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INCREASED SPAN LENGTH FOR THE MGS LONG-SPAN GUARDRAIL SYSTEM PART II: FULL-SCALE CRASH TESTING

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16. Abstract

The objective of this research study was to design and evaluate the MGS long-span design for use with unsupported spans greater than 25 ft (7.6 m). Two full-scale crash tests were conducted to evaluate the MGS long-span system with increased span lengths and the use of UBSP posts adjacent to the long span. Both tests were conducted according to the TL-3 criteria outlined in MASH. Both test nos. MGSLS-1 and MGSLS-2 were conducted with the 2270P vehicle impacting their respective critical impact points at a speed of 62 mph (100 km/h) and an angle of 25 degrees. Test no. MGSLS-1 was conducted to evaluate the potential for vehicle instability by selecting a critical impact point that maximized the interaction of the front wheel of the pickup truck with the wing wall of the culvert. Test no. MGSLS-2 was designed to evaluate the structural capacity of the system by selecting a critical impact point that maximized the potential for pocketing, wheel snag, and rail rupture.

Test no. MGSLS-1 resulted in the vehicle being captured and redirected smoothly by the barrier system with all vehicle decelerations being within the recommended occupant risk limits. Therefore, test no. MGSLS-1 was deemed successful according to the TL-3 safety performance criteria found in MASH. Test no. MGSLS-2 resulted in the vehicle penetrating the barrier and creating multiple detached fragments that could present a safety hazard to oncoming traffic or the occupants of the vehicle. Therefore, test no. MGSLS-2 was deemed unsuccessful according to the TL-3 safety performance criteria.

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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 or 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 Mr. Scott Rosenbaugh, Research Associate Engineer.

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1 INTRODUCTION

1.1 Background

Long-span guardrail systems have been recognized as an effective means of shielding low-fill culverts. These designs are popular due to their ability to safely shield the culvert, while creating minimal construction effort and limiting culvert damage and repair when compared to other systems requiring post attachment to the top of the culvert. However, previous long-span designs were limited by the need to use long sections of nested guardrail to prevent rail rupture and the need to provide large lateral offsets between the barrier and the culvert headwall. The MGS long-span guardrail, as shown in Figure 1, eliminated those two shortcomings by applying the benefits of the Midwest Guardrail System to a long-span design. The MGS long-span system allowed for increased vehicle capture and stability through increased rail height, limited the potential for pocketing and wheel snag through the use of CRT posts adjacent to the unsupported span, and greatly increased the tensile capacity of the rail through the movement of splices away from posts and the use of shallower post embedment. These features allowed the system to be developed without the use of nested guardrail and with reduced lateral barrier offset, which places the back of the guardrail posts in line with the front face of the culvert headwall.

In a previous research study conducted by MwRSF [1-2], two full-scale crash tests were conducted on the MGS long-span system according to the Test Level 3 (TL-3) *Manual for Assessing Safety Hardware* (MASH) requirements for test designation no. 3-11 [1]. The first test, test no. LSC-1, was designed to evaluate the structural capacity of the system by selecting a critical impact point (CIP) that maximized the potential for pocketing, wheel snag, and rail rupture. In test no. LSC-1, a 4,991-lb (2,264-kg) pickup truck impacted the MGS long-span system 8.2 ft (2.5 m) downstream from post no. 13 at a speed of 62.4 mph (100.4 km/h) and an angle of 24.8 degrees, and the vehicle was safely redirected. A second test, test no. LSC-2, was conducted to evaluate the potential for vehicle instability by selecting a CIP that maximized the vehicle extension over the culvert as well as the interaction of the left-front wheel of the pickup truck with the wing wall of the culvert. In test no. LSC-2, a 4,984-lb (2,261-kg) pickup truck impacted the MGS long-span system 41.2 ft (12.6 m) upstream of post no. 14 at a speed of 61.9 mph (99.6 km/h) and an angle of 24.9 degrees, and the vehicle was safely redirected. The MGS long-span guardrail's ability to perform safely without nested rail and a minimal barrier offset made this new barrier a very functional and safe option for protection of low-fill culverts.

Figure 1. MGS Long Span System with 25-ft (7.6-m) Span Length

The use of unsupported lengths longer than 25 ft (7.6 m) was not recommended following the original research project without further analysis and full-scale crash testing. However, the excellent performance of the MGS long-span system in the full-scale crash testing program suggested that longer span lengths may have been possible with the current design. In a previous research study conducted by MwRSF, the MGS long-span system was investigated using LS-DYNA analysis for span lengths of 31¾ ft, 37½ ft, 43¾ ft, and 50 ft (9.5 m, 11.4 m, 13.3 m, and 15.2 m) [3-4]. The increased span lengths were developed by removing an in-line steel post and shifting the three CRT posts. This change ensured that three CRT posts remained adjacent to the unsupported length on either side. This research study determined that simulations of the 25-ft, 31¼-ft, and 37½-ft (7.6-m, 9.5-m, and 11.4-m) span lengths suggested successful performance of these barriers at the TL-3 conditions. There were no vehicle instabilities associated with these span lengths, and the guardrail forces throughout the barrier was comparable and well within acceptable force ranges. The maximum barrier deflections recorded for the 25-ft, 31¼-ft, and 37½-ft (7.6-m, 9.5-m, and 11.4-m) span systems were moderate and well below the theoretical maximum deflection threshold of 96.0 in. (2,438 mm).

In the previous research study, CRT wood posts were utilized directly upstream and downstream from the long span [3-4]. Full-scale crash testing has shown that the placement of CRT posts adjacent to the unsupported span functioned well in reducing wheel snag and pocketing [5-7]. At the 2014 Midwest States Pooled Fund Program's annual meeting, the sponsors determined that the 31¼-ft (9.5-m) MGS long-span guardrail system should undergo full-scale crash testing with Universal Breakaway Steel Posts (UBSP) in lieu of the existing CRT wood posts. Component testing of UBSPs indicated that there was a strong potential for these posts to be utilized in certain CRT post applications [8]. However, it was recommended that any guardrail system that may implement the UBSP should be subjected to full-scale vehicle crash testing. Several states expressed a desire to implement guardrail systems composed entirely of nonproprietary steel posts; since, the properties of wood posts vary due to knots, checks, splits, as well as inspection and grading. In addition, chemically-treated wood posts have been identified by some Departments of Transportation as harmful to the environment, which often requires special consideration during disposal. Thus, this report will discuss the results and findings of two full-scale crash tests conducted on the MGS long-span system with a span length of 31¼ ft (9.5 m) and UBSPs adjacent to the long span in lieu of the CRT wood posts.

1.2 Research Objectives

The objective of this research effort was to design and evaluate the MGS long-span system for use with unsupported spans greater than 25 ft (7.6 m). To accomplish this goal, a span length of 31 ft - 3 in. (9.5 m) was evaluated with two full-scale crash tests. The increased unsupported span length was to be configured to meet the TL-3 safety criteria set forth in MASH.

1.3 Research Scope

Two full-scale crash tests were conducted on the MGS long-span system. Both crash tests, MASH test designation no. 3-11, utilized pickup trucks 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. The first test was conducted to evaluate the potential for vehicle instability by selecting a critical impact point (CIP) that maximized vehicle extension over the culvert and the potential for interaction of the front wheel of the pickup truck with the wing wall of the culvert. The second test was designed to evaluate the structural capacity of the system by utilizing a CIP that would maximize the potential for pocketing, wheel snag, and rail rupture. After the tests were conducted, the test results were analyzed, evaluated, and documented.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 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 hardware, these safety standards consist of the guidelines and procedures published in MASH [9]. According to TL-3 of MASH, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, 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	2,425 (1,100)	62 (100)	25	A,D,F,H,I
	3-11	2270P	5,000 (2,268)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

It was determined that two full-scale crash tests would be required in order to evaluate the MGS long span system with an increased unsupported span length. The pickup truck test, test designation no. 3-11, was deemed more critical of the two vehicles as the more massive truck would induce much higher rail loads and system deflections, thus yielding the highest potential for structural failure of the system and/or vehicle instabilities. Two full-scale crash tests under test designation no. 3-11 were proposed to evaluate the two critical impact points (CIPs) of the barrier system. The first test was conducted to evaluate the potential for vehicle instability by selecting a CIP that maximized vehicle extension over the culvert and the potential for interaction of the front wheel of the pickup truck with the wing wall of the culvert. The second test was designed to evaluate the structural capacity of the system by utilizing a CIP that would maximize the potential for pocketing, wheel snag, and rail rupture.

Previous research suggested that the 1100C small car impact, test designation no. 3-10, was not as critical for evaluation of the MGS long span system with increased span length and was omitted for the evaluation. W-beam barriers struck by small cars have been shown to meet safety performance standards, being essentially rigid (10-16), with no significant potential for occupant risk problems arising from vehicle pocketing or severe wheel snagging on the post or culvert at the downstream end of the unsupported span. Additionally, the MGS has previously been successfully tested at flare rates as high as 5:1 with the 820C vehicle under TL-3, which resulted in an equivalent impact angle for the small car vehicle of 31.8 degrees (17). The MGS was also full-scale crash tested and evaluated under MASH TL-3 with the 1100C vehicle with top rail mounting heights of 34 in. (864 mm) and 36 in. (914 mm) (18). The capture and redirection of the small car in these tests would suggest that capture of the 1100C vehicle was unlikely to be a concern within the unsupported span used in the MGS long span system.

It should be noted that the test matrix detailed herein represents the researchers' best engineering judgement with respect to the MASH safety requirements and their internal evaluation of critical tests necessary to evaluate the crashworthiness of the barrier system. However, the recent switch to new vehicle types as part of the implementation of the MASH criteria and the lack of experience and knowledge with certain barriers could result in unanticipated barrier performance. Thus, any tests within the evaluation matrix deemed non-critical may eventually need to be evaluated based on additional knowledge gained over time or revisions to the MASH criteria.

2.2 Evaluation Criteria

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

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported on the test summary sheet. Additional discussion on PHD, THIV, and ASI is provided in MASH.

2.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil-dependent system, additional W6x16 (W152x23.8) posts were installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, dynamic impact testing was 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) from the ground line. 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 Barriers

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

3 TEST CONDITIONS

3.1 Test Facility

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

3.2 Vehicle Tow and Guidance System

A reverse-cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half 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 [19] was used to steer the test vehicle. A guide flag, attached to the right-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

3.3 Test Vehicle

For test no. MGSLS-1, a 2007 Dodge Ram was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,199 lb (2,358 kg), 4,955 lb (2,248 kg), and 5,120 lb (2,322 kg), respectively. The test vehicle is shown in Figure 2, and vehicle dimensions are shown in Figure 3.

For test no. MGSLS-2, a 2008 Dodge Ram was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,064 lb (2,297 kg), 4,912 lb (2,228 kg), and 5,078 lb (2,303 kg), respectively. The test vehicle is shown in Figure 4, and vehicle dimensions are shown in Figure 5.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [20] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The vertical component of the c.g. for the 2270P vehicle was determined utilizing a procedure published by the Society of Automotive Engineers (SAE) [21]. The location of the final c.g. for test no. MGSLS-1 is shown in Figure 3 and for test no. MGSLS-2 is shown in Figure 5. Data used to calculate the locations of the c.g. and ballast information for both tests 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 Figures 6 and 7. Round, checkered targets were placed on the center of gravity on the left-side door, the right-side door, and the roof of the vehicle.

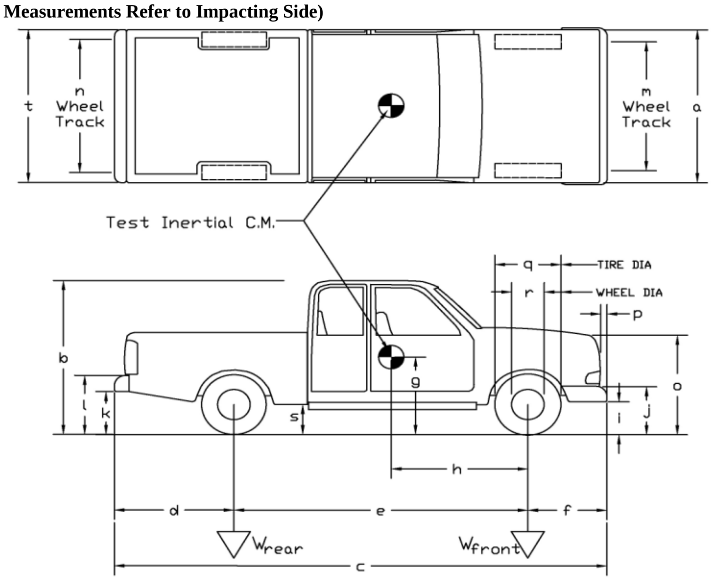
The front wheels of the test vehicle were aligned to vehicle standards, except the toe-in value was adjusted to zero so that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted on the left side of the vehicle’s dash and was fired by a pressure tape switch mounted at the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

Figure 2. Test Vehicle, Test No. MGSLS-1

Date:	**5/15/2015**	**Test Number:**	**MGSLS-1**	**Model:**	**Ram 1500**
Make:	**Dodge**	**Vehicle I.D.#:**	**1d7ha18237a275359**		
Tire Size:	**265/70/R17**	**Year:**	**2007**	**Odometer:**	**205261**

Tire Inflation Pressure: **35**

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



Vehicle Geometry -- in. (mm)

a	**78**	**(1981)**	**b**	**75 1/2**	**(1918)**
c	**228**	**(5791)**	**d**	**47**	**(1194)**
e	**140 3/8**	**(3566)**	**f**	**40 5/8**	**(1032)**
g	**28 2/3**	**(728)**	**h**	**59 8/9**	**(1521)**
i	**14**	**(356)**	**j**	**27 1/2**	**(699)**
k	**21 1/4**	**(540)**	**l**	**29 5/8**	**(752)**
m	**68 1/8**	**(1730)**	**n**	**68**	**(1727)**
o	**45 1/2**	**(1156)**	**p**	**4**	**(102)**
q	**32 1/4**	**(819)**	**r**	**18 1/2**	**(470)**
s	**16 1/4**	**(413)**	**t**	**75 1/4**	**(1911)**

Wheel Center Height Front	**15**	**(381)**
Wheel Center Height Rear	**15 1/8**	**(384)**
Wheel Well Clearance (F)	**35 3/4**	**(908)**
Wheel Well Clearance (R)	**39**	**(991)**
Frame Height (F)	**18 1/4**	**(464)**
Frame Height (R)	**26 1/4**	**(667)**
Engine Type	**V8 Gasoline**	
Engine Size	**5.7L**	
Transmission Type:	**Automatic**	
Drive Type:	**RWD**	

Mass Distribution lb (kg)

Gross Static	**LF**	**1502 (681)**	**RF**	**1439 (653)**
	LR	**1072 (486)**	**RR**	**1107 (502)**

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	**2954 (1340)**	**2841 (1289)**	**2941 (1334)**
W-rear	**2245 (1018)**	**2114 (959)**	**2179 (988)**
W-total	**5199 (2358)**	**4955 (2248)**	**5120 (2322)**

GVWR Ratings

Front	**3700 lb**
Rear	**3900 lb**
Total	**6700 lb**

Dummy Data

Type:	**Hybrid II**
Mass:	**165 lb**
Seat Position:	**Driver**

Note any damage prior to test: **Front bumper fascia cracked, dent and scrape on front passenger fender.**

Figure 3. Vehicle Dimensions, Test No. MGSLS-1

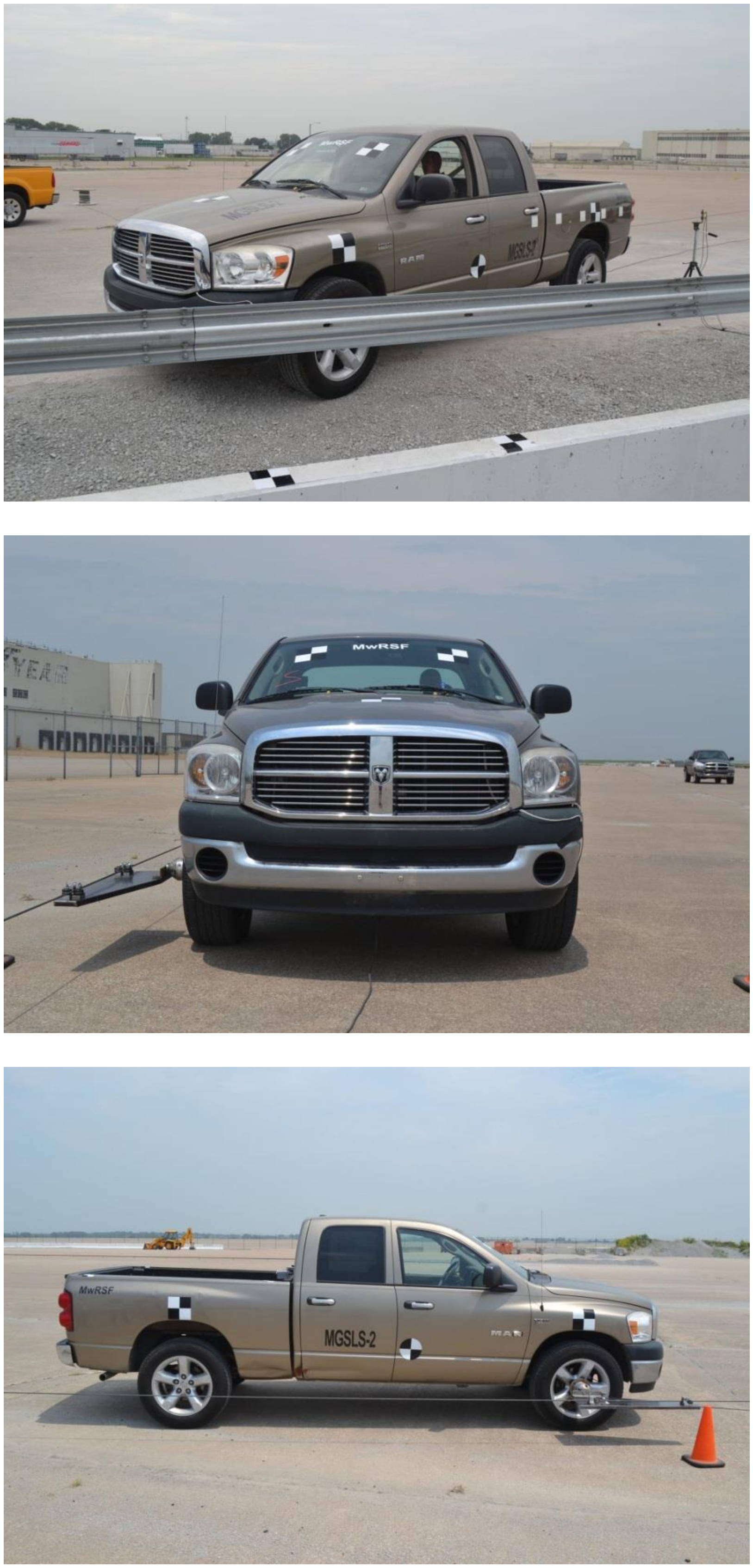
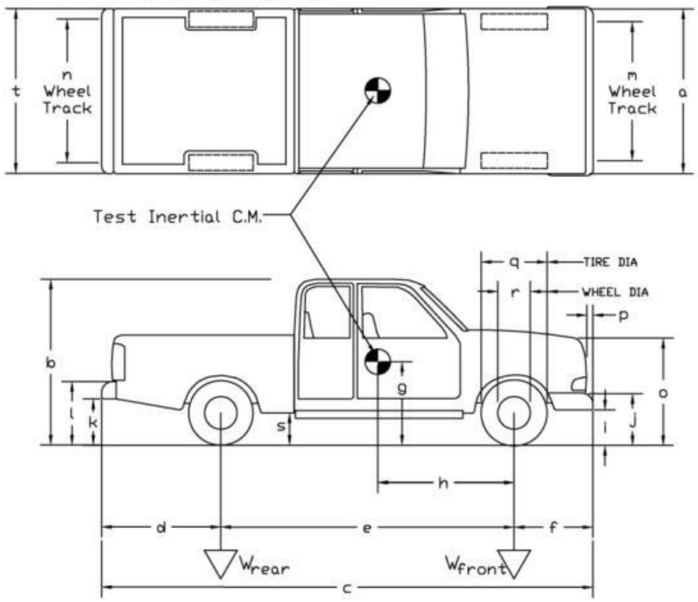


Figure 4. Test Vehicle, Test No. MGSLS-2

Date:	6/30/2015	**Test Number:**	MGSLS-2	**Model:**	RAM 1500
Make:	Dodge	**Vehicle I.D.#:**	1d7ha18218j27749		
Tire Size:	275/60R20	**Year:**	2008	**Odometer:**	158553

Tire Inflation Pressure: 35

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



Vehicle Geometry -- in. (mm)

a	78	(1981)	b	76	(1930)
c	227 3/8	(5775)	d	48 1/8	(1222)
e	140 1/4	(3562)	f	39	(991)
g	29 2/3	(754)	h	60 1/4	(1530)
i	13	(330)	j	29 1/8	(740)
k	21 3/8	(543)	l	30 1/4	(768)
m	68 1/8	(1730)	n	68 1/8	(1730)
o	47 1/8	(1197)	p	3 1/4	(83)
q	32 1/4	(819)	r	21 1/2	(546)
s	16 1/2	(419)	t	75 3/8	(1915)

Wheel Center Height Front	15 1/4	(387)
Wheel Center Height Rear	15 3/4	(400)
Wheel Well Clearance (F)	36 5/8	(930)
Wheel Well Clearance (R)	39 1/8	(994)
Frame Height (F)	20	(508)
Frame Height (R)	26 1/4	(667)
Engine Type	Gasoline	
Engine Size	5.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	

Mass Distribution lb (kg)

Gross Static	LF	1478 (670)	RF	1423 (645)
	LR	1099 (498)	RR	1078 (489)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2900 (1315)	2802 (1271)	2901 (1316)
W-rear	2164 (982)	2110 (957)	2177 (987)
W-total	5064 (2297)	4912 (2228)	5078 (2303)

GVWR Ratings

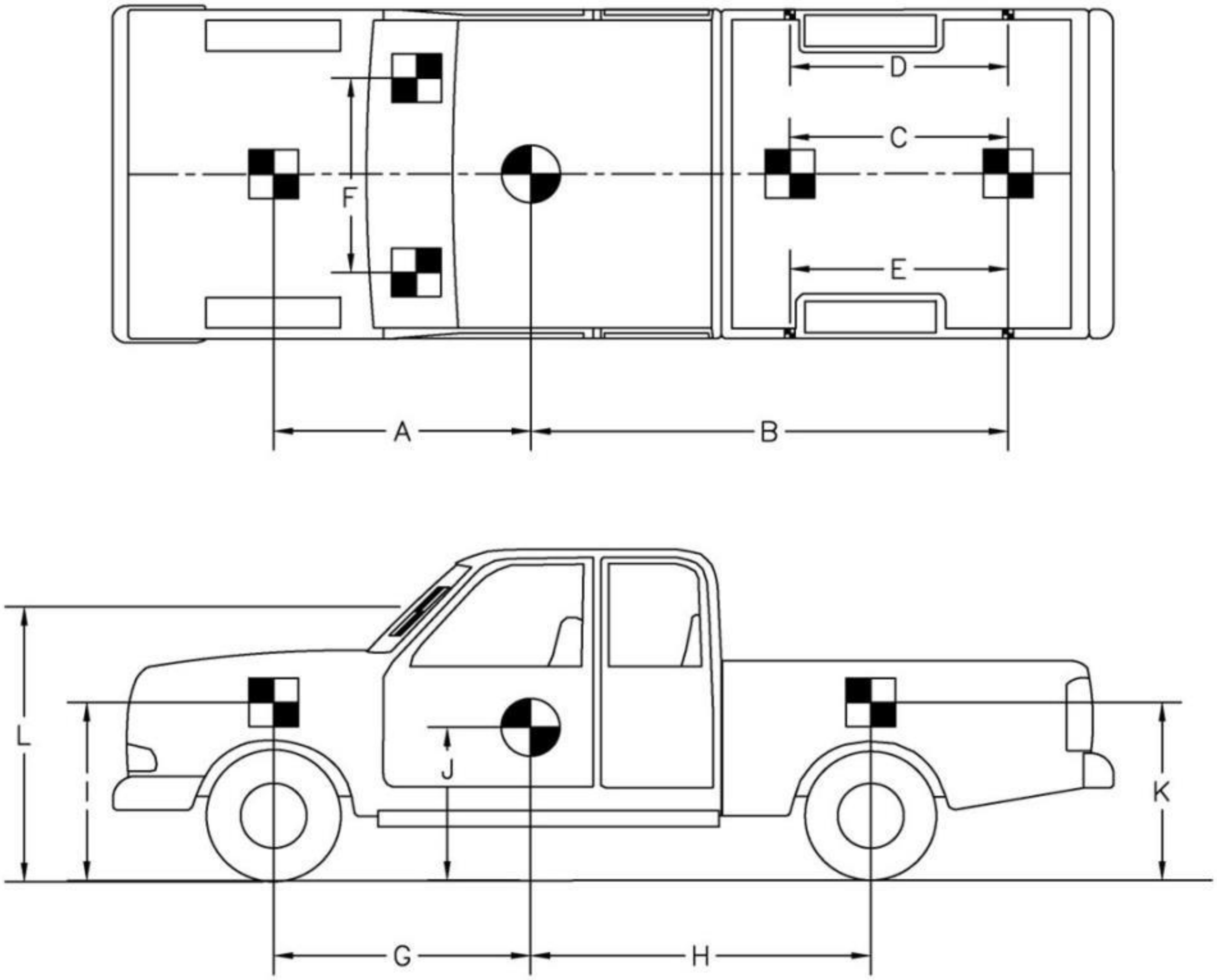
Front	3700 lbs
Rear	3900 lbs
Total	6700 lbs

Dummy Data

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

Note any damage prior to test: Passenger side rear door and rocker panel scrape and dent.

Figure 5. Vehicle Dimensions, Test No. MGSLS-2

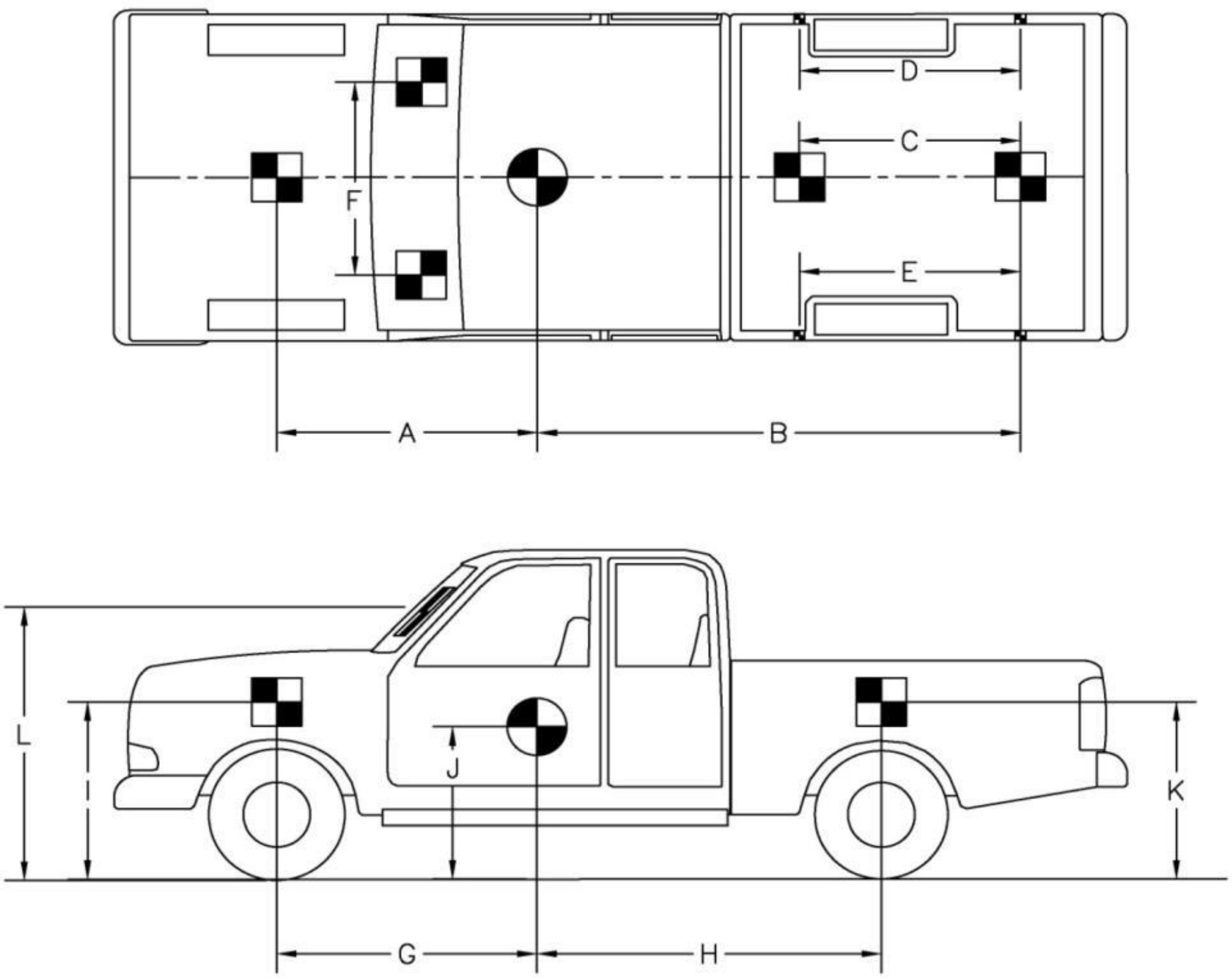


TEST #: MGSLS-1

TARGET GEOMETRY-- in. (mm)

A	74 1/8	(1883)	**E**	64	(1626)	**I**	39 7/8	(1013)
B	108	(2743)	**F**	35 1/2	(902)	**J**	28 5/8	(727)
C	48	(1219)	**G**	59 7/8	(1521)	**K**	43 1/8	(1095)
D	64	(1626)	**H**	80 1/2	(2045)	**L**	65 5/8	(1667)

Figure 6. Target Geometry, Test No. MGSLS-1



TEST #: MGSLS-2

TARGET GEOMETRY-- in. (mm)

A	**74 1/8**	**(1883)**	**E**	**64**	**(1626)**	**I**	**41 1/8**	**(1045)**
B	**112 1/2**	**(2858)**	**F**	**35 3/4**	**(908)**	**J**	**29 5/8**	**(752)**
C	**52**	**(1321)**	**G**	**60 1/4**	**(1530)**	**K**	**43 1/4**	**(1099)**
D	**64**	**(1626)**	**H**	**80 1/8**	**(2035)**	**L**	**66 5/8**	**(1692)**

Figure 7. Target Geometry, Test No. MGSLS-2

3.4 Simulated Occupant

For test nos. MGSLS-1 and MGSLS-2, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the left-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 165 lb (75 kg) for test no. MGSLS-1 and 166 lb (75 kg) for test no. MGSLS-2, was represented by model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH, the dummy was not included in calculating the c.g. location.

3.5 Data Acquisition Systems

3.5.1 Accelerometers

For each test, 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 center of gravity 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 [22].

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 body of a custom-built SLICE 6DX event data recorder and recorded data at 10,000 Hz to the onboard microprocessor. The SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

3.5.2 Rate Transducers

For each test, 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 ARS 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.

3.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the bogie 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.

3.5.4 Load Cells and String Potentiometers

Load cells were installed at the upstream and downstream anchors for test no. MGSLS-1 and MGSLS-2. The load cells were Transducer Techniques model no. TLL-50K with a load range up to 50 kips (222 kN). String potentiometers were also attached to the system at the upstream and downstream anchors for both tests. The string potentiometers were Unimeasure model no. PA-50-70124 with a displacement range up to 50 in. (127 cm). During testing, output voltage signals were sent from the transducers to a National Instruments PCI-6071E data acquisition board, acquired with LabView software, and stored on a personal computer at a sample rate of 10,000 Hz. The positioning and set up of the transducers are shown for both tests in Appendix G.

3.5.5 Digital Photography

Five AOS high-speed digital video cameras, eight GoPro digital video cameras, and four JVC digital video cameras were utilized to film test no. MGSLS-1. However, three of the GoPro digital video cameras were not turned on for the test and did not record it. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 9.

For test no. MGSLS-2, five AOS high-speed digital video cameras, seven GoPro digital video cameras, and four JVC digital video cameras were used. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 10.

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 used to document pre- and post-test conditions for both tests.

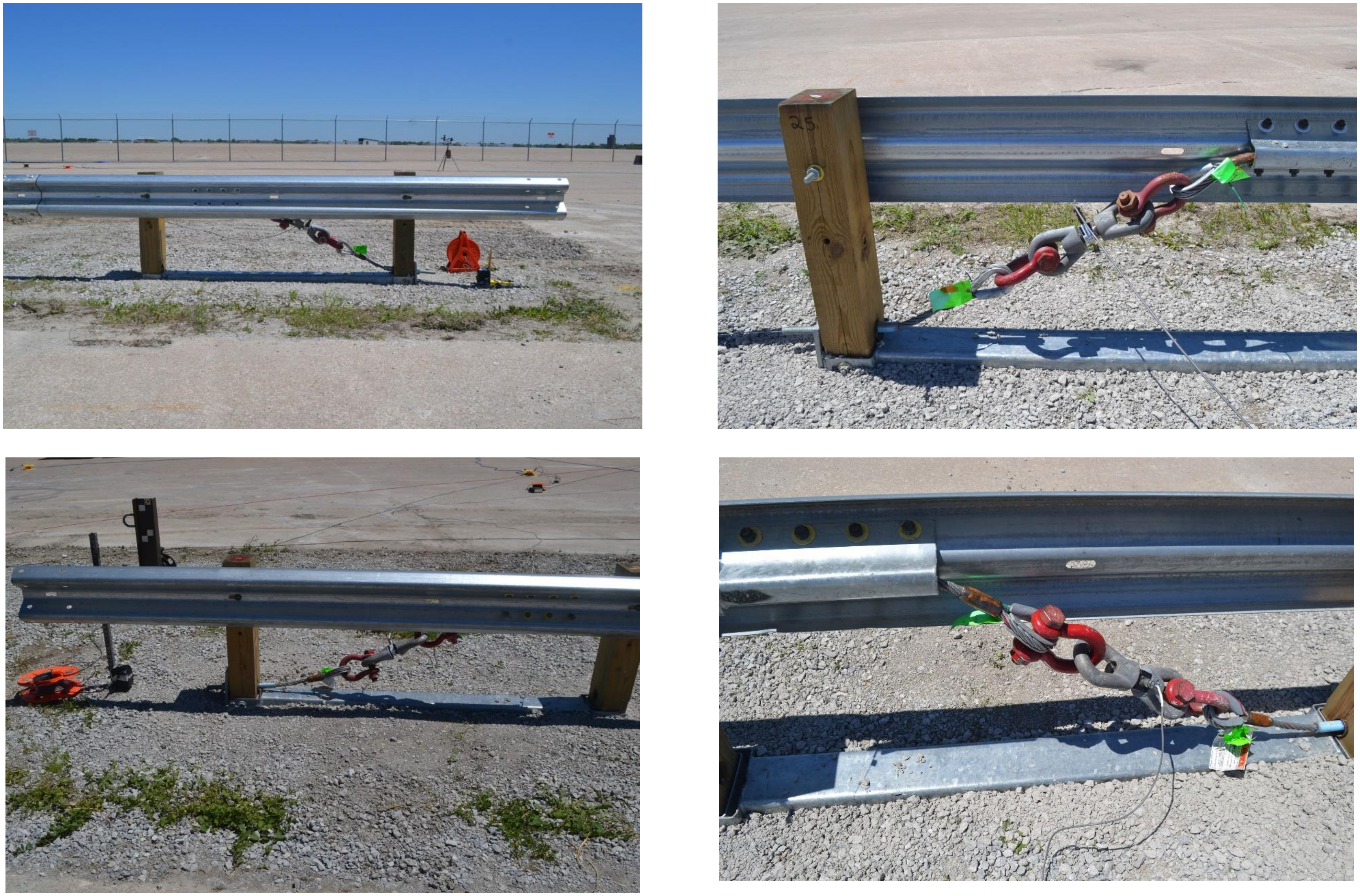
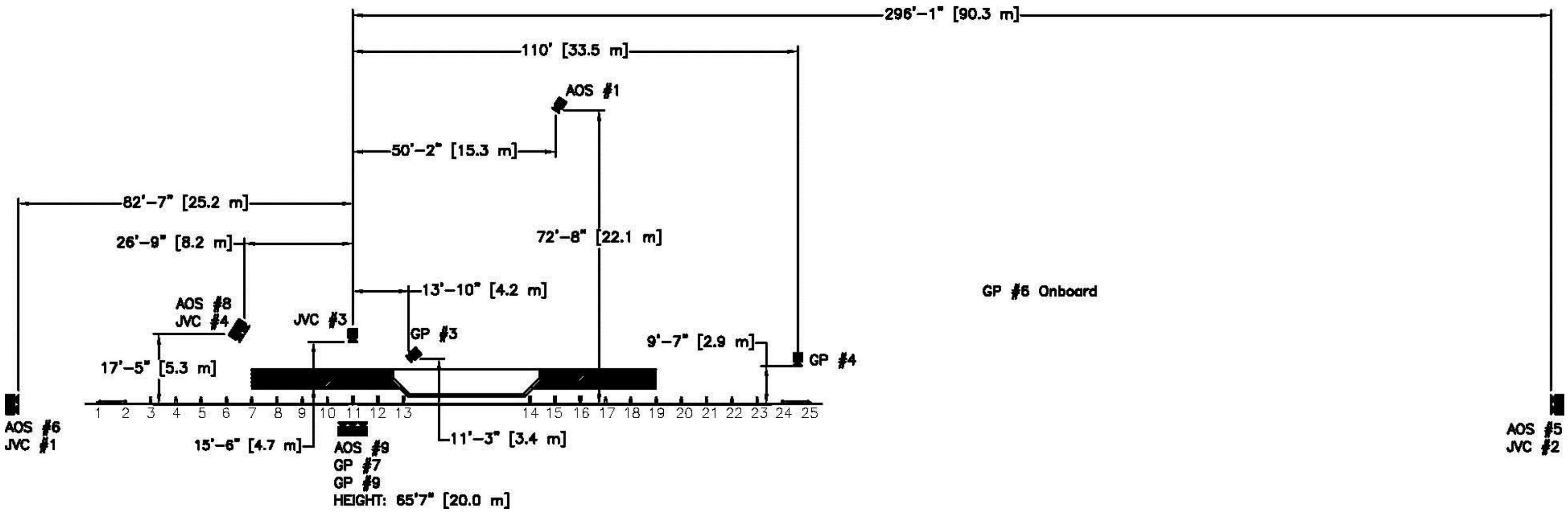
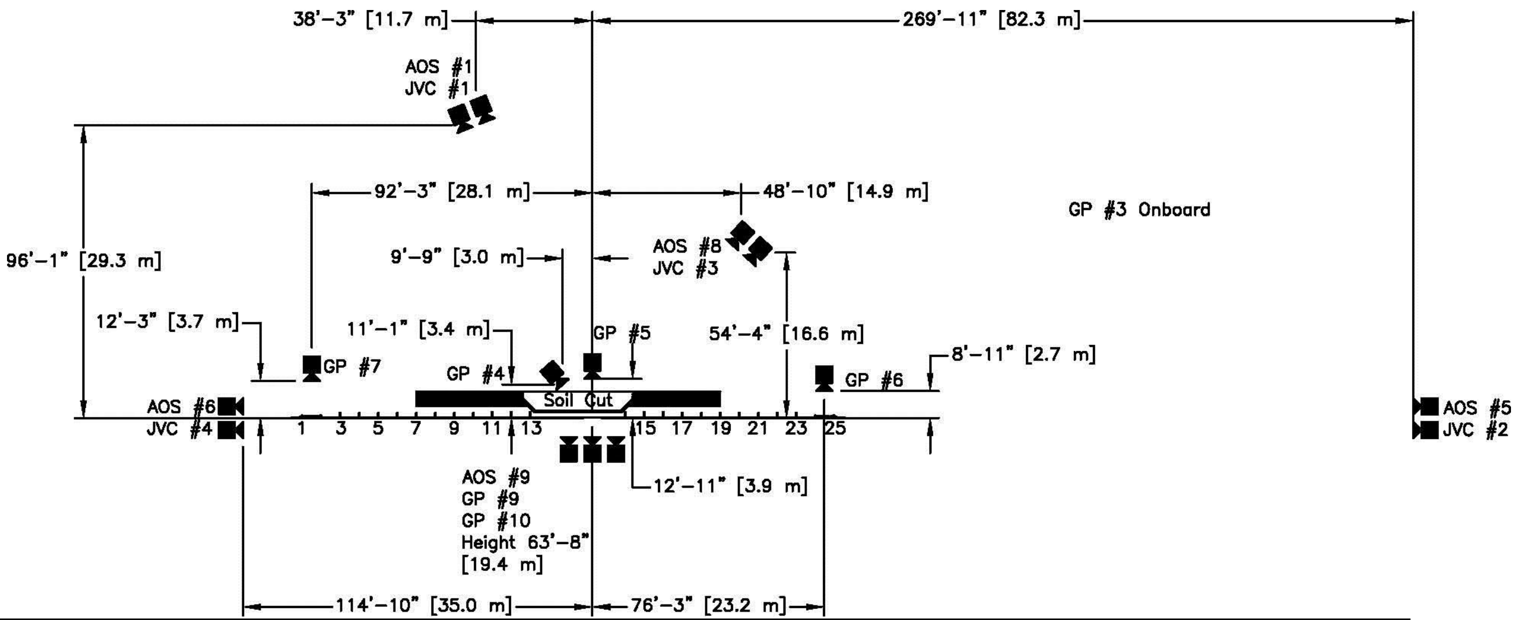


Figure 8. Location of Load Cells and String Potentiometers, Test No. MGSLS-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam CTM	500	Nikkor 20mm Fixed	—
AOS-5	AOS X-PRI Gigabit	500	Vivitar 135mm Fixed	—
AOS-6	AOS X-PRI Gigabit	500	Sigma 28-70mm	50
AOS-8	AOS S-VIT 1531	500	Sigma 28-70mm DG	28
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12mm	—
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	240		
GP-9	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 9. Camera Locations, Speeds, and Lens Settings, Test No. MGSLS-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam	500	Nikkor 20mm Fixed	—
AOS-5	AOS X-PRI	500	Vivitar 135mm Fixed	—
AOS-6	AOS X-PRI	500	Sigma 28-70mm	50
AOS-8	AOS S-VIT 1531	500	Sigma 28-70mm DG	28
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12mm	—
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
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 10. Camera Locations, Speeds, and Lens Settings, Test No. MGSLS-2

4 DESIGN DETAILS TEST NOS. MGSLS-1 AND MGSLS-2

The test installation for the MGS long-span systems was composed of 175 ft (53.3 m) of standard W-beam guardrail supported by breakaway cable terminal (BCT) timber posts, standard steel line posts, universal breakaway steel posts (UBSPs), and a simulated concrete culvert with wingwalls. All posts were spaced at 75 in. (1,905 mm) on center, except for a single 31-ft 3-in. (9.5-m) span located near the center of the guardrail installation, which spanned the simulated concrete culvert. The only dissimilarity between test nos. MGSLS-1 and MGSLS-2 was the impact location. The test layout for test no. MGSLS-1 is shown in Figure 11, while the test layout for test no. MGSLS-2 is shown in Figure 12. Otherwise, all remaining design details for both tests are identical and are shown in Figures 13 through 33. Photographs of the system for test no. MGSLS-1 are shown in Figures 34 through 37 and in Figures 38 through 41 for test no. MGSLS-2. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

A simulated culvert headwall was constructed behind the MGS long-span guardrail in order to simulate any potential vehicle drop off of the edge of the culvert and to simulate the effect of the culvert headwall on the deflection of adjacent guardrail posts during an impact. The design of the headwall was based on a survey of common culvert designs from the sponsoring agencies. The culvert design also included both the upstream and downstream wingwalls as well as a typical slope profile based on representative culvert designs submitted by the sponsoring agencies. The reinforced concrete culvert was 37 ft – 1½ in. (11.3 m) long, as measured parallel to the guardrail from the tip of one wingwall to the tip of the other wingwall. The edge of the culvert parallel to the guardrail was 28 ft – 9 in. (8.8 m) long. Each wingwall was 71 in. (1,803 mm) long and projected away from the system at a 45-degree angle. The culvert was 48 in. (1,219 mm) tall, except at the ends of each wing wall, which were angled down to match the

1V:3H lateral fill slope behind the system to a height of 39¼ in. (997 mm). The design of the culvert can be seen in Figure 15.

The barrier utilized standard 12-gauge (2.7-mm) thick W-beam rails with additional post bolt slots at half-post spacing intervals, as shown in Figures 11, 18, 19, and 31. 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 the midspans between posts, as shown in Figure 18. The lap splice connections between the rail sections were configured to reduce vehicle snag at the splice during the crash test.

The rail was supported by 25 posts, all of which were embedded in a compacted, coarse, crushed limestone material, as recommended by MASH [9]. All of the line posts had embedment depths of 40 in. (1,016 mm. Post nos. 3 through 10 and 17 through 23 were galvanized ASTM A992, W6x8.5 (W152x12.6) steel line posts that measured 72 in. (1,829 mm) long. Post nos. 11 through 16 were 32-in. (813-mm) tall, W6x8.5 (W152x12.6) UBSP steel posts that were attached at the ground line to 6-in. x 8-in. x $^{3}/_{16}$-in. thick (152-mm x 203-mm x 4.8-mm) steel tubes that measured 40 in. (1,106 mm) long. The UBSP posts were positioned 24 in. (610 mm) away from the slope break point of the 1V:3H fill slope. The two UBSP posts nearest to the culvert were offset 15 in. (381 mm) longitudinally away from the culvert headwall. The UBSPs were utilized in place of CRT posts due to a desire by states to not use the chemically treated wood posts. The rail was offset from the steel posts with 6-in. x 12-in. x 14¼-in. long (152-mm x 305-mm x 362-mm) Southern Yellow Pine wood blockouts, as shown in Figure 13. A 16D, 3½ in. (89 mm) double head nail was also driven through a hole in the front flange of each post into the top of the blockout assembly to prevent blockout rotation. The elongated span length was located between post nos. 13 and 14, as shown in Figures 11 and 14.

The upstream and downstream ends of the guardrail installation were configured with a trailing-end anchorage system, as shown in Figures 18 and 36. This guardrail anchorage system was utilized to simulate the strength of other crashworthy end terminals. The anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts, which closely resembled the hardware used in the Modified BCT system and now part of a crashworthy, downstream, trailing-end terminal [25-28]. Post nos. 1, 2, 24, and 25 were breakaway cable terminal (BCT) timber posts that were inserted into 6-ft (1.8-m) long steel foundation tubes, as shown in Figures 21 and 40.

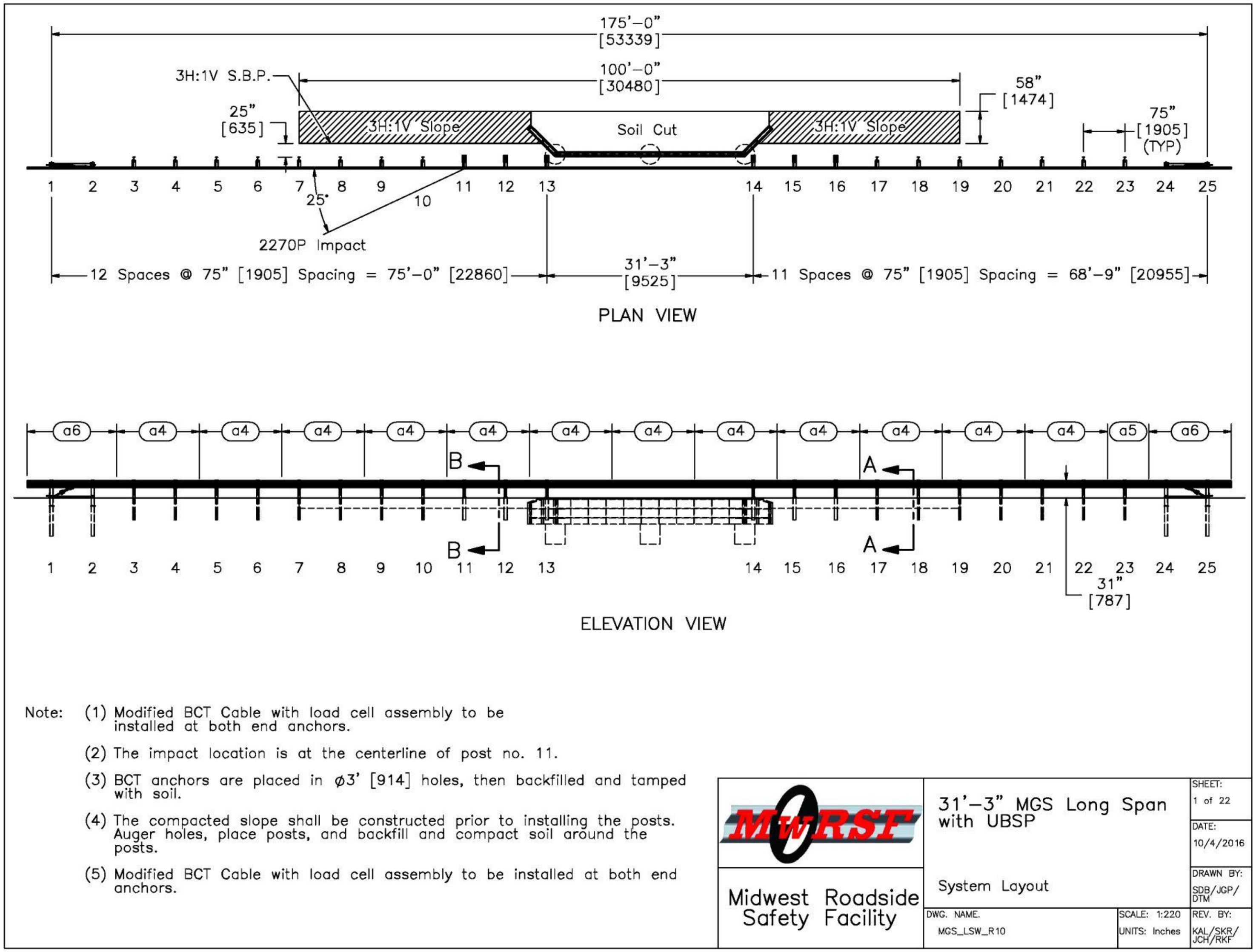


Figure 11. System Layout, Test No. MGSLS-1

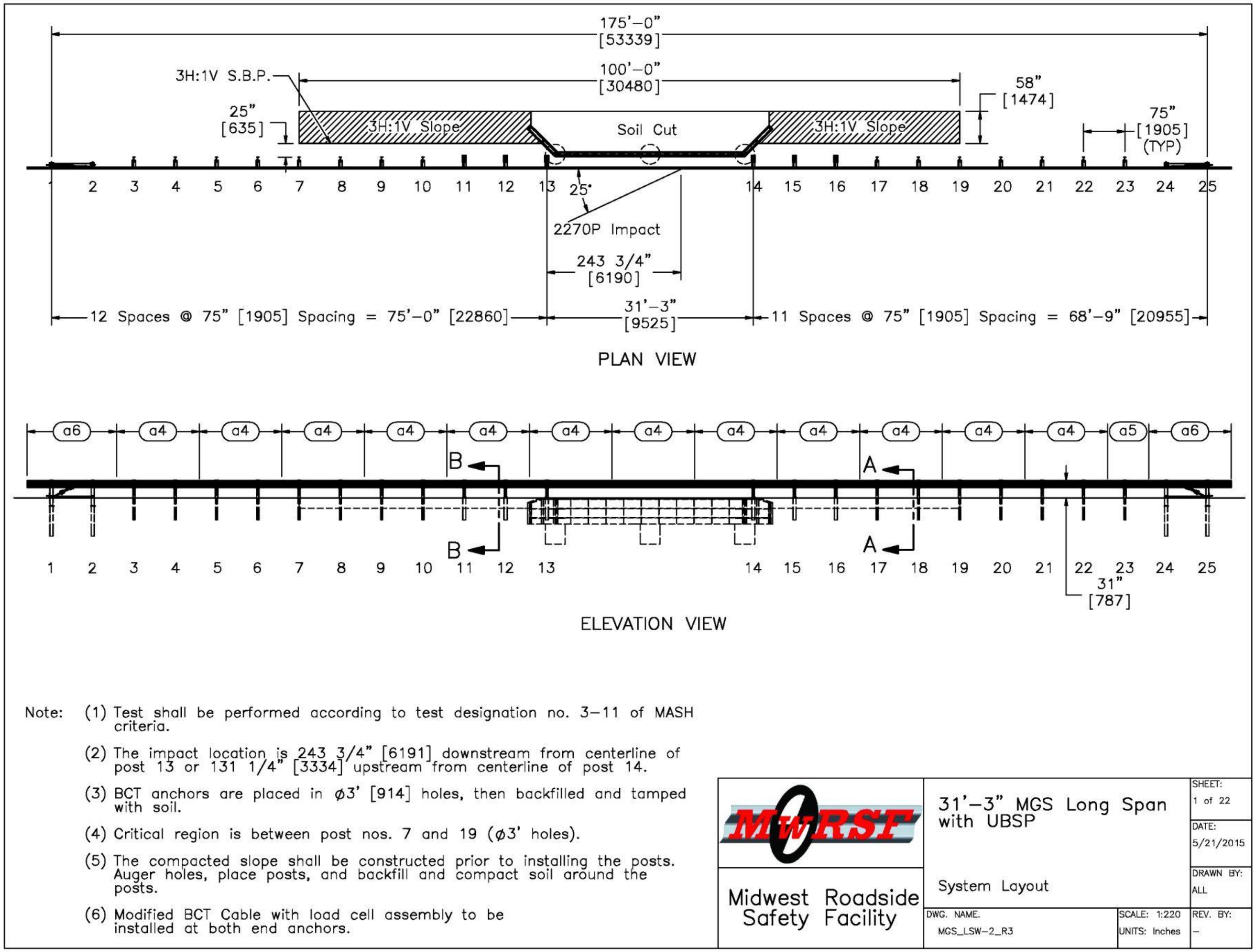


Figure 12. System Layout, Test No. MGSLS-2

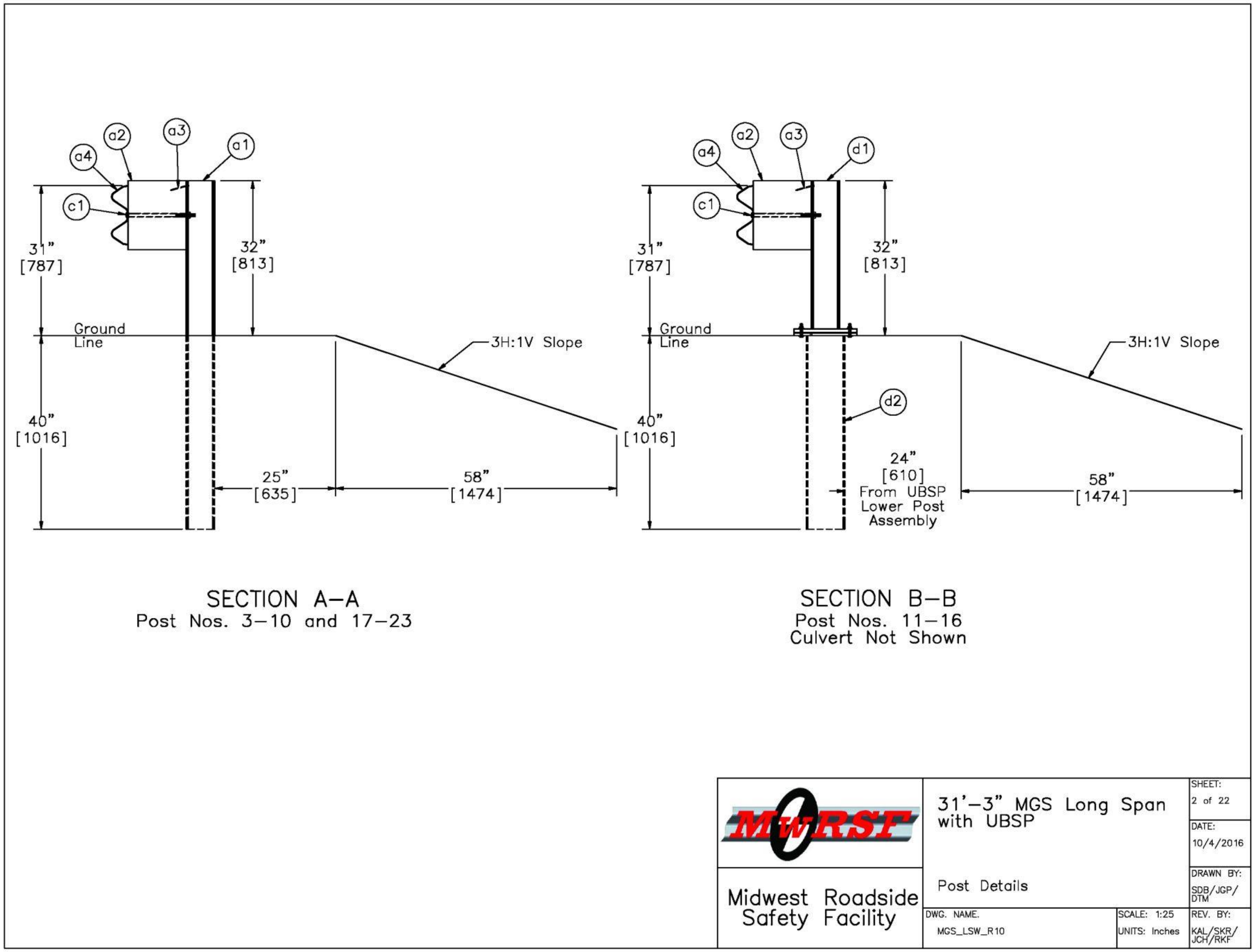


Figure 13. Post Details, Test Nos. MGSLS-1 and MGSLS-2

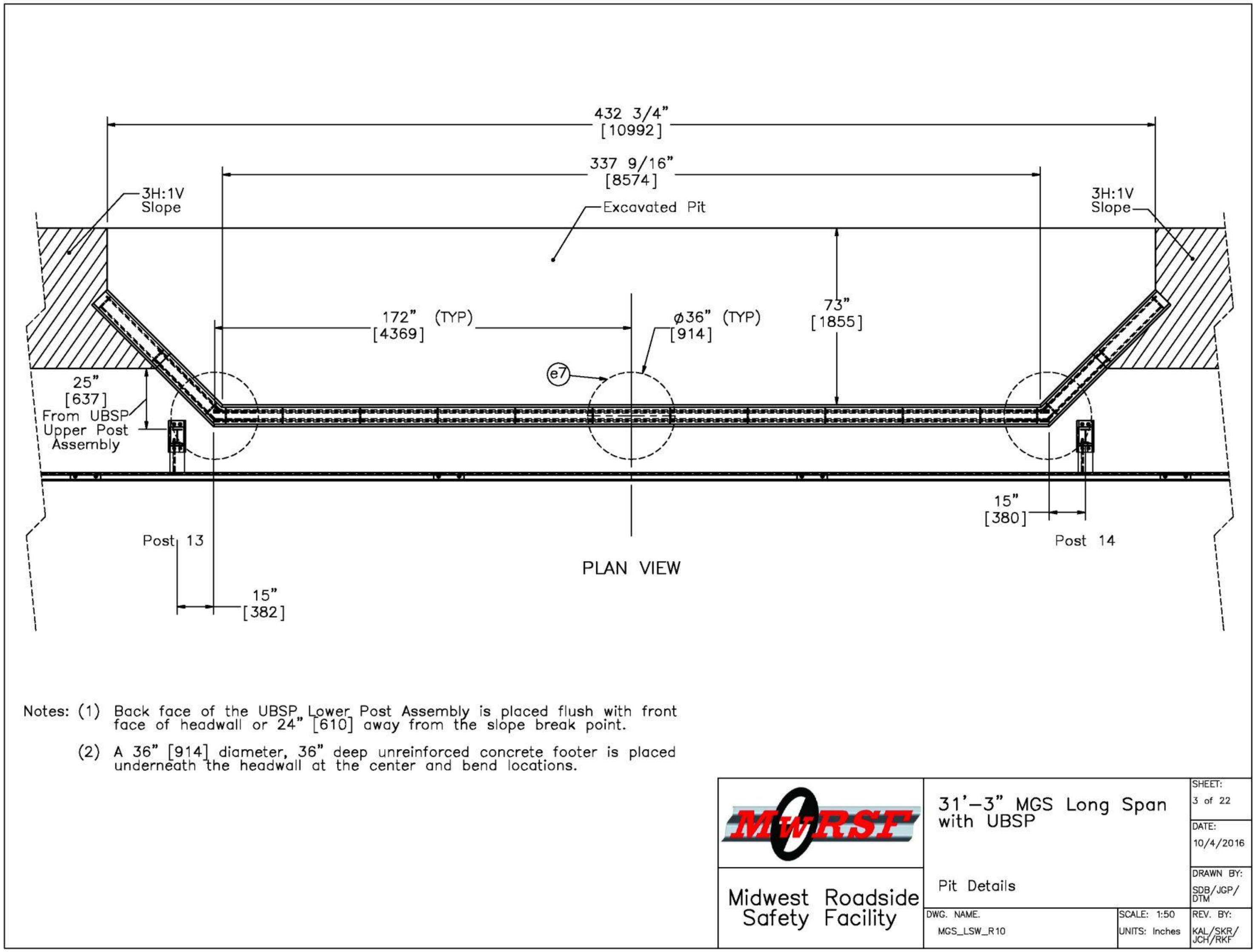


Figure 14. Pit Details, Test Nos. MGSLS-1 and MGSLS-2

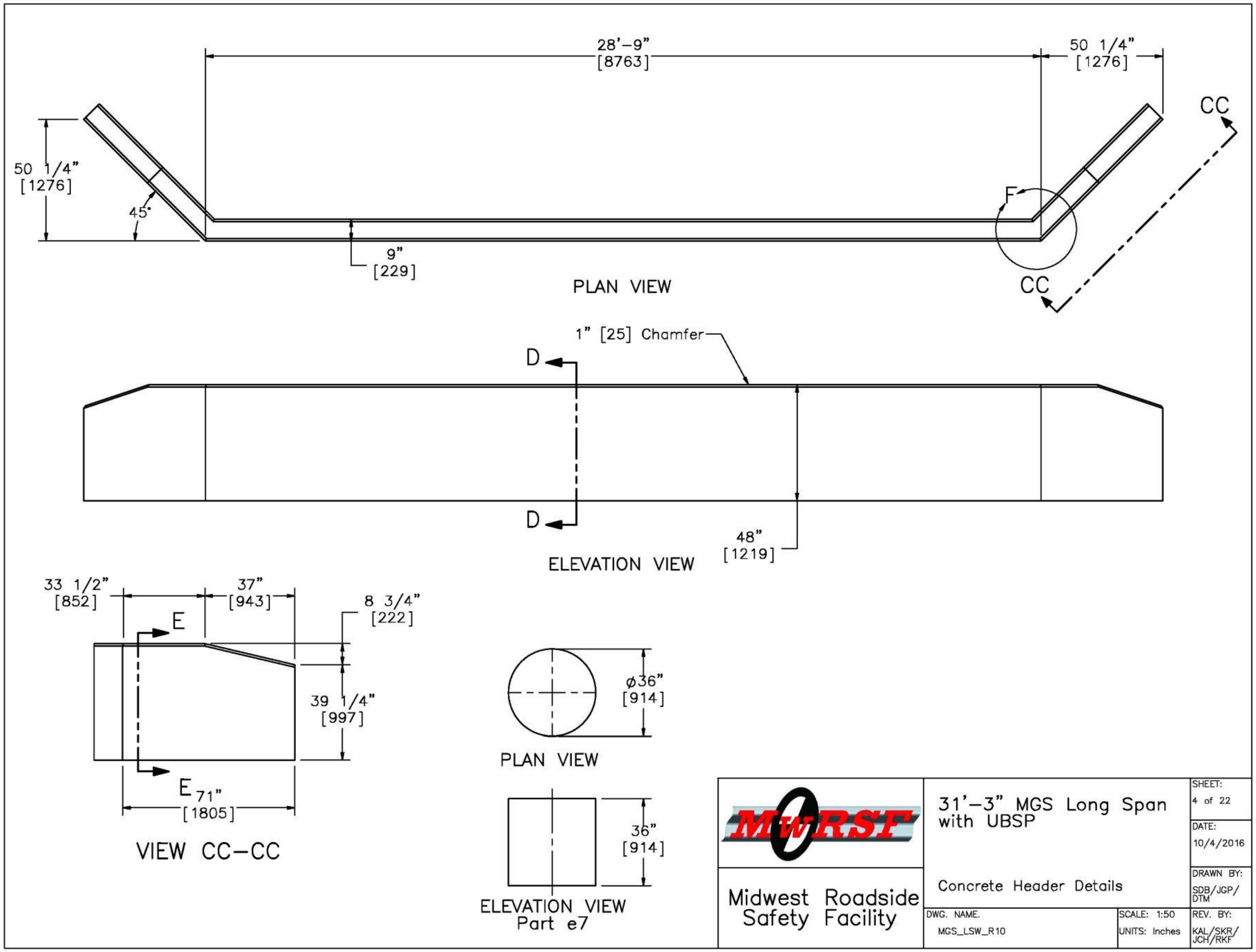


Figure 15. Concrete Header Details, Test Nos. MGSLS-1 and MGSLS-2

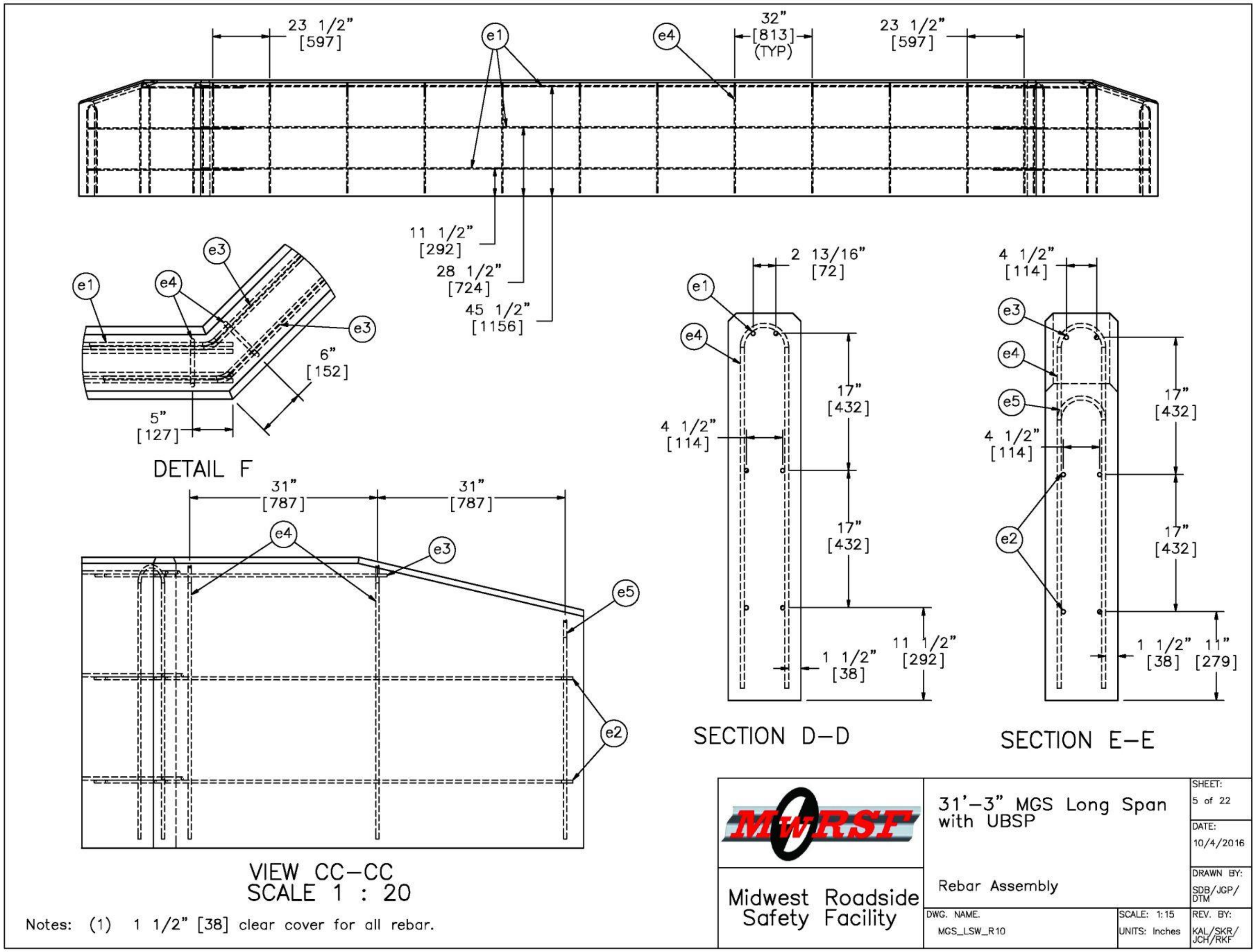


Figure 16. Rebar Assembly, Test Nos. MGSLS-1 and MGSLS-2

Bill of Bars		
Item No.	QTY.	Description
e1	6	#4 Bar – Longitudinal – 345" [8763] long
e2	8	#4 Bar – Bent Longitudinal – 80" [2032] long
e3	4	#4 Bar – Bent Longitudinal – 50" [1270] long
e4	16	#4 Bar – Stirrup – 93" [2362] long
e5	2	#4 Bar – Stirrup – 75" [1905] long

