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MIDWEST GUARDRAIL SYSTEM (MGS) WITH AN OMITTED POST

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16. Abstract

The objective of this research study was to evaluate the MGS (31" tall W-beam guardrail) with an omitted post according to the safety performance criteria provided in MASH. A single full-scale crash test was conducted with the 2270P pickup truck in accordance with MASH test no. 3-11. The small car test, test no. 3-10, was deemed unnecessary as the pickup truck test would result in higher rail loads, a greater propensity for rail rupture, and a greater risk of failure. The test installation utilized standard 6-ft (1.8-m) long steel guardrail posts with 12-in. (305-mm) deep blockouts. A single post was omitted near the center of the 175-ft (53.3-m) long installation.

Test no. MGSMP-1 resulted in the guardrail capturing and smoothly redirecting the 2270P vehicle. The vehicle remained upright, and all vehicle decelerations were within the recommended occupant risk limits. As such, the MGS with an omitted post satisfied the TL-3 safety performance criteria found in MASH.

Following the full-scale crash testing, implementation guidance and recommendations were provided regarding the omission of a post within various MGS configurations, including MGS adjacent to 2:1 fill slopes, MGS on 8:1 approach slopes, MGS in combination with curbs, wood post MGS, non-blocked MGS, terminals and anchorages, MGS stiffness transition to thrie beam approach guardrail transitions, and MGS long-span systems.

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This report was completed with funding from the Federal Highway Administration, U.S. Department of Transportation and the Midwest States Pooled Fund Program. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the state highway departments participating in the Midwest States Pooled Fund Program nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

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

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1 INTRODUCTION

1.1 Problem Statement

Obstructions at post locations within a run of guardrail are a common occurrence. For very short length obstacles, the obstruction may potentially be avoided by using a modified post spacing. However, the only approved method for avoiding obstacles longer than 6.25 ft (1.9 m) is to install a long-span system. The Midwest Guardrail System (MGS) long-span system was developed for situations where one, two, or three consecutive posts are omitted to create unsupported spans of 12.5 ft (3.8 m), 18.75 ft (5.7 m), and 25 ft (7.6 m), respectively [1].

The MGS long-span system was designed with requirements for (1) minimum upstream and downstream lengths and (2) three controlled-releasing terminal (CRT) posts on each side of the unsupported span to prevent pocketing and increased rail loading. These requirements were based on full-scale crash testing of the MGS long-span with a 25-ft (7.6-m) long unsupported span. Prior recommendations have been given to state departments of transportation (DOTs) regarding locations with only one or two posts omitted in a run of standard guardrail. These recommendations have tended to err on the conservative side and require the application of CRT posts adjacent to even a single omitted post due to lack of analysis and crash testing. However, the potential exists to develop more aggressive guidance for omission of one or two posts in a guardrail installation to avoid obstacles if further analysis and testing is performed.

Thus, a need exists to develop more accurate guidance for the omission of a single post in a run of MGS guardrail. The research should seek to evaluate the omitted post without the use of adjacent CRT posts. In addition, the research should provide guidance whether multiple omitted post treatments could be utilized within a long run of continuous guardrail and, if so, the minimum required separation distance between them.

1.2 Objective

The objective of this research effort was to evaluate MGS installations with a single omitted post within the guardrail due to the presence of an obstruction. The research focused on the omission of a post without the use of CRT posts adjacent to the unsupported span. Full-scale crash testing was conducted to evaluate the MGS with a single omitted post according to the Test Level 3 (TL-3) impact safety requirements set forth in the *Manual for Assessing Safety Hardware* (MASH) [2]. Following successful full-scale crash testing, additional investigation was conducted to consider the potential for omission of a single post in multiple locations within a run of guardrail and the corresponding minimum spacing between omitted posts.

1.3 Scope

The research objective was achieved through completion of several tasks. First, a full-scale crash test was conducted on the MGS with an omitted post. The crash test, MASH test designation no. 3-11, utilized a pickup truck weighing approximately 5,000 lb (2,268 kg). The target impact conditions for the test were a speed of 62 mph (100 km/h) and an angle of 25 degrees. Next, the test results were analyzed, evaluated, and documented. Finally, conclusions and recommendations were made that pertain to the safety performance of the MGS with an omitted post.

2 DESIGN DETAILS

The test installation for MGS with one omitted post was comprised of 182 ft – 3½ in. (55.6 m) of standard W-beam guardrail supported by steel posts. All posts were spaced at 75 in. (1,905 mm) on center, except for a single 150-in. (3,810-mm) span located near the center of the guardrail installation, which represented the omitted post in the otherwise standard MGS. Design details for the test installation are shown in Figures 1 through 13. Photographs of the test installation are shown in Figure 14. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The barrier utilized standard 12-gauge (2.66-mm thick) W-beam rails with additional post bolt slots at half-post spacing intervals, as shown in Figures 1, 3, and 12. The W-beam guardrail was mounted with a top-rail height of 31 in. (787 mm) throughout the entire system. Rail splices were located at midspans between posts, as shown in Figure 3. The lap splice connections between the rail sections were configured to reduce vehicle snag potential at the splice during the crash test.

The rail was supported by 28 guardrail posts, all of which were placed in a compacted, coarse, crushed limestone material, as recommended by MASH [2]. Posts nos. 3 through 26 were standard guardrail posts with embedment depths of 40 in. (1,016 mm). These steel line posts were galvanized, ASTM A992, W6x8.5 (W152x12.6) steel sections measuring 72 in. (1,829 mm) long. A 6-in. x 12-in. x 14¼-in. long (152-mm x 305-mm x 362-mm) Southern Yellow Pine wood blockout was used to block the rail away from the front face of each steel post, as shown in Figure 6. A 16D double head nail was also driven through a hole in the front flange of the post into the top of the blockout assembly to prevent rotation of the blockout. The omitted post, or the elongated span length, was located between post nos. 13 and 14, as shown in Figures 1 and 3.

The ends of the installation consisted of guardrail trailing-end anchorage systems, as shown in Figures 4 and 5. This guardrail anchor was developed to simulate the strength of other crashworthy end terminals and was successfully crash tested to MASH TL-3 standards as a trailing-end anchor [3]. As such, post nos. 1, 2, 27, and 28 were breakaway cable terminal (BCT) timber posts inserted into steel foundation tubes, as shown in Figure 7.

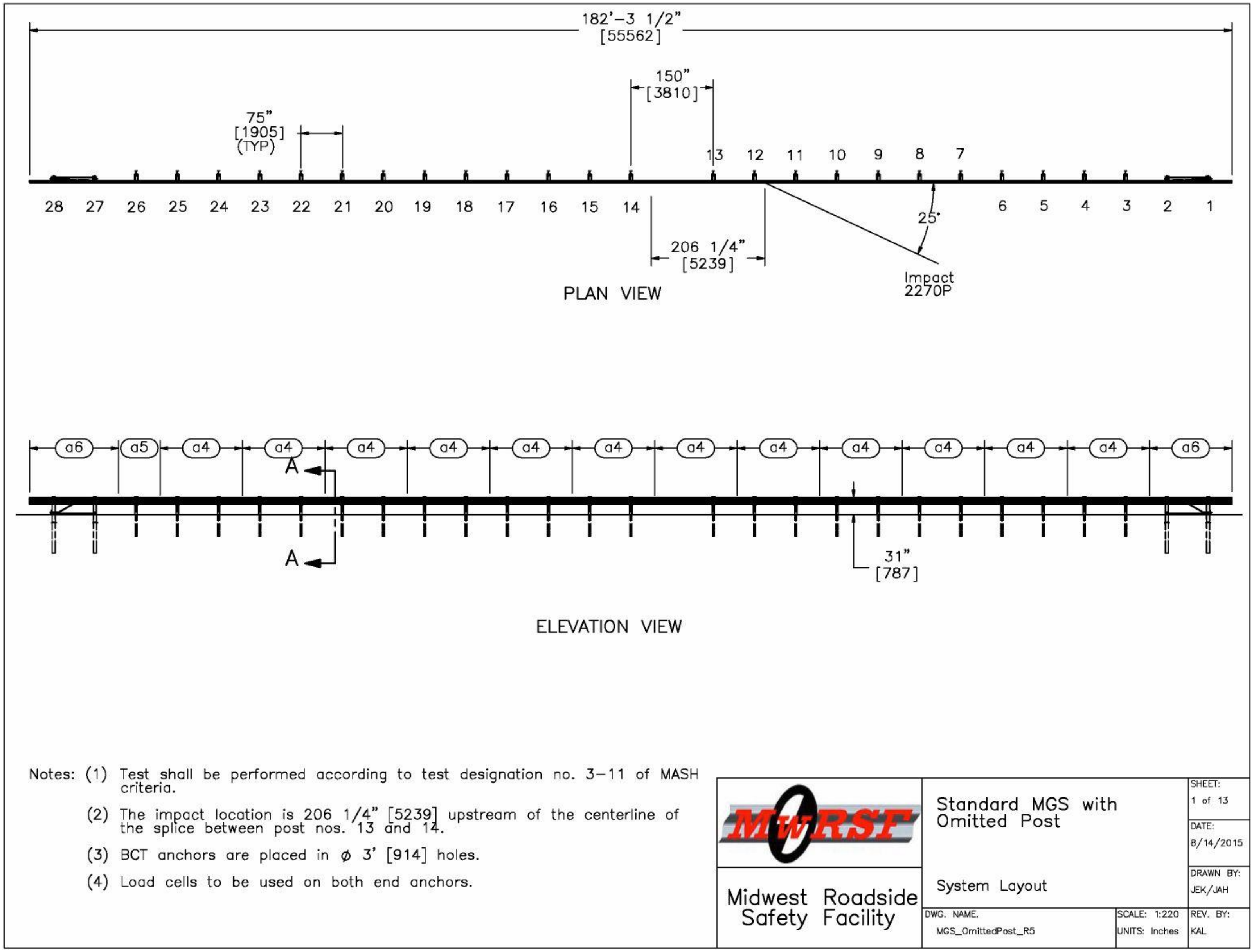


Figure 1. Test Installation Layout, Test No. MGSMP-1

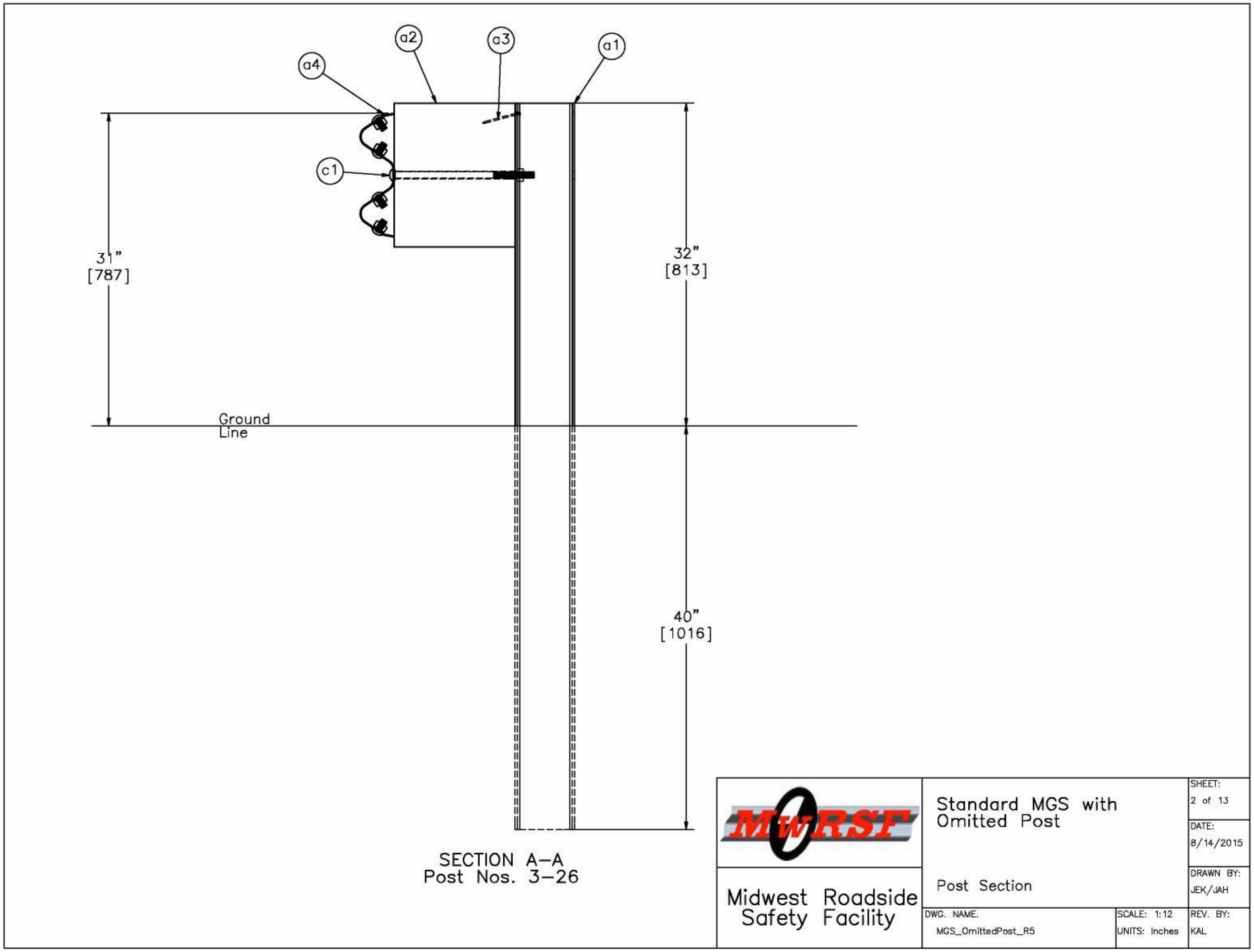
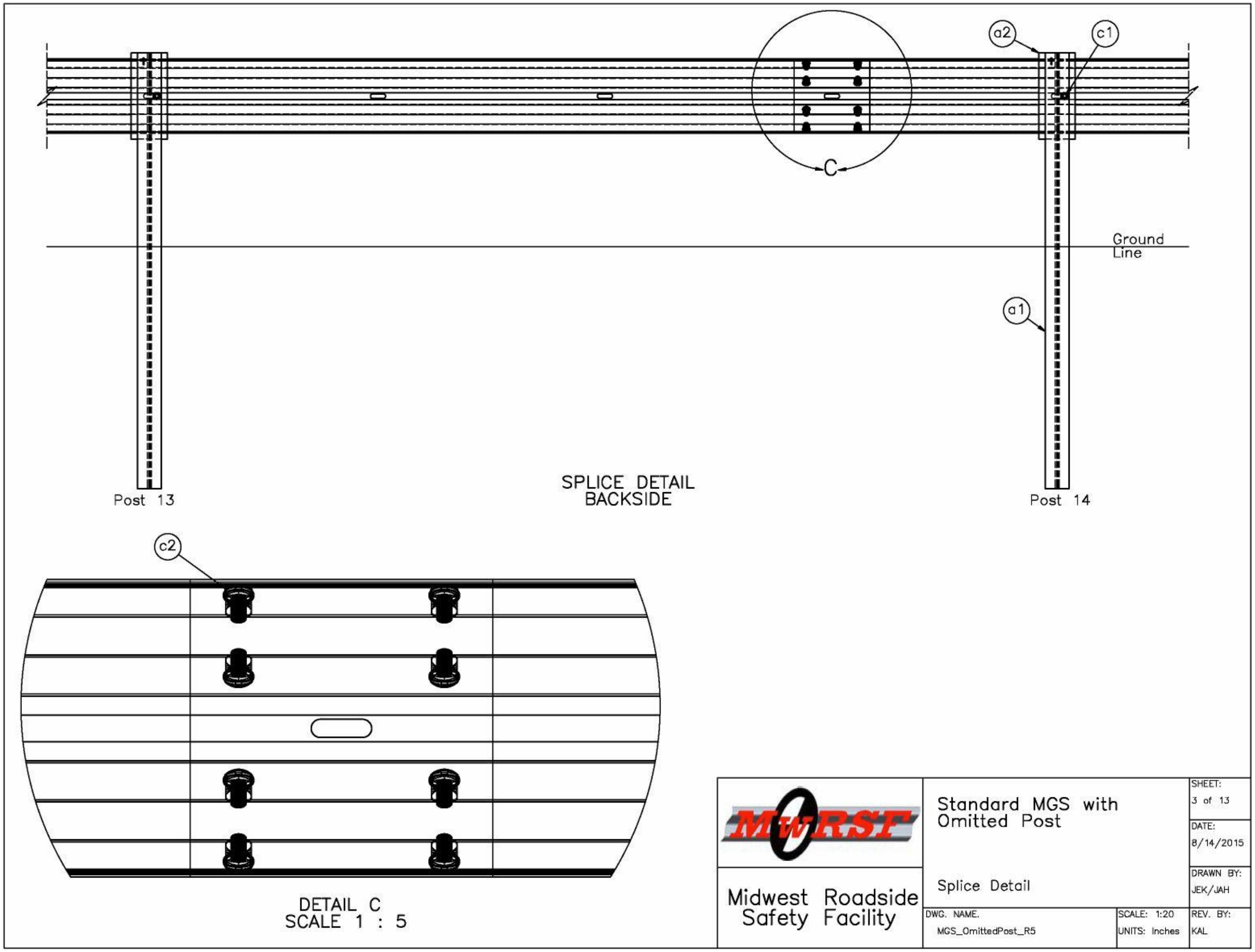


Figure 2. Description of View, Test No. MGSMP-1



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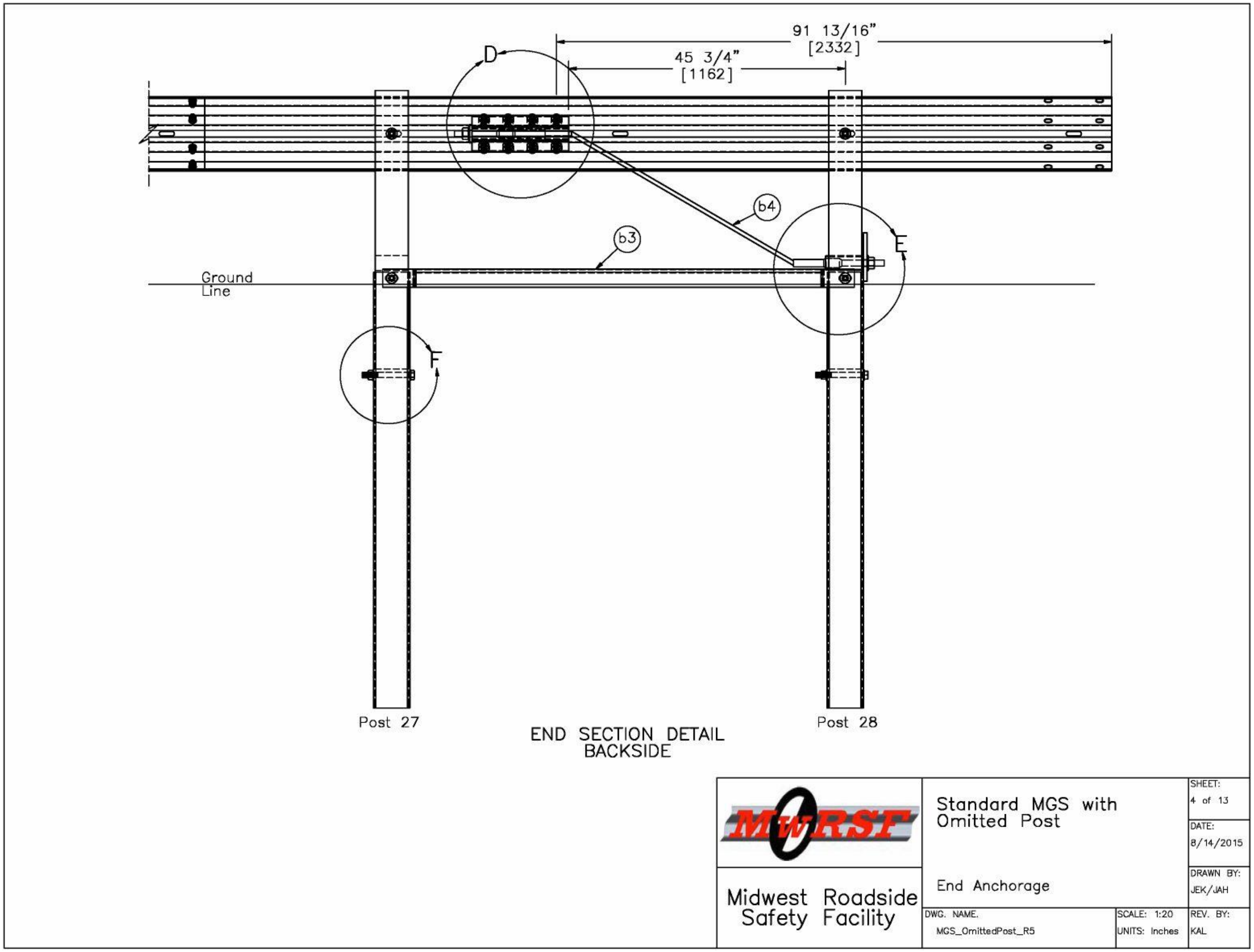
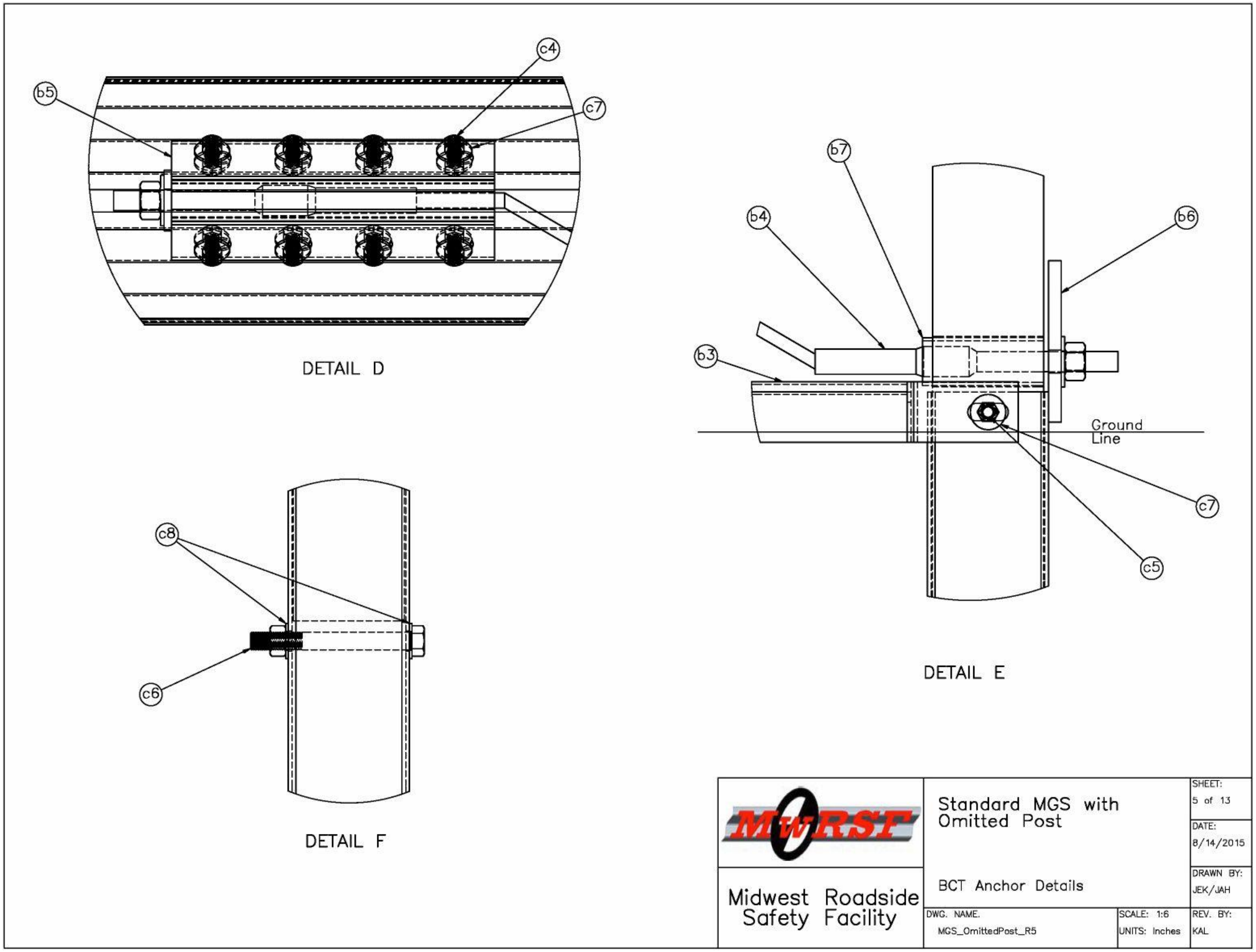


Figure 4. Anchorage Layout, Test No. MGSMP-1



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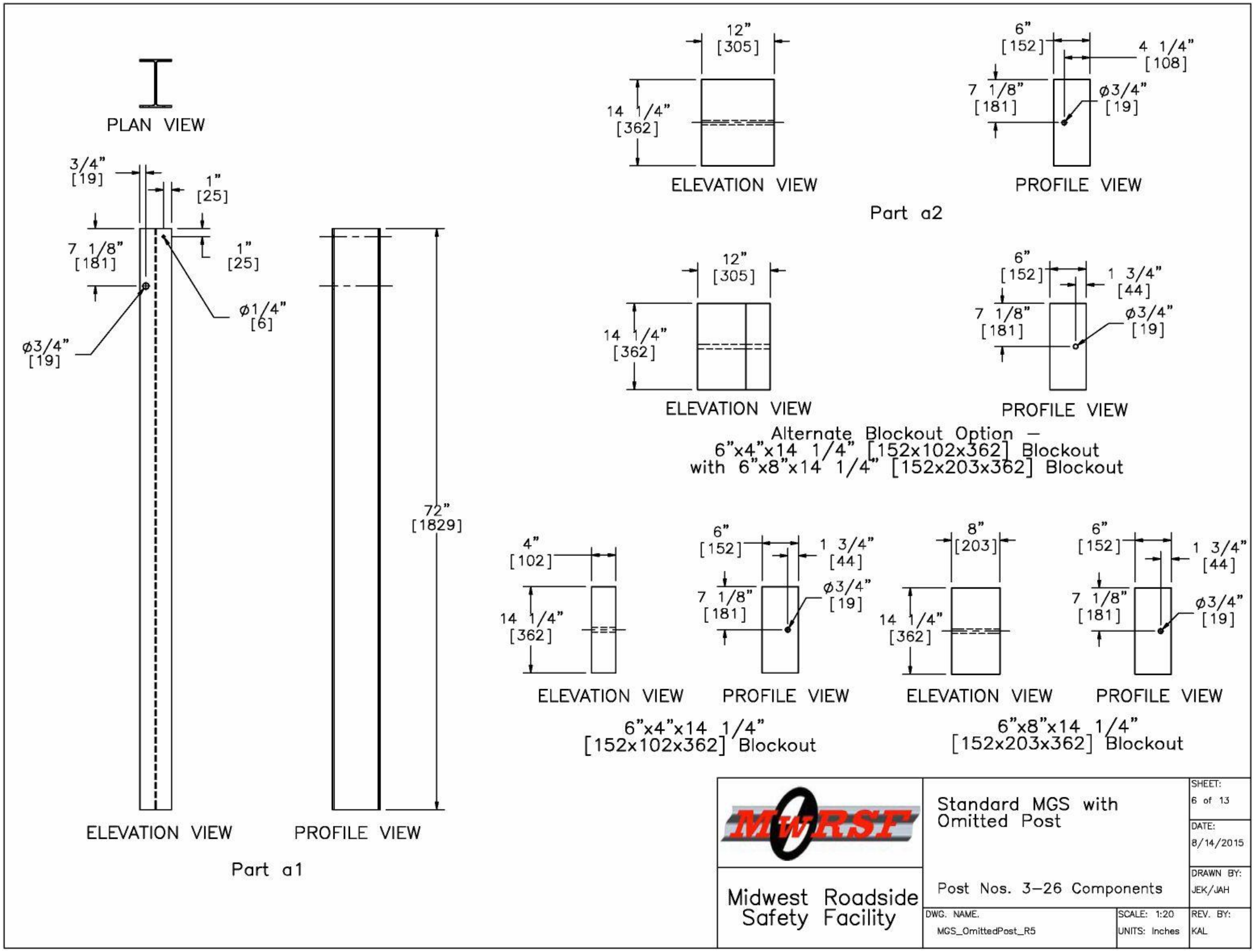

