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PHASE II DEVELOPMENT OF A NON-PROPRIETARY, FOUR-CABLE, HIGH TENSION MEDIAN BARRIER

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16. Abstract (Limit: 200 words)

During the last decade, the use of cable median barriers has risen dramatically. Cable barriers are often utilized in depressed medians with widths ranging from 30 to 50 ft (9.1 to 15.2 m) and with fill slopes as steep as 4H:1V. A careful review of accident records has indicated that passenger vehicles do occasionally penetrate through the standard 3-cable median barrier and enter opposing traffic lanes. As a result, the Midwest States Pooled Fund Program sponsored a research and development project to improve the safety performance of existing, non-proprietary, cable median barriers. These safety improvements included increased cable spacing, increased cable height, the use of four cables, increased cable tension, and optimized cable attachment to posts.

Two Test Level 3 crash tests were performed on a four-cable, high-tension median barrier placed in a 46-ft (14.0-m) wide, 4H:1V V-ditch. All tests were conducted according to the safety performance guidelines provided in the Manual for Assessing Safety Hardware (MASH). The first test utilized an 1100C small car impacting the barrier located 27 ft (8.2 m) laterally away from the front slope break point. The vehicle was contained and redirected by the barrier and deemed acceptable according to the MASH guidelines. The second test utilized a 2270P pickup truck impacting the barrier placed on a downslope and 12 ft (3.7 m) laterally away from the front slope break point. The pickup truck overrode the system and subsequently rolled, thus the second crash test was deemed unacceptable according to the MASH guidelines.

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UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

The Independent Approving Authority (IAA) for the data contained herein was Mr. Mario Mongiardini, Post-Doctoral Research Assistant.

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1 INTRODUCTION

1.1 Background and Problem Statement

The use of cable median barriers has risen dramatically during the last several years. These barriers are most frequently utilized in the medians of suburban or rural freeways that have high traffic volumes, narrow medians, or high accident frequencies. Cable barriers are often placed in depressed medians with widths ranging from 30 to 50 ft (9.1 to 15.2 m) and with fill slopes as steep as 4H:1V. Although cable barriers have been shown to contain and redirect many heavy trucks [1], a careful review of accident records has indicated that passenger vehicles do occasionally penetrate through the standard 3-cable median barrier and enter opposing traffic lanes [2]. A detailed evaluation of low tension non-proprietary cable median barrier accidents seems to indicate that the barrier is most vulnerable when struck from the one cable side [3,4]. Further, crash testing has verified that cables mounted on the back side of the posts are largely ineffective for containing and redirecting an impacting vehicle [5].

Therefore, the Midwest States Pooled Fund Program sponsored a research study at the Midwest Roadside Safety Facility (MwRSF) to improve the safety performance of existing, low-tension, cable median barriers in an effort to reduce cross-over median crashes as well as to reduce dynamic barrier deflections. For this initial effort, MwRSF reviewed existing low-tension, cable median barriers, identified key design features, and developed several prototype four-cable, low-tension median barrier systems [6]. For this study, three full-scale vehicle crash tests were performed using pickup truck and small sedan test vehicles. For the testing program, each cable barrier system was installed on level terrain with the understanding that the final barrier system later would be tested and evaluated in a depressed median. Although the preliminary testing program resulted in both unsuccessful and satisfactory outcomes, members of the Midwest States Pooled Fund Program chose to discontinue the R&D effort to develop an improved low-tension, cable median barrier system. Thus, the Pooled Fund members refocused their resources toward the development of a non-proprietary, high-tension, cable barrier system for use on generally level terrain as well as in depressed medians.

For the R&D effort to develop a new high-tension, cable median barrier, MwRSF designed an improved cable-to-post attachment mechanism that would satisfy predetermined loading requirements, conducted component testing of the new attachment hardware, identified cable end-fittings and splices that could be used in the new barrier system, and performed component testing on existing and modified end-fittings and splices [7]. Following the completion of the initial high-tension study, additional research funding was provided to configure, test, and evaluate the prototype high-tension, cable median barrier system when installed in a depressed median.

A series of three full-scale crash tests were conducted to evaluate the prototype high-tension, cable median barrier in a depressed median [8]. Test no. 4CMB-1 was conducted in compliance with test no. 3-11 of the Manual for Assessing Safety Hardware (MASH) [9] standards with the system located 12 ft (3.7 m) laterally down the foreslope of the 46 ft (14 m) wide, 4H:1V slope v-ditch. The system adequately contained and redirected the vehicle, thus, it was deemed acceptable according to MASH.

The system was slightly modified with respect to placement and orientation within the v-ditch for the next two crash tests. The second full-scale test, test no. 4CMB-2 was conducted according to test no. 3-10 of the MASH standards with the system located 4 ft (1.2 m) laterally up the backslope of the ditch. During the test, the vehicle made contact with the backslope prior to impacting the system, which caused significant deceleration rates prior to impact with the median barrier. The system was still able to contain the vehicle, but due to the deceleration rate, the system was considered to be marginally acceptable.

For the third crash test, heavily compacted soil was added in a region prior to the impact location. Also, the cable heights were lowered so that the bottom cable was 13 ½ in. (343 mm) from the ground, and the middle cables were spaced at 10½ in. (267 mm), leaving the top cable height at 45 in. (1,143 mm). Test no. 4CMB-3 was also conducted according to test no. 3-10 of the MASH standards with the system located 4 ft (1.2 m) laterally up the backslope of the ditch. The vehicle was contained by the system. However, the cables caused significant deformation to the A-pillar on the driver's side of the vehicle. Therefore, the system was deemed unacceptable according to MASH. Following the completion of these full-scale crash tests, additional research funding was provided to re-configure, test, and evaluate the high-tension, cable median barrier system when installed in a depressed median.

The keyway bracket cable clips used for test no. 4CMB-3 released at the desired load, but the remaining attachment caused a snag point for the cables, which produced unacceptable results, as shown in Figure 1. In order to improve the cable release, while maintaining the attachments ability to dissipate energy through post deflection, an angled keyway bolt was developed for use with a keyway slot in the post. The shape of the bolt was optimized so that the cables would not snag on the bolt once they were released. In addition, the angled keyway bolt design utilized fewer parts, was easier to install, and less costly. Development and testing of the angled keyway bolt designed is detailed in a separate report [10]. No other design modifications were made to the system aside from the change in the cable attachment.

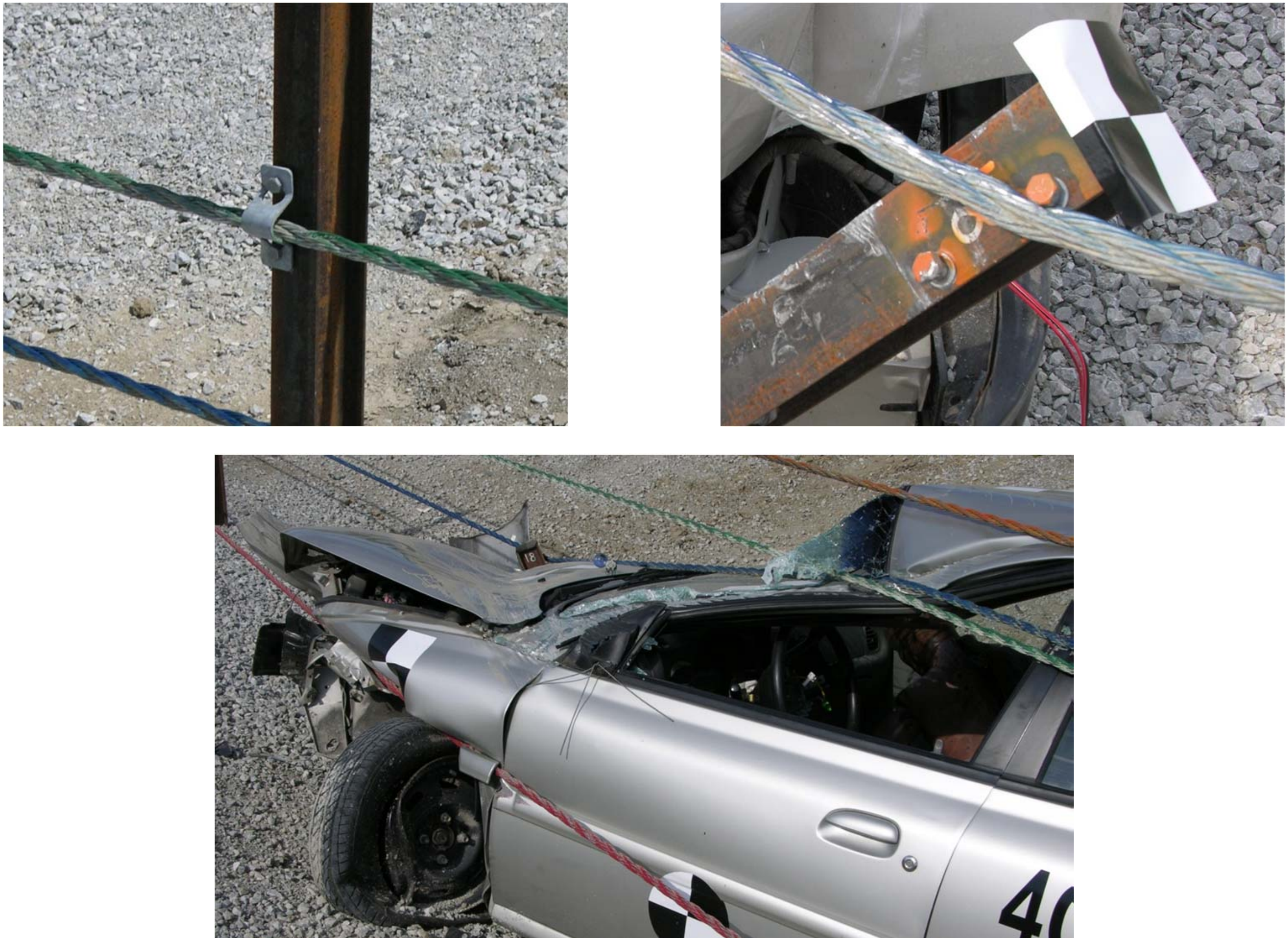


Figure 1. Test No. 4CMB-3: Slotted Bracket, Cable Snag, and A-Pillar Damage

Figure 2. Updated Cable Attachment: Angled Keyway Bolt

1.2 Research Objectives

The primary research objective was to develop an improved, non-proprietary, high-tension, cable median barrier system that would provide acceptable safety performance when installed on generally flat terrain as well as when placed at any location within a depressed median with fill slopes equal to or flatter than 4H:1V. Modifications to the prototype high-tension, cable median barrier were to be made so that the system limited the dynamic barrier deflections using cable-to-post attachment hardware that maximized the energy dissipated by the support posts, while still allowing the cables to release vertically from the attachments at relatively low loads. In addition, the barrier system was to be designed to mitigate vehicle underride and/or override. Finally, the cable median barrier system was to be tested and evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in the MASH.

1.3 Research Scope

The high-tension, cable median barrier system was initially configured using information obtained from MwRSF's prior research studies pertaining to the development of an improved cable median barrier. Design details were prepared for the high-tension, four-cable, median barrier system. The cable median barrier was constructed in a 4H:1V V-ditch section for use in the testing and evaluation program. Two full-scale vehicle crash tests were conducted. The first test utilized a small car, weighing approximately 2,425 lb (1,100 kg), impacting at a speed and angle of 62.1 mph (100.0 km/h) and 25.0 degrees, respectively. The second test utilized a ½-ton Quad Cab pickup truck, weighing approximately 5,000 lb (2,268 kg), impacting at a speed and angle of 62.1 mph (100.0 km/h) and 25.0 degrees, respectively. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made that pertain to the safety performance of the cable barrier systems.

2 DESIGN DETAILS TEST NO. 4CMB-4

The barrier system test installation was comprised of four, high-tension cables in a depressed median, as shown in Figures 3 through 25. Photographs of the test installation are shown in Figures 26 and 27. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The cable barrier system was constructed using a total length of 608 ft (185.3 m) with the majority of the barrier system placed within a simulated depressed median or V-ditch. The test installation consisted of several distinct components, systems, and features: (1) a depressed V-ditch; (2) wire ropes or cables; (3) steel support posts; (4) cable-to-post attachment bolts; (5) cable splice hardware; (6) breakaway end terminal hardware; (7) reinforced concrete foundations; (8) cable end fittings; (9) turnbuckle assemblies; and (10) load cell end assemblies.

A 360-ft (109.7-m) long simulated V-ditch was constructed using an overall width of 46 ft (14.0 m) in combination with 4H:1V side slopes, as shown in Figures 3 and 4. The barrier was constructed 4 ft (1.2 m) laterally from the bottom of the V-ditch on the backslope. Four ¾-in. (19-mm) diameter, Class A galvanized 3x7 (pre-stretched) wire ropes were utilized for the cable rail elements. The cables were supported by 38 posts and anchored at the upstream and downstream ends, as shown in Figure 3. Post nos. 1 and 40 were configured to serve as the upstream and downstream end anchors, respectively, and these locations incorporated breakaway end terminal hardware that were supported by reinforced concrete foundations. Post nos. 2 and 39 consisted of breakaway steel support posts anchored to reinforced concrete foundations. Post nos. 3 through 38 consisted of S3x5.7 (S76x8.5) ASTM A992 steel line posts measuring 90 in. (2,286 mm) in length. The spacing between post nos. 1 and 2 as well as 39 and 40 was 8 ft (2.4 m), while the post spacing between post nos. 2 through 39 was 16 ft (4.9 m). For the standard line posts, the four cables were attached to the posts and placed at 13½ in. (343 mm), 24 in. (610 mm), 34½ in. (876 mm), and 45 in. (1,143 mm) above the ground surface. The top and lower middle cables were attached to the impact side of each post, and the upper middle and lower cables were attached to the non-impact side of each post. Each cable was attached to the line posts using a ¼-in. (6-mm) diameter A449 steel angled keyway bolt. Details for the cable-to-post attachment bracket, mounting hardware, and locations can be found in Figures 18, 19, and 21.

Each of the four wire ropes were spliced together using special cable splice hardware located between post nos. 19 through 22, as shown in Figure 5. At the ends of the cable barrier system, each cable was sloped down to the ground and anchored to a simulated breakaway end terminal system, as shown in Figures 6, 7, and 10 through 13. Post nos. 1 and 40 served as the end cable anchors and consisted of a cable anchor bracket, cable release lever, brass keeper rod, special end fittings, and a reinforced concrete foundation.

As noted previously, posts nos. 2 and 39 served as breakaway steel support posts with attached hanger hardware, as shown in Figures 14 through 17. The S3x5.7 (S76x8.5) posts incorporated a steel bracket plate near the top of the post as well as a slipbase connection near the groundline. Each post was inserted into steel foundation tube assembly and embedded within a reinforced concrete foundation.

Large plastic barrels filled with soil were placed around post nos. 15 through 24 to prevent excess moisture from entering the soil adjacent to the posts, as shown in Figure 20. Since there were cold temperatures and frozen soil during the test installation, the barrels provided better soil conditions around the posts without affecting performance of the posts.

Near the upstream end of the barrier system, one 50,000-lb (222.4-kN) capacity tension load cell was spliced into each of the cable lines between post nos. 4 and 5, as shown in Figures 6 and 8. Details for the load cells, threaded rods, turnbuckles, end fittings, and rod couplers are provided in Figures 8 and 9.

A cable tensioning chart was developed as a function of the ambient air temperature and for use when installing the barrier system, as provided in Table 1. It should be noted that the system was tested with the prescribed cable tension at 100 deg Fahrenheit (37.8 deg Celsius) of 4,213 lb (18.7 kN). MASH requires that cable barrier systems be tested with cable tensions set to the recommended tension at 100 deg Fahrenheit.

It should be noted that the cable attachment hardware used in test no. 4CMB-4 utilized brackets and posts from test no. 4CMB-3 in the non-critical regions of the system where it was believed that the substitution would not influence the results of the test. Additionally, the orientation of some of the posts was reversed such that the location of the cable clip was on the upstream flange rather than the downstream flange. The variation of the hardware used is documented in Figure 25.

Table 1. Pre-Stretched Cable Tension Chart

Ambient Air Temperature (Degrees Fahrenheit)	Cable Tension (lb)
110	4,000
100	4,213
90	4,427
80	4,640
70	4,853
60	5,067
50	5,280
40	5,493
30	5,706
20	5,920
10	6,133
0	6,346
-10	6,560
-20	6,773
-30	6,986
-40	7,200

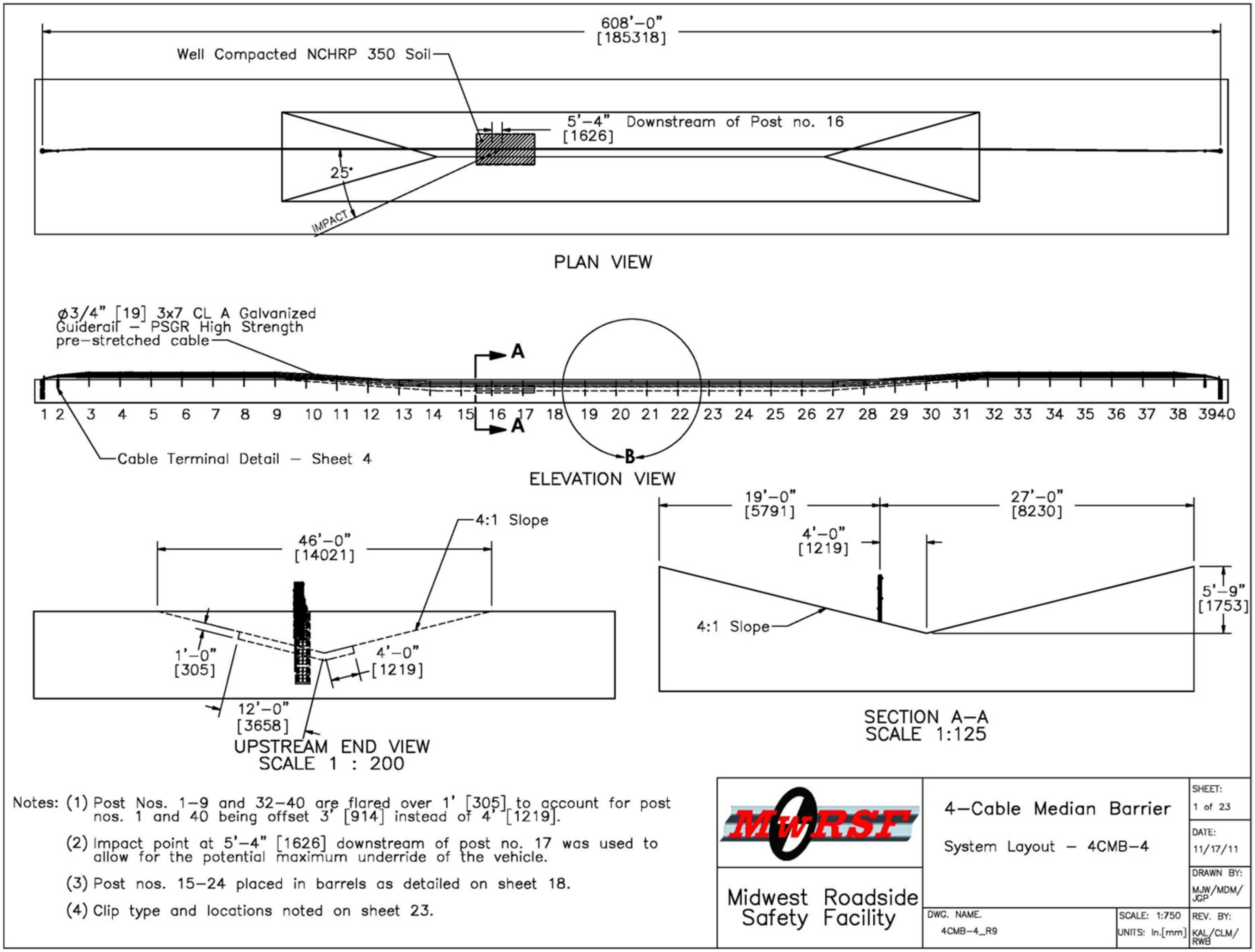


Figure 3. Test Installation Layout, Test No. 4CMB-4

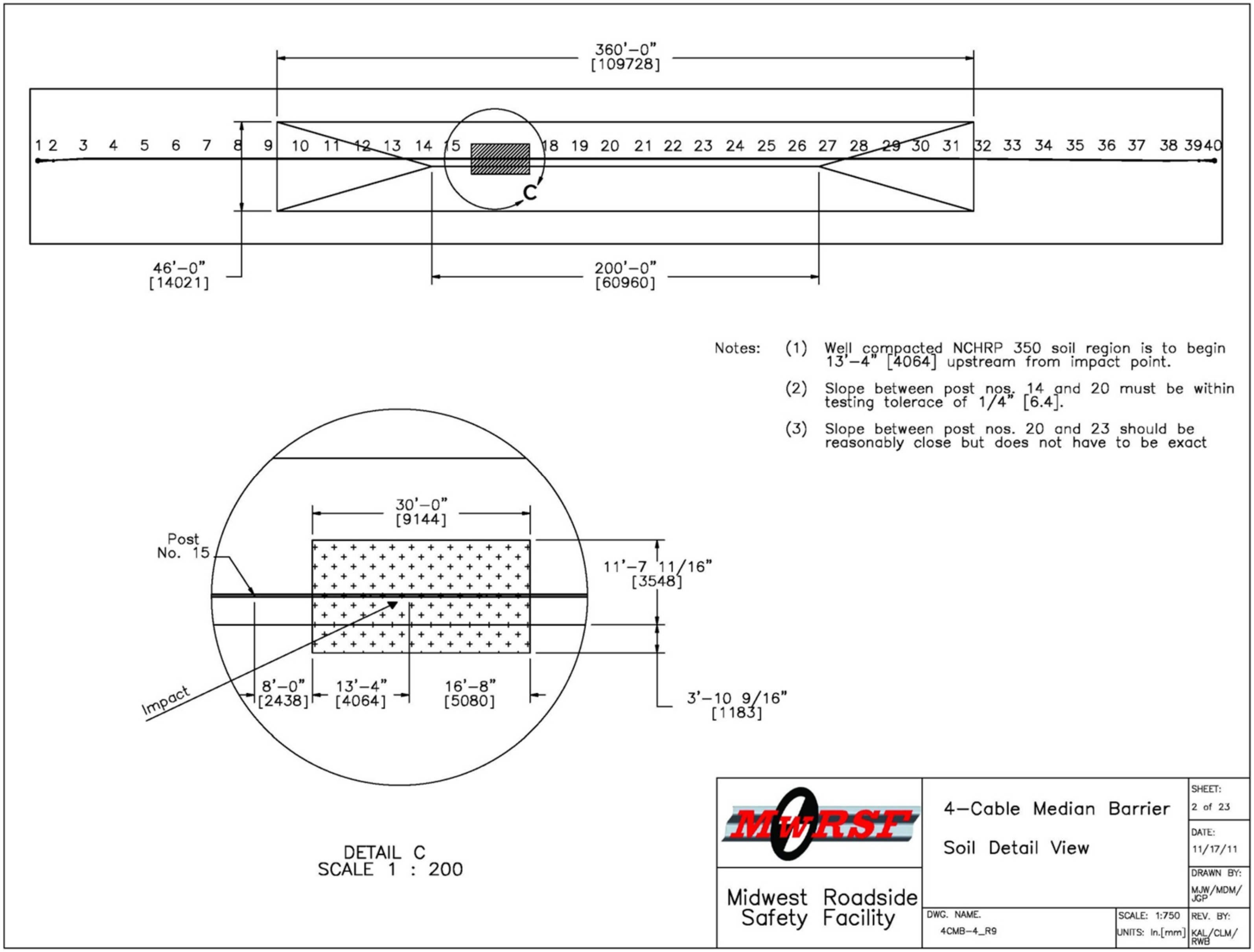


Figure 4. Soil Compaction Layout, Test No. 4CMB-4

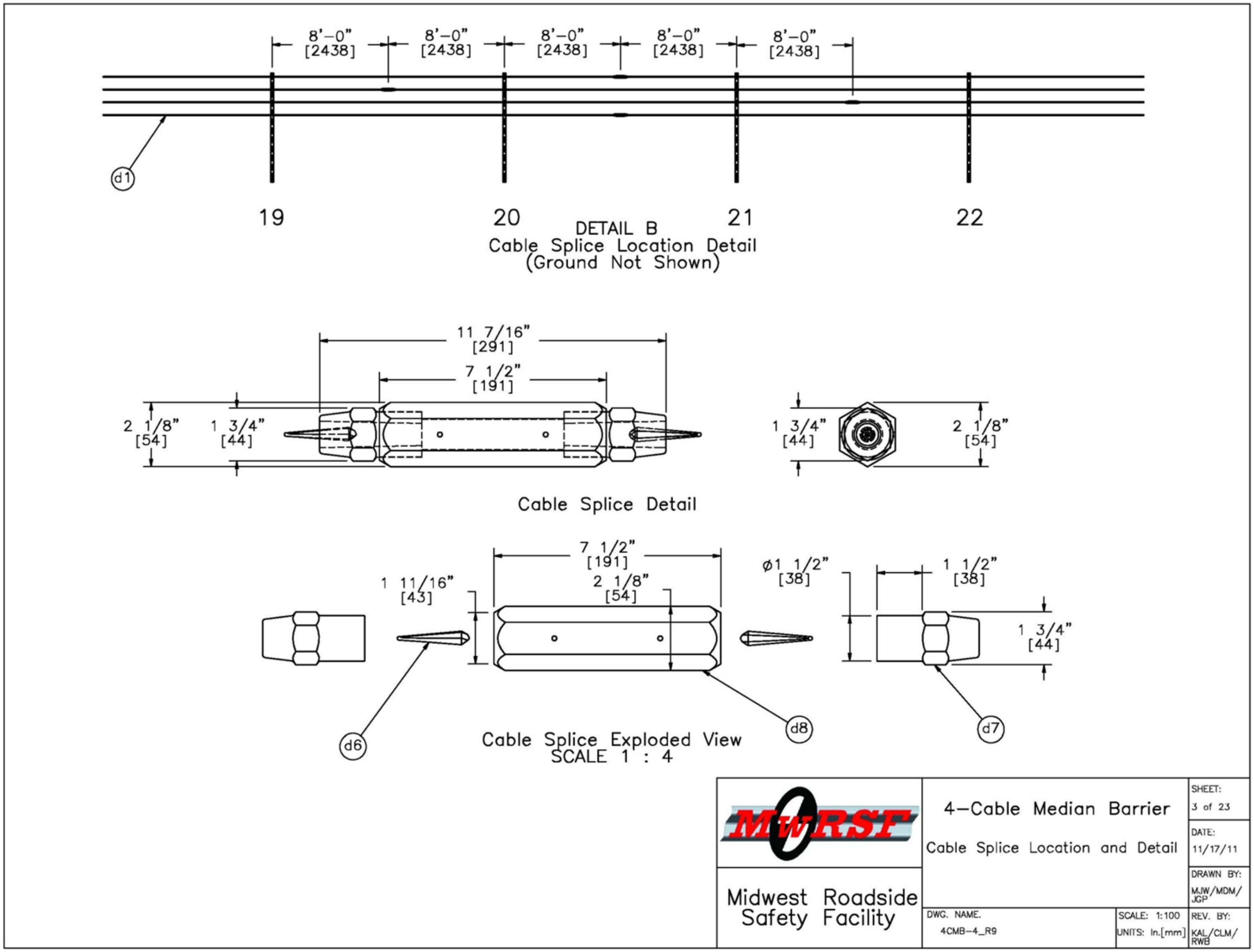


Figure 5. Cable Splice Layout, Test No. 4CMB-4

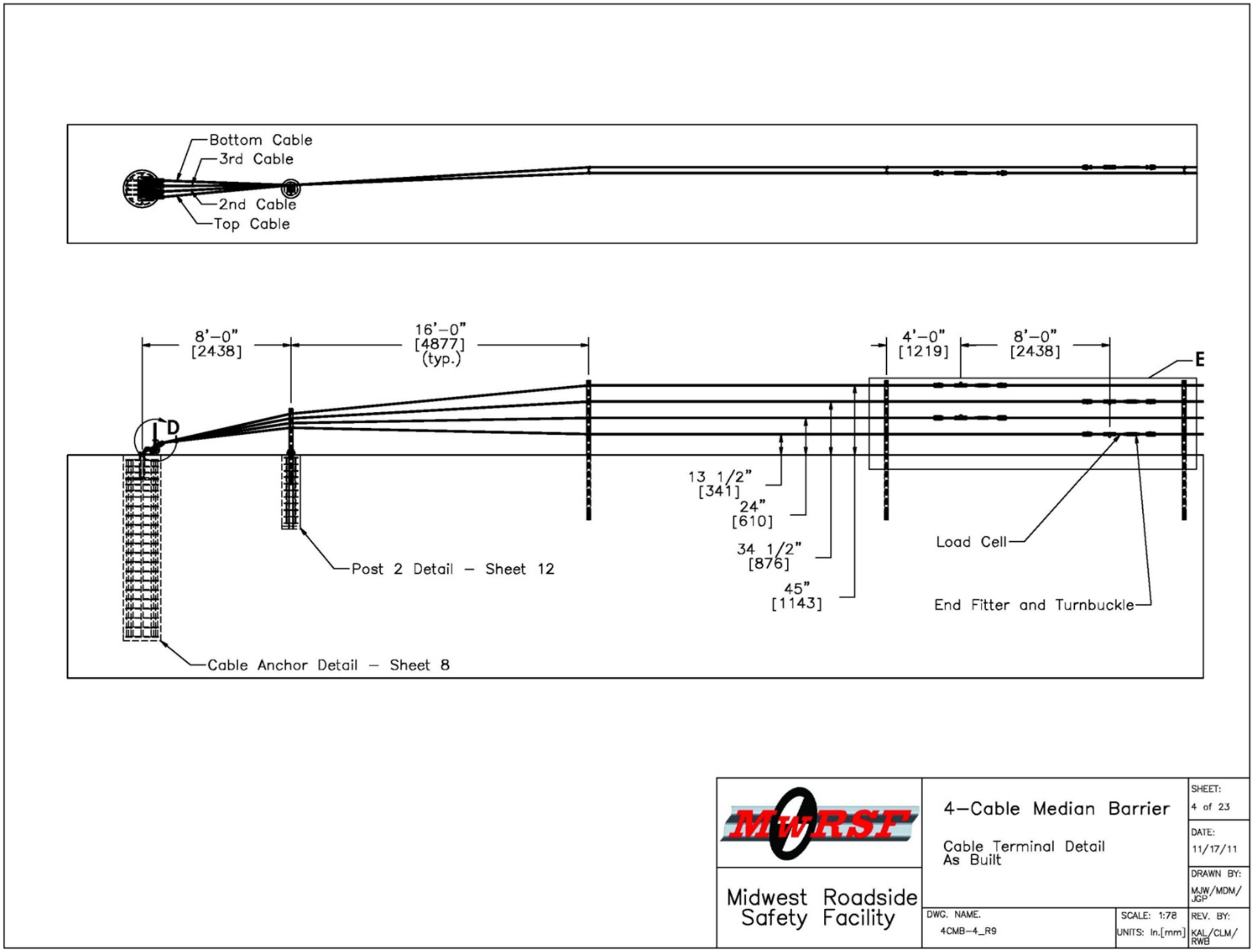


Figure 6. Cable Terminal Layout, Test No. 4CMB-4

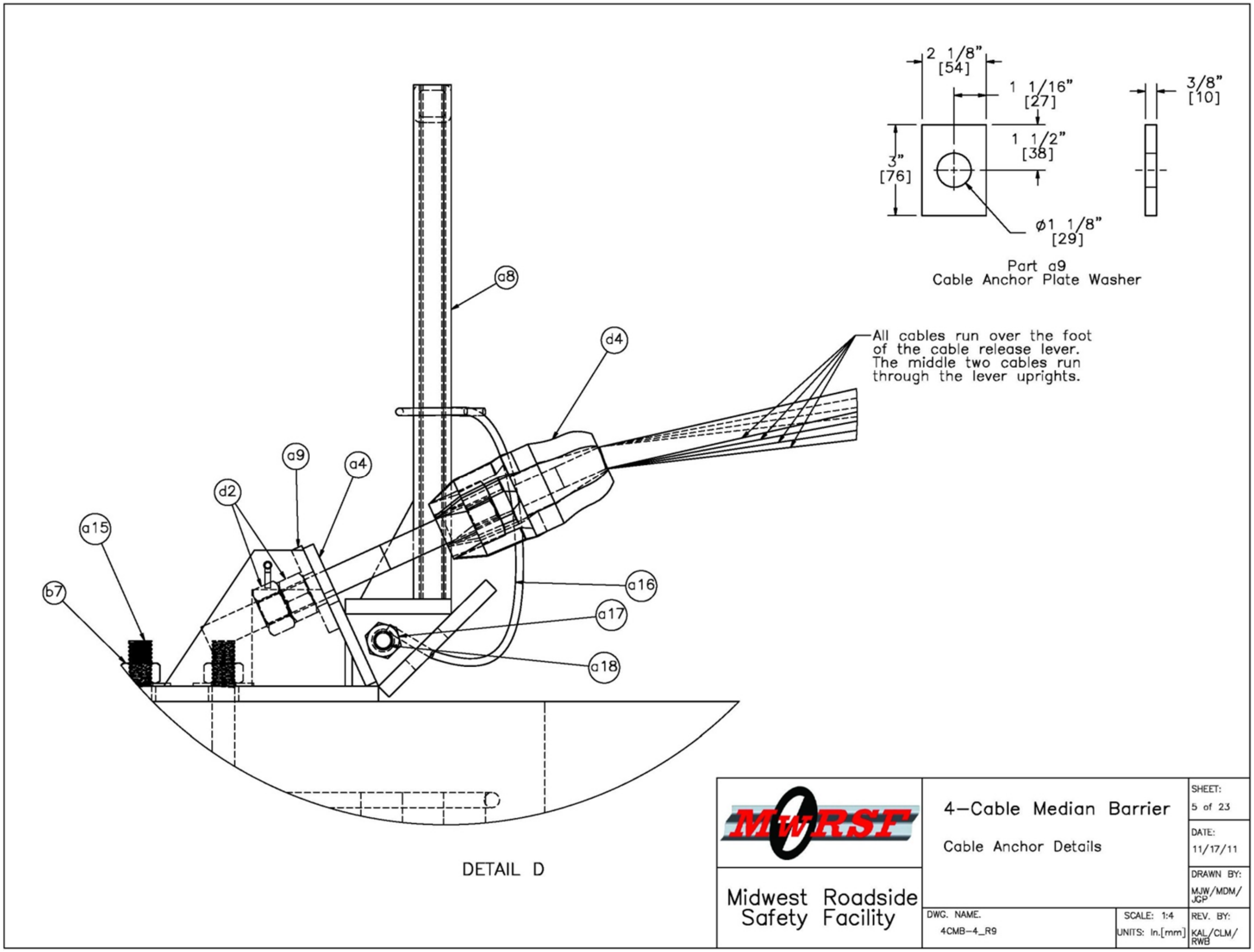


Figure 7. Anchor Details, Test No. 4CMB-4

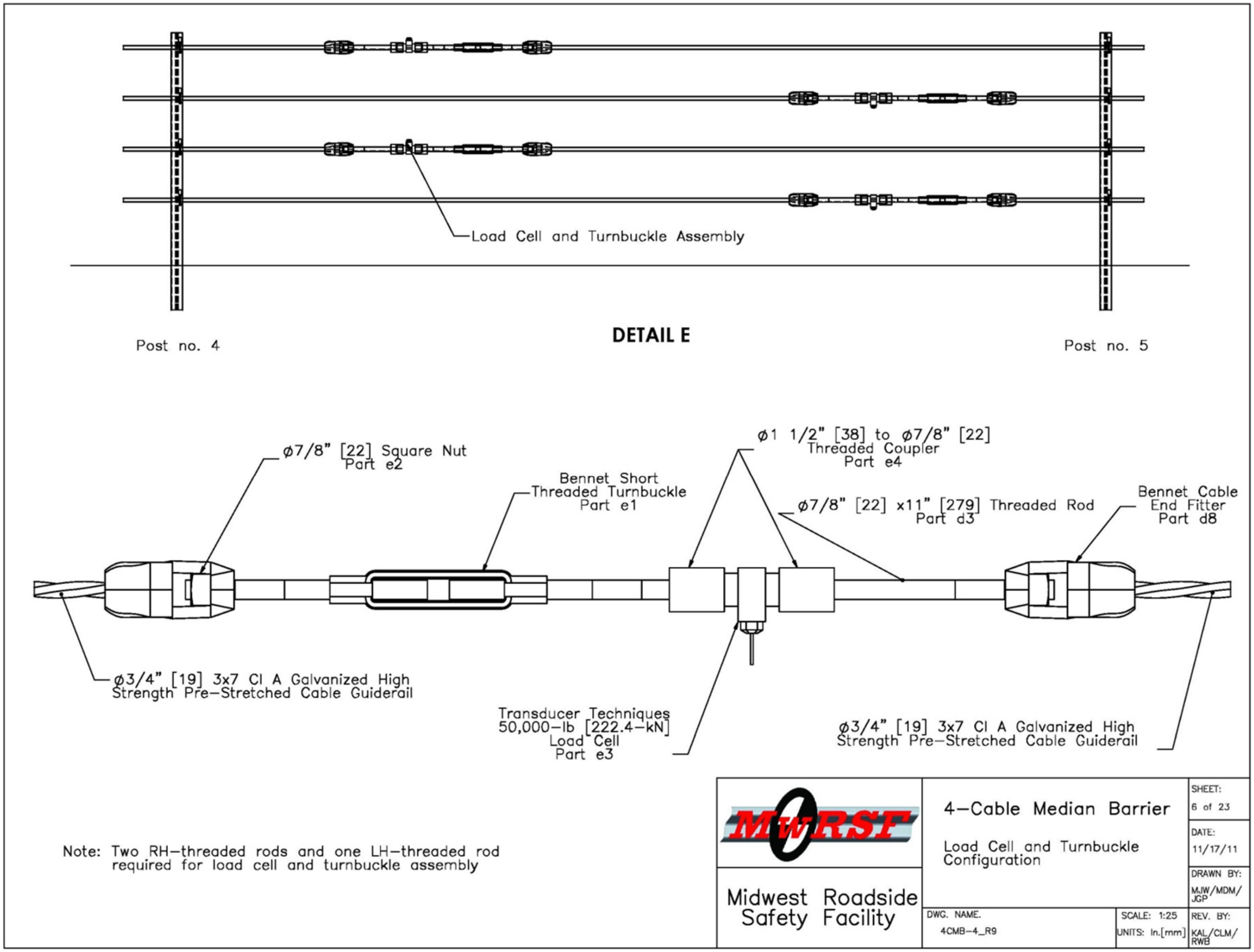


Figure 8. Load Cell Layout, Test No. 4CMB-4

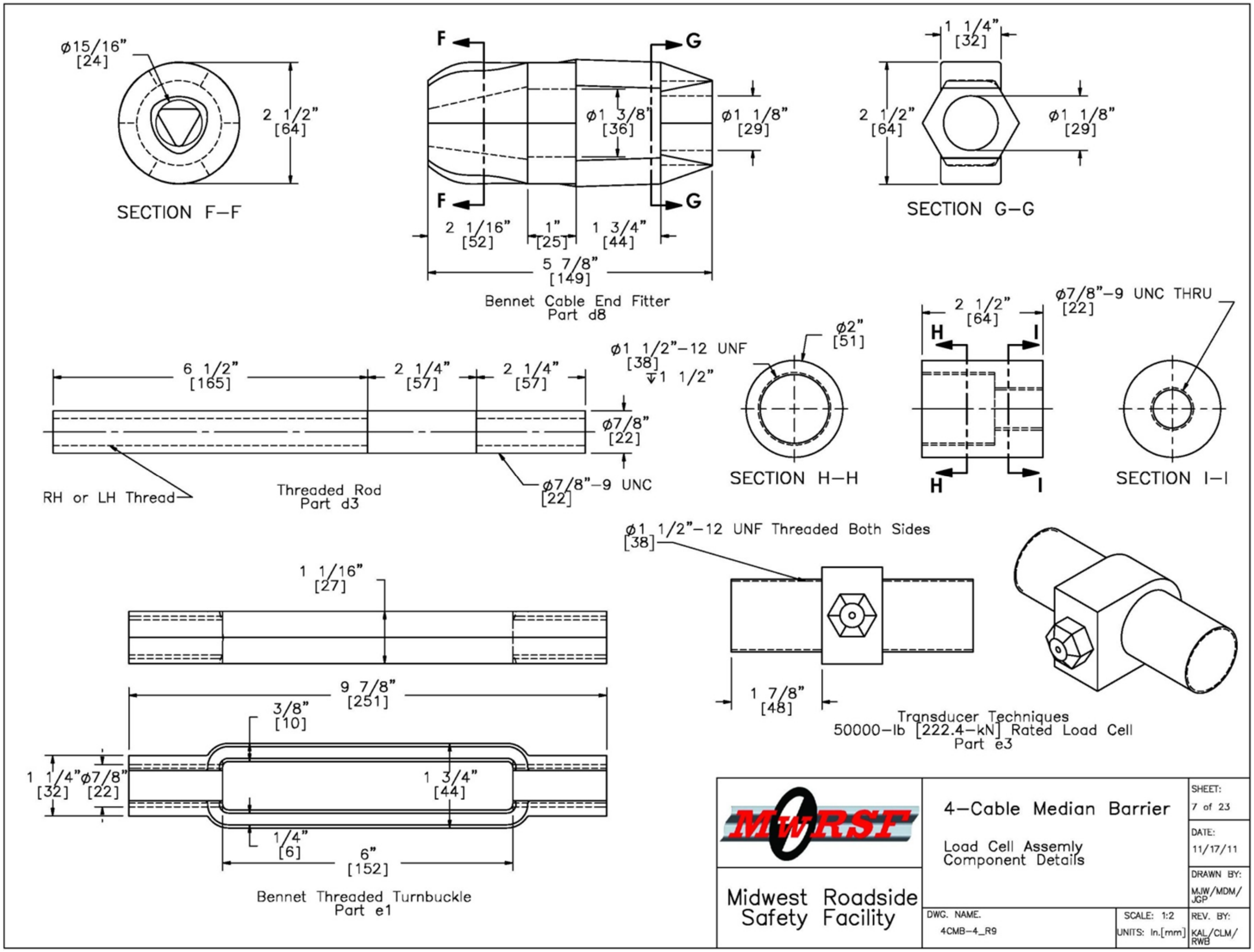
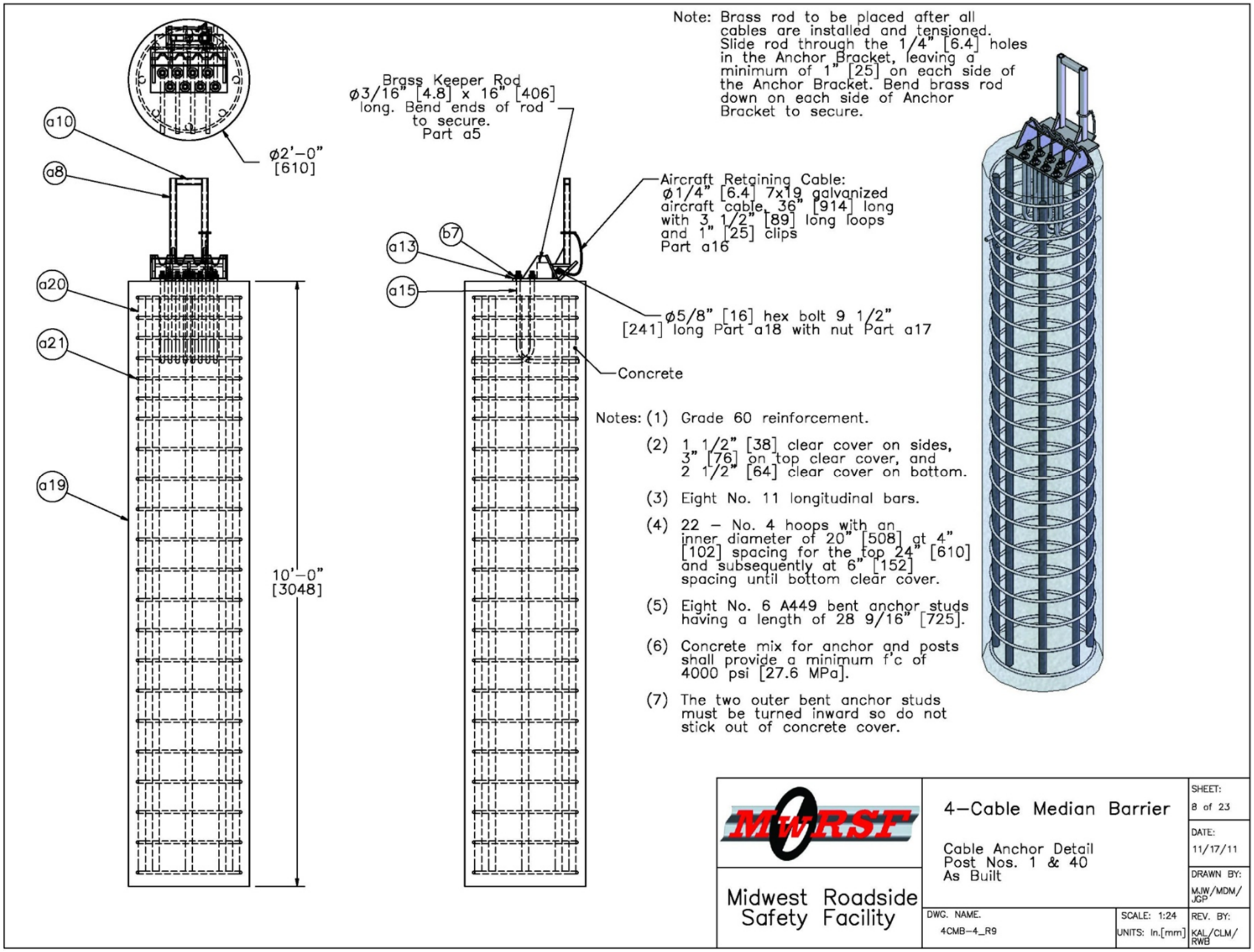


Figure 9. Load Cell Assembly Details, Test No. 4CMB-4



Note: Brass rod to be placed after all cables are installed and tensioned. Slide rod through the 1/4" [6.4] 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.

(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.

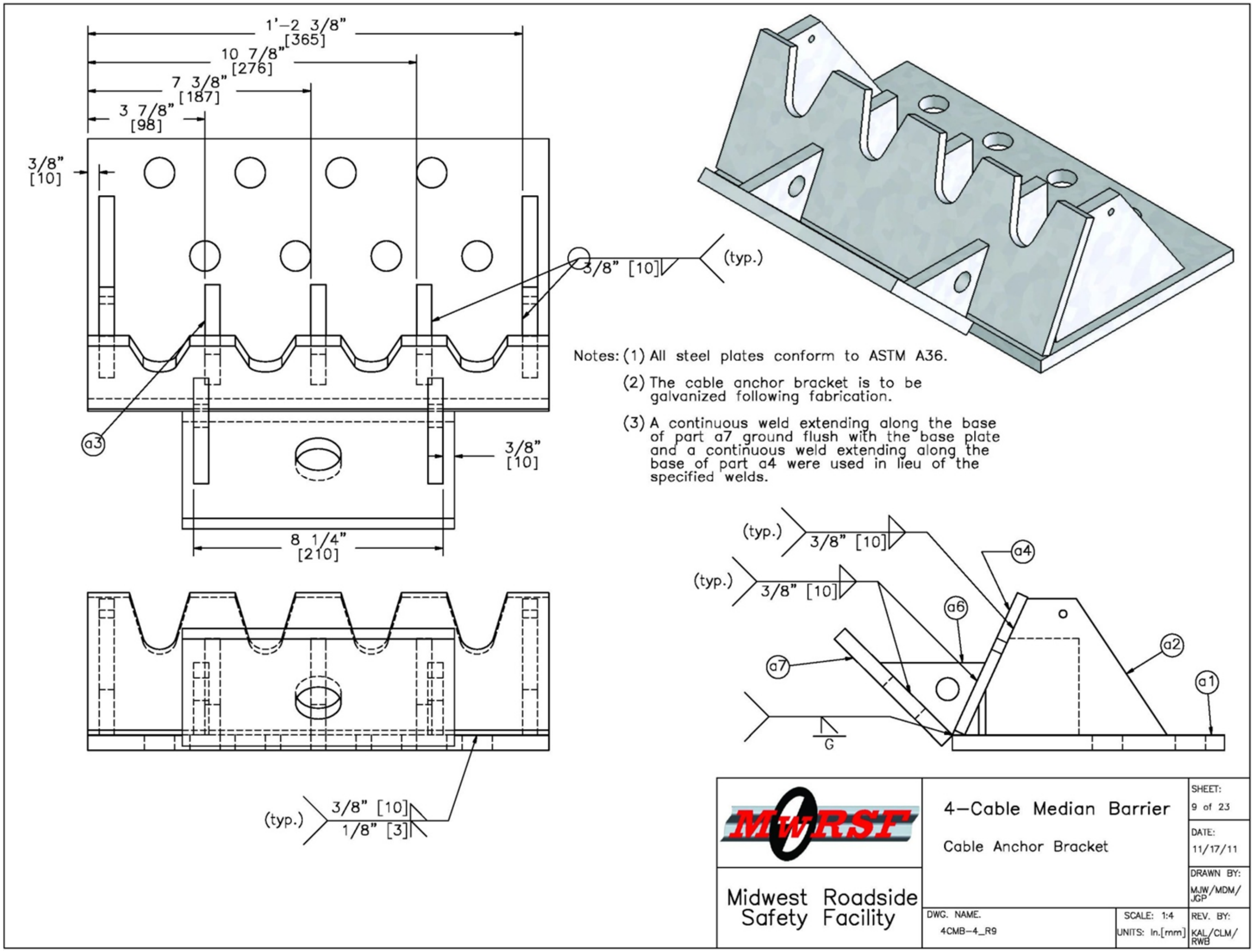
(4) 22 – No. 4 hoops with an inner diameter of 20" [508] at 4" [102] spacing for the top 24" [610] and subsequently at 6" [152] spacing until bottom clear cover.

(5) Eight No. 6 A449 bent anchor studs having a length of 28 9/16" [725].

(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 do not stick out of concrete cover.

Figure 10. Post Nos. 1 and 40 Details, Test No. 4CMB-4



Notes: (1) All steel plates conform to ASTM A36.

(2) The cable anchor bracket is to be galvanized following fabrication.

(3) A continuous weld extending along the base of part a7 ground flush with the base plate and a continuous weld extending along the base of part a4 were used in lieu of the specified welds.

Figure 11. Anchor Bracket Details, Test No. 4CMB-4

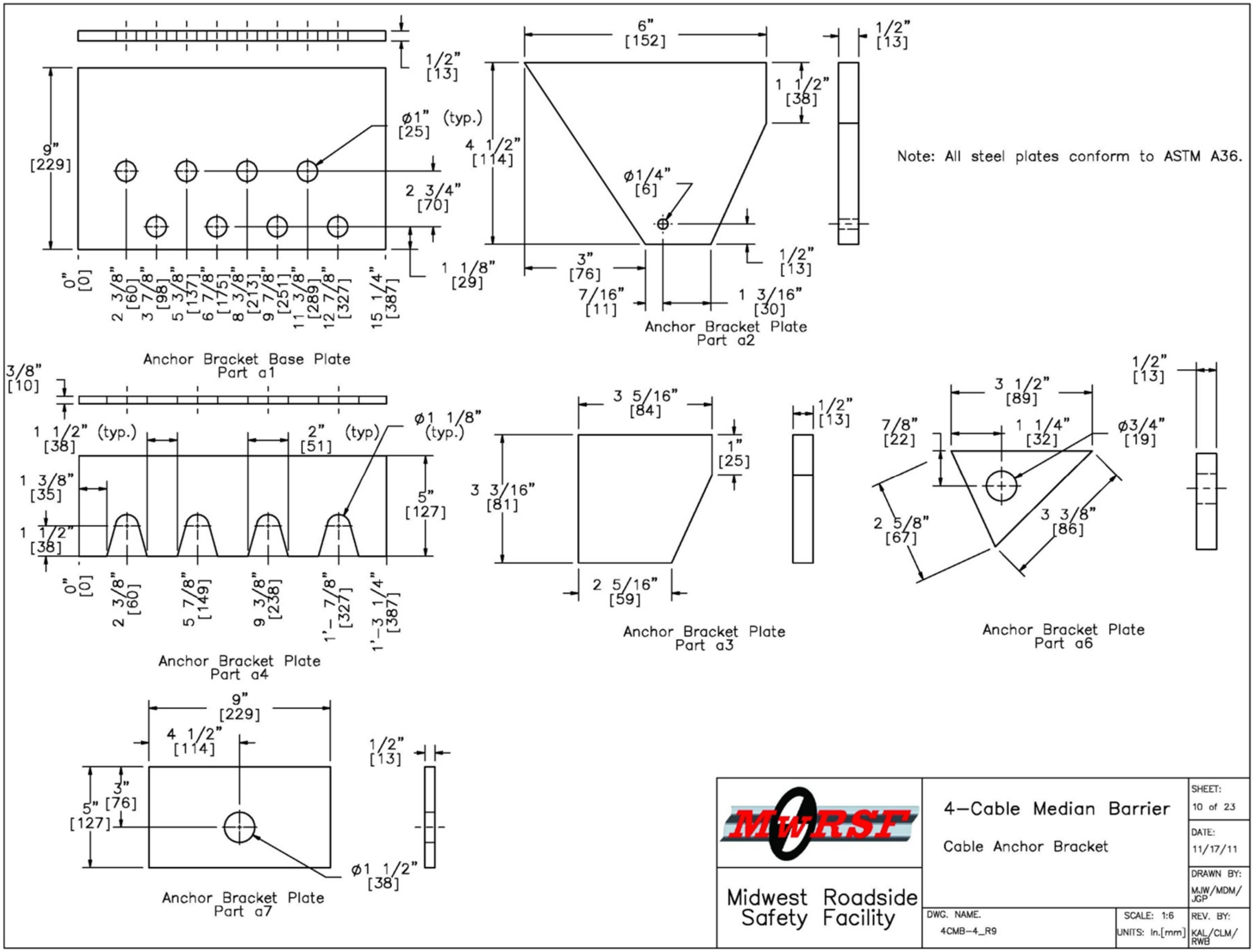


Figure 12. Anchor Bracket Details, Test No. 4CMB-4

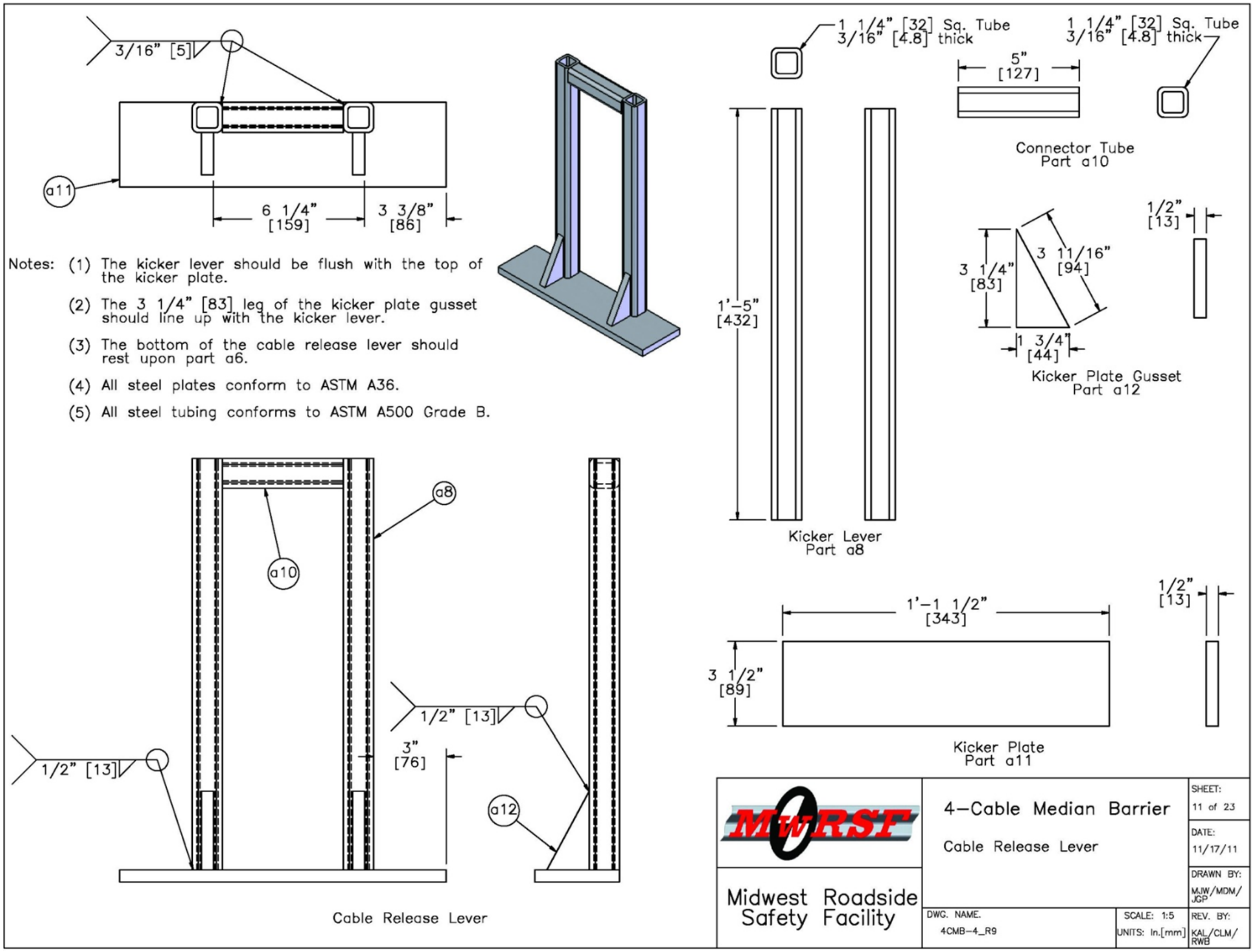
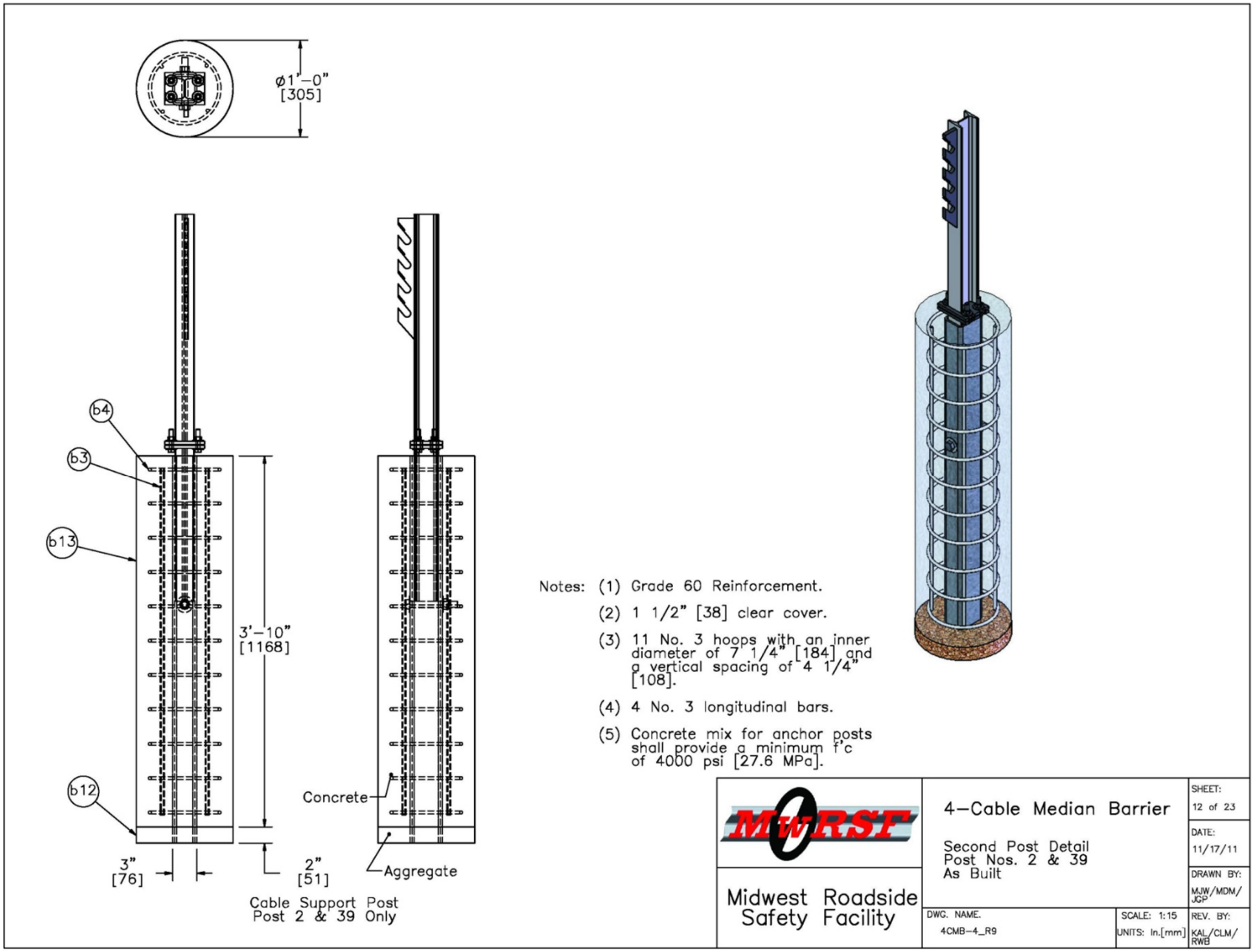


Figure 13. Release Lever Details, Test No. 4CMB-4



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 14. Post Nos. 2 and 39 Details, Test No. 4CMB-4

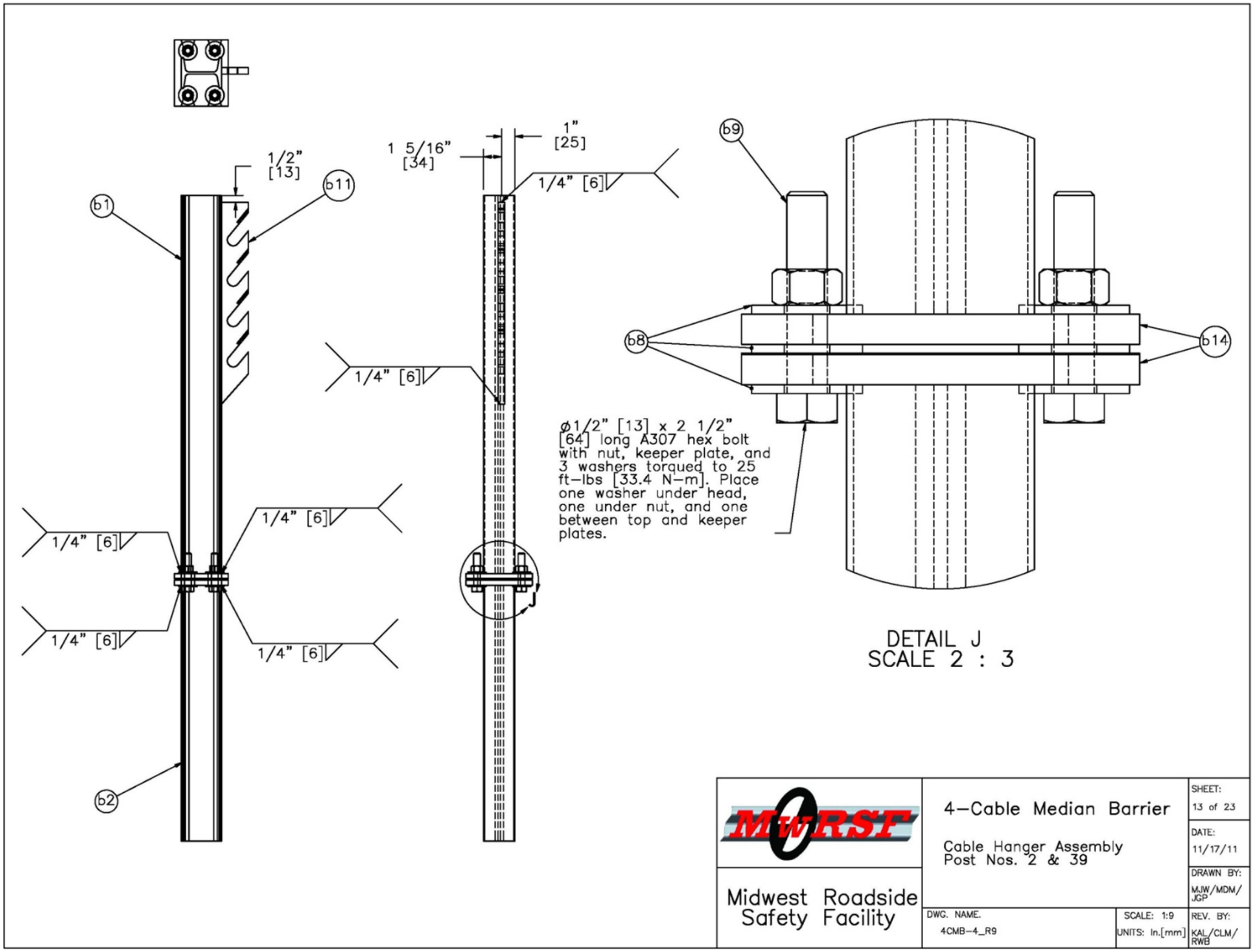


Figure 15. Post Nos. 2 and 39 Details, Test No. 4CMB-4

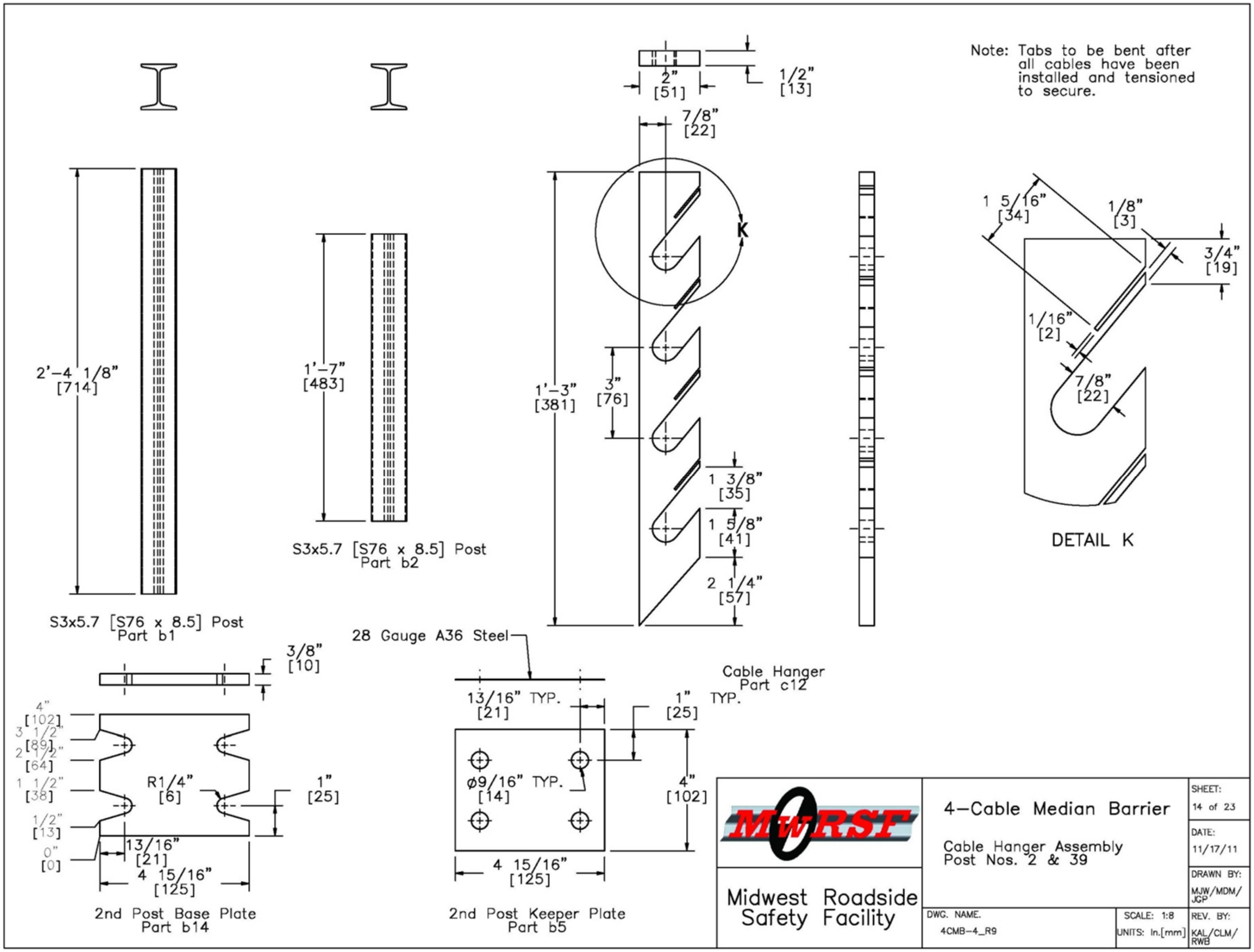


Figure 16. Post Nos. 2 and 39 Details, Test No. 4CMB-4

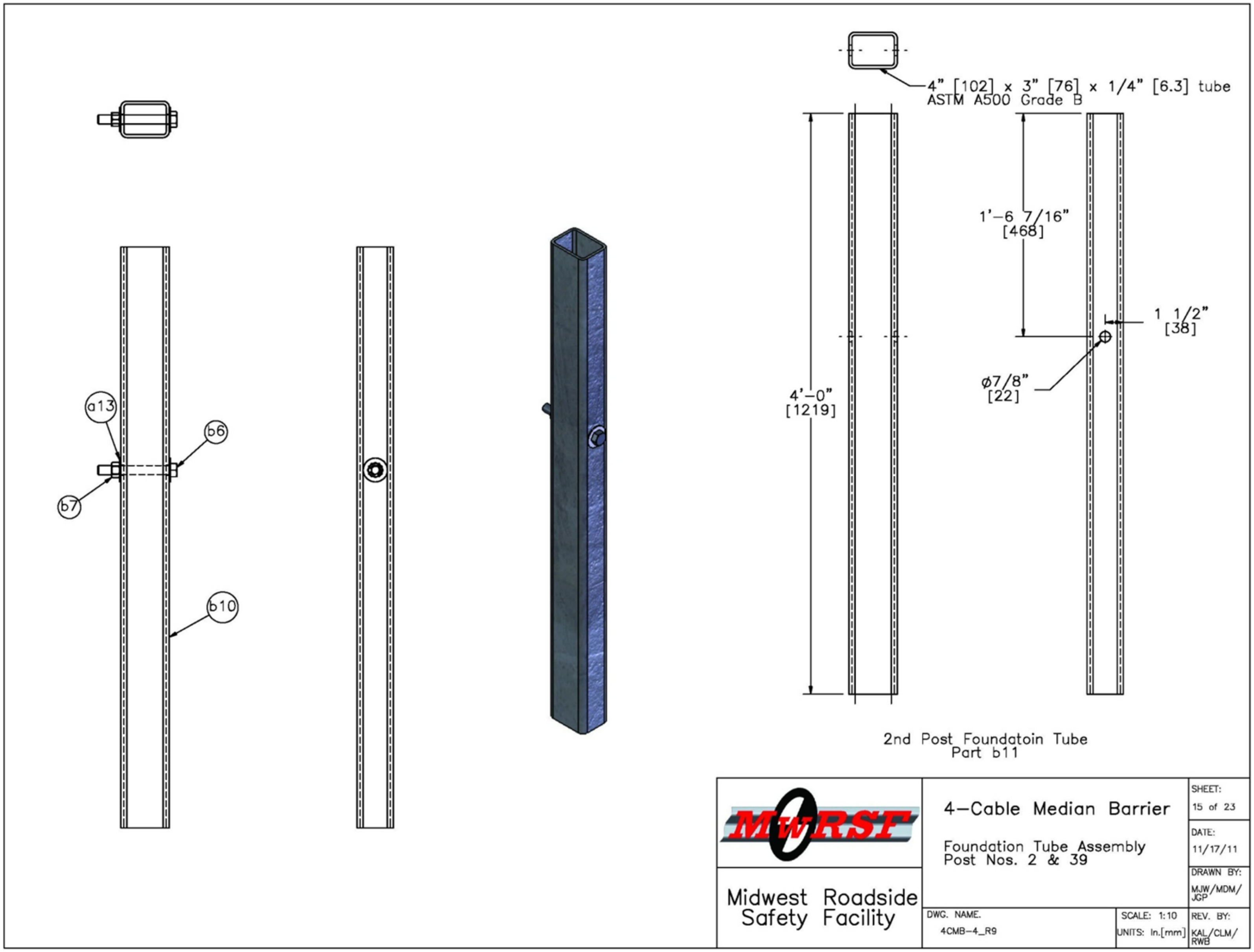


Figure 17. Post Nos. 2 and 39 Details, Test No. 4CMB-4

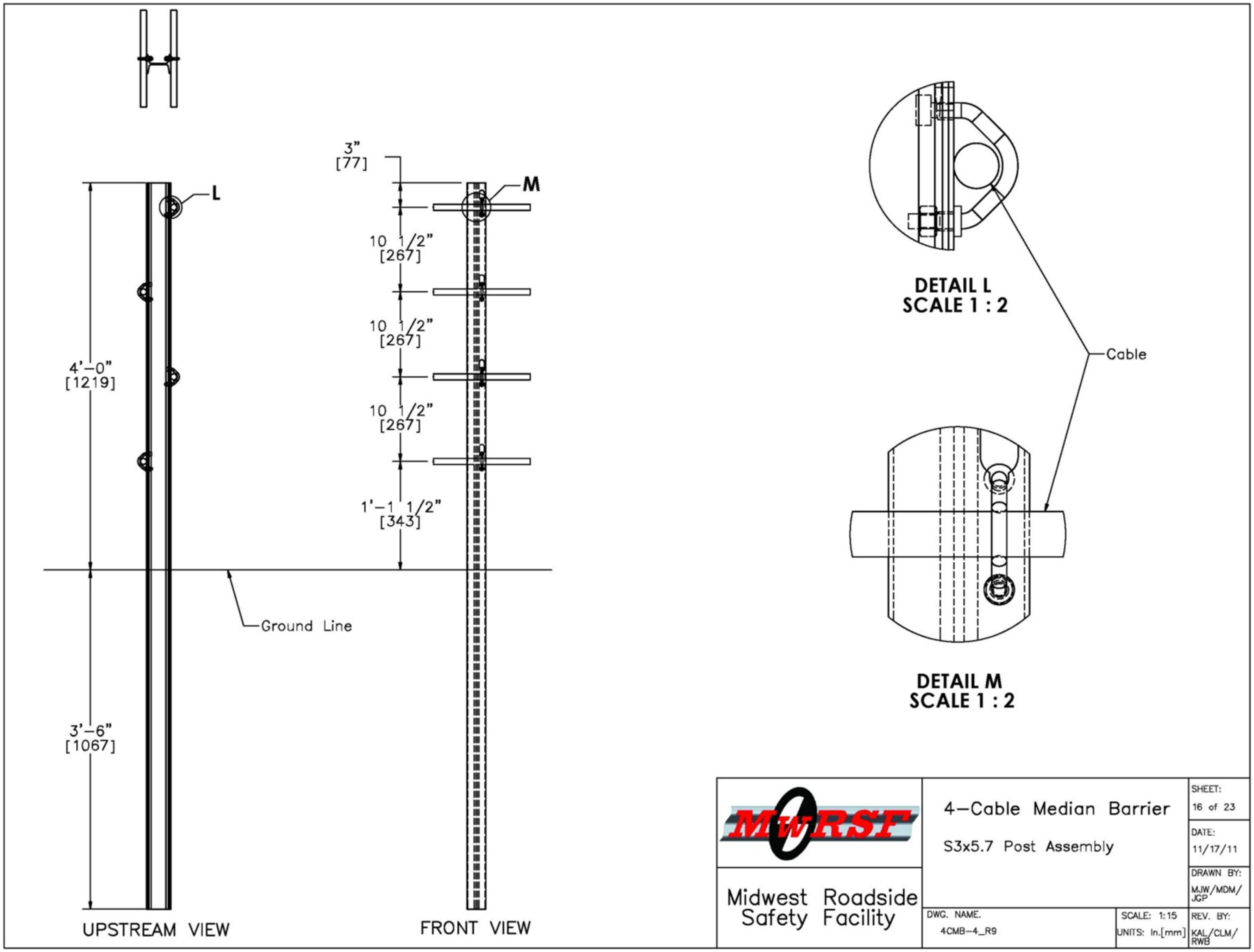


Figure 18. Post Assembly Layout, Test No. 4CMB-4

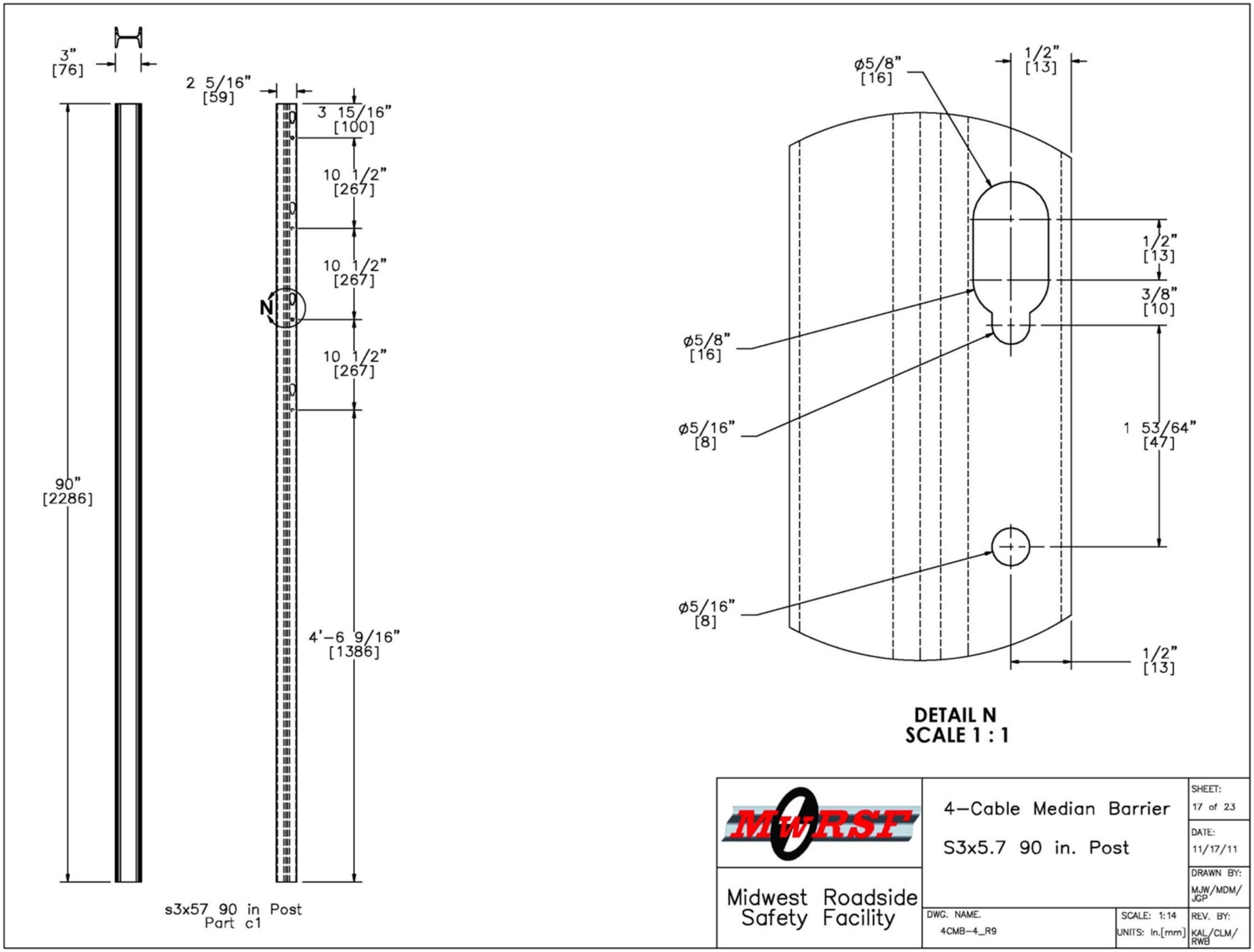


Figure 19. Post Details, Test No. 4CMB-4

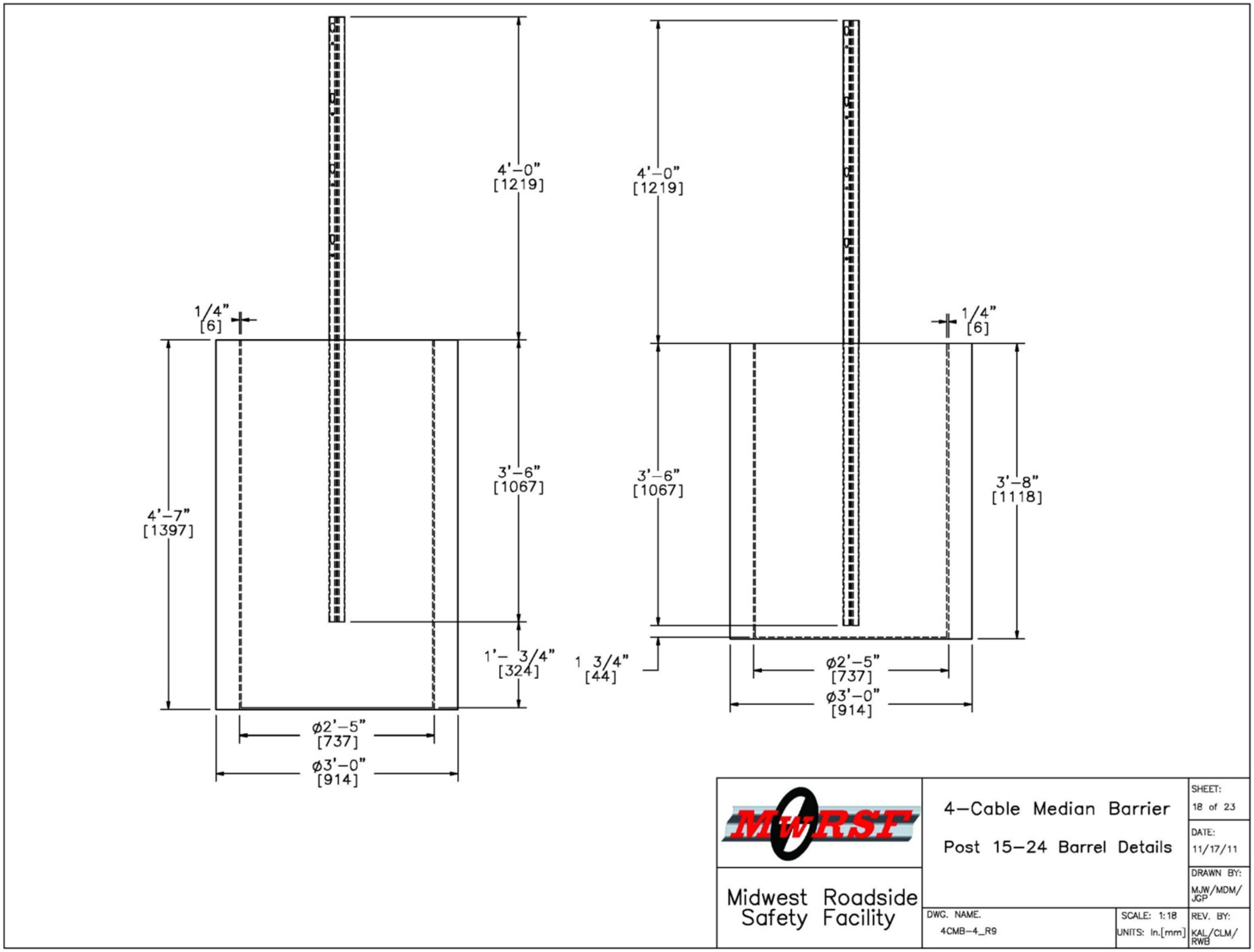
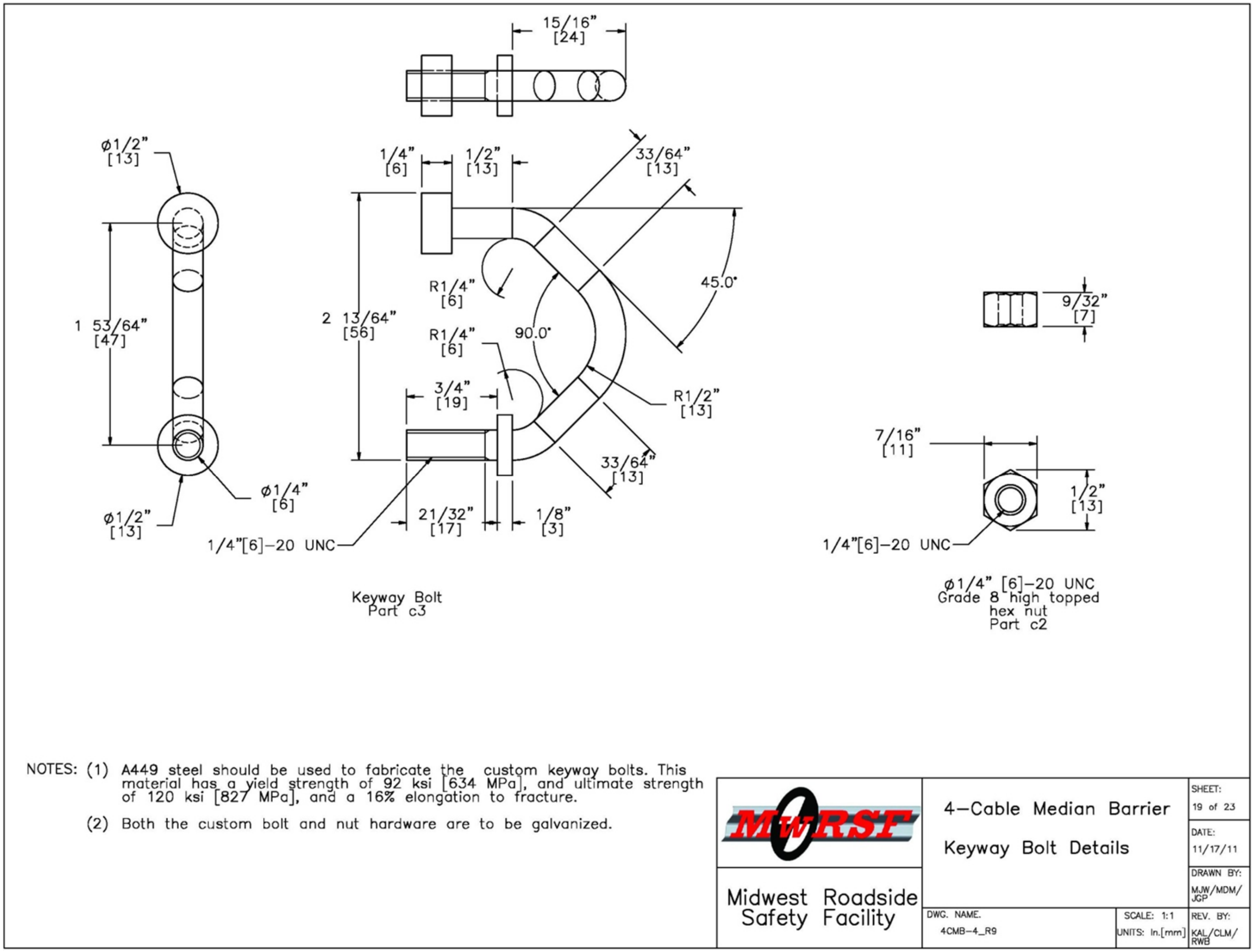