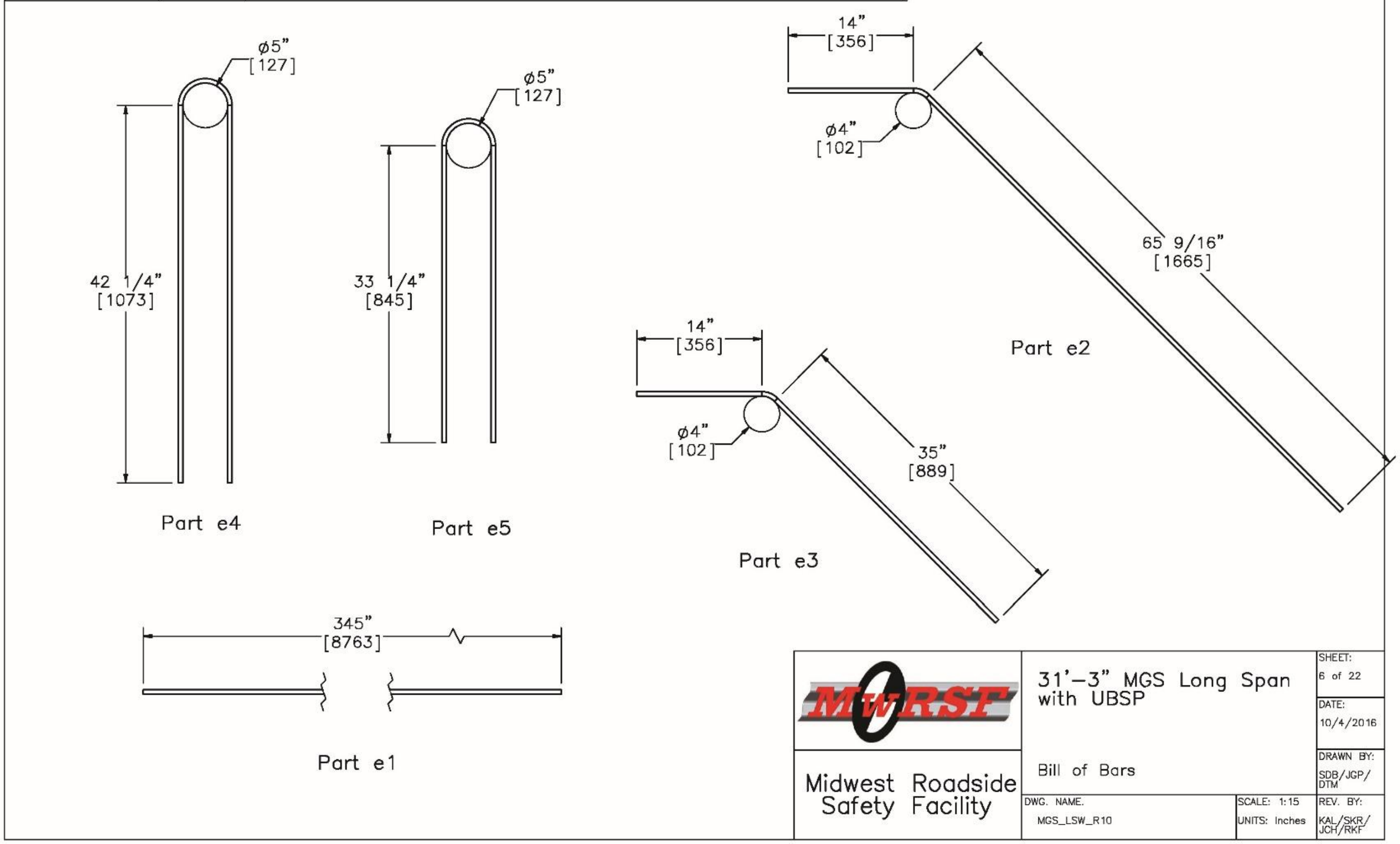


Figure 17. Bill of Bars, Test Nos. MGSLS-1 and MGSLS-2

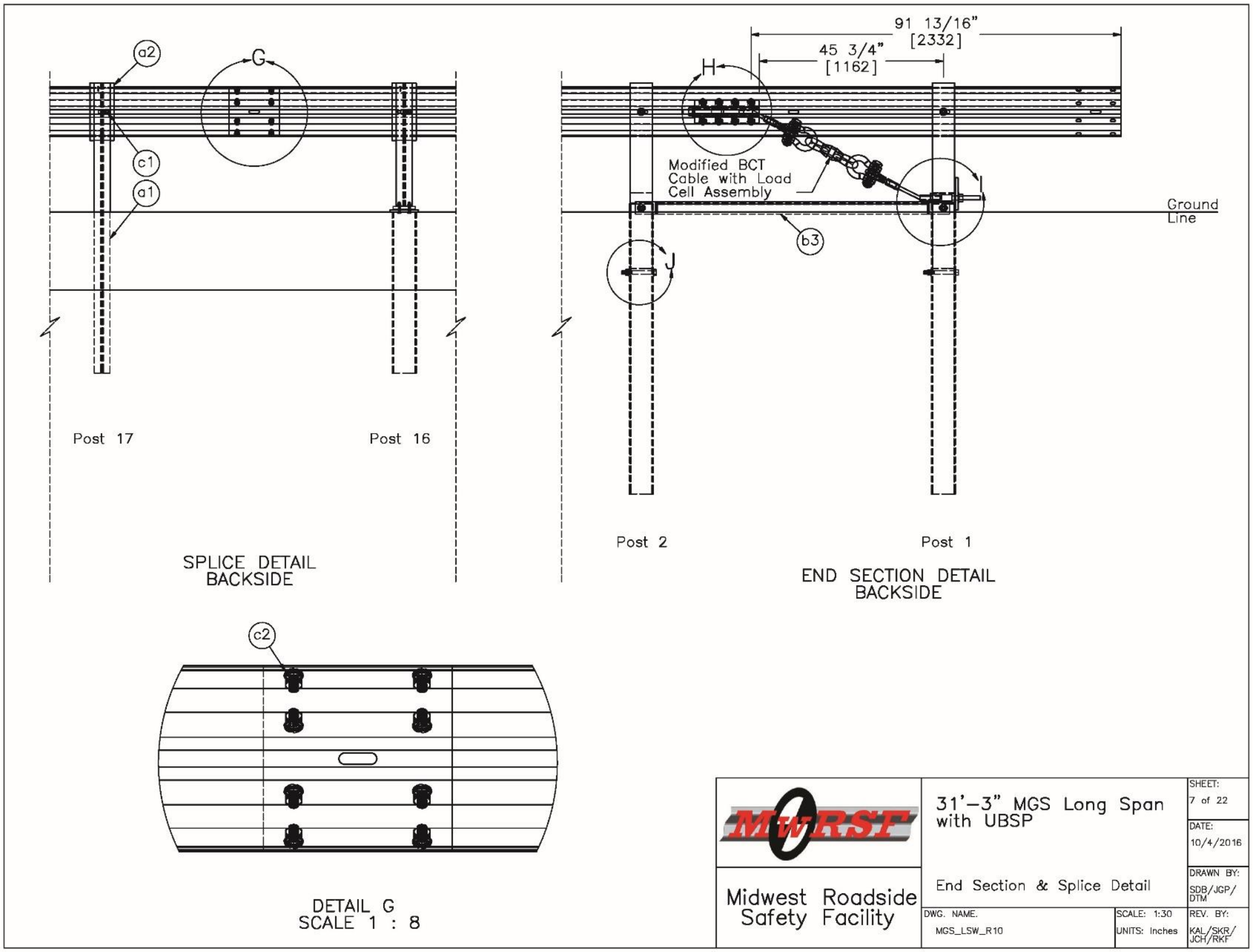


Figure 18. End Section and Splice Detail, Test Nos. MGSLS-1 and MGSLS-2

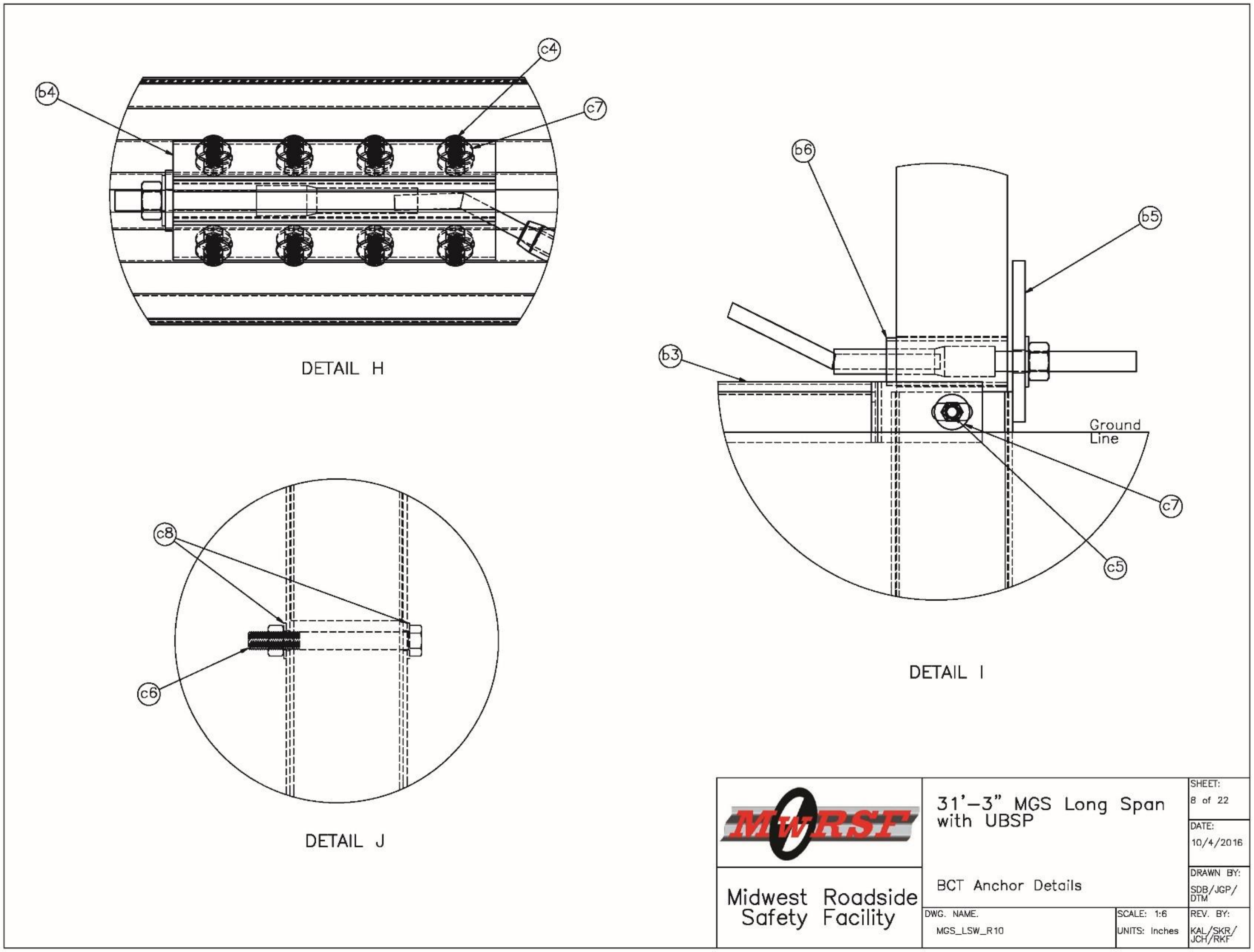


Figure 19. BCT Anchor Details, Test Nos. MGSLS-1 and MGSLS-2

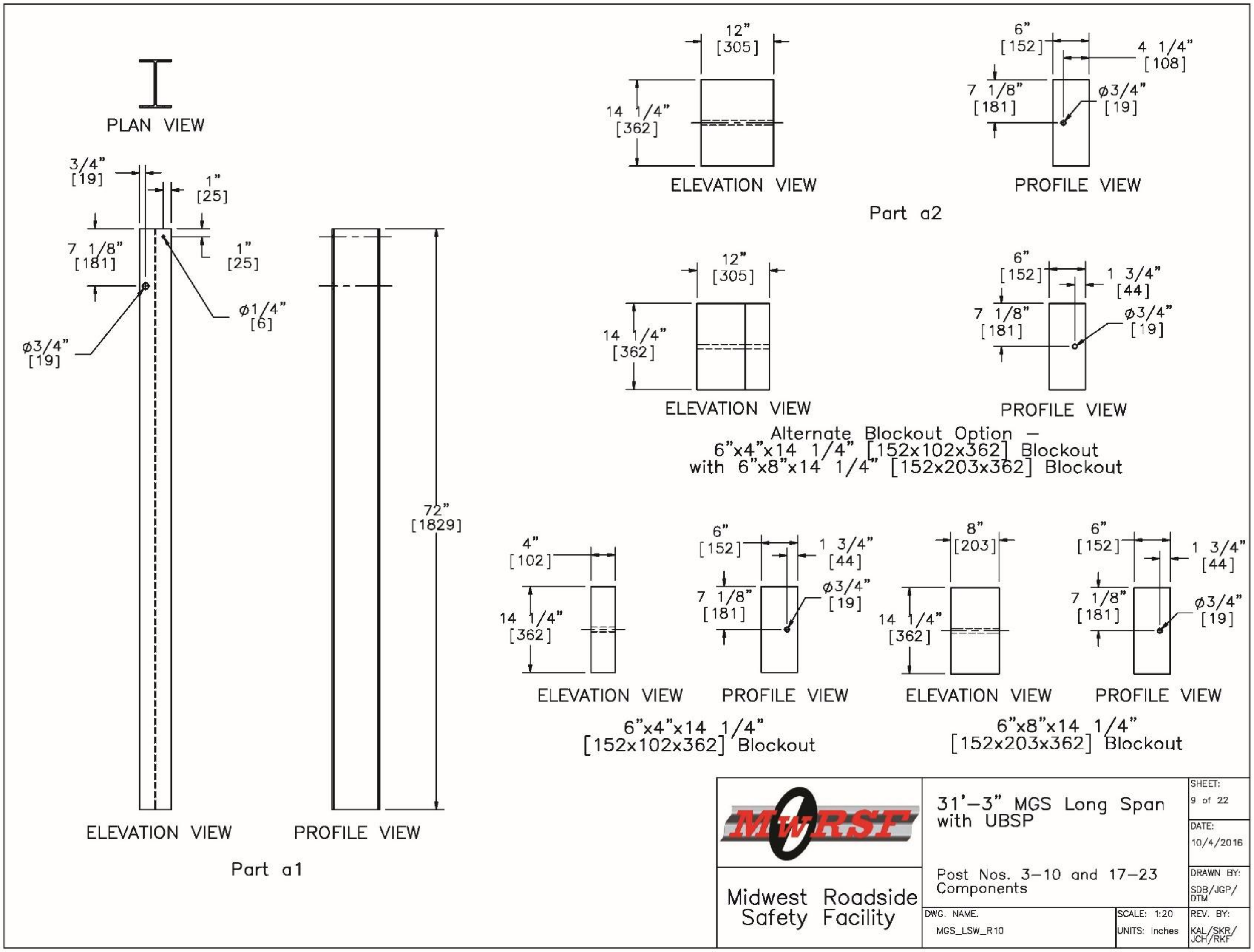


Figure 20. Post Nos. 3 – 10 and 17 – 23 Components, Test Nos. MGSLS-1 and MGSLS-2

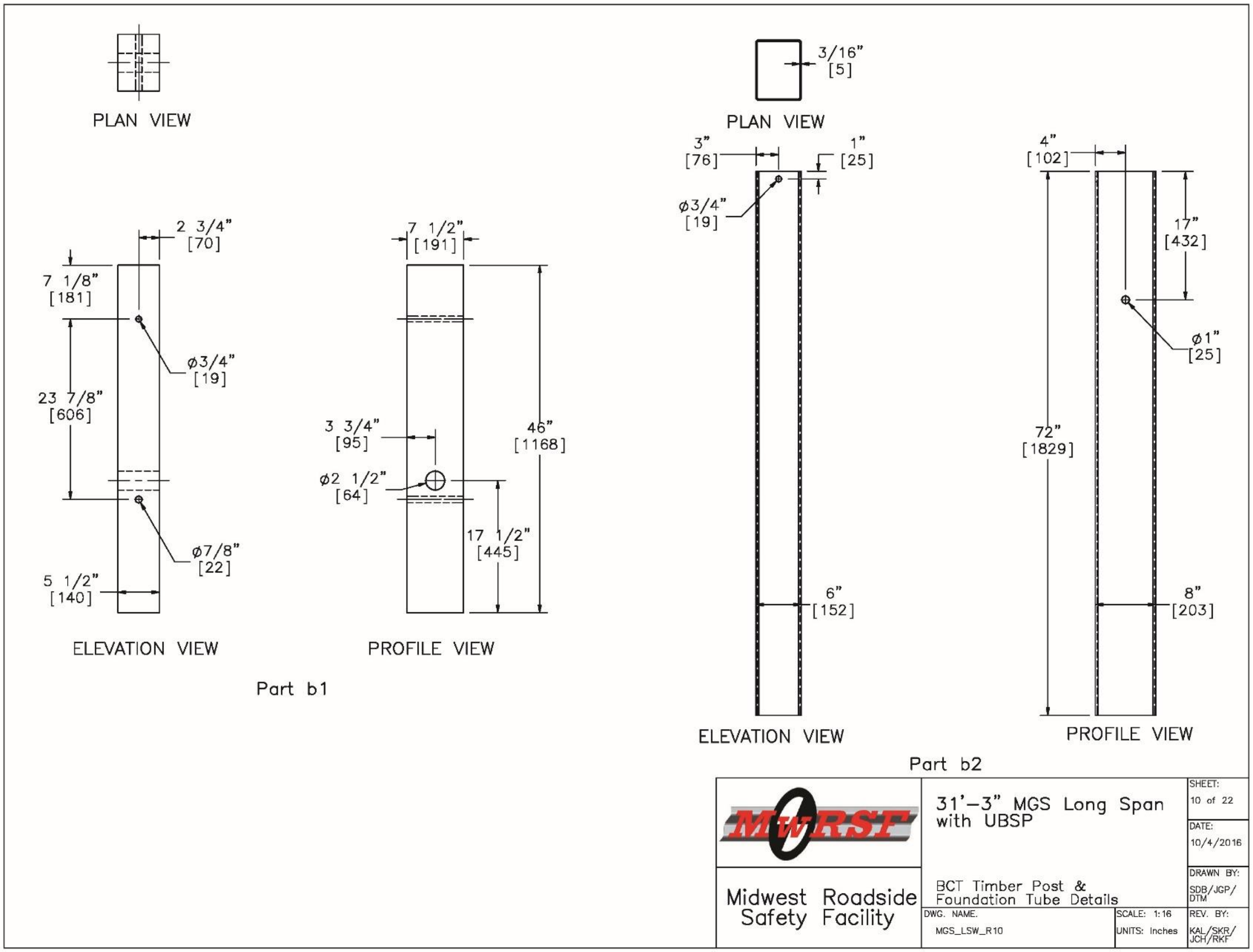


Figure 21. BCT Timber Post and Foundation Tube Details, Test Nos. MGSLS-1 and MGSLS-2

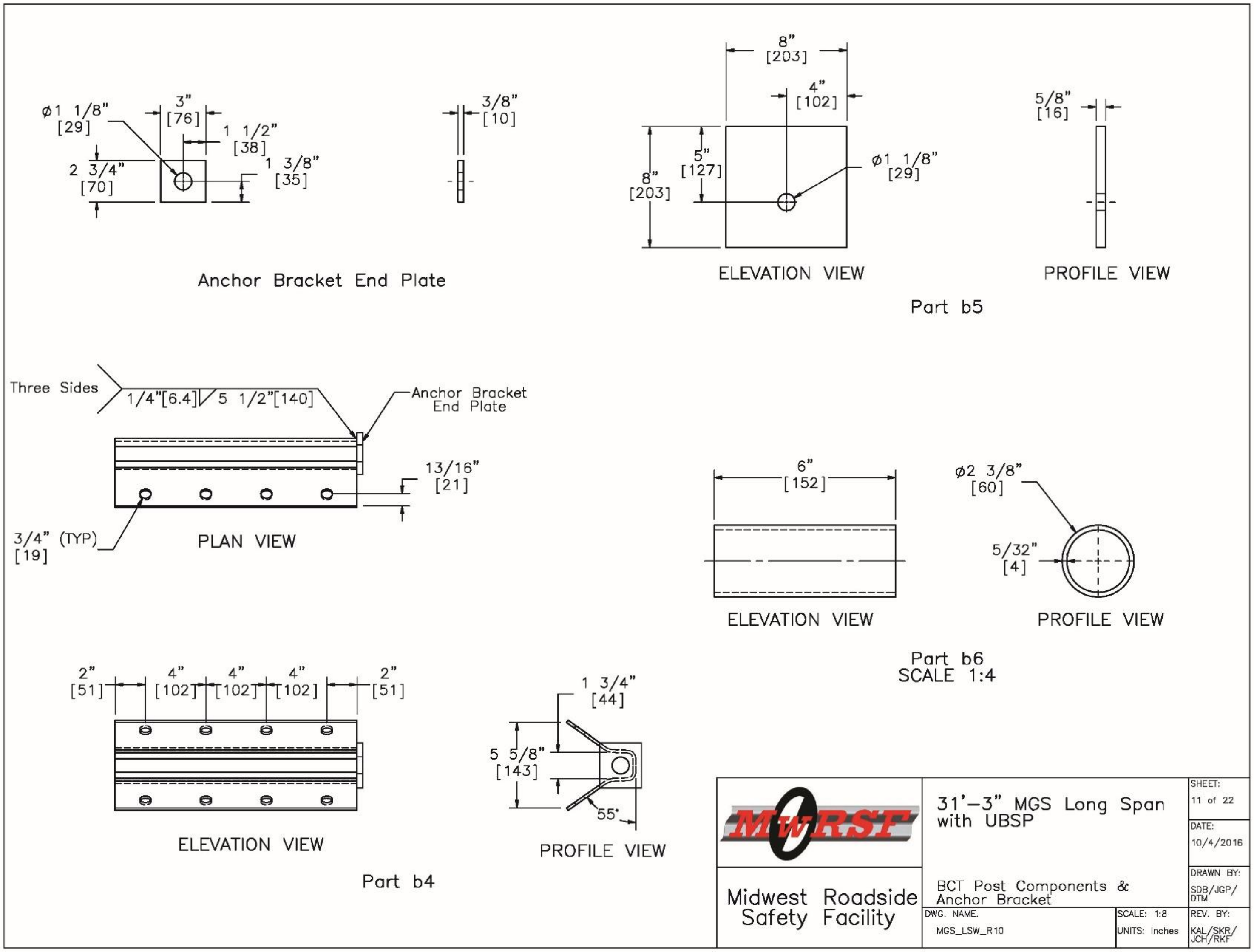


Figure 22. BCT Post Components and Anchor Bracket, Test Nos. MGSLS-1 and MGSLS-2

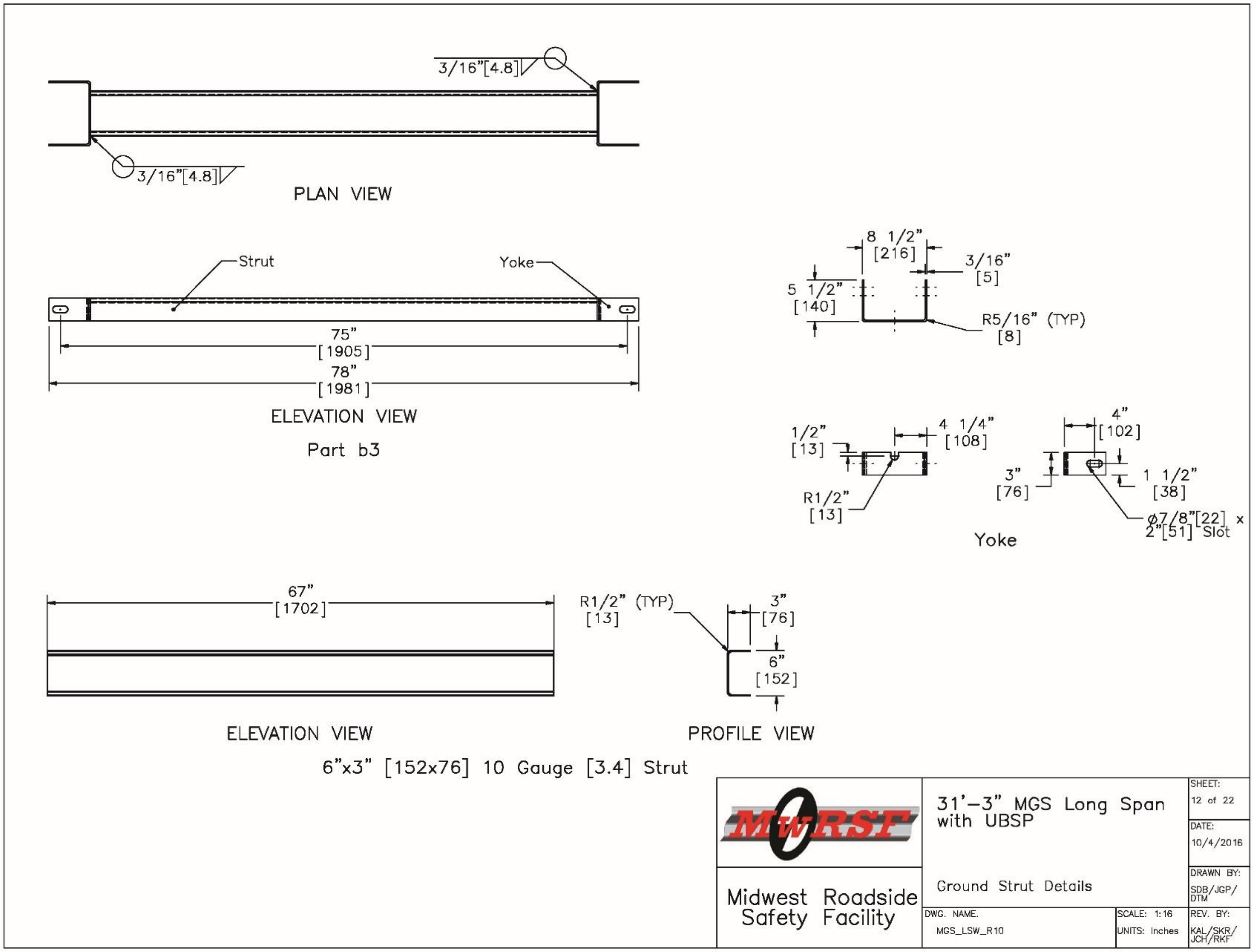


Figure 23. Ground Strut Details, Test Nos. MGSLS-1 and MGSLS-2

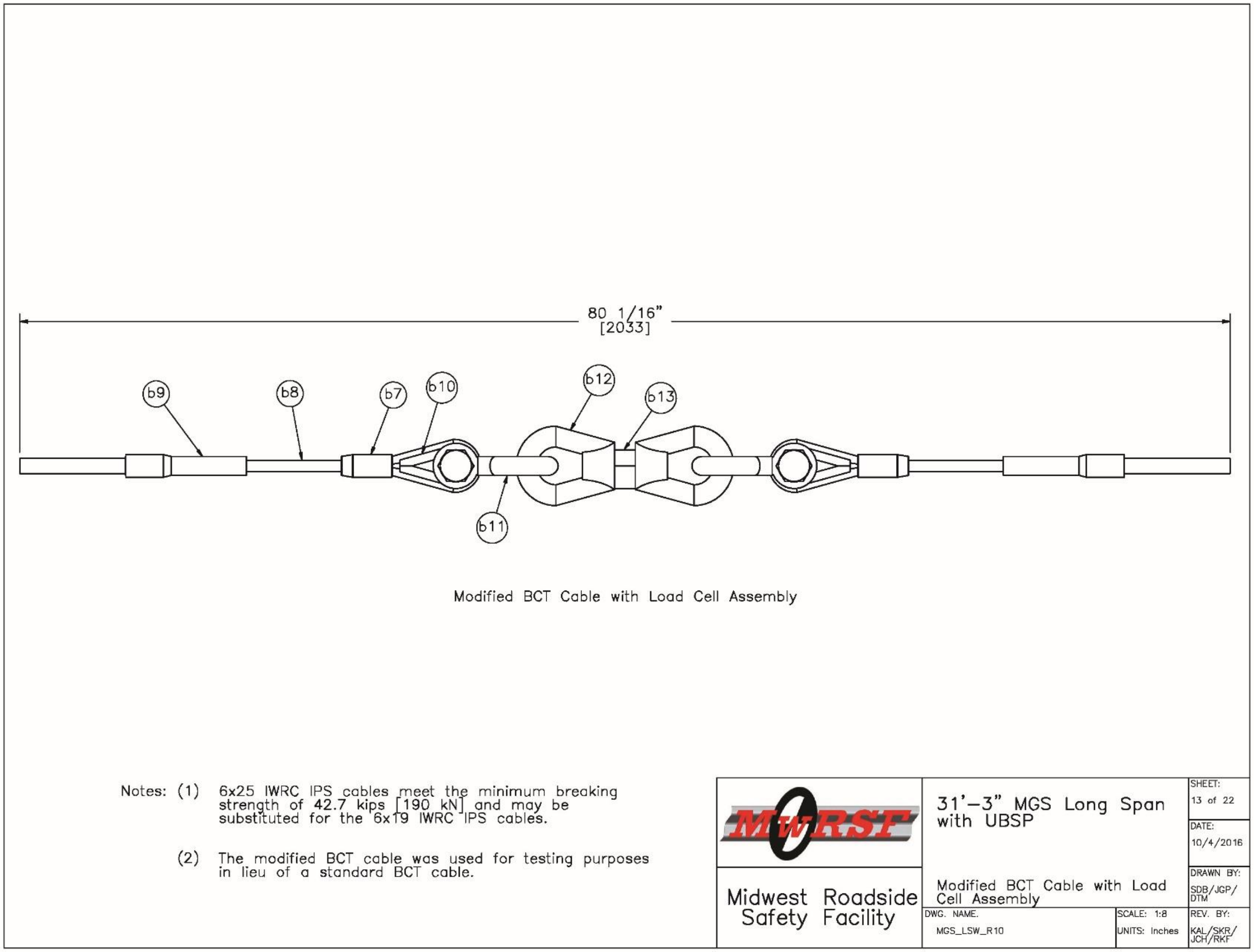


Figure 24. Modified BCT Cable with Load Cell Assembly, Test Nos. MGSLS-1 and MGSLS-2

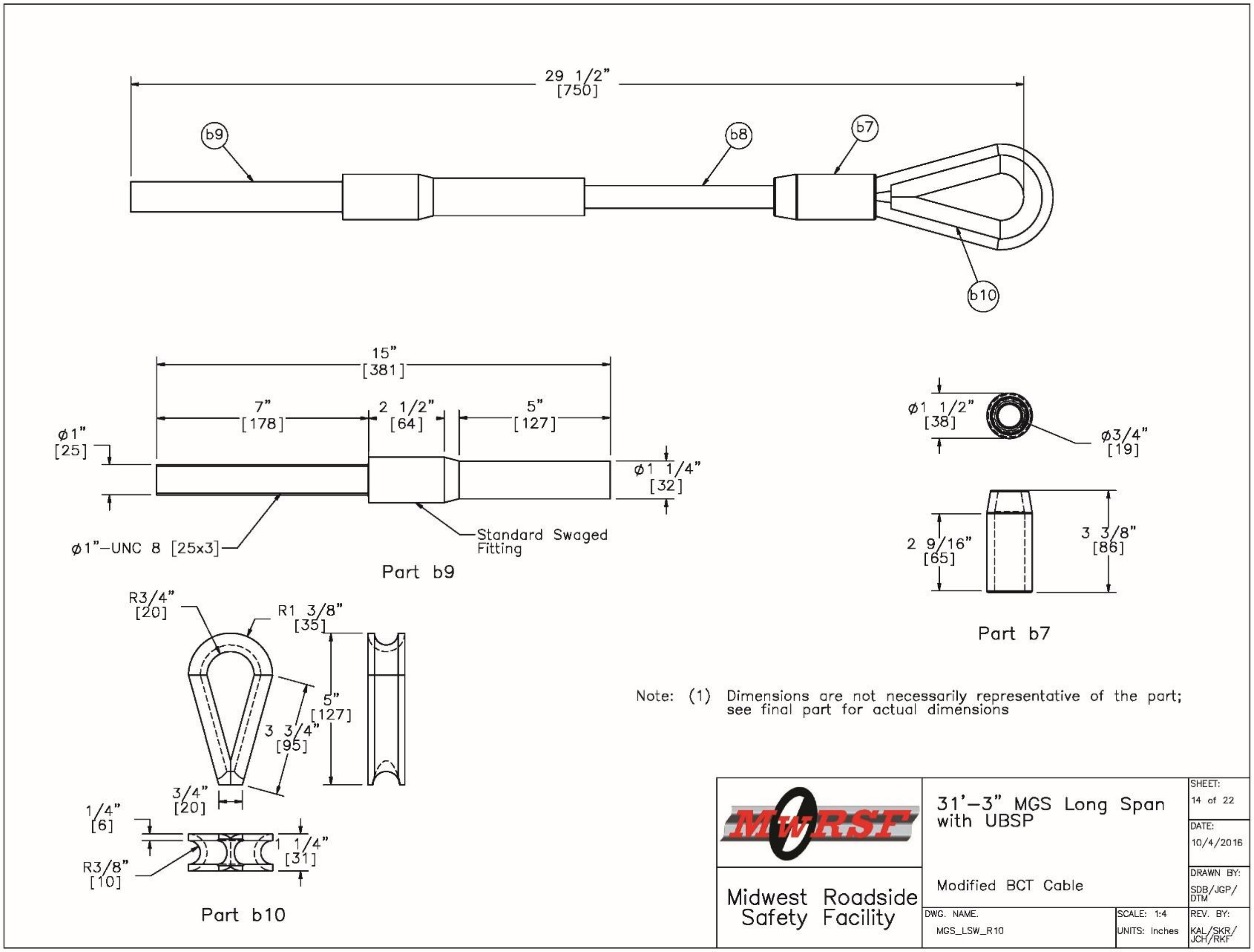


Figure 25. Modified BCT Cable, Test Nos. MGSLS-1 and MGSLS-2

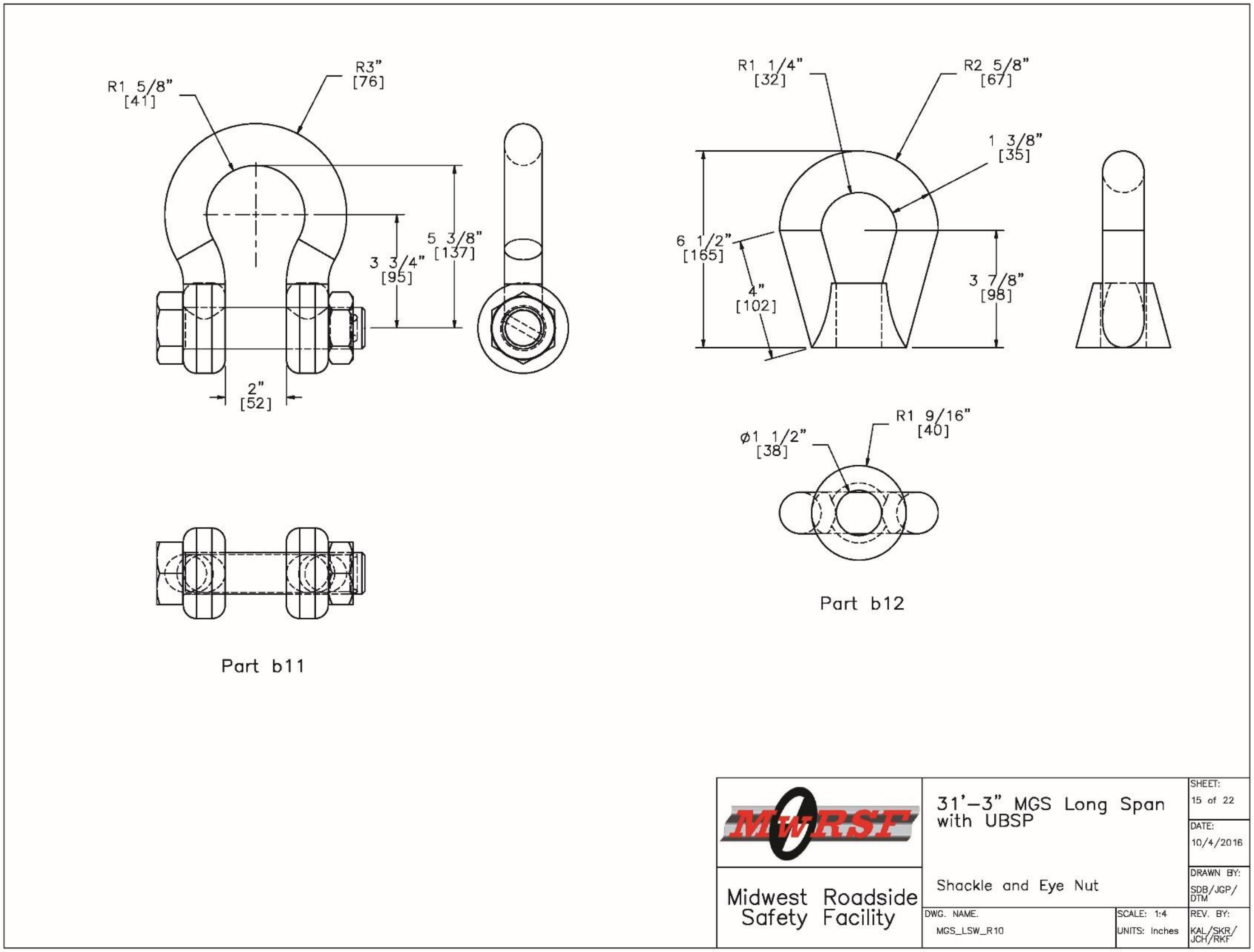


Figure 26. Shackle and Eye Nut, Test Nos. MGSLS-1 and MGSLS-2

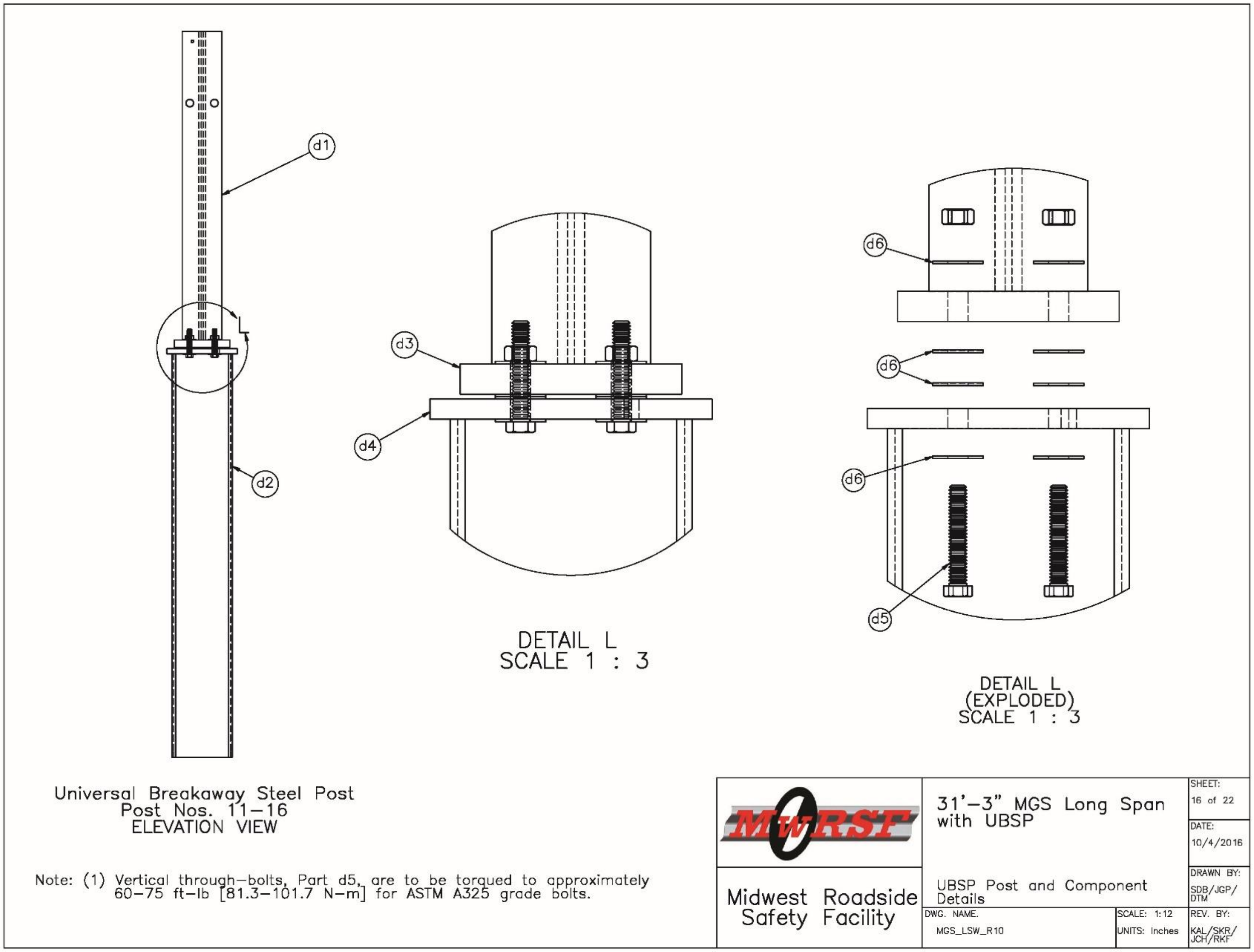


Figure 27. UBSP Post and Component Details, Test Nos. MGSLS-1 and MGSLS-2

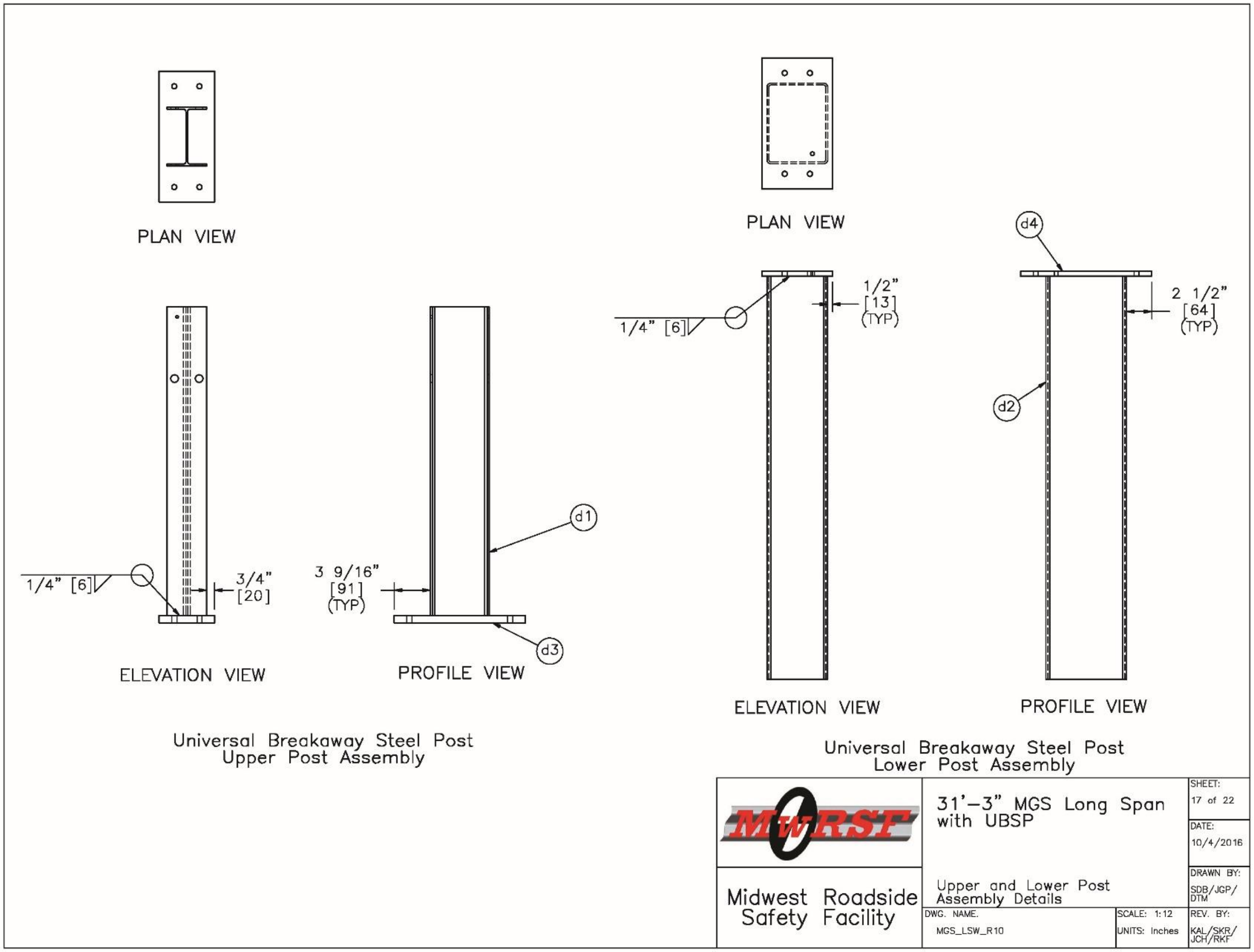


Figure 28. Upper and Lower Post Assembly Details, Test Nos. MGSLS-1 and MGSLS-2

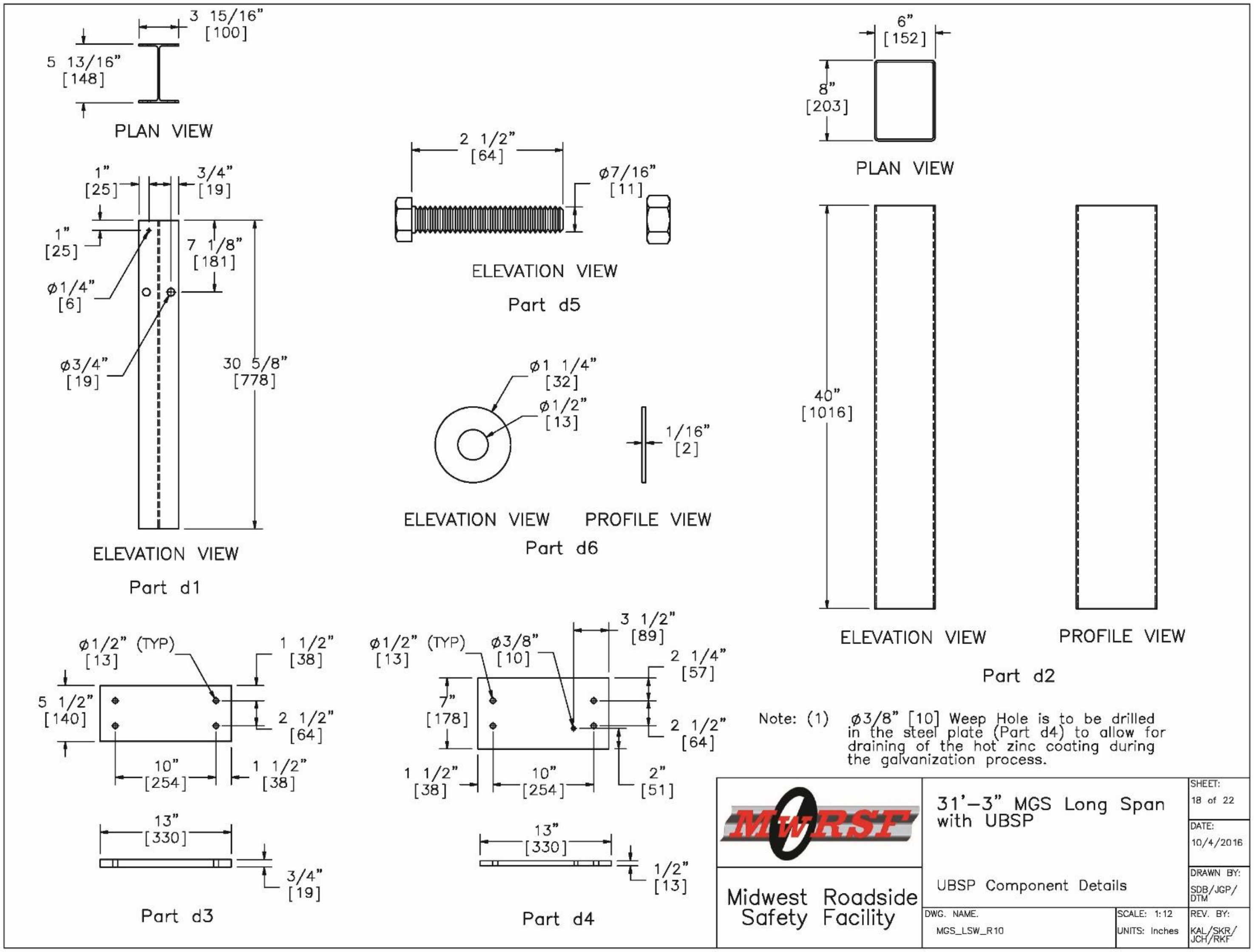


Figure 29. UBSP Component Details, Test Nos. MGSLS-1 and MGSLS-2

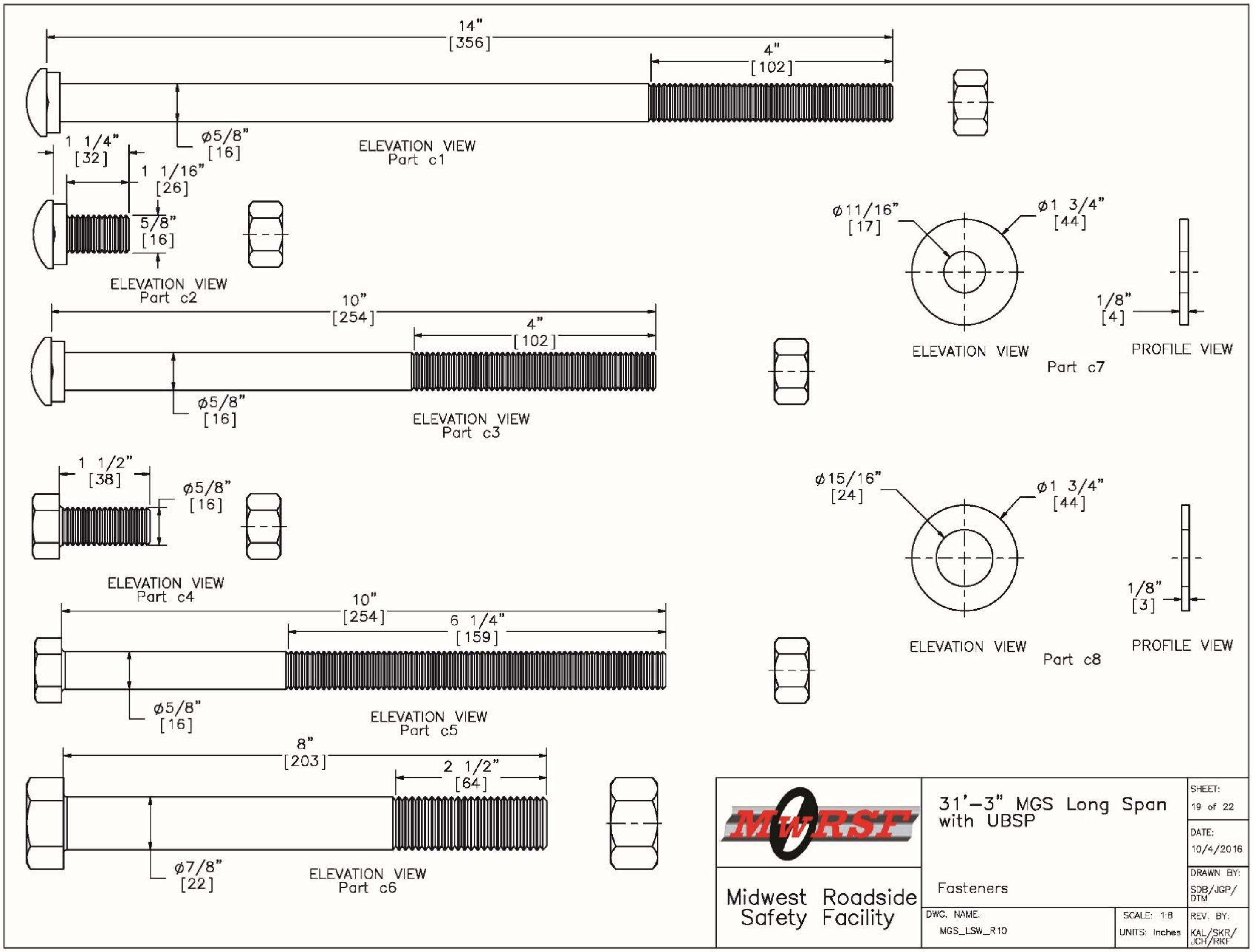


Figure 30. Fasteners, Test Nos. MGSLS-1 and MGSLS-2

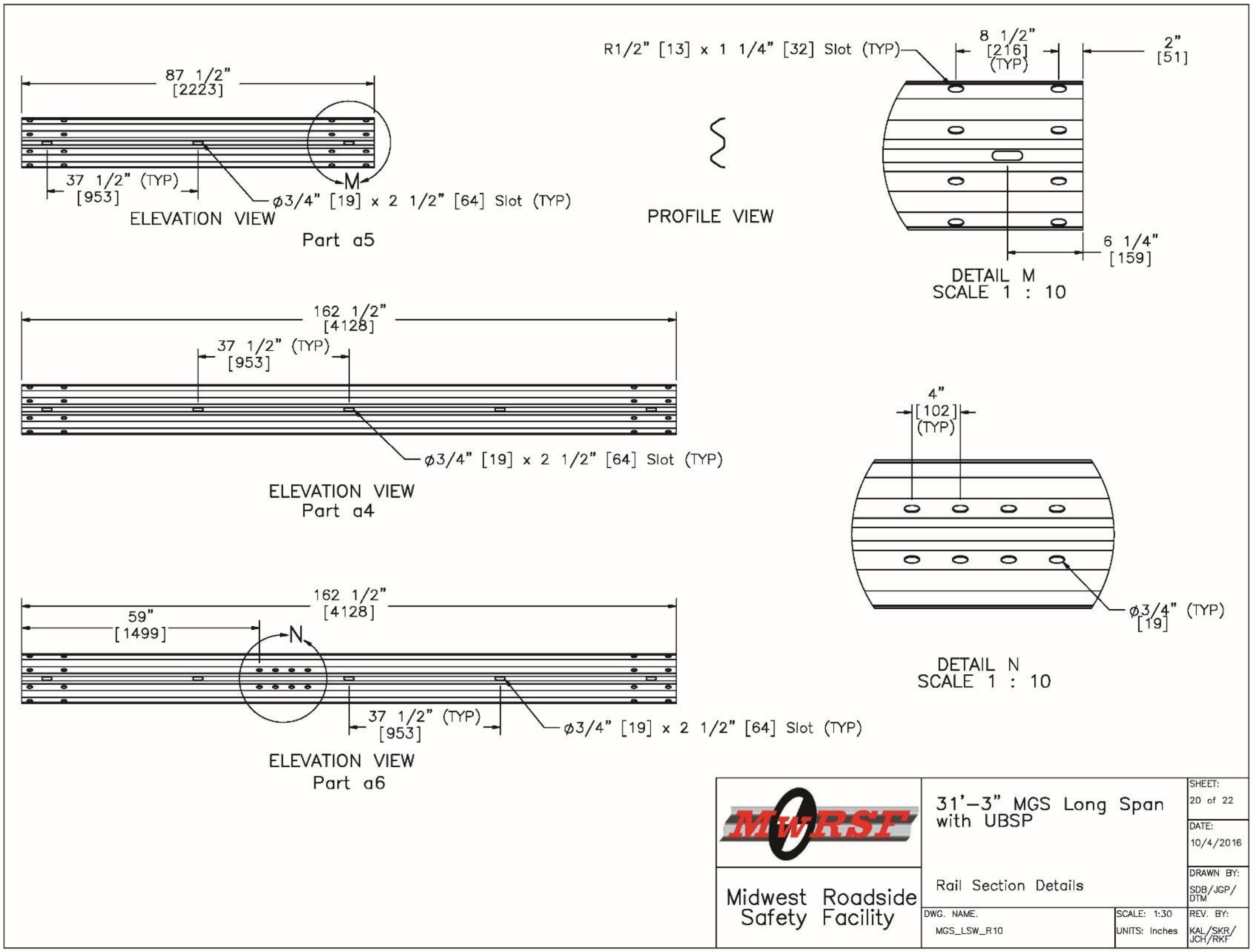


Figure 31. Rail Section Details, Test Nos. MGSLS-1 and MGSLS-2

Item No.	QTY.	Description	Material Specification	Hardware Guide Designation
a1	15	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1829] Steel Post	ASTM A992 Steel Galv., ASTM A36 Steel Galv.	PWE06
a2	21	6x12x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	PDB10a–b
a3	21	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.	–
a6	2	12'–6" [3810] W–Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv.	–
b1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots, 18" [457] above or below ground tension face)	–
b2	4	72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv.	PTE06
b3	2	Strut and Yoke Assembly	ASTM A36 Steel Galv.	–
b4	2	Anchor Bracket Assembly	ASTM A36 Steel Galv.	FPA01
b5	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv.	FPB01
b6	2	2 3/8" [60] O.D. x 6" Long [152] BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv.	FMM02
b7	4	115–HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–
b8	4	3/4" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS Galvanized	–
b9	4	BCT Anchor Cable End Swage Fitting	Grade 5 – Galvanized	–
b10	4	Crosby Heavy Duty HT–3/4" [19] Dia. Cable Thimble	Stock No. 1037773 – Galvanized	–
b11	4	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 – As Supplied	–
b12	4	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNF 12 [M36]	As Supplied, Stock No. 107	–
b13	2	TLL–50K–PTB Load Cell	N/A	–
c1	21	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBB06
c2	112	5/8" [16] Dia. UNC, 1 1/4" [32] Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBB01
c3	4	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBB03
c4	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBX16a
c5	4	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBX16a
c6	4	7/8" [22] Dia. UNC, 8" [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	31'–3" MGS Long Span with UBSP		SHEET: 21 of 22
			DATE: 10/4/2016
	Bill of Materials		DRAWN BY: SDB/JGP/DTM
	DWG. NAME. MGS_LSW_R10	SCALE: None UNITS: Inches	REV. BY: KAL/SKR/JCH/RKF

