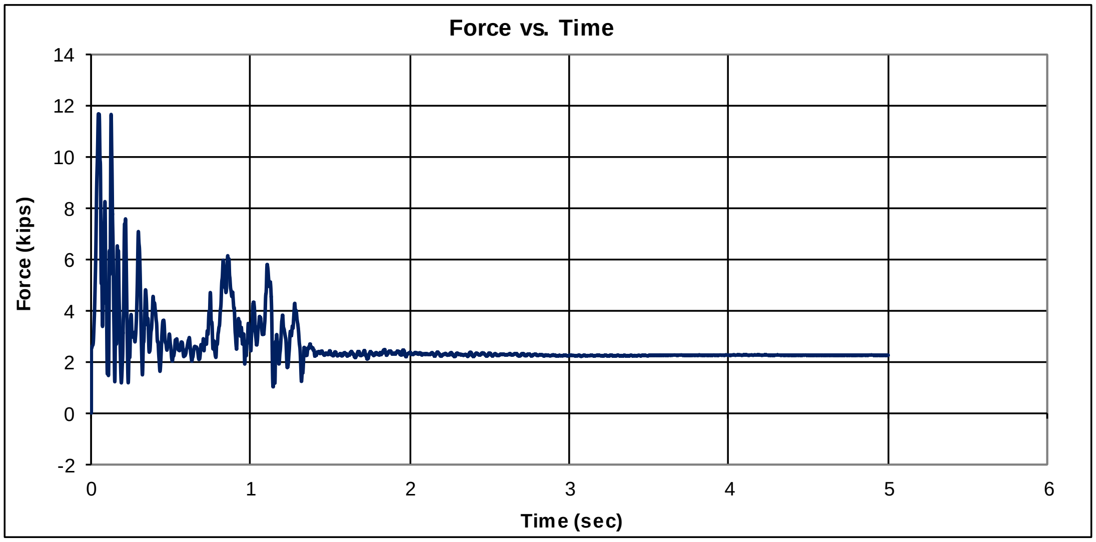


Figure H-5. Load Cell Data, Cable No. 1, Test No. MWP-6

# MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

**Test Information:**

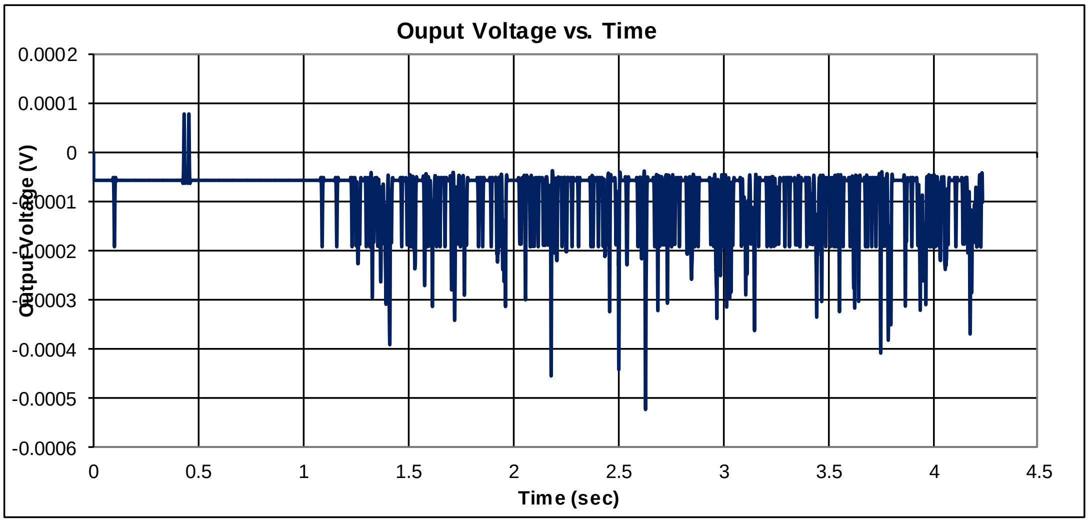
Test No: MWP-6
Date: 1/16/2015
System / Test Article: 4-cable median barrier
SP Location / Component: Upstream Anchor
Additional Notes:

**String Potentiometer Information:**

| | |
|---|---|
| String Pot No.: | 27039203 |
| Calibration Factor: | 19.4483 mV/V/in. |
| Input Voltage (excitation): | 10 Volts |
| Gain: | 1 |
| Full Scale Load: | 1 |
| Sample Rate: | 10000 Hz |
| Cutoff Frequency: | 100 Hz |

**Results:**

| | |
|---|---|
| Max. Displacement: | 0.00 in. |
| Time of Max. Displacement: | 0.454 sec |
| Event Duration: | 5 sec |
| Final Displacement: | 0.00 in. |



