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DEVELOPMENT OF A PCB STEEL COVER PLATE FOR LARGE OPEN JOINTS – PHASE II

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Portable concrete barriers (PCBs) are commonly used to protect work-zone personnel and to shield motorists from hazards in construction areas. It is not uncommon to encounter longitudinal gaps within PCB installations due to the practice of constructing and connecting the barriers from different ends during setup or contractor operations. Longitudinal gaps can also be created due to tensioning issues following an impact event. These gaps can range from 6 in. (152 mm) to a full barrier segment length of 12.5 ft (3.8 m). Longitudinal gaps between adjacent installations of PCB systems pose a serious safety concern for the errant motorist.
The objective of this research study was to develop a treatment for shielding the longitudinal gaps that occur between adjacent installations of PCB systems. The research conducted in this Phase II effort focused on the evaluation of the stiffened, thrie-beam, gap-spanning, hardware that was developed in the Phase I research effort. A test installation composed of 15 PCBs with a longitudinal gap between the eighth and ninth barriers was selected, and full-scale crash testing was conducted on the gap-spanning hardware. Test nos. GSH-1 and GSH-2 were conducted to Manual for Assessing Safety Hardware 2016 (MASH 2016) test designation no. 3-11 in order to evaluate the thrie-beam, gap-spanning hardware of the PCB system. The tests were selected to evaluate the length of need of the system, as well as the transition from the gap-spanning hardware to the PCBs. In both tests, the 2270P vehicle was contained and safely redirected. Recommendations were also provided for system implementation and future installation and are detailed within the report.</td></tr>
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DISCLAIMER STATEMENT

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UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Dr. John Reid, Professor.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

Portable concrete barriers (PCBs) are commonly used to protect work-zone personnel and to shield motorists from hazards in construction areas. It is not uncommon to encounter longitudinal gaps within PCB installations due to the practice of constructing and connecting the barriers from different ends during setup or contractor operations. Longitudinal gaps can also be created during re-tensioning issues following an impact event. These gaps can range from 6 in. (152 mm) to a full barrier segment length of 12.5 ft (3.8 m) and pose a serious safety concern for an errant motorist. Limited guidance is available for shielding this hazardous situation. Past recommendations have been to overlap two runs of barriers to prevent a longitudinal gap in PCB coverage from occurring. However, this method is undesirable due to work-zone space constraints. The necessary length of barrier overlap is relatively large and also requires significant lateral offset between the overlapped segments, which reduces available space in constricted work zones. Thus, a need existed to develop a crashworthy and efficient method for treating longitudinal gaps in adjacent runs of free-standing PCBs.

The Midwest Pooled Fund Program sponsored the Phase I effort to develop potential design concepts to safeguard the variable gaps that occur between adjacent PCB installations [1]. The initial phase of the research program included a literature review of existing PCB gap treatments and the brainstorming of potential crashworthy systems capable of accommodating variable gap lengths. LS-DYNA simulations were then conducted on the potential design concepts. The preferred Phase I design concept was recommended for full-scale crash testing to evaluate its effectiveness for the treatment of longitudinal PCB gaps.

The preferred PCB gap-spanning hardware design comprised two nested thrie-beam guardrail sections attached to the front and back sides of the PCBs adjacent to the longitudinal gap. The nested thrie-beam guardrail sections were attached to the PCBs with thrie-beam terminal connectors using wedge bolt anchors. Steel lateral stiffeners were developed that could be inserted between the parallel guardrail sections in order to strengthen the rails when longer gap lengths were encountered. The number of stiffeners installed between the thrie-beam guardrails could be adjusted depending on the length of the longitudinal gap. To minimize wheel snag during impacts with the system, steel toe plates were configured to span across the longitudinal gap and were anchored to the lower concrete sloped surface of the PCBs. The Phase I research also identified critical impact points for the proposed design concept, however, no funding was allocated for the full-scale crash testing and evaluation of the proposed design concept during the initial phase of the research program. Thus, a need remained to full-scale crash test and evaluate the new system according to the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [2] Test Level 3 (TL-3) safety performance criteria.

1.2 Objective

The objective of the Phase I research effort was to develop a crashworthy prototype system for protecting and shielding the longitudinal gaps between adjacent installations of PCB systems, which vary between 6 in. (152 mm) and 12.5 ft. (3.8 m) in length. Phase II research focused on the evaluation of the stiffened, thrie-beam, PCB gap-spanning hardware that was developed in Phase

I. The system was evaluated according to the TL-3 criteria set forth in MASH 2016. Two full-scale vehicle crash tests were conducted according to MASH 2016 test designation no. 3-11. Recommendations for the implementation and installation of the gap-spanning hardware were provided.

1.3 Scope

The overall research objectives were accomplished through two phases and a series of several tasks. The Phase I research effort began with a literature search to review existing designs and guidance regarding the treatment of longitudinal gaps between adjacent installations of PCB systems. Next, new ideas were brainstormed to identify potential designs for spanning the PCB gaps. A design utilizing a section of stiffened, thrie-beam guardrail was selected as the preferred design concept due to the simplicity and versatility of the design, as well as the use of existing hardware. LS-DYNA computer simulation was used to evaluate and refine the preferred design concept, as well as to estimate the expected impact loads and determine the critical impact points for the full-scale crash testing of the system.

The Phase II research effort detailed herein evaluated the performance of the PCB gap-spanning hardware through full-scale vehicle crash testing. Two full-scale crash tests were conducted under MASH 2016 test designation no. 3-11 on the stiffened, thrie-beam, PCB gap-spanning hardware: the first full-scale crash test evaluated the structural capacity of the gap-spanning hardware, and the second full-scale crash test evaluated the potential for vehicle instability at the overlap of the gap-spanning hardware and the PCBs. Following the completion of full-scale crash testing and evaluation of the barrier's performance, recommendations for implementation and installation of the PCB gap-spanning hardware were made.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Roadside hardware systems, such as the PCB gap spanning hardware evaluated herein, must satisfy impact safety standards 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 2016 [2]. The PCB gap spanning hardware evaluated in this report functions primarily longitudinal barrier. According to TL-3 of MASH 2016, longitudinal barrier systems and their transitions must be subjected to two full-scale vehicle crash tests, as summarized in Table 1. Note that there is no difference between MASH 2009 [3] and MASH 2016 for longitudinal barriers such as the system tested in this project, except that additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016.

Table 1. MASH 2016 TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Barrier Section	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
					Speed, mph (km/h)	Angle, degrees	
Longitudinal Barrier	Length-of-Need	3-10	1100C	2,425 (1,100)	62 (100.0)	25	A,D,F,H,I
		3-11	2270P	5,000 (2,270)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

It should be noted that the MASH 2016 test matrix detailed herein represents the recommended crash tests that should be performed. However, some of these crash tests may be deemed non-critical and unnecessary. For the PCB gap spanning hardware system evaluated herein, the 1100C vehicle test, test designation no. 3-10, was deemed non-critical for evaluation of the barrier system. Previous testing of PCBs and safety shape barriers has indicated that small cars interact in a safe manner with this type of roadside hardware. In test no. 2214NJ-1, a MASH test designation no. 3-10 full-scale crash test was successfully conducted on a permanent New Jersey shape concrete parapet under NCHRP Project 22-14(2) [4]. In Texas A&M Transportation Institute (TTI) test report no. 607911-1&2, a MASH test designation no. 3-10 full-scale crash test was successfully conducted on a free-standing F-shape PCB similar to the barrier used in this study [5]. These two tests indicate that safety shape barriers are capable of successfully capturing and redirecting a 1100C vehicle in both free-standing PCB and permanent concrete parapet applications. Additionally, the increased toe height of New Jersey shape barriers tends to produce increased vehicle climb and instability as compared to the F-shape geometry. Thus, one would expect that the PCB gap-spanning hardware with similar geometry evaluated in this study would perform similarly to these previous MASH 1100C vehicle tests in terms of capture and redirection, and the 1100C vehicle would not be critical for structural loading of the hardware. As such, it was believed that test designation no. 3-10 with the 1100C vehicle would be non-critical for evaluation of the tie-down anchorages for use with F-shape PCBs. MASH 2016 test designation no. 3-11 was the more critical evaluation test due to concerns for increased barrier loading during 2270P impacts and to determine dynamic deflection and working width. Thus, only test designation no. 3-11 was conducted on the PCB gap-spanning hardware evaluated herein. It should be noted that any tests deemed non-critical and unnecessary may eventually need to be performed if additional knowledge gained over time or revisions to the MASH 2016 criteria demonstrates a concern or need.

During the development of the PCB gap-spanning hardware in Phase I, an analysis was performed on the critical impact points (CIPs) for the system. This analysis found that there were two CIPs for the PCB gap-spanning hardware. One CIP was chosen to maximize structural loading of the barrier system, and a second was selected to maximize the potential for vehicle instability. Note that snag of impacting vehicles was considered and evaluated in the CIP analysis. However, the analysis demonstrated that vehicle snag was not a critical behavior due the use of the thrie beam rail and toe plate elements that connect the system to the PCB segments, and any vehicle snag that was observed in the simulation analysis of potential CIPs was less of a concern than the structural loading and vehicle stability CIPs that were identified. Full details on the CIP analysis are provided in the Phase I report [1]. The two identified CIPs were as follows:

1. Analysis of the barrier system with the largest possible barrier gap of 12.5 ft (3.81 m) identified that the structural loading of the PCB gap-spanning hardware was the greatest when the system was impacted 72 in. (1,829 mm) upstream from the first PCB segment on the downstream end of the gap-spanning hardware.

2. Analysis of the barrier system with a small barrier gap of 3 ft (0.91 m) identified the potential for the 2270P vehicle’s front wheel and tire to be held down by the thrie beam rail element spanning the PCB gap when the hardware was impacted where it overlapped the adjacent PCB segments. This behavior tended to induce significant roll motions in the 2270P vehicle, which raised concerns for potential vehicle instability. As such, a second CIP was selected to be 12 in. (305 mm) downstream from the upstream end of the first PCB segment on the downstream end of the gap-spanning hardware.

Based on this CIP analysis, two full-scale crash tests were conducted under MASH test designation no. 3-11 impact conditions. The first test was conducted to evaluate the maximum structural loading of the PCB gap-spanning hardware, and the second test was conducted to evaluate potential vehicle instability.

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 PCB system and gap-spanning hardware 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 2016 [2]. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in MASH 2016.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), the Acceleration Severity Index (ASI), and exit box criteria were determined and reported. Additional discussion on PHD, THIV and ASI is provided in MASH 2016.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barriers

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="9">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

3 TEST CONDITIONS

3.1 Test Facility

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

3.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [6] 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. GSH-1, a 2011 Dodge Ram 1500 Quad Cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 4,984 lb (2,261 kg), 5,005 lb (2,270 kg), and 5,165 lb (2,343 kg), respectively. The test vehicle is shown in Figures 1 and 2, and vehicle dimensions are shown in Figure 3. Note that in Figure 3, vehicle dimension A is out of compliance by ¼ in. (6 mm). The ¼-in. (6-mm) deviation was deemed non-critical to the outcome of the test and, as the vehicle was of acceptable year and model according to MASH 2016, was utilized in the evaluation of the test installation.

For test no. GSH-2, a 2013 Dodge Ram 1500 Quad Cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,196 lb (2,357 kg), 5,013 lb (2,274 kg), and 5,173 lb (2,346 kg), respectively. The test vehicle is shown in Figures 4 and 5, and vehicle dimensions are shown in Figure 6. Note that in Figure 6, vehicle dimension M is out of compliance by ¼ in. (6 mm). The ¼-in. (6-mm) deviation was deemed non-critical to the outcome of the test and, as the vehicle was of acceptable year and model according to MASH 2016, was utilized in the evaluation of the test installation.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [7] was used to determine the vertical component of the c.g. for the pickup trucks. 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 vehicles were suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The location of the final c.g. is shown in Figures 3 and 7 for test no. GSH-1 and Figures

6 and 8 for test no. GSH-2. Data used to calculate the location of the c.g. and ballast information are shown in Appendix A.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 7 and 8 for test nos. GSH-1 and GSH-2, respectively. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

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

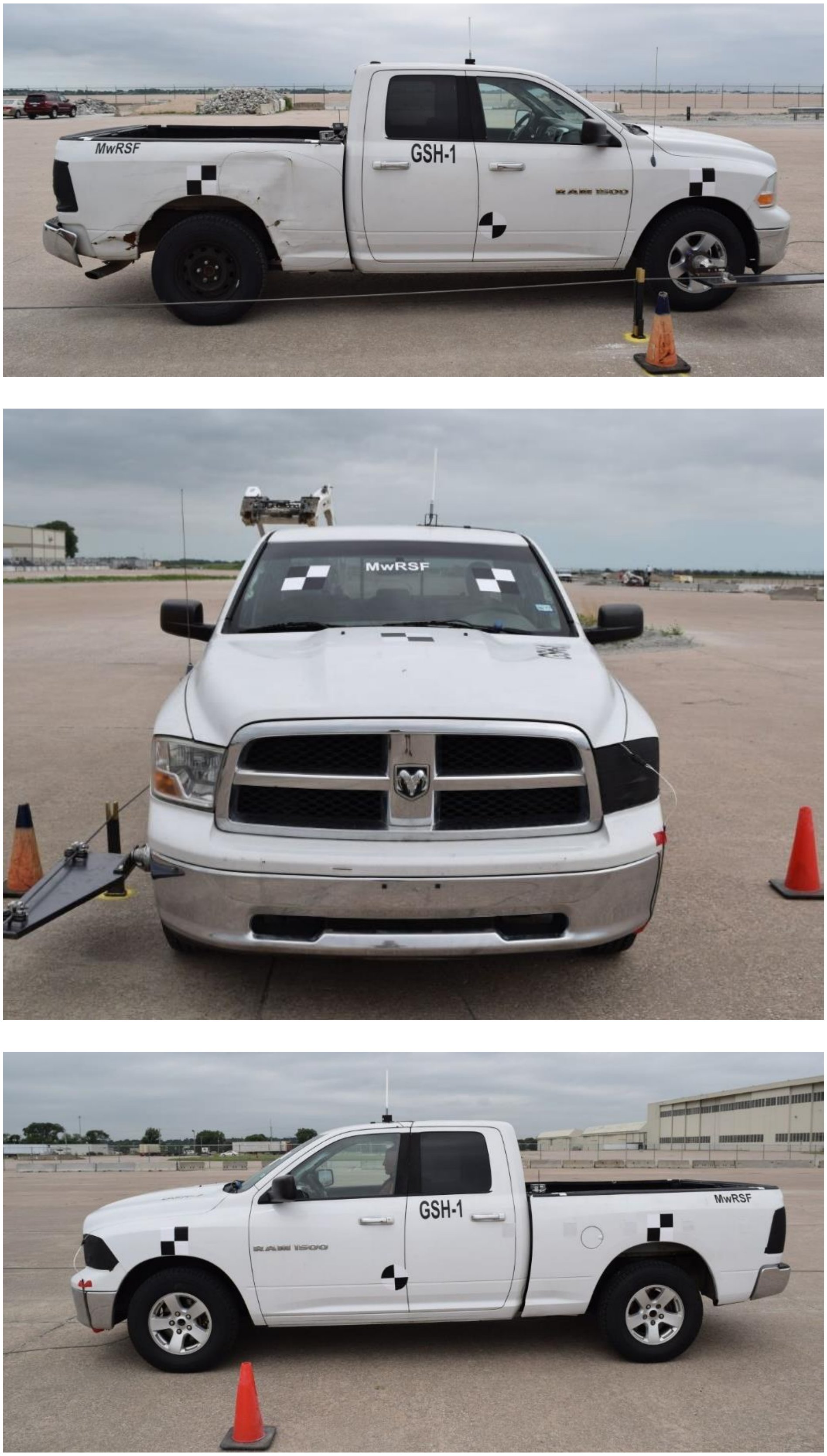


Figure 1. Test Vehicle, Test No. GSH-1

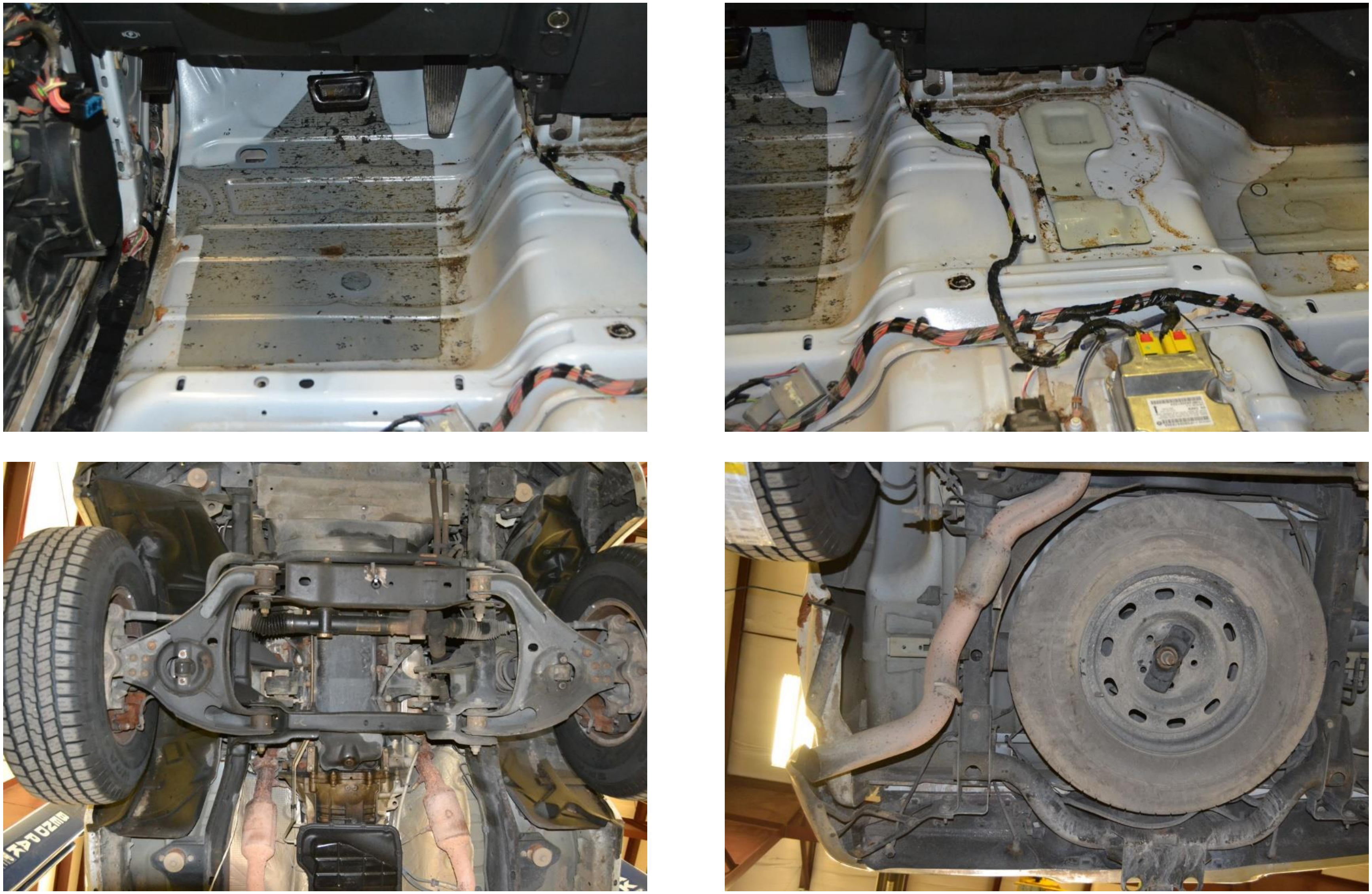
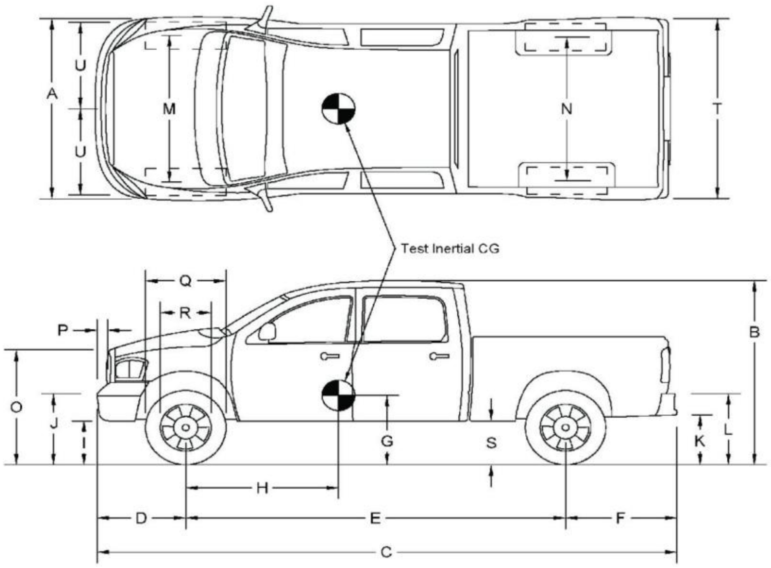


Figure 2. Test Vehicle’s Interior Floorboards and Undercarriage, Test No. GSH-1

Date:	6/28/2018	Test Name:	GSH-1	VIN No:	1D7RB1GP6BS553873
Year:	2011	Make:	Dodge	Model:	Ram 1500 Quad Cab
Tire Size:	p265/70R17	Tire Inflation Pressure:	37 Psi	Odometer:	260114



Vehicle Geometry - in. (mm)
Target Ranges listed below

A:	75 3/4	(1924)	B:	74 1/2	(1892)
	78±2 (1950±50)				
C:	229 1/2	(5829)	D:	38	(965)
	237±13 (6020±325)			39±3 (1000±75)	
E:	140 1/2	(3569)	F:	48 1/2	(1232)
	148±12 (3760±300)				
G:	28 1/16	(713)	H:	62	(1575)
	min: 28 (710)			63±4 (1575±100)	
I:	8 1/4	(210)	J:	26 3/4	(679)
K:	20	(508)	L:	29 1/8	(740)
M:	67 5/8	(1718)	N:	67 5/8	(1718)
	67±1.5 (1700±38)			67±1.5 (1700±38)	
O:	44 5/8	(1133)	P:	5	(127)
	43±4 (1100±75)				
Q:	31 1/8	(791)	R:	18 1/4	(464)
S:	13 1/2	(343)	T:	76 1/4	(1937)

U (impact width): 75 1/4 (1911)

Mass Distribution lb. (kg)

Gross Static	LF	1486 (674)	RF	1403 (636)
	LR	1112 (504)	RR	1164 (528)

Wheel Center Height (Front):	15	(381)
Wheel Center Height (Rear):	15 1/2	(394)
Wheel Well Clearance (Front):	35 3/4	(908)
Wheel Well Clearance (Rear):	38 3/8	(975)
Bottom Frame Height (Front):	12 1/2	(318)
Bottom Frame Height (Rear):	13 1/4	(337)
Engine Type:	Gasoline	
Engine Size:	4.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	
Cab Style:	Quad Cab	
Bed Length:	76"	

Weights lb. (kg)	Curb	Test Inertial	Gross Static
W-front	2852 (1294)	2796 (1268)	2889 (1310)
W-rear	2132 (967)	2209 (1002)	2276 (1032)
W-total	4984 (2261)	5005 (2270)	5165 (2343)
		5000±110 (2270±50)	5165±110 (2343±50)

GVWR Ratings lb.	
Front	3700
Rear	3900
Total	6700

Surrogate Occupant Data	
Type:	Hybrid II
Mass:	160 lbs
Seat Position:	Left/Driver

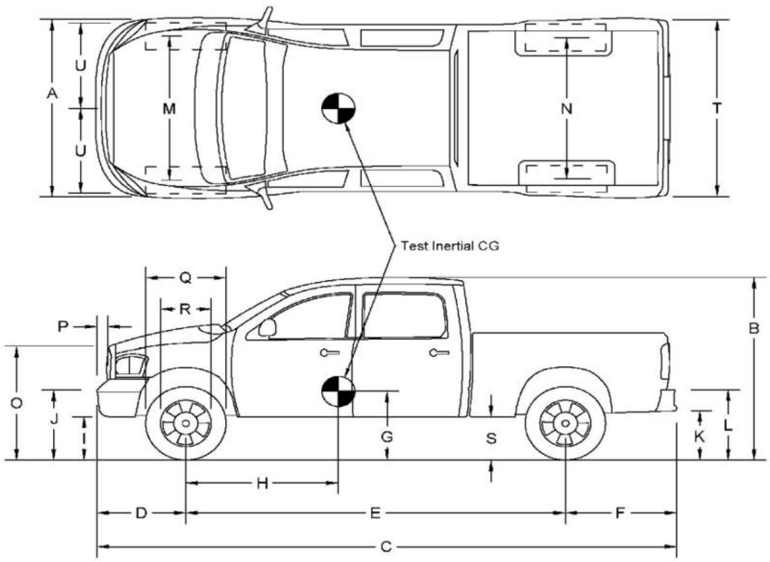
Note any damage prior to test: Right side rear bumper is bent and right side rear quarter pannel has a large dent.

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

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

Figure 5. Test Vehicle’s Interior Floorboards and Undercarriage, Test No. GSH-2

Date:	7/27/2018	Test Name:	GSH-2	VIN No:	1CRR6FTXDS575838
Year:	2013	Make:	Dodge	Model:	Ram 1500
Tire Size:	P275/60R20	Tire Inflation Pressure:	39 Psi	Odometer:	147820



Vehicle Geometry - in. (mm)
Target Ranges listed below

A:	76 3/4 (1949) 78±2 (1950±50)	B:	75 1/2 (1918)
C:	229 1/4 (5823) 237±13 (6020±325)	D:	37 5/8 (956) 39±3 (1000±75)
E:	140 3/8 (3566) 148±12 (3760±300)	F:	48 1/4 (1226)
G:	29 1/16 (738) min: 28 (710)	H:	60 13/16 (1545) 63±4 (1575±100)
I:	13 3/8 (340)	J:	27 1/2 (699)
K:	21 1/2 (546)	L:	30 1/2 (775)
M:	68 3/4 (1746) 67±1.5 (1700±38)	N:	68 1/8 (1730) 67±1.5 (1700±38)
O:	46 (1168) 43±4 (1100±75)	P:	4 3/8 (111)
Q:	32 1/4 (819)	R:	21 1/2 (546)
S:	15 1/8 (384)	T:	76 1/2 (1943)
		U (impact width):	72 1/4 (1835)

Mass Distribution lb. (kg)

Gross Static	LF	1477 (670)	RF	1472 (668)
	LR	1133 (514)	RR	1091 (495)

Wheel Center Height (Front):	16 (406)
Wheel Center Height (Rear):	16 (406)
Wheel Well Clearance (Front):	36 3/4 (933)
Wheel Well Clearance (Rear):	39 3/8 (1000)
Bottom Frame Height (Front):	11 (279)
Bottom Frame Height (Rear):	11 1/2 (292)
Engine Type:	Gasoline
Engine Size:	4.7L V8
Transmission Type:	Automatic
Drive Type:	RWD
Cab Style:	Quad cab
Bed Length:	76"

Weights lb. (kg)	Curb	Test Inertial	Gross Static
W-front	2922 (1325)	2842 (1289)	2949 (1338)
W-rear	2274 (1031)	2171 (985)	2224 (1009)
W-total	5196 (2357)	5013 (2274) 5000±110 (2270±50)	5173 (2346) 5165±110 (2343±50)

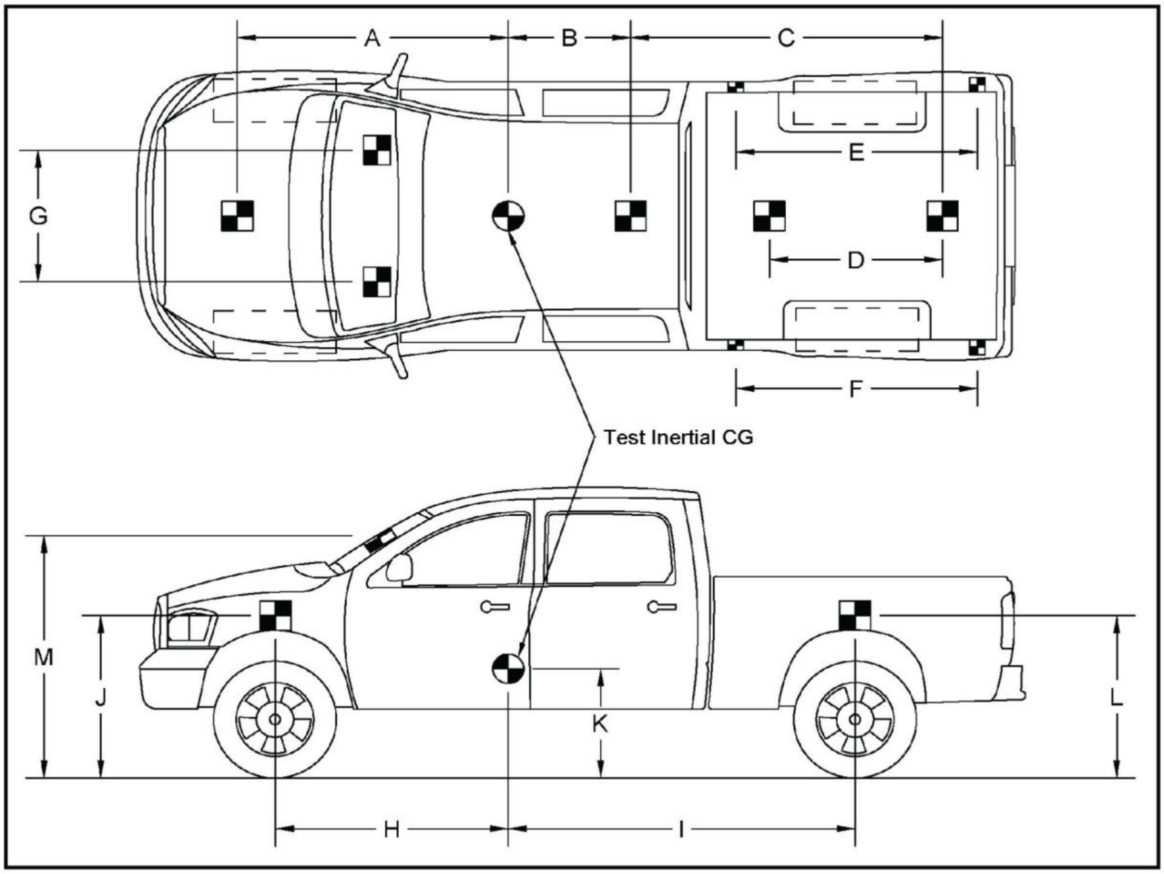
GVWR Ratings lb.	
Front	3700
Rear	3900
Total	6700

Surrogate Occupant Data	
Type:	Hybrid II
Mass:	160 lbs.
Seat Position:	Left/Driver

Note any damage prior to test:

Figure 6. Vehicle Dimensions, Test No. GSH-2

Date:	6/28/2018	Test Name:	GSH-1	VIN:	1D7RB1GP6BS553873
Year:	2011	Make:	Dodge	Model:	Ram 1500 Quad Cab

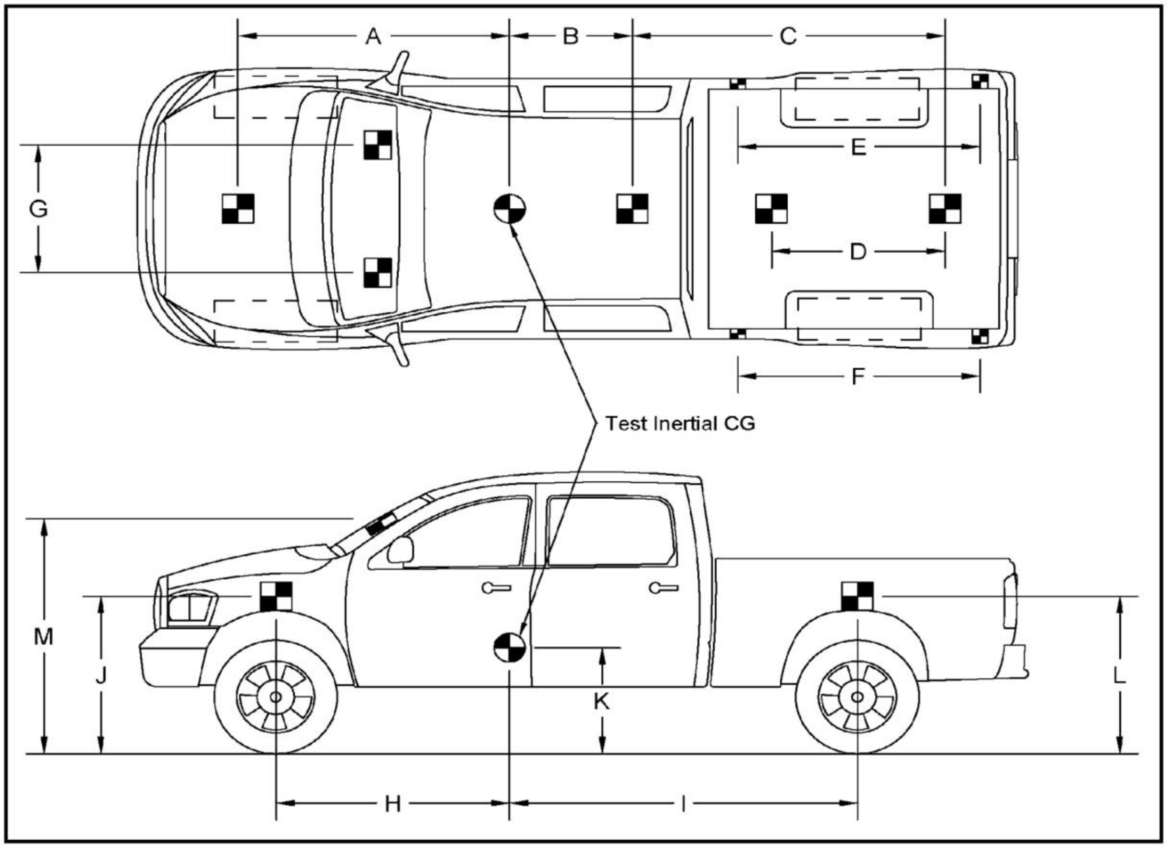


TARGET GEOMETRY-- in. (mm)

A:	65 3/4	(1670)	E:	63 3/8	(1610)	J:	39 3/8	(1000)
B:	28 5/8	(727)	F:	63 3/8	(1610)	K:	28	(711)
C:	101	(2565)	G:	36 1/4	(921)	L:	41 3/4	(1060)
D:	42 3/8	(1076)	H:	62	(1575)	M:	62 3/4	(1594)
			I:	78 1/2	(1994)			

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

Date:	7/27/2018	Test Name:	GSH-2	VIN:	1CRR6FTXDS575838
Year:	2013	Make:	Dodge	Model:	Ram 1500



TARGET GEOMETRY-- in. (mm)

A:	65 7/8	(1673)	E:	63 3/8	(1610)	J:	40 5/8	(1032)
B:	28 7/8	(733)	F:	63 9/16	(1614)	K:	29 1/4	(743)
C:	73 1/8	(1857)	G:	37	(940)	L:	43 1/8	(1095)
D:	40 5/8	(1032)	H:	60 13/16	(1545)	M:	64	(1626)
			I:	79 5/8	(2022)			

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

3.4 Simulated Occupant

For test nos. GSH-1 and GSH-2, a Hybrid II 50th-Percentile, Adult Male Dummy was placed in the left-front seat of the test vehicles with the seat belt fastened. The simulated occupant had a final weight of 160 lb (73 kg) in test nos. GSH-1 and GSH-2. As recommended by MASH 2016, the simulated occupant was not included in calculating the c.g. location.

3.5 Data Acquisition Systems

3.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometer systems were mounted near the c.g. of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [8].

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

3.5.2 Rate Transducers

Two identical angular 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.

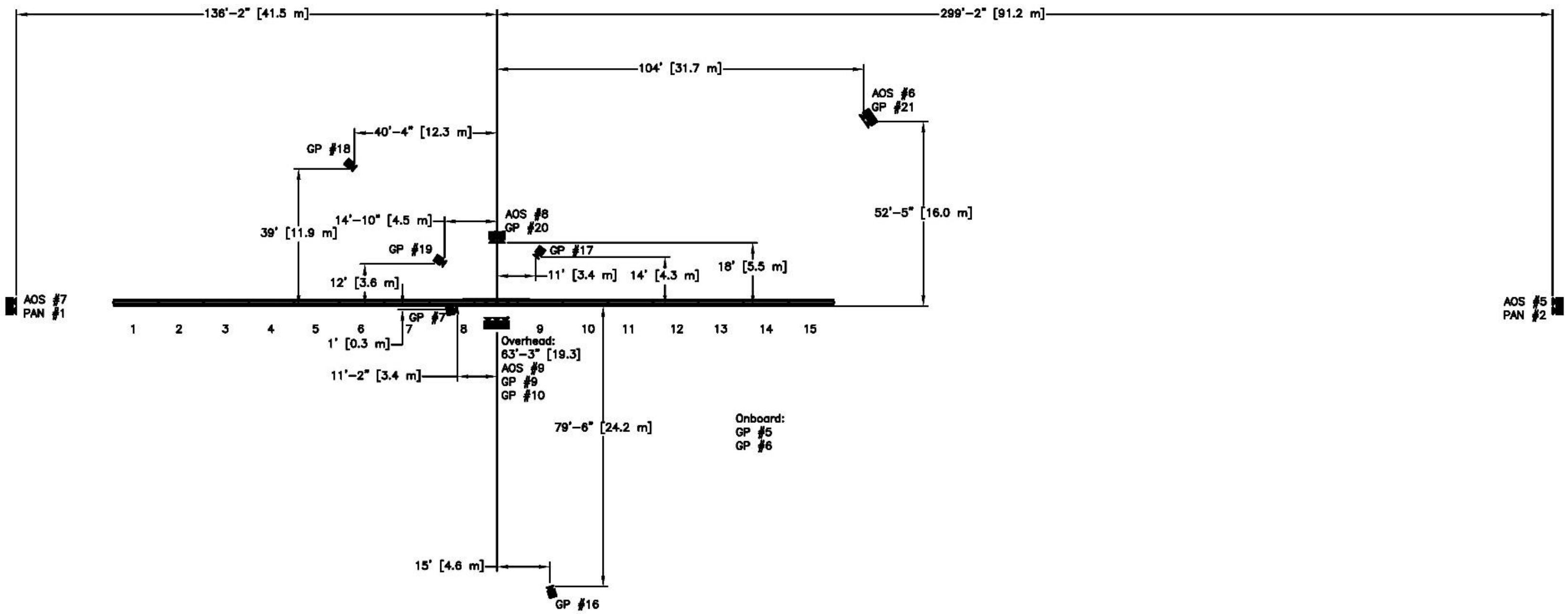
3.5.3 Retroreflective Optic Speed Trap

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 Digital Photography

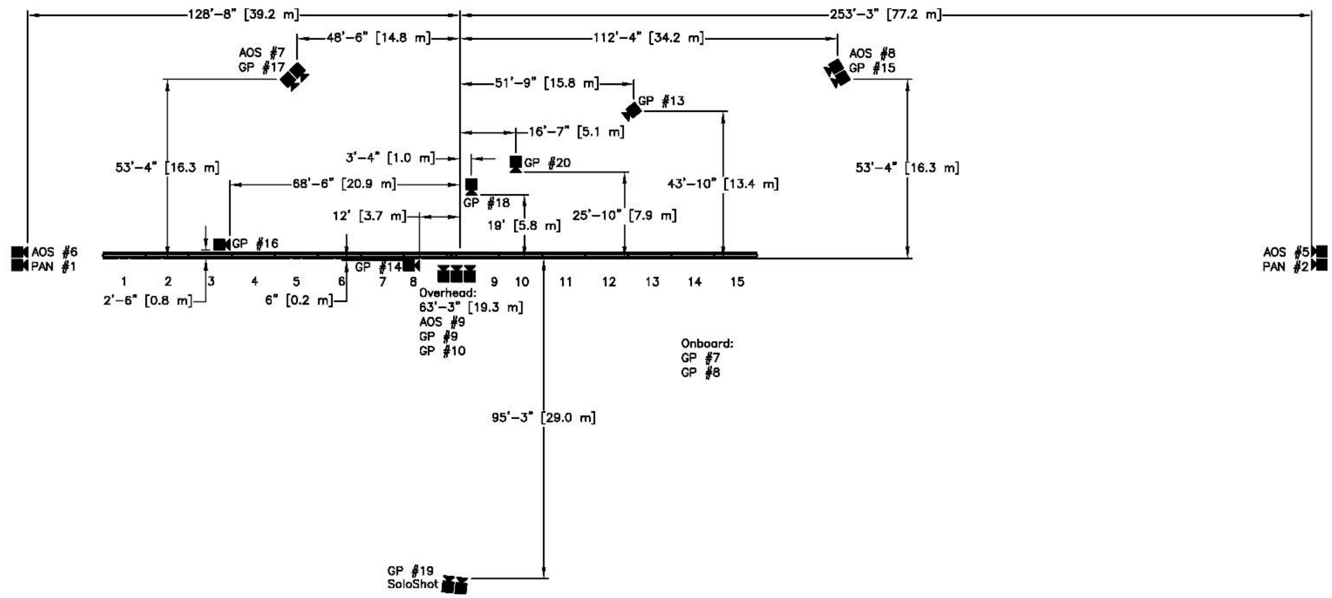
Five AOS high-speed digital video cameras, eleven GoPro digital video cameras, and two Panasonic digital video cameras were utilized to film test no. GSH-1. Five AOS high-speed digital video cameras, eleven GoPro digital video cameras, two Panasonic digital video cameras, and one SoloShot camera was utilized to film test no. GSH-2. 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. GSH-1 and Figure 10 for test no. GSH-2.

The high-speed videos were analyzed using TEMA Motion and Redlake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A digital still camera was also used to document pre- and post-test conditions for each test.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI Gigabit	500	100 mm	
AOS-6	AOS X-PRI Gigabit	500	Fujinon 75 mm	
AOS-7	AOS X-PRI Gigabit	500	Fujinon 50 mm Fixed	
AOS-8	AOS S-VIT 1531	500	Kowa 16 mm	
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12 mm Fixed	
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	30		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	120		
GP-16	GoPro Hero 4	120		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 6	120		
GP-19	GoPro Hero 6	120		
GP-20	GoPro Hero 6	120		
GP-21	GoPro Hero 6	120		
PAN-1	Panasonic HC-V770	60		
PAN-2	Panasonic HC-V770	60		

Figure 9. Camera Locations, Speeds, and Lens Settings, Test No. GSH-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI Gigabit	500	100 mm Fixed	
AOS-6	AOS X-PRI Gigabit	500	Cosmicar 50 mm Fixed	
AOS-7	AOS X-PRI Gigabit	500	Kowa 25 mm Fixed	
AOS-8	AOS S-VIT 1531	500	Fujinon 50 mm Fixed	
AOS-9	AOS TRI-VIT 2236	1,000	Kowa 12 mm fixed	
GP-7	GoPro Hero 4	240		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	120		
GP-13	GoPro Hero 4	60		
GP-14	GoPro Hero 4	240		
GP-15	GoPro Hero 4	240		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	240		
GP-18	GoPro Hero 6	120		
GP-19	GoPro Hero 6	120		
GP-19	GoPro Hero 6	120		
PAN-1	Panasonic HC-V770	120		
PAN-2	Panasonic HC-V770	120		
SOLO	SoloShot	120		

Figure 10. Camera Locations, Speeds, and Lens Settings, Test No. GSH-2

4 DESIGN DETAILS - TEST NO. GSH-1

The barrier system test installation for test no. GSH-1 consisted of a stiffened, thrie-beam section, which spanned across a 12.5-ft (3.8-m) long gap in a series of fifteen PCBs, as shown in Figures 11 through 25. Photographs of the test installation are shown in Figures 26 through 29. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix B.

The PCB gap-spanning hardware was installed on the Midwest F-shape PCB system that has previously been evaluated to MASH TL-3 [9]. The system was composed of fifteen F-shape PCBs, each measuring 12 ft – 6 in. (3.8 m) long with a 5,000 psi (34.5 MPa) minimum concrete compressive strength. The barrier segments were connected by 1¼-in. (32-mm) diameter ASTM A36 steel pins inserted into the ¾-in. (19-mm) diameter, overlapping, reinforcing loop bars extending from the ends of the PCB sections. Details of the PCB connections are shown in Figure 13. Each barrier section was placed on top of the concrete tarmac at the Midwest Roadside Safety Facility (MwRSF) Outdoor Test Site. A 12.5-ft (3.8-m) long gap was placed between barrier nos. 8 and 9, which was covered by the stiffened, thrie-beam guardrail gap-spanning hardware.

The PCB gap-spanning hardware design comprised two nested thrie-beam guardrail sections attached to the front and back sides of the PCBs adjacent to the longitudinal gap. The nested thrie-beam guardrail sections were attached to the PCBs with thrie-beam terminal connectors using wedge bolt anchors. Three steel lateral spacers were inserted between the parallel guardrail sections reduce the unsupported span length of thrie beam panels. The number of stiffeners installed between the thrie-beam guardrails could be adjusted depending on the length of the longitudinal gap. To minimize wheel snag during impacts with the system, steel toe plates were configured to span across the longitudinal gap and were anchored to the lower concrete sloped surface of the PCBs.

The stiffened, thrie-beam guardrail section of the test installation consisted of two nested 12.5-ft (3.8-m) long segments of 12-gauge (2.7-mm) thrie-beam with 10-gauge (3.4-mm) thrie-beam terminal connectors spliced together end-to-end with ⅝-in. diameter × 2-in. long (16-mm × 51-mm) ASTM A307 Grade A guardrail bolts. The guardrail sections with terminal connectors were anchored to both the traffic and non-traffic sides of the PCBs adjacent to the gap using five ¾-in. diameter × 6-in. long (19-mm × 152-mm) Powers Fasteners galvanized wedge bolts at each end. The thrie-beam section on the traffic side of the installation was offset 5 in. (127 mm) upstream relative to the thrie-beam section on the opposite side of the barrier, as shown in Figure 13. The five thrie-beam terminal anchors could not be placed in the standard thrie beam terminal anchor locations for each end of the thrie beam panels due to interference with reinforcing steel in the PCB segments. As such, anchors were installed in alternative positions at some end terminal locations as denoted in Figures 14 and 15.

Three welded steel spacer assemblies, constructed of ¼-in. (6-mm) thick ASTM A36 steel plates, were installed between the two thrie-beam rail sections, which further increased the stiffness and strength of the barrier and gap-spanning hardware, as shown in Figure 12. Additionally, a 229-in. long × ⅝-in. thick (5,817-mm × 16-mm) ASTM A572 Grade 50 steel toe plate was bolted to the base of barrier nos. 8 and 9 on each side of the system. Each steel toe plate spanned the 12.5-ft (3.8-m) long gap and was anchored to the PCB with four ¾-in. diameter × 6-in. long (19-mm × 152-mm) Powers Fasteners galvanized wedge bolts at each toe plate end.

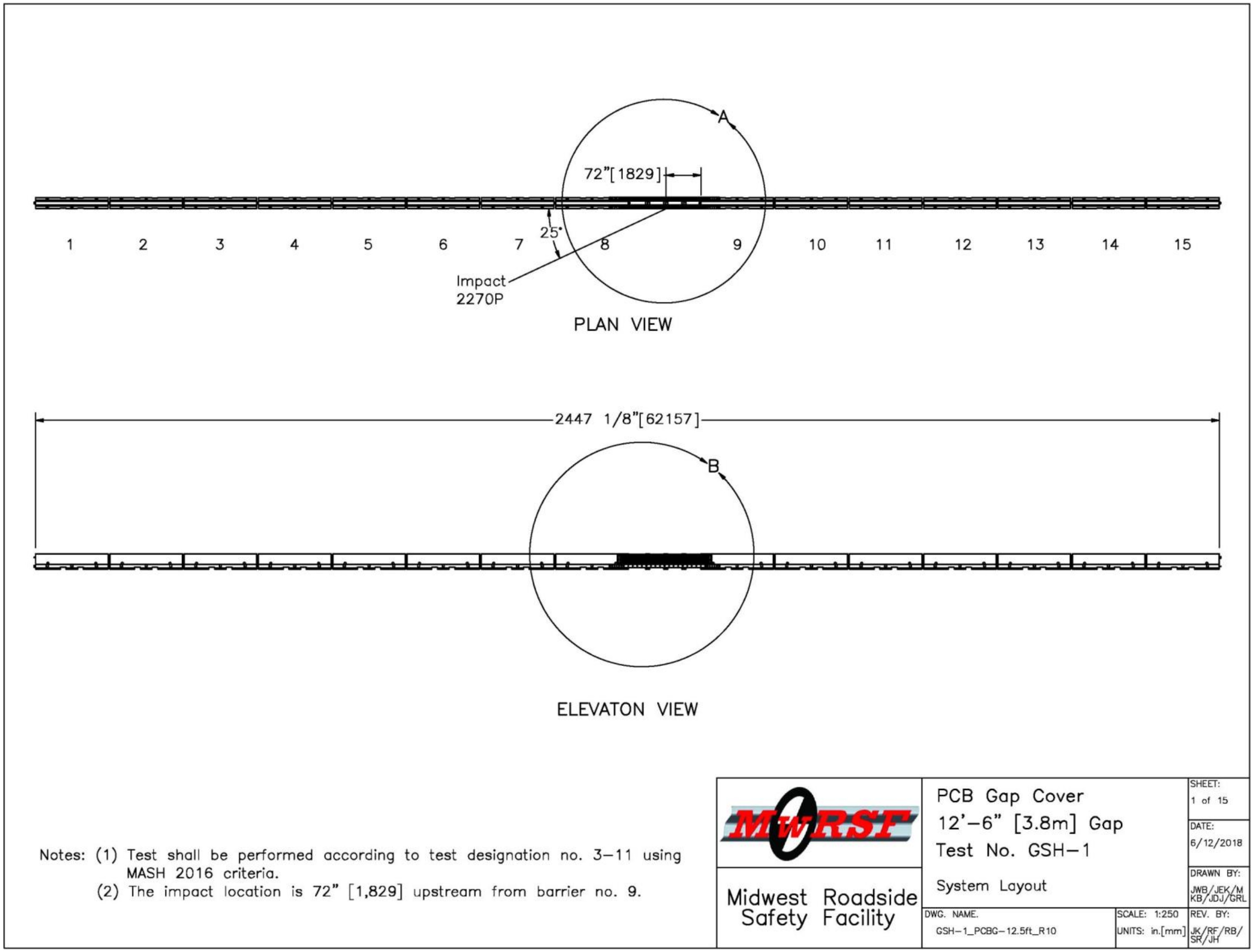


Figure 11. Test Installation Layout, Test No. GSH-1

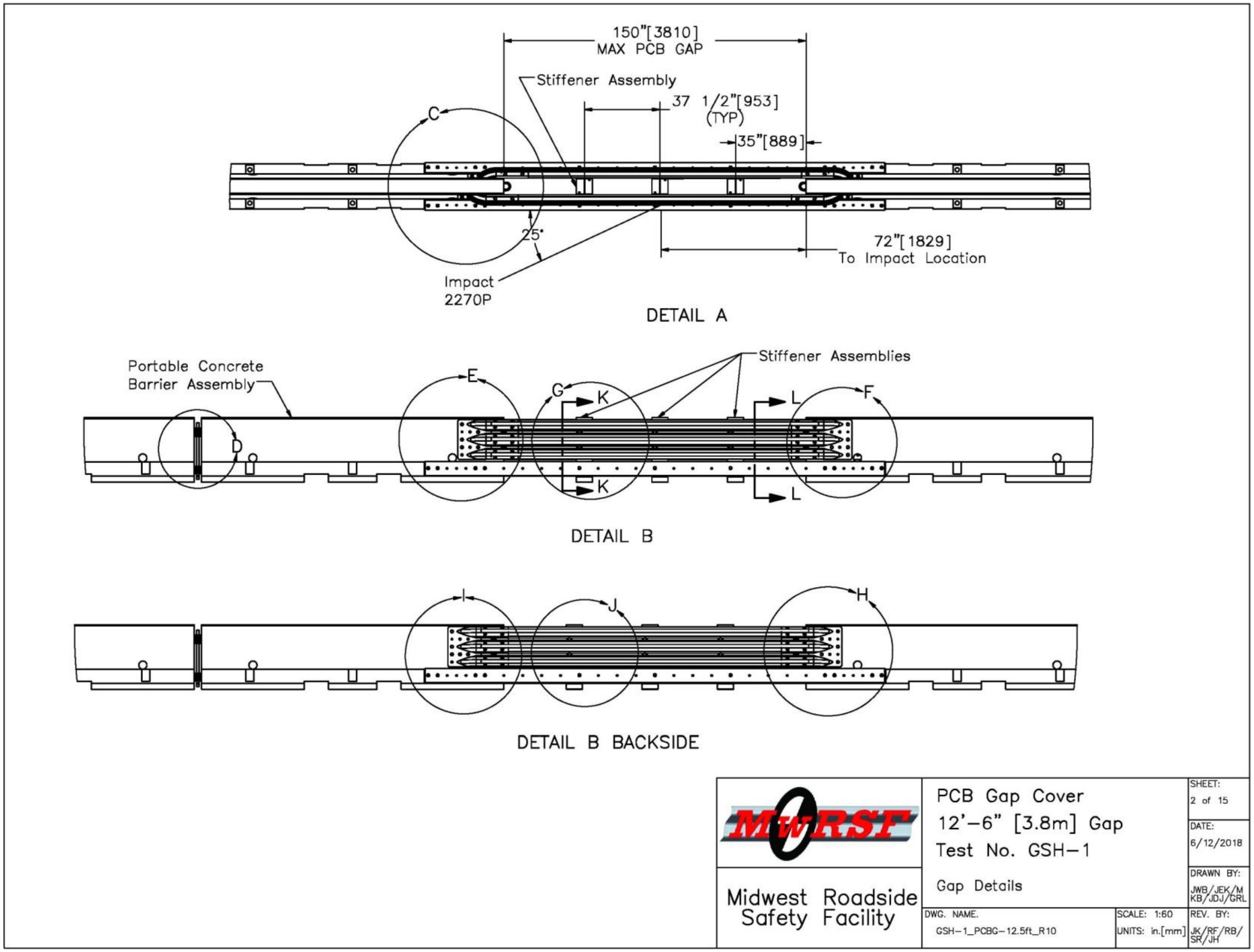


Figure 12. Gap Details, Test No. GSH-1

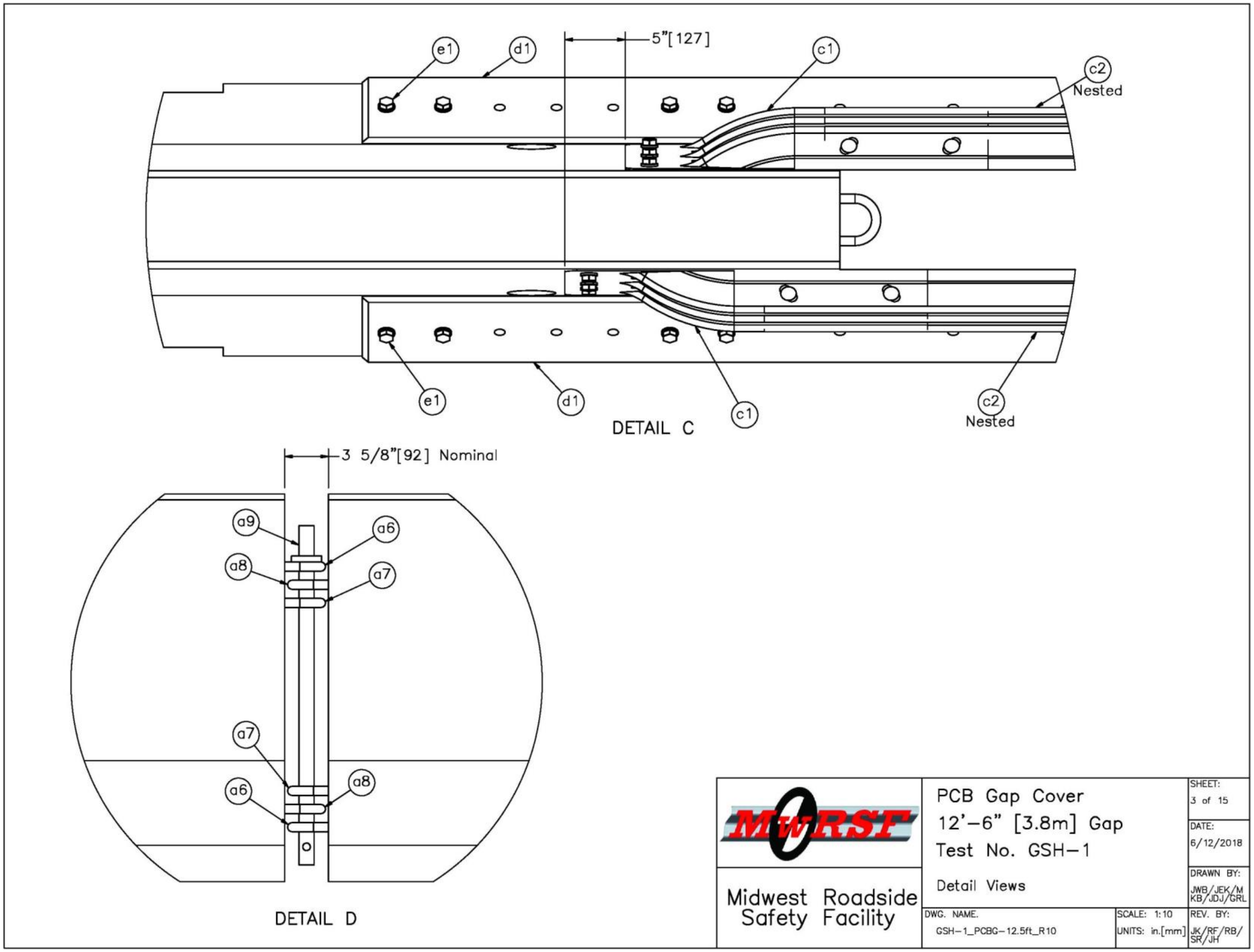


Figure 13. Detail C and Detail D Views, Test No. GSH-1

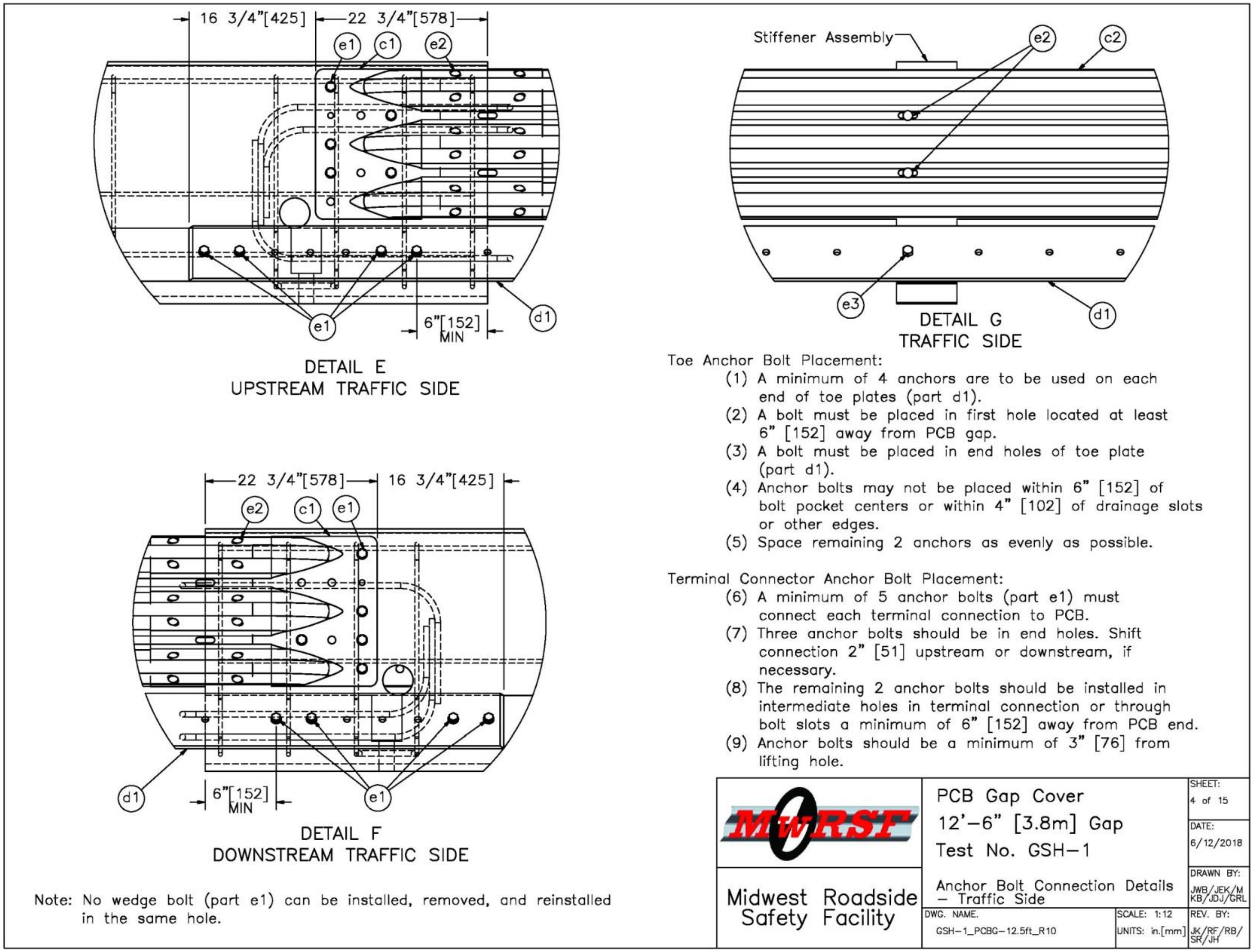


Figure 14. Anchor Bolt Connection Details – Traffic Side, Test No. GSH-1

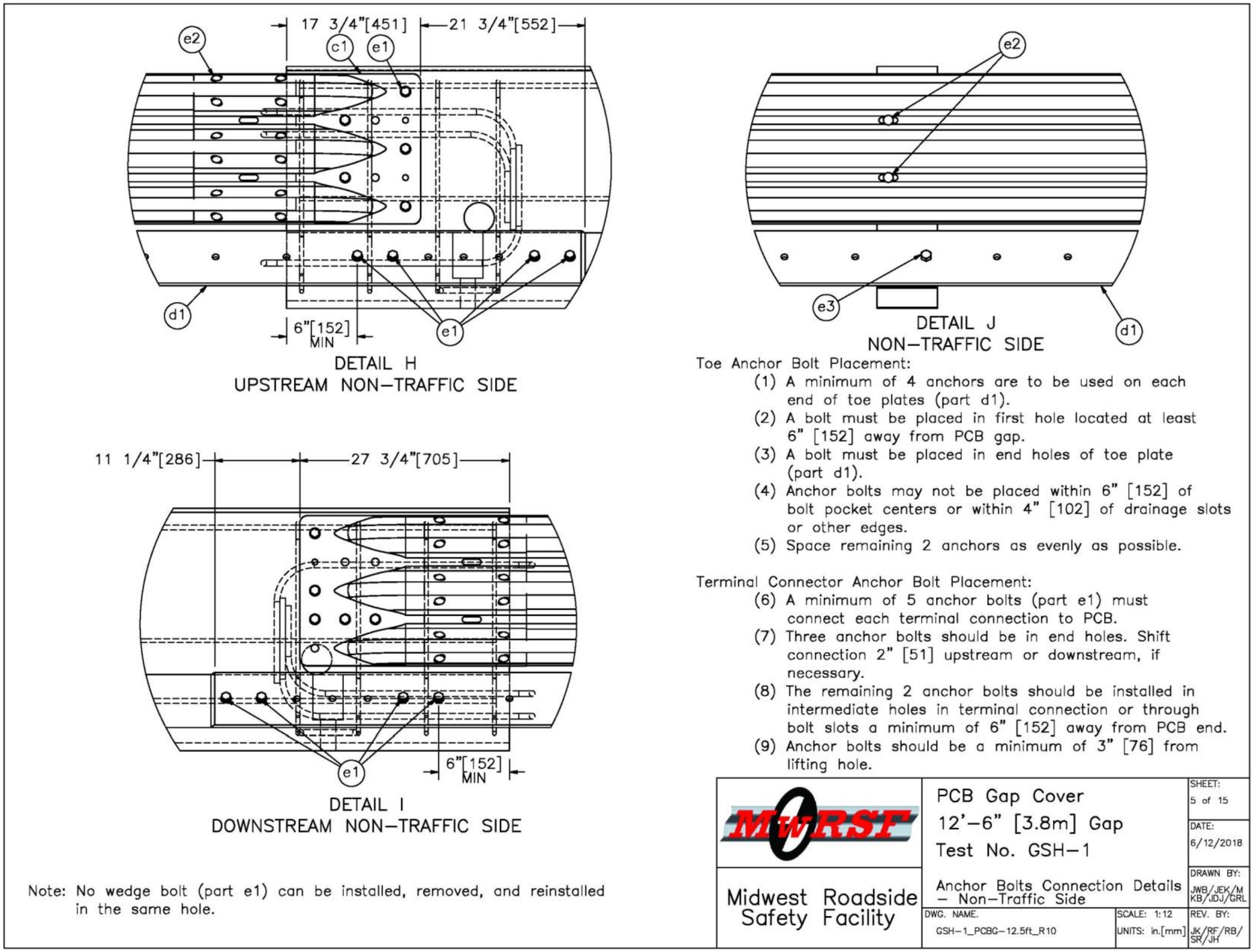


Figure 15. Anchor Bolts Connection Details – Non-Traffic Side, Test No. GSH-1

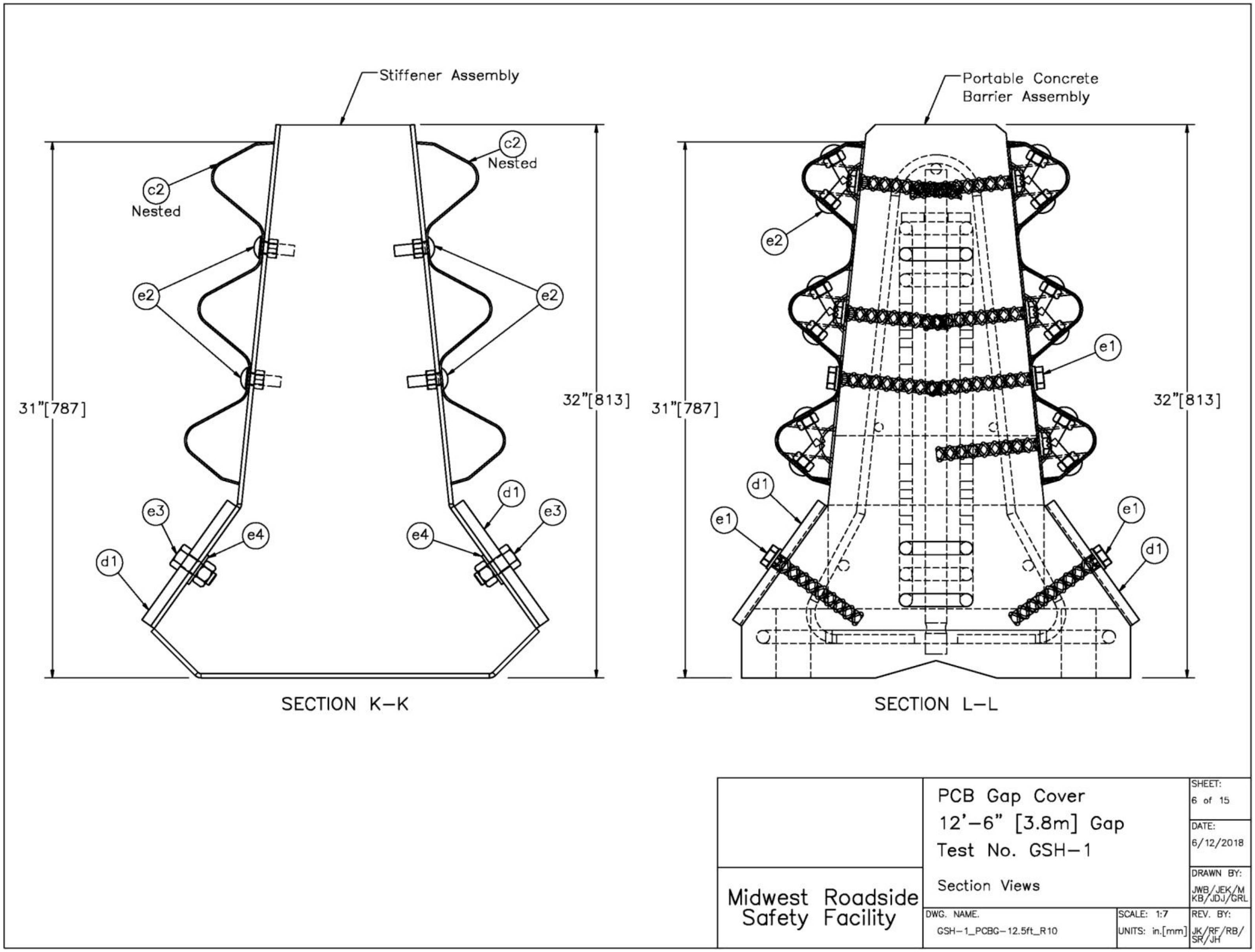
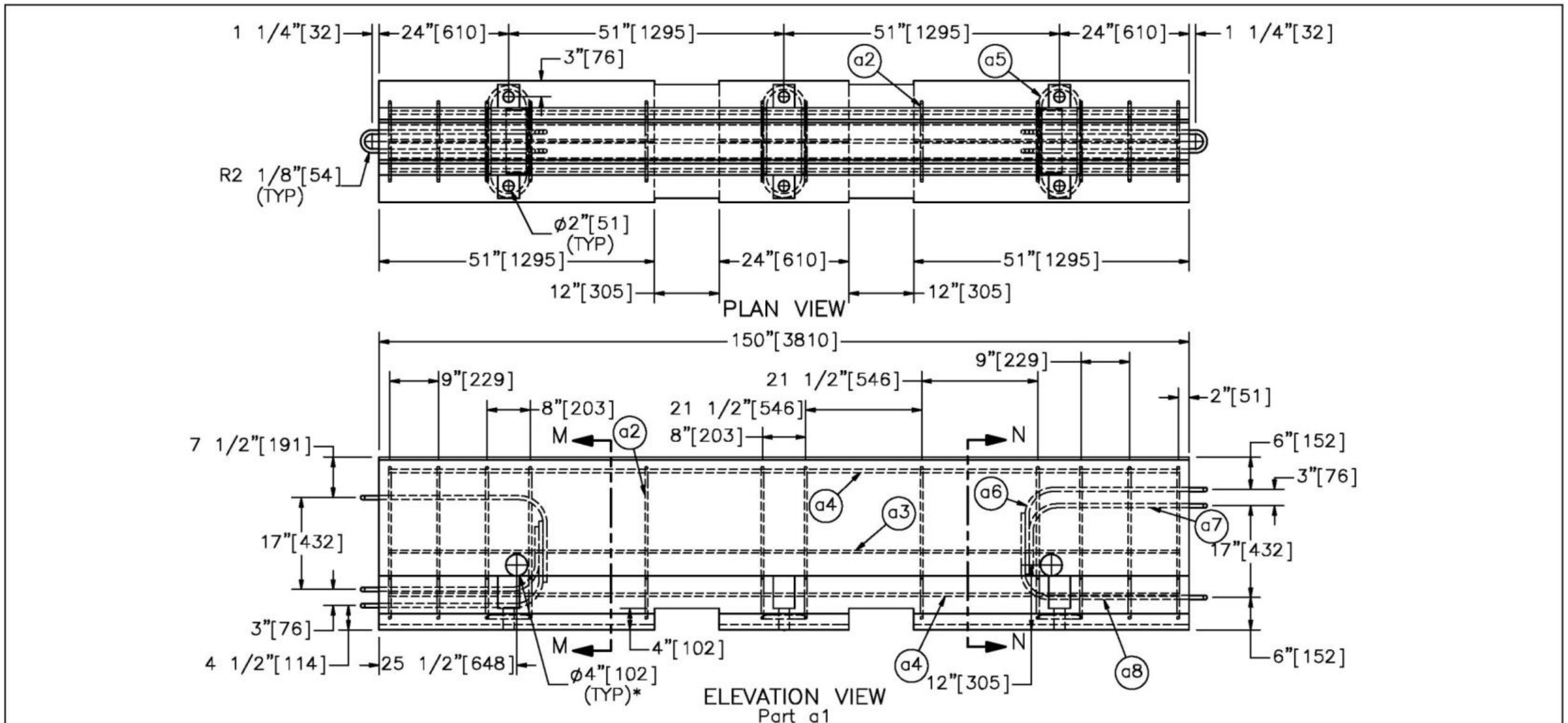