Figure 32. Bill of Materials, Test Nos. MGSLS-1 and MGSLS-2

Item No.	QTY.	Description	Material Specification	Hardware Guide Designation
d1	6	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 30 5/8" [778] Long Steel Post	ASTM A992 Steel Galv.	PWE11
d2	6	6"x8"x3/16" [152x203x5], 40" [1016] Long Steel Tube	ASTM A500 Steel Grade B Galv.	PTE08
d3	6	13"x5 1/2"x3/4" [330x140x19] Upper Base Plate	ASTM A36 Steel Galv.	PWE11
d4	6	13"x7"x1/2" [330x178x13] Lower Base Plate	ASTM A36 Steel Galv.	PTE08
d5	24	7/16" [11] Dia. UNC, 2 1/2" [64] Long Hex Tap Bolt (Fully Threaded) and Nut	Bolt SAE J449 Grade 5/ASTM A325 Galv., Nut ASTM A563DH Galv.	–
d6	96	7/16" [11] Dia. Plain Round Washer	ASTM F844 Galv., ASTM F436 Type 1 Galv.	–
e1	6	#4 Bar – Longitudinal – 345" [8763] long	Grade 60 Steel	–
e2	8	#4 Bar – Bent Longitudinal – 80" [2032] long	Grade 60 Steel	–
e3	4	#4 Bar – Bent Longitudinal – 50" [1270] long	Grade 60 Steel	–
e4	16	#4 Bar – Stirrup – 93" [2362] long	Grade 60 Steel	–
e5	2	#4 Bar – Stirrup – 75" [1905] long	Grade 60 Steel	–
e6	–	Concrete	Minimum f'c=4000 psi	–
e7	3	36" [914] Dia., 36" Long Unreinforced Concrete Footer	Minimum f'c=4000 psi	–

Midwest Roadside Safety Facility

31'–3" MGS Long Span with UBSP

Bill of Materials

SHEET: 22 of 22
DATE: 10/4/2016
DRAWN BY: SDB/JGP/DTM
DWG. NAME. MGS_LSW_R10
SCALE: None
UNITS: Inches
REV. BY: KAL/SKR/JCH/RKF

Figure 33. Bill of Materials Continued, Test Nos. MGSLS-1 and MGSLS-2

Figure 34. Test Installation, Test No. MGSLS-1

Figure 35. Test Installation, Test No. MGSLS-1

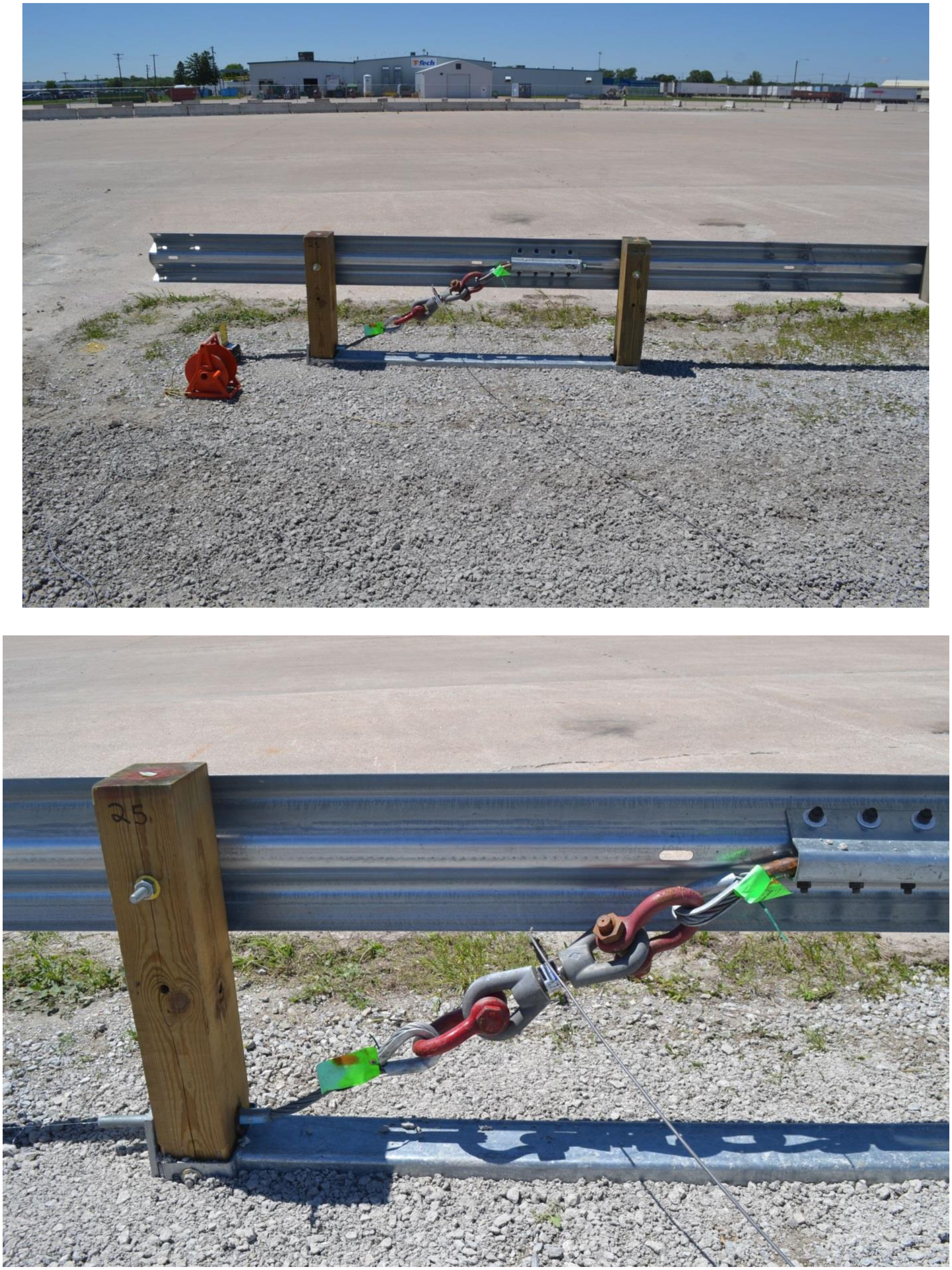


Figure 36. Test Installation Anchorage (Downstream), Test No. MGSLS-1

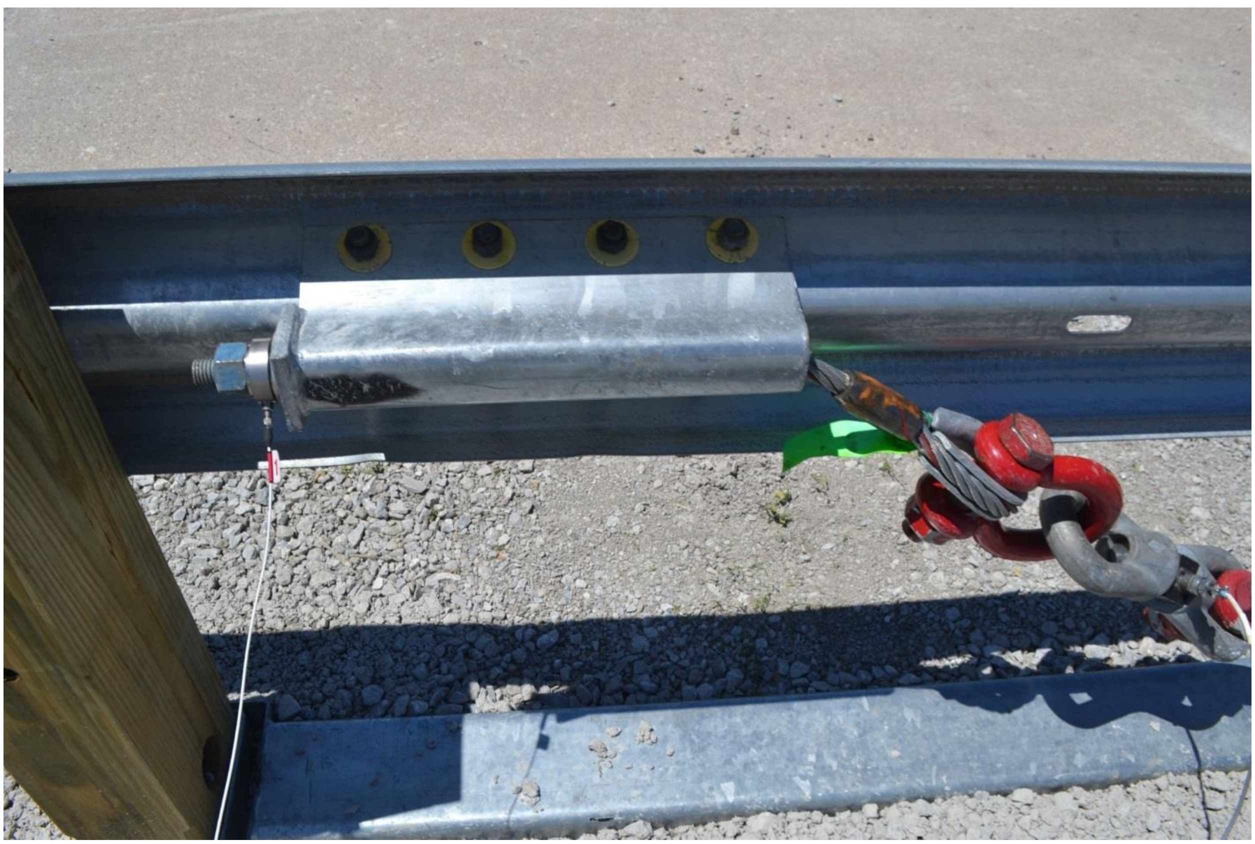


Figure 37. Test Installation Anchorage (Upstream), Test No. MGSLS-1

Figure 38. Test Installation, Test No. MGSLS-2

Figure 39. Test Installation Continued, Test No. MGSLS-2

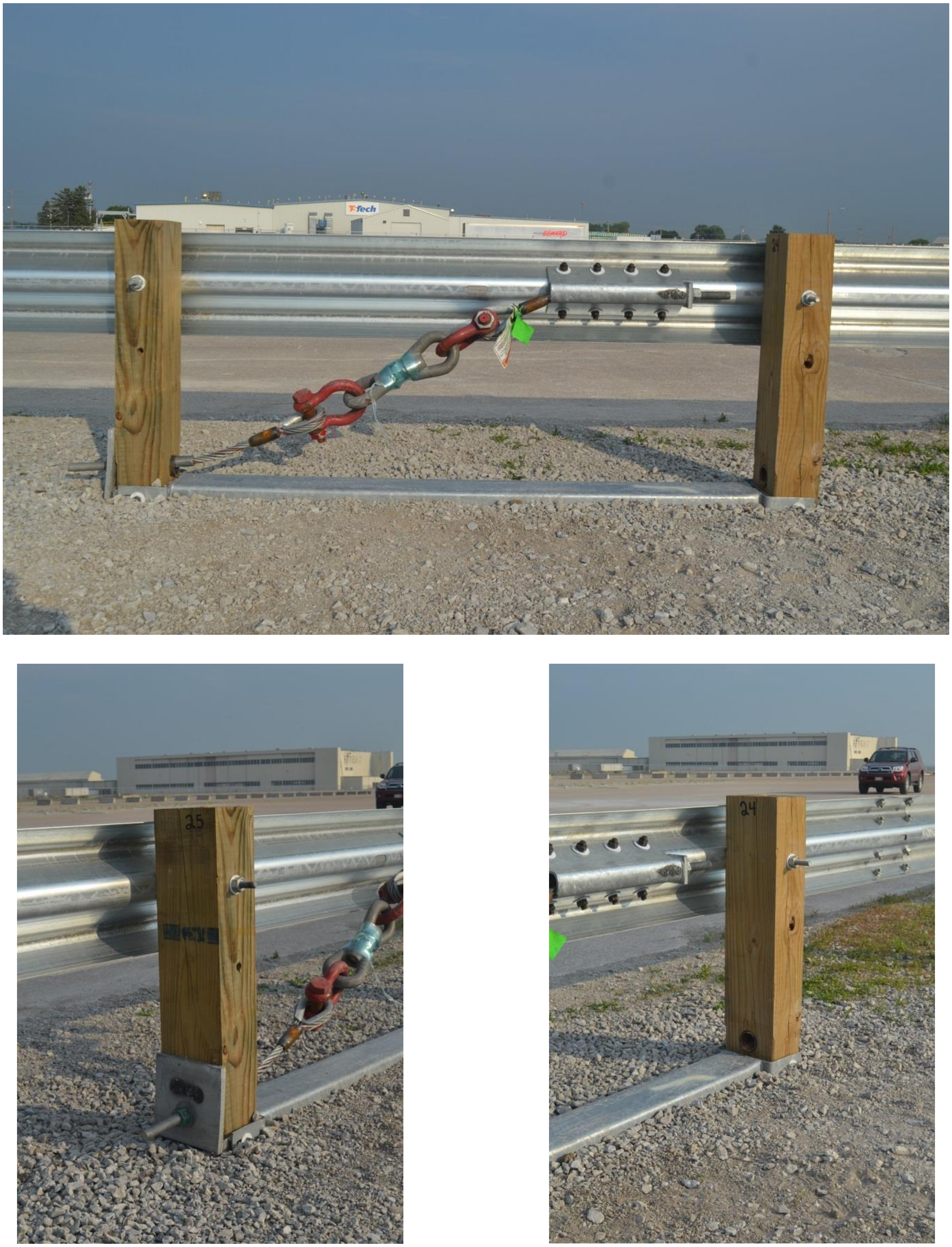


Figure 40. Test Installation Anchorage (Downstream), Test No. MGSLS-2

Figure 41. Test Installation Anchorage (Upstream), Test No. MGSLS-2

5 FULL-SCALE CRASH TEST NO. MGSLS-1

5.1 Static Soil Test

Before full-scale crash test no. MGSLS-1 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

5.2 Test No. MGSLS-1

In accordance with MASH test designation no. 3-11, the 4,955-lb (2,248-kg) pickup truck impacted the MGS long-span system at a speed of 62.7 mph (100.9 km/h) and an angle of 25.3 degrees. A summary of the test results and sequential photographs are shown in Figure 42. Additional sequential photographs are shown in Figures 43 and 44. Documentary photographs of the crash test are shown in Figure 45.

5.3 Weather Conditions

Test no. MGSLS-1 was conducted on May 18, 2015 at approximately 2:45 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), were reported and are shown in Table 3.

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

Temperature	63° F
Humidity	45 %
Wind Speed	16.0 mph
Wind Direction	320° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	1.65 in.
Previous 7-Day Precipitation	2.11 in.

5.4 Test Description

Initial vehicle impact was to occur at the centerline of post no. 11, as shown in Figure 46, which was selected using LS-DYNA analysis to evaluate the potential for vehicle instability by maximizing the interaction of the front wheel of the pickup truck with the wing wall of the culvert [3-4]. The actual point of impact was 1¾ in. (44 mm) downstream from post no. 11. A sequential description of the impact events is contained in Table 4. The vehicle came to rest 30 ft – 10 in. (9.4 m) behind the system and 177 ft – 6 in. (54.1 m) downstream from the point of impact. The vehicle trajectory and final position are shown in Figures 42 and 47.

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

TIME (sec)	EVENT
0	Vehicle's left-front bumper contacted rail between post nos. 11 and 12.
0.004	Post no. 11 deflected backward. Vehicle's left-front bumper deformed.
0.008	Post no. 12 deflected backward. Vehicle's left headlight deformed.
0.012	Vehicle's left fender deformed.
0.014	Post no. 10 deflected backward, and post no. 11 twisted upstream.
0.016	Post no. 12 twisted downstream.
0.018	Post no. 13 twisted downstream.
0.020	Post no. 12 rotated backward.
0.022	Post no. 13 deflected downstream. Soil heave formed on non-traffic flange of post no. 12.
0.024	Vehicle's left-front door deformed W-beam. Bottom corrugation of rail flattened between post nos. 11 and 12.
0.026	Post no. 10 twisted upstream, and post no. 9 deflected backward. Soil heave formed on non-traffic flange of post no. 11. Vehicle's hood deformed.
0.028	Post no. 4 twisted upstream, and post no. 14 twisted downstream.
0.030	Post no. 15 twisted downstream.
0.032	Post no. 9 twisted upstream.
0.036	Post no. 5 twisted upstream. Post no. 8 deflected backward and twisted upstream.
0.038	Post nos. 6 and 7 twisted upstream.
0.04	Post no. 10 deflected downstream. Vehicle yawed away from barrier.
0.041	Post no. 12 bent backward.
0.044	Top corrugation kinked between post nos. 12 and 13.
0.047	Post nos. 13 and 14 deflected backward.

0.050	Soil heave formed on non-traffic flange of post no. 13.
0.052	Post no. 13 rotated backward, and blockout no. 12 detached from rail. Bottom corrugation kinked downstream from post no. 13.
0.053	Post no. 13 bent backward.
0.066	Post no. 12 detached from base.
0.076	Post no. 15 deflected backward.
0.078	Vehicle’s left-front tire entered ditch.
0.082	Vehicle’s left-front tire contacted base of post no. 12.
0.094	Post no. 16 deflected backward. Vehicle pitched upward.
0.100	Post no. 12 detached from blockout no. 12.
0.104	Blockout no. 13 detached from rail.
0.120	Post no. 17 deflected backward.
0.126	Soil heave formed on traffic-side flange of post no. 15.
0.128	Vehicle’s left-front tire contacted base of post no. 13. Vehicle’s left headlight detached. Post no. 13 detached from base.
0.157	Vehicle’s left-front tire entered culvert.
0.164	Post no. 13 detached from blockout no. 13.
0.170	Soil heave formed on non-traffic flange of post no. 14.
0.174	Vehicle rear bumper deformed.
0.181	Post no. 14 bent backward.
0.188	Vehicle’s left-front tire became airborne.
0.224	Vehicle rolled toward barrier.
0.228	Vehicle’s left quarter panel contacted rail.
0.230	Vehicle’s left quarter panel deformed. Vehicle pitched downward as vehicle’s left-rear tire entered ditch.
0.262	Blockout no. 5 detached from rail. Rail became entrapped between vehicle’s left-front tire and left fender.
0.264	Blockout nos. 4 and 6 detached from rail.
0.276	Blockout no. 9 detached from rail.
0.278	Blockout no. 7 detached from rail.
0.304	Vehicle’s left-rear tire entered culvert.
0.334	Vehicle pitched upward.
0.356	Blockout no. 8 detached from rail.
0.362	Vehicle’s left-rear tire became airborne.
0.368	Vehicle was parallel to system.
0.488	Vehicle’s left-front tire contacted downstream end of culvert wall.
0.535	Vehicle’s left-front tire exited culvert.
0.550	Vehicle’s left-front tire contacted base of post no. 14.
0.562	Vehicle pitched downward.
0.566	Vehicle rolled away from barrier.
0.582	Blockout no. 11 detached from rail.
0.598	Vehicle’s left-front wheel detached.
0.604	Blockout no. 14 detached from rail.

0.612	Vehicle's left-rear tire contacted culvert wall.
0.634	Vehicle's left-front bumper contacted blockout no. 15.
0.640	Vehicle's right-front tire regained contact with ground.
0.650	Vehicle's left-rear tire exited culvert.
0.740	Vehicle's left-rear tire exited ditch.
0.814	Vehicle pitched upward.
0.832	Vehicle rolled toward barrier.
0.932	Vehicle's right-rear tire was airborne.
0.942	Vehicle yawed toward barrier.
0.944	Vehicle's left-rear tire regained contact with ground.
0.992	Vehicle's right-front tire became airborne.
1.040	Vehicle exited system at 27.3 mph (44.0 km/h) at an angle of 13.3 degrees.
1.044	Vehicle's right-rear tire regained contact with ground.
1.168	Vehicle pitched downward.
1.216	Vehicle rolled away from barrier.
1.244	Vehicle's right-front tire regained contact with ground.
1.328	Vehicle's front bumper contacted ground.
1.390	Vehicle pitched upward.
1.700	Vehicle pitched downward.
1.904	Vehicle rolled toward barrier.
2.082	Vehicle pitched upward.
3.190	Vehicle came to rest 197 ft – 11 in. (60.3 m) downstream from the point of impact and 30 ft – 10 in. (9.4 m) behind system.

5.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 48 through 55. All system damage photographs depicted in Figures 48 through 55 were taken after the cable anchors were disassembled and removed from the system. Barrier damage consisted of rail deformation, disengagement of the W-beam rail from the posts, bending of the steel posts, fracture of the wooden posts, and damage to the culvert. The length of vehicle contact along the barrier was approximately 52 ft – 8 in. (16.1 m), which spanned from 1¾ in. (44 mm) downstream from the center of post no. 11 through 34 in. (864 mm) downstream from the center of post no. 15.

Deformation of the W-beam rail occurred between post nos. 2 through 16 with the most significant damage occurring where the vehicle initially contacted the barrier between post nos.

11 and 12. Due to the disengagement of the rail, post no. 2 had a kink in the top rail 3 in. (76 mm) upstream from the center of the post. Flattening, scraping, kinking, and bending of the W-beam occurred between post nos. 11 and 12. Flattening of the bottom corrugation began 22 in. (559 mm) upstream from post no. 12 and ended at post no. 13. There was a 39-in. (991-mm) long contact mark that started 25 in. (635 mm) upstream from post no. 12 located 3½ in. (89 mm) from the bottom of the rail. The largest kink was 125 in. (3,175 mm) long at the bottom of the rail starting 33 in. (838 mm) downstream from post no. 11. A 31-in. (787-mm) long dent and gouge occurred 4¾ in. (121 mm) downstream from post no. 11. Tears and bending occurred at the bolt holes between post nos. 2 through 12, 15, and 16. The largest tear was 1 in. (25 mm) at the top bolt hole of post no. 2, and the largest bend was 5 in. (127 mm) long and ¼ in. (6 mm) deep at the top upstream bolt of post no. 10. The rail released from post nos. 2 through 9 and 11 through 23 where the bolt heads pulled through the slots in the rail.

Wood post damage included splitting, rotation, and displacement of the posts. Post no. 1 rotated downstream and had a 3-in. (76-mm) cut located at the top of the guardrail. A 1¾-in. (44-mm) soil gap was found on the upstream face of post no. 1. Post no. 2 had a 25-in. (635-mm) long vertical crack down the post with a 2-in. (51-mm) opening at the top. The downstream end system anchorage rotated upstream and post no. 25 had a 1-in. (25-mm) soil gap on the downstream side of the post.

Steel post damage included twisting, rotation, and detachment from the post bases. Post no. 10 twisted downstream. Post no. 11 rotated backward and twisted downstream. Post no. 15 rotated backward and downstream. Post nos. 12, 13, and 14 disengaged from the rail and the post bases. At post no. 12, the baseplate bent ¼ in. (6.4 mm) downward. At post no. 13, the lower section of the post rotated backward and was found with the two bolts on the front of the baseplate to be missing and the two bolts on the back side bent backward. Soil gaps of 1 in. (25 mm) or less were found at post nos. 1, 2, and 10, while soil heaves and craters were found around post nos. 11 and 13 through 15. Post no. 14 had the largest soil movement with a 40-in. (1,016-mm) diameter by 2-in. (51-mm) tall soil heave and an 18-in. (457-mm) diameter by 10-in. (254-mm) deep soil crater. Post no. 11 also had relatively-large soil movement with a 32-in. (813-mm) diameter by 4-in. (102-mm) tall soil heave and a 6-in. (152-mm) diameter by 22-in. (559-mm) deep soil crater.

An 8-in. longitudinal by 5-in. vertical (203-mm x 127-mm) gouge occurred at the downstream corner of the culvert due to contact from the vehicle's left-front wheel. An 11-in. (279-mm) gouge was located on the top of the culvert that started 169 in. (4,293 mm) upstream from the downstream end of the culvert. Contact marks started 17 in. (432 mm) upstream from the downstream corner and extended 28½ in. (724 mm) downstream. Contact marks from the tire were also located 118 in. (2,997 mm) upstream from the downstream corner extending 54 in. (1,372 mm) downstream and 11 in. (279 mm) below the top of the wall.

The maximum lateral dynamic barrier deflection was 61.6 in. (1,565 mm) at the rail at the third target downstream of post no. 13, as determined from high-speed digital video analysis. The permanent set was 42½ in. (1,080 mm) at the rail at the second target downstream of post no 13. The working width of the system was found to be 64.6 in. (1,641 mm), also determined from high-speed digital video analysis.

5.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 56 through 58. The maximum occupant compartment deformations are listed in Table 5 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH-established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 5. Maximum Occupant Compartment Deformations by Location, Test No. MGSLS-1

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH-ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	¼ (6)	≤ 9 (229)
Floorpan & Transmission Tunnel	¼ (6)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	⅛ (3)	≤ 12 (305)
Side Door (Above Seat)	⅛ (3)	≤ 9 (229)
Side Door (Below Seat)	¼ (6)	≤ 12 (305)
Roof	0	≤ 4 (102)

The majority of the damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The left side of the bumper fractured 23 in. (584 mm) left of center and was kinked 12 in. (305 mm) from the top. An 18-in. x 11-in. (457-mm x 279-mm) piece disengaged from the left fender starting at the hood. The left fender also had a 9-in. (229-mm) deep x 23-in. (584-mm) diameter dent. A 16-in. (406-mm) long kink occurred longitudinally in line with the base of the A-pillar, 6 in. (152 mm) down from the hood. The left fender separated 2 in. (51 mm) from the left-front door, and gouging occurred on the left fender and the left-front door. The top of the plastic wheel well on the left-front side of the vehicle had a 4-in. (102-mm) crack. The left-front rim was dented and kinked. The left-front steering knuckle cracked at the tie rod flange and the wheel bearing disengaged. The left-front wheel disengaged from the vehicle. Tears were also found on the left-front tire. Tears and gouges were found on the left side of the grill, which was partially detached from the vehicle. The left-side headlight disengaged from the vehicle. Contact marks extended the length of the left side of the vehicle. Dents were found on the left-front door near the bottom and the top of the door had separated ½ in. (13 mm). A 25-in. (635-mm) long by 4-in. (102-mm) tall by 2-in. (51-mm) deep dent occurred on the left-rear quarter panel between the wheel well and the rear of the vehicle, 11 in. (279 mm) from the bottom of the panel. The rear bumper was slightly kinked 22 in. (559 mm) left of center. A 5-in. x 2-in. (127-mm x 51-mm) piece of the rear bumper partially disengaged. The front hood had a gap of 2 in. (51 mm) on the right side. Although the steering rack appeared to be intact, power steering fluid was found to be leaking from the vehicle. The roof and all vehicle windows remained undamaged.

5.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 6. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 6. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 42. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

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

Evaluation Criteria		Transducer		MASH Limits
		SLICE-1	SLICE-2 (Primary)	
OIV ft/s (m/s)	Longitudinal	-15.02 (-4.58)	-14.98 (-4.57)	± 40 (12.2)
	Lateral	12.93 (3.94)	11.64 (3.55)	±40 (12.2)
ORA g's	Longitudinal	-15.28	-15.76	± 20.49
	Lateral	5.79	6.13	± 20.49
MAX. ANGULAR DISPL. deg.	Roll	-16.04	-13.64	±75
	Pitch	3.45	-4.03	±75
	Yaw	42.15	41.35	not required
THIV ft/s (m/s)		10.78 (3.29)	11.10 (3.38)	not required
PHD g's		16.17	16.56	not required
ASI		0.48	0.51	not required

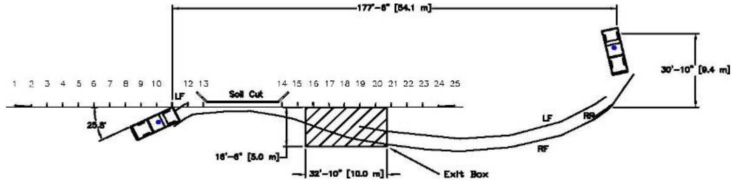
5.8 Load Cells and String Potentiometers

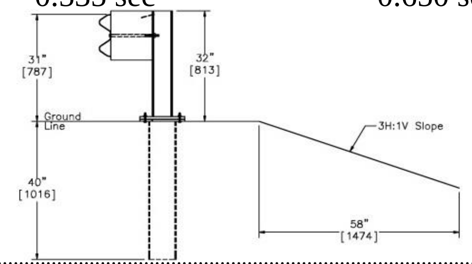
The pertinent data from the load cells and string potentiometers was extracted from the bulk signal and analyzed using the transducer's calibration factor. The recorded data and analyzed results are detailed in Appendix G. The string potentiometers located at the upstream and downstream anchorages registered maximum displacements of 3.41 in. and 3.05 in. (87 mm and 77 mm), respectively. The load cells at the upstream and downstream cable anchorages registered maximum loads of 32.0 kips and 36.4 kips (142.3 kN and 161.9 kN), respectively. The exact moment of impact could not be determined from the transducer data, as impact may have occurred a few milliseconds prior to a measurable signal increase in the data. Thus, the extracted data curves should not be taken as precise time after impact, but rather a general timeline between events within the data curve itself.

5.9 Discussion

The analysis of the test results for test no. MGSLS-1 showed that the MGS long-span with UBSP system 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 13.3 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MGSLS-1, conducted on the 31¼ ft (9.5 m) MGS long-span with the UBSP system, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-11.

0.000 sec 0.157 sec 0.304 sec 0.535 sec 0.650 sec





- Test Agency .... MwRSF
- Test Number MGSLS-1
- Date 5/18/2015
- MASH Test Designation 3-11
- Test Article .... MGS w/ 31' 3" (9.5 m) Long Span and UBSP
- Total Length .... 175 ft (53.3 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)
  - Embedment Depth .... 40 in. (1,016 mm)
  - Spacing .... 75 in. (1,905 mm)
- Key Component – Universal Breakaway Steel Post
  - Shape .... W6 x 8.5 (W152 x 12.6)
  - Length .... 30⁵/₈ in. (778 mm)
  - Spacing .... 75 in. (1,905 mm)
- Soil Type .... Compacted Coarse Crushed Limestone
- Vehicle Make /Model .... 2007 Dodge Ram
  - Curb .... 5,199 lb (2,358 kg)
  - Test Inertial .... 4,955 lb (2,248 kg)
  - Gross Static .... 5,120 lb (2,322 kg)
- Impact Conditions
  - Speed .... 62.7 mph (100.9 km/h)
  - Angle .... 25.3 deg
  - Impact Location .... 1¾ in. (44 mm) DS of Post No. 11
- Impact Severity (IS) .. 124.1 kip-ft (168.2 kJ) > 105.6 kip-ft (143.2 kJ) limit from MASH
- Exit Conditions
  - Speed .... 27.3 mph (44.0 km/h)
  - Angle .... 13.3 deg
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 177 ft – 6 in. (54.1 m) Downstream
-
- Vehicle Damage .... Moderate
  - VDS [23] 11-LFQ-3
  - CDC [24] 11-LYEW-3
  - Maximum Interior Deformation .... ¼ in. (6 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 42½ in. (1,080 mm)
  - Dynamic .... 61.6 in. (1,565 mm)
  - Working Width .... 64.6 in. (1,641 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		SLICE-1	SLICE-2 (Primary)	
OIV ft/s (m/s)	Longitudinal	-15.02 (-4.58)	-14.98 (-4.57)	± 40 (12.2)
	Lateral	12.93 (3.94)	11.64 (3.55)	± 40 (12.2)
ORA g's	Longitudinal	-15.28	-15.76	± 20.49
	Lateral	5.79	6.13	± 20.49
MAX ANGULAR DISP. deg.	Roll	-16.04	-13.64	±75
	Pitch	3.45	-4.03	±75
	Yaw	42.15	41.35	not required
THIV – ft/s (m/s)		10.78 (3.29)	11.10 (3.38)	not required
PHD – g's		16.17	16.56	not required
ASI		0.48	0.51	not required

Figure 42. Summary of Test Results and Sequential Photographs, Test No. MGSLS-1


0.000 sec


0.224 sec


0.488 sec


0.740 sec


0.932 sec


1.216 sec


0.000 sec


0.076 sec


0.224 sec


0.334 sec


0.562 sec


0.814 sec

Figure 43. Additional Sequential Photographs, Test No. MGSLS-1


0.000 sec


0.100 sec


0.234 sec


0.367 sec


0.567 sec


0.767 sec


0.000 sec


0.100 sec


0.234 sec


0.334 sec


0.601 sec


0.767 sec

Figure 44. Additional Sequential Photographs, Test No. MGSLS-1

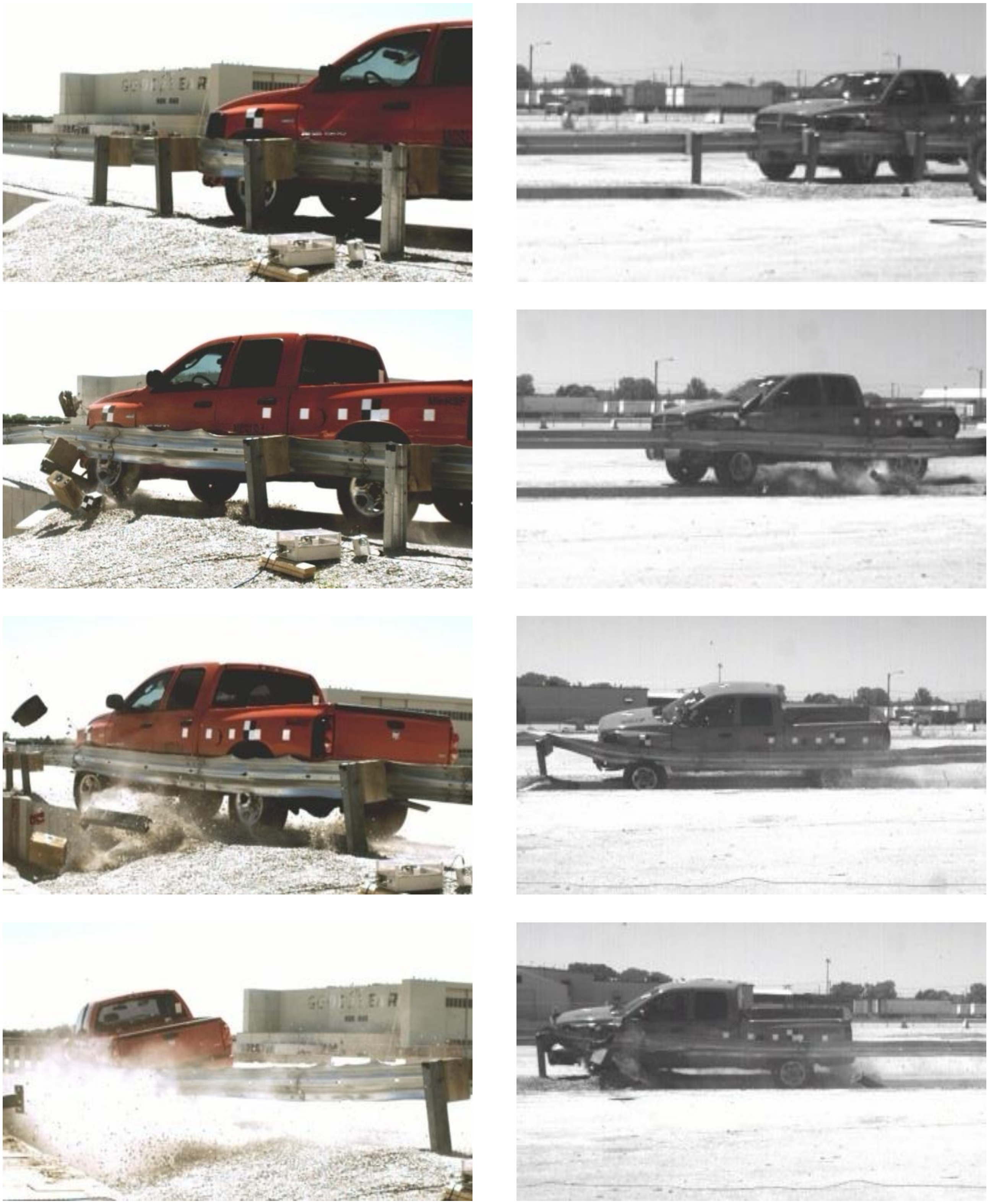


Figure 45. Documentary Photographs, Test No. MGSLS-1

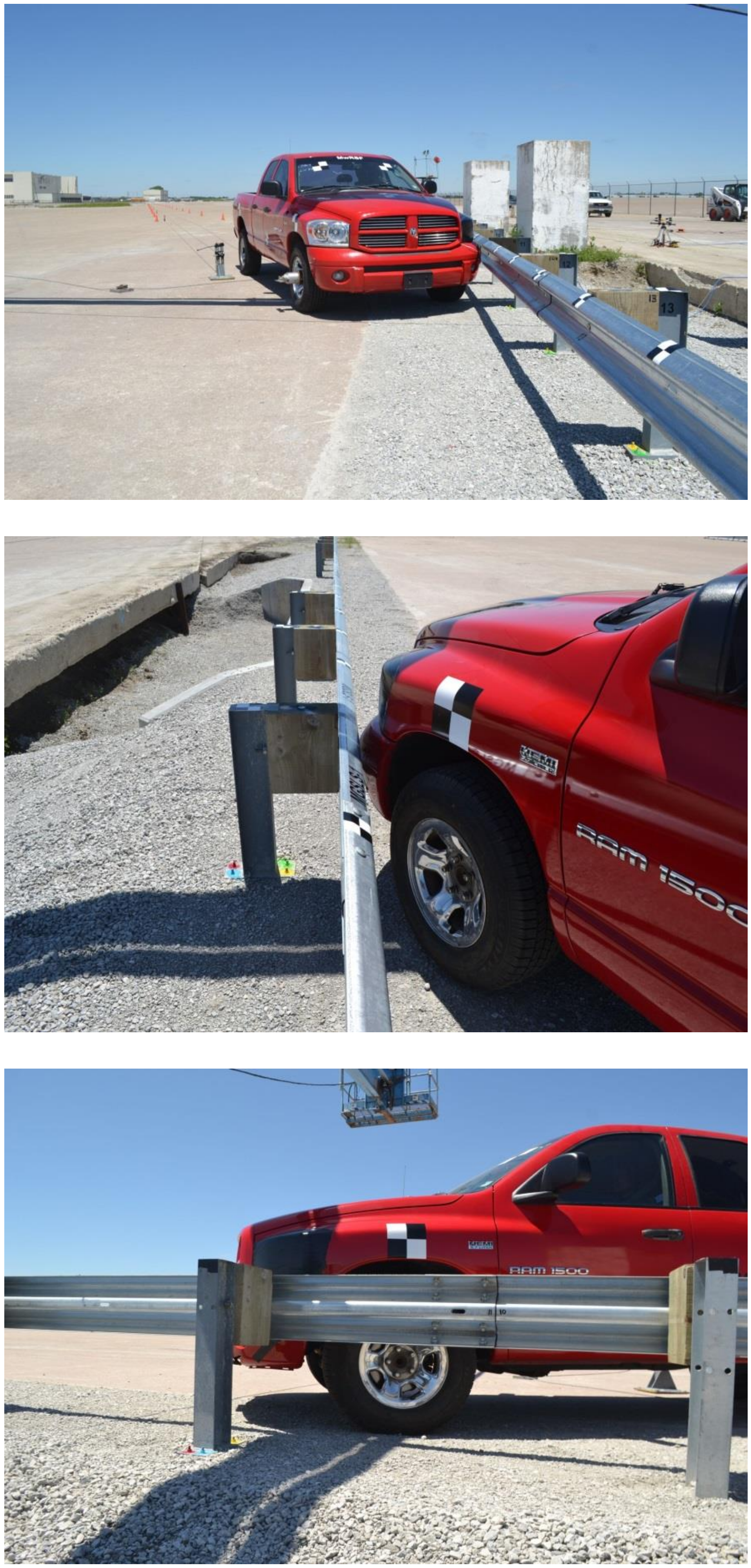


Figure 46. Impact Location, Test No. MGSLS-1

Figure 47. Vehicle Final Position and Trajectory Marks, Test No. MGSLS-1

Figure 48. System Damage, Test No. MGSLS-1

Figure 49. Upstream End Anchor Damage, Test No. MGSLS-1

Figure 50. System Damage Between Post Nos. 3 and 9, Test No. MGSLS-1

Figure 51. Damage Between Post Nos. 10 and 12, Test No. MGSLS-1

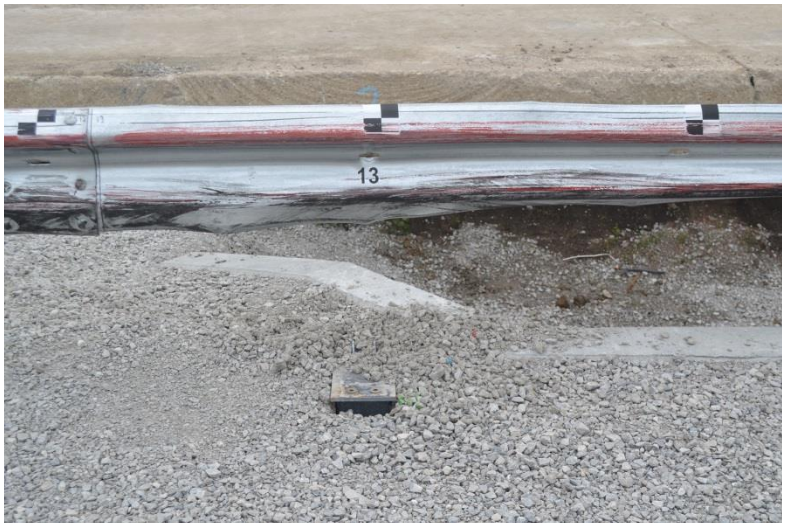


Figure 52. Damage at Post No. 13, Test No. MGSLS-1

Figure 53. Damage Between Post Nos. 13 and 14, Test No. MGSLS-1

Figure 54. Damage Between Post Nos. 14 and 16, Test No. MGSLS-1

Figure 55. Damage Between Post Nos. 17 and 25, Test No. MGSLS-1

Figure 56. Vehicle Damage, Test No. MGSLS-1

Figure 57. Vehicle Damage, Left Fender, Test No. MGSLS-1

Figure 58. Vehicle Undercarriage Damage, Test No. MGSLS-1

6 FULL-SCALE CRASH TEST NO. MGSLS-2

6.1 Static Soil Test

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

6.2 Test No. MGSLS-2

In accordance with MASH test designation no. 3-11, the 4,912-lb (2,228-kg) pickup truck impacted the MGS long-span system at a speed of 61.4 mph (98.8 km/h) and an angle of 26.3 degrees. A summary of the test results and sequential photographs are shown in Figure 62. Additional sequential photographs are shown in Figures 63 and 64. Documentary photographs of the crash test are shown in Figure 65.

6.3 Weather Conditions

Test no. MGSLS-2 was conducted on June 30, 2015 at approximately 2:15 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), were reported and are shown in Table 7.

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

Temperature	83° F
Humidity	57 %
Wind Speed	15.0 mph
Wind Direction	100° from True North
Sky Conditions	Overcast
Visibility	5 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

6.4 Test Description

Initial vehicle impact was to occur 243¾ in. (6,191 mm) downstream from post no. 13 as shown in Figure 66, which was selected using LS-DYNA analysis to maximize the potential for pocketing, wheel snag, and rail rupture [3-4] The actual point of impact was 239⅞ in. (6,093 mm) downstream from post no. 13. A sequential description of the impact events is contained in Table 8. During the test, the downstream anchor system failed and allowed the rail to disengage from the posts and become wrapped around the vehicle. The vehicle penetrated beyond the barrier and came to rest 17 ft – 9 in. (5.4 m) behind the system and 44 ft – 9 in. (13.6 m) downstream from the point of impact. The vehicle trajectory and final position are shown in Figures 62 and 67.

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

TIME (sec)	EVENT
0	Vehicle’s left-front bumper contacted rail upstream from post no. 14.
0.014	Vehicle’s hood deformed.
0.016	Post no. 14 deflected backward.
0.030	Post no. 17 deflected backward.
0.030	Post no. 18 twisted downstream.
0.032	Post no. 15 twisted downstream.
0.032	Post no. 16 twisted downstream.
0.036	Post no. 13 twisted upstream.
0.036	Post no. 15 deflected backward.
0.040	Bottom corrugation of rail flattened upstream from post no. 14.
0.040	Post no. 19 twisted downstream.
0.040	Post no. 20 twisted downstream.
0.042	Post no. 13 deflected backward.
0.064	Soil heave formed on the non-traffic flange of post no. 14.
0.070	Vehicle’s left-front tire entered ditch.
0.076	Top corrugation of rail kinked between post nos. 14 and 15.
0.082	Vehicle yawed away from barrier.
0.084	Vehicle’s left-front door deformed.
0.092	Post no. 16 deflected downstream
0.094	Vehicle’s left-rear door deformed.

0.102	Soil heave formed on non-traffic flange of post no. 15.
0.108	Blockout no. 14 detached from rail.
0.112	Post no. 16 deflected backward, post no. 17 deflected downstream, and blockout no. 17 detached from rail.
0.118	Post no. 14 detached from base, and post no. 18 deflected backward.
0.120	Post no. 17 deflected backward.
0.128	Vehicle’s grille deformed.
0.130	Vehicle’s roof deformed.
0.132	Post no. 25 deflected forward.
0.132	Blockout no. 18 detached from rail.
0.142	Vehicle’s left-front tire contacted post no. 14.
0.142	Downstream anchorage failed, and post no. 24 fractured at ground line.
0.144	Post no. 25 fractured at ground line.
0.152	Vehicle’s left headlight detached.
0.154	Post no. 15 detached from base, and blockout no. 19 detached from rail.
0.164	Blockout no. 20 detached from rail.
0.174	Blockout no. 15 detached from rail.
0.180	Vehicle rolled away from barrier.
0.190	Post no. 14 detached from blockout no. 14.
0.216	Vehicle’s hood opened.
0.228	Post no. 25 detached from rail.
0.248	Vehicle’s left-front tire was airborne, and vehicle’s front bumper contacted blockout no. 16.
0.264	Vehicle’s right headlight deformed.
0.266	Vehicle’s grille detached.
0.274	Post no. 16 detached from base
0.290	Vehicle’s right headlight shattered.
0.318	Vehicle rolled toward barrier.
0.386	Vehicle’s right-front tire was airborne.
0.394	Vehicle’s right-front tire regained contact with ground.
0.400	Vehicle’s left quarter panel deformed.
0.404	Vehicle’s right headlight detached.
0.412	Vehicle’s left taillight deformed.
0.488	Vehicle pitched downward.
0.488	Vehicle’s right-front tire regained contact with ground.
0.596	Vehicle impacted slope on back side of system.
0.652	Vehicle’s airbags deployed.
0.658	Vehicle’s right-front tire became airborne.
0.662	Vehicle pitched upward.
0.668	Vehicle yawed toward barrier.
0.704	Vehicle’s right-front tire regained contact with ground.
0.730	Vehicle’s right mirror contacted rail.
0.730	Vehicle’s right-side mirror deformed.
0.744	Vehicle rolled away from barrier.

0.818	Vehicle's right-side mirror detached.
1.054	Post no. 25 detached from anchor cable.
1.142	Blockout no. 13 detached from rail.
1.260	Vehicle's right-side C-Pillar contacted rail.
1.420	Vehicle rolled toward barrier.
1.590	Vehicle pitched upward.
1.964	Blockout no. 12 detached from rail.

6.5 Barrier Damage

Damage to the barrier system was severe, as shown in Figures 68 through 79. Barrier damage consisted of rail deformation and tearing, disengagement of W-beam rail away from posts, bending of steel posts, fracture of wood posts, and damage to the concrete culvert. The length of vehicle contact along the barrier was approximately 80 ft (24.4 m), which began 239⅞ in. (6.1 m) upstream from post no. 13 and extended through the end of the barrier system.

Deformation of the W-beam rail occurred at post no. 2 as well as between post no. 13 and the downstream end of the barrier system. A majority of the damage occurred between post no. 14 and the downstream end of the system. At post no. 2, the top corrugation of the guardrail was slightly bent. At post no. 13, there was a kink in the guardrail that extended the height of the rail. Numerous kinks were found on the guardrail between post nos. 13 and 14. Flattening of the bottom corrugation on the guardrail began 15 in. (381 mm) upstream from post no. 14 and extended to 16½ in. (419 mm) downstream from post no. 16. The rail released from the posts at post nos. 1, 2, 24, and 25. The rail released from the blockouts at post nos. 3, 5, 6, 9, and 11 through 23. Tearing occurred at post no. 17 at the top corrugation that was 2 in. (51 mm) long, and there was a 1½-in. (38-mm) long tear on the bottom corrugation. There was also a ½-in. (13-mm) long tear at the bottom of the corrugation 17 in. (432 mm) downstream from post no. 16. Tearing was also present on the top of the rail 6 in. (152 mm) upstream from post no. 25 that was 3 in. (76 mm) long by 1¼ in. (32 mm) deep. There was buckling located at post no. 17 that extended through post no. 18 as well as at post nos. 21 through 23. As the vehicle penetrated the barrier system, the W-beam wrapped around the test vehicle and had to be manually dislodged.

Wood post damage included fracturing, gouging, and displacement of posts. Post no. 1 had gouging on the front face due to rail contact. Post no. 2 split vertically along the height of the post through the guardrail bolt hole on the front side of the post. Post nos. 24 and 25 fractured at the ground line and post no. 24 also split along the vertical plane of the centerline of the post. Post no. 25 had a 7½-in. (191-mm) deep by 3-in. (76-mm) wide crack located 2¼ in. (57 mm) downward from the top of the back face of the post, as well as a 3-in. (76-mm) diameter dent on the back downstream face of the post.

Steel post damage included twisting, rotation, and detachment from the post bases. UBSP post nos. 14 through 16 fractured at the ground line. The baseplate for post no. 14 rotated backward, and the back-side upstream flange twisted upstream. The baseplate for post no. 14 was also dented on the back-side and the top of the downstream side. There were also contact marks on the lower 9½ in. (241 mm) of the front face of the post. The front web and flange of post no. 15 twisted upstream, and the base plate rotated backward. There were contact marks found on the top of the front flange of post no. 16 that extended 9¼ in. (235 mm) downstream. Post no. 17 bent downstream, and post no. 18 bent backward 1½ in. (38 mm) at the top of the upstream flange.

Culvert damage included contact marks and spalling. The contact marks began 45¾ in. (1,162 mm) upstream from the downstream wingwall on the top face and extended diagonally across the top face of the wingwall and regained contact 7 in. (178 mm) downstream from the wingwall-to-culvert connection. The tire lost contact when the wingwall began to taper downward. The spalling was limited to a 5-in. (127-mm) x 7½-in. (191-mm) segment that was located on the wingwall located 14½ in. (368 mm) downstream from where the wing wall tapered downward.

The maximum lateral dynamic barrier deflection was found to be 164.2 in. (4,171 mm) at the midspan of the rail between post nos. 17 and 18, as determined from high-speed digital video analysis. As the rail detached and wrapped around the vehicle during the test, the maximum lateral dynamic deflection result obtained from the video analysis is likely inaccurate due to the known position of the vehicle after the conclusion of the test. Since the vehicle came to rest 17 ft – 9 in. (5.4 m) behind the barrier, the maximum lateral dynamic deflection was at least 17 ft – 9 in. (5.4 m) and the permanent set was 17 ft – 9 in. (5.4 m). The working w.idth of the system was not determined due to the vehicle's penetration through the barrier system.

6.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 81 through 85. The maximum occupant compartment deformations are listed in Table 9 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH-established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 9. Maximum Occupant Compartment Deformations by Location, Test No. MGSLS-2

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH-ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	7 1/8 (181)	≤ 9 (229)
Floorpan & Transmission Tunnel	8½ (216)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	3 7/8 (98)	≤ 12 (305)
Side Door (Above Seat)	2¾ (70)	≤ 9 (229)
Side Door (Below Seat)	1 3/8 (35)	≤ 12 (305)
Roof	0	≤ 4 (102)

The majority of the damage was concentrated on the front and left side of the vehicle where initial impact had occurred. The hood and front bumper crushed inward approximately 23 in. (584 mm), and the hood punctured the windshield on the lower-left corner. There was a 1-in. (25-mm) long tear on the right side of the hood that was located 27 in. (686 mm) from the rear edge of the hood. The windshield was impacted 5 in. (127 mm) upward from the bottom edge and 4 in. (102 mm) from the left edge of the windshield that caused a spider crack that extended upward. Both headlights, the left fog light, front grille, front bumper cover, coolant overflow tank, a portion of the radiator core support, and the right side mirror disengaged from the vehicle. The radiator showed contact marks, bending, and was partially detached from its mounts. The fuse box was also partially disengaged from its mounts. The left-front wheel assembly was forced backward and into the firewall, there was 5-in. (127-mm) long gouging on the left-front rim, and the tire was deflated. There were numerous deformations on the body of the vehicle with the most significant occurring on the left-front corner where the initial impact occurred. The left fender was partially disengaged with a 10-in. (254-mm) long tear located near the front of the wheel well. The left front door was separated 8 in. (203 mm) at the top of the door with denting that ran the length of the door and deformations occurring on the middle of the door near the door handle. There was a 15-in. (381-mm) long tear at the bottom of the left-rear door near the rocker that was ½-in. (13-mm) deep. The fuel tank of the vehicle was punctured on the rear edge and was leaking fluid. There was a 19-in. (483-mm) long contact mark on the front-left portion of the roof that extended backward and inward. There was also a 19-in. wide x 9-in. long (483-mm x 229-mm) dent that was ½-in. (13-mm) deep on the left side of the roof 20 in. (508 mm) behind the windshield. The front of the left-rear quarter panel folded inward 9 in. (229 mm) with the fold extending 10 in. (254 mm) rearward from the front of the quarter panel. The left-rear quarter panel had multiple scrapes and dents with the most significant scrape being 16-in. (406-mm) long, beginning 21 in. (533 mm) above the bottom of the quarter panel above the wheel well. The most significant dent was 1½-in. (38-mm) long in front of the rear wheel well, located 15 in. (381 mm) above the bottom of the quarter panel. The rear bumper had three dents, all of which were roughly 1 in. (25 mm) in diameter. The right-side C-pillar had multiple dents. One dent was 6½ in. long by 4½ in. tall (165 mm x 114 mm) and was located 11 in. (279 mm) below the top of the cab. The other dent was 3 in. tall by 4 in. long (76 mm x 102 mm) and was located 5 in. (127 mm) below the top of the cab.

After the guardrail had been removed from the vehicle, it was discovered that the right-front portion of the frame of the vehicle had been crushed inward approximately 23 in. (584 mm), and the right-front fender had an 18¾-in. (476-mm) long tear that extended from the top-front of the fender toward the front wheel well. There was also a partial protrusion outward on the hood near the center hood target, and the hood had separated from itself on the right rear portion near the windshield that created a 15-in. by 2½-in. (381-mm x 64-mm) gap.