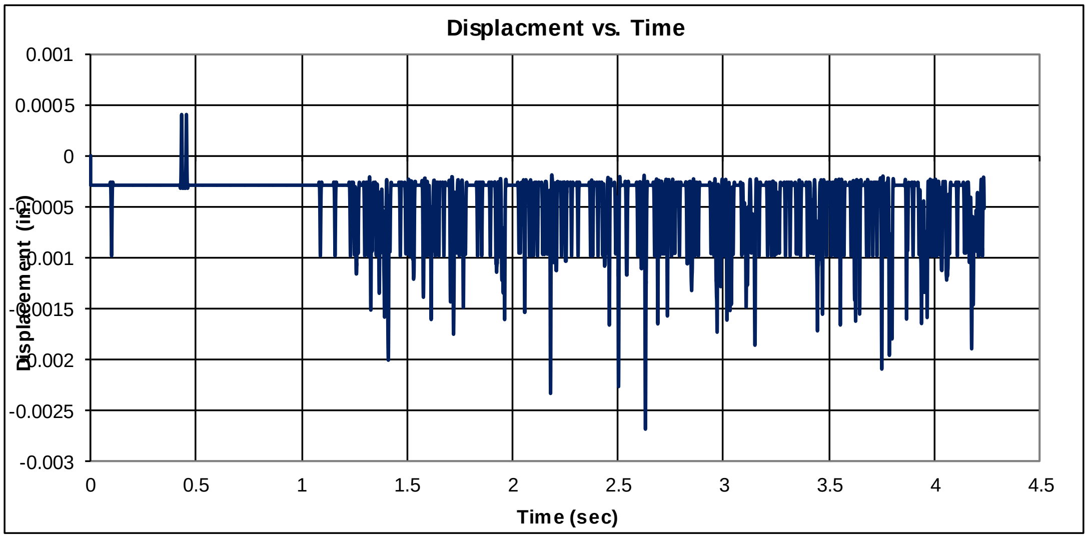


Figure H-6. String Potentiometer Data, Test No. MWP-6

# Appendix I. Accelerometer and Rate Transducer Data Plots, Test No. MWP-7

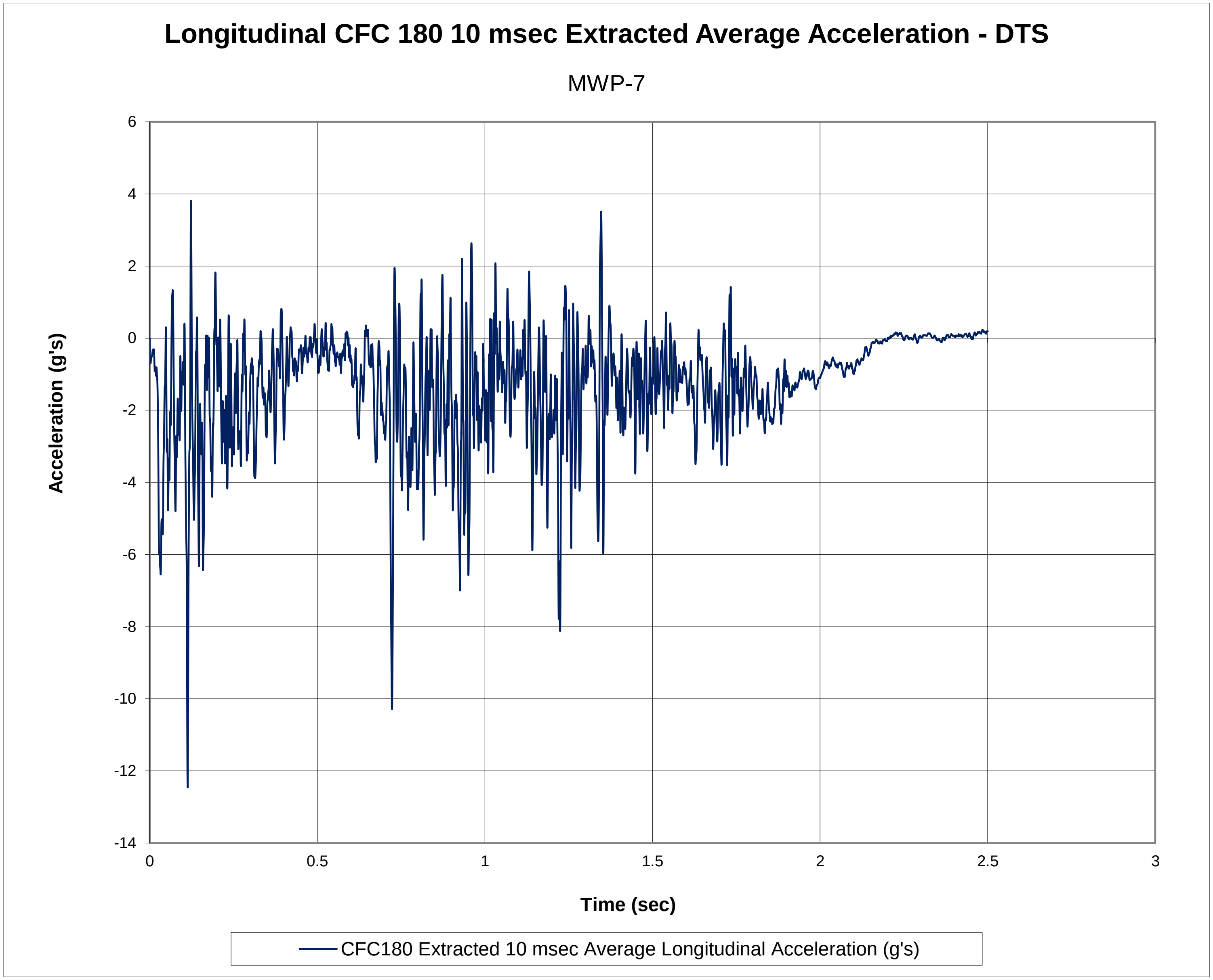


Figure I-1. 10-ms Average Longitudinal Deceleration (SLICE 1), Test No. MWP-7

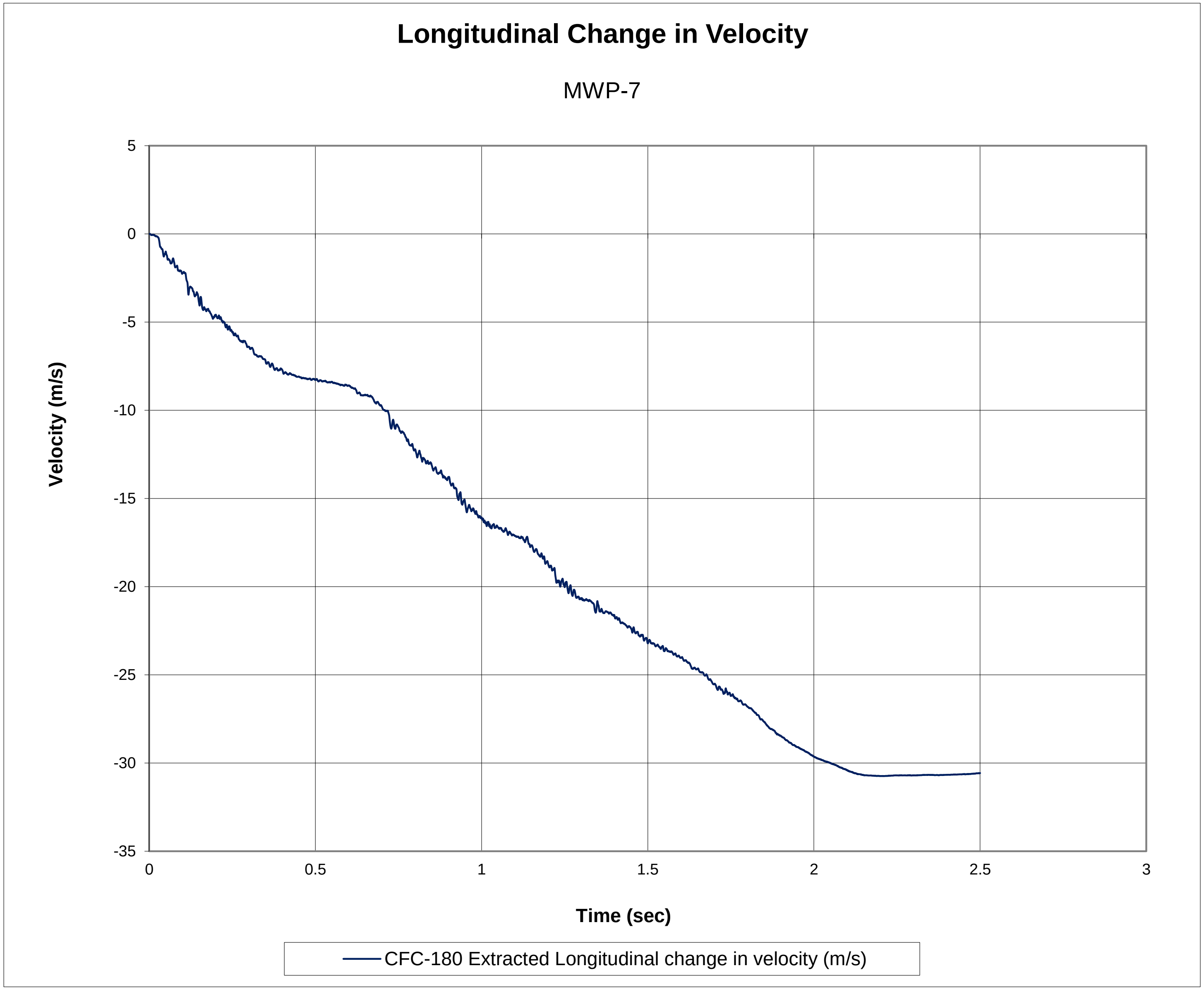


Figure I-2. Longitudinal Occupant Impact Velocity (SLICE 1), Test No. MWP-7

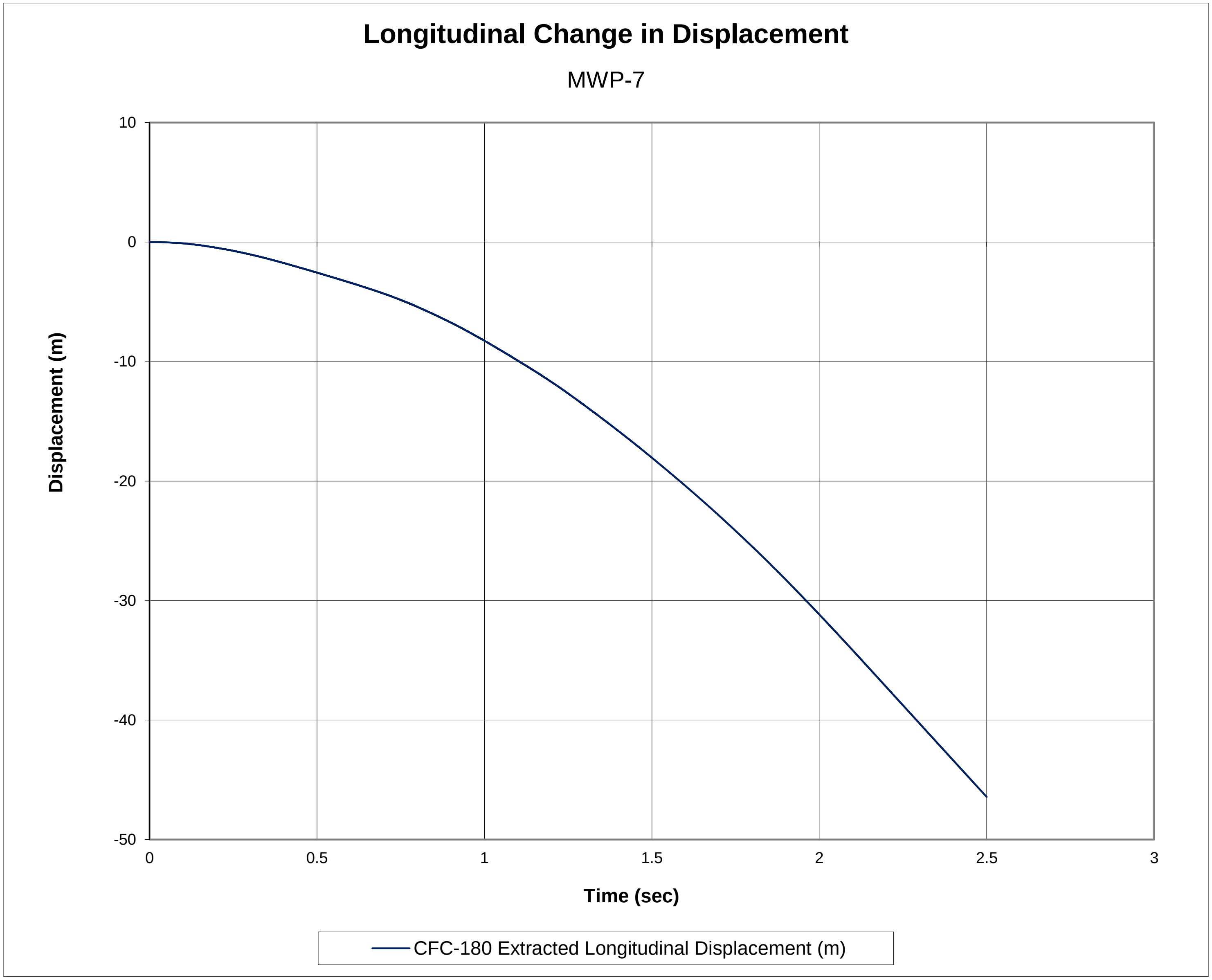


Figure I-3. Longitudinal Occupant Displacement (SLICE 1), Test No. MWP-7

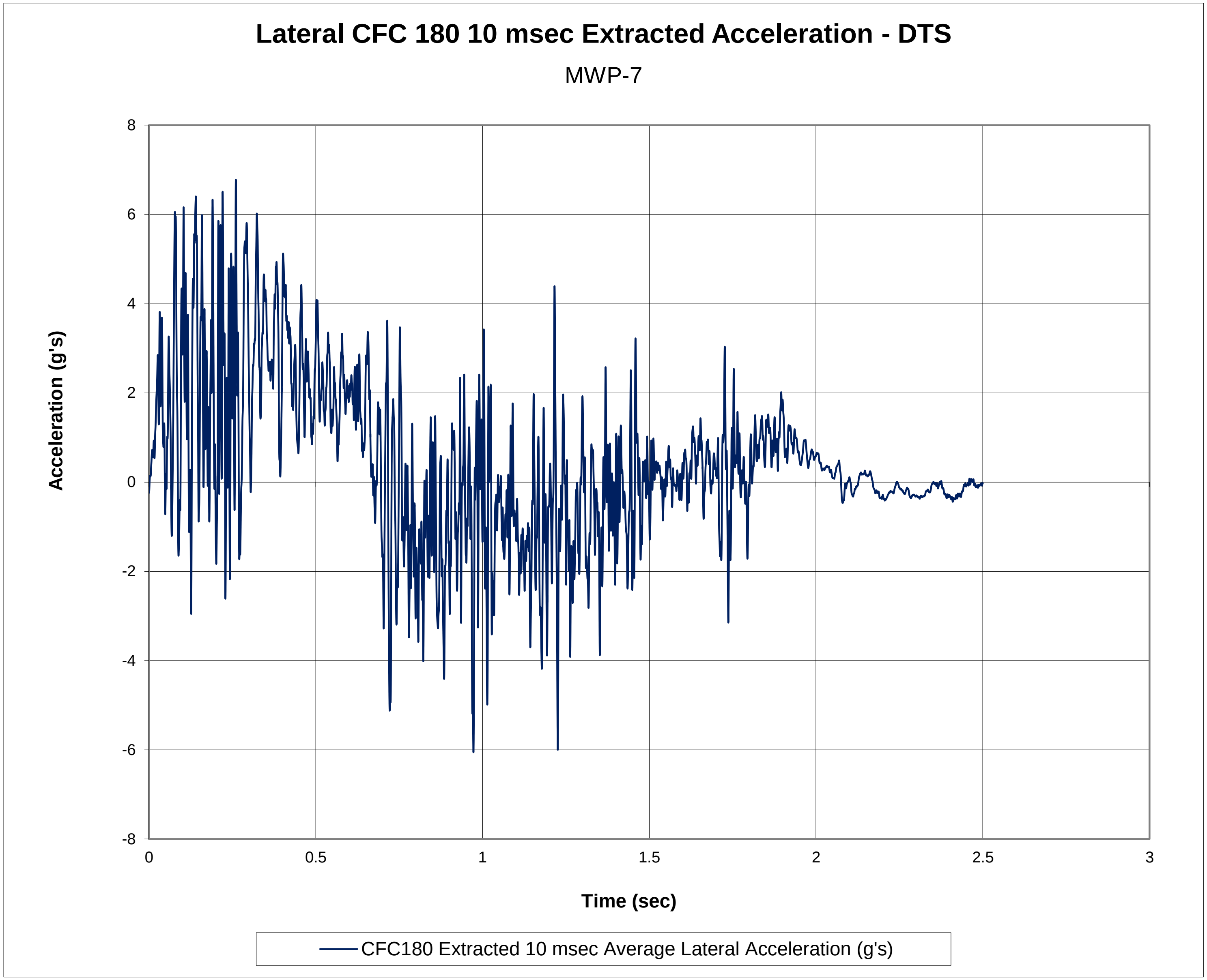


Figure I-4. 10-ms Average Lateral Deceleration (SLICE 1), Test No. MWP-7

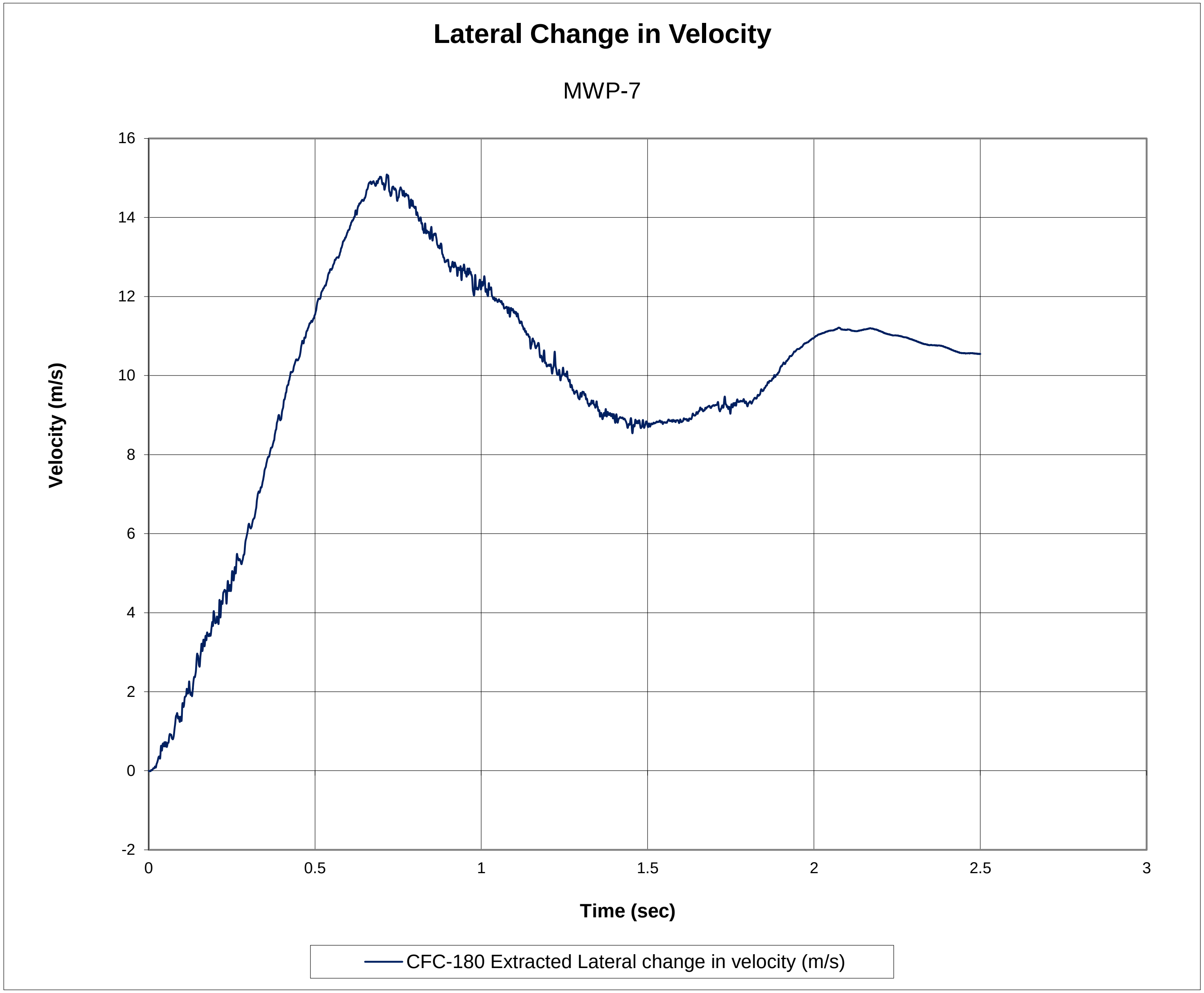