Figure 16. Section K-K and Section L-L Views, Test No. GSH-1



Item No.	QTY.	Description	Material Specification	Hardware Guide
–	15	Portable Concrete Barrier Assembly	–	SWC09
a1	1	Portable Concrete Barrier	Min f'c = 5,000 psi [34.5 MPa]	–
a2	12	#4 [13] Rebar, 72" [1,829] Total Unbent Length	ASTM A615 Gr. 60	–
a3	2	#4 [13] Rebar, 146" [3,708] Total Length	ASTM A615 Gr. 60	–
a4	3	#5 [16] Rebar, 146" [3,708] Total Length	ASTM A615 Gr. 60	–
a5	6	#6 [19] Rebar, 36" [914] Total Unbent Length	ASTM A615 Gr. 60	–
a6	2	#6 [19] Rebar, 101" [2,565] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–
a7	2	#6 [19] Rebar, 91" [2,311] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–
a8	2	#6 [19] Rebar, 102" [2,591] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–

*Hole in tested barrier 1/2" [25] smaller than design.

Midwest Roadside Safety Facility	PCB Gap Cover 12'-6" [3.8m] Gap Test No. GSH-1		SHEET: 7 of 15 / DATE: 6/12/2018
	Portable Concrete Barrier Details		DRAWN BY: JWB/JEK/M KB/JDJ/GRL
	DWG. NAME. GSH-1_PCBG-12.5ft_R10	SCALE: 1:28 UNITS: in.[mm]	REV. BY: JK/RF/RB/ SR/JH

Figure 17. PCB Details, Test No. GSH-1

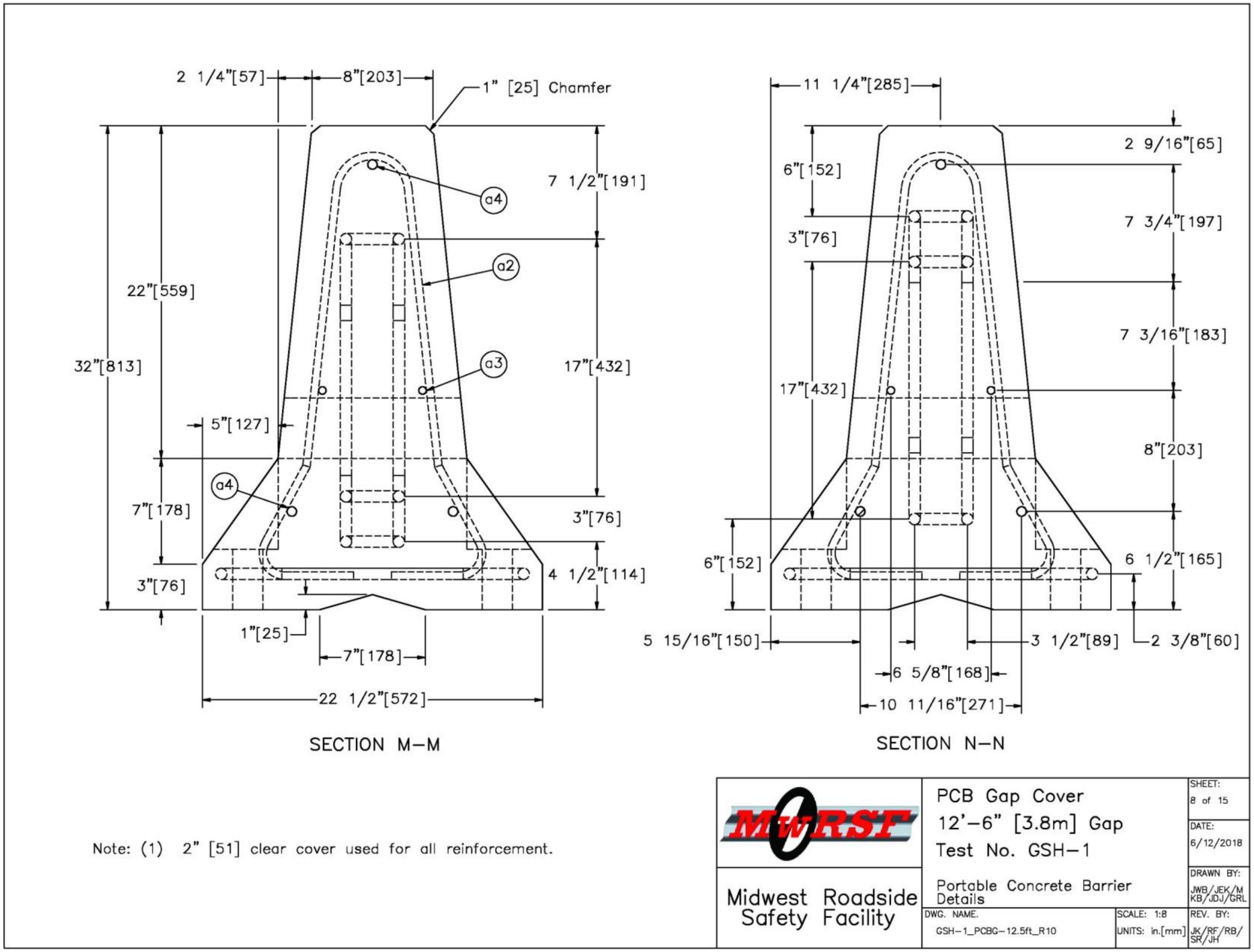
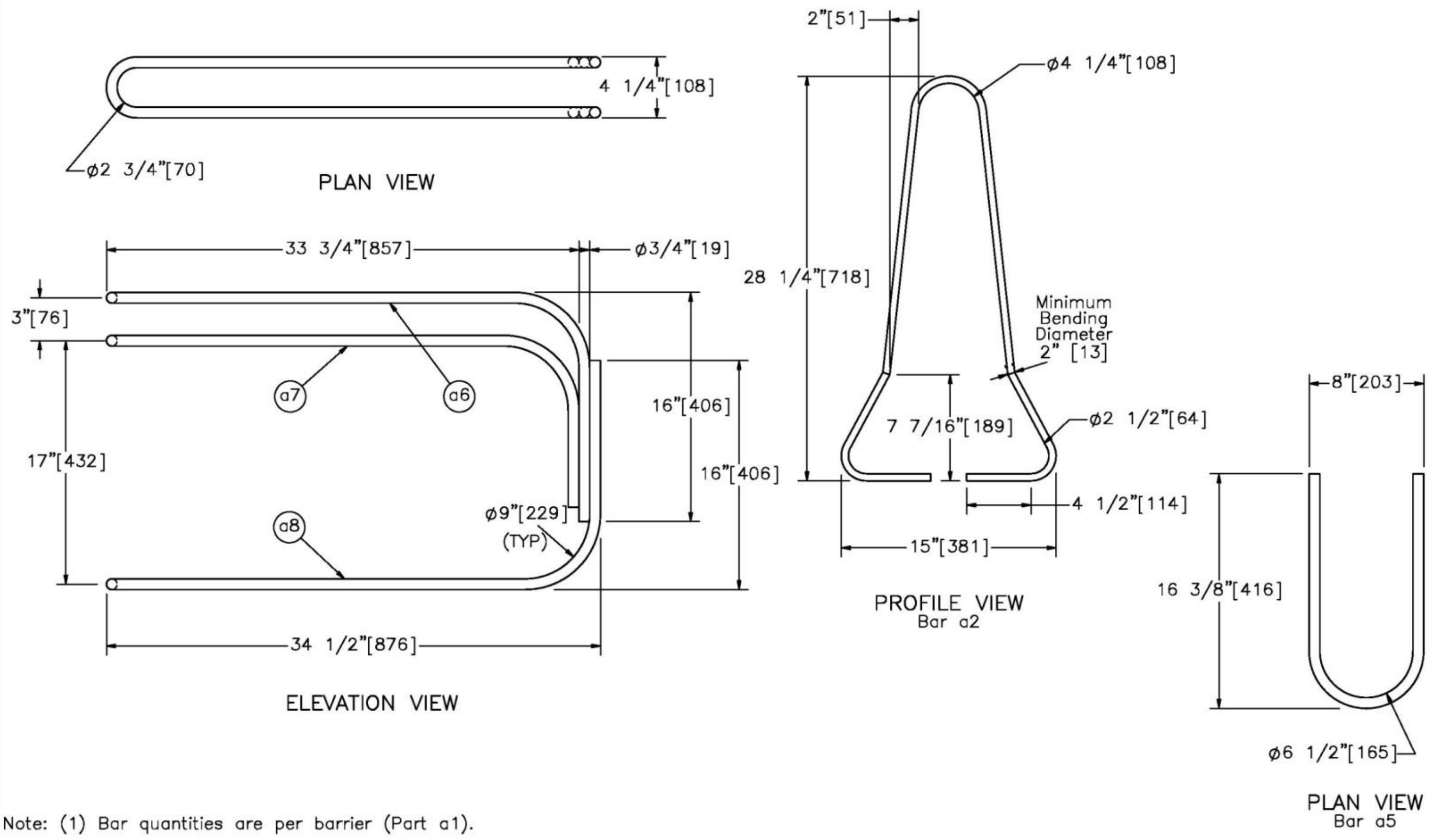


Figure 18. PCB Details, Section M-M and Section N-N, Test No. GSH-1



Note: (1) Bar quantities are per barrier (Part a1).

Bill of Bars				
Bar	QTY	Size	Total Length	Material
a2	12	#4	72"[1829]	A615 Gr.60
a3	2	#4	146"[3708]	A615 Gr.60
a4	3	#5	146"[3708]	A615 Gr.60
a5	6	#6	36"[914]	A615 Gr.60
a6	2	#6	101"[2565]	A709 Gr.70 or A706 Gr.60
a7	2	#6	91"[2311]	A709 Gr.70 or A706 Gr.60
a8	2	#6	102"[2591]	A709 Gr.70 or A706 Gr.60

Midwest Roadside Safety Facility

PCB Gap Cover
12'–6" [3.8m] Gap
Test No. GSH–1

Portable Concrete Barrier Rebar Details

SHEET: 9 of 15
DATE: 6/12/2018
DRAWN BY: JWB/JEK/M KB/JDJ/GRL
DWG. NAME. GSH–1_PCBG–12.5ft_R10
SCALE: 1:10
UNITS: in.[mm]
REV. BY: JK/RF/RB/SR/JH

Figure 19. PCB Rebar Details, Test No. GSH-1

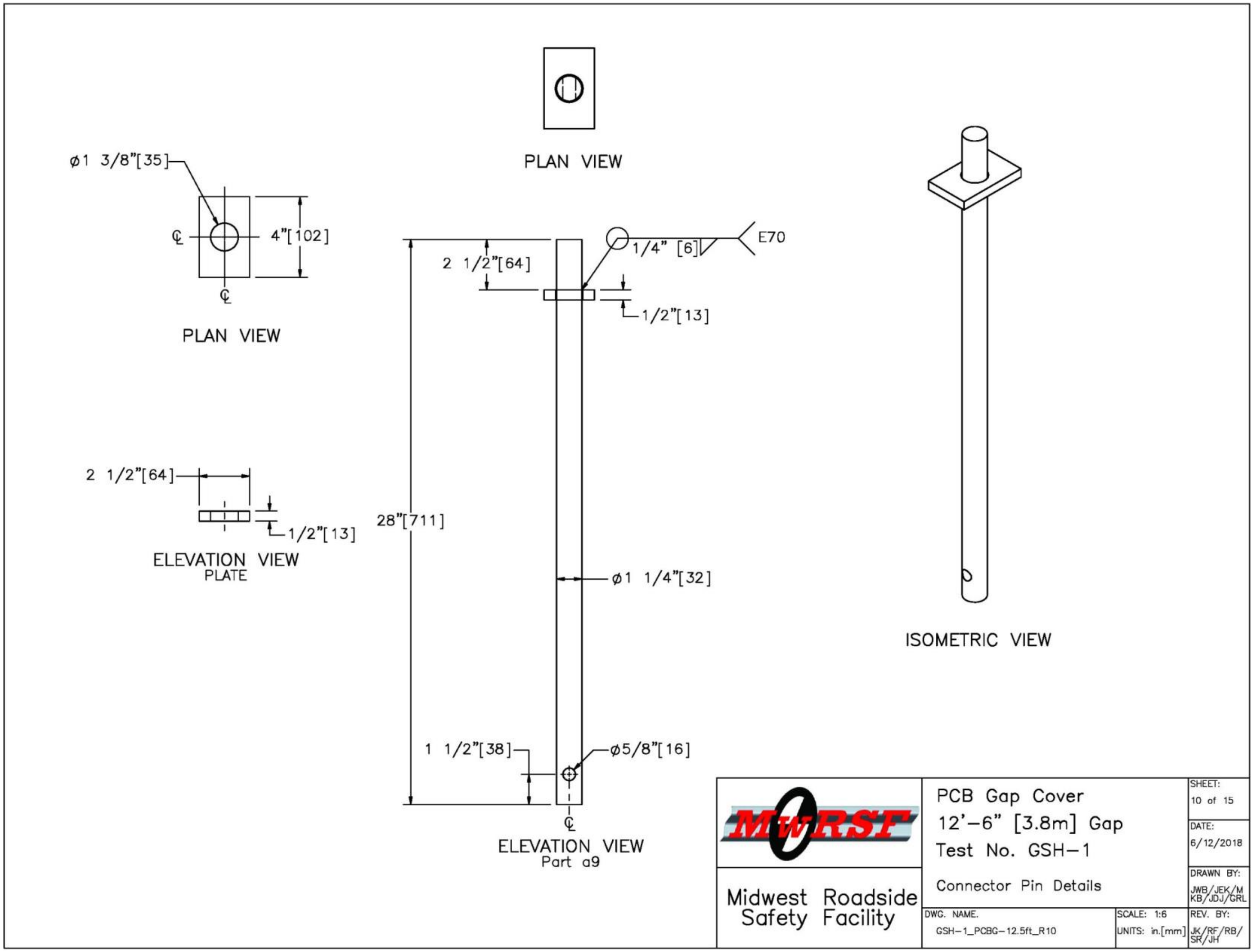
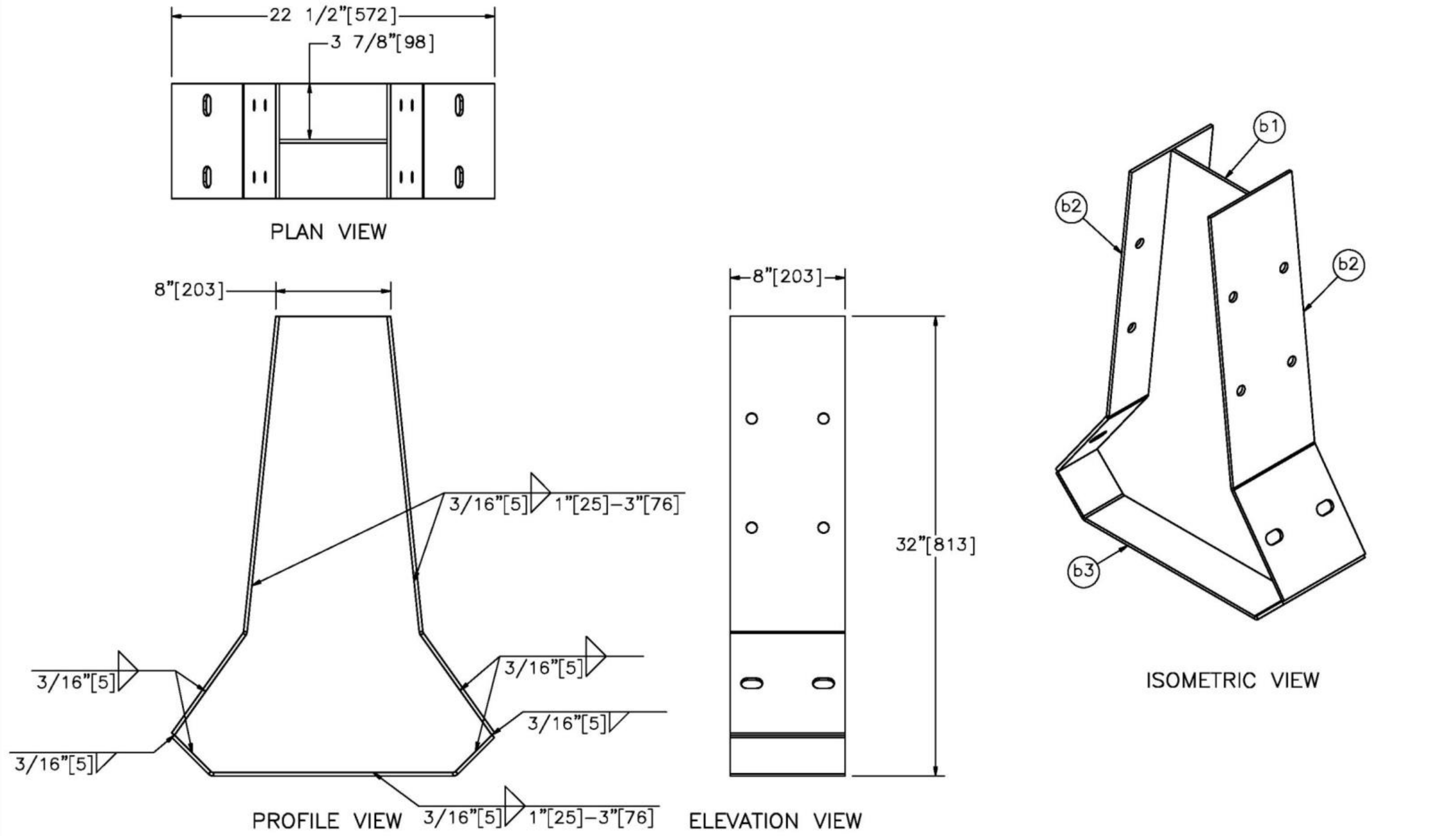


Figure 20. Connector Pin Details, Test No. GSH-1



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	3	Stiffener Assembly	–	ASTM A123
b1	1	31 3/4"x22 1/16"x1/4" [806x561x6] Steel Plate	ASTM A36	–
b2	2	30 3/4"x8"x1/4" [782x203x6] Bent Steel Plate	ASTM A36	–
b3	1	24 7/16"x8"x1/4" [620x203x6] Bent Steel Plate	ASTM A36	–

Midwest Roadside Safety Facility

PCB Gap Cover
12'–6" [3.8m] Gap
Test No. GSH–1

Stiffener Assembly

SHEET: 11 of 15
DATE: 6/12/2018
DRAWN BY: JWB/JEK/M KB/JDJ/GRL
DWG. NAME. GSH–1_PCBG–12.5ft_R10
SCALE: 1:10
UNITS: in.[mm]
REV. BY: JK/RF/RB/ SR/JH

Figure 21. Stiffener Assembly, Test No. GSH-1

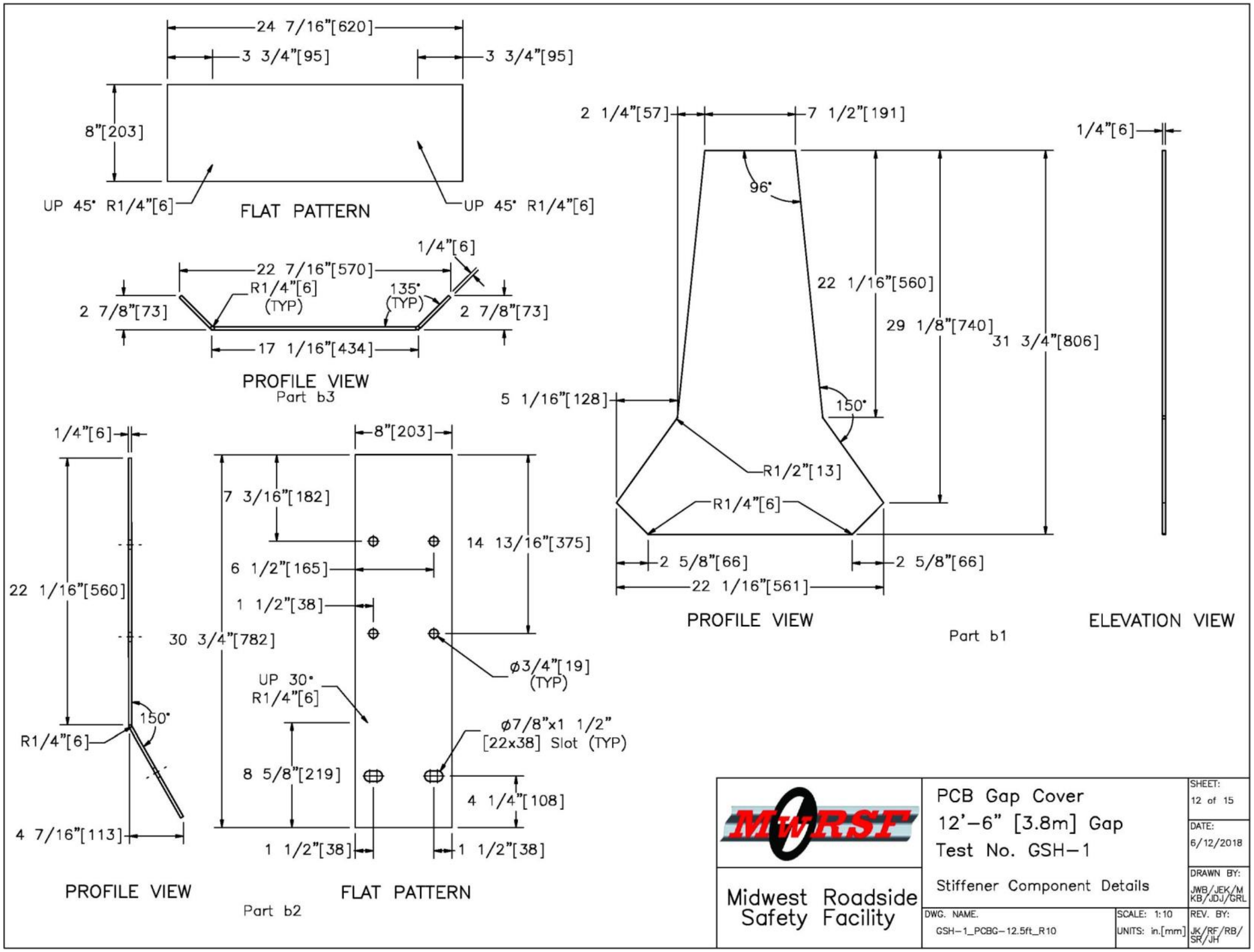


Figure 22. Stiffener Component Details, Test No. GSH-1

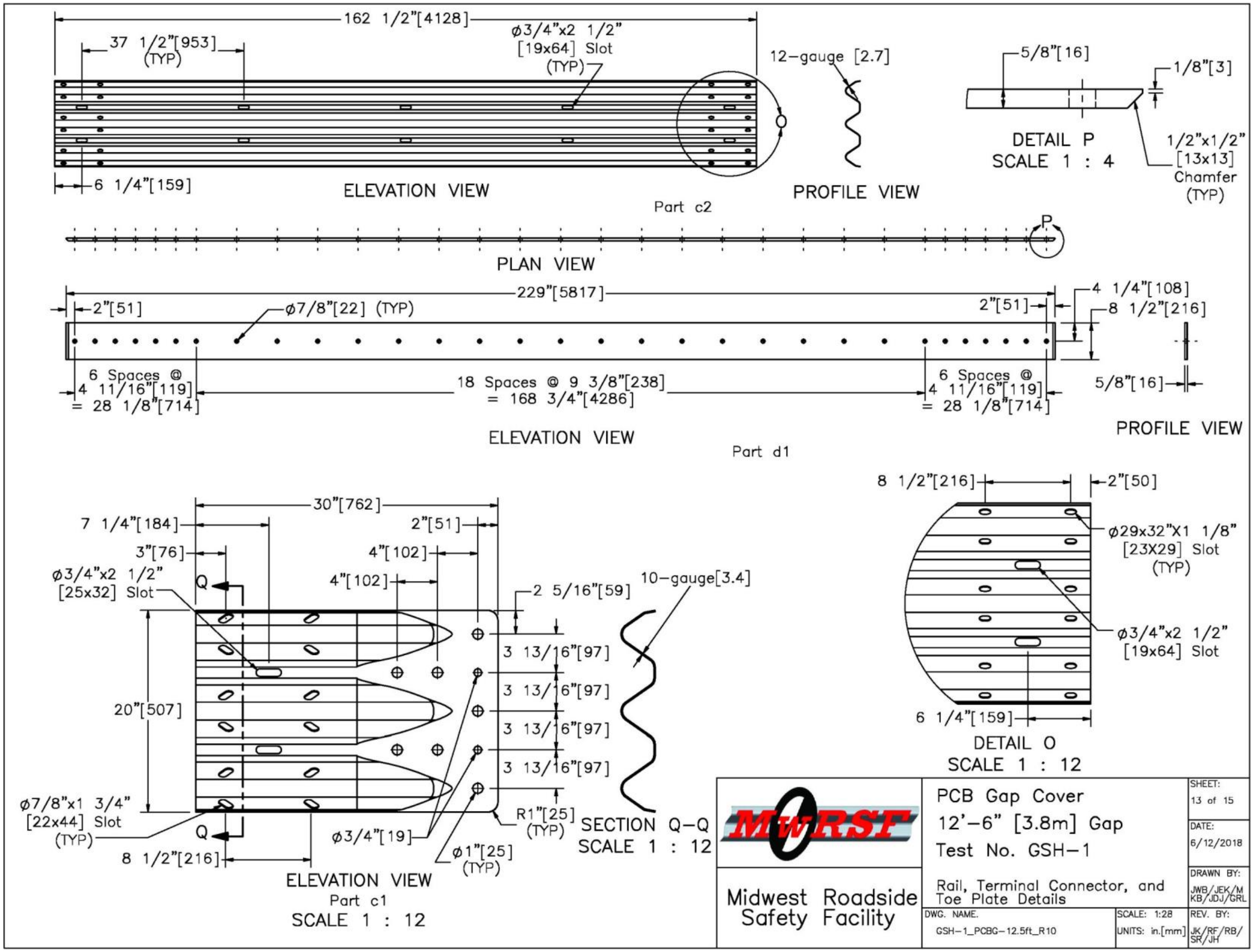


Figure 23. Rail, Terminal Connector, and Toe Plate Details, Test No. GSH-1

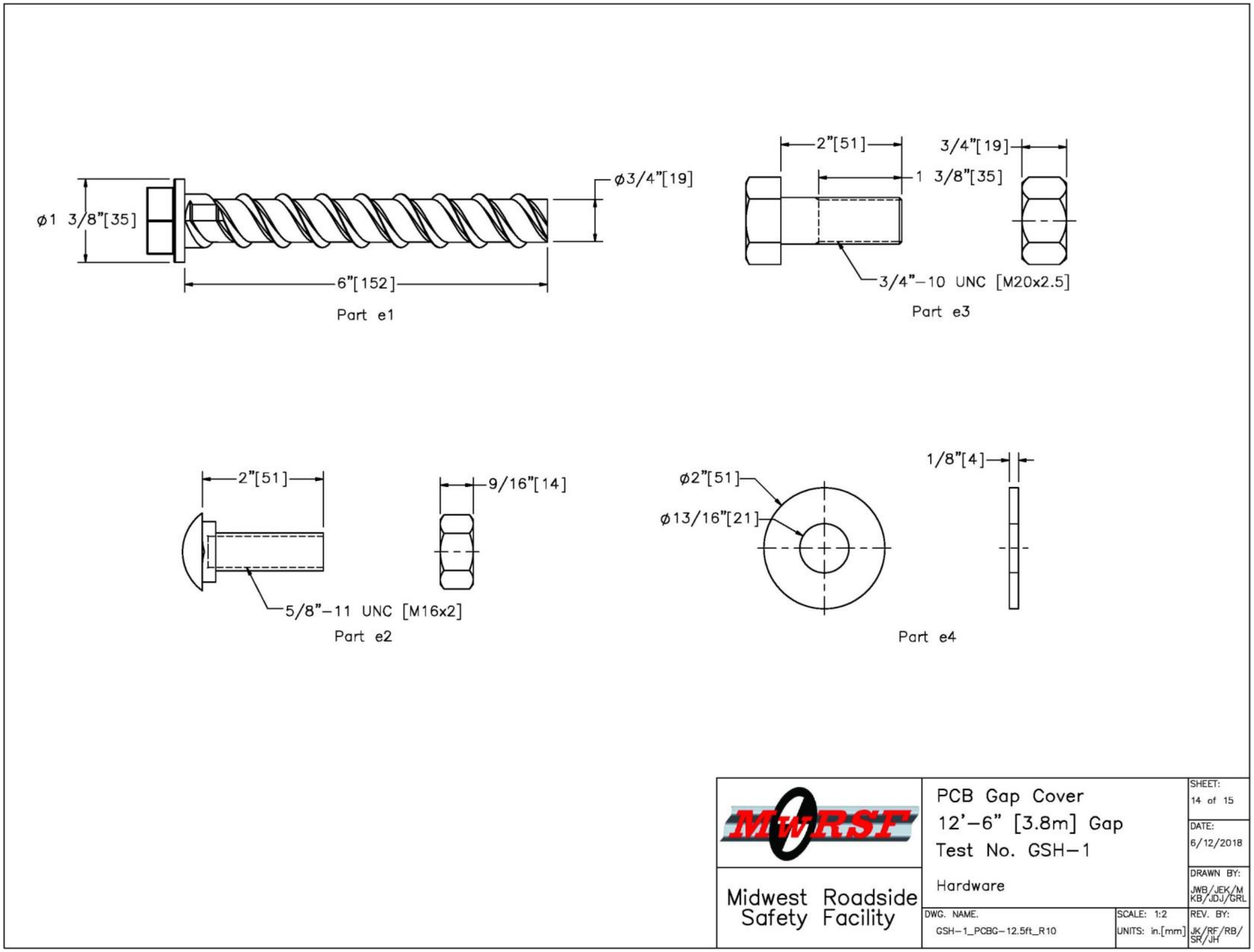


Figure 24. Hardware, Test No. GSH-1

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	15	Portable Concrete Barrier	Min f'c = 5,000 psi [34.5 MPa]	–	–
a2	180	#4 [13] Rebar, 72" [1,829] Total Unbent Length	ASTM A615 Gr. 60	–	–
a3	30	#4 [13] Rebar, 146" [3,708] Total Length	ASTM A615 Gr. 60	–	–
a4	45	#5 [16] Rebar, 146" [3,708] Total Length	ASTM A615 Gr. 60	–	–
a5	90	#6 [19] Rebar, 36" [914] Total Unbent Length	ASTM A615 Gr. 60	–	–
a6	30	#6 [19] Rebar, 101" [2,565] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–	–
a7	30	#6 [19] Rebar, 91" [2,311] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–	–
a8	30	#6 [19] Rebar, 102" [2,591] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–	–
a9	13	1 1/4" [32] Dia., 28" [711] Long Connector Pin	ASTM A36	–	FMW02
b1	3	31 3/4"x22 1/16"x1/4" [806x561x6] Steel Plate	ASTM A36	–	–
b2	6	30 3/4"x8"x1/4" [782x203x6] Bent Steel Plate	ASTM A36	–	–
b3	3	24 7/16"x8"x1/4" [620x203x6] Bent Steel Plate	ASTM A36	–	–
c1	4	10-gauge [3.4] Thrie Beam Terminal Connector	AASHTO M180 Min. Yield Strength = 50 ksi [345 MPa] Min. Ultimate Strength = 70 ksi [483 MPa]	ASTM A123 or A653	RTE01b
c2	4	12'-6" [3,810] 12-gauge [2.7] Thrie Beam Section	AASHTO M180	ASTM A123 or A653	RTM04b
d1	2	229"x8 1/2"x5/8" [5,817x216x16] Steel Plate	ASTM A572 Gr. 50	ASTM A123	–
e1	36	3/4" [19] Dia., 6" [152] Long Powers Fasteners Wedge Bolt+	As Supplied	As Supplied	FBX02
e2	60	5/8"-11 UNC [M16x2], 2" [51] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB02
e3	6	3/4"-10 UNC [M20x2.5], 2" [51] Long Heavy Hex Head Bolt and Nut	Bolt – ASTM F3125 Gr. A325 Type 1 or equivalent Nut – ASTM A563DH or equivalent	ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 or F2833 Gr. 1	FBX20b
e4	6	3/4" [19] Dia. Plain Flat Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC20a

Midwest Roadside Safety Facility

PCB Gap Cover
12'-6" [3.8m] Gap
Test No. GSH-1

Bill of Materials

SHEET: 15 of 15
DATE: 6/12/2018
DRAWN BY: JWB/JEK/M KB/JDJ/GRL
DWG. NAME. GSH-1_PCBG-12.5ft_R10
SCALE: 1:2
UNITS: in.[mm]
REV. BY: JK/RF/RB/SR/JH

Figure 25. Bill of Materials, Test No. GSH-1

Figure 26. Test Installation Photographs, Test No. GSH-1

Figure 27. Test Installation Photographs, Test No. GSH-1

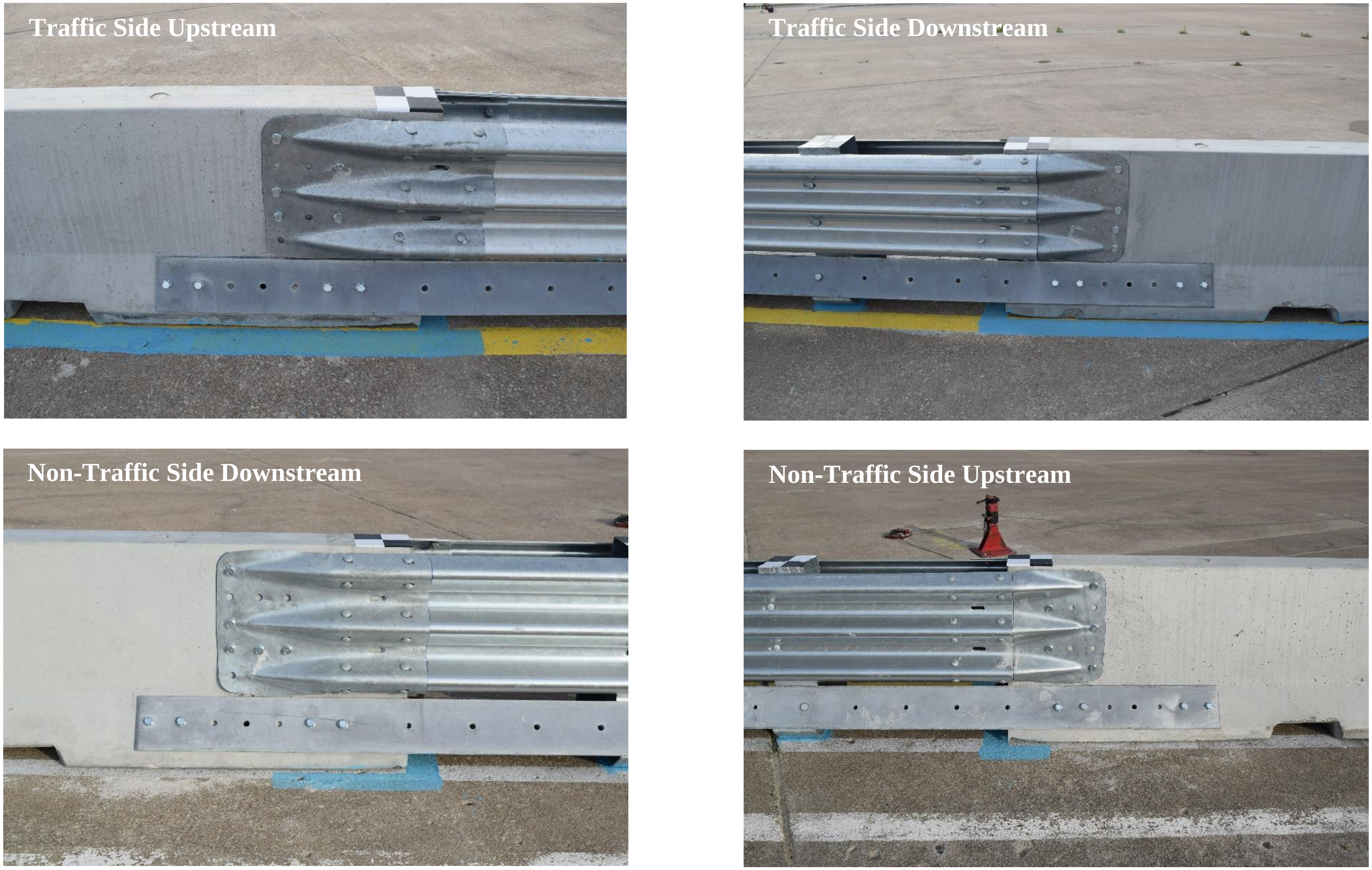


Figure 28. Test Installation Photographs, Gap-Spanning Hardware Anchorage, Test No. GSH-1

Figure 29. Test Installation Photographs, Gap Stiffener Hardware, Test No. GSH-1

5 FULL-SCALE CRASH TEST NO. GSH-1 [12.5-FT (3.8-M) GAP]

5.1 Weather Conditions

Test no. GSH-1 was conducted on June 28, 2018 at approximately 11:45 a.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. GSH-1

Temperature	88° F
Humidity	54 %
Wind Speed	14 mph
Wind Direction	110° from True North
Sky Conditions	Sunny
Visibility	10.0 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	2.34 in.
Previous 7-Day Precipitation	2.49 in.

5.2 Test Description

Test no. GSH-1 was conducted according to MASH test designation no. 3-11. Initial vehicle impact was to occur 72 in. (1,829 mm) upstream from the upstream end of barrier no. 9, as shown in Figure 30, which was selected using LS-DYNA analysis to maximize the structural loading on the hardware. The 5,005-lb (2,270-kg) Dodge quad cab pickup truck impacted the PCB gap-spanning hardware at a speed of 63.3 mph (101.9 km/h) and at an angle of 25.4 degrees. The actual point of impact was 77.1 in. (1,958 mm) upstream from barrier no. 9. The pickup truck impacted the PCB gap-spanning hardware with an impact severity of 123.2 kip-ft (167.1 kJ), which exceeded the minimum 106-kip-ft (144-kJ) limit from MASH 2016.

During the test, the 2270P vehicle was captured and redirected by the thrie beam panels of the gap-spanning hardware. At 0.095 sec after initial impact, the left-front corner of the vehicle reached upstream face of barrier no. 9 and continued to redirect without snagging on the PCB segment downstream from the gap-spanning hardware. As the vehicle continued to redirect along the system, cracking was observed through barrier no. 9 due to the loading of the segment. While this loading was sufficient the crack through the entire barrier segment, majority of the longitudinal reinforcement of the barrier segment remained intact and the continuity of the barrier was maintained. Additionally, the through cracking of the barrier segment was not observed to cause significant vehicle snag nor adversely affect vehicle stability. The impacting vehicle continued to redirect as it moved downstream along the PCB segments until exiting the barrier system at 0.894 sec after impact. The vehicle came to rest 177 ft – 7 in. (54.1 m) downstream from the initial impact point and 17 ft (5.2 m) behind the front face of the barrier system after brakes were applied.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 31 and 32. Documentary photographs of the crash test are shown in Figures 33 and 34. The vehicle trajectory and final position are shown in Figure 35.

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

TIME (sec)	EVENT
0.000	Vehicle's front bumper contacted the barrier 77.1 in. (1,958 mm) upstream from barrier no. 9.
0.002	Vehicle's front bumper deformed.
0.004	Vehicle's left fender contacted rail.
0.006	Vehicle's left-front tire contacted rail.
0.016	Vehicle's left fender deformed.
0.030	Vehicle yawed away from system and vehicle's left-front tire rode up toe plate of gap-spanning hardware.
0.033	Barrier no. 9 deflected laterally.
0.036	Barrier no. 9 cracked on back side between midspan and upstream end of barrier.
0.050	Vehicle's left-front tire was pushed back into wheel well and barrier no. 8 rotated counterclockwise.
0.055	Barrier no. 10 rotated counterclockwise and vehicle pitched upward.
0.092	Barrier no. 9 fractured on back side between midspan and upstream end of barrier.
0.093	Vehicle's front bumper contacted barrier no. 9.
0.106	Vehicle's left-front window shattered.
0.108	Barrier no. 9 fractured on back side upstream end.
0.138	Vehicle's right-front tire became airborne.
0.204	Barrier no. 9 spalled on back side between midspan and upstream end of barrier.
0.208	Vehicle's left-front door contacted barrier no. 9.
0.222	Vehicle's front bumper contacted barrier no. 10.
0.258	Vehicle was parallel to system with a velocity of 47.9 mph (77.1 km/h).
0.266	Barrier no. 9 rolled toward traffic side face of barrier system.
0.329	Barrier no. 10 deflected backward.
0.336	Vehicle's left quarter panel contacted barrier no. 9.
0.354	Vehicle rolled toward system.
0.370	Vehicle pitched downward.
0.387	Vehicle's left-front door contacted barrier no. 10.
0.438	Vehicle's left-rear door contacted barrier no. 10 and deformed.
0.444	Vehicle's right-rear tire became airborne and vehicle's left-front door contacted barrier no. 11.
0.499	Vehicle's left-rear door contacted barrier no. 11.
0.646	Vehicle's right-front tire regained contact with ground.
0.804	Vehicle's left-rear tire contacted barrier no. 12.
0.854	Vehicle's left-rear tire regained contact with ground.

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

TIME (sec)	EVENT
0.894	Vehicle exited system at an angle of 24.7 degrees and a speed of 42.6 mph (68.6 km/h).
0.960	Vehicle's right-rear tire regained contact with ground.
1.130	System came to rest.

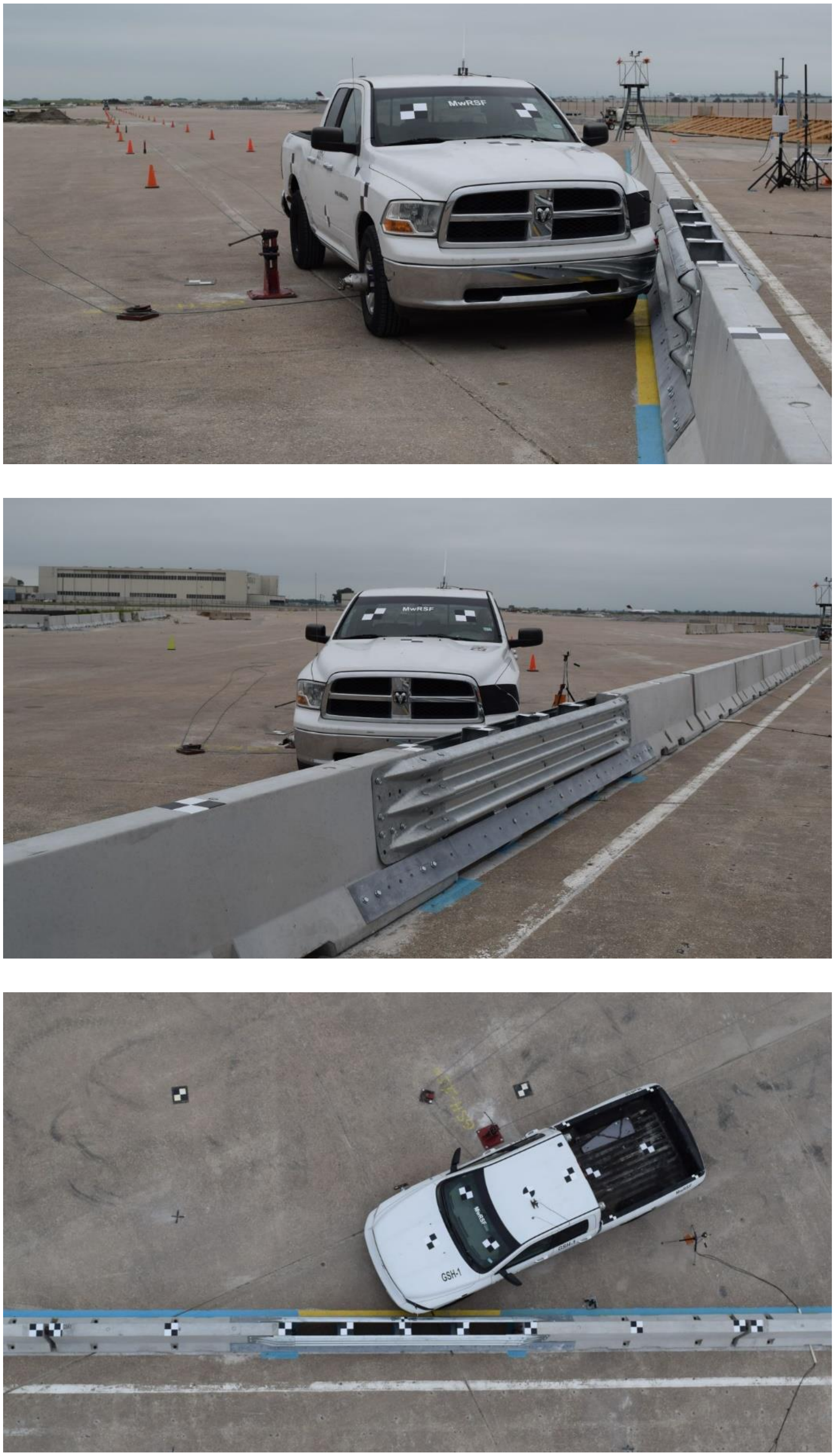
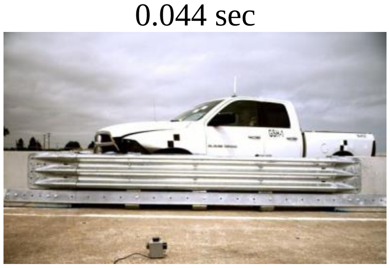


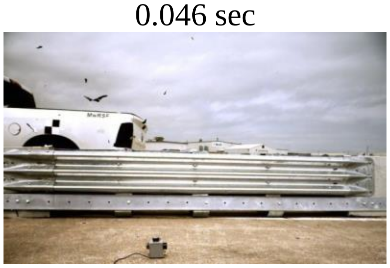
Figure 30. Impact Location, Test No. GSH-1


0.000 sec


0.016 sec


0.044 sec


0.046 sec


0.258 sec


0.894 sec


0.000 sec


0.106 sec

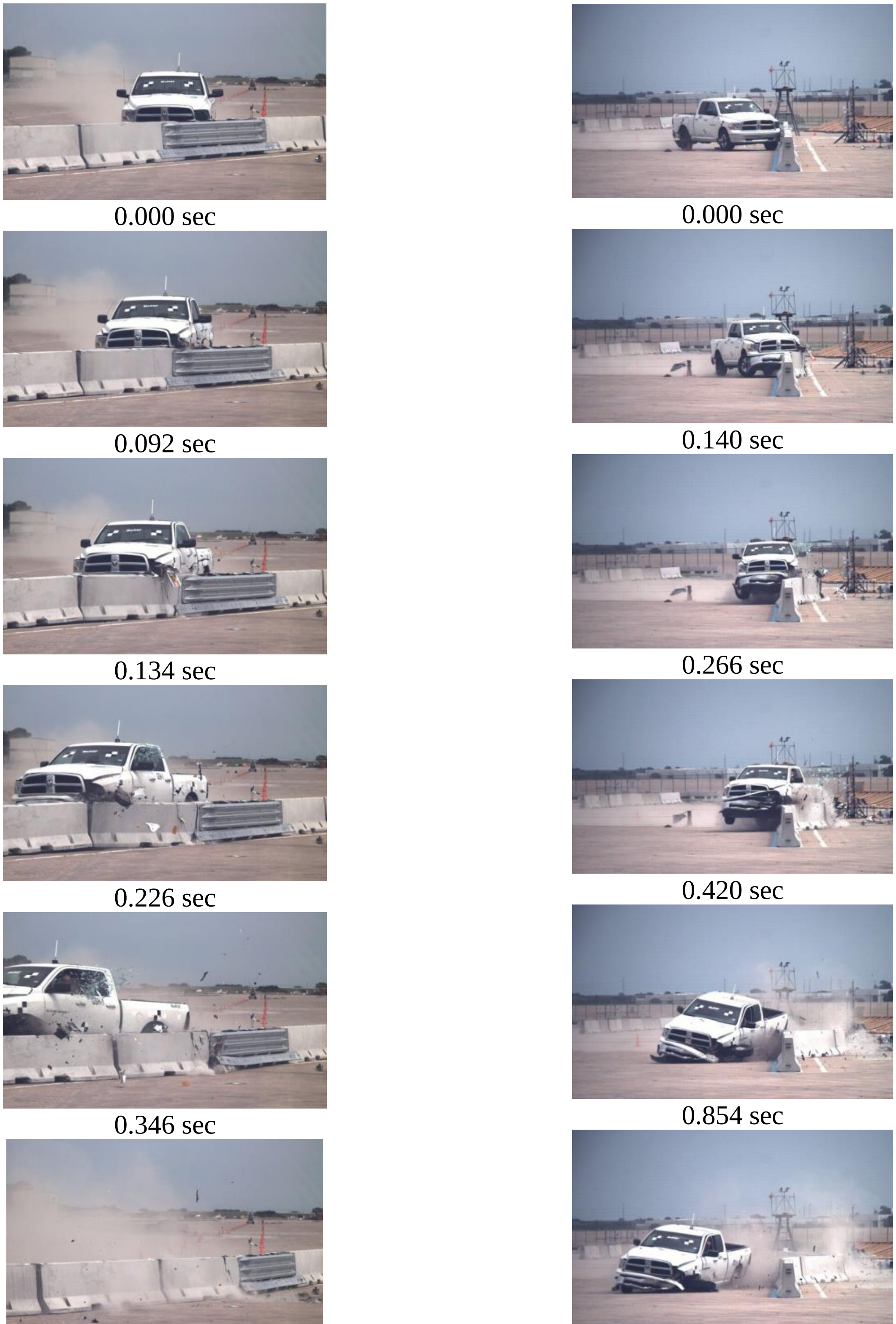

0.258 sec


0.646 sec


0.894 sec


1.130 sec

Figure 31. Sequential Photographs, Test No. GSH-1



0.000 sec | 0.000 sec

0.092 sec | 0.140 sec

0.134 sec | 0.266 sec

0.226 sec | 0.420 sec

0.346 sec | 0.854 sec

1.130 sec | 1.130 sec

Figure 32. Additional Sequential Photographs, Test No. GSH-1

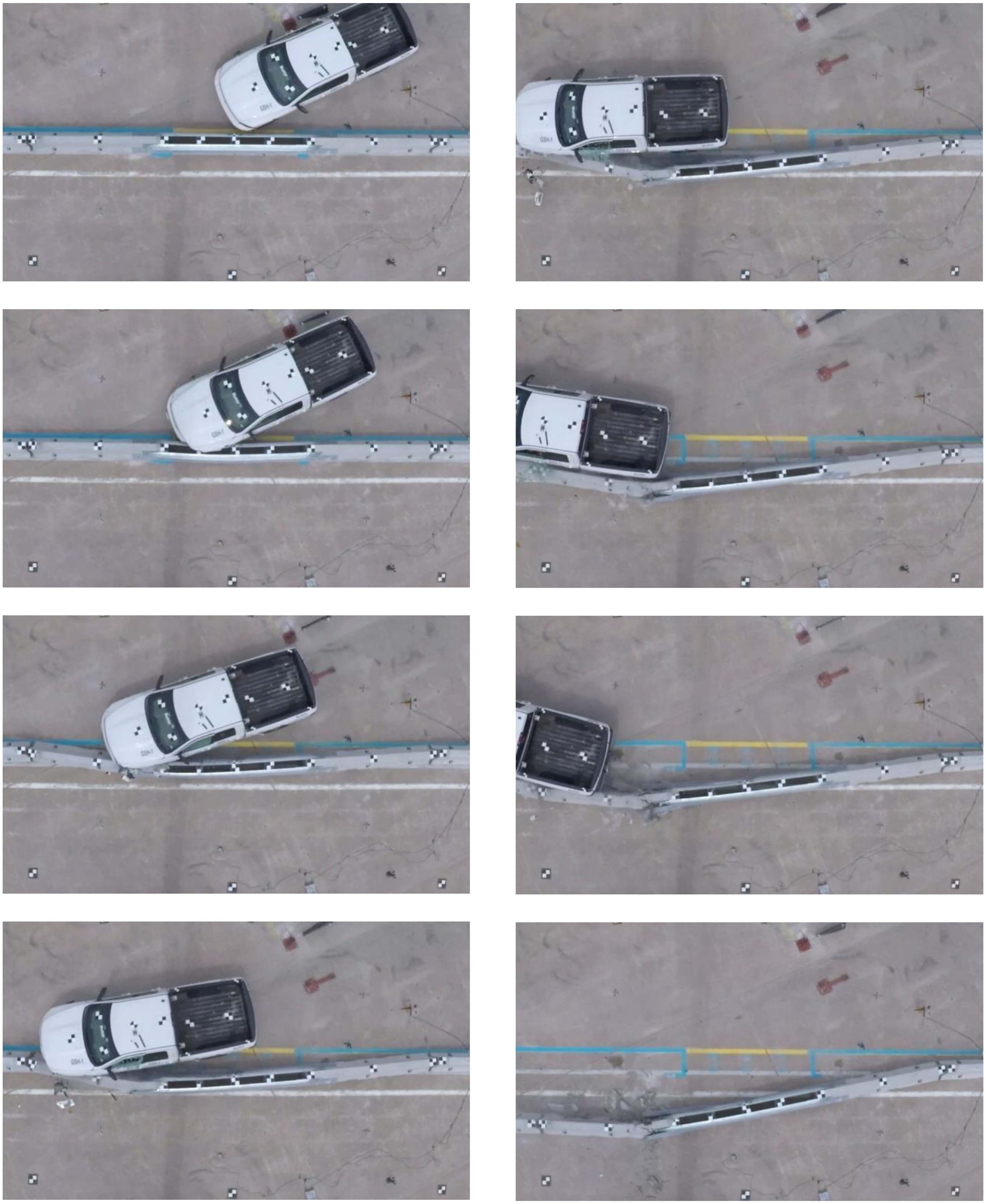


Figure 33. Documentary Photographs, Test No. GSH-1

Figure 34. Additional Documentary Photographs, Test No. GSH-1

Figure 35. Vehicle Final Position and Trajectory Marks, Test No. GSH-1

5.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 36 through 41. Barrier damage consisted of deformation of the thrie-beam guardrail, contact marks on the front face of the thrie-beam and concrete barriers, spalling of the concrete, and concrete cracking and failure. The length of vehicle contact along the barrier was approximately 34 ft – 5 in. (10.5 m), which spanned from 10 in. (254 mm) upstream from the target impact point to the upstream end of barrier no. 11.

