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DYNAMIC EVALUATION OF MGS STIFFNESS TRANSITION WITH CURB

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16. Abstract (Limit: 200 words)

A W-beam to thrie beam stiffness transition with a 4-in. (102-mm) tall concrete curb was developed to connect the 31-in. (787-mm) Midwest Guardrail System (MGS) to a previously-approved thrie beam approach guardrail bridge transition system. This stiffness transition was configured with standard steel posts that are commonly used by several State Departments of Transportation. The toe of a 4-in. (102-mm) tall sloped concrete curb was placed flush with the backside face of the guardrail and extended the length of the transition region. Three full-scale crash tests were conducted according to the Test Level 3 (TL-3) safety standards provided in AASHTO's *Manual for Assessing Safety Hardware* (MASH). During the first test, MASH test no. 3-20, the 1100C small car extended and wedged under the rail and contacted posts while traversing the curb. Subsequently, the W-beam rail ruptured at a splice location. A repeat of MASH test no. 3-20 was performed on an updated design which used a 12-ft 6-in. (3.81-m) long, nested W-beam rail segment upstream from the W-beam to thrie beam transition element. The 1100C small car was successfully contained and redirected. During MASH test no. 3-21, a 2270P pickup truck was successfully contained and redirected. Following the crash testing program, the system was deemed acceptable according to the Test Level 3 (TL-3) safety performance criteria specified in MASH.

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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 Dr. Cody Stolle, Post-Doctoral Research Assistant.

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1 INTRODUCTION

1.1 Background

In 2010, Midwest Roadside Safety Facility (MwRSF) researchers successfully developed and crash tested a simplified, upstream stiffness transition for connecting 31-in. (787-mm) tall Midwest Guardrail System (MGS) to existing, thrie beam approach guardrail transition systems [1-2]. The approach guardrail transition consisted of standard 12-gauge (2.66-mm thick) W-beam guardrail, an asymmetrical 10-gauge (3.42-mm thick) W-beam to thrie beam transition element, standard 12-gauge (2.66-mm thick) thrie beam guardrail, and nested 12-gauge (2.66 mm thick) thrie beam guardrail. The approach guardrail transition was supported by two post types - W6x8.5 (W152x12.6) steel sections and W6x15 (W152x22.3) steel sections - using various spacing. Crash testing was successfully performed in accordance with the Test Level 3 (TL-3) impact safety standards published in the American Association and State Highway Officials (AASHTOs) *Manual for Assessing Safety Hardware* (MASH) [3].

However, this barrier system was not evaluated with a lower concrete curb. The addition of a curb may negatively affect the performance of the system in a number of ways. For example, a curb may cause vehicle instabilities and/or rollovers during redirections in this stiffness-sensitive region. Additionally, small car front ends may become wedged between the curb and the bottom of the W-to-thrie transition segment which can lead to excessive snagging. Therefore, the performance of the MGS stiffness transition installed with curb needed to be evaluated through full-scale testing.

1.2 Objective

The objective of the research project was to evaluate the safety performance of the MGS stiffness transition to thrie beam approach transitions configured with a lower concrete curb. The safety performance evaluation was conducted according to the TL-3 impact safety standards published in MASH.

1.3 Scope

The research objective was achieved through the completion of several tasks. First, an actual test installation was constructed for the MGS stiffness transition attached to a stiff thrie beam approach guardrail transition, including a lower 4-in. (102-mm) concrete curb. Next, three full-scale vehicle crash tests were performed in accordance with TL-3 impact conditions of MASH. The test results were analyzed, evaluated, and documented. Finally, conclusions and recommendations were made that pertain to the safety performance of the stiffness transition between the MGS and a crashworthy thrie beam approach guardrail transition system.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as guardrail transitions, 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. 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. 3-20 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. 3-21 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 1.

Table 1. 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	3-20	1100C	62	100	25	A,D,F,H,I
	3-21	2270P	62	100	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

2.2 Evaluation Criteria

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

2.3 Soil Strength Requirements

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

Table 2. MASH Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 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>

3 TEST CONDITIONS

3.1 Test Facility

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

3.2 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 [4] was used to steer the test vehicle. A guide flag, attached to the right-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (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.

3.3 Test Vehicles

For test no. MWTC-1, a 2007 Kia Rio was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,468 lb (1,119 kg), 2,457 lb (1,114 kg), and 2,623 lb (1,190 kg), respectively. The test vehicle is shown in Figure 1, and vehicle dimensions are shown in Figure 2.

For test no. MWTC-2, a 2007 Kia Rio was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,390 lb (1,084 kg), 2,410 lb (1,093 kg), and 2,575 lb

(1,168 kg), respectively. The test vehicle is shown in Figure 3, and vehicle dimensions are shown in Figure 4.

For test no. MWTC-3, a 2006 Dodge Ram 1500 Quad Cab was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,134 lb (2,329 kg), 4,969 lb (2,254 kg), and 5,135 lb (2,329 kg), respectively. The test vehicle is shown in Figure 5, and vehicle dimensions are shown in Figure 6.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [5] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The vertical component of the c.g. for the 1100C vehicle was estimated based on historical c.g. height measurements. The location of the final c.g. is shown in Figures 2, 4, and 6. Data used to calculate the location of the c.g. and ballast information are shown in Appendix A.

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 Figures 7 through 9. Round, checkered targets were placed on the center of gravity on the left-side door, the right-side door, and the roof of the vehicle. The remaining targets were located so that they could be viewed from the high-speed cameras and used as reference points for video analysis.

Figure 1. Test Vehicle, Test No. MWTC-1

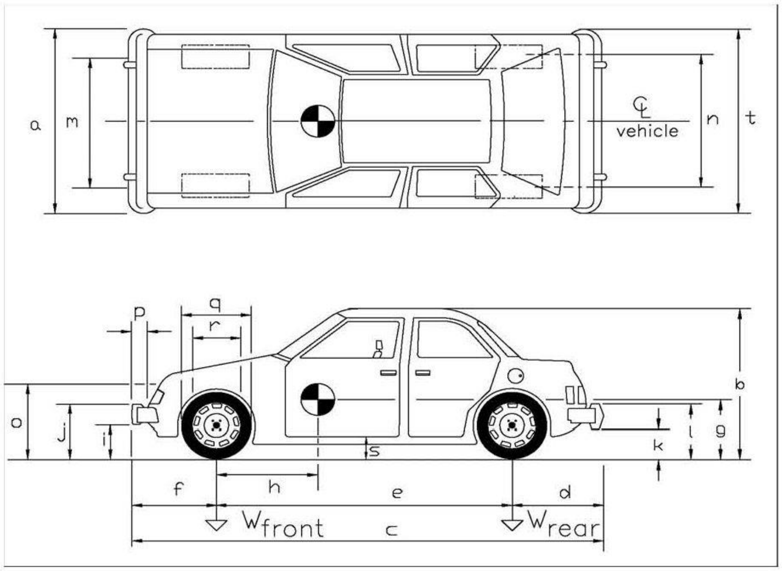
Date: 8/10/2012 **Test Number:** MWTC-1 **Model:** 1100C

Make: Kia Rio Sedan **Vehicle I.D.#:** KNADE123576216804

Tire Size: 185/65 R14 **Year:** 2007 **Odometer:** 146260

Tire Inflation Pressure:

*(All Measurements Refer to Impacting Side)



Vehicle Geometry -- in. (mm)

a	61 1/4	(1556)	b	58	(1473)
c	167	(4242)	d	35 1/2	(902)
e	98 1/2	(2502)	f	33	(838)
g	19	(483)	h	36	(912)
i	9	(229)	j	22 1/2	(572)
k	13	(330)	l	25	(635)
m	57 3/4	(1467)	n	57 3/8	(1457)
o	27 7/8	(708)	p	4	(102)
q	23	(584)	r	15 1/4	(387)
s	11 3/4	(298)	t	62	(1575)

Wheel Center Height Front	10 3/4	(273)
Wheel Center Height Rear	11 1/8	(283)
Wheel Well Clearance (F)	25 1/8	(638)
Wheel Well Clearance (R)	24 7/8	(632)
Frame Height (F)	6 1/4	(159)
Frame Height (R)	15 3/4	(400)
Engine Type	4cyl. Gas	
Engine Size	1.6L	

Mass Distribution lb (kg)

Gross Static	LF	846 (384)	RF	800 (363)
	LR	490 (222)	RR	487 (221)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1594 (723)	1561 (708)	1646 (747)
W-rear	874 (396)	896 (406)	977 (443)
W-total	2468 (1119)	2457 (1114)	2623 (1190)

Transmition Type:

[✓ Automatic] Manual

[✓ FWD] RWD 4WD

GVWR Ratings

Front 1918
Rear 1874
Total 3638

Dummy Data

Type: Hybrid 1
Mass: 166 lbs.
Seat Position: Driver

Note any damage prior to test: none

Figure 2. Vehicle Dimensions, Test No. MWTC-1

Figure 3. Test Vehicle, Test No. MWTC-2

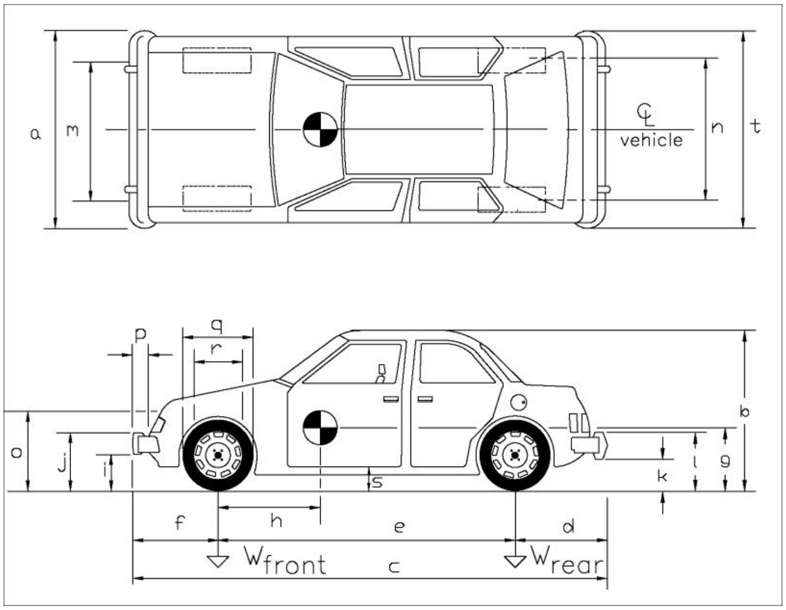
Date: 11/30/2012
Test Number: MWTC-2
Model: 1100C/Rio

Make: Kia
Vehicle I.D.#: KNADE123476250877

Tire Size: 185/65 R14
Year: 2007
Odometer: 92220

Tire Inflation Pressure: 32psi

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



Vehicle Geometry -- in. (mm)

a	62	(1575)	**b**	57 1/4	(1454)
c	166 1/2	(4229)	**d**	37	(940)
e	98 1/2	(2502)	**f**	31	(787)
g	18	(457)	**h**	38	(965)
i	9	(229)	**j**	22 1/2	(572)
k	12 1/2	(318)	**l**	25	(635)
m	57 1/4	(1454)	**n**	57 1/4	(1454)
o	27 3/4	(705)	**p**	4	(102)
q	23	(584)	**r**	15 3/8	(391)
s	11 1/2	(292)	**t**	63 1/4	(1607)

Wheel Center Height Front	10 3/4	(273)
Wheel Center Height Rear	11 1/4	(286)
Wheel Well Clearance (F)	25	(635)
Wheel Well Clearance (R)	25	(635)
Frame Height (F)	6 1/8	(156)
Frame Height (R)	15 7/8	(403)

Engine Type 4 cyl gas

Engine Size 1.6L

Transmition Type:

Automatic [✓ Manual]

[✓ FWD] RWD 4WD

Mass Distribution lb (kg)

Gross Static	**LF**	800 (363)	**RF**	767 (348)
	LR	505 (229)	**RR**	503 (228)

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	1503 (682)	1483 (673)	1567 (711)
W-rear	887 (402)	927 (420)	1008 (457)
W-total	2390 (1084)	2410 (1093)	2575 (1168)

GVWR Ratings

Front 1918
Rear 1874
Total 3638

Dummy Data

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

Note any damage prior to test: None

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

Figure 5. Test Vehicle, Test No. MWTC-3

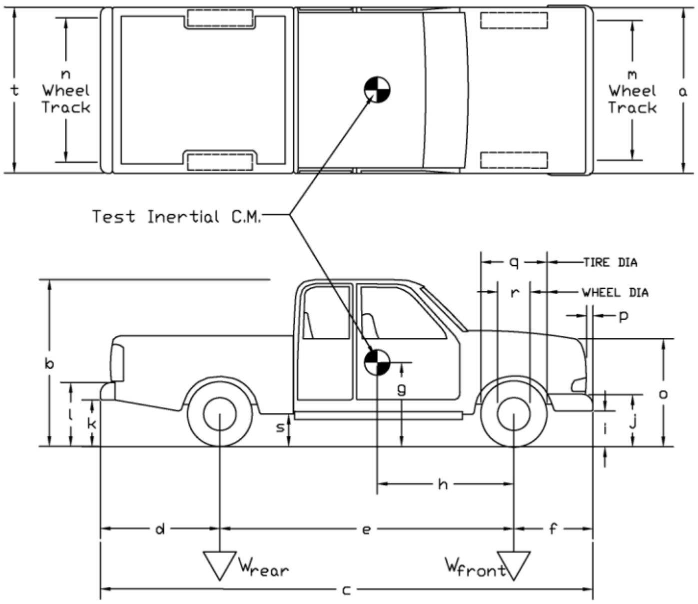
Date: 5/16/2013 **Test Number:** MWTC-3 **Model:** 2270P

Make: Dodge Ram 1500 QC **Vehicle I.D.#:** 1D7HA18N96J103433

Tire Size: 265/70 R17 **Year:** 2006 **Odometer:** 164687

Tire Inflation Pressure: 35psi

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



Vehicle Geometry -- in. (mm)

a 78 1/4 (1988) **b** 74 3/4 (1899)
c 227 1/2 (5779) **d** 47 1/4 (1200)
e 140 1/2 (3569) **f** 39 3/4 (1010)
g 28 1/2 (723) **h** 62 (1576)
i 15 1/4 (387) **j** 27 (686)
k 20 (508) **l** 28 1/2 (724)
m 68 5/8 (1743) **n** 67 1/2 (1715)
o 45 1/2 (1156) **p** 4 (102)
q 31 (787) **r** 18 1/4 (464)
s 15 1/2 (394) **t** 75 1/2 (1918)

Wheel Center Height Front 14 3/4 (375)
Wheel Center Height Rear 14 3/4 (375)
Wheel Well Clearance (F) 35 1/2 (902)
Wheel Well Clearance (R) 37 3/4 (959)
Frame Height (F) 18 1/2 (470)
Frame Height (R) 24 3/4 (629)
Engine Type 8 cyl.
Engine Size 4.7 Liter
Transmition Type:
[✓ Automatic] Manual
FWD [✓ RWD] 4WD

Mass Distribution lb (kg)

Gross Static **LF** 1476 (670) **RF** 1401 (635)
LR 1122 (509) **RR** 1136 (515)

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	2854 (1295)	2774 (1258)	2877 (1305)
W-rear	2280 (1034)	2195 (996)	2258 (1024)
W-total	5134 (2329)	4969 (2254)	5135 (2329)

GVWR Ratings

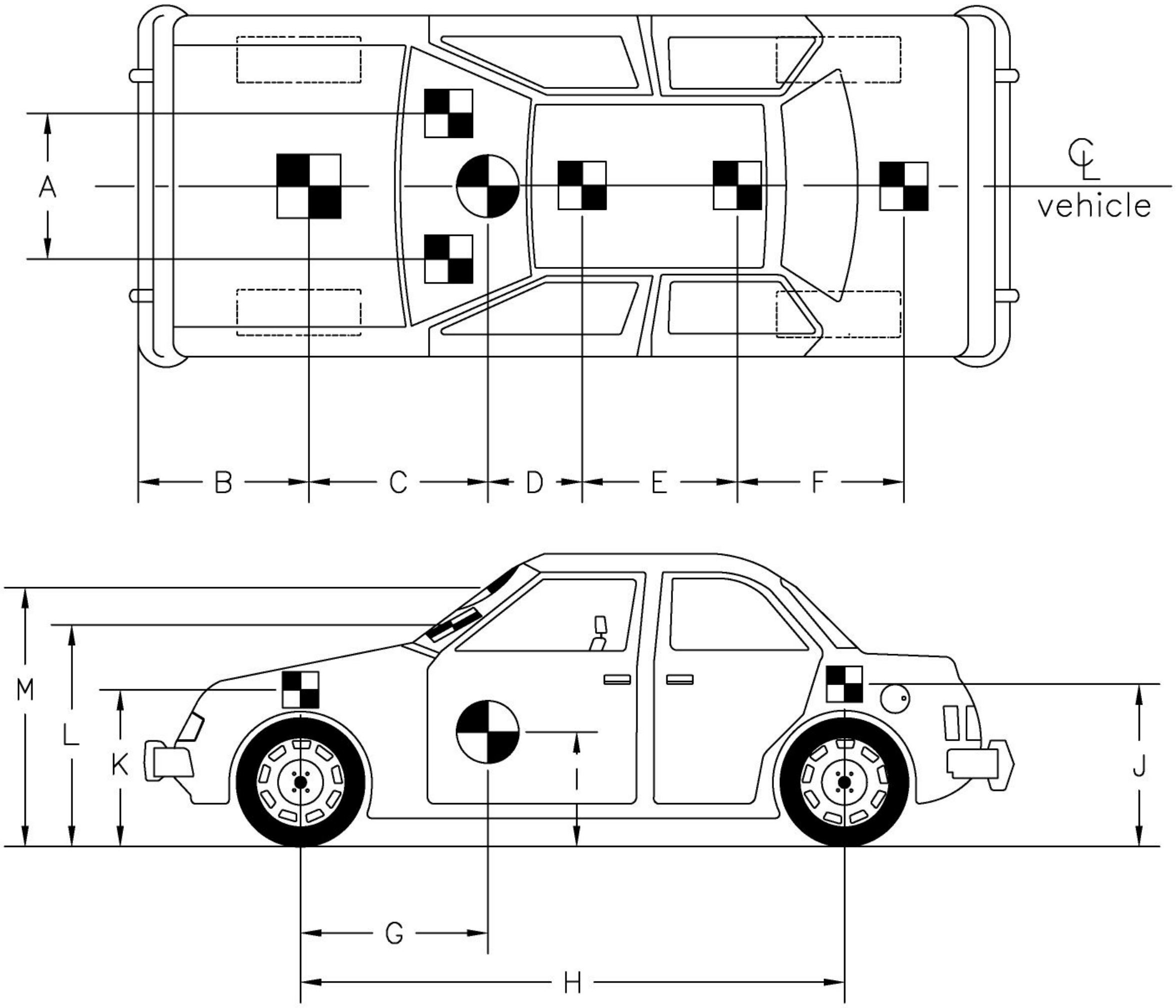
Front 3700
Rear 3900
Total 6700

Dummy Data

Type: Hybrid II
Mass: 166 lbs
Seat Position: Driver

Note any damage prior to test: Lower, right side dent in box quarter panel

Figure 6. Vehicle Dimensions, Test No. MWTC-3

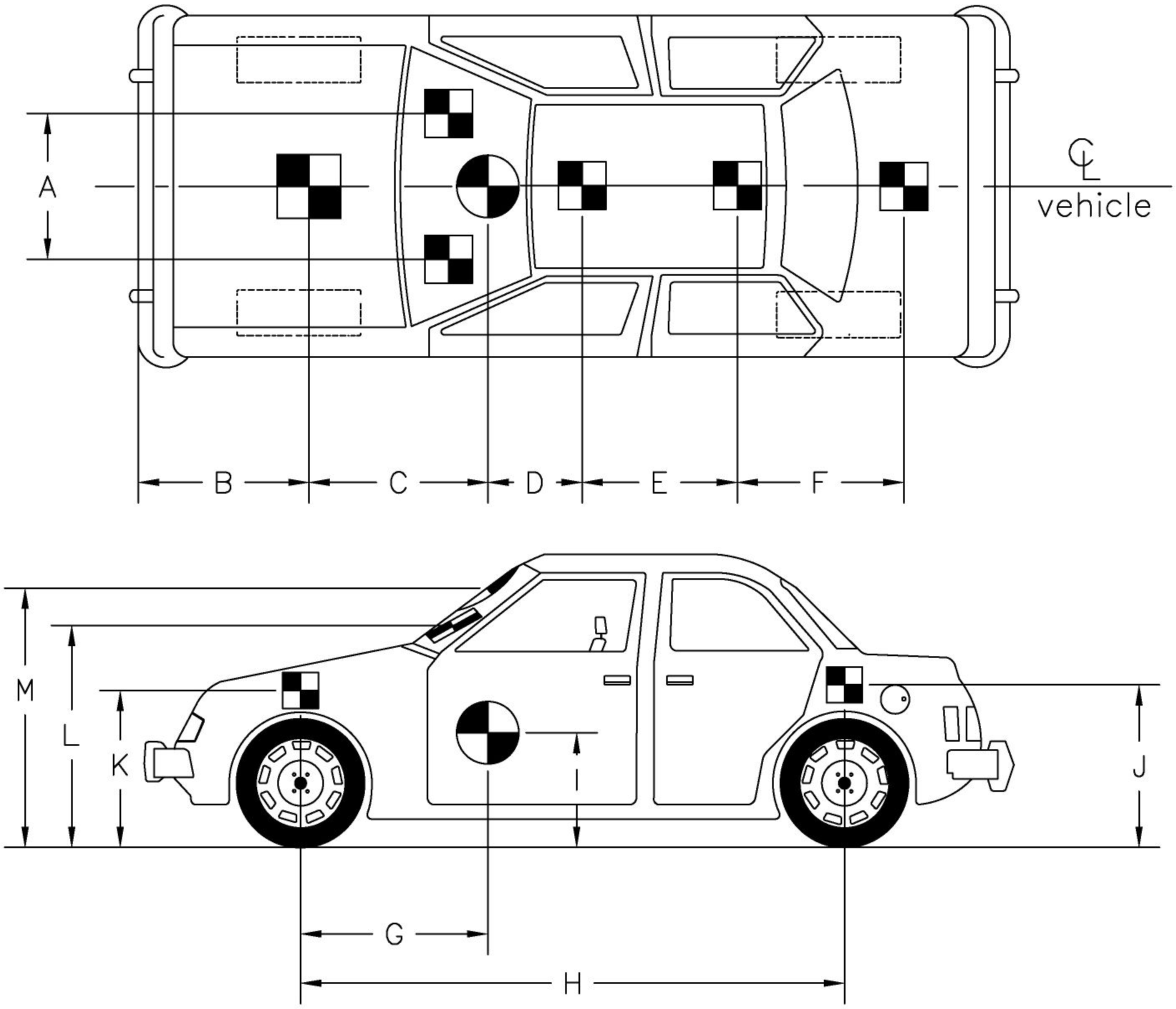


TEST #: MWTC-1

TARGET GEOMETRY-- in. (mm)

A	**32 1/4**	**(819)**	**E**	**42 1/8**	**(1070)**	**I**	**19**	**(483)**
B	**25**	**(635)**	**F**	**36 5/8**	**(930)**	**J**	**29 1/4**	**(743)**
C	**43**	**(1092)**	**G**	**35 7/8**	**(912)**	**K**	**29**	**(737)**
D	**8**	**(203)**	**H**	**98 1/2**	**(2502)**	**L**	**44 3/8**	**(1127)**
						M	**52 5/8**	**(1337)**

Figure 7. Target Geometry, Test No. MWTC-1

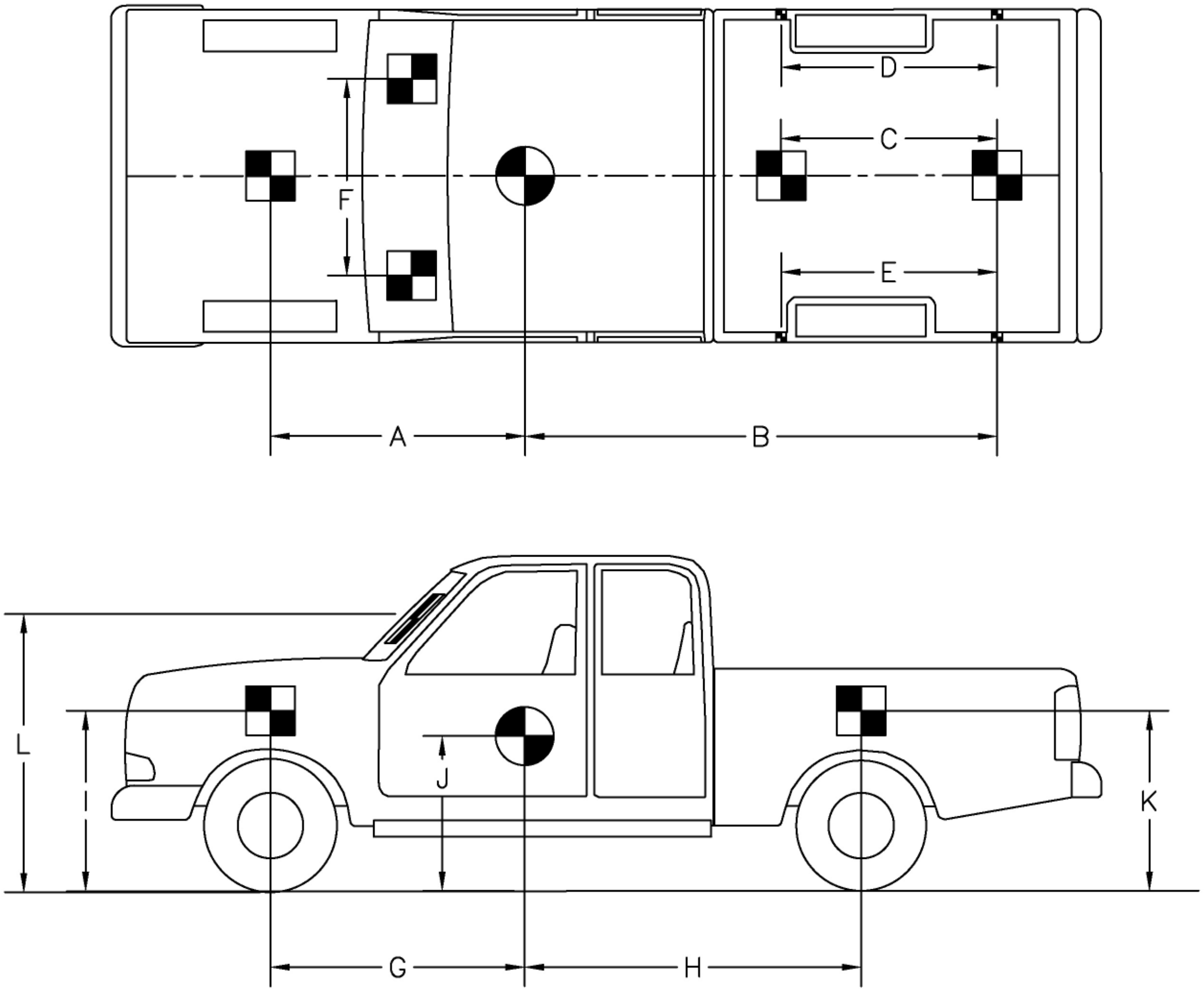


TEST #: MWTC-2

TARGET GEOMETRY-- in. (mm)

A	**35 7/8**	**(911)**	**E**	**39**	**(991)**	**I**	**18**	**(457)**
B	**25 3/8**	**(645)**	**F**	**36 3/4**	**(933)**	**J**	**28 7/8**	**(733)**
C	**44**	**(1118)**	**G**	**38**	**(965)**	**K**	**29**	**(737)**
D	**8 1/2**	**(216)**	**H**	**98 1/2**	**(2502)**	**L**	**44 1/4**	**(1124)**
						M	**53**	**(1346)**

Figure 8. Target Geometry, Test No. MWTC-2



TEST #: MWTC-3

TARGET GEOMETRY-- in. (mm)

A	**75**	**(1905)**	**E**	**64**	**(1626)**	**I**	**40**	**(1016)**
B	**102**	**(2591)**	**F**	**41**	**(1041)**	**J**	**28 1/2**	**(724)**
C	**41**	**(1041)**	**G**	**62**	**(1575)**	**K**	**42**	**(1067)**
D	**64**	**(1626)**	**H**	**78 3/4**	**(2000)**	**L**	**61 1/4**	**(1556)**

Figure 9. Target Geometry, Test No. MWTC-3

The front wheels of the test vehicles 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 on the right side of each vehicle's dash and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact 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.

3.4 Simulated Occupant

For test nos. MWTC-1, MWTC-2, and MWTC-3, 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.

3.5 Data Acquisition Systems

3.5.1 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 center of gravity of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [6].

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

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.

3.5.2 Rate Transducers

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

A second angle rate sensor system, the SLICE MICRO Triax ARS, with a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of rotation of the test vehicles. The angular rate sensors were mounted inside the body of the custom built SLICE 6DX event data recorder and recorded data at 10,000 Hz to the onboard microprocessor. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The “SLICEWare” computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

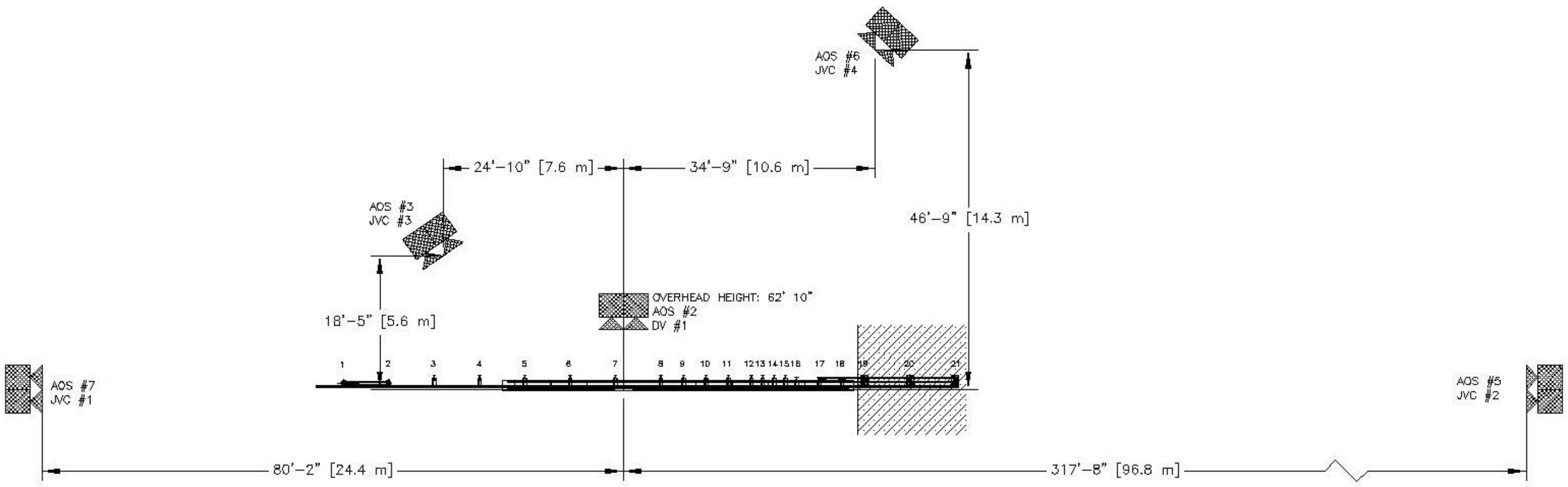
3.5.3 Retro-reflective Optic Speed Trap

The retro-reflective optic speed trap was used to determine the speed of the bogie vehicle before impact. Three retro-reflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the bogie vehicle which reflects the beam of light. When the emitted beam of light was returned to the Emitter/Receiver, a signal was sent to the Optic Control Box, which in turn sent a signal to the data computer as well as activated the External LED box. The computer recorded the signals and the time each occurred. The speed was then calculated using the spacing between the retro-reflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

3.5.4 Digital Photography

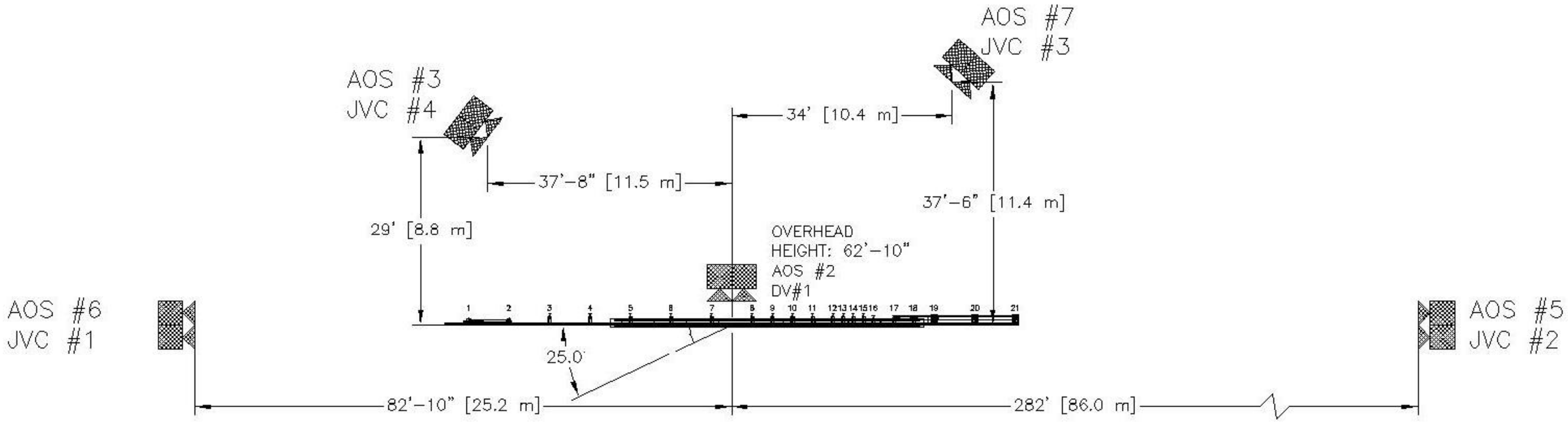
Two AOS VITcam high-speed digital video cameras, three AOS X-PRI high-speed digital video cameras, four JVC digital video cameras, and one Canon digital video cameras were utilized to film test nos. MWTC-1 and MWTC-2. For test no. MWTC-3, two AOS VITcam high-speed digital video cameras, three AOS X-PRI high-speed digital video cameras, four JVC digital video cameras, one Canon digital video camera, and two GoPro Hero 3 digital video cameras were used. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 10 through 12.

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



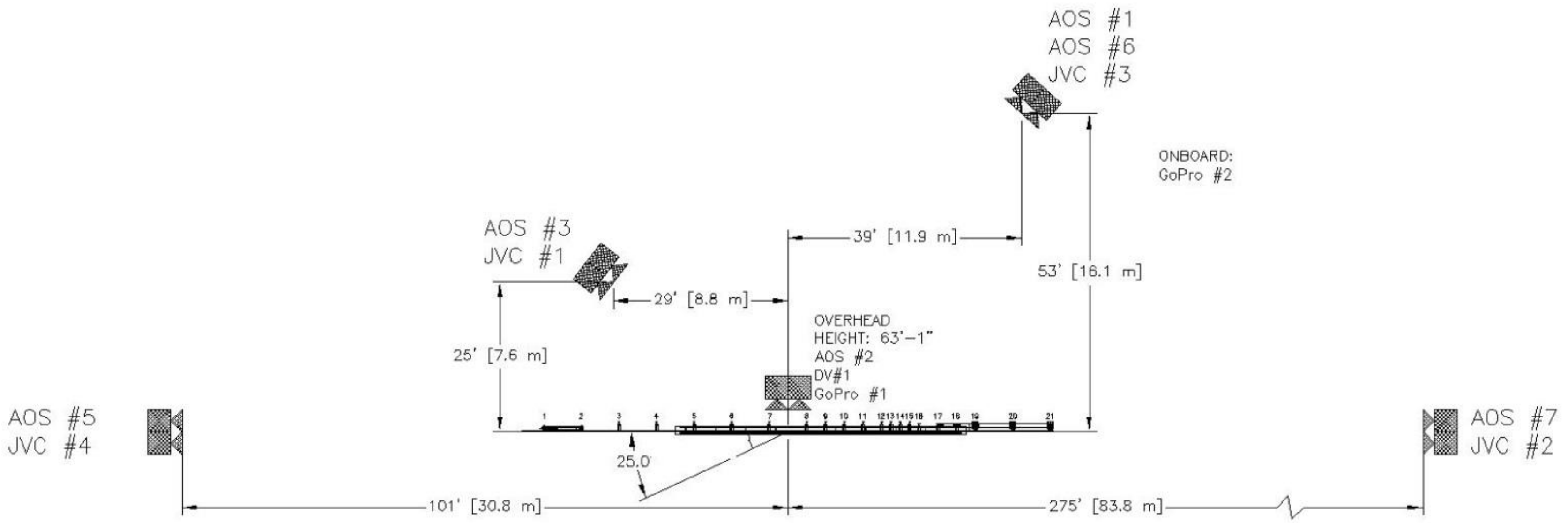
	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	Cosmicar 12.5 mm Fixed	-
	3	AOS Vitcam CTM	500	Sigma 24-70	35
	5	AOS X-PRI Gigabit	500	Canon 17-102	102
	6	AOS X-PRI Gigabit	500	Fujinon 50 mm Fixed	-
	7	AOS X-PRI Gigabit	500	Sigma 50 mm Fixed	-
Digital Video	1	JVC – GZ-MC500 (Everio)	29.97		
	2	JVC – GZ-MG27u (Everio)	29.97		
	3	JVC – GZ-MG27u (Everio)	29.97		
	4	JVC – GZ-MG27u (Everio)	29.97		
	1	Canon ZR90	29.97		
	2	Canon ZR10	29.97		

Figure 10. Camera Locations, Speeds, and Lens Settings, Test No. MWTC-1



	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	Cosmicar 12.5 mm Fixed	-
	3	AOS Vitcam CTM	500	Sigma 24-70	35
	5	AOS X-PRI Gigabit	500	Canon 17-102	102
	6	AOS X-PRI Gigabit	500	Fujinon 50 mm Fixed	-
	7	AOS X-PRI Gigabit	500	Sigma 50 mm Fixed	-
Digital Video	1	JVC – GZ-MC500 (Everio)	29.97		
	2	JVC – GZ-MG27u (Everio)	29.97		
	3	JVC – GZ-MG27u (Everio)	29.97		
	4	JVC – GZ-MG27u (Everio)	29.97		
	1	Canon ZR90	29.97		
	2	Canon ZR10	29.97		

Figure 11. Camera Locations, Speeds, and Lens Settings, Test No. MWTC-2



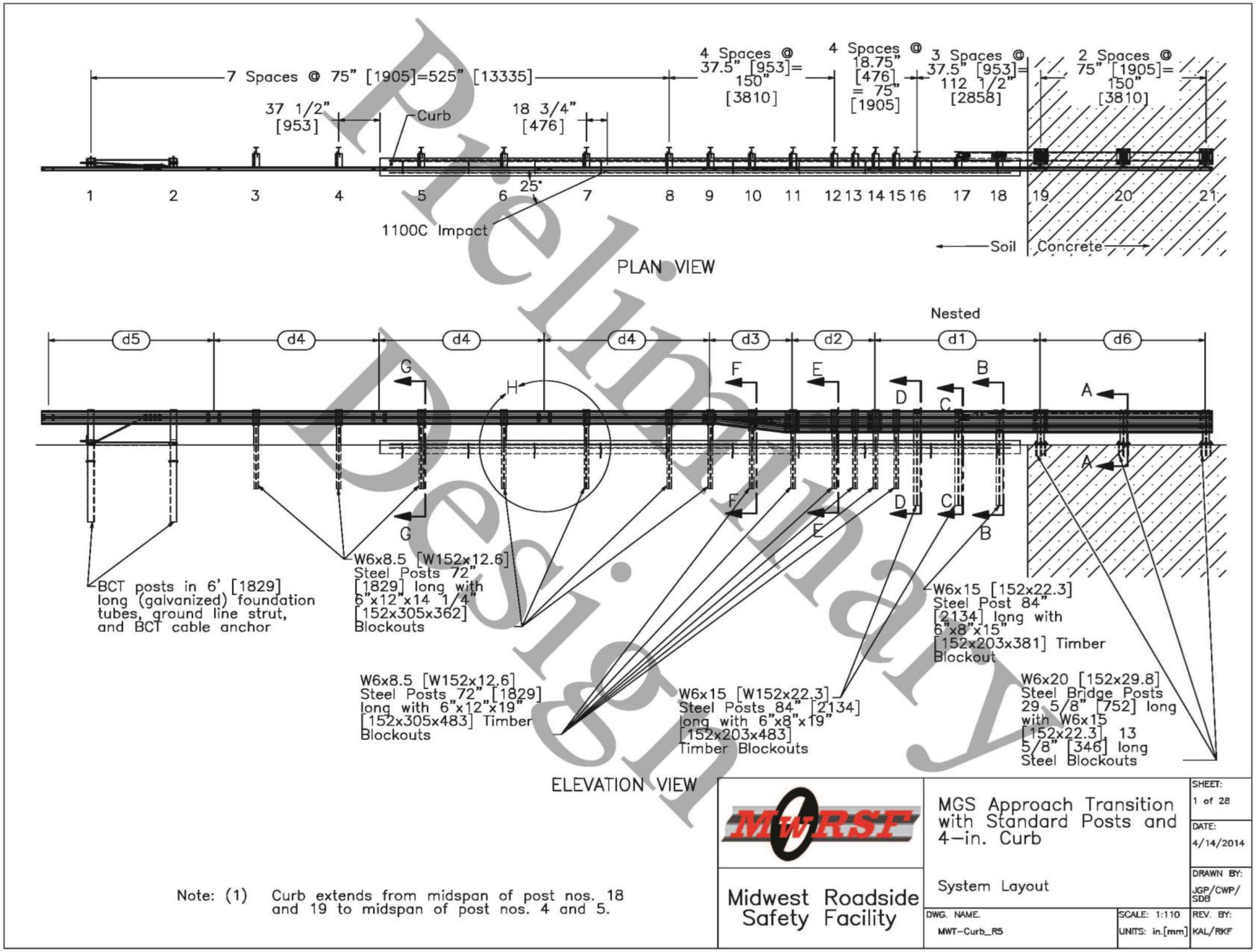
	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	Cosmicar 12.5 mm Fixed	-
	3	AOS Vitcam CTM	500	Nikon 28 mm Fixed	-
	5	AOS X-PRI Gigabit	500	Fujinon 50 mm Fixed	-
	6	AOS X-PRI Gigabit	500	Sigma Macro 50 mm Fixed	-
	7	AOS X-PRI Gigabit	500	Canon 17 102 mm	102
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		
	1	GoPro Hero 3	120		
	2	GoPro Hero 3	120		

Figure 12. Camera Locations, Speeds, and Lens Settings, Test No. MWTC-3

4 DESIGN DETAILS

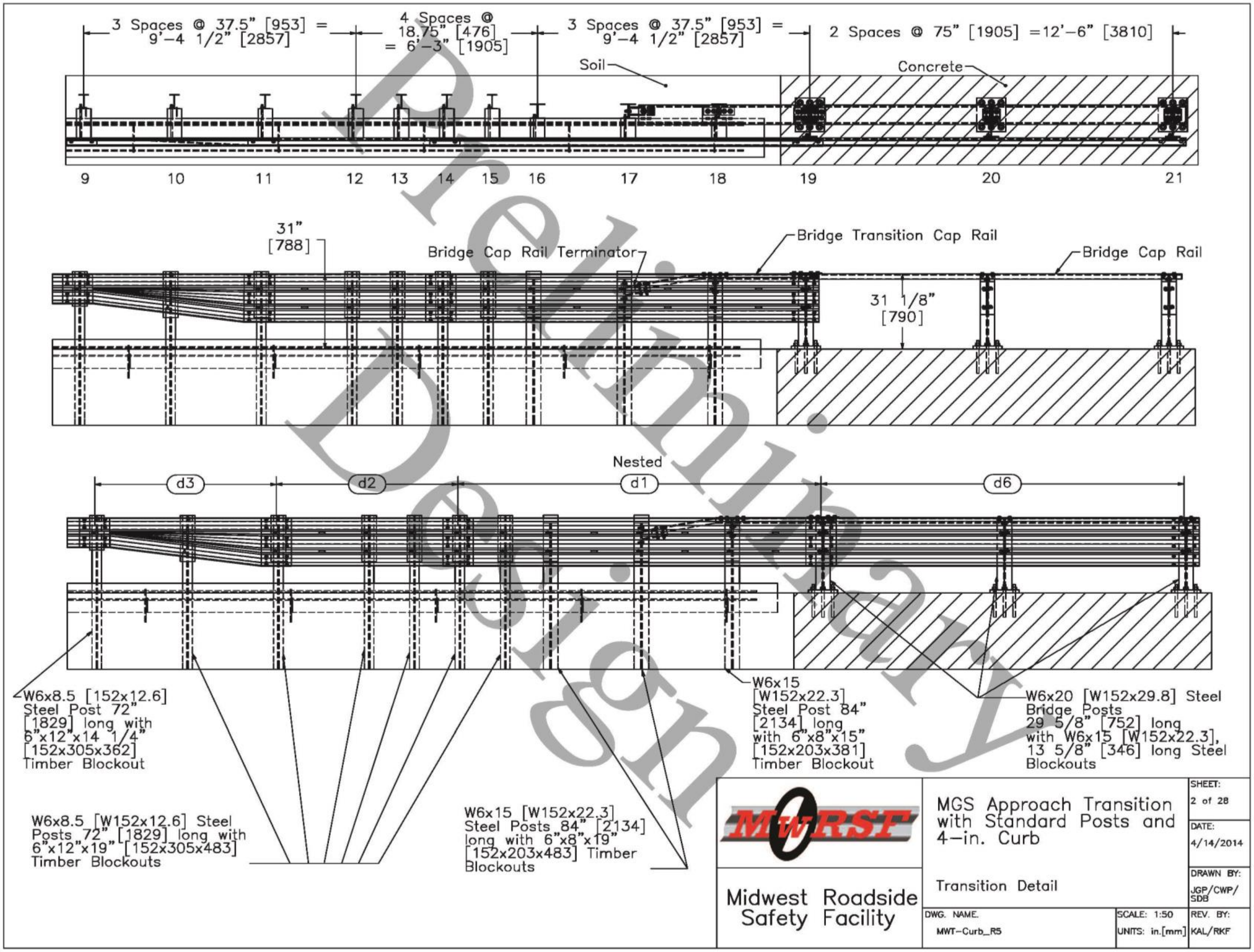
The 87.5 ft (26.7-m) long test installation was constructed for use in test no. MWTC-1, as shown in Figure 13, which consisted of five major structural components: (1) a 12-ft 6-in. (3.8-m) long thrie beam and channel bridge railing system; (2) 12 ft – 6 in. (3.8 m) of nested 12-gauge (2.66 mm thick) thrie beam guardrail; (3) 6 ft – 3 in. (1.9 m) of standard 12-gauge (2.66-mm thick) thrie beam guardrail; (4) a 6-ft - 3-in. (1.9-m) long, asymmetrical 10-gauge (3.42-mm thick) W-beam to thrie beam transition element; and (5) 50 ft (15.2 m) of standard 12-gauge (2.66-mm thick) W-beam rail attached to a simulated anchorage device. All rails had a top rail height of 31 in. (787 mm). Lap-splice connections between the rail sections were configured to reduce vehicle snag at the splices. Design details are shown in Figures 13 through 40. Photographs of the test installation are shown in Figures 41 through 44. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix B.

The guardrail components were supported by two BCT timber posts, 16 steel guardrail posts, and three steel bridge posts. Post nos. 1 and 2 were BCT posts placed in 6-ft (1.8-m) long steel foundation tubes to anchor the system. Post nos. 3 through 15 were galvanized ASTM A36 W6x8.5 (W152x12.6) steel sections measuring 6 ft (1.8 m) long. Post nos. 16 through 18 were galvanized ASTM A36 W6x15 (W152x22.3) steel sections measuring 7 ft (2.1 m) long. The steel posts were placed at various spacings, as shown in Figure 13, in a compacted crushed limestone material that met AASHTO Grade B soil specifications, as recommended in MASH. Bridge post nos. 19 through 21 were galvanized ASTM A36 W6x20 (W152x29.8) steel sections measuring 29⅝ in. (752 mm) long. The thrie beam channel bridge railing system was rigidly attached to the concrete tarmac located at the MwRSF’s outdoor proving grounds.



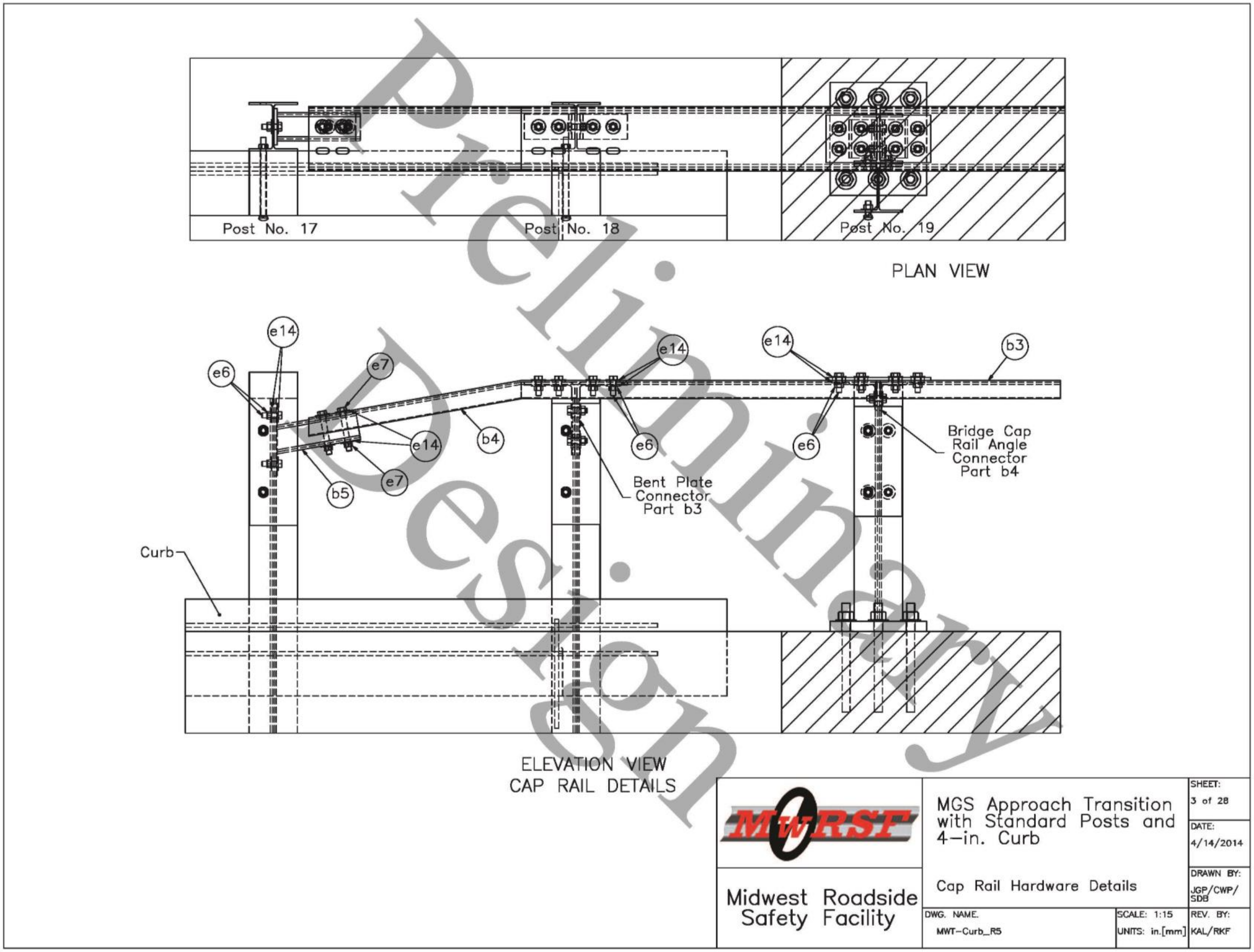
Preliminary Design

Figure 13. System Layout, Test No. MWTC-1



Preliminary Design

Figure 14. Downstream End System Layout, Test No. MWTC-1



Preliminary Design

Figure 15. Cap Rail Hardware Details, Test No. MWTC-1

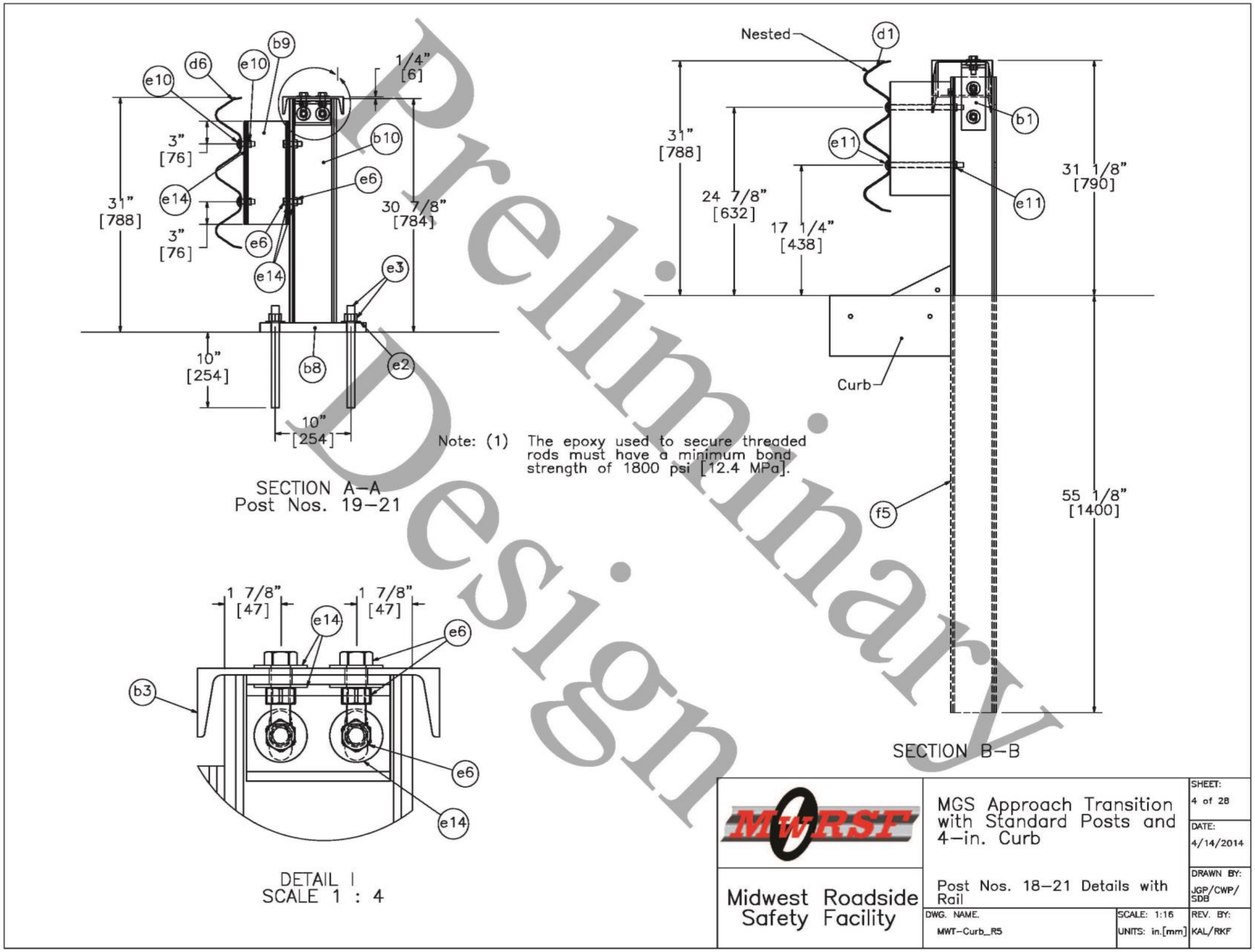


Figure 16. Post Nos. 18 through 21 Details with Rail, Test No. MWTC-1

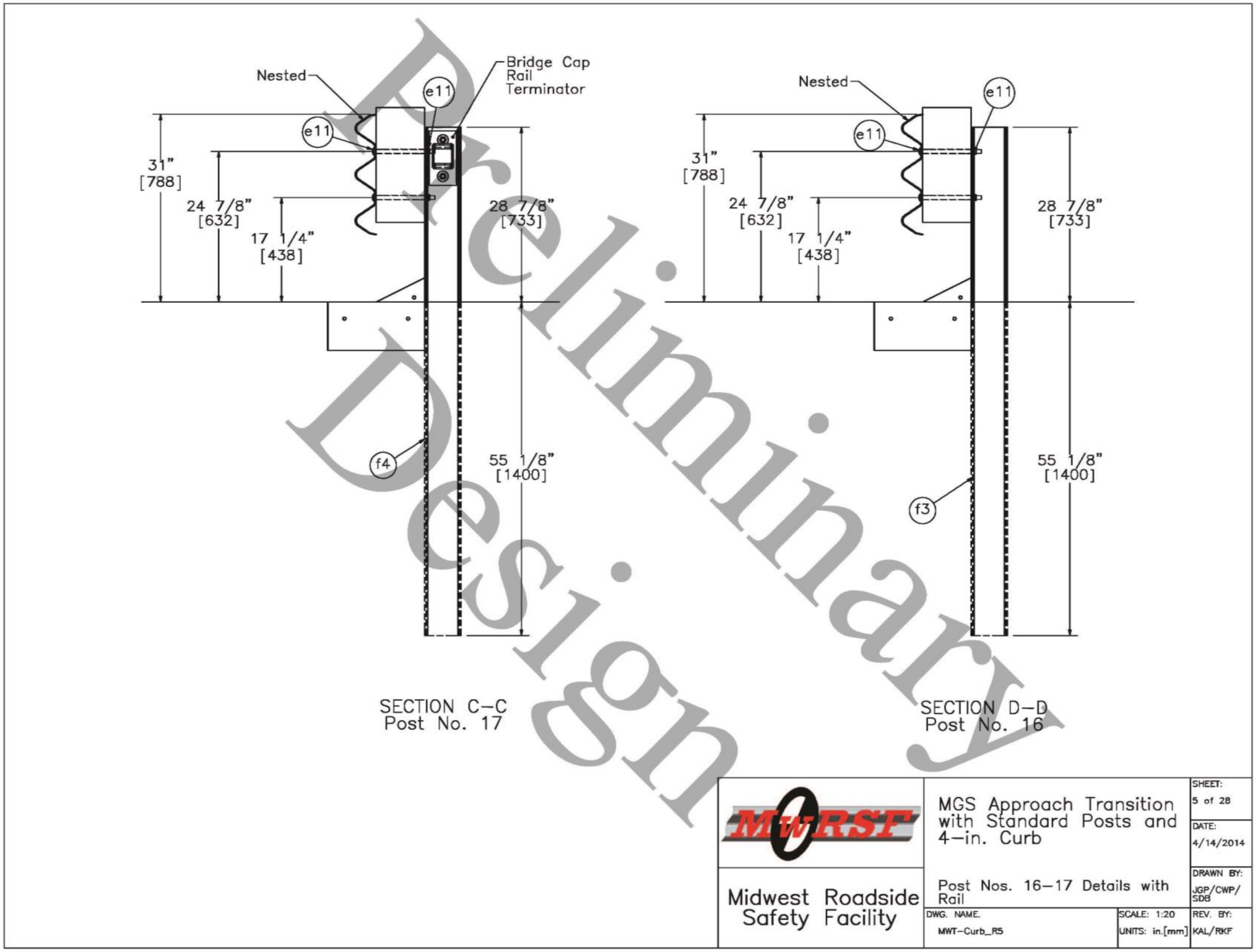
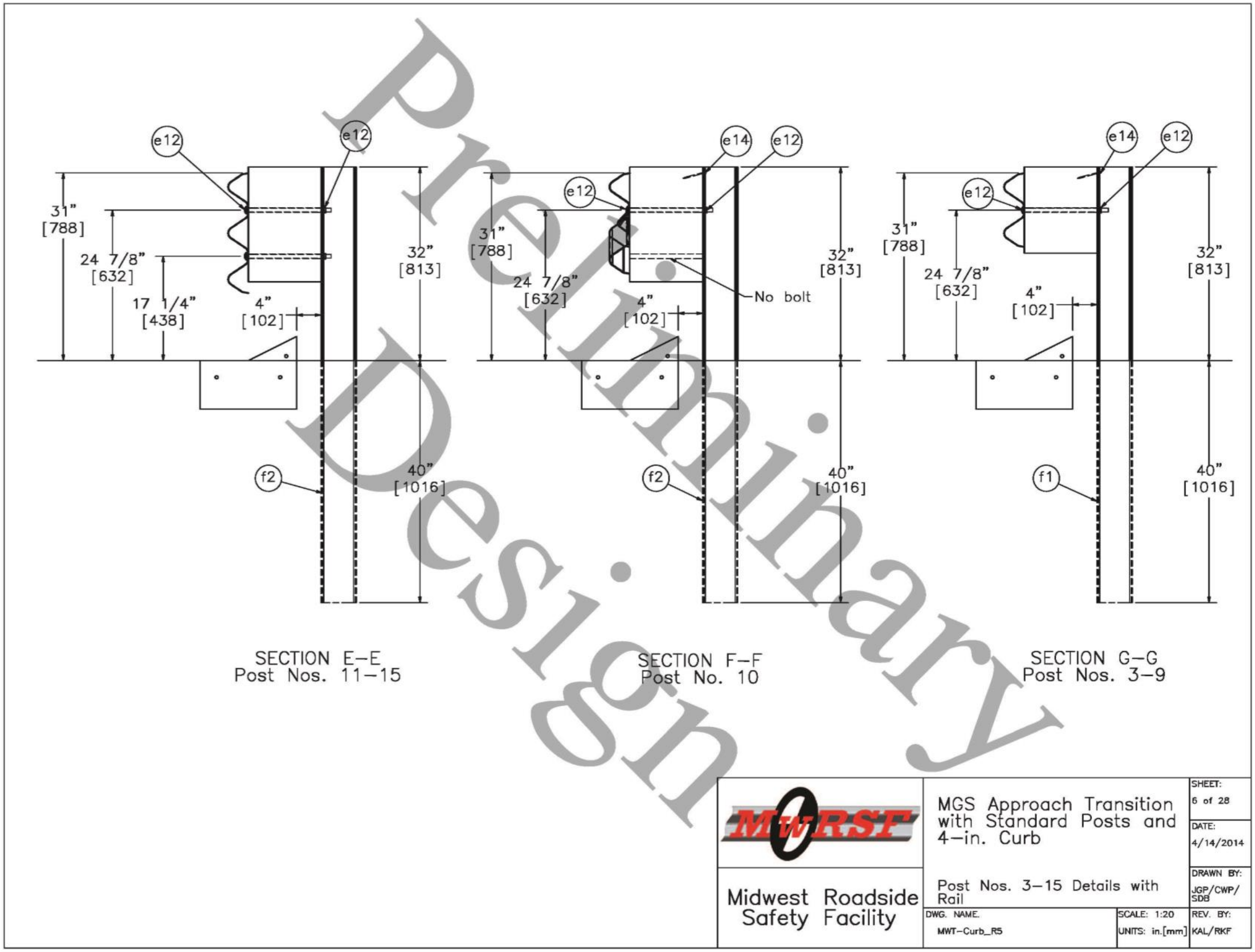
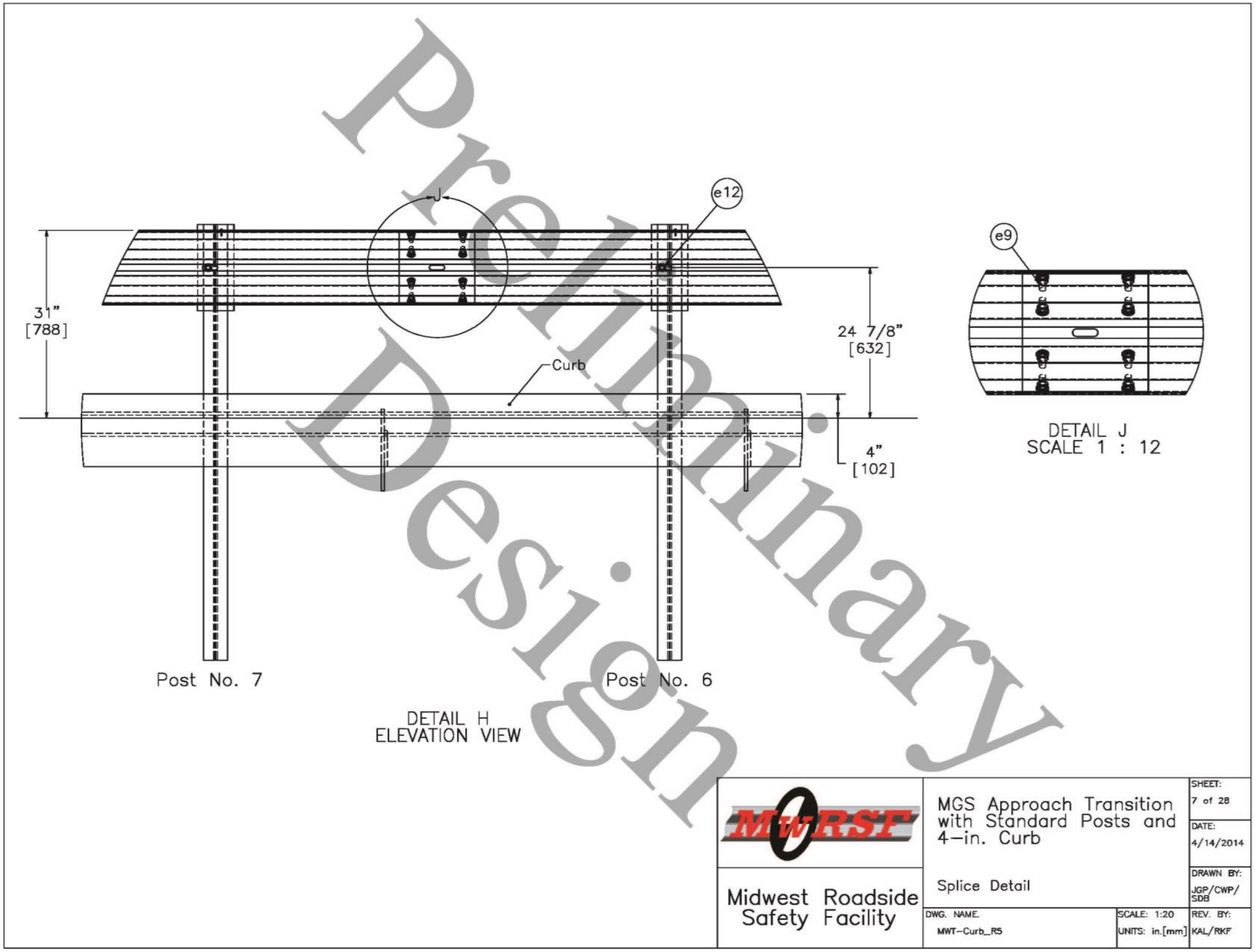


Figure 17. Post Nos. 16 through 17 Details with Rail, Test No. MWTC-1



Preliminary Design

Figure 18. Post Nos. 3 through 15 Details with Rail, Test No. MWTC-1



Preliminary Design

Figure 19. Splice Detail, Test No. MWTC-1

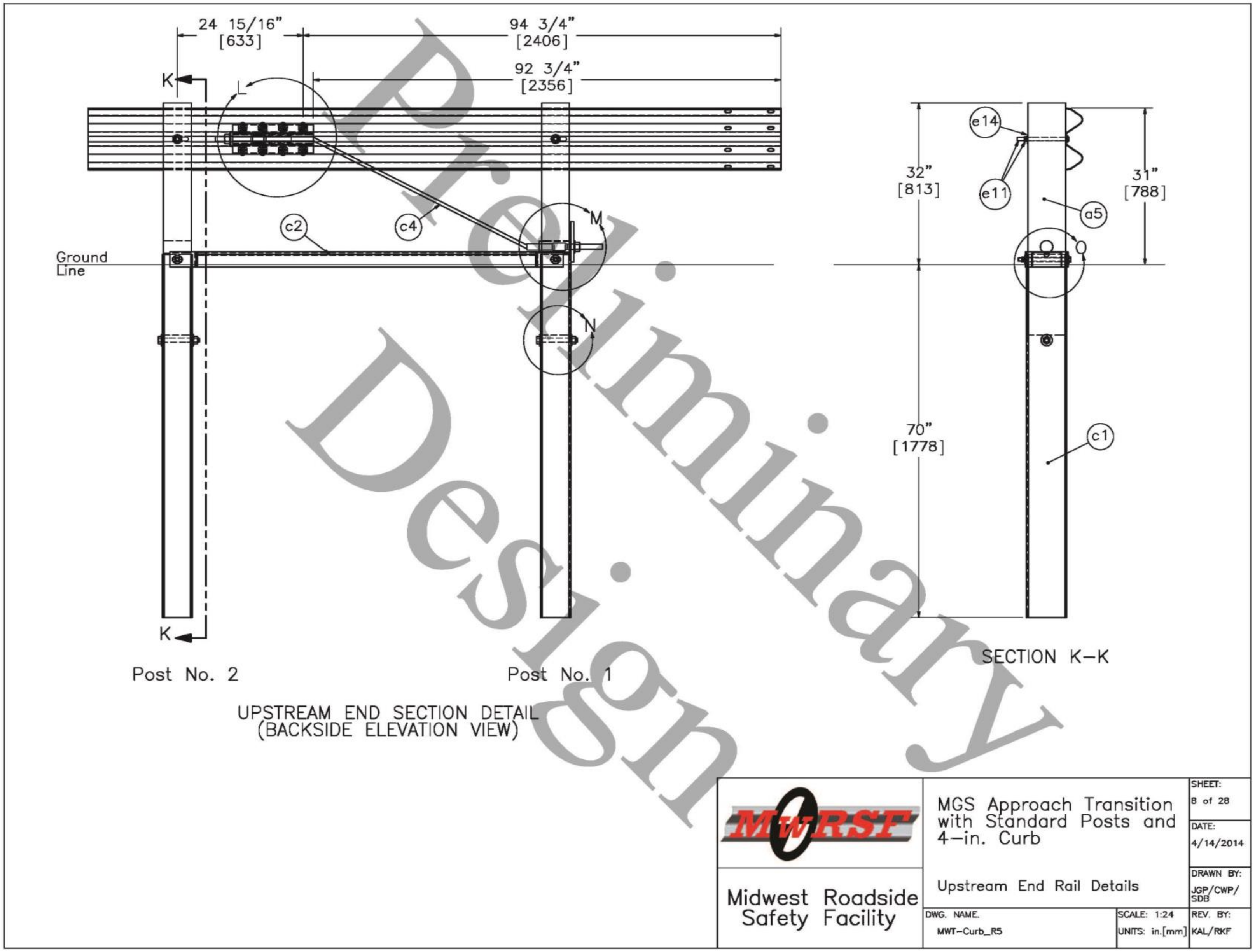


Figure 20. Upstream End Rail Details, Test No. MWTC-1

Preliminary Design

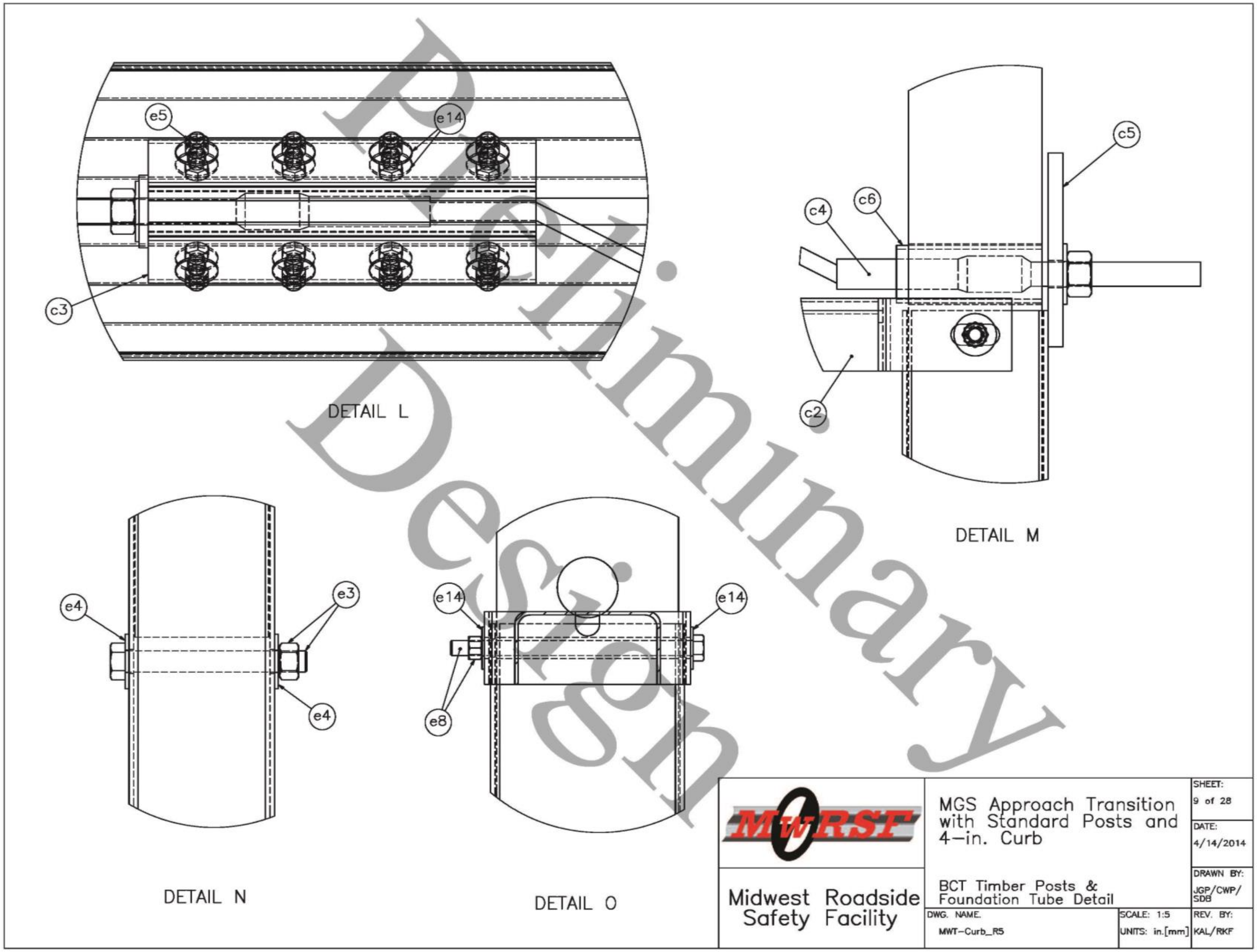


Figure 21. BCT Timber Posts and Foundation Tube Detail, Test No. MWTC-1

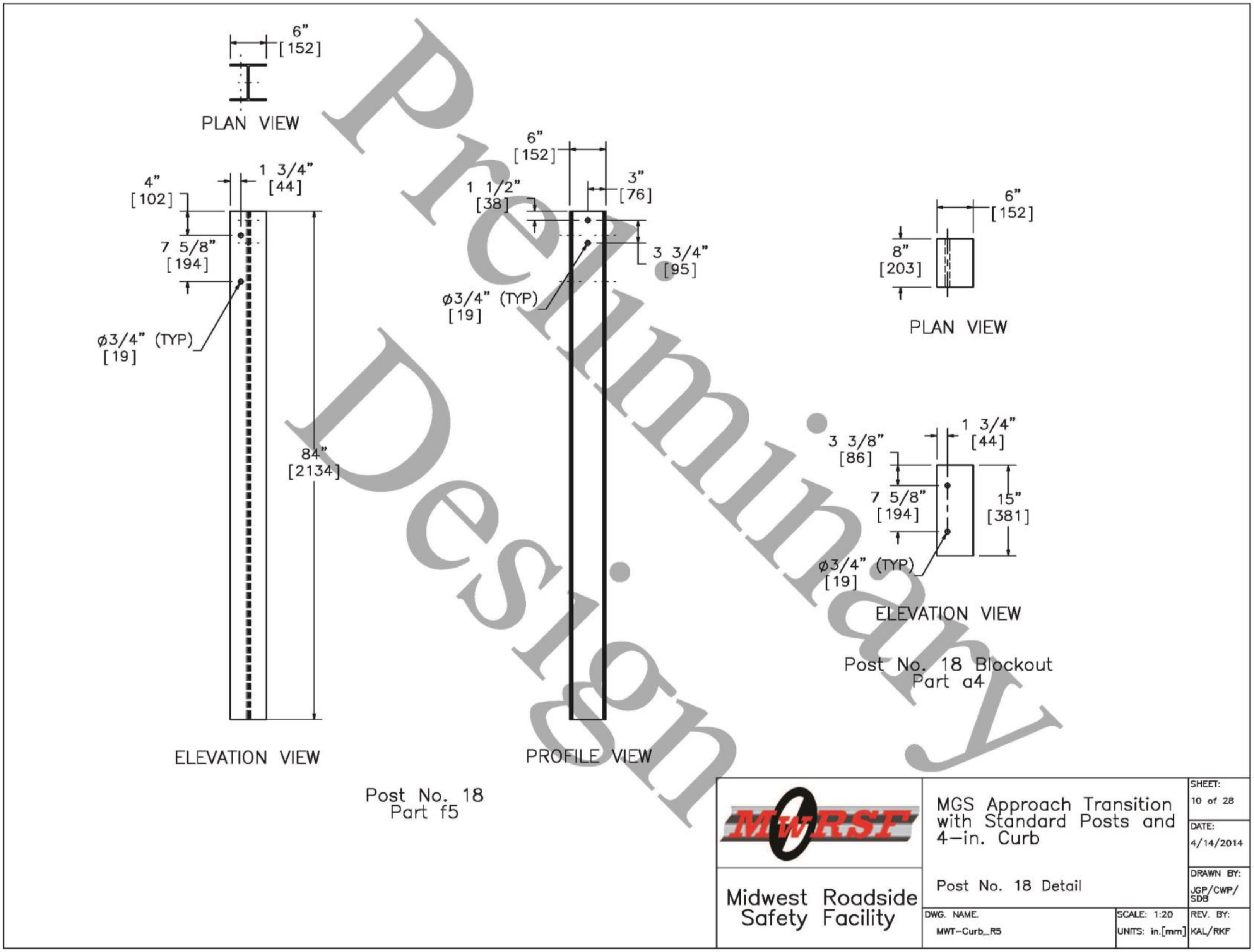
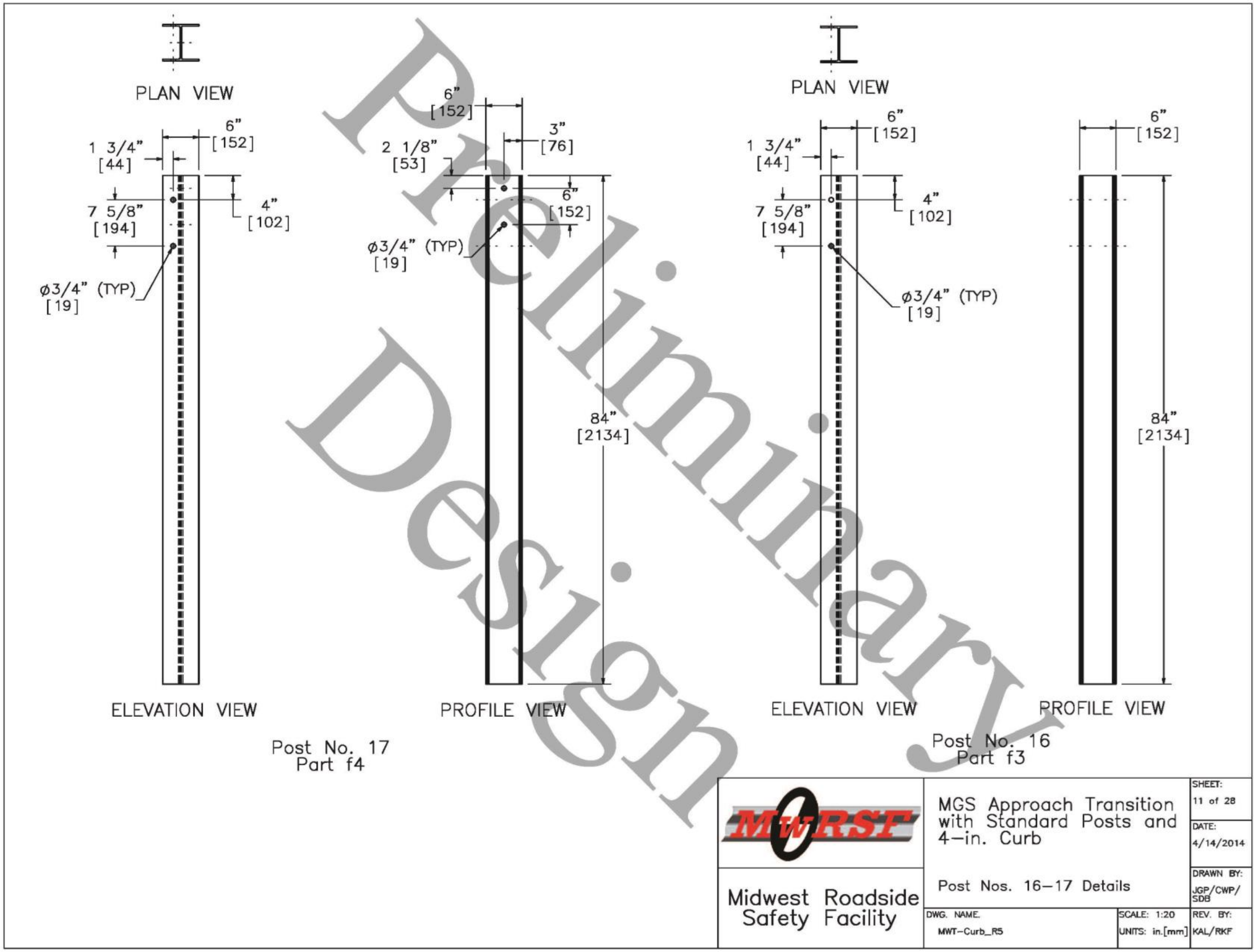


Figure 22. Post No. 18 Detail, Test No. MWTC-1



Preliminary Design

Figure 23. Post Nos. 16 through 17 Details, Test No. MWTC-1

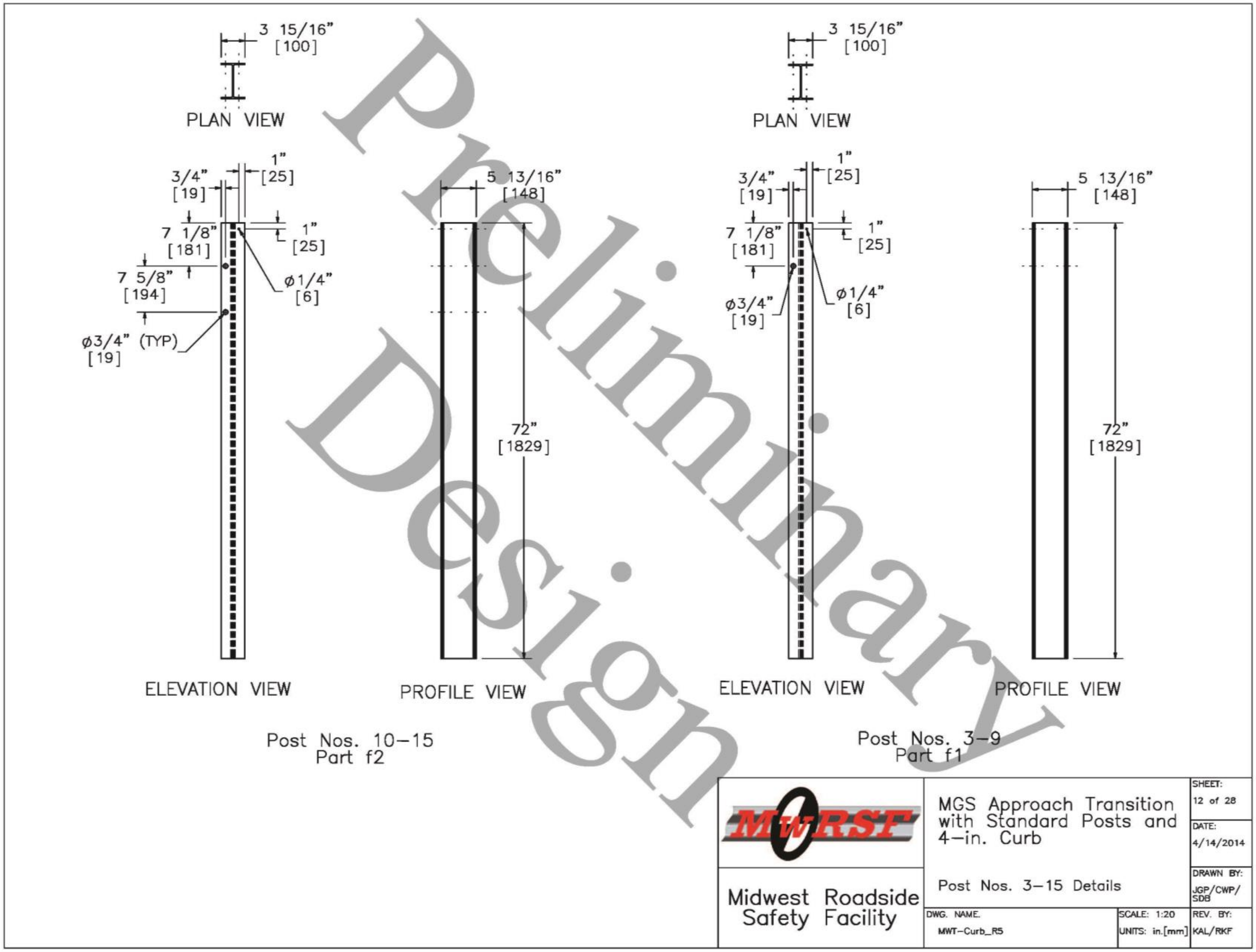


Figure 24. Post Nos. 3 through 15 Details, Test No. MWTC-1

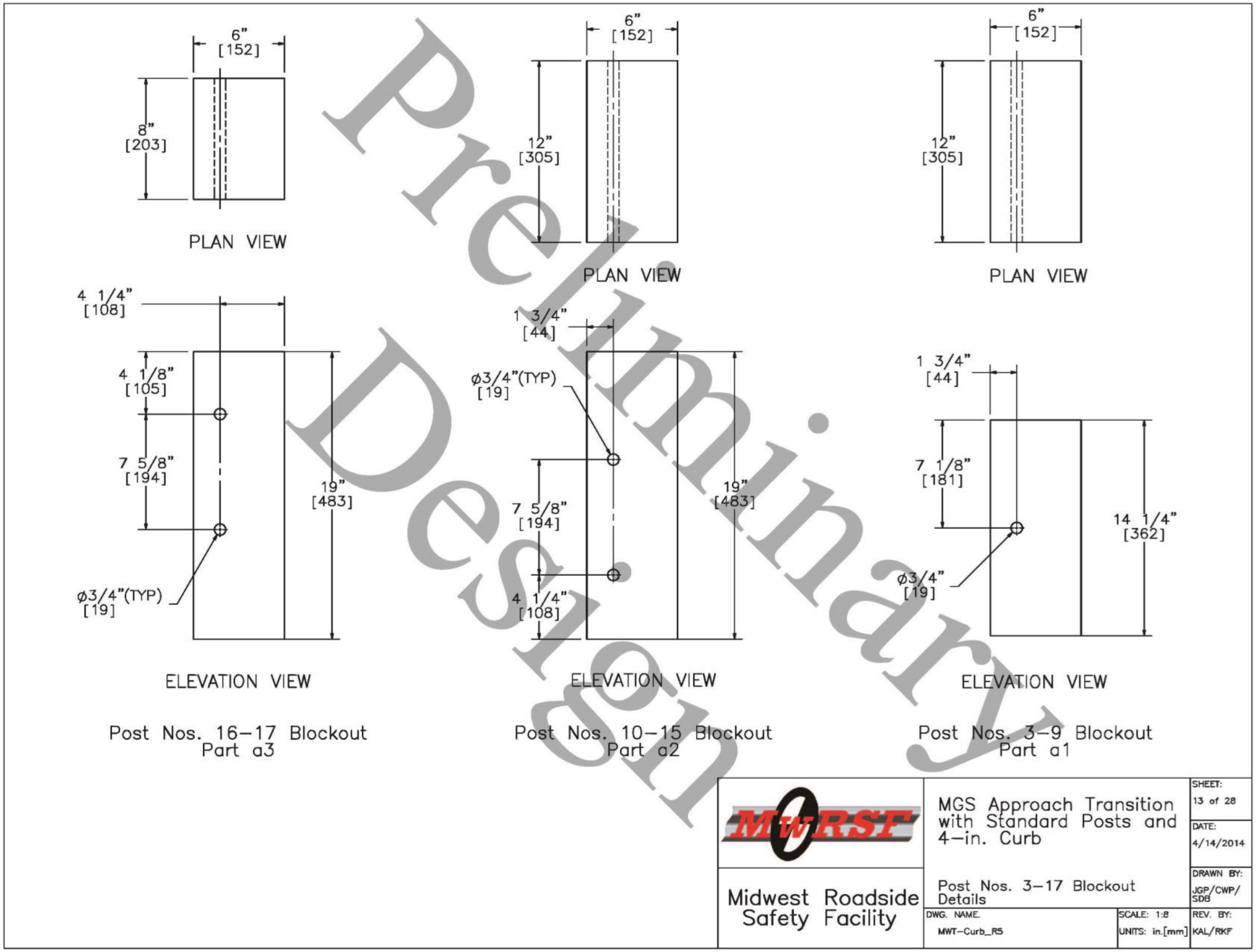
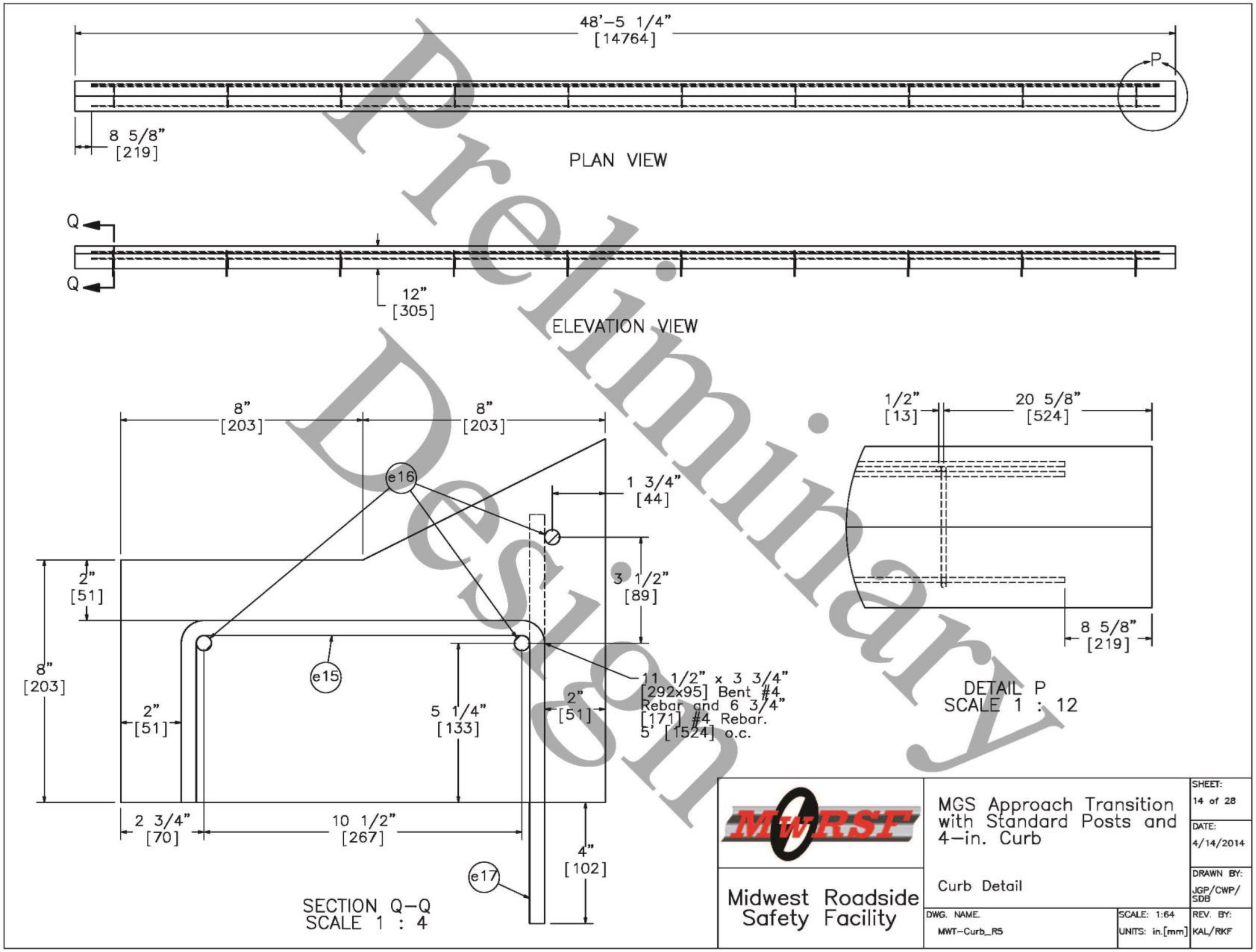
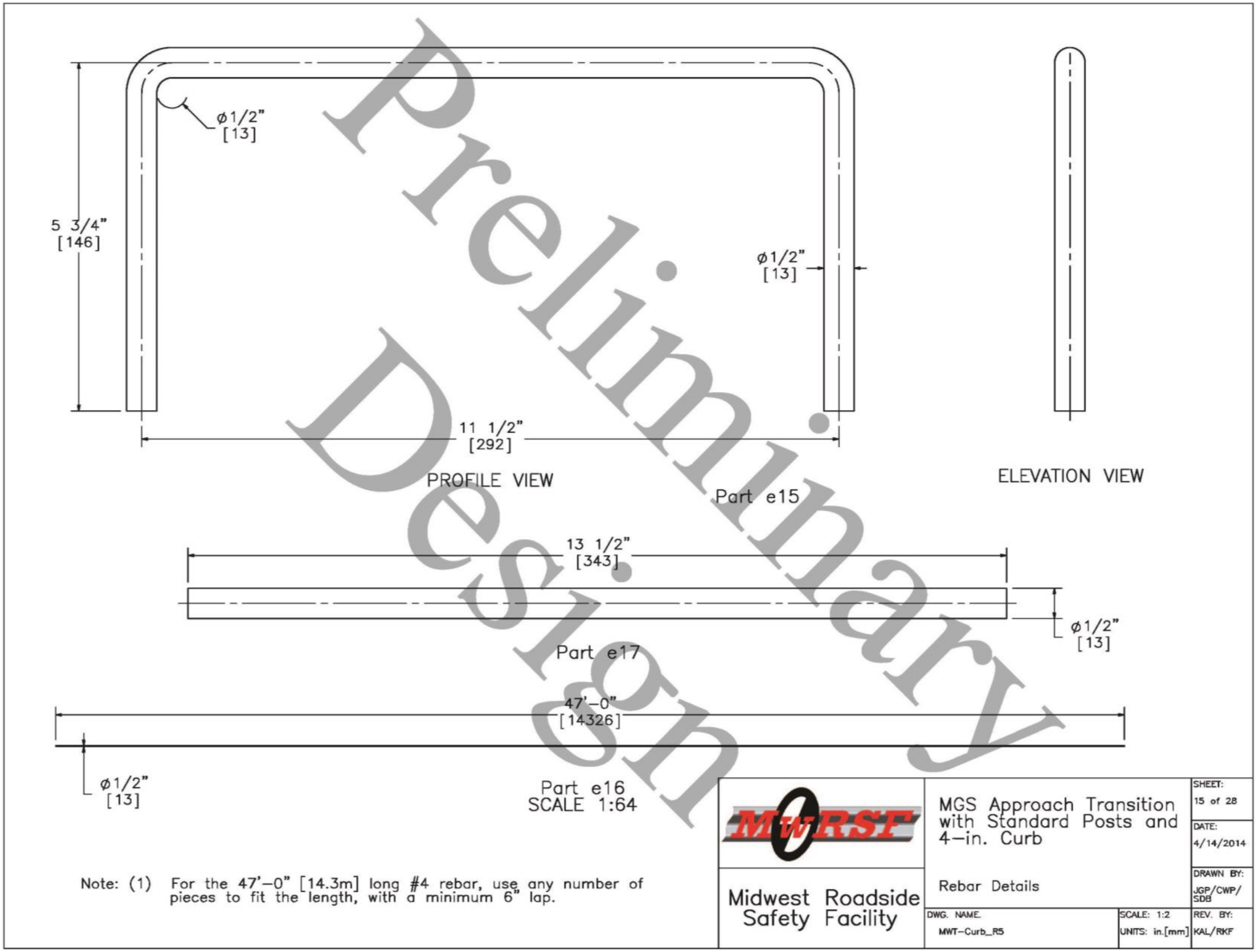


Figure 25. Post Nos. 3 through 17 Blockout Details, Test No. MWTC-1



Preliminary Design

Figure 26. Curb Detail, Test No. MWTC-1



Preliminary Design

Figure 27. Rebar Details, Test No. MWTC-1

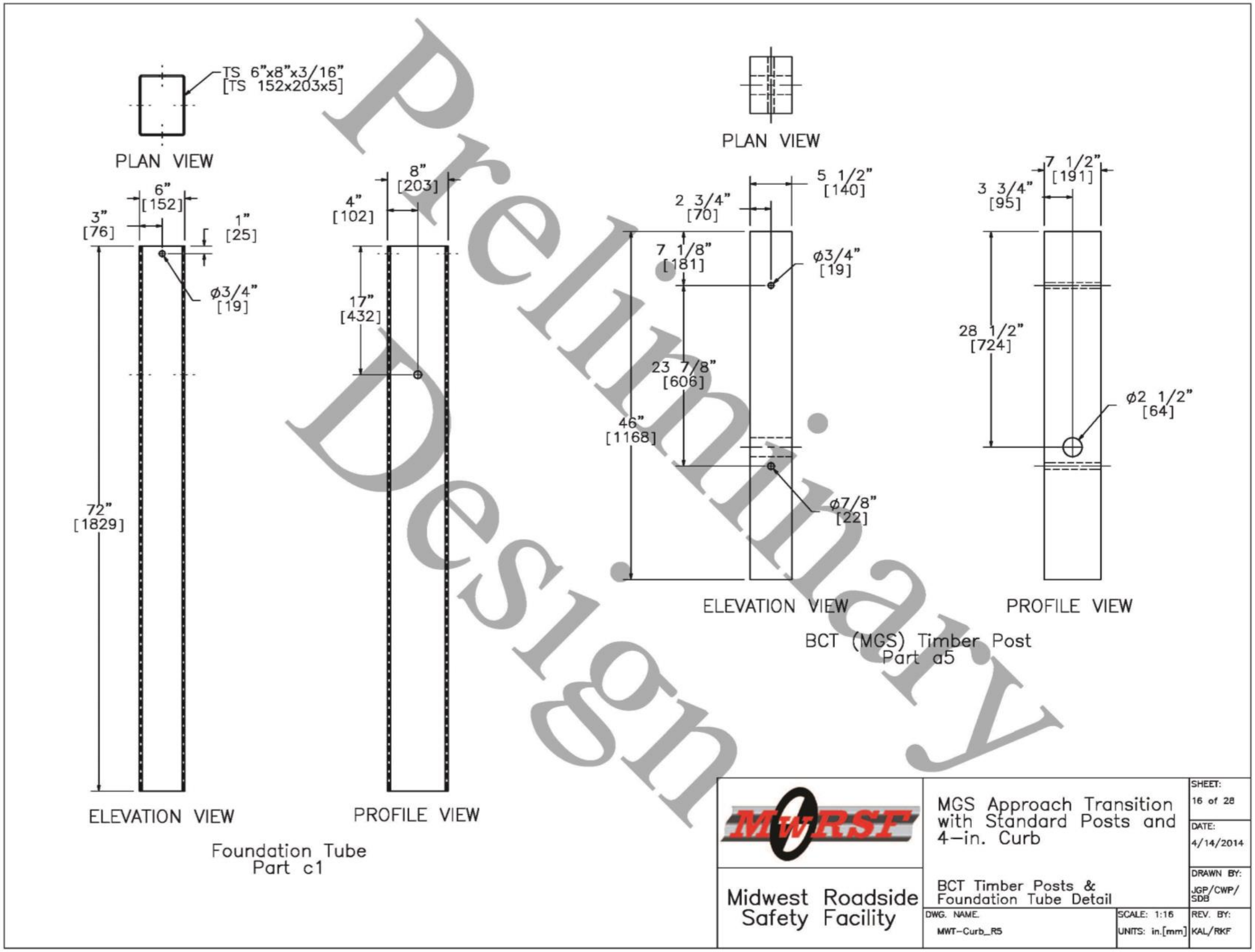


Figure 28. BCT Timber Posts and Foundation Tube Detail, Test No. MWTC-1

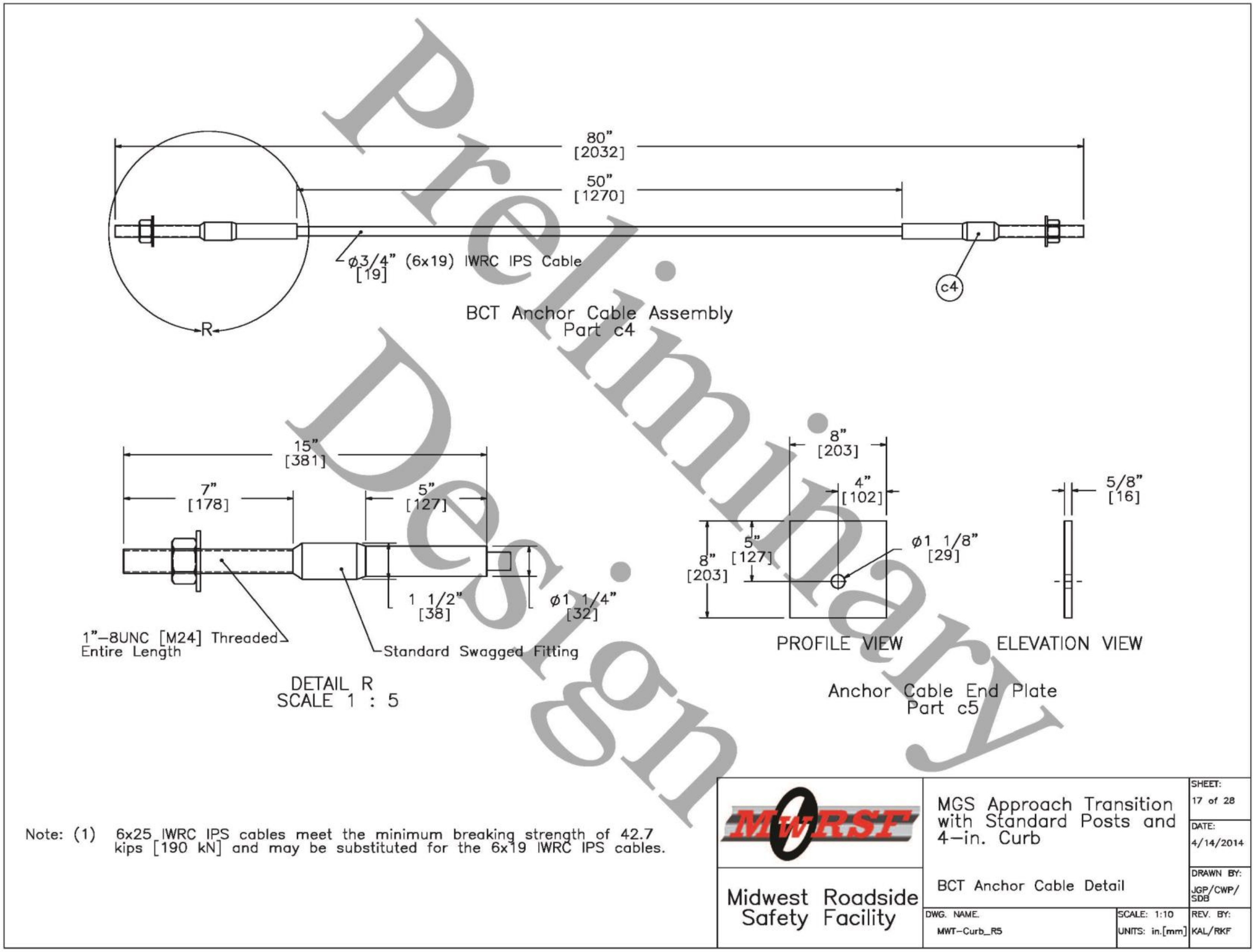
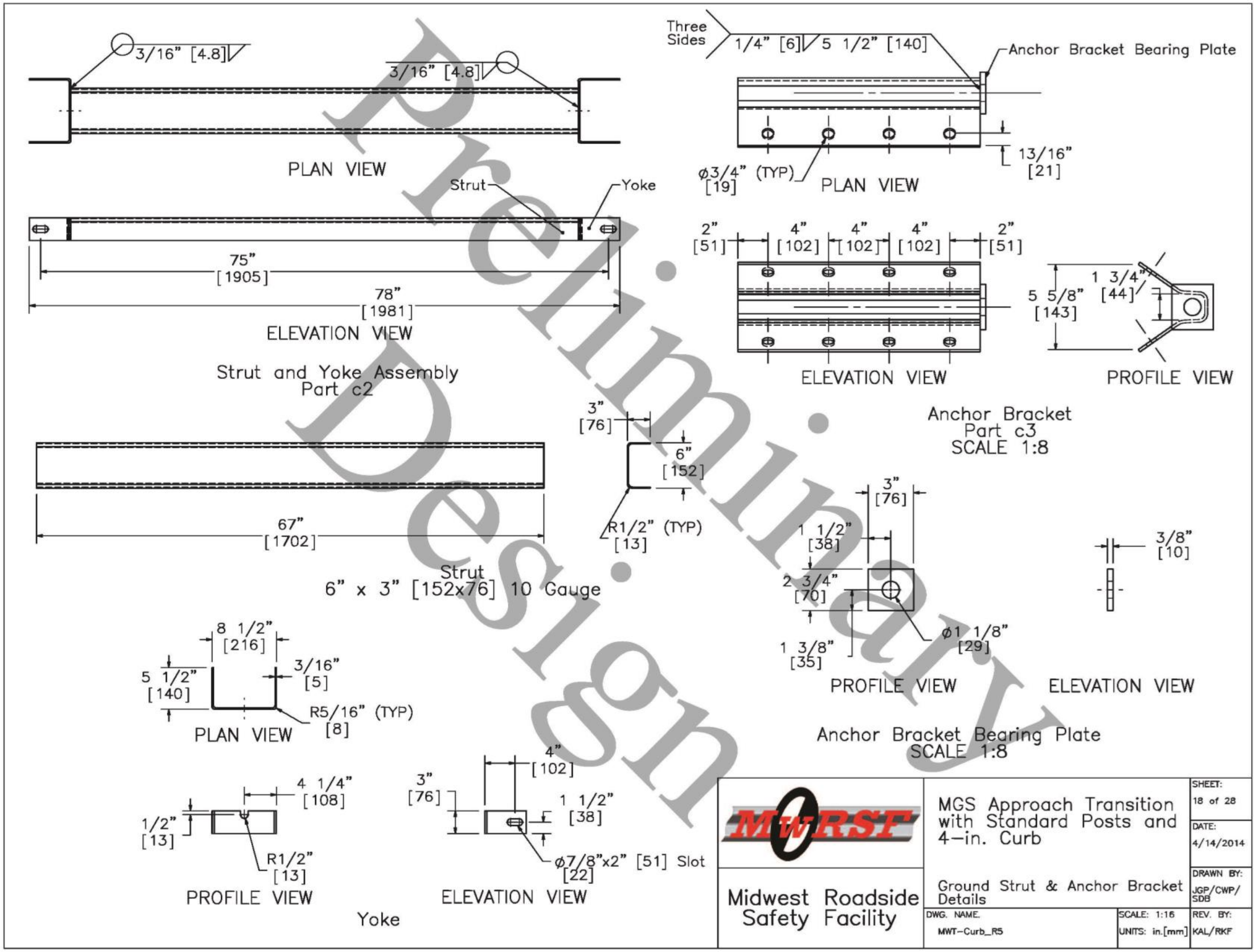
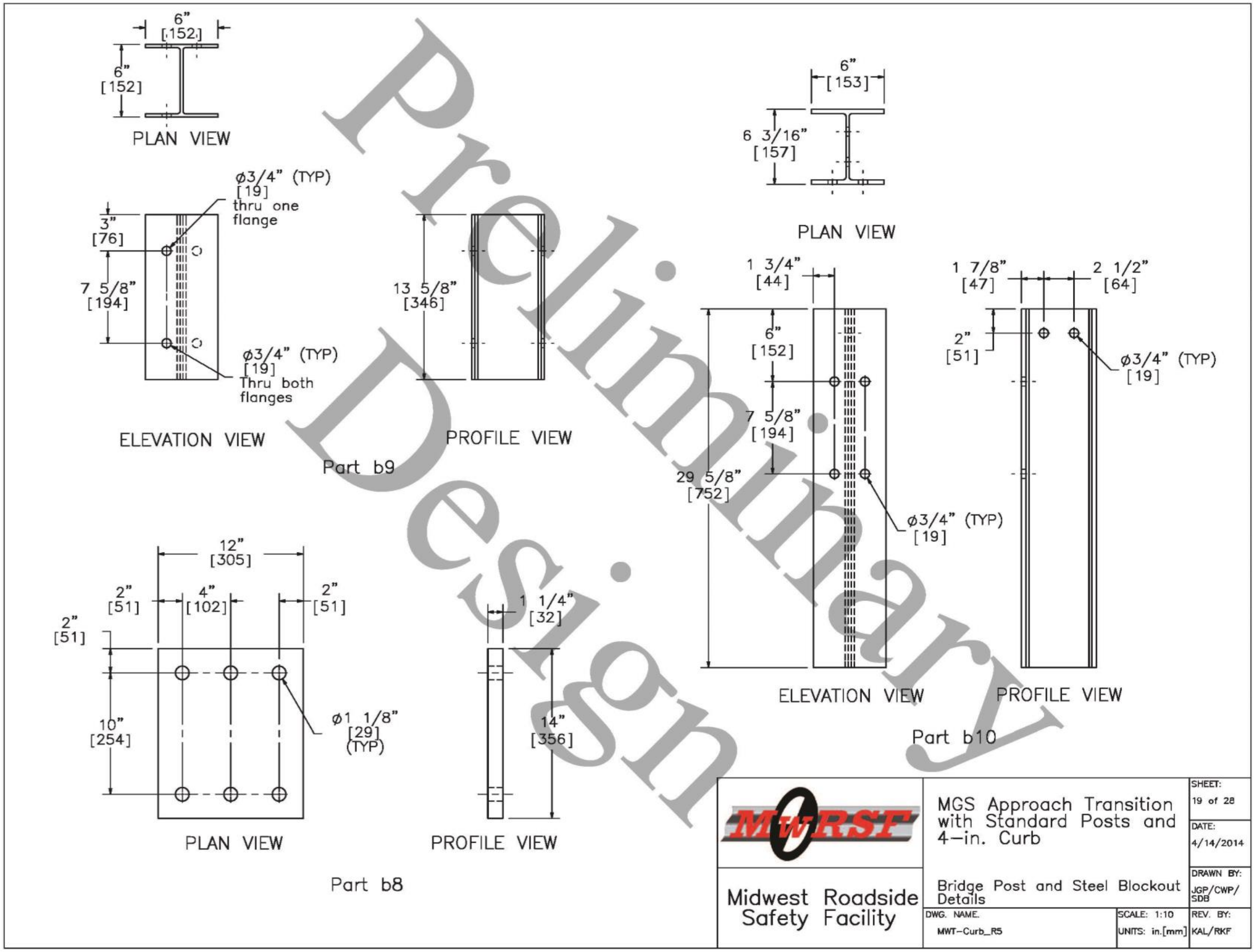