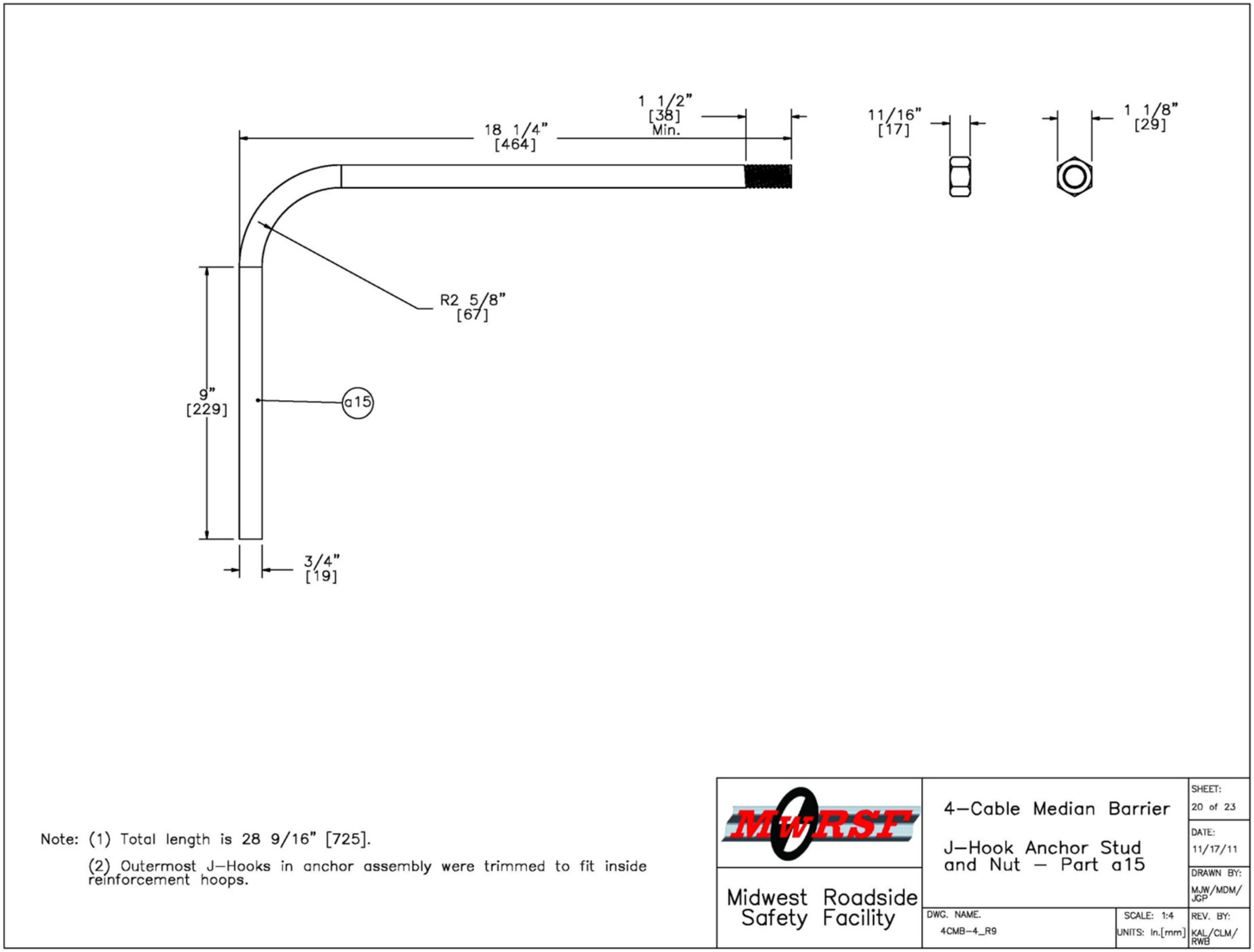
Figure 20. Post Nos. 15-24 Barrel Details, Test No. 4CMB-4



NOTES: (1) A449 steel should be used to fabricate the custom keyway bolts. This material has a yield strength of 92 ksi [634 MPa], and ultimate strength of 120 ksi [827 MPa], and a 16% elongation to fracture.

(2) Both the custom bolt and nut hardware are to be galvanized.

Figure 21. Keyway Bolt Detail, Test No. 4CMB-4



Note: (1) Total length is 28 9/16" [725].

(2) Outermost J-Hooks in anchor assembly were trimmed to fit inside reinforcement hoops.

Figure 22. Anchor Stud Detail, Test No. 4CMB-4

Four Cable Median Barrier Bill of Materials

Item No.	QTY.	Description	Material Spec	Hardware Guide
a1	2	Cable Anchor Base Plate	A36 Steel	FPA02
a2	4	Exterior Cable Plate Gusset	A36 Steel	FPA02
a3	6	Interior Cable Plate Gusset	A36 Steel	FPA02
a4	2	Anchor Bracket Plate	A36 Steel	FPA02
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 Grade B	–
a9	8	CMB High Tension Anchor Plate Washer	A36 Steel	–
a10	2	1.25x1.25x0.1875" [32x32x5] TS CT Kicker Lever Connecting Tube	ASTM A 500 Grade B	–
a11	2	3x10x0.5" [76x254x13] Kicker Plate	A36 Steel	–
a12	4	CT kicker – gusset	A36 Steel	–
a13	20	3/4" [19] Dia. Flat Washer	Grade 2	FWC20a
a15	16	3/4" Dia. J–Hook Anchor and Nut	A449	FRJ16a
a16	2	1/4" [6] Dia. Aircraft Retaining Cable, 36" [914] long	7x19 galvanized	–
a17	2	5/8" [16] Dia. Heavy Hex Nut	Grade 5	–
a18	2	5/8" [16] Dia. x 9 1/2" [241] long Hex Bolt	Grade 5	
a19	2	24" [610] Dia. Concrete Anchor, 120" [3048] long	4,000 psi f'c	–
a20	16	#11 Straight Rebar, 114" [2896] long	Grade 60	–
a21	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	A36	–
b6	2	3/4" [19] Dia. x 6" [152] long Hex Bolt and Nut	A307	FBX20a
b7	2	3/4" [19] Dia. Hex Nut	Grade 2	FNX20a
b8	24	1/2" [13] Dia. Washer	A307	FWC14a
b9	8	1/2" [13] Dia. x 2 1/2" [64] long Hex Bolt and Nut	A307	FBX14a
b10	2	4x3x1/4" [102x76x6] Foundation Tube, 48" [1168] long	ASTM A500 Grade B	–
b11	2	2nd Post Cable Hanger	A36	–
b12	2	2nd Post Anchor Aggregate 12 in, Depth	–	–
b13	2	12" [305] Dia. 2nd Post Concrete Anchor, 46" [1168] long	4,000 psi f'c	–
b14	4	2nd Post Base Plate	A36	–
c1	36	S3x5.7 [S76x8.5] by 90" [1524]	ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A	–
c2	144	1/4" [6] Dia. – 20 UNC Hex Nut High Topped	Grade 8 – Galvanized	–
c3	144	1/4" [6] dia. Keyway bolt	A449 – Galvanized	–

Midwest Roadside Safety Facility

4–Cable Median Barrier
Bill of Materials

SHEET: 21 of 23
DATE: 11/17/11
DRAWN BY: MJW/MDM/JGP
DWG. NAME. 4CMB–4_R9
SCALE: None
UNITS: In.[mm]
REV. BY: KAL/CLM/RWB

Figure 23. Bill of Materials, Test No. 4CMB-4

Four Cable Median Barrier Bill of Materials Continued

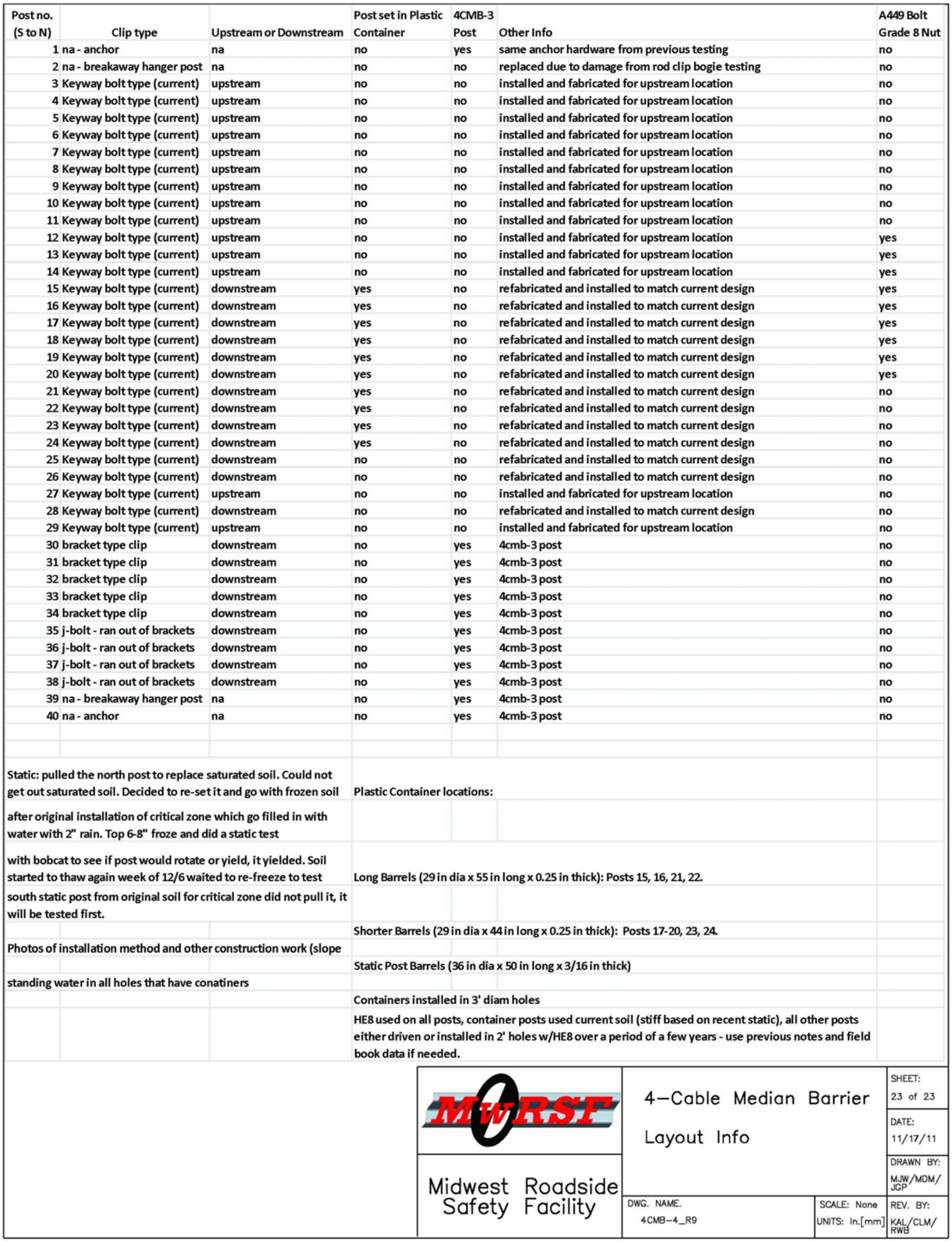
Item No.	QTY.	Description	Material Spec	Hardware Guide
d1	4	3/4" [19] Dia. High Strength Pre-Stretched Cable Guiderail	3x7 Cl A Galvanized	RCM01
d2	16	7/8" [22] Dia. Hex Nut	A563	RCE03
d3	20	7/8" [22] Cable End Threaded Rod	ASTM-A449	RCE03
d4	16	Bennet Cable End Fitter	ASTM-A47	RCE03
d5	16	7/8" Dia. Square Nut	Grade 5	FNS20
d6	8	CMB Splice Cable Insert	Brass (unknown)	–
d7	8	CMB Splice Threaded Rope Connector	Steel (unknown)	–
d8	4	Bennet Cable End Fitter	Steel (unknown)	–
e1	4	Bennet Short Threaded Turnbuckle	Not Specified	–
e2	8	Threaded Loadcell Coupler	N/A	–
e3	4	50,000-lb Load Cell	N/A	–

Midwest Roadside
Safety Facility

4-Cable Median Barrier
Bill of Materials Continued

SHEET: 22 of 23
DATE: 11/17/11
DRAWN BY: MJW/MDM/JGP
DWG. NAME. 4CMB-4_R9
SCALE: None
UNITS: In.[mm]
REV. BY: KAL/CLM/RWB

Figure 24. Bill of Materials, Test No. 4CMB-4



Post no. (S to N)	Clip type	Upstream or Downstream	Post set in Plastic Container	4CMB-3 Post	Other Info	A449 Bolt Grade 8 Nut
1	na - anchor	na	no	yes	same anchor hardware from previous testing	no
2	na - breakaway hanger post	na	no	no	replaced due to damage from rod clip bogie testing	no
3	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
4	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
5	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
6	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
7	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
8	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
9	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
10	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
11	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
12	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	yes
13	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	yes
14	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	yes
15	Keyway bolt type (current)	downstream	yes	no	refabricated and installed to match current design	yes
16	Keyway bolt type (current)	downstream	yes	no	refabricated and installed to match current design	yes
17	Keyway bolt type (current)	downstream	yes	no	refabricated and installed to match current design	yes
18	Keyway bolt type (current)	downstream	yes	no	refabricated and installed to match current design	yes
19	Keyway bolt type (current)	downstream	yes	no	refabricated and installed to match current design	yes
20	Keyway bolt type (current)	downstream	yes	no	refabricated and installed to match current design	yes
21	Keyway bolt type (current)	downstream	yes	no	refabricated and installed to match current design	no
22	Keyway bolt type (current)	downstream	yes	no	refabricated and installed to match current design	no
23	Keyway bolt type (current)	downstream	yes	no	refabricated and installed to match current design	no
24	Keyway bolt type (current)	downstream	yes	no	refabricated and installed to match current design	no
25	Keyway bolt type (current)	downstream	no	no	refabricated and installed to match current design	no
26	Keyway bolt type (current)	downstream	no	no	refabricated and installed to match current design	no
27	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
28	Keyway bolt type (current)	downstream	no	no	refabricated and installed to match current design	no
29	Keyway bolt type (current)	upstream	no	no	installed and fabricated for upstream location	no
30	bracket type clip	downstream	no	yes	4cmb-3 post	no
31	bracket type clip	downstream	no	yes	4cmb-3 post	no
32	bracket type clip	downstream	no	yes	4cmb-3 post	no
33	bracket type clip	downstream	no	yes	4cmb-3 post	no
34	bracket type clip	downstream	no	yes	4cmb-3 post	no
35	j-bolt - ran out of brackets	downstream	no	yes	4cmb-3 post	no
36	j-bolt - ran out of brackets	downstream	no	yes	4cmb-3 post	no
37	j-bolt - ran out of brackets	downstream	no	yes	4cmb-3 post	no
38	j-bolt - ran out of brackets	downstream	no	yes	4cmb-3 post	no
39	na - breakaway hanger post	na	no	yes	4cmb-3 post	no
40	na - anchor	na	no	yes	4cmb-3 post	no

Static: pulled the north post to replace saturated soil. Could not get out saturated soil. Decided to re-set it and go with frozen soil after original installation of critical zone which go filled in with water with 2" rain. Top 6-8" froze and did a static test with bobcat to see if post would rotate or yield, it yielded. Soil started to thaw again week of 12/6 waited to re-freeze to test south static post from original soil for critical zone did not pull it, it will be tested first.

Photos of installation method and other construction work (slope

standing water in all holes that have conatiners

Plastic Container locations:

Long Barrels (29 in dia x 55 in long x 0.25 in thick): Posts 15, 16, 21, 22.

Shorter Barrels (29 in dia x 44 in long x 0.25 in thick): Posts 17-20, 23, 24.

Static Post Barrels (36 in dia x 50 in long x 3/16 in thick)

Containers installed in 3' diam holes

HE8 used on all posts, container posts used current soil (stiff based on recent static), all other posts either driven or installed in 2' holes w/HE8 over a period of a few years - use previous notes and field book data if needed.

Midwest Roadside Safety Facility

4-Cable Median Barrier
Layout Info

SHEET: 23 of 23
DATE: 11/17/11
DRAWN BY: MJW/MDM/JGP
DWG. NAME. 4CMB-4_R9
SCALE: None
UNITS: In.[mm]
REV. BY: KAL/CLM/RWB

Figure 25. Test Installation Layout Information, Test No. 4CMB-4

Figure 26. Post and Keyway Bolt Photographs, Test No. 4CMB-4

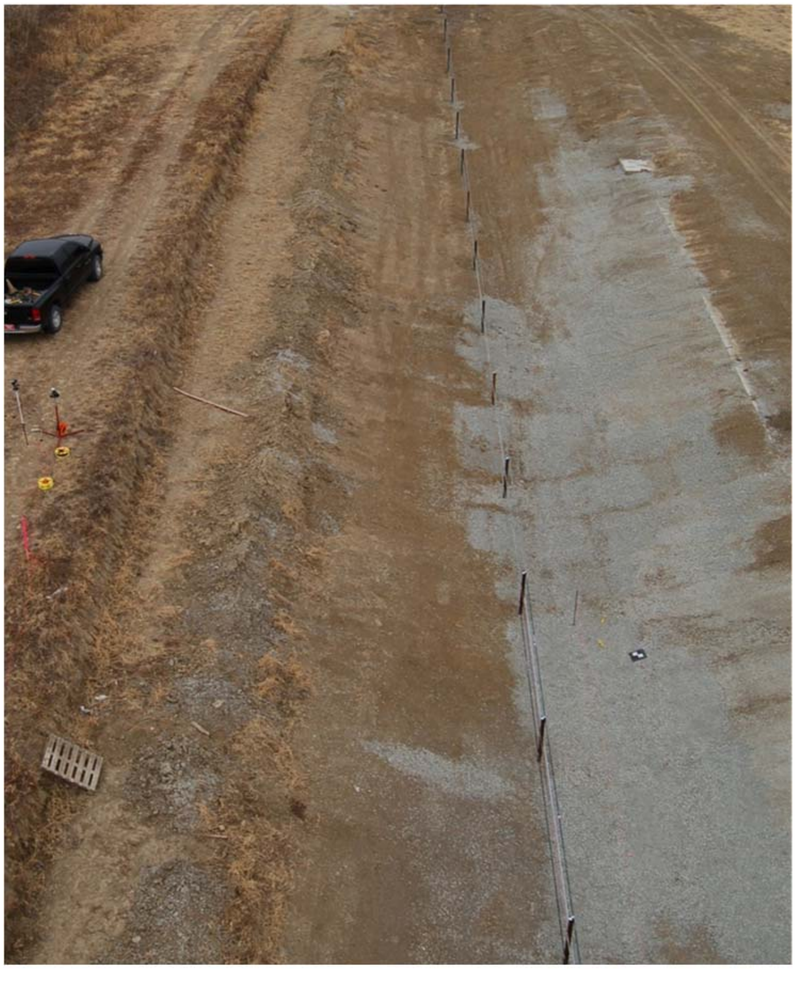


Figure 27. Test Installation Photographs, Test No. 4CMB-4

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as cable median barriers, must satisfy impact safety standards in order to be accepted 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 [9]. According to TL-3 of MASH, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests. The two full-scale crash tests are noted below:

1. Test Designation No. 3-10 consists of a 2,425-lb (1,100-kg) passenger car impacting the system at a nominal speed and angle of 62 mph (100 km/h) and 25 degrees, respectively.

2. Test Designation No. 3-11 consists of a 5,000-lb (2,268-kg) pickup truck impacting the system at a nominal speed and angle of 62 mph (100 km/h) and 25 degrees, respectively.

The test conditions of TL-3 longitudinal barriers are summarized in Table 2.

Table 2. MASH TL-3 Crash Test Conditions

Test Article	Test Designation No.	Test Vehicle	Impact Conditions			Evaluation Criteria [1]
			Speed		Angle (deg)	
			mph	km/h		
Longitudinal Barrier	3-10	1100C	62	100	25	A,D,F,H,I
	3-11	2270P	62	100	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 3.

3.2 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 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 3 and defined in greater detail in MASH. The full-scale vehicle crash test was 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.

3.3 Soil Strength Requirements

In order to limit the variation of soil strength among testing agencies, foundation soil must satisfy the recommended performance characteristics set forth in Chapter 3 and Appendix B of MASH. Testing facilities must first subject the designated soil to a dynamic post test to demonstrate a minimum dynamic load of 7.5 kips (33.4 kN) at deflections between 5 and 20 in. (127 and 508 mm). If satisfactory results are observed, a static test is conducted using an identical test installation. The results from this static test become the baseline requirement for soil strength in future full-scale crash testing in which the designated soil is used. An additional post installed near the impact point is statically tested on the day of full-scale crash test in the same manner as used in the baseline static test. The full-scale crash test can be conducted only if the static test results show a soil resistance equal to or greater than 90 percent of the baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Otherwise, the crash test must be postponed until the soil demonstrates adequate post-soil strength.

Table 3. MASH Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

4 TEST CONDITIONS

4.1 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 University of Nebraska-Lincoln.

4.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [12] was used to steer the test vehicle. A guide flag, attached to the right-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicles

For test no. 4CMB-4, a 2002 Kia Rio Sedan was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,377 lb (1,078 kg), 2,404 lb (1,090 kg), and 2,574 lb (1,168 kg), respectively. The test vehicle is shown in Figure 28, and vehicle dimensions are shown in Figure 29.

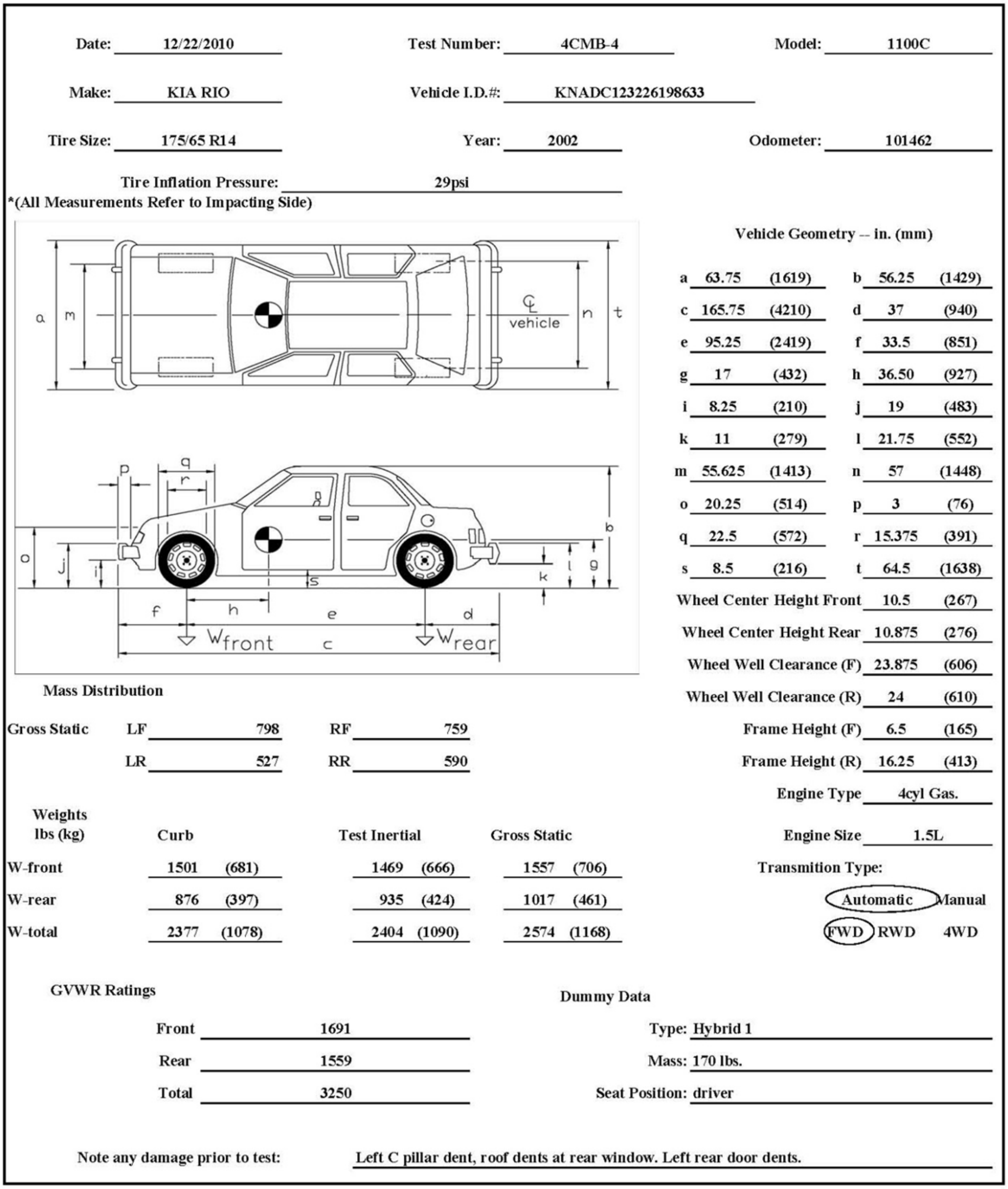
For test no. 4CMB-5, a 2002 Dodge Ram 1500 Quad Cab pickup was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,119 lb (2,322 kg), 4,979 lb (2,258 kg), and 5,149 lb (2,336 kg), respectively. The test vehicle is shown in Figure 30, and vehicle dimensions are shown in Figure 31.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [13] was used to determine the vertical component of the c.g. for the pickup truck. 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 vertical component of the c.g. for the 1100C vehicle was estimated based on historical c.g. height measurements. The location of the final c.g. for test no. 4CMB-4 is shown in Figures 29 and 32. The location of the final c.g. for test no. 4CMB-5 is shown in Figures 31 and 33. 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 the video analysis, as shown in Figure 32 for test no. 4CMB-4 and Figure 33 for test no. 4CMB-5. 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 excpe the toe-in value was 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 vehicle's 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

Figure 28. Test Vehicle, Test No. 4CMB-4



Date: 12/22/2010
Test Number: 4CMB-4
Model: 1100C

Make: KIA RIO
Vehicle I.D.#: KNADC123226198633

Tire Size: 175/65 R14
Year: 2002
Odometer: 101462

Tire Inflation Pressure: 29psi

*(All Measurements Refer to Impacting Side)

Vehicle Geometry -- in. (mm)

a	63.75	(1619)	b	56.25	(1429)
c	165.75	(4210)	d	37	(940)
e	95.25	(2419)	f	33.5	(851)
g	17	(432)	h	36.50	(927)
i	8.25	(210)	j	19	(483)
k	11	(279)	l	21.75	(552)
m	55.625	(1413)	n	57	(1448)
o	20.25	(514)	p	3	(76)
q	22.5	(572)	r	15.375	(391)
s	8.5	(216)	t	64.5	(1638)

Wheel Center Height Front 10.5 (267)
Wheel Center Height Rear 10.875 (276)
Wheel Well Clearance (F) 23.875 (606)
Wheel Well Clearance (R) 24 (610)
Frame Height (F) 6.5 (165)
Frame Height (R) 16.25 (413)
Engine Type 4cyl Gas.
Engine Size 1.5L

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

Mass Distribution

Gross Static	LF	798	RF	759
	LR	527	RR	590

Weights lbs (kg)	Curb	Test Inertial	Gross Static
W-front	1501 (681)	1469 (666)	1557 (706)
W-rear	876 (397)	935 (424)	1017 (461)
W-total	2377 (1078)	2404 (1090)	2574 (1168)

GVWR Ratings

Front 1691
Rear 1559
Total 3250

Dummy Data

Type: Hybrid 1
Mass: 170 lbs.
Seat Position: driver

Note any damage prior to test: Left C pillar dent, roof dents at rear window. Left rear door dents.

Figure 29. Vehicle Dimensions, Test No. 4CMB-4

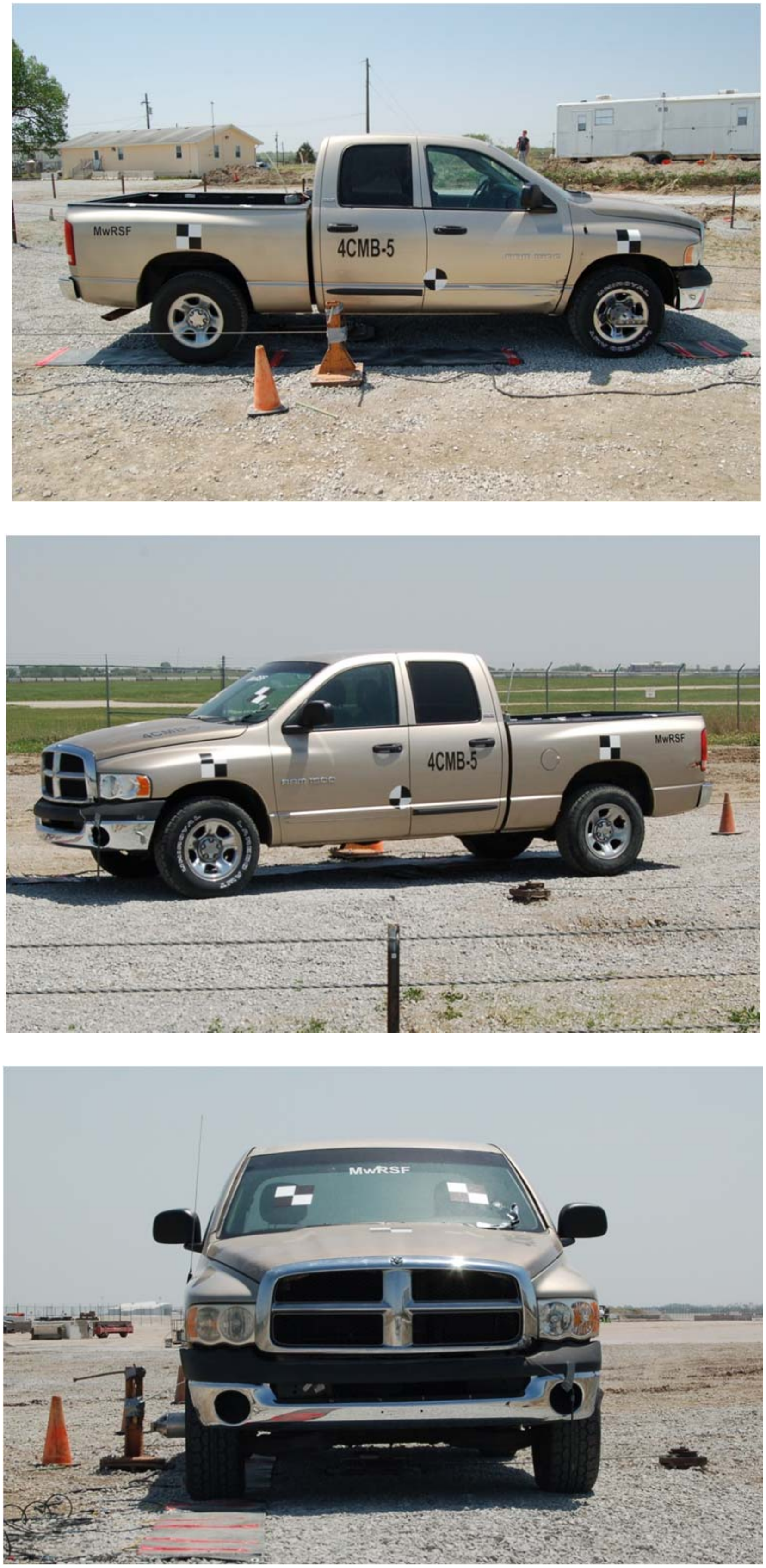
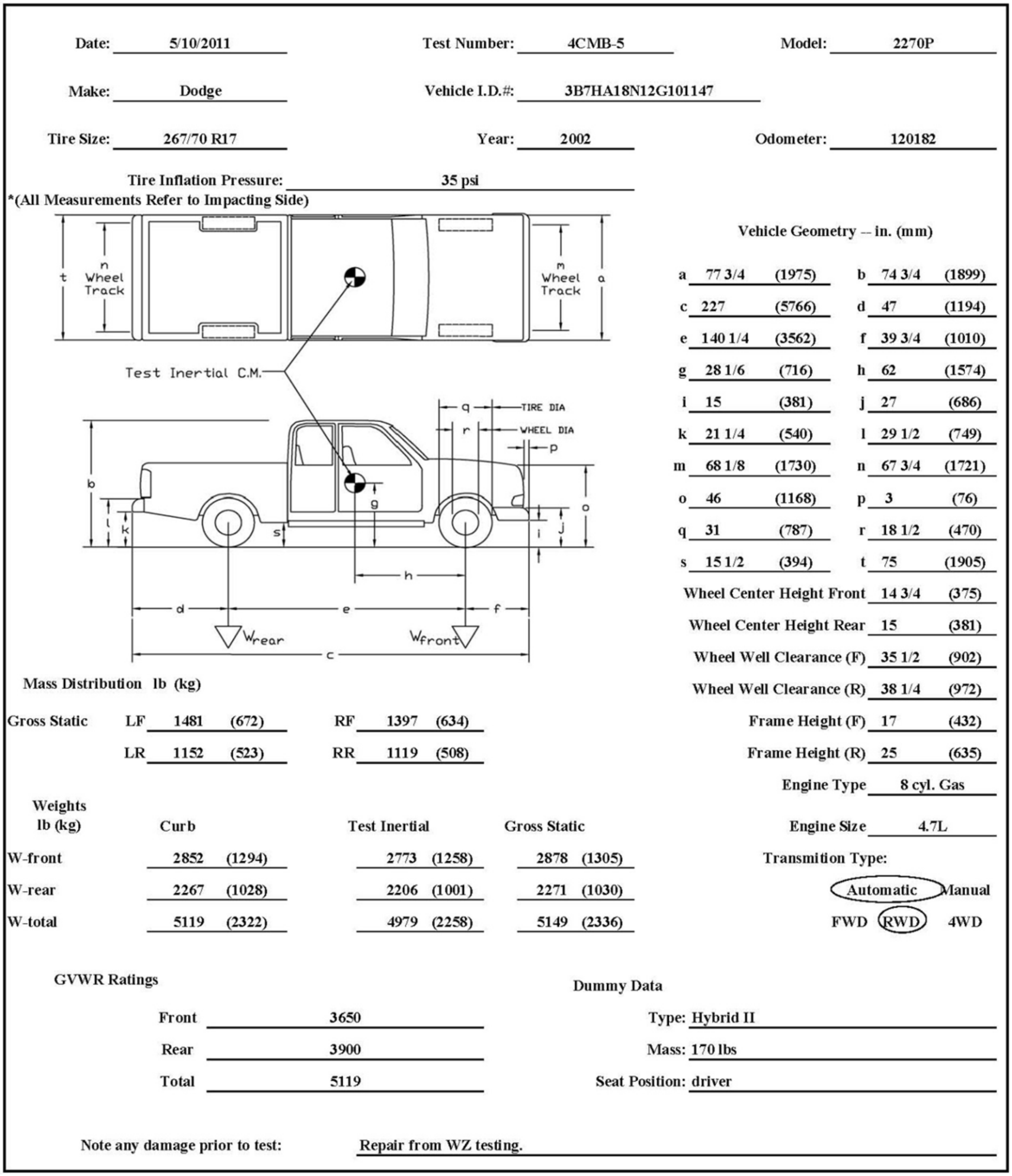


Figure 30. Test Vehicle, Test No. 4CMB-5



Date: 5/10/2011 Test Number: 4CMB-5 Model: 2270P

Make: Dodge Vehicle I.D.#: 3B7HA18N12G101147

Tire Size: 267/70 R17 Year: 2002 Odometer: 120182

Tire Inflation Pressure: 35 psi

*(All Measurements Refer to Impacting Side)

Vehicle Geometry -- in. (mm)

a	77 3/4	(1975)	b	74 3/4	(1899)
c	227	(5766)	d	47	(1194)
e	140 1/4	(3562)	f	39 3/4	(1010)
g	28 1/6	(716)	h	62	(1574)
i	15	(381)	j	27	(686)
k	21 1/4	(540)	l	29 1/2	(749)
m	68 1/8	(1730)	n	67 3/4	(1721)
o	46	(1168)	p	3	(76)
q	31	(787)	r	18 1/2	(470)
s	15 1/2	(394)	t	75	(1905)

Wheel Center Height Front 14 3/4 (375)

Wheel Center Height Rear 15 (381)

Wheel Well Clearance (F) 35 1/2 (902)

Wheel Well Clearance (R) 38 1/4 (972)

Frame Height (F) 17 (432)

Frame Height (R) 25 (635)

Engine Type 8 cyl. Gas

Engine Size 4.7L

Transmition Type:

[✓ Automatic] Manual

FWD [✓ RWD] 4WD

Mass Distribution lb (kg)

Gross Static	LF	1481 (672)	RF	1397 (634)
	LR	1152 (523)	RR	1119 (508)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2852 (1294)	2773 (1258)	2878 (1305)
W-rear	2267 (1028)	2206 (1001)	2271 (1030)
W-total	5119 (2322)	4979 (2258)	5149 (2336)

GVWR Ratings

Front 3650

Rear 3900

Total 5119

Dummy Data

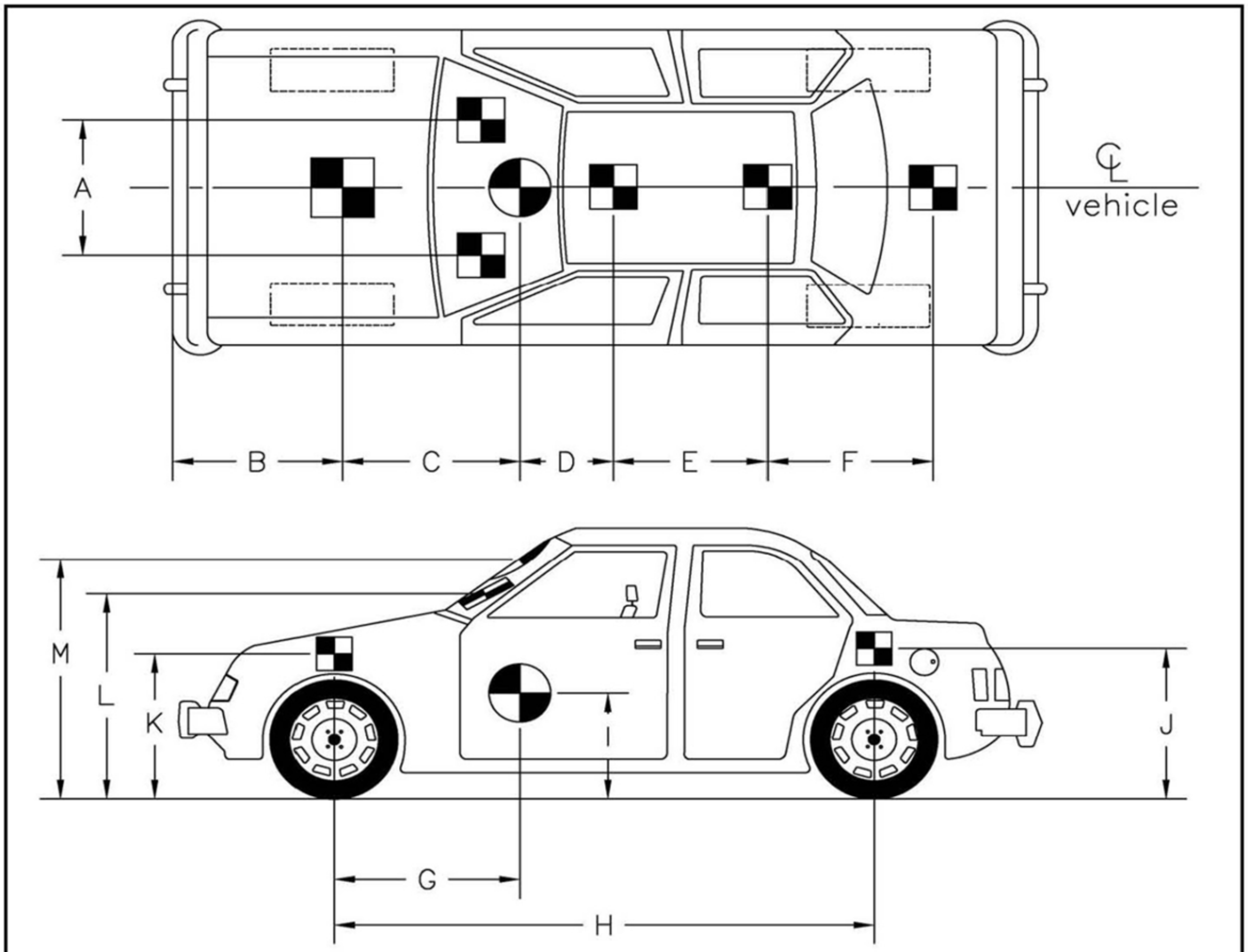
Type: Hybrid II

Mass: 170 lbs

Seat Position: driver

Note any damage prior to test: Repair from WZ testing.

Figure 31. Vehicle Dimensions, Test No. 4CMB-5

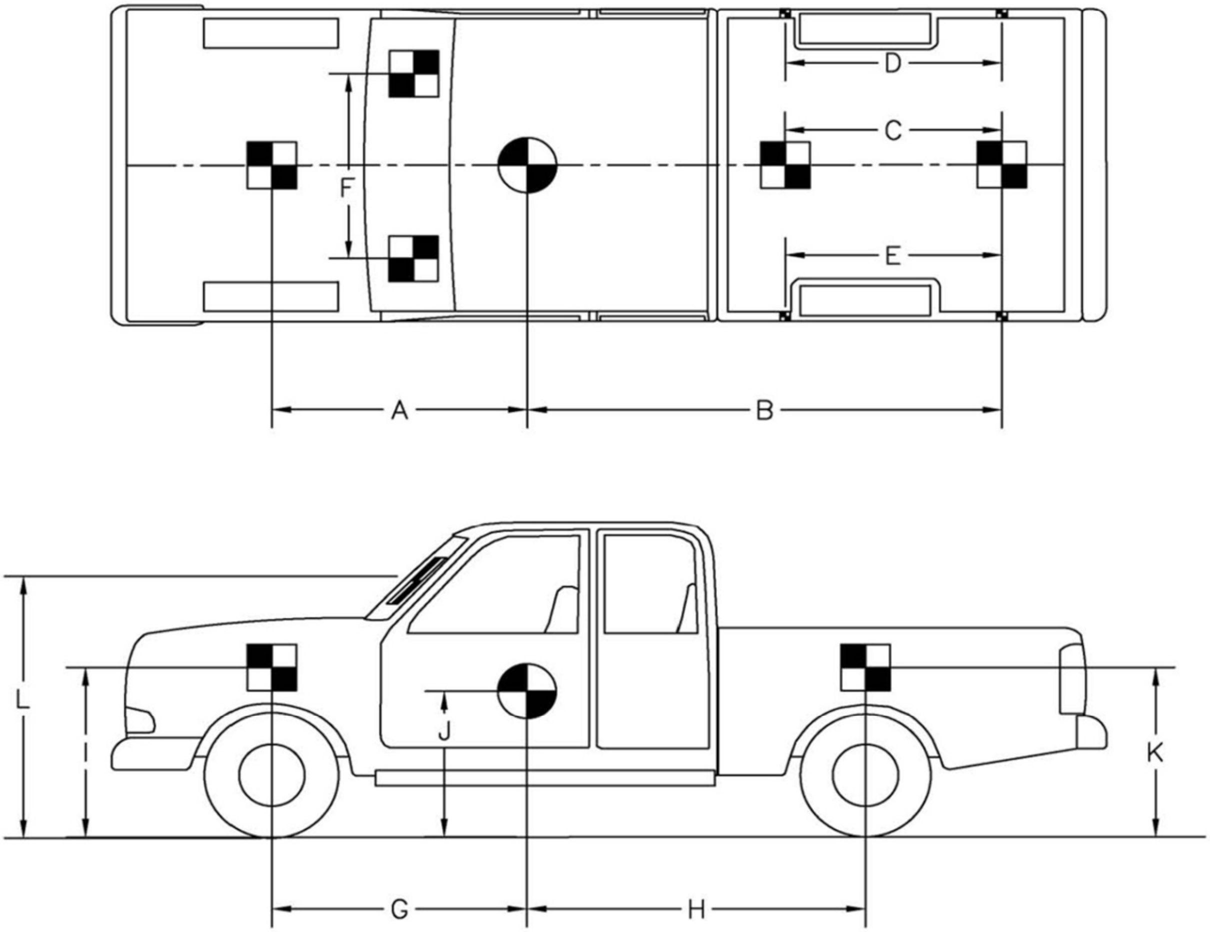


TEST #: 4CMB-4

TARGET GEOMETRY-- in. (mm)

A	33.375	(848)	E	31.625	(803)	I	17	(432)
B	28.125	(714)	F	33.375	(848)	J	28.25	(718)
C	42	(1067)	G	36.5	(927)	K	28	(711)
D	20.25	(514)	H	95.5	(2426)	L	43.25	(1099)
						M	52	(1321)

Figure 32. Target Geometry, Test No. 4CMB-4



TEST #: 4CMB-5

TARGET GEOMETRY-- in. (mm)

A	71 3/8	(1813)	E	37 1/8	(943)	I	40 1/4	(1022)
B	98 3/8	(2499)	F	35 3/4	(908)	J	28	(711)
C	37 1/4	(946)	G	62	(1575)	K	42 1/2	(1080)
D	37 1/2	(953)	H	78 1/4	(1988)	L	60 3/4	(1543)

Figure 33. Target Geometry, Test No. 4CMB-5

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 the vehicles could be brought safely to a stop after the test.

4.4 Simulated Occupant

For test nos. 4CMB-4 and 4CMB-5, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the left-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 170 lb (77 kg), was represented by 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 vehicle c.g. location.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All of the accelerometers were mounted near the center of gravity of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE class 180 Butterworth filter conforming to the SAE J211/1 specifications [11].

The first accelerometer system was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. An additional accelerometer was used to measure the longitudinal acceleration independently at the same sample rate. The accelerometers were configured and controlled using a system developed and manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module

(SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The second system, Model EDR-3, was a triaxial piezoresistive accelerometer system manufactured by IST of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM, a range of ±200 g's, a sample rate of 3,200 Hz, and a 1,120 Hz low-pass filter. The "DynaMax 1 (DM-1)" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

An angle rate sensor, the ARS-1500, with a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of rotation of the test vehicles. The angular rate sensor was mounted on an aluminum block inside the test vehicle near the center of gravity and recorded data at 10,000 Hz to the SIM. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

A second system, an Analog Systems 3-axis rate transducer with a range of 1,200 degrees/sec in each of the three directions (roll, pitch, and yaw), was used to measure the rates of motion of the test vehicles. The rate transducer was mounted inside the body of the EDR-4 6DOF-500/1200 and recorded data at 10,000 Hz to a second data acquisition board inside the EDR-4 6DOF-500/1200 housing. The raw data measurements were then downloaded, converted to the appropriate Euler angles for analysis, and plotted. The “EDR4COM” and “DynaMax Suite” computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate transducer data.

4.5.3 Pressure Tape Switches

For test nos. 4CMB-4 and 4CMB-5, five pressure-activated tape switches, spaced at approximately 6.6-ft (2-m) intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the right-front tire of the test vehicle passed over it. Test vehicle speeds were determined from electronic timing mark data recorded using TestPoint and LabVIEW computer software programs. Strobe lights and high-speed video analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

4.5.4 Digital Cameras

Three AOS VITcam high-speed digital video cameras, three AOS X-PRI high-speed digital video cameras, four JVC digital video cameras, and one Canon digital video camera were utilized to film test no. 4CMB-4. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 34.

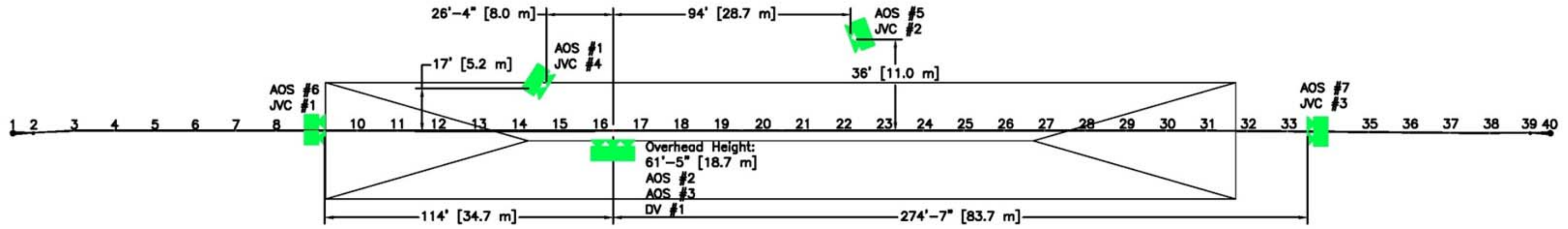
Four AOS VITcam high-speed digital video cameras, three AOS X-PRI high-speed digital video cameras, four JVC digital video cameras, and one Canon digital video camera were utilized to film test no. 4CMB-5. AOS#1 did not trigger and JVC#2 was not powered on. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 35.

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.

4.5.5 Load Cells

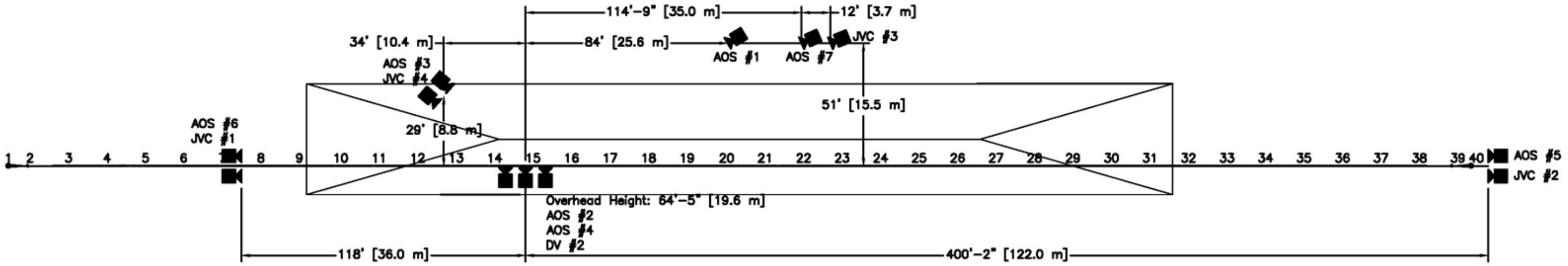
A load cell were installed in line with each of the four cables toward the upstream end of the barrier system for test nos. 4CMB-4 and 4CMB-5. Two additional load cells were installed in line with the top two cables toward the upstream end of the four-cable barrier system for test no. 4CMB-5.

The load cells were manufactured by Transducer Techniques and conformed to model no. TLL-50K with a load range up to 50,000 lb (222.4 kN). During testing, output voltage signals were sent from the load cells to a Keithly Metrabyte DAS-1802HC data acquisition board, acquired with Test Point software, and stored permanently on a personal computer. The data collection rate for the load cells was 10,000 samples per second (10,000 Hz).



	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	AOS Vitcam CTM	500	Fujinon 50 mm fixed	-
	2	AOS Vitcam CTM	500	Kowa 8 mm fixed	-
	3	AOS Vitcam CTM	500	Computar 6.5 mm fixed	-
	5	AOS X-PRI Gigabit	500	Sigma 24-70 mm	24
	6	AOS X-PRI Gigabit	500	Nikon 50 mm fixed	-
	7	AOS X-PRI Gigabit	500	TV Zoom 17-102	75
Digital Video	1	JVC – GZ-MC500 (Everio)	29.97		
	2	JVC – GZ-MG27u (Everio)	29.97		
	3	JVC – GZ-MG27u (Everio)	29.97		
	4	JVC – GZ-MG27u (Everio)	29.97		
	1	Canon ZR90	29.97		

Figure 34. Camera Locations, Speeds, and Lens Settings, Test No. 4CMB-4



	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	AOS Vitcam CTM	500	Cosmicar 12.5 mm fixed	-
	2	AOS Vitcam CTM	500	8 mm fixed	-
	3	AOS Vitcam CTM	500	Sigma 24-70	24
	4	AOS Vitcam CTM	500	Cosmicar 12.5 mm fixed	-
	5	AOS X-PRI Gigabit	500	Sigma 24-135	135
	6	AOS X-PRI Gigabit	500	Sigma 50 fixed	-
	7	AOS X-PRI Gigabit	500	Computar 12.5 mm fixed	-
Digital Video	1	JVC – GZ-MC500 (Everio)	29.97		
	2	JVC – GZ-MG27u (Everio)	29.97		
	3	JVC – GZ-MG27u (Everio)	29.97		
	4	JVC – GZ-MG27u (Everio)	29.97		
	2	Canon ZR10	29.97		

Figure 35. Camera Locations, Speeds, and Lens Settings, Test No. 4CMB-5

5 FULL-SCALE CRASH TEST NO. 4CMB-4

5.1 Static Soil Test

Before full-scale crash test no. 4CMB-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 Test No. 4CMB-4

Test no. 4CMB-4 was a repeat of test no. 4CMB-3 with redesigned cable-to-post attachments. The 2,574-lb (1,168-kg) passenger car impacted the four cable median barrier 4 ft (1.2 m) laterally up from the bottom of the ditch on the backslope at a speed of 61.1 mph (98.4 km/h). The passenger car entered the slope at an angle of 25.8 degrees and impacted the barrier at an angle of 25.7 degrees. A summary of the test results and sequential photographs are shown in Figure 36. Additional sequential photographs are shown in Figures 37 through 39.

5.3 Weather Conditions

Test no. 4CMB-4 was conducted on December 22, 2010 at approximately 4:00 pm. 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. 4CMB-4

Temperature	28° F
Humidity	69 %
Wind Speed	8 mph
Wind Direction	30° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.07 in.

5.4 Test Description

Initial vehicle impact was to occur 5 ft – 4 in. (1.6 m) downstream of post no. 16, as shown in Figure 40, which was selected using an analysis of the vehicle trajectory over the slope to maximize the potential for vehicle underride. The actual point of impact was 5 ft – 4in. (1.6 m) downstream of post no. 16. A sequential description of the impact events is contained in Table 5. The cables were numbered from 1 to 4, from the top to bottom, respectively. The vehicle came to rest parallel to the system captured in the cables 85 ft – 8 in. (26.1 m) downstream and 4 ft – 4 in. (1.3 m) to the left of the initial impact. The vehicle trajectory and final position are shown in Figures 36 and 41.

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

TIME (sec)	EVENT
-0.740	Vehicle entered the slope.
-0.622	Vehicle rolled toward the system.
-0.496	Vehicle became airborne.
-0.084	Front bumper contacted ground.
-0.070	Vehicle rolled away from the system, and right-front tire contacted ground.
-0.028	Right-rear tire contacted ground.
-0.014	Left-front window shattered due to bumper impact with ground.
0.000	Left-front fender impacted cable 4.
0.002	Left-front tire impacted cable 4.
0.008	Left-front quarter panel and hood contacted cable 3.
0.026	Post no. 17 deflected laterally backward.
0.042	Left mirror and A-pillar contacted cable 2.
0.050	Left mirror disengaged.
0.060	Post no. 16 deflected laterally backward, and the vehicle yawed away from the system.
0.068	Left A-pillar contacted cable 1.
0.070	Post no. 16 cable clip 4 released.
0.092	Vehicle deflected post no. 17 downstream, and the bumper disengaged.
0.100	Post no. 18 deflected laterally backward, and post no. 15 cable clip 4 released.
0.104	Post no. 18 cable clip 4 released.

0.112	Post no. 18 cable clip 3 released.
0.134	Post no. 18 cable clip 2 released.
0.138	Post no. 19 deflected laterally backward, and post no. 16 cable clip 3 released.
0.140	Post no. 14 cable clip 4 released.
0.148	Post no. 19 cable clip 3 released.
0.158	Cable 1 passed over roof of vehicle.
0.172	Left headlight disengaged.
0.208	Post no. 16 cable clip 2 released.
0.226	Cables 2 and 3 passed over roof of vehicle.
0.360	Post no. 19 cable clip 4 released.
0.392	Post no. 13 cable clip 4 released.
0.468	Vehicle became parallel to system.
0.562	Post no. 20 cable clip 4 released.
0.608	Post no. 21 cable clip 4 released.
0.640	Post no. 22 cable clip 4 released.
0.668	Post no. 23 cable clip 4 released.
0.672	Vehicle deflected post no. 19 downstream.
0.980	Vehicle deflected post no. 20 downstream.
1.426	Vehicle deflected post no. 21 downstream.
1.940	Vehicle ceased movement downstream.

5.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 42 through 44. Barrier damage consisted of deflected posts and disengaged cables and keyway bolts. At its final resting position, the vehicle was still in contact with the cables; having cable no. 4 on the impact side and the remaining three cables on the non-impact side.

Cable no. 1 disengaged from post nos. 17, 19 through 21, and 33 when the keyway bolts bent and/or fractured. Cable no. 2 disengaged from post nos. 16 through 21. Cable no. 3 disengaged from post nos. 16 through 21. Cable no. 4 disengaged from post nos. 12 through 23.

Post no. 16 was bent backward and cable no. 2 had wrapped around the top of the post and was resting on the cable no. 1 keyway bolt located on the front side of the post. Post no. 17 was bent backward and downstream and also twisted to face downstream. The cable no. 4 keyway slot at post no. 17 was torn, and contact marks occurred at the top of the post on the upstream side of the flanges. Post no. 18 was bent backward slightly, and contact marks and gouging were found near the top of the post on the front side. Post no. 19 was bent downstream, and both flanges were dented at the location of cable no. 4. Post no. 20 was bent downstream and twisted to face downstream. The cable no. 4 keyway slot at post no. 20 was torn, and contact marks were found on the upstream side of the back flange near the top of the post. Post no. 21 was bent downstream with the right-rear wheel of the vehicle was resting on the post. Contact marks were found on the upstream side of both flanges extending the entire height of the post, and cable nos. 3 and 4 keyway slots were deformed. Post no. 22 was bent forward, and a ¾ in. (19 mm) soil gape was found on the back side of the post. Post no. 24 was deflected backward, and a ⅞ in. (22 mm) soil gap was found on the front side of the post.

The maximum lateral permanent set post deflections were not calculated for this test. The maximum lateral dynamic post deflection was 14.8 in. (376 mm) at post no. 18, and the maximum lateral dynamic cable deflection was approximately 78 in. (1981 mm) as determined from high-speed digital video analysis. The working width of the system was found to be 84.1 in. (2,136 mm), also determined from high-speed digital video analysis.

5.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 45 through 48. 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 and the corresponding locations are provided in Appendix D.

Table 6. Maximum Occupant Compartment Deformations by Location, Test No. 4CMB-4

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	¾ (19)	≤ 9 (229)
Floor Pan & Transmission Tunnel	¼ (6)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	½ (13)	≤ 12 (305)
Side Door (Above Seat)	¼ (6)	≤ 9 (229)
Side Door (Below Seat)	0	≤ 12 (305)
Roof	2⅞ (73)	≤ 4 (102)
Windshield	0	≤ 3 (76)

Damage occurred to all sides of the vehicle. The vehicle came to rest in the middle of the system with cable 4 against the left side of the vehicle and cables 1, 2, and 3 against the right side of the vehicle. The right-rear tire came to rest on top of post no. 21. The front bumper cover disengaged on the backslope. Both headlights disengaged near the bottom of the ditch. The left-front fender was dented inward approximately 7 in. (178 mm). The left-front tire was torn on the inner and outer sidewalls. A 5-in. (127-mm) long gouge was found in the left-front rim. The left tie-rod was bent. Cable contact marks extended the length of the vehicle on both the left and right sides. Both side mirrors were disengaged. Denting from the cables occurred on the left side of the hood and left A-pillar. The left 4 in. (102 mm) of the windshield had moderate spiderweb cracking. Gouges were found on the left-rear rim. Folding and denting occurred in the right C-pillar. Both front side windows were shattered. Cable contact marks were found on the right-rear side window. A 7-in. (178-mm) gouge was located below the right-front door 17 in. (432-mm) behind the right-front wheel well. Denting occurred at the center of the front and center of the back of the roof. Denting occurred in the gear box of the transmission and fluid was leaking from it. The vertical bumper horn was torn. A hole was also found in the spare tire storage floorboard.

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 summarized in Figure 36. 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. 4CMB-4

Evaluation Criteria		**Transducer**			**MASH Limits**
		EDR-3	**DTS Set#1**	**DTS Set#2**	
OIV ft/s (m/s)	Longitudinal	-21.00 (-6.40)	-21.59 (-6.58)	-21.22 (-6.47)	≤ 40 (12.2)
	Lateral	10.59 (3.23)	10.40 (3.17)	-	≤40 (12.2)
ORA g's	Longitudinal	-7.82	-6.40	-6.38	≤ 20.49
	Lateral	4.20	-6.31	-	≤ 20.49
THIV ft/s (m/s)		-	22.90 (6.98)	-	not required
PHD g's		-	6.89	-	not required
ASI		0.81	0.73	-	not required

5.8 Load Cell Results

As previously discussed, tension load cells were installed inline with the cables at the upstream end of the barrier system in order to monitor the total load transferred to the anchor with respect to time. The load cell results are summarized in Table 8. The individual cable loads, along with the total combined cable load imparted to the upstream end anchor, were determined and are shown graphically in Figure 49.

As noted previously, the target cable tension was 4,213 lb (18.7 kN) at 100 deg Fahrenheit (37.8 deg Celsius). Prior to the testing, the actual cable tension in the top, upper middle, lower middle, and bottom cables was 4.37 kips (19.42 kN), 4.43 kips (19.70 kN), 4.40 kips (19.55 kN), and 4.45 kips (19.79 kN), respectively. These readings were measured using the cable load cells.

Table 8. Load Cell Results, Test No. 4CMB-4

Cable Location	Sensor Location	Maximum Cable Load		Time[1] (sec)
		kips	kN	
Combined Cables	Upstream End	28.48	126.69	0.192
Top Cable	Upstream End	6.34	28.21	0.260
Upper Middle Cable	Upstream End	6.26	27.83	0.260
Lower Middle Cable	Upstream End	7.80	34.68	0.191
Bottom Cable	Upstream End	9.29	41.34	0.192

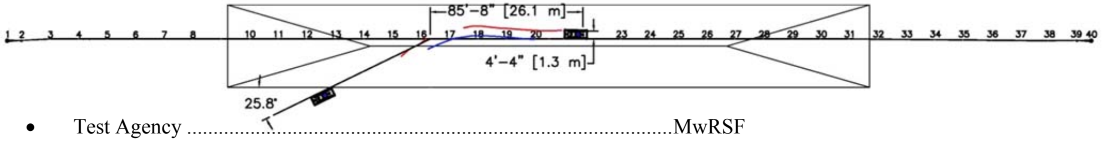
[1] - Time determined from initial vehicle impact with the barrier system.

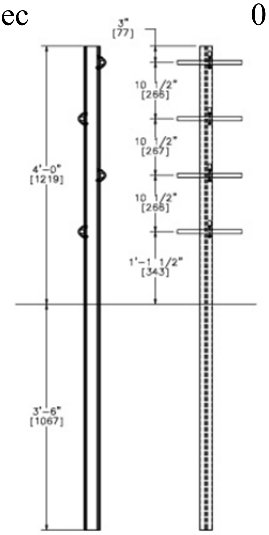
After the crash test, the tension in each cable was measured using the cable load cells. The cable tension at the upstream end and in the top, upper middle, lower middle, and bottom cables was 4.53 kips (20.15 kN), 4.54 kips (20.20 kN), 4.85 kips (21.57 kN), and 4.87 kips (21.67 kN), respectively.

5.9 Discussion

The analysis of the test results for test no. 4CMB-4 showed that the four cable median barrier 4 ft (1.2 m) from the bottom of the ditch on the backslope adequately contained the 1100C vehicle with controlled lateral displacements of the barrier. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor 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 nor under ride the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle did not exit the barrier, thus its trajectory did not violate the bounds of the exit box. Therefore, test no. 4CMB-4 conducted on the four cable median barrier was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-10.