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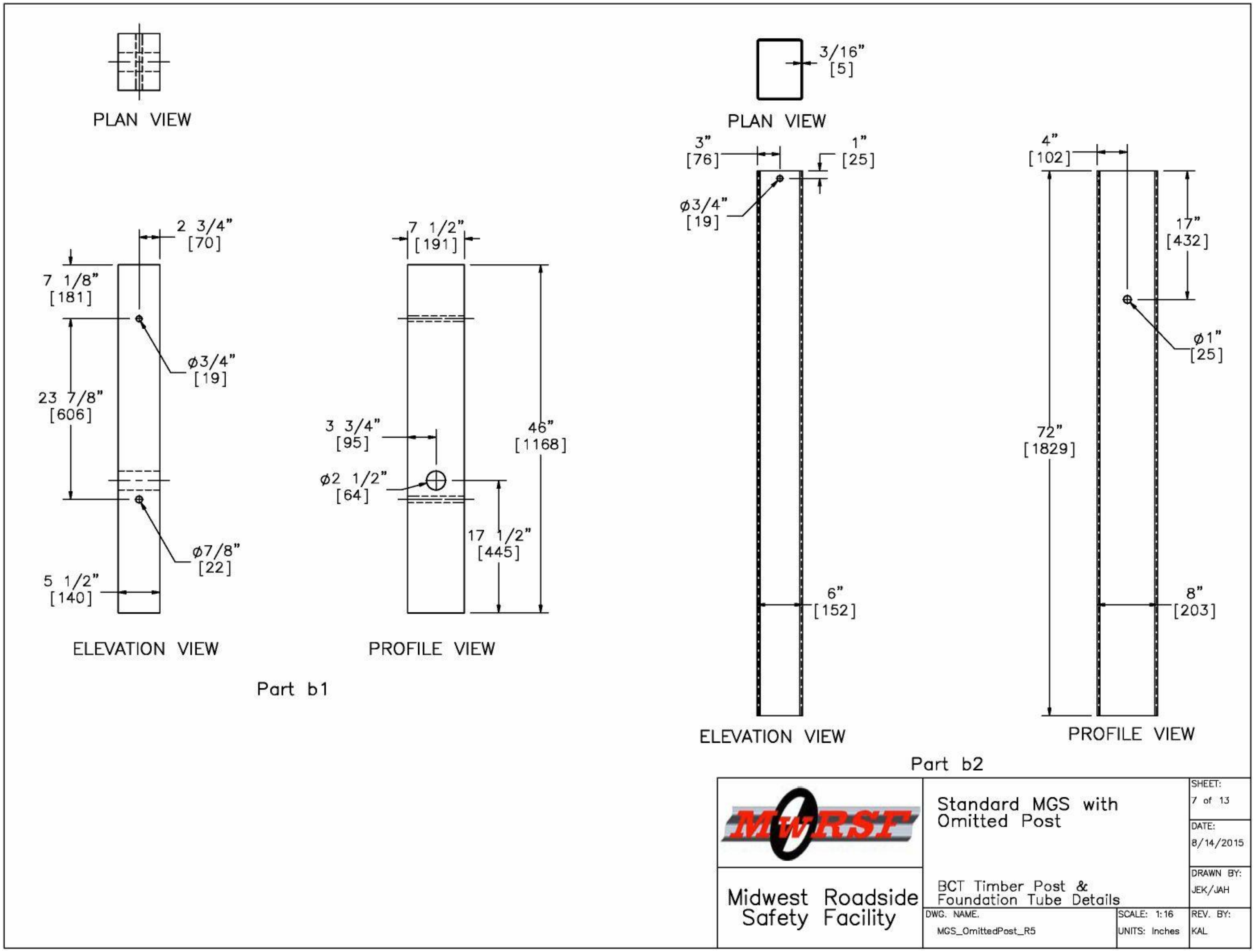

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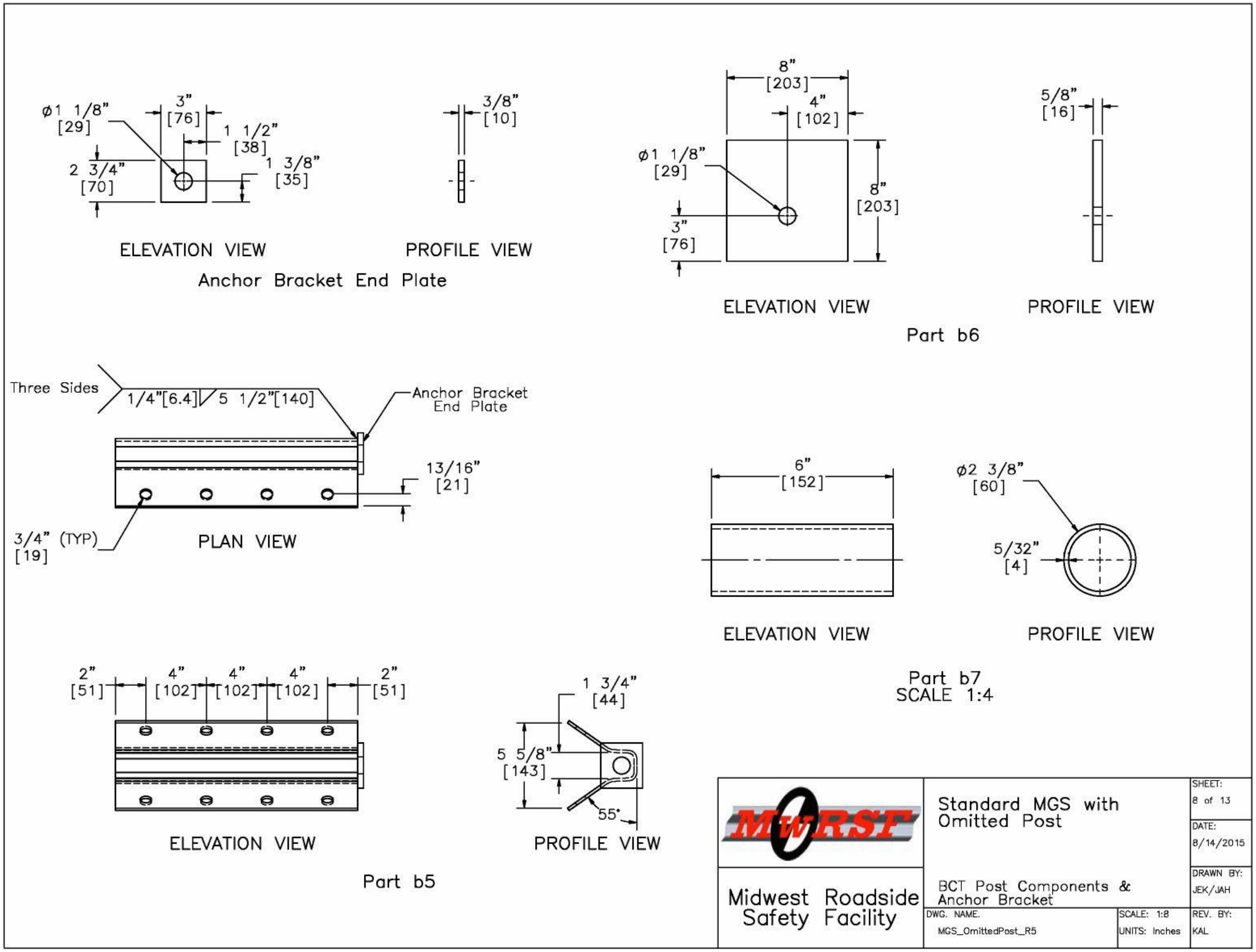

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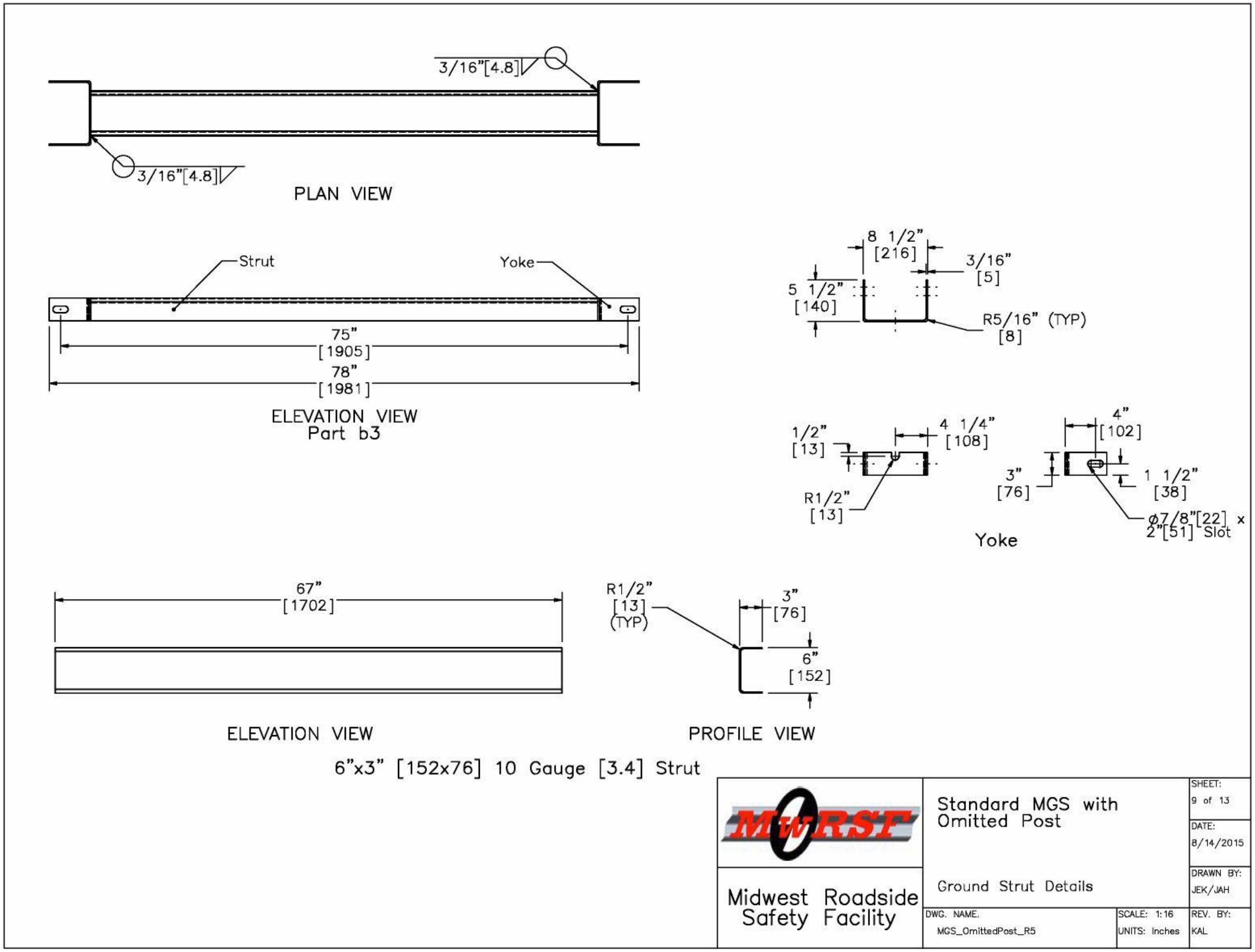

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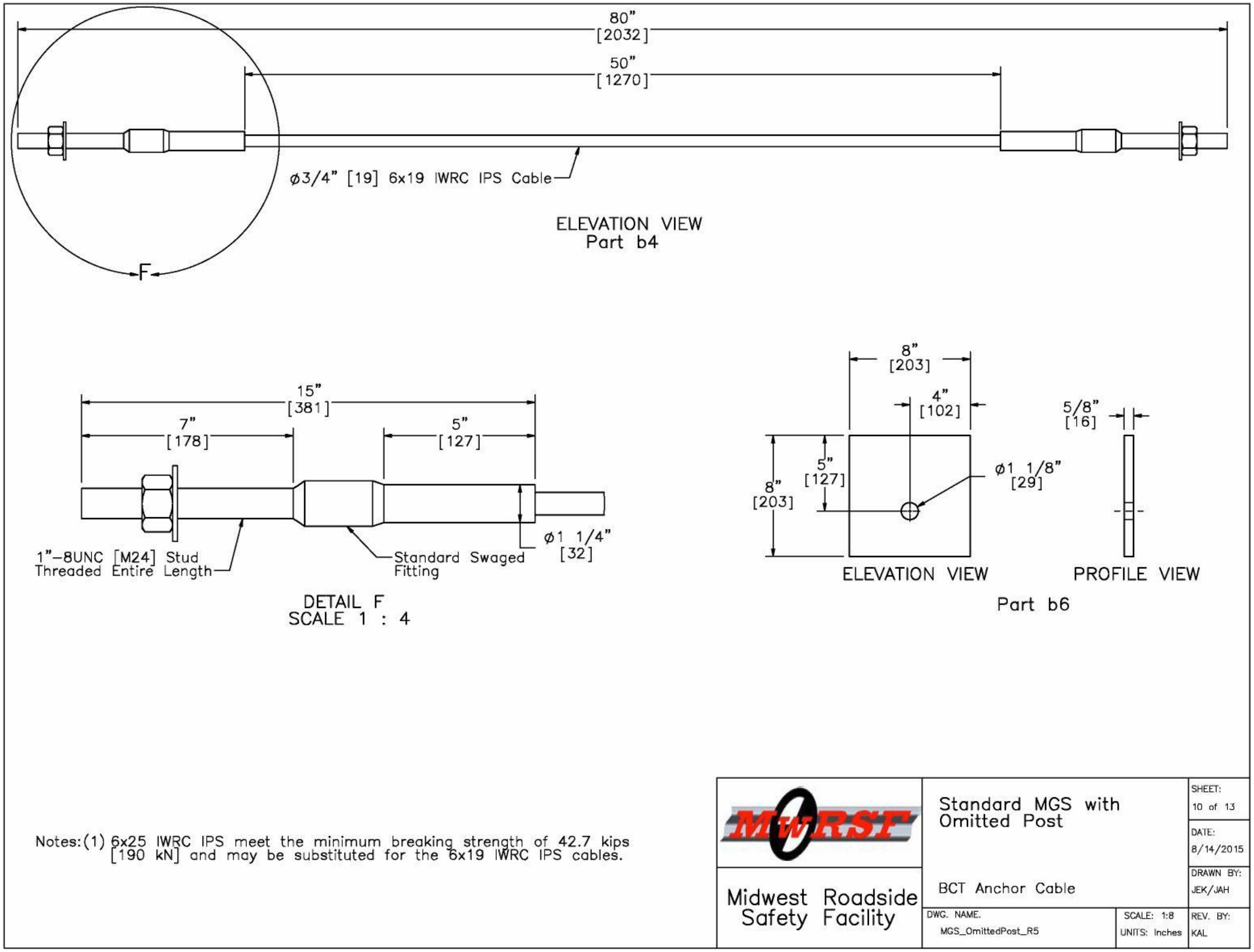
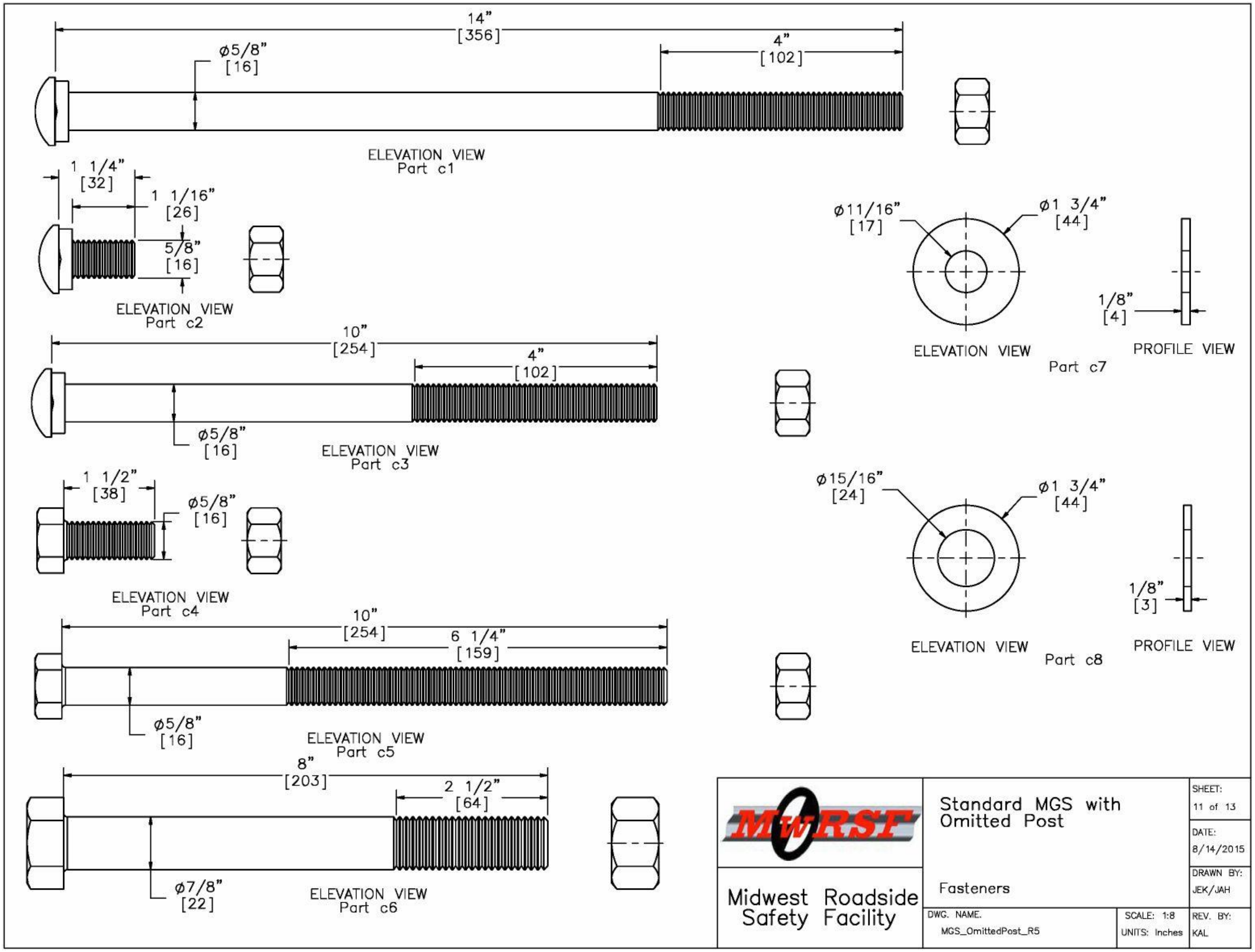


Figure 10. BCT Anchor Cable, Test No. MGSMP-1



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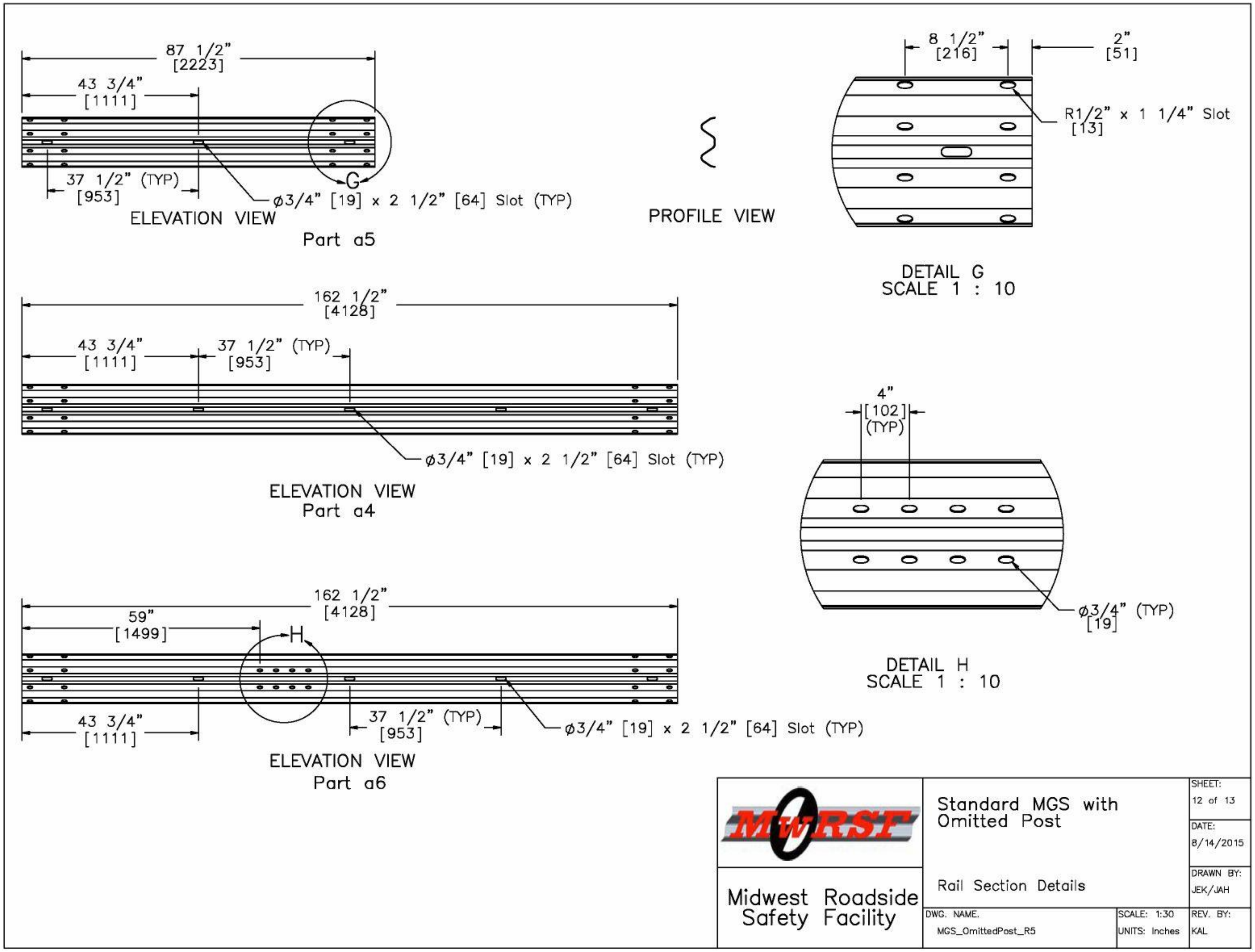


Figure 12. Rail Section Details, Test No. MGSMP-1

Midwest Gu				
Item No.	QTY.	Description	Material Spec	Hardware Guide
a1	24	W6x8.5 [W152x12.6], 72" [1829] Long Steel Post	ASTM A992 Min. 50 ksi [345 MPa] Steel Galv. or W6x9 [W152x13.4] ASTM A36 Min. 36 ksi [248 MPa] Steel Galv.	PWE06
a2	24	6x12x14 1/4" [152x305x362] Timber Blockout for Steel Posts	SYP Grade No.1 or better	PDB10a–b
a3	24	16D Double Head Nail	–	–
a4	12	12'–6" [3810] W–Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv.	RWM04a
a5	1	6'–3" [1905] W–Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv.	RWM04a
a6	2	12'–6" [3810] W–Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv.	RWM14a
b1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots, 18" [457] above or below ground tension face)	PDF01
b2	4	72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv.	PTE06
b3	2	Strut and Yoke Assembly	ASTM A36 Steel Galv.	–
b4	4	BCT Cable Anchor Assembly	ϕ3/4" [19] 6x19 IWRC IPS Galvanized Wire Rope	FCA01
b5	2	Anchor Bracket Assembly	ASTM A36 Steel Galv.	FPA01
b6	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv.	FPB01
b7	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv.	FMM02
c1	24	5/8" Dia. x 14" [M16 x 356] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	FBB06
c2	112	5/8" Dia. x 1 1/4" [M16 x 32] Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	FBB01
c3	4	5/8" Dia. x 10" [M16 x 254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	FBB03
c4	16	5/8" Dia. x 1 1/2" [M16 x 38] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	FBX16a
c5	4	5/8" Dia. x 10" [M16 x 254] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	FBX16a
c6	4	7/8" Dia. x 8" [M22 x 203] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	–
c7	44	5/8" [16] Dia. Plain Round Washer	ASTM F844 Galv.	FWC14a
c8	8	7/8" [22] Dia. Plain Round Washer	ASTM F844 Galv.	–

Midwest Roadside Safety Facility

Standard MGS with Omitted Post

Bill of Materials

SHEET: 13 of 13
DATE: 8/14/2015
DRAWN BY: JEK/JAH
DWG. NAME. MGS_OmittedPost_R5
SCALE: None
UNITS: Inches
REV. BY: KAL

Figure 13. Bill of Materials, Test No. MGSMP-1

Figure 14. Test Installation Photographs, Upstream End, Test No. MGSMP-1

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as W-beam guardrails, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new or modified hardware, these safety standards consist of the guidelines and procedures published in MASH [2]. According to TL-3 of MASH, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1.

Table 1. MASH TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed, mph (km/h)	Angle, deg.	
Longitudinal Barrier	3-10	1100C Small Car	2,425 (1,100)	62 (100)	25	A,D,F,H,I
	3-11	2270P Pickup Truck	5,000 (2,268)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

Following a review of previous MASH testing into W-beam guardrail systems, the pickup truck test was determined to be more critical than the small car test. The more massive truck would induce much higher rail loads and system deflections, yielding the highest potential for structural failure of the system and/or vehicle instabilities. W-beam barriers struck by small cars have been shown to meet safety performance standards with reduced lateral deflection and without significant potential for occupant risk problems [4-12]. Therefore, test no. 3-10 was deemed unnecessary for this project, and only test designation no. 3-11 with the 5,000-lb (2,268-kg) pickup truck was conducted for the system described herein.

3.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of longitudinal barrier systems 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.

3.3 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 the system itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm) measured at a height of 25 in. (635 mm). If dynamic testing near the system is not desired, MASH permits a static test to be conducted instead and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90 percent of the static baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Further details can be found in Appendix B of MASH.

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>

4 TEST CONDITIONS

4.1 Test Facility

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

4.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half those 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 [13] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicles

For test no. MGSMP-1, a 2008 Dodge Ram 1500 pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,057 lb (2,294 kg), 4,934 lb (2,238 kg), and 5,099 lb (2,313 kg), respectively. The test vehicle is shown in Figure 15, and vehicle dimensions are shown in Figure 16.