Figure 29. BCT Anchor Cable Detail, Test No. MWTC-1



Preliminary Design

Figure 30. Ground Strut and Anchor Bracket Details, Test No. MWTC-1



Preliminary Design

Figure 31. Bridge Post and Steel Blockout Details, Test No. MWTC-1

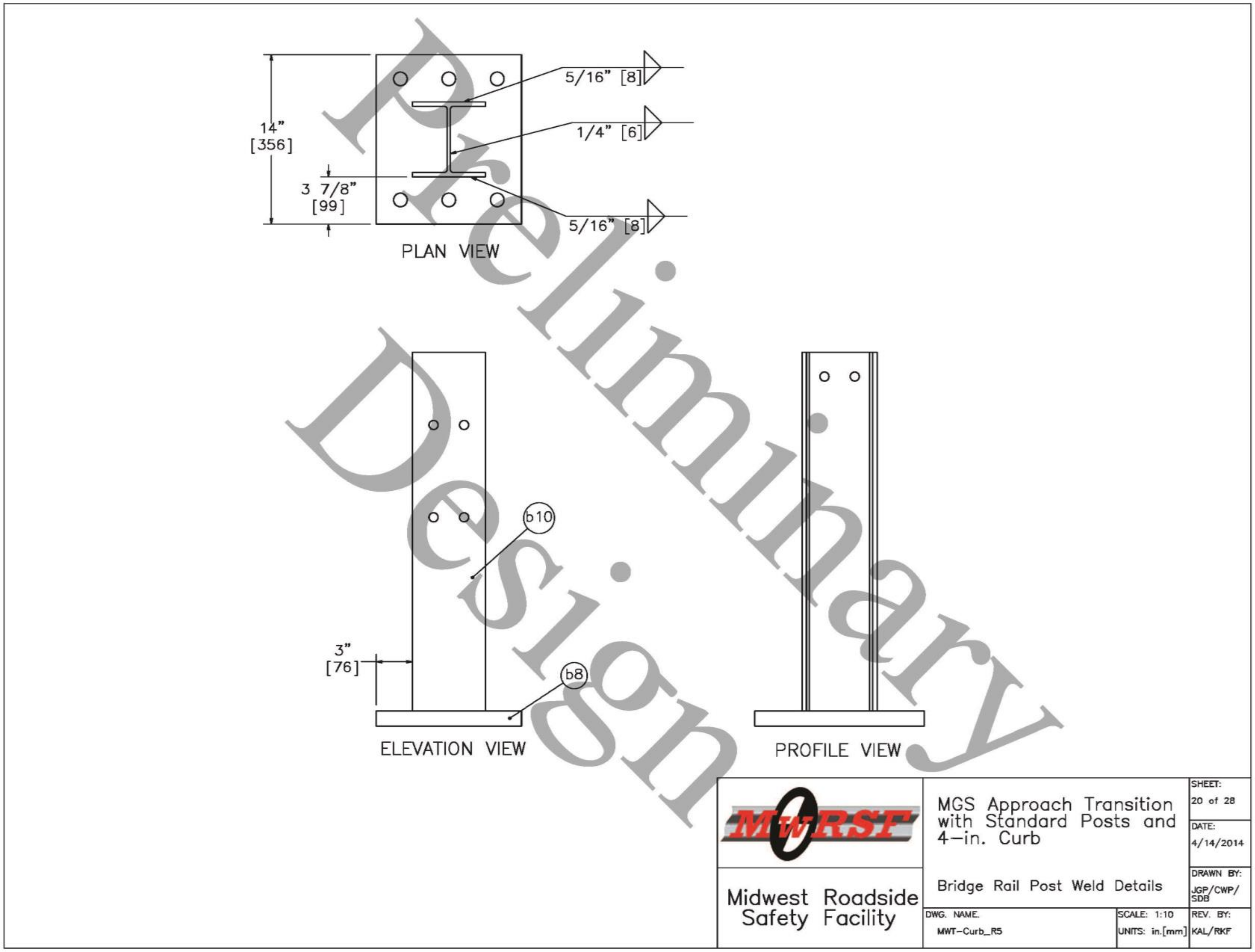
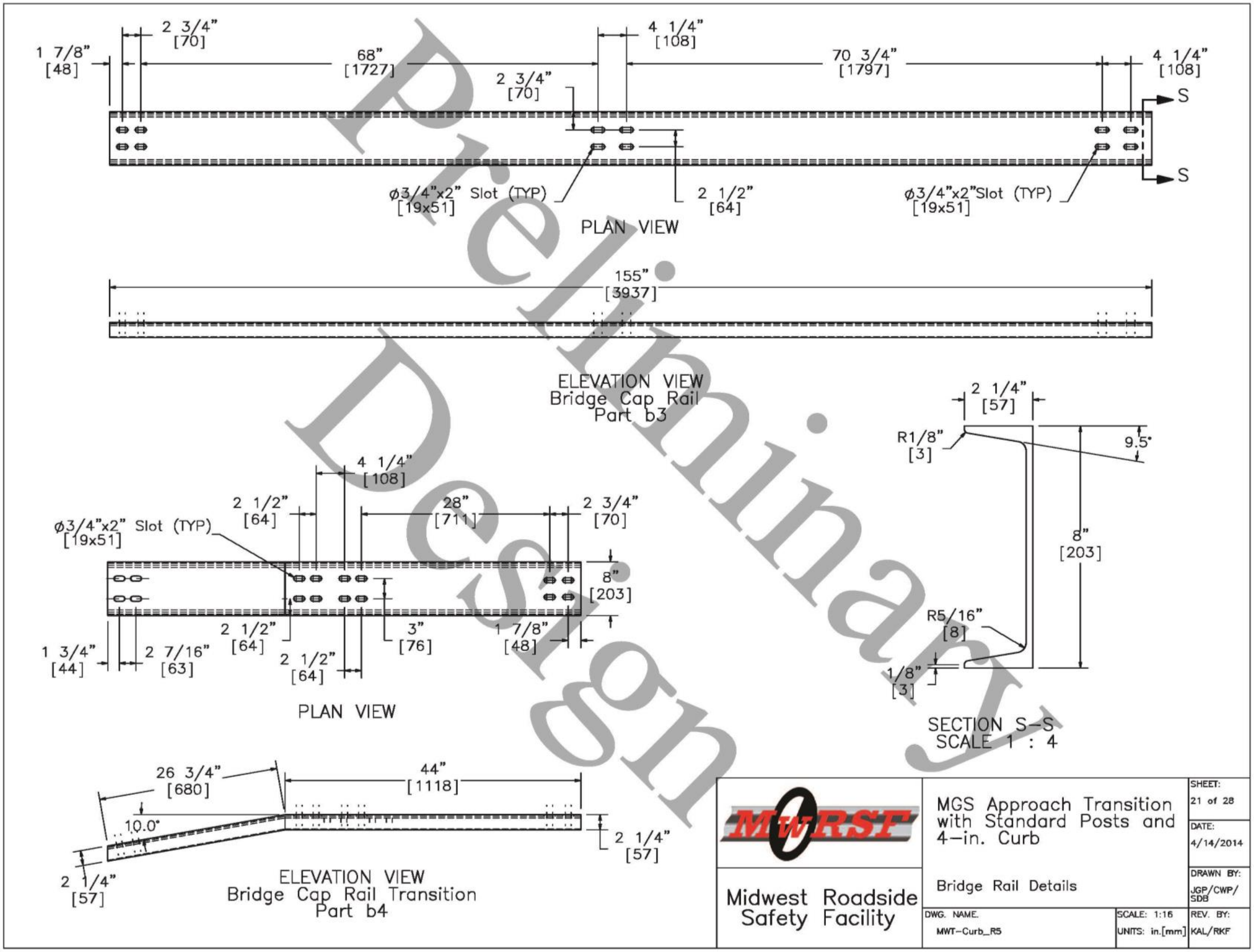
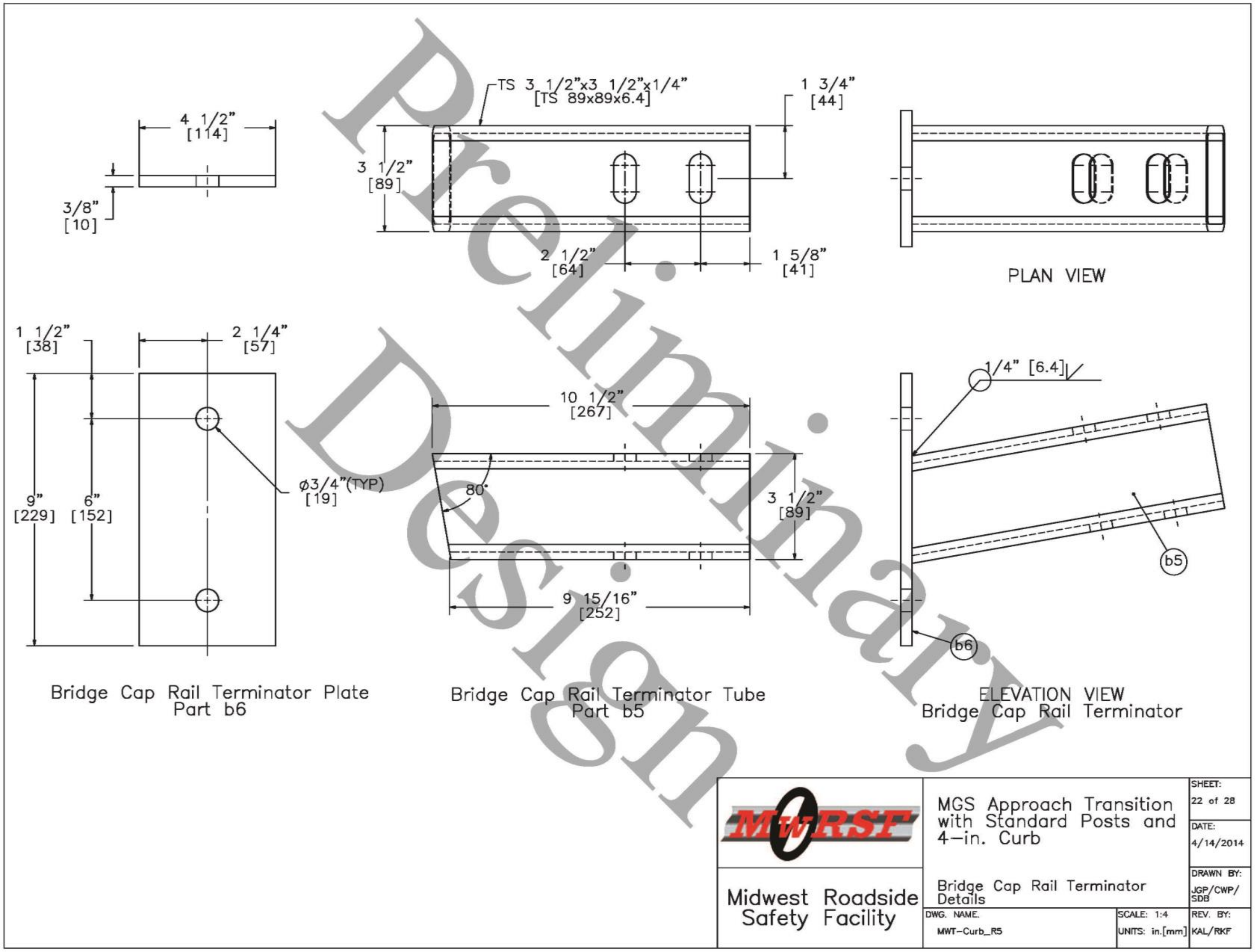


Figure 32. Bridge Rail Post Weld Details, Test No. MWTC-1



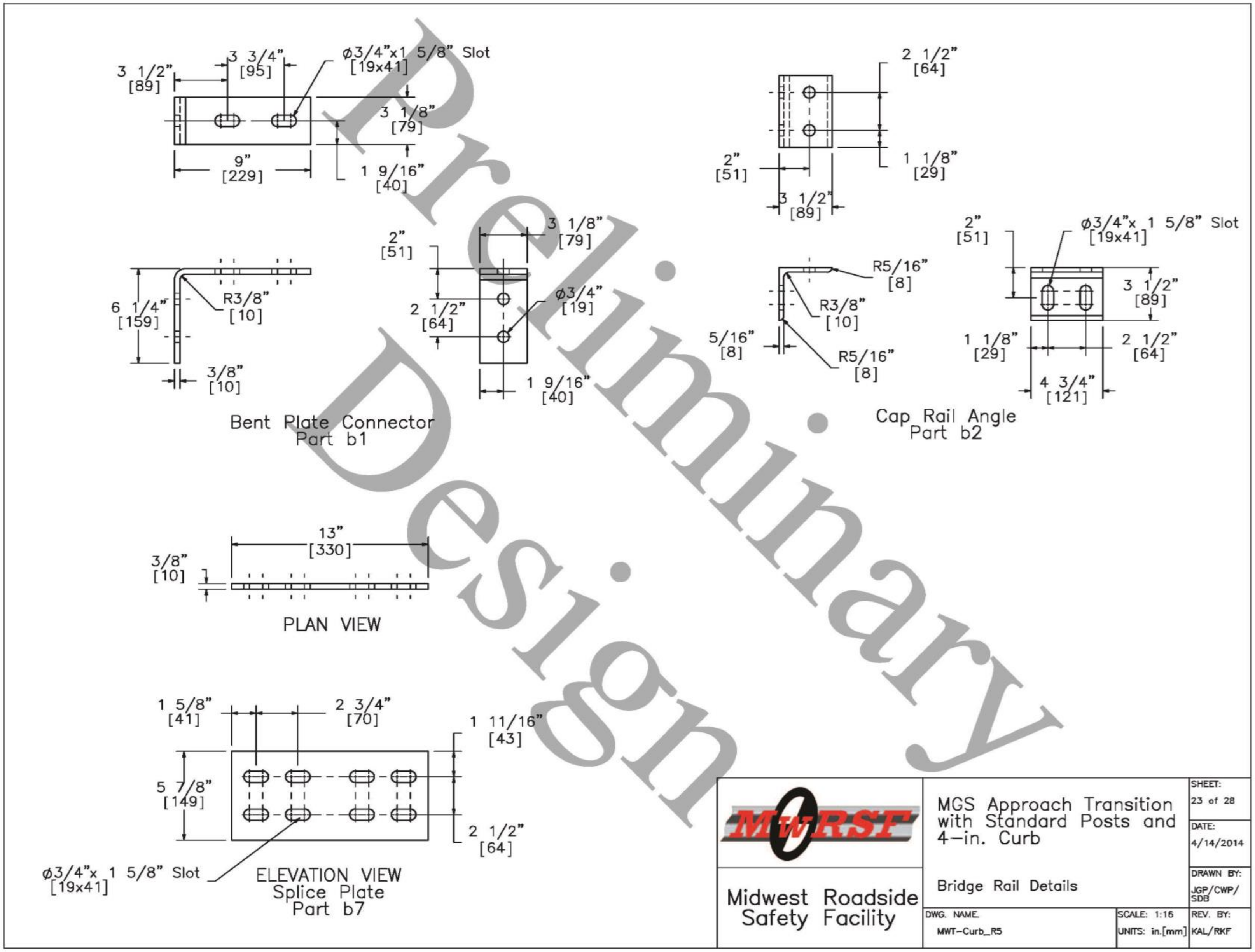
Preliminary
Design

Figure 33. Bridge Rail Details, Test No. MWTC-1



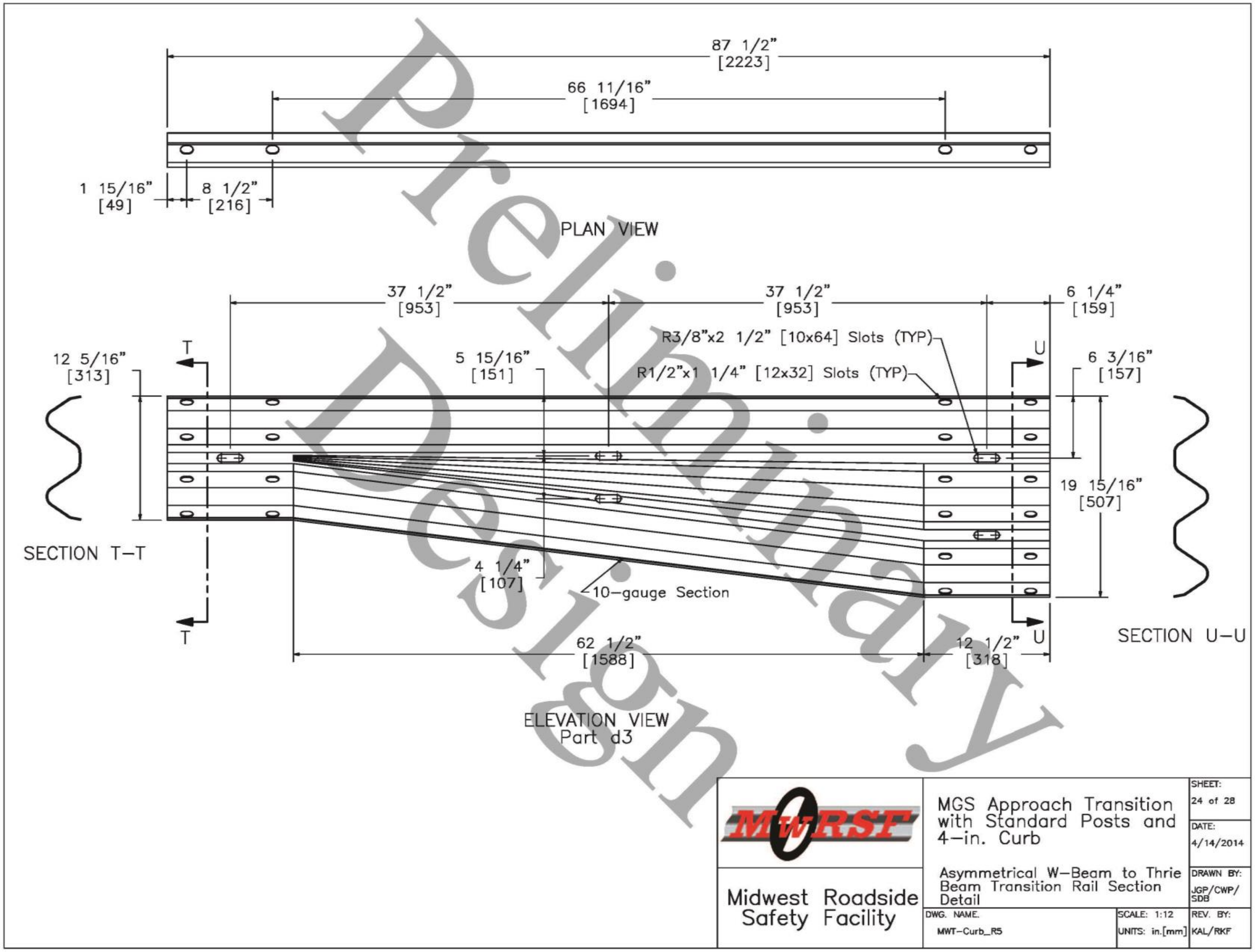
Preliminary Design

Figure 34. Bridge Cap Rail Terminator Details, Test No. MWTC-1



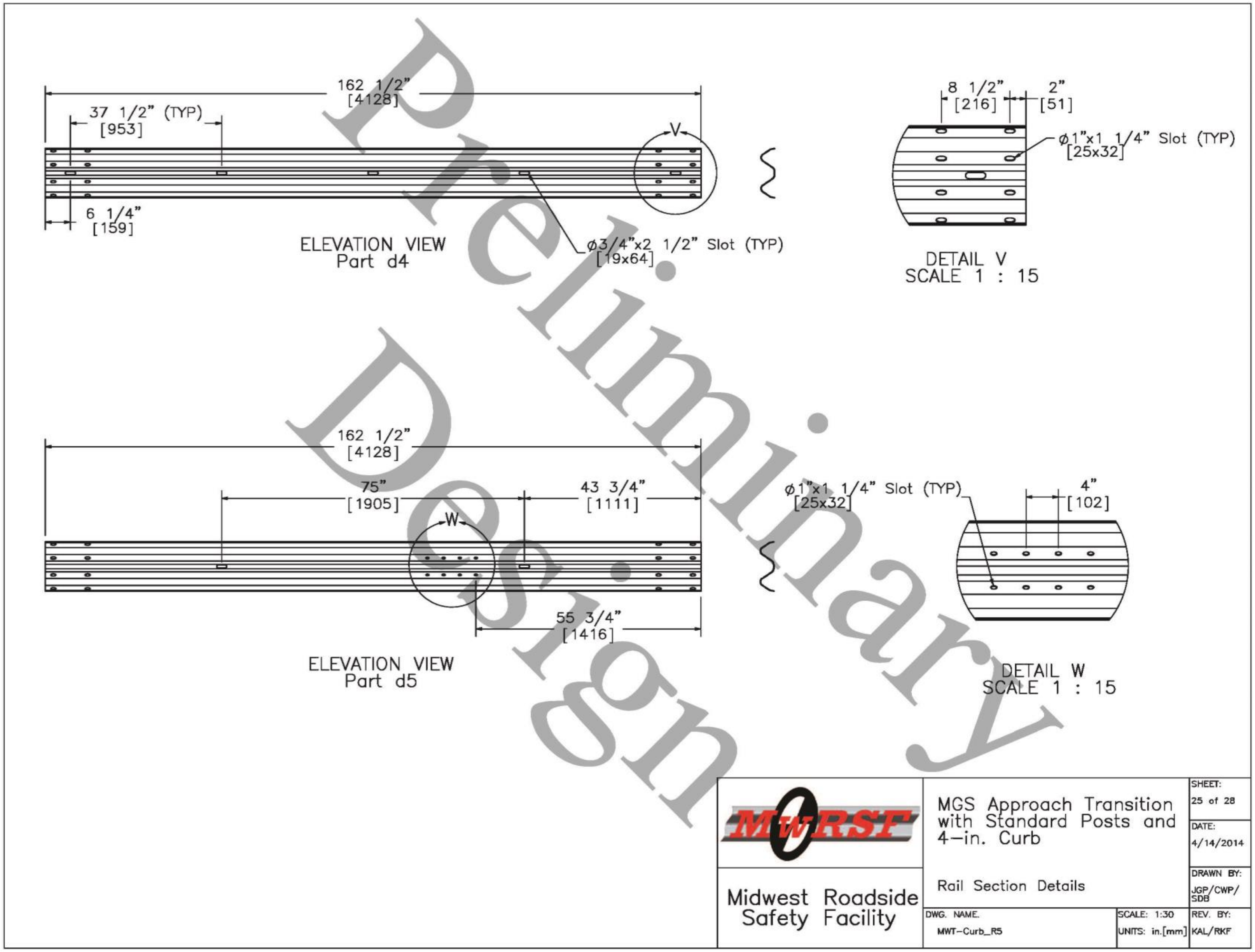
Preliminary Design

Figure 35. Bridge Rail Details, Test No. MWTC-1



Preliminary Design

Figure 36. Asymmetrical W-Beam to Thrie Beam Transition Rail Section Detail, Test No. MWTC-1



Preliminary Design

Figure 37. Rail Section Details, Test No. MWTC-1

Preliminary Design

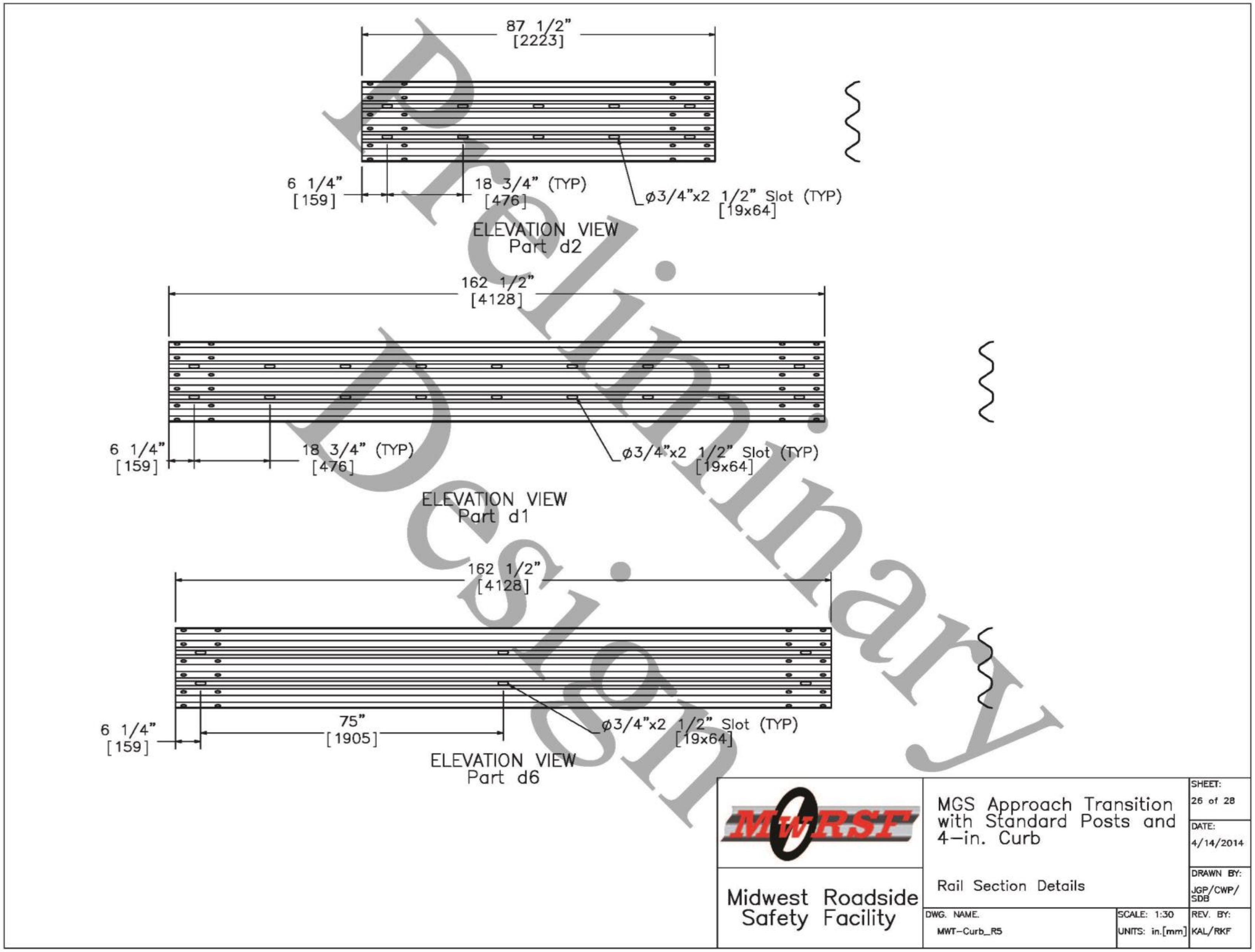


Figure 38. Rail Section Details, Test No. MWTC-1

Preliminary Design

Item No.	QTY.	Description	Material Spec	Hardware Guide
a1	7	6"x12"x14 1/4" [152x305x362] Blockout – Post 3–9	SYP Grade No.1 or better	PDB10a
a2	6	6"x12"x19" [152x305x483] Blockout – Post 10–15	SYP Grade No.1 or better	–
a3	2	6"x8"x19" [152x305x483] Blockout – Post 16–17	SYP Grade No.1 or better	–
a4	1	6"x8"x15" [152x305x381] Blockout – Post 18	SYP Grade No.1 or better	–
a5	2	BCT Timber Post –MGS Height	SYP Grade No.1 or better	PDF01
b1	2	6 1/4"x9"x3/8" [159x229x9.5] Bridge Cap Rail Bent Plate Connector	ASTM A36	–
b2	6	3 1/2"x3 1/2"x5/16" [89x89x7.9] Bridge Cap Rail Angle	ASTM A36	–
b3	1	C8x11.5 [C203x17.1] Bridge Cap Rail	ASTM A36	–
b4	1	C8x11.5 [C203x17.1] Bridge Cap Rail Transition	ASTM A36	–
b5	1	3 1/2"x3 1/2"x1/4" [89x89x6.4] Bridge Cap Rail Terminator Tube	ASTM A36	–
b6	1	9"x4 1/2"x3/8" [229x114x9.5] Terminator Plate	ASTM A36	–
b7	1	5 7/8"x13"x3/8" [149x330x9.5] Bridge Cap Rail Splice Plate	ASTM A36	–
b8	3	12"x14"x1 1/4" [305x356x32] Bridge Cap Connector Plate	ASTM A36	–
b9	3	W6x15 [W152x22.3] Steel Bridge Blockout	ASTM A992	–
b10	3	W6x20 [W152x29.8] Steel Bridge Post – Post Nos. 19–21	ASTM A992	–
c1	2	6"x8"x3/16" [152x203x5],72" [1829] Long Foundation Tube	ASTM A500 Grade B	PTE06
c2	1	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	–
c3	1	Anchor Bracket	ASTM A36	FPA01–02
c4	1	6' [1829] Long BCT Anchor Cable Assembly	3/4" [19] Dia. 6x19 IWRC IPS Wire Rope	FCA01
c5	1	8"x8"x5/8" [203x203x15.9] Anchor Bearing Plate	ASTM A36	FPB01
c6	1	2 3/8" [60] O.D., 6" [152] Long BCT Hole Insert	ASTM A53 Grade B Schedule 40	FMM02
d1	2	12'–6" [3810] Thrie Beam Section	12 gauge AASHTO M180	–
d2	1	6'–3" [1905] Thrie Beam Section	12 gauge AASHTO M180	–
d3	1	6'–3" [1905] W–Beam to Thrie–Beam Transition Section	10 gauge AASHTO M180	RWT02a
d4	3	12'–6" [3810] W–Beam MGS Section	12 gauge AASHTO M180	RWM04a
d5	1	12'–6" [3810] W–Beam MGS End Section	12 gauge AASHTO M180	RWM14a
d6	1	12'–6" [3810] Thrie Beam Section	12 gauge AASHTO M180	RTM02a

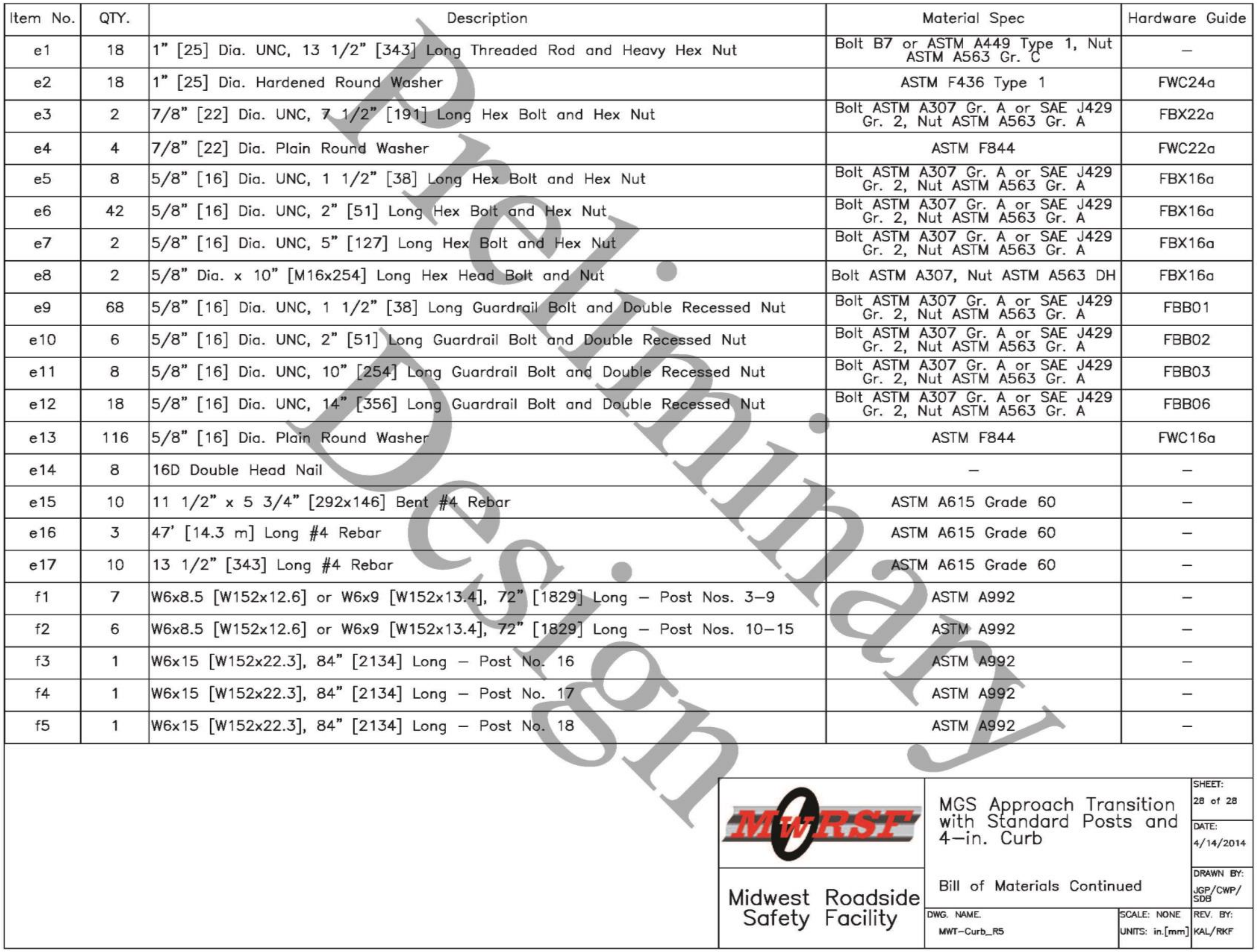
MwRSF
Midwest Roadside Safety Facility

MGS Approach Transition with Standard Posts and 4–in. Curb

Bill of Materials

SHEET: 27 of 28
DATE: 4/14/2014
DRAWN BY: JGP/CWP/SDB
DWG. NAME. MWT–Curb_R5
SCALE: NONE
UNITS: in.[mm]
REV. BY: KAL/RKF

Figure 39. Bill of Materials, Test No. MWTC-1



Item No.	QTY.	Description	Material Spec	Hardware Guide
e1	18	1" [25] Dia. UNC, 13 1/2" [343] Long Threaded Rod and Heavy Hex Nut	Bolt B7 or ASTM A449 Type 1, Nut ASTM A563 Gr. C	–
e2	18	1" [25] Dia. Hardened Round Washer	ASTM F436 Type 1	FWC24a
e3	2	7/8" [22] Dia. UNC, 7 1/2" [191] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX22a
e4	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	FWC22a
e5	8	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a
e6	42	5/8" [16] Dia. UNC, 2" [51] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a
e7	2	5/8" [16] Dia. UNC, 5" [127] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a
e8	2	5/8" Dia. x 10" [M16x254] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 DH	FBX16a
e9	68	5/8" [16] Dia. UNC, 1 1/2" [38] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB01
e10	6	5/8" [16] Dia. UNC, 2" [51] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB02
e11	8	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB03
e12	18	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB06
e13	116	5/8" [16] Dia. Plain Round Washer	ASTM F844	FWC16a
e14	8	16D Double Head Nail	–	–
e15	10	11 1/2" x 5 3/4" [292x146] Bent #4 Rebar	ASTM A615 Grade 60	–
e16	3	47' [14.3 m] Long #4 Rebar	ASTM A615 Grade 60	–
e17	10	13 1/2" [343] Long #4 Rebar	ASTM A615 Grade 60	–
f1	7	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1829] Long – Post Nos. 3–9	ASTM A992	–
f2	6	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1829] Long – Post Nos. 10–15	ASTM A992	–
f3	1	W6x15 [W152x22.3], 84" [2134] Long – Post No. 16	ASTM A992	–
f4	1	W6x15 [W152x22.3], 84" [2134] Long – Post No. 17	ASTM A992	–
f5	1	W6x15 [W152x22.3], 84" [2134] Long – Post No. 18	ASTM A992	–

MwRSF

Midwest Roadside Safety Facility

MGS Approach Transition with Standard Posts and 4–in. Curb

Bill of Materials Continued

SHEET: 28 of 28
DATE: 4/14/2014
DRAWN BY: JGP/CWP/SDB
DWG. NAME. MWT–Curb_R5
SCALE: NONE
UNITS: in.[mm]
REV. BY: KAL/RKF

Preliminary Design

Figure 40. Bill of Materials Continued, Test No. MWTC-1

Figure 41. System Photographs, Test No. MWTC-1

Figure 42. Simulated Anchor and Bridge Rail Photographs, Test No. MWTC-1

Figure 43. Posts in Impact Region, Test No. MWTC-1

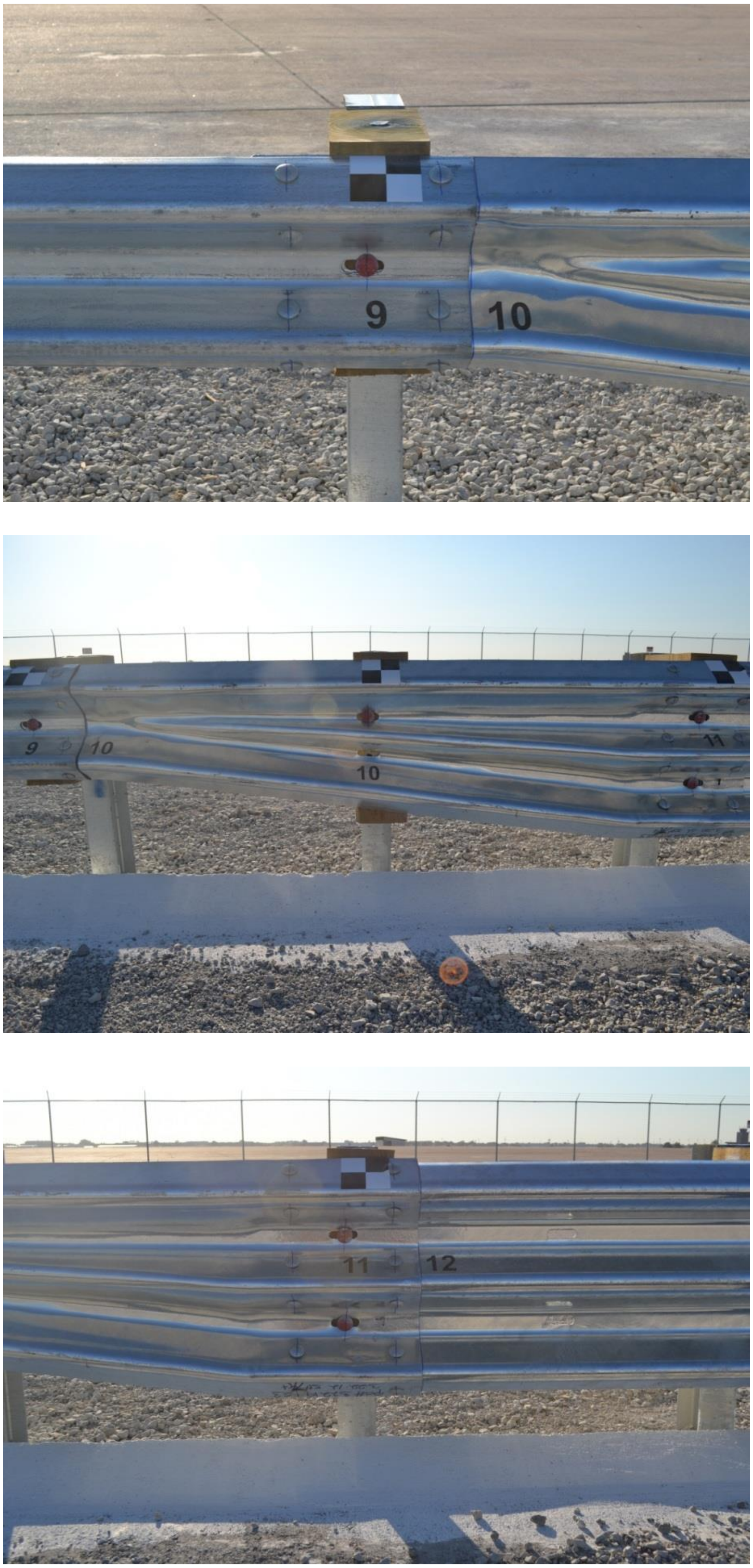


Figure 44. Transition Element Photographs, Test No. MWTC-1

5 FULL-SCALE CRASH TEST NO. MWTC-1

5.1 Static Soil Test

Before full-scale crash test no. MWTC-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 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. MWTC-1

The 2,457-lb (1,114-kg) small passenger car impacted the MGS to thrie beam transition system with curb at a speed of 62.9 mph (101.2 km/h) and at an angle of 25.0 degrees. A summary of the test results and sequential photographs are shown in Figure 45. Additional sequential photographs are shown in Figures 46 and 47.

5.3 Weather Conditions

Test no. MWTC-1 was conducted on August 10, 2012 at approximately 12:00 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

Table 3. Weather Conditions, Test No. MWTC-1

Temperature	77° F
Humidity	40%
Wind Speed	7 mph
Wind Direction	Variable
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	0 in.

5.4 Test Description

Initial vehicle impact was to occur 18¾ in. (476 mm) downstream of post no. 7, as shown in Figure 48, which was selected based on previous testing [1-2]. The actual point of impact was 4 in. (102 mm) upstream of the target impact location. A sequential description of the impact events is contained in Table 4. The vehicle came to rest in front of post no. 11 and was facing the barrier. This location was 15.8 ft (4.8 m) downstream of impact and 4.3 ft (1.3 m) laterally in front of the system. The vehicle trajectory and final position are shown in Figures 45 and 49.

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

TIME (sec)	EVENT
0.000	The vehicle impacted system 14¾ in. (375 mm) downstream from post no. 7.
0.010	The vehicle's left-front bumper underrode guardrail.
0.012	Rail between post nos. 7 and 8 began to kink, and post no. 7 deflected backward.
0.015	Post no. 8 deflected backward and slightly upstream; post no. 9 deflected backward.
0.018	The vehicle's left-front tire overrode curb.
0.020	The guardrail between post nos. 7 and 8 began to flatten.
0.022	Post no. 10 began to deflect upstream.
0.032	The blockout at post no. 8 began to twist.
0.044	Blockout no. 8 began to detach from post no. 8.
0.052	Post no. 9 twisted upstream.
0.060	The blockout at post no. 8 detached from post.
0.068	Vehicle began to pitch downward; guardrail between post nos. 10 and 11 began to deflect upward; vehicle's left-front tire contacted post no. 8.
0.072	The vehicle's front bumper contacted post no. 9.
0.076	The guardrail between post nos. 11 and 12 deflected backwards.
0.084	The blockout at post no. 9 detached from post.
0.116	The vehicle's front bumper contacted post no. 10.
0.118	W-beam guardrail ruptured at splice to W-to-thrie transition segment, at post no. 9.
0.134	The vehicle's front bumper was detached and the vehicle pitched downward.
0.188	The vehicle stopped moving downstream and the rear tires became airborne.
0.258	The vehicle began to yaw toward barrier.
0.350	The rear tires rose above guardrail height.
0.710	The vehicle exited system.
0.786	The vehicle reached a maximum pitch of -36.3 degrees.
1.860	The rear tires first returned to ground.
2.400	Vehicle came to a stop.

5.5 System Damage

Damage to the barrier was severe, as shown in Figures 50 through 52. System damage consisted of deformed guardrail and posts, displaced soil, fractured wooden spacer blockouts, contact marks, and W-beam rail rupture. The length of vehicle contact along the barrier was approximately 17.5 ft (5.3 m), which spanned from 14¾ in. (375 mm) downstream of post no. 7 to post no. 12.

The 12-gauge (2.66-mm thick) W-beam rail ruptured at the splice at post no. 9 with all bolts remaining on the downstream end of the ruptured rail or on the 10 gauge (3.42-mm thick) W-to-thrie transition element, as shown in Figure 51. The guardrail tore from the top, downstream corner of the splice diagonally to the bottom, upstream corner. The downstream edge of the W-beam remained attached to the W-to-thrie transition segment. The downstream end of rail folded back and behind the system at post no. 12.

Rail deformation first occurred with a buckle in the guardrail 4 in. (102 mm) upstream of post no. 7. Contact marks on the rail began 4 in. (102 mm) upstream from targeted impact and extended until post no. 12. Rail flattening occurred from 18 in. (457 mm) upstream of post no. 8 and extended to downstream of post no. 9. The bottom corrugation of the W-to-thrie transition segment folded up from post no. 9 through 11 in. (279 mm) downstream of post no. 10. Two 90 degree buckles were found in the thrie beam rail adjacent to the W-to-thrie transition segment. The first was just downstream of post no. 11 and the second was at post no. 12. A 1½-in. (38-mm) vertical tear occurred at the bottom post bolt at post no. 12. There were also several kinks in the rail throughout the impact region.

Post no. 8 buckled at ground line and bent backward and downstream. Post nos. 9 through 12 also deflected downstream and bent and twisted backward. The front flanges of post nos. 10 and 11 tore at the lower post bolt hole. The rail disengaged from post nos. 7-12. The blockouts at post nos. 5, 13, 16, and 17 were split. The blockouts were disengaged from post nos. 8, 9, and 10. The blockout of post no. 11 had gouging and multiple fractures, while the upstream face of the blockout at post no. 12 fractured at the bottom bolt location.

A 6-in. (152-mm) long gouge was found on top of the curb beginning 27 in. (686 mm) upstream of post no. 8. Gouging also occurred at the top of the curb beginning 23 in. (584 mm) upstream of centerline of post no. 9 and extending to 2 in. (51 mm) downstream from the center line of post no. 11.

5.6 Vehicle Damage

The damage to the vehicle was moderate with most of the damage occurring on the left side of the vehicle, as shown in Figure 53. The maximum occupant compartment deformations are listed in Table 5 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

On the left side of the vehicle, a 20-in. (508-mm) long scrape was found across both doors. A 22-in. (559-mm) long dent was found on the vehicle’s fender and left-front door. The fender was crushed inward and backward at the top, with the bottom of the fender pulled out and away from the door. The left-front tire was torn, and the tire was deflated. The left-front wheel well was partially disengaged. The left-front lower control arm was damaged and both the radiator and left headlight crushed inward. A 3-in. (76-mm) vertical gap was found between the fender and hood.

Table 5. 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	½ (13)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¾ (19)	≤ 12 (305)
Side Door (Above Seat)	¼ (6)	≤ 9 (229)
Side Door (Below Seat)	¼ (6)	≤ 12 (305)
Roof	0	≤ 4 (102)
Windshield	0	≤ 3 (76)

The front bumper and bumper cover were dented and disengaged on the left side. The left-front corner of the hood folded under and the engine cover split. Also, minor spider web cracking occurred in the lower-left corner of the windshield.

On the right side of the car, the top frame around the radiator bent inward. The right bumper frame deflected backward, and the right headlight disengaged. After the vehicle came to rest, fluid leaked under the right-front corner of the vehicle.

5.7 Occupant Risk

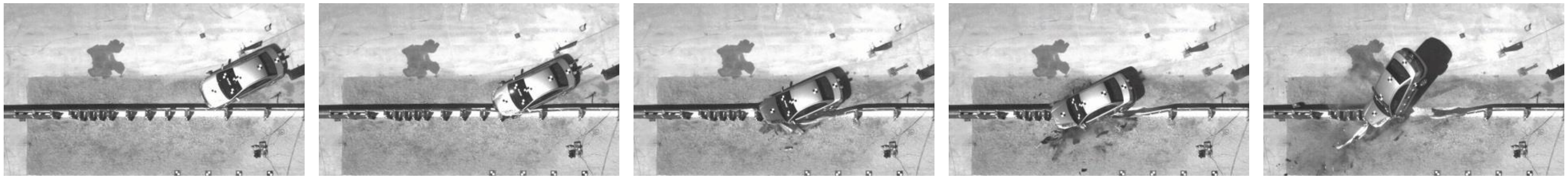
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 6. Note that the OIVs were within the suggested limits provided in MASH, but the longitudinal ORA values exceeded the MASH limits. The calculated THIV, PHD, and ASI values are also shown in Table 6. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 45. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 6. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MWTC-1

Evaluation Criteria		**Transducer**			**MASH Limits**
		DTS	**DTS SLICE**	**EDR-3**	
OIV ft/s (m/s)	Longitudinal	-35.86 (-10.93)	-32.56 (-9.92)	-37.52 (-11.44)	≤ 40 (12.2)
	Lateral	16.45 (5.01)	17.59 (5.36)	16.01 (4.88)	≤ 40 (12.2)
ORA g's	Longitudinal	-21.76	-22.25	-21.23	≤ 20.49
	Lateral	-8.70	-8.51	-8.42	≤ 20.49
THIV ft/s (m/s)		38.78 (11.82)	36.88 (11.24)	NA	not required
PHD g's		23.29	23.79	NA	not required
ASI		1.23	1.26	1.26	not required

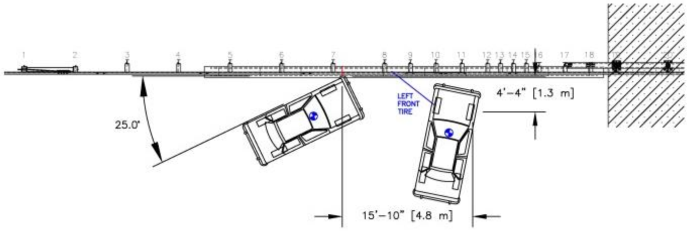
5.8 Discussion

The analysis of the test results for test no. MWTC-1 showed that the MGS to thrie beam transition system with curb did not safely redirect the 1100C vehicle. During the test, components of the small car penetrated under the W-beam rail, while the wheel climbed up and overrode the curb. These events led to heavy upward and lateral vehicle loading on the lower region of the W-beam rail in advance of the splice between the W-beam and asymmetrical transition segment. The W-beam rail ruptured at the splice location, gave way, and allowed the vehicle to snag on a stiff rail element in combination with several exposed transition posts. The presence of a curb under the MGS near a stiff transition likely changed the load direction and magnitude applied to the guardrail in advance of the splice location. In addition, the presence of a curb may also have provided increased soil confinement and/or resistance to post-soil rotation within the guardrail region in advance of the splice location. The wheel interaction with the curb surface and curb back side edge may have contributed to a slightly-altered vehicle trajectory from that observed in the successful small car crash test on the system without a curb. One factor, or even a combination of these factors, likely led to the W-beam rupture at the splice to the W-to-thrie transition element. The failure of the rail allowed the vehicle to travel into the transition region where it contacted stiff rail elements and multiple transition posts. This contact resulted in the vehicle quickly being brought to a stop with excessive longitudinal ORA values. Therefore, test no. MWTC-1, conducted on the MGS to thrie beam transition system with curb, was determined to be unacceptable according to the MASH safety performance criteria for test designation no. 3-20.



0.000 sec 0.044 sec 0.152 sec 0.248 sec 0.710 sec

- Test Agency .... MwRSF
- Test Number MWTC-1
- Date 8/10/12
- MASH Test Designation 3-20
- Test Article .... Stiffness Transition between MGS and Thrie Beam Transition with Curb
- Total Length .... 87.5 ft (26.7 m)
- Height to Top of Rail .... 31 in. (787 mm)
- Steel 12 gauge (2.66 mm) W-Beam Guardrail
  - Segment Location - Single .... Post nos. 1 to 9
- Steel 10 gauge (3.42 mm) W-Beam to Thrie Beam Transition
  - Segment Location .... Post nos. 9 to 11
- Steel 12 gauge (2.66 mm) Thrie Beam Guardrail
  - Segment Location - Single .... Post nos. 11 to 14 and 19 to 21
  - Segment Location - Nested .... Post nos. 14 to 19
- Guardrail Posts
  - Post Nos. 1-2 .... 46 in. (1,168 mm) long, BCT timber posts
  - Post Nos. 3-15 .... 72 in. (1,829 mm) long, W6x8.5 (W152x12.6)
  - Post Nos. 16-18 .... 84 in. (2,134 mm) long, W6x15 (W152x22.3)
  - Post Nos. 19-21 .... 29⅝ in. (752 mm) long, W6x20 (W152x29.8)
- Post Spacing
  - Post Nos. 1-8, 19-21 .... 75 in. (1,905 mm)
  - Post Nos. 8-12, 16-19 .... 37½ in. (953 mm)
  - Post Nos. 12-16 .... 18¾ in. (476 mm)
- Soil Type .... AASHTO Grade B
- Vehicle
  - Make and Model .... 2007 Kia Rio
  - Test Inertial .... 2,457 lb (1,114 kg)
  - Gross Static .... 2,623 lb (1,190 kg)
  - Curb .... 2,468 lb (1,119 kg)
- Impact Conditions
  - Speed .... 62.9 mph (101.2 km/h)
  - Angle .... 25.0 deg
  - Impact Severity (IS) .... 58.0 kip-ft (78.6 kJ) > 51.0 kip-ft (69.1 kJ)
  - Impact Location .... 14¾ in. (375 mm) downstream of post no. 7
- Exit Conditions
  - Speed .... NA
  - Angle .... NA
- Exit Box Criterion .... NA
- Vehicle Stability .... Satisfactory



- Vehicle Stopping Distance .... 15.8 ft (4.8 m) downstream of impact 4.3 ft (1.3 m) laterally in front of system
- Vehicle Damage .... Moderate
  - VDS[7] 11-LFQ-5
  - CDC[8] 11-LFEW2
  - Maximum Interior Deformation .... ¾ in. (19 mm)
- Test Article Damage .... Severe (rail ruptured)
- Maximum Test Article Deflections
  - Permanent Set .... NA (rail ruptured)
  - Dynamic .... NA (rail ruptured)
  - Working Width .... NA (rail ruptured)
- Maximum Angular Displacements
  - Roll .... 13.7° < 75°
  - Pitch .... -36.3° < 75°
  - Yaw .... -54.1°
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		DTS	DTS SLICE	EDR-3	
OIV ft/s (m/s)	Longitudinal	-35.86 (-10.93)	-32.56 (-9.92)	-37.52 (-11.44)	≤ 40 (12.2)
	Lateral	16.45 (5.01)	17.59 (5.36)	16.01 (4.88)	≤ 40 (12.2)
ORA g's	Longitudinal	-21.76	-22.25	-21.23	≤ 20.49
	Lateral	-8.70	-8.51	-8.42	≤ 20.49
THIV – ft/s (m/s)		38.78 (11.82)	36.88 (11.24)	NA	not required
PHD – g's		23.29	23.79	NA	not required
ASI		1.23	1.26	1.26	not required

Figure 45. Summary of Test Results and Sequential Photographs, Test No. MWTC-1

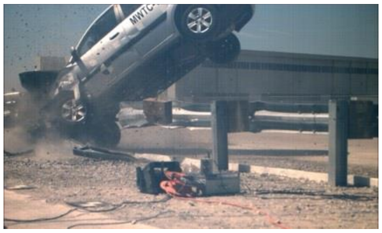
0.000 sec

0.036 sec

0.068 sec

0.110 sec

0.314 sec



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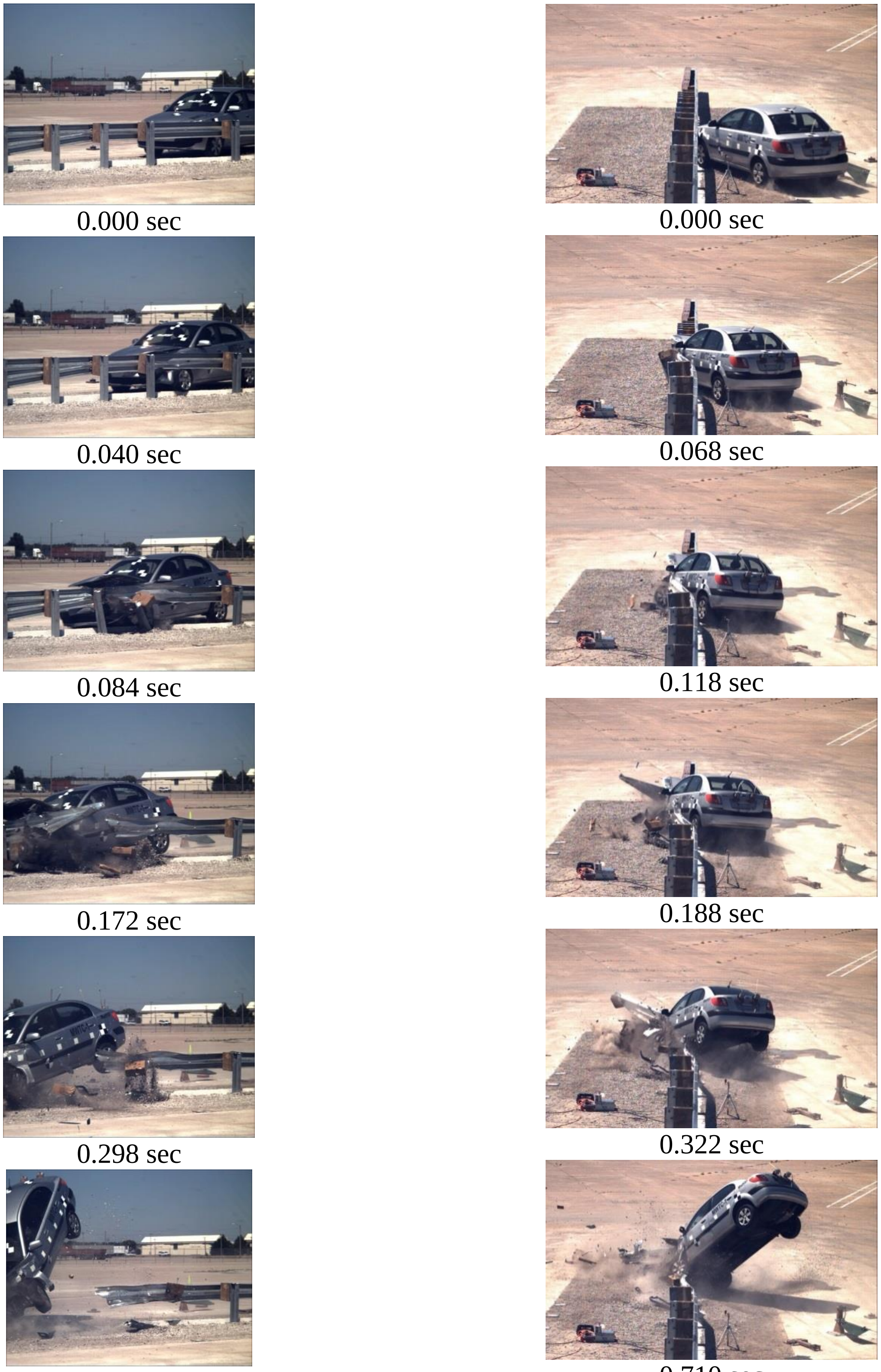
0.198 sec

0.710 sec

Figure 46. Sequential Photographs, Test No. MWTC-1



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0.188 sec

0.298 sec

0.322 sec

0.710 sec

0.710 sec

Figure 47. Additional Sequential Photographs, Test No. MWTC-1

Figure 48. Impact Location, Test No. MWTC-1

Figure 49. Vehicle Final Position, Test No. MWTC-1

Figure 50. System Damage, Test No. MWTC-1

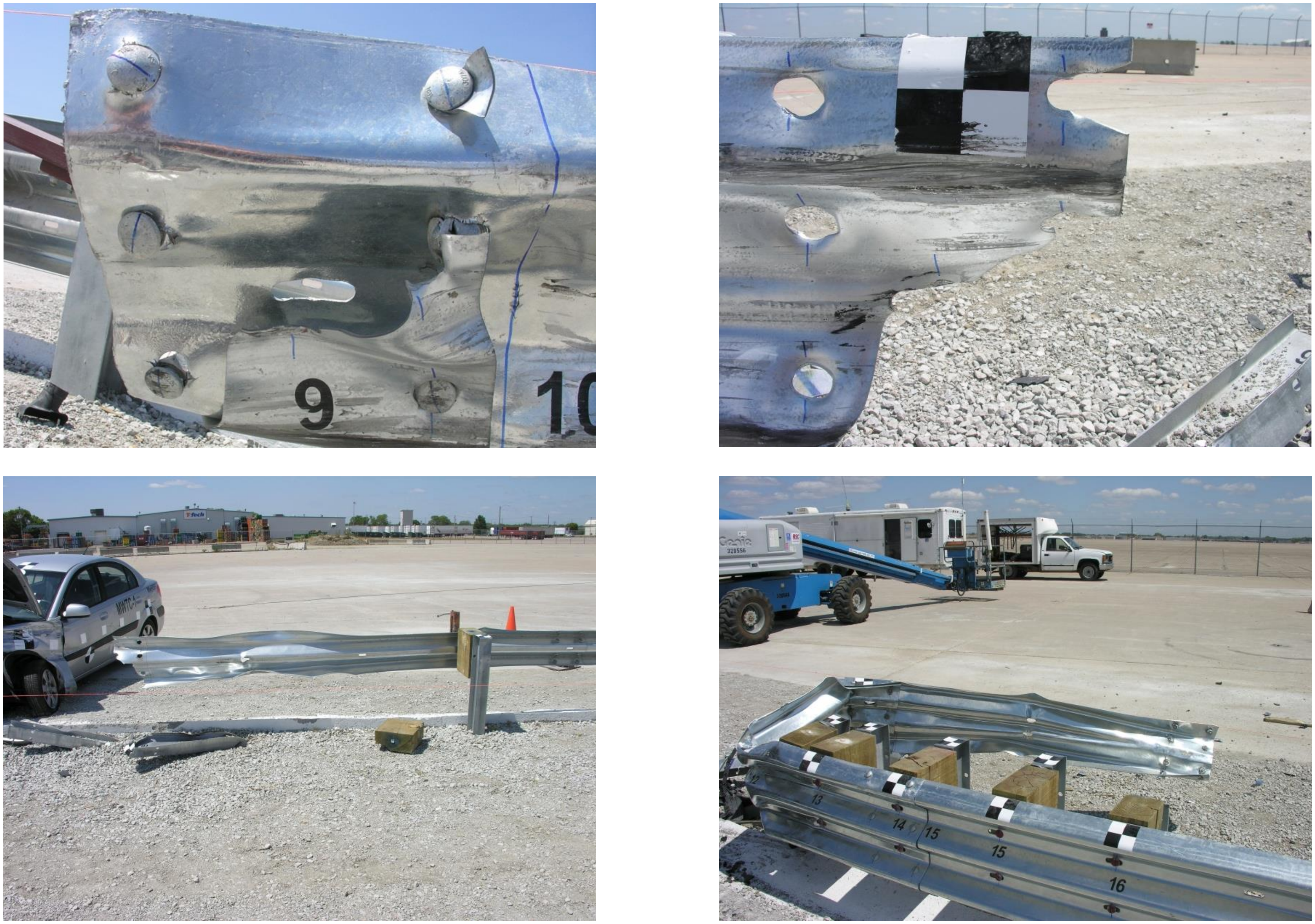


Figure 51. Rail Pocketing and Rupture, Test No. MWTC-1

Figure 52. Post Deflection, Test No. MWTC-1

Figure 53. Vehicle Damage, Test No. MWTC-1

6 DESIGN DETAILS AND MODIFICATIONS AND DETAILS

Due to the rail rupture and subsequent system failure experienced during test no. MWTC-1, design modifications were required to strengthen the rail near the upstream end of the asymmetrical transition element. Thus, an additional 12-gauge (2.66-mm thick) W-beam segment was incorporated into the system such that 12.5 ft (3.8 m) of nested W-beam guardrail preceded the 10-gauge (3.42-mm thick) W-to-thrie transition segment. This minor modification was believed to be sufficient to prevent rail rupture observed during a small car impact just upstream from the asymmetrical element and in combination with a concrete curb.

Design details for test nos. MWTC-2 and MWTC-3 are shown in Figures 54 through 82. The system layouts for these two tests are nearly identical to that of test no. MWTC-1, with only the addition of the 12.5 ft (3.8 m) nested W-beam section prior to the W-to-thrie transition segment. Test no. MWTC-2 used an 1100C crash vehicle and had the same impact point as test no. MWTC-1, 18¾ in. (476 mm) downstream of post no. 7. Test no. MWTC-3 used a 2270P vehicle and had a target impact point 37½ in. (953 mm) downstream of post no. 7. Photographs of the test system are shown in Figure 83. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix B.

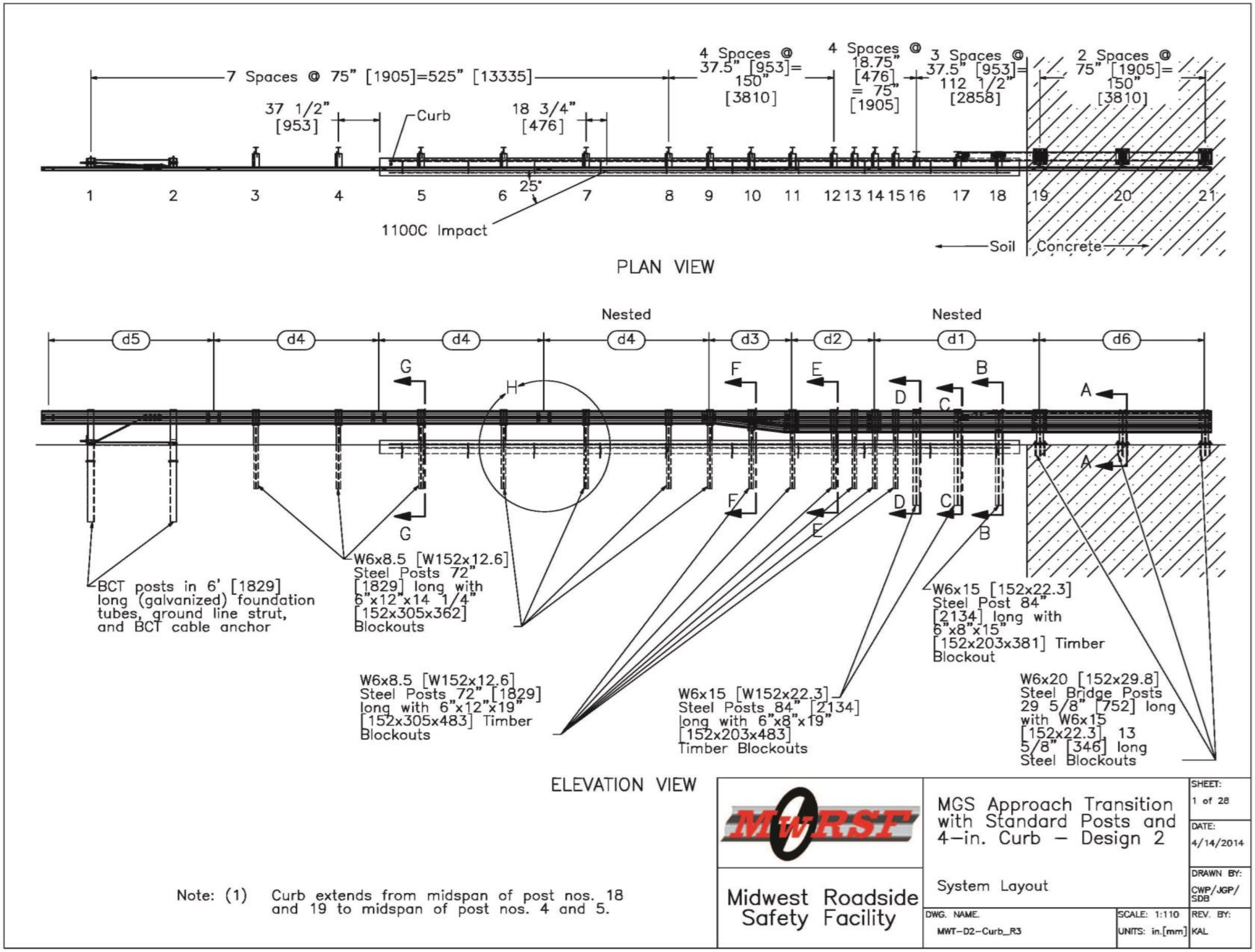


Figure 54. System Layout, Test No. MWTC-2

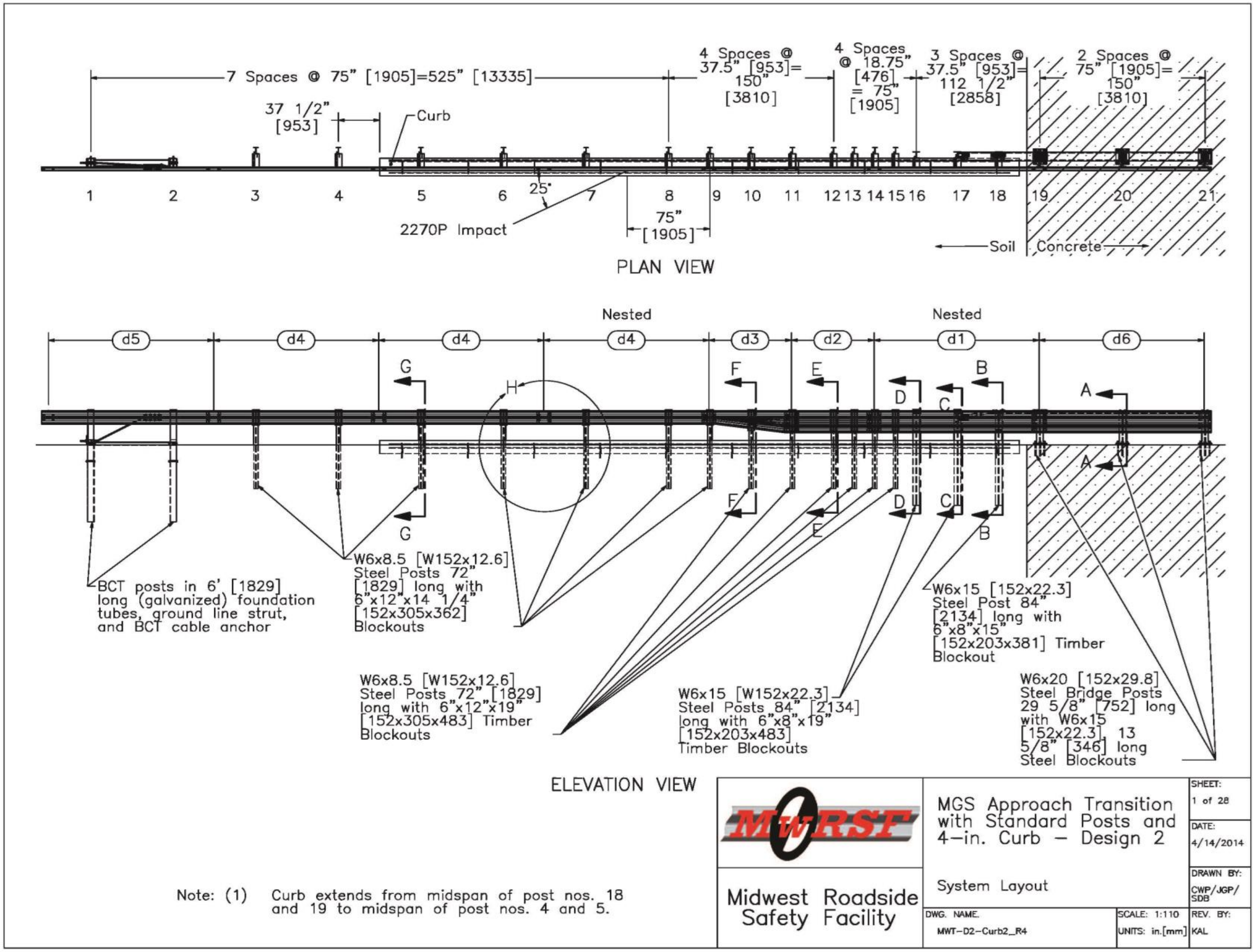


Figure 55. System Layout, Test No. MWTC-3

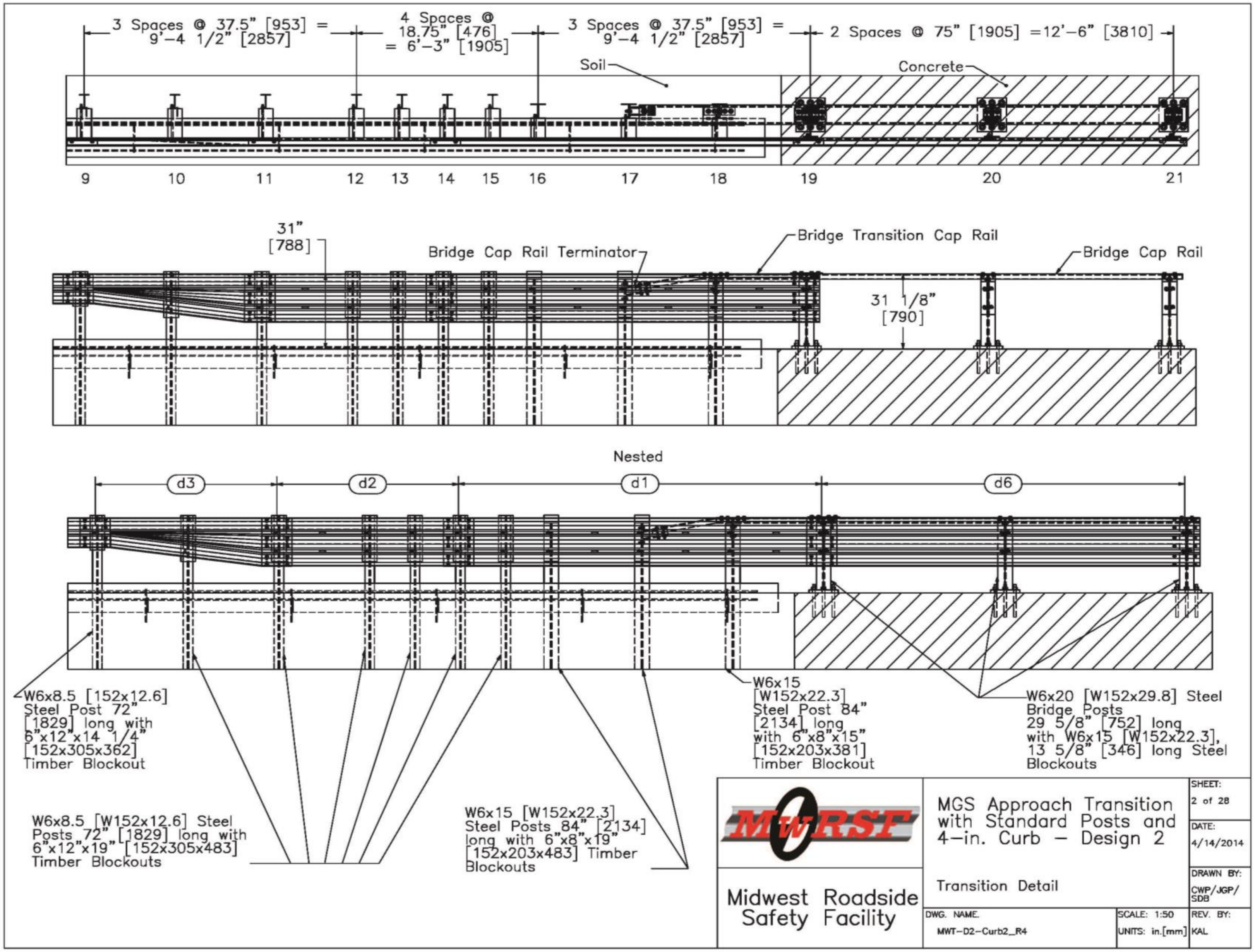


Figure 56. Downstream End System Layout, Test Nos. MWTC-2 and MWTC-3

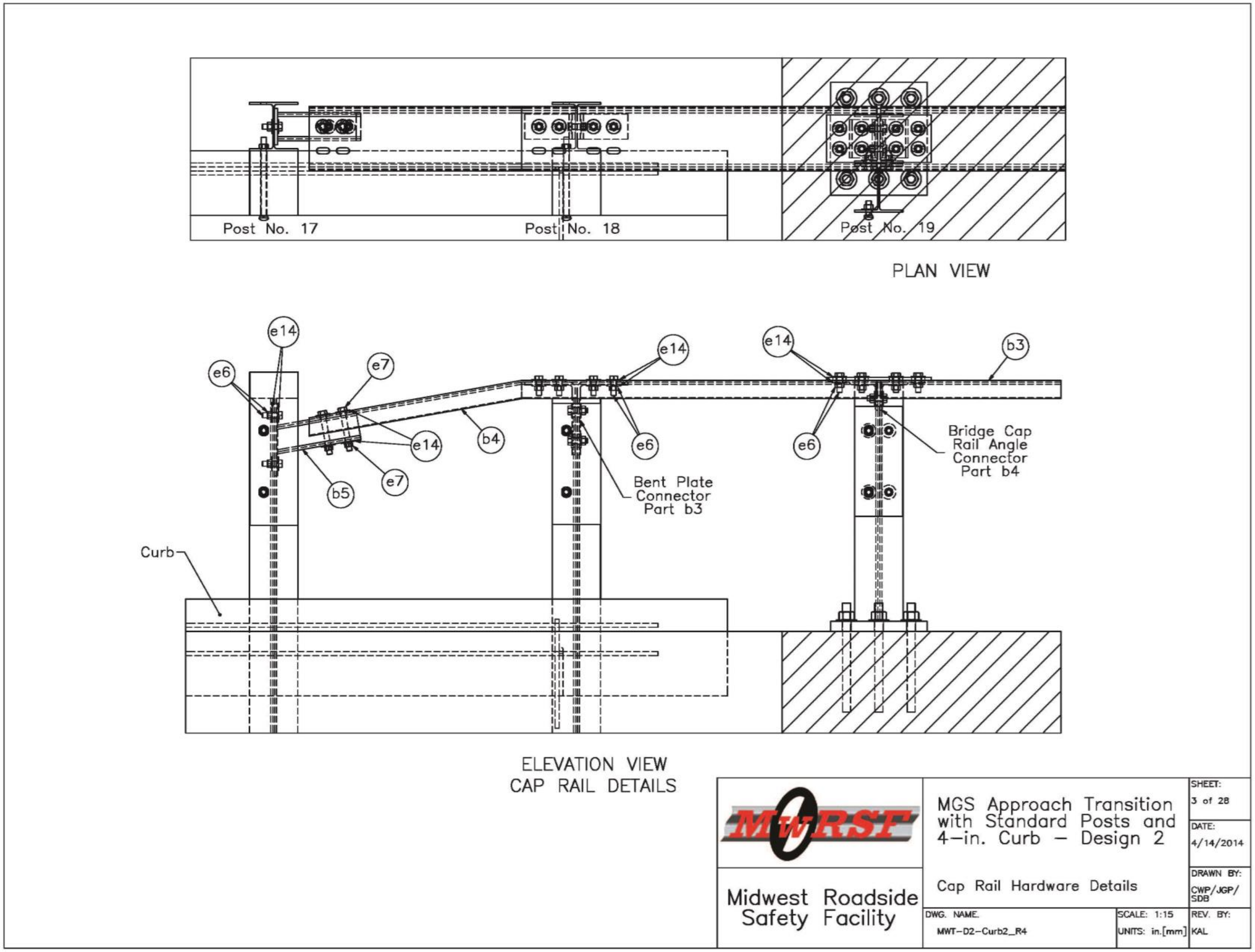


Figure 57. Cap Rail Hardware Details, Test Nos. MWTC-2 and MWTC-3

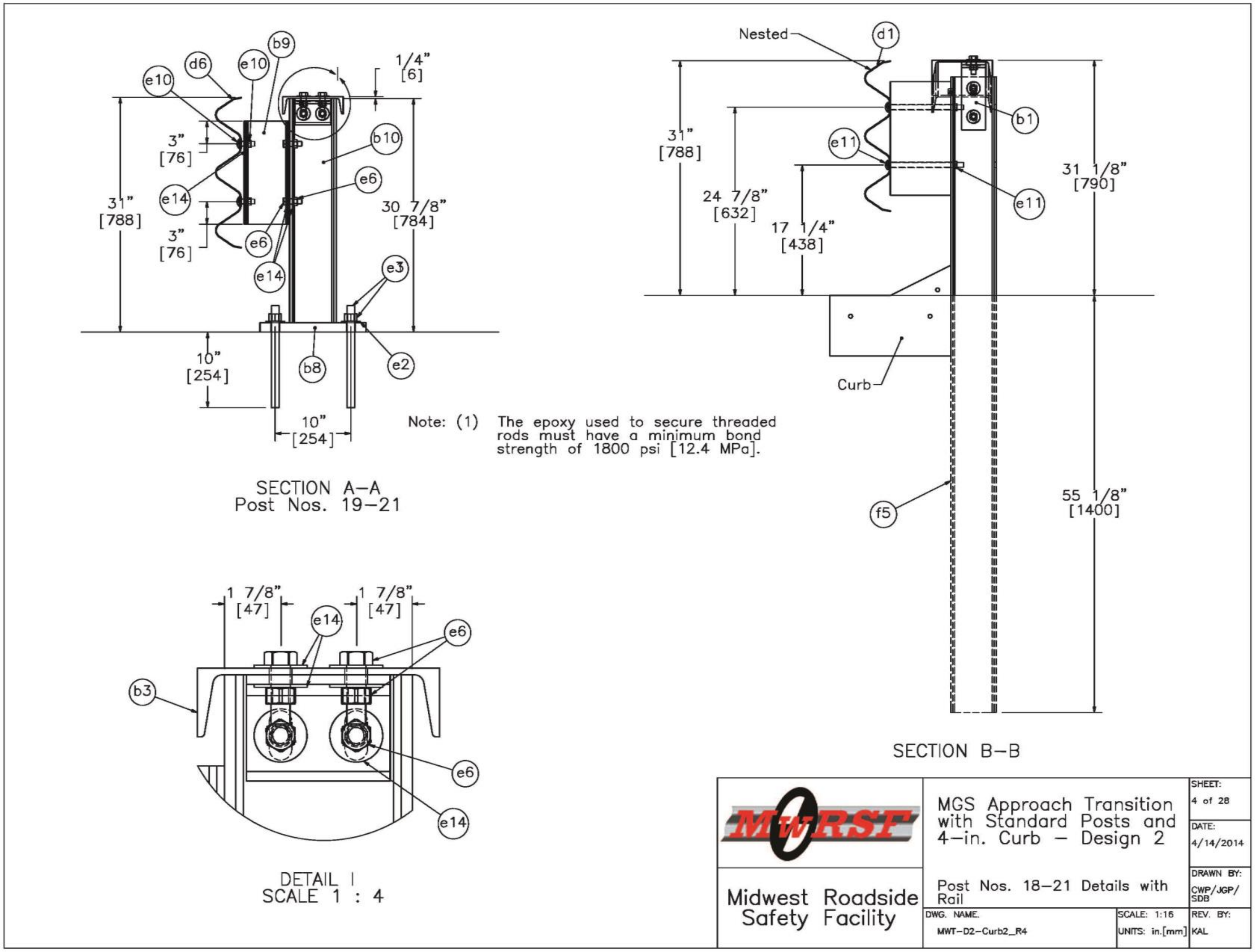


Figure 58. Post Nos. 18 through 21 Details with Rail, Test Nos. MWTC-2 and MWTC-3

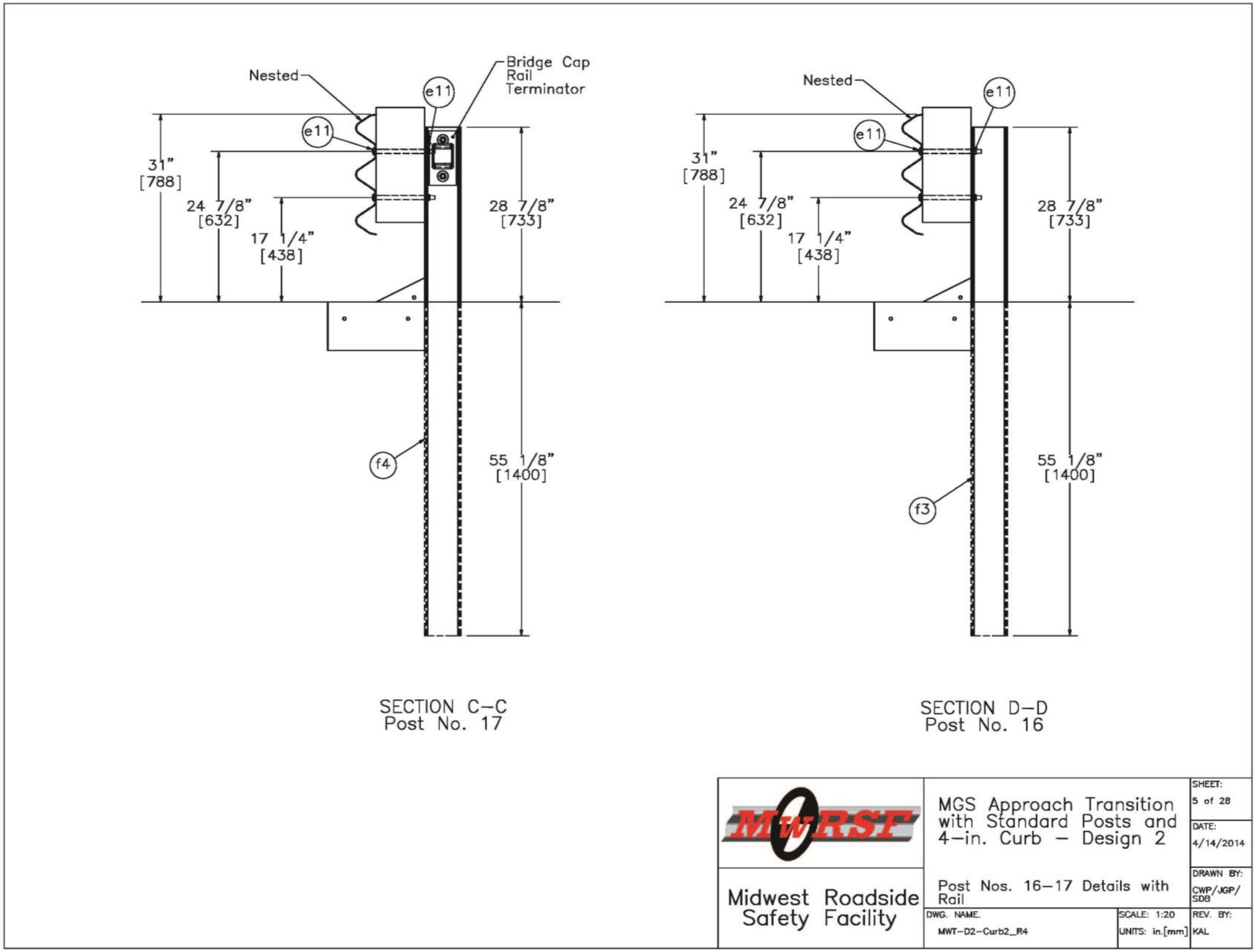


Figure 59. Post Nos. 16 through 17 Details with Rail, Test Nos. MWTC-2 and MWTC-3

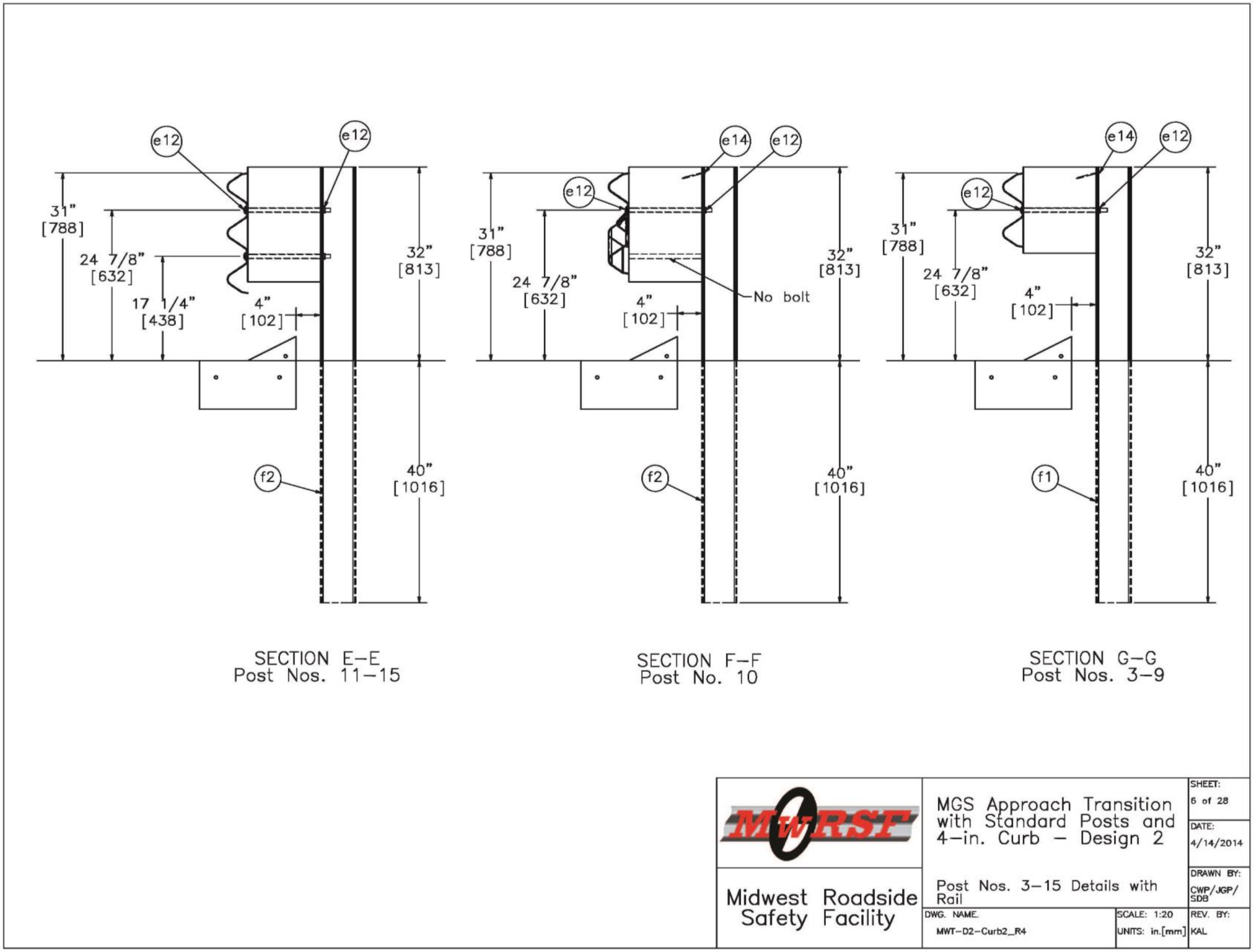


Figure 60. Post Nos. 3 through 15 Details with Rail, Test Nos. MWTC-2 and MWTC-3

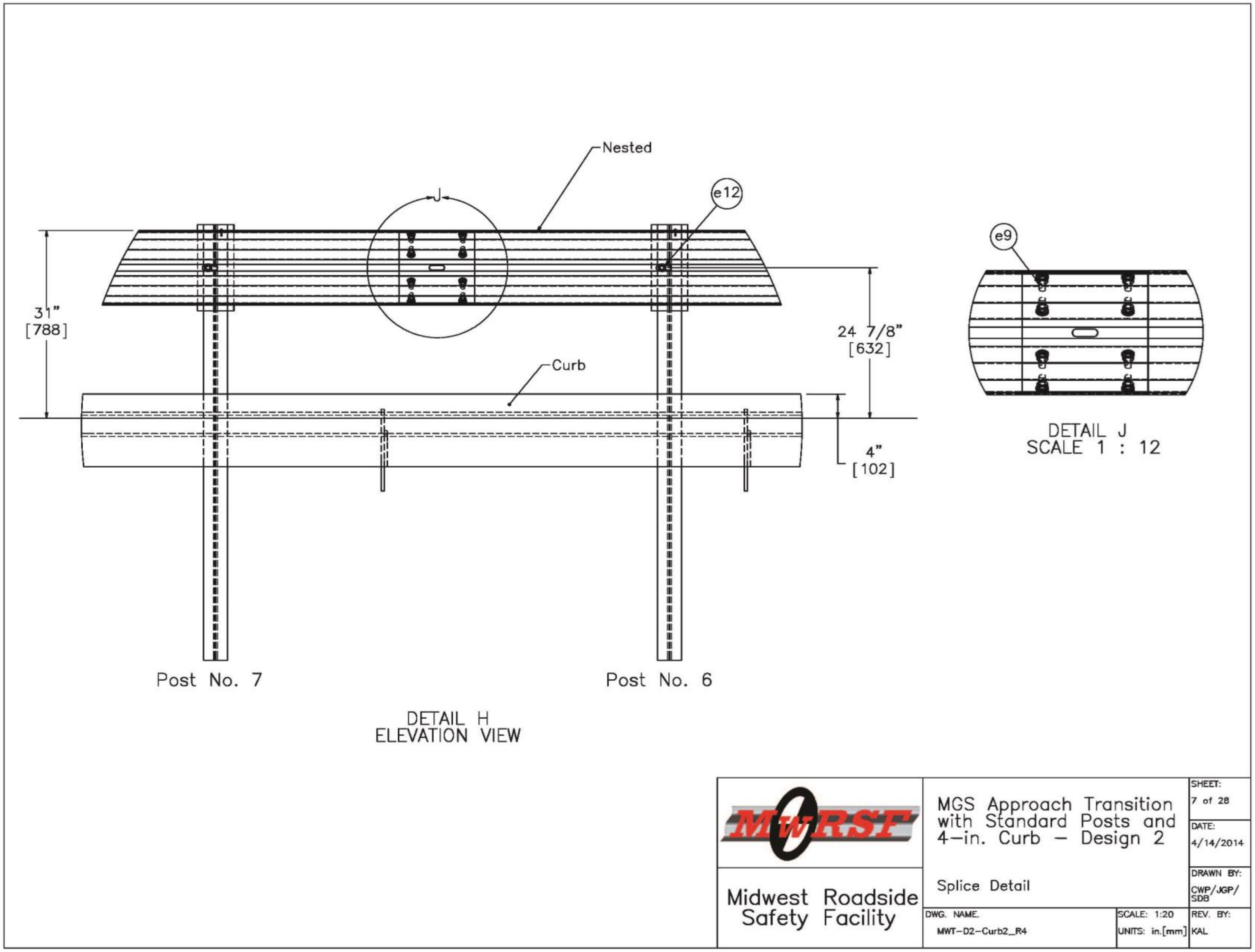


Figure 61. Splice Detail, Test Nos. MWTC-2 and MWTC-3

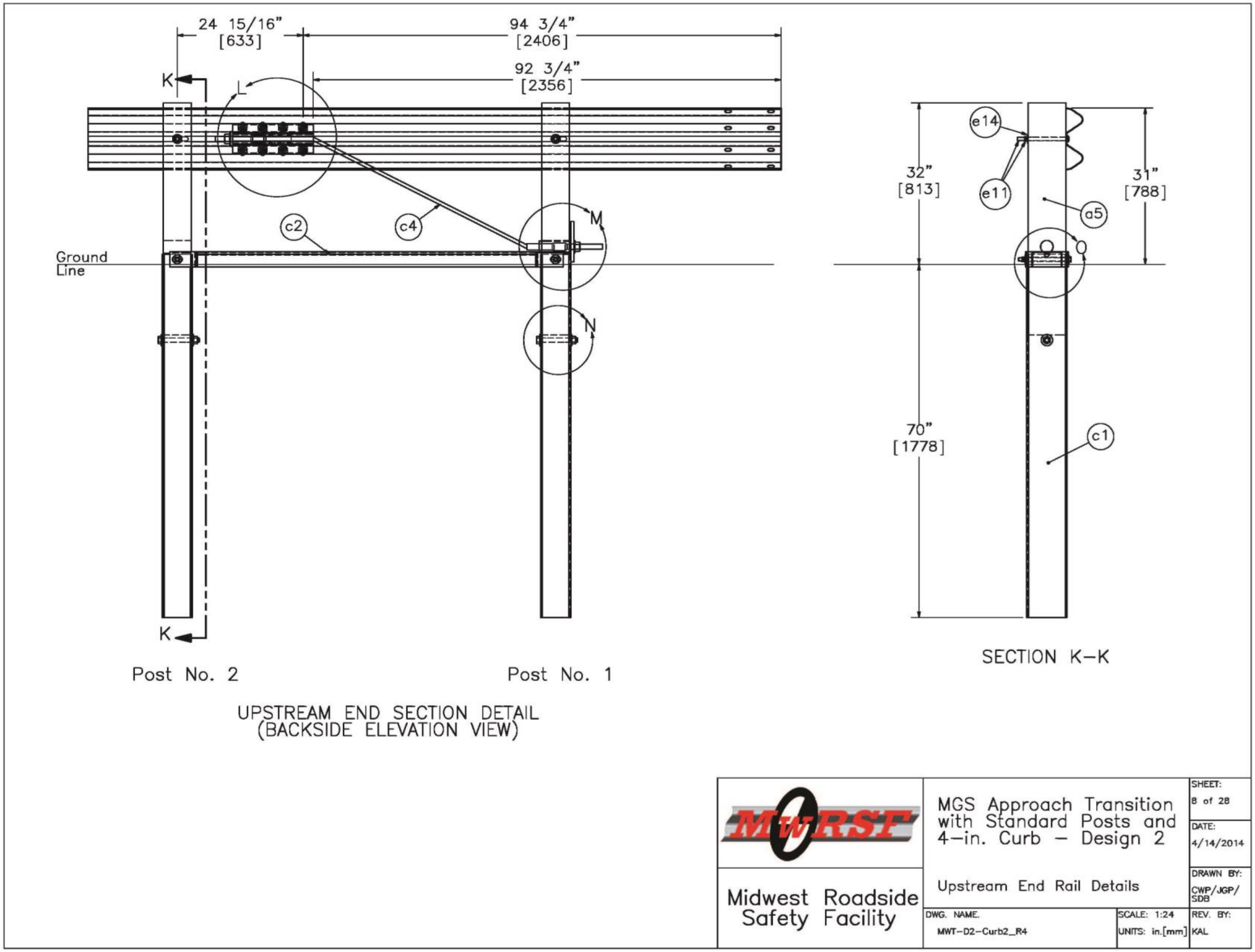


Figure 62. Upstream End Rail Details, Test Nos. MWTC-2 and MWTC-3

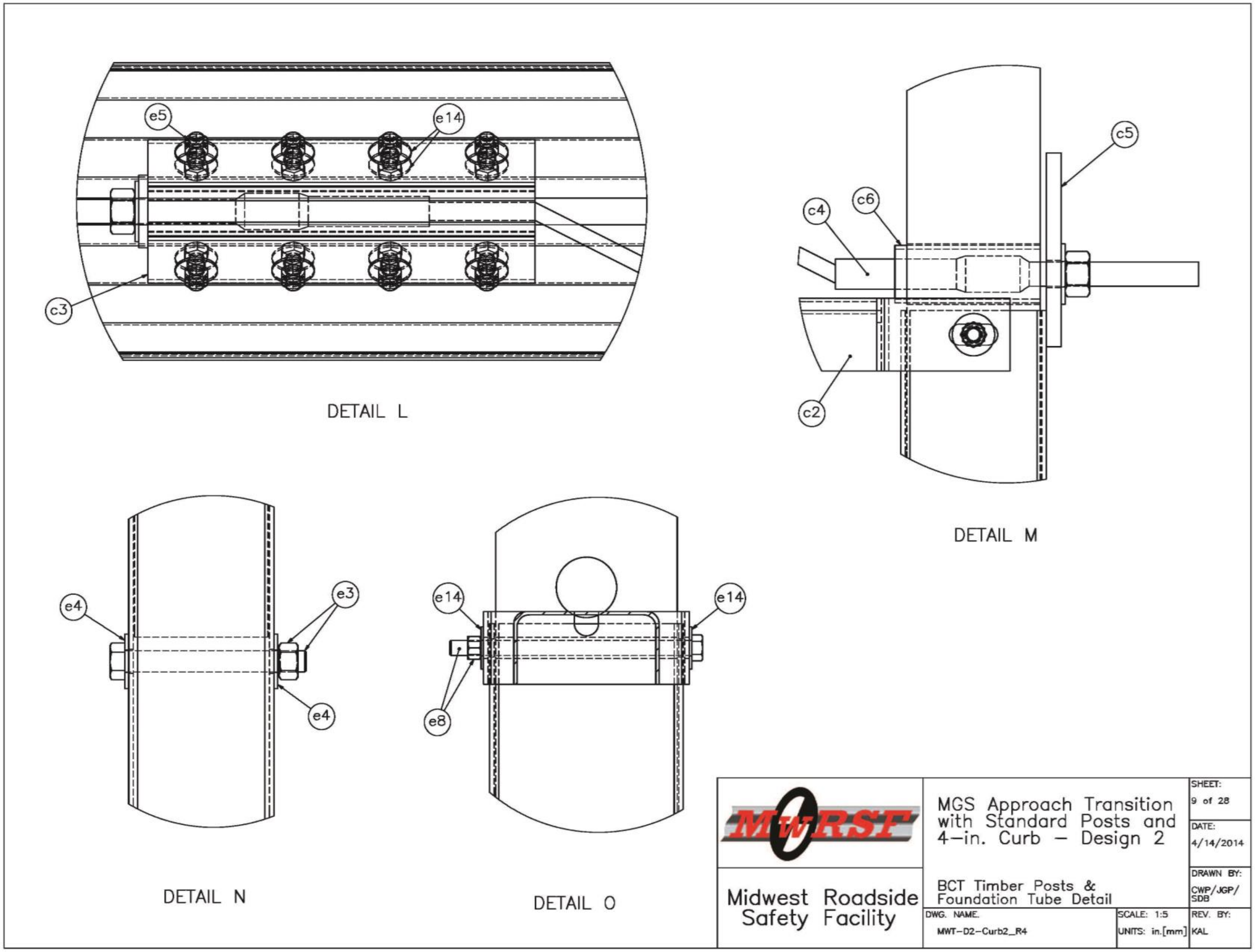


Figure 63. BCT Timber Posts and Foundation Tube Detail, Test Nos. MWTC-2 and MWTC-3