Figure I-5. Lateral Occupant Impact Velocity (SLICE 1), Test No. MWP-7

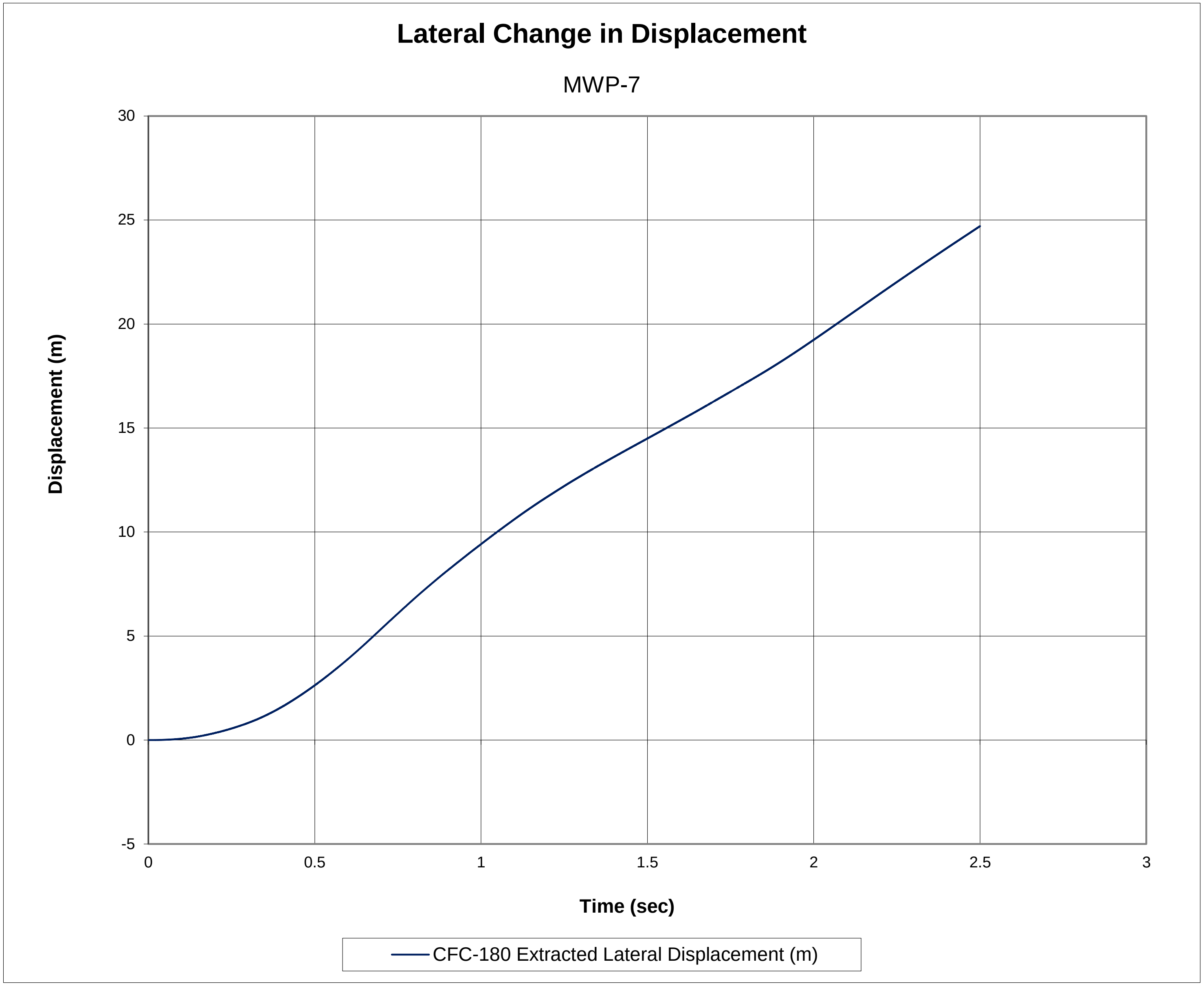


Figure I-6. Lateral Occupant Displacement (SLICE 1), Test No. MWP-7

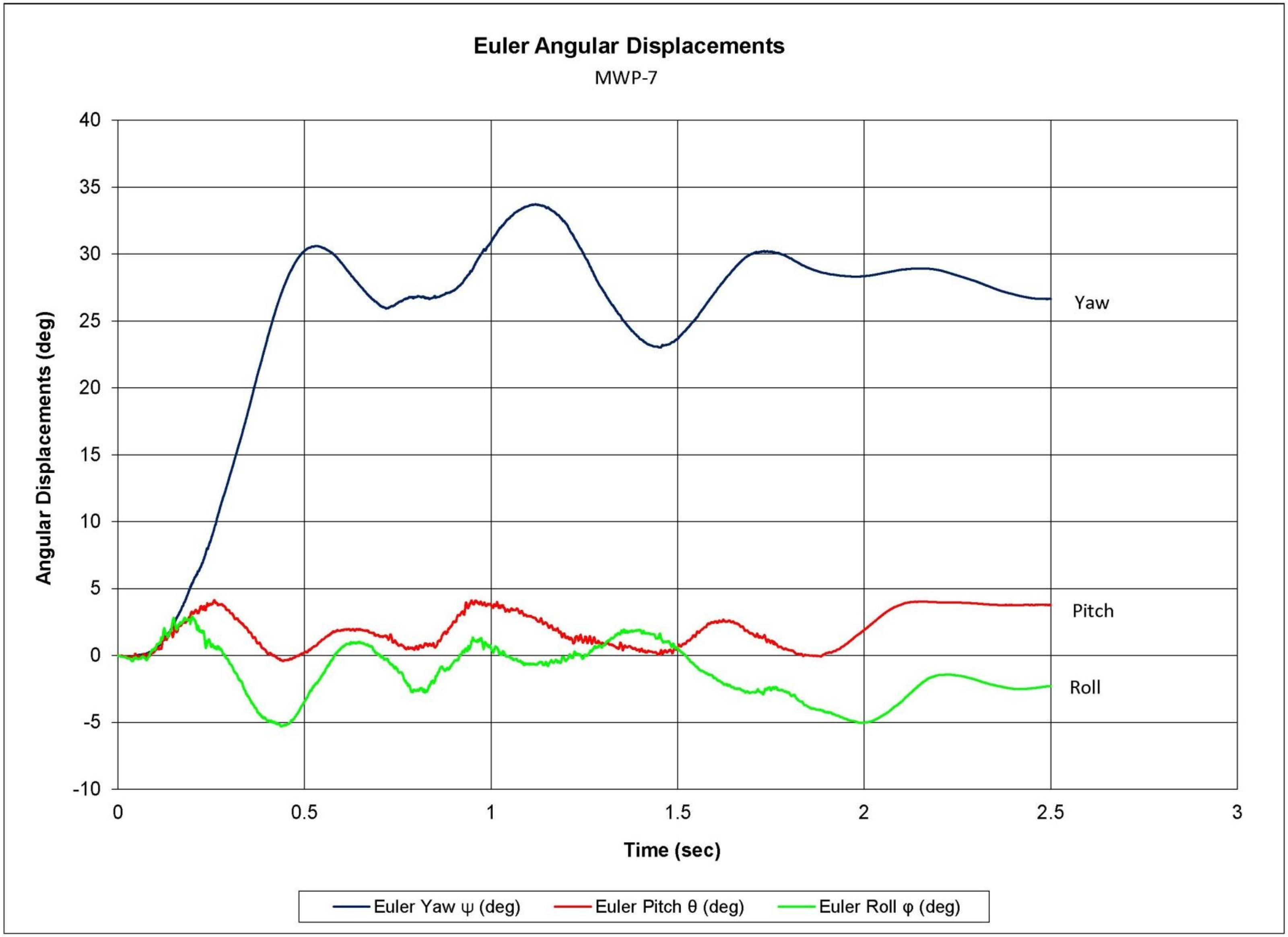


Figure I-7. Vehicle Angular Displacements (SLICE 1), Test No. MWP-7

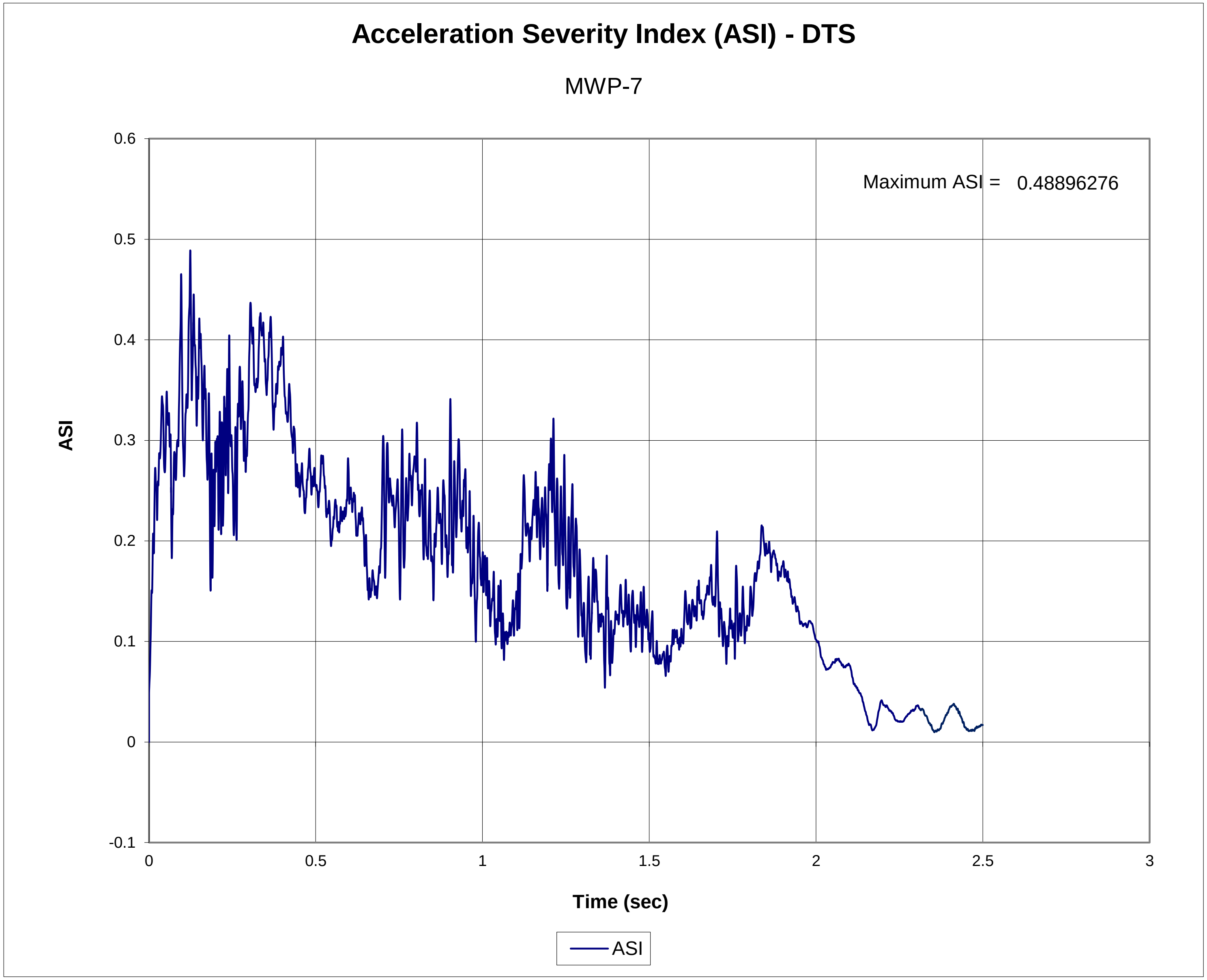


Figure I-8. Acceleration Severity Index (SLICE 1), Test No. MWP-7

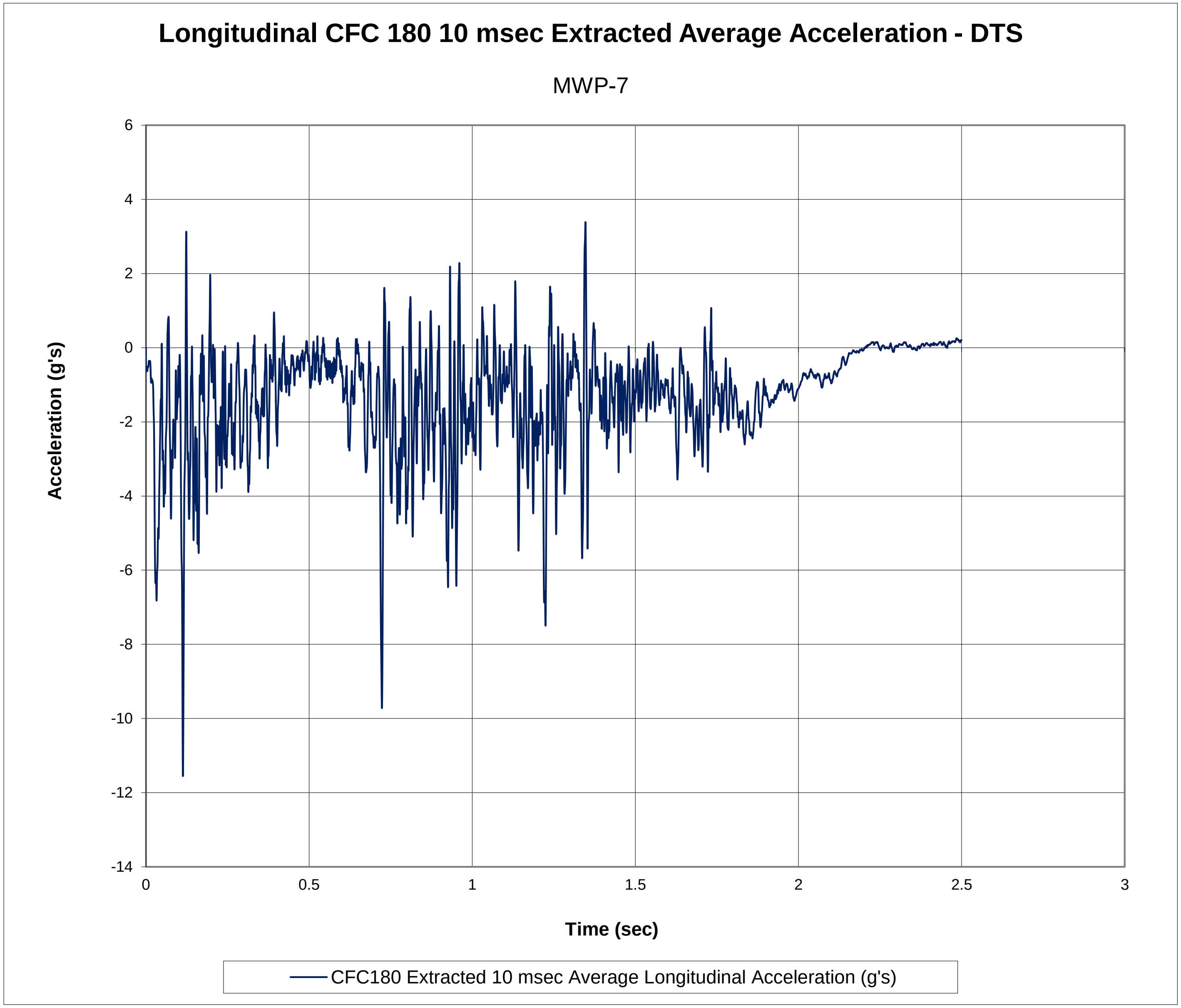


Figure I-9. 10-ms Average Longitudinal Deceleration (SLICE 2), Test No. MWP-7

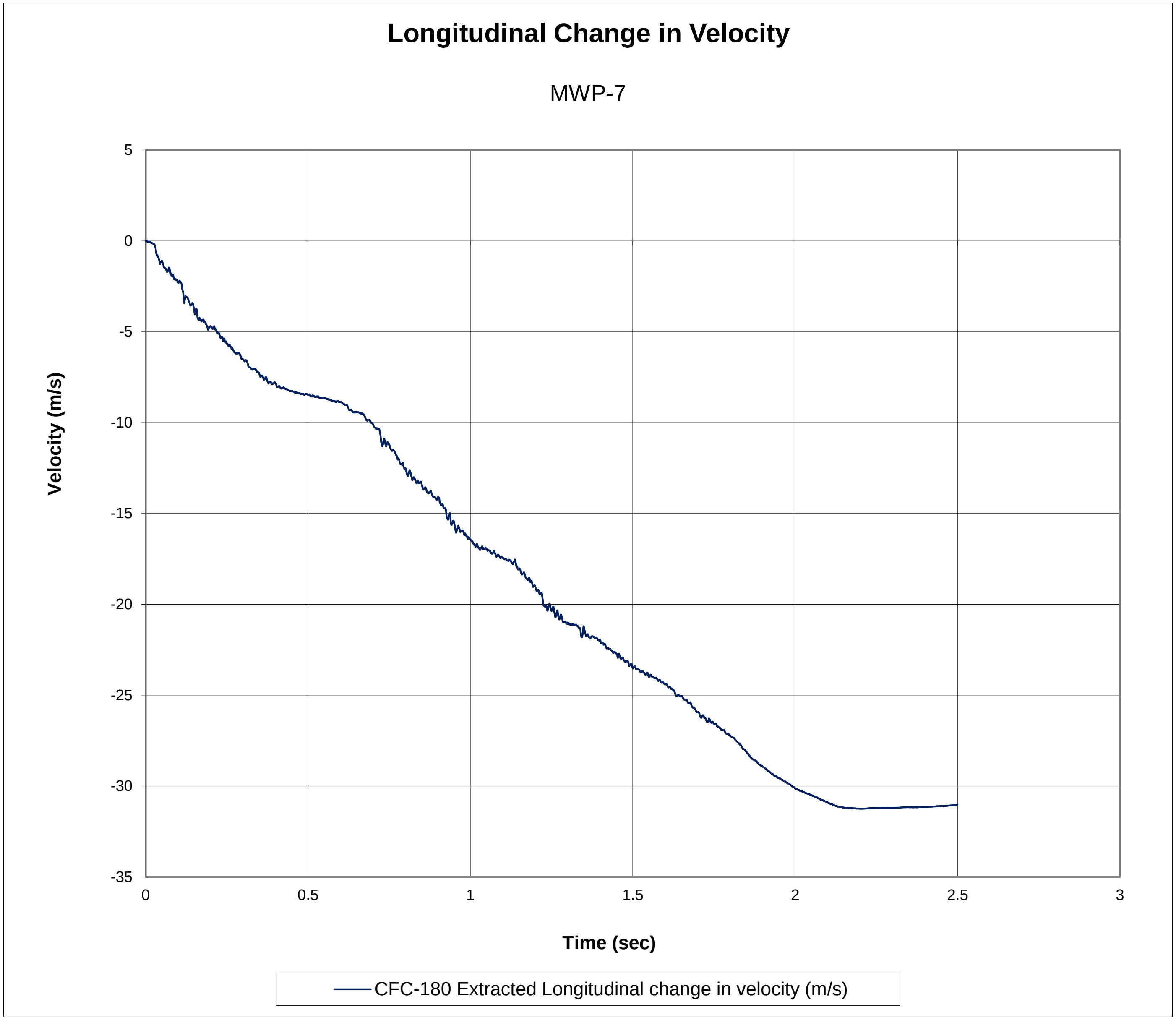


Figure I-10. Longitudinal Occupant Impact Velocity (SLICE 2), Test No. MWP-7