Both airbags deployed. The engine cross-member was crushed rearward 5 in. (127 mm) and upward 2 in. (51 mm), the transmission mounts were twisted, and the oil pan was dented.

The frame of the vehicle buckled in front of the transmission cross-member and near the front of the engine cross-member on the right side of the vehicle. Both front cab mounts were deformed. The left-front cab mount was crushed 5 in. (127 mm) toward the center of the vehicle, 4 in. (102 mm) rearward, and 5 in (127 mm) upward. The right-front cab mount was twisted. The steering rack was fractured at the steering shaft connection, and the left-front lower control arm had a tear that was approximately 1¼ in. (32 mm) long. Note that significant damage to the vehicle's undercarriage and occupant compartment was likely due to contact with the ditch behind the guardrail.

6.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 10. Note that the OIVs were within the suggested limits provided in MASH; however, the longitudinal ORAs were not. The longitudinal ORAs deviated from the suggested limits due to the vehicle's contact with the back side of the ditch after penetrating the barrier system. The calculated THIV, PHD, and ASI values are also shown in Table 10. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 62. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

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

Evaluation Criteria		Transducer		MASH Limits
		SLICE-1	SLICE-2 (Primary)	
OIV ft/s (m/s)	Longitudinal	-13.22 (-4.03)	-12.66 (-3.86)	± 40 (12.2)
	Lateral	10.37 (3.16)	9.42 (2.87)	±40 (12.2)
ORA g's	Longitudinal	-23.68	-24.12	± 20.49
	Lateral	10.57	13.17	± 20.49
MAX. ANGULAR DISPL. deg.	Roll	-15.65	-17.30	±75
	Pitch	16.62	17.61	±75
	Yaw	-29.91	-31.57	not required
THIV ft/s (m/s)		15.91 (4.85)	16.14 (4.92)	not required
PHD g's		23.89	24.47	not required
ASI		1.52	1.47	not required

6.8 Load Cells and String Potentiometers

The pertinent data from the load cells and string potentiometers was extracted from the bulk signal and analyzed using the transducer's calibration factor. The recorded data and analyzed results are detailed in Appendix G. Summarized results from the load cells and string potentiometers can be seen in Figures 59 through 61. The string potentiometers located at the upstream and downstream anchorages registered maximum displacements of 1.85 in. and 21.29 in. (47 mm and 541 mm), respectively. The load cells from the upstream and downstream anchorages registered maximum loads of 24.8 kips and 27.5 kips (110.3 kN and 122.3 kN), respectively. The exact moment of impact could not be determined from the transducer data, as impact may have occurred a few milliseconds prior to a measurable signal increase in the data.

Thus, the extracted data curves should not be taken as precise time after impact, but rather a general timeline between events within the data curve itself.

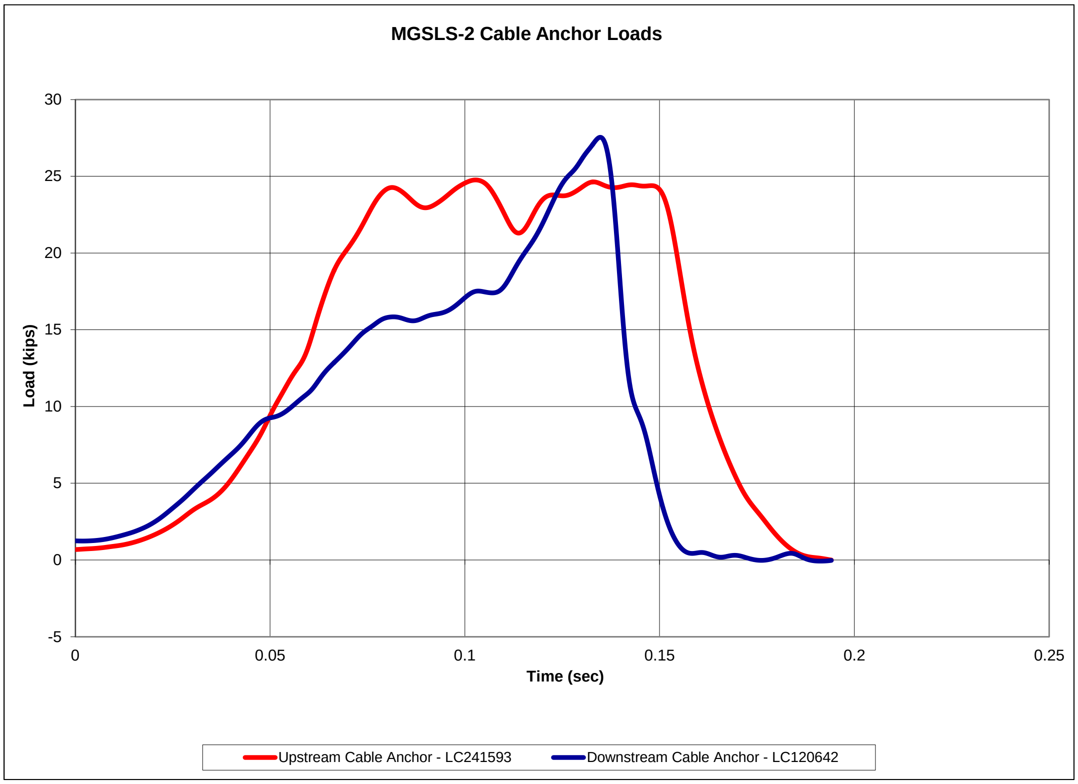


Figure 59. Cable Anchor Loads, Test No. MGSLS-2

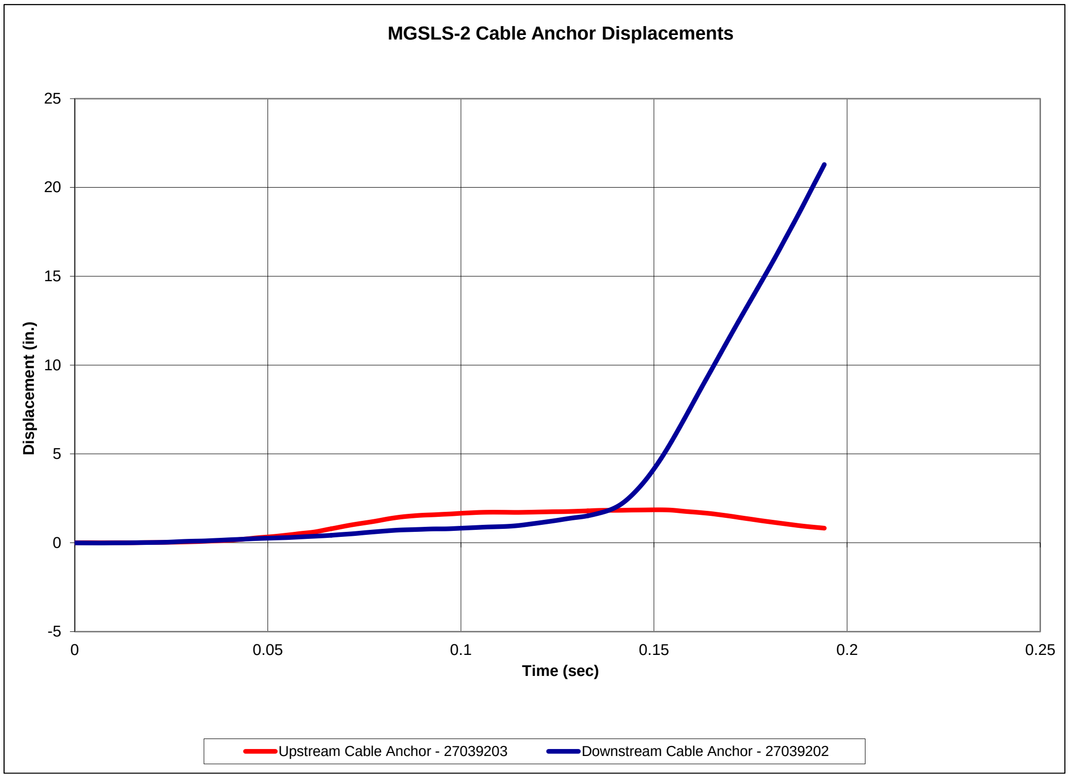


Figure 60. Cable Anchor Displacements, Test No. MGSLS-2

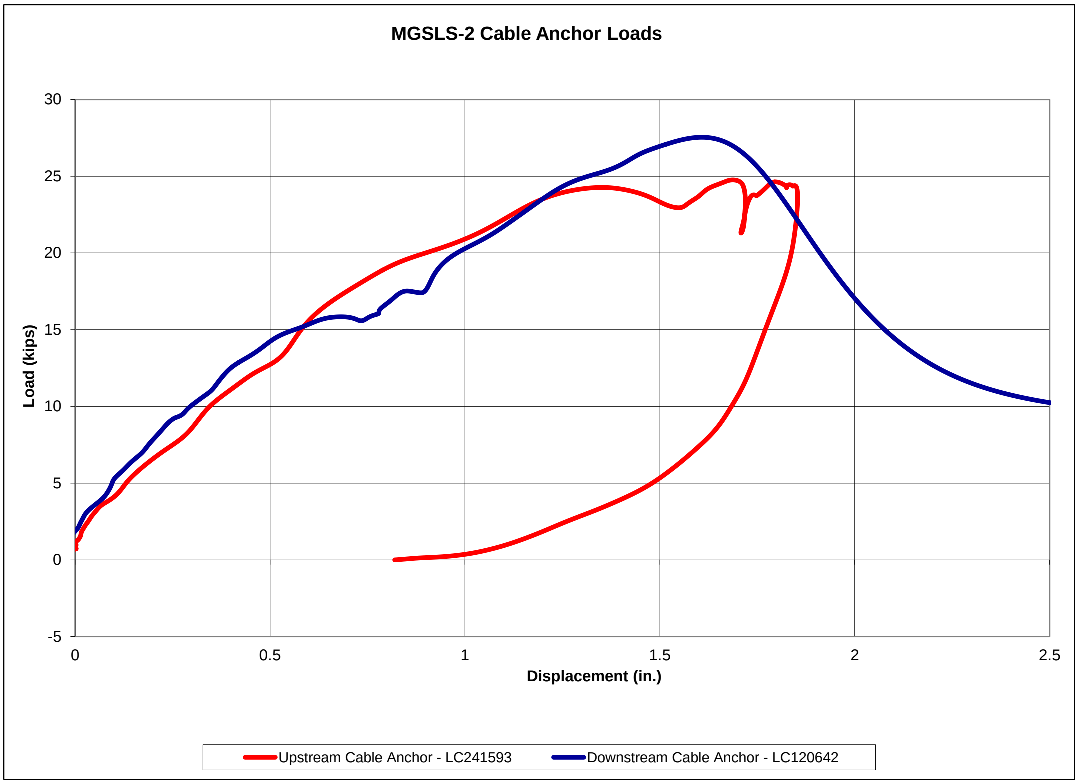


Figure 61. Cable Anchor Load vs. Displacement, Test No. MGSLS-2

6.9 Discussion

The analysis of the test results for test no. MGSLS-2 showed that the MGS long-span with UBSP system did not adequately contain or redirect the 2270P vehicle with controlled lateral displacements of the barrier. There were neither detached elements nor 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 penetrated the barrier but 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. Due to the failure of the downstream anchorage system early in the vehicle redirection, the system did not perform as intended. Thus, the vehicle did not properly exit the system and violated the bounds of the exit box. Therefore, test no. MGSLS-2, conducted on the 31¼-ft (9.5-m) MGS long-span with UBSP system, was determined to be unacceptable according to the MASH safety performance criteria for test designation no. 3-11. Separate analysis of potential factors related to the downstream anchorage system failure and potential system modifications will be addressed in a subsequent Phase III report.

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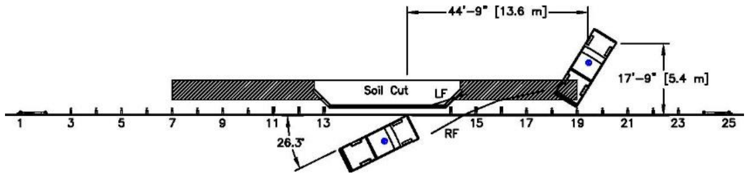

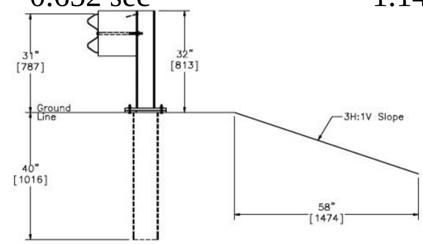

- Test Agency .... MwRSF
- Test Number MGSLS-2
- Date 6/30/2015
- MASH Test Designation 3-11
- Test Article .... MGS w/ 31' 3" (9.5 m) Long Span and UBSP
- Total Length .... 175 ft (53.3 m)
- Key Component - Steel W-Beam Guardrail
  - Thickness .... 12 gauge (2.66 mm)
  - Top Mounting Height .... 31 in. (787 mm)
- Key Component –Steel Post
  - Shape .... W6 x 8.5 (W152 x 12.6)
  - Length .... 72 in. (1,829 mm)
  - Embedment Depth .... 40 in. (1,016 mm)
  - Spacing .... 75 in. (1,905 mm)
- Key Component – Universal Breakaway Steel Post
  - Shape .... W6 x 8.5 (W152 x 12.6)
  - Length .... $30^{5}/_{8}$ in. (778 mm)
  - Spacing .... 75 in. (1,905 mm)
- Soil Type .... Compacted Coarse Crushed Limestone
- Vehicle Make /Model .... 2008 Dodge Ram
  - Curb .... 5,064 lb (2,297 kg)
  - Test Inertial .... 4,912 lb (2,228 kg)
  - Gross Static .... 5,078 lb (2,303 kg)
- Impact Conditions
  - Speed .... 61.4 mph (98.8 km/h)
  - Angle .... 26.3 deg
  - Impact Location .... $239^{7}/_{8}$in (6,093 mm) Downstream of Post no. 13
- Impact Severity (IS) ....110.7 kip-ft (150.0 kJ)>105.6 kip-ft (143.1 kJ) limit from MASH
- Exit Conditions
  - Speed .... N/A
  - Angle .... N/A
- Exit Box Criterion .... Fail
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 44 ft – 9 in. (13.6 m) Downstream
  17 ft – 9 in. (5.4 m) Behind barrier
- Vehicle Damage .... Moderate
  - VDS [23] 11-LFQ-5
  - CDC [24] 11-LYEW-4
  - Maximum Interior Deformation .... 8½ in. (216 mm)
- Test Article Damage .... Severe
- Maximum Test Article Deflections
  - Permanent Set .... 213 in. (5,410 mm)
  - Dynamic .... 164.2 in. (4,171 mm)
  - Working Width .... N/A
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		SLICE-1	SLICE-2 (Primary)	
OIV ft/s (m/s)	Longitudinal	-13.22 (-4.03)	-12.66 (-3.86)	± 40 (12.2)
	Lateral	10.37 (3.16)	9.42 (2.87)	± 40 (12.2)
ORA g's	Longitudinal	-23.68	-24.12	± 20.49
	Lateral	10.57	13.17	± 20.49
MAX ANGULAR DISP. deg.	Roll	-15.65	-17.30	±75
	Pitch	16.62	17.61	±75
	Yaw	-29.91	-31.57	not required
THIV – ft/s (m/s)		15.91 (4.85)	16.14 (4.92)	not required
PHD – g's		23.89	24.47	not required
ASI		1.52	1.47	not required

Figure 62. Summary of Test Results and Sequential Photographs, Test No. MGSLS-2


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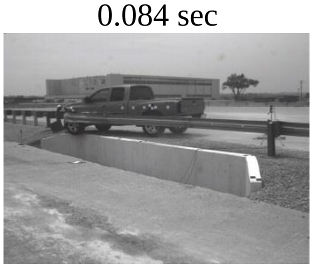
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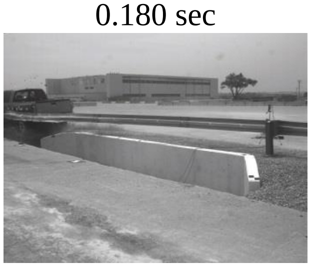
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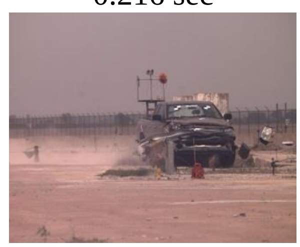
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Figure 63. Additional Sequential Photographs, Test No. MGSLS-2


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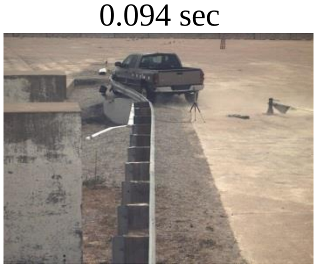
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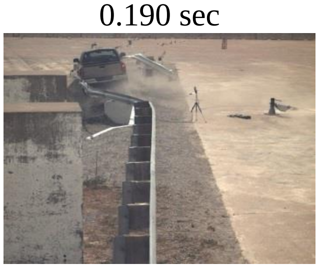
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Figure 64. Additional Sequential Photographs, Test No. MGSLS-2

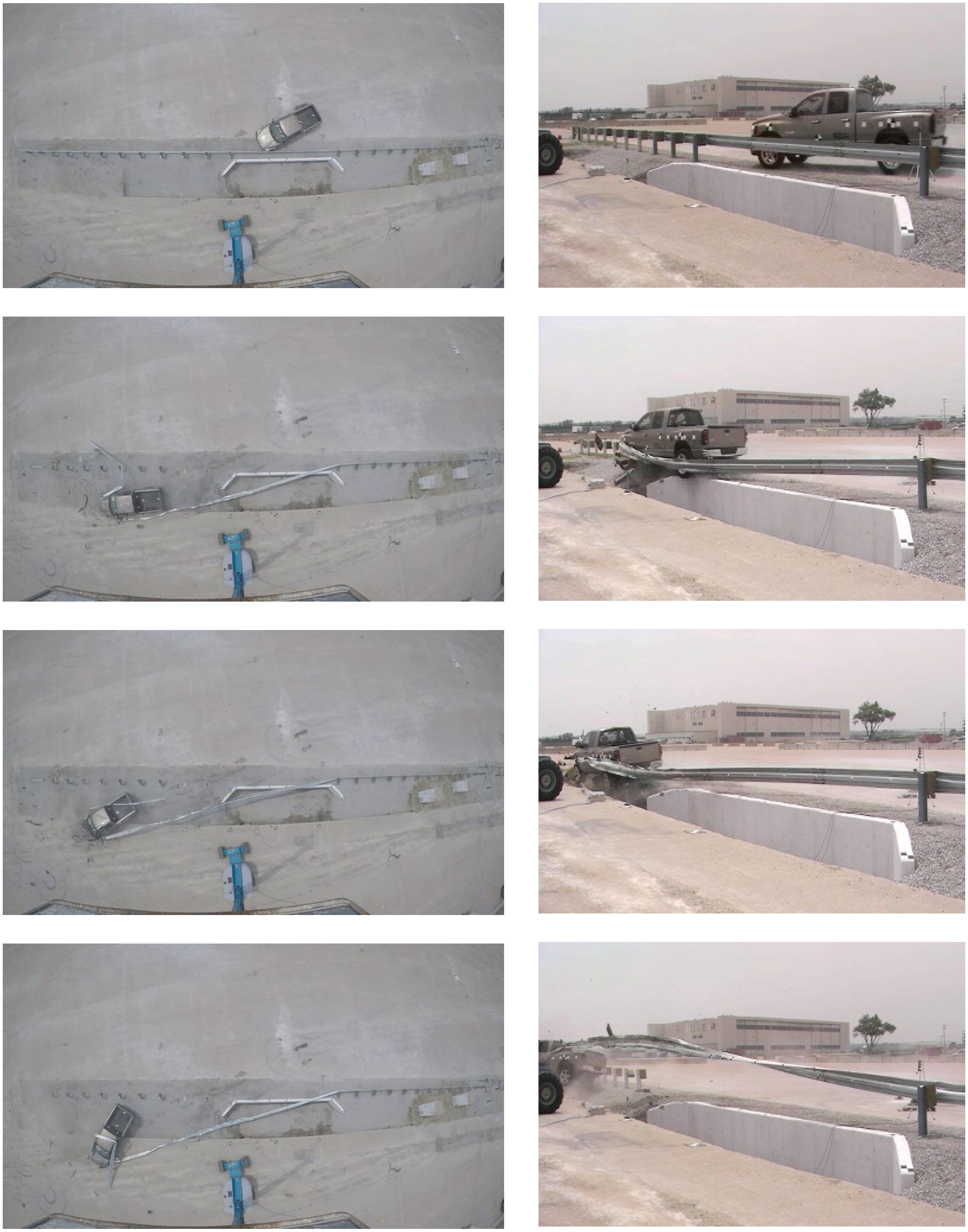

Figure 65. Documentary Photographs, Test No. MGSLS-2

Figure 66. Impact Location, Test No. MGSLS-2

Figure 67. Vehicle Final Position and Trajectory Marks, Test No. MGSLS-2

Figure 68. System Damage, Test No. MGSLS-2

Figure 69. Upstream End Anchor Damage, Test No. MGSLS-2

Figure 70. System Damage Between Post Nos. 3 and 12, Test No. MGSLS-2

Figure 71. Damage at Post No. 13, Test No. MGSLS-2

Figure 72. Damage Between Post Nos. 13 and 14, Test No. MGSLS-2

Figure 73. Damage at Post No. 14, Test No. MGSLS-2

Figure 74. Damage at Post No. 15, Test No. MGSLS-2

Figure 75. Damage at Post No. 16 and Splice 16-17, Test No. MGSLS-2

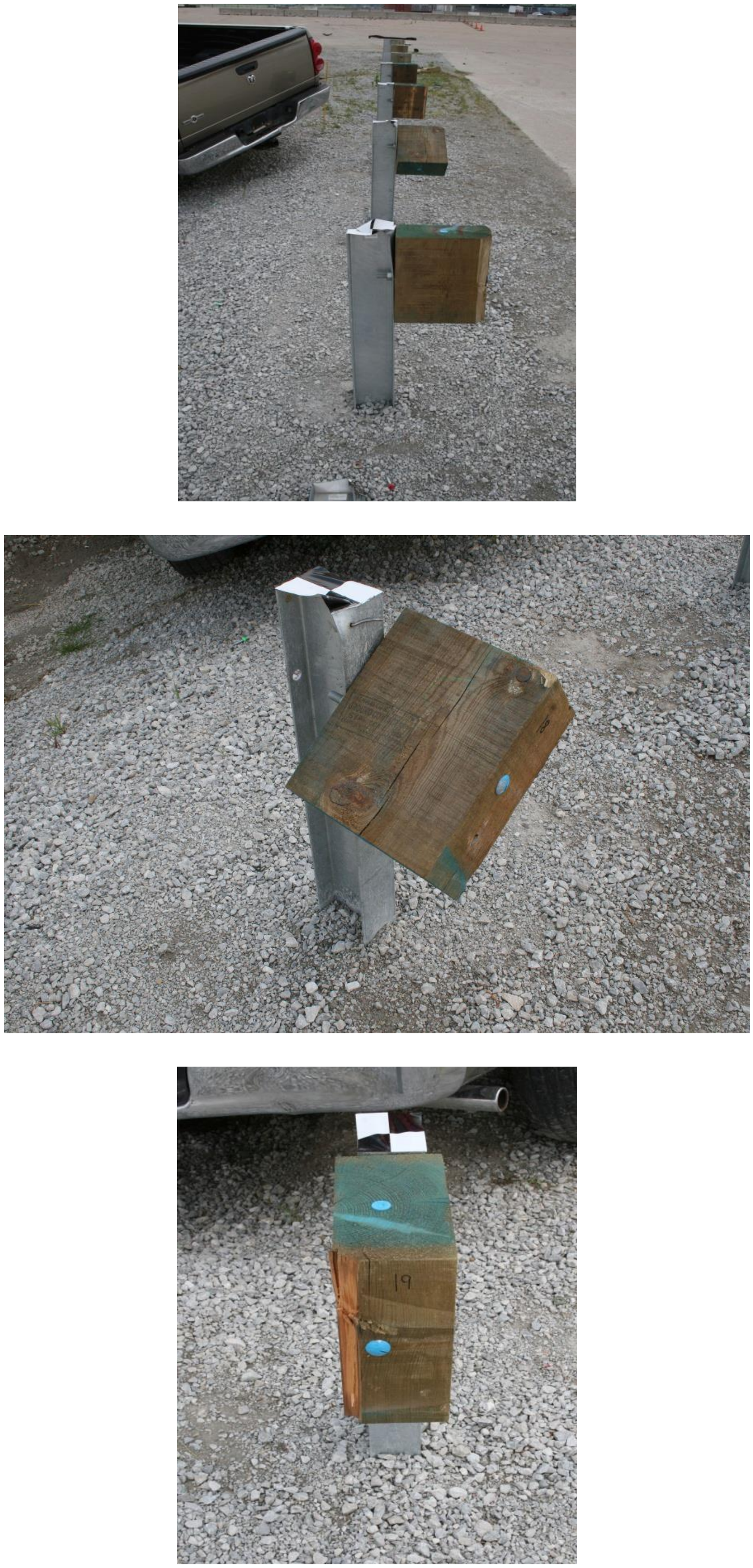

Figure 76. Damage to Post Nos. 17 through 19, Test No. MGSLS-2

Figure 77. Damage to Rail Between Post Nos. 17 through 19, Test No. MGSLS-2

Figure 78. Damage to Barrier System Between Post Nos. 20 through 22, Test No. MGSLS-2

Figure 79. Damage to Post Nos. 23 through 25, Test No. MGSLS-2

Figure 80. Downstream Anchorage Damage, Test No. MGSLS-2

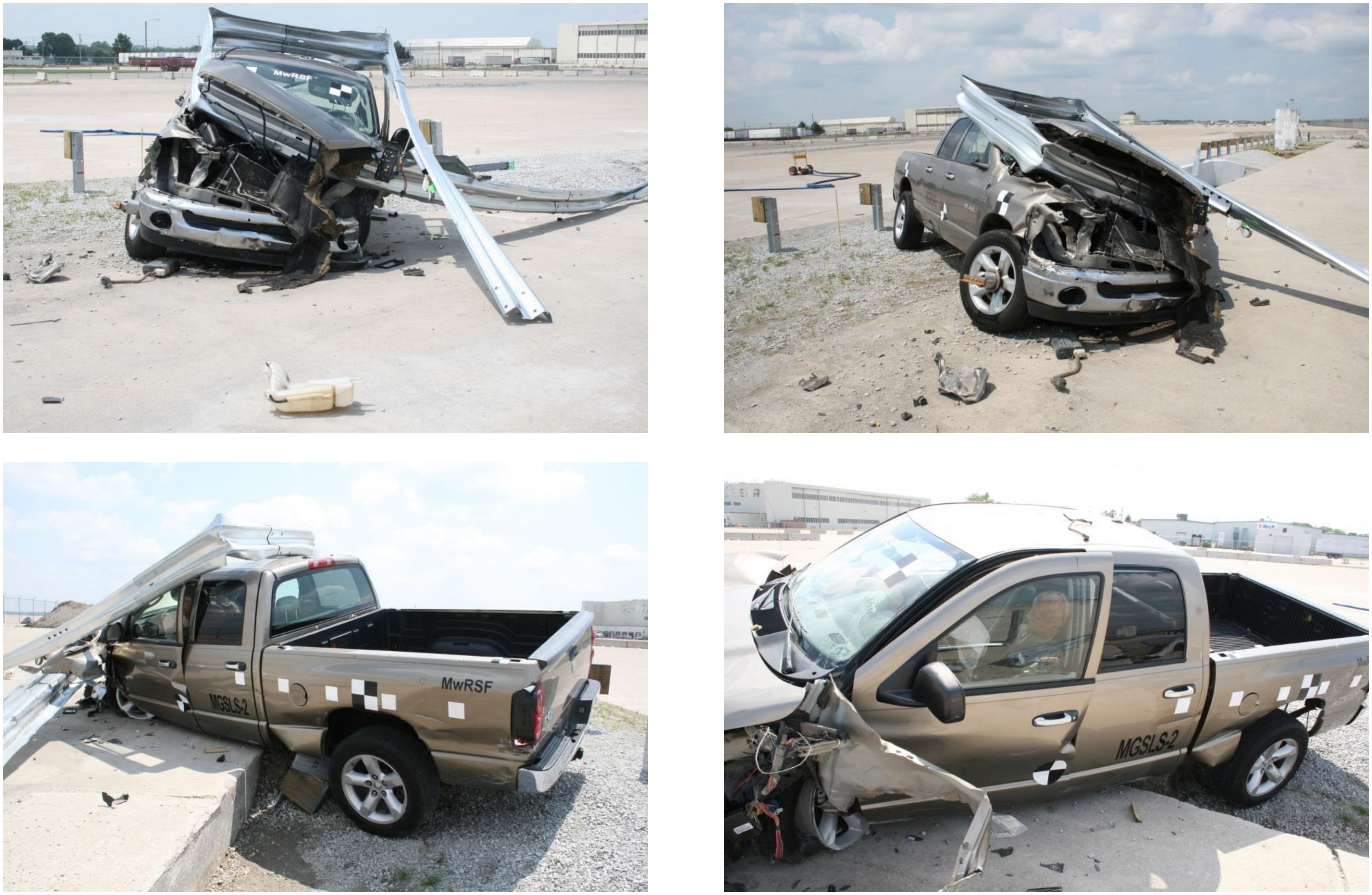

Figure 81. Vehicle Damage, Test No. MGSLS-2

Figure 82. Vehicle Damage, Test No. MGSLS-2

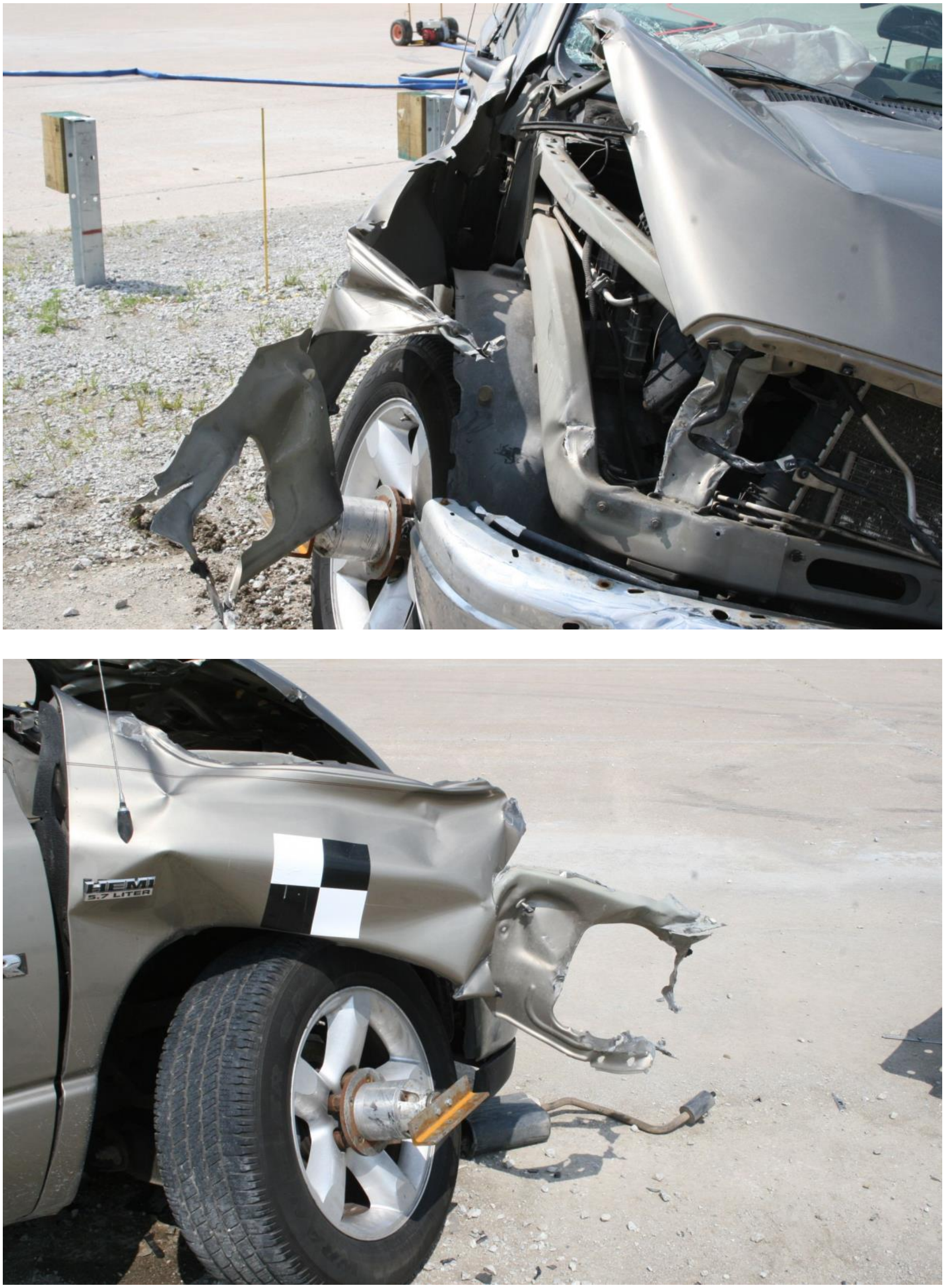

Figure 83. Vehicle Damage, Right Fender, Test No. MGSLS-2

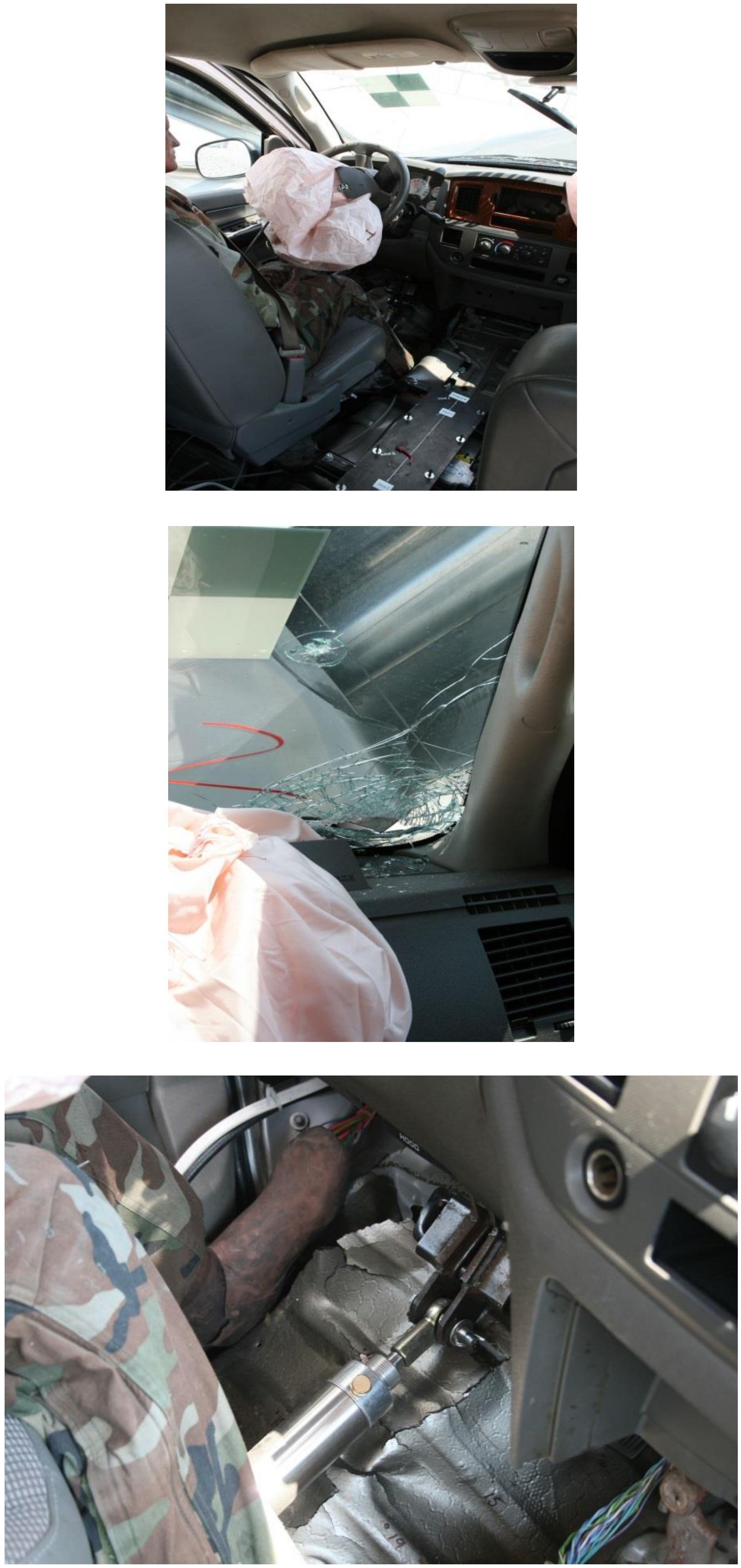

Figure 84. Occupant Compartment Damage, Test No. MGSLS-2

Figure 85. Vehicle Undercarriage Damage, Test No. MGSLS-2

7 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This study investigated the current MGS long-span guardrail system with an unsupported length of 31 ft – 3 in. (9.5 m) as well as the substitution of three UBSP posts on each side of the long span. This study was funded due to interest in shielding longer culvert spans with minimal construction effort as well as limiting culvert damage and repair when compared to other systems requiring post attachment to the top of the culvert. Again, this study focused on increasing the span length of the MGS long span system from 25 ft – 0 in. (7.6 m) to 31 ft – 3 in. (9.5 m). Two full-scale crash tests with pickup trucks were conducted on the MGS long-span system with an increased span length according to the TL-3 MASH requirements for test designation no. 3-11. The first test, MGSLS-1, was conducted to evaluate the potential for vehicle instability by selecting a critical impact point that maximized the interaction of the front wheel with the wingwall of the culvert. The second test, MGSLS-2 utilized a critical impact point that maximized the potential for pocketing, wheel snag, and rail rupture. Both tests utilized 2270P vehicles impacting at a speed of 62 mph (100 km/h) and an angle of 25 degrees.

In test no. MGSLS-1, the 4,955-lb (2,248-kg) pickup truck impacted the MGS long-span system at a speed of 62.7 mph (100.9 km/h), an angle of 25.3 degrees, and at a location 1¾ in. (44 mm) downstream from post no. 11, thus resulting in an impact severity of 124.1 kip-ft (168.2 kJ). After impacting the barrier system, the vehicle exited the system at a speed of 27.3 mph (44.0 km/h) and an angle of 13.3 degrees. The vehicle was successfully contained and smoothly redirected with moderate damage to both the barrier system and the vehicle. All vehicle decelerations, ORAs, and OIVs fell within the recommended safety limits established in MASH. Therefore, test no. MGSLS-1 was successful according to the safety criteria of MASH test designation 3-11.

In test no. MGSLS-2, the 4,912 lb (2,228 kg) pickup truck impacted the MGS long-span system at a speed of 61.4 mph (98.8 km/h), an angle of 26.3 degrees, and at a location 239⁷/₈ in. (6,093 mm) downstream from post no. 13, which resulted in an impact severity of 110.7 kip-ft (150.0 kJ). After impacting the barrier system, the downstream anchor failed and caused the vehicle to penetrate the barrier system. The barrier did not successfully contain nor smoothly redirect the vehicle, and the ORAs exceeded the limits established in MASH. Therefore, test no. MGSLS-2 was unsuccessful according to the safety criteria of MASH test designation 3-11.

Due to the failure of test no. MGSLS-2, design refinements and further testing are necessary on the MGS long-span system for lengths over 25 ft (7.6 m). At this time, it is unclear whether the failure of the downstream anchorage in MGSLS-2 was due to the increased unsupported span, the use of UBSP posts, or some combination of factors. Thus, further analysis of test no. MGSLS-2 as well as recommendations for design refinements and crash testing will be contained in a follow-on Phase III report.

Table 11. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria	Test No. MGSLS-1	Test No. MGSLS-2
Structural Adequacy	A. 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.	S	U
Occupant Risk	D. 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.	S	S
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	S	S
	H. Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits: Occupant Impact Velocity Limits Component | Preferred | Maximum Longitudinal and Lateral | 30 ft/s (9.1 m/s) | 40 ft/s (12.2 m/s)	S	S
	I. The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits: Occupant Ridedown Acceleration Limits Component | Preferred | Maximum Longitudinal and Lateral | 15.0 g's | 20.49 g's	S	U
MASH Test Designation Number		3-11	3-11
Pass/Fail		Pass	Fail

S – Satisfactory U – Unsatisfactory NA - Not Applicable

8 REFERENCES

1. Bielenberg, R.W., Faller, R.K., Rhode, J.R., Reid, J.D., Sicking, D.L., Holloway, J.C., Allison, E.A., and Polivka, K.A., *Midwest Guardrail System for Long-Span Applications*, MwRSF Research Report No. TRP-03-187-07, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, November 16, 2007.

2. Bielenberg, R.W., Faller, R.K., Sicking, D.L., Rhode, J.R., Reid, J.D., *Midwest Guardrail System for Long-Span Culvert Applications*, Paper No. 07-2539, Journal of the Transportation Research Board, Transportation Research Record No. 2025, Transportation Research Board, Washington, D.C., January 2007.

3. Weiland, N.A., Reid, J.D., Faller, R.K., Bielenberg, R.W., Lechtenberg, K.A., *Increased Span Length for the MGS Long-Span Guardrail System*, MwRSF Research Report No. TRP-03-310-14, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, December 17, 2014.

4. Weiland, N.A., Increased Span Length for the MGS Long-Span Guardrail System, Thesis, University of Nebraska – Lincoln, July, 2014.

5. Polivka, K.A., Bielenberg, B.W., Sicking, D.L., Faller, R.K., and Rohde, J.R., *Development of a 7.62-m Long Span Guardrail System*, Final Report to the Midwest States' Regional Pooled Fund Program, Transportation Research Report No. TRP-03-72-99, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, April 6, 1999.

6. Polivka, K.A., Bielenberg, B.W., Sicking, D.L., Faller, R.K., Rohde, J.R., and Keller, E.A., *Development of a 7.62-m Long Span Guardrail System - Phase II*, Final Report to the Midwest States' Regional Pooled Fund Program, Transportation Research Report No. TRP-03-88-99, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, August 13, 1999.

7. Faller, R.K., Sicking, D.L., Polivka, K.A., Rohde, J.R., and Bielenberg, R.W., *A Long-Span Guardrail System for Culvert Applications*, Paper No. 00-0598, Transportation Research Record No. 1720, Transportation Research Board, Washington, D.C., 2000.

8. Price, C.W., Schmidt, T.L., Bielenberg, R.W., Lechtenberg, K.A., Faller, R.K., and Reid, J.D., *Universal Breakaway Steel Post for Other Applications*, Final Report to the Midwest States' Regional Pooled Fund Program, Transportation Research Report No. TRP-03-288-14, Project No. TFP-5(193)-Year 23, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, April 1, 2014.

9. *Manual for Assessing Safety Hardware (MASH)*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.

10. Sicking, D.L., Polivka, K.A., Faller, R.K., Rohde, J.R., Bielenberg, B.W., Reid, J.D., *Performance Evaluation of the Midwest Guardrail System—Update to NCHRP 350 Test No. 3-10 (2214MG-3)*. Final Report to the National Cooperative Highway Research Program, MwRSF Research Report No. TRP-03-172-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, October 11, 2006.

11. Sicking, D.L., Reid, J.D., and Rohde, J.R., *Development of the Midwest Guardrail System*, Paper No. 02-3157, Transportation Research Record No. 1797, Transportation Research Board, Washington, D.C., 2002.

12. Polivka, K.A., Faller, R.K., Sicking, D.L., Reid, J.D., Rohde, J.R., Holloway, J.C., Bielenberg, R.W., and Kuipers, B.D., *Development of the Midwest Guardrail System (MGS) for Standard and Reduced Post Spacing and in Combination with Curbs*, MwRSF Research Report No. TRP-03-139-04, Draft Report to the Midwest States' Regional Pooled Fund Program, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, February 17, 2004.

13. Faller, R.K., Polivka, K.A., Kuipers, B.D., Bielenberg, B.W., Reid, J.D., Rohde, J.R., and Sicking, D.L., *Midwest Guardrail System for Standard and Special Applications*, Paper No. 04-4778, Transportation Research Record No. 1890, Best Paper Award - TRB AFB20 Committee on Roadside Safety Design, Transportation Research Board, Washington D.C., January 2004.

14. Buth, C.E., Campise, W.L., Griffin, III, L.I., Love, M.L., and Sicking, D.L., *Performance Limits of Longitudinal Barrier Systems - Volume I - Summary Report*, Report No. FHWA/RD-86/153, Submitted to the Office of Safety and Traffic Operations, Federal Highway Administration, Performed by Texas Transportation Institute, May 1986.

15. Ivey, D.L., Robertson, R., and Buth, C.E., *Test and Evaluation of W-Beam and Thrie-Beam Guardrails*, Report No. FHWA/RD-82/071, Submitted to the Office of Research, Federal Highway Administration, Performed by Texas Transportation Institute, March 1986.

16. Ross, H.E., Jr., Perera, H.S., Sicking, D.L., and Bligh, R.P., *Roadside Safety Design for Small Vehicles*, National Cooperative Highway Research Program (NCHRP) Report No. 318, Transportation Research Board, Washington, D.C., May 1989.

17. Stolle, C.S., Polivka, K.A., Reid, J.D., Faller, R.K., Sicking, D.L., Bielenberg, R.W., and Rohde, J.R., *Evaluation of Critical Flare Rates for the Midwest Guardrail System (MGS)*, Final Report to the Midwest State's Regional Pooled Fund Program, Transportation Research Report No. TRP-03-191-08, Project No.: SPR-3(017), Project Code: RPFP-04-03 and RPFP-05-05 - Years 14 and 15, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, July 15, 2008.

18. Stolle, C.J., Lechtenberg, K.A., Reid, J.D., Faller, R.K., Bielenberg, R.W., Rosenbaugh, S.K., Sicking, D.L., and Johnson, E.A., *Determination of the Maximum MGS Mounting Height - Phase I Crash Testing*, Final Report to the Midwest State's Regional Pooled

Fund Program, Transportation Research Report No. TRP-03-255-12, Project No.: TPF-5(193), Project Code: RPFP-10-MGS Year 20, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, March 9, 2012.

19. Hinch, J., Yang, T.L., and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, Virginia, 1986.

20. *Center of Gravity Test Code - SAE J874 March 1981*, SAE Handbook Vol. 4, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1986.

21. MacInnis, D., Cliff, W., and Ising, K., *A Comparison of the Moment of Inerita Estimation Techniques for Vehicle Dynamics Simulation*, SAE Technical Paper Series – 970951, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1997.

22. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, NY, July, 2007.

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

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

25. Mongiardini, M., Faller, R.K., Reid, J.D., Sicking, D.L., Stolle, C.S., and Lechtenberg, K.A., *Downstream Anchoring Requirements for the Midwest Guardrail System*, Research Report No. TRP-03-279-13, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 28, 2013.

26. Mongiardini, M., Faller, R.K., Reid, J.D., and Sicking, D.L., *Dynamic Evaluation and Implementation Guidelines for a Non-Proprietary W-Beam Guardrail Trailing-End Terminal*, Paper No. 13-5277, Transportation Research Record No. 2377, Journal of the Transportation Research Board, TRB AFB20 Committee on Roadside Safety Design, Transportation Research Board, Washington D.C., January 2013, pages 61-73.

27. Stolle, C.S., Reid, J.D., Faller, R.K., and Mongiardini, M., *Dynamic Strength of a Modified W-Beam BCT Trailing-End Termination*, Paper No. IJCR 886R1, Manuscript ID 1009308, International Journal of Crashworthiness, Taylor & Francis, Vol. 20, Issue 3, Published online February 23, 2015, pages 301-315.

28. Griffith, M.S., Federal Highway Administration (FHWA). *Eligibility Letter HSST/B-256 for: Trailing-End Anchorage for 31" Tall Guardrail*, December 18, 2015.

9 APPENDICES

Appendix A. Material Specifications

Table A-1. Bill of Materials, Test Nos. MGSLS-1 and MGSLS-2

Item No.	Description	Material Specification	Reference
a1	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829 mm] Long Steel Post	ASTM A992 Steel Galv., ASTM A36 Steel Galv.	H#59056416 R#15-0085 H#1311743
a2	6x12x14 1/4" [152x305x368 mm] Timber Blockout for Steel Posts	SYP Grade No.1 or better	Invoice #43270
a3	16D Double Head Nail	-	n/a
a4	12'-6" [3,810 mm] W-Beam MGS Section	12-gauge [2.7 mm] AASHTO M180 Galv.	H#4614
a5	6'-3" [1,905 mm] W-Beam MGS Section	12-gauge [2.7 mm] AASHTO M180 Galv.	H#515691
a6	12'-6" [3,810 mm] W-Beam MGS End Section	12-gauge [2.7 mm] AASHTO M180 Galv.	H#4614
b1	BCT Timber Post - MGS Height	SYP Grade No. 1 or better (No knots, 18" [457 mm] above or below ground tension face)	R#15-0161 H#19304
b2	72" [1,829 mm] Long Foundation Tube	ASTM A500 Grade B Galv.	R#15-0157 H#0173175
b3	Strut and Yoke Assembly	ASTM A36 Steel Galv.	R#09-0453-8
b4	Anchor Bracket Assembly	ASTM A36 Steel Galv.	H# V911470
b5	8"x8"x5/8" [203x203x16 mm] Anchor Bearing Plate	ASTM A36 Steel Galv.	H#18486
b6	2 3/8" [60 mm] O.D. x 6" [152 mm] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv.	H#280638 R#09-0458
h3	115-HT Mechanical Splice - 3/4" [19 mm] Dia.	As Supplied	n/a
b8	3/4" [190 mm] Dia. 6x19 IWRC IPS Wire Rope	IPS Galvanized	R#15-0284
h1	BCT Anchor Cable End Swage Fitting	Grade 5 - Galvanized	R#15-0285
h4	Crosby Heavy Duty HT-3/4" [19 mm] Dia. Cable Thimble	Stock No. 1037773 - Galvanized	n/a
h5	Crosby G2130 or S2130 Bolt Type Shackle - 1 1/4" [32 mm] Dia. With thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 - As Supplied	n/a
h6	Chicago Hardware Drop-Forged Heavy-Duty Eye Nut - Drilled and Tapped 1 1/2" [38 mm] Dia. - UNF 12 [M36]	As Supplied, Stock No. 107	n/a
h7	TLL-50K-PTB Load Cell	NA	n/a
c1	5/8" [16 mm] Dia. UNC, 14" [356 mm] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	H#13102751 6600679 NF1101335
c2	5/8" [16 mm] Dia. UNC, 1 1/4" [32 mm]	Bolt ASTM A307 Grade A	R#14-0554

	Guardrail Bolt and Nut	Galv., Nut ASTM A563 A Galv.	
c3	5/8" [16 mm] Dia. UNC, 10" [254 mm] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	H#130809L
c4	5/8" [16 mm] Dia. UNC, 1 1/2" [38 mm] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	Rollform Supply
c5	5/8" [16 mm] Dia. UNC, 10" [254 mm] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	JK1110419701
c6	7/8" [22 mm] Dia. UNC, 8" [203 mm] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	04-3280n
c7	5/8" [16 mm] Dia. Plain Round Washer	ASTM F844 Galv.	n/a
c8	7/8" [22 mm] Dia. Plain Round Washer	ASTM F844 Galv.	n/a
d1	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 30 5/8" [778 mm] Long Steel Post	ASTM A992 Steel Galv.	H#55030283
d2	6"x8"x3/16" [152x203x5], 40" [1016 mm] Long Steel Tube	ASTM A500 Steel Grade B Galv.	H#B404986
d3	13"x5 1/2"x3/4" [330x140x19 mm] Upper Base Plate	ASTM A36 Steel Galv.	n/a
d4	13"x7"x1/2" [330x178x13 mm] Lower Base Plate	ASTM A36 Steel Galv.	n/a
d5	7/16" [11] Dia. UNC, 2 1/2" [64 mm] Long Hex Tap Bolt (Fully Threaded) and Nut	Bolt SAE J449 Grade 5/ASTM A325 Galv., Nut ASTM A563DH Galv.	Fastenal Part # 0144506 H#X6288
d6	7/16" [11 mm] Dia. Plain Round Washer	ASTM F844 Galv., ASTM F436 Type 1 Galv.	R#14-0553 Fastenal#1133860 H#0W415 L#27253FN8A
e1	#4 Bar - Longitudinal - 345" [8763 mm] long	Grade 60 Steel	H#112230/ H#57134866
e2	#4 Bar - Bent Longitudinal - 80" [2032 mm] long	Grade 60 Steel	H#112230/ H#57134866
e3	#4 Bar - Bent Longitudinal - 50" [1270 mm] long	Grade 60 Steel	H#112230/ H#57134866
e4	#4 Bar - Stirrup - 93" [2362 mm] long	Grade 60 Steel	H#112230/ H#57134866
e5	#4 Bar - Stirrup - 75" [1905 mm] long	Grade 60 Steel	H#112230/ H#57134866
e6	Concrete	Minimum f'c=4000 psi	R#15-0540
e7	36" [914] Dia., 36" (914 mm) Long Unreinforced Concrete Footer	Minimum f'c=4000 psi	R#15-0532

CERTIFIED MATERIAL TEST REPORT — Page 1/1

GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
STEEL & PIPE SUPPLY CO INC 1050 FORT GIBSON RD CATOOSA,OK 74015-3033 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	992/572-50	Wide Flange Beam / 6 X 9# / 150 X 13.5

LENGTH	WEIGHT	HEAT / BATCH
40'00"	17,280 LB	59056416/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
470022/000010	37690040	ASTM A572/A572M-07 ASTM A6/A6M-11 ASTM A992/A992M-11

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500206835	1327-0000063498	07/12/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.10	0.85	0.011	0.025	0.21	0.27	0.10	0.15	0.033	0.007	0.001	0.013	0.003

CHEMICAL COMPOSITION

CEqvA6 %
0.3

MECHANICAL PROPERTIES

YS KSI	UTS KSI	YS MPa	UTS MPa	G/L Inch	G/L mm
60.1	75.7	418	526	8.000	200.0
60.6	76.2	414	522	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	Y/T rati %
20.20	0.795
21.70	0.794

COMMENTS / NOTES

R#15-0594 MGS Long Span June 2015 SMT
There are two separate heat numbers for
the w6x9 posts and there are three posts
each.

6posts and 3tubes

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

TOM HARRINGTON
QUALITY ASSURANCE MGR.

Figure A-2. MGS Long-Span Two-Part W6X9 Posts, Test Nos. MGSLS-1 and MGSLS-2

GERDAU

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CERTIFIED MATERIAL TEST REPORT

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CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
STEEL & PIPE SUPPLY CO INC 401 NEW CENTURY PKWY NEW CENTURY,KS 66031-1127 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	A992/A572-50	Wide Flange Beam / 6 X 9#

LENGTH	WEIGHT	HEAT / BATCH
50'00"	47,250 LB	55030283/04

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
622435/000020	000000000037690050	1-ASTM A6/A6M-11 2-A992/A992M-11 3-A572/A572M-07

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500213808	1323-0000015005	11/12/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	N %	Pb %
0.16	0.92	0.016	0.029	0.21	0.28	0.11	0.09	0.052	0.017	0.001	0.0100	0.0050

CHEMICAL COMPOSITION

Sn %
0.010

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS 0.2% PSI	YS MPa
23.50	8.000	80200	553	59500	410
19.30	8.000	80500	555	59500	410

MECHANICAL PROPERTIES

YS / UTS %
0.740
0.740

COMMENTS / NOTES

MGS LONG SPAN 2part posts
6posts/2foundation tubes
R#15-0085 August 2014

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure A-3. MGS Long-Span Two-Part W6x9 Posts, Test Nos. MGSLS-1 and MGSLS-2

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 MTR.

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-4. W6x8.5 Posts, Test Nos. MGSLS-1 and MGSLS-2

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 Metlindy

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	Mea #1	6x12 - 14" Rgh	732	18%	9/10 90%	.657 pcf
334	4/20/12	Mea #1	6x12 – 19" Adpt. Rgh	36	17%	1/20 95%	.623 pcf
332	4/19/12	Mea #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-5. Blockouts, Test Nos. MGSLS-1 and MGSLS-2

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

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

R#15-0515
6x12x14 OCD Wood Blockouts
Light Blue Paint

Date: 1/30/15

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery – Milford   BOL# 10050796

Customer PO# 3004 thru 1   Preservative: CCA – C 0.60 pcf

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6814 BLK	6x8-14" BLK Tapered	252	19877	.708 pcf
GR61214 BLK	6x12-14" BlK OCD	168	19815	.603 pcf
↓	↓	420	19814	.681 pcf
↓	↓	588	19809	.694 pcf

I certify the above referenced material has been produced, treated and tested in accordance with and conforms to AASHTO M133 & M168 standards.

Kurt Andres, General Manager   1/30/15 Date

Figure A-6. Blockouts, Test Nos. MGSLS-1 and MGSLS-2

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

MAY 14 2009

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

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

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

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

By: *[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.
Cynthia K Crawford
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-7. Guardrail, Test Nos. MGSLS-1 and MGSLS-2

Certified Analysis

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

MILFORD, NE 68405
Project: RESALE

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

As of: 5/16/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
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-8. Guardrail, Test Nos. MGSLS-1 and MGSLS-2

SPA BLUE PAINT R#15-0161

September 2014 SMT

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-9. BCT Timber Posts, Test Nos. MGSLS-1 and MGSLS-2

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: STOCK

Order Number: 1215324 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2884
BOL Number: 80821 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/14/14

Foundation Tubes Green Paint
R#15-0157 September 2014 SMT

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	701A	.25X11.75X16 CAB ANC	A-36			A3V3361	48,600	69,000	29.1	0.180	0.410	0.010	0.005	0.040	0.270	0.000	0.070	0.001	4
	701A		A-36			JJ4744	50,500	71,900	30.0	0.150	1.060	0.010	0.035	0.240	0.270	0.002	0.090	0.021	4
12	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
15	736G	5'/TUBE SL/.188"X6"X8"FLA	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
12	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
5	783A	5/8X8X8 BEAR PL 3/16 STP	A-36			10903960	56,000	79,500	28.0	0.180	0.810	0.009	0.005	0.020	0.100	0.012	0.030	0.000	4
	783A		A-36			DL13106973	57,000	72,000	22.0	0.160	0.720	0.012	0.022	0.190	0.360	0.002	0.120	0.050	4
20	3000G	CBL 3/4X6'6/DBL	HW			99692													
25	4063B	WD 6'0 POST 6X8 CRT	HW			43360													
15	4147B	WD 3'9 POST 5.5"X7.5"	HW			2401													
20	15000G	6'0 SYT PST/8.5/31" GR HT	A-36			34940	46,000	66,000	25.3	0.130	0.640	0.012	0.043	0.220	0.310	0.001	0.100	0.002	4
10	19948G	.135(10Ga)X1.75X1.75	HW			P34744													
2	33795G	SYT-3"AN STRT 3-HL 6'6	A-36			JJ6421	53,600	73,400	31.3	0.140	1.050	0.009	0.028	0.210	0.280	0.000	0.100	0.022	4
4	34053A	SRT-31 TRM UP PST 2'6.625	A-36			JJ5463	56,300	77,700	31.3	0.170	1.070	0.009	0.016	0.240	0.220	0.002	0.080	0.020	4

1 of 3

Figure A-10. Foundation Tubes, Test Nos. MGSLS-1 and MGSLS-2

625 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.

402-761-3288

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

16:36 05/04/2009

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

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

2 of 4

Figure A-11. Ground Strut, Test Nos. MGSLS-1 and MGSLS-2

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	140755	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-12. Cable Anchor Bracket and Bearing Plate Assemblies, Test Nos. MGSLS-1 and MGSLS-2

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: 4500104152
			PA No: 81163893

SLEEVE MAT CRT

Heat No	Yield P.S.I.	Tensile P.S.I.	Elongation % 2 inch
280638	61,500	86,400	23.00

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

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

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

STEEL VENTURES, LLC dba EXLTUBE

Steve Frerichs
Quality Assurance Manager

104158

Figure A-13. BCT Post Sleeve, Test Nos. MGSLS-1 and MGSLS-2

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801

Customer: GUARDRAIL SYSTEMS, INC
8000 SERUM AVE.