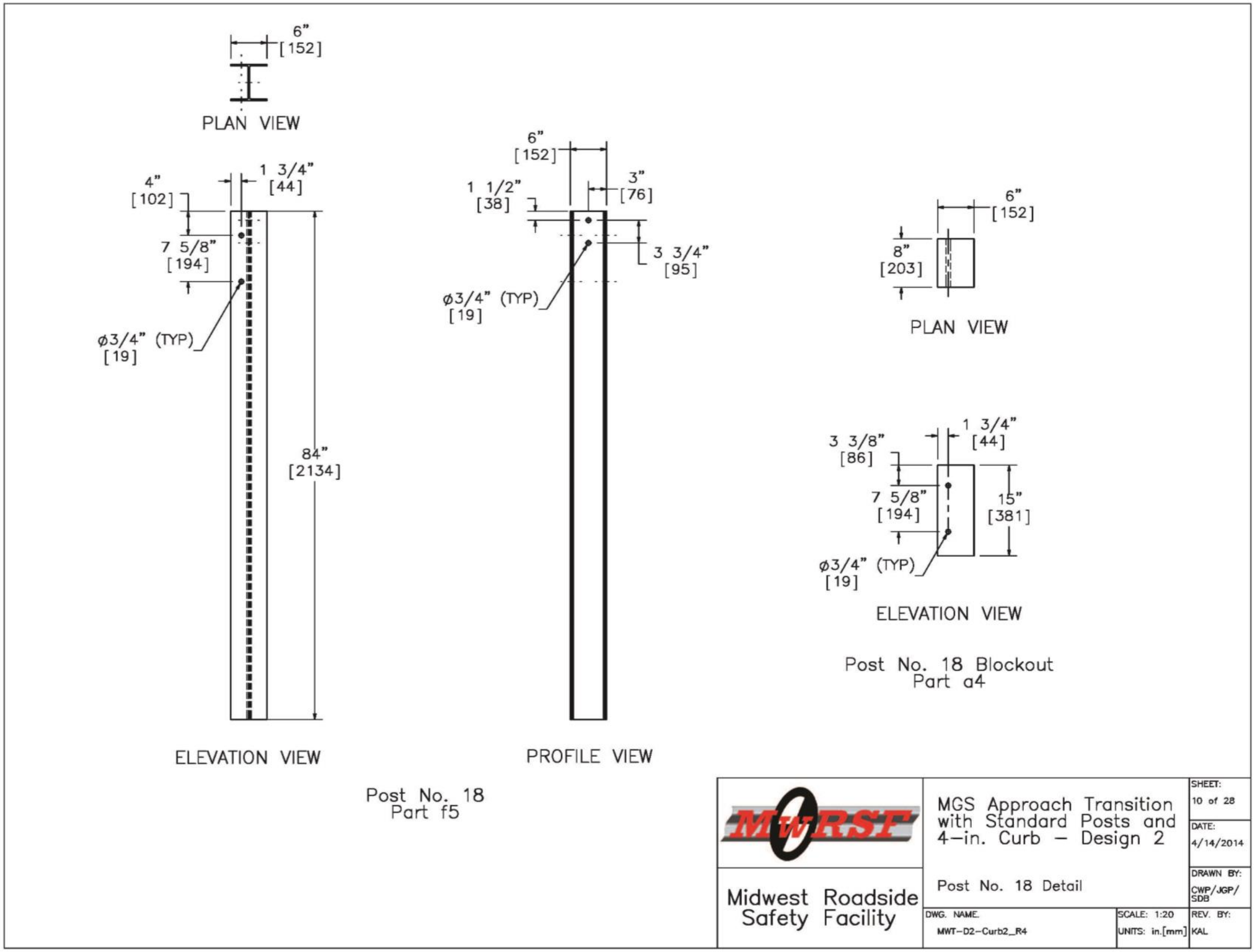


Figure 64. Post No. 18 Detail, Test Nos. MWTC-2 and MWTC-3

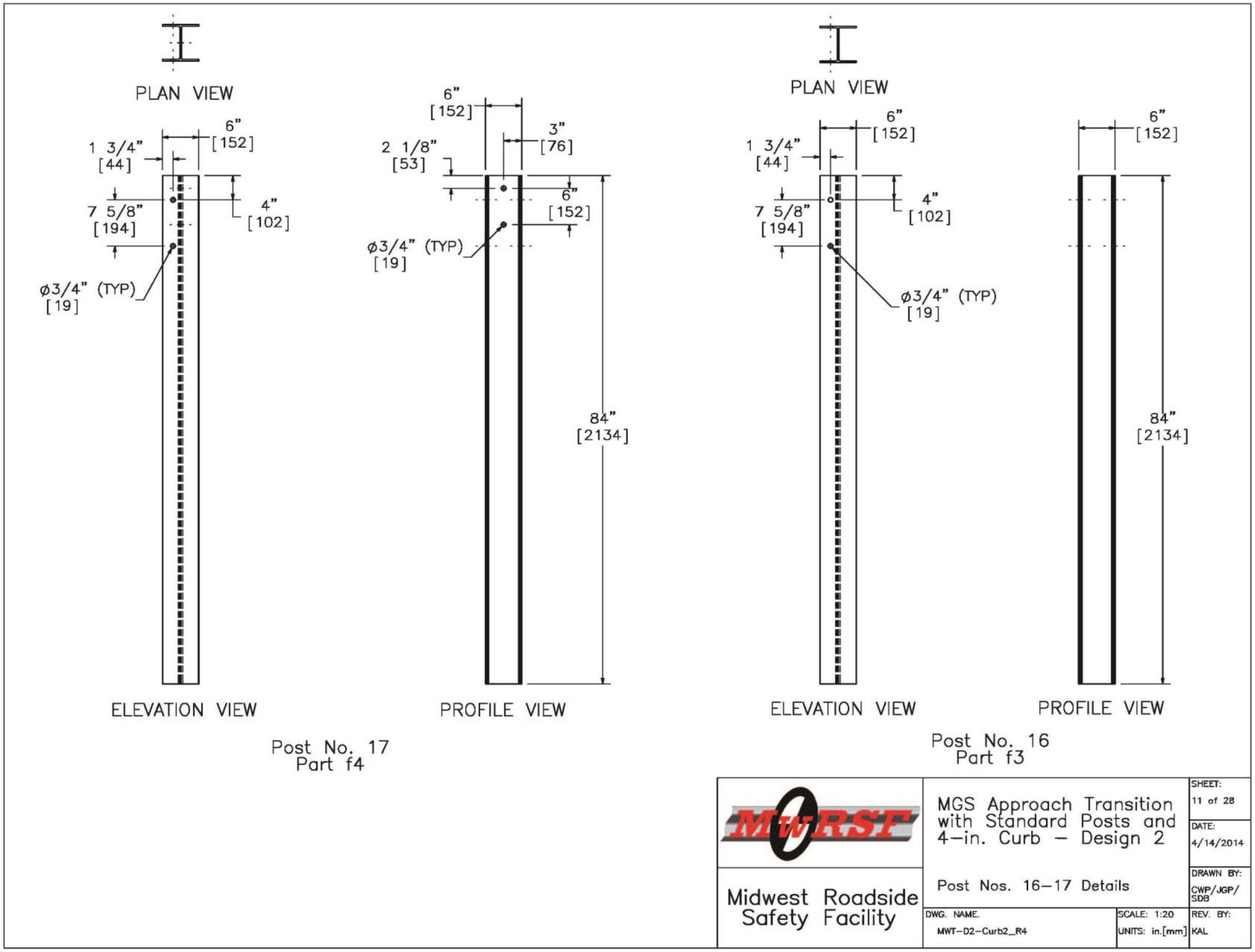


Figure 65. Post Nos. 16 through 17 Details, Test Nos. MWTC-2 and MWTC-3

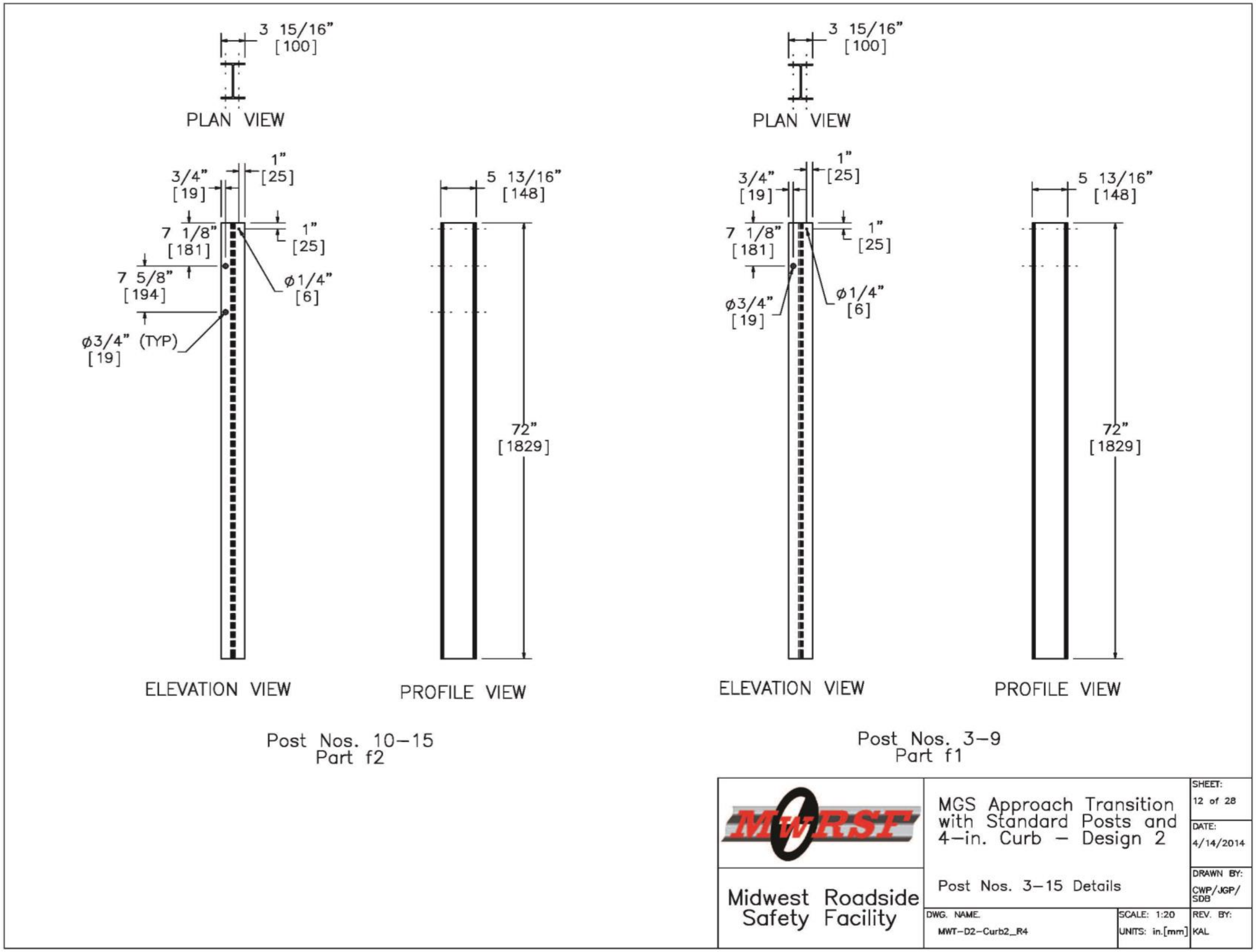


Figure 66. Post Nos. 3 through 15 Details, Test Nos. MWTC-2 and MWTC-3

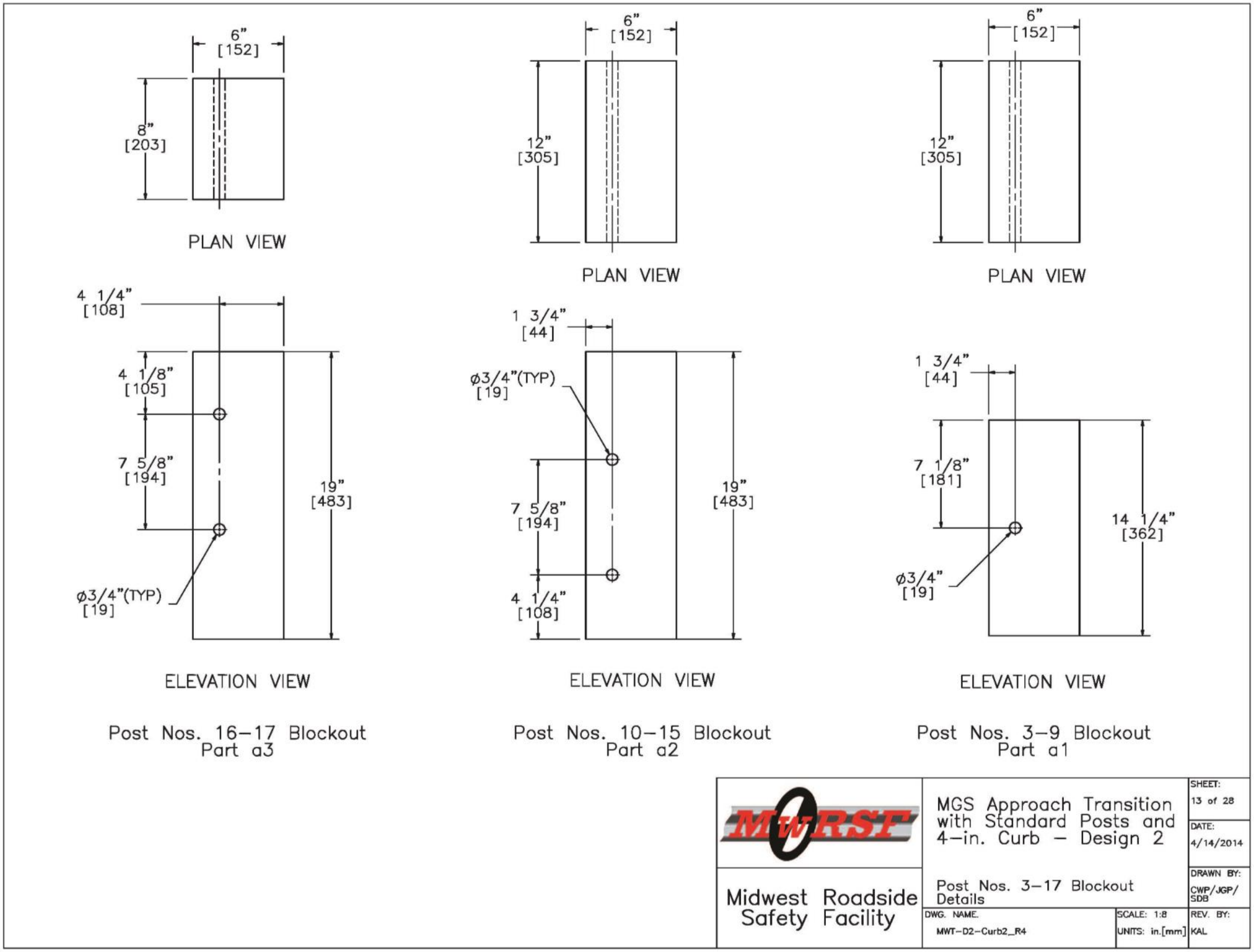


Figure 67. Post Nos. 3 through 17 Blockout Details, Test Nos. MWTC-2 and MWTC-3

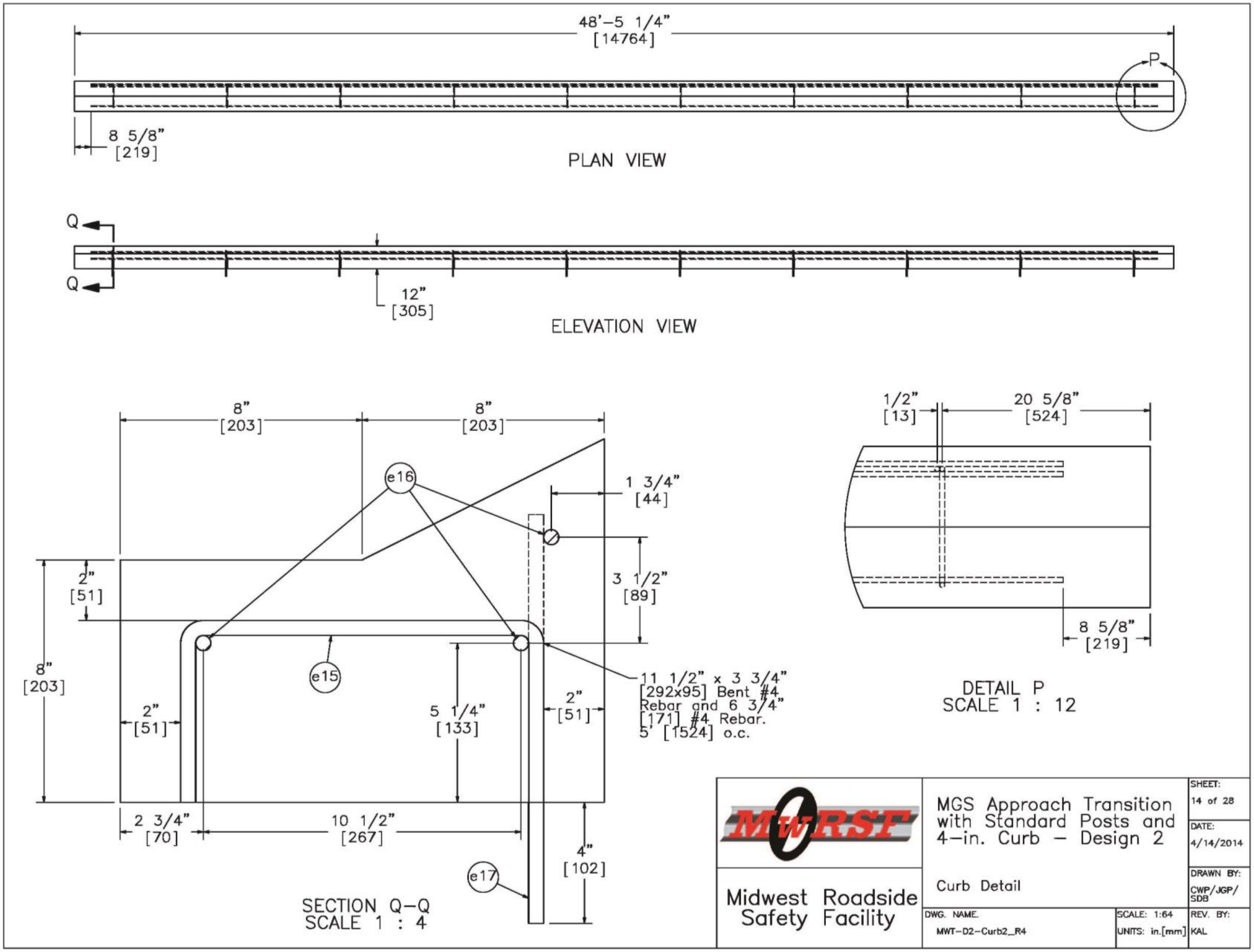


Figure 68. Curb Detail, Test Nos. MWTC-2 and MWTC-3

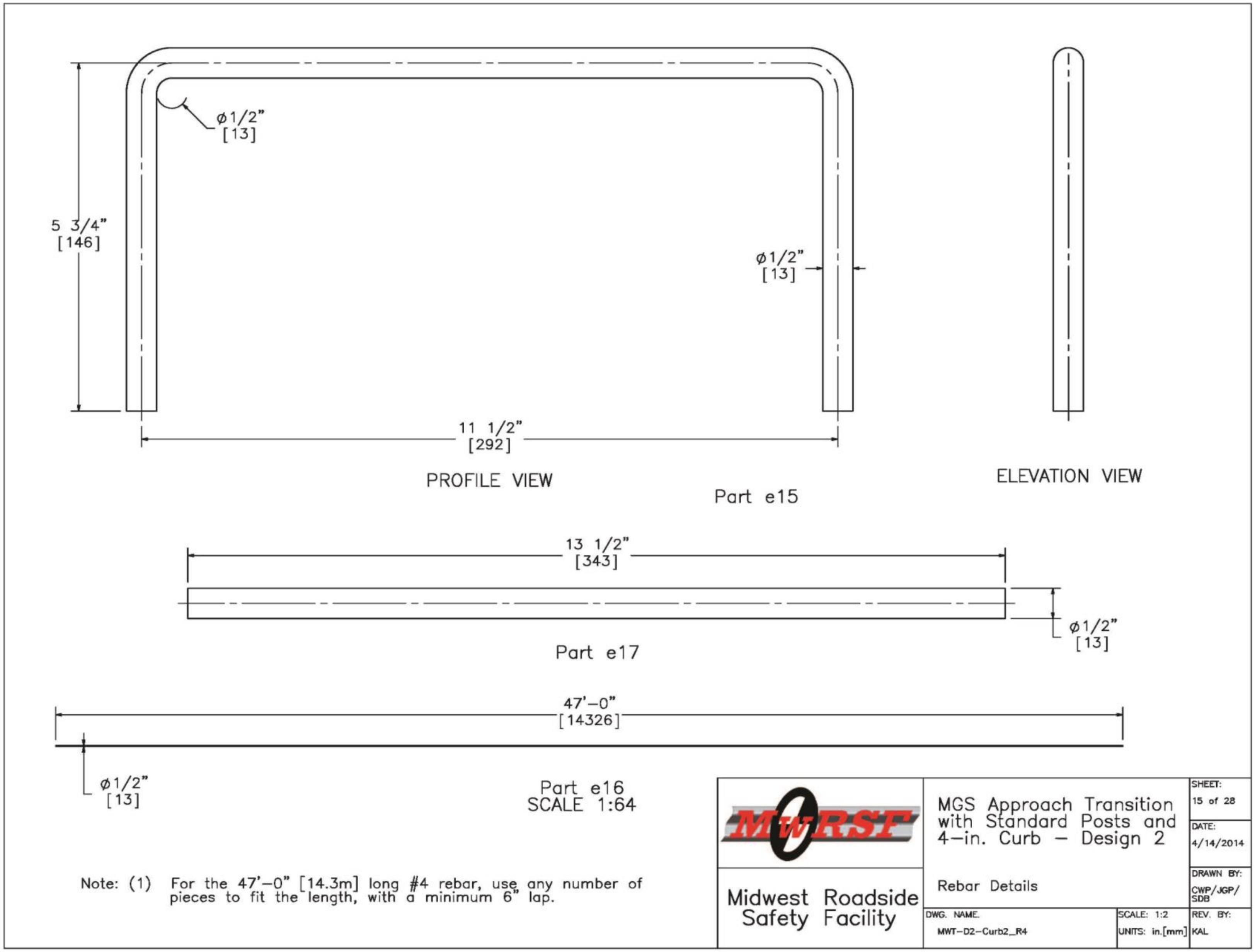


Figure 69. Rebar Details, Test Nos. MWTC-2 and MWTC-3

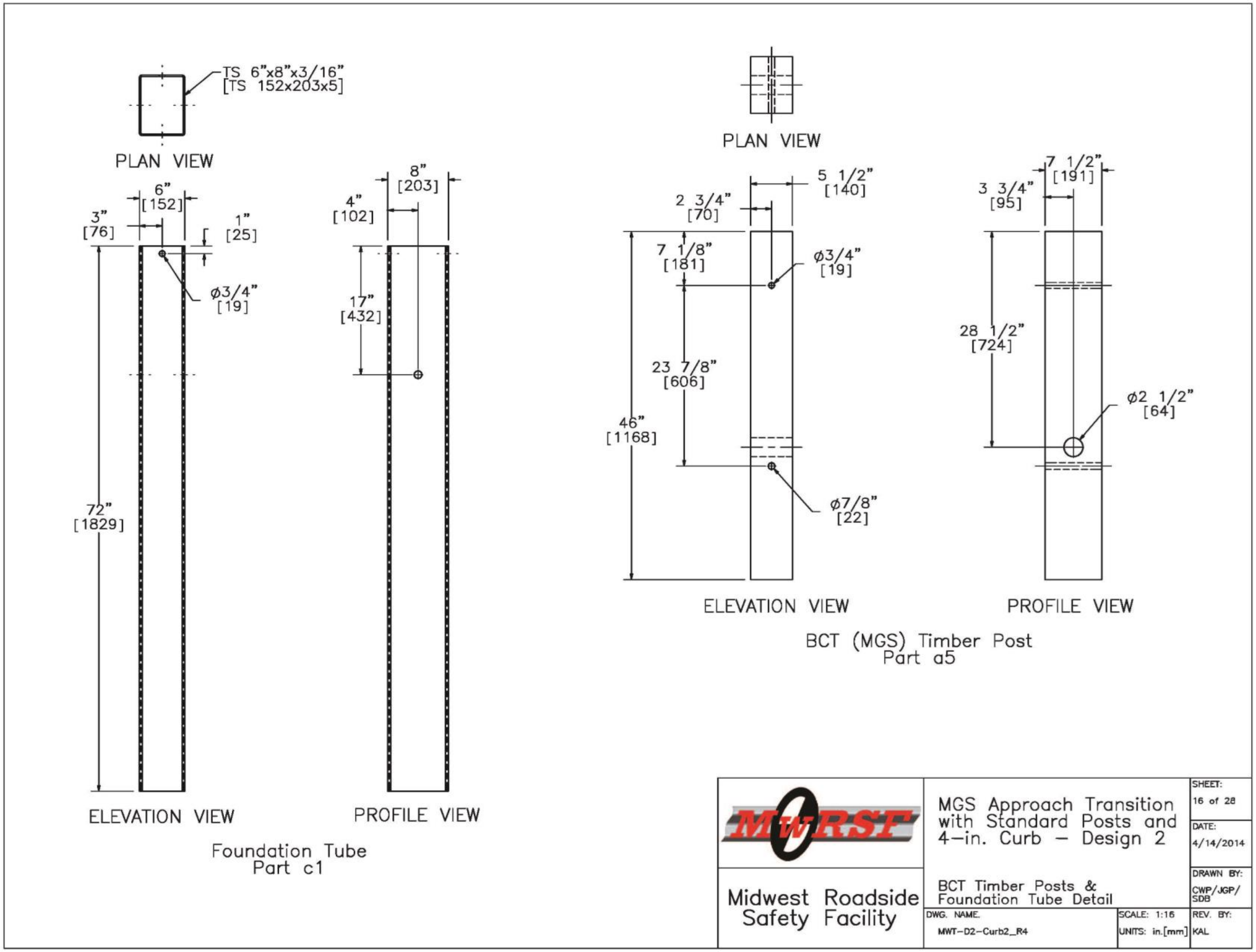


Figure 70. BCT Timber Posts and Foundation Tube Detail, Test Nos. MWTC-2 and MWTC-3

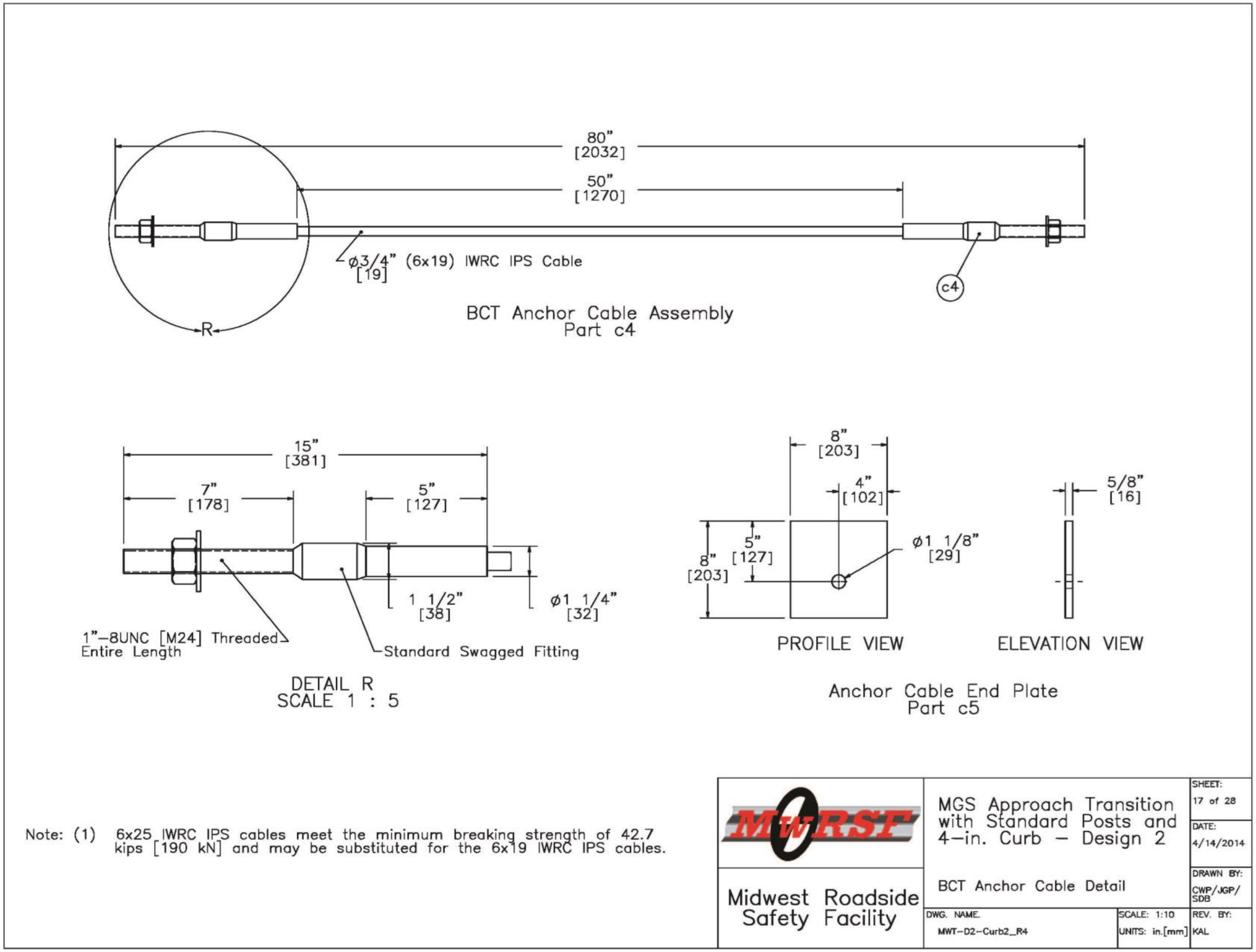


Figure 71. BCT Anchor Cable Detail, Test Nos. MWTC-2 and MWTC-3

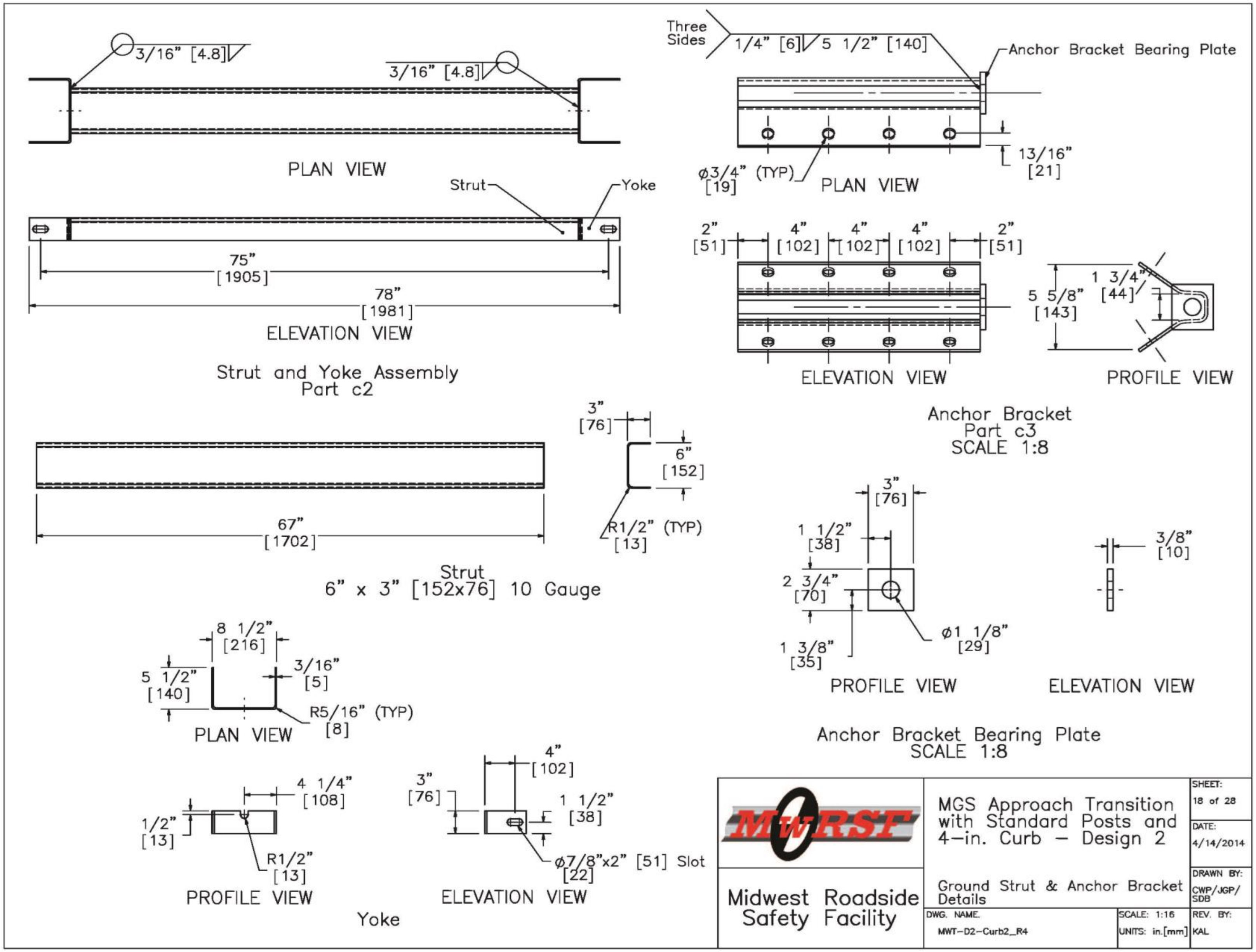


Figure 72. Ground Strut and Anchor Bracket Details, Test Nos. MWTC-2 and MWTC-3

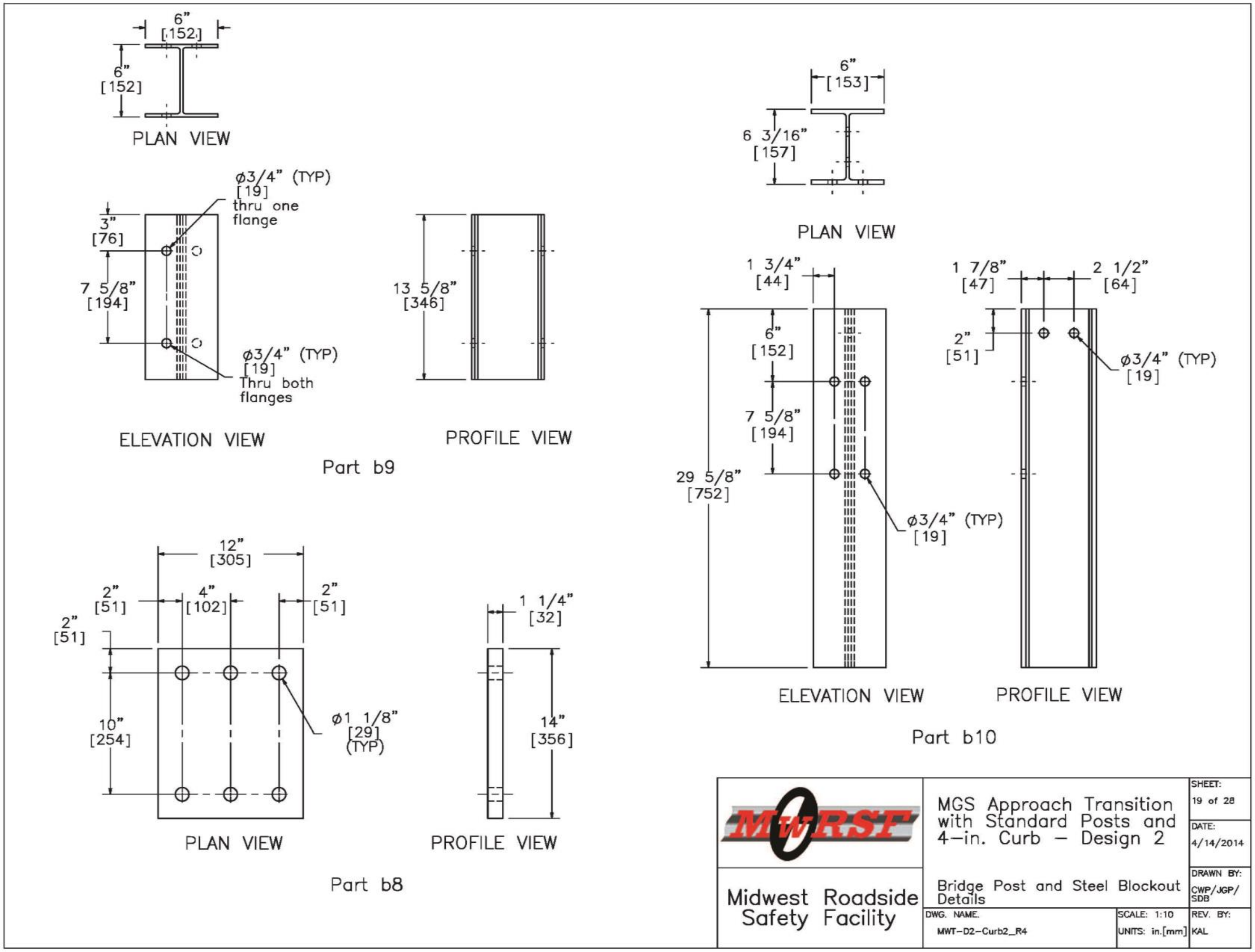


Figure 73. Bridge Post and Steel Blockout Details, Test Nos. MWTC-2 and MWTC-3

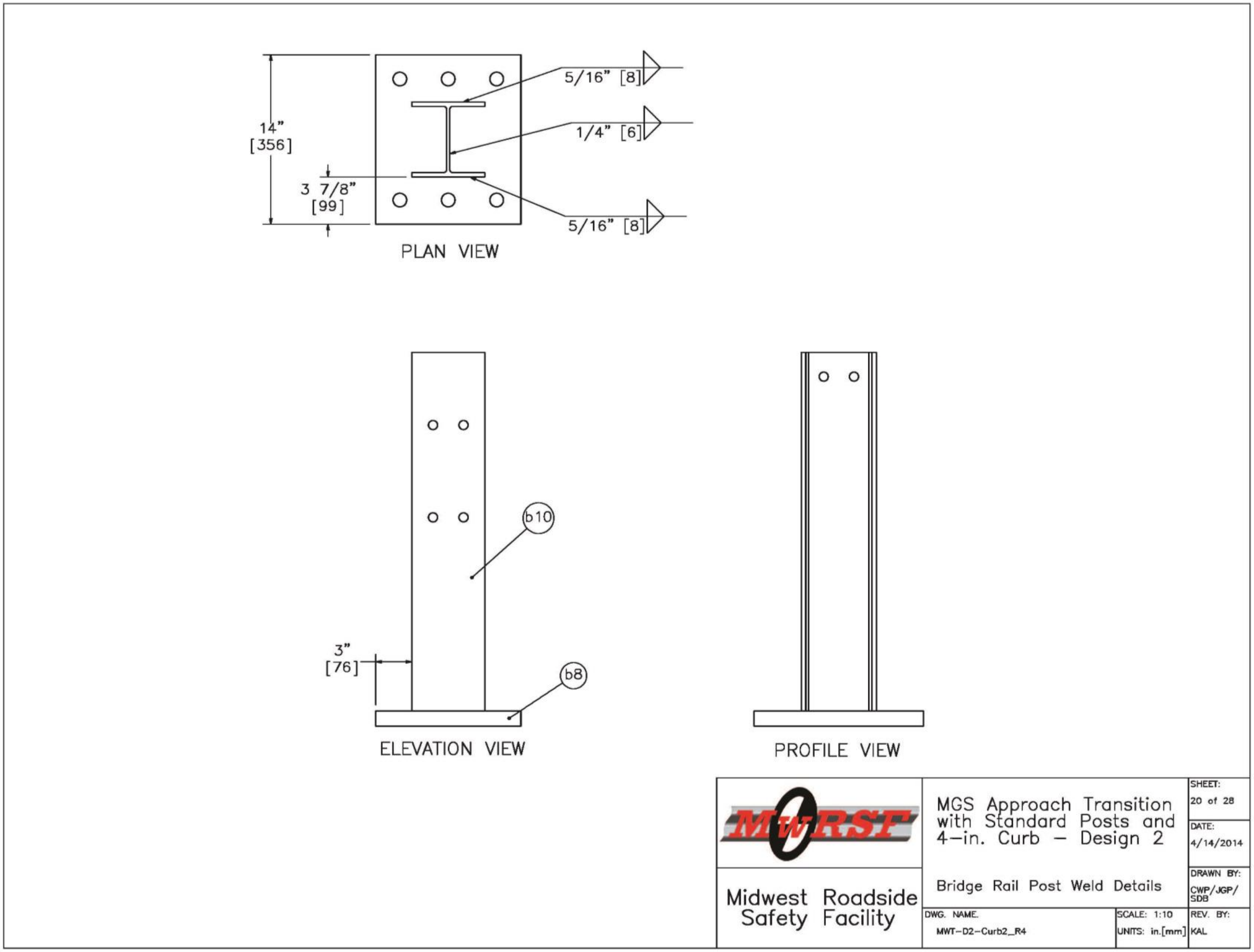


Figure 74. Bridge Rail Post Weld Details, Test Nos. MWTC-2 and MWTC-3

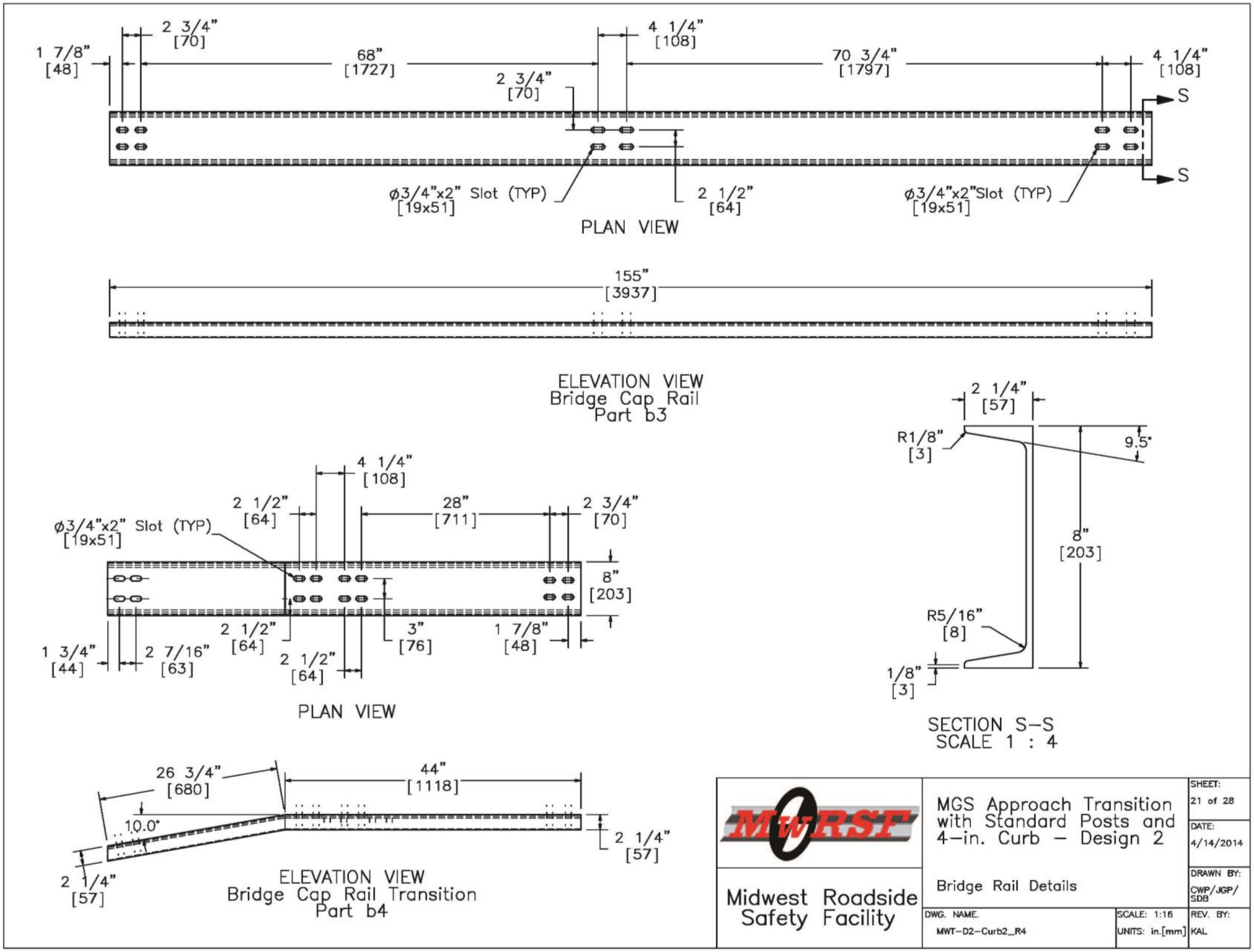


Figure 75. Bridge Rail Details, Test Nos. MWTC-2 and MWTC-3

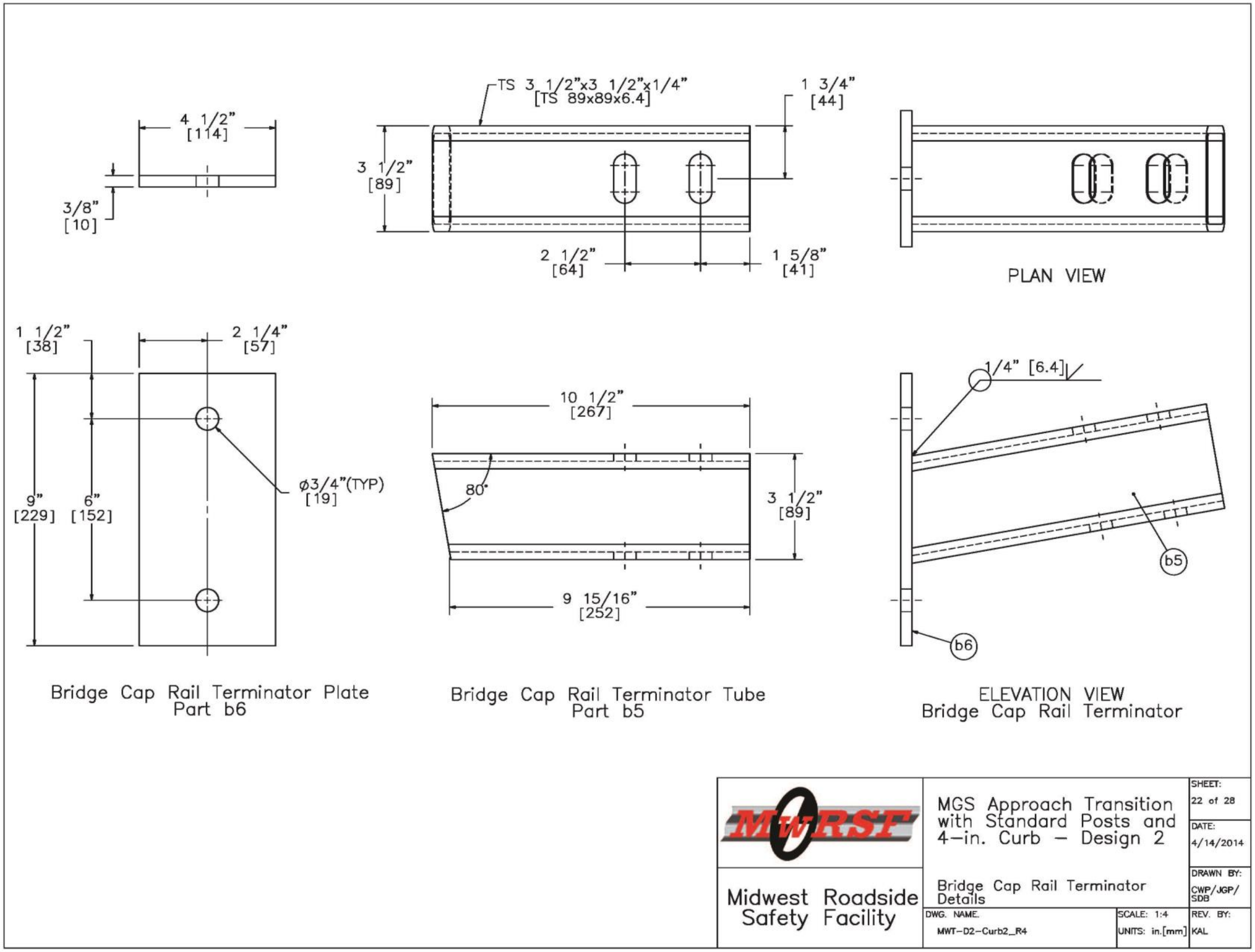


Figure 76. Bridge Cap Rail Terminator Details, Test Nos. MWTC-2 and MWTC-3

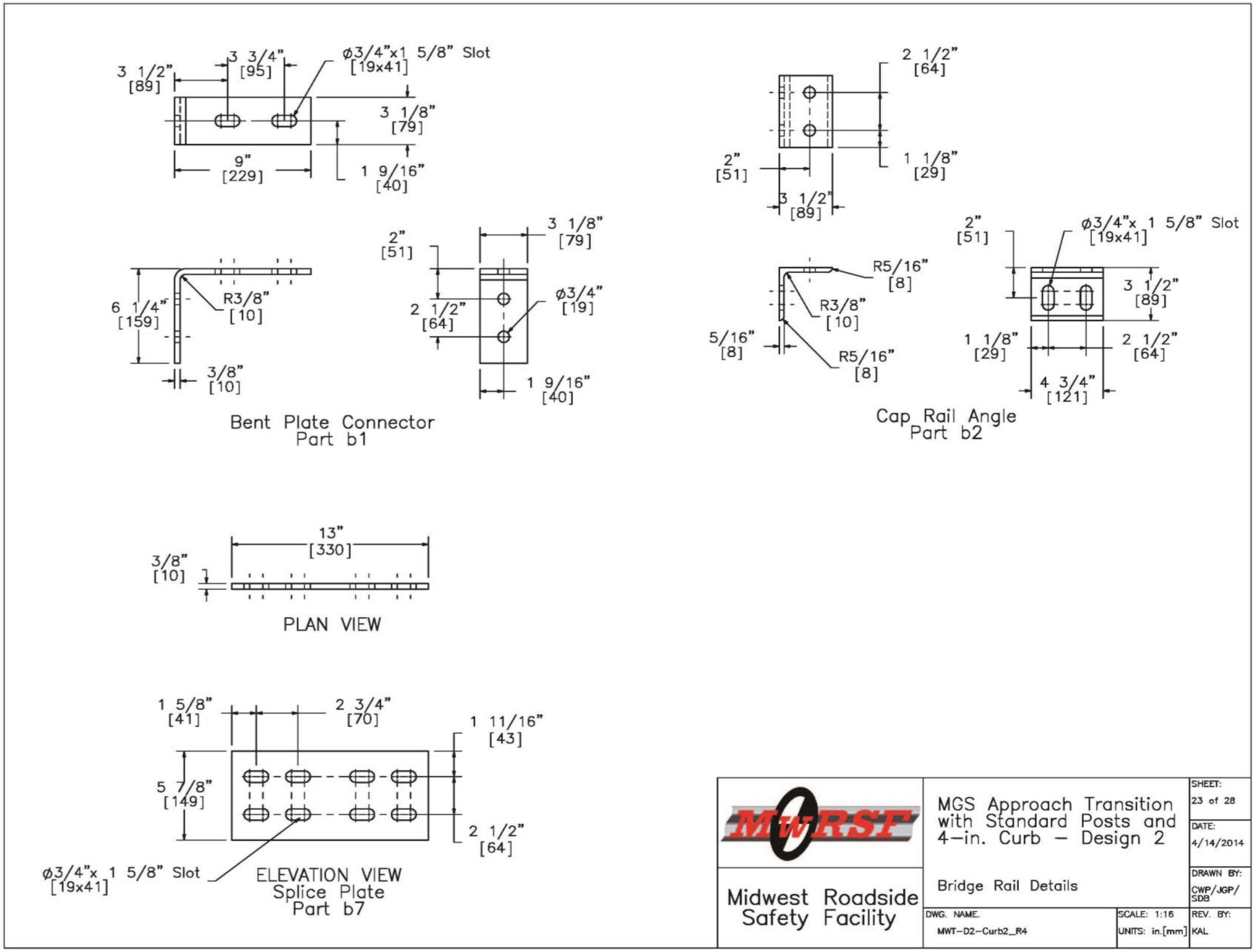


Figure 77. Bridge Rail Details, Test Nos. MWTC-2 and MWTC-3

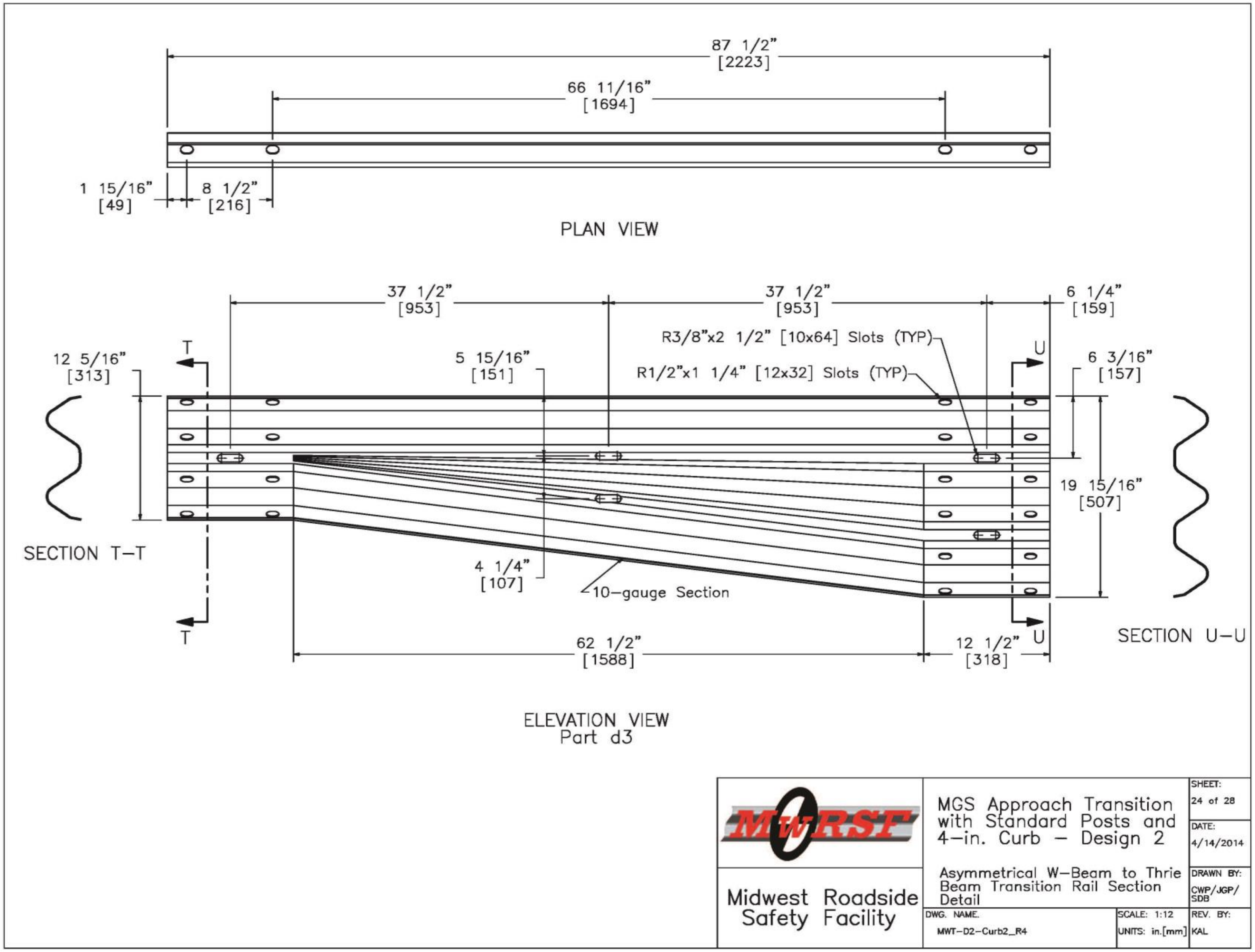


Figure 78. Asymmetrical W-Beam to Thrie Beam Transition Rail Section Detail, Test Nos. MWTC-2 and MWTC-3

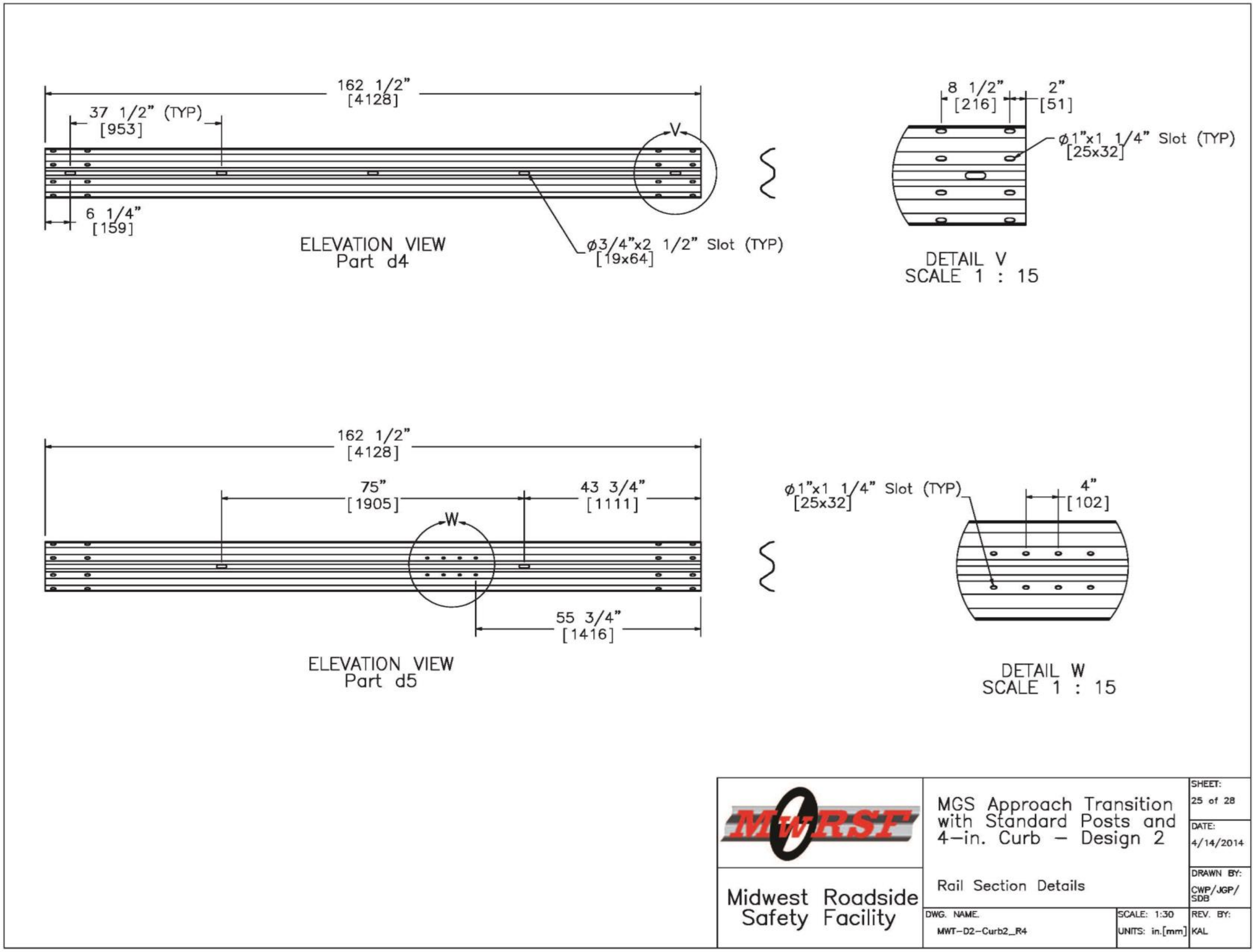


Figure 79. Rail Section Details, Test Nos. MWTC-2 and MWTC-3

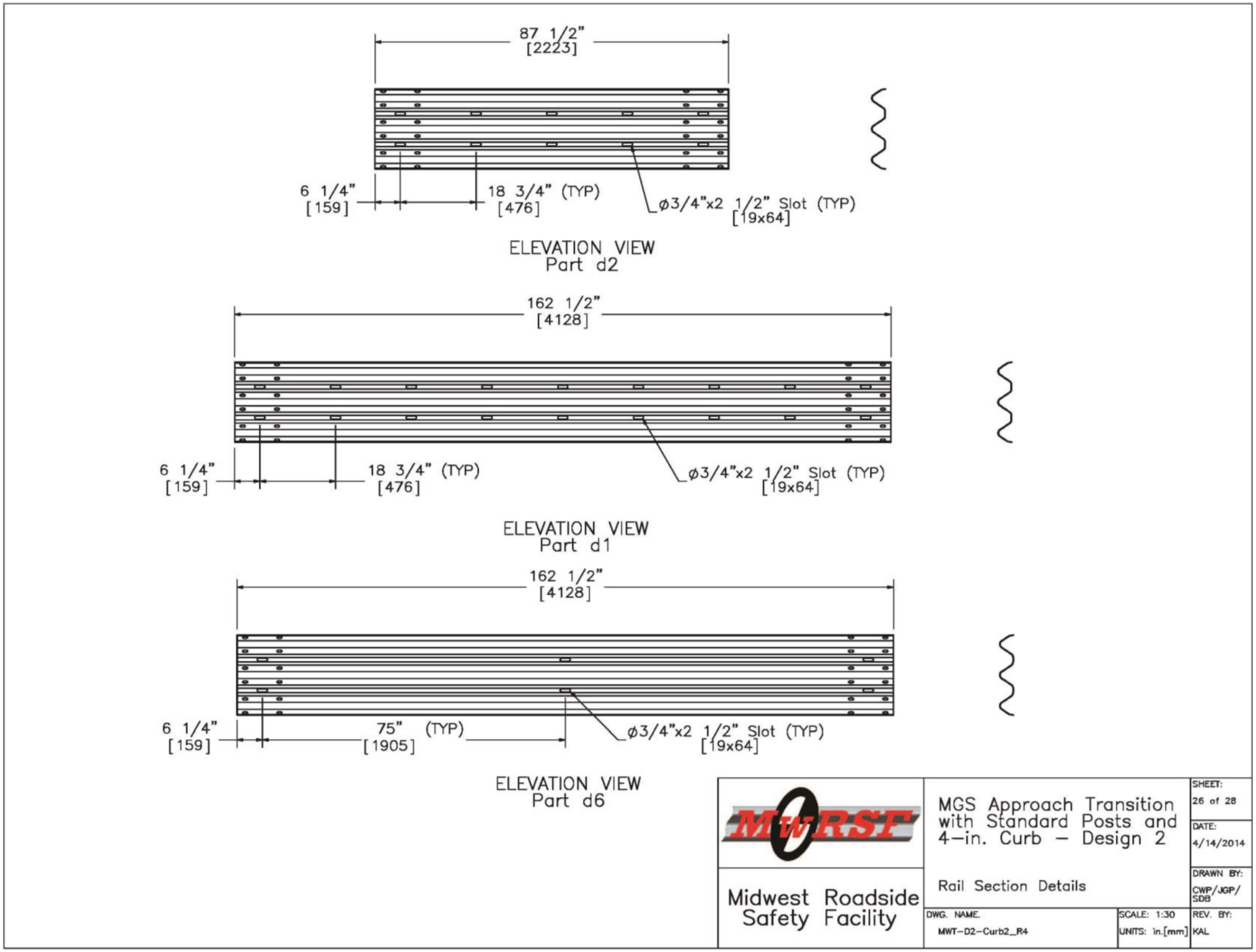


Figure 80. Rail Section Details, Test Nos. MWTC-2 and MWTC-3

Item No.	QTY.	Description	Material Spec	Hardware Guide
a1	7	6"x12"x14 1/4" [152x305x362] Blockout – Post 3–9	SYP Grade No.1 or better	PDB10a
a2	6	6"x12"x19" [152x305x483] Blockout – Post 10–15	SYP Grade No.1 or better	–
a3	2	6"x8"x19" [152x305x483] Blockout – Post 16–17	SYP Grade No.1 or better	–
a4	1	6"x8"x15" [152x305x381] Blockout – Post 18	SYP Grade No.1 or better	–
a5	2	BCT Timber Post –MGS Height	SYP Grade No.1 or better	PDF01
b1	2	6 1/4"x9"x3/8" [159x229x9.5] Bridge Cap Rail Bent Plate Connector	ASTM A36	–
b2	6	3 1/2"x3 1/2"x5/16" [89x89x7.9] Bridge Cap Rail Angle	ASTM A36	–
b3	1	C8x11.5 [C203x17.1] Bridge Cap Rail	ASTM A36	–
b4	1	C8x11.5 [C203x17.1] Bridge Cap Rail Transition	ASTM A36	–
b5	1	3 1/2"x3 1/2"x1/4" [89x89x6.4] Bridge Cap Rail Terminator Tube	ASTM A36	–
b6	1	9"x4 1/2"x3/8" [229x114x9.5] Terminator Plate	ASTM A36	–
b7	1	5 7/8"x13"x3/8" [149x330x9.5] Bridge Cap Rail Splice Plate	ASTM A36	–
b8	3	12"x14"x1 1/4" [305x356x32] Bridge Cap Connector Plate	ASTM A36	–
b9	3	W6x15 [W152x22.3] Steel Bridge Blockout	ASTM A992	–
b10	3	W6x20 [W152x29.8] Steel Bridge Post – Post Nos. 19–21	ASTM A992	–
c1	2	6"x8"x3/16" [152x203x5],72" [1829] Long Foundation Tube	ASTM A500 Grade B	PTE06
c2	1	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	–
c3	1	Anchor Bracket	ASTM A36	FPA01–02
c4	1	6' [1829] Long BCT Anchor Cable Assembly	3/4" [19] Dia. 6x19 IWRC IPS Wire Rope	FCA01
c5	1	8"x8"x5/8" [203x203x15.9] Anchor Bearing Plate	ASTM A36	FPB01
c6	1	2 3/8" [60] O.D., 6" [152] Long BCT Hole Insert	ASTM A53 Grade B Schedule 40	FMM02
d1	2	12'–6" [3810] Thrie Beam Section	12 gauge AASHTO M180	–
d2	1	6'–3" [1905] Thrie Beam Section	12 gauge AASHTO M180	–
d3	1	6'–3" [1905] W–Beam to Thrie–Beam Transition Section	10 gauge AASHTO M180	RWT02a
d4	4	12'–6" [3810] W–Beam MGS Section	12 gauge AASHTO M180	RWM04a
d5	1	12'–6" [3810] W–Beam MGS End Section	12 gauge AASHTO M180	RWM14a
d6	1	12'–6" [3810] Thrie Beam Section	12 gauge AASHTO M180	RTM02a

MwRSF

Midwest Roadside Safety Facility

MGS Approach Transition with Standard Posts and 4–in. Curb – Design 2

Bill of Materials

SHEET: 27 of 28
DATE: 4/14/2014
DRAWN BY: CWP/JGP/SDB
DWG. NAME. MWT–D2–Curb2_R4
SCALE: NONE
UNITS: in.[mm]
REV. BY: KAL

Figure 81. Bill of Materials, Test Nos. MWTC-2 and MWTC-3

Item No.	QTY.	Description	Material Spec	Hardware Guide
e1	18	1" [25] Dia. UNC, 13 1/2" [343] Long Threaded Rod and Heavy Hex Nut	Bolt B7 or ASTM A449 Type 1, Nut ASTM A563 Gr. C	–
e2	18	1" [25] Dia. Hardened Round Washer	ASTM F436 Type 1	FWC24a
e3	2	7/8" [22] Dia. UNC, 7 1/2" [191] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX22a
e4	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	FWC22a
e5	8	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a
e6	42	5/8" [16] Dia. UNC, 2" [51] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a
e7	2	5/8" [16] Dia. UNC, 5" [127] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a
e8	2	5/8" Dia. x 10" [M16x254] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 DH	FBX16a
e9	68	5/8" [16] Dia. UNC, 1 1/2" [38] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB01
e10	6	5/8" [16] Dia. UNC, 2" [51] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB02
e11	8	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB03
e12	18	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB06
e13	116	5/8" [16] Dia. Plain Round Washer	ASTM F844	FWC16a
e14	8	16D Double Head Nail	–	–
e15	10	11 1/2" x 5 3/4" [292x146] Bent #4 Rebar	ASTM A615 Grade 60	–
e16	3	47' [14.3 m] Long #4 Rebar	ASTM A615 Grade 60	–
e17	10	13 1/2" [343] Long #4 Rebar	ASTM A615 Grade 60	–
f1	7	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1829] Long – Post Nos. 3–9	ASTM A992	–
f2	6	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1829] Long – Post Nos. 10–15	ASTM A992	–
f3	1	W6x15 [W152x22.3], 84" [2134] Long – Post No. 16	ASTM A992	–
f4	1	W6x15 [W152x22.3], 84" [2134] Long – Post No. 17	ASTM A992	–
f5	1	W6x15 [W152x22.3], 84" [2134] Long – Post No. 18	ASTM A992	–

Midwest Roadside
Safety Facility

MGS Approach Transition
with Standard Posts and
4–in. Curb – Design 2

Bill of Materials Continued

SHEET: 28 of 28
DATE: 4/14/2014
DRAWN BY: CWP/JGP/SDB
DWG. NAME. MWT–D2–Curb2_R4
SCALE: NONE
UNITS: in.[mm]
REV. BY: KAL

Figure 82. Bill of Materials Continued, Test Nos. MWTC-2 and MWTC-3

Figure 83. System Photographs, Test Nos. MWTC-2 and MWTC-3

7 FULL-SCALE CRASH TEST NO. MWTC-2

7.1 Static Soil Test

Before full-scale crash test no. MWTC-2 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

7.2 Test No. MWTC-2

The 2,410-lb (1,093-kg) small passenger car impacted the MGS to thrie beam transition system with curb at a speed of 61.3 mph (98.7 km/h) and at an angle of 25.6 degrees. A summary of the test results and sequential photographs are shown in Figure 84. Additional sequential photographs are shown in Figures 85 and 86.

7.3 Weather Conditions

Test no. MWTC-2 was conducted on November 30, 2012 at approximately 1:15 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 7.

Table 7. Weather Conditions, Test No. MWTC-2

Temperature	47° F
Humidity	52%
Wind Speed	5 mph
Wind Direction	Variable
Sky Conditions	Clear
Visibility	6 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	0 in.

7.4 Test Description

Initial vehicle impact was to occur 18¾ in. (476 mm) downstream of post no. 7, as shown in Figure 87. The actual point of impact was 11¼ in. (286 mm) downstream of post no. 7. A sequential description of the impact events is contained in Table 8. The vehicle came to rest 43.0 ft (13.1 m) downstream of impact and 3.8 ft (1.2 m) laterally in front of the system. The vehicle trajectory and final position are shown in Figures 84 and 88.

Table 8. Sequential Description of Impact Events, Test No. MWTC-2

TIME (sec)	EVENT
0.000	The vehicle impacted the system 11¼ in. (286 mm) downstream of post no. 7.
0.014	The vehicle’s left-front tire underrode rail; the left-front fender deformed.
0.034	The vehicle’s left-front tire overrode curb.
0.068	The vehicle’s left-front tire contacted and snagged on post no. 8.
0.070	Rail between post nos. 7 and 11 deflected backward, and left-front wheel deformed.
0.100	The blockout at post no. 8 disengaged from post.
0.132	The vehicle’s left-front tire contacted post no. 9, and left rear tire was airborne.
0.144	The rail between post nos. 7 and 9 deflected forward.
0.174	The vehicle’s front bumper contacted ground.
0.176	The vehicle’s left-front tire contacted post no. 10.
0.228	The front-left tire was sliding down backside of curb, and it contacted post no. 11.
0.230	The blockout at post no. 11 fractured.
0.240	The vehicle’s right-rear tire was airborne.
0.242	Vehicle’s front bumper even with post no. 13, and vehicle nearly parallel with system.
0.258	The vehicle’s left-rear tire was airborne.
0.280	Front bumper was detaching from vehicle, and vehicle began to yaw toward barrier.
0.296	The front-left tire impacted post no. 12 and detached from vehicle.
0.312	The vehicle exited system.
2.130	The vehicle came to a stop.

7.5 System Damage

Damage to the barrier was moderate, as shown in Figures 90 and 91. Barrier damage consisted of deformed guardrail and posts, displaced soil, fractured wooden spacer blockouts, and contact marks on sections of guardrail and posts. The length of vehicle contact along the barrier was approximately 18 ft – 5 in. (5.6 m), which spanned from 11¼ in. (286 mm) downstream of post no. 7 to 7 in. (178 mm) downstream of post no. 12.

The contact marks on the rail began 11¼ in. (286 mm) downstream of post no. 7 and continued until 7 in. (178 mm) downstream of post no. 12. The bottom corrugation of the W-beam folded up starting at the midspan of post nos. 7 and 8 and extending to post no. 8. The bottom corrugation flattened between post nos. 8 and 12. There were also various kinks in the rail throughout the impact region. The curb had spalling between post nos. 7 and 8. The rail disengaged from post nos. 8 through 10.

The front face of post no. 7 twisted downstream and rotated backward. Post no. 8 rotated and bent. The flanges and web deformed, and the bolt pulled out of the rail. The front flanges of post nos. 9 through 11 rotated upstream. Post no. 12 twisted downstream and rotated backward. At post no. 8, the back, upstream corner of the blockout partially separated, and the bolt was embedded. The bottom corner on the front, downstream side of the blockout was crushed. The blockout split down the middle and disengaged from post no. 11.

The permanent set deflections of the post and rail system were 16 in. (406 mm) at post no. 8 and 10¼ in. (260 mm) at post no. 9, respectively, as measured in the field. The maximum lateral dynamic post and barrier deflections were 14.4 in. (366 mm) at post no. 9 and 16.4 in. (417 mm) at post no. 8, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 32.5 in. (826 mm), also determined from high-speed digital video analysis.

7.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figure 92. The maximum occupant compartment deformations are listed in Table 9 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 9. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	¾ (19)	≤ 9 (229)
Floor Pan & Transmission Tunnel	½ (13)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	1 (25)	≤ 12 (305)
Side Door (Above Seat)	1 (25)	≤ 9 (229)
Side Door (Below Seat)	1 (25)	≤ 12 (305)
Roof	0	≤ 4 (102)
Windshield	0	≤ 3 (76)

The majority of the damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The left-front tire was deflated, disengaged, and came to rest adjacent to post no. 12. The outside of the rim of the left-front wheel had a 7-in. (178-mm), a 3-in. (76-mm), and an 8-in. (203-mm) long dent, and the side wall of the tire had an 8-in. (203-mm) tear. A 1-in. (25-mm) long tear was found in the rim, and the brake line was severed. The entire left-front fender, the front edge of the left-front door, and the left-front corner of the hood were gouged. Also, the bottom of the left-front fender was torn and pulled away from the vehicle. The side mirror on the left side of the car was partially disengaged.

The left-front headlamp disengaged and the front bumper was only attached on the right side of the vehicle. A 2-in. (51-mm) gap occurred between the door and the B-pillar. Another gap, 2½ in. (64 mm) wide, formed between the front of the hood and the front bumper. Fluid leaked from the front of the car, and the suspension was disengaged. The right-front tire was deflated, and the hub cap fractured.

7.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 10. 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 10. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 84. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

Table 10. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MWTC-2

Evaluation Criteria		**Transducer**			**MASH Limits**
		DTS	**DTS SLICE**	**EDR-3**	
OIV ft/s (m/s)	Longitudinal	-22.23 (-6.78)	-23.04 (-7.02)	-24.21 (-7.38)	≤ 40 (12.2)
	Lateral	22.53 (6.87)	24.14 (7.36)	21.19 (6.46)	≤ 40 (12.2)
ORA g’s	Longitudinal	-15.65	-16.58	-11.72	≤ 20.49
	Lateral	13.45	12.45	10.88	≤ 20.49
THIV ft/s (m/s)		31.66 (9.65)	31.79 (9.69)	NA	not required
PHD g’s		15.69	18.84	NA	not required
ASI		1.32	1.40	1.27	not required

7.8 Discussion

An analysis of the results for test no. MWTC-2 showed that the MGS to thrie beam transition system with curb adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix F, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 11.0 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MWTC-2, conducted on the MGS to thrie beam transition system with curb, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-20.


0.000 sec

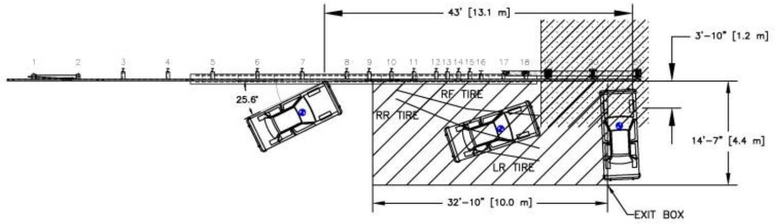
0.162 sec

0.412 sec

0.558 sec

0.772 sec

- Test Agency..MwRSF
- Test Number..MWTC-2
- Date 11/30/12
- MASH Test Designation..3-20
- Test Article ....Stiffness Transition between MGS and Thrie Beam Transition with Curb
- Total Length .... 87.5 ft (26.7 m)
- Height to Top of Rail...31 in. (787 mm)
- Steel 12 gauge (2.66 mm) W-Beam Guardrail
  - Segment Location - Single ....Post no. 1 to Splice 6/7
  - Segment Location - Nested ....Splice 6/7 to Post no. 9
- Steel 10 gauge (3.42 mm) W-Beam to Thrie Beam Transition
  - Segment Location ....Post nos. 9 to 11
- Steel 12 gauge (2.66 mm) Thrie Beam Guardrail
  - Segment Location - Single ....Post nos. 11 to 14 and 19 to 21
  - Segment Location - Nested ....Post nos. 14 to 19
- Guardrail Posts
  - Post Nos. 1-2.........................46 in. (1,168 mm) long, BCT timber posts
  - Post Nos. 3-15............... 72 in. (1,829 mm) long, W6x8.5 (W152x12.6)
  - Post Nos. 16-18.............. 84 in. (2,134 mm) long, W6x15 (W152x22.3)
  - Post Nos. 19-21.............. 29⅝ in. (752 mm) long, W6x20 (W152x29.8)
- Post Spacing
  - Post Nos. 1-8, 19-21..75 in. (1,905 mm)
  - Post Nos. 8-12, 16-19..37½ in. (953 mm)
  - Post Nos. 12-16...18¾ in. (476 mm)
- Soil Type ....AASHTO Grade B
- Vehicle
  - Make and Model ....2007 Kia Rio
  - Test Inertial..2,410 lb (1,093 kg)
  - Gross Static..2,575 lb (1,168 kg)
  - Curb ....2,390 lb (1,084 kg)
- Impact Conditions
  - Speed ....61.3 mph (98.7 km/h)
  - Angle .... 25.6 deg
  - Impact Severity (IS)............56.5 kip-ft (76.6 kJ) > 51.0 kip-ft (69.1 kJ)
  - Impact Location ....11¼ in. (286 mm) downstream of post no. 7
- Exit Conditions
  - Speed ....19.6 mph (31.5 km/h)
  - Angle .... 11.0 deg
- Exit Box Criterion .... Passed
- Vehicle Stability .... Satisfactory



- Vehicle Stopping Distance..........................43.0 ft (13.1 m) downstream of impact
  ....3.8 ft (1.2 m) laterally in front of system
- Vehicle Damage... Moderate
  - VDS[7] 11-LFQ5
  - CDC[8] 11-LFEW2
  - Maximum Interior Deformation..1 in. (25 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set ....16.1 in. (409 mm)
  - Dynamic ....16.4 in. (417 mm)
  - Working Width ....32.5 in. (826 mm)
- Maximum Angular Displacements
  - Roll ....-13.7° < 75°
  - Pitch...-8.6° < 75°
  - Yaw ....-70.7°
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		DTS	DTS SLICE	EDR-3	
OIV ft/s (m/s)	Longitudinal	-22.23 (6.78)	-23.04 (-7.02)	-24.21 (-7.38)	≤ 40 (12.2)
	Lateral	22.53 (6.87)	24.14 (7.36)	21.19 (6.46)	≤ 40 (12.2)
ORA g's	Longitudinal	-15.65	-16.58	-11.72	≤ 20.49
	Lateral	13.45	12.45	10.88	≤ 20.49
THIV – ft/s (m/s)		31.66 (9.65)	31.79 (9.69)	NA	not required
PHD – g's		15.69	18.84	NA	not required
ASI		1.32	1.40	1.27	not required

Figure 84. Summary of Test Results and Sequential Photographs, Test No. MWTC-2

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0.000 sec

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0.080 sec

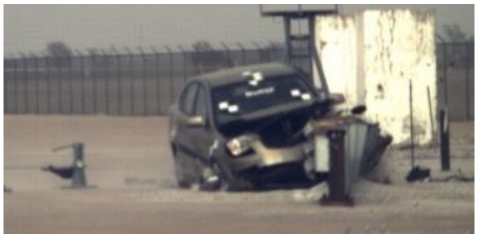

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Figure 85. Sequential Photographs, Test No. MWTC-2

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0.204 sec

0.772 sec

0.366 sec

Figure 86. Additional Sequential Photographs, Test No. MWTC-2

Figure 87. Impact Location, Test No. MWTC-2

Figure 88. Vehicle Final Position, Test No. MWTC-2

Figure 89. Impact Region Damage, Test No. MWTC-2

Figure 90. Rail System Damage, Test No. MWTC-2

Figure 91. Post and Blockout System Damage, Test No. MWTC-2

Figure 92. Vehicle Damage, Test No. MWTC-2

8 FULL-SCALE CRASH TEST NO. MWTC-3

8.1 Static Soil Test

Before full-scale crash test no. MWTC-3 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

8.2 Test No. MWTC-3

The 4,969-lb (2,254-kg) pickup truck impacted the MGS to thrie beam transition system with curb at a speed of 61.0 mph (98.1 km/h) and at an angle of 24.4 degrees. A summary of the test results and sequential photographs are shown in Figure 93. Additional sequential photographs are shown in Figures 94 and 95. The impact severity of test no. MWTC-3 was 108.9 kip-ft (147.6 kJ). This value was larger than the lower bound, as specified by MASH with an 8% reduction, 105.6 kip-ft (143.1 kJ).

8.3 Weather Conditions

Test no. MWTC-3 was conducted on May 16, 2013 at approximately 12:15 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 11.

Table 11. Weather Conditions, Test No. MWTC-3

Temperature	83° F
Humidity	65%
Wind Speed	6 mph
Wind Direction	South
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.01 in.
Previous 7-Day Precipitation	0.08 in.

8.4 Test Description

Initial vehicle impact was to occur 75 in. (1,905 mm) upstream of post no. 9, as shown in Figure 96, which was selected based on previous testing [1-2]. Initial vehicle impact occurred at the targeted impact point. A sequential description of the impact events is contained in Table 12. The vehicle came to rest 101 ft (30.8 m) downstream of impact and 6.4 ft (2.0 m) laterally behind the system. The vehicle trajectory and final position are shown in Figures 93 and 97.

Table 12. Sequential Description of Impact Events, Test No. MWTC-3

TIME (sec)	EVENT
0.000	The vehicle impacted the system 75 in. (1,905 mm) upstream of post no. 9.
0.006	Post nos. 7 and 8 began to deflect backward.
0.014	Post nos. 9 and 10 began to deflect backward.
0.022	The vehicle’s left-front headlight and hood began to deform.
0.030	The guardrail between post nos. 8 and 9 began to flatten.
0.044	The vehicle’s left-front tire began to override the curb of the system.
0.056	The vehicle began to yaw away from barrier.
0.070	The vehicle’s left-front tire underrode the system.
0.078	Post no. 11 began to twist.
0.080	Post no. 12 was deflecting backward.
0.090	The left-front tire impacted post no. 9, ruptured, and deflated.
0.102	Post nos. 13 and 14 were deflecting backward.
0.110	The vehicle’s right rear tire became airborne.
0.140	The left-side door of the vehicle began to deform.
0.160	The vehicle began to pitch downward.
0.192	The vehicle’s left-rear quarter contacted the guardrail between post nos. 7 and 8.
0.206	The occupant was positioned against driver door.
0.218	The vehicle is parallel with system.
0.258	The vehicle’s rear bumper reached the top of rail height between post nos. 7 and 8.
0.300	The vehicle lost contact with rail and came to a stop.
0.326	The vehicle exited system.

8.5 System Damage

Damage to the barrier was moderate, as shown in Figures 99 and 100. System damage consisted of deformed guardrail and posts, fractured wooden posts, displaced soil, gouged wooden spacer blockouts, and contact marks on the guardrail. The length of vehicle contact along the barrier was approximately 18 ft – 2 in. (5.5 m) which spanned from the impact point to 7½ in. (191 mm) upstream of post no. 14.

Flattening of the bottom corrugation began 18 in. (457 mm) upstream of post no. 8 and ended 13 in. (330 mm) upstream of post no. 11. Guardrail bolts pulled through the rail element at post nos. 6, 8, and 10 through 12. There were also several kinks in the rail throughout the impact region.

Post no. 1 partially fractured vertically through the length, on both the upstream and downstream faces. Post nos. 3 through 6 rotated downstream, and post no. 7 rotated backward and upstream. Post no. 8 rotated back and downstream and twisted downstream. The front flange of post no. 9 twisted downstream, and the post rotated backward. The front flange of post no. 10 twisted upstream. Post nos. 10 and 11 bent backward and downstream. Post nos. 12 and 13 rotated backward and downstream. Post no. 12 was also twisted upstream. All blockouts remained attached to their respective posts. The blockouts at post nos. 8, 9, and 11 through 14 were gouged on the top of the blockouts, and the blockout at post no. 10 was twisted 45 degrees.

The permanent set of the rail and posts were 16⅛ in. (410 mm) at post no. 10 and 18⅜ in. (467 mm) at post no. 10, respectively, as measured in the field. The maximum lateral dynamic post and barrier deflections were 23.9 in. (607 mm) at post no. 10 and 22.0 in. (559 mm) at post no. 10, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 40.8 in. (1,036 mm), also determined from high-speed digital video analysis.

8.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figure 101. The maximum occupant compartment deformations are listed in Table 13 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 13. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	1⅛ (29)	≤ 9 (229)
Floor Pan & Transmission Tunnel	½ (13)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	2½ (64)	≤ 12 (305)
Side Door (Above Seat)	1½ (38)	≤ 9 (229)
Side Door (Below Seat)	1½ (38)	≤ 12 (305)
Roof	0	≤ 4 (102)
Windshield	0	≤ 3 (76)

The majority of the damage was concentrated on the left-front corner and left side of the vehicle where impact occurred. The left-front quarter panel deflected inward 10 in. (254 mm), and the left-front bumper was kinked. The left-front headlight and wheel assembly were both detached from the vehicle. Contact marks spanned the left side of the vehicle at the rail height. The left-front wheel well sheet metal tearing was torn at the top. The left-side windshield had spider-web cracking. A 3-in. (76-mm) indentation occurred in the left-front door and an 8-in. (203-mm) crack was found on the left-rear rim. The left-side bumper buckled, and a 3¾-in. (95-mm) gap occurred between the left-rear bumper and the fender. At the final position, brake fluid leaked where the left-front wheel detached. The middle-bottom of the grill had a 4-in. (102-mm) tear. Also, a 2-in. (51-mm) gap occurred at the left-front and right-front hood connections.

8.7 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 14. 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 14. The results of the occupant risk analysis, as determined from the accelerometer data, are also summarized in Figure 93. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix G.

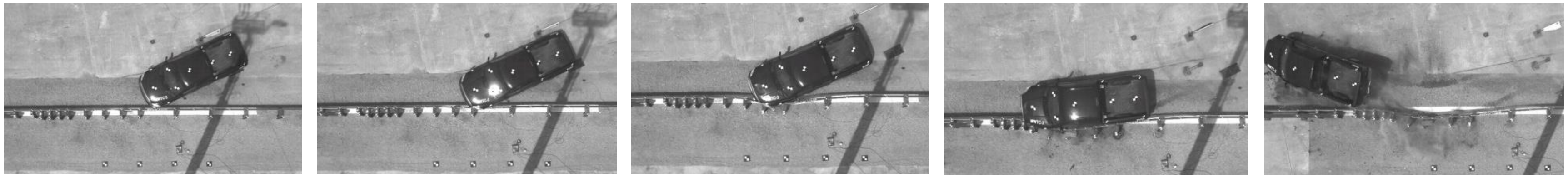
Table 14. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MWTC-3

Evaluation Criteria		**Transducer**			**MASH Limits**
		DTS	**DTS SLICE**	**EDR-3**	
OIV ft/s (m/s)	Longitudinal	-17.62 (-5.37)	-17.46 (-5.32)	-18.77 (-5.72)	≤ 40 (12.2)
	Lateral	16.31 (4.97)	17.79 (5.42)	17.11 (5.22)	≤ 40 (12.2)
ORA g's	Longitudinal	-12.52	-12.29	-13.07	≤ 20.49
	Lateral	10.94	9.18	10.12	≤ 20.49
THIV ft/s (m/s)		23.03 (7.02)	23.75 (7.24)	NA	not required
PHD g's		15.21	14.83	NA	not required
ASI		0.88	0.93	0.92	not required

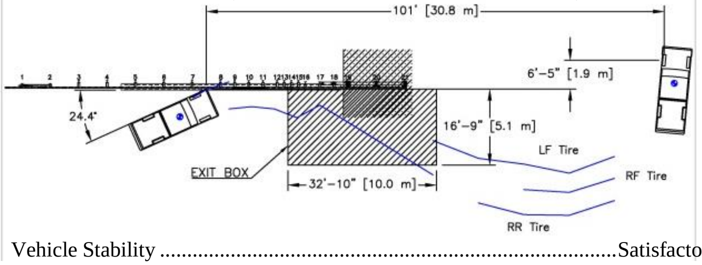
8.8 Discussion

The analysis of the results for test no. MWTC-3 showed that the stiffness transition between the MGS and thrie beam transition with curb adequately contained and redirected the

2270P vehicle with controlled lateral displacements of the barrier. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor override the barrier and remained upright throughout the impact event. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix G, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 11.7 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MWTC-3, conducted on the stiffness transition between the MGS and thrie beam transition with curb, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-21.



- Test Agency ... MwRSF
- Test Number ... MWTC-3
- Date ... 5/16/13
- MASH Test Designation ... 3-21
- Test Article ... Stiffness Transition between MGS and Thrie Beam Transition with Curb
- Total Length ... 87.5 ft (26.7 m)
- Height to Top of Rail ... 31 in. (787 mm)
- Steel 12 gauge (2.66 mm) W-Beam Guardrail
  - Segment Location - Single ... Post no. 1 to Splice 6/7
  - Segment Location - Nested ... Splice 6/7 to Post no. 9
- Steel 10 gauge (3.42 mm) W-Beam to Thrie Beam Transition
  - Segment Location ... Post nos. 9 to 11
- Steel 12 gauge (2.66 mm) Thrie Beam Guardrail
  - Segment Location - Single ... Post nos. 11 to 14 and 19 to 21
  - Segment Location - Nested ... Post nos. 14 to 19
- Guardrail Posts
  - Post Nos. 1-2 ... 46 in. (1,168 mm) long, BCT timber posts
  - Post Nos. 3-15 ... 72 in. (1,829 mm) long, W6x9 (W152x13.4)
  - Post Nos. 16-18 ... 84 in. (2,134 mm) long, W6x15 (W152x22.3)
  - Post Nos. 19-21 ... 29⅝ in. (752 mm) long, W6x20 (W152x29.8)
- Post Spacing
  - Post Nos. 1-8, 19-21 ... 75 in. (1,905 mm)
  - Post Nos. 8-12, 16-19 ... 37½ in. (953 mm)
  - Post Nos. 12-16 ... 18¾ in. (476 mm)
- Soil Type ... AASHTO Grade B
- Vehicle
  - Make and Model ... 2006 Dodge Ram 1500 Quad Cab
  - Test Inertial ... 4,969 lb (2,254 kg)
  - Gross Static ... 5,135 lb (2,329 kg)
  - Curb ... 5,134 lb (2,329 kg)
- Impact Conditions
  - Speed ... 61.0 mph (98.1 km/h)
  - Angle ... 24.4 deg
  - Impact Severity ... 105.8 kip-ft (143.4 kJ) > 105.6 kip-ft (143.2 kJ)
  - Impact Location ... 75 in. (1,905 mm) Upstream of Post No. 9
- Exit Conditions
  - Speed ... 38.3 mph (61.7 km/h)
  - Angle ... 11.7 deg
- Exit Box Criterion ... Passed



- Vehicle Stability ... Satisfactory
- Vehicle Stopping Distance ... 101 ft (30.8 m) downstream of impact ... 6.4 ft (2.0 m) laterally behind system
- Vehicle Damage ... Moderate
  VDS[7] ... 11-LFQ4
  CDC[8] ... 11-LFEW2
  Maximum Interior Deformation ... 2½ in. (64 mm)
- Test Article Damage ... Moderate
- Maximum Test Article Deflections
  - Permanent Set ... 17.8 in. (452 mm)
  - Dynamic ... 23.9 in. (607 mm)
  - Working Width ... 40.8 in. (1,036 mm)
- Maximum Angular Displacements
  - Roll ... -21.8° < 75°
  - Pitch ... -10.8° < 75°
  - Yaw ... 55.4°
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		DTS	DTS SLICE	DTS	
OIV ft/s (m/s)	Longitudinal	-17.62 (-5.37)	-17.46 (-5.32)	-18.77 (-5.72)	≤ 40 (12.2)
	Lateral	16.31 (4.97)	17.79 (5.42)	17.11 (5.22)	≤ 40 (12.2)
ORA g's	Longitudinal	-12.52	-12.29	-13.07	≤ 20.49
	Lateral	10.94	9.18	10.12	≤ 20.49
THIV – ft/s (m/s)		23.02 (7.02)	23.75 (7.24)	NA	not required
PHD – g's		15.21	14.83	NA	not required
ASI		0.88	0.93	0.92	not required

Figure 93. Summary of Test Results and Sequential Photographs, Test No. MWTC-3

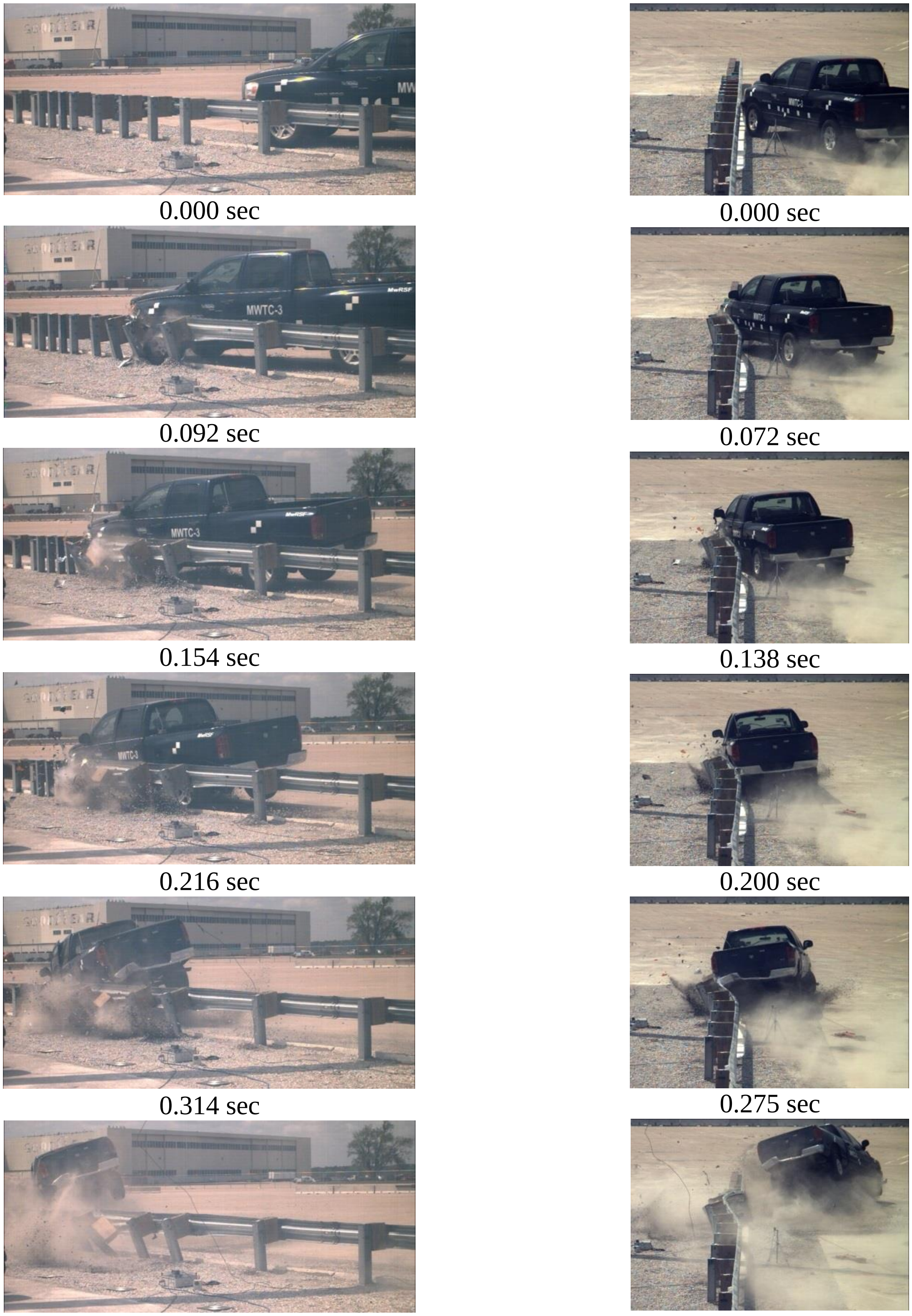


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Figure 94. Sequential Photographs, Test No. MWTC-3

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0.696 sec

Figure 95. Additional Sequential Photographs, Test No. MWTC-3

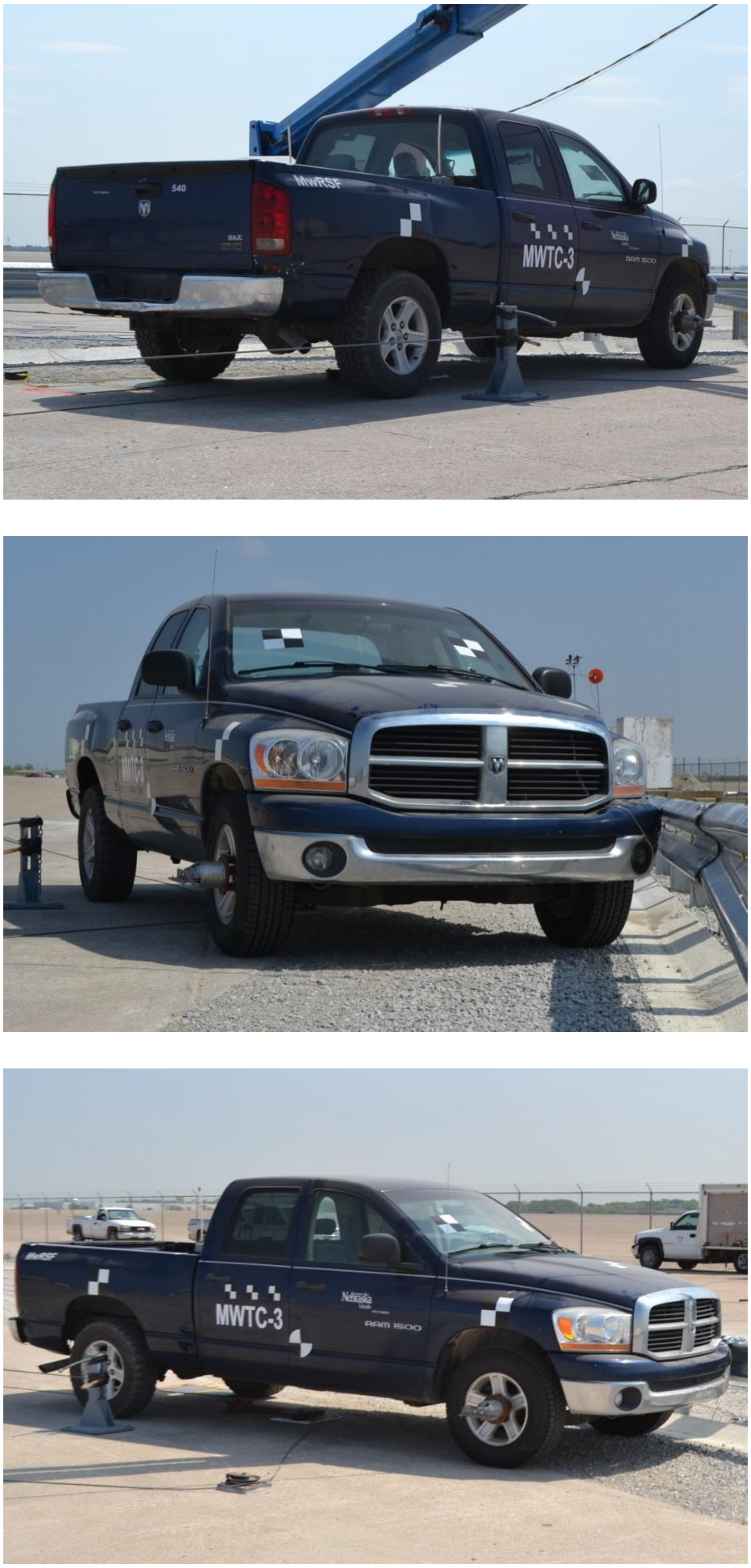

Figure 96. Impact Location, Test No. MWTC-3

Figure 97. Vehicle Final Position, Test No. MWTC-3

Figure 98. System Damage Overview, Test No. MWTC-3

Figure 99. System Damage, Test No. MWTC-3

Figure 100. System Damage, Test No. MWTC-3

Figure 101. Vehicle Damage, Test No. MWTC-3

9 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this study was to evaluate the MGS stiffness transition between W-beam guardrail and thrie beam approach transitions with a 4-in. (102-mm) curb. The MGS stiffness transition incorporated an asymmetrical W-beam to thrie beam transition element, standard MGS, and single and nested thrie beam sections with both guardrail and bridge posts. In 2010, the stiffness transition configuration was previously crash tested without a curb by MwRSF researchers.

Three full-scale crash tests were conducted on the modified stiffness transition according to the TL-3 safety performance criteria found in MASH. A summary of the safety performance evaluation for all three tests is provided in Table 15. The initial crash test, test no. MWTC-1, was performed according to test designation no. 3-20 of MASH with an 1100C small car. During the test, components of the small car penetrated under the W-beam rail, while the wheel climbed up and overrode the curb. These events led to heavy upward and lateral forces on the lower region of the guardrail in advance of the splice between the W-beam and asymmetrical transition segments. The W-beam rail ruptured at the splice location and plastically hinged away from impact, which contributed to snag on a combination of stiff rail elements and several exposed transition posts. Subsequently, the longitudinal ORA values exceeded the MASH limits. Therefore, test no. MWTC-1 was determined to be unacceptable according to test designation 3-20 of MASH.

In an effort to strengthen the rail near the upstream end of the transition, an additional 12-gauge (2.66-mm) W-beam segment was incorporated into the barrier system such that 12.5 ft (3.8 m) of nested guardrail preceded the asymmetric W-to-thrie transition segment. MASH test designation 3-20 was then repeated on the modified system with the same conditions and target impact point as used in test no. MWTC-1. For test no. MWTC-2, the small car was safely contained and redirected with moderate damage to the car and barrier. The test did not pose any significant risk to the occupants of the vehicle as the measured ORA and OIV values were within MASH safety limits. Therefore, test no. MWTC-2 was determined to be acceptable according to test designation no. 3-20 of MASH.

The third full-scale crash test, test no. MWTC-3, was performed with a 2270P pickup truck using the same system configuration as test no. MWTC-2, but it used a different impact point. The vehicle was safely contained and redirected with moderate damage to both the barrier system and the vehicle. Occupant compartment deformation was held to a minimum, and the measured ORA and OIV values were within MASH safety limits. Therefore, test no. MWTC-3 was determined to be acceptable according to test designation no. 3-21 of MASH.

Upon the successful completion of the MASH TL-3 testing matrix, the modified stiffness transition between the MGS and thrie beam approach guardrail transition with curb was found to satisfy current safety standards. Since a very stiff thrie beam approach guardrail transition was used in the full-scale crash testing program, the upstream stiffness transition developed herein should be applicable to most other thrie beam approach guardrail transition systems. Details concerning the attachment of the upstream stiffness transition to other thrie beam transition systems can be found in the 2010 report on the original development of the stiffness transition [1].

The use of nested W-beam rail at the upstream end of the W-to-thrie transition segment will be required for transition installations that utilize lower curbs. The use of nested rail was shown to sufficiently increase the strength of the system to prevent rail tearing. Additionally, rail nesting adjacent to the upstream end of the transition element aided to decrease vehicle pocketing and snag. These same benefits could also be gained if the modified (nested) version of the stiffness transition was utilized for installations without curbs. Thus, system installations without curbs have the option to use either the original MGS stiffness transition design or the modified, nested, MGS stiffness transition.

As detailed in Chapter 6, the curb was installed above ground line and without additional soil backfill. Thus, the ground surface underneath and behind the barrier remained level with the roadway surface and not the top of curb. This configuration was selected as a critical design to test in order to allow a vehicle’s wheel to snag or catch on the backside of the curb, thus potentially leading to increased propensity for vehicle instabilities or wheel/bumper snag on strong posts. However and if used, the 4 in. (102 mm) of extra soil backfill would result in increased post embedment, increased post-soil resistance, and a slightly stiffer and stronger barrier system. Impacts into the stiffened transition system would likely result in reduced lateral barrier displacements. Thus, the MGS stiffness transition was tested and evaluated without the extra soil fill, but it was believed that installation later could occur with or without soil backfill.

In order to ensure the safety performance of the MGS stiffness, the 4-in. (102-mm) tall curb should be placed through the entire length of the stiffness transition. Thus, the curb should be extended a minimum of 37.5 ft (11.4 m) from the bridge parapet before either being terminated or transitioning to a 6-in. (152-mm) high AASHTO Type B curb. Additionally, it is recommended to utilize a minimum length of 3 ft (0.9 m) for any curb shape transitions or terminations (e.g. transitioning from 4-in. (102-mm) curb to no curb).