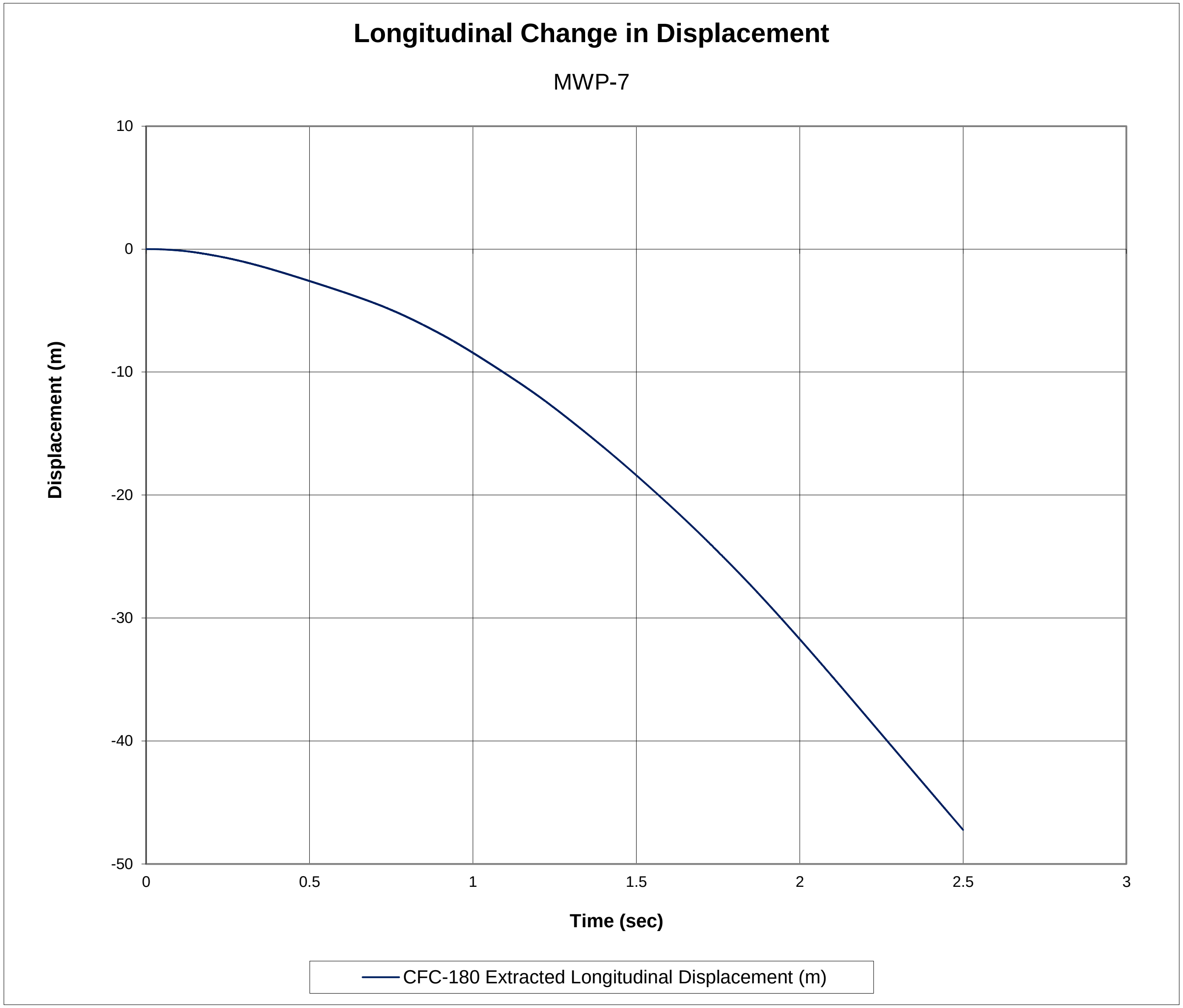


Figure I-11. Longitudinal Occupant Displacement (SLICE 2), Test No. MWP-7

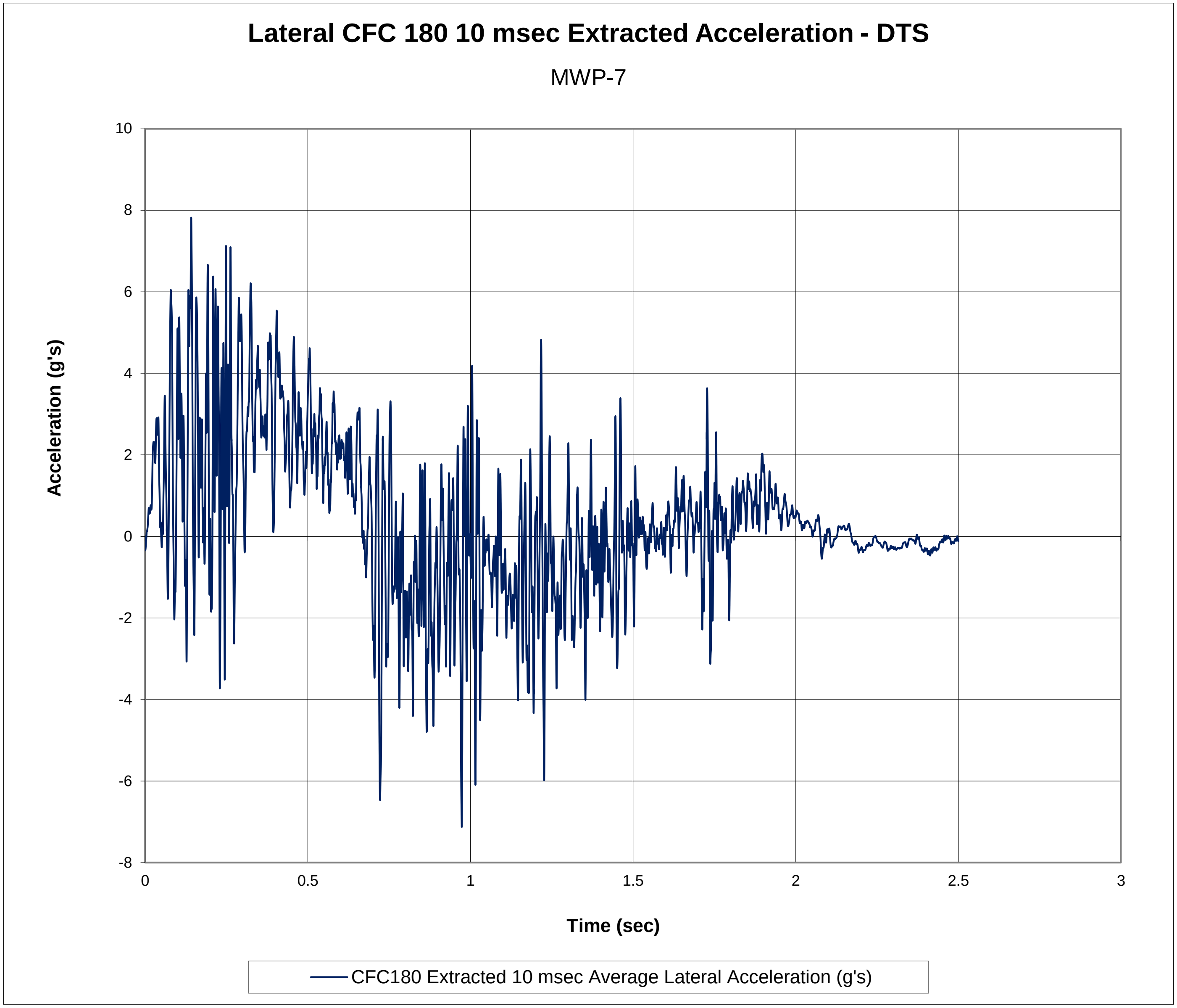


Figure I-12. 10-ms Average Lateral Deceleration (SLICE 2), Test No. MWP-7

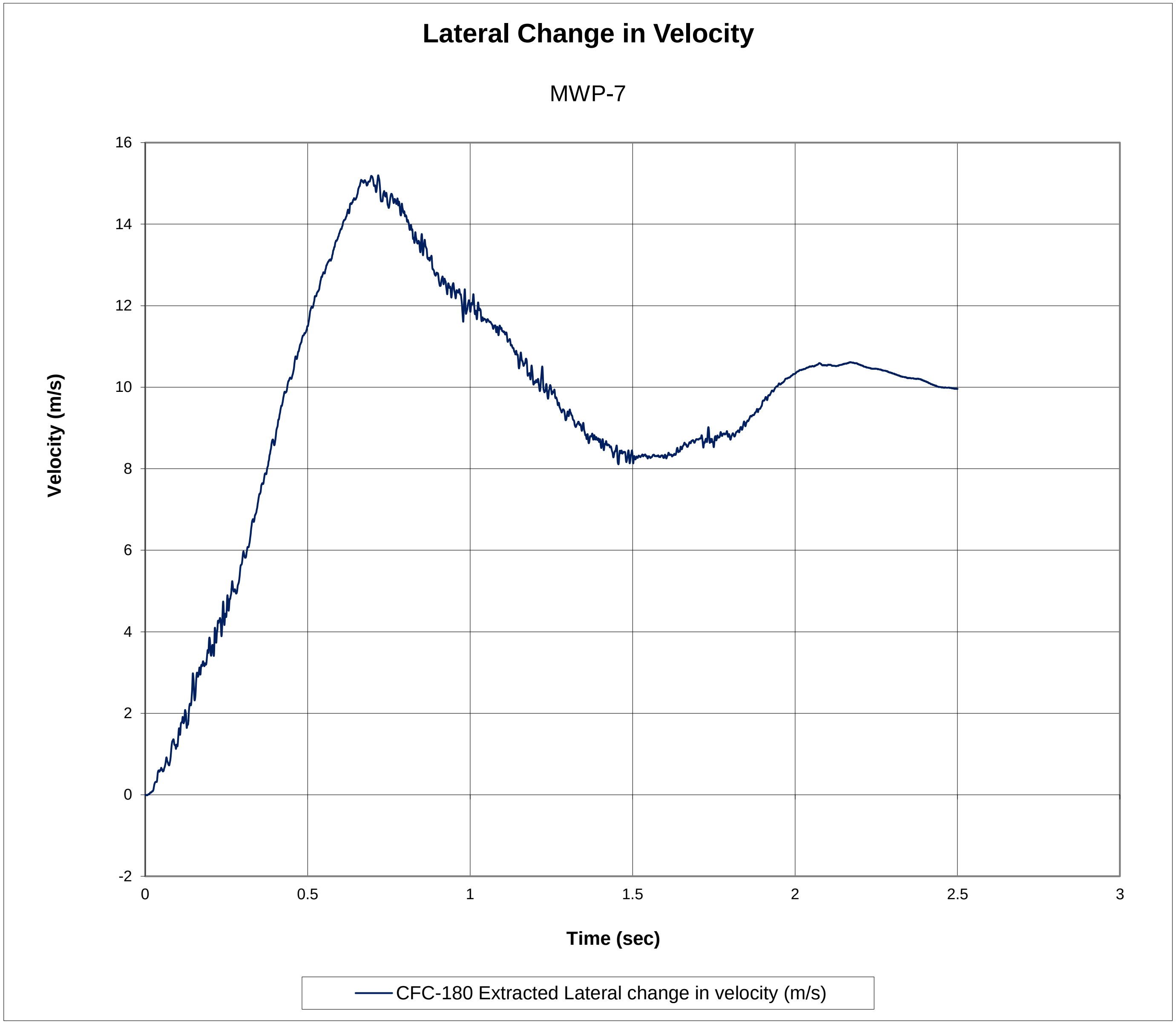


Figure I-13. Lateral Occupant Impact Velocity (SLICE 2), Test No. MWP-7

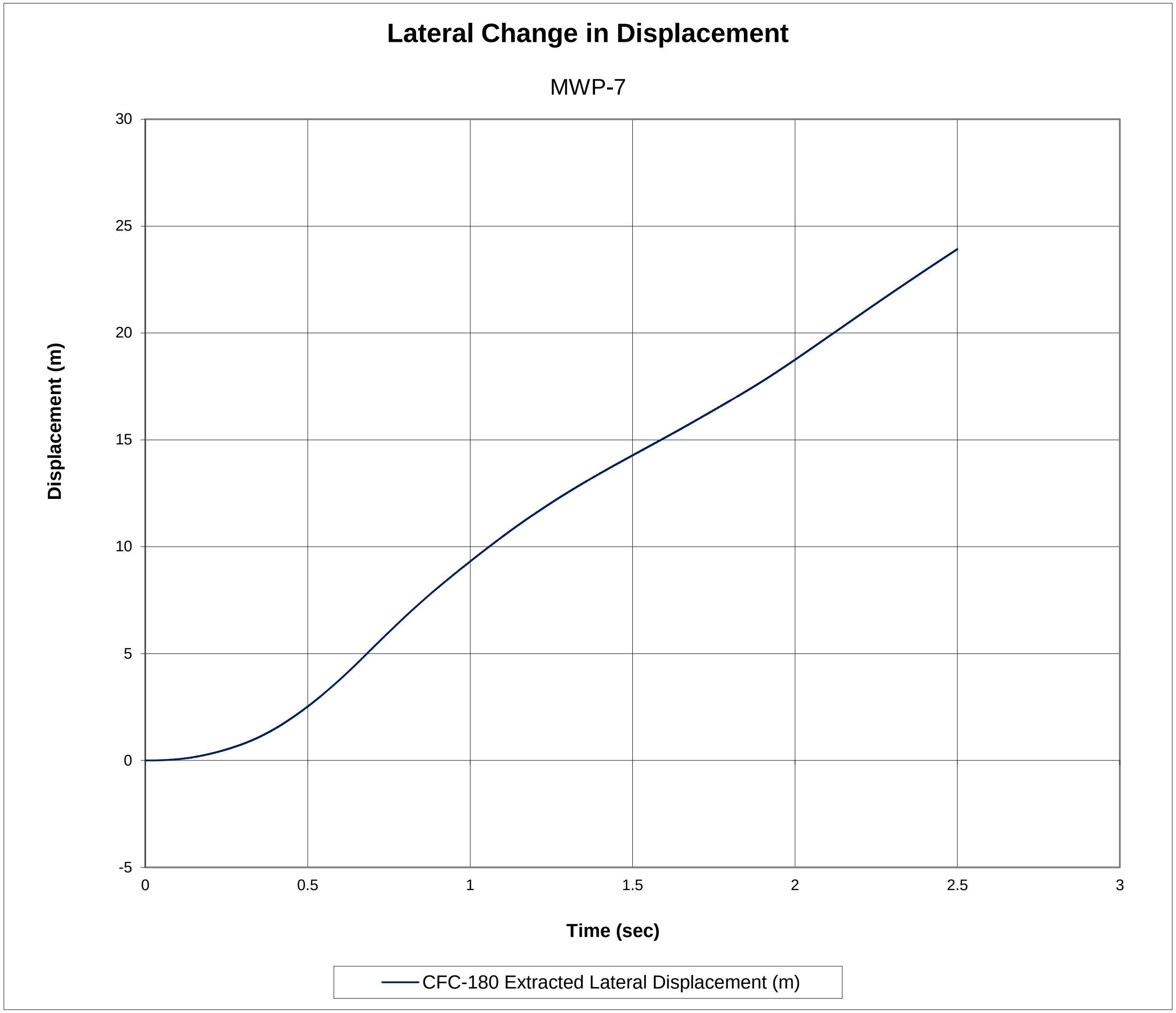


Figure I-14. Lateral Occupant Displacement (SLICE 2), Test No. MWP-7

Figure I-15. Vehicle Angular Displacements (SLICE 2), Test No. MWP-7

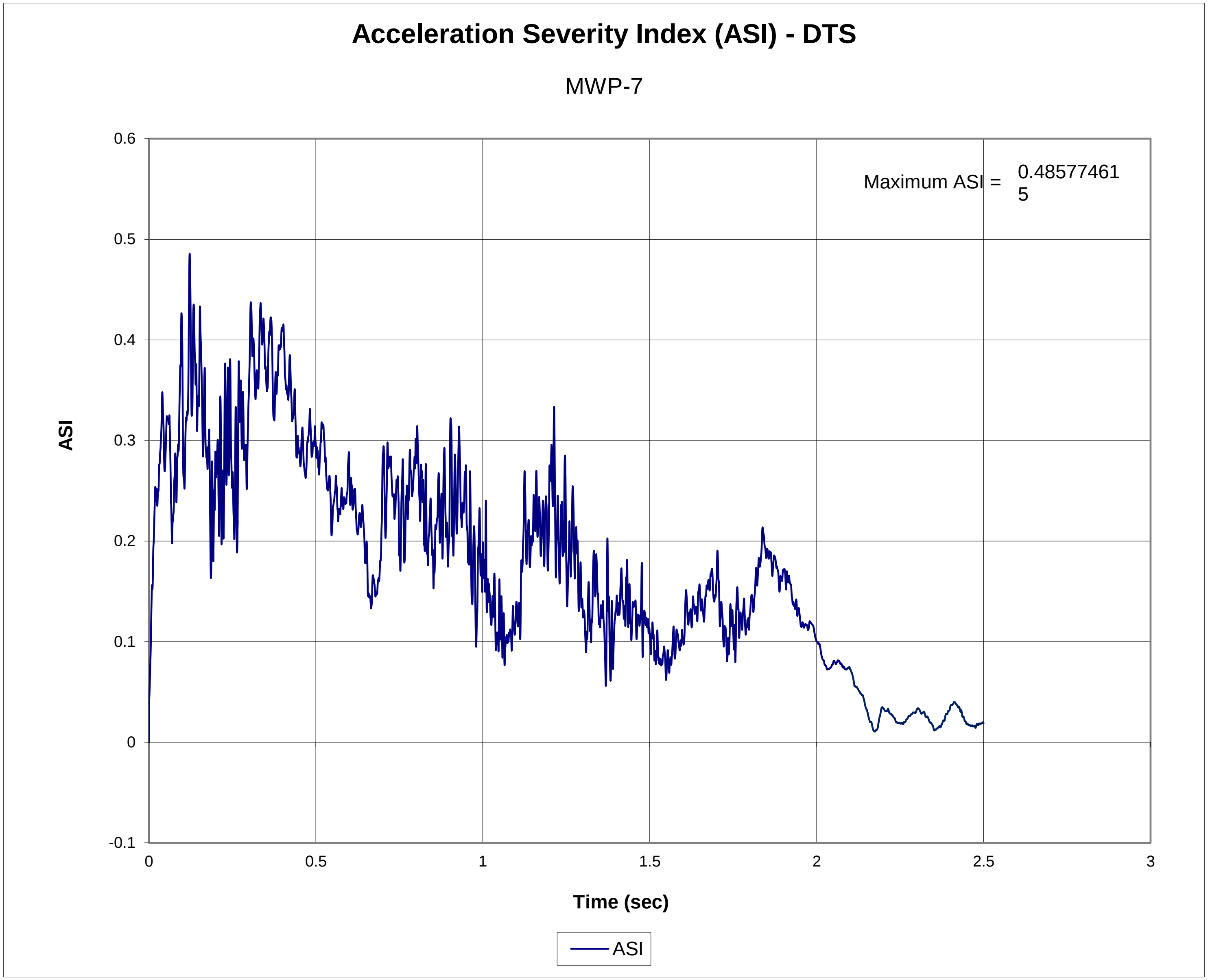


Figure I-16. Acceleration Severity Index (SLICE 2), Test No. MWP-7