0.000 sec 0.092 sec 0.292 sec 0.468 sec 0.668 sec





- Test Agency .... MwRSF
- Test Number 4CMB-4
- Date 12/22/2010
- MASH Test Designation 3-10
- Test Article .... Four Cable Median Barrier
- Total Length .... 608 ft (185 m)
- Key Component – Wire Rope
  - Diameter .... ¾ in. (19 mm)
  - Specification 3x7
  - Top Cable Height .... 45 in. (1,143 mm)
  - Bottom Cable Height .... 13½ in. (343 mm)
  - Incremental Spacing .... 10½ in. (267 mm)
- Key Component – Post Nos. 3-38
  - Length .... 90 in. (2,286 mm)
  - Shape S3x5.7 (S76x8.5)
  - Spacing .... 16 ft (4.9 m)
- Soil Type .... Grading B AASHTO M147-65 (1990)
- Vehicle Make /Model .... 2002 Kia Rio Sedan
  - Curb .... 2,377 lb (1,078 kg)
  - Test Inertial .... 2,404 lb (1,090 kg)
  - Gross Static .... 2,574 lb (1,168 kg)
- Impact Conditions
  - Speed .... 61.1 mph (98.4 km/h)
  - Angle Entered Slope .... 25.8 deg
  - Angle Impacted Barrier .... 25.7 deg
  - Impact Location .... 5 ft – 4 in. (1.6 m) downstream of post no. 16
- Exit Conditions
  - Speed .... N/A
  - Angle .... N/A
- Exit Box Criterion .... N/A
- Vehicle Stability .... Acceptable
- Vehicle Stopping Distance .... 85 ft – 8 in. (26.1 m) downstream of impact
  4 ft – 4in. (1.3 m) to the left of impact
- Vehicle Damage .... Moderate
  - VDS[14] .... 11-LD-3 and 01-RD-3
  - CDC[15] .... 11LFES2 and 01RFES2
  - Maximum Interior Deformation .... 2⅞ in. (73 mm)
- Test Article Damage .... Moderate
- MaximumTest Article Deflections
  - Permanent Set .... N/A
  - Dynamic (Cable) .... 78 in. (1,981 mm)
  - Working Width .... 84.1 in. (2,136 mm)
- Maximum Angular Displacements [DTS]
  - Roll .... 24.07 ° < 75°
  - Pitch .... 10.05 ° < 75°
  - Yaw .... 33.84 °
- Impact Severity (IS).... 57.9 kip-ft (77.1 kJ) > 51 kip-ft (69.7 kJ) limit from MASH
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		EDR-3	DTS Set#1	DTS Set#2	
OIV ft/s (m/s)	Longitudinal	-21.00 (-6.40)	-21.59 (-6.58)	-21.22 (-6.47)	≤ 40 (12.2)
	Lateral	10.59 (3.23)	10.40 (3.17)	-	≤ 40 (12.2)
ORA g's	Longitudinal	-7.82	-6.40	-6.38	≤ 20.49
	Lateral	4.20	-6.31	-	≤ 20.49
THIV – ft/s (m/s)		-	22.90 (6.98)	-	Not required
PHD – g's		-	6.89	-	Not required
ASI		0.81	0.73	-	Not required

Figure 36. Summary of Test Results and Sequential Photographs, Test No. 4CMB-4


0.000 sec


0.038 sec


0.066 sec


0.134 sec


0.204 sec


0.322 sec


-0.622 sec


0.000 sec

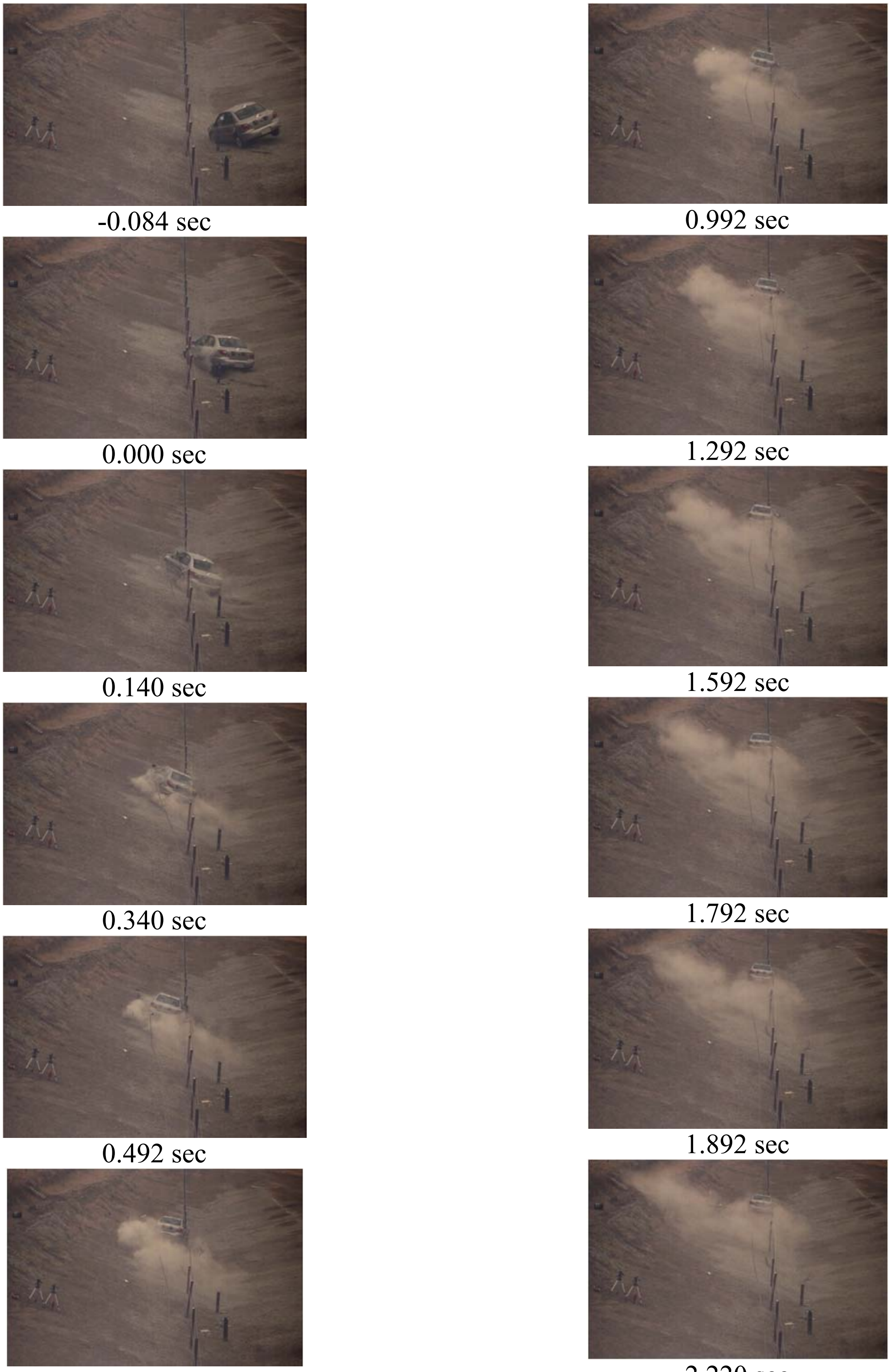

0.272 sec


0.472 sec


0.672 sec


0.972 sec

Figure 37. Additional Sequential Photographs, Test No. 4CMB-4



-0.084 sec

0.000 sec

0.140 sec

0.340 sec

0.492 sec

0.792 sec

0.992 sec

1.292 sec

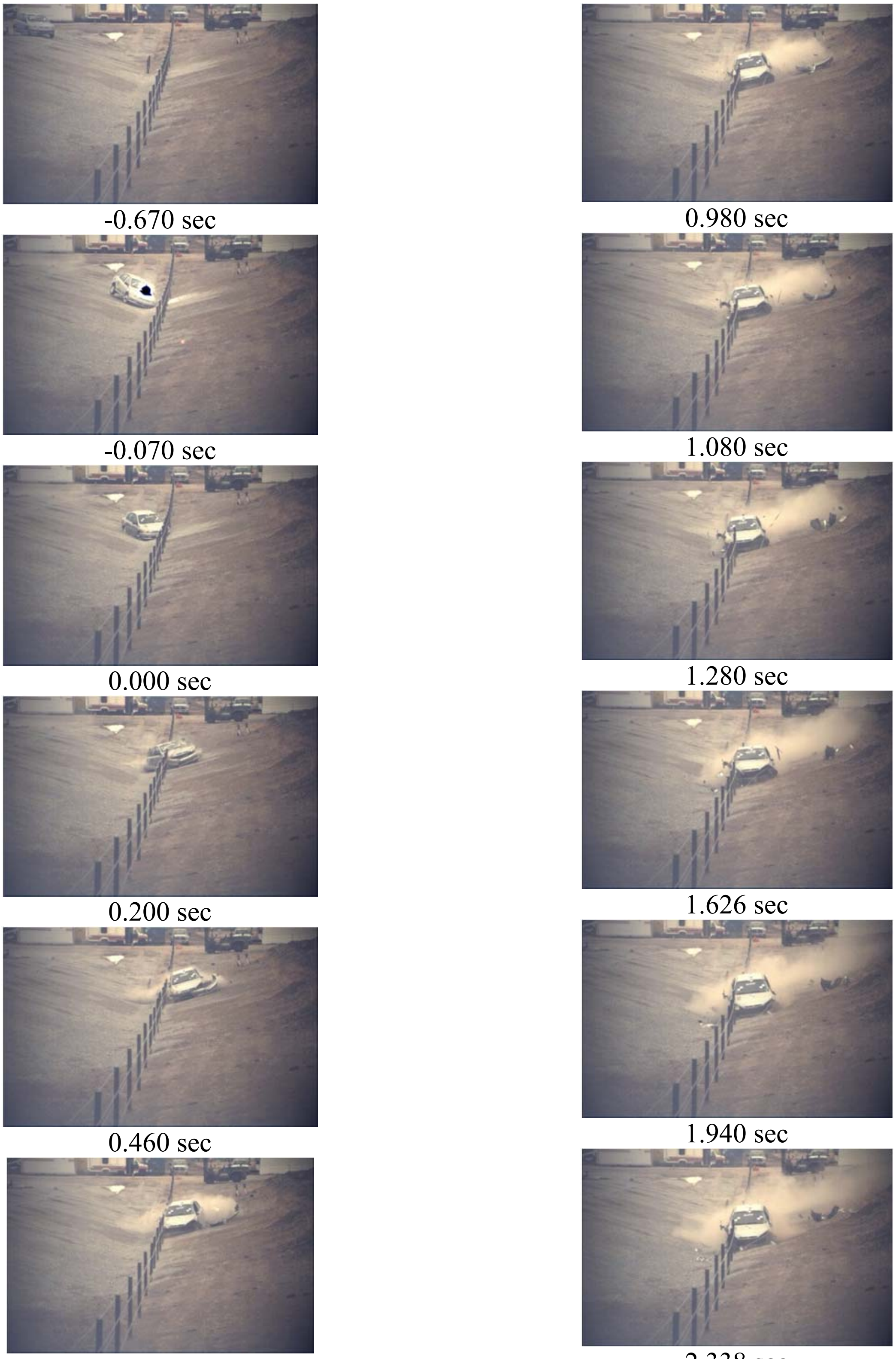
1.592 sec

1.792 sec

1.892 sec

2.220 sec

Figure 38. Additional Sequential Photographs, Test No. 4CMB-4



-0.670 sec

-0.070 sec

0.000 sec

0.200 sec

0.460 sec

0.768 sec

0.980 sec

1.080 sec

1.280 sec

1.626 sec

1.940 sec

2.338 sec

Figure 39. Additional Sequential Photographs, Test No. 4CMB-4

Figure 40. Impact Location, Test No. 4CMB-4

Figure 41. Vehicle Final Position and Trajectory Marks, Test No. 4CMB-4

Figure 42. System Damage, Test No. 4CMB-4

Figure 43. Post and Keyway Bolt Damage, Test No. 4CMB-4

Figure 44. Post and Keyway Bolt Damage, Test No. 4CMB-4

Figure 45. Vehicle Damage, Test No. 4CMB-4

Figure 46. Vehicle Damage, Test No. 4CMB-4

Figure 47. Undercarriage Damage, Test No. 4CMB-4

Figure 48. Occupant Compartment Damage, Test No. 4CMB-4

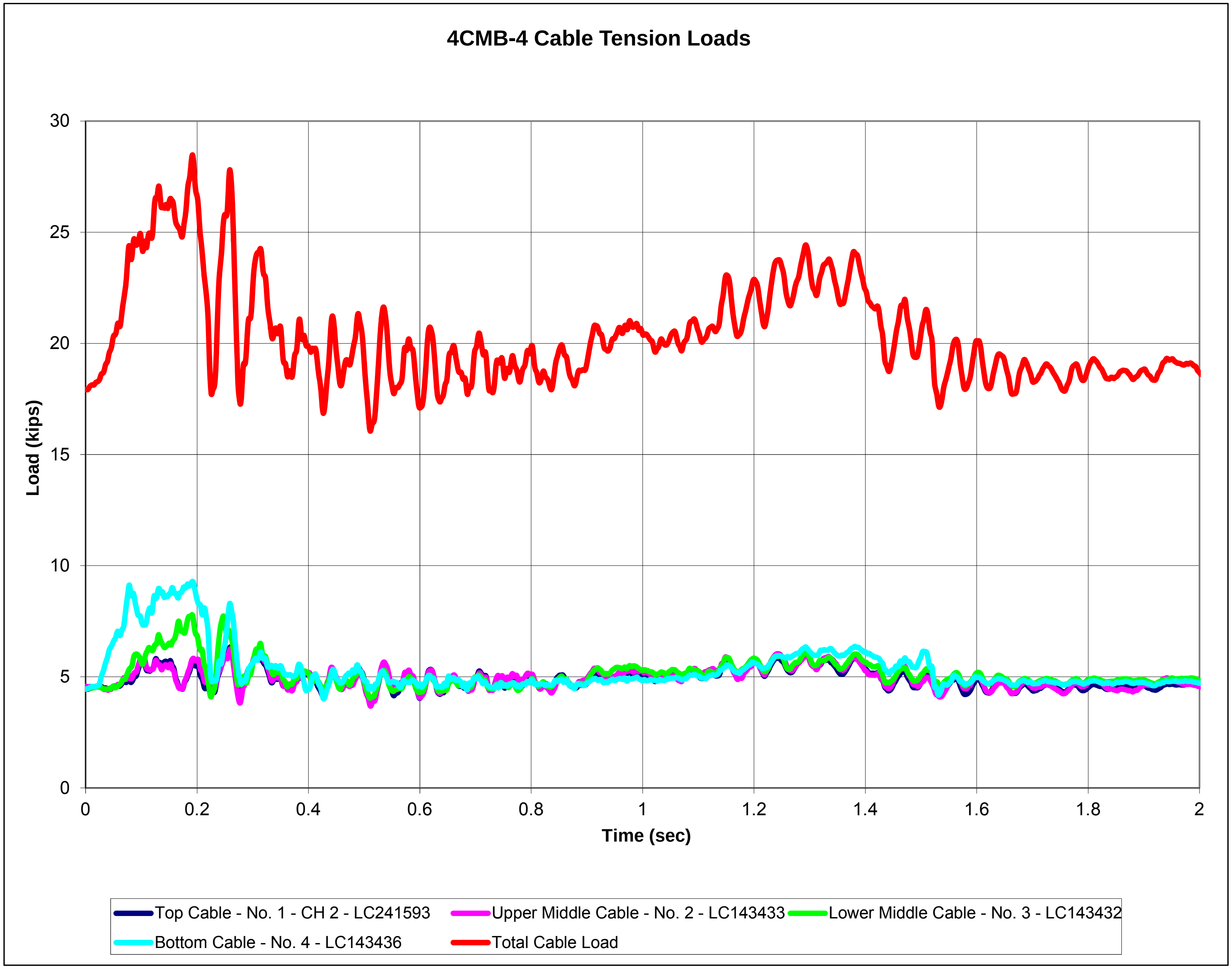
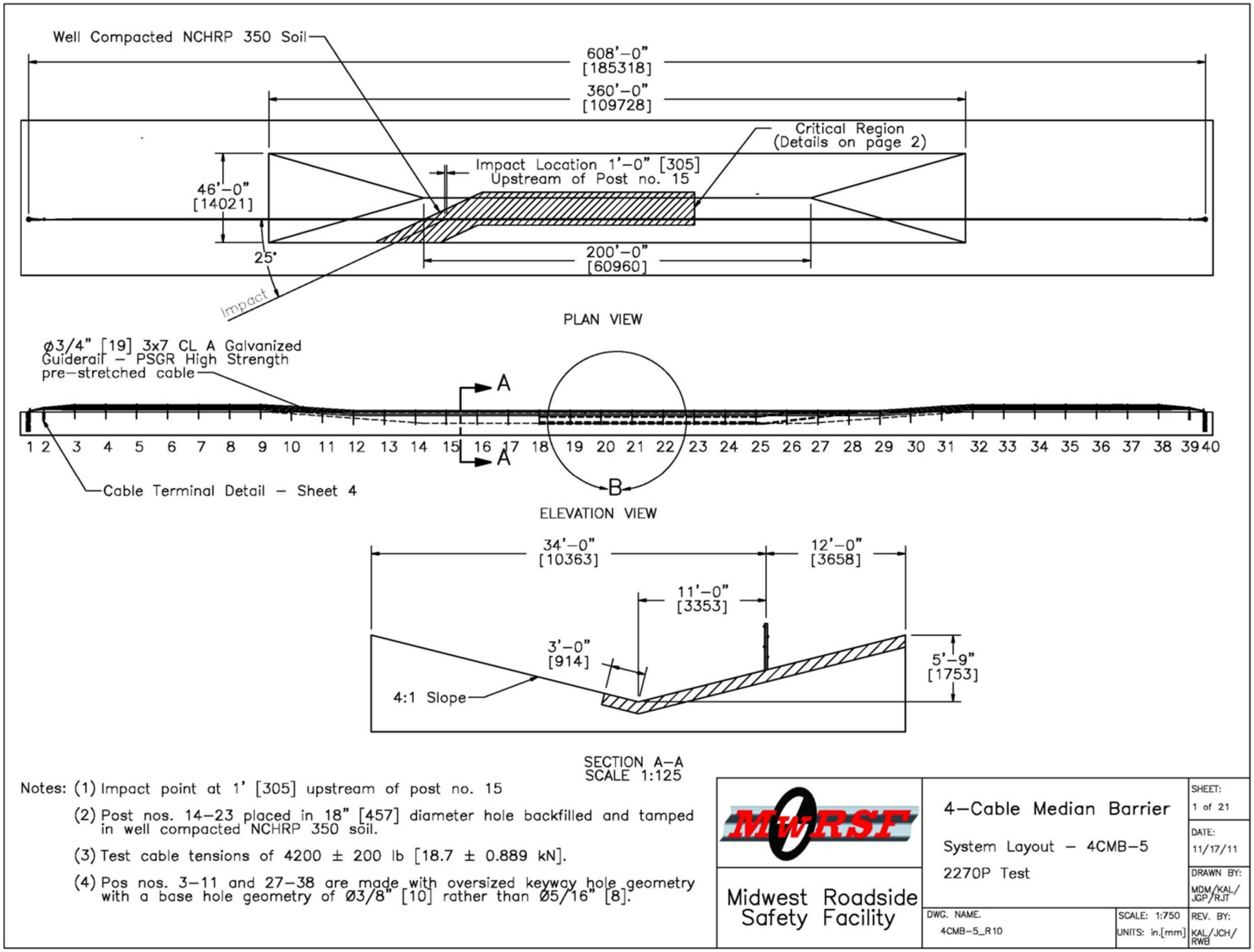


Figure 49. Cable Tension vs. Time, Test No. 4CMB-4

6 DESIGN DETAILS TEST NO. 4CMB-5

The barrier system test installation was comprised of four, high-tension cables in a depressed median, as shown in Figures 50 through 70. Photographs of the test installation are shown in Figures 71 and 72. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The system design for test no. 4CMB-5 was the same as the design for 4CMB-4, with some minor modifications and a different location in the V-ditch. The barrier was constructed 12 ft (3.7 m) laterally down from slope break point on the foreslope. The top and lower middle cables were attached to the impact side of each post, and the upper middle and lower cables were attached to the non-impact side of each post. The plastic barrels that were located around posts in test no. 4CMB-4 were not utilized for test no. 4CMB-5 due to drier conditions and warmer temperatures.



Notes: (1) Impact point at 1' [305] upstream of post no. 15

(2) Post nos. 14–23 placed in 18" [457] diameter hole backfilled and tamped in well compacted NCHRP 350 soil.

(3) Test cable tensions of 4200 ± 200 lb [18.7 ± 0.889 kN].

(4) Pos nos. 3–11 and 27–38 are made with oversized keyway hole geometry with a base hole geometry of Ø3/8" [10] rather than Ø5/16" [8].

Figure 50. Test Installation Layout, Test No. 4CMB-5

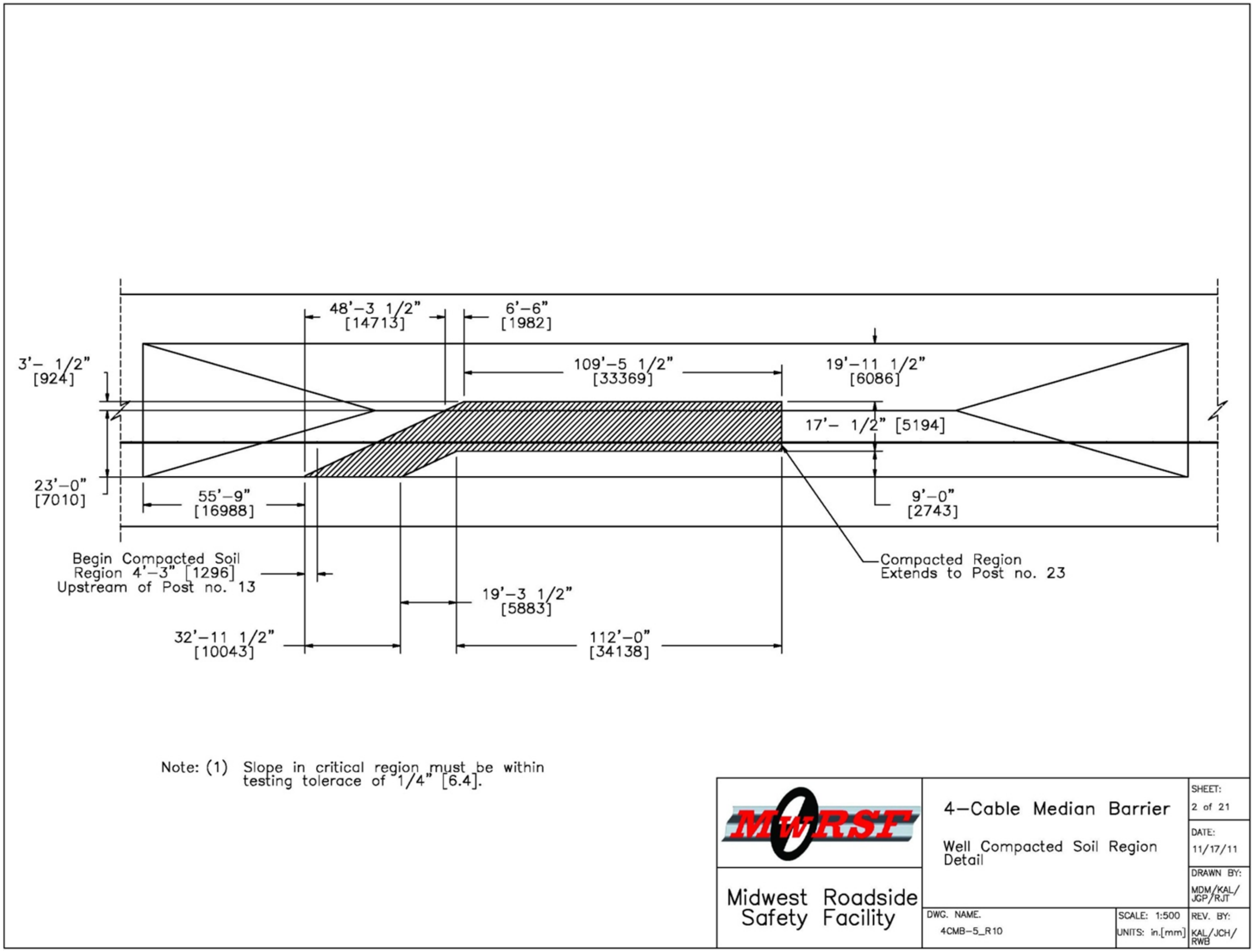


Figure 51. Soil Compaction Layout, Test No. 4CMB-5

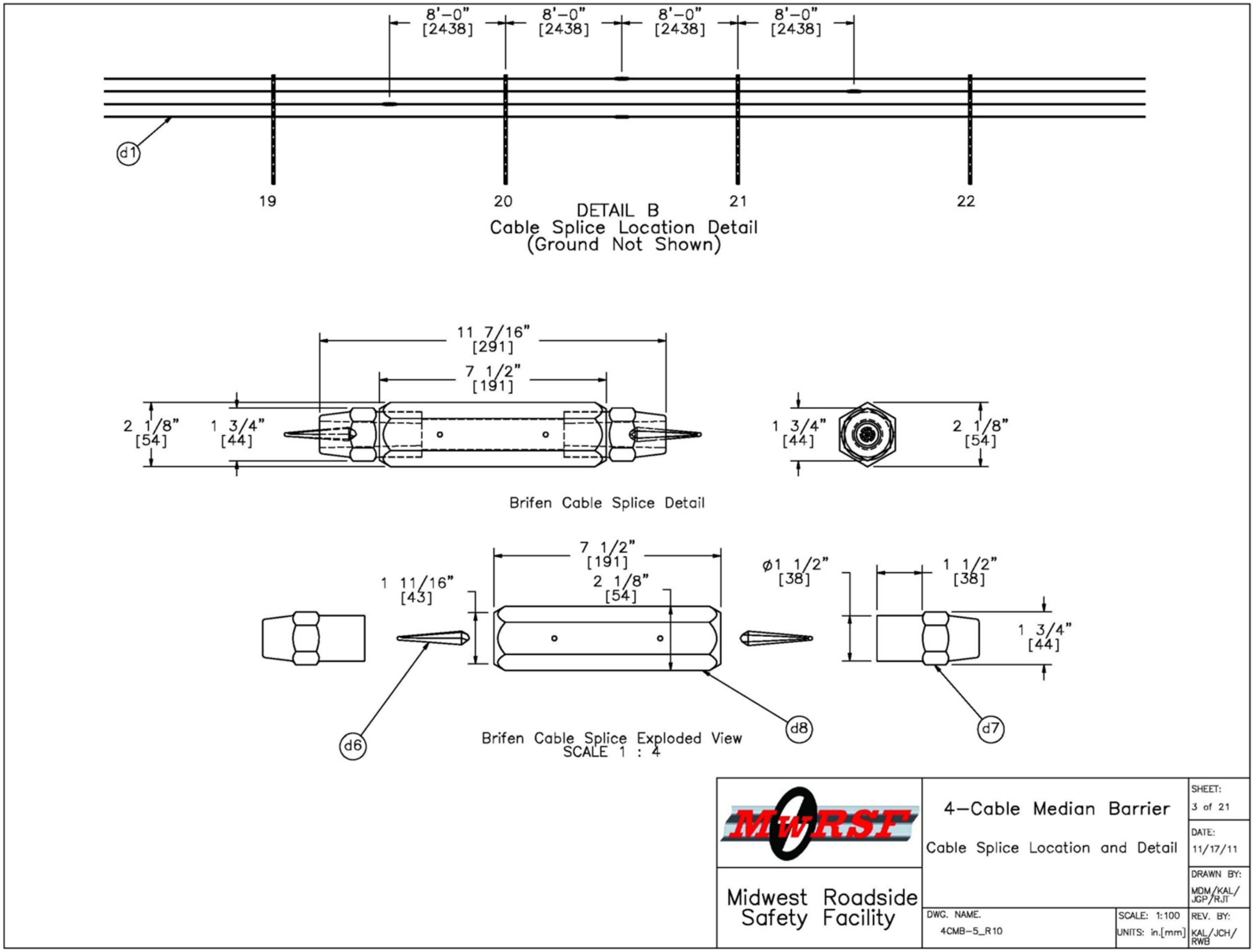


Figure 52. Cable Splice Layout, Test No. 4CMB-5

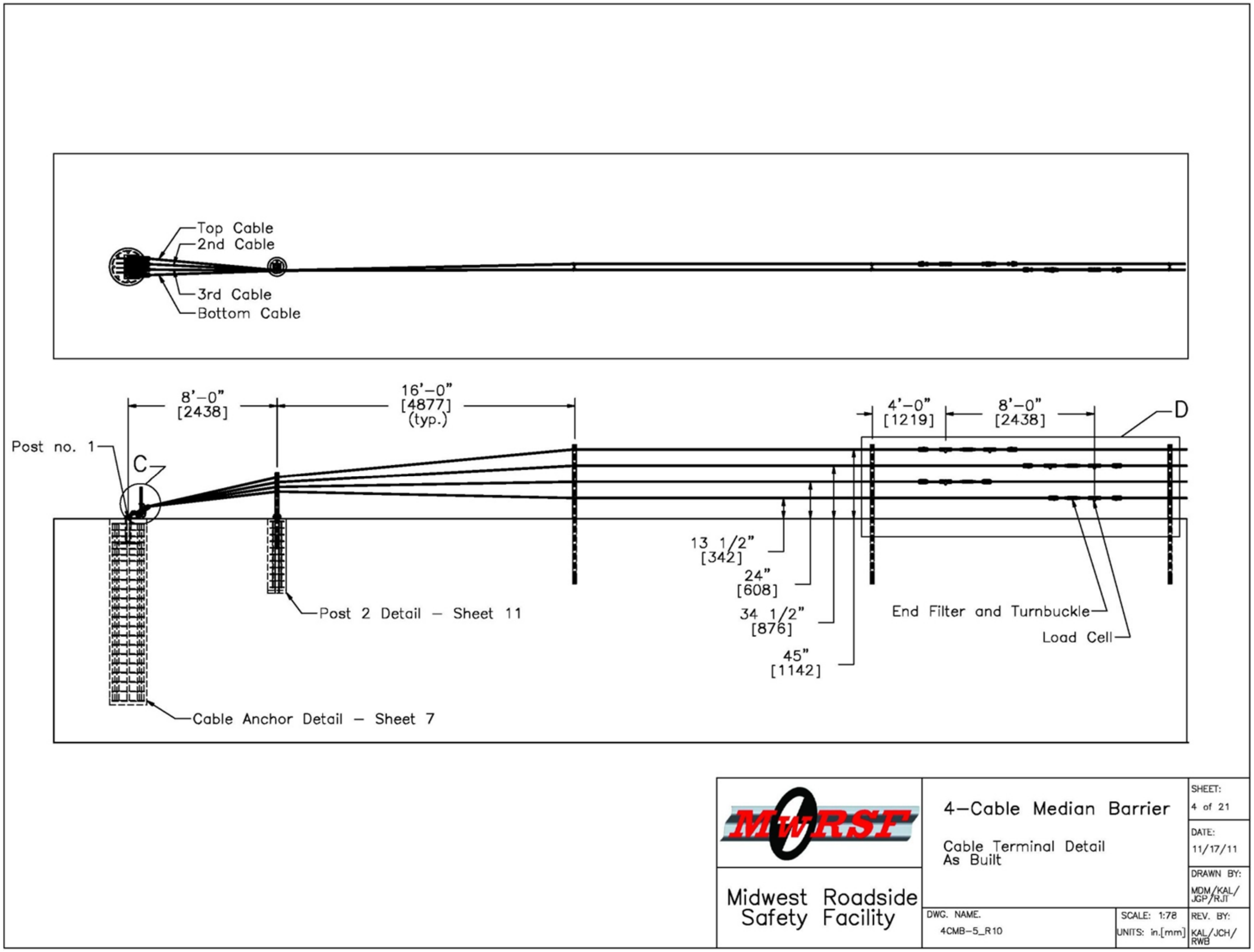


Figure 53. Cable Terminal Layout, Test No. 4CMB-5

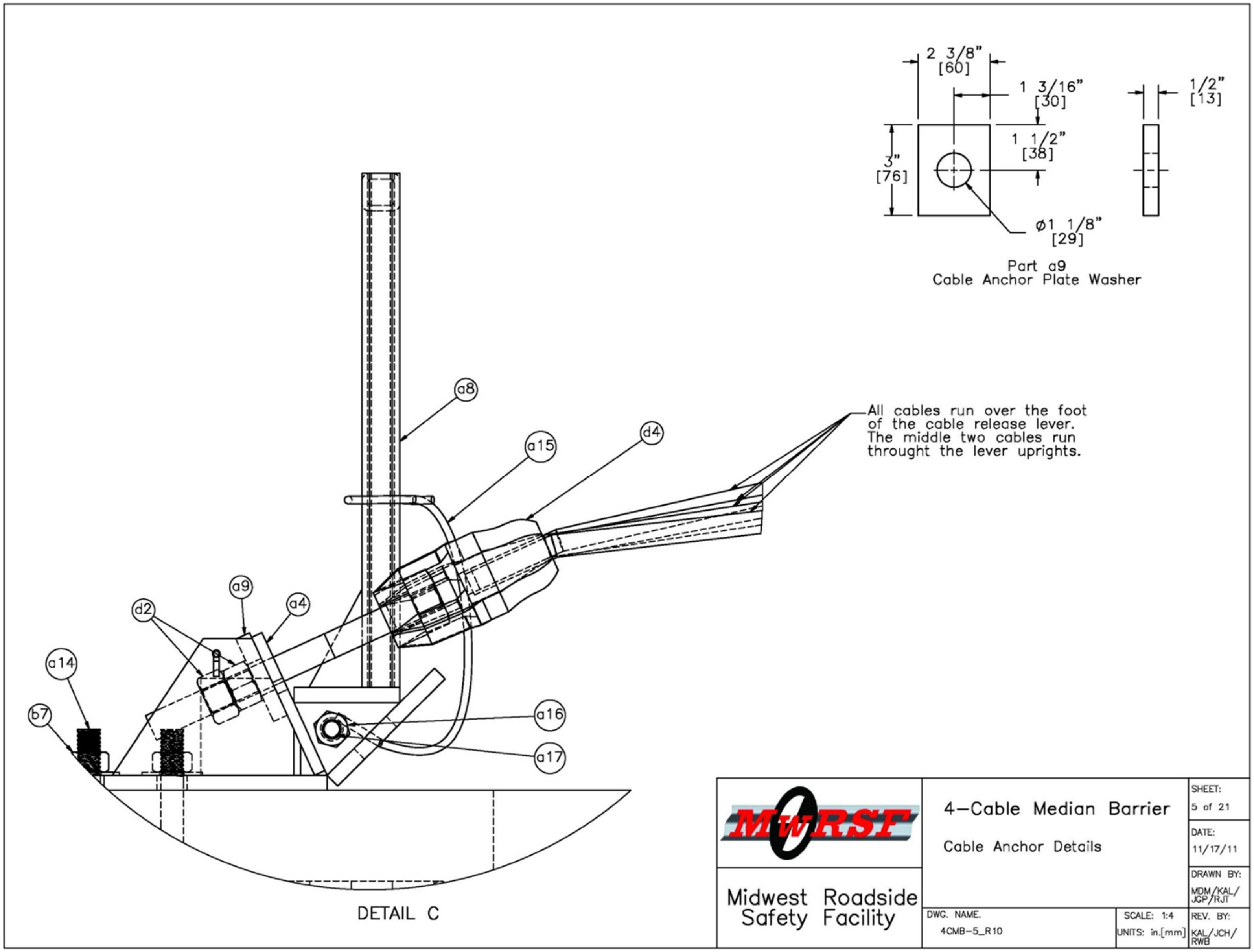


Figure 54. Anchor Details, Test No. 4CMB-5

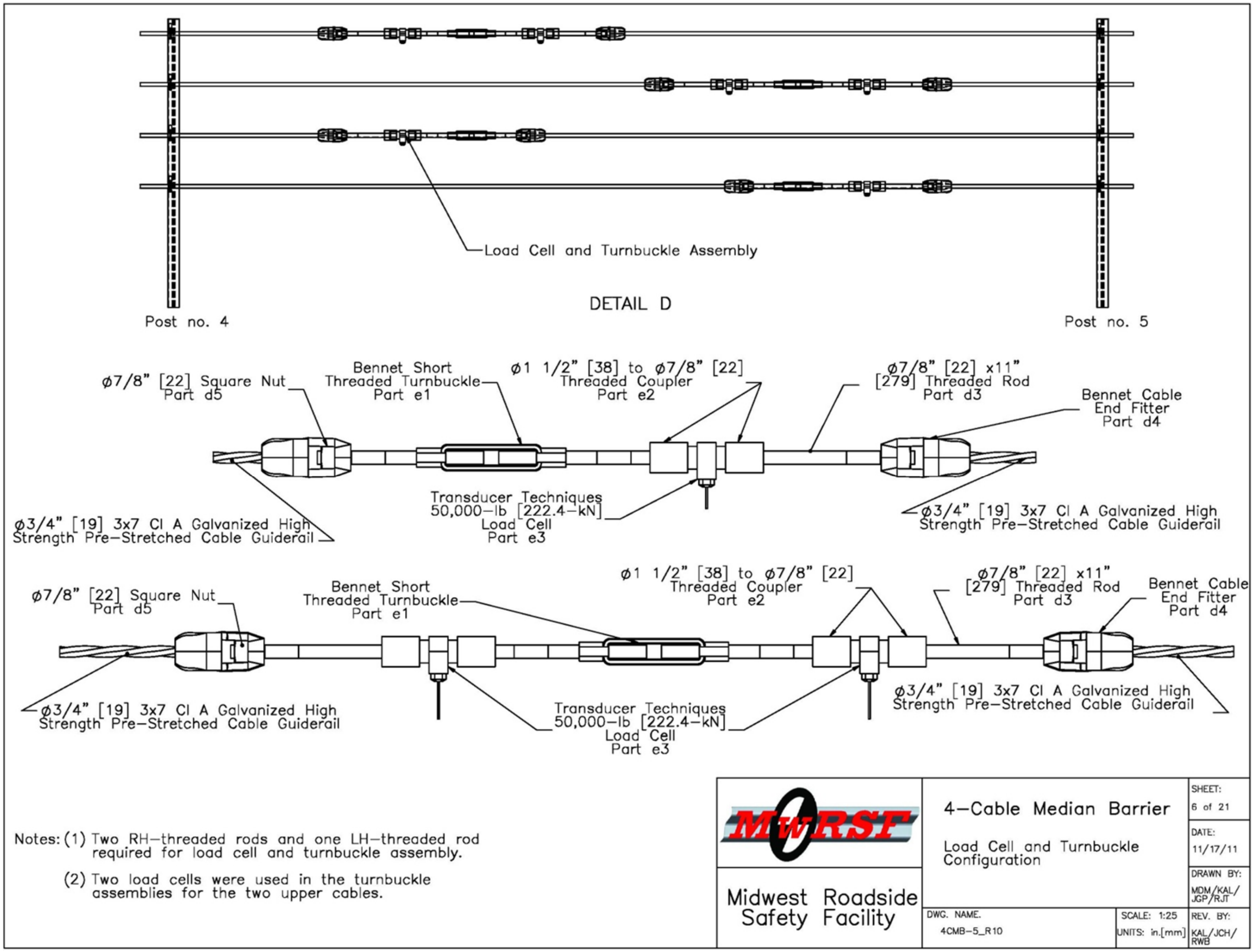


Figure 55. Load Cell Layout, Test No. 4CMB-5

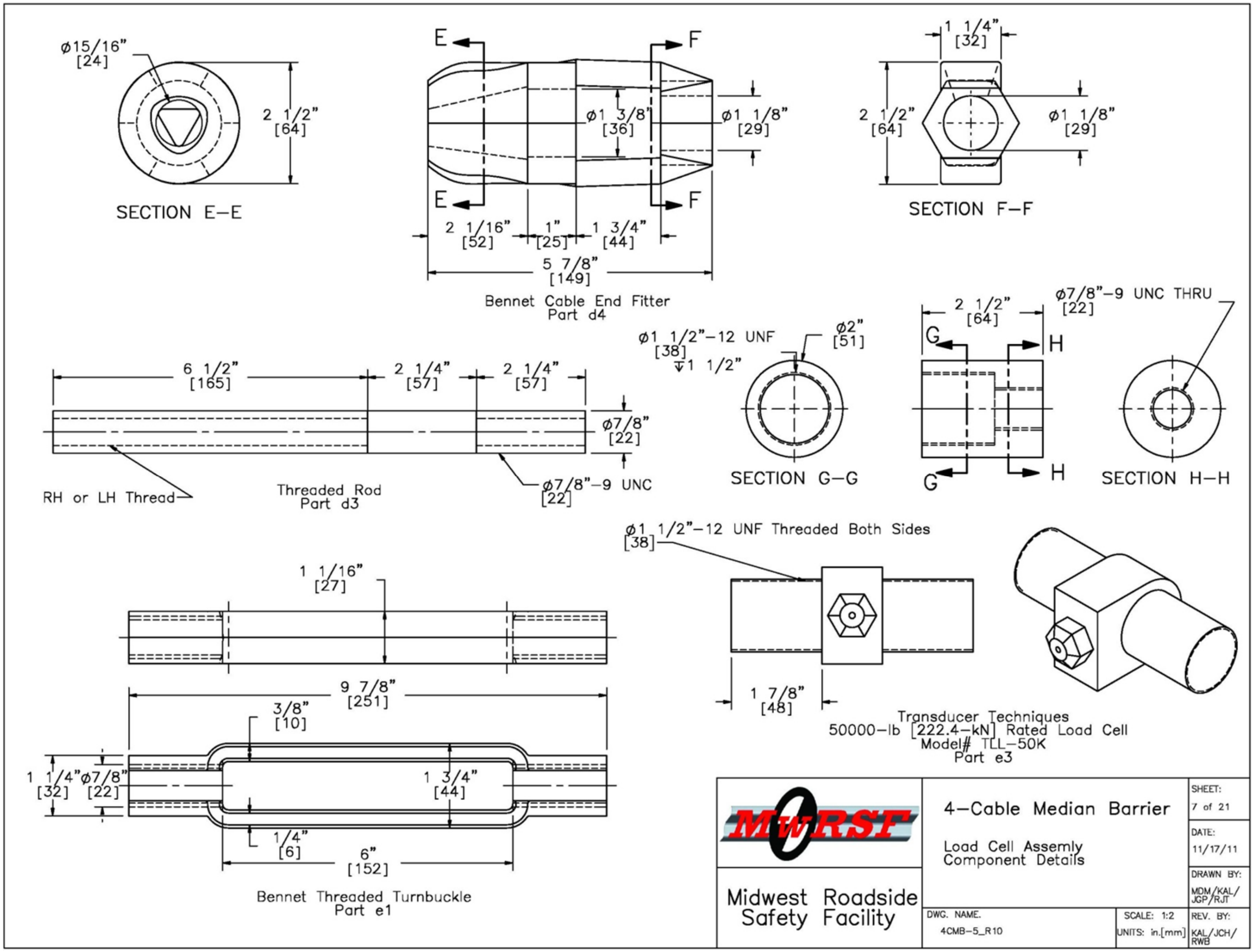
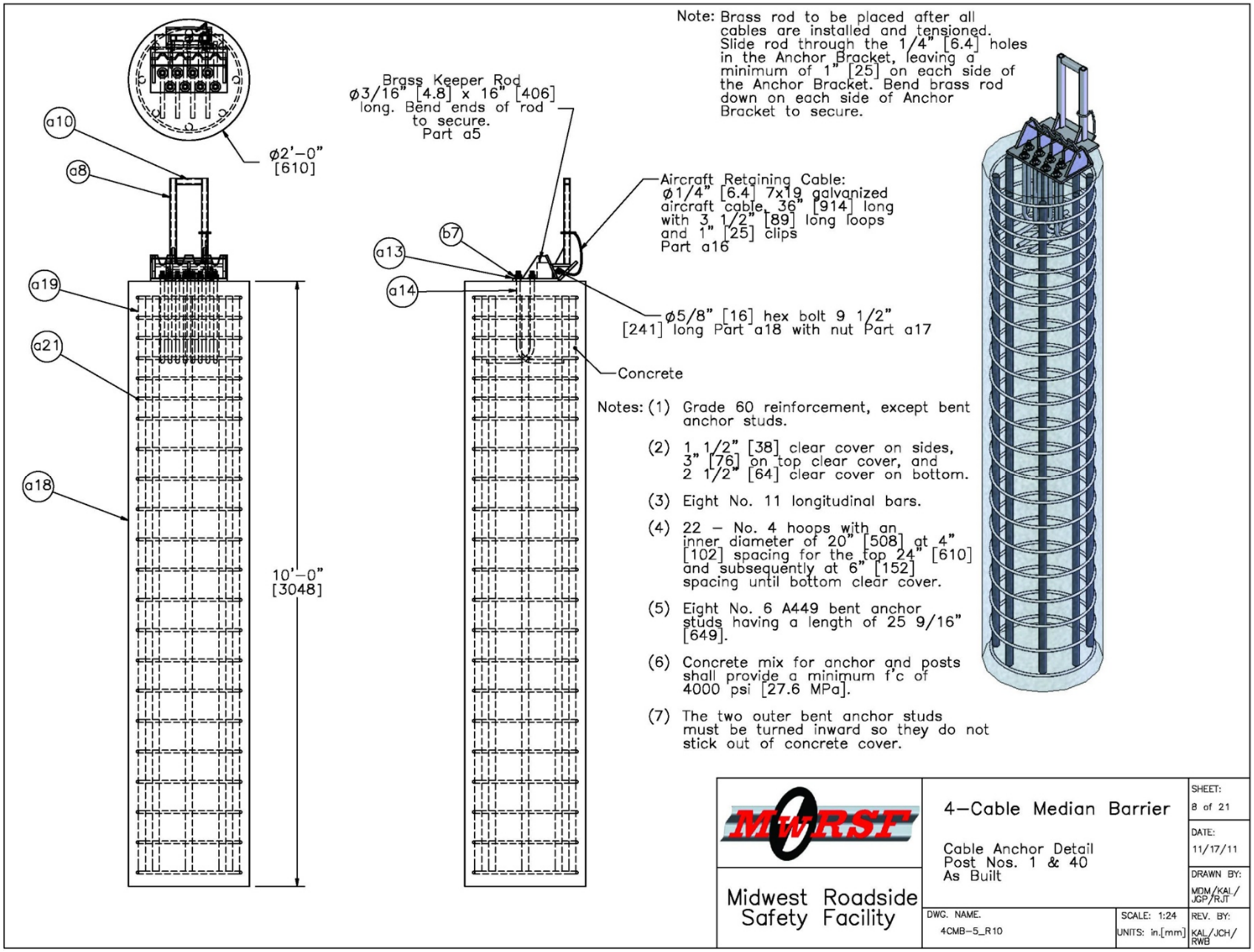


Figure 56. Load Cell Assembly Details, Test No. 4CMB-5



Note: Brass rod to be placed after all cables are installed and tensioned. Slide rod through the 1/4" [6.4] 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 57. Post Nos. 1 and 40 Details, Test No. 4CMB-5

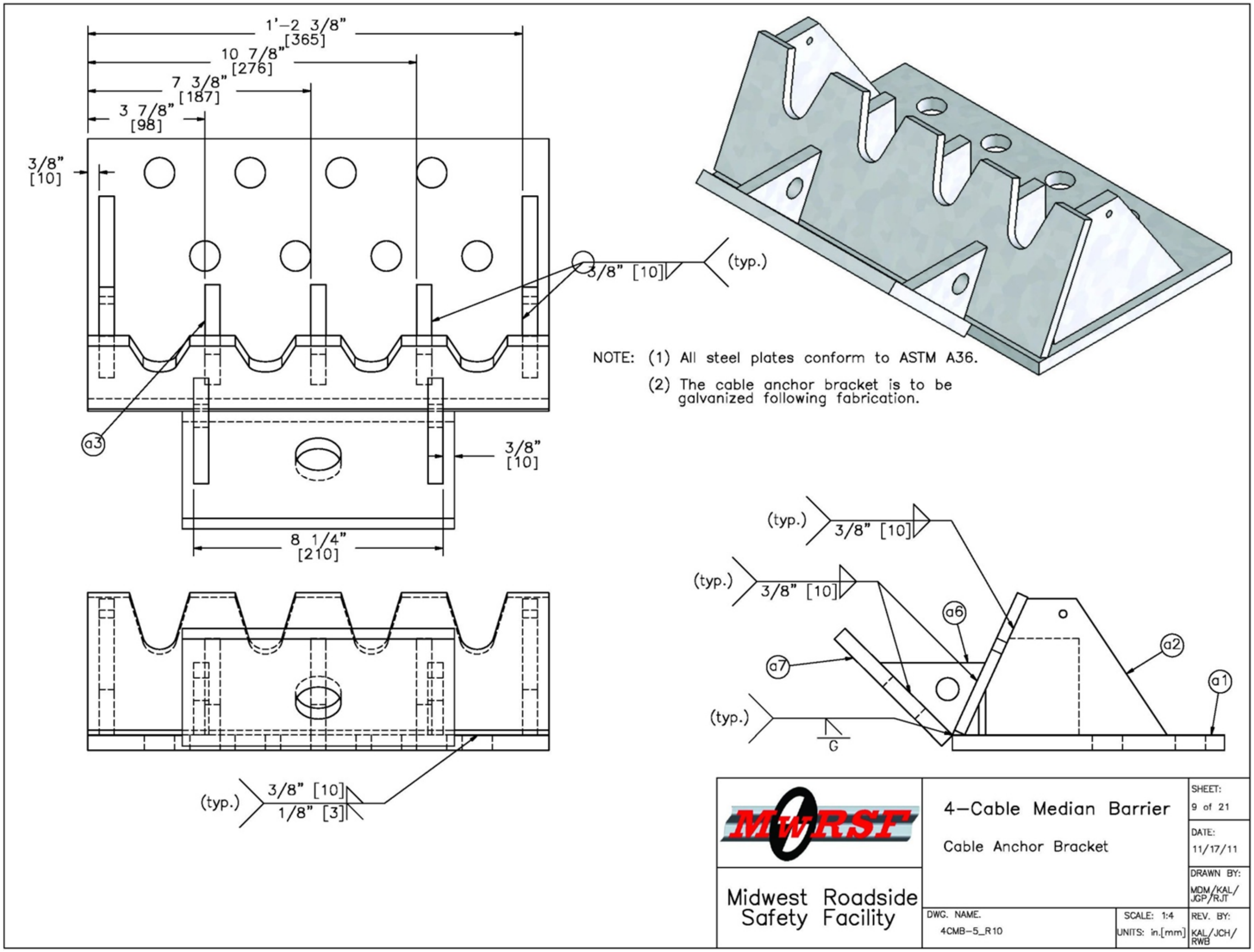


Figure 58. Anchor Bracket Details, Test No. 4CMB-5

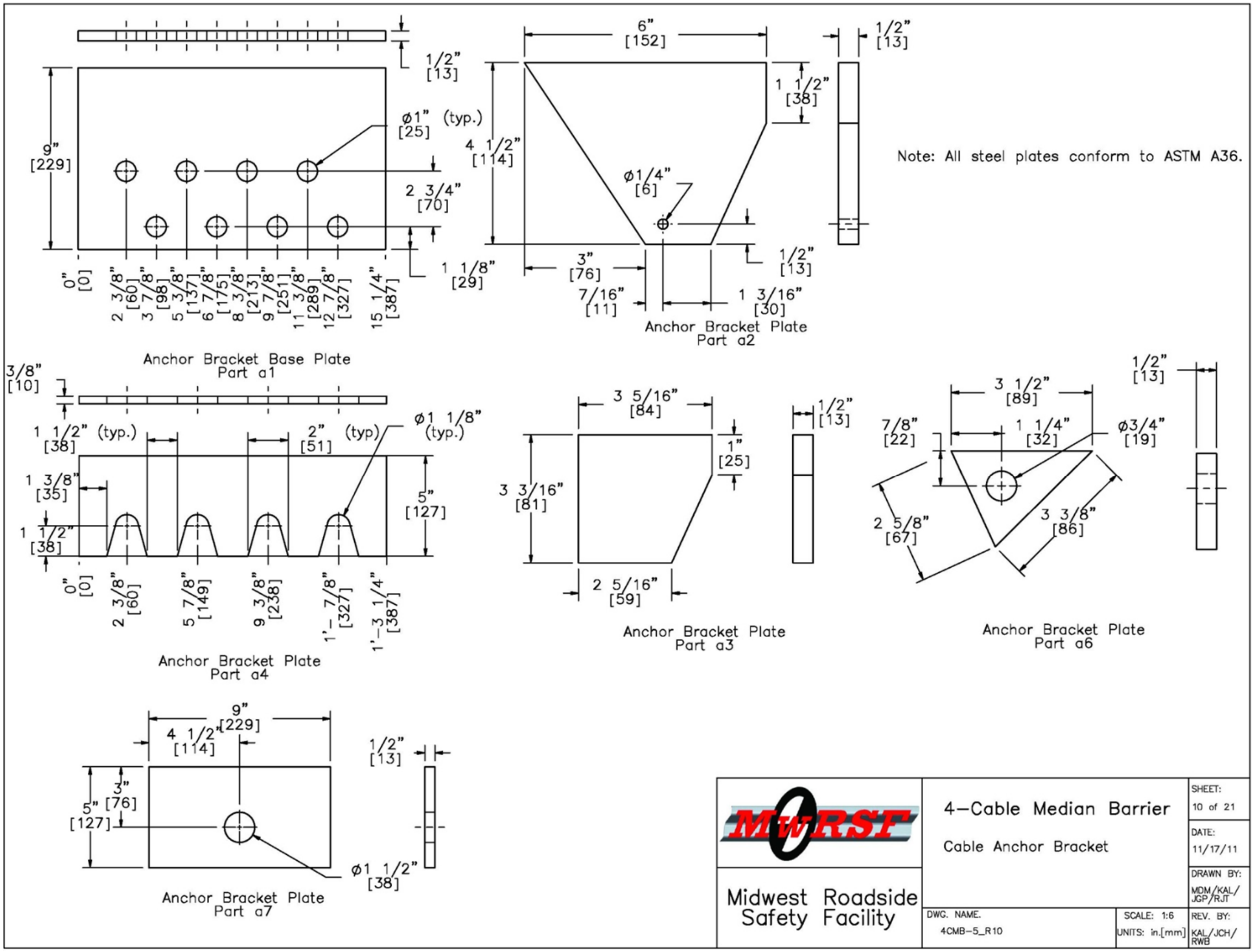
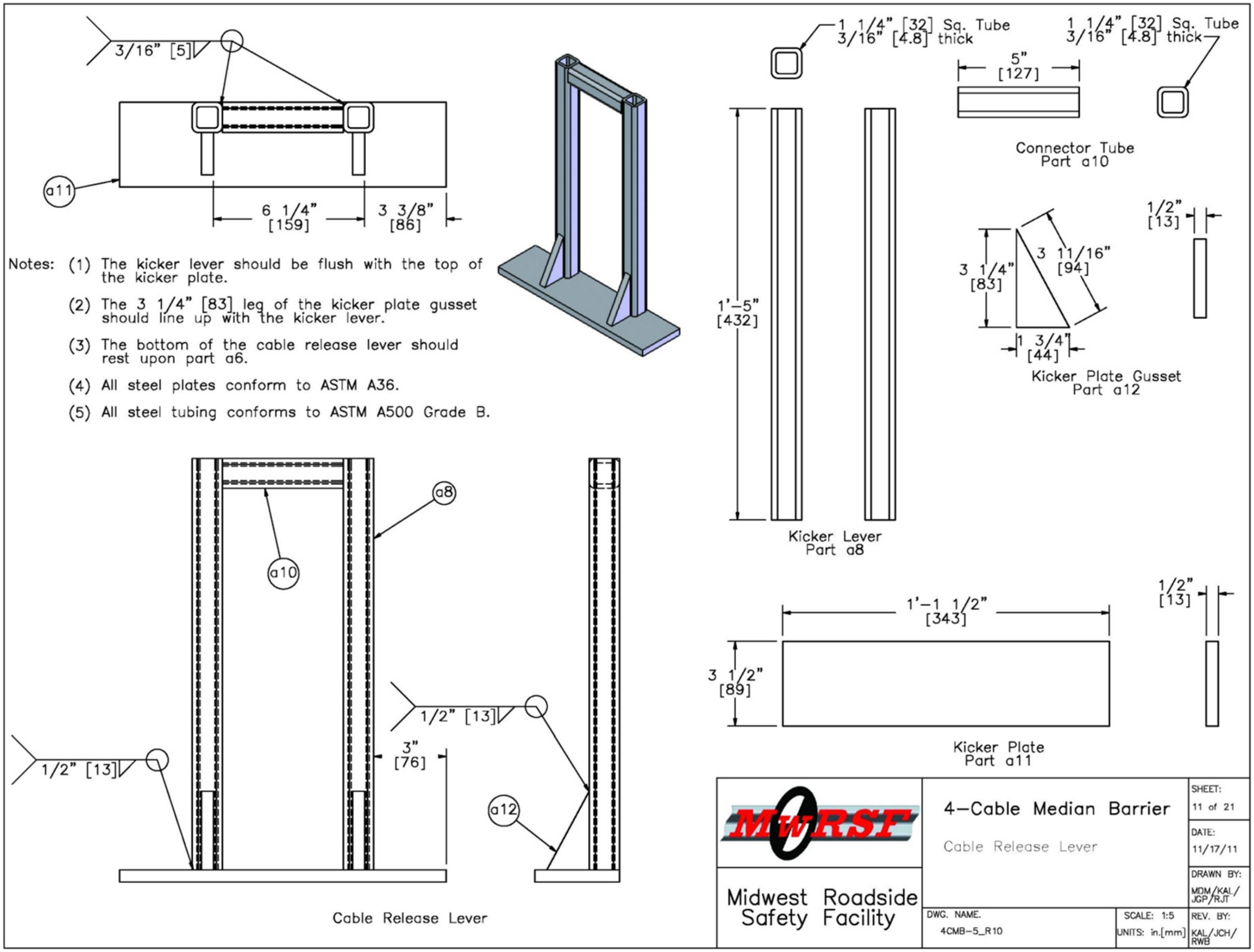
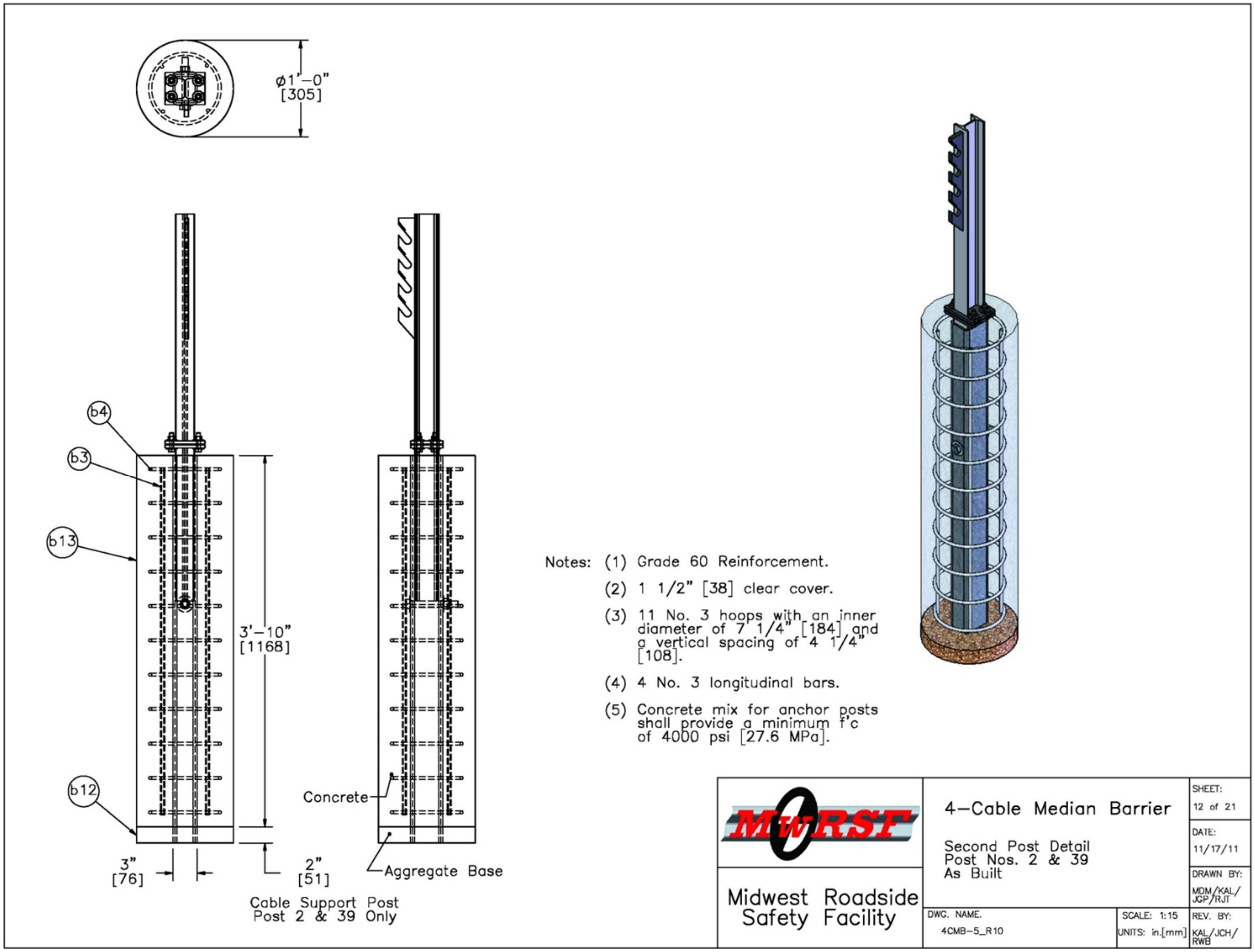


Figure 59. Anchor Bracket Details, Test No. 4CMB-5



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 60. Release Lever Details, Test No. 4CMB-5



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 61. Post Nos. 2 and 39 Details, Test No. 4CMB-5

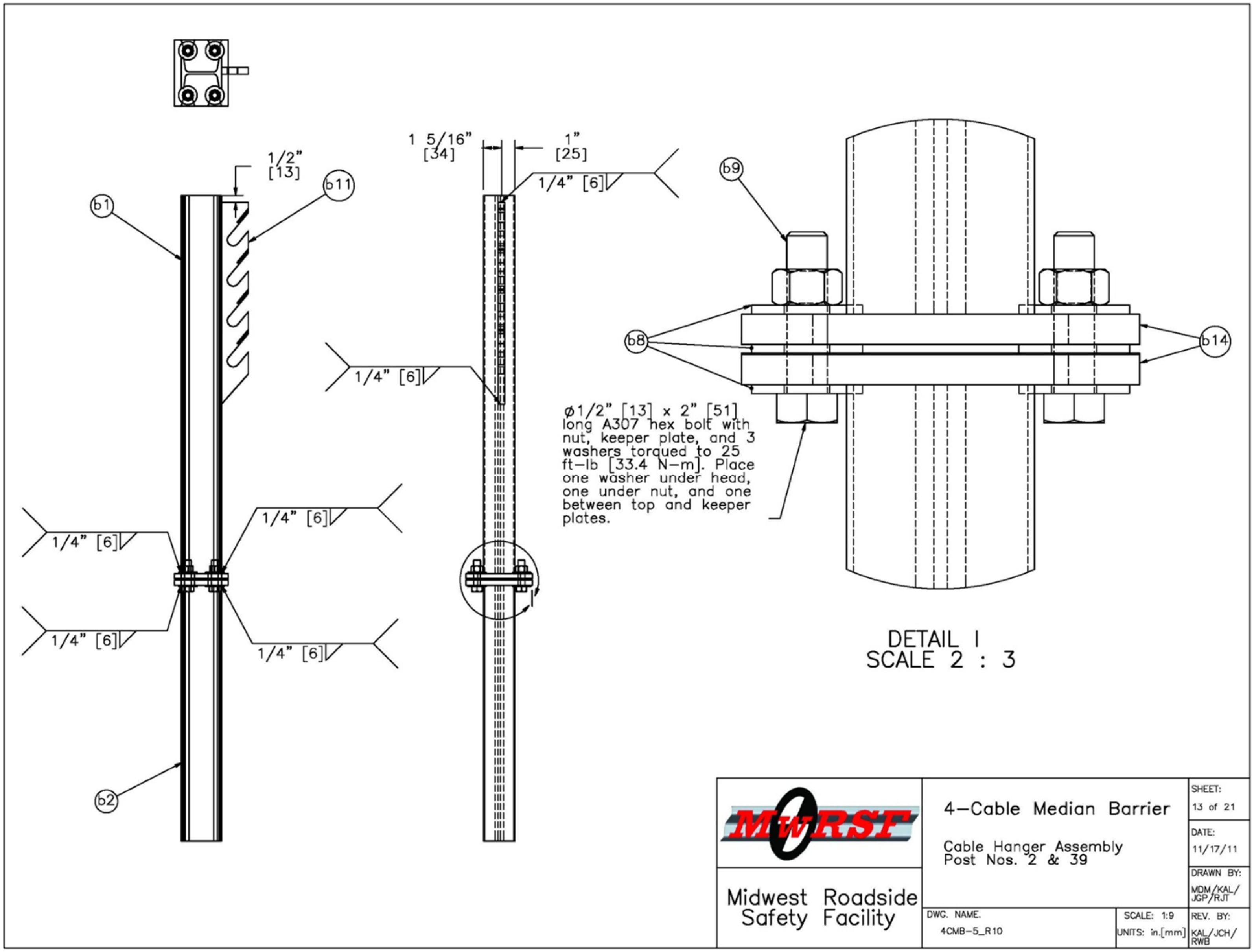


Figure 62. Post Nos. 2 and 39 Details, Test No. 4CMB-5

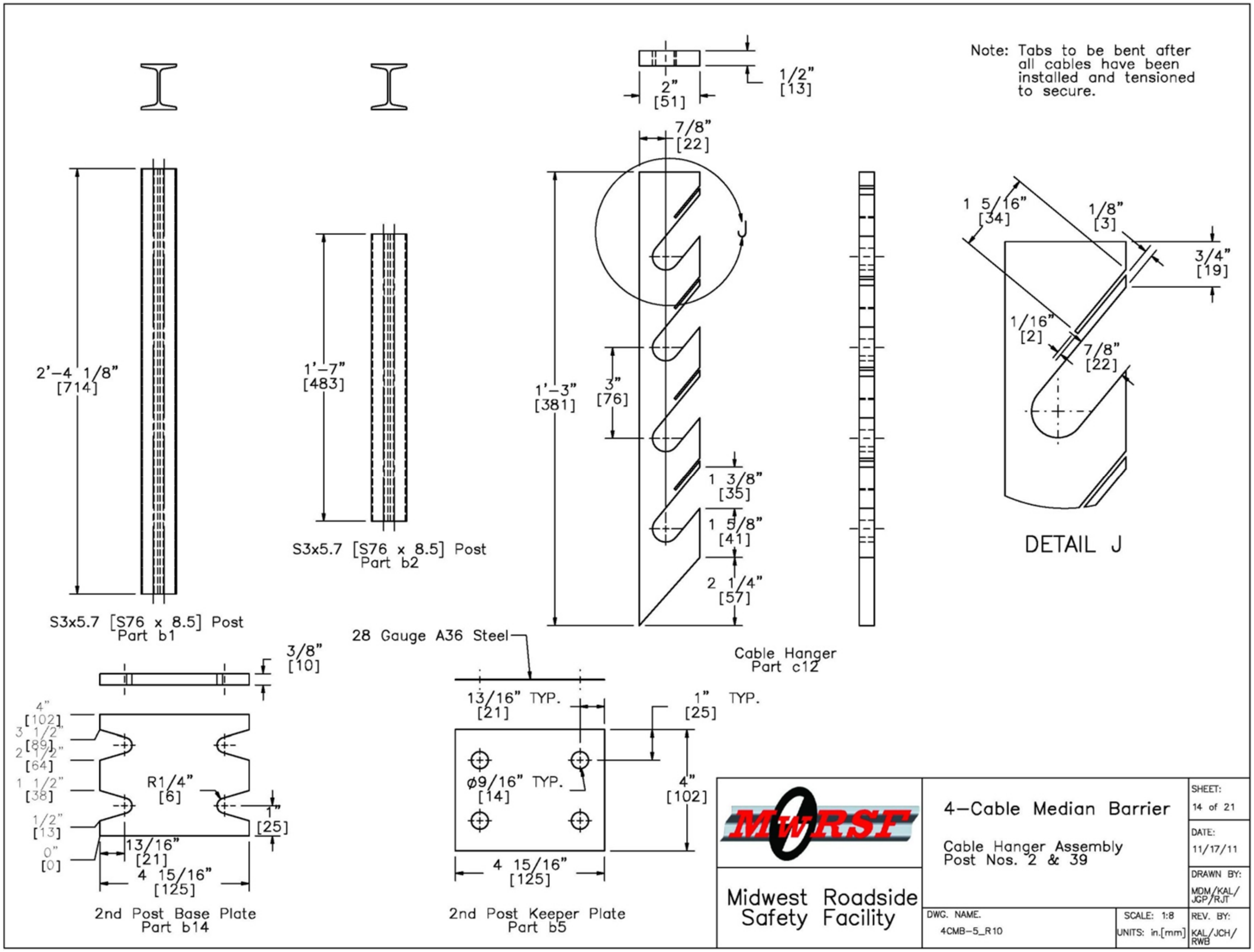


Figure 63. Post Nos. 2 and 39 Details, Test No. 4CMB-5

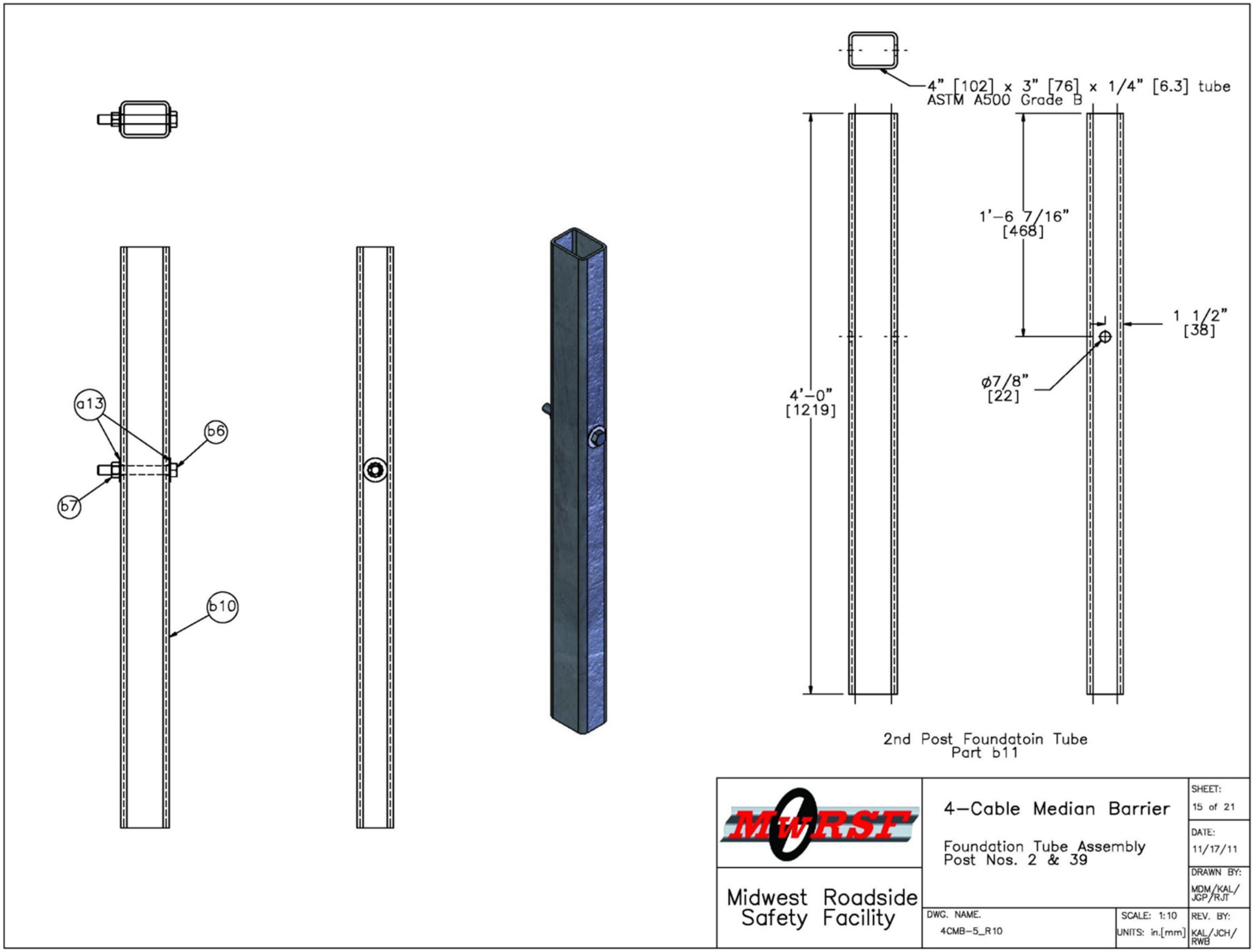


Figure 64. Post Nos. 2 and 39 Details, Test No. 4CMB-5

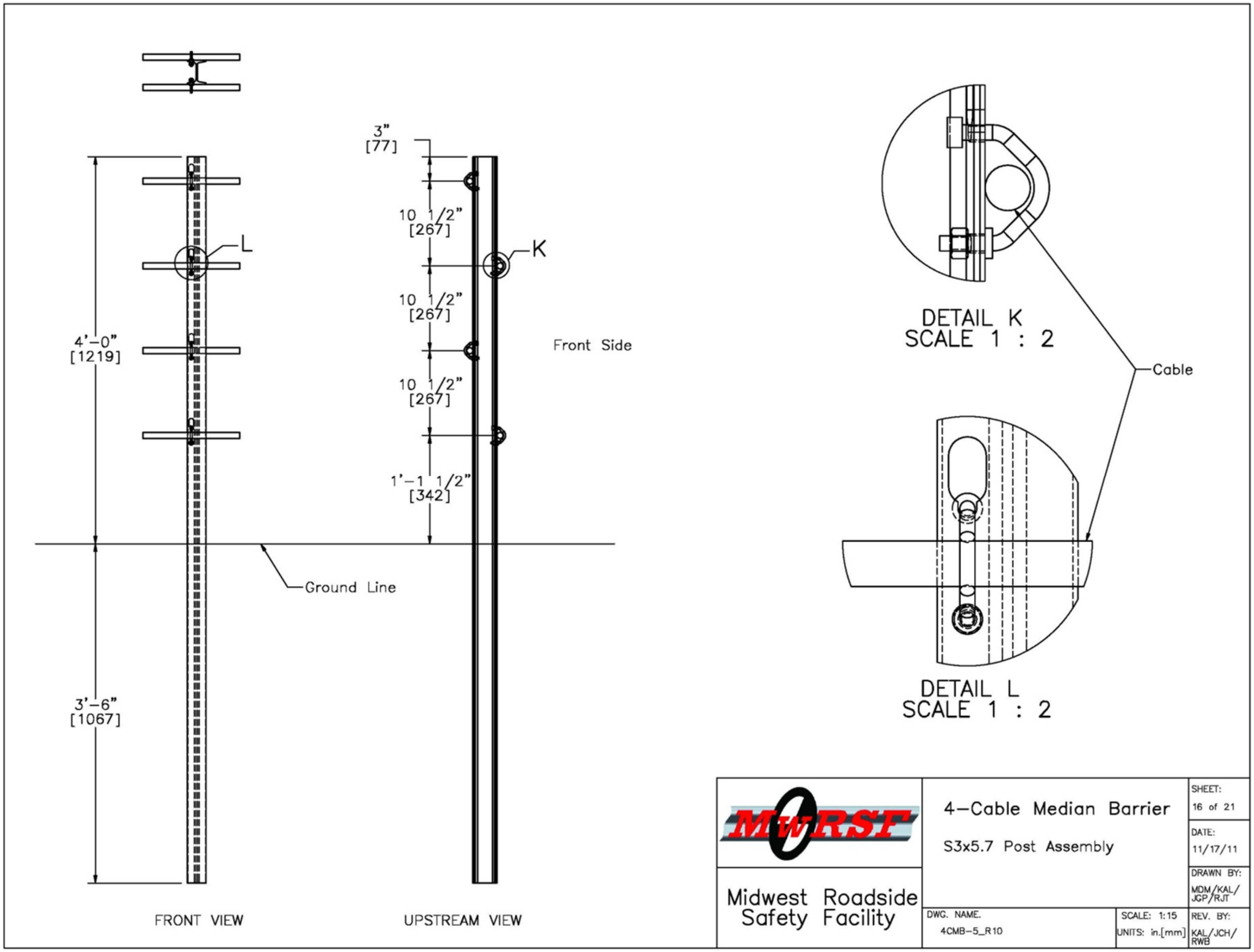


Figure 65. Post Assembly Layout, Test No. 4CMB-5

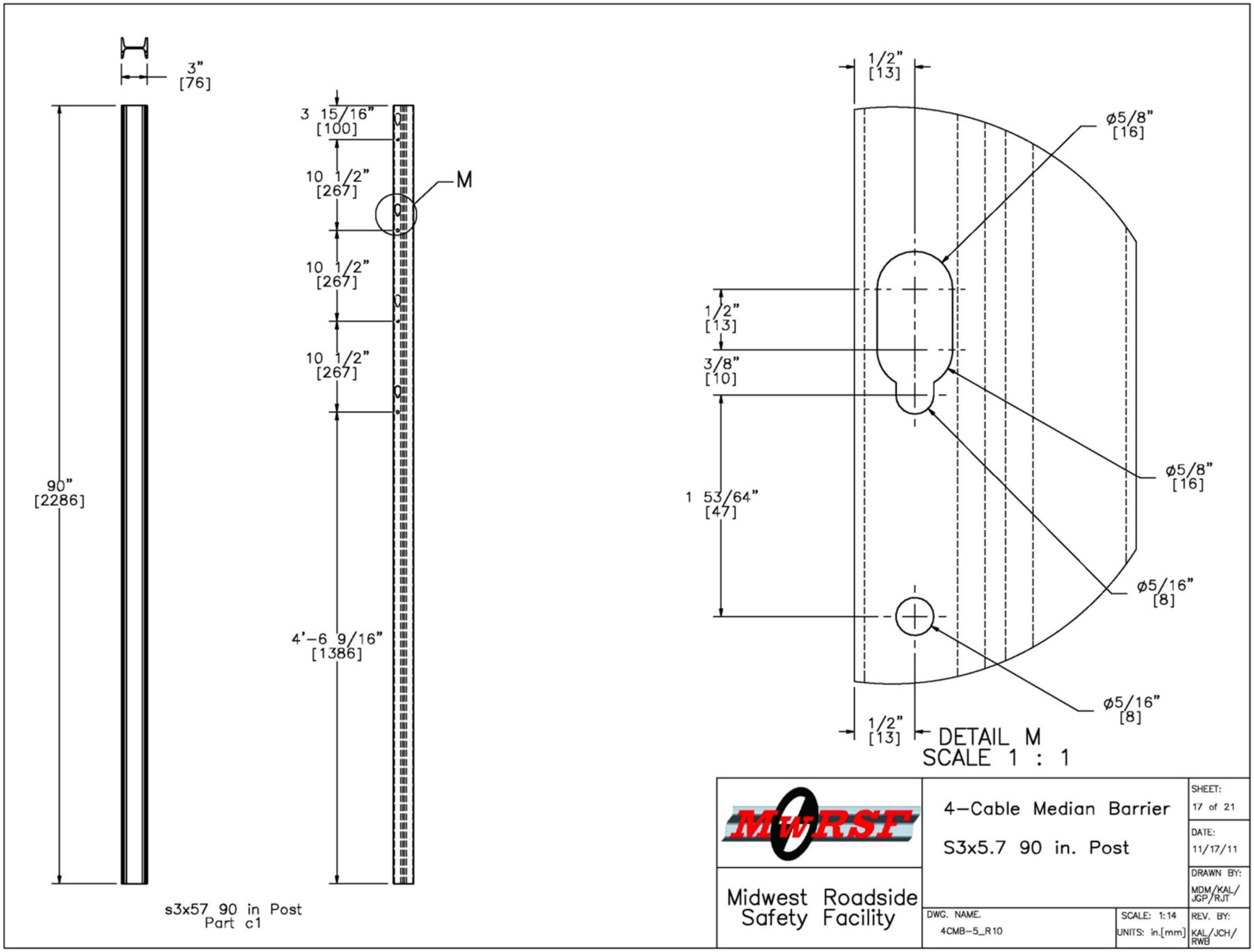
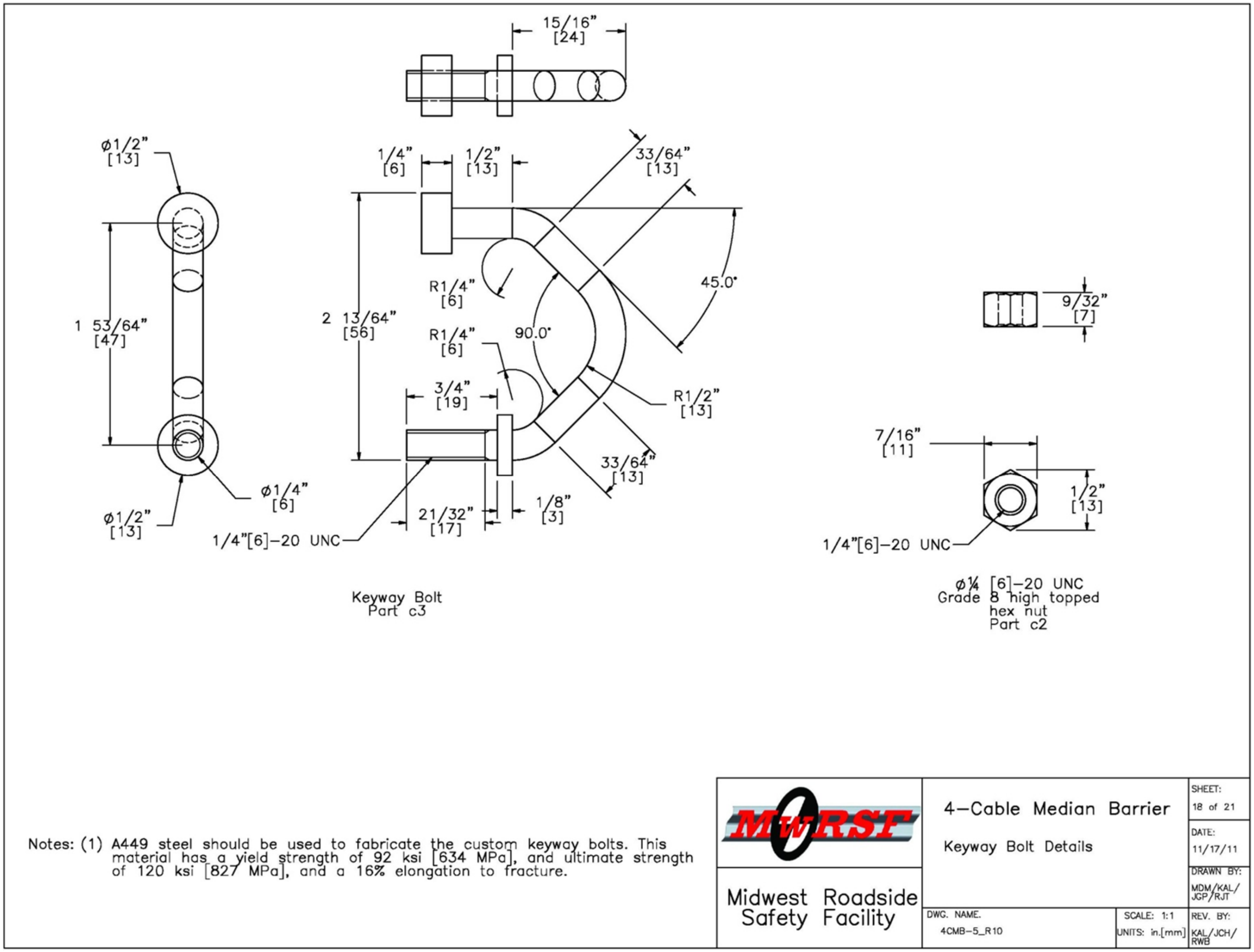


Figure 66. Post Details, Test No. 4CMB-5



Notes: (1) A449 steel should be used to fabricate the custom keyway bolts. This material has a yield strength of 92 ksi [634 MPa], and ultimate strength of 120 ksi [827 MPa], and a 16% elongation to fracture.