The modified MGS stiffness transition to a thrie beam approach guardrail transition was 37 ft – 6 in. (11.4 m) in length (as measured from the first bridge post to the upstream end of the nested W-beam rail segment) and had 34 ft – 4.5 in. (10.5 m) of standard MGS between the stiffness transition and the upstream BCT wood anchor post. Guardrail end terminals are designed, crash tested, and evaluated for use when directly attached to semi-rigid W-beam guardrail systems, instead of stiffer approach guardrail transitions. The introduction of stiffer (nested) rail segments may potentially lead to degraded performance of crashworthy terminals. Additionally, the placement of the upstream end anchorage too close to the stiffness transition may negatively affect system performance, thus potentially resulting in excessive barrier deflections, vehicle pocketing, wheel snagging on posts, vehicle-to-barrier override, or other vehicle instabilities. Thus, the following implementation guidelines should be considered when utilizing the modified MGS stiffness transition. Although the reference point was changed to the upstream end of the nested rail segment, these recommendations result in the same system lengths upstream of the W-to-thrie transition segment that were recommended previously for the original transition system design without nesting [1].

1. The length of W-beam guardrail installed upstream of the nested W-beam section is recommended to be greater than or equal to the total system length of an acceptable TL-3 guardrail end terminal. Thus, the guardrail terminal's interior end (identified by stoke length) should not intrude into the nested W-beam section of the modified MGS stiffness transition.

2. A recommended minimum barrier length of 34 ft – 4½ in. (10.5 m) is to be installed beyond the upstream end of the nested W-beam section, which includes standard MGS, a crashworthy guardrail end terminal, and an acceptable anchorage system.

3. For flared guardrail applications, a minimum length of 12.5 ft (3.8 m) is recommended between the upstream end of the nested W-beam section and the start of the flared section (i.e. bend between flare and tangent sections).

The original MGS stiffness transition was recommended for use in either the tested configuration, Design K, or a configuration which included an additional post at the upstream end of the transition, Design L [1]. The additional post of Design L would be located at the midpoint of the first full post spacing upstream of the W-to-thrie transition segment and within the nested W-beam section of the modified MGS stiffness transition (between post nos. 7 and 8 in Figure 54). Although it provided a longer system length, Design L had foreseeable safety performance benefits, such as reductions in vehicle pocketing, snag, and system deflection.

These benefits would also apply to systems installed in combination with curb. Thus, either design can be implemented within the modified MGS stiffness transition.

The MGS stiffness transition was successfully crash tested and evaluated for use with a thrie beam approach guardrail transition where all posts were installed in level terrain. Therefore, this stiffness transition should be implemented with a minimum of 2 ft (0.61 m) of level or gently-sloped fill placed behind the posts, unless special design provisions are made to account for decreased post-soil resistance. Additionally, it is unknown as to whether a non-blocked version of the MGS installed adjacent to the new stiffness transition will negatively affect the system. The safety performance of non-blocked MGS in conjunction with the modified stiffness transition can only be verified through the use of full-scale crash testing. As such, it is recommended that a minimum of 12.5 ft (3.8 m) of standard MGS with spacer blocks be placed adjacent to the modified stiffness transition (upstream end of the nested rail section) prior to transitioning to a non-blocked, 31-in. (787-mm) tall, W-beam guardrail system.

Table 15. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. MWTC-1</th><th>Test No. MWTC-2</th><th>Test No. MWTC-3</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>U</td><td>S</td><td>S</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D.</td><td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td><td>S</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
</table></td><td>S</td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table></td><td>U</td><td>S</td><td>S</td></tr>
<tr><td colspan="3">MASH Test Designation</td><td>3-20</td><td>3-20</td><td>3-21</td></tr>
<tr><td colspan="3">Pass/Fail</td><td>Fail</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

10 REFERENCES

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11 APPENDICES

Appendix A. Vehicle Center of Gravity Determination

MWTC-1 Vehicle: 1100C

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)
+	Unbalasted Car (curb)	2468
+	Brake receivers/wires	6
+	Brake Frame	6
+	Brake Cylinder	22
+	Strobe Battery	6
+	Hub	20
+	CG Plate (EDRs)	10
+	DTS	17
-	Battery	-33
-	Oil	-13
-	Interior	-28
-	Fuel	0
-	Coolant	-8
-	Washer fluid	0
BALLAST	Spare tire	-27
	Misc.	
	Misc.	

Estimated Total Weight 2446 lb

wheel base 98.5 in.

MASH targets			**Test Inertial**	**Difference**
Test Inertial Wt (lb)	2420	(+/-)55	2457	37.0
Long CG (in.)	39	(+/-)4	35.92	-3.07977
Lateral CG (in.)	N/A		0.409989	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	793	801
Rear	448	426

FRONT	1594	lb
REAR	874	lb
TOTAL	2468	lb

Dummy = 166lbs.

TEST INERTIAL WEIGHT (lb)

(from scales)

	Left	Right
Front	774	787
Rear	437	459

FRONT	1561	lb
REAR	896	lb
TOTAL	2457	lb

Figure A-1. Vehicle Mass Distribution, Test No. MWTC-1

MWTC-2 Vehicle: 1100C/Rio

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)
+	Unbalasted Car (curb)	2390
+	Brake receivers/wires	5
+	Brake Frame	5
+	Brake Cylinder	22
+	Strobe Battery	6
+	Hub	20
+	CG Plate (EDRs)	10
+	DTS	17
-	Battery	-33
-	Oil	-8
-	Interior	-28
-	Fuel	0
-	Coolant	0
-	Washer fluid	-8
BALLAST	Water	0
	Spare Tire	
	Misc.	

Estimated Total Weight 2398 lb

wheel base 98.75 in.

MASH targets			**Test Inertial**	**Difference**
Test Inertial Wt (lb)	2420	(+/-)55	2410	-10.0
Long CG (in.)	39	(+/-)4	37.98	-1.01608
Lateral CG (in.)	N/A		0.522614	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	744	759
Rear	451	436

FRONT 1503 lb
REAR 887 lb
TOTAL 2390 lb

Dummy = 166lbs.

TEST INERTIAL WEIGHT (lb)
(from scales)

	Left	Right
Front	731	752
Rear	452	475

FRONT 1483 lb
REAR 927 lb
TOTAL 2410 lb

Figure A-2. Vehicle Mass Distribution, Test No. MWTC-2

MWTC-3 Vehicle: 2270P

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vert CG (in.)	Vert M (lb-in.)
+	Unbalasted Truck (Curb)	5134	28.32279	145409.2
+	Brake receivers/wires	6	52.5	315
+	Brake Frame	5	27	135
+	Brake Cylinder (Nitrogen)	22	27	594
+	Strobe/Brake Battery	5	32	160
+	Hub	27	14.9375	403.3125
+	CG Plate (EDRs)	8	32	256
-	Battery	-43	41	-1763
-	Oil	-8	17	-136
-	Interior	-74	22	-1628
-	Fuel	-156	21	-3276
-	Coolant	-15	37	-555
-	Washer fluid	-8	40	-320
BALLAST	Water	0	21	0
	DTS	21	30	630
	Misc.			0
				140224.5

Estimated Total Weight (lb)	4924
Vertical CG Location (in.)	28.47776

wheel base (in.) 140.5

MASH Targets		**Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)		5000 ± 110	4969	-31.0
Long CG (in.)		63 ± 4	62.06	-0.93570
Lat CG (in.)		NA	0.2671	NA
Vert CG (in.)	≥	28	28.48	0.47776

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	1494	1360
Rear	1129	1151
FRONT	2854 lb	
REAR	2280 lb	
TOTAL	5134 lb	

TEST INERTIAL WEIGHT (lb)

(from scales)

	Left	Right
Front	1389	1385
Rear	1076	1119
FRONT	2774 lb	
REAR	2195 lb	
TOTAL	4969 lb	

Figure A-3. Vehicle Mass Distribution, Test No. MWTC-3

Appendix B. Material Specifications

Table B-1. Bill of Materials for Test No. MWTC-1

Item No.	QTY.	Description	Material Spec	Hardware Guide	Reference
a1	7	6"x12"x14 1/4" [152x305x362] Blockout - Post 3-9	SYP Grade No.1 or better	PDB10a	COC Invoice #43270
a2	6	6"x12"x19" [152x305x483] Blockout - Post 10-15	SYP Grade No.1 or better	-	COC Invoice #43688
a3	2	6"x8"x19" [152x305x483] Blockout - Post 16-17	SYP Grade No.1 or better	-	COC Invoice #43688
a4	1	6"x8"x15" [152x305x381] Blockout - Post 18	SYP Grade No.1 or better	-	COC Invoice #43688
a5	2	BCT Timber Post -MGS Height	SYP Grade No. 1 or better	PDF01	COC Invoice #2589 and #2598
b1	2	6 1/4"x9"x3/8" [159x229x9.5] Bridge Cap Rail Bent Plate Connector	ASTM A36	-	H#85211
b2	6	3 1/2"x3 1/2"x5/16" [89x89x7.9] Bridge Cap Rail Angle	ASTM A36	-	H#85211
b3	1	C8x11.5 [C203x17.1] Bridge Cap Rail	ASTM A36	-	H#85211
b4	1	C8x11.5 [C203x17.1] Bridge Cap Rail Transition	ASTM A36	-	H#85211
b5	1	3 1/2"x3 1/2"x1/4" [89x89x6.4] Bridge Cap Rail Terminator Tube	ASTM A36	-	H#85211
b6	1	9"x4 1/2"x3/8" [229x114x9.5] Terminator Plate	ASTM A36	-	H#85211
b7	1	5 7/8"x13"x3/8" [149x330x9.5] Bridge Cap Rail Splice Plate	ASTM A36	-	H#85211
b8	3	12"x14"x1 1/4" [305x356x32] Bridge Cap Connector Plate	ASTM A36	-	H#85211
b9	3	W6x15 [W152x22.3] Steel Bridge Blockout	ASTM A992	-	H#22514790
b10	3	W6x20 [W152x29.8] Steel Bridge Post	ASTM A992	-	H#11959830
c1	2	72" [1829] Long Foundation Tube	A500 Grade B	PTE05	H#A13386
c2	1	Strut and Yoke Assembly	ASTM A36	-	COC Invoice #1093497
c3	1	Anchor Bracket	ASTM A36	FPA01-02	H#V911470
c4	1	6' [1829] Long BCT Anchor Cable Assembly	3/4" [19] Dia. 6x19 IWRC IPS Wire Rope	FCA01	H#M39999B
c5	1	8"x8"x5/8" [203x203x15.9] Anchor Bearing Plate	ASTM A36	FPB01	H#18486
c6	1	2 3/8" [60] O.D., 6" [152] Long BCT Hole Insert	ASTM A53 Grade B Schedule 40	FMM02	H#280638
d1	3	12'-6" [3810] Thrie Beam Section - 1/4 Post Spacing	12 gauge AASHTO M180	-	H#151877
d2	1	6'-3" [1905] Thrie Beam Section - 1/4 Post Spacing	12 gauge AASHTO M180	-	H#154420
d3	1	6'-3" [1905] W-Beam to Thrie-Beam Transition Section	10 gauge AASHTO M180	RWT02a	H#1106510
d4	3	12'-6" [3810] W-Beam MGS Section	12 gauge AASHTO M180	RWM04a	H#4614
d5	1	12'-6" [3810] W-Beam MGS End Section	12 gauge AASHTO M180	RWM14a	H#4614

e1	18	1" [25] Dia. UNC, 13 1/2" [343] Long Threaded Rod and Heavy Hex Nut	Bolt B7 or ASTM A449 Type 1, Nut ASTM A563 Gr. C	-	LOT#F2N0985600
e2	18	1" [25] Dia. Hardened Round Washer	ASTM F436 Type 1	FWC24a	LOT#017718
e3	2	7/8" [22] Dia. UNC, 7 1/2" [191] Long Hex Bolt and Hex Nut	ASTM A307 Gr. A, SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX22a	H#10100058-3
e4	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	FWC22a	H#10100058-3
e5	8	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Bolt and Hex Nut	ASTM A307 Gr. A, SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	LOT#090123B
e6	42	5/8" [16] Dia. UNC, 2" [51] Long Hex Bolt and Hex Nut	ASTM A307 Gr. A, SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	LOT#11032541C3
e7	2	5/8" [16] Dia. UNC, 5" [127] Long Hex Bolt and Hex Nut	ASTM A307 Gr. A, SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	H#01069
e8	2	5/8" [16] Dia. UNC, 10" [254] Long Hex Bolt and Hex Nut	ASTM A307 Gr. A, SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	H#780337
e9	68	5/8" [16] Dia. UNC, 1 1/2" [38] Long Guardrail Bolt and Double Recessed Nut	ASTM A307 Gr. A, SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB01	LOT#1335055
e10	6	5/8" [16] Dia. UNC, 2" [51] Long Guardrail Bolt and Double Recessed Nut	ASTM A307 Gr. A, SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB02	H#5074697
e11	8	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Double Recessed Nut	ASTM A307 Gr. A, SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB03	H#JK1110419701
e12	18	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Double Recessed Nut	ASTM A307 Gr. A, SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB06	H#JK1110419701
e13	116	5/8" [16] Dia. Plain Round Washer	ASTM F844	FWC16a	n/a
e14	8	16D Double Head Nail	-	-	n/a
e15	10	11 1/2" x 5 3/4" [292x146] Bent #4 Rebar	ASTM A615 Grade 60	-	H#K117810
e16	3	47' [14.3 m] Long #4 Rebar	ASTM A615 Grade 60	-	H#K117810
e17	10	13 1/2 [343] Long $4 Rebar	ASTM A615 Grade 60	-	H#K117810
f1	7	W6x8.5 [W152x12.6] 72" [1829] long - Post Nos. 3-9	ASTM A992	-	LOT#5239AA-1
f2	6	W6x8.5 [W152x12.6] 72" [1829] long - Post Nos. 10-15	ASTM A992	-	LOT#5239AA-1
f3	1	W6x15 [W152x22.3] 84" [2134] long - Post No. 16	ASTM A992	-	H#11952390
f4	1	W6x15 [W152x22.3] 84" [2134] long - Post No. 17	ASTM A992	-	H#11952390
f5	1	W6x15 [W152x22.3] 84" [2134] long - Post No. 18	ASTM A992	-	H#11952390
-	-	EPOXY	AC100+ GOLD	-	LOT#C020
-	-	Concrete	minimum 3500 psi.	-	TICKET#4139567

Table B-2. Bill of Materials for Test No. MWTC-2

Item No.	QTY.	Description	Material Spec	Hardware Guide	Reference
a1	7	6"x12"x14 1/4" [152x305x362] Blockout - Post 3-9	SYP Grade No.1 or better	PDB10a	COC Invoice #43270
a2	6	6"x12"x19" [152x305x483] Blockout - Post 10-15	SYP Grade No.1 or better	-	COC Invoice #44149
a3	2	6"x8"x19" [152x305x483] Blockout - Post 16-17	SYP Grade No.1 or better	-	COC Invoice #44149
a4	1	6"x8"x15" [152x305x381] Blockout - Post 18	SYP Grade No.1 or better	-	COC Invoice #44149
a5	2	BCT Timber Post -MGS Height	SYP Grade No.1 or better	PDF01	COC Invoice #2589 and #2598
b1	2	6 1/4"x9"x3/8" [159x229x9.5] Bridge Cap Rail Bent Plate Connector	ASTM A36	-	H#85211
b2	6	3 1/2"x3 1/2"x5/16" [89x89x7.9] Bridge Cap Rail Angle	ASTM A36	-	H#85211
b3	1	C8x11.5 [C203x17.1] Bridge Cap Rail	ASTM A36	-	H#85211
b4	1	C8x11.5 [C203x17.1] Bridge Cap Rail Transition	ASTM A36	-	H#85211
b5	1	3 1/2"x3 1/2"x1/4" [89x89x6.4] Bridge Cap Rail Terminator Tube	ASTM A36	-	H#85211
b6	1	9"x4 1/2"x3/8" [229x114x9.5] Terminator Plate	ASTM A36	-	H#85211
b7	1	5 7/8"x13"x3/8" [149x330x9.5] Bridge Cap Rail Splice Plate	ASTM A36	-	H#85211
b8	3	12"x14"x1 1/4" [305x356x32] Bridge Cap Connector Plate	ASTM A36	-	H#85211
b9	3	W6x15 [W152x22.3] Steel Bridge Blockout	ASTM A992	-	H#11952390
b10	3	W6x20 [W152x29.8] Steel Bridge Post - Post Nos. 19-21	ASTM A992	-	H#11959830
c1	2	6"x8"x3/16" [152x203x5],72" [1829] Long Foundation Tube	ASTM A500 Grade B	PTE06	H#A13386
c2	1	Strut and Yoke Assembly	ASTM A36	-	COC Invoice #1093497
c3	1	Anchor Bracket	ASTM A36	FPA01-02	H#V911470
c4	1	6' [1829] Long BCT Anchor Cable Assembly	3/4" [19] Dia. 6x19 IWRC IPS Wire Rope	FCA01	H#M39999B
c5	1	8"x8"x5/8" [203x203x15.9] Anchor Bearing Plate	ASTM A36	FPB01	H#18486
c6	1	2 3/8" [60] O.D., 6" [152] Long BCT Hole Insert	ASTM A53 Grade B Schedule 40	FMM02	H#280638
d1	2	12'-6" [3810] Thrie Beam Section - 1/4 Post Spacing	12 gauge AASHTO M180	-	H#4174436
d2	1	6'-3" [1905] Thrie Beam Section - 1/4 Post Spacing	12 gauge AASHTO M180	-	H#154420
d3	1	6'-3" [1905] W-Beam to Thrie-Beam Transition Section	10 gauge AASHTO M180	RWT02a	H#4174436
d4	4	12'-6" [3810] W-Beam MGS Section	12 gauge AASHTO M180	RWM04a	H#4614
d5	1	12'-6" [3810] W-Beam MGS End Section	12 gauge AASHTO M180	RWM14a	H#4614

e1	18	1" [25] Dia. UNC, 13 1/2" [343] Long Threaded Rod and Heavy Hex Nut	Bolt B7 or ASTM A449 Type 1, Nut ASTM A563 Gr. C	-	LOT#F2N0985600
e2	18	1" [25] Dia. Hardened Round Washer	ASTM F436 Type 1	FWC24a	LOT#017718
e3	2	7/8" [22] Dia. UNC, 7 1/2" [191] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX22a	H#10100058-3
e4	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	FWC22a	H#10100058-3
e5	8	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	LOT#090123B
e7	2	5/8" [16] Dia. UNC, 5" [127] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	H#01069
e8	2	5/8" [16] Dia. UNC, 10" [254] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	LOT#10083111C3
e9	68	5/8" [16] Dia. UNC, 1 1/2" [38] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB01	LOT#1335055
e10	6	5/8" [16] Dia. UNC, 2" [51] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB02	H#5074697
e6	42	5/8" [16] Dia. UNC, 2" [51] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	LOT#11032541C3
e11	8	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB03	H#JK1110419701
e12	18	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB06	H#JK1110419701
e13	116	5/8" [16] Dia. Plain Round Washer	ASTM F844	FWC16a	n/a
e14	8	16D Double Head Nail	-	-	n/a
e15	10	11 1/2" x 5 3/4" [292x146] Bent #4 Rebar	ASTM A615 Grade 60	-	H#K117810
e16	3	47' [14.3 m] Long #4 Rebar	ASTM A615 Grade 60	-	H#K117810
e17	10	13 1/2" [343] Long #4 Rebar	ASTM A615 Grade 60	-	H#K117810
f1	7	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1829] Long - Post Nos. 3-9	ASTM A992	-	LOT#5239AA-1
f2	6	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1829] Long - Post Nos. 10-15	ASTM A992	-	LOT#5239AA-1
f3	1	W6x15 [W152x22.3], 84" [2134] Long - Post No. 16	ASTM A992	-	H#11952390
f4	1	W6x15 [W152x22.3], 84" [2134] Long - Post No. 17	ASTM A992	-	H#11952390
f5	1	W6x15 [W152x22.3], 84" [2134] Long - Post No. 18	ASTM A992	-	H#11952390
-	-	EPOXY	AC100+ GOLD	-	LOT#C020
		Concrete Curb NEW	minimum 3500 psi.	-	TICKET#4139567

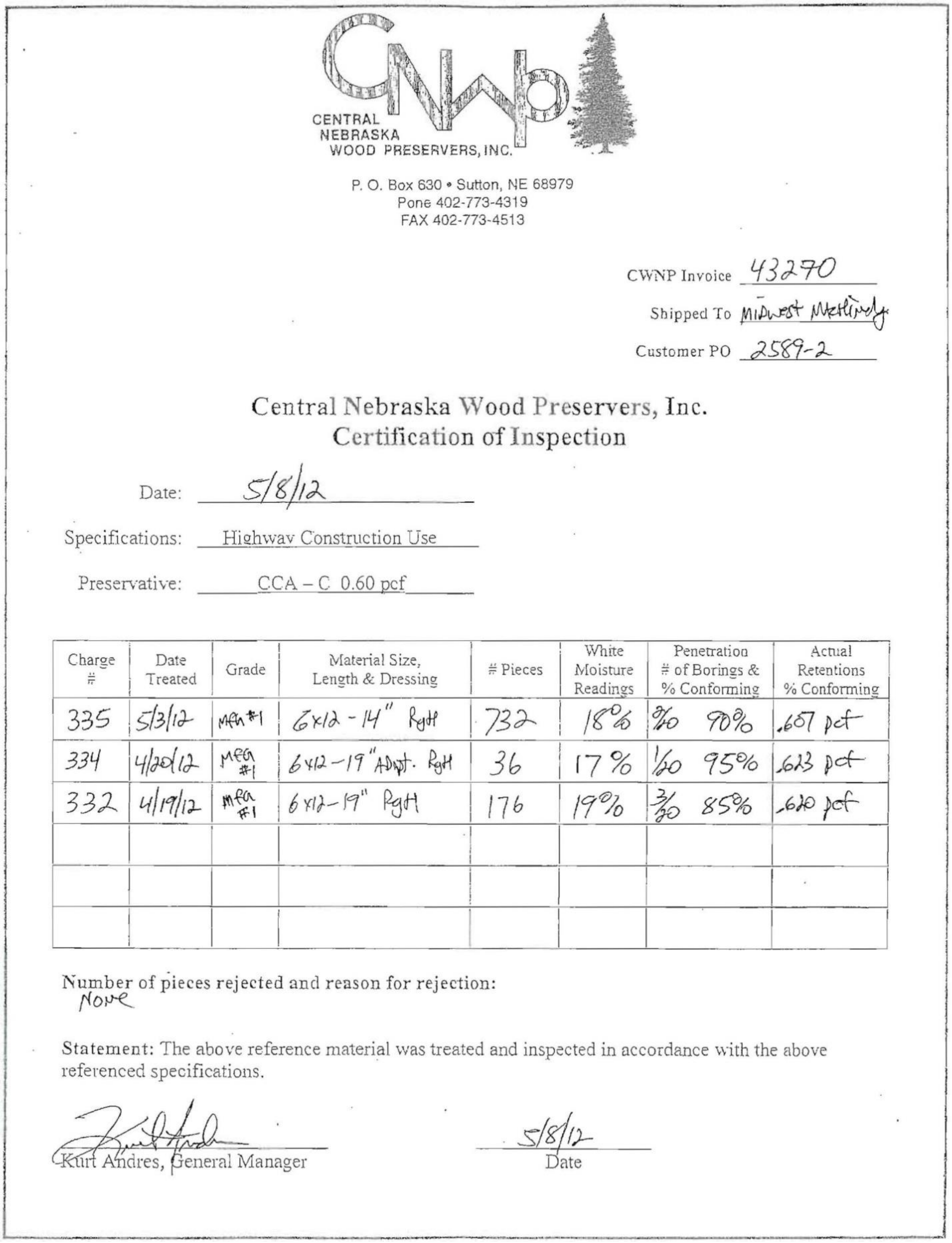
Table B-3. Bill of Materials for Test No. MWTC-3

Item No.	QTY.	Description	Material Spec	Hardware Guide	Reference
a1	7	6"x12"x14 1/4" [152x305x362] Blockout - Post 3-9	SYP Grade No.1 or better	PDB10a	COC Invoice #43270
a2	6	6"x12"x19" [152x305x483] Blockout - Post 10-15	SYP Grade No.1 or better	-	COC Invoice #44149
a3	2	6"x8"x19" [152x305x483] Blockout - Post 16-17	SYP Grade No.1 or better	-	COC Invoice #44149
a4	1	6"x8"x15" [152x305x381] Blockout - Post 18	SYP Grade No.1 or better	-	COC Invoice #44149
a5	2	BCT Timber Post -MGS Height	SYP Grade No.1 or better	PDF01	COC Invoice #2589 and #2598
b1	2	6 1/4"x9"x3/8" [159x229x9.5] Bridge Cap Rail Bent Plate Connector	ASTM A36	-	H#85211
b2	6	3 1/2"x3 1/2"x5/16" [89x89x7.9] Bridge Cap Rail Angle	ASTM A36	-	H#85211
b3	1	C8x11.5 [C203x17.1] Bridge Cap Rail	ASTM A36	-	H#85211
b4	1	C8x11.5 [C203x17.1] Bridge Cap Rail Transition	ASTM A36	-	H#85211
b5	1	3 1/2"x3 1/2"x1/4" [89x89x6.4] Bridge Cap Rail Terminator Tube	ASTM A36	-	H#85211
b6	1	9"x4 1/2"x3/8" [229x114x9.5] Terminator Plate	ASTM A36	-	H#85211
b7	1	5 7/8"x13"x3/8" [149x330x9.5] Bridge Cap Rail Splice Plate	ASTM A36	-	H#85211
b8	3	12"x14"x1 1/4" [305x356x32] Bridge Cap Connector Plate	ASTM A36	-	H#85211
b9	3	W6x15 [W152x22.3] Steel Bridge Blockout	ASTM A992	-	H#11952390
b10	3	W6x20 [W152x29.8] Steel Bridge Post - Post Nos. 19-21	ASTM A992	-	H#11959830
c1	2	6"x8"x3/16" [152x203x5],72" [1829] Long Foundation Tube	ASTM A500 Grade B	PTE06	H#A13386
c2	1	Strut and Yoke Assembly	ASTM A36	-	COC Invoice #1093497
c3	1	Anchor Bracket	ASTM A36	FPA01-02	H#V911470
c4	1	6' [1829] Long BCT Anchor Cable Assembly	3/4" [19] Dia. 6x19 IWRC IPS Wire Rope	FCA01	H#M39999B
c5	1	8"x8"x5/8" [203x203x15.9] Anchor Bearing Plate	ASTM A36	FPB01	H#18486
c6	1	2 3/8" [60] O.D., 6" [152] Long BCT Hole Insert	ASTM A53 Grade B Schedule 40	FMM02	H#280638
d1	3	12'-6" [3810] Thrie Beam Section - 1/4 Post Spacing	12 gauge AASHTO M180	-	H#4174436
d2	1	6'-3" [1905] Thrie Beam Section - 1/4 Post Spacing	12 gauge AASHTO M180	-	H#154420
d3	1	6'-3" [1905] W-Beam to Thrie-Beam Transition Section	10 gauge AASHTO M180	RWT02a	H#4174436
d4	4	12'-6" [3810] W-Beam MGS Section	12 gauge AASHTO M180	RWM04a	H#4614
d5	1	12'-6" [3810] W-Beam MGS End Section	12 gauge AASHTO M180	RWM14a	H#4614

e1	18	1" [25] Dia. UNC, 13 1/2" [343] Long Threaded Rod and Heavy Hex Nut	Bolt B7 or ASTM A449 Type 1, Nut ASTM A563 Gr. C	-	LOT#F2N0985600
e2	18	1" [25] Dia. Hardened Round Washer	ASTM F436 Type 1	FWC24a	LOT#017718
e3	2	7/8" [22] Dia. UNC, 7 1/2" [191] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX22a	H#10100058-3
e4	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	FWC22a	H#10100058-3
e5	8	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	LOT#090123B
e7	2	5/8" [16] Dia. UNC, 5" [127] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	H#01069
e8	2	5/8" [16] Dia. UNC, 10" [254] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	LOT#10083111C3
e9	68	5/8" [16] Dia. UNC, 1 1/2" [38] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB01	LOT#1335055
e10	6	5/8" [16] Dia. UNC, 2" [51] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB02	H#5074697
e6	42	5/8" [16] Dia. UNC, 2" [51] Long Hex Bolt and Hex Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBX16a	LOT#11032541C3
e11	8	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB03	SEE TABLE A-4
e12	18	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Double Recessed Nut	Bolt ASTM A307 Gr. A or SAE J429 Gr. 2, Nut ASTM A563 Gr. A	FBB06	SEE TABLE A-4
e13	116	5/8" [16] Dia. Plain Round Washer	ASTM F844	FWC16a	n/a
e14	8	16D Double Head Nail	-	-	n/a
e15	10	11 1/2" x 5 3/4" [292x146] Bent #4 Rebar	ASTM A615 Grade 60	-	H#K117810
e16	3	47' [14.3 m] Long #4 Rebar	ASTM A615 Grade 60	-	H#K117810
e17	10	13 1/2" [343] Long #4 Rebar	ASTM A615 Grade 60	-	H#K117810
f1	7	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1829] Long - Post Nos. 3-9	ASTM A992	-	LOT#5239AA-1
f2	6	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1829] Long - Post Nos. 10-15	ASTM A992	-	LOT#5239AA-1
f3	1	W6x15 [W152x22.3], 84" [2134] Long - Post No. 16	ASTM A992	-	H#11952390
f4	1	W6x15 [W152x22.3], 84" [2134] Long - Post No. 17	ASTM A992	-	H#11952390
f5	1	W6x15 [W152x22.3], 84" [2134] Long - Post No. 18	ASTM A992	-	H#11952390
		New Concrete Curb	SG3500		TICKET#4141778

Table B-4. Post Bolt Specifications for Test No. MWTC-3

Post 1	10" - Yellow
Post 2	10" - Yellow
Post 3	14" - Red
Post 4	14" - Red
Post 5	14" - Yellow
Post 6	14" - Yellow
Post 7	14" - Yellow
Post 8	14" - Yellow
Post 9	14" - Yellow
Post 10	14" - Yellow
Post 11	14" Blue x2
Post 12	14" - Yellow x2
Post 13	14" - Yellow x2
Post 14	14" Blue x2
Post 15	14" - Red x2
Post 16	14" - Red x2
Post 17	14" - Red x2
Post 18	14" - Red x2



CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

CWNP Invoice 43270
Shipped To Midwest Machinery
Customer PO 2589-2

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Date: 5/8/12

Specifications: Highway Construction Use

Preservative: CCA – C 0.60 pcf

Charge #	Date Treated	Grade	Material Size, Length & Dressing	# Pieces	White Moisture Readings	Penetration # of Borings & % Conforming	Actual Retentions % Conforming
335	5/3/12	MGA #1	6x12 - 14" RgH	732	18%	2/20 90%	.657 pcf
334	4/20/12	MGA #1	6x12 – 19" ADapt. RgH	36	17 %	1/20 95%	.623 pcf
332	4/19/12	MGA #1	6x12 – 19" RgH	176	19%	3/20 85%	.620 pcf

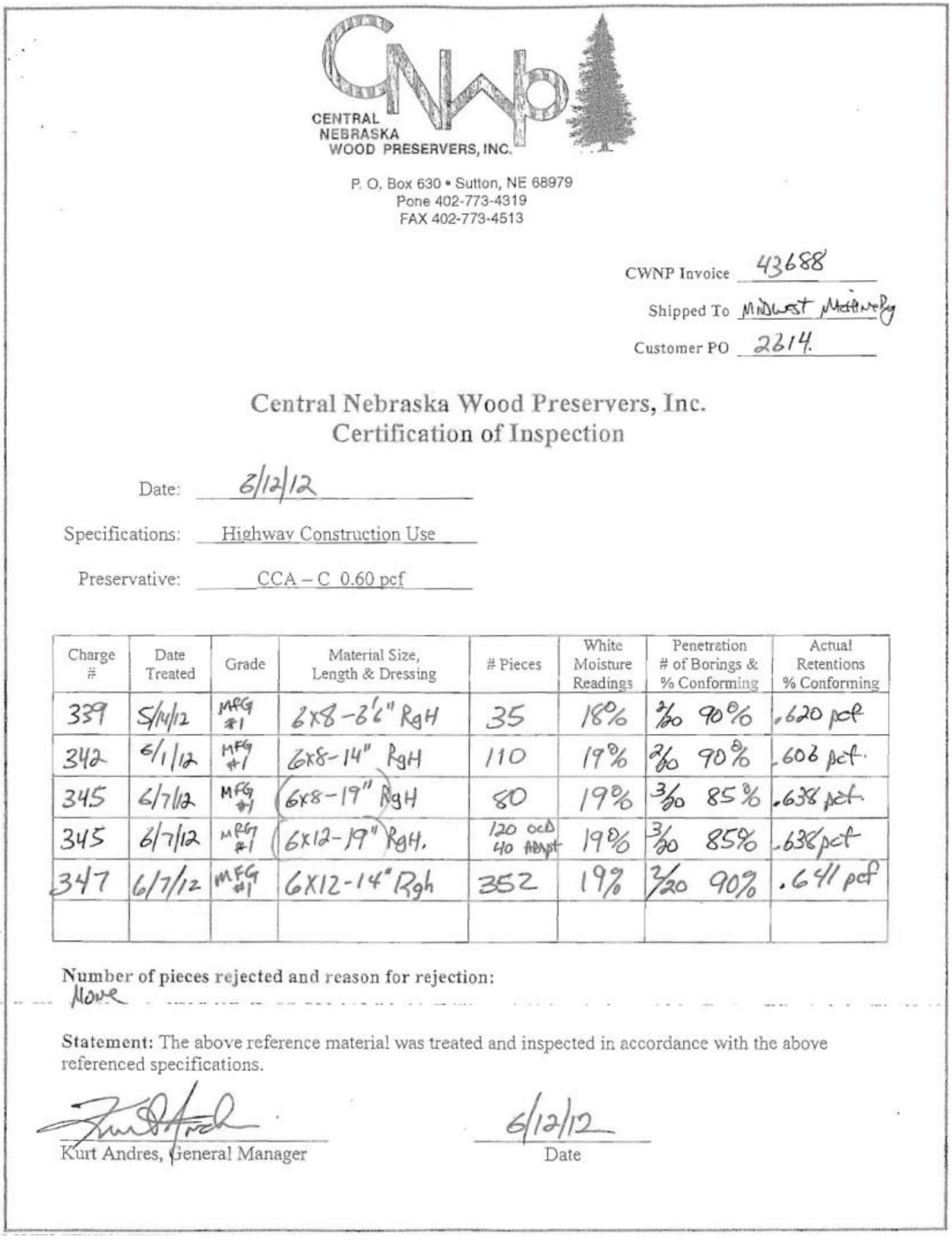
Number of pieces rejected and reason for rejection:
None

Statement: The above reference material was treated and inspected in accordance with the above referenced specifications.

Kurt Andres, General Manager

5/8/12
Date

Figure B-2. Wood Blockouts for Test Nos. MWTC-1 through MWTC-3



CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

CWNP Invoice 43688

Shipped To MidWest Machinery

Customer PO 2214.

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Date: 6/12/12

Specifications: Highway Construction Use

Preservative: CCA – C 0.60 pcf

Charge #	Date Treated	Grade	Material Size, Length & Dressing	# Pieces	White Moisture Readings	Penetration # of Borings & % Conforming	Actual Retentions % Conforming
339	5/14/12	MFG #1	6x8-6'6" RgH	35	18%	2/20 90%	.620 pcf
342	6/1/12	MFG #1	6x8-14" RgH	110	19%	2/20 90%	.606 pcf.
345	6/7/12	MFG #1	6x8-19" RgH	80	19%	3/20 85%	.638 pcf.
345	6/7/12	MFG #1	6x12-19" RgH.	120 ocD 40 Abspt	19%	3/20 85%	.638 pcf
347	6/7/12	MFG #1	6X12-14" Rgh	352	19%	2/20 90%	.641 pcf

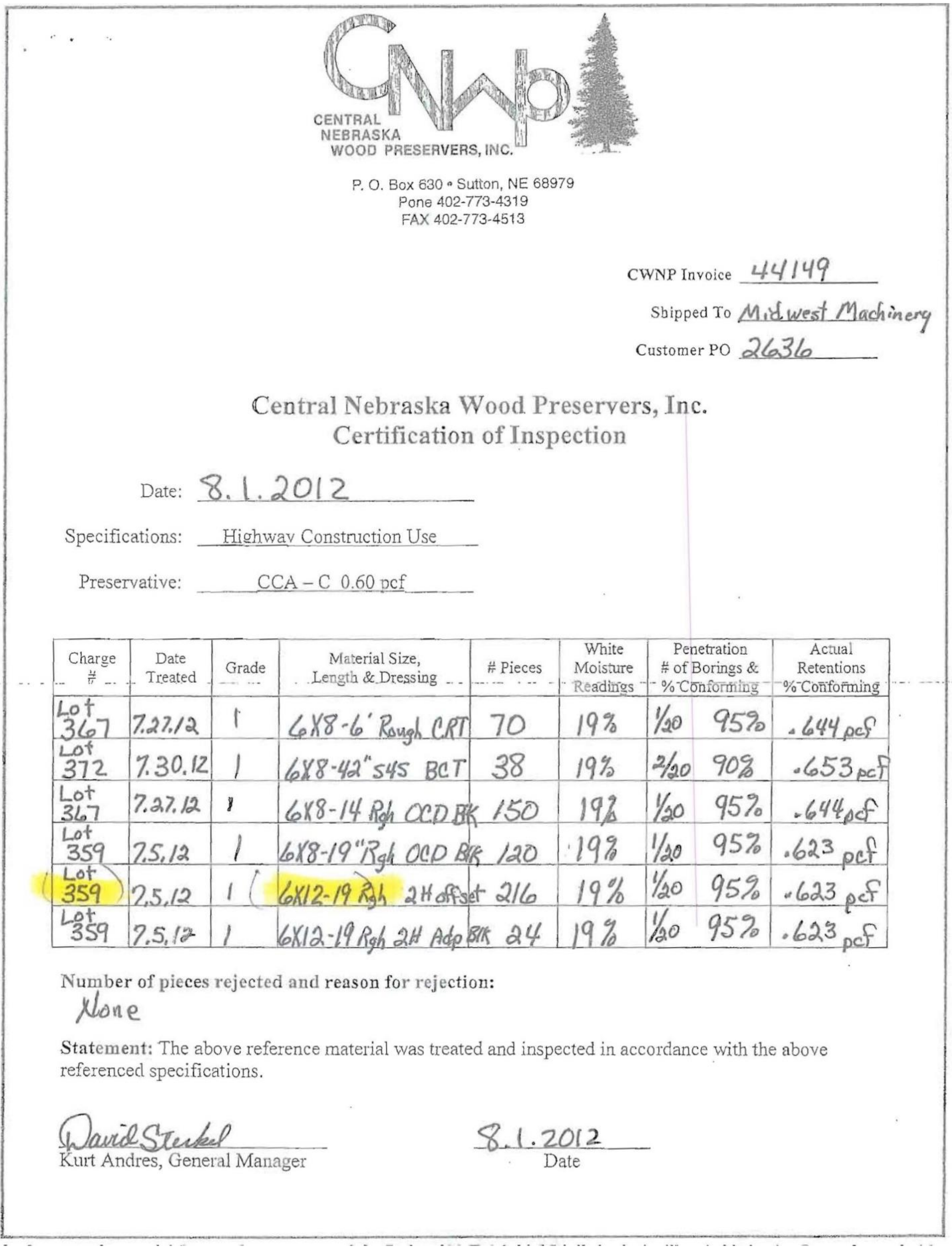
Number of pieces rejected and reason for rejection:
None

Statement: The above reference material was treated and inspected in accordance with the above referenced specifications.

Kurt Andres, General Manager

6/12/12
Date

Figure B-3. Wood Blockouts for Test No. MWTC-1



CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

CWNP Invoice 44149

Shipped To Midwest Machinery

Customer PO 2636

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Date: 8.1.2012

Specifications: Highway Construction Use

Preservative: CCA – C 0.60 pcf

Charge #	Date Treated	Grade	Material Size, Length & Dressing	# Pieces	White Moisture Readings	Penetration # of Borings & % Conforming	Actual Retentions % Conforming
Lot 367	7.27.12	1	6X8-6' Rough CRT	70	19%	1/20 95%	.644 pcf
Lot 372	7.30.12	1	6X8-42" S4S BCT	38	19%	2/20 90%	.653 pcf
Lot 367	7.27.12	1	6X8-14 Rgh OCD BK	150	19%	1/20 95%	.644 pcf
Lot 359	7.5.12	1	6X8-19" Rgh OCD Blk	120	19%	1/20 95%	.623 pcf
Lot 359	7.5.12	1	6X12-19 Rgh 2H offset	216	19%	1/20 95%	.623 pcf
Lot 359	7.5.12	1	6X12-19 Rgh 2H Adp Blk	24	19%	1/20 95%	.623 pcf

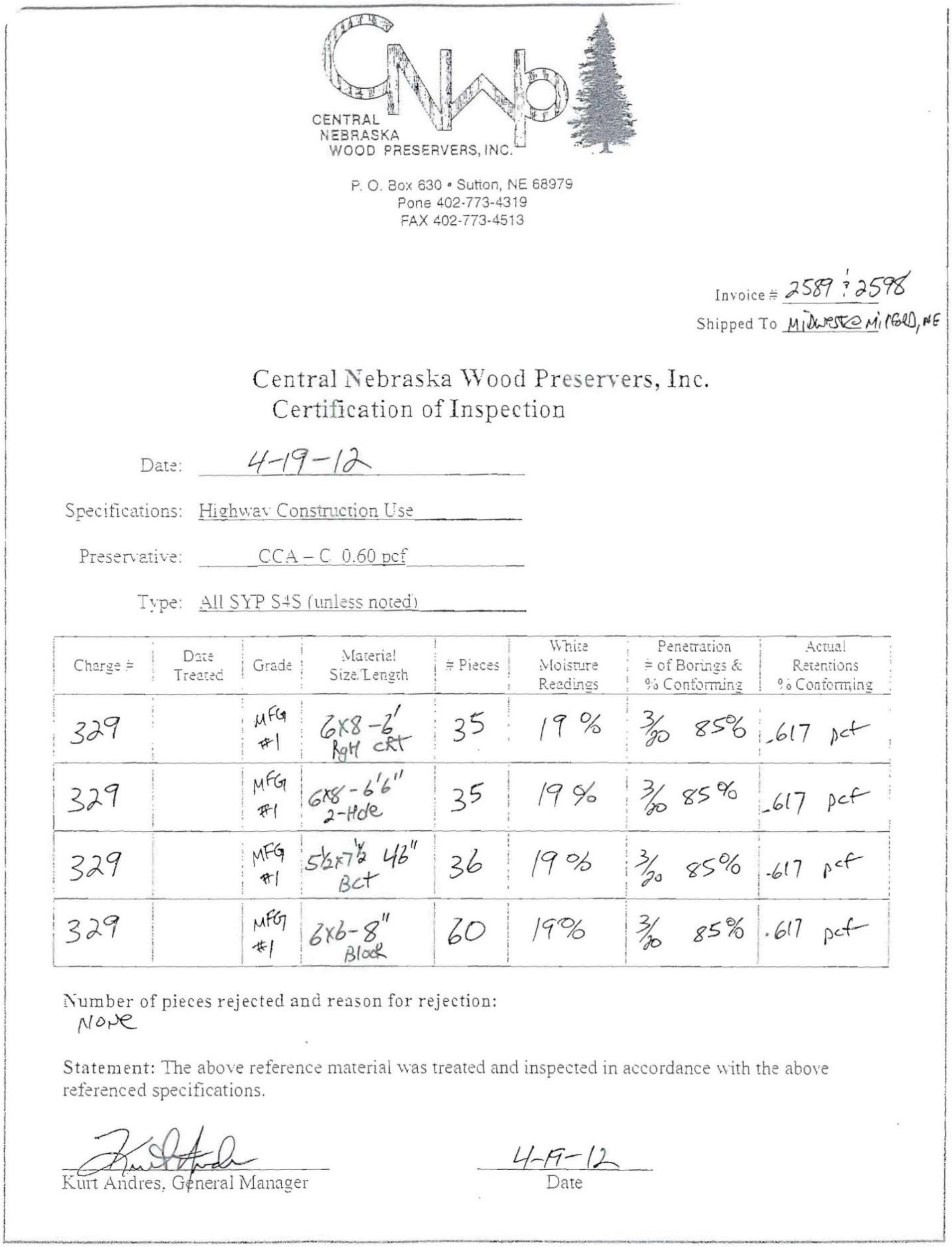
Number of pieces rejected and reason for rejection:
None

Statement: The above reference material was treated and inspected in accordance with the above referenced specifications.

David Steckel
Kurt Andres, General Manager

8.1.2012
Date

Figure B-4. Wood Blockouts for Test Nos. MWTC-2 and MWTC-3



CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

Invoice # 2589 ; 2598
Shipped To MIDWEST@ MILFORD, NE

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Date: 4-19-12

Specifications: Highway Construction Use

Preservative: CCA – C 0.60 pcf

Type: All SYP S4S (unless noted)

Charge #	Date Treated	Grade	Material Size/Length	# Pieces	White Moisture Readings	Penetration # of Borings & % Conforming	Actual Retentions % Conforming
329		MFG #1	6x8-6' Rgh CRT	35	19 %	3/20 85%	.617 pcf
329		MFG #1	6x8-6'6" 2-Hole	35	19 %	3/20 85 %	.617 pcf
329		MFG #1	5½x7½ 46" BCT	36	19 %	3/20 85%	.617 pcf
329		MFG #1	6x6-8" Block	60	19%	3/20 85%	.617 pcf

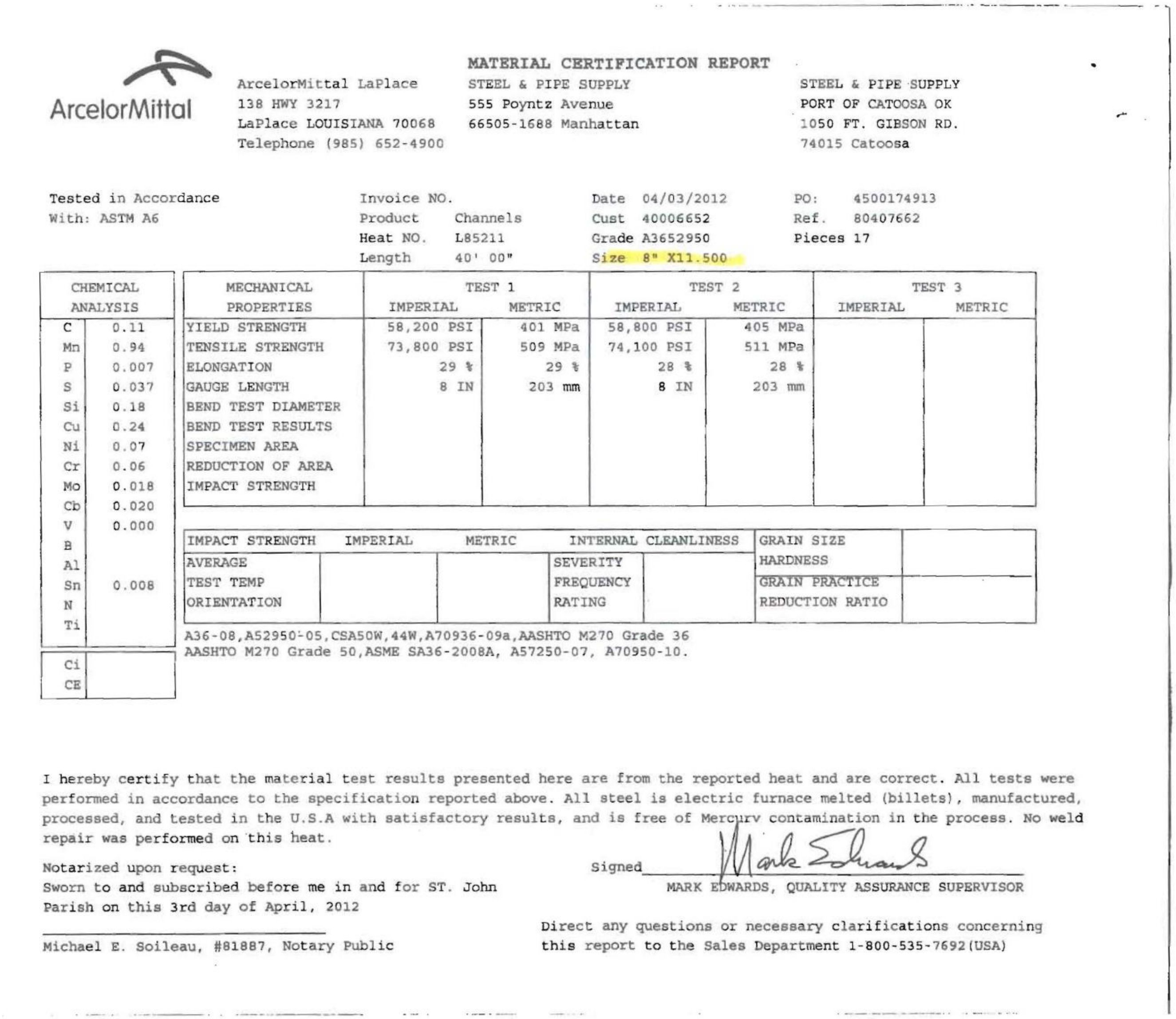
Number of pieces rejected and reason for rejection:
None

Statement: The above reference material was treated and inspected in accordance with the above referenced specifications.

Kurt Andres, General Manager

4-19-12
Date

Figure B-5. BCT Posts for Test Nos. MWTC-1 through MWTC-3



ArcelorMittal

MATERIAL CERTIFICATION REPORT

ArcelorMittal LaPlace
138 HWY 3217
LaPlace LOUISIANA 70068
Telephone (985) 652-4900

STEEL & PIPE SUPPLY
555 Poyntz Avenue
66505-1688 Manhattan

STEEL & PIPE SUPPLY
PORT OF CATOOSA OK
1050 FT. GIBSON RD.
74015 Catoosa

Tested in Accordance
With: ASTM A6

Invoice NO.
Product Channels
Heat NO. L85211
Length 40' 00"

Date 04/03/2012
Cust 40006652
Grade A3652950
Size 8" X11.500

PO: 4500174913
Ref. 80407662
Pieces 17

CHEMICAL ANALYSIS	
C	0.11
Mn	0.94
P	0.007
S	0.037
Si	0.18
Cu	0.24
Ni	0.07
Cr	0.06
Mo	0.018
Cb	0.020
V	0.000
B	
Al	
Sn	0.008
N	
Ti	
Ci	
CE	

MECHANICAL PROPERTIES	TEST 1		TEST 2		TEST 3	
	IMPERIAL	METRIC	IMPERIAL	METRIC	IMPERIAL	METRIC
YIELD STRENGTH	58,200 PSI	401 MPa	58,800 PSI	405 MPa		
TENSILE STRENGTH	73,800 PSI	509 MPa	74,100 PSI	511 MPa		
ELONGATION	29 %	29 %	28 %	28 %		
GAUGE LENGTH	8 IN	203 mm	8 IN	203 mm		
BEND TEST DIAMETER						
BEND TEST RESULTS						
SPECIMEN AREA						
REDUCTION OF AREA						
IMPACT STRENGTH						

IMPACT STRENGTH	IMPERIAL	METRIC	INTERNAL CLEANLINESS		GRAIN SIZE HARDNESS	
AVERAGE TEST TEMP ORIENTATION			SEVERITY FREQUENCY RATING		GRAIN PRACTICE REDUCTION RATIO	

A36-08,A52950-05,CSA50W,44W,A70936-09a,AASHTO M270 Grade 36
AASHTO M270 Grade 50,ASME SA36-2008A, A57250-07, A70950-10.

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 specification reported above. All steel is electric furnace melted (billets), manufactured, processed, and tested in the U.S.A with satisfactory results, and is free of Mercury contamination in the process. No weld repair was performed on this heat.

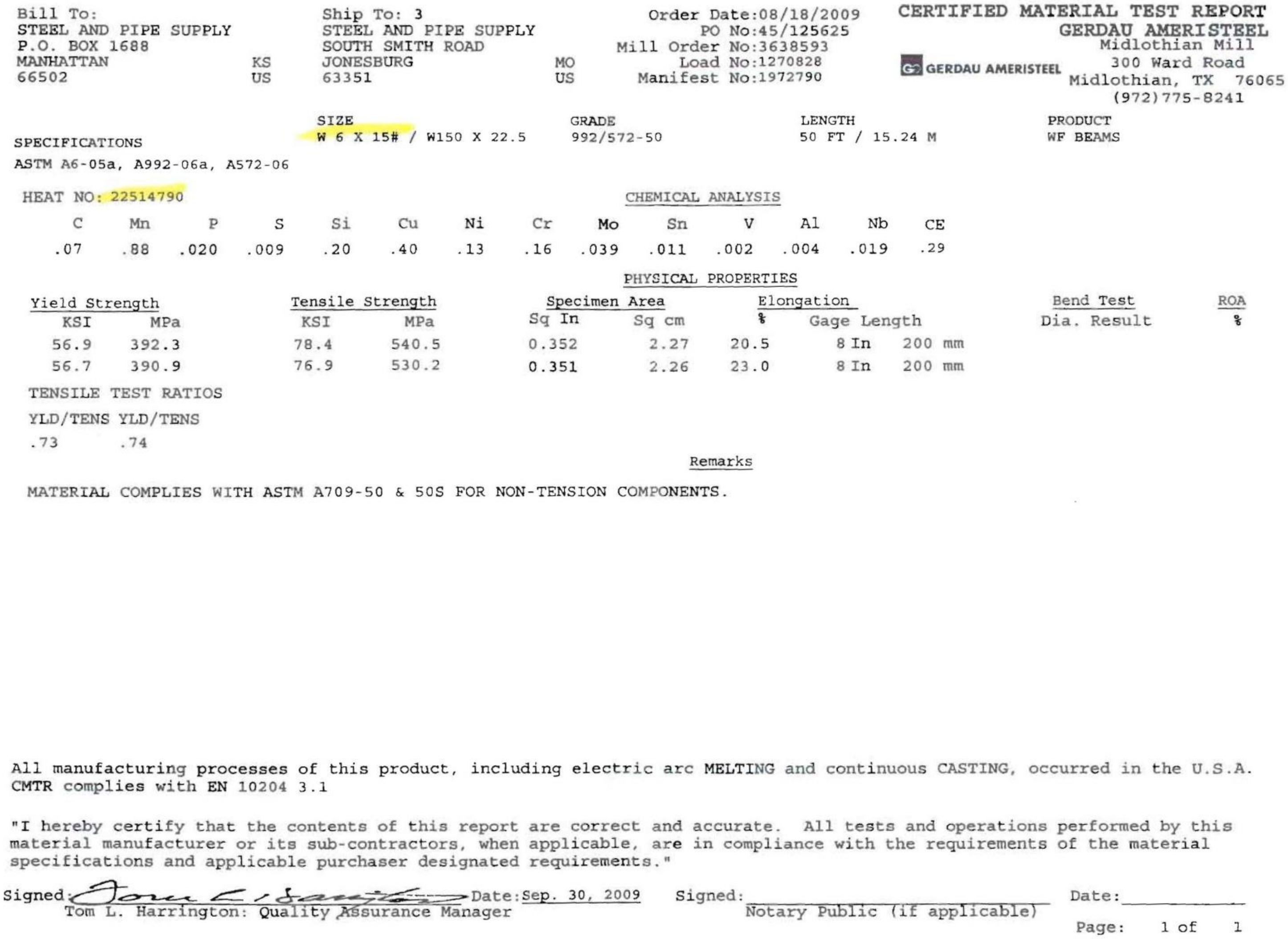
Notarized upon request:
Sworn to and subscribed before me in and for ST. John Parish on this 3rd day of April, 2012

Michael E. Soileau, #81887, Notary Public

Signed Mark Edwards
MARK EDWARDS, QUALITY ASSURANCE SUPERVISOR

Direct any questions or necessary clarifications concerning this report to the Sales Department 1-800-535-7692(USA)

Figure B-6. Bridge Cap Assembly for Test Nos. MWTC-1 through MWTC-3



Bill To:
STEEL AND PIPE SUPPLY
P.O. BOX 1688
MANHATTAN KS
66502 US

Ship To: 3
STEEL AND PIPE SUPPLY
SOUTH SMITH ROAD
JONESBURG MO
63351 US

Order Date:08/18/2009
PO No:45/125625
Mill Order No:3638593
Load No:1270828
Manifest No:1972790

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

GERDAU AMERISTEEL

SPECIFICATIONS	SIZE	GRADE	LENGTH	PRODUCT
ASTM A6-05a, A992-06a, A572-06	W 6 X 15# / W150 X 22.5	992/572-50	50 FT / 15.24 M	WF BEAMS

HEAT NO: 22514790

CHEMICAL ANALYSIS

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	Nb	CE
.07	.88	.020	.009	.20	.40	.13	.16	.039	.011	.002	.004	.019	.29

PHYSICAL PROPERTIES

Yield Strength		Tensile Strength		Specimen Area		Elongation			Bend Test		ROA
KSI	MPa	KSI	MPa	Sq In	Sq cm	%	Gage Length		Dia.	Result	%
56.9	392.3	78.4	540.5	0.352	2.27	20.5	8 In	200 mm			
56.7	390.9	76.9	530.2	0.351	2.26	23.0	8 In	200 mm			

TENSILE TEST RATIOS

YLD/TENS	YLD/TENS
.73	.74

Remarks

MATERIAL COMPLIES WITH ASTM A709-50 & 50S FOR NON-TENSION COMPONENTS.

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

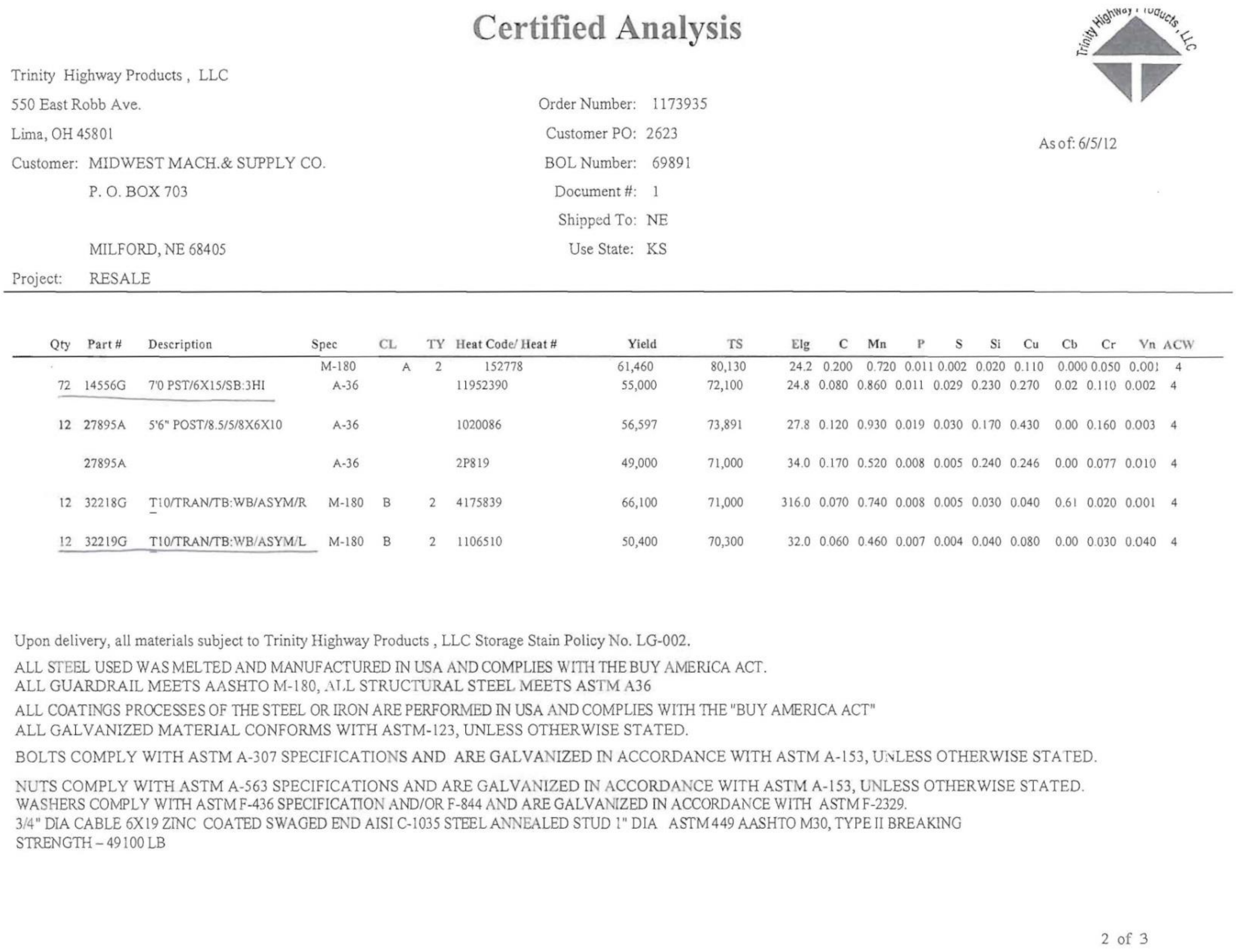
"I hereby certify that the contents of this report are correct and accurate. All tests and operations performed by this material manufacturer or its sub-contractors, when applicable, are in compliance with the requirements of the material specifications and applicable purchaser designated requirements."

Signed: Date:Sep. 30, 2009
Tom L. Harrington: Quality Assurance Manager

Signed:________________ Date:__________
Notary Public (if applicable)

Page: 1 of 1

Figure B-7. Steel Blockout for Test No. MWTC-1



Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1173935
Customer PO: 2623
BOL Number: 69891
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/5/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
			M-180	A	2	152778	61,460	80,130	24.2	0.200	0.720	0.011	0.002	0.020	0.110	0.000	0.050	0.001	4
72	14556G	7'0 PST/6X15/SB:3HI	A-36			11952390	55,000	72,100	24.8	0.080	0.860	0.011	0.029	0.230	0.270	0.02	0.110	0.002	4
12	27895A	5'6" POST/8.5/5/8X6X10	A-36			1020086	56,597	73,891	27.8	0.120	0.930	0.019	0.030	0.170	0.430	0.00	0.160	0.003	4
	27895A		A-36			2P819	49,000	71,000	34.0	0.170	0.520	0.008	0.005	0.240	0.246	0.00	0.077	0.010	4
12	32218G	T10/TRAN/TB:WB/ASYM/R	M-180	B	2	4175839	66,100	71,000	316.0	0.070	0.740	0.008	0.005	0.030	0.040	0.61	0.020	0.001	4
12	32219G	T10/TRAN/TB:WB/ASYM/L	M-180	B	2	1106510	50,400	70,300	32.0	0.060	0.460	0.007	0.004	0.040	0.080	0.00	0.030	0.040	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

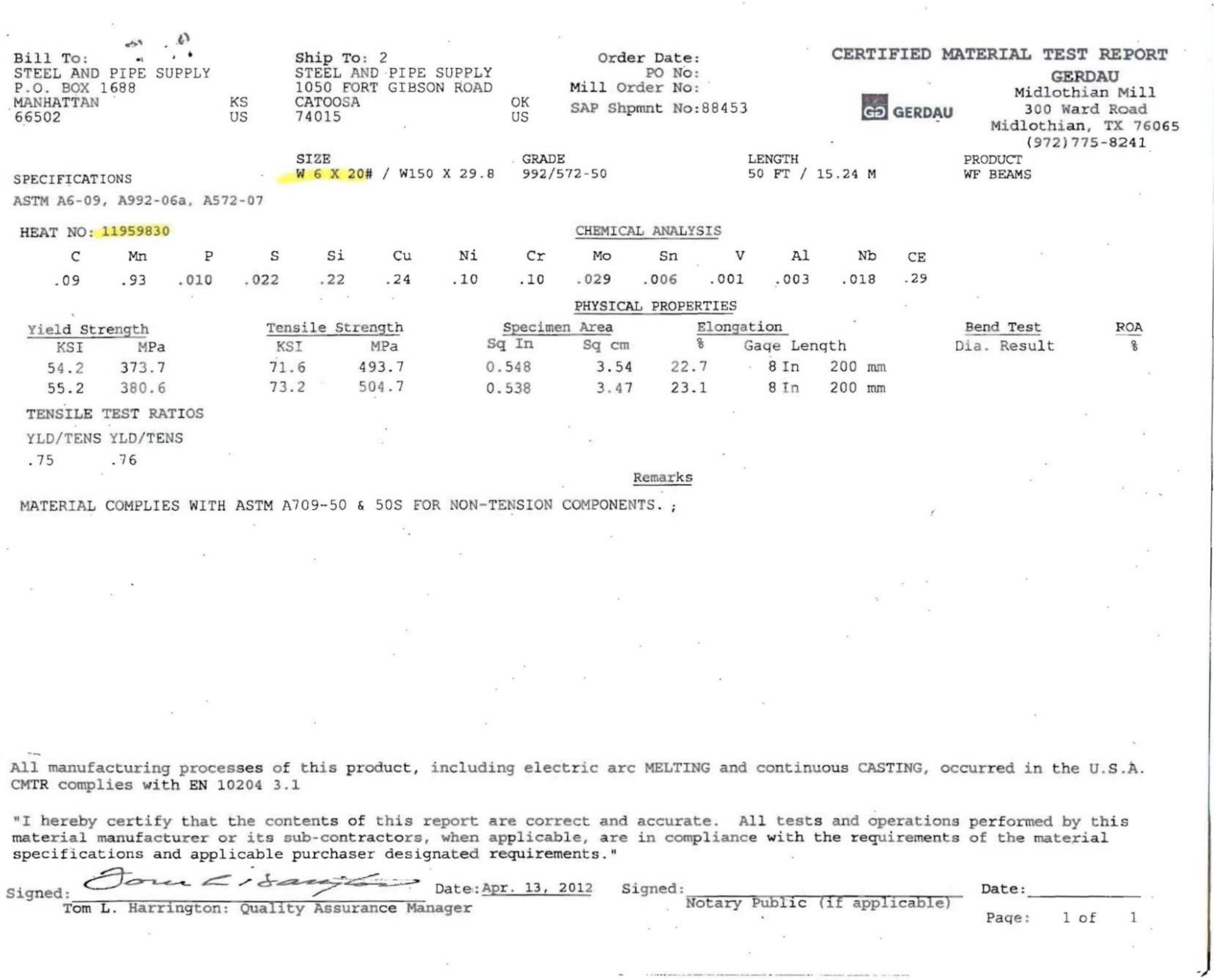
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.

BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

2 of 3

Figure B-8. Transition Section for Test No. MWTC-1, Steel Blockout for Test Nos. MWTC-2 and MWTC-3, and Post Nos. 16 through 18 for Test Nos. MWTC-1 through MWTC-3



Bill To:
STEEL AND PIPE SUPPLY
P.O. BOX 1688
MANHATTAN KS
66502 US

Ship To: 2
STEEL AND PIPE SUPPLY
1050 FORT GIBSON ROAD
CATOOSA OK
74015 US

Order Date:
PO No:
Mill Order No:
SAP Shpmnt No:88453

CERTIFIED MATERIAL TEST REPORT

GERDAU
Midlothian Mill
300 Ward Road
Midlothian, TX 76065
(972)775-8241

SPECIFICATIONS	SIZE	GRADE	LENGTH	PRODUCT
	W 6 X 20# / W150 X 29.8	992/572-50	50 FT / 15.24 M	WF BEAMS

ASTM A6-09, A992-06a, A572-07

HEAT NO: 11959830

CHEMICAL ANALYSIS

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	Nb	CE
.09	.93	.010	.022	.22	.24	.10	.10	.029	.006	.001	.003	.018	.29

PHYSICAL PROPERTIES

Yield Strength		Tensile Strength		Specimen Area		Elongation			Bend Test		ROA
KSI	MPa	KSI	MPa	Sq In	Sq cm	%	Gage Length		Dia.	Result	%
54.2	373.7	71.6	493.7	0.548	3.54	22.7	8 In	200 mm			
55.2	380.6	73.2	504.7	0.538	3.47	23.1	8 In	200 mm			

TENSILE TEST RATIOS

YLD/TENS	YLD/TENS
.75	.76

Remarks

MATERIAL COMPLIES WITH ASTM A709-50 & 50S FOR NON-TENSION COMPONENTS. ;

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

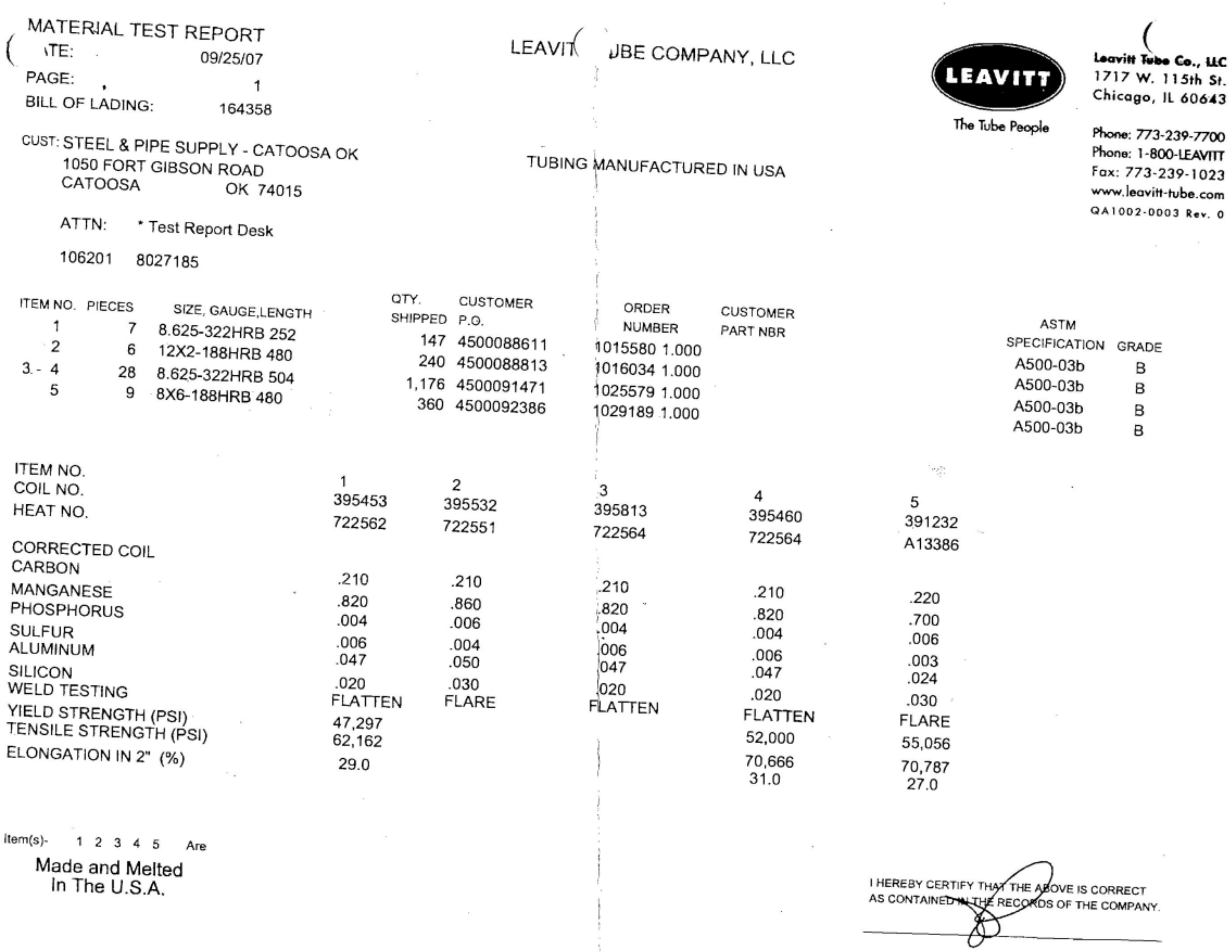
"I hereby certify that the contents of this report are correct and accurate. All tests and operations performed by this material manufacturer or its sub-contractors, when applicable, are in compliance with the requirements of the material specifications and applicable purchaser designated requirements."

Signed: Tom L Harrington Date: Apr. 13, 2012
Tom L. Harrington: Quality Assurance Manager

Signed: ____________________ Date: __________
Notary Public (if applicable)

Page: 1 of 1

Figure B-9. Post Nos. 19 through 21 for Test Nos. MWTC-1 through MWTC-3



MATERIAL TEST REPORT

TE: 09/25/07
PAGE: 1
BILL OF LADING: 164358

LEAVIT UBE COMPANY, LLC

LEAVITT
The Tube People

Leavitt Tube Co., LLC
1717 W. 115th St.
Chicago, IL 60643

Phone: 773-239-7700
Phone: 1-800-LEAVITT
Fax: 773-239-1023
www.leavitt-tube.com
QA1002-0003 Rev. 0

CUST: STEEL & PIPE SUPPLY - CATOOSA OK
1050 FORT GIBSON ROAD
CATOOSA OK 74015

TUBING MANUFACTURED IN USA

ATTN: * Test Report Desk

106201 8027185

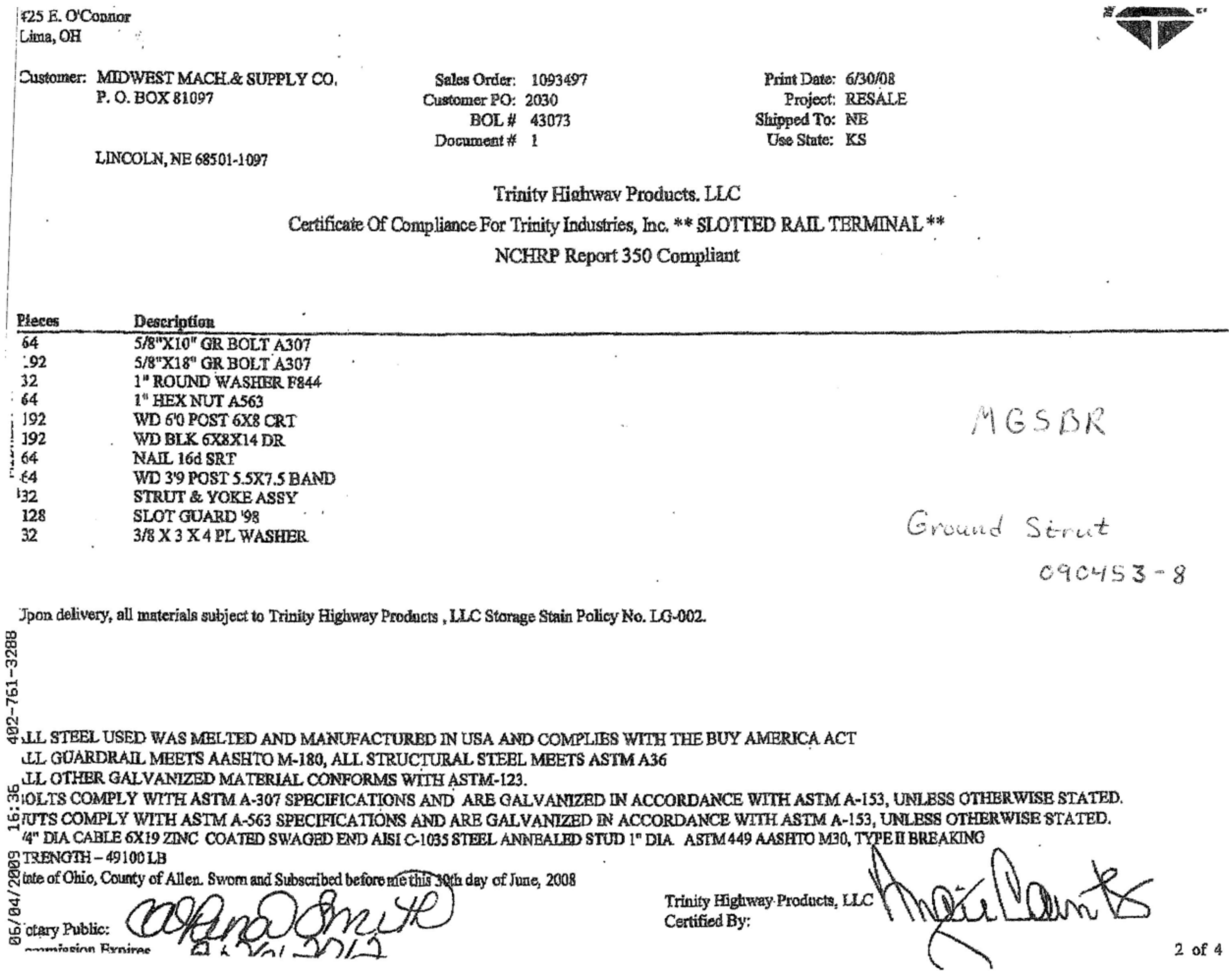
ITEM NO.	PIECES	SIZE, GAUGE,LENGTH	QTY. SHIPPED	CUSTOMER P.O.	ORDER NUMBER	CUSTOMER PART NBR	ASTM SPECIFICATION	GRADE
1	7	8.625-322HRB 252	147	4500088611	1015580 1.000		A500-03b	B
2	6	12X2-188HRB 480	240	4500088813	1016034 1.000		A500-03b	B
3.- 4	28	8.625-322HRB 504	1,176	4500091471	1025579 1.000		A500-03b	B
5	9	8X6-188HRB 480	360	4500092386	1029189 1.000		A500-03b	B

ITEM NO.	1	2	3	4	5
COIL NO.	395453	395532	395813	395460	391232
HEAT NO.	722562	722551	722564	722564	A13386
CORRECTED COIL					
CARBON	.210	.210	.210	.210	.220
MANGANESE	.820	.860	.820	.820	.700
PHOSPHORUS	.004	.006	.004	.004	.006
SULFUR	.006	.004	006	.006	.003
ALUMINUM	.047	.050	047	.047	.024
SILICON	.020	.030	020	.020	.030
WELD TESTING	FLATTEN	FLARE	FLATTEN	FLATTEN	FLARE
YIELD STRENGTH (PSI)	47,297			52,000	55,056
TENSILE STRENGTH (PSI)	62,162			70,666	70,787
ELONGATION IN 2" (%)	29.0			31.0	27.0

Item(s)- 1 2 3 4 5 Are
Made and Melted
In The U.S.A.

I HEREBY CERTIFY THAT THE ABOVE IS CORRECT
AS CONTAINED IN THE RECORDS OF THE COMPANY.

Figure B-10. Foundation Tube for Test Nos. MWTC-1 through MWTC-3



425 E. O'Connor
Lima, OH

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products. LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

Pieces	Description
64	5/8"X10" GR BOLT A307
192	5/8"X18" GR BOLT A307
32	1" ROUND WASHER F844
64	1" HEX NUT A563
192	WD 6'0 POST 6X8 CRT
192	WD BLK 6X8X14 DR
64	NAIL 16d SRT
64	WD 3'9 POST 5.5X7.5 BAND
32	STRUT & YOKE ASSY
128	SLOT GUARD '98
32	3/8 X 3 X 4 PL WASHER

MGSBR

Ground Strut

090453-8

Jpon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

06/04/2009 16:36 402-761-3288

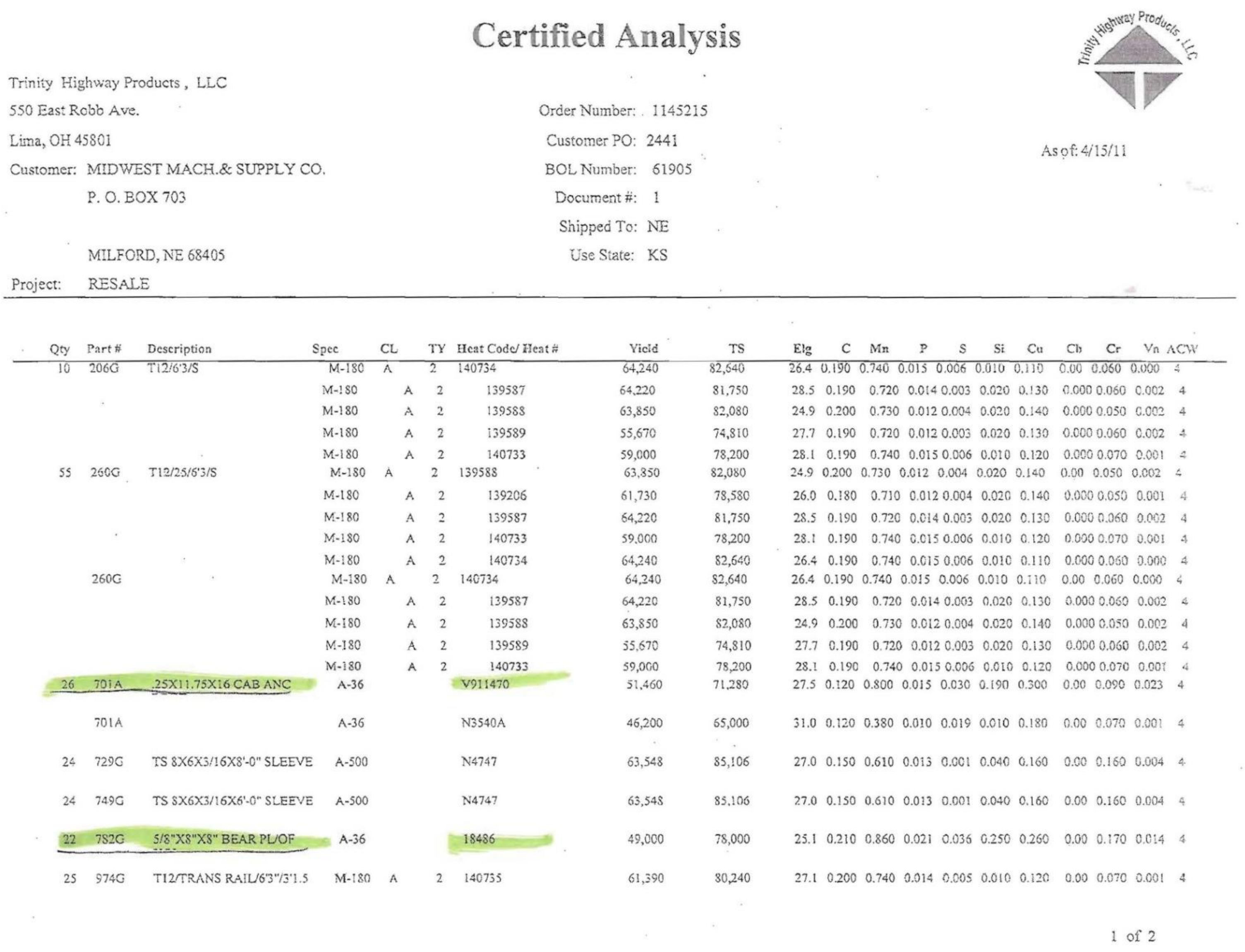
LL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
LL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
LL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
OLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
UTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING
TRENGTH – 49100 LB
tate of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

otary Public:
ommission Expires [illegible]

Trinity Highway Products, LLC
Certified By:

2 of 4

Figure B-11. Strut and Yoke Assembly for Test Nos. MWTC-1 through MWTC-3



Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

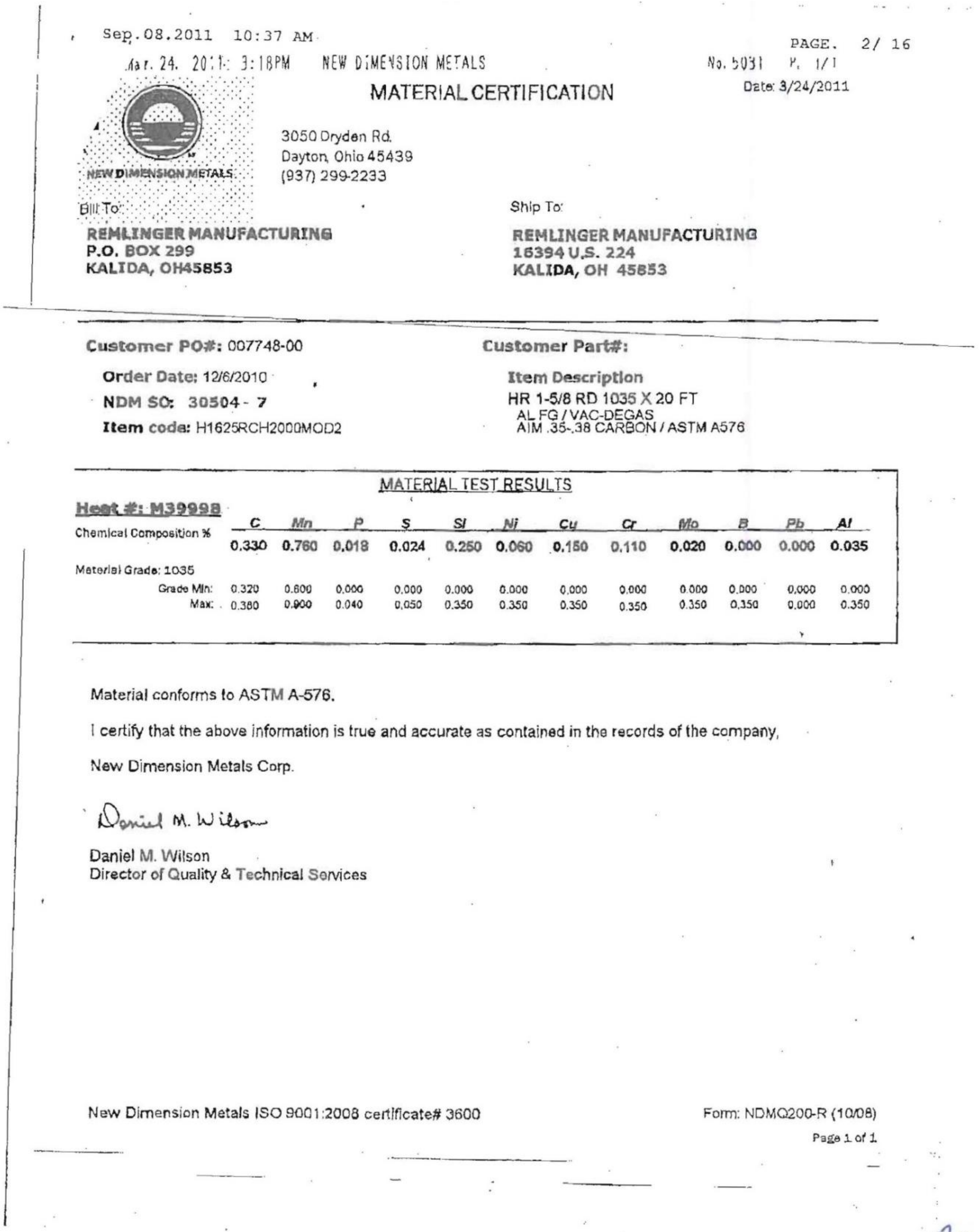
Order Number: 1145215
Customer PO: 2441
BOL Number: 61905
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/15/11

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	206G	T12/6'3/S	M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	0.000	4
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	0.002	4
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	4
55	260G	T12/25/6'3/S	M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.00	0.050	0.002	4
			M-180	A	2	139206	61,730	78,580	26.0	0.180	0.710	0.012	0.004	0.020	0.140	0.000	0.050	0.001	4
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	4
			M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.000	0.060	0.000	4
	260G		M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	0.000	4
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	0.002	4
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	4
26	701A	.25X11.75X16 CAB ANC	A-36			V911470	51,460	71,280	27.5	0.120	0.800	0.015	0.030	0.190	0.300	0.00	0.090	0.023	4
	701A		A-36			N3540A	46,200	65,000	31.0	0.120	0.380	0.010	0.019	0.010	0.180	0.00	0.070	0.001	4
24	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	0.004	4
24	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	0.004	4
22	782G	5/8"X8"X8" BEAR PL/OF	A-36			18486	49,000	78,000	25.1	0.210	0.860	0.021	0.036	0.250	0.260	0.00	0.170	0.014	4
25	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	140735	61,390	80,240	27.1	0.200	0.740	0.014	0.005	0.010	0.120	0.00	0.070	0.001	4

1 of 2

Figure B-12. Anchor Bracket and Bearing Plate for Test Nos. MWTC-1 through MWTC-3



Sep.08.2011 10:37 AM PAGE. 2/ 16

Mar. 24. 2011 3:18PM NEW DIMENSION METALS No. 5031 P. 1/1

MATERIAL CERTIFICATION

Date: 3/24/2011

NEW DIMENSION METALS

3050 Dryden Rd.
Dayton, Ohio 45439
(937) 299-2233

Bill To:
REMLINGER MANUFACTURING
P.O. BOX 299
KALIDA, OH45853

Ship To:
REMLINGER MANUFACTURING
16394 U.S. 224
KALIDA, OH 45853

Customer PO#: 007748-00

Order Date: 12/6/2010
NDM SO: 30504 - 7
Item code: H1625RCH2000MOD2

Customer Part#:

Item Description
HR 1-5/8 RD 1035 X 20 FT
AL FG / VAC-DEGAS
AIM .35-.38 CARBON / ASTM A576

MATERIAL TEST RESULTS

Heat #: M39998

	C	Mn	P	S	Si	Ni	Cu	Cr	Mo	B	Pb	Al
Chemical Composition %	0.330	0.760	0.018	0.024	0.250	0.060	0.150	0.110	0.020	0.000	0.000	0.035
Material Grade: 1035												
Grade Min:	0.320	0.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max:	0.380	0.900	0.040	0.050	0.350	0.350	0.350	0.350	0.350	0.350	0.000	0.350

Material conforms to ASTM A-576.

I certify that the above information is true and accurate as contained in the records of the company,

New Dimension Metals Corp.

Daniel M. Wilson

Daniel M. Wilson
Director of Quality & Technical Services

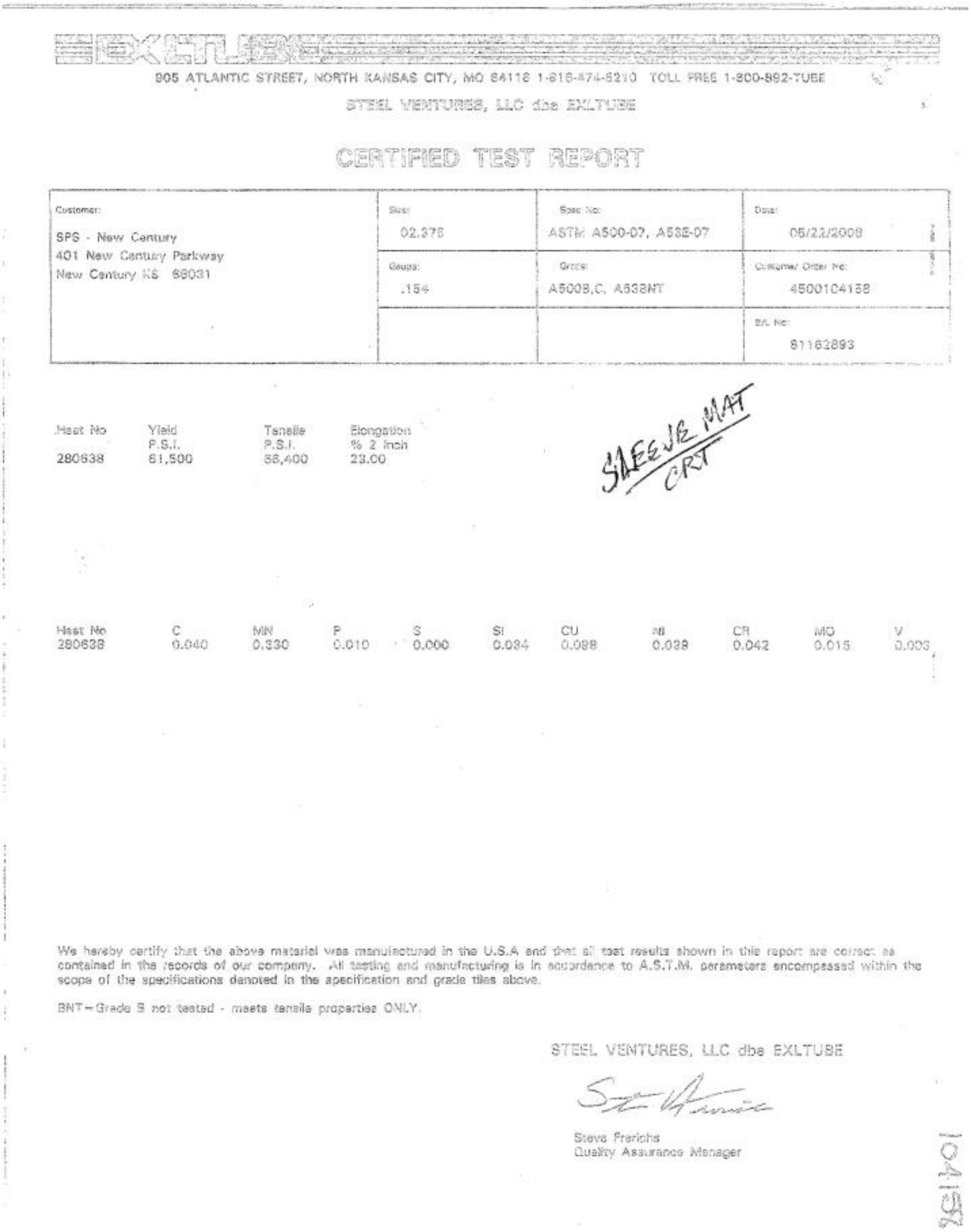
New Dimension Metals ISO 9001:2008 certificate# 3600

Form: NDMQ200-R (10/08)

Page 1 of 1

2/

Figure B-13. Anchor Cable Assembly for Test Nos. MWTC-1 through MWTC-3



EXLTUBE

905 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 - New Century
401 New Century Parkway
New Century KS 66031

Size: 02.375

Spec No: ASTM A500-07, A53E-07

Date: 05/22/2008

Gauge: .154

Grade: A500B,C, A53BNT

Customer Order No: 4500104158

B/L No: 81162893

Heat No	Yield P.S.I.	Tensile P.S.I.	Elongation % 2 inch
280638	61,500	66,400	23.00

SLEEVE MAT
CRT

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
280638	0.040	0.330	0.010	0.000	0.034	0.098	0.038	0.042	0.015	0.003

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.

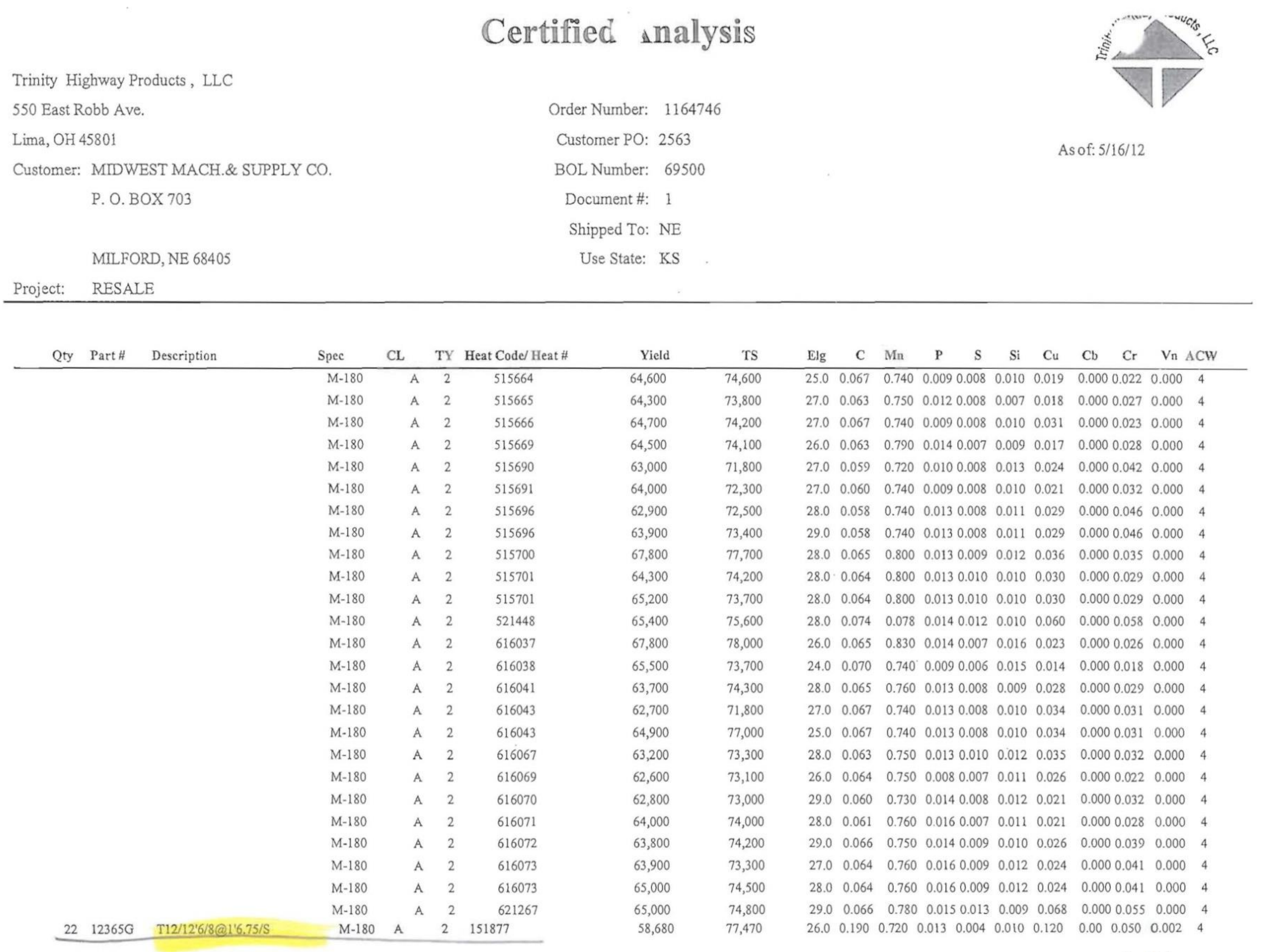
BNT – Grade B not tested - meets tensile properties ONLY.

STEEL VENTURES, LLC dba EXLTUBE

Steve Frerichs
Quality Assurance Manager

104158

Figure B-14. BCT Hole Insert for Test Nos. MWTC-1 through MWTC-3



Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

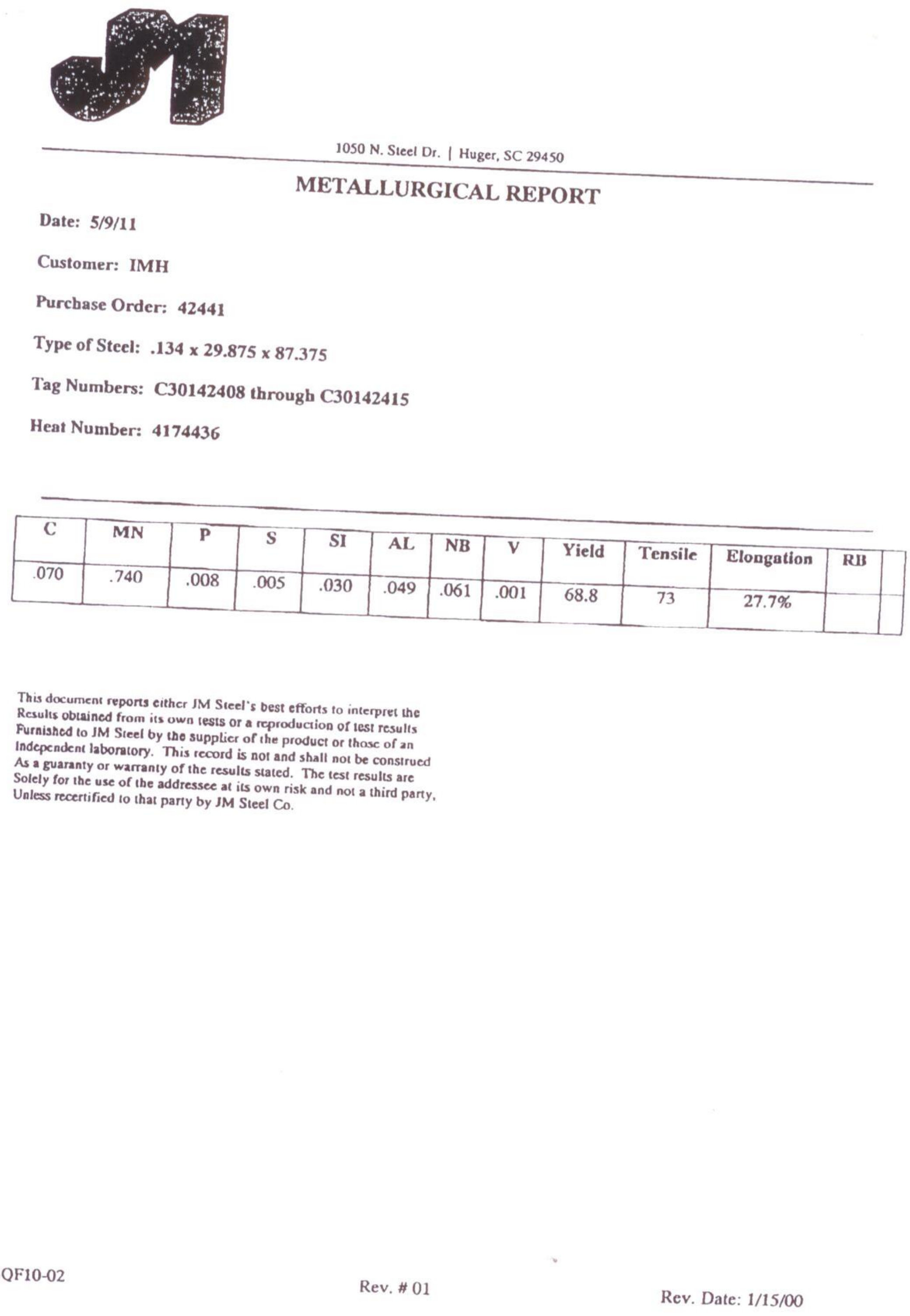
Order Number: 1164746
Customer PO: 2563
BOL Number: 69500
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/16/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
			M-180	A	2	515664	64,600	74,600	25.0	0.067	0.740	0.009	0.008	0.010	0.019	0.000	0.022	0.000	4
			M-180	A	2	515665	64,300	73,800	27.0	0.063	0.750	0.012	0.008	0.007	0.018	0.000	0.027	0.000	4
			M-180	A	2	515666	64,700	74,200	27.0	0.067	0.740	0.009	0.008	0.010	0.031	0.000	0.023	0.000	4
			M-180	A	2	515669	64,500	74,100	26.0	0.063	0.790	0.014	0.007	0.009	0.017	0.000	0.028	0.000	4
			M-180	A	2	515690	63,000	71,800	27.0	0.059	0.720	0.010	0.008	0.013	0.024	0.000	0.042	0.000	4
			M-180	A	2	515691	64,000	72,300	27.0	0.060	0.740	0.009	0.008	0.010	0.021	0.000	0.032	0.000	4
			M-180	A	2	515696	62,900	72,500	28.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515696	63,900	73,400	29.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515700	67,800	77,700	28.0	0.065	0.800	0.013	0.009	0.012	0.036	0.000	0.035	0.000	4
			M-180	A	2	515701	64,300	74,200	28.0	0.064	0.800	0.013	0.010	0.010	0.030	0.000	0.029	0.000	4
			M-180	A	2	515701	65,200	73,700	28.0	0.064	0.800	0.013	0.010	0.010	0.030	0.000	0.029	0.000	4
			M-180	A	2	521448	65,400	75,600	28.0	0.074	0.078	0.014	0.012	0.010	0.060	0.000	0.058	0.000	4
			M-180	A	2	616037	67,800	78,000	26.0	0.065	0.830	0.014	0.007	0.016	0.023	0.000	0.026	0.000	4
			M-180	A	2	616038	65,500	73,700	24.0	0.070	0.740	0.009	0.006	0.015	0.014	0.000	0.018	0.000	4
			M-180	A	2	616041	63,700	74,300	28.0	0.065	0.760	0.013	0.008	0.009	0.028	0.000	0.029	0.000	4
			M-180	A	2	616043	62,700	71,800	27.0	0.067	0.740	0.013	0.008	0.010	0.034	0.000	0.031	0.000	4
			M-180	A	2	616043	64,900	77,000	25.0	0.067	0.740	0.013	0.008	0.010	0.034	0.000	0.031	0.000	4
			M-180	A	2	616067	63,200	73,300	28.0	0.063	0.750	0.013	0.010	0.012	0.035	0.000	0.032	0.000	4
			M-180	A	2	616069	62,600	73,100	26.0	0.064	0.750	0.008	0.007	0.011	0.026	0.000	0.022	0.000	4
			M-180	A	2	616070	62,800	73,000	29.0	0.060	0.730	0.014	0.008	0.012	0.021	0.000	0.032	0.000	4
			M-180	A	2	616071	64,000	74,000	28.0	0.061	0.760	0.016	0.007	0.011	0.021	0.000	0.028	0.000	4
			M-180	A	2	616072	63,800	74,200	29.0	0.066	0.750	0.014	0.009	0.010	0.026	0.000	0.039	0.000	4
			M-180	A	2	616073	63,900	73,300	27.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
			M-180	A	2	616073	65,000	74,500	28.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
			M-180	A	2	621267	65,000	74,800	29.0	0.066	0.780	0.015	0.013	0.009	0.068	0.000	0.055	0.000	4
22	12365G	T12/12'6/8@1'6.75/S	M-180	A	2	151877	58,680	77,470	26.0	0.190	0.720	0.013	0.004	0.010	0.120	0.00	0.050	0.002	4

2 of 4

Figure B-15. 12’-6” Thrie Beam Section for Test No. MWTC-1



1050 N. Steel Dr. | Huger, SC 29450

METALLURGICAL REPORT

Date: 5/9/11

Customer: IMH

Purchase Order: 42441

Type of Steel: .134 x 29.875 x 87.375

Tag Numbers: C30142408 through C30142415

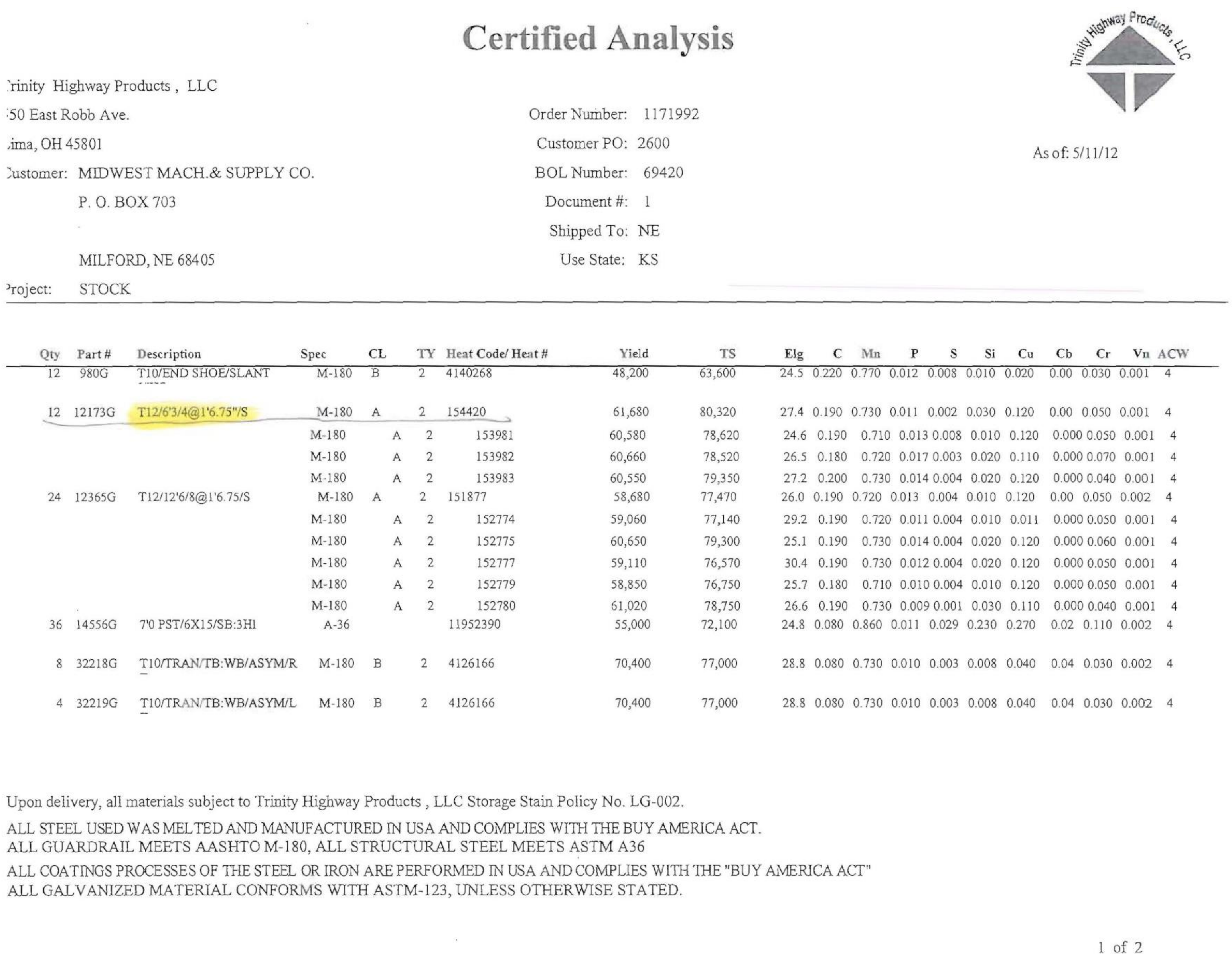
Heat Number: 4174436

C	MN	P	S	SI	AL	NB	V	Yield	Tensile	Elongation	RB	
.070	.740	.008	.005	.030	.049	.061	.001	68.8	73	27.7%		

This document reports either JM Steel's best efforts to interpret the Results obtained from its own tests or a reproduction of test results Furnished to JM Steel by the supplier of the product or those of an Independent laboratory. This record is not and shall not be construed As a guaranty or warranty of the results stated. The test results are Solely for the use of the addressee at its own risk and not a third party, Unless recertified to that party by JM Steel Co.