# Appendix J. Load Cell and String Potentiometer Data, Test No. MWP-7

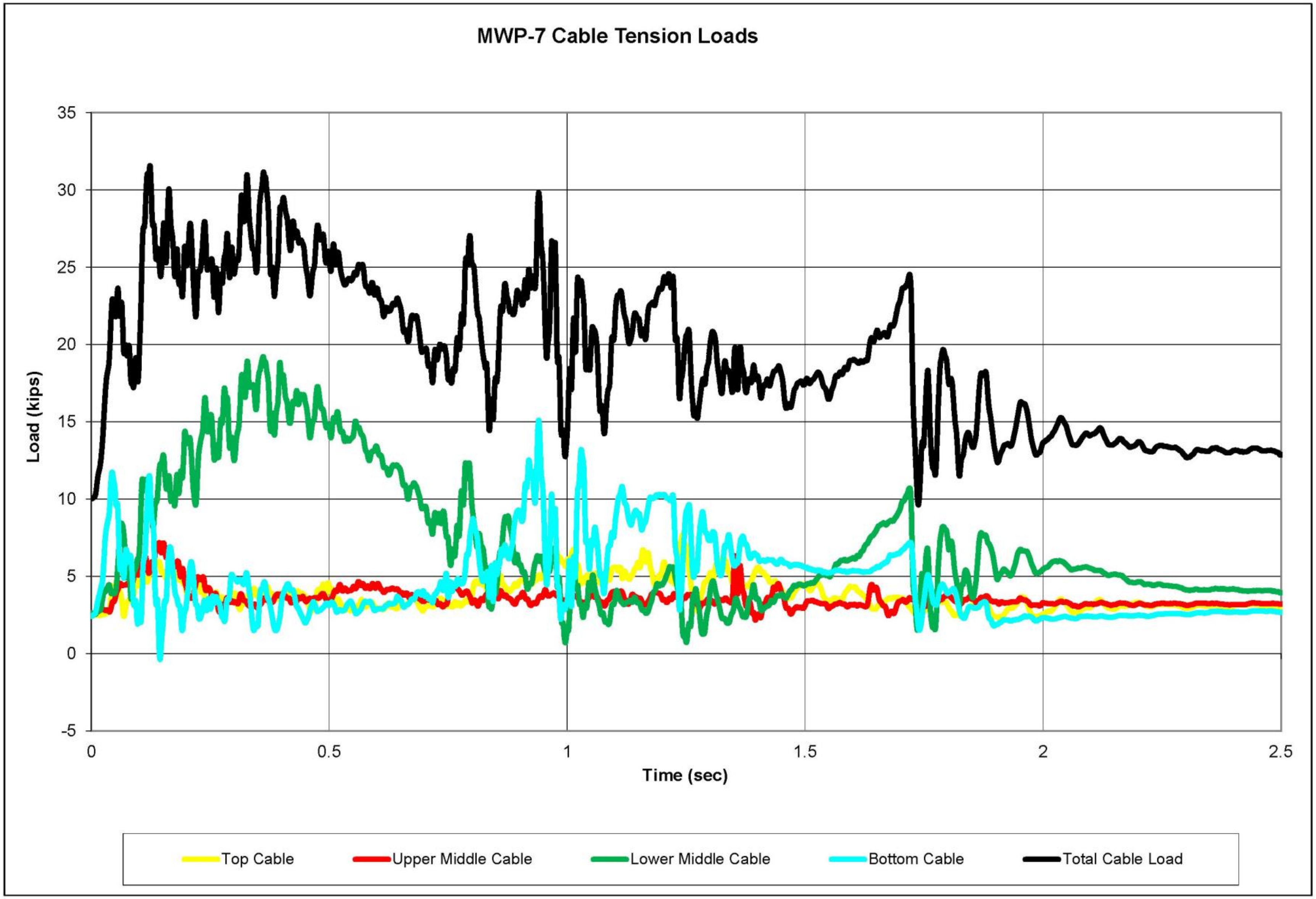


Figure J-1. Combined Load Cell Data, Test No. MWP-7

# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

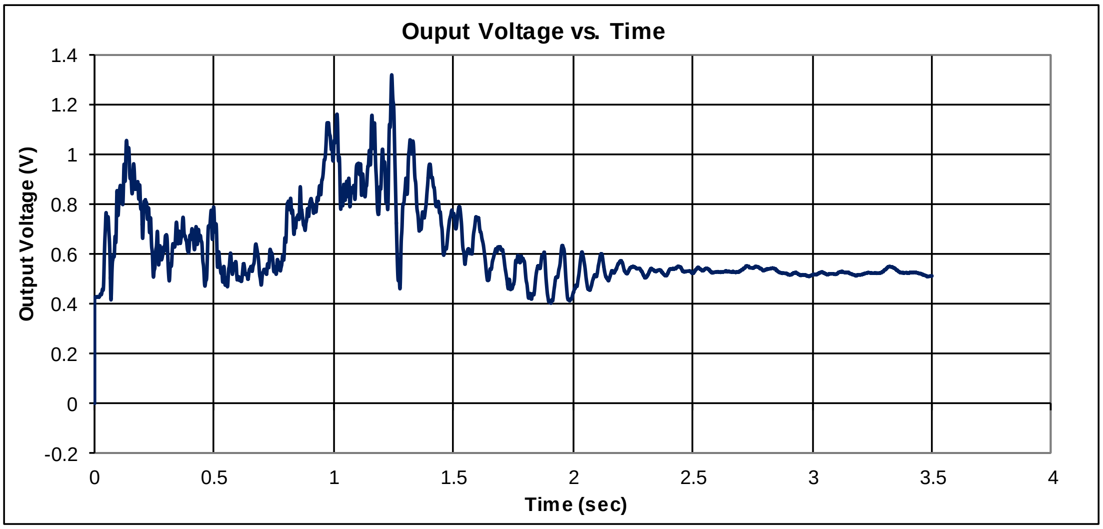
Test No: MWP-7
Date: 2/24/2015
System / Test Article: 4-cable median barrier
LC Location / Component: Top Cable - US of Impact
Additional Notes:

**Load Cell Information:**

Load Cell No.: 143435
Calibration Factor: 2.1539 mv/V
Input Voltage (excitation): 10 Volts
Gain: 400
Full Scale Load: 50 kips
Sample Rate: 10000 Hz
Cutoff Frequency: 100 Hz

**Results:**

Preload: 0 kips
Max. Load: 7.66 kips
Time of Max. Load: 1.2421 sec
Event Duration: 3.5 sec