Tire marks were visible on the front face of the gap-spanning hardware as well as on barrier nos. 9, 10, and 11. Barrier no. 8 had minor damage. Two cracks occurred, which extended across the front, top, and rear faces of barrier no. 8 at 9½ in. (241 mm) and 25 in. (635 mm) downstream from the midspan of the barrier.

Additional damage was noted on the gap-spanning hardware. A 10-in. long × 2-in. tall (254-mm × 51-mm) dent occurred 4 in. (102 mm) upstream from the target impact point on the bottom corrugation of the thrie-beam section and at 14 in. (356 mm) downstream from the target impact point on the middle corrugation of the thrie-beam section. At 18 in. (457 mm) downstream from the target impact point, the middle corrugation buckled. The lower valley bolt connecting the thrie-beam section to the internal spacer assembly located directly upstream from barrier no. 9 pulled out during the impact event, as shown in Figure 38. A 2-in. × 2-in. (51-mm × 51-mm) dent occurred on the middle corrugation of the thrie-beam transition 46 in. (1,168 mm) downstream from the target impact point. The front ⅝-in. (16-mm) thick steel toe plate bent approximately 1½ in. (38 mm) toward the center of the system 19 in. (483 mm) downstream from the impact point target. All eight of the ¾-in. (19-mm) diameter wedge bolts that fastened the downstream ends of the front and rear toe plates to barrier no. 9 disengaged due to concrete fracture.

Barrier no. 9 damage included significant cracking and spalling. At 4 in. (102 mm) downstream from the upstream edge of barrier no. 9, spalling occurred, and an 8½-in. long × 3-in. wide × ¼-in thick (216-mm × 76-mm × 6-mm) piece of concrete disengaged from the top front corner of the barrier. A crack occurred across the top of barrier no. 9 at a distance of 25 in. (635 mm) from the upstream end of the segment. Significant cracking occurred 30½ in. (775 mm) downstream from the upstream end of barrier no. 9. The cracking extended through the entire width of the barrier and led to major spalling, measuring 18 in. (457 mm) wide and 3½ in. (89 mm) deep, which caused layers of concrete to disengage from the front and rear faces of the barrier. Additionally, one of the longitudinal rebar on the backside of barrier no. 9 fractured in tension at the location of the concrete fracture, as shown in Figure 40. At 9 in. (229 mm) downstream from the upstream end of barrier no. 9, the front toe of the barrier disengaged, which extended 63 in. (1,600 mm) long and 3½ in. (89 mm) deep. A 30-in. (762-mm) long section of the rear face toe of barrier no. 9 also disengaged 13 in. (330 mm) downstream from the upstream end on the non-traffic side face. Further cracking on barrier no. 9 occurred on the front, top, and rear faces 55 in. (1,397 mm) downstream from the upstream end of the barrier. Further toe disengagement occurred on the front face of barrier no. 9, 83 in. (2,108 mm) downstream from the upstream end. The disengaged toe section was 55 in. long × 9½ in. tall × 3 in. deep (1,397 mm × 241 mm × 76 mm).

On barrier no. 10, spalling occurred on the upstream front top corner of the barrier, which was 1½ in long × 2 in. wide × ¼ in. deep (38 mm × 51 mm × 6 mm). Additional spalling occurred 52 in. (1,321 mm) downstream from the upstream end on the front toe of the barrier. Barrier no.

10 cracked along the front, top, and rear faces 69 in. (1,753 mm) downstream from the upstream end of the barrier.

The maximum lateral permanent set of the barrier system was 81.6 in. (2,073 mm), which occurred at the upstream end of barrier no. 9, as determined from high-speed digital video analysis. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 81.6 in. (2,073 mm) located at the steel toe plate at the upstream end of barrier no. 9, as determined from high-speed digital video analysis. The working width of the system was found to be 99.1 in. (2,517 mm), also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 42.

Figure 36. Overall System Damage, Test No. GSH-1

Figure 37. Overall System Damage (Non-traffic Side), Test No. GSH-1

Figure 38. Thrie-Beam Damage, Test No. GSH-1

Figure 39. Barrier No. 9 Damage, Test No. GSH-1

Figure 40. Longitudinal Rebar Shear, Non-Traffic Side, Barrier No. 9, Test No. GSH-1

Figure 41. PCB Gap-Spanning Hardware Connection Damage, Test No. GSH-1

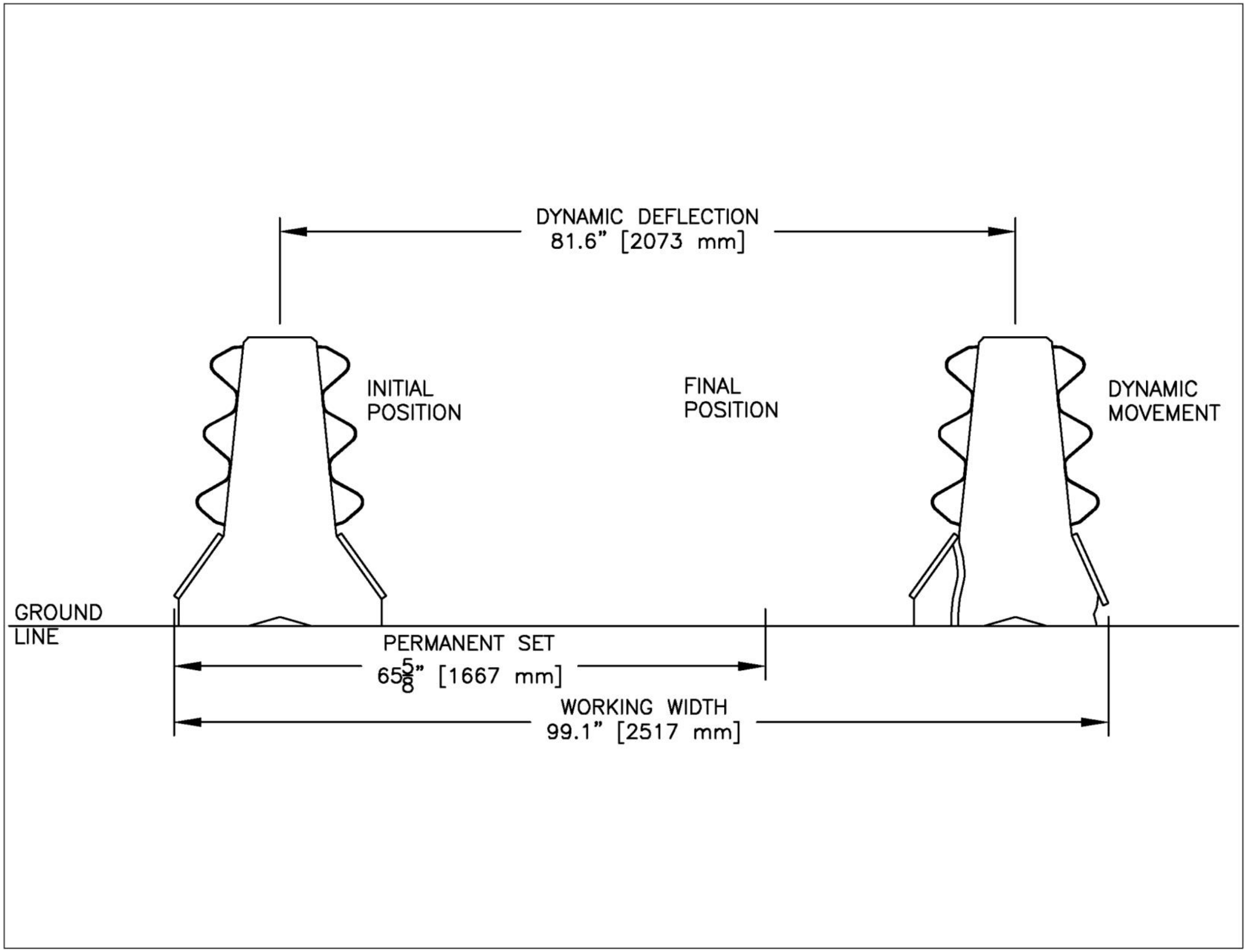


Figure 42. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. GSH-1

5.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 43 through 45. The maximum occupant compartment intrusions are listed in Table 6, along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment and none of the established MASH 2016 deformation limits were violated. Outward deformations, which are denoted as negative numbers in Appendix C, are not considered crush toward the occupant, and are not evaluated by MASH 2016 criteria.

The majority of damage was concentrated on the left-front corner and left side of the vehicle, where the impact had occurred. The left side of the bumper was crushed inward and backward, as shown in Figure 44. The left-front fender was dented and bent behind the left-front wheel and pushed into the left-front door. The left-front steel rim and tire disengaged from the vehicle. The left upper control arm was bent upward and inward into the engine bay and the left-side steering knuckle assembly disengaged from the vehicle. The left side of the frame and the left bumper mounting plate were both bent inward toward the center of the vehicle. The left-rear tire was deflated. The left-side headlight and fog light disengaged from the vehicle during impact. Denting and scraping were observed on the left side of the vehicle, primarily at the left-front door. The left-front and left-rear doors were slightly ajar at the top of the doorframe, and each door had a small puncture located at the base of the door. The rear bumper was twisted, and the left side of the rear bumper was dented and scuffed. A gap occurred between the hood and both the left and right fenders due to the deformation of the hood and fenders. The left-front window shattered during the test due to contact with the test dummy’s head at 106 ms after impact, but the roof and remaining window glass remained undamaged.

Figure 43. Vehicle Damage, Test No. GSH-1

Figure 44. Front-Left Vehicle Damage, Test No. GSH-1

Figure 45. Test Vehicle's Post Test Interior Floorboards and Undercarriage, Test No. GSH-1

Table 6. Maximum Occupant Compartment Intrusion by Location, Test No. GSH-1

LOCATION	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	7.2 (183)	≤ 9 (229)
Floor Pan & Transmission Tunnel	0.0 (0)	≤ 12 (305)
A-Pillar	0.5 (13)	≤ 5 (127)
A-Pillar (Lateral)	0.0 (0)	≤ 3 (76)
B-Pillar	0.5 (13)	≤ 5 (127)
B-Pillar (Lateral)	0.0 (0)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	1.0 (25)	≤ 12 (305)
Side Door (Above Seat)	0.0 (0)	≤ 9 (229)
Side Door (Below Seat)	0.7 (18)	≤ 12 (305)
Roof	0.4 (10)	≤ 4 (102)
Windshield	0.0 (0)	≤ 3 (76)
Side Window	Shattered due to contact with dummy's head	No shattering resulting from contact with structural member of test article
Dash	0.5 (13)	N/A

N/A – No MASH 2016 criteria exist for this location

5.5 Occupant Risk

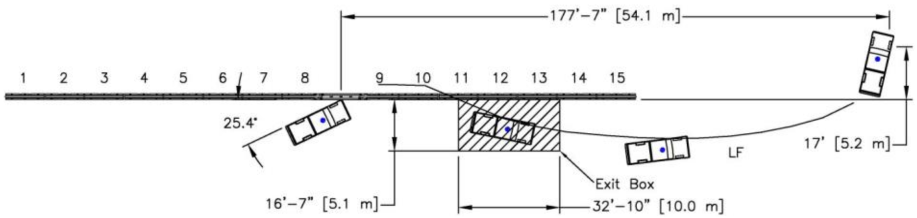
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 7. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 7. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix D.

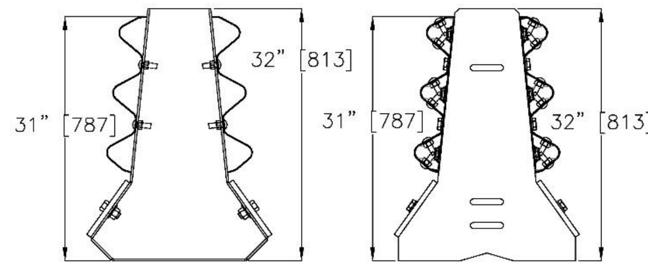
Table 7. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. GSH-1

Evaluation Criteria		**Transducer**		**MASH 2016 Limits**
		SLICE-1	**SLICE-2 (primary)**	
OIV ft/s (m/s)	Longitudinal	-19.19 (-5.85)	-18.59 (-5.67)	±40 (12.2)
	Lateral	16.29 (4.96)	18.01 (5.49)	±40 (12.2)
ORA g's	Longitudinal	15.57	15.38	±20.49
	Lateral	8.59	7.14	±20.49
Maximum Angular Displacement deg.	Roll	-15.8	-11.2	±75
	Pitch	-7.5	-9.0	±75
	Yaw	47.4	46.7	not required
THIV ft/s (m/s)		24.99 (7.62)	25.70 (7.83)	not required
PHD g's		15.85	15.51	not required
ASI		1.03	1.08	not required

5.6 Discussion

The analysis of the test results for test no. GSH-1 showed that the PCB gap-spanning hardware adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 46. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix D, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 24.7 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. GSH-1 conducted on the PCB system gap-spanning hardware was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.





Stiffener Section PCB Section

- Test Agency .... MwRSF
- Test Number GSH-1
- Date 6/28/2018
- MASH 2016 Test Designation No. 3-11
- Test Article .... PCB Gap-Spanning Hardware
- Total Length .... 203 ft-11⅛ in. (62.2 m)
- Key Component – Concrete Barrier
  - Length .... 150 in. (3,810 mm)
  - Width .... 22.5 in. (572 mm)
  - Height .... 32 in. (813 mm)
- Key Component – Thrie-Beam Guardrail
  - Length .... 150 in. (3,810 mm)
  - Thickness .... 12 gauge (2.7 mm)
- Vehicle Make /Model .... 2011 Dodge Ram 1500 Quad Cab
  - Curb .... 4,984 lb (2,261 kg)
  - Test Inertial .... 5,005 lb (2,270 kg)
  - Gross Static .... 5,165 lb (2,343 kg)
- Impact Conditions
  - Speed .... 63.3 mph (101.9 km/h)
  - Angle .... 25.4 deg.
  - Impact Location .... 77.1 in. (1,958 mm) US from Barrier No. 9
- Impact Severity ...... 123.2 kip-ft (167.1 kJ) > 106 kip-ft (144 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 42.6 mph (68.6 km/h)
  - Angle .... 24.7 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 177 ft – 7 in. (54.1 m) downstream
  17 ft (5.2 m) laterally behind
- Vehicle Damage .... Moderate
  - VDS [10] 11-LFQ-4
  - CDC [11] 11-LYEW-3
  - Maximum Interior Deformation .... 7.2 in. (183 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 81.6 in. (2,073 mm)
  - Dynamic .... 81.6 in. (2,073 mm)
  - Working Width .... 99.1 in. (2,517 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-19.19 (-5.85)	-18.59 (-5.67)	±40 (12.2)
	Lateral	16.29 (4.96)	18.01 (5.49)	±40 (12.2)
ORA g's	Longitudinal	15.57	15.38	±20.49
	Lateral	8.59	7.14	±20.49
Maximum Angular Displacement deg.	Roll	-15.8	-11.2	±75
	Pitch	-7.5	-9.0	±75
	Yaw	47.4	46.7	not required
THIV – ft/s (m/s)		24.99 (7.62)	25.70 (7.83)	not required
PHD – g's		15.85	15.51	not required
ASI		1.03	1.08	not required

Figure 46. Summary of Test Results and Sequential Photographs, Test No. GSH-1

6 DESIGN DETAILS TEST NO. GSH-2

The barrier system test installation for test no. GSH-2 was composed of the same general barrier hardware that was in test no. GSH-1, but the longitudinal gap between barrier nos. 8 and 9 was reduced to 36 in. (914 mm) wide, as shown in Figures 47 through 61. Photographs of the test installation are shown in Figures 62 through 65. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix B.

The gap-spanning hardware remained the same as used in test no. GSH-1, but the number of stiffener assemblies installed between the two nested thrie-beam sections was reduced from three in test no. GSH-1 to one in test no. GSH-2 due to the reduction in gap length. The reduced gap length also resulted in the anchors for the thrie-beam guardrail sections being mounted farther upstream on barrier no. 8 and farther downstream on barrier no. 9; since, the thrie-beam guardrail sections remained 12.5 ft (3.8 m) in length, as previously tested. The guardrail sections with terminal connectors were anchored to both the traffic and non-traffic sides of the PCBs adjacent to the gap using five ¾-in. diameter × 6-in. long (19-mm × 152-mm) Powers Fasteners galvanized wedge bolts at each end. The thrie-beam section on the traffic side of the installation was again offset 5 in. (127 mm) upstream relative to the thrie-beam section on the opposite side of the barrier, as shown in Figure 49. Additionally, a 229-in. long × ⅝-in. thick (5,817-mm × 16-mm) ASTM A572 Grade 50 steel toe plate was bolted to the base of barrier nos. 8 and 9 on each side of the system. Each of the steel toe plates spanned the 12.5-ft (3.8-m) long gap and were anchored to the PCB with four ¾-in. diameter × 6-in. long (19-mm × 152-mm) Powers Fasteners galvanized wedge bolts at each toe plate end.

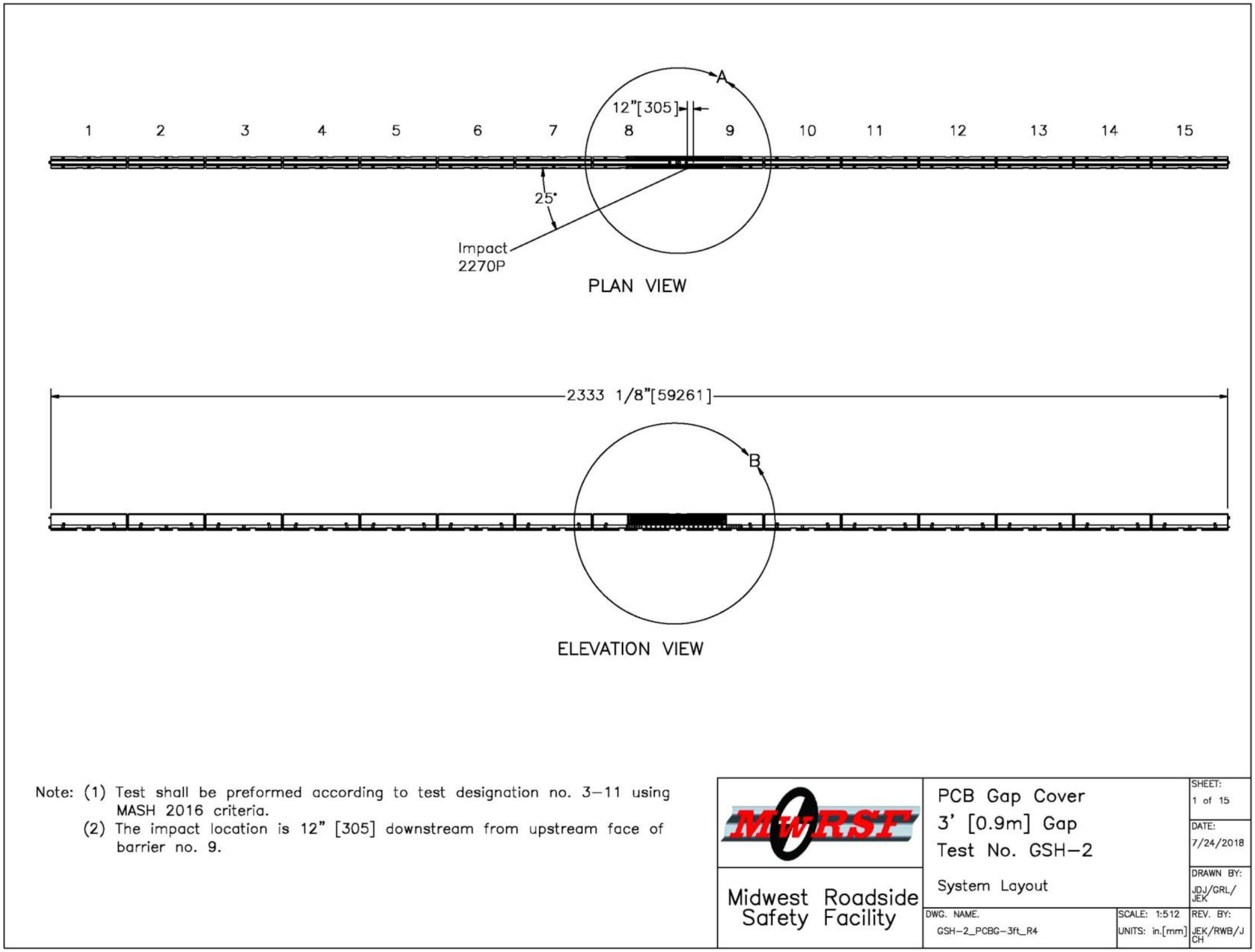


Figure 47. Test Installation Layout, Test No. GSH-2

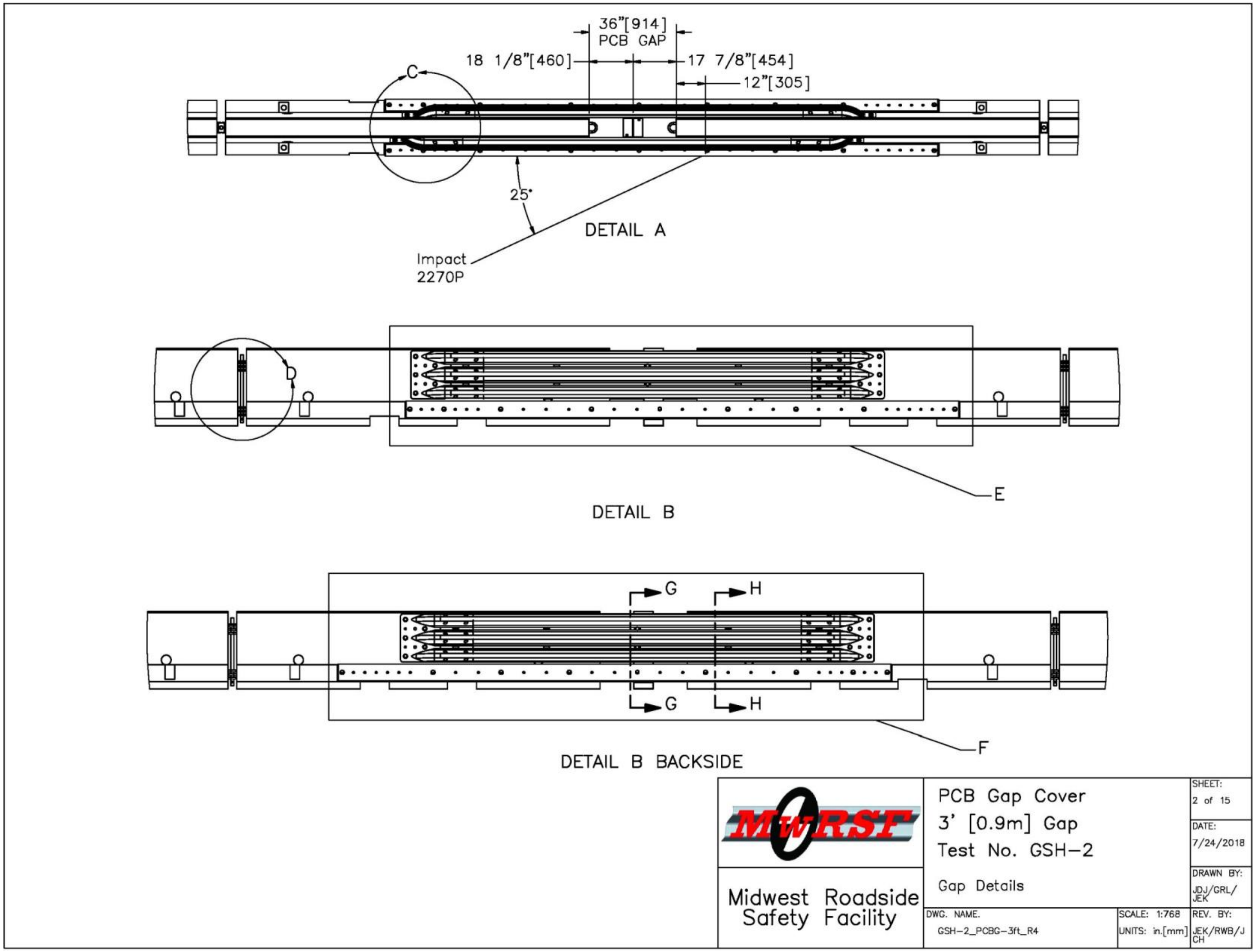


Figure 48. Gap Details, Test No. GSH-2

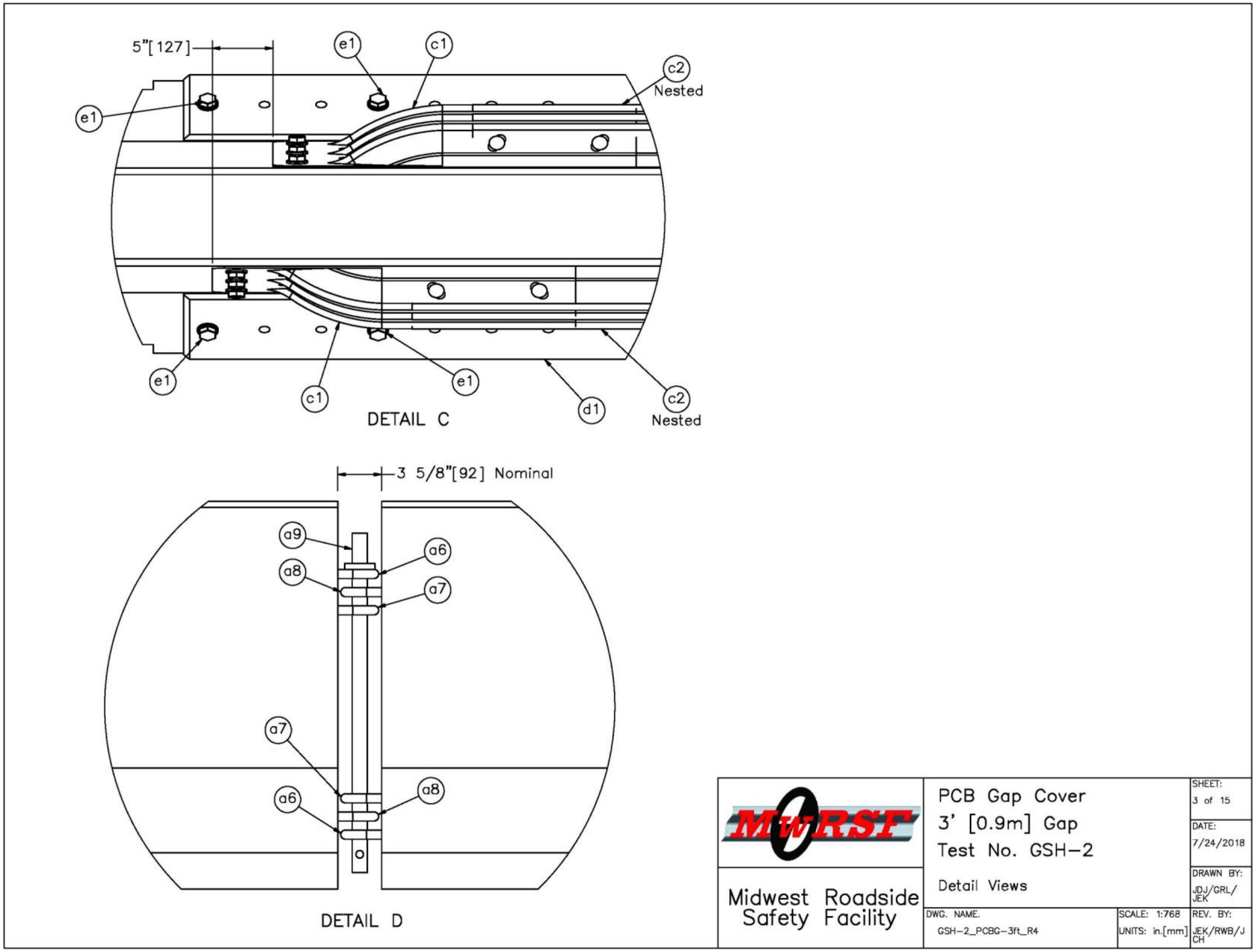
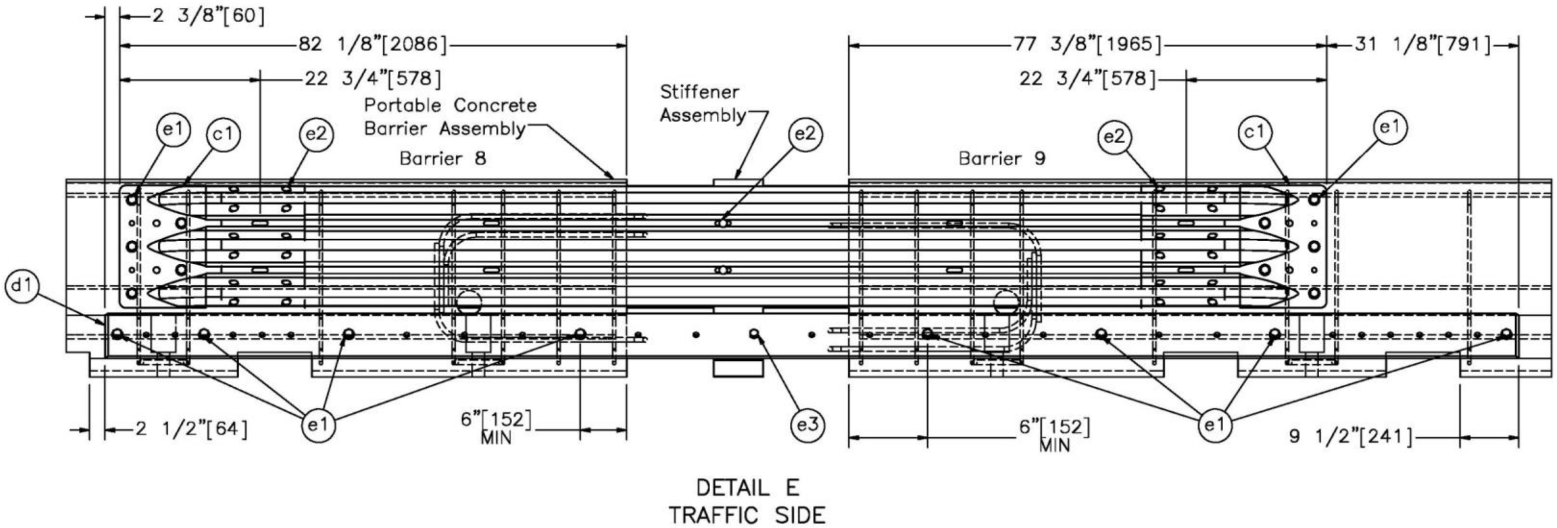


Figure 49. Detail C and Detail D Views, Test No. GSH-2



Toe Anchor Bolt Placement:

(1) A minimum of 4 anchors are to be used on each end of toe plates (part d1).
(2) A bolt must be placed in the first hole located at least 6" [152] away from PCB gap.
(3) A Bolt must be placed in end holes of toe plate (part d1).
(4) Anchor Bolts may not be placed with 6" [152] of bolt pocked centers or within 4" [102] of drainage slots or other edges
(5) Space remaining 2 anchors as evenly as possible.

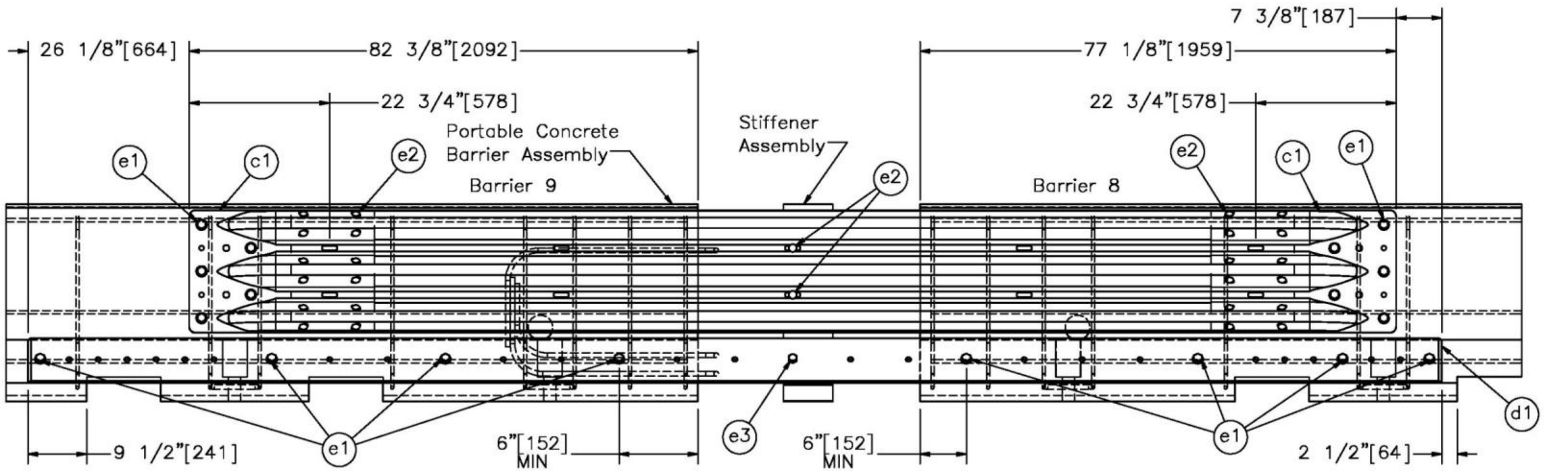
Terminal Connector Anchor Bolt Placement:

(6) A minimum of 5 anchor bolts (part e1) must connect each terminal connection to PCB.
(7) Three anchor bolts should be in end holes. Shift connection 2" [51] upstream or downstream, if necessary.
(8) The remaining 2 anchor bolts should be installed in intermediate holes in terminal connection or through bolt slots a minimum of 6" [152] away from PCB end.
(9) Anchor bolts should be a minimum of 3" [76] from lifting hole.

Note: No wedge bolt (part e1) can be installed, removed, and reinstalled in the same hole.
* Anchors nearest the gap were installed in drilled holes 3" [76] upstream of the locations shown to avoid rebar interference.

MwRSF	PCB Gap Cover 3' [0.9m] Gap Test No. GSH-2		SHEET: 4 of 15 DATE: 7/24/2018
Midwest Roadside Safety Facility	Anchor Bolt Connection Details – Traffic Side		DRAWN BY: JDJ/GRL/JEK
	DWG. NAME. GSH-2_PCBG-3ft_R4	SCALE: 1:768 UNITS: in.[mm]	REV. BY: JEK/RWB/JCH

Figure 50. Anchor Bolt Connection Details – Traffic Side, Test No. GSH-2



DETAIL F
NON–TRAFFIC SIDE

Toe Anchor Bolt Placement:

(1) A minimum of 4 anchors are to be used on each end of toe plates (part d1).
(2) A bolt must be placed in the first hole located at least 6" [152] away from PCB gap.
(3) A Bolt must be placed in end holes of toe plate (part d1).
(4) Anchor Bolts may not be placed with 6" [152] of bolt pocked centers or within 4" [102] of drainage slots or other edges
(5) Space remaining 2 anchors as evenly as possible.

Terminal Connector Anchor Bolt Placement:

(6) A minimum of 5 anchor bolts (part e1) must connect each terminal connection to PCB.
(7) Three anchor bolts should be in end holes. Shift connection 2" [51] upstream or downstream, if necessary.
(8) The remaining 2 anchor bolts should be installed in intermediate holes in terminal connection or through bolt slots a minimum of 6" [152] away from PCB end.
(9) Anchor bolts should be a minimum of 3" [76] from lifting hole.

Note: No wedge bolt (part e1) can be installed, removed, and reinstalled in the same hole.

Midwest Roadside Safety Facility	PCB Gap Cover 3' [0.9m] Gap Test No. GSH–2		SHEET: 5 of 15 DATE: 7/24/2018
	Anchor Bolt Connection Details – Non Traffic Side		DRAWN BY: JDJ/GRL/JEK
	DWG. NAME. GSH–2_PCBG–3ft_R4	SCALE: 1:768 UNITS: in.[mm]	REV. BY: JEK/RWB/JCH

Figure 51. Anchor Bolt Connection Details – Non-Traffic Side, Test No. GSH-2

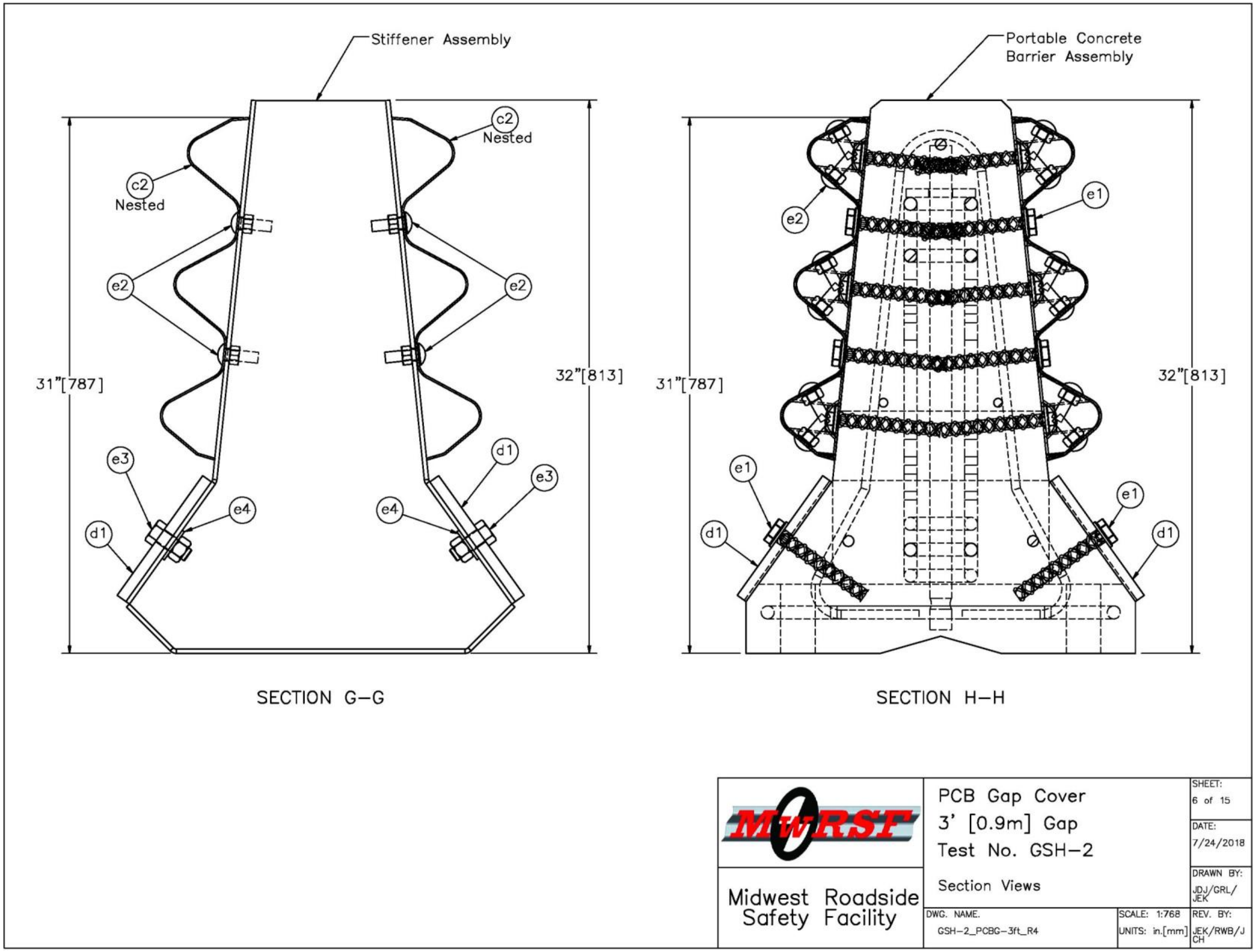
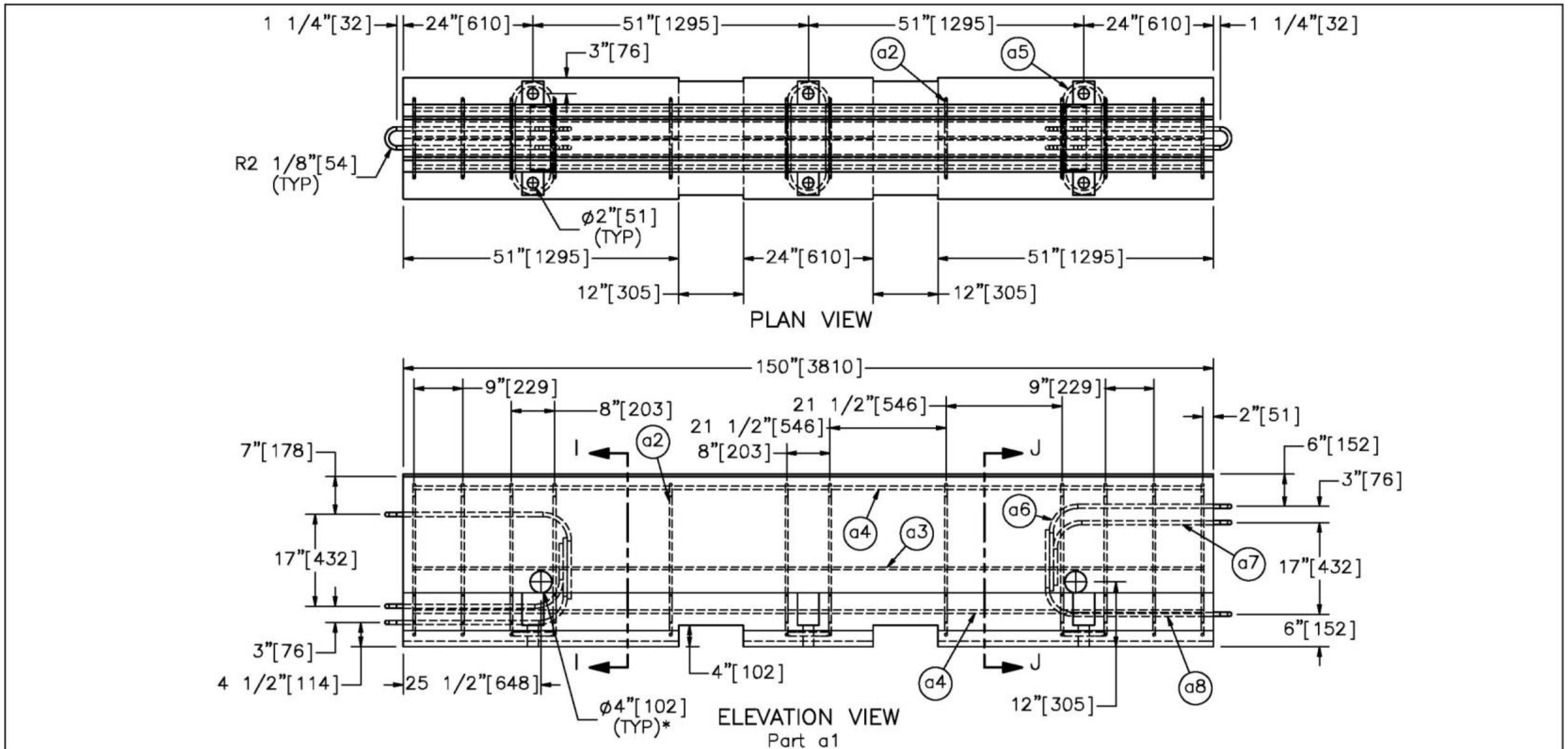


Figure 52. Section G-G and Section H-H Views, Test No. GSH-2



Item No.	QTY.	Description	Material Specification	Hardware Guide
–	15	Portable Concrete Barrier Assembly	–	SWC09
a1	1	Portable Concrete Barrier	Min f'c = 5,000 psi [34.5 MPa]	–
a2	12	#4 [13] Rebar, 72" [1,829] Total Unbent Length	ASTM A615 Gr. 60	–
a3	2	#4 [13] Rebar, 146" [3,708] Total Length	ASTM A615 Gr. 60	–
a4	3	#5 [16] Rebar, 146" [3,708] Total Length	ASTM A615 Gr. 60	–
a5	6	#6 [19] Rebar, 36" [914] Total Unbent Length	ASTM A615 Gr. 60	–
a6	2	#6 [19] Rebar, 101" [2,565] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–
a7	2	#6 [19] Rebar, 91" [2,311] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–
a8	2	#6 [19] Rebar, 102" [2,591] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–

*Hole in tested barrier 1/2" [25] smaller than design

Midwest Roadside Safety Facility

PCB Gap Cover
3' [0.9m] Gap
Test No. GSH-2

Portable Concrete Barrier Details

SHEET:	DATE:	DRAWN BY:	DWG. NAME.	SCALE:	UNITS:	REV. BY:
7 of 15	7/24/2018	JDJ/GRL/JEK	GSH-2_PCBG-3ft_R4	1:64	in.[mm]	JEK/RWB/JCH

Figure 53. PCB Details, Test No. GSH-2

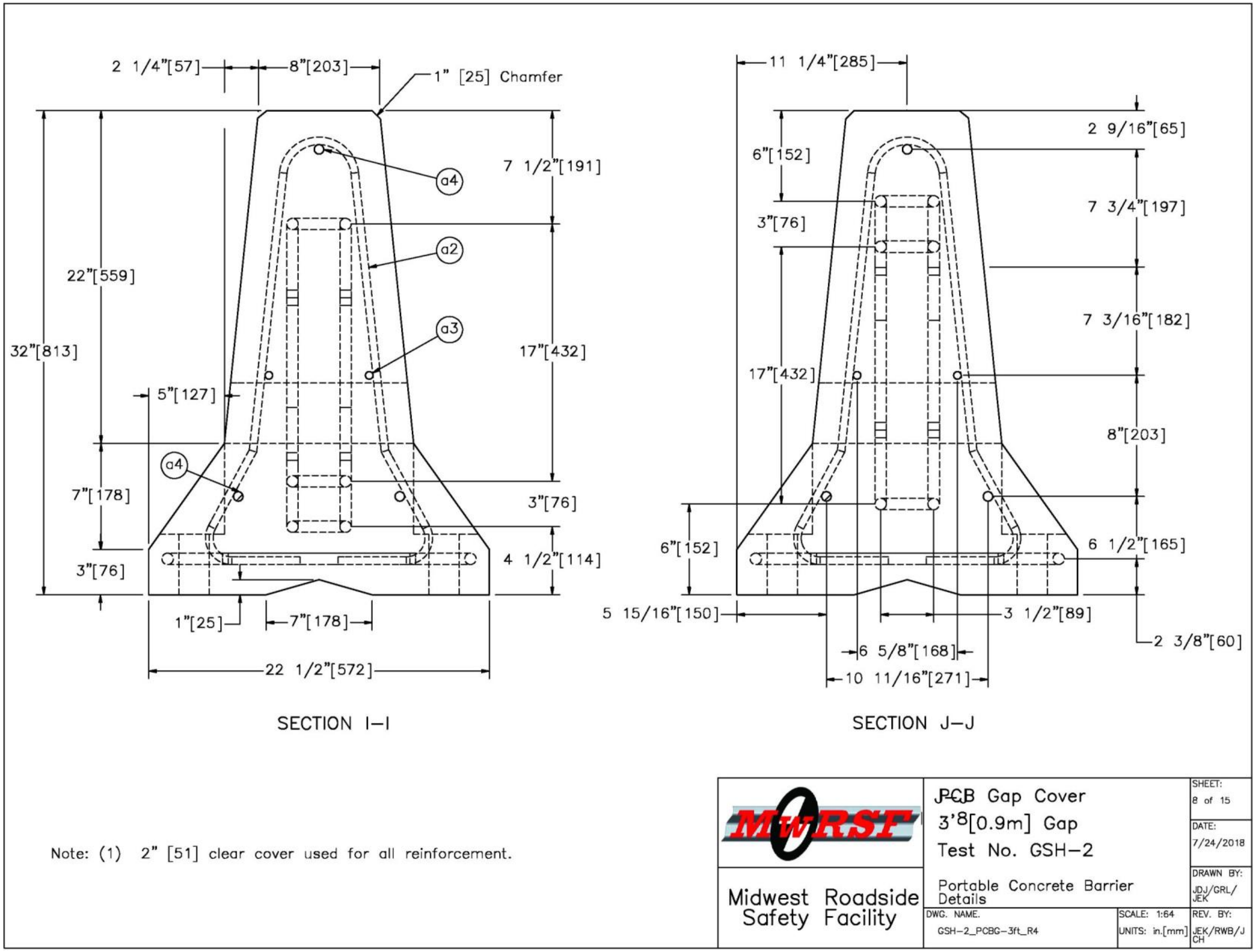
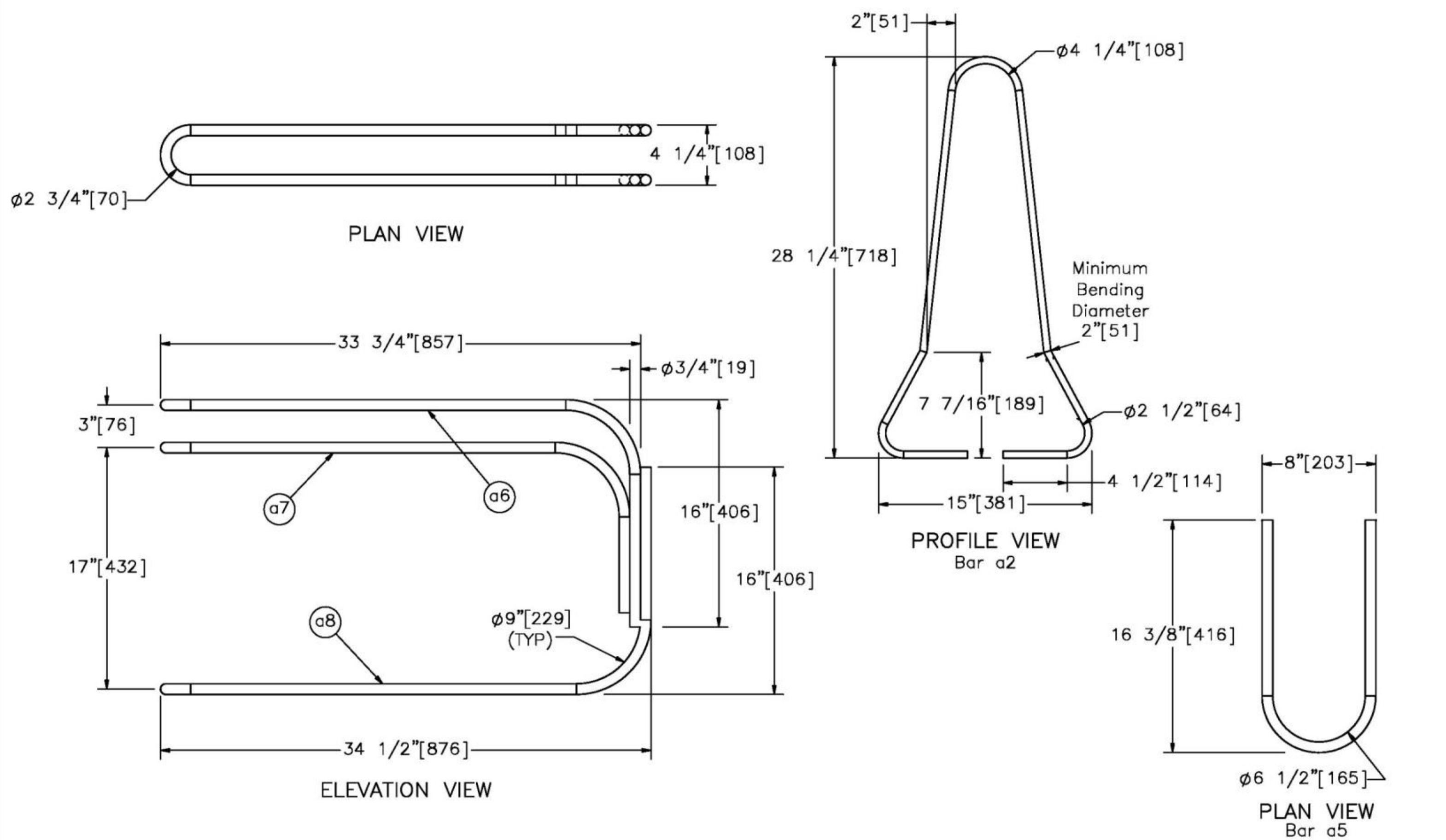


Figure 54. PCB Details, Section I-I and Section J-J, Test No. GSH-2



Note: (1) Bar quantities are per barrier (Part a1).

Bill of Bars				
Bar	QTY	Size	Total Length	Material
a2	12	#4	72"[1829]	A615 Gr.60
a3	2	#4	146"[3708]	A615 Gr.60
a4	3	#5	146"[3708]	A615 Gr.60
a5	6	#6	36"[914]	A615 Gr.60
a6	2	#6	101"[2565]	A709 Gr.70 or A706 Gr.60
a7	2	#6	91"[2311]	A709 Gr.70 or A706 Gr.60
a8	2	#6	102"[2591]	A709 Gr.70 or A706 Gr.60

Midwest Roadside Safety Facility

PCB Gap Cover
3' [0.9m] Gap
Test No. GSH-2

Portable Concrete Barrier Rebar Details

SHEET: 9 of 15
DATE: 7/24/2018
DRAWN BY: JDJ/GRL/JEK
DWG. NAME. GSH-2_PCBG-3ft_R4
SCALE: 1:8
UNITS: in.[mm]
REV. BY: JEK/RWB/JCH

Figure 55. PCB Rebar Details, Test No. GSH-2

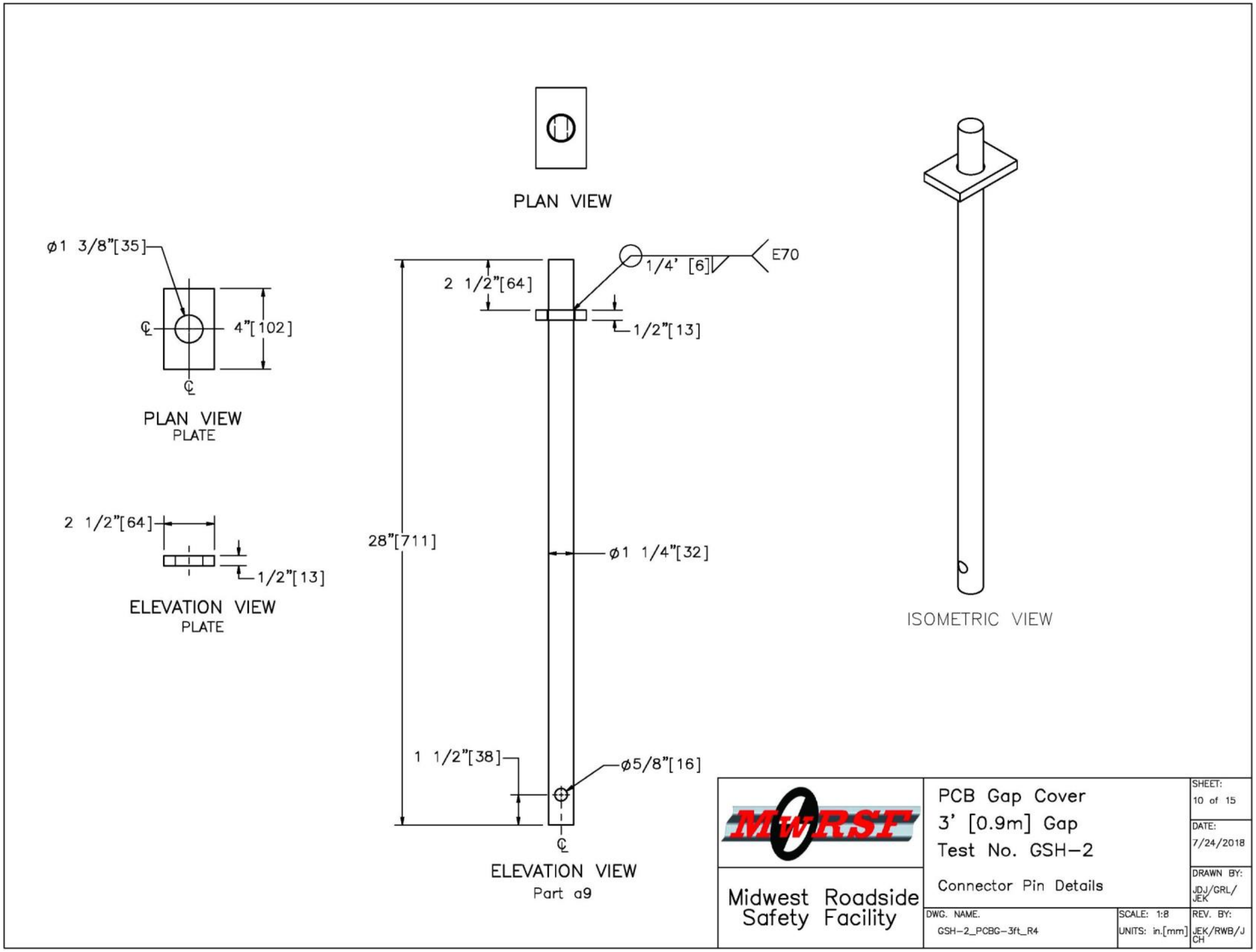
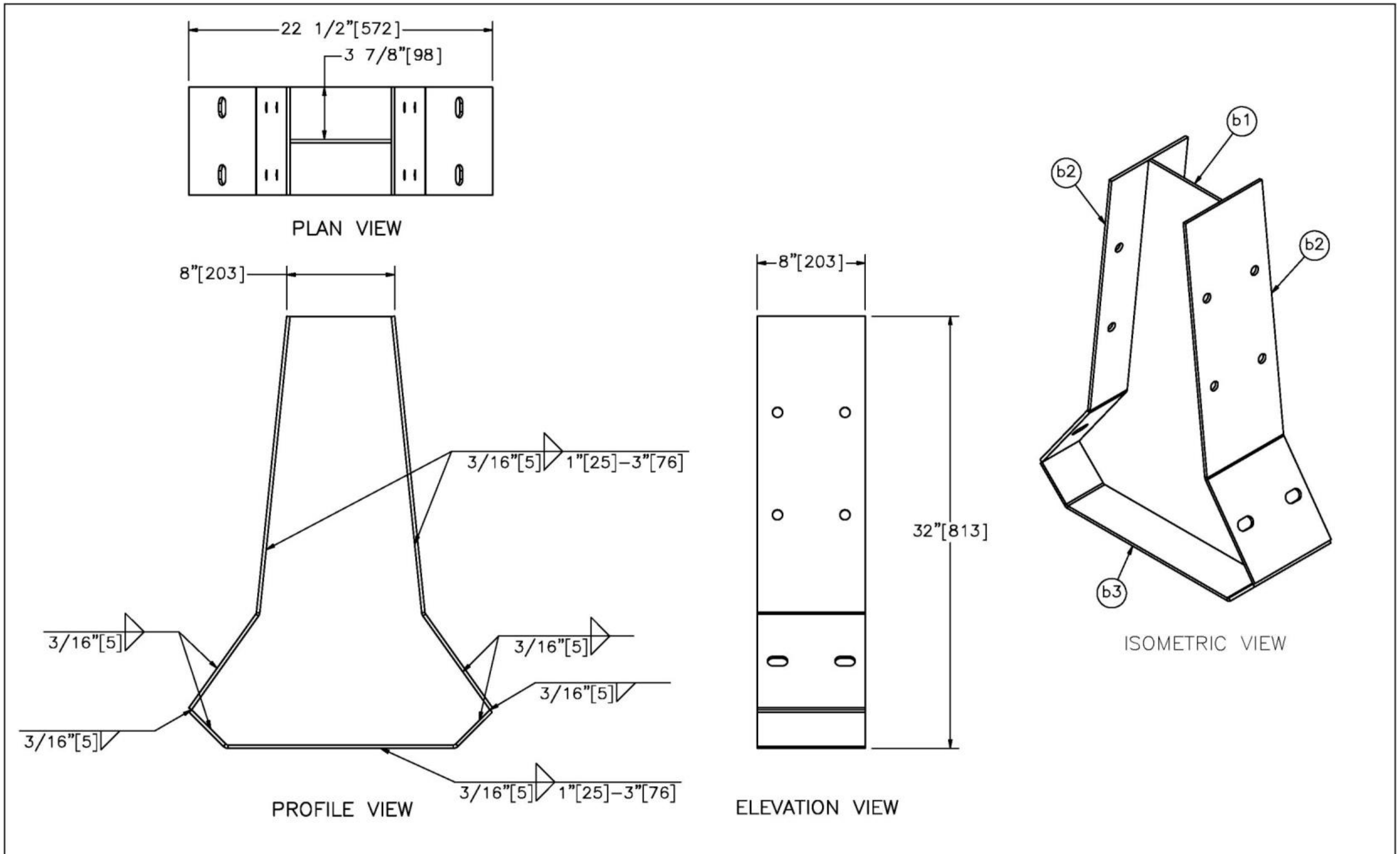


Figure 56. Connector Pin Details, Test No. GSH-2



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Stiffner Assembly	–	ASTM A123
b1	1	31 3/4"x22 1/16"x1/4" [806x561x6] Steel Plate	ASTM A36	–
b2	2	30 3/4"x8"x1/4" [782x203x6] Bent Steel Plate	ASTM A36	–
b3	1	24 7/16"x8"x1/4" [620x203x6] Bent Steel Plate	ASTM A36	–

MwRSF
Midwest Roadside Safety Facility

PCB Gap Cover
3' [0.9m] Gap
Test No. GSH-2
Stiffener Assembly

SHEET: 11 of 15
DATE: 7/24/2018
DRAWN BY: JDJ/GRL/JEK
DWG. NAME. GSH-2_PCBG-3ft_R4
SCALE: 1:16
UNITS: in.[mm]
REV. BY: JEK/RWB/JCH