Figure 67. Keyway Bolt Detail, Test No. 4CMB-5

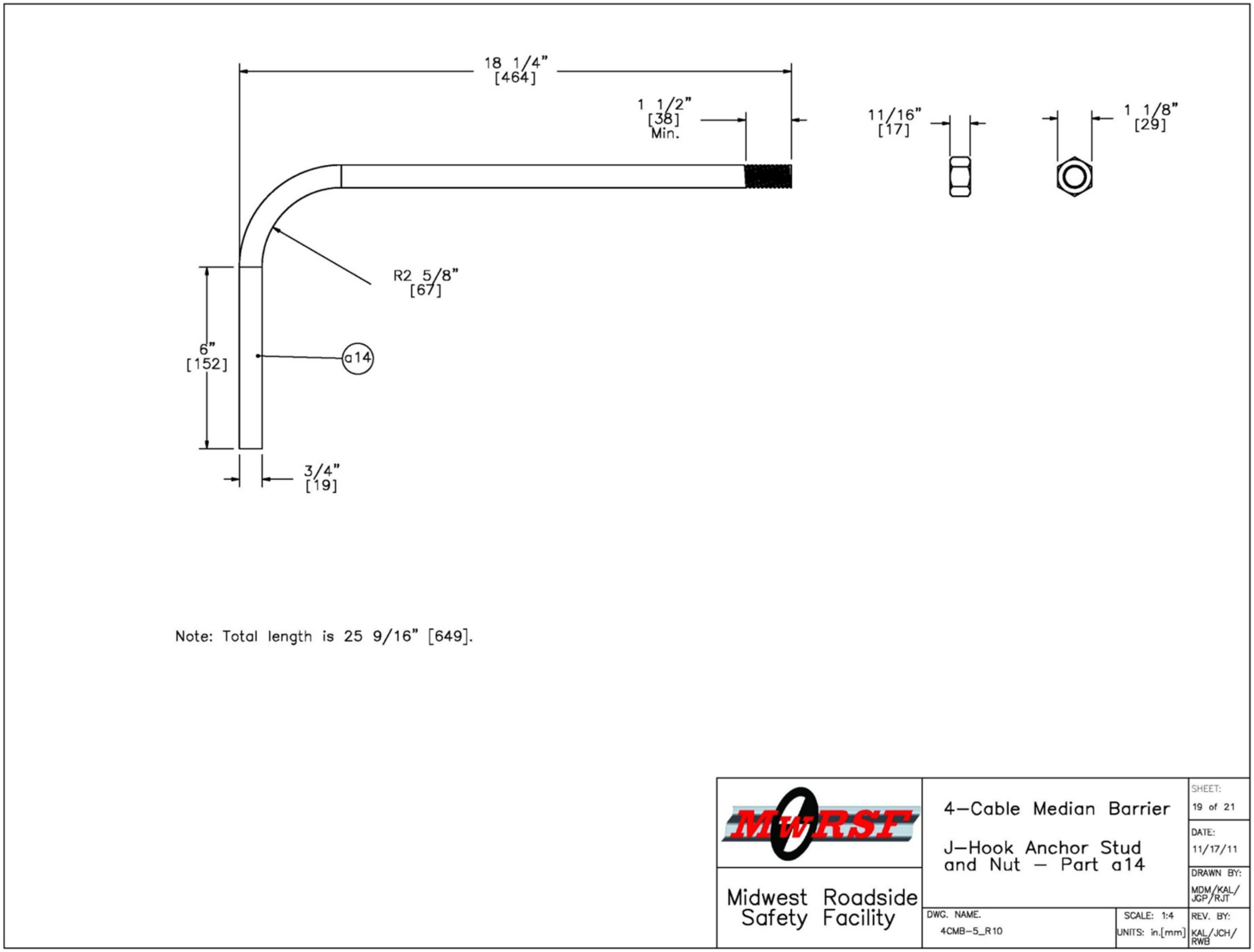


Figure 68. Anchor Stud Detail, Test No. 4CMB-5

Item No.	QTY.	Description	Material Spec	Hardware Guide
a1	2	Cable Anchor Base Plate	A36 Steel	FPA02
a2	4	Exterior Cable Plate Gusset	A36 Steel	FPA02
a3	6	Interior Cable Plate Gusset	A36 Steel	FPA02
a4	2	Anchor Bracket Plate	A36 Steel	FPA02
a5	2	3/16" Dia. Brass Keeper Rod, 14" long	Brass	–
a6	4	Release Gusset	A36 Steel	–
a7	2	Release Lever Plate	A36 Steel	–
a8	4	1.25x1.25x0.1875" TS CT Kicker Lever Tube	ASTM A500 Grade B	–
a9	8	CMB High Tension Anchor Plate Washer	A36 Steel	–
a10	2	1.25x1.25x0.1875" TS CT Kicker Lever Connecting Tube	ASTM A 500 Grade B	–
a11	2	3x10x0.5" Kicker Plate	A36 Steel	–
a12	4	CT kicker – gusset	A36 Steel	–
a13	20	3/4" Dia. Flat Washer	Grade 2	FWC20a
a14	16	3/4" Dia. J-Hook Anchor and Nut	A449	FRJ16a
a15	2	1/4" Dia. Aircraft Retaining Cable, 36" long	7x19 galvanized	–
a16	2	5/8" Dia. Heavy Hex Nut	Grade 5	–
a17	2	5/8" Dia. x 9 1/2" long Hex Bolt	Grade 5	
a18	2	24" Dia. Concrete Anchor, 120" long	4,000 psi f'c	–
a19	16	#11 Straight Rebar, 114" long	Grade 60	–
a20	44	#4 Anchor Hoop Rebar with 21" Dia.	Grade 60	–
b1	2	S3x5.7 Post by 28 1/8"	ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A	–
b2	2	S3x5.7 Post by 19"	ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A	
b3	8	#3 Straight Rebar, 43" long	Grade 60	–
b4	22	7 1/4" Dia. No. 3 Hoop Reinforcement	Grade 60	–
b5	2	2nd Post Keeper Plate, 28 Gauge	A36	–
b6	2	3/4" Dia. x 6" long Hex Bolt and Nut	A307	FBX20a
b7	18	3/4" Dia. Hex Nut	Grade 2	FNX20a
b8	24	1/2" Dia. Washer	A307	FWC14a
b9	8	1/2" Dia. x 2" long Hex Bolt and Nut	A307	FBX14a
b10	2	4x3x1/4" Foundation Tube, 48" long	ASTM A500 Grade B	–
b11	2	2nd Post Cable Hanger	A36	–
b13	2	12" Dia. 2nd Post Concrete Anchor, 46" long	4,000 psi f'c	–
b14	4	2nd Post Base Plate	A36	–
c1	36	S3x5.7 by 90"	ASTM A572 GR50–07, ASTM A709 GR50–09A, ASTM A992–06A	–
c2	144	1/4" Dia. – 20 UNC High Topped Hex Nut	Grade 8 – Galvanized	–
c3	144	1/4" Dia. Keyway bolt	A449 – Galvanized	–

MwRSF

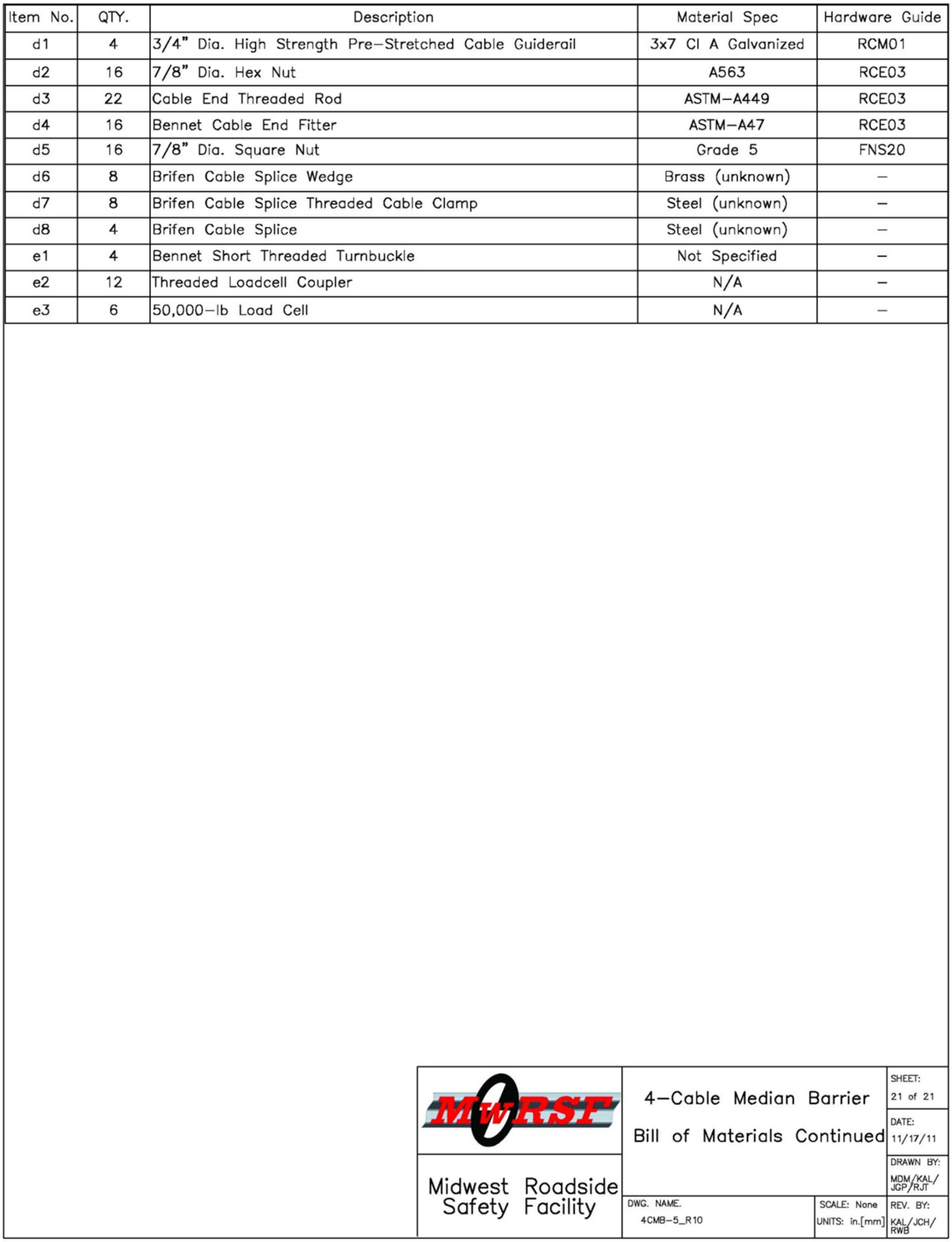
Midwest Roadside Safety Facility

4–Cable Median Barrier

Bill of Materials

SHEET: 20 of 21
DATE: 11/17/11
DRAWN BY: MDM/KAL/JGP/RJT
DWG. NAME. 4CMB–5_R10
SCALE: None
UNITS: in.[mm]
REV. BY: KAL/JCH/RWB

Figure 69. Bill of Materials, Test No. 4CMB-5



Item No.	QTY.	Description	Material Spec	Hardware Guide
d1	4	3/4" Dia. High Strength Pre-Stretched Cable Guiderail	3x7 Cl A Galvanized	RCM01
d2	16	7/8" Dia. Hex Nut	A563	RCE03
d3	22	Cable End Threaded Rod	ASTM-A449	RCE03
d4	16	Bennet Cable End Fitter	ASTM-A47	RCE03
d5	16	7/8" Dia. Square Nut	Grade 5	FNS20
d6	8	Brifen Cable Splice Wedge	Brass (unknown)	–
d7	8	Brifen Cable Splice Threaded Cable Clamp	Steel (unknown)	–
d8	4	Brifen Cable Splice	Steel (unknown)	–
e1	4	Bennet Short Threaded Turnbuckle	Not Specified	–
e2	12	Threaded Loadcell Coupler	N/A	–
e3	6	50,000-lb Load Cell	N/A	–

Midwest Roadside Safety Facility

4-Cable Median Barrier
Bill of Materials Continued

SHEET: 21 of 21
DATE: 11/17/11
DRAWN BY: MDM/KAL/JGP/RJT
DWG. NAME. 4CMB-5_R10
SCALE: None
UNITS: in.[mm]
REV. BY: KAL/JCH/RWB

Figure 70. Bill of Materials, Test No. 4CMB-5

Figure 71. Post and Keyway Bolt Photographs, Test No. 4CMB-5

Figure 72. Test Installation Photographs, Test No. 4CMB-5

7 FULL-SCALE CRASH TEST NO. 4CMB-5

7.1 Static Soil Test

Before full-scale crash test no. 4CMB-5 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results are shown in Appendix C. Although the static soil force was just below the minimum baseline for the first 12 in. (305 mm) of deflection, the weak post section capacity is sufficiently low to allow the post to yield before soil failure would occur. Thus, the soil would provide adequate strength, and full-scale crash testing could be conducted on the barrier system.

7.2 Test No. 4CMB-5

The 5,149-lb (2,336-kg) pickup truck impacted the four cable median barrier 12 ft (3.7 m) laterally down from the slope break point at a speed of 61.8 mph (99.5 km/h). The pickup truck entered the slope at an angle of 26.5 degrees and impacted the barrier at an angle of 27.7 degrees. A summary of the test results and sequential photographs are shown in Figure 73. Additional sequential photographs are shown in Figures 74 through 77.

7.3 Weather Conditions

Test no. 4CMB-5 was conducted on May 10, 2011 at approximately 3:45 pm. 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. 4CMB-5

Temperature	95° F
Humidity	19 %
Wind Speed	15 mph
Wind Direction	220° from True North
Sky Conditions	Sunny
Visibility	10.0 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.0 in.
Previous 7-Day Precipitation	0.03 in.

7.4 Test Description

Initial vehicle impact was to occur 1 ft (0.3 m) upstream of post no. 15, as shown in Figure 78, which was selected using an analysis of the vehicle trajectory over the slope which would impact near a post causing the greatest potential to override the post and cables. The actual point of impact was 1 ft (0.3 m) upstream of post no. 15. A sequential description of the impact events is contained in Table 10. The cables were numbered from 1 to 4, from the top to bottom, respectively. The vehicle came to rest behind the barrier, 99 ft – 6 in. (30.3 m) downstream, straddling the bottom of the v-ditch with the rear of the pickup adjacent to the backside of the barrier. The vehicle trajectory and final position are shown in Figures 73 and 79.

Table 10. Sequential Description of Impact Events, Test No. 4CMB-5

TIME (sec)	EVENT
-0.254	Left-front tire became airborne, and the vehicle started to roll toward the barrier.
-0.084	Right-front tire became airborne, and the front of the vehicle pitched down.
0.000	Left-front bumper impacted post no. 15, and post no. 15 deflected downstream and backward.
0.002	Left-front wheel contacted cable no. 2.
0.038	Post no. 16 deflected backward.
0.044	Post no. 14 deflected backward.
0.048	Left-front tire contacted cable no. 1.
0.066	Left-front tire overrrode cable no. 2.

0.070	Post no. 13 deflected backward.
0.078	Post no. 17 deflected backward, and the left-front tire overrode cable no. 1.
0.080	Post no. 15 deflected forward and upstream.
0.120	The undercarriage of the vehicle deflected post no. 15 backward and downstream, and post no. 12 deflected backward.
0.142	Post no. 11 deflected backward.
0.174	Left-rear tire contacted and bent post no. 15 backward and downstream.
0.180	Post no. 10 deflected backward.
0.190	Post no. 18 deflected backward.
0.192	Post no. 16 deflected downstream.
0.202	Left-rear tire overrode cable no. 2.
0.220	Left-rear tire overrode cable no. 1.
0.224	Post no. 19 deflected backward.
0.260	Cable no. 3 released from post no. 15.
0.278	Cable no. 1 released from post no. 15, and post no. 10 deflected backward.
0.302	Right-rear tire contacted post no. 16.
0.306	Cable no. 1 released from post no. 17.
0.368	Vehicle cleared post line.
0.378	Right-rear axle snagged on cable no. 2.
0.394	Left-front tire contacted the ground.
0.408	Cable no. 3 released from post no. 14.
0.430	Cable no. 2 released from post no. 17.
0.436	Left-front bumper contacted backslope, and vehicle pitched downward, and yawed and rolled downstream.
0.438	Cable no. 3 released from post no. 17.
0.460	Cable no. 4 released from post no. 17.
0.468	Right-rear tire overrode cable no. 1.
0.484	Cable no. 2 released from post no. 15.
0.488	Vehicle rolled downstream.
0.536	Cable no. 3 released from post no. 18.
0.576	Cable no. 4 released from post no. 16.
0.664	Cable no. 2 released from post no. 18.
0.668	Cable no. 1 released from post no. 18.
0.796	Cable no. 2 ruptured.
0.980	Vehicle had rolled 90 degrees.
1.092	Right-rear quarter panel contacted ground.
1.180	Vehicle had rolled 180 degrees.
1.372	Left-side doors contacted the ground.
1.608	Vehicle had rolled 270 degrees.
2.654	Vehicle had rolled 540 degrees.
2.920	Vehicle had rolled 630 degrees.

7.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 80 through 82. Tension was released in the cables prior to taking all post-test documentation photos. Barrier damage consisted of deflected posts and disengaged cables and keyway bolts.

Cable no. 1 disengaged from post nos. 15 through 17 when the keyway bolts bent and/or fractured. Cable no. 2 disengaged from post nos. 13 through 19. Cable no. 2 also fractured approximately between post nos. 17 and 18 after it snagged on the rear end of the pickup truck. Cable no. 3 disengaged from post nos. 14 through 17. Cable no. 4 disengaged from post nos. 16 and 17.

Cable no. 2 disengaged from the load cell that was located downstream of post no. 6. Post no. 6 was deflected slightly upstream. The back flange of post no. 8 was slightly bent around the cable no. 1 keyway slot. Post nos. 9 and 10 were deflected slightly downstream. Post no. 11 was deflected slightly backward, and the cable no. 2 keyway bolt was slightly bent. Post no. 12 was deflected backward, and the cable no. 2 keyway bolt was slightly bent. Post nos. 13 and 14 were deflected backward and slightly downstream, and the front flanges were scratched around the location of cable no. 2. Post no. 15 was bent downstream, and the front face was twisted to face downstream. The front flange of post no. 15 was also scratched and deformed around the location of cable nos. 2 and 4. Post no. 16 was bent downstream, and the front face was twisted to face downstream. The front and back flange of post no. 16 was dented at the location of cable no. 2, and the front flange of the post was scratched at the location of cable no. 4. Post no. 17 was bent downstream, and scratches were found on the front flange at the location of cable no. 2. Post no. 18 was deflected backward, and the front flange was twisted to face upstream and had localized buckling at the groundline. Post no. 19 was deflected backward and downstream, and the front flange was twisted to face slightly downstream at the groundline. Post no. 20 was deflected slightly backward, and the cable no. 2 keyway bolt was bent but the cable did not disengage. Cable no. 1 was pulled out of the splice located downstream of post no. 20 by ³⁄₁₆ in. (5 mm) on the upstream side of the splice and ½ in. (13 mm) on the downstream side of the splice. Post no. 21 was deflected slightly backward. Cable no. 2 was pulled out of the splice located upstream of post no. 22 by ⅜ in. (10 mm) on the upstream side of the splice and ⅜ in. (10 mm) on the downstream side of the splice, as shown in Figure 82.

The movement of soil during the test is documented in Table 11. A 166-in. (4,216-mm) long by 68-in. (1,727-mm) wide soil crater was located on the backslope where the front of the pickup truck impacted.

The maximum lateral permanent post deflections were not calculated for this test. The maximum lateral dynamic post deflection was 57.5 in. (1,461 mm) at post no. 17 and the maximum lateral dynamic cable deflection was approximately 101.5 in. (2,578 mm) in cable 2 just prior to failure, as determined from high-speed digital video analysis. The working width of the system was not calculated for this test.

7.6 Vehicle Damage

The damage to the vehicle was severe, as shown in Figures 83 through 86. The maximum occupant compartment deformations are listed in Table 12 along with the deformation limits established in MASH for various areas of the occupant compartment. The roof deformation of 15½ in. (394 mm) exceeded the MASH limit of 4 in. (102 mm). Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 11. Soil Documentation, Test No. 4CMB-5

Soil Gap[1] Size and Location					Soil Heave[2]			Soil Crater[3]		
Post No.	Upstream in. (mm)	Downstream in. (mm)	Front in. (mm)	Back in. (mm)	Diameter in. (mm)	Height in. (mm)	Location in. (mm)	Dimensions in. (mm)	Depth in. (mm)	Location in. (mm)
8		¼ (6)		¼ (6)						
9		½ (13)	½ (13)							
10			½ (13)							
11								3x4 (76x102)	3 (76)	Front
12				¼ (6)						
13								5x9 (127x229)	5 (127)	Front
14								15x16 (381x406)	5 (127)	All Around
15								15x12 (381x305)	4 (102)	All Around
16								13x12 (330x305)	6 (152)	All Around
17					5 (127)	2 (51)	Downstream	13x12 (330x305)	6 (152)	Upstream
18								12x12 (305x305)	8 (203)	All Around
19								10x9 (254 x229)	5 (127)	All Around
20								10x3 (254x76)	5 (127)	Front
21			1¾ (44)							

[1] A soil gap is the gap between the face of the post and undisturbed soil at ground level.

[2] A soil heave is the accumulation of soil that forms near a post as energy is dissipated through the ground due to post deflection.

[3] A soil crater is the absence of soil around the base of a post due to the soil being pushed away by the post.

Table 12. Maximum Occupant Compartment Deformations by Location, Test No. 4CMB-5

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	1¾ (44)	≤ 9 (229)
Floor Pan & Transmission Tunnel	½ (13)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	½ (13)	≤ 12 (305)
Side Door (Above Seat)	1½ (38)	≤ 9 (229)
Side Door (Below Seat)	1½ (38)	≤ 12 (305)
Roof	15½ (394)	≤ 4 (102)
Windshield	0	≤ 3 (76)

Damage occurred to all sides of the vehicle due to the rollover. The plastic bumper cover was disengaged and torn on the right side, and the bumper was dented near the center and the left side. The front frame member was bent and torn. The hood was crushed and ajar. The left side of the grill was fractured. The dash was fractured and deformed upward. The left side of the roof was severely crushed. The windshield was shattered and torn on the left side. The left headlight was disengaged and fractured. The left-front upper control arm, tie rod, and brakes were disengaged. The left-front lower control arm was fractured. The left fender was crushed inward at the front and deformed outward by the left-front door. The front and top of the left-front door and mirror were crushed inward. Both left windows were shattered and disengaged. The left-rear door was crushed at the top. The left-rear quarter panel was crushed inward behind the wheel. Both taillights disengaged. The tailgate disengaged on the right side. The right-rear quarter panel was scratched and dented behind the wheel well. The front of the right side of the box was crushed inward. The right-rear shock mount and shock fractured and disengaged. The right-front door was slightly ajar. Denting occurred at the lower-front of the right-front door. The right mirror was disengaged. The right fender was dented at the front. The right-front tire was deflated. The right headlight disengaged. The oil pan was dented.

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 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 13. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 73. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

Table 13. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. 4CMB-5

Evaluation Criteria		**Transducer**			**MASH Limits**
		EDR-3	**DTS Set#1**	**DTS Set#2**	
OIV ft/s (m/s)	Longitudinal	-11.80 (-3.60)	-10.72 (-3.27)	-10.56 (-3.22)	≤ 40 (12.2)
	Lateral	6.47 (1.97)	5.07 (1.55)	-	≤40 (12.2)
ORA g's	Longitudinal	-18.63	-17.20	-16.98	≤ 20.49
	Lateral	-5.60	-9.80	-	≤ 20.49
THIV ft/s (m/s)		-	11.67 (3.56)	-	not required
PHD g's		-	17.86	-	not required
ASI		1.13	1.06	-	not required

7.8 Load Cell Results

As previously discussed, tension load cells were installed inline with the cables at the upstream end of the barrier system in order to monitor the total load transferred to the anchor with respect to time. The load cell results are summarized in Table 14. The individual cable loads, along with the total combined cable load imparted to the upstream end anchor, were determined and are shown graphically in Figure 88.

As noted previously, the target cable tension was 4,213 lb (18.7 kN) at 100 deg Fahrenheit (37.8 deg Celsius). Prior to the testing, the actual cable tension in the top, upper middle, lower middle, and bottom cables was 4.27 kips (19.01 kN), 4.25 kips (18.92 kN), 4.06 kips (18.05 kN), and 4.25 kips (18.88 kN), respectively. These readings were measured using the cable load cells. The tension in the top and upper middle cables as measured from the second set of upstream load cells were 4.28 kips (19.02 kN) and 4.23 kips (18.81 kN), respectively.

Table 14. Load Cell Results, Test No. 4CMB-5

Cable Location	Sensor Location	Maximum Cable Load		Time[1] (sec)
		kips	kN	
Combined Cables	Upstream End	40.09	178.33	0.448
Top Cable	Upstream End	11.70	52.05	0.453
Upper Middle Cable	Upstream End	18.36	81.66	0.666
Lower Middle Cable	Upstream End	11.95	53.16	0.440
Bottom Cable	Upstream End	6.08	27.04	0.654
Top Cable	Upstream End Set#2	11.37	50.60	0.453
Upper Middle Cable	Upstream End Set#2	18.99	84.48	0.666

[1] - Time determined from initial vehicle impact with the barrier system.

After the crash test, the tension in each cable was measured using the cable load cells. The cable tension at the upstream end and in the top, upper middle, lower middle, and bottom cables was 2.89 kips (12.87 kN), 0 kips (0 kN), 3.03 kips (13.48 kN), and 3.73 kips (16.61 kN), respectively. The tension in the top and upper middle cables as measured from the second set of upstream load cells were 2.89 kips (12.87 kN) and 0 kips (0 kN), respectively.

7.9 Discussion

The analysis of the test results for test no. 4CMB-5 showed that the four cable median barrier 12 ft (3.7 m) laterally down from the slope break point did not adequately contain nor redirect the 2270P vehicle since the vehicle overrode the barrier and subsequently rolled. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Significant deformations of the roof did occur when the vehicle rolled. Vehicle roll, pitch, and yaw angular displacements are shown in Appendix F. After impact, the vehicle was located on the back side of the barrier. Therefore, test no. 4CMB-5 conducted on four cable median barrier was determined to be unacceptable according to the MASH safety performance criteria for test designation no. 3-11.

Following the analysis of test no. 4CMB-5, the researchers concluded that the failure of the test was directly attributed to failure to capture the impacting vehicle and the subsequent override of the system. The failure of the system to capture the vehicle was caused by the vehicle impacting post no. 15 prior to engaging the top cable. Post no. 15 deflected laterally back as well as longitudinally downstream. Impacting the post was shown to be critical, as the motion of the post caused the cables to be pulled down and prevent them from capturing the vehicle bumper.

Based on the results of this test, there may be a need to utilize different, or modified, cable attachments at the various cable heights in the system. It may be necessary to modify the vertical release properties of the upper cable attachments such that they release under very low forces and deflections in order to prevent the cables from being pulled downward, as observed in test no. 4CMB-5. It was noted in this test that the location of the vehicle bumper in relation to the top cable was marginal with respect to the potential for vehicle capture, even prior to the pulldown of the cables by the post, as shown in Figure 87. These modifications, along with others will be considered as the research effort moves forward.

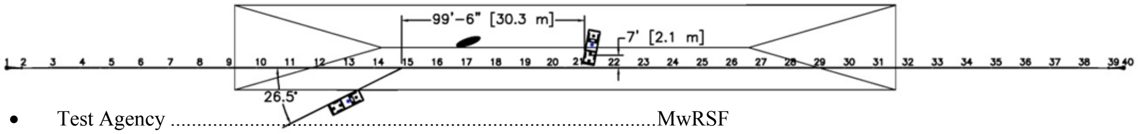
0.000 sec

0.306 sec

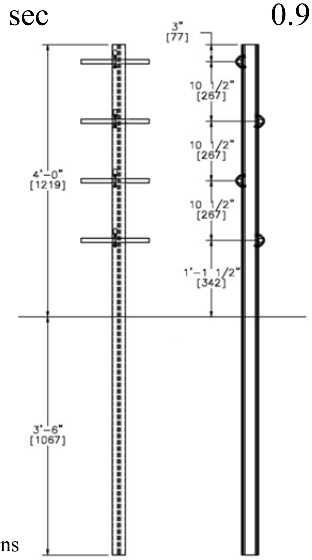
0.600 sec

0.764 sec

0.964 sec



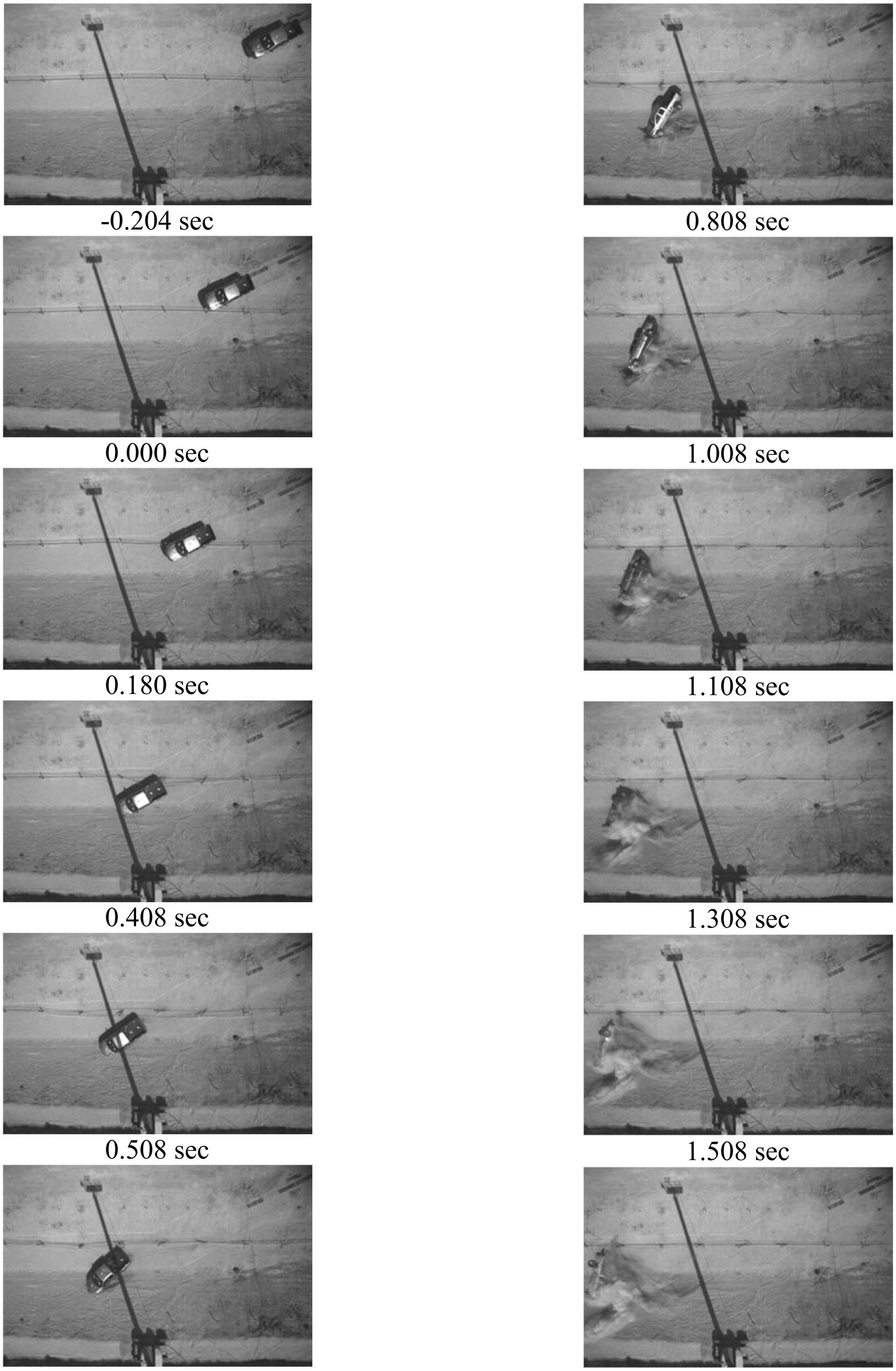
- Test Agency .... MwRSF
- Test Number 4CMB-5
- Date 5/10/2011
- MASH Test Designation 3-11
- Test Article .... Four Cable Median Barrier
- Total Length .... 608ft (185 m)
- Key Component – Wire Rope
  - Diameter .... ¾ in. (19 mm)
  - Specification 3x7
  - Top Cable Height .... 45 in. (1,143 mm)
  - Bottom Cable Height .... 13½ in. (343 mm)
  - Incremental Spacing .... 10½ in. (267 mm)
- Key Component – Post Nos. 3-38
  - Length .... 90 in. (2,286 mm)
  - Shape S3x5.7 (S76x8.5)
  - Spacing .... 16 ft (4.9 m)
- Soil Type .... Grading B AASHTO 147-65 (1990)
- Vehicle Make /Model .... 2002 Dodge Ram 1500 Quad Cab Pickup
  - Curb .... 5,119 lb (2,322 kg)
  - Test Inertial .... 4,979 lb (2,258 kg)
  - Gross Static .... 5,149 lb (2,336 kg)
- Impact Conditions
  - Speed .... 61.8 mph (99.5 km/h)
  - Angle Entered Slope .... 26.5 deg
  - Angle Impacted Barrier .... 27.7 deg
  - Impact Location .... 1 ft (0.3 m) upstream of post no. 15
- Exit Conditions
  - Speed .... NA
  - Angle .... NA
- Exit Box Criterion .... NA
- Vehicle Stability .... Unacceptable - Rolled
- Vehicle Stopping Distance .... 99 ft – 6 in. (30.3 m) downstream of impact
  7 ft (2.1 m) to the left of impact
- Vehicle Damage .... Severe
  - VDS[14] .... 11-L&T-5
  - CDC[15] 11TYAO4
  - Maximum Interior Deformation .... 15½ in. (394 mm)
- Test Article Damage .... Moderate



- MaximumTest Article Deflections
  - Permanent Set .... NA
  - Dynamic (Cable) .... 101.5 in. (2,578 mm)
  - Working Width .... NA
- Maximum Angular Displacements [DTS]
  - Roll .... 738.4 ° > 75°
  - Pitch .... 21.5 ° < 75°
  - Yaw .... 57.8 °
- Impact Severity (IS) .... 126.6 kip-ft (171.7 kJ) > 106 kip-ft (144 kJ)
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		EDR-3	EDR-4	DTS	
OIV ft/s (m/s)	Longitudinal	-11.80 (-3.60)	-10.72 (-3.27)	-10.56 (-3.22)	≤ 40 (12.2)
	Lateral	6.47 (1.97)	5.07 (1.55)	-	≤ 40 (12.2)
ORA g's	Longitudinal	-18.63	-17.20	-16.98	≤ 20.49
	Lateral	-5.60	-9.80	-	≤ 20.49
THIV – ft/s (m/s)		-	11.67 (3.56)	-	not required
PHD – g's		-	17.86	-	not required
ASI		1.13	1.06	-	not required

Figure 73. Summary of Test Results and Sequential Photographs, Test No. 4CMB-5



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0.000 sec

0.180 sec

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0.508 sec

0.608 sec

0.808 sec

1.008 sec

1.108 sec

1.308 sec

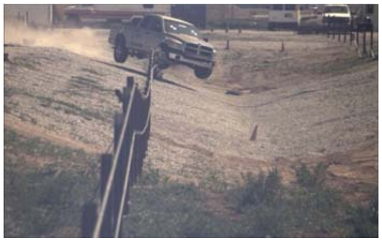
1.508 sec

1.608 sec

Figure 74. Additional Sequential Photographs, Test No. 4CMB-5


-0.254 sec


0.000 sec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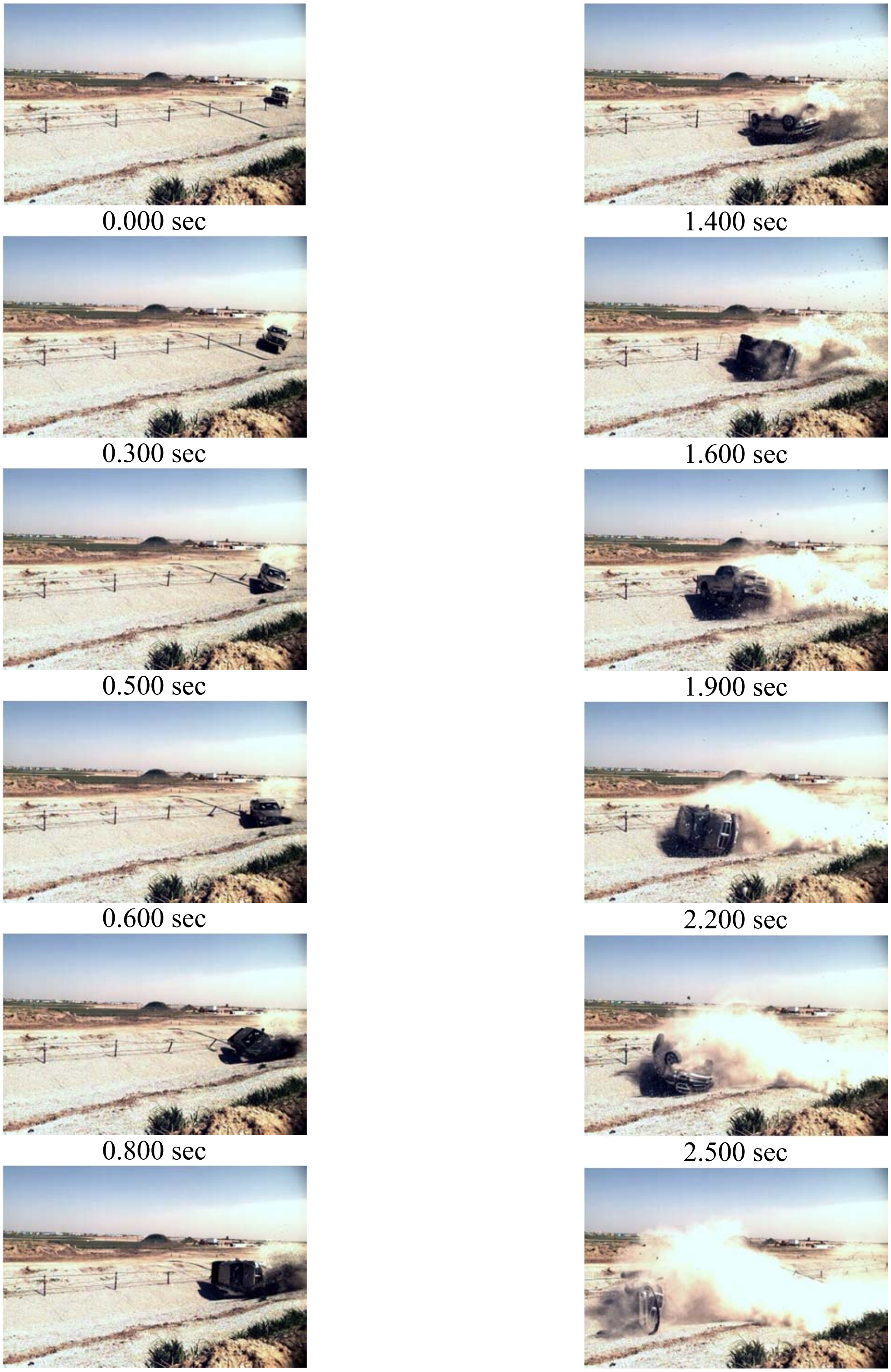
1.300 sec


1.400 sec

Figure 75. Additional Sequential Photographs, Test No. 4CMB-5



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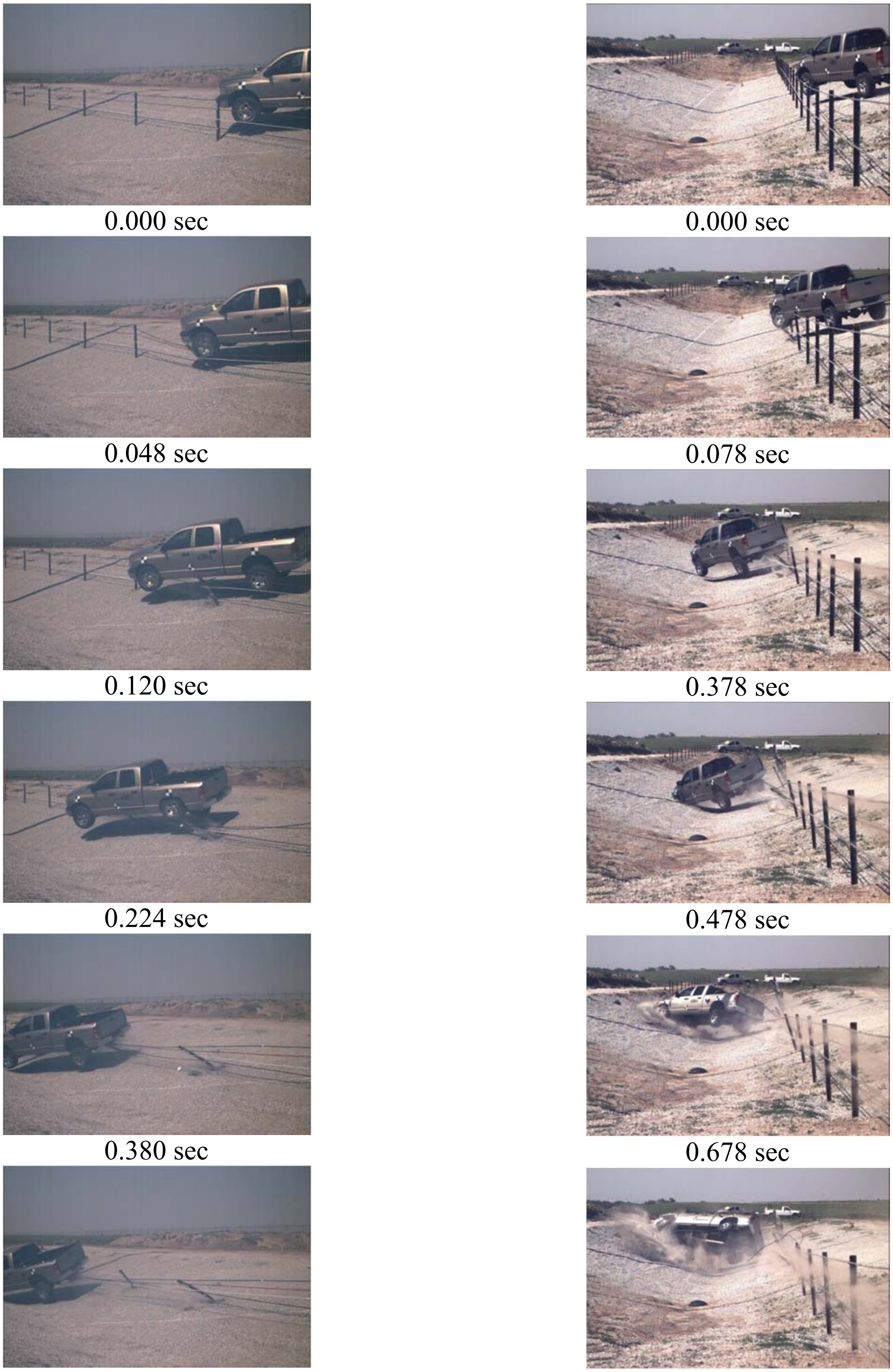
2.920 sec

Figure 76. Additional Sequential Photographs, Test No. 4CMB-5



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0.380 sec

0.468 sec

0.000 sec

0.078 sec

0.378 sec

0.478 sec

0.678 sec

0.878 sec

Figure 77. Additional Sequential Photographs, Test No. 4CMB-5

Figure 78. Impact Location, Test No. 4CMB-5

Figure 79. Vehicle Final Position and Trajectory Marks, Test No. 4CMB-5

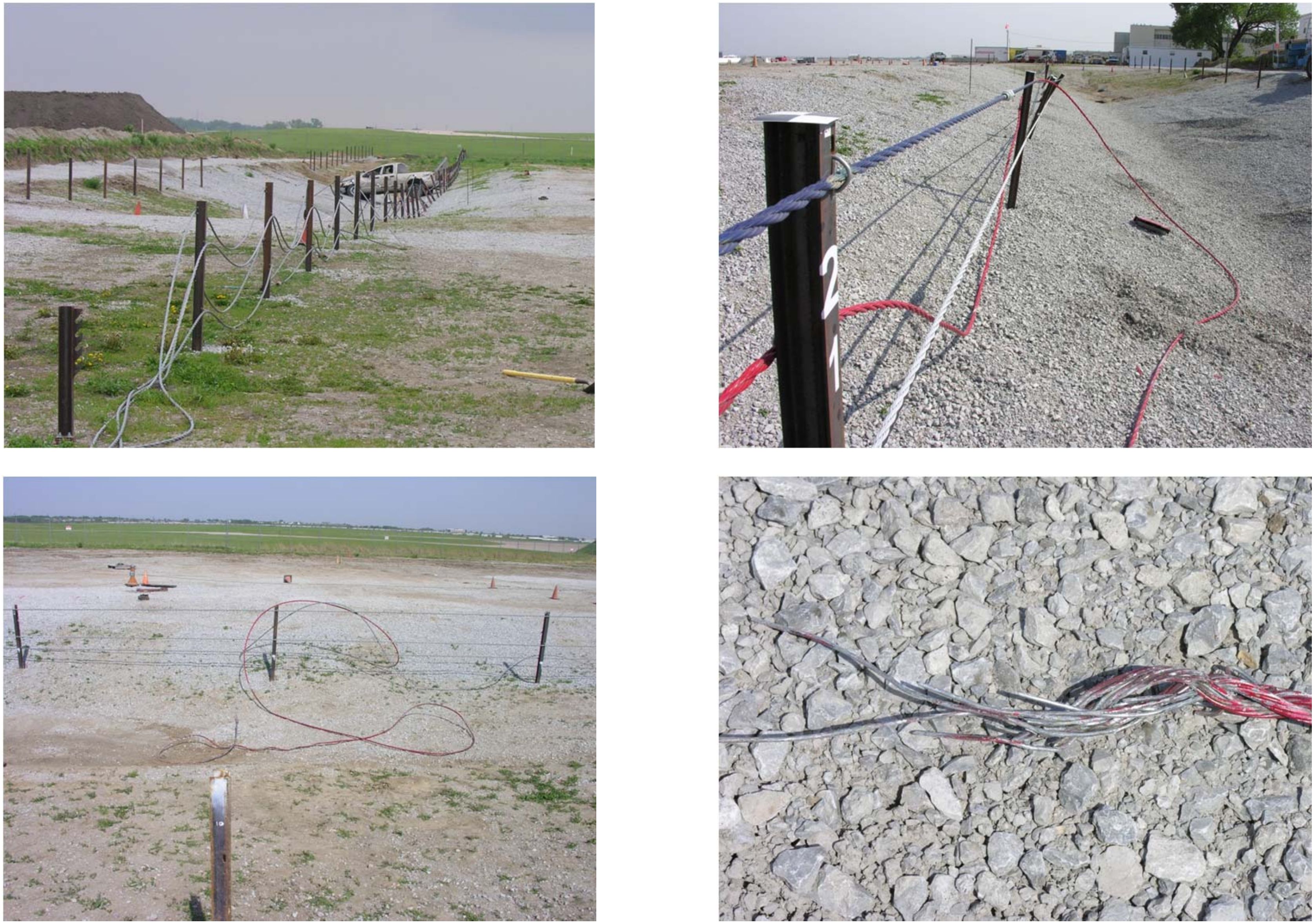

Figure 80. System Damage, Test No. 4CMB-5

Figure 81. Post Damage, Test No. 4CMB-5

Figure 82. Post and Splice Damage, Test No. 4CMB-5

Figure 83. Vehicle Damage, Test No. 4CMB-5

Figure 84. Vehicle Damage, Test No. 4CMB-5

Figure 85. Occupant Compartment Damage, Test No. 4CMB-5

Figure 86. Undercarriage Damage, Test No. 4CMB-5

Figure 87. Bumper-to-Cable Relation at Impact, Test No. 4CMB-5

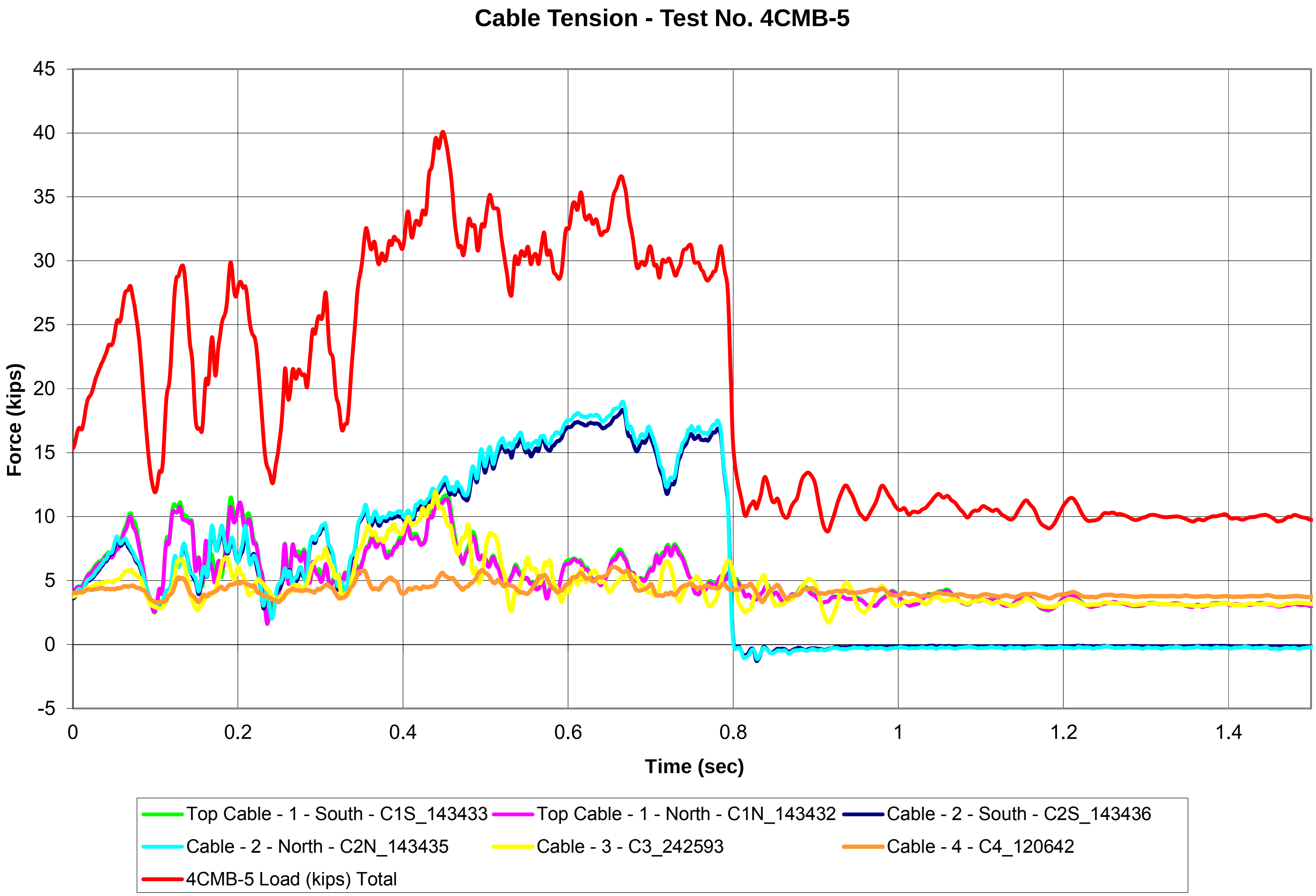

Figure 88. Cable Tension vs. Time, Test No. 4CMB-5

8 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A high-tension, four-cable barrier system was developed for median applications where side slopes as steep as 4H:1V can be found in a V-ditch configuration. The barrier system was designed for placement anywhere within the sloped median. The barrier system was developed with several other goals in mind. First of all, since the barrier was intended for use in a sloped median, it was important that the barrier be capable of redirecting errant vehicles when impacted on either side of the barrier. Second, the barrier was intended to have relatively low deflections as compared to other cable systems. Reduced deflections would allow for the cable barrier system to be placed in more locations. Third, the system was expected to redirect a large range of vehicles with different bumper and c.g. heights. Fourth, the barrier was intended to maintain an open aesthetic appeal. Finally, the system was expected to be constructed for easy maintenance in the event of a crash.

Two full-scale vehicle crash tests were performed according to the safety performance guidelines found in MASH on a cable barrier system installed at various locations within the 46-ft (14.0 m) wide ditch with 4H:1V side slopes. A summary of the safety performance evaluations is shown in Table 15.

The first full-scale crash test, test no. 4CMB-4, consisted of a 2,574-lb (1,168-kg) passenger car impacting the cable median barrier at a speed of 61.1 mph (98.4 km/h). The passenger car entered the slope at an angle of 25.8 degrees and impacted the barrier at an angle of 25.7 degrees. The system was located 4 ft (1.2 m) laterally up from the bottom of the ditch on the backslope. The impact point for this test was 5 ft – 4 in. (1.6 m) downstream of post no. 16. The system adequately contained and redirected the vehicle. Therefore, the system passed test designation 3-10 of the MASH standards.

The second full-scale crash test, test no. 4CMB-5, consisted of a 5,149-lb (2,336-kg) pickup truck impacting the cable median barrier at a speed of 61.8 mph (99.5 km/h). The pickup truck entered the slope at an angle of 26.5 degrees and impacted the barrier at an angle of 27.7 degrees. The system was located 12 ft (3.7 m) laterally down from the slope break point. The pickup truck overrode the system and subsequently rolled. Therefore, the system did not pass test designation 3-11 of the MASH standards.

The failure of the system in test no. 4CMB-5 illustrated several critical points with respect to cable median barrier design. First, impacting the barrier at a line post is critical as it increases the potential for the system cables to be pulled downward by the deflecting post and decreases the propensity for vehicle capture. Second, the results of this test indicated that cable attachments for the critical upper cable need to be designed to release the cable before it is pulled down by the deflected post. Finally, test no. 4CMB-5 indicated that 45 in. (1,143 mm) top cable heights may be the minimum allowable top cable height for cable median barriers installed anywhere in a V-ditch.

Table 15. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. 4CMB-4</th><th>Test No. 4CMB-5</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>U</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td><td>S</td><td>U</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>U</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

9 REFERENCES

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

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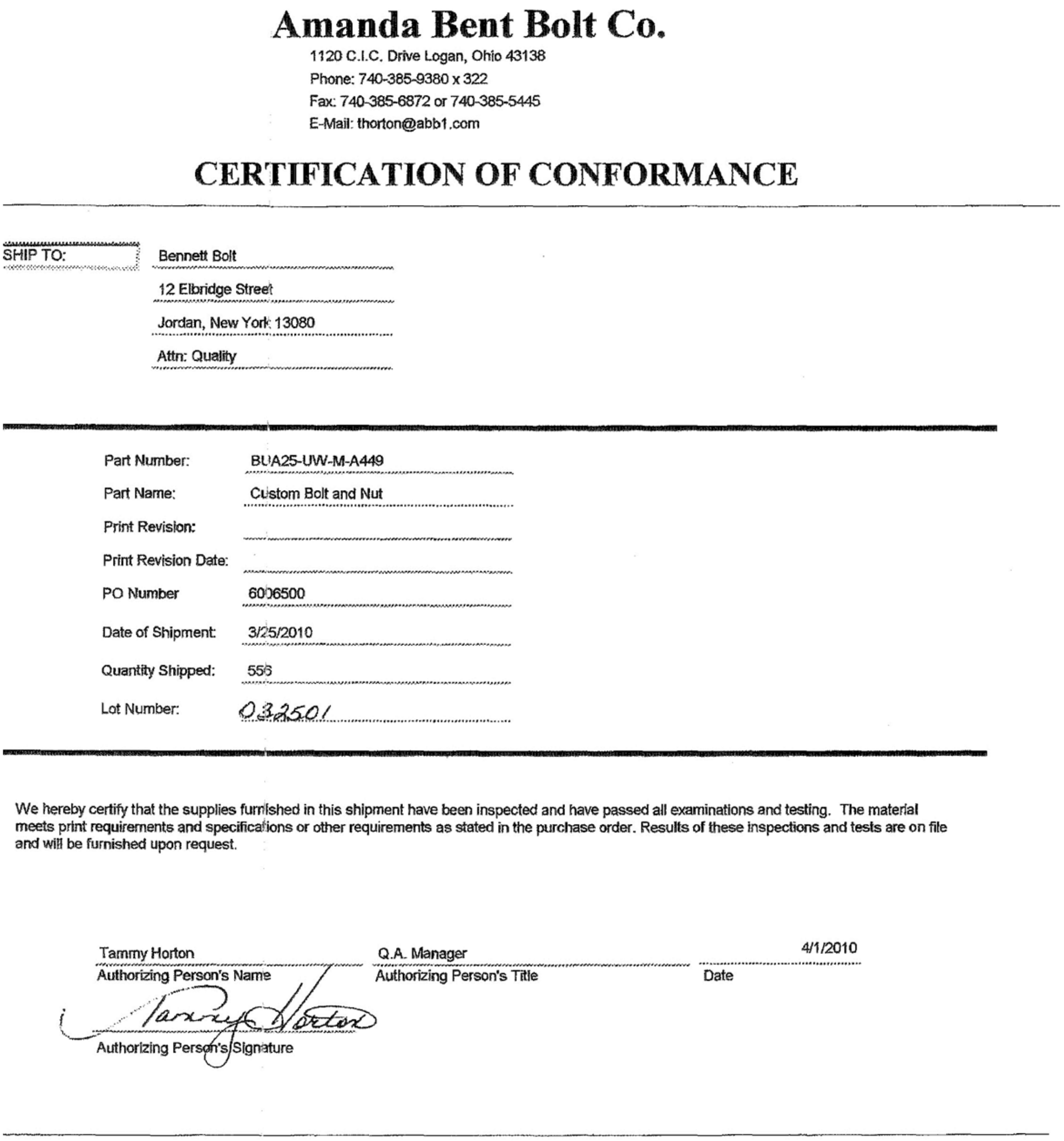
10 APPENDICES

Appendix A. Material Specifications



Amanda Bent Bolt Co.

1120 C.I.C. Drive Logan, Ohio 43138
Phone: 740-385-9380 x 322
Fax: 740-385-6872 or 740-385-5445
E-Mail: thorton@abb1.com

CERTIFICATION OF CONFORMANCE

SHIP TO:

Bennett Bolt
12 Elbridge Street
Jordan, New York 13080
Attn: Quality

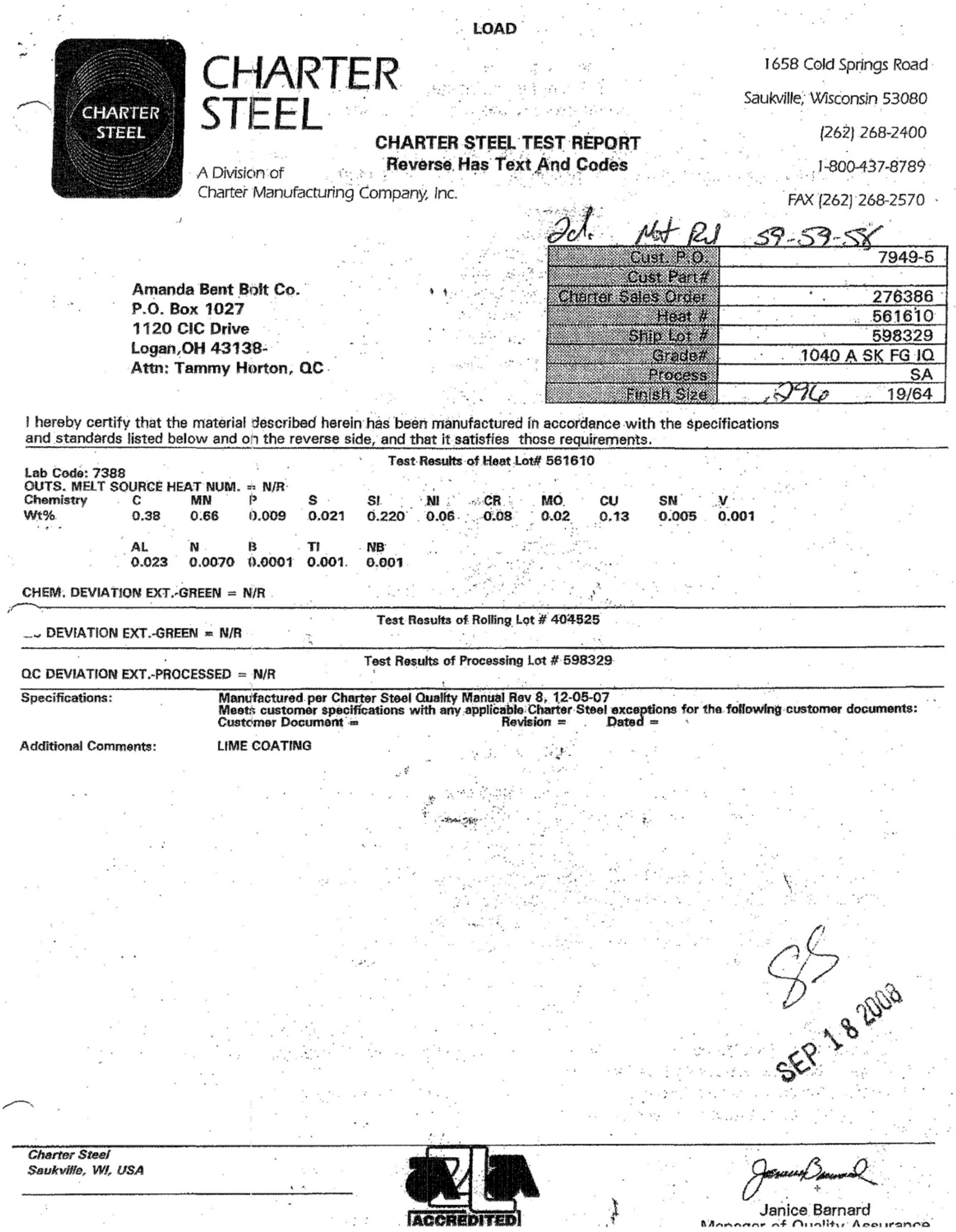
Part Number:	BUA25-UW-M-A449
Part Name:	Custom Bolt and Nut
Print Revision:	
Print Revision Date:	
PO Number	6006500
Date of Shipment:	3/25/2010
Quantity Shipped:	556
Lot Number:	032501

We hereby certify that the supplies furnished in this shipment have been inspected and have passed all examinations and testing. The material meets print requirements and specifications or other requirements as stated in the purchase order. Results of these inspections and tests are on file and will be furnished upon request.

Tammy Horton	Q.A. Manager	4/1/2010
Authorizing Person's Name	Authorizing Person's Title	Date

Tammy Horton
Authorizing Person's Signature

Figure A-1. Keyway Bolt



LOAD

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

2d. Mat Rel 59-59-58

Amanda Bent Bolt Co.
P.O. Box 1027
1120 CIC Drive
Logan,OH 43138-
Attn: Tammy Horton, QC

Cust. P.O.	7949-5
Cust Part#	
Charter Sales Order	276386
Heat #	561610
Ship Lot #	598329
Grade#	1040 A SK FG IQ
Process	SA
Finish Size	.296 19/64

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side, and that it satisfies those requirements.

Test Results of Heat Lot# 561610

Lab Code: 7388
OUTS. MELT SOURCE HEAT NUM. = N/R

Chemistry	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
Wt%	0.38	0.66	0.009	0.021	0.220	0.06	0.08	0.02	0.13	0.005	0.001
	AL	N	B	TI	NB						
	0.023	0.0070	0.0001	0.001	0.001						

CHEM. DEVIATION EXT.-GREEN = N/R

Test Results of Rolling Lot # 404525

DEVIATION EXT.-GREEN = N/R

Test Results of Processing Lot # 598329

QC DEVIATION EXT.-PROCESSED = N/R

Specifications: Manufactured per Charter Steel Quality Manual Rev 8, 12-05-07
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = Revision = Dated =

Additional Comments: LIME COATING

SEP 18 2008

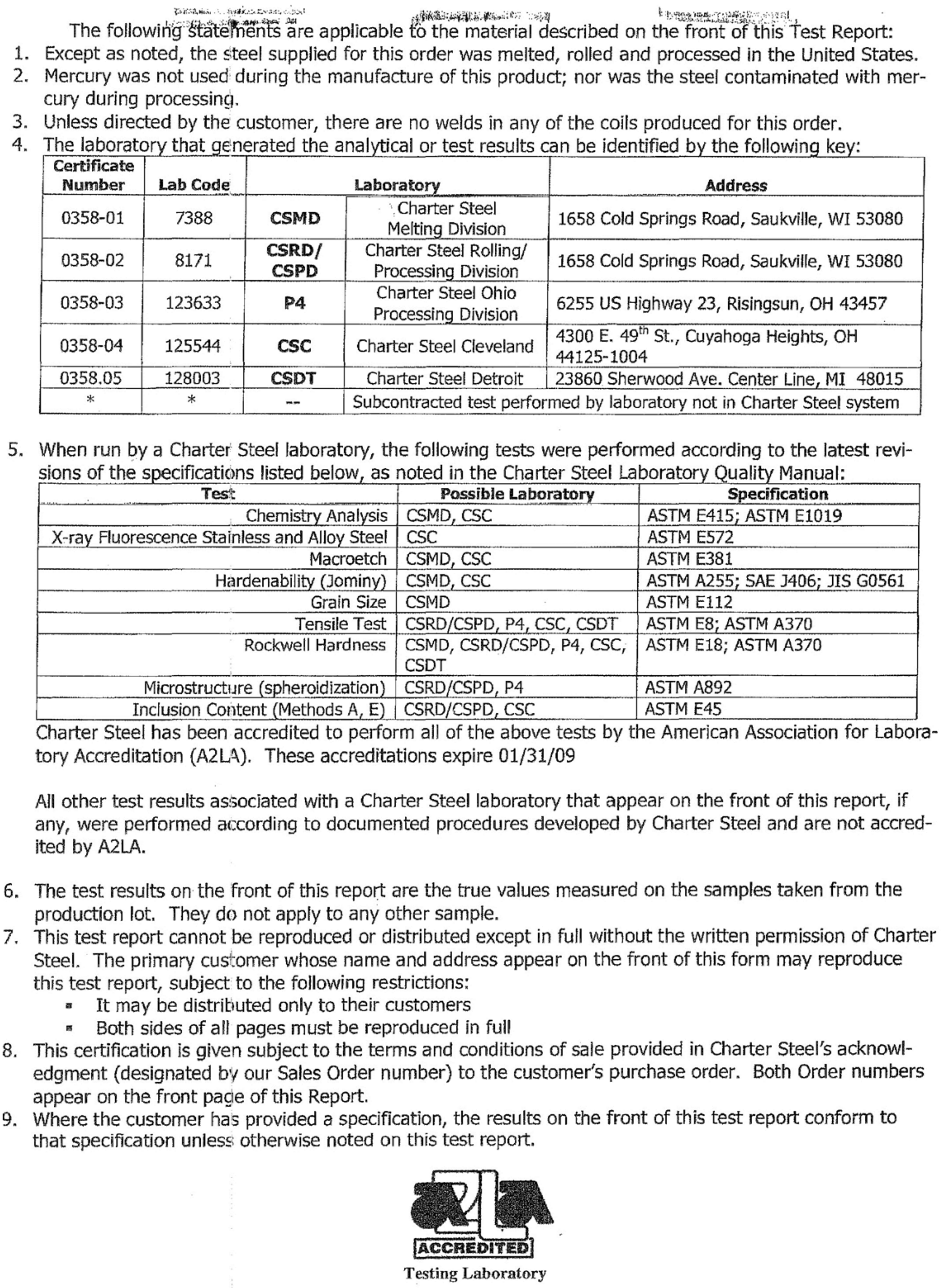
Charter Steel
Saukville, WI, USA

ACCREDITED

Janice Barnard

Janice Barnard

Figure A-2. Keyway Bolt



The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled and processed in the United States.
2. Mercury was not used during the manufacture of this product; nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	**CSMD**	Charter Steel Melting Division	1658 Cold Springs Road, Saukville, WI 53080
0358-02	8171	**CSRD/ CSPD**	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	**P4**	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	**CSC**	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
0358.05	128003	**CSDT**	Charter Steel Detroit	23860 Sherwood Ave. Center Line, MI 48015
*	*	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Possible Laboratory	Specification
Chemistry Analysis	CSMD, CSC	ASTM E415; ASTM E1019
X-ray Fluorescence Stainless and Alloy Steel	CSC	ASTM E572
Macroetch	CSMD, CSC	ASTM E381
Hardenability (Jominy)	CSMD, CSC	ASTM A255; SAE J406; JIS G0561
Grain Size	CSMD	ASTM E112
Tensile Test	CSRD/CSPD, P4, CSC, CSDT	ASTM E8; ASTM A370
Rockwell Hardness	CSMD, CSRD/CSPD, P4, CSC, CSDT	ASTM E18; ASTM A370
Microstructure (spheroidization)	CSRD/CSPD, P4	ASTM A892
Inclusion Content (Methods A, E)	CSRD/CSPD, CSC	ASTM E45

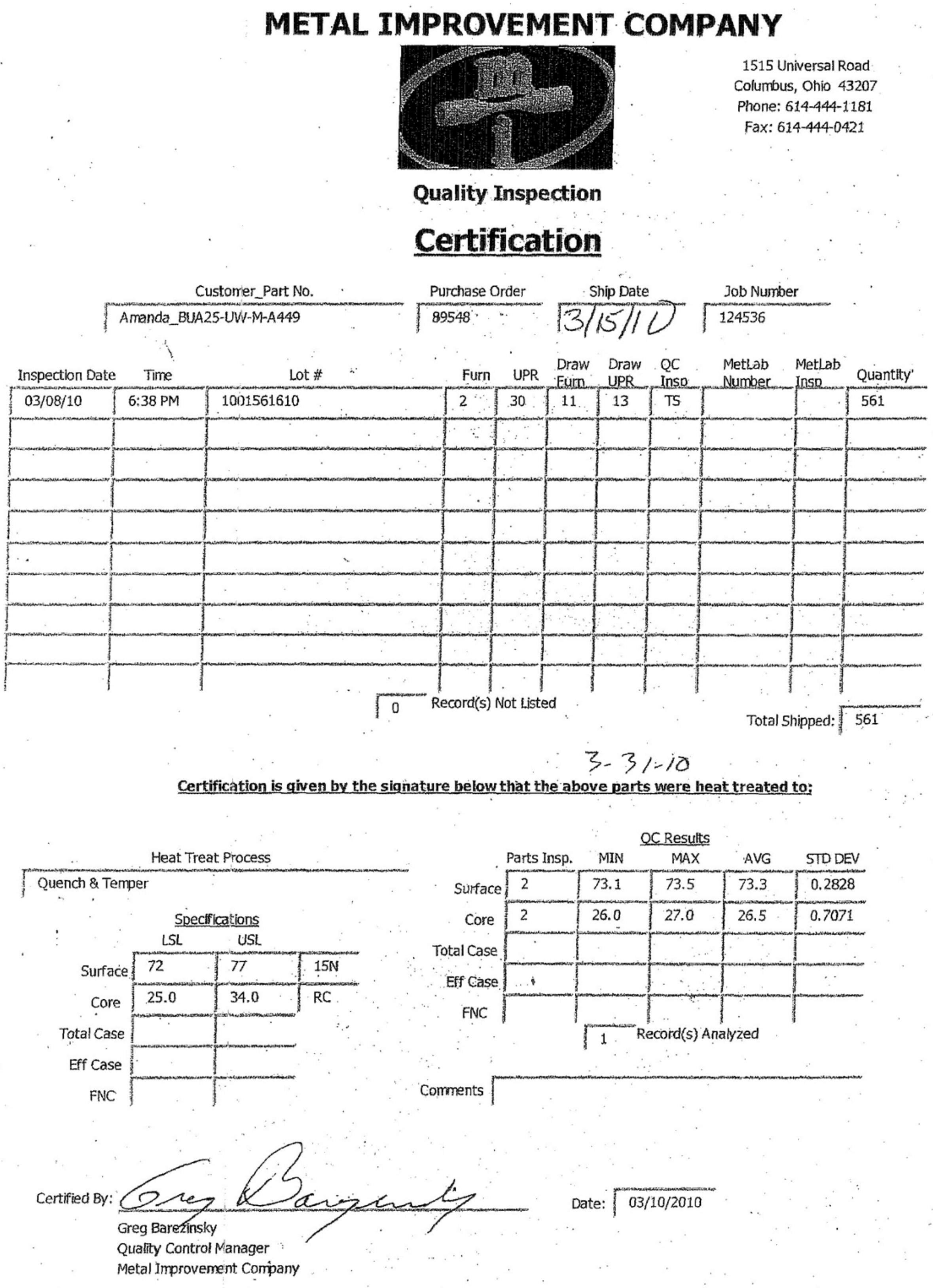
Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/09

All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report, subject to the following restrictions:
    - It may be distributed only to their customers
    - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgment (designated by our Sales Order number) to the customer's purchase order. Both Order numbers appear on the front page of this Report.
9. Where the customer has provided a specification, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

ACCREDITED
Testing Laboratory

Figure A-3. Keyway Bolt



METAL IMPROVEMENT COMPANY

1515 Universal Road
Columbus, Ohio 43207
Phone: 614-444-1181
Fax: 614-444-0421

Quality Inspection

Certification

Customer_Part No.	Purchase Order	Ship Date	Job Number
Amanda_BUA25-UW-M-A449	89548	3/15/10	124536

Inspection Date	Time	Lot #	Furn	UPR	Draw Furn	Draw UPR	QC Insp	MetLab Number	MetLab Insp	Quantity
03/08/10	6:38 PM	1001561610	2	30	11	13	TS			561

0 Record(s) Not Listed

Total Shipped: 561

3-31-10

Certification is given by the signature below that the above parts were heat treated to:

Heat Treat Process: Quench & Temper

Specifications

	LSL	USL	
Surface	72	77	15N
Core	25.0	34.0	RC
Total Case			
Eff Case			
FNC			

QC Results

	Parts Insp.	MIN	MAX	AVG	STD DEV
Surface	2	73.1	73.5	73.3	0.2828
Core	2	26.0	27.0	26.5	0.7071
Total Case					
Eff Case					
FNC					