Final Load: 2.97 kips



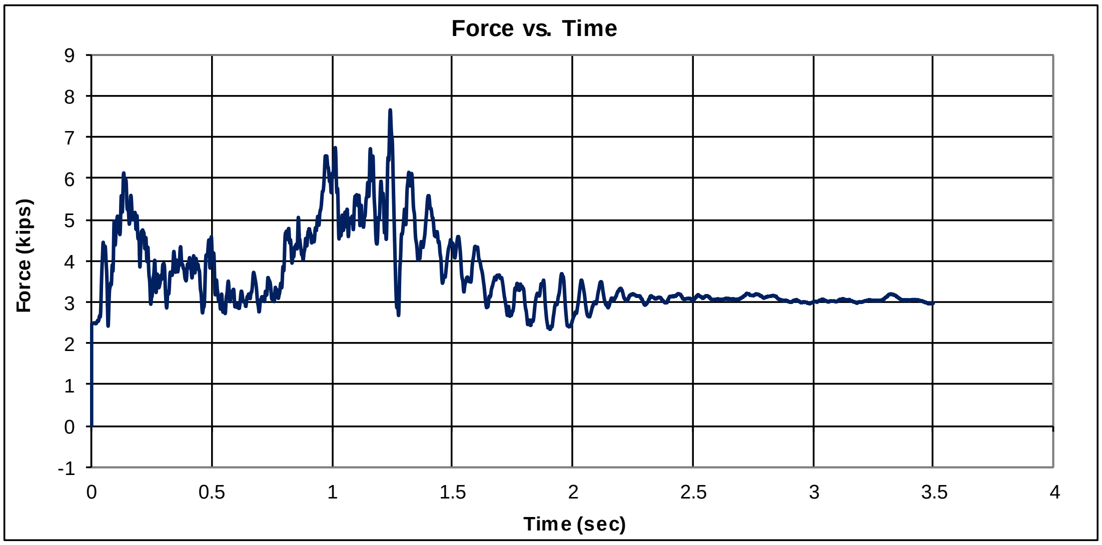


Figure J-2. Load Cell Data, Cable No. 4, Test No. MWP-7

# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

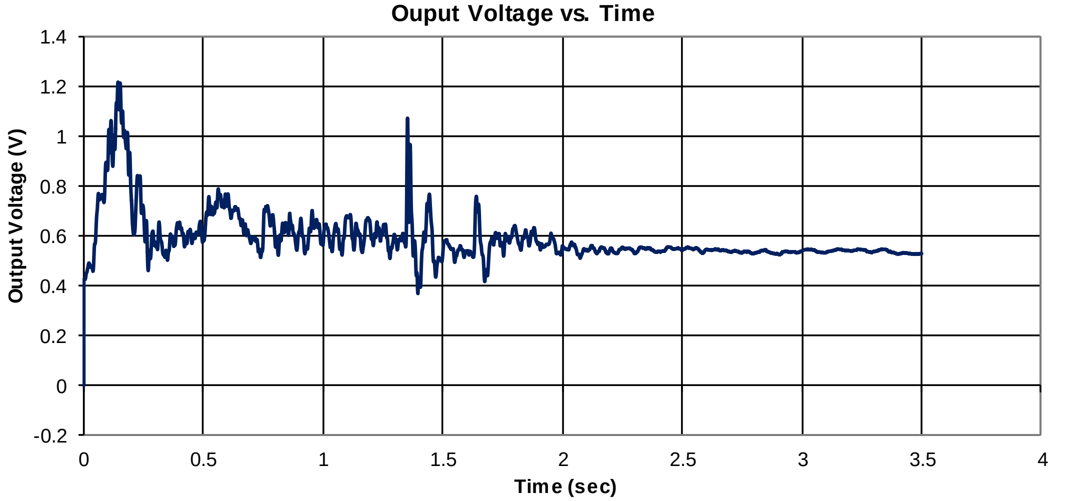
Test No: MWP-7
Date: 2/24/2015
System / Test Article: 4-cable median barrier
LC Location / Component: Top Middle Cable - US of Impact
Additional Notes:

**Load Cell Information:**

Load Cell No.: 120642
Calibration Factor: 2.11878 mv/V
Input Voltage (excitation): 10 Volts
Gain: 400
Full Scale Load: 50 kips
Sample Rate: 10000 Hz
Cutoff Frequency: 100 Hz

**Results:**

Preload: 0 kips
Max. Load: 7.18 kips
Time of Max. Load: 0.1429 sec
Event Duration: 3.5 sec