RALSTON, NE 68127

Sales Order: 1210536
Customer PO: VERBAL TRENT
BOL # 79448
Document # 1

Print Date: 12/6/13
Project: RESALE
Shipped To: NE
Use State: NE

Trinity Highway Products, LLC

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

NCHRP Report 350 Compliant

Pieces	Description	Part No
1	12/6"/FLANGE PROTECTOR	000007G
79	12/12'6/S SRT-1	000030G
79	12/12'6/S SRT-2	000039G
49	3/16X12.5X16 CAB ANC BRKT	000700A
49	12/BUFFER/ROLLED	000907G
49	CBL 3/4X6'6/DBL SWG/NOHWD	003000G
98	5/16" ROUND WASHER WIDE	003240G
98	5/16" HEX NUT A563	003245G
588	5/8" WASHER F844 A/W	003300G
3,283	5/8" GR HEX NUT	003340G
2,548	5/8"X1.25" GR BOLT	003360G
392	5/8"X1.5" HEX BOLT A307	003380G
98	5/8"X1.75" HEX BOLT A325	003391G
196	5/8"X2" GR BOLT	003400G
98	1" ROUND WASHER F844	003900G
98	1" HEX NUT A563	003910G
98	5/16"X1.75 HXBTA307 1-1/8	004211G
49	5/8"X1.75" SLTDCNTRSKBOLT	004419G
196	SLOT GUARD '98	009960G
49	12/9'4.5/3'1.5/S	010967G
245	6'0 SYT PST/8.5/31" GR HT	015000G
49	HBA-3"ANG STRUT 2-HL 6'6"	033875G
49	CASS-CBL BRKT FOR CRP PST	033909G
49	SRT-31/27 LOWER PST 6'4	034052A
49	SRT-31 TRM UP PST 2'6.625	034053A
49	W-BEAM GD RL SHELF ANGLE	034054G

R#15-0284 and R#15-0285
BCT Cables
purchased and some converted to
2part Cables at Omaha Slings
January 2015 SMT

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

1 of 2

Figure A-14. Wire Rope, Test Nos. MGSLS-1 and MGSLS-2

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801

Customer:	GUARDRAIL SYSTEMS, INC	Sales Order:	1210536	Print Date:	12/6/13
	8000 SERUM AVE.	Customer PO:	VERBAL TRENT	Project:	RESALE
		BOL #	79448	Shipped To:	NE
		Document #	1	Use State:	NE
	RALSTON, NE 68127				

Trinitv Highwav Products. LLC

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

NCHRP Report 350 Compliant

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

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

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 6th day of December, 2013

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

STATE OF OHIO ★ ANGELA COUNTS ★ NOTARY PUBLIC ID# 2011NT6014 Commission Expires January 22, 2016 AUGLAIZE COUNTY

Trinity Highway Products, LLC
Certified By:
Quality Assurance

2 of 2

Figure A-15. End Terminal Cable Fitting, Test Nos. MGSLS-1 and MGSLS-2

5/8"x14" Post Bolts
Green Paint R#14-0554
July 2014 SMT

3540G

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
DATE SHIPPED: 01/13/14

INVOICE #:

LOT#: 25512

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 76,318 78,539 78,075 76,380

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

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

Deada Melomas
APPROVED SIGNATORY

1/14/14
DATE

Figure A-16. 14-in. (356-mm) Guardrail Post Bolts, Test Nos. MGSLS-1 and MGSLS-2

FASTENERS & FITTINGS INC.

901 STEELES AVENUE EAST
MILTON, ONTARIO L9T 5H3
PHONE: (905) 670-2503 FAX: (905) 670-2506, TOLL FREE: 1-800-613-4094

ISO 9001
REGISTERED COMPANY

CERTIFICATE OF CONFORMANCE

CUSTOMER	: ROLL FORM GROUP	OUR PACKING SLIP NO:	: 66192
CUSTOMER PO NO	: 18329	OUR INVOICE NO:	: ---
ITEM	: GUARDRAIL BOLT	SUPPLIER INVOICE NO	: HSW07046
SIZE	: 5/8" - 11 x 14" H.D.G	BULK LOT NO / PO No.	: 1017
HEAT NO	: 6600679	DATE	: 12-Jun-07

No	Test Item	Specs / Standards / Criteria	Result
1	Appearance	Per ASTM F 812-95	OK
2	Thread	Go & No Go and P.D & M.D	OK
3	Mark		307 A N
4	Coating Thickness	CSA-CSAG-164-M Class 5(Min 65um or 2.54 mills)Avg.	70.8
5	Mass of Coating	CSA-CSAG-164-M Class 5(Min 460g/m2 or 1.5 oz/ft2)Avg.	505.3
6	Dimensions	Head Diameter(31.80-34.85)	32.36-33.51
		Head Height(7.20-10.26)	8.62-9.39
		Shoulder Width O(22.25-23.77)	22.68-23.21
		Shoulder Width V(15.08-16.66)	15.76-16.33
		Shoulder Depth P(4.78-6.29)	5.61-6.01
		Length(351.03-359.15)	353.77-355.20
7	Tensile Strength	Min 60,000 PSI	61,500-64,000 PSI
8	Material	Per ASTM (A307)	OK

Material Chemical Composition:

C	Si	Mn	P	S
%	%	%	%	%
0.12	0.18	0.46	0.028	0.02

Hot Dip Galvanizing Inspection Certificate: (Test Standard CSAG-164-M class 5)

Test of No.	Weight of coating test							G/m² over
1	70	73	70	69	72	72	71.0	506.9
2	72	68	72	72	68	72	70.7	504.6
3	69	72	70	68	72	72	70.5	503.4
4	71	70	71	72	69	71	70.7	504.6
5	72	70	72	72	71	69	71.0	506.9
Average of The Average							70.8	505.3

Muhammad Ashraf
905-670-2503 ext 328
16 Aug 2011

2-0063-11X1400"SGUG (HSW07046) WO# 11165 PPS# 66192 CustPO# 18329 Aug16-2011

Figure A-17. 14-in. (356-mm) Guardrail Post Bolts, Test Nos. MGSLS-1 and MGSLS-2

3540G

INSPECTION CERTIFICATE

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

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER P.O.: 143227

INVOICE #: 946256 **DATE SHIPPED:** 6/20/11

LOT #: 22191

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

	SPECIFICATION	ACTUAL		
TENSILE RESULTS:	60,000 min.	81,460	70,642	76,898
		81,389	70,341	76,623
HARDNESS RESULTS:	SPECIFICATION 100 MAX	80.63	83.90	84.00
		86.33	77.90	85.00

COATING: ASTM SPECIFICATION F2329 HOT DIP GALVANIZE

STEEL SUPPLIER: NUCOR, CHARTER, NUCOR

HEAT NO. NF11101335, 10132120, NF11101336

QUANTITY AND DESCRIPTION:

18,900 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. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE U.S.A.. WE FURTHER CERTIFY 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 REQUIREMENTS PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
21 DAY OF June 20 11
Diane Rasmussen

Linda Melonas 6/21/11
APPROVED SIGNATORY DATE

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

Figure A-18. 14-in. (356-mm) Guardrail Bolts, Test Nos. MGSLS-1 and MGSLS-2

33606

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

TEST REPORT

NVLAP LAB CODE 200654-0

Lab No: 14030196F
KEITH HAMBURG
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 03/12/2014
Heat Code: 140314B
Heat Number:
PO or Work Order: 55-80329
Test Spec: F606 ASTM METHODS
Other Information:

Completion Date: 03/13/2014
Weld Spec:
Material Type: A 307 A
Material Size: 5/8" x 1-1/4" G R B

OTHER TEST:

Type: HARDNESS ROCKWELL BW — Quantity amount: 20
Test Spec: E-18

Bolt "A": 85.6 - 85.8 - 86.6 - 86.8

Bolt "B": 88.5 - 88.4 - 89.1 - 89.0

Bolt "C": 87.8 - 86.8 - 87.6 - 87.4

Bolt "D": 88.8 - 88.6 - 88.0 - 88.2

Bolt "E": 88.1 - 87.6 - 87.2 - 87.3

Type: HEAD MARKINGS — Quantity amount: 1
TRN USA 307A R

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-14. This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Lab Director: Michael S. Beaton, PE

Page 1 of 1

Figure A-19. 1 ¼-in. (32-mm) Bolts, Test Nos. MGSLS-1 and MGSLS-2

5/8x10" post bolt
R#14-0207 Green Paint

8/26/13

3500G

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 Brown 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-20. 10-in. (254-mm) Post Bolts, Test Nos. MGSLS-1 and MGSLS-2

FASTENERS & FITTINGS INC
901 STEELES AVENUE EAST MILTON, ONTARIO L9T 5H3
TEL: (905) 670-2503 FAX: (905) 670-2506 TOLL FREE: 1-800-613-4094

ISO 9001
REGISTERED COMPANY

TO: ROLL FORM GROUP

CERTIFICATE OF CONFORMANCE

WE HEREBY CERTIFY THAT THE FOLLOWING PRODUCT (S):
UNDER FF "PPS" # 191135 AND YOUR ORDER # 24825 CONFORMS TO THE FOLLOWING SPECIFIED STANDARD (S).

SIZE	DESCRIPTION	REFERENCED IFI or OTHER STANDARD	Made In	RoHS Compliant	
				Yes	No
5/8-11x 1 1/2	UNC GR2 CAPSCREW H.D.G WITH NUTS	Bolt: ANSI B 18.2.1 (1981) Nut: ANSI B 18.2.2 (1986)	CHINA	X	

MUHAMMAD ASHRAF
905-670-2503 Ext 328

Fasteners & Fittings Page 1 16 AUG 2011

Figure A-21. 1 ½-in. (38-mm) Bolts and Nuts, Test Nos. MGSLS-1 and MGSLS-2

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

May 24, 2012

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

Date: May 24,2012

Original Mill Test Report

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

Chemical Analysis – Weight Percent

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

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

Tensile and Hardness Test Results

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

Comments

Test results meet mechanical requirements of specification.

Figure A-22. 10-in. (254-mm) Hex Bolts, Test Nos. MGSLS-1 and MGSLS-2

CERTIFIED MATERIAL TEST REPORT
FOR ASTM A307, GRADE A - MACHINE BOLTS

FACTORY:LIANYUNGANGSHI PINGXIN FASTENER CO.,LTD DATE: 9/Nov/07
ADDRESS:No.3 jingsan Road,Biotechnology Park,Haizhou Bay,Haitou Town,Ganyu County,Lianyungang CHINA
MFG LOT NUMBER: M-NBPX0339-31
CUSTOMER:
PO NUMBER:17071802

SAMPE SIZE: ACC. TO ASME B18 . 18 . 2M - 93 PART NO:00026-3464-451
SIZE: 7/8-9X8 ZP QNTY: 1440 PCS
HEADMARKS: 307A PLUS PX MANU.DATE:

STEEL PROPERTIES: Q235 25mm
STEEL GRADE: HEAT NUMBER: 04-3280n

CHEMISTRY SPEC:	C %*100 0.29max	Mn%*100 1.20 max	P %*1000 0.04max	S %*1000 0.05max
TEST:	0.15	0.45	0.024	0.033

DIMENSIONAL INSPECTIONS SPECIFICATION: ASME B18.2.1 - 2010

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	***********************************	******************	********	********
VISUAL	ASTM F788/F788M-08	PASSED	100	0
THREAD	ASME B1.3	PASSED	32	0
WIDTH FLATS	1.269-1.312	1.279-1.302	8	0
WIDTH A/C	1.447-1.516	1.457-1.506	8	0
HEAD HEIGHT	0.531-0.604	0.541-0.584	8	0
BODY DIA.	0.8660-0.8750	0.8677-0.8741	8	0
THREAD LENGTH	2.25	2.28-2.38	8	0
LENGTH	7.80-8.16	7.82-8.14	8	0

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307-2010 GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	******************	******************	******************	********	********
CORE HARDNESS :	ASTM F606-2010a	69-100 HRB	92-95 HRB	8	0
WEDGE TENSILE:	ASTM F606-2010a	Min 60 KSI	82-85 KSI	4	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	******************	******************	******************	********	********
COATINGS OF ZINC	ASTM F1941	Min 4 μm	5 μm	4	0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

Figure A-23. 8-in. (203-mm) Bolts, Test Nos. MGSLS-1 and MGSLS-2

CERTIFIED MATERIAL TEST REPORT

Page 1/1

GERDAU

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
STEEL & PIPE SUPPLY CO INC 401 NEW CENTURY PKWY NEW CENTURY,KS 66031-1127 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	A992/A572-50	Wide Flange Beam / 6 X 9#

LENGTH	WEIGHT	HEAT / BATCH
50'00"	47,250 LB	55030283̸04

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
622435/000020	000000000037690050	1-ASTM A6/A6M-11 2-A992/A992M-11 3-A572/A572M-07

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500213808	1323-0000015005	11/12/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	N %	Pb %
0.16	0.92	0.016	0.029	0.21	0.28	0.11	0.09	0.052	0.017	0.001	0.0100	0.0050

CHEMICAL COMPOSITION

Sn %
0.010

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS 0.2% PSI	YS MPa
23.50	8.000	80200	553	59500	410
19.30	8.000	80500	555	59500	410

MECHANICAL PROPERTIES

YS / UTS %
0.740
0.740

COMMENTS / NOTES

MGS LONG SPAN 2part posts
6posts/2foundation tubes
R#15-0085 August 2014

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure A-24. MGS Long-Span Posts and Tubes, Test Nos. MGSLS-1 and MGSLS-2

SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

STEEL & PIPE SUPPLY COMPANY INC.

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 06/03/2014
TIME 09:26:24
USER WILLIAMR

SOLD TO

SHIP TO
13715
Warehouse 0030
310 Smith Road
Jonesburg MO 63351

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40223279-0010	701672120TM	1/2 72 X 120 A36 TEMPERPASS STPMLPL	8	9,801.600			06/03/2014

Chemical Analysis

Heat No. B404986 Vendor SEVERSTAL COLUMBUS DOMESTIC Mill SEVERSTAL COLUMBUS Melted and Manufactured in the USA
Batch 0002961904 8 EA 9,801.600 LB Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.2000	0.8000	0.0070	0.0020	0.0200	0.0500	0.0600	0.0100	0.0001	0.1000	0.0300	0.0010	0.0020	0.0020	0.0085	0.0050

Mechanical/ Physical Properties

Mill Coil No. B404986-04

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
77600.000	54100.000	30.10	0	0.000	0	NA			
75100.000	50450.000	33.60	0	0.000	0	NA			
73900.000	49600.000	33.30	0	0.000	0	NA			
75400.000	53900.000	32.60	0	0.000	0	NA			

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.

Figure A-25. MGS Long-Span Posts and Tubes, Test Nos. MGSLS-1 and MGSLS-2

Jinn Her Enterprise Co., Ltd.

No. 107, SHIN-LO ST, KANGSHAN, 820 KAOHSIUNG, TAIWAN R. O. C
TEL : +886 (07) 6229801 FAX : +886 (07) 6223750 • +886 (07) 6211503

CERTIFICATE OF INSPECTION

1 / 1

CUSTOMER NAME	: FASTENAL COMPANY PURCHASING-IMPORT TRAFFIC	REPORT NO	: JH14073005004
CUSTOMER'S ADDRESS	: 4730 N. SERVICE DRIVE, WINONA MN. 55987 U.S.A.,TEL : 507-313-7575 FAX: 507-494-7833	REPORT DATE	: 2014/08/07
		BOLT LOT NO	: B366508Z1
		BOLT MATERIAL	: SAE 1038
ORDER NUMBER	: 120200845	BOLT HEAT NO	: X6288
PART NUMBER	: 0144506	NUT LOTNO	:
DESCRIPTION	: HEX TAP BOLT G5, HD MARK : 3 RADIAL LINES & "JH"	NUT MATERIAL	:
		NUT HEAT NO	:
		WASHER LOT NO	:
SIZE	: 7/16-14X2-1/2	WASHER MATERIAL	:
FINISH	: H.T. ZINC & CLEAR 5 MICRON, TRIVALENT CHROMATE	WASHER HEAT NO	:
SHIP QUANTITY	: 12950.0	ASSEMBLY LOT NO	:
BOLT MFR.	: JINN HER ENTERPRISE CO.,LTD.	BOLT MFR. DATE	: 2014/6/24
NUT MFR.	:	NUT MFR. DATE	:
WASHER MFR.	:	WASHER MFR. DATE	:

BOLT DIMENSIONAL INSPECTION — INSPECTION : 2014/07/12
SPECIFICATION : ASME B18.2.1-2012 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
WIDTH ACROSS CORNERS	JIS B1071	0.6980-0.7220	inch	0.7035-0.7070	8	8	0
WIDTH ACROSS FLATS	JIS B1071	0.6120-0.6250	inch	0.6149-0.6169	8	8	0
HEIGHT	JIS B1071	0.2720-0.2910	inch	0.2803-0.2826	8	8	0
LENGTH	JIS B1071	2.4400-2.5400	inch	2.4842-2.4905	8	8	0
THREAD	ASME B1.3	NONE	N/A	PASS	8	8	0

BOLT MECHANICAL INSPECTION — INSPECTION : 2014/07/07
SPECIFICATION : ASTM F2328-2005 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
COMPLETELY DEC. DEPTH	ASTM F2328	MAX 0.0006	inch	PASS	1	1	0
BASE METAL	ASTM F2328	MIN 0.0220	inch	PASS	1	1	0

BOLT MECHANICAL INSPECTION — INSPECTION : 2014/07/07
SPECIFICATION : SAE J429 APR2013 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
SURFACE HARDNESS	ASTM F606	MAX 54.0	HR30N	50.0-51.0	8	8	0
CORE HARDNESS	ASTM F606	25.0-34.0	HRC	30.0-31.0	8	8	0
TENSILE STRENGTH	ASTM F606	MIN 120.0	ksi	138.0-140.0	4	4	0
PROOF LOAD	ASTM F606	MIN 85.0	ksi	PASS	1	1	0

BOLT FINISH INSPECTION — INSPECTION : 2014/07/12
SPECIFICATION : ASTM F1941-2010 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
THICKNESS OF COATING	ASTM A754/A754M	MIN 0.00020	inch	0.00039-0.00050	4	4	0

BOLT APPEARANCE INSPECTION — INSPECTION : 2014/07/12
SPECIFICATION : ASTM F788/F788M-13 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
GENERAL WORKMANSHIP、MARKING	VISION	NONE	N/A	PASS	8	8	0

CHEMICAL ANALYSIS %

HEAT NO	C-x100	MN-x100	P-x1000	S-x1000	SI-x100	CU-x100	NI-x100	CR-x100	MO-x100	AL-x1000	B-x10000	V-x100
X6288	36	69	13	4	21	6	2	4		3		

BOLT MARKING

R#15-0595 7/16" Gr. 5 Bolts
MGS Long Span June 2015 SMT
H#X6288 L#B366508Z1

Remark : 1.Lab is accredited according to ISO/IEC17025 requirements. This certificate is valid with signature of Wen-Da Tsai.
2.This test certificate is responsible for designated samples only. This test certificate only relates to the items listed and tested, it's not allowed to be partially used.
3.The above composition is quoted from original mill certs which is not in the scope of Lab Accreditation.
4.This test certificate in accordance with EN 10204 type 3.1.
5.Unless specified by the customer, the latest version of the testing specs was used.
6.Quality System conforms to ISO 9001 requirements and certified by TUV .

120200845

0144506

B366508Z1

Figure A-26. 2 ½-in. (64-mm) Bolts, Test Nos. MGSLS-1 and MGSLS-2

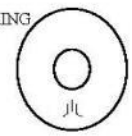
HEXICO ENTERPRISE CO., LTD.

NO.355-3,SEC. 3,CHUNG SHAN ROAD,KAU-JEN,TAINAN,TAIWAN,R.O.C.
TEL : 886 - 6 - 2390616 FAX : 886 - 6 - 2308947

MGS Long Span
7/16" Washers
R# 14-0553
June 2014 SMT

INSPECTION CERTIFICATE

MARKING



CUSTOMER	FASTENAL COMPANY		
PART NAME	USS (ANSI B18.22.1 TYPE A-W - 1965 R1998) WASHERS		
SIZE	7/16 "	DATE	July 10, 2013
PART NO.	WYA3C3500S2KM	REPORT NO.	1020710-08
CUST. PART NO.	1133860	SHIPPING NO.	
MATERIAL	1050 / 1.8 mm	ORDER NO.	120165457
HEAT(COIL) NO.	0W415	DOCUMENT NO.	10201006
LOT QTY	67,500 PCS	LOT NO.	27253FN8A
STANDARD OF SAMPLING SCHEME	ANSI / ASME B18.18.2 M-1993		
HARDNESS TEST METHOD	ASTM F606-2010		
COATING TEST METHOD	ASTM B499-2009		

DIMENSIONS IN inch

INSPECTION ITEM		SPECIFICATION	TEST QTY	INSPECTION RESULTS		REMARKS
				MIN.	MAX.	
1	OUTSIDE DIAMETER	1.2430 - 1.2800	8	1.2528	1.2543	
2	INSIDE DIAMETER	0.4950 - 0.5150	8	0.5051	0.5063	
3	THICKNESS	0.0640 - 0.1040	8	0.0673	0.0717	
4	HARDNESS	HRC 38 - 45	5	39.0	41.3	
5	COATING (BAKED)	ZINC YELLOW 5 μm	5	8.8	10.7	
6	SALT SPRAY TEST	96 hrs. No White Rust	4	OK		
7	APPEARANCE	VISUAL	100	OK		

INSPECTED BY *Yu Tain Lin* CERTIFIED BY *Jing Yeh Tsao*

Figure A-27. 7/16-in. (11-mm) Washers, Test Nos. MGSLS-1 and MGSLS-2

中國鋼鐵
CHINASTEEL

10201006

品質證明書
TEST CERTIFICATE

中國鋼鐵股份有限公司
CHINA STEEL CORPORATION
中華民國高雄市小港區中鋼路1號
1 CHUNG KANG ROAD HSIAO KANG, KAOHSIUNG (812)
TAIWAN, REPUBLIC OF CHINA
TEL: (07)802-1111 FAX: (07)802-2511, (07)801-9427

H0191-01 COMPANY REGISTRATION NUMBER: 30414175 1159

客戶名稱 SOLD TO	三星科技股份有限公司 SAN SHING FASTECH CORP.	產品名稱 PRODUCT	HR SHEET-COIL P-O(MILL EDGE)
		發票號碼 INVOICE NO.	KQ11198492
		證明書編號 CERTIFICATE NO.	020105H0191
規格名稱 SPEC.	SAE 1050 P-O, MSQ, GENERAL PURPOSES(GP), MILL EDGE ALL GAUGES ARE NOMINAL	客戶編號 CUSTOMER NO.	68040606
		中鋼訂單編號 CSC ORDER NO.	JH4906A
		交運日期 SHIPPING DATE	JAN. 04, 2013
		證明書日期 T/C ISSUE DATE	JAN. 05, 2013
檢驗 INSP.	CSC MILL INSPECTION T/C 01	客戶訂單編號 CUST. ORDER NO.	

項目 ITEM NO.	產品序號 LABEL NO.	厚度 THICK. mm	寬度 WIDTH mm	長度 LENGTH mm	數量 QTY	質量 MASS kg	爐號 HEAT NO.	鋼捲號碼 COIL NO.	試片編號 SAMPLE ID.
001	VA32172	1.80	950	COIL	1	6,875	2L710	1342501	
	VA32173	"	"	"	1	6,840	2L710	1342501	
	VA32175	"	"	"	1	6,350	0W415	1342502	
			TOTAL:		3	20,065			

化學成分 CHEMICAL ANALYSIS %

Label No.	C X10²	Mn X10²	P X10³	S X10³	Si X10²	Cu X10²	Ni X10²	Cr X10²	Mo X10²	Al X10³	N X10³	Nb X10³	Ti X10³	V X10³	備註 REMARK
VA32172	49	63	19	4	1	1	1	11	Tr	48	3	1	1	1	
VA32173	"	"	"	"	"	"	"	"	"	"	"	"	"	"	
VA32175	48	64	18	3	1	1	1	11	Tr	46	2	Tr	1	Tr	

註釋 NOTES

Tr: TRACE ELEMENT WITH ITS CONTENT CONFORMING TO THE SPECIFICATION

三星科技股份有限公司 無幅射污染證明經銷商專用章

文傑林

SURVEYOR TO

茲證明本表所列產品，均依材料規格製造及試驗，並符合規格之要求。
WE HEREBY CERTIFY THAT MATERIAL DESCRIBED HEREIN HAS BEEN MANUFACTURED AND TESTED WITH SATISFACTORY RESULTS IN ACCORDANCE WITH THE REQUIREMENT OF THE ABOVE MATERIAL SPECIFICATION.

Chih-Chung Wu

冶金技術處處長
GENERAL MANAGER, METALLURGICAL DEPARTMENT

Figure A-28. 7/16-in. (11-mm) Washers, Test Nos. MGSLS-1 and MGSLS-2

CAUTION
FRESH CONCRETE

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

Ready Mixed Concrete Company

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

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
01	24033000	5.00	0108	7596			10:59	05/07/15	1187772

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R	LOADS
00003	3	CIA---MWRSS				15

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4800 NW 35TH	NORTH OF THE NORTH GOODYEAR HANGER	JAMES 450-6250

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UNIT PRICE	AMOUNT
5.00	5.00	5.00	24033000	L4000 TYPE 3	$117.89	$589.45
				SLUMP: 4.00		
				MINIMUM HAUL		20.00
						$609.45
					SUBTOTAL	
					TAX	$609.45
					TOTAL	$609.45

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 0 GAL RECEIVED BY [signature]

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
0108	7596	user	1187772	2684	10:59	5/7/15

Load Size Mix Code Returned Qty Mix Age Seq Load ID

Materia	Description	DesiQty	Required	Batched	%Var	%Moistur	ActuaWat
G47B	47B GRAVEL	2090 lb	10680. lb	10640 lb	-0.37%	2.20% M	27 gl
L47B	47B ROCK	909 lb	4568 lb	4540 lb	-0.61%	0.50% M	3 gl
CEM3	CEMENT TYPE3	611 lb	3055 lb	3060 lb	0.16%		
WATER	WATER	35.0 GL	149.7 GL	148.6 GL	-0.76%		148.6 gl
AIR	MB-AE 90 AIR ENTR	4.00 oz	20.00 oz	20.00 oz	0.00%		

Actual Num Batches: 1 Manual 10:59:07
Load Total: 19481 lb Design 0.478 Water/Cement 0.488 A Design 175.0 gl Actual 178.7 gl To Add: 0.0 gl
Slump: 4.00 in # Water in Truck: 0.0 GL Adjust Water: 0.0 GL / Load Trim Water: 0.0 GL/ CYD
Actual W/C Ratio: 0.058 Actual Water: 179 gl Batched Cement: 3060 lb Allowable Water: 1,283 gl

R#15-0540 MGS Long Span Concrete Wall

May 2015 SMT

ORIGINAL

Figure A-29. MGS Long-Span Concrete Wall, Test Nos. MGSLS-1 and MGSLS-2

CAUTION
FRESH CONCRETE

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

Ready Mixed Concrete Company

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

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
01	24013000	3.00	0108	7596			14:32	04/30/15	1187674

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003	3	CIA---MWRSS				45

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4800 NW 35TH	NORTH OF THE NORTH GOODYEAR HANGER	JAMES 450-6250

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UNIT PRICE	AMOUNT
3.00	3.00	3.00	24013000	L4000	$110.25	$330.75
				SLUMP: 4.00		
				MINIMUM HAUL		40.00
						$370.75
					SUBTOTAL	
					TAX	$370.75
					TOTAL	$370.75

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 5 GAL

RECEIVED BY [signature]

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
0108	7596	user	1187674	2587	14:32	4/30/15

Load Size Mix Code Returned Qty Mix Age Seq Load ID

Materia	Description	DesiQty	Required	Batched	%Var	%Moistur	Actua	Wat
G47B	47B GRAVEL	2106 lb	6444 lb	6420 lb	-0.38%	2.00%	M	15 gl
L47B	47B ROCK	916 lb	2756 lb	2740 lb	-0.59%	0.30%	M	1 gl
CEM1	CEM 1/2	611 lb	1833 lb	1840 lb	0.38%			
WATER	WATER	31.5 GL	81.4 GL	81.0 GL	-0.45%			81.0 gl
AIR	MB-AE 90 AIR ENTR	3.50 oz	10.50 oz	10.00 oz	-4.76%			

Actual Num Batches: 1 Manual 14:32:03
Load Total: 11677 lb Design 0.430 Water/Cement 0.440 A Design 94.5 gl Actual 97.1 gl To Add: 0.0 gl
Slump: 4.00 in # Water in Truck: 0.0 GL Adjust Water: 0.0 GL / Load Trim Water: 0.0 GL/ CYD
Actual W/C Ratio: 0.053 Actual Water: 97 gl Batched Cement: 1840 lb Allowable Water: 694 gl

Concrete Footings MGS LONG SPAN
R#15-0532 APR 2015 SMT

ORIGINAL

Figure A-30. MGS Long-Span Concrete Footings, Test Nos. MGSLS-1 and MGSLS-2

Appendix B. Vehicle Center of Gravity Determination

Test: MGSLS-1 Vehicle: Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vert CG (in.)	Vert M (lb-in.)
+	Unbalasted Truck (Curb)	5199	28.58224	148599.1
+	Brake receivers/wires	6	53.5	321
+	Brake Frame	7	28	196
+	Brake Cylinder (Nitrogen)	22	29.5	649
+	Strobe/Brake Battery	5	33	165
+	Hub	26	15	390
+	CG Plate (EDRs)	8	33	264
-	Battery	-42	43	-1806
-	Oil	-8	24	-192
-	Interior	-103	28	-2884
-	Fuel	-161	21	-3381
-	Coolant	-9	37	-333
-	Washer fluid	-8	38	-304
BALLAST	Water	0		0
	Supplemental battery	8	26	208
	Misc.			0
				141892.1

Estimated Total Weight (lb)	4950
Vertical CG Location (in.)	28.66506

Wheel Base (in.) 140.375

MASH Targets	Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	4955	-45.0
Long CG (in.)	63 ± 4	59.89	-3.11044
Lat CG (in.)	NA	0.473896	NA
Vert CG (in.)	28 or greater	28.67	0.66506

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	1525	1429
Rear	1117	1128

FRONT	2954 lb
REAR	2245 lb
TOTAL	5199 lb

TEST INERTIAL WEIGHT (lb)

(from scales)

	Left	Right
Front	1413	1428
Rear	1030	1084

FRONT	2841 lb
REAR	2114 lb
TOTAL	4955 lb

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

Test: MGSLS-2 Vehicle: RAM 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vert CG (in.)	Vert M (lb-in.)
+	Unbalasted Truck (Curb)	5064	29.73189	150562.3
+	Brake receivers/wires	6	52.75	316.5
+	Brake Frame	9	28	252
+	Brake Cylinder (Nitrogen)	22	29.5	649
+	Strobe/Brake Battery	5	33.5	167.5
+	Hub	26	15.5	403
+	CG Plate (EDRs)	8	32.5	260
-	Battery	-43	41	-1763
-	Oil	-12	23	-276
-	Interior	-70	27	-1890
-	Fuel	-152	20.5	-3116
-	Coolant	-12	38	-456
-	Washer fluid	-7	41	-287
BALLAST	Water	75	16	1200
	Supplemental Battery	14	26.5	371
	Misc.			0
				146393.3

Estimated Total Weight (lb)	4933
Vertical CG Location (in.)	29.67633

Wheel Base (in.) 140.25

MASH Targets	Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	4912	-88.0
Long CG (in.)	63 ± 4	60.25	-2.75417
Lat CG (in.)	NA	0.124822	NA
Vert CG (in.)	28 or greater	29.68	1.67633

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	1473	1427
Rear	1103	1061

FRONT	2900 lb
REAR	2164 lb
TOTAL	5064 lb

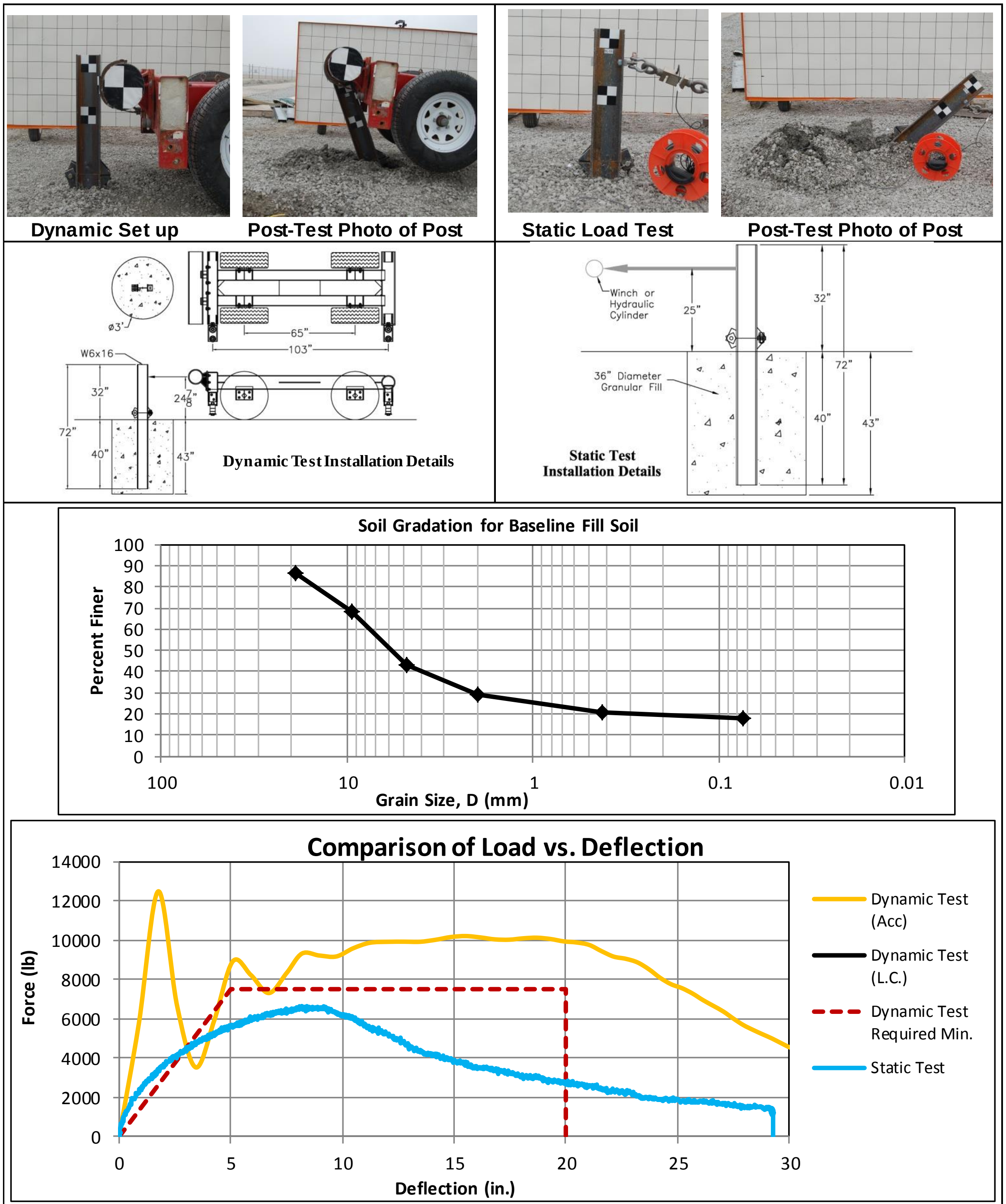
TEST INERTIAL WEIGHT (lb)
(from scales)

	Left	Right
Front	1396	1406
Rear	1051	1059

FRONT	2802 lb
REAR	2110 lb
TOTAL	4912 lb

Figure B-2. Vehicle Mass Distribution, Test No. MGSLS-2

Appendix C. Static Soil Tests

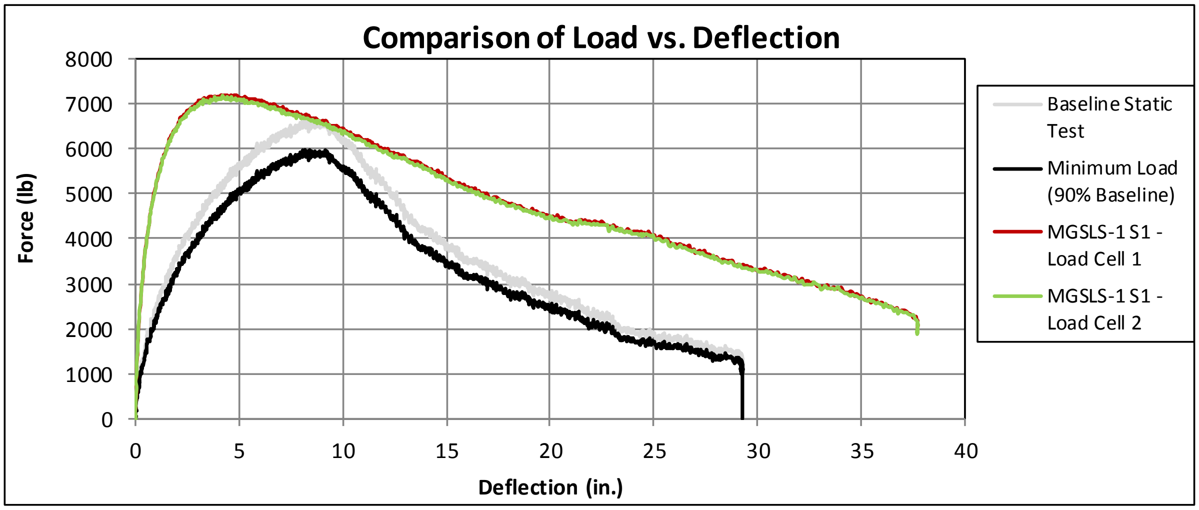


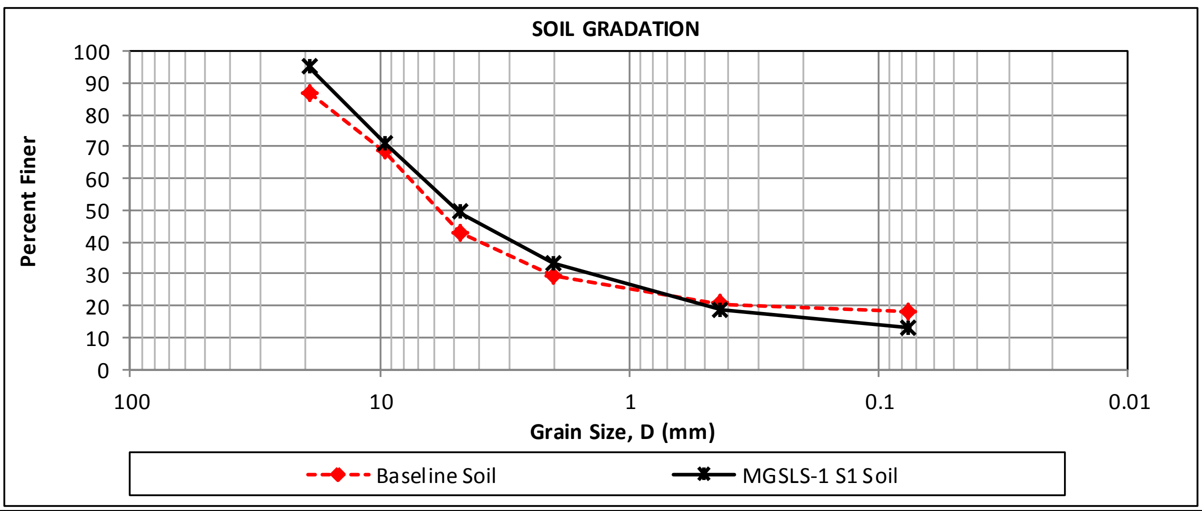
Date..	4/4/2012	
Test Facility & Site Location.....................	Midwest Roadside Safety Facility	
In situ soil description (ASTM D2487).........	Well-Graded Gravel (GW)	
Fill material description (ASTM D2487)......	Well-Graded Gravel (GW) (see sieve analyses above)	
Description of fill placement procedure.....	3 Pass, 8" Lift	
Bogie Weight..	1844 lb	836 kg
Impact Velocity....................................	20.1 mph	32.3 km/h

Figure C-1. Soil Strength, Initial Calibration Tests

Static Load Test Setup

Post-Test Photo of Post

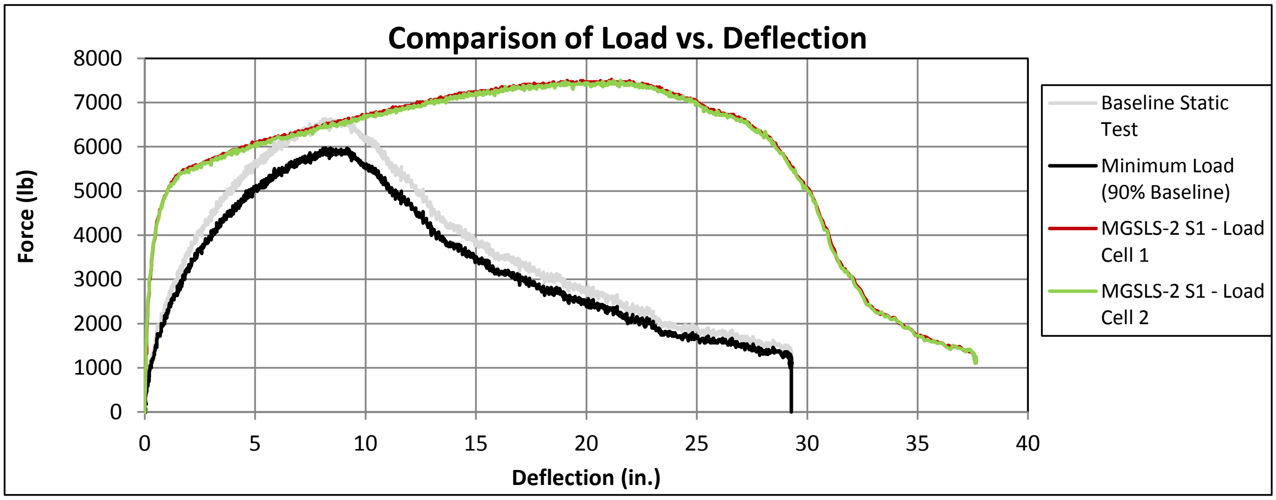


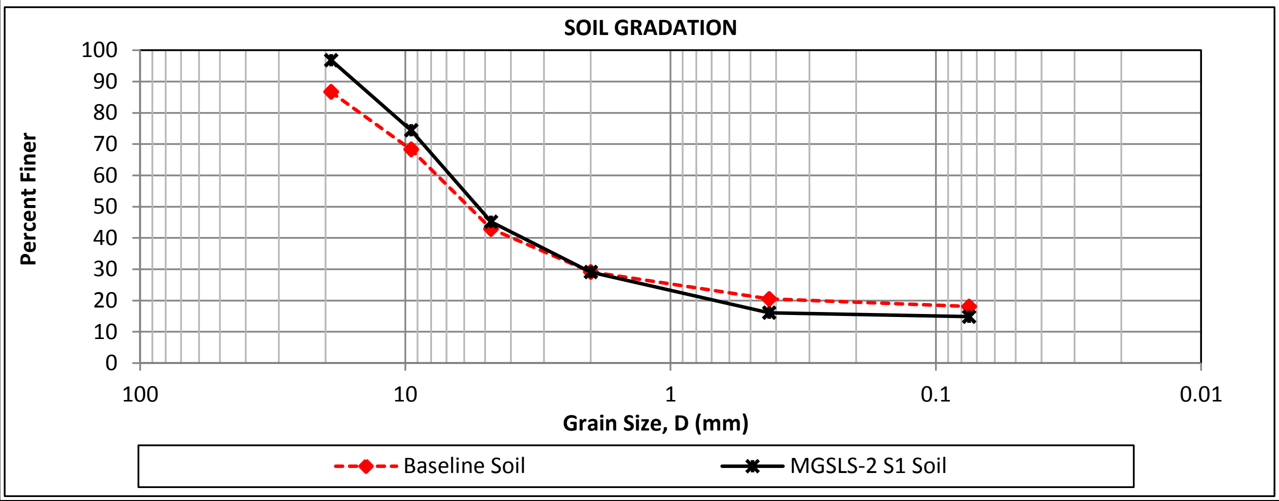


Date...	5/18/2015
Test Facility & Site Location.....................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487).........	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)......	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.....	8-inch lifts tamped with a pneumatic compactor

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

Static Load Test Setup	Post-Test Photo of Post
	





Date	6/28/2015
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8-inch lifts tamped with a pneumatic compactor

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

Appendix D. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSLS-1
VEHICLE: Dodge Ram 1500

-0.3006 0.1229 0.1587

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	31.436	-27.556	5.284	31.227	-27.550	5.438	-0.210	0.006	0.155
2	33.584	-24.592	4.920	33.341	-24.570	5.020	-0.244	0.021	0.100
3	33.839	-20.111	4.564	33.621	-20.147	4.700	-0.218	-0.037	0.136
4	33.818	-15.375	4.200	33.606	-15.346	4.292	-0.212	0.029	0.092
5	29.614	-27.582	2.883	29.457	-27.501	3.027	-0.156	0.080	0.144
6	31.972	-23.435	1.999	31.715	-23.499	2.139	-0.257	-0.064	0.140
7	33.156	-20.023	0.617	32.981	-20.065	0.776	-0.175	-0.042	0.159
8	33.075	-15.165	0.665	32.874	-15.177	0.761	-0.201	-0.012	0.096
9	27.230	-29.041	-0.128	27.022	-28.960	-0.052	-0.208	0.081	0.076
10	28.320	-23.867	-1.466	28.094	-23.812	-1.377	-0.226	0.055	0.089
11	28.828	-18.309	-1.631	28.733	-18.246	-1.482	-0.095	0.063	0.149
12	27.877	-12.295	-1.414	27.662	-12.370	-1.349	-0.215	-0.075	0.066
13	24.264	-29.227	-2.791	24.107	-29.176	-2.688	-0.156	0.051	0.103
14	24.210	-21.976	-3.453	24.065	-21.999	-3.347	-0.144	-0.024	0.106
15	24.212	-16.876	-3.913	24.064	-16.848	-3.817	-0.148	0.028	0.096
16	24.037	-11.778	-4.411	23.737	-11.803	-4.302	-0.301	-0.025	0.109
17	19.888	-28.795	-4.510	19.703	-28.809	-4.440	-0.185	-0.014	0.070
18	19.842	-24.086	-4.870	19.700	-24.043	-4.791	-0.142	0.043	0.080
19	19.741	-18.203	-5.413	19.582	-18.212	-5.331	-0.159	-0.009	0.082
20	19.847	-12.316	-5.971	19.725	-12.319	-5.889	-0.121	-0.003	0.082
21	10.899	-29.484	-4.137	10.688	-29.361	-4.055	-0.212	0.123	0.082
22	10.964	-24.046	-4.575	10.789	-24.088	-4.516	-0.175	-0.043	0.059
23	10.881	-17.693	-5.150	10.727	-17.776	-5.097	-0.154	-0.084	0.054
24	10.826	-12.879	-5.599	10.671	-12.876	-5.549	-0.155	0.003	0.050
25	1.153	-27.676	0.022	1.023	-27.621	0.065	-0.130	0.055	0.043
26	1.069	-21.006	-0.606	0.903	-20.956	-0.574	-0.166	0.050	0.031
27	1.154	-16.186	-1.083	0.963	-16.177	-1.042	-0.191	0.009	0.041
28	1.929	-7.207	0.575	1.811	-7.196	0.592	-0.117	0.010	0.016

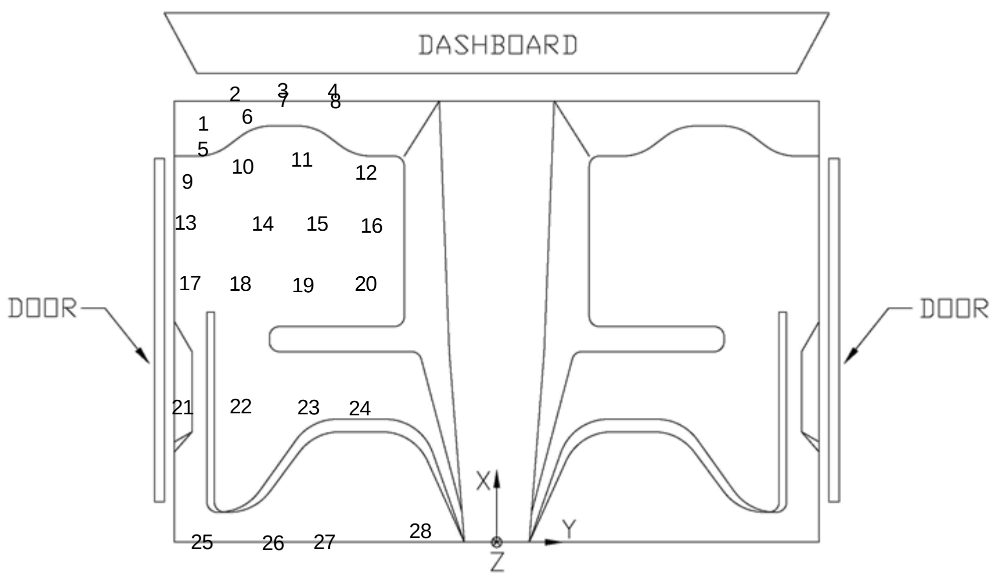


Figure D-1. Floorpan Deformation Data – Set 1, Test No. MGSLS-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MGSLS-1 -0.3043 1.3306 0.0846
VEHICLE: Dodge Ram 1500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	48.995	-34.070	6.813	48.703	-34.010	6.762	-0.292	0.060	-0.051
2	51.116	-31.038	6.354	50.812	-31.019	6.332	-0.304	0.019	-0.021
3	51.314	-26.521	5.947	51.047	-26.477	5.979	-0.267	0.044	0.033
4	51.235	-21.832	5.499	50.983	-21.789	5.584	-0.253	0.042	0.085
5	47.205	-34.094	4.435	46.974	-34.017	4.450	-0.231	0.077	0.015
6	49.443	-29.950	3.400	49.158	-29.970	3.435	-0.284	-0.020	0.035
7	50.583	-26.663	1.986	50.356	-26.613	2.041	-0.227	0.050	0.055
8	50.448	-21.707	1.936	50.185	-21.645	1.995	-0.263	0.062	0.060
9	44.754	-35.625	1.360	44.486	-35.649	1.414	-0.268	-0.024	0.054
10	45.747	-30.386	-0.041	45.484	-30.425	-0.021	-0.263	-0.039	0.020
11	46.205	-24.805	-0.285	46.016	-24.837	-0.228	-0.189	-0.032	0.056
12	45.217	-18.896	-0.128	44.937	-18.859	-0.158	-0.280	0.037	-0.031
13	41.854	-35.822	-1.224	41.573	-35.798	-1.223	-0.281	0.024	0.002
14	41.673	-28.585	-1.995	41.397	-28.679	-1.977	-0.276	-0.093	0.018
15	41.607	-23.527	-2.528	41.361	-23.471	-2.520	-0.247	0.056	0.008
16	41.381	-18.462	-3.094	41.148	-18.473	-3.085	-0.233	-0.011	0.009
17	37.418	-35.552	-2.923	37.208	-35.540	-2.927	-0.210	0.012	-0.004
18	37.317	-30.709	-3.361	37.065	-30.777	-3.356	-0.252	-0.068	0.005
19	37.120	-24.902	-3.989	36.848	-24.957	-3.983	-0.272	-0.055	0.006
20	37.117	-19.113	-4.629	36.990	-19.082	-4.594	-0.127	0.030	0.035
21	28.389	-36.246	-2.465	28.128	-36.308	-2.482	-0.261	-0.061	-0.017
22	28.400	-30.803	-2.994	28.214	-29.473	-3.189	-0.185	1.331	-0.196
23	28.206	-24.519	-3.645	28.009	-24.558	-3.648	-0.198	-0.039	-0.002
24	28.179	-19.824	-4.186	27.938	-19.697	-4.179	-0.241	0.127	0.007
25	18.719	-34.494	1.707	18.524	-34.464	1.703	-0.194	0.030	-0.004
26	18.532	-27.847	0.974	18.323	-27.875	0.987	-0.208	-0.028	0.013
27	18.531	-23.112	0.449	18.231	-23.104	0.470	-0.300	0.008	0.021
28	19.246	-14.075	1.964	19.051	-14.050	1.972	-0.195	0.025	0.008

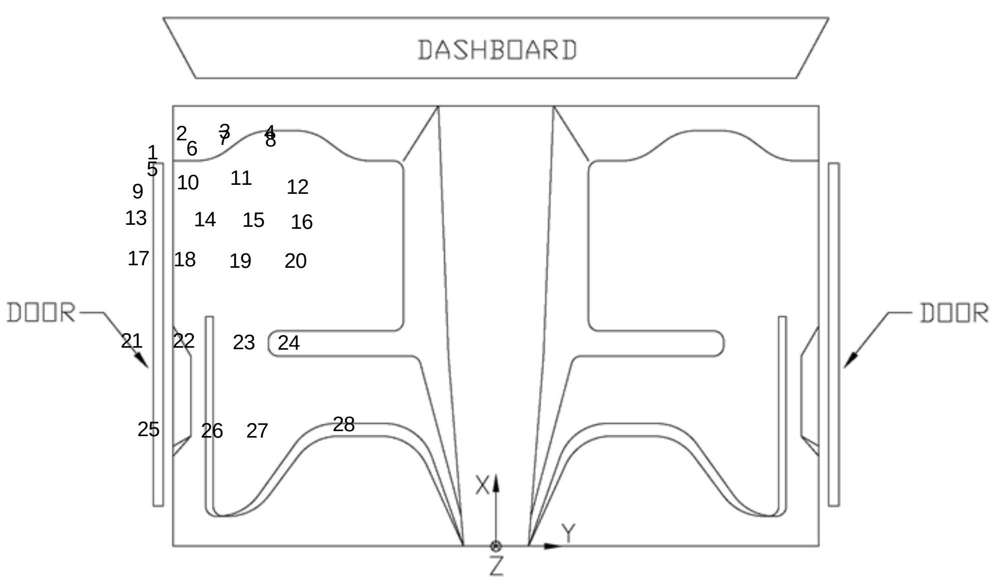


Figure D-2. Floorpan Deformation Data – Set 2, Test No. MGSLS-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MGSLS-1
VEHICLE: Dodge Ram 1500

-0.4536 0.1932 0.1773

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	16.0958	-28.8427	27.5548	15.7072	-28.7751	27.6587	-0.3886	0.0676	0.1039
	2	14.7201	-16.263	28.4746	14.4638	-16.187	28.566	-0.2563	0.076	0.0914
	3	14.1917	1.8776	26.7483	13.9044	1.9306	26.7656	-0.2873	0.053	0.0173
	4	13.2816	-29.5409	19.191	13.0181	-29.4959	19.275	-0.2635	0.045	0.084
	5	12.4669	-10.5768	16.8582	12.2019	-10.561	16.9373	-0.265	0.0158	0.0791
	6	11.2408	0.3508	15.5582	10.9663	0.4394	15.5452	-0.2745	0.0886	-0.013
SIDE PANEL	7	21.0212	-31.653	6.9538	20.8267	-31.5394	7.0133	-0.1945	0.1136	0.0595
	8	20.8417	-32.1091	2.2808	20.6726	-32.0341	2.3216	-0.1691	0.075	0.0408
	9	26.0817	-31.8523	6.2952	25.8244	-31.8397	6.3838	-0.2573	0.0126	0.0886
IMPACT SIDE DOOR	10	-12.511	-32.4482	24.5294	-12.9646	-32.5362	24.7044	-0.4536	-0.088	0.175
	11	0.257	-32.5427	23.6883	-0.1425	-32.5633	23.8095	-0.3995	-0.0206	0.1212
	12	13.2261	-32.537	22.8397	12.8846	-32.4488	22.9795	-0.3415	0.0882	0.1398
	13	-10.4517	-33.6179	8.8057	-10.7814	-33.6731	8.983	-0.3297	-0.0552	0.1773
	14	2.4858	-33.6086	5.8145	2.0544	-33.5516	5.9382	-0.4314	0.057	0.1237
	15	15.4791	-34.5394	1.832	15.091	-34.3462	1.8311	-0.3881	0.1932	-0.0009
ROOF										

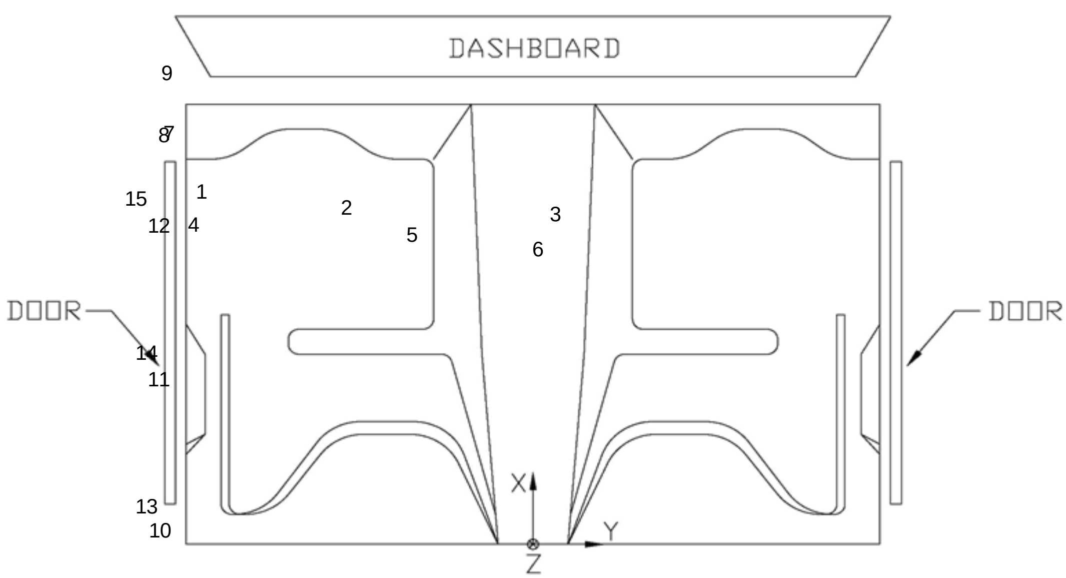


Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. MGSLS-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MGSLS-1
VEHICLE: Dodge Ram 1500

-0.4803 0.1826 0.1501

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	33.797	-35.145	29.155	33.457	-35.111	29.202	-0.340	0.034	0.046
	2	32.243	-22.580	29.891	31.977	-22.554	29.920	-0.267	0.026	0.029
	3	31.573	-4.524	27.950	31.292	-4.423	27.929	-0.281	0.101	-0.021
	4	30.960	-36.008	20.823	30.671	-35.986	20.845	-0.289	0.022	0.022
	5	29.879	-17.158	18.142	29.615	-17.092	18.181	-0.263	0.066	0.039
	6	28.529	-6.128	16.728	28.290	-6.155	16.784	-0.239	-0.027	0.056
SIDE PANEL	7	38.644	-38.214	8.562	38.394	-38.098	8.599	-0.249	0.116	0.037
	8	38.500	-38.735	3.922	38.215	-38.658	3.904	-0.285	0.077	-0.019
	9	43.628	-38.370	7.832	43.394	-38.355	7.903	-0.235	0.015	0.071
IMPACT SIDE DOOR	10	5.279	-39.123	26.383	4.840	-39.229	26.521	-0.438	-0.106	0.138
	11	18.030	-39.123	25.389	17.563	-39.123	25.539	-0.467	0.000	0.150
	12	30.986	-38.943	24.519	30.557	-38.900	24.546	-0.429	0.042	0.027
	13	7.223	-40.489	10.684	6.818	-40.568	10.780	-0.405	-0.080	0.096
	14	20.110	-40.385	7.599	19.637	-40.337	7.715	-0.473	0.048	0.117
	15	33.128	-41.230	3.537	32.648	-41.047	3.426	-0.480	0.183	-0.111
ROOF										

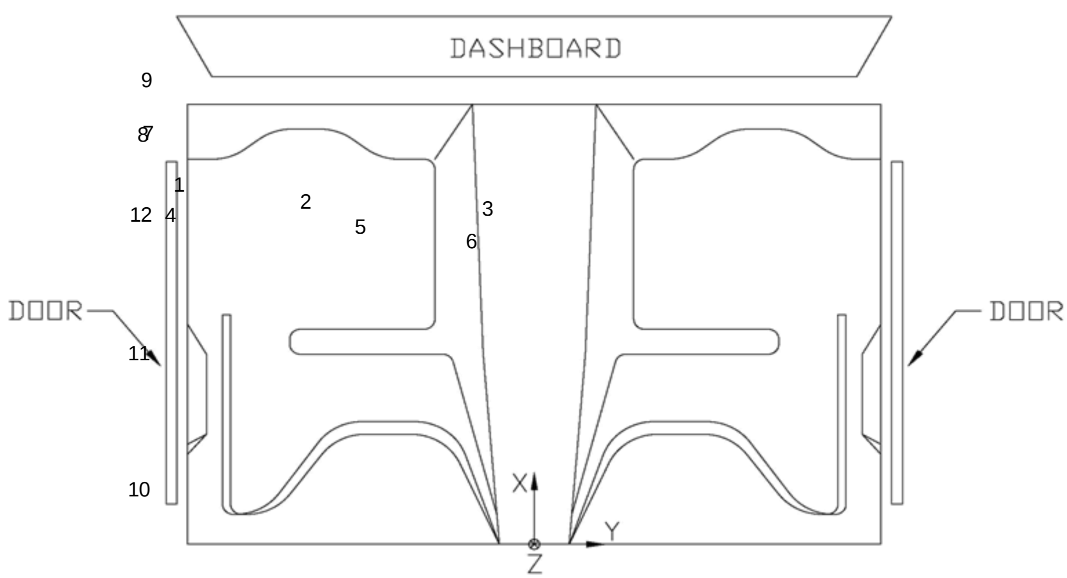
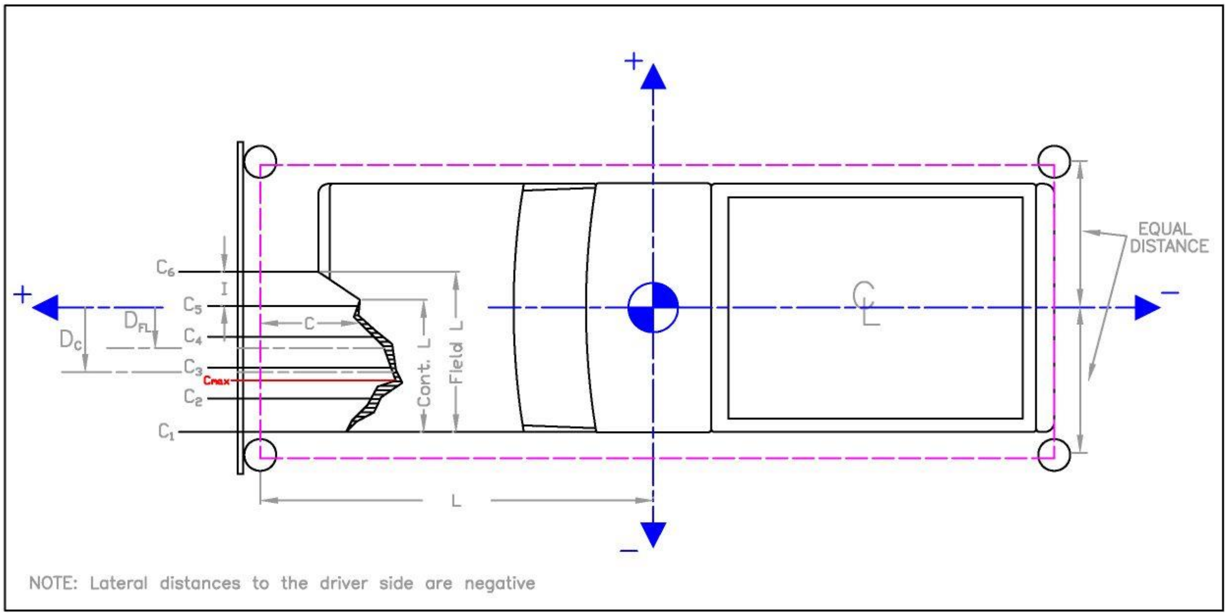


Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. MGSLS-1

Date: 5/26/2015 **Test Number:** MGSLS-1

Make: Dodge **Model:** Ram 1500 **Year:** 2007



Blue Cells to be filled out Before Test
Orange Cells to Be filled out After Test

	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	**101 1/4**	**(2572)**
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)**

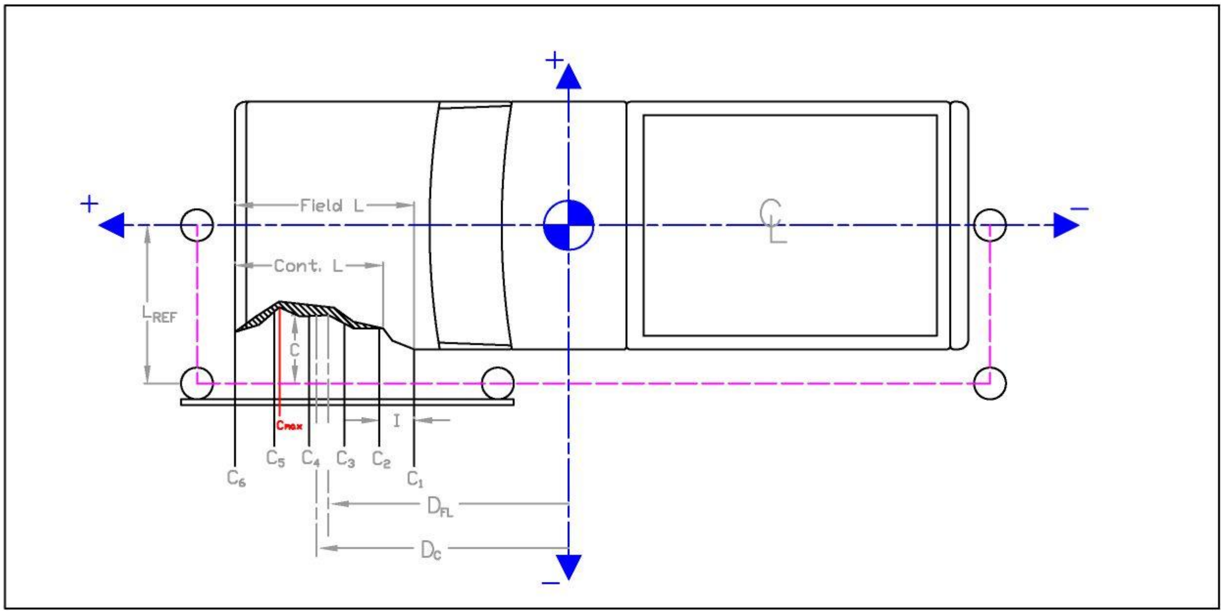
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurments are filled out.

