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Evaluation of a Non-Proprietary, High-Tension, Four-Cable Median Barrier on Level Terrain

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EVALUATION OF A NON-PROPRIETARY, HIGH-TENSION, FOUR-CABLE MEDIAN BARRIER ON LEVEL TERRAIN

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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 occasionally penetrate through the standard three-cable median barrier and enter opposing traffic lanes. As a result, the Midwest States Regional 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 keyway bolts.

For this study, one Test Level 3 (TL-3) full-scale crash test was performed on the improved high-tension, four-cable median barrier according to the Manual for Assessing Safety Hardware (MASH). The cable barrier system was configured with cable heights of 13½ in. (343 mm), 24 in. (610 mm), 34½ in. (876 mm), and 45 in. (1,143 mm) above the ground surface The improved barrier system was intended to satisfy impact safety standards when placed on either a 4H:1V slope or on level terrain. Because barrier penetration was a prime concern, the crash test utilized a 1500A full-sized passenger sedan to impact the barrier in order to investigate the significance of the 10½-in. (267-mm) cable spacing. The vehicle was contained by the barrier, but significant damage occurred to the occupant compartment. As such, the results from the crash test did not meet the MASH impact safety standards.

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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.

INDEPENDENT APPROVING AUTHORITY

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 experienced large increases in traffic volumes. 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, a careful review of accident records has indicated that passenger vehicles occasionally penetrate through the standard three-cable median barrier and enter opposing traffic lanes. A detailed evaluation of non-proprietary, low-tension cable median barrier accidents seems to indicate that the barrier is most vulnerable when struck from the side with one cable [1]. Further, crash testing has demonstrated that cables mounted on the back side of support posts are often ineffective for containing and redirecting an impacting vehicle [2].

Therefore, the Midwest States Regional 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 low-tension, four-cable median barrier systems [3]. Three full-scale vehicle crash tests were performed according to the National Cooperative Highway Research Program (NCHRP) Report No. 350 [4] conditions using pickup truck and small car 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 crash tested and evaluated in a depressed median. Although the preliminary testing program resulted in both unsuccessful and successful outcomes, members of the Midwest States Regional Pooled Fund Program chose to discontinue the research and development (R&D) effort to develop an improved low-tension, cable median barrier system. Instead, the Pooled Fund members refocused their resources toward the development of a non-proprietary, high-tension, cable barrier system for use on level terrain as well as in depressed medians.

For the high-tension, cable median barrier R&D effort, MwRSF designed an improved keyway bracket attachment mechanism that would satisfy predetermined loading requirements, conducted component testing of the new keyway bolts, 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 [5]. 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 [6]. Test no. 4CMB-1 was conducted in compliance with test designation no. 3-11 of the Manual for Assessing Safety Hardware (MASH) [7] standards with the system located 12 ft (3.7 m) laterally down the foreslope of a 46-ft (14-m) wide, 4H:1V V-ditch. The system adequately contained and redirected the vehicle; thus, it was deemed acceptable according to the MASH safety performance criteria.

The placement and orientation of the system within the V-ditch was slightly modified for the next two crash tests. Test no. 4CMB-2 was conducted according to designated test no. 3-10 of the MASH standards with the system located 4 ft (1.2 m) laterally up the backslope from the centerline of a 46-ft (14-m) wide, 4H:1V ditch. During the test, the vehicle made contact with the backslope with a soft-soilcondition prior to impacting the system, which caused significant deceleration prior to impact with the median barrier. The system contained the vehicle, but due to the deceleration and change in longitudinal velocity prior to impact, the barrier system's performance was considered to be marginally acceptable according to the MASH impact safety standards.

Following the outcome of the prior test, heavily-compacted soil was added in a region prior to the impact location. The cable heights were also lowered such that the bottom cable was 13½ in. (343 mm) above the ground and the middle cables were spaced at 10½ in. (267 mm) apart, with the top cable at 45 in. (1,143 mm). Test no. 4CMB-3 was conducted according to MASH test designation no. 3-10 with the system located 4 ft (1.2 m) laterally up the backslope of a 46-ft (14-m) wide, 4H:1V V-ditch. The vehicle was contained by the system. However, the cables caused significant deformation to the A-pillar on the left side of the vehicle. Therefore, the system was deemed unacceptable according to the MASH safety performance criteria. 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 brackets used during the previous three tests had released at the desired load, but the remaining bolt heads created a snag point for the cables, producing unacceptable results. Therefore, the cable-to-post attachment hardware needed to be redesigned. Through a second round of component design and testing, a continuous keyway bolt in conjunction with a keyway slot in the post was developed. The shape of the keyway bolt was optimized such that the cables would not snag on the keyway bolt once released [8].

Two additional full-scale tests were conducted to evaluate the high-tension, cable median barrier in a depressed median with the new keyway bolts [2]. Test no. 4CMB-4 was conducted according to MASH test designation no. 3-10 with the system located 4 ft (1.2 m) laterally up the backslope of a 46-ft (14-m) wide, 4H:1V V-ditch. The system adequately contained and redirected the vehicle and was deemed acceptable according to the MASH safety performance criteria.

Test no. 4CMB-5 was conducted according to MASH test designation no. 3-11 on a system utilizing the new keyway bolts and located 12 ft (3.7 m) laterally down the foreslope of a 46-ft (14-m) wide, 4H:1V V-ditch. The vehicle overrode the system and subsequently rolled over after impacting the backslope.

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. Design modifications were to be made to the prototype high-tension, cable median barrier in order to limit dynamic barrier deflections through the use of keyway bolts which maximized the energy dissipated by the support posts. In addition, the barrier system was to be designed to mitigate vehicle penetration through the system. Finally, the cable median barrier system was to be crash tested and evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in MASH. This crash test was to be performed to evaluate the 10½-in. (267-mm) cable spacing for mitigating the penetration concerns of passenger vehicles with narrow front ends. This test was also to be performed prior to addressing the failure observed in test no. 4CMB-5.

1.3 Research Scope

The high-tension, cable median barrier system was configured using the same design that was used for test nos. 4CMB-4 and 4CMB-5. The cable barrier was constructed on level terrain and then subjected to a full-scale vehicle crash test. The crash test utilized a full-sized passenger sedan weighing approximately 3,300 lb (1,497 kg), impacting at a target speed and angle of 62 mph (100 km/h) and 25 degrees, respectively. The test results were documented, analyzed, and evaluated. Conclusions and recommendations were then made that pertain to the safety performance of the cable barrier system.

2 DESIGN DETAILS

The same barrier design that was utilized for test nos. 4CMB-4 and 4CMB-5 was again used for the system evaluation on level terrain [2]. Design details are shown in Figures 1 through 9. Photographs of the test installation are shown in Figures 21 through 24. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The total length of the cable barrier system was 608 ft (185.3 m). The test installation consisted of several distinct components: (1) wire ropes or cables; (2) steel support posts; (3) keyway bolts; (4) cable splice hardware; (5) breakaway end terminal hardware; (6) reinforced concrete foundations; (7) cable end fittings; and (8) turnbuckle assemblies.

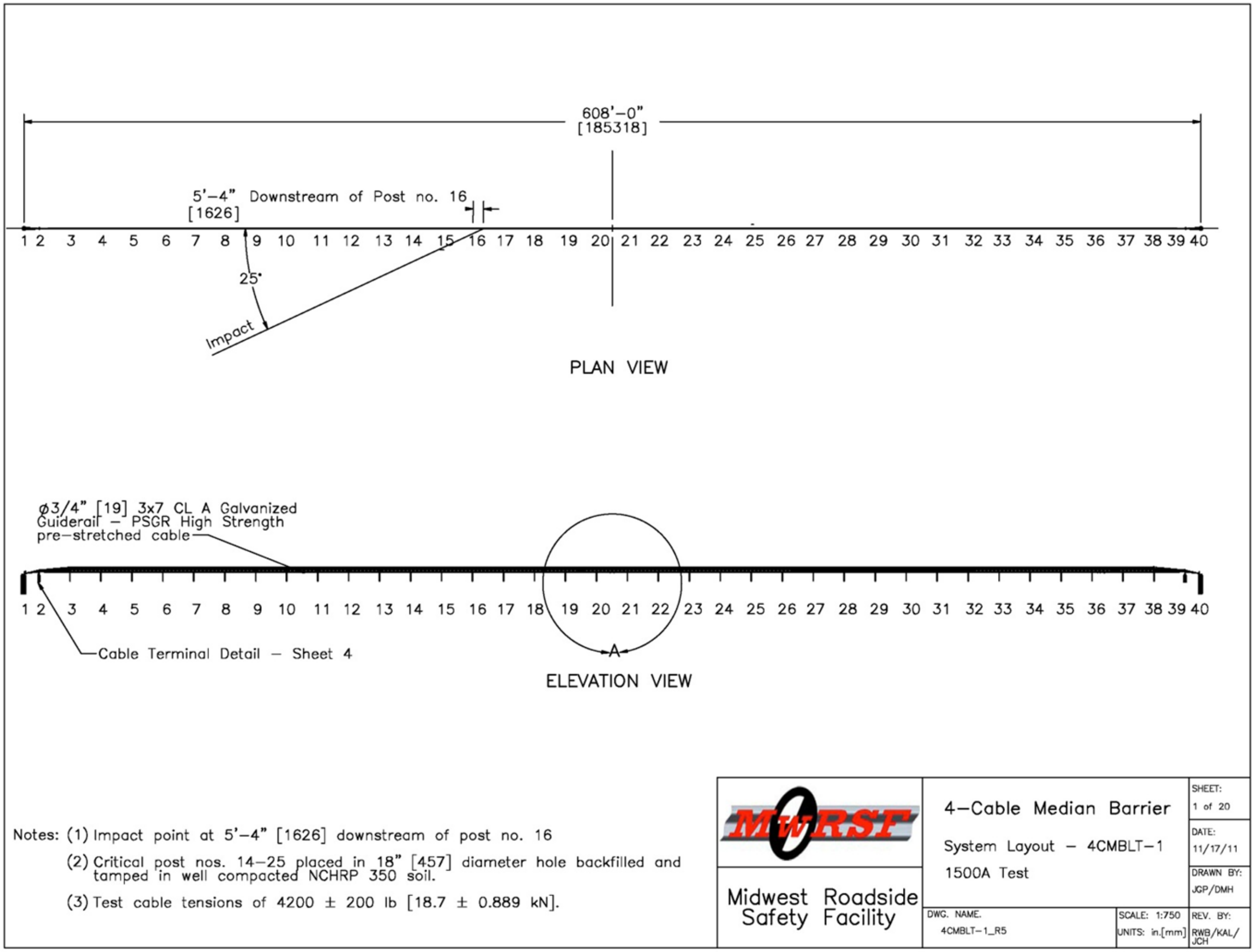
Four ¾-in. (19-mm) diameter, Class A galvanized 3x7 (pre-stretched) wire ropes were utilized for the cable rail elements. The cables were supported by 38 posts and anchored at the upstream and downstream ends, as shown in Figure 1. Post nos. 1 and 40 were configured to serve as the upstream and downstream end anchors, respectively. These locations incorporated breakaway end terminal hardware 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) standard steel line posts measuring 90 in. (2,286 mm) in length. The spacing between post nos. 1 and 2 as well as post nos. 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 located 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 (cable no. 1) and lower-middle (cable no. 3) cables were attached to the non-impact side of each post, while the upper-middle (cable no. 2) and bottom (cable no. 4) cables were attached to the impact side of each post, as shown in Figure 15. Each cable was attached to the line posts using a ¼-in. (6.4-

mm) diameter A449 steel keyway bolt. Details for the keyway bolt, mounting hardware, and locations are shown in Figures 15 through 17.

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 2. At the ends of the cable barrier system, each cable was sloped down to the ground and anchored to a breakaway end terminal system, as shown in Figures 3, 4, and 7 through 10. 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, post nos. 2 and 39 served as breakaway steel support posts with attached hanger hardware, as shown in Figures 11 through 14. These 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 a steel foundation tube assembly and embedded within a reinforced concrete foundation.

A cable tensioning chart was developed as a function of the ambient air temperature for use when installing the barrier system, as provided in Table 1. MASH specifies that all cable systems are to be tested and evaluated using thesystem’s design tension corresponding to 100 degrees Fahrenheit. As a result, the cables were pre-tensioned using a target value of 4,213 lb (18.7 kN).



Notes: (1) Impact point at 5'–4" [1626] downstream of post no. 16

(2) Critical post nos. 14–25 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].

Figure 1. Test Installation Layout, Test No. 4CMBLT-1

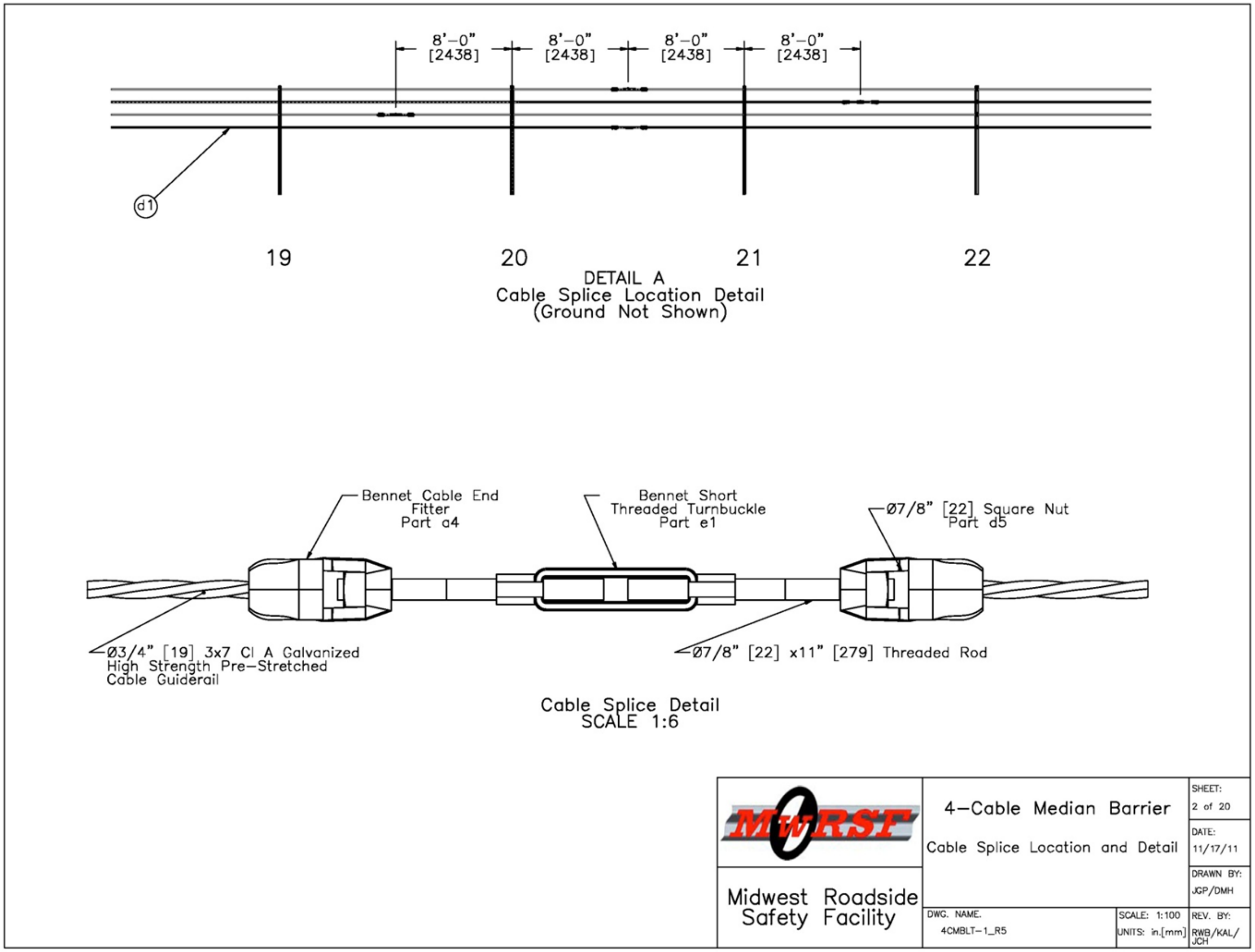


Figure 2. Cable Splice Layout, Test No. 4CMBLT-1

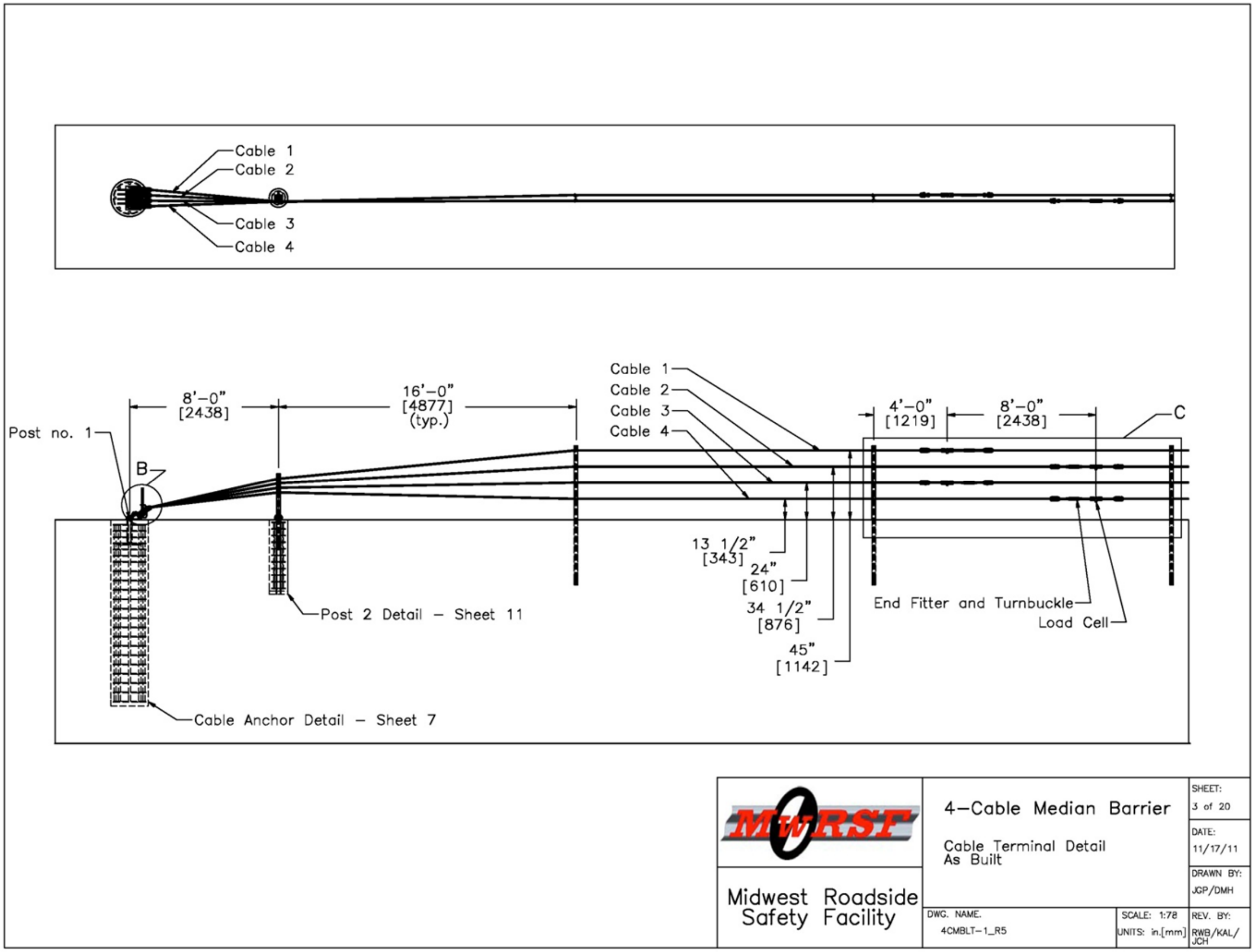


Figure 3. Cable Terminal Layout, Test No. 4CMBLT-1

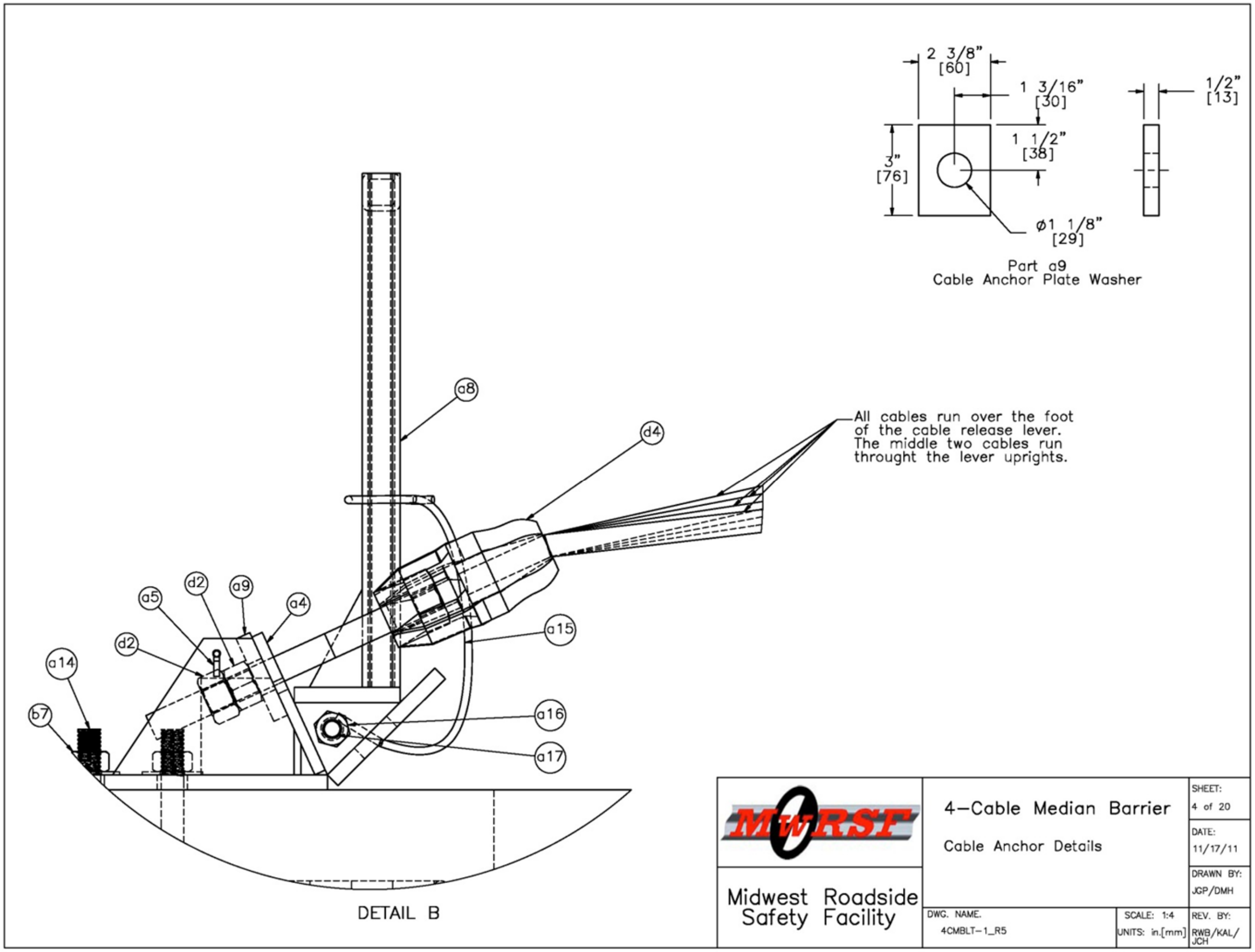


Figure 4. Anchor Details, Test No. 4CMBLT-1

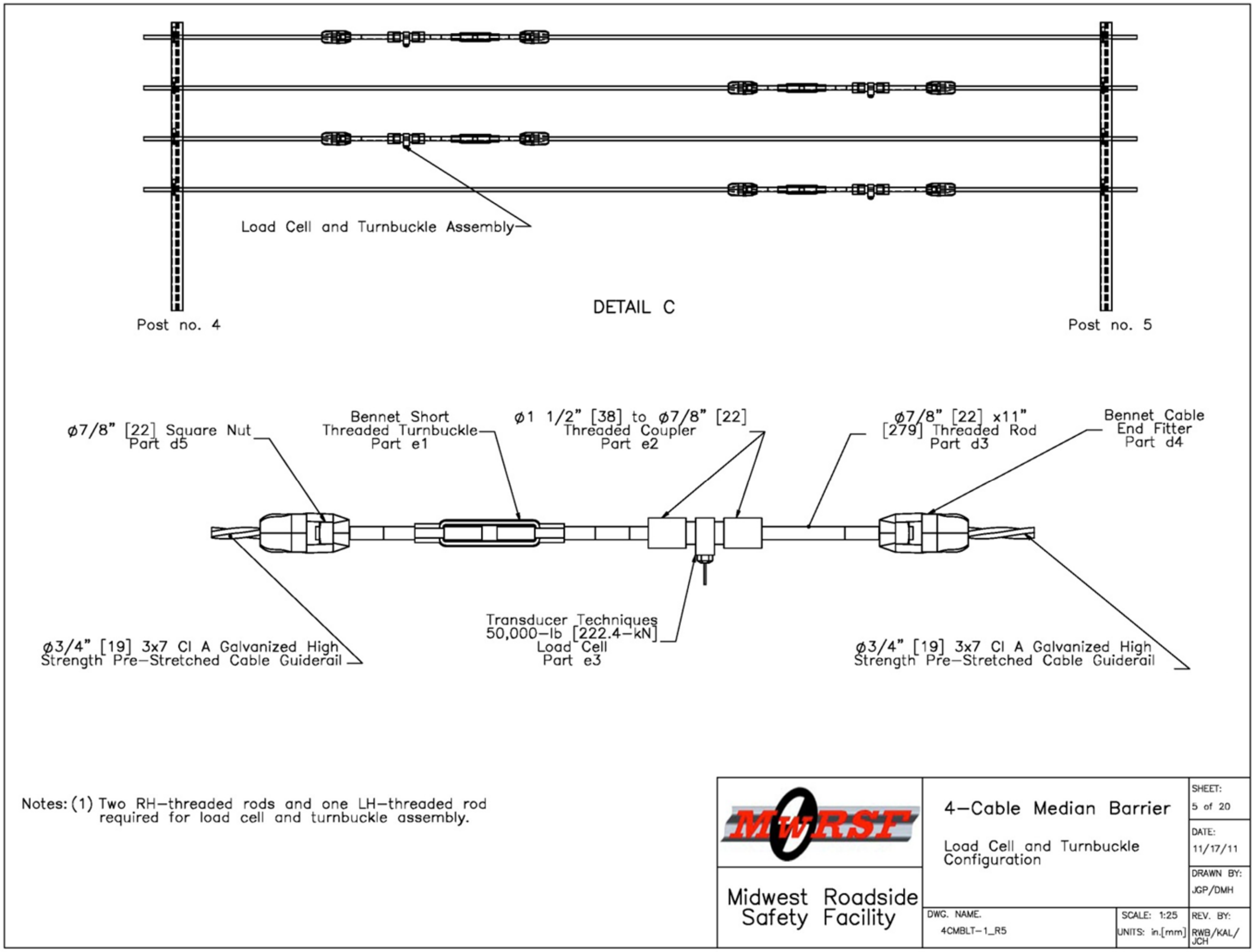


Figure 5. Load Cell Layout, Test No. 4CMBLT-1

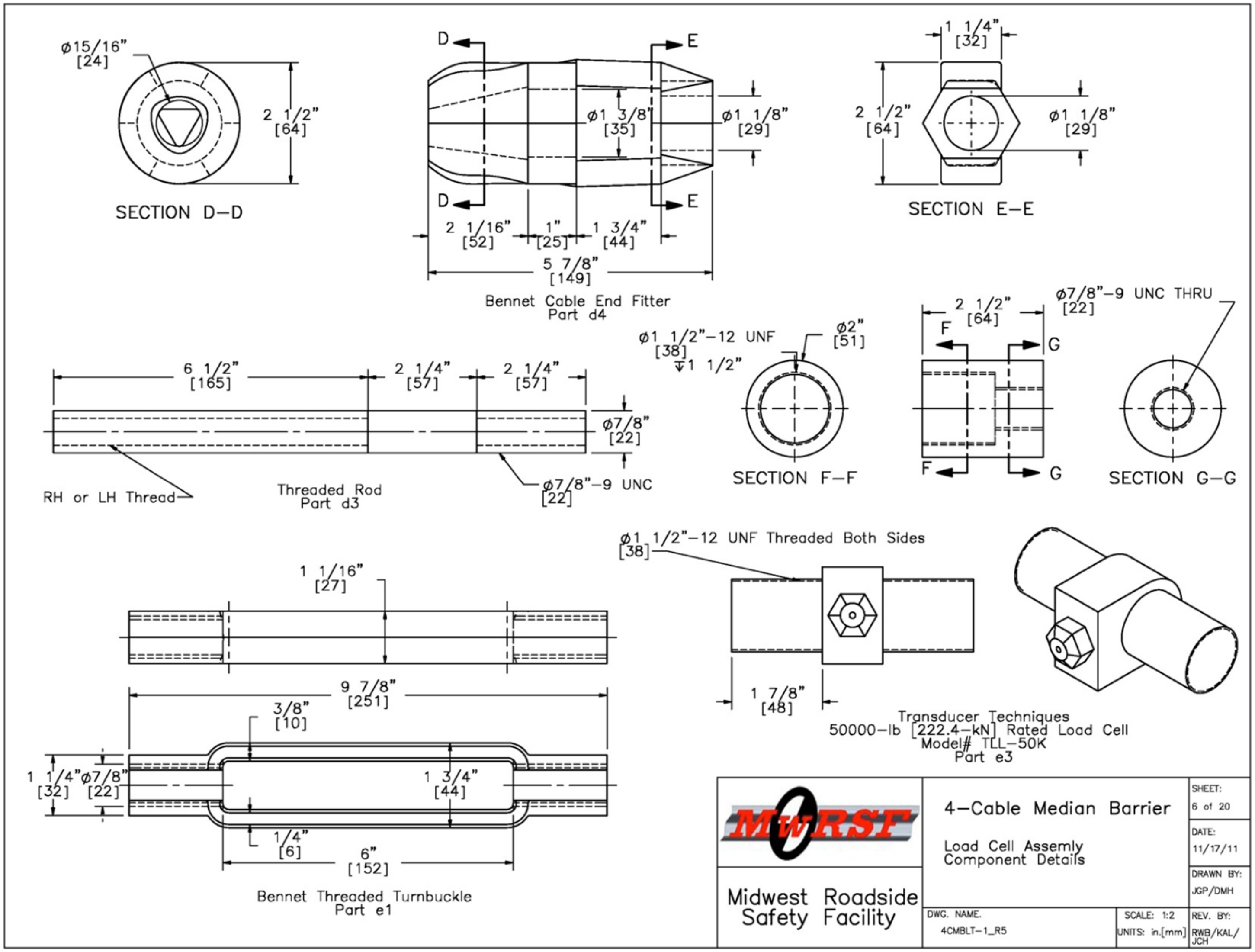
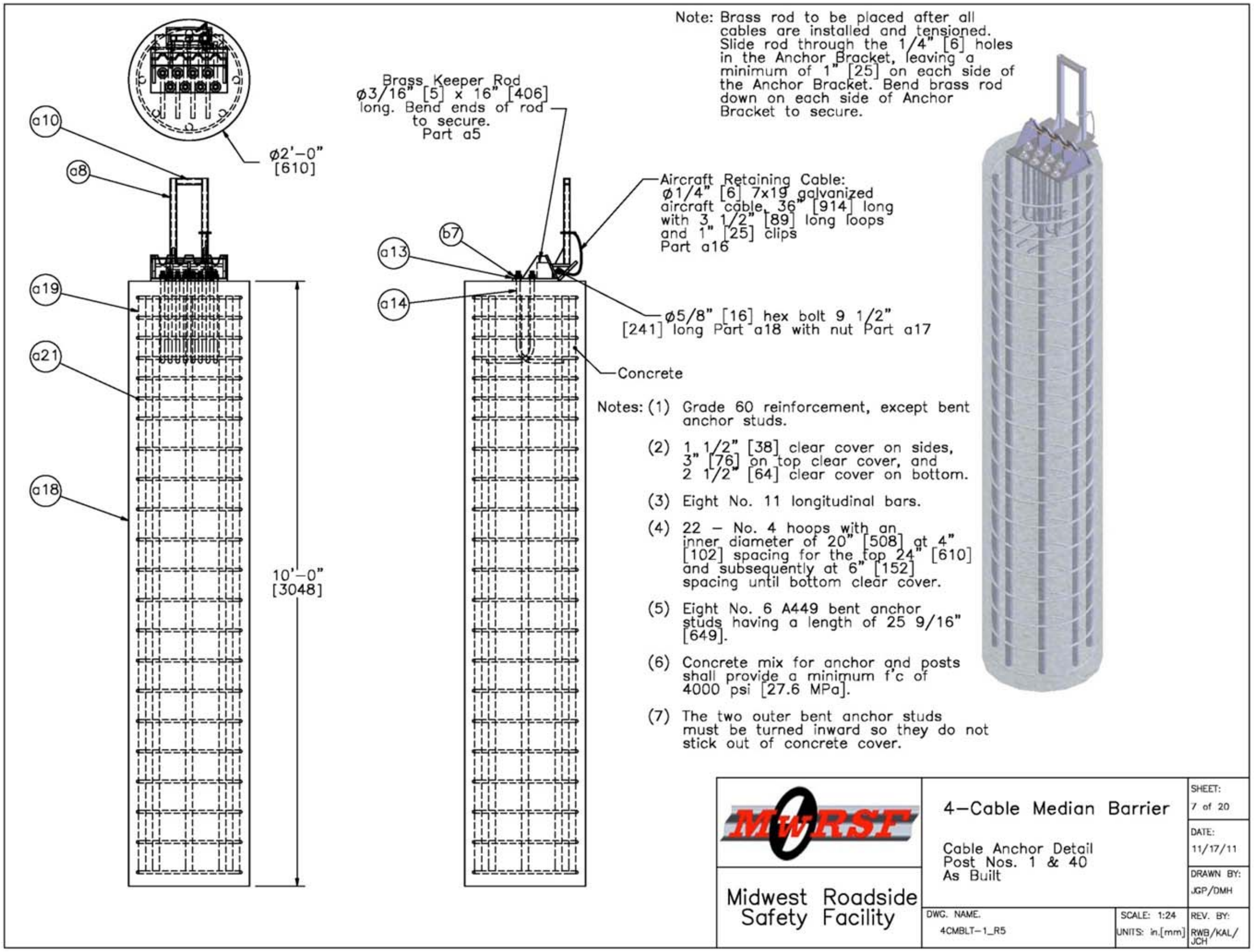


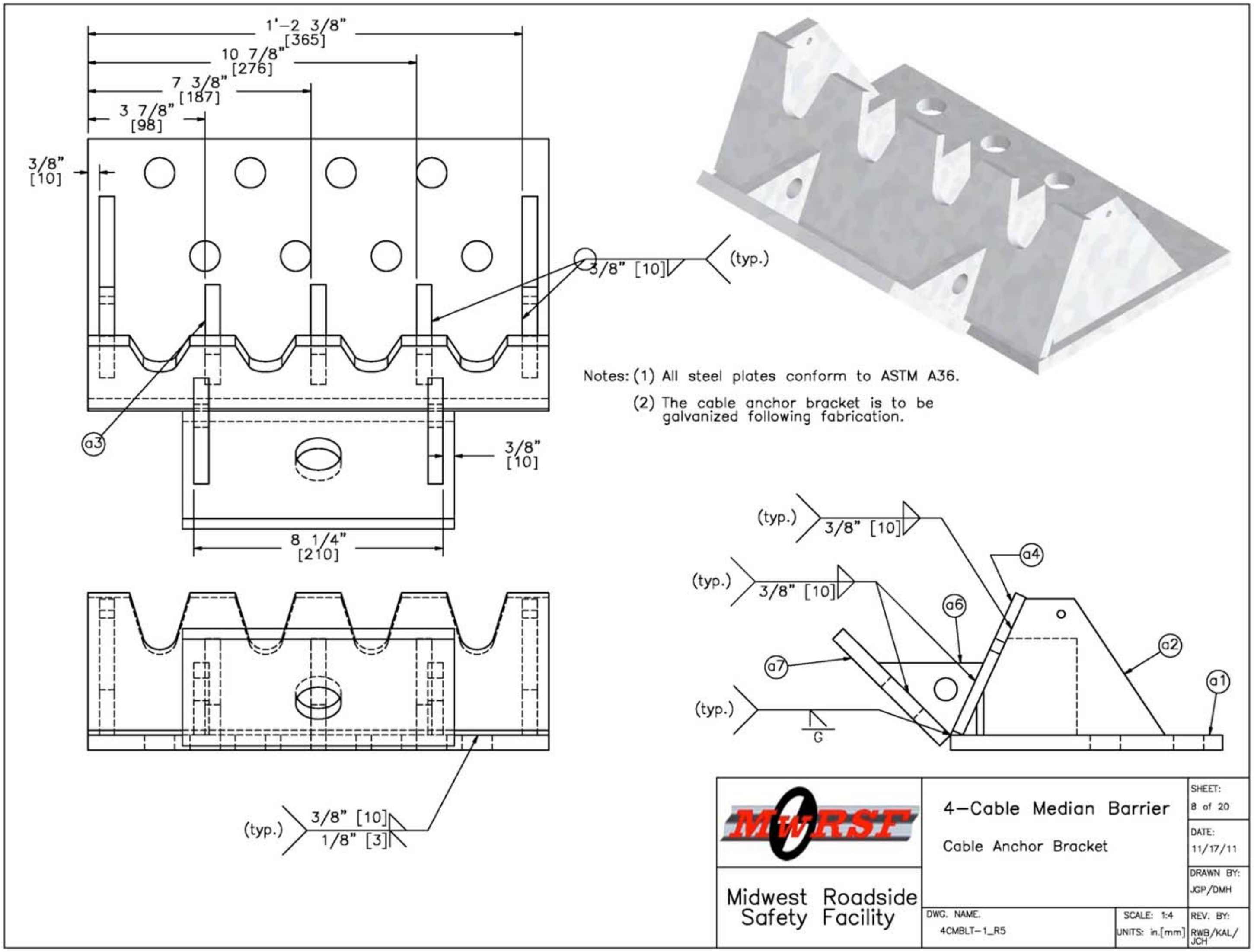
Figure 6. Load Cell Assembly Details, Test No. 4CMBLT-1



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

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

Figure 7. Post Nos. 1 and 40 Details, Test No. 4CMBLT-1



Notes: (1) All steel plates conform to ASTM A36.
(2) The cable anchor bracket is to be galvanized following fabrication.

Figure 8. Anchor Bracket Details, Test No. 4CMBLT-1

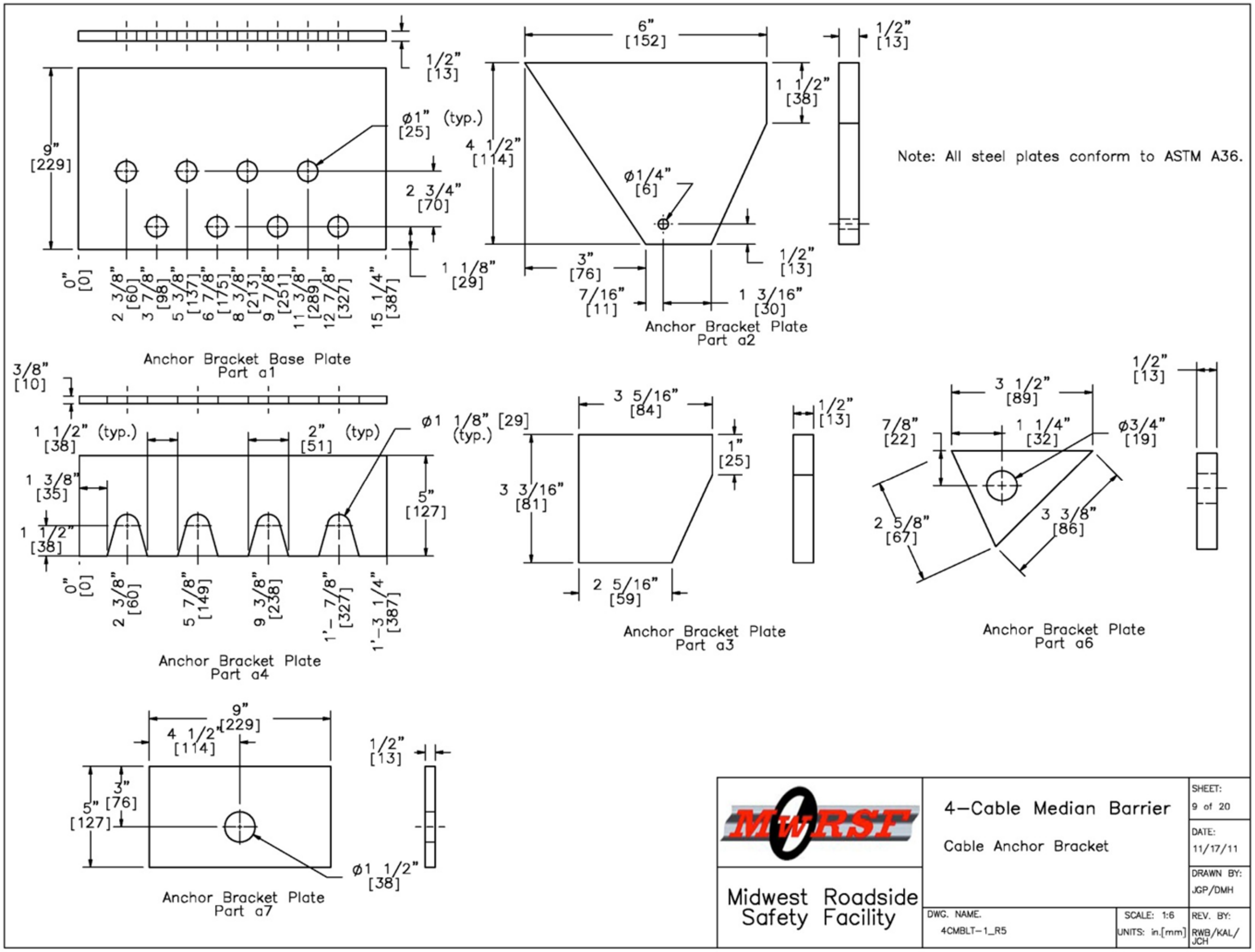
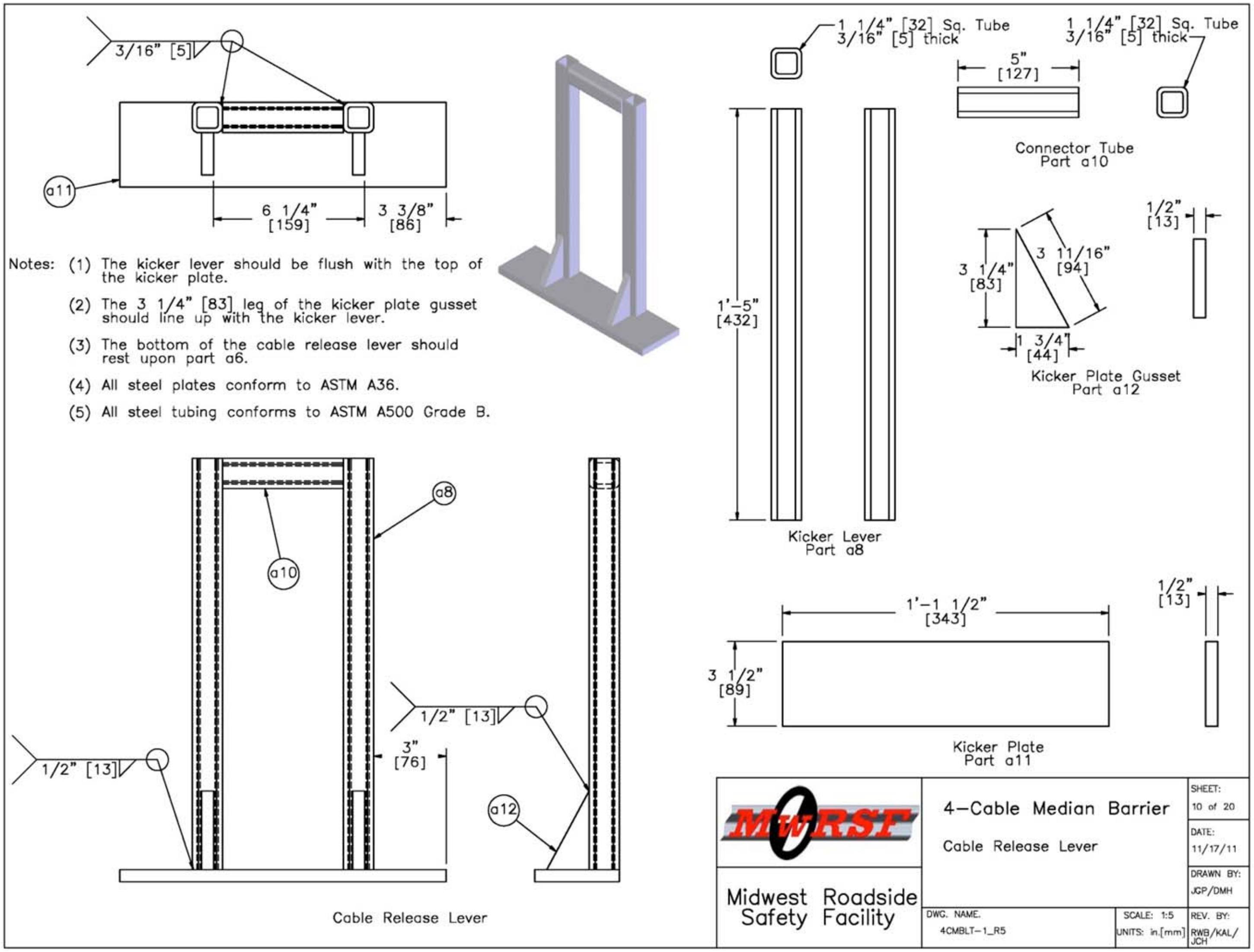


Figure 9. Anchor Bracket Details, Test No. 4CMBLT-1



Notes: (1) The kicker lever should be flush with the top of the kicker plate.

(2) The 3 1/4" [83] leg of the kicker plate gusset should line up with the kicker lever.

(3) The bottom of the cable release lever should rest upon part a6.

(4) All steel plates conform to ASTM A36.

(5) All steel tubing conforms to ASTM A500 Grade B.