Figure 57. Stiffener Assembly, Test No. GSH-2

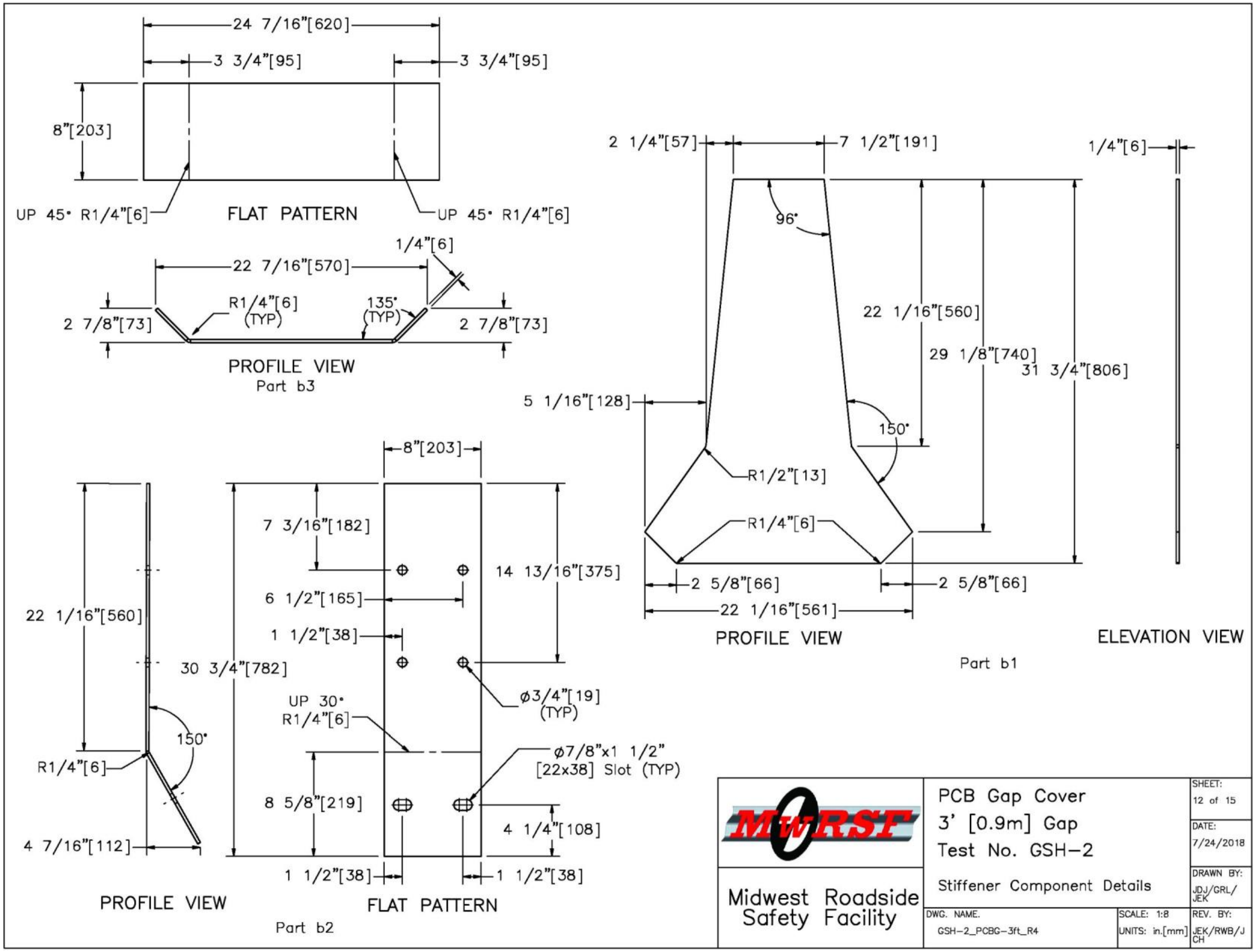


Figure 58. Stiffener Component Details, Test No. GSH-2

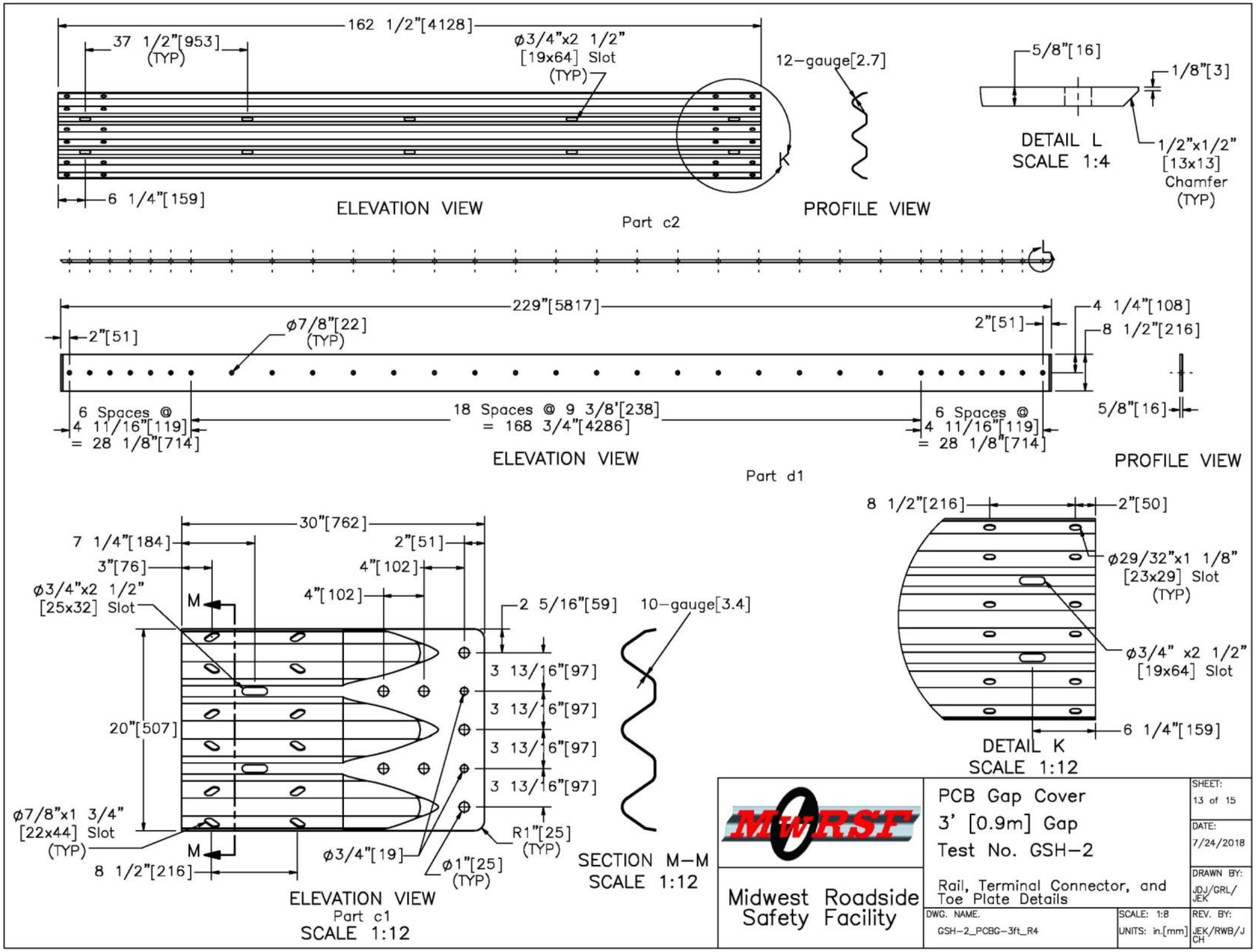


Figure 59. Rail, Terminal Connector, and Toe Plate Details, Test No. GSH-2

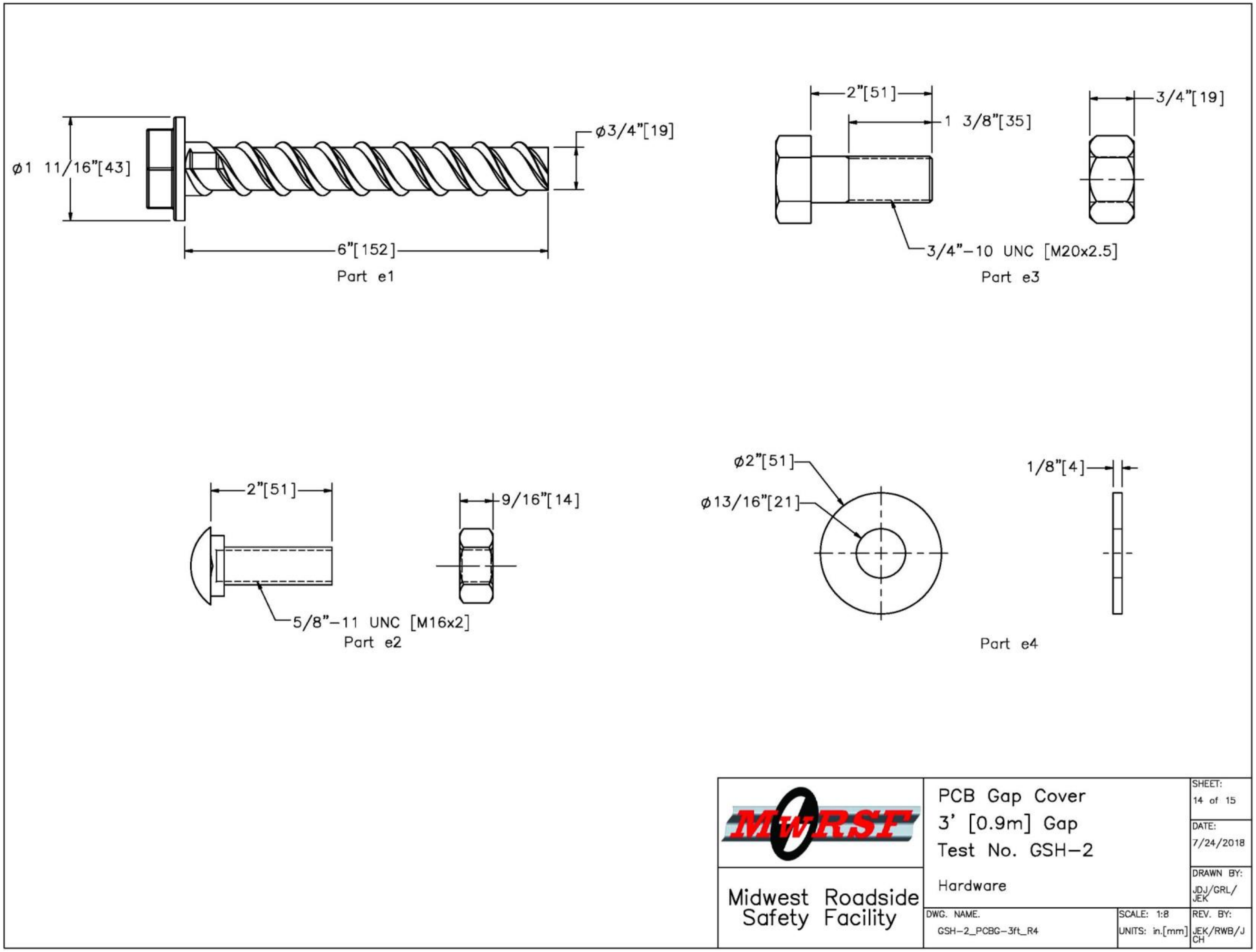


Figure 60. Hardware, Test No. GSH-2

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	15	Portable Concrete Barrier	Min f'c = 5,000 psi [34.5 MPa]	–	–
a2	180	#4 [13] Rebar, 72" [1,829] Total Unbent Length	ASTM A615 Gr. 60	–	–
a3	30	#4 [13] Rebar, 146" [3,708] Total Length	ASTM A615 Gr. 60	–	–
a4	45	#5 [16] Rebar, 146" [3,708] Total Length	ASTM A615 Gr. 60	–	–
a5	90	#6 [19] Rebar, 36" [914] Total Unbent Length	ASTM A615 Gr. 60	–	–
a6	30	#6 [19] Rebar, 101" [2,565] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–	–
a7	30	#6 [19] Rebar, 91" [2,311] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–	–
a8	30	#6 [19] Rebar, 102" [2,591] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	–	–
a9	13	1 1/4" [32] Dia., 28" [711] Long Connector Pin	ASTM A36	–	FMW02
b1	1	31 3/4"x22 1/16"x1/4" [806x561x6] Steel Plate	ASTM A36	–	–
b2	2	30 3/4"x8"x1/4" [782x203x6] Bent Steel Plate	ASTM A36	–	–
b3	1	24 7/16"x8"x1/4" [620x203x6] Bent Steel Plate	ASTM A36	–	–
c1	4	10–gauge [3.4] Thrie Beam Terminal Connector	AASHTO M180 Min. Yield Strength = 50 ksi [345 MPa] Min. Ultimate Strength = 70 ksi [483 MPa]	ASTM A123 or A653	RTE01b
c2	4	12'–6" [3,810] 12–gauge [2.7] Thrie Beam Section	AASHTO M180	ASTM A123 or A653	RTM04b
d1	2	229"x8 1/2"x5/8" [5,817x216x16] Steel Plate	ASTM A572 Gr. 50	ASTM A123	–
e1	36	3/4" [19] Dia., 6" [152] Long Powers Fasteners Wedge Bolt+	As Supplied	As Supplied	FBX02
e2	52	5/8"–11 UNC [M16x2], 2" [51] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB02
e3	2	3/4"–10 UNC [M20x2.5], 2" [51] Long Heavy Hex Head Bolt and Nut	Bolt – ASTM F3125 Gr. A325 Type 1 or equivalent Nut – ASTM A563DH or equivalent	ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 or F2833 Gr. 1	FBX20b
e4	2	3/4" [19] Dia. Plain Flat Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC20a

Midwest Roadside Safety Facility

PCB Gap Cover
3' [0.9m] Gap
Test No. GSH–2

Bill of Materials

SHEET: 15 of 15
DATE: 7/24/2018
DRAWN BY: JDJ/GRL/JEK
DWG. NAME. GSH–2_PCBG–3ft_R4
SCALE: 1:8
UNITS: in.[mm]
REV. BY: JEK/RWB/JCH

Figure 61. Bill of Materials, Test No. GSH-2

Figure 62. Test Installation Photographs, Test No. GSH-2

Figure 63. Test Installation Photographs, Test No. GSH-2

Figure 64. Test Installation Photographs, Test No. GSH-2

Figure 65. Test Installation Photographs, Gap-Spanning Hardware Anchorage, Test No GSH-2

7 FULL-SCALE CRASH TEST NO. GSH-2 [3-FT (0.9-M) GAP]

7.1 Weather Conditions

Test no. GSH-2 was conducted on July 27, 2018 at approximately 11:30 a.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 8.

Table 8. Weather Conditions, Test No. GSH-2

Temperature	78° F
Humidity	47 %
Wind Speed	7 mph
Wind Direction	50° from True North
Sky Conditions	Cloudy
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

7.2 Test Description

Initial vehicle impact was to occur 12 in. (305 mm) downstream from the upstream end of barrier no. 9, as shown in Figure 66, which was selected using LS-DYNA analysis to evaluate the stability of the vehicle during impact. The 5,013-lb (2274-kg) Dodge quad cab pickup truck impacted the PCB gap-spanning hardware at a speed of 61.9 mph (99.6 km/h) and at an angle of 24.9 degrees. The actual point of impact was 14.4 in. (366 mm) downstream from the upstream end of barrier no. 9. The pickup truck impacted the PCB gap-spanning hardware with an impact severity of 113.4 kip-ft (153.7 kJ), which exceeded the minimum 106 kip-ft (144-kJ) limit from MASH 2016. During the impact, the vehicle was captured and redirected by the combination of the gap-spanning hardware and the PCB segments. While some roll and pitch of the vehicle was observed, vehicle stability remained satisfactory throughout the impact event. The vehicle came to rest 176 ft – 8 in. (53.8 m) downstream from the initial impact point and 2 in. (51 mm) in front of the face on the traffic side of the barrier system after brakes were applied.

A detailed description of the sequential impact events is contained in Table 9. Sequential photographs are shown in Figures 67 and 68. Documentary photographs of the crash test are shown in Figures 69 and 70. The vehicle trajectory and final position are shown in Figure 71.

Table 9. Sequential Description of Impact Events, Test No. GSH-2

TIME (sec)	EVENT
0.000	Vehicle's front bumper contacted rail 14.4 in. (366 mm) downstream from upstream end of barrier no. 9.
0.006	Vehicle's windshield cracked, left-front tire contacted barrier no. 9, and left fender contacted rail.
0.014	Vehicle's left fender contacted barrier no. 9.
0.030	Barrier no. 9 rolled away from traffic-side face of system.
0 042	Barrier no. 8 spalled on backside, downstream end.
0.044	Barrier no. 8 rotated counterclockwise, and vehicle's front bumper reached end of thrie beam rail and contacted face of barrier no. 9.
0.056	Vehicle's left-front door contacted rail and deformed.
0.062	Barrier no. 9 cracked on back side between midspan and downstream end of barrier.
0.064	Barrier no. 7 rotated clockwise.
0.066	Barrier no. 8 spalled on backside, upstream end, and barrier no. 9 deflected backward.
0.070	Barrier no. 10 rotated clockwise, and vehicle rolled toward system.
0.078	Barrier no. 9 cracked, and portion detached from back side between midspan and downstream end of barrier.
0.094	Vehicle's right-front tire became airborne.
0.098	Vehicle pitched upward.
0.114	Barrier no. 8 deflected backward, and barrier no. 11 rotated counterclockwise.
0.120	Barrier no. 10 rolled away from traffic side of system.
0.122	Barrier no. 8 rolled toward traffic side of system.
0.126	Surrogate occupant's head crossed door threshold.
0.130	Vehicle's front bumper contacted barrier no. 10.
0.136	Vehicle's left-front tire ruptured.
0.152	Vehicle's right-rear tire became airborne.
0.160	Barrier no. 11 cracked on back side between midspan and upstream end of barrier.
0.262	Vehicle was parallel to system with velocity of 47.9 mph (77.1 km/h).
0.274	Vehicle's left-rear door contacted barrier no. 10.
0.276	Vehicle's left quarter panel contacted barrier no. 9.
0.286	Vehicle's front bumper contacted barrier no. 11.
0.334	Vehicle pitched downward.
0.342	Vehicle's left-front tire became airborne.

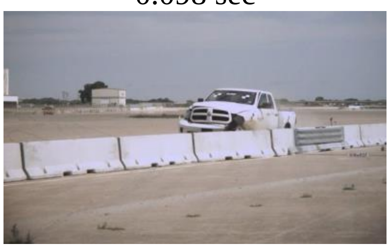
Table 10. Sequential Description of Impact Events, Test No. GSH-2, Cont.

TIME (sec)	EVENT
0.432	Vehicle’s left-rear tire became airborne.
0.442	Barrier no. 11 spalled on back side between midspan and upstream end of barrier.
0.586	Vehicle’s left-front tire regained contact with ground.
0.602	Vehicle’s left-rear door contacted barrier no. 12.
0.624	Vehicle’s left quarter panel contacted barrier no. 12.
0.652	Vehicle exited system at an angle of 11.5 degrees at a speed of 45.9 mph (73.8 km/h).
0.662	Vehicle’s front bumper contacted ground.
0.730	Vehicle yawed toward system.
1.052	Barrier system came to rest.
1.150	Vehicle pitched upward.
1.478	Vehicle’s right-front tire regained contact with ground.
1.626	Vehicle’s left-rear and right-rear tires regained contact with ground.
1.744	Vehicle rolled toward system.
1.762	Vehicle pitched downward.
1.838	Vehicle’s right-rear tire became airborne.
2.082	Vehicle pitched upward.
2.096	Vehicle rolled away from system.
2.284	Vehicle’s right-rear tire regained contact with ground.

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


0.000 sec


0.098 sec


0.200 sec


0.278 sec


0.458 sec


0.652 sec


0.000 sec


0.042 sec


0.120


0.220 sec


0.398 sec

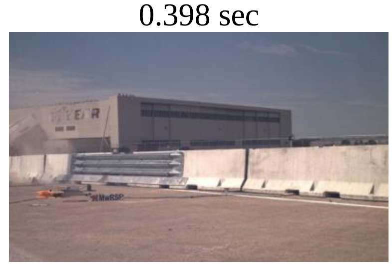
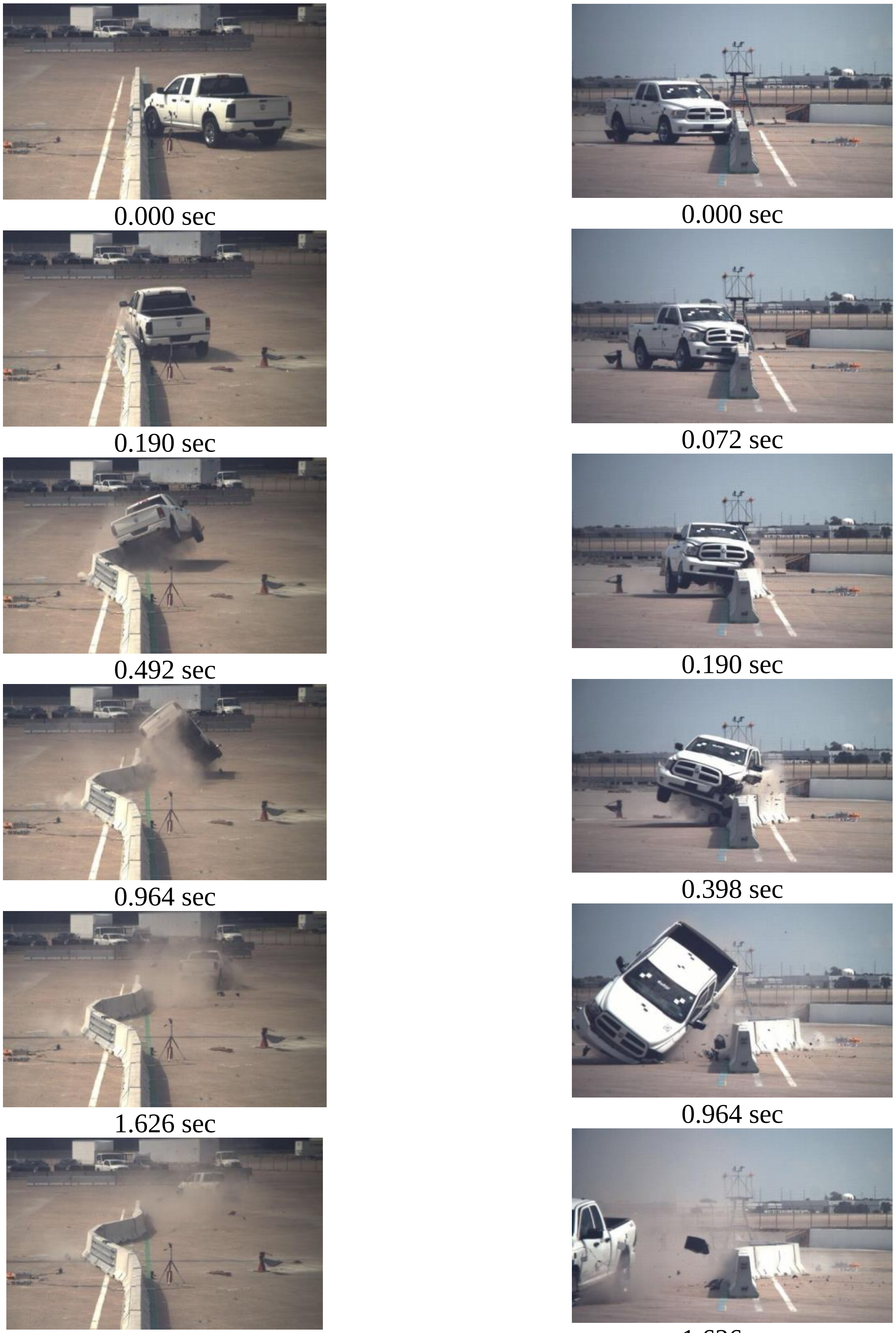

1.150 sec

Figure 67. Sequential Photographs, Test No. GSH-2



0.000 sec

0.190 sec

0.492 sec

0.964 sec

1.626 sec

2.524 sec

0.000 sec

0.072 sec

0.190 sec

0.398 sec

0.964 sec

1.626 sec

Figure 68. Additional Sequential Photographs, Test No. GSH-2

Figure 69. Documentary Photographs, Test No. GSH-2

Figure 70. Additional Documentary Photographs, Test No. GSH-2

Figure 71. Vehicle Final Position and Trajectory Marks, Test No. GSH-2

7.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 72 through 78. Barrier damage consisted of deformation of the thrie-beam guardrail, contact marks on the front face of the thrie-beam and concrete segments, spalling of the concrete, and concrete cracking and failure. The length of vehicle contact along the barrier was approximately 24 ft – 2 in. (7.4 m), which spanned from 12 in. (305 mm) upstream from the center of the impact point target to 13 in. (330 mm) upstream from the downstream end of barrier no. 10. Secondary contact marks also occurred, which were 6 ft – 4 in. (1.9 m) in length and spanned from 57 in. (1,448 mm) upstream from the downstream end of barrier no. 11 to 19 in. (483 mm) downstream from the upstream end of barrier no. 12.

A 3½-in. long × 2-in. tall (89-mm × 51-mm) kink occurred on the bottom corrugation of the thrie-beam guardrail section 5 in. (127 mm) upstream from the target impact point. Two additional kinks occurred on the thrie-beam guardrail section located at the center of the target impact point on the middle and bottom corrugations. An 11-in. long × 1½-in. tall (279-mm × 38-mm) section of the thrie-beam guardrail middle corrugation flattened 2 in. (51 mm) downstream from the target impact point. At 4 in. (102 mm) downstream from the target impact point, a 5-in. long × 1½-in tall (127-mm × 38-mm) kink occurred on the bottom corrugation of the thrie-beam guardrail section. A 9½-in. long × 2½-in. tall (241-mm × 64-mm) dent was found on the middle corrugation of the thrie-beam guardrail 16 in. (406 mm) downstream from the target impact point, as shown in Figure 74. A 14-in. long × ½-in. tall (356-mm × 13-mm) kink occurred 28 in. (711 mm) downstream from the target impact point on the middle corrugation of the thrie-beam guardrail section. Additional rail flattening occurred 29 in. (737 mm) downstream from the target impact point on the middle corrugation measuring 20 in. long x 1½ in. tall (508 mm × 38 mm).

Damage to barrier no. 9 primarily consisted of cracking and spalling of the concrete. Cracking, which began at the middle of the barrier's top face and extended vertically down the rear face of the barrier to the ground, was observed 1½ in. (38 mm) downstream from the target impact point. Toe spalling occurred from the upstream end of barrier no. 9 to 110 in. (2,794 mm) downstream. Further cracking occurred 5½ in. (140 mm) downstream from the centerline of barrier no. 9 and extended across the entire height of the rear face, the top face, and 4 in. (102 mm) down the front face below the top edge. Concrete spalling occurred 13 in. (330 mm) downstream from the centerline of barrier no. 9 and 4½ in. (114 mm) from the top edge of the barrier. Additional cracking was found 24 in. (610 mm) downstream from the centerline of barrier no. 9, which started in the center of the top face of the barrier and extended down the entire height of the rear face of the barrier. Concrete spalling occurred 20½ in. (521 mm) below the top edge of the barrier at 25 in. (635 mm) downstream from the centerline of barrier no. 9, and at the anchor pocket located 54 in. (1,372 mm) downstream from the centerline of barrier no. 9. At 46 in. (1,168 mm) downstream from the target impact point, a 6-in. long × 2¼-in. wide × ¼-in. deep (152-mm ×57-mm × 6-mm) piece of concrete disengaged from the top of barrier no. 9. Additional toe spalling occurred 39 in. (991 mm) upstream from the downstream end of barrier no. 9 on the rear face the barrier, which disengaged a 9-in. long × 11-in. wide × 8-in. deep (229-mm × 279-mm × 203-mm) piece of concrete and resulted in the pull out of the farthest downstream toe plate anchor bolt on the rear face of the barrier, as shown in Figure 75.

Concrete spalling and contact marks were found on barrier no. 10, as shown in Figure 77. Minor concrete spalling occurred 1 in. (25 mm) downstream from the upstream end of the barrier.

Additional spalling occurred near the base of the barrier 20 in. (508 mm) upstream and 58 in. (1,473 mm) downstream from the centerline of barrier no. 10. Concrete cracking occurred 23 in. (584 mm) upstream of the centerline of barrier no. 10 on both the front and rear faces of the barrier. Damage to barrier no. 11 consisted primarily of concrete spalling. A 21½-in. long × 7½-in. wide × 3½-in. tall (546-mm × 191-mm × 89-mm) piece of concrete disengaged from the front toe on the front face of barrier no. 11, 10 in. (254 mm) downstream from the upstream edge of the barrier. On the non-traffic side of barrier no. 11, toe pull out occurred 24 in. (610 mm) downstream from the upstream edge of the barrier at the location of the anchor pocket, as shown in Figure 78. Additional spalling was found along the top face of barrier no. 11. Minor concrete spalling was also found on the front face of the upstream end of barrier no. 12.

The maximum lateral permanent set of the barrier system was 61⅜ in. (1,559 mm), which occurred at the upstream end of barrier no. 10, as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 62.7 in. (1,593 mm) at the upstream end of barrier no. 10, as determined from high-speed digital video analysis. The working width of the system was found to be 85.2 in. (2,164 mm), also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 79.

Figure 72. Overall System Damage, Test No. GSH-2

Figure 73. Overall System Damage (Non-traffic Side), Test No. GSH-2

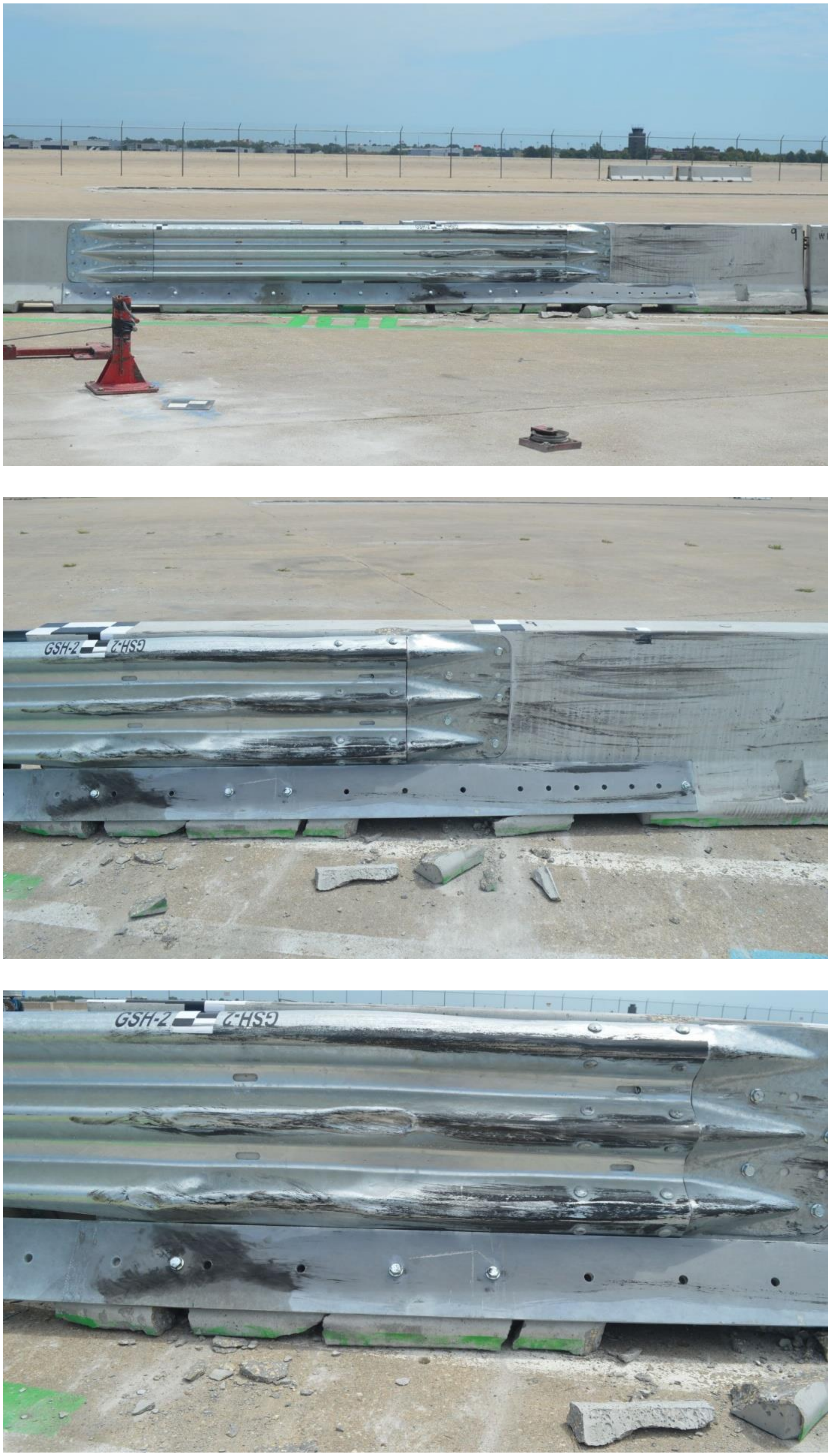


Figure 74. Thrie-Beam and Barrier No. 9 Damage, Test No. GSH-2

Figure 75. Barrier No. 9 Damage, Test No. GSH-2

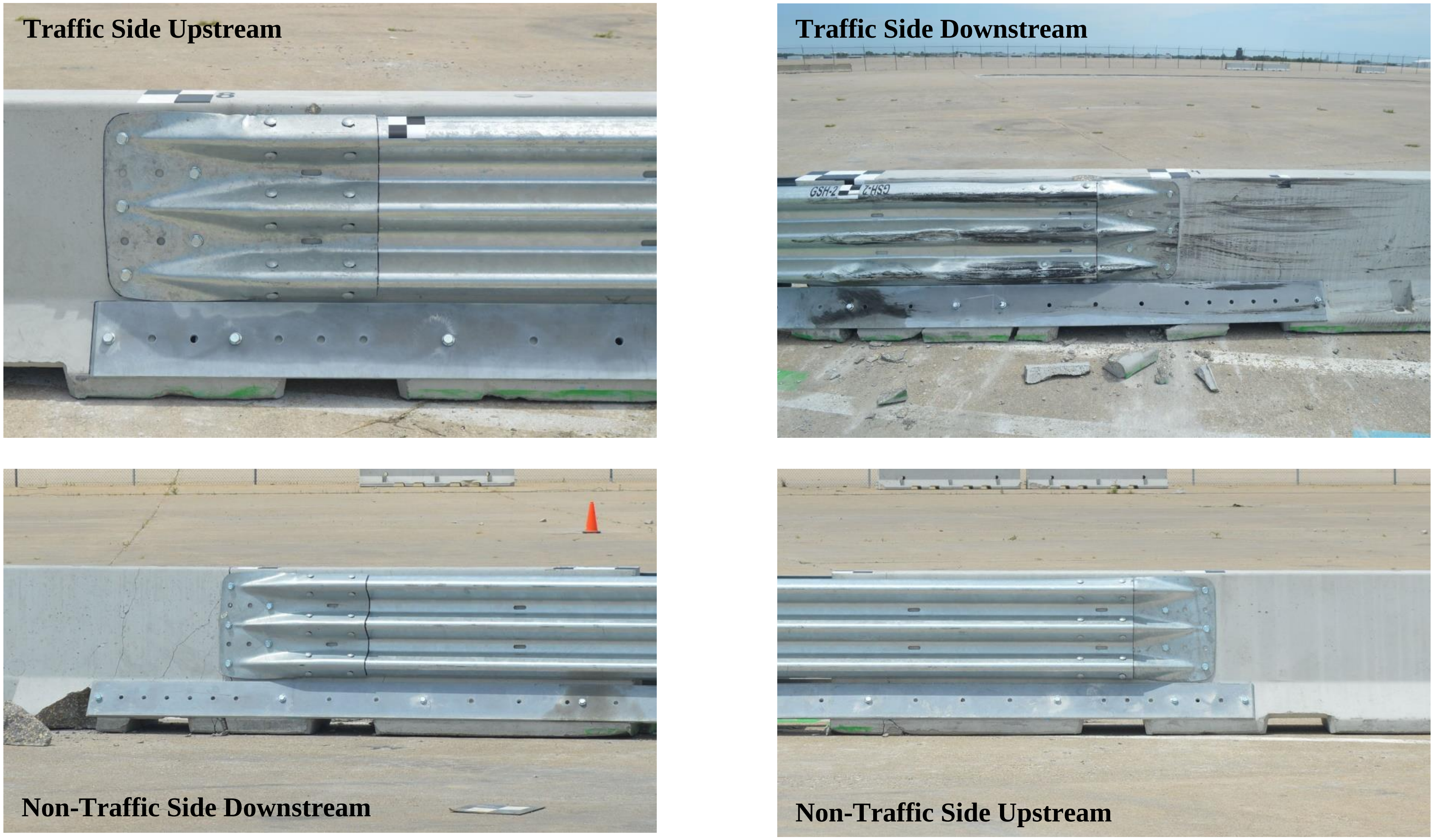


Figure 76. PCB Gap-Spanning Hardware Connection Damage, Test No. GSH-2

Figure 77. Barrier No. 10 Damage, Test No. GSH-2

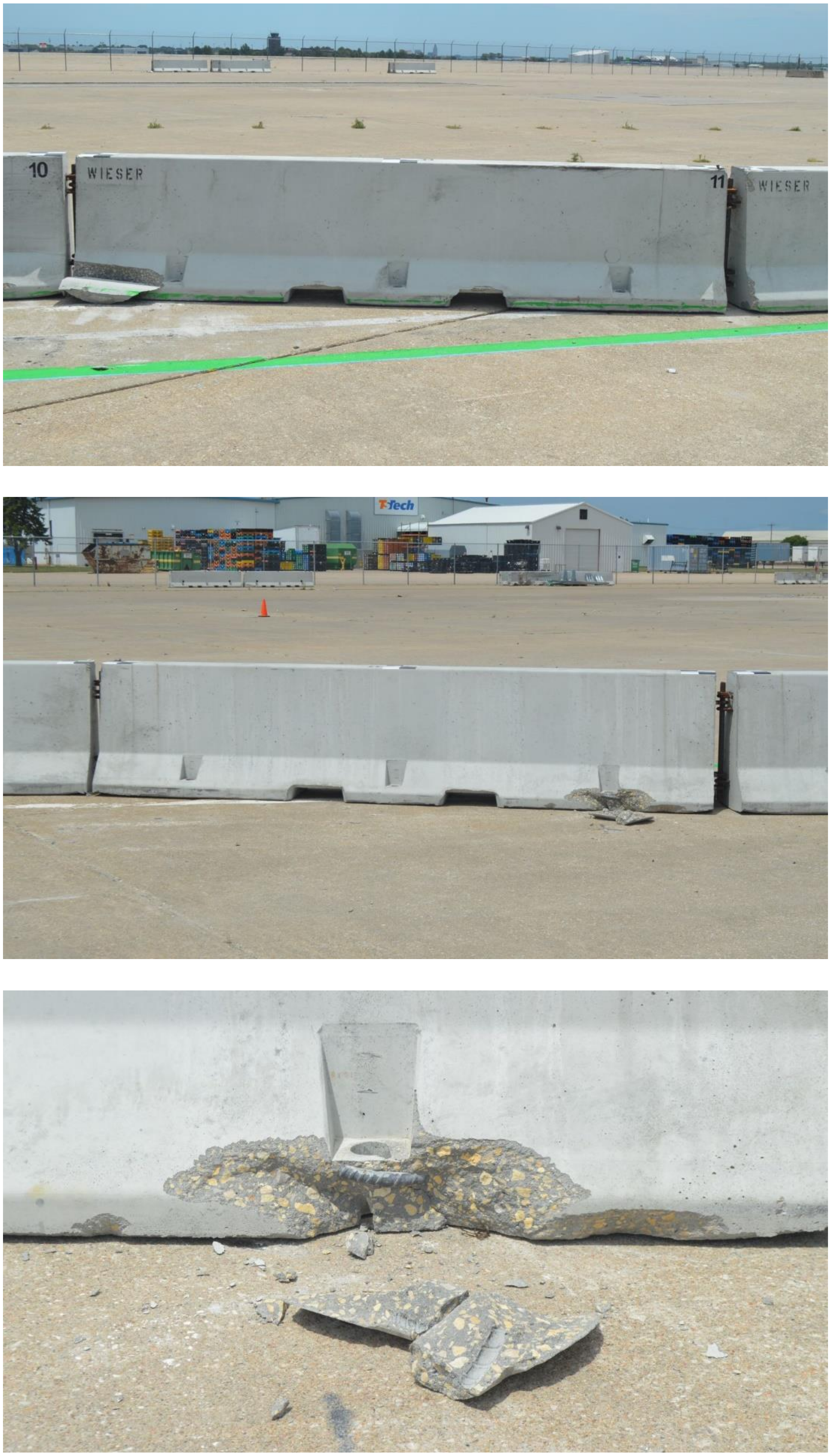


Figure 78. Barrier No. 11 Damage, Test No. GSH-2

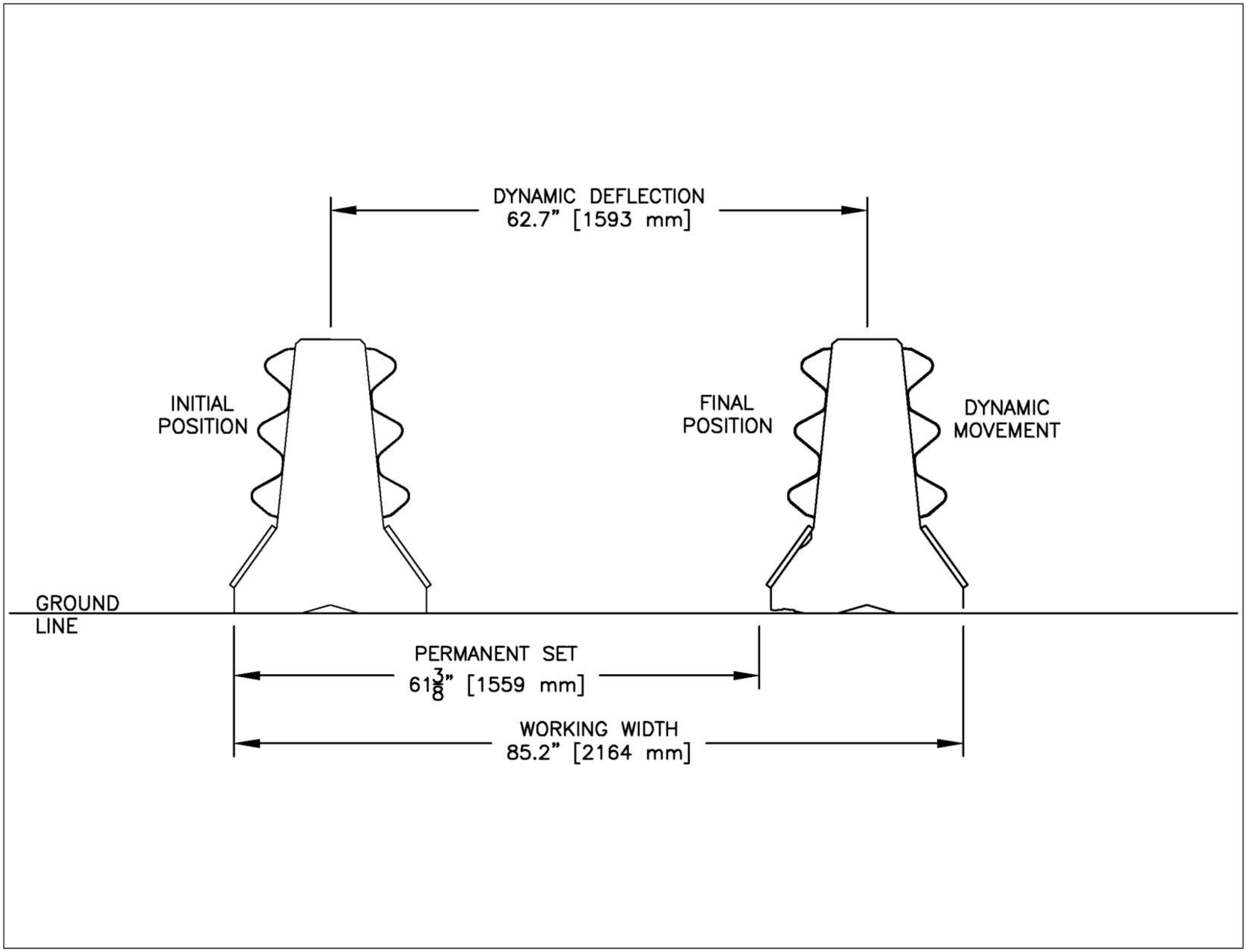


Figure 79. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. GSH-2

7.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 80 through 83. The maximum occupant compartment deformations are listed in Table 11 along with the deformation limits established in MASH 2016 for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment and none of the established MASH 2016 deformation limits were violated. Outward deformations, which are denoted as negative numbers in Appendix C, are not considered crush toward the occupant, and are not evaluated by MASH 2016 criteria.

Majority of damage was concentrated on the left-front corner and left side of the vehicle, where the impact had occurred. The front bumper fractured at the lower-left corner of the grille and the entire front bumper disengaged from the vehicle. The left-front fender was pushed upward near the door panel and was dented and torn behind the left-front wheel. The left-front steel rim was severely deformed with tears and significant crushing, as shown in Figure 82. The sway/anti-roll bar disengaged from the lower control arm on the front left side of the vehicle. The lower-left control arm disengaged and fractured into three pieces. The left-side tie rod fractured at the steering knuckle joint and disengaged. The rear engine cross member buckled downward, and the frame buckled inward in front of the rear transmission mount on the left side of the vehicle. The engine and transmission shifted due to the fracture of two of the four engine mount bolts on the left side of the vehicle. The left-front tire was torn along the tread and deformed.

The left-side headlight and fog light were removed from the vehicle. Denting and scraping were observed on the entire left side of the vehicle with majority of the damage located at the left-front and left-rear doors, as shown in Figure 81. The left-front door was ajar at the top of the door frame, and creases were found in the sheet metal on both the left-front and left-rear doors. The left-rear steel rim was crushed, and a puncture and scuff marks were found on the tire. The left side of the rear bumper was dented and scuffed below the left taillight. A gap occurred between the hood and both the left and right fenders due to deformation from impact. The roof was undamaged following the test, and the side windows remained intact. The windshield was cracked prior to the test, and further cracking was observed on the left side of the windshield following the test.

Figure 80. Vehicle Damage, Test No. GSH-2

Figure 81. Left-Side Vehicle Damage, Test No. GSH-2

Figure 82. Front-Left Vehicle Damage, Test No. GSH-2

Figure 83. Test Vehicle’s Post-Test Interior Floorboards and Undercarriage, Test No. GSH-2

Table 11. Maximum Occupant Compartment Intrusion by Location, Test No. GSH-2

LOCATION	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	2.9 (74)	≤ 9 (229)
Floor Pan & Transmission Tunnel	0.5 (13)	≤ 12 (305)
A-Pillar	0.1 (3)	≤ 5 (127)
A-Pillar (Lateral)	0.0 (0)	≤ 3 (76)
B-Pillar	0.3 (8)	≤ 5 (127)
B-Pillar (Lateral)	0.0 (0)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	0.7 (18)	≤ 12 (305)
Side Door (Above Seat)	0.0 (0)	≤ 9 (229)
Side Door (Below Seat)	0.0 (0)	≤ 12 (305)
Roof	0.1 (3)	≤ 4 (102)
Windshield	0.0 (0)	≤ 3 (76)
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	0.8 (20)	N/A

N/A – No MASH 2016 criteria exist for this location

7.5 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 12. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 12. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

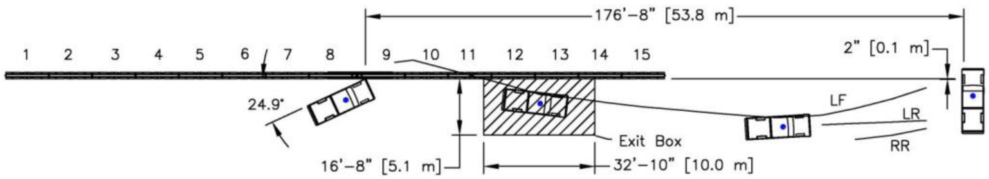
Table 12. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. GSH-2

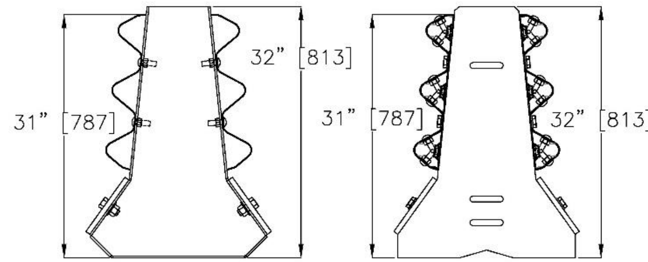
Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-16.68 (-5.08)	-16.09 (-4.91)	±40 (12.2)
	Lateral	17.13 (5.22)	18.79 (5.73)	±40 (12.2)
ORA g's	Longitudinal	-4.21	-4.22	±20.49
	Lateral	11.71	9.41	±20.49
Maximum Angular Displacement deg.	Roll	-44.6	-40.2	±75
	Pitch	-16.8	-18.8	±75
	Yaw	46.7	44.3	not required
THIV ft/s (m/s)		24.03 (7.33)	25.76 (7.85)	not required
PHD g's		11.80	9.54	not required
ASI		1.27	1.36	not required

7.6 Discussion

The analysis of the test results for test no. GSH-2 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 84. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 4.2 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. GSH-2 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.

0.000 sec | 0.092 sec | 0.278 sec | 0.442 sec | 0.652 sec





Stiffener Section PCB Section

- Test Agency .... MwRSF
- Test Number GSH-2
- Date 7/27/2018
- MASH 2016 Test Designation No. 3-11
- Test Article .... PCB Gap-Spanning Hardware
- Total Length .... 194 ft – 5⅛ in. (59.3 m)
- Key Component – Concrete Barrier
  - Length .... 150 in. (3,810 mm)
  - Width .... 22.5 in. (572 mm)
  - Height .... 32 in. (813 mm)
- Key Component – Thrie-Beam Guardrail
  - Length .... 150 in. (3,810 mm)
  - Thickness .... 12-gauge (2.7 mm)
- Vehicle Make /Model .... 2013 Dodge Ram 1500 Quad Cab
  - Curb .... 5,196 lb (2,357 kg)
  - Test Inertial .... 5,013 lb (2,274 kg)
  - Gross Static .... 5,173 lb (2,346 kg)
- Impact Conditions
  - Speed .... 61.9 mph (99.6 km/h)
  - Angle .... 24.9 deg.
  - Impact Location .... 14.4 in. (366 mm) DS from US edge of barrier no. 9
- Impact Severity ...... 113.4 kip-ft (153.7 kJ) > 106 kip-ft (144 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 37.9 mph (61.0 km/h)
  - Angle .... 4.2 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 176 ft – 8 in. (53.8 m) downstream
  2 in. (51 mm) laterally in front
- Vehicle Damage .... Moderate
  - VDS [10] 11-LFQ-4
  - CDC [11] 11-LYEW-3
  - Maximum Interior Deformation .... 2.9 in. (74 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 61⅜ in. (1,559 mm)
  - Dynamic .... 62.7 in. (1,593 mm)
  - Working Width .... 85.2 in. (2,164 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-16.68 (-5.08)	-16.09 (-4.91)	±40 (12.2)
	Lateral	17.13 (5.22)	18.79 (5.73)	±40 (12.2)
ORA g's	Longitudinal	-4.21	-4.22	±20.49
	Lateral	11.71	9.41	±20.49
Maximum Angular Displacement deg.	Roll	-44.6	-40.2	±75
	Pitch	-16.8	-18.8	±75
	Yaw	46.7	44.3	Not required
THIV – ft/s (m/s)		24.03 (7.33)	25.76 (7.85)	Not required
PHD – g's		11.80	9.54	Not required
ASI		1.27	1.36	Not required

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

8 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

8.1 Summary and Conclusions

In order to evaluate the performance of the stiffened, thrie-beam, gap-spanning hardware, two full-scale crash tests, test no. GSH-1 and test no. GSH-2, were conducted on a fifteen-barrier long PCB system with gap-spanning hardware placed across barrier nos. 8 and 9. The two full-scale crash tests were performed according to the TL-3 safety performance criteria defined in MASH 2016 for test designation no. 3-11. A summary of the test evaluation for both tests is provided in Table 13.

Analysis of the barrier system with the largest possible barrier gap of 12.5 ft (0.91 m) identified that the structural loading of the PCB gap-spanning hardware was the greatest when the system was impacted 72 in. (1,829 mm) upstream from the first PCB segment on the downstream end of the gap-spanning hardware. Test no. GSH-1 was conducted to evaluate the maximum structural loading of the gap-spanning hardware at this impact point. In test no. GSH-1, the 5,005-lb (2,270-kg) pickup truck impacted the PCB system with gap-spanning hardware at a speed of 63.3 mph (101.9 km/h) and at an angle of 25.4 degrees, resulting in an impact severity of 123.2 kip-ft (167.1 kJ). After impacting the PCB system with gap-spanning hardware, the vehicle exited the system at a speed of 42.6 mph (68.6 km/h) and an angle of 24.7 degrees. The vehicle was successfully contained and redirected with moderate damage to both the vehicle and the barrier system. All vehicle decelerations and occupant compartment deformations fell within the recommended safety limits established in MASH 2016. Therefore, test no. GSH-1 was successful according to the safety criteria of MASH 2016 test designation no. 3-11.

Analysis of the barrier system with a small barrier gap of 3 ft (3.81 m) identified the potential for the front wheel and tire of the 2270P vehicle to be held down by the thrie beam rail element spanning the PCB gap when the hardware was impacted in a region where it overlapped the adjacent PCB segments. This behavior tended to induce significant roll motions in the 2270P vehicle which raised concerns for potential vehicle instability. As such, a second CIP was selected 12 in. (305 mm) downstream from the upstream end of the first PCB segment on the downstream end of the gap-spanning hardware. Test no. GSH-2 was conducted to evaluate potential vehicle instability at this impact point. In test no. GSH-2, the 5,013-lb (2,274-kg) quad cab pickup truck impacted the transition from the gap-spanning hardware to the PCBs at a speed of 61.9 mph (99.6 km/h) and at an angle of 24.9 degrees, resulting in an impact severity of 113.4 kip-ft (153.7 kJ). After impacting the transition from the gap-spanning hardware to the PCBs, the vehicle exited the system at a speed of 37.9 mph (61.0 km/h) and an angle of 4.2 degrees. The vehicle was successfully contained and redirected with moderate damage to both the vehicle and the barrier system. All vehicle decelerations and occupant compartment deformations fell within the recommended safety limits established in MASH 2016. Therefore, test no. GSH-2 was successful according to the safety criteria of MASH 2016 test designation no. 3-11.

Based on the two successful full-scale crash testing at two critical impact points, the PCB gap-spanning hardware system detailed herein meets all the safety requirements for MASH 2016 TL-3.

Table 13. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. GSH-1</th><th>Test No. GSH-2</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="5">Occupant Risk</td><td rowspan="2">D.</td><td>1. 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.</td><td>S</td><td>S</td></tr>
<tr><td>2. Deformations of or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Impact Velocity Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td colspan="3">MASH 2016 Test Designation No.</td><td>3-11</td><td>3-11</td></tr>
<tr><td colspan="3">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

8.2 Recommendations

The MASH 2016 TL-3 PCB gap-spanning hardware system detailed herein was evaluated using full-scale crash testing at two critical impact points and with two different gap widths. Real-world installations will require spanning a range of gaps from the maximum tested length of 12.5 ft (3.81 m) to lengths as short as 6 in. (152 mm). Application of the barrier to these varied installation widths requires implementation guidance. Additionally, there are other considerations for the implementation of the barrier system that fall outside the as-tested design. Implementation guidance for the PCB gap spanning hardware is discussed in the subsequent sections.

8.2.1 Gap Lengths and Rail Spacers

As noted previously, longitudinal gaps for the PCB gap spanning hardware may vary between 12.5 ft (3.81 m) to lengths as small as 6 in. (152 mm). Installation of the gap-spanning hardware over variable gap lengths must follow basic guidance to allow for proper installation of the spacers and positioning of the hardware across the longitudinal gap. This guidance is outlined below and summarized in Table 14. In the table, gap-spanning hardware position refers to the thrie beam rail, toe plate, and associated spacers. The rail and toe plate remain in the same positions relative to the spacers regardless of the gap size. Similarly, the spacers are only included or removed based on gap length. The position is defined as the midspan of the assembled hardware relative to the center of the gap between adjacent PCBs.

1. For a longitudinal gap length of 0 ft < x ≤ 1 ft (0 mm < x ≤ 305 mm), no rail spacer is required, as shown in Figure 85.

2. For a longitudinal gap length of 1 ft < x ≤ 4 ft (305 mm < x ≤ 1,219 mm), the gap spanning hardware should be centered over the gap and one rail spacer should be installed, as shown in Figure 86.

3. For a longitudinal gap length of 4 ft < x ≤ 7 ft (1,219 mm < x ≤ 2,134 mm), the gap spanning hardware should be offset 18¾ in. (476 mm) upstream or downstream from the midspan of the longitudinal gap and two rail spacers should be installed. The offset of the gap spanning hardware will allow the two rail spacers to be centered and spaced evenly within the gap, as shown in Figure 87.

4. For a longitudinal gap length of 7 ft < x ≤ 12.5 ft (2,134 mm < x ≤ 3,810 mm), the gap spanning hardware should be centered over the gap and three rail spacers should be installed, as shown in Figure 88.

Table 14. PCB Gap Spanning Hardware Position and Rail Spacer Recommendations for Variable Gap Lengths

Longitudinal Gap Length (ft) [mm]	**No. of Rail Spacers**	**Gap-Spanning Hardware Position**
4” ft < x ≤ 1 ft [0 mm < x ≤ 305 mm]	0	Centered
1 ft < x ≤ 4 ft [305 mm < x ≤ 1,219 mm]	1	Centered
4 ft < x ≤ 7 ft [1,219 mm < x ≤ 2,134 mm]	2	Offset 18¾ in. [476 mm]
7 ft < x ≤ 12.5 ft [2,134 mm < x ≤ 3,810 mm]	3	Centered

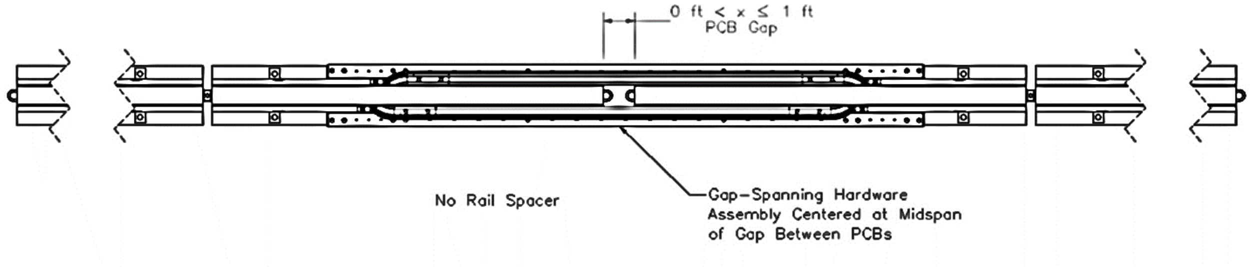


Figure 85. PCB Gap-Spanning Hardware Schematic, Gap Length = 0 ft < x ≤ 1 ft

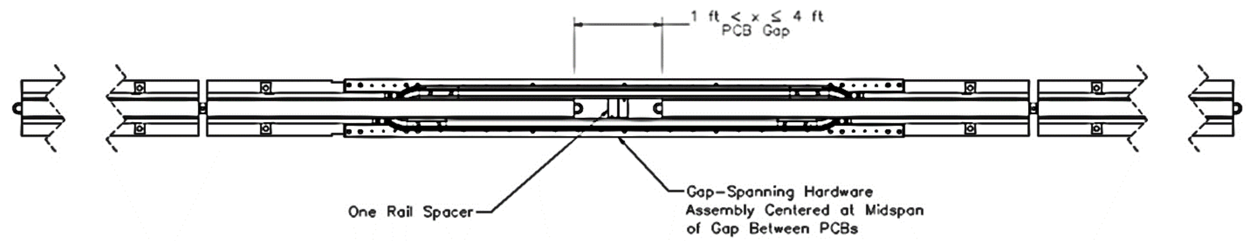


Figure 86. PCB Gap-Spanning Hardware Schematic, Gap Length = 1 ft < x ≤ 4 ft

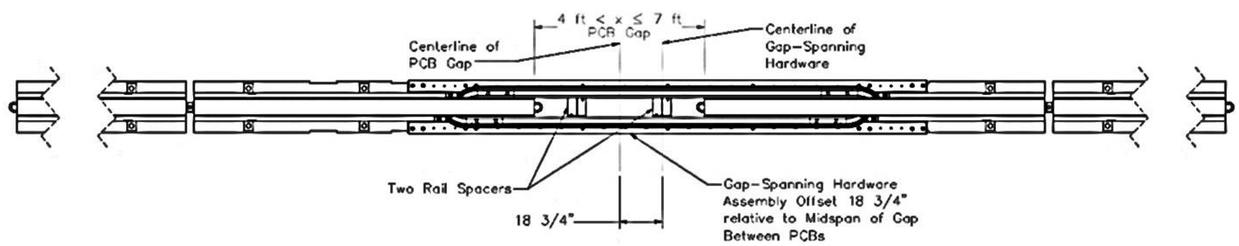


Figure 87. PCB Gap-Spanning Hardware Schematic, Gap Length = 4 ft < x ≤ 7 ft

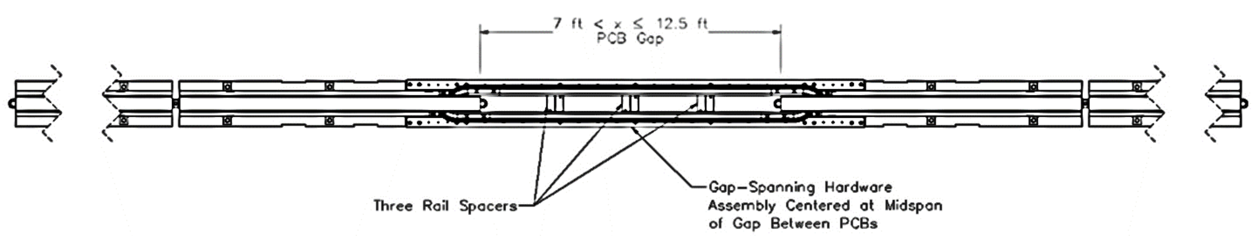


Figure 88. PCB Gap-Spanning Hardware Schematic, Gap Length = 7 ft < x ≤ 12.5 ft

8.2.2 Thrie Beam Anchoring

The PCB gap-spanning hardware requires anchoring of the thrie beam rail segments on the front and back of the system to the face of the adjacent PCBs with thrie beam terminal connectors and mechanical anchors. To provide proper anchorage and account for potential interference with reinforcing steel within the barrier when accommodating variable gaps, guidance is provided for the installation of the anchors to ensure proper anchorage capacity and function.

1. For all installations, the thrie beam rail segments on the front and back of the system must be offset 5 in. (127 mm) longitudinally to prevent interference between the anchor hardware from opposing sides of the system.

2. A minimum of five anchor bolts (part e1) must connect the thrie beam terminal connectors on each end of the rail segments to the adjacent PCB segments. The default installation is to install three anchors in the upper, lower, and middle locations of the outer, vertical row of anchor holes in the terminal connectors and two anchors in the innermost vertical row of anchor holes in the terminal connector, similar to a standard thrie beam terminal connection for approach guardrail transitions.

3. A minimum of three anchors should be installed in the outer vertical row of the thrie beam terminal connector. If vertical steel is encountered during installation that prevents proper installation of these anchors, installers should shift the gap-spanning hardware installation 2 in. (51 mm) upstream or downstream, as needed.

4. The remaining two anchor bolts should be installed in intermediate holes in the thrie beam terminal connector. These anchors should be installed a minimum distance of 6 in. (152 mm) from the end of the PCB segment.

5. All anchors should be placed a minimum distance of 3 in. (76 mm) from lifting holes or other voids in the barrier.

Examples of these thrie beam anchorage recommendations can be seen in the CAD details for the as-tested barrier systems in this report.

8.2.3 Toe Plate Anchoring

Similarly, the steel toe plate on the lower section of the PCB gap-spanning hardware must be anchored to the PCB segments on each end of the longitudinal barrier gap. However, as the gap width varies, the anchors may not be able to be installed due to interference with reinforcing steel, anchor bolt pockets, and proximity to the end of the barrier segment. The following recommendations are provided for anchoring the toe plate to the adjacent PCB segments.

1. A minimum of four anchors are required on each end of the plate to anchor to the adjacent PCB segments.

2. Anchors may not be placed within 6 in. (152 mm) of the center of an anchor bolt pocket in the PCB or within 4 in. (102 mm) of drainage slots or other edges.

3. One anchor must be placed in the first hole located at a minimum of 6 in. (152 mm) away from the end of the PCB segment. If reinforcing steel in the barrier prevents installation of an anchor in the anchor location nearest to the end of the PCB segment, a field-drilled anchor hole can be drilled in the anchor plate a minimum of 3 in. (76 mm) longitudinally from existing holes in the toe plate to accommodate this anchor placement. Note that the field-drilled hole should be spray galvanized to limit potential corrosion.

4. One anchor must be placed in the final anchor hole at the end of each toe plate. If reinforcing steel or other feature of the barrier segment prevents installation of an anchor in the anchor location nearest to the end of the PCB segment, then the next closest hole to the end of the toe plate should be used. Alternatively, the toe plate may be shifted upstream or downstream to allow proper anchor installation, while making sure that the intermediate holes in the toe plate still allow for attachment to the rail spacers.