Final Load: 3.13 kips



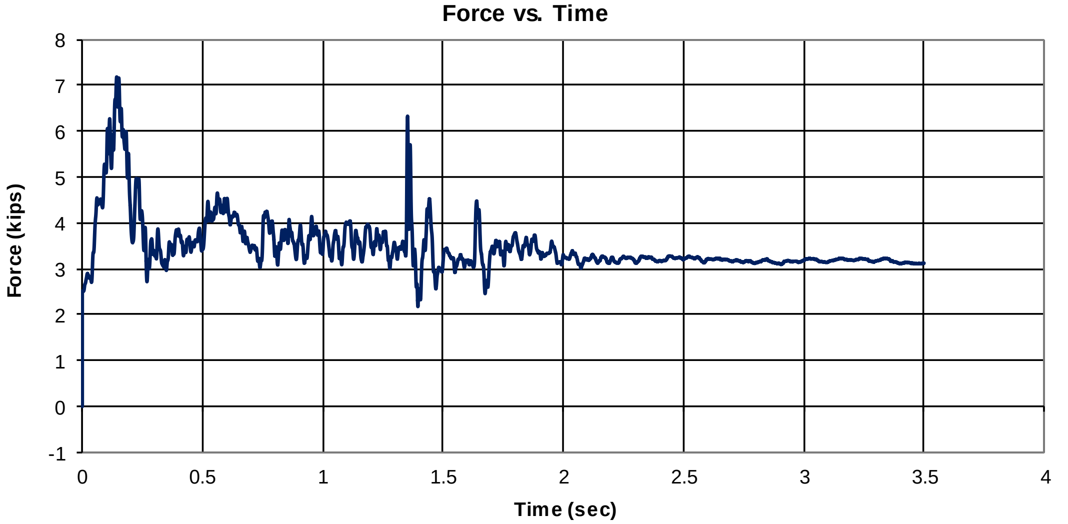


Figure J-3. Load Cell Data, Cable No. 3, Test No. MWP-7

# MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

**Test Information:**

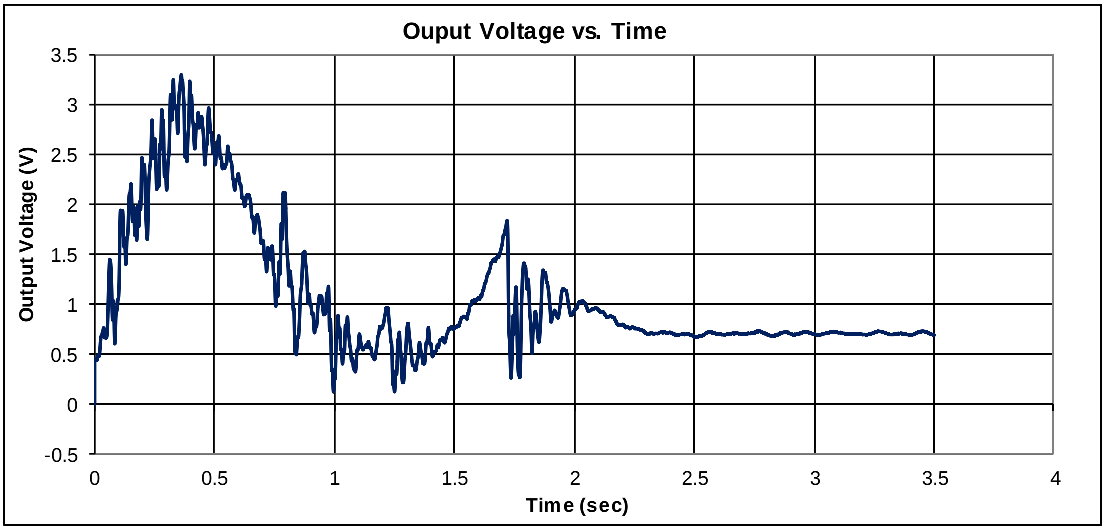
Test No: MWP-7
Date: 2/24/2015
System / Test Article: 4-cable median barrier
LC Location / Component: Bottom Middle Cable - US of Impact
Additional Notes:

**Load Cell Information:**

| | |
|---|---|
| Load Cell No.: | 143436 |
| Calibration Factor: | 2.14575 mv/V |
| Input Voltage (excitation): | 10 Volts |
| Gain: | 400 |
| Full Scale Load: | 50 kips |
| Sample Rate: | 10000 Hz |
| Cutoff Frequency: | 100 Hz |