Midwest Roadside Safety Facility

4-Cable Median Barrier

Cable Release Lever

SHEET: 10 of 20

DATE: 11/17/11

DRAWN BY: JGP/DMH

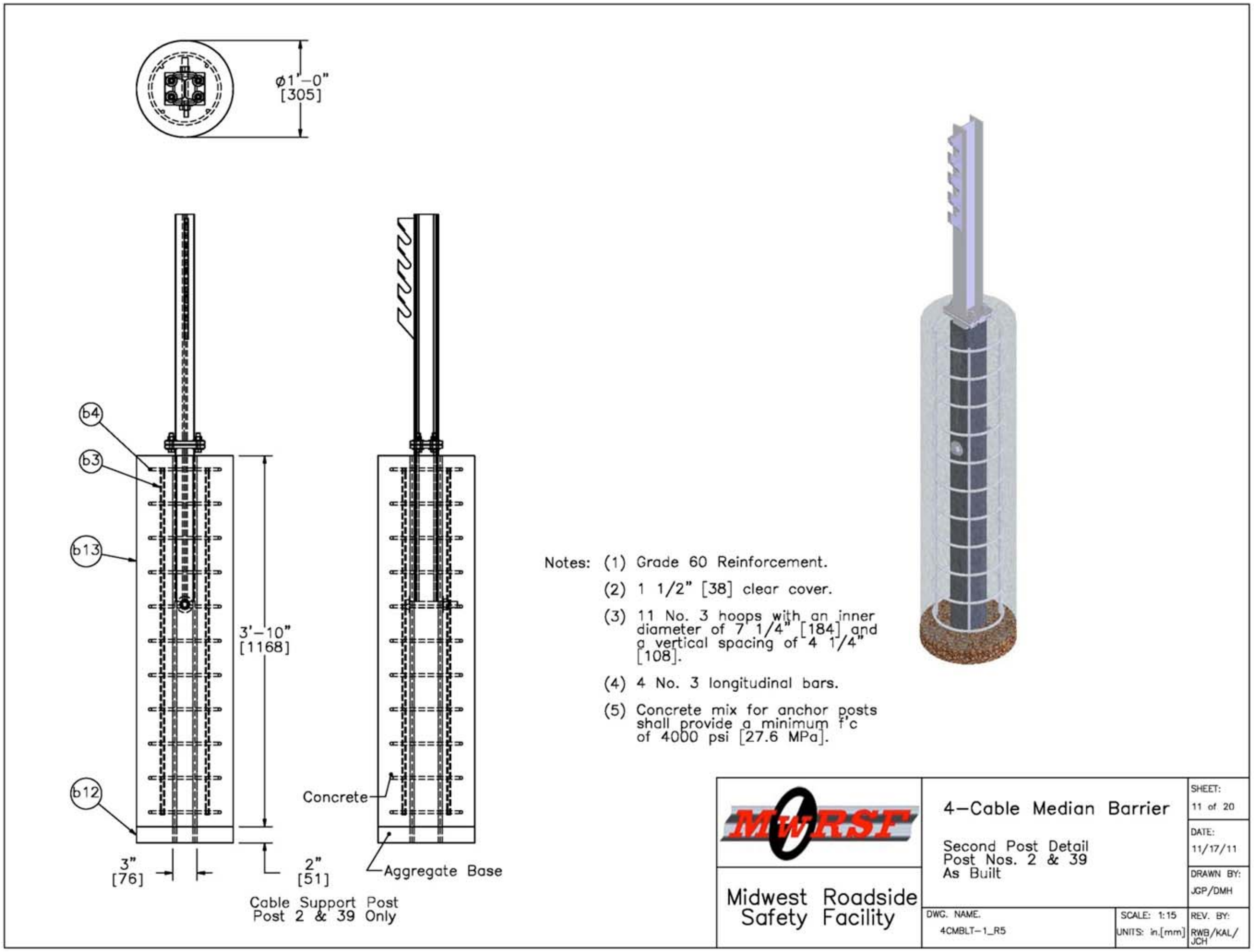
DWG. NAME. 4CMBLT-1_R5

SCALE: 1:5

UNITS: in.[mm]

REV. BY: RWB/KAL/JCH

Figure 10. Release Lever Details, Test No. 4CMBLT-1



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].

Midwest Roadside
Safety Facility

4–Cable Median Barrier

Second Post Detail
Post Nos. 2 & 39
As Built

SHEET: 11 of 20
DATE: 11/17/11
DRAWN BY: JGP/DMH
DWG. NAME. 4CMBLT–1_R5
SCALE: 1:15
UNITS: in.[mm]
REV. BY: RWB/KAL/JCH

Figure 11. Post Nos. 2 and 39 Details, Test No. 4CMBLT-1

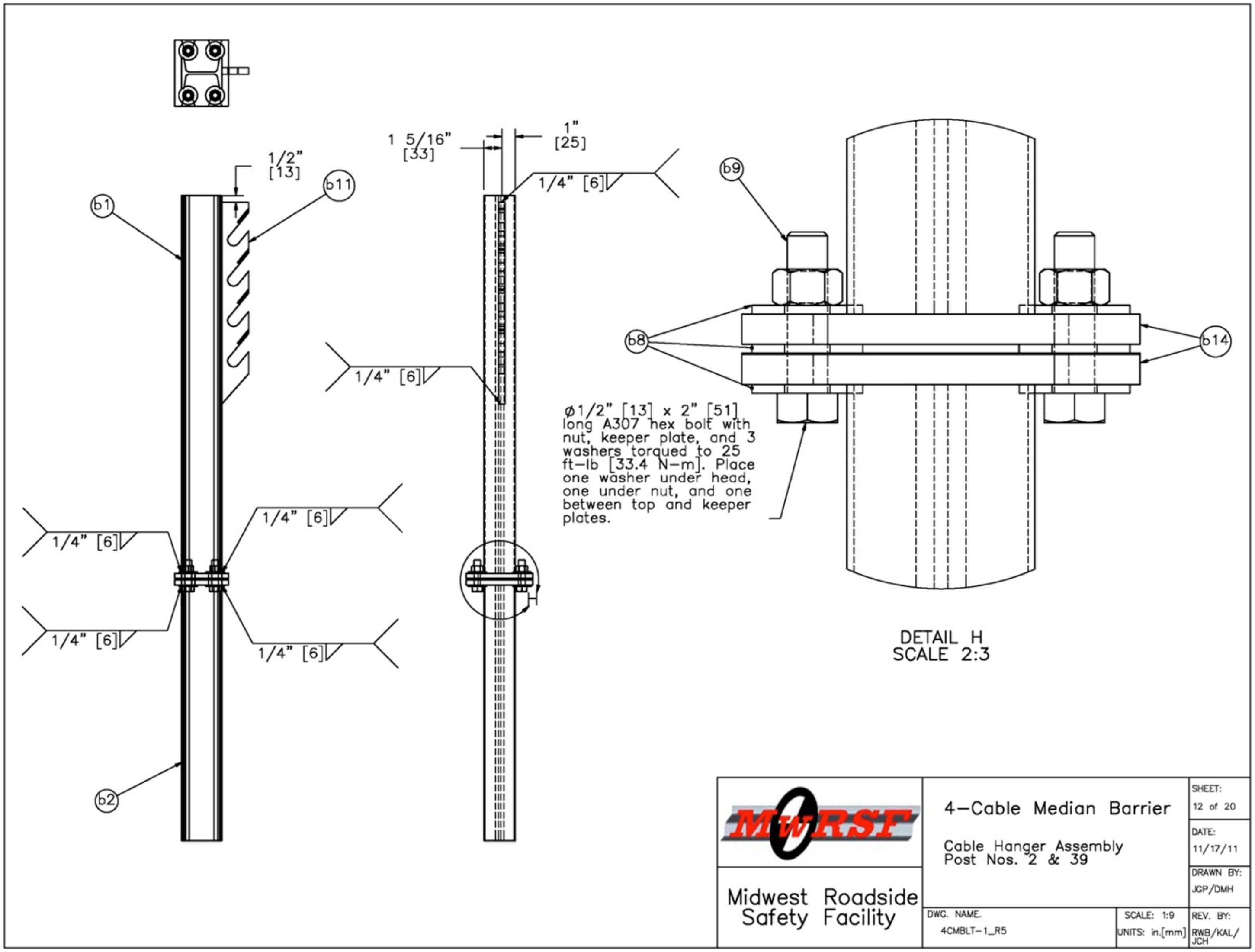


Figure 12. Post Nos. 2 and 39 Details, Test No. 4CMBLT-1

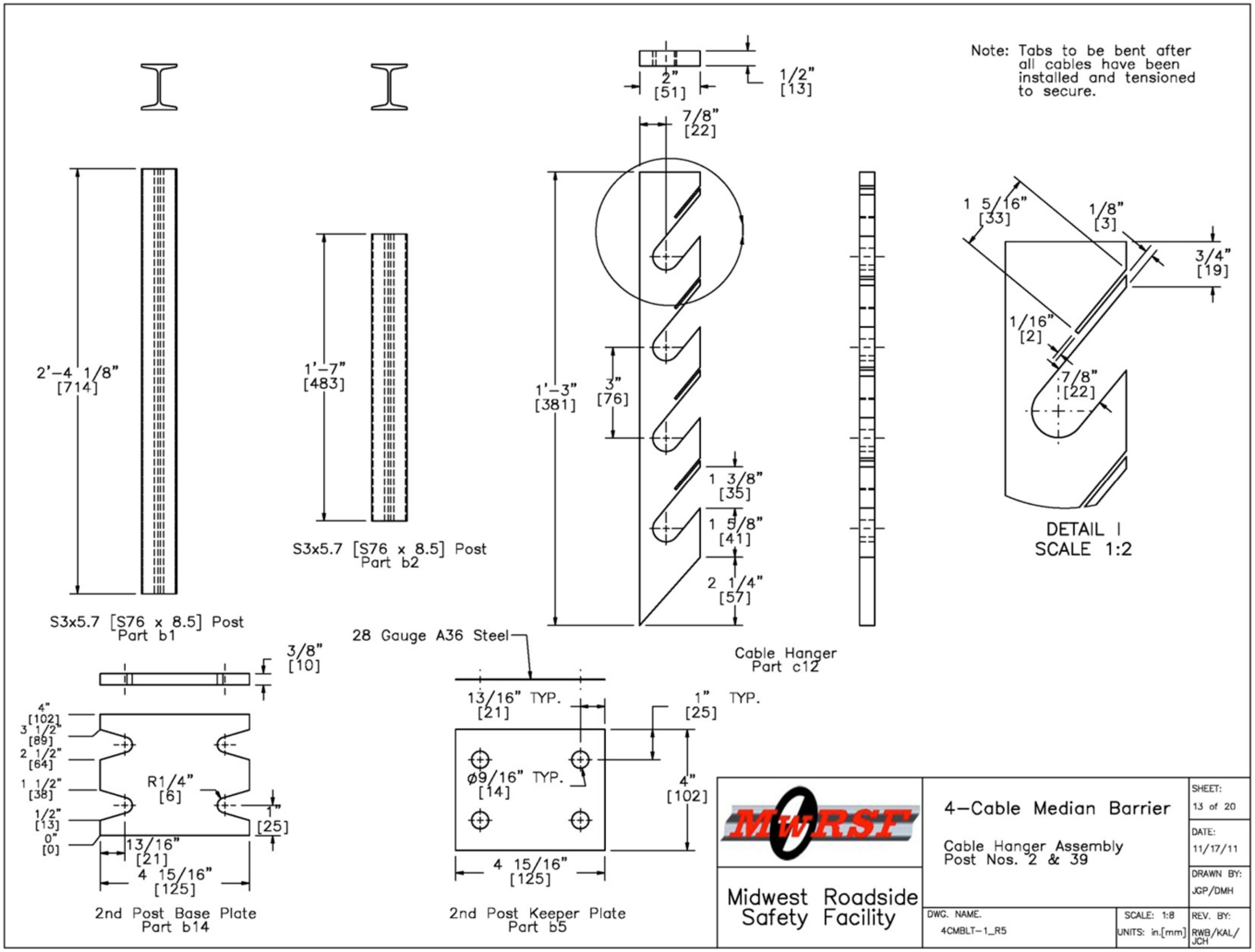


Figure 13. Post Nos. 2 and 39 Details, Test No. 4CMBLT-1

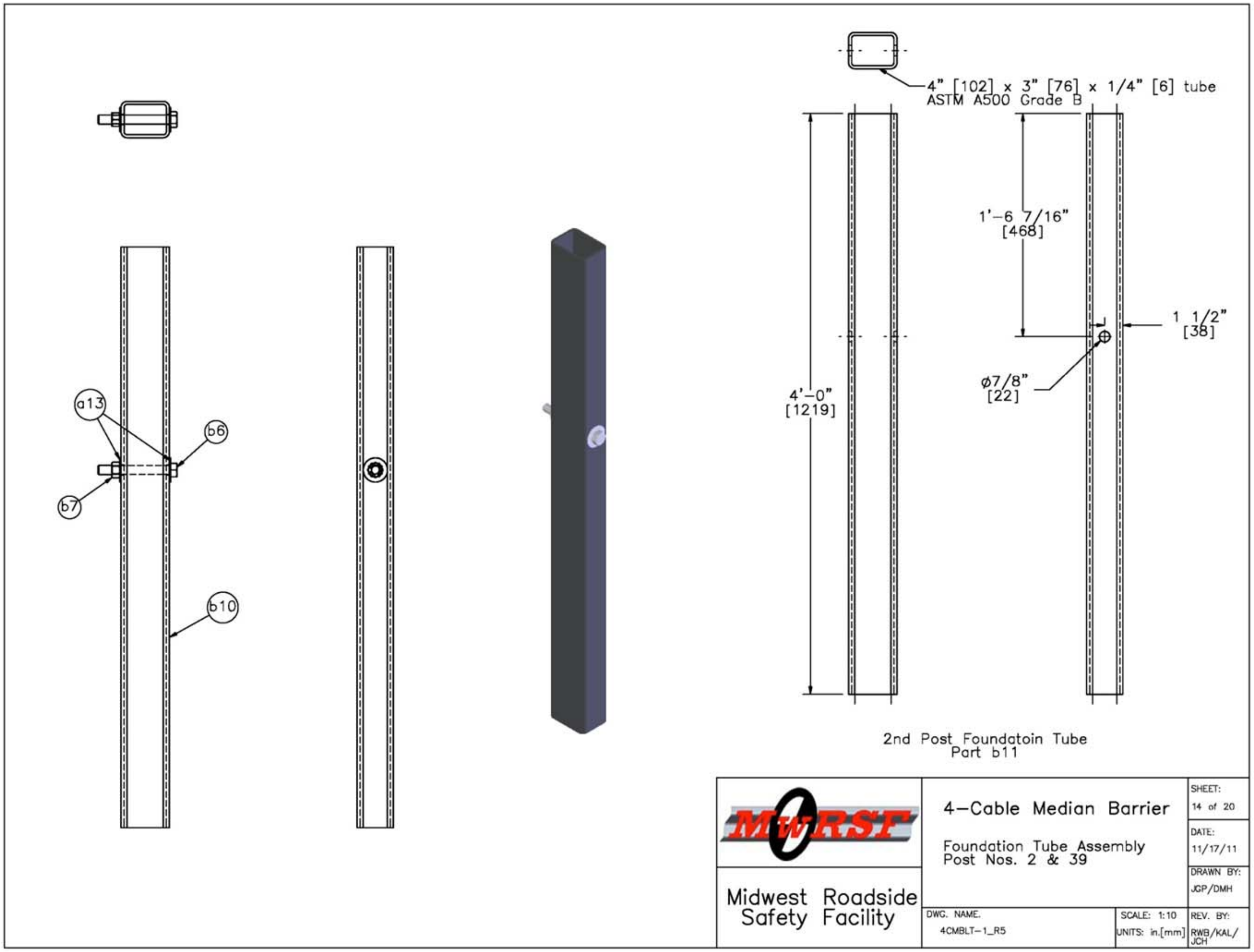


Figure 14. Post Nos. 2 and 39 Details, Test No. 4CMBLT-1

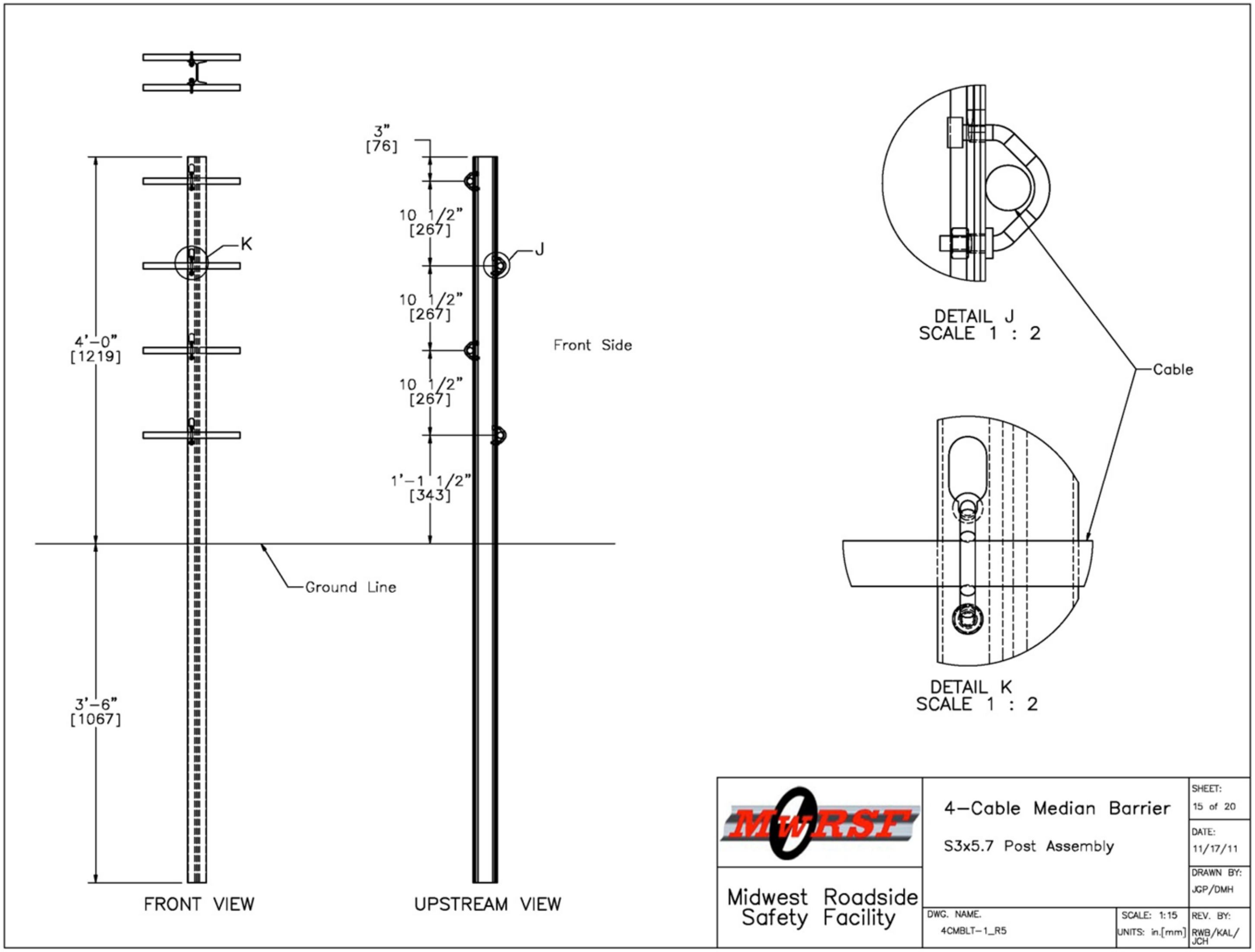


Figure 15. Post Assembly Layout, Test No. 4CMBLT-1

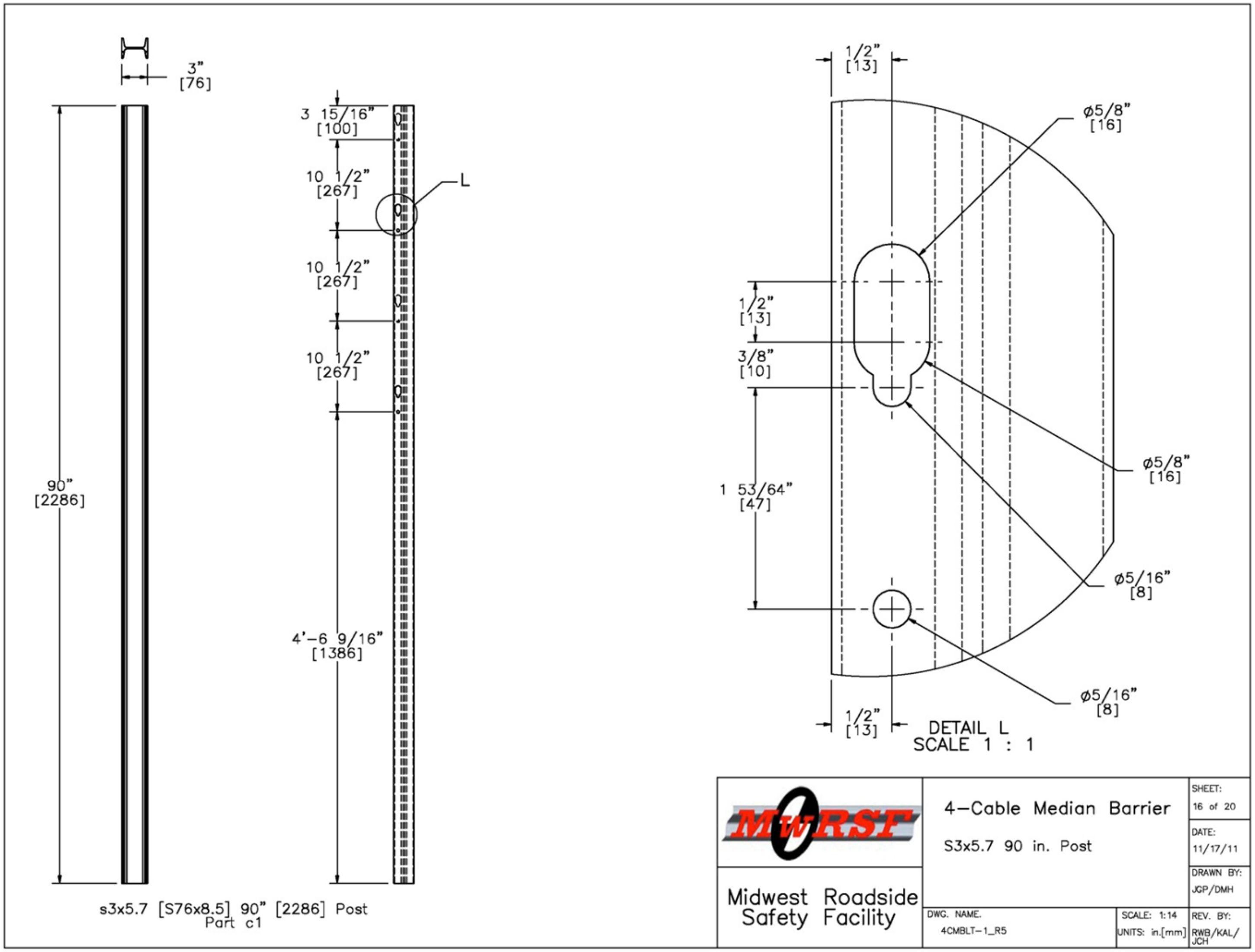
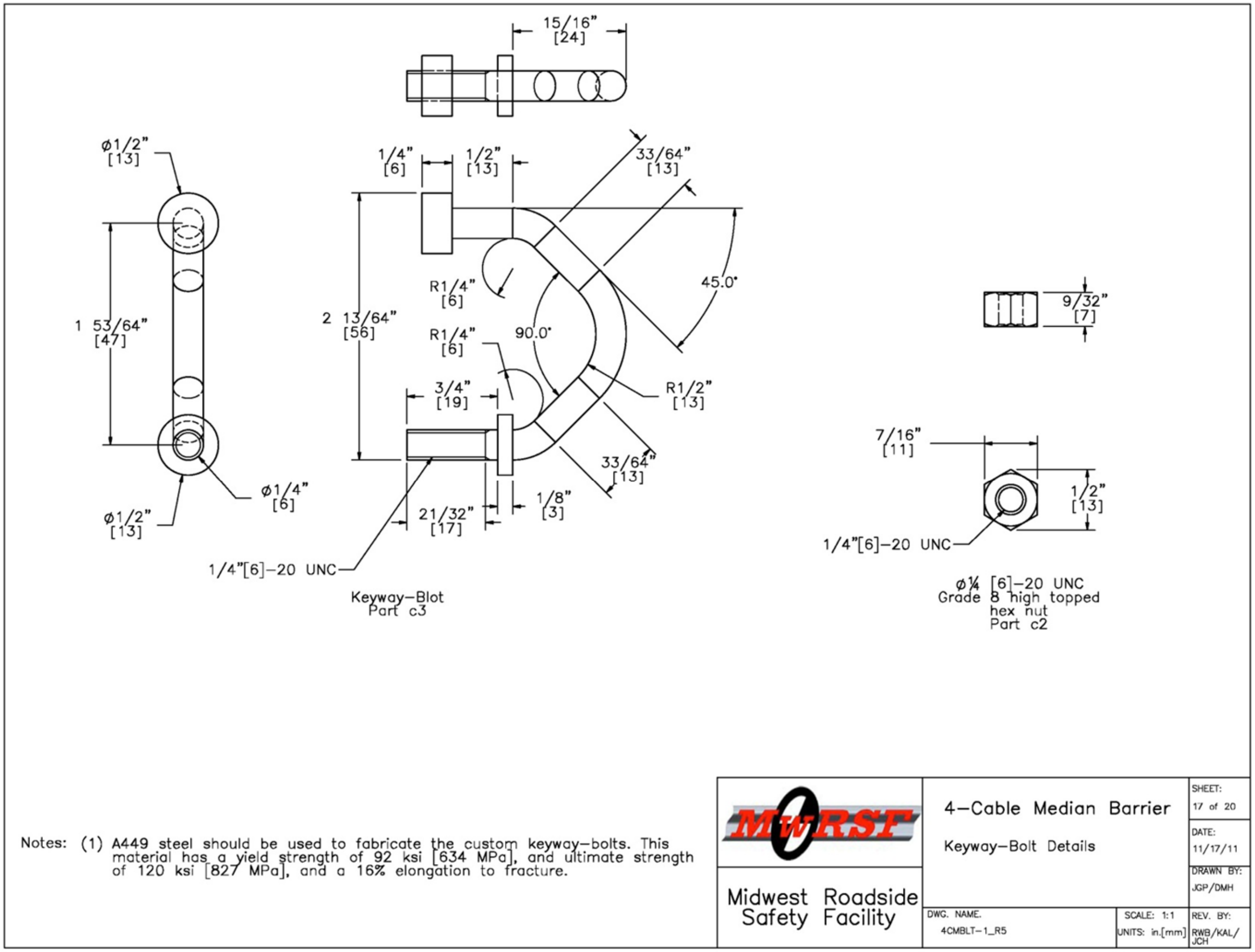


Figure 16. Post Nos. 3 through 38 Details, Test No. 4CMBLT-1



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 17. Keyway Bolt Detail, Test No. 4CMBLT-1

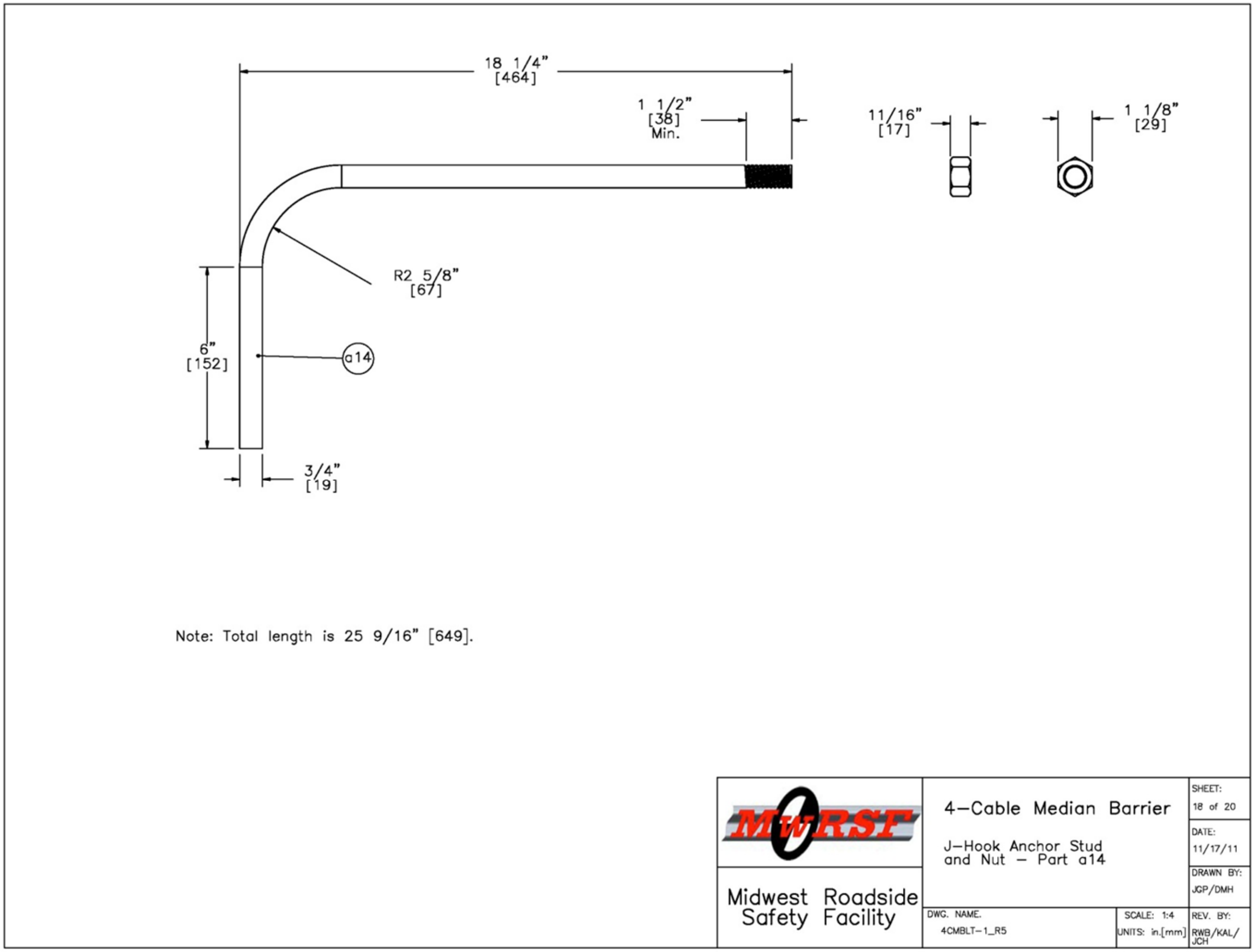
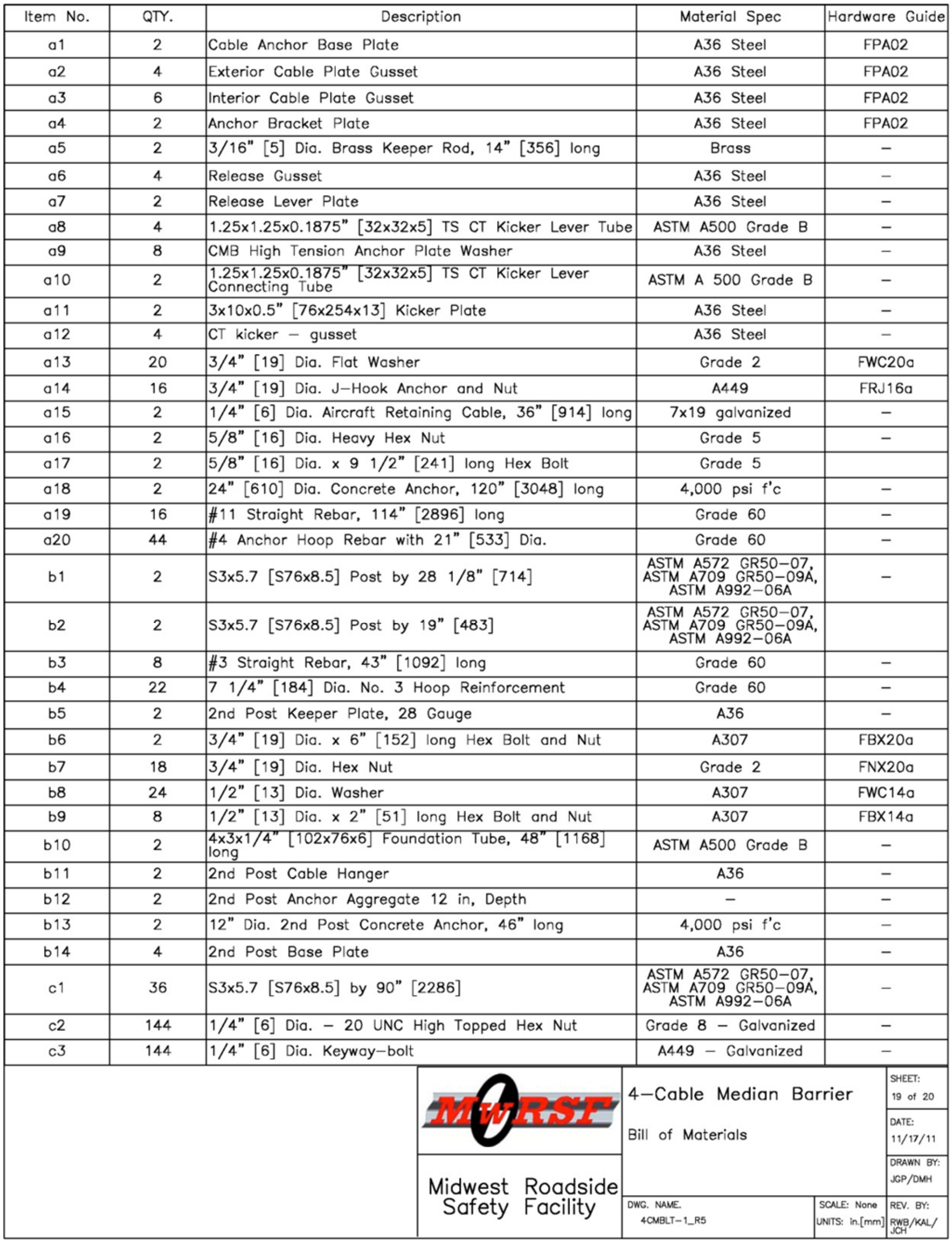


Figure 18. Anchor Stud Detail, Test No. 4CMBLT-1



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
a14	16	3/4" [19] Dia. J-Hook Anchor and Nut	A449	FRJ16a
a15	2	1/4" [6] Dia. Aircraft Retaining Cable, 36" [914] long	7x19 galvanized	–
a16	2	5/8" [16] Dia. Heavy Hex Nut	Grade 5	–
a17	2	5/8" [16] Dia. x 9 1/2" [241] long Hex Bolt	Grade 5	
a18	2	24" [610] Dia. Concrete Anchor, 120" [3048] long	4,000 psi f'c	–
a19	16	#11 Straight Rebar, 114" [2896] long	Grade 60	–
a20	44	#4 Anchor Hoop Rebar with 21" [533] Dia.	Grade 60	–
b1	2	S3x5.7 [S76x8.5] Post by 28 1/8" [714]	ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A	–
b2	2	S3x5.7 [S76x8.5] Post by 19" [483]	ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A	
b3	8	#3 Straight Rebar, 43" [1092] long	Grade 60	–
b4	22	7 1/4" [184] Dia. No. 3 Hoop Reinforcement	Grade 60	–
b5	2	2nd Post Keeper Plate, 28 Gauge	A36	–
b6	2	3/4" [19] Dia. x 6" [152] long Hex Bolt and Nut	A307	FBX20a
b7	18	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" [51] 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" Dia. 2nd Post Concrete Anchor, 46" long	4,000 psi f'c	–
b14	4	2nd Post Base Plate	A36	–
c1	36	S3x5.7 [S76x8.5] by 90" [2286]	ASTM A572 GR50-07, ASTM A709 GR50-09A, ASTM A992-06A	–
c2	144	1/4" [6] Dia. – 20 UNC High Topped Hex Nut	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: 19 of 20

DATE: 11/17/11

DRAWN BY: JGP/DMH

DWG. NAME. 4CMBLT-1_R5

SCALE: None
UNITS: in.[mm]

REV. BY: RWB/KAL/JCH

Figure 19. Bill of Materials, Test No. 4CMBLT-1

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	28	Cable End Threaded Rod	ASTM–A449	RCE03
d4	24	Bennet Cable End Fitter	ASTM–A47	RCE03
d5	24	7/8" [22] Dia. Square Nut	Grade 5	FNS20
e1	8	Bennet Short Threaded Turnbuckle	Not Specified	–
e2	8	Threaded Loadcell Coupler	N/A	–
e3	4	50,000–lb [222.4–kN] Load Cell	N/A	–

Midwest Roadside Safety Facility

4–Cable Median Barrier

Bill of Materials Continued

SHEET: 20 of 20
DATE: 11/17/11
DRAWN BY: JGP/DMH
DWG. NAME. 4CMBLT–1_R5
SCALE: None
UNITS: in.[mm]
REV. BY: RWB/KAL/JCH

Figure 20. Bill of Materials (continued), Test No. 4CMBLT-1

Figure 21. Test Installation, Test No. 4CMBLT-1

Figure 22. Test Installation, Test No. 4CMBLT-1

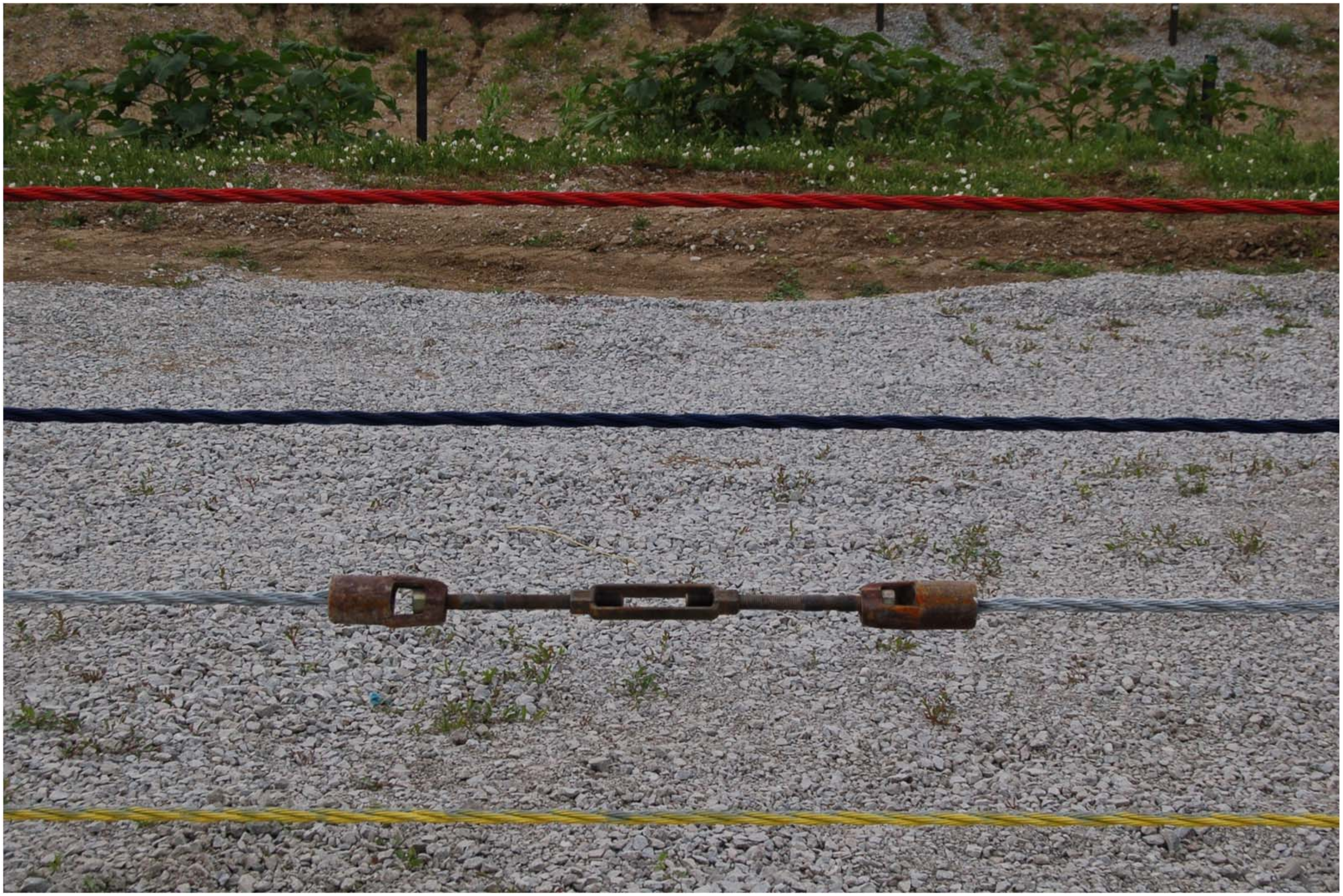


Figure 23. Cable Splice, Test No. 4CMBLT-1

Figure 24. Post and Keyway Bolt, Test No. 4CMBLT-1

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

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 [7]. 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.

For test no. 4CMBLT-1, it was desired to use a heavier vehicle than the 1100C, while maintaining the low hood height and narrow front profile in order to maximize the likelihood of penetration through the system. Therefore, the test was to be conducted with a 1500A vehicle as specified in MASH. A search was conducted to find a vehicle that fit the 1500A vehicle criteria and had an optimal bumper height to maximize penetration. A list of full-size sedans with target minimum and maximum bumper heights of 10 in. (254 mm) and 24 in. (610 mm), respectively, was compiled, as shown in Table 4. Using this data, the 2006 Ford Taurus was selected as a critical test vehicle due to its narrow front-end profile and consequently increased likelihood of penetrating the barrier system. The 2006 Ford Taurus represented a vehicle with substantial sales volume, a low front-end hood height, and reasonable opportunity for the front bumper to wedge between the cables positioned at 13½ in. (343 mm) and 24 in. (610 mm) above the ground.

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>

Table 4. 2005-2008 Passenger Sedan Options

Year	Make	Model	Bottom Bumper Height (in.)	Top Bumper Height (in.)	Front Engine Hood Height (in.)
2005	Buick	Lacrosse	10	19.5	28
2006	Buick	Lacrosse	10.5	21	27.5
2007	Buick	Lacrosse	10.5	20	28.5
2005	Buick	LeSabre	13	20	29
2008	Chevrolet	HHR	14.5	20	33
2005	Chevrolet	Impala	11	21	28
2005	Ford	Five Hundred	10	22	31
2007	Ford	Five Hundred	10	22	32
2007	Ford	Focus	11	21	27.5
2006	Ford	Taurus	10	21	25
2005	Honda	Accord	10.5	21	27
2006	Honda	Accord	10.5	21	26
2007	Honda	Accord	11	20.5	27
2006	Hyundai	Azera	11	21.5	30
2005	Lexus	ES330	10	21.5	28.5
2006	Lexus	ES330	10.5	21.5	24
2007	Mercedes-Benz	E350	10	19.5	29.5
2006	Mercury	Milan	10	23	28.5
2007	Mercury	Milan	10	22	29
2006	Mercury	Montigo	11	22.5	32
2007	Pontiac	Vibe	10	24	30.5
2007	Saab	95	10.5	21	28
2005	Subaru	Legacy	10	19	26
2005	Subaru	Outback	10.5	22	29
2007	Subaru	Outback	11	22.5	29
2008	Suzuki	Reno	10.5	21	27.5
2007	Toyota	Corolla	10	22	29
2008	Toyota	Corolla	11	22	29.5
2006	Volvo	S60	11.5	20	28
		Average	10.7	21.2	28.5

1 in = 25.4 mm

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 four-cable median barrier to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles.

For longitudinal barriers, only the evaluation criteria for structural adequacy and occupant risk are required. Although not required, the post-impact vehicle trajectory provides important information about the way in which the barrier redirects the vehicle during impact. The 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) between deflections of 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.

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 [9] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (10-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. 4CMBLT-1, a 2006 Ford Taurus was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 3,212 lb (1,457 kg), 3,300 lb (1,497 kg), and 3,470 lb (1,574 kg), respectively. The test vehicle is shown in Figure 25, and vehicle dimensions are shown in Figure 26.