5. The remaining two anchors should be spaced as evenly as possible along the toe plate

Examples of these toe plate anchorage recommendations can be seen in the CAD details for the as-tested barrier systems in this report.

8.2.4 Minimum System Length

The PCB gap-spanning hardware system tested herein was evaluated with eight barrier segments upstream and downstream from the longitudinal barrier gap. PCB systems redirect errant vehicles through a combination of various forces and mechanisms, including inertial resistance developed by the acceleration of several barrier segments, lateral friction loads, and the tensile loads developed from the mass and friction of the barrier segments upstream and downstream from the impacted region. As such, the number of barriers upstream and downstream from the longitudinal barrier gap will affect performance of the PCB gap-spanning hardware system, and reduced numbers of PCB segments adjacent to the gap may degrade barrier performance. It is recommended that a minimum of eight barrier segments be installed both upstream and downstream from any longitudinal barrier gap to ensure that the safety performance of the barrier is retained similar to the as-tested system.

8.2.5 Other Barrier Types

The PCB gap spanning hardware system described herein was designed for use with the Midwest F-shape PCB system. Therefore, it should not be used with other PCB systems or joint designs without further study. Although this gap spanning hardware system may potentially be adapted to other approved temporary concrete barrier systems, it would be necessary to consider several factors, such as barrier connections, segment lengths, reinforcement, and geometry.

9 MASH EVALUATION

A design for spanning longitudinal gaps in an F-shape PCB system was evaluated to determine its compliance with MASH 2016 TL-3 evaluation criteria. The PCB gap-spanning hardware design comprised two nested thrie-beam guardrail sections attached to the front and back sides of the PCBs adjacent to the longitudinal gap. The nested thrie-beam guardrail sections were attached to the PCBs with thrie-beam terminal connectors using wedge bolt anchors. Three steel lateral spacers were inserted between the parallel guardrail sections reduce the unsupported span length of thrie beam panels. The number of stiffeners installed between the thrie-beam guardrails could be adjusted depending on the length of the longitudinal gap. To minimize wheel snag during impacts with the system, steel toe plates were configured to span across the longitudinal gap and were anchored to the lower sloped concrete surface of the PCBs.

9.1.1 Test Matrix

The PCB gap spanning hardware evaluated in this report functions primarily as a longitudinal barrier. According to TL-3 of MASH 2016, longitudinal barrier systems and their transitions must be subjected to two full-scale vehicle crash tests, as summarized in Table 15.

Table 15. MASH 2016 TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Barrier Section	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
					Speed, mph (km/h)	Angle, degrees	
Longitudinal Barrier	Length-of-Need	3-10	1100C	2,425 (1,100)	62 (100.0)	25	A,D,F,H,I
		3-11	2270P	5,000 (2,270)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

It should be noted that the MASH 2016 test matrix detailed herein represents the recommended crash tests that should be performed. However, some of these crash tests may be deemed non-critical and unnecessary. For the PCB gap spanning hardware system evaluated herein, the 1100C vehicle test, test designation no. 3-10, was deemed non-critical for evaluation of the barrier system. Previous testing of PCBs and safety shape barriers has indicated that small cars interact in a safe manner with this type of roadside hardware. In test no. 2214NJ-1, a MASH test designation no. 3-10 full-scale crash test was successfully conducted on a permanent New Jersey shape concrete parapet under NCHRP Project 22-14(2) [4]. In Texas A&M Transportation Institute (TTI) test report no. 607911-1&2, a MASH test designation no. 3-10 full-scale crash test was successfully conducted on a free-standing F-shape PCB similar to the barrier used in this study [5]. These two tests indicate that safety shape barriers are capable of successfully capturing and redirecting a 1100C vehicle in both free-standing PCB and permanent concrete parapet applications. Additionally, the increased toe height of New Jersey shape barriers tends to produce increased vehicle climb and instability as compared to the F-shape geometry. Thus, one would expect that the PCB gap-spanning hardware with similar geometry evaluated in this study would perform similarly to these previous MASH 1100C vehicle tests in terms of capture and redirection, and the 1100C vehicle would not be critical for structural loading of the hardware. As such, it was believed that test designation no. 3-10 with the 1100C vehicle would be non-critical for evaluation of the tie-down anchorages for use with F-shape PCBs. MASH 2016 test designation no. 3-11 was the more critical evaluation test due to concerns for increased barrier loading during 2270P impacts and to determine dynamic deflection and working width. Thus, only test designation no. 3-11 was conducted on the PCB gap-spanning hardware evaluated herein. It should be noted that any tests deemed non-critical and unnecessary may eventually need to be performed if additional knowledge gained over time or revisions to the MASH 2016 criteria demonstrates a concern or need.

During the development of the PCB gap-spanning hardware in Phase I, an analysis was performed on the critical impact points (CIPs) for the system. This analysis found that there were two CIPs for the PCB gap-spanning hardware. One CIP was chosen to maximize structural loading of the barrier system, and a second was selected to maximize the potential for vehicle instability. Note that snag of impacting vehicles was considered and evaluated in the CIP analysis. However, the analysis demonstrated that vehicle snag was not a critical behavior due the use of the thrie beam rail and toe plate elements that connect the system to the PCB segments, and any vehicle snag that was observed in the simulation analysis of potential CIPs was less of a concern than the structural loading and vehicle stability CIPs that were identified. Full details on the CIP analysis are provided in the Phase I report [1]. The two identified CIPs were as follows:

1. Analysis of the barrier system with the largest possible barrier gap of 12.5 ft (3.81 m) identified that the structural loading of the PCB gap-spanning hardware was the greatest when the system was impacted 72 in. (1,829 mm) upstream from the first PCB segment on the downstream end of the gap-spanning hardware.

2. Analysis of the barrier system with a small barrier gap of 3 ft (0.91 m) identified the potential for the 2270P vehicle’s front wheel and tire to be held down by the thrie beam rail element spanning the PCB gap when the hardware was impacted where it overlapped the adjacent PCB segments. This behavior tended to induce significant roll motions in the 2270P vehicle, which raised concerns for potential vehicle instability. As such, a second CIP was selected to be 12 in. (305 mm) downstream from the upstream end of the first PCB segment on the downstream end of the gap-spanning hardware.

Based on this CIP analysis, two full-scale crash tests were conducted under MASH test designation no. 3-11 impact conditions. The first test was conducted to evaluate the maximum structural loading of the PCB gap-spanning hardware, and the second test was conducted to evaluate potential vehicle instability.

9.1.2 Full-Scale Crash Test Results

The results of the MASH TL-3 full-scale crash testing of the PCB Gap spanning hardware system are summarized below. A summary of the full-scale crash testing is provided in Table 16.

1. Test no. GSH-1 – Test no. GSH-1 was conducted to evaluate the maximum structural loading of the gap-spanning hardware at a critical impact point. In test no. GSH-1, the 5,005-lb (2,270-kg) quad cab pickup truck impacted the PCB system with gap-spanning hardware at a speed of 63.3 mph (101.9 km/h) and at an angle of 25.4 degrees, resulting in

an impact severity of 123.2 kip-ft (167.1 kJ). After impacting the PCB system with gap-spanning hardware, the vehicle exited the system at a speed of 42.6 mph (68.6 km/h) and an angle of 24.7 degrees. The vehicle was successfully contained and redirected with moderate damage to both the vehicle and the barrier system. All vehicle decelerations and occupant compartment deformations fell within the recommended safety limits established in MASH 2016. Therefore, test no. GSH-1 was successful according to the safety criteria of MASH 2016 test designation no. 3-11.

2. Test no. GSH-2 - Test no. GSH-2 was conducted to evaluate potential vehicle instability at a critical impact point. In test no. GSH-2 the 5,013-lb (2,274-kg) quad cab pickup truck impacted the transition from the gap-spanning hardware to the PCBs at a speed of 61.9 mph (99.6 km/h) and at an angle of 24.9 degrees, resulting in an impact severity of 113.4 kip-ft (153.7 kJ). After impacting the transition from the gap-spanning hardware to the PCBs, the vehicle exited the system at a speed of 37.9 mph (61.0 km/h) and an angle of 4.2 degrees. The vehicle was successfully contained and redirected with moderate damage to both the vehicle and the barrier system. All vehicle decelerations and occupant compartment deformations fell within the recommended safety limits established in MASH 2016. Therefore, test no. GSH-2 was successful according to the safety criteria of MASH 2016 test designation no. 3-11.

Table 16. MASH 2016 TL-3 Crash Test Summary for PCB Gap-Spanning Hardware

MwRSF Test No.	MASH Test Designation	MwRSF Report No.	Date of Test	Pass/Fail	System Version
GSH-1	3-11	TRP-03-387b-20	06/28/18	Pass	12.5 ft (3.81 m) Gap
GSH-2	3-11	TRP-03-387b-20	07/27/18	Pass	3 ft (0.91 m) Gap

9.1.3 MASH 2016 Evaluation

Based on the two successful full-scale crash testing at two critical impact points, the PCB gap-spanning hardware system detailed herein meets the safety requirements for MASH 2016 TL-3.

10 REFERENCES

1. Ranjha, S.A., Bielenberg, R.W., Rosenbaugh, S.K., and Faller, R.K., *Development of a PCB Steel Cover Plate for Large Open Joints Phase - I*, Report No. TRP-03-387a-20, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, Draft Report.

2. *Manual for Assessing Safety Hardware (MASH), Second Edition*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2016.

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

4. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, R.W., Reid, J.D., and Coon, B.A., *Performance Evaluation of the Permanent New Jersey Safety Shape Barrier - Update to NCHRP 350 Test No. 3-10 (2214NJ-1)*, Report No. TRP-03-177-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 13, 2006.

5. Sheikh, N.M., Menges, W.L., Kuhn, D.L., *MASH TL-3 Testing and Evaluation of Free-Standing Portable Concrete Barrier*, Test Report No. 607911-1&2, Texas A&M Transportation Institute, Texas A&M University, College Station, Texas, May 2017.

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

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

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

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

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

11 APPENDICES

Appendix A. Vehicle Center of Gravity Determination

Date:	**6/28/2018**	**Test Name:**	**GSH-1**	**VIN:**	**1D7RB1GP6BS553873**
Year:	**2011**	**Make:**	**Dodge**	**Model:**	**Ram 1500 Quad Cab**

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)	Vertical CG (in.)	Vertical M (lb.-in.)
+	Unballasted Truck (Curb)	4984	28.558751	142336.81
+	Hub	19	15	285
+	Brake activation cylinder & frame	8	29 3/8	235
+	Pneumatic tank (Nitrogen)	30	26	780
+	Strobe/Brake Battery	5	26	130
+	Brake Receiver/Wires	6	51 1/8	306.75
+	CG Plate including DAS	42	31 1/2	1323
-	Battery	-46	41 3/8	-1903.25
-	Oil	-9	18	-162
-	Interior	-78	50 1/4	-3919.5
-	Fuel	-170	17	-2890
-	Coolant	-10	36	-360
-	Washer fluid	-1	38 1/4	-38.25
+	Water Ballast (In Fuel Tank)	137	16	2192
+	Onboard Supplemental Battery	13	25 1/2	331.5
+	Smart Barrier Provisions	9	24.5	220.5
+	Spare Tire	65	22 1/8	1438.125
				140305.69

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

Estimated Total Weight (lb.)	5004
Vertical CG Location (in.)	28.0387

Vehicle Dimensions for C.G. Calculations

Wheel Base:	140.5	in.	Front Track Width:	67.625	in.
			Rear Track Width:	67.625	in.

Center of Gravity	**2270P MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb.)	5000 ± 110	5005	5.0
Longitudinal CG (in.)	63 ± 4	62.010889	-0.98911
Lateral CG (in.)	NA	0.3715659	NA
Vertical CG (in.)	28 or greater	28.04	0.03871

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb.)

	Left	Right
Front	1474	1378
Rear	1041	1091

FRONT	2852	lb.
REAR	2132	lb.
TOTAL	4984	lb.

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1406	1390
Rear	1069	1140

FRONT	2796	lb.
REAR	2209	lb.
TOTAL	5005	lb.

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

Date:	6/28/2018	Test Name:	GSH-1	VIN:	1D7RB1GP6BS553873
Year:	2011	Make:	Dodge	Model:	Ram 1500 Quad Cab

Vehicle CG Determination

VEHICLE	Equipment	Long CG (in.)	Lat CG (in.)	Long M (lb.-in.)	Lat M (lb.-in.)
+	Unballasted Truck (Curb)	60	-0.312074	299040	-1555.375
+	Hub	0	22.875	0	434.625
+	Brake activation cylinder & frame	39 1/4	-20	314	-160
+	Pneumatic tank (Nitrogen)	71	23	2130	690
+	Strobe/Brake Battery	83 1/4	19 1/2	416.25	97.5
+	Brake Receiver/Wires	104 1/8	0	624.75	0
+	CG Plate including DAS	67 3/4	0	2845.5	0
-	Battery	-6 5/8	-28	304.75	1288
-	Oil	6 3/4	-3	-60.75	27
-	Interior	63 1/2	0	-4953	0
-	Fuel	120	-18	-20400	3060
-	Coolant	-26 7/8	0	268.75	0
-	Washer fluid	-30	-19	30	19
+	Water Ballast (In Fuel Tank)	120	-18	16440	-2466
+	Onboard Supplemental Battery	66 1/2	17 3/8	864.5	225.875
+	Smart Barrier Provisions	68	-21 1/2	612	-193.5
+	Spare Tire	167 1/4	0	10871.25	0
				309348	1467.125

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

	Long	Lat
Estimated CG Location (in.)	61.82014	0.29319

Calibrated Scales Used

Equipment Type	Manufacturer	Serial #	Capacity
Pad Scale	Pennsylvania Scale	95-228908	5000 lbs.
Pad Scale	Pennsylvania Scale	95-228909	5000 lbs.
Race Wheel Scales	Intercomp	22033056	1500/pad

Figure A-2. Vehicle Mass Distribution, Test No. GSH-1, Cont.

Date:	7/27/2018	Test Name:	GSH-2	VIN:	1CRR6FTXDS575838
Year:	2013	Make:	Dodge	Model:	Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)	Vertical CG (in.)	Vertical M (lb.-in.)
+	Unballasted Truck (Curb)	5196	29.387125	152695.5
+	Hub	19	16	304
+	Brake activation cylinder & frame	7	31.5	220.5
+	Pneumatic tank (Nitrogen)	30	28 5/8	858.75
+	Strobe/Brake Battery	5	28.5	142.5
+	Brake Receiver/Wires	6	53 5/8	321.75
+	CG Plate including DAS	42	32.75	1375.5
-	Battery	-42	42.5	-1785
-	Oil	-7	17.75	-124.25
-	Interior	-93	60.125	-5591.625
-	Fuel	-169	17.75	-2999.75
-	Coolant	-13	41	-533
-	Washer fluid	-4	39 7/8	-159.5
+	Water Ballast (In Fuel Tank)			0
+	Onboard Supplemental Battery	13	28.5	370.5
+	Smart	9	25.25	227.25
				0
				145323.13

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

Estimated Total Weight (lb.) 4999
Vertical CG Location (in.) 29.0704

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140.375 in.
Front Track Width: 68.75 in.
Rear Track Width: 68.125 in.

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb.)	5000 ± 110	5013	13.0
Longitudinal CG (in.)	63 ± 4	60.792764	-2.20724
Lateral CG (in.)	NA	0.2116061	NA
Vertical CG (in.)	28 or greater	29.07	1.07044

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb.)

	Left	Right
Front	1446	1476
Rear	1167	1107

FRONT	2922	lb.
REAR	2274	lb.
TOTAL	5196	lb.

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1389	1453
Rear	1102	1069

FRONT	2842	lb.
REAR	2171	lb.
TOTAL	5013	lb.

Figure A-3. Vehicle Mass Distribution, Test No. GSH-2

Date:	7/27/2018	Test Name:	GSH-2	VIN:	1CRR6FTXDS575838
Year:	2013	Make:	Dodge	Model:	Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Long CG (in.)	Lat CG (in.)	Long M (lb.-in.)	Lat M (lb.-in.)
+	Unballasted Truck (Curb)	60.375	-0.197568	313708.5	-1026.562
+	Hub	0	23.75	0	451.25
+	Brake activation cylinder & frame	37.25	-21	260.75	-147
+	Pneumatic tank (Nitrogen)	72 7/8	-22 3/8	2186.25	-671.25
+	Strobe/Brake Battery	74.125	17	370.625	85
+	Brake Receiver/Wires	107.25	0	643.5	0
+	CG Plate including DAS	65.5	0	2751	0
-	Battery	-9.125	-27	383.25	1134
-	Oil	-2.125	4	14.875	-28
-	Interior	64 7/8	0	-6033.375	0
-	Fuel	103 5/8	-26.5	-17512.63	4478.5
-	Coolant	-20 3/8	2 1/2	264.875	-32.5
-	Washer fluid	-30.75	-18.5	123	74
+	Water Ballast (In Fuel Tank)	103.625	-26.5	0	0
+	Onboard Supplemental Battery	66.5	18	864.5	234
+	Smart	79.75	19.5	717.75	175.5
				0	0
Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle				298742.9	4726.938

	Long	Lat
Estimated CG Location (in.)	59.76053	0.945577

Calibrated Scales Used			
Equipment Type	Manufacturer	Serial #	Capacity
Pad Scale	Pennsylvania Scale	95-228908	5000 lbs.
Pad Scale	Pennsylvania Scale	95-228909	5000 lbs.
Race Wheel Scales	Intercomp	22033056	1500/pad
USE #2 HUB			

Figure A-4. Vehicle Mass Distribution, Test No. GSH-2, Cont.

Appendix B. Material Specifications

Table B-1. Bill of Materials, Test Nos. GSH-1 and GSH-2

Item No.	Description	Material Specification	Reference
a1	Portable Concrete Barrier	Min f'c = 5,000 psi [34.5 MPa]	
a2	#4 [13] Rebar, 72" [1,829] Total Unbent Length	ASTM A615 Gr. 60	585826, 585655
a3	#4 [13] Rebar, 146" [3,708] Total Length	ASTM A615 Gr. 60	585826, 585655
a4	#5 [16] Rebar, 146" [3,708] Total Length	ASTM A615 Gr. 60	KN16100227, KN16102104, KN16102105, KN16102106
a5	#6 [19] Rebar, 36" [914] Total Unbent Length	ASTM A615 Gr. 60	KN15102677, KN1610493, KN16101494, 16102891
a6	#6 [19] Rebar, 101" [2,565] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	16100656
a7	#6 [19] Rebar, 91" [2,311] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	16100656
a8	#6 [19] Rebar, 102" [2,591] Total Unbent Length	ASTM A709 Gr. 70 or A706 Gr. 60	16100656
a9	1 1/4" [32] Dia., 28" [711] Long Connector Pin	ASTM A36	6218817
b1	31 3/4"x22 1/16"x1/4" [806x561x6] Steel Plate	ASTM A36	H#18024561
b2	30 3/4"x8"x1/4" [782x203x6] Bent Steel Plate	ASTM A36	H#18024561
b3	24 7/16"x8"x1/4" [620x203x6] Bent Steel Plate	ASTM A36	H#18024561
c1	10-gauge [3.4] Thrie-Beam Terminal Connector	AASHTO M180 Min. Yield Strength = 50 ksi [345 MPa] Min. Ultimate Strength = 70 ksi [483 MPa]	H#A81568
c2	12'-6" [3,810] 12-gauge [2.7] Thrie-Beam Section	AASHTO M180	R#18-865 HC#L30918 H#222878
d1	229"x8 1/2"x5/8" [5,817x216x16] Steel Plate	ASTM A572 Gr. 50	H#L109612
e1	3/4" [19] Dia., 6" [152] Long Powers Fasteners Wedge Bolt+	As Supplied	PO# Zoro 19532469 Grainger Sales Order# 1322294683
e2	5/8"-11 UNC [M16x2], 2" [51] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	R#18-865 Bolts: H#10517060 Nuts: 10508780
e3	3/4"-10 UNC [M20x2.5], 2" [51] Long Heavy Hex Head Bolt and Nut	Bolt - ASTM F3125 Gr. A325 Type 1 or equivalent Nut - ASTM A563DH or equivalent	Bolt: H#HH64028 Nut: H#HI05508
e4	3/4" [19] Dia. Plain Flat Washer	ASTM F844	P#1133186 C#480006711 L#M-SWE0412140-6

WIESER CONCRETE PRODUCTS, INC.
W3716 U.S. HWY 10 • MAIDEN ROCK, WI 54750
(715) 647-2311 800-325-8456 Fax (715) 647-5181
Website: www.wieserconcrete.com

CONCRETE TEST RESULTS

PROJECT: Barrier

Testing By: Jason Hendricks

CONCRETE SUPPLIER Wieser Concrete

ACI GRADE 1

SET	TEST	POUR DATE	RESULTS	AVERAGE	TEST TYPE
1	1		6897		
	2	5/31/2016	6993	**6945**	28 Day
	3				
2	1		7319		
	2	6/28/2017	7448	**7384**	28 Day
	3				
3	1				
	2				
	3				
4	1				
	2				
	3				
5	1				
	2				
	3				
6	1				
	2				
	3				
7	1				
	2				
	3				

Signature

Figure B-1. PCB Certification, Test Nos. GSH-1 and GSH-2

EVRAZ ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

2100 S. Freeway
Pueblo, CO 81004 USA

MATERIAL TEST REPORT

Date Printed: 15-APR-16

Date Shipped: 15-APR-16 **Product:** DEF #4 (1/2") **Specification:** ASTM A615/A706 Gr 60

FWIP: 52825704 **Customer:** ERMS **Cust. PO:**

CHEMICAL ANALYSIS (In Weight %, uncertainty of measurement 0.005%) (Heat cast 03/10/16)

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ti
585826	0.27	1.23	0.007	0.017	0.23	0.22	0.10	0.15	0.026	0.003	0.036	0.0006	0.000	0.010	0.0097	0.001

Carbon Equivalent = 0.496

#4?

MECHANICAL PROPERTIES **(Tensiles test date 03/11/16)**

Heat Number	Sample No.		Yield (Psi)	Ultimate (Psi)	Elongation (%)	Reduction (%)	Bend	Wt/ft
585826	01		70780	99670	16.6		OK	0.676
		(MPa)	488.0	687.2				
585826	02		67431	96900	15.0		OK	0.676
		(MPa)	464.9	668.1				

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.
ERMS also certifies this material to be free from Mercury contamination.

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

Methods used: ASTM A370, A510, A615, A706.

Material test report shall not be reproduced except in full, without approval of the company.

Valoree Varick
General Supervisor of Quality

Figure B-2. #4 (13-mm) Rebar ASTM A615 Gr. 60, Test Nos. GSH-1 and GSH-2

EVRAZ ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

2100 S. Freeway
Pueblo, CO 81004 USA

MATERIAL TEST REPORT

Date Printed: 09-MAY-16

Date Shipped: 09-MAY-16 **Product:** DEF #4 (1/2") **Specification:** ASTM A615/A706 Gr 60

FWIP: 52825704 **Customer:** ERMS **Cust. PO:**

CHEMICAL ANALYSIS (In Weight %, uncertainty of measurement 0.005%) (Heat cast 03/02/16)

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ti
585655	0.25	1.24	0.008	0.020	0.22	0.20	0.09	0.13	0.022	0.003	0.040	0.0005	0.000	0.010	0.0094	0.001

Carbon Equivalent = 0.475

.45

MECHANICAL PROPERTIES **(Tensiles test date 03/09/16)**

Heat Number	Sample No.		Yield (Psi)	Ultimate (Psi)	Elongation (%)	Reduction (%)	Bend	Wt/ft
585655	01		63597	93340	14.9		OK	0.669
		(MPa)	438.5	643.6				
585655	02		63712	94340	15.1		OK	0.669
		(MPa)	439.3	650.5				

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.
ERMS also certifies this material to be free from Mercury contamination.

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

Methods used: ASTM A370, A510, A615, A706.

Material test report shall not be reproduced except in full, without approval of the company.

Valoree Varick
General Supervisor of Quality

Figure B-3. #4 (13-mm) Rebar ASTM A615 Gr. 60, Test Nos. GSH-1 and GSH-2

SOLD TO: ADELPHIA METALS I LLC
411 MAIN ST E
NEW PRAGUE, MN 56071-

NUCOR
NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT Page: 1

SHIP TO: ADELPHIA METALS
C/O MIDWEST TERMINAL SERVICES
1745 165TH STREET
HAMMOND, IN 46320-

Ship from:
MTR #: 0000111719
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

Date: 21-Mar-2016
B.L. Number: 516780
Load Number: 271160

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative. NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS: YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	CHEMICAL TESTS: C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	817659												
KN1610022601	Nucor Steel - Kankakee Inc	73,843	107,760	15.9%	OK	-3.6%	.40	1.05	.016	.052	.20	.45	
KN16100226	16/#5 Rebar	509MPa	743MPa			.035	.22	.16	.076	.008	.001		
	60' A615M GR420 (Gr60)												
	ASTM A615/A615M-15 GR 60[420]												
	AASHTO M31-07												
	Melted 01/15/16 Rolled 01/21/16												
PO# =>	817659												
KN1610022701	Nucor Steel - Kankakee Inc	73,261	107,856	16.9%	OK	-3.6%	.39	1.08	.014	.043	.18	.46	
KN16100227	16/#5 Rebar	505MPa	744MPa			.035	.20	.14	.071	.009	.001		
	60' A615M GR420 (Gr60)							.57					
	ASTM A615/A615M-15 GR 60[420]												
	AASHTO M31-07												
	Melted 01/15/16 Rolled 01/21/16												

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Matt Luymes

Figure B-4. #5 (16-mm) Rebar ASTM A615 Gr. 60, Test Nos. GSH-1 and GSH-2

SOLD TO:	ADELPHIA METALS I LLC 411 MAIN ST E NEW PRAGUE, MN 56071-
SHIP TO:	ADELPHIA METALS C/O MIDWEST TERMINAL SERVICES 1745 165TH STREET HAMMOND, IN 46320-

NUCOR

NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT

Page: 1

Ship from:
MTR #: 0000121420
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

Date: 13-May-2016
B.L. Number: 520718
Load Number: 273861

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS					CHEMICAL TESTS						
		YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	818290												
KN1610210401	Nucor Steel - Kankakee Inc	68,538	103,575	13.9%	OK	-3.5%	.38	1.04	.018	.054	.22	.32	
KN16102104	16/#5 Rebar	473MPa	714MPa			.038	.17	.16	.058	.007	.001		
	60' A615M GR420 (Gr60)												
	ASTM A615/A615M-15 GR 60[420]												
	AASHTO M31-07						.55						
	Melted 04/14/16 Rolled 04/21/16												
PO# =>	818290												
KN1610210501	Nucor Steel - Kankakee Inc	67,674	105,004	14.4%	OK	-3.4%	.39	1.05	.017	.050	.21	.30	
KN16102105	16/#5 Rebar	467MPa	724MPa			.038	.15	.17	.054	.008	.001		
	60' A615M GR420 (Gr60)												
	ASTM A615/A615M-15 GR 60[420]							.57					
	AASHTO M31-07												
	Melted 04/14/16 Rolled 04/21/16												
PO# =>	818290												
KN1610210601	Nucor Steel - Kankakee Inc	67,874	105,201	15.0%	OK	-3.4%	.39	1.06	.015	.055	.21	.31	
KN16102106	16/#5 Rebar	468MPa	725MPa			.038	.16	.14	.054	.008	.001		
	60' A615M GR420 (Gr60)												
	ASTM A615/A615M-15 GR 60[420]							.57					
	AASHTO M31-07												
	Melted 04/14/16 Rolled 04/21/16												

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Matt Luymes

Matt Luymes

Figure B-5. #5 (16-mm) Rebar ASTM A615 Gr. 60, Test Nos. GSH-1 and GSH-2

NUCOR
NSKNK-KANKAKEE, IL

MILL CERTIFICATION DETAILS

Purchase Order #:	816680	**Heat #:**	KN15106277
Customer:	ADELPHIA METALS I LLC - NEW PRAGUE	**Customer Part #:**	
Bill of Lading :	516339	**Length:**	30'0"
Certified By :	Matt Luymes	**Date:**	10/22/2015
Lot #:	KN1510627701	**Tag #:**	KN1513125877
Grade:	ASTM A615/A615M-15 GR 60[420] AASHTO M31-07	**Size :**	# 6(19) RS
Melt Date :	10/22/2015	**Divison :**	NSKNK-Kankakee, IL
Qty Shipped LBS:	12978	**Qty Shipped PCS :**	288
Comments:		**Roll Date :**	10/23/2015

Chemical Properties -Wt.%

C	Mn	Si	S	P	Cu	Cr	Ni	Mo
0.38	1.08	0.19	0.049	0.022	0.30	0.17	0.18	0.061

V	Nb	Sn
0.0082	0.002	0.015

<54

Physical Properties

	Imperial-psi
Tensile:	106877
Yield:	69535
Elongation (in 8 inches):	13.25
Elongation (in 2 inches):	
Bend Test:	OK

Carbon Equiv:

I hereby certify that the material described herein has been manufactured in accordance with the specification and standards listed above and that it satisfies those requirements. All melting and manufacturing process were performed in the United States of America unless otherwise noted on the mill test report.

Matt Luymes

Matt Luymes, Chief Metallurgist

Figure B-6. #6 (19-mm) Rebar ASTM A615 Gr. 60, Test Nos. GSH-1 and GSH-2

SOLD TO:	ADELPHIA METALS I LLC 411 MAIN ST E NEW PRAGUE, MN 56071-
SHIP TO:	ADELPHIA METALS 411 MAIN STREET EAST NEW PRAGUE, MN 56071-

NUCOR

NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT

Page: 1

Ship from:
MTR #: 0000113084
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

Date: 29-Mar-2016
B.L. Number: 517308
Load Number: 271293

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS: YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	CHEMICAL TESTS: C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	817443												
KN1610149301	Nucor Steel - Kankakee Inc	68,277	105,530	14.3%	OK	-3.9%	.39	1.09	.016	.044	.20	.32	
KN16101493	19/#6 Rebar	471MPa	728MPa			.053	.16	.13	.066	.008	.001	.018	
	40' A615M GR420 (Gr60)												
	ASTM A615/A615M-15 GR 60[420]								.57				
	AASHTO M31-07												
	Melted 03/22/16 Rolled 03/24/16												
PO# =>	817443												
KN1610149401	Nucor Steel - Kankakee Inc	67,771	105,567	14.6%	OK	-4.1%	.40	1.08	.016	.047	.20	.36	
KN16101494	19/#6 Rebar	467MPa	728MPa			.050	.16	.14	.065	.008	.001	.019	
	40' A615M GR420 (Gr60)												
	ASTM A615/A615M-15 GR 60[420]												
	AASHTO M31-07								.58				
	Melted 03/22/16 Rolled 03/24/16												

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Matt Luymes

Matt Luymes

Figure B-7. #6 (19-mm) Rebar ASTM A615 Gr. 60, Test Nos. GSH-1 and GSH-2

Page: 1

SOLD TO: ADELPHIA METALS I LLC
411 MAIN ST E
NEW PRAGUE, MN 56071-

NUCOR
NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT

Ship from:
MTR #: 0000112570
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

SHIP TO: ADELPHIA METALS
411 MAIN STREET EAST
NEW PRAGUE, MN 56071-

Date: 24-Mar-2016
B.L. Number: 517112
Load Number: 271351

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS: YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	CHEMICAL TESTS: C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	817132												
KN1610065601	Nucor Steel - Kankakee Inc	76,513	99,415	15.8%	OK		.16	1.12	.010	.021	.22	.37	.37
KN16100656	3/4" (.7500) Round	528MPa	685MPa				.17	.10	.071	.061 0	.00		
	24' A706												
	ASTM A706/A706M-09b GR60 [420]												
	TEN/YD = 1.3												
	Melted 02/11/16 Rolled 02/14/16												

3/4" smooth

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Matt Luymes

Figure B-8. #6 (19-mm) Rebar ASTM A706 Gr. 60, Test Nos. GSH-1 and GSH-2

GERDAU

US-ML-ST PAUL
1678 RED ROCK ROAD
SAINT PAUL, MN 55119
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO / CUSTOMER BILL TO	GRADE	SHAPE / SIZE	
Challman and Company P.O. #: 9730	A36	Round Bar / 1 1/4"	
	LENGTH: 20'00"	WEIGHT: 9,300 LB	HEAT / BATCH: 62138817/06

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
2571711/000010		ASME SA36 ASTM A6-14, A36-14 ASTM A709-13A, AASHTO M270-12

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
03046178M3	1332-0000031395	07/29/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Sn %
0.19	0.75	0.012	0.027	0.22	0.28	0.18	0.18	0.033	0.003	0.001	0.013

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS KSI	UTS MPa	YS KSI	YS MPa
31.20	8.000	71.4	492	48.9	0
28.80	8.000	71.7	495	49.3	0

GEOMETRIC CHARACTERISTICS
R:R
24.45

HARDENABILITY
DI A255
Inch
0.74

COMMENTS / NOTES

Material 100% melted and rolled in the USA. Manufacturing processes for this steel, which may include scrap melted in an electric arc furnace and hot rolling, has been performed at Gerdau St. Paul Mill, 1678 Red Rock Rd., St. Paul, Minnesota, USA. All products produced from strand cast billets. Silicon killed (deoxidized) steel. No weld repairment performed. Steel not exposed to mercury or any liquid alloy which is liquid at ambient temperatures during processing or while in Gerdau St. Paul Mill's possession. Any modification to this certification as provided by Gerdau - St. Paul Mill without the expressed written consent of Gerdau St. Paul Mill negates the validity of this test report. This report shall not be reproduced except in full, without the expressed written consent of Gerdau St. Paul Mill. Gerdau St. Paul Mill is not responsible for the inability of this material to meet specific applications.
Roll batch 62138817/06 roll dtd 7/14/2015
ASME SA36/SA36M-13

RECEIVED JAN 25 2016

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

Bhaskar
BHASKAR YALAMANCHILI
QUALITY DIRECTOR

ALEX BRANDENBURG
QUALITY ASSURANCE MGR.

Barrier Pins

Figure B-9. 1¼-in. (32-mm) Diameter Connector Pin, Test Nos. GSH-1 and GSH-2

STEEL AND PIPE SUPPLY
SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 04/03/2018
TIME 11:48:43
USER WF-BATCH

SOLD TO: 66031-1127

SHIP TO: 13716
Kansas City Warehouse
401 New Century Parkway
NEW CENTURY KS

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40303469-0010	70872120TM	1/4 72 X 120 A36 TEMPERPASS STPMLPL	11	6,738.600			04/02/2018

Chemical Analysis

Heat No. 18024561 Vendor BIG RIVER STEEL LLC DOMESTIC Mill BIG RIVER STEEL LLC **Melted and Manufactured in the USA**
Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.1900	0.8300	0.0080	0.0040	0.0200	0.0400	0.0500	0.0120	0.0001	0.1200	0.0280	0.0010	0.0030	0.0010	0.0060	0.0042

Mechanical / Physical Properties

Mill Coil No. 18024561-04

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
71300.000	51200.000	29.60			0	NA			
73800.000	53300.000	26.60			0	NA			
73800.000	51700.000	29.00			0	NA			
73900.000	52300.000	29.80			0	NA			

Batch 0005226507 11 EA 6,738.600 LB
Batch 0005226497 16 EA 9,801.600 LB
Batch 0005226477 16 EA 9,801.600 LB
Batch 0005226500 16 EA 9,801.600 LB
Batch 0005226496 16 EA 9,801.600 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

Figure B-10. ¼-in. (6-mm) Steel Plate, Test Nos. GSH-1 and GSH-2

15Feb17 15:39 T E S T C E R T I F I C A T E No: C 3273

Sold By:
METALS USA CARBON FLAT ROLLED, INC
FLAT ROLLED - JEFFERSONVILLE
702 PORT ROAD
JEFFERSONVILLE IN 47130
Tel: 812-288-8906

P/O No 70019788
Rel
S/O No C 141019-001
B/L No Shp
Inv No Inv

Sold To: (6535)
ROADWAY CONSTRUCTION PRODUCTS
A MID-PARK COMPANY
511 WEST MAIN STREET
CLARKSON KY 42726

Ship To: (000)
ROADWAY CONSTRUCTION PRODUCTS
A MID-PARK COMPANY
511 WEST MAIN STREET
CLARKSON KY 42726

Tel: 270-242-2571 Fax: 270-242-9288

CERTIFICATE of ANALYSIS and TESTS Cert. No: C 3273
15Feb17

Part No G10045BS
HOT ROLLED SHEET 50,000 MIN YIELD
10 GA X 61.5000" X 92.7500"

Pcs 197 Wgt 43,901

Heat Number	Tag No	Mill Tag	Pcs	Wgt
A81568	690520	1376986	20	4,457
	RB=<88.8>/YLD1=<56.1>/TENS=<78.8>/ELON=<26.8>			
A81568	690521	1376986	20	4,457
	RB=<88.8>/YLD1=<56.1>/TENS=<78.8>/ELON=<26.8>			
A81568	690522	1376986	20	4,457
	RB=<88.8>/YLD1=<56.1>/TENS=<78.8>/ELON=<26.8>			
A81568	690523	1376986	20	4,457
	RB=<88.8>/YLD1=<56.1>/TENS=<78.8>/ELON=<26.8>			
A81568	690524	1376986	20	4,457
	RB=<88.8>/YLD1=<56.1>/TENS=<78.8>/ELON=<26.8>			
A81568	690525	1376986	20	4,457
	RB=<88.8>/YLD1=<56.1>/TENS=<78.8>/ELON=<26.8>			
A81568	690526	1376986	20	4,457
	RB=<88.8>/YLD1=<56.1>/TENS=<78.8>/ELON=<26.8>			
A81568	690527	1376986	20	4,457
	RB=<88.8>/YLD1=<56.1>/TENS=<78.8>/ELON=<26.8>			
A81568	690528	1376986	20	4,457
	RB=<88.8>/YLD1=<56.1>/TENS=<78.8>/ELON=<26.8>			
A81568	690529	1376986	17	3,788
	RB=<88.8>/YLD1=<56.1>/TENS=<78.8>/ELON=<26.8>			

Heat Number	*** Chemical Analysis ***
A81568	C=<0.20> Mn=<0.70> P=<0.010> S=<0.002> Si=<0.03> Al=<0.025>

WE HEREBY CERTIFY THAT THIS DATA WAS
FURNISHED TO US BY OUR SUPPLIER OR RESULTED FROM
TESTS PERFORMED IN A RECOGNIZED LABORATORY.

Page: 1 ....Continued

Figure B-11. 10-gauge (4-mm) Thrie-Beam Terminal Connector, Test Nos. GSH-1 and GSH-2

NUCOR
NUCOR STEEL GALLATIN

Nucor Steel Gallatin
4831 U.S. Highway 42 West
Ghent, KY 41045-9704
Phone: 1(800)581-3853 Fax: (859)567-3165

METALLURGICAL CERTIFICATION

Invoice To: Metals USA-Flat Rolled-Jeffersonville
702 Port Rd
Jeffersonville, IN 47130

Ship To: Metals USA-Flat
Rolled-Jeffersonville
Pick Up
702 Port Road
Jeffersonville, IN 47130

Date: 9/29/2016
Customer No: 27599
Customer P.O.: C42117

Mill Order No: 201815-1 **Customer Reference No:** NA **Load No:** 680178

This product was melted and manufactured in the USA to meet the requirements of: ASTM A1011-15 SS Gr 50 modified w/ 70 ksi min ten, C 0.26 max, P 0.02max, S 0.05 max, Si 0.04 max
HR Sheet Steel Bands

Ordered Size: Min 0.126 (in.) X 62.25 (in.) X Coil
Min 3.2 (mm) X 1581 (mm) X Coil

Coil Number(s): 1376986

CHEMICAL ANALYSIS (Weight %)

Heat No	C	Mn	P	S	Si	Cu	Ni	Cr	Mo
A81568	0.20	0.70	0.010	0.002	0.03	0.11	0.03	0.04	0.02
	Al	Ca	Nb	V	B	Ti	N	Sn	
	0.025	0.0014	0.000	0.001	0.0001	0.001	0.0065	0.005	

MECHANICAL PROPERTIES

Coil Tested	1376985	1376986						
Yield Strength(ksi)	56.1	57.6						
Yield Strength(mpa)	387	397						
Tensile Strength(ksi)	78.8	81.5						
Tensile Strength(mpa)	543	562						
% Elongation	26.8	23.0						
N-Value	0.16	0.15						
N-Value Range	5-15%	5-15%						
Hardness(HRBW)	88.8	85.4						
Test Section	MID	MID						
Orientation	Long	Long						
Test Method	ASTM	ASTM						

BEND TEST RESULTS

Coil ID #	Orientation	Diameter/radius of mandrel	No. of cracks	Size of cracks	Pass/ Fail

Hot rolled coils manufactured through Nucor Steel Gallatin do not contain welds or weld repairs at the time of shipment (from mill).
Mercury was not added during production of the material. The material was produced using a fully killed fine grain practice.

This product is in compliance with DFARS 252.225, the Buy American Act.

Above tests performed in accordance to ASTM standards. For yield strength determined using 0.2% offset method and elongation determined using after fracture method or JIS Z2241, E18, E415, and E1019 and are correct as contained in the records of the company.

The elongation original gauge length is 2 inches for ASTM test method and 1.97 inches for JIS test method.
Above test results were performed in accordance to EN 10204 3.1

Bend tests were conducted in accordance with ISO 7438, ASTM E290 or JIS Z2248 using the press, guided, two support and a mandrel bend method at a 180 degree bend. Bend test specimen is longer than 8" and wider than 0.8".

This report shall not be reproduced, except in full, without written approval of the undersigned laboratory managers.
[illegible]

Stephen S. Sipple
Chemical Laboratory
Mechanical Laboratory
steve.sipple@nucor.com

The information contained in this report may be confidential information intended only for the use of the individual or entity named above. If the reader of this message is not the intended recipient, you are hereby notified that any dissemination, distribution, or copying of this communication is strictly prohibited. If you have received this communication in error, please notify us immediately by telephone and destroy the original message. Thank You.

Page 1 of 1

Figure B-12. 10-gauge (4-mm) Thrie-Beam Terminal Connector, Test Nos. GSH-1 and GSH-2

Certified Analysis

Trinity Highway Products , LLC

550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH & SUPPLY CO
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1291981 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3554
BOL Number: 103620 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 3/7/18

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
50	211G	T12/12'6/3'1.5/S			2	L30918													
			M-180	A	2	222878	64,680	81,820	25.2	0.180	0.740	0.012	0.003	0.020	0.130	0.000	0.070	0.002	4
50	261G	T12/25/3'1.5/S			2	L30918													
			M-180	A	2	222878	64,680	81,820	25.2	0.180	0.740	0.012	0.003	0.020	0.130	0.000	0.070	0.002	4
15	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			A712224	79,860	80,000	25.8	0.050	0.810	0.008	0.002	0.030	0.090	0.000	0.050	0.003	4
50	12173G	T12/6'3/4@1'6.75"/S			2	L34417													
			M-180	A	2	220022	63,060	80,170	26.6	0.180	0.720	0.012	0.002	0.020	0.090	0.000	0.060	0.001	4
			M-180	A	2	220023	61,250	79,890	23.1	0.190	0.730	0.011	0.005	0.010	0.120	0.000	0.070	0.001	4
			M-180	A	2	220390	59,530	79,920	23.0	0.190	0.730	0.009	0.003	0.020	0.110	0.000	0.050	0.002	4
			M-180	A	2	220022	63,060	80,170	26.6	0.180	0.720	0.012	0.002	0.020	0.090	0.000	0.060	0.001	4
			M-180	A	2	220023	61,250	79,890	23.1	0.190	0.730	0.011	0.005	0.010	0.120	0.000	0.070	0.001	4
			M-180	A	2	220390	59,530	79,920	23.0	0.190	0.730	0.009	0.003	0.020	0.110	0.000	0.050	0.002	4
60	12365G	T12/12'6/8@1'6.75/S			2	L32917													
			M-180	A	2	216682	60,950	80,100	24.8	0.190	0.710	0.011	0.003	0.020	0.130	0.000	0.070	0.002	4
			M-180	A	2	216683	65,000	82,920	22.8	0.190	0.730	0.013	0.002	0.020	0.130	0.000	0.060	0.001	4
			M-180	A	2	216682	60,950	80,100	24.8	0.190	0.710	0.011	0.003	0.020	0.130	0.000	0.070	0.002	4
			M-180	A	2	216683	65,000	82,920	22.8	0.190	0.730	0.013	0.002	0.020	0.130	0.000	0.060	0.001	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

1 of 2

Figure B-13. 12-gauge (3-mm) Thrie-Beam Section, Test Nos. GSH-1 and GSH-2

Certified Analysis

Trinity Highway Products , LLC

550 East Robb Ave.

Lima, OH 45801 Phn:(419) 227-1296

Customer: MIDWEST MACH & SUPPLY CO

P. O. BOX 703

MILFORD, NE 68405

Project: RESALE

Order Number: 1291981 Prod Ln Grp: 3-Guardrail (Dom)

Customer PO: 3554

BOL Number: 103620 Ship Date:

Document #: 1

Shipped To: NE

Use State: NE

As of: 3/7/18

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & 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 7th day of March, 2018 .

Notary Public: Jamie L Davis
Commission Expires: 3 22 2021

NOTARIAL SEAL STATE OF OHIO
JAMIE L DAVIS
Notary Public, State of Ohio
My Commission Expires
March 22, 2021

Certified By: Trinity Highway Products, LLC
Quality Assurance

2 of 2

Figure B-14. 12-gauge (3-mm) Thrie-Beam Section, Test Nos. GSH-1 and GSH-2

BAYOU STEEL GROUP

MATERIAL CERTIFICATION REPORT

BAYOU STEEL GROUP
(LAPLACE)
138 HWY 3217
LaPlace LOUISIANA 70068
Telephone (985) 652-4900

STEEL & PIPE SUPPLY
555 Poyntz Avenue
MANHATTAN KS 66505-1688
USA

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

Tested in Accordance
With: ASTM A6

Sales Order	178467-1	Date	09/27/2017	PO:	4500294453
Product	Flat bars	Cust	40006652	Ref.	80990975
Heat NO.	L109612	Grade	A3652950	Pieces	14
Cust.Mat.		Length	20' 00"	Weight	4765.6
Size	F8X5/8X17.02 * LP				

CHEMICAL ANALYSIS	
C	0.12
Mn	0.94
P	0.009
S	0.020
Si	0.20
Cu	0.36
Ni	0.18
Cr	0.22
Mo	0.054
Cb	0
V	0.030
B	
Al	
Sn	0.008
N	
Ti	

Ci	6.0
CE	0.37

MECHANICAL PROPERTIES	TEST 1 IMPERIAL	TEST 1 METRIC	TEST 2 IMPERIAL	TEST 2 METRIC	TEST 3 IMPERIAL	TEST 3 METRIC
YIELD STRENGTH	51500 PSI	355 MPa	52300 PSI	361 MPa		
TENSILE STRENGTH	72200 PSI	498 MPa	72700 PSI	501 MPa		
ELONGATION	34 %	34 %	34 %	34 %		
GAUGE LENGTH	8 IN	203 mm	8 IN	203 mm		
BEND TEST DIAMETER						
BEND TEST RESULTS						
SPECIMEN AREA						
REDUCTION OF AREA						
IMPACT STRENGTH						

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

This heat makes the following grades: A36-14, A52950-14, G40.21-CSA50W, CSA44W, A70936-13a, ASME SA36-2010, A57250-12a, A70950-13a, and the following AASHTO M270 Grades: 36, 50, and 345. Heat is free of Mercury contamination in the process. This material is Hot Rolled Carbon Steel.EN10204-3.1B.

I hereby certify that the material test results presented here are from the reported heat and are correct. All tests were performed in accordance to the specification reported above. All steel is electric arc furnace melted (billets), manufactured, processed, tested in the U.S.A with satisfactory results. No weld repair was performed on this heat.

Notarized upon request:
Sworn to and subscribed before me on this 27th day of September, 2017

Signed ________
MARK EDWARDS, QUALITY ASSURANCE SUPERVISOR

Notary Public ________ Parish/County ________

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

Figure B-15. ⅝-in. (16-mm) Steel Plate, Test Nos. GSH-1 and GSH-2

GRAINGER
FOR THE ONES WHO GET IT DONE

May 30 2018

Certificate of Conformance

W.W. Grainger, Inc.
100 Grainger Parkway
Lake Forest, IL. 60045-5201

Attn: MWRSF UNIVERSITY OF NEBRASKA
ZORO
ASBURY DR
BUFFALO GROVE, IL, 60089-4525

Fax #

Grainger Sales Order #: 1322294683
Customer PO #: Zoro 19532469

Dear MWRSF UNIVERSITY OF NEBRASKA
As you requested, we are providing you with the following information. We certify that, to the best of Grainger's actual knowledge, the products described below conform to the respective manufacturer's specifications as described and approved by the manufacturer.

Item #	Description	Vendor Part #	Catalog Page #	Order Quantity
30TA80	Shelving Anchor Screw,Stl,6"L,3/4"D,PK	7286SD-PWR	2164	3.000

Shea Gallup
Process Management Analyst
Compliance Team
Grainger Industrial Supply

Figure B-16. ¾-in. (19-mm) Diameter Wedge Bolt, Test Nos. GSH-1 and GSH-2

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: 188686

SHIPPER #: 062591
DATE SHIPPED: 02/12/2018

LOT#: B1518

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 67,013
67,597

HARDNESS: 100 max 68.50
68.70

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
ROGERS GALVANIZE: B1518

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si
CHARTER STEEL	1010	10517060	.10	.43	.007	.010	.07

QUANTITY AND DESCRIPTION:

1,000 PCS 5/8" X 2" GUARD RAIL BOLT
P/N 3400G

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
13th DAY OF February, 20 18
Merry F Shane

Linda McLomas
APPROVED SIGNATORY

2/13/18
DATE

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Figure B-17. ⅝-in. (16-mm) Diameter Guardrail Bolt, Test Nos. GSH-1 and GSH-2

CHARTER STEEL
A Division of Charter Manufacturing Company, Inc.

LOAD

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

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Rockford Bolt & Steel
126 Mill St.
Rockford,IL-61101
Kind Attn :Linda McComas

Cust P.O.	P37844
Customer Part #	100905
Charter Sales Order	70081990
Heat #	10517060
Ship Lot #	4497128
Grade	1010 A AK FG RHQ 19/32
Process	HRSA
Finish Size	19/32
Ship date	01-NOV-17

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 10517060

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.10	.43	.007	.010	.070	.04	.08	.01	.08	.005	.001
	AL	N	B	TI	NB						
	.032	.0060	.0001	.001	.001						

Test results of Rolling Lot # 1225526

REDUCTION RATIO=109:1

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 05/12/17
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M Revision = 16 Dated = 01-DEC-16

Additional Comments:

Melt Source:
Charter Steel
Saukville, WI, USA

Trip: 1189981

ACCREDITED Testing Laboratory

Page 1 of 2

This MTR supersedes all previously dated MTRs for this order

Janice Barnard Division Mgr. of Quality Assurance
barnardJ@chartersteel.com
Printed Date : 11/01/2017

Figure B-18. ⅝-in. (16-mm) Diameter Guardrail Bolt, Test Nos. GSH-1 and GSH-2

DECKER
SINCE 1927 www.deckernut.com

DECKER MANUFACTURING CORPORATION
703 N. Clark Street
Albion, Michigan 49224
P: 517.629.3955 • F: 517.629.3535

HIGHWAY - FINISHED GOODS
GREGORY FINISHED GOODS
CANTON, OH 44710

Printed: 11/13/2017 11:13:54 AM
November 13, 2017

PRODUCT MATERIAL CERTIFICATION

CUSTOMER PART NUMBER : 1000G
CUSTOMER P.O. NUMBER : 37992

INVOICE: 142381

LOT NUMBER:	17-52-038	DESCRIPTION:	5/8 GRD RAIL NUT .031
DATE:	Aug 27, 2017	QUANTITY:	104,000
HEAT NUMBER:	10508780	MATERIAL SUPPLIER:	CHARTER STEEL
MATERIAL:	STEEL - C1010		

We certify the product above was manufactured at DECKER MANUFACTURING CORPORATION from the specified raw material and that said product is certified to be manufactured, randomly sampled, tested and/or inspected and conforms to applicable specifications. We additionally certify that said raw material was domestically manufactured in the United States of America and that said raw material was manufactured free of mercury contamination.

The items were processed under the Decker Quality Manual. The current revision is dated January 12, 2005
No welding was performed.

This document accurately represents values and statements provided by our suppliers accredited testing facility. The original metallurgical test report shall be retained on file by DECKER MANUFACTURING CORPORATION for a period of not less than (10) years.

CHEMICAL ANALYSIS BY MATERIAL SUPPLIER

CARBON :	.09	PHOSPHOROUS :	.006
MANGANESE :	.47	SULFUR :	.008

DECKER MANUFACTURING CORPORATION

Russel L. Wilson
Quality Assurance Manager

The above results pertain only to the items tested. This report shall not be reproduced except in full without the approval of this testing facility.

Figure B-19. ⅝-in. (16-mm) Diameter Guardrail Nut, Test Nos. GSH-1 and GSH-2

CHARTER STEEL
A Division of Charter Manufacturing Company, Inc.

EMAIL

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

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Decker Manufacturing Corp.
703 N. Clark St.
Albion,MI-49224

Cust P.O.	50366-1709
Customer Part #	1.125 1010
Charter Sales Order	30137947
Heat #	10508780
Ship Lot #	4486179
Grade	1010 A AK FG RHQ 1-1/8
Process	HRCC
Finish Size	1-1/8
Ship date	27-AUG-17

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 10508780

Lab Code: 7388

CHEM %Wt	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
	.09	.47	.006	.008	.080	.04	.08	.01	.08	.006	.001

AL	N	B	TI	NB
.022	.0070	.0001	.001	.001

Test results of Rolling Lot # 1221251

	# of Tests	Min Value	Max Value	Mean Value	
ROCKWELL B (HRBW)	3	59	61	60	RB LAB = 0358-02
ROD SIZE (Inch)	16	1.122	1.131	1.127	
ROD OUT OF ROUND (Inch)	8	.003	.008	.005	

REDUCTION RATIO=30:1

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 05/12/17
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M Revision = 16 Dated = 01-DEC-16

Additional Comments:

Melt Source:
Charter Steel
Saukville, WI, USA

Trip: 1166878

ACCREDITED Testing Laboratory

Page 1 of 2

This MTR supersedes all previously dated MTRs for this order

Janice Barnard Division Mgr. of Quality Assurance
barnardJ@chartersteel.com
Printed Date : 08/27/2017

Figure B-20. ⅝-in. (16-mm) Diameter Guardrail Nut, Test Nos. GSH-1 and GSH-2

INSPECTION CERTIFICATE

Certificate No. : J420141216068
P/O No. : 240104530
L/C No. : FASTENAL(INDIANAPOLIS 활)
Date issued : 2014.12.16
Date Shipped : 2014.12.05
Date Tested : 2014.11.28
Date Manufactured : 2014.11.18
Specifications : Set : ASTM A325 - 10
Bolt : ASTM A325 - 10
Nut : ASTM A563 - 07a
Washer :

Customer : FASTENAL(INDIANAPOLIS)
Description : STR H/H B N I A325 TY1 DH HDG
Size : 3/4-10UNCx2
Surface Condition : HDG
Set Lot No. : 2005569700
Q'ty Shipped : 6,000 SETS
Marking : Bolt : A325,KPF LOGO
Nut : DH,KPF LOGO
Washer :

KPF FACTORY : 50, CHUNGJUSANDAN 5-RO, CHUNGJU-SI CHUNGCHEONGBUK-DO, KOREA 380-250
TEL : (043)849 - 1114 FAX : (043)849 - 1234

FIELD OF TESTING : MECHANCICAL TESTING
LAB. ID. : 111983
CERT. NO. : 0882.01

STANDARD OF CERTIFIED : ISO/TS 16949, ISO 9001, ISO 14001
CERTIFICAT NO. : TS-01899, AC-01899, EAC-01899

STANDARD OF CERTIFIED : EN 14399-1,2,4,5,6,10
CERTIFICAT NO. : 1020 - CPD - 070038467

1. Chemical Composition (%)

Division			C x100	Si x100	Mn x100	P x1000	S x1000	Cr x100	Mo x100	Ni x100	B x10000	Cu X100
Bolt	Spec.	Min.	30	10	60						5	
		Max.	52	30		40	50				30	
Heat No.	HH64028		33	20	78	11	3	18			24	1
Nut	Spec.	Min.	20		60							
		Max.	55			40	50					
Heat No.	HI05508		45	24	75	13	4	21		2	18	5
Washer	Spec.	Min.										
		Max.										
Heat No.												

2. Mechanical Properties
2.1 Bolt
- Lot No : 2005569600
- Grade : A325 TY1

Division		Hardness Surface	Hardness Core (n= 4)	Specimen Tensile Yield Strength	Tensile Strength	Elongation	Reduction of Area	Proof Load Load (n= 3)	Proof Load Elongation	Wedge Tensile Load (n= 3)
Unit	Min.							LBF		LBF
	Max.		HRC						in	
Spec.	Min.							28,400		40,100
	Max.		34						0.0005	
Results	Min.		HRC 30					28,400	0.0001	46,069
	Max.		31					28,400	0.0002	46,475
	Avg.		31					28,400	0.0001	46,207
	Wedge Angele									6 °
Tested By			B.S.KANG					B.S.KANG		B.S.KANG

2.2 Nut
- Lot No : 1003610201
- Grade : GR.DH

Division		Hardness (n= 5)	Proof Load (n= 5)	
Unit	Min.	HRC	LBF	
	Max.	HRC		
Spec.	Min.	24	50,100	
	Max.	38		
Results	Min.	HRC 31	50,100	
	Max.	33	50,100	
	Avg.	32	50,100	GOOD
Tested By		B.S.KANG	B.S.KANG	

2.3 Washer
- Lot No :
- Grade :

Division		Hardness
Unit	Min.	
	Max.	
Spec.	Min.	
	Max.	
Results	Min.	
	Max.	
	Avg.	
Tested By		

3. Assembly Lot Tension Test

Division		Axial Tension
Unit	Min.	
	Max.	
Spec.	Min.	
	Max.	
Results	Min.	
	Max.	
	Avg.	
Tested By		

4. Visual & Thread Inspection

Division	Appearance	Thread
Bolt	OK	OK
Nut	OK	OK
Washer	OK	-

Reference : PART NO : 0123455M
ALL FASTENERS MEET THE REQUIREMENTS OF THE (FQA)
AND RECORDS OF COMPLIANCE ARE ON FILE

This is to certify that the above results are true and correct in every details

Terry Kim
Chief of Quality Management Dept.