1 Record(s) Analyzed

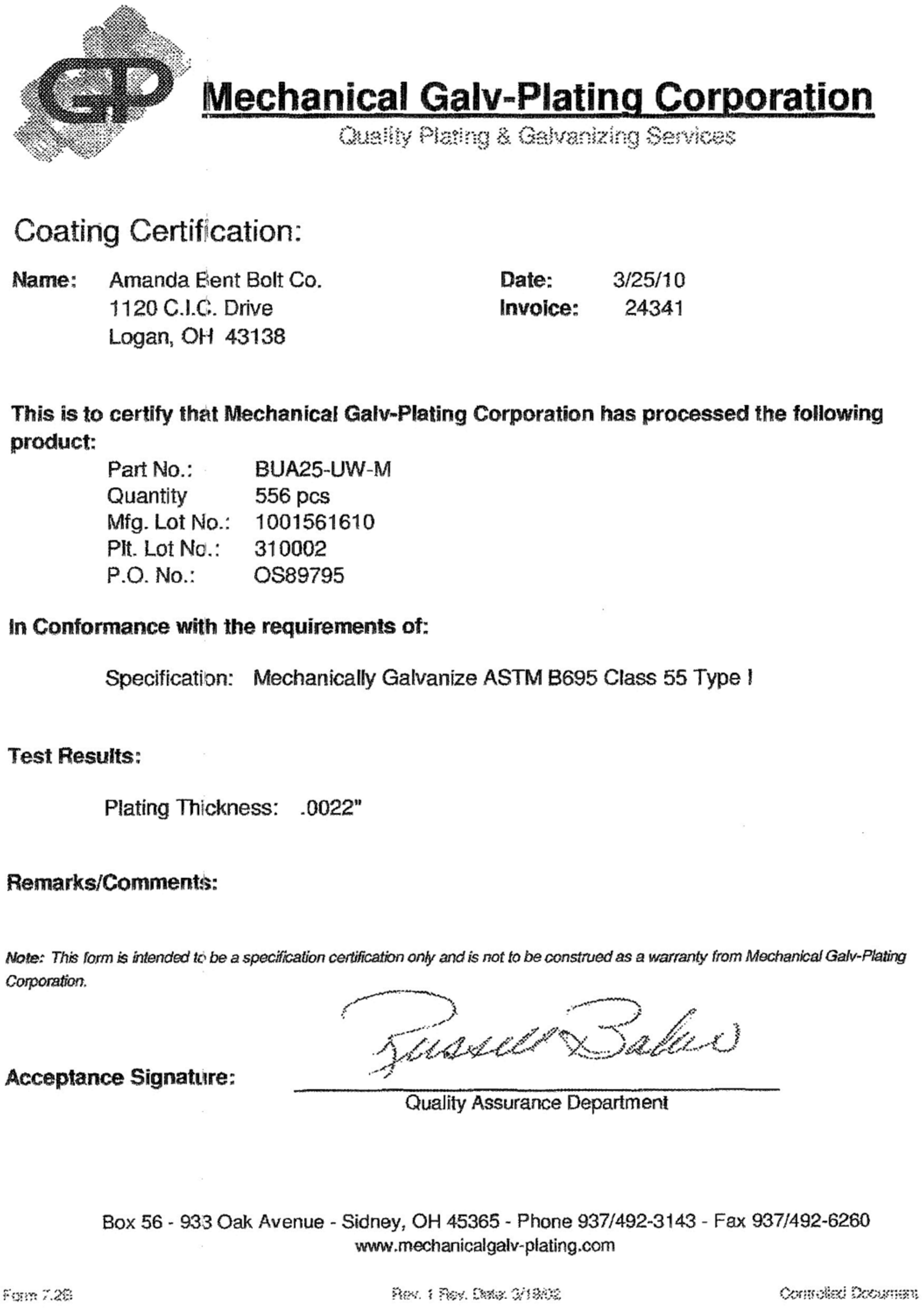
Comments:

Certified By: Greg Barezinsky

Date: 03/10/2010

Greg Barezinsky
Quality Control Manager
Metal Improvement Company

Figure A-4. Keyway Bolt



Mechanical Galv-Plating Corporation

Quality Plating & Galvanizing Services

Coating Certification:

Name: Amanda Bent Bolt Co.
1120 C.I.C. Drive
Logan, OH 43138

Date: 3/25/10
Invoice: 24341

This is to certify that Mechanical Galv-Plating Corporation has processed the following product:

Part No.:	BUA25-UW-M
Quantity	556 pcs
Mfg. Lot No.:	1001561610
Plt. Lot No.:	310002
P.O. No.:	OS89795

In Conformance with the requirements of:

Specification: Mechanically Galvanize ASTM B695 Class 55 Type I

Test Results:

Plating Thickness: .0022"

Remarks/Comments:

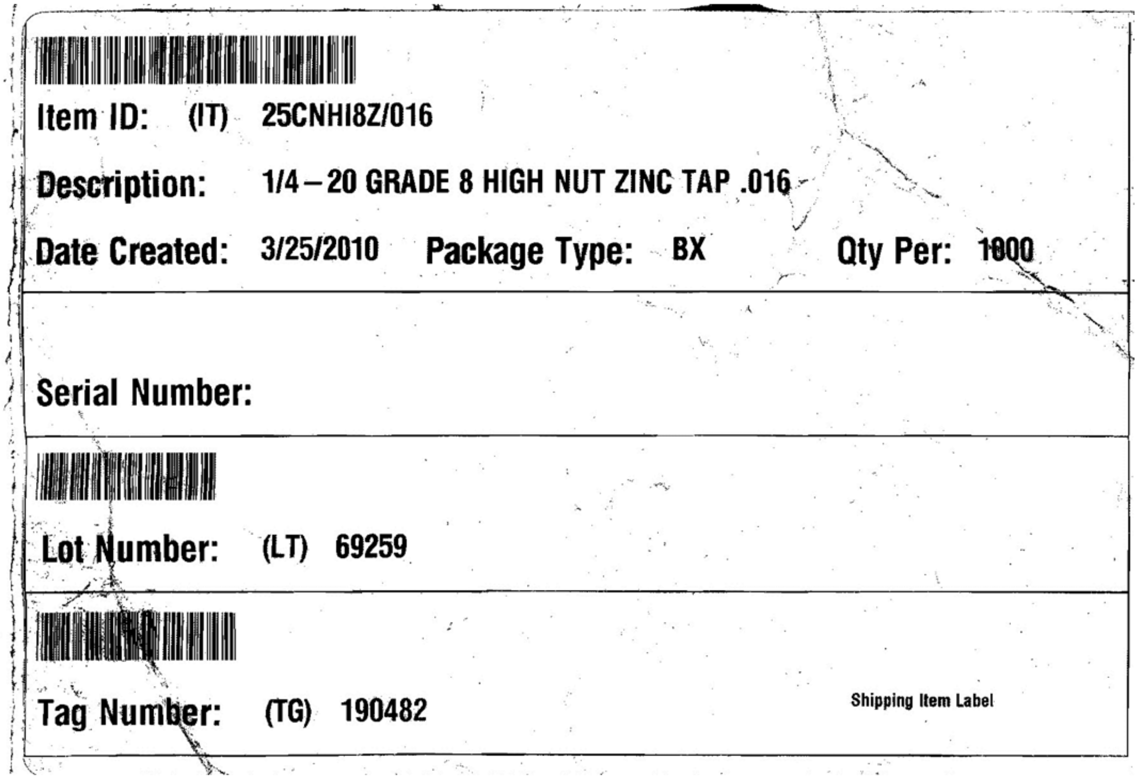
Note: *This form is intended to be a specification certification only and is not to be construed as a warranty from Mechanical Galv-Plating Corporation.*

Acceptance Signature: Russell Baker
Quality Assurance Department

Box 56 - 933 Oak Avenue - Sidney, OH 45365 - Phone 937/492-3143 - Fax 937/492-6260
www.mechanicalgalv-plating.com

Form 7.28 Rev. 1 Rev. Date: 3/19/02 Controlled Document

Figure A-5. Keyway Bolt



Item ID: (IT) 25CNHI8Z/016

Description: 1/4 – 20 GRADE 8 HIGH NUT ZINC TAP .016

Date Created: 3/25/2010 **Package Type:** BX **Qty Per:** 1000

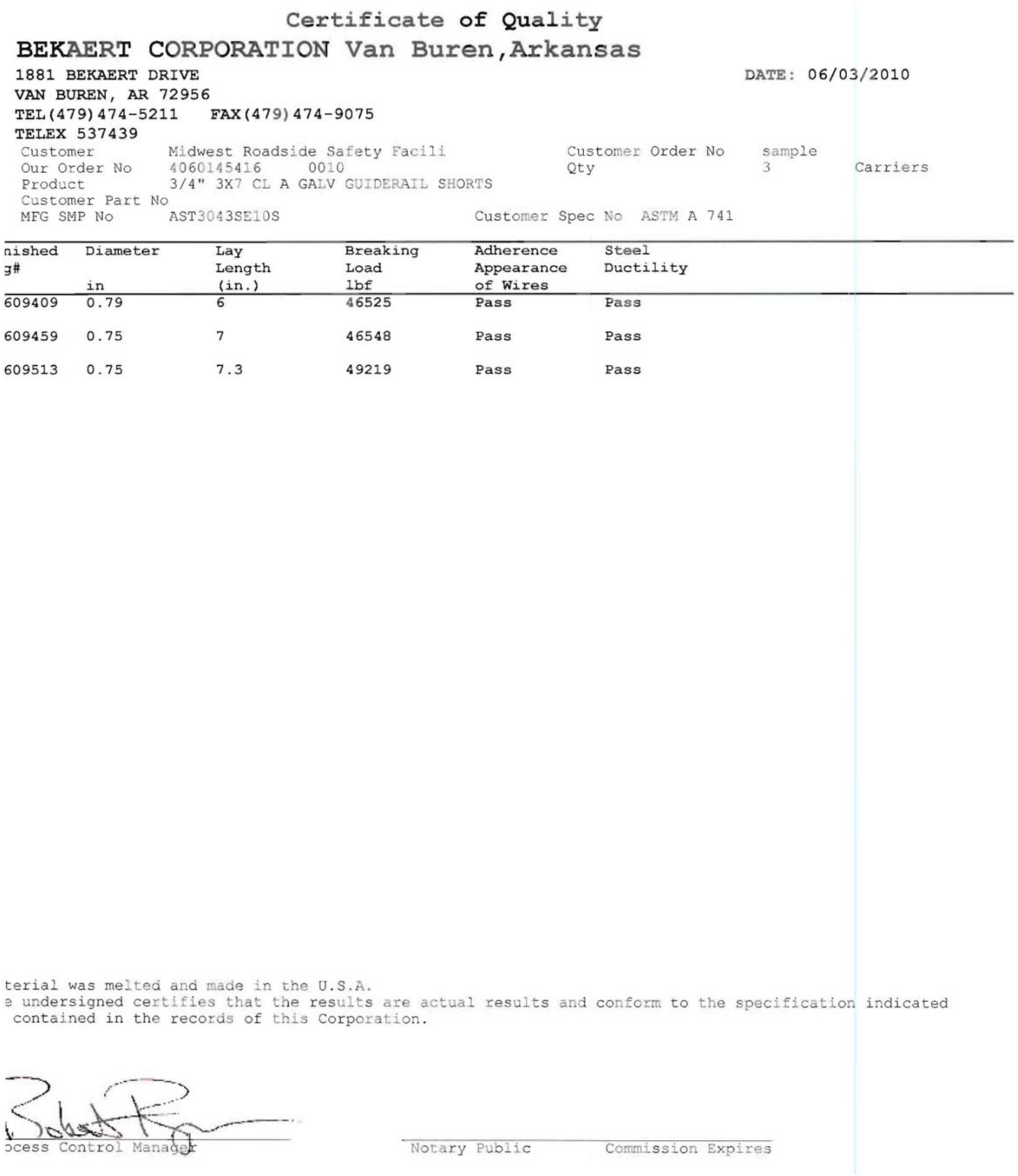
Serial Number:

Lot Number: (LT) 69259

Tag Number: (TG) 190482

Shipping Item Label

Figure A-6. Keyway Bolt Hex Nut



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

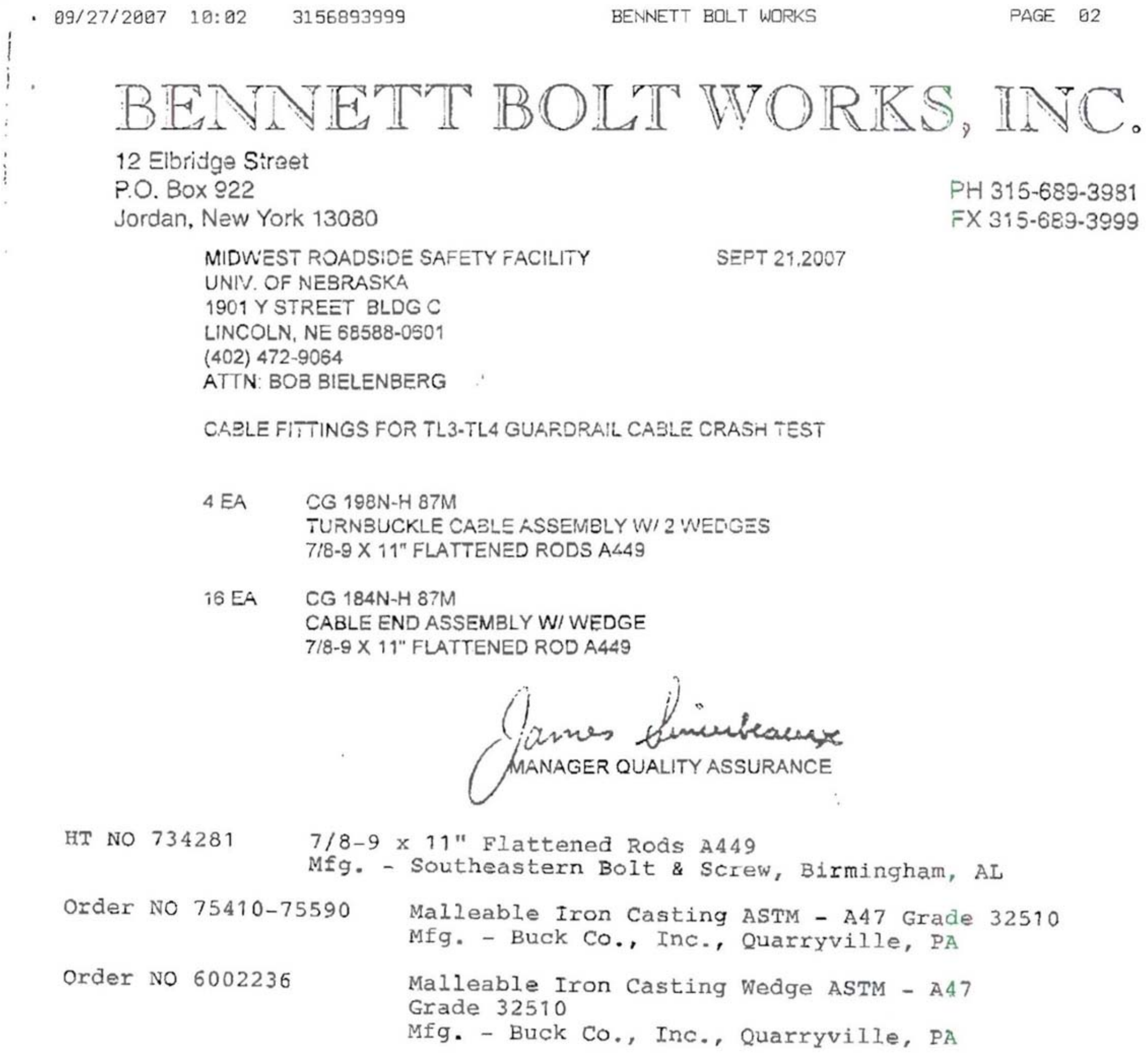
nished g#	Diameter in	Lay Length (in.)	Breaking Load lbf	Adherence Appearance of Wires	Steel Ductility
609409	0.79	6	46525	Pass	Pass
609459	0.75	7	46548	Pass	Pass
609513	0.75	7.3	49219	Pass	Pass

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-7. Wire Rope



09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 02

BENNETT BOLT WORKS, INC.

12 Elbridge Street
P.O. Box 922
Jordan, New York 13080

PH 315-689-3981
FX 315-689-3999

MIDWEST ROADSIDE SAFETY FACILITY
UNIV. OF NEBRASKA
1901 Y STREET BLDG C
LINCOLN, NE 68588-0601
(402) 472-9064
ATTN: BOB BIELENBERG

SEPT 21,2007

CABLE FITTINGS FOR TL3-TL4 GUARDRAIL CABLE CRASH TEST

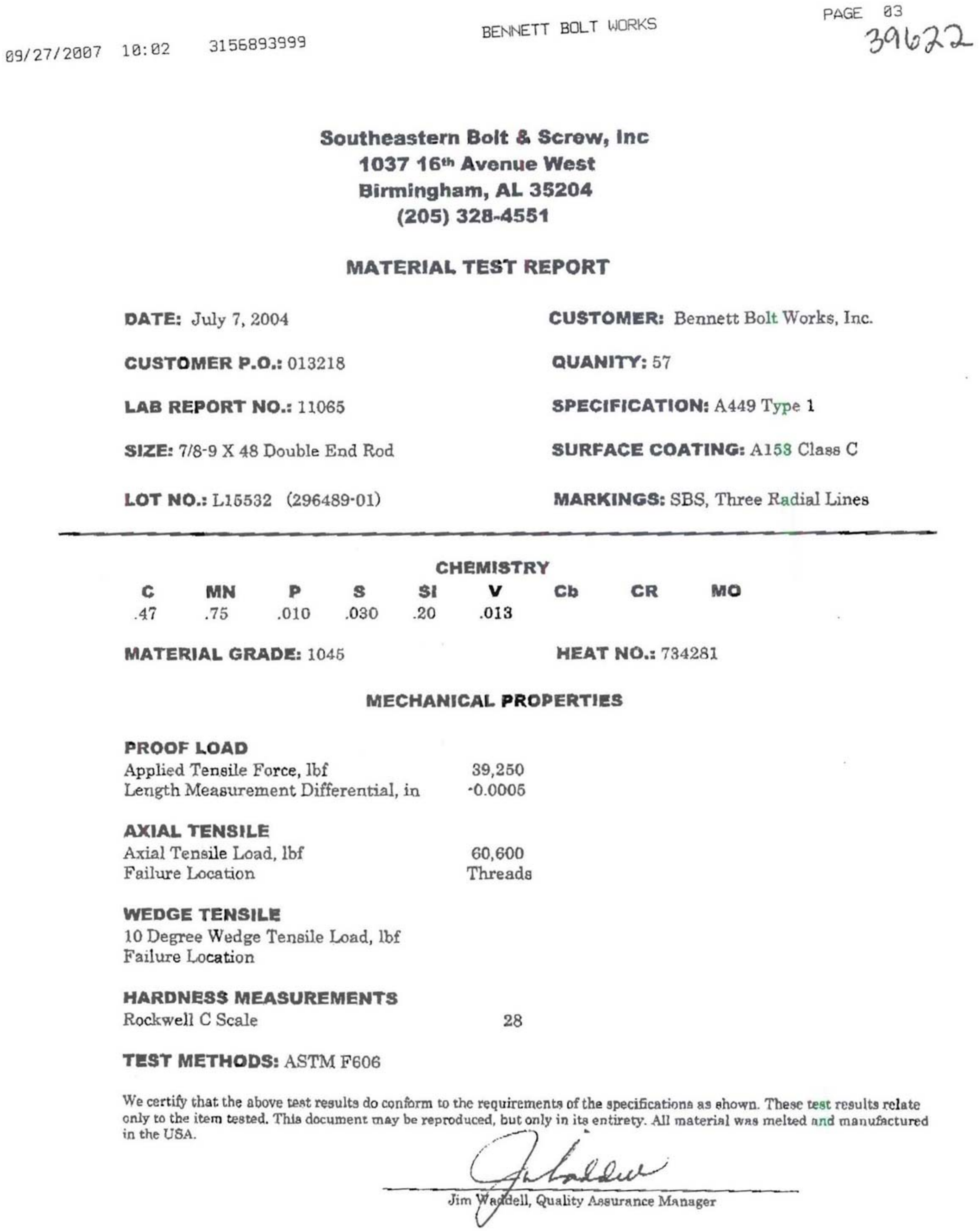
4 EA	CG 198N-H 87M TURNBUCKLE CABLE ASSEMBLY W/ 2 WEDGES 7/8-9 X 11" FLATTENED RODS A449
16 EA	CG 184N-H 87M CABLE END ASSEMBLY W/ WEDGE 7/8-9 X 11" FLATTENED ROD A449

James

MANAGER QUALITY ASSURANCE

HT NO 734281	7/8-9 x 11" Flattened Rods A449 Mfg. - Southeastern Bolt & Screw, Birmingham, AL
Order NO 75410-75590	Malleable Iron Casting ASTM - A47 Grade 32510 Mfg. - Buck Co., Inc., Quarryville, PA
Order NO 6002236	Malleable Iron Casting Wedge ASTM - A47 Grade 32510 Mfg. - Buck Co., Inc., Quarryville, PA

Figure A-8. Cable Turnbuckle and End Assembly



09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 03

39622

Southeastern Bolt & Screw, Inc
1037 16th Avenue West
Birmingham, AL 35204
(205) 328-4551

MATERIAL TEST REPORT

DATE: July 7, 2004

CUSTOMER: Bennett Bolt Works, Inc.

CUSTOMER P.O.: 013218

QUANITY: 57

LAB REPORT NO.: 11065

SPECIFICATION: A449 Type 1

SIZE: 7/8-9 X 48 Double End Rod

SURFACE COATING: A153 Class C

LOT NO.: L15532 (296489-01)

MARKINGS: SBS, Three Radial Lines

CHEMISTRY

C	MN	P	S	SI	V	Cb	CR	MO
.47	.75	.010	.030	.20	.013			

MATERIAL GRADE: 1045

HEAT NO.: 734281

MECHANICAL PROPERTIES

PROOF LOAD

Applied Tensile Force, lbf	39,250
Length Measurement Differential, in	-0.0005

AXIAL TENSILE

Axial Tensile Load, lbf	60,600
Failure Location	Threads

WEDGE TENSILE

10 Degree Wedge Tensile Load, lbf	
Failure Location	

HARDNESS MEASUREMENTS

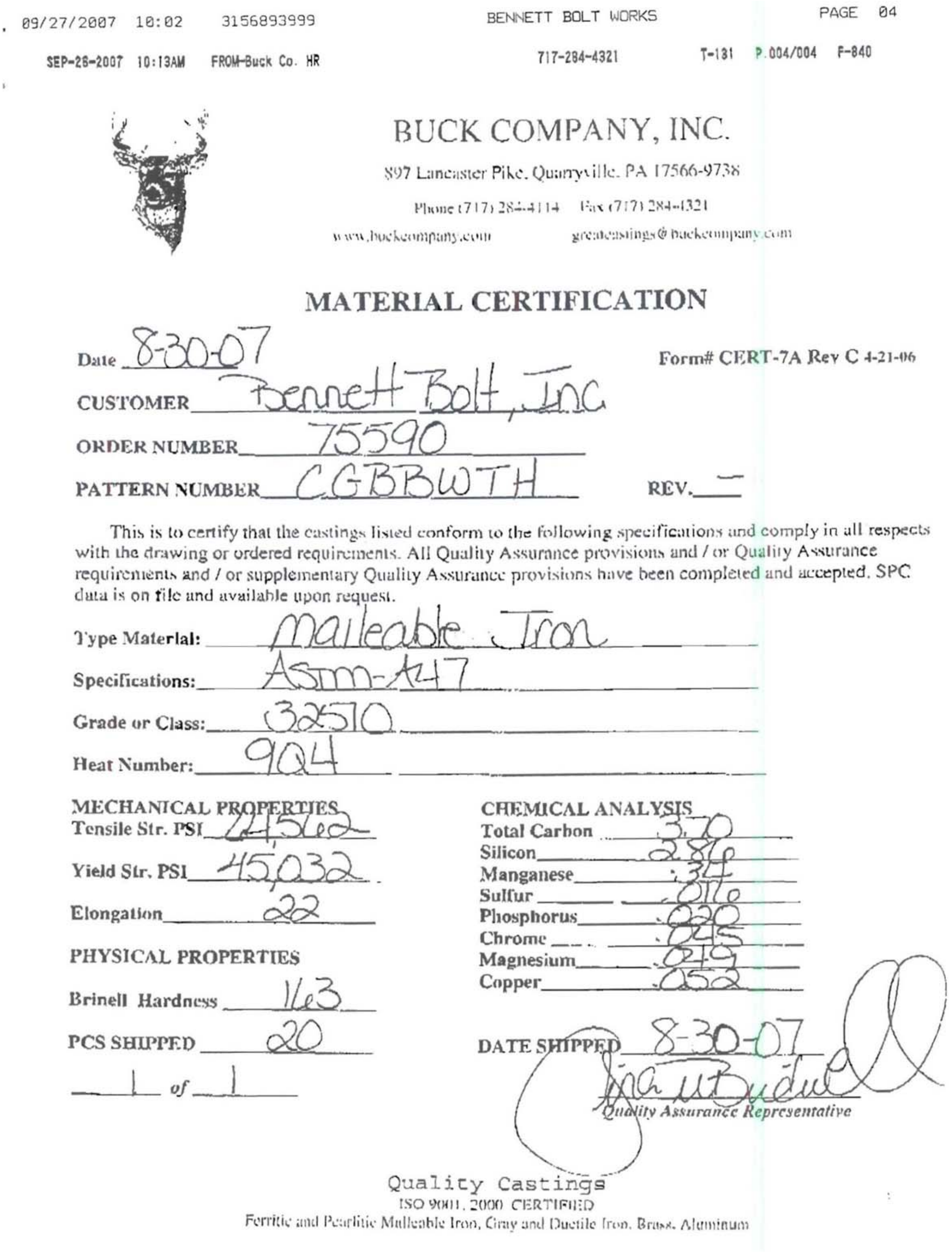
Rockwell C Scale	28

TEST METHODS: ASTM F606

We certify that the above test results do conform to the requirements of the specifications as shown. These test results relate only to the item tested. This document may be reproduced, but only in its entirety. All material was melted and manufactured in the USA.

Jim Waddell, Quality Assurance Manager

Figure A-9. Cable End Assembly



09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 04

SEP-26-2007 10:13AM FROM-Buck Co. HR 717-284-4321 T-131 P.004/004 F-840

BUCK COMPANY, INC.

897 Lancaster Pike, Quarryville, PA 17566-9738

Phone (717) 284-4114 Fax (717) 284-4321

www.buckcompany.com greatcastings@buckcompany.com

MATERIAL CERTIFICATION

Date 8-30-07

Form# CERT-7A Rev C 4-21-06

CUSTOMER Bennett Bolt, Inc

ORDER NUMBER 75590

PATTERN NUMBER CGBBWTH

REV. —

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

Type Material: Malleable Iron

Specifications: ASTM-A47

Grade or Class: 32510

Heat Number: 9Q4

MECHANICAL PROPERTIES

Tensile Str. PSI 24,562

Yield Str. PSI 45,032

Elongation 22

PHYSICAL PROPERTIES

Brinell Hardness 163

PCS SHIPPED 20

1 of 1

CHEMICAL ANALYSIS

Total Carbon 3.70

Silicon 2.86

Manganese .34

Sulfur .016

Phosphorus .020

Chrome .045

Magnesium .049

Copper .052

DATE SHIPPED 8-30-07

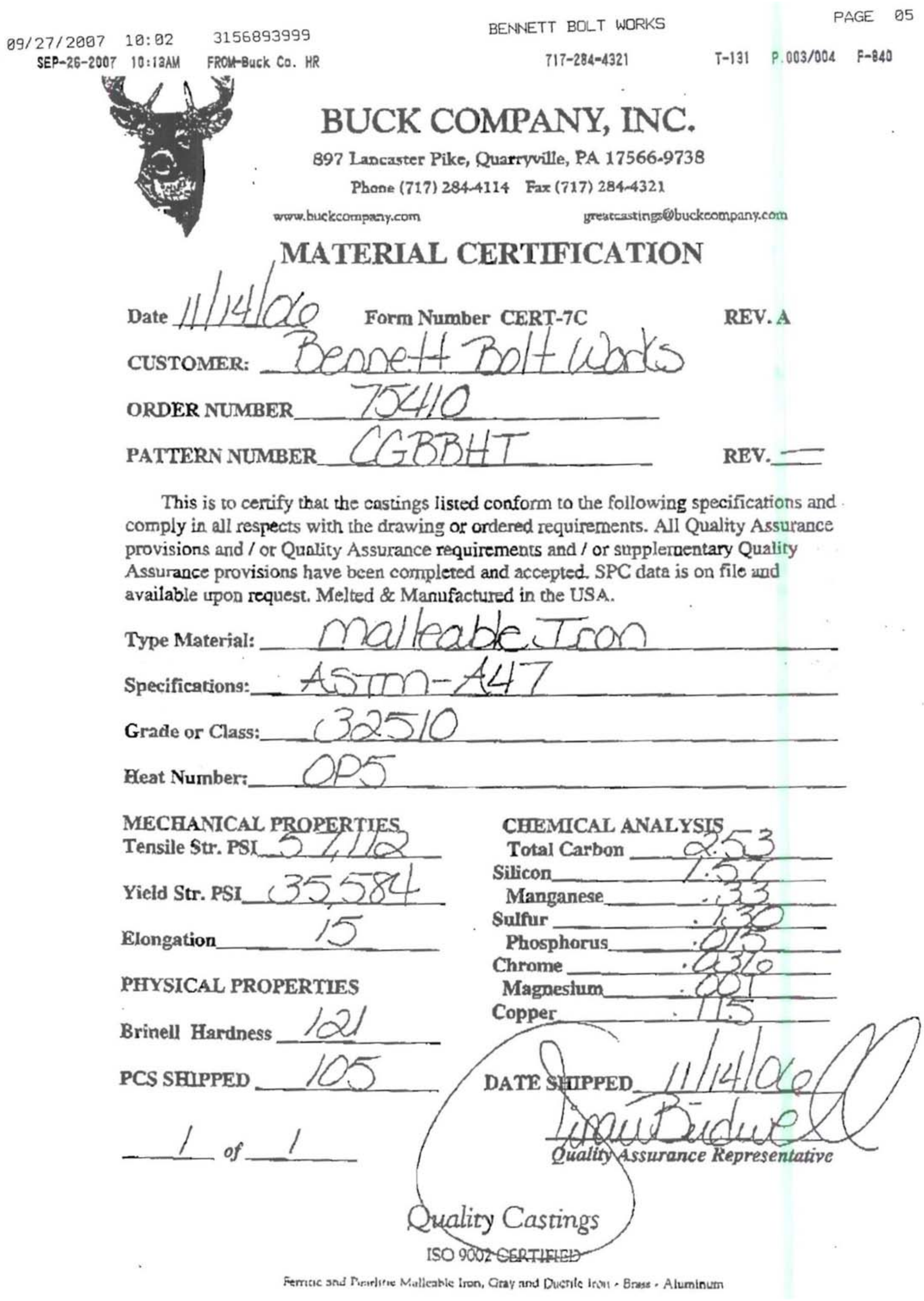
Quality Assurance Representative

Quality Castings

ISO 9001, 2000 CERTIFIED

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

Figure A-10. Cable End Assembly



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

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

MATERIAL CERTIFICATION

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

CUSTOMER: Bennett Bolt Works

ORDER NUMBER 75410

PATTERN NUMBER CGBBHT **REV.** —

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

Type Material: Malleable Iron

Specifications: ASTM-A47

Grade or Class: 32510

Heat Number: OP5

MECHANICAL PROPERTIES
Tensile Str. PSI 57,112
Yield Str. PSI 35,584
Elongation 15

PHYSICAL PROPERTIES
Brinell Hardness 121
PCS SHIPPED 105

CHEMICAL ANALYSIS
Total Carbon 2.53
Silicon 1.57
Manganese .33
Sulfur .130
Phosphorus .015
Chrome .036
Magnesium .001
Copper .115

DATE SHIPPED 11/14/06

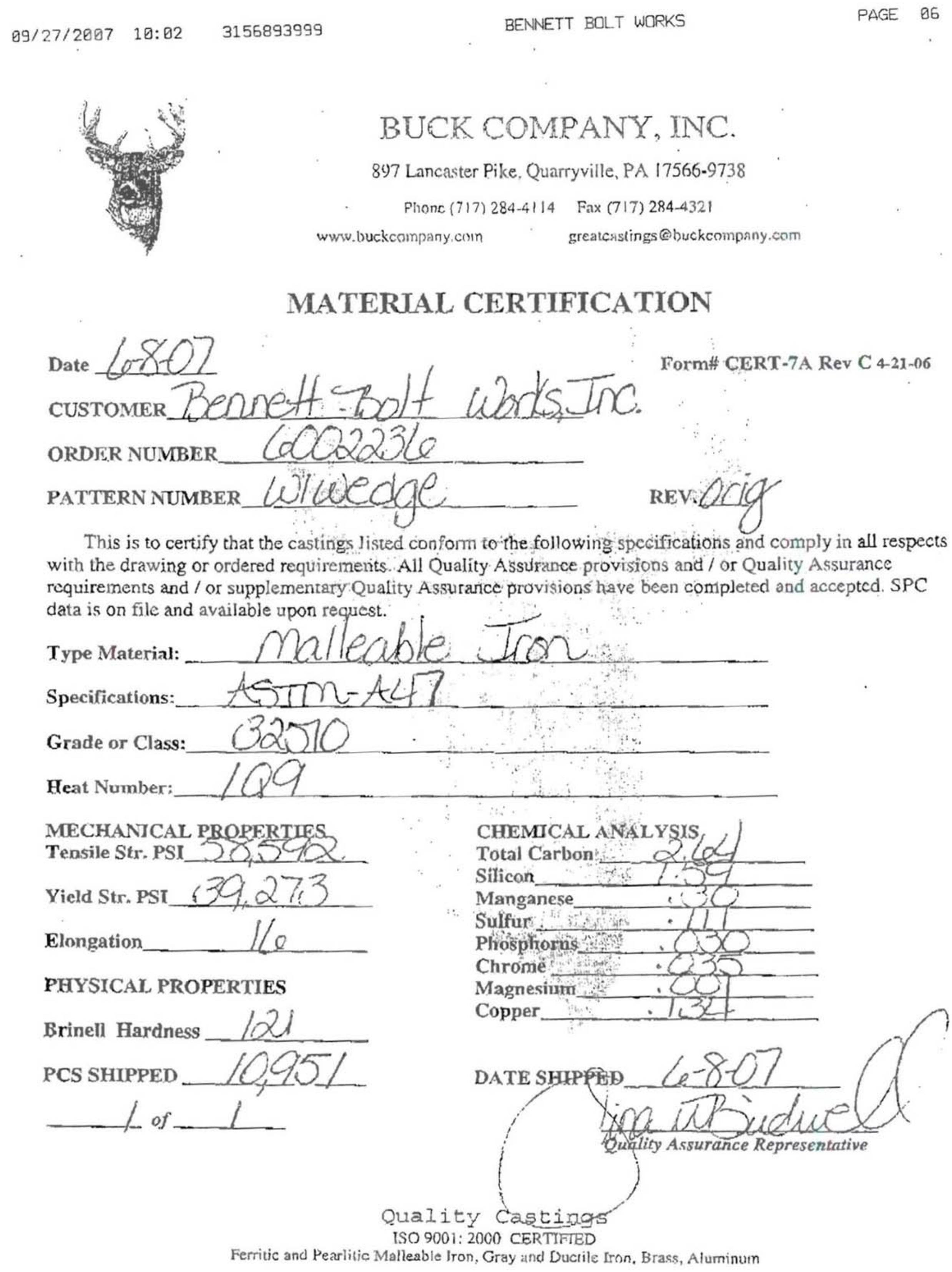
Quality Assurance Representative

1 of 1

Quality Castings
ISO 9002 CERTIFIED

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

Figure A-11. Cable End Assembly



09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 06

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

MATERIAL CERTIFICATION

Date 6-8-07

Form# CERT-7A Rev C 4-21-06

CUSTOMER Bennett Bolt Works, Inc.

ORDER NUMBER 6002236

PATTERN NUMBER W1 wedge **REV.** orig

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

Type Material: Malleable Iron

Specifications: ASTM-A47

Grade or Class: 32510

Heat Number: 1Q9

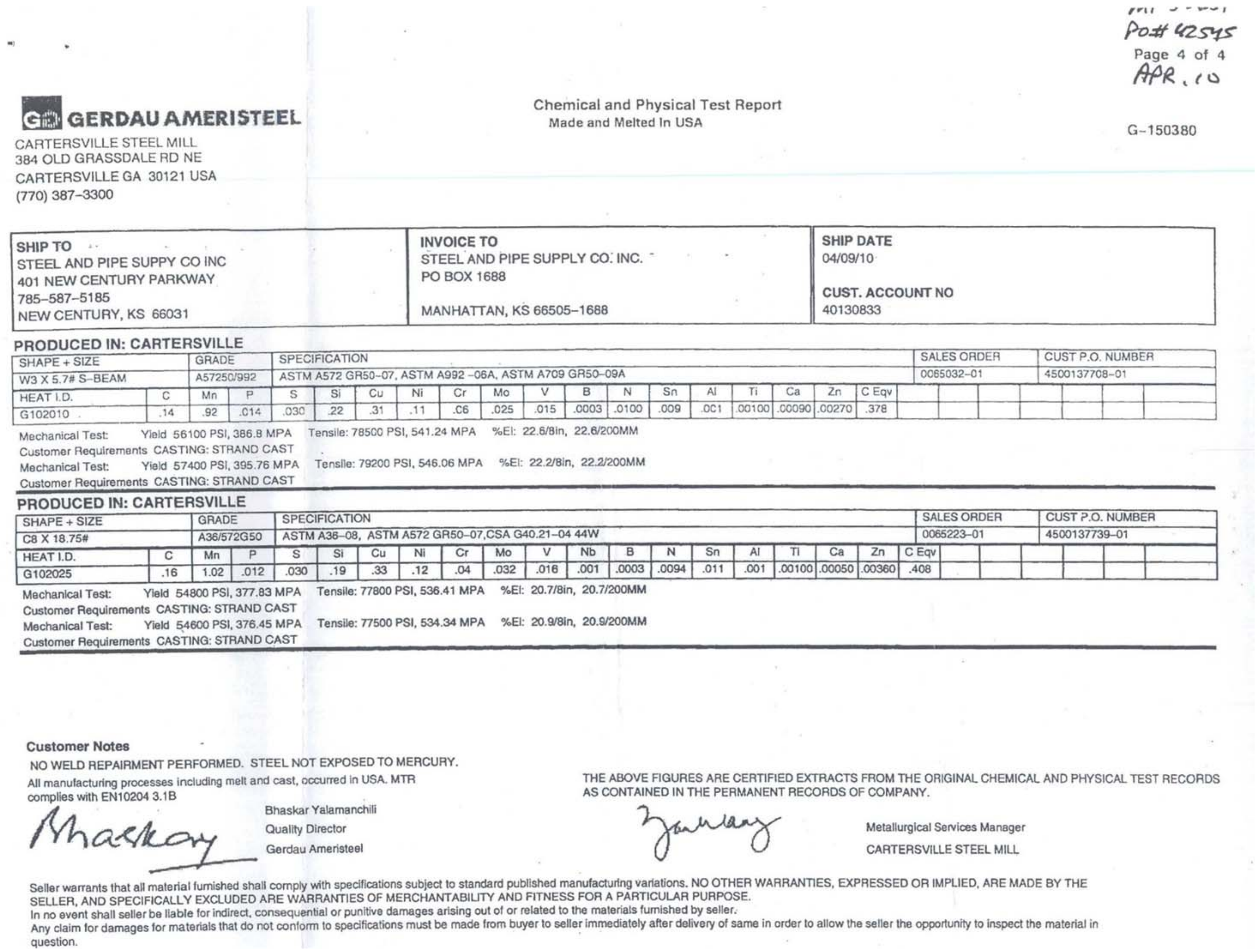
MECHANICAL PROPERTIES		**CHEMICAL ANALYSIS**	
Tensile Str. PSI	58,592	**Total Carbon**	2.64
		Silicon	1.59
Yield Str. PSI	39,273	**Manganese**	.30
		Sulfur	.11
Elongation	16	**Phosphorus**	.030
		Chrome	.035
PHYSICAL PROPERTIES		**Magnesium**	.001
		Copper	.134
Brinell Hardness	121		
PCS SHIPPED	10,951	**DATE SHIPPED**	6-8-07

1 of 1

Quality Assurance Representative

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

Figure A-12. Cable End Assembly



Po# 42545

Page 4 of 4

APR. 10

G-150380

GERDAU AMERISTEEL

CARTERSVILLE STEEL MILL
384 OLD GRASSDALE RD NE
CARTERSVILLE GA 30121 USA
(770) 387-3300

Chemical and Physical Test Report
Made and Melted In USA

SHIP TO	INVOICE TO	SHIP DATE
STEEL AND PIPE SUPPY CO INC 401 NEW CENTURY PARKWAY 785-587-5185 NEW CENTURY, KS 66031	STEEL AND PIPE SUPPLY CO. INC. PO BOX 1688 MANHATTAN, KS 66505-1688	04/09/10 **CUST. ACCOUNT NO** 40130833

PRODUCED IN: CARTERSVILLE

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
W3 X 5.7# S-BEAM	A57250/992	ASTM A572 GR50-07, ASTM A992 -06A, ASTM A709 GR50-09A	0065032-01	4500137708-01

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	B	N	Sn	Al	Ti	Ca	Zn	C Eqv
G102010	.14	.92	.014	.030	.22	.31	.11	.C6	.025	.015	.0003	.0100	.009	.0C1	.00100	.00090	.00270	.378

Mechanical Test: Yield 56100 PSI, 386.8 MPA Tensile: 78500 PSI, 541.24 MPA %El: 22.6/8in, 22.6/200MM
Customer Requirements CASTING: STRAND CAST
Mechanical Test: Yield 57400 PSI, 395.76 MPA Tensile: 79200 PSI, 546.06 MPA %El: 22.2/8in, 22.2/200MM
Customer Requirements CASTING: STRAND CAST

PRODUCED IN: CARTERSVILLE

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
C8 X 18.75#	A36/572G50	ASTM A36-08, ASTM A572 GR50-07,CSA G40.21-04 44W	0065223-01	4500137739-01

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv
G102025	.16	1.02	.012	.030	.19	.33	.12	.04	.032	.016	.001	.0003	.0094	.011	.001	.00100	.00050	.00360	.408

Mechanical Test: Yield 54800 PSI, 377.83 MPA Tensile: 77800 PSI, 536.41 MPA %El: 20.7/8in, 20.7/200MM
Customer Requirements CASTING: STRAND CAST
Mechanical Test: Yield 54600 PSI, 376.45 MPA Tensile: 77500 PSI, 534.34 MPA %El: 20.9/8in, 20.9/200MM
Customer Requirements CASTING: STRAND CAST

Customer Notes
NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
All manufacturing processes including melt and cast, occurred in USA. MTR complies with EN10204 3.1B

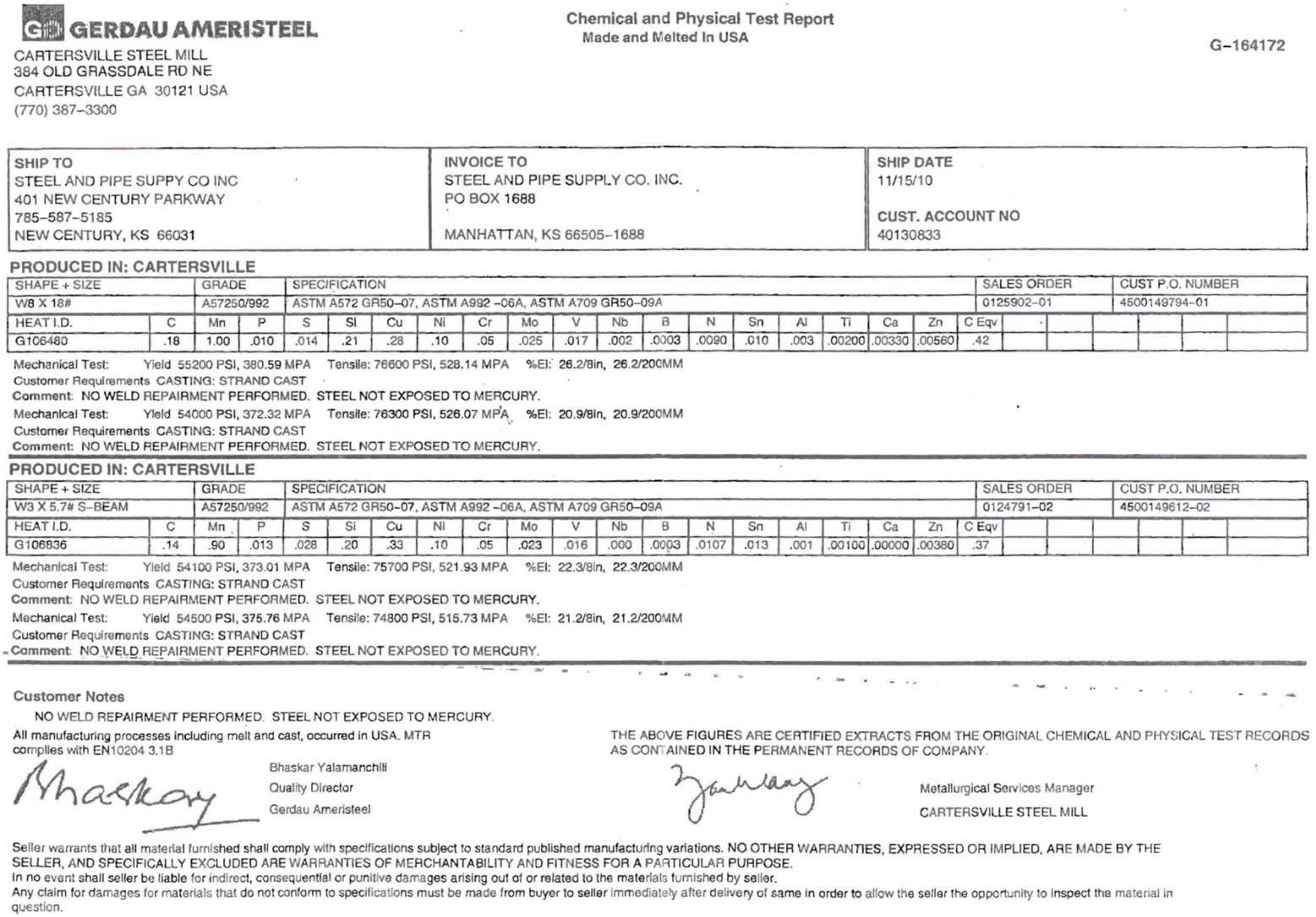
THE ABOVE FIGURES ARE CERTIFIED EXTRACTS FROM THE ORIGINAL CHEMICAL AND PHYSICAL TEST RECORDS AS CONTAINED IN THE PERMANENT RECORDS OF COMPANY.

Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

Metallurgical Services Manager
CARTERSVILLE 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-13. S3x5.7 Posts, Test No. 4CMB-4



GERDAU AMERISTEEL

CARTERSVILLE STEEL MILL
384 OLD GRASSDALE RD NE
CARTERSVILLE GA 30121 USA
(770) 387-3300

Chemical and Physical Test Report
Made and Melted In USA

G-164172

SHIP TO	INVOICE TO	SHIP DATE
STEEL AND PIPE SUPPY CO INC 401 NEW CENTURY PARKWAY 785-587-5185 NEW CENTURY, KS 66031	STEEL AND PIPE SUPPLY CO. INC. PO BOX 1688 MANHATTAN, KS 66505-1688	11/15/10 **CUST. ACCOUNT NO** 40130833

PRODUCED IN: CARTERSVILLE

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
W8 X 18#	A57250/992	ASTM A572 GR50-07, ASTM A992 -06A, ASTM A709 GR50-09A	0125902-01	4500149794-01

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv						
G106480	.18	1.00	.010	.014	.21	.28	.10	.05	.025	.017	.002	.0003	.0090	.010	.003	.00200	.00330	.00560	.42						

Mechanical Test: Yield 55200 PSI, 380.59 MPA Tensile: 76600 PSI, 528.14 MPA %El: 26.2/8in, 26.2/200MM
Customer Requirements CASTING: STRAND CAST
Comment: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
Mechanical Test: Yield 54000 PSI, 372.32 MPA Tensile: 76300 PSI, 526.07 MPA %El: 20.9/8in, 20.9/200MM
Customer Requirements CASTING: STRAND CAST
Comment: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

PRODUCED IN: CARTERSVILLE

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
W3 X 5.7# S-BEAM	A57250/992	ASTM A572 GR50-07, ASTM A992 -06A, ASTM A709 GR50-09A	0124791-02	4500149612-02

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv						
G106836	.14	.90	.013	.028	.20	.33	.10	.05	.023	.016	.000	.0003	.0107	.013	.001	.00100	.00000	.00380	.37						

Mechanical Test: Yield 54100 PSI, 373.01 MPA Tensile: 75700 PSI, 521.93 MPA %El: 22.3/8in, 22.3/200MM
Customer Requirements CASTING: STRAND CAST
Comment: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
Mechanical Test: Yield 54500 PSI, 375.76 MPA Tensile: 74800 PSI, 515.73 MPA %El: 21.2/8in, 21.2/200MM
Customer Requirements CASTING: STRAND CAST
Comment: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

Customer Notes

NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

All manufacturing processes including melt and cast, occurred in USA. MTR complies with EN10204 3.1B

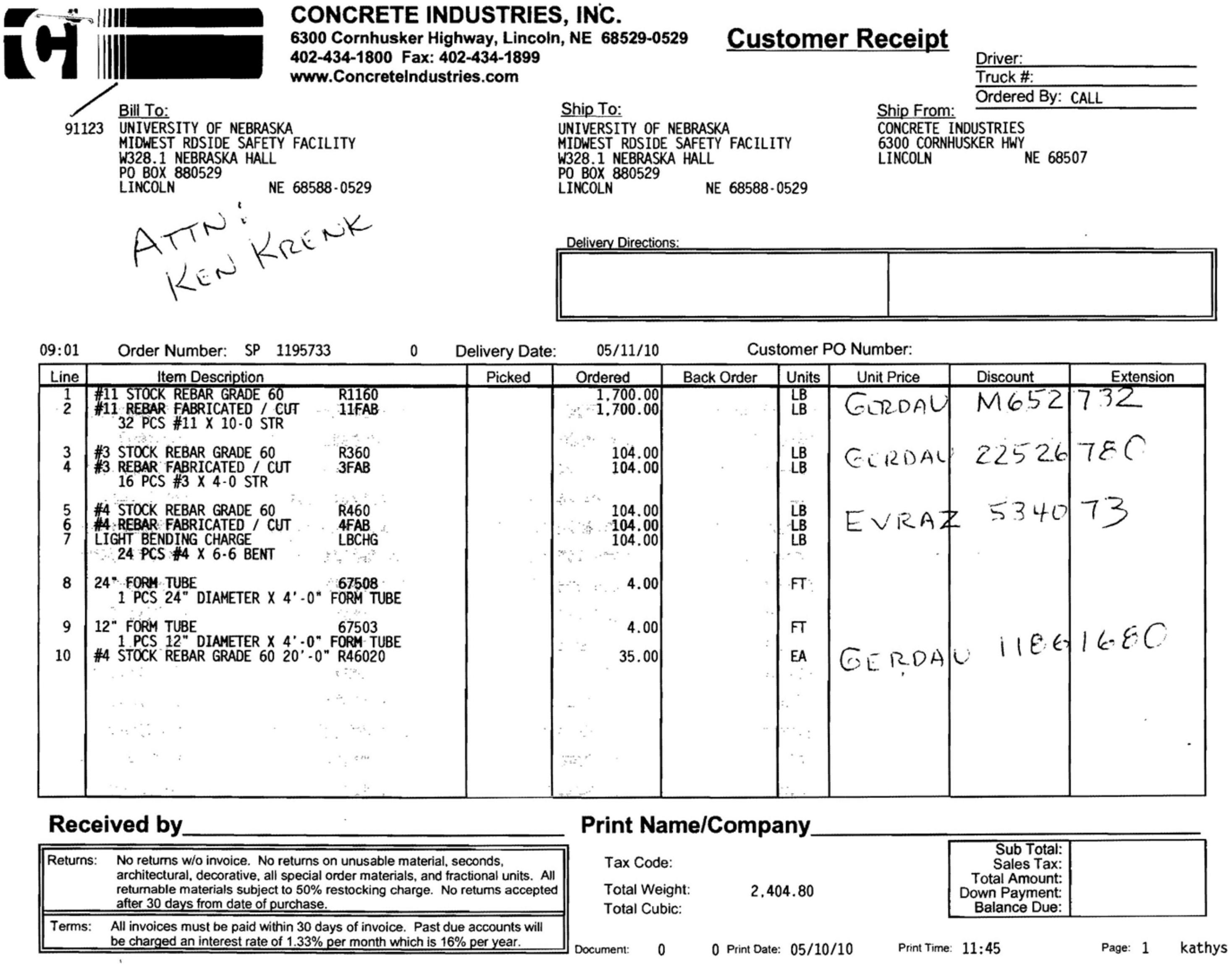
Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

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
CARTERSVILLE 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-14. S3x5.7 Posts, Test No. 4CMB-5



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

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

ATTN: KEN KRENK

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

Received by____________________ **Print Name/Company**____________________

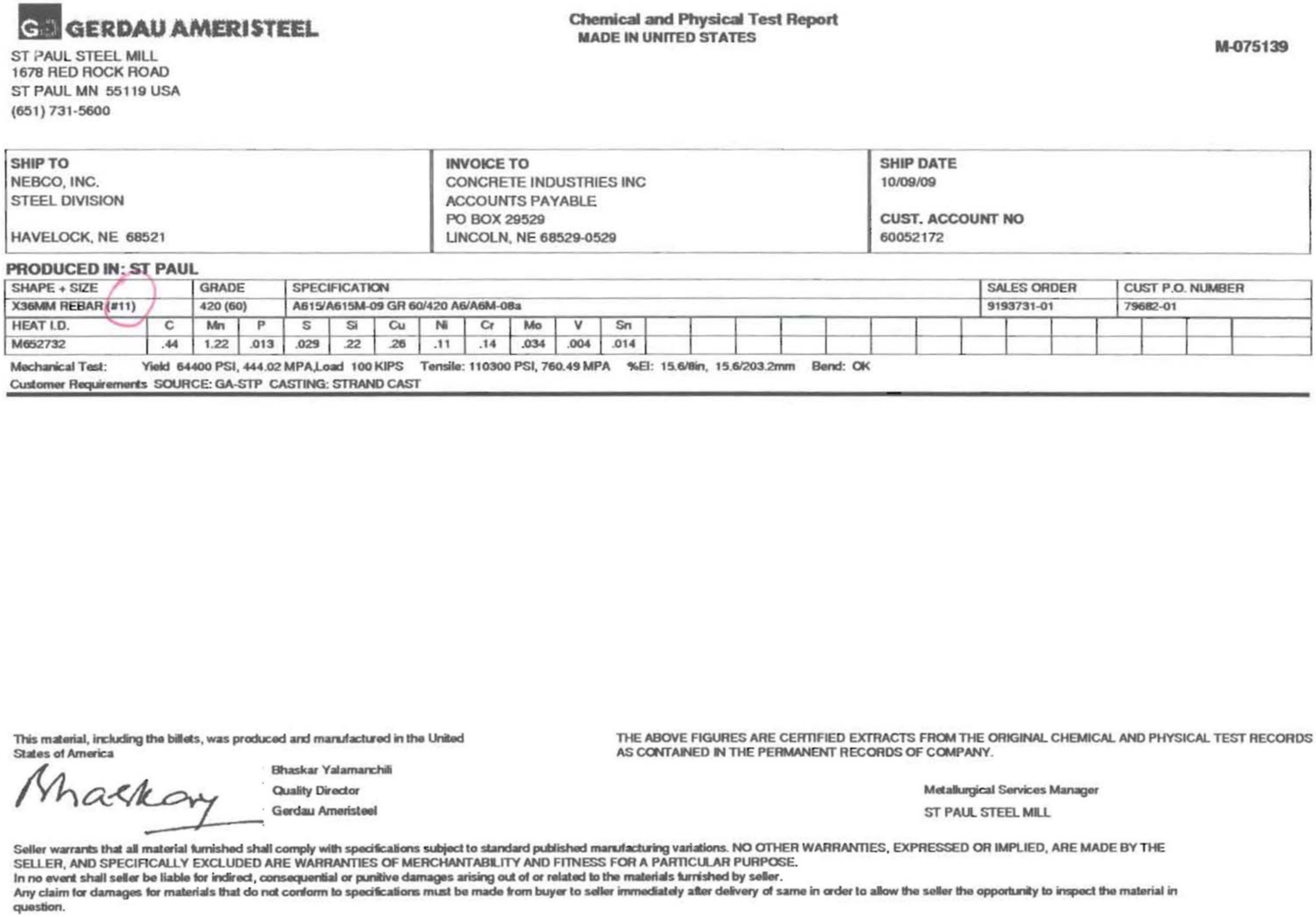
Returns:	No returns w/o invoice. No returns on unusable material, seconds, architectural, decorative, all special order materials, and fractional units. All returnable materials subject to 50% restocking charge. No returns accepted after 30 days from date of purchase.
Terms:	All invoices must be paid 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-15. Foundation Rebar



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

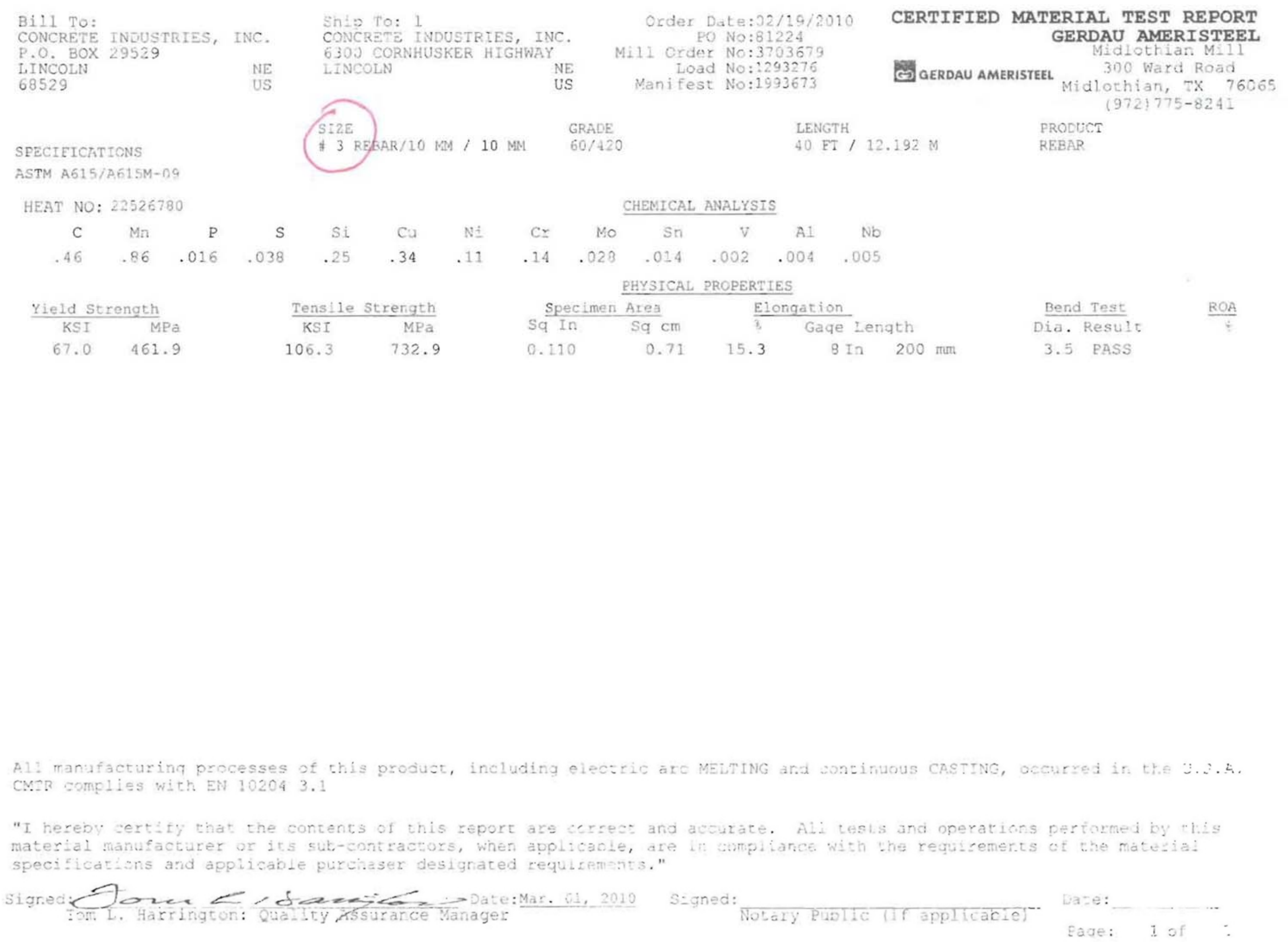
Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

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-16. Foundation Rebar



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

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			Bend Test		ROA
KSI	MPa	KSI	MPa	Sq In	Sq cm	%	Gage Length		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."

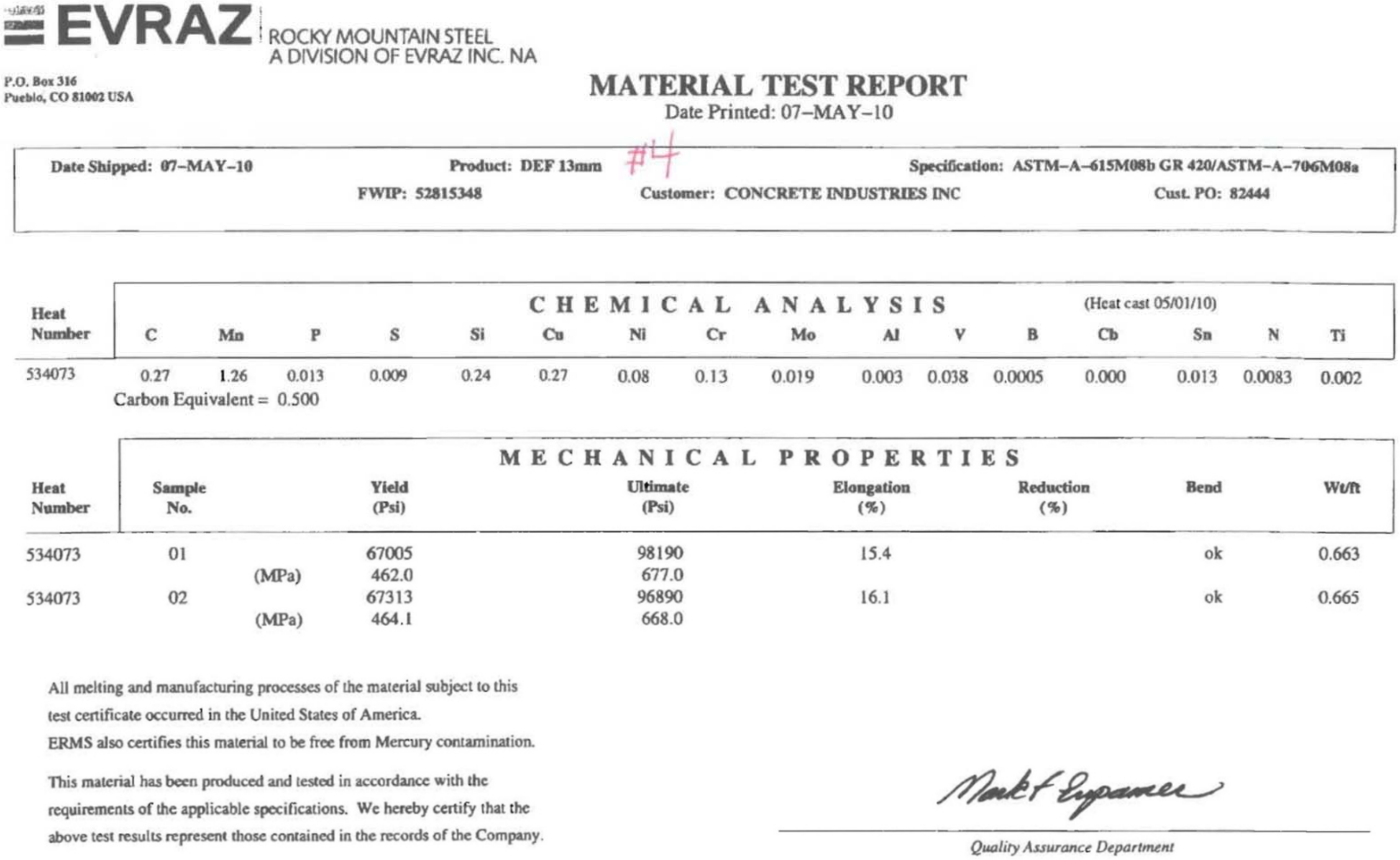
Signed: Date:Mar. 01, 2010
Tom L. Harrington: Quality Assurance Manager

Signed: ______________________
Notary Public (If applicable)

Date: ________

Page: 1 of 1

Figure A-17. Foundation Rebar



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

C H E M I C A L A N A L Y S I S (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

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

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 Expamer

Quality Assurance Department

Figure A-18. Foundation Rebar

E&A PRODUCTS ® COMPANY

Phone 763-493-3222
Fax 763-493-3214

June 16 , 2010

Carroll Distributing
205 S. Iowa Avenue
Ottumwa IA 52501

Certificate of Compliance

PO# 102556

32-Pcs ¾-10 x 18" + 9" HK ASTM-A449 Anchor Bolt HDG
1 HHN & 1 F436 FW HT# 0224800

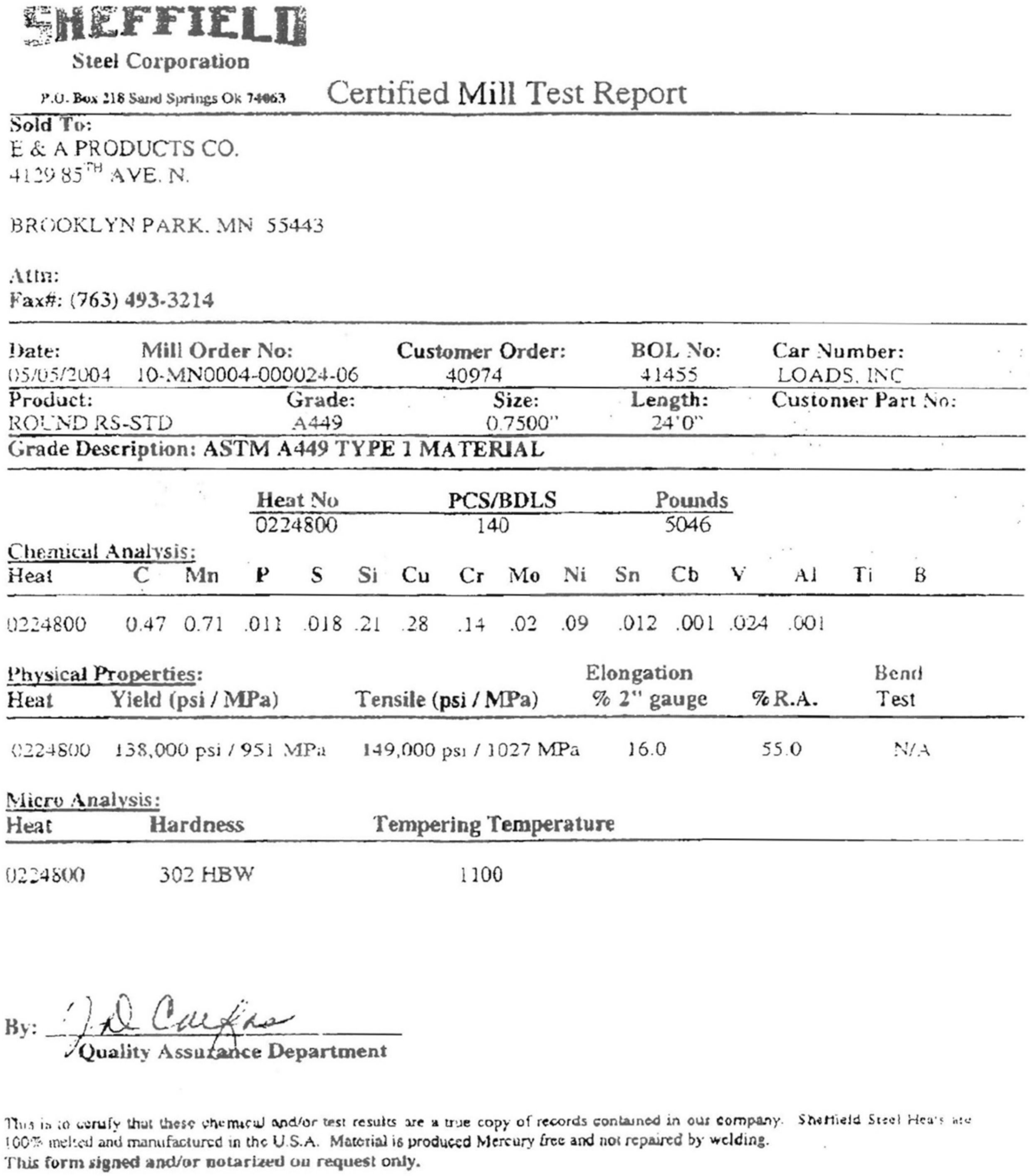
Melted & Manufactured In USA

We hereby certify that to the best of our knowledge and belief the subject material is manufactured to and will meet the dimensional and mechanical properties required in accordance with:

ASTM-A449,ASTM-A153

Certification Clerk Lisa Murphy
Lisa Murphy

Figure A-19. J-Hook Anchor



SHEFFIELD
Steel Corporation
P.O. Box 218 Sand Springs Ok 74063

Certified Mill Test Report

Sold To:
E & A PRODUCTS CO.
4129 85TH AVE. N.

BROOKLYN PARK, MN 55443

Attn:
Fax#: (763) 493-3214

Date:	**Mill Order No:**	**Customer Order:**	**BOL No:**	**Car Number:**
05/05/2004	10-MN0004-000024-06	40974	41455	LOADS, INC

Product:	**Grade:**	**Size:**	**Length:**	**Customer Part No:**
ROUND RS-STD	A449	0.7500"	24'0"	

Grade Description: ASTM A449 TYPE 1 MATERIAL

Heat No	PCS/BDLS	Pounds
0224800	140	5046

Chemical Analysis:

Heat	C	Mn	P	S	Si	Cu	Cr	Mo	Ni	Sn	Cb	V	Al	Ti	B
0224800	0.47	0.71	.011	.018	.21	.28	.14	.02	.09	.012	.001	.024	.001		

Physical Properties:

Heat	Yield (psi / MPa)	Tensile (psi / MPa)	Elongation % 2" gauge	% R.A.	Bend Test
0224800	138,000 psi / 951 MPa	149,000 psi / 1027 MPa	16.0	55.0	N/A

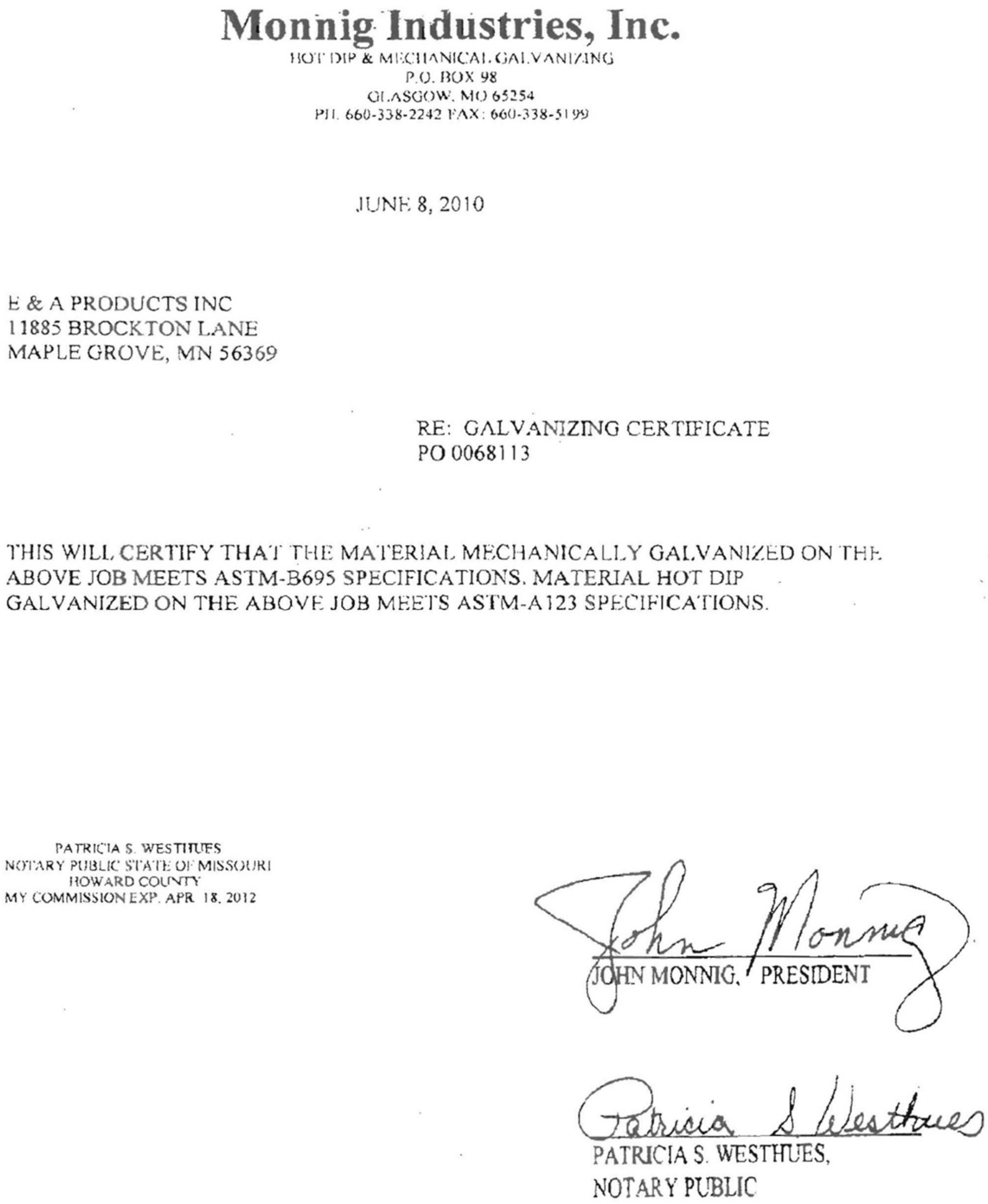
Micro Analysis:

Heat	Hardness	Tempering Temperature
0224800	302 HBW	1100

By: ______________________
Quality Assurance Department

This is to certify that these chemical and/or test results are a true copy of records contained in our company. Sheffield Steel Heats are 100% melted and manufactured in the U.S.A. Material is produced Mercury free and not repaired by welding.
This form signed and/or notarized on request only.

Figure A-20. J-Hook Anchor



Monnig Industries, Inc.
HOT DIP & MECHANICAL GALVANIZING
P.O. BOX 98
GLASGOW, MO 65254
PH. 660-338-2242 FAX: 660-338-5199

JUNE 8, 2010

E & A PRODUCTS INC
11885 BROCKTON LANE
MAPLE GROVE, MN 56369

RE: GALVANIZING CERTIFICATE
PO 0068113

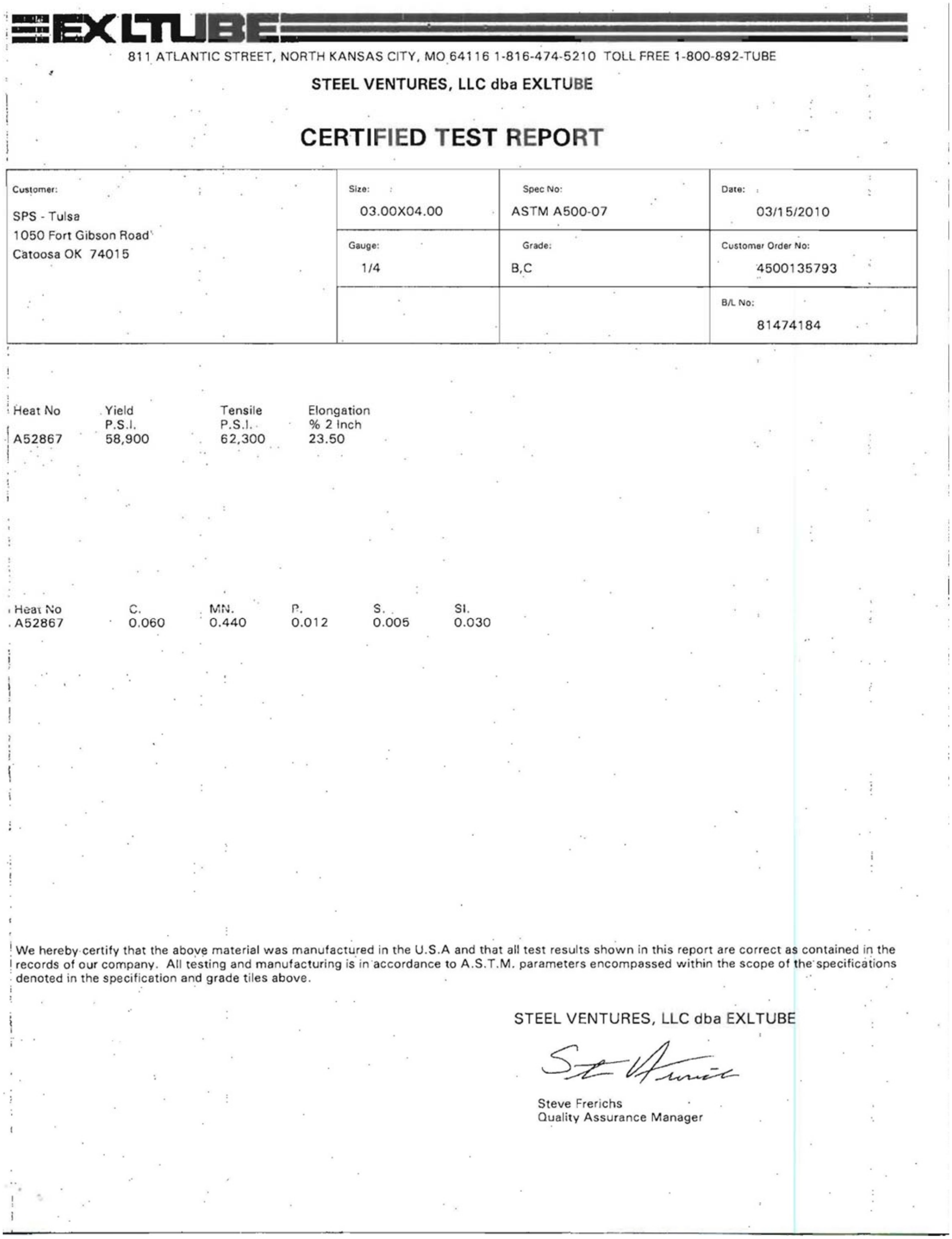
THIS WILL CERTIFY THAT THE MATERIAL MECHANICALLY GALVANIZED ON THE ABOVE JOB MEETS ASTM-B695 SPECIFICATIONS. MATERIAL HOT DIP GALVANIZED ON THE ABOVE JOB MEETS ASTM-A123 SPECIFICATIONS.