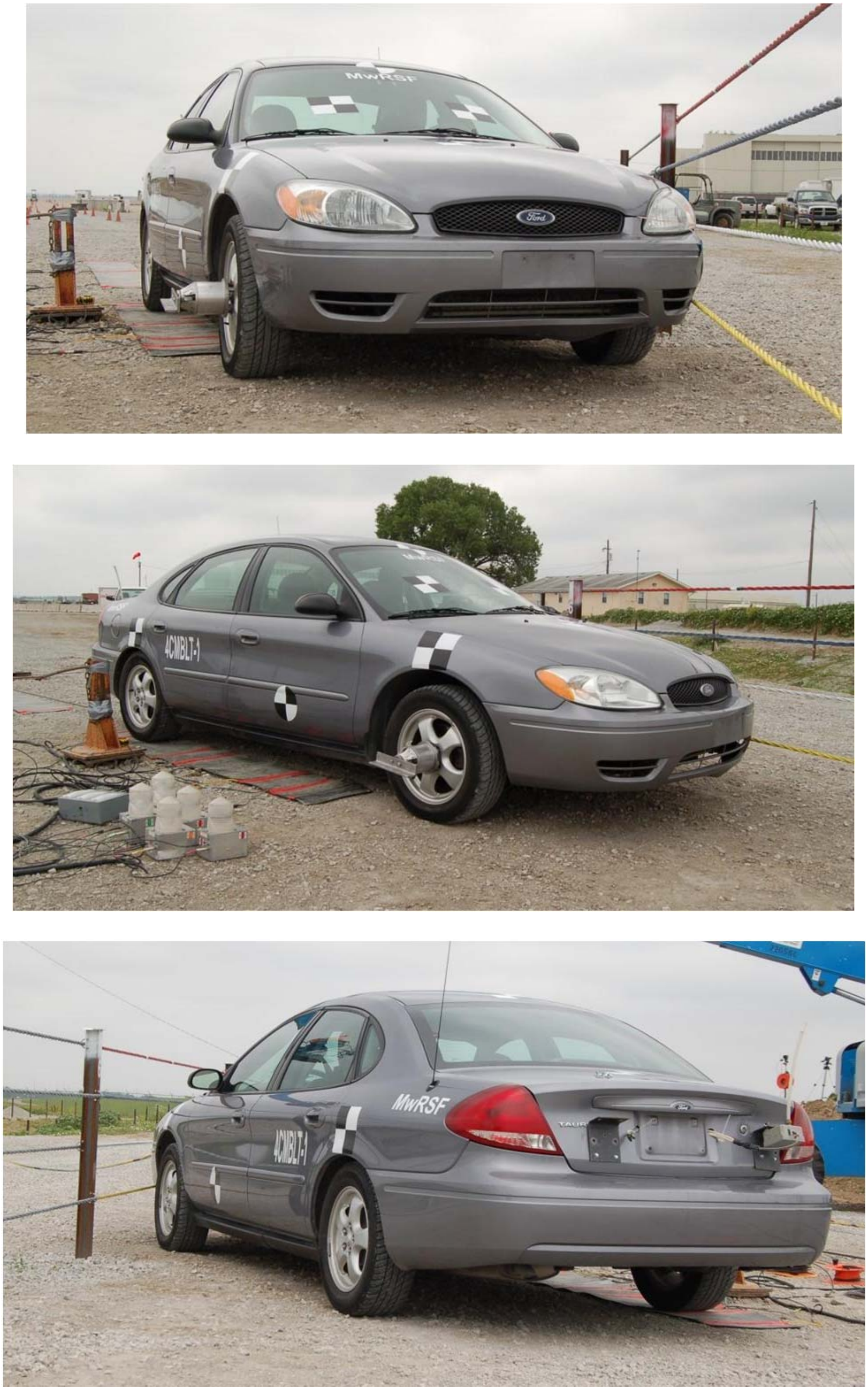
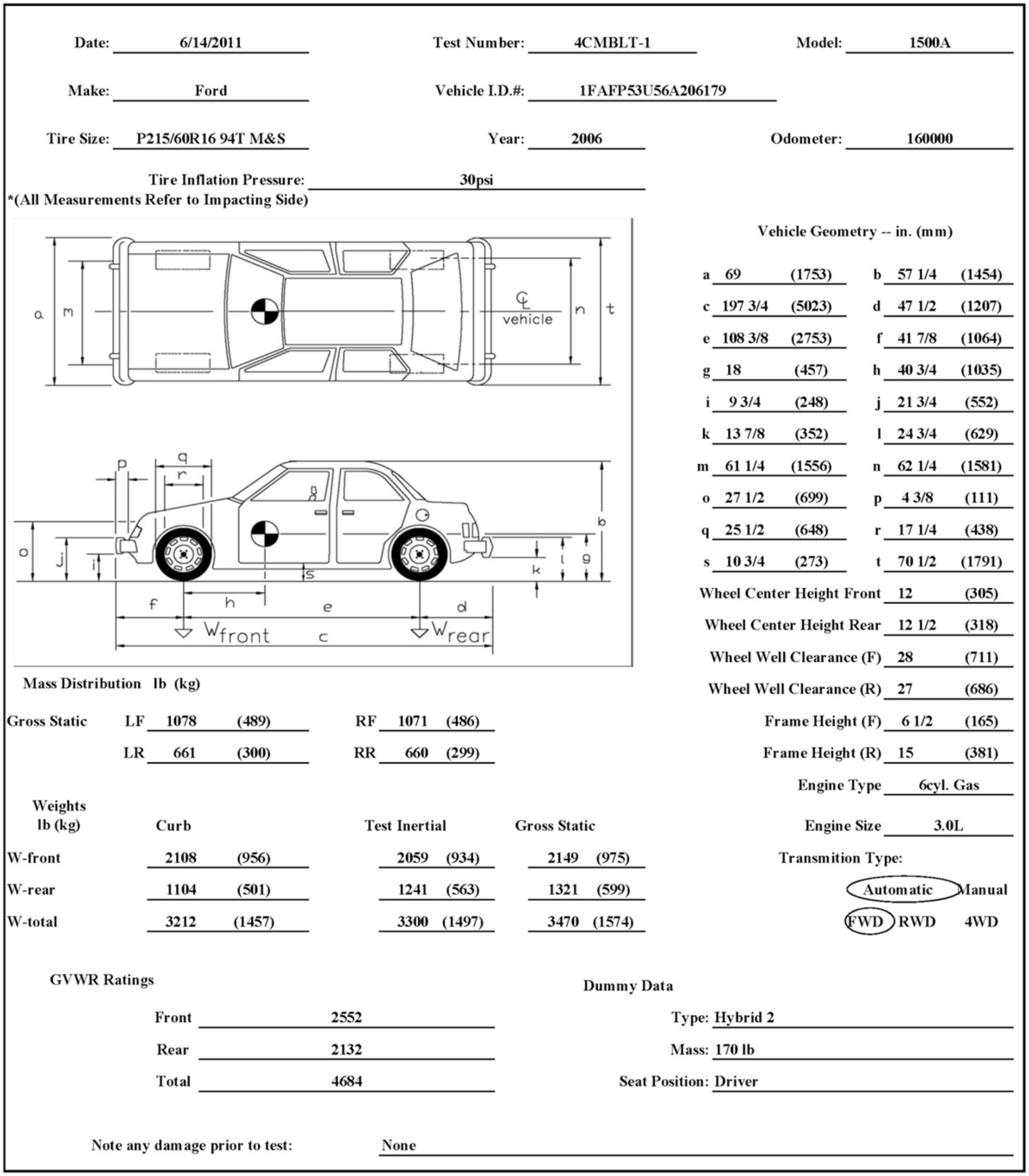


Figure 25. Test Vehicle, Test No. 4CMBLT-1



Date: 6/14/2011 **Test Number:** 4CMBLT-1 **Model:** 1500A

Make: Ford **Vehicle I.D.#:** 1FAFP53U56A206179

Tire Size: P215/60R16 94T M&S **Year:** 2006 **Odometer:** 160000

Tire Inflation Pressure: 30psi

*(All Measurements Refer to Impacting Side)

Vehicle Geometry -- in. (mm)

a	69	(1753)	b	57 1/4	(1454)
c	197 3/4	(5023)	d	47 1/2	(1207)
e	108 3/8	(2753)	f	41 7/8	(1064)
g	18	(457)	h	40 3/4	(1035)
i	9 3/4	(248)	j	21 3/4	(552)
k	13 7/8	(352)	l	24 3/4	(629)
m	61 1/4	(1556)	n	62 1/4	(1581)
o	27 1/2	(699)	p	4 3/8	(111)
q	25 1/2	(648)	r	17 1/4	(438)
s	10 3/4	(273)	t	70 1/2	(1791)

Wheel Center Height Front	12	(305)
Wheel Center Height Rear	12 1/2	(318)
Wheel Well Clearance (F)	28	(711)
Wheel Well Clearance (R)	27	(686)
Frame Height (F)	6 1/2	(165)
Frame Height (R)	15	(381)
Engine Type	6cyl. Gas	
Engine Size	3.0L	

Mass Distribution lb (kg)

Gross Static	LF	1078 (489)	RF	1071 (486)
	LR	661 (300)	RR	660 (299)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2108 (956)	2059 (934)	2149 (975)
W-rear	1104 (501)	1241 (563)	1321 (599)
W-total	3212 (1457)	3300 (1497)	3470 (1574)

Transmition Type:

[✓ Automatic] Manual

[✓ FWD] RWD 4WD

GVWR Ratings

Front 2552
Rear 2132
Total 4684

Dummy Data

Type: Hybrid 2
Mass: 170 lb
Seat Position: Driver

Note any damage prior to test: None

Figure 26. Vehicle Dimensions, Test No. 4CMBLT-1

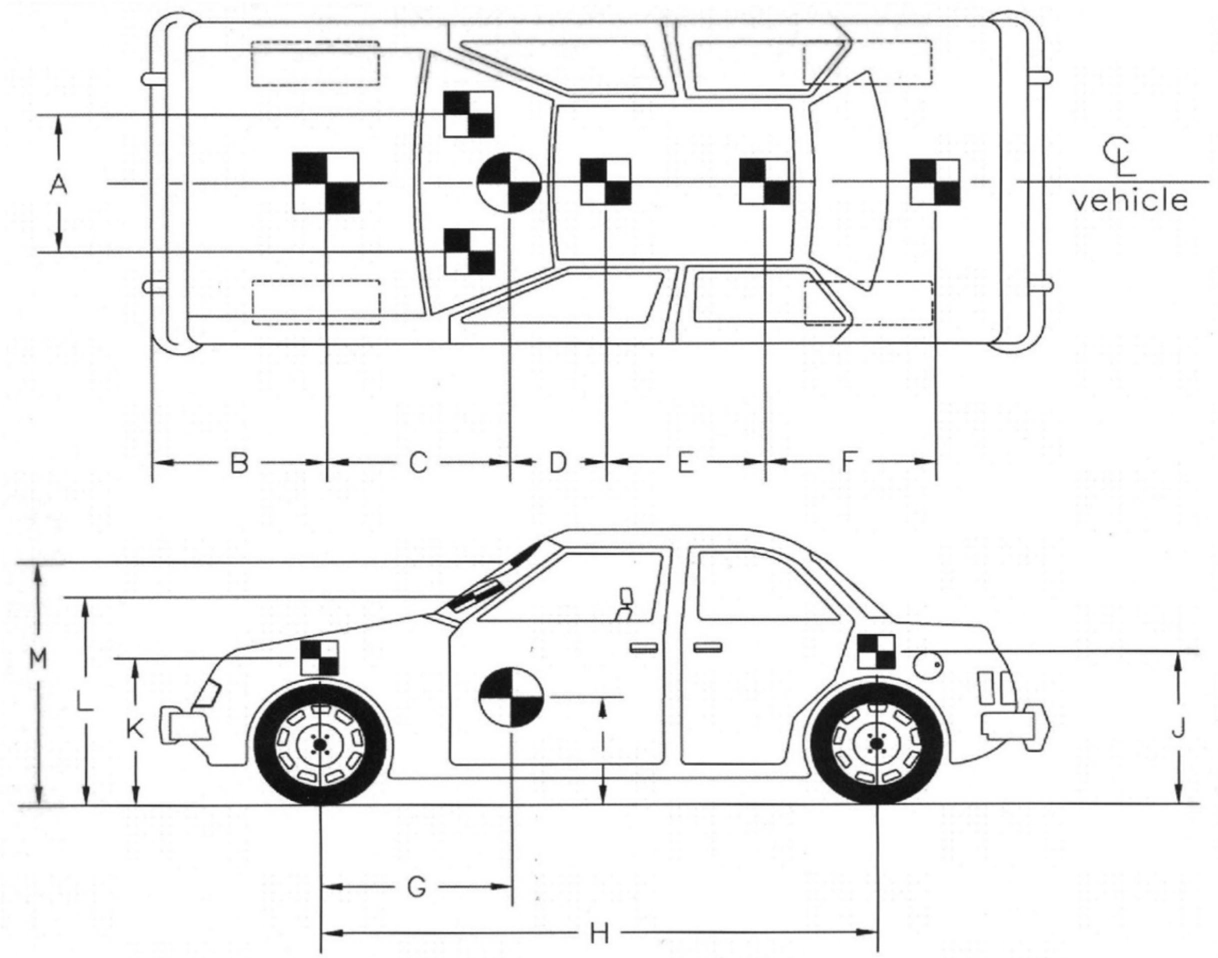
The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The vertical component of the c.g. for the 1500A vehicle was estimated based on historical c.g. height measurements. The location of the final c.g. is shown in Figures 26 and 27. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 27. Round, checkered targets were placed at the center of gravity on the left-side door, the right-side door, and the roof of the vehicle.

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

4.4 Simulated Occupant

For test no 4CMBLT-1, 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 c.g. location.



TEST #: 4CMBLT-1

TARGET GEOMETRY-- in. (mm)

A	26	(660)	**E**	41	(1041)	**I**	18	(457)
B	35 1/2	(902)	**F**	40 1/8	(1019)	**J**	31	(787)
C	46	(1168)	**G**	40 3/8	(1026)	**K**	31 3/4	(806)
D	15 3/8	(391)	**H**	108 3/8	(2753)	**L**	43 3/4	(1111)
						M	53 1/8	(1349)

Figure 27. Target Geometry, Test No. 4CMBLT-1

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Three 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 c.g. of the test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [10].

The 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. 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-4 6DOF-500/1200, was a triaxial piezoresistive accelerometer system manufactured by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-4 6DOF-500/1200 was configured with 24 MB of RAM, a range of ±500 g’s, a sample rate of 10,000 Hz, and a 1,677 Hz anti-aliasing filter. The “EDR4COM” and “DynaMax Suite” computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The third 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 angular 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 vehicle. 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 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 vehicle. 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 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 Load Cells

Four load cells were installed in-line within the system, one per cable, toward the upstream end of the four-cable barrier system. 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, and acquired with TestPoint software. The data collection rate for the load cells was 10,000 samples per second (10,000 Hz).

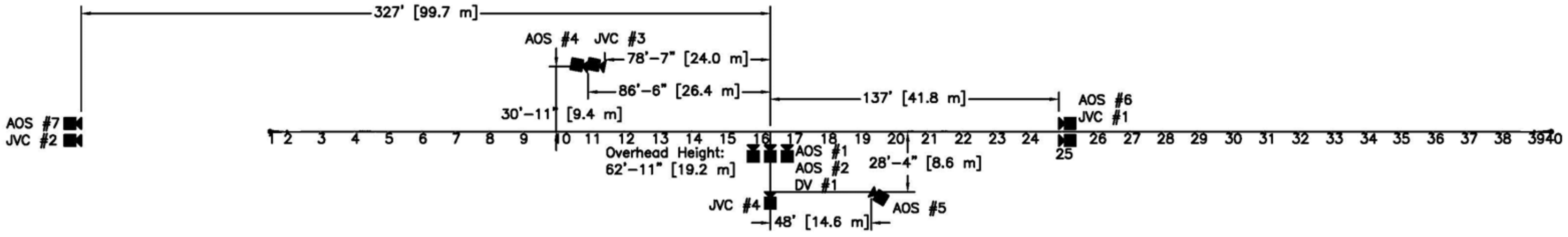
4.5.4 Pressure Tape Switches

For test no. 4CMBLT-1, five pressure-activated tape switches, spaced at approximately 6.56-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.

4.5.5 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. 4CMBLT-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 28.

The high-speed digital 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 digital videos. A Nikon D50 digital still camera was also used to document pre- and post-test conditions for the test.



	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	AOS Vitcam CTM	500	Cosmicar 12.5mm Fixed	-
	2	AOS Vitcam CTM	500	Kowa 8mm Fixed	-
	4	AOS Vitcam CTM	500	Sigma 24-135mm	28mm
	5	AOS X-PRI Gigabit	500	Fujinon 50mm Fixed	-
	6	AOS X-PRI Gigabit	500	Sigma 50mm Fixed	-
	7	AOS X-PRI Gigabit	500	Canon 17-102mm	102mm
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 28. Camera Locations, Speeds, and Lens Settings, Test No. 4CMBLT-1

5 FULL-SCALE CRASH TEST NO. 4CMBLT-1

5.1 Static Soil Test

Before full-scale crash test no. 4CMBLT-1 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 post-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. 4CMBLT-1

The 3,300-lb (1,497-kg) car impacted the four-cable median barrier at a speed of 62.2 mph (100.1 km/h) and at an angle of 25.3 degrees. A summary of the test results and sequential photographs are shown in Figure 29. Additional sequential photographs are shown in Figure 30 through Figure 33.

5.3 Weather Conditions

Test no. 4CMBLT-1 was conducted on June 14, 2011 at approximately 3:00 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 5 [11].

Table 5. Weather Conditions, Test No. 4CMBLT-1

Temperature	76° F
Humidity	67 %
Wind Speed	10 mph
Wind Direction	300° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.06 in.
Previous 7-Day Precipitation	0.15 in.

5.4 Test Description

Initial vehicle impact was to occur 64 in. (1,626 mm) downstream from post no. 16, as shown in Figure 34, which was selected using an analysis of the vehicle trajectory to maximize the potential for vehicle penetration through the system. A sequential description of the impact events is provided by Table 6. The vehicle came to rest 123 ft (37.5 m) downstream from impact within the system. The vehicle trajectory and final position are shown in Figures 29 and 35.

Table 6. Sequential Description of Impact Events, Test No. 4CMBLT-1

TIME (sec)	EVENT
0.000	The left-front bumper impacted cable 4 (bottom cable).
0.010	The left-front quarter panel contacted cable 3 and deformed. The left-front tire contacted cable 4.
0.022	The left-front quarter panel contacted cable 2 and post no. 17 deflected downstream.
0.066	The left-front tire overrode cable 4.
0.076	The left A-pillar contacted cable 1, and the front bumper contacted post no. 17, which bent and rotated downstream.
0.090	Cables 2 and 3 disengaged from post no. 17, and post no. 18 deflected backward.
0.100	The left-side mirror disengaged from the vehicle.
0.104	Cable 1 disengaged from post no. 17, and post no. 16 deflected backward.
0.114	Cable 3 disengaged from post no. 18, and cable 4 disengaged from post no. 17.
0.124	The left-rear tire contacted cable 4.
0.136	The left headlight disengaged from the vehicle.
0.142	Post no. 19 deflected backward, and cable 3 disengaged from post no. 19.
0.158	The left-rear tire overrode cable 4.
0.164	The left-front window shattered, and the left A-pillar was crushed inward by cable 3.
0.180	The vehicle began to roll away from the system.
0.208	Cable 2 disengaged from post no. 16, and the windshield shattered on the left side.
0.214	The left-front tire lost contact with the ground as the vehicle continued to roll.
0.246	Cable 2 disengaged from post no. 18.
0.266	Cable 1 disengaged from post no. 18.
0.272	Cable 2 disengaged from post no. 19.
0.304	Cable 1 disengaged from post no. 19.

0.332	Post no. 20 deflected backward.
0.382	The left-rear tire lost contact with the ground as the vehicle continued to roll.
0.426	Cable 3 disengaged from post no. 20.
0.448	Post no. 21 deflected backward, and the right-rear window shattered.
0.660	The vehicle reached its maximum roll angle away from system.
0.684	The right-rear quarter panel contacted post no. 19, which rotated downstream.
0.726	The vehicle was parallel to the system at a speed of 44.3 mph (71.2 km/h).
0.748	The right-front bumper contacted post no. 20, which rotated downstream.
0.770	Cable 2 disengaged from post no. 20.
0.780	Cable 1 disengaged from post no. 20.
0.820	Cable 4 disengaged from post no. 20.
0.852	The vehicle began to roll toward the system.
0.974	Cable 4 disengaged from post no. 21.
1.004	Cable 4 disengaged from post no. 22. The right A-pillar deformed, and the right side of the windshield shattered due to contact with cable 1.
1.022	The left-rear tire contacted the ground, and the left-front bumper contacted post no. 21, which rotated downstream.
1.034	Cable 3 disengaged from post no. 21.
1.042	The left-front tire contacted the ground.
1.052	The roll angle was approximately zero, the left side of the vehicle deformed, and cable 1 disengaged from post no. 21.
1.056	Post no. 22 deflected forward.
1.140	The vehicle began to roll away from the system.
1.288	The vehicle ceased rolling away from the system.
1.346	The left-front bumper contacted post no. 22, which rotated downstream.
1.752	The left-front bumper contacted post no. 23, which rotated downstream.
1.834	Cable 1 disengaged from post no. 23.
2.266	The vehicle contacted post no. 24, which rotated downstream.

5.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 36 through 49. Barrier damage consisted of detached cables and bent and rotated posts. The length of vehicle contact along the barrier was approximately 123 ft (37.5 m), which spanned from 5 ft – 4 in. (1.6 m) upstream from the centerline of post no. 16 to 4 in. (102 mm) downstream from the centerline of post no. 24.

The button head of cable no. 2 keyway bolt on post no. 16 released from the keyway, but the bolt remained attached to the post. The button head of cable nos. 1 and 2 keyway bolts on post no. 17 released from the keyway and deformed. The keyway bolt for cable no. 3 on post no. 17 fractured through the shank, while the keyway bolt for cable no. 4 fractured through the threads and disengaged. The button head of the keyway bolts for cable nos. 1 and 2 on post nos. 18 and 19 disengaged from the keyway and deformed. Cable no. 3 keyway bolt on post nos. 18 and 19 disengaged. The keyway bolts for cable nos. 1 and 2 on post no. 20 released from the keyway and deformed, the keyway bolt for cable no. 3 fractured through the threads, and the keyway bolt for cable no. 4 disengaged. The keyway bolts for cable nos. 1, 2, and 3 on post nos. 21 and 23 disengaged and deformed, and the keyway bolt for cable no. 4 disengaged. Keyway bolts for cable nos. 1 and 4 on post no. 22 fractured through the shank. The keyway bolt for cable no. 2 on post no. 22 disengaged and flattened, while the keyway bolt for cable no. 3 disengaged. The keyway bolts for cable nos. 1 and 2 on post no. 24 disengaged and flattened, while the keyway bolts for cable nos. 3 and 4 on post no. 24 disengaged. The keyway bolt for cable no. 1 on post no. 25 disengaged and flattened, while the keyway bolt for cable no. 2 on post no. 25 pushed upward and began to disengage.

Post nos. 15, 16, and 25 rotated backwards through the soil. Post no. 17 bent slightly backward and downstream to the ground. Post no. 18 bent and rotated backward and downstream. Post no. 19 twisted and bent to approximately 45 degrees downstream. Post nos. 20, 22, and 23 twisted and bent downstream to the ground. Post nos. 21 and 24 bent downstream to the ground. The keyway was bent due to button head pull through for cable no. 1 on post nos.

20 and 21, cable no. 2 on post no. 18, cable 3 on post nos. 17, 19, 21, and 23, and cable no. 4 on post nos. 19 through 23 and 25.

The maximum permanent set of the post was 20¼ in. (514 mm), which occurred at post no. 17, as measured in the field. The maximum lateral dynamic deflection of the post and rail was 24.0 in. (610 mm) and 94.5 in. (2,400 mm), respectively, at post no. 20 as determined from high-speed digital video analysis. The working width of the system was found to be 111.2 in. (2,824 mm), also determined from high-speed digital video analysis.

5.6 Vehicle Damage

The damage to the vehicle was extensive, as shown in Figures 50 through 52. The maximum occupant compartment deformations are listed in Table 7 along with the deformation limits established in MASH for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 7. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	½ (13)	≤ 9 (229)
Floor Pan & Transmission Tunnel	NA	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	1¼ (32)	≤ 9 (229)
Side Door (Below Seat)	1 (25)	≤ 12 (305)
Roof	4 (102)	≤ 4 (102)
Dash	¼ (6)	NA
A-Pillar	4½ (114)	NA

Deformation to the roof was not measured post-test because a suitable reference point was unavailable due to the damage sustained. It was believed that the maximum deformation occurred on the roof of the vehicle. However, due to the lack of a reference point, an accurate measurement was unavailable, but it was estimated to be near, or exceeding, the 4-in. (102mm) limit set by MASH.

The damage to the vehicle was concentrated on the left-front corner with substantial damage to the sides and roof of the vehicle. The windshield experienced extensive damage with spider-web cracking throughout. The windshield disengaged from the roof near the middle of the vehicle spanning approximately 16 in. (406 mm). A 6-in. vertical by 15-in. horizontal (152-mm by 381-mm) tear occurred to the bottom left corner of the windshield where cable no. 2 laid on the vehicle. The front bumper cover fractured and disengaged, except for an 18-in. (457-mm) segment attached to the right-front corner. Foam from the front bumper disengaged and came to rest 127 ft (38.7 m) downstream and 3 ft (0.9 m) in front of the impact location. The left side of the engine hood sustained contact marks from cable nos. 1 and 2.

The left-front headlight disengaged and came to rest 129 ft (39.3 m) downstream and 57 ft (17.4 m) behind the impact location. The left-front quarter panel folded behind itself and encountered a 4-in. (102-mm) long tear. The left-front wheel well liner sustained a 12-in. (305-mm) long tear. The left-front steel rim encountered contact marks from cable nos. 3 and 4. A gouge was found along the entire left side with cable no. 3 in contact with the left side of the vehicle. Contact marks from the cable no. 2 were located on the left-side A-pillar, the left-side B-pillar, the left-rear door window, and the left-side C-pillar. The left-side A-pillar was crushed inward and the left-side C-pillar was flattened. The left-side mirror disengaged from the vehicle. The left-side of the roof was kinked above the B-pillar. The left-front and left-rear window glass were shattered. The left-rear door panel bowed away from the window, and the bottom of the door bent outward. Contact marks from cable no. 3 were found on the left-rear tire and the left portion of the rear bumper cover.

The right-rear tail light shattered. The right-rear quarter panel encountered contact marks from cable no. 4, 2- and 3-in. (51- and 76-mm) diameter dents, and folding near the right-rear door. Contact marks from cable no. 4 and a 2-in. (51-mm) diameter dent were found on the right-rear door. The right-front, and rear, windows were shattered. Contact marks from cable no. 4 were found on the right-rear tire. Contact marks from cable no. 1 were found on the right-side A-pillar, B-pillar, and C-pillar. The right-side A-pillar was crushed inward. Contact marks from cable no. 4 extended the length of the right side of the vehicle. The right-front steel rim sustained contact marks from cable no. 4 and 4-in (102-mm) gouge. The right-front wheel well liner was partially disengaged. The right-front bumper cover bent and sustained a 5- and 8-in. (127- and 203-mm) tear. The right-front headlight cracked. The right-front corner of the hood kinked above the right-front headlight. The entire roof sustained contact marks from cable no. 1, and it buckled upward at the midpoint of the windshield. The right-side of the roof bent downward from the front to approximately the B-pillar. A 2.5-ft (0.8-m) diameter dent was located near the right-side of the roof. A 2-in. (51-mm) long tear with an 8-in. (203-mm) crease was found in the left-side floor pan.

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 8. 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 8. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 29. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 8. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. 4CMBLT-1

Evaluation Criteria		**Transducer**		**MASH Limits**
		EDR-3	**DTS**	
OIV ft/s (m/s)	Longitudinal	-9.61 (-2.93)	-10.30 (-3.14)	≤ 40 (12.2)
	Lateral	10.80 (3.29)	8.66 (2.64)	≤40 (12.2)
ORA g's	Longitudinal	-5.71	-6.80	≤ 20.49
	Lateral	8.52	12.47	≤ 20.49
THIV ft/s (m/s)		NA	14.26 (4.34)	not required
PHD g's		NA	14.92	not required
ASI		0.46	0.48	not required

5.8 Load Cell Results

Tension load cells were installed within the cables at the upstream end of the system in order to monitor the total load transferred to the anchor. The maximum load values measured by the transducers are summarized in Table 9. 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 53.

As noted previously, the target cable tension was 4.2 kips (18.7 kN) at 100 deg Fahrenheit (37.8 deg Celsius). Prior to the testing, the actual cable tension in cable nos. 1 through 4 was 4.53 kips (20.14 kN), 4.49 kips (19.98 kN), 4.43 kips (19.70 kN), and 4.51 kips (20.07 kN), respectively. These readings were measured using the cable load cells.

Following the crash test, the cable tension in cable nos. 1 through 4 was 4.42 kips (19.65 kN), 4.56 kips (20.30 kN), 4.87 kips (21.66 kN), and 5.32 kips (23.66 kN), respectively.

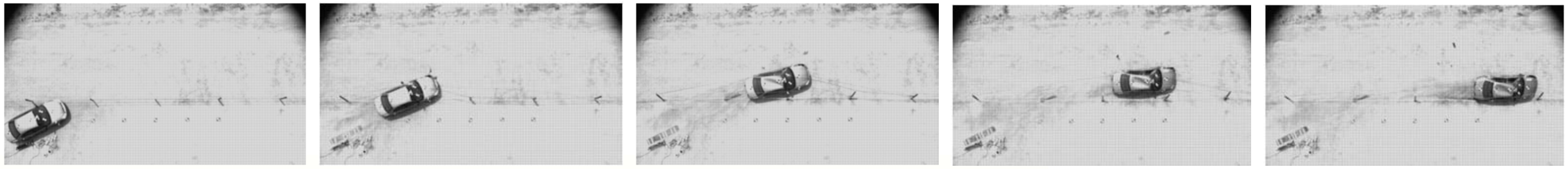
Table 9. Load Cell Results, Test No. 4CMBLT-1

Cable Location	Sensor Location	Maximum Cable Load		Time[1] (sec)
		kips	kN	
Combined Cables	Upstream End	41.34	183.91	0.401
Top Cable	Upstream End	10.42	46.34	1.025
Upper Middle Cable	Upstream End	14.07	62.60	0.300
Lower Middle Cable	Upstream End	18.28	81.32	0.457
Bottom Cable	Upstream End	14.76	65.64	1.007

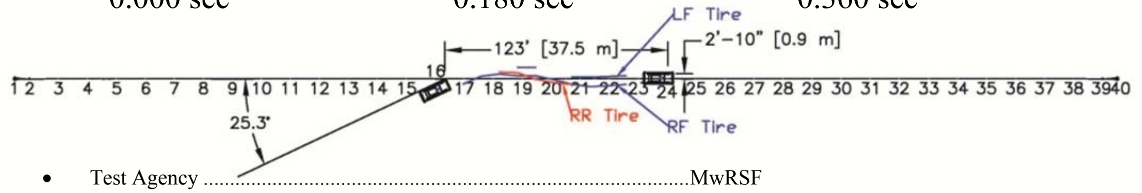
1 - Time determined from initial vehicle impact with the barrier system.

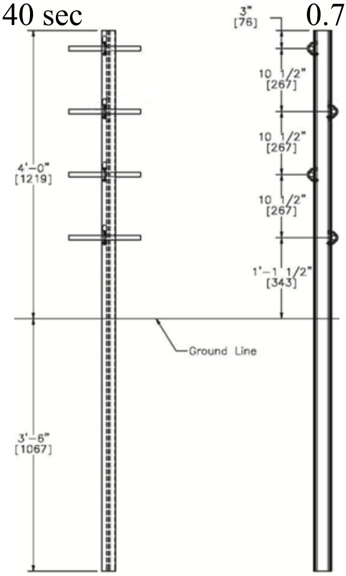
5.9 Discussion

The analysis of the test results for test no. 4CMBLT-1 showed that the high-tension, four-cable median barrier placed on level terrain adequately contained and redirected the 1500A vehicle with controlled lateral displacements of the barrier. However, cable no. 2 cut through the windshield and penetrated into the occupant compartment. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle did not exit the system and its trajectory stayed within the bounds of the exit box. Therefore, the results for test no. 4CMBLT-1 were determined to be unacceptable according to the MASH safety performance criteria due to windshield and occupant compartment penetration.



0.000 sec 0.180 sec 0.360 sec 0.540 sec 0.720 sec

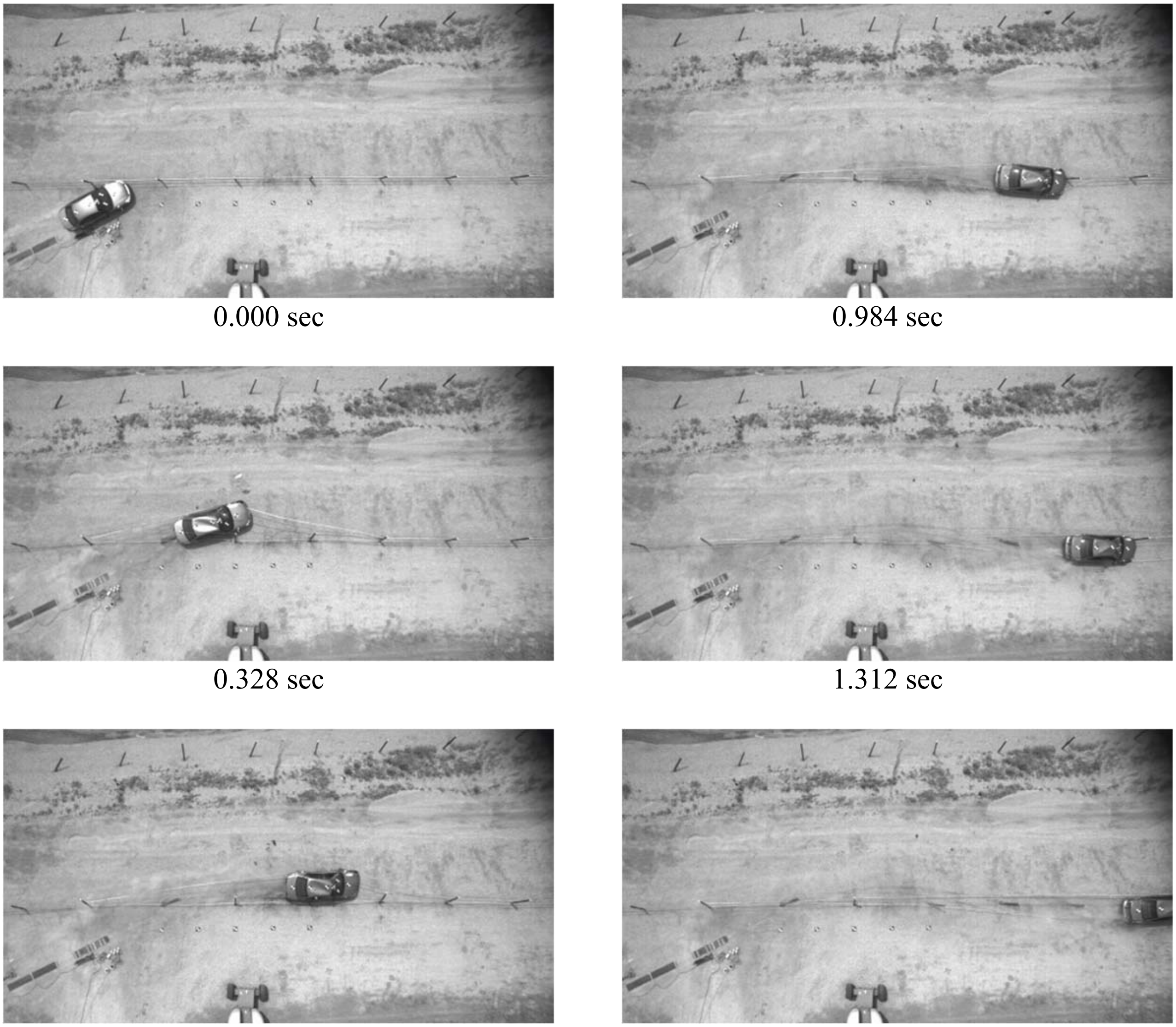




- Test Agency .... MwRSF
- Test Number 4CMBLT-1
- Date 6/14/2011
- MASH Test Designation .... Modified 3-10
- Test Article .... Four-Cable Median Barrier on Level Terrain
- Total Length .... 608 ft (185 m)
- Key Component - Cable
  - Size .... 3x7, ¾-in. (19-mm) diameter
  - Top Cable Height .... 45 in. (1,143 mm)
  - Bottom Cable Height .... 13½ in. (343 mm)
  - Incremental Cable Spacing .... 10½ in. (267 mm)
  - Number of Cables 4
- Key Component - Post
  - Length .... 90 in. (2,286 mm)
  - Shape S3x5.7 (S76x8.5)
  - Spacing .... 16 ft (4.88 m)
- Soil Type .... Compacted, coarse, crushed limestone
- Vehicle Make /Model .... 2006 Ford Taurus
  - Curb .... 3,212 lb (1,457 kg)
  - Test Inertial .... 3,300 lb (1,497 kg)
  - Gross Static .... 3,470 lb (1,574 kg)
- Impact Conditions
  - Speed .... 62.2 mph (100.1 km/h)
  - Angle .... 25.3 deg
  - Impact Location .... 64 in. (1,626 mm) downstream of post no. 16
- Exit Box Criterion .... NA (did not exit system)
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 123 ft (37.5 m)
- Vehicle Damage .... Extensive
  - VDS[12] .... 10-L&T-6
  - CDC[13] 11-TYYS-5
  - Maximum Interior Deformation .... 4½ in. (133 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 20¼ in. (514 mm)
  - Dynamic .... 94.5 in. (2,400 mm)
  - Working Width .... 111.2in. (2,824 mm)
- Maximum Angular Displacements
  - Roll .... 22.15 ° < 75 °
  - Pitch .... 4.16 ° < 75 °
  - Yaw .... 32.12 °
- Impact Severity (IS) .... 78.0 kip-ft (105.8 kJ)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		EDR-3	DTS	
OIV ft/s (m/s)	Longitudinal	-9.61 (-2.93)	-10.30 (-3.14)	≤ 40 (12.2)
	Lateral	10.80 (3.29)	8.66 (2.64)	≤ 40 (12.2)
ORA g's	Longitudinal	-5.71	-6.80	≤ 20.49
	Lateral	8.52	12.47	≤ 20.49
THIV – ft/s (m/s)		NA	14.26 (4.34)	not required
PHD – g's		NA	14.92	not required
ASI		0.46	0.48	not required