4QF10-02 Rev. # 01 Rev. Date: 1/15/00

Figure B-16. 12’-6” Thrie Beam Section and 6’-3” Transition Section for Test Nos. MWTC-2 and MWTC-3



Certified Analysis

rinity Highway Products , LLC
50 East Robb Ave.
ima, OH 45801
ustomer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
roject: STOCK

Order Number: 1171992
Customer PO: 2600
BOL Number: 69420
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/11/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
12	980G	T10/END SHOE/SLANT	M-180	B	2	4140268	48,200	63,600	24.5	0.220	0.770	0.012	0.008	0.010	0.020	0.00	0.030	0.001	4
12	12173G	T12/6'3/4@1'6.75"/S	M-180	A	2	154420	61,680	80,320	27.4	0.190	0.730	0.011	0.002	0.030	0.120	0.00	0.050	0.001	4
			M-180	A	2	153981	60,580	78,620	24.6	0.190	0.710	0.013	0.008	0.010	0.120	0.000	0.050	0.001	4
			M-180	A	2	153982	60,660	78,520	26.5	0.180	0.720	0.017	0.003	0.020	0.110	0.000	0.070	0.001	4
			M-180	A	2	153983	60,550	79,350	27.2	0.200	0.730	0.014	0.004	0.020	0.120	0.000	0.040	0.001	4
24	12365G	T12/12'6/8@1'6.75/S	M-180	A	2	151877	58,680	77,470	26.0	0.190	0.720	0.013	0.004	0.010	0.120	0.00	0.050	0.002	4
			M-180	A	2	152774	59,060	77,140	29.2	0.190	0.720	0.011	0.004	0.010	0.011	0.000	0.050	0.001	4
			M-180	A	2	152775	60,650	79,300	25.1	0.190	0.730	0.014	0.004	0.020	0.120	0.000	0.060	0.001	4
			M-180	A	2	152777	59,110	76,570	30.4	0.190	0.730	0.012	0.004	0.020	0.120	0.000	0.050	0.001	4
			M-180	A	2	152779	58,850	76,750	25.7	0.180	0.710	0.010	0.004	0.010	0.120	0.000	0.050	0.001	4
			M-180	A	2	152780	61,020	78,750	26.6	0.190	0.730	0.009	0.001	0.030	0.110	0.000	0.040	0.001	4
36	14556G	7'0 PST/6X15/SB:3H1	A-36			11952390	55,000	72,100	24.8	0.080	0.860	0.011	0.029	0.230	0.270	0.02	0.110	0.002	4
8	32218G	T10/TRAN/TB:WB/ASYM/R	M-180	B	2	4126166	70,400	77,000	28.8	0.080	0.730	0.010	0.003	0.008	0.040	0.04	0.030	0.002	4
4	32219G	T10/TRAN/TB:WB/ASYM/L	M-180	B	2	4126166	70,400	77,000	28.8	0.080	0.730	0.010	0.003	0.008	0.040	0.04	0.030	0.002	4

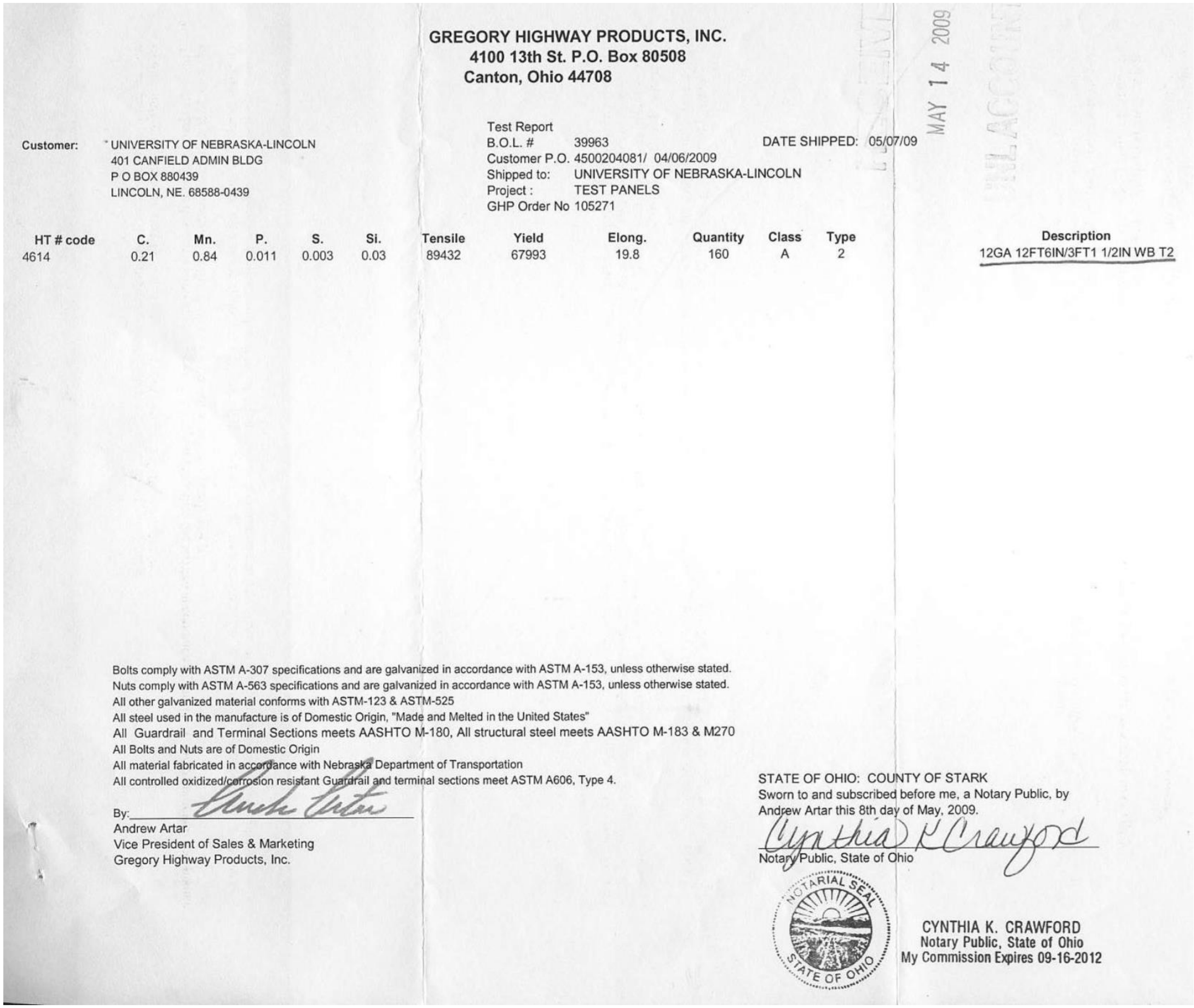
Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.

1 of 2

Figure B-17. 6’-3” Thrie Beam Section for Test Nos. MWTC-1 through MWTC-3



GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. P.O. Box 80508
Canton, Ohio 44708

MAY 14 2009

Test Report
B.O.L. # 39963
DATE SHIPPED: 05/07/09
Customer P.O. 4500204081/ 04/06/2009
Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
Project : TEST PANELS
GHP Order No 105271

Customer: UNIVERSITY OF NEBRASKA-LINCOLN
401 CANFIELD ADMIN BLDG
P O BOX 880439
LINCOLN, NE. 68588-0439

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
4614	0.21	0.84	0.011	0.003	0.03	89432	67993	19.8	160	A	2	12GA 12FT6IN/3FT1 1/2IN WB T2

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-525
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: Andrew Artar
Andrew Artar
Vice President of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 8th day of May, 2009.
Cynthia K Crawford
Notary Public, State of Ohio

CYNTHIA K. CRAWFORD
Notary Public, State of Ohio
My Commission Expires 09-16-2012

Figure B-18. 12’-6” W-Beam MGS Sections for Test Nos. MWTC-1 through MWTC-3

Figure B-19. Heavy Hex Nut for Test Nos. MWTC-1 through MWTC-3

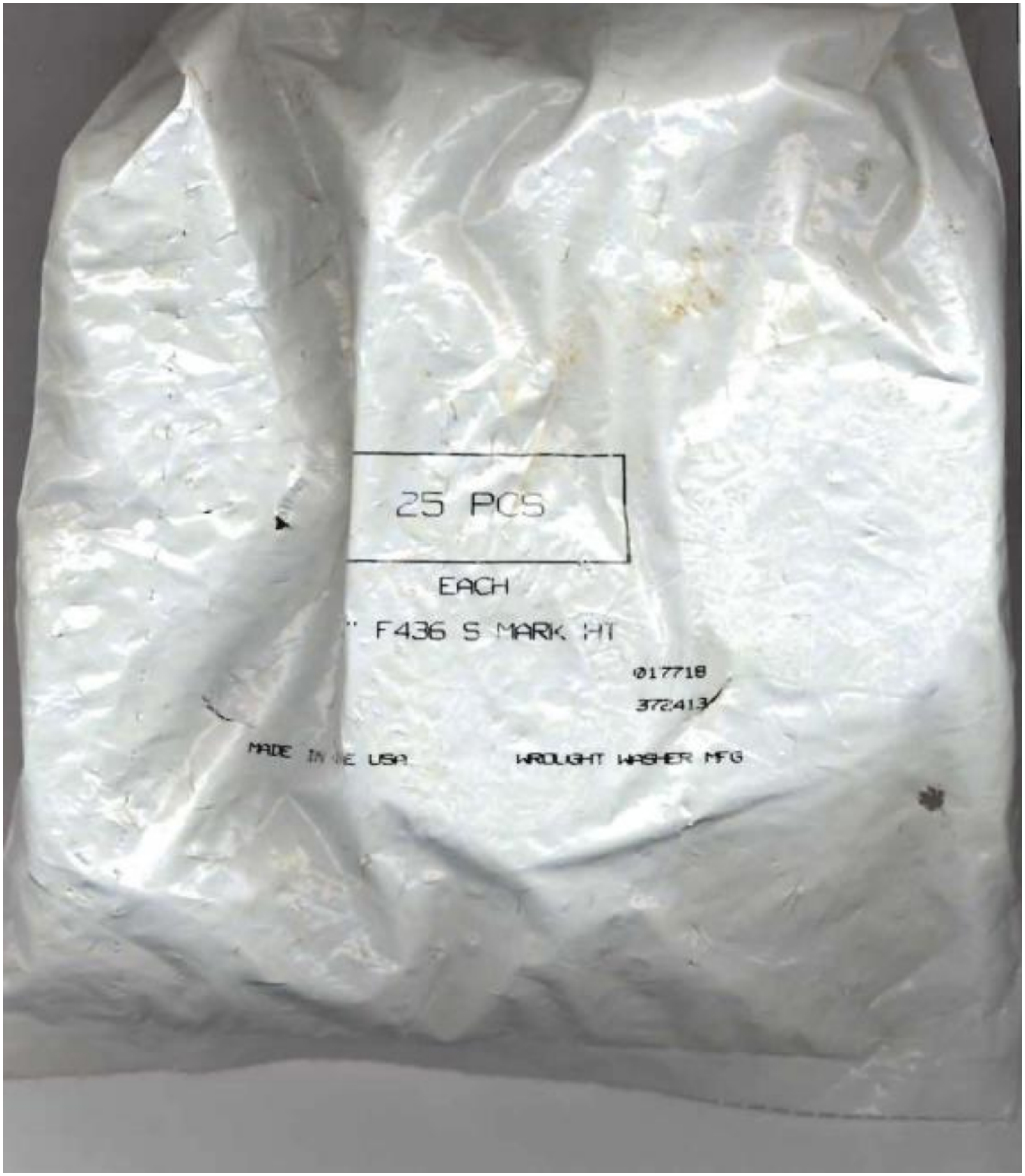
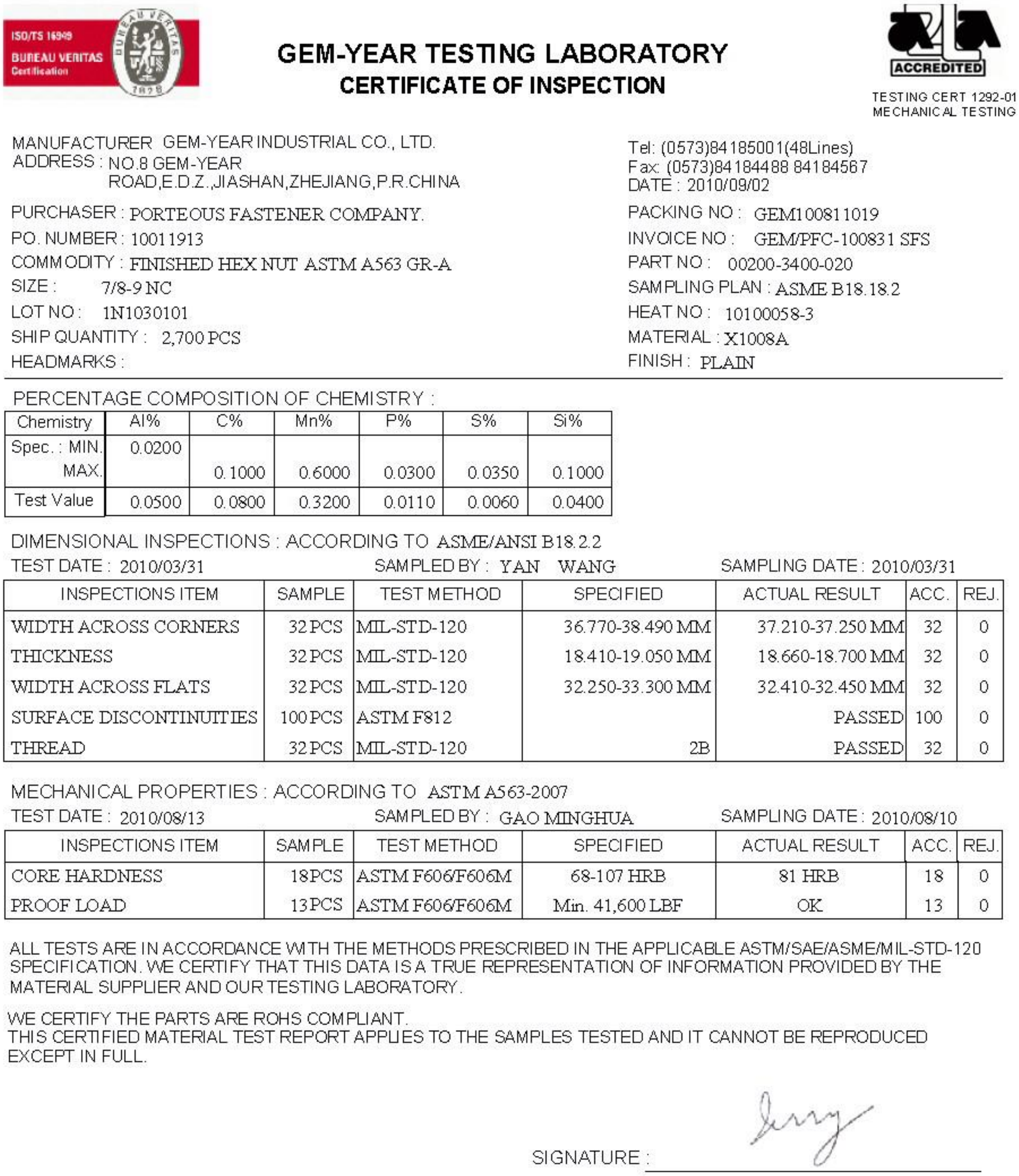


Figure B-20. 1” Dia. Hardened Round Washer for Test Nos. MWTC-1 through MWTC-3



ISO/TS 16949
BUREAU VERITAS
Certification

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

ACCREDITED
TESTING CERT 1292-01
MECHANICAL TESTING

MANUFACTURER GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR
ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2010/09/02

PURCHASER : PORTEOUS FASTENER COMPANY.
PO. NUMBER : 10011913
COMMODITY : FINISHED HEX NUT ASTM A563 GR-A
SIZE : 7/8-9 NC
LOT NO : 1N1030101
SHIP QUANTITY : 2,700 PCS
HEADMARKS :

PACKING NO : GEM100811019
INVOICE NO : GEM/PFC-100831 SFS
PART NO : 00200-3400-020
SAMPLING PLAN : ASME B18.18.2
HEAT NO : 10100058-3
MATERIAL : X1008A
FINISH : PLAIN

PERCENTAGE COMPOSITION OF CHEMISTRY :

Chemistry	Al%	C%	Mn%	P%	S%	Si%
Spec. : MIN.	0.0200					
MAX.		0.1000	0.6000	0.0300	0.0350	0.1000
Test Value	0.0500	0.0800	0.3200	0.0110	0.0060	0.0400

DIMENSIONAL INSPECTIONS : ACCORDING TO ASME/ANSI B18.2.2
TEST DATE : 2010/03/31 SAMPLED BY : YAN WANG SAMPLING DATE : 2010/03/31

INSPECTIONS ITEM	SAMPLE	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	32 PCS	MIL-STD-120	36.770-38.490 MM	37.210-37.250 MM	32	0
THICKNESS	32 PCS	MIL-STD-120	18.410-19.050 MM	18.660-18.700 MM	32	0
WIDTH ACROSS FLATS	32 PCS	MIL-STD-120	32.250-33.300 MM	32.410-32.450 MM	32	0
SURFACE DISCONTINUITIES	100 PCS	ASTM F812		PASSED	100	0
THREAD	32 PCS	MIL-STD-120	2B	PASSED	32	0

MECHANICAL PROPERTIES : ACCORDING TO ASTM A563-2007
TEST DATE : 2010/08/13 SAMPLED BY : GAO MINGHUA SAMPLING DATE : 2010/08/10

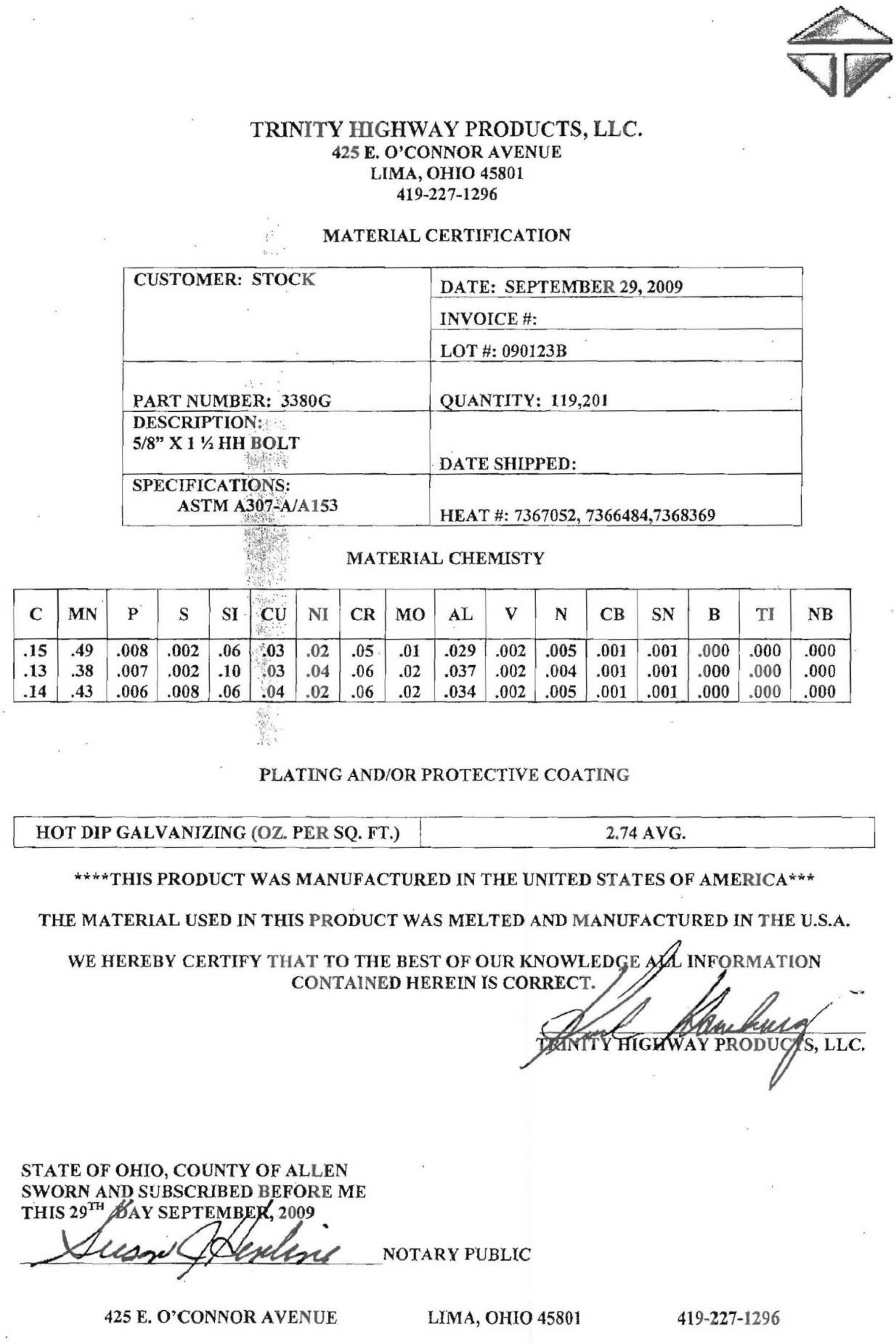
INSPECTIONS ITEM	SAMPLE	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	18PCS	ASTM F606/F606M	68-107 HRB	81 HRB	18	0
PROOF LOAD	13PCS	ASTM F606/F606M	Min. 41,600 LBF	OK	13	0

ALL TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM/SAE/ASME/MIL-STD-120 SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

WE CERTIFY THE PARTS ARE ROHS COMPLIANT.
THIS CERTIFIED MATERIAL TEST REPORT APPLIES TO THE SAMPLES TESTED AND IT CANNOT BE REPRODUCED EXCEPT IN FULL.

SIGNATURE :

Figure B-21. ⅞” Dia., 7½” Long Hex Bolt for Test Nos. MWTC-1 through MWTC-3



TRINITY HIGHWAY PRODUCTS, LLC.
425 E. O'CONNOR AVENUE
LIMA, OHIO 45801
419-227-1296

MATERIAL CERTIFICATION

CUSTOMER: STOCK	DATE: SEPTEMBER 29, 2009 INVOICE #: LOT #: 090123B
PART NUMBER: 3380G	QUANTITY: 119,201
DESCRIPTION: 5/8" X 1 ½ HH BOLT	DATE SHIPPED:
SPECIFICATIONS: ASTM A307-A/A153	HEAT #: 7367052, 7366484,7368369

MATERIAL CHEMISTY

C	MN	P	S	SI	CU	NI	CR	MO	AL	V	N	CB	SN	B	TI	NB
.15	.49	.008	.002	.06	.03	.02	.05	.01	.029	.002	.005	.001	.001	.000	.000	.000
.13	.38	.007	.002	.10	.03	.04	.06	.02	.037	.002	.004	.001	.001	.000	.000	.000
.14	.43	.006	.008	.06	.04	.02	.06	.02	.034	.002	.005	.001	.001	.000	.000	.000

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZING (OZ. PER SQ. FT.)	2.74 AVG.

******THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA*****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A.

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

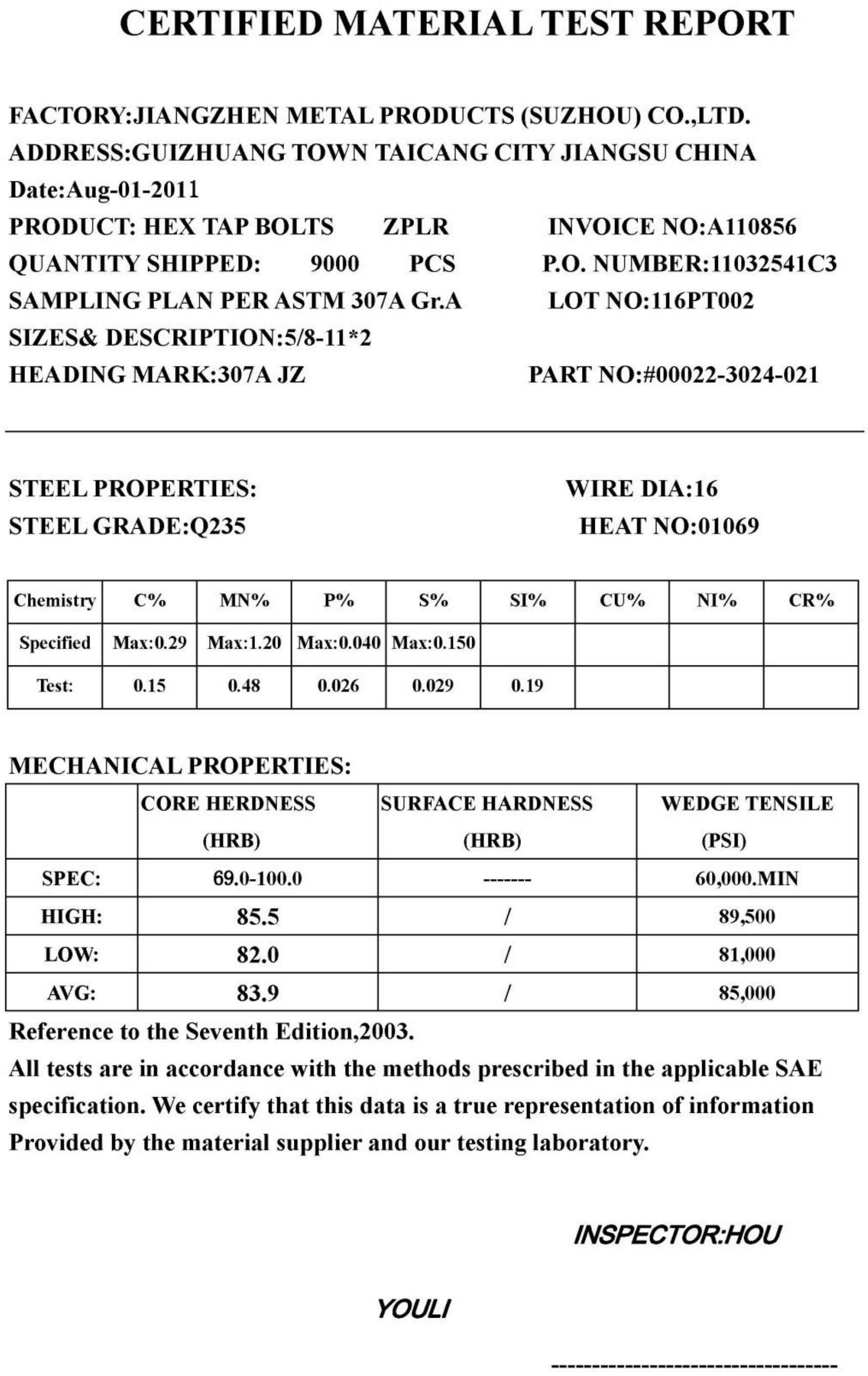
TRINITY HIGHWAY PRODUCTS, LLC.

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME
THIS 29TH DAY SEPTEMBER, 2009

Susan J Henkins **NOTARY PUBLIC**

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296

Figure B-22. ⅝" Dia., 1½" Long Hex Bolt for Test Nos. MWTC-1 through MWTC-3



CERTIFIED MATERIAL TEST REPORT

FACTORY:JIANGZHEN METAL PRODUCTS (SUZHOU) CO.,LTD.
ADDRESS:GUIZHUANG TOWN TAICANG CITY JIANGSU CHINA
Date:Aug-01-2011
PRODUCT: HEX TAP BOLTS ZPLR INVOICE NO:A110856
QUANTITY SHIPPED: 9000 PCS P.O. NUMBER:11032541C3
SAMPLING PLAN PER ASTM 307A Gr.A LOT NO:116PT002
SIZES& DESCRIPTION:5/8-11*2
HEADING MARK:307A JZ PART NO:#00022-3024-021

STEEL PROPERTIES: WIRE DIA:16
STEEL GRADE:Q235 HEAT NO:01069

Chemistry	C%	MN%	P%	S%	SI%	CU%	NI%	CR%
Specified	Max:0.29	Max:1.20	Max:0.040	Max:0.150				
Test:	0.15	0.48	0.026	0.029	0.19			

MECHANICAL PROPERTIES:

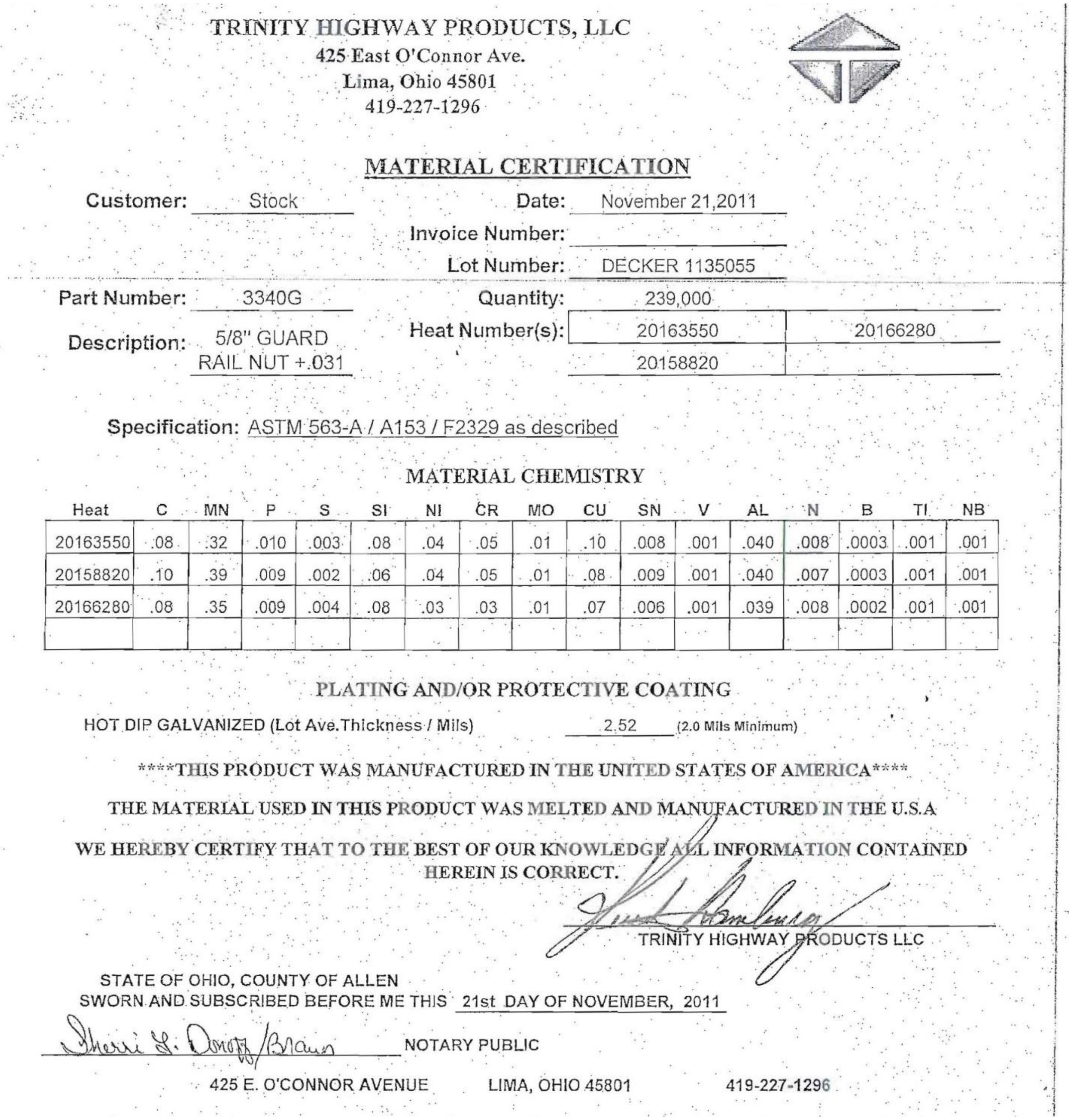
	CORE HERDNESS (HRB)	SURFACE HARDNESS (HRB)	WEDGE TENSILE (PSI)
SPEC:	69.0-100.0	-------	60,000.MIN
HIGH:	85.5	/	89,500
LOW:	82.0	/	81,000
AVG:	83.9	/	85,000

Reference to the Seventh Edition,2003.
All tests are in accordance with the methods prescribed in the applicable SAE specification. We certify that this data is a true representation of information Provided by the material supplier and our testing laboratory.

INSPECTOR:HOU

YOULI

Figure B-23. ⅝” Dia, 2” Long Hex Bolt for Test Nos. MWTC-1 through MWTC-3 and ⅝” Dia. 5” Long Hex Bolt for Test Nos. MWTC-2 and MWTC-3



TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

MATERIAL CERTIFICATION

Customer: Stock

Date: November 21,2011

Invoice Number:

Lot Number: DECKER 1135055

Part Number: 3340G

Quantity: 239,000

Description: 5/8" GUARD RAIL NUT +.031

Heat Number(s): 20163550 20166280 20158820

Specification: ASTM 563-A / A153 / F2329 as described

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20163550	.08	.32	.010	.003	.08	.04	.05	.01	.10	.008	.001	.040	.008	.0003	.001	.001
20158820	.10	.39	.009	.002	.06	.04	.05	.01	.08	.009	.001	.040	.007	.0003	.001	.001
20166280	.08	.35	.009	.004	.08	.03	.03	.01	.07	.006	.001	.039	.008	.0002	.001	.001

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.52 (2.0 Mils Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

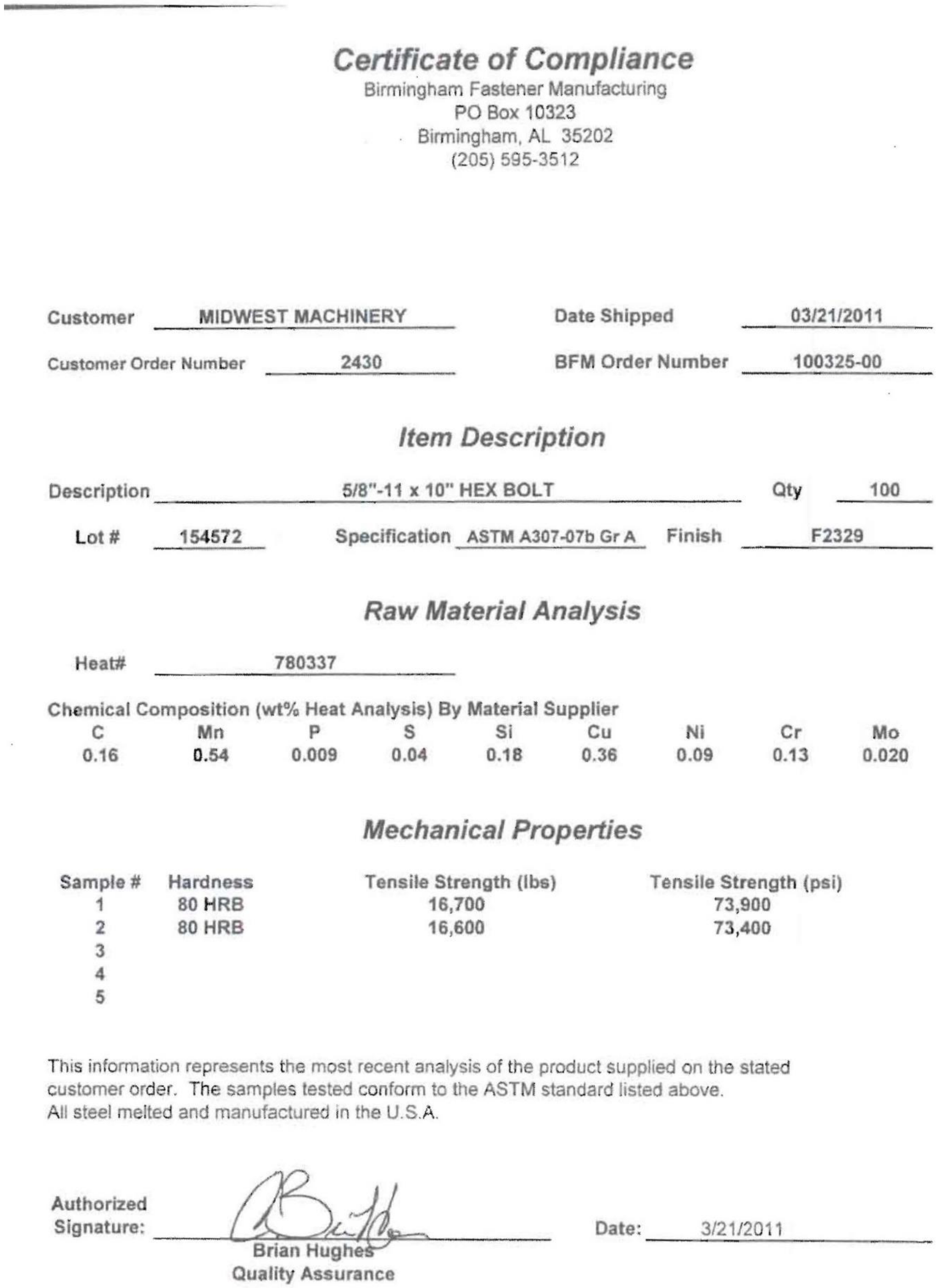
TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 21st DAY OF NOVEMBER, 2011

NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296

Figure B-24. ⅝” Dia., 1½” Long Guardrail Bolt for Test Nos. MWTC-1 through MWTC-3



Certificate of Compliance

Birmingham Fastener Manufacturing
PO Box 10323
Birmingham, AL 35202
(205) 595-3512

Customer MIDWEST MACHINERY **Date Shipped** 03/21/2011

Customer Order Number 2430 **BFM Order Number** 100325-00

Item Description

Description 5/8"-11 x 10" HEX BOLT **Qty** 100

Lot # 154572 **Specification** ASTM A307-07b Gr A **Finish** F2329

Raw Material Analysis

Heat# 780337

Chemical Composition (wt% Heat Analysis) By Material Supplier

C	Mn	P	S	Si	Cu	Ni	Cr	Mo
0.16	0.54	0.009	0.04	0.18	0.36	0.09	0.13	0.020

Mechanical Properties

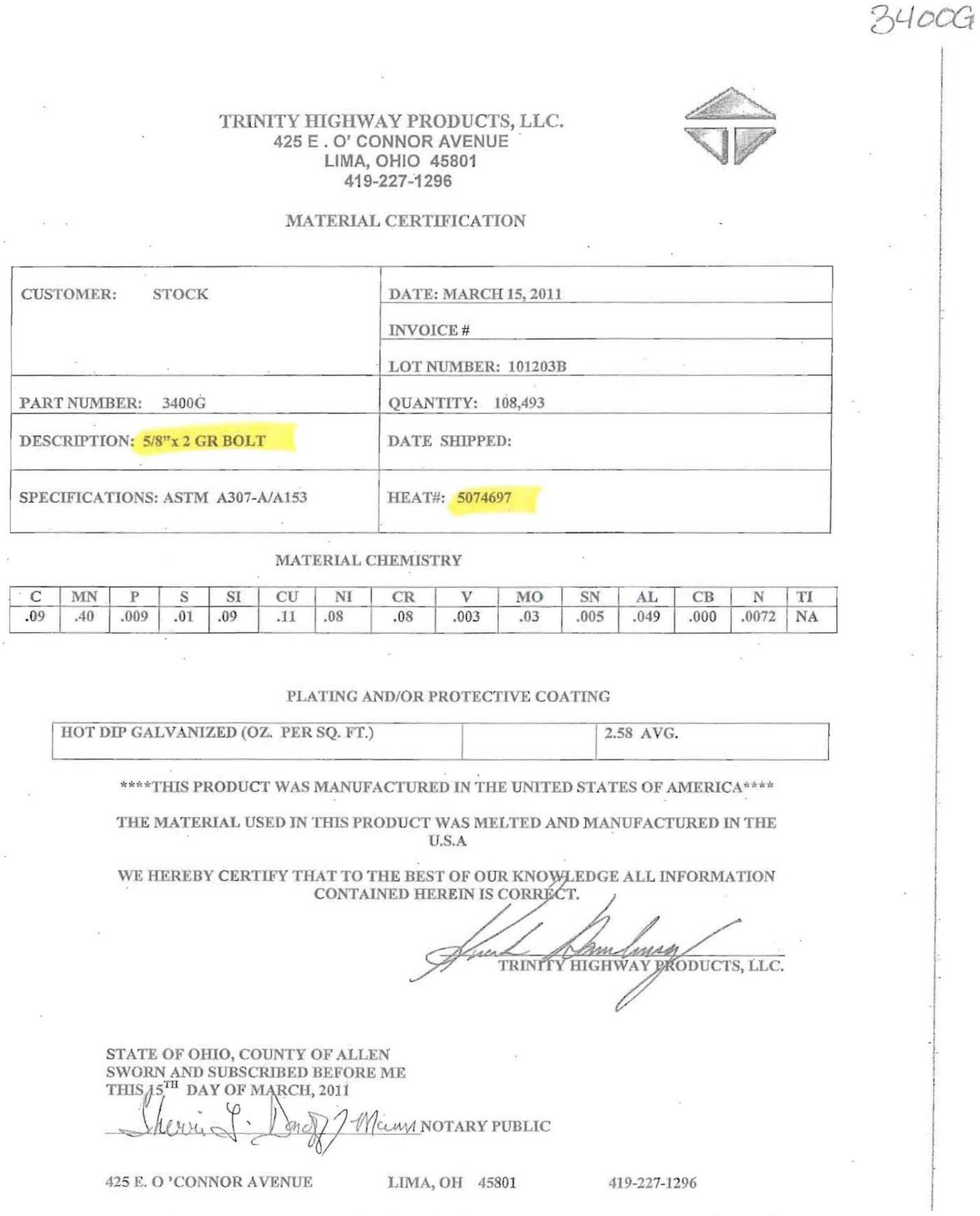
Sample #	Hardness	Tensile Strength (lbs)	Tensile Strength (psi)
1	80 HRB	16,700	73,900
2	80 HRB	16,600	73,400
3			
4			
5			

This information represents the most recent analysis of the product supplied on the stated customer order. The samples tested conform to the ASTM standard listed above.
All steel melted and manufactured in the U.S.A.

Authorized Signature: **Date:** 3/21/2011

Brian Hughes
Quality Assurance

Figure B-25. ⅝” Dia., 10” Long Hex Bolt for Test No. MWTC-1



3400G

TRINITY HIGHWAY PRODUCTS, LLC.
425 E . O' CONNOR AVENUE
LIMA, OHIO 45801
419-227-1296

MATERIAL CERTIFICATION

CUSTOMER: STOCK
DATE: MARCH 15, 2011
INVOICE #
LOT NUMBER: 101203B
PART NUMBER: 3400G
QUANTITY: 108,493
DESCRIPTION: 5/8"x 2 GR BOLT
DATE SHIPPED:
SPECIFICATIONS: ASTM A307-A/A153
HEAT#: 5074697

MATERIAL CHEMISTRY

C	MN	P	S	SI	CU	NI	CR	V	MO	SN	AL	CB	N	TI
.09	.40	.009	.01	.09	.11	.08	.08	.003	.03	.005	.049	.000	.0072	NA

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZED (OZ. PER SQ. FT.)		2.58 AVG.

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A

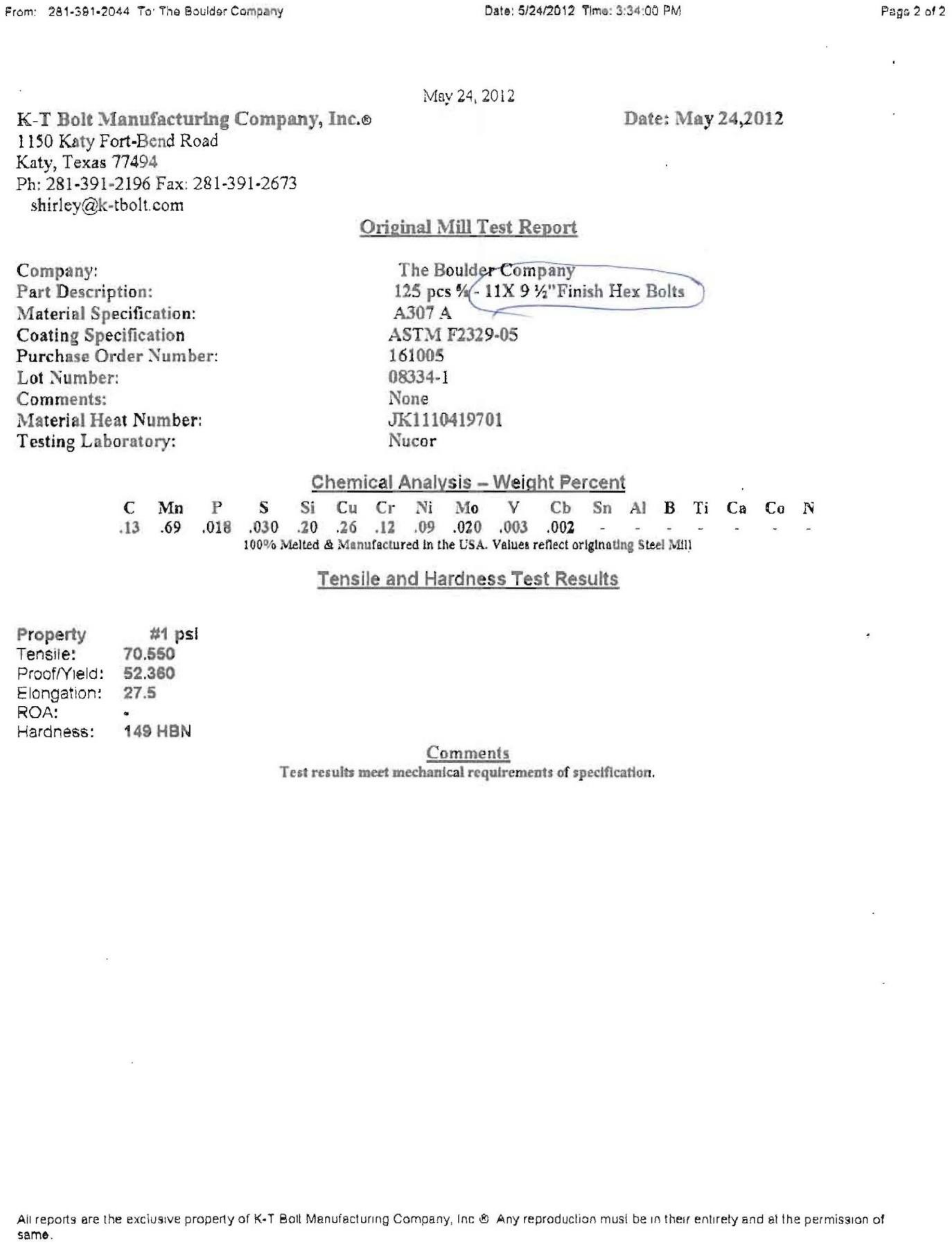
WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

TRINITY HIGHWAY PRODUCTS, LLC.

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME
THIS 15TH DAY OF MARCH, 2011
NOTARY PUBLIC

425 E. O 'CONNOR AVENUE LIMA, OH 45801 419-227-1296

Figure B-26. ⅝" Dia., 2" Long Guardrail Bolt for Test Nos. MWTC-1 through MWTC-3



From: 281-391-2044 To: The Boulder Company Date: 5/24/2012 Time: 3:34:00 PM Page 2 of 2

May 24, 2012

K-T Bolt Manufacturing Company, Inc.®
1150 Katy Fort-Bend Road
Katy, Texas 77494
Ph: 281-391-2196 Fax: 281-391-2673
shirley@k-tbolt.com

Date: May 24,2012

Original Mill Test Report

Company:	The Boulder Company
Part Description:	125 pcs ⅝ - 11X 9 ½"Finish Hex Bolts
Material Specification:	A307 A
Coating Specification	ASTM F2329-05
Purchase Order Number:	161005
Lot Number:	08334-1
Comments:	None
Material Heat Number:	JK1110419701
Testing Laboratory:	Nucor

Chemical Analysis – Weight Percent

C	Mn	P	S	Si	Cu	Cr	Ni	Mo	V	Cb	Sn	Al	B	Ti	Ca	Co	N
.13	.69	.018	.030	.20	.26	.12	.09	.020	.003	.002	-	-	-	-	-	-	-

100% Melted & Manufactured in the USA. Values reflect originating Steel Mill

Tensile and Hardness Test Results

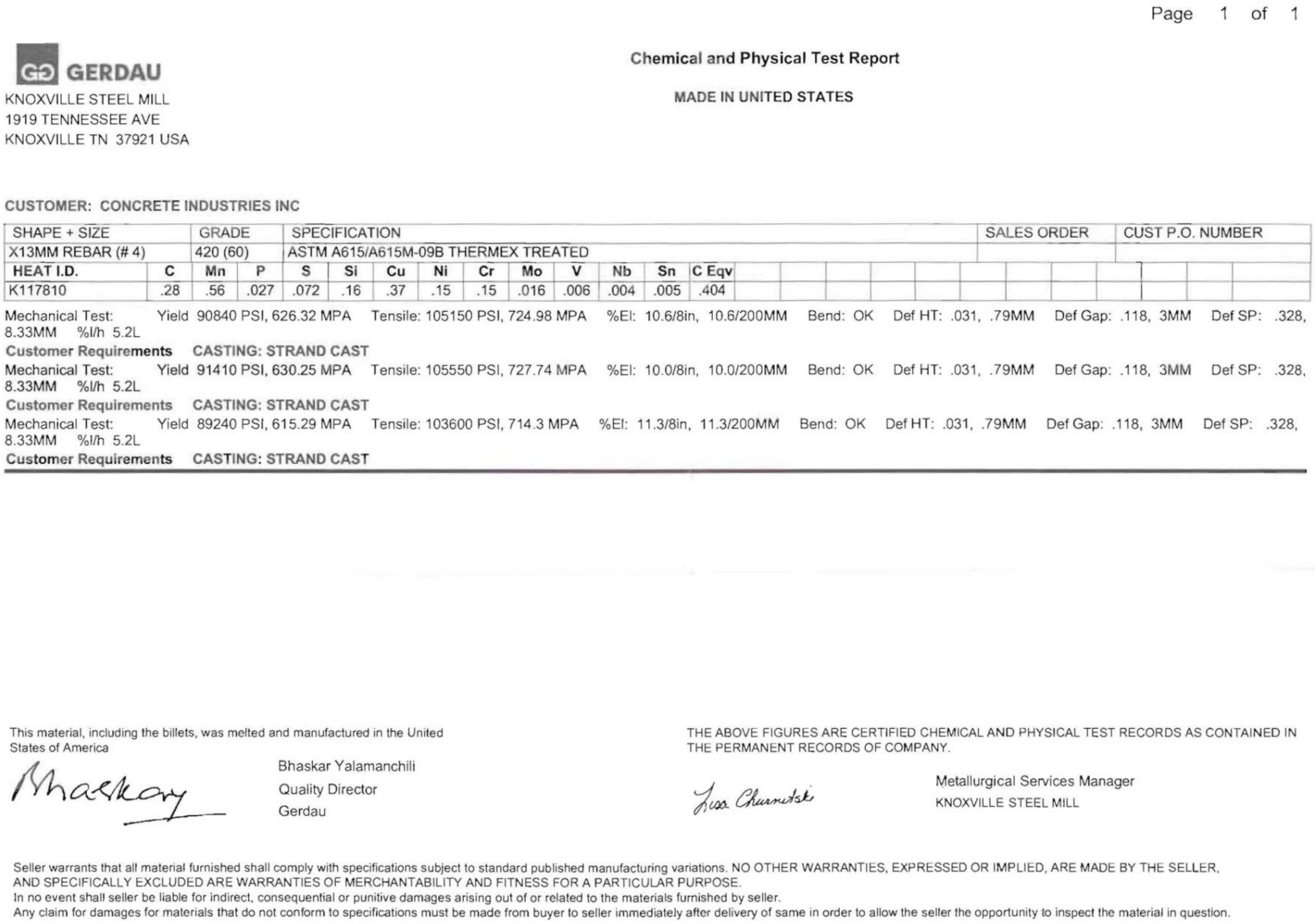
Property	#1 psi
Tensile:	70.550
Proof/Yield:	52.360
Elongation:	27.5
ROA:	-
Hardness:	149 HBN

Comments

Test results meet mechanical requirements of specification.

All reports are the exclusive property of K-T Bolt Manufacturing Company, Inc ® Any reproduction must be in their entirety and at the permission of same.

Figure B-27. ⅝” Dia., 10” Long and 14” Long Guardrail Bolt for Test Nos. MWTC-1 through MWTC-3



Page 1 of 1

GERDAU

KNOXVILLE STEEL MILL
1919 TENNESSEE AVE
KNOXVILLE TN 37921 USA

Chemical and Physical Test Report

MADE IN UNITED STATES

CUSTOMER: CONCRETE INDUSTRIES INC

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
X13MM REBAR (# 4)	420 (60)	ASTM A615/A615M-09B THERMEX TREATED		

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	Sn	C Eqv
K117810	.28	.56	.027	.072	.16	.37	.15	.15	.016	.006	.004	.005	.404

Mechanical Test: Yield 90840 PSI, 626.32 MPA Tensile: 105150 PSI, 724.98 MPA %El: 10.6/8in, 10.6/200MM Bend: OK Def HT: .031, .79MM Def Gap: .118, 3MM Def SP: .328, 8.33MM %l/h 5.2L

Customer Requirements CASTING: STRAND CAST

Mechanical Test: Yield 91410 PSI, 630.25 MPA Tensile: 105550 PSI, 727.74 MPA %El: 10.0/8in, 10.0/200MM Bend: OK Def HT: .031, .79MM Def Gap: .118, 3MM Def SP: .328, 8.33MM %l/h 5.2L

Customer Requirements CASTING: STRAND CAST

Mechanical Test: Yield 89240 PSI, 615.29 MPA Tensile: 103600 PSI, 714.3 MPA %El: 11.3/8in, 11.3/200MM Bend: OK Def HT: .031, .79MM Def Gap: .118, 3MM Def SP: .328, 8.33MM %l/h 5.2L

Customer Requirements CASTING: STRAND CAST

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

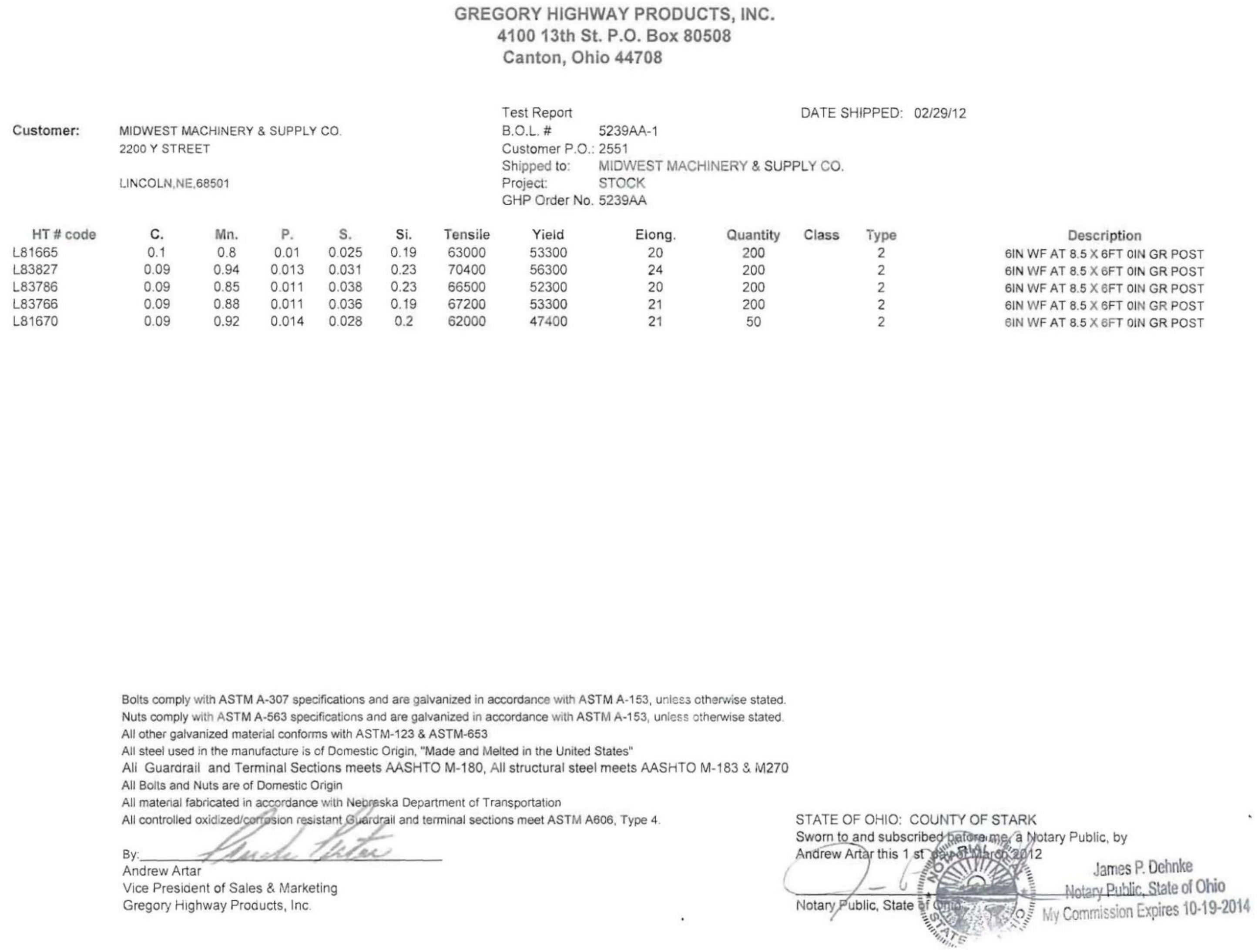
Bhaskar Yalamanchili
Quality Director
Gerdau

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

Metallurgical Services Manager
KNOXVILLE 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 B-28. #4 Rebar for Test Nos. MWTC-1 through MWTC-3



GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. P.O. Box 80508
Canton, Ohio 44708

Test Report
DATE SHIPPED: 02/29/12

Customer:
MIDWEST MACHINERY & SUPPLY CO.
2200 Y STREET

LINCOLN,NE,68501

B.O.L. # 5239AA-1
Customer P.O.: 2551
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
Project: STOCK
GHP Order No. 5239AA

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
L81665	0.1	0.8	0.01	0.025	0.19	63000	53300	20	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L83827	0.09	0.94	0.013	0.031	0.23	70400	56300	24	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L83786	0.09	0.85	0.011	0.038	0.23	66500	52300	20	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L83766	0.09	0.88	0.011	0.036	0.19	67200	53300	21	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L81670	0.09	0.92	0.014	0.028	0.2	62000	47400	21	50		2	6IN WF AT 8.5 X 6FT 0IN GR POST

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

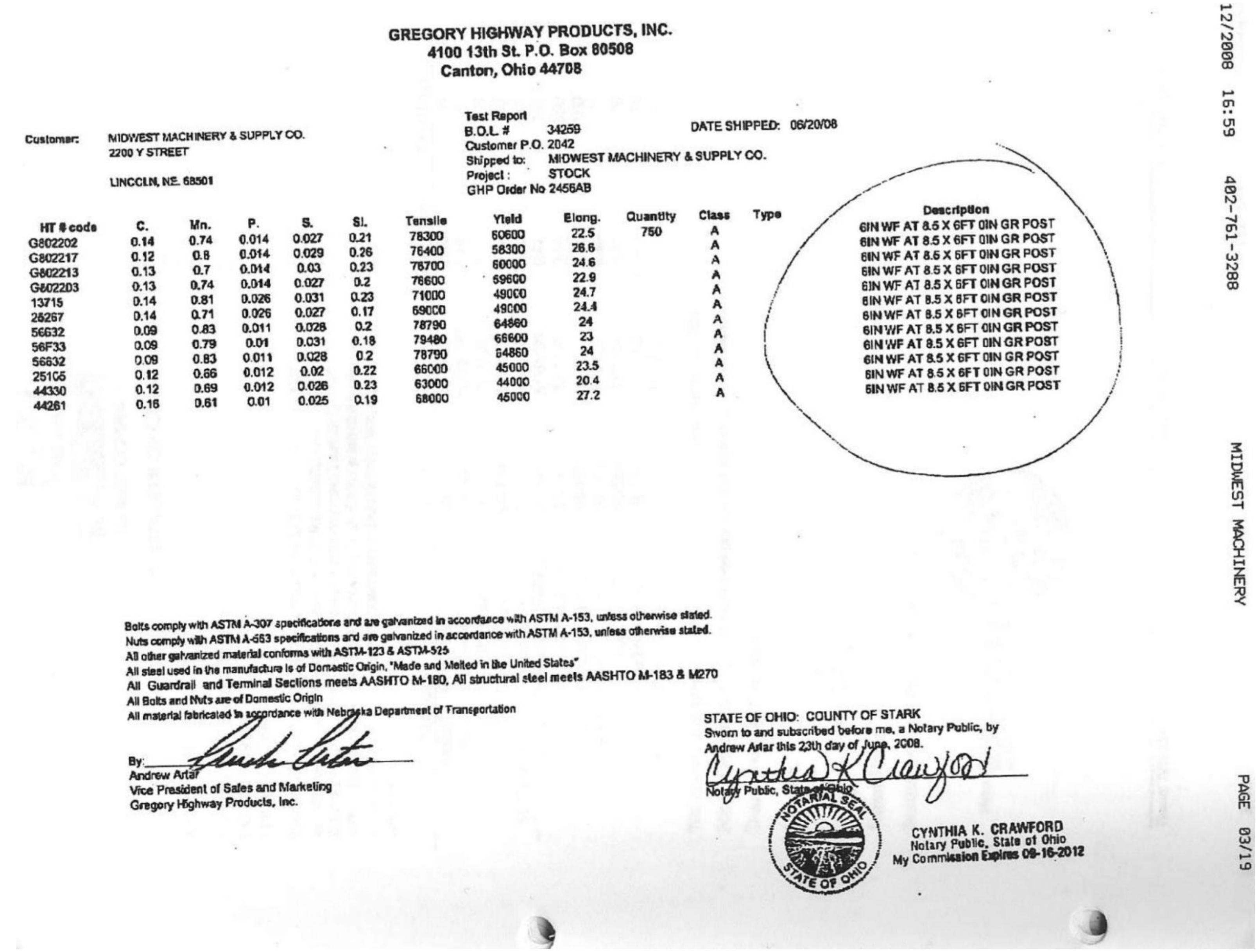
By:
Andrew Artar
Vice President of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 1 st day of March 2012

Notary Public, State of Ohio

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2014

Figure B-29. W6x8.5 72” Long Posts for MWTC-1 through MWTC-3



12/2008 16:59 402-761-3288 MIDWEST MACHINERY PAGE 03/19

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. P.O. Box 80508
Canton, Ohio 44708

Customer: MIDWEST MACHINERY & SUPPLY CO.
2200 Y STREET

LINCOLN, NE. 68501

Test Report
B.O.L # 34259
Customer P.O. 2042
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
Project : STOCK
GHP Order No 2456AB

DATE SHIPPED: 06/20/08

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
G802202	0.14	0.74	0.014	0.027	0.21	78300	60600	22.5	750	A		6IN WF AT 8.5 X 6FT 0IN GR POST
G802217	0.12	0.8	0.014	0.029	0.26	76400	58300	26.6		A		6IN WF AT 8.5 X 6FT 0IN GR POST
G802213	0.13	0.7	0.014	0.03	0.23	76700	60000	24.6		A		6IN WF AT 8.5 X 6FT 0IN GR POST
G802203	0.13	0.74	0.014	0.027	0.2	76600	69600	22.9		A		6IN WF AT 8.5 X 6FT 0IN GR POST
13715	0.14	0.81	0.026	0.031	0.23	71000	49000	24.7		A		6IN WF AT 8.5 X 6FT 0IN GR POST
26267	0.14	0.71	0.026	0.027	0.17	69000	49000	24.4		A		6IN WF AT 8.5 X 6FT 0IN GR POST
56632	0.09	0.83	0.011	0.028	0.2	78790	64860	24		A		6IN WF AT 8.5 X 6FT 0IN GR POST
56F33	0.09	0.79	0.01	0.031	0.18	79480	66600	23		A		6IN WF AT 8.5 X 6FT 0IN GR POST
56632	0.09	0.83	0.011	0.028	0.2	78790	64860	24		A		6IN WF AT 8.5 X 6FT 0IN GR POST
25105	0.12	0.66	0.012	0.02	0.22	66000	45000	23.5		A		6IN WF AT 8.5 X 6FT 0IN GR POST
44330	0.12	0.69	0.012	0.026	0.23	63000	44000	20.4		A		6IN WF AT 8.5 X 6FT 0IN GR POST
44261	0.16	0.61	0.01	0.025	0.19	68000	45000	27.2		A		6IN WF AT 8.5 X 6FT 0IN GR POST

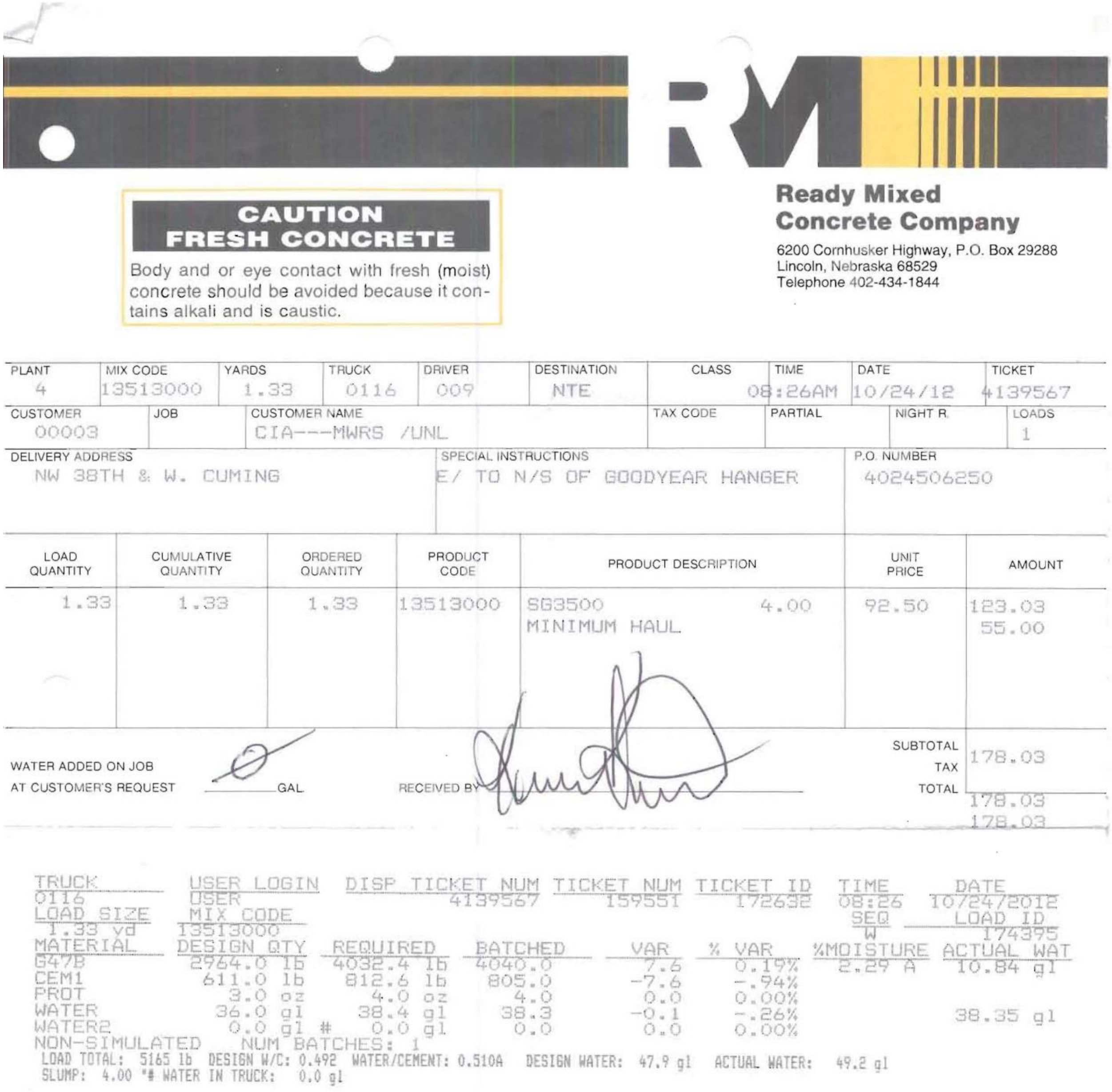
Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-525
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation

By: ____________
Andrew Artar
Vice President of Sales and Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 23th day of June, 2008.
Cynthia K Crawford
Notary Public, State of Ohio

CYNTHIA K. CRAWFORD
Notary Public, State of Ohio
My Commission Expires 09-16-2012

Figure B-30. W6x8.5 72" Long Posts for Test Nos. MWTC-2 and MWTC-3



Ready Mixed Concrete Company

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

CAUTION FRESH CONCRETE

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

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
4	13513000	1.33	0116	009	NTE		08:26AM	10/24/12	4139567

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003		CIA---MWRS /UNL				1

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
NW 38TH & W. CUMING	E/ TO N/S OF GOODYEAR HANGER	4024506250

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION		UNIT PRICE	AMOUNT
1.33	1.33	1.33	13513000	SG3500	4.00	92.50	123.03
				MINIMUM HAUL			55.00

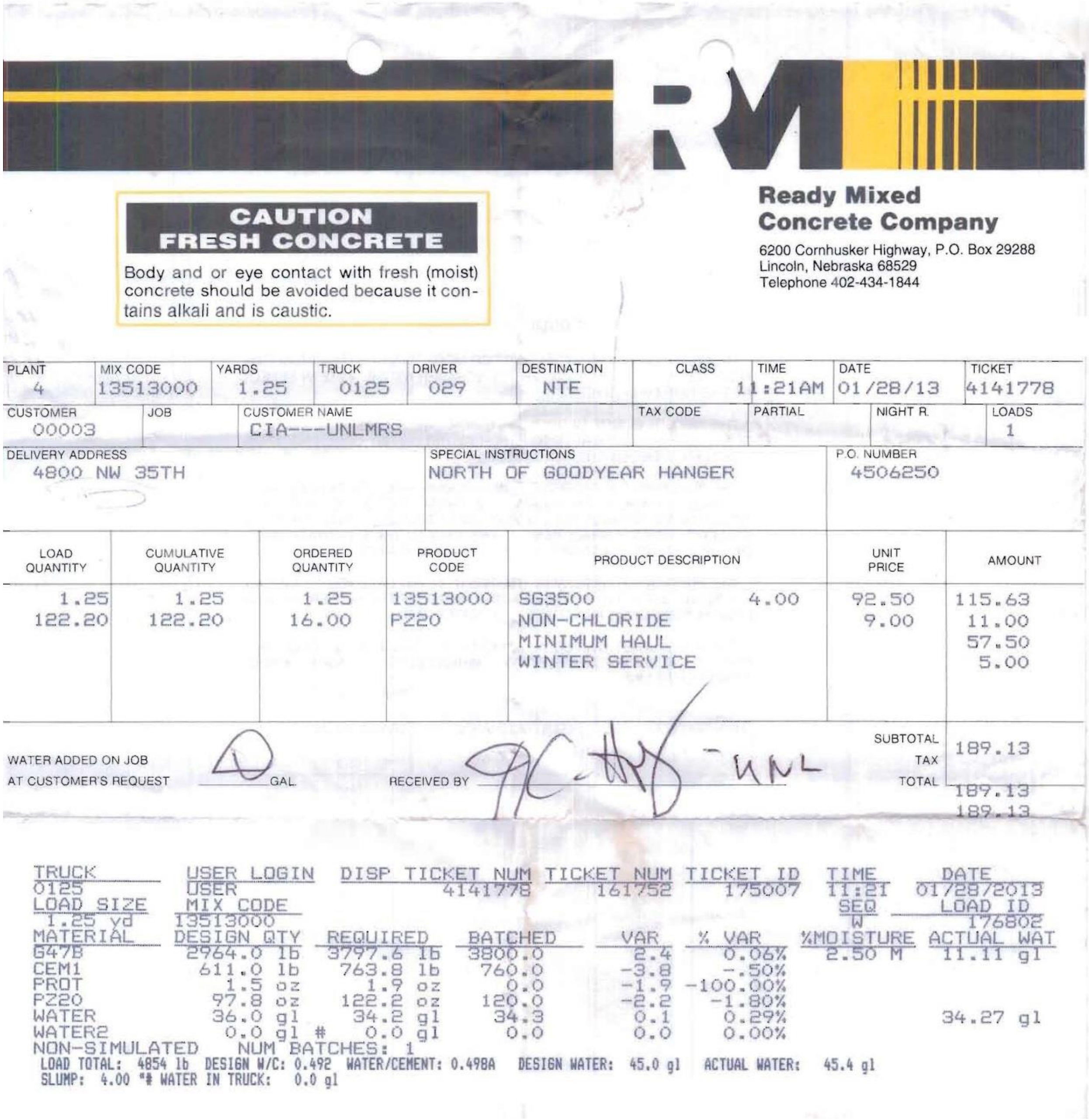
WATER ADDED ON JOB AT CUSTOMER'S REQUEST 0 GAL

RECEIVED BY

SUBTOTAL 178.03
TAX 178.03
TOTAL 178.03

```
TRUCK         USER LOGIN  DISP TICKET NUM TICKET NUM TICKET ID  TIME     DATE
0116          USER                4139567     159551    172632  08:26  10/24/2012
LOAD SIZE     MIX CODE                                          SEQ      LOAD ID
 1.33 yd     13513000                                            W        174395
MATERIAL     DESIGN QTY  REQUIRED    BATCHED       VAR   % VAR  %MOISTURE ACTUAL WAT
G47B          2964.0 lb  4032.4 lb   4040.0        7.6    0.19%  2.29 A   10.84 gl
CEM1           611.0 lb   812.6 lb    805.0       -7.6    -.94%
PROT             3.0 oz     4.0 oz      4.0        0.0    0.00%
WATER           36.0 gl    38.4 gl     38.3       -0.1    -.26%            38.35 gl
WATER2           0.0 gl #   0.0 gl      0.0        0.0    0.00%
NON-SIMULATED    NUM BATCHES: 1
 LOAD TOTAL:  5165 lb  DESIGN W/C: 0.492  WATER/CEMENT: 0.510A   DESIGN WATER:  47.9 gl   ACTUAL WATER:   49.2 gl
 SLUMP:  4.00 "# WATER IN TRUCK:   0.0 gl
```

Figure B-31. Concrete Curb for Test Nos. MWTC-1 and MWTC-2



CAUTION
FRESH CONCRETE

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

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

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
4	13513000	1.25	0125	029	NTE		11:21AM	01/28/13	4141778

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

DELIVERY ADDRESS: 4800 NW 35TH
SPECIAL INSTRUCTIONS: NORTH OF GOODYEAR HANGER
P.O. NUMBER: 4506250

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UNIT PRICE	AMOUNT
1.25	1.25	1.25	13513000	SG3500 4.00	92.50	115.63
122.20	122.20	16.00	PZ20	NON-CHLORIDE	9.00	11.00
				MINIMUM HAUL		57.50
				WINTER SERVICE		5.00

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 0 GAL.
RECEIVED BY - UNL

SUBTOTAL 189.13
TAX
TOTAL 189.13
189.13

```
TRUCK          USER LOGIN  DISP TICKET NUM TICKET NUM TICKET ID  TIME     DATE
0125           USER               4141778     161752    175007  11:21  01/28/2013
LOAD SIZE      MIX CODE                                          SEQ      LOAD ID
 1.25 yd      13513000                                            W        176802
MATERIAL      DESIGN QTY   REQUIRED     BATCHED       VAR    % VAR   %MOISTURE ACTUAL WAT
G47B           2964.0 lb   3797.6 lb    3800.0        2.4    0.06%   2.50 M    11.11 gl
CEM1            611.0 lb    763.8 lb     760.0       -3.8    -.50%
PROT              1.5 oz      1.9 oz       0.0       -1.9 -100.00%
PZ20             97.8 oz    122.2 oz     120.0       -2.2   -1.80%
WATER            36.0 gl     34.2 gl      34.3        0.1    0.29%              34.27 gl
WATER2            0.0 gl #    0.0 gl       0.0        0.0    0.00%
NON-SIMULATED    NUM BATCHES: 1
 LOAD TOTAL:  4854 lb  DESIGN W/C: 0.492  WATER/CEMENT: 0.498A   DESIGN WATER:  45.0 gl   ACTUAL WATER:   45.4 gl
 SLUMP:  4.00 "# WATER IN TRUCK:   0.0 gl
```

Figure B-32. Concrete Curb for Test No. MWTC-3

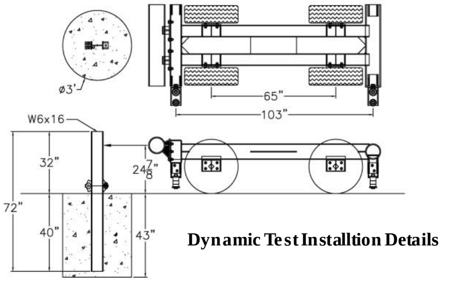
Appendix C. Static Soil Tests

Dynamic Set up

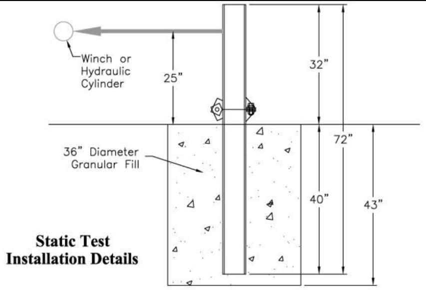
Post-Test Photo of Post

Static Load Test

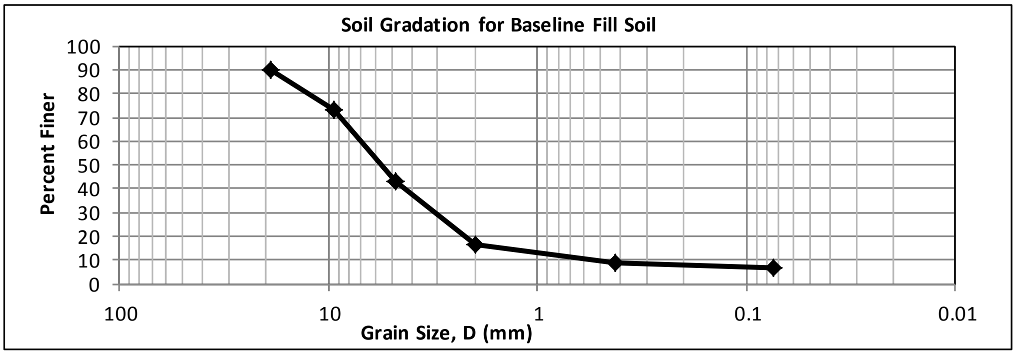
Post-Test Photo of Post



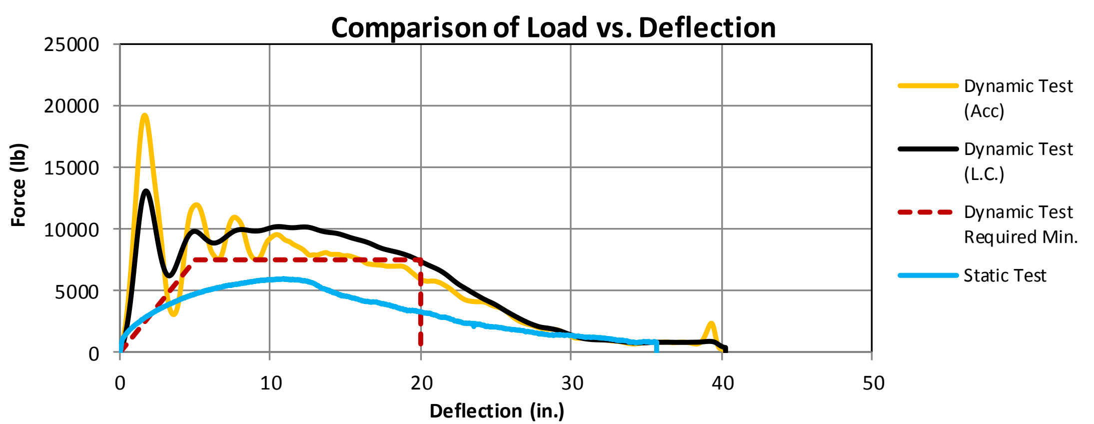
Dynamic Test Installtion Details



Static Test Installation Details



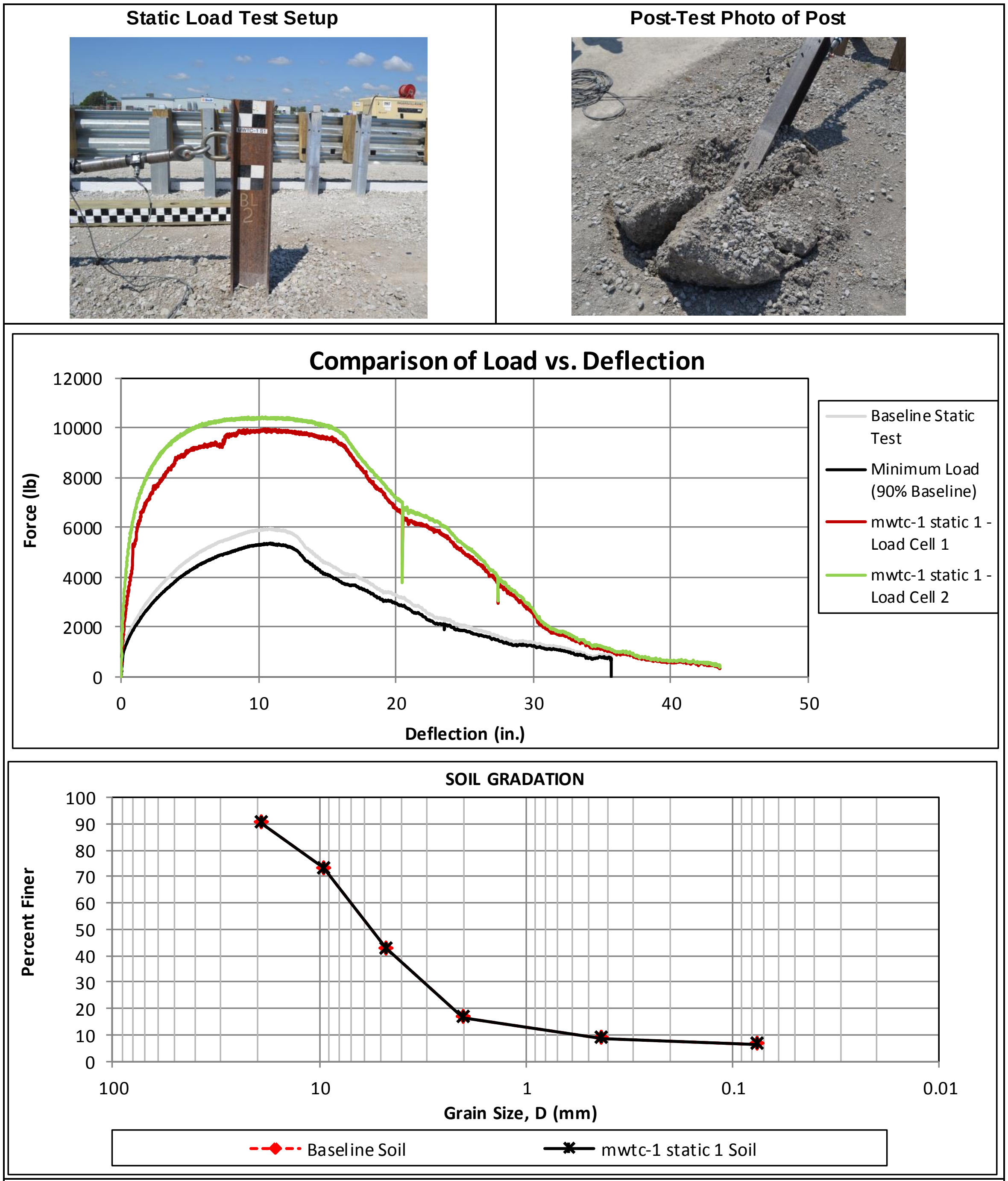
Soil Gradation for Baseline Fill Soil



Comparison of Load vs. Deflection

Date	3/20/2012
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well Graded Gravel (GW)
Fill material description (ASTM D2487)	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8" lift 3-4 passes
Bogie Weight	1,843 lb
Impact Velocity	20.02 mph

Figure C-1. Soil Strength, Initial Calibration Tests



Date.. 8/9/2012

Test Facility & Site Location..................... Midwest Roadside Safety Facility

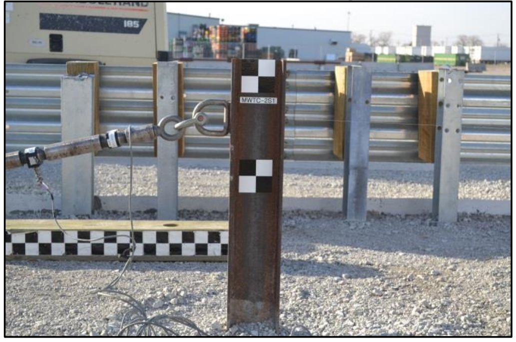
In situ soil description (ASTM D2487)......... Well Graded Gravel (GW)

Fill material description (ASTM D2487)...... Well Graded Gravel (GW) (see sieve analyses above)

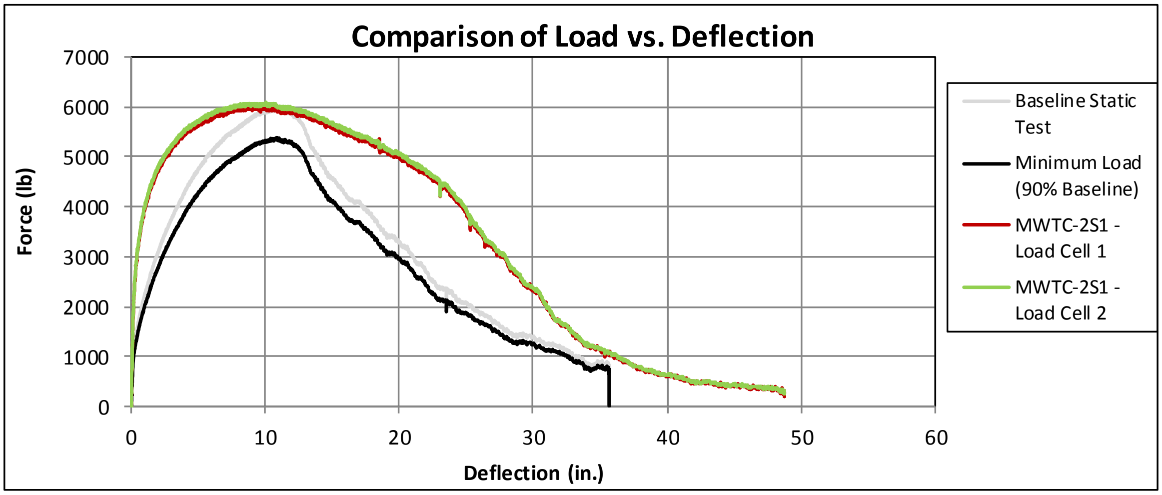
Description of fill placement procedure..... 8-inch lifts tamped with a pneumatic compactor

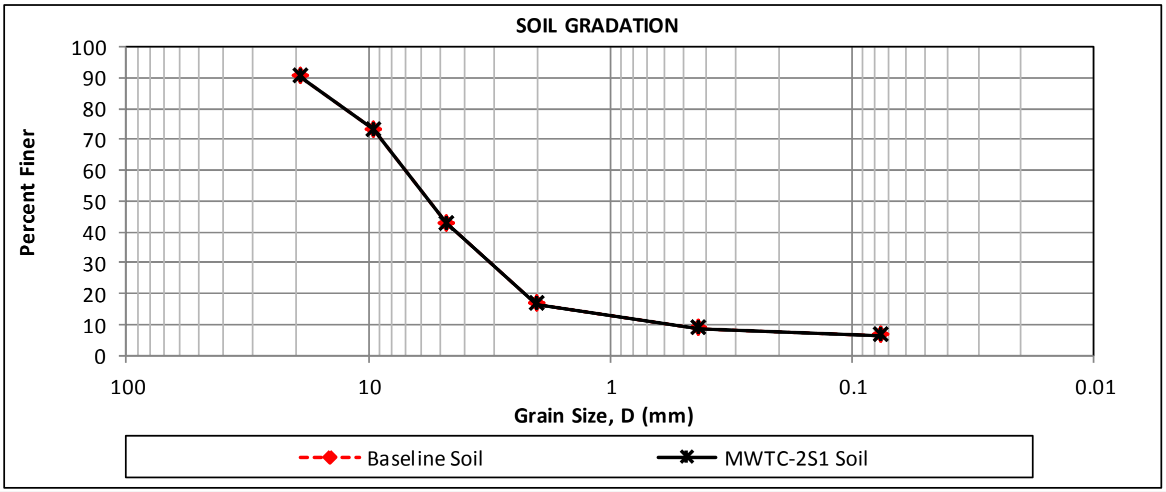
Figure C-2. Static Soil Test, Test No. MWTC-1

Static Load Test Setup



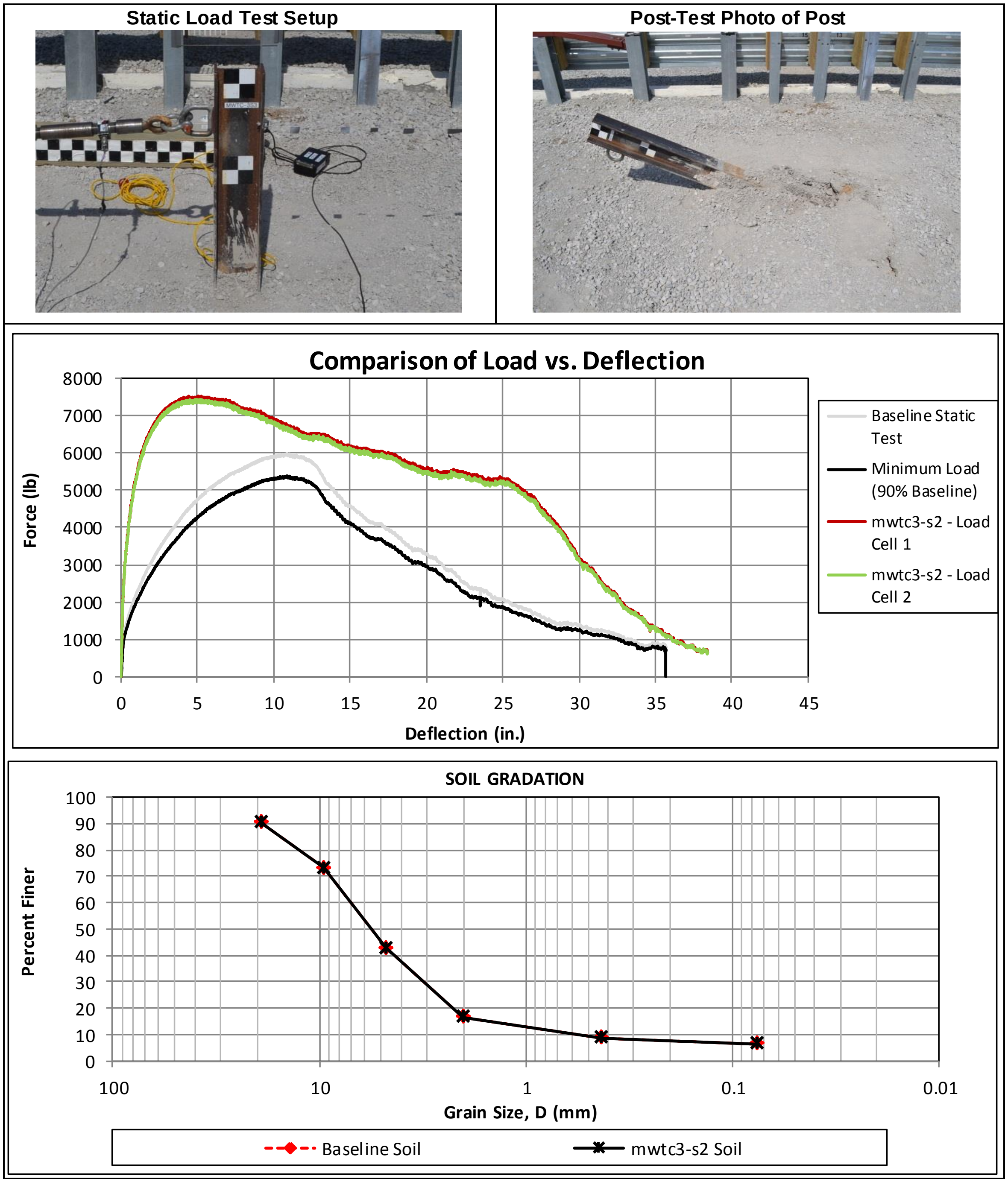
Post-Test Photo of Post





Date..11/28/2012
Test Facility & Site Location.....................Midwest Roadside Safety Facility
In situ soil description (ASTM D2487).........Well Graded Gravel (GW)
Fill material description (ASTM D2487)......Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.....8-inch lifts tamped with a pneumatic compactor

Figure C-3. Static Soil Test, Test No. MWTC-2



Date.. 5/15/2013
Test Facility & Site Location..................... Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)......... Well Graded Gravel (GW)
Fill material description (ASTM D2487)...... Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure..... 8-inch lifts tamped with a pneumatic compactor

Figure C-4. Static Soil Test, Test No. MWTC-3

Appendix D. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH

TEST: MWTC-1
VEHICLE: 1100C

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

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
F1	28 1/4	-15 1/2	-2 3/4	28	-15	-3	- 1/4	1/2	- 1/4
2	28	-10	-3	28	-10	-3 1/4	0	0	- 1/4
3	27 1/2	- 3/4	-3 1/2	27 3/4	-1 1/2	-3 3/4	1/4	- 3/4	- 1/4
4	25	-15 1/2	-4 3/4	25	-15 1/2	-5	0	0	- 1/4
5	25 1/2	-9 1/2	-4 3/4	25 1/4	-9 1/2	-4 3/4	- 1/4	0	0
6	25 1/4	-1 1/4	-4 1/2	25 1/4	-1	-5	0	1/4	- 1/2
7	20 1/2	-20 1/2	-5 1/4	20 1/2	-21	-5 1/2	0	- 1/2	- 1/4
8	21 3/4	-15 1/2	-5 1/2	21 3/4	-16 1/2	-5 3/4	0	-1	- 1/4
9	21 1/2	-9	-6	21 1/4	-9 1/4	-6 1/4	- 1/4	- 1/4	- 1/4
10	20 1/2	-1 1/4	-5 3/4	20 1/2	-1 1/2	-6	0	- 1/4	- 1/4
11	16 3/4	-20	-5 3/4	16 3/4	-20	-6	0	0	- 1/4
12	17	-15 1/4	-5 3/4	17	-15 1/4	-6	0	0	- 1/4
13	17	-9	-6	17	-9 1/4	-6 1/4	0	- 1/4	- 1/4
14	16 1/2	-1 3/4	-6 1/4	16 3/4	-2	-6 1/2	1/4	- 1/4	- 1/4
15	12 1/2	-20 1/2	-6	13	-20 1/4	-6 1/4	1/2	1/4	- 1/4
16	12 1/2	-14 1/2	-6	13	-14 3/4	-6 1/4	1/2	- 1/4	- 1/4
17	13	-8 3/4	-6 1/4	13 1/4	-9	-6 1/2	1/4	- 1/4	- 1/4
18	13	-2	-6 1/2	13	-2	-7	0	0	- 1/2
19	9	-19	-6 1/2	9	-18 3/4	-6 1/2	0	1/4	0
20	9	-14 1/4	-6	9	-14	-6 1/4	0	1/4	- 1/4
21	9 1/4	-9 1/4	-6 1/4	9	-9	-6 1/2	- 1/4	1/4	- 1/4
22	9 1/4	-1 3/4	-6 1/2	9	-2	-6 3/4	- 1/4	- 1/4	- 1/4
23	2	-17	-2 1/2	2	-17	-2 1/2	0	0	0
24	2	-12 1/2	-2 3/4	2	-12 1/2	-3	0	0	- 1/4
25	2	-8	-3	2	-8	-3 1/4	0	0	- 1/4
26	2	-4 1/2	-3 1/4	2	-4 1/2	-3 1/2	0	0	- 1/4
27							0	0	0
28							0	0	0
29							0	0	0
30							0	0	0
31							0	0	0

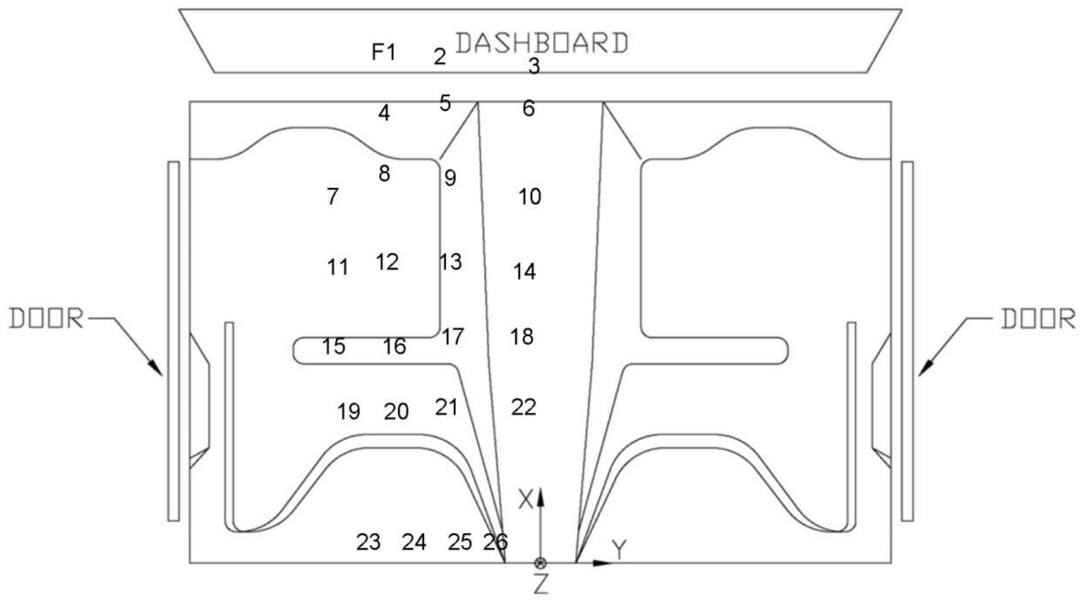


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. MWTC-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MWTC-1
VEHICLE: 1100C

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

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	38 3/4	-20 1/2	-2	38 1/2	-20 1/4	-2	- 1/4	1/4	0
2	38 1/2	-15 1/2	-2 1/4	38 1/2	-15 1/2	-2 1/4	0	0	0
3	38 1/4	-6 3/4	-3	38	-5 3/4	-3	- 1/4	1	0
4	35 1/2	-20 3/4	-4	35 1/2	-20 3/4	-4	0	0	0
5	36	-14 3/4	-4	35 3/4	-15	-3 3/4	- 1/4	- 1/4	1/4
6	36	-6 1/4	-4	36	-6 1/2	-4 1/4	0	- 1/4	- 1/4
7	31	-26 1/2	-4 1/2	31	-26 1/4	-5	0	1/4	- 1/2
8	32 1/4	-21 1/4	-5	32 1/4	-21 1/4	-5	0	0	0
9	32	-14 1/2	-5 1/2	32	-15 1/4	-5 1/2	0	- 3/4	0
10	31 1/4	-6 3/4	-5	31	-6 3/4	-5	- 1/4	0	0
11	27 1/4	-26	-5 1/4	27 1/4	-26	-5 1/2	0	0	- 1/4
12	27 1/2	-20 3/4	-5 1/4	27 1/2	-20 3/4	-5 1/2	0	0	- 1/4
13	27 1/2	-14 3/4	-5 1/2	27 3/4	-14 1/2	-5 3/4	1/4	1/4	- 1/4
14	27	-7 1/4	-5 3/4	27 1/4	-7 1/2	-6	1/4	- 1/4	- 1/4
15	23 1/4	-26 3/4	-5 1/2	23 1/2	-26 1/4	-5 1/2	1/4	1/2	0
16	23 1/2	-20 1/2	-5 1/2	23 1/2	-20 1/4	-5 3/4	0	1/4	- 1/4
17	23 1/2	-14 1/2	-5 3/4	23 3/4	-14 1/2	-6	1/4	0	- 1/4
18	23	-7 1/2	-6	23 1/2	-7 1/2	-6 1/4	1/2	0	- 1/4
19	19 3/4	-24 1/2	-6	19 1/2	-24 1/4	-6	- 1/4	1/4	0
20	19 3/4	-20	-5 3/4	19 1/2	-19 3/4	-5 3/4	- 1/4	1/4	0
21	19 3/4	-15	-6	19 1/2	-14 1/2	-6	- 1/4	1/2	0
22	19 3/4	-7 1/2	-6	19 3/4	-7 1/2	-6 1/4	0	0	- 1/4
23	12 1/2	-22 3/4	-2 1/4	12 1/2	-22 1/2	-2 1/2	0	1/4	- 1/4
24	12 1/2	-18	-2 3/4	12 1/2	-18	-2 3/4	0	0	0
25	12 1/2	-13 3/4	-3	12 1/2	-13 1/2	-3	0	1/4	0
26	12 1/2	-10	-3	12 1/2	-10	-3	0	0	0
27							0	0	0
28							0	0	0
29							0	0	0
30							0	0	0
31							0	0	0

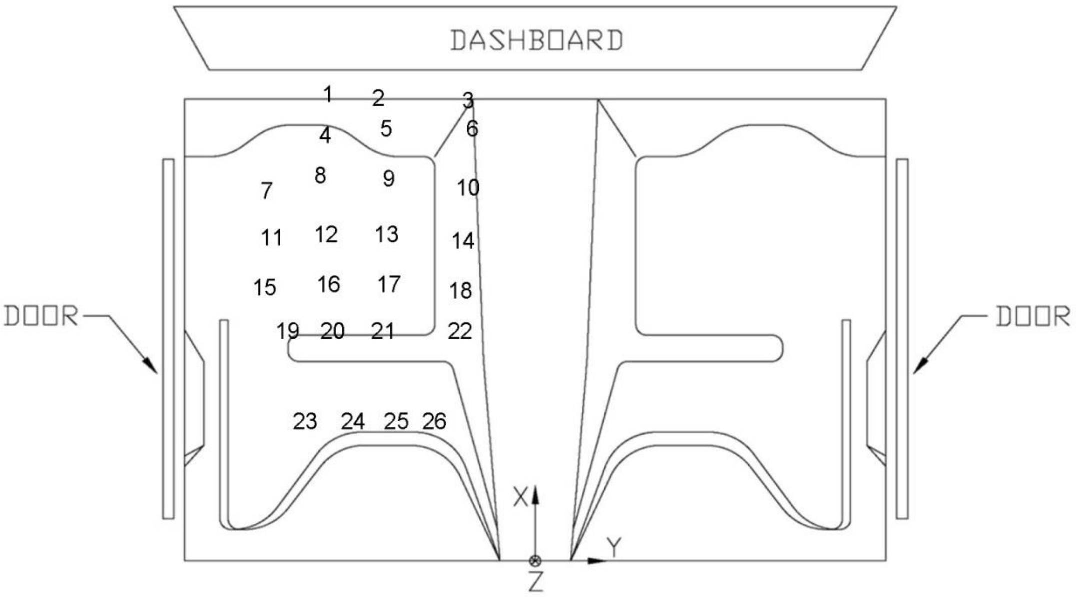


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. MWTC-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MWTC-1
VEHICLE: 1100C