KPF

Figure B-21. ¾-in. (19-mm) Diameter, 2-in. (51-mm) Long Heavy Hex Head Bolt and Nut, Test Nos. GSH-1 and GSH-2

TEST REPORT

USS FLAT WASHER, HDG

CUSTOMER:	DATE: **2017-12-28**
PO NUMBER: **480006711**	MFG LOT NUMBER: **M-SWE0412140-6**
SIZE: **3/4**	PART NO: **1133186**
HEADMARKS:	QNTY: **7,500 PCS**

DIMENSIONAL INSPECTIONS — SPECIFICATION: **ASME B18.21.1(2009)**

CHARACTERISTICS	SPECIFIED		ACTUAL RESULT	ACC.	REJ.
**********************	*************************************		*******************	********	********
APPEARANCE	**ASTM F788-07**		**PASSED**	**100**	**0**
OUTSIDE DIA	**1.993-2.030**		**2.001-2.004**	**8**	**0**
INSIDE DIA	**0.805-0.842**		**0.833-0.836**	**8**	**0**
THICKNESS	**0.122-0.177**		**0.126-0.131**	**8**	**0**
HOT DIP GALVANIZED	**ASTM A153 class C. RoHS Compliant**	**Min 0.0017"**	**Min 0.0019 In**	**8**	**0**

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

MFG ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD.
检验专用章
QUANLITY CONTROL

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

IFI & MORGAN LTD. ***ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China***

Figure B-22. ¾-in. (19-mm) Diameter Plain Flat Washer, Test Nos. GSH-1 and GSH-2

Appendix C. Vehicle Deformation Records

Date: 6/28/2018 Test Name: GSH-1 VIN: 1D7RB1GP6BS553873
Year: 2011 Make: Dodge Model: Ram 1500 Quad Cab

VEHICLE DEFORMATION
FLOOR PAN - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	57.1460	-7.6147	-1.6978	56.9031	-8.4487	-1.3764	0.2429	-0.8340	0.3214	0.9262	0.4029	X, Z
	2	59.3411	-11.5870	-0.4601	55.9962	-12.3718	-2.3088	3.3449	-0.7848	-1.8487	3.9015	3.3449	X
	3	59.6154	-15.1736	-0.5795	54.3605	-14.9119	-3.9867	5.2549	0.2617	-3.4072	6.2683	5.2549	X
	4	59.1791	-17.9480	-1.0035	53.3244	-17.4146	-4.8651	5.8547	0.5334	-3.8616	7.0338	5.8547	X
	5	58.2258	-20.5800	-2.2762	53.8901	-20.5270	-4.8364	4.3357	0.0530	-2.5602	5.0354	4.3357	X
	6	54.2366	-7.3605	1.9091	53.6732	-7.7778	2.1803	0.5634	-0.4173	0.2712	0.7517	0.6253	X, Z
	7	54.3793	-11.6005	1.9052	52.2504	-11.6146	1.3445	2.1289	-0.0141	-0.5607	2.2015	2.1289	X
	8	54.5684	-14.9041	1.8165	51.0579	-14.6516	0.6385	3.5105	0.2525	-1.1780	3.7115	3.5105	X
	9	54.6228	-18.3947	1.7987	50.8734	-18.1029	0.1639	3.7494	0.2918	-1.6348	4.1007	3.7494	X
	10	54.8620	-21.8933	1.6626	52.0019	-21.4064	0.0887	2.8601	0.4869	-1.5739	3.3007	2.8601	X
FLOOR PAN (Z)	11	47.9699	-7.2439	5.1145	48.0767	-7.2995	6.0036	-0.1068	-0.0556	0.8891	0.8972	0.8891	Z
	12	48.1285	-11.5130	5.0513	48.1653	-11.5115	6.3528	-0.0368	0.0015	1.3015	1.3020	1.3015	Z
	13	48.1610	-14.8942	5.0498	47.9080	-14.9103	5.8886	0.2530	-0.0161	0.8388	0.8763	0.8388	Z
	14	48.3016	-18.3919	5.0236	47.8417	-18.4307	5.7091	0.4599	-0.0388	0.6855	0.8264	0.6855	Z
	15	48.3519	-21.8684	5.0173	47.8385	-21.8808	5.9581	0.5134	-0.0124	0.9408	1.0718	0.9408	Z
	16	44.4312	-7.4425	5.2128	44.5148	-7.3664	5.9394	-0.0836	0.0761	0.7266	0.7353	0.7266	Z
	17	44.4961	-10.1990	5.1932	44.5895	-10.1192	5.9269	-0.0934	0.0798	0.7337	0.7439	0.7337	Z
	18	44.5856	-14.4194	5.1678	44.7484	-14.3954	5.9246	-0.1628	0.0240	0.7568	0.7745	0.7568	Z
	19	44.5052	-17.7049	5.1888	44.7246	-17.7208	5.9487	-0.2194	-0.0159	0.7599	0.7911	0.7599	Z
	20	44.5558	-22.4507	5.1462	44.7694	-22.4665	6.1728	-0.2136	-0.0158	1.0266	1.0487	1.0266	Z
	21	39.9347	-6.4836	5.3228	40.0267	-6.5111	5.9448	-0.0920	-0.0275	0.6220	0.6294	0.6220	Z
	22	39.9988	-9.3701	5.5539	40.0977	-9.3528	6.2052	-0.0989	0.0173	0.6513	0.6590	0.6513	Z
	23	40.0381	-13.6381	5.4148	40.1518	-13.7357	6.0347	-0.1137	-0.0976	0.6199	0.6378	0.6199	Z
	24	40.0164	-18.3064	5.3711	40.2273	-18.3674	6.1755	-0.2109	-0.0610	0.8044	0.8338	0.8044	Z
	25	40.2800	-22.3070	5.3573	40.4762	-22.3500	6.3159	-0.1962	-0.0430	0.9586	0.9794	0.9586	Z
	26	35.5660	-6.7220	5.3367	35.6447	-6.7819	5.8782	-0.0787	-0.0599	0.5415	0.5505	0.5415	Z
	27	35.5357	-9.0873	5.4621	35.5531	-9.0510	6.0309	-0.0174	0.0363	0.5688	0.5702	0.5688	Z
	28	35.5084	-13.0360	5.3844	35.5890	-13.1154	5.9540	-0.0806	-0.0794	0.5696	0.5807	0.5696	Z
	29	35.4227	-17.3358	5.3502	35.6062	-17.4637	5.9901	-0.1835	-0.1279	0.6399	0.6779	0.6399	Z
	30	35.6781	-21.5112	5.3665	35.8893	-21.5669	5.9145	-0.2112	-0.0557	0.5480	0.5899	0.5480	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

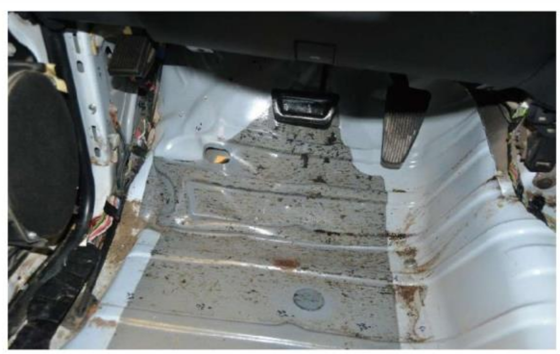
Pretest Floor Pan	Posttest Floor Pan
	

Figure C-1. Floor Pan Deformation Data – Set 1, Test No. GSH-1

Date: 6/28/2018 Test Name: GSH-1 VIN: 1D7RB1GP6BS553873
Year: 2011 Make: Dodge Model: Ram 1500 Quad Cab

VEHICLE DEFORMATION
FLOOR PAN - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	60.3898	-26.1285	-5.6751	59.9148	-26.9757	-5.2241	0.4750	-0.8472	0.4510	1.0709	0.6550	X, Z
	2	62.6418	-30.0677	-4.4338	59.0730	-30.9101	-6.1701	3.5688	-0.8424	-1.7363	4.0572	3.5688	X
	3	62.9712	-33.6496	-4.5548	57.4854	-33.4709	-7.8625	5.4858	0.1787	-3.3077	6.4083	5.4858	X
	4	62.5785	-36.4300	-4.9819	56.4924	-35.9872	-8.7521	6.0861	0.4428	-3.7702	7.1729	6.0861	X
	5	61.6691	-39.0754	-6.2591	57.1056	-39.0907	-8.7273	4.5635	-0.0153	-2.4682	5.1882	4.5635	X
	6	57.4667	-25.9213	-2.0763	56.6558	-26.3626	-1.6834	0.8109	-0.4413	0.3929	1.0033	0.9011	X, Z
	7	57.6741	-30.1586	-2.0827	55.2965	-30.2187	-2.5355	2.3776	-0.0601	-0.4528	2.4211	2.3776	X
	8	57.9139	-33.4589	-2.1731	54.1543	-33.2719	-3.2547	3.7596	0.1870	-1.0816	3.9166	3.7596	X
	9	58.0216	-36.9482	-2.1931	54.0253	-36.7245	-3.7380	3.9963	0.2237	-1.5449	4.2904	3.9963	X
	10	58.3146	-40.4427	-2.3308	55.2046	-40.0102	-3.8144	3.1100	0.4325	-1.4836	3.4728	3.1100	X
FLOOR PAN (Z)	11	51.1899	-25.9026	1.1111	51.0322	-25.9788	2.1106	0.1577	-0.0762	0.9995	1.0147	0.9995	Z
	12	51.4137	-30.1688	1.0455	51.1834	-30.1897	2.4508	0.2303	-0.0209	1.4053	1.4242	1.4053	Z
	13	51.4978	-33.5490	1.0419	50.9806	-33.5909	1.9776	0.5172	-0.0419	0.9357	1.0699	0.9357	Z
	14	51.6919	-37.0442	1.0137	50.9691	-37.1115	1.7899	0.7228	-0.0673	0.7762	1.0628	0.7762	Z
	15	51.7953	-40.5195	1.0052	51.0174	-40.5618	2.0312	0.7779	-0.0423	1.0260	1.2883	1.0260	Z
	16	47.6543	-26.1553	1.1992	47.4721	-26.0999	2.0270	0.1822	0.0554	0.8278	0.8494	0.8278	Z
	17	47.7613	-28.9105	1.1780	47.5890	-28.8512	2.0087	0.1723	0.0593	0.8307	0.8505	0.8307	Z
	18	47.9153	-33.1290	1.1499	47.8134	-33.1245	1.9977	0.1019	0.0045	0.8478	0.8539	0.8478	Z
	19	47.8850	-36.4153	1.1686	47.8403	-36.4499	2.0142	0.0447	-0.0346	0.8456	0.8475	0.8456	Z
	20	48.0081	-41.1598	1.1230	47.9565	-41.1949	2.2279	0.0516	-0.0351	1.1049	1.1067	1.1049	Z
	21	43.1434	-25.2652	1.2970	42.9715	-25.3133	2.0099	0.1719	-0.0481	0.7129	0.7349	0.7129	Z
	22	43.2509	-28.1506	1.5263	43.0846	-28.1542	2.2644	0.1663	-0.0036	0.7381	0.7566	0.7381	Z
	23	43.3557	-32.4173	1.3845	43.2067	-32.5354	2.0844	0.1490	-0.1181	0.6999	0.7253	0.6999	Z
	24	43.4055	-37.0854	1.3377	43.3522	-37.1657	2.2153	0.0533	-0.0803	0.8776	0.8829	0.8776	Z
	25	43.7301	-41.0815	1.3219	43.6613	-41.1443	2.3481	0.0688	-0.0628	1.0262	1.0304	1.0262	Z
	26	38.7788	-25.5703	1.2983	38.5946	-25.6510	1.9190	0.1842	-0.0807	0.6207	0.6525	0.6207	Z
	27	38.7842	-27.9359	1.4220	38.5369	-27.9216	2.0661	0.2473	0.0143	0.6441	0.6901	0.6441	Z
	28	38.8175	-31.8844	1.3416	38.6354	-31.9847	1.9804	0.1821	-0.1003	0.6388	0.6718	0.6388	Z
	29	38.7975	-36.1850	1.3042	38.7189	-36.3323	2.0069	0.0786	-0.1473	0.7027	0.7223	0.7027	Z
	30	39.1166	-40.3560	1.3185	39.0652	-40.4305	1.9235	0.0514	-0.0745	0.6050	0.6117	0.6050	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan

Posttest Floor Pan

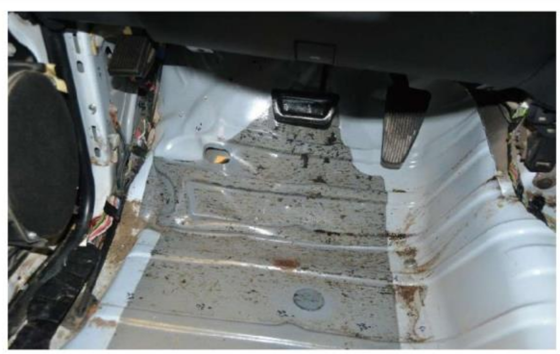


Figure C-2. Floor Pan Deformation Data – Set 2, Test No. GSH-1

Date: 7/27/2018 Test Name: GSH-2 VIN: 1CRR6FTXDS575838
Year: 2013 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
FLOOR PAN - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	57.8900	-20.8990	-1.6667	55.3731	-19.2158	-3.0912	2.5169	1.6832	-1.4245	3.3462	2.5169	X
	2	59.0216	-17.8270	-0.8558	57.6931	-17.5045	-1.2684	1.3285	0.3225	-0.4126	1.4280	1.3285	X
	3	59.2342	-15.1622	-0.9692	58.5882	-15.1827	-0.6759	0.6460	-0.0205	0.2933	0.7098	0.7095	X, Z
	4	59.0287	-12.0021	-0.8802	58.6697	-12.0133	-0.4893	0.3590	-0.0112	0.3909	0.5309	0.5307	X, Z
	5	57.0319	-9.4376	-1.6166	56.8023	-9.2697	-1.1727	0.2296	0.1679	0.4439	0.5272	0.4998	X, Z
	6	53.6167	-21.8976	2.0498	51.3822	-20.5484	0.8733	2.2345	1.3492	-1.1765	2.8631	2.2345	X
	7	53.5165	-18.5508	2.1059	52.8155	-18.1318	2.5584	0.7010	0.4190	0.4525	0.9337	0.8344	X, Z
	8	53.4148	-15.4708	2.1649	53.1737	-15.1190	3.0151	0.2411	0.3518	0.8502	0.9512	0.8837	X, Z
	9	53.4453	-12.3900	2.1573	53.2332	-12.1181	2.8471	0.2121	0.2719	0.6898	0.7712	0.7217	X, Z
	10	53.5198	-9.5578	2.1255	53.3536	-9.2808	2.6483	0.1662	0.2770	0.5228	0.6145	0.5486	X, Z
FLOOR PAN (Z)	11	50.5485	-22.2374	3.6929	49.0049	-21.1750	3.3856	1.5436	1.0624	-0.3073	1.8989	-0.3073	Z
	12	50.5309	-18.9595	3.6995	50.1428	-18.4413	4.5903	0.3881	0.5182	0.8908	1.1012	0.8908	Z
	13	50.5046	-15.8163	3.7200	50.3790	-15.3702	4.7921	0.1256	0.4461	1.0721	1.1680	1.0721	Z
	14	50.5950	-13.3005	3.6862	50.4093	-12.8307	4.5820	0.1857	0.4698	0.8958	1.0284	0.8958	Z
	15	50.5454	-9.9744	3.7260	50.3771	-9.5118	4.3940	0.1683	0.4626	0.6680	0.8298	0.6680	Z
	16	46.9732	-22.4751	5.0130	46.6652	-21.9074	6.3768	0.3080	0.5677	1.3638	1.5090	1.3638	Z
	17	46.9864	-19.3271	5.0227	46.8313	-18.7444	6.2711	0.1551	0.5827	1.2484	1.3864	1.2484	Z
	18	46.9476	-16.6303	5.0324	46.8115	-16.1403	6.1166	0.1361	0.4900	1.0842	1.1975	1.0842	Z
	19	46.8663	-13.5456	5.0502	46.7025	-13.0290	5.9209	0.1638	0.5166	0.8707	1.0256	0.8707	Z
	20	47.0640	-9.9705	5.0545	46.9188	-9.5048	5.6950	0.1452	0.4657	0.6405	0.8051	0.6405	Z
	21	43.3159	-22.9453	5.0795	43.2177	-22.3720	6.8948	0.0982	0.5733	1.8153	1.9062	1.8153	Z
	22	43.3175	-19.1575	5.0844	43.2148	-18.6935	6.5019	0.1027	0.4640	1.4175	1.4950	1.4175	Z
	23	43.4080	-16.3010	5.0915	43.2404	-15.7864	6.1803	0.1676	0.5146	1.0888	1.2159	1.0888	Z
	24	43.5235	-13.5498	5.0970	43.4062	-12.9894	5.9534	0.1173	0.5604	0.8564	1.0302	0.8564	Z
	25	43.4414	-9.7446	5.1036	43.2965	-9.2824	5.6846	0.1449	0.4622	0.5810	0.7564	0.5810	Z
	26	37.3182	-23.3993	5.1224	37.3196	-22.9068	6.5958	-0.0014	0.4925	1.4734	1.5535	1.4734	Z
	27	37.4651	-19.4002	5.1124	37.4000	-18.9618	6.3931	0.0651	0.4384	1.2807	1.3552	1.2807	Z
	28	37.5081	-16.0369	5.1196	37.3641	-15.5672	6.0392	0.1440	0.4697	0.9196	1.0426	0.9196	Z
	29	37.4714	-12.7311	5.1300	37.3045	-12.2415	5.7174	0.1669	0.4896	0.5874	0.7827	0.5874	Z
	30	37.5456	-9.4394	5.1398	37.4409	-9.0041	5.6016	0.1047	0.4353	0.4618	0.6432	0.4618	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan	Posttest Floor Pan
	

Figure C-3. Floor Pan Deformation Data – Set 1, Test No. GSH-2

Date: 7/27/2018 Test Name: GSH-2 VIN: 1CRR6FTXDS575838
Year: 2013 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
FLOOR PAN - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	59.6170	-40.9259	-5.2987	57.3181	-39.4971	-6.9655	2.2989	1.4288	-1.6668	3.1788	2.2989	X
	2	60.7793	-37.8681	-4.4773	59.6540	-37.8140	-5.1367	1.1253	0.0541	-0.6594	1.3054	1.1253	X
	3	61.0252	-35.2061	-4.5880	60.5767	-35.5034	-4.5431	0.4485	-0.2973	0.0449	0.5400	0.4507	X, Z
	4	60.8575	-32.0437	-4.4996	60.6979	-32.3351	-4.3586	0.1596	-0.2914	0.1410	0.3609	0.2130	X, Z
	5	58.8982	-29.4549	-5.2517	58.8676	-29.5685	-5.0498	0.0306	-0.1136	0.2019	0.2337	0.2042	X, Z
	6	55.3012	-41.8732	-1.6180	53.2983	-40.7759	-3.0125	2.0029	1.0973	-1.3945	2.6759	2.0029	X
	7	55.2413	-38.5255	-1.5617	54.7569	-38.3764	-1.3247	0.4844	0.1491	0.2370	0.5595	0.5393	X, Z
	8	55.1767	-35.4445	-1.5024	55.1520	-35.3680	-0.8691	0.0247	0.0765	0.6333	0.6384	0.6338	X, Z
	9	55.2447	-32.3643	-1.5087	55.2501	-32.3682	-1.0391	-0.0054	-0.0039	0.4696	0.4696	0.4696	Z
	10	55.3540	-29.5332	-1.5389	55.4072	-29.5329	-1.2397	-0.0532	0.0003	0.2992	0.3039	0.2992	Z
FLOOR PAN (Z)	11	52.2155	-42.1760	-0.0006	50.9054	-41.3703	-0.5072	1.3101	0.8057	-0.5066	1.6193	-0.5066	Z
	12	52.2378	-38.8982	0.0070	52.0742	-38.6503	0.6991	0.1636	0.2479	0.6921	0.7531	0.6921	Z
	13	52.2496	-35.7549	0.0283	52.3488	-35.5823	0.8993	-0.0992	0.1726	0.8710	0.8935	0.8710	Z
	14	52.3710	-33.2404	-0.0038	52.4120	-33.0435	0.6874	-0.0410	0.1969	0.6912	0.7199	0.6912	Z
	15	52.3615	-29.9140	0.0368	52.4226	-29.7247	0.4969	-0.0611	0.1893	0.4601	0.5013	0.4601	Z
	16	48.6268	-42.3705	1.2897	48.5473	-42.0705	2.4773	0.0795	0.3000	1.1876	1.2275	1.1876	Z
	17	48.6783	-39.2229	1.3006	48.7539	-38.9100	2.3697	-0.0756	0.3129	1.0691	1.1165	1.0691	Z
	18	48.6722	-36.5258	1.3109	48.7677	-36.3060	2.2133	-0.0955	0.2198	0.9024	0.9337	0.9024	Z
	19	48.6284	-33.4404	1.3292	48.6989	-33.1937	2.0149	-0.0705	0.2467	0.6857	0.7321	0.6857	Z
	20	48.8695	-29.8680	1.3364	48.9606	-29.6727	1.7871	-0.0911	0.1953	0.4507	0.4996	0.4507	Z
	21	44.9636	-42.7961	1.3257	45.0925	-42.4908	2.9848	-0.1289	0.3053	1.6591	1.6919	1.6591	Z
	22	45.0113	-39.0087	1.3320	45.1376	-38.8129	2.5892	-0.1263	0.1958	1.2572	1.2786	1.2572	Z
	23	45.1365	-36.1534	1.3408	45.2012	-35.9067	2.2655	-0.0647	0.2467	0.9247	0.9592	0.9247	Z
	24	45.2855	-33.4039	1.3482	45.4032	-33.1122	2.0371	-0.1177	0.2917	0.6889	0.7573	0.6889	Z
	25	45.2497	-29.5980	1.3555	45.3415	-29.4043	1.7652	-0.0918	0.1937	0.4097	0.4624	0.4097	Z
	26	38.9607	-43.1770	1.3187	39.1891	-42.9510	2.6677	-0.2284	0.2260	1.3490	1.3867	1.3490	Z
	27	39.1563	-39.1800	1.3113	39.3203	-39.0074	2.4624	-0.1640	0.1726	1.1511	1.1755	1.1511	Z
	28	39.2403	-35.8174	1.3201	39.3286	-35.6129	2.1060	-0.0883	0.2045	0.7859	0.8169	0.7859	Z
	29	39.2438	-32.5114	1.3313	39.3123	-32.2870	1.7815	-0.0685	0.2244	0.4502	0.5077	0.4502	Z
	30	39.3579	-29.2209	1.3428	39.4902	-29.0516	1.6637	-0.1323	0.1693	0.3209	0.3862	0.3209	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan

Posttest Floor Pan

Figure C-4. Floor Pan Deformation Data – Set 2, Test No. GSH-2

Date: 6/28/2018 Test Name: GSH-1 VIN: 1D7RB1GP6BS553873
Year: 2011 Make: Dodge Model: Ram 1500 Quad Cab

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	43.6356	-19.3788	-28.8045	43.8975	-19.6834	-28.4517	-0.2619	-0.3046	0.3528	0.5346	0.5346	X, Y, Z
	2	43.4904	-7.1421	-28.5003	43.6833	-7.4835	-28.1568	-0.1929	-0.3414	0.3435	0.5213	0.5213	X, Y, Z
	3	43.7793	4.1506	-27.8679	44.0140	3.8639	-27.5280	-0.2347	0.2867	0.3399	0.5028	0.5028	X, Y, Z
	4	40.7525	-20.1101	-13.3053	40.6995	-20.3141	-12.9834	0.0530	-0.2040	0.3219	0.3848	0.3848	X, Y, Z
	5	39.8141	-7.6008	-13.2496	39.8161	-7.7812	-12.9493	-0.0020	-0.1804	0.3003	0.3503	0.3503	X, Y, Z
	6	37.3894	4.5516	-13.4497	37.4500	4.3196	-13.2472	-0.0606	0.2320	0.2025	0.3139	0.3139	X, Y, Z
SIDE PANEL (Y)	7	52.6862	-27.1852	-3.1461	52.4980	-26.2859	-2.7274	0.1882	0.8993	0.4187	1.0097	0.8993	Y
	8	48.9673	-27.2384	-1.4329	48.7539	-26.2694	-1.1297	0.2134	0.9690	0.3032	1.0375	0.9690	Y
	9	49.0377	-27.2502	-5.0678	48.8765	-26.5169	-4.7041	0.1612	0.7333	0.3637	0.8343	0.7333	Y
IMPACT SIDE DOOR (Y)	10	16.4523	-30.4722	-16.0648	16.3047	-31.1529	-15.5066	0.1476	-0.6807	0.5582	0.8926	-0.6807	Y
	11	30.1158	-30.6523	-15.6363	29.9873	-31.0999	-15.0767	0.1285	-0.4476	0.5596	0.7280	-0.4476	Y
	12	39.3235	-29.7448	-16.3665	39.1894	-30.0268	-15.8359	0.1341	-0.2820	0.5306	0.6157	-0.2820	Y
	13	17.8801	-29.8526	-0.5417	17.6403	-29.5840	-0.1719	0.2398	0.2686	0.3698	0.5161	0.2686	Y
	14	28.5336	-30.2175	0.7622	28.3363	-29.6902	1.2892	0.1973	0.5273	0.5270	0.7712	0.5273	Y
	15	36.8824	-30.2127	0.7404	36.6486	-29.4919	1.3500	0.2338	0.7208	0.6096	0.9725	0.7208	Y
ROOF - (Z)	16	27.3343	-16.8088	-44.4221	27.4828	-17.3010	-44.0664	-0.1485	-0.4922	0.3557	0.6252	0.3557	Z
	17	28.8545	-10.9106	-44.6524	29.0794	-11.4441	-44.3062	-0.2249	-0.5335	0.3462	0.6746	0.3462	Z
	18	29.7494	-5.8687	-44.7522	29.9243	-6.3465	-44.4429	-0.1749	-0.4778	0.3093	0.5954	0.3093	Z
	19	30.2374	-0.7781	-44.8119	30.4527	-1.3407	-44.5098	-0.2153	-0.5626	0.3021	0.6739	0.3021	Z
	20	30.4671	3.8495	-44.8088	30.5710	3.3012	-44.5617	-0.1039	0.5483	0.2471	0.6103	0.2471	Z
	21	18.7411	-18.0915	-45.7614	18.8580	-18.5432	-45.4132	-0.1169	-0.4517	0.3482	0.5822	0.3482	Z
	22	19.3626	-12.5280	-46.1049	19.5102	-13.0278	-45.7808	-0.1476	-0.4998	0.3241	0.6137	0.3241	Z
	23	20.0679	-6.2461	-46.3700	20.2094	-6.7570	-46.0816	-0.1415	-0.5109	0.2884	0.6035	0.2884	Z
	24	20.1448	-2.8096	-46.5383	20.2301	-3.3362	-46.2690	-0.0853	-0.5266	0.2693	0.5976	0.2693	Z
	25	21.1560	2.8892	-46.5589	21.3611	2.4371	-46.2942	-0.2051	0.4521	0.2647	0.5626	0.2647	Z
	26	10.2756	-17.5942	-46.2596	10.3496	-18.0872	-45.8964	-0.0740	-0.4930	0.3632	0.6168	0.3632	Z
	27	10.0362	-11.4743	-46.7013	10.1258	-11.9549	-46.3754	-0.0896	-0.4806	0.3259	0.5876	0.3259	Z
	28	10.0657	-5.2486	-46.9666	10.2405	-5.6209	-46.6801	-0.1748	-0.3723	0.2865	0.5012	0.2865	Z
	29	10.0001	-0.8469	-47.0710	10.1796	-1.3195	-46.8178	-0.1795	-0.4726	0.2532	0.5654	0.2532	Z
	30	10.0261	3.0530	-47.1152	10.1947	2.5413	-46.8786	-0.1686	0.5117	0.2366	0.5884	0.2366	Z
A-PILLAR Maximum (X, Y, Z)	31	47.9425	-25.8056	-28.3412	48.4075	-26.3077	-28.0267	-0.4650	-0.5021	0.3145	0.7532	0.3145	Z
	32	44.6927	-25.0367	-31.2597	44.9502	-25.5888	-30.8399	-0.2575	-0.5521	0.4198	0.7398	0.4198	Z
	33	42.1329	-23.9507	-33.1098	42.2914	-24.4491	-32.7156	-0.1585	-0.4984	0.3942	0.6549	0.3942	Z
	34	39.0119	-23.4351	-35.4895	39.1727	-23.9023	-35.0654	-0.1608	-0.4672	0.4241	0.6511	0.4241	Z
	35	35.2991	-22.4564	-37.6019	35.4767	-22.9428	-37.2126	-0.1776	-0.4864	0.3893	0.6478	0.3893	Z
	36	32.0716	-22.5917	-40.2358	32.2971	-23.0985	-39.7519	-0.2255	-0.5068	0.4839	0.7361	0.4839	Z
A-PILLAR Lateral (Y)	31	47.9425	-25.8056	-28.3412	48.4075	-26.3077	-28.0267	-0.4650	-0.5021	0.3145	0.7532	-0.5021	Y
	32	44.6927	-25.0367	-31.2597	44.9502	-25.5888	-30.8399	-0.2575	-0.5521	0.4198	0.7398	-0.5521	Y
	33	42.1329	-23.9507	-33.1098	42.2914	-24.4491	-32.7156	-0.1585	-0.4984	0.3942	0.6549	-0.4984	Y
	34	39.0119	-23.4351	-35.4895	39.1727	-23.9023	-35.0654	-0.1608	-0.4672	0.4241	0.6511	-0.4672	Y
	35	35.2991	-22.4564	-37.6019	35.4767	-22.9428	-37.2126	-0.1776	-0.4864	0.3893	0.6478	-0.4864	Y
	36	32.0716	-22.5917	-40.2358	32.2971	-23.0985	-39.7519	-0.2255	-0.5068	0.4839	0.7361	-0.5068	Y
B-PILLAR Maximum (X, Y, Z)	37	4.6671	-22.9917	-40.3122	4.8100	-23.3846	-39.8804	-0.1429	-0.3929	0.4318	0.6010	0.4318	Z
	38	7.8976	-24.5578	-35.9044	7.9816	-24.8823	-35.4897	-0.0840	-0.3245	0.4147	0.5332	0.4147	Z
	39	5.3634	-26.5931	-29.9093	5.4588	-26.8222	-29.4229	-0.0954	-0.2291	0.4864	0.5461	0.4864	Z
	40	8.4690	-26.9283	-27.5801	8.5868	-27.1297	-27.0989	-0.1178	-0.2014	0.4812	0.5348	0.4812	Z
B-PILLAR Lateral (Y)	37	4.6671	-22.9917	-40.3122	4.8100	-23.3846	-39.8804	-0.1429	-0.3929	0.4318	0.6010	-0.3929	Y
	38	7.8976	-24.5578	-35.9044	7.9816	-24.8823	-35.4897	-0.0840	-0.3245	0.4147	0.5332	-0.3245	Y
	39	5.3634	-26.5931	-29.9093	5.4588	-26.8222	-29.4229	-0.0954	-0.2291	0.4864	0.5461	-0.2291	Y
	40	8.4690	-26.9283	-27.5801	8.5868	-27.1297	-27.0989	-0.1178	-0.2014	0.4812	0.5348	-0.2014	Y

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure C-5. Occupant Compartment Deformation Data – Set 1, Test No. GSH-1

Date: 6/28/2018 Test Name: GSH-1 VIN: 1D7RB1GP6BS553873
Year: 2011 Make: Dodge Model: Ram 1500 Quad Cab

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	46.9425	-38.0586	-32.8273	47.2193	-38.3257	-32.4348	-0.2768	-0.2671	0.3925	0.5496	0.5496	X, Y, Z
	2	46.6057	-25.8260	-32.5118	46.8173	-26.1314	-32.1090	-0.2116	-0.3054	0.4028	0.5480	0.5480	X, Y, Z
	3	46.7167	-14.5309	-31.8677	46.9715	-14.7821	-31.4489	-0.2548	-0.2512	0.4188	0.5508	0.5508	X, Y, Z
	4	44.0223	-38.8504	-17.3380	43.9561	-39.0469	-16.9841	0.0662	-0.1965	0.3539	0.4102	0.4102	X, Y, Z
	5	42.8889	-26.3573	-17.2733	42.8810	-26.5291	-16.9216	0.0079	-0.1718	0.3517	0.3915	0.3915	X, Y, Z
	6	40.2759	-14.2439	-17.4695	40.3318	-14.4650	-17.1994	-0.0559	-0.2211	0.2701	0.3535	0.3535	X, Y, Z
SIDE PANEL (Y)	7	56.0327	-45.7490	-7.1479	55.7943	-44.8654	-6.6859	0.2384	0.8836	0.4620	1.0252	0.8836	Y
	8	52.3096	-45.8618	-5.4465	52.0426	-44.9103	-5.1066	0.2670	0.9515	0.3399	1.0451	0.9515	Y
	9	52.3916	-45.8689	-9.0812	52.1865	-45.1463	-8.6809	0.2051	0.7226	0.4003	0.8512	0.7226	Y
IMPACT SIDE DOOR (Y)	10	19.8952	-49.5868	-20.1843	19.7423	-50.2500	-19.6555	0.1529	-0.6632	0.5288	0.8619	-0.6632	Y
	11	33.5584	-49.5545	-19.7127	33.4203	-49.9893	-19.1583	0.1381	-0.4348	0.5544	0.7180	-0.4348	Y
	12	42.7532	-48.5031	-20.4129	42.6085	-48.7738	-19.8694	0.1447	-0.2707	0.5435	0.6242	-0.2707	Y
	13	21.2643	-48.9607	-4.6562	20.9791	-48.7022	-4.3104	0.2852	0.2585	0.3458	0.5174	0.2585	Y
	14	31.9180	-49.1609	-3.3190	31.6681	-48.6490	-2.7970	0.2499	0.5119	0.5220	0.7726	0.5119	Y
	15	40.2658	-49.0261	-3.3143	39.9761	-48.3240	-2.6948	0.2897	0.7021	0.6195	0.9801	0.7021	Y
ROOF - (Z)	16	30.6523	-35.7271	-48.4939	30.8465	-36.1523	-48.1237	-0.1942	-0.4252	0.3702	0.5963	0.3702	Z
	17	32.0812	-29.8057	-48.7138	32.3546	-30.2710	-48.3403	-0.2734	-0.4653	0.3735	0.6563	0.3735	Z
	18	32.8978	-24.7504	-48.8059	33.1221	-25.1608	-48.4595	-0.2243	-0.4104	0.3464	0.5820	0.3464	Z
	19	33.3066	-19.6527	-48.8592	33.5742	-20.1473	-48.5108	-0.2676	-0.4946	0.3484	0.6615	0.3484	Z
	20	33.4642	-15.0221	-48.8510	33.6218	-15.5040	-48.5499	-0.1576	-0.4819	0.3011	0.5897	0.3011	Z
	21	22.0844	-37.1421	-49.8617	22.2484	-37.5224	-49.5160	-0.1640	-0.3803	0.3457	0.5395	0.3457	Z
	22	22.6203	-31.5693	-50.1979	22.8180	-31.9967	-49.8661	-0.1977	-0.4274	0.3318	0.5761	0.3318	Z
	23	23.2285	-25.2769	-50.4547	23.4227	-25.7152	-50.1470	-0.1942	-0.4383	0.3077	0.5696	0.3077	Z
	24	23.2524	-21.8394	-50.6195	23.3920	-22.2940	-50.3253	-0.1396	-0.4546	0.2942	0.5592	0.2942	Z
	25	24.1748	-16.1256	-50.6314	24.4347	-16.5041	-50.3299	-0.2599	-0.3785	0.3015	0.5493	0.3015	Z
	26	13.6139	-36.7762	-50.3862	13.7365	-37.1950	-50.0399	-0.1226	-0.4188	0.3463	0.5571	0.3463	Z
	27	13.2806	-30.6603	-50.8228	13.4213	-31.0657	-50.5039	-0.1407	-0.4054	0.3189	0.5346	0.3189	Z
	28	13.2139	-24.4347	-51.0821	13.4406	-24.7299	-50.7915	-0.2267	-0.2952	0.2906	0.4722	0.2906	Z
	29	13.0800	-20.0345	-51.1824	13.3147	-20.4295	-50.9183	-0.2347	-0.3950	0.2641	0.5300	0.2641	Z
	30	13.0454	-16.1346	-51.2228	13.2711	-16.5688	-50.9689	-0.2257	-0.4342	0.2539	0.5513	0.2539	Z
A-PILLAR Maximum (X, Y, Z)	31	51.3475	-44.4180	-32.3565	51.8279	-44.8815	-32.0050	-0.4804	-0.4635	0.3515	0.7544	0.3515	Z
	32	48.0952	-43.6969	-35.2845	48.3739	-44.2079	-34.8332	-0.2787	-0.5110	0.4513	0.7365	0.4513	Z
	33	45.5246	-42.6491	-37.1417	45.7071	-43.1040	-36.7190	-0.1825	-0.4549	0.4227	0.6472	0.4227	Z
	34	42.4035	-42.1797	-39.5307	42.5919	-42.5985	-39.0827	-0.1884	-0.4188	0.4480	0.6416	0.4480	Z
	35	38.6827	-41.2568	-41.6540	38.8922	-41.6898	-41.2455	-0.2095	-0.4330	0.4085	0.6311	0.4085	Z
	36	35.4659	-41.4398	-44.2982	35.7277	-41.8872	-43.8007	-0.2618	-0.4474	0.4975	0.7185	0.4975	Z
A-PILLAR Lateral (Y)	31	51.3475	-44.4180	-32.3565	51.8279	-44.8815	-32.0050	-0.4804	-0.4635	0.3515	0.7544	-0.4635	Y
	32	48.0952	-43.6969	-35.2845	48.3739	-44.2079	-34.8332	-0.2787	-0.5110	0.4513	0.7365	-0.5110	Y
	33	45.5246	-42.6491	-37.1417	45.7071	-43.1040	-36.7190	-0.1825	-0.4549	0.4227	0.6472	-0.4549	Y
	34	42.4035	-42.1797	-39.5307	42.5919	-42.5985	-39.0827	-0.1884	-0.4188	0.4480	0.6416	-0.4188	Y
	35	38.6827	-41.2568	-41.6540	38.8922	-41.6898	-41.2455	-0.2095	-0.4330	0.4085	0.6311	-0.4330	Y
	36	35.4659	-41.4398	-44.2982	35.7277	-41.8872	-43.8007	-0.2618	-0.4474	0.4975	0.7185	-0.4474	Y
B-PILLAR Maximum (X, Y, Z)	37	8.0714	-42.2664	-44.4618	8.2492	-42.5926	-44.0651	-0.1778	-0.3262	0.3967	0.5435	0.3967	Z
	38	11.3120	-43.7864	-40.0452	11.4219	-44.0536	-39.6628	-0.1099	-0.2672	0.3824	0.4793	0.3824	Z
	39	8.7909	-45.8669	-34.0601	8.8995	-46.0480	-33.6136	-0.1086	-0.1811	0.4465	0.4939	0.4465	Z
	40	11.8940	-46.1561	-31.7215	12.0205	-46.3140	-31.2750	-0.1265	-0.1579	0.4465	0.4902	0.4465	Z
B-PILLAR Lateral (Y)	37	8.0714	-42.2664	-44.4618	8.2492	-42.5926	-44.0651	-0.1778	-0.3262	0.3967	0.5435	-0.3262	Y
	38	11.3120	-43.7864	-40.0452	11.4219	-44.0536	-39.6628	-0.1099	-0.2672	0.3824	0.4793	-0.2672	Y
	39	8.7909	-45.8669	-34.0601	8.8995	-46.0480	-33.6136	-0.1086	-0.1811	0.4465	0.4939	-0.1811	Y
	40	11.8940	-46.1561	-31.7215	12.0205	-46.3140	-31.2750	-0.1265	-0.1579	0.4465	0.4902	-0.1579	Y

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure C-6. Occupant Compartment Deformation Data – Set 2, Test No. GSH-1

Date:	6/28/2018	Test Name:	GSH-1	VIN:	1D7RB1GP6BS553873
Year:	2011	Make:	Dodge	Model:	Ram 1500 Quad Cab

Reference Set 1				Reference Set 2			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]	Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	0.4	≤ 4	Z	Roof	0.4	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.5	≤ 5	Z	A-Pillar Maximum	0.5	≤ 5	Z
A-Pillar Lateral	-0.5	≤ 3	Y	A-Pillar Lateral	-0.4	≤ 3	Y
B-Pillar Maximum	0.5	≤ 5	Z	B-Pillar Maximum	0.4	≤ 5	Z
B-Pillar Lateral	-0.2	≤ 3	Y	B-Pillar Lateral	-0.2	≤ 3	Y
Toe Pan - Wheel Well	7.0	≤ 9	X, Z	Toe Pan - Wheel Well	7.2	≤ 9	X, Z
Side Front Panel	1.0	≤ 12	Y	Side Front Panel	1.0	≤ 12	Y
Side Door (above seat)	-0.3	≤ 9	Y	Side Door (above seat)	-0.3	≤ 9	Y
Side Door (below seat)	0.7	≤ 12	Y	Side Door (below seat)	0.7	≤ 12	Y
Floor Pan	-0.5	≤ 12	Z	Floor Pan	-0.6	≤ 12	Z
Dash - no MASH requirement	0.5	NA	X, Y, Z	Dash - no MASH requirement	0.5	NA	X, Y, Z

[A] Items highlighted in red do not meet MASH allowable deformations.

[B] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle interior crush:

Figure C-7. Maximum Occupant Compartment Deformation by Location, Test No. GSH-1

Date: 7/27/2018 Test Name: GSH-2 VIN: 1CRR6FTXDS575838
Year: 2013 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	42.6399	-18.9891	-29.4088	42.5797	-19.4197	-29.4079	0.0602	-0.4306	0.0009	0.4348	0.4348	X, Y, Z
	2	43.3084	-7.4504	-28.6598	43.2567	-7.9746	-28.4604	0.0517	-0.5242	0.1994	0.5632	0.5632	X, Y, Z
	3	43.5586	4.1709	-28.3215	43.5251	3.6868	-28.0654	0.0335	0.4841	0.2561	0.5487	0.5487	X, Y, Z
	4	40.2588	-21.2875	-13.3140	39.6945	-21.8024	-12.9966	0.5643	-0.5149	0.3174	0.8272	0.8272	X, Y, Z
	5	40.0434	-8.6283	-12.5067	39.6950	-9.0600	-12.4045	0.3484	-0.4317	0.1022	0.5641	0.5641	X, Y, Z
	6	36.2246	4.2201	-17.0444	36.1036	3.7160	-16.8826	0.1210	0.5041	0.1618	0.5431	0.5431	X, Y, Z
SIDE PANEL (Y)	7	48.0281	-28.0417	-2.0371	47.4408	-27.4782	-2.0245	0.5873	0.5635	0.0126	0.8140	0.5635	Y
	8	48.1308	-28.0424	-5.4639	47.5695	-27.6735	-5.4286	0.5613	0.3689	0.0353	0.6726	0.3689	Y
	9	52.4609	-28.0475	-4.3107	51.7147	-27.3047	-4.3575	0.7462	0.7428	-0.0468	1.0539	0.7428	Y
IMPACT SIDE DOOR (Y)	10	37.4389	-30.3668	-16.5499	36.9869	-31.0503	-16.4582	0.4520	-0.6835	0.0917	0.8246	-0.6835	Y
	11	28.2348	-31.1763	-16.3525	27.8196	-32.1100	-16.1246	0.4152	-0.9337	0.2279	1.0470	-0.9337	Y
	12	17.9967	-30.8423	-16.6748	17.6056	-31.9852	-16.5280	0.3911	-1.1429	0.1468	1.2169	-1.1429	Y
	13	38.0112	-29.2088	-6.3247	37.4394	-29.4015	-6.2583	0.5718	-0.1927	0.0664	0.6070	-0.1927	Y
	14	29.5275	-31.2942	-3.6153	29.0481	-31.6584	-3.5414	0.4794	-0.3642	0.0739	0.6066	-0.3642	Y
	15	17.8171	-30.4734	-3.0873	17.4368	-30.9670	-2.9835	0.3803	-0.4936	0.1038	0.6317	-0.4936	Y
ROOF - (Z)	16	26.7907	-16.2976	-44.6363	26.7832	-16.8837	-44.5828	0.0075	-0.5861	0.0535	0.5886	0.0535	Z
	17	28.5057	-9.5240	-44.8968	28.5529	-10.0508	-44.8140	-0.0472	-0.5268	0.0828	0.5354	0.0828	Z
	18	29.4614	-3.6335	-44.9964	29.4885	-4.2396	-44.8940	-0.0271	-0.6061	0.1024	0.6153	0.1024	Z
	19	29.8689	1.0087	-45.0230	29.8593	0.3645	-44.9194	0.0096	0.6442	0.1036	0.6525	0.1036	Z
	20	29.8988	5.0259	-45.0362	29.8784	4.4105	-44.9301	0.0204	0.6154	0.1061	0.6248	0.1061	Z
	21	16.6960	-16.7747	-46.1456	16.6336	-17.3330	-46.0829	0.0624	-0.5583	0.0627	0.5653	0.0627	Z
	22	16.7637	-10.6532	-46.4692	16.8037	-11.2270	-46.4080	-0.0400	-0.5738	0.0612	0.5784	0.0612	Z
	23	16.5122	-5.8652	-46.6597	16.5641	-6.4088	-46.5998	-0.0519	-0.5436	0.0599	0.5493	0.0599	Z
	24	17.4117	0.0656	-46.8560	17.3989	-0.5506	-46.7963	0.0128	0.6162	0.0597	0.6192	0.0597	Z
	25	17.4081	4.5367	-46.8850	17.5039	3.9999	-46.8209	-0.0958	0.5368	0.0641	0.5490	0.0641	Z
	26	8.5927	-16.1581	-46.4836	8.5494	-16.7034	-46.4380	0.0433	-0.5453	0.0456	0.5489	0.0456	Z
	27	8.9590	-10.2773	-46.8426	9.0017	-10.8653	-46.7897	-0.0427	-0.5880	0.0529	0.5919	0.0529	Z
	28	9.3712	-5.4020	-47.0314	9.2992	-5.9319	-46.9836	0.0720	-0.5299	0.0478	0.5369	0.0478	Z
	29	9.6100	-0.2834	-47.1449	9.6043	-0.8426	-47.1034	0.0057	-0.5592	0.0415	0.5608	0.0415	Z
	30	9.9762	4.9302	-47.1618	9.9608	4.3176	-47.1235	0.0154	0.6126	0.0383	0.6140	0.0383	Z
A-PILLAR Maximum (X, Y, Z)	31	46.7383	-26.3650	-29.7360	46.8312	-27.0590	-29.6415	-0.0929	-0.6940	0.0945	0.7065	0.0945	Z
	32	45.0425	-26.0202	-31.1225	45.0228	-26.6708	-31.1274	0.0197	-0.6506	-0.0049	0.6509	0.0197	X
	33	42.4741	-25.3261	-32.7924	42.5449	-26.0138	-32.7730	-0.0708	-0.6877	0.0194	0.6916	0.0194	Z
	34	39.7385	-24.7148	-34.6905	39.7404	-25.3617	-34.6998	-0.0019	-0.6469	-0.0093	0.6470	0.0000	NA
	35	36.1292	-24.0330	-37.6662	36.1982	-24.6742	-37.6052	-0.0690	-0.6412	0.0610	0.6478	0.0610	Z
	36	32.2011	-23.2401	-39.6552	32.2339	-23.8663	-39.6381	-0.0328	-0.6262	0.0171	0.6273	0.0171	Z
A-PILLAR Lateral (Y)	31	46.7383	-26.3650	-29.7360	46.8312	-27.0590	-29.6415	-0.0929	-0.6940	0.0945	0.7065	-0.6940	Y
	32	45.0425	-26.0202	-31.1225	45.0228	-26.6708	-31.1274	0.0197	-0.6506	-0.0049	0.6509	-0.6506	Y
	33	42.4741	-25.3261	-32.7924	42.5449	-26.0138	-32.7730	-0.0708	-0.6877	0.0194	0.6916	-0.6877	Y
	34	39.7385	-24.7148	-34.6905	39.7404	-25.3617	-34.6998	-0.0019	-0.6469	-0.0093	0.6470	-0.6469	Y
	35	36.1292	-24.0330	-37.6662	36.1982	-24.6742	-37.6052	-0.0690	-0.6412	0.0610	0.6478	-0.6412	Y
	36	32.2011	-23.2401	-39.6552	32.2339	-23.8663	-39.6381	-0.0328	-0.6262	0.0171	0.6273	-0.6262	Y
B-PILLAR Maximum (X, Y, Z)	37	3.9324	-23.4156	-39.4771	3.9441	-23.8891	-39.3181	-0.0117	-0.4735	0.1590	0.4996	0.1590	Z
	38	7.5501	-25.9836	-32.5961	7.4070	-26.4067	-32.3891	0.1431	-0.4231	0.2070	0.4923	0.2516	X, Z
	39	4.7990	-27.5137	-24.5706	4.6553	-27.8479	-24.4070	0.1437	-0.3342	0.1636	0.3989	0.2177	X, Z
	40	8.8936	-27.7818	-19.9165	8.7564	-28.0854	-19.7267	0.1372	-0.3036	0.1898	0.3834	0.2342	X, Z
B-PILLAR Lateral (Y)	37	3.9324	-23.4156	-39.4771	3.9441	-23.8891	-39.3181	-0.0117	-0.4735	0.1590	0.4996	-0.4735	Y
	38	7.5501	-25.9836	-32.5961	7.4070	-26.4067	-32.3891	0.1431	-0.4231	0.2070	0.4923	-0.4231	Y
	39	4.7990	-27.5137	-24.5706	4.6553	-27.8479	-24.4070	0.1437	-0.3342	0.1636	0.3989	-0.3342	Y
	40	8.8936	-27.7818	-19.9165	8.7564	-28.0854	-19.7267	0.1372	-0.3036	0.1898	0.3834	-0.3036	Y

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure C-8. Occupant Compartment Deformation Data – Set 1, Test No. GSH-2

Date: 7/27/2018 Test Name: GSH-2 VIN: 1CRR6FTXDS575838
Year: 2013 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	44.6458	-39.0721	-33.1491	44.8600	-39.2935	-33.2983	-0.2142	-0.2214	-0.1492	0.3423	0.3423	X, Y, Z
	2	45.4476	-27.5422	-32.3947	45.6762	-27.8579	-32.3469	-0.2286	-0.3157	0.0478	0.3927	0.3927	X, Y, Z
	3	45.8356	-15.9248	-32.0544	46.0890	-16.2007	-31.9498	-0.2534	-0.2759	0.1046	0.3889	0.3889	X, Y, Z
	4	42.1005	-41.3396	-17.0751	41.8764	-41.6405	-16.8995	0.2241	-0.3009	0.1756	0.4142	0.4142	X, Y, Z
	5	42.0316	-28.6786	-16.2698	42.0338	-28.8991	-16.3063	-0.0022	-0.2205	-0.0365	0.2235	0.2235	X, Y, Z
	6	38.4073	-15.7855	-20.8399	38.6216	-16.0791	-20.7983	-0.2143	-0.2936	0.0416	0.3659	0.3659	X, Y, Z
SIDE PANEL (Y)	7	49.6914	-48.1861	-5.7325	49.5048	-47.4133	-5.8954	0.1866	0.7728	-0.1629	0.8115	0.7728	Y
	8	49.8232	-48.1884	-9.1584	49.6453	-47.6100	-9.2990	0.1779	0.5784	-0.1406	0.6213	0.5784	Y
	9	54.1430	-48.2458	-7.9684	53.7903	-47.2932	-8.2105	0.3527	0.9526	-0.2421	1.0442	0.9526	Y
IMPACT SIDE DOOR (Y)	10	39.1985	-50.3845	-20.3347	39.0677	-50.8536	-20.3733	0.1308	-0.4691	-0.0386	0.4885	-0.4691	Y
	11	29.9838	-51.0824	-20.2154	29.8865	-51.7985	-20.0782	0.0973	-0.7161	0.1372	0.7356	-0.7161	Y
	12	19.7537	-50.6245	-20.6246	19.6767	-51.5459	-20.5245	0.0770	-0.9214	0.1001	0.9300	-0.9214	Y
	13	39.6979	-49.2322	-10.1051	39.4980	-49.2110	-10.1714	0.1999	0.0212	-0.0663	0.2117	0.0212	Y
	14	31.1669	-51.2145	-7.4677	31.0677	-51.3628	-7.4900	0.0992	-0.1483	-0.0223	0.1798	-0.1483	Y
	15	19.4632	-50.2518	-7.0391	19.4638	-50.5261	-6.9808	-0.0006	-0.2743	0.0583	0.2804	-0.2743	Y
ROOF - (Z)	16	28.9602	-36.1906	-48.5107	29.1604	-36.5594	-48.5392	-0.2002	-0.3688	-0.0285	0.4206	-0.0285	Z
	17	30.7592	-29.4383	-48.7567	31.0164	-29.7492	-48.7623	-0.2572	-0.3109	-0.0056	0.4035	-0.0056	Z
	18	31.7870	-23.5599	-48.8483	32.0251	-23.9501	-48.8379	-0.2381	-0.3902	0.0104	0.4572	0.0104	Z
	19	32.2509	-18.9229	-48.8715	32.4536	-19.3511	-48.8614	-0.2027	-0.4282	0.0101	0.4739	0.0101	Z
	20	32.3295	-14.9063	-48.8845	32.5234	-15.3056	-48.8716	-0.1939	-0.3993	0.0129	0.4441	0.0129	Z
	21	18.8736	-36.5456	-50.1056	19.0124	-36.8815	-50.0819	-0.1388	-0.3359	0.0237	0.3642	0.0237	Z
	22	19.0182	-30.4254	-50.4287	19.2603	-30.7782	-50.4058	-0.2421	-0.3528	0.0229	0.4285	0.0229	Z
	23	18.8263	-25.6347	-50.6214	19.0818	-25.9573	-50.5982	-0.2555	-0.3226	0.0232	0.4122	0.0232	Z
	24	19.7992	-19.7153	-50.8102	19.9907	-20.1101	-50.7906	-0.1915	-0.3948	0.0196	0.4392	0.0196	Z
	25	19.8500	-15.2445	-50.8392	20.1528	-15.5612	-50.8144	-0.3028	-0.3167	0.0248	0.4389	0.0248	Z
	26	10.7815	-35.8309	-50.5124	10.9383	-36.1507	-50.4710	-0.1568	-0.3198	0.0414	0.3586	0.0414	Z
	27	11.2221	-29.9550	-50.8683	11.4651	-30.3188	-50.8202	-0.2430	-0.3638	0.0481	0.4401	0.0481	Z
	28	11.6949	-25.0851	-51.0538	11.8251	-25.3895	-51.0124	-0.1302	-0.3044	0.0414	0.3337	0.0414	Z
	29	11.9966	-19.9699	-51.1653	12.1944	-20.3044	-51.1305	-0.1978	-0.3345	0.0348	0.3902	0.0348	Z
	30	12.4261	-14.7611	-51.1791	12.6156	-15.1491	-51.1487	-0.1895	-0.3880	0.0304	0.4329	0.0304	Z
A-PILLAR Maximum (X, Y, Z)	31	48.6572	-46.4971	-33.4415	49.0165	-46.9854	-33.5148	-0.3593	-0.4883	-0.0733	0.6107	0.0000	NA
	32	46.9775	-46.1319	-34.8423	47.2194	-46.5746	-35.0082	-0.2419	-0.4427	-0.1659	0.5311	0.0000	NA
	33	44.4320	-45.4069	-36.5339	44.7568	-45.8865	-36.6641	-0.3248	-0.4796	-0.1302	0.5937	0.0000	NA
	34	41.7202	-44.7628	-38.4552	41.9688	-45.1993	-38.6027	-0.2486	-0.4365	-0.1475	0.5235	0.0000	NA
	35	38.1448	-44.0377	-41.4615	38.4478	-44.4674	-41.5228	-0.3030	-0.4297	-0.0613	0.5293	0.0000	NA
	36	34.2436	-43.1975	-43.4837	34.5024	-43.6099	-43.5723	-0.2588	-0.4124	-0.0886	0.4949	0.0000	NA
A-PILLAR Lateral (Y)	31	48.6572	-46.4971	-33.4415	49.0165	-46.9854	-33.5148	-0.3593	-0.4883	-0.0733	0.6107	-0.4883	Y
	32	46.9775	-46.1319	-34.8423	47.2194	-46.5746	-35.0082	-0.2419	-0.4427	-0.1659	0.5311	-0.4427	Y
	33	44.4320	-45.4069	-36.5339	44.7568	-45.8865	-36.6641	-0.3248	-0.4796	-0.1302	0.5937	-0.4796	Y
	34	41.7202	-44.7628	-38.4552	41.9688	-45.1993	-38.6027	-0.2486	-0.4365	-0.1475	0.5235	-0.4365	Y
	35	38.1448	-44.0377	-41.4615	38.4478	-44.4674	-41.5228	-0.3030	-0.4297	-0.0613	0.5293	-0.4297	Y
	36	34.2436	-43.1975	-43.4837	34.5024	-43.6099	-43.5723	-0.2588	-0.4124	-0.0886	0.4949	-0.4124	Y
B-PILLAR Maximum (X, Y, Z)	37	5.9744	-43.0307	-43.5456	6.2135	-43.2785	-43.3712	-0.2391	-0.2478	0.1744	0.3860	0.1744	Z
	38	9.5022	-45.6415	-36.6342	9.6155	-45.8395	-36.4278	-0.1133	-0.1980	0.2064	0.3076	0.2064	Z
	39	6.6647	-47.1373	-28.6322	6.8124	-47.2464	-28.4575	-0.1477	-0.1091	0.1747	0.2535	0.1747	Z
	40	10.7161	-47.4544	-23.9435	10.8905	-47.5355	-23.7600	-0.1744	-0.0811	0.1835	0.2658	0.1835	Z
B-PILLAR Lateral (Y)	37	5.9744	-43.0307	-43.5456	6.2135	-43.2785	-43.3712	-0.2391	-0.2478	0.1744	0.3860	-0.2478	Y
	38	9.5022	-45.6415	-36.6342	9.6155	-45.8395	-36.4278	-0.1133	-0.1980	0.2064	0.3076	-0.1980	Y
	39	6.6647	-47.1373	-28.6322	6.8124	-47.2464	-28.4575	-0.1477	-0.1091	0.1747	0.2535	-0.1091	Y
	40	10.7161	-47.4544	-23.9435	10.8905	-47.5355	-23.7600	-0.1744	-0.0811	0.1835	0.2658	-0.0811	Y

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure C-9. Occupant Compartment Deformation Data – Set 2, Test No. GSH-2

Date: 7/27/2018 Test Name: GSH-2 VIN: 1CRR6FTXDS575838
Year: 2013 Make: Dodge Model: Ram 1500

Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]	Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Reference Set 1				**Reference Set 2**			
Roof	0.1	≤ 4	Z	Roof	0.0	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.1	≤ 5	Z	A-Pillar Maximum	0.0	≤ 5	NA
A-Pillar Lateral	-0.6	≤ 3	Y	A-Pillar Lateral	-0.4	≤ 3	Y
B-Pillar Maximum	0.3	≤ 5	X, Z	B-Pillar Maximum	0.2	≤ 5	Z
B-Pillar Lateral	-0.3	≤ 3	Y	B-Pillar Lateral	-0.1	≤ 3	Y
Toe Pan - Wheel Well	2.9	≤ 9	X, Z	Toe Pan - Wheel Well	2.8	≤ 9	X, Z
Side Front Panel	0.7	≤ 12	Y	Side Front Panel	1.0	≤ 12	Y
Side Door (above seat)	-0.7	≤ 9	Y	Side Door (above seat)	-0.5	≤ 9	Y
Side Door (below seat)	-0.2	≤ 12	Y	Side Door (below seat)	0.0	≤ 12	Y
Floor Pan	0.3	≤ 12	Z	Floor Pan	0.5	≤ 12	Z
Dash - no MASH requirement	0.8	NA	X, Y, Z	Dash - no MASH requirement	0.8	NA	X, Y, Z

[A] Items highlighted in red do not meet MASH allowable deformations.