	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	NA	NA	-39	-(991)	29	(737)	-8 1/4	-(210)	NA	NA
C_2	NA	NA	-35 1/9	-(892)	21	(533)			NA	NA
C_3	18 1/2	(470)	-31 1/5	-(792)	17	(431)			9 7/9	(248)
C_4	10 1/4	(260)	-27 1/3	-(693)	15	(383)			3 4/9	(88)
C_5	4 3/4	(121)	-23 2/5	-(594)	13 1/2	(342)			- 4/9	-(12)
C_6	3 1/2	(89)	-19 1/2	-(495)	12 4/9	(316)			- 2/3	-(17)
C_{MAX}	18 1/2	(470)	-31 1/4	-(794)	17	(431)			9 7/9	(248)

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

Date: 5/26/2015 **Test Number:** MGSLS-1

Make: Dodge **Model:** Ram 1500 **Year:** 2007



Blue Cells to be filled out Before Test
Orange Cells to Be filled out After Test

	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}:	-13 1/2	-(343)
Width of Contact Damage:	228	(5791)
Distance from vehicle c.g. to center of contect damage - D_C:	-13 1/2	-(343)

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	9	(229)	-127 1/2	-(3238)	16	(406)	-7	-(178)	0	()
C_2	4 1/4	(108)	-81 8/9	-(2080)	10 1/2	(267)			3/4	(19)
C_3	4 1/4	(108)	-36 2/7	-(922)	11 5/8	(295)			- 3/8	-(10)
C_4	4 1/4	(108)	9 1/3	(237)	11 1/4	(286)			0	()
C_5	NA	NA	55	(1395)	10 1/2	(267)			NA	NA
C_6	NA	NA	100 1/2	(2553)	37	(940)			NA	NA
C_{MAX}	12	(305)	78	(1981)	11 1/4	(286)			7 3/4	(197)

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

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSLS-2
VEHICLE: Dodge RAM 1500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	31.314	-26.328	6.072	28.481	-22.797	10.857	-2.833	3.530	4.785
2	33.164	-23.414	5.366	29.917	-19.088	8.476	-3.247	4.326	3.110
3	33.549	-18.717	3.871	32.475	-18.604	6.995	-1.074	0.113	3.124
4	33.460	-13.929	3.147	32.450	-12.914	4.171	-1.010	1.016	1.024
5	29.171	-26.467	3.490	26.812	-22.725	9.613	-2.359	3.742	6.123
6	30.861	-23.164	2.302	28.020	-18.943	8.770	-2.841	4.221	6.469
7	32.130	-19.751	0.805	NA	NA	NA	#VALUE!	#VALUE!	#VALUE!
8	31.272	-15.232	0.143	NA	NA	NA	#VALUE!	#VALUE!	#VALUE!
9	26.949	-27.180	-0.408	22.934	-22.551	7.645	-4.015	4.629	8.053
10	27.856	-22.584	-1.061	24.145	-17.423	7.435	-3.712	5.161	8.495
11	27.879	-17.519	-1.481	24.887	-13.582	5.344	-2.992	3.937	6.825
12	26.899	-9.973	-2.218	25.593	-8.331	0.292	-1.305	1.642	2.510
13	20.197	-27.769	-4.056	17.832	-23.298	1.982	-2.365	4.472	6.038
14	20.235	-21.863	-4.501	16.977	-18.031	2.789	-3.258	3.832	7.290
15	20.141	-15.031	-5.181	18.136	-12.733	-0.672	-2.005	2.298	4.509
16	20.186	-10.595	-5.637	19.862	-10.175	-3.842	-0.324	0.420	1.795
17	16.655	-28.172	-4.057	15.147	-24.731	0.421	-1.508	3.441	4.478
18	16.451	-22.293	-4.527	13.705	-19.013	1.187	-2.746	3.280	5.714
19	16.486	-16.527	-5.121	14.341	-13.743	-1.077	-2.145	2.784	4.044
20	14.162	-5.689	0.778	14.098	-5.442	1.440	-0.064	0.247	0.662
21	10.666	-28.115	-3.851	10.382	-25.347	-1.848	-0.284	2.768	2.004
22	10.609	-22.122	-4.347	9.021	-19.533	-1.336	-1.588	2.589	3.010
23	10.629	-14.539	-5.140	9.836	-12.407	-4.037	-0.793	2.132	1.103
24	8.693	-5.503	0.125	8.563	-5.430	0.567	-0.130	0.073	0.443
25	1.001	-26.397	0.081	2.350	-25.034	0.109	1.349	1.363	0.027
26	0.876	-19.891	-0.580	1.775	-18.580	-0.591	0.899	1.311	-0.011
27	0.779	-13.974	-1.190	1.079	-12.725	-1.321	0.300	1.248	-0.132
28	1.488	-6.023	0.553	1.816	-5.918	1.170	0.328	0.105	0.617

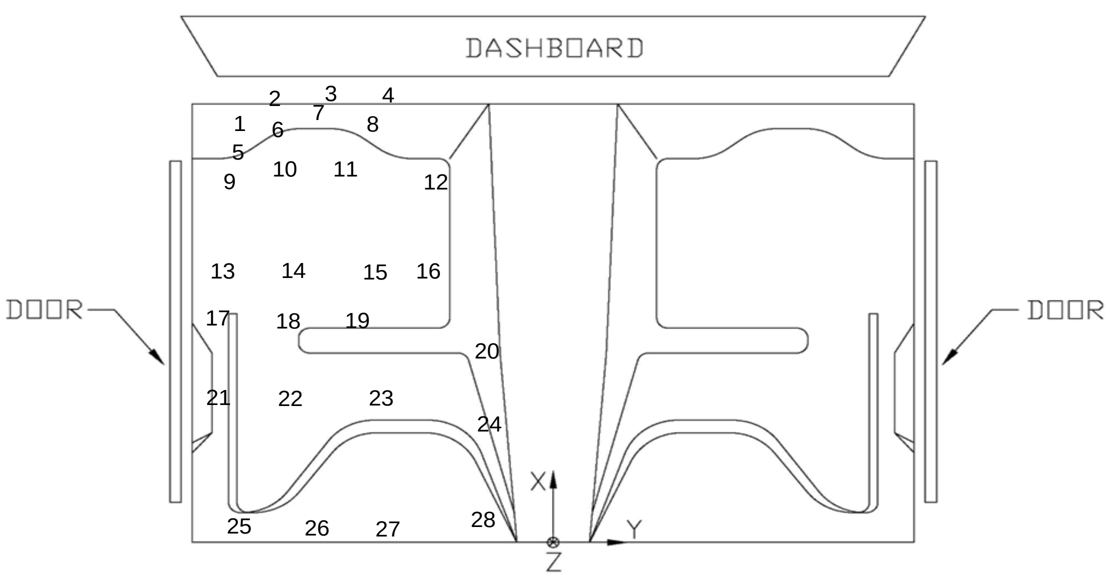


Figure D-7. Floorpan Deformation Data Set 1, Test No. MGSLS-2

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MGSLS-2
VEHICLE: Dodge RAM 1500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	47.637	-32.916	7.332	45.167	-30.192	11.629	-2.470	2.724	4.298
2	49.575	-30.048	6.589	46.723	-27.275	9.332	-2.852	2.773	2.744
3	49.961	-25.443	4.997	47.663	-24.792	6.402	-2.298	0.650	1.405
4	49.918	-20.665	4.187	48.736	-19.881	4.840	-1.182	0.784	0.654
5	45.495	-33.115	4.880	43.160	-30.052	9.853	-2.335	3.062	4.974
6	47.187	-29.851	3.532	44.098	-26.298	9.271	-3.089	3.553	5.739
7	48.494	-26.508	1.957	NA	NA	NA	#VALUE!	#VALUE!	#VALUE!
8	47.796	-21.946	1.076	NA	NA	NA	#VALUE!	#VALUE!	#VALUE!
9	43.174	-33.876	1.029	39.073	-29.615	7.875	-4.101	4.261	6.846
10	44.062	-29.360	0.218	39.890	-24.446	7.823	-4.172	4.914	7.605
11	44.142	-24.308	-0.335	41.246	-20.590	6.102	-2.897	3.718	6.437
12	43.288	-16.736	-1.237	42.169	-14.807	1.051	-1.119	1.929	2.287
13	36.354	-34.504	-2.436	33.993	-29.905	2.274	-2.361	4.599	4.709
14	36.488	-28.592	-3.054	33.208	-24.671	3.297	-3.280	3.921	6.352
15	36.375	-21.762	-3.935	34.483	-19.234	0.154	-1.892	2.528	4.089
16	36.483	-17.342	-4.489	36.212	-16.426	-2.931	-0.271	0.916	1.558
17	32.816	-34.854	-2.360	31.262	-31.197	0.597	-1.554	3.657	2.957
18	32.683	-28.979	-2.995	29.891	-25.490	1.639	-2.793	3.490	4.635
19	32.734	-23.246	-3.747	30.612	-20.149	-0.337	-2.122	3.098	3.410
20	30.677	-12.220	1.899	30.545	-12.056	2.644	-0.132	0.163	0.746
21	26.822	-34.733	-2.031	26.480	-31.671	-1.709	-0.342	3.062	0.322
22	26.802	-28.772	-2.688	25.262	-25.822	-0.923	-1.540	2.950	1.765
23	26.925	-21.147	-3.708	26.123	-18.573	-3.184	-0.802	2.573	0.524
24	25.086	-11.986	1.343	25.026	-11.823	1.798	-0.060	0.163	0.455
25	17.250	-32.757	2.056	18.390	-31.313	0.292	1.140	1.444	-1.764
26	17.199	-26.274	1.211	17.945	-24.810	-0.039	0.746	1.464	-1.250
27	17.097	-20.393	0.445	17.376	-18.909	-0.459	0.279	1.484	-0.903
28	17.972	-12.430	1.955	18.310	-12.185	2.364	0.338	0.245	0.408

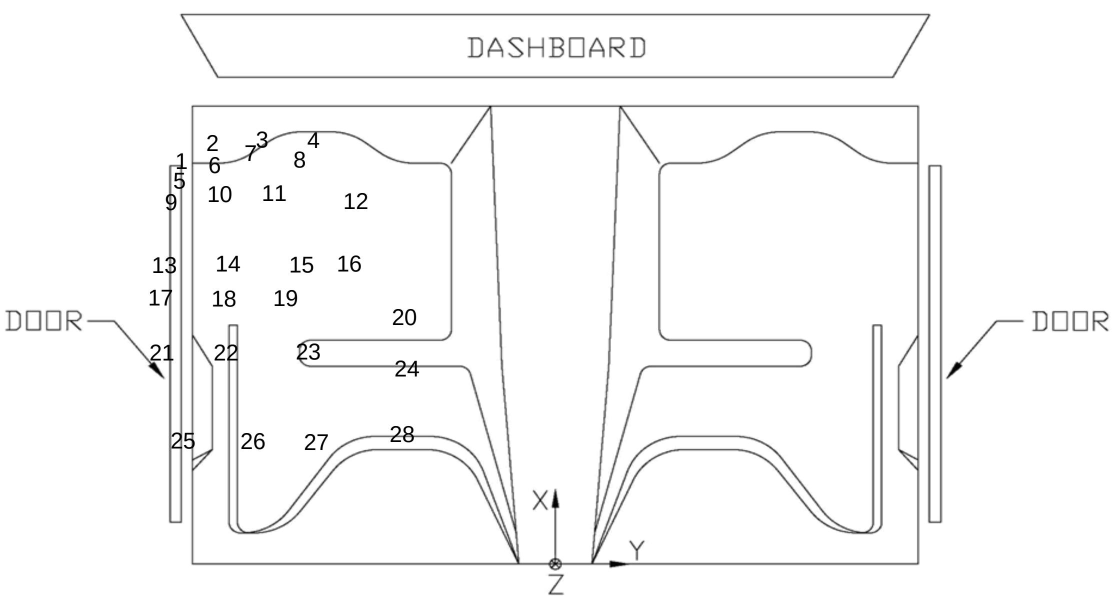


Figure D-8. Floorpan Deformation Data Set 2, Test No. MGSLS-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MGSLS-2
VEHICLE: Dodge RAM 1500

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	15.753	-27.483	27.827	17.371	-24.978	30.646	1.617	2.505	2.819
	2	14.275	-14.348	28.739	15.682	-11.875	30.351	1.407	2.473	1.613
	3	13.403	3.777	26.903	14.381	6.065	26.751	0.978	2.288	-0.153
	4	12.842	-28.195	19.470	14.079	-26.574	22.557	1.237	1.622	3.088
	5	12.009	-9.448	17.262	12.759	-8.100	18.488	0.750	1.348	1.226
	6	10.635	2.331	15.648	11.194	3.497	15.821	0.559	1.166	0.173
SIDE PANEL	7	20.930	-30.237	7.540	21.388	-28.941	11.136	0.458	1.296	3.596
	8	21.065	-30.749	2.254	20.662	-27.243	6.136	-0.403	3.506	3.882
	9	26.178	-30.349	6.113	25.927	-26.524	9.924	-0.250	3.825	3.810
IMPACT SIDE DOOR	10	-10.467	-31.368	23.916	-9.583	-32.221	26.109	0.884	-0.853	2.193
	11	0.305	-31.339	23.575	1.209	-32.034	25.946	0.904	-0.695	2.371
	12	10.865	-31.192	23.067	11.695	-31.169	25.592	0.829	0.023	2.525
	13	-10.628	-32.480	8.676	-9.469	-33.279	10.865	1.159	-0.799	2.188
	14	1.479	-32.393	8.090	2.601	-32.785	10.439	1.123	-0.393	2.350
	15	10.682	-32.301	6.450	11.643	-30.947	8.934	0.960	1.353	2.484
ROOF										

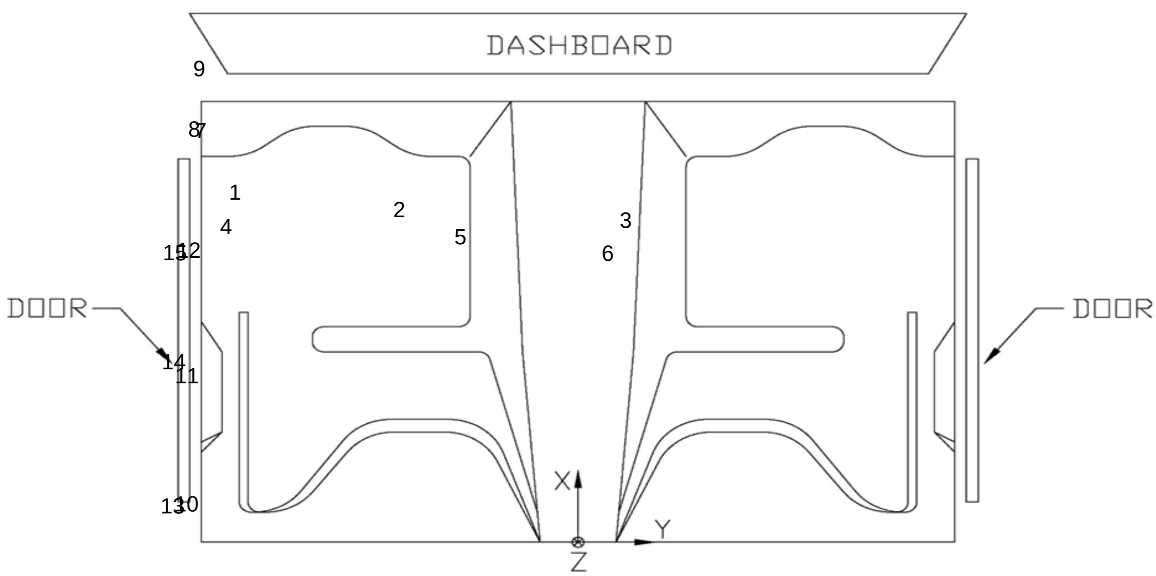


Figure D-9. Occupant Compartment Deformation Set 1, Test No. MGSLS-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MGSLS-2
VEHICLE: Dodge RAM 1500

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	32.608	-33.317	29.535	33.640	-33.198	30.791	1.031	0.119	1.257
	2	31.243	-20.147	30.068	32.120	-20.059	31.148	0.877	0.088	1.080
	3	30.571	-2.071	27.754	31.205	-1.938	28.590	0.634	0.133	0.836
	4	29.481	-34.215	21.233	30.177	-34.226	22.624	0.696	-0.011	1.391
	5	28.805	-15.514	18.480	29.179	-15.580	19.608	0.374	-0.066	1.128
	6	27.554	-3.788	16.618	27.802	-3.817	17.539	0.248	-0.030	0.921
SIDE PANEL	7	37.281	-36.679	9.198	37.447	-36.102	11.010	0.166	0.576	1.812
	8	37.310	-37.336	3.939	36.768	-34.085	6.093	-0.542	3.251	2.154
	9	42.570	-36.899	7.613	41.949	-33.749	9.936	-0.621	3.150	2.323
IMPACT SIDE DOOR	10	6.209	-36.979	26.288	6.492	-39.657	25.894	0.283	-2.678	-0.394
	11	17.028	-37.096	25.671	17.333	-39.651	25.668	0.305	-2.556	-0.003
	12	27.589	-37.091	24.937	27.736	-38.953	25.314	0.147	-1.862	0.377
	13	5.729	-38.519	11.008	6.462	-39.886	10.528	0.733	-1.367	-0.480
	14	17.838	-38.596	10.182	18.579	-39.580	10.116	0.741	-0.984	-0.066
	15	27.053	-38.648	8.388	27.682	-37.822	8.757	0.629	0.826	0.369
ROOF										

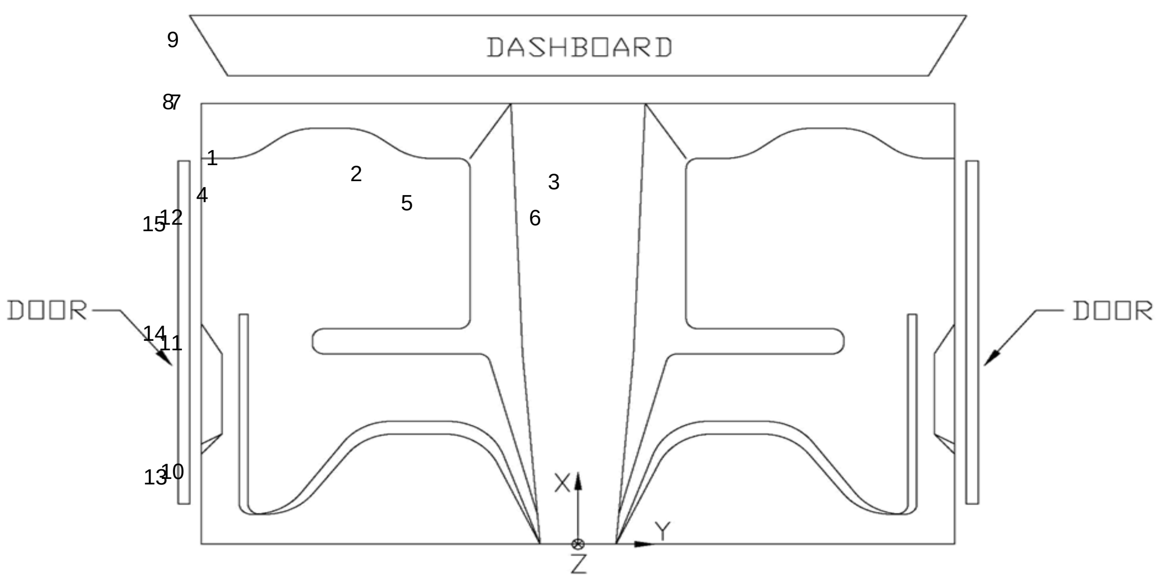
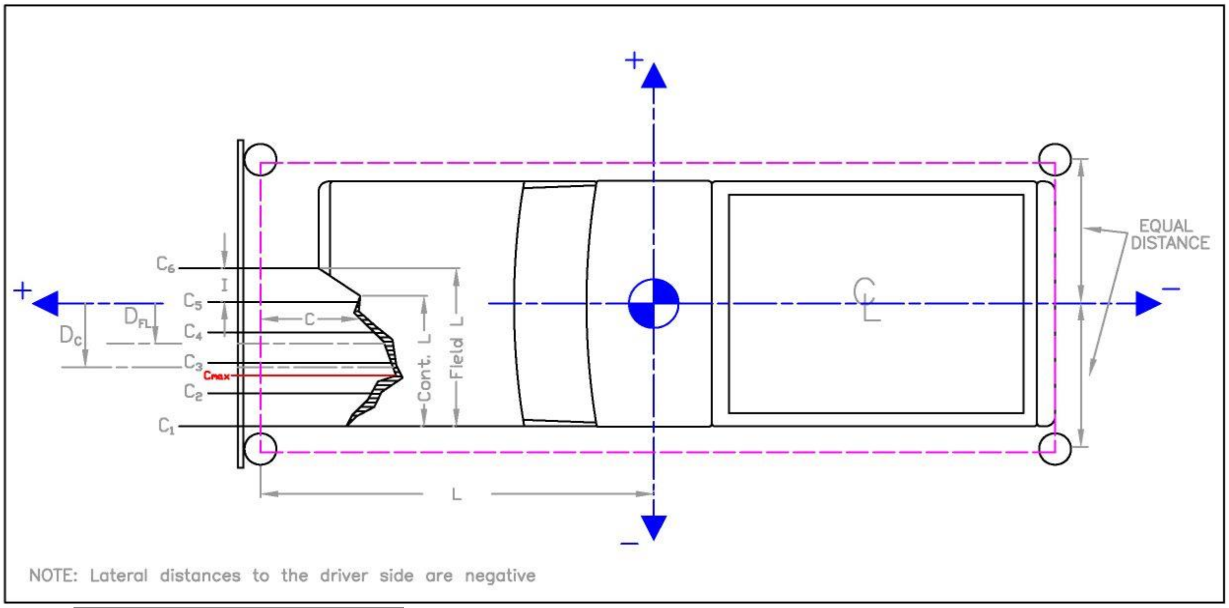


Figure D-10. Occupant Compartment Deformation Set 2, Test No. MGSLS-2

Date: 7/2/2015 **Test Number:** MGSLS-2

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



Blue Cells to be filled out Before Test
Orange Cells to Be filled out After Test

	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	100	(2540)
Total Vehicle Width:	78	(1981)
Width of contact and induced crush - Field L:	78	(1981)
Crush measurement spacing interval (L/5) - I:	15.6	(396)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	78	(1981)
Distance from center of vehicle to center of contect damage - D_C:	0	()

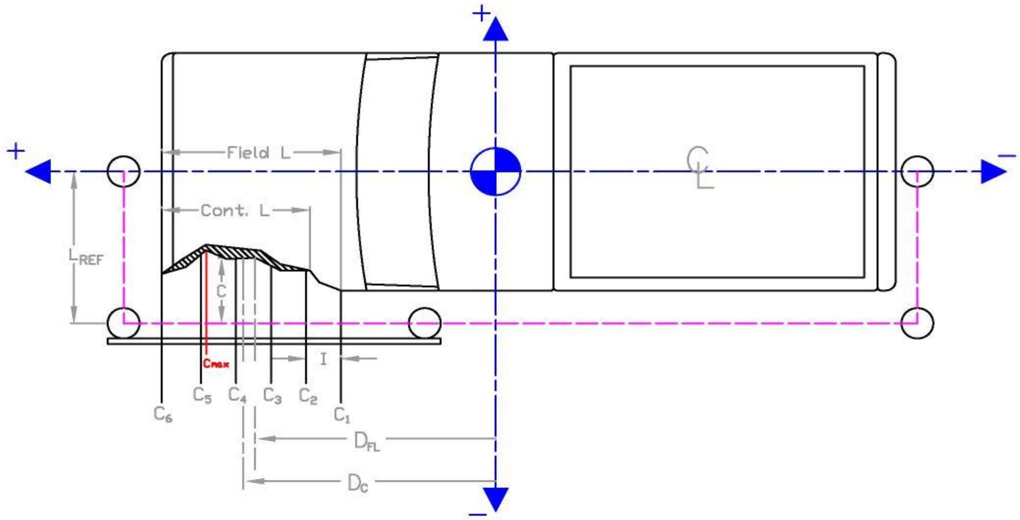
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurments are filled out.

	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	NA	NA	-39	-(991)	29	(737)	-10	-(254)	NA	NA
C_2	13 1/2	(343)	-23 2/5	-(594)	13 1/2	(342)			10	(255)
C_3	5 3/4	(146)	-7 4/5	-(198)	10 1/2	(267)			5 1/4	(133)
C_4	2 3/4	(70)	7 4/5	(198)	10 1/2	(266)			2 1/4	(57)
C_5	3 1/4	(83)	23 2/5	(594)	13 2/5	(340)			- 1/7	-(4)
C_6	NA	NA	39	(991)	29	(737)			NA	NA
C_{MAX}	23	(584)	30	(762)	16 1/8	(410)			16 7/8	(429)

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

Date: 7/2/2015 **Test Number:** MGSLS-2

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



Blue Cells to be filled out Before Test
Orange Cells to Be filled out After Test

	in.	(mm)
Distance from centerline to reference line - L_{REF}:	47 1/4	(1200)
Total Vehicle Length:	227.375	(5775)
Width of contact and induced crush - Field L:	227 3/8	(5775)
Crush measurement spacing interval (L/5) - I:	45.476	(1155)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-14 1/3	-(364)
Width of Contact Damage:	227 1/3	(5774)
Distance from vehicle c.g. to center of contect damage - D_C:	-14 3/8	-(365)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)
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	12	(305)	-128	-(3252)	15 3/8	(391)	-2 3/4	-(70)	- 5/8	-(16)
C_2	9	(229)	-82 1/2	-(2096)	10 1/2	(267)			1 1/4	(32)
C_3	9 1/4	(235)	-37	-(941)	11 4/7	(294)			4/9	(11)
C_4	10 3/4	(273)	8 2/5	(214)	11 1/4	(286)			2 1/4	(57)
C_5	NA	NA	53 8/9	(1369)	10 1/2	(267)			NA	NA
C_6	NA	NA	99 3/8	(2524)	37	(940)			NA	NA
C_{MAX}	19	(483)	69	(1753)	10 1/2	(267)			11 1/4	(286)