Figure 15. Test Vehicle, Test No. MGSMP-1

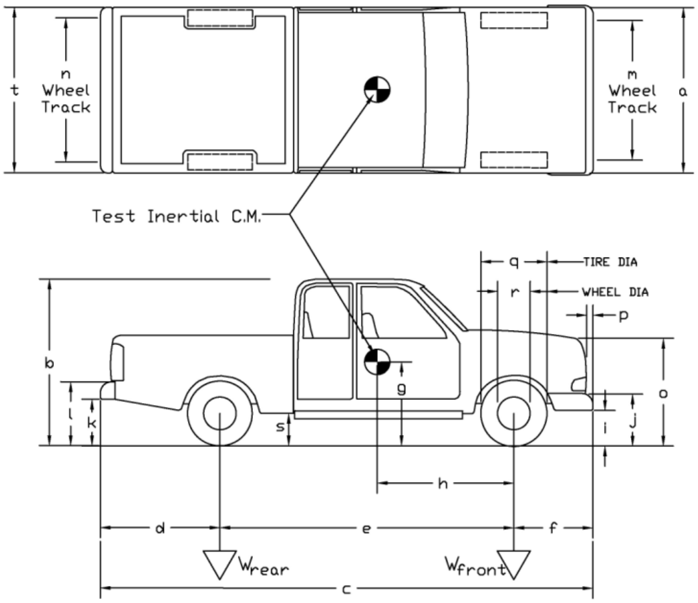
Date: 4/28/2015 **Test Number:** MGSMP-1 **Model:** Ram 1500

Make: Dodge **Vehicle I.D.#:** 1d7ha18n28s606069

Tire Size: 265/70/R17 **Year:** 2008 **Odometer:** 247328

Tire Inflation Pressure: 35

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



Vehicle Geometry -- in. (mm)

a	78	(1981)	b	75 1/8	(1908)
c	228	(5791)	d	47 1/4	(1200)
e	140 1/4	(3562)	f	40 1/2	(1029)
g	28 3/4	(730)	h	61	(1549)
i	15	(381)	j	26 1/2	(673)
k	21	(533)	l	29 1/2	(749)
m	67 1/2	(1715)	n	67 5/8	(1718)
o	44 3/4	(1137)	p	3	(76)
q	32	(813)	r	18 1/2	(470)
s	15 1/2	(394)	t	75 1/4	(1911)

Wheel Center Height Front	15	(381)
Wheel Center Height Rear	15	(381)
Wheel Well Clearance (F)	35	(889)
Wheel Well Clearance (R)	38 1/4	(972)
Frame Height (F)	18 1/2	(470)
Frame Height (R)	25 1/2	(648)
Engine Type	Gasoline	
Engine Size	4.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	

Mass Distribution lb (kg)

Gross Static	**LF**	1450 (658)	**RF**	1439 (653)
	LR	1106 (502)	**RR**	1104 (501)

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	2871 (1302)	2789 (1265)	2889 (1310)
W-rear	2186 (992)	2145 (973)	2210 (1002)
W-total	5057 (2294)	4934 (2238)	5099 (2313)

GVWR Ratings

Front	3700 lb
Rear	3900 lb
Total	6700 lb

Dummy Data

Type:	Hybrid II
Mass:	165 lb
Seat Position:	Passenger

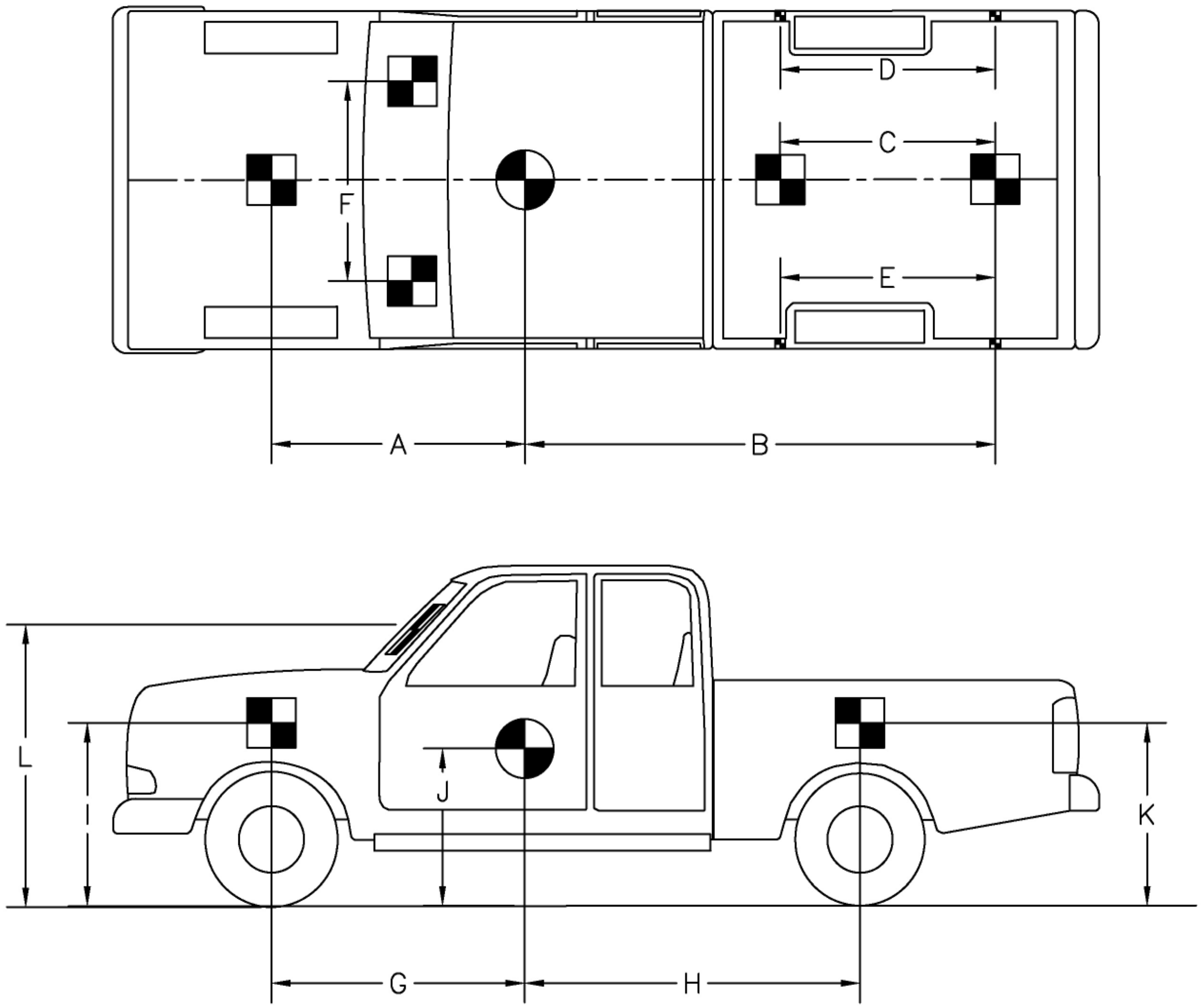
Note any damage prior to test: Passenger side box side dent and scrape.

Figure 16. Vehicle Dimensions, Test No. MGSMP-1

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [14] 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 location of the final c.g. is shown in Figures 16 and 17. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 17. Round, checkered targets were placed at the c.g. location on the left-front door, the right-front door, and the roof of the vehicle.

The front wheels of the test vehicle were aligned to vehicle standards, except the toe-in value was adjusted to zero so that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted on the right side of the vehicle's dash and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact 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.



TEST #: MGSMP-1

TARGET GEOMETRY-- in. (mm)

A	**75 1/8**	**(1908)**	**E**	**63 7/8**	**(1622)**	**I**	**39 1/4**	**(997)**
B	**103 3/4**	**(2635)**	**F**	**35 3/4**	**(908)**	**J**	**28 3/4**	**(730)**
C	**48 1/8**	**(1222)**	**G**	**61**	**(1549)**	**K**	**42 1/2**	**(1080)**
D	**63 7/8**	**(1622)**	**H**	**79 1/4**	**(2013)**	**L**	**65 1/4**	**(1657)**

Figure 17. Target Geometry, Test No. MGSMP-1

4.4 Simulated Occupant

For test no. MGSMP-1, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the right-front seat of the test vehicle, with the seat belt fastened. The dummy, which had a final weight of 165 lb (75 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.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both of the accelerometers were mounted near the c.g. of the test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filters conforming to SAE J211/1 specifications [15].

The two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The acceleration sensors were mounted inside the bodies of custom-built SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

Two identical angle rate sensor systems mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders were used to measure the rates of rotation of the test vehicle. Each

SLICE MICRO Triax Angle Rate Sensor had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessors. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

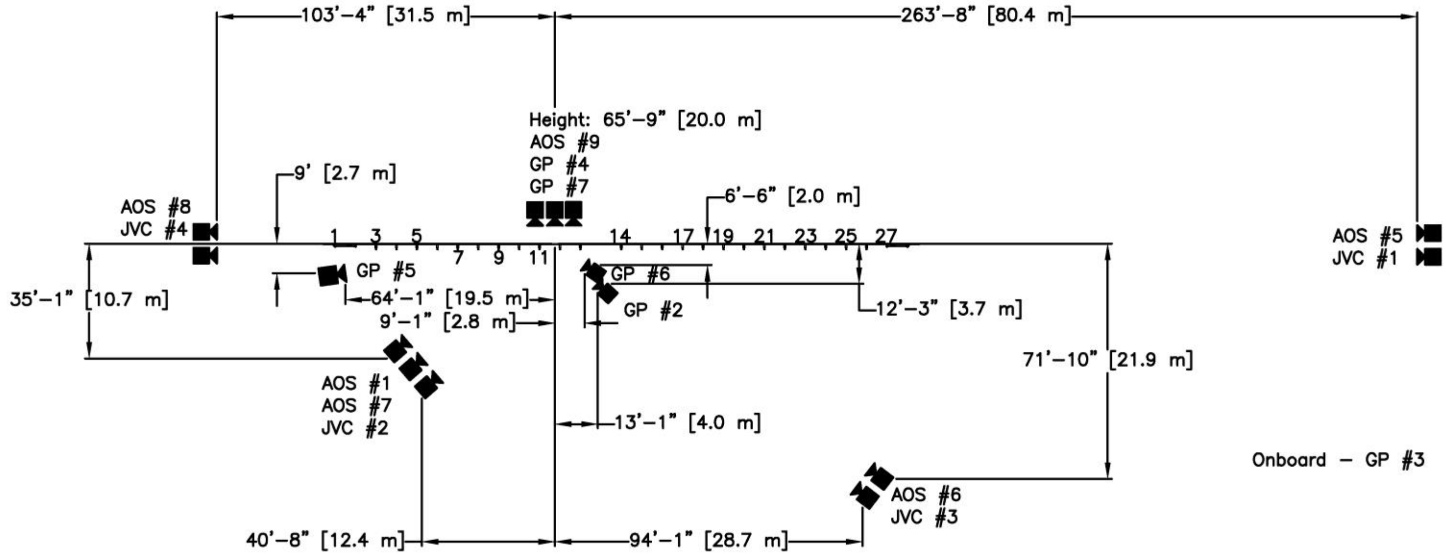
4.5.3 Retroreflective Optic Speed Trap

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

4.5.4 Digital Photography

Six AOS high-speed digital video cameras, six GoPro digital video cameras, and four JVC digital video cameras were utilized to film test no. MGSMP-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 18.

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
AOS-1	AOS Vitcam CTM	500	Sigma 50 mm Fixed	-
AOS-5	AOS X-PRI	500	Vivitar 135 mm Fixed	-
AOS-6	AOS X-PRI	500	Sigma 28-70	50
AOS-7	AOS X-PRI	500	Sigma 28-70 DG	70
AOS-8	AOS S-VIT 1531	500	Fujinon 50 mm Fixed	-
AOS-9	AOS TRI-VIT 2236	500	Kowa 8 mm Fixed	-
GP-2	GoPro Hero 3	120		
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
JVC-1	JVC – GZ-MC500 (Everio)	29.97		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 18. Camera Locations, Speeds, and Lens Settings, Test No. MGSMP-1

5 FULL-SCALE CRASH TEST NO. MGSMP-1

5.1 Selection of Critical Impact Point

Computer simulations with BARRIER VII [16] were utilized to select the critical impact point for full-scale crash test. The barrier was modeled as a 175-ft (53.3-m) long MGS installation with a single post at the center of the guardrail removed. A simulated 2270P vehicle was prescribed an impact speed and angle of 62 mph (100 km/h) and 25 degrees, respectively, and impacted the barrier at various points between 75 in. and 225 in. (1,905 mm and 5,715 mm) upstream of the omitted post. A total of ten simulations were conducted, and the results are summarized in Table 3. Ultimately, the critical impact point was selected as 168.75 in. (4,286 mm) upstream of the omitted post since this location maximized the deflection of the system, rail loads at the splice within the unsupported span length, and vehicle-to-post snag potential.

Table 3. Summary of BARRIER VII Results by Impact Point

Impact Point Distance US of Omitted Post (in.)	Rail		Wheel Snag		Pocketing	
	Max. Defl. (in.)	Max Force (kips)	Max. Snag Pt. 1 (in.)	Max. Snag Pt. 2 (in.)	37.5-in Slope (deg.)	75-in. Slope (deg.)
225	46.99	60.83	10.68	9.23	-23.2	-22.6
187.5	49.98	60.49	13.14	7.47	-23.9	-22.7
178.125	50.51	60.28	13.7	8.67	-20.9	-20.9
168.75	50.72	60.53	14.18	9.74	-20.1	-19.2
159.325	47.63	59.32	12.42	8.15	-20.2	-19.7
150	46.68	59.75	12.88	8.76	-21.6	-21.2
140.625	47.75	59.13	13.27	10.02	-20.5	-19.2
131.25	48.42	57.61	13.55	11.17	-20.9	-20.0
112.5	49.48	57.57	12.9	12.2	-22.8	-21.8
75	46.02	59.15	12.48	10.88	-21.6	-20.7

5.2 Static Soil Test

Before full-scale crash test no. MGSMP-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.

5.3 Weather Conditions

Test no. MGSMP-1 was conducted on April 29, 2015 at approximately 1:45 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), were reported and are shown in Table 4.

Table 4. Weather Conditions, Test No. MGSMP-1

Temperature	72° F
Humidity	29%
Wind Speed	10 mph
Wind Direction	20° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.30 in.

5.4 Test No. MGSMP-1

The 4,934-lb (2,238-kg) pickup truck impacted the standard MGS with an omitted post at a speed of 63.4 mph (102.1 km/h) and an angle of 25.3 degrees. A summary of the test results and sequential photographs are shown in Figure 19. Additional sequential photographs are shown in Figures 20 and 21.

5.5 Test Description

Initial vehicle impact was to occur 206¼ in. (5,239 mm) upstream from the centerline of the splice between post nos. 13 and 14, or 168¾ in. (4,286 mm) upstream from the location of the omitted post, as shown in Figure 22. The actual point of impact was ½ in. (13 mm) downstream from the targeted impact point. A sequential description of the impact events is contained in Table 5. The vehicle came to rest 108 ft – 11 in. (33.2 m) downstream from the point of impact and 45 ft – 9 in. (13.9 m) laterally behind the barrier system. The vehicle trajectory and final position are shown in Figures 19 and 23.

Table 5. Sequential Description of Impact Events, Test No. MGSMP-1

TIME (sec)	EVENT
0.000	Vehicle right-front bumper contacted rail between post nos. 11 and 12, and vehicle front bumper began to deform.
0.004	Post no. 12 began to deflect backward, and the vehicle right fender began to deform.
0.010	Post no. 11 began to deflect backward.
0.012	Vehicle right headlight contacted rail.
0.014	Post no. 13 began to deflect backward.
0.016	Vehicle grill began to deform.
0.020	Post no. 10 began to deflect backward, and vehicle right headlight shattered.
0.022	Vehicle right-front door began to deform.
0.024	Post no. 14 began to deflect backward.
0.026	Post no. 1 began to deflect downstream.
0.030	The vehicle hood began to deform, and vehicle right-front tire contacted rail.
0.032	The W-beam rail flattened between post nos. 12 and 13.
0.054	Vehicle began to yaw away from barrier.
0.062	Post nos. 15 and 16 began to deflect backward.
0.066	Post no. 13 began to bend backward, post no. 14 began to deflect downstream, and vehicle began to roll toward barrier.
0.074	The rail detached from post no. 13.
0.082	Vehicle pitched downward.

0.100	Post nos. 17 and 18 began to deflect backward.
0.114	Post no. 2 began to twist upstream.
0.120	Vehicle began to roll away from barrier.
0.128	Vehicle right-front tire contacted post no. 13.
0.180	Post no. 2 split in half vertically through the guardrail bolt hole.
0.186	Rail released from post nos. 1 and 2.
0.188	Rail released from post no. 14.
0.204	Vehicle right-front corner contacted the W-beam rail splice between post nos. 13 and 14.
0.224	Vehicle front bumper contacted post no. 14.
0.236	Rail released from post no. 3, and post no. 4 began to deflect forward.
0.262	Rail released from post no. 4.
0.268	Rail released from post no. 5.
0.280	Vehicle right-front tire contacted post no. 15.
0.288	Rail released from post no. 15.
0.304	Rail had released from post nos. 6 through 9.
0.310	Vehicle was parallel to system at a speed of 43.1 mph (69.4 km/h).
0.330	Vehicle front bumper contacted post no. 15.
0.416	Vehicle front bumper contacted post no. 16, and the rail released from bolt at post no. 16.
0.456	Vehicle hood became unlatched and began to swing open.
0.472	Vehicle right-front tire contacted post no. 16.
0.494	Vehicle right-front wheel detached.
0.690	Detached right-front tire contacted post no. 17.
0.698	Vehicle began to roll toward barrier.
0.826	Vehicle right-rear tire began to override detached right-front tire.
0.898	Vehicle lost contact with system at a speed of 27.9 mph (44.9 km/h) and at angle of 14.0 degrees.
0.994	Vehicle began to yaw toward barrier.
2.030	Vehicle was again parallel with system as it was hooking around downstream end of the installation.
8.500	Vehicle came to rest approximately 109 ft (33 m) downstream from impact and 45 ft – 9 in. (13.9 m) laterally behind test installation.

5.6 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 24 through 28. Barrier damage consisted of rail deformation, disengagement of the W-beam rail from the posts, bending of the steel posts, and fracture of wooded posts. The length of vehicle contact along the barrier was approximately 39 ft – 9¼ in. (12.1 m), which spanned from 18¼ in. (464 mm) upstream from the centerline of post no. 12 through 9 in. (229 mm) downstream from post no. 17.

Deformation of the W-beam rail occurred between post nos. 11 through 17. Flattening occurred on the bottom corrugation of the rail from the midspan between post nos. 12 and 13 to 13 in. (330 mm) upstream from the midspan between post nos. 14 and 15. A 25-in. (635-mm) long dent was found at the bottom of the rail starting 8 in. (203 mm) upstream from post no. 16. A kink was found in the rail around the blockout of post no. 17. All splice locations were measured before and after the test. A maximum splice movement of ⅝ in. (16 mm) was recorded at two adjacent splices in the contact region, which were located between post nos. 13 and 14 and between post nos. 15 and 16. The rail released from post nos. 1 through 9 and 13 through 17 where the bolt head pulled through the slots in the rail.

Although the post bolts pulled through the rail at the upstream anchor, the cable anchor remained intact between the rail and the bottom of post no. 1, as shown in Figure 28. Two tears, ¾ in. (19 mm) and ½ in. (13 mm) long, occurred in the rail at the bolt location of post no. 1. Post no. 2 was split down the center through the bolt hole. A 1-in. (25-mm) soil gap was found on the upstream side of post no. 1. The downstream anchorage was undamaged, except for a $^{1}/_{16}$-in. (2-mm) soil gap found on the downstream side of the foundation tubes.

Post nos. 11 through 17 were all bent and/or rotated backward and downstream, while post nos. 7 through 10 were also displaced downstream. Post nos. 13 through 16 were severely bent at ground line due to the vehicle running over them, as shown in Figure 25. Blockouts were disengaged from post nos. 13 through 15.

The maximum lateral permanent rail and post deflections were 40½ in. (1,029 mm) at the midspan between post nos. 14 and 15 and 25 in. (635 mm) at post no. 13, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 49.0 in. (1,243 mm) at the rail between the midspan between post nos. 13 and 14 and post no. 14 and 21.0 in. (533 mm) at post no. 13, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 50.1 in. (1,272 mm), also determined from high-speed digital video analysis.

5.7 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 29 and 30. The maximum occupant compartment deformations are listed in Table 6 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH-established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 6. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH-ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toepan	¼ (6)	≤ 9 (229)
Floorpan & Transmission Tunnel	¼ (6)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	¼ (6)	≤ 9 (229)
Side Door (Below Seat)	⅜ (10)	≤ 12 (305)
Roof	0	≤ 4 (102)
Windshield	0	≤ 3 (76)

The majority of the damage was concentrated on the right-front corner and right side of the vehicle where impact occurred. A 1¾-in. (44-mm) separation formed between the hood and the grill. The right-front corner of the bumper was crushed inward. The right headlight disengaged. A 5-in. (127-mm) dent formed on the fender located behind the headlight location. The right-front tire was disengaged and had a ¾-in. (19-mm) tear in its sidewall. The right-front wheel steel rim had a 1½-in. (38-mm) diameter gouge and bending around the entire edge of the rim. Additional gouges were found on the hub cap. The steering linkage broke, and the control arm was fractured. The right-front brake hose was cut. Contact marks were found on the entire length of the right side of the vehicle, starting 20 in. (508 mm) from the bottom of the right-front door and ending 9½ in. (241 mm) from the bottom of the right-rear bumper. The right-front door had a 12-in. (305-mm) long tear approximately 18 in. (457 mm) below the window. Gouges and dents were found on the right-front door. A 3-in. wide x 1-in. deep x 10-in. long (76-mm x 25-mm x 254-mm) gouge was found on the rear corner of the right-rear bumper. The right-rear tire ruptured.

5.8 Occupant Risk

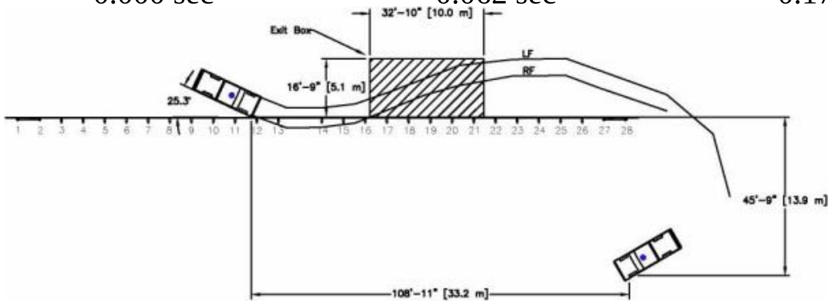
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 7. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 7. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 19. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E. Note, the SLICE-2 unit was designated as the primary accelerometer unit during this test, as it was mounted closer to the c.g. of the vehicle.

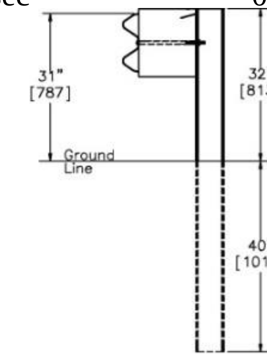
Table 7. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSMP-1

Evaluation Criteria		Transducer		MASH Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-13.63 (-4.15)	-15.80 (-4.82)	≤ 40 (12.2)
	Lateral	-14.08 (-4.29)	-14.60 (-4.45)	≤40 (12.2)
ORA g's	Longitudinal	-10.29	-10.34	≤ 20.49
	Lateral	-7.94	-7.30	≤ 20.49
MAX. ANGULAR DISPL. deg.	Roll	11.79	7.87	≤75
	Pitch	-5.12	-6.04	≤75
	Yaw	-42.92	-43.23	not required
THIV ft/s (m/s)		18.79 (5.73)	19.62 (5.98)	not required
PHD g's		11.44	11.61	not required
ASI		0.74	0.72	not required

5.9 Discussion

The analysis of the test results for test no. MGSMP-1 showed that the longitudinal barrier adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. There were no detached elements or fragments which showed potential for penetrating the occupant compartment or presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate or ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable, because they did not adversely influence occupant risk safety criteria or cause rollover. After impact, the vehicle exited the barrier at an angle of 14.0 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MGSMP-1, conducted on the MGS with a single omitted post, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-11.