Figure 29. Summary of Test Results and Sequential Photographs, Test No. 4CMBLT-1



0.000 sec

0.984 sec

0.328 sec

1.312 sec

0.656

1.640 sec

Figure 30. Additional Sequential Photographs, Test No. 4CMBLT-1

0.000 sec 0.000 sec

0.144 sec 0.128 sec

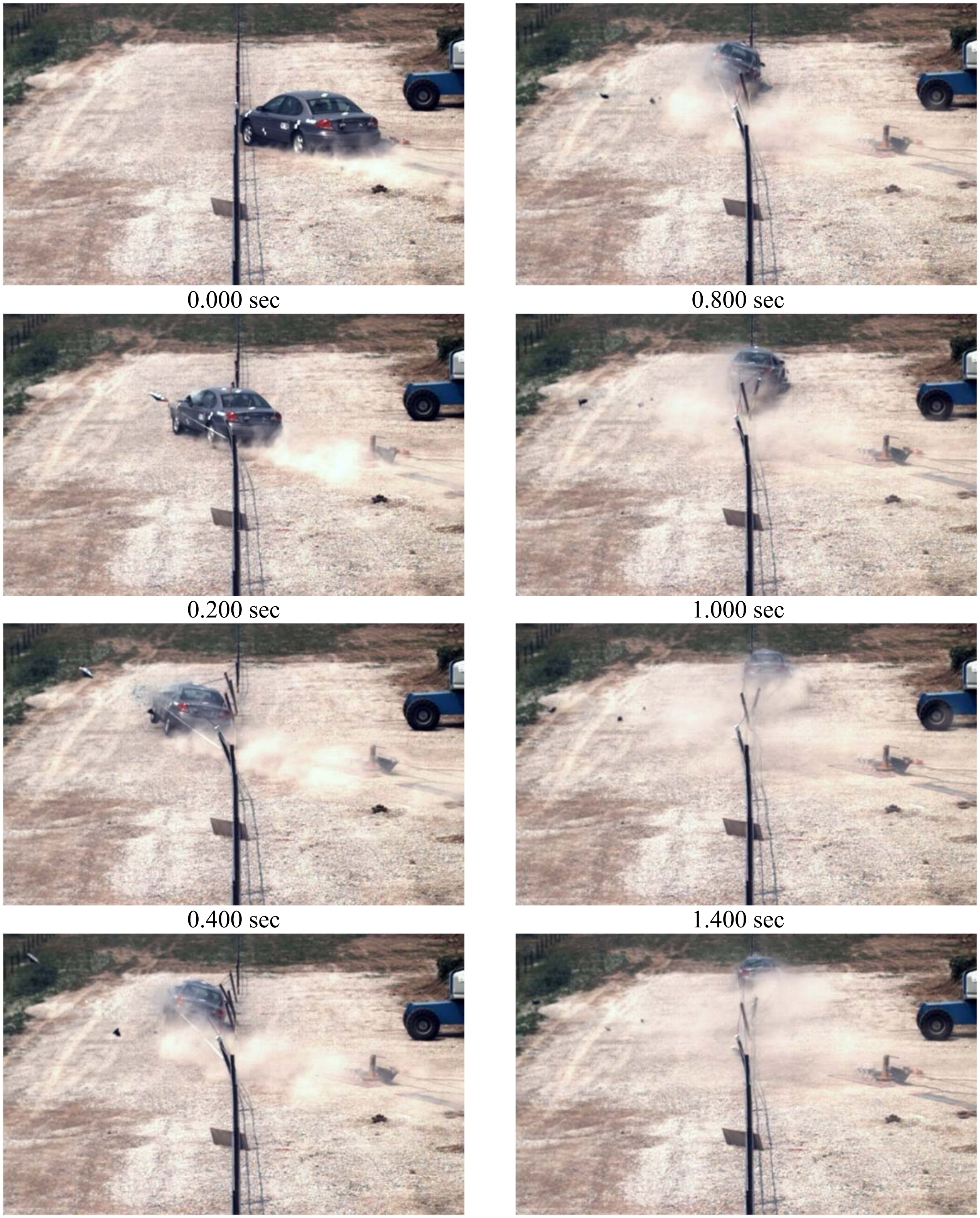
0.288 sec 0.256 sec

0.432 sec 0.384 sec

0.576 sec 0.512 sec

0.720 sec 0.640 sec

Figure 31. Additional Sequential Photographs, Test No. 4CMBLT-1



0.000 sec

0.800 sec

0.200 sec

1.000 sec

0.400 sec

1.400 sec

0.600 sec

1.800 sec

Figure 32. Additional Sequential Photographs, Test No. 4CMBLT-1

0.000 sec

0.308 sec

0.616 sec

0.924 sec

1.232 sec

1.540 sec

1.848 sec

2.156 sec

Figure 33. Additional Sequential Photographs, Test No. 4CMBLT-1

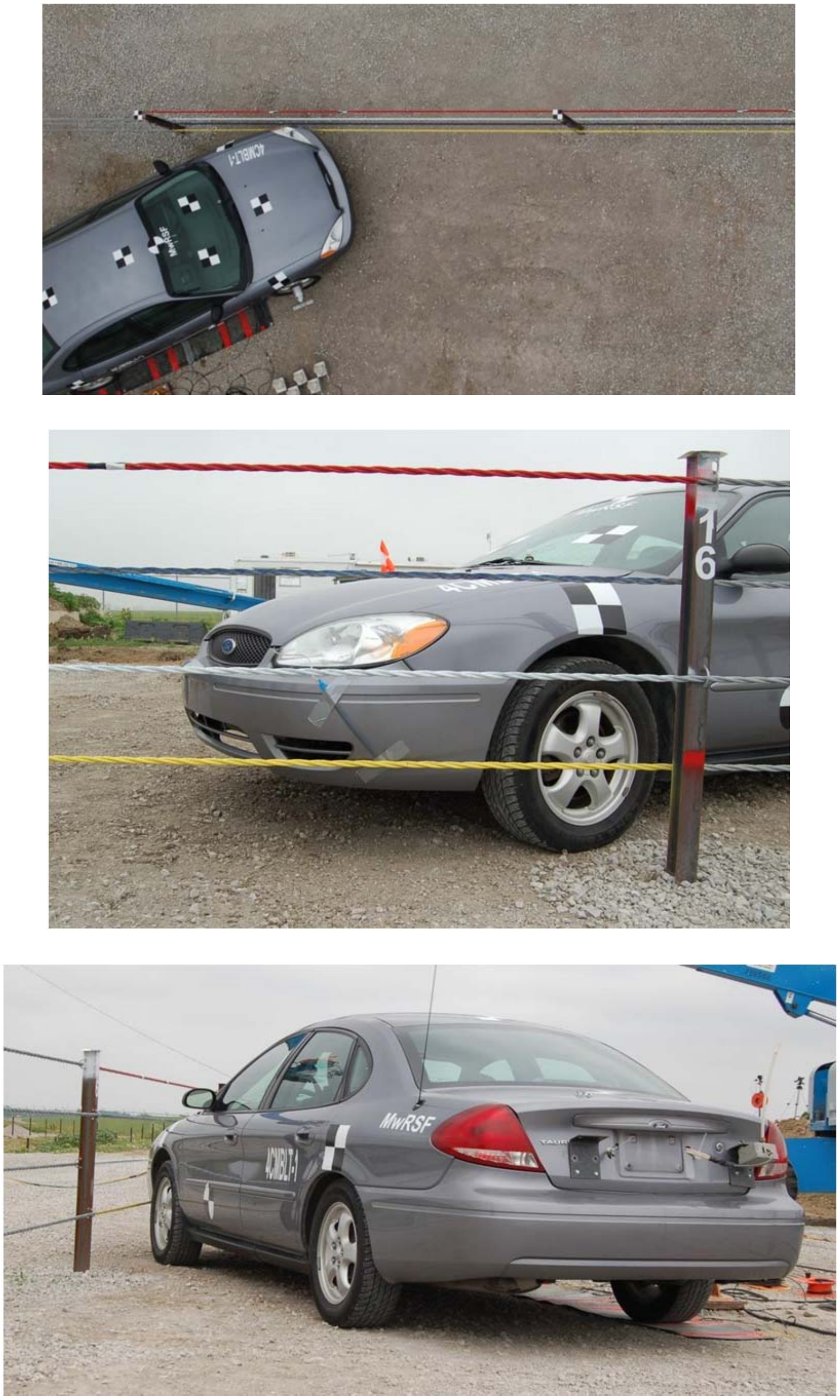


Figure 34. Impact Location, Test No. 4CMBLT-1

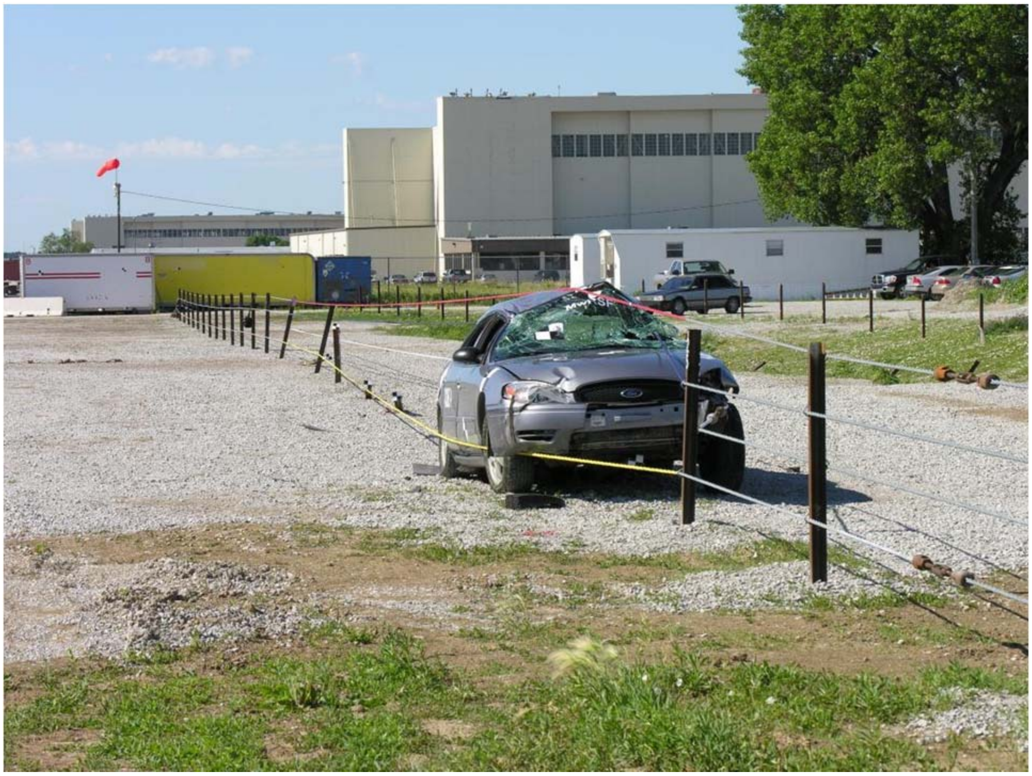


Figure 35. Vehicle Final Position, Test No. 4CMBLT-1

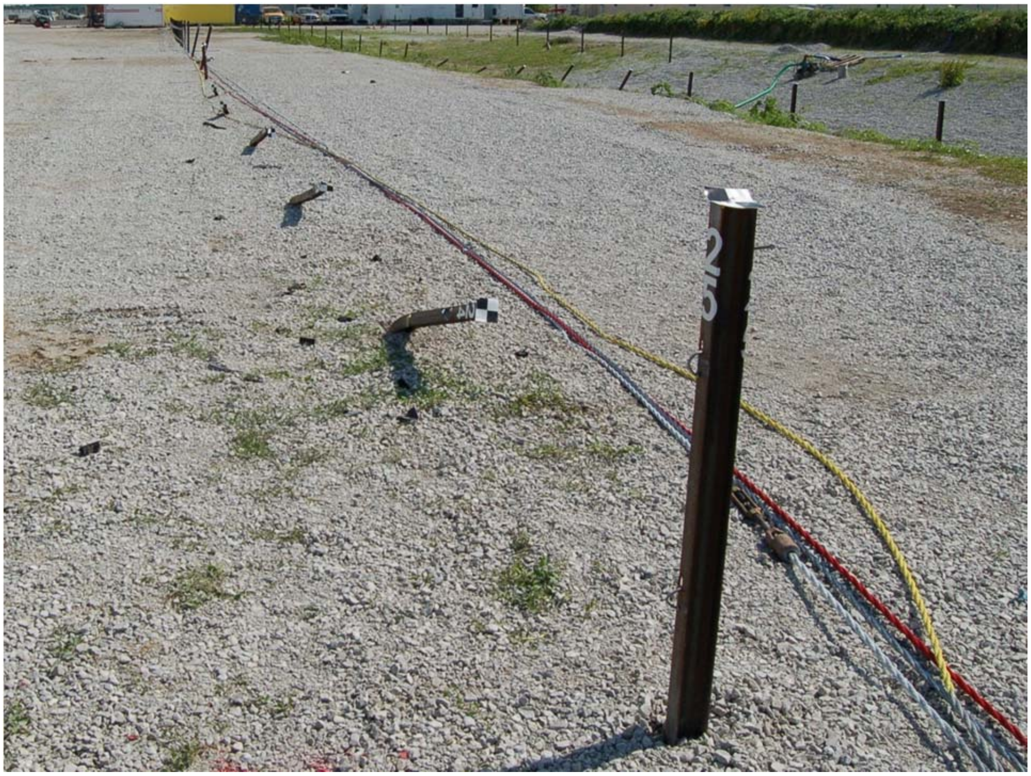


Figure 36. System Damage, Test No. 4CMBLT-1

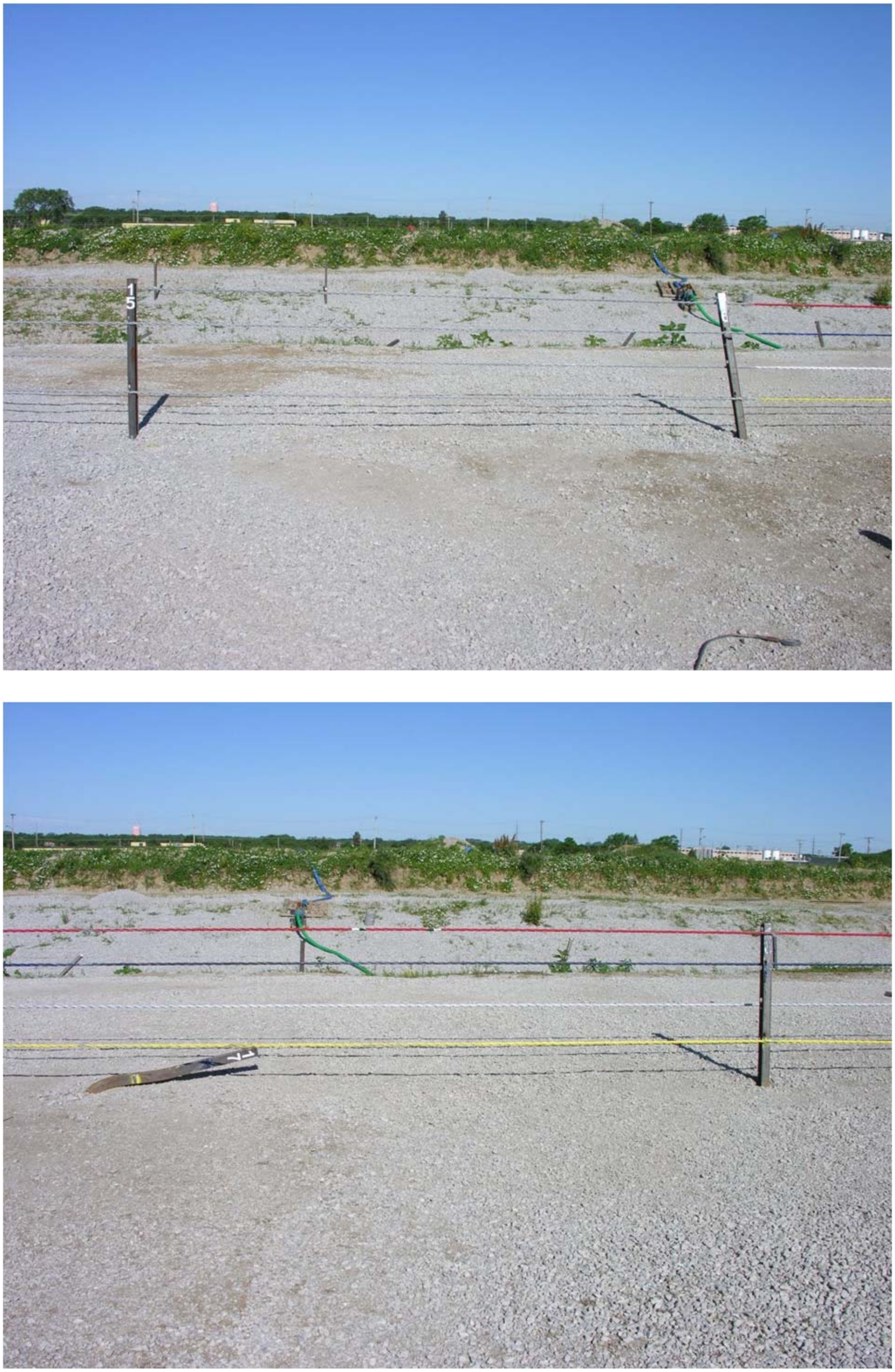


Figure 37. Post Nos. 15 through 18 System Damage, Test No. 4CMBLT-1

Figure 38. Post Nos. 19 through 22 System Damage, Test No. 4CMBLT-1

Figure 39. Post No. 15 Damage, Test No. 4CMBLT-1

Figure 40. Post No. 16 Damage, Test No. 4CMBLT-1

Figure 41. Post No. 17 Damage, Test No. 4CMBLT-1

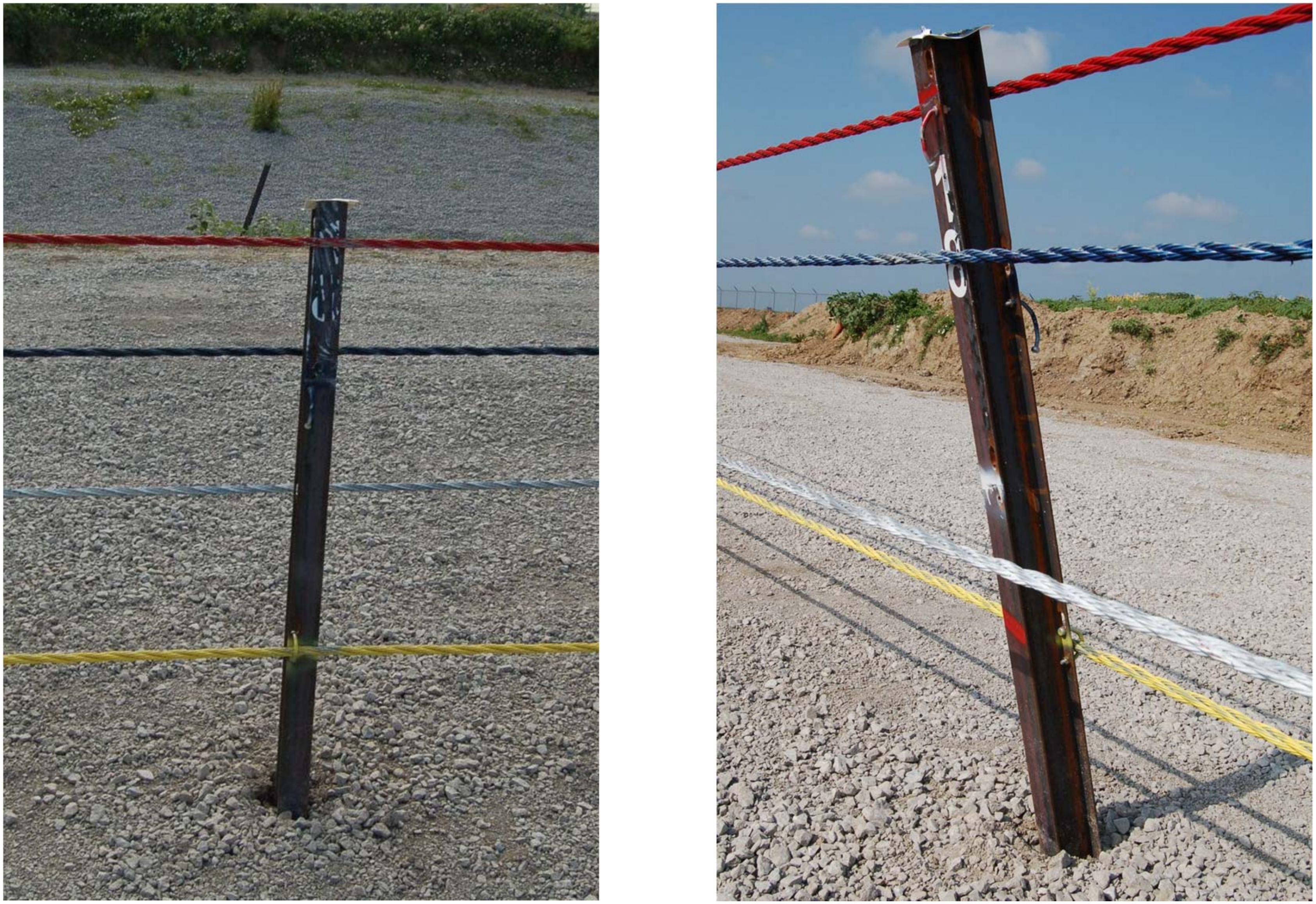


Figure 42. Post No. 18 Damage, Test No. 4CMBLT-1

Figure 43. Post No. 19 Damage, Test No. 4CMBLT-1

Figure 44. Post No. 20 Damage, Test No. 4CMBLT-1

Figure 45. Post No. 21 Damage, Test No. 4CMBLT-1

Figure 46. Post No. 22 Damage, Test No. 4CMBLT-1

Figure 47. Post No. 23 Damage, Test No. 4CMBLT-1

Figure 48. Post No. 24 Damage, Test No. 4CMBLT-1

Figure 49. Post No. 25 Damage, Test No. 4CMBLT-1

Figure 50. Vehicle Damage, Test No. 4CMBLT-1

Figure 51. Vehicle Damage, Test No. 4CMBLT-1

Figure 52. Vehicle Damage, Test No. 4CMBLT-1

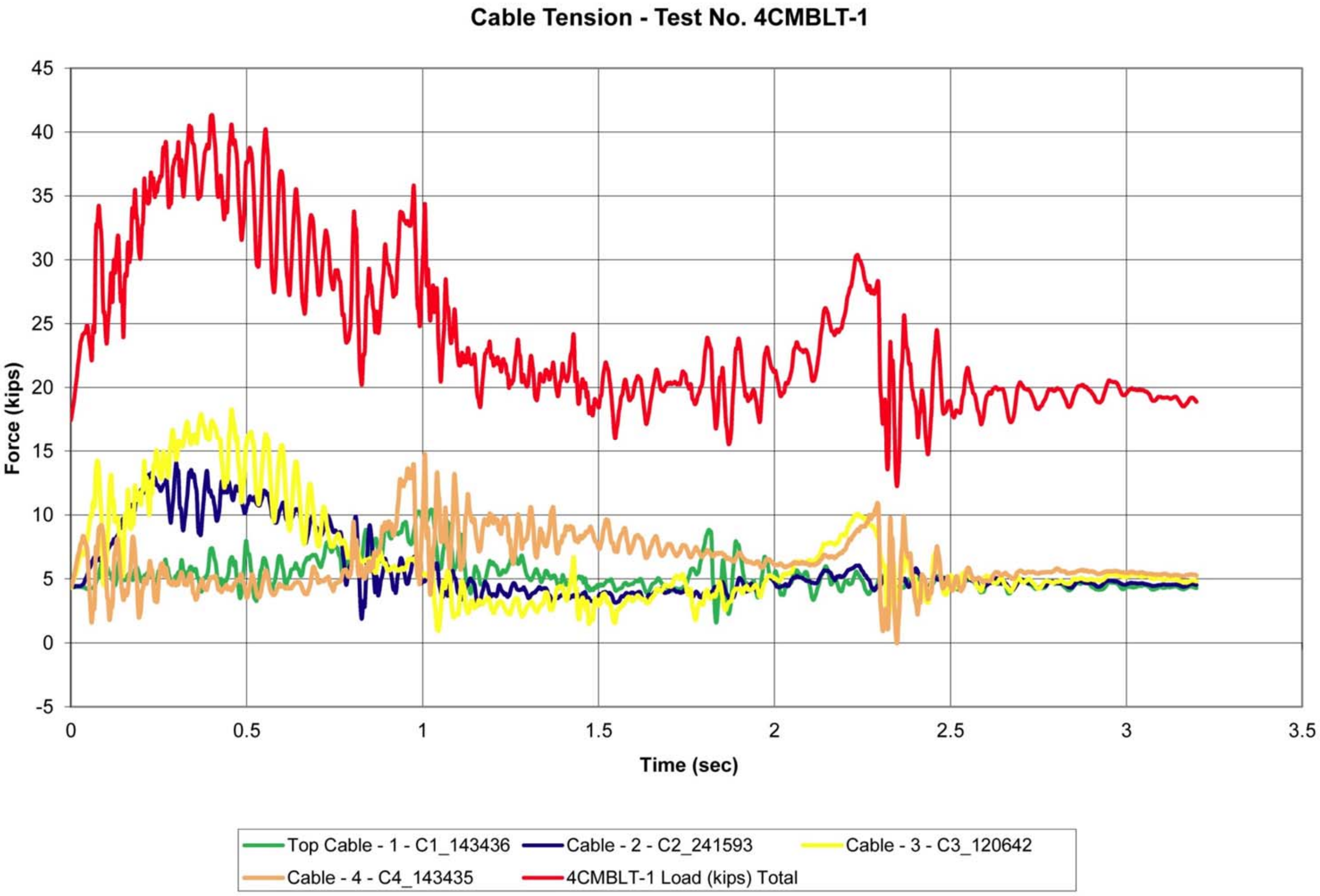


Figure 53. Cable Tension vs. Time, Test No. 4CMBLT-1

6 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this study was to evaluate the high-tension, four-cable median barrier developed by MwRSF. The barrier design had previously shown promise during full-scale crash tests in which it was placed at a variety of locations inside of a 4H:1V V-ditch. However, the performance of the barrier on level terrain was unknown. Further, researchers at MwRSF desired to evaluate the potential for vehicle penetrations through the barrier system prior to modifying the design following the failure of test no. 4CMB-5. Therefore, the high-tension, four-cable median barrier with keyway bolt was installed on level terrain and subjected to a MASH TL-3 crash test utilizing a 1500A passenger vehicle to maximize the risk of vehicle penetration.

During the full-sale crash test, test no. 4CMBLT-1, the 3,470-lb (1,574-kg) passenger vehicle impacted the cable median barrier at a speed of 62.2 mph (100.1 km/h) and at an angle of 25.3 degrees. The system adequately contained the vehicle and brought it to a stop while still in contact with the system. However, extensive occupant compartment deformation was found in the vehicle's roof, windshield, and A-pillar. Further, the cable penetrated and cut through the windshield of the vehicle. Therefore, the safety performance of the high-tension, four-cable median barrier was unacceptable when evaluated according to the TL-3 impact safety standards found in MASH. A summary of the MASH safety performance evaluation results for this test is shown in Table 10.

After reviewing the high-speed video of test no. 4CMBLT-1, it was determined that the excessive damage to the roof, windshield, and A-pillar was caused by cable no. 2. While the vehicle was redirecting, this cable was in contact with the A-pillar and did not slide up and over the top of the vehicle as anticipated. The cable also did not release away from post no. 18 (the second post downstream from initial impact) as early as predicted. These two phenomena resulted in a high lateral load being imparted to the vehicle's A-pillar, which eventually caused it to crush along with the windshield and roof.

This unsuccessful MASH test has indicated a need for alterations to the existing high-tension, four-cable median barrier design before full-scale testing may continue. A few of the possible changes that will be considered during the redesign phase are listed below.

- A reduction in the pre-tension of the cables to reduce the load on the A-pillar.
- Alterations to the heights or vertical spacing of the cables.
- Changing the top two cable attachment locations from the side of the post to the middle of the post.
- A reduction in the strength of the post to encourage post bending and prevent cable hard points (as exhibited by post no. 18).
- A change in the number of cables used in the barrier system.
- Altering the design of the cable-to-post attachment to provide easier vertical cable release.
- Modification of the cable-to-post attachment keyway on the post to provide quicker release of the button head.

Table 10. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. 4CMBLT-1</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D.</td><td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td><td>U</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
</table></td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table></td><td>S</td></tr>
<tr><td colspan="3">MASH Test Designation No.</td><td>Modified 3-10</td></tr>
<tr><td colspan="3">Pass/Fail</td><td>Fail</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

7 REFERENCES

1. Stolle, C.S. and Sicking, D.L., *Cable Median Barrier Failure Analysis and Prevention*, Draft Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-275-12, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, July 23, 2012.

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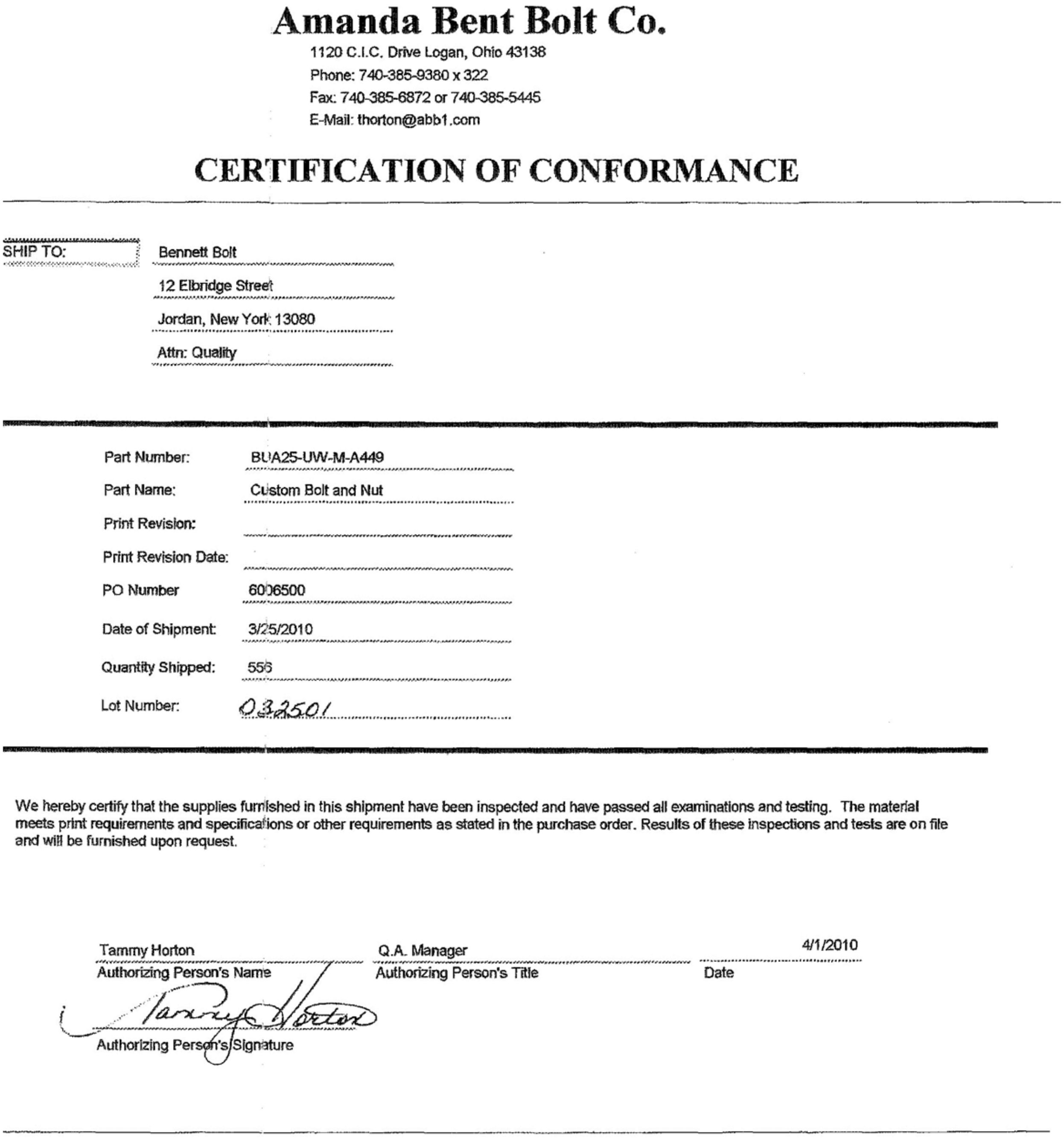
11. Quality Controlled Local Climatological Data, Available: <http://cdo.ncdc.noaa.gov/qclcd/QCLCD>, [2011, August 8].

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

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

8 APPENDICES

Appendix A. Material Specifications



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

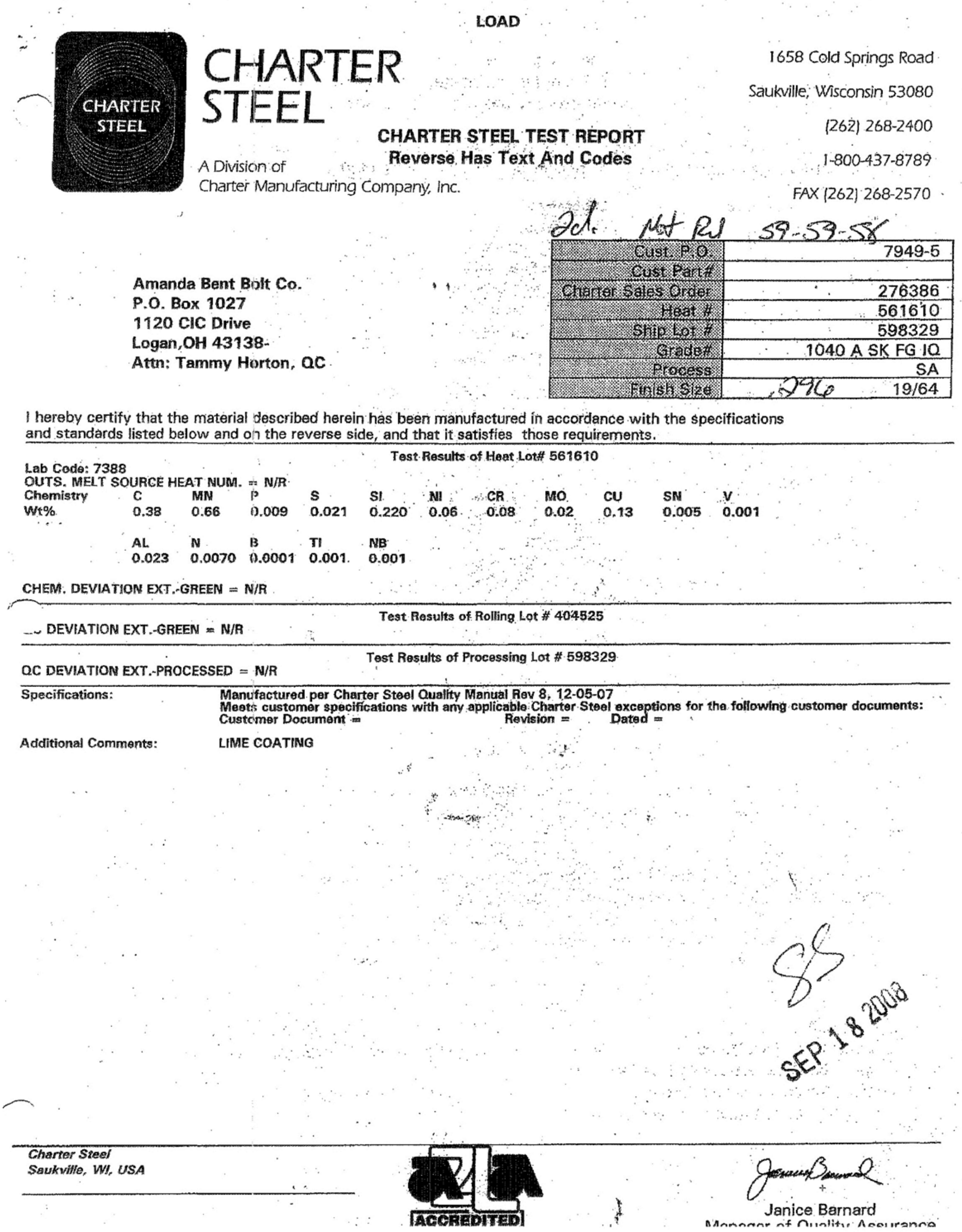
Part Number: BUA25-UW-M-A449
Part Name: Custom Bolt and Nut
Print Revision:
Print Revision Date:
PO Number 6006500
Date of Shipment: 3/25/2010
Quantity Shipped: 556
Lot Number: 032501

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

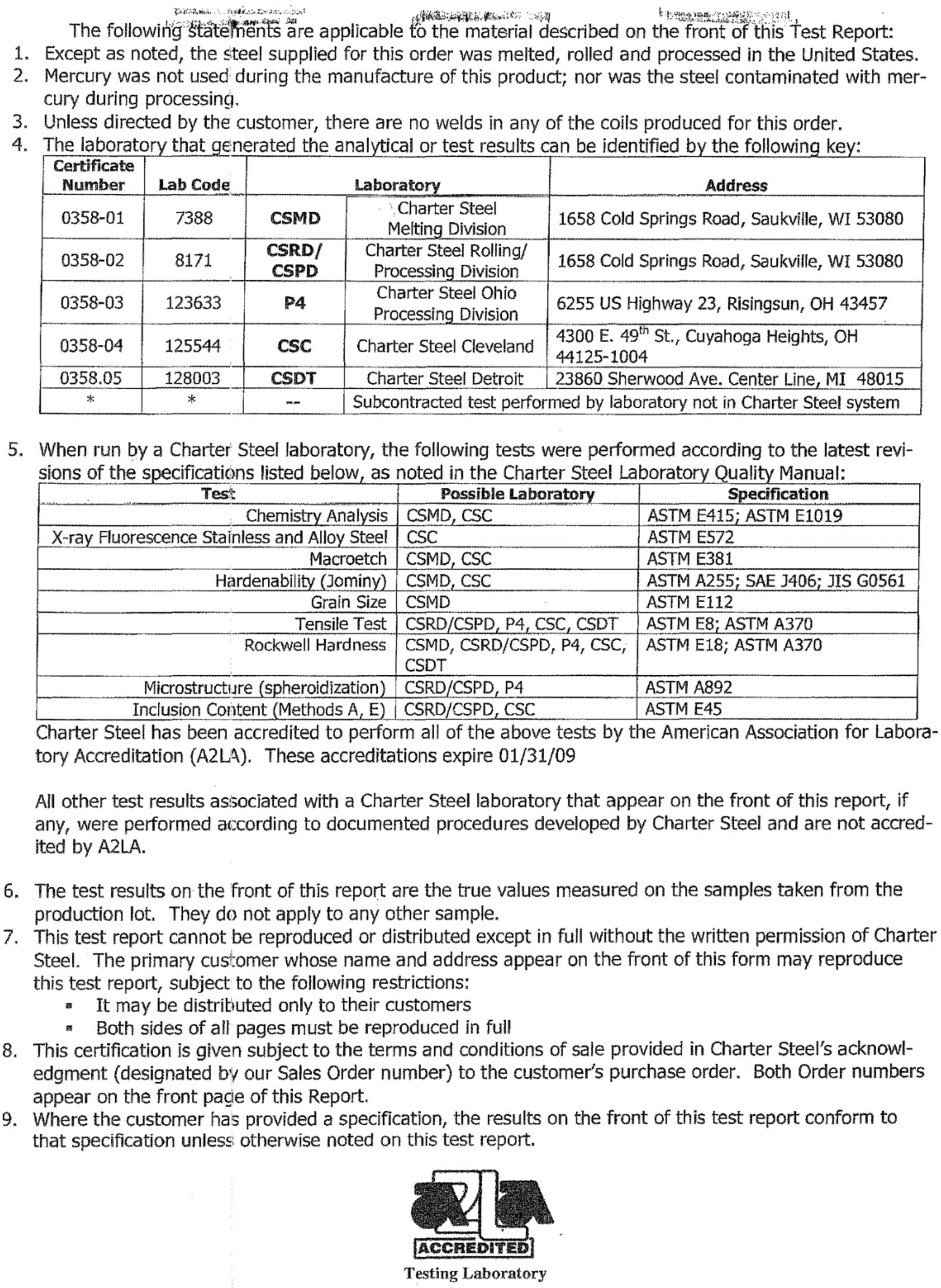
SEP 18 2008

Charter Steel
Saukville, WI, USA

ACCREDITED

Janice Barnard
Janice Barnard
Manager of Quality Assurance

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

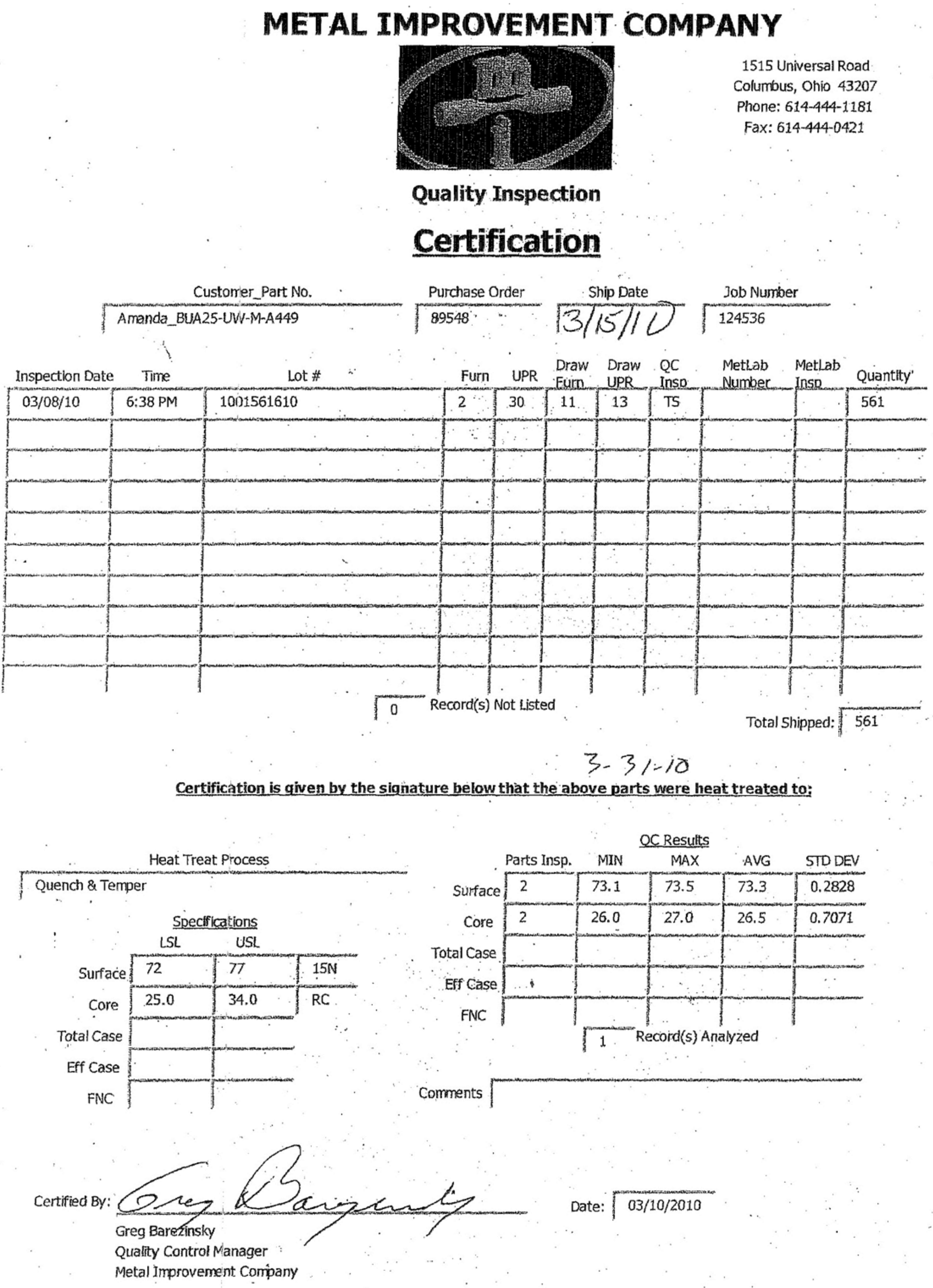
Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/09

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.

A2LA
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					

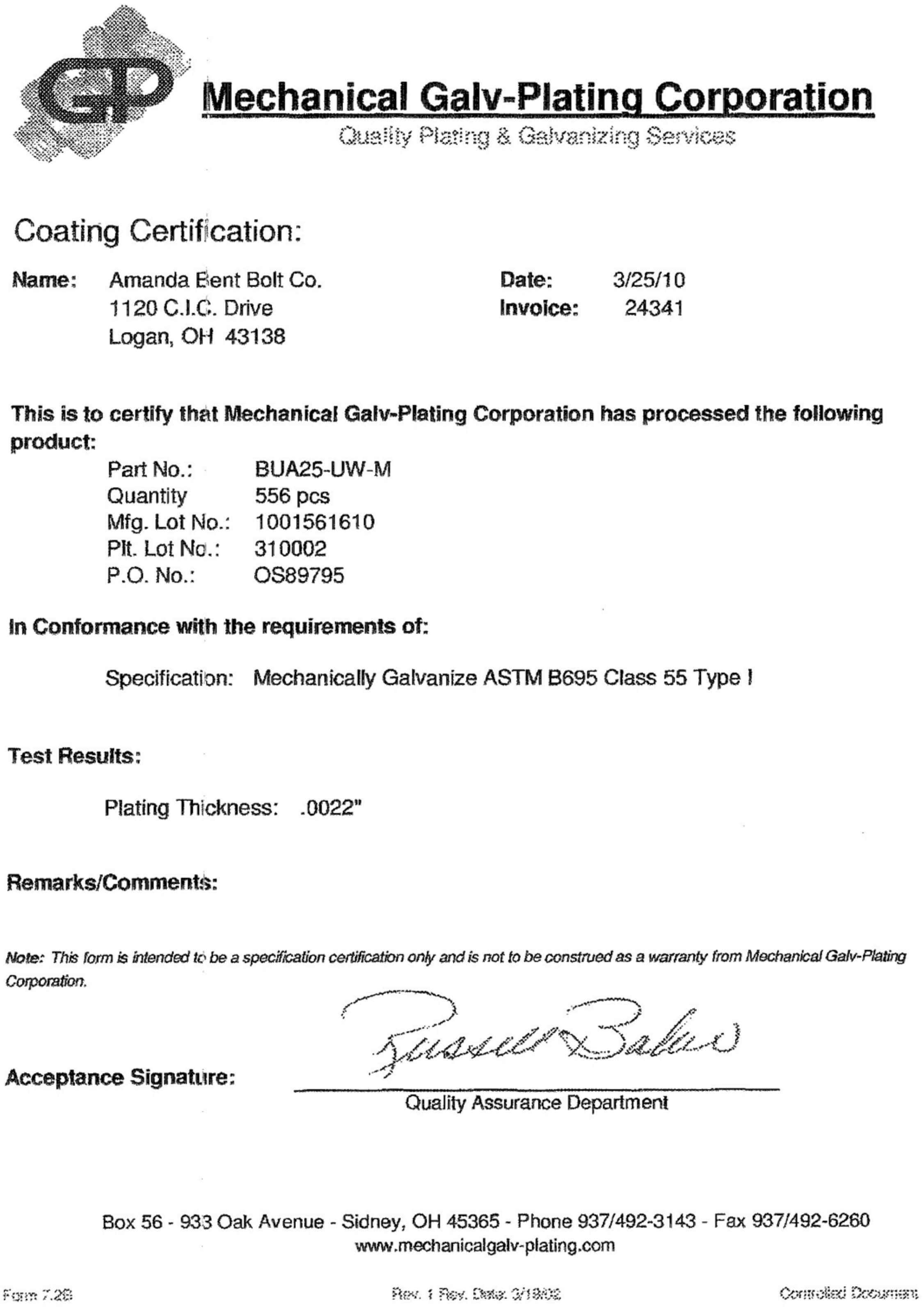
1 Record(s) Analyzed

Comments:

Certified By:
Greg Barezinsky
Quality Control Manager
Metal Improvement Company

Date: 03/10/2010

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:

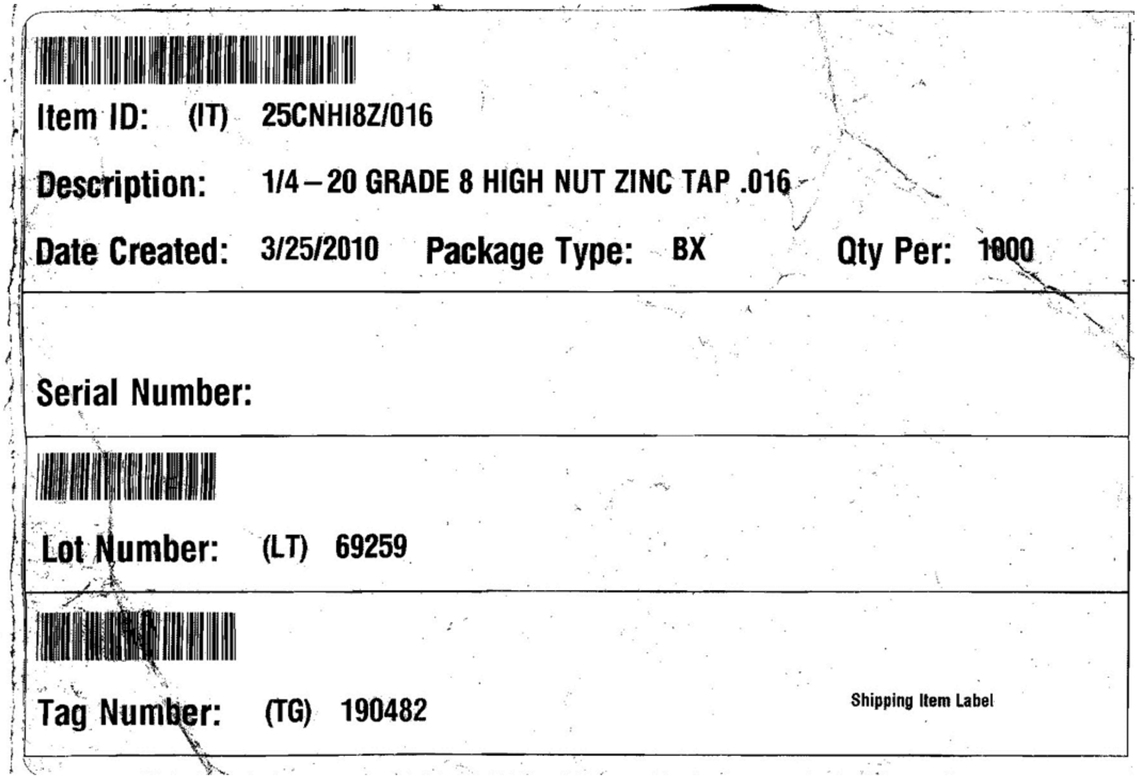
Note: This form is intended to be a specification certification only and is not to be construed as a warranty from Mechanical Galv-Plating Corporation.