[B] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

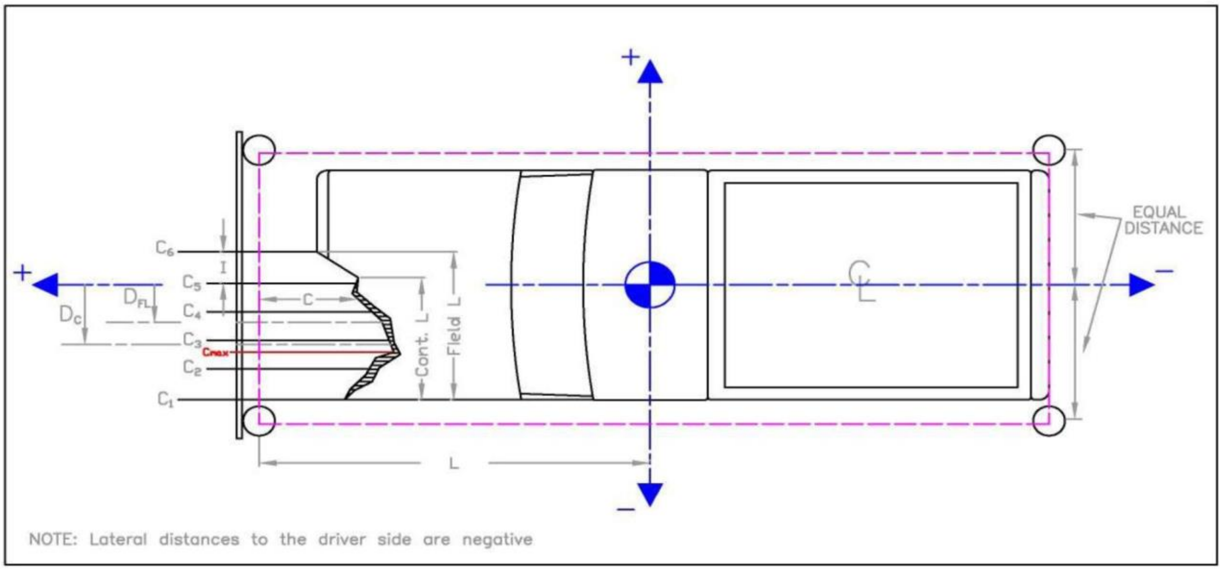
[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle interior crush:

Figure C-10. Maximum Occupant Compartment Deformation by Location, Test No. GSH-2

Date:		Test Name:	GSH-1	VIN:	1D7RB1GP6BS553873
Year:	2011	Make:	Dodge	Model:	Ram 1500 Quad Cab



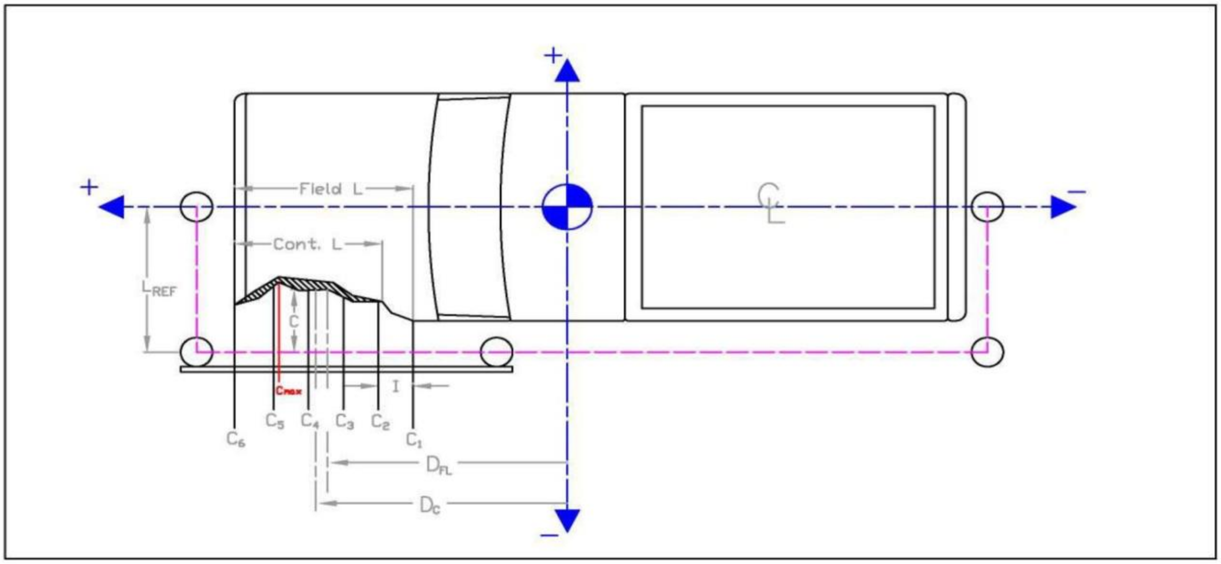
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	112	(2845)
Total Vehicle Width:	75 3/4	(1924)
Width of contact and induced crush - Field L:	75 3/4	(1924)
Crush measurement spacing interval (L/5) - I:	15 1/8	(384)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	75 3/4	(1924)
Distance from center of vehicle to center of contact 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 measurements 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	n/a	#VALUE!	-37 7/8	-(962)	22 1/2	(572)	6	(152)	#VALUE!	#VALUE!
C_2	20 1/4	(514)	-22 3/4	-(578)	6 3/8	(162)			7 7/8	(200)
C_3	8 1/4	(210)	-7 5/8	-(194)	4 1/4	(108)			-2	-(51)
C_4	7 3/4	(197)	7 1/2	(191)	4 1/4	(108)			-2 1/2	-(64)
C_5	12 3/8	(314)	22 5/8	(575)	6	(152)			3/8	(10)
C_6	n/a	#VALUE!	37 3/4	(959)	19 7/8	(505)			#VALUE!	#VALUE!
C_{MAX}	33	(838)	27 3/8	(695)	7 5/8	(194)			19 3/8	(492)

Figure C-11. Exterior Vehicle Crush (NASS) - Front, Test No. GSH-1

Date:	1/0/1900	Test Name:	GSH-1	VIN:	1D7RB1GP6BS553873
Year:	2011	Make:	Dodge	Model:	Ram 1500 Quad Cab



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	48	(1219)
Total Vehicle Length:	229 1/2	(5829)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-4 1/4	-(108)
Width of contact and induced crush - Field L:	229 1/2	(5829)
Crush measurement spacing interval (L/5) - I:	45 7/8	(1165)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-14 3/4	-(375)
Width of Contact Damage:	229 1/2	(5829)
Distance from vehicle c.g. to center of contact damage - D_C:	-14 3/4	-(375)

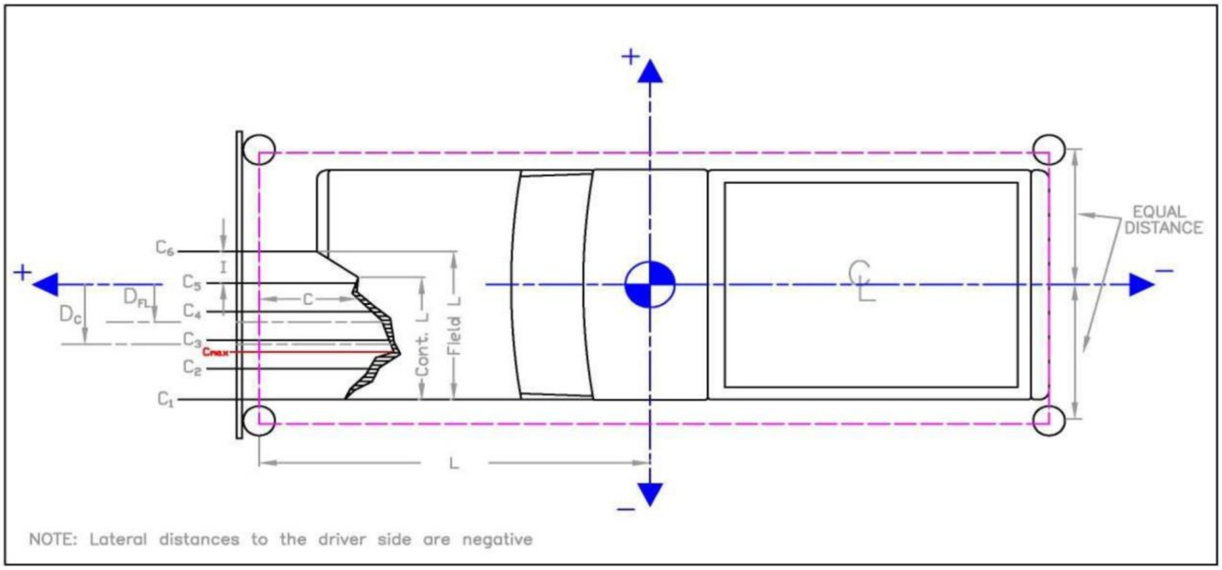
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)

NOTE: All values must be filled out above before crush measurements 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	n/a	#VALUE!	-129 1/2	-(3289)	33 1/2	(851)	4	(102)	#VALUE!	#VALUE!
C_2	n/a	#VALUE!	-83 5/8	-(2124)	5 1/2	(140)			#VALUE!	#VALUE!
C_3	10 3/4	(273)	-37 3/4	-(959)	5 3/4	(146)			1	(25)
C_4	10 1/2	(267)	8 1/8	(206)	5	(127)			1 1/2	(38)
C_5	n/a	#VALUE!	54	(1372)	5 1/2	(140)			#VALUE!	#VALUE!
C_6	34 1/4	(870)	99 7/8	(2537)	7 7/8	(200)			22 3/8	(568)
C_{MAX}	39	(991)	102 1/4	(2597)	9 3/4	(248)			25 1/4	(641)

Figure C-12. Exterior Vehicle Crush (NASS) - Side, Test No. GSH-1

Date:		Test Name:	GSH-2	VIN:	1CRR6FTXDS575838
Year:	2013	Make:	Dodge	Model:	Ram 1500



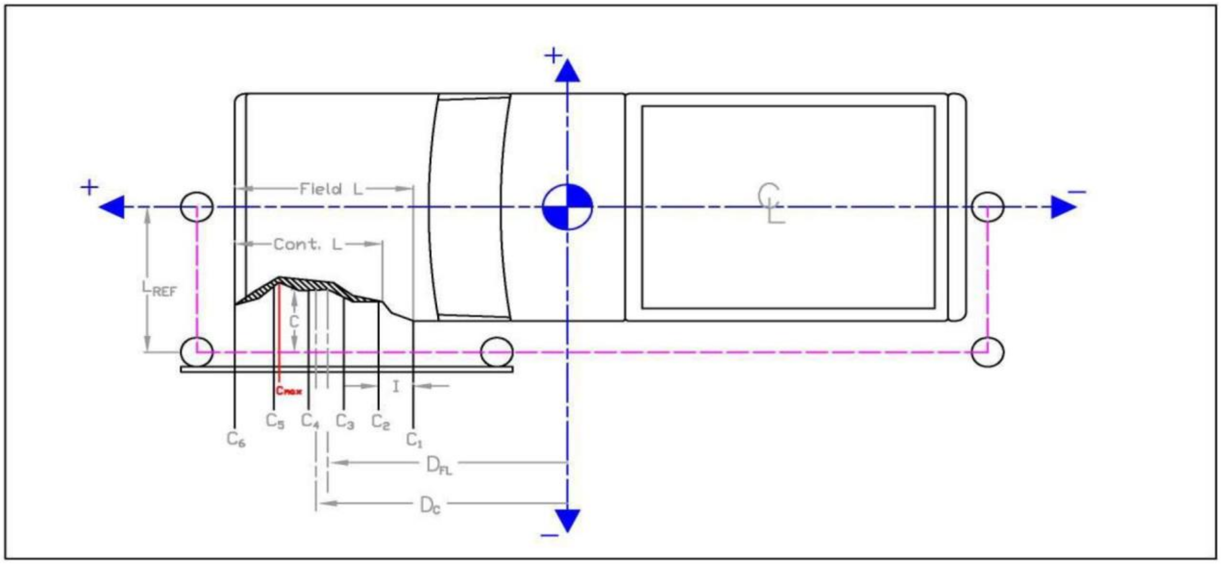
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	123 1/2	(3137)
Total Vehicle Width:	76 3/4	(1949)
Width of contact and induced crush - Field L:	32	(813)
Crush measurement spacing interval (L/5) - I:	6 3/8	(162)
Distance from center of vehicle to center of Field L - D_{FL}:	-23	-(584)
Width of Contact Damage:	32	(813)
Distance from center of vehicle to center of contact damage - D_C:	-23	-(584)

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 measurements 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	n/a	#VALUE!	-39	-(991)	22 1/2	(572)	18 4/7	(471)	#VALUE!	#VALUE!
C_2	n/a	#VALUE!	-32 5/8	-(829)	11 5/8	(295)			#VALUE!	#VALUE!
C_3	44 1/2	(1130)	-26 1/4	-(667)	7 1/8	(181)			18 4/5	(478)
C_4	27	(686)	-19 7/8	-(505)	5 5/8	(143)			2 4/5	(71)
C_5	25 3/8	(645)	-13 1/2	-(343)	4 3/4	(121)			2	(52)
C_6	24 1/2	(622)	-7 1/8	-(181)	4 1/4	(108)			1 2/3	(43)
C_{MAX}	44 1/2	(1130)	-32 5/8	-(829)	11 5/8	(295)			14 1/3	(364)

Figure C-13. Exterior Vehicle Crush (NASS) - Front, Test No. GSH-2

Date:	1/0/1900	Test Name:	GSH-2	VIN:	1CRR6FTXDS575838
Year:	2013	Make:	Dodge	Model:	Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	54	(1372)
Total Vehicle Length:	229 1/4	(5823)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-5 4/7	-(141)
Width of contact and induced crush - Field L:	229 1/4	(5823)
Crush measurement spacing interval (L/5) - I:	45 7/8	(1165)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-16 1/8	-(410)
Width of Contact Damage:	229 1/4	(5823)
Distance from vehicle c.g. to center of contact damage - D_C:	-16 1/8	-(410)

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 measurements 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	n/a	#VALUE!	-130 3/4	-(3321)	33 1/2	(851)	10	(254)	#VALUE!	#VALUE!
C_2	n/a	#VALUE!	-84 7/8	-(2156)	5 1/2	(140)			#VALUE!	#VALUE!
C_3	16	(406)	-39	-(991)	5 3/4	(146)			1/4	(6)
C_4	14 3/4	(375)	6 7/8	(175)	5	(127)			- 1/4	-(6)
C_5	n/a	#VALUE!	52 3/4	(1340)	5 1/2	(140)			#VALUE!	#VALUE!
C_6	n/a	#VALUE!	98 5/8	(2505)	8 1/8	(206)			#VALUE!	#VALUE!
C_{MAX}	33 3/4	(857)	92	(2337)	6 1/4	(159)			17 1/2	(445)