- Test Agency .... MwRSF
- Test Number MGSMP-1
- Date 4/29/15
- MASH Test Designation 3-11
- Test Article .... MGS with Omitted Post
- Total Length .... 182 ft – 3½ in. (55.6 m)
- Key Component – Steel W-Beam Guardrail
  - Thickness .... 12 gauge (2.66 mm)
  - Top Mounting Height .... 31 in. (787 mm)
- Key Component – Steel Post
  - Shape .... W6 x 8.5 (W152 x 12.6)
  - Length .... 72 in. (1,829 mm)
  - Post nos. 1-12, 15-28 Spacing .... 75 in. (1,905 mm)
  - Post nos. 13-14 Spacing .... 150 in. (3,810 mm)
  - Embedment Depth .... 40 in. (1,016 mm)
- Key Component – Wood Blockout
  - Post Nos. 3-26 .... 6 x 12 x 14¼ in. (152 x 305 x 362 mm)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... 2008 Dodge Ram 1500
  - Curb .... 5,057 lb (2,294 kg)
  - Test Inertial .... 4,934 lb (2,238 kg)
  - Gross Static .... 5,099 lb (2,313 kg)
- Impact Conditions
  - Speed .... 63.4 mph (102.1 km/h)
  - Angle .... 25.3 deg
  - Impact Location ...... 205¾ in. (5,226 mm) US of Splice between Post nos. 13 and 14
- Impact Severity (IS) .... 121.3 kip-ft (164.4 kJ) > 105.6 kip-ft (143.2 kJ)
- Exit Conditions
  - Speed .... 27.9 mph (44.9 km/h)
  - Angle .... 14.0 deg
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 108 ft – 11 in. (33.2 m) downstream
  45 ft – 9 in. (13.9 m) laterally behind
- Vehicle Damage .... Minimal
  - VDS [17] 01-RFQ-4
  - CDC [18] 01-RYEW-3
  - Maximum Interior Deformation .... ⅜ in. (10 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 40½ in. (1,029 mm)
  - Dynamic .... 49.0 in. (1,243 mm)
  - Working Width .... 50.1 in. (1,272 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-13.63 (-4.15)	-15.80 (-4.82)	≤ 40 (12.2)
	Lateral	-14.08 (-4.29)	-14.60 (-4.45)	≤ 40 (12.2)
ORA g's	Longitudinal	-10.29	-10.34	≤ 20.49
	Lateral	-7.94	-7.30	≤ 20.49
MAX ANGULAR DISP. deg.	Roll	11.79	7.87	≤75
	Pitch	-5.12	-6.04	≤75
	Yaw	-42.92	-43.23	not required
THIV – ft/s (m/s)		18.79 (5.73)	19.62 (5.98)	not required
PHD – g's		11.44	11.61	not required
ASI		0.74	0.72	not required

Figure 19. Summary of Test Results and Sequential Photographs, Test No. MGSMP-1

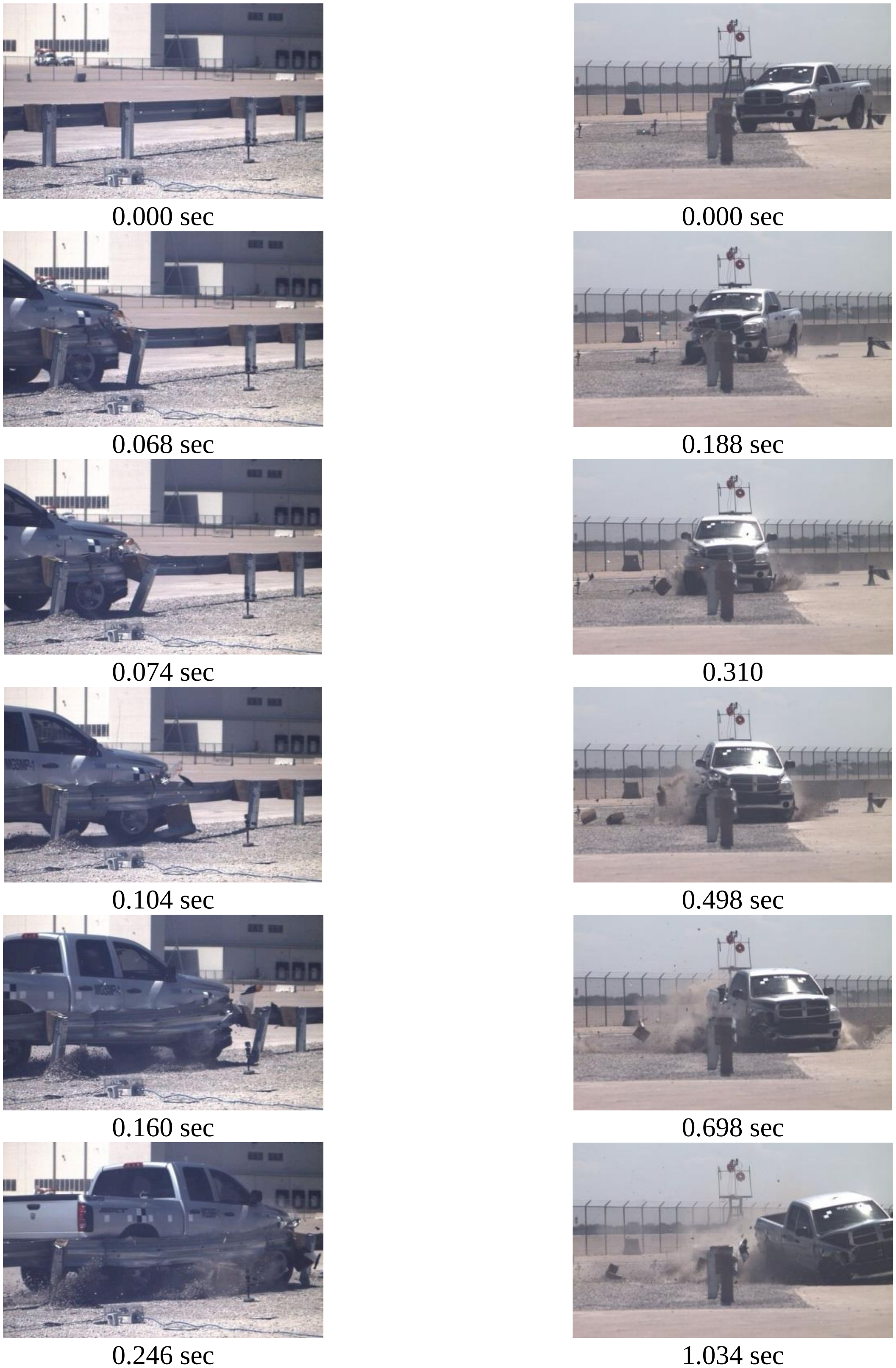


Figure 20. Additional Sequential Photographs, Test No. MGSMP-1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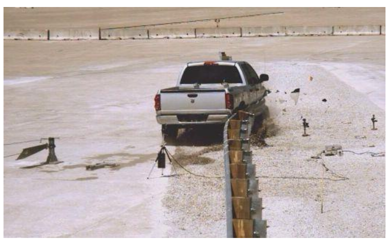
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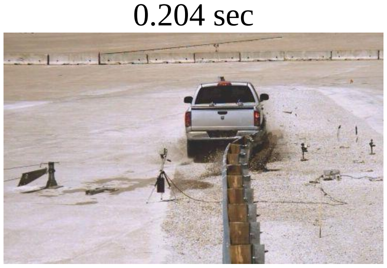
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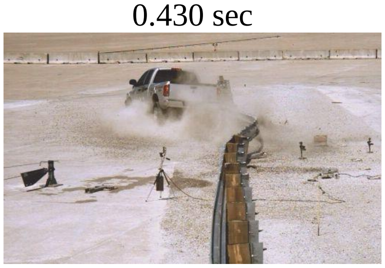
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Figure 21. Additional Sequential Photographs, Test No. MGSMP-1

Figure 22. Impact Location, Test No. MGSMP-1

Figure 23. Vehicle Final Position and Trajectory, Test No. MGSMP-1

Figure 24. System Damage, Test No. MGSMP-1

Figure 25. Rail Damage Between Post Nos. 12 and 17, Test No. MGSMP-1

Figure 26. Post nos. 7 through 13 Damage, Test No. MGSMP-1

Figure 27. Post nos. 14 through 17 Damage, Test No. MGSMP-1

Figure 28. Upstream Anchor Damage, Test No. MGSMP-1

Figure 29. Vehicle Damage, Test No. MGSMP-1

Figure 30. Undercarriage, Test No. MGSMP-1

6 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This study consisted of crash testing and evaluation of standard MGS with an omitted post. The omitted post created an unsupported span of 12.5 ft (3.8 m). No other modifications were made to the MGS. One full-scale crash test was performed according to the TL-3 safety performance criteria defined in MASH, test designation no. 3-11.

Test no. MGSMP-1 consisted of a 4,934-lb (2,238-kg) pickup truck impacting the MGS with an omitted post at a speed of 63.4 mph (102.1 km/h) and an angle of 25.3 degrees, resulting in an impact severity of 121.3 kip-ft (164.4 kJ). The vehicle was contained and smoothly redirected with only moderate damage sustained by the system and the vehicle. All vehicle decelerations fell within the recommended safety limits, so test no. MGSMP-1 passed the safety criteria of MASH test designation no. 3-11. A summary of the safety performance evaluation is provided in Table 8.

MASH test designation no. 3-10 with the small car was not conducted as part of the study. Previous testing of the MGS with small cars has not shown a propensity for vehicle underride, excessive snag, vehicle instability, or excessive decelerations. Without crashworthiness concerns for the system in combination with small cars, MASH test designation no. 3-10 was considered unnecessary, and the evaluation of the system focused on its structural integrity. Therefore, the MGS with an omitted post was deemed to be acceptable according to the TL-3 safety performance criteria for longitudinal barriers presented in MASH.

The evaluation and conclusions provided herein relate to the omission of a single support post within the MGS. Until further evaluation is conducted, omitting more than one consecutive post within a standard MGS installation is not recommended due to concerns for excessive pocketing and rail rupture. If a roadside obstruction prevents two or three consecutive posts from being installed properly, an MGS long-span system, with three CRT posts on each side of the increased span length, should be utilized to treat the area [1].

Though not evaluated as part of this study, the omission of multiple non-consecutive posts within an MGS instillation may also lead to increased deflections, increased rail loads, and increased pocketing. Therefore, sufficient distance between omitted posts within an MGS instillation is necessary to ensure proper system performance. During test MGSMP-1, the truck was in contact with the guardrail for about 40 ft (12.2 m). Thus, at least 40 ft (12.2 m) of standard MGS is recommended between the increased unsupported spans created by the post omissions. Rounding up to the nearest post spacing with a 75-in. (1,905-mm) interval, results in a minimum distance of 43.75 ft (13.3 m) between unsupported spans. Subsequently, the distance between omitted posts is recommended to be at least 56.25 ft (17.1 m), as shown in Figure 31. This distance is equivalent to saying a single post may be omitted at every 9th post along an MGS installation.

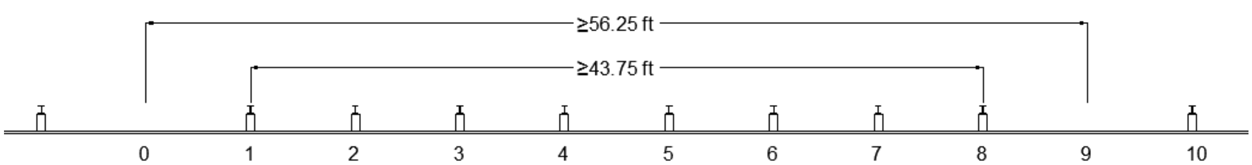


Figure 31. Minimum Recommended Distance between Omitted Posts

A comparison of the safety performance between various MGS configurations and special applications is shown in Tables 9 and 10. The MGS with an omitted post performs similarly to other MGS applications in terms of vehicle decelerations (OIV and ORA) and exit conditions. However, the omission of a single post increases the dynamic deflection and working width of the guardrail system. Consequently, when omitting a post, the required clear space behind the guardrail installation increases. This increased deflection associated with the omission of a post will also affect the performance of the guardrail adjacent to the omitted post. Therefore, the specific configuration of the guardrail, the location of the post within the system, and the roadside conditions should be considered prior to omitting a post from the MGS. Recommendations on proper implementation of an omitted post within various MGS configurations and special applications are provided in Chapter 7.

Table 8. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. MGSMP-1</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td><td>S</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td></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>
<tr><td colspan="5">MASH Test Designation Number</td><td>3-11</td></tr>
<tr><td colspan="5">Pass/Fail</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

Table 9. Comparison of MASH 3-11 Tests on Variations of MGS

Test No.	MGSMP-1	2214MG-2	MGSGW-2	MGSNB-1	MGSWP-1	MGSSYP-1	MGSMIN-1	MGS221-2	MGSS-1	405160-20-1
System Note	Omitted Post	Standard	Atop MSE Wall	Non-Blocked	White Pine Posts	SYP Posts	75 ft System Length	2:1 Slope	2:1 Slope	2:1 slope
Reference		[19]	[20]	[21]	[22]	[23]	[24]	[25]	[26]	[27]
MASH Test	3-11	3-11	3-11	3-11	3-11	3-11	3-11	3-11	3-11	3-11
Vehicle Wt. (lb)	4934	5000	4999	5011	4999	5029	4956	5013	4992	5044
Post Type	Steel W6x8.5	Steel W6x8.5	Steel W6x8.5	Steel W6x8.5	Wood 6"x8"	Wood 6"x8"	Steel W6x8.5	Steel - 9-ft W6x8.5	Steel W6x8.5	Steel - 8-ft W6x8.5
Blockout Depth (in.)	12	12	-	-	12	12	12	12	12	8
Terrain/Slope	Level	Level	3:1 SBP	Level	Level	Level	Level	2:1 SBP	2:1 SBP	12" down 2:1 SBP
Impact Severity (kip-ft)	121.1	122.2	128.2	115.0	127.0	115.3	116.9	116.7	124.3	123.0
Working Width (in.)	50.1	48.6	45.2	43.2	58.4	53.8	48.8	64.2	77.4	55
Dyn. Deflection (in.)	49	43.9	35.7	34.1	46.3	40	42.2	57.6	72.9	52
Contact Length (ft)	40	34	26	24	31	34	37	41	50	~38
No. Posts Struck by Vehicle	4 (+ omitted)	4	3	3	3	4	4	4	4	4
ORA Long. (g's) Lat. (g's)	 -10.34 -7.30	 -8.23 6.93	 -11.99 -8.91	 -11.49 -12.91	 -8.25 -10.13	 -8.14 -8.51	 -8.70 6.16	 -11.66 5.38	 -7.14 5.41	 -9.0 6.9
OIV Long. (ft/s) Lat. (ft/s)	 -15.8 -14.60	 -15.32 -15.62	 -17.85 -18.26	 -17.13 -18.67	 -15.27 -16.14	 -13.25 -14.74	 -14.48 14.66	 -16.18 12.80	 -3.69 4.12	 -15.1 15.4
Exit Time (sec)	0.898	0.718	0.452	0.504	0.618	0.652	0.7	0.726	0.966	0.550
Exit Velocity (mph)	27.9	39.6	43.8	47.4	39.6	37.8	32.9	38.6	40.5	NA
Exit Angle (deg.)	-14	-13.5	-20.4	-14.4	-16.6	-15.7	-13	-17.4	-16	-10

SBP – Slope Break Point

Table 10. Comparison of MASH 3-10 Tests on Variations of MGS

Test	2214MG-3	MGSGW-1	MGSNB-2	MGSSYP-2	420020-5	405160-20-2
System Notes	Standard	Atop MSE Wall	Non-Blocked	SYP Posts	8-in Blockouts	8-in. Blockout 2:1 slope
Reference	[28]	[20]	[21]	[23]	[29]	[27]
MASH Test	3-10	3-10	3-10	3-10	3-10	3-10
Vehicle Wt. (lb)	2422	2427	2408	2442	2435	2429
Post Type	Steel W6x8.5	Steel W6x8.5	Steel W6x8.5	Wood 6"x8"	Steel W6x8.5	Steel - 8-ft W6x8.5
Blockout Depth (in.)	12	-	-	12	8	8
Terrain/Slope	Level	3:1 SBP	Level	Level	Level	12" down 2:1 SBP
Impact Severity (kip-ft)	55.1	55.1	59.2	56.4	55.4	56.3
Working Width (in.)	42.3	35.7	34.5	39.7	28.6	37
Dyn. Deflection (in.)	35.9	27.4	29.1	22.2	19	32
Contact Length (ft)	27	24	21	23	~30	~30
No. Posts Struck by Vehicle	3	4	4	2	4	3
ORA Long. (g's) Lat. (g's)	-16.14 -8.37	-13.78 -7.81	-10.20 -6.30	-13.04 -9.30	-8.8 6.8	-7.3 6.8
OIV Long. (ft/s) Lat. (ft/s)	-14.83 -17.13	-25.87 -17.07	-31.26 -15.83	-15.72 -20.93	-21.0 17.4	-17.4 16.1
Exit Time (sec)	0.53	0.726	0.404	0.484	0.814	0.545
Exit Velocity (mph)	30.1	10.2	25.7	35.7	29.2	31.3
Exit Angle (deg.)	-14.1	-58.3	-19.1	-13.6	-15	-32.3

SBP – Slope Break Point

7 IMPLEMENTATION GUIDANCE

7.1 Background

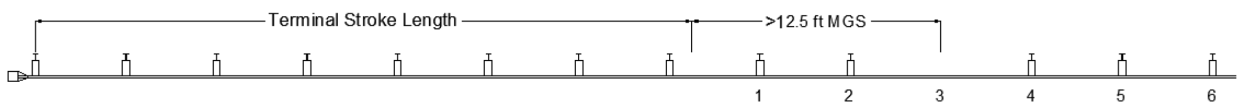
As previously noted, the research detailed herein demonstrated that the MGS with an omitted post performed in an acceptable manner according to the TL-3 safety standards of MASH. However, multiple variations of the MGS system have been developed for special applications, which may be more sensitive to the omission of a post. These special applications include terminals and anchorages, MGS stiffness transition to thrie beam approach guardrail transitions, MGS long-span system, MGS adjacent to 2:1 fill slopes, MGS on 8:1 approach slopes, MGS in combination with curbs, wood post MGS, and MGS without blockouts. Since multiple MGS variations are available, recommendations regarding the omission of a post will likely vary depending on the nature and behavior of the special applications listed above.

The following sections provide implementation guidance and/or recommendations regarding post omission within MGS special applications. These recommendations are intended to ensure comparable safety performance of the guardrail systems and are based on the full-scale testing and any associated research available at the conclusion of this project. Although some installation sites will require systems outside the bounds of these recommendations, the reasoning behind these recommendations should be considered along with other roadside treatments when selecting the final site specific design.

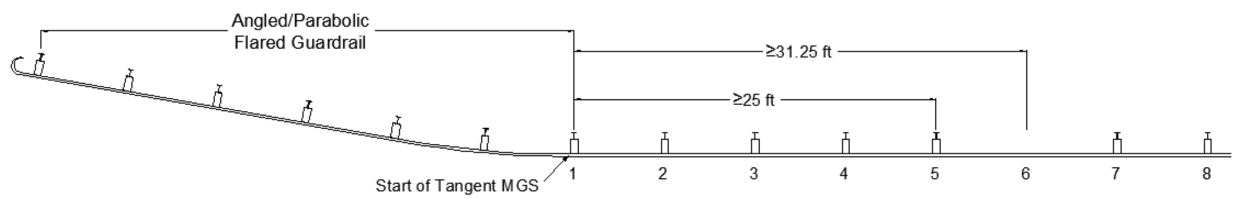
7.2 Guardrail Terminals and Anchorages

Multiple W-beam guardrail end terminals have been developed for use with the MGS. Guardrail terminals are sensitive systems that have been carefully designed to satisfy safety performance standards. Omitting a post within a terminal region could significantly degrade the system's crashworthiness. Thus, for energy absorbing terminals, it is recommended to have greater than 12.5 ft (3.8 m) of standard MGS between the inner end of a guardrail terminal, identified by system stroke length, and the omitted post. In other words, the first post eligible for omission is the third guardrail post from the inner end of the terminal, or end of stroke length, as shown in Figure 32.

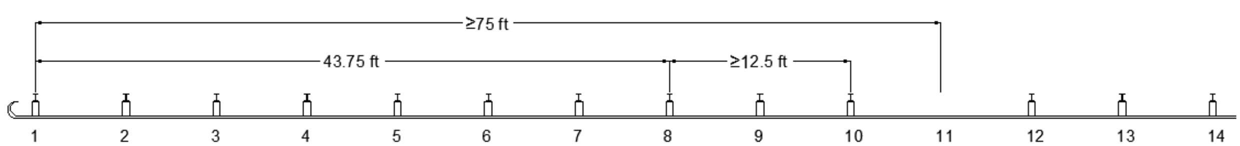
Non-energy absorbing terminals typically flare away from the roadway utilizing either an angled or parabolic geometry. Both geometric layouts result in increased effective impact angles, which result in increased system deflections for impacts on or near the flared terminal. Due to the increase in system deflections associated with guardrail flares, at least 25 ft (7.6 m) of tangent MGS should be used to separate a flared guardrail terminal and the enlarged span length, making the sixth post on the tangent length of MGS eligible for omission, as shown in Figure 32.



a)



b)



c)

Figure 32. Recommended Distance Between Omitted Posts and a) Energy-Absorbing Terminals, b) Flared Terminals, and c) Trailing-End Guardrail Anchorages

Omitting a post near guardrail anchorages may also affect system performance. Guidance has been previously provided for length-of-need and working width for MGS trailing-end anchorages [3]. However, omitting a post near guardrail anchorages would likely change system performance, rendering these recommendations erroneous. From the noted study, impacts beyond 43.75 ft (13.3 m) from the end post resulted in consistent redirection and working width. It is recommended that no omitted posts be located within this outer 43.75 ft (13.3 m) or the adjacent 12.5 ft (3.8 m) of MGS. Thus, the location of the first allowable omitted post would be 75 ft (22.9 m) from the anchorage post, or the 11th post of the installation, as shown previously in Figure 32.

7.3 MGS Stiffness Transition

The MGS stiffness transition was previously developed to connect standard MGS to various thrie beam, approach guardrail transitions. Both steel post and wood post versions of the MGS stiffness transition have been developed as well as a configuration for use adjacent to roadside curbs [30-32]. Within these previous studies, it was recommended that 25 ft (7.2 m) of guardrail be utilized between the upstream end of the asymmetrical W-to-thrie transition element and any guardrail flares. Since an omitted post results in reduced rail stiffness and increased rail deflections, it is similarly recommended that at least 25 ft (7.2 m) of guardrail separate the W-to-thrie transition element and the elongated span resulting from an omitted post. Adding in the extra 37.5 in. (953 mm) post spacing required to transition between full- and half-post spacing, the distance between the asymmetrical element and the elongated span should be at least 28 ft – 1.5 in. (8.6 m). Thus, an omitted post should be at least 34 ft – 4.5 in. (10.5 m) away from the upstream end of the W-to-thrie transition element, as shown in Figure 33.

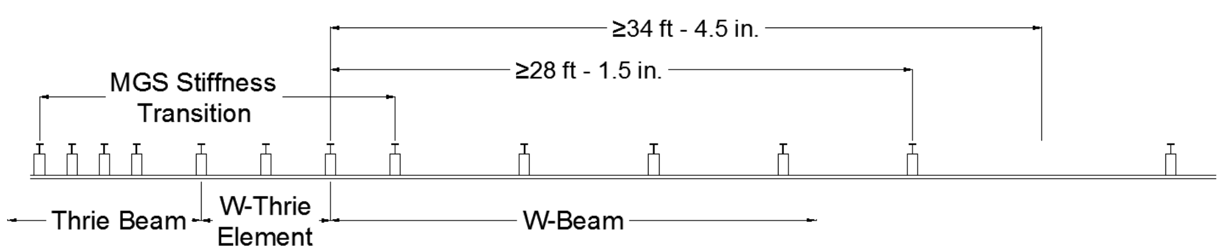


Figure 33. Recommended Distance Between Omitted Posts and MGS Stiffness Transition

As discussed in Section 7.7, it is not recommended to omit a post from an MGS installation with curb. However, many guardrail transitions incorporate a curb beneath the rail. To ensure proper performance of the transition, the curb should extend the entire length of the transition, or from the rigid parapet to the upstream end of the nested W-beam [32]. Therefore, the curb should be terminated within the MGS between the nested W-beam rail of the transition and the elongated span length resulting from the omitted post. Additionally, it is recommended to utilize a minimum length of 3 ft (0.9 m) for any curb shape transitions, including terminations.

7.4 MGS Long-Span System

The MGS long-span guardrail system was successfully full-scale crash tested using an unsupported length of 25 ft (7.6 m) and three CRT posts adjacent to each end of the unsupported span [1]. These CRT posts were incorporated into the system in order to mitigate concerns for wheel snag on posts adjacent to the unsupported span when traversing from the unsupported span to the downstream standard guardrail. The combination of the enlarged unsupported span length and the breakaway CRT posts led to system deflections and working widths much higher than the standard MGS adjacent to both sides of the long span system. Since omitting a post also increased system deflections, these two special applications of the MGS need to be separated to ensure one system does not negatively affect the performance of the other. Therefore, it is recommended that 37.5 ft (11.4 m) of standard MGS be utilized between the outer CRT post of a long-span system and the enlarged span length resulting from an omitted post. Thus, an omitted post should be at least 43.75 ft (13.3 m), or the 7th post, away from the outer CRT post of a long-span system, as shown in Figure 34.

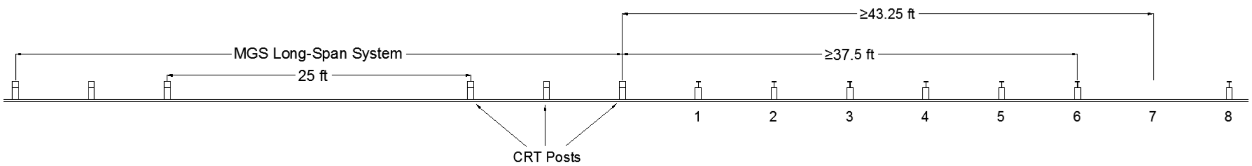


Figure 34. Recommended Distance Between Omitted Posts and MGS Long-Span System.

7.5 MGS Adjacent to 2:1 Slopes

Full-scale crash testing has been successfully conducted on three different configurations of the MGS placed on or adjacent to 2:1 fill slopes [25-27]. These configurations varied in the length of the posts and the placement of the posts relative to the slope break point. However, the lack of soil backfill behind the guardrail posts resulted in increased system deflections and working widths for all three MGS configurations, as shown previously in Table 9. The omission of a guardrail post has also been shown to increase system deflection and working width. Therefore, it is not recommended to omit guardrail posts within MGS systems located on, or at the slope break point of, 2:1 fill slopes due to concerns for excessive deflections and an increased risk of guardrail pocketing and vehicle instabilities.

7.6 MGS on 8:1 Approach Slopes

Previously, full-scale crash testing was successfully performed on the MGS installed on an 8:1 approach slope with the W-beam positioned 5 ft (1.5 m) laterally behind the slope break point [33]. This testing program was conducted according to the NCHRP Report No. 350 impact safety standards using both an 820C small car and a 2000P pickup truck. From the crash testing program, the mounting height of the blocked MGS relative to the airborne trajectory of the front bumper and impact-side wheels was deemed critical for satisfactorily containing the 2000P pickup truck. Both the bumper and c.g. height of the MASH 2270P pickup are higher than the old 2000P pickup. Thus, there are concerns that the same system may be unable to successfully capture the pickup truck according to the current safety standards of MASH. The omission of a post within the system would only increase the risk of excessive deflections and/or vehicle override. Since the system was never evaluated to MASH standards, it is not recommended to omit guardrail posts with an MGS installation placed on approach slopes until further evaluation is conducted.

7.7 MGS in Combination with Curbs

During the original development of the MGS, the system was evaluated in combination with a 6-in. (152-mm) tall curb placed 6 in. (152 mm) in front of the face of the guardrail [4]. The full-scale crash testing of this configuration was conducted with the 2000P vehicle of NCHRP Report No. 350. Unfortunately, the MGS in combination with curbs has never been evaluated with a small car or to the safety performance criteria of MASH. Additionally, recent MASH small car testing of the MGS stiffness transition with curb resulted in W-beam rail rupture due to partial vehicle underride and a vertical load being imparted to the rail [32]. An omitted post within an MGS installation with curb may cause similar results as the vehicle would be allowed to travel further into the system and impart vertical loads to the W-beam rail. Therefore, it is not recommended to omit posts within an MGS installation with curb until further evaluation is conducted.

7.8 Wood Post MGS

Wood post versions of the MGS utilizing 6-in. x 8-in. (152-mm xx 203-mm) posts of both Southern Yellow Pine and White Pine timber species were previously tested in accordance with MASH safety performance standards [22, 23]. The full-scale testing illustrated that the MGS performed similarly when utilizing either W6x8.5 (W152x12.6) steel posts or 6-in. x 8-in. (152-mm xx 203-mm) wood posts. System deflections, working widths, and vehicle decelerations were all similar between these MGS configurations, as shown previously in Tables

9 and 10. As such, omitting a post within a wood post system should result in similar behavior and performance to the system evaluated herein. Therefore, it is recommended to utilize the same implementation guidelines and restrictions described herein when omitting a post within a wood post MGS installation.

7.9 MGS without Blockouts

Previously, full-scale crash testing was successfully performed on the MGS without blockouts. The installation utilized standard steel guardrail posts and 12-in. (305-mm) long backup plates to prevent contact between the rail and the posts and reduce the probability of rail tearing. The system was successfully crash tested to MASH safety standards using both the 2270P and 1100C vehicles [21]. However, omitting a post within a non-blocked MGS installation may negatively affect system performance. An omitted post would increase system deflections, which would increase the propensity for guardrail pocketing and possible rail tearing. The increased deflections may also allow an impacting vehicle to override the guardrail posts and result in floorpan tearing. Recent testing of small cars overriding weak, steel posts with exposed edges has resulted in tearing of the vehicle floorpan and intrusion into the occupant compartment [34]. Due to these concerns, it is not recommended to omit posts within non-blocked MGS installations until further evaluation is conducted.

7.10 MGS with 8-in. (203-mm) Blockouts

All of the concerns raised in the previous section discussing non-blocked MGS installations may apply to other configurations utilizing a blockout depth less than the 12-in. (305-mm) depth tested herein. However, it is also recognized that there are blockout depths less than 12 in. (305 mm) that would likely satisfy MASH perform standards when used in MGS installations with an omitted post. Unfortunately, the minimum blockout depth required to ensure proper performance for systems with an omitted post remains unknown until further evaluation is conducted. However, the performance of 8-in. (203-mm) and 12-in. (305-mm) blockouts has been shown to be similar [35], so the effect of an omitted post within an MGS installation of either blockout type should also be similar. Thus, it is recommended to utilize the same implementation guidelines and restrictions presented herein when omitting a post within an MGS installation with 8-in. (203-mm) blockouts.