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	34 3/4	-49 3/4	22	35	-50	22	1/4	- 1/4	0
	A2	35 1/4	-32 1/4	22 1/4	35 1/2	-32 1/4	21 3/4	1/4	0	- 1/2
	A3	35	-27	22 1/2	35	-27	22	0	0	- 1/2
	A4	30 1/4	-50 3/4	17 1/2	30 1/4	-51	17 1/2	0	- 1/4	0
	A5	29	-34 1/4	15 1/2	29	-34	15 1/2	0	1/4	0
	A6	27	-30	15	27	-30	14 1/4	0	0	- 3/4
SIDE PANEL	B1	18 1/2	-24 1/4	1	18 1/2	-24 1/4	1	0	0	0
	B2	19 1/2	-24 1/2	3	19 1/4	-24 1/4	3	- 1/4	1/4	0
	B3	22 1/2	-24 3/4	- 3/4	22 1/2	-25 1/2	-1	0	- 3/4	- 1/4
IMPACT SIDE DOOR	C1	4 1/4	-34 1/4	22	4 1/2	-34 1/2	22 1/4	1/4	- 1/4	1/4
	C2	14 3/4	-33 1/4	21 1/2	14 1/2	-33	21 1/4	- 1/4	1/4	- 1/4
	C3	25 3/4	-31 3/4	20 3/4	25 1/2	-32	20 1/2	- 1/4	- 1/4	- 1/4
	C4	5 1/4	-28 1/4	11 1/2	5 1/2	-28 1/4	11 1/2	1/4	0	0
	C5	11	-28	11 1/2	11	-28	11 1/2	0	0	0
	C6	19	-27 1/4	11 1/2	19	-27 1/4	11 1/2	0	0	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

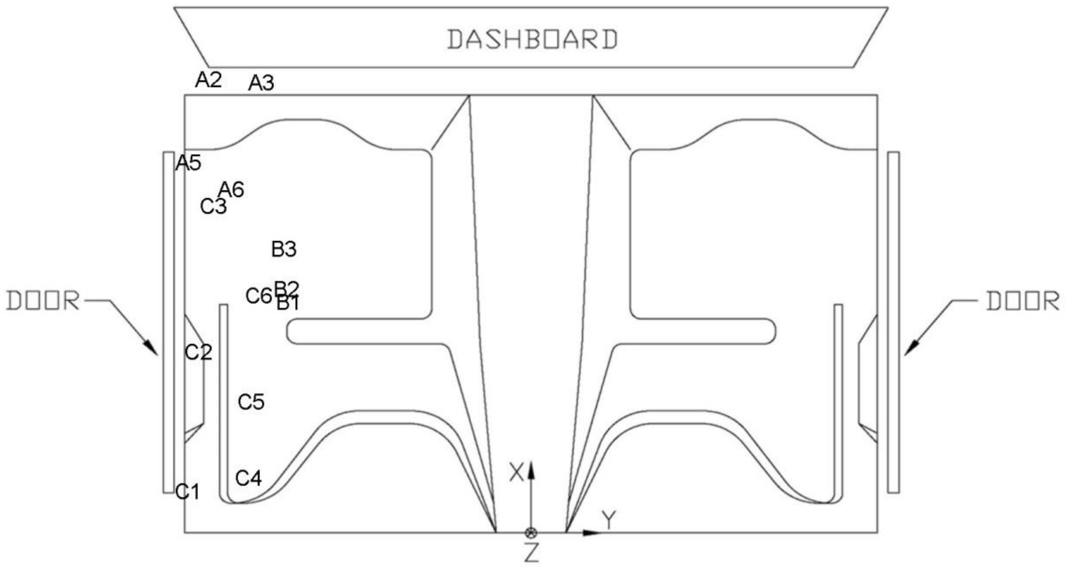


Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. MWTC-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MWTC-1
VEHICLE: 1100C

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	49 3/4	-49 1/2	22 1/2	50	-49 1/2	22 1/4	1/4	0	- 1/4
	A2	48 3/4	-31 1/4	22 1/2	48 3/4	-31 1/2	22	0	- 1/4	- 1/2
	A3	48 1/4	-25 3/4	22 1/2	48 1/4	-26	22	0	- 1/4	- 1/2
	A4	46	-50 1/4	18	46	-51	17 1/2	0	- 3/4	- 1/2
	A5	43 1/2	-33	15 3/4	43 1/2	-33 1/4	15 1/2	0	- 1/4	- 1/4
	A6	41 1/4	-28 3/4	15	41	-29	14 3/4	- 1/4	- 1/4	- 1/4
SIDE PANEL	B1	28 1/4	-25	1 3/4	28 1/2	-24 3/4	1	1/4	1/4	- 3/4
	B2	29 1/4	-25 1/2	3 3/4	29	-25 1/4	3	- 1/4	1/4	- 3/4
	B3	32 1/2	-27	0	32 1/2	-27	- 1/2	0	0	- 1/2
IMPACT SIDE DOOR	C1	9 1/4	-38	22	9	-38	21 1/2	- 1/4	0	- 1/2
	C2	19 1/2	-36 3/4	21 1/2	19 1/2	-37	21	0	- 1/4	- 1/2
	C3	30 1/2	-36 1/2	21	30 1/4	-36 1/2	20 3/4	- 1/4	0	- 1/4
	C4	10 1/2	-32 1/2	11 1/4	10 1/2	-32 3/4	11	0	- 1/4	- 1/4
	C5	16 1/4	-32 1/4	11 1/2	16 1/4	-32 1/4	11	0	0	- 1/2
	C6	24 1/4	-32 1/4	11 3/4	24 1/4	-32 1/2	11 1/4	0	- 1/4	- 1/2
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

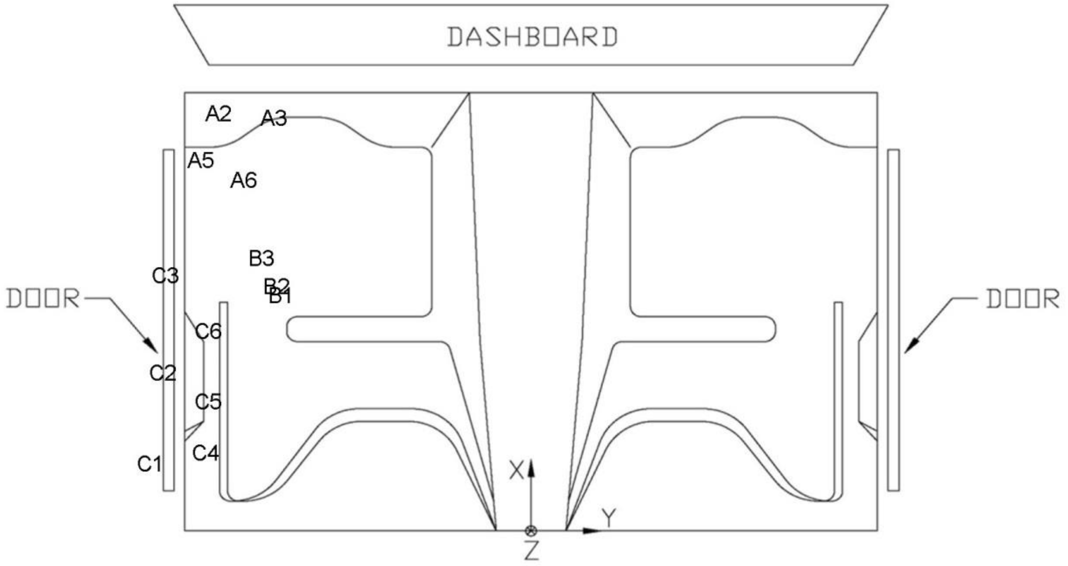
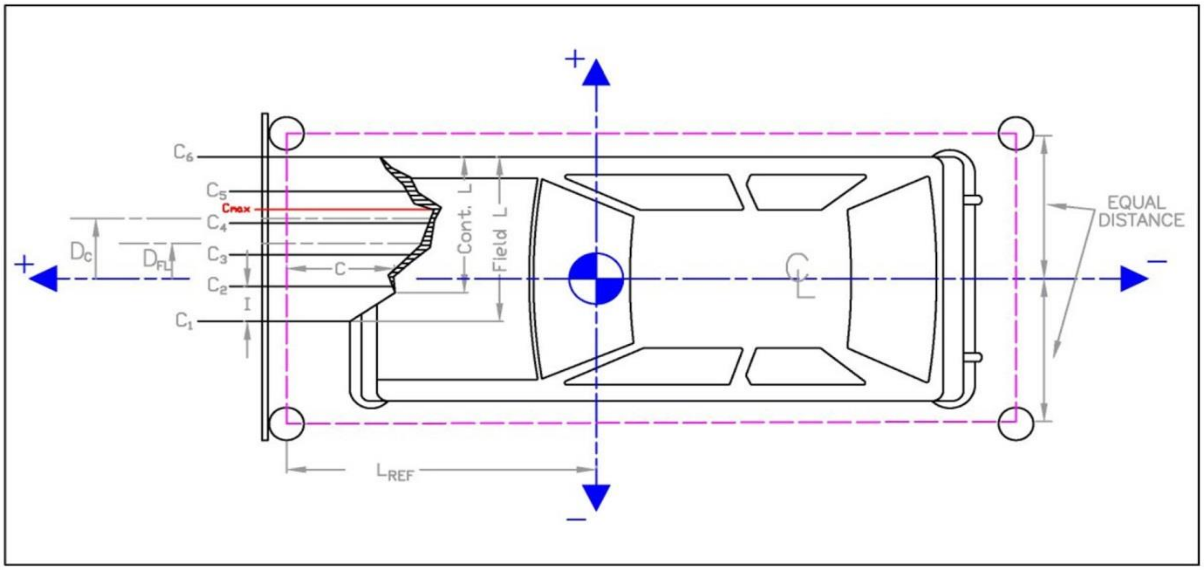


Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. MWTC-1

Date: 8/22/2012
Test Number: MWTC-1
Make: Kia Rio Sedan
Model: 1100C
Year: 2007



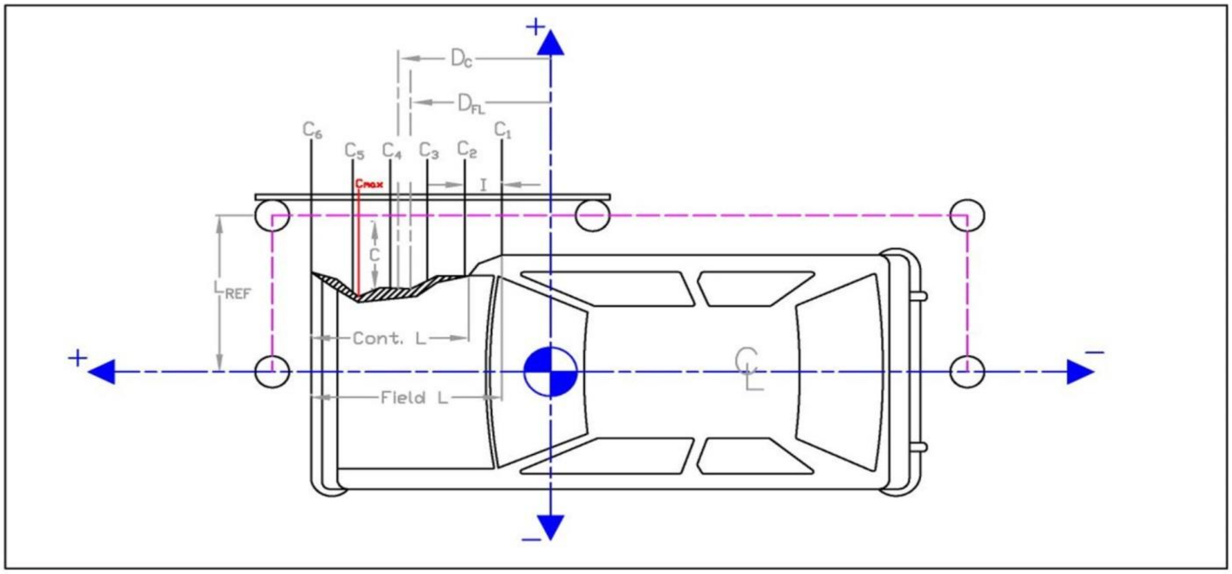
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	74	(1880)
Width of contact and induced crush - Field L:	61 1/4	(1556)
Crush measurement spacing interval (L/5) - I:	12 1/4	(311)
Distance from center of vehicle to center of Field L - D_{FL}:	-1	-(25)
Width of Contact Damage:	61 1/4	(1556)
Distance from center of vehicle to center of contect damage - D_C:	0	()

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

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-31 5/8	-(803)	28 1/5	(716)	-1	-(23)	NA	NA
C_2	15 1/2	(394)	-19 3/8	-(492)	11 3/5	(294)			4 5/6	(123)
C_3	17 3/4	(451)	-7 1/8	-(181)	9 4/9	(240)			9 2/9	(234)
C_4	16	(406)	5 1/8	(130)	9 1/3	(237)			7 3/5	(193)
C_5	9 3/4	(248)	17 3/8	(441)	11	(279)			- 1/3	-(8)
C_6	na	NA	29 5/8	(752)	18 2/7	(464)			NA	NA
C_{MAX}	18	(457)	-3	-(76)	9 1/4	(235)			9 2/3	(246)

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

Date: 8/22/2012
Test Number: MWTC-1
Make: Kia Rio Sedan
Model: 1100C
Year: 2007

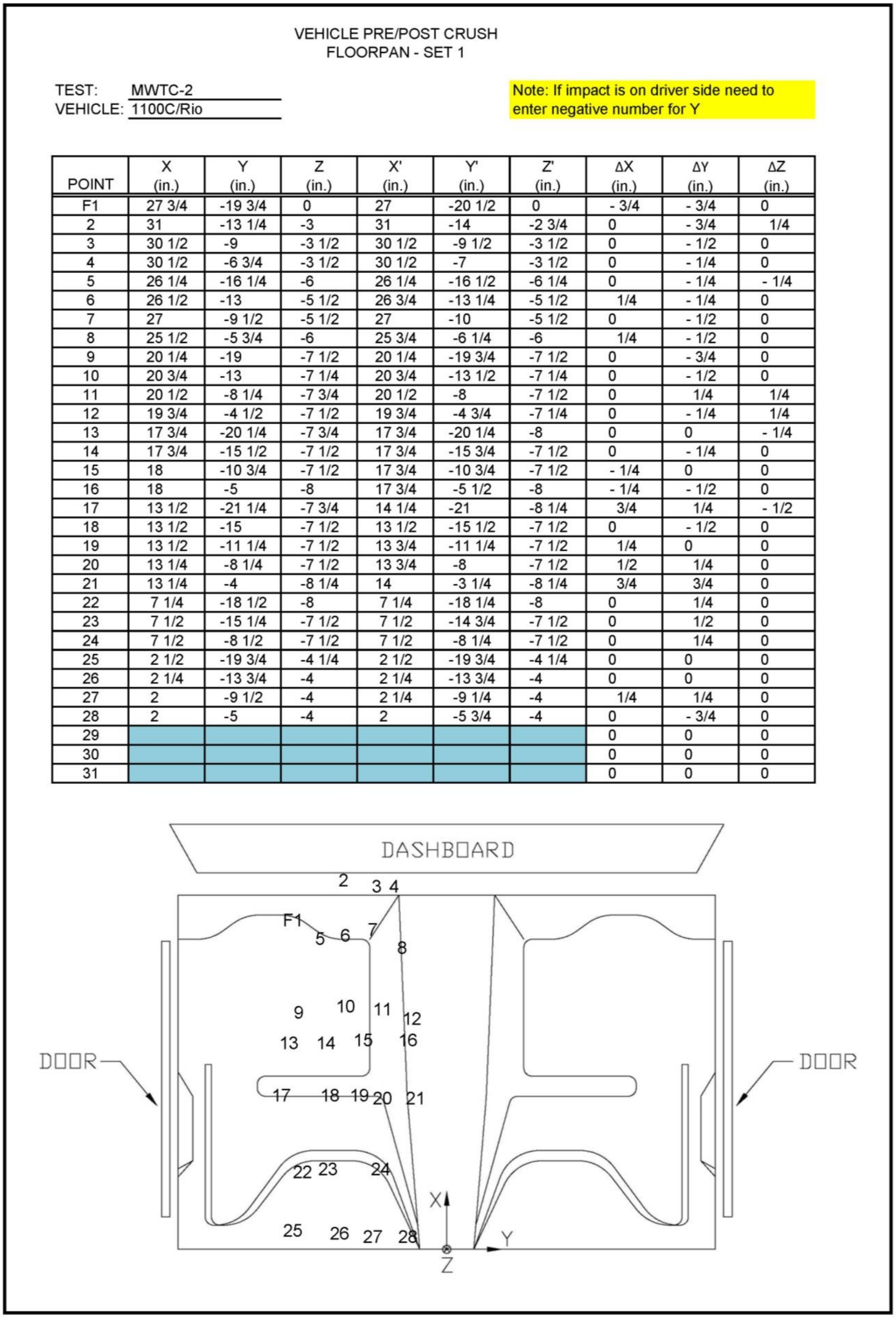


	in.	(mm)
Distance from centerline to reference line - L_{REF}:	42	(1067)
Width of contact and induced crush - Field L:	69	(1753)
Crush measurement spacing interval (L/5) - I:	13.8	(351)
Distance from vehicle c.g. to center of Field L - D_{FL}:	34.5	(876)
Width of Contact Damage:	69	(1753)
Distance from vehicle c.g. to center of contect damage - D_C:	34.5	(876)

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	10	(254)	0	()	3.13	(79)	6	(152)	0.9	(22)
C_2	10.5	(267)	13.8	(351)	3.13	(79)			1.4	(35)
C_3	12.5	(318)	27.6	(701)	4.38	(111)			2.1	(54)
C_4	21.5	(546)	41.4	(1052)	4.00	(102)			11.5	(292)
C_5	22	(559)	55.2	(1402)	4.75	(121)			11.3	(286)
C_6	na	NA	69	(1753)	25.50	(648)			NA	NA
C_{MAX}	21.5	(546)	41.4	(1052)	4.00	(102)			11.5	(292)

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



VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MWTC-2
VEHICLE: 1100C/Rio

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.)
F1	27 3/4	-19 3/4	0	27	-20 1/2	0	- 3/4	- 3/4	0
2	31	-13 1/4	-3	31	-14	-2 3/4	0	- 3/4	1/4
3	30 1/2	-9	-3 1/2	30 1/2	-9 1/2	-3 1/2	0	- 1/2	0
4	30 1/2	-6 3/4	-3 1/2	30 1/2	-7	-3 1/2	0	- 1/4	0
5	26 1/4	-16 1/4	-6	26 1/4	-16 1/2	-6 1/4	0	- 1/4	- 1/4
6	26 1/2	-13	-5 1/2	26 3/4	-13 1/4	-5 1/2	1/4	- 1/4	0
7	27	-9 1/2	-5 1/2	27	-10	-5 1/2	0	- 1/2	0
8	25 1/2	-5 3/4	-6	25 3/4	-6 1/4	-6	1/4	- 1/2	0
9	20 1/4	-19	-7 1/2	20 1/4	-19 3/4	-7 1/2	0	- 3/4	0
10	20 3/4	-13	-7 1/4	20 3/4	-13 1/2	-7 1/4	0	- 1/2	0
11	20 1/2	-8 1/4	-7 3/4	20 1/2	-8	-7 1/2	0	1/4	1/4
12	19 3/4	-4 1/2	-7 1/2	19 3/4	-4 3/4	-7 1/4	0	- 1/4	1/4
13	17 3/4	-20 1/4	-7 3/4	17 3/4	-20 1/4	-8	0	0	- 1/4
14	17 3/4	-15 1/2	-7 1/2	17 3/4	-15 3/4	-7 1/2	0	- 1/4	0
15	18	-10 3/4	-7 1/2	17 3/4	-10 3/4	-7 1/2	- 1/4	0	0
16	18	-5	-8	17 3/4	-5 1/2	-8	- 1/4	- 1/2	0
17	13 1/2	-21 1/4	-7 3/4	14 1/4	-21	-8 1/4	3/4	1/4	- 1/2
18	13 1/2	-15	-7 1/2	13 1/2	-15 1/2	-7 1/2	0	- 1/2	0
19	13 1/2	-11 1/4	-7 1/2	13 3/4	-11 1/4	-7 1/2	1/4	0	0
20	13 1/4	-8 1/4	-7 1/2	13 3/4	-8	-7 1/2	1/2	1/4	0
21	13 1/4	-4	-8 1/4	14	-3 1/4	-8 1/4	3/4	3/4	0
22	7 1/4	-18 1/2	-8	7 1/4	-18 1/4	-8	0	1/4	0
23	7 1/2	-15 1/4	-7 1/2	7 1/2	-14 3/4	-7 1/2	0	1/2	0
24	7 1/2	-8 1/2	-7 1/2	7 1/2	-8 1/4	-7 1/2	0	1/4	0
25	2 1/2	-19 3/4	-4 1/4	2 1/2	-19 3/4	-4 1/4	0	0	0
26	2 1/4	-13 3/4	-4	2 1/4	-13 3/4	-4	0	0	0
27	2	-9 1/2	-4	2 1/4	-9 1/4	-4	1/4	1/4	0
28	2	-5	-4	2	-5 3/4	-4	0	- 3/4	0
29							0	0	0
30							0	0	0
31							0	0	0

Figure D-7. Floor Pan Deformation Data – Set 1, Test No. MWTC-2

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MWTC-2
VEHICLE: 1100C/Rio

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	36 3/4	-24 1/2	0	36	-25	0	- 3/4	- 1/2	0
2	40	-18	-3	40	-18 1/2	-3	0	- 1/2	0
3	39 1/2	-13 3/4	-3 1/2	39 1/2	-14 3/4	-3 1/2	0	-1	0
4	39 1/4	-10	-3 3/4	39 1/4	-11	-4	0	-1	- 1/4
5	35 1/4	-21	-6	35 1/4	-21 1/2	-6 1/4	0	- 1/2	- 1/4
6	35 1/2	-17	-5 1/2	35 1/2	-17 3/4	-5 1/2	0	- 3/4	0
7	36	-14	-5 1/2	36	-14 3/4	-5 3/4	0	- 3/4	- 1/4
8	34 1/2	-9 1/2	-6 1/4	34 3/4	-10 1/4	-6 1/2	1/4	- 3/4	- 1/4
9	29 1/4	-24 1/2	-7 1/4	29 1/4	-24 3/4	-7 1/2	0	- 1/4	- 1/4
10	29 3/4	-17 3/4	-7 1/2	29 3/4	-18 1/4	-7 1/2	0	- 1/2	0
11	29 1/2	-12 1/2	-7 3/4	29 1/2	-13	-7 3/4	0	- 1/2	0
12	28 3/4	-9 1/2	-7 1/2	28 3/4	-9 1/2	-7 3/4	0	0	- 1/4
13	26 3/4	-25 1/2	-7 1/2	27	-25 3/4	-8	1/4	- 1/4	- 1/2
14	26 3/4	-20 1/2	-7 1/2	27	-20 3/4	-7 3/4	1/4	- 1/4	- 1/4
15	27	-15	-7 3/4	27	-15 1/2	-8	0	- 1/2	- 1/4
16	26 1/2	-9 3/4	-8 1/4	26 3/4	-10 1/2	-8 1/4	1/4	- 3/4	0
17	22 1/2	-26	-7 3/4	23 1/4	-25 3/4	-8	3/4	1/4	- 1/4
18	22 1/2	-20 1/2	-7 1/2	22 3/4	-20 1/2	-7 3/4	1/4	0	- 1/4
19	22 1/2	-16 1/4	-7 1/2	22 3/4	-16 1/4	-7 3/4	1/4	0	- 1/4
20	22 1/4	-13	-7 3/4	22 3/4	-13 1/2	-7 3/4	1/2	- 1/2	0
21	22	-8 3/4	-8 1/2	22 3/4	-9 1/2	-8 3/4	3/4	- 3/4	- 1/4
22	16 1/4	-23 1/2	-7 3/4	15 3/4	-23 3/4	-8	- 1/2	- 1/4	- 1/4
23	16 1/2	-20 1/2	-7 1/2	16 1/4	-20 1/2	-7 3/4	- 1/4	0	- 1/4
24	16 1/2	-13	-7 3/4	16 1/2	-13 1/2	-7 3/4	0	- 1/2	0
25	11 3/4	-24 3/4	-4	11 1/2	-24 1/2	-4	- 1/4	1/4	0
26	11 1/4	-18 3/4	-4	11	-18 1/2	-4	- 1/4	1/4	0
27	11	-14 1/4	-4	11	-14 1/4	-4 1/4	0	0	- 1/4
28	11	-10	-4 1/4	11	-10	-4 1/2	0	0	- 1/4
29							0	0	0
30							0	0	0
31							0	0	0

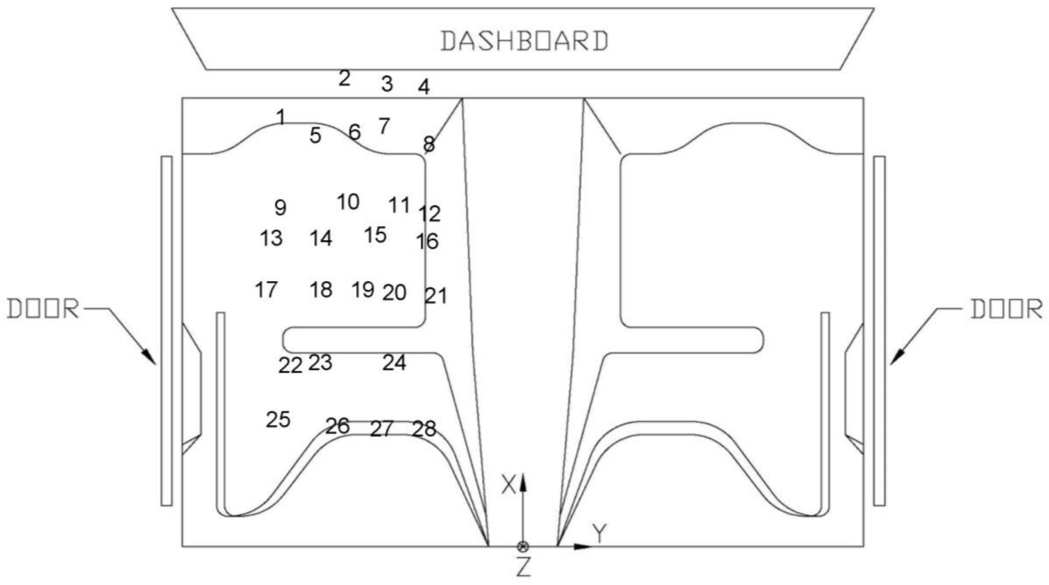
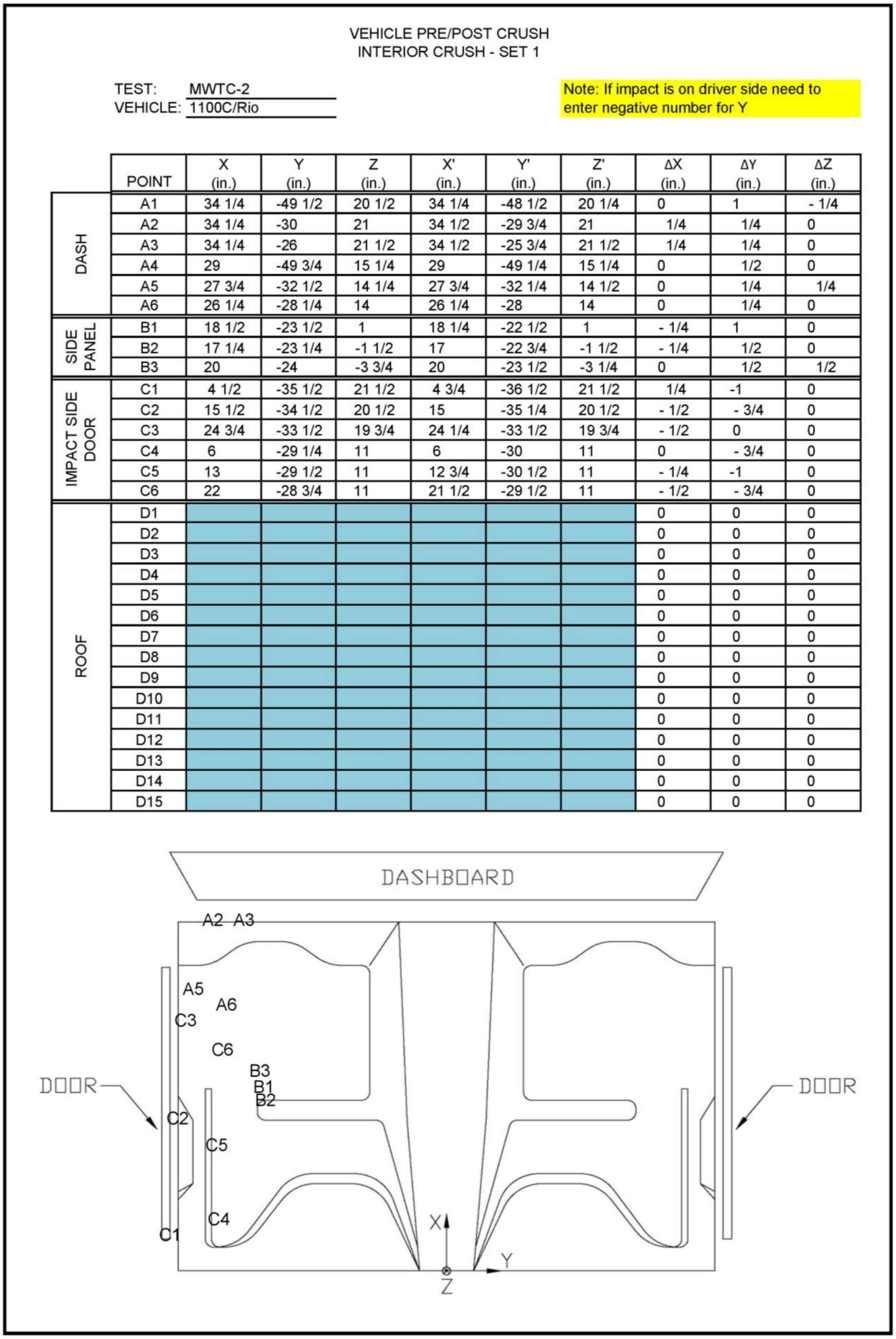


Figure D-8. Floor Pan Deformation Data – Set 2, Test No. MWTC-2



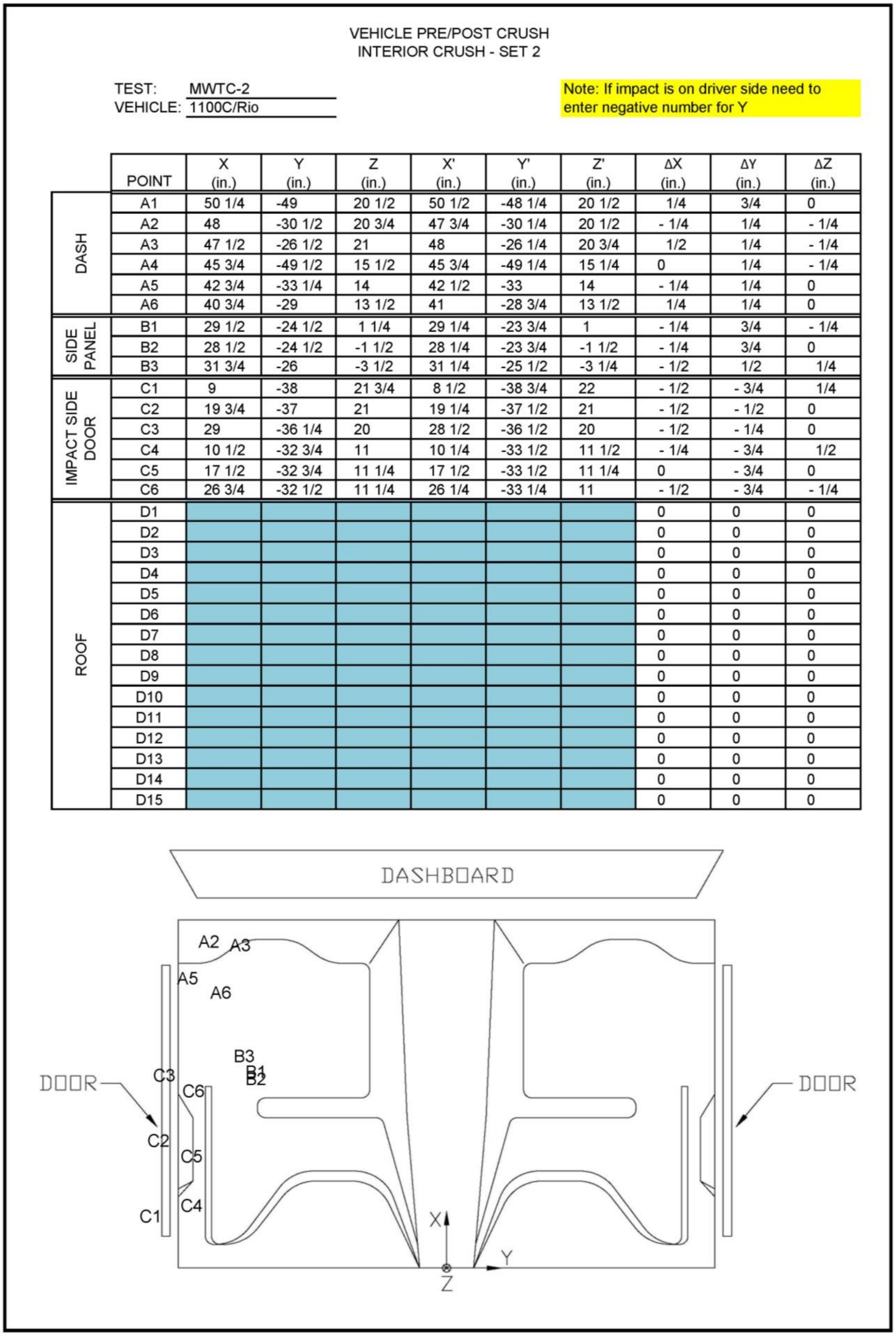
VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MWTC-2
VEHICLE: 1100C/Rio

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	34 1/4	-49 1/2	20 1/2	34 1/4	-48 1/2	20 1/4	0	1	- 1/4
	A2	34 1/4	-30	21	34 1/2	-29 3/4	21	1/4	1/4	0
	A3	34 1/4	-26	21 1/2	34 1/2	-25 3/4	21 1/2	1/4	1/4	0
	A4	29	-49 3/4	15 1/4	29	-49 1/4	15 1/4	0	1/2	0
	A5	27 3/4	-32 1/2	14 1/4	27 3/4	-32 1/4	14 1/2	0	1/4	1/4
	A6	26 1/4	-28 1/4	14	26 1/4	-28	14	0	1/4	0
SIDE PANEL	B1	18 1/2	-23 1/2	1	18 1/4	-22 1/2	1	- 1/4	1	0
	B2	17 1/4	-23 1/4	-1 1/2	17	-22 3/4	-1 1/2	- 1/4	1/2	0
	B3	20	-24	-3 3/4	20	-23 1/2	-3 1/4	0	1/2	1/2
IMPACT SIDE DOOR	C1	4 1/2	-35 1/2	21 1/2	4 3/4	-36 1/2	21 1/2	1/4	-1	0
	C2	15 1/2	-34 1/2	20 1/2	15	-35 1/4	20 1/2	- 1/2	- 3/4	0
	C3	24 3/4	-33 1/2	19 3/4	24 1/4	-33 1/2	19 3/4	- 1/2	0	0
	C4	6	-29 1/4	11	6	-30	11	0	- 3/4	0
	C5	13	-29 1/2	11	12 3/4	-30 1/2	11	- 1/4	-1	0
	C6	22	-28 3/4	11	21 1/2	-29 1/2	11	- 1/2	- 3/4	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

Figure D-9. Occupant Compartment Deformation Data – Set 1, Test No. MWTC-2



VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MWTC-2
VEHICLE: 1100C/Rio

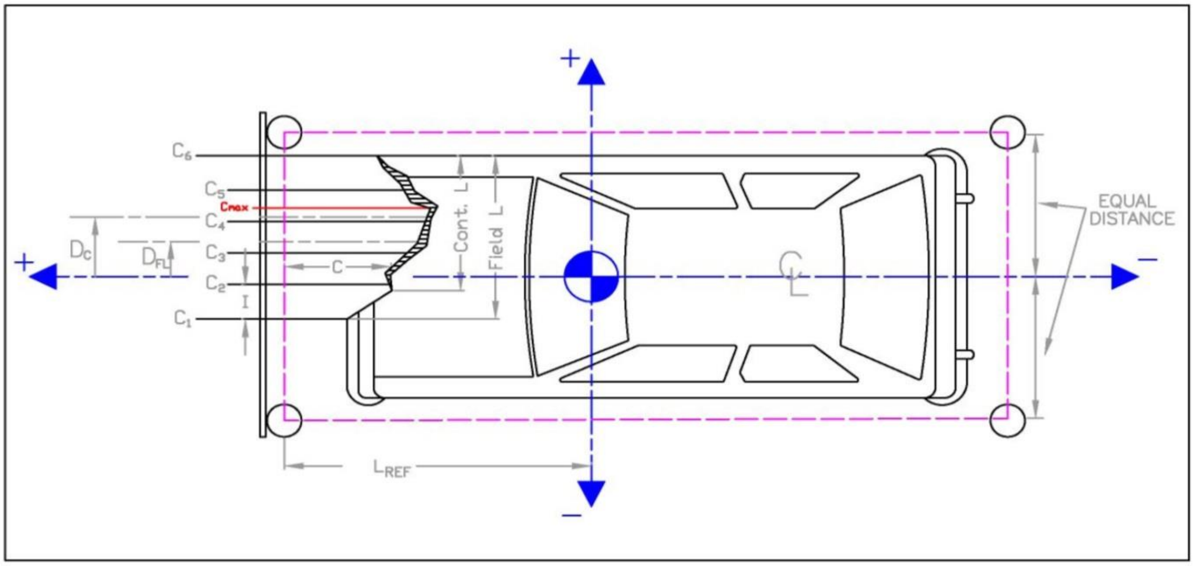
Note: If impact is on driver side need to enter negative number for Y

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	50 1/4	-49	20 1/2	50 1/2	-48 1/4	20 1/2	1/4	3/4	0
	A2	48	-30 1/2	20 3/4	47 3/4	-30 1/4	20 1/2	- 1/4	1/4	- 1/4
	A3	47 1/2	-26 1/2	21	48	-26 1/4	20 3/4	1/2	1/4	- 1/4
	A4	45 3/4	-49 1/2	15 1/2	45 3/4	-49 1/4	15 1/4	0	1/4	- 1/4
	A5	42 3/4	-33 1/4	14	42 1/2	-33	14	- 1/4	1/4	0
	A6	40 3/4	-29	13 1/2	41	-28 3/4	13 1/2	1/4	1/4	0
SIDE PANEL	B1	29 1/2	-24 1/2	1 1/4	29 1/4	-23 3/4	1	- 1/4	3/4	- 1/4
	B2	28 1/2	-24 1/2	-1 1/2	28 1/4	-23 3/4	-1 1/2	- 1/4	3/4	0
	B3	31 3/4	-26	-3 1/2	31 1/4	-25 1/2	-3 1/4	- 1/2	1/2	1/4
IMPACT SIDE DOOR	C1	9	-38	21 3/4	8 1/2	-38 3/4	22	- 1/2	- 3/4	1/4
	C2	19 3/4	-37	21	19 1/4	-37 1/2	21	- 1/2	- 1/2	0
	C3	29	-36 1/4	20	28 1/2	-36 1/2	20	- 1/2	- 1/4	0
	C4	10 1/2	-32 3/4	11	10 1/4	-33 1/2	11 1/2	- 1/4	- 3/4	1/2
	C5	17 1/2	-32 3/4	11 1/4	17 1/2	-33 1/2	11 1/4	0	- 3/4	0
	C6	26 3/4	-32 1/2	11 1/4	26 1/4	-33 1/4	11	- 1/2	- 3/4	- 1/4
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

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

Date: 5/20/2013 **Test Number:** MWTC-2

Make: Kia **Model:** 1100C/Rio **Year:** 2007



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	77 7/8	(1978)
Width of contact and induced crush - Field L:	62	(1575)
Crush measurement spacing interval (L/5) - I:	12 2/5	(315)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	31	(787)
Distance from center of vehicle to center of contect damage - D_C:	15 1/2	(394)

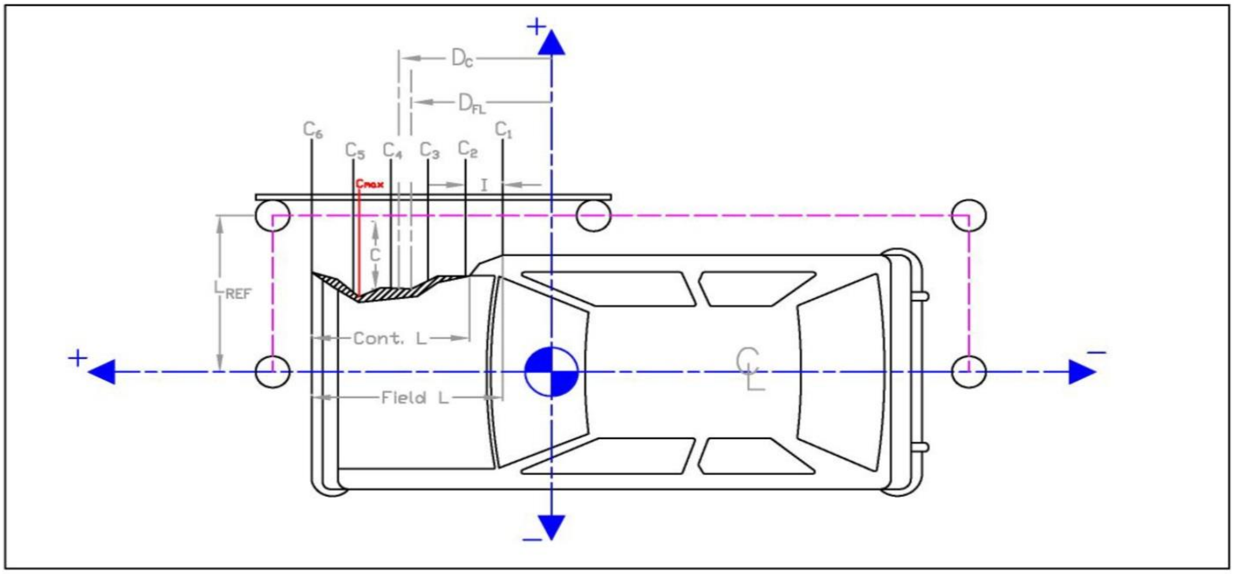
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-31	-(787)	24 1/3	(618)	8/9	(23)	NA	NA
C_2	25	(635)	-18 3/5	-(472)	11 1/3	(289)			12 3/4	(324)
C_3	6 1/4	(159)	-6 1/5	-(157)	9 2/5	(239)			-4	-(102)
C_4	3	(76)	6 1/5	(157)	9 3/8	(238)			-7 1/4	-(185)
C_5	4 1/2	(114)	18 3/5	(472)	11 2/7	(287)			-7 2/3	-(195)
C_6	23	(584)	31	(787)	24 1/3	(618)			-2 1/5	-(56)
C_{MAX}	25	(635)	-18 1/2	-(470)	11 2/7	(287)			12 5/6	(326)

Figure D-11. Exterior Vehicle Crush (NASS) - Front, Test No. MWTC-2

Date: 5/20/2013 **Test Number:** MWTC-2

Make: Kia **Model:** 1100C/Rio **Year:** 2007



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	34.75	(883)
Width of contact and induced crush - Field L:	69	(1753)
Crush measurement spacing interval (L/5) - I:	13.8	(351)
Distance from vehicle c.g. to center of Field L - D_{FL}:	34.5	(876)
Width of Contact Damage:	69	(1753)
Distance from vehicle c.g. to center of contect damage - D_C:	34.5	(876)

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	2.75	(70)	0	()	3.13	(79)	-1.25	-(32)	0.9	(22)
C_2	3.75	(95)	13.8	(351)	3.13	(79)			1.9	(48)
C_3	na	NA	27.6	(701)	4.38	(111)			NA	NA
C_4	na	NA	41.4	(1052)	4.00	(102)			NA	NA
C_5	15.75	(400)	55.2	(1402)	4.75	(121)			12.3	(311)
C_6	na	NA	69	(1753)	25.50	(648)			NA	NA
C_{MAX}	15.75	(400)	55.2	(1402)	4.75	(121)			12.3	(311)

Figure D-12. Exterior Vehicle Crush (NASS) - Side, Test No. MWTC-2

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MWTC-3
VEHICLE: 2270P

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

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

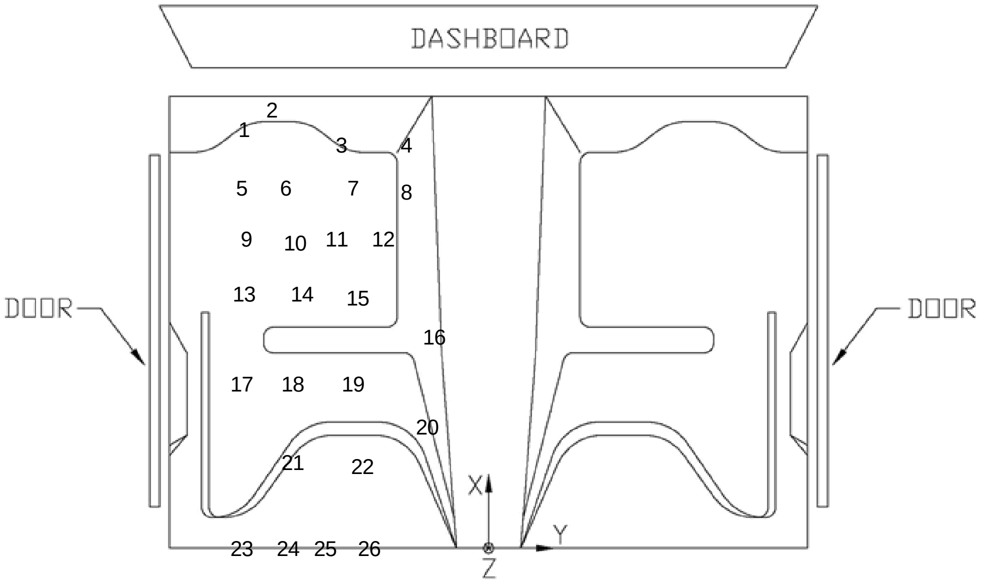


Figure D-13. Floor Pan Deformation Data – Set 1, Test No. MWTC-3

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MWTC-3
VEHICLE: 2270P

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

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	43 1/2	-32 3/4	-1 3/4	43	-32 1/4	-1	- 1/2	1/2	3/4
2	45	-29 3/4	-2	45	-29 3/4	-1 3/4	0	0	1/4
3	43	-22 1/2	-3 3/4	43	-22 3/4	-3 1/2	0	- 1/4	1/4
4	42 3/4	-15 1/2	-3	42 3/4	-16 1/4	-3	0	- 3/4	0
5	40	-33	-5 1/2	40	-33	-5 1/4	0	0	1/4
6	40	-28 1/4	-5 1/2	40 1/4	-28 1/2	-5 1/4	1/4	- 1/4	1/4
7	40	-21 1/4	-5 1/4	40	-21 1/4	-5	0	0	1/4
8	40	-15 1/2	-5 1/4	40	-16	-5	0	- 1/2	1/4
9	36 3/4	-32 3/4	-7 1/4	36 3/4	-33	-6 3/4	0	- 1/4	1/2
10	37	-27 1/2	-7	36 3/4	-28	-6 3/4	- 1/4	- 1/2	1/4
11	36 3/4	-23	-7	36 3/4	-23 3/4	-6 3/4	0	- 3/4	1/4
12	36 3/4	-18	-7	36 3/4	-17 1/2	-6 3/4	0	1/2	1/4
13	33 1/4	-33	-7 1/2	33 1/2	-32 1/2	-7	1/4	1/2	1/2
14	33 1/4	-27	-7 1/2	33 1/2	-27	-7	1/4	0	1/2
15	33 1/4	-20 3/4	-7 1/4	33 1/4	-20 1/2	-7	0	1/4	1/4
16	30 1/4	-12 1/4	- 1/2	30 1/4	-12 1/4	0	0	0	1/2
17	27 1/2	-33 1/4	-7 3/4	27 1/4	-33	-7	- 1/4	1/4	3/4
18	27 3/4	-27 1/2	-7 1/2	27 1/4	-27 1/2	-7 1/4	- 1/2	0	1/4
19	27 3/4	-21 1/4	-7 1/2	27 1/4	-21 1/4	-7 1/4	- 1/2	0	1/4
20	24 3/4	-13 1/4	-1 1/2	24 1/2	-13	-1 1/4	- 1/4	1/4	1/4
21	22 1/2	-27 3/4	-7 3/4	22 1/2	-27 1/2	-7 1/2	0	1/4	1/4
22	22 1/2	-20 1/2	-7 3/4	22 1/2	-20	-7 1/2	0	1/2	1/4
23	17 1/4	-33 1/4	-4 1/4	17 1/4	-32 3/4	-3 3/4	0	1/2	1/2
24	17 1/4	-28 1/2	-4	17 1/4	-28	-3 3/4	0	1/2	1/4
25	17 1/4	-24 1/2	-4 1/4	17 1/4	-24	-3 3/4	0	1/2	1/2
26	17	-19 1/2	-4	17	-19 1/2	-3 3/4	0	0	1/4
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28							0	0	0
29							0	0	0
30							0	0	0
31							0	0	0

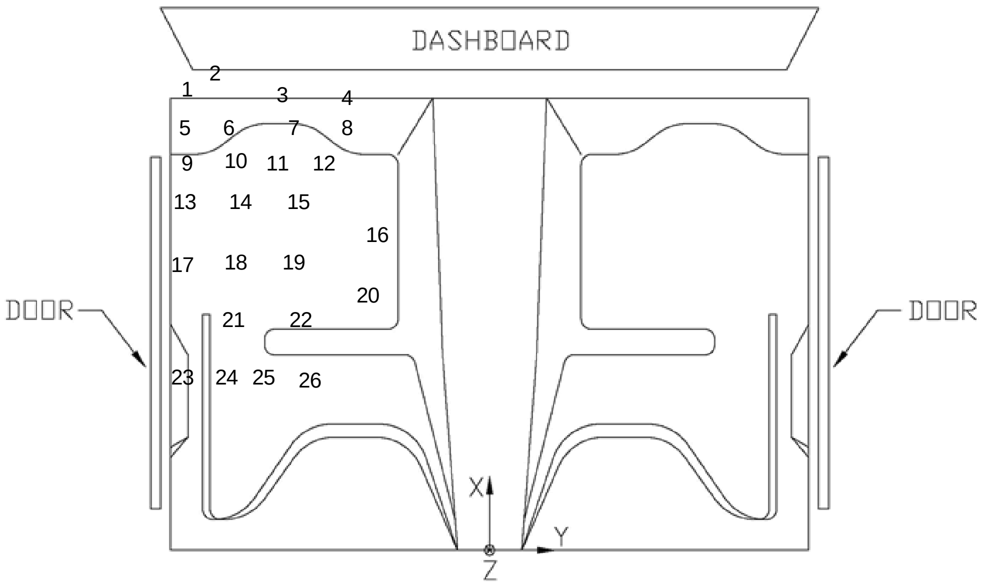


Figure D-14. Floor Pan Deformation Data – Set 2, Test No. MWTC-3

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MWTC-3
VEHICLE: 2270P

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	40 1/2	-54	26 3/4	40 3/4	-53 1/2	27	1/4	1/2	1/4
	A2	40 1/2	-41 1/2	26 1/2	40 1/2	-41 1/4	27	0	1/4	1/2
	A3	40 1/4	-34 3/4	27	40 1/2	-34 1/2	27 1/2	1/4	1/4	1/2
	A4	36	-56 3/4	21	36	-56 1/4	21 1/4	0	1/2	1/4
	A5	32 3/4	-45	16	32 3/4	-45 1/4	16 1/2	0	- 1/4	1/2
	A6	33 1/2	-35	18 3/4	33 3/4	-35 1/2	19 3/4	1/4	- 1/2	1
SIDE PANEL	B1	37 1/4	-24 1/2	1 1/4	37	-22	1 3/4	- 1/4	2 1/2	1/2
	B2	37 1/4	-24 3/4	-2 3/4	37 1/4	-23 1/4	-2 3/4	0	1 1/2	0
	B3	39 3/4	-24 3/4	-1 3/4	39 1/2	-23	-1 1/2	- 1/4	1 3/4	1/4
IMPACT SIDE DOOR	C1	8 1/2	-41	20 3/4	7 3/4	-42 1/2	20 3/4	- 3/4	-1 1/2	0
	C2	17 1/2	-41	20 1/4	16 1/2	-42	20 1/2	-1	-1	1/4
	C3	24 3/4	-41	20 1/4	23 1/2	-41 1/2	20 1/2	-1 1/4	- 1/2	1/4
	C4	7	-35	5	6	-36	5	-1	-1	0
	C5	18 1/2	-35 1/4	3 1/4	17 1/4	-34 1/4	3 1/2	-1 1/4	1	1/4
	C6	23 1/2	-35	4 1/2	22 1/4	-33 3/4	4 3/4	-1 1/4	1 1/4	1/4
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

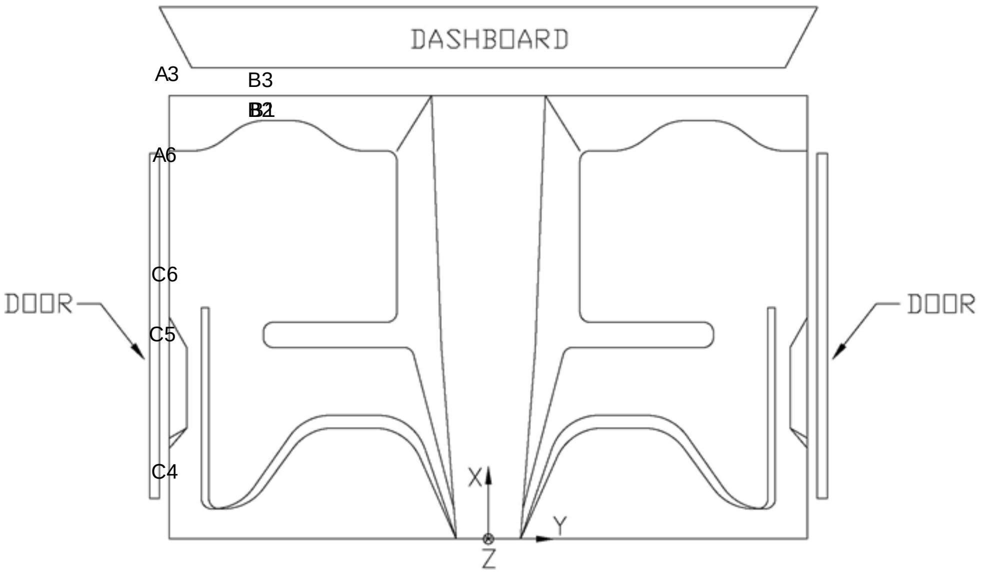


Figure D-15. Occupant Compartment Deformation Data – Set 1, Test No. MWTC-3

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MWTC-3
VEHICLE: 2270P

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	53 1/4	-53 3/4	25 3/4	53 1/4	-54	26 1/2	0	- 1/4	3/4
	A2	53	-41 1/2	26 1/4	53	-41 1/2	26 1/2	0	0	1/4
	A3	50 1/4	-34 3/4	26 3/4	50 1/2	-34 1/2	27	1/4	1/4	1/4
	A4	49 3/4	-56 3/4	20	49 1/2	-56 1/2	20 1/2	- 1/4	1/4	1/2
	A5	46 3/4	-45 1/2	15 1/2	47	-44 3/4	16	1/4	3/4	1/2
	A6	44 1/2	-36	18 3/4	44 3/4	-35	19	1/4	1	1/4
SIDE PANEL	B1	35 3/4	-24 3/4	3/4	35 1/4	-22 1/2	1 1/4	- 1/2	2 1/4	1/2
	B2	35 1/4	-24 3/4	-3 1/2	35 1/4	-23 1/4	-3	0	1 1/2	1/2
	B3	37 3/4	-25 1/4	-2 1/4	37 1/2	-24	-2	- 1/4	1 1/4	1/4
IMPACT SIDE DOOR	C1	12	-45 1/2	19 1/4	11	-46 3/4	20	-1	-1 1/4	3/4
	C2	21 1/4	-44 3/4	19 1/4	20	-45 3/4	19 3/4	-1 1/4	-1	1/2
	C3	28 1/4	-44 1/4	19 1/4	27	-45	20	-1 1/4	- 3/4	3/4
	C4	12 1/2	-40	3 1/2	11 1/4	-40 3/4	4 1/4	-1 1/4	- 3/4	3/4
	C5	24	-39 1/2	2	22 1/2	-38 1/2	2 3/4	-1 1/2	1	3/4
	C6	29	-39 1/2	3 1/2	27 1/2	-38	4	-1 1/2	1 1/2	1/2
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

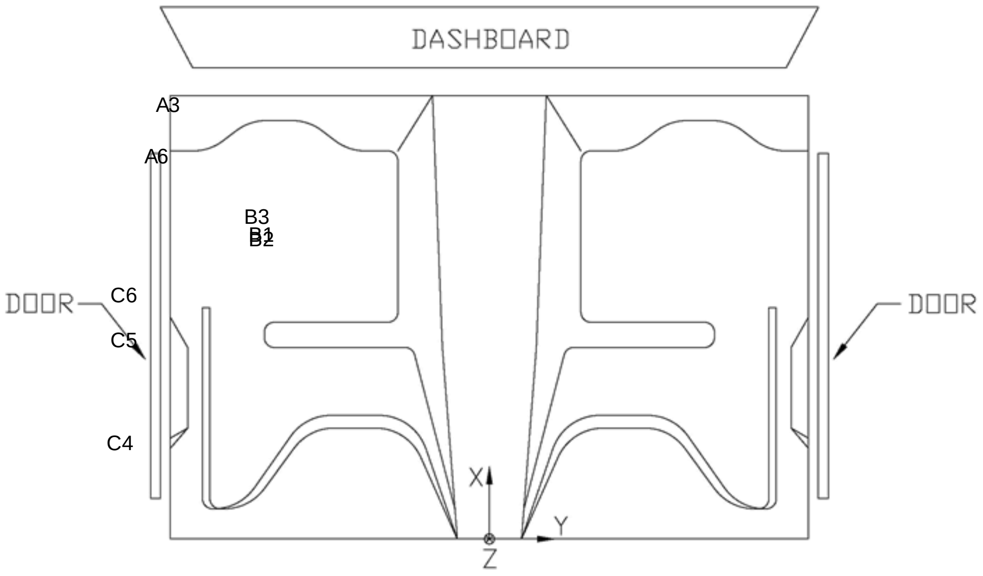
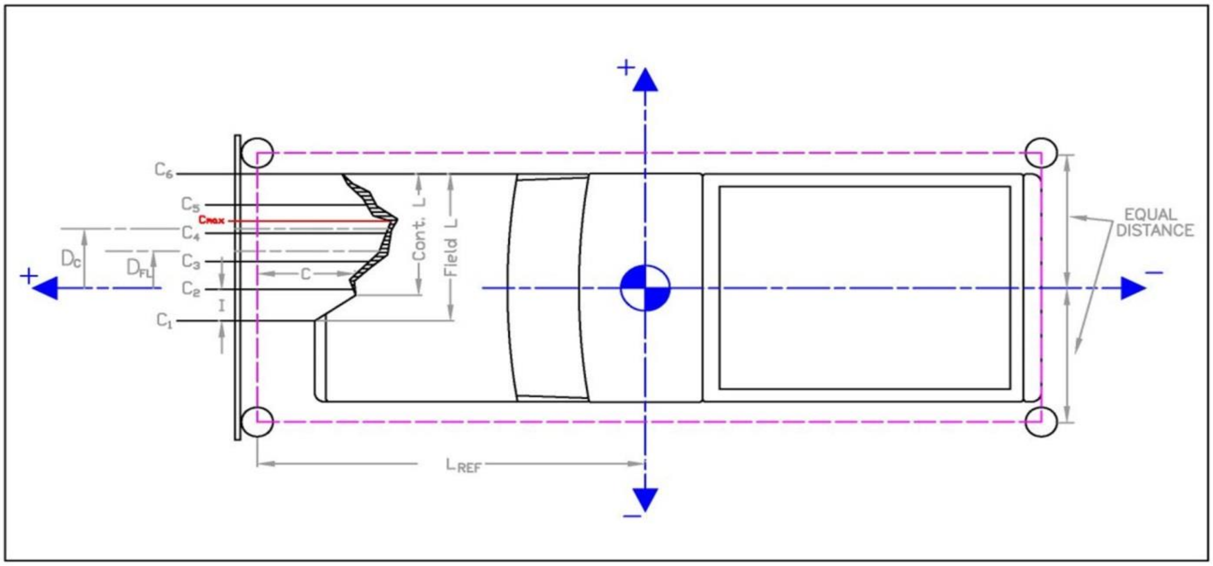


Figure D-16. Occupant Compartment Deformation Data – Set 2, Test No. MWTC-3

Date: 5/17/2013
Test Number: MWTC-3

Make: Dodge Ram 1500 QC
Model: 2270P
Year: 2006



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	113 1/4	(2877)
Width of contact and induced crush - Field L:	39 1/8	(994)
Crush measurement spacing interval (L/5) - I:	7.825	(199)
Distance from center of vehicle to center of Field L - D_{FL}:	19.5625	(497)
Width of Contact Damage:	24 5/8	(625)
Distance from center of vehicle to center of contect damage - D_C:	26 4/5	(681)

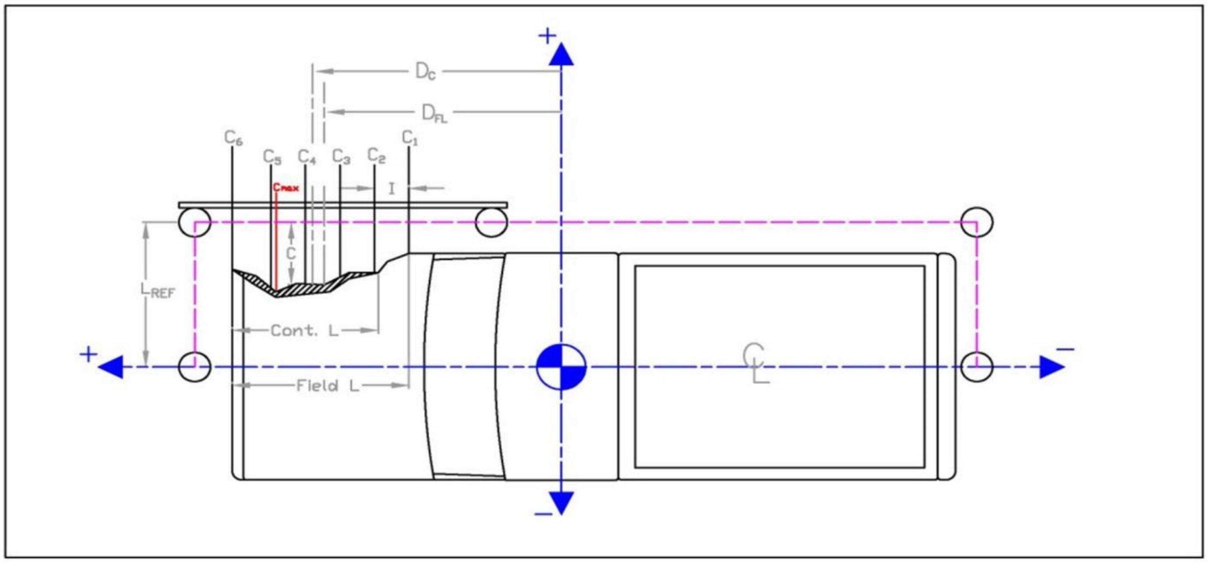
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	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	11 3/4	(298)	0	()	10 1/4	(260)	1 2/3	(43)	- 1/5	-(5)
C_2	11 1/2	(292)	7 5/6	(199)	10 1/2	(266)			- 2/3	-(17)
C_3	13 1/2	(343)	15 2/3	(398)	11 2/3	(296)			1/6	(4)
C_4	20 1/2	(521)	23 1/2	(596)	13 2/5	(340)			5 3/7	(138)
C_5	NA	NA	31 1/3	(795)	17	(431)			NA	NA
C_6	NA	NA	39 1/8	(994)	29	(737)			NA	NA
C_{MAX}	21 3/4	(552)	25	(635)	14	(357)			6	(152)

Figure D-17. Exterior Vehicle Crush (NASS) - Front, Test No. MWTC-3

Date: 5/17/2013 **Test Number:** MWTC-3

Make: Dodge Ram 1500 QC **Model:** 2270P **Year:** 2006



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	45 3/4	(1162)
Width of contact and induced crush - Field L:	227 1/2	(5779)
Crush measurement spacing interval (L/5) - I:	45.5	(1156)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-12	-(305)
Width of Contact Damage:	227 1/2	(5779)
Distance from vehicle c.g. to center of contect damage - D_C:	-8 1/8	-(206)

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	11 1/2	(292)	-125 3/4	-(3194)	16	(406)	-4 1/4	-(108)	- 1/4	-(6)
C_2	8 1/4	(210)	-80 1/4	-(2038)	10 1/2	(267)			2	(51)
C_3	5 1/4	(133)	-34 3/4	-(883)	11 5/8	(295)			-2 1/8	-(54)
C_4	7 1/2	(191)	10 3/4	(273)	11 1/4	(286)			1/2	(13)
C_5	NA	NA	56 1/4	(1429)	10 1/2	(267)			NA	NA
C_6	NA	NA	101 3/4	(2584)	35 1/4	(895)			NA	NA
C_{MAX}	18 1/2]	(470)	78	(1981)	11 1/4	(286)			11 1/2	(292)