Figure C-14. Exterior Vehicle Crush (NASS) - Side, Test No. GSH-2

Appendix D. Accelerometer and Rate Transducer Data Plots, Test No. GSH-1

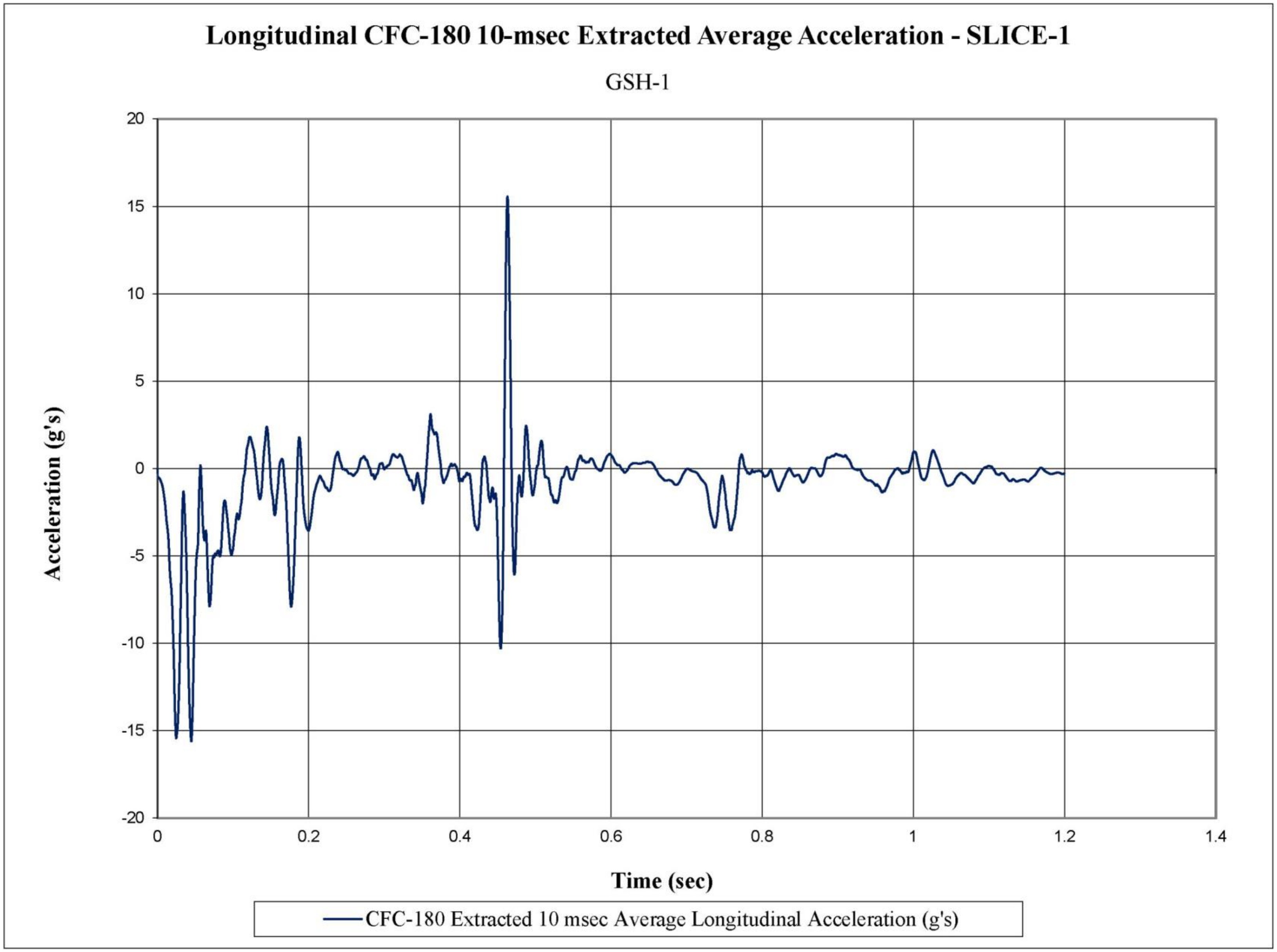


Figure D-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. GSH-1

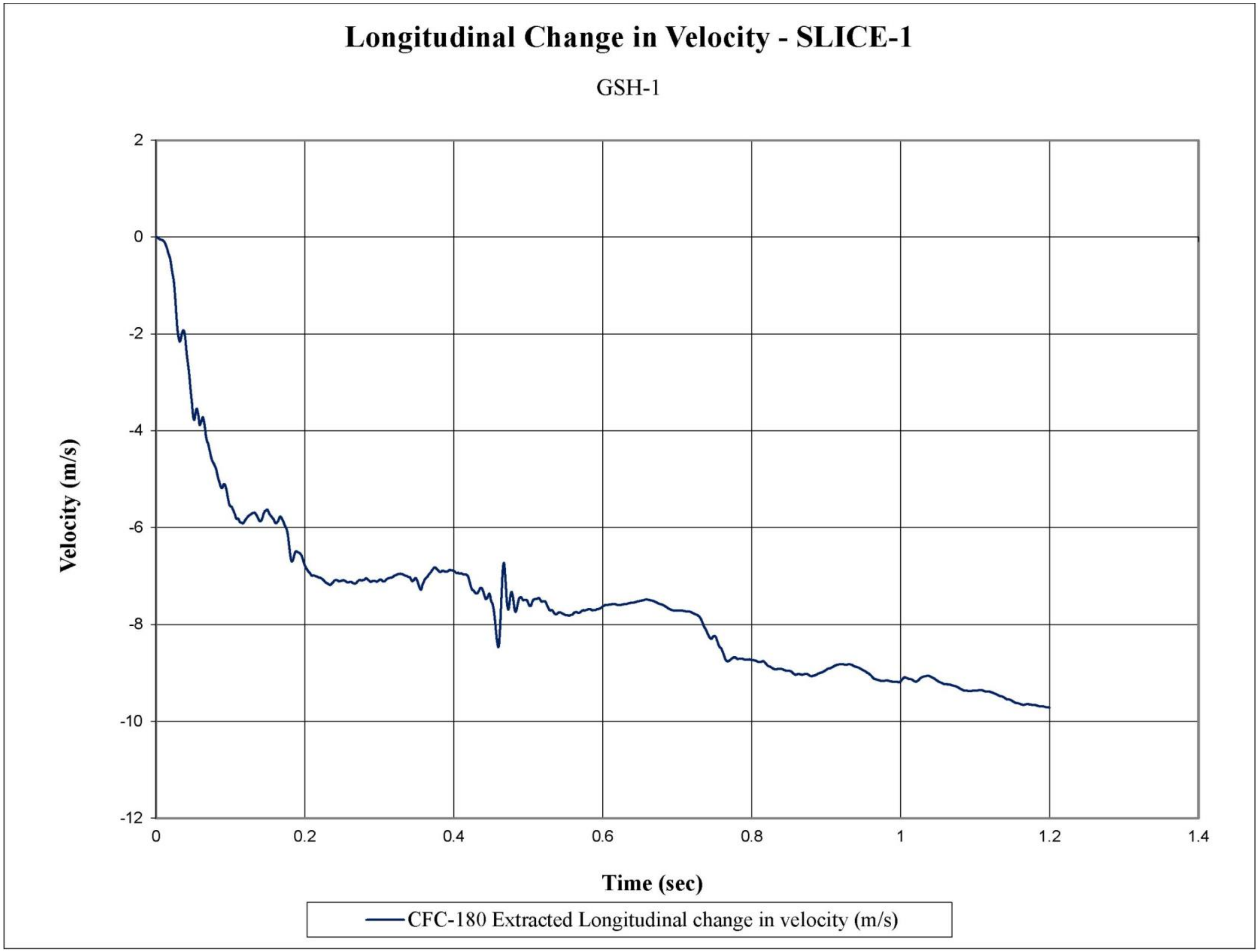


Figure D-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. GSH-1

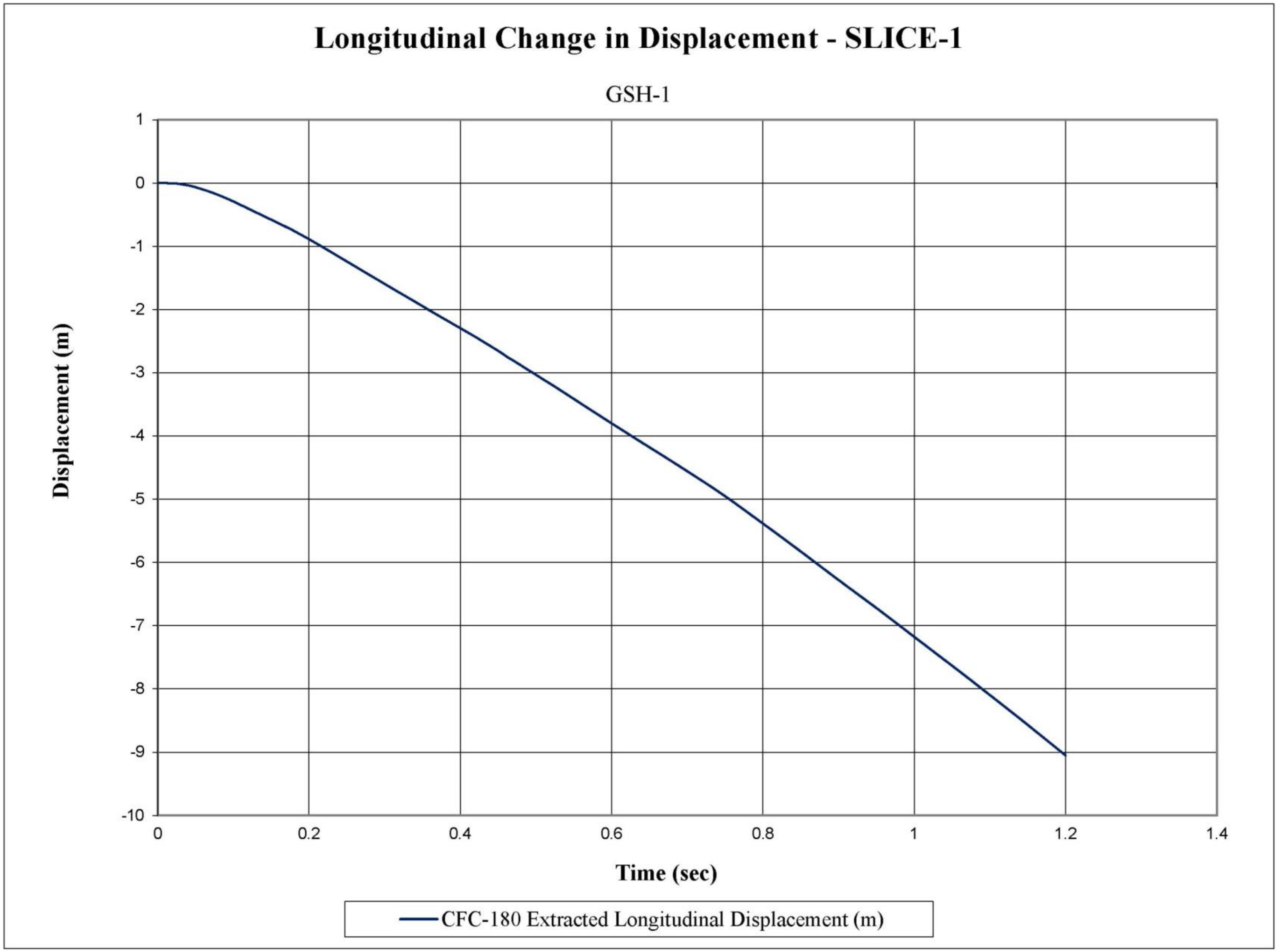


Figure D-3. Longitudinal Occupant Displacement (SLICE-1), Test No. GSH-1

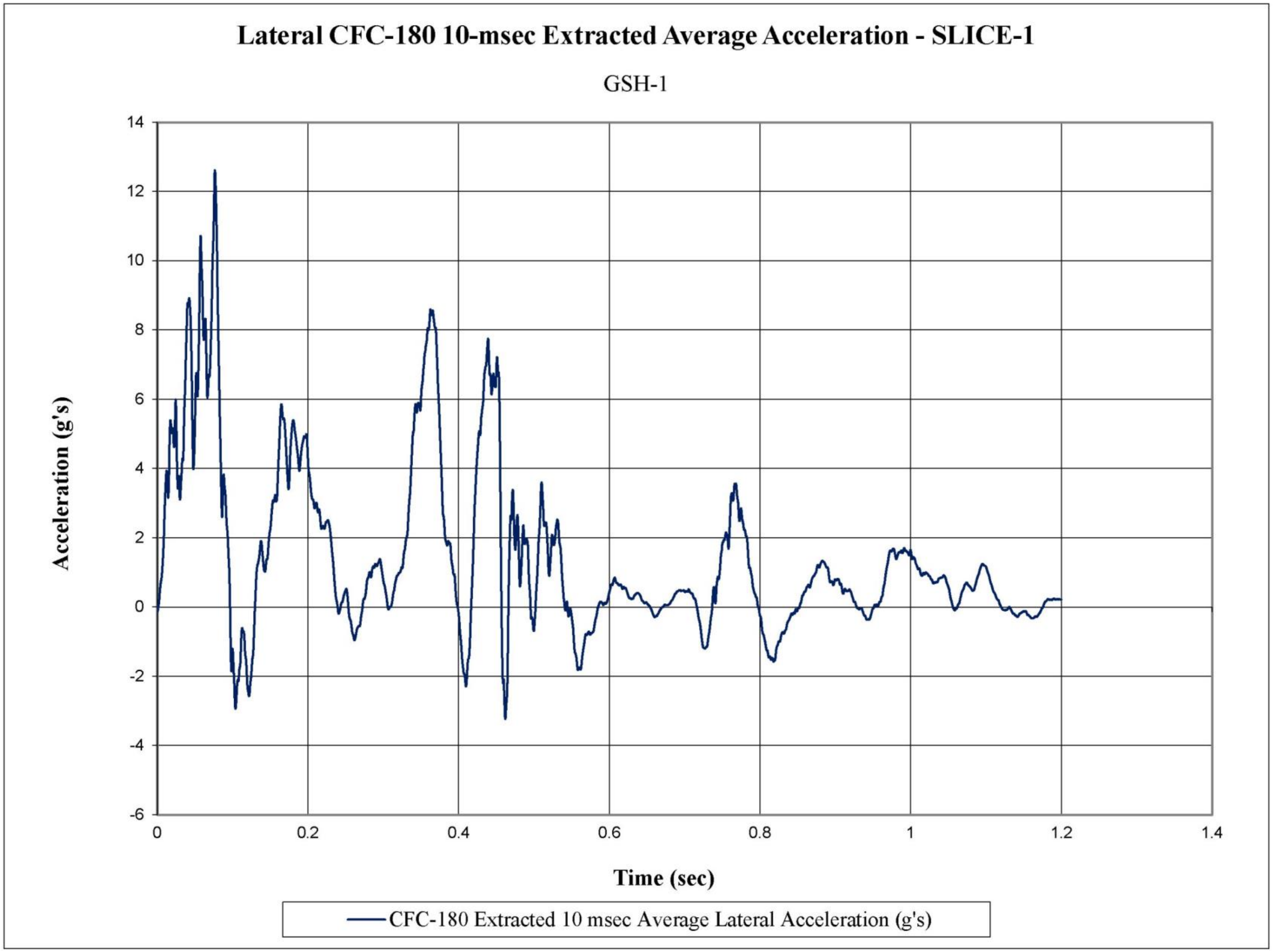


Figure D-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. GSH-1

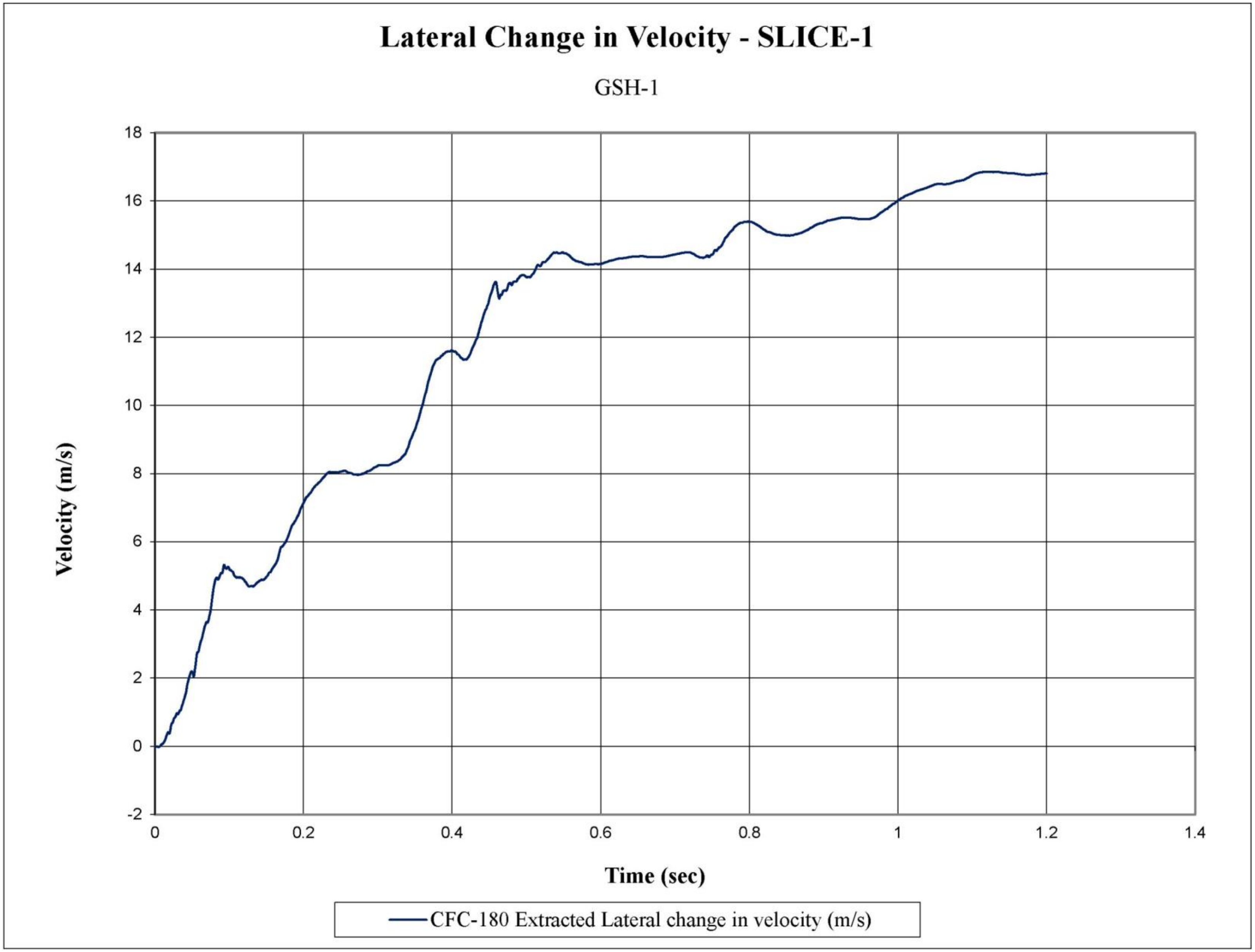


Figure D-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. GSH-1

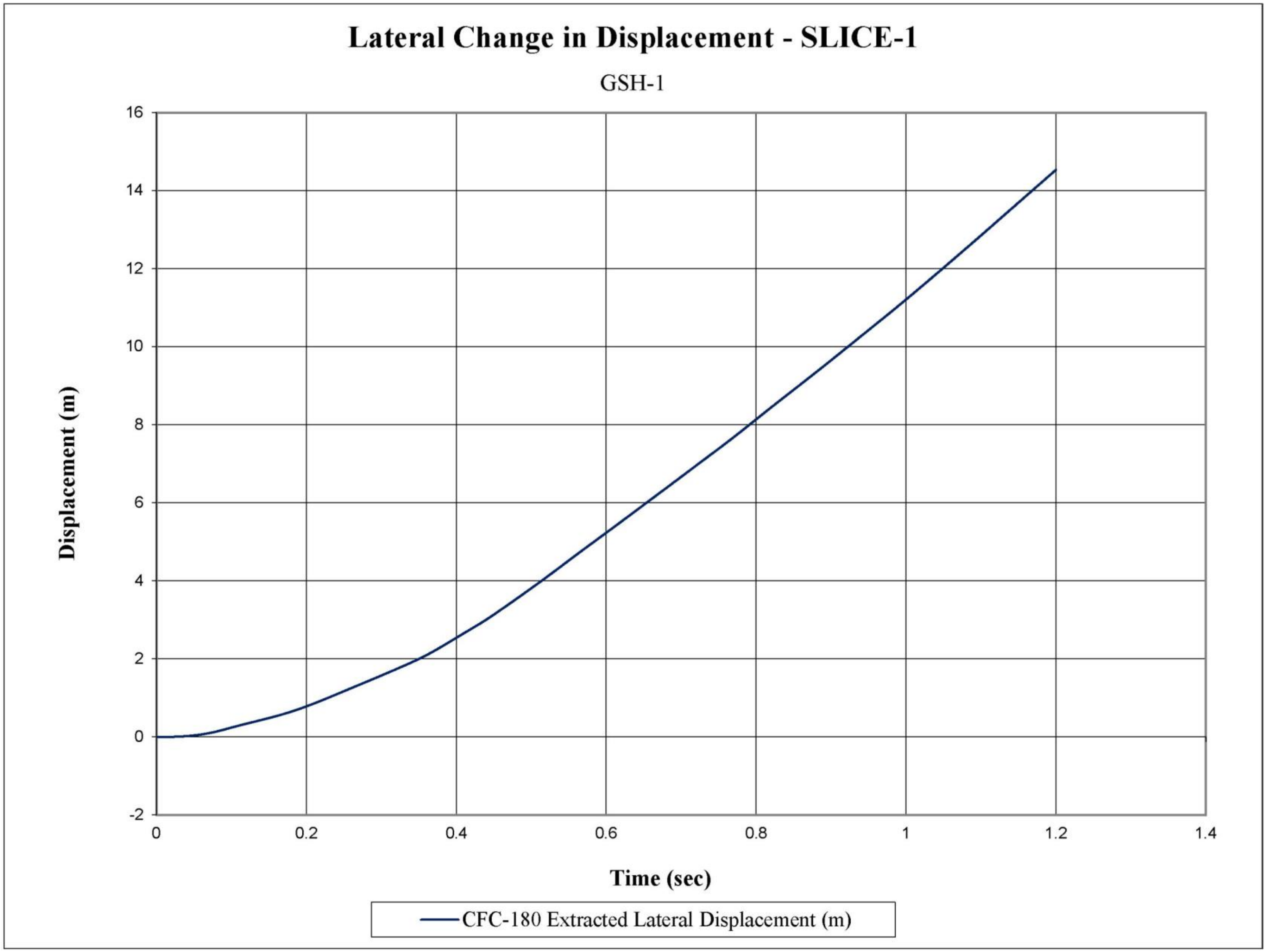


Figure D-6. Lateral Occupant Displacement (SLICE-1), Test No. GSH-1

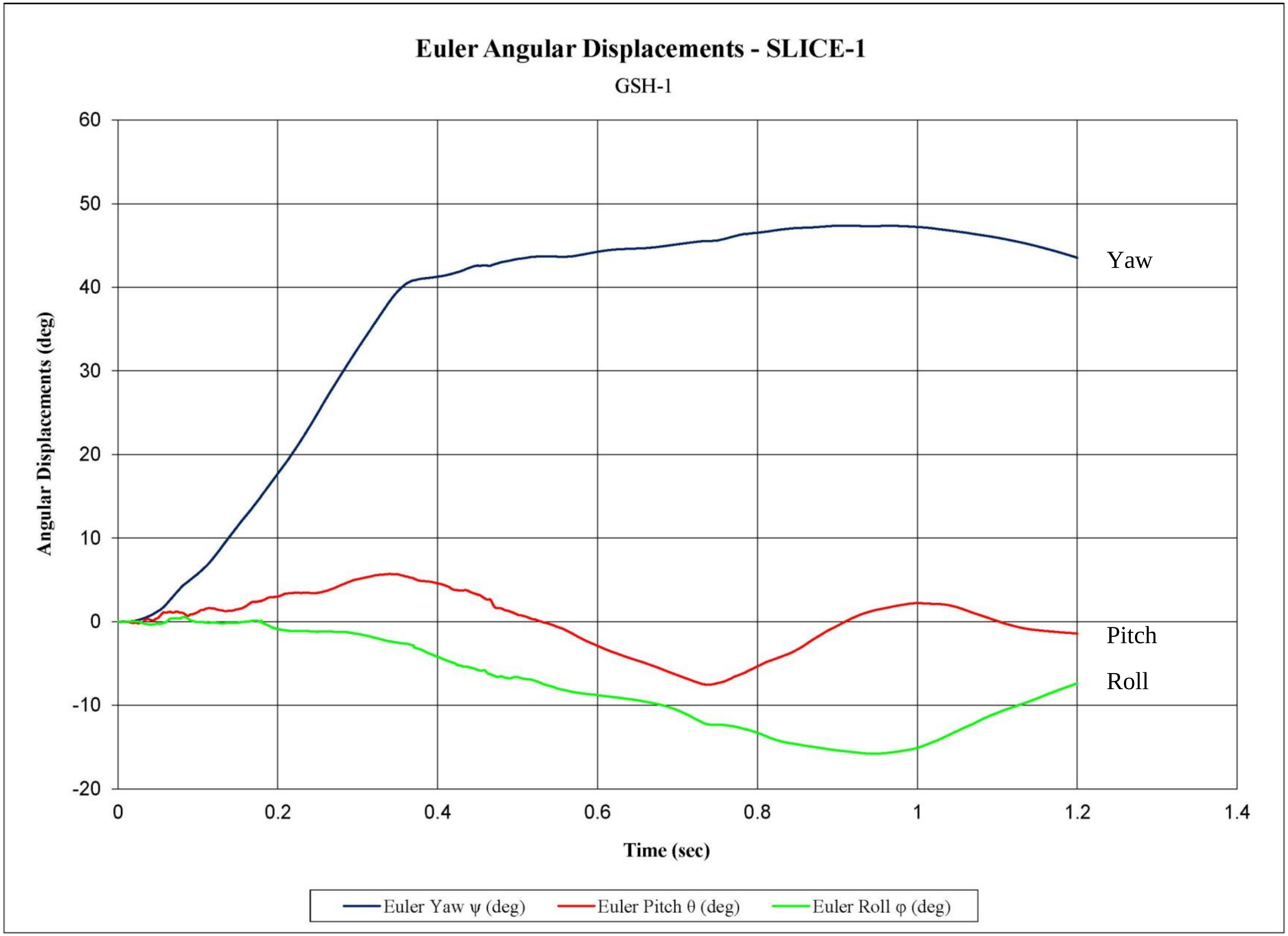


Figure D-7. Vehicle Angular Displacements (SLICE-1), Test No. GSH-1

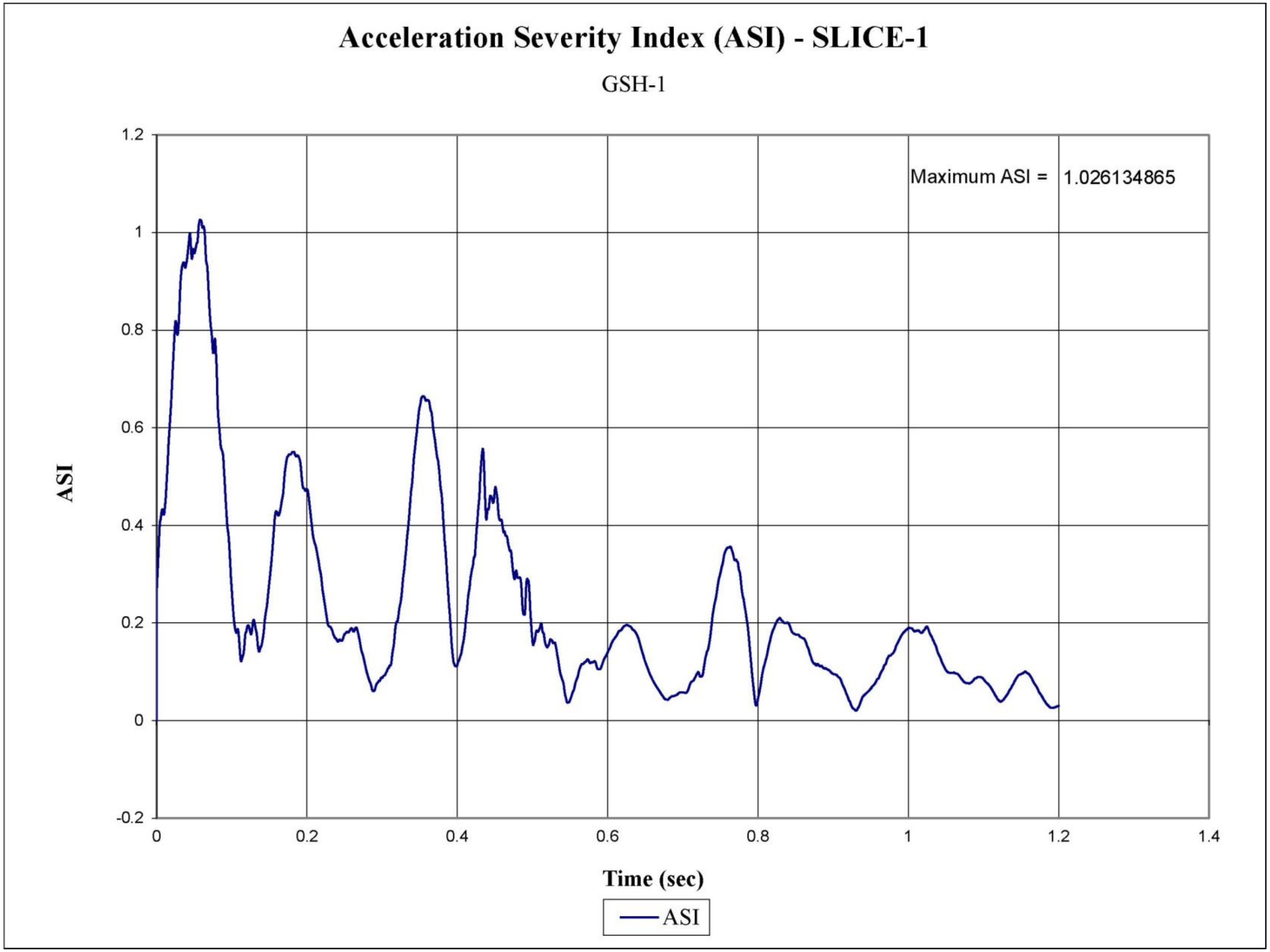


Figure D-8. Acceleration Severity Index (SLICE-1), Test No. GSH-1

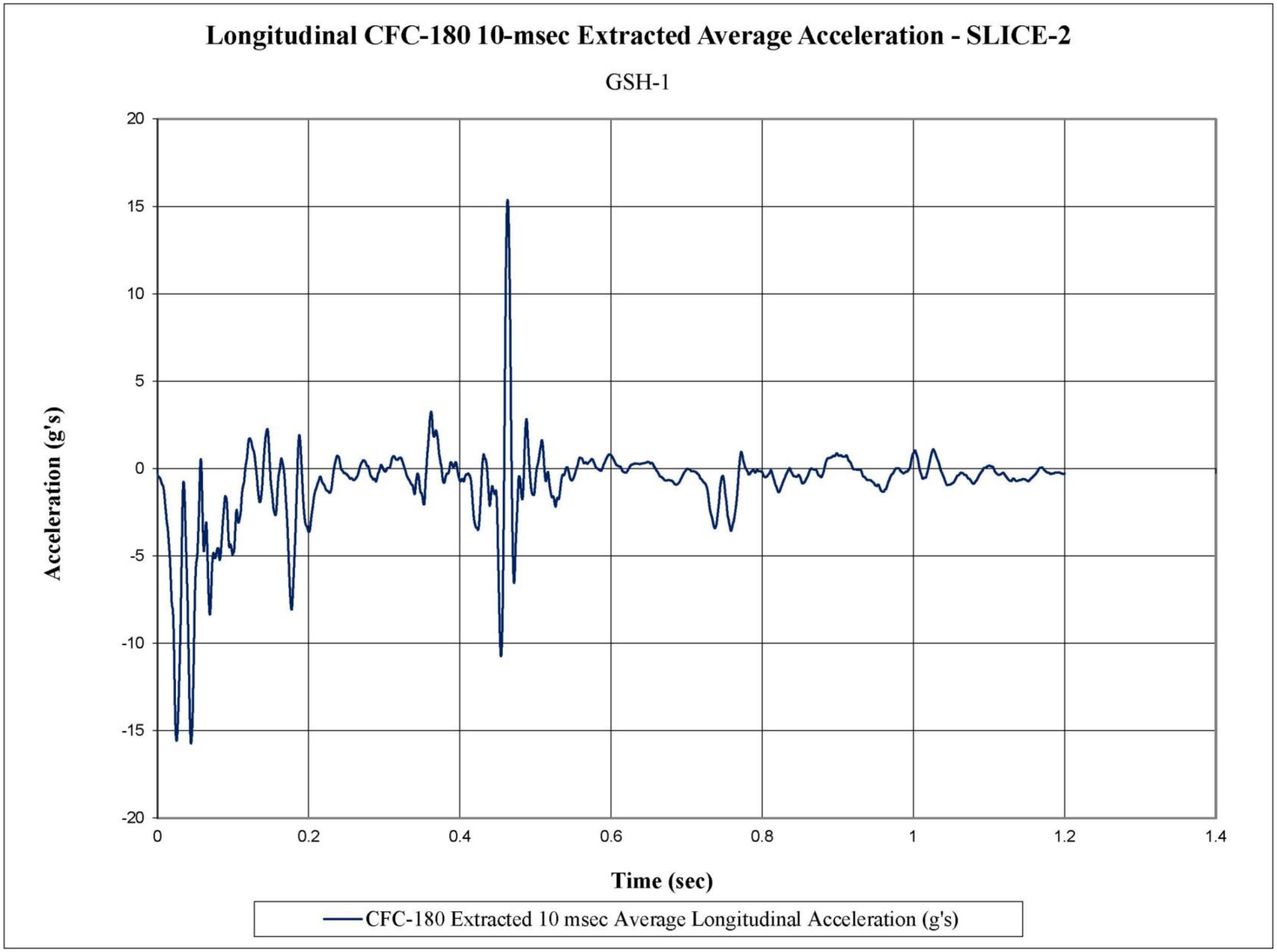


Figure D-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. GSH-1

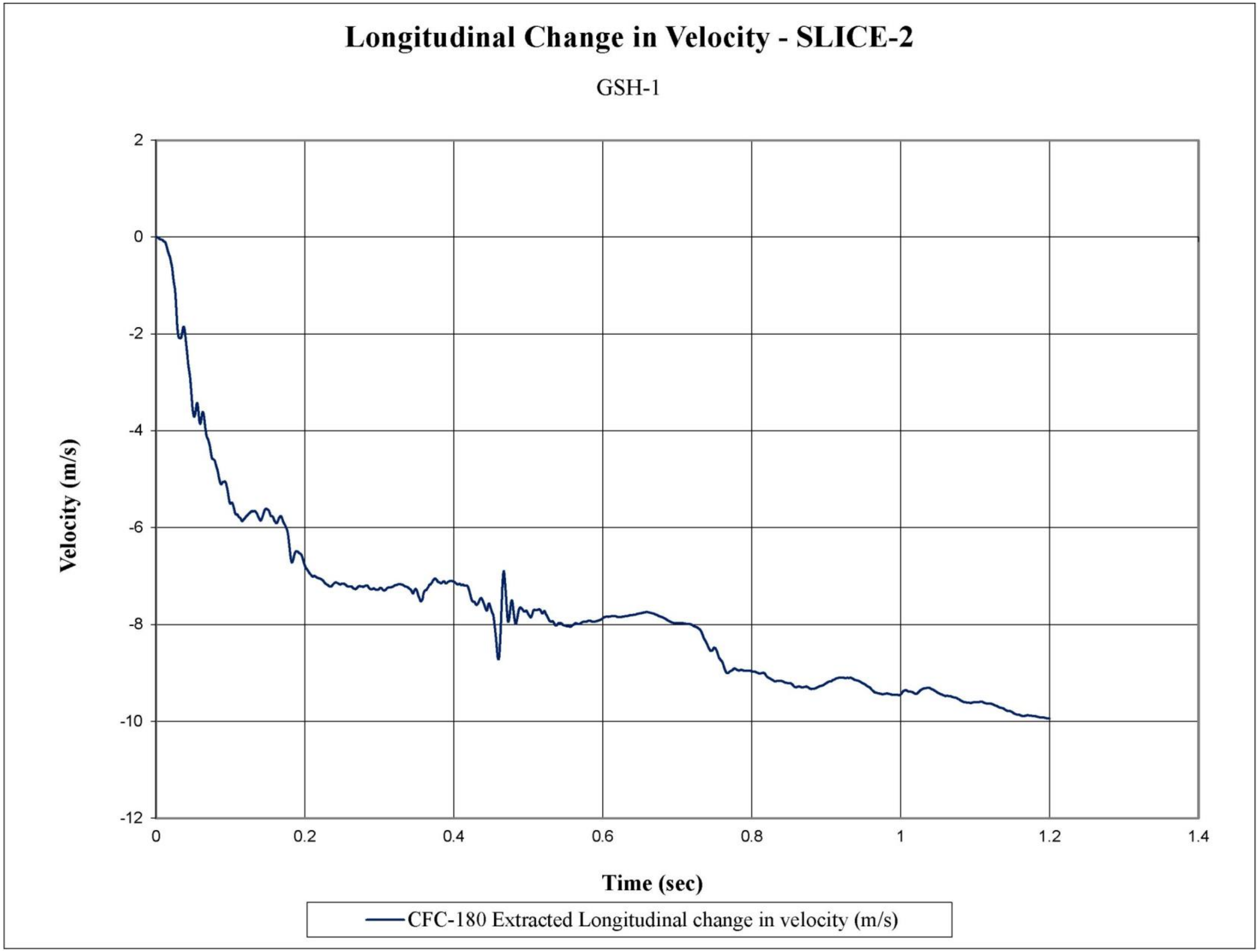


Figure D-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. GSH-1

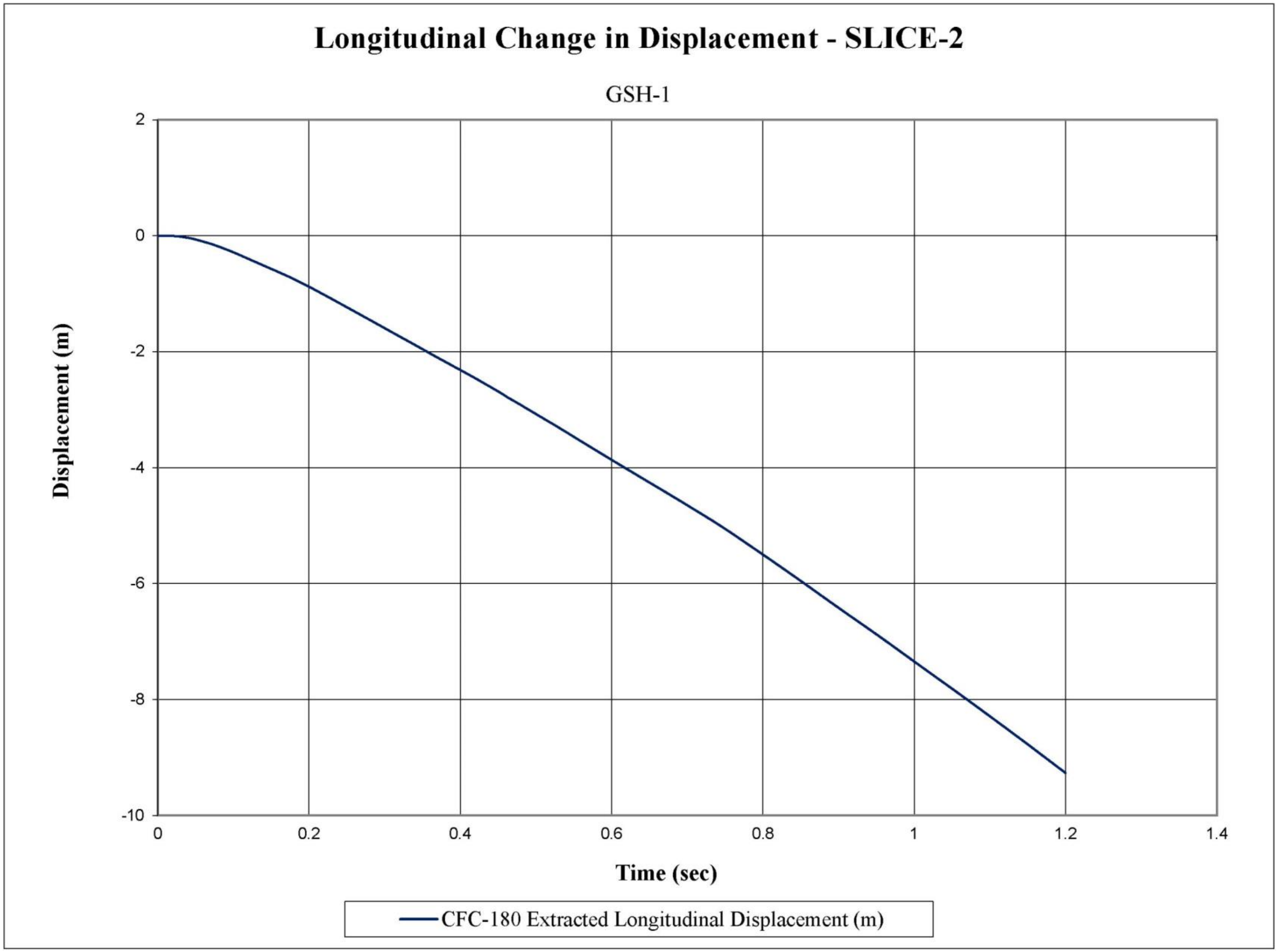


Figure D-11. Longitudinal Occupant Displacement (SLICE-2), Test No. GSH-1

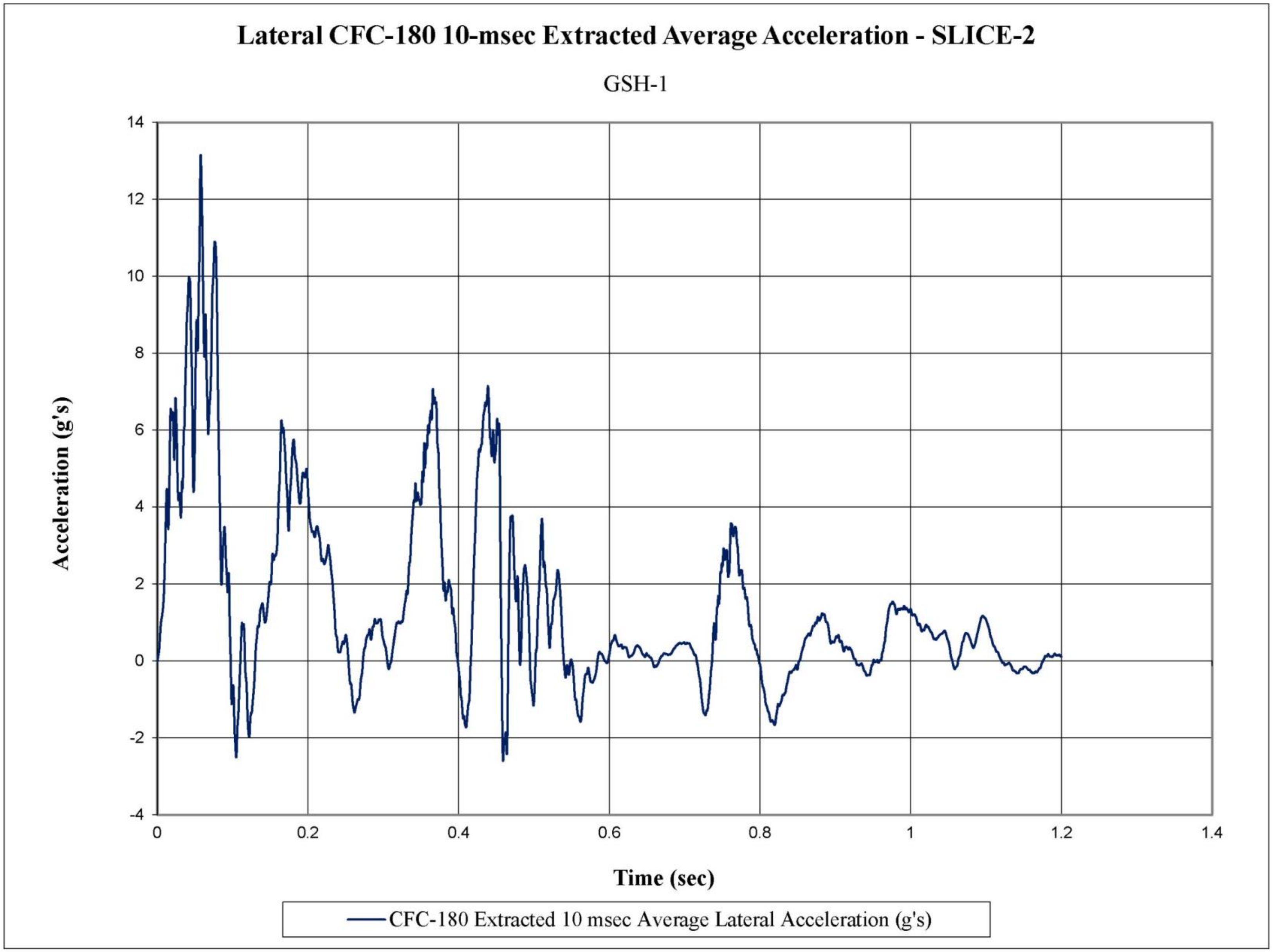


Figure D-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. GSH-1

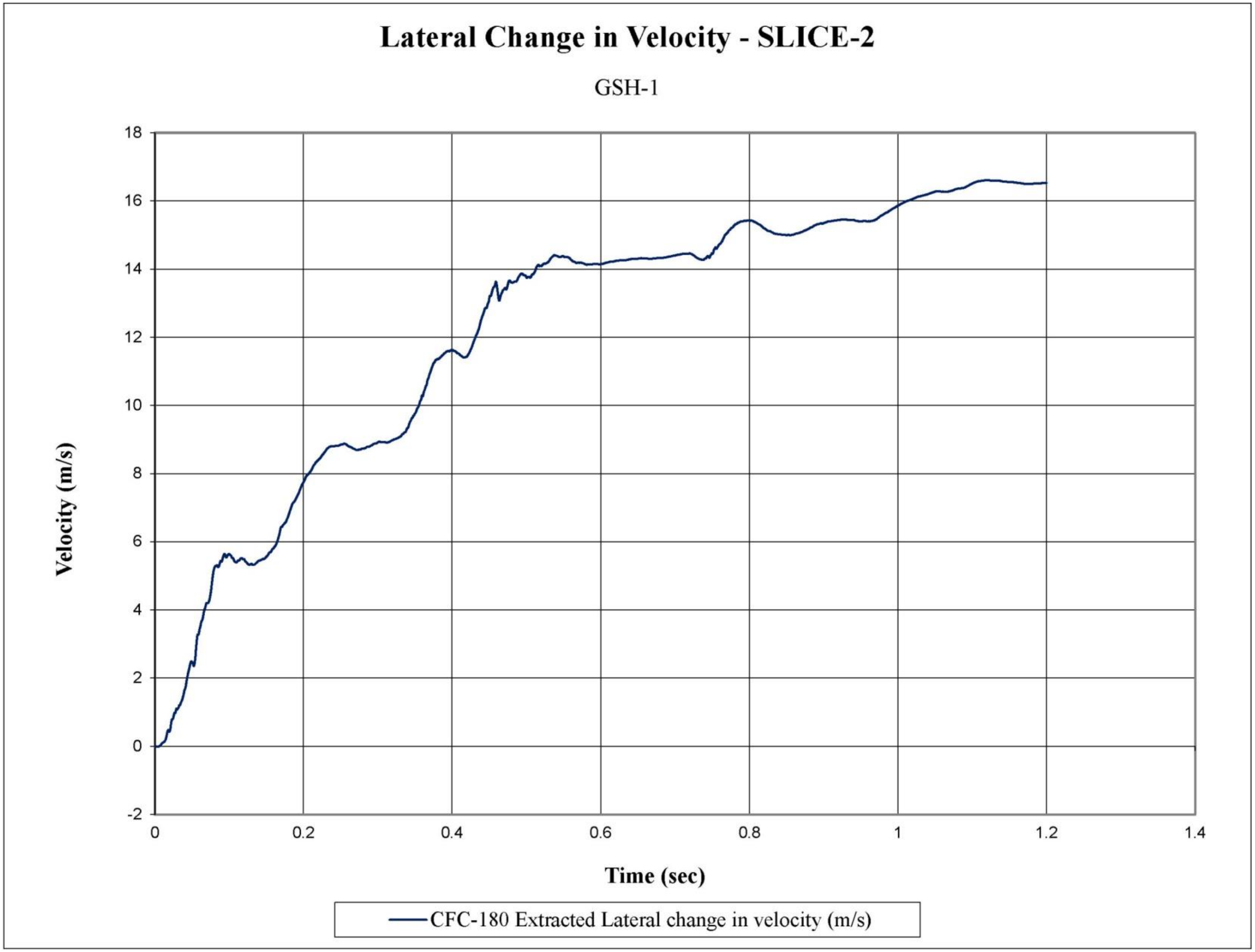


Figure D-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. GSH-1

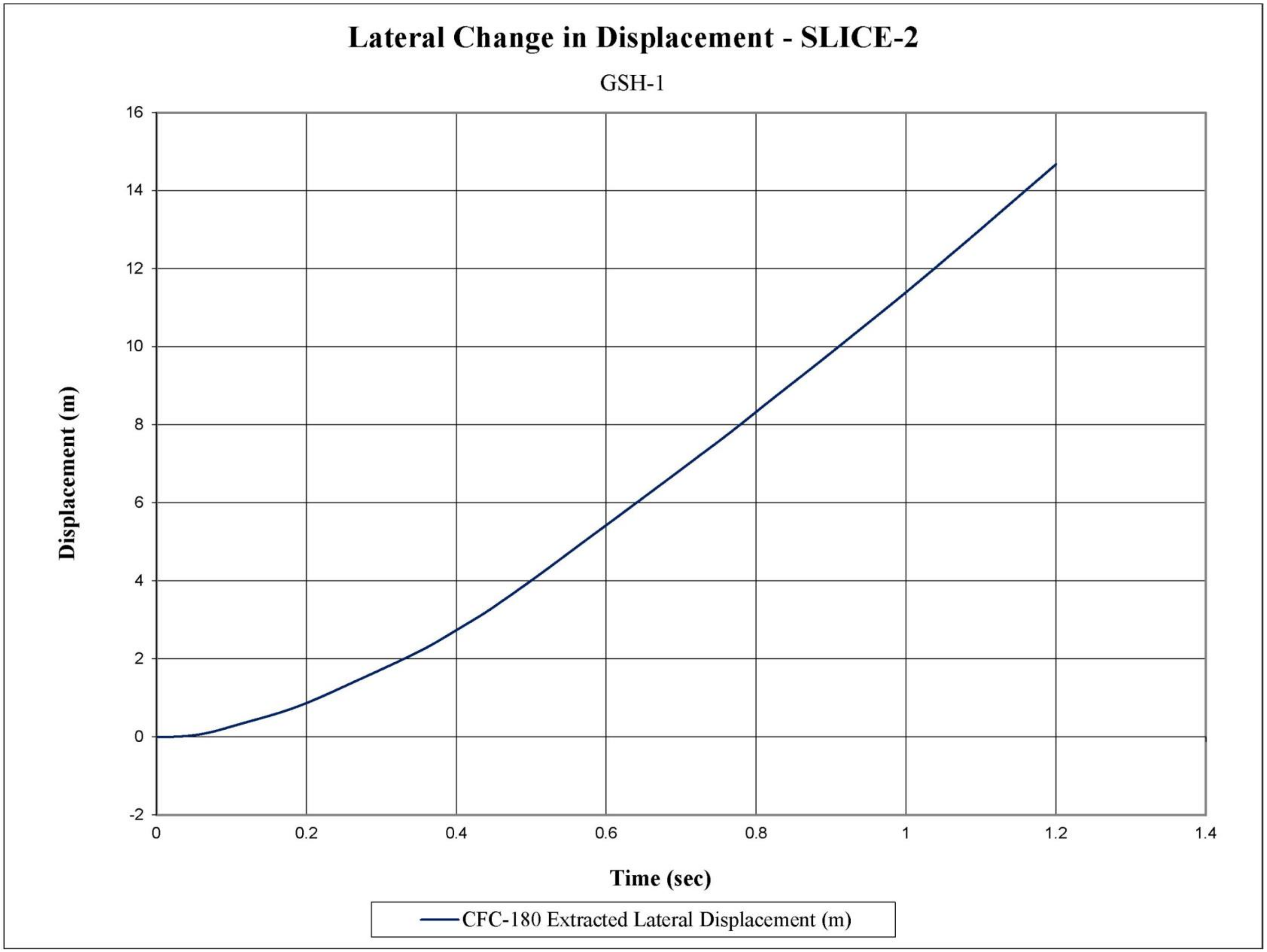


Figure D-14. Lateral Occupant Displacement (SLICE-2), Test No. GSH-1

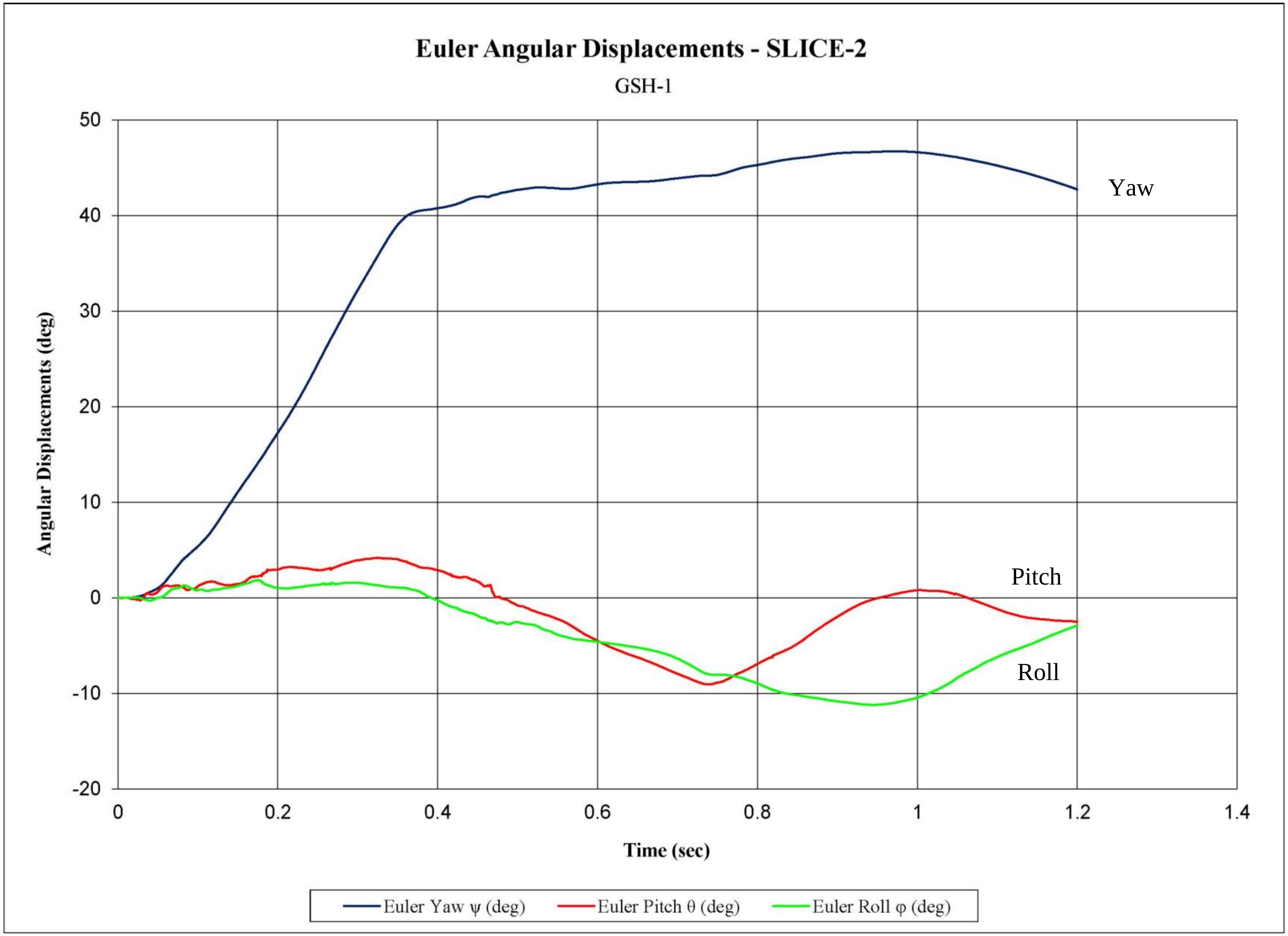


Figure D-15. Vehicle Angular Displacements (SLICE-2), Test No. GSH-1

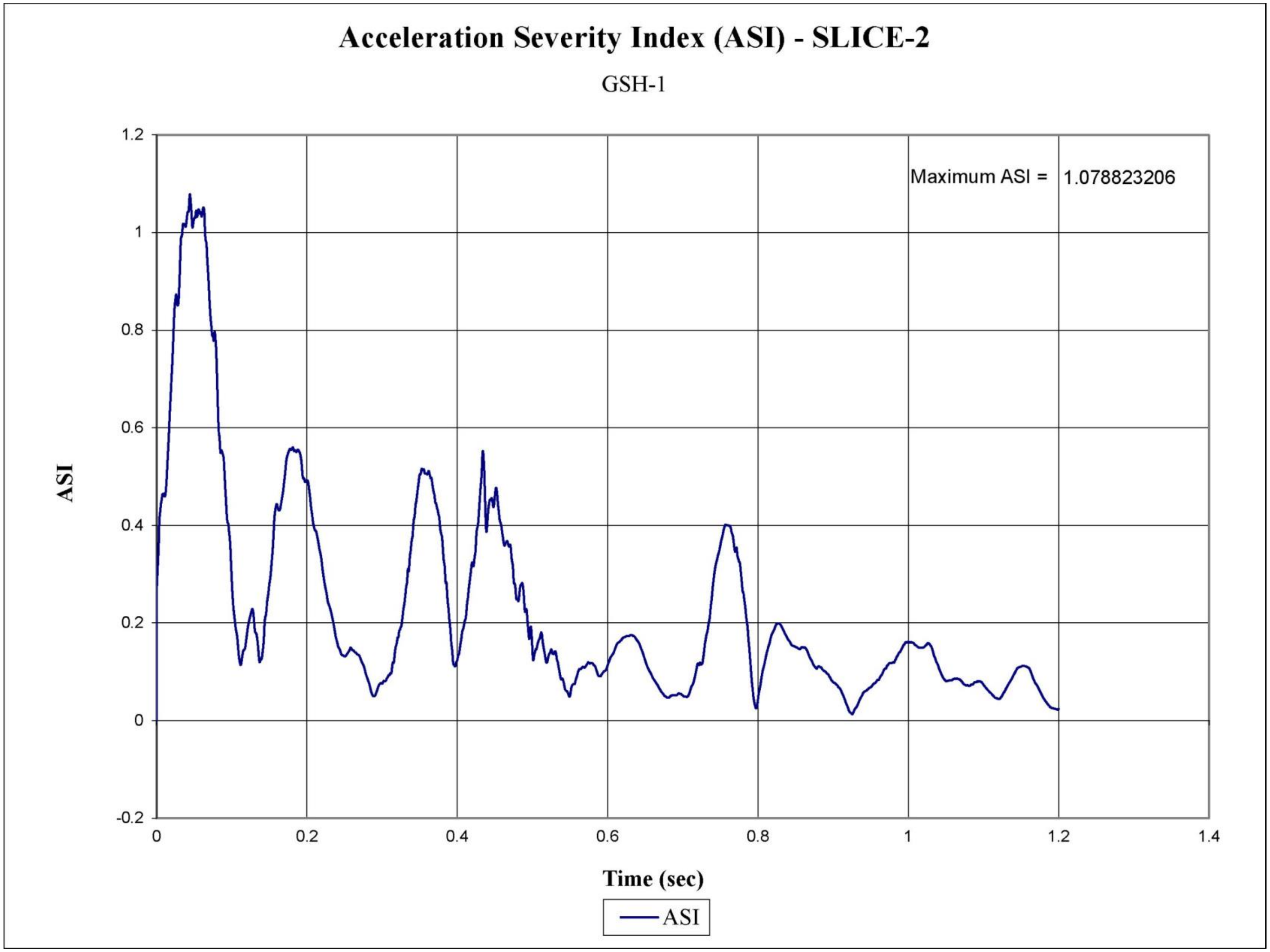


Figure D-16. Acceleration Severity Index (SLICE-2), Test No. GSH-1

Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. GSH-2

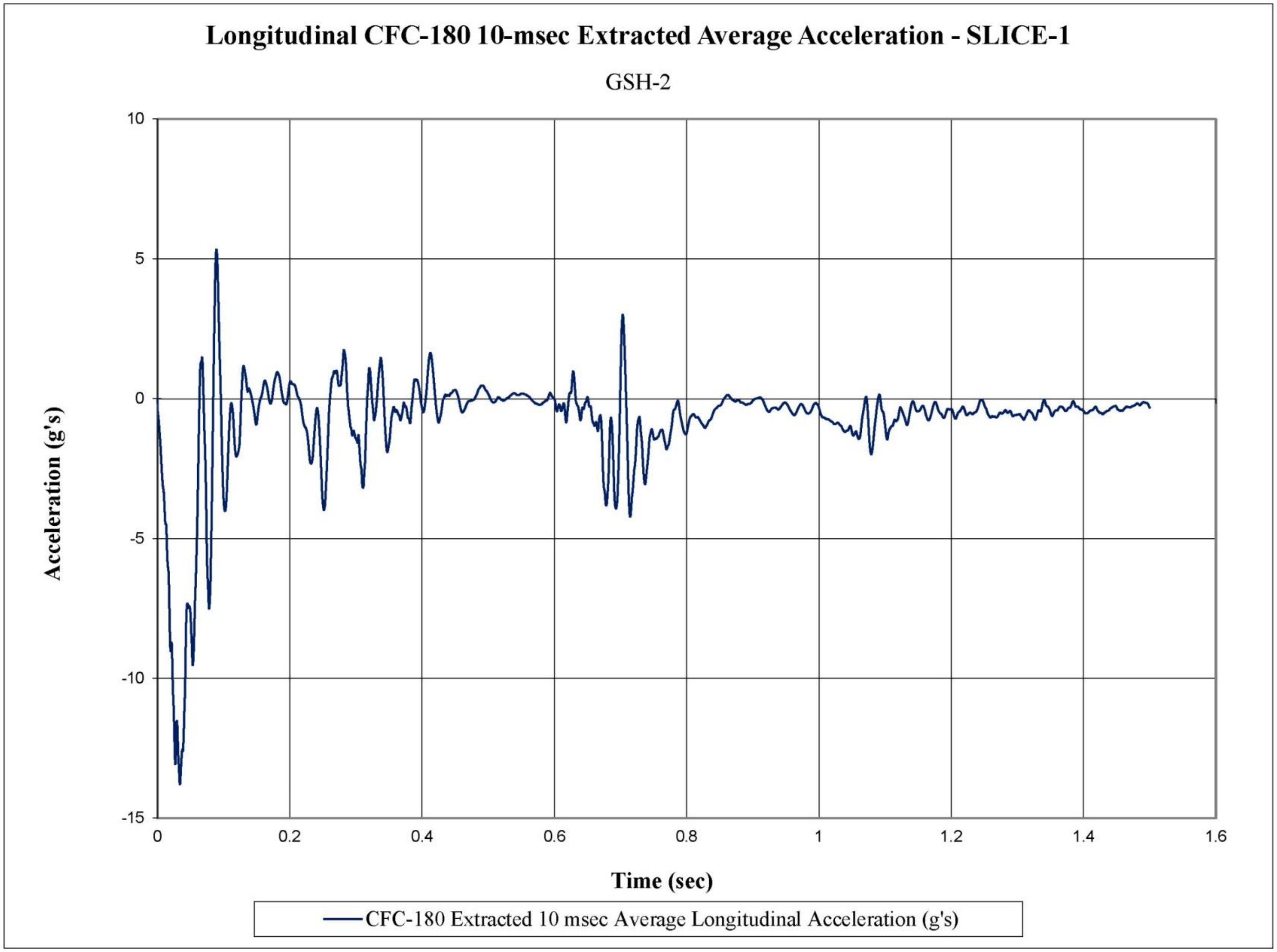


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. GSH-2

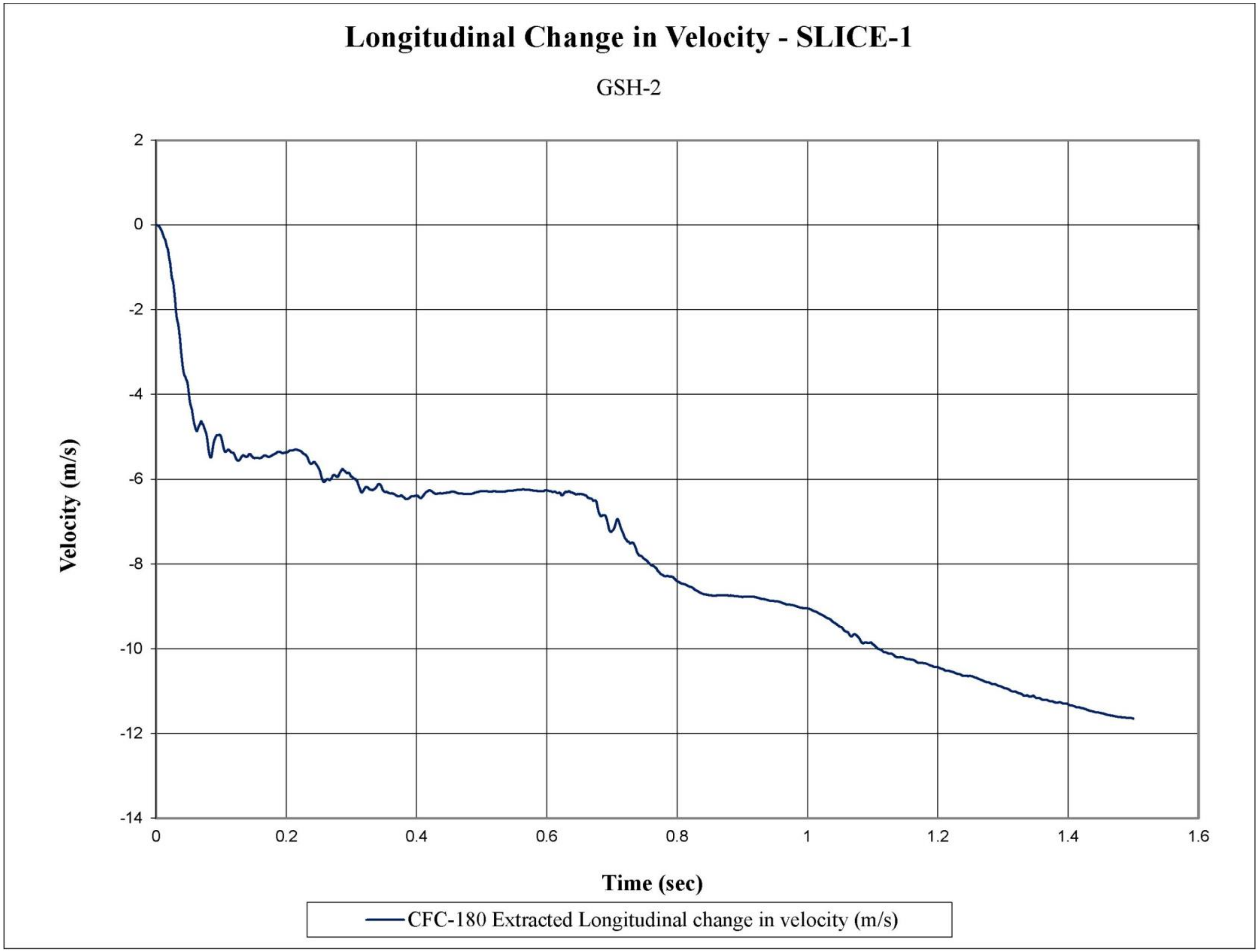


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. GSH-2

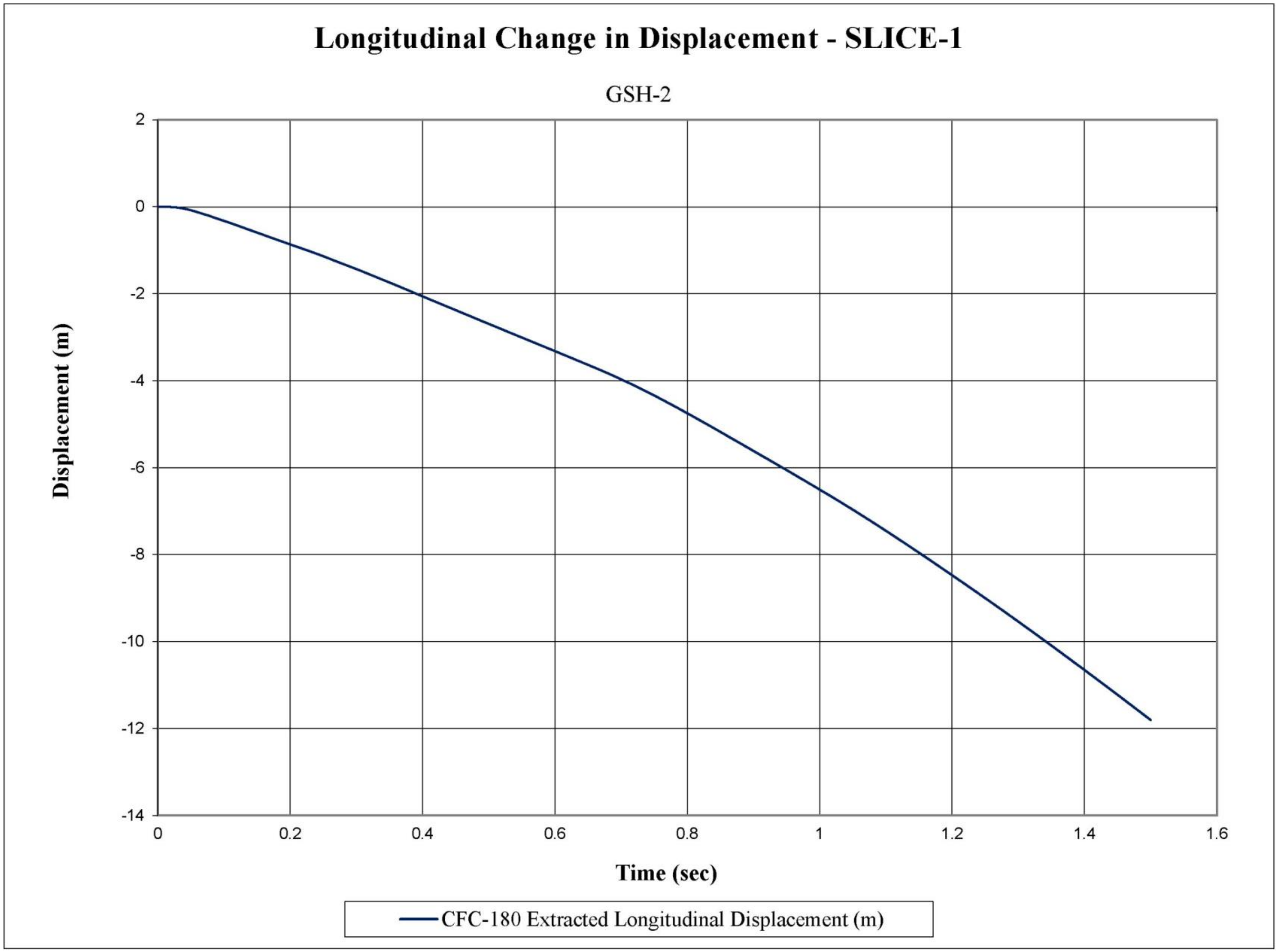


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. GSH-2

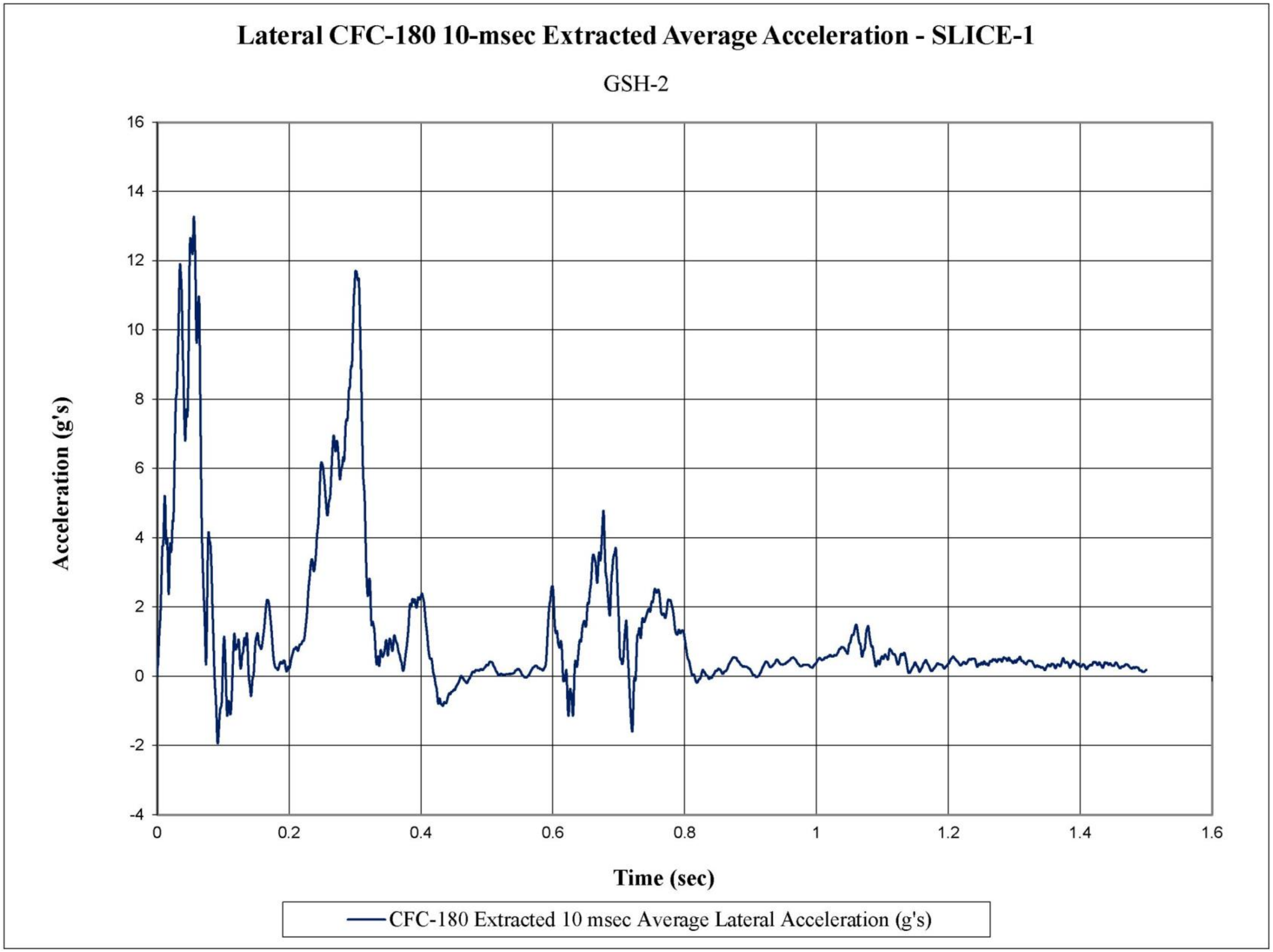


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. GSH-2

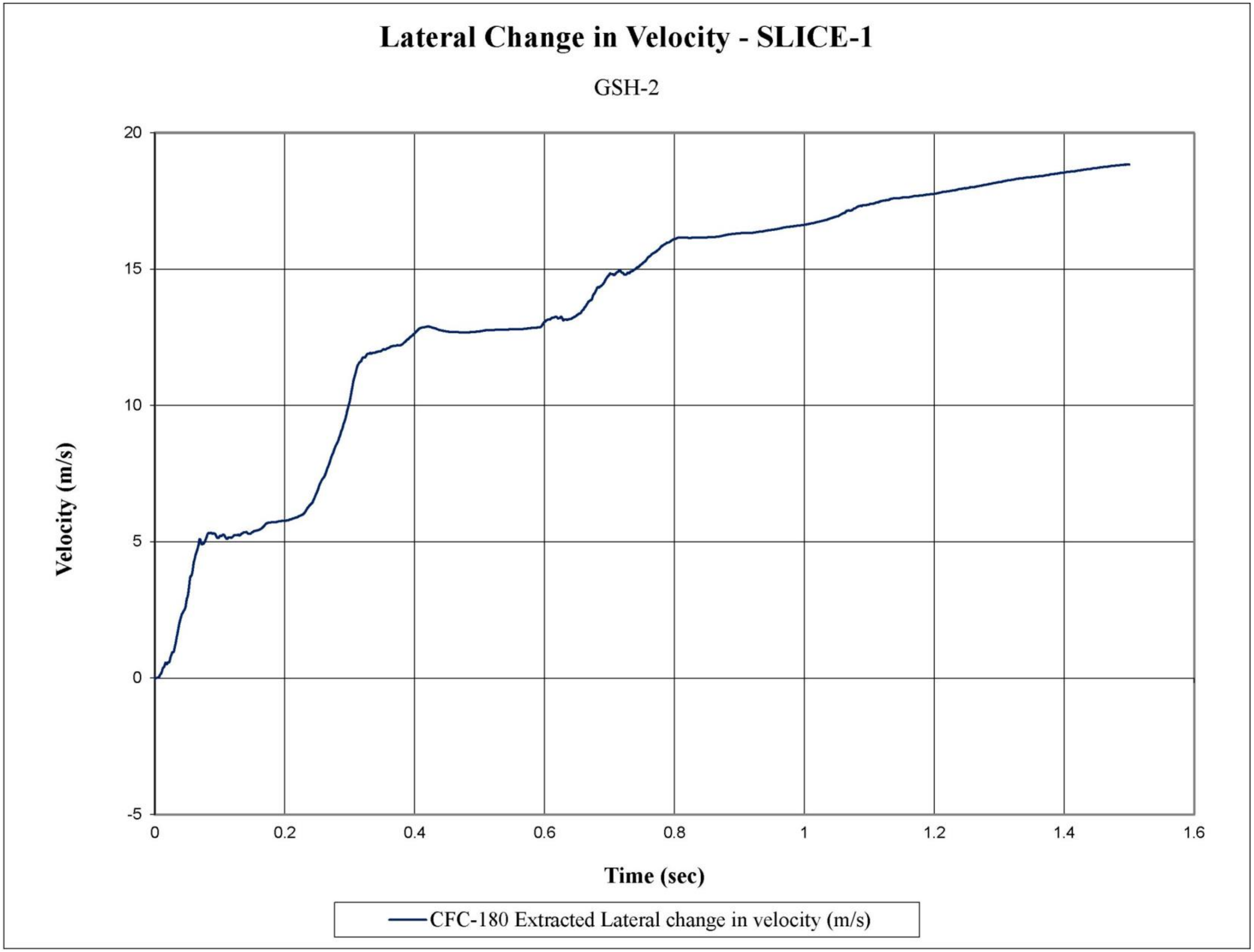


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. GSH-2

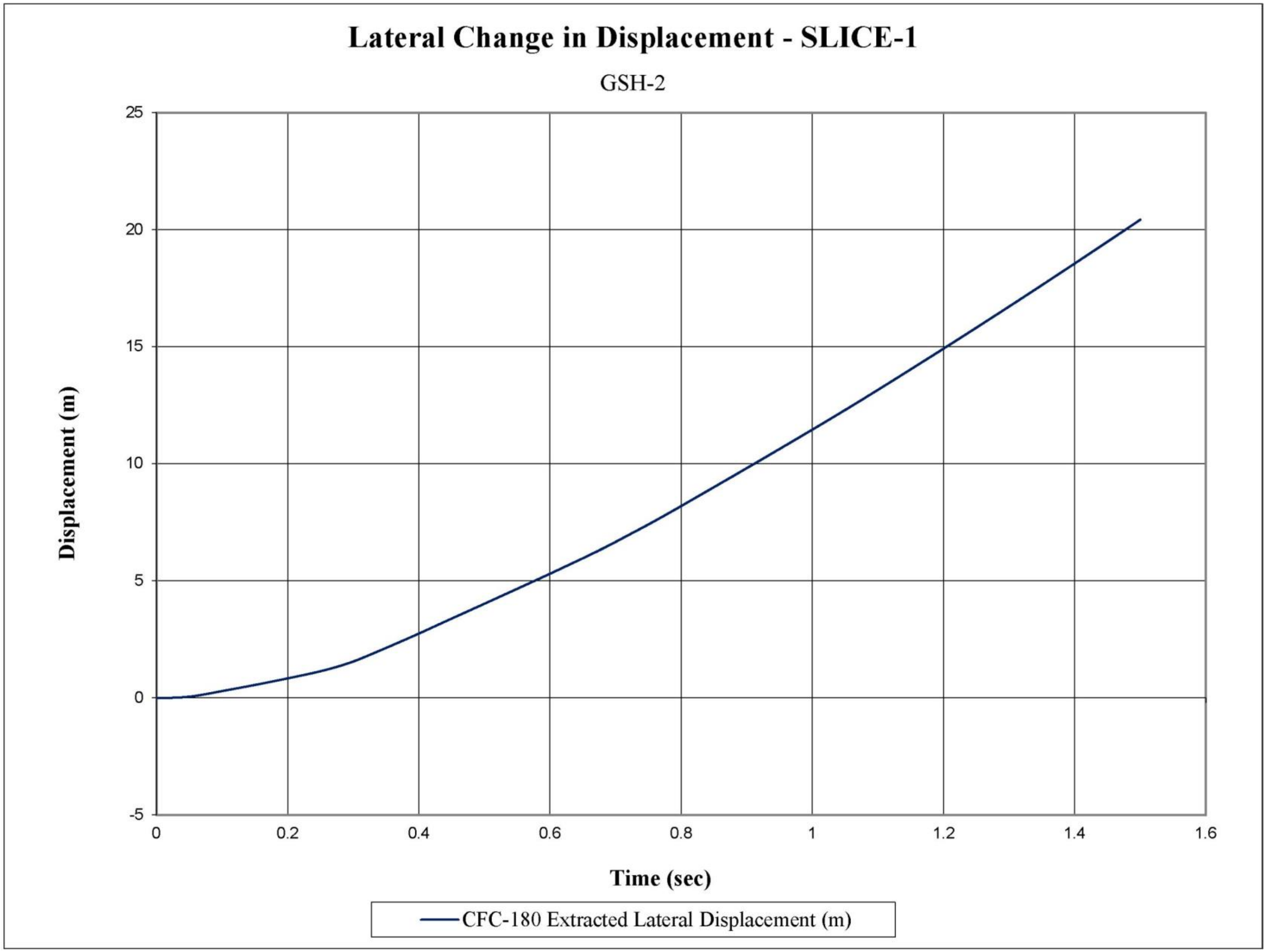


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. GSH-2

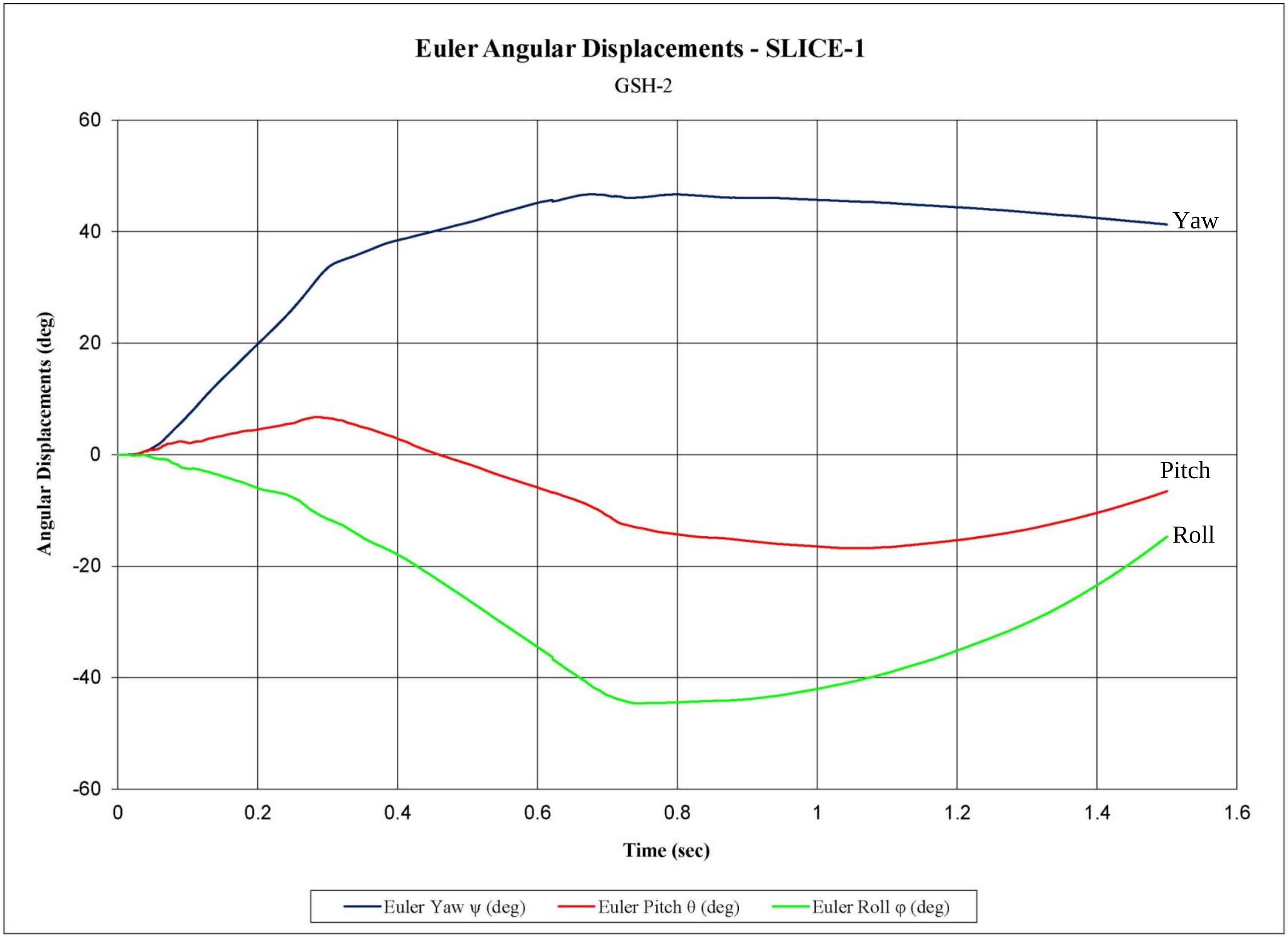


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. GSH-2

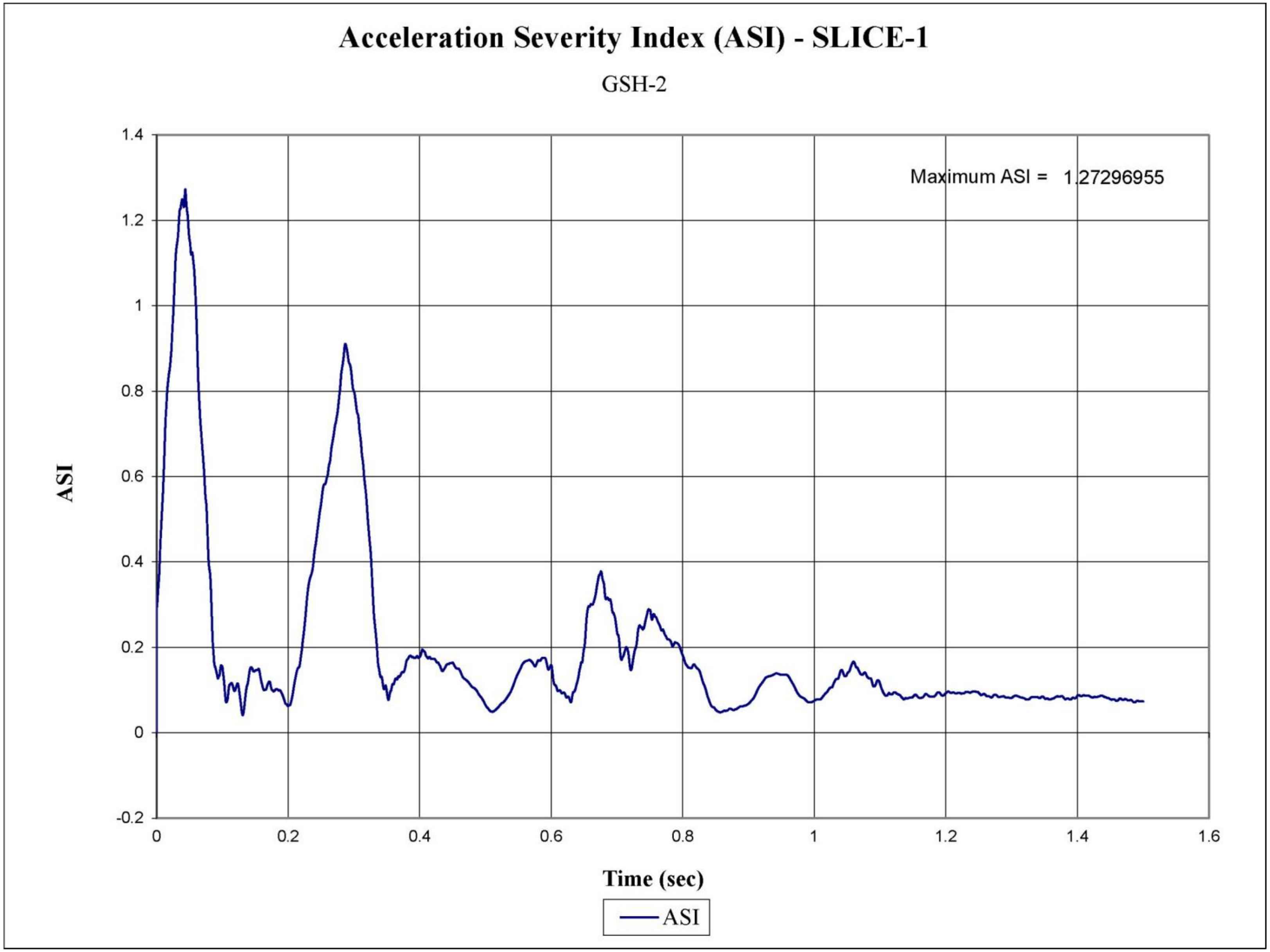


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. GSH-2

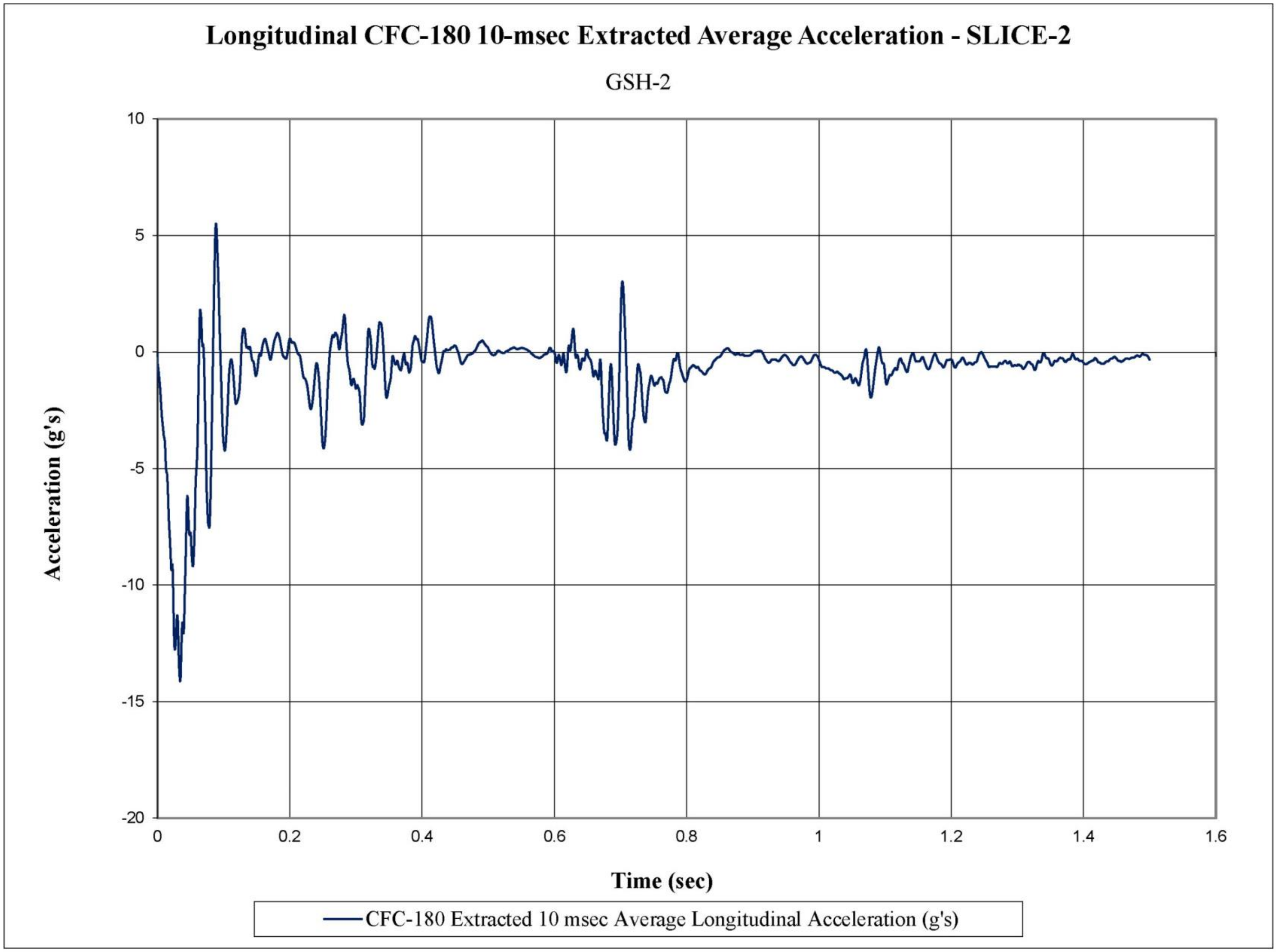


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. GSH-2

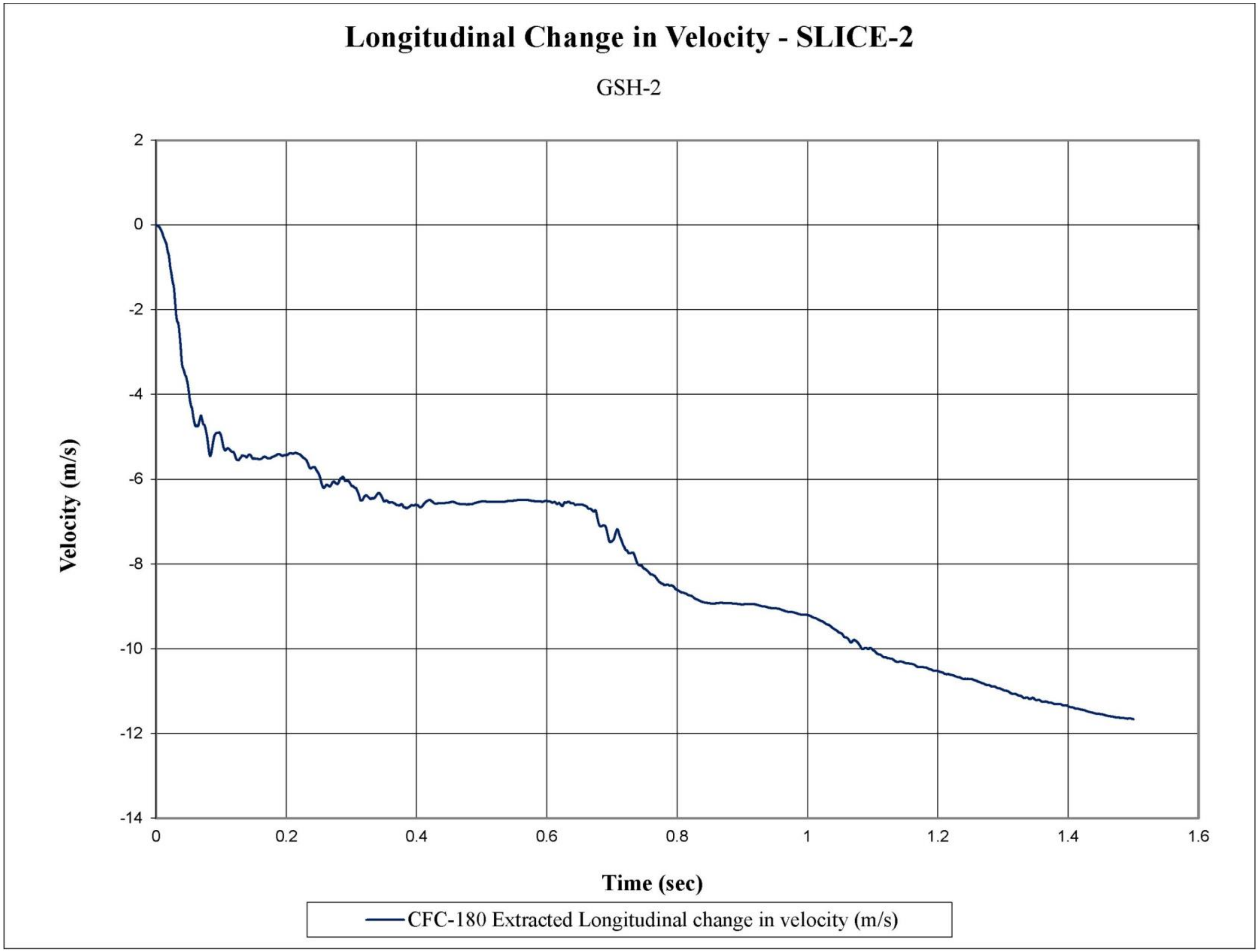


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. GSH-2

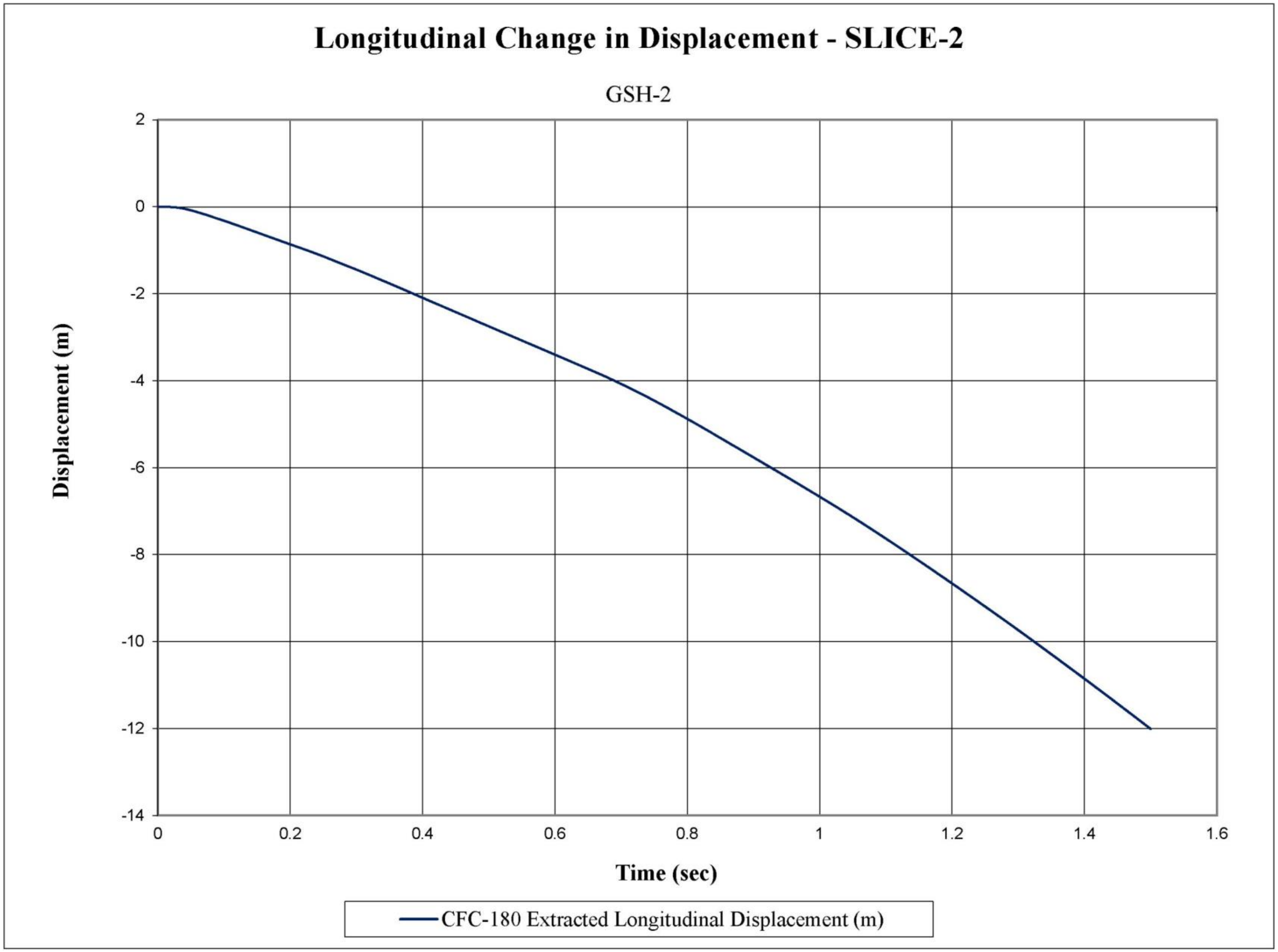


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. GSH-2

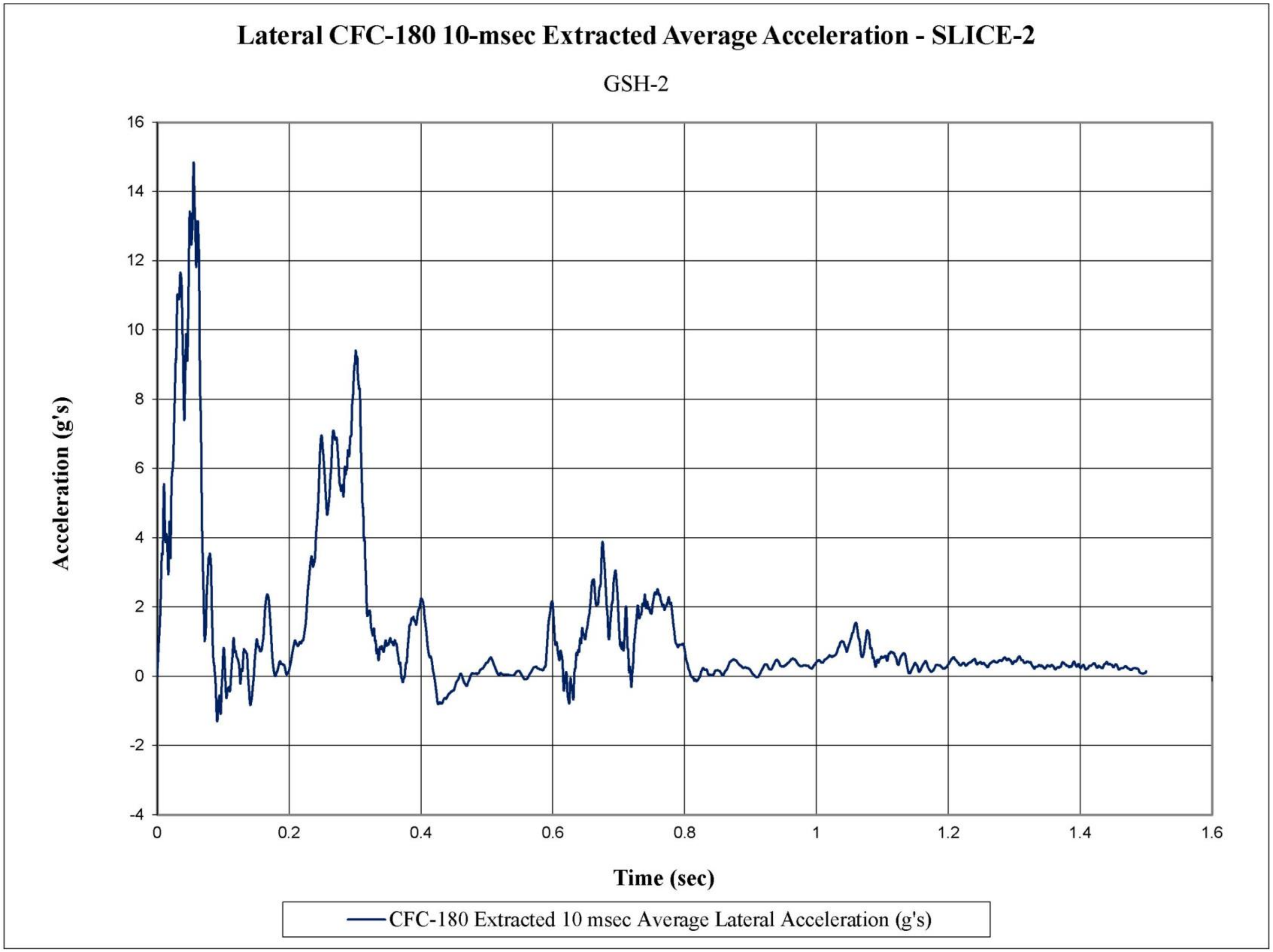


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. GSH-2

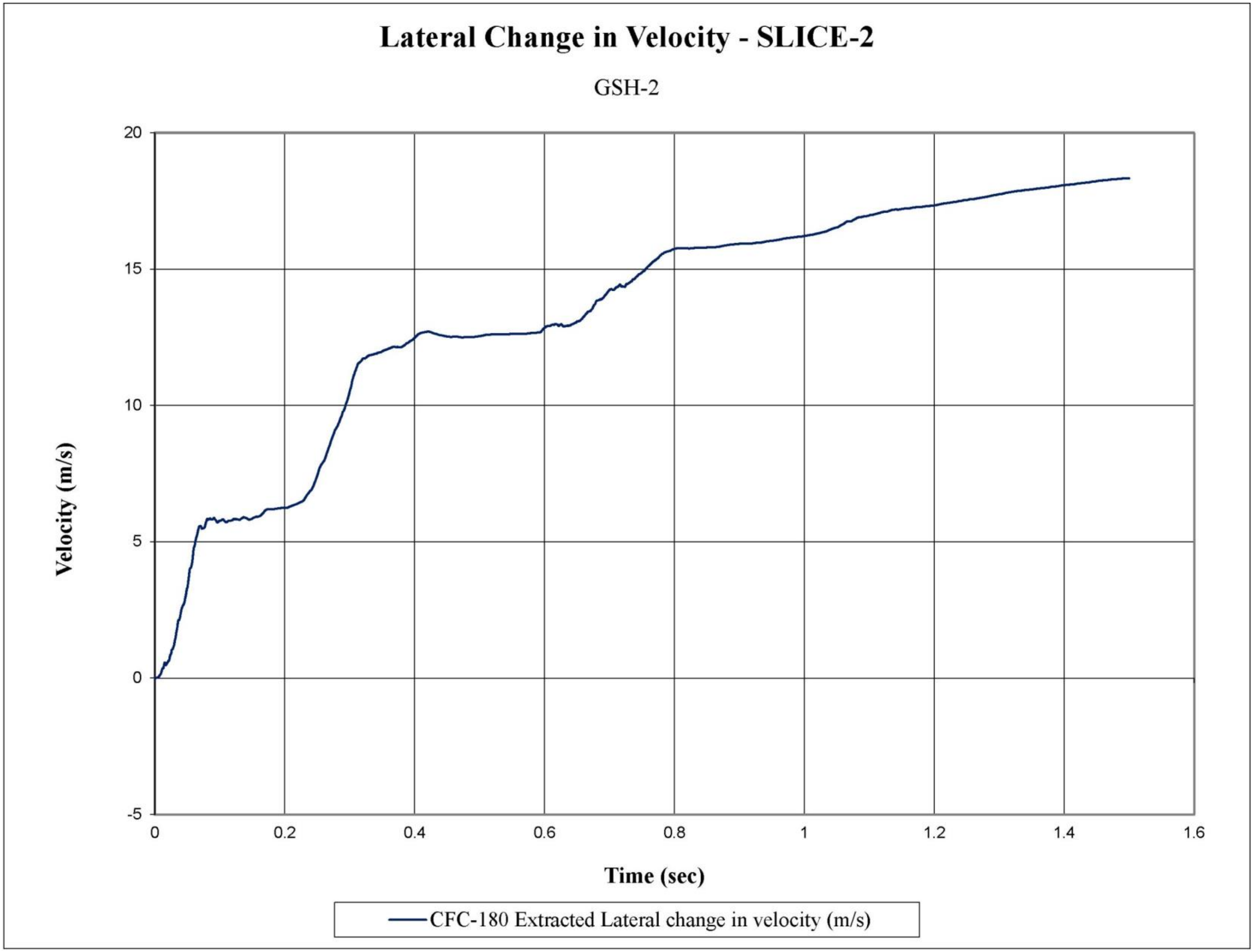


Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. GSH-2

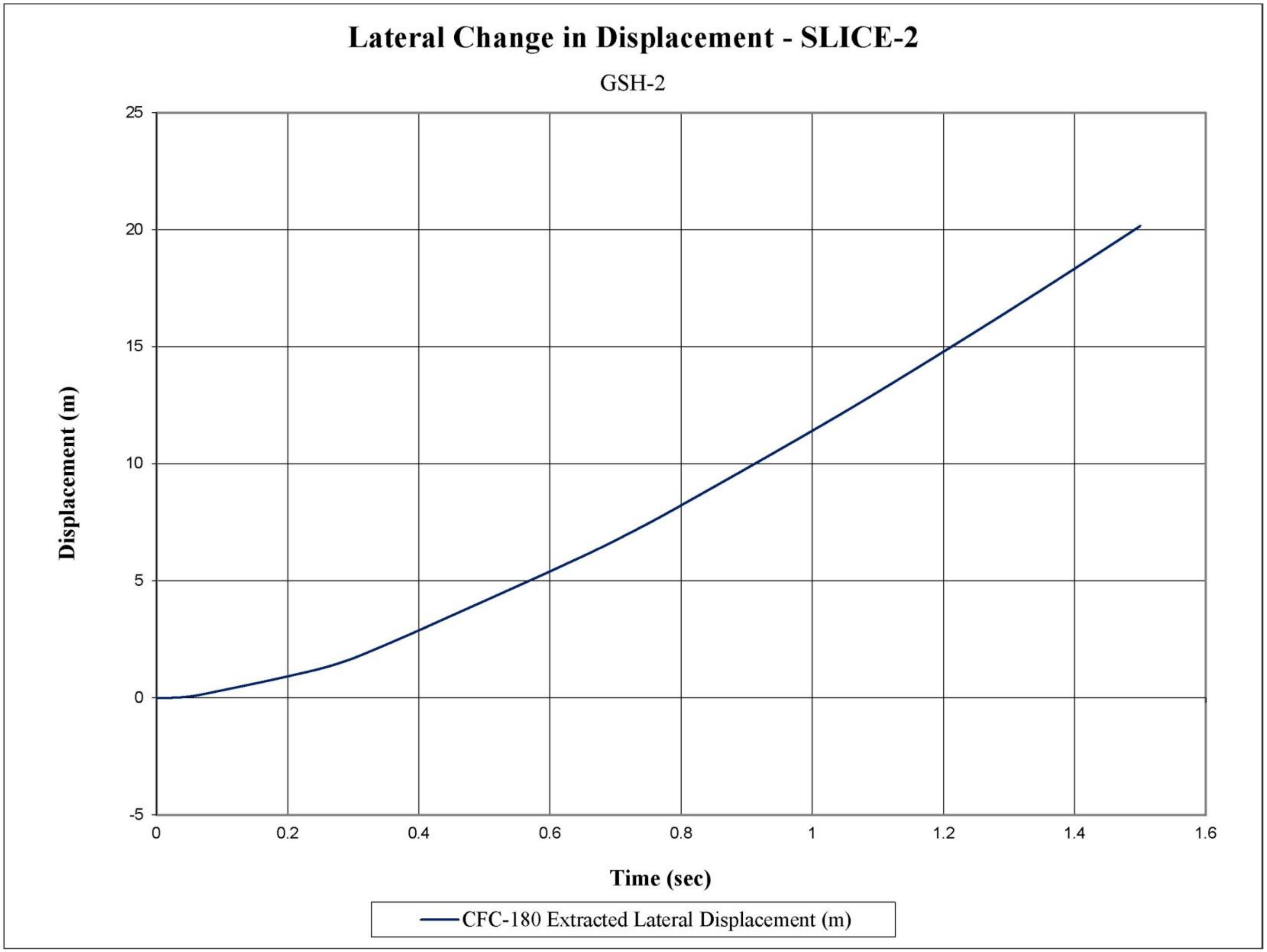


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. GSH-2

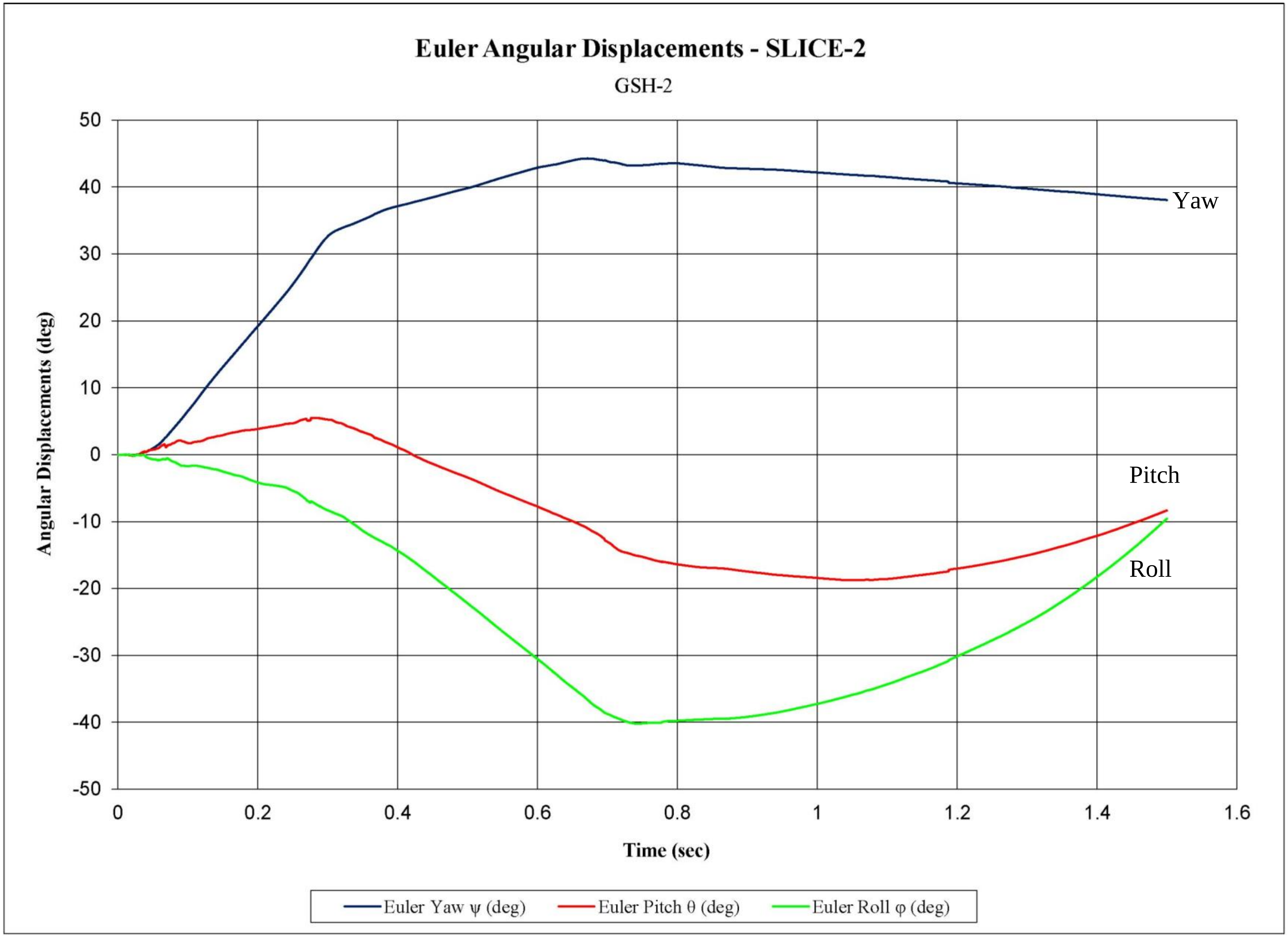


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. GSH-2

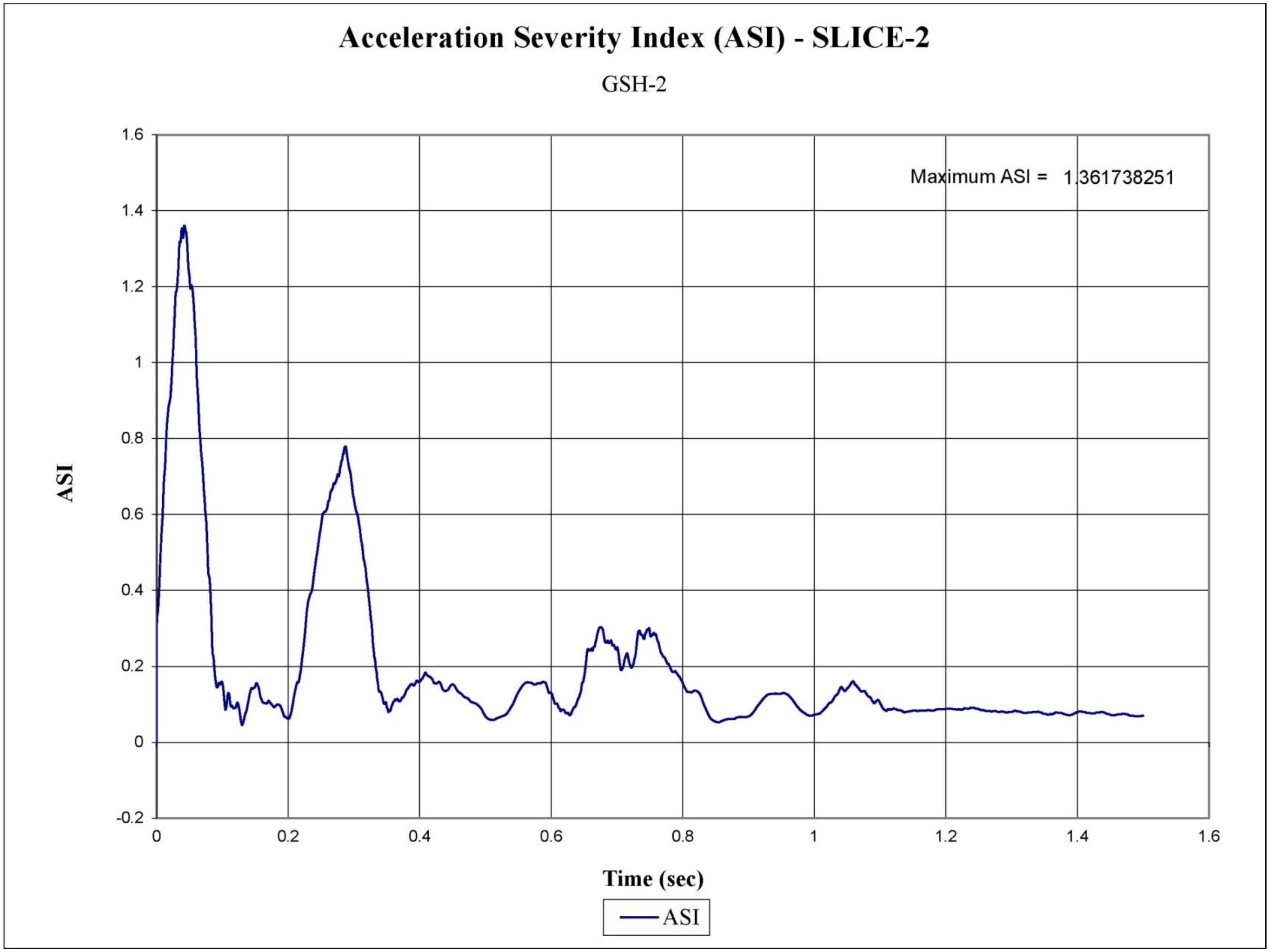


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. GSH-2

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