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9 APPENDICES

Appendix A. Material Specifications

Description	Material Specification	Reference
W6x8.5 [W152x12.6], 72" [1829] Long Steel Post	ASTM A992 Min. 50 ksi [345 MPa] Steel Galv. or W6x9 [W152x13.4] ASTM A36 Min. 36 ksi [248 MPa] Steel Galv.	Heat# 1311743
6x12x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	C.O.I. – 5/8/2012
16D Double Head Nail	-	BC - 764666139107
12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv.	H# 4614
6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv.	Order # 1164746
12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv.	H# 4614
BCT Timber Post - MGS Height	SYP Grade No. 1 or better (No knots, 18" [457] above or below ground tension face)	C.O.I. – 4/19/2012 C.O.I. – 9/15/2014
72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv.	Heat # Y85912
Strut and Yoke Assembly	ASTM A36 Steel Galv.	Order # 1093497
BCT Cable Anchor Assembly	3/4" [19] 6x19 IWRC IPS Galvanized Wire Rope	Order # 1207548
Anchor Bracket Assembly	ASTM A36 Steel Galv.	Heat # 4153095
8”x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv.	Heat # 18486
2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv.	Heat # 280638
5/8” Dia. x 14” [M16 x 356] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	Lot # 25512
5/8” Dia. x 1 1/4” [M16 x 32] Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	Lot # 140314B
5/8” Dia. x 10” [M16 x 254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	Lot # 130809L
5/8” Dia. x 1 1/2” [M16 x 38] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	Order # 1093497
5/8” Dia. x 10” [M16 x 254] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	Heat # JK1110419701
7/8” Dia. x 8” [M22 x 203] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	Lot # 17071802
5/8" [16] Dia. Plain Round Washer	ASTM F844 Galv.	n/a
7/8" [22] Dia. Plain Round Washer	ASTM F844 Galv.	Heat # 8280072

Figure A-1. Bill of Materials, Test No. MGSMP-1

HIGHWAY SAFETY CORP

P.O. BOX 358
GLASTONBURY, CT 06033

CERTIFICATE OF COMPLIANCE/ANALYSIS REPORT

SOLD TO:

MIDWEST MACHINERY & SUPPLY
P.O. BOX 703
Milford, NE, USA

SHIP TO:

MIDWEST MACHINERY & SUPPLY
MILFORD

INVOICE / S.O.: 0176846 / 0121723
CUSTOMER P.O.: 2932

REFERENCE: STOCK
DATE SHIPPED: 5/27/2014

QTY:	HEAT/LOT NO:	ITEM NUMBER:	YIELD:	CC: / TENSILE:	%ELONG:	DESCRIPTION: / C:	Mn:	P:	S:	Si:	Cl:	Type	ACW
850		T-POG060080600		IB-B0600800		THRIE POST W06 x 008.5# x 06'00 GALV							
(550)	1311748												
				IB-B0600800									
(300)	1311743												

ALL STEEL USED IN MANUFACTURING IS MADE AND MELTED IN THE USA, INCLUDING HARDWARE FASTENERS, AND COMPLIES WITH THE BUY AMERICA ACT. ALL COATINGS PROCESSES ARE PERFORMED IN THE USA AND COMPLY WITH THE BUY AMERICA ACT. BOLTS COMPLY WITH ASTMA-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTMA-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153 UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 AND/OR F-844 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153 UNLESS OTHERWISE STATED. ALL GUARDRAIL MEETS AASHTO M-180, AND ALL STRUCTURAL STEEL MEETS AASHTO M-270. ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTMA-123. ALL OTHER ITEMS COMPLY WITH AASHTO M-111, M-165, M-133, M-265, ASTM A36, ASTMA-709, ASTMA-123, ASTM A505, AND ASTMA588 SPECIFICATIONS IF APPLICABLE. COMPLIANCE WITH ALL SPECIFICATIONS OF DEPARTMENT OF PUBLIC WORKS, DEPARTMENT OF HIGHWAYS AND TRANSPORTATION, DIVISION OF ROADS AND BRIDGES AND STATE HIGHWAY ADMINISTRATION IS MET IN ALL RESPECTS.

HIGHWAY SAFETY CORPORATION

[signature]
QUALITY ASSURANCE MANAGER

NOTARIZED UPON REQUEST:
STATE OF CONNECTICUT COUNTY OF HARTFORD
SWORN AND SUBSCRIBED BEFORE ME THIS 29 DAY OF May, 20 14

Margaret J Satalino
Notary Public

MARGARET J. SATALINO
NOTARY PUBLIC
MY COMMISSION EXPIRES OCT. 31, 2016

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Figure A-2. Steel Posts, Test No. MGSMP-1

NUCOR STEEL - BERKELEY
P.O. Box 2259
Mt. Pleasant, S.C. 29464
Phone: (843) 336-6000

CERTIFIED MILL TEST REPORT

10/14/13 7:20:46
100% MELTED AND MANUFACTURED IN THE USA
All beams produced by Nucor-Berkeley are cast and rolled to a fully killed and fine grain practice.
Mercury has not been used in the direct manufacturing of this material.

Sold To: HIGHWAY SAFETY CORP
PO BOX 358

GLASTONBURY, CT 06033

Ship To: HIGHWAY SAFETY CORP
473 WEST FAIRGROUND STREET

MARION, OH 43301

Customer #.: 352 - 3
Customer PO: 0001574038
B.O.L. #...: 1038540
MOS: T

SPECIFICATIONS: Tested in accordance with ASTM specification A6-13/A6M-12 and A370. Quality Manual Rev #27.
ASME : SA-36 07a
ASTM : A992-11:A36-12/A529-05-50/A572 5012a/A70913 50s
CSA : CSA-44W/G40.21-50w/G40.21300W/G40.21350w

IB-B0600800

Description	Heat# Grade(s) Test/Heat JW	Yield/ Tensile Ratio	Yield (PSI) (MPa)	Tensile (PSI) (MPa)	Elong %	C Cr xxxxxx	Mn Mo Ti	P Sn xxxxxx	S B xxxxxx	Si V N	Cu Nb xxxxxx	Ni xxxxxx CI	CE1 CE2 Pcm
W6X8.5	1311748	.79	54100	68100	27.20	.06	.83	.008	.032	.20	.17	.05	.23
042' 00.00"	A992-11		373	470		.03	.01	.0088	.0003	.003	.014		.2627
W150X12.6		.80	55200	68900	27.74		.001			.0054		4.13	.1263
012.8016m	ANS		381	475	42 Pc(s)	14,994 lbs						Inv#:	0
W6X8.5	1311743	.81	57600	71200	28.29	.07	.88	.009	.027	.24	.17	.05	.24
042' 00.00"	A992-11		397	491		.04	.01	.0088	.0003	.004	.016		.2835
W150X12.6		.81	58400	71900	27.46		.001			.0057		4.19	.1335
012.8016m	ANS		403	496	84 Pc(s)	29,988 lbs						Inv#:	0

2 Heat(s) for this MIR.

Elongation based on 8' (20.32cm) gauge length. 'No Weld Repair' was peformed.
CI = 26.01Cu+3.88Ni+1.20Cr+1.49Si+17.28P-(7.29Cu*Ni)-(9.10Ni*P)-33.39(Cu*Cu)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B

CE1 = C+(Mn/6)+((Cr+Mo+V)/5)+((Ni+Cu)/15)
CE2 = C+((Mn+Si)/6)+((Cr+Mo+V+Cb)/5)+((Ni+Cu)/15)

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with material specifications, and when designated by the Purchaser, meet applicable specifications.

Bruce A. Work
Metallurgist

Figure A-3. Steel Posts, Test No. MGSMP-1

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" Adpt. 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 A-4. Wood Blockouts, Test No. MGSMP-1

Figure A-5. 16D Double Head Nail, Test No. MGSMP-1

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

MAY 14 2009

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

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

DATE SHIPPED: 05/07/09

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: [signature]
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.

[signature]
Notary Public, State of Ohio

NOTARIAL SEAL STATE OF OHIO

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

Figure A-6. 12-ft 6-in. (3.8-m) Long W-Beam, Test No. MGSMP-1

Certified `\nalysis

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
50	6G	12/6'3/S	M-180	A	2	515691	64,000	72,300	27.0	0.060	0.740	0.009	0.008	0.010	0.021	0.04	0.032	0.000	4
			M-180	A	2	4111321	63,100	80,200	29.0	0.210	0.710	0.009	0.007	0.010	0.030	0.000	0.030	0.000	4
			M-180	A	2	515659	67,000	75,200	26.0	0.064	0.790	0.012	0.008	0.008	0.022	0.000	0.025	0.000	4
			M-180	A	2	515660	66,800	74,300	27.0	0.064	0.740	0.012	0.006	0.009	0.017	0.000	0.025	0.000	4
			M-180	A	2	515662	63,900	72,900	28.0	0.064	0.770	0.010	0.006	0.009	0.016	0.000	0.025	0.000	4
			M-180	A	2	515663	64,900	76,500	21.0	0.064	0.740	0.009	0.007	0.007	0.023	0.000	0.026	0.000	4
			M-180	A	2	515668	66,700	75,500	27.0	0.063	0.770	0.014	0.007	0.010	0.024	0.000	0.030	0.000	4
			M-180	A	2	515668	70,200	80,800	21.0	0.063	0.770	0.014	0.007	0.010	0.024	0.000	0.030	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	515687	63,400	74,100	30.0	0.068	0.750	0.012	0.010	0.008	0.025	0.000	0.060	0.000	4
			M-180	A	2	515687	65,100	74,400	28.0	0.068	0.750	0.012	0.010	0.008	0.025	0.000	0.060	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	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	616068	62,900	71,600	27.0	0.061	0.740	0.013	0.010	0.012	0.027	0.000	0.064	0.000	4
			M-180	A	2	616068	66,700	74,200	30.0	0.061	0.740	0.013	0.010	0.012	0.027	0.000	0.064	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
30	60G	12/25/6'3/S	M-180	A	2	4111321	63,100	80,200	29.0	0.210	0.710	0.009	0.007	0.010	0.030	0.00	0.030	0.000	4
			M-180	A	2	515656	63,600	73,600	27.0	0.066	0.720	0.012	0.006	0.011	0.021	0.000	0.026	0.000	4
			M-180	A	2	515658	64,800	74,300	26.0	0.069	0.740	0.010	0.006	0.011	0.022	0.000	0.021	0.000	4
			M-180	A	2	515659	67,000	75,200	26.0	0.064	0.790	0.012	0.008	0.008	0.022	0.000	0.025	0.000	4
			M-180	A	2	515663	64,900	76,500	21.0	0.064	0.740	0.009	0.007	0.007	0.023	0.000	0.026	0.000	4

1 of 4

Figure A-7. 6-ft 3-in. (1.9-m) Long W-Beam, Test No. MGSMP-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: 1164746
Customer PO: 2563
BOL Number: 69500
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/16/12

State of Ohio, County of Allen. Sworn and subscribed before me this 16th day of May, 2012
Notary Public:
Commission Expires 1/23/2016

STATE OF OHIO
ANGELA COUNTS
NOTARY PUBLIC
ID# 2011NT0014
Commission Expires
January 23, 2016
AUGLAIZE COUNTY

Trinity Highway Products , LLC
Certified By:
Quality Assurance

4 of 4

Figure A-8. 6-ft 3-in. (1.9-m) Long W-Beam, Test No. MGSMP-1

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 cut	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 A-9. BCT Timber Posts, Test No. MGSMP-1

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

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

CWNP Invoice 10050010
Shipped To MidWest - Milford
Customer PO 2881

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Date: 9/15/14

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
19297	9/11/14	#1	5½x7½x6'6" – Post	252	18%	3/20 85%	.664 pcf
19304	9/12/14.	#1	5½x7½x23" Block.	252	16%	1/20 95%	.639 pcf
19304	9/12/14	#1	5½x7½x46" BCT	42	16%	1/20 95%	.639 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

9/15/14
Date

Figure A-10. BCT Timber Posts, Test No. MGSMP-1

Certified Analysis

Trinity Highway Products , LLC
425 E. O'Connor
Lima, OH
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097
Project: STOCK

Order Number: 1108107
Customer PO: 2132
BOL Number: 48341
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/22/09

MIDWEST MACHINERY

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	C49037	64,600	88,600	21.2	0.210	0.880	0.010	0.000	0.030	0.080	0.000	0.060	0.010	4
25	736G	5'/TUBE SL/.188"X6"X8"FLA	A-500			Y85912	56,500	72,980	37.0	0.210	0.770	0.009	0.006	0.016	0.010	0.00	0.020	0.001	4
6	742G	6'0 TUBE SL/.188X8X6	A-500			Y85912	56,500	72,980	37.0	0.210	0.770	0.009	0.006	0.016	0.010	0.00	0.020	0.001	4
26	764G	1/4"X24"X24"SOIL PLATE	A-36			I20039	46,660	73,630	26.9	0.190	0.520	0.012	0.003	0.020	0.090	0.00	0.040	0.000	4
12	923G	BRONSTAD 98" W/O	M-180	A	2	I22209	63,590	82,010	26.6	0.190	0.730	0.015	0.004	0.020	0.110	0.00	0.040	0.000	4
4	927G	10/END SHOE/EXT	M-180	B	2	A814375	59,770	78,641	27.4	0.210	0.750	0.017	0.005	0.030	0.090	0.00	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 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.
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

State of Ohio, County of Allen. Sworn and subscribed before me this 22nd day of May, 2009
Notary Public: [signature]
Commission Expires 11 28 2012

Trinity Highway Products , LLC
Certified By: [signature]
Quality Assurance

4 of 7

06/04/2009 16:35 402-751-3288

Figure A-11. Foundation Tubes, Test No. MGSMP-1

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

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 OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
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.
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

State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public: [signature]
Commission Expires [handwritten date]

Trinity Highway Products, LLC
Certified By: [signature]

2 of 4

05/04/2009 16:36 402-761-3288

Figure A-12. Strut and Yoke Assembly, 10-in. Long Hex Bolt, Test No. MGSMP-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: 1207548   Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 2822
BOL Number: 78777   Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 10/29/13

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 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
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.
X 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 – 46000 LB

State of Ohio, County of Allen. Sworn and subscribed before me this 29th day of October, 2013

Notary Public: Angela Counts
Commission Expires: 1/23/2016

STATE OF OHIO ★ ANGELA COUNTS ★ NOTARY PUBLIC ID# 2011NT0014 Commission Expires January 22, 2016 AUGLAIZE COUNTY

Trinity Highway Products, LLC
Certified By: [signature]
Quality Assurance

Figure A-13. BCT Cable Anchor Assembly, Test No. MGSMP-1

Certified Analysis

Trinity Highway Products, LLC
2548 N.E. 28th St.
Ft Worth, TX
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Project: RESALE

Order Number: 1095199
Customer PO: 2041
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/6'3/S	M-180	A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	6'0 TUBE SL/.188X8X6	A-500			A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.180	0.830	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	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 OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
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.

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

State of Texas, County of Tarrant. Sworn and subscribed before me this 20th day of June, 2008

Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products, LLC
Certified By: Stefanie Ond.s

Figure A-14. Anchor Bracket Assembly, Test No. MGSMP-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: 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 A-15. Anchor Bearing Plate, Test No. MGSMP-1

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	0.088	0.039	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

1044158

Figure A-16. BCT Post Sleeve, Test No. MGSMP-1

CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 159892

SHIPPER#: 050883

INVOICE #: DATE SHIPPED: 01/13/14

LOT#: 25512

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 78,318
78,539
78,075
78,380

HARDNESS: 100 max 86.80
86.76
86.00
90.10

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si	Cu	Ni	Cr	Mo
NUCOR	1010	NF13102751	13	.60	.009	.026	.18				

QUANTITY AND DESCRIPTION:

9,100 PCS 5/8" X 14" GUARD RAIL BOLT
P/N 3540G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENT PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS 14 DAY OF January 2014
Diana Rasmussen

Deuda Melomas
APPROVED SIGNATORY

1/14/14
DATE

OFFICIAL SEAL
DIANA RASMUSSEN
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/15/14

Figure A-17. ⅝-in. (16-mm) Dia. UNC, 14-in. (356-mm) Long Guardrail Bolt and Nut, Test No. MGSMP-1

3366G

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

FAXED & CERTIFIED
MAY 12 2014
Trinity Highway Products, LLC

MATERIAL CERTIFICATION

Customer: Stock

Date: May 7,2014

Invoice Number:

Lot Number: 140314B

Part Number: 3360G

Quantity: 119,129 Pcs.

Description: 5/8" x 1 1/4" GR BOLT

Heat Numbers:	
20289510	71,711
20294010	47,418

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20289510	.09	.34	.007	.004	.05	.03	.06	.01	.08	.007	.001	.030	.007	.0002	.001	.001
20294010	.09	.34	.008	.003	.07	.03	.04	.02	.09	.004	.001	.029	.3008	.0002	.001	.001

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.43 (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 12th day of May 2014

NOTARIAL SEAL STATE OF OHIO
SHERRI BRAUN
Notary Public, State of Ohio
My Commission Expires
April 20, 2019

NOTARY PUBLIC

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

Figure A-18. ⅝-in. (16-mm) Dia. UNC, 1¼-in. (32-mm) Guardrail Bolt and Nut, Test No. MGSMP-1

35006

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

MATERIAL CERTIFICATION

Customer: Stock

Date: August 16, 2013

Invoice Number:

Lot Number: 130809L

Part Number: 3500G

Quantity: 16,233 Pcs.

Description: 5/8" x 10" G.R. Bolt

Heat Numbers: 10240100 10,820; 10231650 5,413

PASSED & CERTIFIED
AUG 20 2013
Trinity Highway Products, LLC
Dallas, Texas Plant 99

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
10240100	.09	.49	.01	.007	.09	.04	.09	.02	.08	.008	.002	.023	.005	.0001	.001	.001
10231650	.09	.49	.008	.011	.09	.05	.08	.02	.09	.006	.002	.023	.007	.0001	.001	.001

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.51 (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 19th day of Aug 2013

Sheri Braun NOTARY PUBLIC

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

STATE OF OHIO NOTARY PUBLIC ID# 2009NT0139 Commission Expires April 20, 2014 ALLEN COUNTY

Figure A-19. ⅝-in. (16-mm) Dia. UNC, 10-in. (254-mm) Long Guardrail Bolt and Nut, Test No. MGSMP-1

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.® Date: May 24,2012
1150 Katy Fort-Bend Road
Katy, Texas 77494
Ph: 281-391-2196 Fax: 281-391-2673
shirley@k-tbolt.com

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:	70.560
Proof/Yield:	52.360
Elongation:	27.5
ROA:	-
Hardness:	149 HBN

Comments

Test results meet mechanical requirements of specification.

Figure A-20. ⅝-in. (16-mm) Dia. UNC, 10-in. (254-mm) Long Hex Head Bolt and Nut, Test No. MGSMP-1

Figure A-21. ⅞-in. (22-mm) Dia. UNC, 8-in. (203-mm) Long Hex Head Bolt and Nut, Test No. MGSMP-1

Figure A-22. ⅞-in. (22-mm) Dia. Plain Round Washer, Test No. MGSMP-1

Appendix B. Vehicle Center of Gravity Determination

Test: MGSMP-1 Vehicle: Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vert CG (in.)	Vert M (lb-in.)
+	Unbalasted Truck (Curb)	5057	28.90226	146158.8
+	Brake Receivers/Wires	6	53	318
+	Brake Frame	7	26.5	185.5
+	Brake Cylinder (Nitrogen)	22	27	594
+	Strobe/Brake Battery	5	32	160
+	Hub	26	15	390
+	CG Plate (EDRs)	8	32.75	262
-	Battery	-43	42	-1806
-	Oil	-9	22	-198
-	Interior	-83	28	-2324
-	Fuel	-153	21	-3213
-	Coolant	-14	36	-504
-	Washer Fluid	-8	34	-272
BALLAST	Water	102	18	1836
	Supplemental Battery	8	27	216
	Misc.			0
				141803.3

Estimated Total Weight (lb)	4931
Vertical CG Location (in.)	28.7575

wheel base (in.) 140.25

MASH Targets	Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	4934	-66.0
Long CG (in.)	63 ± 4	60.97	-2.02792
Lat CG (in.)	NA	-0.75313	NA
Vert CG (in.)	28 or greater	28.76	0.75750

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

CURB WEIGHT (lb)

	Left	Right
Front	1467	1404
Rear	1111	1075

FRONT	2871 lb
REAR	2186 lb
TOTAL	5057 lb

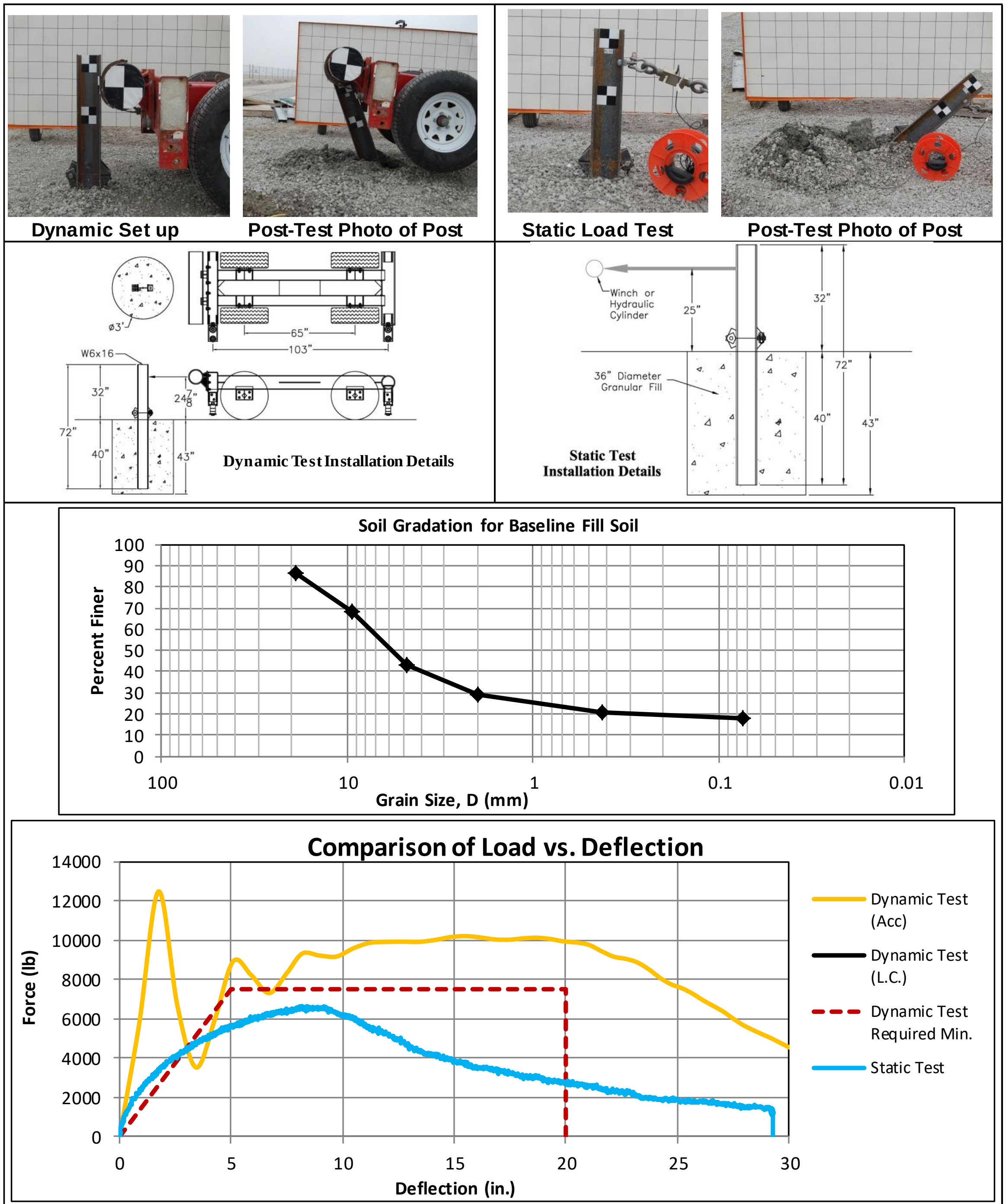
TEST INERTIAL WEIGHT (lb)
(from scales)

	Left	Right
Front	1437	1352
Rear	1085	1060

FRONT	2789 lb
REAR	2145 lb
TOTAL	4934 lb

Figure B-1. Vehicle Mass Distribution, Test No. MGSMP-1

Appendix C. Static Soil Tests

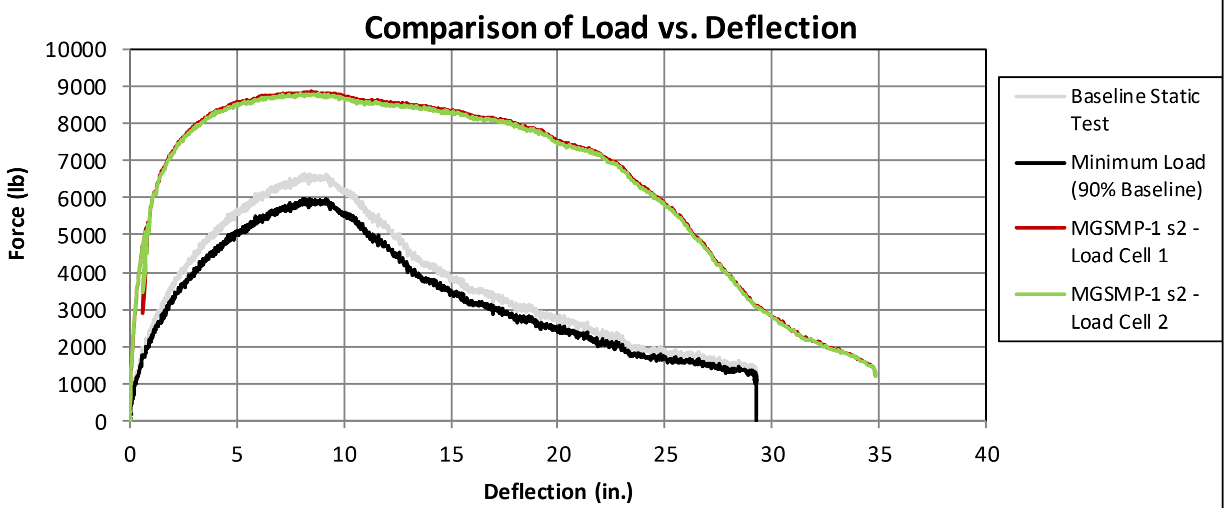


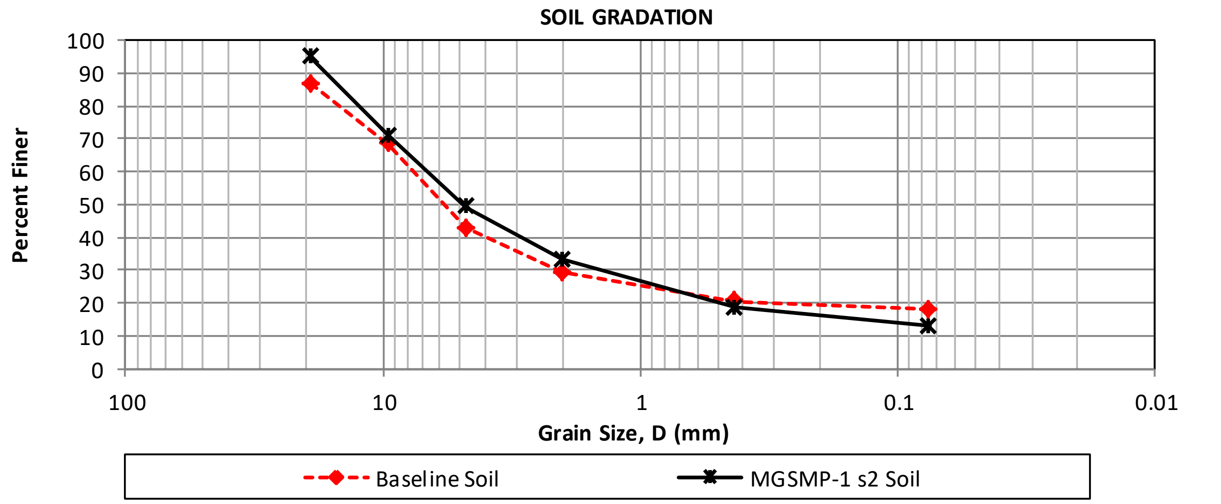
Date..	4/4/2012
Test Facility & Site Location.....................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)..........	Well Graded Gravel (GW)
Fill material description (ASTM D2487)......	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.....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