PATRICIA S. WESTHUES
NOTARY PUBLIC STATE OF MISSOURI
HOWARD COUNTY
MY COMMISSION EXP. APR. 18, 2012

John Monnig
JOHN MONNIG, PRESIDENT

Patricia S Westhues
PATRICIA S. WESTHUES,
NOTARY PUBLIC

Figure A-21. J-Hook Anchor



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

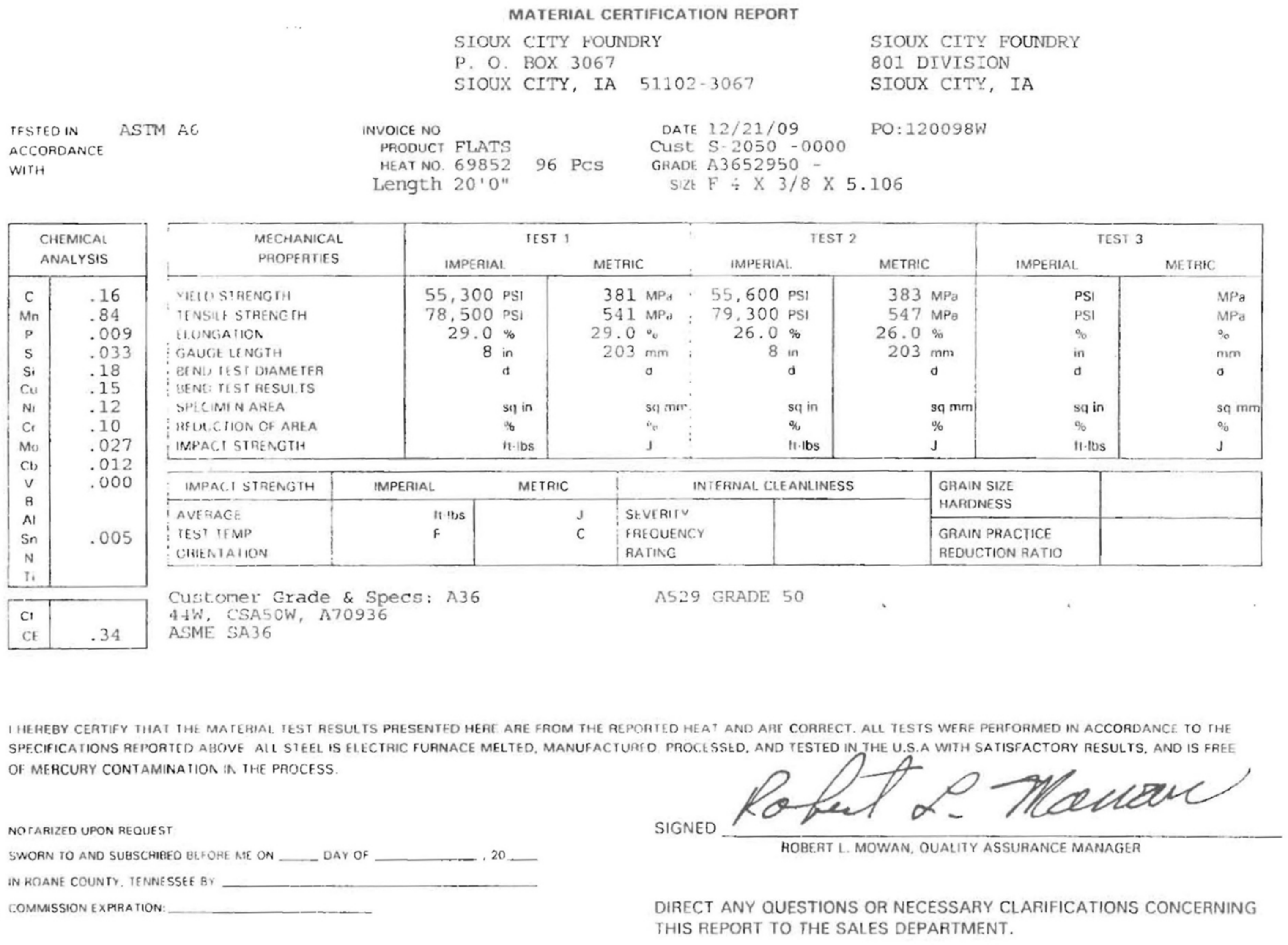
Heat No	C.	MN.	P.	S.	SI.
A52867	0.060	0.440	0.012	0.005	0.030

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-22. Post Nos. 2 and 39 Foundation Tube



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 HARDNESS	
AVERAGE	ft-lbs	J	SEVERITY		GRAIN PRACTICE REDUCTION RATIO	
TEST TEMP	F	C	FREQUENCY			
ORIENTATION			RATING			

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

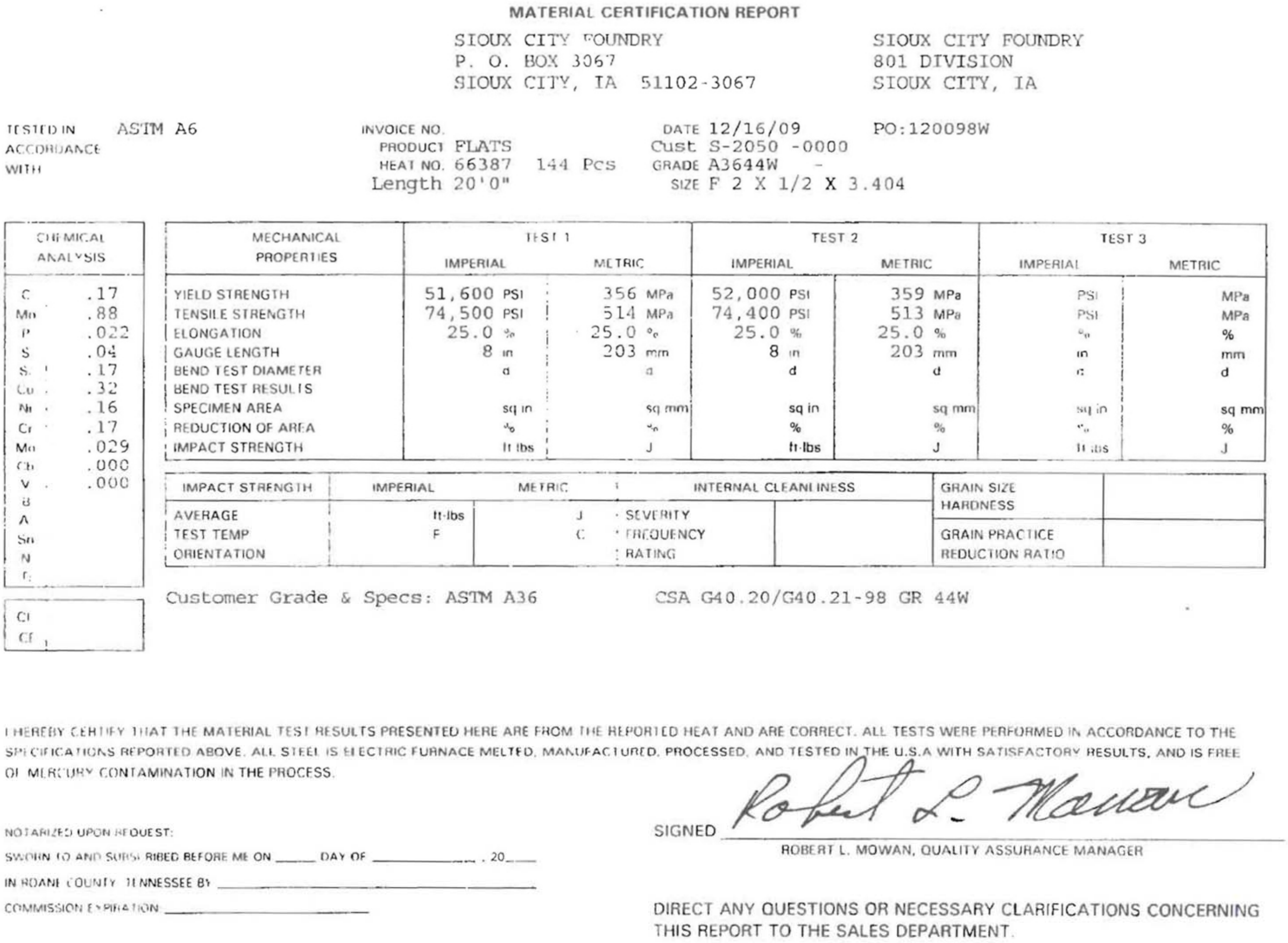
I HEREBY CERTIFY THAT THE MATERIAL TEST RESULTS PRESENTED HERE ARE FROM THE REPORTED HEAT AND ARE CORRECT. ALL TESTS WERE PERFORMED IN ACCORDANCE TO THE SPECIFICATIONS REPORTED ABOVE. ALL STEEL IS ELECTRIC FURNACE MELTED, MANUFACTURED, PROCESSED, AND TESTED IN THE U.S.A WITH SATISFACTORY RESULTS, AND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

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-23. Post Nos. 2 and 39 Base Plate



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	
AVERAGE	ft-lbs	J	SEVERITY	
TEST TEMP	F	C	FREQUENCY	
ORIENTATION			RATING	

GRAIN SIZE HARDNESS	
GRAIN PRACTICE REDUCTION RATIO	

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-24. Post Nos. 2 and 39 Cable Retainer

PFC

1 PK QTY 50 EA ZINC BLUE

HEX SCREWS
COARSE THREAD

PFC
307A

1/2 – 13 X 2

PART # 00026 – 2824 – 401

0 82893 40236 9

0 87302 65931 0

PFC LOT NO (K) 10052401C3

MFG Lot No.: 1N1070407

BOX SEALED TO SECURE INTEGRITY

1/2 – 13

FINISHED HEX NUTS COARSE

EVECEK RoHS CHINA

(1) 1JY35

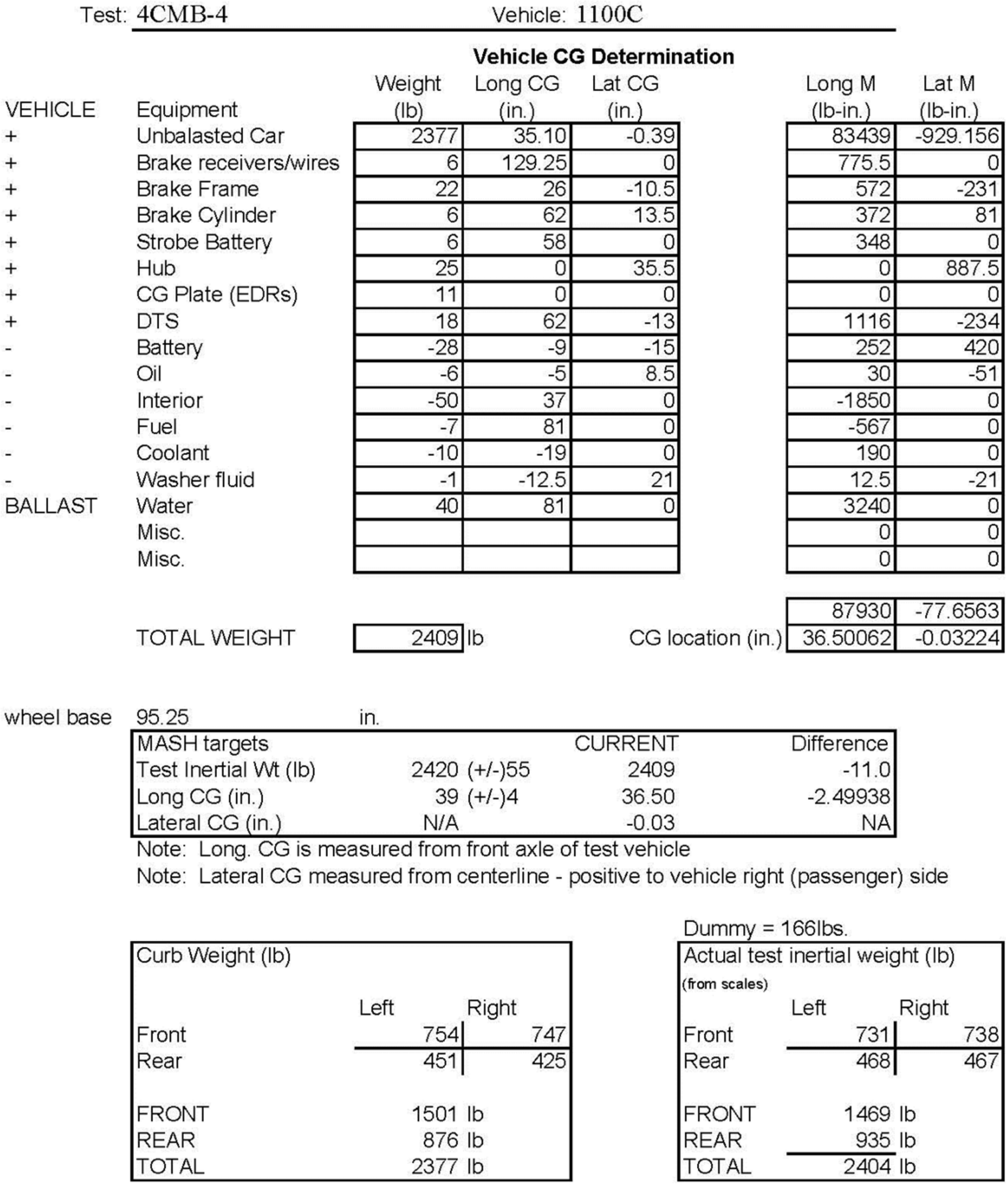
H#8270018 PCS./PZS.5LB
Made in/Hecho en China
LOT#HO1476653

0 08236 83067 5

Flat Washers USS
Arandelas Planas USS
1/2
M12.7

Figure A-25. Post Nos. 2 and 39 Bolt Assembly

Appendix B. Vehicle Center of Gravity Determination



Test: 4CMB-4 Vehicle: 1100C

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Long CG (in.)	Lat CG (in.)	Long M (lb-in.)	Lat M (lb-in.)
+	Unbalasted Car	2377	35.10	-0.39	83439	-929.156
+	Brake receivers/wires	6	129.25	0	775.5	0
+	Brake Frame	22	26	-10.5	572	-231
+	Brake Cylinder	6	62	13.5	372	81
+	Strobe Battery	6	58	0	348	0
+	Hub	25	0	35.5	0	887.5
+	CG Plate (EDRs)	11	0	0	0	0
+	DTS	18	62	-13	1116	-234
-	Battery	-28	-9	-15	252	420
-	Oil	-6	-5	8.5	30	-51
-	Interior	-50	37	0	-1850	0
-	Fuel	-7	81	0	-567	0
-	Coolant	-10	-19	0	190	0
-	Washer fluid	-1	-12.5	21	12.5	-21
BALLAST	Water	40	81	0	3240	0
	Misc.				0	0
	Misc.				0	0
					87930	-77.6563
	TOTAL WEIGHT	2409 lb		CG location (in.)	36.50062	-0.03224

wheel base 95.25 in.

MASH targets		CURRENT	Difference
Test Inertial Wt (lb)	2420 (+/-)55	2409	-11.0
Long CG (in.)	39 (+/-)4	36.50	-2.49938
Lateral CG (in.)	N/A	-0.03	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	754	747
Rear	451	425

FRONT	1501 lb
REAR	876 lb
TOTAL	2377 lb

Dummy = 166lbs.

Actual test inertial weight (lb)
(from scales)

	Left	Right
Front	731	738
Rear	468	467

FRONT	1469 lb
REAR	935 lb
TOTAL	2404 lb

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

Test: 4CMB-5 Vehicle: 2270P

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Long CG (in.)	Lat CG (in.)	Vert CG (in.)	Long M (lb-in.)	Lat M (lb-in.)	Vert M (lb-in.)
+	Unbalasted Truck(Curb)	4899	62.1343	-0.64484	28.20813	304395.9	-3159.09	138191.6
+	Brake receivers/wires	6	116	0	51	696	0	306
+	Brake Frame	5	34	-17.25	31	170	-86.25	155
+	Brake Cylinder (Nitrogen)	28	74	22	29	2072	616	812
+	Strobe/Brake Battery	5	74	2	30	370	10	150
+	Hub	25	0	44	14.75	0	1100	368.75
+	CG Plate (EDRs)	8	54	0	32	432	0	256
-	Battery	0	0	0	0	0	0	0
-	Oil	0	0	0	0	0	0	0
-	Interior	0	0	0	0	0	0	0
-	Fuel	0	0	0	0	0	0	0
-	Coolant	0	0	0	0	0	0	0
-	Washer fluid	0	0	0	0	0	0	0
BALLAST	Water				0	0	0	0
	Misc. (DTS)	17	74		27	1258	0	459
	Misc.					0	0	0
						309393.9	-1519.34	140698.4
	TOTAL WEIGHT	4993 lb			CG location (in.)	61.96554	-0.30429	28.17913

wheel base 140.25

Calculated Test Inertial Weight

MASH Targets	Targets	CURRENT	Difference
Test Inertial Weight (lb)	5000 ± 110	4993	-7.0
Long CG (in.)	63 ± 4	61.97	-1.03446
Lat CG (in.)	NA	-0.30	NA
Vert CG (in.)	≥ 28	28.18	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)
(previously stripped)

	Left	Right
Front	1401	1306
Rear	1095	1097
FRONT	2707 lb	
REAR	2192 lb	
TOTAL	4899 lb	

Actual test inertial weight (lb)
(from scales)

	Left	Right
Front	1390	1383
Rear	1108	1098
FRONT	2773 lb	
REAR	2206 lb	
TOTAL	4979 lb	

Figure B-2. Vehicle Mass Distribution, Test No. 4CMB-5

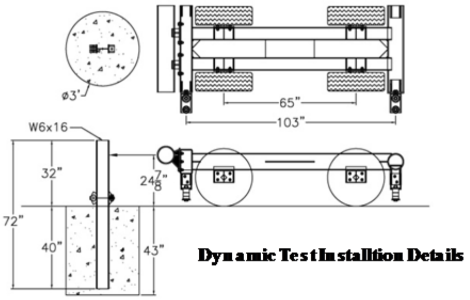
Appendix C. Static Soil Tests

Dynamic Set up

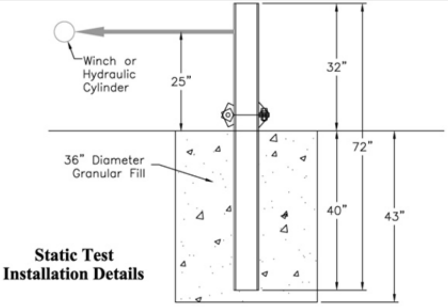
Post-Test Photo of Post

Static Load Test

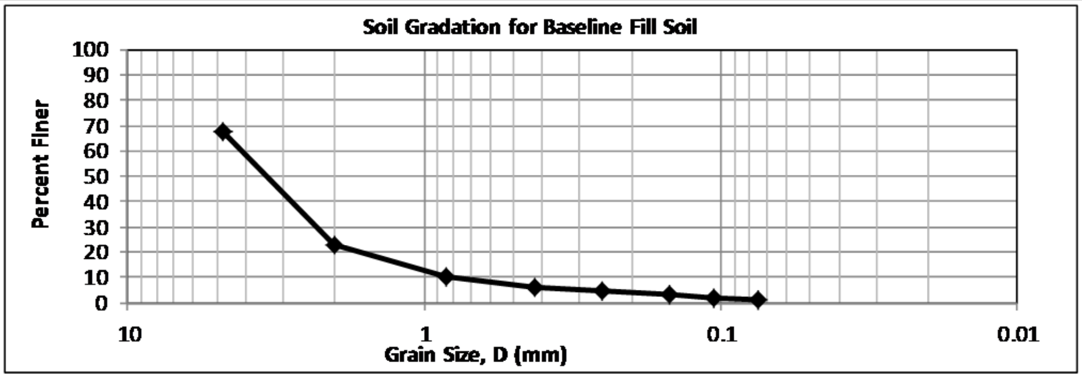
Post-Test Photo of Post

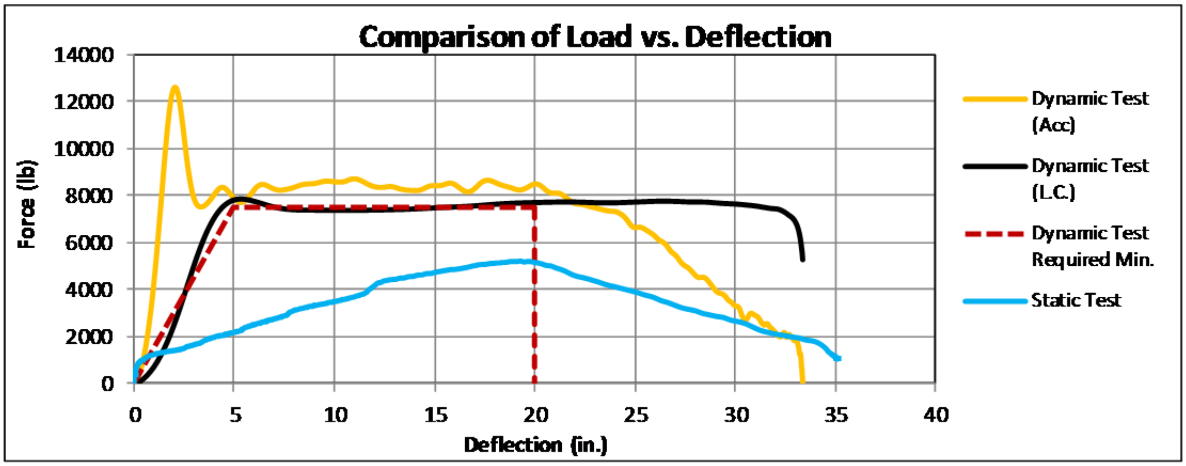


Dynamic Test Installtion Details



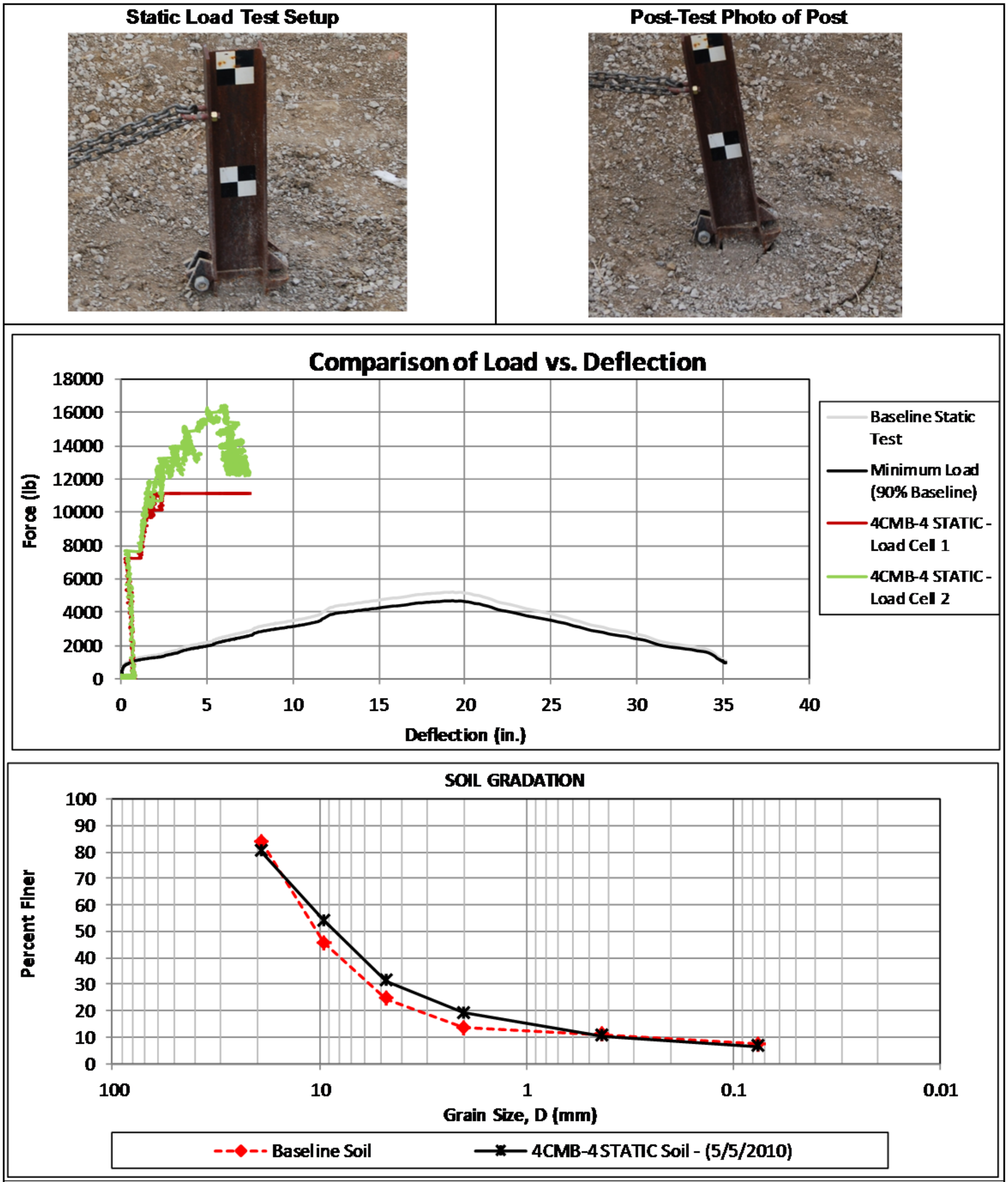
Static Test Installation Details





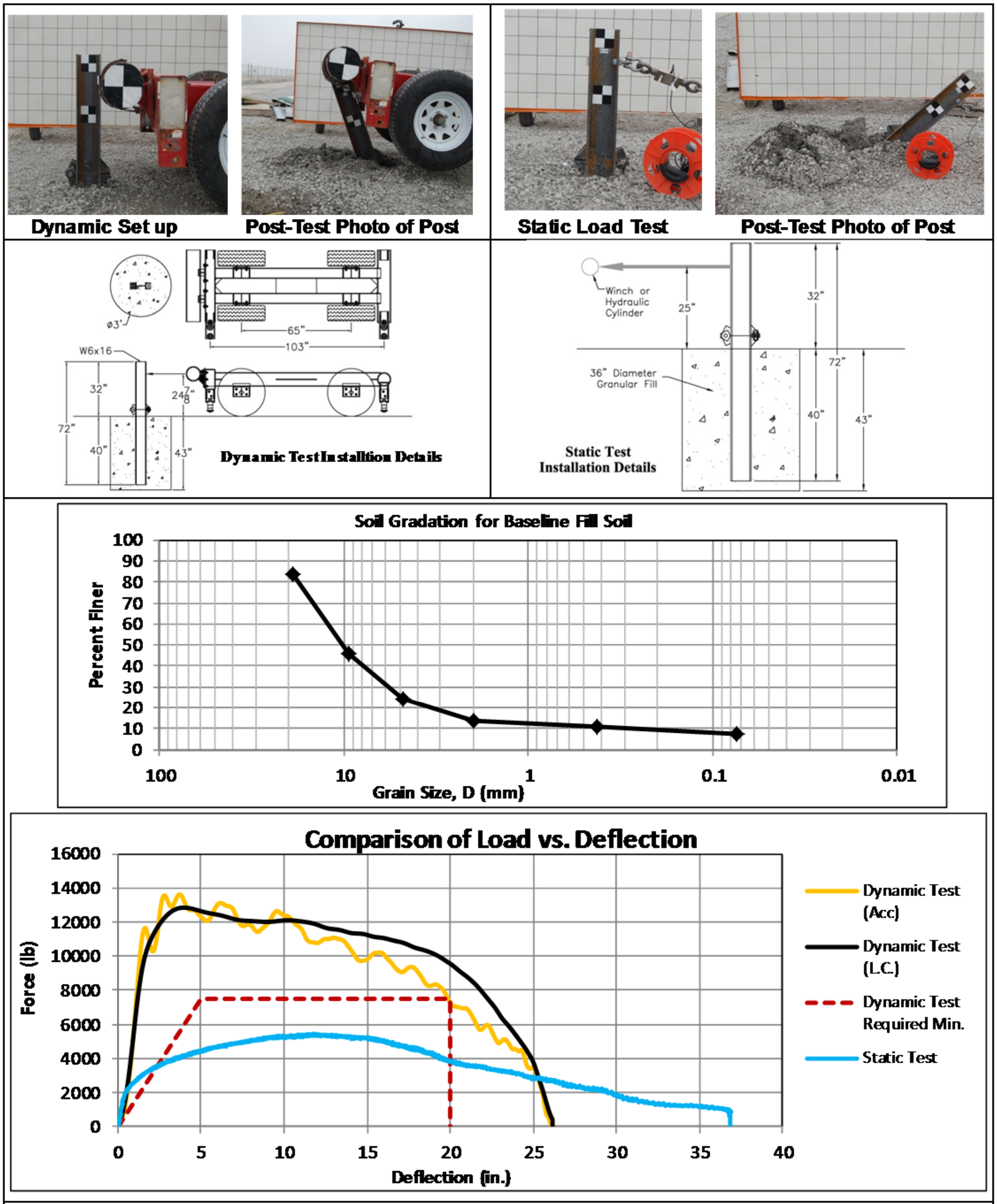
Date	7/7/2005
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well Graded Gravel (GW)
Fill material description (ASTM D2487)	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	6-inch lifts tamped with a pneumatic compactor
Bogie Weight	1605 lbs
Impact Velocity	19.08 mph

Figure C-1. Soil Strength, Initial Calibration Tests, Test No. 4CMB-4



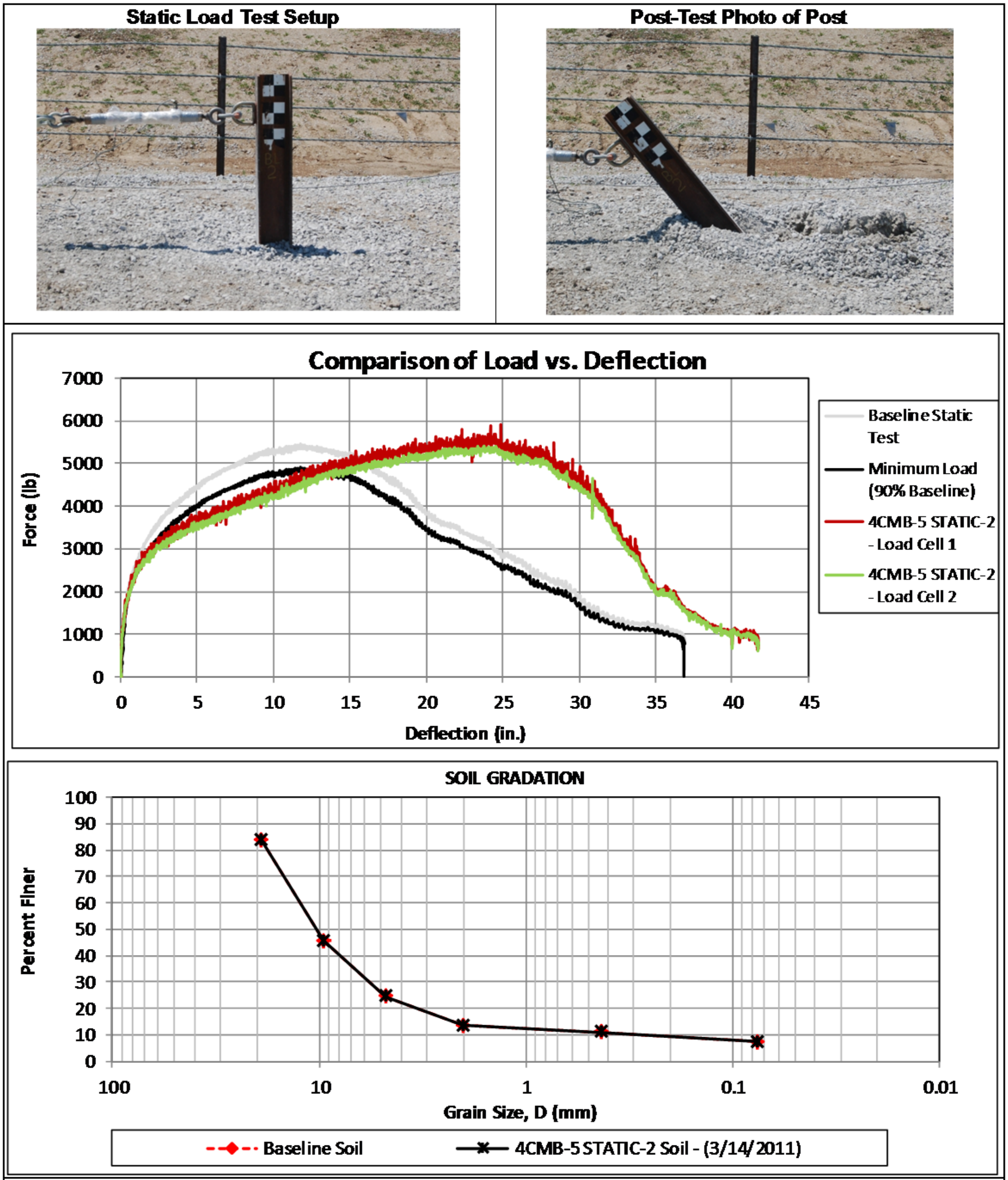
Date	12/22/2010
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well Graded Gravel (GW)
Fill material description (ASTM D2487)	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8-inch lifts tamped with a pneumatic compactor

Figure C-2. Static Soil Test, Test No. 4CMB-4



Date	3/28/2011
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-in. Lifts, High Compaction, Pnuematic Tamper
Bogie Weight	1,727 lb
Impact Velocity	18.81 mph

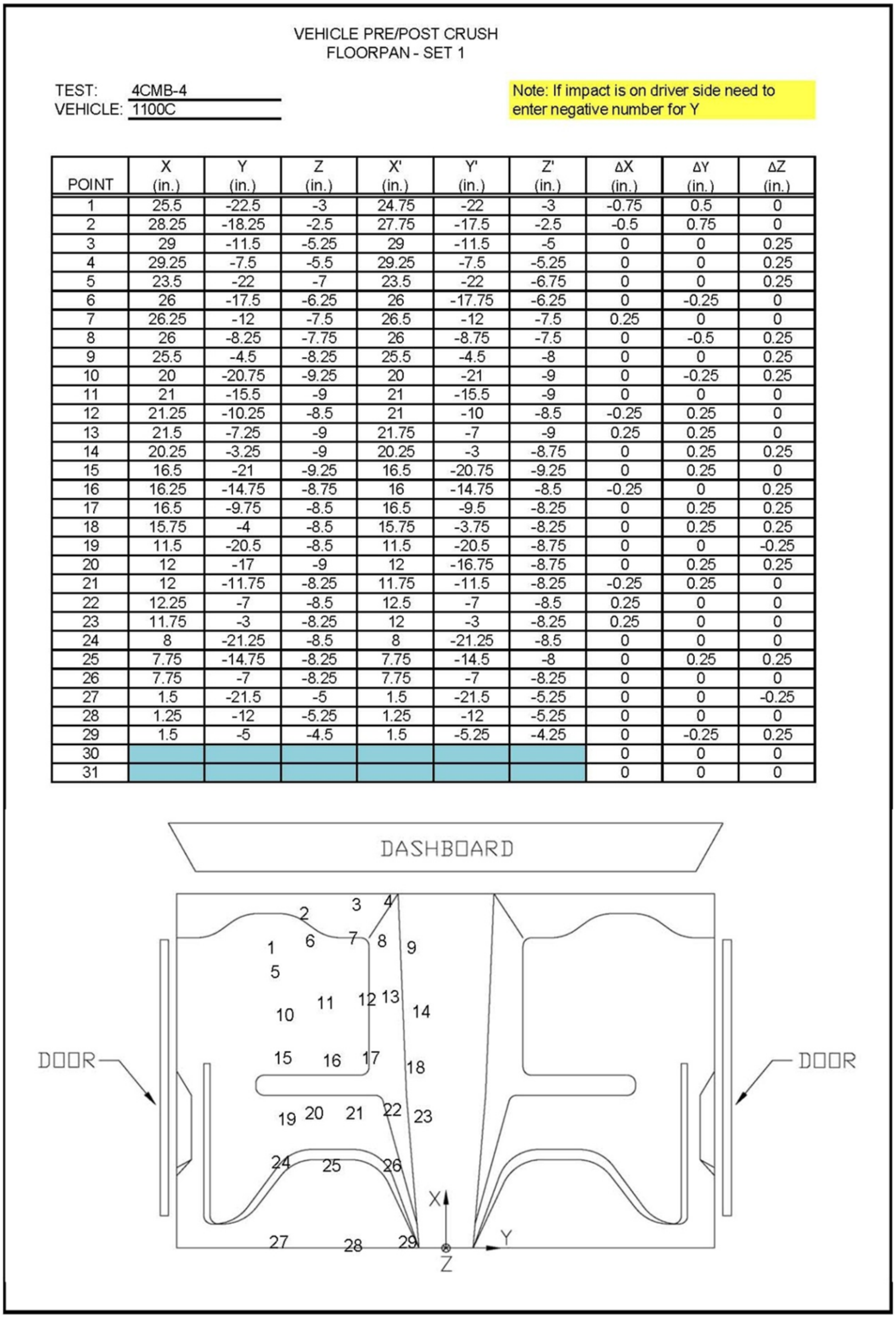
Figure C-3. Soil Strength, Initial Calibration Tests, Test No. 4CMB-5



Date	5/9/2011
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-4. Static Soil Test, Test No. 4CMB-5

Appendix D. Vehicle Deformation Records



VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: 4CMB-4
VEHICLE: 1100C

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	25.5	-22.5	-3	24.75	-22	-3	-0.75	0.5	0
2	28.25	-18.25	-2.5	27.75	-17.5	-2.5	-0.5	0.75	0
3	29	-11.5	-5.25	29	-11.5	-5	0	0	0.25
4	29.25	-7.5	-5.5	29.25	-7.5	-5.25	0	0	0.25
5	23.5	-22	-7	23.5	-22	-6.75	0	0	0.25
6	26	-17.5	-6.25	26	-17.75	-6.25	0	-0.25	0
7	26.25	-12	-7.5	26.5	-12	-7.5	0.25	0	0
8	26	-8.25	-7.75	26	-8.75	-7.5	0	-0.5	0.25
9	25.5	-4.5	-8.25	25.5	-4.5	-8	0	0	0.25
10	20	-20.75	-9.25	20	-21	-9	0	-0.25	0.25
11	21	-15.5	-9	21	-15.5	-9	0	0	0
12	21.25	-10.25	-8.5	21	-10	-8.5	-0.25	0.25	0
13	21.5	-7.25	-9	21.75	-7	-9	0.25	0.25	0
14	20.25	-3.25	-9	20.25	-3	-8.75	0	0.25	0.25
15	16.5	-21	-9.25	16.5	-20.75	-9.25	0	0.25	0
16	16.25	-14.75	-8.75	16	-14.75	-8.5	-0.25	0	0.25
17	16.5	-9.75	-8.5	16.5	-9.5	-8.25	0	0.25	0.25
18	15.75	-4	-8.5	15.75	-3.75	-8.25	0	0.25	0.25
19	11.5	-20.5	-8.5	11.5	-20.5	-8.75	0	0	-0.25
20	12	-17	-9	12	-16.75	-8.75	0	0.25	0.25
21	12	-11.75	-8.25	11.75	-11.5	-8.25	-0.25	0.25	0
22	12.25	-7	-8.5	12.5	-7	-8.5	0.25	0	0
23	11.75	-3	-8.25	12	-3	-8.25	0.25	0	0
24	8	-21.25	-8.5	8	-21.25	-8.5	0	0	0
25	7.75	-14.75	-8.25	7.75	-14.5	-8	0	0.25	0.25
26	7.75	-7	-8.25	7.75	-7	-8.25	0	0	0
27	1.5	-21.5	-5	1.5	-21.5	-5.25	0	0	-0.25
28	1.25	-12	-5.25	1.25	-12	-5.25	0	0	0
29	1.5	-5	-4.5	1.5	-5.25	-4.25	0	-0.25	0.25
30							0	0	0
31							0	0	0

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

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: 4CMB-4
VEHICLE: 1100C

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	34.75	-21	-2.25	34.25	-20.5	-2.25	-0.5	0.5	0
2	37.5	-16.75	-2	37	-16.25	-2	-0.5	0.5	0
3	38.5	-10.25	-5	38.25	-10.5	-5	-0.25	-0.25	0
4	38.75	-5.75	-5.5	38.5	-6	-5.5	-0.25	-0.25	0
5	33	-20.5	-6	33	-20.25	-6.25	0	0.25	-0.25
6	35.75	-16	-5.75	35.75	-15.75	-6	0	0.25	-0.25
7	36	-10.5	-7.25	36	-10.25	-7.25	0	0.25	0
8	35.5	-6.75	-7.75	35.5	-7.25	-7.75	0	-0.5	0
9	35	-2.75	-8.5	35	-3	-8.5	0	-0.25	0
10	29.75	-19.5	-8.5	29.5	-19.25	-8.5	-0.25	0.25	0
11	30.75	-14.25	-8.75	30.75	-14	-8.5	0	0.25	0.25
12	30.75	-8.75	-8.5	30.75	-8.5	-8.5	0	0.25	0
13	31.25	-5.75	-9.25	31.5	-5.5	-9.25	0.25	0.25	0
14	29.75	-1.5	-9	29.75	-1.75	-9	0	-0.25	0
15	26	-19.5	-8.5	26.25	-19.5	-8.5	0.25	0	0
16	26	-12.5	-8.5	26	-13	-8.5	0	-0.5	0
17	26.25	-8	-8.5	26.25	-8	-8.25	0	0	0.25
18	25.25	-2.5	-8.5	25.25	-2.25	-8.5	0	0.25	0
19	21	-19	-8	21	-19	-8	0	0	0
20	21.75	-15.5	-8.5	21.75	-15.5	-8.5	0	0	0
21	21.5	-10.5	-8	21.5	-10.25	-8	0	0.25	0
22	22	-6	-8.5	22	-5.5	-8.5	0	0.5	0
23	21.25	-1.75	-8.5	21.25	-2	-8.5	0	-0.25	0
24	17.75	-20	-7.75	17.75	-20	-7.75	0	0	0
25	17.5	-13.25	-7.75	17.75	-13	-7.75	0.25	0.25	0
26	17.5	-5.75	-8.25	17.25	-5.75	-8.25	-0.25	0	0
27	11.25	-20.25	-4.5	11.25	-20	-4.5	0	0.25	0
28	11	-10.5	-5	11	-10.75	-5	0	-0.25	0
29	11	-3.5	-4.5	11.25	-3.5	-4.5	0.25	0	0
30							0	0	0
31							0	0	0

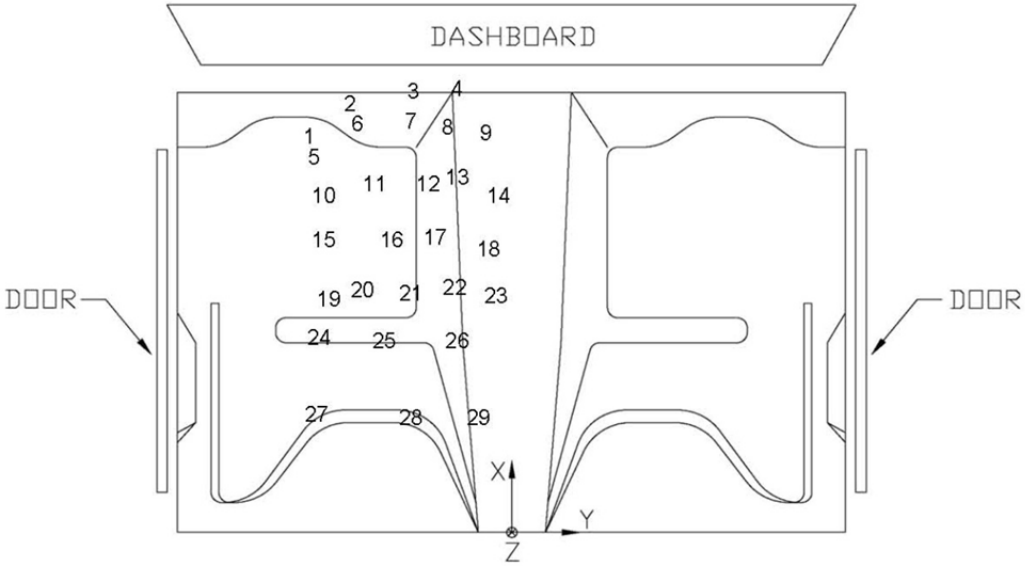
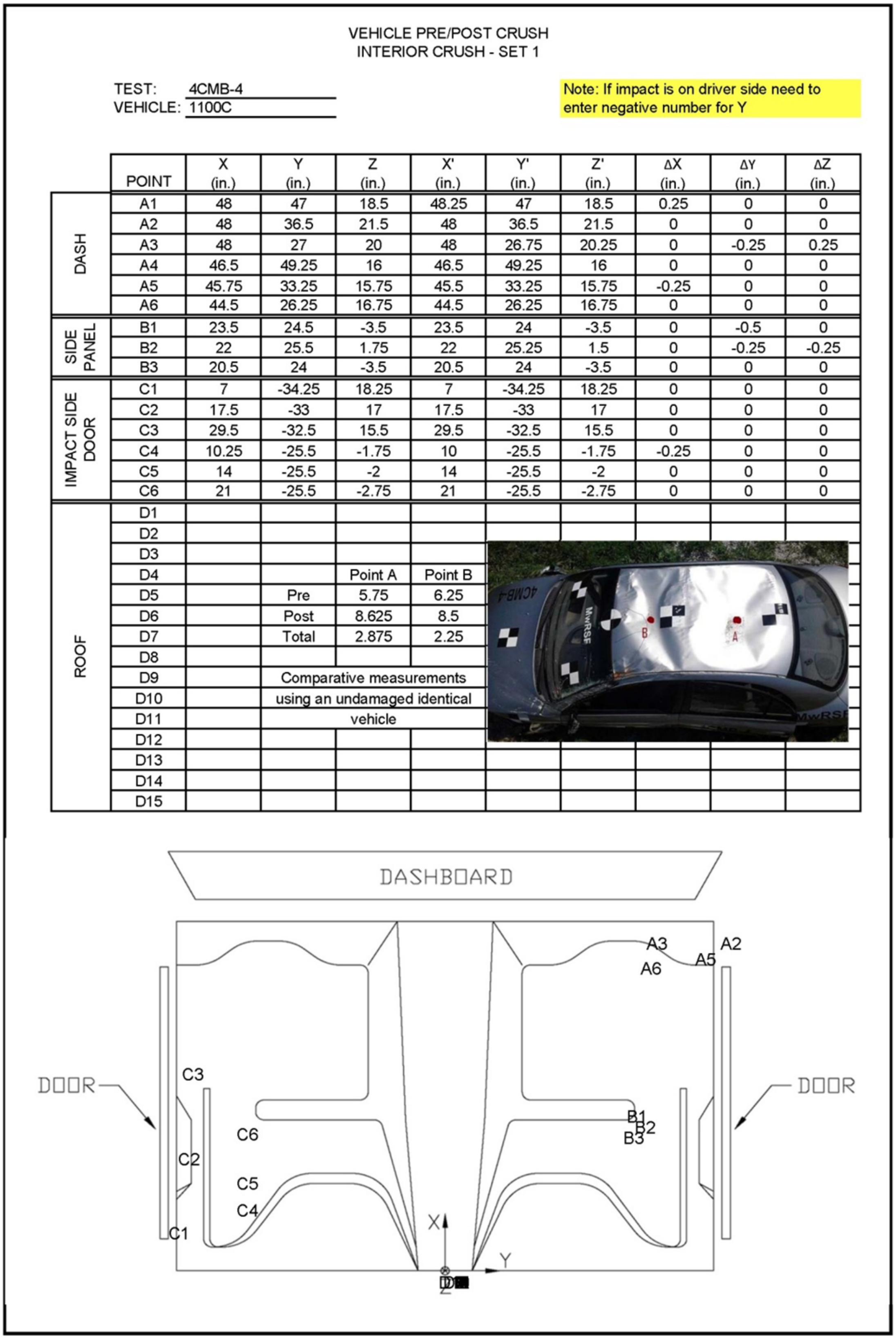


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. 4CMB-4



VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: 4CMB-4
VEHICLE: 1100C

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	48	47	18.5	48.25	47	18.5	0.25	0	0
	A2	48	36.5	21.5	48	36.5	21.5	0	0	0
	A3	48	27	20	48	26.75	20.25	0	-0.25	0.25
	A4	46.5	49.25	16	46.5	49.25	16	0	0	0
	A5	45.75	33.25	15.75	45.5	33.25	15.75	-0.25	0	0
	A6	44.5	26.25	16.75	44.5	26.25	16.75	0	0	0
SIDE PANEL	B1	23.5	24.5	-3.5	23.5	24	-3.5	0	-0.5	0
	B2	22	25.5	1.75	22	25.25	1.5	0	-0.25	-0.25
	B3	20.5	24	-3.5	20.5	24	-3.5	0	0	0
IMPACT SIDE DOOR	C1	7	-34.25	18.25	7	-34.25	18.25	0	0	0
	C2	17.5	-33	17	17.5	-33	17	0	0	0
	C3	29.5	-32.5	15.5	29.5	-32.5	15.5	0	0	0
	C4	10.25	-25.5	-1.75	10	-25.5	-1.75	-0.25	0	0
	C5	14	-25.5	-2	14	-25.5	-2	0	0	0
	C6	21	-25.5	-2.75	21	-25.5	-2.75	0	0	0
ROOF	D1									
	D2									
	D3									
	D4			Point A	Point B					
	D5		Pre	5.75	6.25					
	D6		Post	8.625	8.5					
	D7		Total	2.875	2.25					
	D8									
	D9		Comparative measurements using an undamaged identical vehicle							
	D10									
	D11									
	D12									
	D13									
	D14									
	D15									

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

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: 4CMB-4
VEHICLE: 1100C

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	32.75	46.5	19.25	32.5	46.5	19	-0.25	0	-0.25
	A2	34.5	35.75	21.75	34.25	35.75	22	-0.25	0	0.25
	A3	33	27.25	20	33	27.25	20	0	0	0
	A4	30.5	48.5	16.5	30.5	48.5	16.75	0	0	0.25
	A5	30	33.5	15.5	29.75	33.5	15.5	-0.25	0	0
	A6	29.25	27	16	29	27	16	-0.25	0	0
SIDE PANEL	B1	33	24.5	-2.75	33	24	-2.75	0	-0.5	0
	B2	31.25	23.75	2.5	31.25	23.5	2.5	0	-0.25	0
	B3	30	23.75	-2.75	30	23.5	-2.75	0	-0.25	0
IMPACT SIDE DOOR	C1	10.5	-32.5	19	10.5	-32.5	19.25	0	0	0.25
	C2	21	-32	17.75	21	-32	17.75	0	0	0
	C3	33	-31.5	16.25	33	-31.25	16.25	0	0.25	0
	C4	16.5	-24	-1	16.25	-24	-0.75	-0.25	0	0.25
	C5	20.25	-24	-1	20	-24	-1.25	-0.25	0	-0.25
	C6	27.5	-24	-1.75	27.5	-24	-2	0	0	-0.25
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

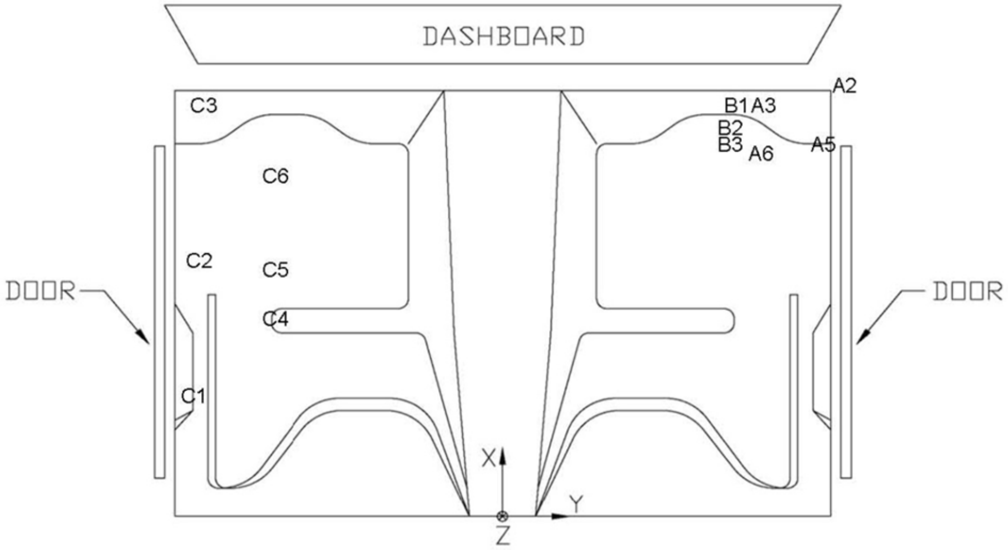
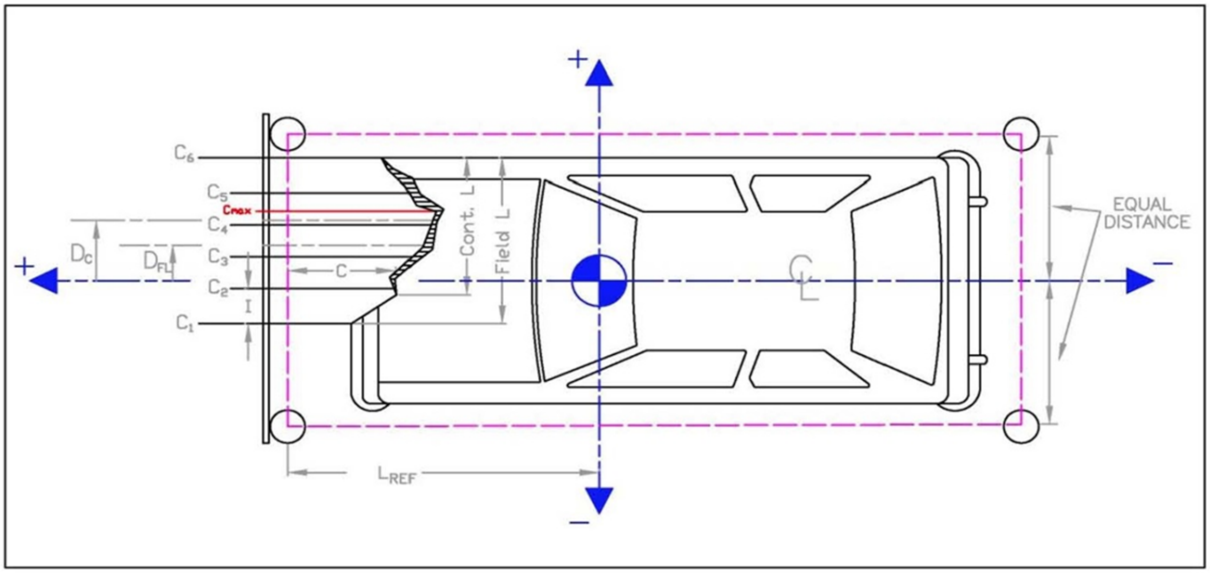


Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. 4CMB-4

Date: 6/1/2011 **Test Number:** 4CMB-4

Make: KIA RIO **Model:** 1100C **Year:** 2002

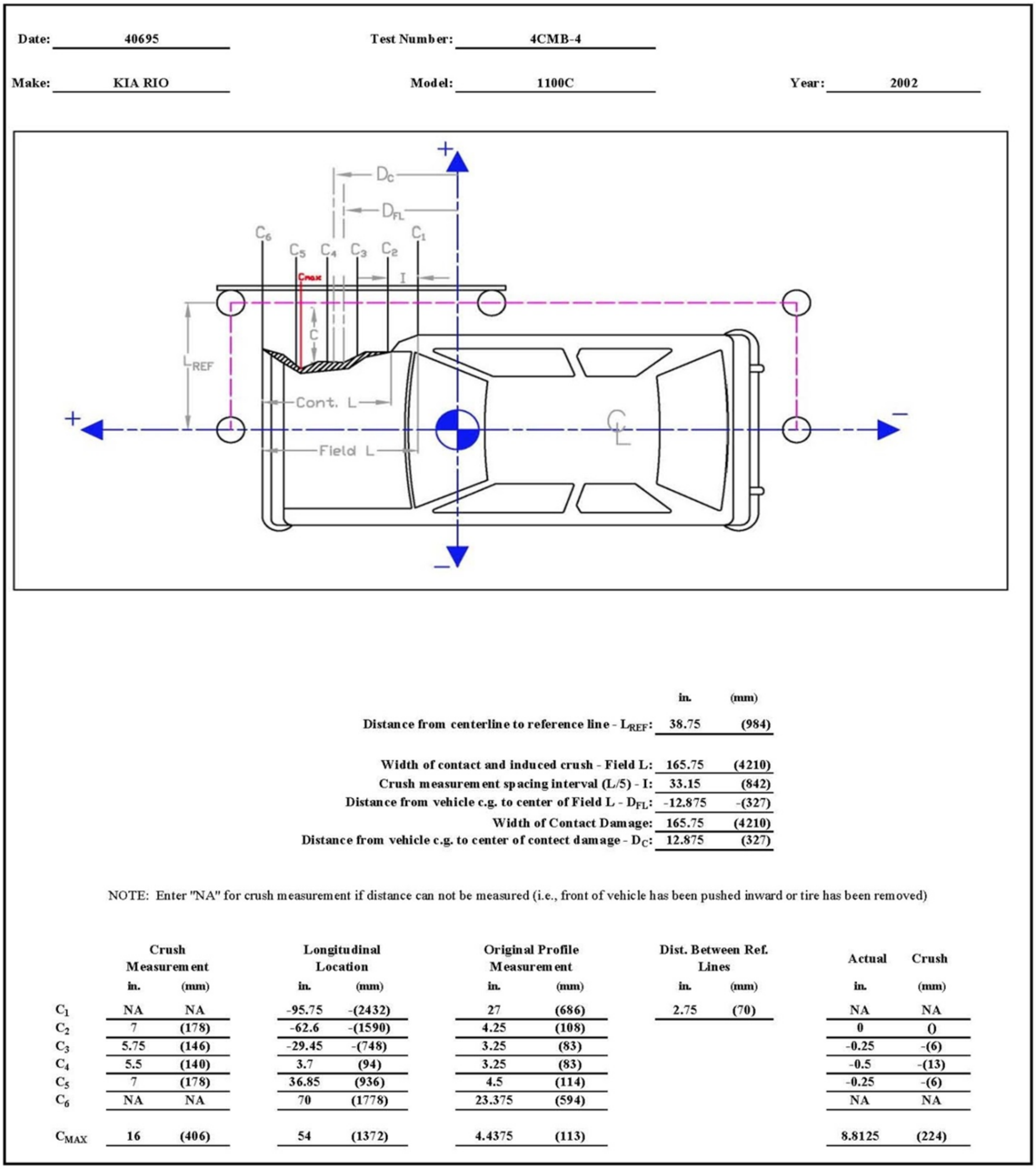


	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	72.75	(1848)
Width of contact and induced crush - Field L:	63.75	(1619)
Crush measurement spacing interval (L/5) - I:	12.75	(324)
Distance from center of vehicle to center of Field L - D_{FL}:	0	0
Width of Contact Damage:	63.75	(1619)
Distance from center of vehicle to center of contect damage - D_C:	31.875	(810)

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	-31.875	-(810)	30.625	(778)	-6.500623	-(165)	NA	NA
C_2	8.75	(222)	-19.125	-(486)	10.0156	(254)			5.234998	(133)
C_3	6.75	(171)	-6.375	-(162)	7.75	(197)			5.500623	(140)
C_4	6.25	(159)	6.375	(162)	7.75	(197)			5.000623	(127)
C_5	7.25	(184)	19.125	(486)	9.9375	(252)			3.813123	(97)
C_6	NA	NA	31.875	(810)	29.4219	(747)			NA	NA
C_{MAX}	21	(533)	-21	-(533)	11.1875	(284)			16.31312	(414)

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



Date: 40695
Test Number: 4CMB-4
Make: KIA RIO
Model: 1100C
Year: 2002

	in.	(mm)
Distance from centerline to reference line - L_{REF}:	38.75	(984)
Width of contact and induced crush - Field L:	165.75	(4210)
Crush measurement spacing interval (L/5) - I:	33.15	(842)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-12.875	-(327)
Width of Contact Damage:	165.75	(4210)
Distance from vehicle c.g. to center of contect damage - D_C:	12.875	(327)

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

	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	-95.75	-(2432)	27	(686)	2.75	(70)	NA	NA
C_2	7	(178)	-62.6	-(1590)	4.25	(108)			0	()
C_3	5.75	(146)	-29.45	-(748)	3.25	(83)			-0.25	-(6)
C_4	5.5	(140)	3.7	(94)	3.25	(83)			-0.5	-(13)
C_5	7	(178)	36.85	(936)	4.5	(114)			-0.25	-(6)
C_6	NA	NA	70	(1778)	23.375	(594)			NA	NA
C_{MAX}	16	(406)	54	(1372)	4.4375	(113)			8.8125	(224)

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

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: 4CMB-5
VEHICLE: 2270P

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	29	-28 1/2	-2 1/4	27 1/4	-28	-2	-1 3/4	1/2	1/4
2	32	-22	-3 1/2	31	-22	-3	-1	0	1/2
3	33	-17 3/4	-3	32 1/2	-17 3/4	-2 1/2	- 1/2	0	1/2
4	29 3/4	-11 1/4	0	29 1/2	-11	0	- 1/4	1/4	0
5	26 3/4	-29	-5 3/4	26	-29	-6	- 3/4	0	- 1/4
6	28 1/4	-23 1/2	-6 1/4	28	-23 3/4	-6 1/4	- 1/4	- 1/4	0
7	27 1/2	-18 1/4	-6	27 1/4	-18 1/2	-6	- 1/4	- 1/4	0
8	26	-10 1/2	-6	25 3/4	-10 3/4	-6	- 1/4	- 1/4	0
9	22 1/2	-28 3/4	-9 1/2	22 1/2	-29	-9 3/4	0	- 1/4	- 1/4
10	22 1/2	-22 1/2	-9	22 1/4	-22 3/4	-9 1/4	- 1/4	- 1/4	- 1/4
11	22 1/2	-16 1/2	-8 3/4	22 1/2	-17 1/4	-8 3/4	0	- 3/4	0
12	22 1/2	-10 3/4	-8 1/4	22 1/4	-10 1/2	-8 1/2	- 1/4	1/4	- 1/4
13	16 1/4	-27 3/4	-10 1/2	16 1/4	-27 1/2	-10 1/2	0	1/4	0
14	16 1/2	-23 1/4	-10	16 1/2	-23 1/2	-10 1/4	0	- 1/4	- 1/4
15	16 1/2	-17 3/4	-9 3/4	16 1/2	-18 1/4	-9 3/4	0	- 1/2	0
16	16 1/2	-11 3/4	-9 1/4	16 1/2	-12 1/2	-9 1/4	0	- 3/4	0
17	13 1/2	-7	-2 1/4	13 3/4	-7	-2 1/4	1/4	0	0
18	12	-27 3/4	-10 1/2	11 3/4	-28 1/2	-10 3/4	- 1/4	- 3/4	- 1/4
19	12 1/4	-22 3/4	-10	12 1/4	-23	-10 1/4	0	- 1/4	- 1/4
20	12 1/4	-17 1/4	-9 3/4	12 1/4	-17 1/2	-9 3/4	0	- 1/4	0
21	12 1/4	-12 1/2	-9 1/2	12	-12 1/2	-9 1/4	- 1/4	0	1/4
22	10	-7	-2 3/4	10	-7	-2 3/4	0	0	0
23	6 1/2	-27	-10 1/4	6 1/2	-27 1/4	-10 1/2	0	- 1/4	- 1/4
24	6 1/2	-18 1/2	-9 1/2	6 1/2	-19 1/4	-9 3/4	0	- 3/4	- 1/4
25	5	-7 3/4	-3 1/4	5	-7 3/4	-3 1/4	0	0	0
26	3/4	-26 1/2	-6	3/4	-26 3/4	-6 1/2	0	- 1/4	- 1/2
27	3/4	-18 1/4	-5 1/2	3/4	-18 1/4	-5 3/4	0	0	- 1/4
28	1	-7 1/4	-2 1/4	1	-7 1/4	-2 1/4	0	0	0
29							0	0	0
30							0	0	0
31							0	0	0

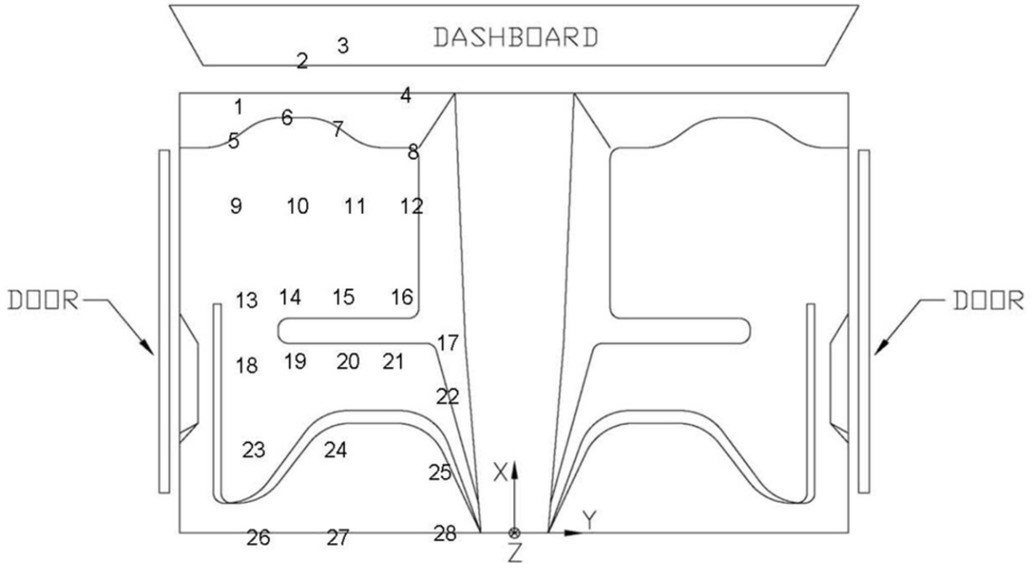


Figure D-7. Floor Pan Deformation Data – Set 1, Test No. 4CMB-5

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: 4CMB-5
VEHICLE: 2270P

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	52	-25 3/4	-1 1/2	50 1/4	-25 3/4	-1	-1 3/4	0	1/2
2	55	-18 3/4	-2 3/4	54 1/4	-19	-1 3/4	- 3/4	- 1/4	1
3	56	-15 1/4	-2 1/2	55 1/2	-14 3/4	-2	- 1/2	1/2	1/2
4	52 1/2	-8 1/4	0	52 1/4	-8 1/2	- 1/2	- 1/4	- 1/4	- 1/2
5	50	-26 1/2	-4 3/4	49 1/4	-26 1/2	-4 3/4	- 3/4	0	0
6	51 3/4	-20 1/2	-5 1/2	51 1/2	-20 3/4	-5 1/4	- 1/4	- 1/4	1/4
7	51	-15 1/2	-5 3/4	50 1/2	-15 3/4	-5 3/4	- 1/2	- 1/4	0
8	49 1/2	-7 1/2	-6	49	-7 3/4	-5 3/4	- 1/2	- 1/4	1/4
9	46 1/4	-25	-8 1/2	46 1/4	-25 1/4	-8 1/2	0	- 1/4	0
10	46	-20	-8 1/2	46	-20	-8 1/2	0	0	0
11	46	-14 3/4	-8 1/2	46	-14 3/4	-8 1/4	0	0	1/4
12	46	-8	-8 1/4	46	-8 1/2	-8 1/4	0	- 1/2	0
13	40	-25 1/4	-9 1/2	40	-25 1/4	-9 1/2	0	0	0
14	40	-20 1/4	-9 1/2	40	-20 1/2	-9 1/4	0	- 1/4	1/4
15	40	-15	-9 1/4	40	-14 3/4	-9 1/4	0	1/4	0
16	40	-9 1/4	-9 1/4	40	-9 1/4	-9	0	0	1/4
17	36 3/4	-4 1/2	-2 1/4	37	-4 1/2	-2 1/4	1/4	0	0
18	35 3/4	-25	-9 3/4	35 1/2	-25 1/2	-9 3/4	- 1/4	- 1/2	0
19	36	-20	-9 1/2	35 3/4	-20 1/4	-9 1/2	- 1/4	- 1/4	0
20	35 3/4	-14 1/2	-9 1/4	35 3/4	-14 3/4	-9 1/2	0	- 1/4	- 1/4
21	35 1/2	-9 1/2	-9 1/4	35 1/2	-9	-9 1/4	0	1/2	0
22	33	-4 3/4	-3	33 1/4	-4 1/2	-3	1/4	1/4	0
23	30 1/4	-24 1/4	-9 1/4	30	-24 1/4	-9 1/2	- 1/4	0	- 1/4
24	30	-16	-9 1/4	30	-16	-9 1/4	0	0	0
25	28 1/4	-5	-3 1/2	28 1/2	-5	-3 1/2	1/4	0	0
26	24 1/4	-24	-5 1/2	24 1/4	-24 1/2	-5 1/2	0	- 1/2	0
27	24 1/4	-15 3/4	-5 1/4	24 1/4	-16	-5 1/4	0	- 1/4	0
28	24 1/4	-4 3/4	-2 1/2	24 1/4	-5	-2 1/2	0	- 1/4	0
29							0	0	0
30							0	0	0
31							0	0	0

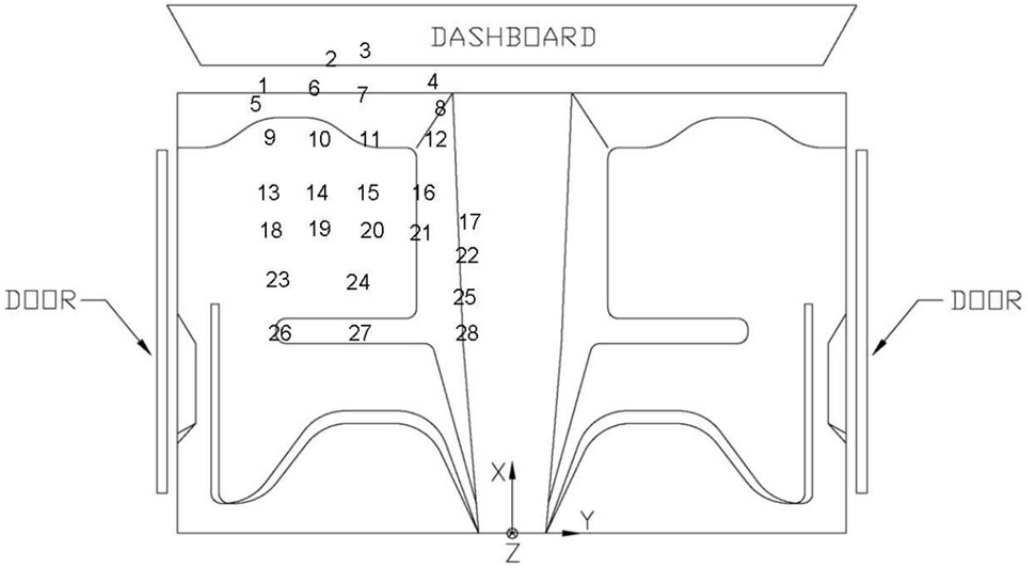


Figure D-8. Floor Pan Deformation Data – Set 2, Test No. 4CMB-5

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: 4CMB-5
VEHICLE: 2270P

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	44 1/4	-60 1/2	22 3/4	43	-60	21 3/4	-1 1/4	1/2	-1
	A2	44 1/4	-50 1/4	24	43	-49 3/4	23 1/2	-1 1/4	1/2	- 1/2
	A3	44 1/2	-33 3/4	25 1/2	44	-33	25	- 1/2	3/4	- 1/2
	A4	38	-62	12	36 3/4	-61 1/4	11	-1 1/4	3/4	-1
	A5	38	-45	13 1/4	37 1/2	-44 1/2	13	- 1/2	1/2	- 1/4
	A6	36	-36 3/4	11 1/4	35 3/4	-36 1/4	11	- 1/4	1/2	- 1/4
SIDE PANEL	B1	37 1/4	-24 1/4	- 1/2	37	-24 1/4	-1	- 1/4	0	- 1/2
	B2	37 1/2	-24 1/4	-7 1/4	37 1/2	-24 1/2	-7 3/4	0	- 1/4	- 1/2
	B3	39 1/2	-24	-5 1/2	39 1/4	-24 3/4	-6	- 1/4	- 3/4	- 1/2
IMPACT SIDE DOOR	C1	6 1/2	-40 3/4	17 1/4	6	-40 1/2	17	- 1/2	1/4	- 1/4
	C2	18	-40 1/2	16 3/4	17 1/2	-39 1/4	16 1/4	- 1/2	1 1/4	- 1/2
	C3	30	-40 3/4	16 1/4	29 1/2	-39 1/4	15 3/4	- 1/2	1 1/2	- 1/2
	C4	2 1/4	-34 3/4	0	3	-35	0	3/4	- 1/4	0
	C5	16 1/4	-34 1/2	- 1/4	16 1/4	-36	- 3/4	0	-1 1/2	- 1/2
	C6	22	-34 1/4	0	21 3/4	-35 1/2	- 1/2	- 1/4	-1 1/4	- 1/2
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	Maximum Roof Damage:			Pre	44 1/4		0	0	0
	D8				Post	28 3/4		0	0	0
	D9	Comparative measurements			Total	15 1/2		0	0	0
	D10	Using an undamaged Identical						0	0	0
	D11		Vehicle					0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

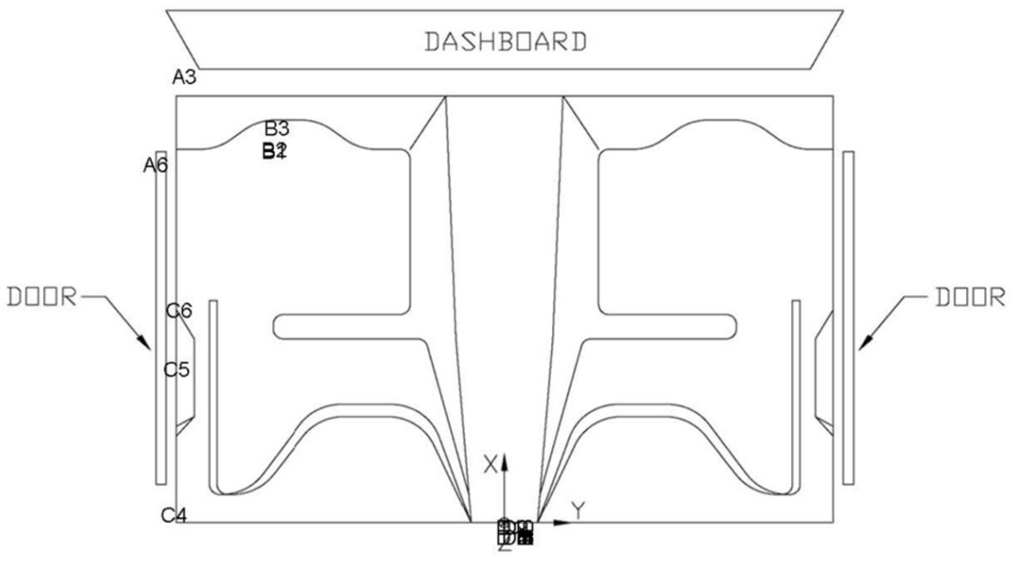
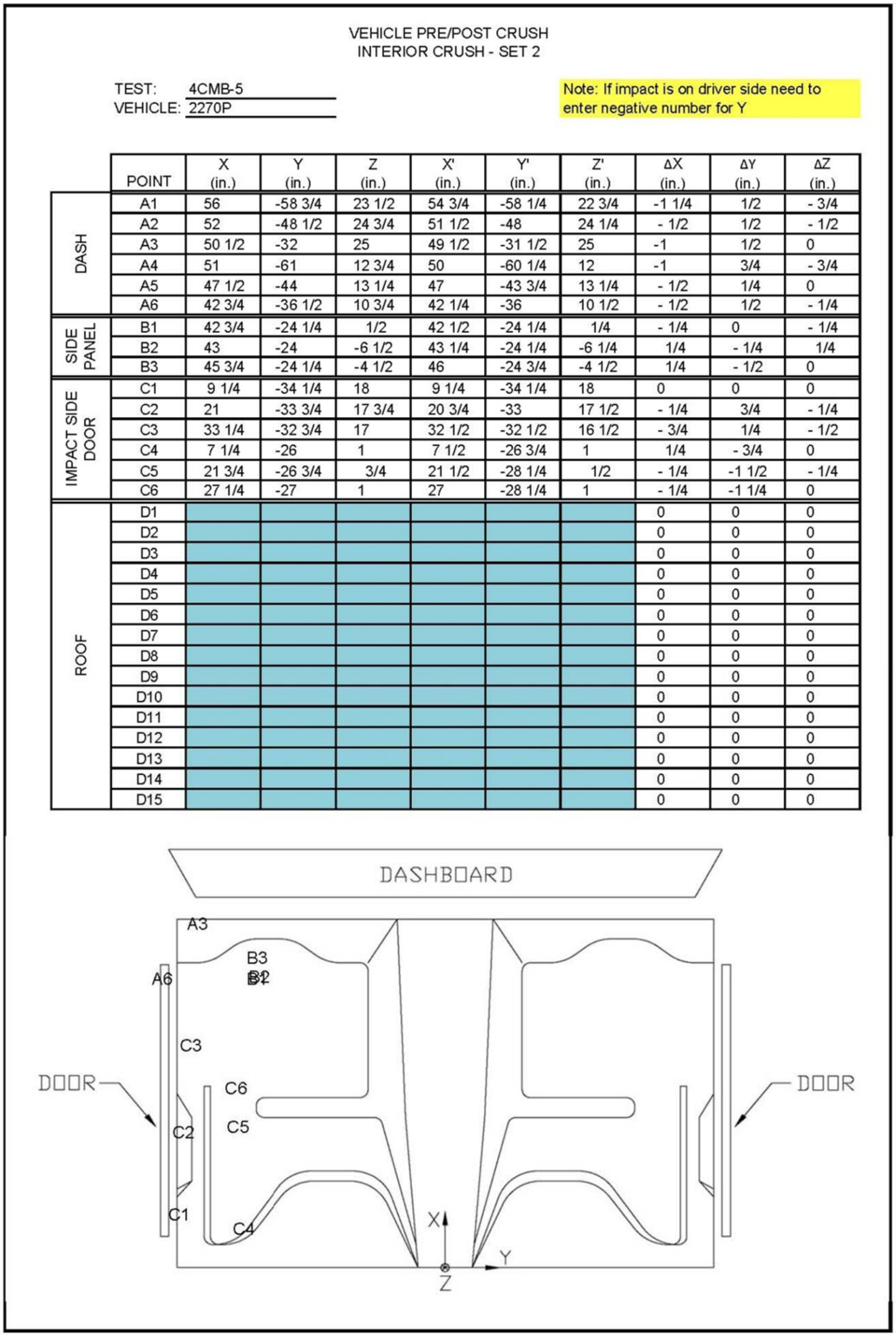