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: 3/18/02 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

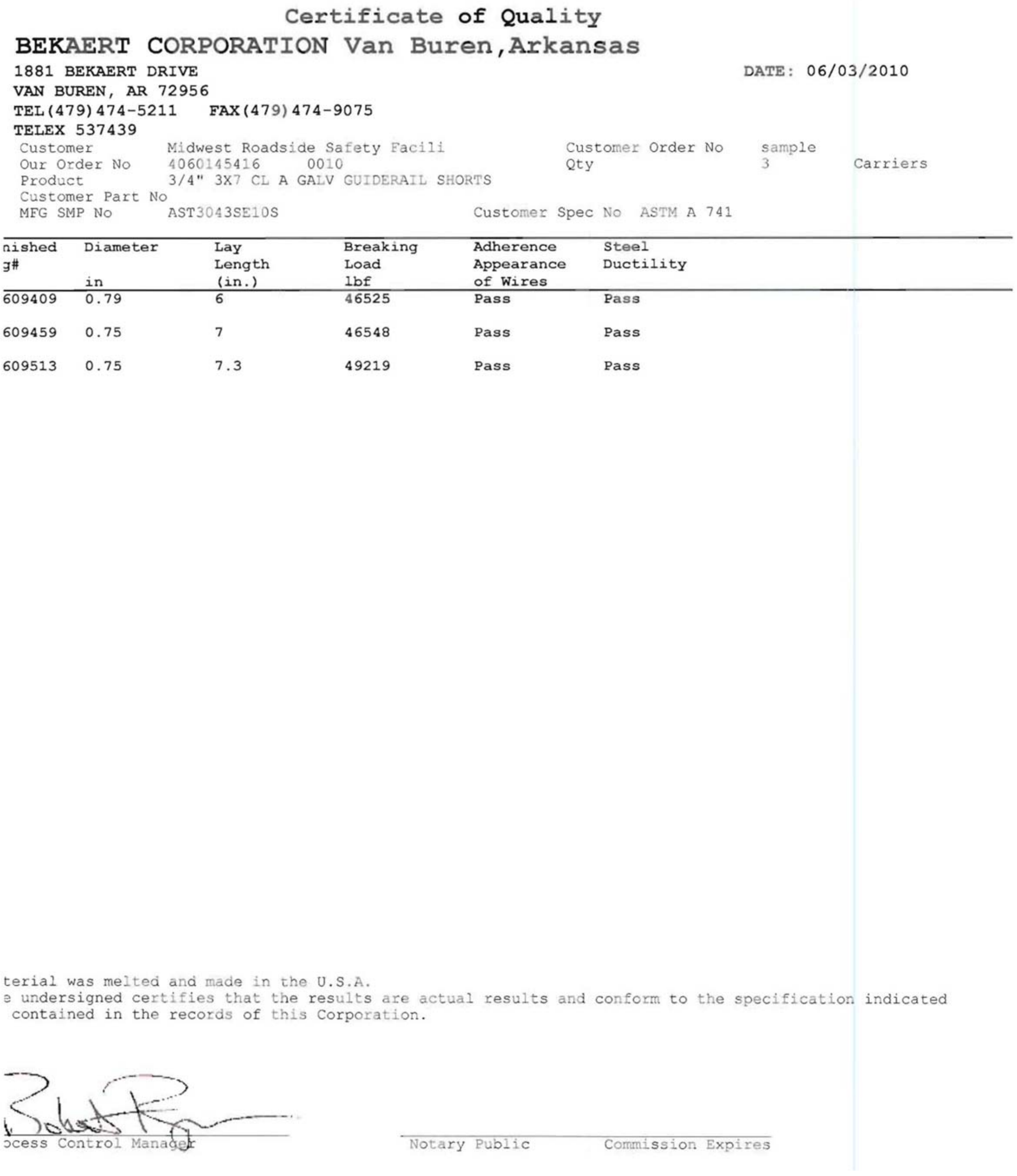
Serial Number:

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

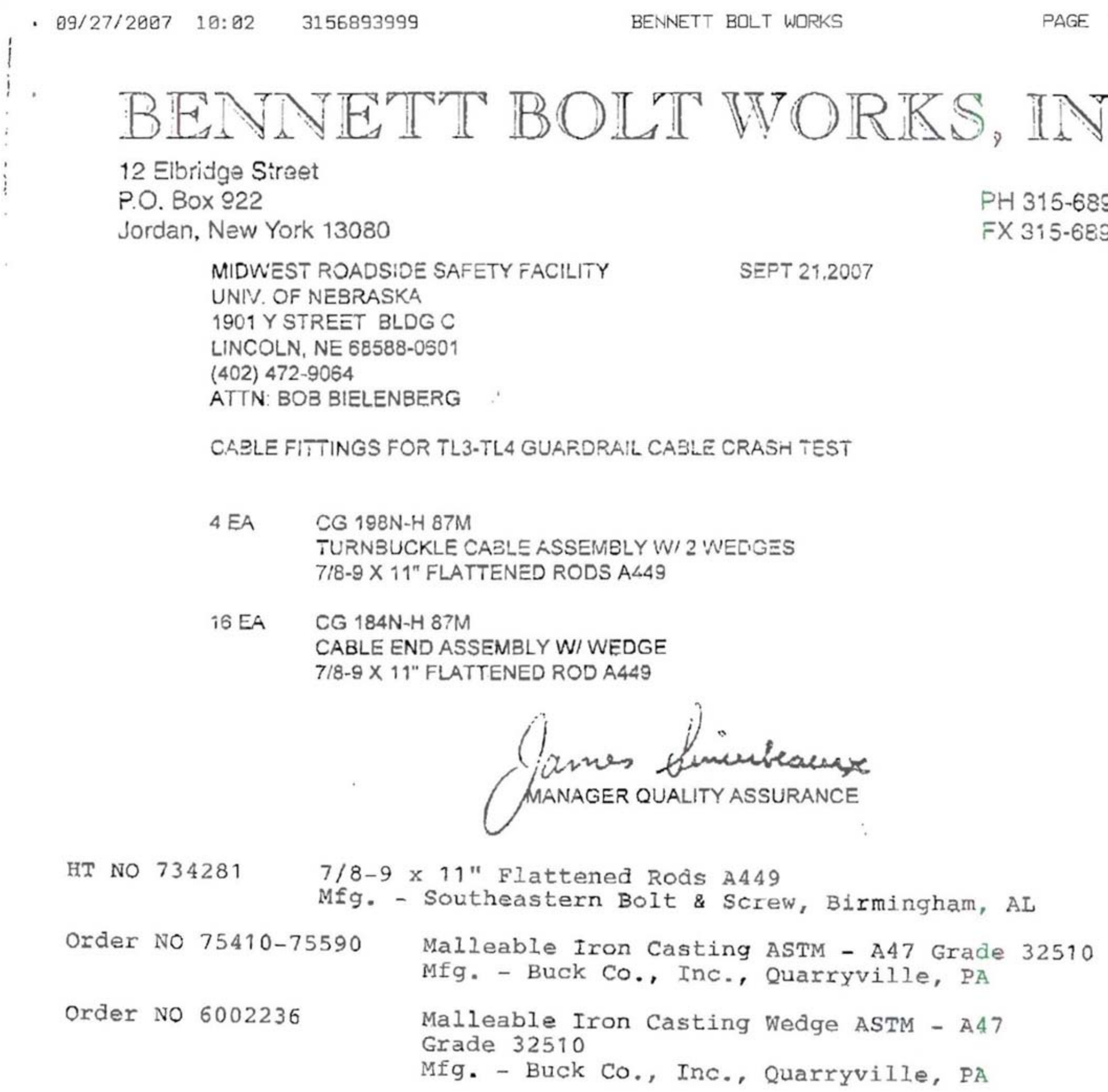
nished g#	Diameter in	Lay Length (in.)	Breaking Load lbf	Adherence Appearance of Wires	Steel Ductility
609409	0.79	6	46525	Pass	Pass
609459	0.75	7	46548	Pass	Pass
609513	0.75	7.3	49219	Pass	Pass

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 SEPT 21,2007
UNIV. OF NEBRASKA
1901 Y STREET BLDG C
LINCOLN, NE 68588-0601
(402) 472-9064
ATTN: BOB BIELENBERG

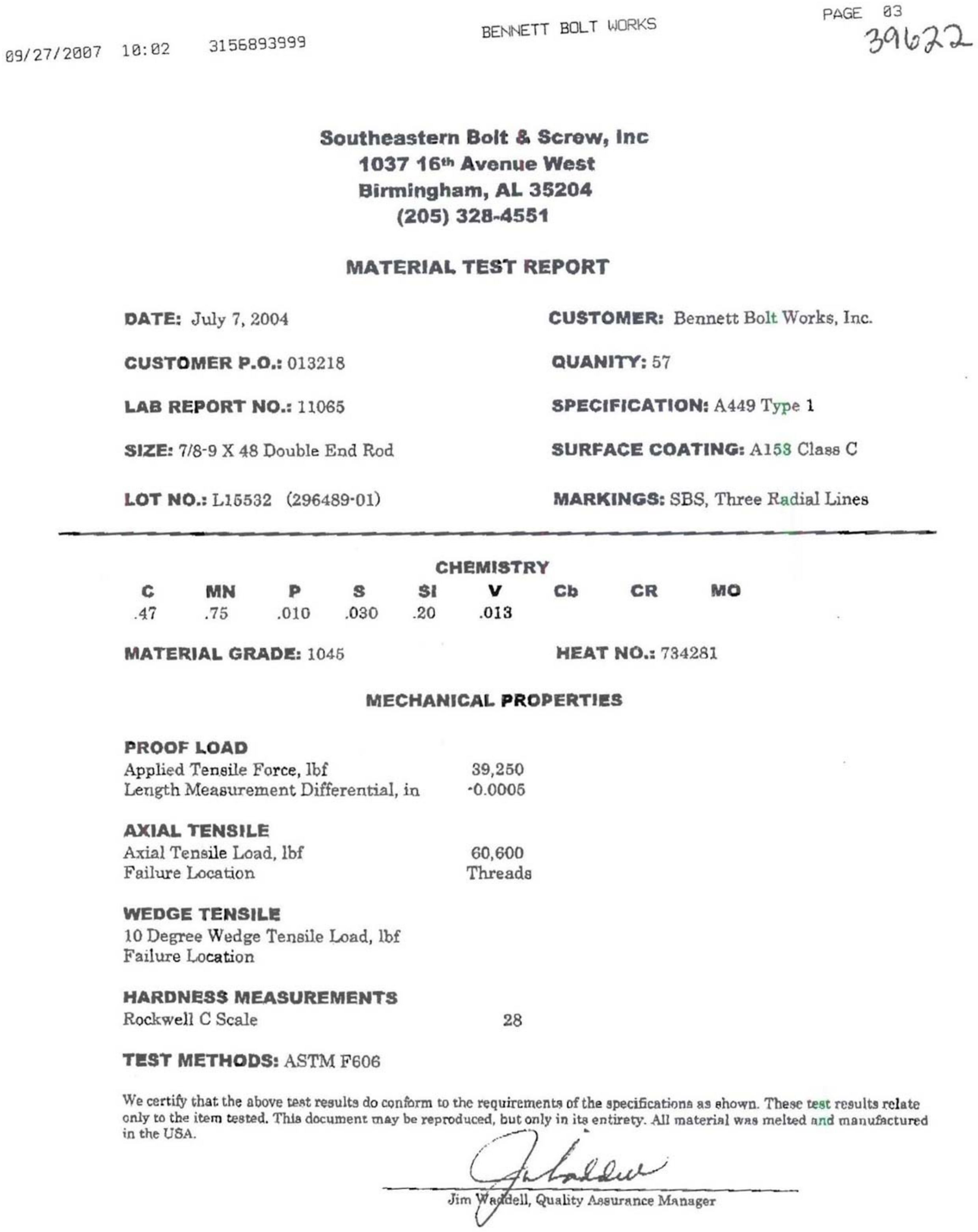
CABLE FITTINGS FOR TL3-TL4 GUARDRAIL CABLE CRASH TEST

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

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

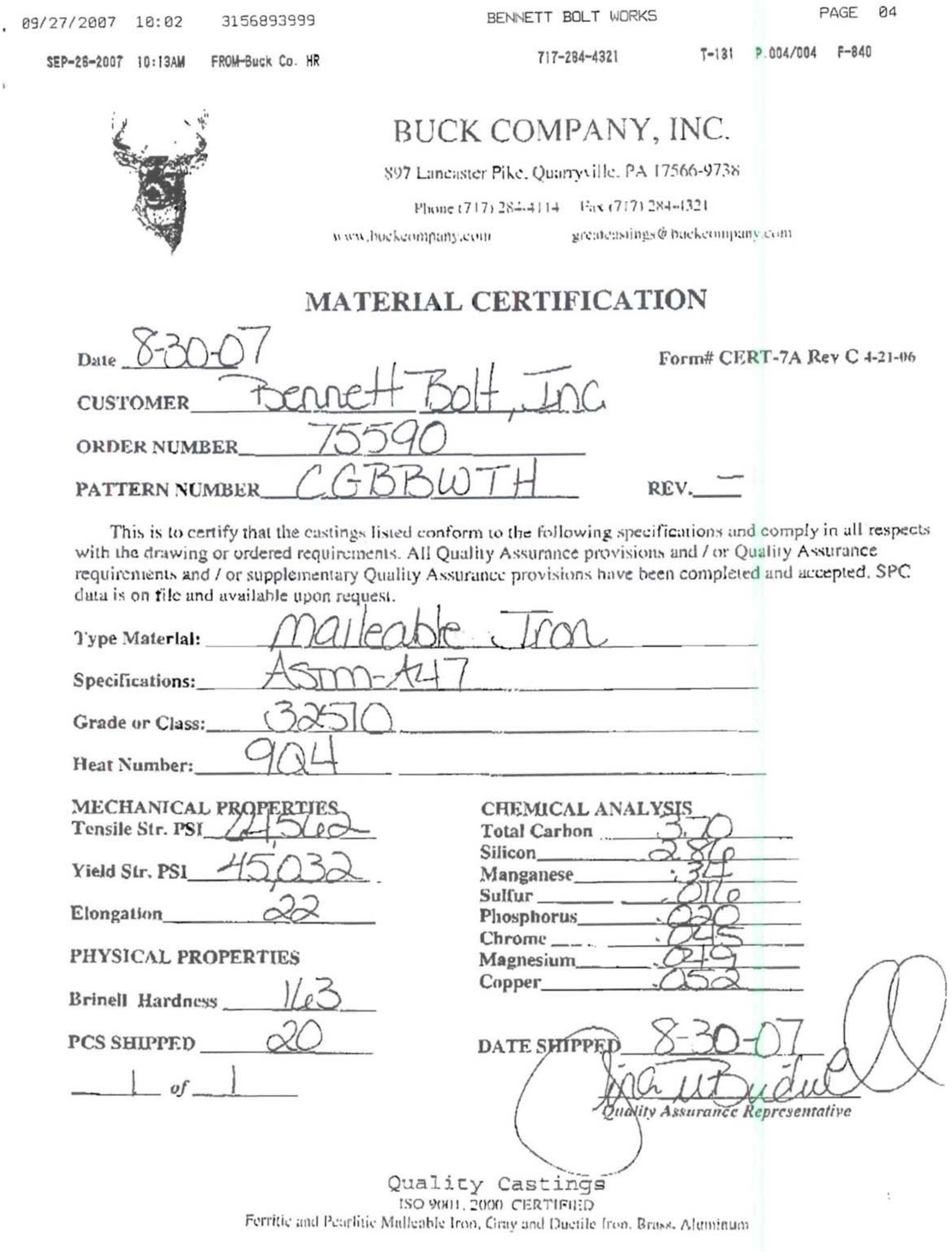
Rockwell C Scale	28

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		CHEMICAL ANALYSIS	
Tensile Str. PSI	64,562	Total Carbon	3.70
Yield Str. PSI	45,032	Silicon	2.86
Elongation	22	Manganese	.34
		Sulfur	.016
		Phosphorus	.020
		Chrome	.045
		Magnesium	.049
		Copper	.052

PHYSICAL PROPERTIES

Brinell Hardness 163

PCS SHIPPED 20

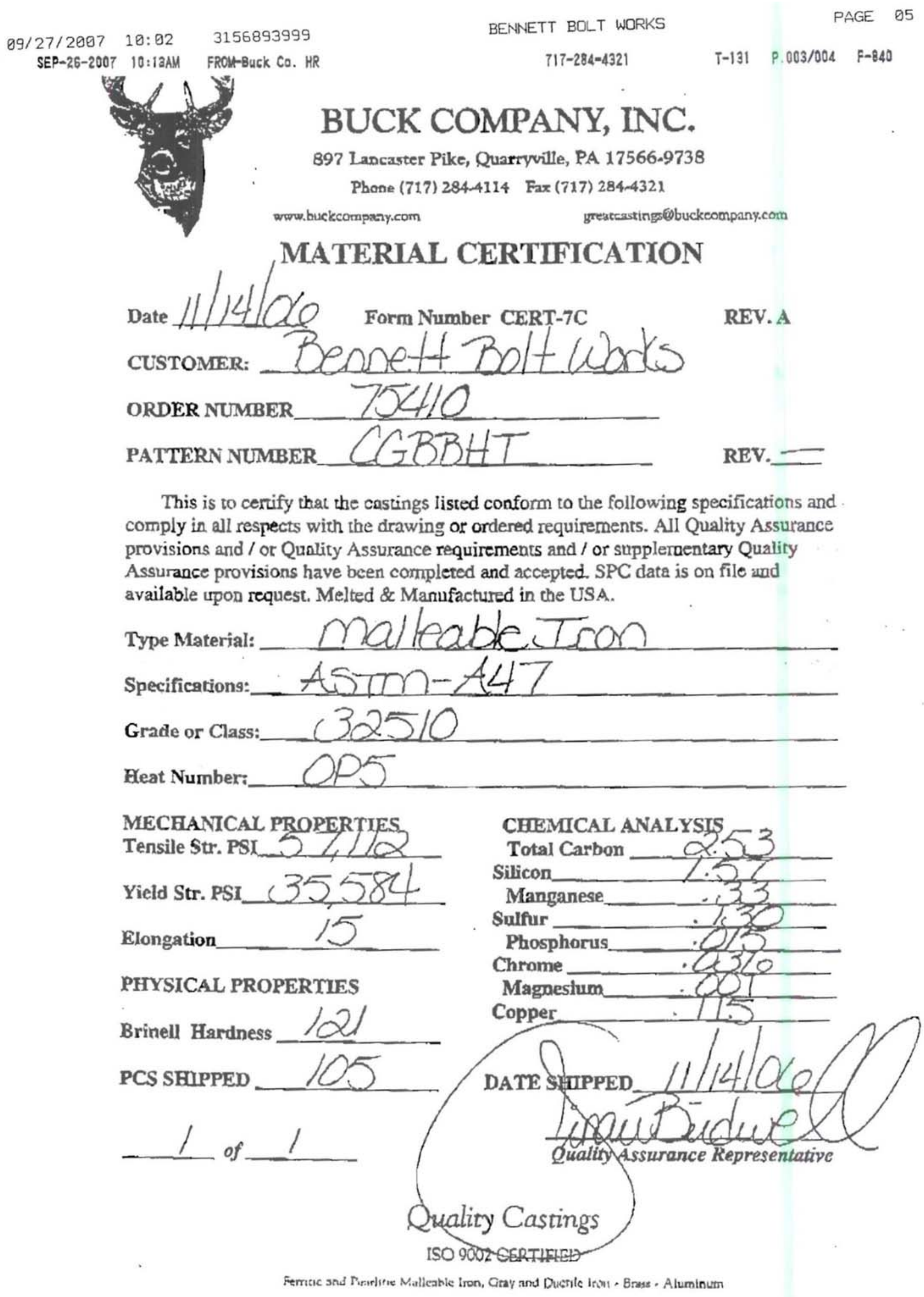
1 of 1

DATE SHIPPED 8-30-07

Quality Assurance Representative

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

Figure A-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

1 of 1

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

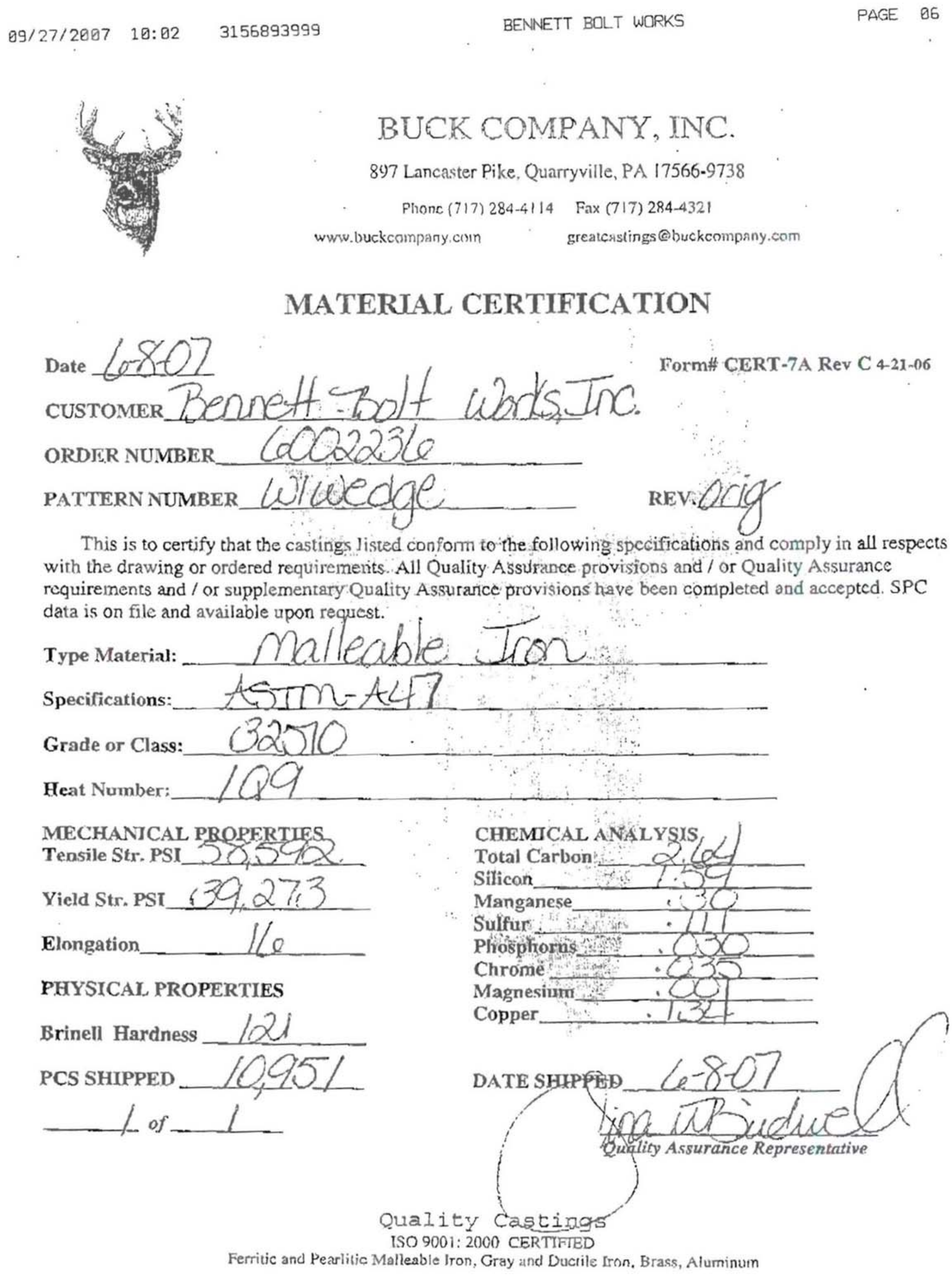
Quality Assurance Representative

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 W1wedge **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

Tensile Str. PSI 58,592

Yield Str. PSI 39,273

Elongation 16

PHYSICAL PROPERTIES

Brinell Hardness 121

PCS SHIPPED 10,951

1 of 1

CHEMICAL ANALYSIS

Total Carbon 2.64

Silicon 1.59

Manganese .30

Sulfur .111

Phosphorus .030

Chrome .035

Magnesium .001

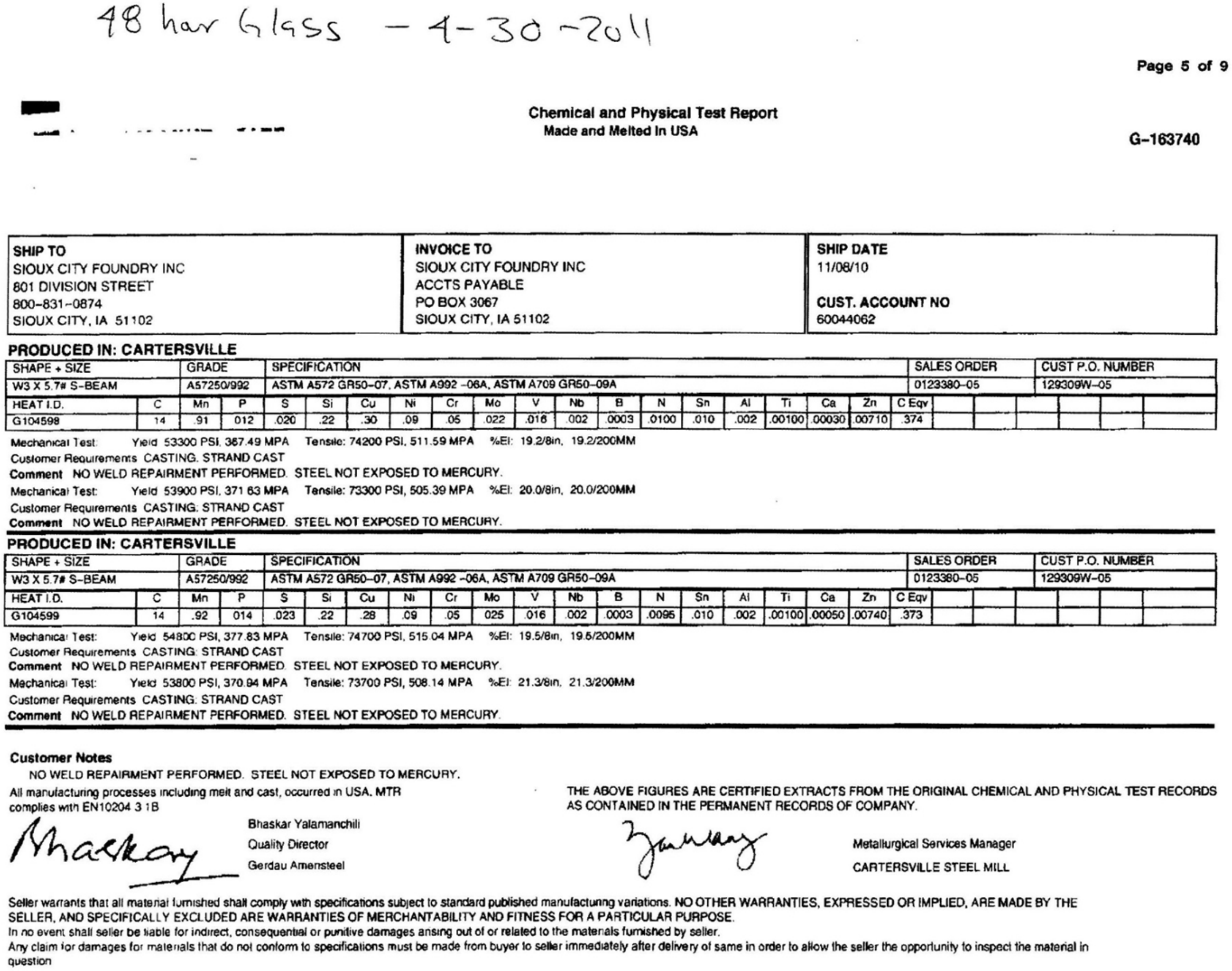
Copper .134

DATE SHIPPED 6-8-07

Lisa M Bidwell
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



48 har Glass - 4-30-2011

Page 5 of 9

[redacted]

Chemical and Physical Test Report
Made and Melted In USA

G-163740

SHIP TO SIOUX CITY FOUNDRY INC 801 DIVISION STREET 800-831-0874 SIOUX CITY, IA 51102	**INVOICE TO** SIOUX CITY FOUNDRY INC ACCTS PAYABLE PO BOX 3067 SIOUX CITY, IA 51102	**SHIP DATE** 11/08/10 **CUST. ACCOUNT NO** 60044062

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	0123380-05	129309W-05

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv						
G104598	14	.91	012	.020	.22	.30	.09	.05	.022	.016	.002	.0003	.0100	.010	.002	.00100	.00030	.00710	.374						

Mechanical Test: Yield 53300 PSI, 367.49 MPA Tensile: 74200 PSI, 511.59 MPA %El: 19.2/8in, 19.2/200MM
Customer Requirements CASTING, STRAND CAST
Comment NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
Mechanical Test: Yield 53900 PSI, 371 63 MPA Tensile: 73300 PSI, 505.39 MPA %El: 20.0/8in, 20.0/200MM
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	0123380-05	129309W-05

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv						
G104599	14	.92	014	.023	.22	.28	.09	.05	025	.016	.002	.0003	.0095	.010	.002	.00100	.00050	.00740	.373						

Mechanical Test: Yield 54800 PSI, 377.83 MPA Tensile: 74700 PSI, 515.04 MPA %El: 19.5/8in, 19.5/200MM
Customer Requirements CASTING: STRAND CAST
Comment NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
Mechanical Test: Yield 53800 PSI, 370.94 MPA Tensile: 73700 PSI, 508.14 MPA %El: 21.3/8in, 21.3/200MM
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

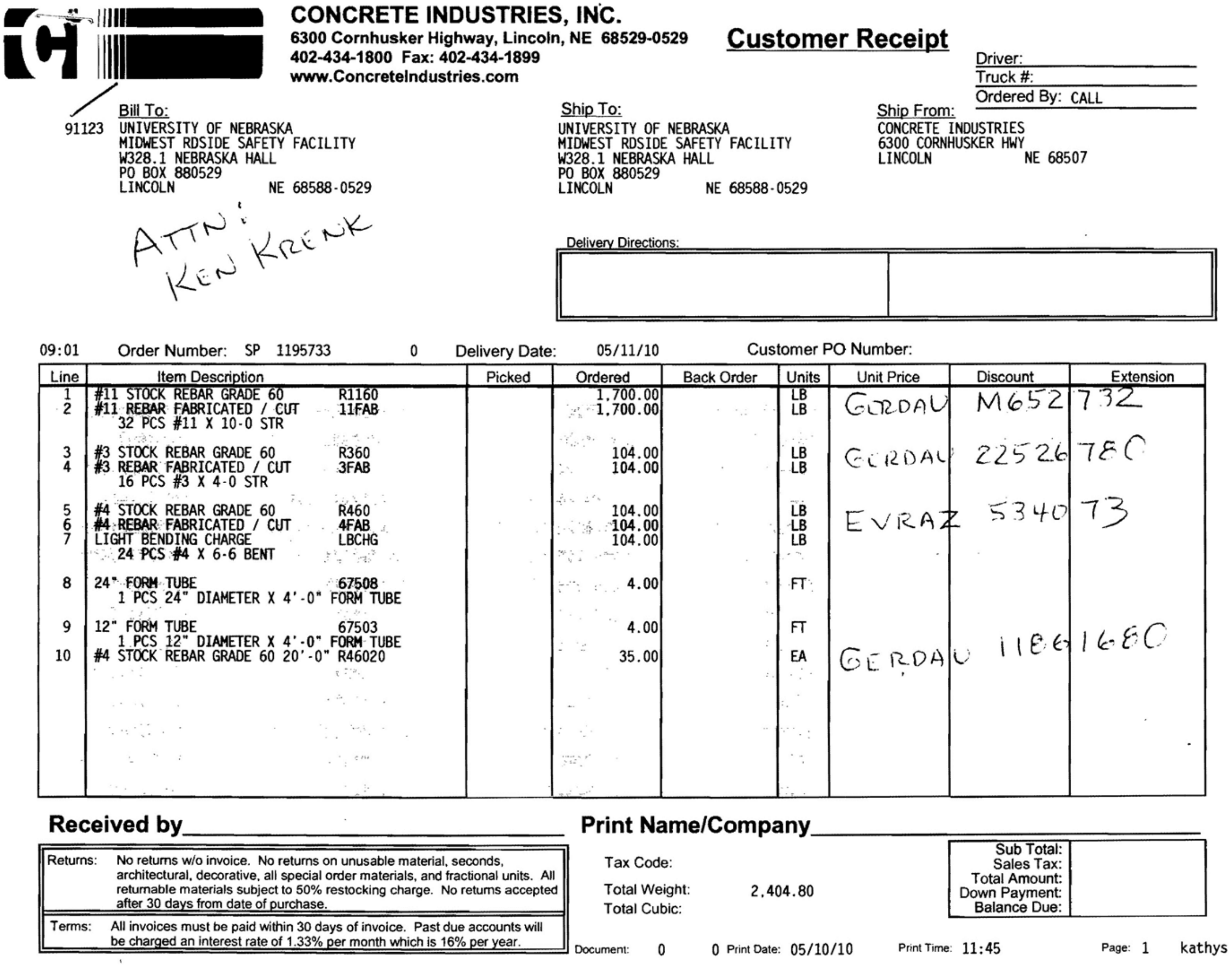
Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

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-13. S3x5.7 Posts



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

Customer Receipt

Driver:
Truck #:
Ordered By: CALL

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

ATTN: KEN KRENK

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

Ship From:
CONCRETE INDUSTRIES
6300 CORNHUSKER HWY
LINCOLN NE 68507

Delivery Directions:

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

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

Received by__________ **Print Name/Company**__________

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

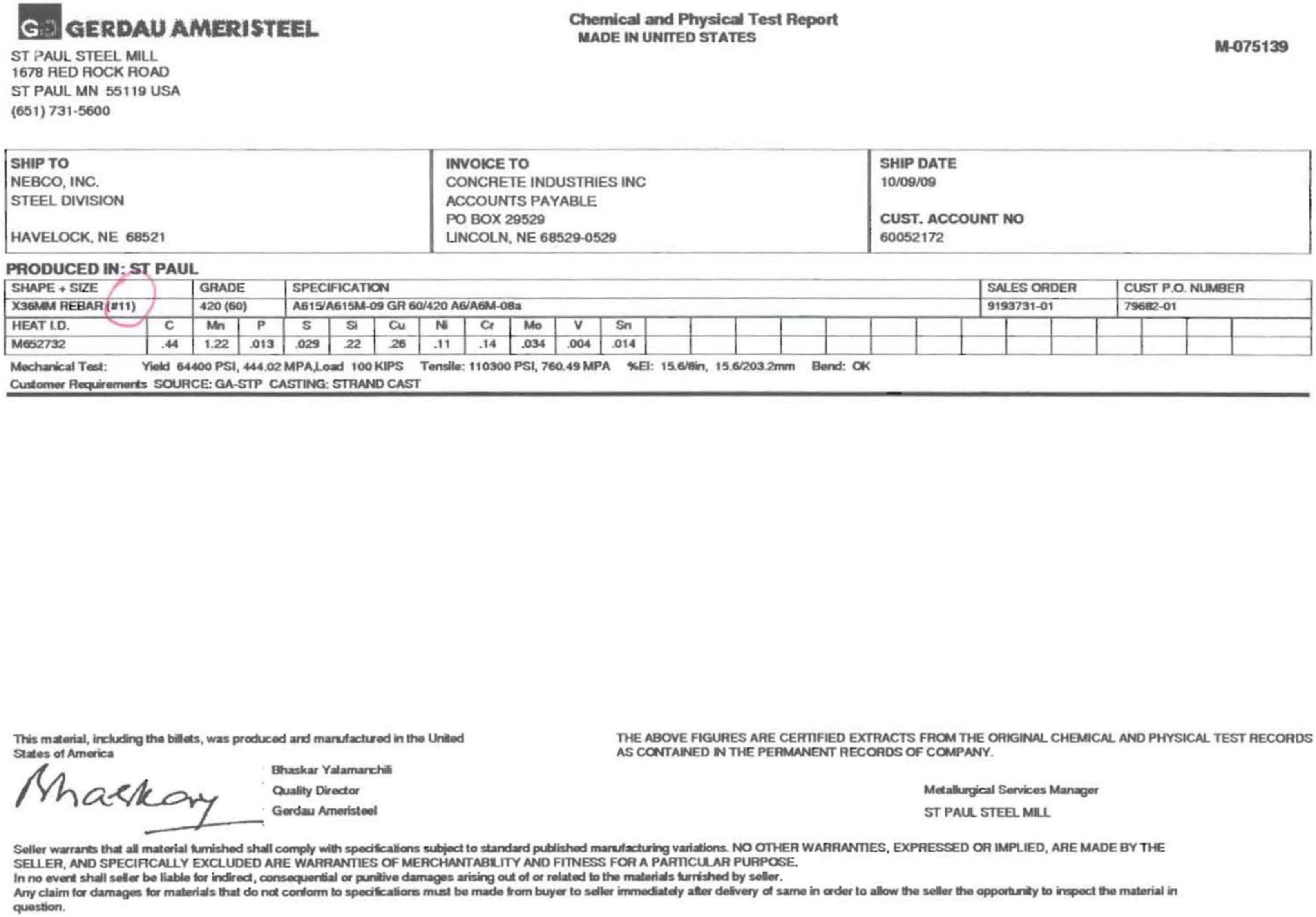
Terms: All invoices must be paid within 30 days of invoice. Past due accounts will be charged an interest rate of 1.33% per month which is 16% per year.

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

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

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

Figure A-14. 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	**INVOICE TO**	**SHIP DATE**
NEBCO, INC. STEEL DIVISION HAVELOCK, NE 68521	CONCRETE INDUSTRIES INC ACCOUNTS PAYABLE PO BOX 29529 LINCOLN, NE 68529-0529	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

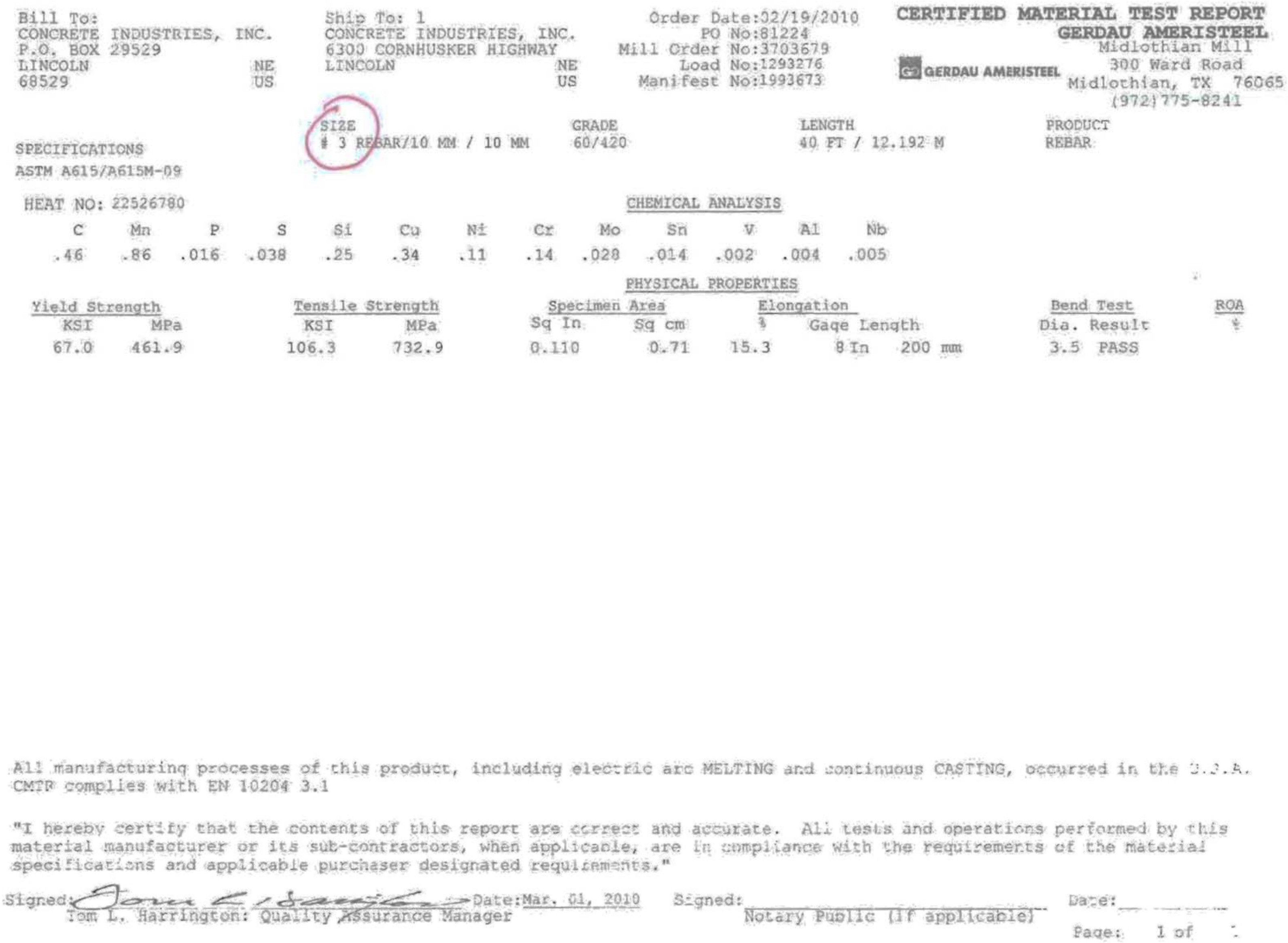
THE ABOVE FIGURES ARE CERTIFIED EXTRACTS FROM THE ORIGINAL CHEMICAL AND PHYSICAL TEST RECORDS AS CONTAINED IN THE PERMANENT RECORDS OF COMPANY.

Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

Metallurgical Services Manager
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-15. 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
ASTM A615/A615M-09

SIZE	GRADE	LENGTH	PRODUCT
# 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."

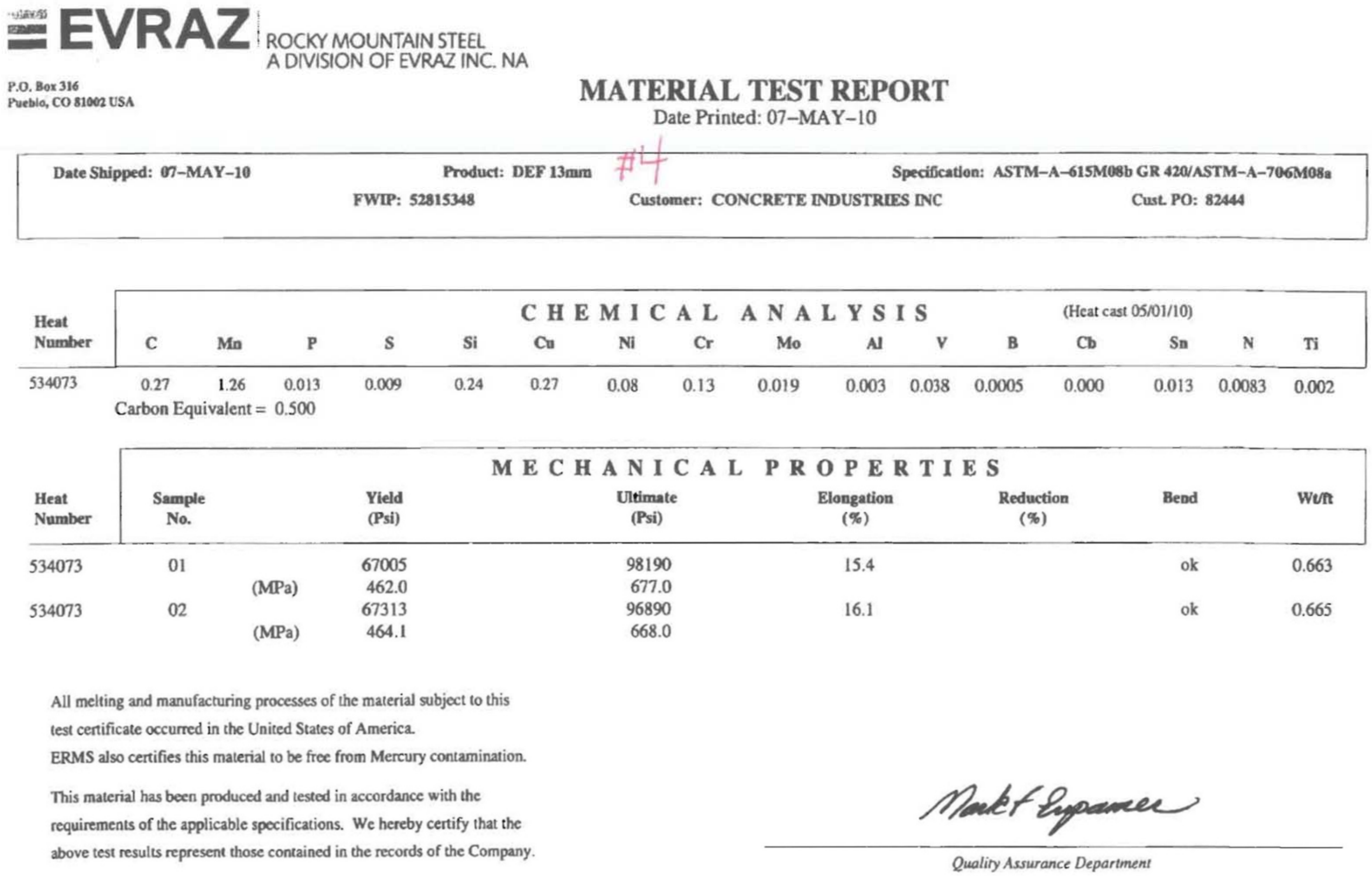
Signed: Date:Mar. 01, 2010
Tom L. Harrington: Quality Assurance Manager

Signed:______________________
Notary Public (If applicable)

Date:__________

Page: 1 of

Figure A-16. 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

CHEMICAL ANALYSIS (Heat cast 05/01/10)

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

Carbon Equivalent = 0.500

MECHANICAL PROPERTIES

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

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.

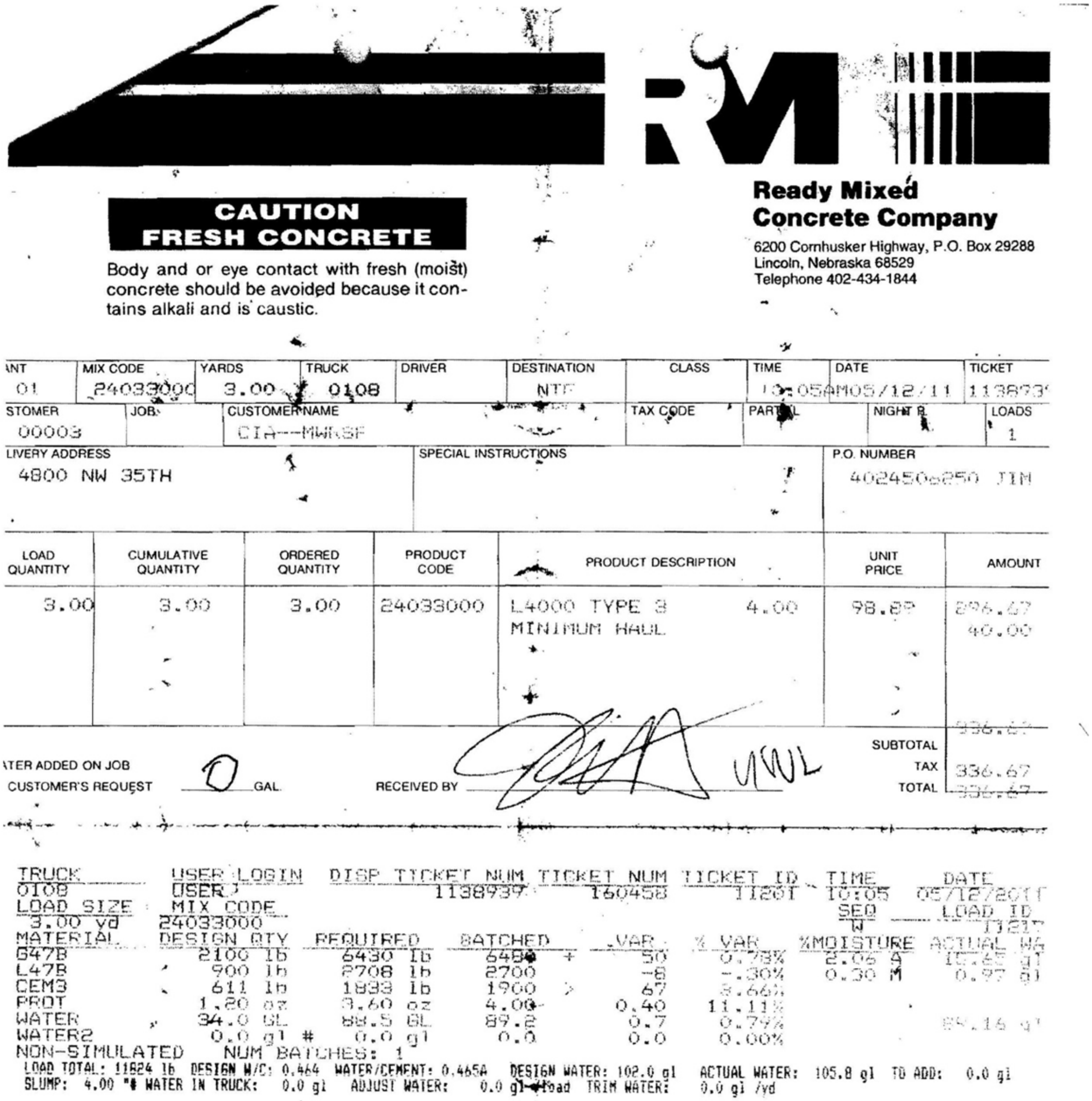
ERMS also certifies this material to be free from Mercury contamination.

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

Mark Espanoza

Quality Assurance Department

Figure A-17. Foundation Rebar



CAUTION
FRESH CONCRETE

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

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

NT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
01	24033000	3.00	0108		NTF		10:05AM	05/12/11	11389

STOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003		CIA--MWRSF				1

LIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4800 NW 35TH		402450e250 JIM

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION		UNIT PRICE	AMOUNT
3.00	3.00	3.00	24033000	L4000 TYPE 3	4.00	98.89	296.67
				MINIMUM HAUL			40.00

SUBTOTAL 336.67
TAX 336.67
TOTAL 336.67

TER ADDED ON JOB CUSTOMER'S REQUEST 0 GAL.