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

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

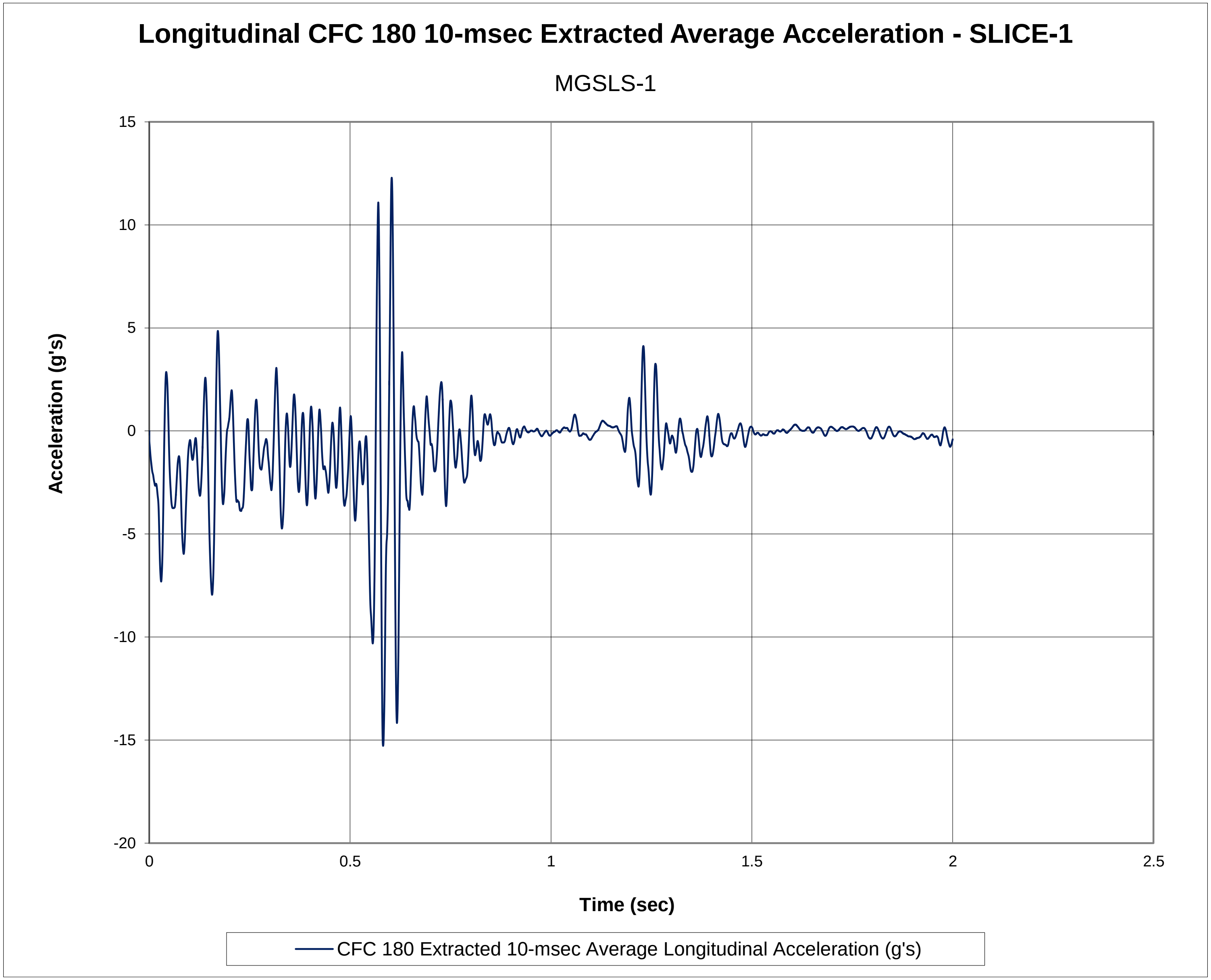


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSLS-1

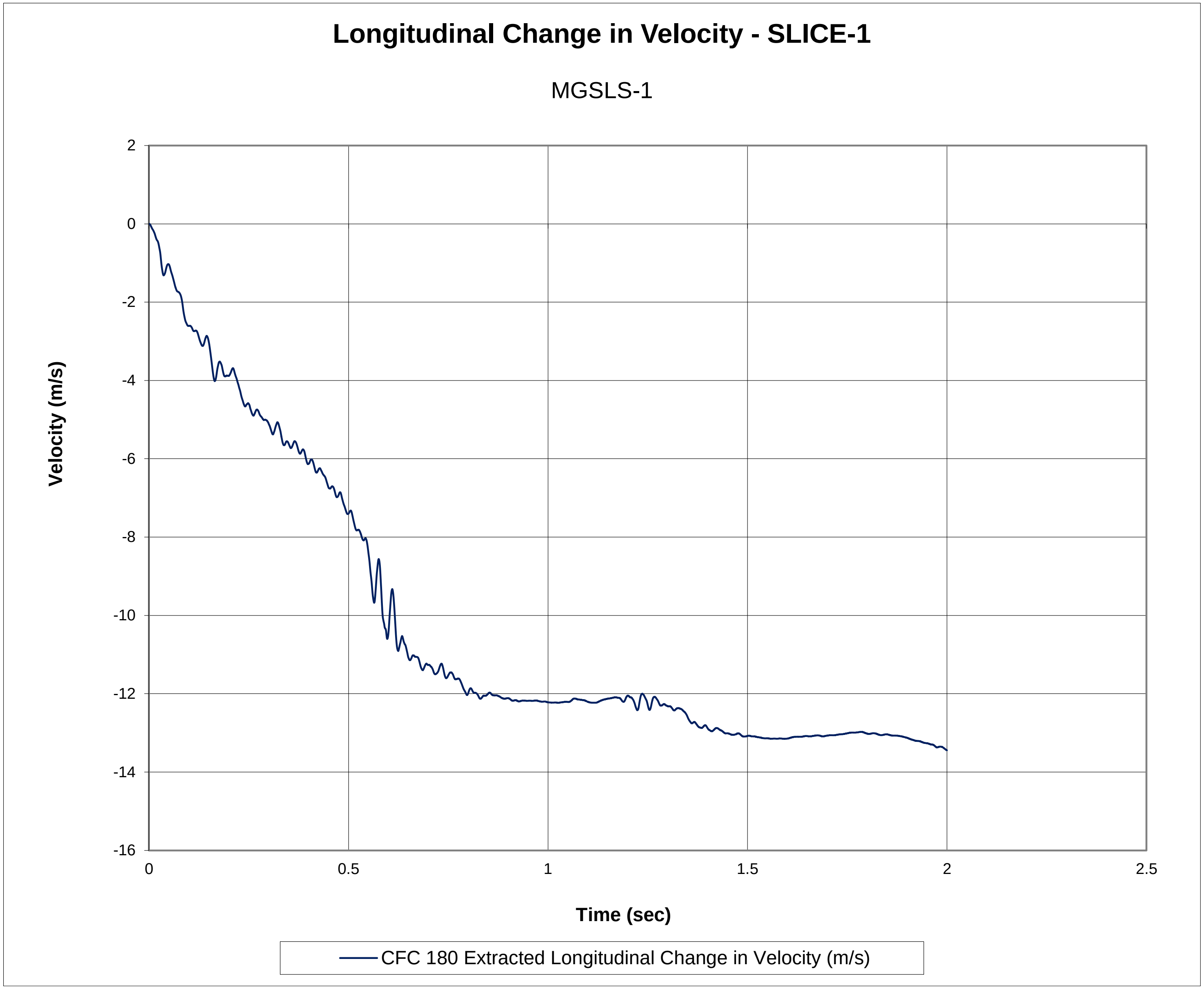


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MGSLS-1

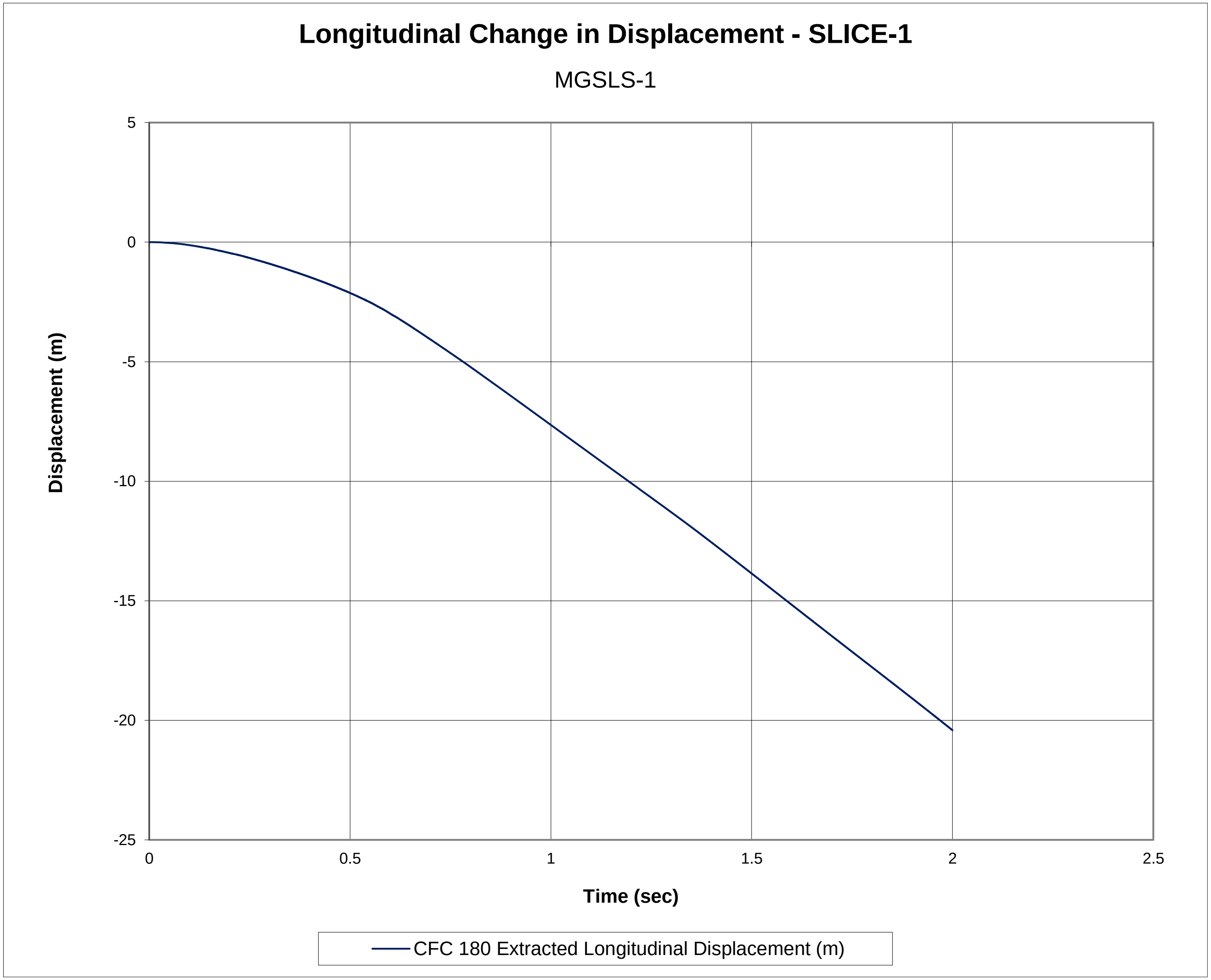


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSLS-1

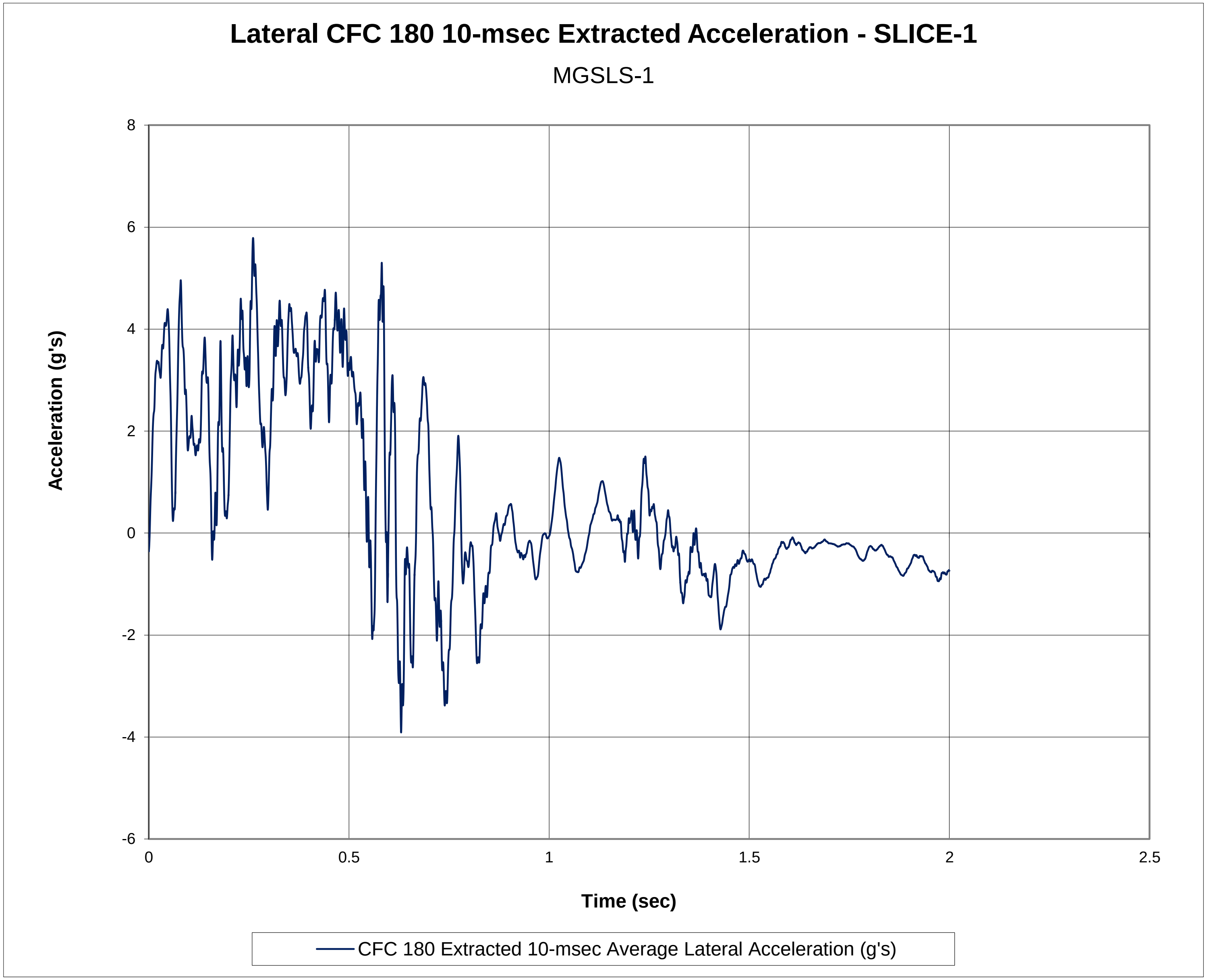


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSLS-1

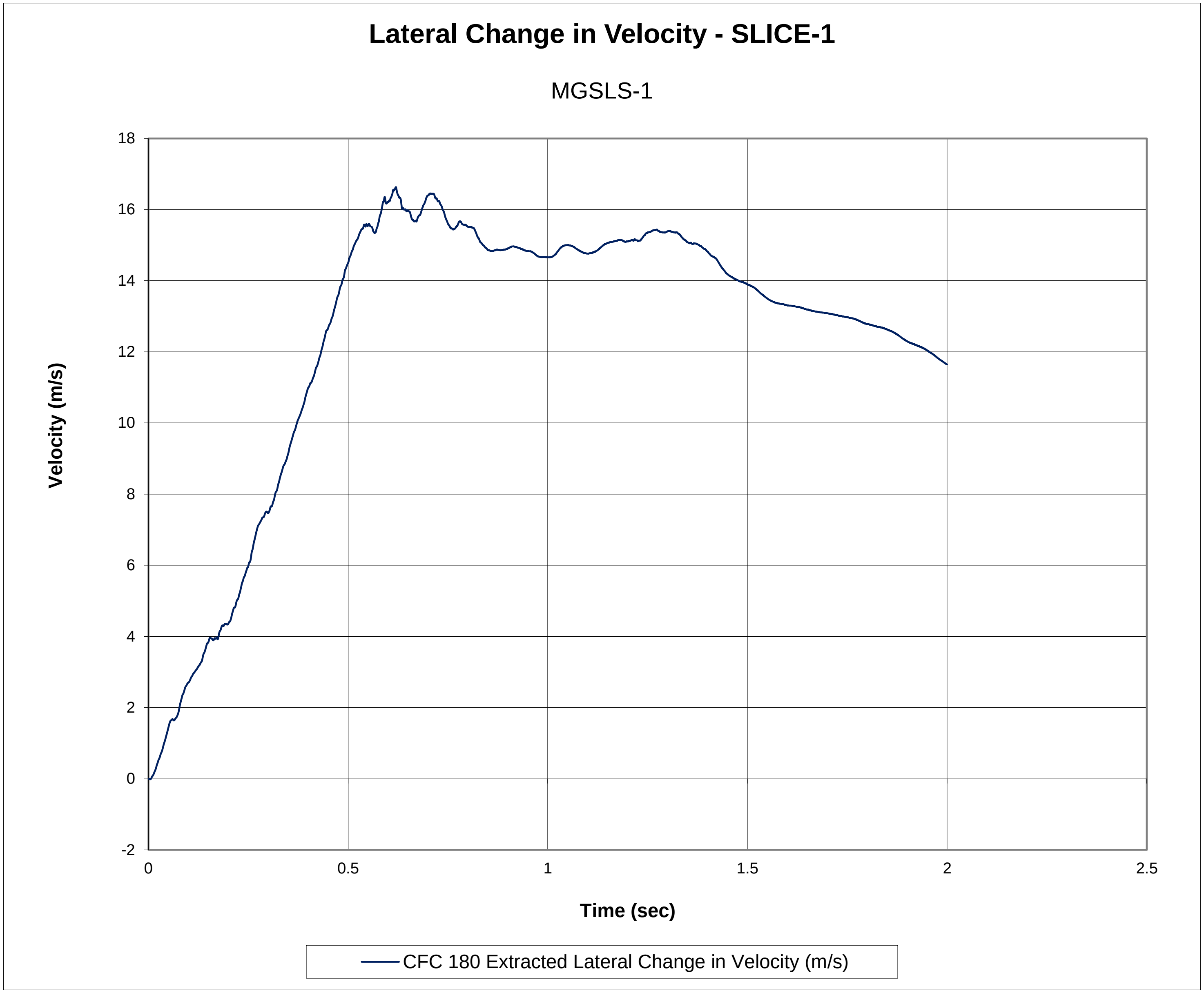


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MGSLS-1

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

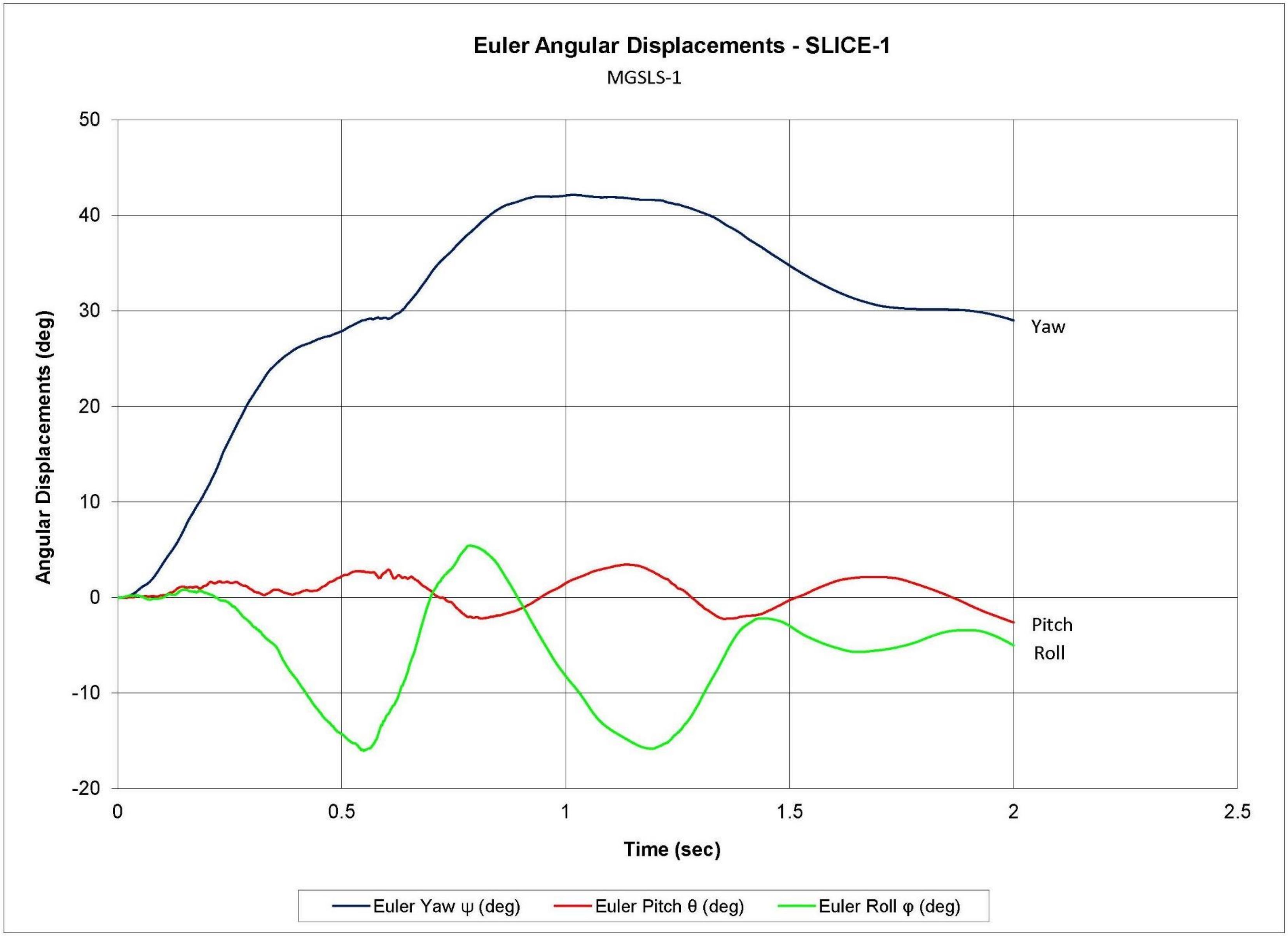


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. MGSLS-1

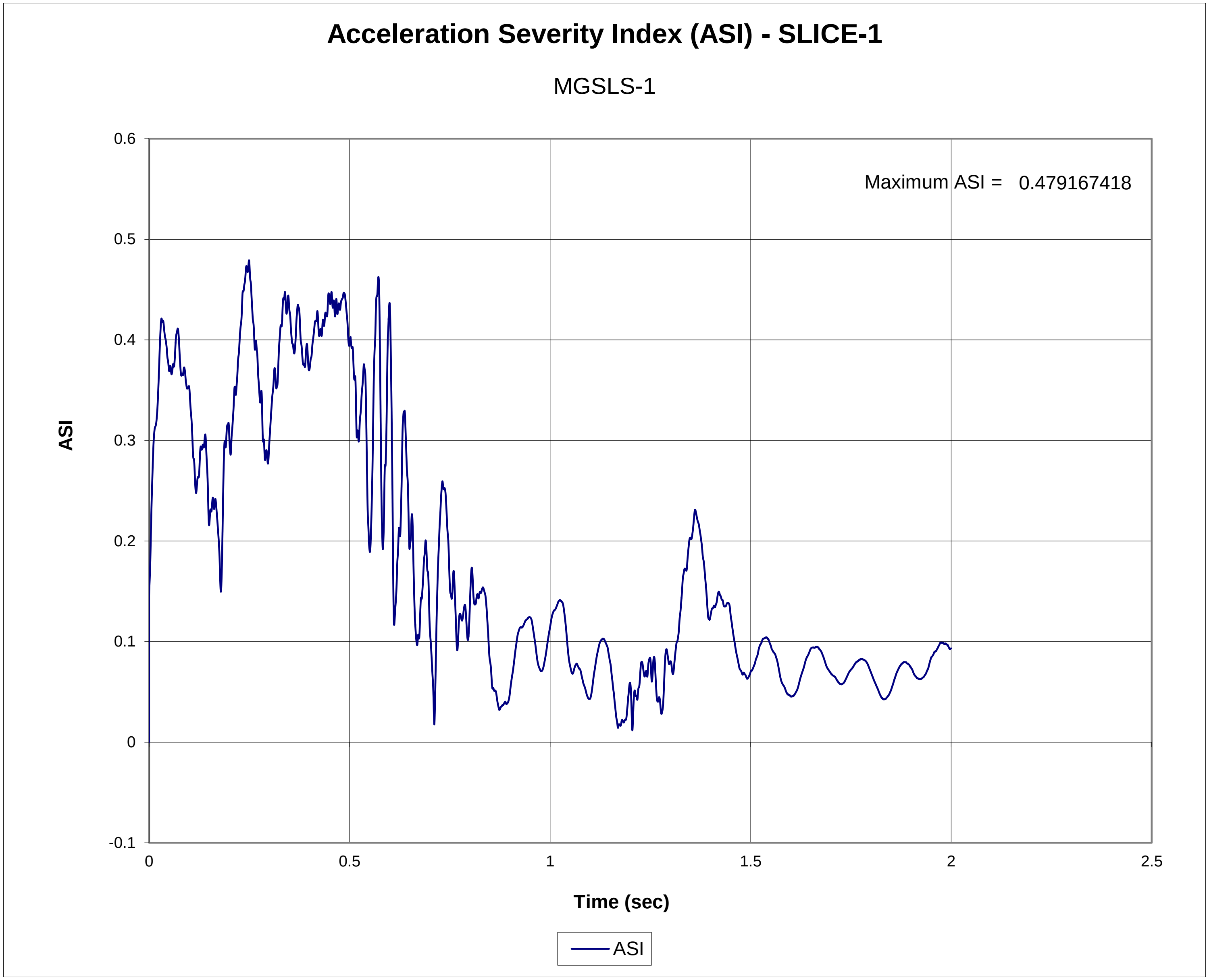


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. MGSLS-1

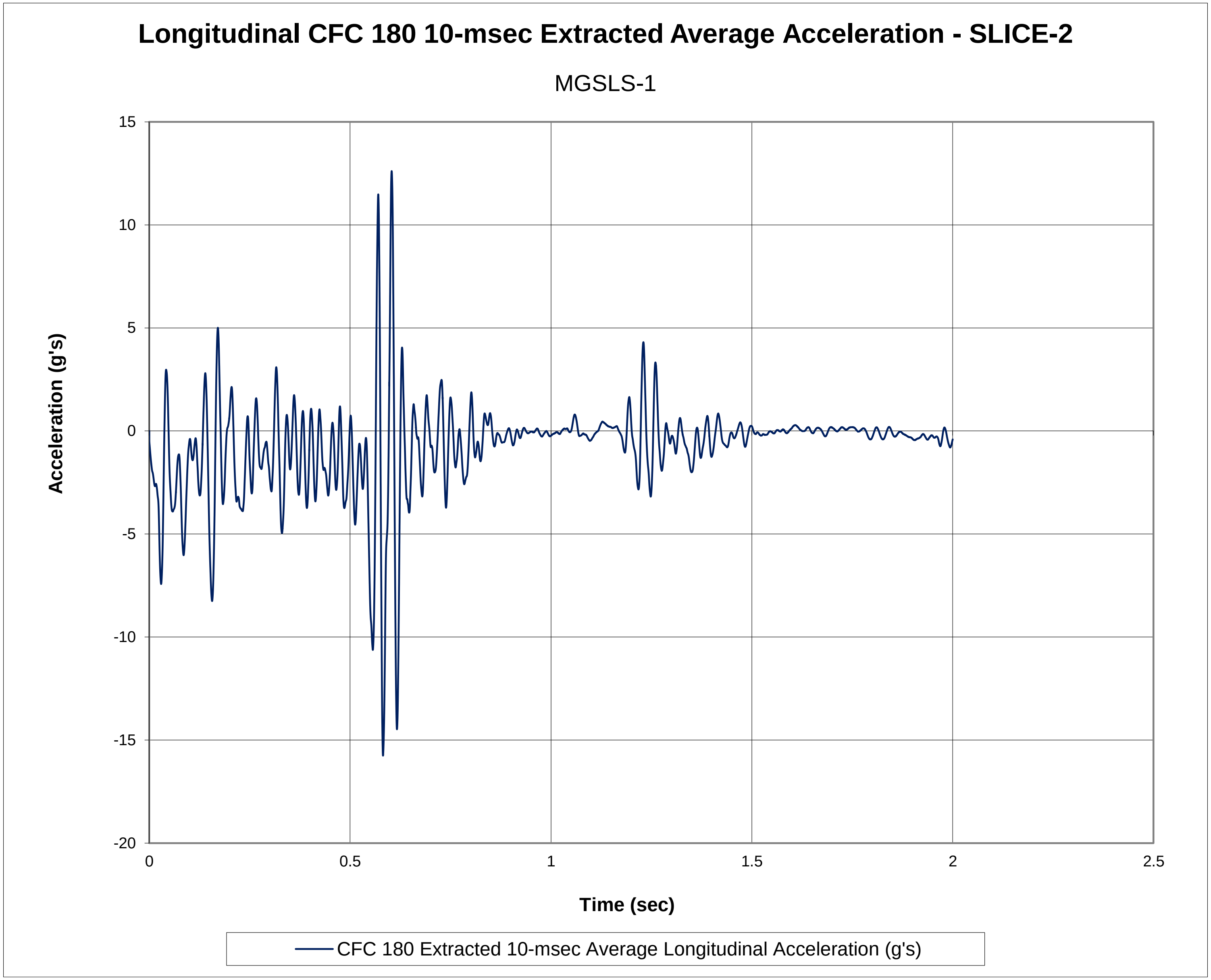


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSLS-1

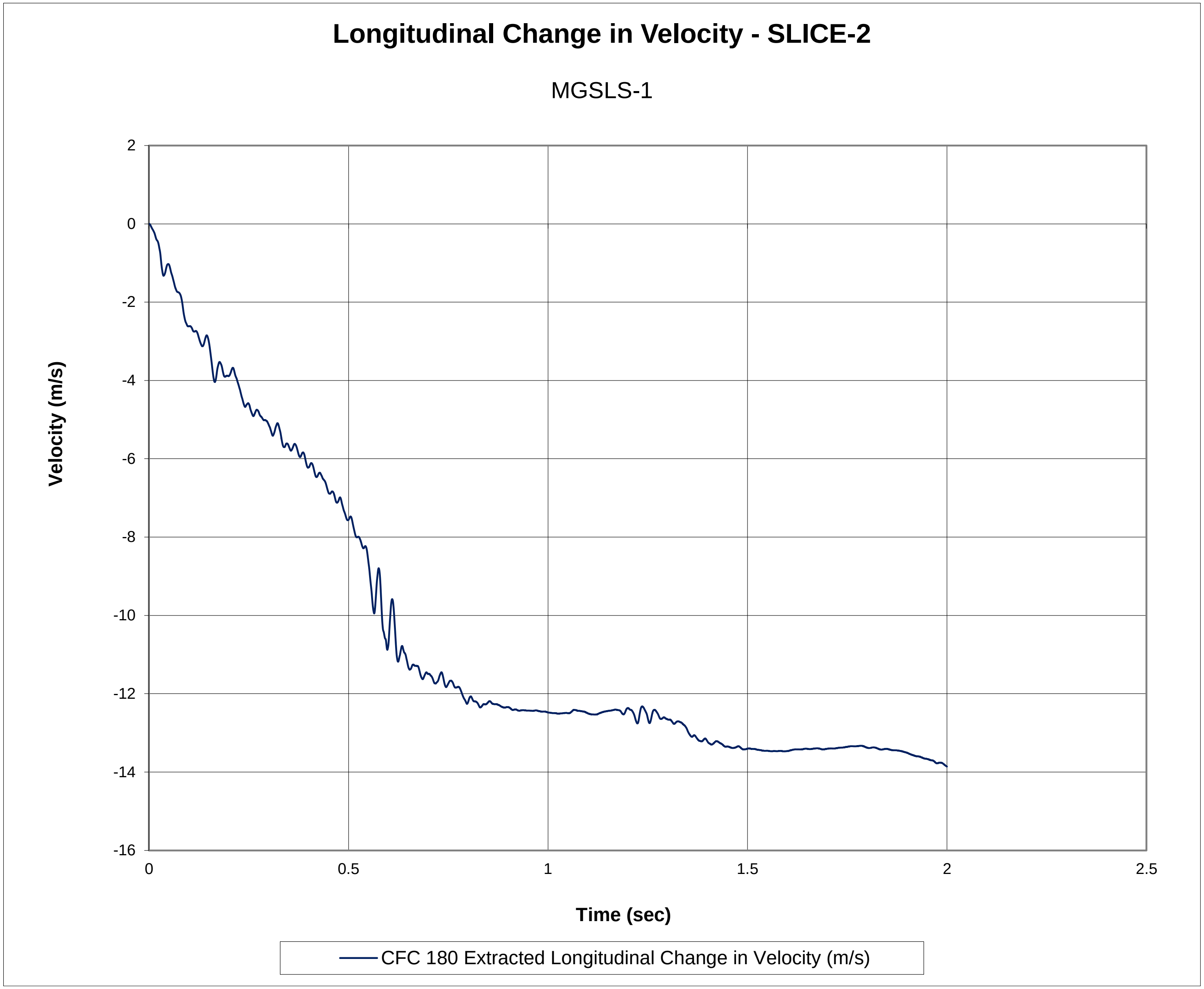


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MGSLS-1

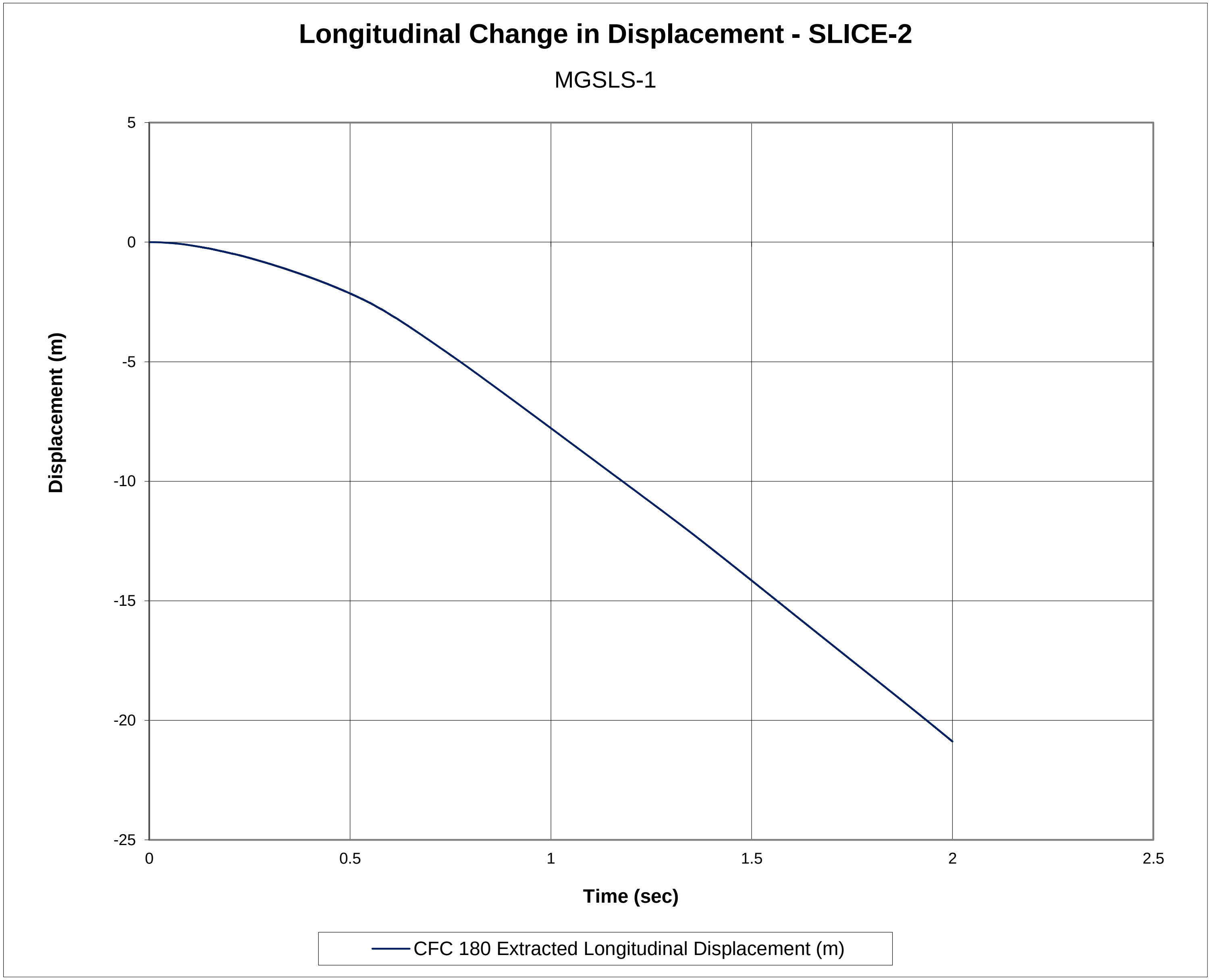


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSLS-1

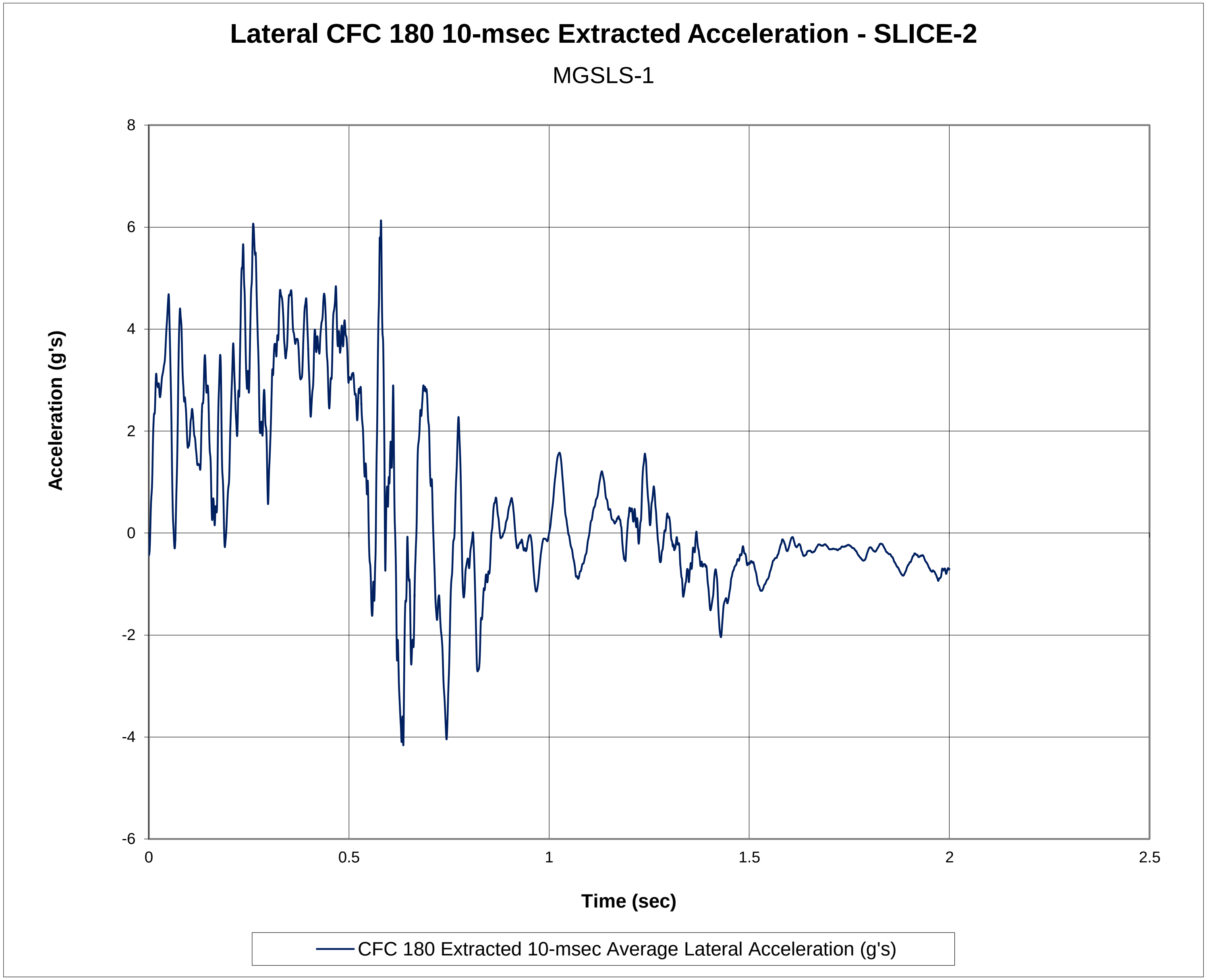


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSLS-1

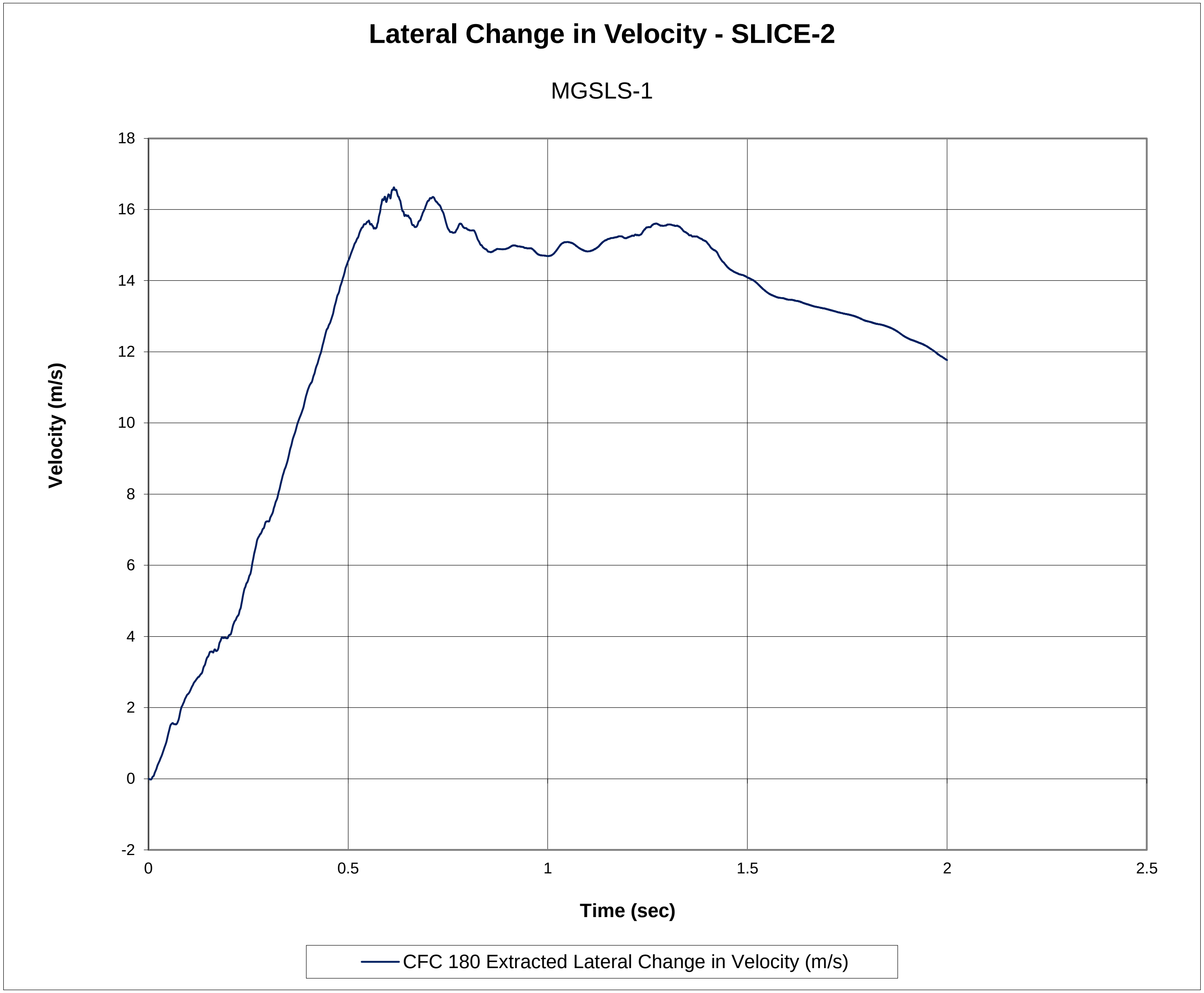


Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MGSLS-1

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

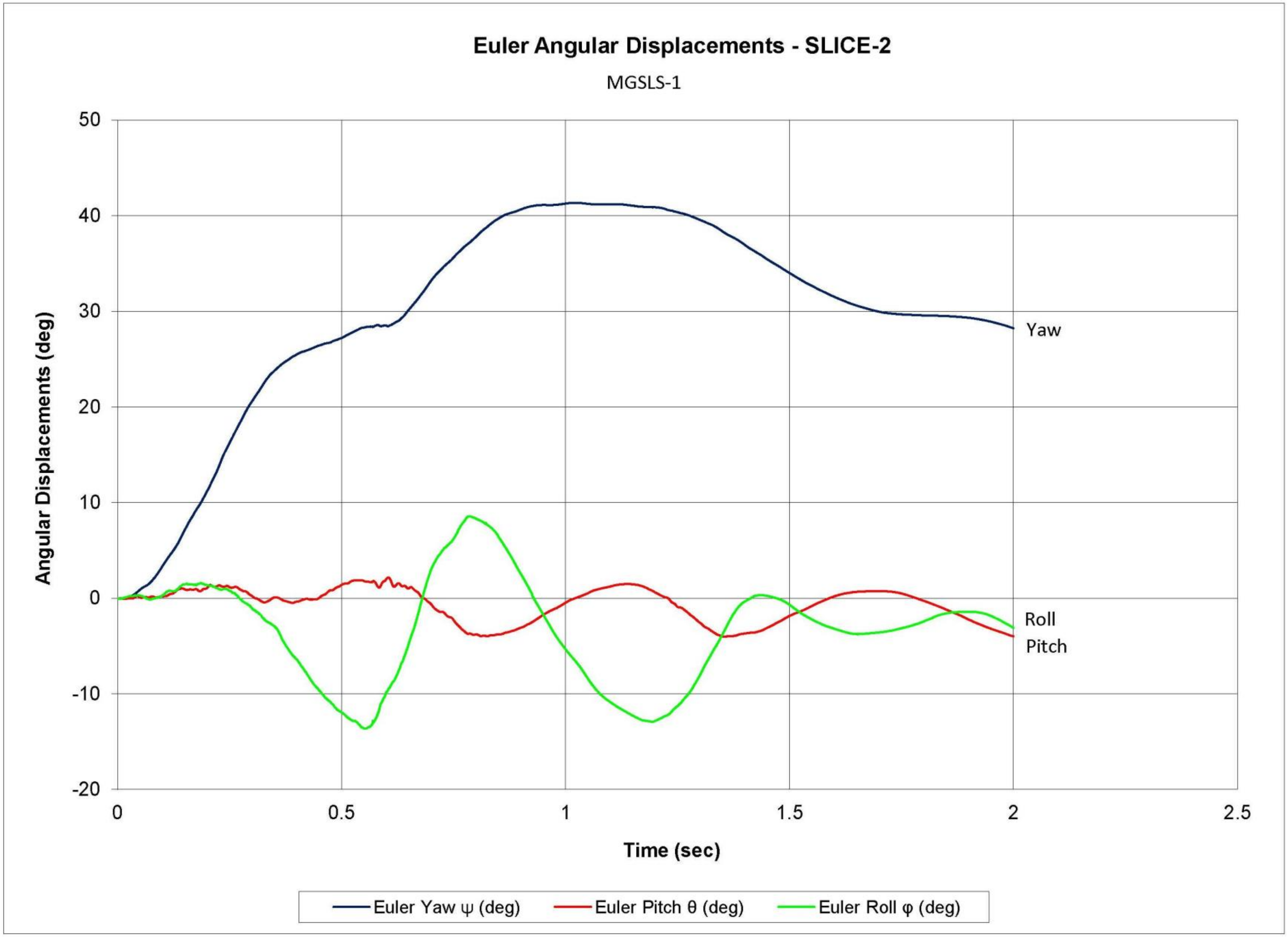


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. MGSLS-1

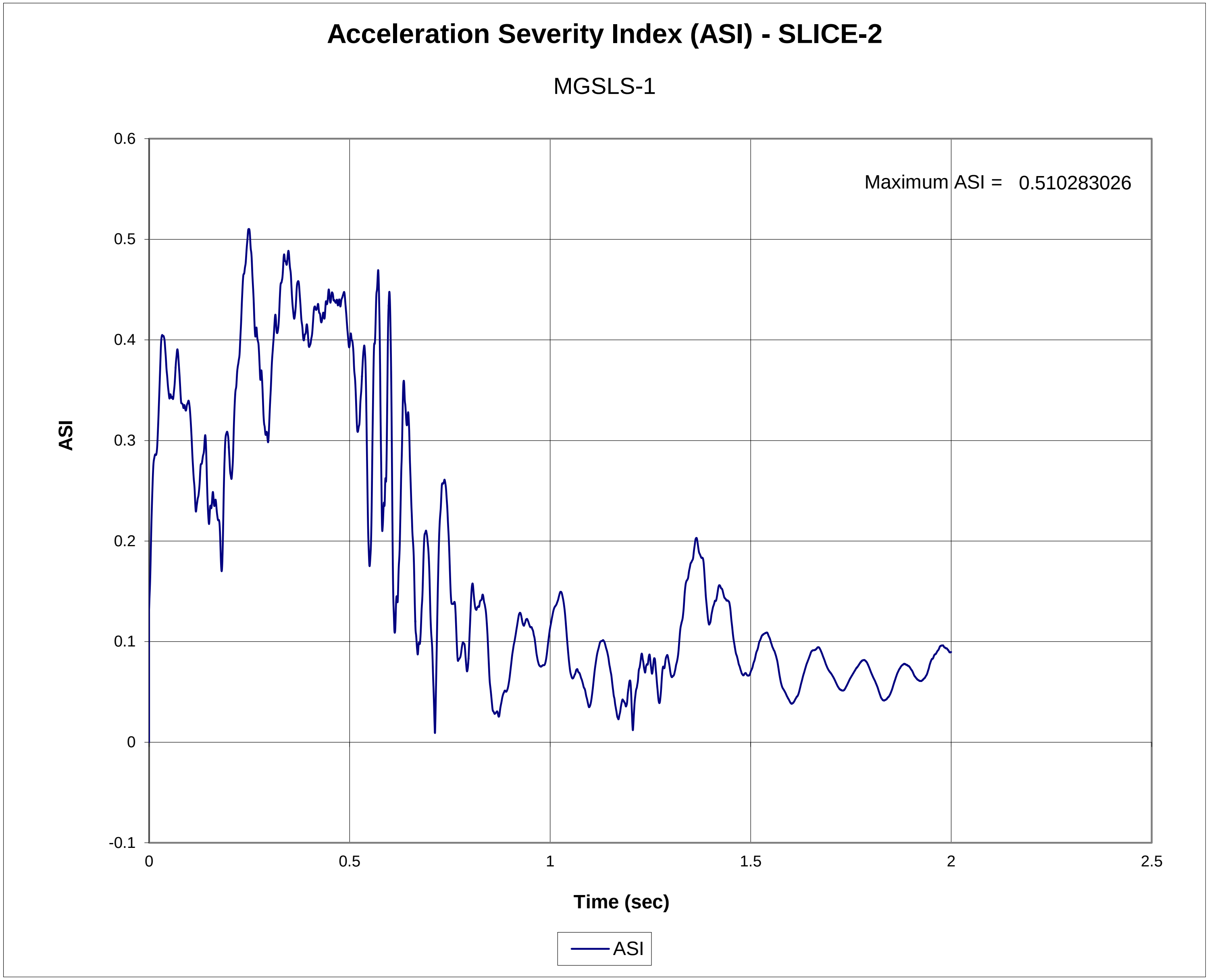


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. MGSLS-1

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

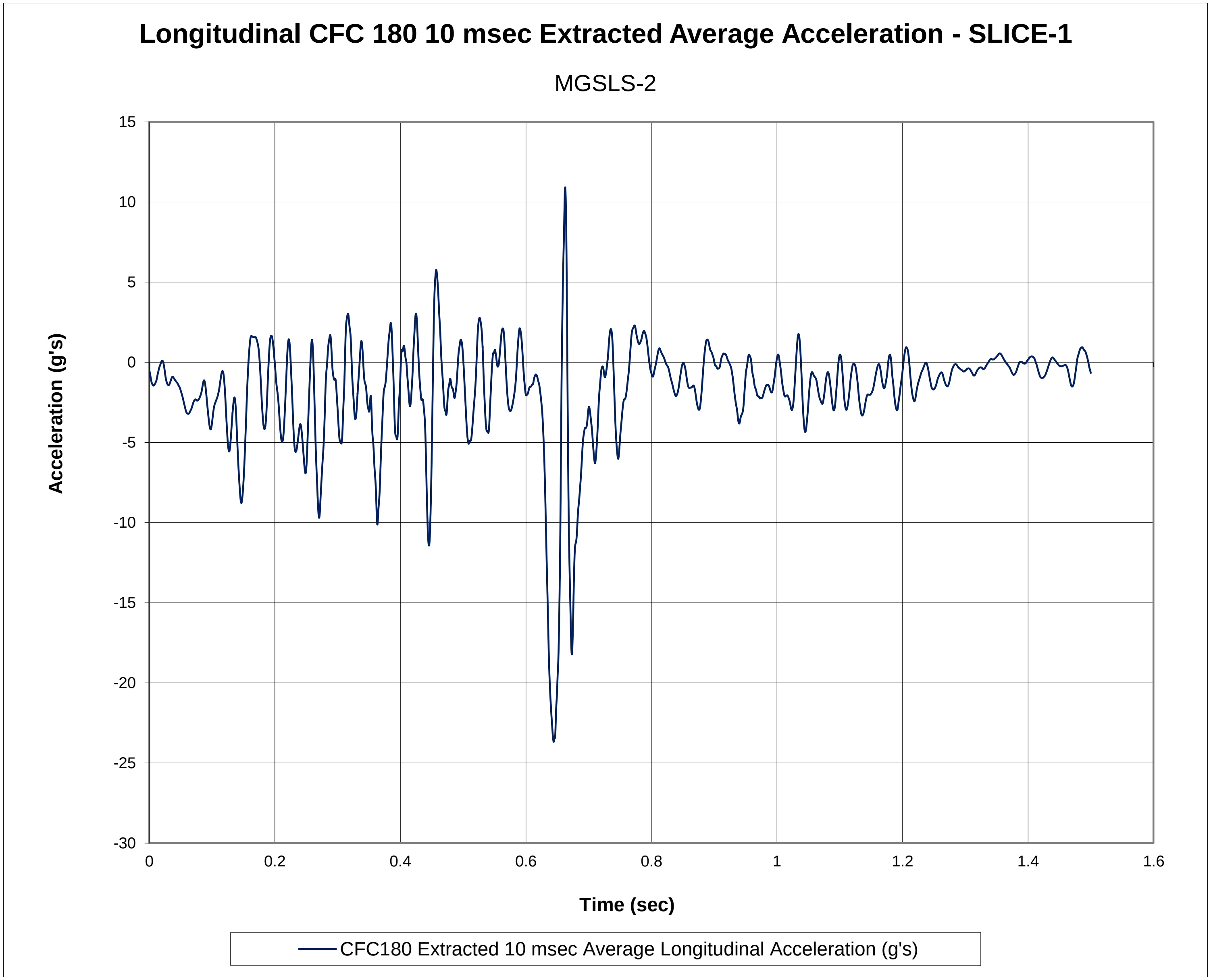


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSLS-2

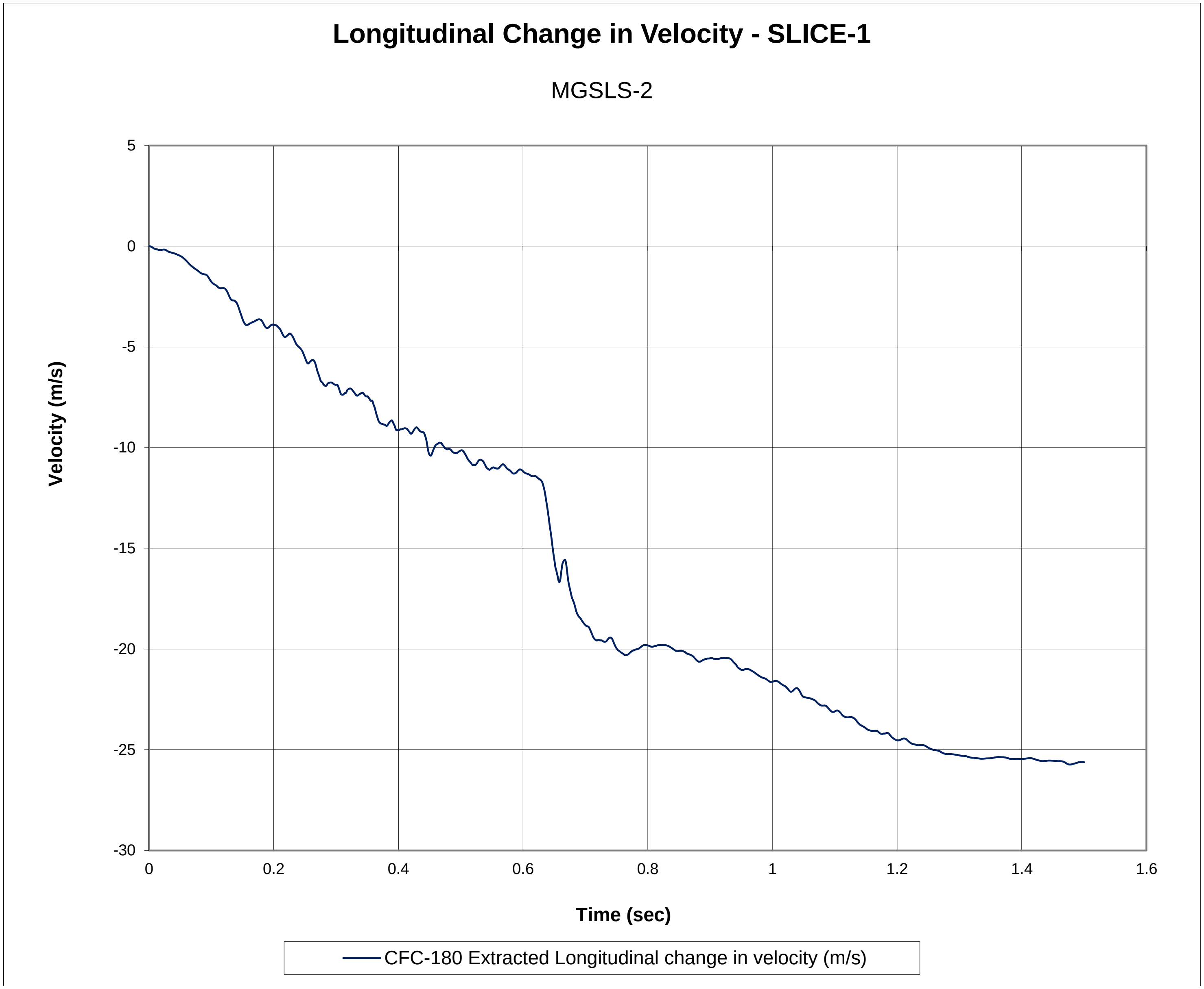


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MGSLS-2

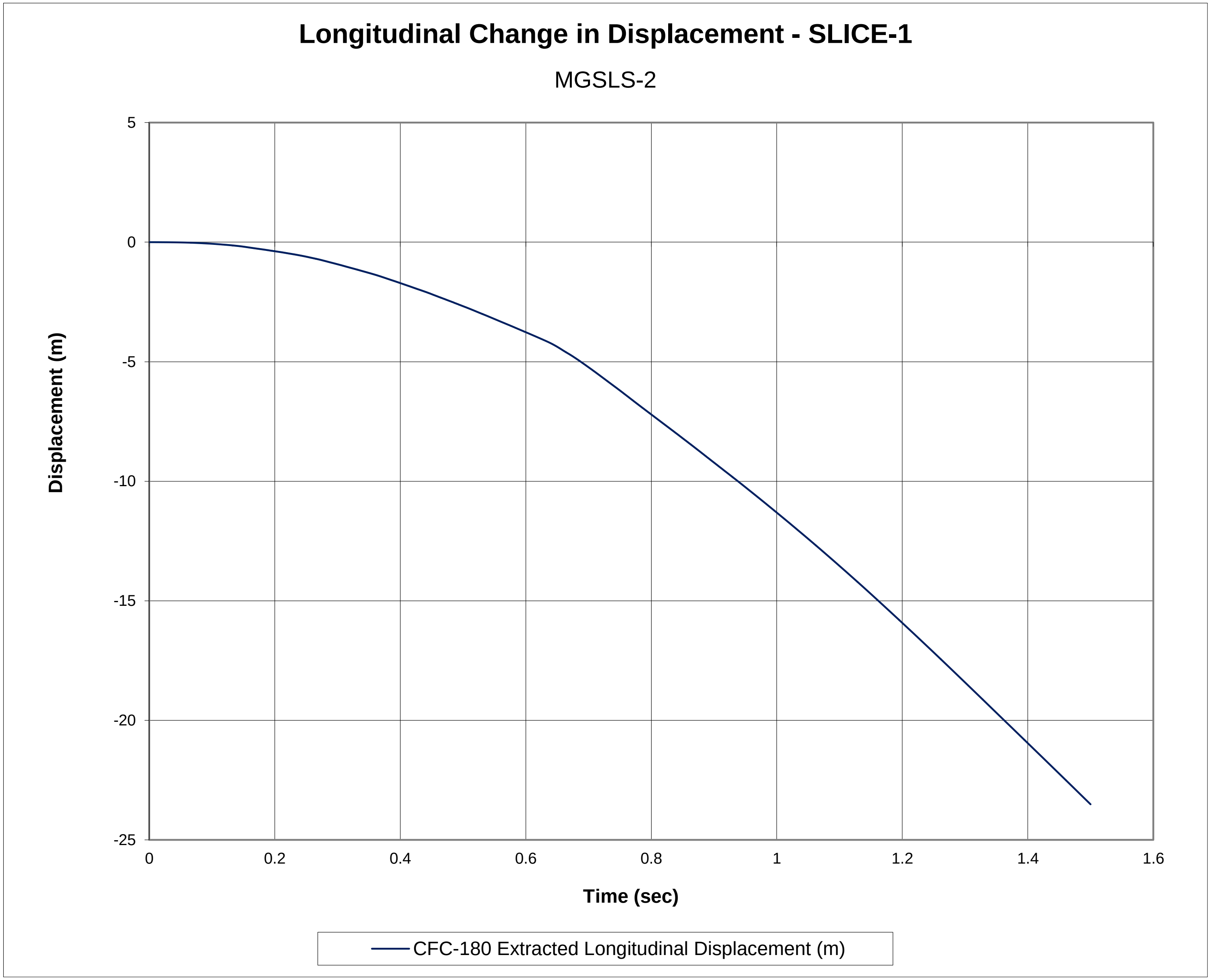


Figure F-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSLS-2

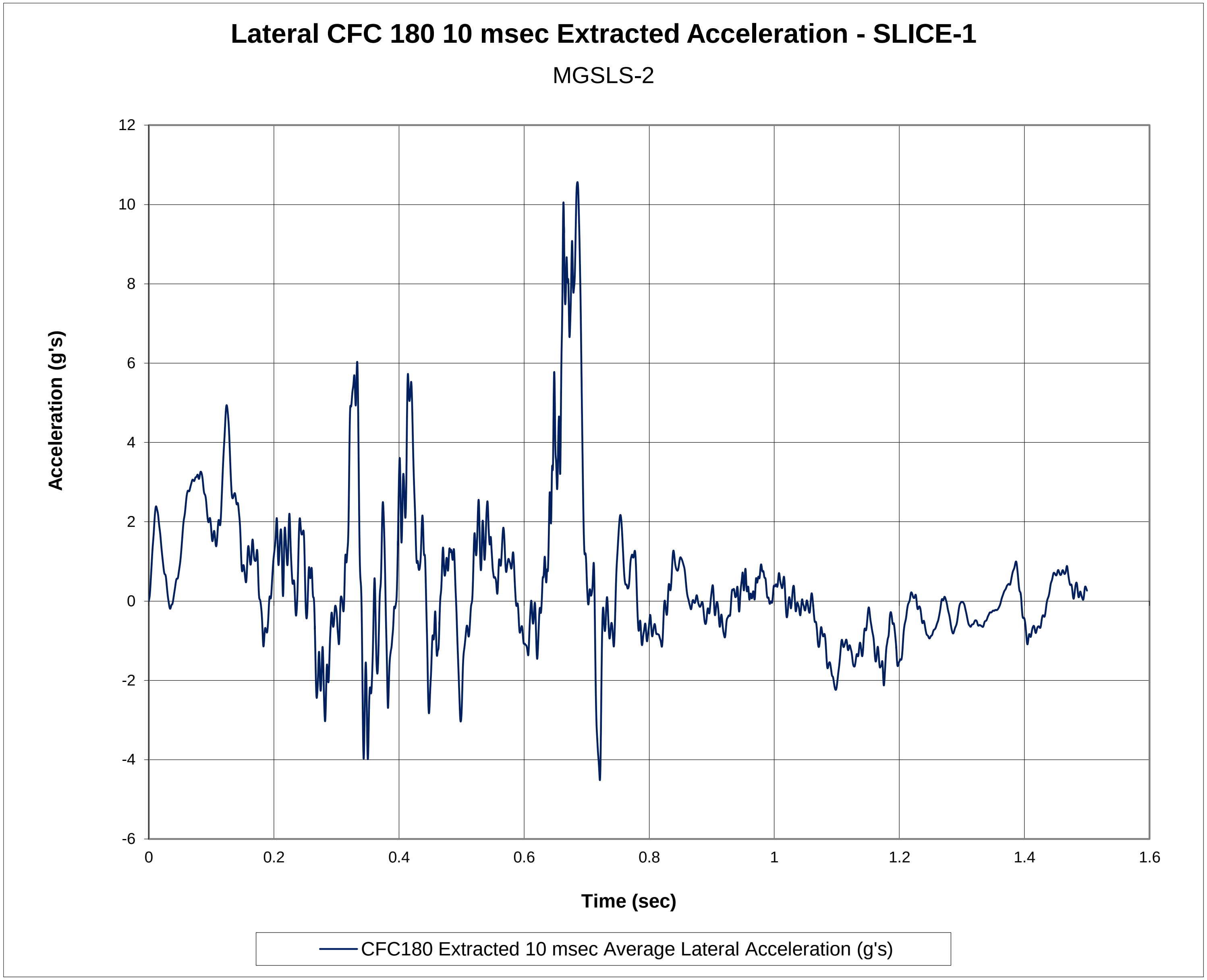


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSLS-2

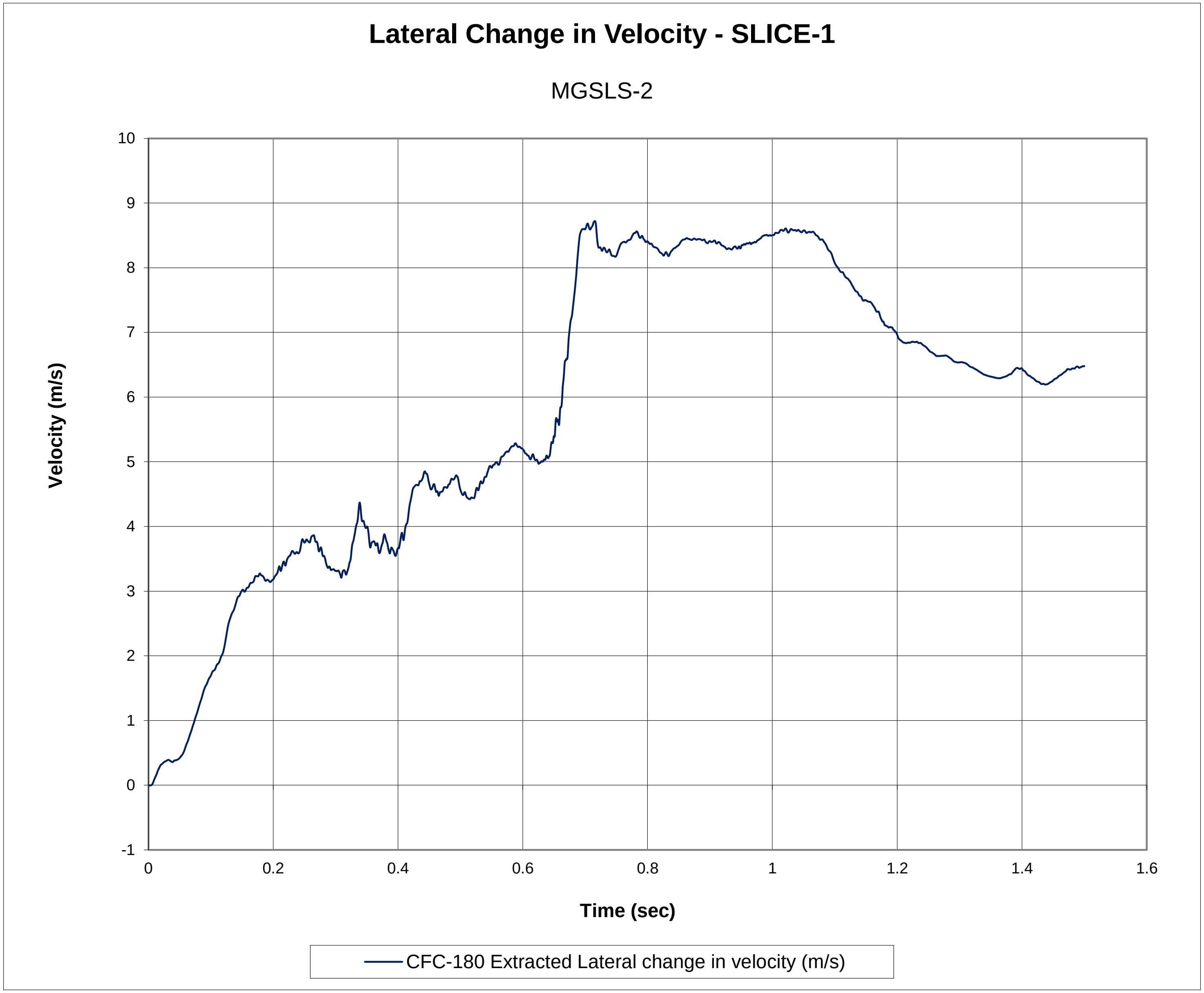


Figure F-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MGSLS-2

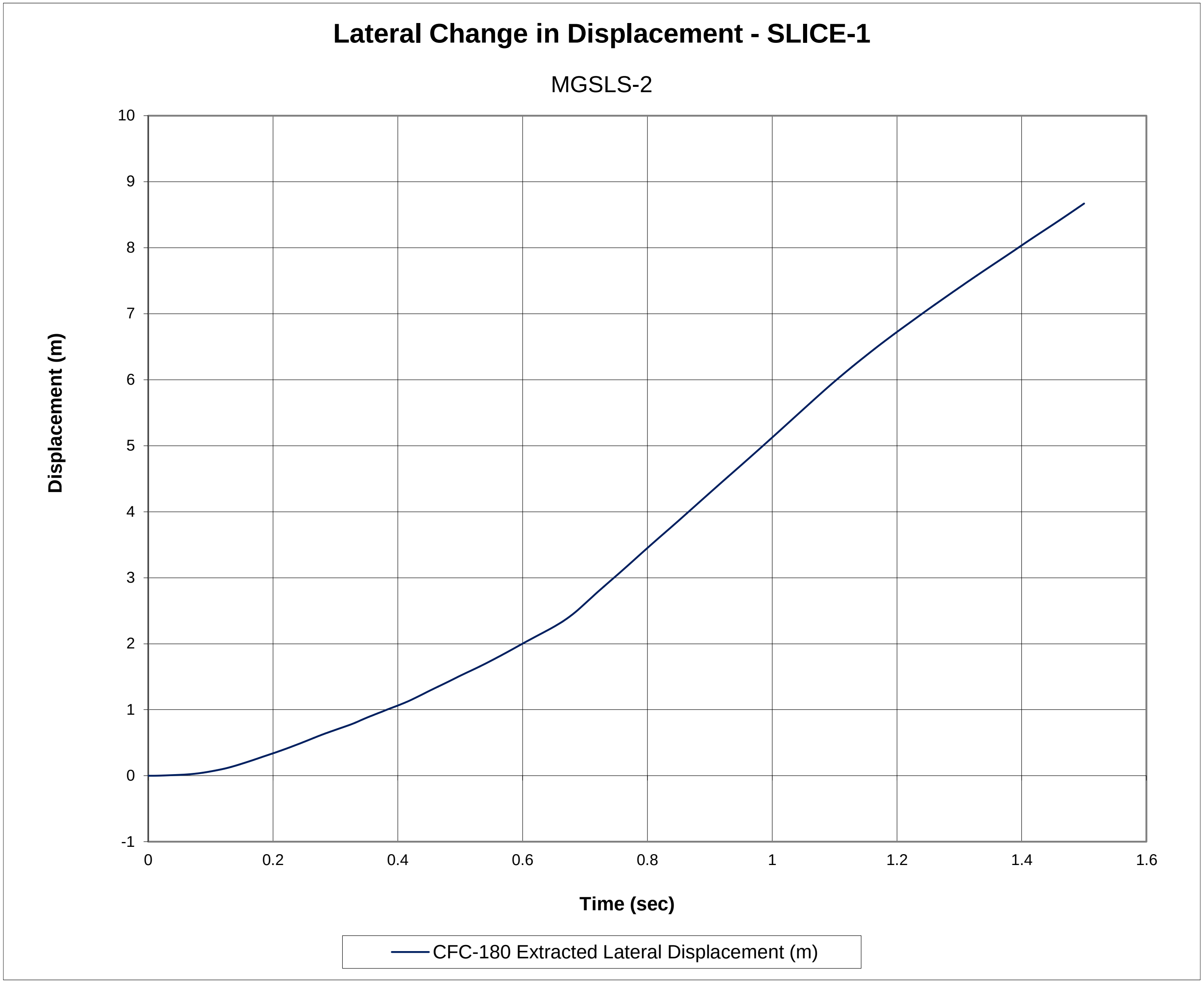


Figure F-6. Lateral Occupant Displacement (SLICE-1), Test No. MGSLS-2

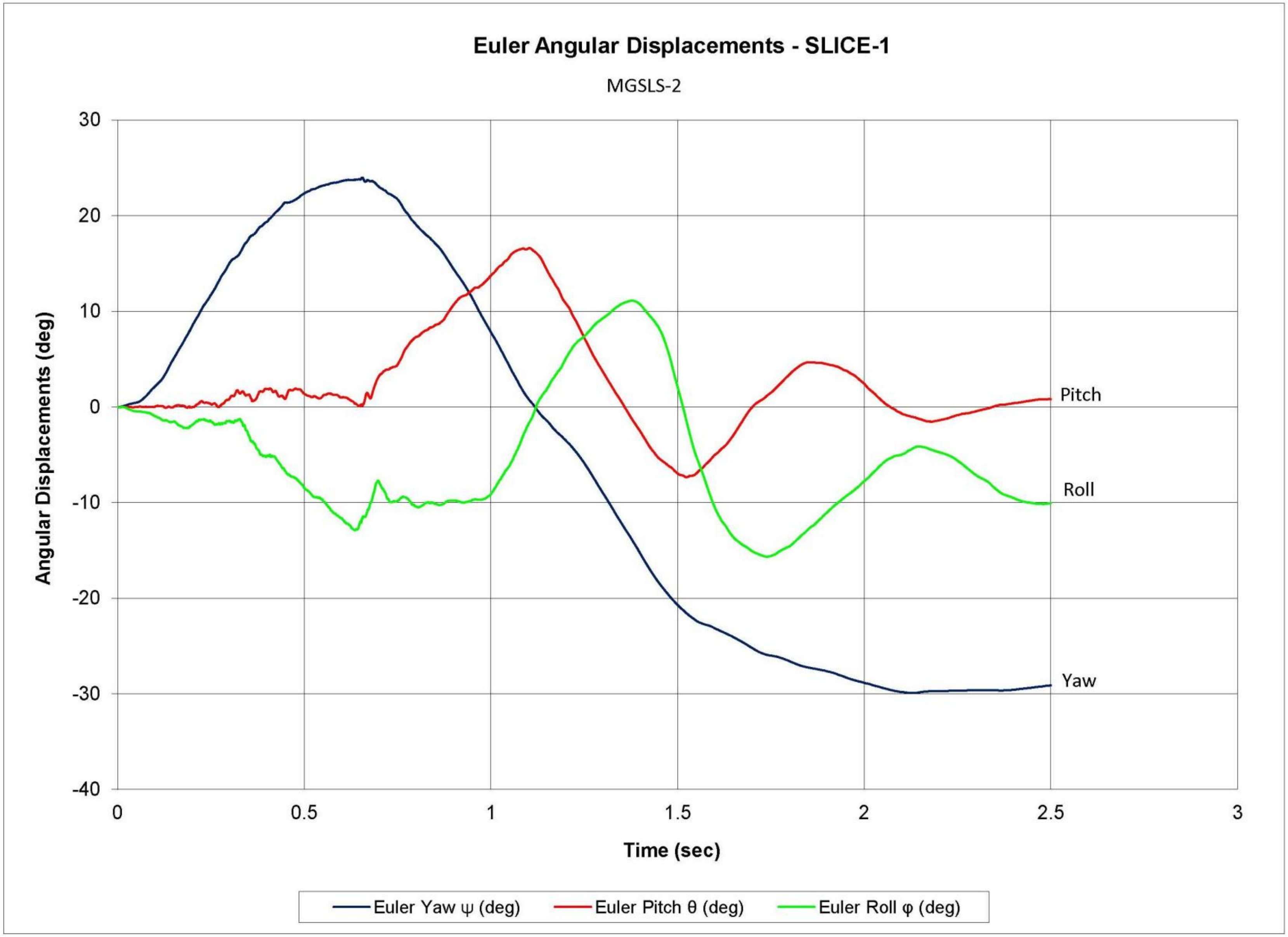


Figure F-7. Vehicle Angular Displacements (SLICE-1), Test No. MGSLS-2

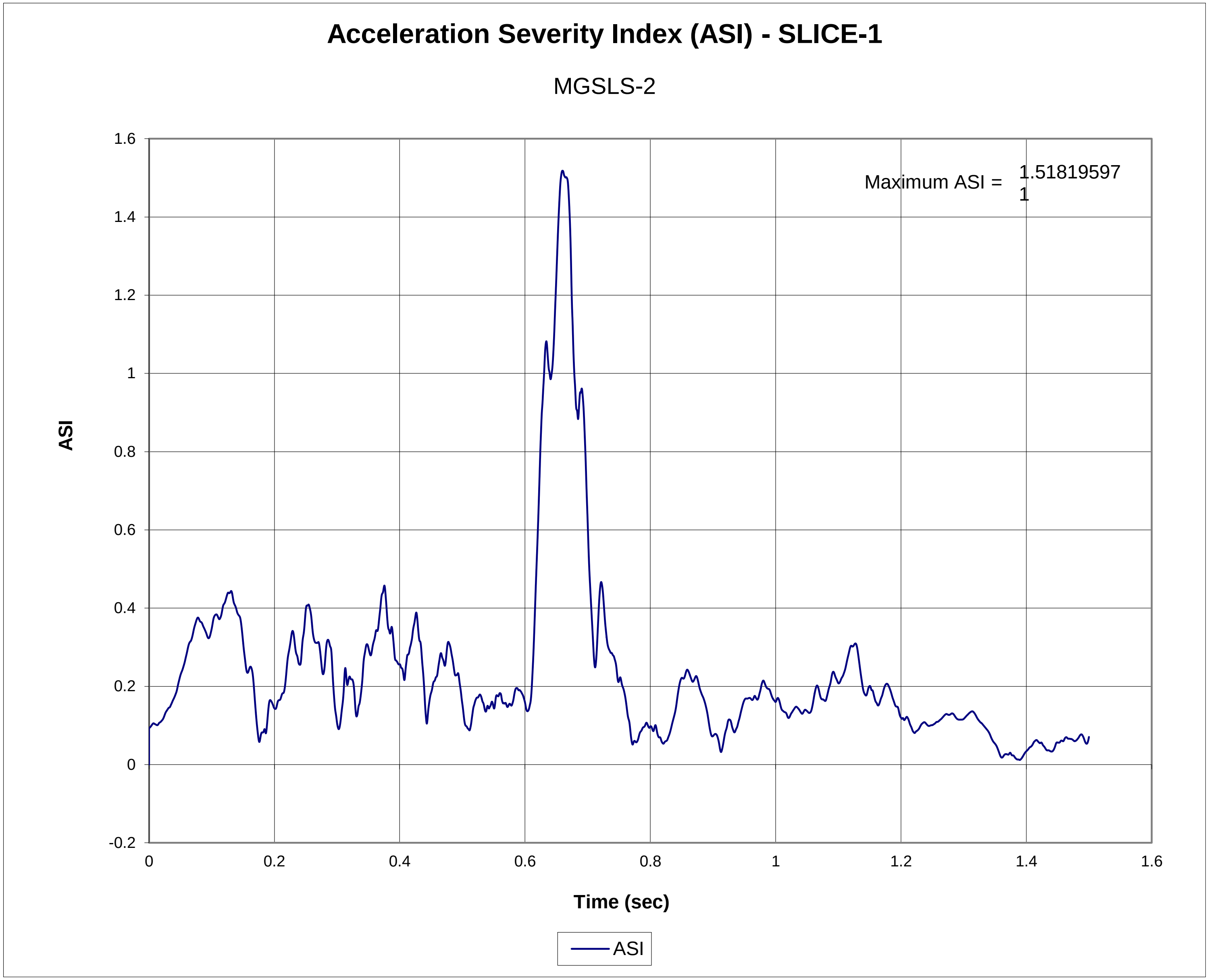


Figure F-8. Acceleration Severity Index (SLICE-1), Test No. MGSLS-2

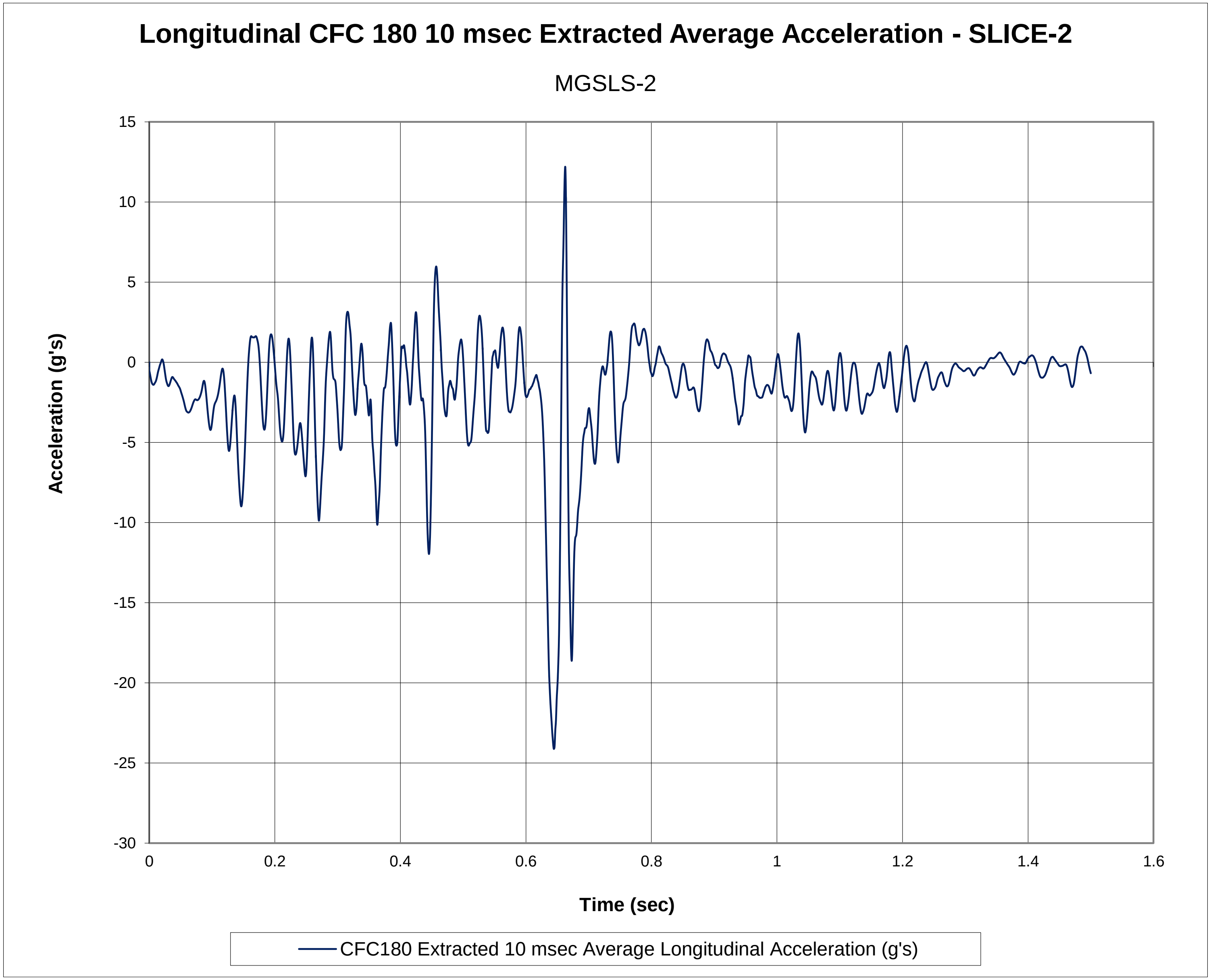


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSLS-2

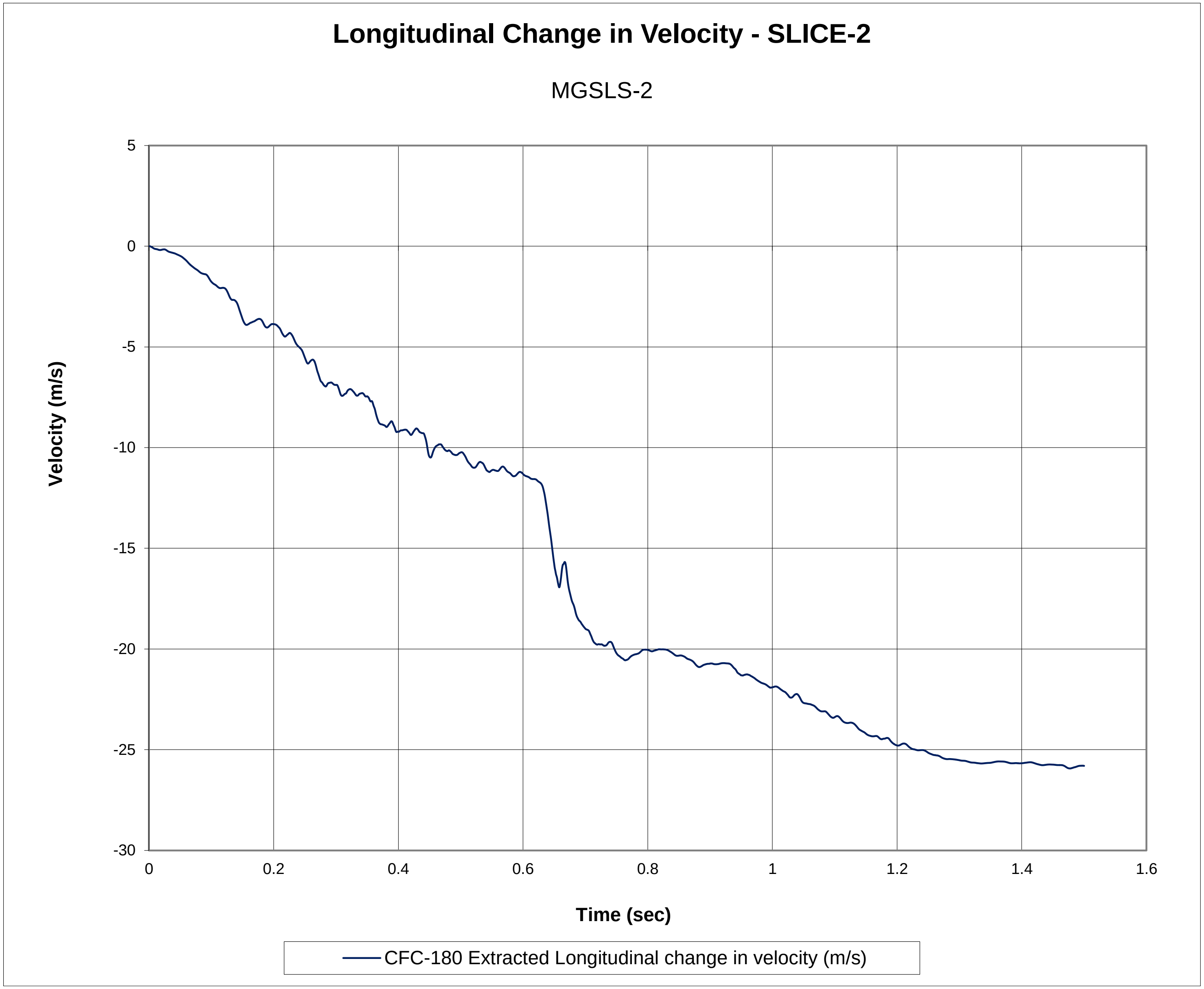


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MGSLS-2

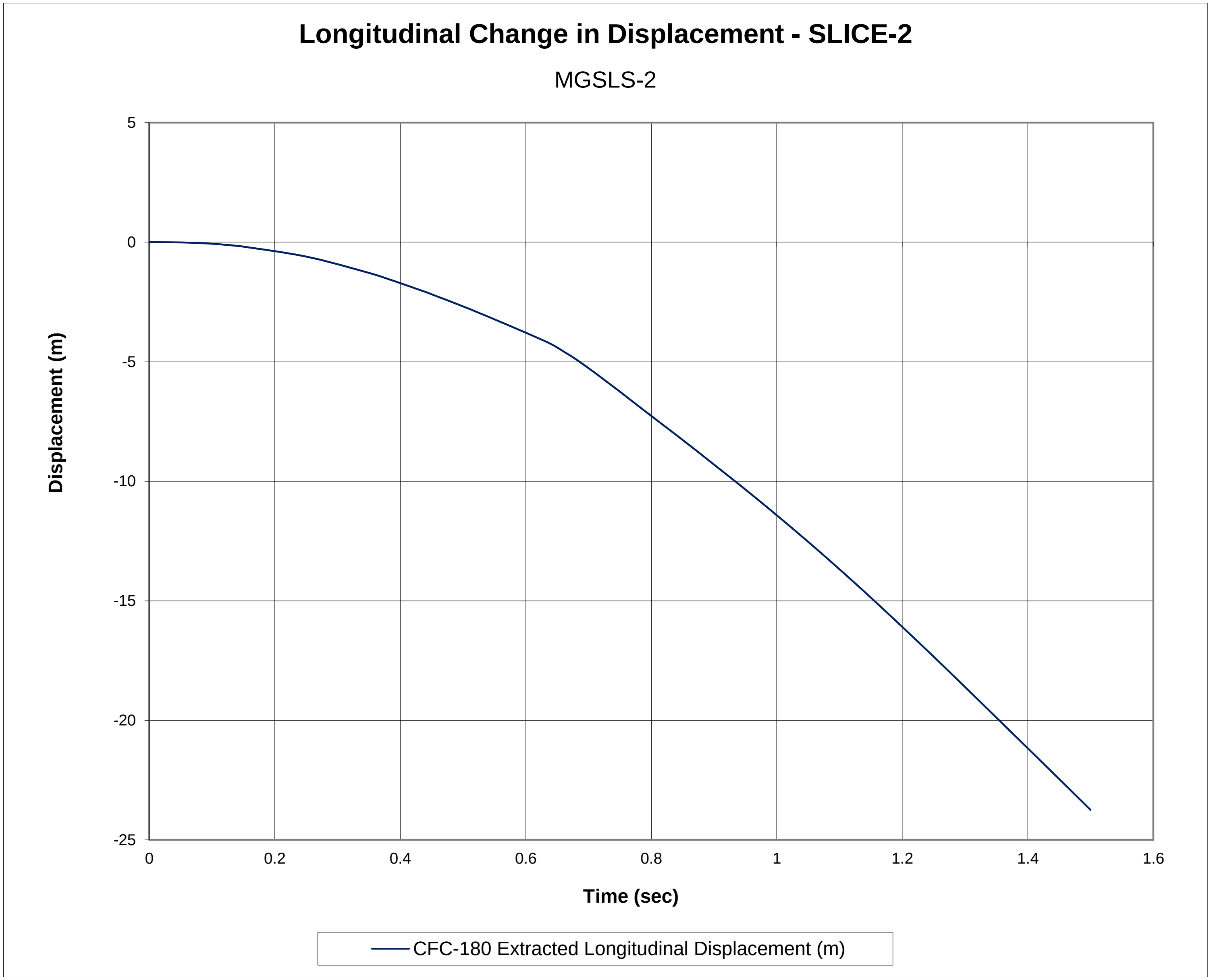


Figure F-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSLS-2

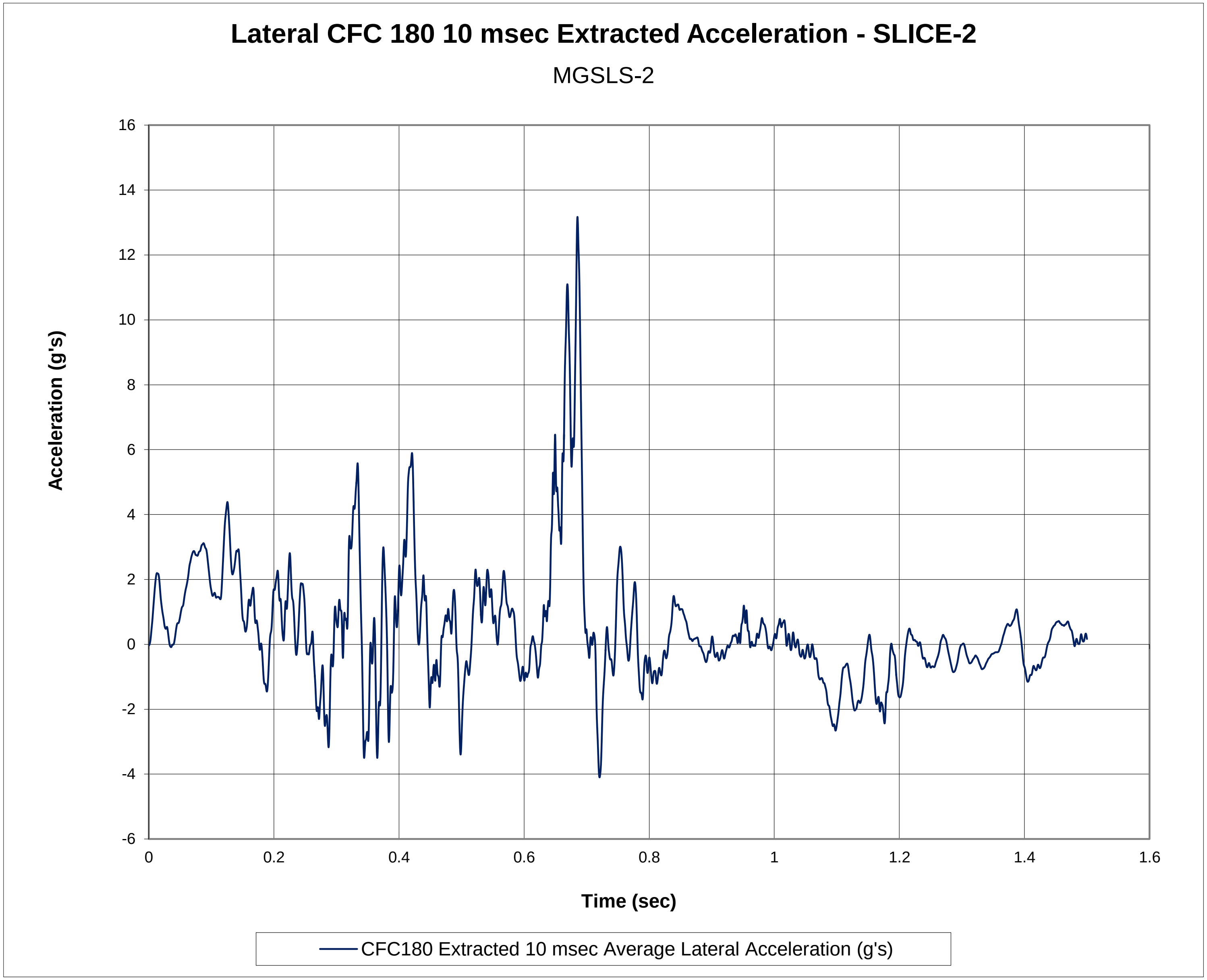


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSLS-2

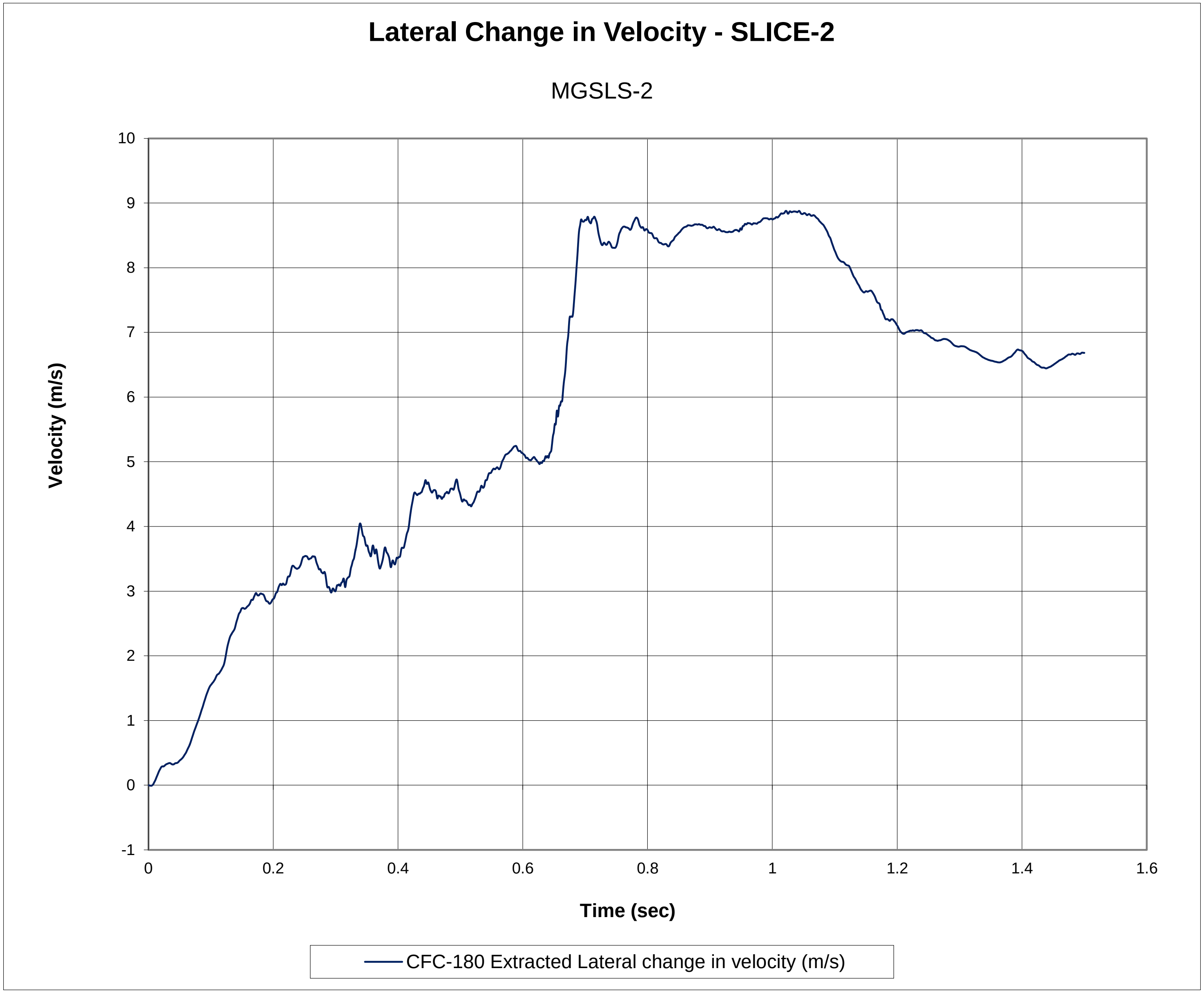


Figure F-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MGSLS-2

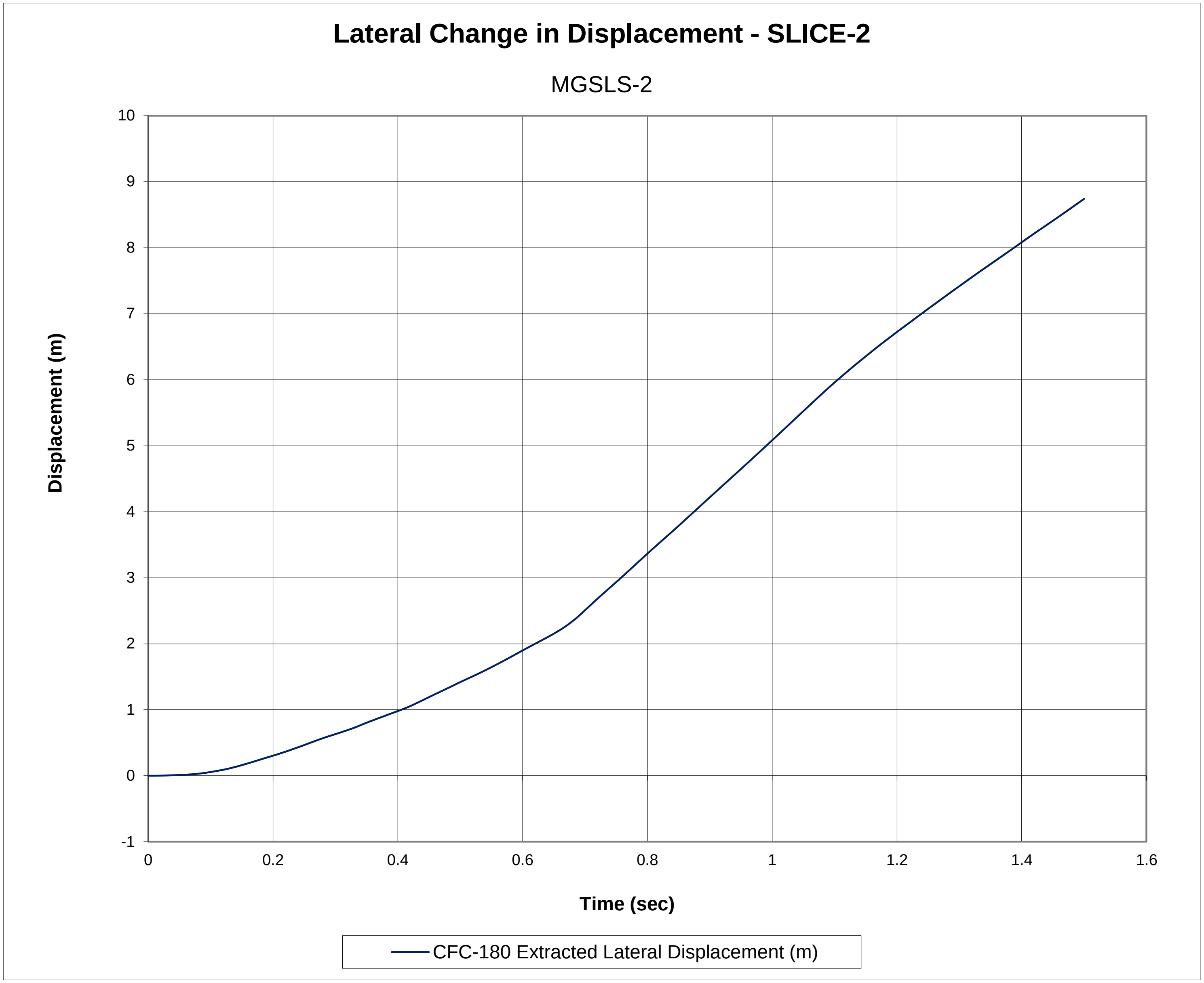


Figure F-14. Lateral Occupant Displacement (SLICE-2), Test No. MGSLS-2

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

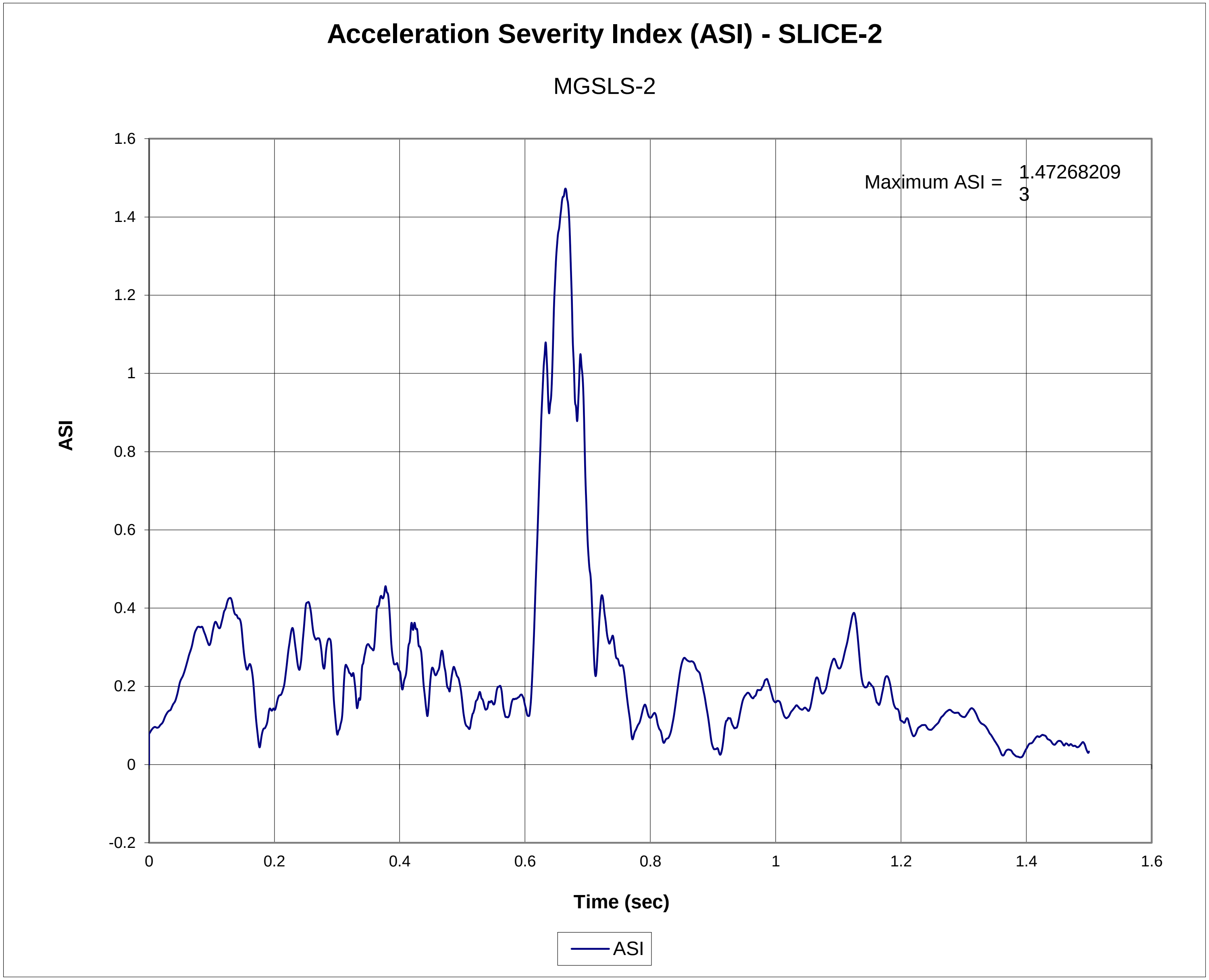


Figure F-16. Acceleration Severity Index (SLICE-2), Test No. MGSLS-2

Appendix G. Load Cell and String Potentiometer Data

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

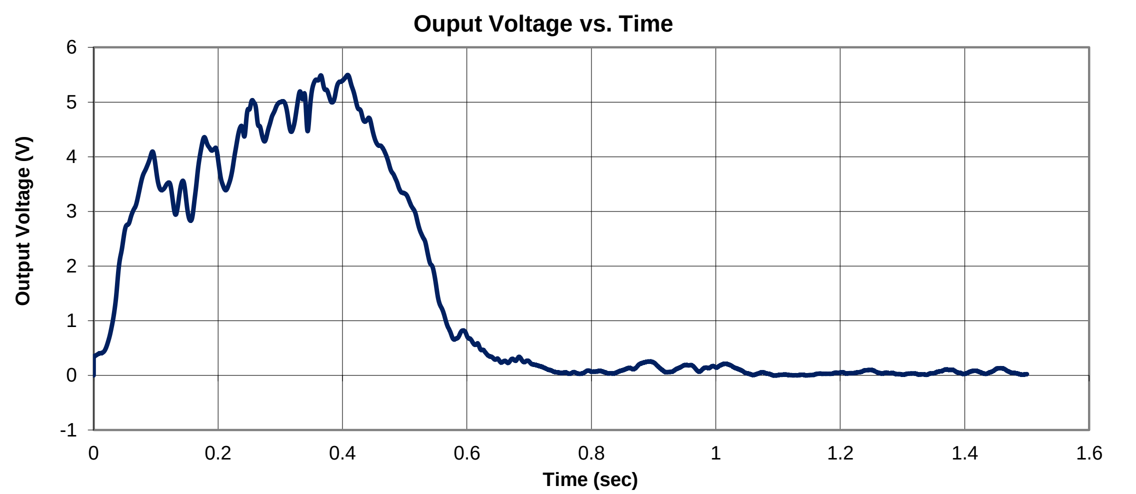
Test No:	MGSLS-1
Date:	5/18/2015
System / Test Article:	MGS Long Span - 31.25 ft
LC Location / Component:	Upstream Cable Anchorage
Additional Notes:	

Load Cell Information:

Load Cell No.:	143436
Calibration Factor:	2.14575 mv/V
Input Voltage (excitation):	9.99 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	32.04 kips
Time of Max. Load:	0.4084 sec
Event Duration:	1.5 sec
Final Load:	0.13 kips



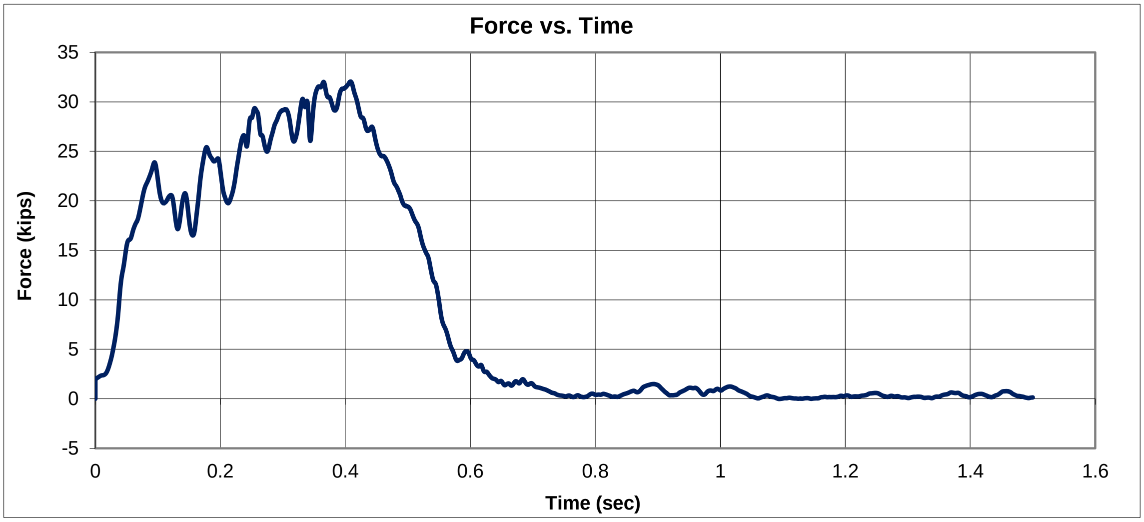


Figure G-1. Load Cell Data, Upstream Cable Anchorage No. 1, Test No. MGSLS-1

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

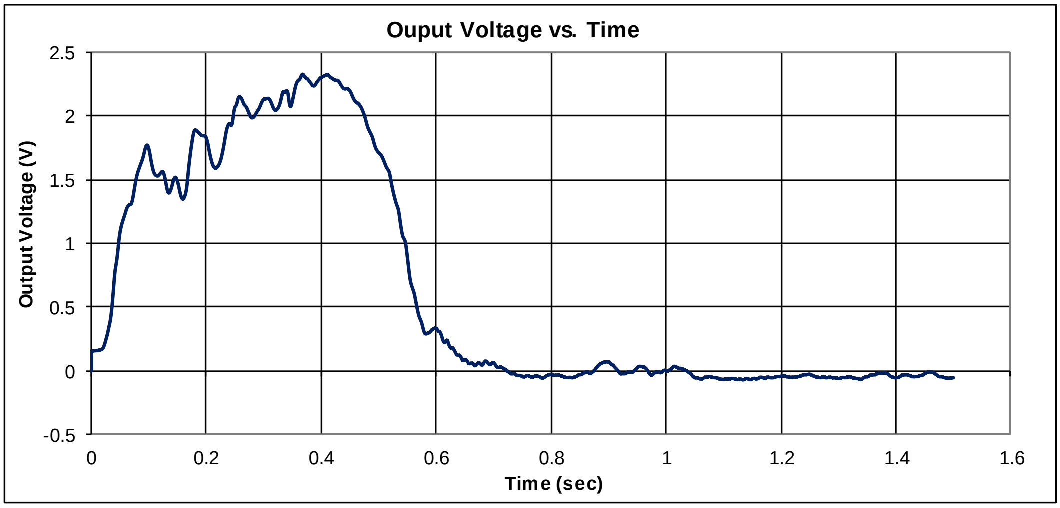
Test No:	MGSLS-1
Date:	5/18/2015
System / Test Article:	MGS Long Span - 31.25 ft
LC Location / Component:	Upstream Cable Anchorage
Additional Notes:	

Load Cell Information:

Load Cell No.:	PCB - 1377
Calibration Factor:	0.064 mv/V
Input Voltage (excitation):	NA Volts
Gain:	NA
Full Scale Load:	80 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	36.38 kips
Time of Max. Load:	0.3675 sec
Event Duration:	1.5 sec
Final Load:	-0.81 kips



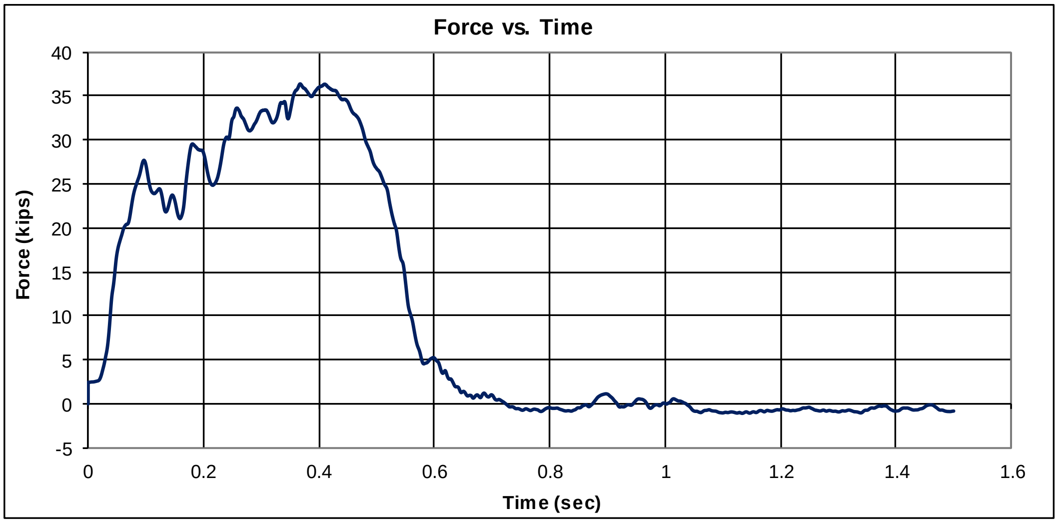


Figure G-2. Load Cell Data, Upstream Cable Anchorage No. 2, Test No. MGSLS-1

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

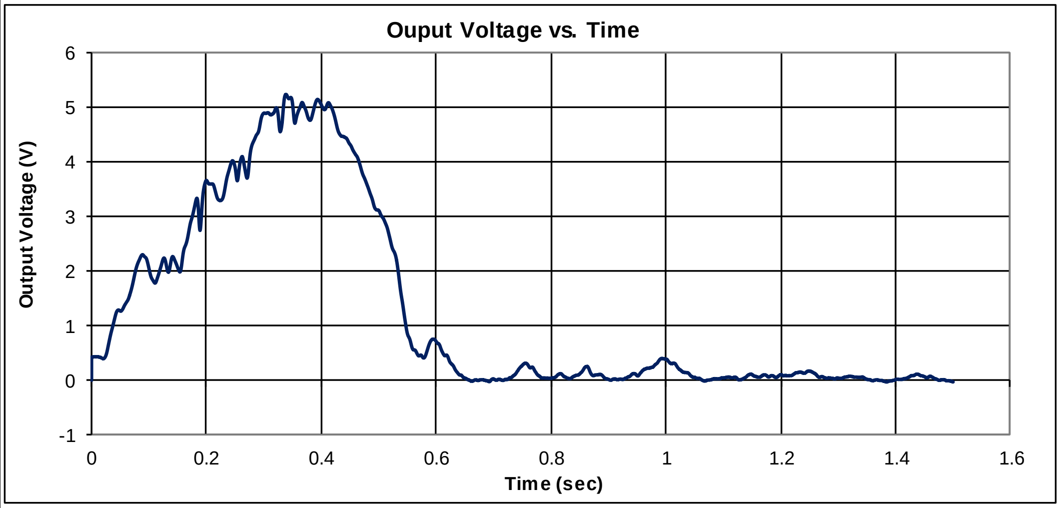
Test No:	MGSLS-1
Date:	5/18/2015
System / Test Article:	MGS Long Span - 31.25 ft
LC Location / Component:	Downstream Cable Anchorage
Additional Notes:	

Load Cell Information:

Load Cell No.:	120642
Calibration Factor:	2.1186 mv/V
Input Voltage (excitation):	9.99 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	30.91 kips
Time of Max. Load:	0.3385 sec