Figure D-9. Occupant Compartment Deformation Data – Set 1, Test No. 4CMB-5



VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: 4CMB-5
VEHICLE: 2270P

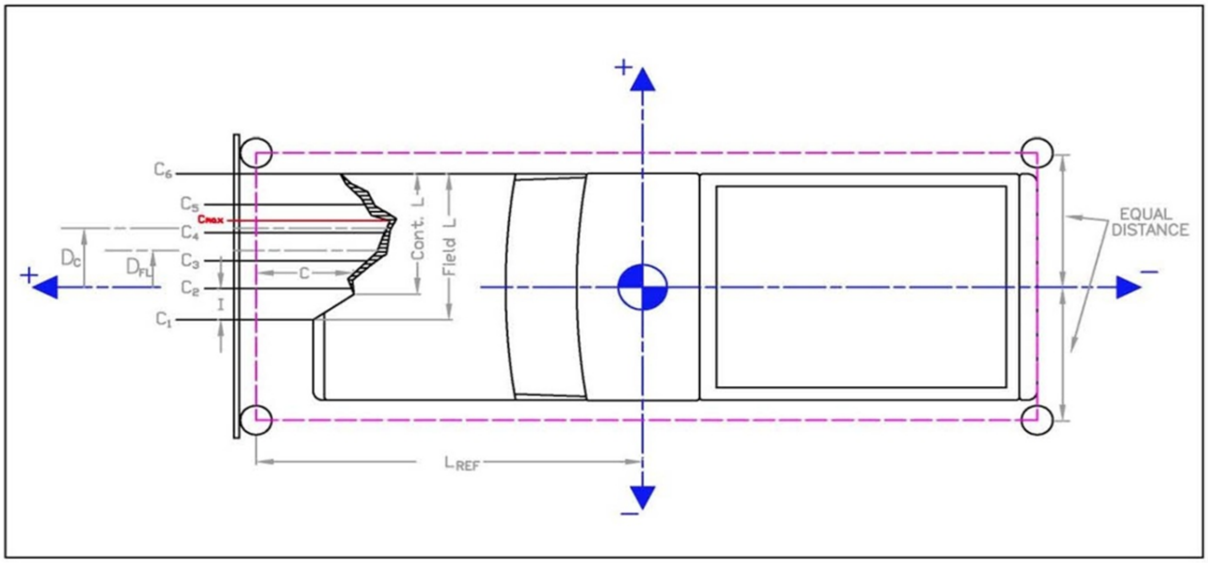
Note: If impact is on driver side need to enter negative number for Y

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	56	-58 3/4	23 1/2	54 3/4	-58 1/4	22 3/4	-1 1/4	1/2	- 3/4
	A2	52	-48 1/2	24 3/4	51 1/2	-48	24 1/4	- 1/2	1/2	- 1/2
	A3	50 1/2	-32	25	49 1/2	-31 1/2	25	-1	1/2	0
	A4	51	-61	12 3/4	50	-60 1/4	12	-1	3/4	- 3/4
	A5	47 1/2	-44	13 1/4	47	-43 3/4	13 1/4	- 1/2	1/4	0
	A6	42 3/4	-36 1/2	10 3/4	42 1/4	-36	10 1/2	- 1/2	1/2	- 1/4
SIDE PANEL	B1	42 3/4	-24 1/4	1/2	42 1/2	-24 1/4	1/4	- 1/4	0	- 1/4
	B2	43	-24	-6 1/2	43 1/4	-24 1/4	-6 1/4	1/4	- 1/4	1/4
	B3	45 3/4	-24 1/4	-4 1/2	46	-24 3/4	-4 1/2	1/4	- 1/2	0
IMPACT SIDE DOOR	C1	9 1/4	-34 1/4	18	9 1/4	-34 1/4	18	0	0	0
	C2	21	-33 3/4	17 3/4	20 3/4	-33	17 1/2	- 1/4	3/4	- 1/4
	C3	33 1/4	-32 3/4	17	32 1/2	-32 1/2	16 1/2	- 3/4	1/4	- 1/2
	C4	7 1/4	-26	1	7 1/2	-26 3/4	1	1/4	- 3/4	0
	C5	21 3/4	-26 3/4	3/4	21 1/2	-28 1/4	1/2	- 1/4	-1 1/2	- 1/4
	C6	27 1/4	-27	1	27	-28 1/4	1	- 1/4	-1 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-10. Occupant Compartment Deformation Data – Set 2, Test No. 4CMB-5

Date: 6/1/2011 **Test Number:** 4CMB-5

Make: Dodge **Model:** 2270P **Year:** 2002



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	112.25	(2851)
Width of contact and induced crush - Field L:	38.875	(987)
Crush measurement spacing interval (L/5) - I:	7.775	(197)
Distance from center of vehicle to center of Field L - D_{FL}:	-19.4375	-(494)
Width of Contact Damage:	38.875	(987)
Distance from center of vehicle to center of contect damage - D_C:	19.4375	(494)

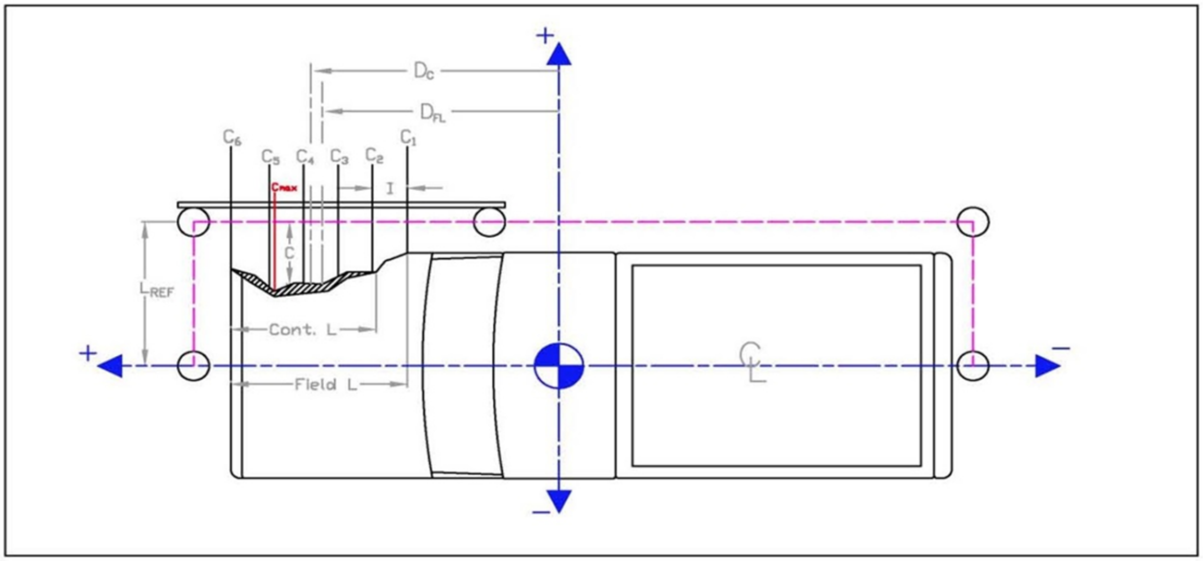
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	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	-38.875	-(987)	29.00	(737)	0.53	(14)	NA	NA
C_2	26.25	(667)	-31.1	-(790)	16.98	(431)			8.7	(222)
C_3	15	(381)	-23.325	-(592)	13.47	(342)			1.0	(25)
C_4	12.5	(318)	-15.55	-(395)	11.70	(297)			0.3	(7)
C_5	12	(305)	-7.775	-(197)	10.50	(267)			1.0	(25)
C_6	11.25	(286)	0	()	10.25	(260)			0.5	(12)
C_{MAX}	26.25	(667)	-31	-(787)	16.81	(427)			8.9	(226)

Figure D-11. Exterior Vehicle Crush (NASS) - Front, Test No. 4CMB-5

Date: 6/1/2011 **Test Number:** 4CMB-5

Make: Dodge **Model:** 2270P **Year:** 2002



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	50	(1270)
Width of contact and induced crush - Field L:	59.75	(1518)
Crush measurement spacing interval (L/5) - I:	11.95	(304)
Distance from vehicle c.g. to center of Field L - D_{FL}:	89.625	(2276)
Width of Contact Damage:	59.75	(1518)
Distance from vehicle c.g. to center of contect damage - D_C:	71.875	(1826)

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

	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	9	(229)	59.75	(1518)	10.50	(267)	0	0	-1.5	-(38)
C_2	NA	NA	71.7	(1821)	10.50	(267)			NA	NA
C_3	14.5	(368)	83.65	(2125)	11.69	(297)			2.8	(71)
C_4	25	(635)	95.6	(2428)	19.25	(489)			5.8	(146)
C_5	NA	NA	107.55	(2732)	37.00	(940)			NA	NA
C_6	NA	NA	119.5	(3035)	37.00	(940)			NA	NA
C_{MAX}	15.5	(394)	75.5	(1918)	10.50	(267)			5.0	(127)

Figure D-12. Exterior Vehicle Crush (NASS) - Side, Test No. 4CMB-5

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

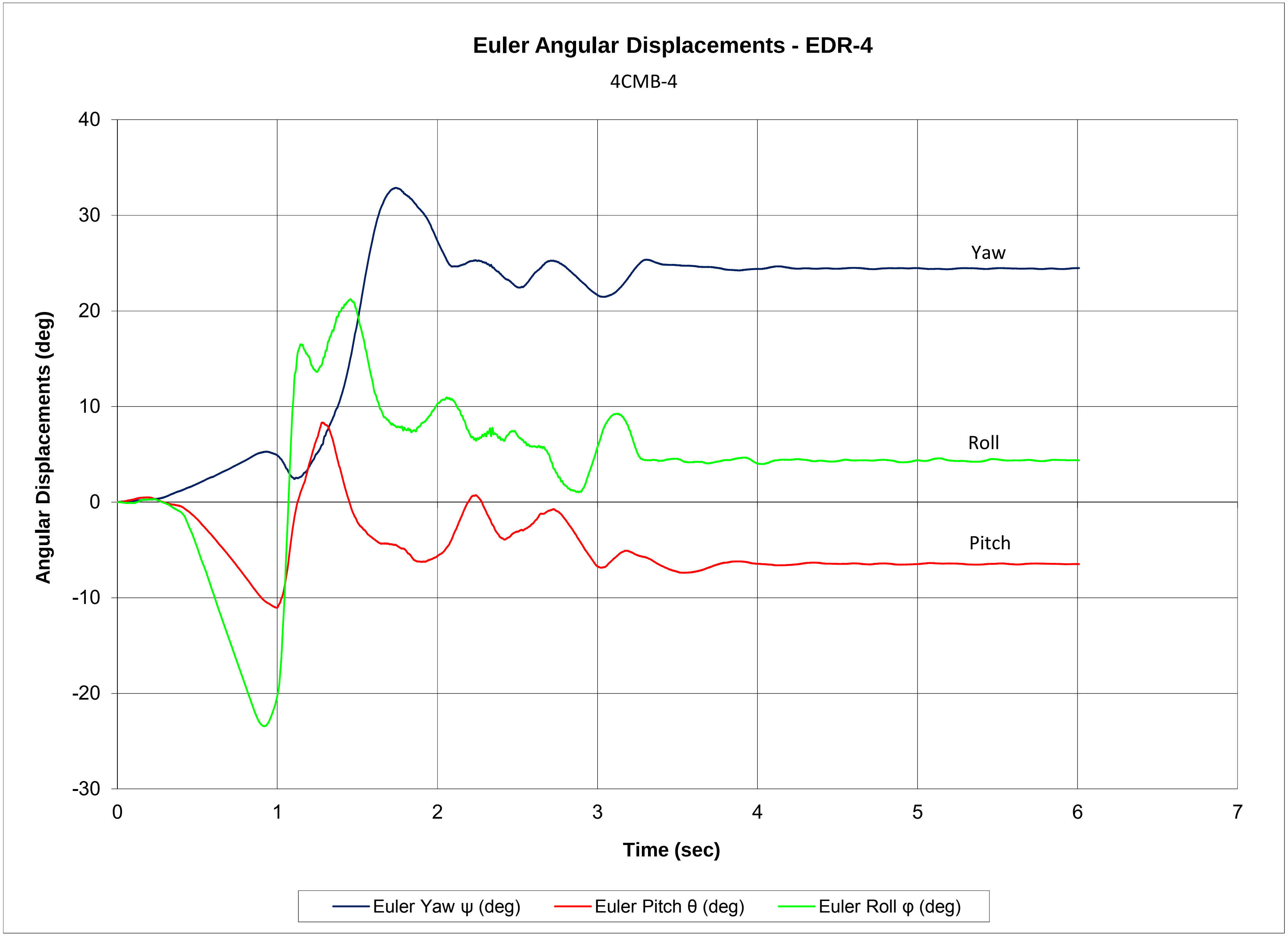


Figure E-1. Vehicle Angular Displacements (EDR-4), Test No. 4CMB-4

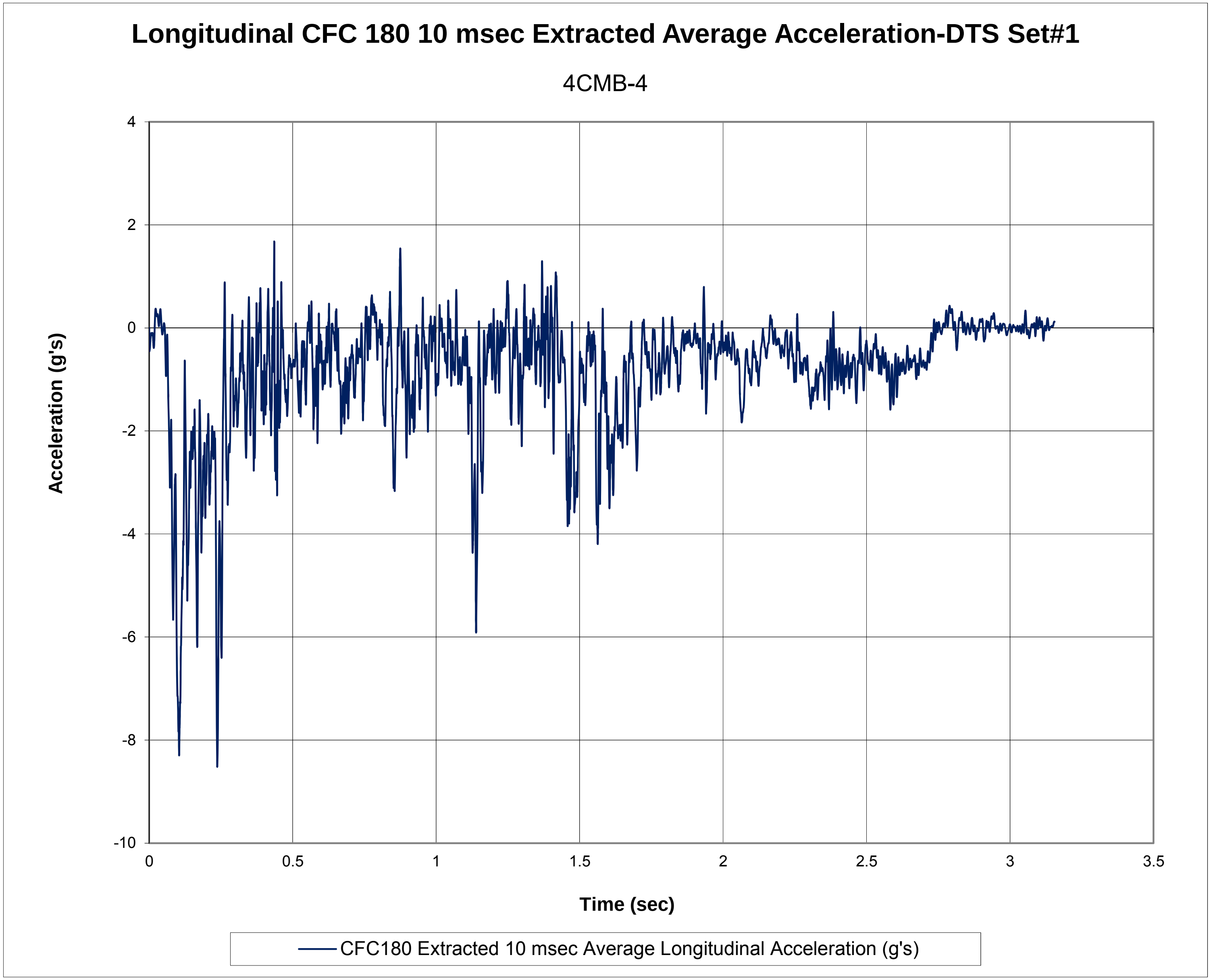


Figure E-2. 10-ms Average Longitudinal Deceleration (DTS Set#1), Test No. 4CMB-4

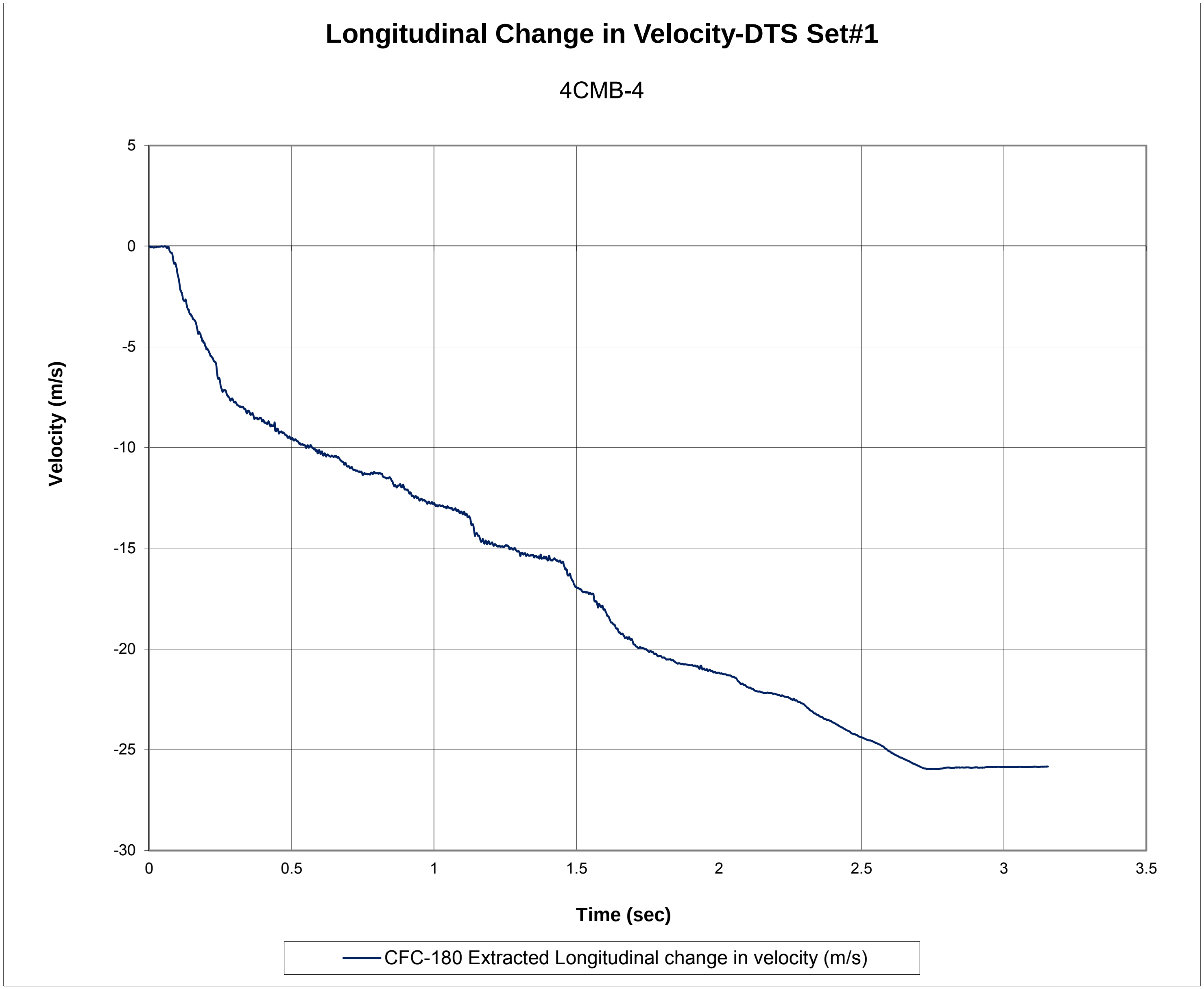


Figure E-3. Longitudinal Occupant Impact Velocity (DTS Set#1), Test No. 4CMB-4

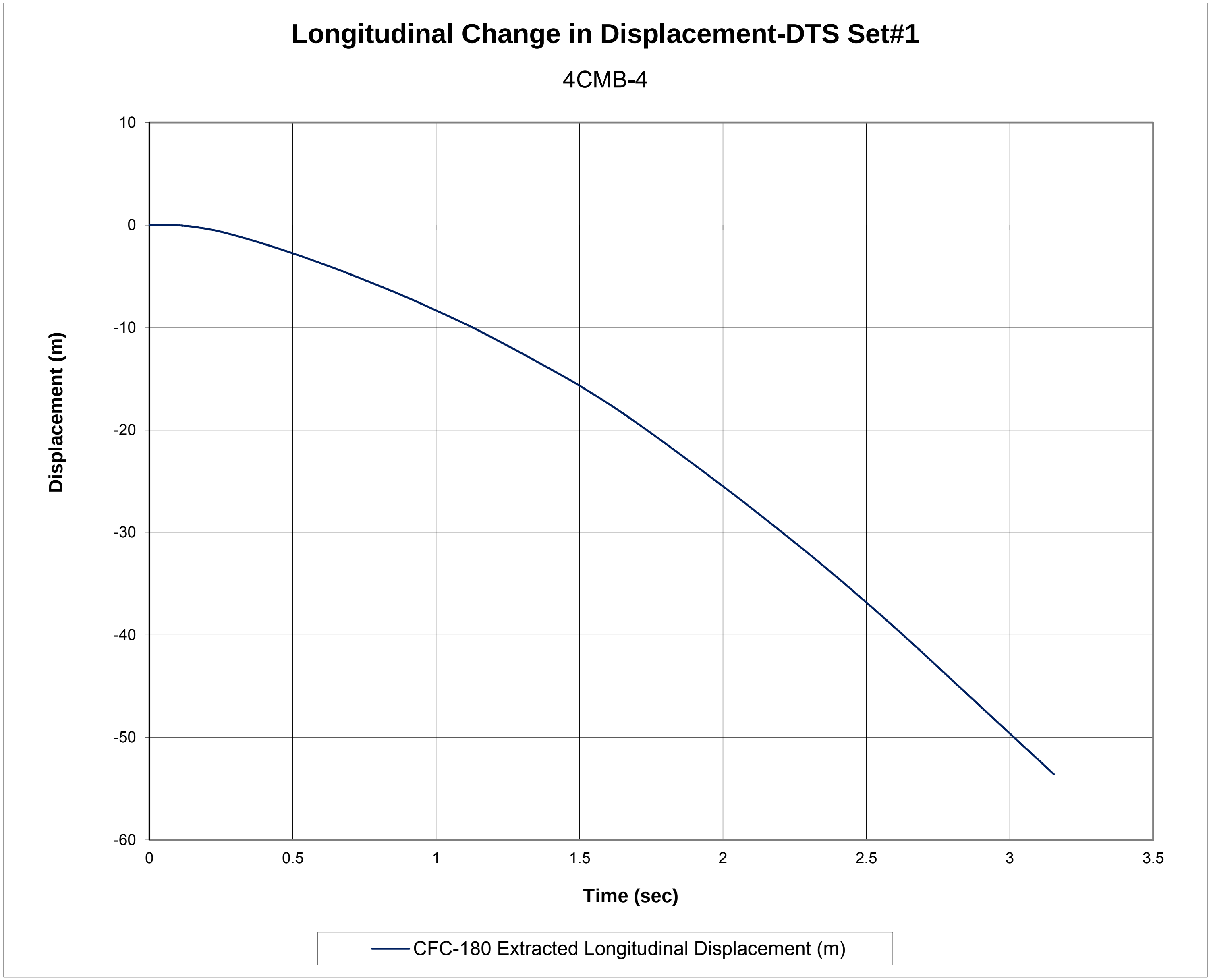


Figure E-4. Longitudinal Occupant Displacement (DTS Set#1), Test No. 4CMB-4

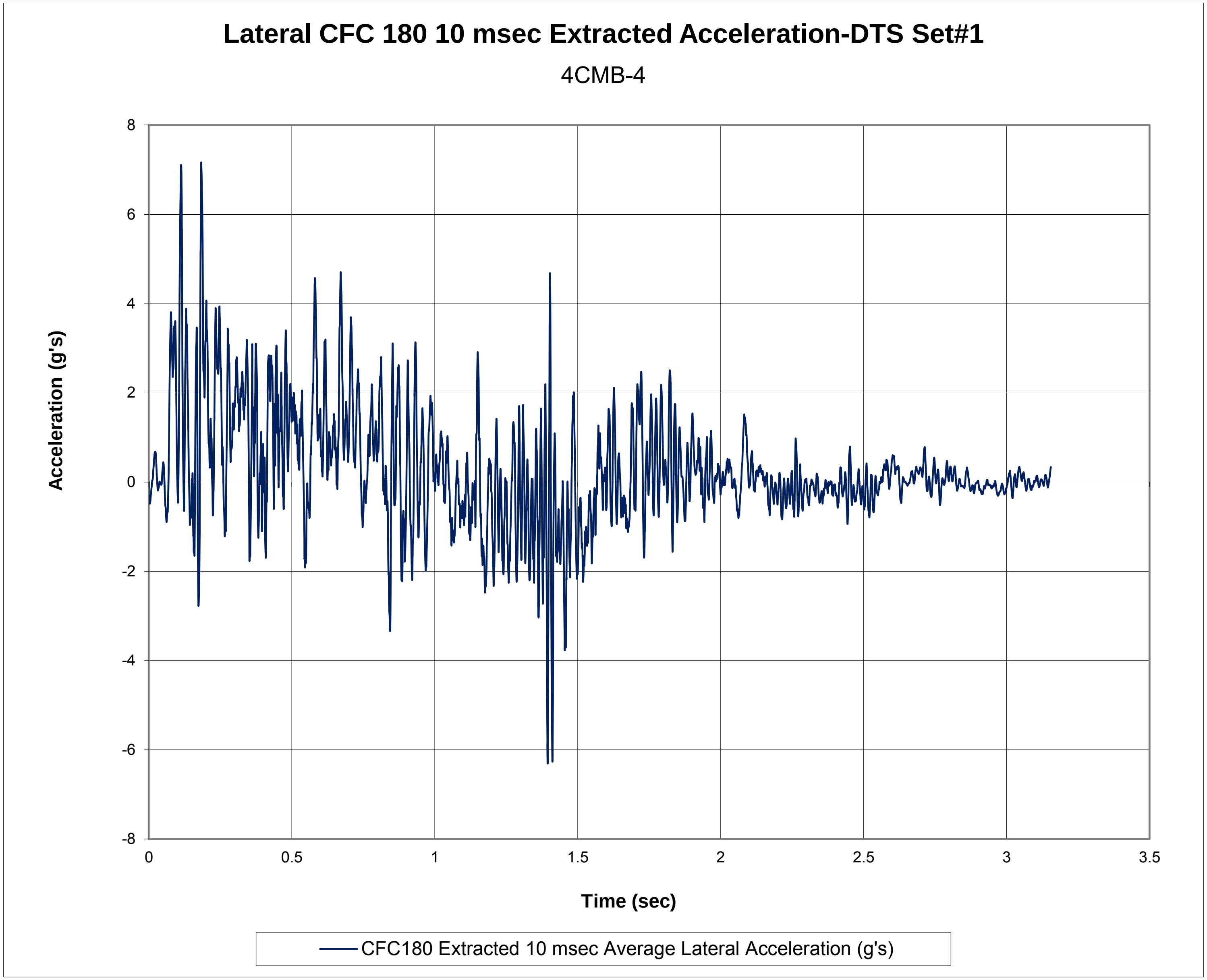


Figure E-5. 10-ms Average Lateral Deceleration (DTS Set#1), Test No. 4CMB-4

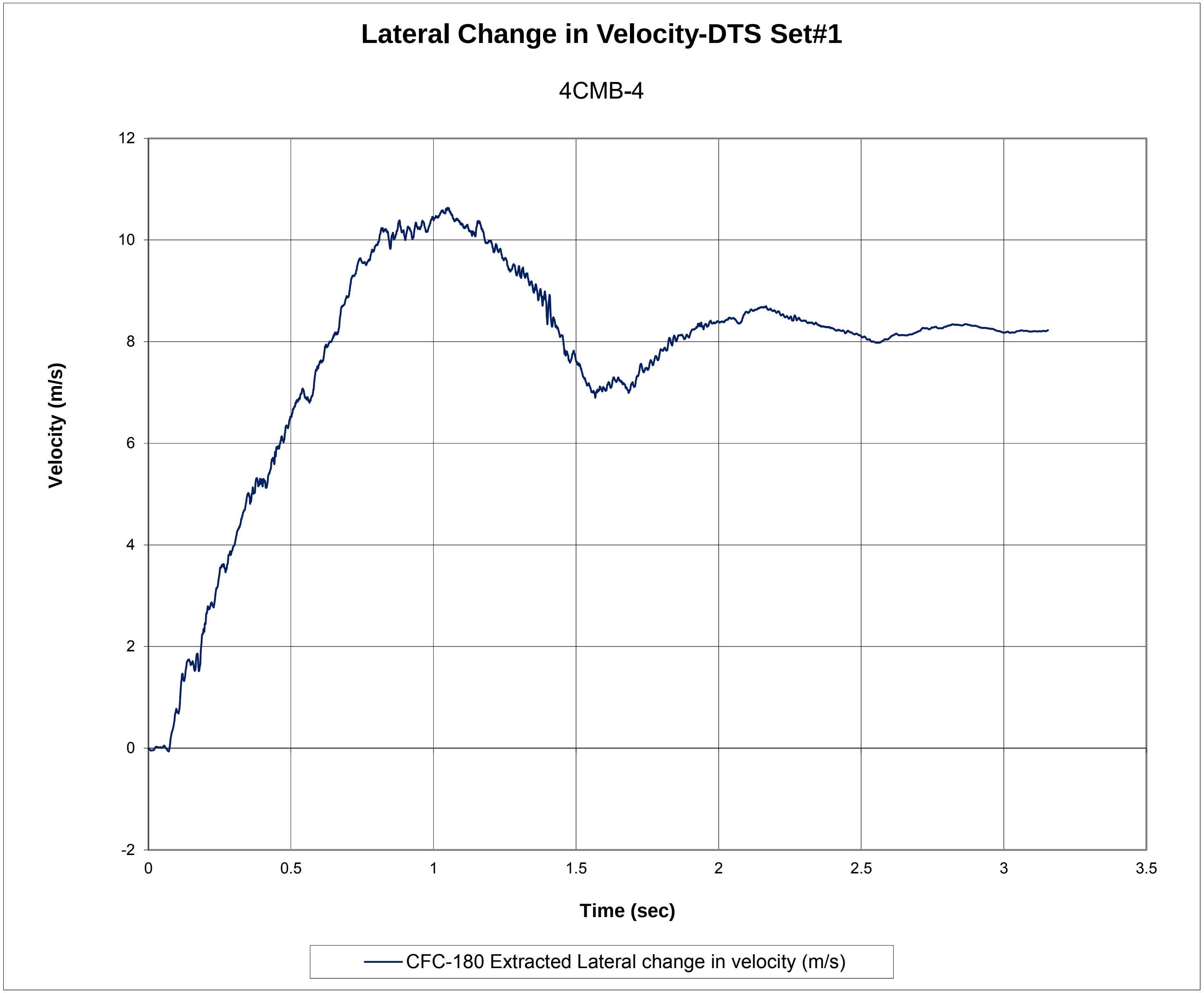


Figure E-6. Lateral Occupant Impact Velocity (DTS Set#1), Test No. 4CMB-4

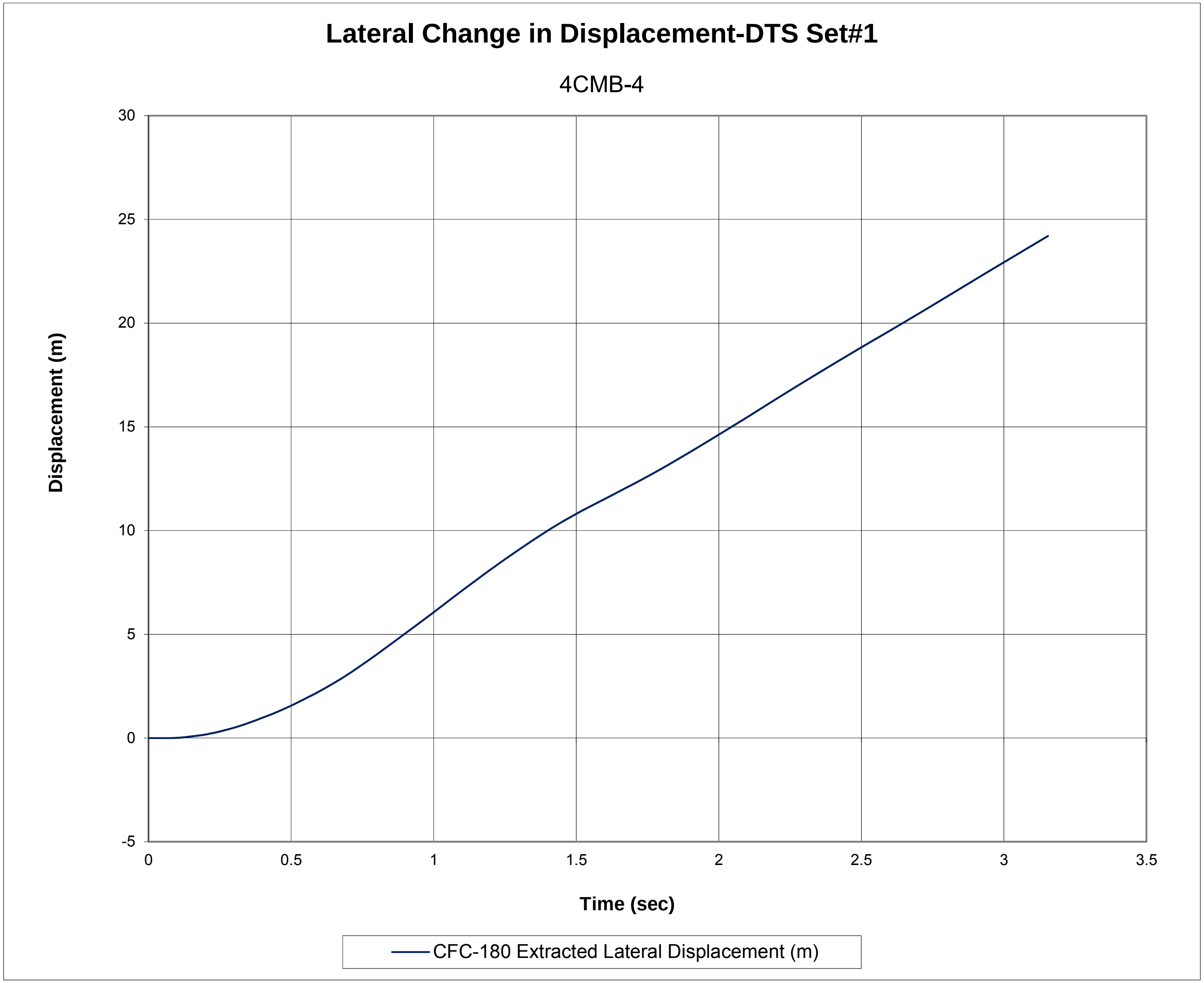


Figure E-7. Lateral Occupant Displacement (DTS Set#1), Test No. 4CMB-4

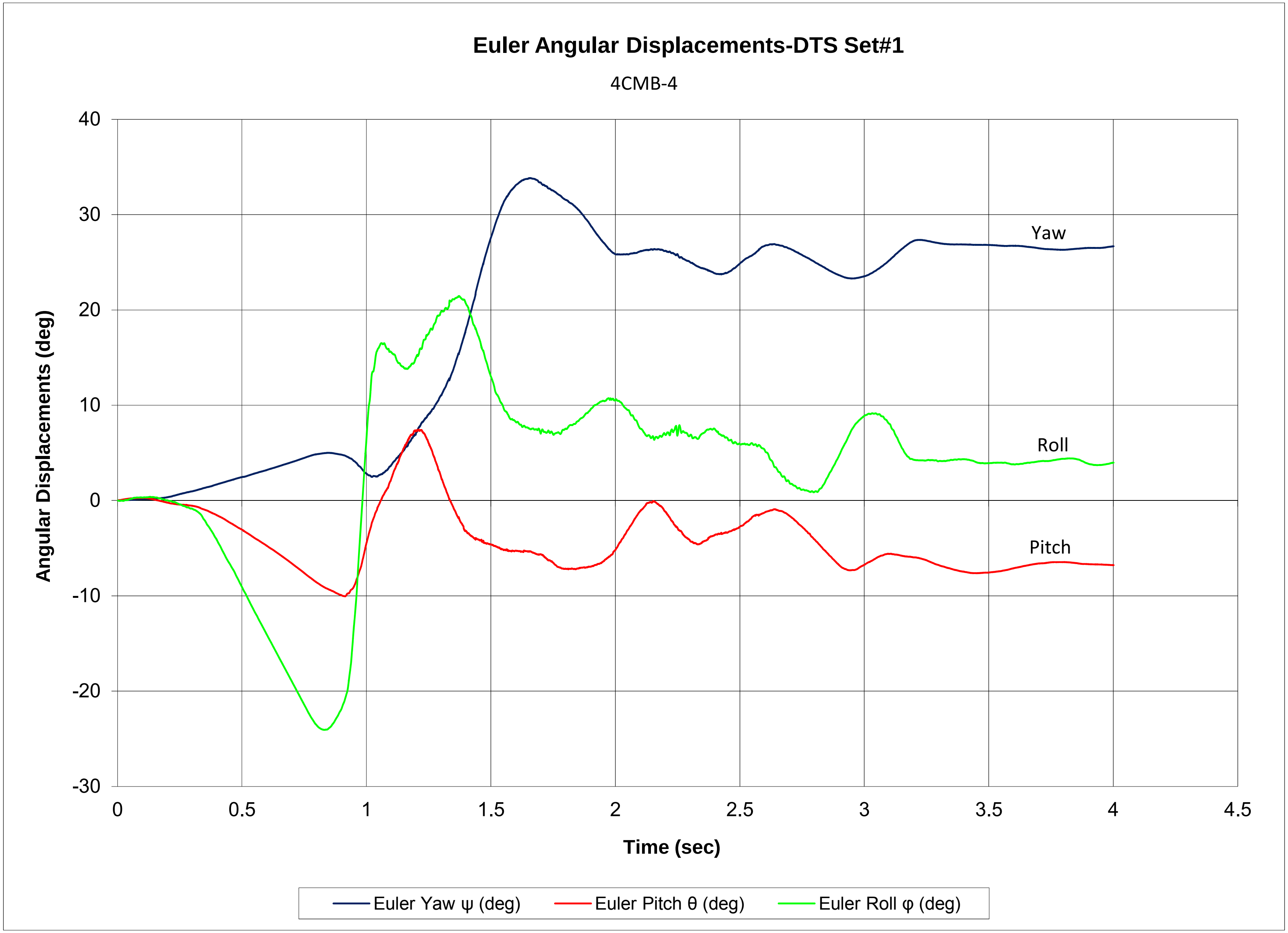


Figure E-8. Vehicle Angular Displacements (DTS Set#1), Test No. 4CMB-4

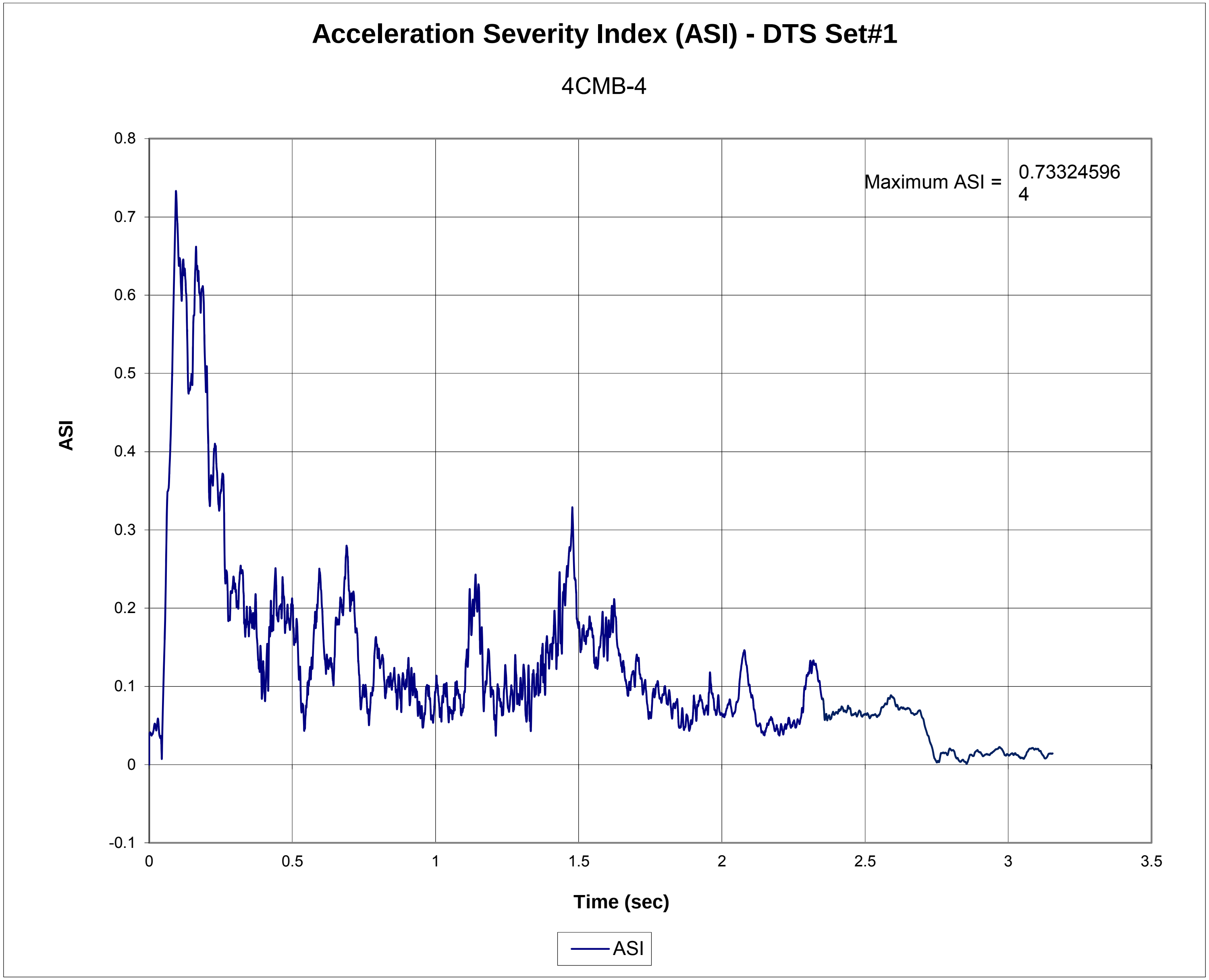


Figure E-9. Acceleration Severity Index (DTS Set#1), Test No. 4CMB-4

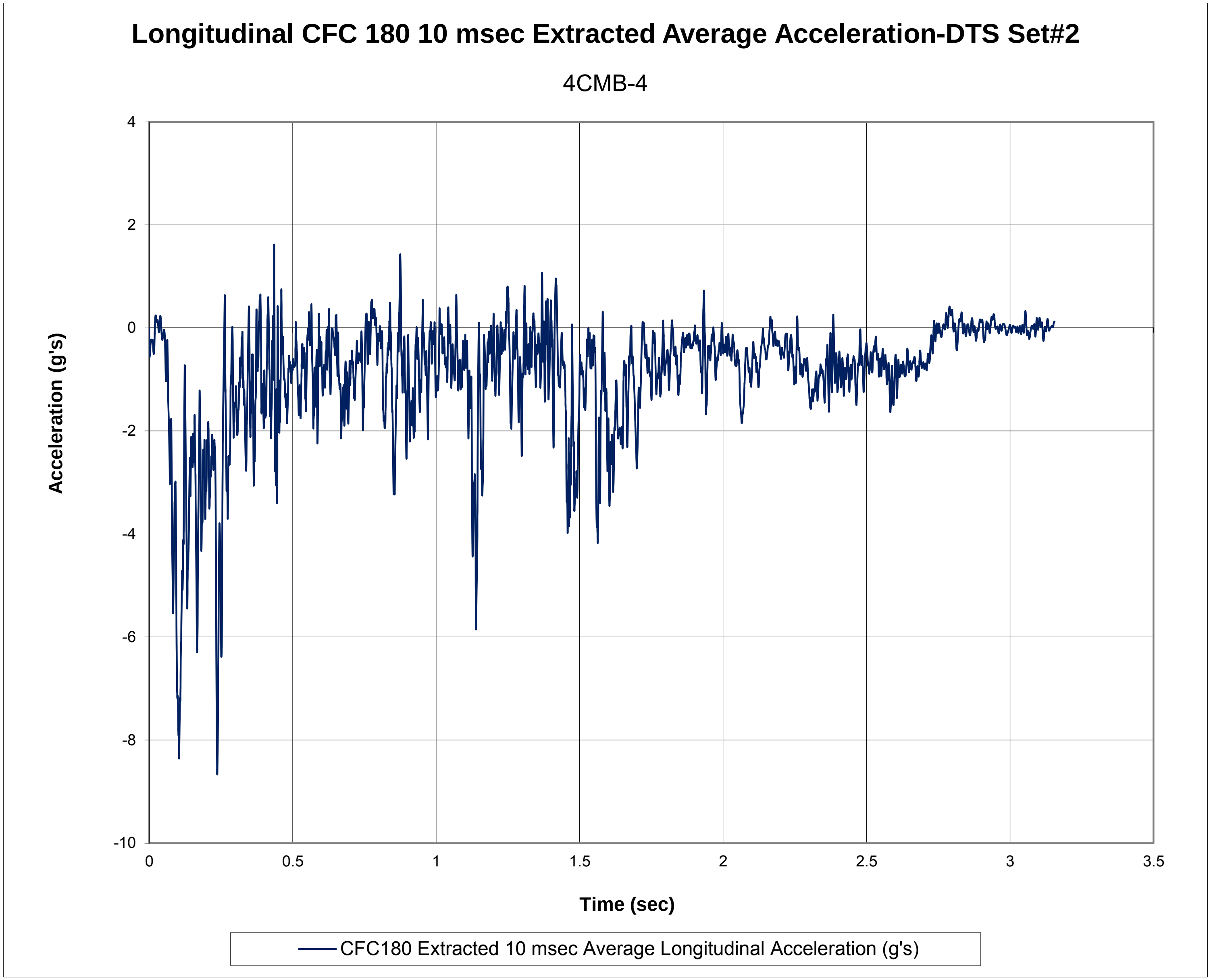


Figure E-10. 10-ms Average Longitudinal Deceleration (DTS Set#2), Test No. 4CMB-4