RECEIVED BY

```
TRUCK          USER LOGIN   DISP TICKET NUM  TICKET NUM  TICKET ID  TIME      DATE
0108           USER                 1138939      160458      11201  10:05   05/12/2011
LOAD SIZE      MIX CODE                                             SEQ       LOAD ID
 3.00 yd       24033000                                              W          11217
MATERIAL       DESIGN QTY    REQUIRED     BATCHED       VAR    % VAR   %MOISTURE  ACTUAL WA
G47B             2100 lb      6430 lb     6480  +        50    0.78%   2.06 A     15.65 gl
L47B              900 lb      2708 lb     2700           -8    -.30%   0.30 M      0.97 gl
CEM3              611 lb      1833 lb     1900  >        67    3.66%
PROT             1.20 oz      3.60 oz     4.00         0.40   11.11%
WATER            34.0 GL      88.5 GL     89.2          0.7    0.79%              89.16 gl
WATER2            0.0 gl #     0.0 gl      0.0          0.0    0.00%
NON-SIMULATED     NUM BATCHES: 1
 LOAD TOTAL: 11824 lb  DESIGN W/C: 0.464  WATER/CEMENT: 0.465A  DESIGN WATER: 102.0 gl  ACTUAL WATER:  105.8 gl  TO ADD:  0.0 gl
 SLUMP:  4.00 "# WATER IN TRUCK:  0.0 gl  ADJUST WATER:  0.0 gl/load  TRIM WATER:  0.0 gl /yd
```

Figure A-18. Foundation Concrete

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

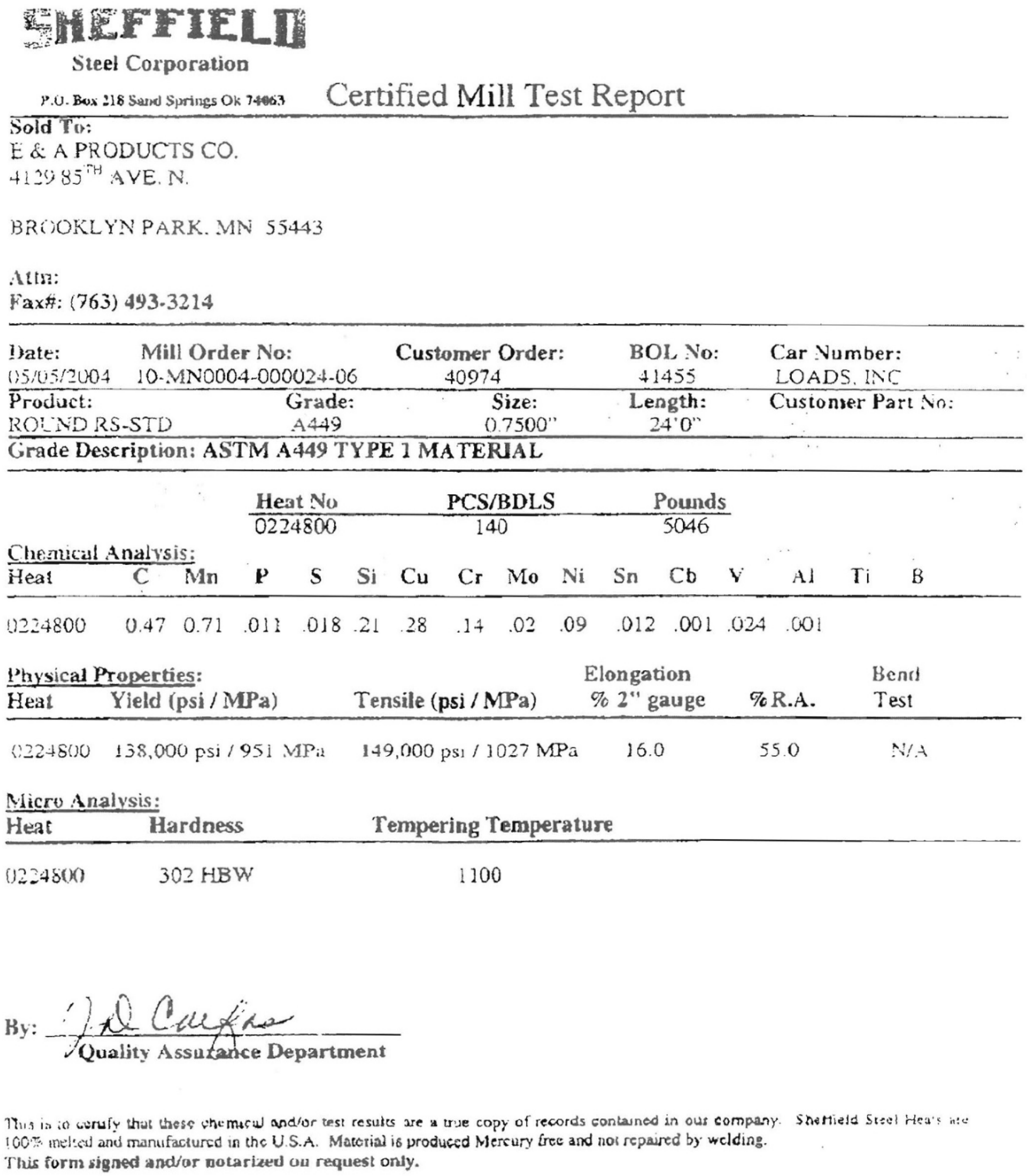
Melted & Manufactured In USA

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

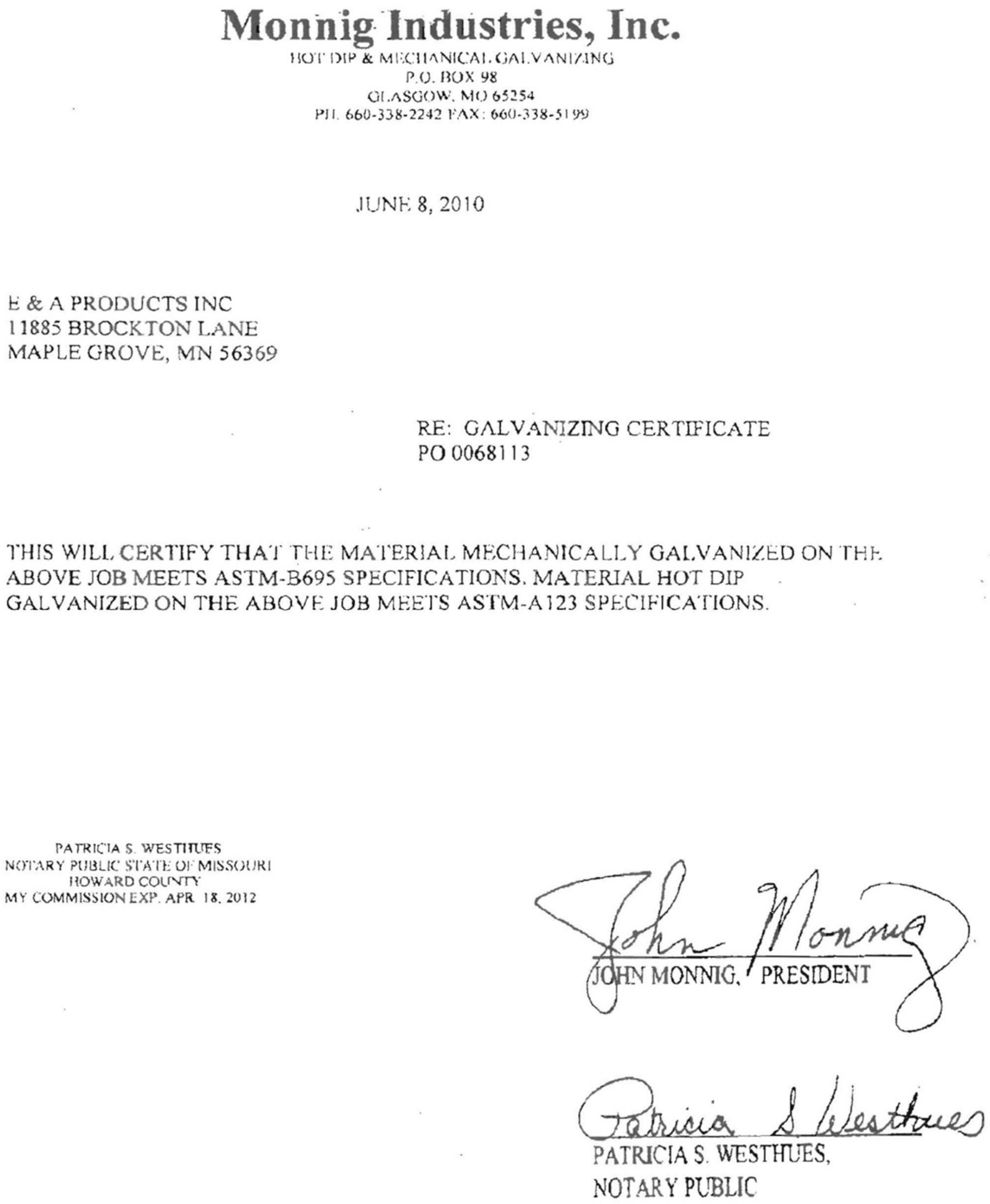
Micro Analysis:

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

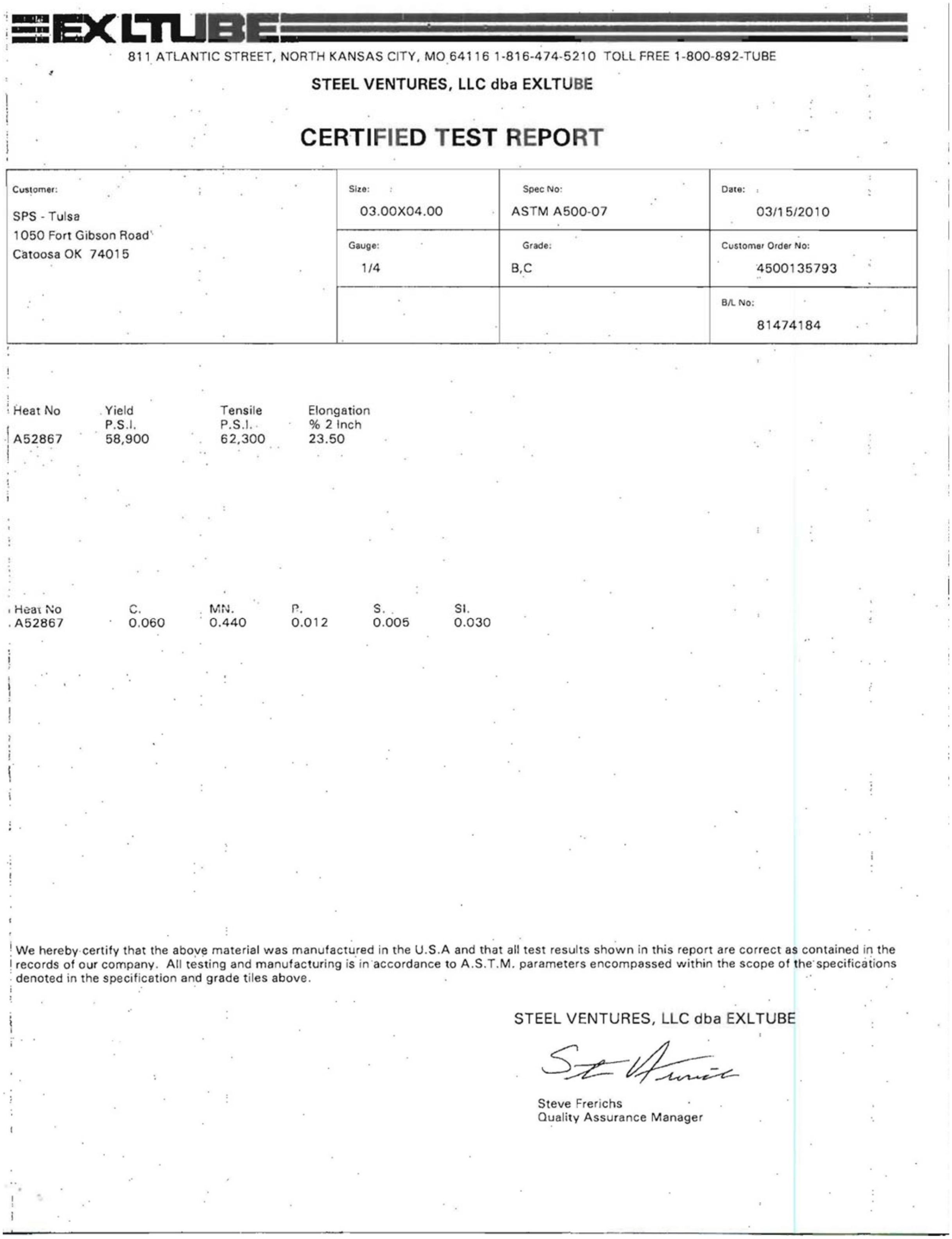
THIS WILL CERTIFY THAT THE MATERIAL MECHANICALLY GALVANIZED ON THE ABOVE JOB MEETS ASTM-B695 SPECIFICATIONS. MATERIAL HOT DIP GALVANIZED ON THE ABOVE JOB MEETS ASTM-A123 SPECIFICATIONS.

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

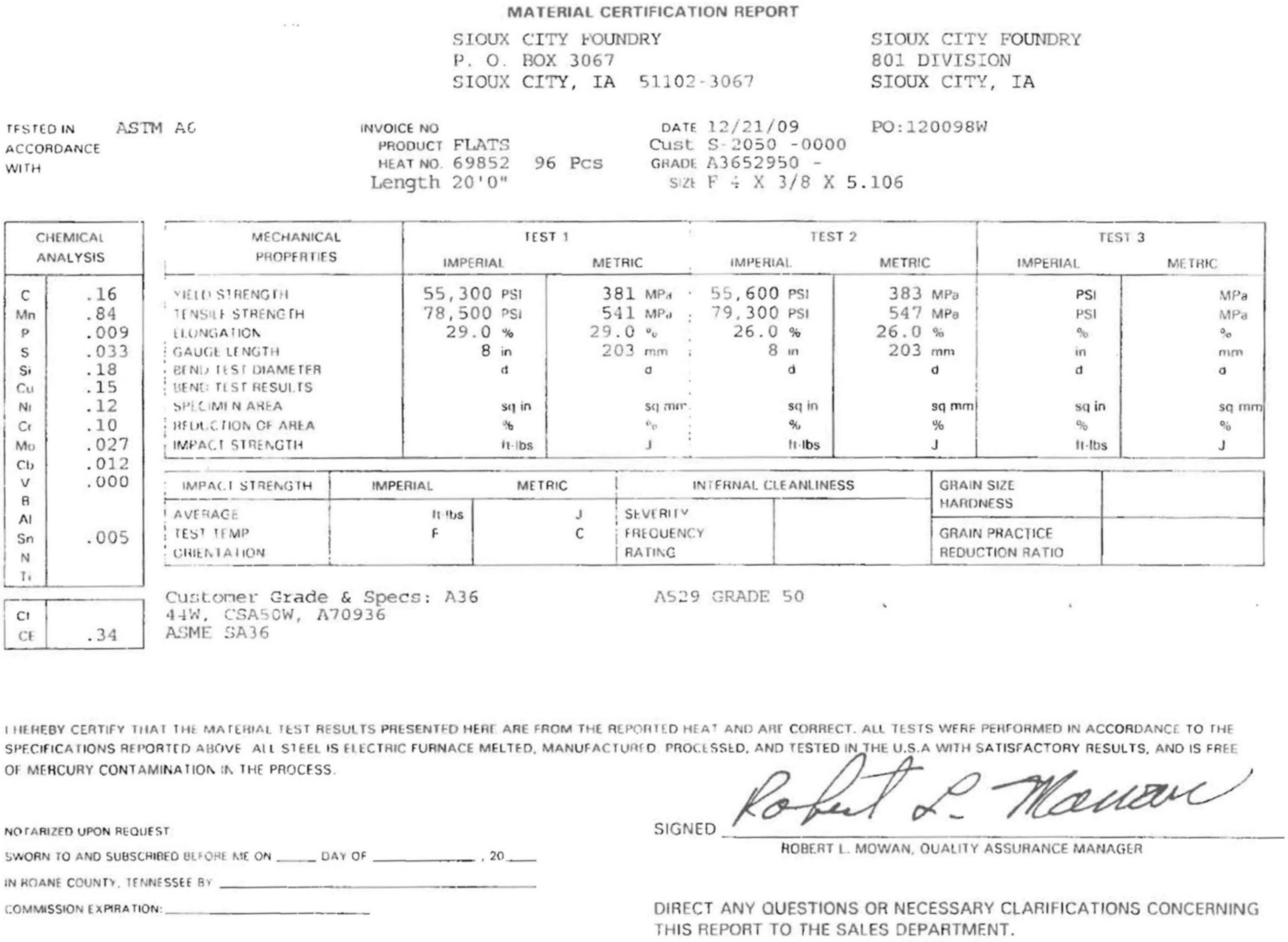
Heat No	C.	MN.	P.	S.	SI.
A52867	0.060	0.440	0.012	0.005	0.030

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 ____________________

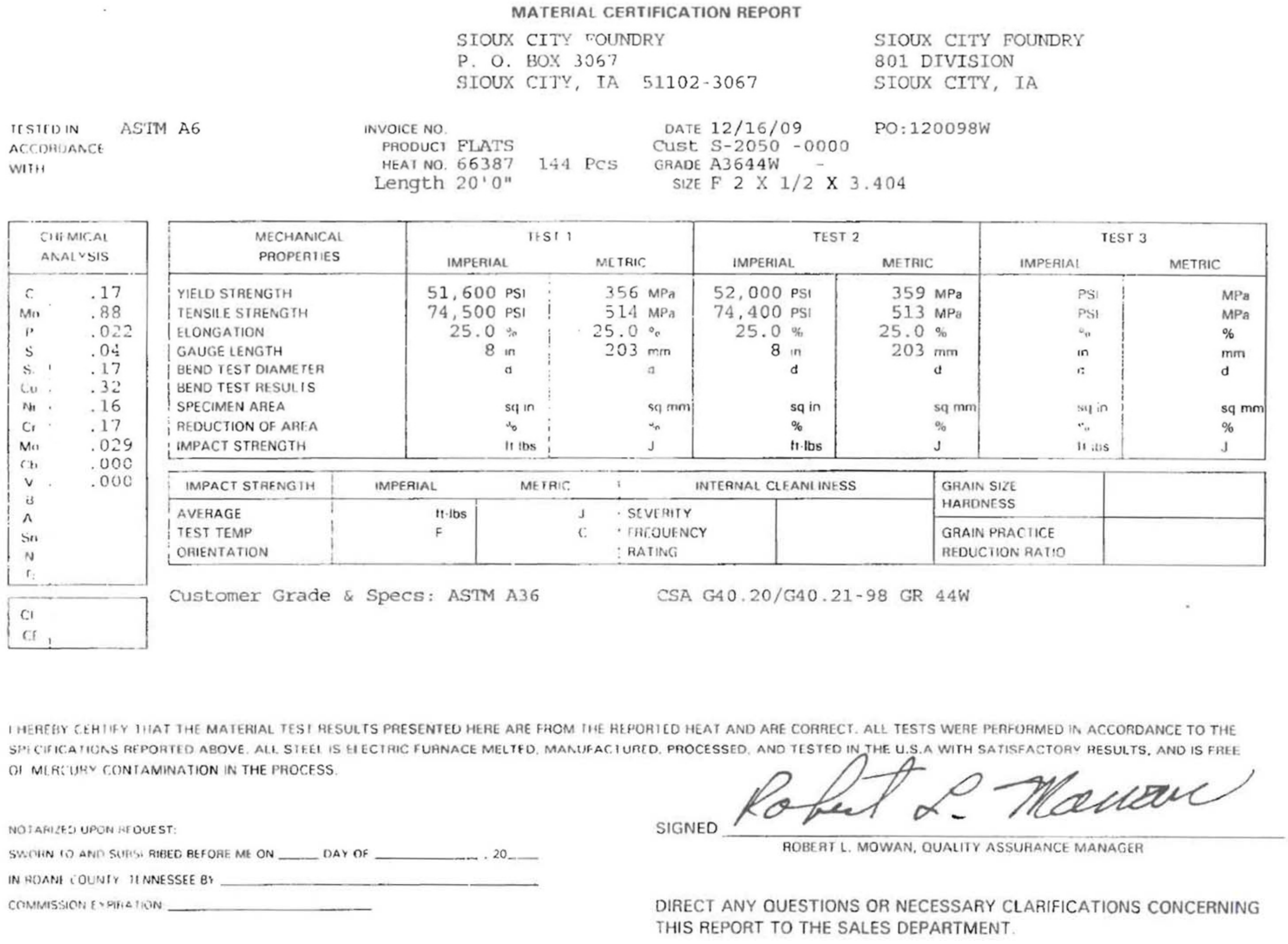
COMMISSION EXPIRATION: ____________________

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	
Al	
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

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

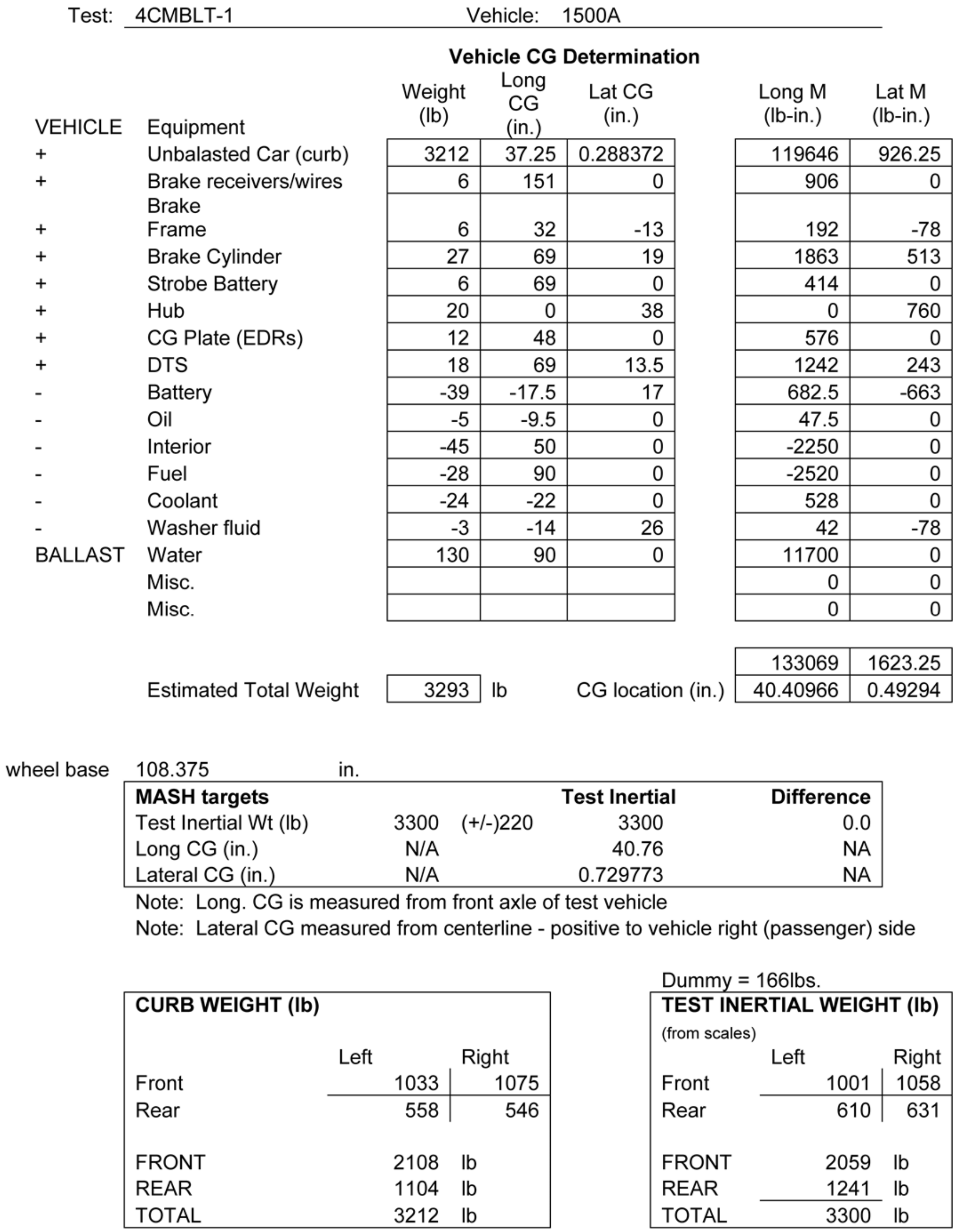
H#8270018 PCS./PZS.5LB
Made in/Hecho en China
LOT#HO1476653

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: 4CMBLT-1 Vehicle: 1500A

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Long CG (in.)	Lat CG (in.)	Long M (lb-in.)	Lat M (lb-in.)
+	Unbalasted Car (curb)	3212	37.25	0.288372	119646	926.25
+	Brake receivers/wires	6	151	0	906	0
+	Brake Frame	6	32	-13	192	-78
+	Brake Cylinder	27	69	19	1863	513
+	Strobe Battery	6	69	0	414	0
+	Hub	20	0	38	0	760
+	CG Plate (EDRs)	12	48	0	576	0
+	DTS	18	69	13.5	1242	243
-	Battery	-39	-17.5	17	682.5	-663
-	Oil	-5	-9.5	0	47.5	0
-	Interior	-45	50	0	-2250	0
-	Fuel	-28	90	0	-2520	0
-	Coolant	-24	-22	0	528	0
-	Washer fluid	-3	-14	26	42	-78
BALLAST	Water	130	90	0	11700	0
	Misc.				0	0
	Misc.				0	0
					133069	1623.25
	Estimated Total Weight	3293	lb	CG location (in.)	40.40966	0.49294

wheel base 108.375 in.

MASH targets			Test Inertial	Difference
Test Inertial Wt (lb)	3300	(+/-)220	3300	0.0
Long CG (in.)	N/A		40.76	NA
Lateral CG (in.)	N/A		0.729773	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	1033	1075
Rear	558	546

FRONT 2108 lb
REAR 1104 lb
TOTAL 3212 lb

Dummy = 166lbs.

TEST INERTIAL WEIGHT (lb)

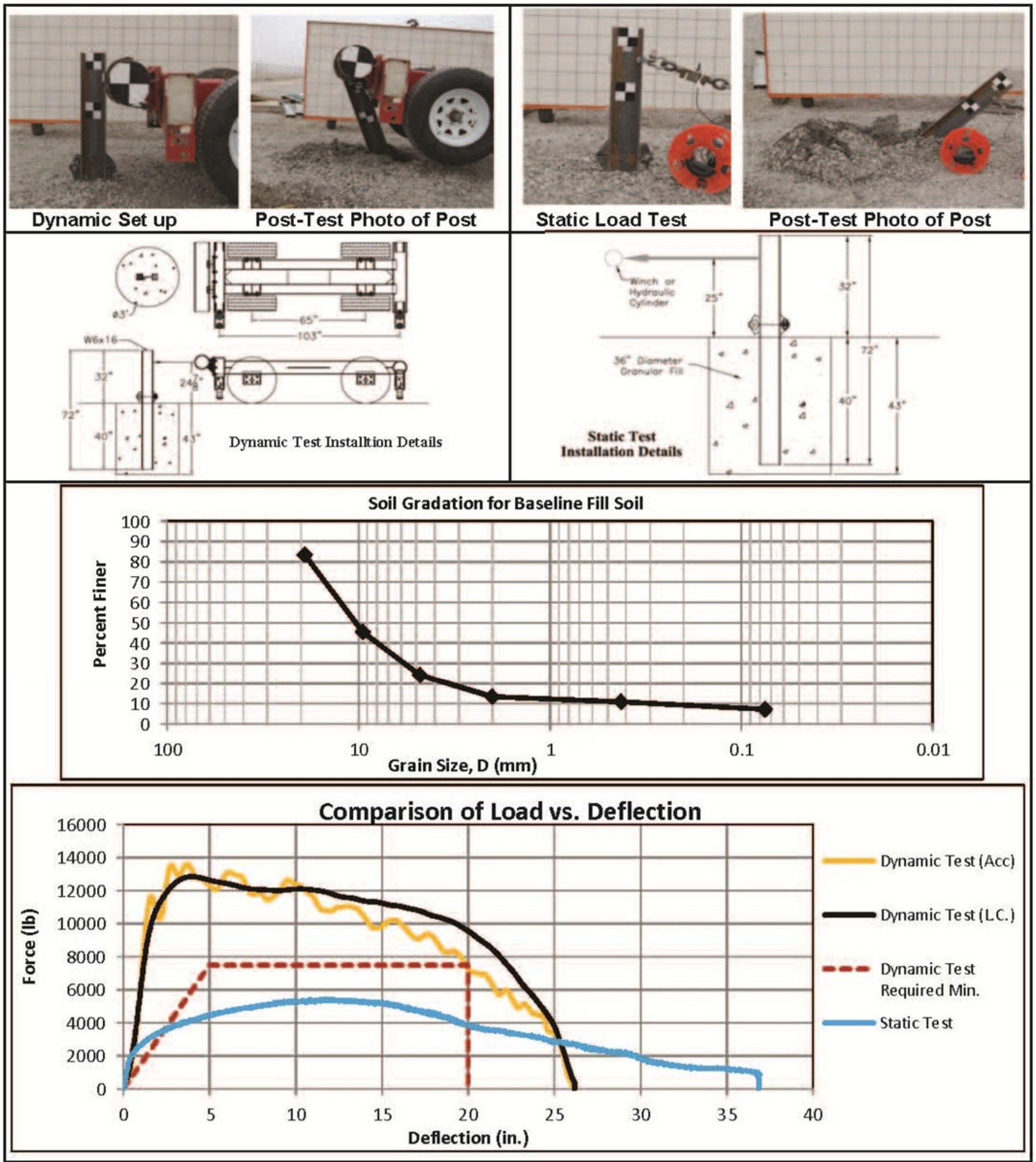
(from scales)

	Left	Right
Front	1001	1058
Rear	610	631

FRONT 2059 lb
REAR 1241 lb
TOTAL 3300 lb

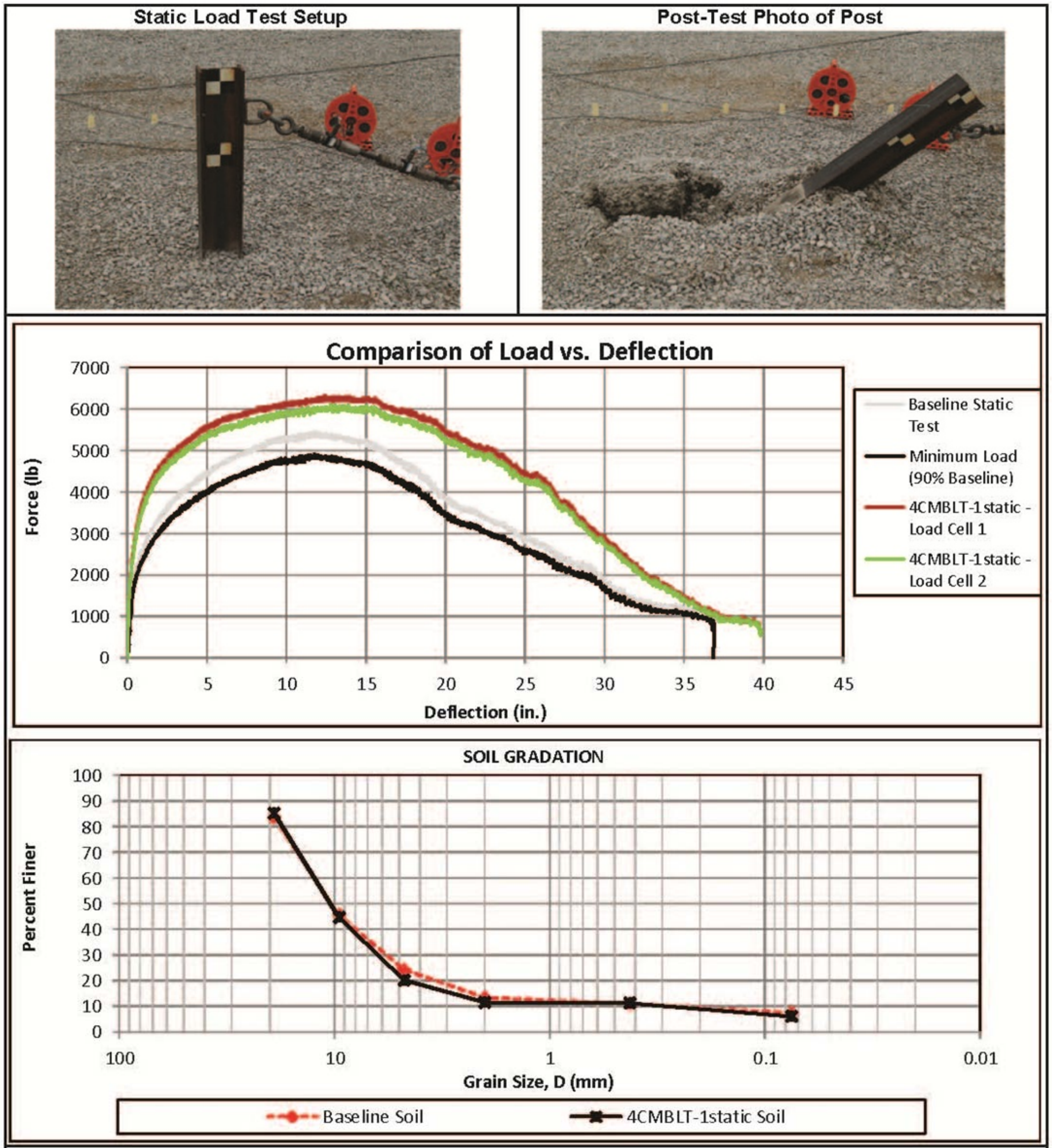
Figure B-1. Vehicle Mass Distribution, Test No. 4CMBLT-1

Appendix C. Static Soil Tests



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-1. Static Soil Test, Test No. 4CMBLT-1



Date	6/14/2011
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-2. Static Soil Test, Test No. 4CMBLT-1

Appendix D. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: 4CMBLT-1
VEHICLE: 1500A

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	27 1/4	-21 1/4	0	27 1/4	-21 1/4	NA	0	0	NA
2	30	-16 3/4	-2 1/4	30	-17	NA	0	- 1/4	NA
3	29	-11 1/2	-3	29	-12	NA	0	- 1/2	NA
4	27 3/4	-5 3/4	-4	27 3/4	-6	NA	0	- 1/4	NA
5	24 1/4	-22	-5	24 1/4	-21 3/4	NA	0	1/4	NA
6	25 1/4	-17 3/4	-5 1/2	25 1/4	-17 3/4	NA	0	0	NA
7	26	-14	-5 1/2	26	-13 3/4	NA	0	1/4	NA
8	25 1/2	-7 3/4	-5 1/2	25 1/2	-8	NA	0	- 1/4	NA
9	20 1/4	-22 3/4	-5 3/4	20 1/4	-22 3/4	NA	0	0	NA
10	20 1/2	-17 1/4	-6 1/4	20 3/4	-17 3/4	NA	1/4	- 1/2	NA
11	20 3/4	-13	-6 1/2	20 3/4	-12 3/4	NA	0	1/4	NA
12	21	-7 1/4	-6 1/2	20 3/4	-7 3/4	NA	- 1/4	- 1/2	NA
13	21	-1 1/2	-1 1/2	21	-1 1/4	NA	0	1/4	NA
14	13 3/4	-25 1/4	-4 3/4	14	-25 1/2	NA	1/4	- 1/4	NA
15	15 1/4	-21	-6	15 1/4	-20 3/4	NA	0	1/4	NA
16	15 3/4	-15 3/4	-6 1/2	15 3/4	-15 3/4	NA	0	0	NA
17	15 1/4	-10 3/4	-6 1/2	15 1/4	-11 1/4	NA	0	- 1/2	NA
18	16	-2 1/4	-1 3/4	16	-2 1/4	NA	0	0	NA
19	10 1/2	-25	-4 3/4	10 1/2	-25	NA	0	0	NA
20	11 1/4	-21 1/4	-6	11	-21	NA	- 1/4	1/4	NA
21	11 3/4	-15	-6 1/2	11 3/4	-15 1/2	NA	0	- 1/2	NA
22	12	-9 1/4	-6 1/2	11 3/4	-9 1/2	NA	- 1/4	- 1/4	NA
23	11 1/2	-2 3/4	-2 1/2	11 1/2	-2 3/4	NA	0	0	NA
24	5 1/2	-24 1/4	-4 3/4	5 1/4	-24 1/2	NA	- 1/4	- 1/4	NA
25	7 1/2	-18 1/4	-6	7 1/4	-18 1/2	NA	- 1/4	- 1/4	NA
26	7 1/4	-10 3/4	-5 1/2	7	-10 3/4	NA	- 1/4	0	NA
27	7	-2 3/4	-2 1/4	7	-2 3/4	NA	0	0	NA
28							0	0	0
29							0	0	0
30	Note-all measurements marked "NA"						0	0	0
31	were not taken due to reference compromise						0	0	0

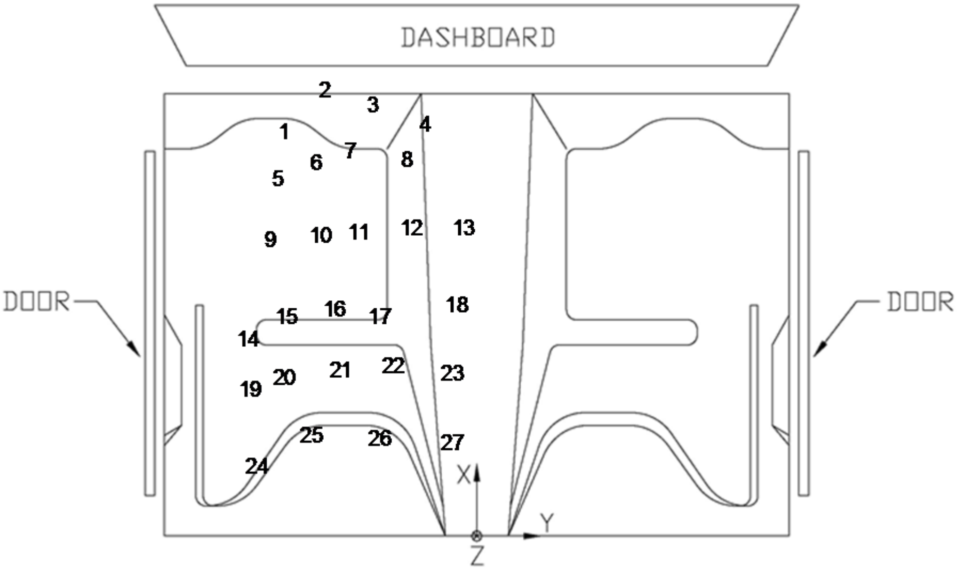


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. 4CMBLT-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: 4CMBLT-1
VEHICLE: 1500A

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	30	-53 3/4	20 1/4	30 1/4	NA	NA	1/4	NA	NA
	A2	34	-49	24	34 1/4	NA	NA	1/4	NA	NA
	A3	35 1/4	-35 1/2	24 1/2	35 1/2	NA	NA	1/4	NA	NA
	A4	31 1/4	-48 1/4	19 1/4	31 1/2	NA	NA	1/4	NA	NA
	A5	31 1/4	-34	19 1/2	31 1/2	NA	NA	1/4	NA	NA
	A6	31	-28	19 1/2	31	NA	NA	0	NA	NA
SIDE PANEL	B1	34 3/4	-25 1/2	1/2	34 3/4	-25 3/4	NA	0	- 1/4	NA
	B2	36 1/4	-24 3/4	3/4	36 1/4	-24 3/4	NA	0	0	NA
	B3	33 3/4	-25	-2 1/2	33 3/4	-25	NA	0	0	NA
IMPACT SIDE DOOR	C1	5 1/4	-37 1/4	21 1/4	5	-36 1/4	NA	- 1/4	1	NA
	C2	16 1/4	-34 3/4	21	16 1/4	-34	NA	0	3/4	NA
	C3	25 3/4	-37 1/4	21	25 3/4	-36 3/4	NA	0	1/2	NA
	C4	2	-31 3/4	9 1/2	2	-31	NA	0	3/4	NA
	C5	14 1/2	-28 3/4	8 3/4	14 1/2	-28	NA	0	3/4	NA
	C6	22 3/4	-31 3/4	9	22 3/4	-31 1/2	NA	0	1/4	NA
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

Note-all measurements marked "NA" were not taken due to reference compromise

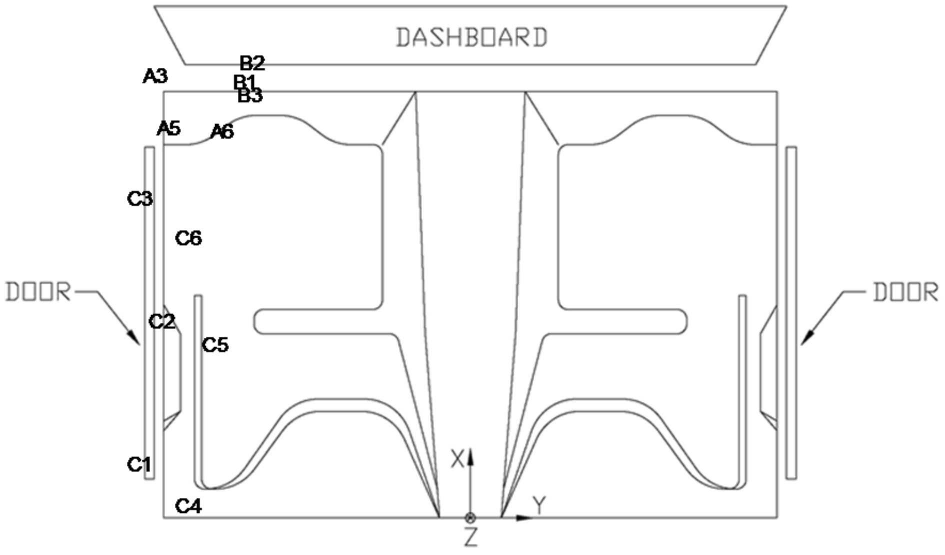


Figure D-2. Occupant Compartment Deformation Data – Set 1, Test No. 4CMBLT-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: 4CMBLT-1
VEHICLE: 1500A

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	39 3/4	-24	0	39 3/4	-24	NA	0	0	NA
2	42 3/4	-19 3/4	-2	42 3/4	-19 1/2	NA	0	1/4	NA
3	41 3/4	-14 1/4	-3	41 3/4	-14 1/4	NA	0	0	NA
4	40 3/4	-7 1/2	-4	41	-7 1/2	NA	1/4	0	NA
5	37 1/4	-24	-5	37 1/4	-24 1/4	NA	0	- 1/4	NA
6	38 1/4	-20 1/4	-5 1/2	38 1/4	-20	NA	0	1/4	NA
7	39	-16 1/4	-5	38 3/4	-16	NA	- 1/4	1/4	NA
8	38 1/2	-10	-5 1/2	38 1/2	-9 3/4	NA	0	1/4	NA
9	33 1/4	-25 1/2	-5 3/4	33	-25 1/4	NA	- 1/4	1/4	NA
10	33 3/4	-19 3/4	-6	33 1/2	-20	NA	- 1/4	- 1/4	NA
11	34	-15 1/4	-6 1/4	33 3/4	-15	NA	- 1/4	1/4	NA
12	34 1/4	-10	-6 1/2	34	-10	NA	- 1/4	0	NA
13	33 3/4	-4	-1 1/2	33 3/4	-4 1/4	NA	0	- 1/4	NA
14	27	-28	-4 3/4	27	-28	NA	0	0	NA
15	28 1/2	-23 1/2	-6	28 1/4	-23 1/4	NA	- 1/4	1/4	NA
16	29	-17 1/2	-6 1/4	28 3/4	-18	NA	- 1/4	- 1/2	NA
17	28 1/2	-13	-6 1/4	28 1/2	-13 1/2	NA	0	- 1/2	NA
18	29	-5	-1 3/4	29	-5	NA	0	0	NA
19	23 1/2	-27 1/2	-4 1/2	23 1/2	-27 1/2	NA	0	0	NA
20	24 1/4	-23 1/2	-6	24 1/4	-23 3/4	NA	0	- 1/4	NA
21	25	-17 1/2	-6 1/4	24 3/4	-17 1/2	NA	- 1/4	0	NA
22	25 1/4	-11 1/2	-6 1/4	25	-11 3/4	NA	- 1/4	- 1/4	NA
23	24 1/4	-5 1/2	-2 1/4	24 1/4	-5 1/2	NA	0	0	NA
24	18 3/4	-27	-4 1/2	18 1/2	-26 3/4	NA	- 1/4	1/4	NA
25	20 3/4	-20	-6	20 1/2	-20 1/2	NA	- 1/4	- 1/2	NA
26	20 1/2	-13	-5 1/4	20 1/4	-13 1/4	NA	- 1/4	- 1/4	NA
27	19 3/4	-5 1/2	-2	19 3/4	-5 3/4	NA	0	- 1/4	NA
28							0	0	0
29		Note-all measurements marked "NA" were					0	0	0
30		not taken due to reference compromise					0	0	0
31							0	0	0

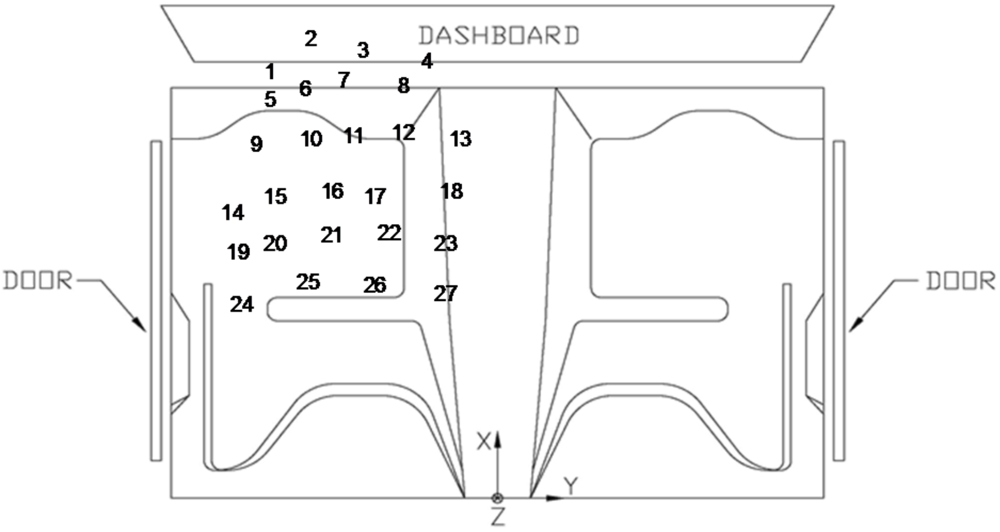


Figure D-3. Floor Pan Deformation Data – Set 2, Test No. 4CMBLT-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: 4CMBLT-1
VEHICLE: 1500A

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	47 3/4	-52 3/4	20 1/4	47 3/4	NA	NA	0	NA	NA
	A2	51	-48	24 1/4	51	NA	NA	0	NA	NA
	A3	51 1/4	-34 3/4	24 3/4	51 1/4	NA	NA	0	NA	NA
	A4	49 1/2	-47 1/2	19 1/2	49 1/2	NA	NA	0	NA	NA
	A5	47 3/4	-33 1/4	19 3/4	47 1/2	NA	NA	- 1/4	NA	NA
	A6	47 1/2	-27 1/2	19 3/4	47 1/4	NA	NA	- 1/4	NA	NA
SIDE PANEL	B1	22 1/2	-24	1/2	22 1/4	-24	NA	- 1/4	0	NA
	B2	24	-23 1/4	3/4	24	-23 1/2	NA	0	- 1/4	NA
	B3	21	-23	-2 1/2	21	-23	NA	0	0	NA
IMPACT SIDE DOOR	C1	9 3/4	-38 3/4	21 1/2	9 3/4	-37 1/2	NA	0	1 1/4	NA
	C2	21	-38 3/4	21 1/4	21	-37 3/4	NA	0	1	NA
	C3	30	-38 3/4	21	30	-38	NA	0	3/4	NA
	C4	8 1/4	-34	10	8 1/4	-33	NA	0	1	NA
	C5	21	-34	9	21	-33 1/4	NA	0	3/4	NA
	C6	29 1/4	-34	9	29 1/4	-33 1/4	NA	0	3/4	NA
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		Note-all measurements marked "NA" were not taken due to reference compromise					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