**Results:**

| | |
|---|---|
| Preload: | 0 kips |
| Max. Load: | 19.21 kips |
| Time of Max. Load: | 0.3614 sec |
| Event Duration: | 3.5 sec |
| Final Load: | 4.02 kips |



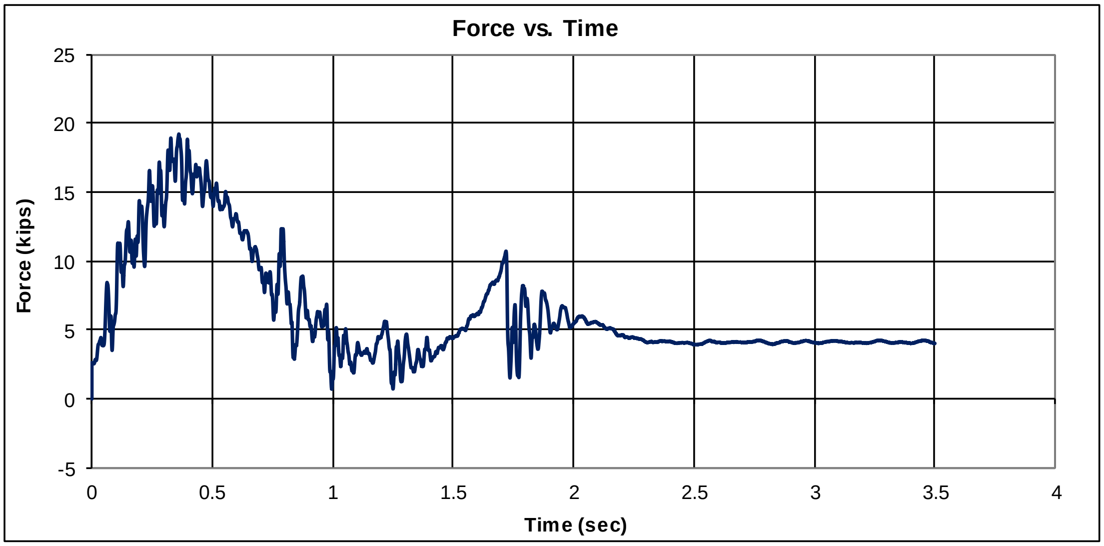


Figure J-4. Load Cell Data, Cable No. 2, Test No. MWP-7

# MIDWEST ROADSIDE SAFETY FACILITY

## Load Cell Summary

**Test Information:**

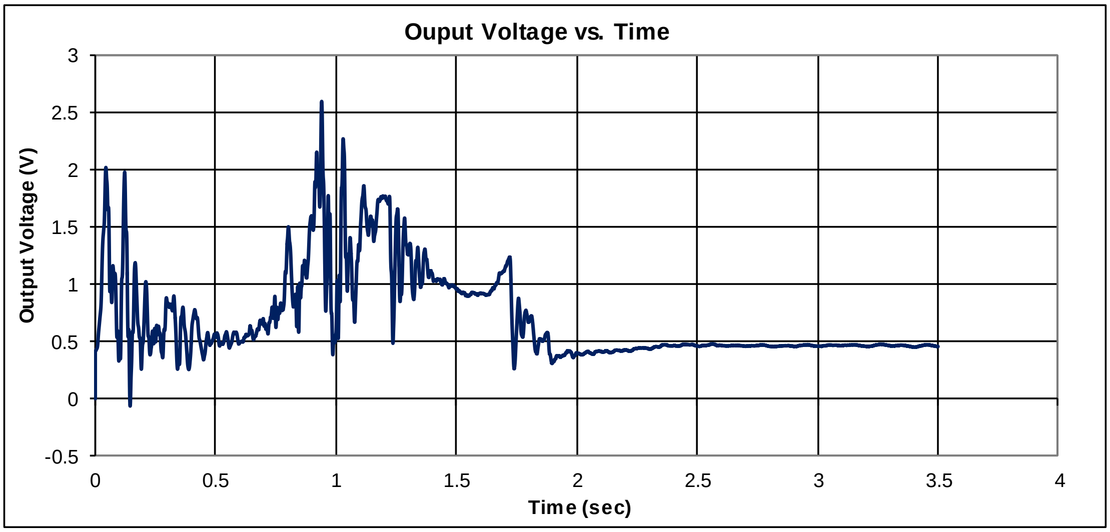
|  |  |
|---|---|
| Test No: | MWP-7 |
| Date: | 2/24/2015 |
| System / Test Article: | 4-cable median barrier |
| LC Location / Component: | Bottom Cable - US of Impact |
| Additional Notes: |  |

**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: | 0 kips |
| Max. Load: | 15.10 kips |
| Time of Max. Load: | 0.9403 sec |
| Event Duration: | 3.5 sec |
| Final Load: | 2.66 kips |



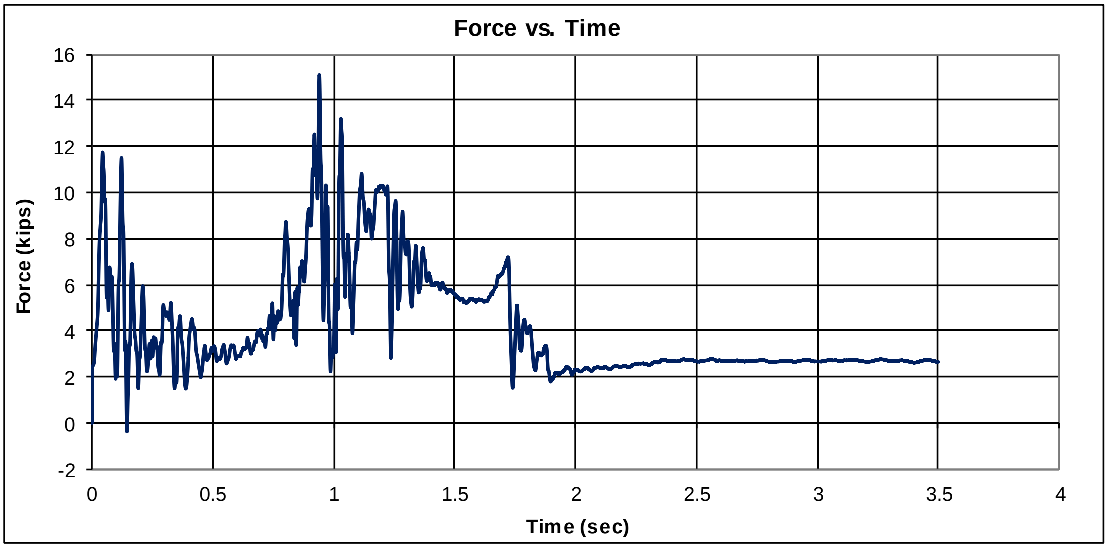


Figure J-5. Load Cell Data, Cable No. 1, Test No. MWP-7

# MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

**Test Information:**

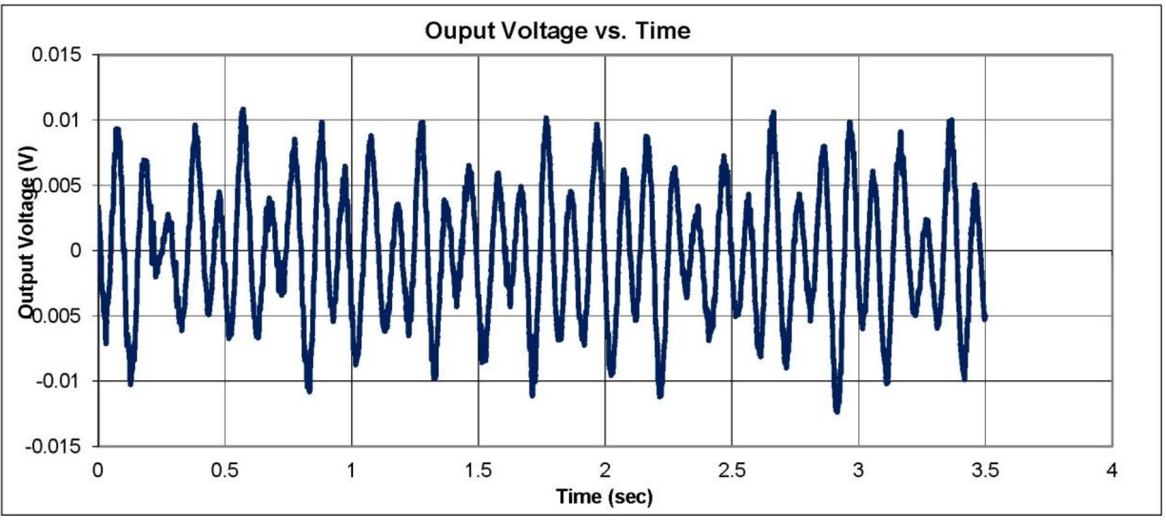
Test No: MWP-7
Date: 2/24/2015
System / Test Article: 4-cable median barrier
SP Location / Component: Upstream Anchor
Additional Notes:

**String Potentiometer Information:**

String Pot No.: 27039203
Calibration Factor: 19.4483 mV/V/in.
Input Voltage (excitation): 10 Volts
Gain: 1
Full Scale Load: 1
Sample Rate: 10000 Hz
Cutoff Frequency: 100 Hz

**Results:**

Max. Displacement: 0.06 in.
Time of Max. Displacement: 0.5714 sec
Event Duration: 3.5 sec
Final Displacement: -0.03 in.



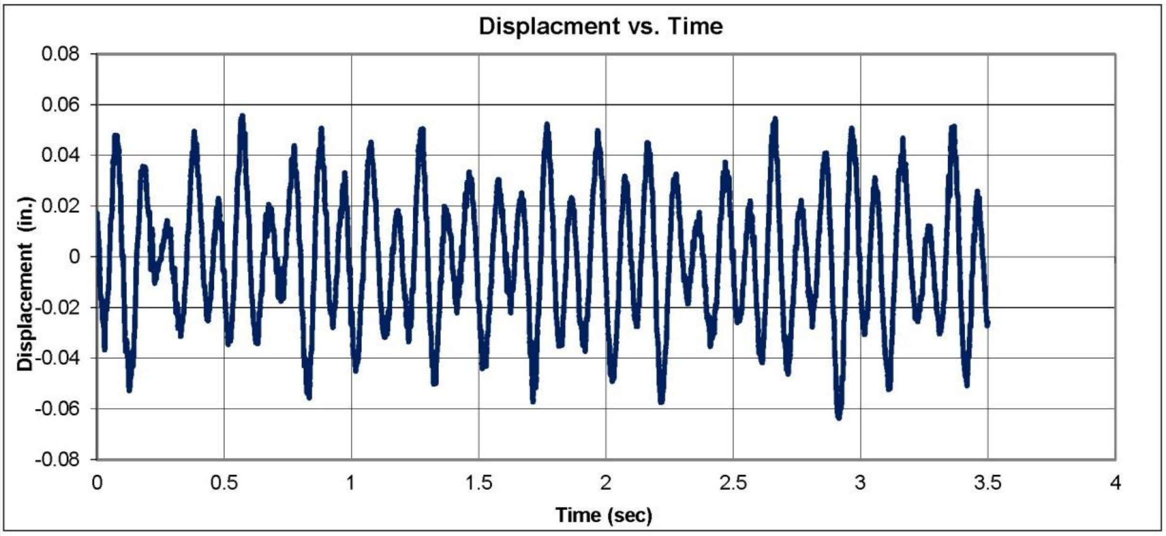


Figure J-6. String Potentiometer Data, Test No. MWP-7

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