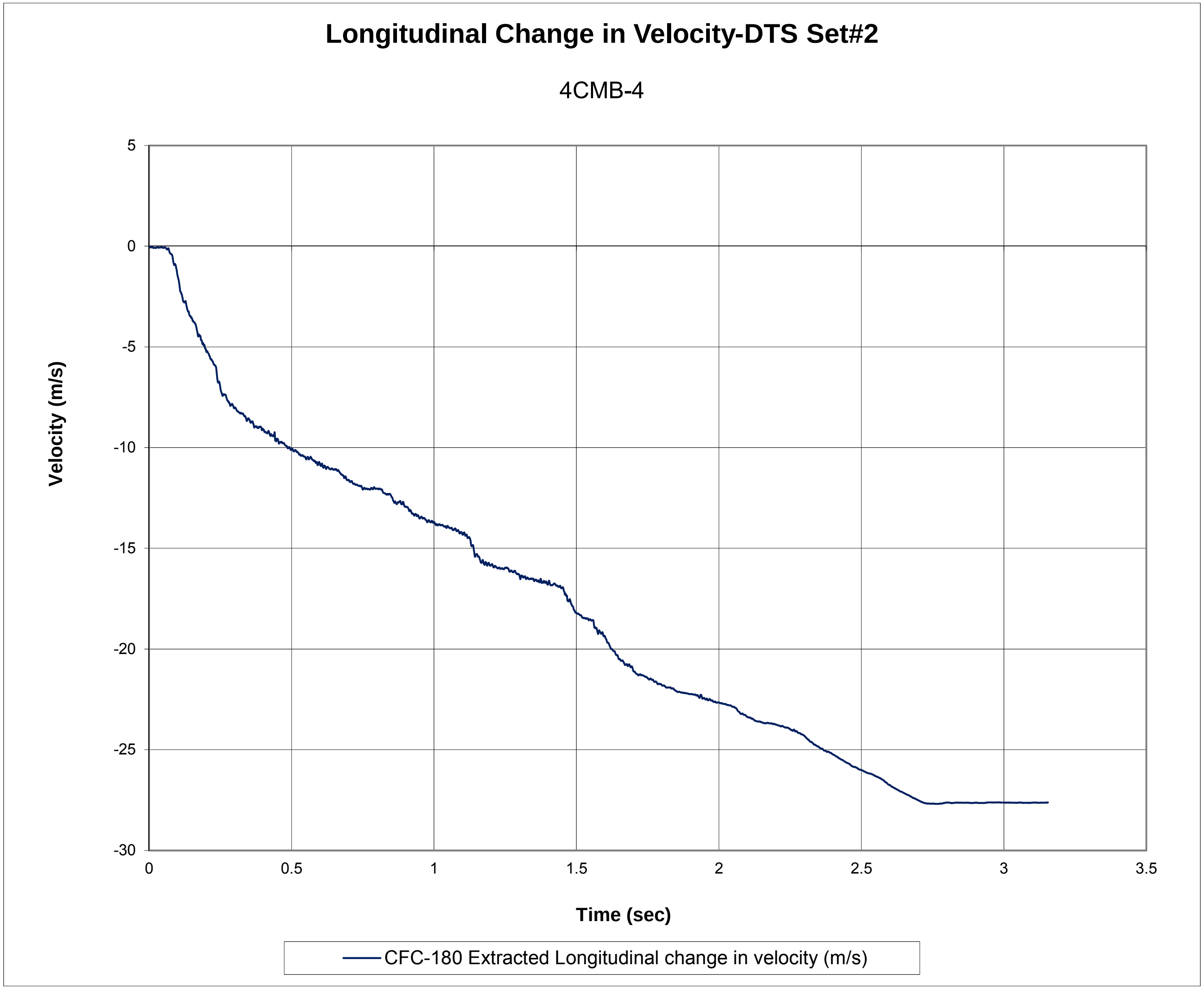


Figure E-11. Longitudinal Occupant Impact Velocity (DTS Set#2), Test No. 4CMB-4

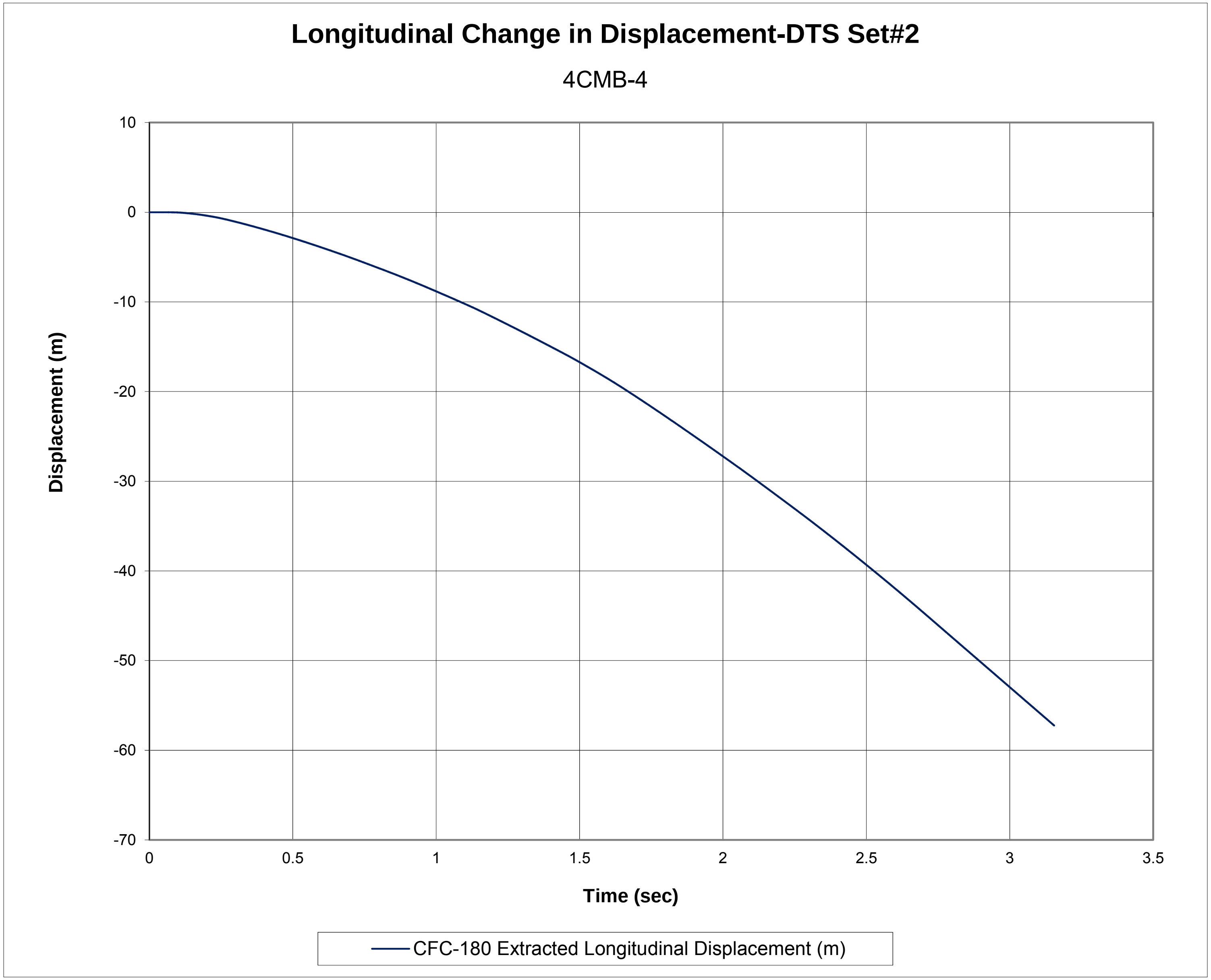


Figure E-12. Longitudinal Occupant Displacement (DTS Set#2), Test No. 4CMB-4

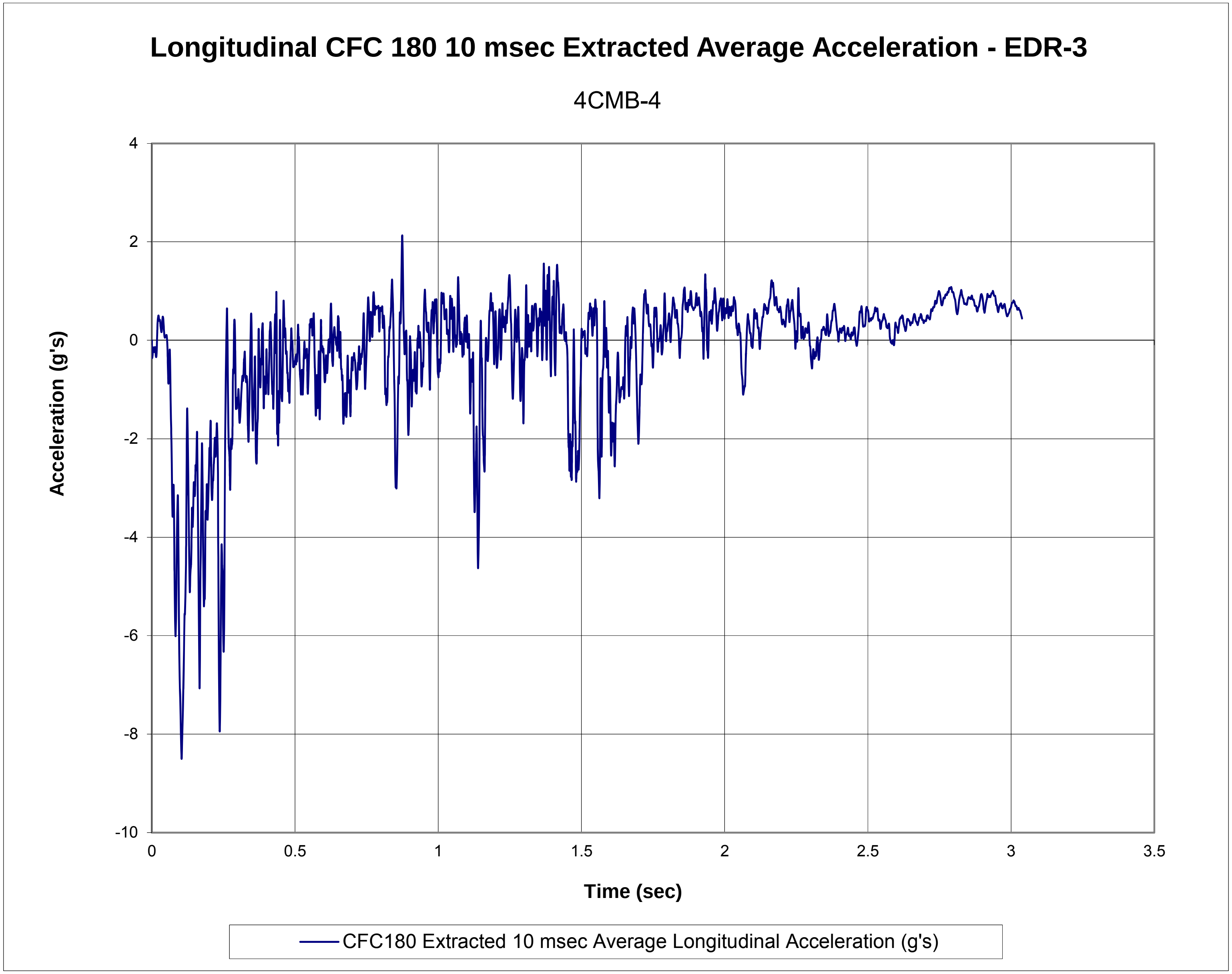


Figure E-13. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. 4CMB-4

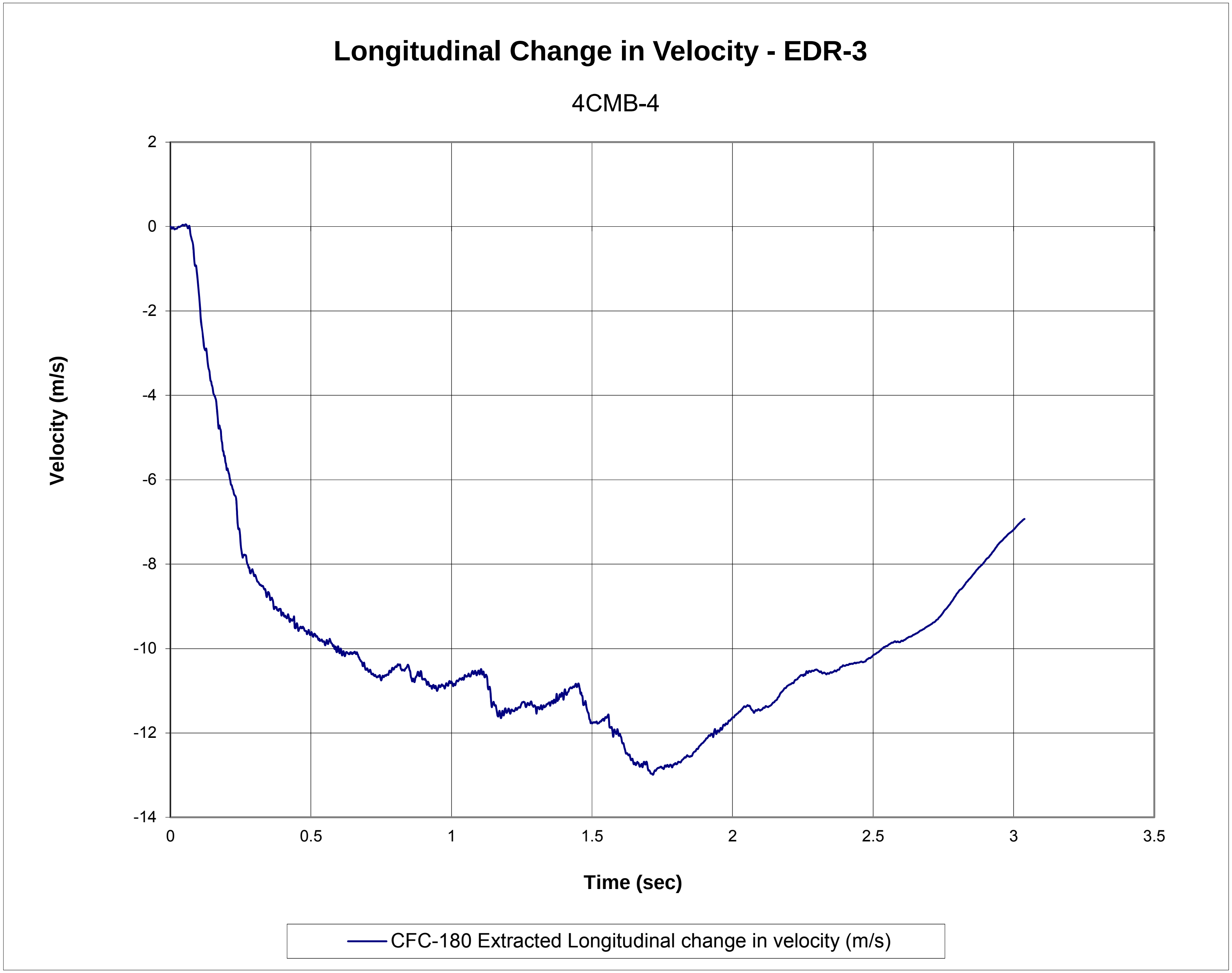


Figure E-14. Longitudinal Occupant Impact Velocity (EDR-3), Test No. 4CMB-4

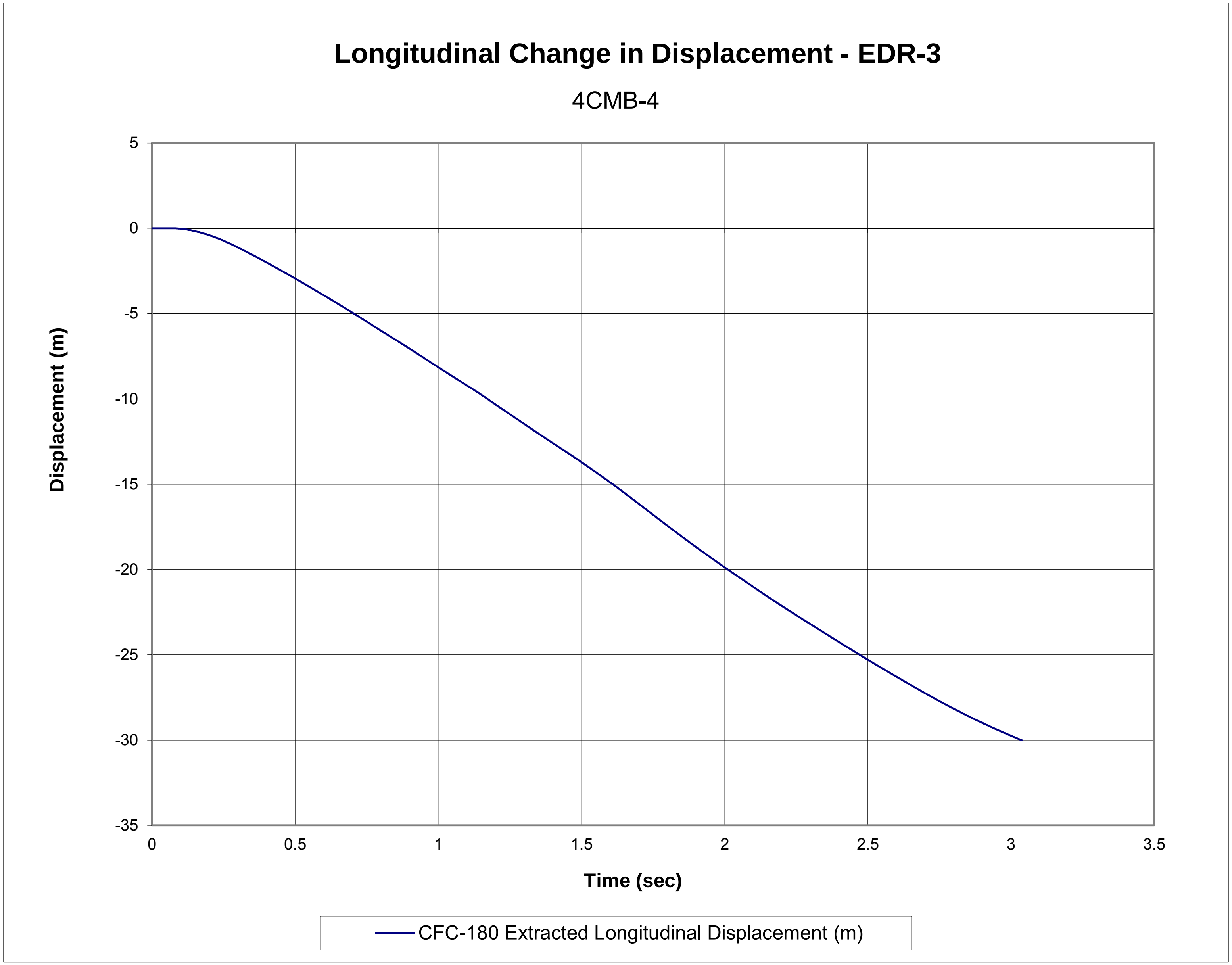


Figure E-15. Longitudinal Occupant Displacement (EDR-3), Test No. 4CMB-4

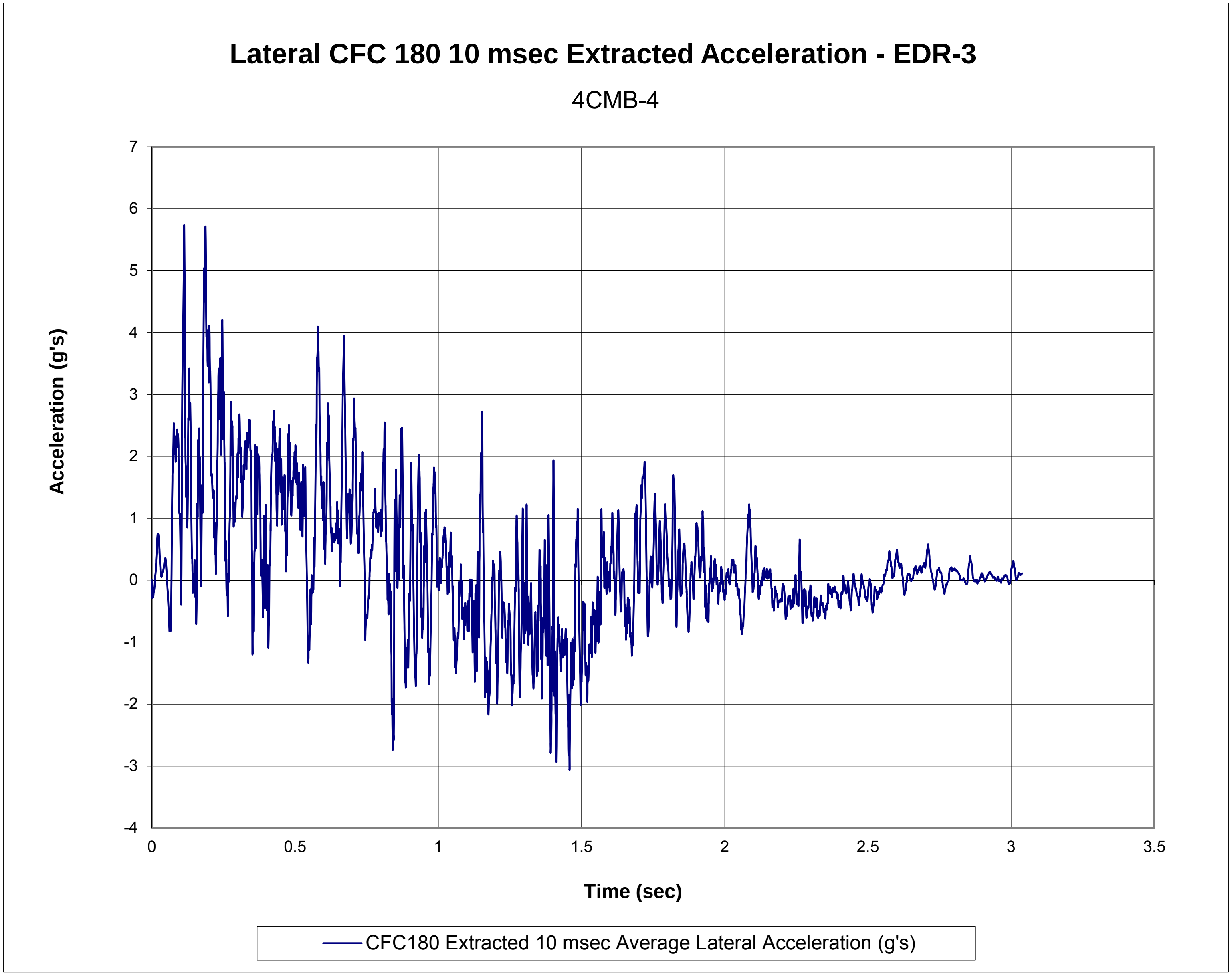


Figure E-16. 10-ms Average Lateral Deceleration (EDR-3), Test No. 4CMB-4

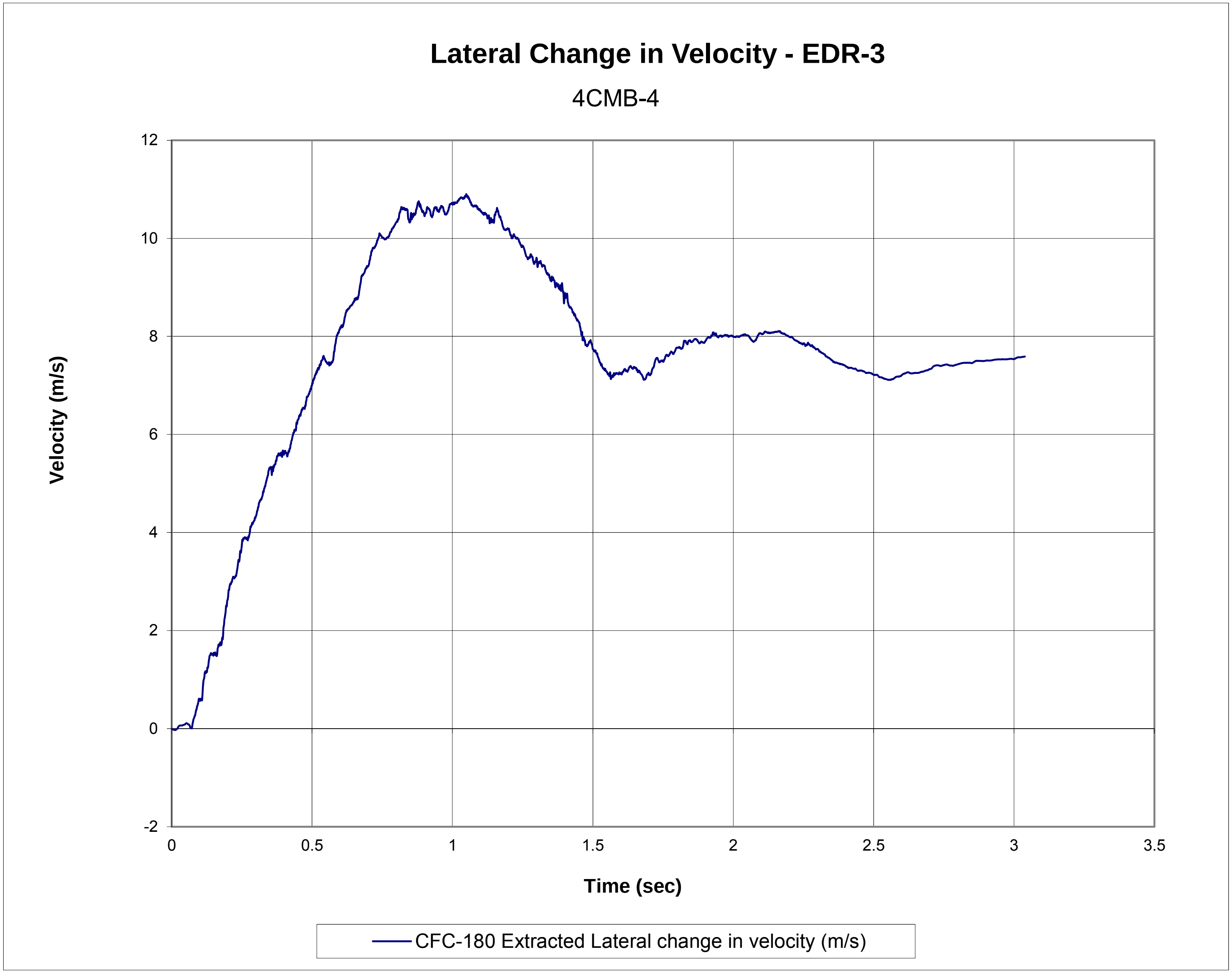


Figure E-17. Lateral Occupant Impact Velocity (EDR-3), Test No. 4CMB-4

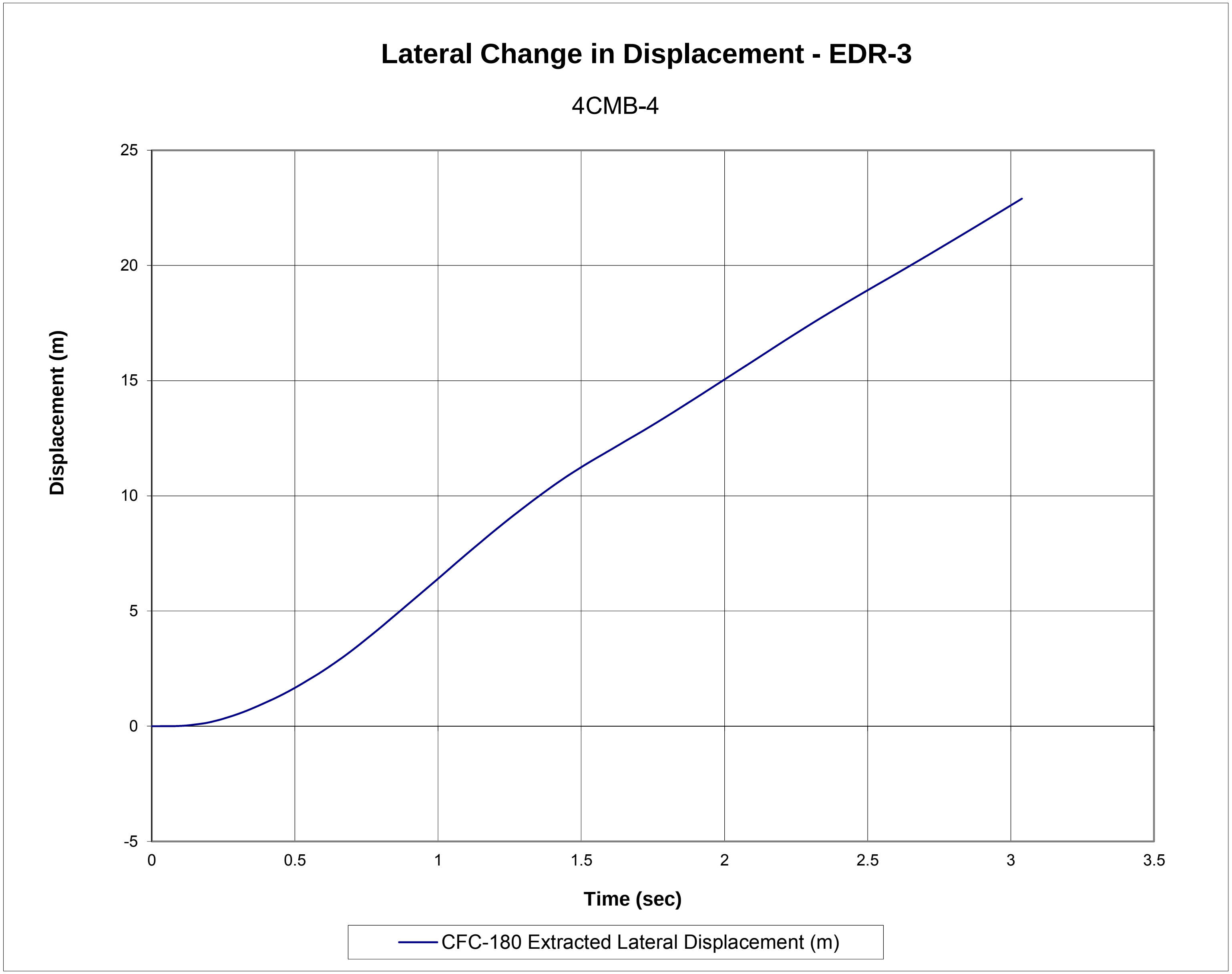


Figure E-18. Lateral Occupant Displacement (EDR-3), Test No. 4CMB-4

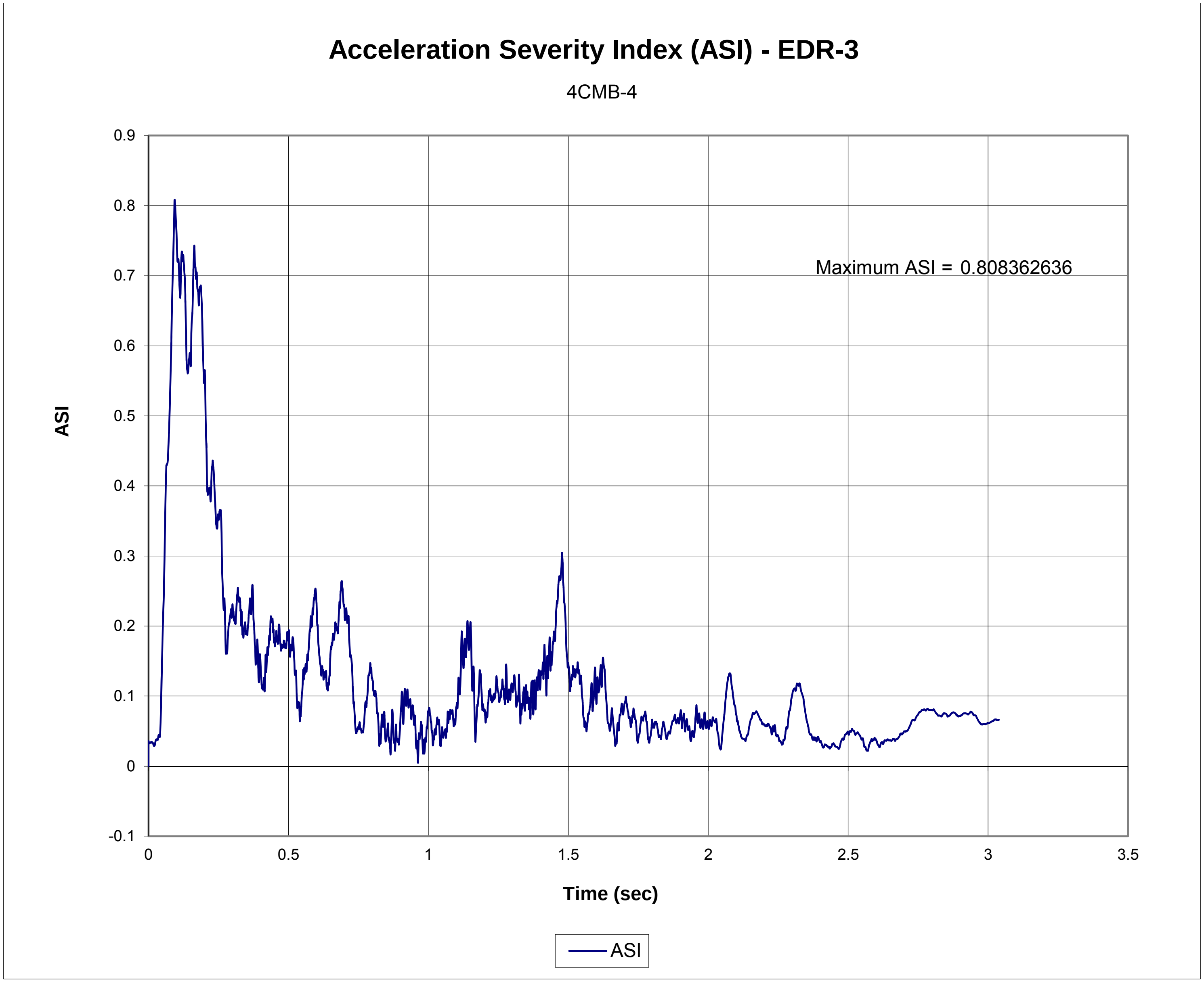


Figure E-19. Acceleration Severity Index (EDR-3), Test No. 4CMB-4

Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. 4CMB-5

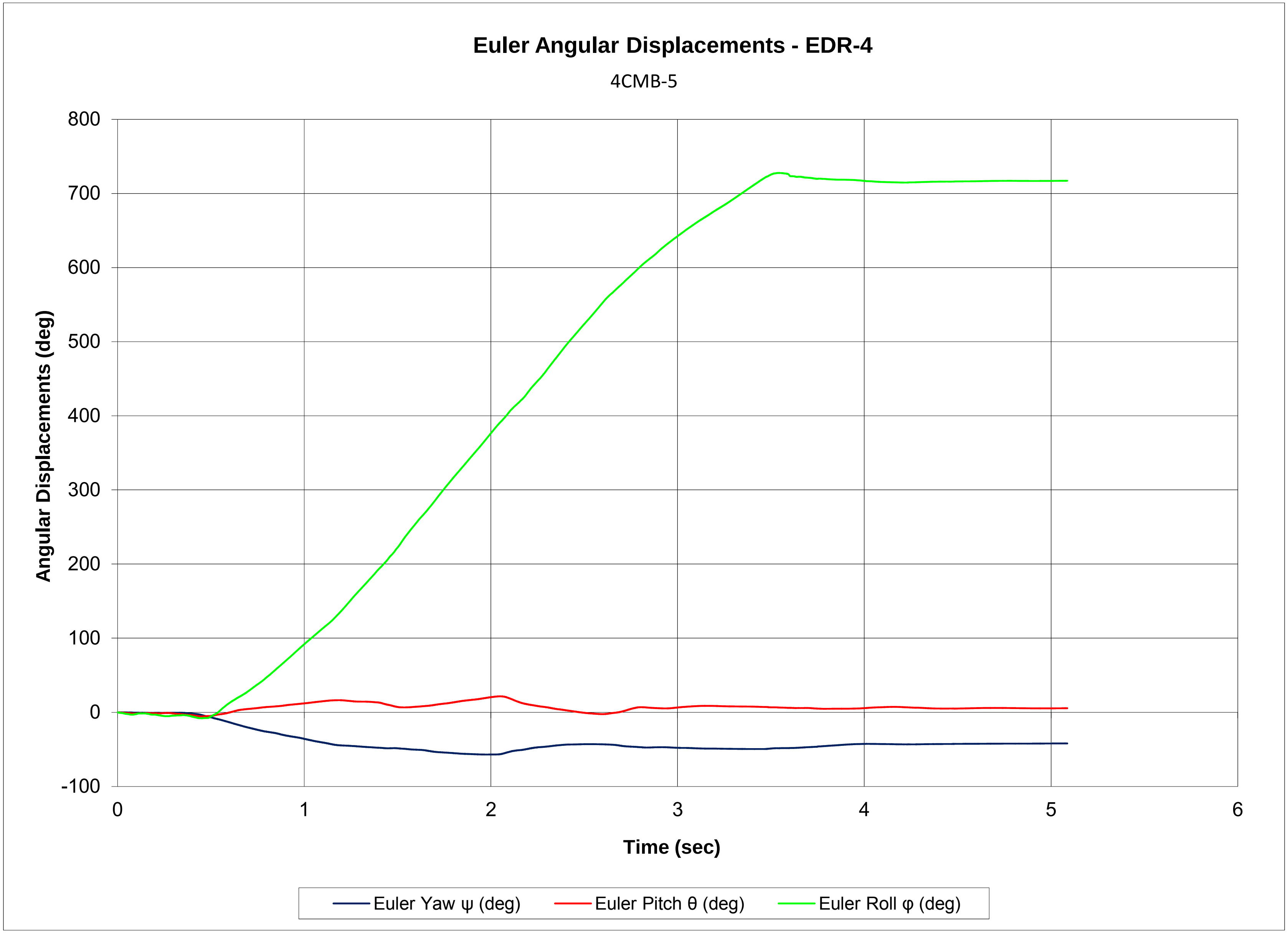


Figure F-1. Vehicle Angular Displacements (EDR-4), Test No. 4CMB-5

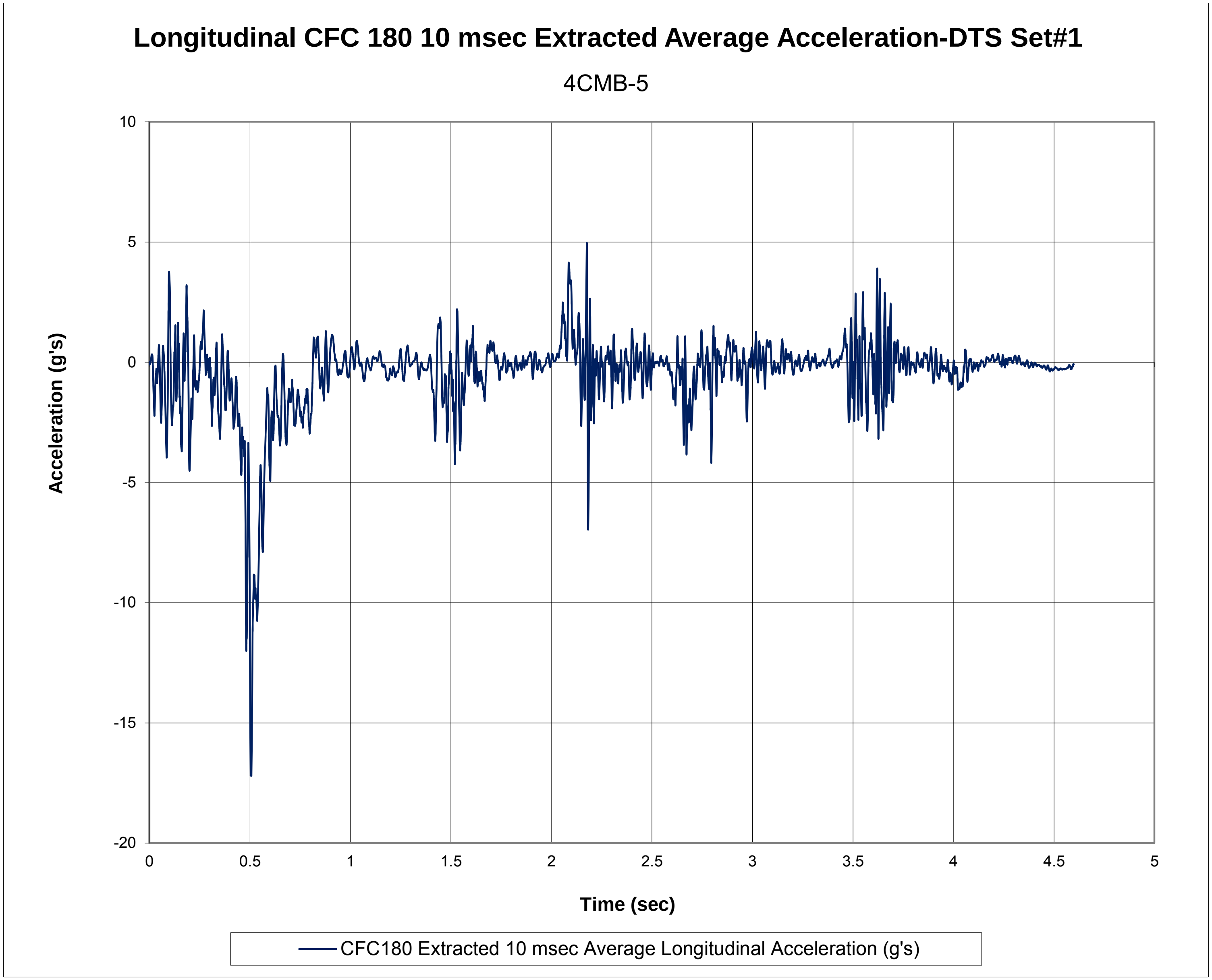


Figure F-2. 10-ms Average Longitudinal Deceleration (DTS Set#1), Test No. 4CMB-5

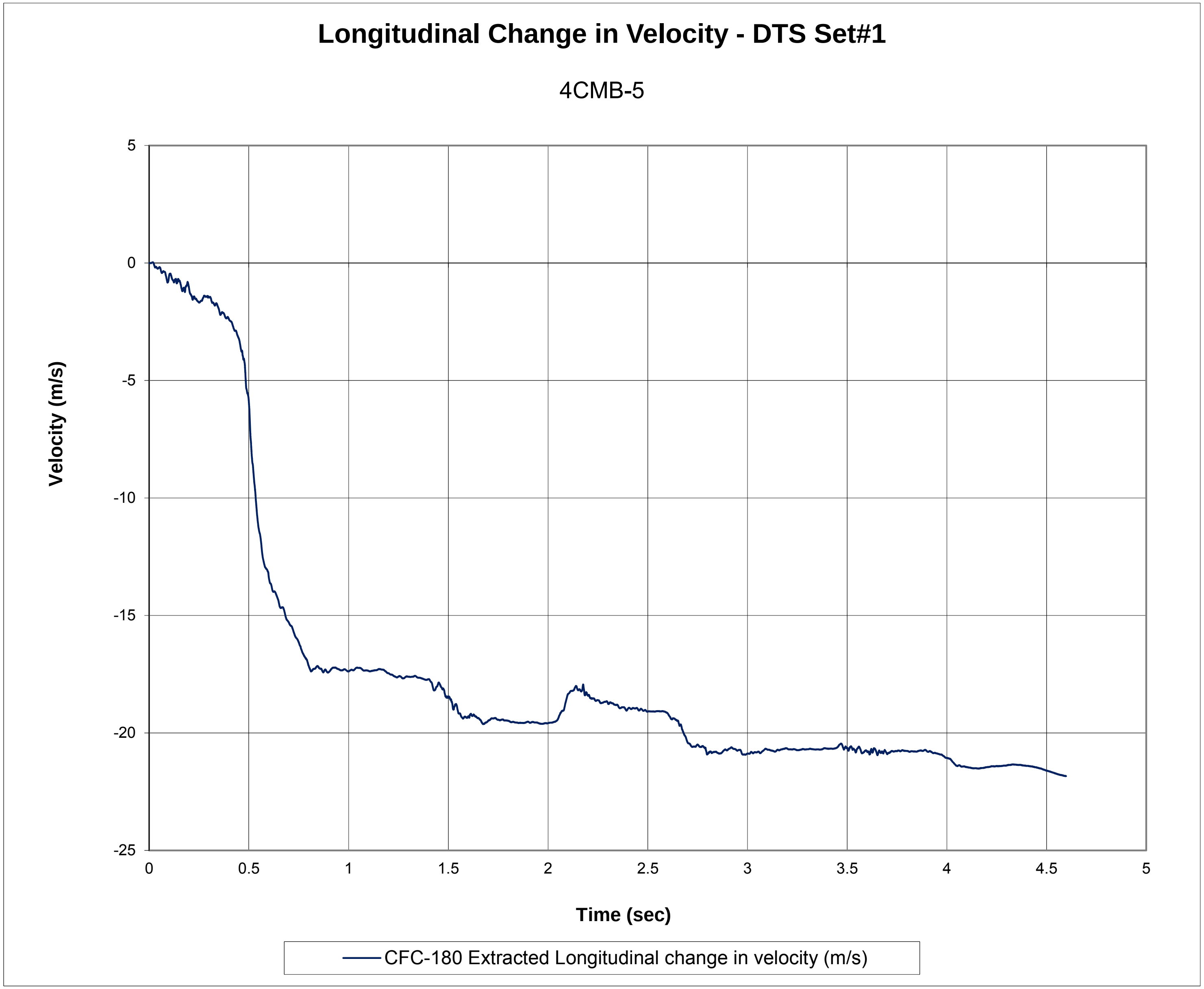


Figure F-3. Longitudinal Occupant Impact Velocity (DTS Set#1), Test No. 4CMB-5

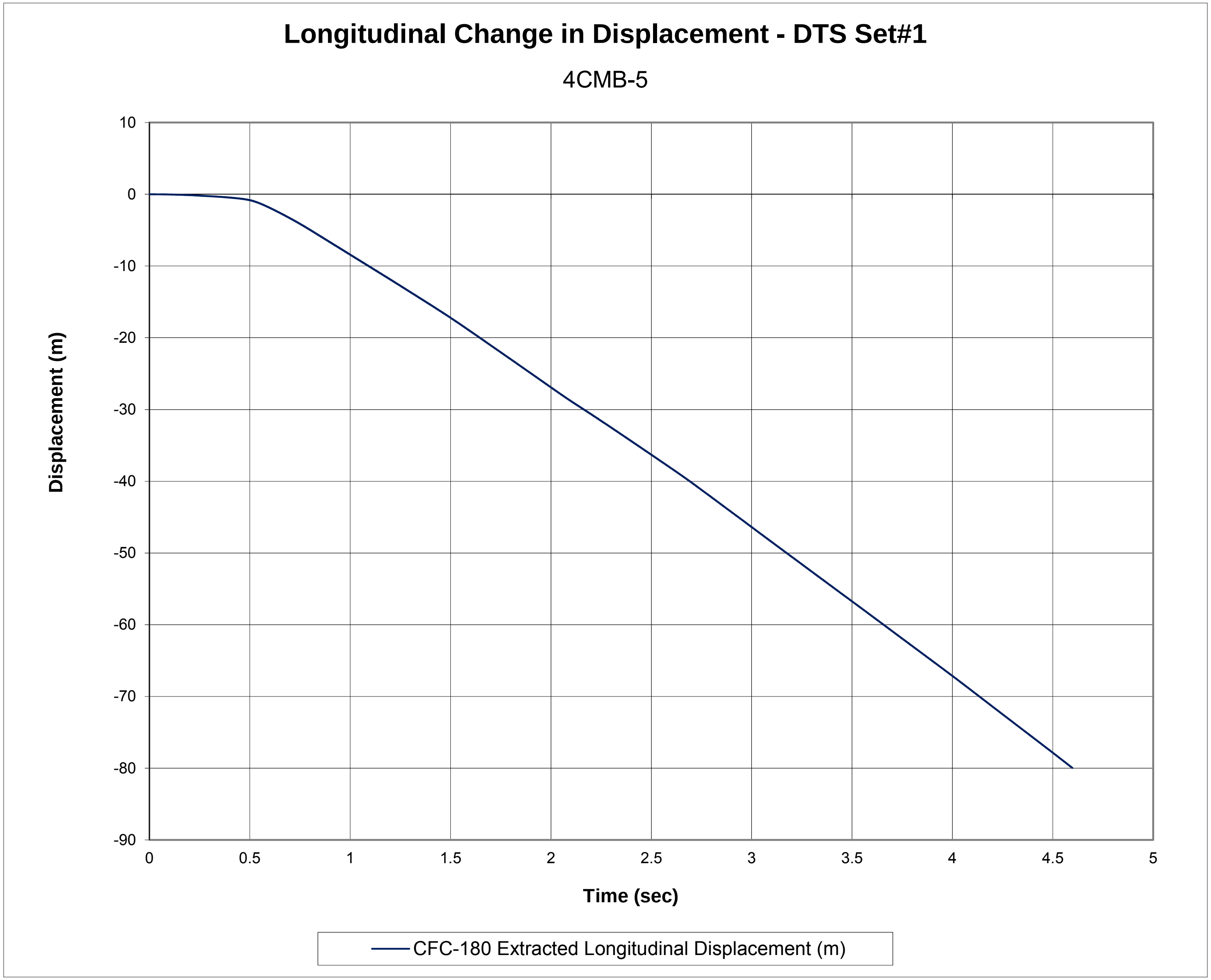


Figure F-4. Longitudinal Occupant Displacement (DTS Set#1), Test No. 4CMB-5

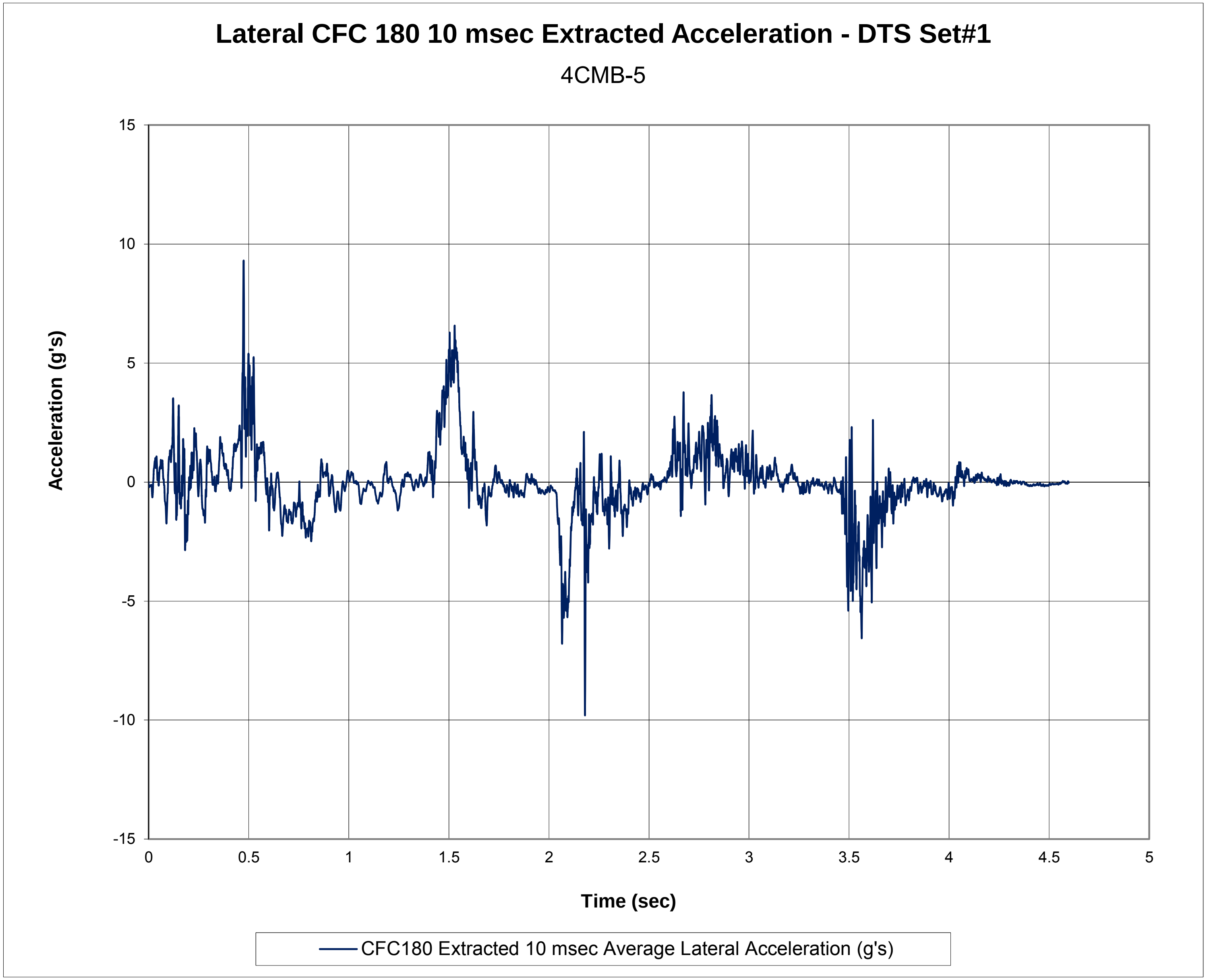


Figure F-5. 10-ms Average Lateral Deceleration (DTS Set#1), Test No. 4CMB-5

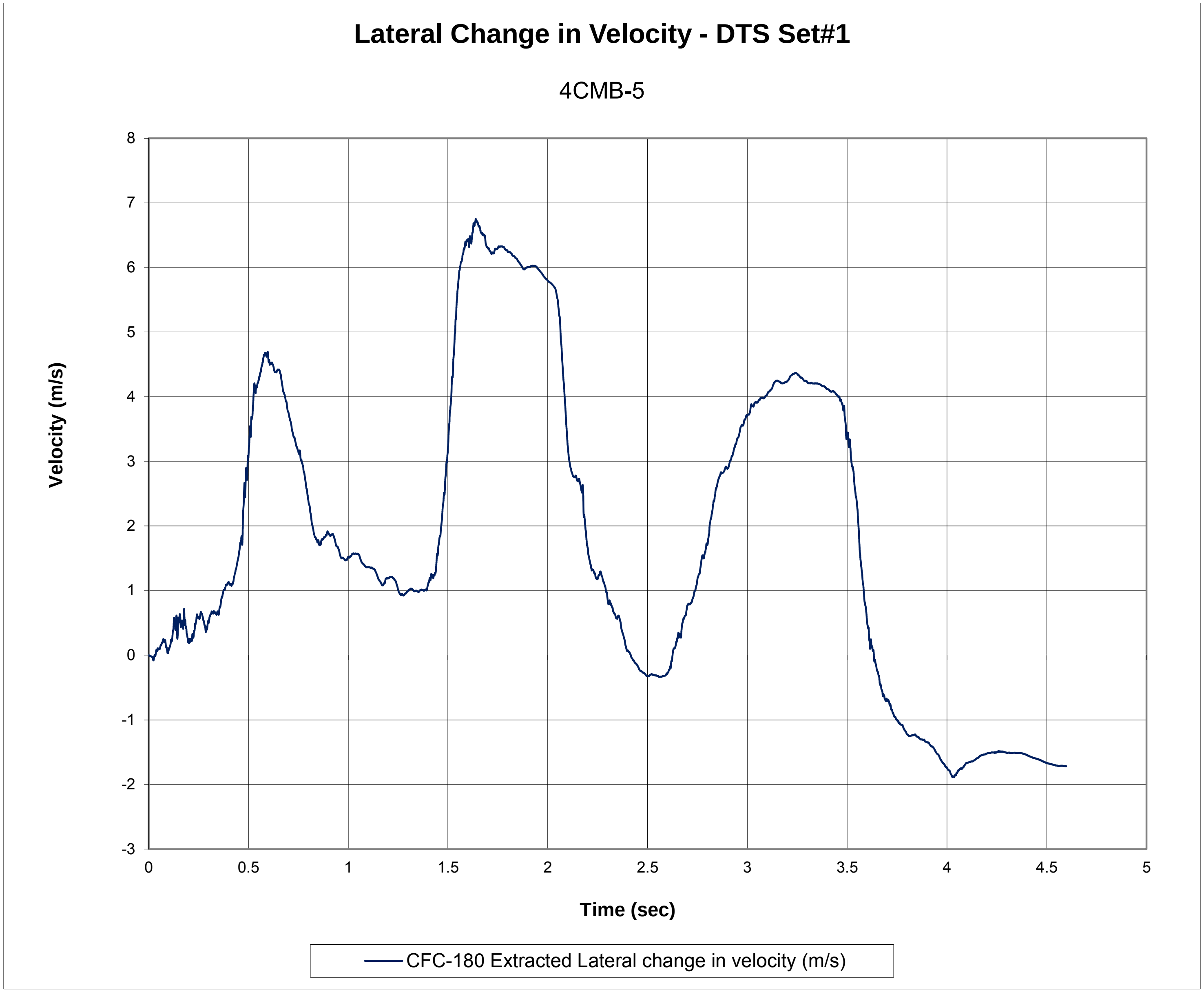


Figure F-6. Lateral Occupant Impact Velocity (DTS Set#1), Test No. 4CMB-5

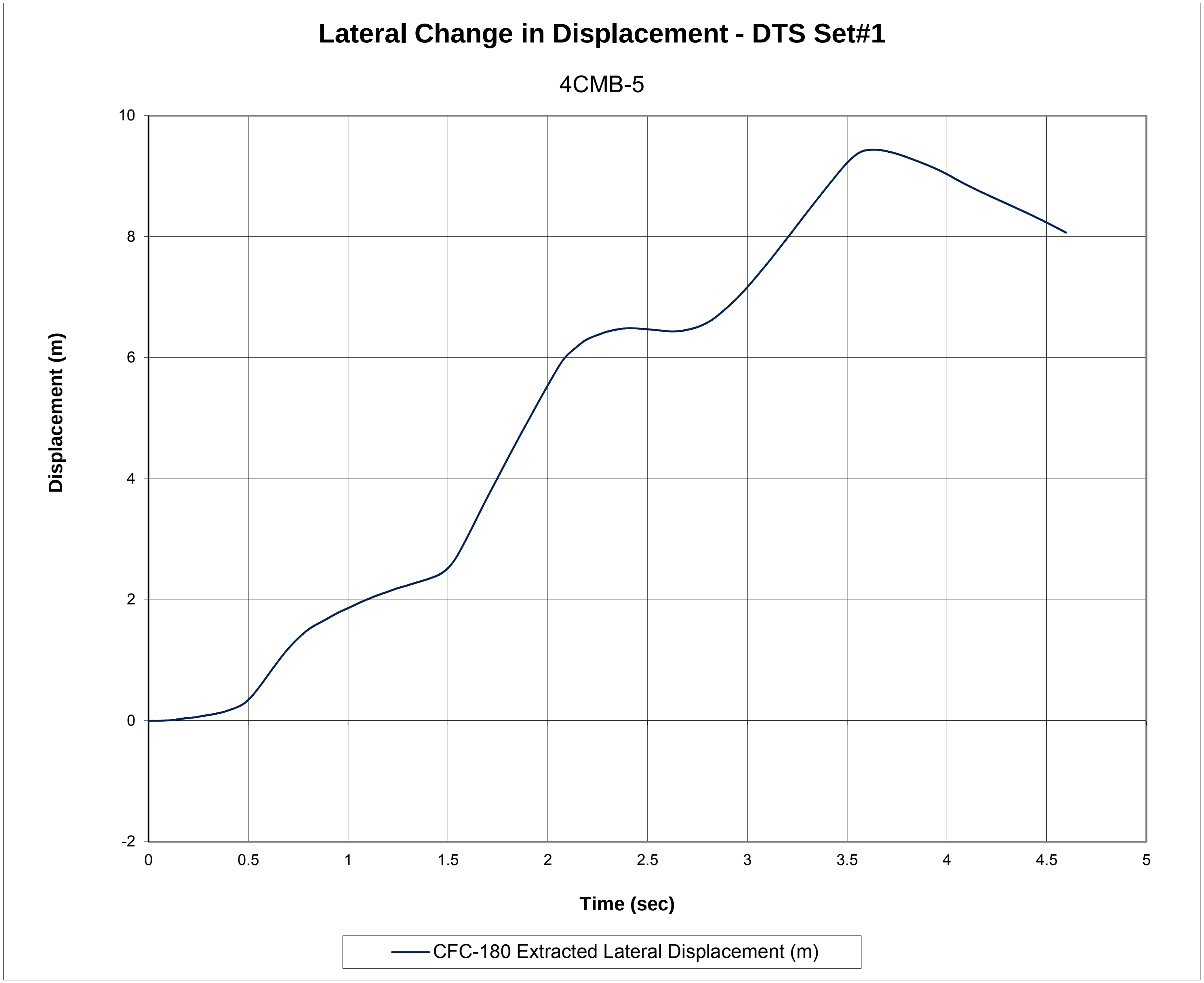


Figure F-7. Lateral Occupant Displacement (DTS Set#1), Test No. 4CMB-5

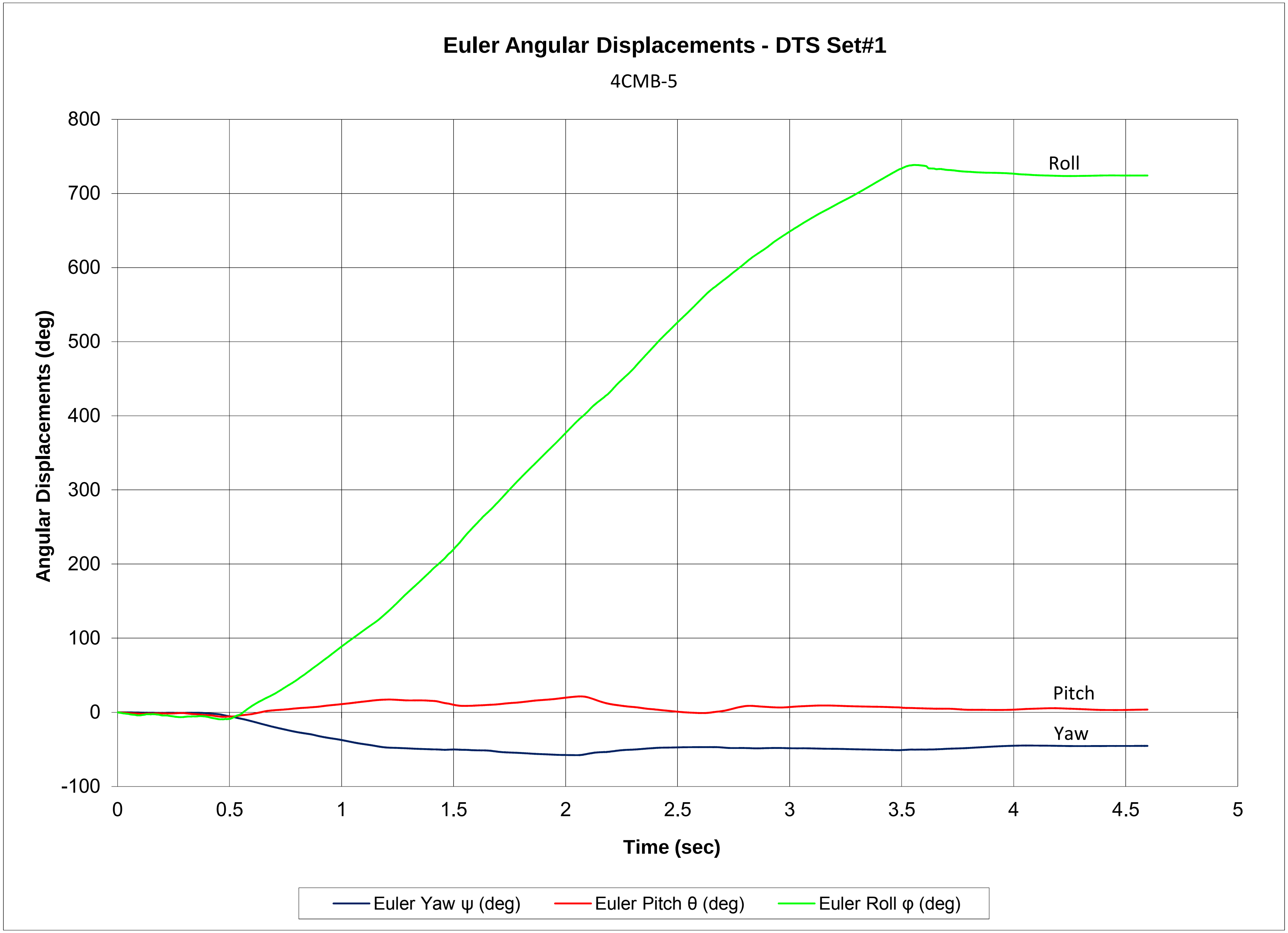


Figure F-8. Vehicle Angular Displacements (DTS Set#1), Test No. 4CMB-5

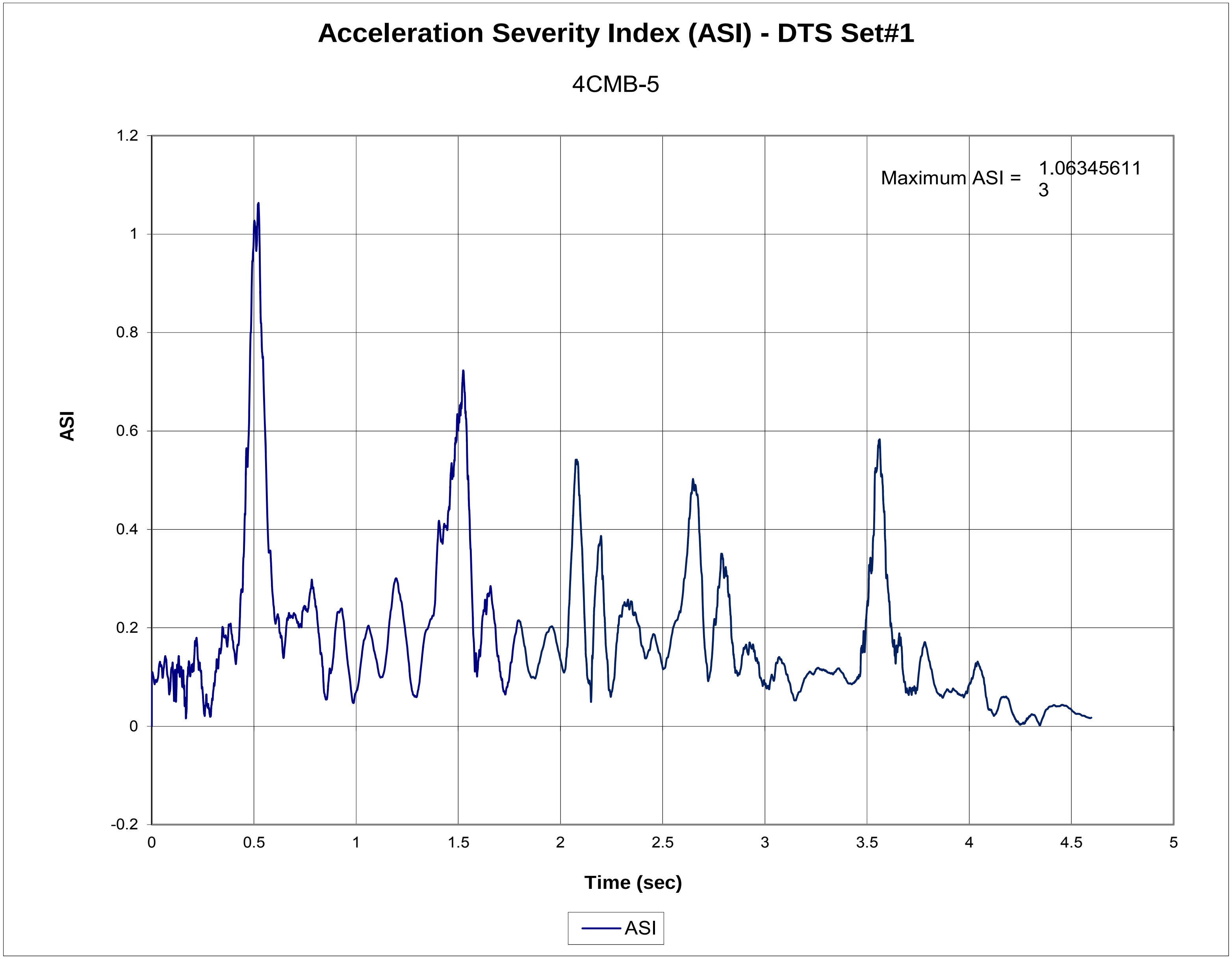


Figure F-9. Acceleration Severity Index (DTS Set#1), Test No. 4CMB-5

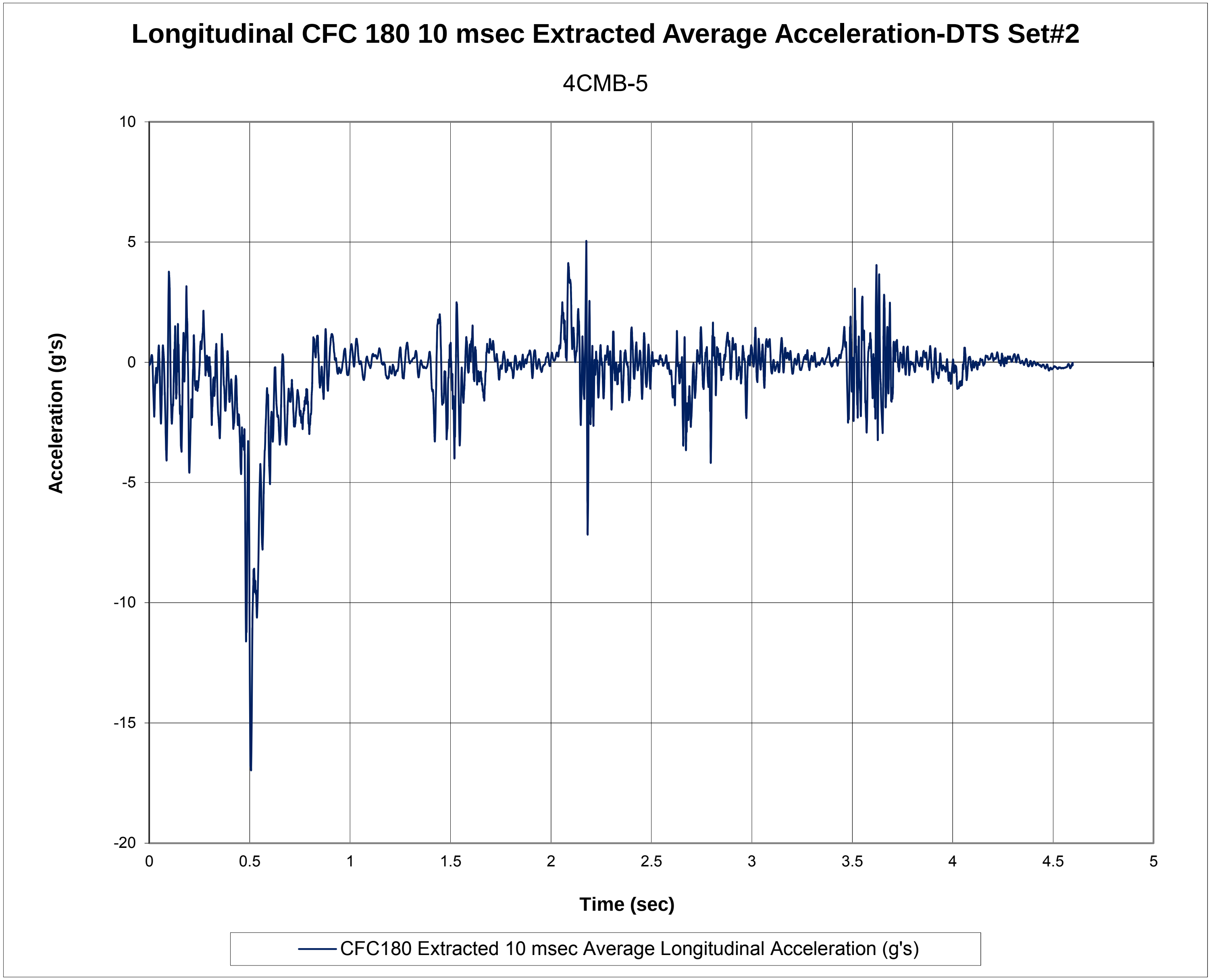


Figure F-10. 10-ms Average Longitudinal Deceleration (DTS Set#2), Test No. 4CMB-5

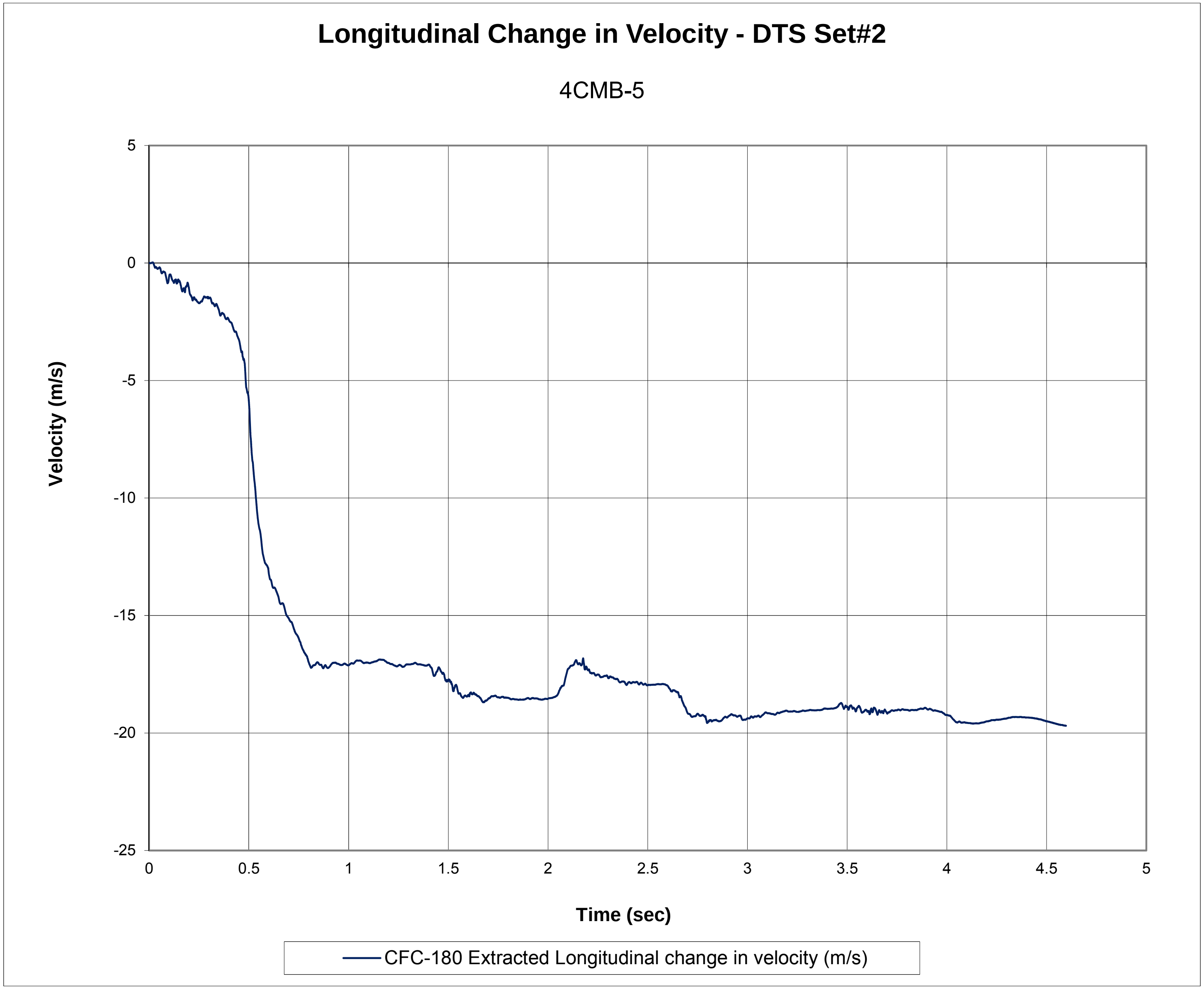


Figure F-11. Longitudinal Occupant Impact Velocity (DTS Set#2), Test No. 4CMB-5

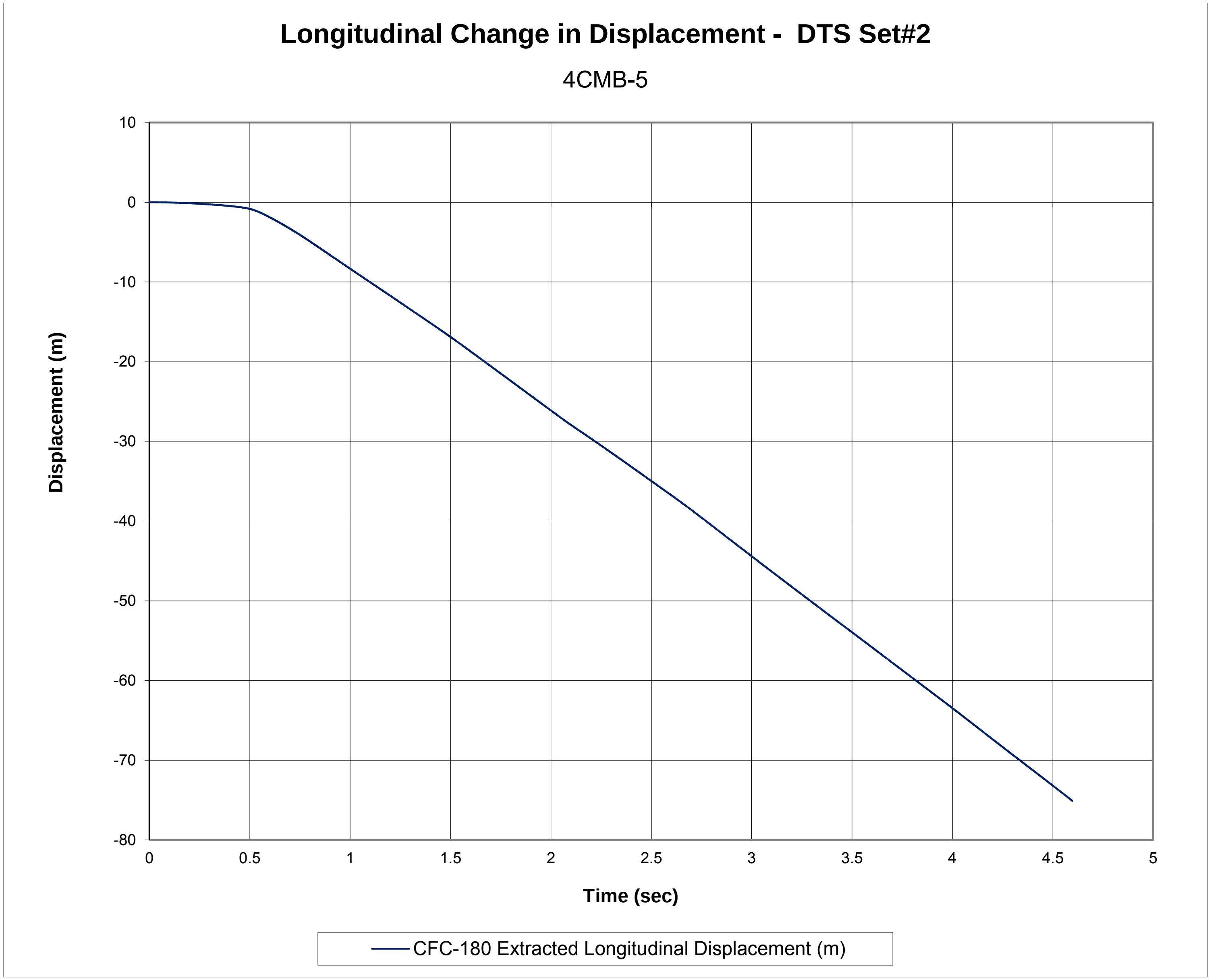


Figure F-12. Longitudinal Occupant Displacement (DTS Set#2), Test No. 4CMB-5

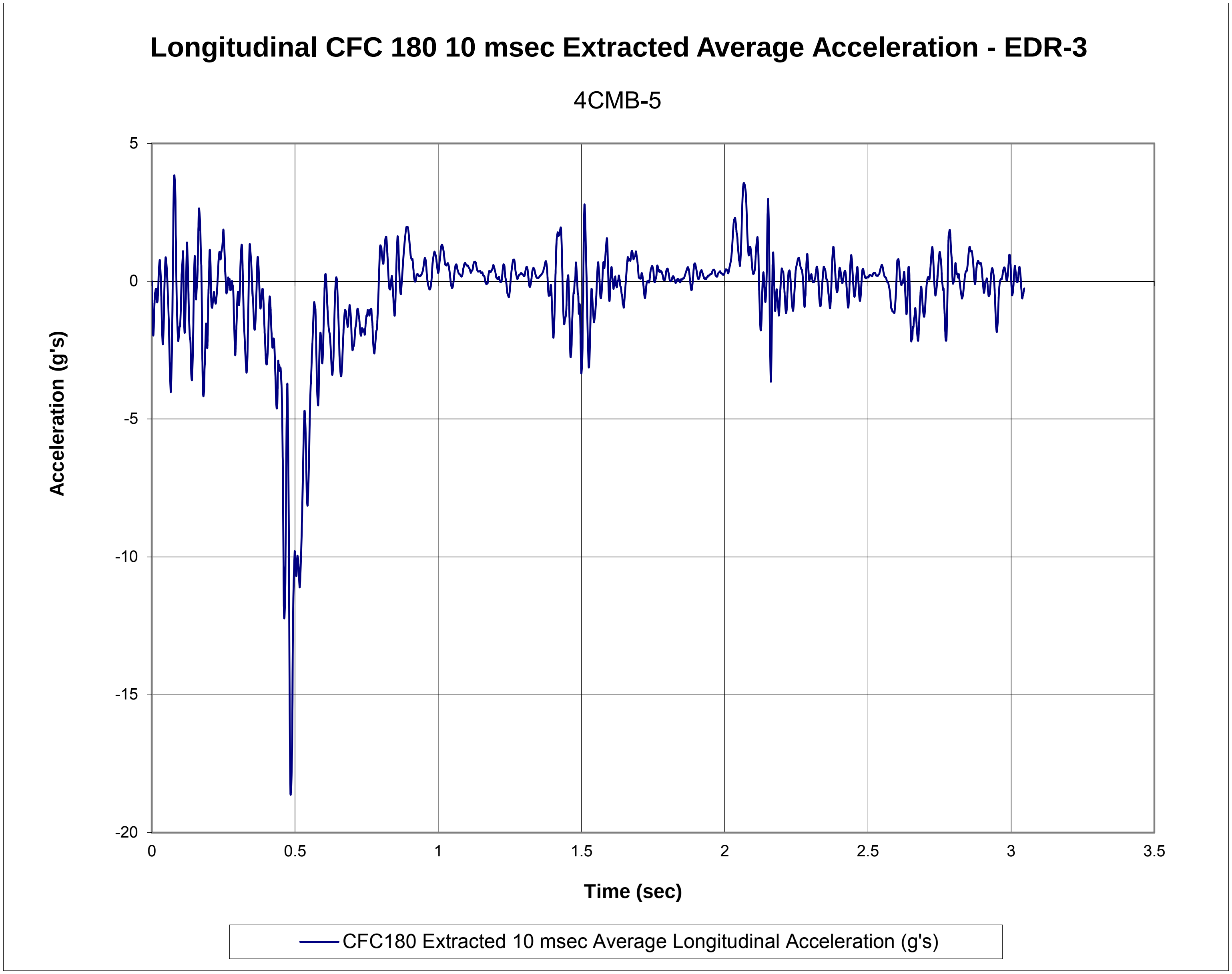


Figure F-13. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. 4CMB-5

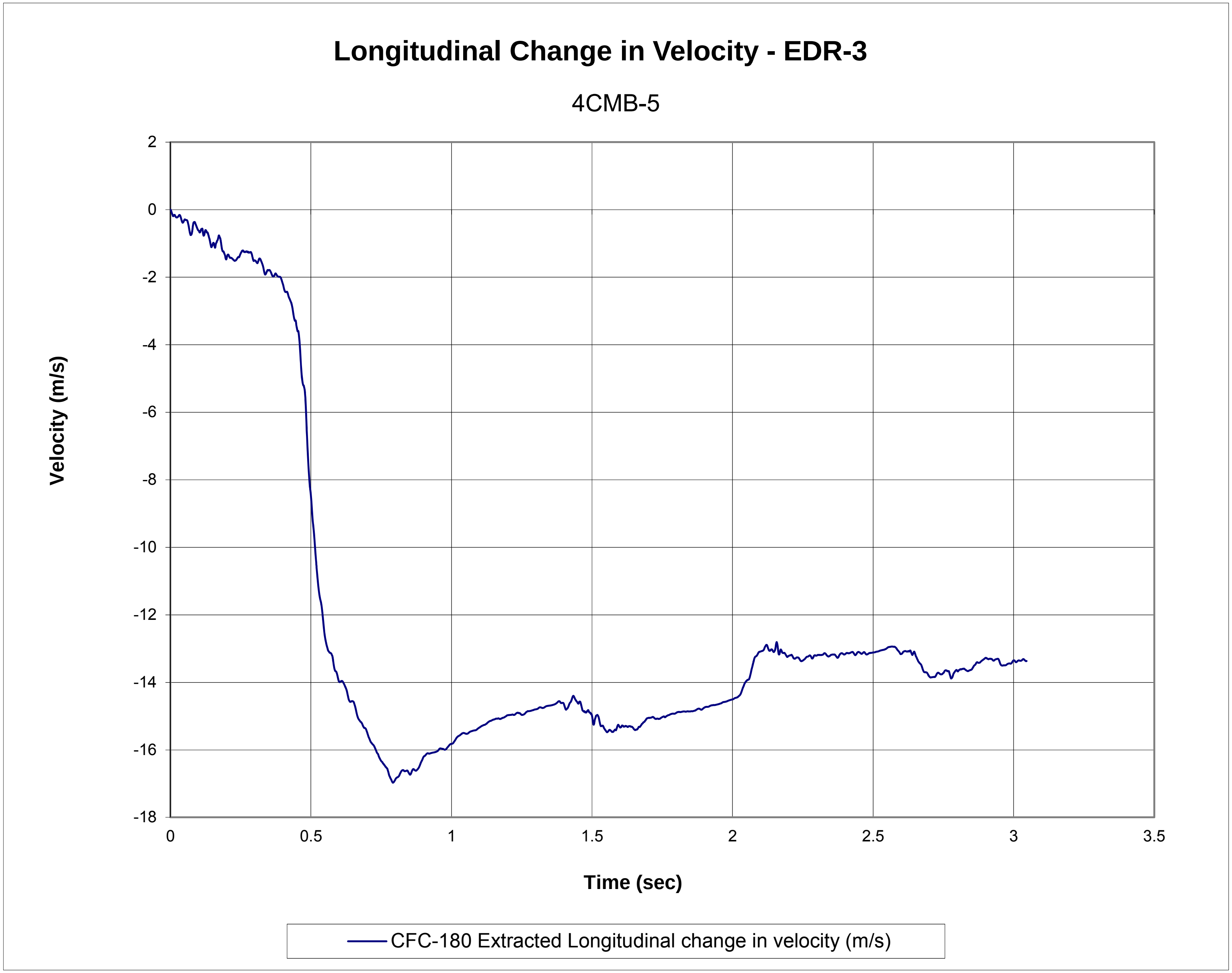


Figure F-14. Longitudinal Occupant Impact Velocity (EDR-3), Test No. 4CMB-5

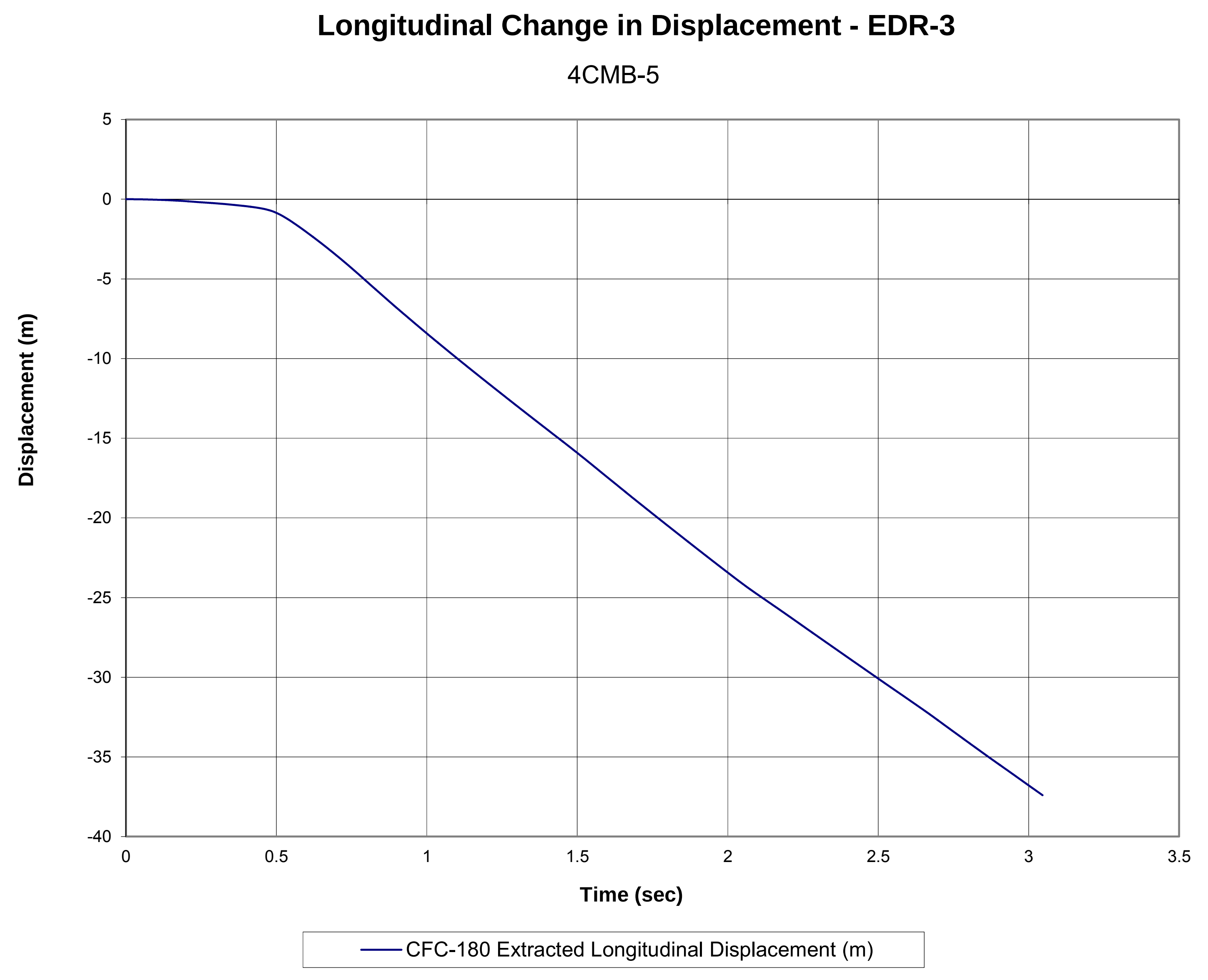


Figure F-15. Longitudinal Occupant Displacement (EDR-3), Test No. 4CMB-5

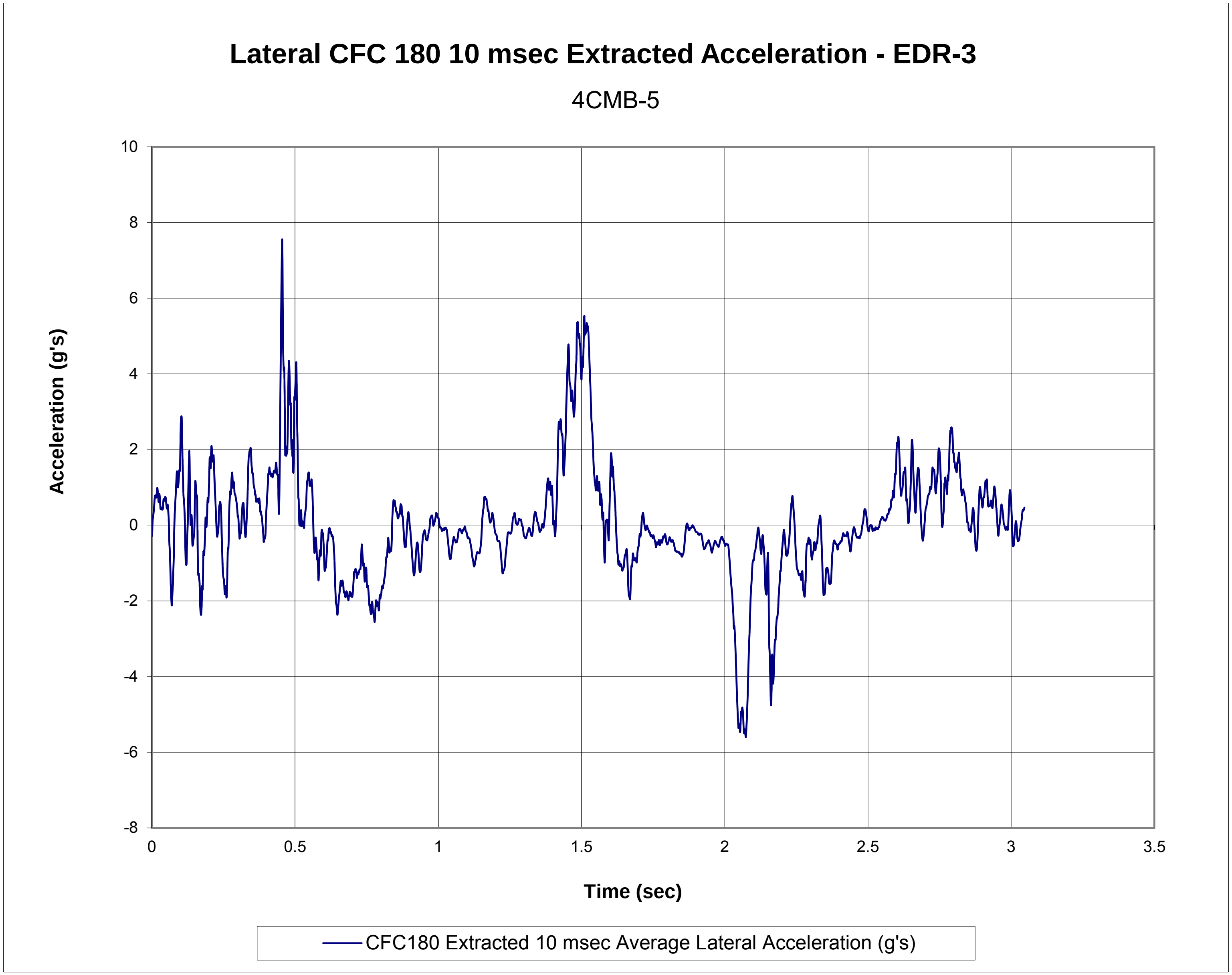


Figure F-16. 10-ms Average Lateral Deceleration (EDR-3), Test No. 4CMB-5

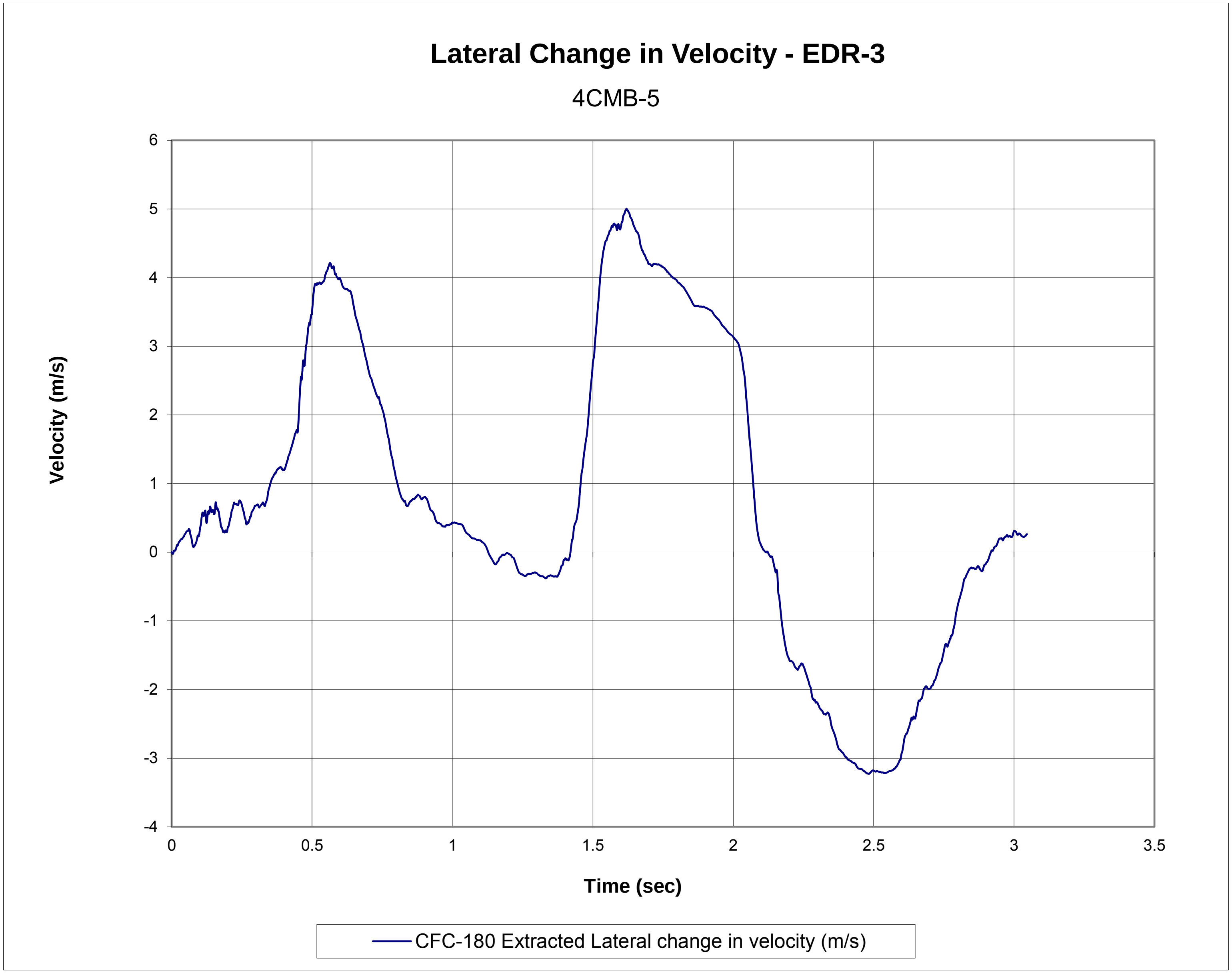


Figure F-17. Lateral Occupant Impact Velocity (EDR-3), Test No. 4CMB-5 4CMB-4

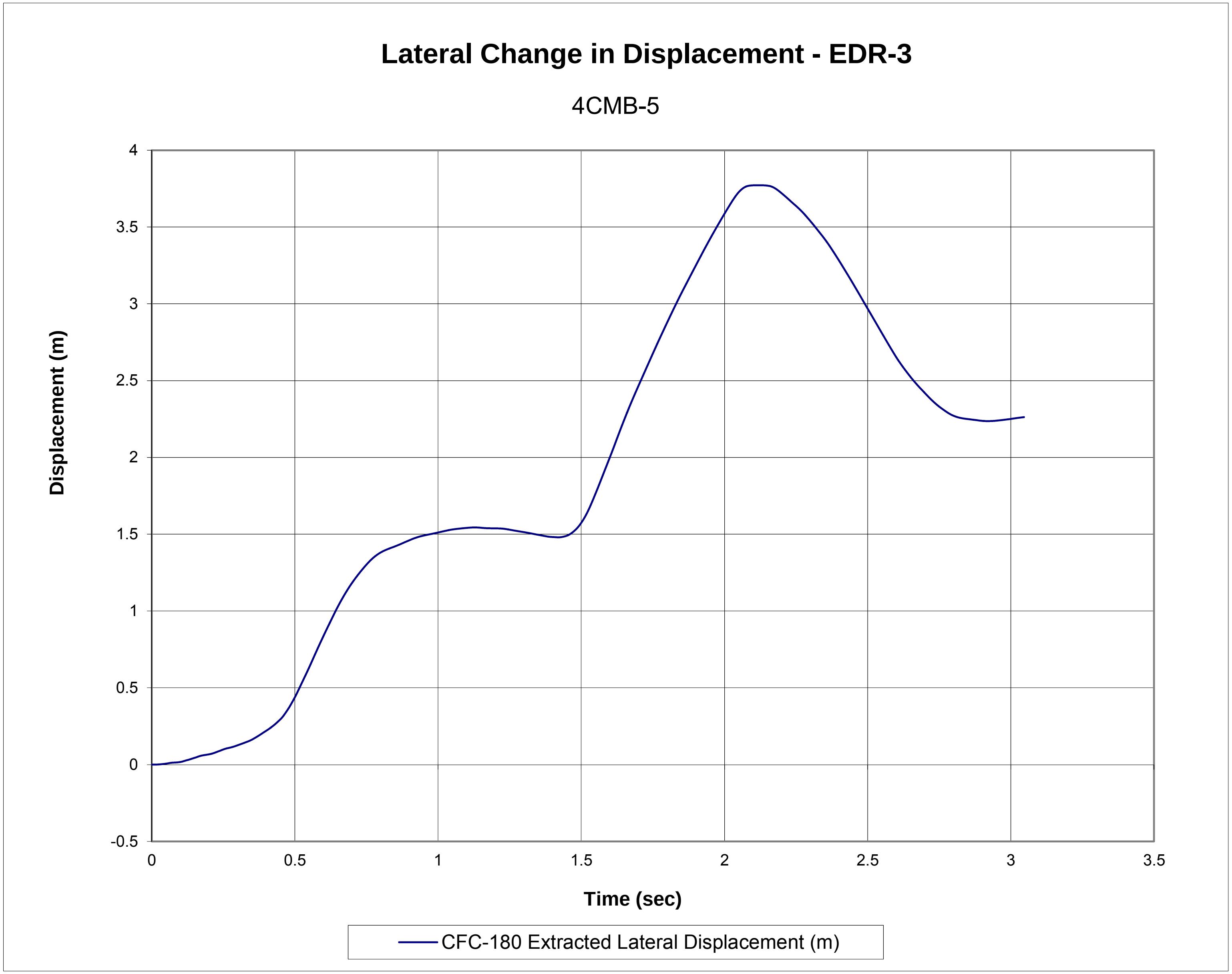


Figure F-18. Lateral Occupant Displacement (EDR-3), Test No. 4CMB-5

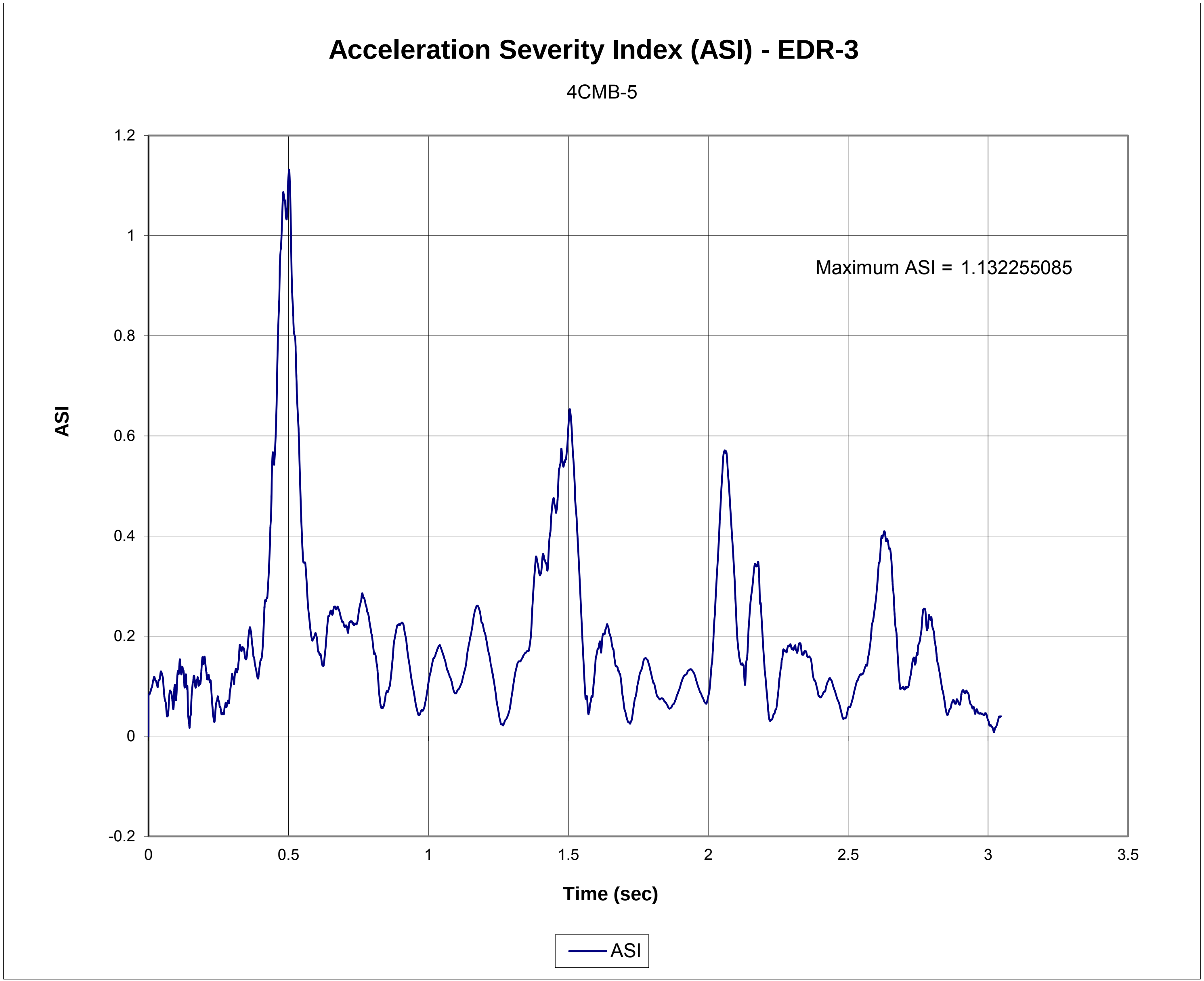


Figure F-19. Acceleration Severity Index (EDR-3), Test No. 4CMB-5

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