Figure C-1. Soil Strength, Initial Calibration Tests

Static Load Test Setup

Post-Test Photo of Post





Date..	4/29/2015
Test Facility & Site Location.....................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487).........	Well Graded Gravel (GW)
Fill material description (ASTM D2487)......	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.....	8-inch lifts tamped with a pneumatic compactor

Figure C-2. Static Soil Test S2, Test No. MGSMP-1

Appendix D. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSMP-1
VEHICLE: Dodge Ram 1500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	27.416	-13.031	-0.919	27.372	-13.109	-0.820	-0.044	-0.078	0.099
2	28.872	-17.567	-4.079	28.874	-17.626	-3.957	0.002	-0.059	0.122
3	30.529	-22.753	-5.277	30.508	-22.780	-5.173	-0.021	-0.027	0.104
4	28.648	-28.194	-3.650	28.501	-28.004	-3.429	-0.147	0.189	0.221
5	24.543	-11.462	-1.110	24.392	-11.491	-1.016	-0.151	-0.030	0.094
6	24.719	-15.852	-3.701	24.670	-15.841	-3.582	-0.049	0.012	0.119
7	24.884	-20.837	-7.366	24.865	-20.866	-7.298	-0.019	-0.028	0.067
8	25.486	-28.186	-6.919	25.366	-28.151	-6.897	-0.120	0.035	0.022
9	20.983	-10.268	-1.664	20.936	-10.309	-1.602	-0.047	-0.041	0.063
10	21.306	-15.228	-4.529	21.241	-15.202	-4.463	-0.065	0.026	0.066
11	21.477	-20.046	-8.249	21.476	-20.027	-8.201	-0.001	0.020	0.048
12	21.343	-28.033	-8.239	21.367	-28.057	-8.187	0.024	-0.024	0.052
13	17.206	-11.019	-3.633	17.198	-10.994	-3.619	-0.008	0.025	0.014
14	17.410	-14.227	-5.876	17.414	-14.191	-5.854	0.004	0.036	0.022
15	17.369	-19.447	-9.101	17.400	-19.468	-9.073	0.031	-0.020	0.029
16	17.384	-29.188	-9.157	17.372	-29.206	-9.145	-0.012	-0.018	0.013
17	13.176	-5.590	-1.212	13.190	-5.575	-1.198	0.014	0.014	0.014
18	13.753	-12.760	-7.563	13.756	-12.831	-7.632	0.003	-0.071	-0.069
19	13.888	-19.373	-8.208	13.956	-19.393	-8.204	0.068	-0.021	0.004
20	13.752	-29.374	-8.282	13.757	-29.334	-8.268	0.005	0.040	0.014
21	7.217	-4.761	-0.412	7.212	-4.757	-0.423	-0.005	0.004	-0.011
22	8.195	-12.314	-6.699	8.166	-12.290	-6.707	-0.029	0.023	-0.007
23	8.259	-19.792	-6.707	8.278	-19.779	-6.723	0.019	0.013	-0.017
24	8.480	-29.716	-6.906	8.515	-29.704	-6.911	0.035	0.012	-0.006
25	1.452	-6.599	1.579	1.459	-6.588	1.564	0.007	0.012	-0.015
26	0.244	-12.216	-0.805	0.224	-12.198	-0.845	-0.021	0.018	-0.040
27	0.137	-18.278	-0.784	0.161	-18.280	-0.829	0.024	-0.002	-0.045
28	0.082	-27.328	-0.829	0.065	-27.292	-0.832	-0.017	0.035	-0.004

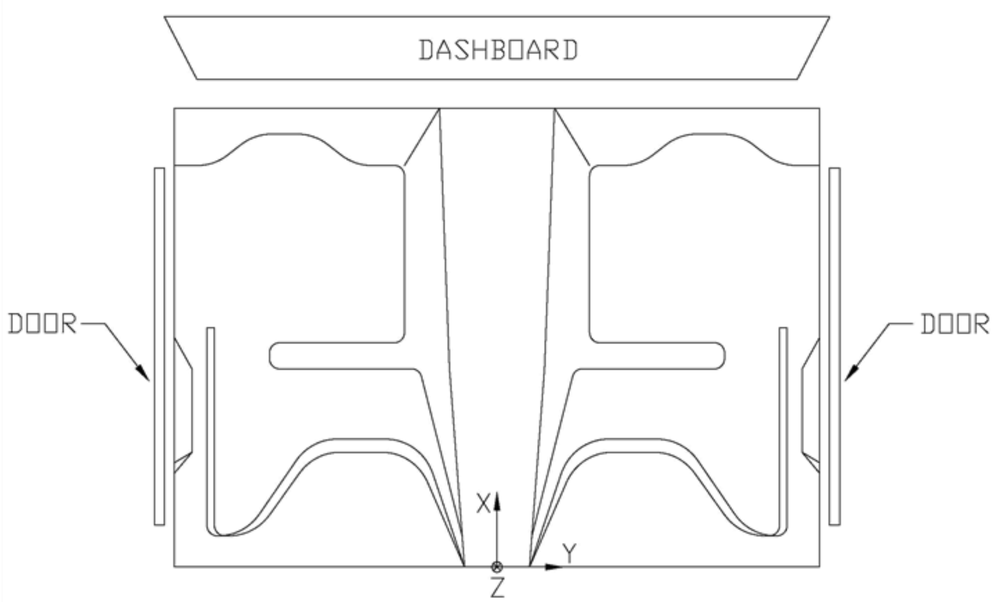


Figure D-1. Floorpan Deformation Data – Set 1, Test No. MGSMP-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MGSMP-1
VEHICLE: Dodge Ram 1500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	43.081	-19.597	3.909	43.022	-20.125	2.100	-0.059	-0.528	-1.810
2	45.397	-23.991	0.988	45.355	-23.937	-1.247	-0.042	0.054	-2.236
3	47.362	-29.144	0.056	47.389	-28.863	-2.938	0.027	0.281	-2.994
4	45.161	-34.596	0.792	45.036	-34.310	-2.916	-0.125	0.286	-3.708
5	40.361	-17.981	3.048	40.261	-18.364	1.402	-0.100	-0.383	-1.646
6	41.258	-22.256	0.342	41.236	-22.110	-1.763	-0.022	0.146	-2.105
7	42.414	-26.988	-3.426	42.598	-26.360	-6.187	0.184	0.628	-2.761
8	42.962	-34.441	-3.232	43.042	-33.689	-7.059	0.080	0.752	-3.827
9	37.067	-16.774	1.593	37.040	-16.925	0.088	-0.027	-0.151	-1.505
10	38.175	-21.539	-1.329	38.222	-21.219	-3.477	0.047	0.320	-2.148
11	39.408	-26.148	-5.137	39.583	-25.259	-7.852	0.176	0.889	-2.715
12	39.401	-34.196	-5.578	39.594	-33.103	-9.409	0.192	1.093	-3.831
13	33.964	-17.398	-1.371	34.035	-17.075	-3.025	0.071	0.323	-1.655
14	34.795	-20.464	-3.634	34.931	-19.805	-5.675	0.136	0.659	-2.041
15	35.703	-25.531	-7.030	35.915	-24.292	-9.703	0.212	1.239	-2.672
16	35.781	-35.220	-7.623	36.008	-33.875	-11.683	0.227	1.345	-4.059
17	29.371	-12.070	0.170	29.380	-12.055	-0.854	0.009	0.014	-1.024
18	31.711	-18.897	-6.178	31.915	-17.947	-8.086	0.204	0.950	-1.908
19	32.106	-25.484	-7.114	32.328	-24.279	-9.869	0.222	1.205	-2.755
20	32.078	-35.435	-7.764	32.362	-34.058	-11.904	0.284	1.377	-4.141
21	23.421	-11.275	-0.633	23.457	-11.137	-1.656	0.035	0.138	-1.023
22	26.071	-18.446	-6.832	26.313	-17.434	-8.741	0.242	1.012	-1.909
23	26.222	-25.968	-7.225	26.484	-24.713	-10.162	0.261	1.255	-2.937
24	26.623	-35.791	-7.887	26.910	-34.459	-12.192	0.288	1.332	-4.305
25	17.273	-13.155	-0.373	17.356	-13.054	-1.770	0.083	0.101	-1.398
26	16.796	-18.679	-3.297	16.947	-18.075	-5.470	0.151	0.604	-2.173
27	16.795	-24.774	-3.641	16.967	-24.020	-6.636	0.172	0.754	-2.995
28	16.835	-33.716	-4.173	17.058	-32.888	-8.416	0.223	0.828	-4.243

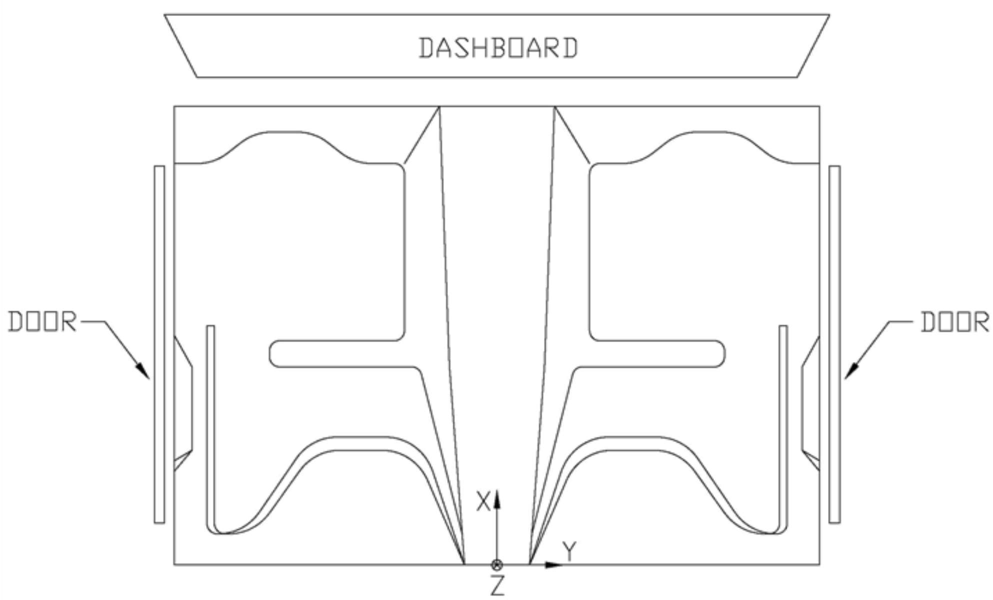


Figure D-2. Floorpan Deformation Data – Set 2, Test No. MGSMP-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MGSMP-1
VEHICLE: Dodge Ram 1500

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH (A1-A6)	1	19.460	0.924	25.407	19.353	0.926	25.483	-0.107	0.001	0.077
	2	20.473	-9.673	23.651	20.356	-9.679	23.726	-0.117	-0.006	0.075
	3	20.283	-31.783	21.882	20.078	-31.750	21.932	-0.205	0.033	0.050
	4	15.410	1.193	18.102	15.347	1.168	18.177	-0.063	-0.026	0.075
	5	15.159	-10.487	15.721	15.061	-10.511	15.713	-0.098	-0.025	-0.007
	6	15.563	-31.128	15.617	15.456	-31.133	15.710	-0.107	-0.006	0.093
SIDE PANEL (B1-B3)	7	20.462	-32.456	-0.003	20.412	-32.213	0.072	-0.050	0.243	0.075
	8	19.324	-32.430	-5.127	19.258	-32.284	-5.096	-0.066	0.146	0.031
	9	24.788	-32.481	-2.791	24.766	-32.365	-2.641	-0.022	0.116	0.149
IMPACT SIDE DOOR (C1-C6)	10	15.823	-34.731	18.594	15.358	-34.633	18.777	-0.466	0.098	0.182
	11	4.075	-34.618	21.989	3.638	-34.684	22.188	-0.437	-0.067	0.199
	12	-8.302	-34.392	25.649	-8.783	-34.631	25.727	-0.482	-0.239	0.078
	13	15.304	-34.722	-3.019	14.852	-34.381	-2.835	-0.452	0.341	0.184
	14	1.159	-33.958	1.395	0.769	-33.741	1.573	-0.390	0.218	0.178
	15	-12.234	-34.156	6.491	-12.687	-34.183	6.693	-0.453	-0.027	0.202
ROOF (D1-D15)										

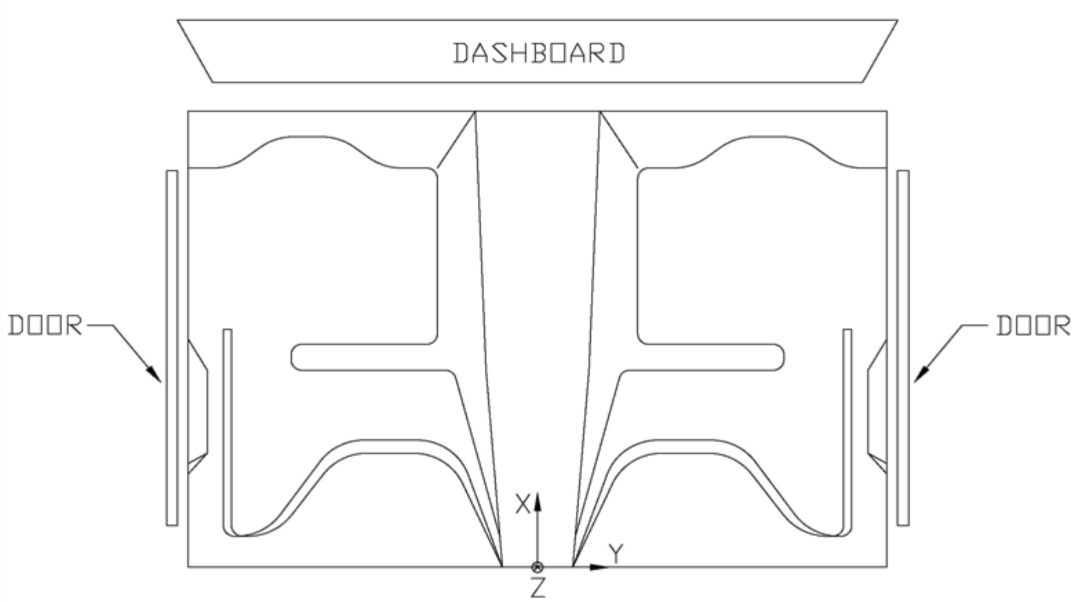


Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. MGSMP-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MGSMP-1
VEHICLE: Dodge Ram 1500

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH (A1-A6)	1	28.196	-7.093	27.848	27.587	-10.959	27.233	-0.609	-3.866	-0.614
	2	29.735	-17.568	25.839	29.212	-21.122	23.816	-0.523	-3.554	-2.024
	3	30.223	-39.515	22.855	29.750	-42.392	17.758	-0.473	-2.876	-5.097
	4	26.233	-6.409	19.726	25.831	-9.289	19.307	-0.402	-2.880	-0.419
	5	26.750	-17.916	16.651	26.435	-20.151	14.608	-0.315	-2.234	-2.043
	6	27.376	-38.465	15.593	27.104	-40.386	10.733	-0.272	-1.922	-4.860
SIDE PANEL (B1-B3)	7	36.358	-39.017	1.856	36.357	-38.722	-2.742	-0.001	0.295	-4.598
	8	36.604	-38.703	-3.389	36.767	-37.772	-7.926	0.164	0.931	-4.537
	9	41.243	-38.910	0.346	41.334	-38.521	-4.206	0.091	0.389	-4.552
IMPACT SIDE DOOR (C1-C6)	10	26.858	-42.280	18.307	26.157	-44.432	12.948	-0.701	-2.151	-5.359
	11	14.648	-42.291	18.500	13.905	-44.630	12.805	-0.743	-2.339	-5.695
	12	1.782	-42.211	18.633	1.071	-44.724	12.649	-0.711	-2.512	-5.983
	13	32.191	-41.096	-2.449	31.924	-40.070	-7.452	-0.268	1.026	-5.003
	14	17.414	-40.495	-2.166	17.110	-39.683	-7.199	-0.304	0.812	-5.033
	15	3.143	-40.913	-0.899	2.782	-40.520	-6.279	-0.361	0.393	-5.380
ROOF (D1-D15)										

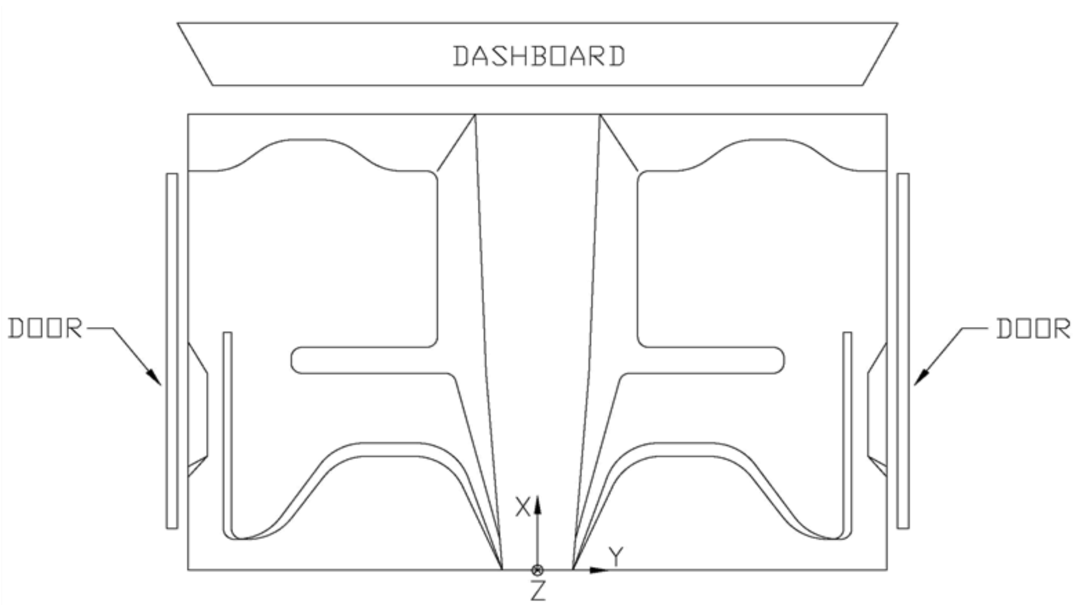
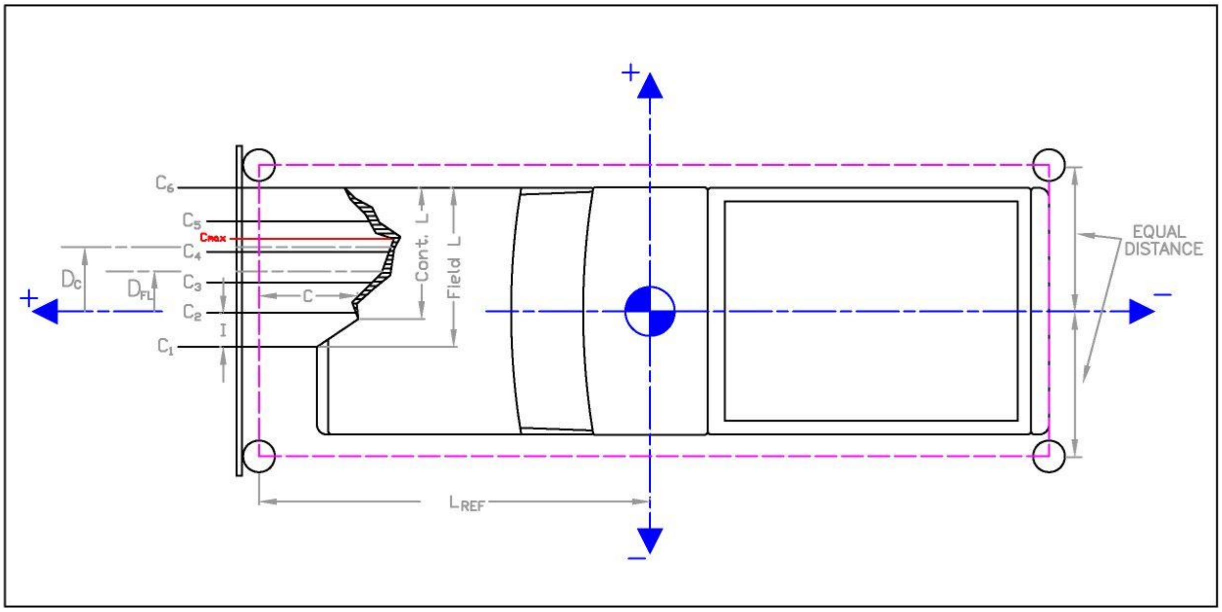


Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. MGSMP-1

Date:	**4/30/2015**	**Test Number:**	**MGSMP-1**		
Make:	**Dodge**	**Model:**	**Ram 1500**	**Year:**	**2008**



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	**101 3/4**	**(2584)**
Total Vehicle Width:	**78**	**(1981)**
Width of contact and induced crush - Field L:	**19 1/2**	**(495)**
Crush measurement spacing interval (L/5) - I:	**3.9**	**(99)**
Distance from center of vehicle to center of Field L - D_{FL}:	**29.25**	**(743)**
Width of Contact Damage:	**19 1/2**	**(495)**
Distance from center of vehicle to center of contact damage - D_C:	**29 1/4**	**(743)**

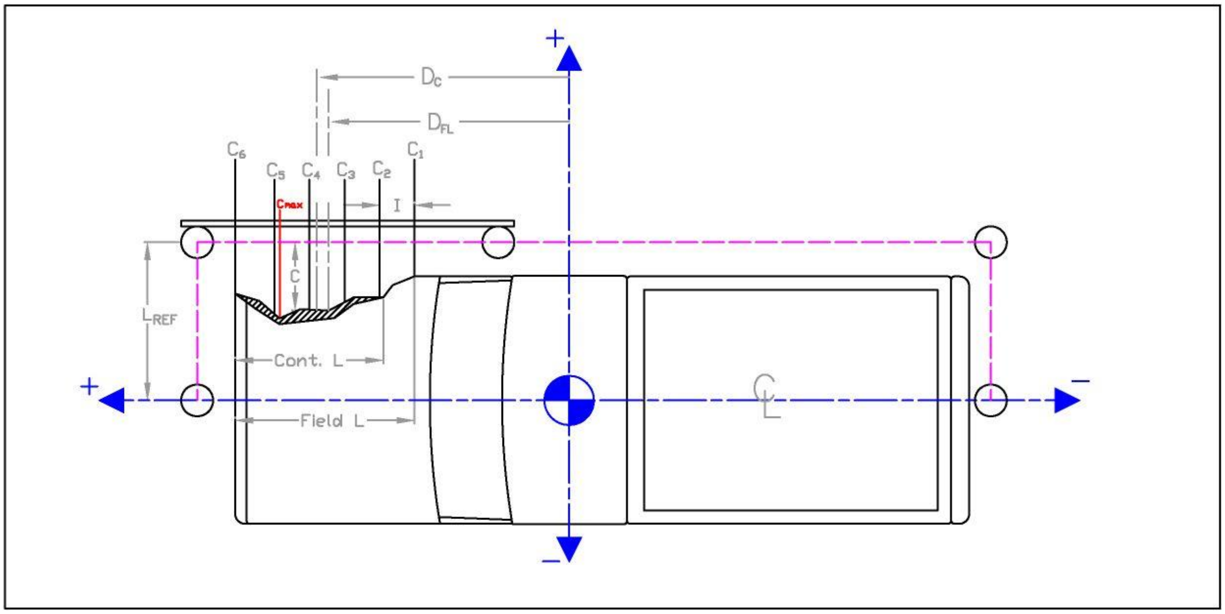
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurments are filled out.