Figure D-18. Exterior Vehicle Crush (NASS) - Side, Test No. MWTC-3

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

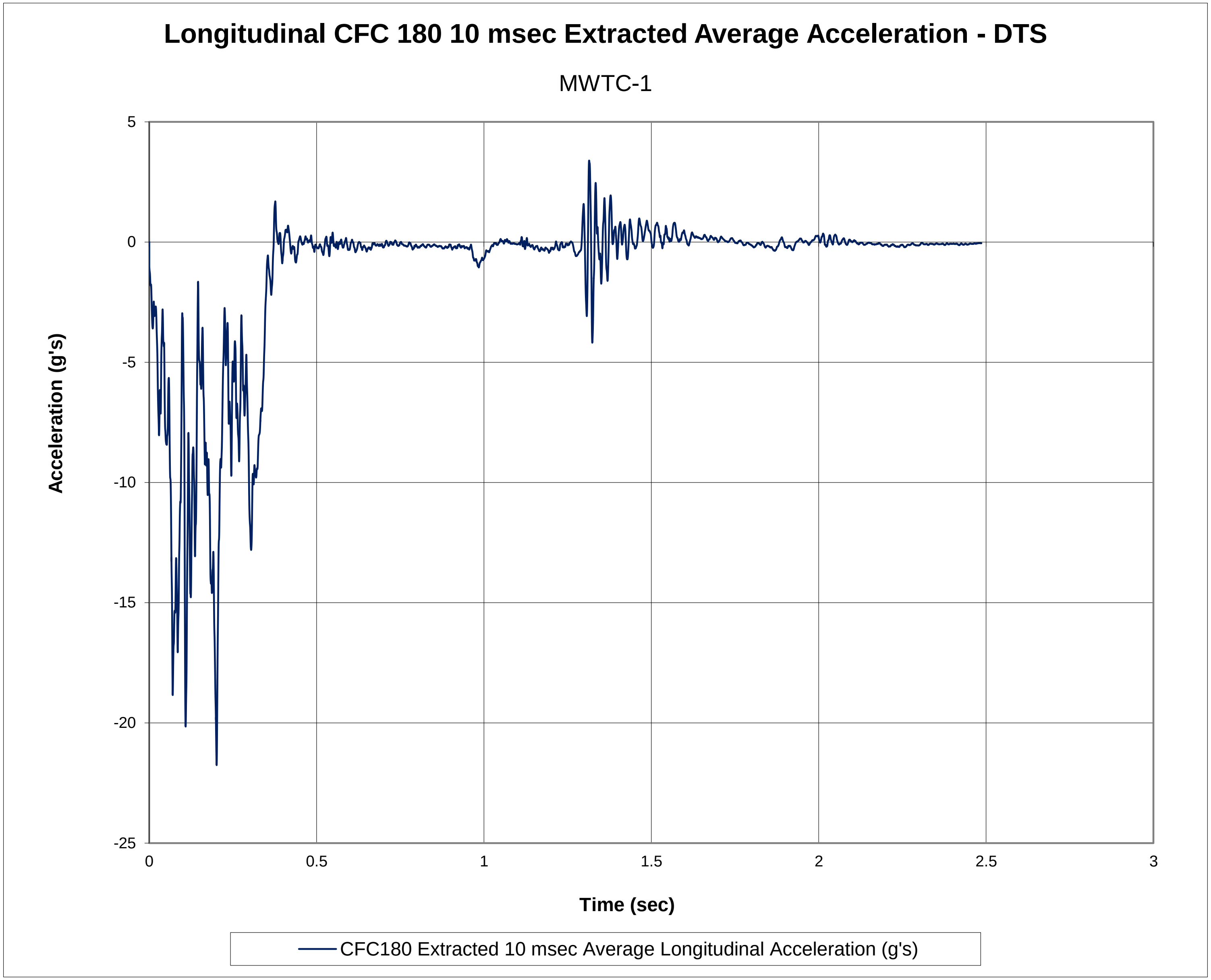


Figure E-1. 10-ms Average Longitudinal Deceleration (DTS), Test No. MWTC-1

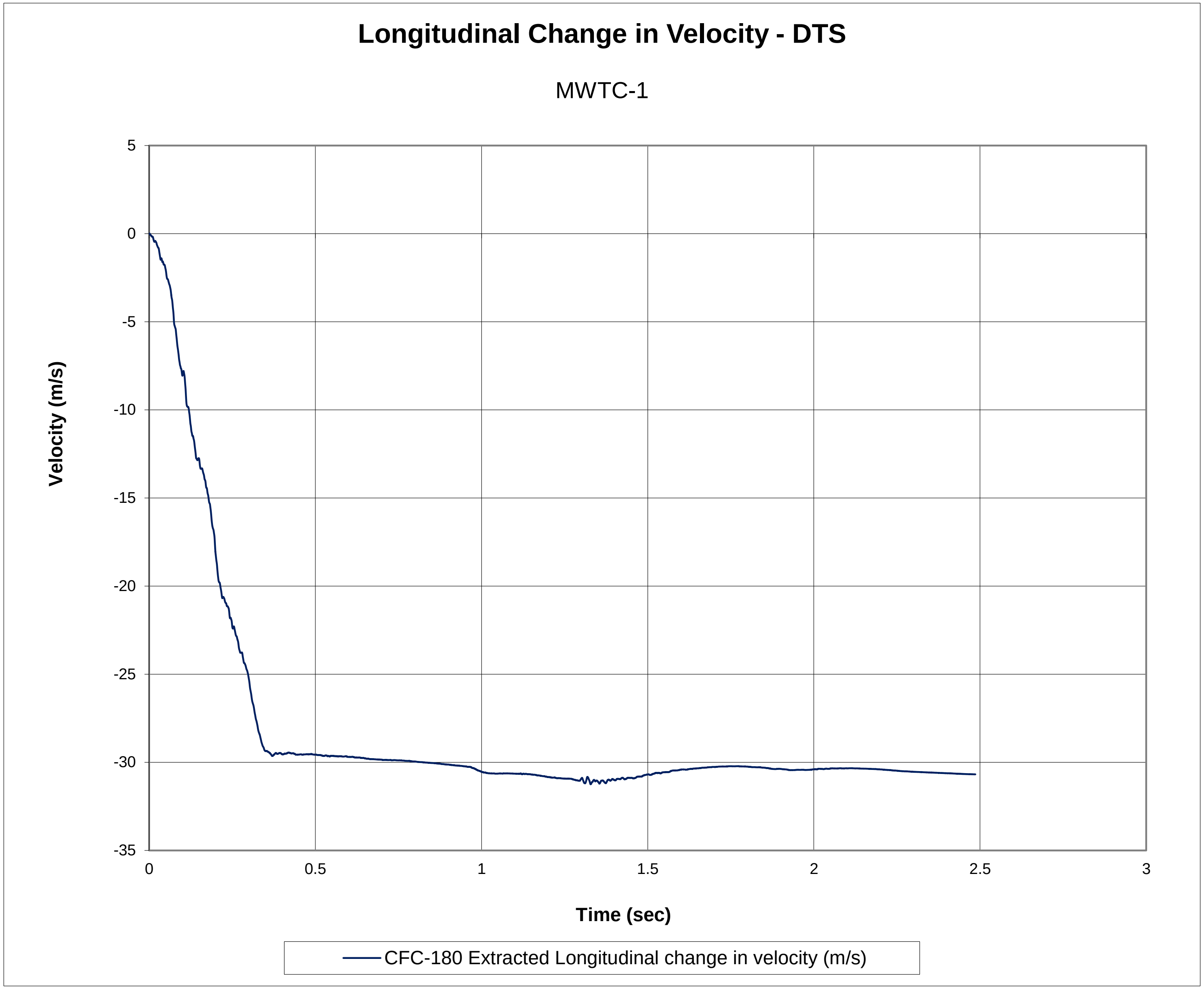


Figure E-2. Longitudinal Occupant Impact Velocity (DTS), Test No. MWTC-1

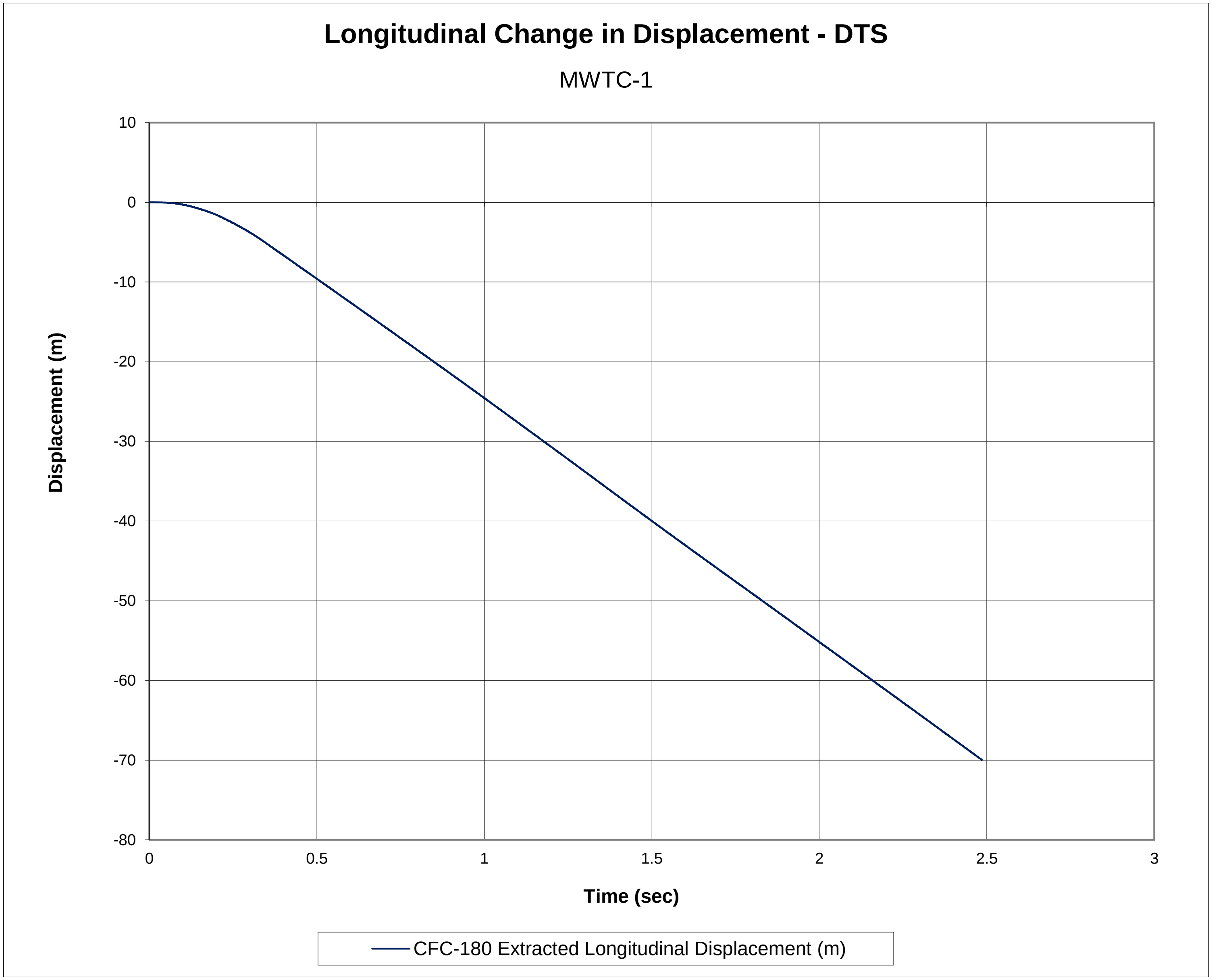


Figure E-3. Longitudinal Occupant Displacement (DTS), Test No. MWTC-1

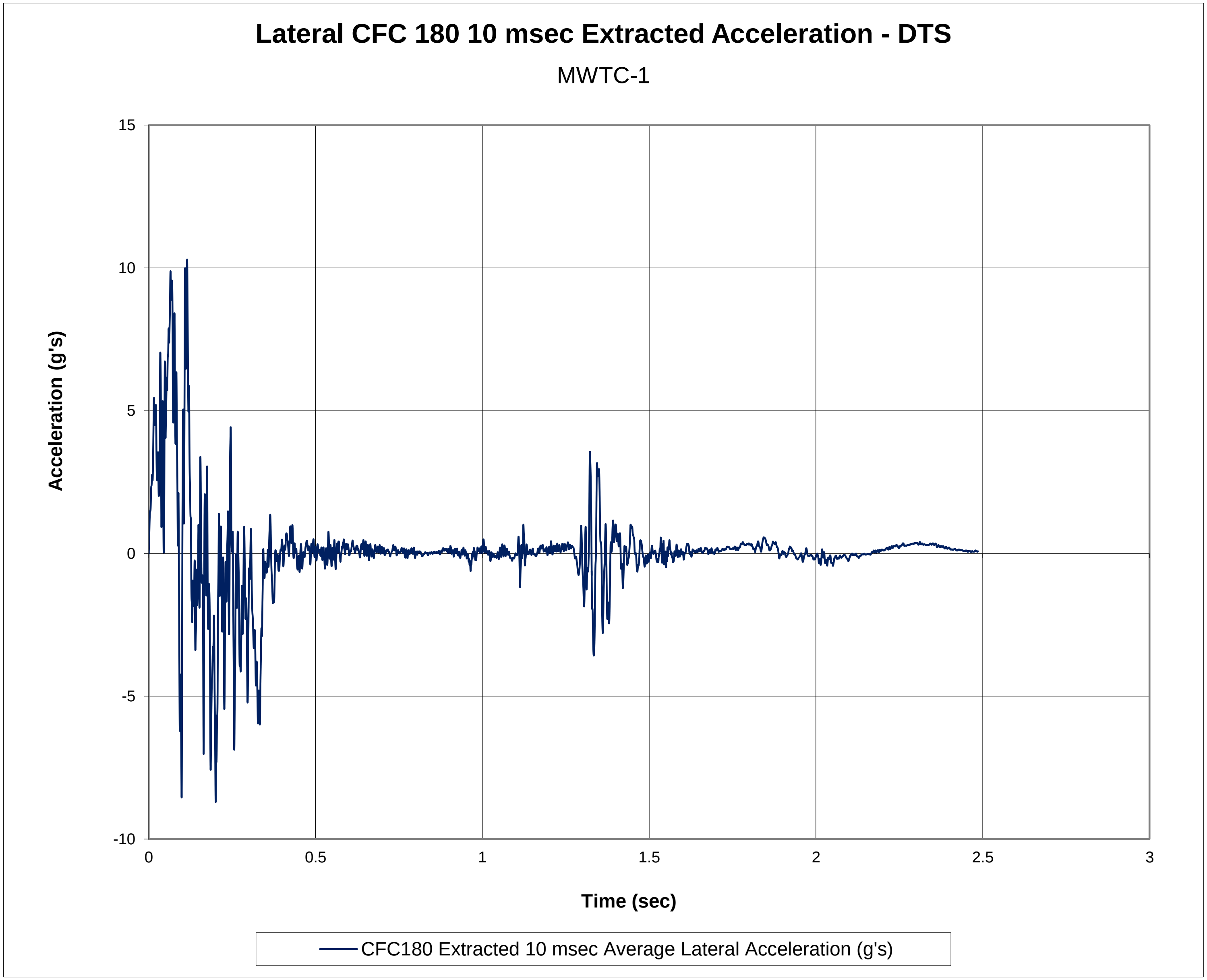


Figure E-4. 10-ms Average Lateral Deceleration (DTS), Test No. MWTC-1

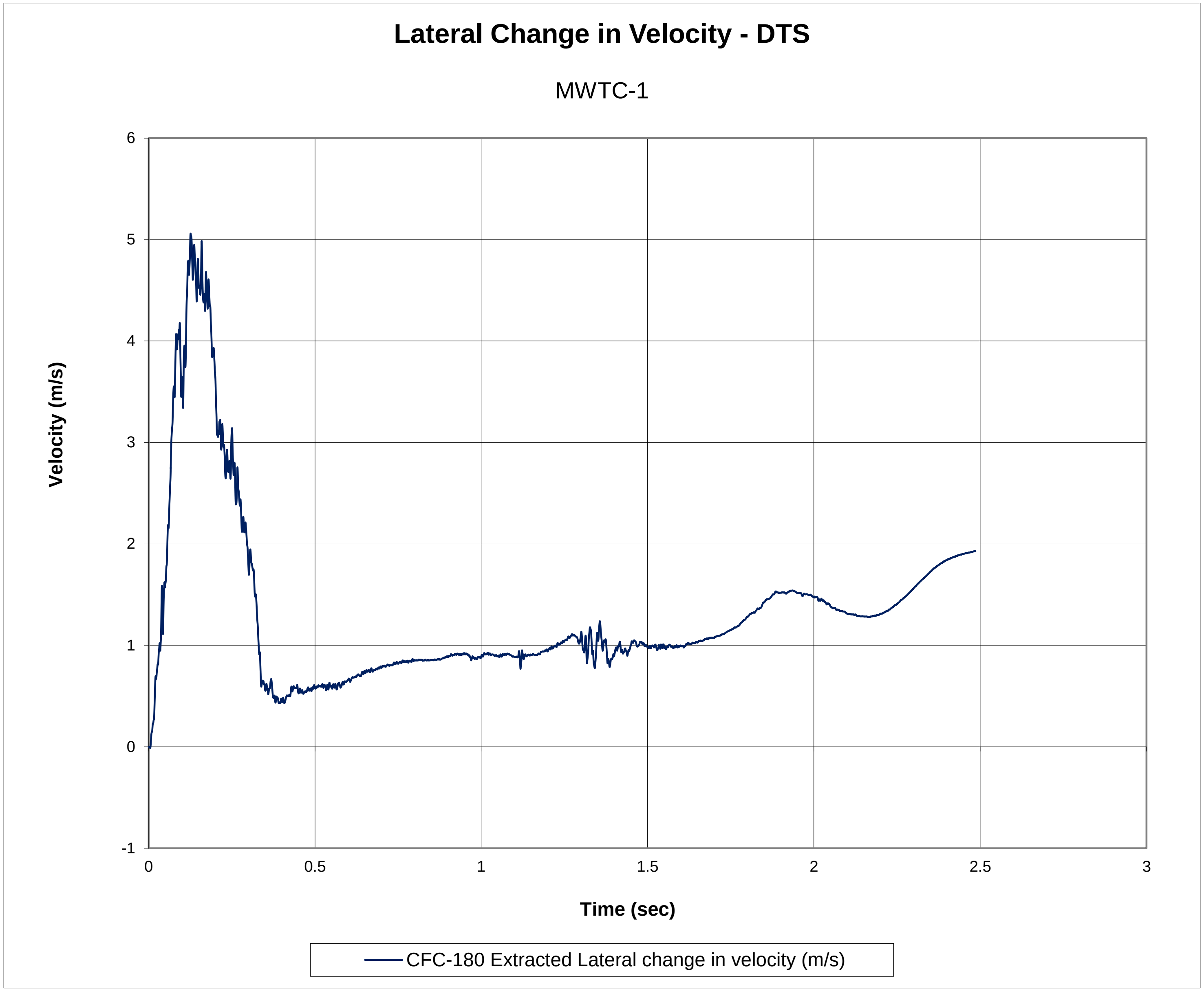


Figure E-5. Lateral Occupant Impact Velocity (DTS), Test No. MWTC-1

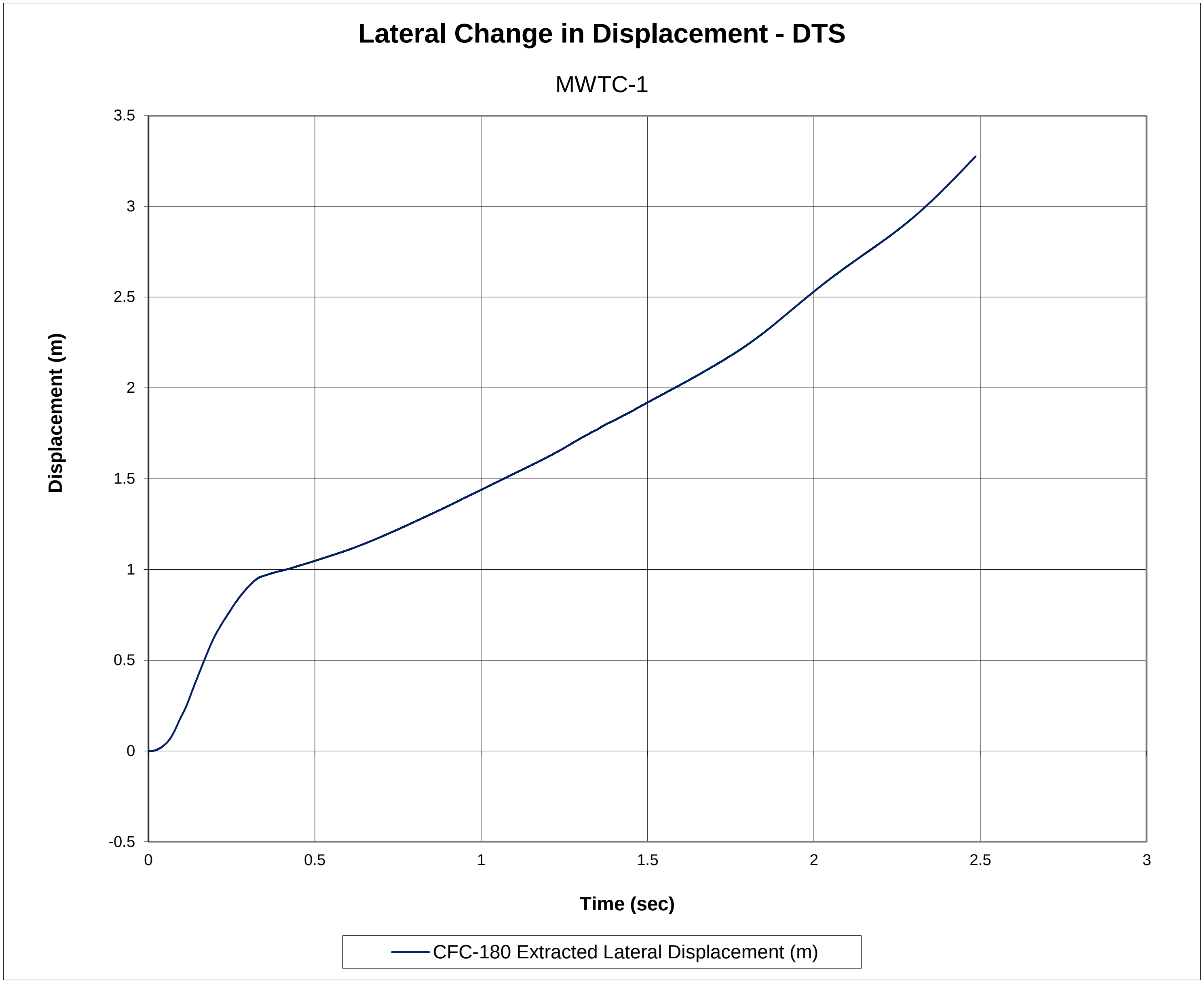


Figure E-6. Lateral Occupant Displacement (DTS), Test No. MWTC-1

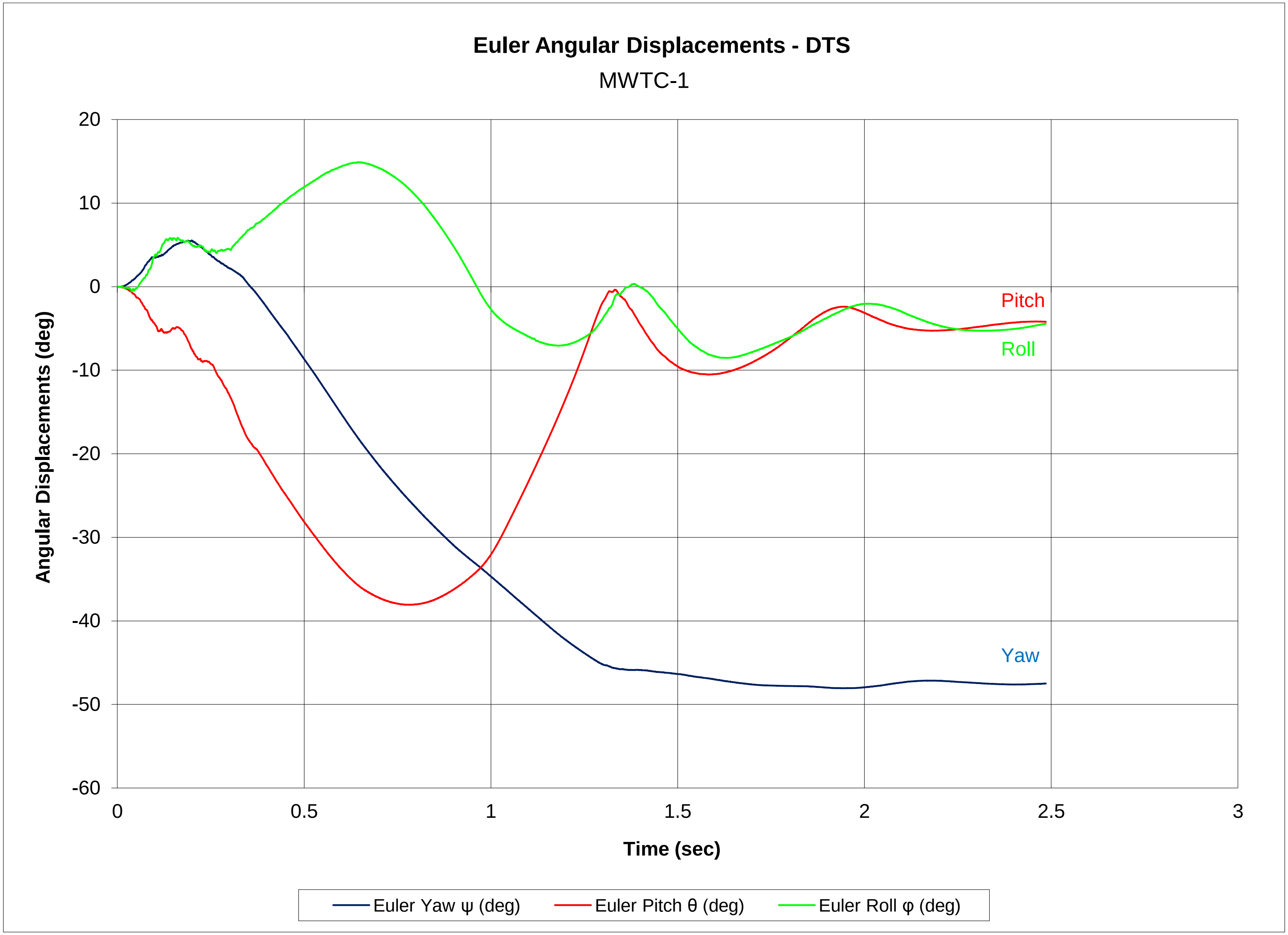


Figure E-7. Vehicle Angular Displacements (DTS), Test No. MWTC-1

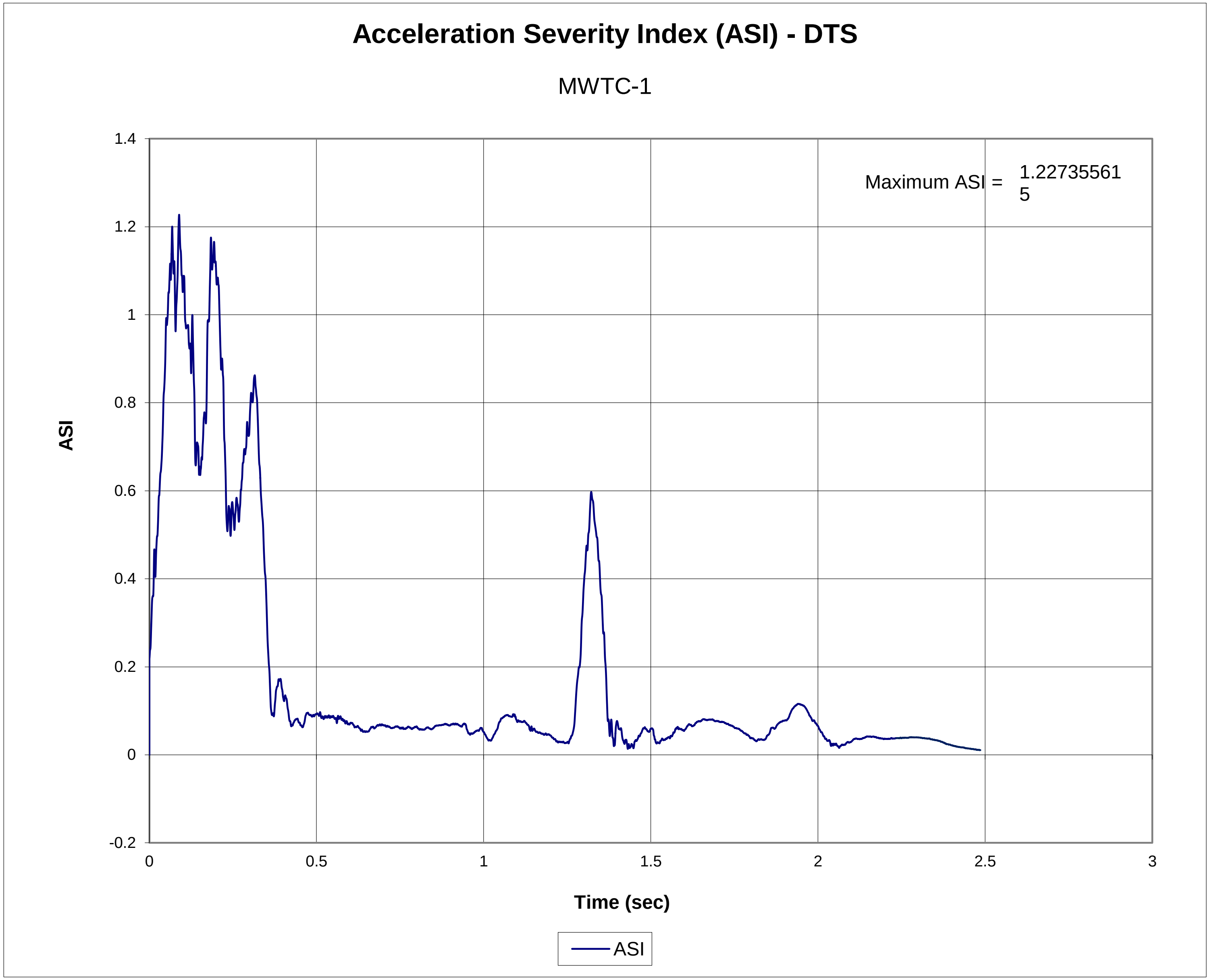


Figure E-8. Acceleration Severity Index (DTS), Test No. MWTC-1

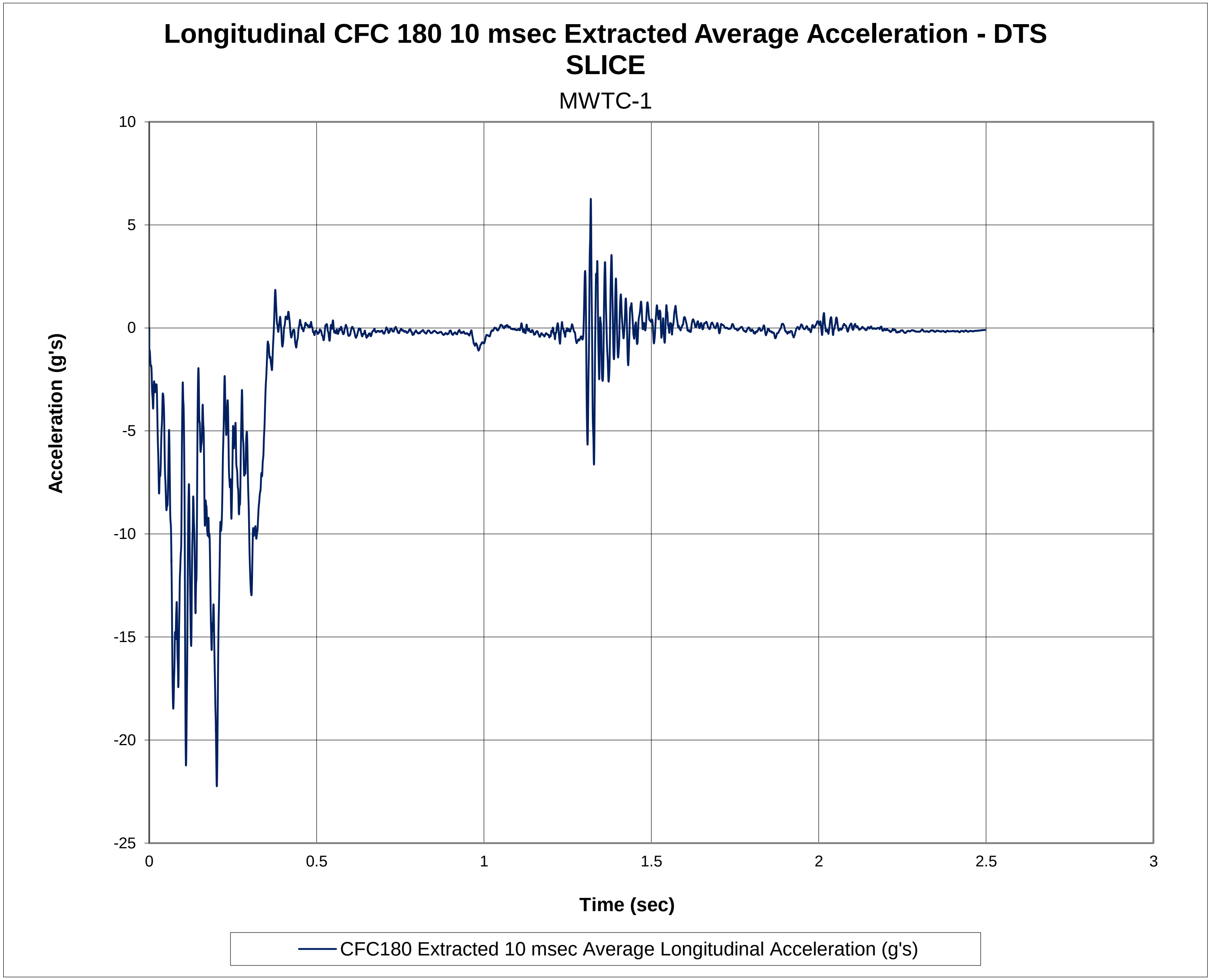


Figure E-9. 10-ms Average Longitudinal Deceleration (DTS SLICE), Test No. MWTC-1

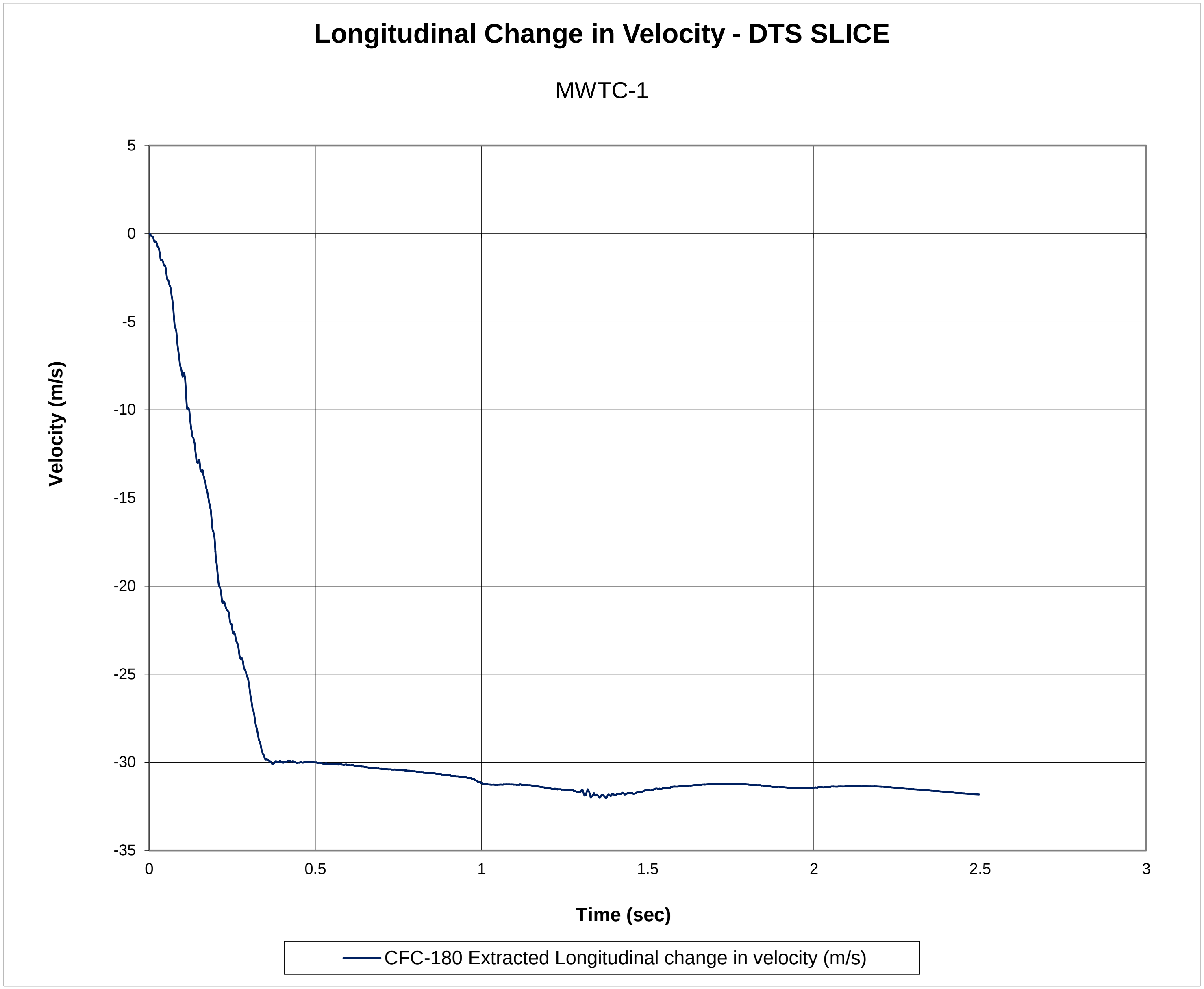


Figure E-10. Longitudinal Occupant Impact Velocity (DTS SLICE), Test No. MWTC-1

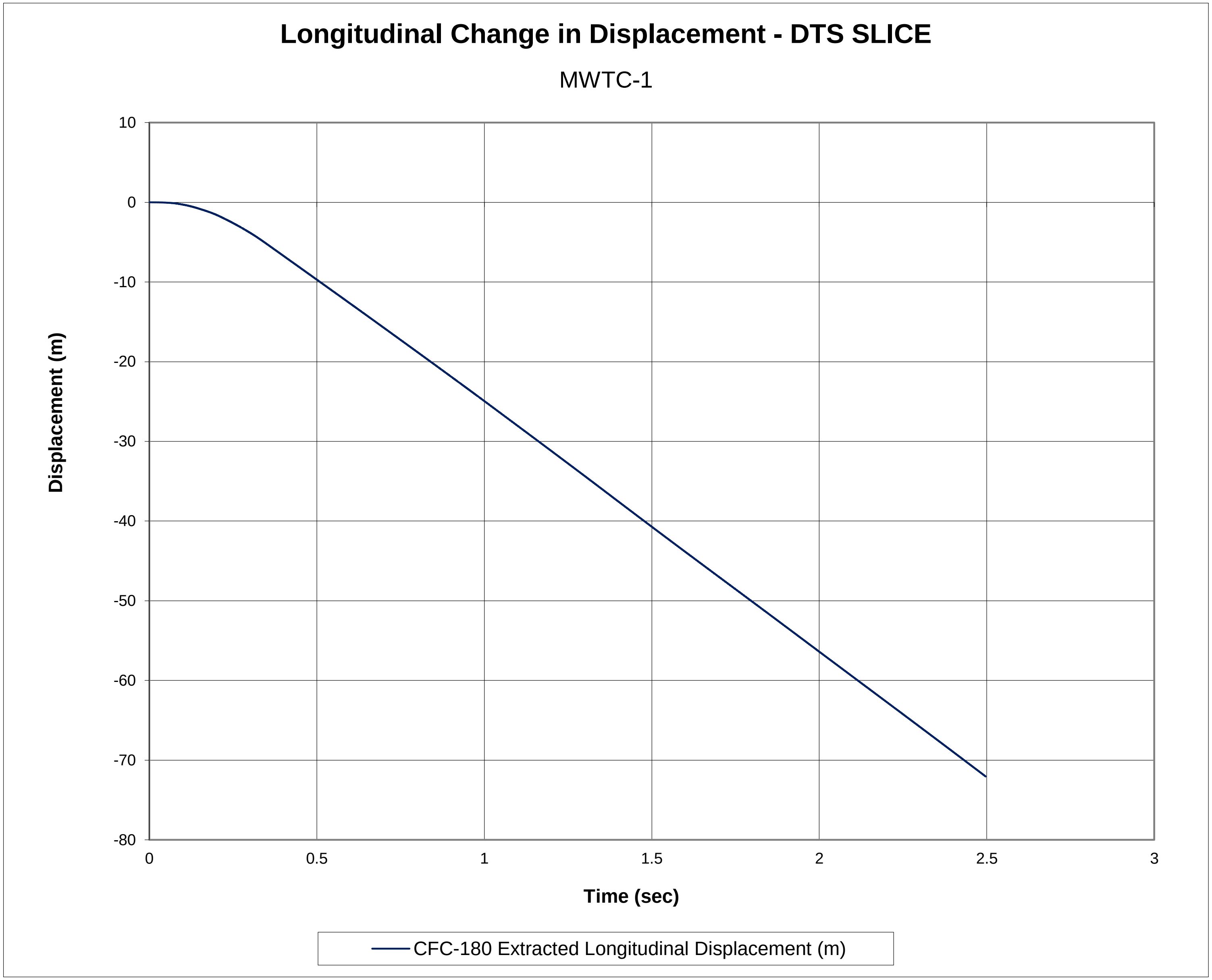


Figure E-11. Longitudinal Occupant Displacement (DTS SLICE), Test No. MWTC-1

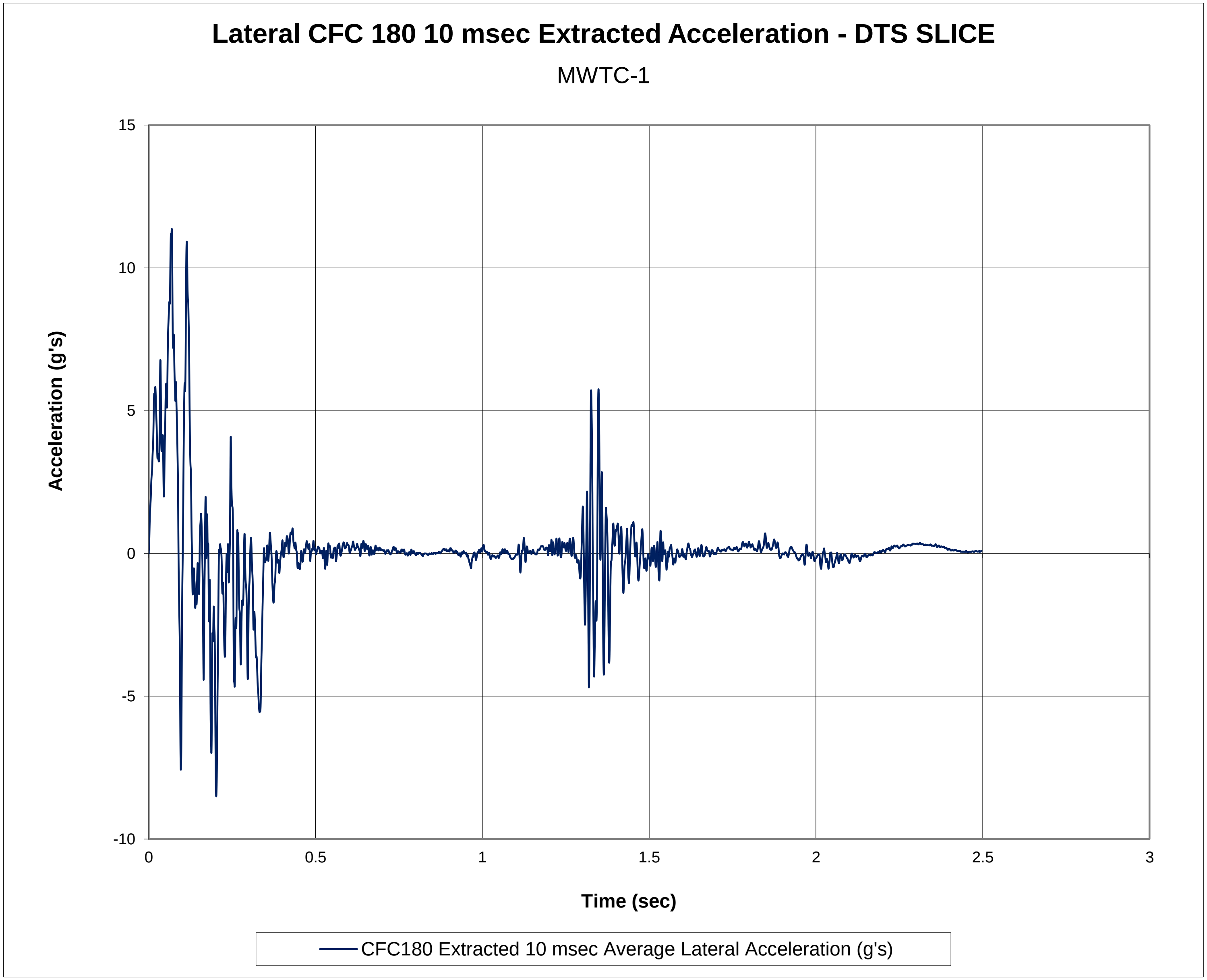


Figure E-12. 10-ms Average Lateral Deceleration (DTS SLICE), Test No. MWTC-1

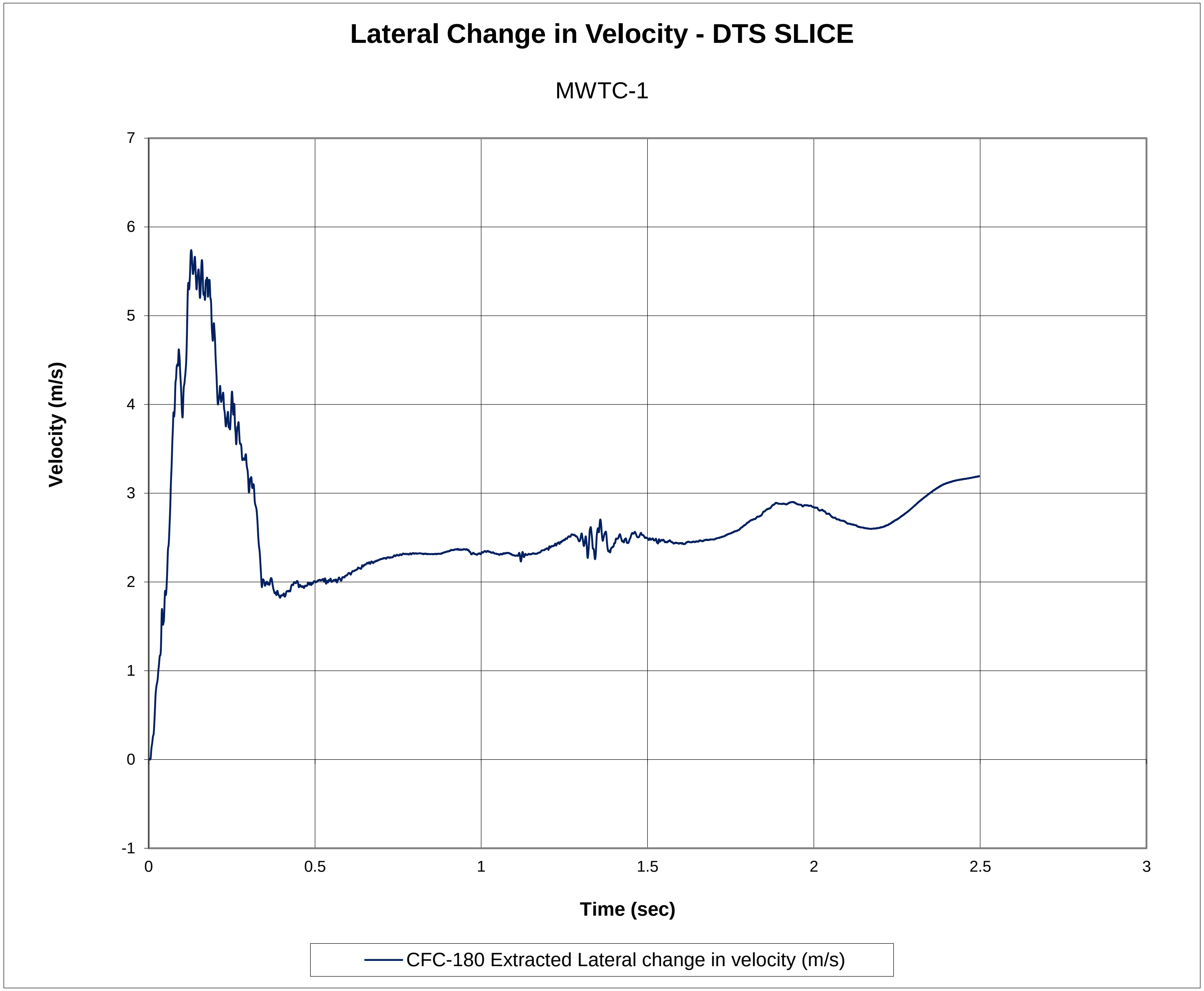


Figure E-13. Lateral Occupant Impact Velocity (DTS SLICE), Test No. MWTC-1

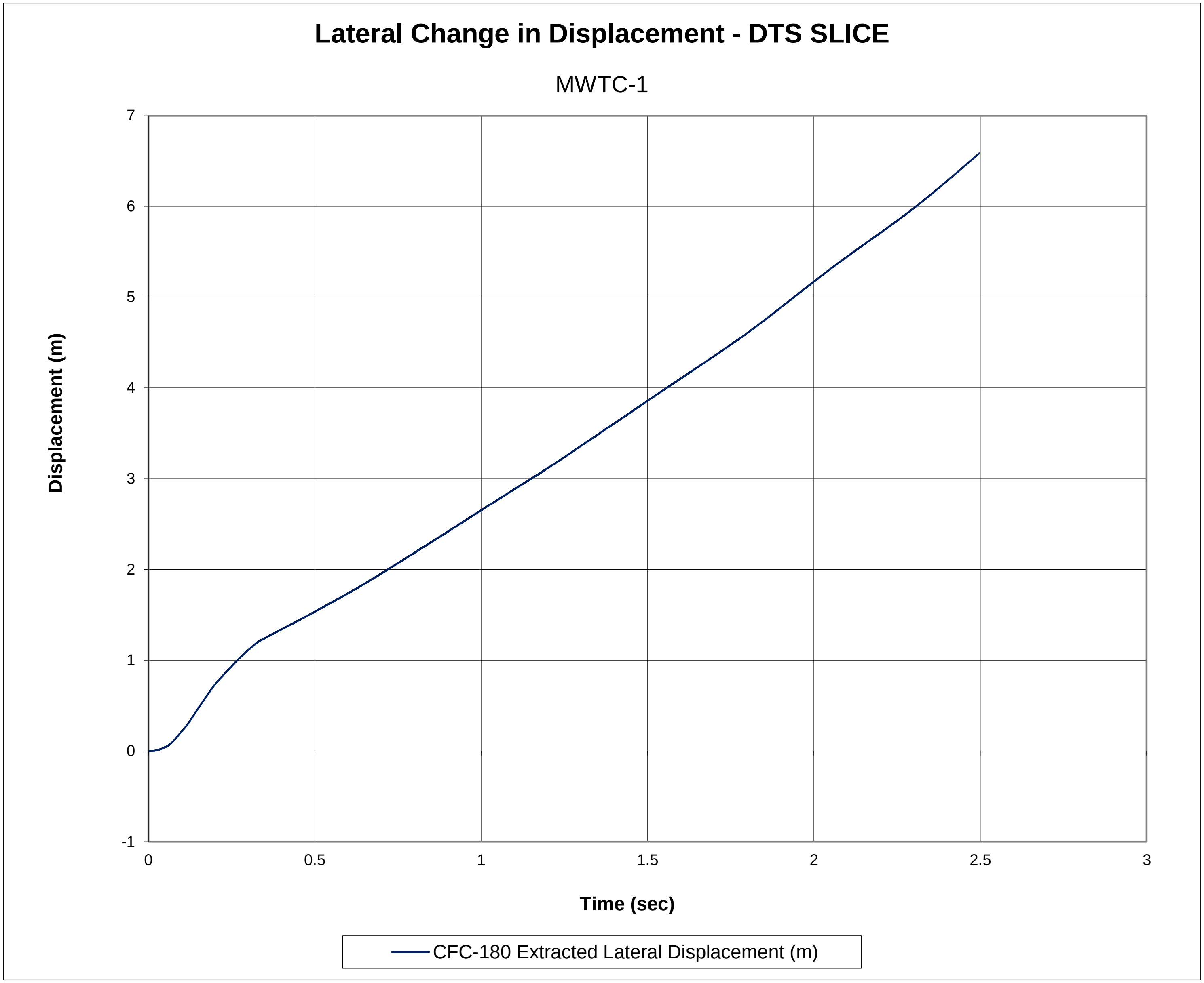


Figure E-14. Lateral Occupant Displacement (DTS SLICE), Test No. MWTC-1

Figure E-15. Vehicle Angular Displacements (DTS SLICE), Test No. MWTC-1

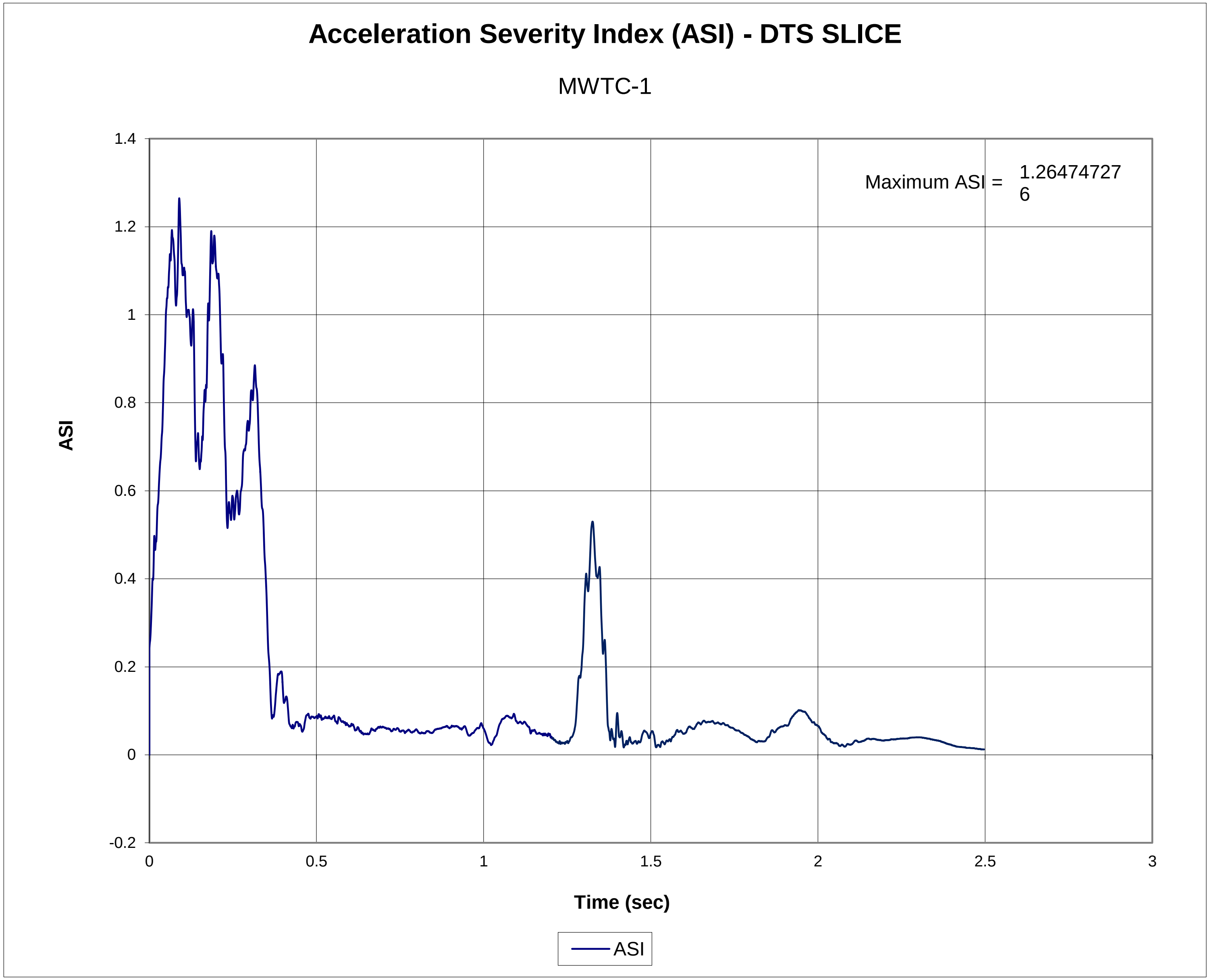


Figure E-16. Acceleration Severity Index (DTS SLICE), Test No. MWTC-1

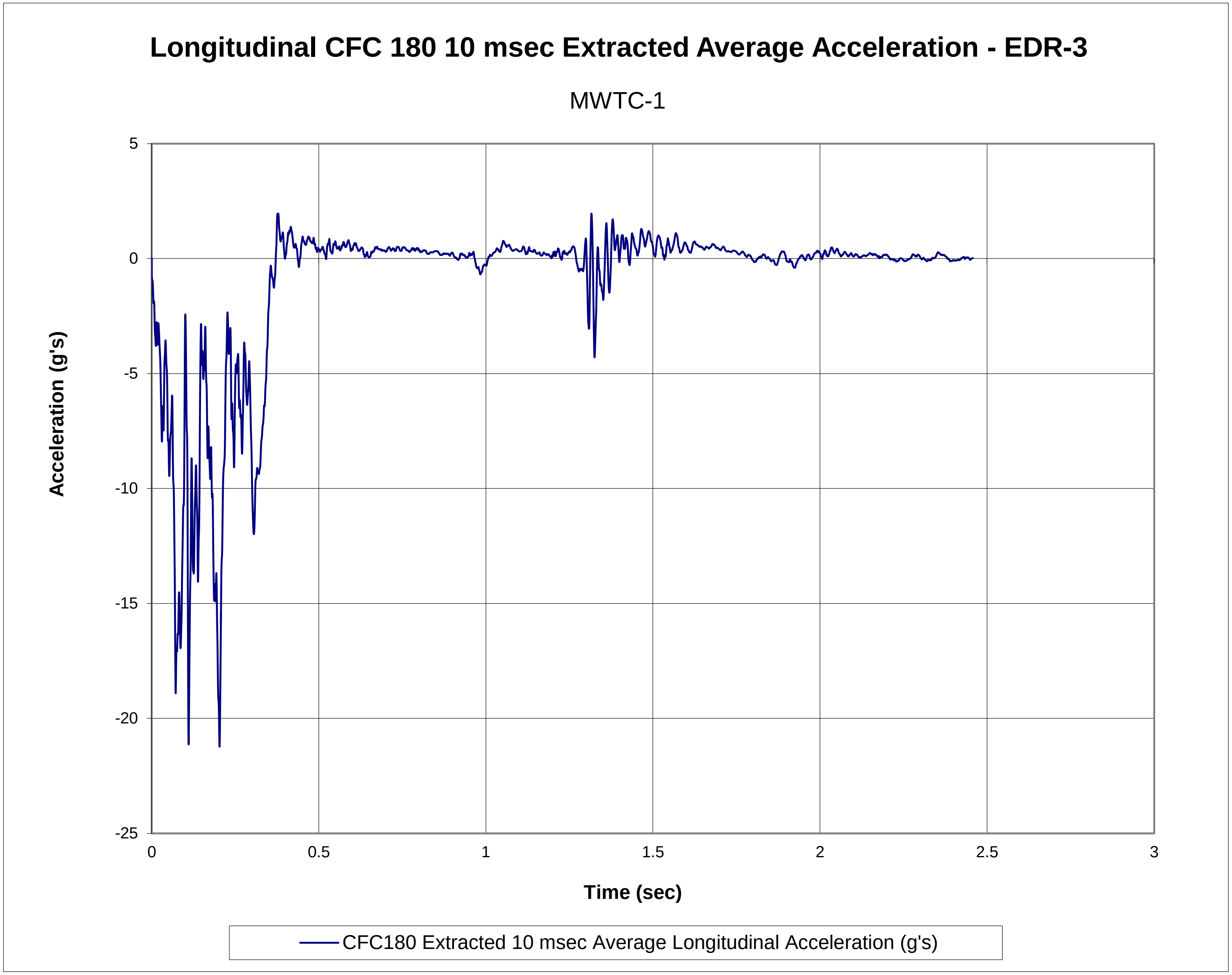


Figure E-17. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. MWTC-1

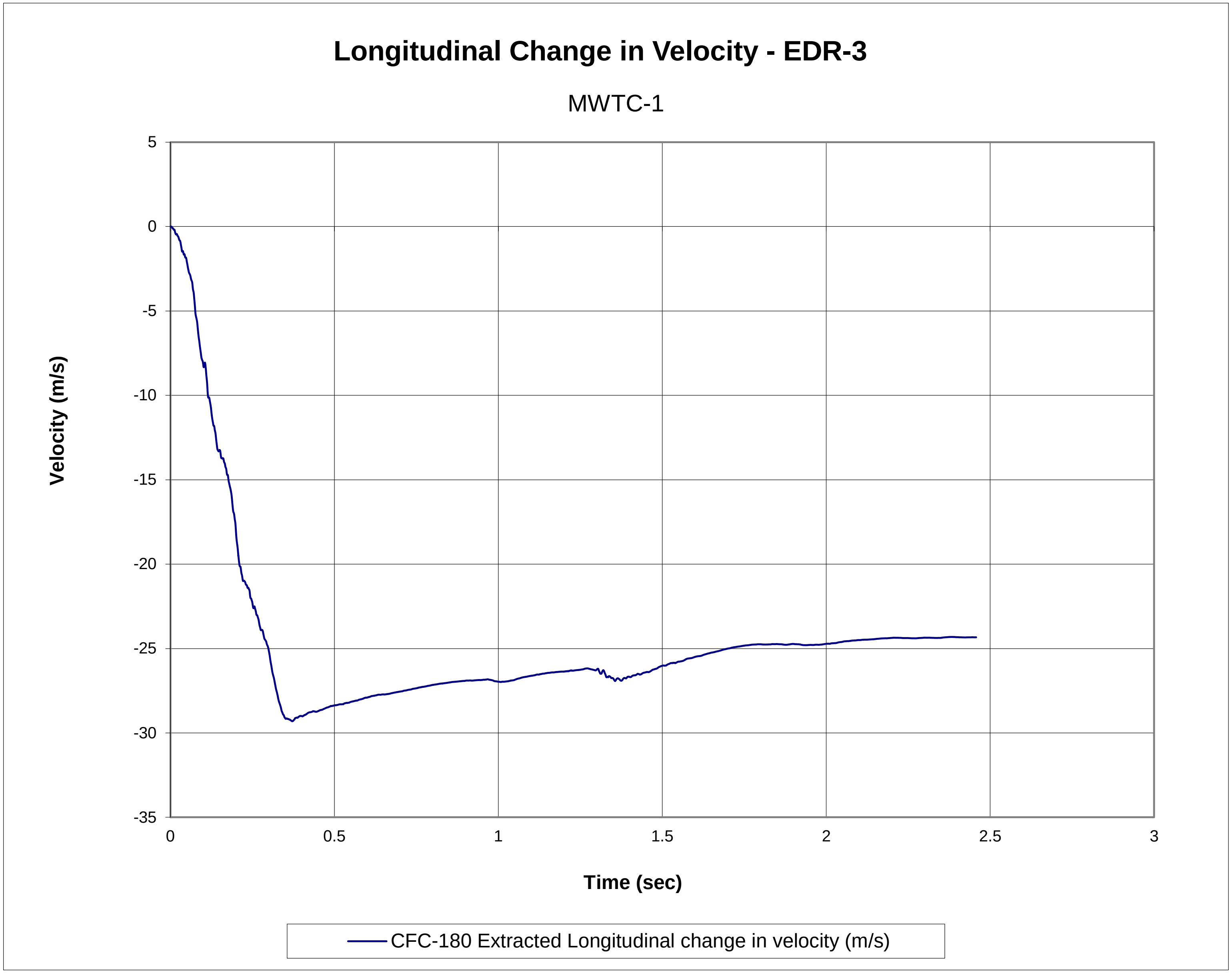


Figure E-18. Longitudinal Occupant Impact Velocity (EDR-3), Test No. MWTC-1

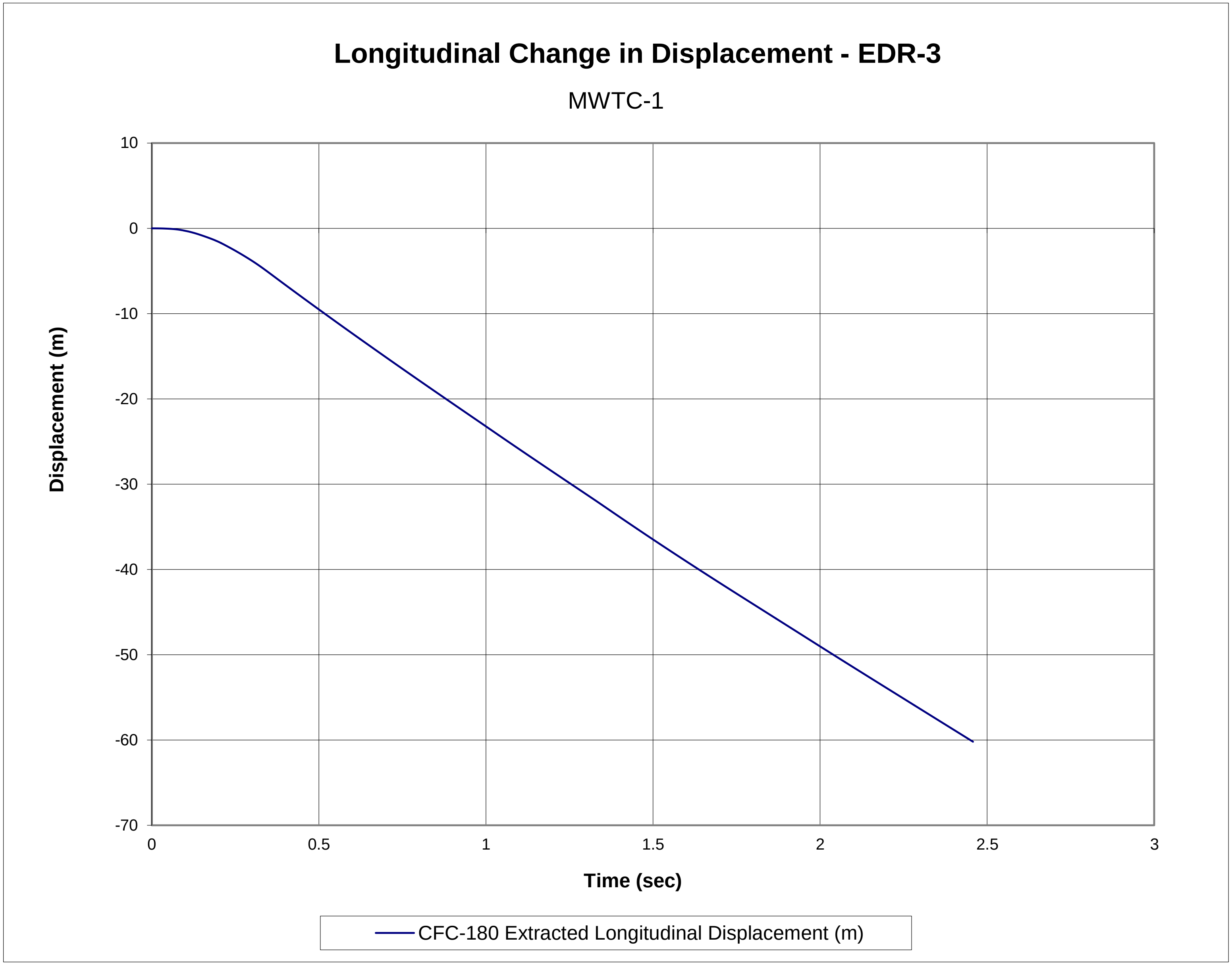


Figure E-19. Longitudinal Occupant Displacement (EDR-3), Test No. MWTC-1

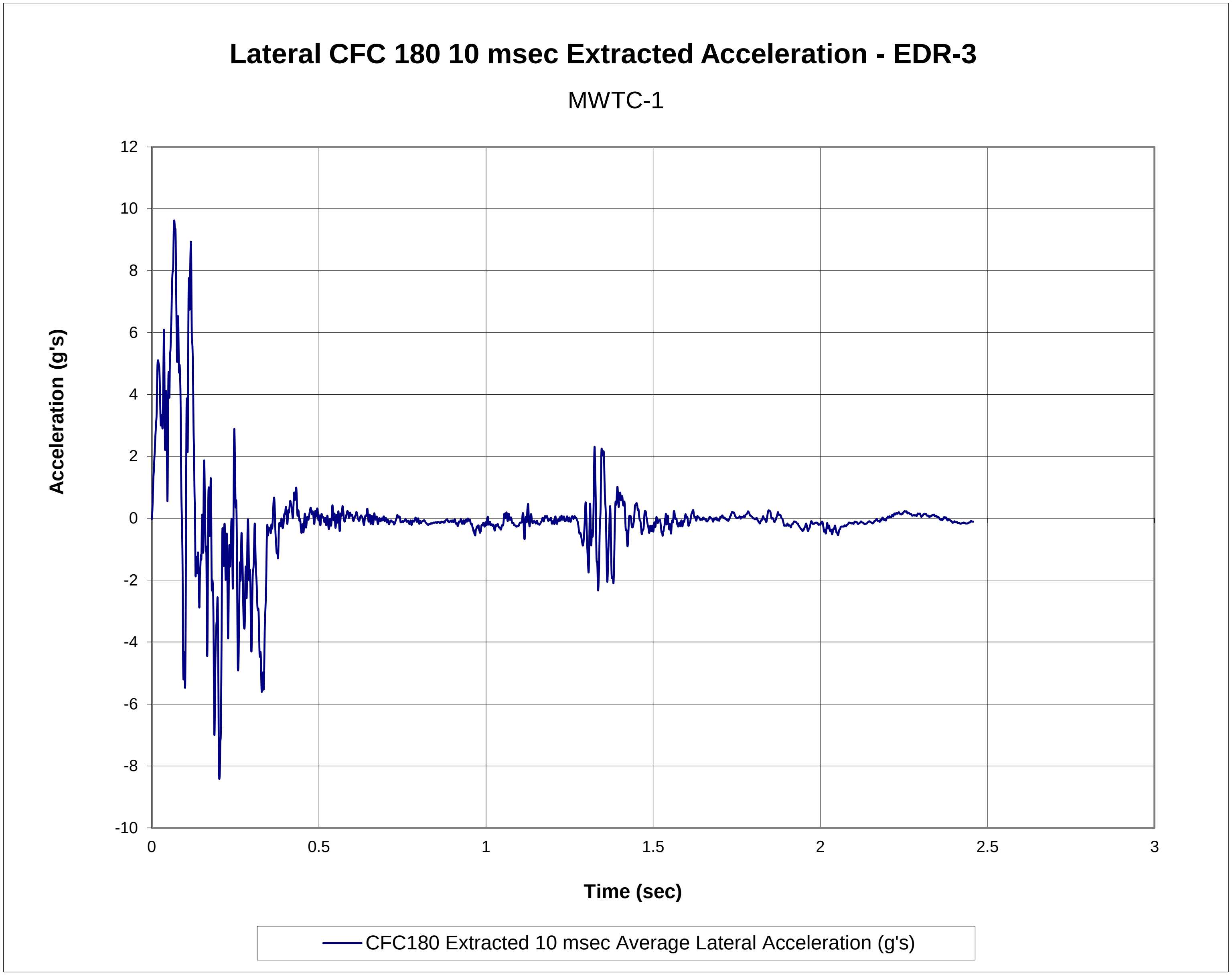


Figure E-20. 10-ms Average Lateral Deceleration (EDR-3), Test No. MWTC-1

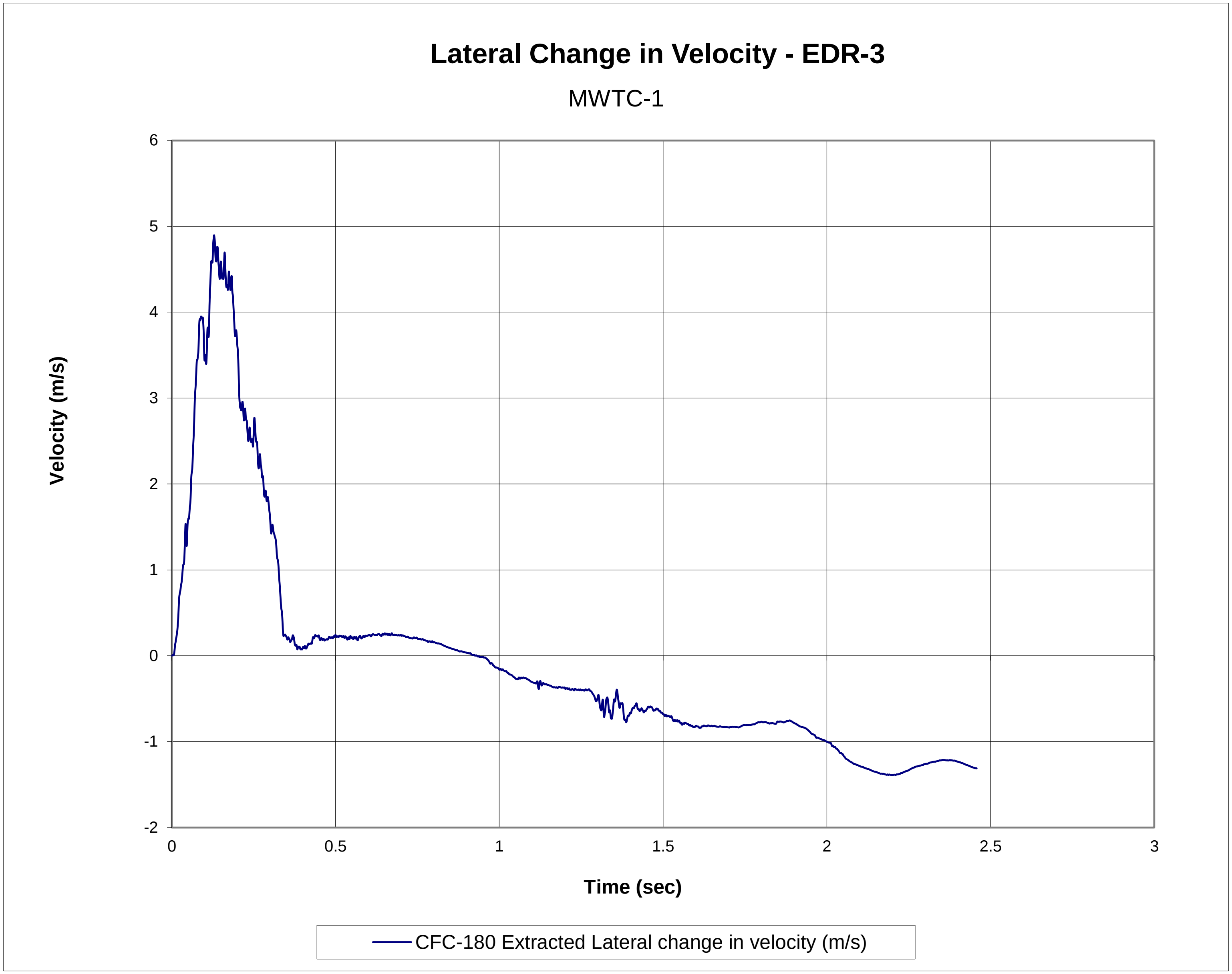


Figure E-21. Lateral Occupant Impact Velocity (EDR-3), Test No. MWTC-1

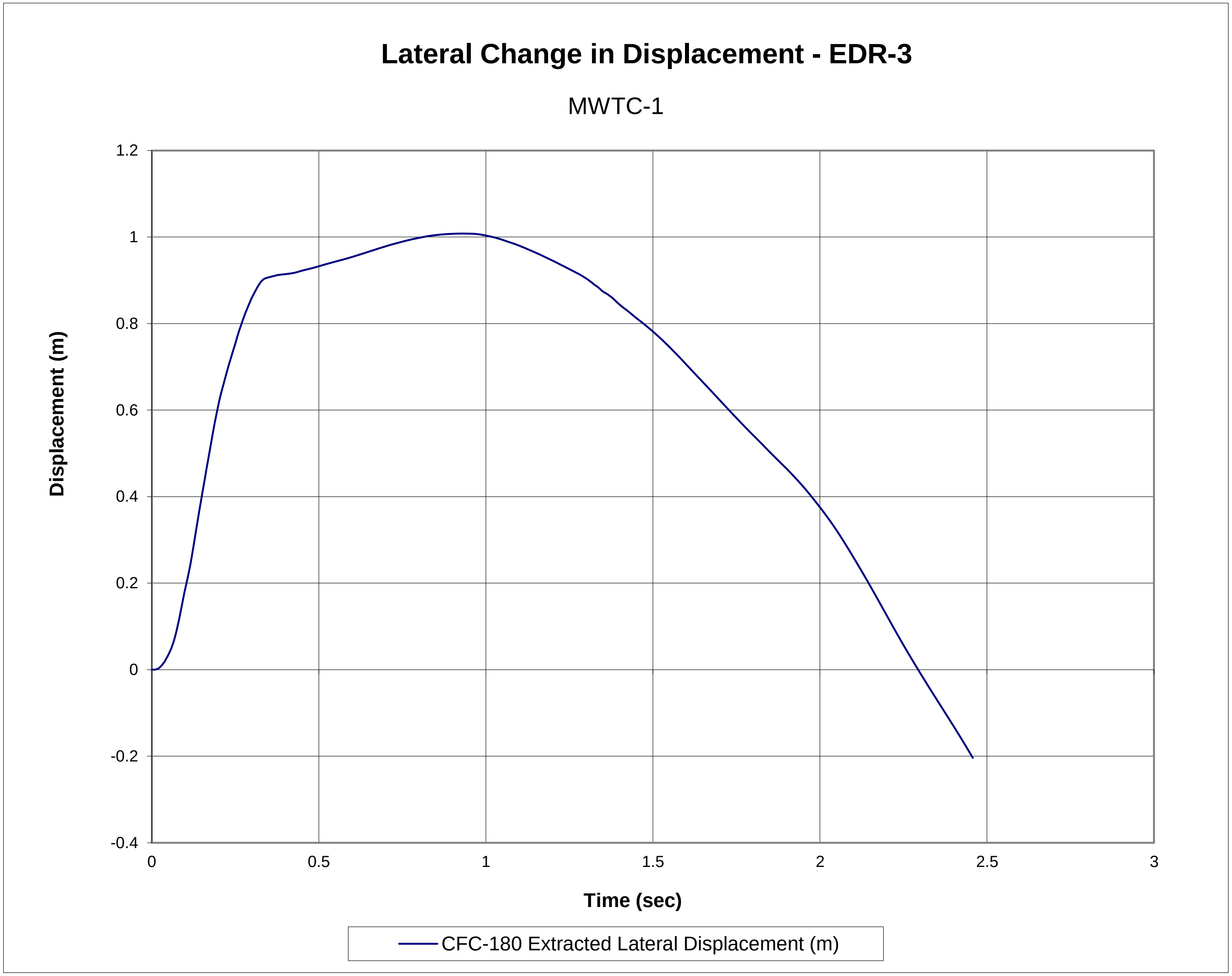


Figure E-22. Lateral Occupant Displacement (EDR-3), Test No. MWTC-1

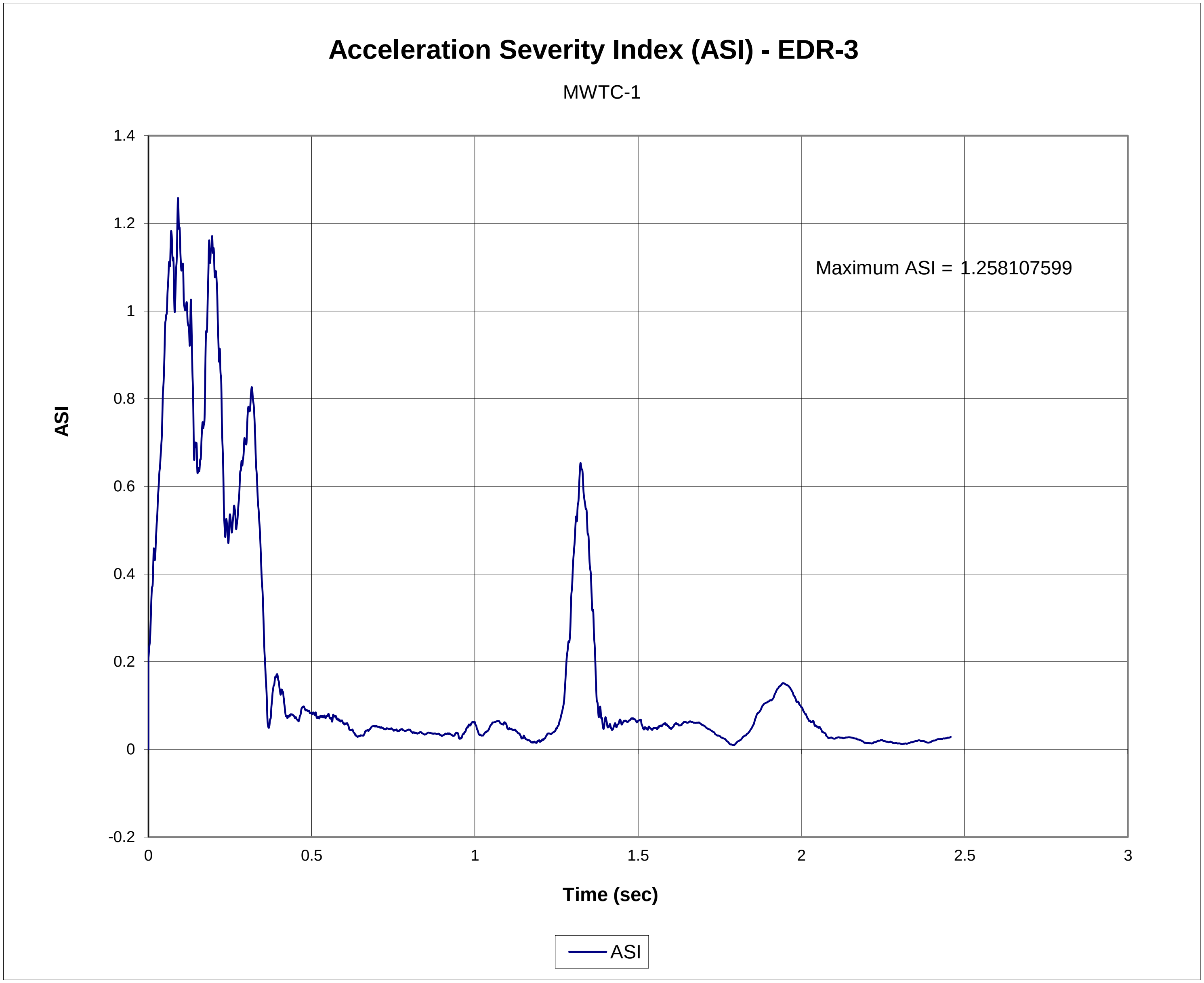


Figure E-23. Acceleration Severity Index (EDR-3), Test No. MWTC-1

Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. MWTC-2

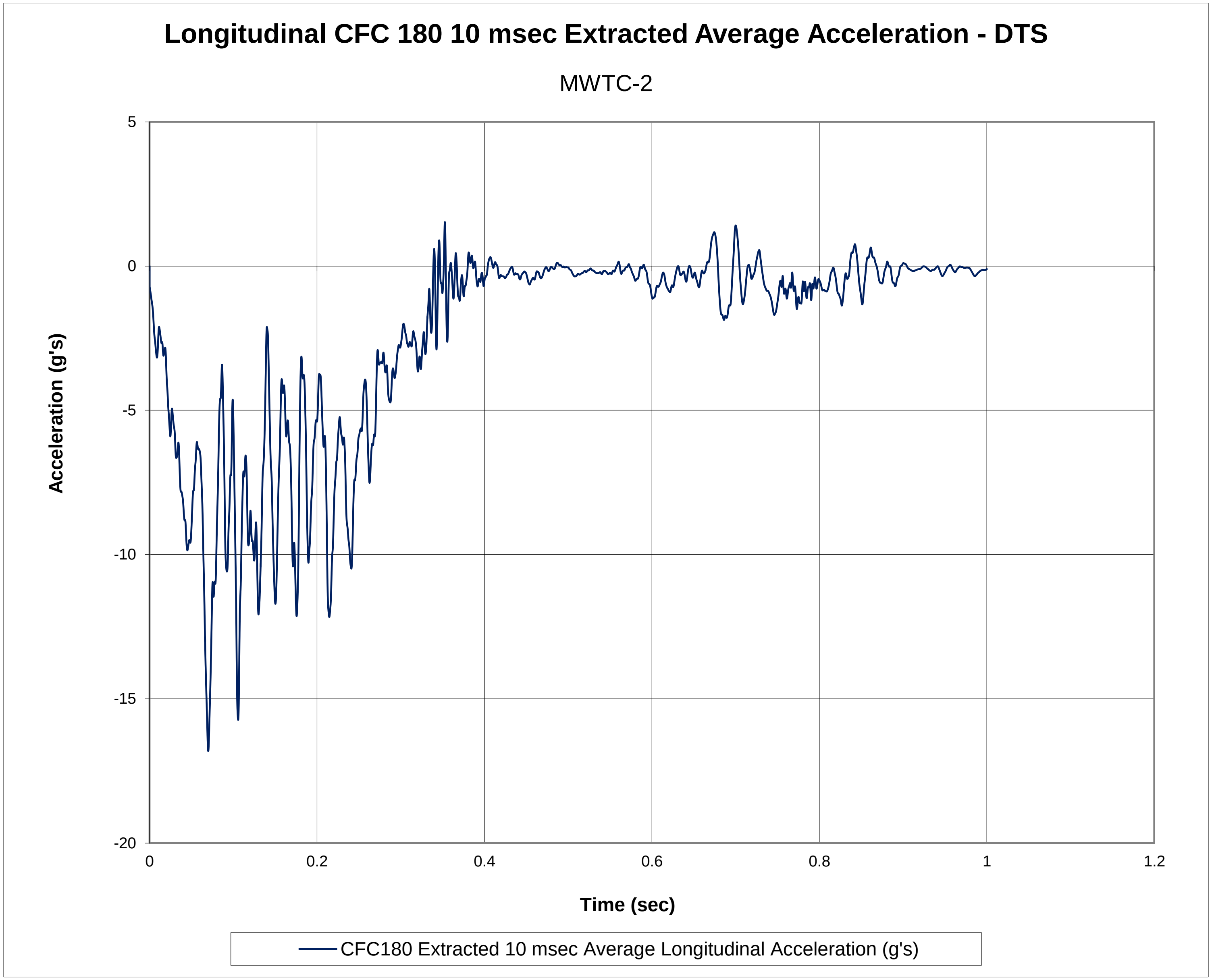


Figure F-1. 10-ms Average Longitudinal Deceleration (DTS), Test No. MWTC-2

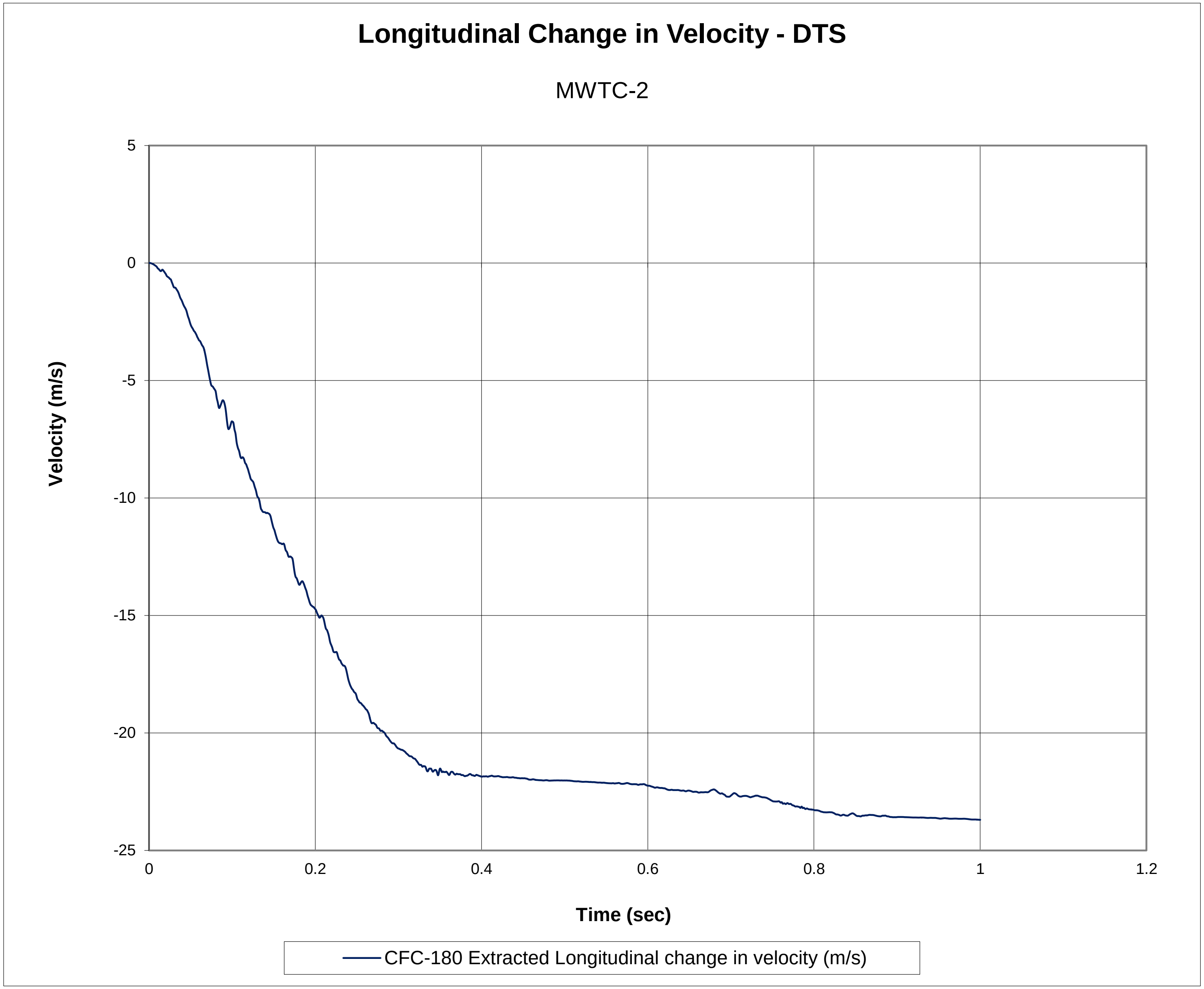


Figure F-2. Longitudinal Occupant Impact Velocity (DTS), Test No. MWTC-2

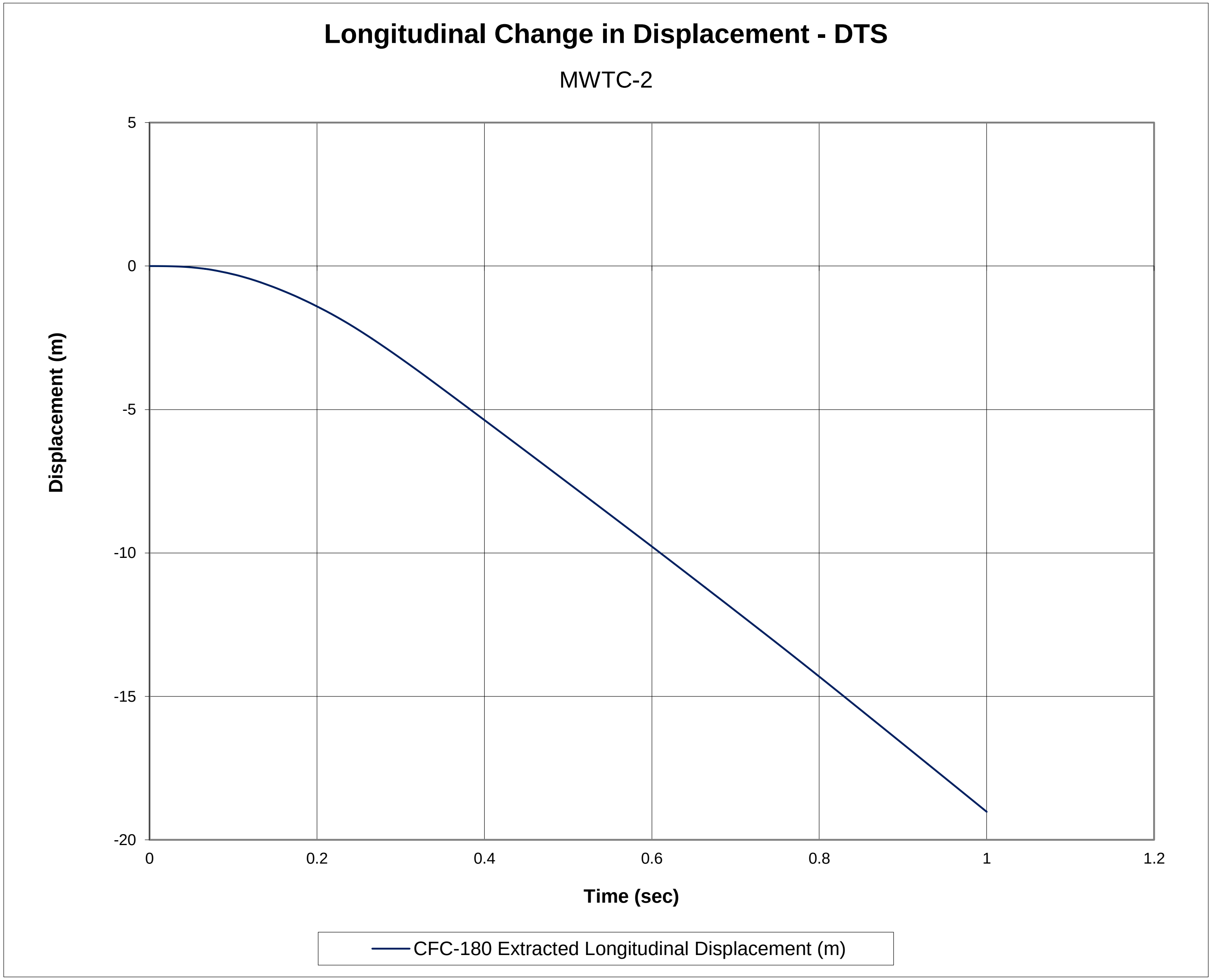


Figure F-3. Longitudinal Occupant Displacement (DTS), Test No. MWTC-2

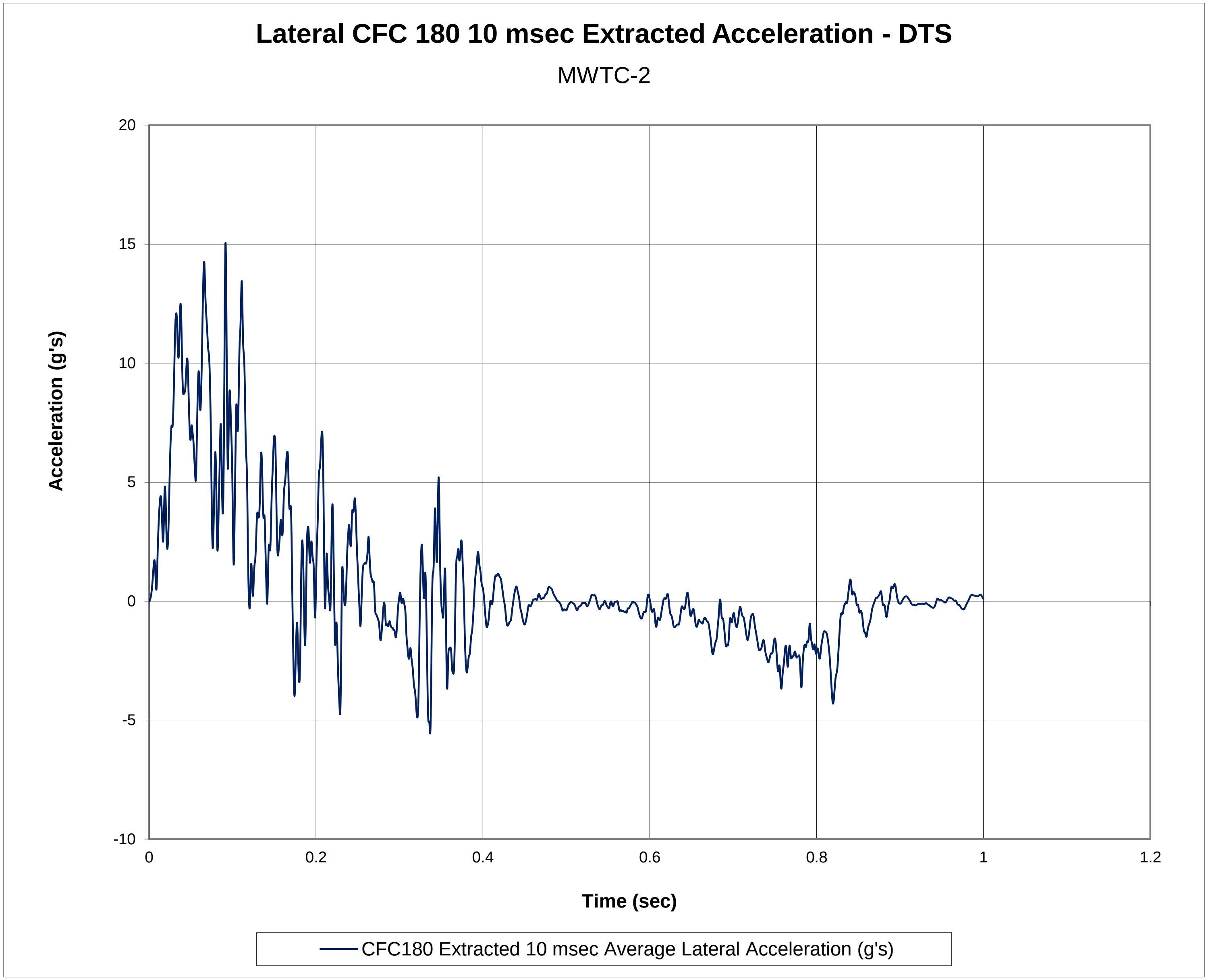


Figure F-4. 10-ms Average Lateral Deceleration (DTS), Test No. MWTC-2

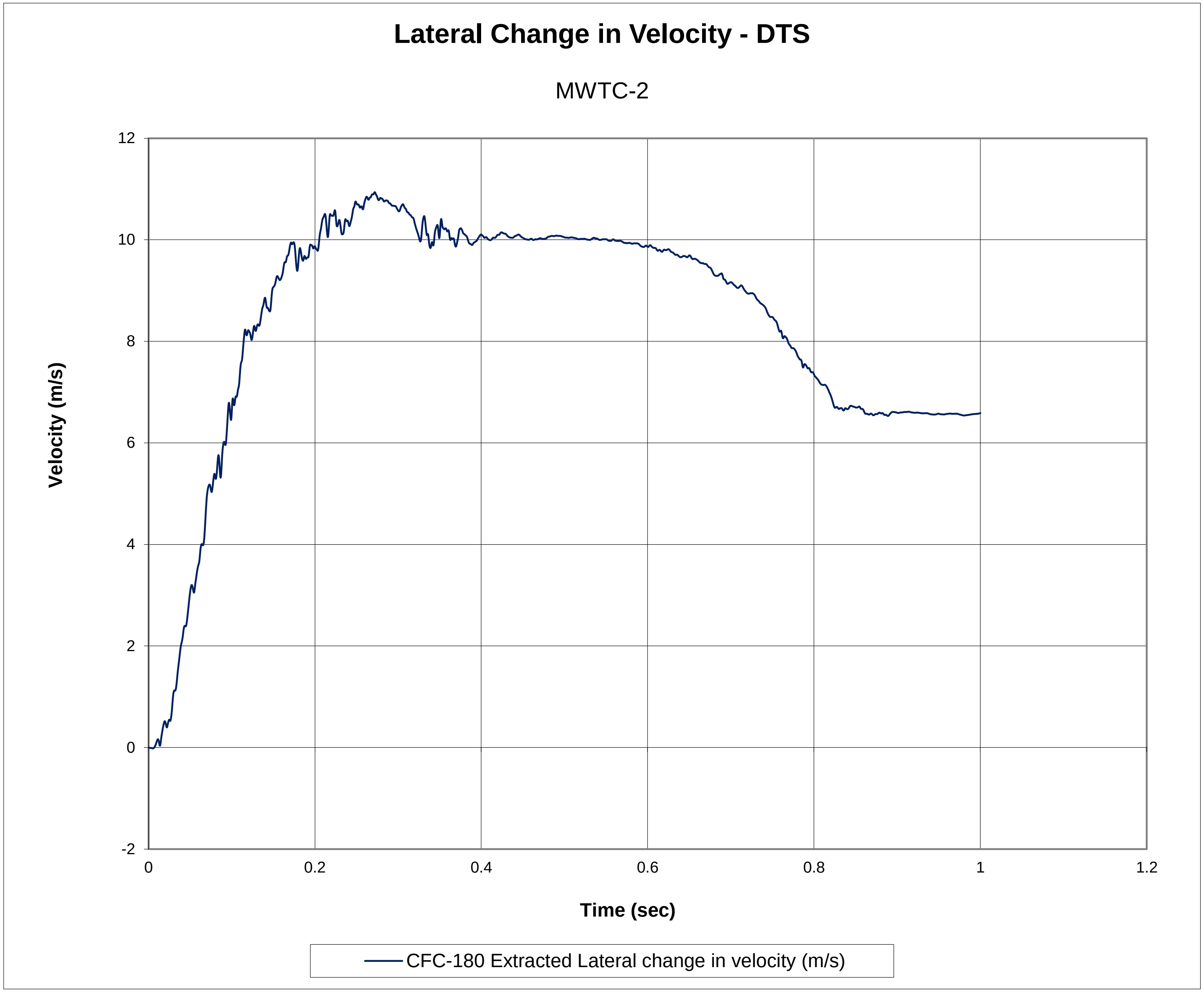


Figure F-5. Lateral Occupant Impact Velocity (DTS), Test No. MWTC-2

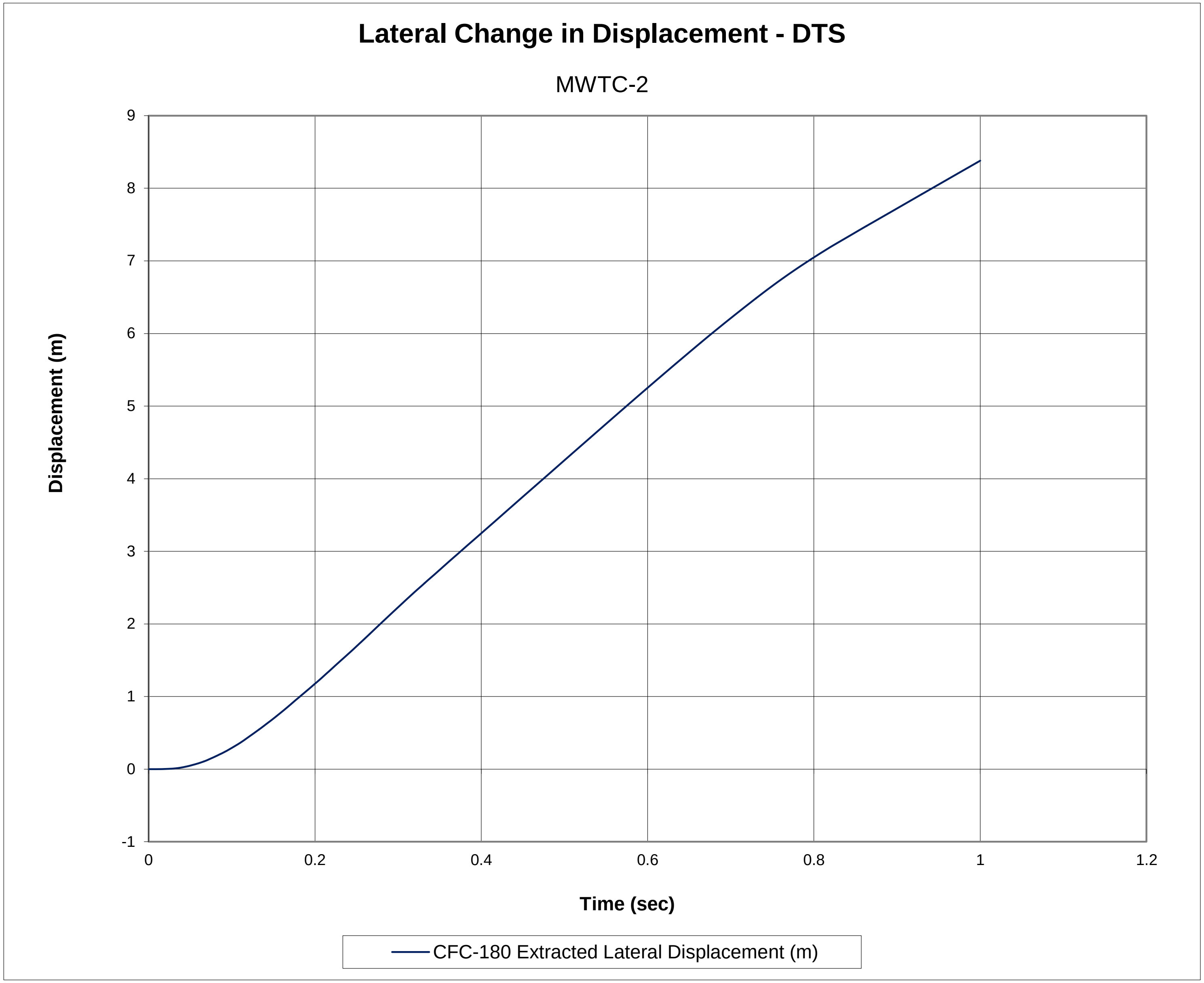


Figure F-6. Lateral Occupant Displacement (DTS), Test No. MWTC-2

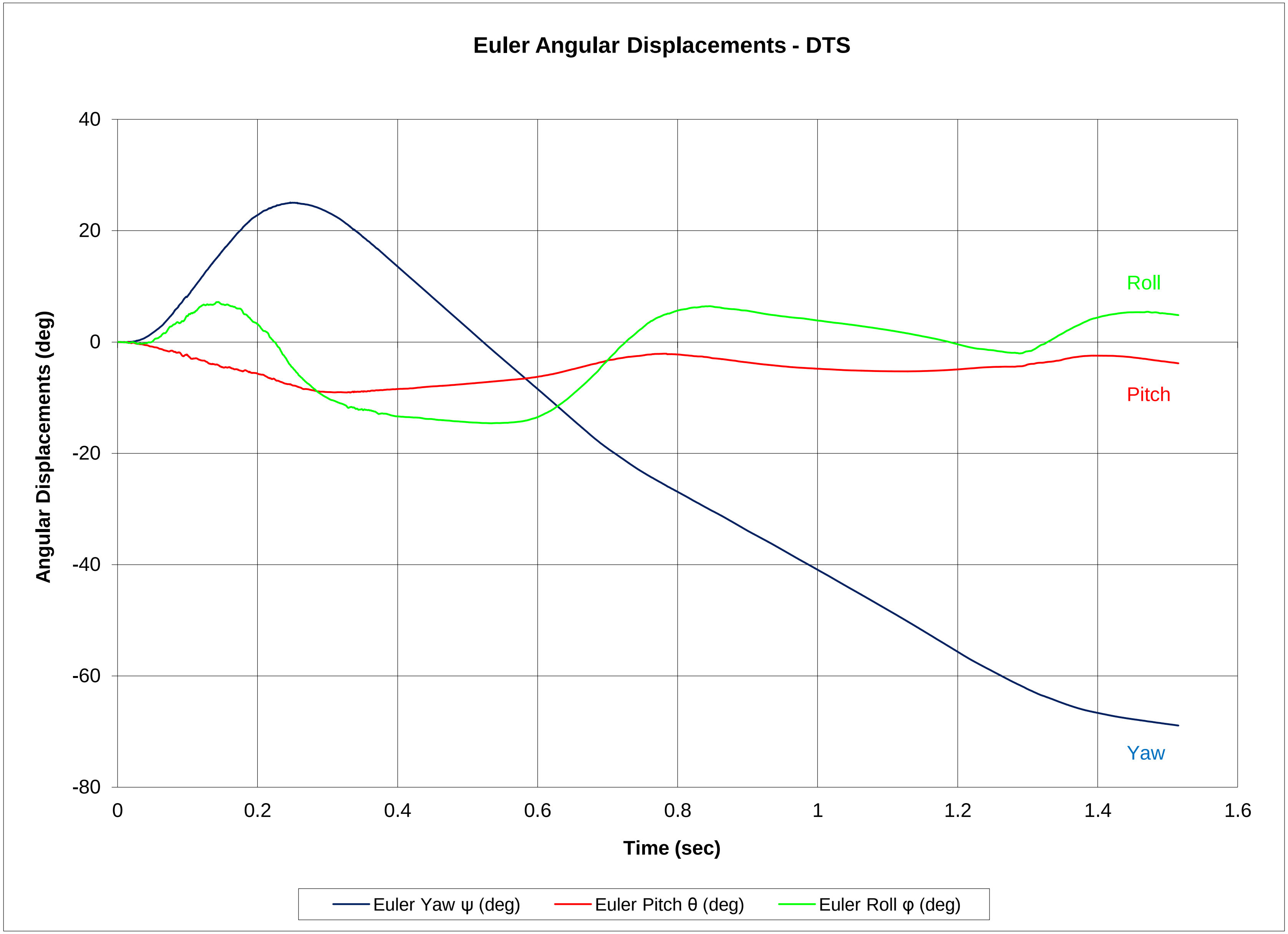


Figure F-7. Vehicle Angular Displacements (DTS), Test No. MWTC-2

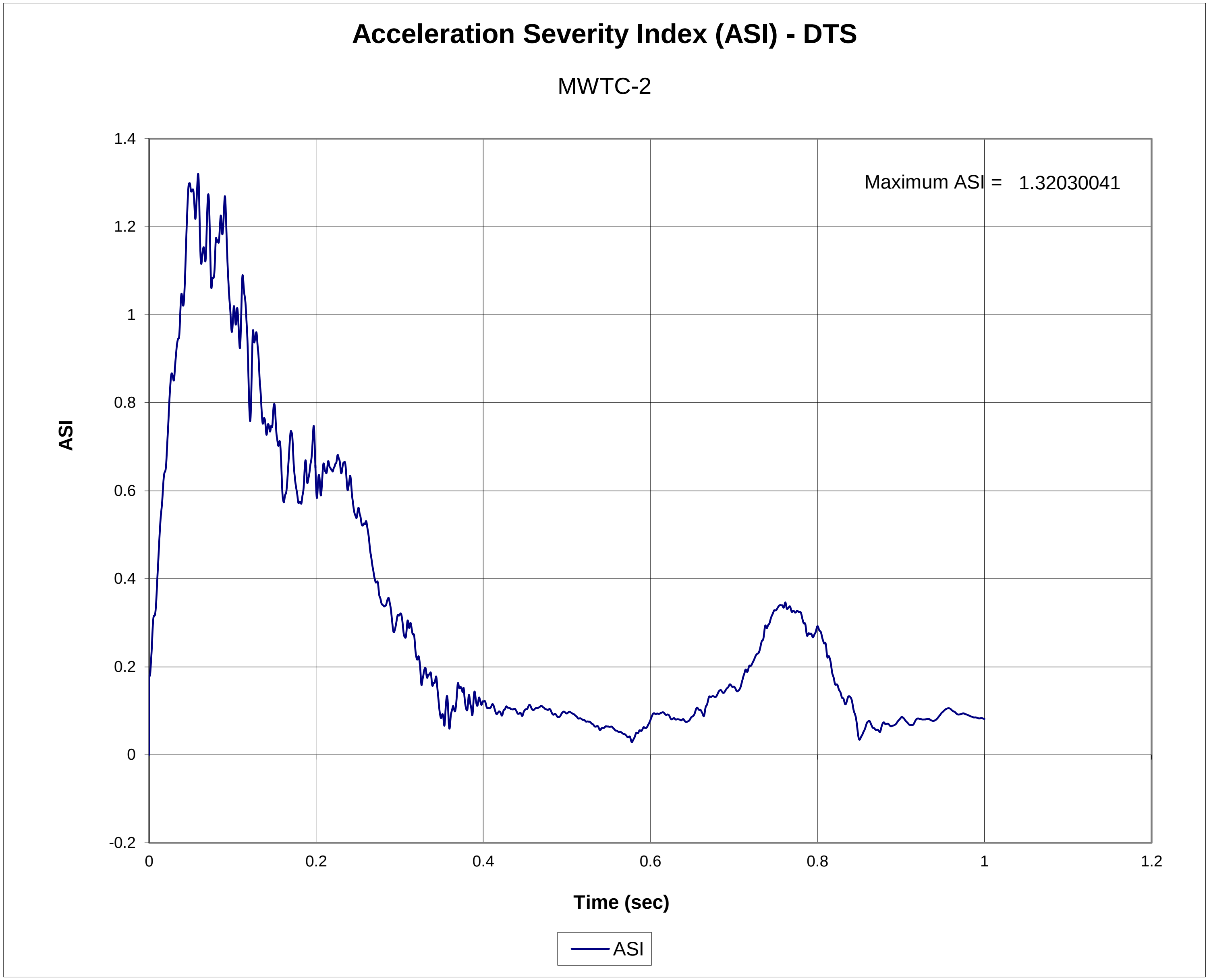


Figure F-8. Acceleration Severity Index (DTS), Test No. MWTC-2

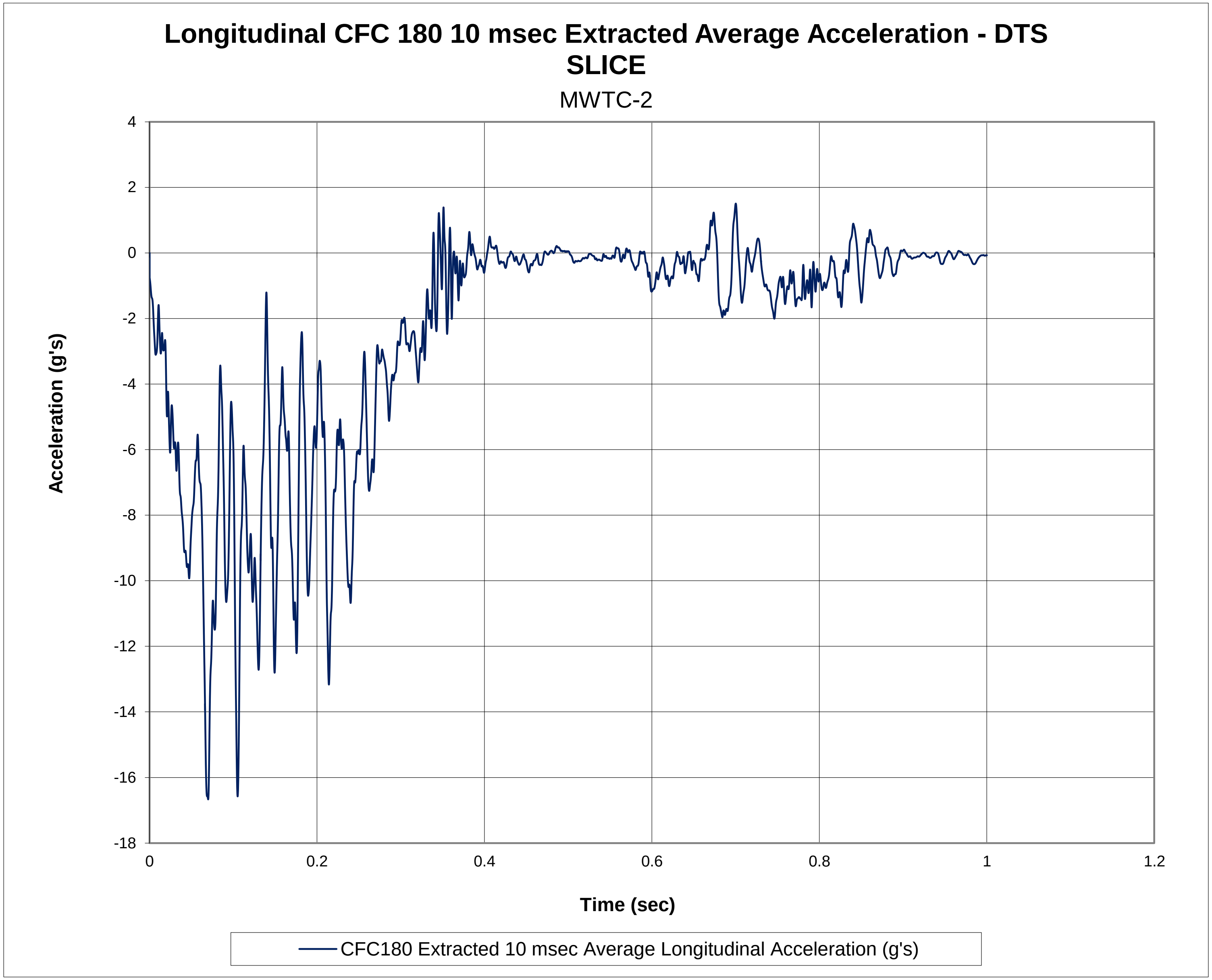


Figure F-9. 10-ms Average Longitudinal Deceleration (DTS SLICE), Test No. MWTC-2

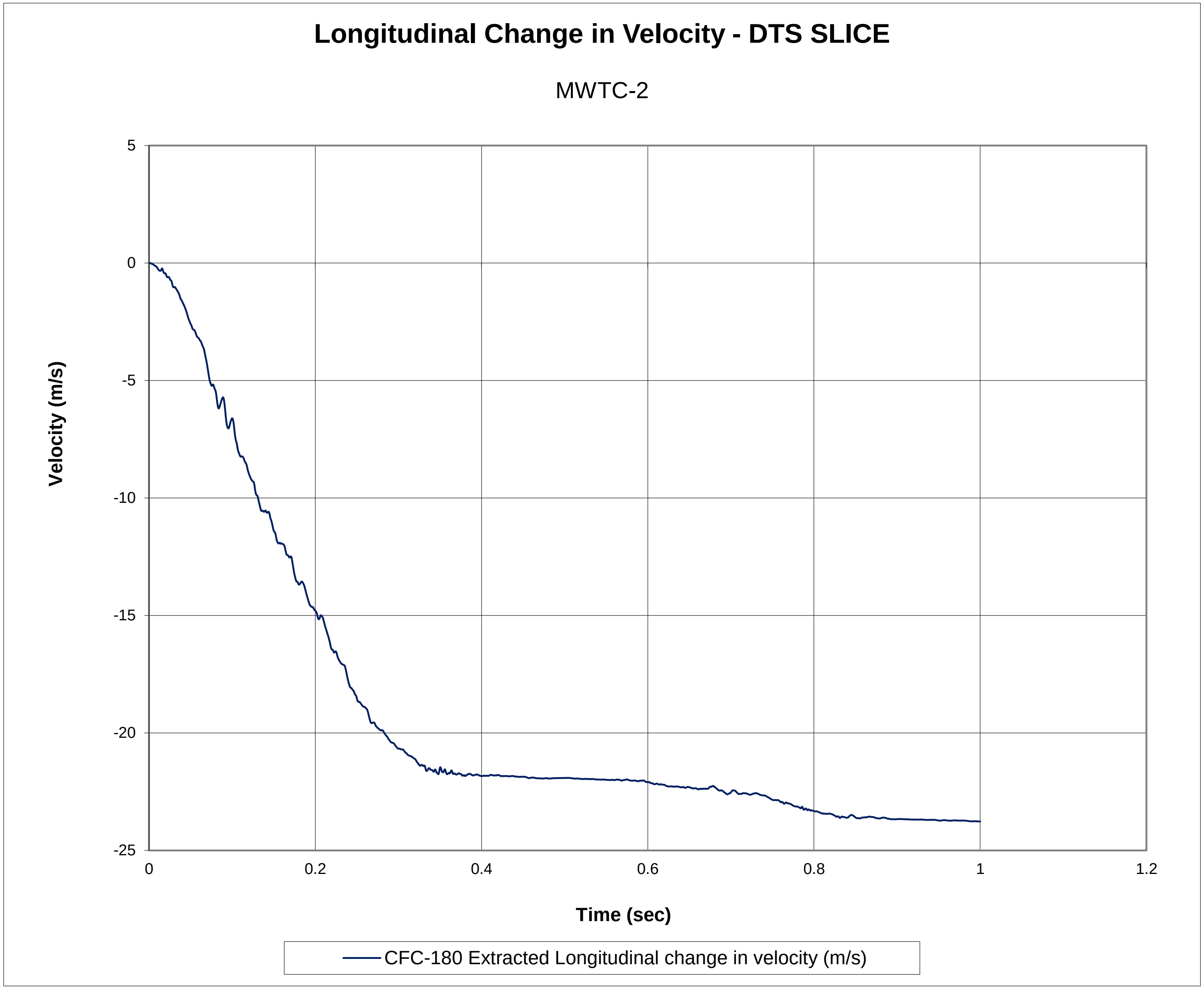


Figure F-10. Longitudinal Occupant Impact Velocity (DTS SLICE), Test No. MWTC-2

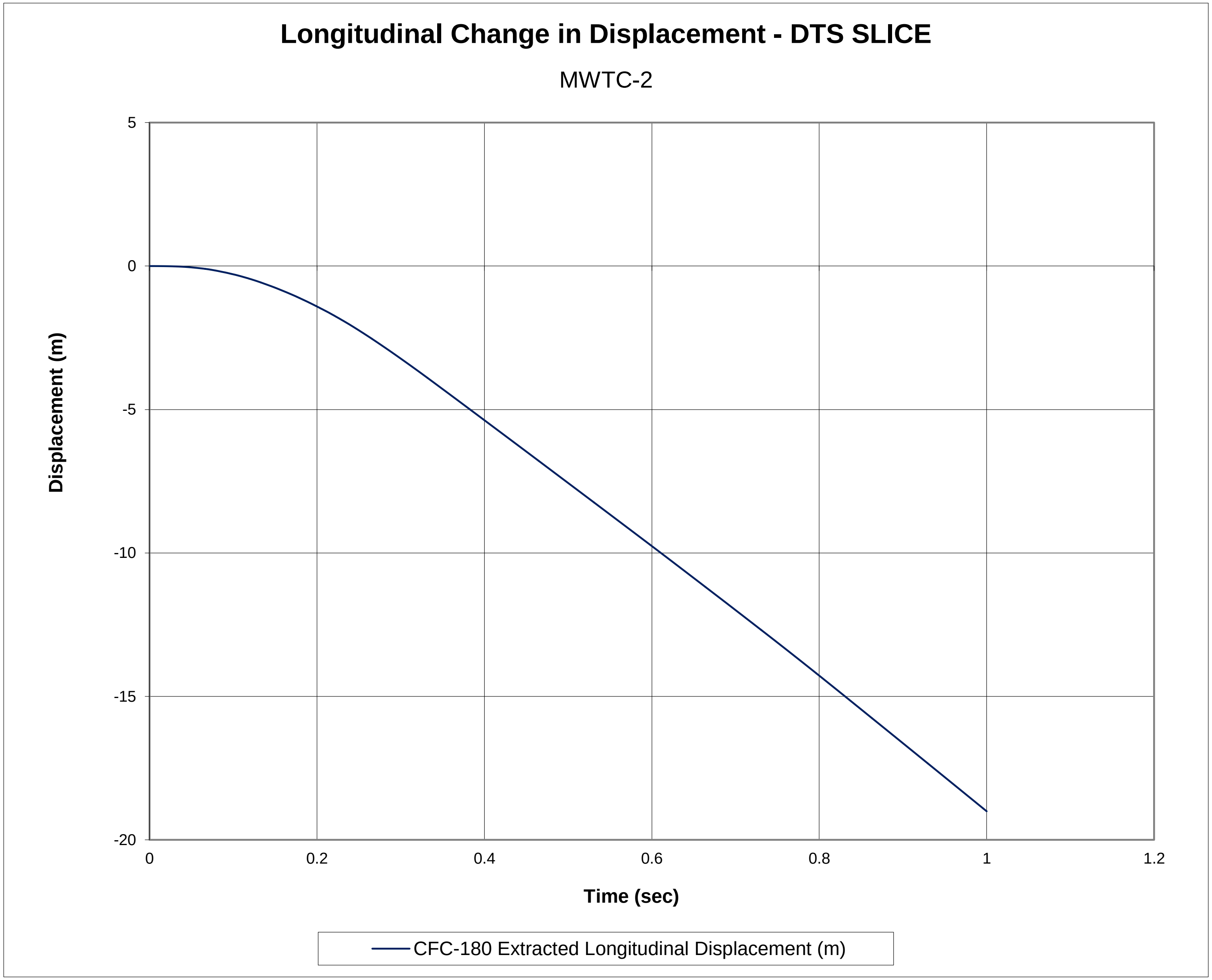


Figure F-11. Longitudinal Occupant Displacement (DTS SLICE), Test No. MWTC-2

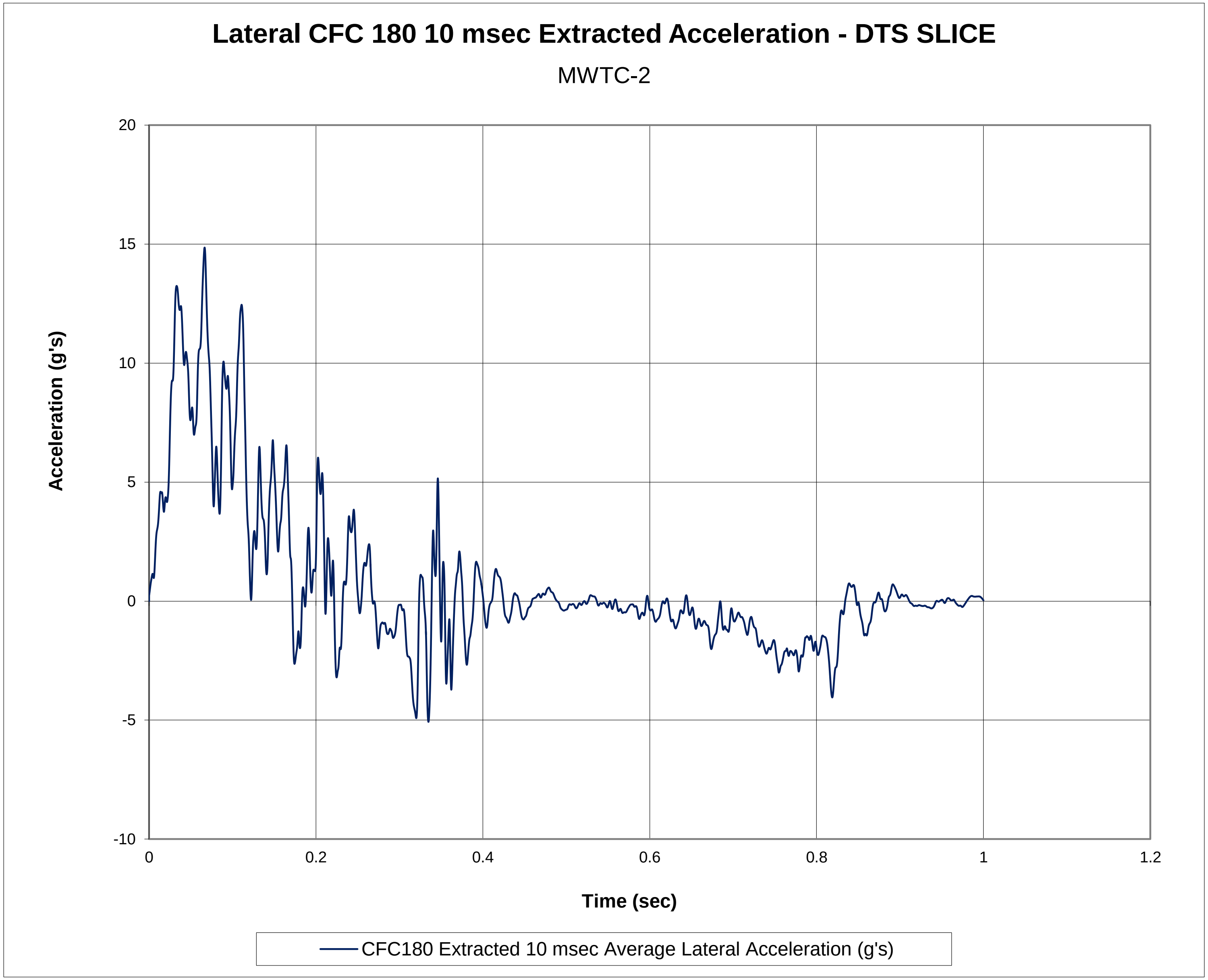