Event Duration:	1.5 sec
Final Load:	-0.17 kips



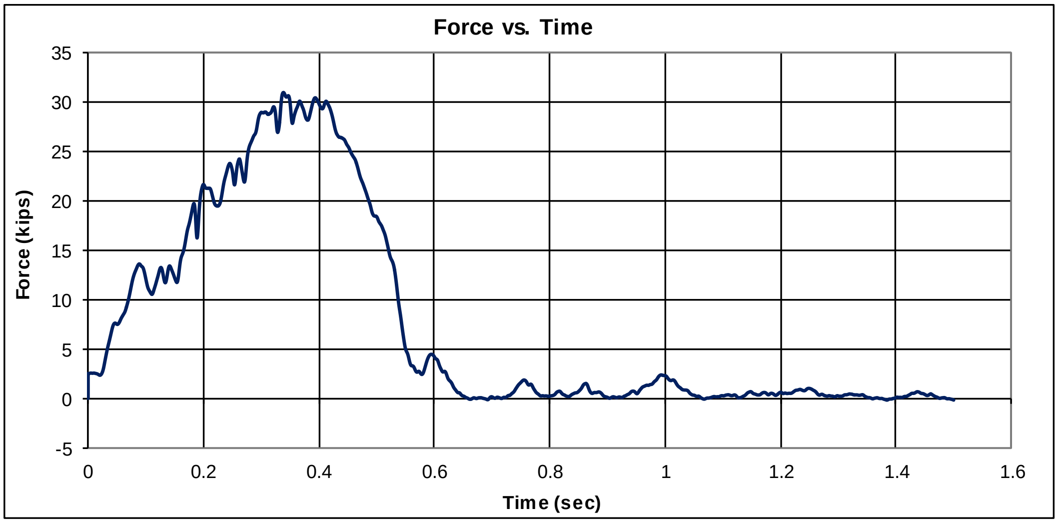


Figure G-3. Load Cell Data, Downstream Cable Anchorage, Test No. MGSLS-1

MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

Test Information:

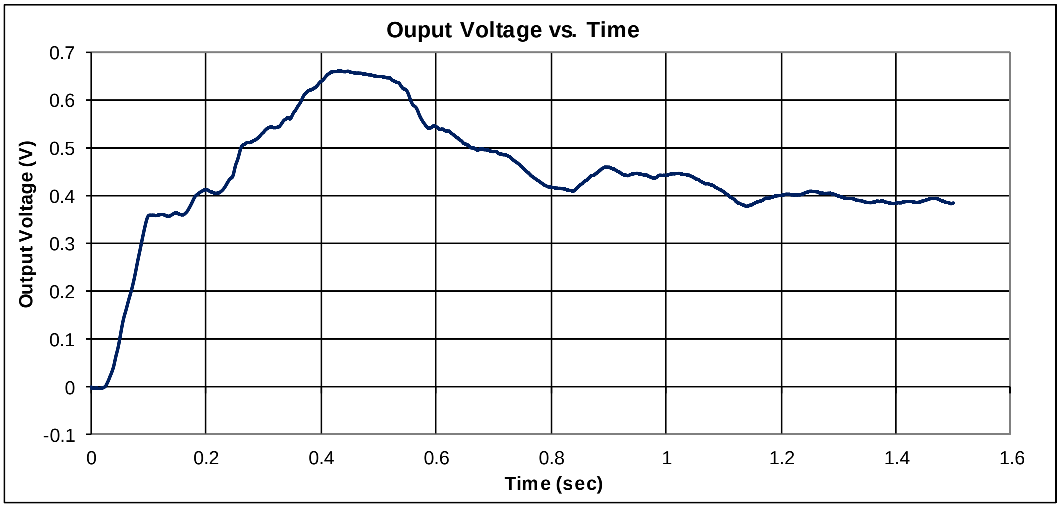
Test No:	MGSLS-1
Date:	5/18/2015
System / Test Article:	MGS Long Span - 31.25 ft
SP Location / Component:	Upstream Cable Anchorage
Additional Notes:	

String Potentiometer Information:

String Pot No.:	27039203
Calibration Factor:	19.4 mV/V/in.
Input Voltage (excitation):	9.99 Volts
Gain:	1
Full Scale Load:	1
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Max. Displacement:	3.41 in.
Time of Max. Displacement:	0.4316 sec
Event Duration:	1.5 sec
Final Displacement:	1.99 in.



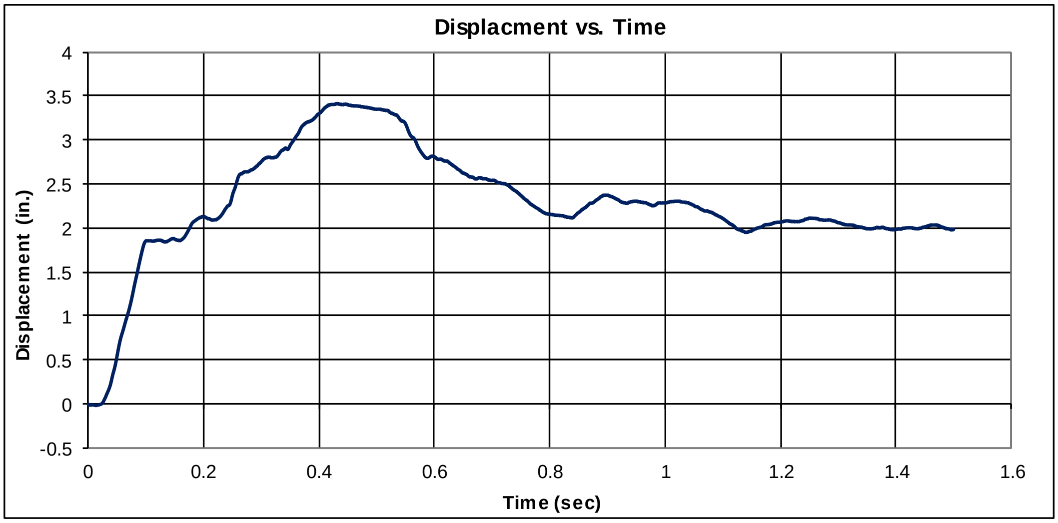


Figure G-4. String Potentiometer Data, Upstream Cable Anchorage, Test No. MGSLS-1

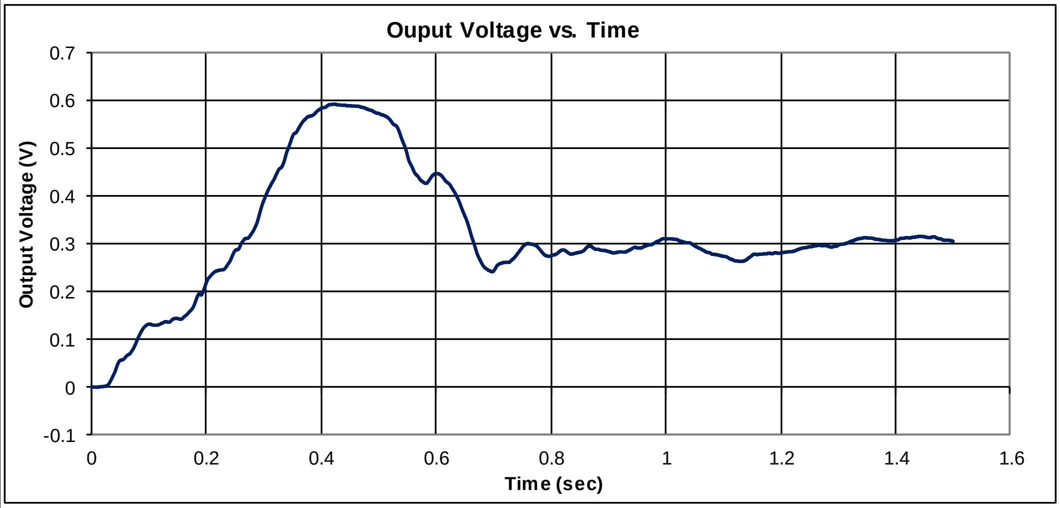
MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

Test Information:

Test No:	MGSLS-1
Date:	5/18/2015
System / Test Article:	MGS Long Span - 31.25 ft
SP Location / Component:	Downstream Cable Anchorage
Additional Notes:	

String Potentiometer Information:		**Results:**	
String Pot No.:	27039202	Max. Displacement:	3.05 in.
Calibration Factor:	19.448 mV/V/in.	Time of Max. Displacement:	0.4235 sec
Input Voltage (excitation):	9.99 Volts	Event Duration:	1.5 sec
Gain:	1	Final Displacement:	1.57 in.
Full Scale Load:	1		
Sample Rate:	10000 Hz		
Cutoff Frequency:	100 Hz		



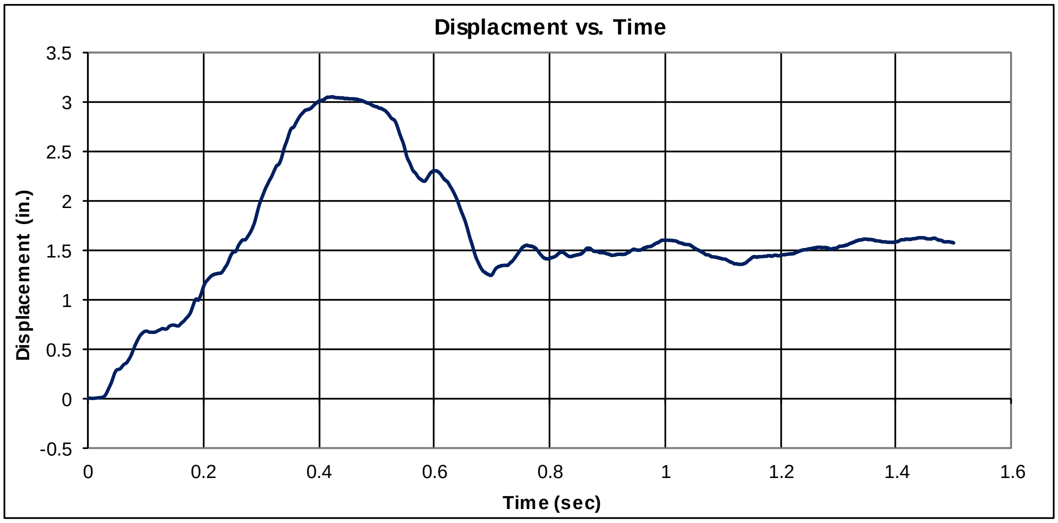


Figure G-5. String Potentiometer Data, Downstream Cable Anchorage, Test No. MGSLS-1

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

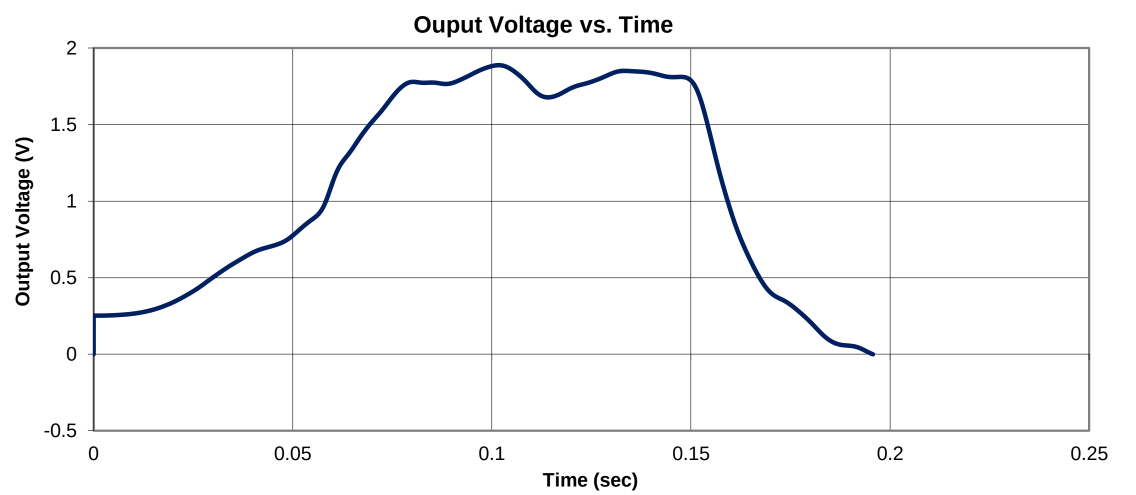
Test No:	MGSLS-2
Date:	6/30/2015
System / Test Article:	MGS Long Span - 31.25 ft
LC Location / Component:	Upstream Cable Anchorage
Additional Notes:	Downstream cable anchor failed during vehicle redirection

Load Cell Information:

Load Cell No.:	PCB - 1379	
Calibration Factor:	0.0645	mv/V
Input Voltage (excitation):	NA	Volts
Gain:	NA	
Full Scale Load:	80	kips
Sample Rate:	10000	Hz
Cutoff Frequency:	100	Hz

Results:

Preload:	0	kips
Max. Load:	29.28	kips
Time of Max. Load:	0.1017	sec
Event Duration:	0.1957	sec
Final Load:	0.00	kips



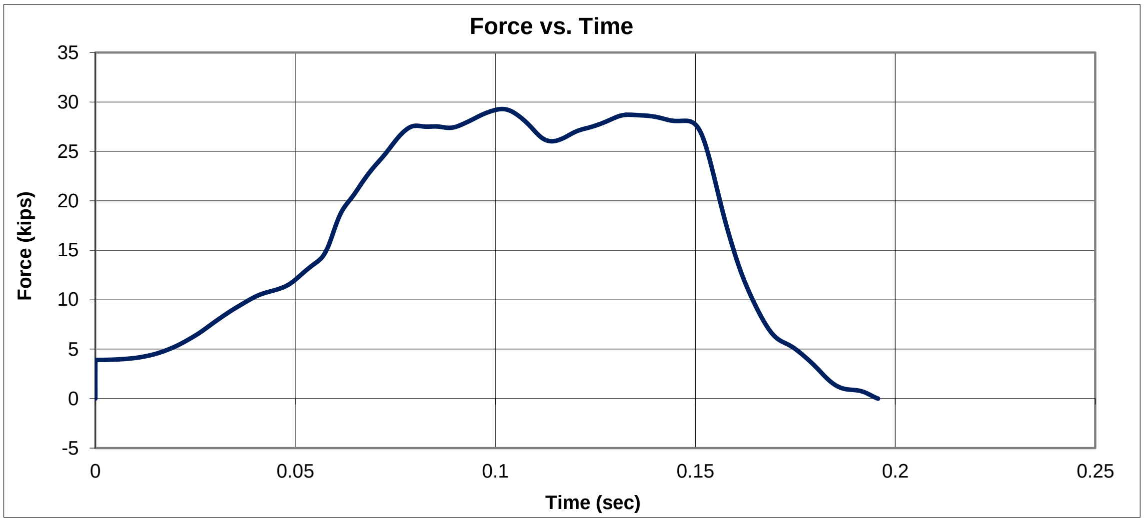


Figure G-6. Load Cell Data, Upstream Cable Anchorage No. 1, Test No. MGSLS-2

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

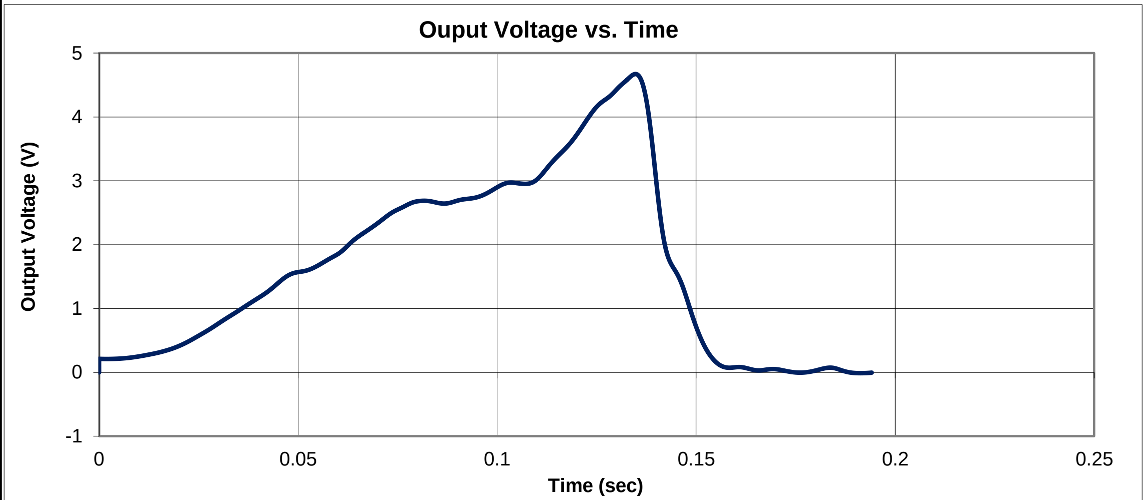
Test No:	MGSLS-2
Date:	6/30/2015
System / Test Article:	MGS Extended Long Span
LC Location / Component:	Downstream Cable Anchor
Additional Notes:	Downstream cable anchor failed during vehicle redirection

Load Cell Information:

Load Cell No.:	120624
Calibration Factor:	2.11878 mv/V
Input Voltage (excitation):	10.01 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	27.54 kips
Time of Max. Load:	0.1348 sec
Event Duration:	0.1941 sec
Final Load:	-0.03 kips



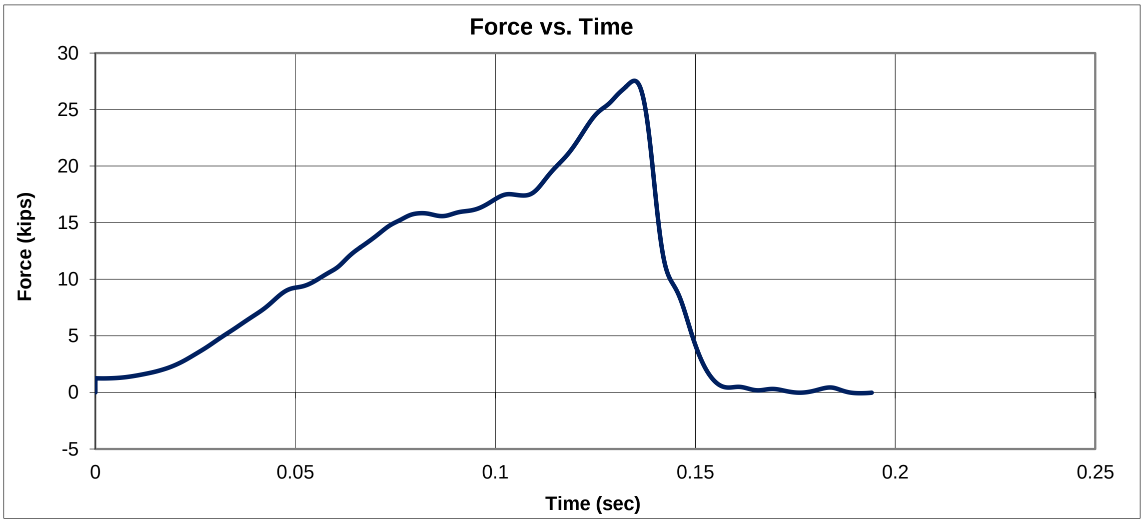


Figure G-7. Load Cell Data, Downstream Cable Anchorage, Test No. MGSLS-2

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

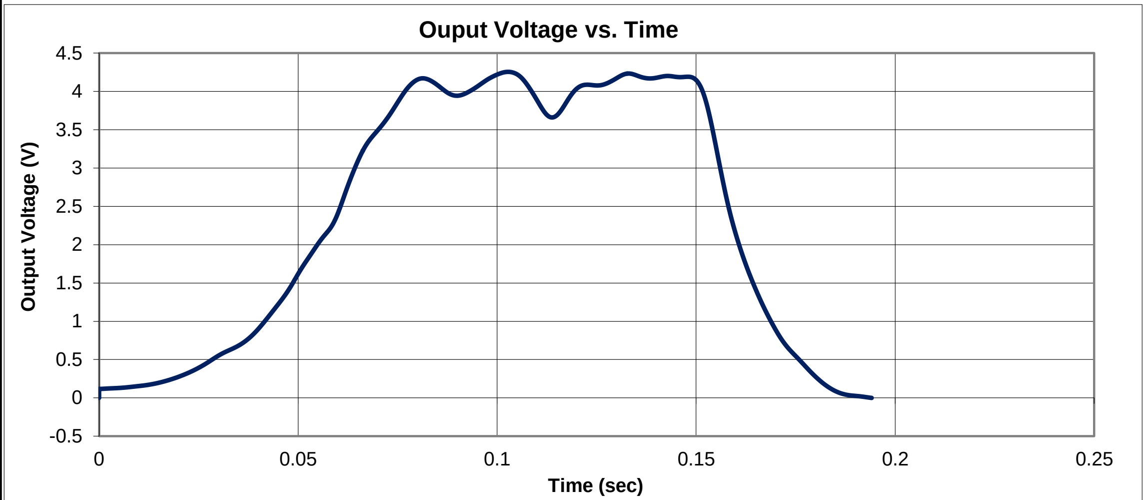
Test No:	MGSLS-2
Date:	6/30/2015
System / Test Article:	MGS Extended Long Span
LC Location / Component:	Upstream Cable Anchor
Additional Notes:	Downstream cable anchor failed during vehicle redirection

Load Cell Information:

Load Cell No.:	241593
Calibration Factor:	2.14857 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	24.76 kips
Time of Max. Load:	0.1028 sec
Event Duration:	0.1941 sec
Final Load:	0.00 kips



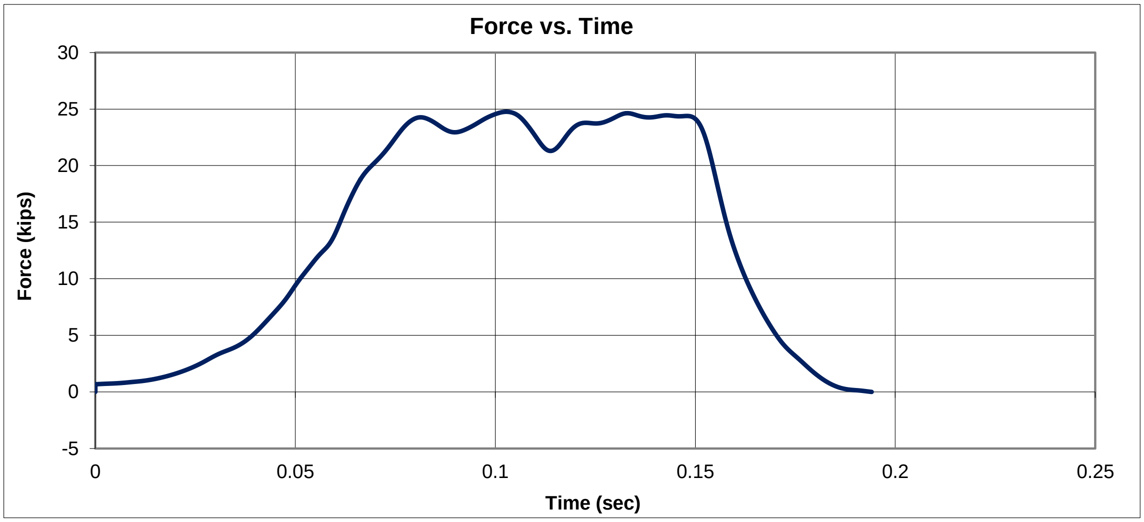


Figure G-8. Load Cell Data, Upstream Cable Anchorage, No. 2, Test No. MGSLS-2

MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

Test Information:

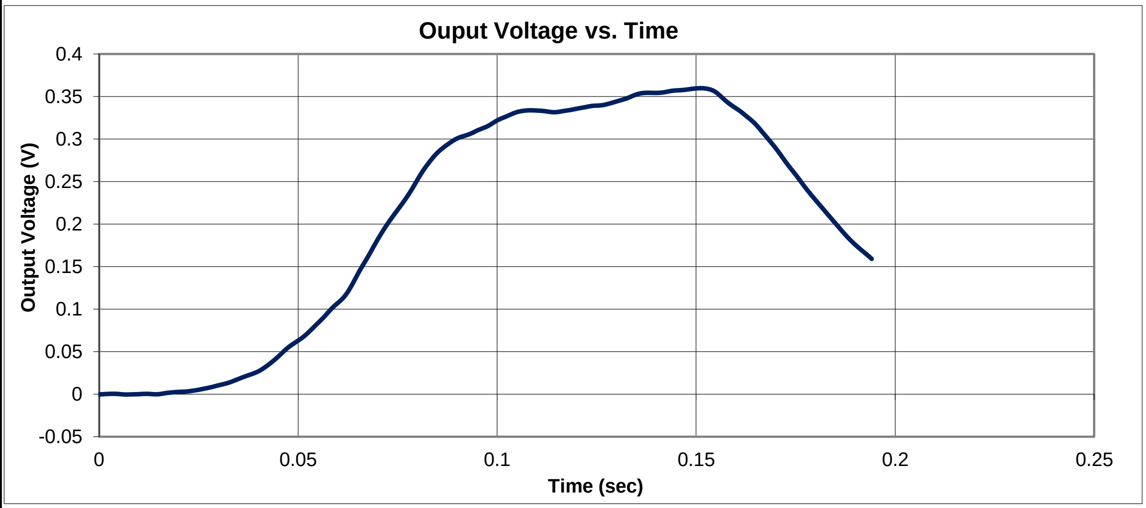
Test No:	MGSLS-2
Date:	6/30/2015
System / Test Article:	MGS Long Span - 31.25 ft
SP Location / Component:	Upstream Cable Anchorage
Additional Notes:	Downstream cable anchor failed during vehicle redirection

String Potentiometer Information:

String Pot No.:	27039203	
Calibration Factor:	19.4	mV/V/in.
Input Voltage (excitation):	10.01	Volts
Gain:	1	
Full Scale Load:	1	
Sample Rate:	10000	Hz
Cutoff Frequency:	100	Hz

Results:

Max. Displacement:	1.85	in.
Time of Max. Displacement:	0.1512	sec
Event Duration:	0.1941	sec
Final Displacement:	0.82	in.



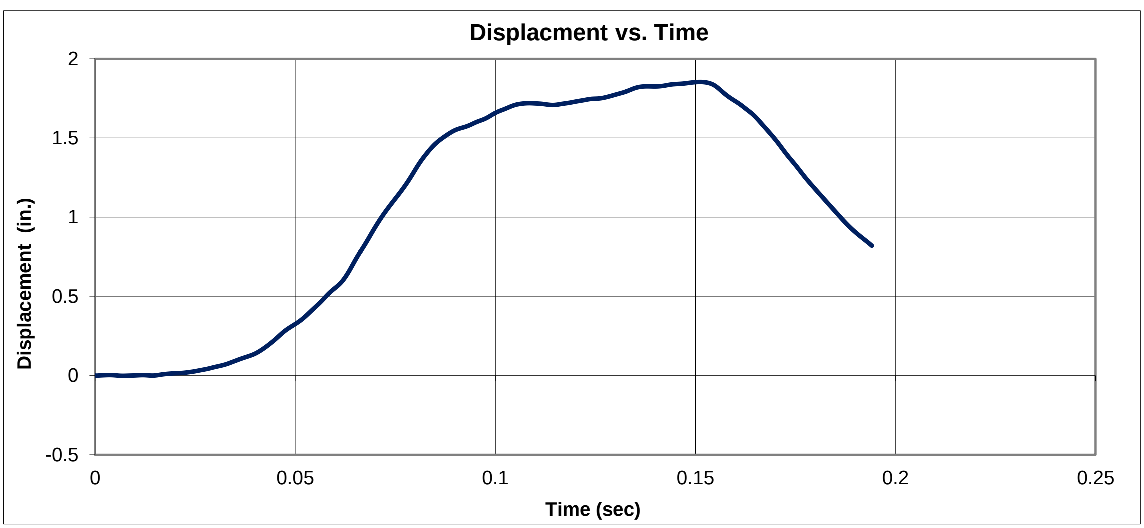


Figure G-9. String Potentiometer Data, Upstream Cable Anchorage, Test No. MGSLS-2

MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

Test Information:

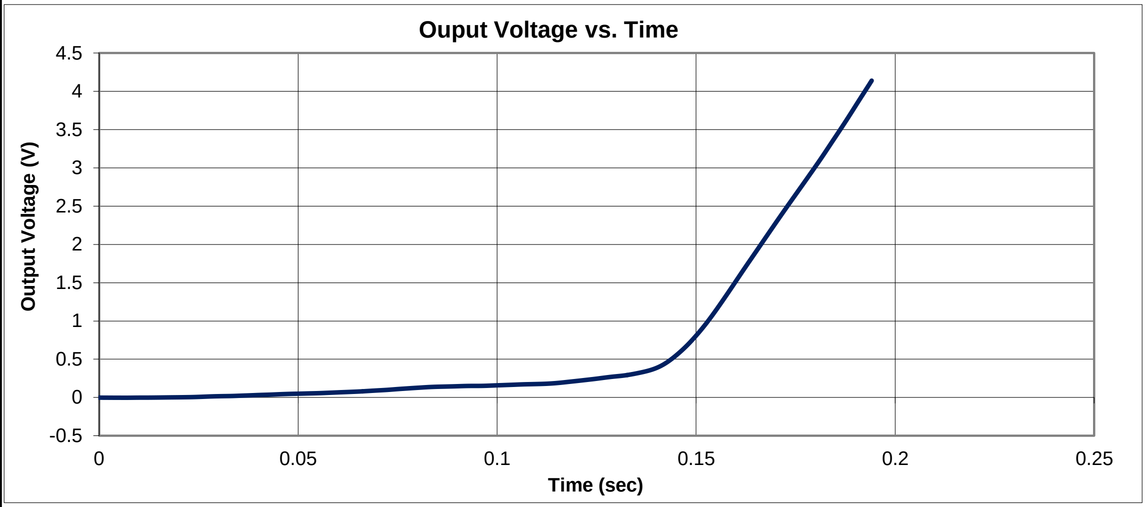
Test No:	MGSLS-2
Date:	6/30/2015
System / Test Article:	MGS Long Span - 31.25 ft
SP Location / Component:	Downstream Cable Anchorage
Additional Notes:	Downstream cable anchor failed during vehicle redirection

String Potentiometer Information:

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

Results:

Max. Displacement:	21.29	in.
Time of Max. Displacement:	0.1941	sec
Event Duration:	0.1941	sec
Final Displacement:	21.29	in.



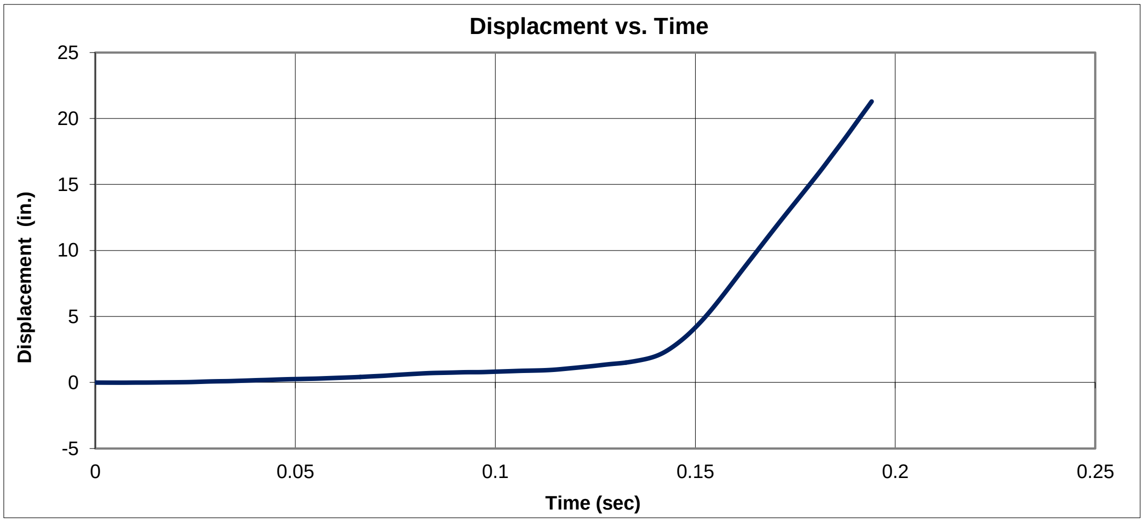


Figure G-10. String Potentiometer Data, Downstream Cable Anchorage, Test No. MGSLS-2

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