	Crush Measurement		**Lateral Location**		**Original Profile Measurement**		**Dist. Between Ref. Lines**		**Actual**	**Crush**
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	**3 1/2**	**(89)**	**19 1/2**	**(495)**	**12 2/5**	**(315)**	**-9**	**-(228)**	**0**	**(2)**
C_2	**5 1/2**	**(140)**	**23 2/5**	**(594)**	**13 2/5**	**(340)**			**1**	**(27)**
C_3	**9 1/4**	**(235)**	**27 2/7**	**(693)**	**15**	**(380)**			**3 1/4**	**(83)**
C_4	**21 1/4**	**(540)**	**31 1/5**	**(792)**	**16 4/5**	**(427)**			**13 2/5**	**(341)**
C_5	**NA**	**NA**	**35**	**(892)**	**20 5/8**	**(524)**			**NA**	**NA**
C_6	**NA**	**NA**	**39**	**(991)**	**29**	**(737)**			**NA**	**NA**
C_{MAX}	**21 1/4**	**(540)**	**30**	**(762)**	**16 1/8**	**(410)**			**14**	**(358)**

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

Date: 4/30/2015 **Test Number:** MGSMP-1

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



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	43	(1092)
Total Vehicle Length:	228	(5791)
Width of contact and induced crush - Field L:	228	(5791)
Crush measurement spacing interval (L/5) - I:	45.6	(1158)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-12 1/2	-(318)
Width of Contact Damage:	228	(5791)
Distance from vehicle c.g. to center of contact damage - D_C:	-12 1/2	-(318)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	8 7/8	(225)	-126 1/2	-(3214)	16	(406)	-7	-(178)	- 1/8	-(3)
C_2	5	(127)	-81	-(2056)	10 1/2	(267)			1 1/2	(38)
C_3	4 1/2	(114)	-35 1/3	-(897)	11 5/8	(295)			- 1/8	-(3)
C_4	4 3/4	(121)	10 1/4	(261)	11 1/4	(286)			1/2	(13)
C_5	NA	NA	55 7/8	(1419)	10 1/2	(267)			NA	NA
C_6	NA	NA	101 1/2	(2577)	37	(940)			NA	NA
C_{MAX}	16 1/4	(413)	82	(2083)	11 4/7	(294)			11 2/3	(297)