Figure F-12. 10-ms Average Lateral Deceleration (DTS SLICE), Test No. MWTC-2

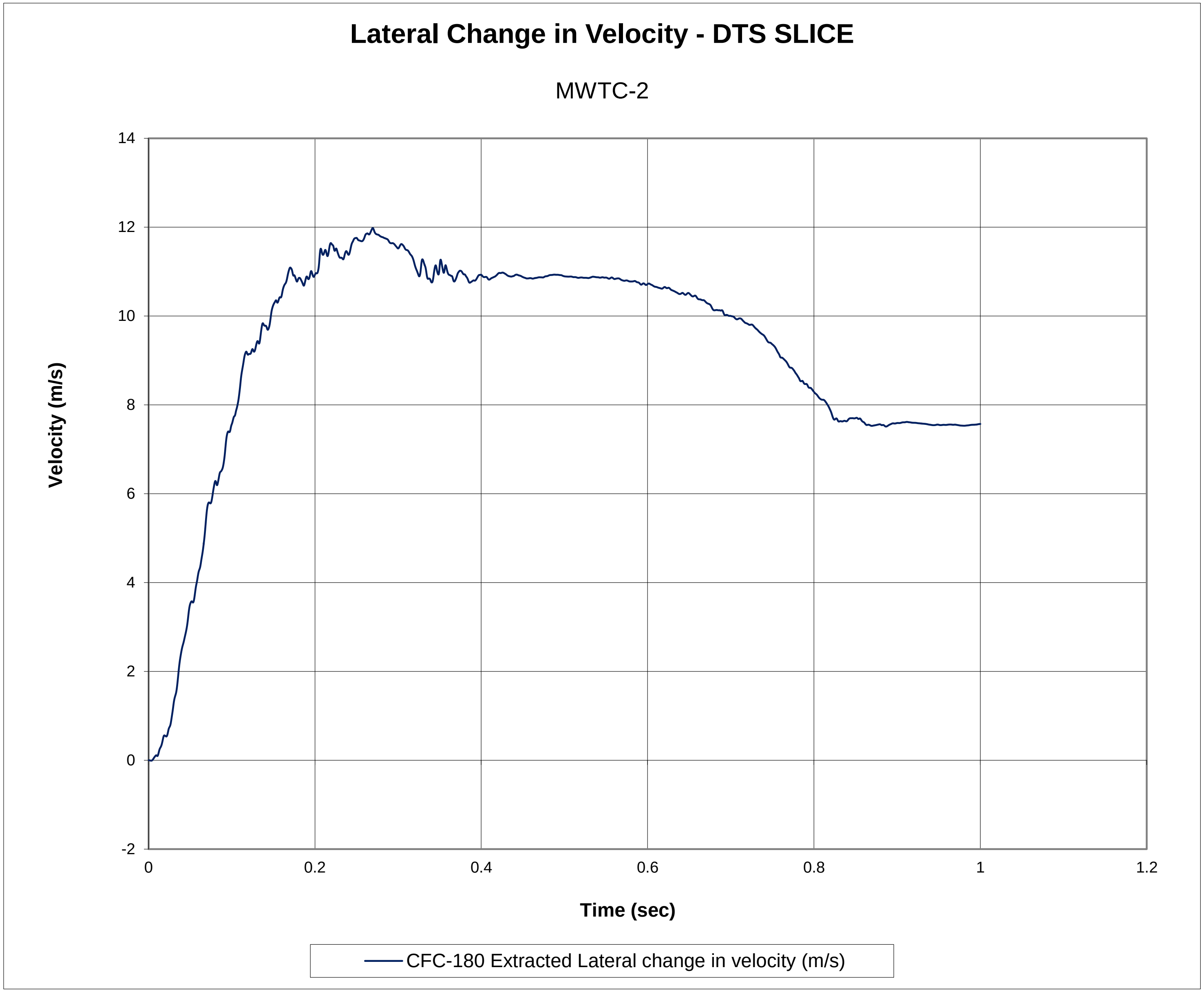


Figure F-13. Lateral Occupant Impact Velocity (DTS SLICE), Test No. MWTC-2

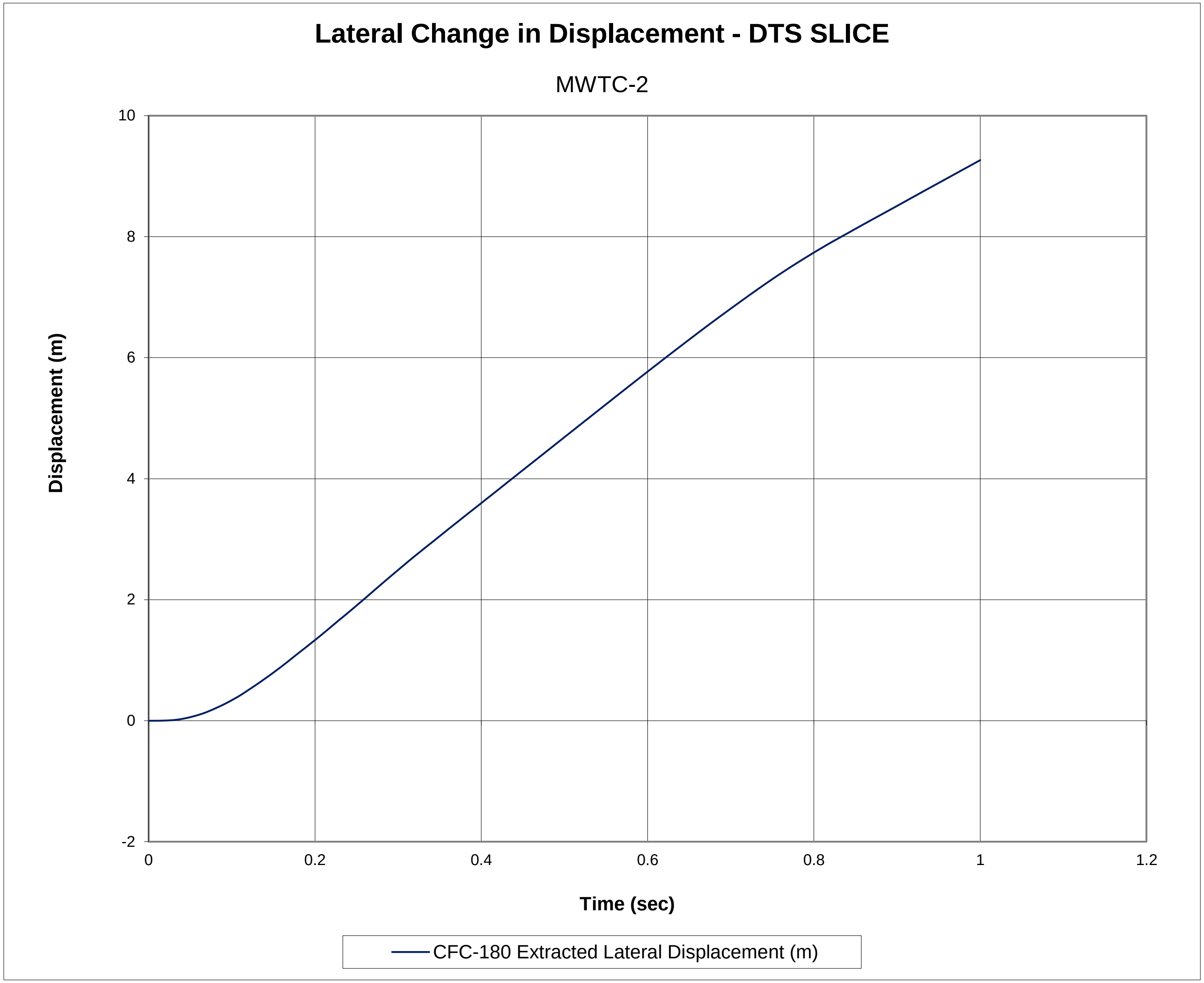


Figure F-14. Lateral Occupant Displacement (DTS SLICE), Test No. MWTC-2

Figure F-15. Vehicle Angular Displacements (DTS SLICE), Test No. MWTC-2

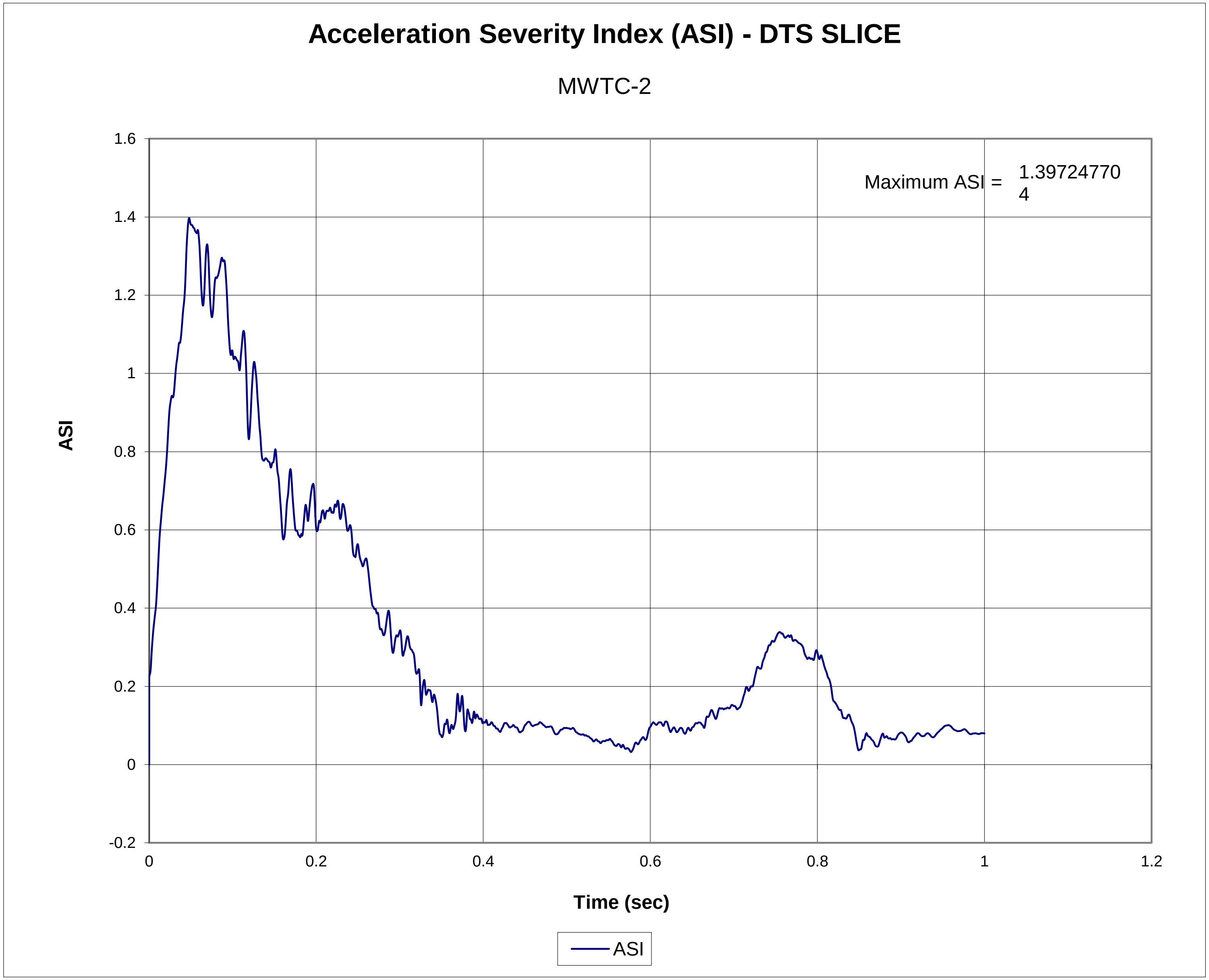


Figure F-16. Acceleration Severity Index (DTS SLICE), Test No. MWTC-2

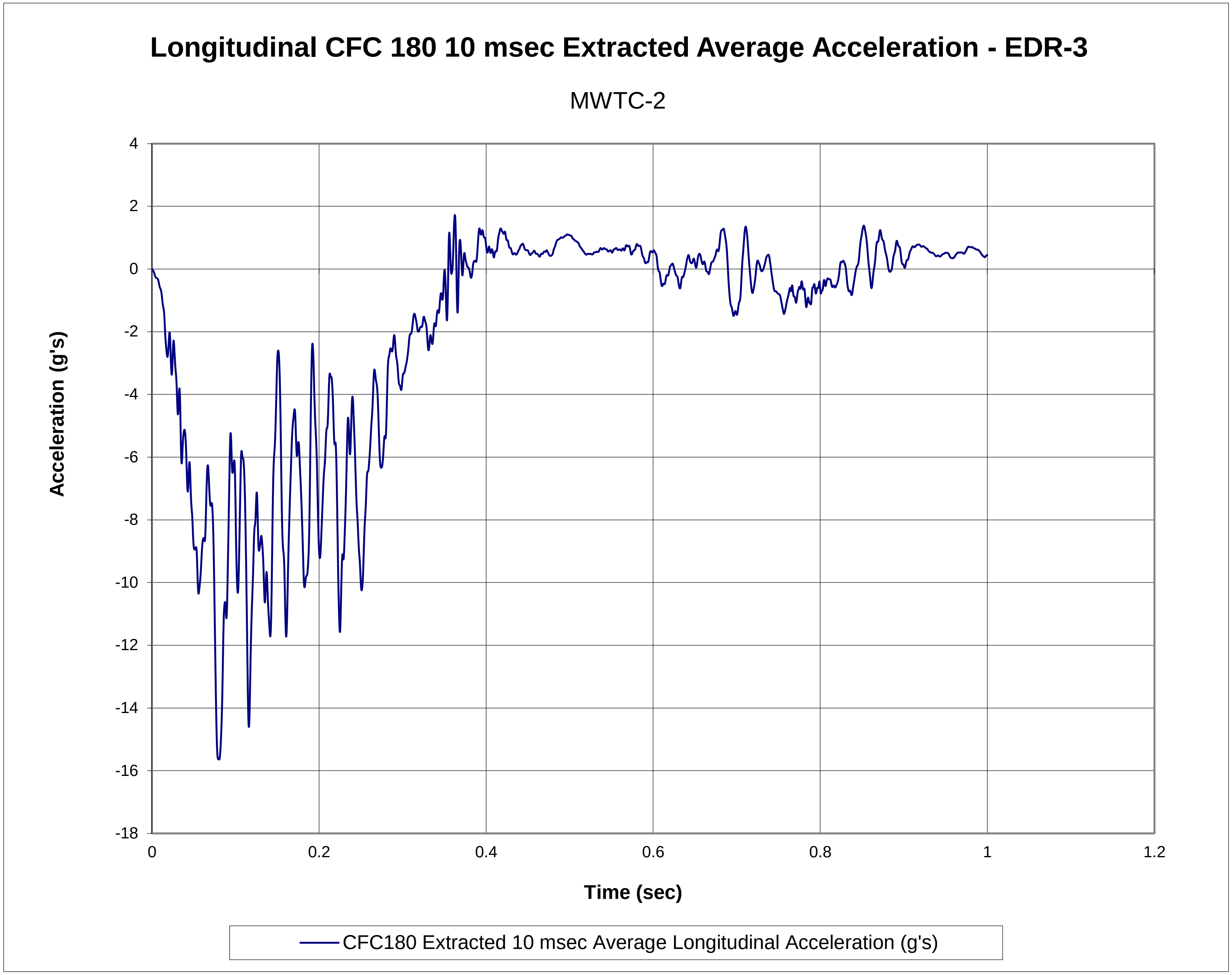


Figure F-17. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. MWTC-2

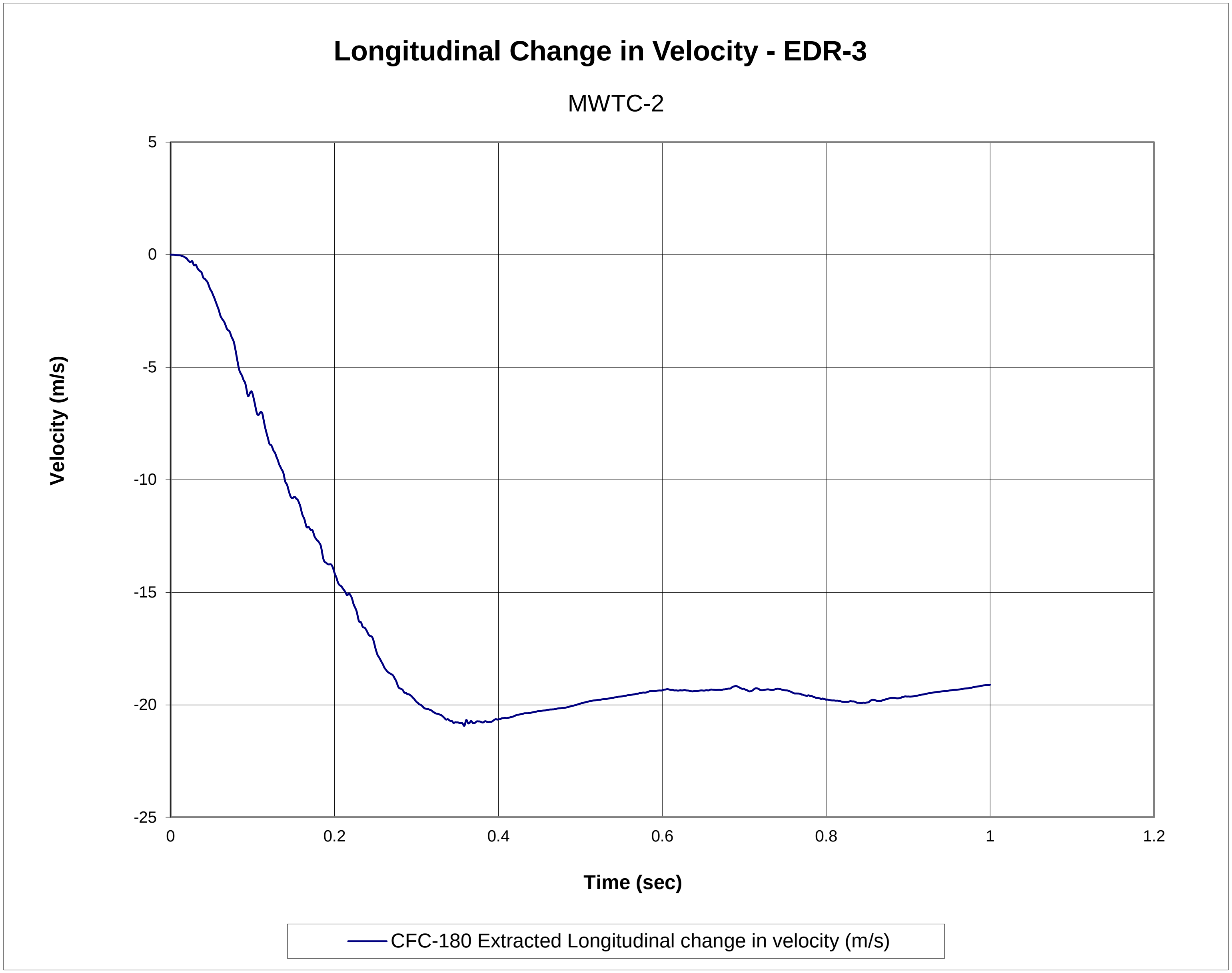


Figure F-18. Longitudinal Occupant Impact Velocity (EDR-3), Test No. MWTC-2

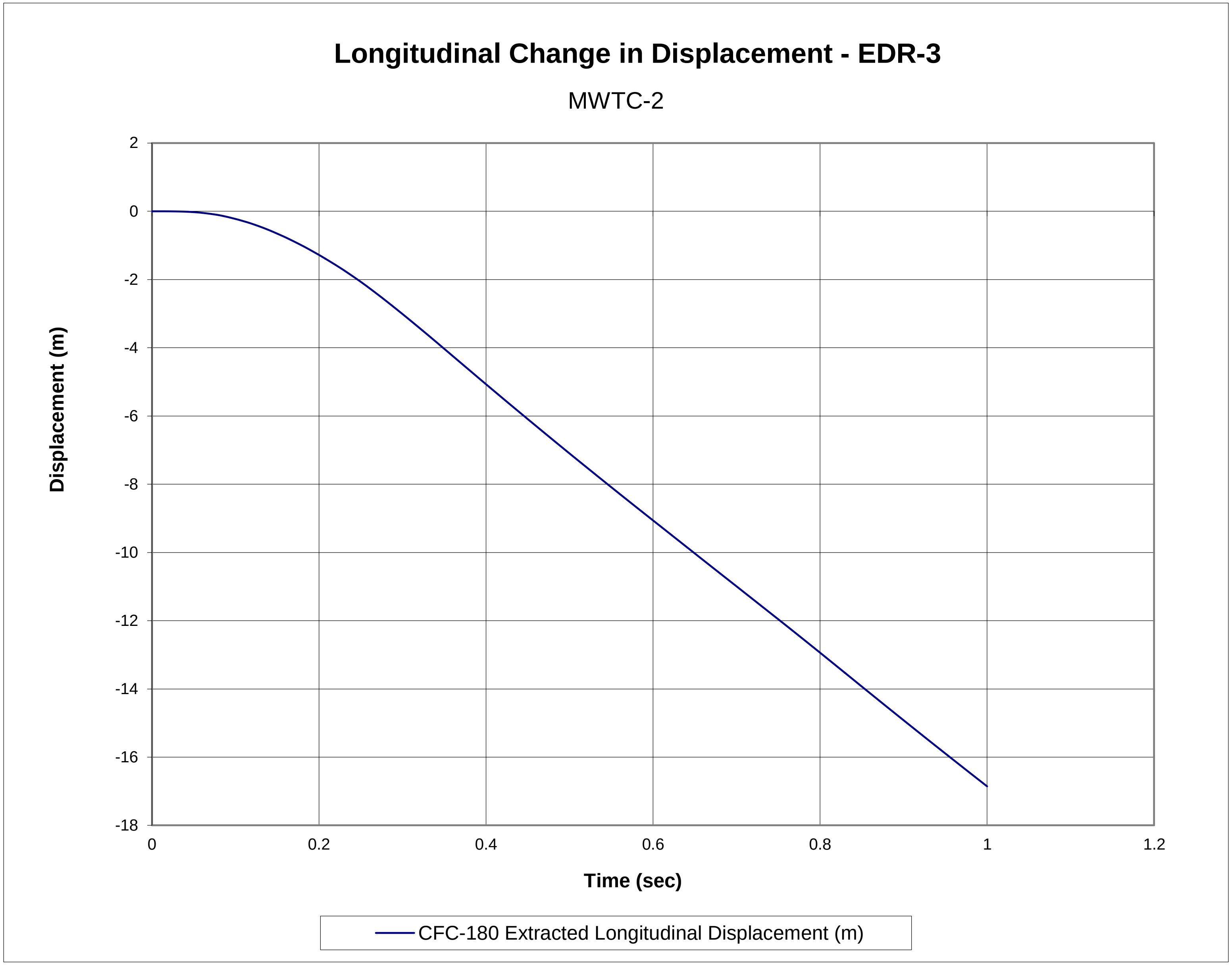


Figure F-19. Longitudinal Occupant Displacement (EDR-3), Test No. MWTC-2

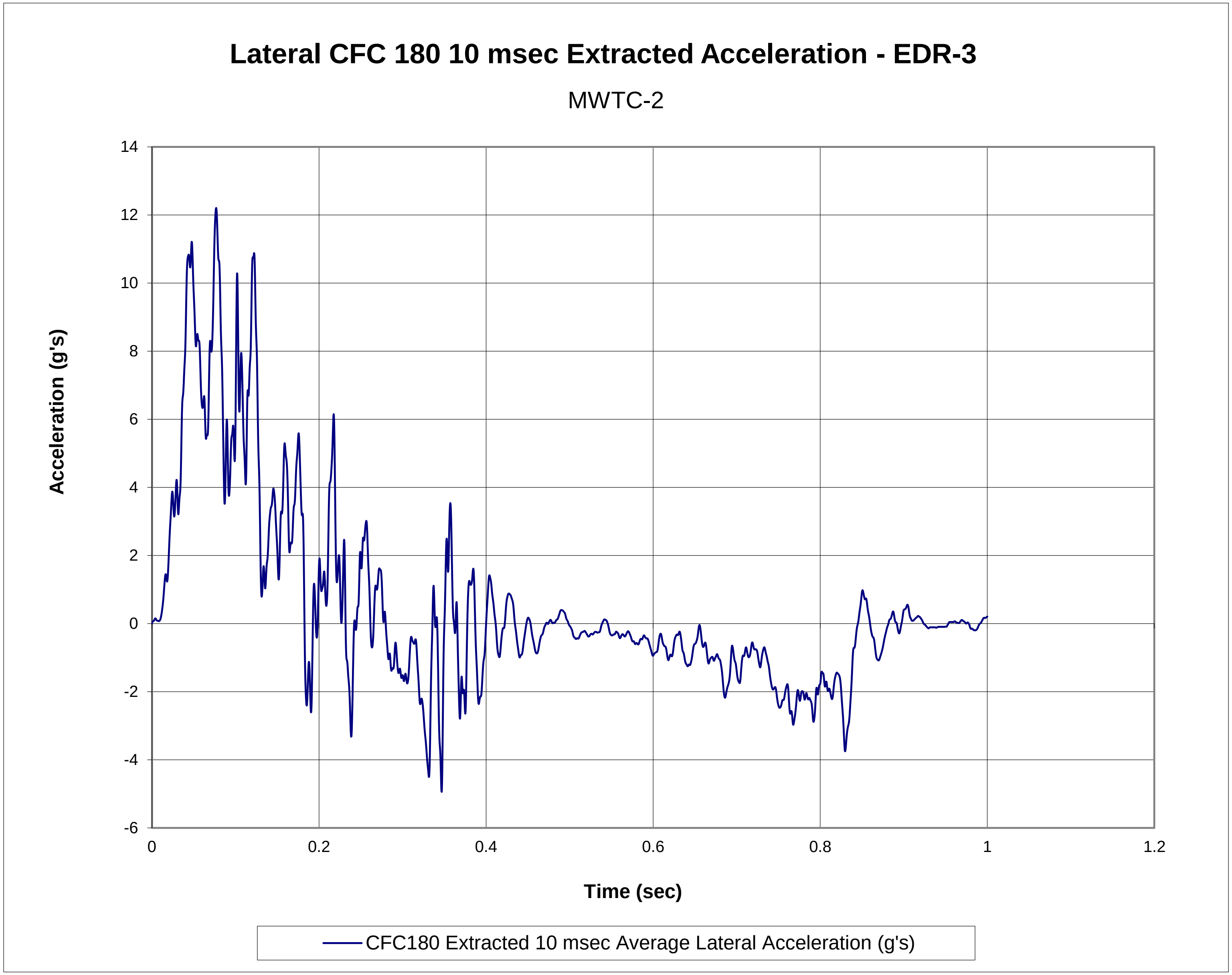


Figure F-20. 10-ms Average Lateral Deceleration (EDR-3), Test No. MWTC-2

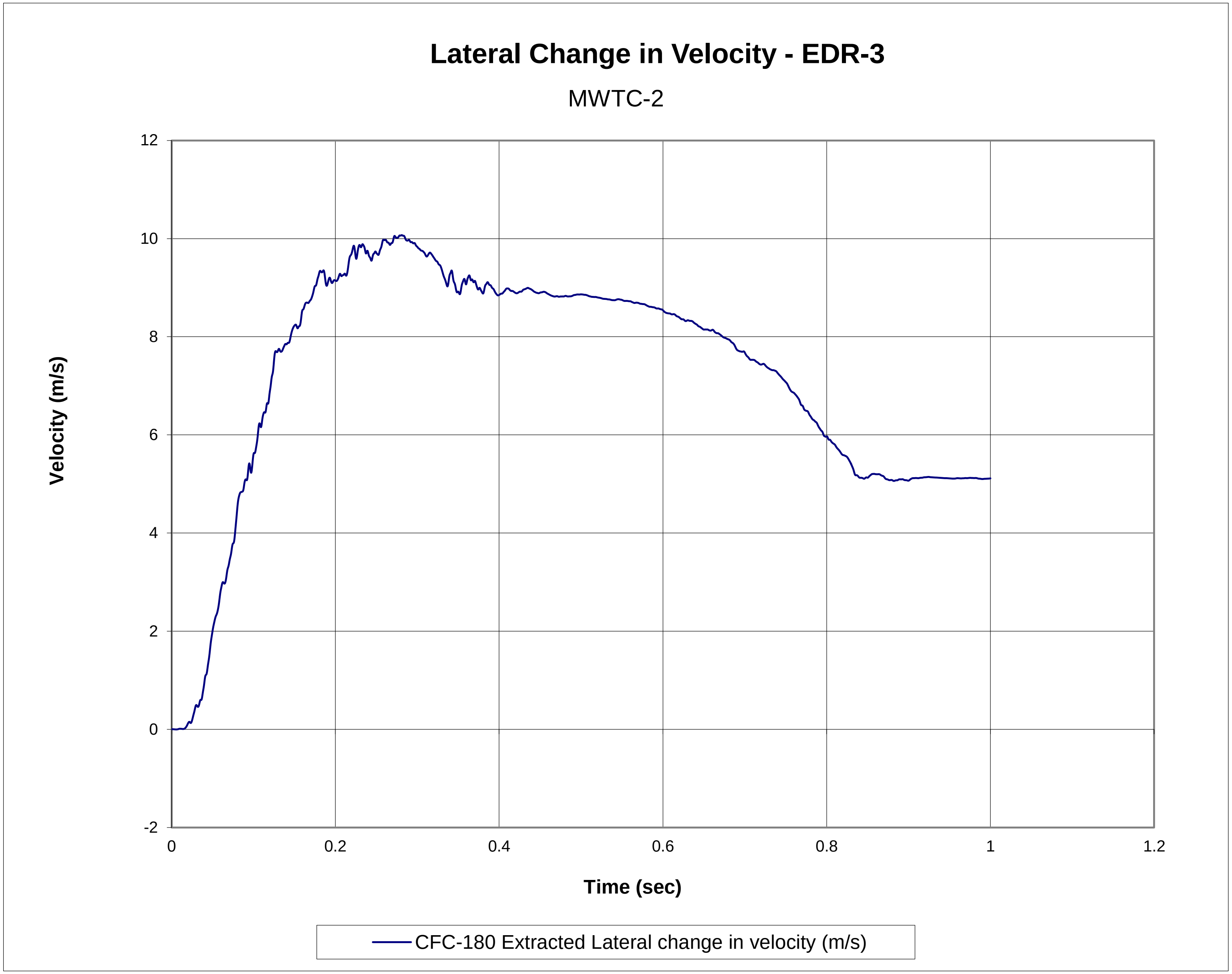


Figure F-21. Lateral Occupant Impact Velocity (EDR-3), Test No. MWTC-2

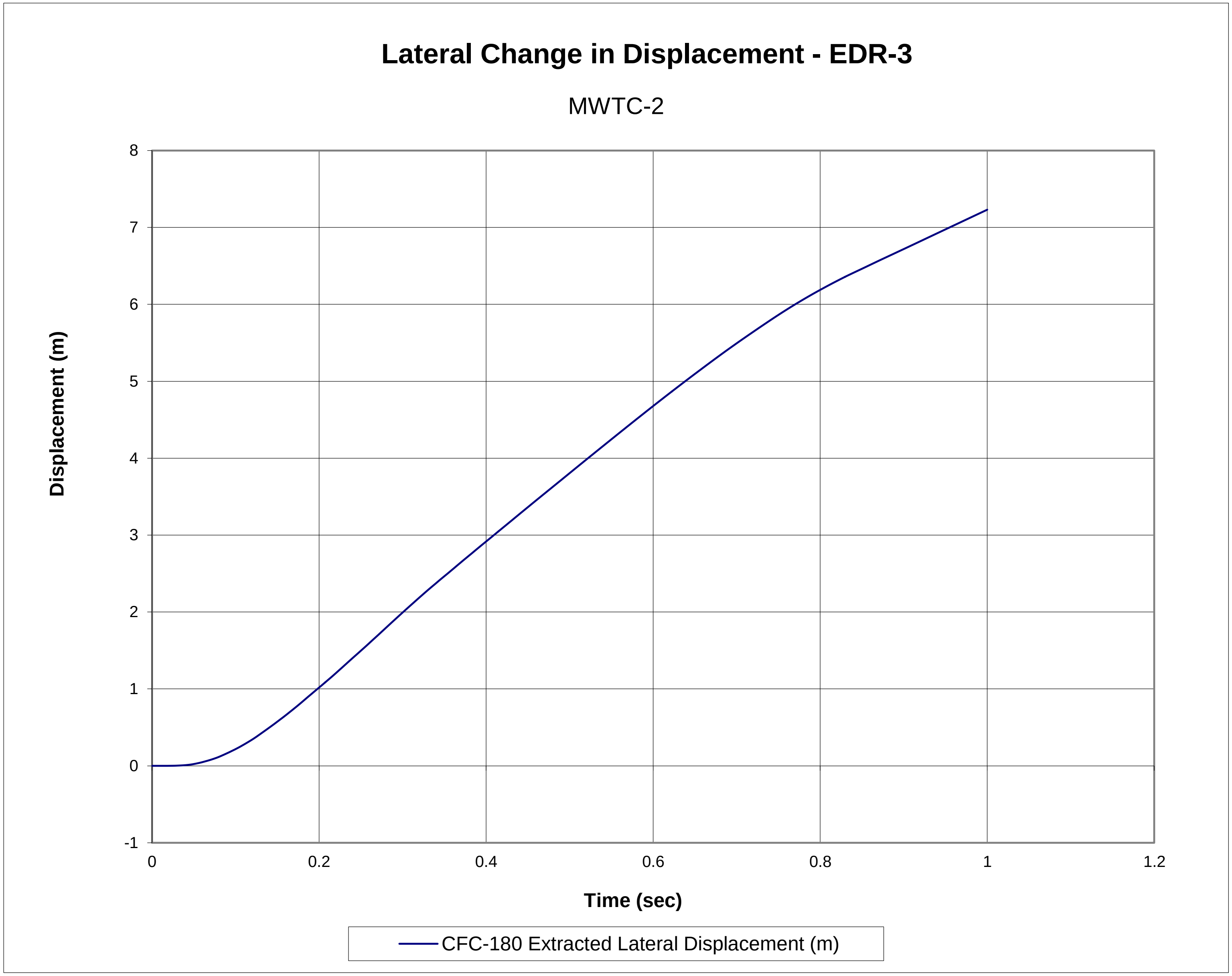


Figure F-22. Lateral Occupant Displacement (EDR-3), Test No. MWTC-2

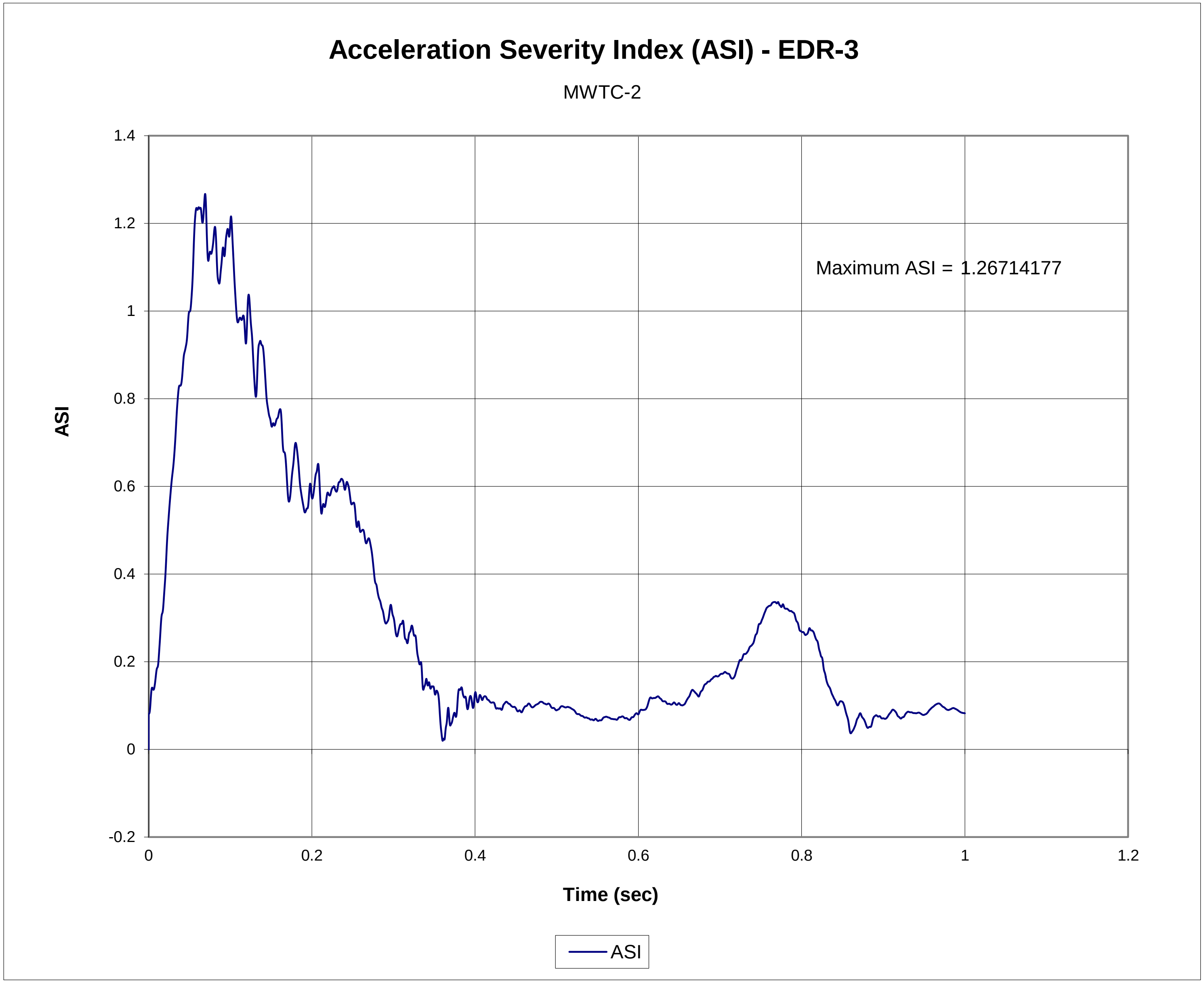


Figure F-23. Acceleration Severity Index (EDR-3), Test No. MWTC-2

Appendix G. Accelerometer and Rate Transducer Data Plots, Test No. MWTC-3

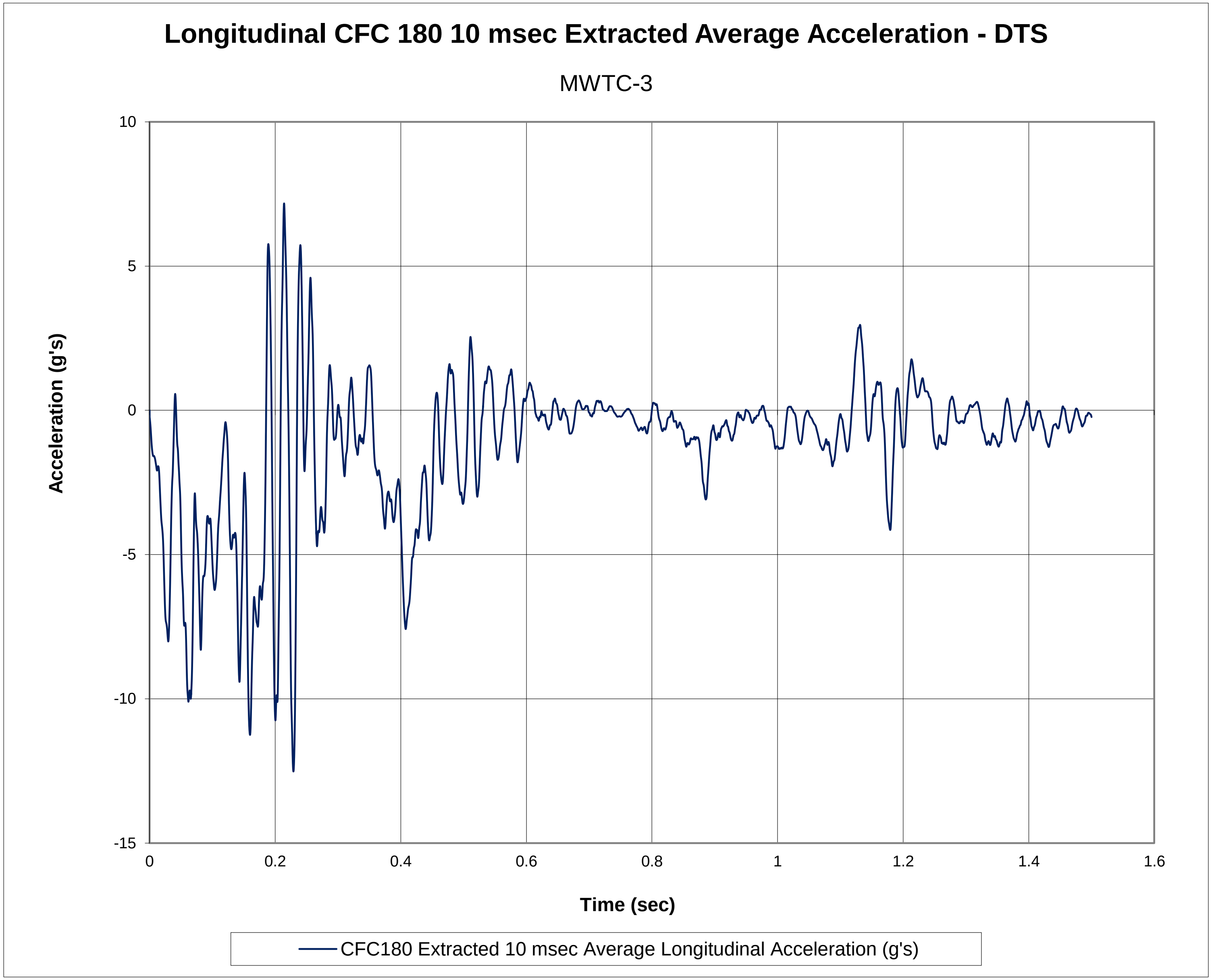


Figure G-1. 10-ms Average Longitudinal Deceleration (DTS), Test No. MWTC-3

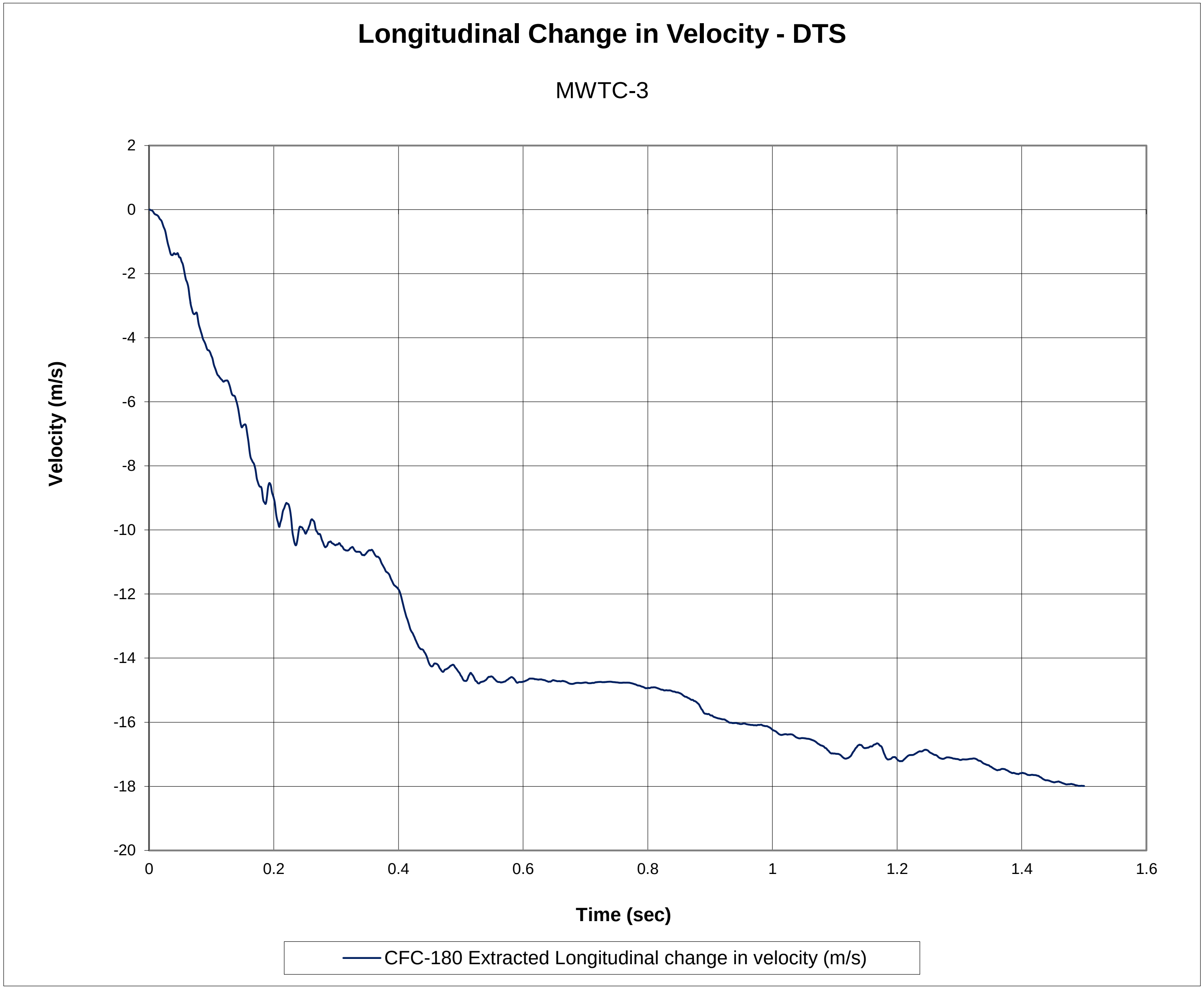


Figure G-2. Longitudinal Occupant Impact Velocity (DTS), Test No. MWTC-3

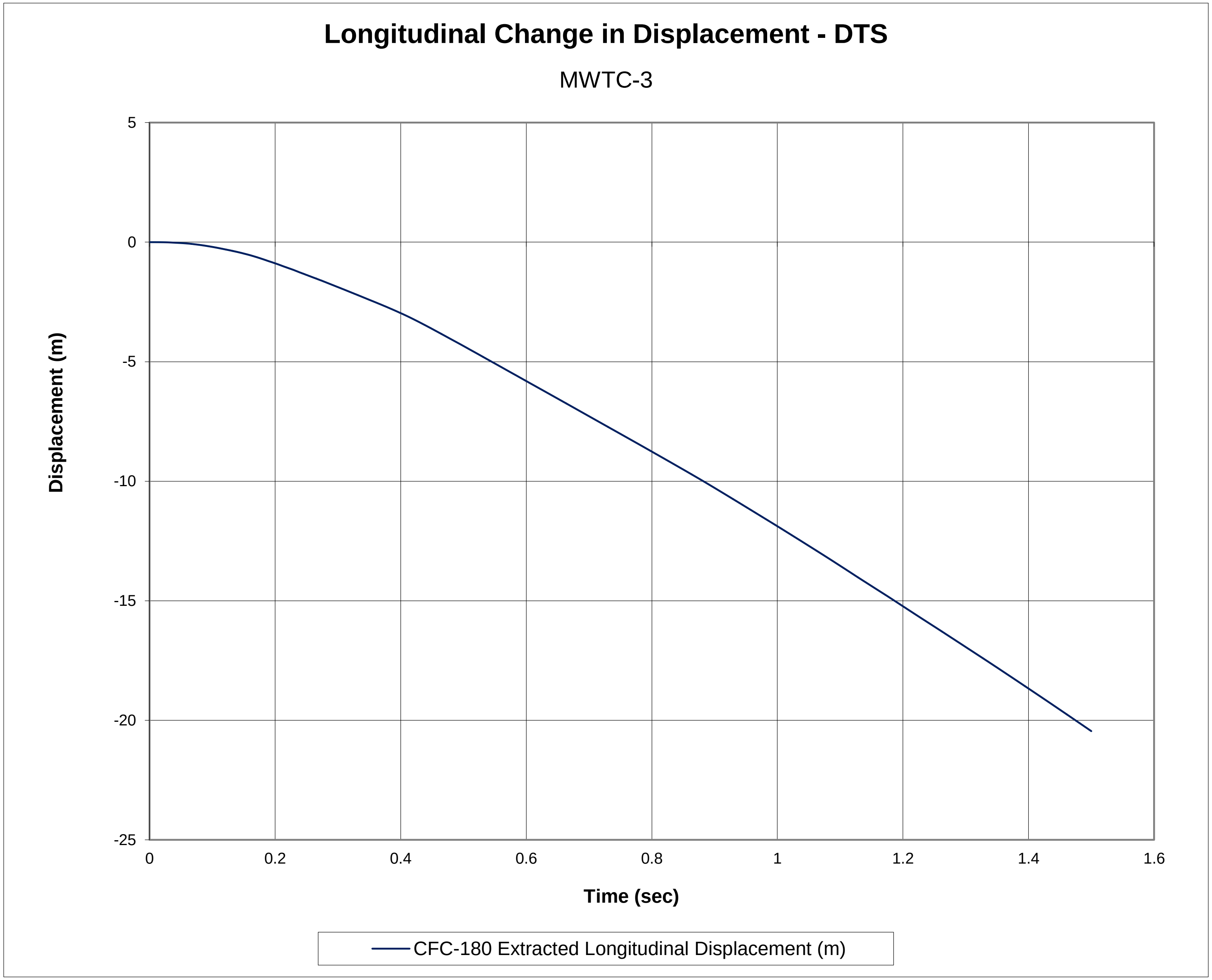


Figure G-3. Longitudinal Occupant Displacement (DTS), Test No. MWTC-3

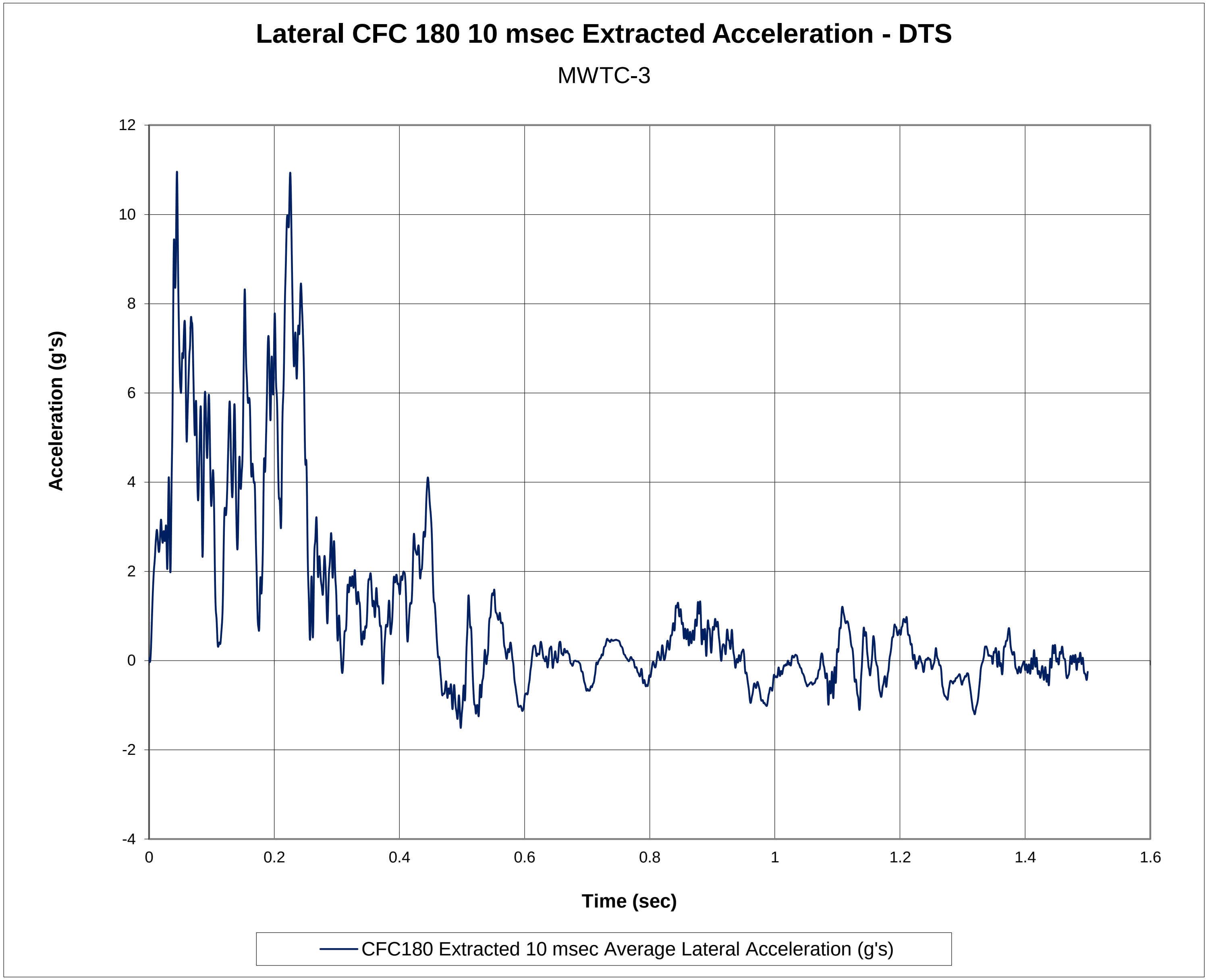


Figure G-4. 10-ms Average Lateral Deceleration (DTS), Test No. MWTC-3

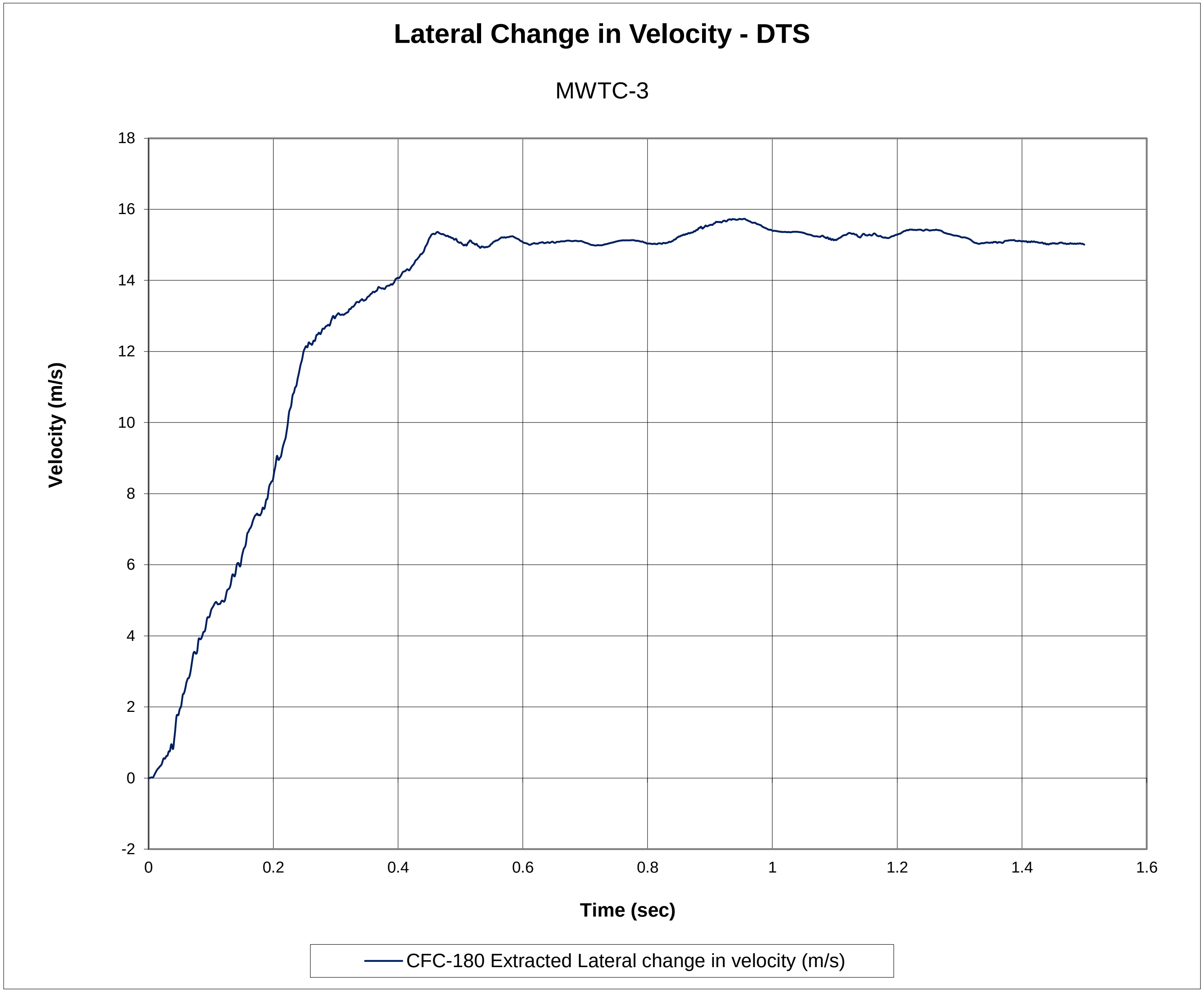


Figure G-5. Lateral Occupant Impact Velocity (DTS), Test No. MWTC-3

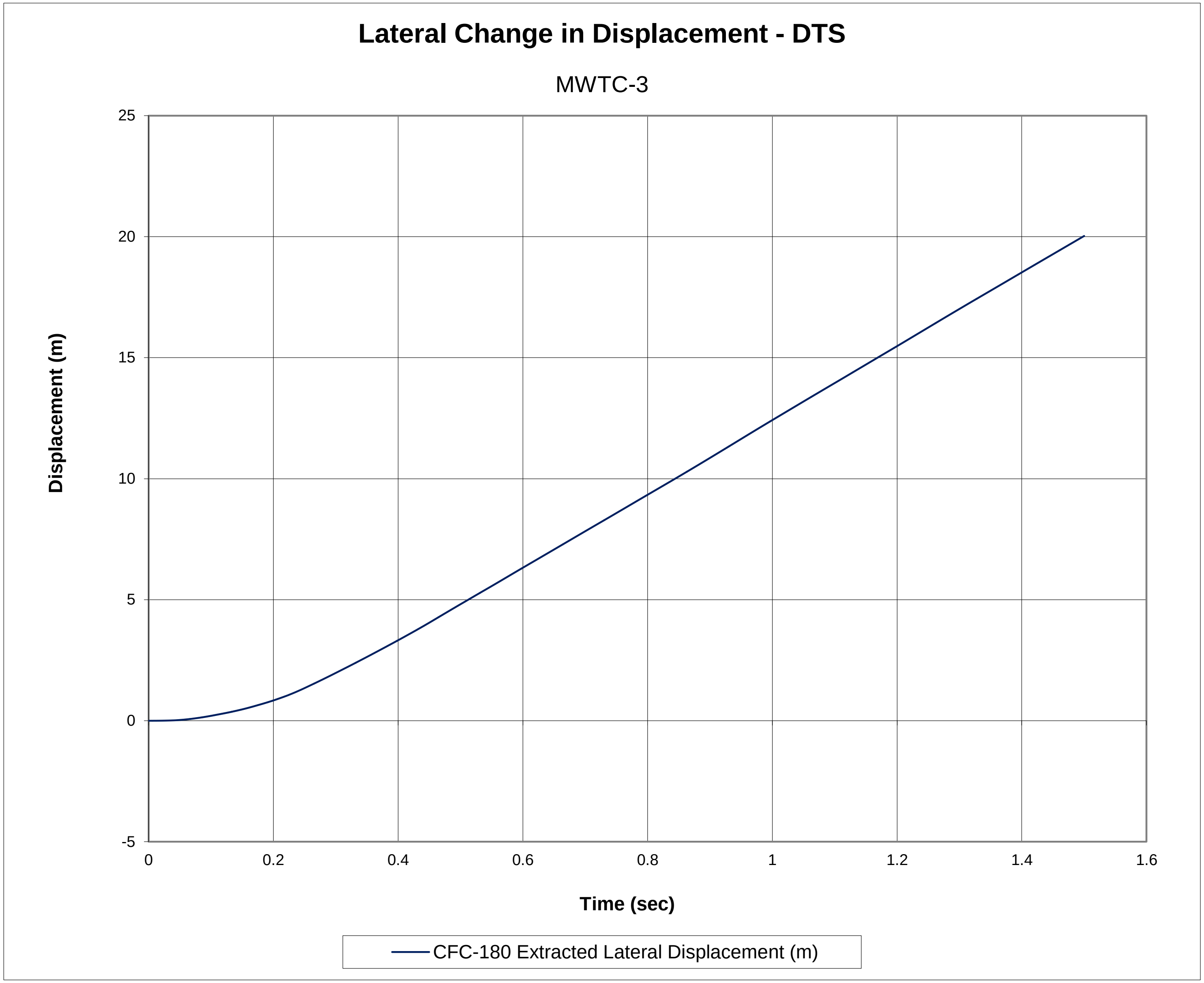


Figure G-6. Lateral Occupant Displacement (DTS), Test No. MWTC-3

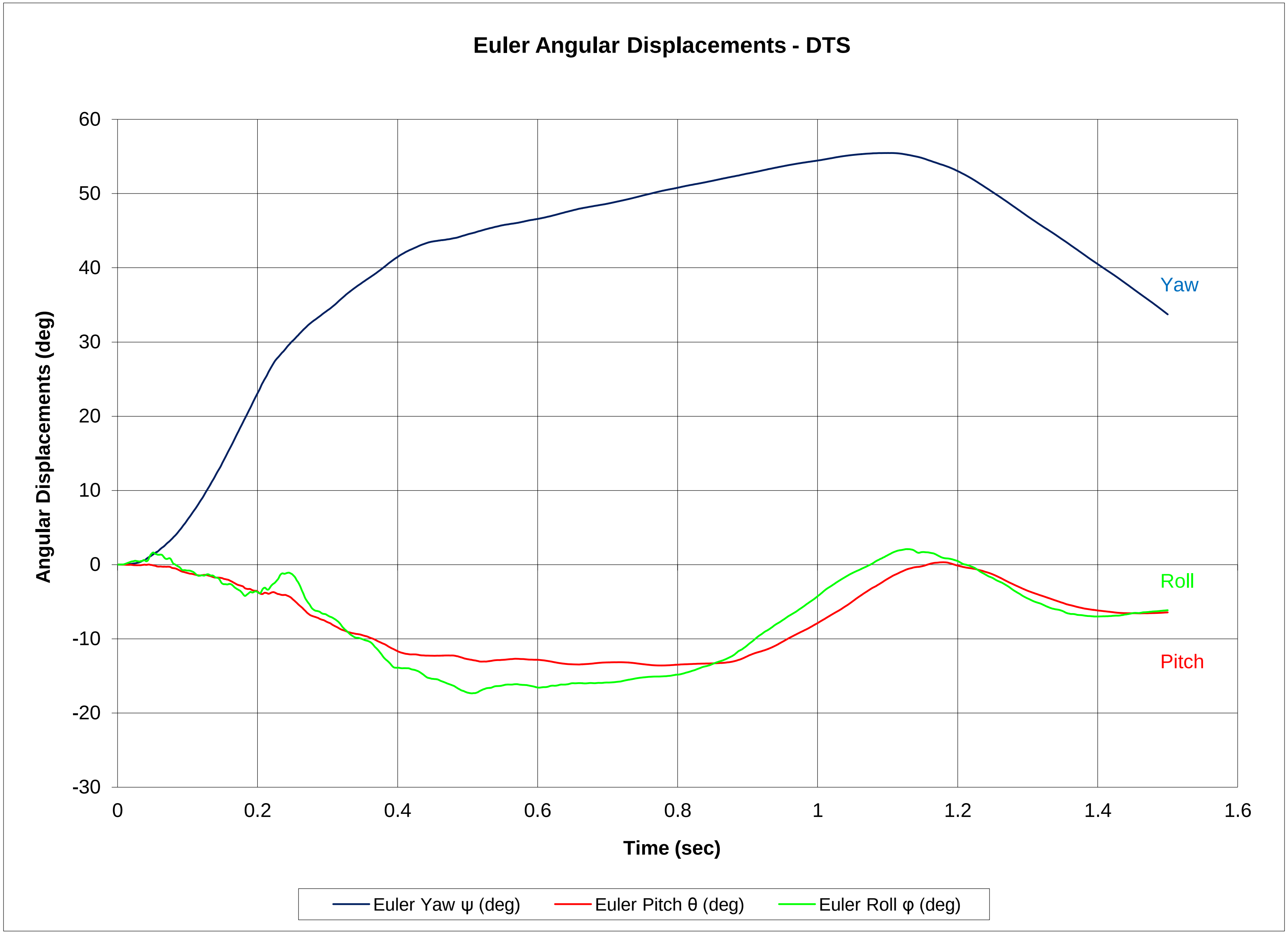


Figure G-7. Vehicle Angular Displacements (DTS), Test No. MWTC-3

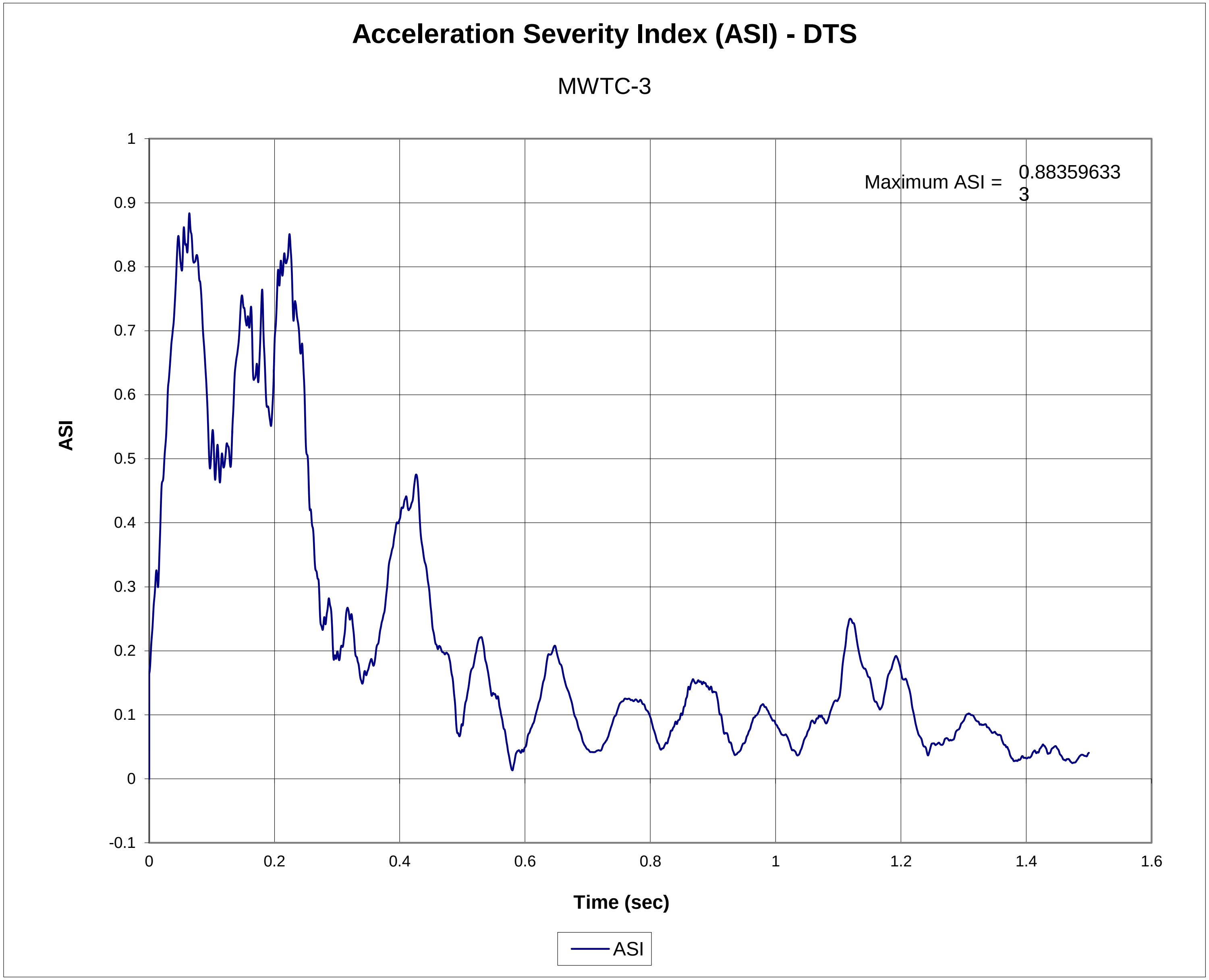


Figure G-8. Acceleration Severity Index (DTS), Test No. MWTC-3

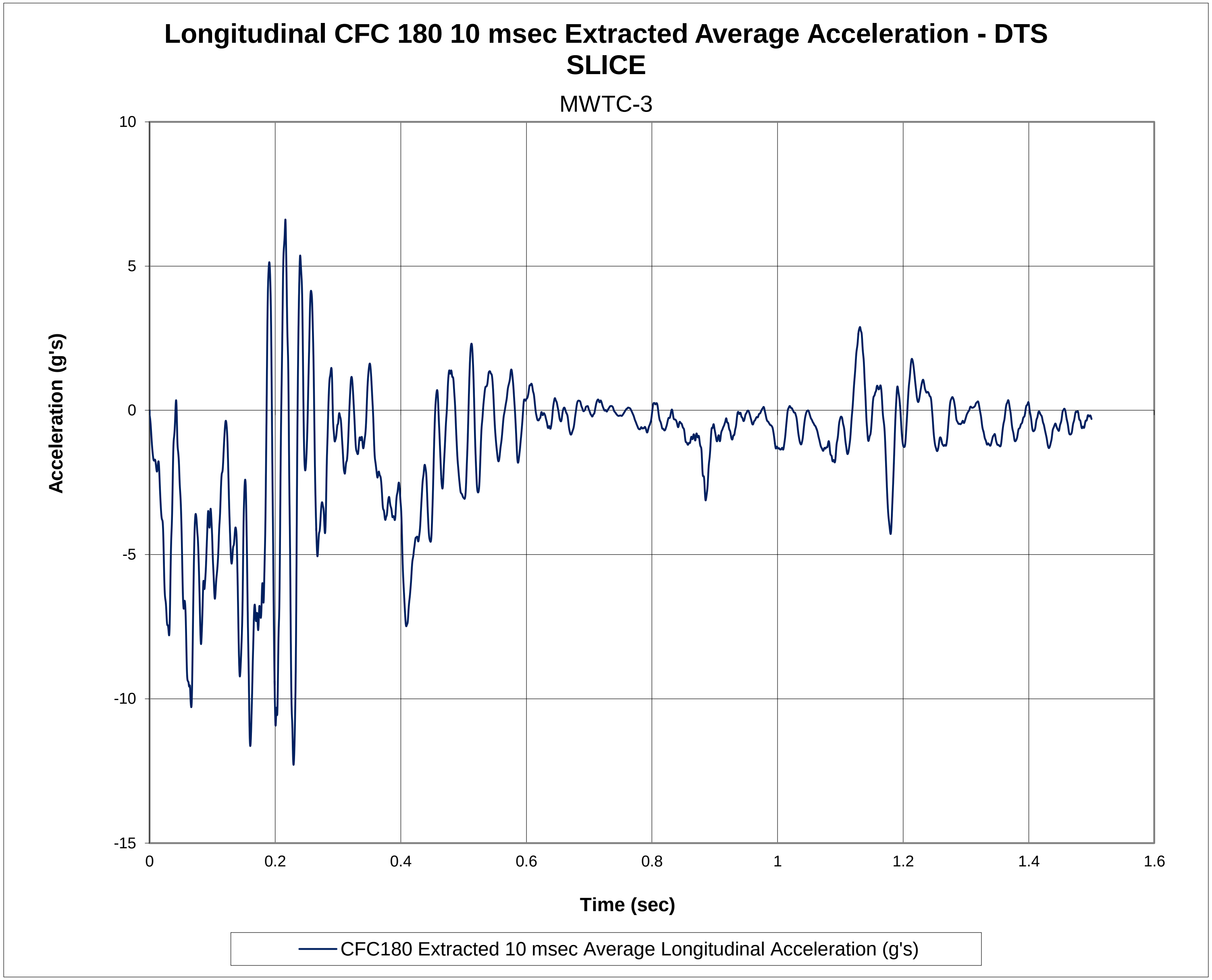


Figure G-9. 10-ms Average Longitudinal Deceleration (DTS SLICE), Test No. MWTC-3

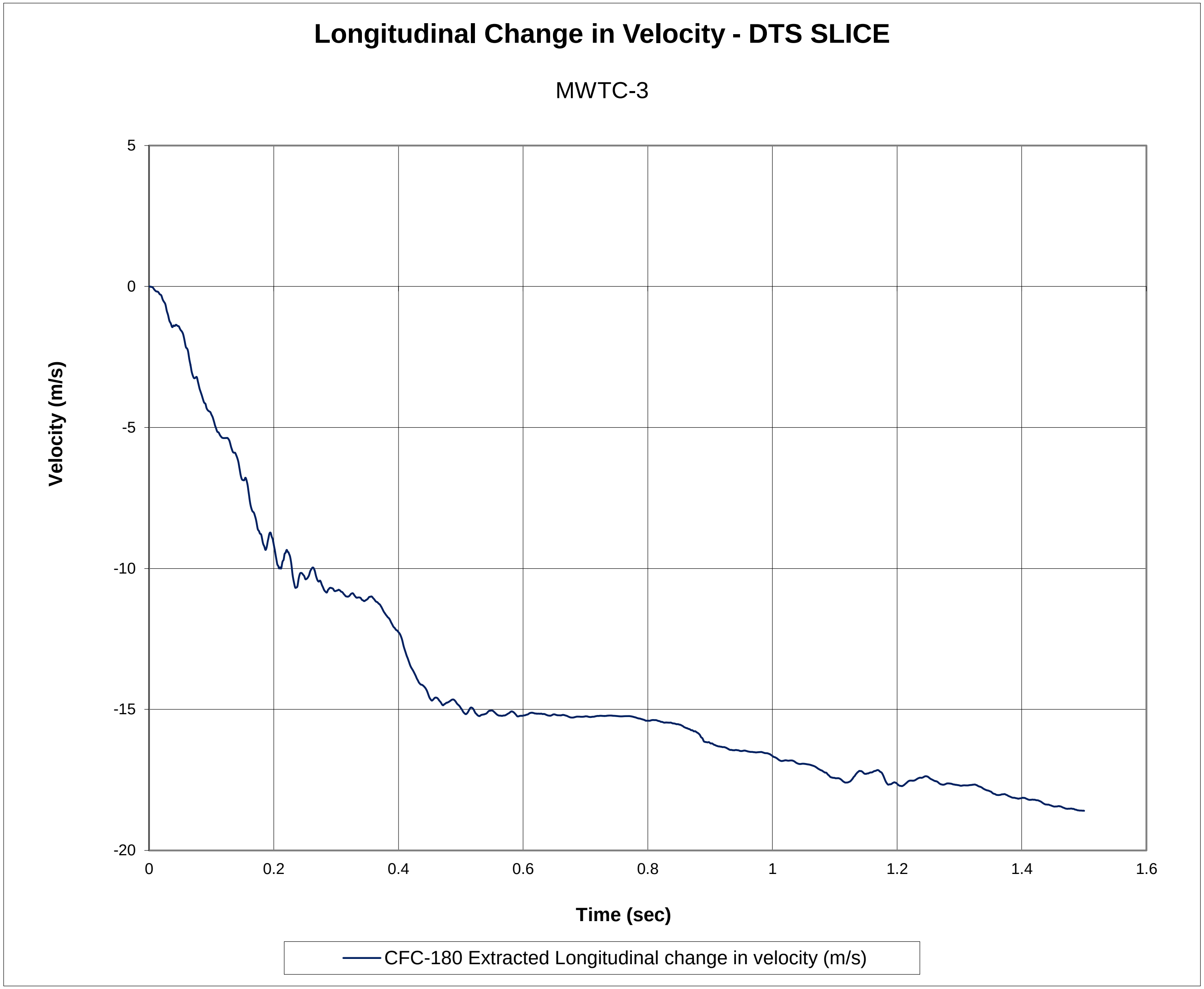


Figure G-10. Longitudinal Occupant Impact Velocity (DTS SLICE), Test No. MWTC-3

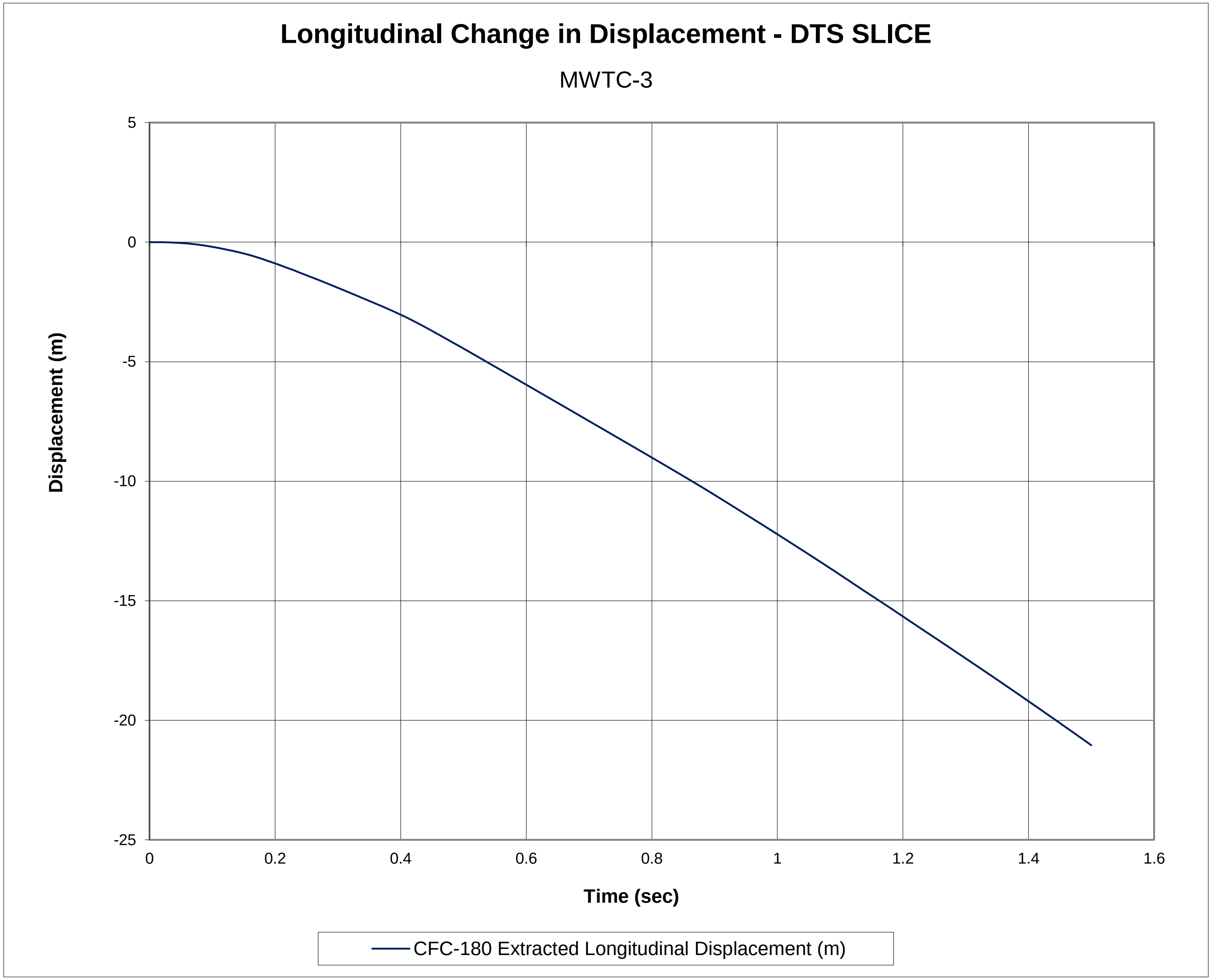


Figure G-11. Longitudinal Occupant Displacement (DTS SLICE), Test No. MWTC-3

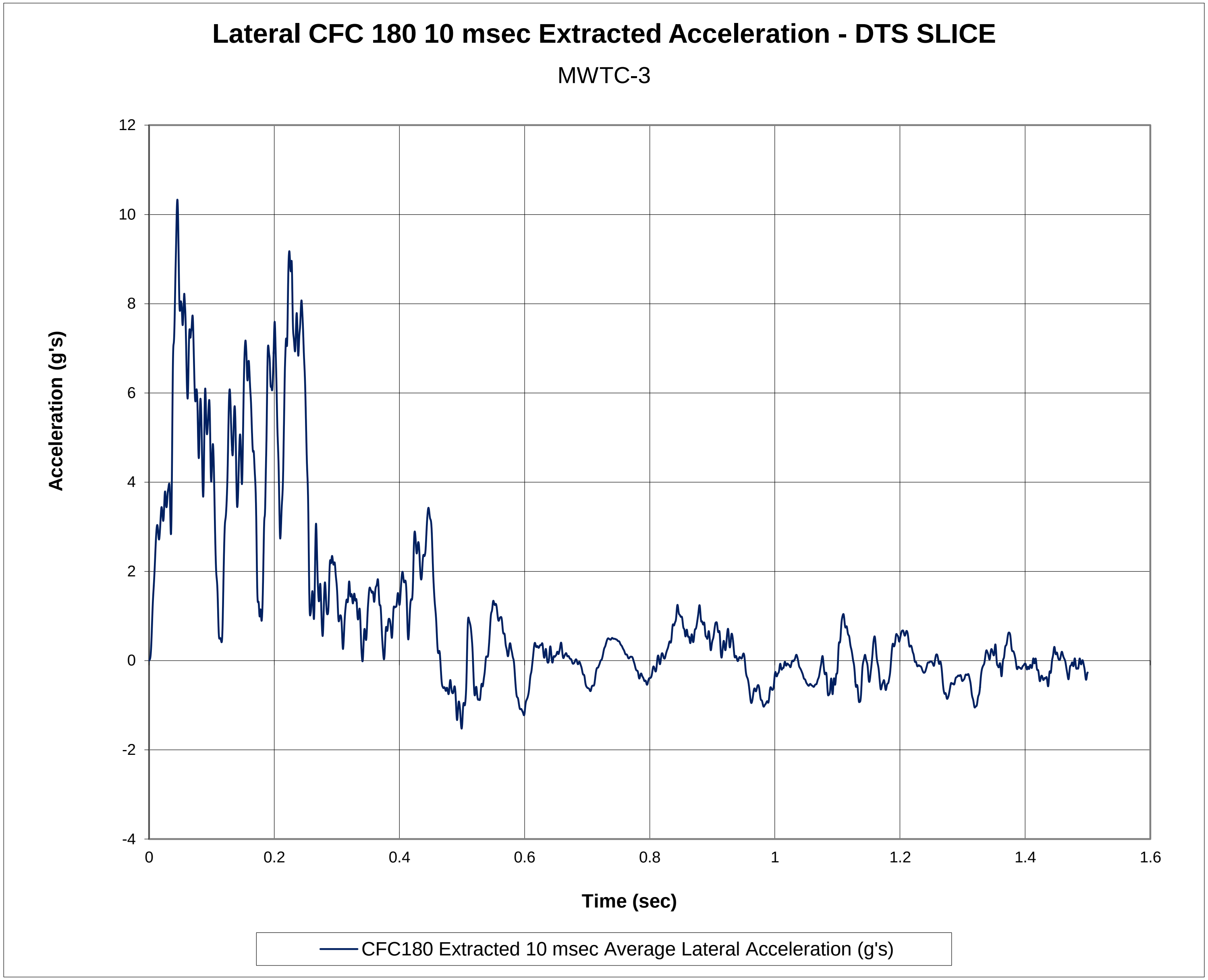


Figure G-12. 10-ms Average Lateral Deceleration (DTS SLICE), Test No. MWTC-3

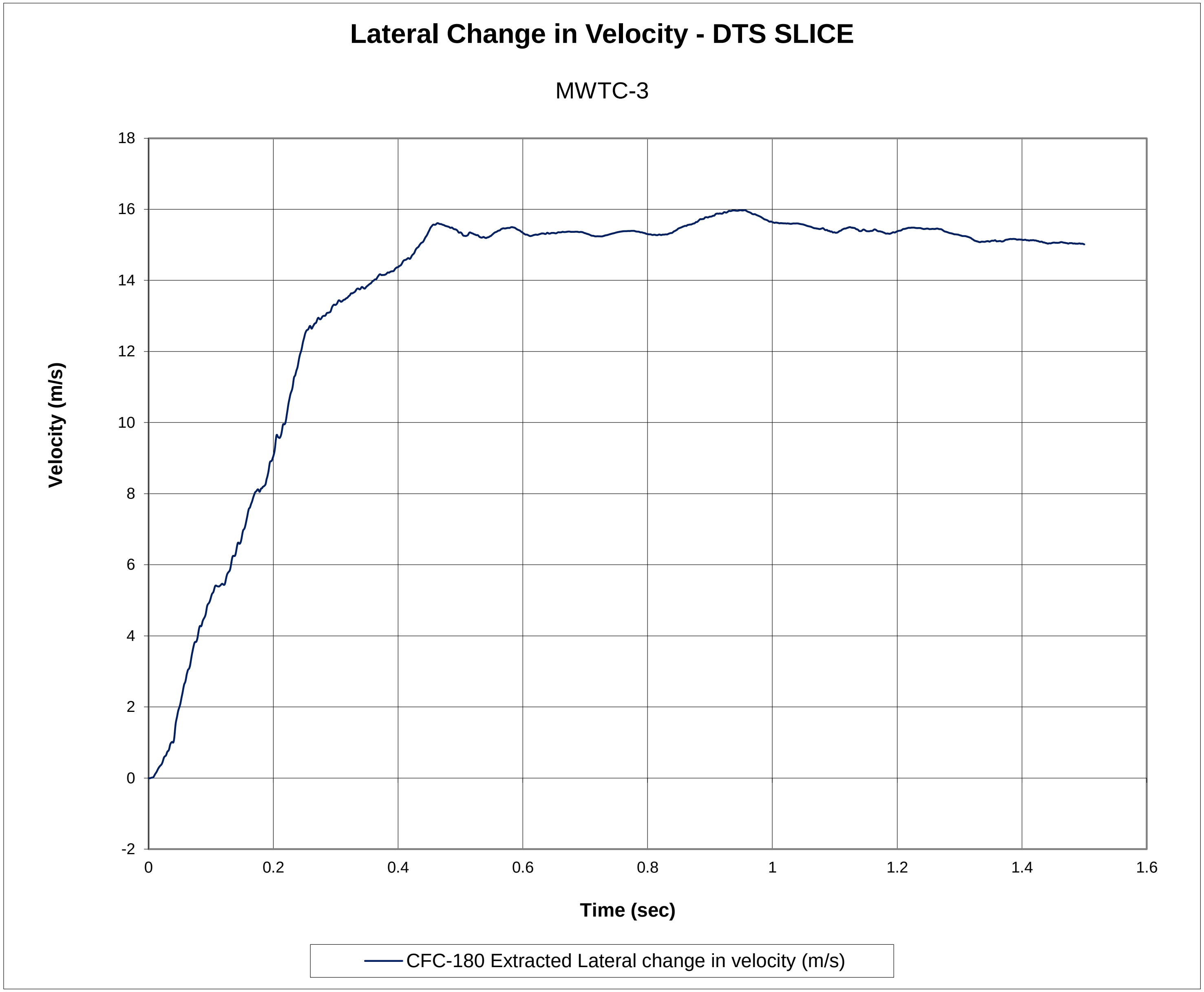


Figure G-13. Lateral Occupant Impact Velocity (DTS SLICE), Test No. MWTC-3

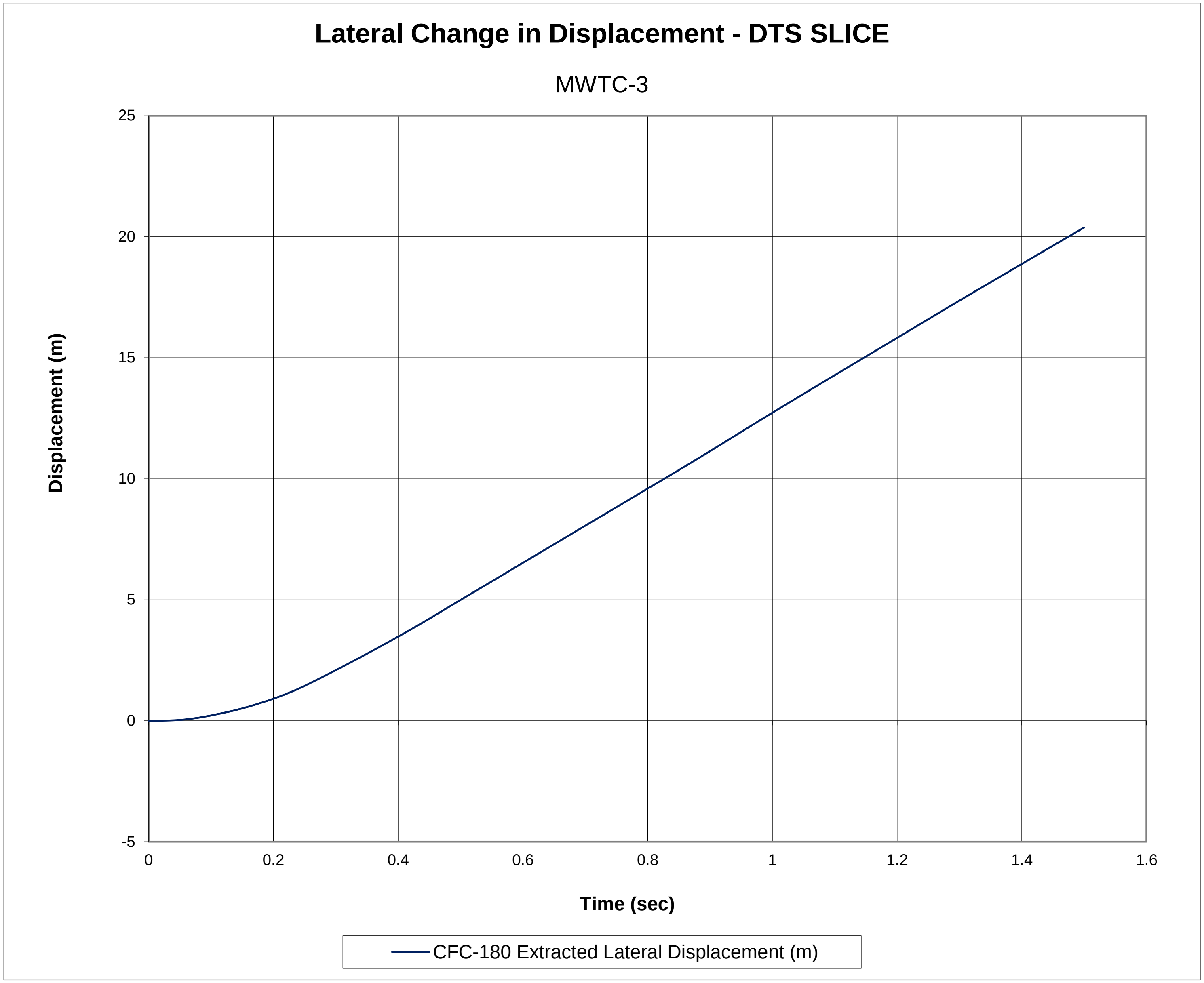


Figure G-14. Lateral Occupant Displacement (DTS SLICE), Test No. MWTC-3

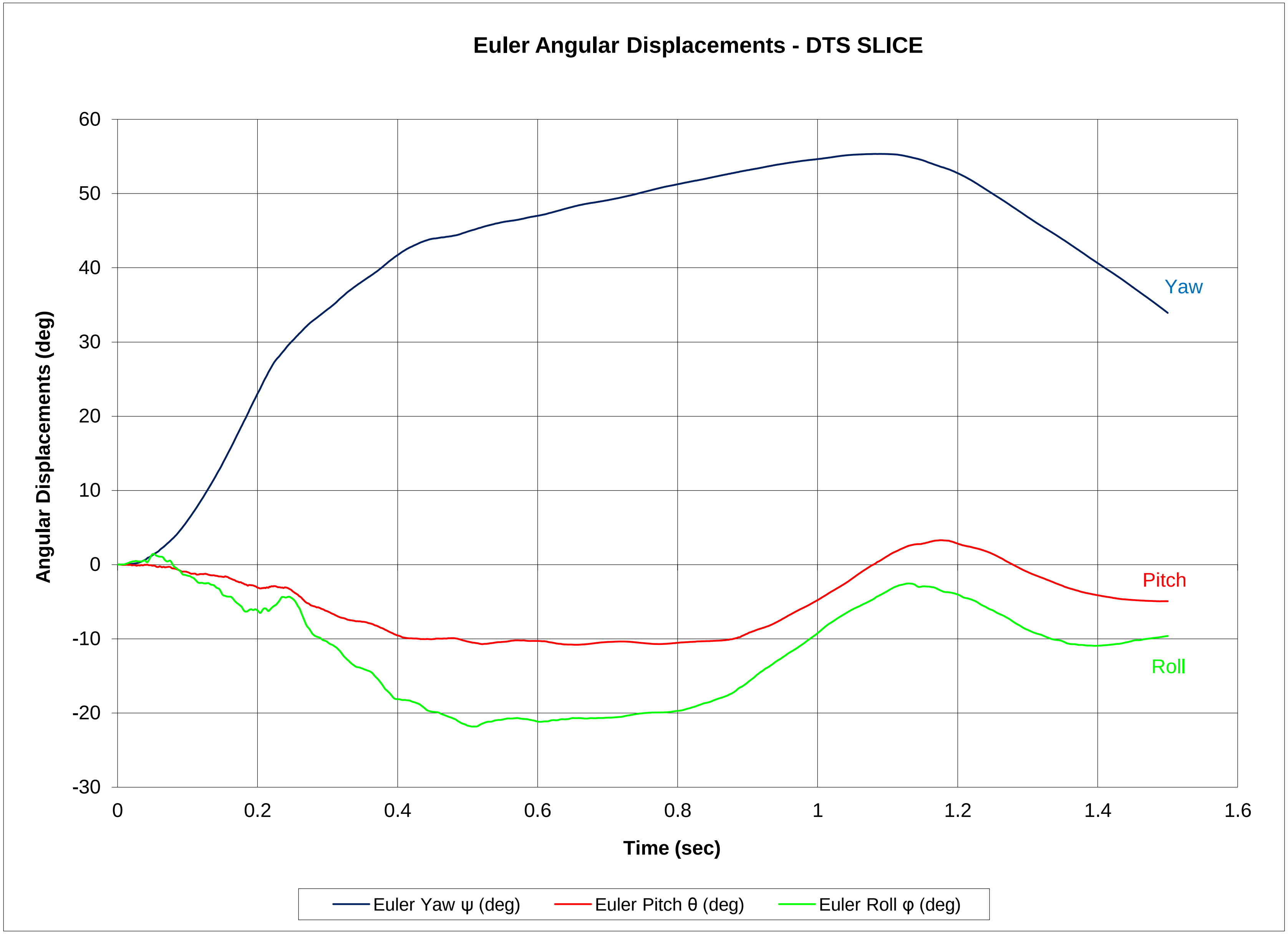


Figure G-15. Figure 102. Vehicle Angular Displacements (DTS SLICE), Test No. MWTC-3

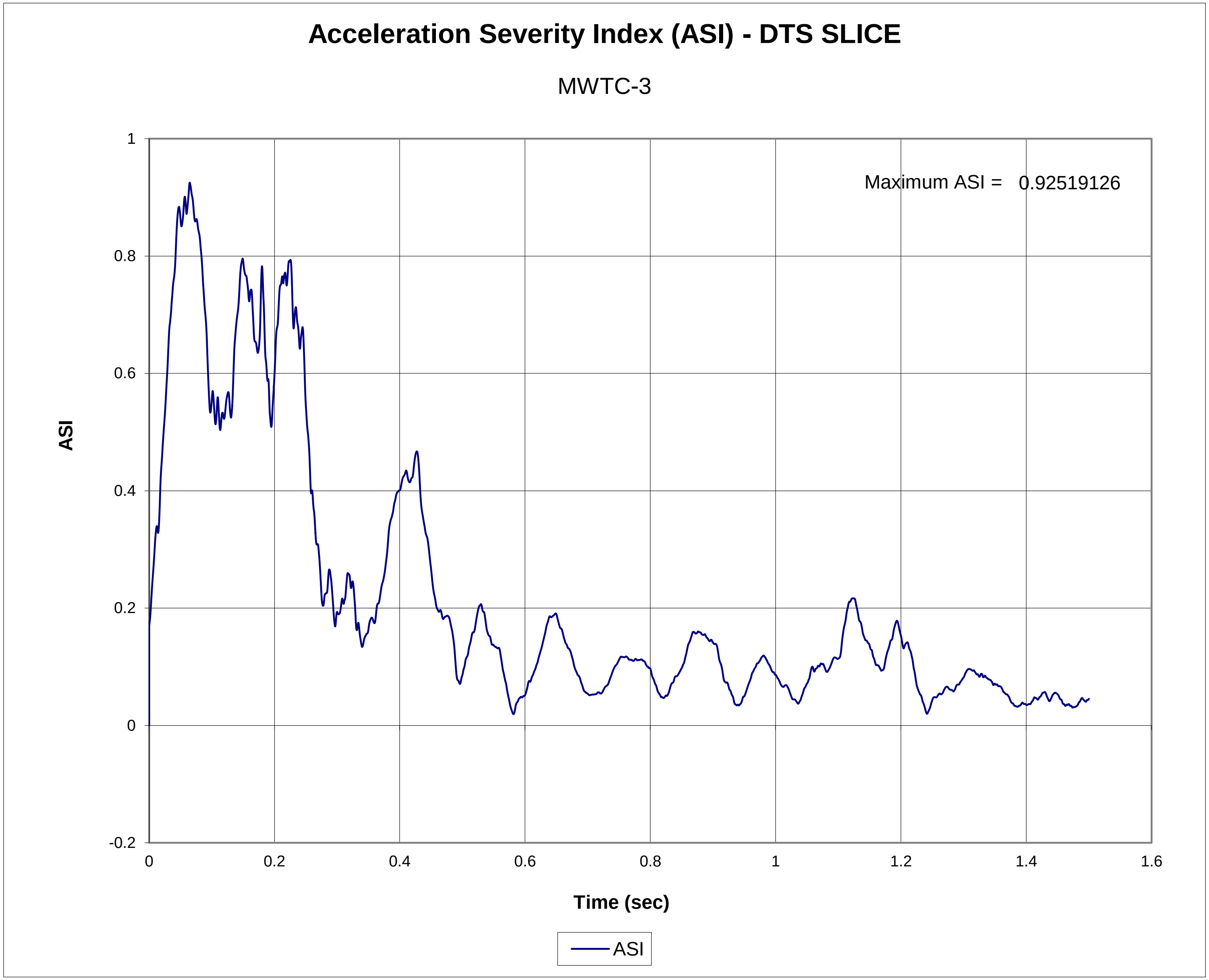


Figure G-16. Acceleration Severity Index (DTS SLICE), Test No. MWTC-3

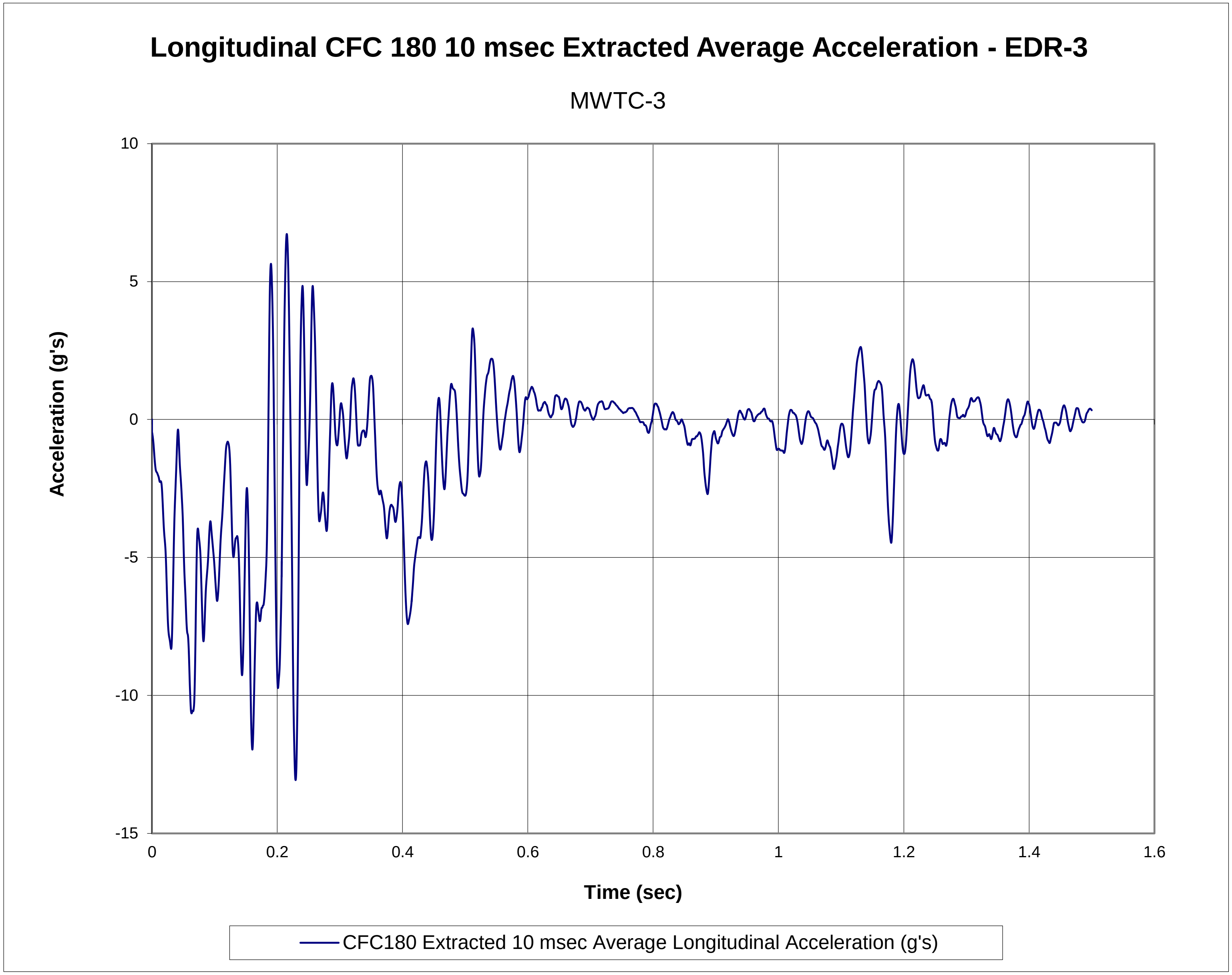


Figure G-17. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. MWTC-3

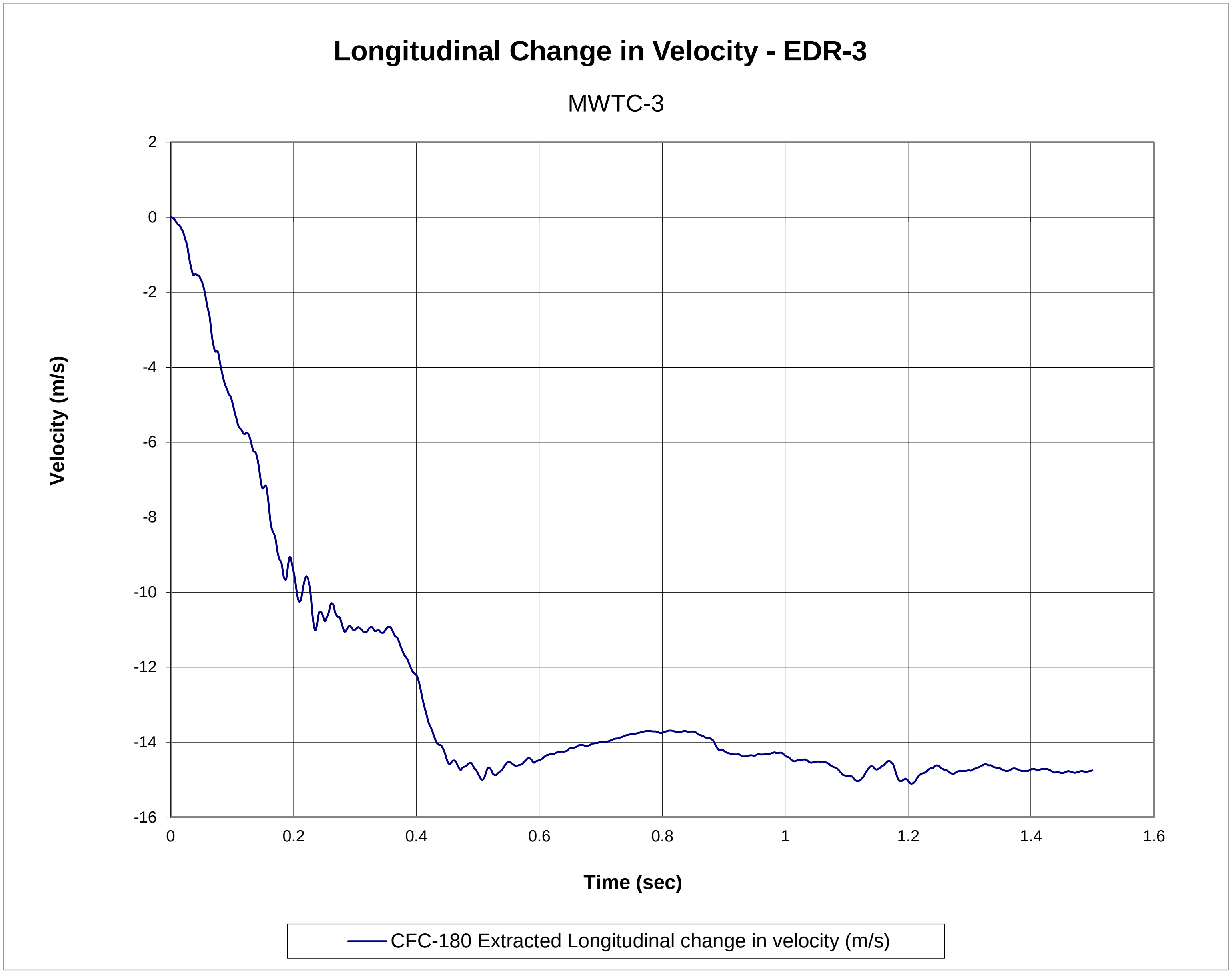


Figure G-18. Longitudinal Occupant Impact Velocity (EDR-3), Test No. MWTC-3

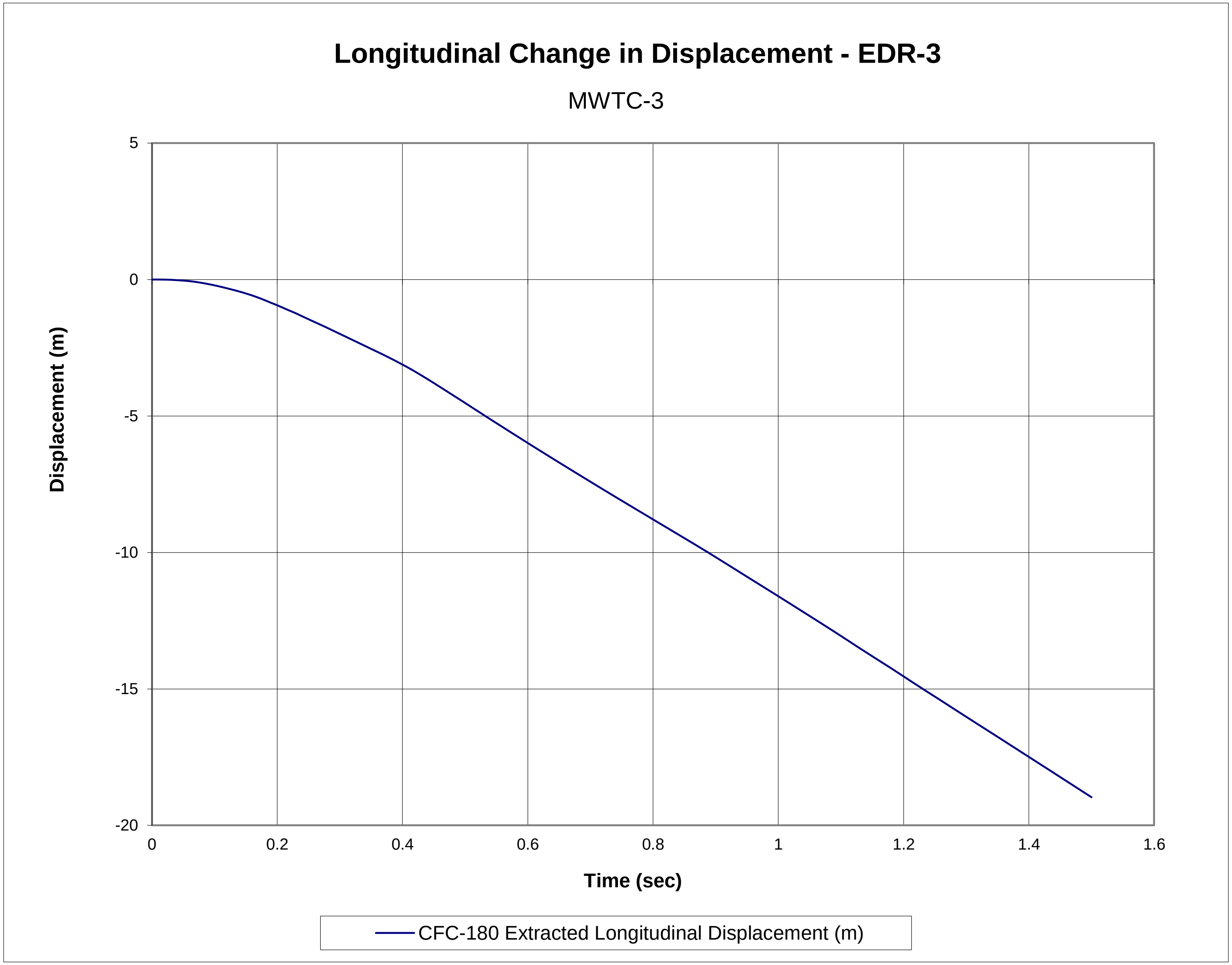


Figure G-19. Longitudinal Occupant Displacement (EDR-3), Test No. MWTC-3

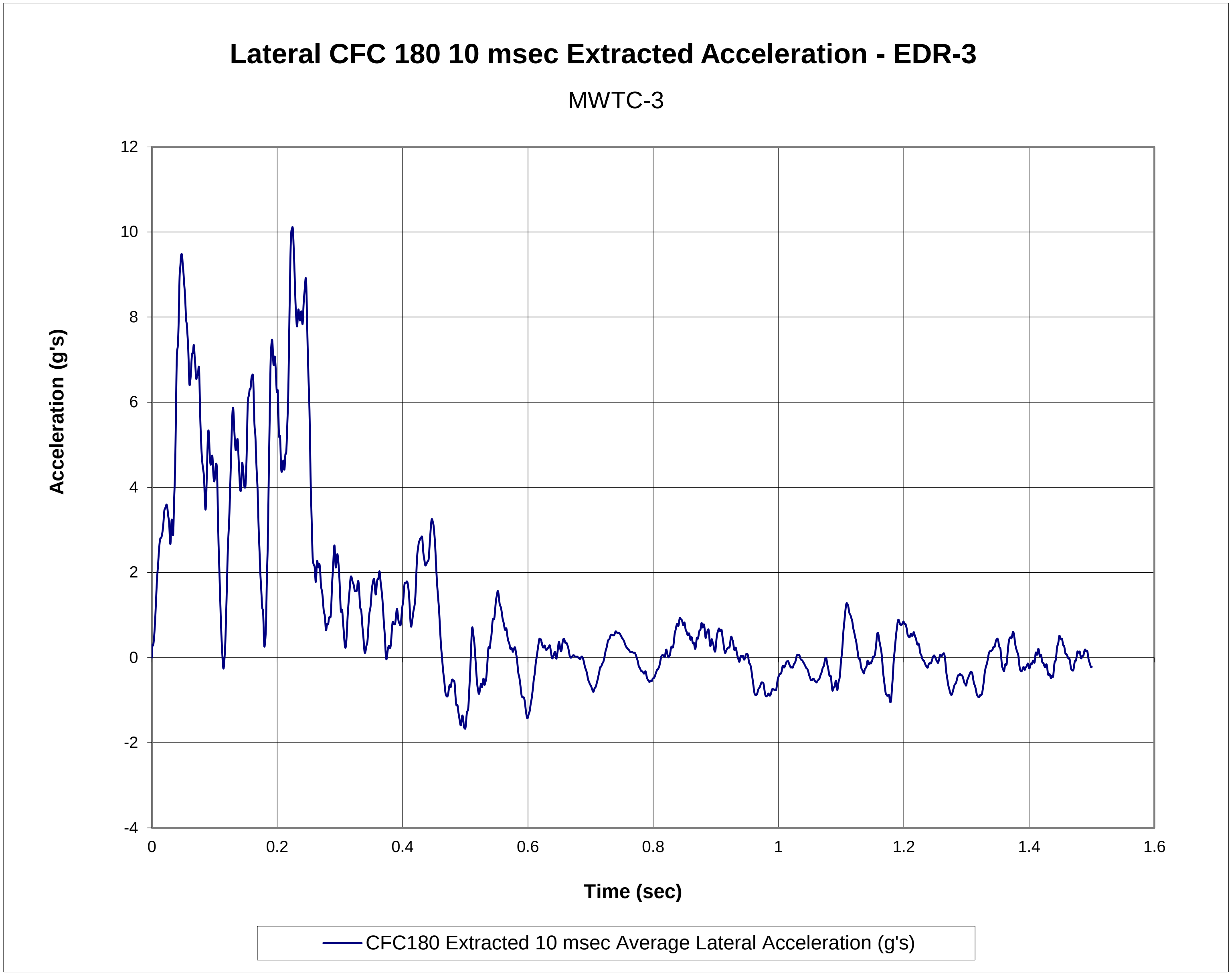


Figure G-20. 10-ms Average Lateral Deceleration (EDR-3), Test No. MWTC-3

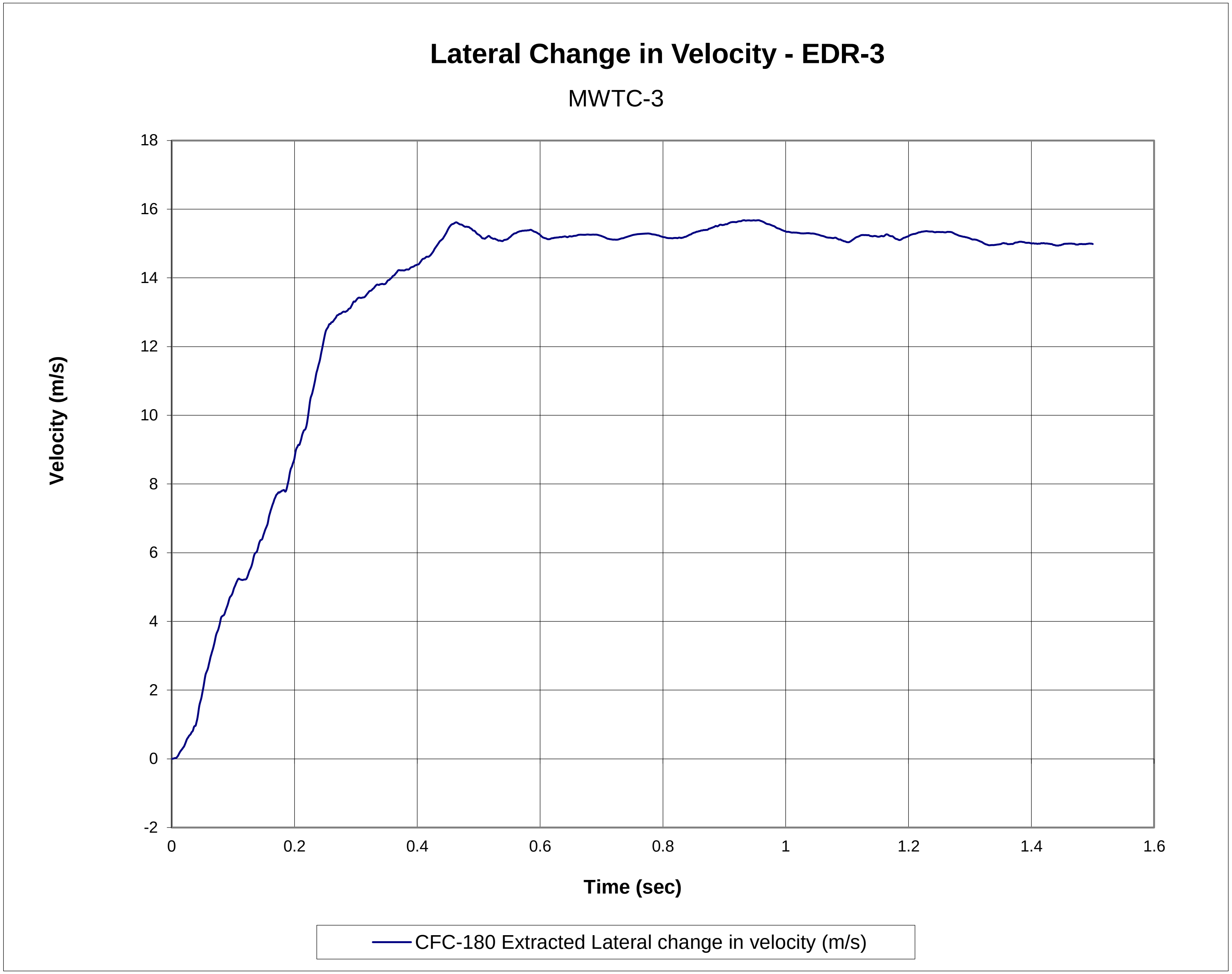


Figure G-21. Lateral Occupant Impact Velocity (EDR-3), Test No. MWTC-3

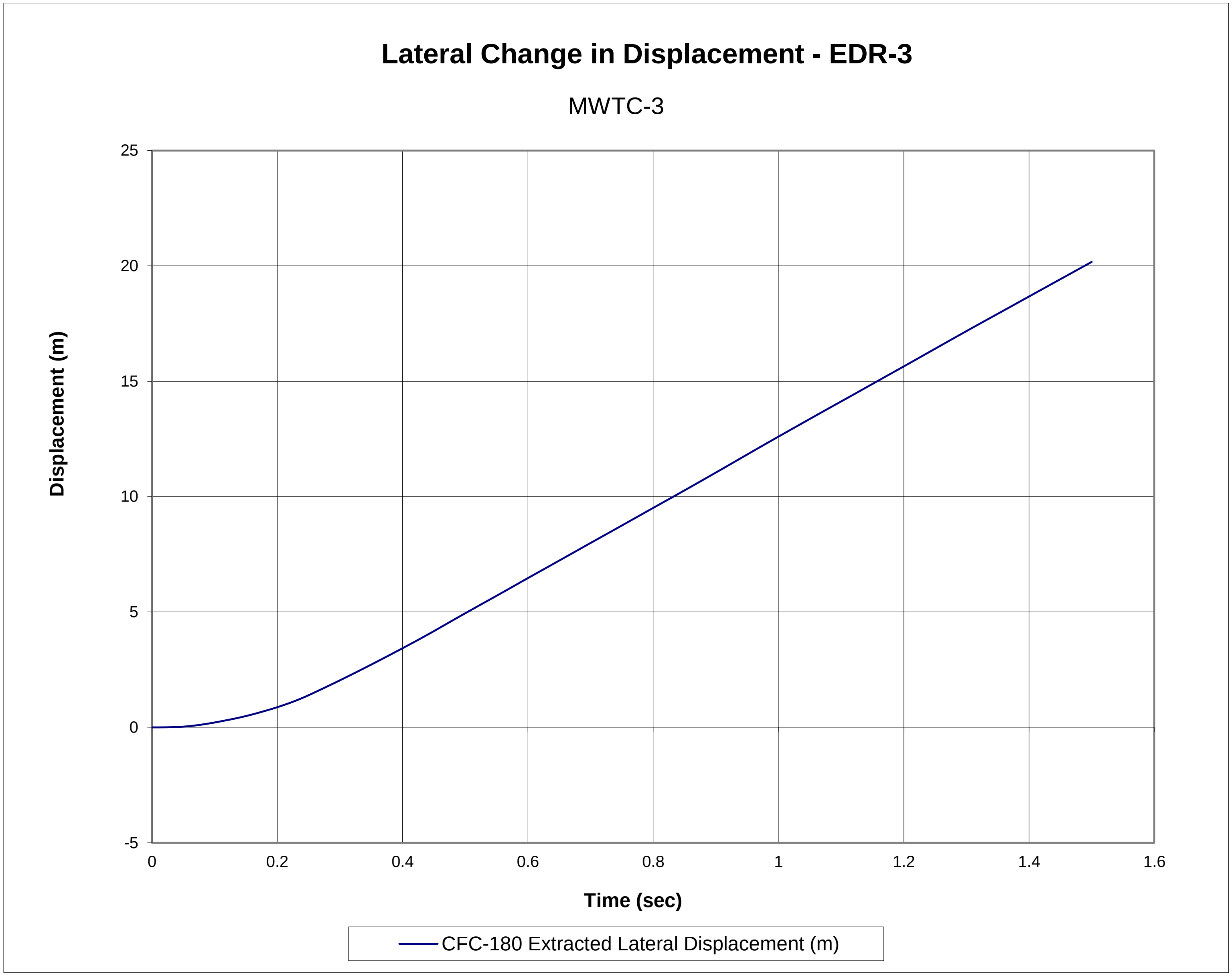


Figure G-22. Lateral Occupant Displacement (EDR-3), Test No. MWTC-3

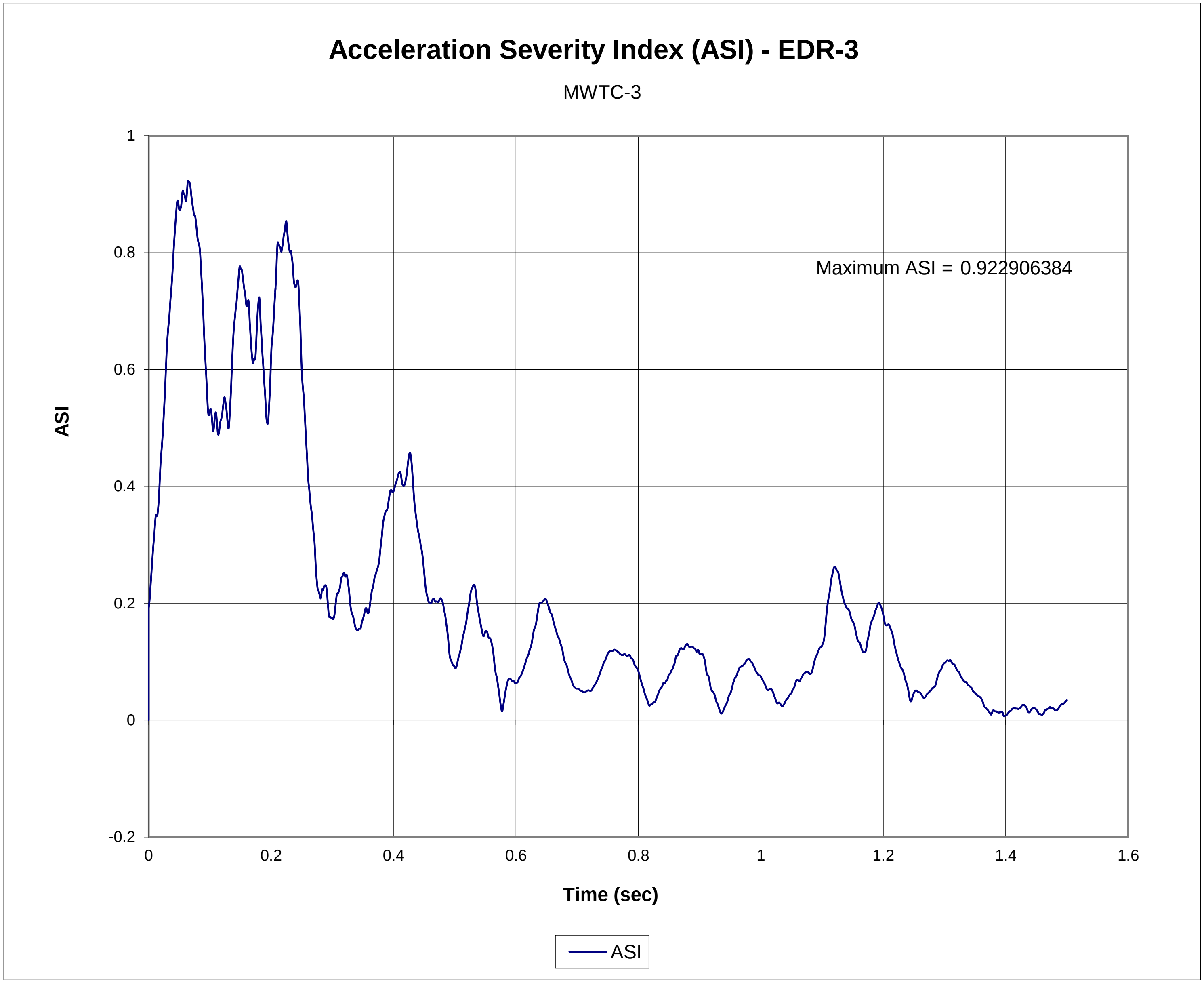


Figure G-23. Acceleration Severity Index (EDR-3), Test No. MWTC-3

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