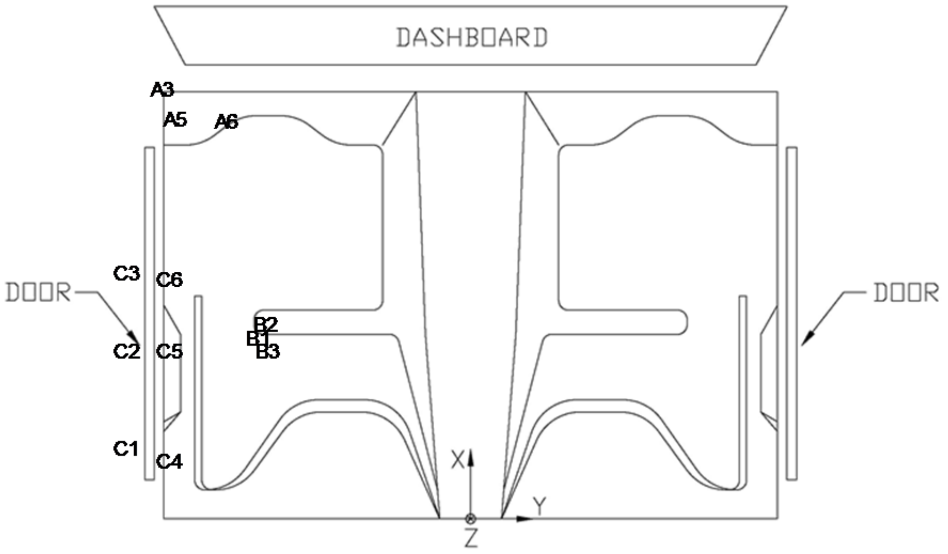


Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. 4CMBLT-1

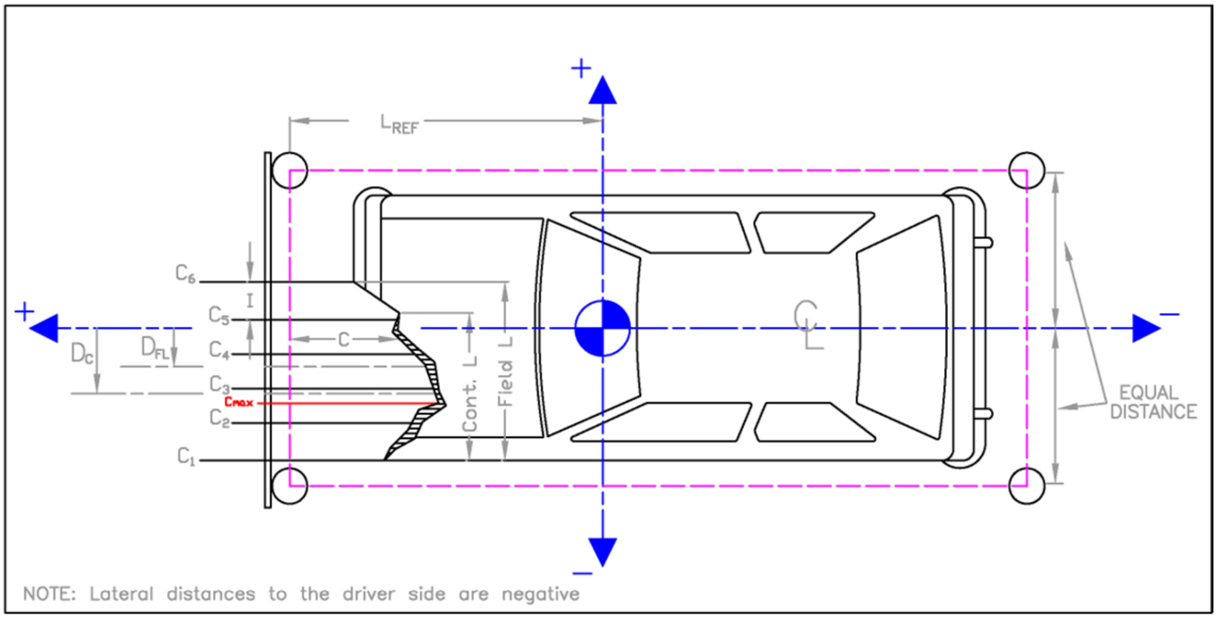
Date: 8/16/2011

Test Number: 4CMBLT-1

Make: Ford

Model: 1500A

Year: 2006



NOTE: Lateral distances to the driver side are negative

	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	93	(2362)
Width of contact and induced crush - Field L:	69	(1753)
Crush measurement spacing interval (L/5) - I:	13.8	(351)
Distance from center of vehicle to center of Field L - D_{FL}:	0	0
Width of Contact Damage:	69	(1753)
Distance from center of vehicle to center of contact damage - D_C:	0	0

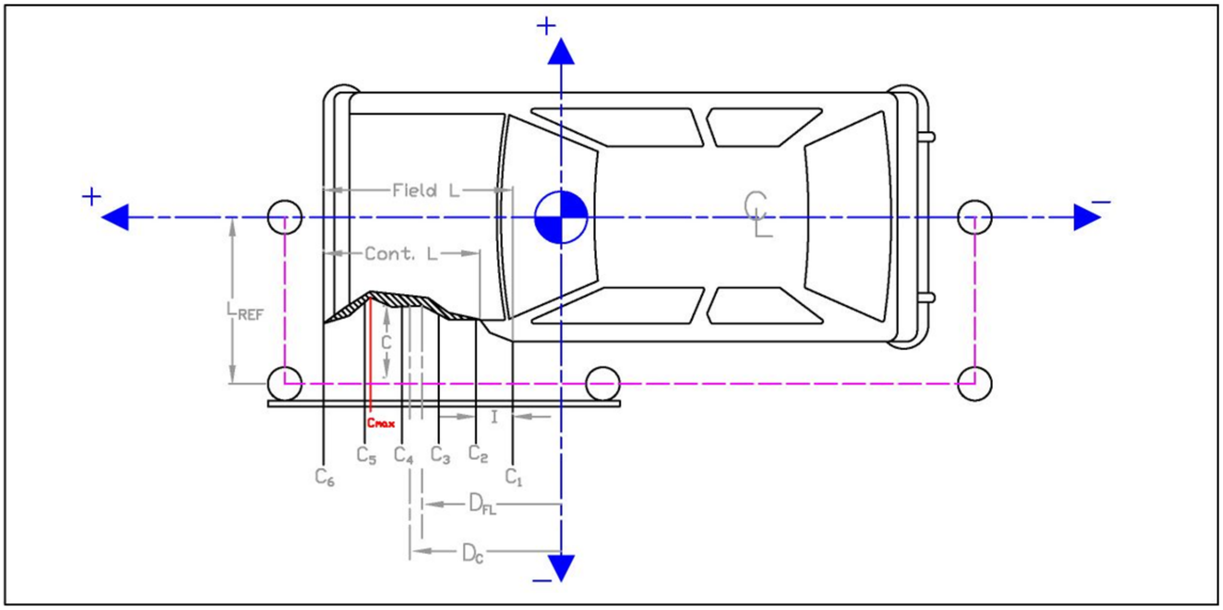
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	NA	NA	-34 1/2	-(876)	32 3/4	(832)	4 1/4	(108)	NA	NA
C_2	14.25	(362)	-20 2/3	-(526)	9 1/2	(242)			1/2	(12)
C_3	15.5	(394)	-6 8/9	-(175)	6 2/3	(170)			4 4/7	(116)
C_4	15.25	(387)	7	(175)	6 5/7	(170)			4 1/3	(109)
C_5	13	(330)	20 5/7	(526)	9 4/9	(240)			- 2/3	-(17)
C_6	NA	NA	34 1/2	(876)	32 3/4	(832)			NA	NA
C_{MAX}	15.75	(400)	10 1/2	(267)	7	(179)			4 4/9	(113)

Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. 4CMBLT-1

Date: 8/16/2011 **Test Number:** 4CMBLT-1

Make: Ford **Model:** 1500A **Year:** 2006



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	39	(991)
Width of contact and induced crush - Field L:	197 3/4	(5023)
Crush measurement spacing interval (L/5) - I:	39.55	(1005)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-17.125	-(435)
Width of Contact Damage:	197 3/4	(5023)
Distance from vehicle c.g. to center of contect damage - D_C:	16 5/8	(422)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	NA	NA	-116	-(2946)	12 4/7	(319)	-4	-(102)	NA	NA
C_2	4	(102)	-76 4/9	-(1942)	8 5/8	(219)			- 5/8	-(16)
C_3	3	(76)	-37	-(937)	6 3/4	(171)			1/4	(6)
C_4	3.5	(89)	2 2/3	(67)	6 7/8	(175)			5/8	(16)
C_5	4.75	(121)	42 1/5	(1072)	8 1/8	(206)			5/8	(16)
C_6	NA	NA	81 3/4	(2076)	8 1/8	(206)			NA	NA
C_{MAX}	10.5	(267)	67	(1702)	8 1/8	(206)			6 3/8	(162)

Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. 4CMBLT-1

Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. 4CMBLT-1

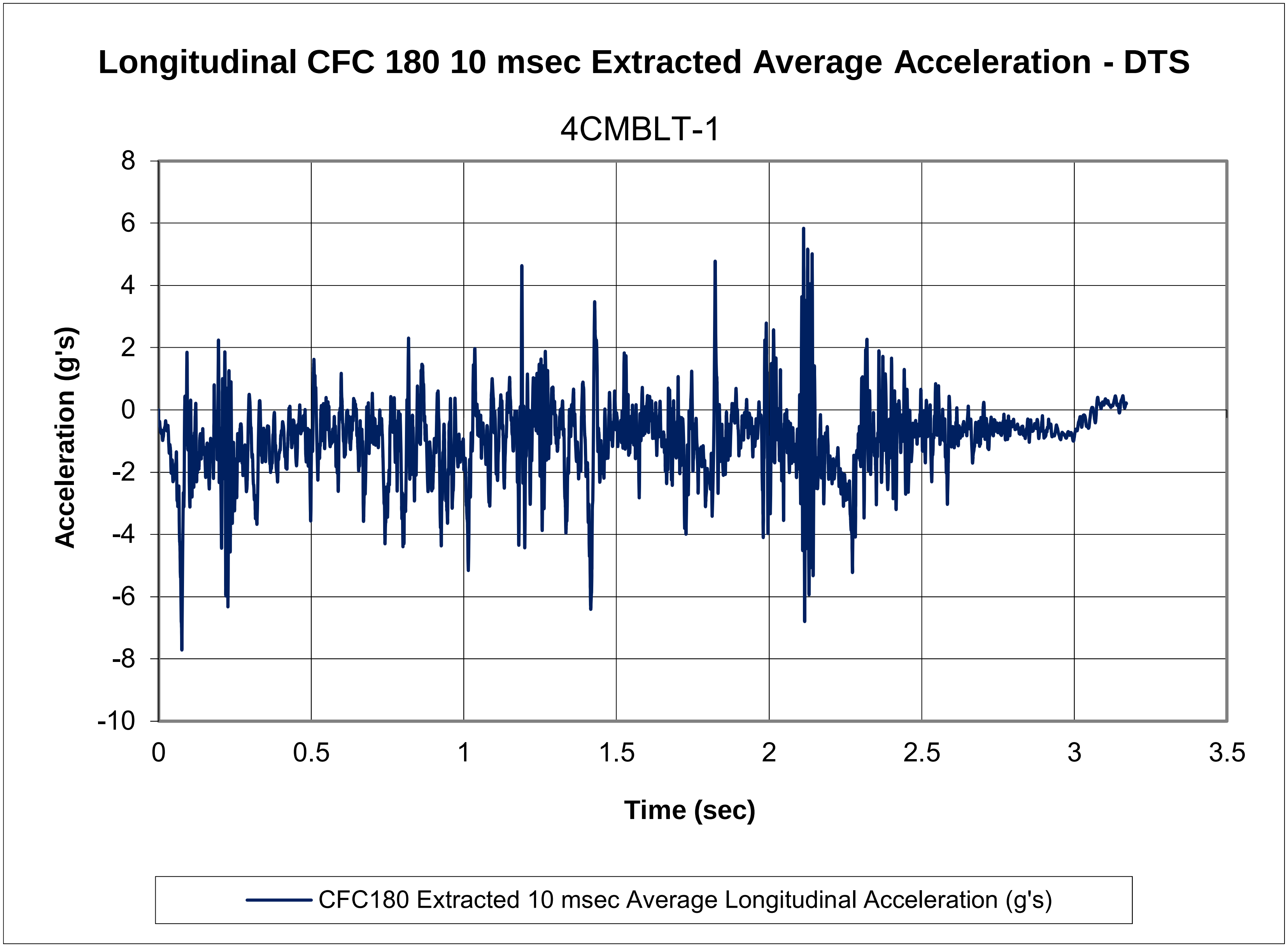


Figure E-1. 10-ms Average Longitudinal Deceleration (DTS), Test No. 4CMBLT-1

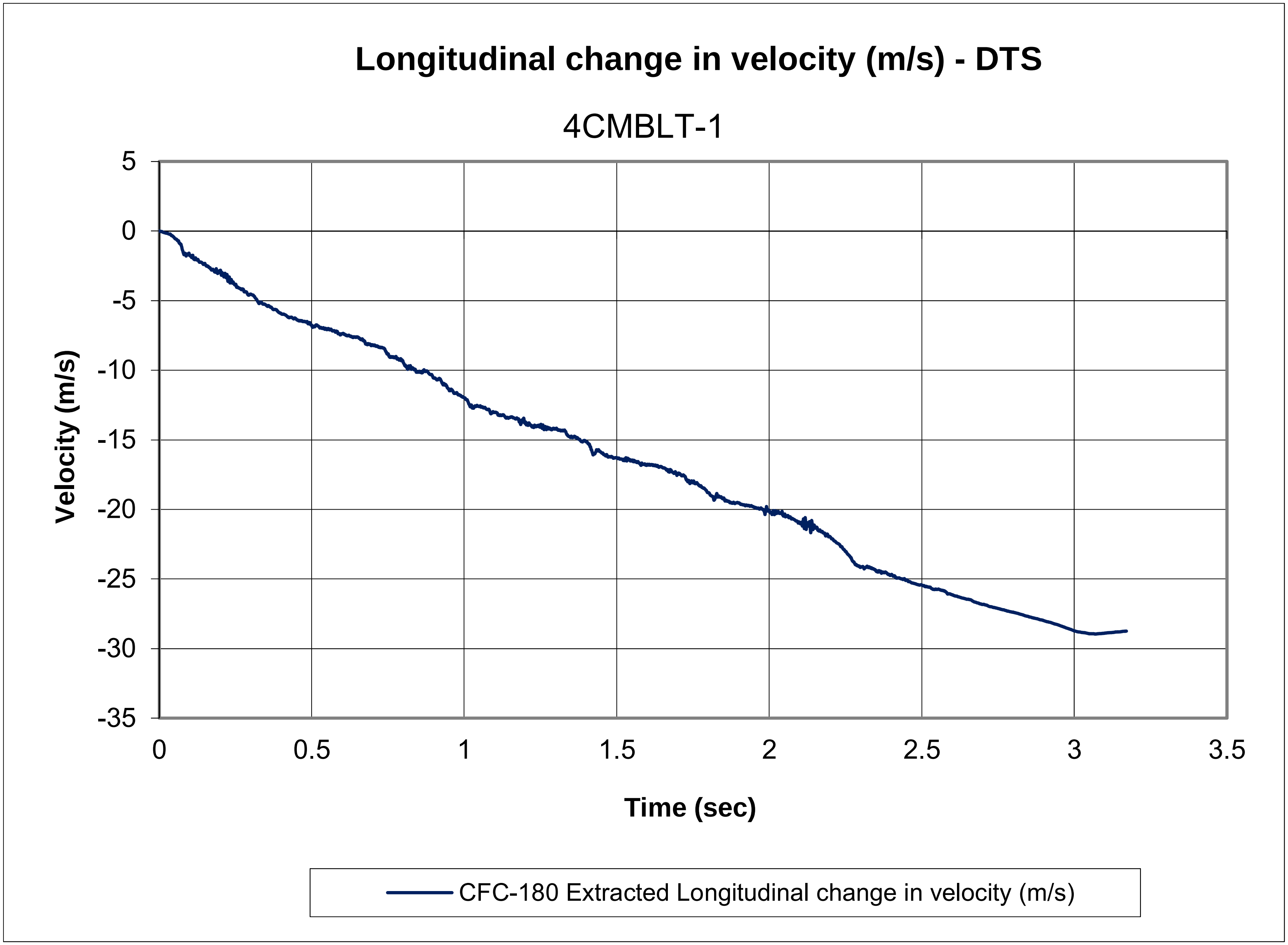


Figure E-2. Longitudinal Occupant Impact Velocity (DTS), Test No. 4CMBLT-1

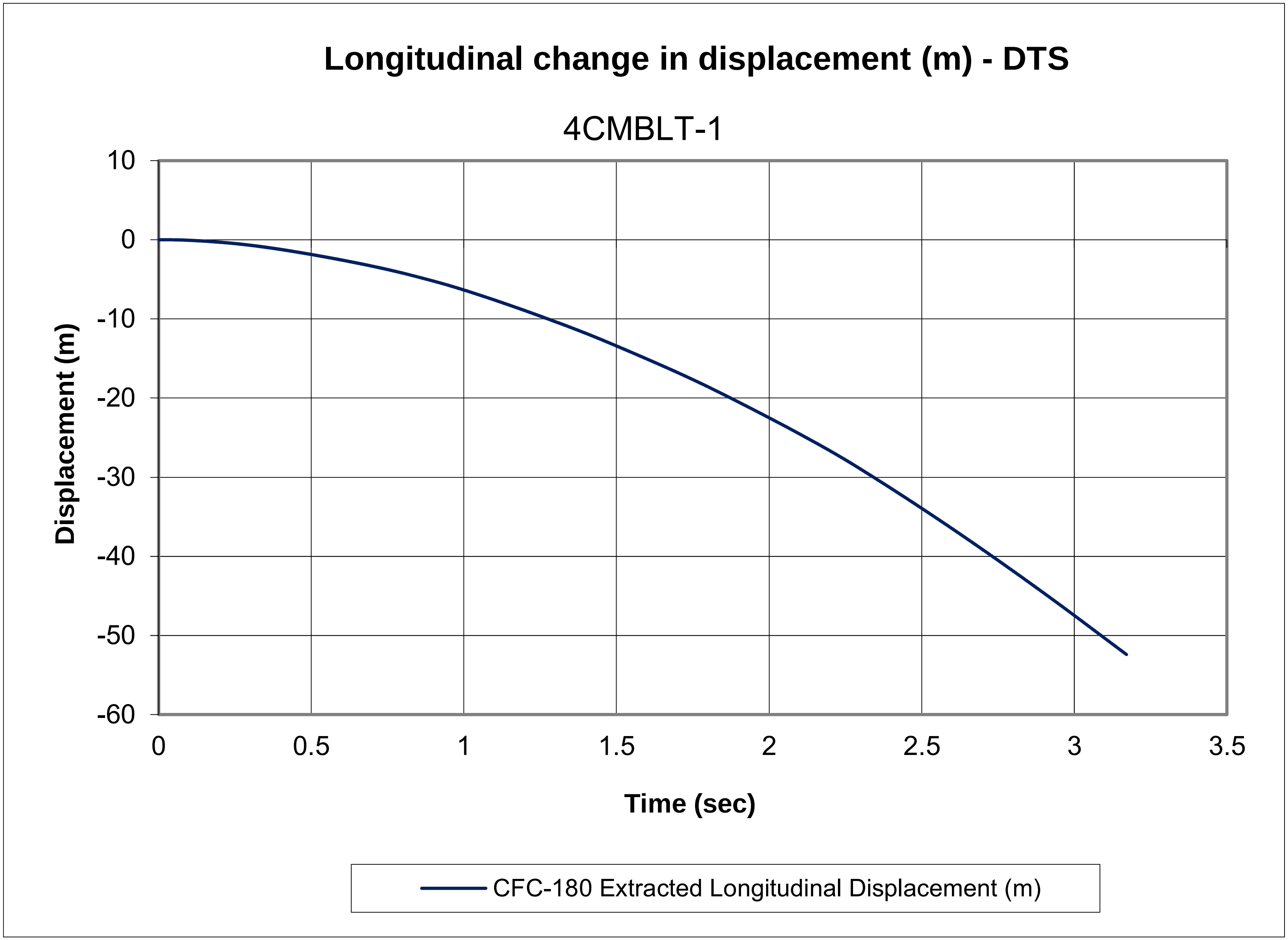


Figure E-3. Longitudinal Occupant Displacement (DTS), Test No. 4CMBLT-1

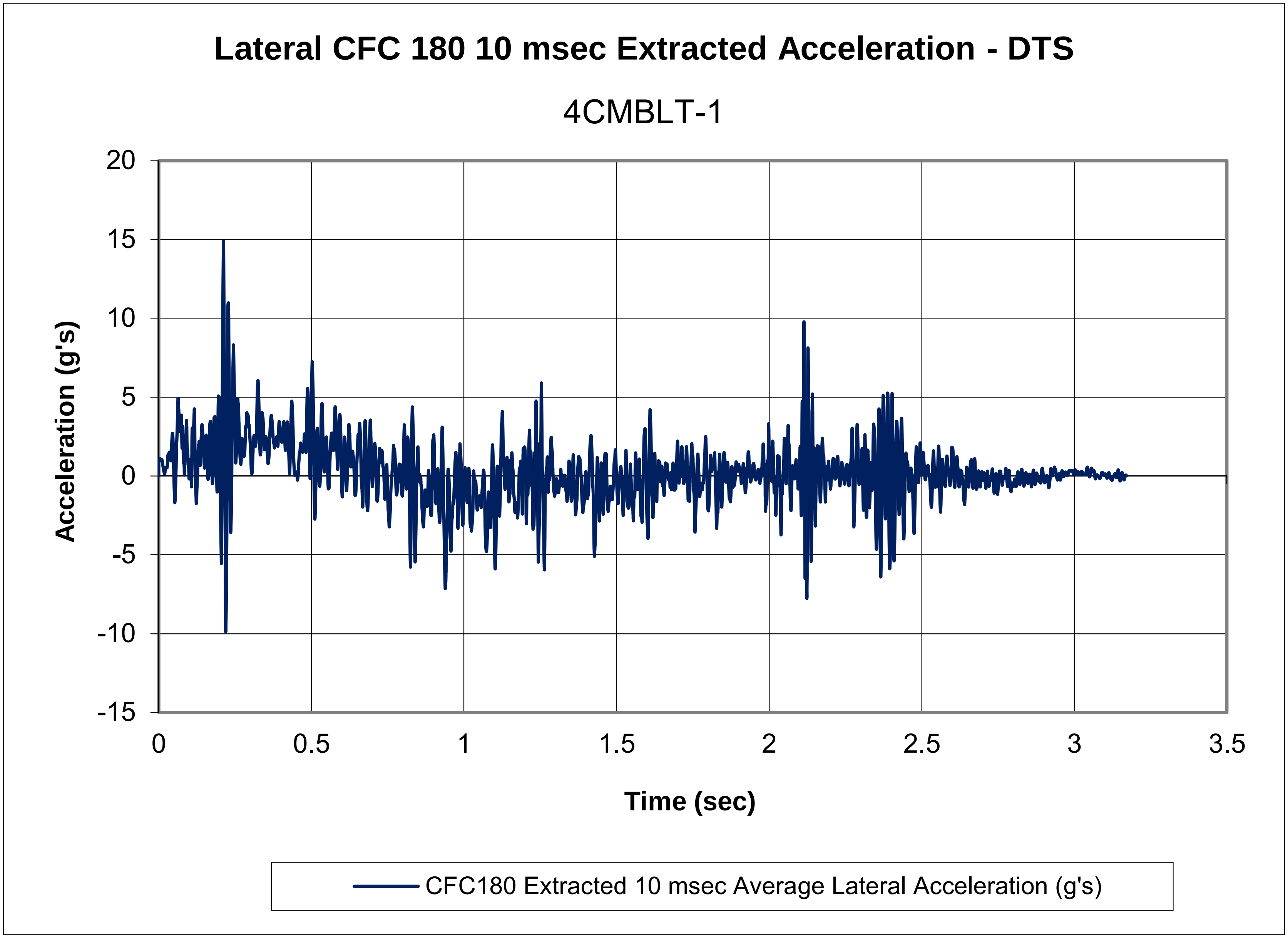


Figure E-4. 10-ms Average Lateral Deceleration (DTS), Test No. 4CMBLT-1

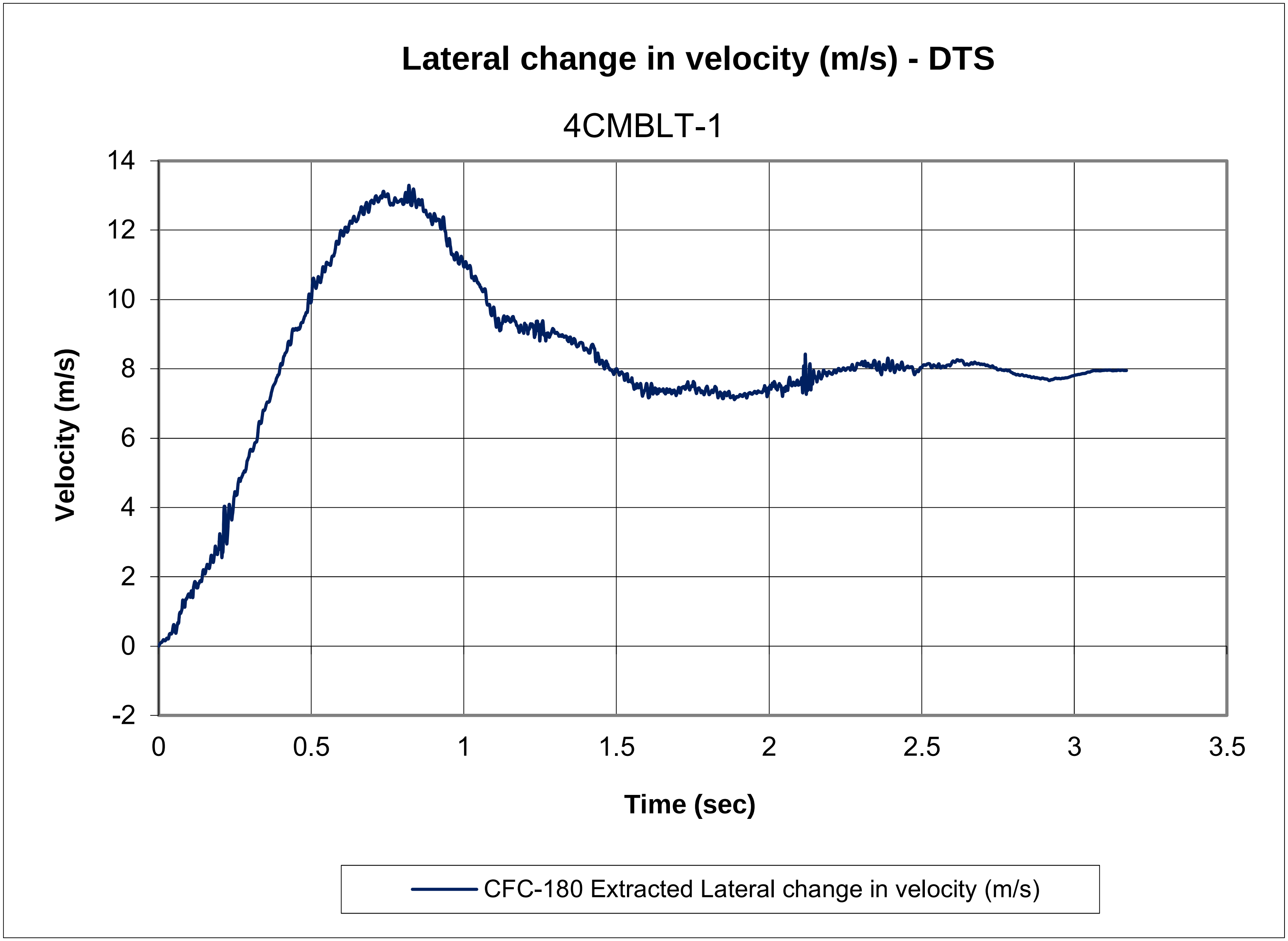


Figure E-5. Lateral Occupant Impact Velocity (DTS), Test No. 4CMBLT-1

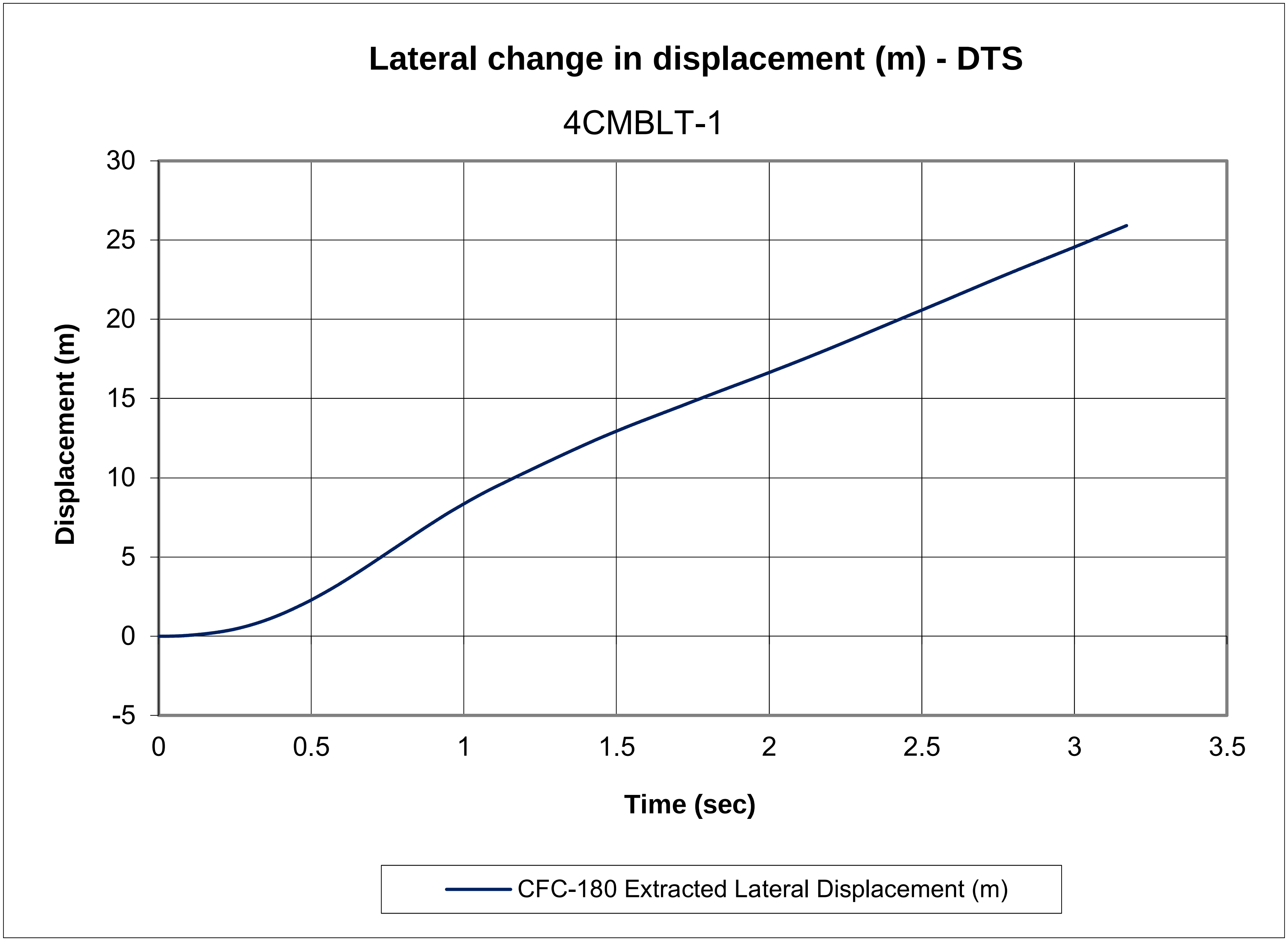


Figure E-6. Lateral Occupant Displacement (DTS), Test No. 4CMBLT-1

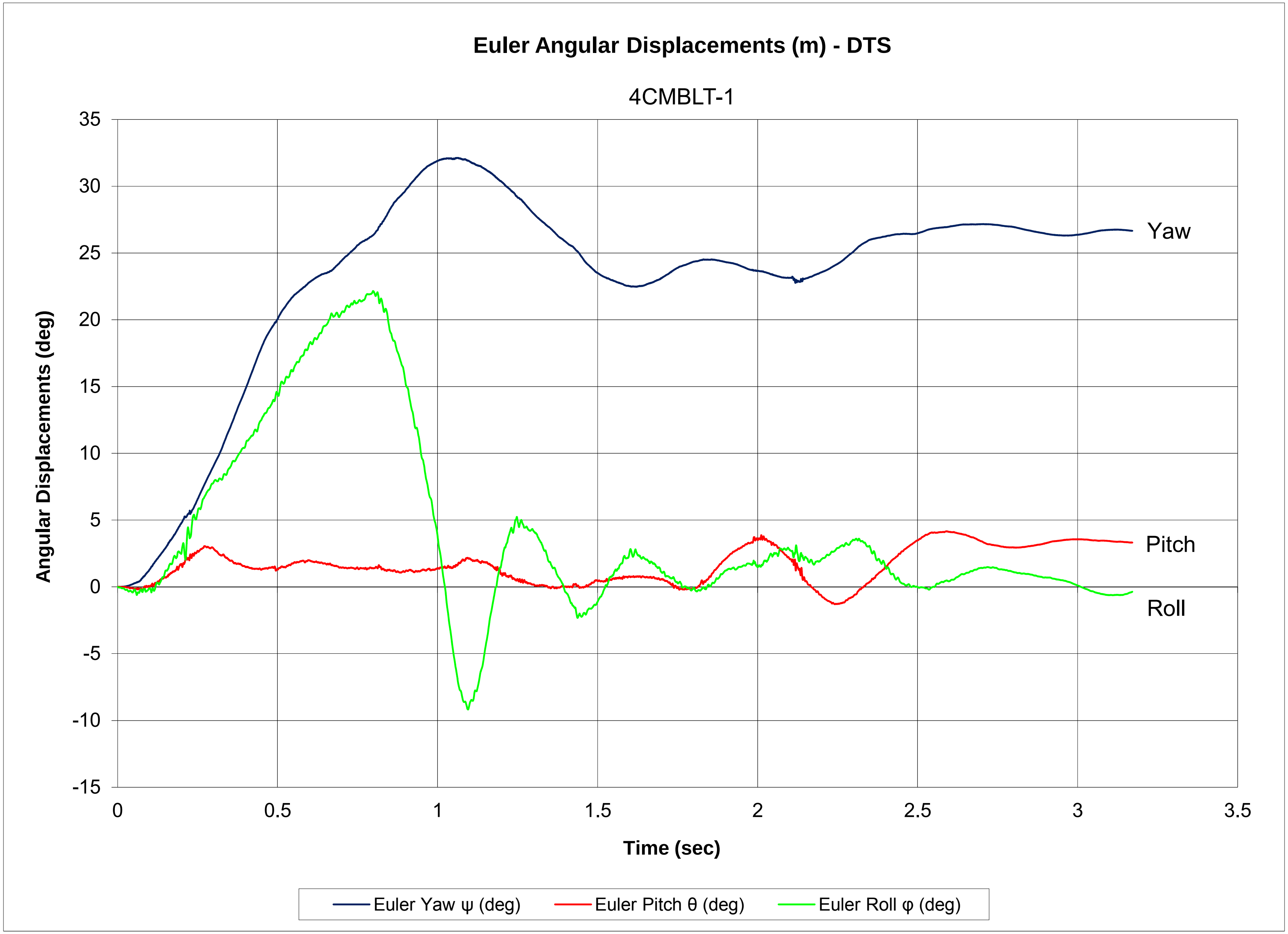


Figure E-7. Vehicle Angular Displacements (DTS), Test No. 4CMBLT-1

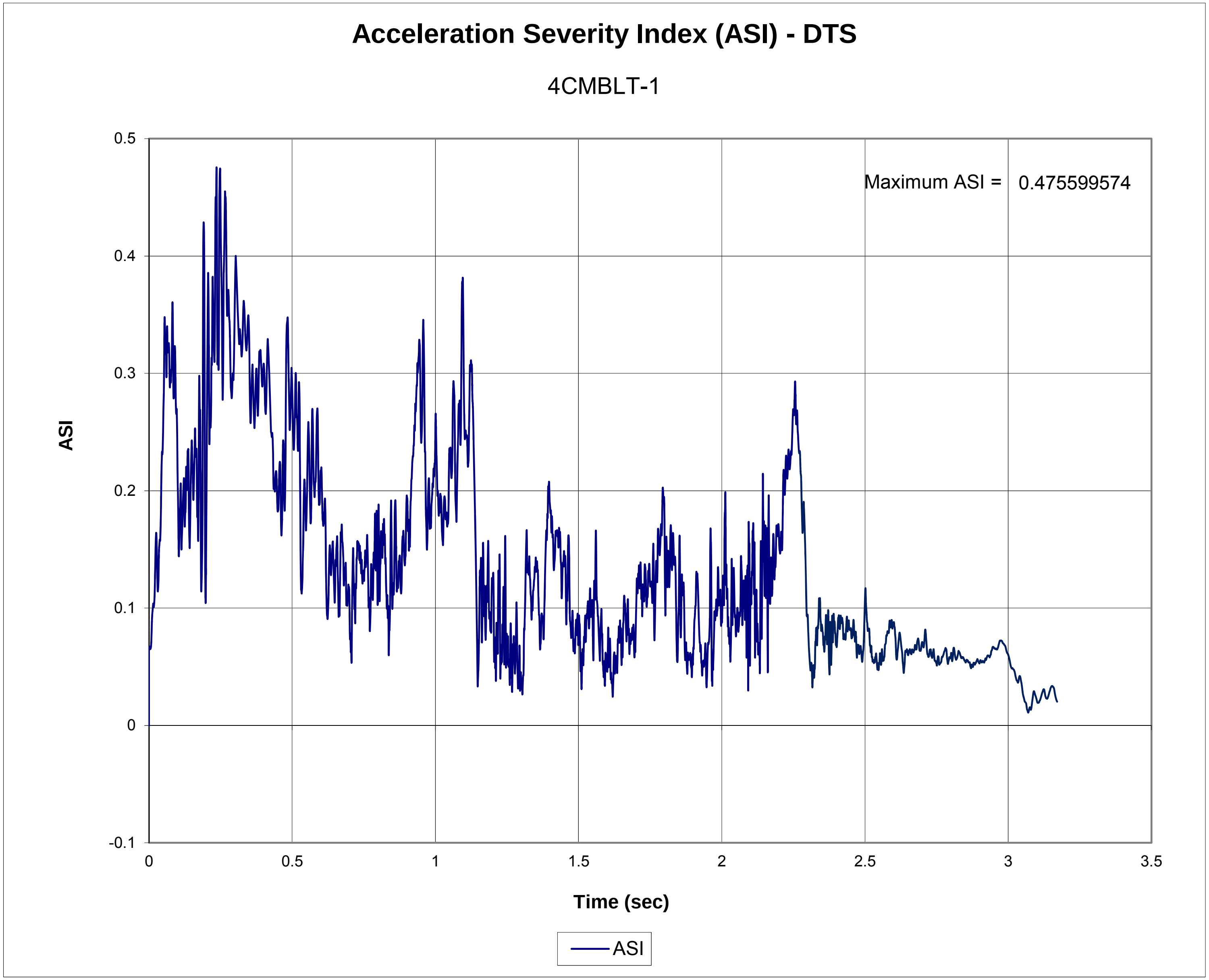


Figure E-8. Acceleration Severity Index (DTS), Test No. 4CMBLT-1

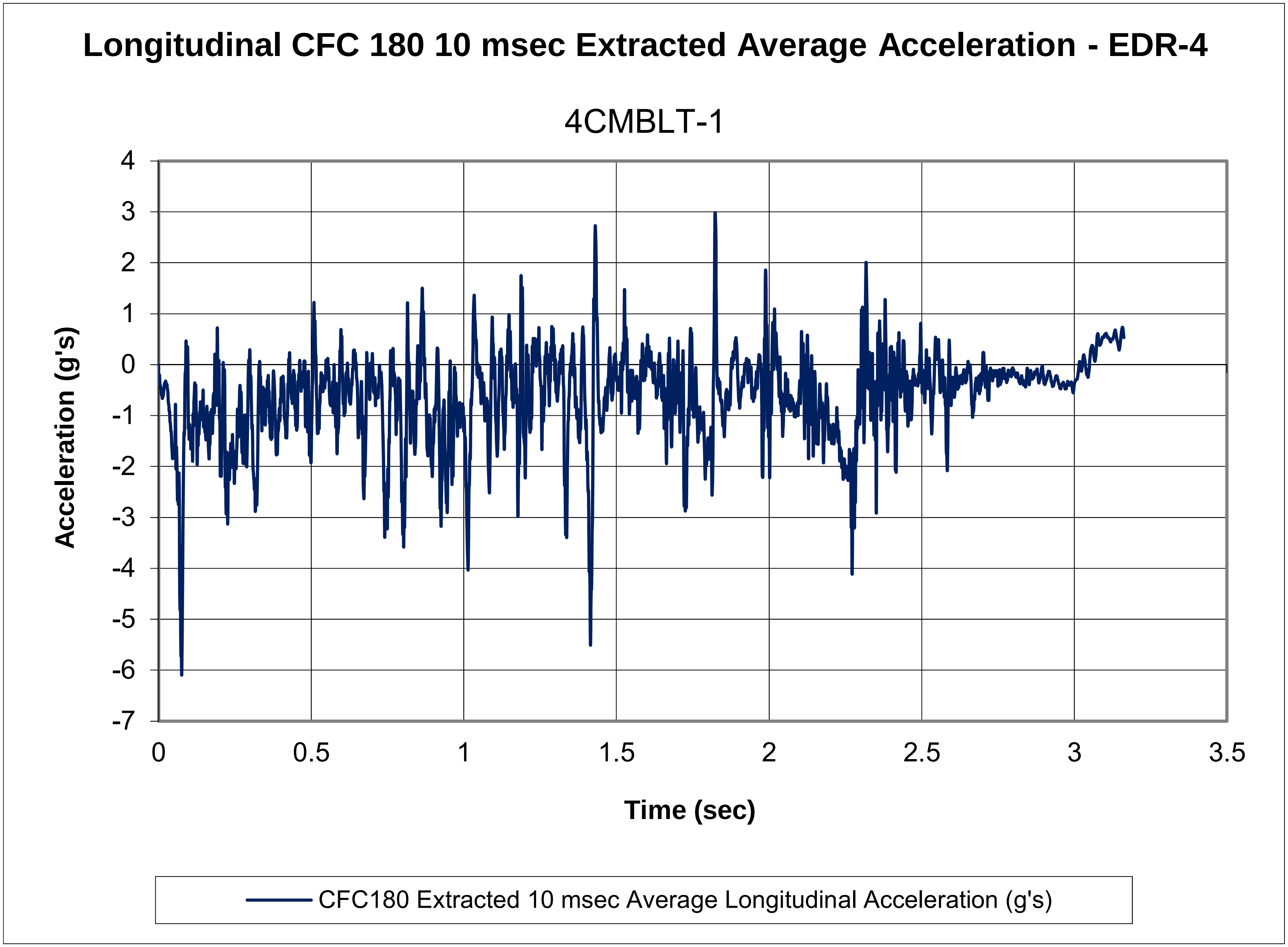


Figure E-9. 10-ms Average Longitudinal Deceleration (EDR-4), Test No. 4CMBLT-1

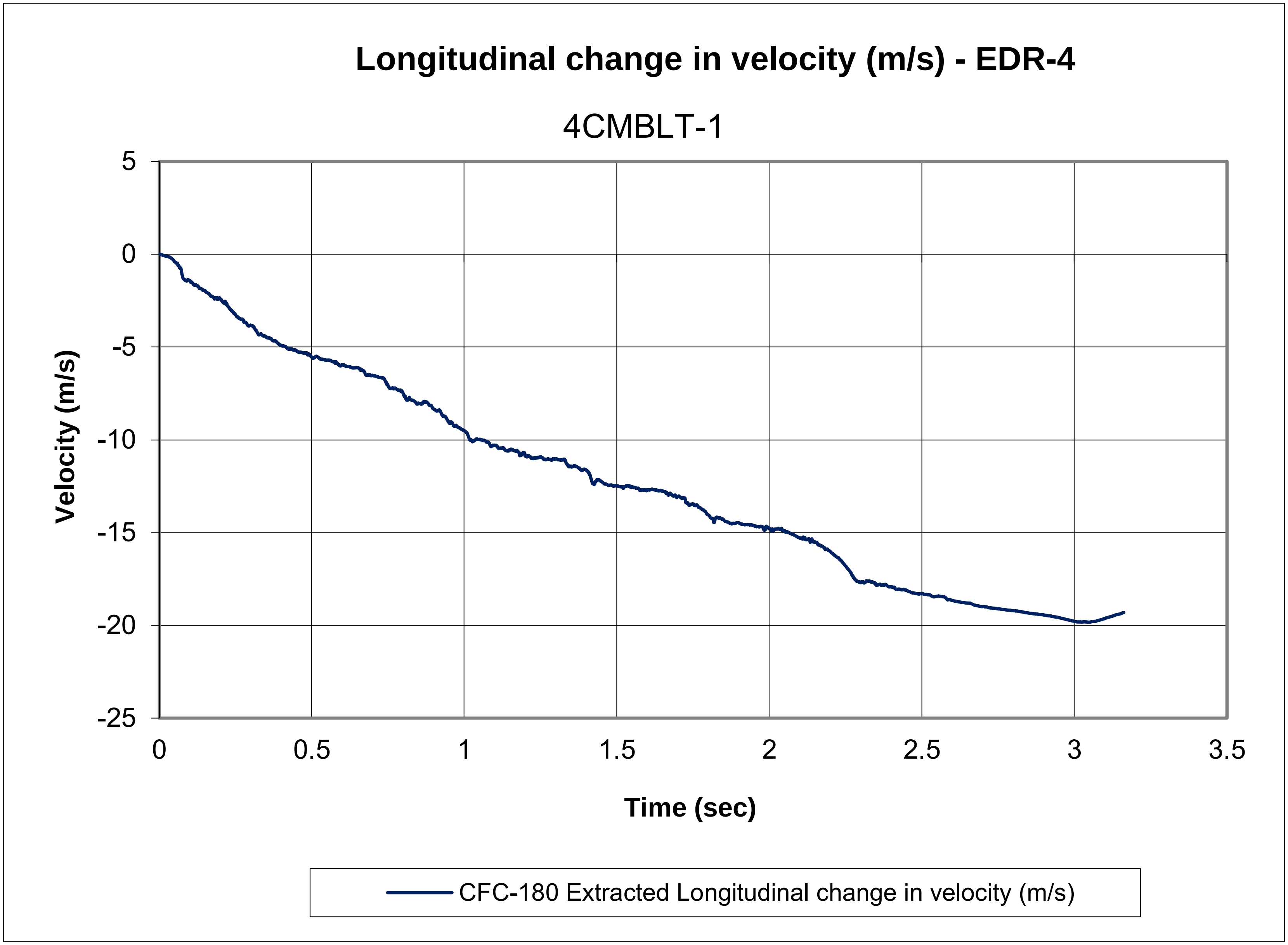


Figure E-10. Longitudinal Occupant Impact Velocity (EDR-4), Test No. 4CMBLT-1

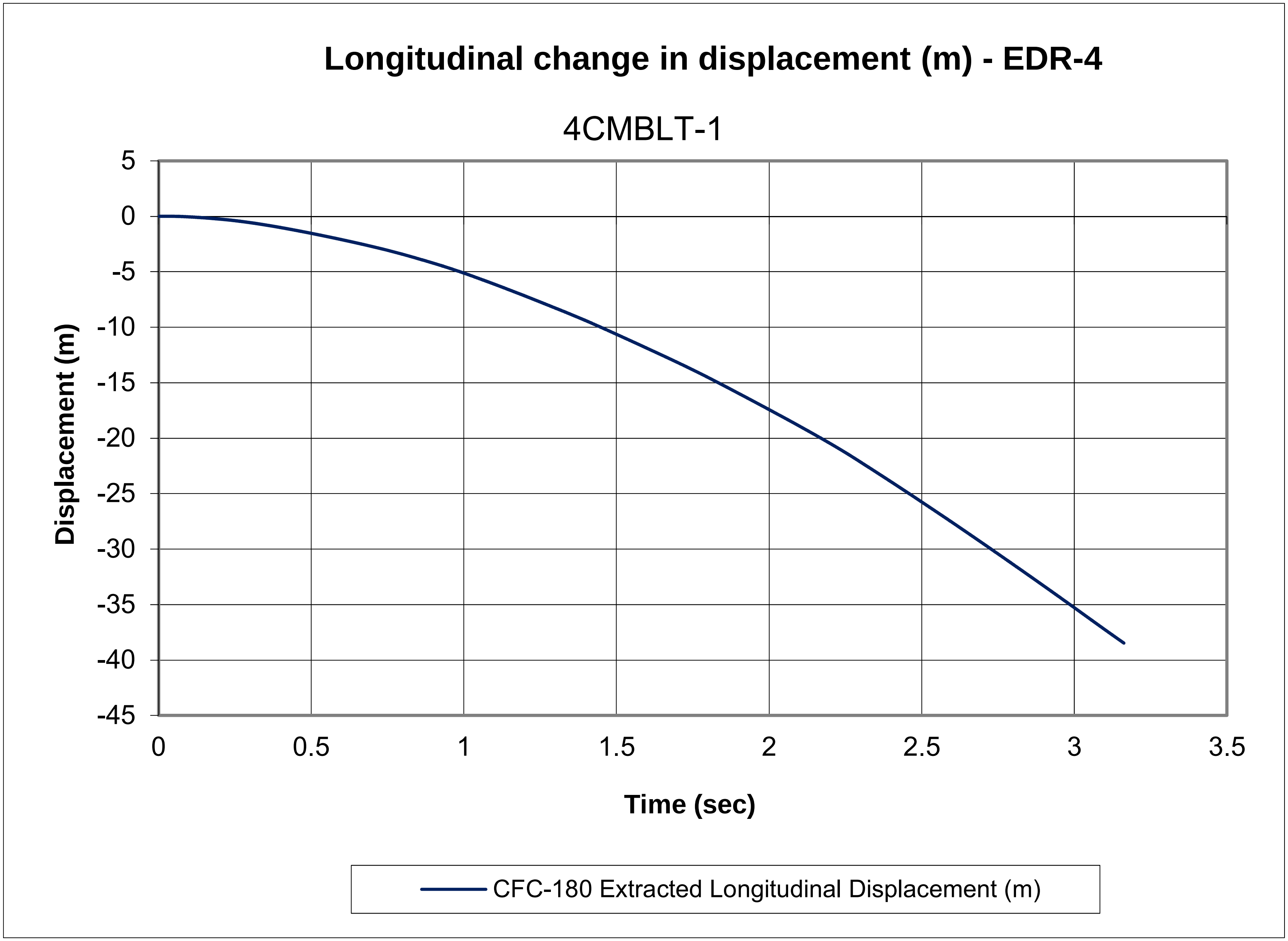


Figure E-11. Longitudinal Occupant Displacement (EDR-4), Test No. 4CMBLT-1

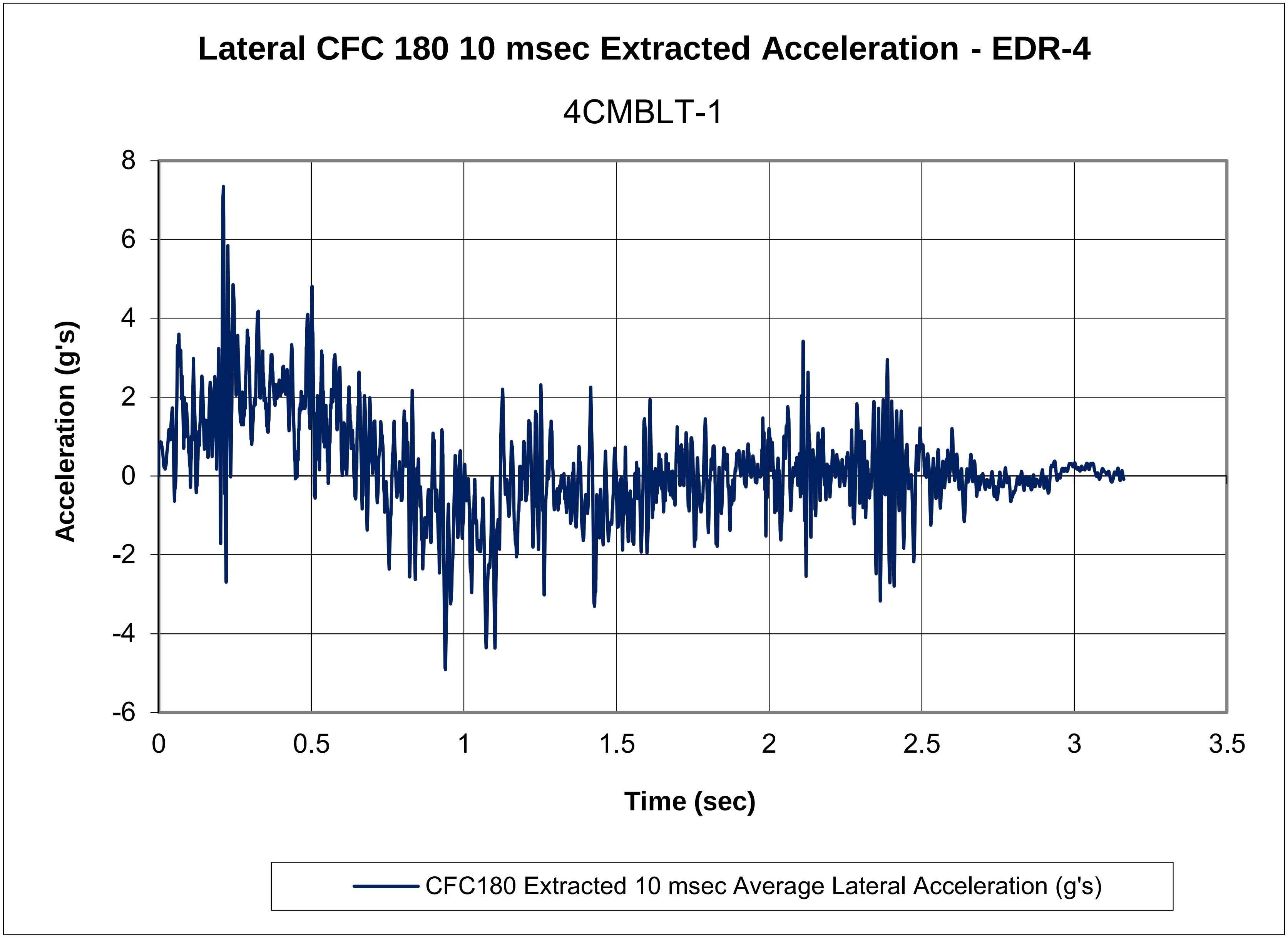


Figure E-12. 10-ms Average Lateral Deceleration (EDR-4), Test No. 4CMBLT-1

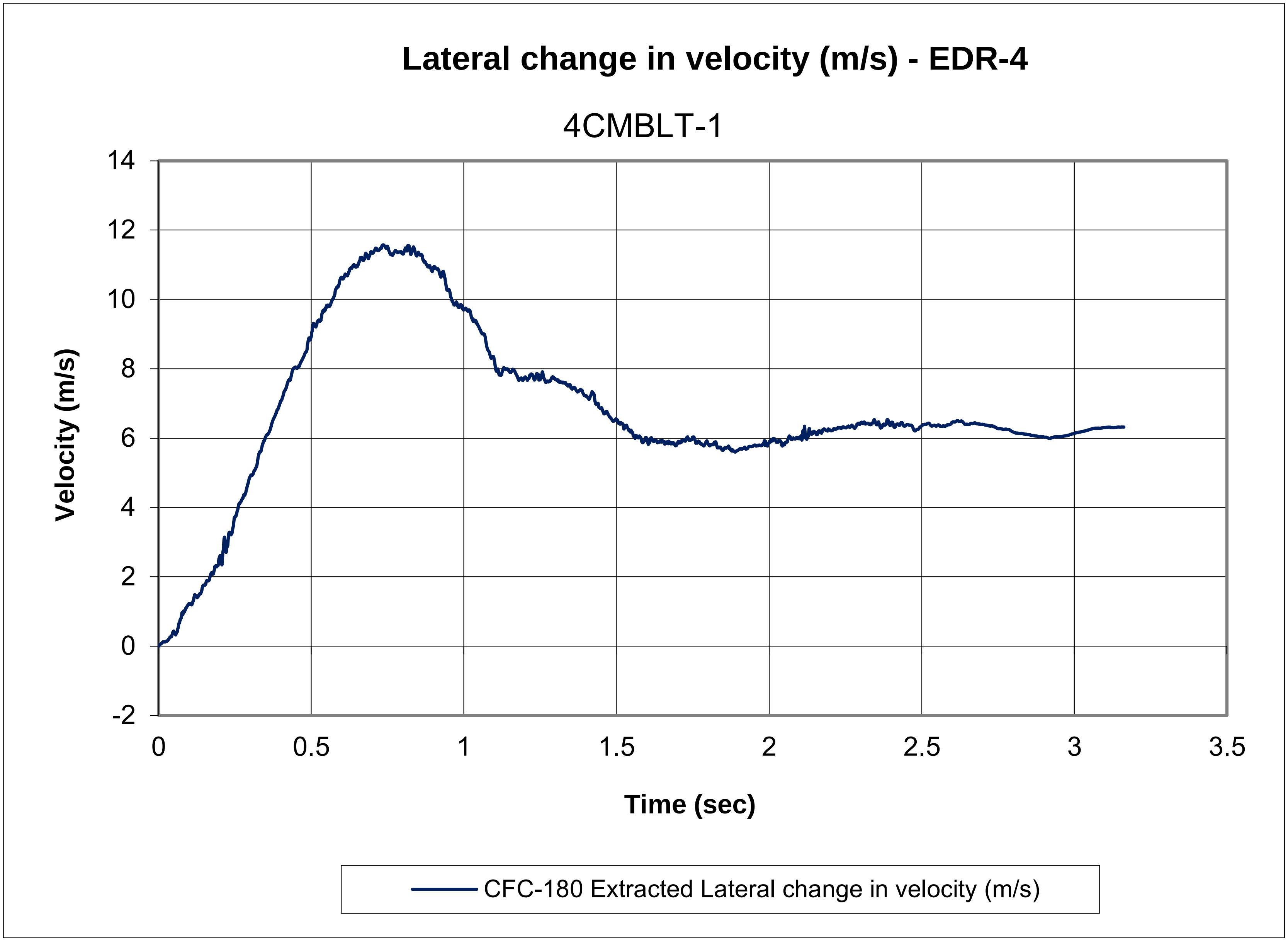


Figure E-13. Lateral Occupant Impact Velocity (EDR-4), Test No. 4CMBLT-1

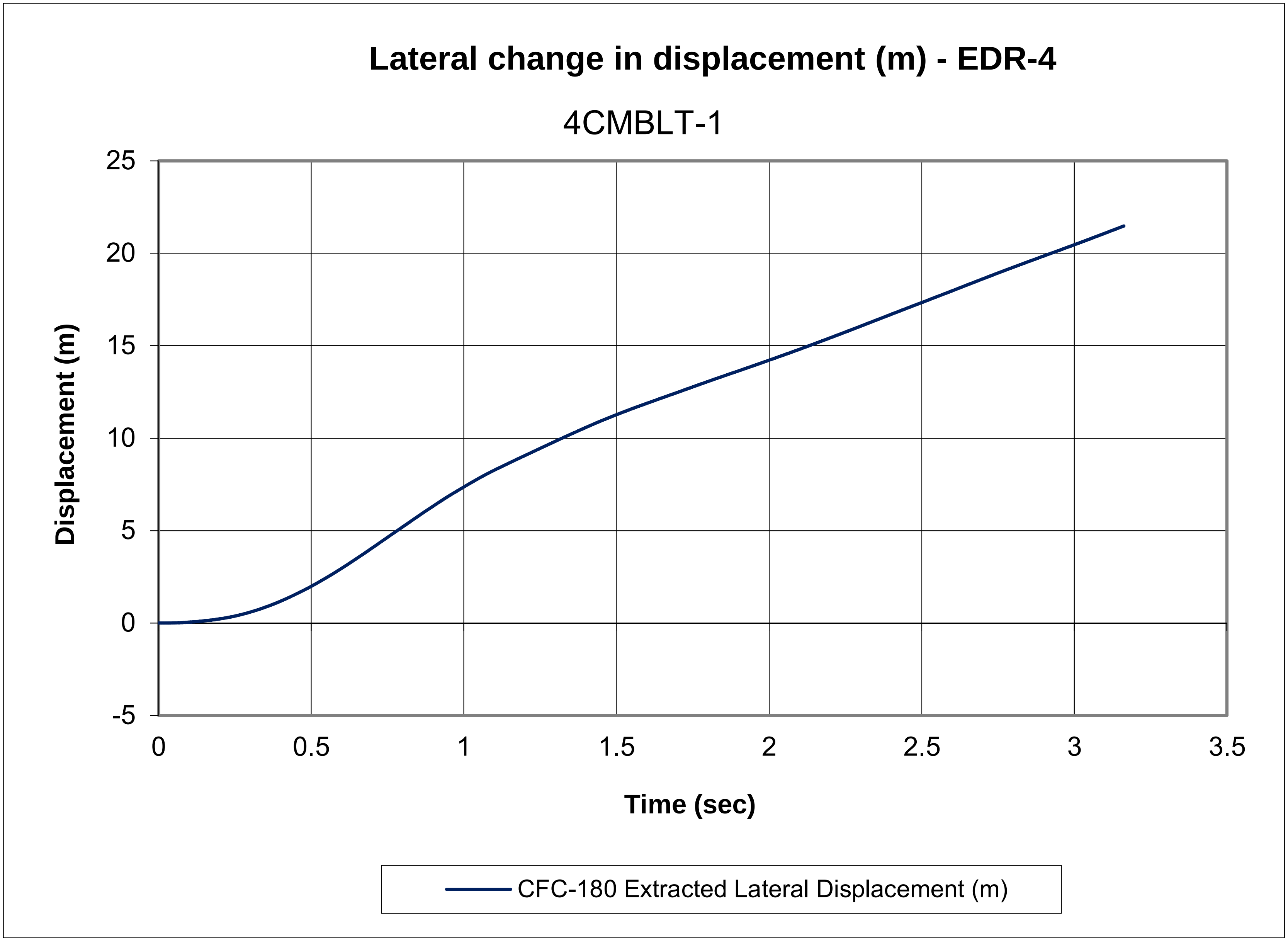


Figure E-14. Lateral Occupant Displacement (EDR-4), Test No. 4CMBLT-1

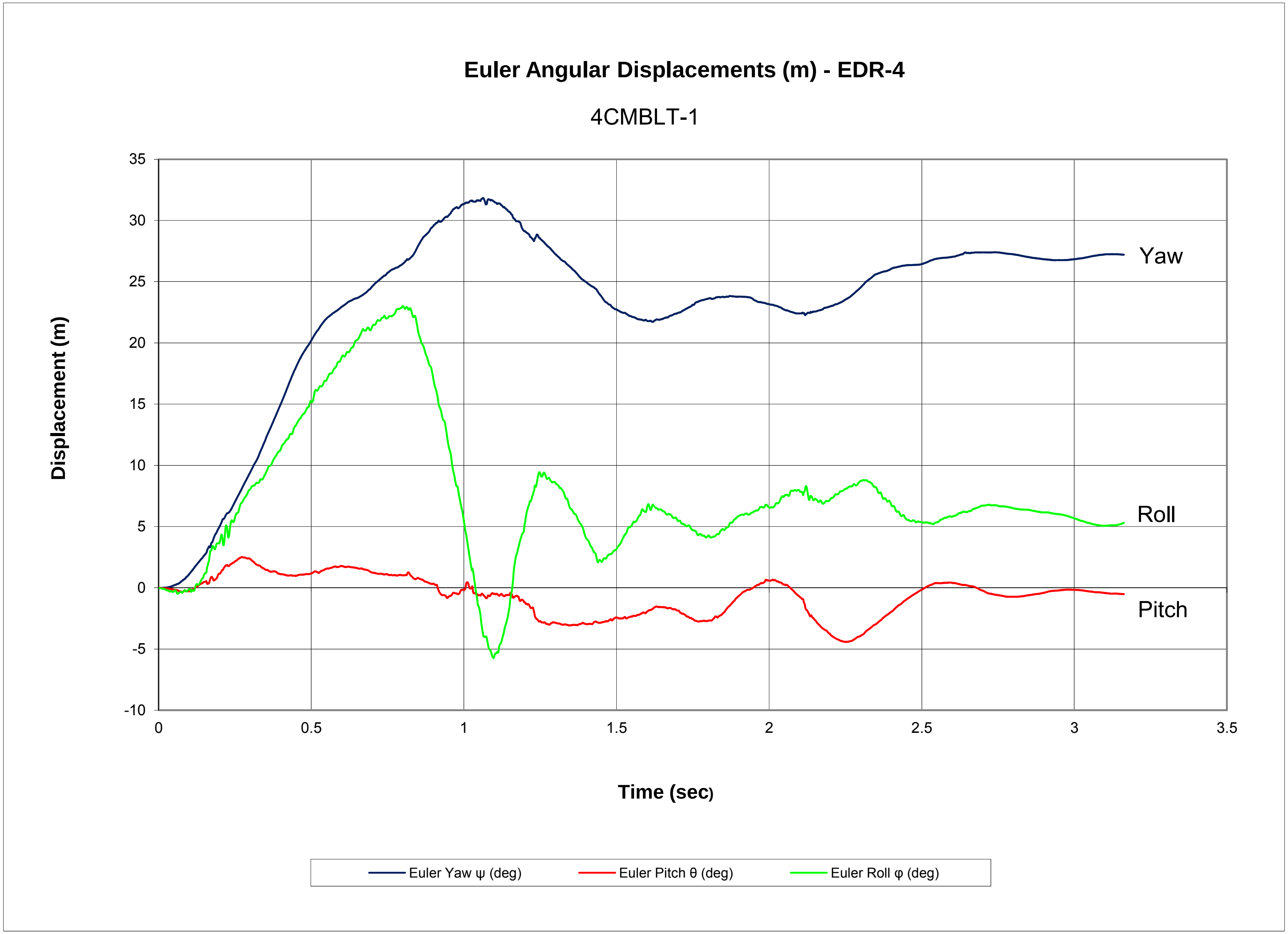


Figure E-15. Vehicle Angular Displacements (EDR-4), Test No. 4CMBLT-1

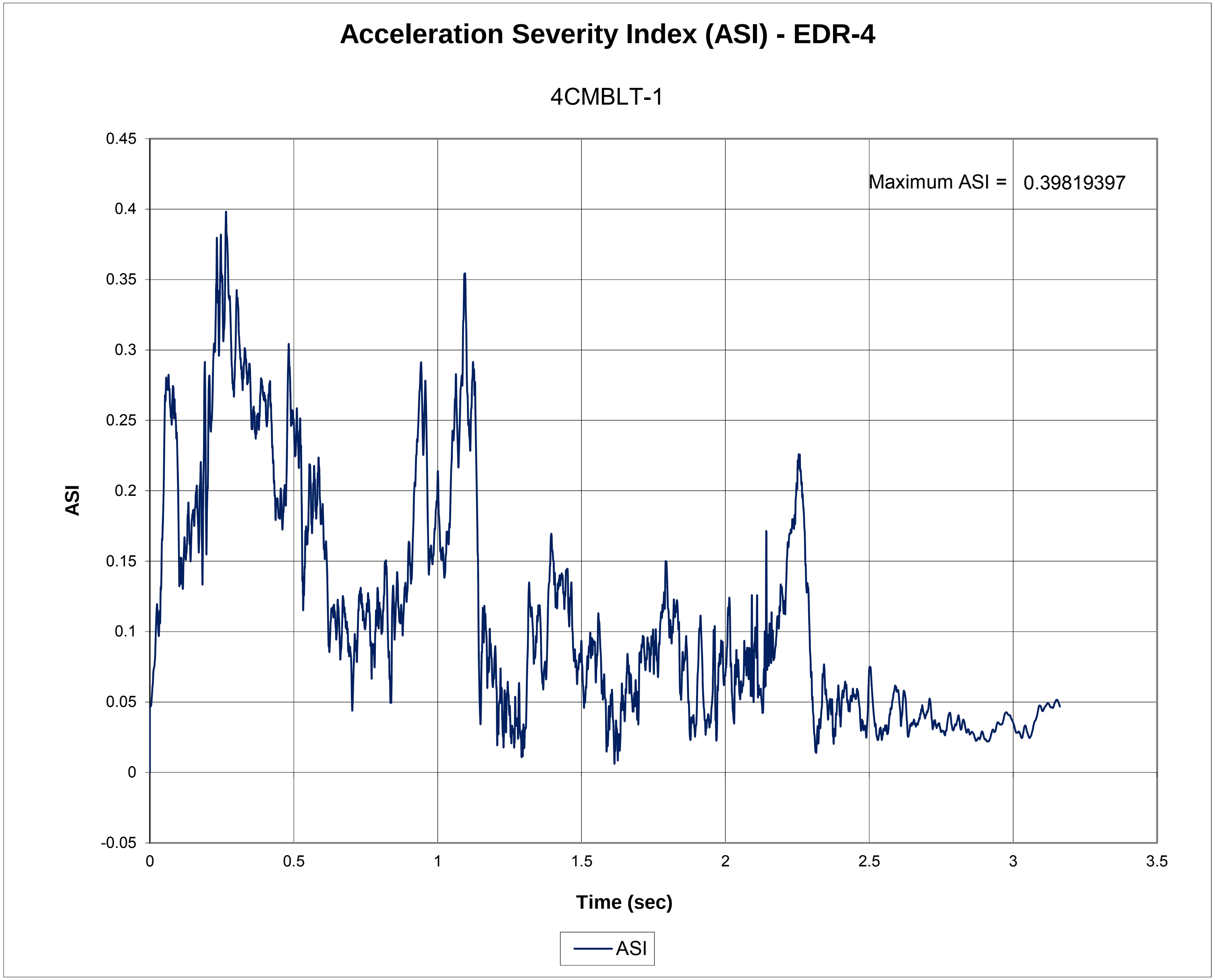


Figure E-16. Acceleration Severity Index (EDR-4), Test No. 4CMBLT-1

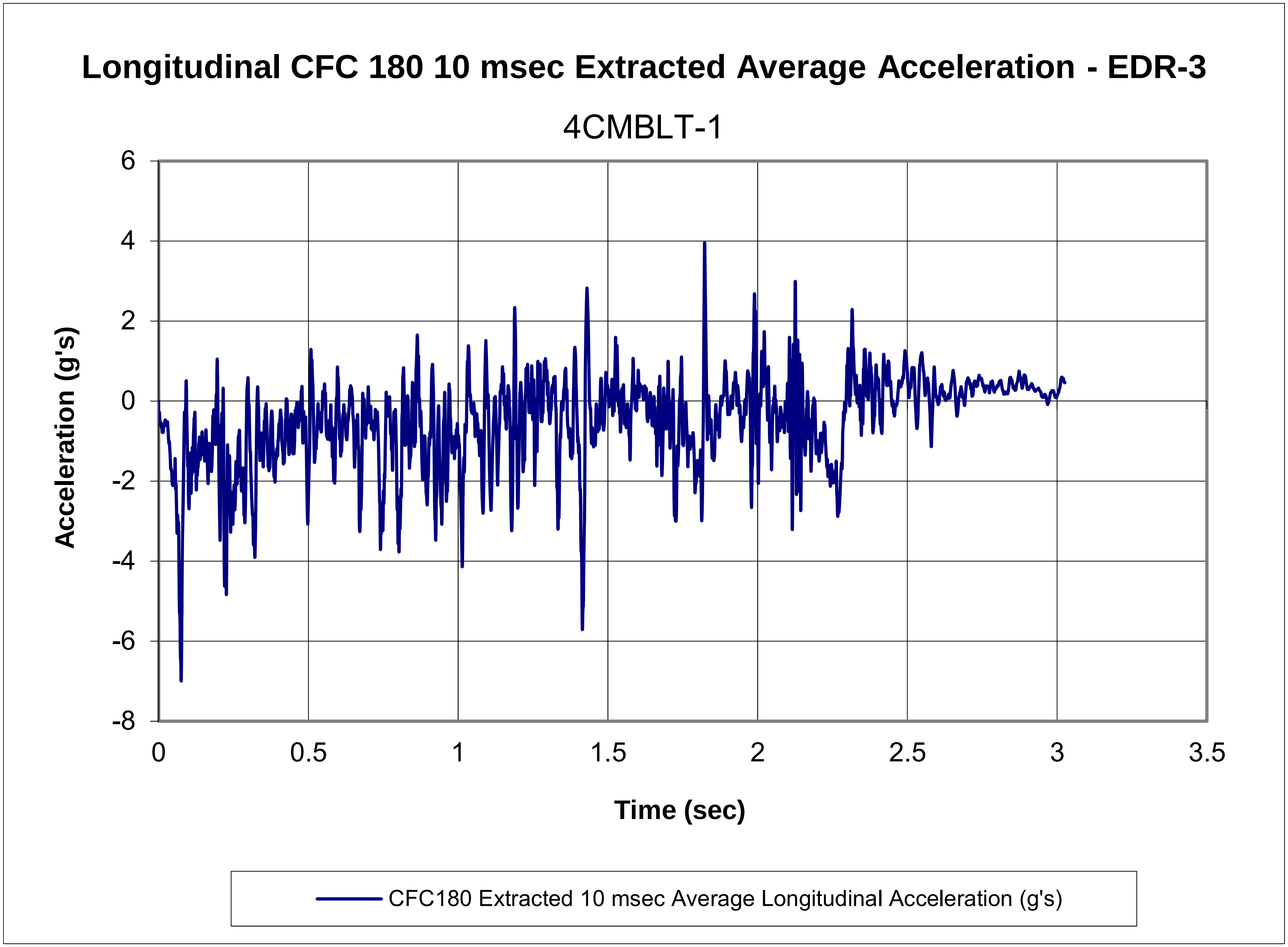


Figure E-17. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. 4CMBLT-1

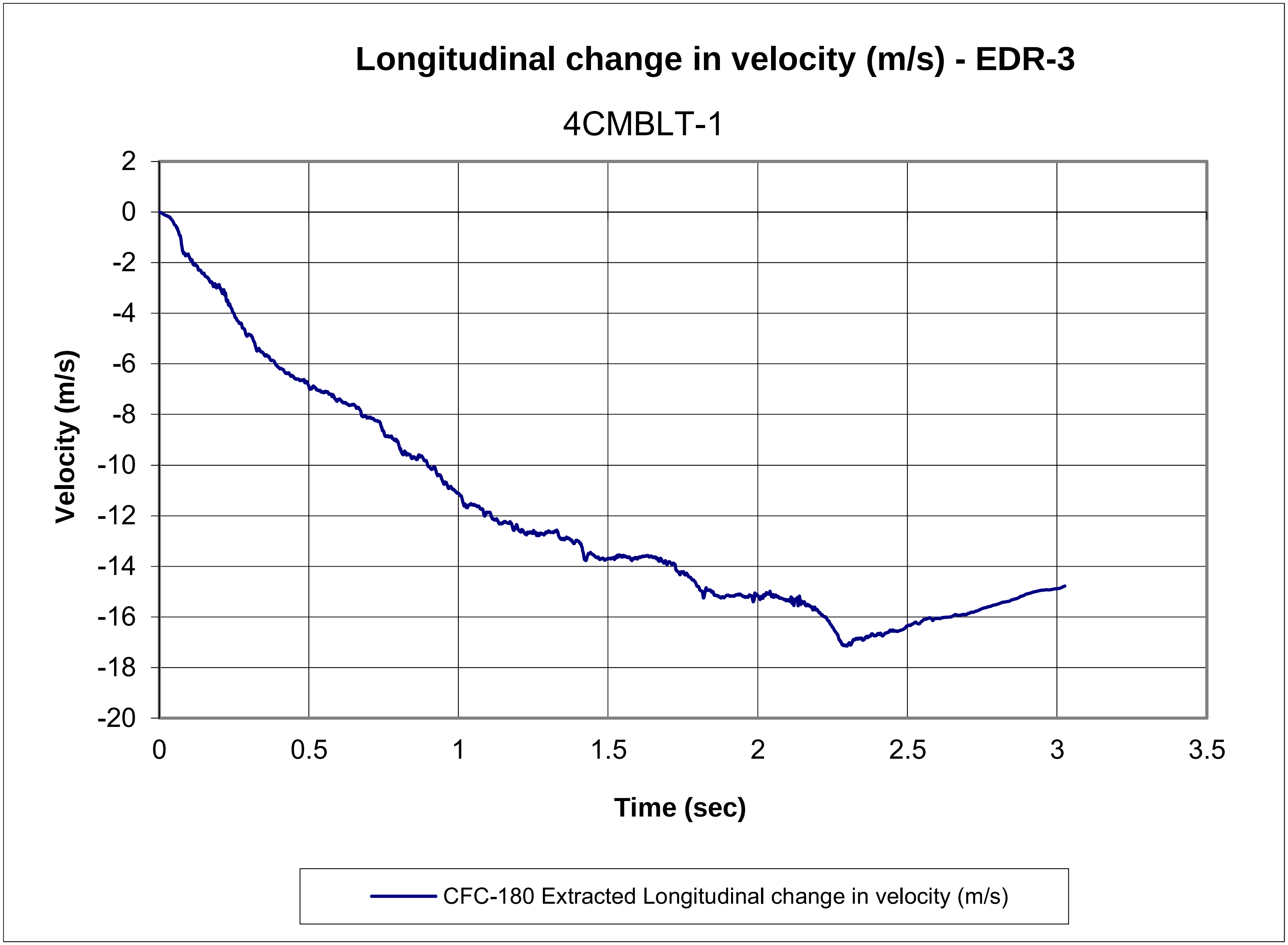


Figure E-18. Longitudinal Occupant Impact Velocity (EDR-3), Test No. 4CMBLT-1

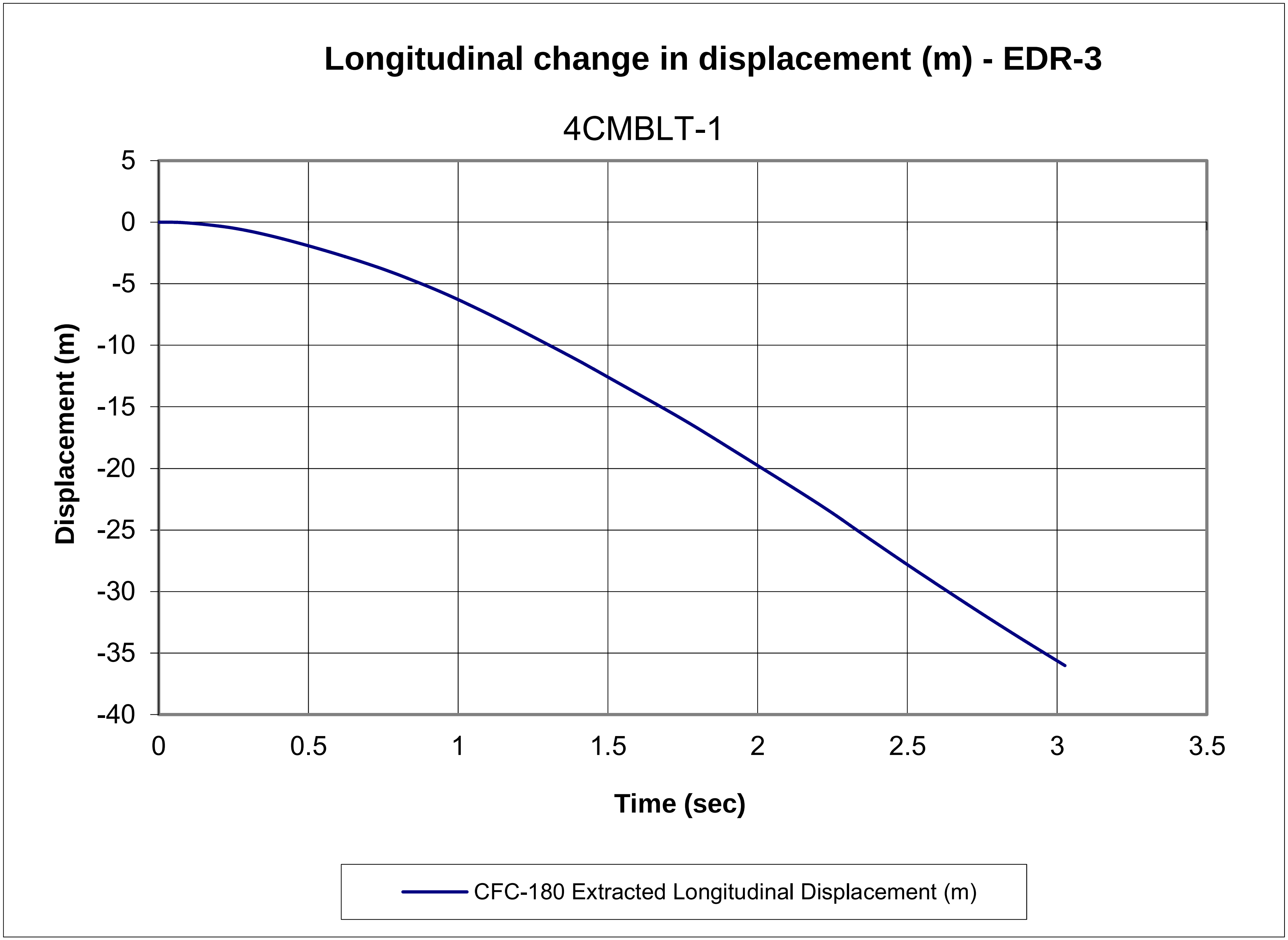


Figure E-19. Longitudinal Occupant Displacement (EDR-3), Test No. 4CMBLT-1

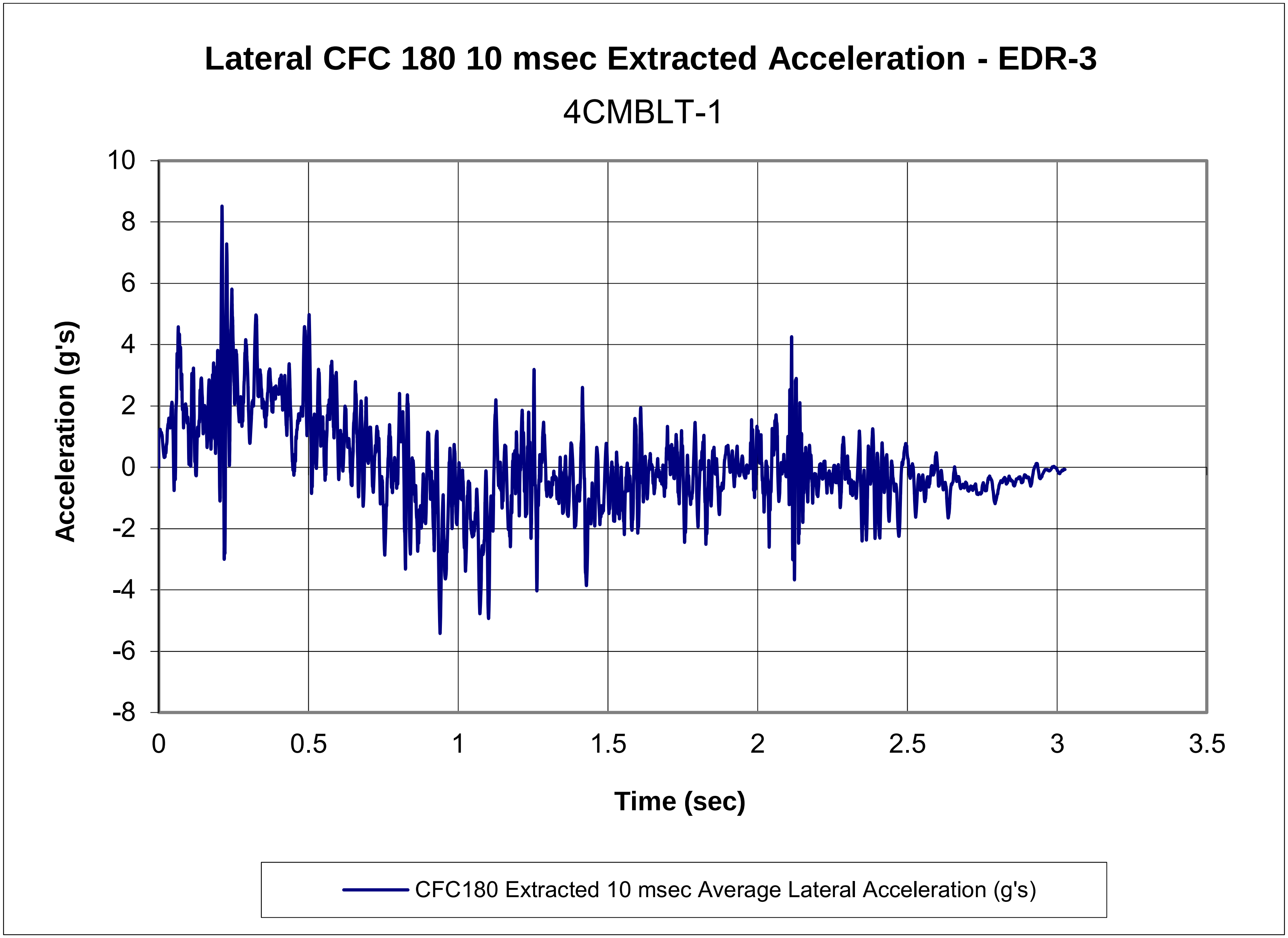


Figure E-20. 10-ms Average Lateral Deceleration (EDR-3), Test No. 4CMBLT-1

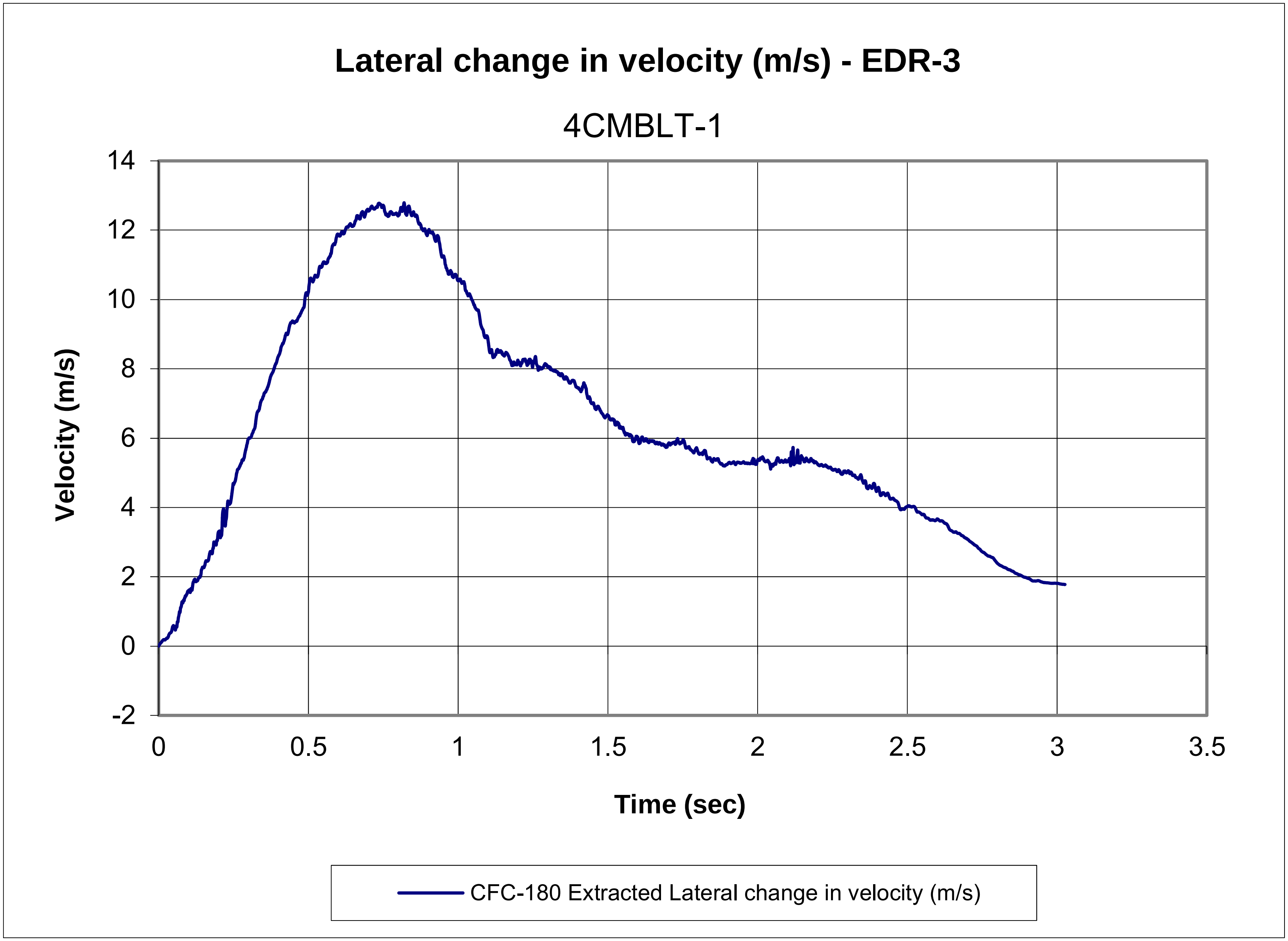


Figure E-21. Lateral Occupant Impact Velocity (EDR-3), Test No. 4CMBLT-1

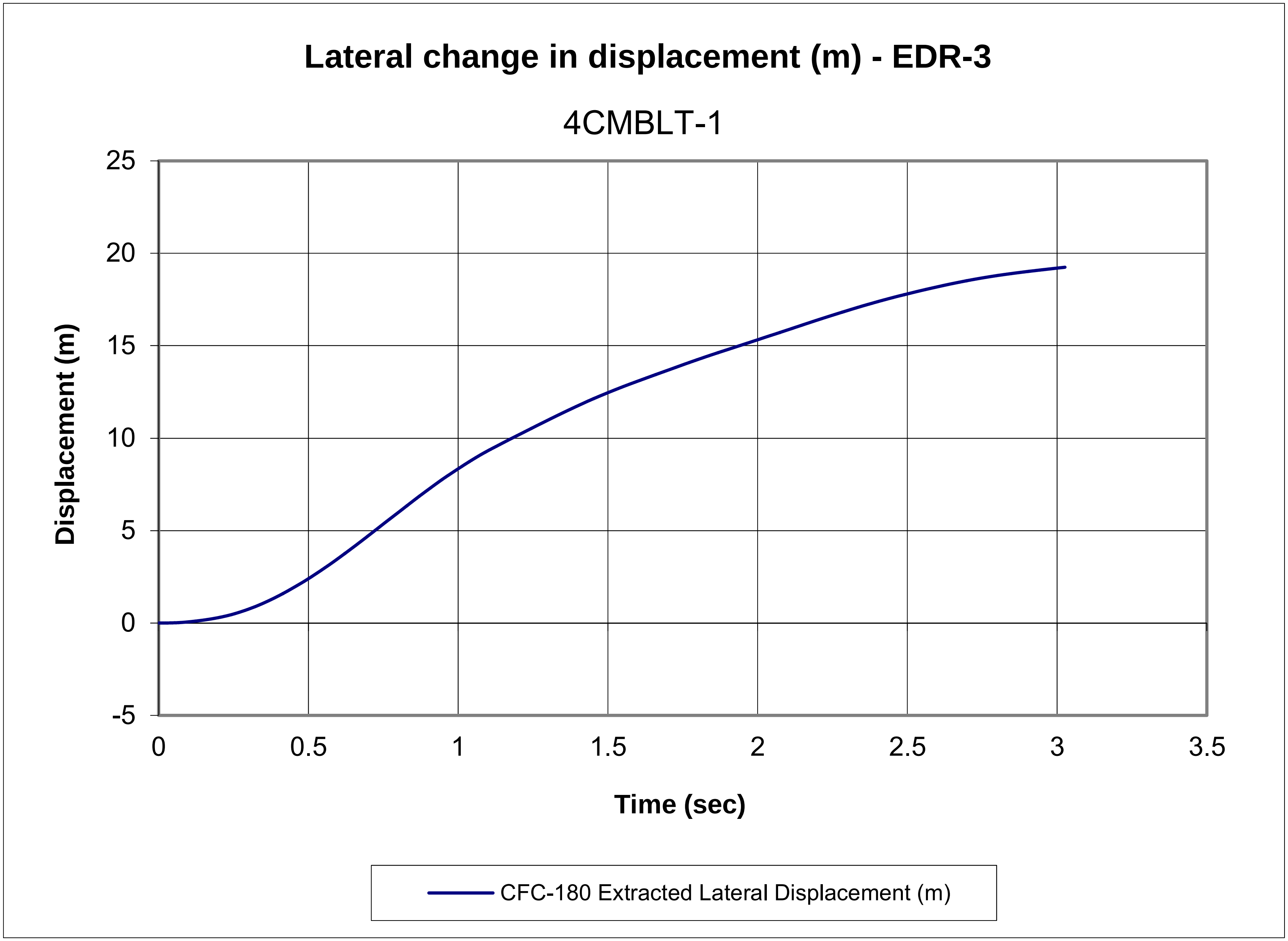


Figure E-22. Lateral Occupant Displacement (EDR-3), Test No. 4CMBLT-1

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