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

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

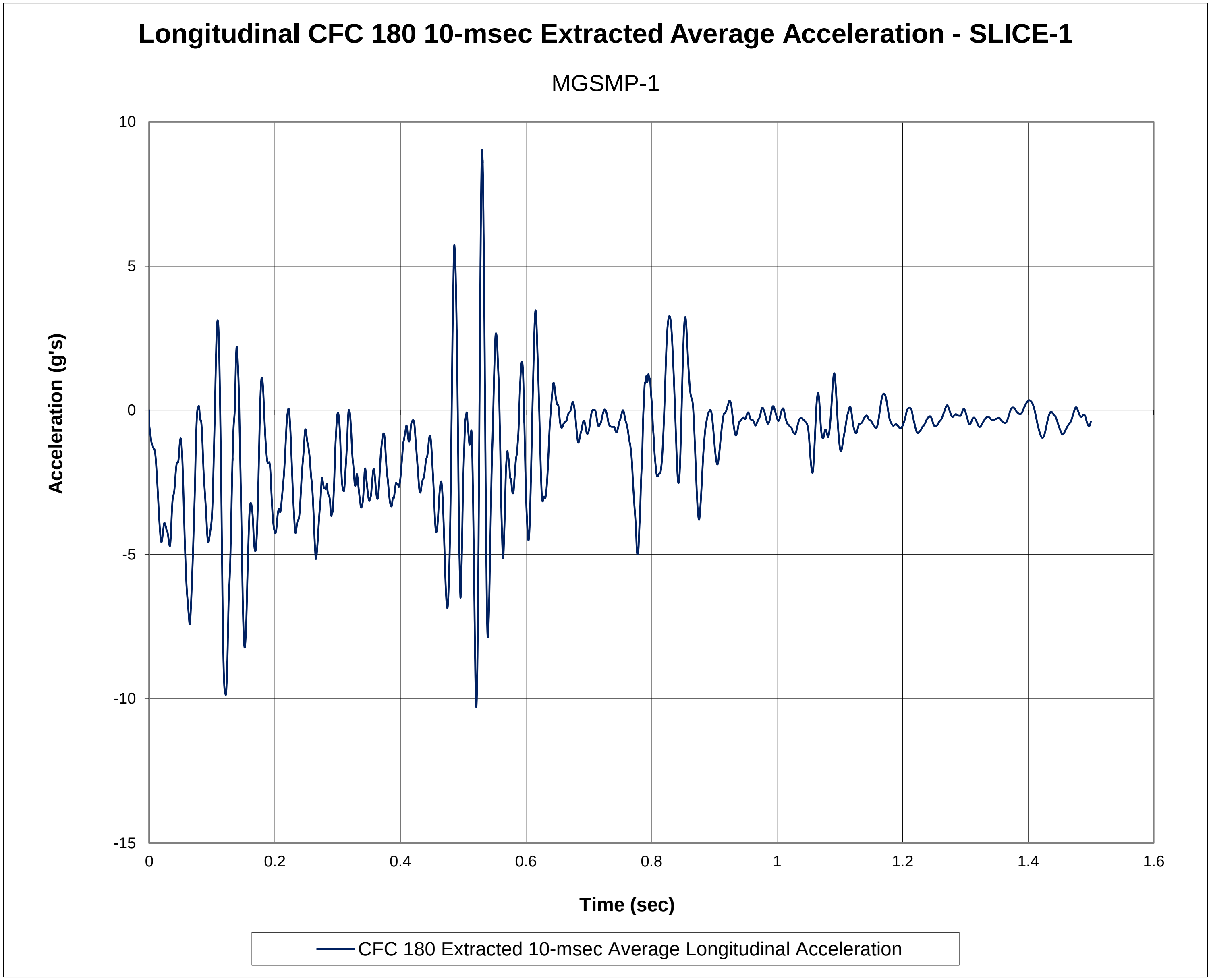


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSMP-1

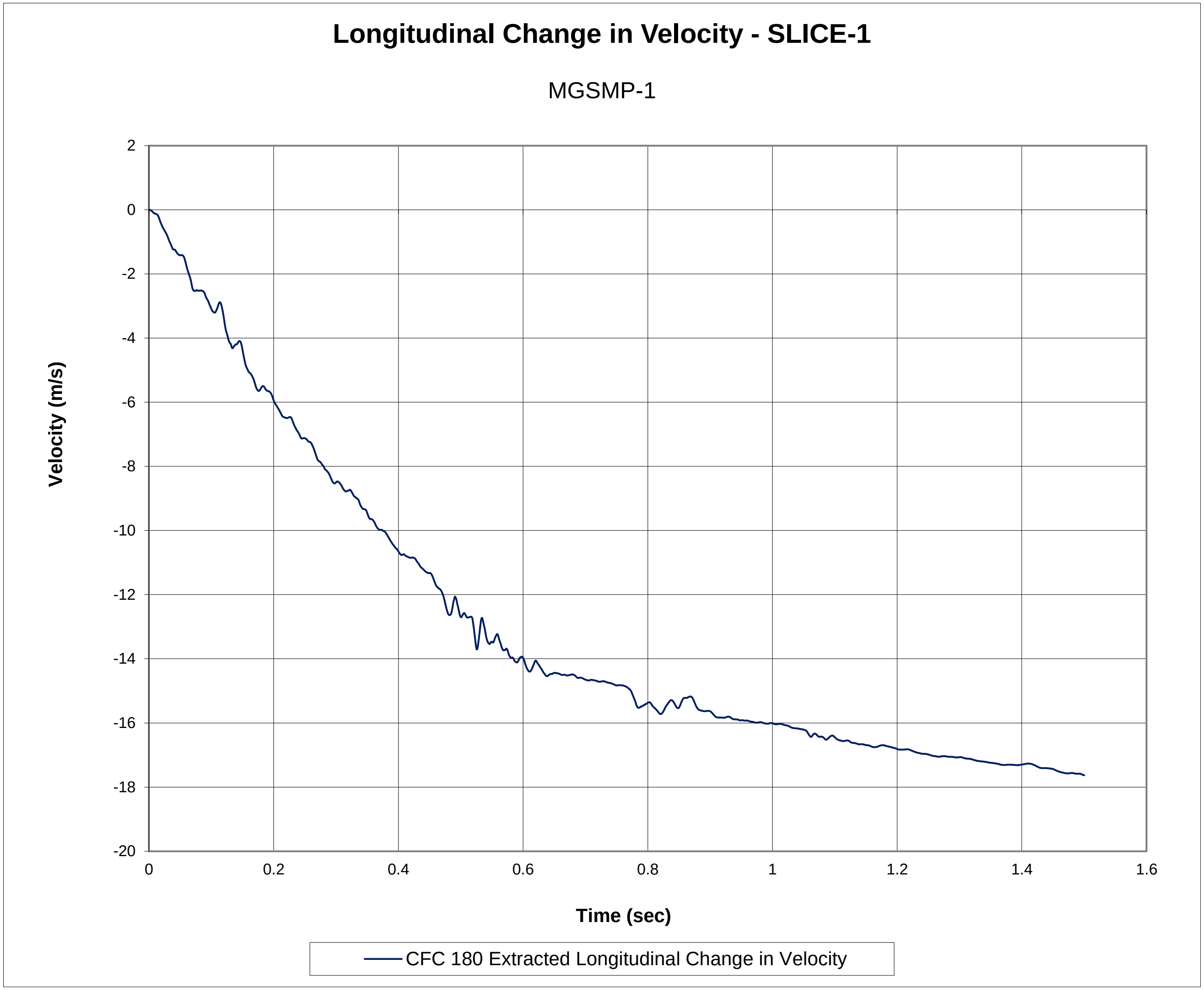


Figure E-2. Longitudinal Change in Velocity (SLICE-1), Test No. MGSMP-1

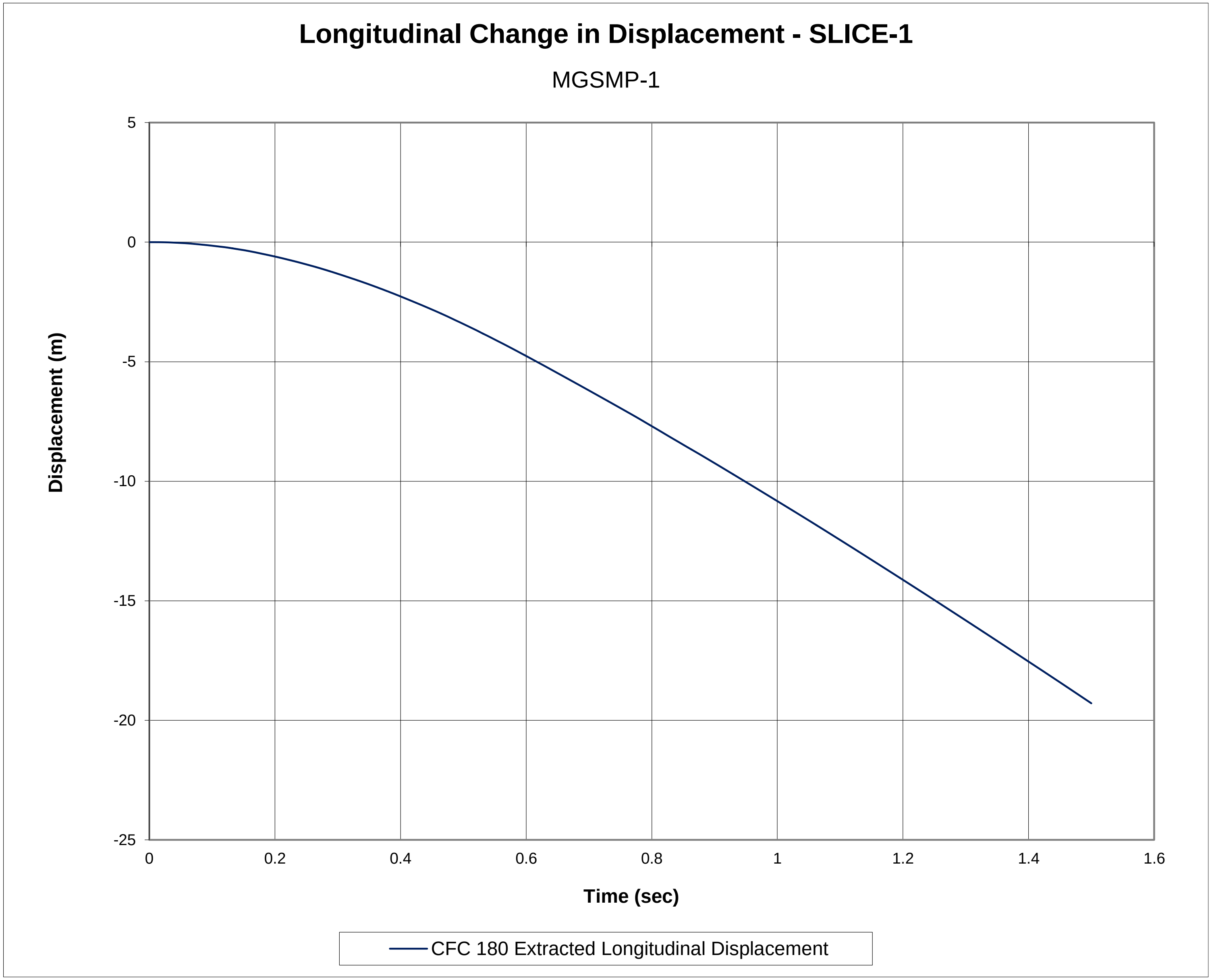


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSMP-1

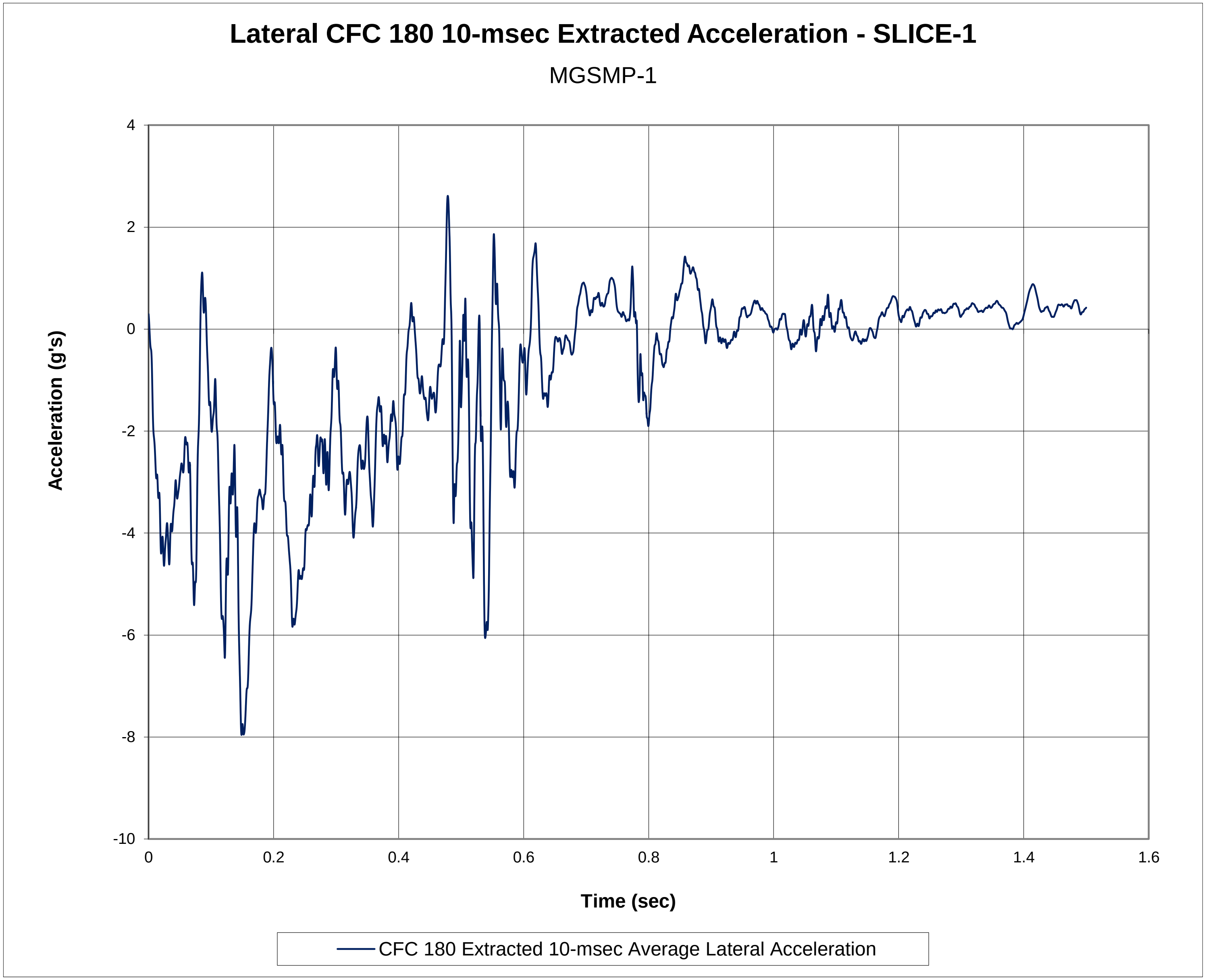


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSMP-1

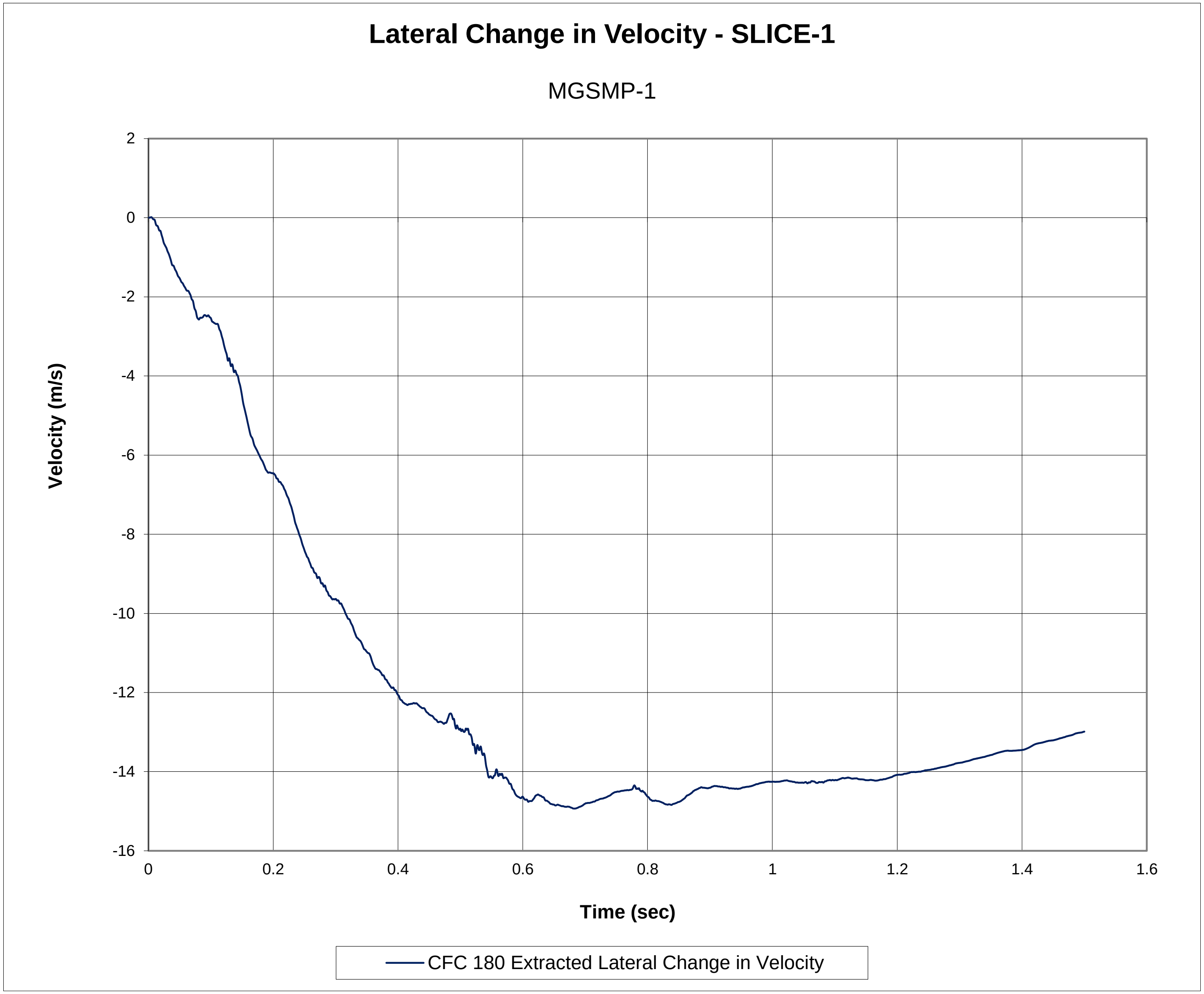


Figure E-5. Lateral Change in Velocity (SLICE-1), Test No. MGSMP-1

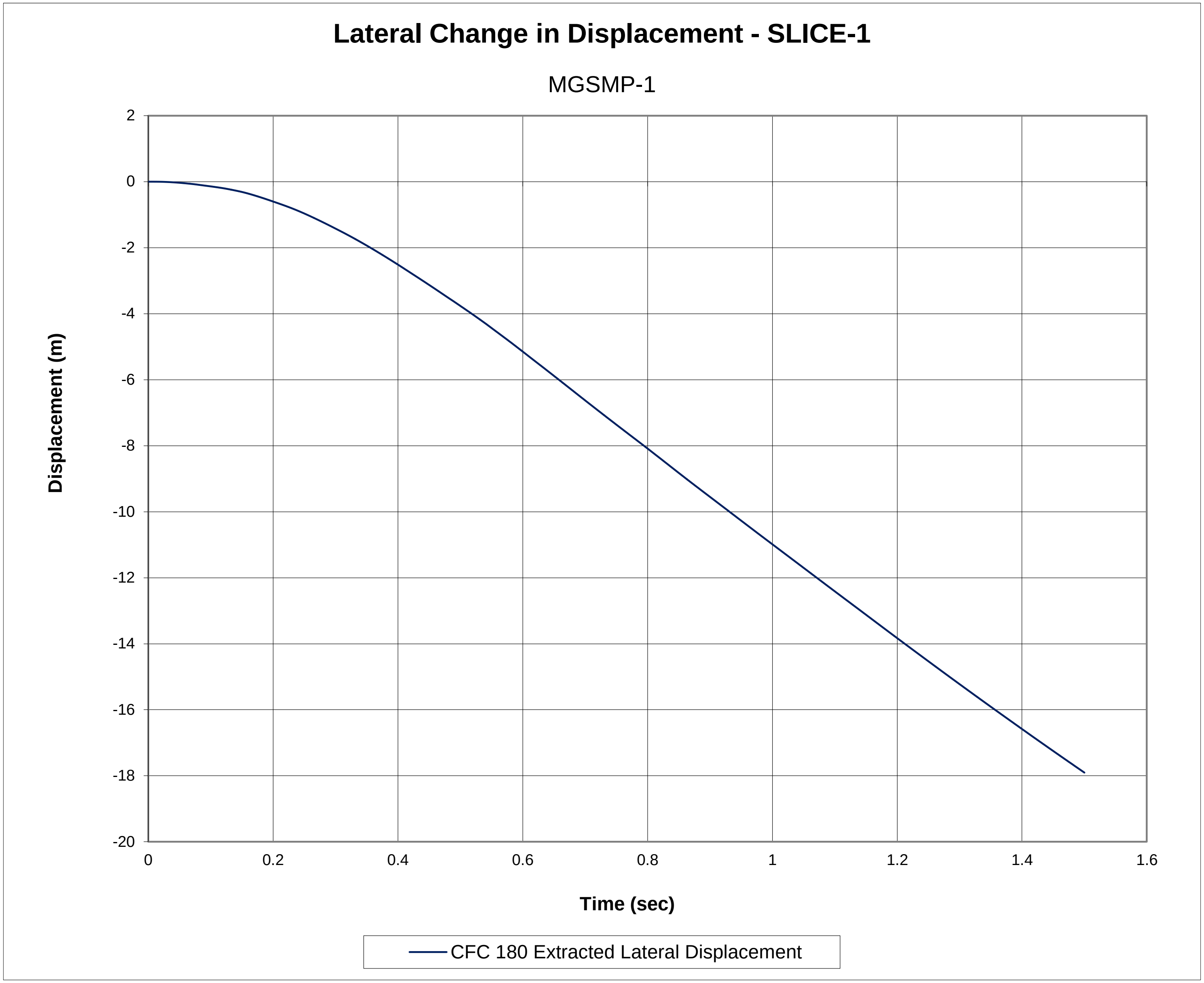


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. MGSMP-1

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

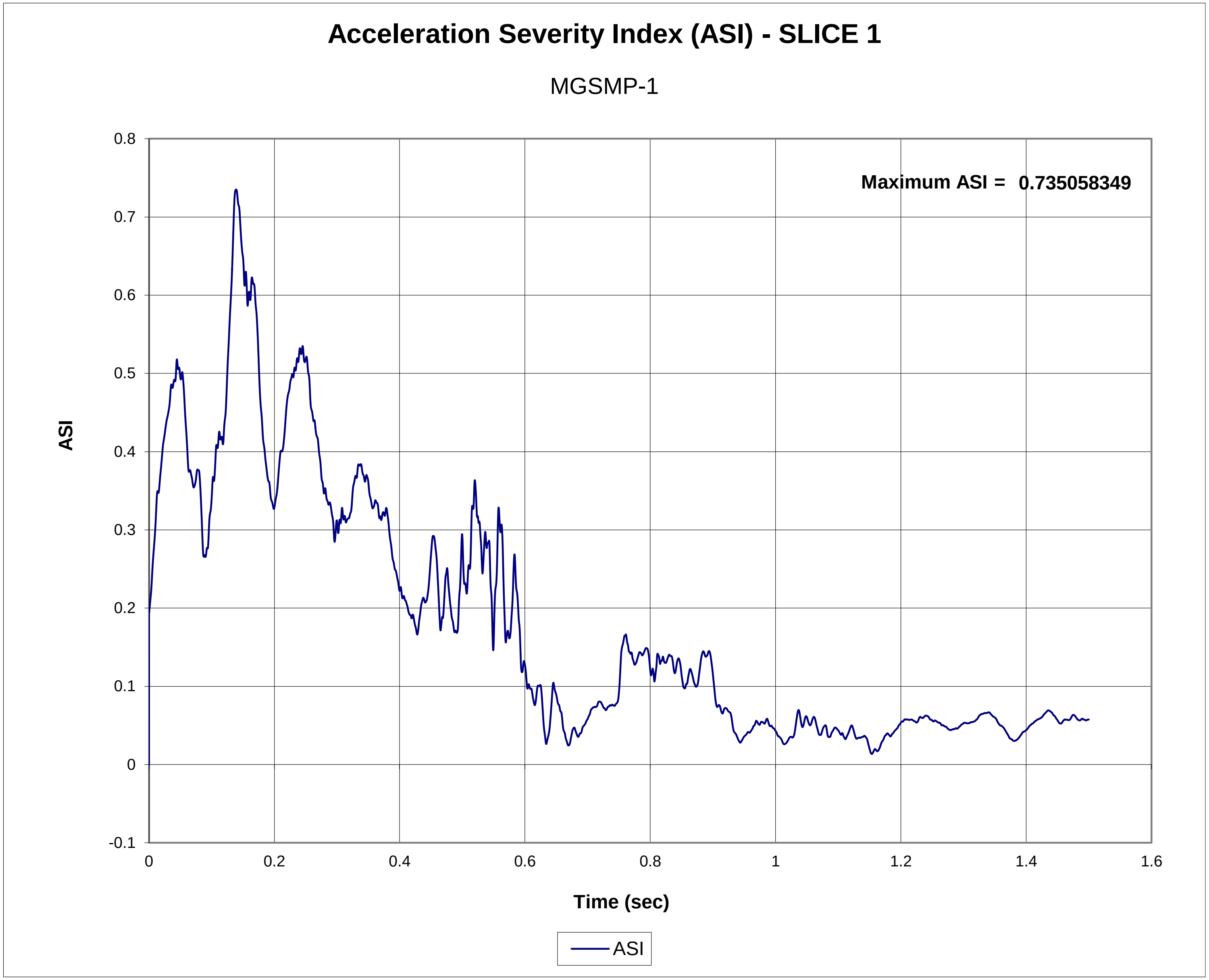


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. MGSMP-1

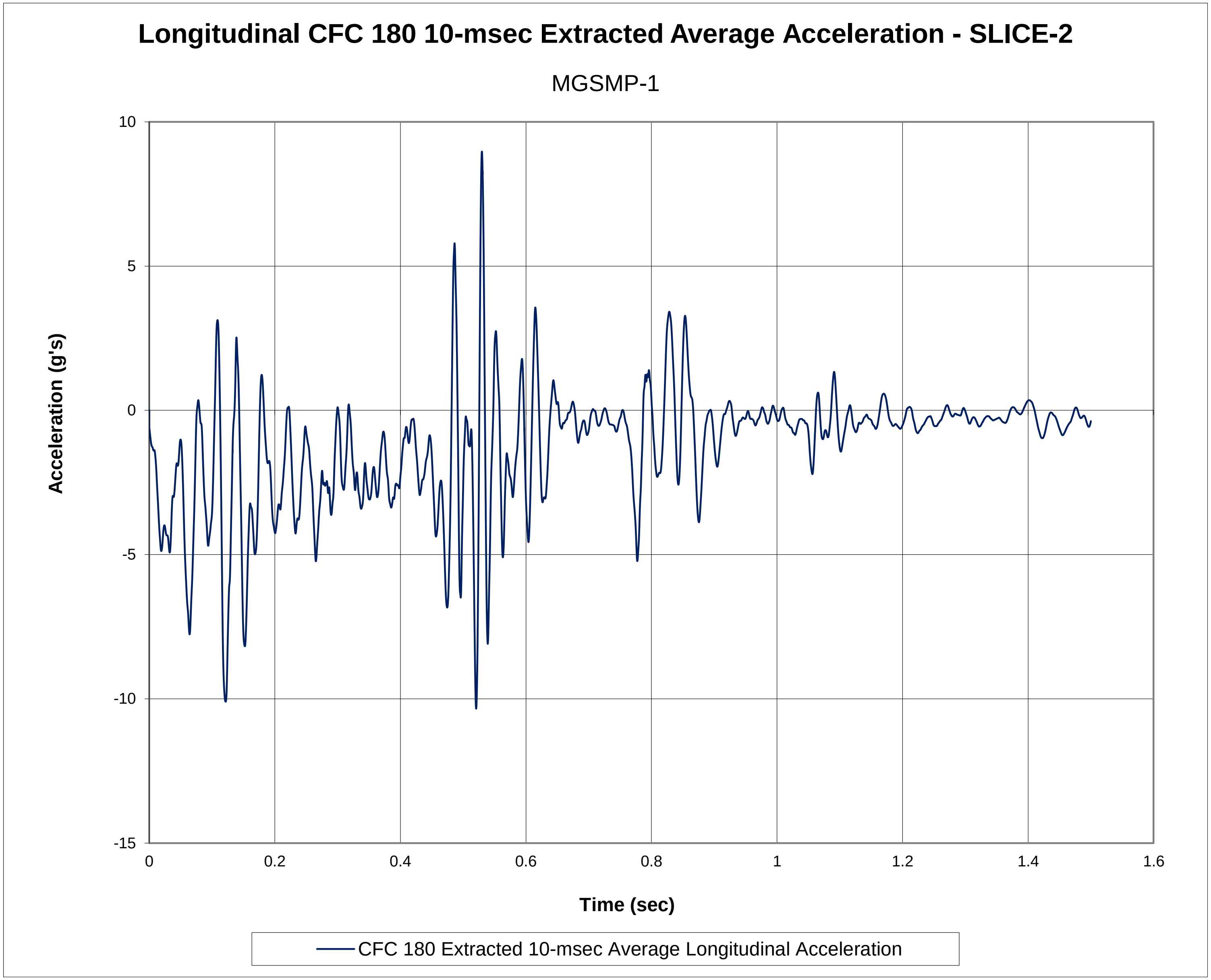


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSMP-1

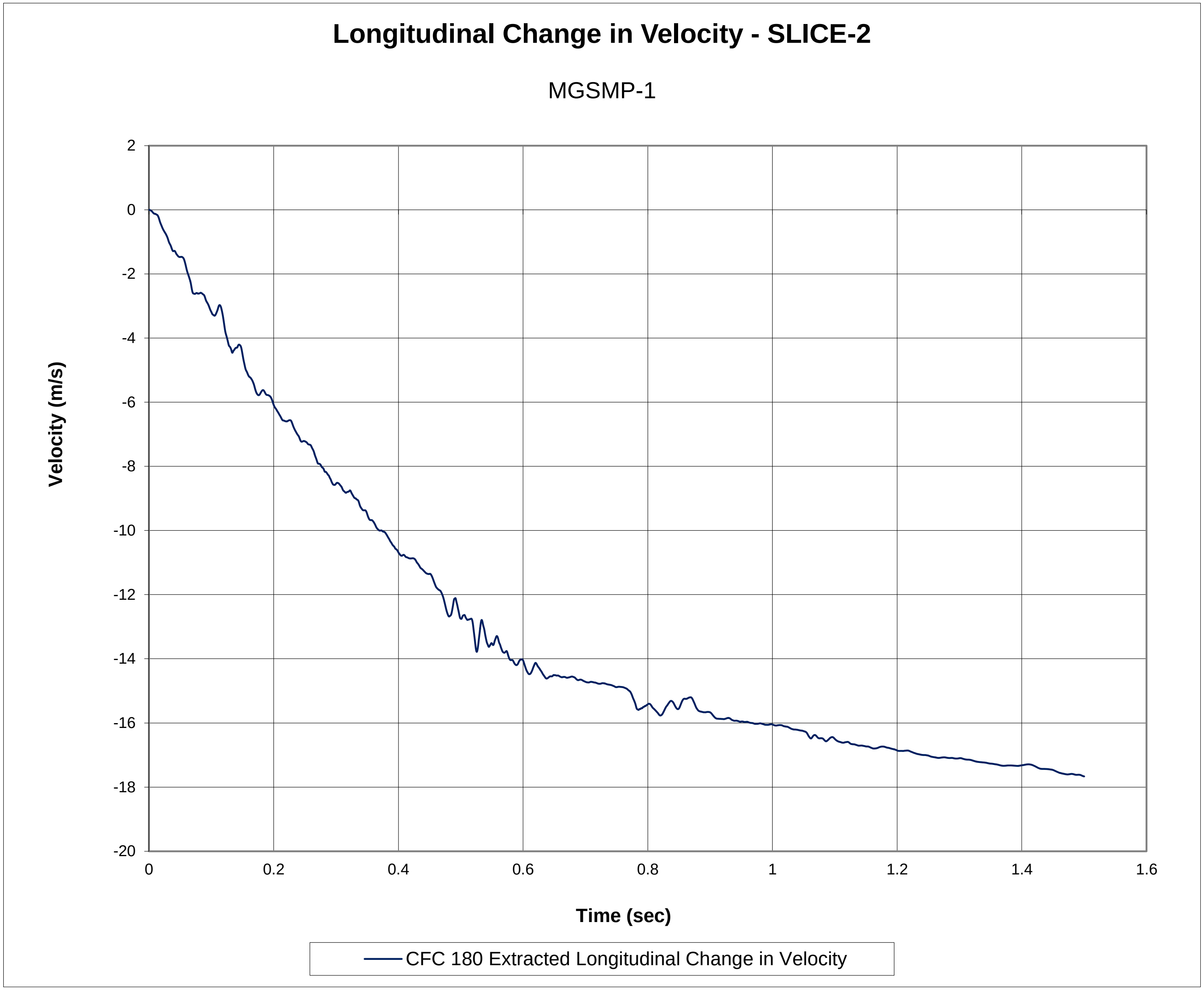


Figure E-10. Longitudinal Change in Velocity (SLICE-2), Test No. MGSMP-1

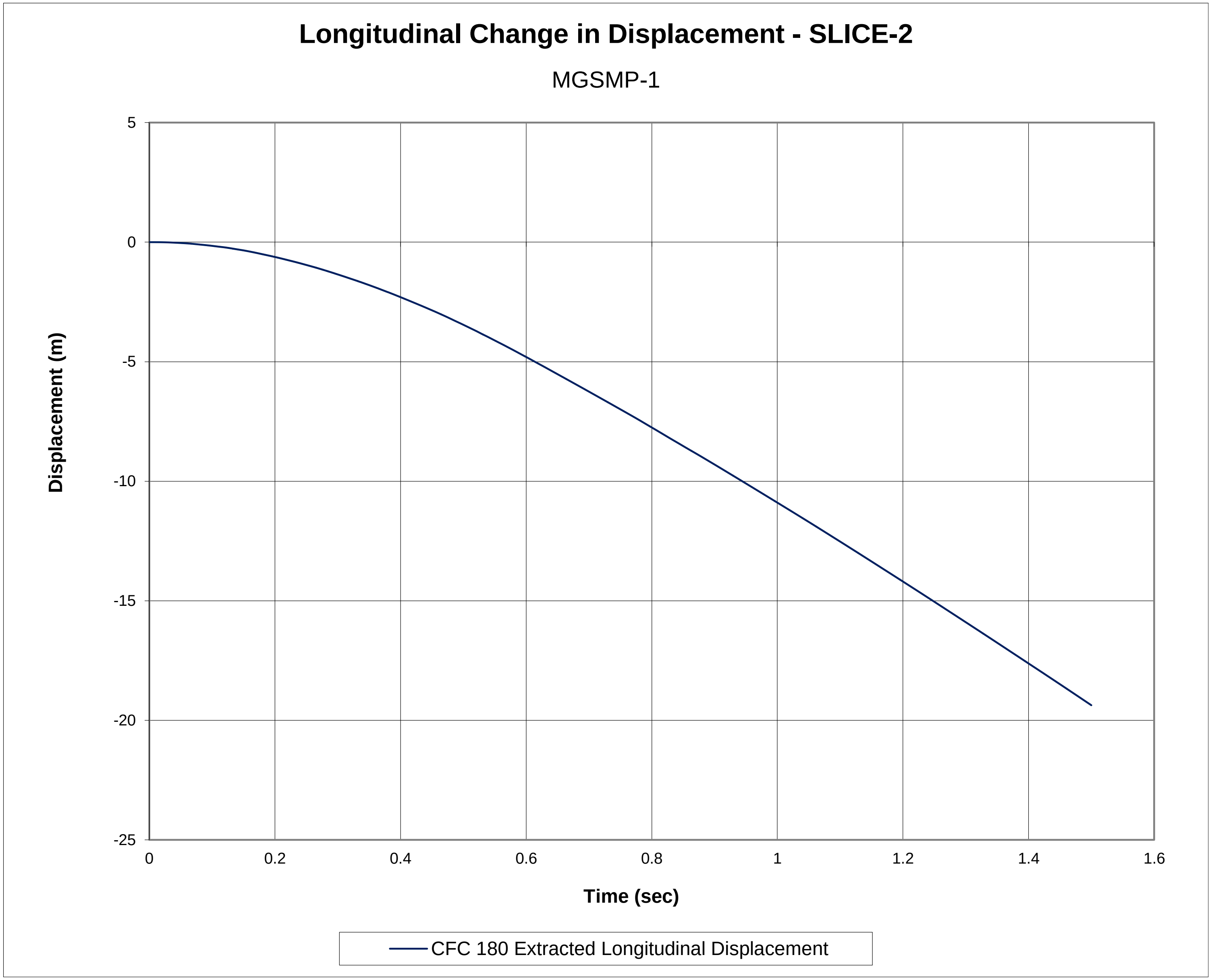


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSMP-1

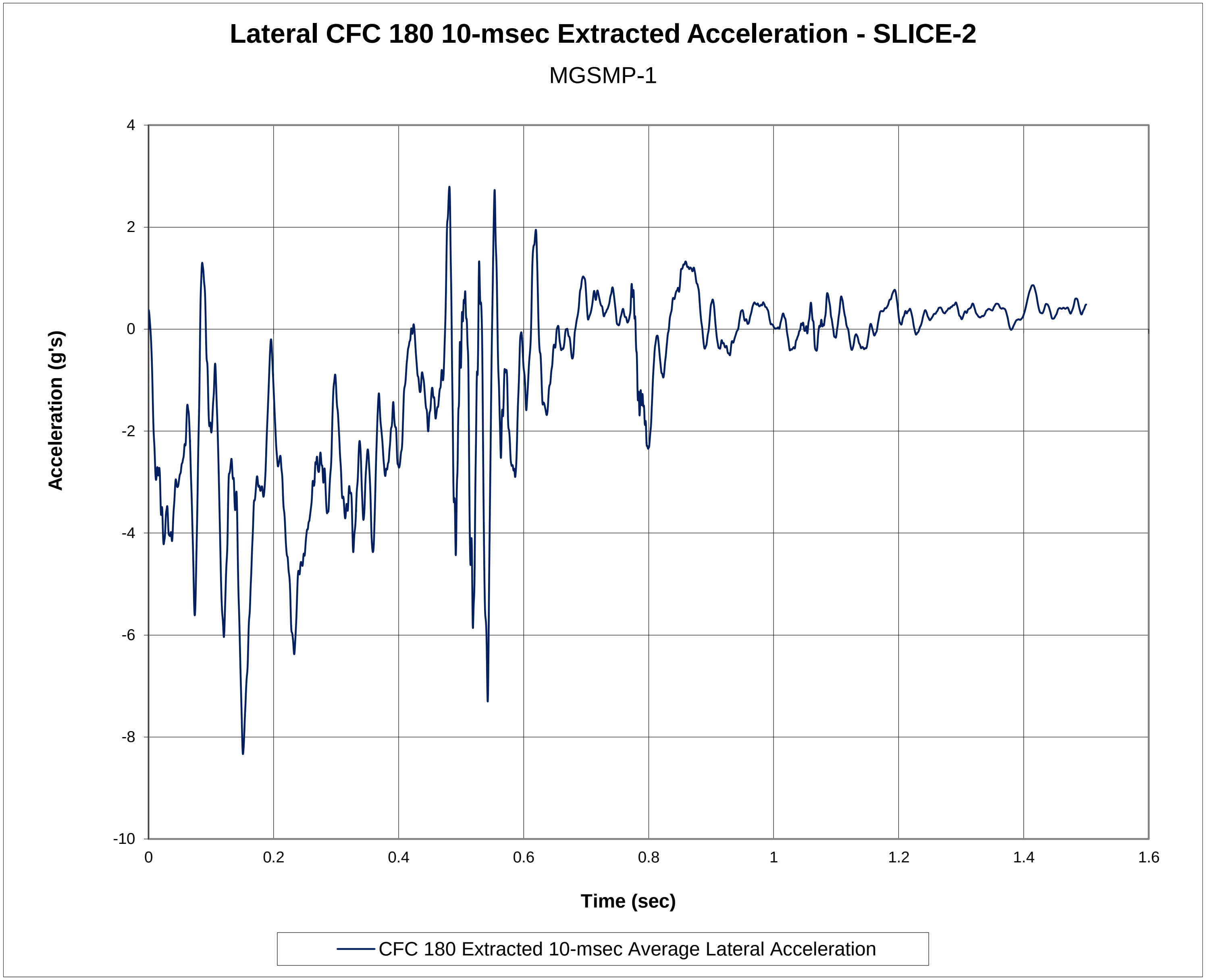


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSMP-1

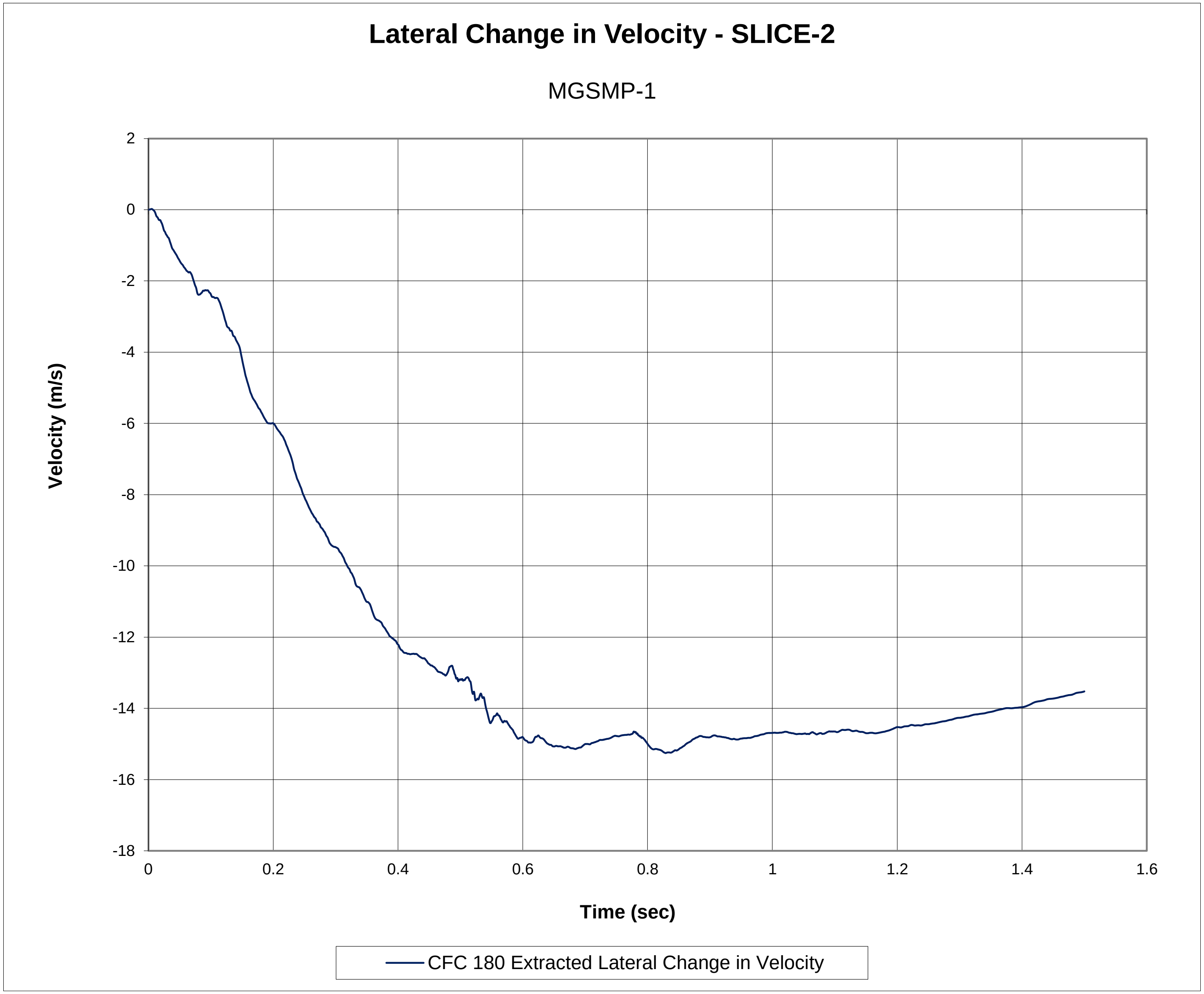


Figure E-13. Lateral Change in Velocity (SLICE-2), Test No. MGSMP-1

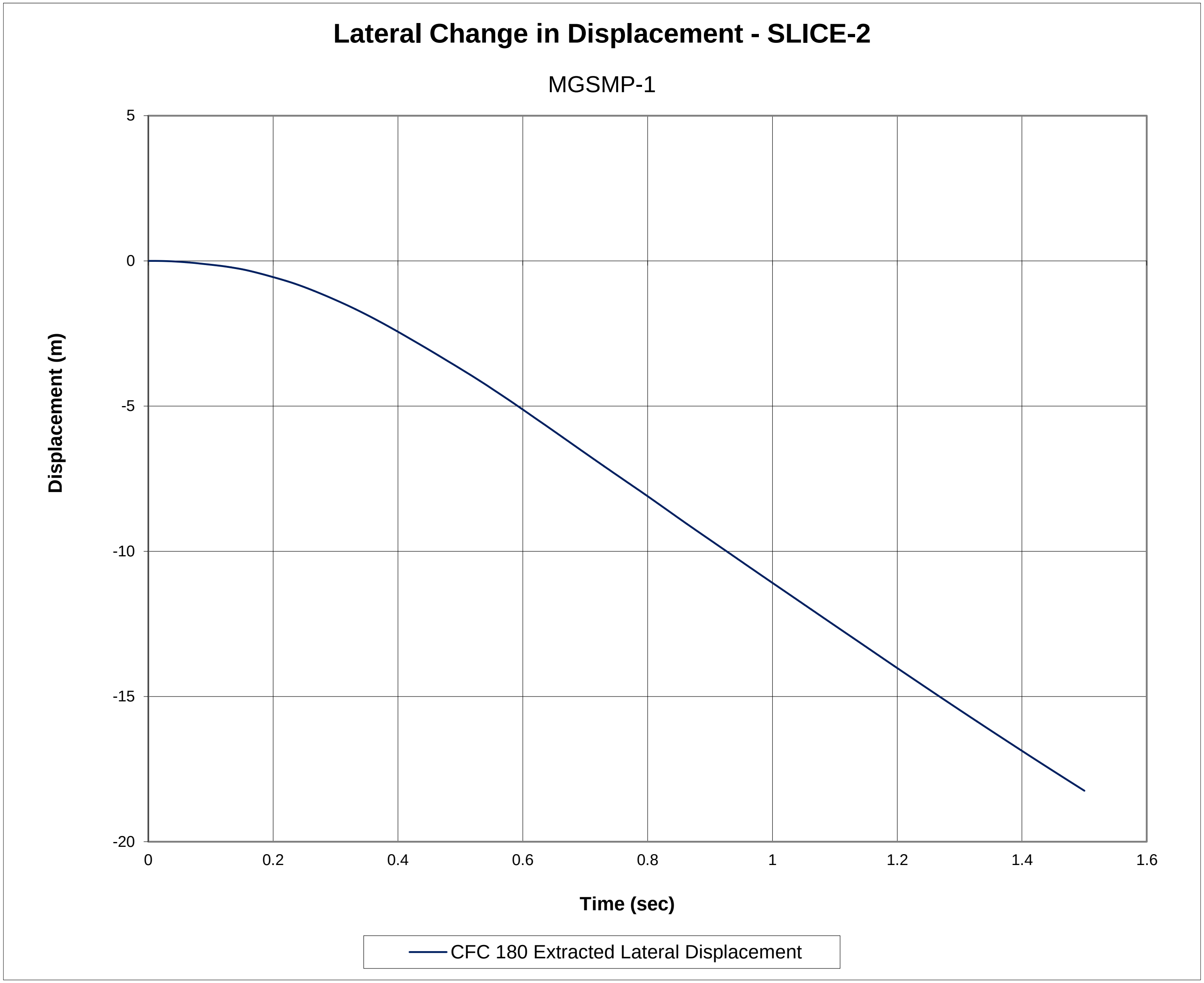


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. MGSMP-1

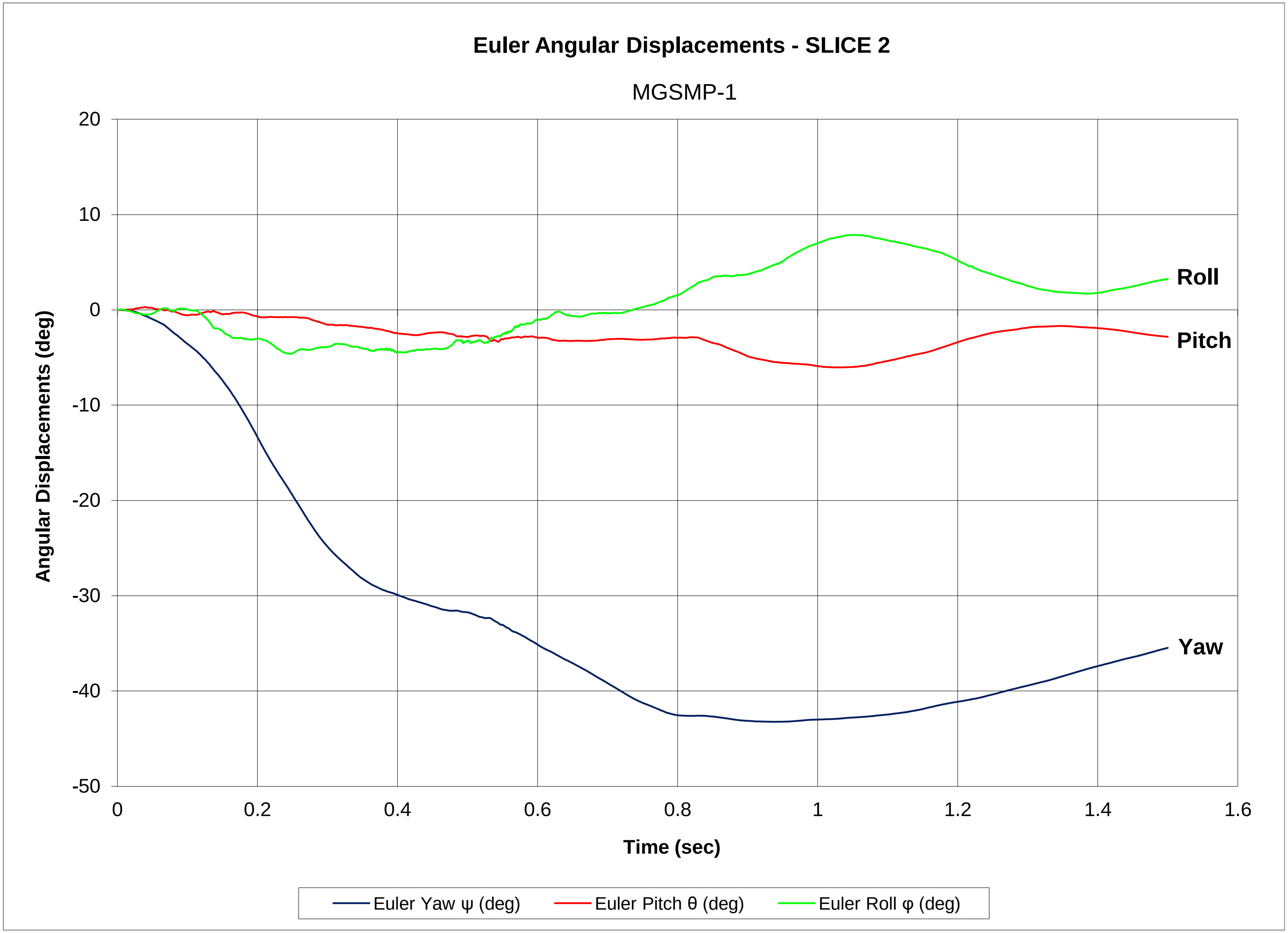


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. MGSMP-1

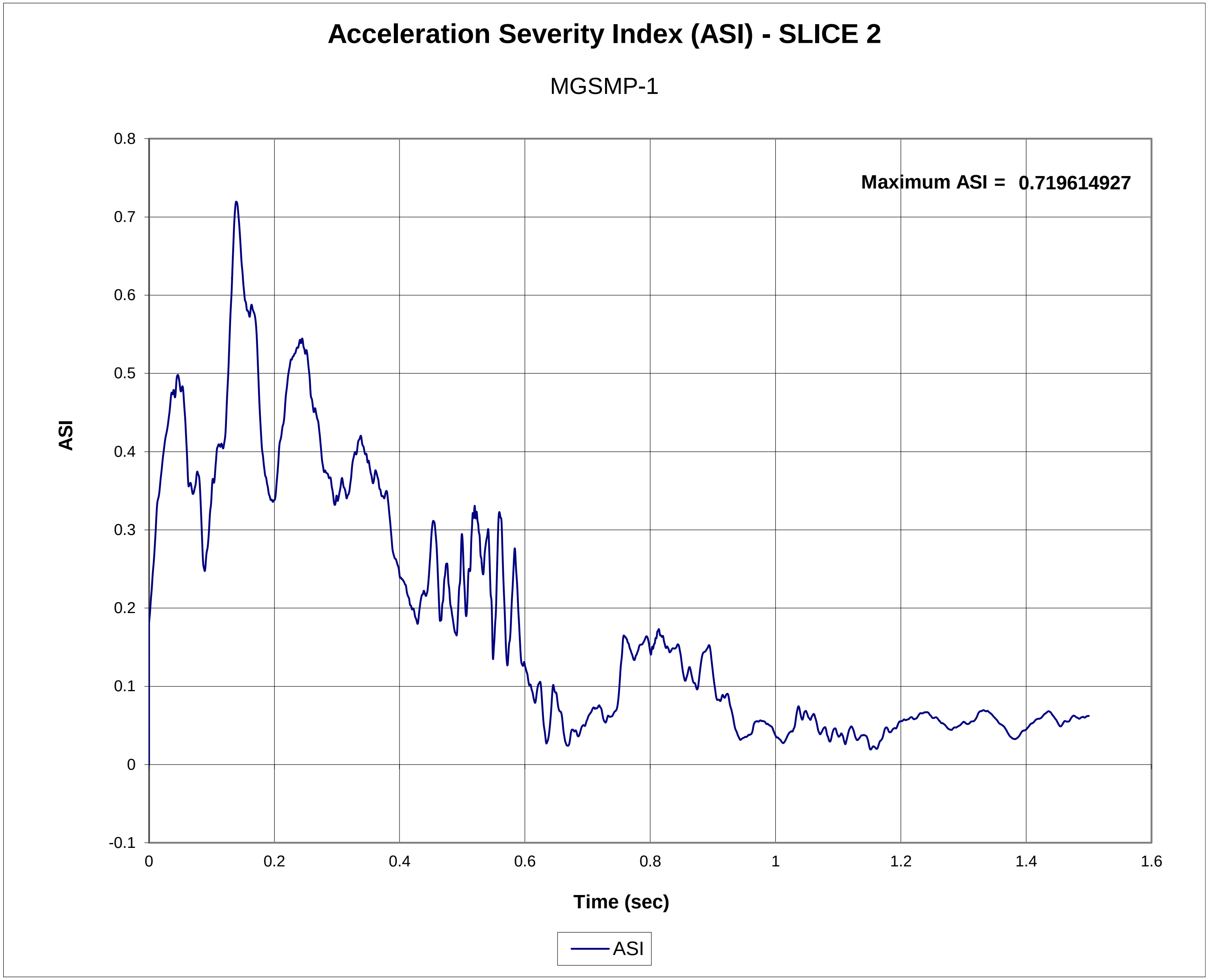


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. MGSMP-1

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